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INTRODUCTION

Meteorology and climatology research is conducted presently in Poland by a wide circle of scientists at universities, Polish Academy of Science and other research institutions. This monograph presents selected issues related to the above mentioned thematic field together with the latest research results of the authors of subsequent chapters.

The first three chapters were devoted to analyses which applied historical data. Also the outline of the history of meteorological network in the Polish Kingdom in the 19th century was presented. This part of the country was then named Galicia by the Austrian partitioner. Despite partitions of Poland, new meteorological stations were established, first in Warsaw in 1779, and later on in Kraków in 1792. Meteorological network in Galicia was founded by Physiographic Committee and its Meteorological Section in 1865. The second chapter presents the history of heliographic and actinometric observations for the area of today's Poland, since their beginning to the onset of the second world war. First regular measurements of insolation were started in 1883 in Kraków. Systematic actinometric measurements were started in 1900 in Warsaw by W. Gorczyński. Intense development of heliographic network began after the first world war. The third chapter was devoted to the analysis of the Wrocław measurement series conducted by David von Grebner which is the oldest measurement series in Poland. The measurements were conducted in the years 1710-1721 and involved atmospheric pressure and air temperature.

The next chapter presents the comparison of the results of meteorological measurements obtained both by using standard methods and from the automatic station in the Agro- and Hydrometeorology Wrocław-Swojec Observatory of Wroclaw University of Environmental and Life Sciences for the period of 2000-2009.

The fifth chapter analyses daily values of air temperature, relative humidity, wind velocity, atmospheric pressure, the number of precipitation days and state of the sky for the period from May to September gathered in the station in Ustka, taking into consideration bioclimatic conditions such as: subjective temperature index STI, heat load of organism HL, predicted insulation of clothing Iclp and weather evaluation index WEI for the needs of tourism and recreation.

The aim of the next presented research was to establish the intensity of the urban heat island and its variability in the course of the day and night in conditions of light and heavy cloudiness. Although urban areas occupy a relatively small area of the country, their population density causes that the conditions in such islands affect most of the country population hence the research into the city climatic conditions seems quite crucial.

Chapter seven characterizes the frequency and intensity of atmospheric thaws in the region of Bydgoszcz considering the multiannual trend in this phenomenon which occurs from late fall to early spring and affects most of Poland area due to the flat countryside.

The next two chapters are devoted to precipitation. The influence of precipitation on air pollution has been considered, particularly on the concentration of suspended particulates (PM10), and the selected characteristics of precipitation conditions in north-eastern Poland have been analyzed with an emphasis on the frequency of the occurrence of vegetation period (IV-IX) with shortage and surplus of precipitation, according to Kaczorowska criterion.

The chapters from tenth to thirteenth present the issues concerning types of atmospheric circulation, atmospheric instability, vorticity field, convection phenomena including probability of storms.

The next chapter discusses the eddy covariance method which is nowadays the main tool used for measuring mass and energy flux exchange between various ecosystems and the atmosphere. Although this type of research can be classified as micrometeorological, these phenomena are definitely dependent on the weather course.

The following two chapters contain the results of the study of multiannual change in the precipitation conditions. The first refers to spruce stand stability in the lower Beskid Śląski forest area, and the second to marshland area in the Promotion Forest Complex Rychtalskie Forest.

The last, seventeenth, chapter of the monograph discusses the principles of meteorological data quality monitoring for the data gathered from automatic measurement stations. The results indicate that even regularly serviced measurement stations are not capable of maintaining absolute continuity and reliability of measurements and require quality monitoring.

The presented monograph is a review of the meteorological and climatology research conducted currently in Poland which will allow the reader to learn about its scope and the latest achievements.

Dr Jacek Leśny

1. THE DEVELOPMENT OF THE IDEA OF WEATHER OBSERVATIONS IN GALICIA

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INTRODUCTION

In Europe, the second half of the 18th century coincided with the period of Enlightenment. It was the time of new philosophical thought, a tendency to turn to observations of the natural environment, and therefore, also a period of development of new branches of natural sciences. The idea of performing of both animate and inanimate nature relatively quickly seeped into Poland. In 1773 the Committee of National Education was established, ushering in abroad interest in mathematical and natural sciences. The discovery of the laws of physics controlling the atmosphere and inventions of new instruments enabling numerical re cording of weather patterns and their particular elements formed the basis for future meteorological observations. In Polish Kingdom, new instruments were introduced relatively quickly: mercury barometers and thermometers, also hygrometers were soon in use (Tamulewicz 1997). They were installed in the homes of landowners and wealthier townsmen, as well as in research institutions. The first meteorological station was established in Warsaw, the capital of the Polish Kingdom, in 1779 (Lorenc 2000). Subsequently, another station was created at the Astronomical Observatory of the Jagiellonian University in Krakow (Trepińska 1997, 2005). Its first head, Professor Jan Śniadecki – a mathematician, astronomer, author of the book (in Polish, Śniadecki 1837): *Jeografia czyli matematyczne i fizyczne opisanie Ziemi (Geography or mathematical and physical description of the Earth*), did not think highly of the meteorology of the time as a science (Trepińska 2007). However, under the influence of the weather observation ideas he came cross during his studies in Western Europe countries, he started instrumental and visual weather observation in Krakow on the 1st May 1792. Śniadecki developed a detailed instruction for performing the observations (Trepińska 1997) and recording their results in special observation diaries (Trepińska 1982). Unfortunately, the political events that ensued in the Polish Kingdom impeded the execution of scientific plans, as the Kingdom partitioned and occupied by its neighbors.

A BRIEF HISTORY OF SOUTHERN POLAND AT THE TIME OF THE PARTITION

The very promising development of scientific research and higher education in the Polish Kingdom was obliterated by political events – three consecutive partitions of the Polish lands which took place in the last three decades of the 18th century.

The first partition deal was signed between Russia, Prussia and Austria on the 5th of August 1772. The second partition, by Russia and Prussia, occurred on the 23rd of January 1793, while the third was signed on the 3rd of January 1795 by Russia, Prussia and Austria (Davies 1991).

The south-western part of the Polish Kingdom became a province of the Habsburg Empire. These lands became known as the Kingdom of Galicia, Lodomeria and the Great Duchy of Krakow (from 1846). Along with the incorporation of smaller duchies and individual cities, the area repeatedly changed and was generally referred to as Galicia, with the capital being Lwow (now Lviv) from 1803. Krakow's history was generally also very diverse: in 1809 it was incorporated into the Duchy of Warsaw, then it became a Free City in 1815, and in 1846 it was directly annexed by Austria, becoming the Grand Duchy of Krakow (Adamczewski 1996).

Western Galicia with Krakow included the lands located along the upper Vistula River, up to the San River, to the east flanked by eastern Galicia with Lwow.
The third partition dealt a heavy blow to the development of scientific research and higher education in the Polish lands. Galicia was governed centrally by the imperial authorities of Austria until 1867, when it regained some autonomy with the establishment of the so-called National Parliament (Sejm Krajowy) the National Department (Wydział Krajowy) and the National School Council (Rada Szkolna Krajowa). However, it only slightly influenced the economic growth and educational development, due to persistent money shortages.

METEOROLOGICAL OBSERVATIONS AT THE JAGIELLONIAN UNIVERSITY ASTRONOMICAL OBSERVATORY DURING THE PARTITIONS

Professor Jan Śniadecki wrote his *Jeografia…* "*weeping over tombstone of his fatherland*". For a few years he stepped away from politics, turning to natural sciences. When creating his work, he had a sentence from Horace in mind, which advised people against marveling at base and menial thongs, but rather encouraged them to turn their thoughts to loftier matters, to look for what restrains the seas, find out what regulates the year, what governs moon eclipses and acknowledge the harmony of the world (Śniadecki 1837).

Professor Jan Śniadecki's biography is an excellent example of the life of a scholar of Age of Enlightenment – he was both a man of science and a great humanist. His *Jeografia…* indicates a great impact exerted on Śniadecki by the brilliant geographer, traveler and discoverer Alexander von Humboldt and his works. In his studies, Śniadecki dedicated entire chapters to the atmosphere of the Earth, winds and seasons all across the globe. Appointed by the Commission of National Education, he went on two long travels to Western Europe between 1778 and 1781 he visited scholars and studies mathematics at the Universities of Leipzig, Gottingen, Leiden, Utrecht and The Hague. He also visited Paris and Vienna, and in 1787 he studied in England at the University of Cambridge and with astronomers in Slough, London. Coming back to Krakow through Paris and Germany, he stopped in Mannheim, which boasted a plant manufacturing instruments used investigate to atmosphere the Earth, including thermometers and mercury barometers. Śniadecki also described the work of the Meteorological Society, which, established and financed by the duke-elector of the Palatinate, Charles Theodore, collected records of weather observations from a network called *Societas Meteorologica Palatina,* created in the second half of the 18th century (Schönwiese 1997). After his return to Krakow, he was appointed as the first director of the Astronomical Observatory, becoming the founder and patron of the meteorological station. He personally recorded the readings of the instruments and visual observation in records diaries.

In the years that followed the 3rd partition of Poland, the Jagiellonian University grappled with financial and staffing difficulties. Śniadecki left Krakow in 1803, moving to Vilnius City. Meteorological observations at the Krakow-based Observatory continued, albeit irregularly. The situation improved when the astronomer Maximilian Weisse from Austria was appointed head of the Observatory in 1825, introducing a new observation schedule, purchasing new instruments and rearranging the records. From then on, Krakow's astronomers conducted their observations uninterruptedly, even during the world wars of the 20th century. A great effort was given in the Astronomical Observatory to the development and maintaining of its meteorological activity. The results were published in monthly review, some of these materials were sent to the Central Meteorological Office in Vienna by Professor F. Karliński, director of Observatory in 1862-1902. The station was handed over by the Observatory to the Department of Climatology of the Institute of Geography of the Jagiellonian University in 1976.

Under Austrian rule, the Jagiellonian University was entitled to hold lectures in Polish. The first Chair for Geography was established in 1849. It was created and first headed by Wincenty Pol (1807-1872), who promulgated observations of the natural environment and understood the importance of geographical regionalization (Jackowski, Sołjan 2007). W. Poll developed the scientific terminology used in many geographical studies, including numerous notions related to weather and climate. Unfortunately, the Austrian authorities disapproved of the activity of the Chair of Geography and soon deposed W. Pol as its head.

METEOROLOGICAL AND CLIMATOLOGIC SOCIETIES AND ASSOCIATIONS

In the first decades of the 19^{th} century, scientific and economic associations were created, focusing on the natural environment and its investigations. It is worth mentioned several associations, whose work became an inspiration for collecting weather data, which later served as a basis for studies of the climate conditions of particular areas. Several examples of such organizations can be found below.

In 1816 Krakow saw the establishment of the Krakow Scientific Society (Towarzystwo Naukowe Krakowskie). In 1857 the Balneological Committee of the Krakow Scientific Society was set up and entrusted with the task of elaborating the conditions of treatment for spa towns and conducting weather observations. The Committee included mainly medical doctors representing major spa towns, such as Michał Zieleniewski from Krynica, or doctor Warszauer from Szczawnica, as well as research fellows from the University: Franciszek Karliński, who later became director of Observatory and Daniel Wierzbicki – assistant professor at the Observatory. Professor Józef Dietl, president of the Committee, recommended performing meteorological observations according to the guide developed by Professor Stefan Kuczyński in 1860 (Hanik 1972). Observations were mainly carried out in summer. Their results were sporadically published in medical reviews, but most of them remained unpublished. The Balneological Committee of the Scientific Society operated until 1877, cooperating with the Physiographic Committee.

As early as in 1865, members of the Balneological Committee, after a fervent address published in the *Czas (Time)* daily, established the Physiographic Committee (Hanik 1972, Mietelski 1986), which for many years brought together the University's top scholars. The main aim of the organization was to prepare research and scientific studies helping to gain broader knowledge on the physiographic and the natural environment of Galicia region. The Committee was comprised of the following Sections: Orographical (Geological), Meteorological, Zoological, Botanical, also Agriculture one. The Meteorological Section took over the task of conducting weather observations for the purposes of the Balneological Committee in spa towns. The main goal of the Meteorology Section was to conduct climatologic research on the northern and north-eastern slopes of the Carpathian Mountains and in the foothills, collecting meteorological and magnetic data, as well as information on water levels in rivers and the results of phenological observations carried out in Galicia. When performing meteorological observations, Austrian guidelines were initially used, later substituted by guidelines developed by S. Kuczyński (Kuczyński 1867). For a long time, the Meteorological Section was headed by Professor Franciszek Karliński, director of the Observatory, appointed in 1869. His appointment proved very beneficial for controlling and recording observation results. Many of Karliński's publications were run by Austrian scientific magazines (e.g. *Meteorologische Zeitschrift).* Numerous studies, charts and graphs remained in manuscripts. Karliński was also involved in correspondence regarding meteorological data and its exchange, as well as regarding magnetic measurements (Mietelski 1986).

Between 1871 and 1873, the Academy of Arts and Sciences was formed in Krakow. Other societies, such as Krakow Agricultural Society (*Towarzystwo Rolnicze Krakowskie*), which was comprised of landowners and later also peasants, promulgated modern methods of agricultural economy between 1845 and 1919.

In 1819 the Galician Economic Society (*Galicyjskie Towarzystwo Gospodarcze*) was called into being in Lwow, as a specialized scientific association mainly for landowners. It became especially active after 1845, organizing farming training courses and contributed to development of this branch of the economy. Also in Lwow, the Society of Farming Circles of Galicia (*Towarzystwo Kółek Rolniczych w Galicji*) was established in 1882, with the aim to propagate general and agriculture-related education. Research into animate and inanimate nature, as well phyto- and zoophenological observations, coupled with weather ones, were highly appreciated. Until the last 25 years of the 19th century the new centers for agrometeorological and meteorological investigation were organized, e.g. the agronomy school in Dublany (the village near town Drohobycz), the Agricultural College of the Jagiellonian University, and new meteorological station at the summit of Czarnohora Mt. (Eastern Carpathian Mts.)

THE GALICIAN METEOROLOGICAL NETWORK

The Physiographic Committee was a scientific society, bringing together representatives of pure and natural sciences, academics, teachers of high school and physicians interested in scientific research and in development of natural sciences. The Meteorological Section, which is of particular interest to us, was very active, producing a copious body of studies preserved until today. A network of meteorological stations in Galician territory was created (Hanik 1972) in 1865. The exact number of stations varied between 19 and 45 – in certain years their number was significantly higher due to cooperation with other institutions which managed meteorological stations, also through including precipitation stations in the network (Hanik 1972). These institutions included: the Tatra Society (*Towarzystwo Tatrzańskie*) established in 1874, the Melioration Bureau of the National Chamber (*Biuro Melioracyjne przy Wydziale Krajowym*), created in 1879, the Board of Forestry and Domains (*Dyrekcja Lasów i Domen*) and the Galician Forestry Society (*Galicyjskie Towarzystwo Leśne*).

The first station of the Tatra Society were established in 1876, thinks to an initiative of Father Wojciech Roszek and Professor Leopold Świerz (Hanik 1972, Radwańska-Paryska, Paryski 1973). The members of the Society set very broad goals for themselves and their organization, concerning both scientific research and environmental protection, but they opened their stations for cooperation with the Meteorological Section.

Ordered by the Melioration Bureau, precipitation station were established, but functioned only in the warm half of the year. In addition, limnimetric stations were opened, mainly in connection with hydraulic engineering projects, and especially with the Dniestr River training effort. In 1881, on the initiative of T. Stanecki, new stations were established, whose activity can be considered as the beginning of a network of stations of the Department of Hydrographic Bureau in Lwow, created in 1895 as a division of the Central Hydrographic Bureau in Vienna. Guidelines for performing (“ombrometric”) measurements at the precipitation stations were developed by A. Kędzior (Hanik 1972). The Hydrographical Bureau collaborated the Physiographic Committee, but the results of the observations carried out at its stations were published in the *Annals of the Central Hydrographical Bureau* in Vienna. Issues 12-14 were the ones dedicated to observations performed in Galicia.

The results of the observations carried out at the meteorological stations of the Board of Forestry and Domains, later known as the Directorate of Forests and

State Assets (*Dyrekcja Lasów i Dóbr Państwowych*) have probably been lost, or are kept in hardly accessible archives. The Galician Forestry Society planned to establish a network of phenological stations, but it turned out that their functioning was hampered due to acquiring permanent observation staff and money shortages (Hanik 1972). Professor of Lwow University, Tomasz Strzelecki was very active as cooperating with the Physiographic Committee.

The development of the Galician network of meteorological stations can be divided into three periods. During the first stage, from 1865 to 1885, the main field if interest was organizational work and the establishment of new or the incorporation of existing stations. The second period, between 1886 and 1903, brought an increase in the importance and authority of the Meteorological Section, which assumed patronage over weather observations carried out by other institutions. The third stage (1904-1919) meant gradual limitation of the Section's work, especially field work, while the *Materials for the Climatography of Galicia* was still published.

THE ANNALS: MATERIALS FOR THE CLIMATOGRAPHY OF GALICIA COLLECTED BY METEOROLOGICAL SECTION OF THE PHYSIOGRAPHIC COMMITTEE

The annals entitled *Materials for the climatography of Galicia*, published regularly from 1867 to 1914, contain the results of daily weather observations presented according to the same pattern: readings of air pressure, temperature, humidity, cloudiness, wind parameters, precipitation, as well as the results of phytophenological and zoophenological observations (Piotrowicz 2007). The results of observations were collected and verified by employees of the Astronomical Observatory of the Jagiellonian University, which at the same time became the central institution collecting such valuable materials. Employees of special merit were Professors Stefan Kuczyński – a physicist and the first president if the Physiographic Committee, Franciszek Karliński and Daniel Wierzbicki, Ph.D. – an astronomer and meteorologist, and an enthusiastic weather observer, who taught others how to conduct field observation. Cooperation with other institutions and societies, such as the above mentioned Tatra Society, or the governmental Hydrographic Bureau in Lwow, resulted in the acquisition of many valuable materials in the form of additional readings, accounts of the observed occurrences and atmospheric and phonological phenomena. The Galician meteorological network was subsidized by the National Chamber, but all too the funding proved too scarce. Principals of secondary schools often helped with the purchase of meteorological instruments.

Despite financial difficulties, the annals published by the Physiographic Committee as the Reports of the Physiographic Committee, with copies published in separate volumes as the *Materials for the Climatography of Galicia collected by the Meteorological Section of Physiographic Committee,* were issued regularly. The number of readings of particular parameters and the number of stations varied depending on the supplied observation data. In addition, the annals included broad and detailed descriptions of cases of occurrence of hail and disastrous hailstorm in Galicia. They also featured the number of people and livestock killed or struck by lightning. Usually, these numbers referred to several or several dozen cases a year. Reports were drafted systematically in cooperation with insurance companies. Most of them drafted by the invaluable senior research fellow of the Astronomical Observatory, Daniel Wierzbicki, Ph.D.

Almost all the annals, from as early as 1867, included lists of water levels of major rivers and their tributaries – from the Upper Vistula River to the Upper Dniestr River. In the 1880s, there were 40 water-gauges along the main rivers, including 6 measurements points along the Dniestr River (up to Zaleszczyki Village). The water level data were used by the Hydrographical Bureau in bridge building projects for the railroad. The 1868 issue of the *Materials for the Climatography of Galicia,* included a note of floating wood down the Skawa River and then down the Vistula from the town of Sucha (small town) to Krakow. Under favorable weather conditions, it took the wood 4 days to reach Krakow.

From 1876, the Astronomical Observatory regularly issued monthly reports in German: *Meteorologische Beobachtungen angestellt auf der k.k. Sternwarte in Krakau*. The reports were made available as ordered by the authorities (Mietelski 1997).

The annals preserved until today are an invaluable source of knowledge on the weather conditions prevailing in a large part of the Polish lands, as well as a sound foundation for today's avid interest in climate variability.

HAIL AND HAILSTORMS

As mentioned above, the *Materials…* regularly included details and precise description of the occurrences of hailstorm, with a specification of their aftermath. Such disasters, exceptionally harmful for agriculture, repeated almost every year, with different intensities. In 1869, a map of hailstorm paths in Galicia was drawn up. In general terms, hailstorm disasters happened twice as often in eastern Galicia, i.e. east of the San River. In certain years, as many as several hundred municipalities in Galicia were hit by torrential rains and hailstorms. Crops, still before harvest, were completely destroyed, which was meticulously noted in the reports. Page 223 of the *Materials…*published in 1886 shows the "number of days with hail and municipalities from 1867 to 1885". The reports imply that the size of damage sustained by landowners and rural communities was huge as a result of the hailstorm.

Great destruction of crops and orchards was observed in certain years, although years in which the results of excessive precipitation was not disastrous, e.g. 1870, were also mentioned. Great crop losses were recorded in 1871 (ten cases of hailstorms) and 1872 – both replete with disasters occurring within two large hailstorm belts – the northern reaching from town Myślenice to town Hrubieszów and the southern from village Barwałd to Płaszów near Krakow. Hailstones the size of pigeon eggs or of a fist was observed. In 1879, 10 cases of hailstorm were recorded. They destroyed mainly the municipalities located at the Prut and Dniestr Rivers, while 37 people were struck dead by lightning. Year 1882 was a "*dreadful year for farming*", especially in the east, where 5 cases of hailstorms were observed. New hail damage was recorded in 1883 – on the 16th June, after a violent hailstorm near Kołaczyce (currently located in the Podkarpacie Region), the town *"looked like after a Tatar attack"*, with destroyed fields and households and orchards stripped of leaves and fruit and up to 47 persons died struck by lightning in that year. Later year 1892 brought a difficult spring and summer, with numerous hailstorms, tornadoes and continuous rains, especially in June and July. A total of 1.465 villages in 67 (out of 80) districts suffered some damage.

SCIENTIFIC STUDIES AND DESCRIPTIONS OF UNUSUAL WEATHER PHENOMENA IN THE *MATERIALS FOR THE CLIMATOGRAPHY OF GALICIA*

Some volumes of the "*Materials…*" include articles recounting the results of unique studies and meteorological and climatologic observations. They are very interesting and present an overview of the development of relevant research. It is worth mentioning selected titles of the articles and considering their content.

Ana article by J. Rivoli, a forestry officer from Kórnik, village in Wielkopolska (Rivoli 1870) titled "O*n the influence of forest on the temperature of the lower layers of air*" ("*O wpływie lasów na temperaturę najniższych warstw powietrza"*) opens with an overview of the results of European and American research carried out by leading specialists in natural sciences. Current microclimatic research confirms such statements as the following: *"the forest neutralizes the effects of night-*

time heat irradiation, due to the fact that it shades the Earth and therefore, the temperature of the layer of air over woodlands is higher than that over fields". The Wielkopolska plains, according to the author, were very convenient place to carry out such studies. The author collected the results of weather and air humidity observations from the years 1866-1868 around Kórnik and published them in Poznań. He also presented his investigations on "*the influence of forests on the temperature of winter winds*", which currently seem somewhat controversial. In turn, his observations from the chapter entitled "*The forest during night-time irradiation*", which contains an interpretation of the results of his own research, seem more reasonable. The author states that shortly before dawn, the difference in temperature between the fields and the forest reaches even 2°R (2.5°C). The forest is cooler, but with stronger winds the difference disappears. He also notes that over an empty field, even the faintest breeze results in mixed air, whereas in the forest cooler air layers persist, which in harmful for vegetation. During still and fair nights, plants including young trees are chilled up to a certain height, which is harmful. The overall climatic conclusion – "*forest contribute to milder winters*" – was formed to support the protection of forests against excessive felling. This study proves the author's avid interests as an active forestry officer, his ability to interpret the phenomena he observed and certain scientific inquisitiveness, as he repeatedly drew on works written by reputed scholars of the time.

An example of a reliable description of an unusual and dangerous weather phenomenon is a study by M. Sławiński (1877) entitled "*A tornado in Kołomyja 13/06/1876*". At 2 p.m., at a air temperature of 26.3 °C, a tornado appeared from a Cumulonimbus cloud, with an SE wind, and then, over the Prut River "*…it lifted a barn up in the air, leaving just one wall with a cow lying next to it…The heaved-up objects twirled in the air with a swish, and their remains fell scattered over the entire area from the field to the Prut… An entire gate was seen revolving in the air around its diagonal, and a man was spotted being carried by the tornado… The din lasted for two minutes…then rain came about half an hour after the tornado…*" It needs to be added that mentions of such dangerous weather phenomena appeared several times in the "*Materials for the Climatography of Galicia*". They were more frequent in the eastern part of the region.

Tygodnik Rolniczy Krakowski (*The Krakow Forming Weekly*), issues 27-28, 1884, ran a story on the hailstorm near the town Stryj, along a strip of 2 km on the 15th of June 1884. According to the "*Materials…*" this was thee largest hailstorm in the summer of 1884, destroying crops in 122 municipalities in 20 districts from town Jarosław to town Tarnopol. June of that year also saw flooding of the Vistula River, than San River, the upper Dniestr River and their tributaries.

A study by D. Wierzbicki (Wierzbicki 1886) presenting the measurements of precipitation and evaporation in Krakow between 1850 and 1886 proved very helpful in the analysis of precipitation patterns in Krakow. A precise description of measurement instruments which no longer exist is significant not only historically, but it also very helpful in the reconstruction of daily and monthly precipitation totals for the 19th century and in testing the homogeneity of precipitation series (Twardosz 1997).

The "*Materials…*" for 1889 include an article entitled "*The most important results of hourly observations of air pressure in Krakow performed from 1858 to 1888*", written by one of the assistant professors of the Observatory, B. Buszczyński, Ph.d. (Buszczyński 1890). The author used the readings from paper strips from a Kreil's barograph purchased by M. Weisse (Trepińska 1982). This study should also be considered as a climatology paper, especially since the Krakow series of air pressure measurements is one of the best preserved in Poland.

The 1892 issue of the "*Materials…*" features a list of precipitation measurements taken by. F. Karliński entitled: "*The results of seven year-long hourly measurements of rain performed at the Astronomical Observatory in Krakow*" (Karliński 1893). It is an example of the use of previously collected data in a publication, in order to disseminate the results of observations for scientific purposes and possibly also for further application.

From the climatologic point of view, the article entitled "*The daily course of air pressure in Tarnopol and its relationship with other meteorological elements, and comments on the reasons behind this phenomenon*" by Władysław Satke (1895) is a scientific paper. Satke, an eager observer and proponent of weather observation, presented a very accurate interpretation of the relationship between air pressure, temperature oscillations and general weather conditions.

The 1895 (published in 1896) incorporated a publication by Ludwik Birkenmajer titled "*Materials for the geomagnetism in the Polish Tatra Mountains*" and records of temperature and hypsometric measurements of several spring in the Tatra Mts. The same volume also presented an original paper by the above mentioned W. Satke (1896) entitled "*The temperature of snow in the winter of 1893/1894 in Tarnopol*"(248-255). The author performed measurements of the temperature at the surface of the snow cover five times a day. He distinguished four snow periods throughout winter and stated that temperature at a time of reduced cloudiness (from 0 to 5 degrees of cloud coverage on a 10-degree scale) equaled on average –11.9°C, whereas at a time of high cloudiness (between 6 and 10) the temperature was much higher: -3.4 °C, on average.

Ozonometric observations (Olecki 1997) belong to pioneering atmosphere related research started in Krakow's Astronomical Observatory. In the 19th century, it was commonly believed that the content of ozone – the three-atom oxygen already known at the time – in the air had an impact on human health. Ozone measurements were started in 1853 in the Botanical Gardens, initially to the north-west of the Observatory and later to the south west. Observations were carried out twice a day, by determining the colour of the so-called Schönbein strips. The results were noted down in meteorological diaries. D. Wierzbicki developed a series of ozonometric measurements and presented it in a very comprehensive publication (Wierzbicki 1881). It is one of the longest scientifically elaborated measurement series of ozone content in the air in the 19th century (Olecki 1997).

The aurora borealis observed in February 1871 in Krakow and even on south in Makow Podhalański, and in 1871 also in Jarosław, can be a proof of perfect visibility, which is tantamount to a lack of air pollution. The aurora borealis (also known as northern lights) was also visible in Lwow in November 1872. It is worth remembering that there was no question of electrical lighting being used back then…

Measurement of magnetic declination at the Astronomical Observatory started relatively early, in 1839. The position of the magnetic needle was recorded every morning and afternoon. The measurements continued for over 120 years (Mietelski 1997). They were quite regularly reported in the "*Materials for the Climatography of Galicia*".

AS ATTEMPT TO ASSESS THE WORK OF THE METEOROLOGICAL SECTION OF THE PHYSIOGRAPHIC COMMITTEE

Galicia was a province located at the periphery of the Imperial-Royal Monarchy – an economically backward, poor region. Few young people (boys only) received secondary or higher education. The number of teachers and other school employees was insufficient, to secure a constant and effective development of education, especially as regards experimental and natural sciences. The establishment of meteorological stations and the development of methods for conducting meteorological observations and their elaboration were modeled after a well-developed network of stations in Austria. However, such a system required constant subsidies, which were only provided in some years and always insufficient.

There were no funds to purchase basic meteorological instruments, or to ensure even meager remuneration for observers. Therefore, the great effort and understanding of the need to maintain this network of stations, so important for the development of meteorology should be even more appreciated. The great amount of work performed by professors and scholars and the establishment of the Physiographic Committee which functioned effectively for many years deserves much credit. The data collected with such meticulousness has luckily been preserved. It is necessary to emphasize the very thorough approach o the work, both in terms of the observations and their verification and preparation for release. Currently, the data is used in many relevant studies concerning the very topical issue of contemporary global warming and its results. In the light of the long series of measurements of air pressure, temperature and precipitation, one question in especially pertinent – is climate change really as significant as it is widely assumed? Has the number of disastrous weather phenomena such as torrential rains, river overflows, floods, hailstorms or really soared? Or is it only that observation technique has been perfected? There is no doubt that the 19th century saw the onset of the so-called contemporary warming process, but was it caused by human activity or by nature itself? There is no unequivocal answer to this question. The records of long-term weather observations are a basis for further scientific research. However, it seems that the vast legacy left by the people of the past centuries is still only partially used.

The Galician series of meteorological observations were already appreciated during the 19th century and were utilized in the studies of European physicians and meteorologists such as W. Dove, R. Assmann, and J. Hann.

Recent researches get the very good opinion about the activity and publications former Meteorological Network in Galicia and other Polish Lands.

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2. THE OLDEST HELIOGRAPHIC AND ACTINOMETRIC MEASUREMENTS IN POLAND*

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INTRODUCTION

Solar radiation is the principal source of energy for processes occurring in the atmosphere. As a consequence, it is one of the key factors that influence the global climate (climate forcing agents). The time of incoming direct solar radiation and the amount of radiant power are both very important for research on climate and its changes.

The first actinometric and heliographic measurements were made possible only when suitable instruments were invented and constructed. The most commonly used heliograph was built by Campbell in 1859, and then improved by Stokes in 1879 (Słomka 1957). Other types of heliographs (Gorczyński 1910, Smosarski 1910, Wójcik and Marciniak 1993) were less popular. The first measurements of sunshine duration in Poland were taken already in the 1880s, so soon after the glass heliograph was introduced.

Also in the 19th century work began on the construction of devices that would allow measurement of the amount of energy carried by solar radiation. In 1830, Nobili constructed a thermocouple used to measure radiation, and in 1833 Melloni built a thermo-electrical pile (a battery of thermocouples). In 1837, a French physician named Pouillet, using a pyrheliometer of his own design, performed the first measurements of direct solar radiation. At the end of the 19th century and early in the 20th century more measuring instruments were developed by Ångström (1893), Abbot (1902, 1905) and Michelson (1905), among others. Thanks to the construction and systematic improvement of the instruments, studies of solar radiation were becoming more and more popular. At that time actinometric measurements were also carried out in the territory of Poland with the first measurements of solar radiation taken in Nowa Aleksandria (as Puławy was then called) at the end of the 19th century (Bogdańska *et al*. 2002).

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The purpose of this work is to present the history of heliographic and actinometric observations in the area of present-day Poland from their onset until the outbreak of World War II. Due to a difficult geopolitical situation the development of heliographic and actinometric observations in the territory of today's Poland followed an irregular pattern. The first observations of solar radiation on our land were made in the time when Poland was partitioned between Russia, Prussia and Austria. As a consequence, in the territory of Poland there were measuring stations supervised by partitioner countries as well as Polish stations.

Information about the oldest heliographic and actinometric measurements can be found in a number of sources. The issue was addressed by Gorczyński (1903, 1910, 1911, 1914a, 1914b, 1939a, 1939b, 1939c, 1939d, 1945, 1950, 1951, 1955), Smosarski (1910), Merecki (1914), Fedorowicz (1925), Stenz (1925, 1930, 1959), Gorczyński and Ostrowski (1934), Chełchowski (1954), Trybowski (1955), Słomka (1957), Zinkiewicz (1962), Morawska (1963), Wójcik and Marciniak (1993), Miętus *et al.* (1994), Bogdańska *et al*. (2002), Górski and Górska (2002), Podogrocki (2002), Bryś and Bryś (2005), Matuszko (2007, 2009), Podstawczyńska (2007), Lewik *et al*. (2010), Przybylak (2010) and others.

HELIOGRAPHIC MEASUREMENTS

In the 19th century, heliographic measurements were performed in a lot of places around today's Poland. Some of them were made by meteorological services (Russian, Prussian or Austrian), and some by Polish institutions or organisations.

On the coast, the measurements were performed in a few locations. The *Klimakunde des Deutschen Reiches* of 1939 contains the data for a few dozen stations situated in the territory annexed by Prussia. These include Warszewo near Szczecin, Kołobrzeg and Tczew, for which the data concerns the years of 1891-1930 (*Klimakunde*… 1939). Measurements of sunshine duration in Kołobrzeg began a little earlier, i.e. in 1890, which means that the station holds one of the longest series of observations in Poland (Gorczyński 1939a, 1939d). The same measurements in Tczew were started as early as in Kołobrzeg, in 1890. For Tczew and Warszewo Polish sources show shorter periods of activity as compared to the information found in the German reference. According to Gorczyński (1939a, 1939d), the station in Tczew closed in 1910, and in 1909 there was a break in the measurements of sunshine duration (Stenz 1930). In the case of Warszewo the measurements began in 1913, according to the studies of Miętus *et al*. (1994).

Measurements of sunshine duration were also performed at the stations situated in the Bay of Gdańsk. However, they were started much later than in other parts of the coast. At the time of Prussian partition none of the stations had the equipment to measure sunshine duration in the Bay (Gorczyński 1951). The measurements were only started in free Poland, as part of activities of the State Meteorological Institute (PIM). The first station to operate was the one situated in Nowy Port (the future district of Gdańsk) in 1920. It was a Maritime Observatory, whose director in 1920-1925 was L.Lorkiewicz. In 1927 the Observatory was moved to Gdynia, whereas in Gdańsk-Wrzeszcz the Observatory of the Free City of Gdańsk was established (Gorczyński 1951). The first meteorological station in the area of Gdynia was probably situated near the building of the harbour master's office, and it started measurements of sunshine duration in May 1923 (Miętus *et al.* 1994). From 1928 a temporary actinometric establishment, being a subsidiary of the Observatory of the Free City of Gdańsk, was set up in Sopot (Gorczyński 1951). Measurements of sunshine were also performed on the Hel Peninsula, where a heliograph was installed in August 1931 (Miętus et al. 1994). Another one of the heliographic stations in the north of Poland is Wigry, where measurements were started in 1932 (Gorczyński 1939a).

The measurements were also performed in a number of places in central Poland. In Warsaw they began as early as in 1903. There, on the terrace of the Meteorological Office at the Museum of Industry and Agriculture (ul. Krakowskie Przedmieście No. 66) a photographic heliograph was installed and in 1904 a Campbell-Stokes heliograph (Smosarski 1910, Gorczyński 1939c). In 1915, due to military activities the measuring was moved to the building of the Warsaw Scientific Society (TNW) at Śniadeckich 8, where the measurements were taken on a terrace. In May 1923 the observations were discontinued at that location. From 1919 observations were carried out at the Pump Station at Czerniakowska 124, however only after the measurements performed on the terrace of the TNW building were finished the series of observations from the Pump Station became complete and suitable for a written study (Gorczyński 1939c). The locations of the said measuring sites are shown on Figure 1. According to Gorczyński (1939c), there were also other heliographs in Warsaw operated (at least temporarily) at the Astronomical Observatory of the Józef Piłsudski University, at the Central Military Weather Station and at the Warsaw University of Life Sciences (SGGW) in Rakowiecka street.

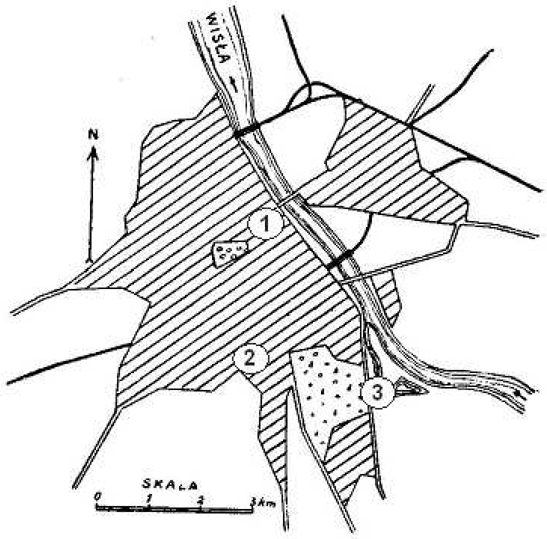

Fig. 1. Locations where solar radiation was measured in Warsaw in the years of 1903-1939, according to E. Stenz (as cited in Gorczyński 1939c).
1 – The Museum of Industry and Agriculture (ul. Krakowskie Przedmieście 77),
2 – The Warsaw Scientific Society (ul. Śniadeckich 8),
3 – The Pump Station (ul. Czerniakowska 124).

Before World War II measurements of sunshine duration in Central Poland were also carried out in other places. According to the *Klimakunde des Deutschen Reiches* (1939) for the years of 1891 – 1930 there are measurement results for such cities as Bydgoszcz, Szamotuły, Gorzów Wielkopolski and Zielona Góra. References to Szamotuły and Bydgoszcz are also provided by Stenz (1930). According to him, the observations in Bydgoszcz were carried out by Germans from 1909 until 1918, whereas Polish observations cover the period from 1921 until 1926 and are referred to as 'very inaccurate' (Stenz 1930). According to Gorczyński (1939a), the station at Szamotuły was closed in 1910. In Poznań observations of sunshine duration began in 1911 and lasted until 1918. After a break they were resumed in May and lasted until December 1919 and started again in the summer of 1920 (Stenz 1930). In Skierniewice measurements began in 1926 (Gorczyński 1939a). In Łódź measurements of sunshine duration were started at the airfield of Lublinek in 1932, however due to a lack of professionalism the pre-war results are inhomogeneous (Podstawczyńska 2007). Short series of observations were also found in Grudziądz (from 1932), Ciechocinek (from 1932), Ostrów Wielkopolski (from 1932), Rawicz (1932-1933), Gołębiew-Kutno (from 1931), Niepokalanów (1931-1936) and Otwock (1932-1935) (Gorczyński 1939a). The station at Grodzisk near Warsaw is worth mentioning, because it provided data for comparative analyses of the climate in the city and in the country. The station operated in the years of 1910-1915 (Gorczyński 1911, 1939a).

One of the longest series of sunshine duration measurements in Poland is in Puławy. The history of its heliographic measurements has been described in detail by Górski and Górska (2000). The first measurements of sunshine duration in Puławy were taken at the Meteorological Observatory of the Institute of Farming and Forestry at the end of the 19th century. From the earliest time of the measurements in Puławy only the data for three months (July through September) of 1894 remained. The instrument used at that time was a Wieliczko type heliograph. A regular recording of the measurements, using a Campbell-Stokes heliograph, began in Puławy in October 1923. Initially, the heliograph was installed at the weather station situated in the vegetable garden of the Institute. However, as the location was partially shaded, in March 1938 the heliograph was relocated to a better place (nevertheless, still with a restricted sky view) (Górski, Górska 2000).

For 10 years measurements of sunshine duration were carried out in Dęblin. According to Gorczyński (1939a), the station operated there in the years of 1896-1905, which was confirmed by Stenz (1930).

Measurements of sunshine duration were also performed at a number of stations situated in the area of present-day southern Poland, such as Głubczyce and Bystrzyca Kłodzka, for which the data for 1891-1930 was published in *Klimakunde…* (1939). One of the most important stations there, as far as the length of series is concerned, is the one in Wrocław. The history of observations carried out in Wrocław was presented by such authors as Słomka (1957) and Bryś and Bryś (2005). Measurements of sunshine duration in Wrocław began in 1891 at the Astronomical Tower of the University of Wrocław (Bryś and Bryś 2005), whereas Słomka (1957) gives an earlier date, 1 July 1889, as the beginning of regular observations. The location was subsequently changed a few times. In the years of 1921-1922 the measurements were taken at the new Astronomical Tower in Park Szczytnicki, from 1923 onwards in the district of Krzyki and from 1936 at the airfield of Gądów Mały (Bryś and Bryś 2005).

Very early, in June 1883, i.e. soon after the modern heliograph was developed, measurements of sunshine duration began in Kraków (Gorczyński 1910). Since the very beginning the heliograph has always been in the same place, on the roof of the Collegium Śniadeckiego (Matuszko 2007). Interestingly, in 1887 the

Campbell-Stokes heliograph was supplemented with a Jordan photographic heliograph. A comparison of the indications of the two instruments between 1887 and 1907 was made by Gorczyński (1910).

A few years before World War II broke out in the south of Poland measurements were performed in Katowice in 1932, according to Gorczyński (1939a). In the earlier period (1911-1918) sunshine duration was measured in Pszczyna (Gorczyński 1939a).

The mountains were also covered by measurements of sunshine duration. In the Karkonosze Mountains already in 1900 observations were started at the highest point – on Mt Śnieżka (Bogdańska *et al.* 2002). In the Carpathian Mountains the measurements were performed e.g. in Rabka in June 1934, first at a meteorological site, and from May 1937, on the second-floor balcony of St. Therese Junior Secondary School. In both locations the sky view was not completely clear, therefore in September 1937 the heliograph was moved for the third time and was situated on the roof of the Sanatorium of the Railway Family. In its third place, although showing a good sky view factor, the disadvantage was the difficulty of operation (Trybowski 1955).

Another important place of heliographic measurements is also Zakopane, where they began in January 1912. At first, the heliograph was installed on Równia Krupowa, an open meadow, and then moved onto the roof of the Tatra Museum. In the years of 1919 and 1921-1928 there were breaks in the functioning of the instrument (Stenz 1930). A new series followed continuously from October 1923 (Stenz 1930) until 1938 (Gorczyński 1939a, 1939d) or longer. Just before the outbreak of WWII, in 1938 another heliograph was installed at the top of Mt Kasprowy Wierch (Gorczyński 1939a).

In the West Carpathians measurements were also carried out in Cieszyn, where – according to Gorczyński – a new series of observations covers the years of 1925-1938, whereas the measurements in Szczawnica started in 1936 (Gorczyński 1939a).

ACTINOMETRIC MEASUREMENTS

The first measurements of solar radiation on the Polish land were performed in 1894 in Nowa Aleksandria, i.e. the present-day Puławy (Górski, Górska 2000; Bogdańska *et al*. 2002). Later, developments in actinometry and the construction of instruments resulted in popularization of actinometric measurements. In some locations they were performed systematically over long periods of time, however in other places there were only short, sporadic series.

The Meteorological Office at the Museum of Industry and Agriculture in Warsaw, headed by Gorczyński, was an important contributor to the development of Polish actinometry. From the end of 1899 an Ångström compensation pyrheliometer was used there to perform measurements and calibration of relative measuring instruments. Besides, the Office used a Chwolson's thermoelectric actinometer and, later on, a Michelson's bimetallic actinometer (Gorczyński 1951). Measurements of solar radiation covered all its components: direct, dispersed and total. The different types of radiation were measured by means of a versatile solarimeter (Fig. 2), used already in the interwar period.

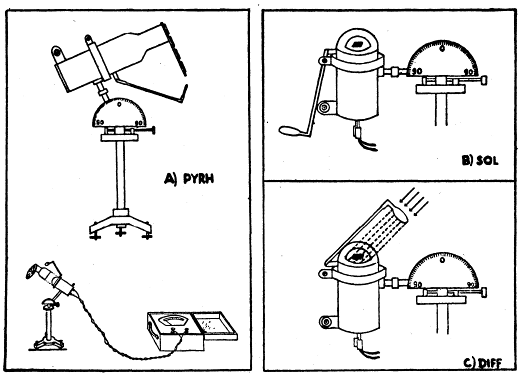

Fig. 2. Gorczyński's solarimeter used for measurement of direct (A), total (B) and dispersed radiation (C) (Gorczyński 1945)

On the coast, in Gdańsk Nowy Port measurements of solar radiation and other phenomena began when the Polish Maritime Observatory of the State Meteorological Institute (PIM) was opened in 1920. That is where in 1924 Gorczyński first attempted measurements by means of a solarimeter of his own design, equipped with a Moll's thermopile and built at Kipp's factory (Gorczyński 1945, 1951). In the Observatory, besides the solarimeter, there were solarigraphs, pyrheliometers and actinographs. On the coast, solar radiation was later measured also in Gdańsk-Wrzeszcz (from 1931), where the measurements were taken on the same type of instruments as in Nowy Port. An actinograph was used there from 1931, and a solarigraph from 1932. The output of recorders was from time to time compared with the indications of the Ångström compensation pyrheliometer (Gorczyński 1951). In 1928 actinometric measurements began in Sopot, and a longer actinometric series was recorded also for Kołobrzeg (Gorczyński 1951).

Systematic actinometric measurements were started by W. Gorczyński in Warsaw at the end of 1900 (Gorczyński 1903). In 1900-1914 they were taken at the upper platform of the Museum of Industry and Agriculture, and in 1915 the measuring site was moved to the Warsaw Scientific Society at Śniadeckich 8, where it was in operation until 1922. From 1923 until World War II the measurements were performed at the Pump Station at Czerniakowska 124 (Mackiewicz 1954). In 1910 the Meteorological Observatory was opened in Grodzisk, approximately 34 kilometres south-west of Warsaw. As it was already said earlier, the purpose of the Observatory was to enable studies on the differences between the climate in the city and the rural areas. One of the meteorological phenomena analysed there was also solar radiation, measured by means of an Ångström compensation pyrheliometer (Gorczyński 1911).

Short series of measurements were recorded for Ursynów (Gorczyński 1951), and Remiszewice in the district (county) of Łódź (June- uly 1932) and Januszewice in the district of Opoczno (August-October 1932) (Gorczyński and Ostrowski 1933). In the two latter places the measurements were made with the same kind of instruments, allowing assessment of direct, dispersed and total radiation. For Remiszewice, a 13-day-long series of observations was recorded, whereas for Januszewice 25 measurement days were available. At both stations the measurements were taken as frequently as possible on each day, from dawn to dusk (Gorczyński and Ostrowski 1934). The collected data series were used to compare the results with the Warsaw actinometric series.

In the years of 1929-1941 measurements of solar radiation by means of a Michelson-Marten actinometer were performed in Racibórz (Silesia) by Mainka (Mackiewicz 1957). In the Wrocław district of Krzyki measurements were carried out from 1929 until 1932, supplemented by the measurements taken with an actinograph at the Wrocław University of Technology between February and May 1932 (Stenz 1959).

Actinometric measurements were also carried out in the mountains. For the Sudetes there are no long series of measurements available for the time before World War I, as they took place in short periods of single days or isolated months. On 20 August 1912 research was conducted at the top and the foot of Mt Śnieżka by W. Marten, and in the 1930s at Mt Sowia by Stenz (September-November 1931 and March-November 1932) (Stenz 1959).

The first pyrheliometric measurements at the foot the Tatra Mountains were taken in Zakopane by August Witkowski. It was a short series comprising two summer months of July and August 1903. Studies of solar radiation in the mountains were also conducted by Edward Stenz. These took place e.g. in January, April and September 1924 in a few different locations in Zakopane and were performed by means of a Michelson actinometer and an Ångström pyrheliometer (Stenz 1925). E. Stenz also recorded a day series (of 11 April 1923) in the Beskid Wyspowy mountain range, and performed the first ever winter measurements in the mountains (the Gąsienicowa Pasture) in January 1933.

The first measurement series recorded in the mountains and covering whole years were collected by Fedorowicz in Zakopane in the years of 1935-1938 and by Stenz at the observatory on Mt Kasprowy Wierch in 1938-1939 (Stenz 1959).

SUMMARY

Due to difficult geopolitical situation the history of meteorological observations, including actinometry, for the territory of today's Poland is very complex. Research was conducted by both Polish organisations and meteorological services of the neighbouring countries. The oldest heliographic observations in Poland are – at the same time – some of the oldest in the world. The first regular measurements of sunshine duration were started at the Astronomical Observatory of the Jagiellonian University in Kraków in 1883 (Gorczyński 1910), and regular actinometric measurements began a few years after the heliographic observations. They were closely connected with Gorczyński, the manager of the Meteorological Office at the Museum of Industry and Agriculture in Warsaw and began in 1900 (Gorczyński 1950). An intensive growth of the measurement network fell on the interwar period of 1918-1939.

The early introduction of actinometric observations in the area of Poland and their subsequent considerable increase in the Polish interwar period are essential for the development of actinometry in Poland. The observations are an important source of historical data, indispensable for the study of climate. They also provided a basis for further developments in actinometric research in the later years.

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3. AIR TEMPERATURE IN WROCŁAW (BRESLAU) IN THE PERIOD 1710-1721 BASED ON MEASUREMENTS MADE BY DAVID VON GREBNER

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INTRODUCTION

The history of early-instrumental meteorological observations in Poland is quite rich and is among the longest in the world. The first observations were made in Warsaw in late 1654 or early 1655, while the temperature series described and analysed here is the second oldest instrumental series in Poland. Temperature and atmospheric pressure observations were made in Wrocław (Breslau, nowadays south-west Poland) from April 1710 to December 1721 by the physician David von Grebner and both series are now the longest surviving Polish series of their kind (Grebner 1723, for more details see also Przybylak 2010).

David von Grebner used the Florentine thermometer (Thermometrum Academiae Florentinae), which had a brass scale with a star in the middle, above which were 80 degrees and below which were 100 degrees (Landsberg 1983). The results of his observations are available in unpublished form in the Library of Wrocław University. For purposes of comparison, another Wrocław physician – Johann Kanold (1679-1729) – began meteorological measurements in Silesia (e.g. Wrocław, Oława, and Legnica) and in other European countries in 1717. He recorded measurements in Wrocław up to 1726, and then from 1727 to 1730 they were continued by Andreas Elias Büchner (1701-1769), a professor of medicine at Wrocław University (Brázdil and Valášek 2002, Munzar 2003, Brázdil *et al*. 2008). These included measurements of air temperature, air pressure, wind direction and general descriptions of weather. Measurements were taken three times a day and the results were published in an encyclopaedic series *Sammlung Von Natur- und Medicin-, Wie auch hierzu gehörigen Kunst- und Literatur-Geschichten* (the so-called *Breslauer Sammlung* – Wrocław Collection).

In the early-instrumental measurement period observers used thermometers with unknown individualised scales which are difficult to convert to the scales used in present-day instruments. That is why comparison of temperature changes between historical times and the present-day is rather difficult. At the first half of the 18th century all over Europe, thermometers based on the Florentine thermometer (Magnum Thermometrum Academiae Florentinae) have often been used. However, these instruments were different from those originally constructed in Italy. For example, in Europe (including Italy) Florentine thermometers with 180-degree, 200-degree or even with 360-degree scales were used (Middleton 1966, Quinn and Compton 1975). Moreover, the two fixed points used in the construction of today's thermometers (freezing and boiling points) were not used in these thermometers. That is why, even comparison of temperature measurements made by different thermometers of the same type can be impossible, if the instruments were not identical and more research is still needed to solve the problem of converting the old scales to new ones. Some work has already been done on this issue (e.g. Camuffo 2002a, 2002b, Cocheo and Camuffo 2002), however, similar investigations are needed for other copies of thermometers. At present the only way we can compare the historical and present climate is by using the index method for available temperature measurements (for more details about this method see, e.g. Pfister 1992 or Przybylak *et al.* 2005).

For the purposes of describing the present temperature characteristics in Wrocław the following studies have been used: Kosiba (1948), Pyka (1991, 1998), Dubicka (1996), Dubicka and Pyka (2001).

DATA AND METHODS

Temperature data for Wrocław (Fig. 1) used in the present paper generally cover the period from 18th April 1710 to 31st December 1721. The series, however, contains two big gaps: i) from 3rd September 1712 to 26th October 1713 and ii) from 25th July to 31st August 1717. As a result, years with incomplete data have been excluded from this analysis. In the source documents there is no information about the precise location of these measurements, the exposition of the thermometer or its height above ground level (Landsberg 1983, Pyka 2003). However, it is quite possible that the thermometer was installed in a window.

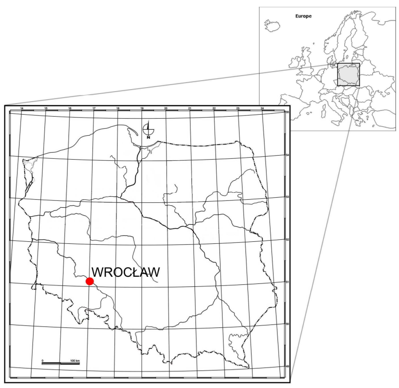
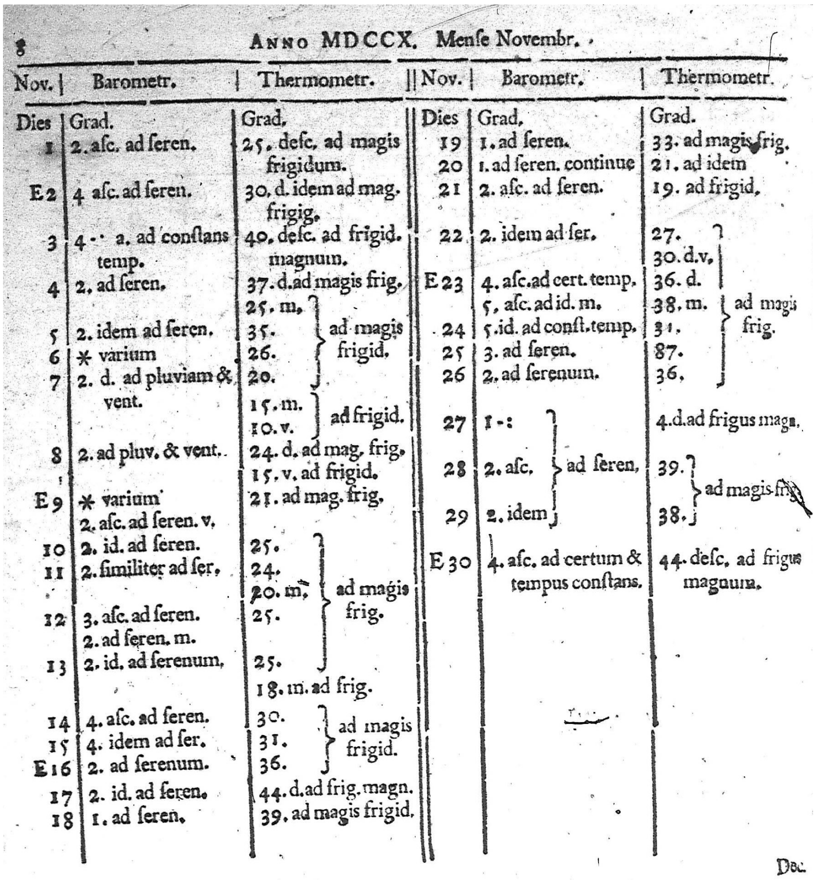


Fig. 1. Location of Wrocław in Poland and Europe

Air temperature measurements were made once a day (usually in the morning), but during periods when there were extreme weather changes measurements were made more frequently, i.e. two to three times a day or more (Fig. 2). Complete data, however, only exist for the morning hours, and therefore it is only these which have been used for the analysis.


ANNO MDCCX. Menſe Novembr.

Nov.	Barometr.	Thermometr.	Nov.	Barometr.	Thermometr.
Dies	Grad.	Grad.	Dies	Grad.	Grad.
1	2. aſc. ad ſeren.	25. deſc. ad magis frigidum.	19	1. ad ſeren.	33. ad magis frig.
			20	1. ad ſeren. continue	21. ad idem
E2	4 aſc. ad ſeren.	30. d. idem ad mag. frigig.	21	2. aſc. ad ſeren.	19. ad frigid.
3	4 ·· 2. ad conſtans temp.	40. deſc. ad frigid. magnum.	22	2. idem ad ſer.	27.
					30. d.v.
4	2. ad ſeren.	37. d. ad magis frig.	E23	4. aſc. ad cert. temp.	36. d.
		25. m.		5. aſc. ad id. m.	38. m. ad magis frig.
5	2. idem ad ſeren.	35. ad magis frigid.	24	5. id. ad conſt. temp.	31.
6	✻ varium	26.	25	3. ad ſeren.	37.
7	2. d. ad pluviam & vent.	20.	26	2. ad ſerenum.	36.
		15. m. ad frigid.			
		10. v.	27	1. : ad ſeren.	4. d. ad frigus magn.
8	2. ad pluv. & vent.	24. d. ad mag. frig.	28	2. aſc.	39. ad magis frig.
		15. v. ad frigid.			
E9	✻ varium	21. ad mag. frig.	29	2. idem	38.
	2. aſc. ad ſeren. v.				
10	2. id. ad ſeren.	25. ad magis frig.	E30	4. aſc. ad certum & tempus conſtans.	44. deſc. ad frigus magnum.
11	2. ſimiliter ad ſer.	24.			
		20. m.			
12	3. aſc. ad ſeren.	25.			
	2. ad ſeren. m.				
13	2. id. ad ſerenum.	25.			
		18. m. ad frig.			
14	4. aſc. ad ſeren.	30. ad magis frigid.			
15	4. idem ad ſer.	31.			
E16	2. ad ſerenum.	36.			
17	2. id. ad ſeren.	44. d. ad frig. magn.			
18	1. ad ſeren.	39. ad magis frigid.			

Dec.

Fig. 2. Example of source data document for Wrocław (1710-1721) (Grebner 1723)

The Florentine thermometer had a brass scale divided into 180 sections with a star in the middle (Fig. 3). In addition, the scale had descriptions of different categories of thermal sensations (Tab. 1). Data were digitised and their quality was checked. All standard statistical calculations were conducted and the results were shown in Florentine degrees (hereafter deg.).

Table 1. Thermal sensation descriptions on the scale of the Florentine thermometer used in Wrocław, 1710-1721

Thermal sensation	Range in F.S. deg.
Hot and dry ("*ad calidissimus*")	>60
Very warm ("*ad magis calidum*")	40- 60
Warm ("*ad calidum*")	20-40
Moderation ("*temperatum*")	0-20
Cold ("*ad frigidum*")	–20-0
Very cold ("*ad magis frigidum*")	–40-–20
Frost ("*ad frigidus Magnum*")	–60-–40
Sharp frost ("*ad frigidissimus*")	<–60

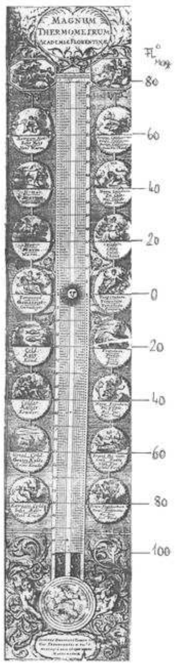


Fig. 3. Magnum Thermometrum Academiae Florentine (www.freunde-alteretterinstrumente.de; 06.2010)

RESULTS AND DISCUSSION

The absolute range of air temperatures in the study period oscillated from –91.0 (31^{st} Dec. 1711) to 55.0 (23^{rd} Jul. 1712) Florentine scale degrees. Annual mean air temperature in the period 1710-1721 (excluding the incomplete years 1712, 1713 and 1717) reached –12.6 deg. On average, the warmest month was July (20.1 deg.) while the coldest was January (–46.4 deg.) (Fig. 4). In these months air temperatures of above +20.0 deg. (July) and below –20.0 deg. (January) were recorded with the greatest frequency of occurrence.

The coolest year in the study period was 1711 (–17.8 deg.) and the warmest was 1719 (–7.8 deg.). In the warmest year both winter and summer were also the warmest with mean temperatures of –36.0 deg. and 26.4 deg., respectively. On the other hand, the very cold averages of 1711 were the result of very low winter and autumn temperatures, the lowest of the whole study period. On average, autumn (–11.6 deg.) was warmer than spring (–14.4 deg.) (Tab. 2). Only for summer was the mean air temperature above 0.0 deg (Fig. 5).

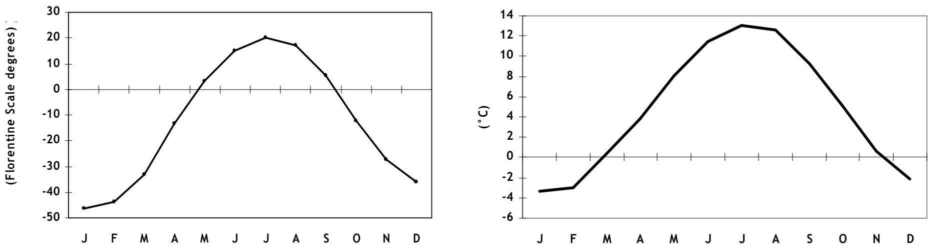


Fig. 4. Annual courses of air temperature in Wrocław, 1710-1721 (upper graph) and 1970-1981 (lower graph). (Explanations: J, F, M, … – January, February, March,

Table 2. Mean seasonal values of air temperature in Wrocław in the period 1710-1721 in Florentine Thermometer Scale degrees

Month	deg	Month	deg	Month	deg	Season	deg
Jan.	–46.4	May	3.3	Sep.	5.3	Winter	–41.9
Feb.	–43.7	Jun.	14.9	Oct.	–12.1	Spring	–14.4
Mar.	–33.0	Jul.	20.1	Nov.	–27.1	Summer	17.3
Apr.	–13.4	Aug.	17.1	Dec.	–36.0	Autumn	–11.6

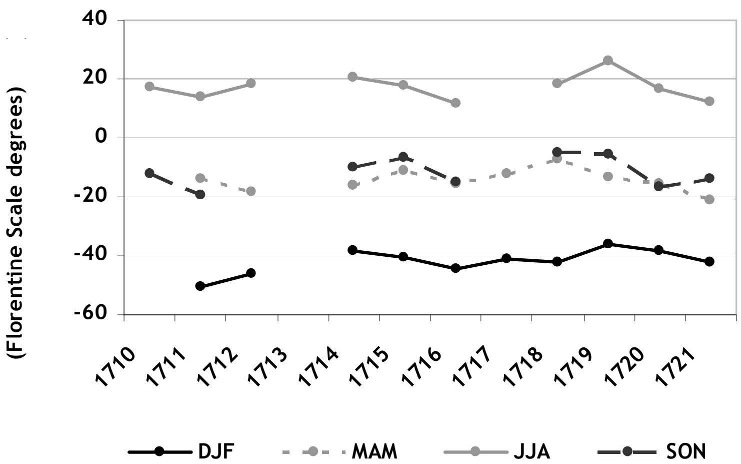


Fig. 5. Year-to-year courses of mean seasonal values of air temperature in Wrocław, 1710-1721. (Explanations: DJF, MAM, … – winter, spring, …)

Anomalies of annual mean air temperatures (with reference to the whole period) show two periods with positive values, and probably three periods with negative values (Fig. 6). The patterns of occurrence of temperature anomalies in autumn are similar to those of annual anomalies. On the other hand, winter anomalies increased gradually from the beginning to the end of the study period. A similar increase (though not quite as clear) can be observed for the summer air temperature anomalies. The spring was clearly warmer in the second part of the study period.

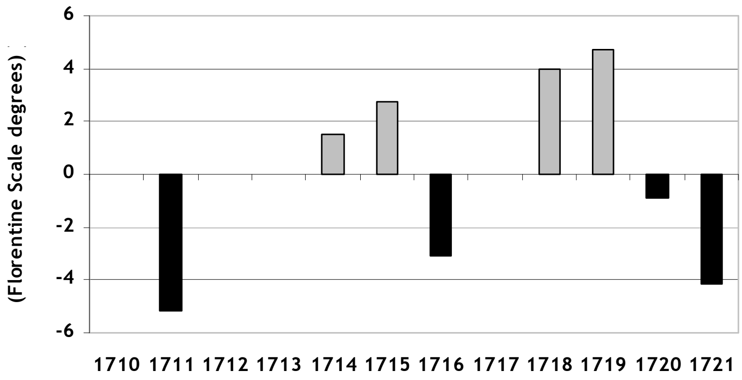


Fig. 6. Year-to-year course of mean annual air temperature anomalies in Wrocław in the period 1710-1721

The thermometer scale had descriptions of thermal sensation which are set every 20 deg. Based on these descriptions the frequency of occurrence of each category was calculated (Fig. 7). In winter, temperatures of below -20.0 deg. dominated with a frequency of 99%. The highest frequency of "sharp frost" was noted in January and February. In summer temperatures above +20.0 deg. occurred with a frequency of 97%. The extreme warm thermal sensations "hot and dry" occurred only in July and August.

Due to the difficulties in scale conversion, a detailed comparison of the temperatures in Wrocław in the study period with contemporary temperature conditions is still not possible. However, it is possible to compare some features of the annual courses. The comparison of such data from the historical period with contemporary data from the 20th century (1970-1981) shows similar annual runs of air temperature; in both cases the highest and lowest mean monthly temperatures occurred in July and January, respectively (Fig. 4).

From the literature we know that the beginning of the 18th century is colder than the second half of the 20th century (Przybylak 2007, 2008). This period is considered as the close of the Little Ice Age (Lamb 1977, after Brázdil et al. 2005). The first twenty years of the 18th century are about 0.5°C cooler throughout

Europe than the 20th century (Brázdil *et al*. 2005). This is confirmed by the high frequency of occurrence of categories of thermal sensations described as “very cold”, “frost” and “sharp frost”, during winter in the period 1710-1721. However, we should remember, that the analysed data are from morning measurements, and therefore should be compared to minimum temperature rather than to the daily mean. The comparison of the data measured with minimum temperature from Wrocław is being tested and results of this work will be published in a separate paper.

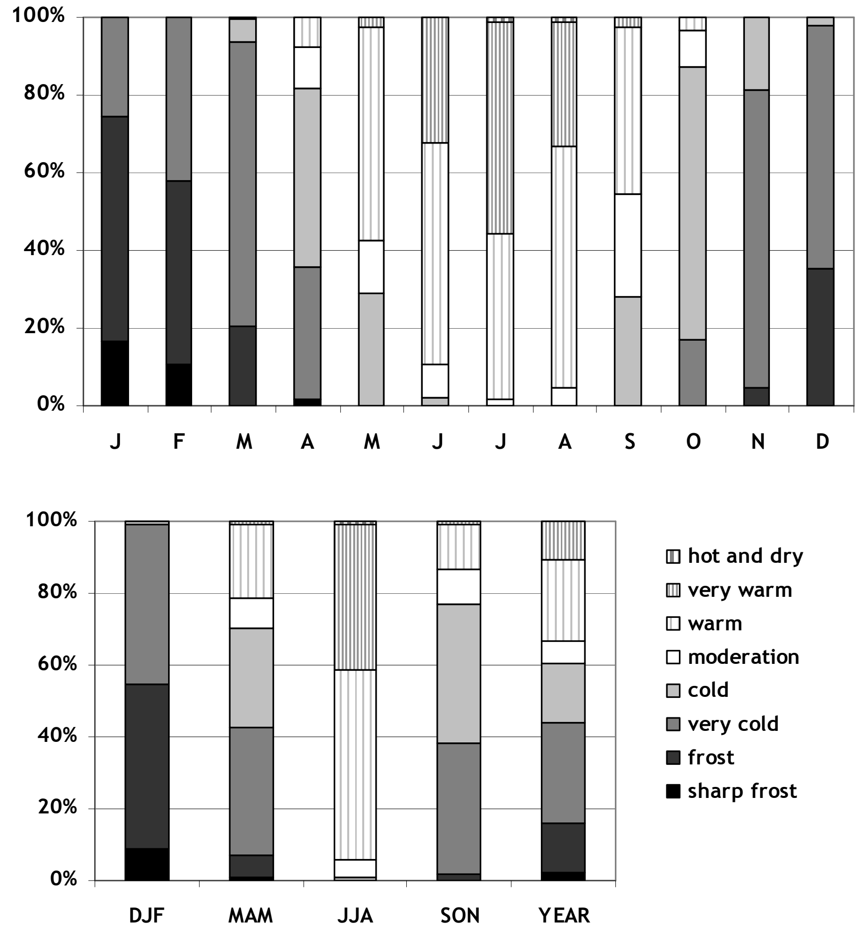


Fig. 7. Frequency of occurrence of specific categories of thermal sensations based on the scale used on the Florentine Thermometer (Wrocław, 1710-1721). (Explanations as in Fig. 4 and 5, respectively)

CONCLUSIONS

1. The thermal conditions in Wrocław in the period 1710-1721 were cool, with a high frequency of temperatures lower than –20.0 deg. In the study period mean annual temperature values show an increasing tendency.
2. Winter air temperature had the strongest influence on annual mean air temperature in Wrocław, which was coldest in the coldest year and warmest in the warmest year in the period 1710-1721. Winter air temperature maintains this influence in the present climate.
3. There is a great need to convert the scale of the Florentine thermometer used in Wrocław (1710-1721) into Celsius. Attempts to do this up to now have not met with any success.

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4. COMPARISON BETWEEN OBJECTIVE AND SUBJECTIVE METHOD OF CLASSIFICATION OF ATMOSPHERIC CIRCULATION FOR AREA OF POLAND

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INTRODUCTION

A typological procedure of atmospheric circulation in the subjective method (SM) developed by Osuchowska-Klein (1978) is based on a subjective estimation of synoptic situations by comparison with circulation model types. Such procedure can lead to different interpretations of synoptic situations if it is made by different people (than author of classification). In such a procedure there is a problem with updating of calendar of atmospheric circulation for a longer time. There was an attempt to solve this problem though the objective method (OM). To the automation of Osuchowska-Klein's SM, Jenkinson and Collison method was used (Jenkinson, Collison 1977). This method was used for automation of the Lamb classification for the British Islands (Jones *et al.* 1992). The objective method was also useful in analyses of relation between atmospheric circulation and different meteorological parameters, among others, in Sweden (Linderson 2001), Estonia (Post *et al*. 2002), the Iberian Peninsula (Trigo and DaCamara 2000, Spellman 2000, Goodess and Palutikof 1998). The objective method was, with some changes, adapted to Osuchowska-Klein's method. In the comparison with Jenkinson and Collison method, new criteria were developed for the determination three atmospheric circulation types distinguished by Osuchowska-Klein: central anticyclonic, south intermediate between cyclonic and anticyclonic and unclassified. The detailed description of the objective method scheme is presented in the study of Piotrowski (2009).

The main objective of the study was to check the adaptation degree of the objective method to subjective method of classification of atmospheric circulation developed by Osuchowska-Klein for the area of Poland. The adaptation degree was checked by the frequency of atmospheric circulation types determined by the use of the objective method during particular atmospheric circulation types determined by the use of the subjective method. Another way was the interpretation of selected synoptic situations according to the objective and subjective classifications. Moreover, the spatial distribution of air pressure at sea level (SLP) on model maps of atmospheric circulation types distinguished by Osuchowska-Klein was compared with maps of spatial distribution of average standardized values of SLP during adequate atmospheric circulation types determined by the use of the objective method. An influence of particular atmospheric circulation types determined by the use of the objective and subjective methods for selected meteorological parameters (air temperature, total precipitation, water vapour pressure) in two seasons – winter and summer was also analyzed.

DATA

The procedure of determination of circulation types by the use of the objective method is based mainly on two circulation indices – shear vorticity and geostrophic wind. Geostrophic wind was also used as atmospheric circulation index for Poland area by Lityński (1969), Wibig (1994), Ustrnul (1998), Kożuchowski (2003). Both indices mentioned above were calculated by the use of mean daily air pressure at sea level (SLP) from grid points about resolution $2.5^{o}\times2.5^{o}$. Air pressure data come from NCEP-NCAR reanalysis database (Kalnay *et al.* 1996) and include data from 1958 to1990. From the same period there are data in form of daily atmospheric circulation types determined by Osuchowska-Klein (1978, 1991). To characteristic of influence of atmospheric circulation types (determined by the use of the subjective and objective method) on meteorological parameters, there were used data from meteorological station in central Poland (Łódź-Lublinek; $51^{o}44$’N, $19^{o}24$’E). The data include daily average, daily maximum and minimum air temperature, daily total precipitation, water vapour pressure from 12 GMT for two seasons – summer and winter. Osuchowska-Klein’s classification does not take into account the northerly circulation. The OM takes into consideration this sector, because the frequency of northerly circulation is similar to frequency from easterly and southerly sectors, which was taken into consideration in the SM (Piotrowski 2009). In the OM, the northerly sector is divided into two parts $337^{o}30$’-360^{o} and 0^{o}-$22^{o}30$’. First part was added to north-westerly cyclonic and anticyclonic types and second part to north-easterly and easterly cyclonic type and north-easterly anticyclonic type. This procedure can be seen in names of atmospheric circulation types and their letter symbols. In case of the subjective types, letter symbols remained unchanged. In the OM letter symbols are changed. They are connected with direction of geostrophic flow (capital letters) and with characters of circulation (lower cases letters). The set of symbols for all types in the OM together with adequate symbols in the SM (in brackets) is following: NEaN (E) – anticyclonic north-easterly partly northerly, E-SEa (E_1) – anticyclonic easterly and south-easterly, S-SWa (D_2C) – anticyclonic southerly and south-westerly, Wa (C_2D) – anticyclonic westerly, NWaN (E_2C) – anticyclonic north-westerly partly northerly, NE-EcN (E_0) – cyclonic north-easterly and easterly partly northerly, SEc (F) – cyclonic south-easterly, Sc (B) – cyclonic southerly, SWc (D) – cyclonic south-westerly, Wc (A) – cyclonic westerly, NWcN (CB) – cyclonic north-westerly partly northerly, Ca (G) – central anticyclonic, Sac (BE) – southerly intermediate between anticyclonic and cyclonic, X (X) – unclassified.

The three similarity degrees to model chart of atmospheric circulation type in the SM are omitted in the OM. This partition is helpful in case of the subjective classification, but generates additional types of atmospheric circulation. It complicates statistical analysis.

RESULTS

A frequency of atmospheric circulation types determined by the use of the SM during particular atmospheric circulation types determined by the use of the OM (Fig. 1.) gives the information about a adaptation degree of the OM to the SM.

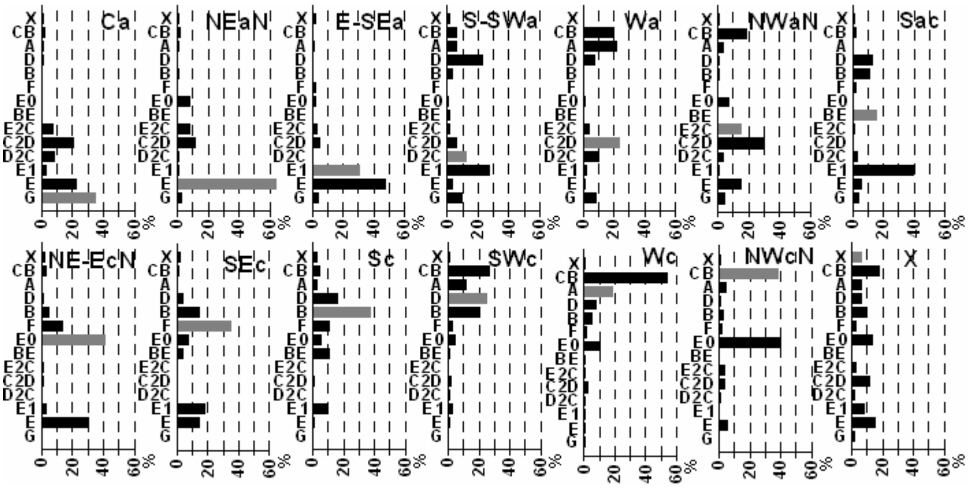

Fig. 1. Relative frequency of atmospheric circulation types determined by the use of the subjective method during types determined by the use of the objective method

The highest concurrence of interpretation of synoptic situations in both methods is visible in case of the NEaN (E) circulation type. It's an effect of the similar location of anticyclonic center over Scandinavia and a high annual frequency E type in the comparison with frequency NEaN type (Fig. 2). Anticyclonic types show better the concurrence of interpretation of synoptic situations (37.2% cases) than cyclonic types (25.4% cases). Some of the same types in both methods (S-SWa and C_2D, NWaN and E_2C, NWcN and CB) differ considerably from each other in annual frequency of occurrence (Fig. 2). This is the effect of the different methodology. The SM is based on comparisons of synoptic charts from main standard time during a day. A final effect is determination of daily atmospheric circulation by the use of model charts taking into consideration three similarity degrees to a model chart. The OM is based mainly on atmospheric circulation indices (geostrophic wind and shear vorticity), which are useful in determination of direction of geostrophic flow and character of atmospheric circulation. In the SM is of prime importance a locations of surface pressure centers, while in the OM a location of pressure centers is a result of pressure differences, principally in the centre of the area. The view of synoptic situations (for example such as in Figure 3) during atmospheric circulation types determined by the use of the OM shows that the direction of air flow can be the same during the different locations of baric system. A constant location of baric system usually assures inflow of air masses from the same area, but in many cases it is also possible during different location of baric system. The reasons of different interpretation of synoptic situations in both methods are well visible too in the location of baric systems on model charts in the SM and on maps that present standardized values of SLP for selected atmospheric circulation types in the OM (Fig. 4).

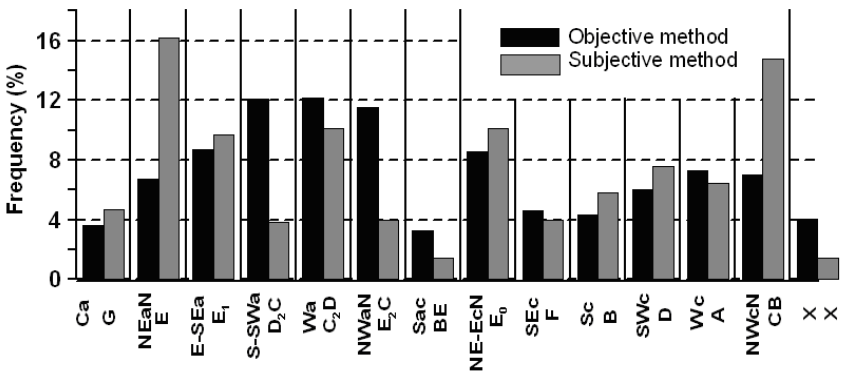

Fig. 2. Annual relative frequency of atmospheric circulation types determined by the use of the objective and subjective method

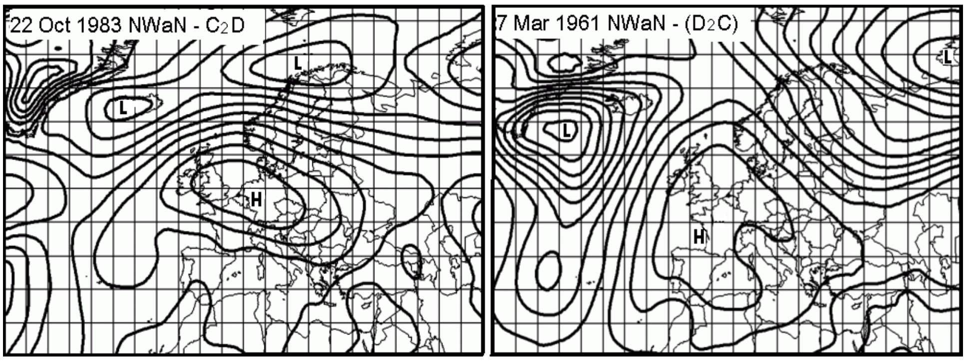

Fig. 3. Examples of interpretation of synoptic situations (on the basis of charts of distribution of average daily values of SLP) according to the objective and subjective method

Atmospheric circulation types have an influence on a forming specific weather types. It's very difficult to affirm, on the basis of values of meteorological parameters, which method is the best one in approximating the influence of atmospheric circulation on weather conditions, because many factors may influence it. Moreover, average values of meteorological parameters can depend on mistakes in interpretation of synoptic situations. Supposing that the OM interpreted atmospheric circulation almost correctly, Figure 1 informs for example that the D type is often interpreted in the OM as the S-SWa, Sac and Sc circulation. It is reflected in higher values of air temperature and lower precipitation during the D type in summer in the comparison with the SWc type. Some atmospheric circulation types give higher deviations of selected meteorological parameters (air temperature, total precipitation, water vapour pressure) then norm in annual course. Values of deviations can indicate approximately, which method of classification of atmospheric circulation gives better results. For example, average daily air temperature in winter (Fig. 5) is lower in most cases of anticyclonic circulation (with the exception of the Wa and NWaN types) determined by the use of the OM than by the use of the SM. The highest differences of air temperature in winter between both methods range to 3.5^{o}C in case of the NWaN (E_2C) type and 3.3^{o}C in case of the S-SWa (D_2C) type. E_2C circulation type is connected with very cold advection air masses from very chilled Greenland. However, in the OM, warmer air masses inflow very often over Poland from sea areas from the same direction. In case of the S-SWa (D_2C) type, a high difference of air temperature results from a location of a high center over the Mediterranean Sea in the SM (Fig.4). This location prefers advection of warm masses from south-westerly direction.

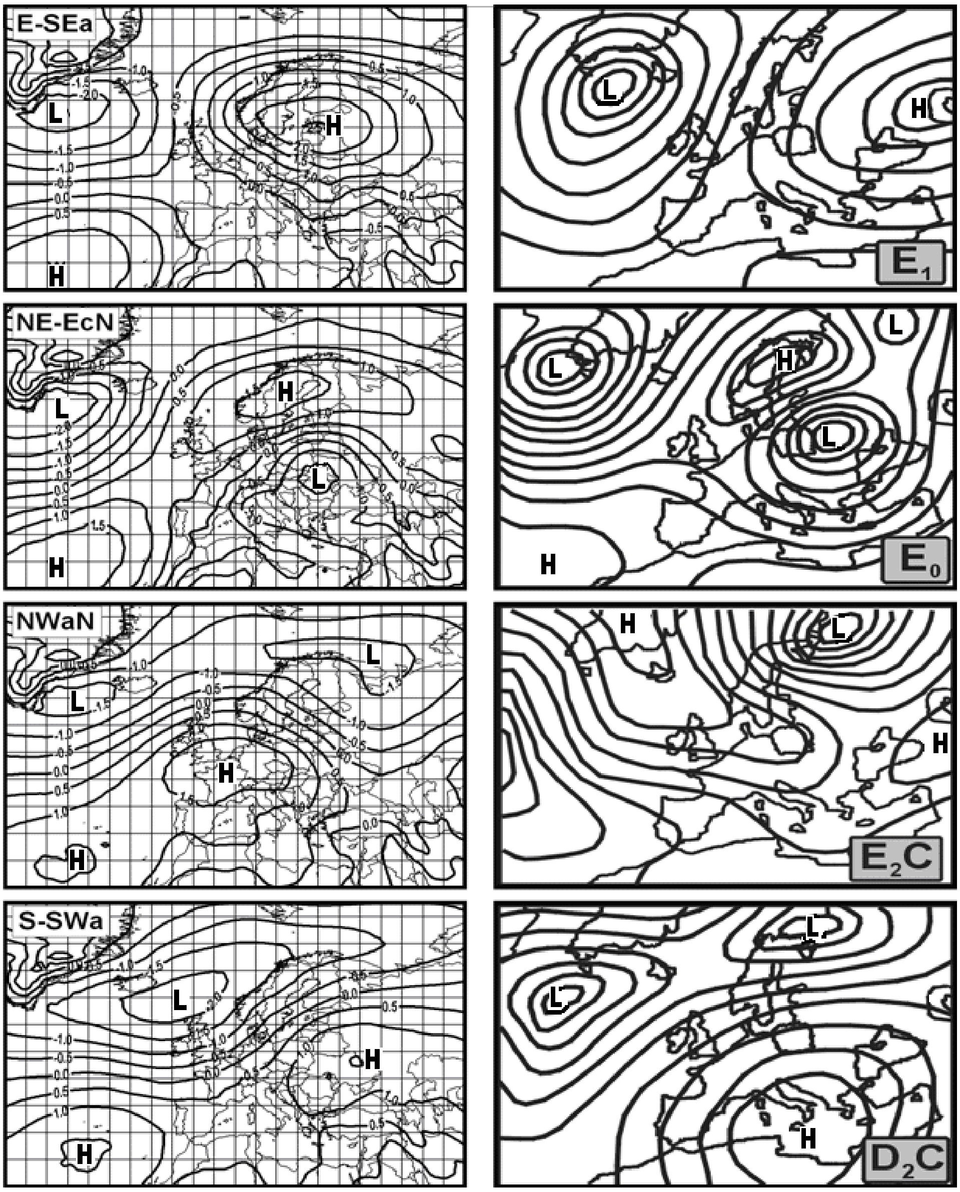

Fig. 4. The spatial distribution of pressure systems on charts of standardized values of SLP during atmospheric circulation types determined by the use of the objective method (left panel) and model charts of atmospheric circulation types determined by the use of the subjective method (right panel)

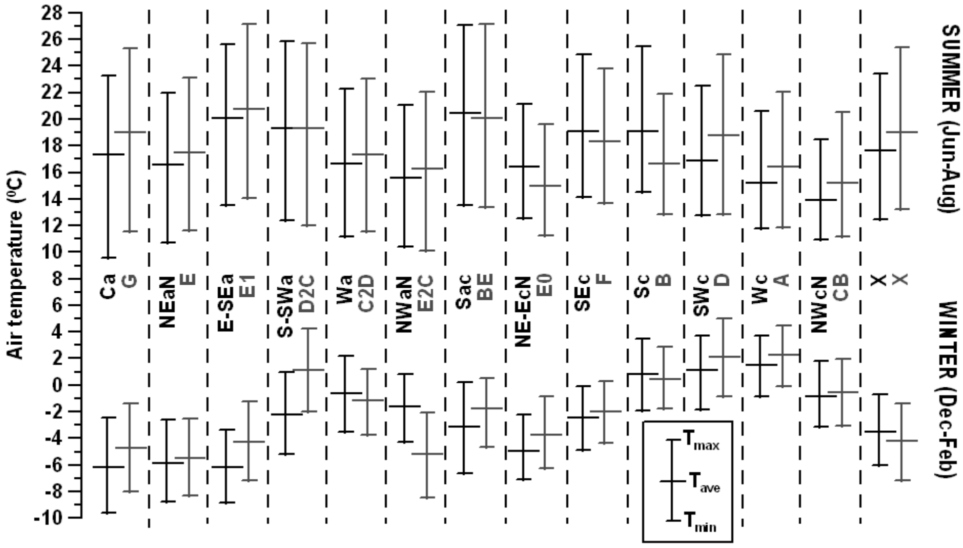

Fig. 5. Mean values of daily average (T_{ave}), maximum (T_{max}) and minimum (T_{min}) air temperature during atmospheric circulation types determined by the use of the objective and subjective method in summer and winter

In the OM the center high quite often occurs over area to the north of the Black Sea. From this region, in winter, cold air masses flow over Poland. In summer differences of air temperature during adequate circulation types in both methods are higher in case of cyclonic circulation than anticyclonic circulation. For example – during the NWcN, Wc, SWc circulation is colder than during the adequate CB, A, D types and is warmer during the NE-EcN, S and SEc circulation than during the adequate E_0, B and F circulation types.

The comparison of median values of water vapour pressure in winter (Fig. 6) during circulation types determined by the use of the SM and OM shows that the highest differences between values of this parameter occurred during the atmospheric circulation types: S-SWa (D_2C), NWaN (E_2C) and Sac (BE). It is mainly resulted from differences of air temperature in winter. In summer during the Ca and E-SEa circulation types, the content of water vapor in air is considerably lower than during adequate to them types in the SM and particularly high during the NE-EcN and Sc types in the comparison with the adequate E_0 and B types. In case of the Ca and E-SEa types the low water vapour pressure is connected with intense insolation during day. Following the E-SEa circulation in summer brings very dry and warm continental air masses over the area of Poland. A source area has an influence on moisture properties of air. It is clearly visible in cases of the NE-EcN and Sc types. During the NE-EcN circulation wet air masses are often transported from the area of the Black Sea. In case of the same circulation in the SM air masses are drier because of the location of the baric center (Fig. 4).

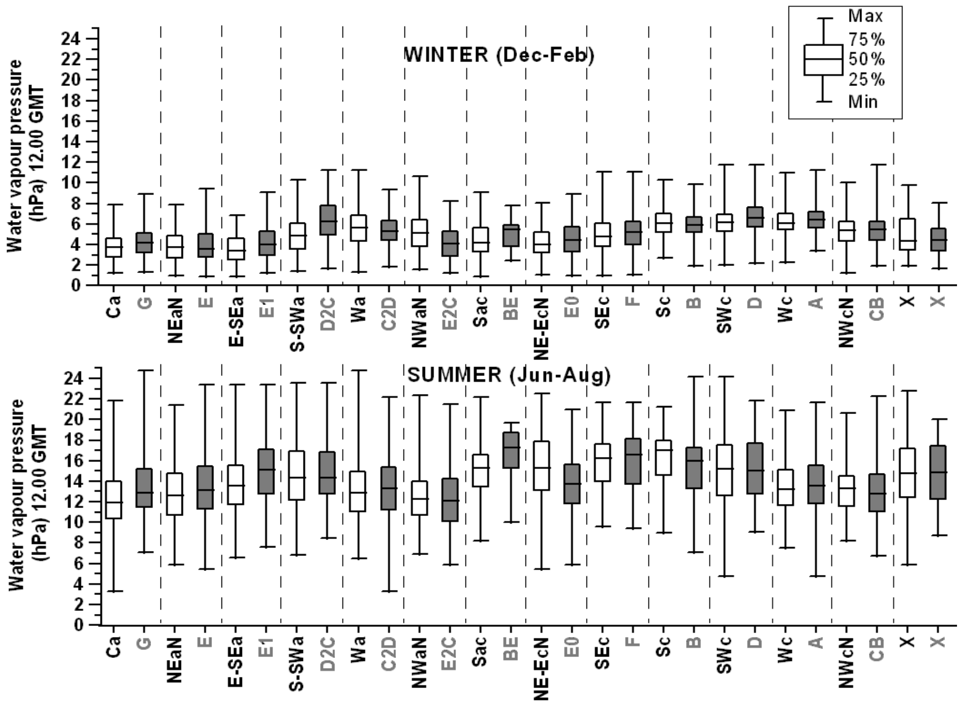

Fig. 6. Quartiles of water vapour pressure during circulation types determined by the use of the objective and subjective method in winter and summer

Differences of total precipitation in summer are higher between corresponding atmospheric circulation types in both methods than in winter. In summer all anticyclonic circulation types in the OM give lower precipitation than adequate to them types in the SM. In case of the cyclonic types situations is reverse with the exception of the southerly cyclonic circulation. During this circulation sometimes the low that control an advection is a long distance from Poland and cloudiness zone with precipitation that is connected with a low does not every time covers the Poland area. Generally, in summer total precipitation is lower during the anticyclonic circulation (about 22.5%) and higher during the cyclonic circulation (about 14.7%) in the case of the OM in comparison with the SM. In winter precipitation is lower about 12,1% during the anticyclonic types and higher about 2,4% during the cyclonic types comparing the OM with the SM.

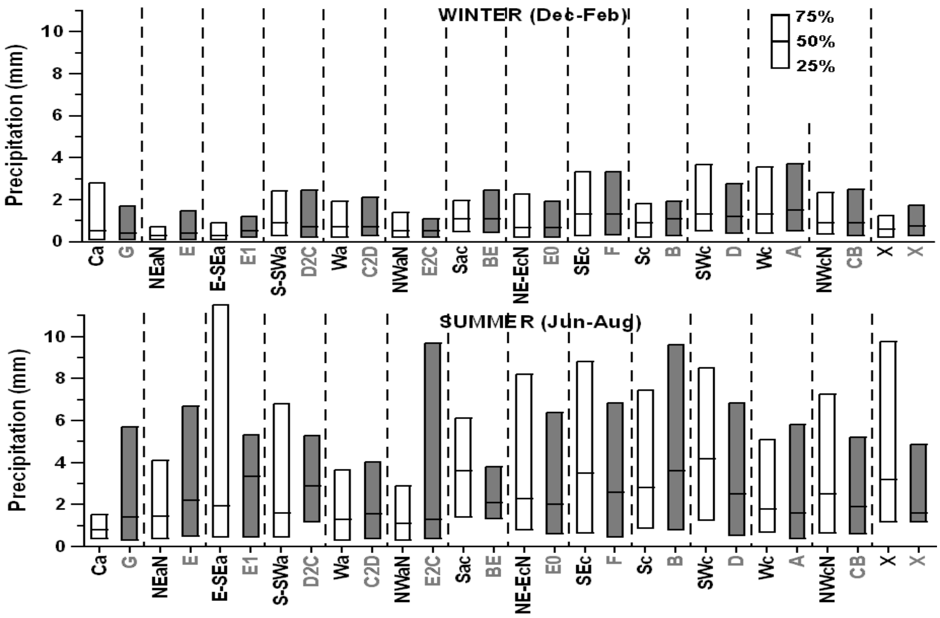

Fig. 7. Quartiles of average daily precipitation calculated for days with precipitation greater or equal 0.1 mm during types determined by the use of the objective and subjective method in winter and summer

CONCLUSIONS

In many cases, different average values of meteorological parameters occurred during the same circulation types determined by the use of the objective and subjective method. Many relations (for example lower precipitation and air temperature during the anticyclonic circulation and higher precipitation during the cyclonic circulation in case of the objective method in comparison with the subjective method) indicate that the weather conditions are a slightly better approximated during objective circulation types. Analysis of selected synoptic situations revealed differences in an interpretation of given synoptic situations in both methods. It is reflected in differences of frequency of corresponding to each other atmospheric circulation types in both methods. Coincidence of the same atmospheric circulation types in a given day does not occur often in both methods.

Coincidence of anticyclonic types occurs in 30.0% of cases and cyclonic types in 32.3% of cases. In spite of these differences, the objective method is possible to create the time continuing calendar of atmospheric circulation types.

The low degree of adaptation of the objective method in relation to the subjective method of atmospheric circulation classification results from:

1. Different data were used to determine a daily circulation type. In the objective method to calculate circulation indices, there were used average daily values of atmospheric pressure at see level. In case of the subjective method, there were used synoptic charts from several main standard time during day. On the basis of this charts, it was classified of synoptic situations to a daily atmospheric circulation type by comparison with model charts. In the subjective method, a comparison of charts from several main standard times can lead to mistakes in interpretation of synoptic situations. Particularly, comparisons are very difficult in case of a significant differences of distribution of SLP between main standard times. However, daily average values of air pressure used in objective method cover up a dynamic of chances of baric field.
2. Quality of data. In the subjective method, interpretation of synoptic situation on the basis of synoptic charts with high values of isobar interval can lead to problems with proper estimation of situations in case of weakly gradient of air pressure.
3. Differences in location of baric systems, which control atmospheric circulation. In the subjective method especially take into consideration a location baric systems and less for a course of isobars across the area of Poland. The view of synoptic situations during particular circulation types determined by the use of the OM shows that a course of isobars is also very important.

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5. THE ATMOSPHERIC CIRCULATION INFLUENCE ON INSTABILITY CONDITIONS OVER EUROPE

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INTRODUCTION

The atmospheric circulation (together with solar radiations and water vapor circulation) is the main factor that is creating weather conditions. The analysis of relationship between atmospheric circulation and selected weather elements need to identify low-frequency variability pattern.

Two main methods – the teleconnection method and principle component analysis are used in empirical studies to do this for low-frequencies variability pattern. The teleconnection method obtains temporal correlations in a meteorological parameter between one given geographical location and all other in the domain. This procedure is repeated using every possible point as the base point. The locations producing the highest correlation fields accepted as the "centers of actions".

The principle component analysis (PCA) created the eigenvectors of the crosscorrelation matrix are individually scaled according to the amount of total data variance they explain and then linearly transformed under certain constrains to obtain the major circulation pattern. Using this method Barnston and Livezey (1987) computed ten monthly spatial variability modes in a hemispheric 700 hPa dataset, Rogers (1990) in a Northern Hemisphere sea level pressure. Clinet and Martin (1992) described circulation pattern over Europe and North Atlantic. This works relevant few dominant teleconnection patterns referred to as the North Atlantic Oscillation, East Atlantic/Western Russia pattern, Scandinavia pattern.

The European climate conditions are created by a large scale meridional oscillation of atmospheric mass between the subtropical anticyclone near the Azores and the subpolar low pressure system near the Iceland, terms North Atlantic Oscillation (NAO). Numbers of different studies have shown relevance of the NAO to the winter temperature over the Atlantic and European sector (Hurrel 1995, Hurrel i von Loon 1997, Toumenvirth *et al*. 2000, Greatbatch 2000, Huang *et al.* 2006). Additional studies have established links between NAO pattern and precipitations anomalies. Positive anomaly values of precipitations are concerted in the northern Europe and extend from Greenland to northern Russia. Southern Europe is characterized by negative precipitation anomalies (Alexandersson 1996, Almerza and Lopez 1996, Wibig 2001).

The second pattern used in this study, terms East Atlantic, (abbreviate EA) consist of north-south dipole of anomaly centers spanning the North Atlantic. The positive phase of the EA pattern is associated with positive anomalies of surface temperatures in Europe due to modulations in the subtropical influence intensity. It is also associated with above-average precipitation over northern Europe and negative anomalies of precipitation over southern Europe.

The Scandinavia Pattern (SCAND) is the third circulation type used in this study. The positive phase of this pattern is associated with blocking anticyclones occurred over Scandinavian Peninsula and western Russia. During the positive phase of this pattern temperature below-average occurred over western Europe. It is also associated with above-average precipitation above central and southern Europe.

The time series of instability indices values shows periods with higher and lower values of instability conditions. There is the question then - how the atmospheric circulations determine the instability conditions over different regions of Europe. The purpose of this work is to determine links between instability conditions and selected modes of atmospheric variability.

DATA AND METHODS

The investigation of spatial distribution of relationship between instability conditions and atmospheric circulation is based on radiosounding data and type of atmospheric circulation. Radiosounding measurements are from 41 stations, taken at 00 UTC, covering the area between 35N and 65N, and between 10W and 50E, from the period 1993-2007. The stations used in this study are shown in Figure 1. This selected group of radiosounding stations contains the most complete data series.

The radiosounding data sets are used to calculate selected indices: Convective Available Potential Energy (CAPE), Vertical Total (VT), KI-index (KI), Total Totals (TTI). These indices are calculated by combined measurements of thermal and moisture properties.

CAPE is a vertically integrated index and measures the cumulative buoyant energy in the free convective layer from the level of free convection (LFC) to the equilibrium level (EL) (Doswell and Rasmusen 1994, Ye *et al*. 1997, Blanchard 1998). The formal definition is given by:

$$CAPE = g\int_{LFC}^{EL}\left(\frac{T_{VP}-T_{VE}}{T_{VE}}\right)dz \qquad (1)$$

where T_{VP} is the virtual temperature of the parcel and T_{VE} is the virtual temperature of the environment.

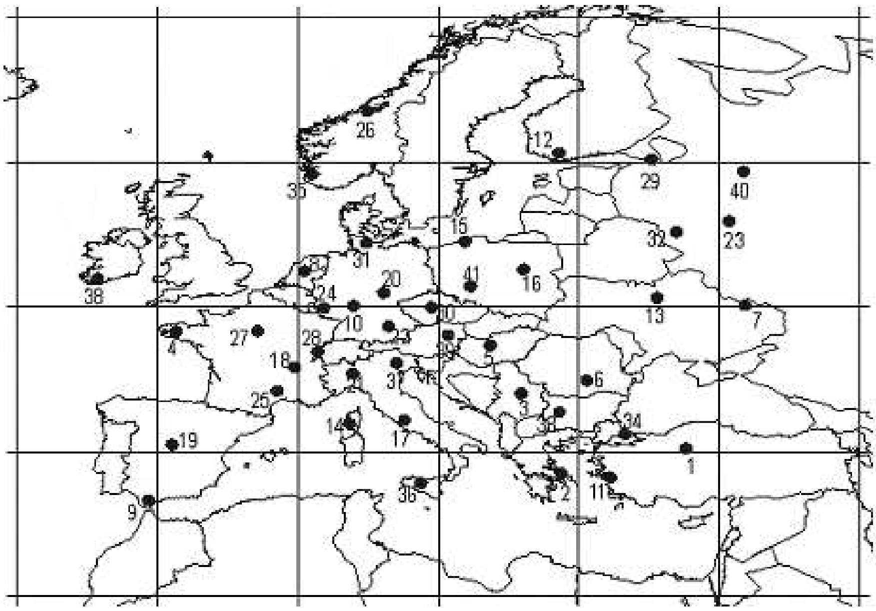

Fig. 1. Geographical distribution of the stations used
1 – Ankara, 2 – Athinai, 3 – Beograd, 4 – Brest, 5 – Budapest, 6 – Bucuresti, 7 – Kharkiv, 8 – De Bilt, 9 – Gibraltar, 10 – Idar, 11 – Izmir, 12 – Jokioinen, 13 – Kyiv, 14 – Ajaccio (Corsica), 15 – Leba, 16 – Legionowo, 17 – Lire, 18 – Lyon, 19 – Madrid, 20 – Meiningen, 21 – Milano, 22 – Muenchen, 23 – Moscva, 24 – Nancy, 25 – Nimes, 26 – Orland, 27 – Trappes (Paris), 28 – Payerne, 29 – St.Petersburg, 30 – Praha, 31 – Shleswig, 32 – Smolensk, 33 – Sofia, 34 – Istanbul, 35 – Stavanger, 36 – Trapani (Sicilia), 37 – Udine, 38 –Valentia, 39 –Wien, 40 –Vologda, 41 – Wroclaw.

The next group of indices, describing the convective and severe weather potential, are calculated by combined measurements of the thermal and moisture properties. The high lapse ratio between low and mid-troposphere and moist air near the surface generate good conditions for thunderstorm live.

The first of them, VT-index, is calculated as a difference of temperature between 850 hPa and 500 hPa levels.

$$VT = \left(T_{850} - T_{500}\right) \qquad (2)$$

where T_{850}, T_{500} are the temperatures at 850 and 500 hPa levels.

The KI-index measures air mass thunderstorm potential by direct indication of vertical temperature lapse rate between 850 and 500 hPa levels, lower atmospheric moisture, and very indirect indications of the vertical extent of the moisture layer. The KI-index is expressed as (George 1960):

$$KI = \left(T_{850} - T_{500}\right) + \left(Td_{850} - Tdd_{700}\right) \tag{3}$$

where Td_{850} is the dew point temperature at 850 hPa level, Tdd_{700} is the dew point temperature depression at 700 hPa level.

The Total Totals parameter (TTI) assesses the instability conditions, on the basis of the temperature difference between 850 and 500 hPa and the difference between dew point at 850 hPa level and the temperature at 500 hPa (Miller 1972):

$$TTI = \left(T_{850} - T_{500}\right) + \left(Td_{850} - T_{500}\right) \tag{4}$$

When values of these indices increase, it means that the atmospheric stability decreases. According to many observations and investigations, it is common to say that severe weather events occur when VT-index exceeds 26, KI-index exceeds 25, and TT-index exceeds 49. This subjective selection of instability indices represents different methods of assessing the instability conditions.

The monthly average values of instability indices ware compare with the circulation type such: NAO, EA and SCAND (Barnston and Livezey 1987). These values are taken from NOAA server (http//www.cpc.ncep.noaa.gov).

The relationship between instability conditions and circulation types is based on linear correlation coefficient. The correlation was calculated for summer monthly values from May to August. The assessment of statistically significance is based on t-Student procedure. The values of correlations coefficient greater than 0.45 and 0.65 are statistically significant at 0.9 and 0.99 level.

RESULTS

The research on relationship between instability indices and circulation types has indicated that there are correlations between changes in atmospheric pressure in the North Atlantic and European sector and instability conditions over Europe.

In May, the positive correlations between NAO index and VT, TTI and KI indices are observed over south-east Europe. The strongest correlations are observed over Alp area and southern France: above 0.2 and 0.4 appropriately for VT, TTI and KI indices. The special distribution of correlation coefficient between selected instability indices and SCAND circulation type shows elongated zone from Ireland to Turkey with positive values of correlation coefficient (Fig. 2).

In June (Fig. 3), the investigation shows large area with negative values of correlation coefficient between selected instability indices and NAO type. There is characteristic region from Ireland to central Europe with the highest values of correlation coefficient statistically significant at 0.9 and 0.99 levels. In the case of SCAND index, there is noticed large area with positive values of correlation coefficient (0.4-0.6), especially over eastern part of researched domain.

In July and August (Fig. 4 and 5), the correlations between NAO index and TTI, KI indices in spatial distribution presented south-north differences. Northern Europe is characterized by negative values of correlations coefficient (0-0.2) with maximum located in Scandinavia peninsula and Central Europe (0.4-0.6). Over southern part of researched domain there are noticed positive values of correlation coefficient (0.2-0.6). During the positive phase of NAO the south Europe is influenced by air mass from Africa. Warm, dry air crossing the Mediterranean Sea becomes wet and unstable. The positive values of NAO index indicated western air mass over north and central Europe. Cold air mass from Atlantic tends to decrease instability conditions. The strongest correlation is noticed between SCAND index and KI and TTI instability indices. Over central Europe correlation coefficient reached values 0.4-0.6 statistically significant at 0.9 and 0.99 levels. The blocking anticyclones located over Scandinavia and western Russia stop air mass over central Europe and developed instability conditions due to summer higher insolation.

Similar analysis of correlation of changes instability conditions with EA circulation type become very weak and not significant over the most area and not continuous in space (Fig. 2-5). The EA pattern mainly occurred during winter period when the correlation between air temperature and precipitations is significant.

The analysis of relationship between atmospheric circulation and selected instability indices shows that the correlation is not sustained in time and space. The annual course of investigated indices shows different moment of maximum. For example, annual course of VT and TTI indices shows the highest monthly values in May or June, but KI and CAPE indices reached maximum in July and August (Siedlecki 2009). This could create the changeability in spatial distribution of correlation coefficient between selected indices and circulations modes. The previous investigations show that the strongest correlation between NAO, EA, SCAND indices and temperature or precipitation is noticed in winter months. During the summer the relationships is the weakest. In presented maps the values of correlations coefficient are small and statistically insignificant. It means that the presented relationship is mostly accidental.

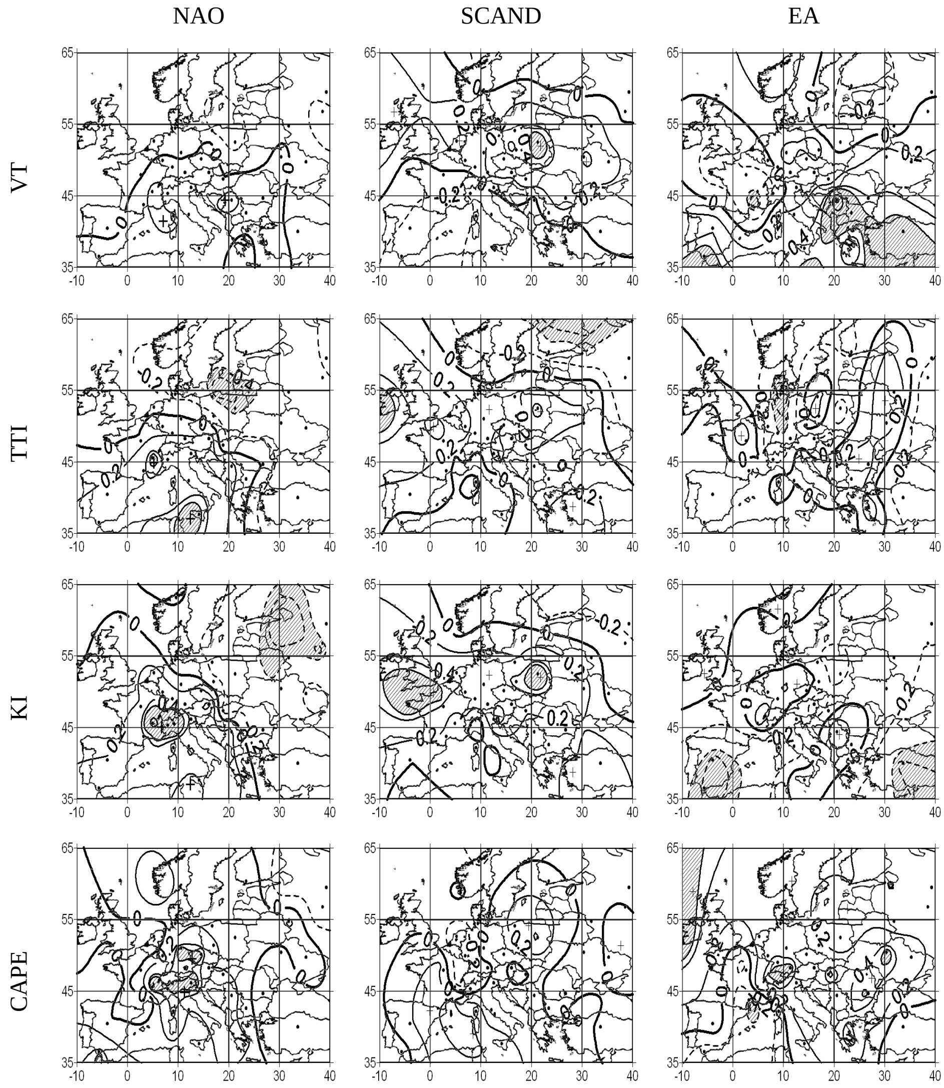

Fig. 2. Geographical distribution of correlations coefficient between selected instability indices and NAO, SCAND and EA indices in May (dash area – statistically significant at 0.9 level, diagonal cross area – statistically significant at 0.99 level)

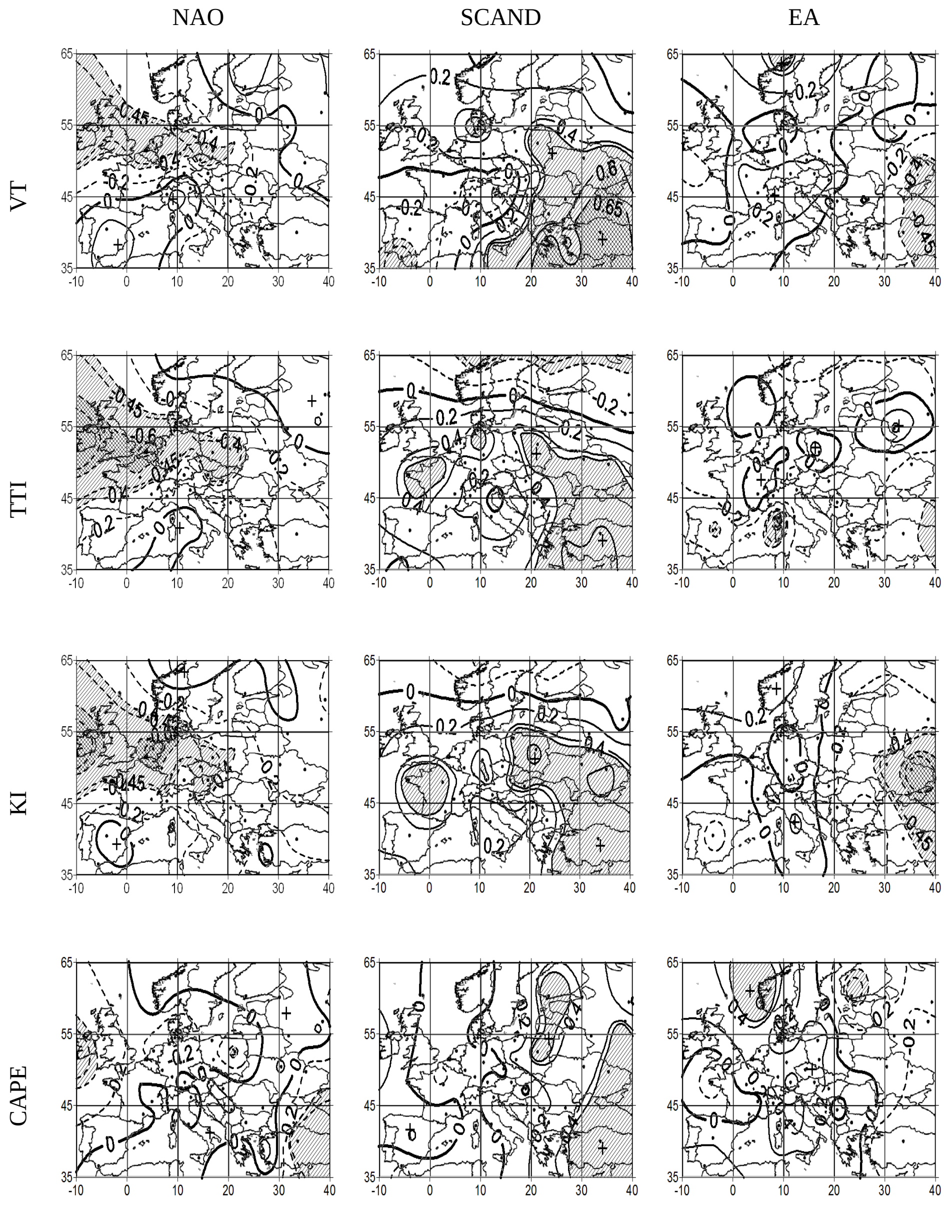

Fig. 3. The same as in Fig. 2, but for June

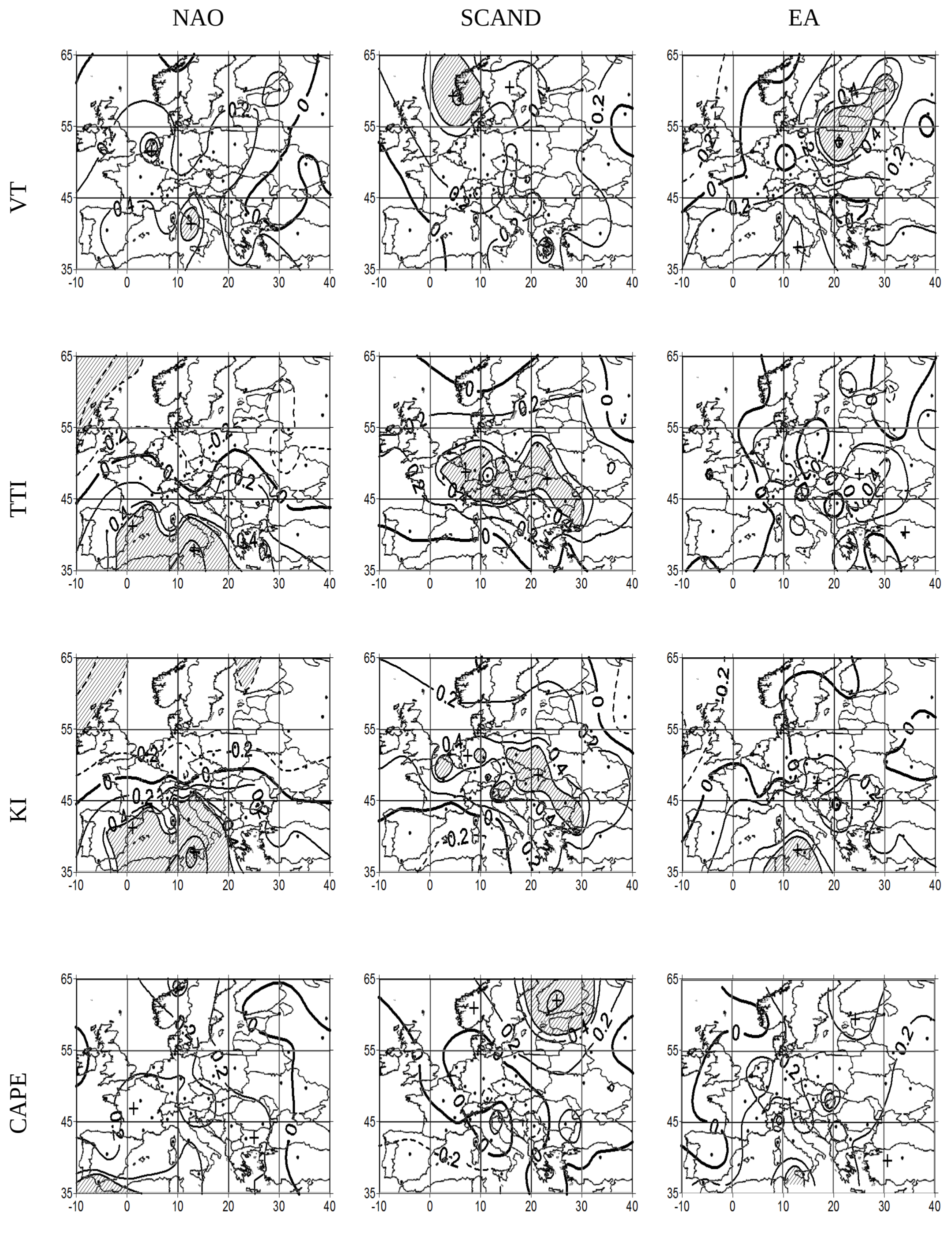

Fig. 4. The same as in Fig. 2, but for July

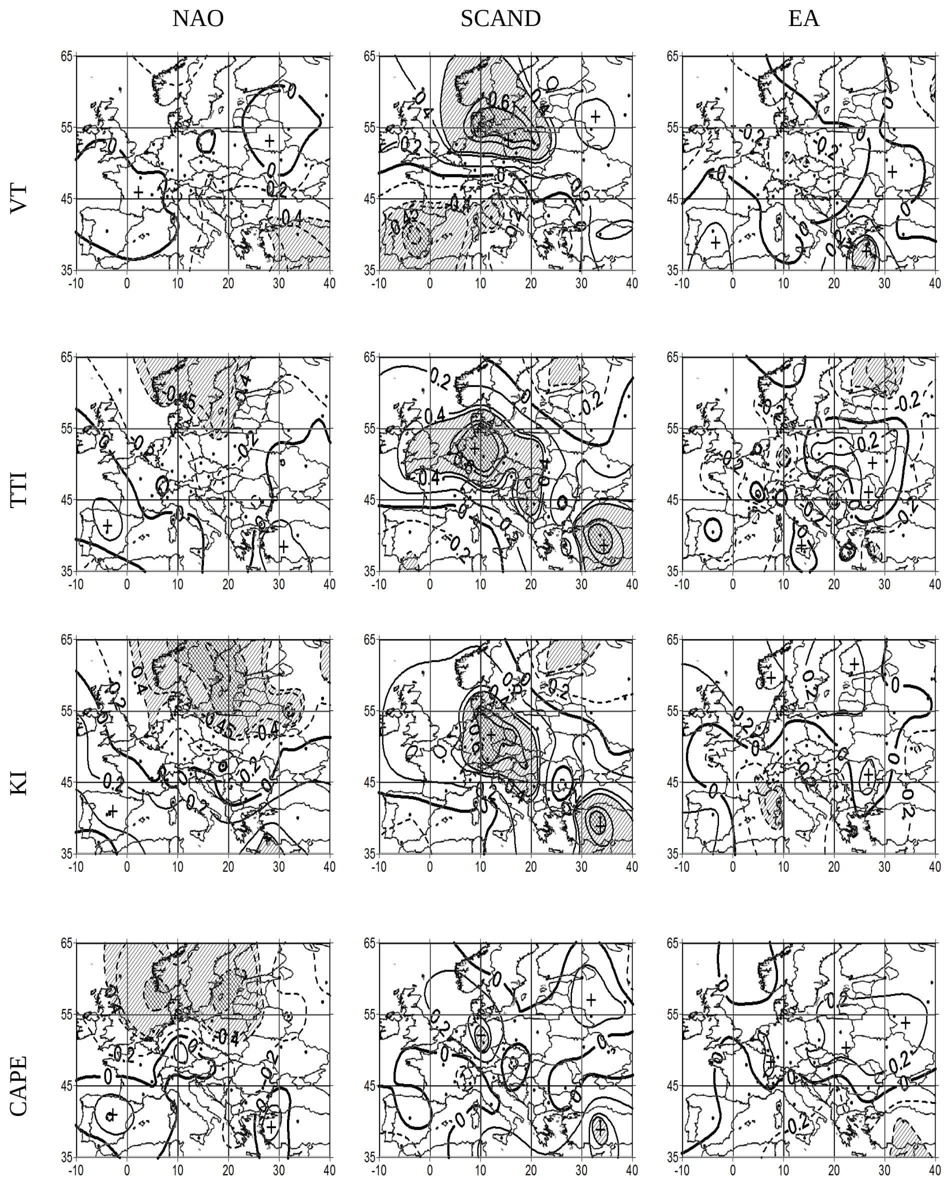

Fig. 5. The same as in Fig. 2, but for August

CONCLUSIONS

European climate observations show that different years have different meteorological characteristics. Some years were generally hot and dry and sometimes large amounts of snow and precipitations were observed. Meteorologist would say that air temperature and precipitations are related to the atmospheric circulation pattern over the North Atlantic-European sector (Wanner *et al.* 2001).

The vast number of detailed studies described the regional climate of the NAO. Especially, the investigators are interested in relationship with temperature and precipitation. The NAO pattern and others has distinct upper tropospheric feature. Some investigations show correlations between the monthly geopotential high and the NAO (Luterbacher *et al.*, 1999). The opposite phases of selected circulation patterns have pronounced in cyclone tracks variations. For example, during positive NAO months the main cyclone track has a northeastward orientation, parallel to the North American east coast and crossing midocean southeast of Greenland (Rogers 1990). In the negative polarity mode, cyclone crossing the western Atlantic move eastward, along latitude 45°N (Rogers 1990). In SCAN negative mode the highest cyclone frequencies is observed over northern Europe. From May through September, during the positive phase of SCAN pattern anomalously high pressure is observed over Scandinavia. This is connected with a north-eastward extension of the Azores high. The different geopotential high, different cyclone track and different air mass frequency have implications in the instability conditions.

The character of correlations between instability conditions and circulations indices in summer months, from May to August, and their spatial distributions have been presented by isocorrelates maps. The investigation shows that the relationship between instability indices (VT, TTI, KI and CAPE) and circulators types such NAO, EA and SCAND is not sustainable in space and time. The strongest correlation coefficient are observed between VT, TTI, KI instability indices and SCAND pattern over east part of researched domain in June and over Central Europe during July and August. The analysis of relationship between KI and TTI indices and NAO type shows that during the July and August over northern Europe there is noticed negative values of correlation coefficient. During that time the southern Europe is characterized by positive values of correlation coefficient but statistically insignificant. The poorest relationship is noticed between selected instability indices and EA circulation type.

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6. STATISTICAL ANALYSIS OF RELATIVE AIR HUMIDITY AND SATURATION DEFICIT MEASUREMENT RESULTS ACCORDING TO STANDARD AND AUTOMATIC METHODS IN WROCŁAW-SWOJEC OBSERVATORY FROM THE PERIOD 2000-2009*

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INTRODUCTION

Direct comparison of the results of meteorological measurement according to standard (manual) and automatic station is difficult for two main reasons. Firstly, precision of instruments differs significantly (in particular it concerns wind speed and direction, radiation balance, heat balance and precipitation measurements). Secondly, the frequency of measurement is completely different. If measurement by means of various devices is accomplished in the same time, theoretically measured values should be identical. In practice, it occurs rarely. Mean daily values collected by standard method are counted on the basis of several terminal values by simple arithmetical formulas according to valid regulation for meteorological station network which oblige in a given country. Averages from automatic stations are calculated on the ground of programmed recording frequency; usually every hour. The different manner of calculating daily meteorological statistics could influence on continuity and homogeneity of the long-time series gathered in the period of standard instruments applying. The simplest way to avoid this problem is to count mean values according to automatic station not from all 24 hours, but from terminal measurements, the same when standard data are gathered. This is possible to achieve with small changes in AWS recording procedures.

In Polish meteorological literature, first papers concerning the comparison of results of measurement according to different instruments appeared in the end of 20th century (Szwejkowski 1999). In general, they regard measured meteorological parameters like temperature and precipitation. Fewer publications considered measurement of moisture air condition (Łabędzki *et al.* 2001, Roguski *et al.* 2001,

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Rojek and Rojek 2001, Mazurczyk *et al.* 2001, Gąsiorek *et al.* 2009). In native literature it is possible to find synthetical studies about methodical problems as well (Kuśmierek 2008, Lorenc 2006, Some problems… 2001). From numerous foreign elaborations Joyce's publication (Joyce *et al*. 2001) published in compact publishing house should be taken into consideration. A lot of papers from this subject appeared in materials published after international scientific conferences dedicated the issue of automatic meteorological stations and instruments and methods of observation (for example in Geneva in the year 2006, in St. Petersburg in the year 2008).

This paper presents the comparison of the results of the relative air humidity and saturation deficit ten-day period values (counted on the basis of mean daily averages) measured by standard and automatic observing instruments in Agro- and Hydrometeorology Wrocław-Swojec Observatory University of Environmental and Life Sciences from the period 2000-2009. The publication presents the study of statistical estimation of the relevance and frequency of differences occurrence between standard and automatic station.

MATERIAL AND METHODS

Standard relative air humidity measurements were executed using August psychrometer placed in meteorological screen (readings at 7, 13, 19 CET) and daily thermohygrograph (readings at 1 CET). According to valid regulation for climatological stations, daily averages of relative air humidity were calculated from 4, while saturation deficit from 3 terminal observations (excluding 1 CET).

Automatic meteorological station Campbell Sci. Ltd. (CR23X model) is equipped with air temperature and humidity sensor MP 100 A Rotronic which is installed in the same meteorological screen. It was programmed to record all measured parameters per minute. On the basis of these values logger generates hourly and daily reports. For example: relative air humidity from 1 CET is calculated as an average of 60 values from 0.30 to 1.29 CET. For automatic station, mean daily values are calculated as an arithmetic average of values from 24 hours.

Saturation deficit was read from psychrometric tables by A. Rojecki using daily averages of air temperature and humidity (according to both measurement methods). Ten-day period averages were calculated on the basis of mean daily values ten-day period averages were calculated.

The hypothesis of the normality of analyzed variables distribution was verified by examining elementary descriptive parameters (coefficient of variation, kurtosis and asymmetry), histograms, normal probability graphs and according to W Shapiro-Wilk test, which is the strongest of all available tests to estimate the normality of variables distribution ($\alpha = 0.05$). Furthermore, homogeneity of variables' variation has been studied (Levene test, F test, Brown-Forsyth test) for the relevance level $\alpha = 0.05$. Student's test was used for estimating relevance of differences for groups with homogeneous variations. In case of non-homogeneous variations, Cochran-Cox test was applied ($\alpha = 0.05$ in both cases).

The comparison of values measured by two methods and relevance of differences between them was defined by correlation coefficients, linear regression and tests which examine the relevance of differences for independent samples using STATISTICA program (8.0 version).

In the studied period of 2000-2009, especially in winter, 5 disturbances occurred in power supply of automatic station and sensors' failures. Appropriate averages for this period excluded lacking data.

RESEARCH RESULTS AND DISCUSSION

The comparison of relative air humidity and saturation deficit averages from the nine-year period (2000-2008) in successive ten-day periods differs in some extent. In case of relative air humidity for each decade, values measured by standard method were lower than values from the automatic station. The smallest differences between both methods were observed in summer months (about 1-2%), while the greatest differences occurred in late autumn and in winter.

The comparison of ten-day period averages of saturation deficit shows far greater differences. In all ten-day periods of the year, values from standard station exceed the values from automatic station. Maximum differences, which exceeded 4 hPa, were found in summer months, whereas minimum differences (about 0.5 hPa) appeared in December and January.

Results reached by authors of this paper are in accordance with publications of other authors. Roguski *et al.* (2001) claimed that saturation deficit measured by standard method as a mean value from 7, 13 and 19 CET was higher in vegetation period on average by about 21% than values from automatic station (averages from 24 hours). Saturation deficit mean daily values from 7, 13 and 21 CET are much more similar to the automatic data. Authors of other publications acquired similar differences (Łabędzki *et al.* 2001). Relative air humidity comparison included in Szwejkowski's paper (1999) pointed at that mean annual values of this parameter according to standard station differ from 24-hours averages data to the according automatic method by about 2.8%. In case of averages counted from three terminal observations according to automatic station differences came to 4.8%.

The earlier publication written by one of the authors of this paper contains the comparison of two moisture air condition indicators from the one-year period (Rojek *et al.* 2001). Maximum relative air humidity differences between both methods, which reached 4%, appeared in months from October to January. In all months, saturation deficit values measured according to standard method were higher than values from automatic station. The greatest differences reached 0.5 hPa in May and June.

The reason of such a high and statistically significant disparities in both procedures (especially in case of saturation deficit) is the fact that the values from night hours are excluded from an official Polish meteorological network formula for counting daily averages. Lorenc (2006), in her publication, presents (inter alia) calculation results of relative air humidity counted using different formulas and for different number of observations. Relative air humidity mean daily values from three terminal measurements in particular days was lower even up to 13% than daily averages calculated from eight values per a day. Mean monthly values counted by this manner differ in summer even by 7%.

These results remarkably explain quite small differences between relative air humidity ten-day period values gathered using both measurement methods at Wroclaw-Swojec Observatory. In contrary to saturation deficit, calculations concerning relative air humidity included daily average values from 1 CET.

Similar problem was found in case of saturation deficit. It results from excluding evening and night values in mean daily value formula. Bryś (2003) describes this issue in her publication. Discussing long-time saturation deficit observation series (1946-2000) in several places in Wrocław, author pays attention to non-homogeneity in 1978, after a change of the evening observation time. Until 1978, mean daily values were calculated from 7, 13, 21 (value from 21 was taken twice) and later from 7, 13, 19. After the change of daily saturation deficit calculation formula, differences are in the range between 0.4 hPa and 0.8 hPa and are far greater on particular days (especially in July and August).

Very interesting data, concerning this issue may be found in the publication of measurement's results from Brno (Bil-Knozová and Rožnovský 2006). Authors of this paper have accomplished measurements using two types of automatic stations (Vaisala and HOBO) and two kinds of standard instruments: August psychrometer and hygrometer. Maximum relative air humidity mean daily values disparities measured by August psychrometer and Vaisala station vary from 15.3% (higher humidity value according to automatic station) to 17.3% from psychrometer. Extreme differences between hygrometer and Vaisala station measurements reach from 8.3% (higher values measured by Vaisala station) to 15.7% (higher values gathered by hygrometer). Disparities between hygrometer and Hobo station measurements are in a similar range – from 9.1% to 15.3%. Daily averages from all-year period between hygrometer and HOBO differ by 3.6%, while between hygrometer and Vaisala by 4.2%. Appropriate differences among measurements executed using August psychrometer and two kinds of automatic stations amount to 2.4% for Vaisala station and 3.6% for HOBO. It is interesting and should be taken into consideration that data from two automatic stations differs against each other, in spite of the same average counting formula. The mean annual difference of daily values comes to 0.46% indeed, but the highest temporary disparity amounts to 35.7%.

The next stage of both methods comparison was the frequency of differences occurrence delimitation between daily values in established intervals. For relative air humidity, classes were set every 2%, while in case of saturation deficit every 2 hPa. Frequency is defined as a number of cases where the difference between standard station value an automatic station value falls into deliminated class range. Thus 20 for relative air humidity and 9 for saturation deficit frequency intervals were obtained.

Relative air humidity frequency of differences occurrence distribution is close to normal (Fig. 1). The greatest number of events (18.9%) occurs in the interval from –1 to –3%, then 565 events (i.e. 17.4%) in class from –3 to –5%. The smallest disparities between both methods (from –1 to 1%) occurred 513 times, which amounts to 15.8% of all daily values in the nine-year analyzing period. Maximum deviations in eight less numerous classes account for 0.9% of all differences.

Contrary to relative air humidity, frequency of differences occurrence results received for saturation deficit was completely different (Fig. 2). Distribution of this parameter is characterized by unmistakable asymmetry with a marked domination of two classes of frequency. The smallest disparities (from –1 to 1 hPa) occur most often (1232 events i.e. 38.0%). A little fewer values (1221 i.e. 37.7%) were found in the interval from 1 to 3 hPa. Four classes of differences frequency which occur rarely (from –1 to –3 hPa and above 9 hPa) amount to 0.7% of all values.

From among several meteorological parameters analyzed in Durło's (2001) publication, the vapour pressure daily averages should be taken into consideration as very interesting. The comparison of standard and automatic methods considers only one-year period and in this time the mean annual disparity of vapour pressure came to 0.8 hPa. Author, in his paper, inserted table with frequency of differences occurrence of daily values as well. Maximum number of events (above 53%) was found in class from –0.65 to 0.56 hPa.

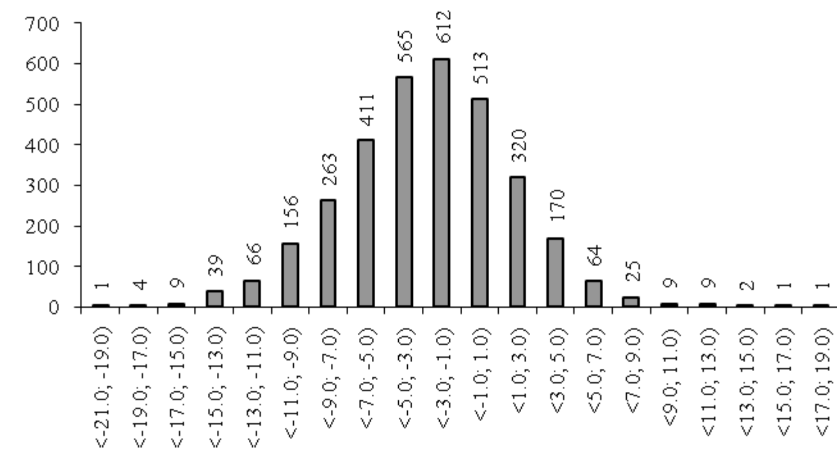

Fig. 1. Frequency of differences occurrence between relative air humidity (%) according to standard and automatic station during the period 2000-2008

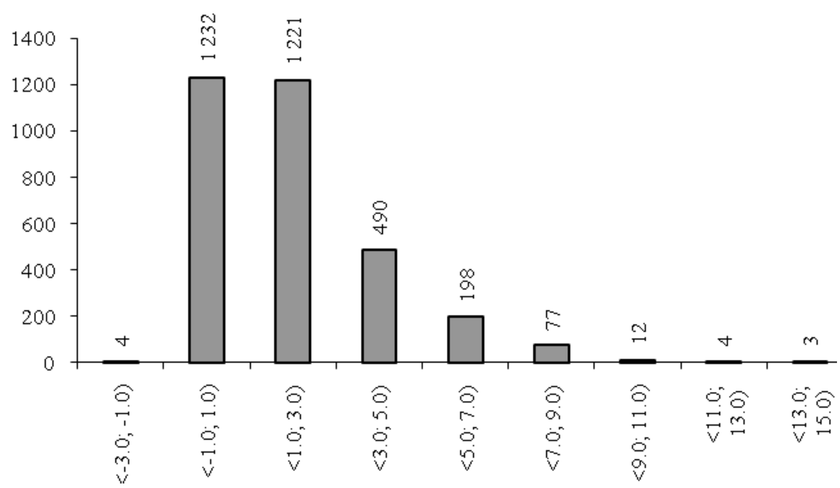

Fig. 2. Frequency of differences occurrence between saturation deficit (hPa) according to standard and automatic station during the period 2000-2008

Before choosing appropriate statistical test, it was verified if there were any grounds to reject the hypothesis of analyzing moisture air condition parameters normality of distribution. The study of variables elementary descriptive parameters (coefficient of variation, kurtosis and asymmetry) was conducted. These coefficients and indicators values didn’t exclude normal distribution. W Shapiro-Wilk test, which is the strongest from all available tests to estimate the normality of variables distribution (for relevance level $\alpha = 0.05$) was the final step of verifying assumed hypothesis. The normality of variables distribution entitles to use parametric statistical tests for estimating relevance of differences between both methods. For pairs of variables the variation homogeneity was studied (Levene test, F test, Brown-Forsyth test), for the same relevance level $\alpha = 0.05$. In majority of events, for groups with homogeneous variations, differences relevance was estimated by Student's t-test, while in case of non-homogeneous variations Cochran-Cox test was applied.

Estimated relevance of differences results for relative air humidity measured by standard and automatic station are inserted in Table 1. Results obtained to daily averages were studied for all ten-day periods in successive decades from the period 2000-2008. Regarding editorial limitations (table size) only data from three primaries (2000-2002) and three last years of analyzing period was presented in this paper. In the first period, differences were statistically significant only in the first decade of December 2000. In the year 2006, the number of ten-day periods like that came to 5 (one in October and November and every decade in December). The number of statistically significant differences in case of relative air humidity measured by two methods in the year 2007 and 2008 was marked higher and amount to almost a half of all decades in this time.

Similar procedure concerning saturation deficit was compiled in Table 2. This table shows diametrically opposite results (in comparison with relative air humidity). In the greater part of ten-day periods results of tests pointed at statistically relevant differences (for relevance level $\alpha = 0.05$). In the year 2006 it amount to 10, in the year 2007 and 2008 only 3 decades in each year with non-relevant differences.

Despite of relatively large differences for both moisture air condition indicators, there is a close relation between them. Figures 3 and 4 show linear correlation dependence for 36 decade averages (all year) gathered by standard and automatic station. Relative air humidity correlation coefficient is very high and amount to $r = 0.998$, while for saturation deficit measured by both methods is weaker, but also high ($r = 0.989$). Authors of other publication (Mazurczyk *et al*. 2001) received similar high and positive correlation results for shorter period.

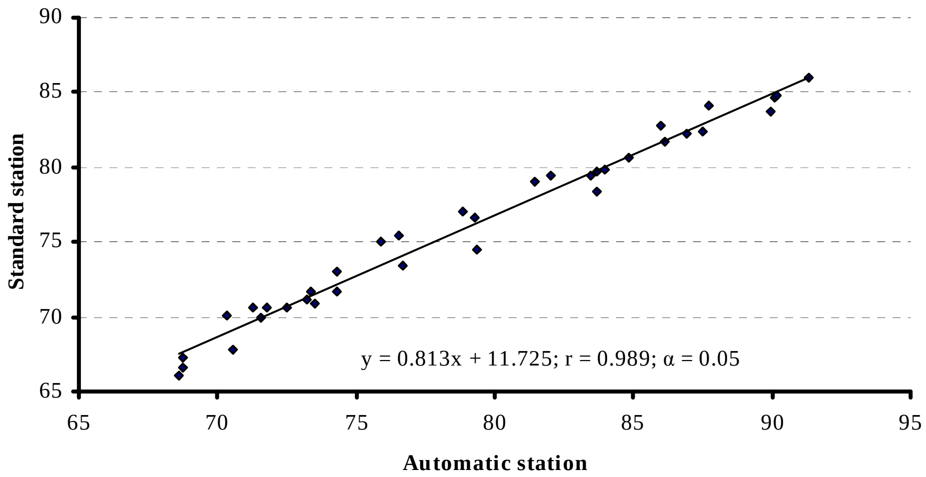

Fig. 3. Relation between ten-day period values of relative air humidity (%) from the period 2000-2008 according to standard and automatic station

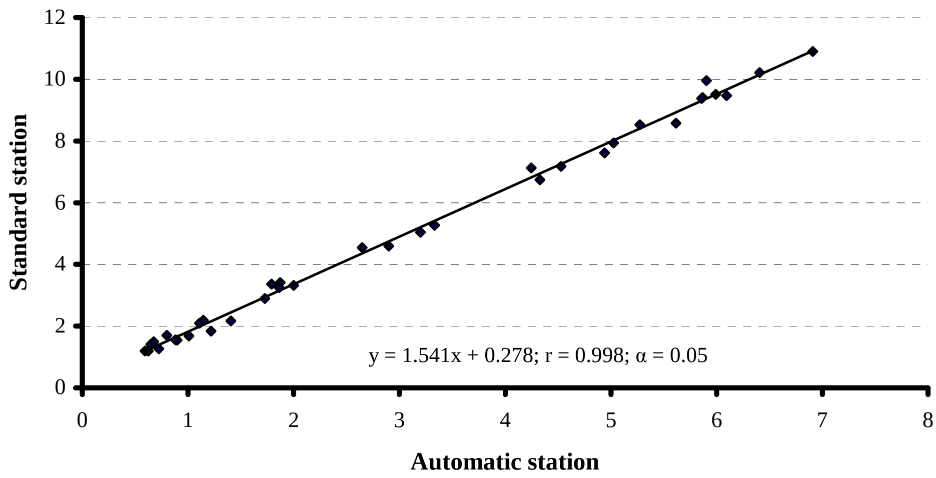

Fig. 4. Relation between ten-day period values of saturation deficit (hPa) from the period 2000-2008 according to standard and automatic station

Relative air humidity data contained in the same paper (Mazurczyk *et al*. 2001) differ from results from Wrocław-Swojec Observatory measurement in one, significant point. According to quoted authors, statistical analysis show, that relative air humidity data don't have normal distribution. Despite this fact, relevance of differences levels tests prove that there is no reason to reject zero hypothesis. P-values, depending on kind of test, contain in the interval from 0.145 to 0.917, so these values are marked higher from the received level α = 0.05. In conclusion, authors confirm that both measurement methods may be applied exchangeably.

In addition, relevance of correlation coefficients analysis (Tab. 3, 4) confirms its high values obtained in this study. In case of relative air humidity (Tab. 3), in first as well as last period of the research, the number of non-significant coefficients is inconspicuous. In the year 2000, 2001, 2002 and 2008 in all ten-day periods, relations between two methods was statistical significant. In the year 2006 and 2007, two decades with non-significant correlation coefficients occurred (all in winter months).

Similar results have been obtained in the case of saturation deficit (Tab. 4). In the year 2000 and 2001, there was no ten-day periods with non-significant coefficients, in the year 2002 and 2008 occurred one decade for each year, in the year 2007 – three and in the year 2005 four decades, in which correlation coefficients were statistically non-significant.

For examining the correctness of proposed regression equations, they were verified on the independent material from six months of the year 2009 (Tab. 5). In this table relative air humidity and saturation deficit ten-day period averages gathered according to standard, automatic measurement and calculated by regression equations from Figures 3 and 4 were inserted. Results of this verification were satisfactory. In the case of saturation deficit in all 18 decades values from proposed equation were much more similar to standard station data than to averages from automatic measurements. Results for relative air humidity were similar. Only in the third decade of April the value according to regression equation was equal to automatic average and it differ from standard value at 4%. On the whole, research results entitle to recommend obtained linear regression equations.

Table 5. Ten-day period values of relative air humidity (%) and saturation deficit (hPa) according to standard station, automatic station and calculated by regression equations in the year 2009

Months	Ten-day period	Relative air humidity (%)			Saturation deficit (hPa)		
		Standard station	Automatic station	Quotient of regression equation	Standard station	Automatic station	Quotient of regression equation
January	1	88	92	87	0.5	0.3	0.7
	2	86	92	87	1.0	0.4	0.8
	3	85	95	89	1.2	0.3	0.7
February	4	84	94	88	1.3	0.4	0.9
	5	89	96	90	0.6	0.2	0.6
	6	83	93	88	1.4	0.4	1.0
March	7	78	89	84	2.5	1.0	1.8
	8	79	90	85	1.9	0.7	1.4
	9	74	84	80	2.6	1.2	2.2
April	10	68	72	71	7.4	3.6	5.7
	11	64	71	69	6.6	3.5	5.6
	12	58	62	62	9.4	5.5	8.7
May	13	61	68	67	8.5	4.5	7.2
	14	68	76	73	7.1	3.4	5.5
	15	76	82	78	6.6	3.1	5.1
June	16	75	83	79	5.6	2.5	4.1
	17	72	78	75	7.0	3.7	6.0
	18	88	95	89	3.3	0.9	1.6

CONCLUSIONS

1. Differences of moisture air condition parameters measured by two methods have different signs. Relative air humidity according to standard station was lower than automatic in all ten-day periods in the year. Ten-day period averages of saturation deficit from standard method were always higher.
2. Saturation deficit ten-day period values gathered by standard method, in 70% of all decades from the whole of analyzing period differs significantly from values measured by automatic station. In case of relative air humidity non-significant differences prevail and amount to 13.9% of all ten-day period values.

3. Frequency of differences occurrence distributions according to both methods for two moisture air condition indicators was different. Relative air humidity frequency of differences occurrence was similar to normal distribution, while distribution of saturation deficit frequency was deeply asymmetric with a marked domination of two classes of frequency.

4. The verification of suggested regression equations (which transform data from automatic measurements into standard station data) on independent material from year 2009, confirmed effectiveness of proposing method. These equations may be used to creating homogeneous long-time series after changing data from automatic station to standard.

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7. EVALUATION OF BIOCLIMATE OF THE USTKA REGION FOR THE NEEDS OF RECREATION AND TOURISM

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INTRODUCTION

The town of Ustka is situated in the Pobrzeże Koszalińskie (Littoral Koszalin region) macroregion at the estuary of the river Słupia, and it functions as a spa or a small harbour, mainly a fishing one and at the same time it is a suburban bathing place for the inhabitants of the town of Słupsk. A wide sandy beach, a lot of sunshine and high emission of aerosols from the surface of the sea as well as the vicinity of a strip of dunes overgrown with a pine wood constitute a large attraction of the seaside natural environment in the region of Ustka. Recreational surface amounts to about 120 km^2 in which a complex of sea values, used for recreation and health improvement, dominates. Here, various diseases are cured: diseases of peripheral vessels, of respiratory system, of nervous system and rheumatic and endocrinological diseases using the sodium chloride, bromide and iodide waters occurring in this area. Ustka has sanatoria with a capacity of 1400 people and the accommodation for about 10 thousand people in the lodgings (Czerwiński 1997, Kondracki l988, Kozłowska-Szczęsna 1981, Lijewski *et al*. 2002, Łabuz 2008).

In the region of Ustka there is a bend of the coast line southwards which reduces the west wind speed and smoothes bioclimatic conditions of this region.

Among the factors that decide about the possibility of using leisure and tourism in the given area, the weather should be mentioned, as its course makes it easier or completely impossible to realize the planned forms of recreation. The region of Ustka, similarly to the remaining part of the coast, is characterized by large variability of the weather, particularly in winter and early spring (Atlas … 2004). The largest stability of the weather is characteristic of August and May (Błażejczyk 2004, Girjatowicz 2006, Koźmiński, Michalska 2005, Miętus *et al*. 2004).

The climatic and bioclimatic conditions of the Ustka region were the subject of several studies, mainly in the monograph on the resort written by Kozłowska-

Szczęsna (1981) and Kozłowska-Szczęsna *et al*. (2002), and then in the articles by Chabior (2004) and Girjatowicz (2006), and also by Kwiecień (1969) and Woś (1967). The information concerning the sunshine in the zone of the Baltic coast is included in the work by Koźmiński and Michalska (2006), and that with regard to thermal and humidity conditions – in the Atlas of resources and climatic threats in Pomerania (2004). Variability of extreme temperatures (along with their trends) in the zone of the Baltic coast is described in the works by Koźmiński and Michalska (2008 a and b).

The mentioned climatic and bioclimatic studies mainly refer to the earlier periods and due to the fast changes of the climate as well as to the improvement of statistical methods, there is a need to undertake new studies on the bioclimate and to assess the trend of its changes and that is the aim of this analysis.

MATERIAL AND METHODS

The material used in this study was based on daily (24hr) results of the measurements and observations from the station in Ustka concerning the air temperature (maximum, minimum and mean), relative humidity of air, wind speed, atmospheric pressure, number of days with precipitation >0.1 and >1.0 mm and the state of the sky: medium-level clouds and low-level clouds from the period of April-September over the years 1986-2005.

In the first part of the study the number of days of the following character was calculated: comfort days (t_{max} 18-23°C), warm (t_{max}>25°C) and very hot (t_{max}>30°C) days, days of daily (24hr) amplitude of air temperature >8° and >12°C, of daily relative humidity of air > 85% and 95%, days with pressure changing every 24 hours within the values of >8 and >12 hPa, days with precipitation >0.1and >1.0 mm per the period of 24hrs and with wind speed >8 and >10 $m \cdot s^{-1}$. Moreover, in the study decade values of real and relative sunshine were taken into consideration. In the second part of the study the bioclimatic indices were used in order to evaluate climatic factors favourable to and limiting the conditions of recreation in the region of Ustka, such as: subjective temperature index STI, heat load of organism index HL, predicted insulation of clothing index Iclp and weather evaluation index WEI (Błażejczyk 2004).

On the basis of the STI index the frequency of occurrence of different classes of heat sensation according to months and days was worked out:

STI (°C)	descriptive characteristics of the weather
below –38.0	– extremely cold weather

from –38.0 up to -20.0	– very cold weather
from –19.9 up to –0.5	– cold weather
from –0.5 up to 22.5	– cool weather
from 22.5 up to 32.0	– comfortable weather
from 32.0 up to 46.0	– warm weather
from 46.0 up to 55.0	– hot weather
above 55.0	– very hot weather

The values of the index of heat load of organism HL fall in the following intervals:

HL	Heat Load:
0.250 and less	– very strong – cold stress
from above 0.250 to 0.820	– strong – cold stress
from above 0.820 to 0.975	– slight – cool stress
from above 0.975 to 1.025	– minimum heat load
from above 1.025 to 1.180	– slight – warm stress
from above 1.180 to 1.750	– strong – heat stress
above 1.750	–very strong – heat stress

The evaluation of thermal environment by means of the predicted insulation of clothing index Iclp:

Iclp (clo)	Thermal environment:
< 0.30	– very warm
0.31-0.80	– warm
0.81-1.20	– neutral
1.21-2.00	– cool
2.01-3.00	– cold
3.01-4.00	– very cold
> 4.00	– arctic

Then the weather conditions were characterized with regard to their usefulness for various forms of recreation and tourism using the index of weather evaluation $_{avg}$ (Błażejczyk 2004). Four possible forms of recreation have been identified in the study: sunbathing (SB), airbathing (AB), walking and quiet field workshops (MR) and intensive marches, walking and cycling tourism (AR).

On the bases of average values of the WEI$_{avg}$ (SB, AB, MR, AR) indices the following classification of weather usefulness was accepted:

< 0.5	– unfavourable weather
from 0.5 to less than 1.2	– moderately favourable weather
from 1.2 to less than 2.0	– favourable weather
from 2.0	– very favourable weather

The above partial indices were the basis to calculate the total group WEI_{tot} index in successive days in the warm half-year. The differentiated values of this index made it possible to evaluate the weather conditions in the region of Ustka.

WEI_{tot}	
below 3.5	– unfavourable conditions
from 3.5 to less than 5.0	– moderately favourable conditions
from 5.0 to less than 6.5	– favourable conditions
from 6.5 to less than 8.0	– very favourable conditions
from 8.0	– markedly favourable conditions

ANALYSIS OF THE RESULTS

In the region of Ustka the average annual total of hours with the sun amounts to 1647. In this, 75 % of the annual total falls into the warm half-year and in summer the real sunshine is five times as large as in winter and in spring it is nearly twice as large as in autumn. The coastal zone, particularly the area around Władysławowo and Hel, but except for the region of Darłowo, belongs, next to Polesie Lubelskie, to the sunniest areas in the country (Bogdańska 2005, Koźminski and Michalska 2005). The largest number of hours with the sun is recorded in May – on average 8.2 hours per day and in July – 7.9 hours, but in different years these values may vary from 4.9 to 11.1 hours in May and from 4.7 to 13.4 hours in July (Tab. 1). Fig 1 shows that in individual decades of the warm half-year there are large fluctuations of mean daily real sunshine, particularly in the second decade of May – from 1.8 to 13.2 hours. There is a significant decrease in the duration time of sunshine in the second decade of July, both in average values and in extreme ones. In the warm half-year (April-September) a positive, but not significant linear trend of real sunshine totals is observed in May and in July and a negative one in September.

In the vegetation period the relative sunshine exceeds 50% only in May and in the remaining months it varies from 34.4% in September to 49.4% in August (Tab. 1). As far as the decade arrangement is concerned, distinctive with regard to the sunshine are the second decade of May and the first decade of July (Fig. 1). Minimum human organism's requirements for the real sunshine amount to at least 4 hours daily. A period longer than that occurs with a 50% probability from the third decade of March to the first decade of October, reaching 100% in the first decade of June and in the first and second decade of August. Whereas a 50% probability of exceeding the period of 6 hours per day occurs from the third decade of April to the third decade of August and a period of more than 8 hours can only occur in the second and third decade of May and in the first decade of June (Tab. 2).

Table 1. Average (hours) daily (a), maximum (b), minimum (c) and relative sunshine (d, %) and the coefficient of variation in % (e) of real sunshine in Ustka Years 1976-2000

Statistical characteristic	April	May	June	July	Aug	Sept
a	5.6	8.2	7.5	7.9	7.4	4.4
b	8.4	11.1	9.8	13.4	10.0	5.6
c	3.2	4.9	3.9	4.7	5.6	2.6
d	40.0	51.1	44.0	47.3	49.4	34.4
e	23	20	22	27	17	21

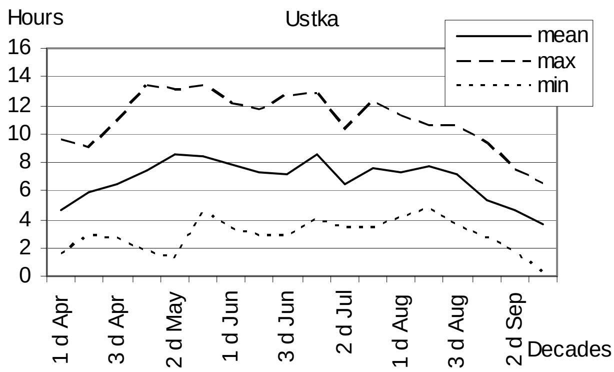


Fig. 1. The mean, maximum, minimum daily sunshine (hours) according to decades in the warm half-year. Years 1971-2000

Table 2. Probability (%) of exceeding 2, 4, 6, 8 i 10 (hours) with the sun according to decades in Ustka

Hours	April			May			June		
	1	2	3	1	2	3	1	2	3
2	92	98	97	98	99	99	100	99	94
4	64	85	85	90	95	94	96	93	83
6	25	48	58	70	82	80	79	72	63
8	4	12	26	41	58	55	46	38	39
10			7	17	31	29	16	11	18
Hours	**July**			**Aug**			**Sept**		
	1	2	3	1	2	3	1	2	3
2	98	98	99	100	100	98	98	98	83
4	93	87	93	96	99	90	79	68	41
6	79	59	75	75	86	68	36	14	8
8	56	24	43	36	43	37	6		1
10	31	6	16	8	8	13			

The average number of thermoneutral days (t_{max} 18-23^{o}C) clearly increases from April (2 days) to July and August (16 days in each month) so as to decrease in September to 8 days (Fig. 2). In the light of these data, the thermal conditions pervading in the region of Ustka in summer (June-August) should be regarded as favourable to the recreation, which Girjatowicz and Chabior (1991) and Kwiecień (1969) showed in their works. Whereas burdensome to a human being are regarded the hot days with a maximum temperature >25^{o}C, which can occur as early as from the third decade of April up to the end of September with a maximum from the third decade of June to the second decade of August – on average 2 days (Fig. 3). It happened, however, that there were years in which even 13 hot days were recorded in July (in 1994) and 16 in August (in 2002) or they occurred in sequences, as for example in 1984 – from 23rd April to 2nd August. Noteworthy is the fact of a small number of hot days in the first decade of May and in the second decade of June and July. This is connected with an increase in an inflow of polar maritime air (Kwiecień 1969, Woś 1967). In the analyzed period of 1986-2005 a positive tendency of a hot days number is recorded in the warm half-year.

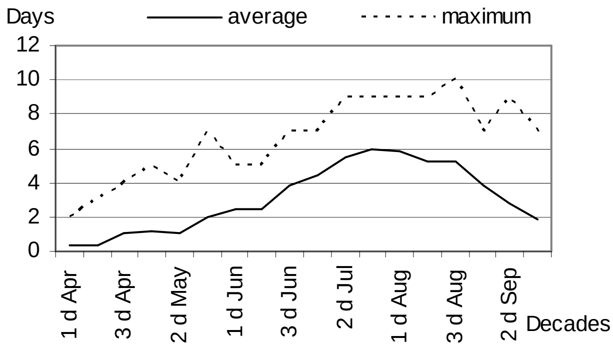


Fig. 2. The mean and maximum number of comfort days (t_{max} 18-23^{o}C) according to decades. Years 1986-2005

Very hot days with a maximum temperature >30^{o}C occur in the Ustka region very rarely, mainly at the beginning of July and at the end of July and the beginning of August (on average, about 1 day) – although in some years they are observed even over a period of several days in a month, e.g. in 1994. The highest maximum temperature of air in the investigated multiannual period was recorded on 10th August, 1992 – 37.8^{o}C, and this, along with a large interdaily variability of temperature amounting to above 11^{o}C and a change in pressure of above 8 hPa, constituted large thermal burden to the organism.

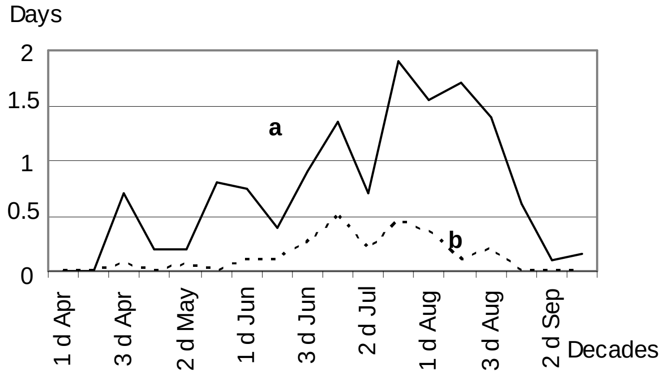


Fig. 3. The mean number of days with maximum air temperature >25^o (a) and >30^{o}C (b) according to decades. Years 1986-2005

The daily amplitude above 8^{o}C, accepted as the difference between t_{max} and t_{min}, is most frequently observed in May and in August, on average 12 days in a month. In turn, the daily amplitude of air temperature of the value >12^{o}C occurs most often in May – on average 4 days and least frequently in September – about 2.5 days, showing slight fluctuations month by month (Fig. 4).

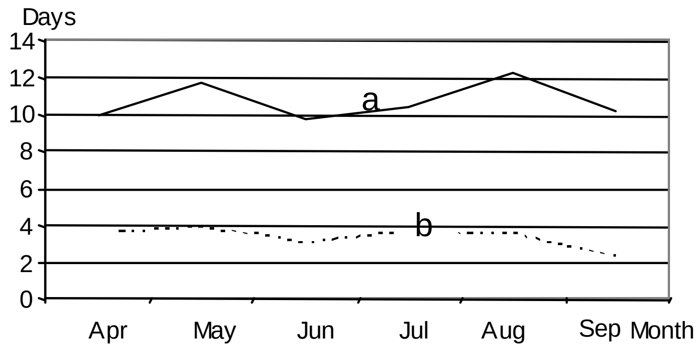


Fig. 4. The mean number of days with the daily amplitude of air temperature >8^o (a) and 12^{o}C (b). Years 1986-2005

Out of the indicators determining humidity conditions of air, the relative humidity, the value of which >85% is sensed as very humid air, is often applied **(**Boksa and Boguckij 1980). In the region of Ustka the mentioned value is recorded in April and in September, on average every three days, in May, July and August – every 3-4 days and in July – every 4 days (Fig. 5). The relative humidity >85% occurs least frequently at the end of June and the beginning of July, on average every 4-5 days. There are years in which in a given 10 day period in the warm-half year the number of days with very humid air can vary between 6 and 9. It should be emphasized that at the mean daily relative humidity > 85%, in the night it reaches 100%. A more unfavourable feeling of air humidity takes place at values >95%, which occur in April and June on average one day and in July and August only from 0.20 to 0.25 of day (Fig. 5). During the period from April to September, out of the 20 analyzed years, the largest number of days with mean daily relative humidity above 85% occurred in the years 1987 and 1988, as large a value as 42% over the period from April to September and the smallest number of such days was recorded in the years 1993 and 1992 – 19 and 22%, respectively.

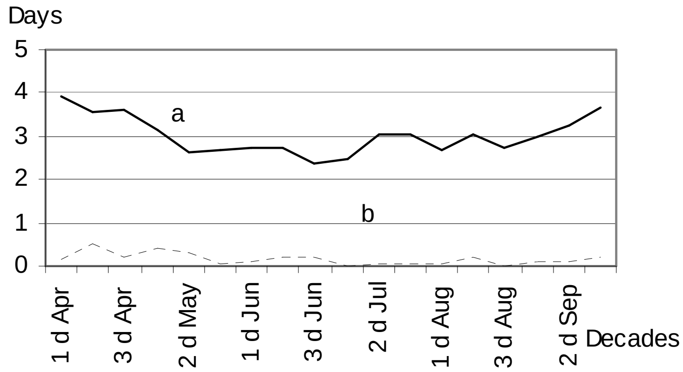


Fig. 5. The mean number of days with relative humidity of air >85% (a) and >95% (b). Years 1986-2005

Apart from the above described meteorological factors burdensome to a human being, the largest threat to human's health are daily changes in atmospheric pressure above 8 hPa and particularly above 12 hPa. In this regard, April is particularly unfavourable in which there are on average more than 5 days with the changes above 8 hPa and about 2 days with the changes above 12 hPa (Fig. 6). There are slightly fewer days with varying pressure in September – about 4 and 1 days, respectively. The interdaily changes in atmospheric pressure >8 hPa are observed least frequently in summer months (June-August) – on average, up to 2 days. In the investigated multiannual period large changes in the pressure (>12 hPa) occurred very rarely. A maximum interdaily change in the pressure – 18.7 hPa was recorded in September in 1995.

The largest burden due to atmospheric precipitation is characteristic of July and September in which the percentage contribution of the number of days with precipitation >0.1 mm to the total of days amounts respectively to 42 and 41% and with precipitation >1.0 mm – 28% in each month (Fig. 7). In this regard, particularly unfavourable are the second decade of July and the third decade of August in which there were rainfalls on average every two days. Over the years 1986-2005 the smallest number of days with such precipitation was noticed in the last decade of April and the first decade of May – on average, with precipitation >0.1 mm every three days and with precipitation >1.0 mm every five days. The calculated temporal trends (1986-2005) for the number of days with precipitation >0.1 mm turned out to be positive in the months from April to August, out of which in May they were statistically significant ($\alpha = 0.05$) and highly significant ($\alpha = 0.01$) in June, whereas a negative and non-significant trend occurred in September.

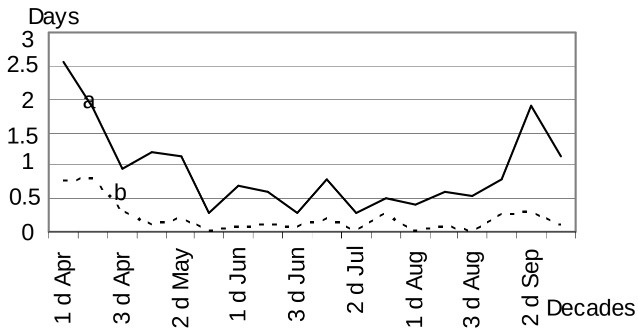


Fig. 6. The mean number of days with the interdaily difference of pressure >8 (a) and >12 hPa (b). Years 1986-2005

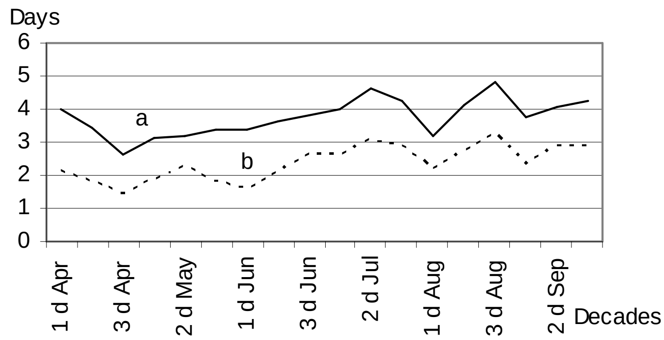


Fig. 7. The mean number of days with precipitation >0.1 (a) and >1.0 mm (b). Years 1986-2005

Wind of the speed >10 m s^{-1}, due to its small frequency of occurrence, on average 2 days in a month – from April to August and about 3 days in September, did not constitute large burden to the recreation in this region of the coast. Maximum speeds of wind in Ustka in the analyzed summer half-year vary from 13 m s^{-1} in May to 19 m s^{-1} in April. The small speed of wind in Ustka, as compared with other stations on the coast, results, among other things, from the bend of the seashore in this region where the winds from the western sector are prevailing (Atlas … 2004).

Subjective thermal feelings of a human, staying outdoors can be determined by the subjective temperature index STI – based on the analysis of the human's thermal balance. In the region of Ustka in April the weather that occurs in the analyzed 20 year period is, on average, of a cool type and starting from the second decade of July – a comfort type (Fig. 8). Whereas in the remaining period (from the third decade of July to the second decade of August) the warm weather occurs and in September the comfort weather again. Of all the analyzed days from April to September (1986-2005), the most frequent was the warm (37%) and cool weather (31%), and less frequent the comfort type (25%), whereas the hot (4%) and cold weather (3%) – sporadic, and there were only 2 cases of the very hot kind in the whole 20 year period (Fig. 9). It should be emphasized that the above assessment of thermal feelings by means of the STI values was based on mean daily values of meteorological elements which reflect weather conditions for various forms of recreation during a long summer day.

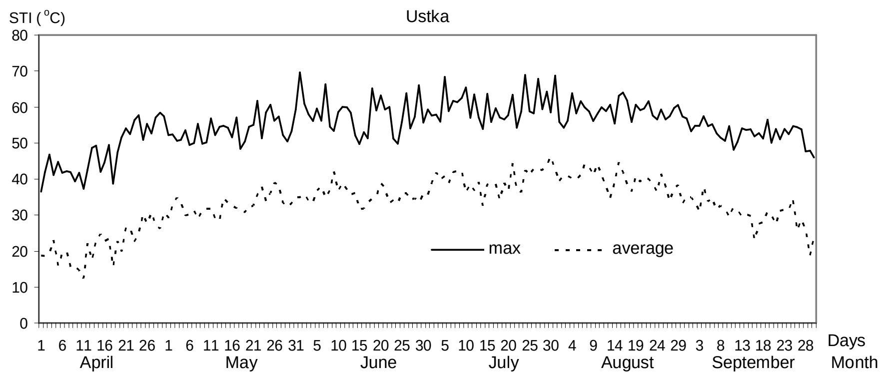


Fig. 8. The course of mean and maximum sensible temperature STI according to days. Years 1986-2005

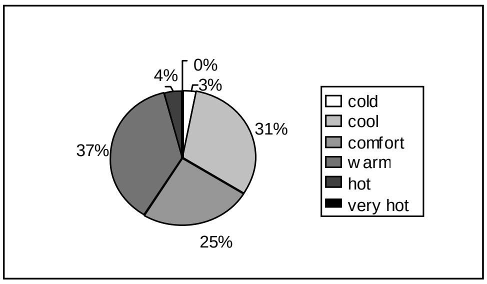
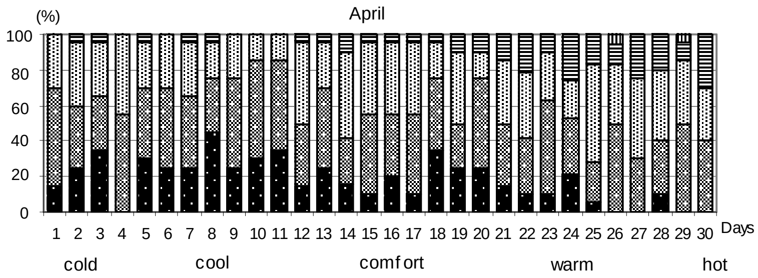


Fig. 9. Frequency (%) of the occurrence of heat sensation classes according to STI in the April-September. Years 1986-2005

In order to present human's biothermal heat sensations in a more detailed way, the frequency of years with 6 classes of heat sensation was worked out – from cold to very hot according to days over the period from April to September (Fig. 10). The weather that occurs in the Ustka region is of a cool type which, along with the cold type, is characterized by the largest frequency of years (from 60 to 80%) in the first and second decade of this month. In the third decade of April there is an increase in the frequency of years with the comfort and warm weather and even hot days appear. In May days with the cold weather occur sporadically and the dominant heat sensation is comfort, the occurrence frequency of which decreases at the end of May in favour of warm days. The warm weather type occurs from June to the first decade of September being dominant from the last decade of July to the first decade of August - and in some days even in 80% of the investigated years. In summer, cool days also occur in about 20-30%, less often comfort days, particularly in August. In this month the frequency of years with hot days varies from several to about 20% – particularly in the second decade. Years with the heat sensation – very hot, occurred only twice (29 June and 29 July 1994). Such small frequency of very hot days resulted from the fact that in the STI index the daily values and not those from the noon (12 o'clock) were taken into account. In September the frequency of years with hot and comfort days is still prevailing, particularly in the first and third decade and the intensification of the cool weather type is characteristic of the middle of this month. A distinguishing feature of bioclimate of the coast, including the region of Ustka, is large variability of heat sensations in 2-3 day sequences and day by day (Koźmiński and Michalska 2008 a, b, c).

A good indicator for the assessment of heat load of a human, staying in the open air, is a heat load index HL considering the effect of the balance of heat exchange, the amount of absorbed solar radiation and evaporation loss of heat (Błażejczyk 2004). The heat load that occurs in the region of Ustka in April, May and in September is on average of a minimum value and from June to August the load causing the stress of warmth is not large, although in the first decade of August the load may even be strong and can result in the stress of heat (Fig. 11).


April
(%)
100
80
60
40
20
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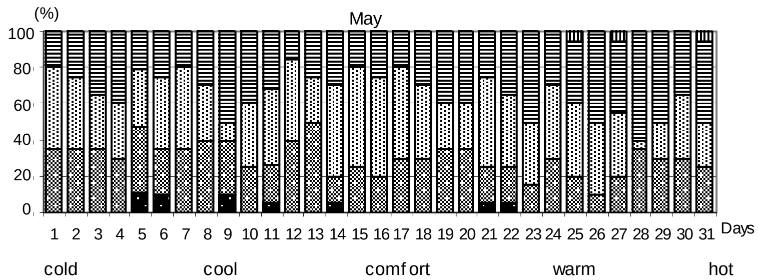
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
Days
cold
cool
comfort
warm
hot


May
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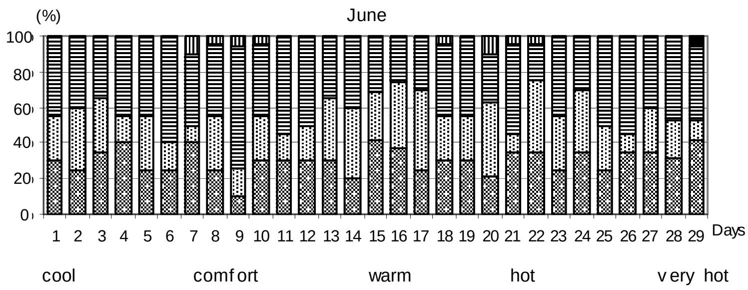
June
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1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29
Days
cool
comfort
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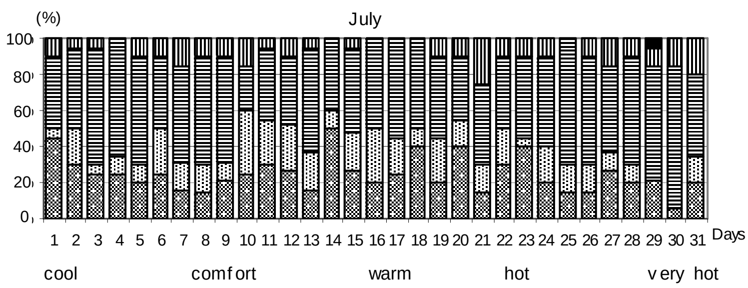
hot
very hot


July
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Days
cool
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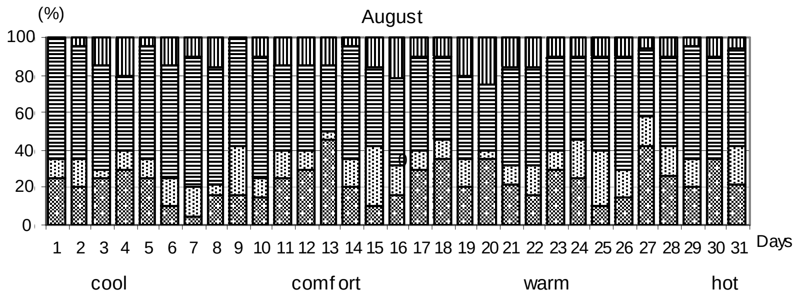

Fig. 10. Frequency of the years (%) heat sensation classes STI according to months and days. Years 1986-2005

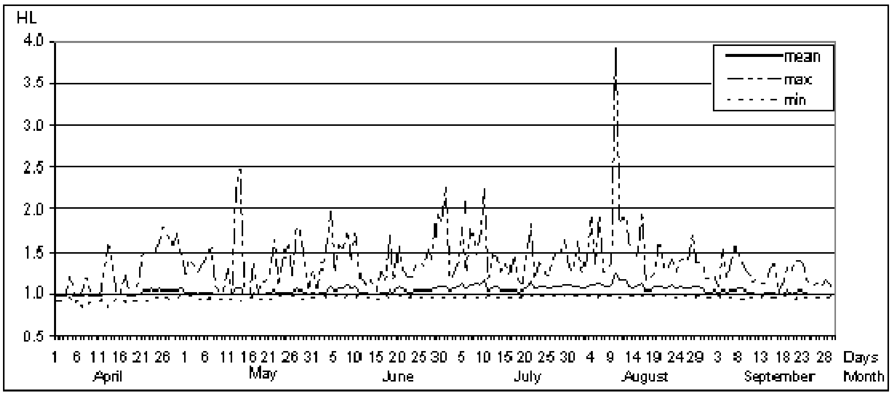

Fig. 11. Mean, maximum and minimum heat load of the organism HL according to days. Years 1986-2005

The course of maximum values of HL shows that days with a very strong thermal load occurred quite often, and also, but sporadically days with a very strong heat load of the organism (the stress of heat). It happened on 10 August 1992 when the analyzed index HL had an exceptionally high value – 3.935, resulting, among other things, from very high extreme temperatures (37.8^{o}C max and 23.0^{o}C min) as well as from the daily mean (33.3^{o}C). The organism's load caused by a stress of the cool is not large in the region of Ustka and it mainly occurs in April what is indicated by the course of the minimum HL values (Fig. 11).

Taking the climatic conditions of Ustka into consideration, predicted insulation of clothes ensuring thermal comfort to people staying in the open field

(Fig.12). In April the average values of the Iclp index varying from 1.2 to 1.6 point to the occurrence of cool thermal conditions. In May, June and in September the occurring conditions are neutral (Iclp from 0.8 to 1.2), and in July and August – warm (Iclp from 0.6 to 0.8).

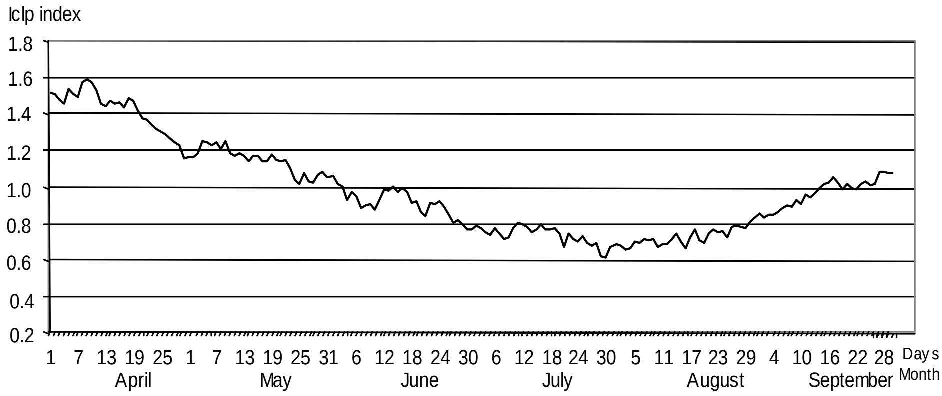

Fig. 12. Mean values of the Iclp index of predicted insulation of the clothing according to days. Years 1986-2005

For the evaluation of the usefulness of the weather to different forms of recreation, partial WEI_{avg} indices were used and this made it possible to work out the so called weather calendars (Fig. 13-16). The best conditions for sunbathing (WEI_{avg}-SB), using clothing of appropriate thermal insulation pervade in the region of Ustka in May, for the weather is very favourable in 55% of days and in the remaining days it is favourable (Fig. 13). In the period from June to August the very favourable weather occurs more or less every three days and in September the favourable weather is dominant (83%). Also in April the favourable weather (53%) to sunbathing dominates and the moderately favourable weather occurs less frequently (40%), however, in this month clothing for transitory seasons should be used (Kozłowska-Szczęsna *et al.* 2002).

A dominating type of weather for airbathing (WEI_{avg}AB) is the favourable weather occurring in above 70% of days in a month, except for the first half of April and this along with the very favourable weather creates optimum conditions for this form of recreation (Fig. 14).

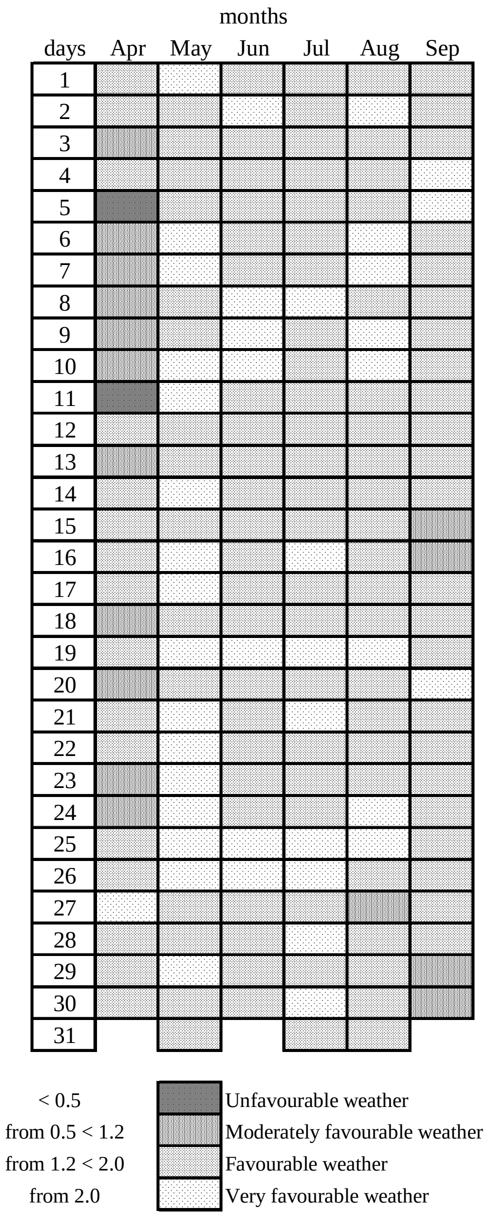

Fig. 13. A calendar of weather usefulness for sunbathing according to days and months on the basis of the $WEI_{avg.}$ index (SB). Years 1986-2005

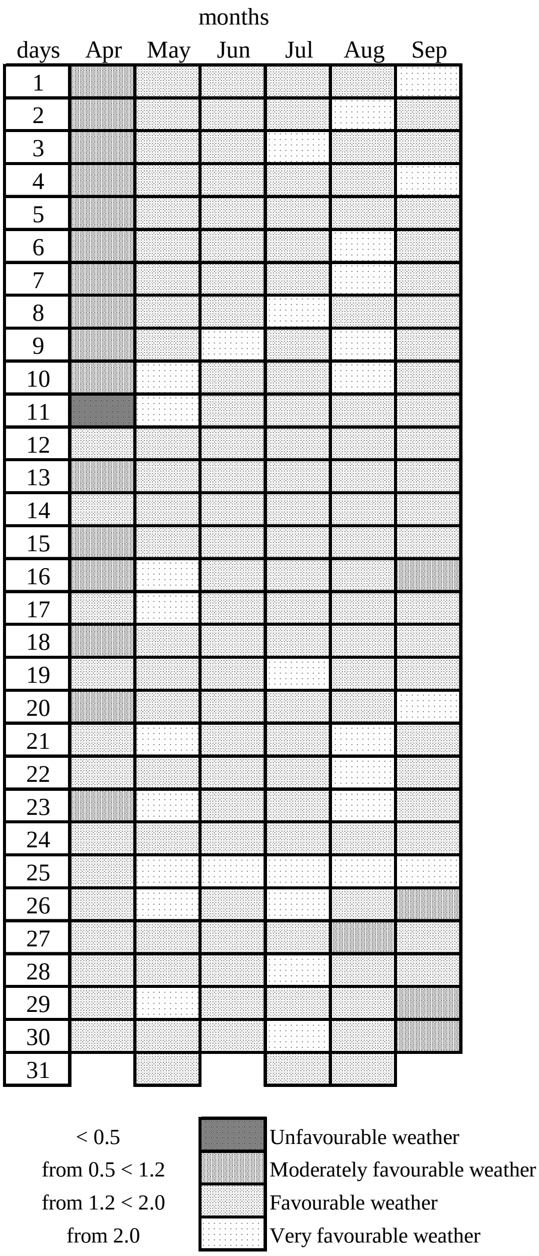

Fig. 14. A calendar of weather usefulness for airbathing according to days and months on the basis of the $WEI_{avg.}$ index (AB). Years 1986-2005

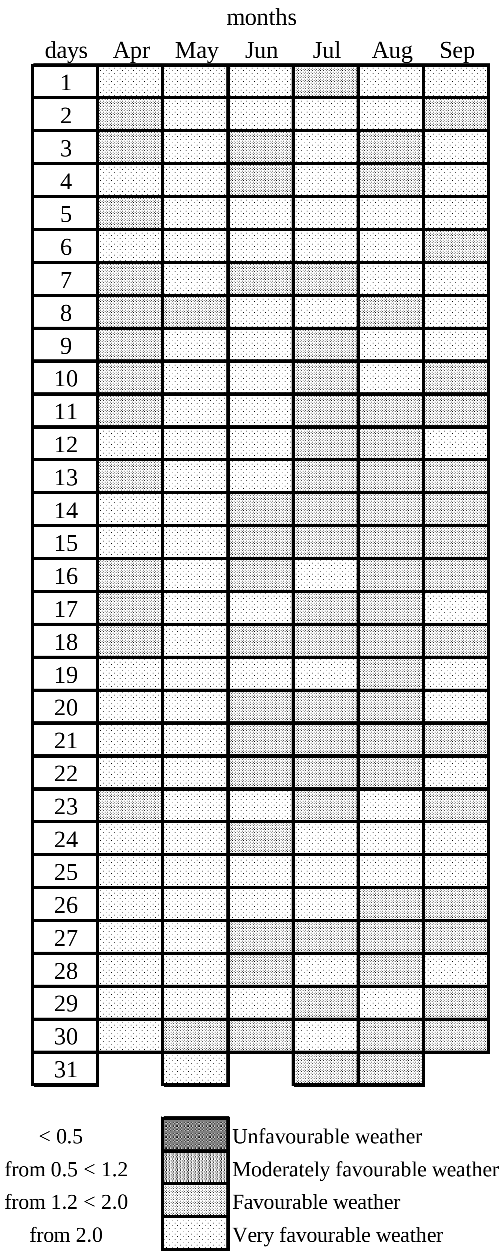

Fig. 15. A calendar of weather usefulness for walking and quiet field workshops according to days and months on the basis of the WEIavg. index (MR).Years 1986-2005

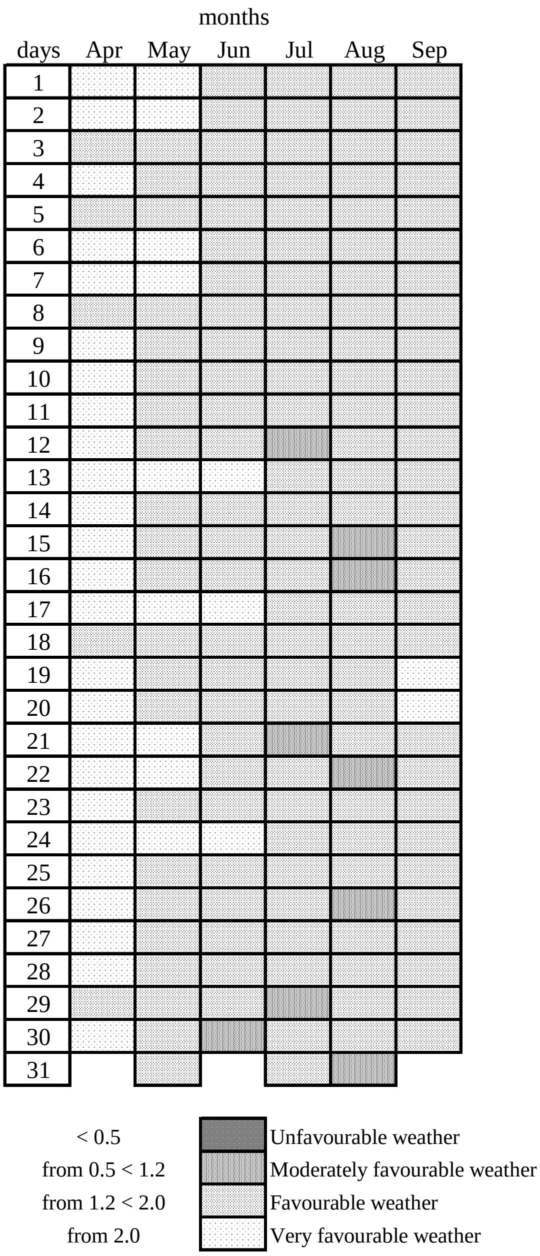

Fig. 16. A calendar of weather usefulness for intensive marches, walking and cycling tourism according to days and months on the basis of the WEI_{avg}. index (AR). Years 1986-2005

In the warm-half of the year the weather conditions for mild recreation ($WEI_{avg}MR$) are favourable in July and August (70% of days), and very favourable – from 19 April to 13 June (Fig. 15). In the remaining days of this half-year, the favourable weather occurs in turns with the very favourable weather.

As to the intensive recreation ($WEI_{avg}AR$) the most favourable conditions prevail in April – nearly in all the days of the month (Fig. 16). This type of the very favourable weather occurs in about 30% in May and in 10% in June. Whereas in July and in August the favourable weather with a few days of moderately favourable type occurs. In September the favourable weather dominates.

Adding the average values of four partial indices WEI_{avg} (SB+AB+MR+AR), a total index of evaluation WEI_{tot} was obtained, the course of which in the successive days of the warm half-year was shown in Figure17. In the region of Ustka dominant are very favourable weather conditions for various forms of recreation and tourist activities (using clothing of appropriate thermal insulation) and only in the first half of April and at the end of September favourable conditions dominate.

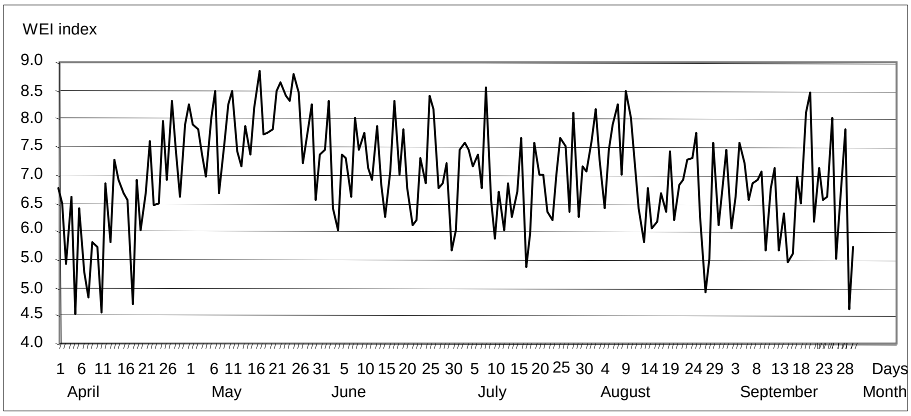

Fig. 17. A course of the summary WEI_{tot} index of bioclimatic conditions according to days. Years 1986-2005

In the averaged values of WEI_{tot} used for the assessment of bioclimatic conditions no unfavourable weather conditions were observed in the discussed half-year, whereas in May, particularly from 16 to 26 there were markedly favourable conditions, which also occurred sporadically in the remaining months. The bioclimatic conditions of Ustka presented in the study are representative of the northern part of the coast and this is reflected by an increased speed of wind, variability of weather conditions and an increased number of days with heat sensation of cold and very cold (Chabior 2004; Kozłowska-Szczęsna *et al*. 2002, Koźmiński and Michalska 2008b). For these reasons, a potential period of leisure in the region of Ustka compared to the region of Świnoujście is shorter by about two weeks.

CONCLUSIONS

1. In the region of Ustka the best sunshine conditions for recreation in the warm half-year are recorded in May (8.2 hours) and in July (7.9 hours), and thermoneutral conditions – in July and in August (on average every two days).
2. Hot (t_{max}>25°) and very hot days (t_{max}>30°), due to their very small frequency of occurrence do not constitute a larger burden for rest and recreation, although sporadic appearance of the years in which such temperatures will be recorded in sequences of several days should be taken into account.
3. In summer, during a period of the largest number of tourists at the seaside, the interdaily changes in pressure >8 hPa occur, on average, 2 days in a month, and changes >12 hPa occur very rarely.
4. A burdensome character of the weather caused by relative humidity of the air – above 85%, is the smallest from the third decade of June to the first decade of July – on average, every 4-5 days and it is the largest in April and in September – on average, every three days.
5. Daily amplitudes of the air temperature above 12°C, due to their small frequency – on average 3 to 4 days in a month, do not constitute a larger burden on the organism.
6. Out of several discussed meteorological thermal factors, the days with precipitation, the largest number of which occurs in the second decade of July and the third decade of August (on average every two days), are burdensome for various forms of spending free time.
7. A dominating type of weather is the warm weather (37% of days of the whole half-year), and then the cool weather (31%), comfort days occur in 25%, and days with the cold and hot weather – 3 and 4%, respectively .
8. Considering the multiannual period, in the warm half-year dominant are the days with a slight heat load of organism, causing stress of heat (HL) – mainly from June to August, and in the remaining months – days with a minimum heat load.

9. Throughout the whole summer half-year the weather conditions pervading in the region of Ustka are favourable for sunbathing, using clothing of appropriate insulation, and in May they are even very favourable. However, in this month a low temperature of air is a limiting factor. In April, the moderately favourable weather occurs, on average, every three days and sporadically – unfavourable. Similar weather conditions are for airbathing.

10. In the region of Ustka the most favourable weather conditions for walking and for slightly intensive field activities are recorded in all the months of the warm half-year, and for intensive marches and for hiking and cycling – mainly in April.

11. Solar, biothermal, humidity and precipitation conditions occurring in the Ustka region make it possible to lengthen the most intensive tourist season, lasting at present from mid June to August by about 45 days i.e. from the middle of May to the middle of September.

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8. FORMATION OF URBAN HEAT ISLAND IN WARSAW IN CONDITIONS OF VARIABLE CLOUDINESS IN 2003-2008

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INTRODUCTION

Continuous territorial development of cities leads to their increasingly distinct influence on shaping of a local climate. Except for the influence of urban agglomerations on the quality of atmospheric air, densely built-up areas, to a different extent, can modify, among other things, wind and solar conditions and convectional processes. Changes in properties of the atmosphere lowest layer caused by urban development lead to modification of all components of the heat balance of this layer. Despite the fact that solar radiation income in cities is lower than in suburban areas e.g. in Warsaw by 20% in winter and 5-10% in summer (Kłysik after Kozłowska-Szczęsna, Podogrodzki 1995), the city, as it was proved by numerous research studies, constitutes a "heat island" in comparison with not built-up surroundings. It is caused by considerable thermal capacity of artificial areas in the city, marked by a diverse albedo, heat release during combustion processes of fossil fuels, more difficult radiation of the heat or a reduced quantity of actual evaporation.

The phenomenon of the urban heat island (UHI) and the causes of its occurrence are widely described in the literature. It is commonly known that the intensity of the UHI is strictly dependent both on a season of the year, the time of day and also on weather conditions. Moreover, every UHI possesses individual characteristics, reliant on the size and urban development of a city, the character of surface features and other things (Lewińska 1991, Fortuniak 2003, Lorenc 2004, Szymanowski 2004).

Previous research have shown that the urban heat island in Warsaw is a frequent phenomenon but it does not occur every day and its intensity is the highest in the city centre during summer nights. Weather conditions in winter are less conducive to the appearance of high thermal contrasts but during long-lasting high-pressure systems the formation of an intense UHI may take place (Gołaszewski *et al.* 2007).

The current work made an attempt at determining the intensity of the UHI caused by the Warsaw agglomeration occurring in conditions of variable cloudiness in different months and seasons of the year.

MATERIAL AND METHOD

The research was based on meteorological data made accessible by WIOŚ, coming from 6 automatic measurement stations located in areas of different building development types in Warsaw and outside the city. The above-mentioned stations work in accordance with the Air Quality Assessment System of the Mazovian Province.

In order to determine the intensity of the urban heat island, differences between air temperature $dT_{U\text{-}R}$, recorded at particular stations located in Warsaw (MzWarKrucza, MzWarNiepodKom, MzWarTarKondra, MzWarUrsynów) and Piastów (MzPiastPułask) and temperature measured at the regional background station in Legionowo (MzLegionZegIMGW), which is situated outside Warsaw, were calculated. This station is located about 10 km from the northern border of the city, which causes that with relatively low frequency of southerly winds little influence of the agglomeration is noticeable.

In order to determine the intensity of the UHI of a different degree of cloudiness, at first pressure systems occurring above Warsaw in the considered period were analysed. Examining the pressure systems, certain days were selected for further analysis: days with stable cloudiness – cloudless ones ($0 \leq N \leq 2$) and cloudy ones (with cloudiness of $6 < N \leq 8$ based on an 8-degree scale). In order to conduct it, the work used IMGW Daily Meteorological Bulletins and data gathered in the Institute of Meteorology and Climatology of SGGW concerning daily observations of a degree of cloudiness. This way, two sets of measurement days were created (a set of cloudless days having 448 cases and a set of cloudy days – 641), on the basis of which further analyses were conducted.
The base of calculations was average, 10-minute values of air temperature measured by means of sensors placed in radiation shields, recorded at the above-mentioned stations in the period from 01.09.2003 to 31.12.2008. Using the data, basic climatological characteristics were determined i.e.: average hourly, daily, monthly and yearly values of air temperature.

Average hourly air temperature diffrerences between the analysed stations and the station in Legionowo served as a basis for preparation of the following:

- frequency distribution of these differences in the warm (months IV-IX) and the cold (months X-III) season of the year, during day and night,
- a chart of average differences $dT_{U\text{-}R}$ for all measurement stations in the warm and cold season of the year,
- graphical presentation of development and disappearance of the urban heat island in the course of the year, at different times of day and night shown by means of isopleths of average temperature differences between

the stations located in Warsaw and the station outside the city. To prepare the charts the program Surfer-8 was used.

Description of stations (on the basis of data from WIOŚ in Warsaw):

Station Legionowo (MzLegionZegIMGW) – a regional backgriund station, situated on the premises of IMGW, on a grassy, open area (at a distance from a forest). The station is marked by good ventilation, a distance from main roads amounts to about 80 m. The assumed area representativeness of the station amounts to a diameter of several dozen kilometres.

Station Krucza (MzWarKrucza) – an urban background station, situated in the centre of Warsaw in a densely built-up area (which forms a kind of well-shaped area), consisting of five-storey buildings that fulfil residential and commercial functions. At a distance of about 10m from the station there is a car park and about 50 m from the station there is four-lane Krucza Street which is characterised by traffic density of about 20,000 vehicles/24h. Percentage of green areas in this place is extremely low.

Traffic station (MzWarNiepodKom) – situated in Niepodległości Avenue in the centre of Warsaw, in a street canyon, by the roadway of a 6-lane street (one of the streets with the highest traffic density), with a tram line. At a distance of 5 m from the western side of the station there are 5-storey buldings and from the eastern side at a distance of about 30m equally tall buildings.

Station Targówek (MzWarTarKondra) – an urban background station, situated at Kondratowicza Street in Warsaw in the northern part of the city, on the premises of the Bródno Hospital. The closest vicinity of the station is covered with grassy vegetation. At a distance of about 80 m from the western side there is a park and at a distance of 50 m from the eastern side there are hospital buildings. A distance from a wide and busy Kondratowicza Street amounts to about 100 m.

Station Wokalna (MzWarUrsynów) – an urban background station, situated in Ursynów i.e. the southern part of the city on a grassy and concrete ground. At a distance of 150-300 m there are 4-storey buildings, nearby development is well laid out. A distance from Bartoka Street, which is marked by quite high traffic density amounts to approximately 200 m.

Station Piastów (MzPiastPułask) – an urban background station, located at Pułaskiego Street outside the Warsaw agglomeration (approximately 2 km from the western border of Warsaw) so that it would represent urban background of a town with a population of less than 50 thousand. It is situated on the premises of a school on a grassy and concrete ground, a distance from the roadway of a nearby street amounts to 25-30 m (the street is characterised by low traffic density). On the northern side of the station there is a road and single-family houses and at a distance of 100 m from the eastern side there are 8-storey buildings. At a distance of 30 m from the southern side there is a school gym and from the western side (at the same distance) there are 3-storey school buildings.

RESULTS

As it was shown by the previous research on the Warsaw urban heat island, the phenomenon is recorded throughout the year and throughout the day and night (Gołaszewski *et al.* 2007). The current results of the analysis of the course of average hourly values of thermal contrasts between the city and suburban areas in the analysed years 2003-2008 are presented in Table 1.

It is clearly noticeable that the highest thermal contrasts proving the intensity of the UHI were recorded at the stations located in the centre of the city, on cloudless days and in the warm season of the year (Fig. 1).

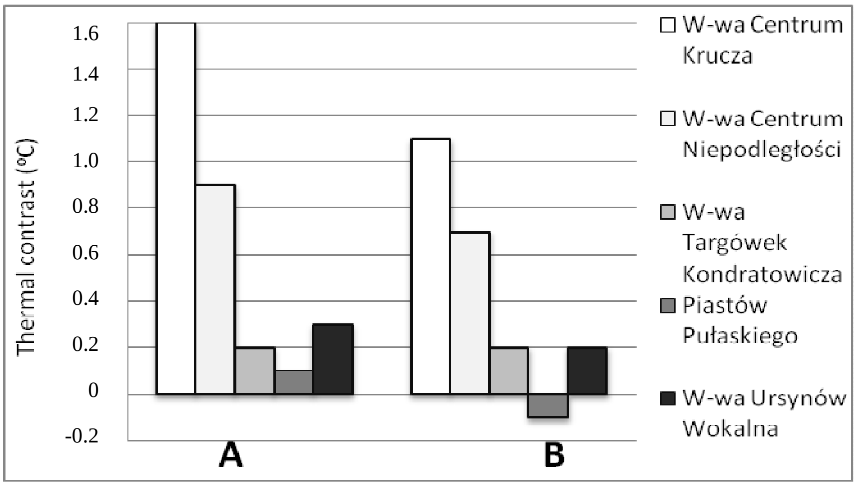


Fig. 1. Frequency of thermal contrast during days (A) and nights (B) with cloudiness of $0 < N \leq 2$

On **cloudless days in the warm season of the year** at the Centrum Krucza station average hourly temperature differences $dT_{U\text{-}R}$ changed within a range from 0.8°C in the afternoon (6-7 p.m. of UTC+1) to 2.5°C after the sunset. At the second station located in the city centre, the Centrum Niepdległości station, temperature differences were lower and were within a range from –0.1°C at 4-5 p.m. (UTC+1) to 2.0°C after the sunset.

With a growing distance from the centre, thermal contrasts grow weaker and are within a range from –0.4 to 0.5°C at the Targówek Kondratowicza station and from –0.1 to 0.8°C at the Ursynów Wokalna station.

Table 1

Table 1

On **cloudless days in the cold season of the year** the analysed thermal contrasts were considerably lower than those recorded in summer, they were also marked by slower changes. It mainly results from lower values of the energy flux of heat balance components. The exception was the Targówek Kondratowicza station where temperature differences between the city and areas outside the city increased and changed within a range from 0.1°C after the sunset to 0.8°C before the sunrise. The UHI, however, was recorded throughout the day and night at all stations located in Warsaw. The centre, in comparison with its surroundings, was the warmest part of the city but the intensity of the UHI was substantially lower than the intensity recorded on summer cloudless days. At the Krucza station, contrast dT_{U-R} was within a range from 0.8°C after the sunset to 1.6°C in the morning. At the Centrum Niepodległości station the UHI also remained during the day and night but its intensity was lower, within a range from 0.2°C at 1-3 p.m. to 1.4°C in the morning. Like in the warm season of the year, a growing distance from the centre causes a decrease in the intensity of the UHI, e.g. at the Ursynów Wokalna station dT_{U-R} was within a range from 0.1°C after the sunset to 0.7°C in the morning. In the case of the Piastów Piłsudskiego station, the course of thermal contrasts is similar to the ones observed at the stations located in Warsaw but the intensity of the appearing heat island is considerably lower, which can be explained by the fact that this station is located beyond the borders of thermal influence of the Warsaw agglomeration.

The average intensity of the UHI on cloudy days in the warm and cold season of the year in the analysed years 2003 – 2008 was presented in Figure 2.

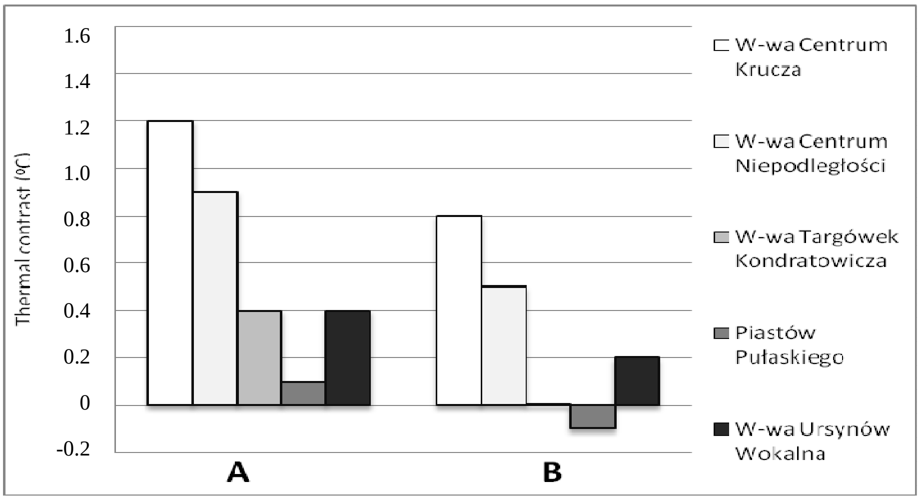


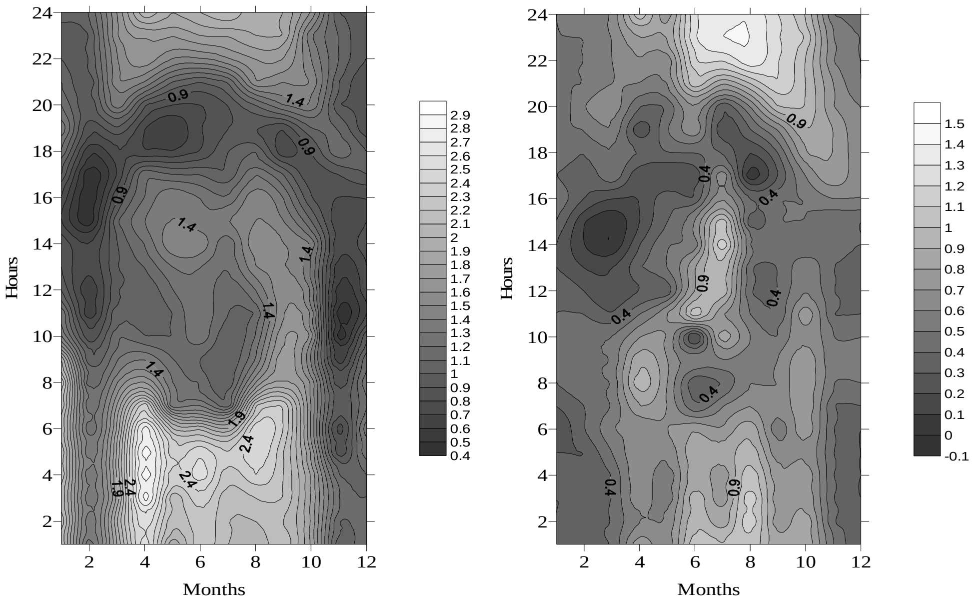
Fig. 2. Frequency of thermal contrast during days (A) and nights (B) with cloudiness of $7 \leq N \leq 8$

On **cloudy days** (cloudiness of $7 \leq N \leq 8$) **in the warm season of the year** the occurrence of the heat island was recorded at all stations in Warsaw and the highest thermal contrasts were recorded in the central part of the city (Tab. 1). The heat island was clearly developed but the the range of changes in average hourly temperature differences dT_{U-R} was much smaller than on cloudless days. At the Centrum Krucza station the intensity of the UHI was within a range from 0.7 to 1.5°C (whereas on cloudless days these were differences of 0.8-2.5°C), and at Niepodległości Avenue the differences were within a range between 0.3 and 1.2°C (on cloudless days –0.1-2.0°C). Similarly, lower and more balanced values of temperature contrasts between the city and the suburbs were recorded at the remaining, more distant from the centre stations. Changes in the intensity of the UHI at both stations (Targówek Kondratowicza and Ursynów Wokalna) were the same and amounted to 0.0-0.4°C.

On **cloudy days in the cold season of the year** the heat island was least noticeable and the range of changes in average hourly temperature contrasts dT_{U-R} was definitely the smallest. At the Centrum Krucza station, the UHI was marked by thermal contrasts within a range between 0.6°C and 0.9°C, at the Centrum Niepodległości station between 0.3°C and 0.6°C and in the southern part of the city (Ursynów Wokalna) between 0.1°C and 0.3°C. Such an equal course of thermal contrasts between the city and its surroundings can give evidence of anthropogenic heat, which becomes a decisive factor during the formation of the UHI in this period. Only at the Targówek Kondratowicza station (situated on a grassy ground near a park), periodically, there occurred positive thermal contrasts (between 6 p.m-0 a.m.) and negative ones (from 1 a.m. to 10 a.m.). On days with heavy cloudiness air temperature in Piastów was the lowest out of all the stations.

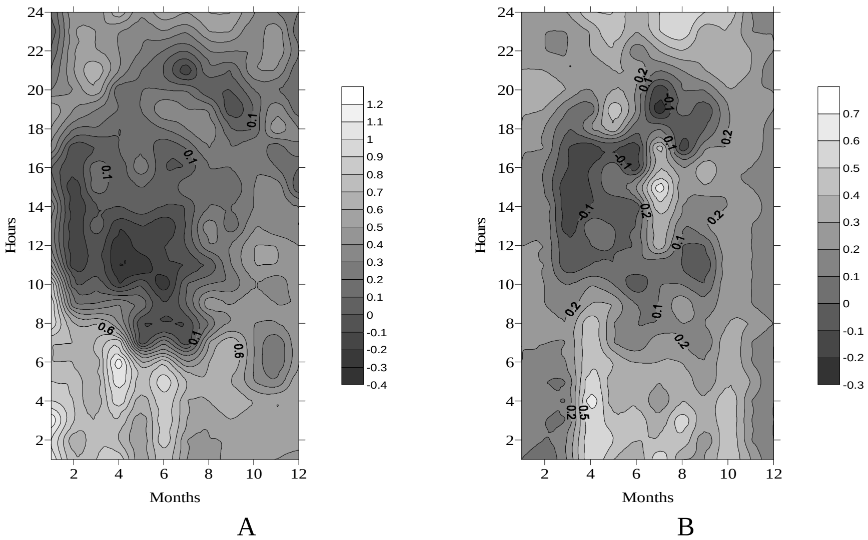
Most vividly, appearance and disappearance of the UHI at different times of day and night, throughout the year in conditions of variable cloudiness, are presented by isopleths (Figs. 3 and 4), which are a graphical image of development of the UHI at two selected stations located in the city centre – Krucza and in its southern part – Ursynów Wokalna.

As it can be seen, cloudless days (Fig. 3) are conducive to high effective emission which, combined with high thermal inertia of the city, gives higher heat income to the active surface leading to an increase in the intensity of the UHI. It is particularly visible in summer months in the centre of Warsaw (Fig. 3A) and less distinctly in Ursynów Wokalna (Fig. 3B). On the other hand, an increase in cloudiness limiting the income of direct radiation and decreasing effective emission leads to considerably smaller differences between the city and the areas outside the city (Fig. 4).



A B

Fig. 3. Graphical image of appearance and disappearance of the UHI in the course of the year, during twenty-four hours for the analysed stations: Centrum Krucza (A) and Ursynów Wokalna (B) – during days with cloudiness of $0 < N \leq 2$



A B

Fig. 4. Graphical image of appearance and disappearance of the urban heat island in the course of the year, during twenty-four hours for the analysed stations: Centrum Krucza (A) and Ursynów Wokalna (B) – during days with cloudiness of $7 \leq N \leq 8$

Additionally, in winter months more frequent, stronger and longer lasting cyclonic movements of air masses leading to increased air change in the city are conducive to it, thus effectively limiting a possibility of formation of a heat island.

The obtained results, regardless of a degree of cloudiness, confirm the fact, known from the literature, that after the sunset there occurs quick development of the UHI, of which intensity increase (especially in the first period of the night) lasts until the sunrise. The rising sun causes heating up of open suburban areas of lower thermal inertia, leading to a substantial decrease in the intensity of the UHI during successive hours of the day (and even to disappearance on cloudless days). Summer and winter variability of temperature differences are marked by a generally similar daily course but by highly different intensity (Figs. 3, 4).

The above-described regularities are reflected in occurrence frequencies of thermal contrasts $dT_{U-R} > 2^{o}C$ in particular hours of the considered days (Tab. 2). The highest frequency of the occurrence of the highest thermal contrasts was recorded at the stations in the centre. On cloudless days, contrasts $dT_{U-R} > 2^{o}C$ were more often recorded in the late-night and morning hours in the cold season of the year (up to 63% of cases at 5 and 6 a.m.), whereas in summer the frequency of the appearance of such intensive contrasts was more balanced – about 30%, at its peak rising to 34%. At the remaining stations the occurrence frequency of the heat island of the intensity higher than $2^{o}C$ was much lower and did not exceed 10%.

During cloudy nights the occurrence frequency of the UHI of intensity of $dT_{U-R} > 2^{o}C$ was much lower than in summer. Higher temperature differences were more often recorded in the city centre in the warm season of the year (up to 22% in night hours), whereas in winter up to 8%. At the remaining stations, the UHI of intensity exceeding $2^{o}C$ was recorded sporadically – up to 3% of cases.

Distributions of the frequency of air temperature differences between the stations in Warsaw and the station in Legionowo are presented in Table 3. It is noticeable that the highest temperature contrasts between the city and its surroundings occurred with low cloudiness.

At the Krucza station, $dT_{U-R} > 2^{o}C$ constituted 61% during the day and as much as 81.1% at night and at the Niepodległości station respectively 44.1% and 70.1%. At the remaining stations, the occurrence frequency of thermal contrasts $>2^{o}C$ oscillated between 15 and 21%. Negative thermal contrasts recorded during cloudless days and cloudless nights were mainly recorded at the stations located outside the centre. At the Targówek Kondratowicza station the records were: respectively 5.5% and 3%, at the Ursynów Wokalna station 3.2% and 0.4%, whereas at the Centrum Niepodległości station respectively 0.4% and 1.2%, and 0% at the Krucza station. Most often, negative contrasts were recorded in Piastów – during the day 7.6% and at night 7.9%.

Table 2

Table 2

Table 3

An increase in cloudiness caused a considerable drop in the intensity of the UHI. The occurrence frequency of contrasts with values of >2^{o}C is two or sometimes three times lower than on cloudless days. During cloudy days and nights thermal contrast within a range of 0.1-1.0^{o}C occurred most often. Only at the Centrum Krucza station a balanced distribution of thermal contrasts of different intensity was recorded (irrespective of the time of day and night). A considerable increase of the occurrence frequency of negative thermal contrasts is noticeable only at the station in Piastów (an increase up to 16.4 during the day and 17.8% at night). At the remaining stations (in comparison with cloudless days) changes are minor – up to about 3%.

The results of the work show big importance of microclimatic conditions of the closest vicinity of urban measurement points and the city spatial structure for formation of thermal contrasts between the Legionowo station and the four stations located in Warsaw and Piastów. For this reason, beyond any doubt, one should agree with Fortuniak's opinion (2003) on the necessity of standardisation of urban climate research, which will make possible comparability of obtained results, also – from different cities.

CONCLUSIONS

It results from the conducted in the current work analysis of average hourly air temperature differences between the atmosphere monitoring stations in the Warsaw agglomeration and the regional background station in Legionowo that in the examined period:

- regardless of a degree of cloudiness, after the sunset there occurs quick development of the UHI (Urban Heat Island), of which increase in intensity usually grows stronger in the first part of the night and lasts until the sunrise. In the successive hours of the day, because of quicker heating up of open areas outside the city marked by lower thermal inertia, the UHI of considerably lower intensity is recorded (or even it disappears on cloudless days).
- both summer and winter variability of temperature changes $dT_{U\text{-}R}$ are marked by a generally similar daily course but highly different intensity – lower and more balanced on cloudy days,
- the Warsaw urban heat island was the biggest and most frequently recorded in the city centre during cloudless nights,
- with a growing distance from the city centre, in areas with more scattered development, the Warsaw urban heat island also occurred but its occurrence frequency and its intensity weakened,
- at the station in Piastów, located outside the Warsaw agglomeration, low positive thermal contrasts in comparison with the station outside the town mainly occurred during cloudless nights.

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10. THE INFLUENCE OF PRECIPITATION CONDITIONS ON THE CONCENTRATION OF SUSPENDED PARTICULATES PM10

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INTRODUCTION

In the group of meteorological elements shaping the spreading and dispersion of gas and particulates pollutants, an important role is played by precipitation conditions (Holst *et al.* 2008, Kasprzycki 1969, Rost *et al*. 2009, Walczewski, 1997, Velders and Matthijsen, 2009). However, their contribution to the cleaning of air is smaller than that of the dynamic elements determining the intensity of vertical and horizontal exchange of air (Czarnecka and Kalbarczyk 2008, Keary *et al*. 1998, Kulig 1981, Majewski *et al*. 2009). As Gawryś reports (1981), following Głowiak, about 30% of suspended particulates is removed from the air by the activity of electrostatic and gravitation forces and the remaining part is washed out by atmospheric precipitation. The cleaning role of precipitation as a main factor of the so called "wet deposition" or "wet stream", depends on many features of the phenomenon itself as well as the character of pollution. In the determination of washing out of pollutants by precipitation, in mathematical, deterministic models of their spreading, the following factors are taken into consideration: the character of precipitation, the time of duration, the intensity, the distribution of rain drops size and the speed of their fall as well as the type and chemical properties of pollutants and the diameter of aerosol particles (Głowiak *et al*. 1985, Juda and Chróściel 1974, Markiewicz 2004). The complexity of reasons determining the process of the washing out of pollutants and very large variability of ambient concentration as well as variability and discontinuity of precipitation cause that the qualitative evaluation of precipitation effectiveness is very difficult and even, in many deterministic models, it is determined, out of necessity, by means of only one parameter, namely, a washing out coefficient, approximated by analytical methods (Markiewicz 2004). A large limit in the description of the precipitation effect on variability of ambient concentration by means of statistical methods is the range and availability of standard measurements and observations of the phenomenon within the range of the IMGW (weather stations) network. They make it possible to carry out the analysis, mainly on the basis of decade (10 day periods) or monthly precipitation totals and frequency of their occurrence, and moreover, deriving mainly from a different location than that of the measurements of ambient concentration (Czarnecka *et al*. 2007, Czarnecka and Kalbarczyk 2008). Larger possibilities appeared in 2005 along with the start of a standardized system of monitoring the quality of air, the integral part of which is automatic, continuous registration of main meteorological elements, including atmospheric precipitation and an equally important thing, it is carried out in the place of the measurements of ambient concentration. For these reasons, the aim of this work was an attempt of statistical evaluation of precipitation effectiveness in removing suspended particulates PM10 as the pollutants most frequently disturbing the standards of the air quality in our country.

MATERIALS AND METHODS

The basic material consisted of average hourly concentrations of suspended particulates PM10 and the atmospheric precipitation totals over the years 2005-2007, registered within the frames of the system, monitoring the air quality, carried out by Voivodeship Inspectorates of Environmental Protection. Because not all immission stations functioning in individual towns have an identical range of the carried out measurements, the final choice of the materials constituting the basis of the description was decided according to the completeness of results embracing ambient concentration and atmospheric precipitation from the same location. This condition was satisfied only by seven stations situated in towns of central and southern parts of the country. Due to the observational gaps in the measurement series of immission or atmospheric precipitation in many selected stations, the final number of the basic series of hourly results amounted to about 156 thousand. All the stations represent an urban or suburban area of residential or residential and recreational character and are classified by Voivodeship Inspectorates of Environmental Protection as the stations of the urban background.

The basis for the analysis were hourly and daily values (mean or totals) according to seasons of the year or months, also considering the daytime and the time of night. It was assumed that independently of the season of the year, the daytime lasts from 7 am to 6 pm and the night – from 7 pm to 6 am according to the UTC. The amount of hourly and daily concentrations of suspended particulates PM 10 was assessed according to the alert and permissible levels listed in the Minister of Environmental Protection Regulation of 3 March 2008. Dz.U. nr 47 (Journal of Laws No 47). The influence of precipitation conditions on variability of the immission of suspended particulates PM10 was determined by the method of the regression analysis taking into consideration two levels of significance $\alpha = 0.05$ and $\alpha = 0.01$.

RESULTS AND DISCUSSION

In the years 2005-2007 average daily concentrations of suspended particulates, recorded in seven towns, selected for the analysis, varied from about 1 to 532 $\mu g \cdot m^{-3}$ and hourly averages – even up to 861 $\mu g\ m^{-3}$. The contribution of daily concentrations of above 50 $\mu g\ m^{-3}$, which, in accordance with the norm, can be exceeded with the frequency up to 35 days per year (Regulation ..., 2008), amounted to nearly 20% in the analysed three years. Although the largest amount of the immission of suspended particulates PM10 was characteristic of January 2006, the above mentioned permissible levels were also exceeded in 2005 and in 2007. Whereas the cases of exceeding an hour alert level amounting to 200 $\mu g\ m^{-3}$, was recorded only in 2006 (in the town of Radom in nine days) and once in 2007 in the town of Cieszyn. As Figure 1 shows, in nearly 50% of the cases, daily concentration of suspended particulates PM10 varied within the range of 10-30 $\mu g\ m^{-3}$, with a slight advantage of class 20-30 $\mu g\ m^{-3}$. Concentrations of above 100 $\mu g\ m^{-3}$ were recorded in about 3% of days.

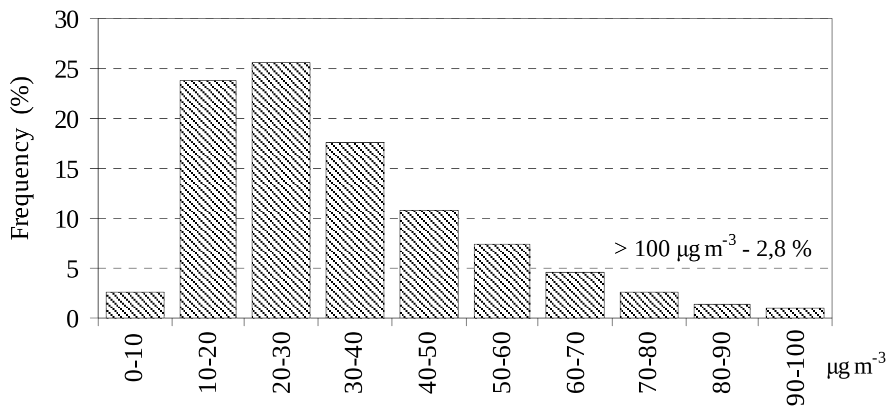

Fig. 1. Frequency of occurrence (%) of the recognized average daily classes of suspended particulates PM10 over the years 2005-2007

In the analysed three year series of daily data, the contribution of days without precipitation amounted to about 60 (Fig. 2). The smallest difference in the frequency of days with precipitation and without precipitation, about 13%, was characteristic of calendar summer, whereas in the remaining seasons of the year, the advantage of days without precipitation over the days with precipitation was considerably higher – in spring and autumn almost twice as large. In all the seasons of the year, precipitation occurred most often (in about 40% of cases) in individual days. Precipitation recorded in two successive days constituted half the number of cases of one day and the frequency of precipitation sequences longer than 4 days or more, did not exceed, on the whole, 10%. Precipitation lasting longer was recorded more often in spring, whereas less frequently in summer and autumn. In the years 2005-2007 precipitation recorded during the daytime (from 7 am to 6 pm) had a slight advantage over the night precipitation (7 pm – 8 am) and it was the largest in winter. A slight difference between the daytime and the time of night was also observed in respect of the precipitation amount average. Whereas contrastive conditions concerning the amount of precipitation occurred in summer and winter. During the calendar summer, mean hourly totals of precipitation, both those of the daytime and the night, amounted to about 1.4 mm and were more than twice as large as in winter (Fig. 2).

The introductory stage of the analysis aiming to show the effect of precipitation on the air pollution with suspended pollutants PM10 was the comparison of the amount of immission in series of days with and without precipitation. As the analysis of Figure 3 shows, average daily concentrations of suspended particulates PM10 not exceeding 20 $\mu g\ m^{-3}$ occurred equally often (those up to 10 $\mu g\ m^{-3}$ even more often) in days with precipitation as well as in days without precipitation. A washing out role of atmospheric precipitation began to be noticeable only at the concentrations of 20-30 $\mu g\ m^{-3}$, however, significantly clearer – starting from the daily immission exceeding 30 $\mu g\ m^{-3}$.

Whereas the largest daily concentrations of above 100 $\mu g\ m^{-3}$, occurred with the frequency of about 90% in days without atmospheric precipitation. The washing out role of the precipitation in relation to the air pollution with suspended particulates is also confirmed by the comparison of one hour concentrations occurring during precipitation which, depending on the station, were by 21 to 34 % smaller than those recorded in situations without precipitation (Fig. 4).

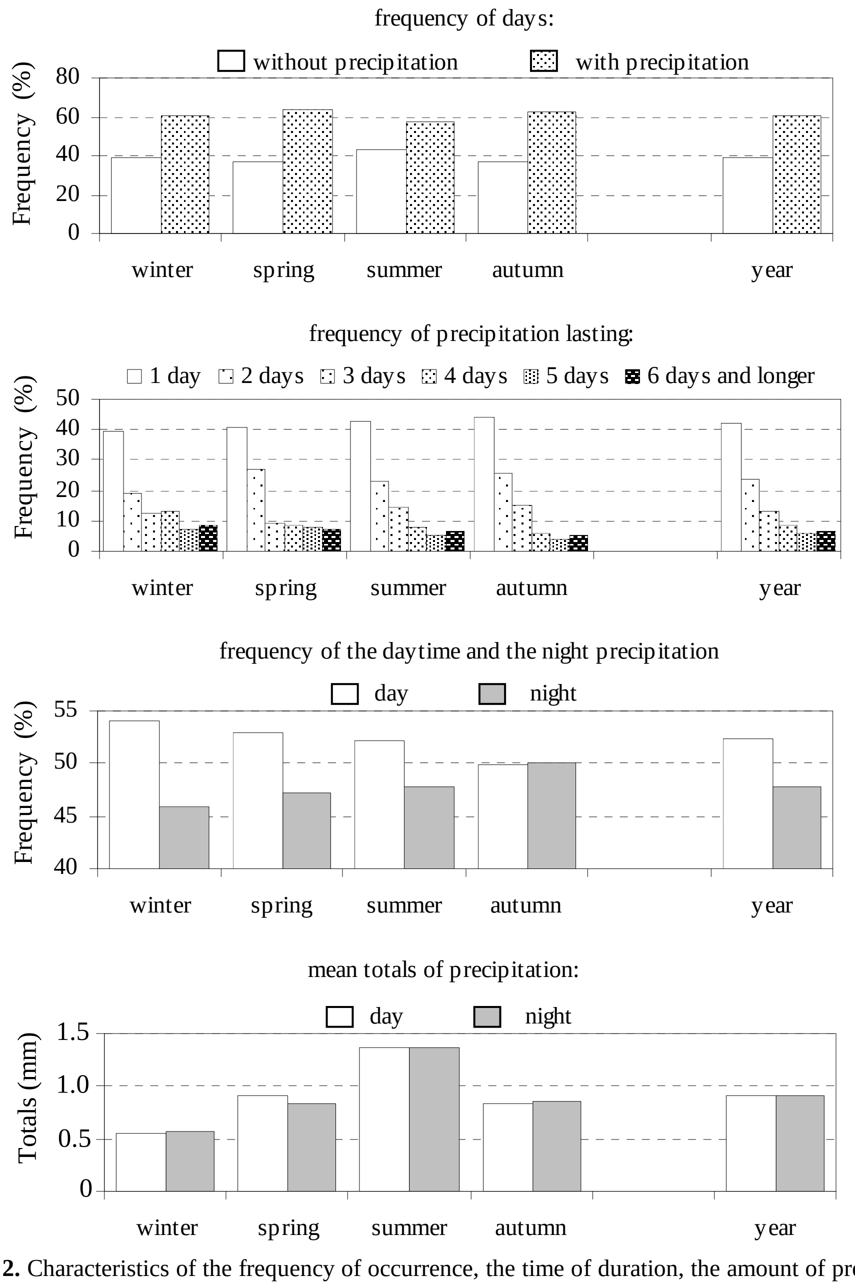

Fig. 2. Characteristics of the frequency of occurrence, the time of duration, the amount of precipitation according to seasons of year and periods of day over the years 2005-2005

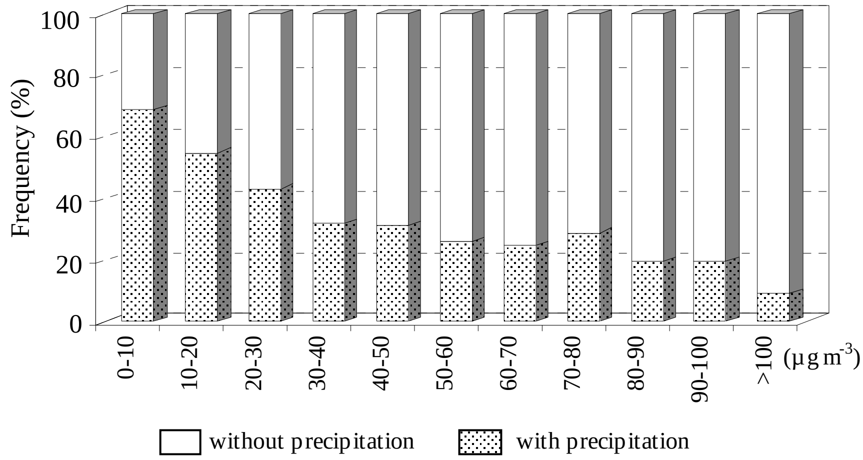

Fig. 3. Frequency of occurrence (%) of the recognized average daily classes of suspended particulates PM10 in the days with and without precipitation over the years 2005-2007

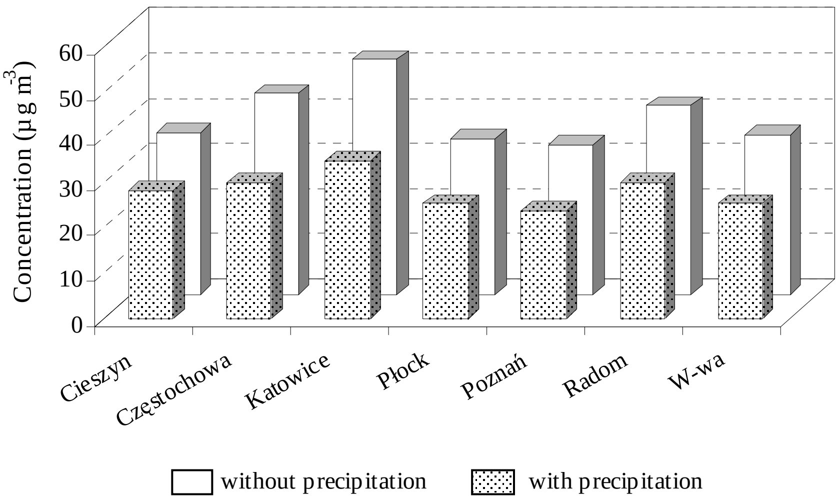

Fig. 4. Average hourly concentrations ($\mu g \cdot m^{-3}$) of suspended particulates PM10 over the years 2005-2007

However the difference between the concentration of suspended particulates in the days with precipitation and without precipitation depended on the season of the year (Fig. 5). In winter the immission of the suspended particulates in days of the occurrence of precipitation was by 36% smaller than in days without precipitation, whereas in summer – only by 13%. While in spring and autumn, the decrease in the concentration of particulates under the influence of precipitation was similar.

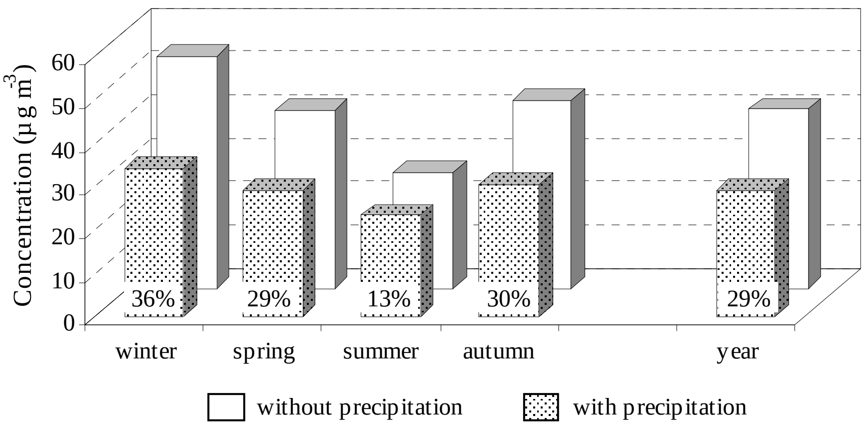

Fig. 5. Average daily concentrations (µg m^{-3}) of suspended particulates PM10 in the days with and without precipitation according to the seasons of year over the years 2005-2007

In all seasons of the year a larger decrease in the average immission of suspended particulates in series of days with precipitation, in comparison to series of days without precipitation, became noticeable in the time of night (Fig. 6), despite the fact that the frequency and the amount of night precipitation were similar like those of the daytime. A decrease in the immission during night precipitation as compared to the immission during the night without precipitation varied from 23% in summer to 42% in spring, whereas under the conditions of precipitation occurring in the daytime as compared to the immission in the days without precipitation – the decrease varied from 5% in summer to 34% in autumn.

The decrease in the concentration of suspended particulates PM10 under the influence of precipitation showed particularly large contrasts between the daytime and the time of night in summer.

The significance of precipitation as a factor of wet deposition of particulates pollutants is also confirmed by the results of the analysis of regression between average daily concentrations of particulates and daily totals of precipitation which turned out to be statistically significant for most of months and calendar seasons of the year. However, coefficients of determination, although significant at $\alpha = 0.01$, were very small and they did not exceed 5%. The influence of precipitation on variability of immission of particulates turned out to be insignificant, particularly in summer. Whereas the analysis of regression carried out in reference to the characteristic range of particulates concentrations, e.i. from 10 to 30 µg m^{-3}, and also the analysis limited exclusively to the series of days with precipitation, gave the results exclusively statistically insignificant.

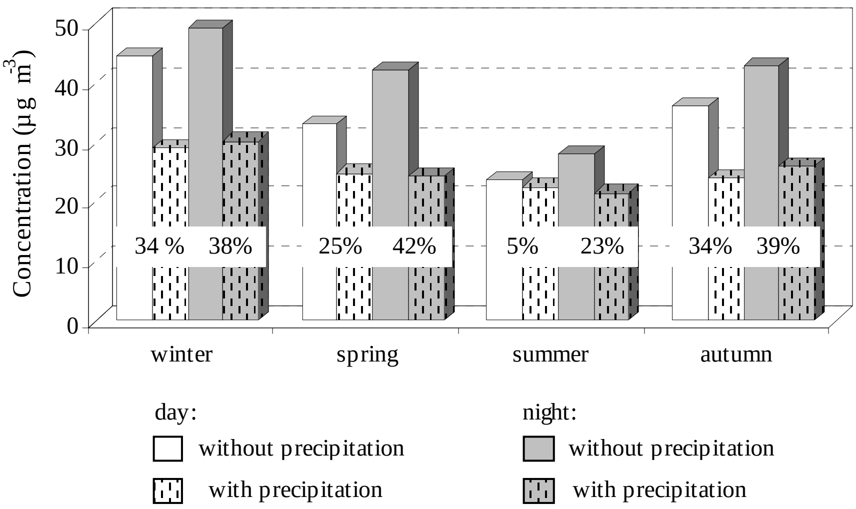

Fig. 6. Average daily concentrations (µg·m^{-3}) of suspended particulates PM10 in the days with and without precipitation in the daytime and in the night over the years 2005-2007

In order to provide the details to the evaluation of the role of precipitation as a factor of wet deposition, periods embracing the day before precipitation, the day or a sequence of days with precipitation and the day after precipitation were selected from the set of basic data. The sets selected in this way, included not only the cases of a decrease in the immission under the influence of precipitation (as compared to the immission on the day of preceding the precipitation), but also numerous situations in which an increase in the immission was recorded. This was also confirmed under the conditions observed in Warsaw (Majewski *et al*. 2009). Despite this, in all the seasons of the year, average daily concentrations of suspended particulates PM10 in the days of the occurrence of precipitation were by 11 to 29% smaller than the day before (Fig. 7). It means that a real decrease in the concentration of particulates on the day of the occurrence of precipitation, as compared to the day directly preceding precipitation, was smaller than it had been stated earlier (Fig. 5) on the basis of the comparison of the immission in the independent of one another, differing in number series of days with and without precipitation. Whereas, the smallest effectiveness of precipitation was confirmed in respect to the removal of particulates pollutants in summer, however a positive cleaning effect still maintained the following day. But in the remaining seasons of the year, the concentrations of particulates the next day after precipitation showed an increase, in spring even up to the level not much smaller than before its occurrence.

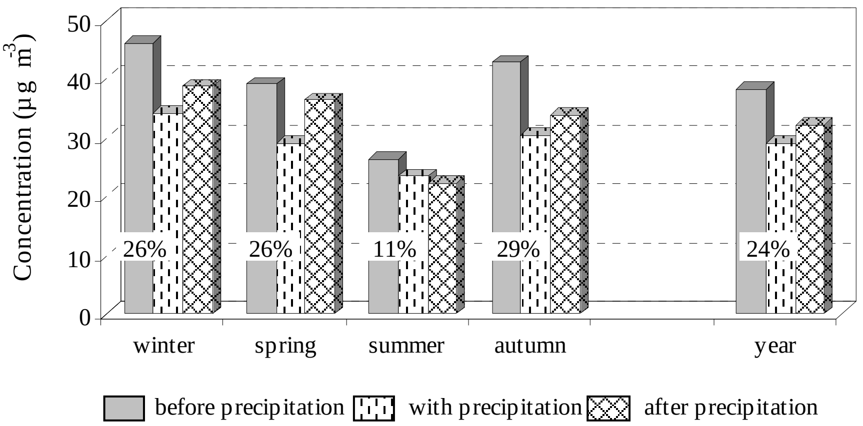

Fig. 7. Average daily concentrations (µg m^{-3}) of suspended particulates PM10 in the days before precipitation, with precipitation and after precipitation, over the years 2005-2007

The evaluation of the decrease in the immission of particulates under the influence of precipitation carried out for different combinations and ranges of its amount during a year, showed that the most effective was precipitation of the total from 8 to 20 mm, independently of the duration time (Fig. 8). It resulted in the largest reduction of the immission not only on the day of precipitation, but also still on the next day. A different comparative analysis of average daily concentrations of PM10 particulates in relation to the duration of precipitation, expressed by sequences of days, independently of its amount, also carried out for the whole year, indicates definitely the smallest effectiveness of one day precipitation (Fig. 9). A decrease in the concentration of particulates under the influence of longer lasting precipitation did not show very large differentiation in relation to the number of precipitation series, as it varied from 21 to 31% of the concentration recorded before the occurrence of precipitation period. The largest decrease in the immission was caused by precipitation occurring in five day sequences, but directly after them, like in the case of longer sequences (> 6 days), the concentrations showed a rapid increase.

Whereas the washing out effect of precipitation, still maintaining next day, became noticeable only at precipitation occurring in 4 successive days.

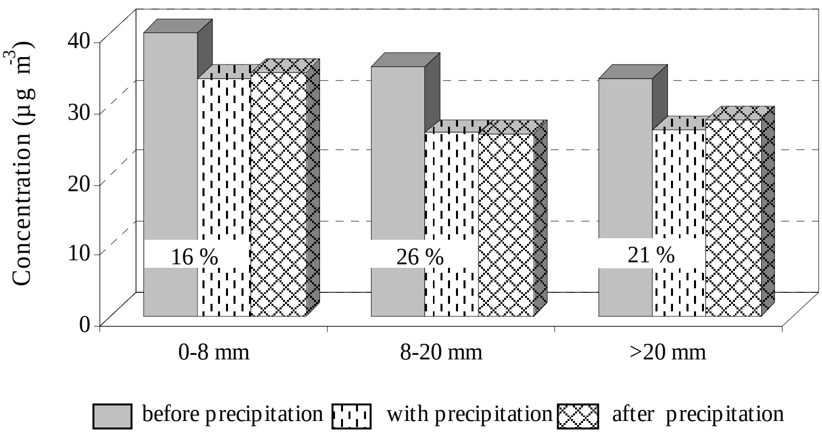

Fig. 8. Average daily concentrations (µg m^{-3}) of suspended particulates PM10 in the days before precipitation, with precipitation and after precipitation, according to the daily total of precipitation, over the years 2005-2007

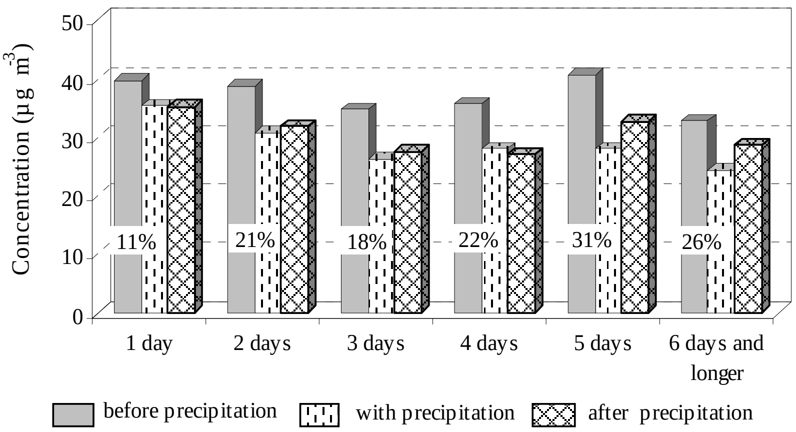

Fig. 9. Average daily concentrations (µg m^{-3}) of suspended particulates PM10 in the days before precipitation, with precipitation and after precipitation, in the series of precipitation of different length, over the years 2005-2007

The effectiveness of precipitation in removing particulates and gas pollutants depends not only on many features of the phenomenon itself, but it can be conditioned by their initial concentration. The differences observed in the effectiveness of precipitation can be conditioned by a clear daily and yearly structure of the particulates immission. In the analysed three year series of the data, the suspended particulates concentrations in winter amounted to about 40 µg m^{-3} and were twice as large as in summer, and in all the seasons of the year twice as large the imission was recorded in the night hours. A significant influence of the initial concentration on the effectiveness of washing out SO_2 was illustrated by the results of measurements made in the region of the power station in Turów. Rainfalls removed as much as 80% of SO_2 masses when its concentration amounted to 650 µg m^{-3} and only 40% at pollution 10 times smaller. With reference to NO_x the relationship was much less reliable and in the case of volatile particulates, it was statistically insignificant – Lisowski (1984).

The analysis of regression, carried out for all the seasons of the year, showed a statistically significant influence of the PM10 concentration in the day preceding the precipitation on the concentration of particulates not only in the days of its occurrence, but also on the first day after precipitation. For these reasons, continuing the statistical evaluation of the effectiveness of precipitation, the average daily concentration of particulates on the day of the occurrence of precipitation was taken into consideration. What is more, from the series analysed earlier, embracing the day preceding the precipitation, the day before precipitation, the day or days in which precipitation occurred and the day after precipitation, all the cases in which the concentrations of particulates increased despite the precipitation, were eliminated. The results of the analysis carried out both for different daily totals of precipitation and also for different concentrations of particulates are included in Table 1. In most cases the influence of the amount of precipitation on variability of the concentrations of suspended particulates PM10, including the concentrations before precipitation, turned out to be insignificant (Tab. 1). A statistically significant role of the amount of precipitation became noticeable mainly in the occurrence, with the intensity and the total of precipitation, additionally considering the amount of immission before the precipitation, gave in most periods of winter and spring, whereas it was insignificant in summer. The most significant results were obtained in regard to precipitation of the totals of up to 8 mm. The analysis carried out exclusively for this amount of precipitation, separately for the particulates concentrations >20 and > 30 µg m^{-3}, gave better results – in most cases statistically significant at $\alpha = 0.01$ (Tab. 2). However, the coefficients of partial determination did not exceed 10%. The daily precipitation of up to 8 mm had the largest influence on variability of the immission of particulates in autumn and winter, smaller in spring, whereas, once again its insignificant role was confirmed in summer.

Table 1. Coefficients of partial determination r^2 (%) defining the decrease in the average daily concentration of suspended particulates PM10 under the influence of different totals of precipitation, taking into account concentrations on the day before precipitation

Seasons	r^2/n	Total	< 8 mm	8-20 mm	> 20 mm
Spring	r^2	4.7*	6.7*	°	16.8*
	n	137	81	28	28
Summer	r^2	°	°	°	°
	n	159	86	45	28
Autumn	r^2	°	7.9**	°	°
	n	203	141	44	18
Winter	r^2	2.6*	7.3**	13,1**	°
	n	153	109	33	11
Year	r^2	1.1*	5.5**	°	°
	n	652	417	150	85

n – number of cases; ** significant at $\alpha = 0.01$; * at $\alpha = 0.05$; ° non-significant at $\alpha = 0.05$.

Table 2. Coefficients of partial determination r^2 (%) defining the decrease in the average daily concentration of suspended particulates PM10 under the influence of the totals of precipitation < 8 mm, taking into account concentrations on the day before precipitation

Seasons	r^2/n	Concentration before precipitation	
		> 20 μg m^{-3}	>30 μg m^{-3}
Spring	r^2	6.9*	8.5*
	n	78	61
Summer	r^2	°	°
	n	73	42
Autumn	r^2	8.4**	7.7**
	n	131	110
Winter	r^2	7.2**	9.0**
	n	101	83
Year	r^2	7.1**	8.4**
	n	283	148

n – number of cases; **significant at $\alpha = 0.01$; * at $\alpha = 0.05$; ° non-significant at $\alpha = 0.05$.

An attempt to evaluate the effectiveness of precipitation in removing particulates pollutants, requiring an analysis based on hourly values due to their intensity, was carried out on the example of Częstochowa. Correlation between a decrease in the immission of particulates under the influence of precipitation and its intensity turned out to be statistically insignificant. This is consistent with the results for Warsaw obtained by Majewski *et al*. (2009). Whereas the evaluation of the relationship between a decrease in the concentration of particulates in the hour ending the precipitation, as compared to the concentration in the hour before its periods (seasons of the year and periods of the day) the results statistically significant (Tab. 3). The discussed features of precipitation played a contradictory role in removing particulates pollutants, as the rising totals of precipitation caused a larger decrease in the immission, whereas the growth in the intensity of precipitation decreased the effectiveness of washing out. This is consistent with opinions on the larger effectiveness of long-lasting precipitation, particularly that of large totals (Głowiak *et al*. 1985, Kasprzycki 1969, Majewski *et al.* 2009, van der Wal and Janssen 2000), as opposed to occasional showers and storms, cleaning the air in a small degree and only for a short time. As Głowiak *et al.* (1985) report, the largest washing out activity take place in the drizzle, but only in relation to particulates of a larger aerodynamic diameter of grains, above 10 µm.

Table 3. Coefficients of partial determination r^2 (%) defining the decrease in the average hourly concentration of suspended particulates PM10 according to the intensity and the totals of precipitation, taking into account concentrations before precipitation, in Częstochowa over the years 2005-2007

Period	r^2 (%)		Number of cases
	Totals precipitation	Intensity	
Year	(+) 18.7**	(–) 14.4**	151
Day	(+) 8.9**	(–) 13.5**	71
Night	(+) 29.1**	(–) 21.6**	80
Spring	(+) 34.9**	°	25
Summer	(+) 11.9*	(–) 12.3*	40
Night	(+) 31.5**	(–) 36.8**	23
Autumn	°	°	30
Winter	(+) 36.5**	(–) 14.2*	47
Night	(+) 58.1**	(–) 26.8**	29

+/– positive/negative influence; ** significant at $\alpha = 0.01$; * at $\alpha = 0.05$; ° non-significant at $\alpha = 0.05$.

Values of the coefficients of partial determination, describing the contribution of the amount and intensity of precipitation to the explanation of variability of the particulates immission, taking their initial concentration into account, varied in a wide range from about 9 to 58% and the significance of both features of the phenomenon changed depending on the season of the year and the time of the day. In the scale of the whole year, the intensity of precipitation played a not much smaller role than its total, but in the daytime – distinctly larger, whereas in the time of the night – smaller. A particularly large influence of the precipitation intensity on the effectiveness of removing particulates pollutants and on the amount of immission was observed during the night in the calendar summer. During the night, both in summer and in winter, the effect of both discussed factors was clearly the largest.

Definitely better results of the analysis based on hourly values of the discussed variables, even only for one station, show much larger possibilities of demonstrating the washing out function of precipitation, depending on different features of the phenomenon. The results of continued studies will be presented in another description.

CONCLUSIONS

1. In the years 2005-2007, the average concentrations of suspended particulates PM10, recorded in series of hours and days with precipitation, were by 10 to 35% lower than the concentrations recorded before the phenomenon occurred.
2. Larger average differences between daily concentrations of PM10 particulates in the series with precipitation and the series without precipitation occurred in winter and in all the seasons in the night.
3. The smallest differences between daily concentrations of PM10 particulates in the series with precipitation and the series without precipitation were recorded in summer, but contrary to the remaining seasons, the washing out effect was sill maintained the following day.
4. In the scale of the whole year, the largest increase in the average immission of suspended particulates PM10 was caused by precipitation of the totals of 8 to 20 mm occurring both in individual days and in sequences of successive days and in reference to the duration time, by precipitation occurring in four day periods, independently of its amount.
5. Due to large variability of the concentrations of suspended particulates PM10, not only day by day, but also hour by hour, it seems necessary, while eva-

luating the washing out role of precipitation, to take into consideration the amount of the immission from the period (day or hour) before the precipitation.

6. Statistical evaluation of the effectiveness of atmospheric precipitation, carried out on the basis of daily data, made it possible to prove only a slight, positive effect of the increase in the precipitation amount on the reduction in the immission of suspended particulates in spring, autumn and winter. It particularly concerns the precipitation of the totals of up to 8 mm, and shows its insignificant role in summer.

7. The analysis of hourly values of both variables gives definitely larger possibilities to evaluate the washing out role of atmospheric precipitation, not only in respect if its amount, but also its intensity.

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11. SELECTED CHARACTERISTICS OF PRECIPITATION CONDITIONS OF THE NORTH-EASTERN POLAND IN THE YEARS 1951-2000

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INTRODUCTION

Precipitation is one of the most important factors determining the growth and yielding of plants and their amount and distribution have a significant effect on the agroclimate development (Dzieżyc 1989, Olechnowicz-Bobrowska 1970). The high spatial and temporal variability of precipitation has an unfavourable effect on satisfying the water requirements of plants. The area of north-eastern Poland is a region quite abundant in precipitation, but in some years, it proves unsatisfactory for crop plants. The excessive rainfall frequently occurring in this area also poses a threat to plant production (Atlas...2001, Koźmiński 1986, Szwejkowski *et al*. 2002, Woś 1999).

The aim of the study is to present temporal and spatial characteristics of the sequences of precipitation-free days, frequency of days with precipitation and the occurrence of deficiencies or excess of rainfall in the vegetation period (IV-IX) for the area of north-eastern Poland in the period of 1951-2000.

MATERIALS AND METHODS

On the basis of an analysis of 1951-2000 precipitation data from 11 stations (Białystok, Elbląg, Kętrzyn, Lidzbark Warmiński, Mikołajki, Mława, Myszyniec, Olsztyn, Ostrołęka, Prabuty and Suwałki) and weather posts of the Institute of Meteorology and Water Management (Banie Mazurskie, Białobrzegi, Brodnica) the following values were determined:

- the mean numbers of days with precipitation of ≥0.0 mm, ≥1.0 mm, ≥5.0 mm, ≥10.0 mm, ≥20.0 mm and ≥30.0 mm in the vegetation period (IV-IX);
- the mean numbers of precipitation-free sequences lasting ≥10, ≥15 and ≥20 days in individual months from April to September and in the entire vegetation period (IV-IX). While determining precipitation-free periods, it was assumed that the precipitation-free sequence lasting 10-15 was interrupted by one day with precipitation ≥1.5 mm or by two subsequent days

with the total amount of precipitation ≥1.5 mm, while precipitation-free sequences lasting longer than 15 and 20 days are interrupted by one day with precipitation ≥2.0 mm or two consecutive days with a total amount of precipitation ≥2.0 mm (Koźmiński 1986). A given precipitation-free sequence was included into the period under analysis when at least 60% of the days from this sequence occurred in this period. If 50% of days from the precipitation-free period fell on two subsequent months, the sequence was included into the second month;

- the frequency of precipitation deficiency or excess in the vegetation period (IV-IX), according to the Kaczorowska's criterion (1962).

In the area of north-eastern Poland, spatial diversity of the mean number of days with precipitation of ≥0.0 mm in the vegetation period (IV-IX) was presented graphically, by drawing maps with isolines every 5 days, for values ≥1.0 mm, ≥5.0 and ≥10.0 mm isolines were drawn every day, and for values ≥20.0 and ≥30.0 mm – every 0.1 of the day.

Maps presenting the mean frequency of precipitation-free sequences of ≥10, ≥15 and ≥20 days in the vegetation period were prepared by drawing isolines every 0.1, and for the frequency of vegetation periods with precipitation deficiency or excess according to the classification by Kaczorowska, isolines run every 2%.

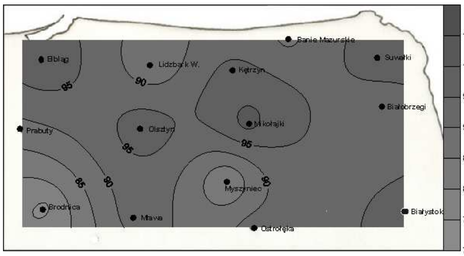
All calculations were performed using the statistical software suite STATISTICA[1]. The SURFER application was used for analysing and graphically presenting the material[2].

RESULTS AND DISCUSSION

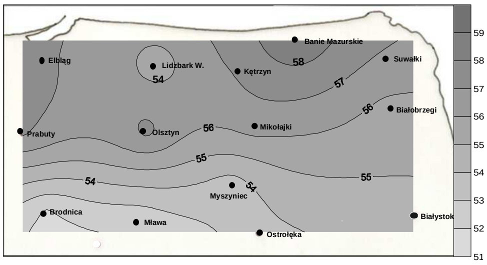
Number of days with precipitation

In the vegetation period (IV-IX), in the majority of the area under examination (Fig. 1a) the average number of days with precipitation ≥0.0 mm was 90-95. Higher values (over 95 days) occurred in its central part, including the Olsztyn Lakeland, the Great Mazurian Lakeland and the Elbląg Hills, the Suwałki Lakeland and the vicinities of Białystok; while the lowest (below 85 days) were found

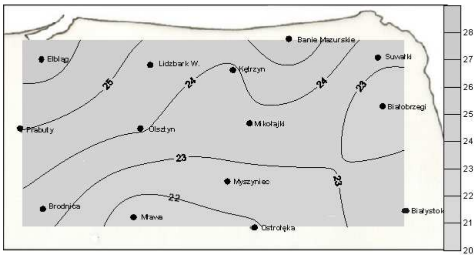
[1]StatSoft, Inc. (2007). STATISTICA (data analysis software system), version 8.0. www.statsoft.com.
[2]Surfer Version 8.05 – May 11 2004 Surface Mapping System 1993-2004 Golden Software, Inc. Serial Number WS – 075888-1983



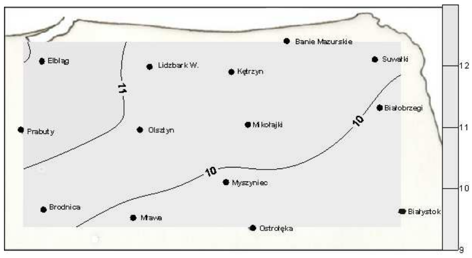
a) Numbers of days with precipitation ≥ 0.0 mm



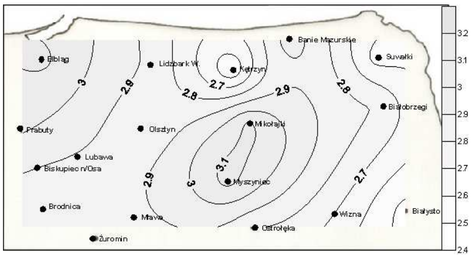
b) Numbers of days with precipitation ≥ 1.0 mm



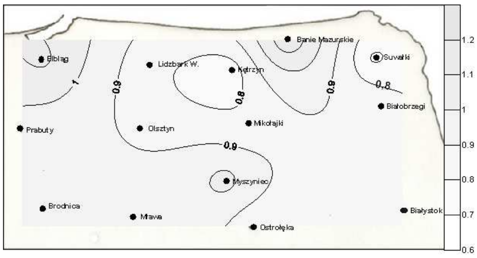
c) Numbers of days with precipitation ≥ 5.0 mm



d) Numbers of days with precipitation ≥ 10.0 mm



e) Numbers of days with precipitation ≥ 20.0 mm



f) Numbers of days with precipitation ≥ 30.0 mm

Fig. 1. Average of many years (1951-2000) numbers of days with precipitation ≥0.0 mm, ≥1.0 mm, ≥5.0 mm, ≥10.0 mm ≥20.0 mm and ≥30.0 mm in the vegetation period from April to September in north-eastern Poland

for the Chełmno-Dobrzyń Lakeland and the vicinity of Myszyniec. Isolines representing values of the mean number of days with daily precipitation of ≥1.0 mm (Fig.1b) generally ran latitudinally, and decreased from 56-58 days in the north of the area under analysis (except for the vicinity of Lidzbark Warmiński) to 52 days in the south. The mean numbers of days with daily precipitation exceeding ≥5.0 and ≥10.0 mm (Fig. 1cd) were the highest in the northern (>25 days) and the north-western (>11 days) part of the area under examination, generally decreasing southwards and south-westwards. On average, during the vegetation period in the most part of the area (Fig. 1e), 2.8-2.9 days with daily precipitation of ≥20.0 mm were recorded. More such days (3.0-3.1) fell for Elbląg Hills and the vicinities of Mikołajki and Myszyniec, and less (<2.7) – on Sępopol Lowlands and the zone along the western border of Poland, from Suwałki to Białystok. On average, days with daily precipitation ≥30.0 mm were scarce (0.7-1.1), while the values higher than 0.9 days concerned the vicinities of Banie Mazurskie and the western part of the region, while the lowest values (<0.9 days) concerned the eastern region (Fig. 1f).

The mean numbers of days with daily precipitation ≥0.0 mm in the vegetation period (IV-IX) calculated for the area of north-eastern Poland by Nowicka and Grabowska (1989) for the multi-year period of 1951-1970 were close to the values obtained in this study. The lowest values were recorded in Biskupiec, Giżycko, Ostróda and Myszyniec (77 days) and the highest (up to over 95 days) were in Kętrzyn, Olsztyn and Mikołajki. On average, during the compared multi-year periods, about 50% of days with low precipitation fell for a vegetation period. In addition, higher categories of precipitation were prevalent in summer months. In Poland during the vegetation period (IV-X), the average number of days with very poor precipitation (0.1-1.0 mm) is much higher in comparison to days with heavy precipitation (20.1-30.0 mm) (Olechnowicz-Bobrowska 1970).

Classification of precipitation according to Kaczorowska's criterion

During the vegetation periods (IV-IX) of the 1951-2000 multi-year period, (Fig. 2a), the average precipitation, according to Kaczorowska's classification, was the lowest (20-24%) in the western part of the examined area, i.e. between Elbląg and Brodnica. To the east of this zone, the course of isolines was meridional and their values regularly increased, accounting for 36-38% in the Great Mazurian Lakeland to 40-42% in Myszyniec and Ostrołęka. In eastern edges of the region, between Suwałki and Białystok, the mean frequencies of average precipitation in the vegetation periods were slightly lower and amounted to 34-36%. Spatial distribution of isolines representing percentage frequencies of dry and very dry vegetation periods was generally latitudinal, while their average values within these ranges were arranged otherwise (Fig. 2bc). Dry vegetation periods were most frequently recorded in the southern and the western part of the examined area (from 24% up to more than 26%), and least frequently (<18%) in its northern part, i.e. in the vicinities of Lidzbark Warmiński and from Banie Mazurskie to Białobrzegi. On the other hand, the highest frequencies

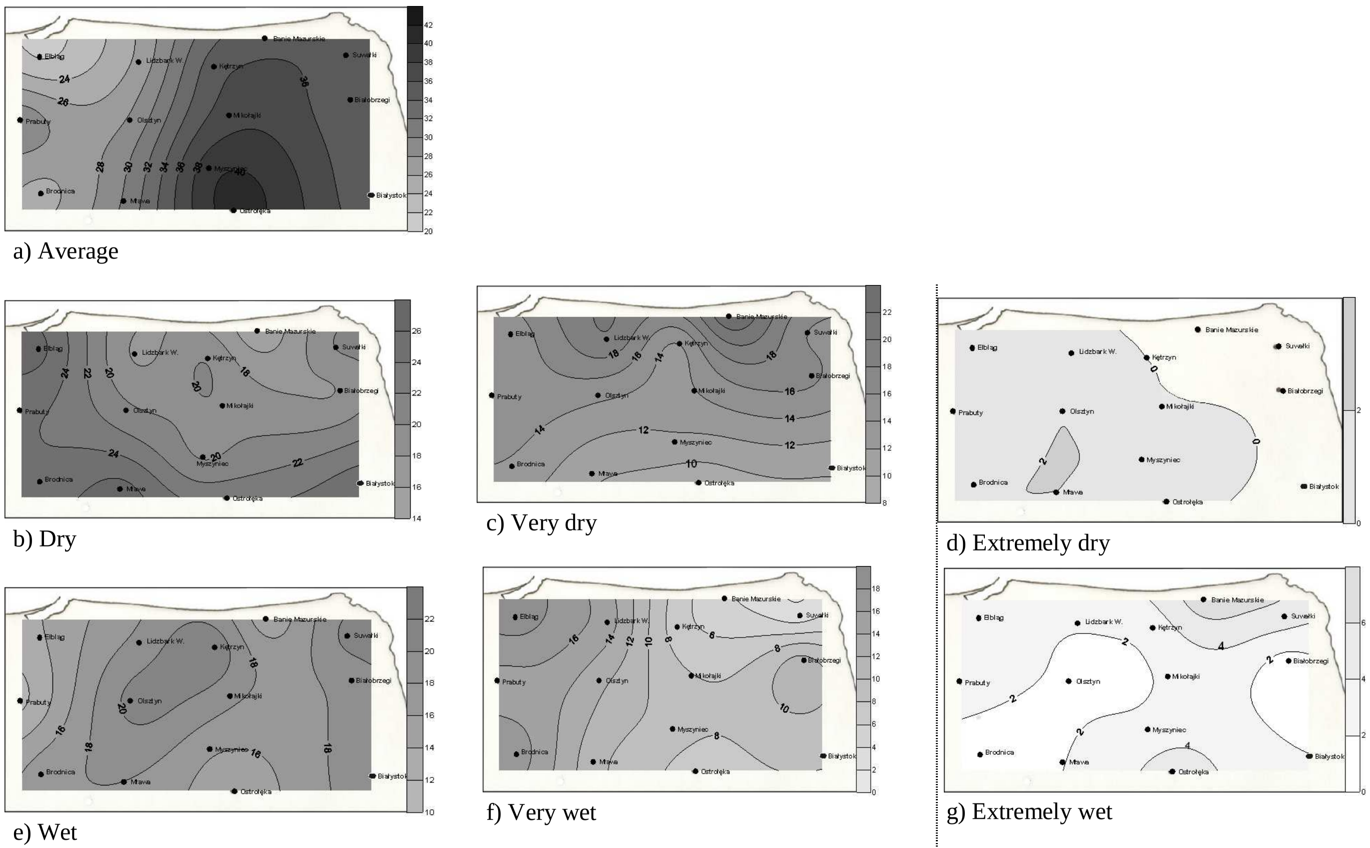


Fig. 2. Average frequency (%) of occurrence season of vegetation (IV-IX) with deficiencies and excess of precipitation according to the Kaczorowska's criterion in the north-eastern Poland in the years 1951-2000

of very dry vegetation periods (from 16% to >20%) were observed in these regions, and the lowest (<10%) was in its southern zone – from Mława to Białystok (Fig. 2c). In turn, extremely dry vegetation periods (Fig. 2d), of frequency below 2%, occurred in the majority of the region – in its western zone, while the highest values (>2%) were observed only between Olsztyn and Mława. Wet vegetation periods with frequency >20% were recorded in the region of Olsztyn and Kętrzyn and in the Suwałki Lakeland; and periods with frequency <16% were recorded in the western part of the analysed area and in the vicinity of Banie Mazurskie and Ostrołęka (Fig. 2e). The average frequencies of the very wet vegetation period in the strip from Elbląg in the north to Brodnica in the south amounted to 16-18%, and decreased eastwards (Fig. 2f). In the zone of rarely occurring (4-8%) very wet vegetation periods (from Banie Mazurskie and Suwałki in the north to Ostrołęka in the south), the highest frequencies (4-6%) of particularly wet vegetation periods were established (Fig. 2g). The characteristics of mean frequencies of vegetation periods with a deficiency or excess of precipitation, according to Kaczorowska's criterion, for some localities of north-eastern Poland and the 50-year period under examination, were presented in research by Banaszkiewicz and Grabowska (2009); Banaszkiewicz et al. (2009), and they concerned the Iława Lakeland and the Chełmno-Dobrzyń Lakeland, as well as the Narew Valley and the Biebrza Valley. A comparison of the assumed classification of precipitation in the vegetation period (IV-IX) in the Suwałki Lakeland in 1971-2000 and 1951-2000 revealed the occurrence of a similar frequency of average years in Suwałki (46%) in both multi-year periods, but a lower (22%) frequency of average vegetation periods in this locality in the 30-year period (Banaszkiewicz *et al*. 2007).

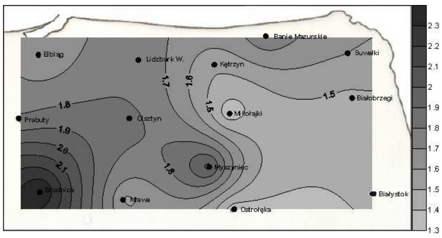
Precipitation-free sequences

An analysis of the occurrence of precipitation-free periods lasting ≥10 days in subsequent months of vegetation (Tab.1) demonstrated that they occurred most frequently in April, May and September (0.2-0.5), and slightly less often in other months. Precipitation-free sequences lasting ≥15 days were also typically recorded in these months. No precipitation-free periods lasting ≥20 days in June and July were found for any of the localities under examination, while such periods occurred with the mean frequency of 0.1 in other months of the multi-year period under analysis.

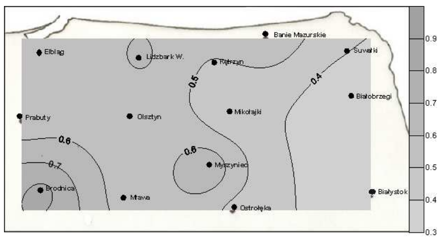
Table 1. Average of many years (1951-2000) numbers of non-precipitation day sequences lasting ≥10, ≥15 and ≥20 days in the particular month from April to September in the vegetation period (IV-IX) in the north-eastern Poland in the years 1951-2000

Station	IV			V			VI			VII			VIII			IX		
	> 10	>15	>20	> 10	>15	>20	> 10	>15	>20	> 10	>15	>20	> 10	>15	>20	> 10	>15	>20
Banie Maz.	0.5	0.2	0.1	0.3	0.1	0.0	0.3	0.1	0.0	0.3	0.1	0.0	0.3	0.1	0.0	0.2	0.1	0.0
Białobrzegi	0.2	0.1	0.0	0.2	0.0	0.0	0.2	0.0	0.0	0.2	0.1	0.0	0.3	0.1	0.0	0.3	0.1	0.0
Białystok	0.2	0.0	0.0	0.2	0.1	0.0	0.2	0.0	0.0	0.2	0.1	0.0	0.3	0.1	0.0	0.3	0.1	0.0
Brodnica	0.4	0.2	0.0	0.5	0.1	0.0	0.3	0.1	0.0	0.3	0.1	0.0	0.4	0.1	0.0	0.5	0.2	0.1
Elbląg	0.3	0.1	0.0	0.4	0.1	0.0	0.2	0.0	0.0	0.3	0.1	0.0	0.3	0.1	0.0	0.2	0.1	0.0
Kętrzyn	0.3	0.1	0.0	0.3	0.0	0.0	0.3	0.1	0.0	0.2	0.0	0.0	0.2	0.1	0.0	0.3	0.1	0.0
Lidzbark Warm.	0.3	0.1	0.1	0.4	0.1	0.0	0.2	0.1	0.0	0.3	0.1	0.0	0.3	0.1	0.0	0.3	0.1	0.0
Mikołajki	0.3	0.1	0.0	0.3	0.1	0.0	0.2	0.0	0.0	0.1	0.1	0.0	0.2	0.1	0.0	0.2	0.1	0.0
Mława	0.3	0.1	0.0	0.3	0.1	0.0	0.2	0.0	0.0	0.2	0.1	0.0	0.2	0.1	0.1	0.3	0.1	0.0
Myszyniec	0.4	0.2	0.1	0.4	0.1	0.1	0.3	0.1	0.0	0.3	0.1	0.0	0.3	0.0	0.0	0.4	0.2	0.1
Olsztyn	0.3	0.1	0.0	0.4	0.0	0.0	0.3	0.1	0.0	0.2	0.1	0.0	0.3	0.1	0.0	0.3	0.1	0.0
Ostrołęka	0.3	0.1	0.0	0.2	0.0	0.0	0.2	0.1	0.0	0.2	0.1	0.0	0.2	0.1	0.0	0.3	0.1	0.1
Prabuty	0.3	0.1	0.0	0.4	0.0	0.0	0.3	0.1	0.0	0.2	0.1	0.0	0.3	0.1	0.0	0.4	0.1	0.0
Suwałki	0.2	0.0	0.0	0.3	0.1	0.0	0.2	0.1	0.0	0.3	0.1	0.0	0.4	0.0	0.0	0.3	0.1	0.0

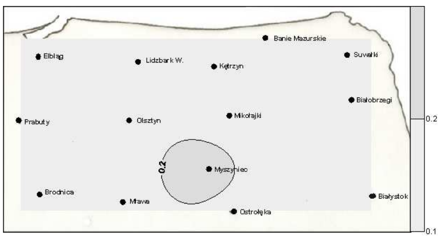
In the vegetation periods (IV-IX), in 1951-2000, as illustrated in Figure 3a, the mean number of precipitation-free sequences ≥10 days was the lowest in the south-eastern part of the examined region (the Land of the Great Mazurian Lakes, the Narew Valley and the Biebrza Valley, as well as Białystok Upland) amounting to 1.3-1.6. Values of 1.8-1.9 concerned the Iława Lakeland and the Olsztyn Lakeland. Their higher number (>2) was established in the Chełmno-Dobrzyń Lakeland and in the Kurpie Plains. The spatial distribution of the frequency of precipitation-free sequences lasting ≥15 days was similar to the distribution of ten-day sequences, but their number was lower, accounting for 0.3-0.4 in the eastern borders of the region (vicinities of Suwałki, Białobrzegi and Białystok) and from 0.6-0.7 in the Kurpie Plains to 0.7-0.8 in the Chełmno-Dobrzyń Lakeland (Fig. 3b). The mean number of precipitation-free sequences (0.2) lasting ≥20 days was established only in the vicinity of Myszyniec (Fig. 3c); while in the remaining area of north-eastern Poland this value ranged from <0.2 to 0.1. The threat of the occurrence of precipitation-free sequences of all categories under examination (≥10, ≥15 and ≥20 days) was the highest in the vicinity of Myszyniec, while of those lasting ≥10 and ≥15 was in the area around Brodnica.



a) ≥10 days



b) ≥15 days



c) ≥20 days

Fig. 3. Average of many years (1951-2000) numbers of non-precipitation day sequences lasting ≥10, ≥15 and ≥20 days in the vegetation period from April to September in the north-eastern Poland in the years 1951-2000

The mean number of precipitation-free sequences of ≥10 and ≥15 days in the entire vegetation period (IV-IX) was lower in the 50-year period analysed in this study, 1951-2000, than in the period of 1951-1970 (Nowicka, Grabowska 1989) in Lidzbark Warmiński, Olsztyn, Kętrzyn and Mikołajki. In the case of sequences lasting ≥20 days, this number was the same in Lidzbark Warmiński and higher in Olsztyn, while lower in Kętrzyn and Mikołajki. The comparison also showed that the number of sequences of all categories under examination was lower in Białobrzegi, Elbląg, Kętrzyn, Lidzbark Warmiński, Mikołajki, Myszyniec, Olsztyn, Prabuty and in Suwałki in the 50-year period of 1951-2000 than in the period of 1971-2000 (Banaszkiewicz *et al*. 2004, 2007).

CONCLUSIONS

An analysis of selected precipitation indicators calculated for north-eastern Poland for 1951-2000 made it possible to formulate the following conclusions:

1. Isolines representing the spatial distribution of the mean number of days with precipitation of ≥1.0 and ≥5.0 mm in the vegetation period (IV-IX) revealed a similar and generally latitudinal arrangement; values of the mean number of days with precipitation in these categories decreased from the north to the south (≥1.0 mm) and from the north-west to the south-east (≥5.0 mm).
2. The frequencies of dry and very dry vegetation periods and very wet and particularly wet vegetation periods (according to Kaczorowska's classification) were reversed, i.e. a more frequent occurrence of very dry periods was found for the areas with the lowest frequency of dry vegetation periods (the northern part of the region under examination). On the other hand, the most frequent occurrence of particularly wet periods was observed in the areas where the frequency of very wet vegetation periods was low (in the strip from Banie Mazurskie and Suwałki in the north to Ostrołęka in the south).
3. The spatial distributions of the frequency of precipitation-free sequences lasting ≥10 and ≥15 days in the vegetation period (IV-IX) were similar: they occurred most frequently in the south-western part of the area under examination and least frequently in the south-eastern part. The threat of precipitation-free sequences of all categories under examination (≥10, ≥15 and ≥20 days) was the highest in the vicinity of Myszyniec, while of those lasting ≥10 and ≥15 was in the region of Brodnica.
4. In the areas with the lowest number of days with low precipitation (≥1.0 and ≥5.0 mm) and at the same time, with the most frequent occurrence of dry vegetation periods (selected according to Kaczorowska's classification) i.e. in the

western and south-western part of the region, precipitation-free sequences of all categories under analysis (≥10, ≥15 and ≥20 days) were recorded most frequently.

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9. VARIABILITY OF ATMOSPHERIC THAW EVENTS IN THE AREA OF BYDGOSZCZ

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INTRODUCTION

According to Meteorological Glossary (2003), a mid-winter *thaw* is a temporary weather event lasting for a few days, during which air temperature increases above 0°C, leading to melting of snow and ice. A mid-winter thaw is most often a consequence of an advection of warm air. Atmospheric thaw events interlaced with periods of cold and frost are characteristic for most winters in Poland. It has been observed that frequency, duration, and intensity of thaws are lowest in the north-eastern part of Poland, and evidently increase towards the western regions (Czarnecka 1990, 2009, Mrugała 1988, Olba-Zięty and Grabowski 2005). Depending on the kind of human activity, as well as their duration and intensity, thaws may represent a direct or indirect threat, though they may have an advantageous effect as well. Mid-winter thaws negatively affect winter crops since they lead to their dehardening and deteriorate the stability and thermal insulation properties of the snow cover (Czarnecka 1998, 2009). On the other hand, thaws increase winter water retention, thus lowering the risk of intense springtime floods; first of all, however, increased water content in soil alleviates the consequences of atmospheric droughts. This is particularly important for water-deficient regions, such as the area surrounding Bydgoszcz. Moreover, the hydrological role of thaws becomes more important in terms of both observed and predicted increase of wintertime temperatures accompanied by the uncertainty of precipitation trends. Due to all these, we have undertaken this study aimed at an analysis of frequency, duration, and intensity of atmospheric thaws in the discussed region in terms of the long-term pattern of changes.

MATERIAL AND METHODS

The study was based on daily mean air temperatures measured at 200 cm above ground level. The data were recorded at a meteorological station in the city of Bydgoszcz, Poland, between November and March, during the years 1946-

2005. According to Kuziemski (1967), atmospheric thaws were defined as two- or more days' periods with a 24-hour mean temperature above 0^{o}C, which followed at least a three-day sequence of a mean daily temperature below 0^{o}C. Winter thaws, which were followed by returns of thermal winter, were distinguished from spring thaws, which end the winter and lead to a permanent increase in temperature above 0^{o}C. Duration of wintertime atmospheric thaws was expressed as a total number of days in thaw, as well as a number of uninterrupted sequences of up to 5, 6 to 10, 11 to 20, and over 20 consecutive days; these time intervals, however, were applied to mid-winter thaws only. The intensity of thaws was determined as ten-day mean daily air temperatures within the defined periods of winter thaws, as well as by frequency of the following temperature ranges: 0.1-1.5, 1.6-3.0, 3.1-4.5, 4.6-6.0, 6.1-7.5, and >7.6^{o}C. For the long-term analysis of the effect, linear regression was used with the significance levels of $\alpha = 0.05$ and $\alpha = 0.01$; the coefficient of variability (in %) was calculated as a ratio of mean to standard deviation.

Considering the works of numerous authors (Baranowski 2001, Kożuchowski and Żmudzka 2002, Kuziemski 1971, Marsz and Styszyńska 2001, Mrugała 1987, 1988), who demonstrated that the variability of winter thermal conditions heavily depends on the atmospheric circulation, we analysed the effect of the North Atlantic Oscillation (NOA) on the presence of atmospheric thaws, using the index of Jones *et al*. (1997).

RESULTS AND DISCUSSION

The first mid-winter thaw in the vicinity of Bydgoszcz appears usually on 12 December, whereas the spring thaw, which ends the thermal winter, starts on 12 March (Fig. 1). Both these dates, however, exhibit a great year-to-year variability, with distinctly higher variations in the previous date. Namely, standard deviation of the beginning of the first winter thaw is 26 days, whereas that for spring thaw, 18 days only. Examples of the contrasting year-to-year differences in the beginning of the first winter thaw include the winter seasons of 1981/82 and 1982/83. In the previous winter, the first mid-winter thaw began as early as on 10 October, whereas in the following winter, it started as late as on 23 February. Most often, however, every fourth year on average, the first mid-winter thaw starts during the last ten days of November. In about 40% of cases, the first thaw appear within the last ten days of November and the first ten days of December (Fig. 2). If we consider all the sixty winters, 1945/46-2004/05, the soonest spring thaws, which started as early as in the first ten days of January, were observed during two subsequent winters, 1988/89 and 1989/90. The beginning of a winter-ending springtime thaw, however, is usually observed during the second and third ten-day periods of March, with frequencies about 35% and 25%, respectively.

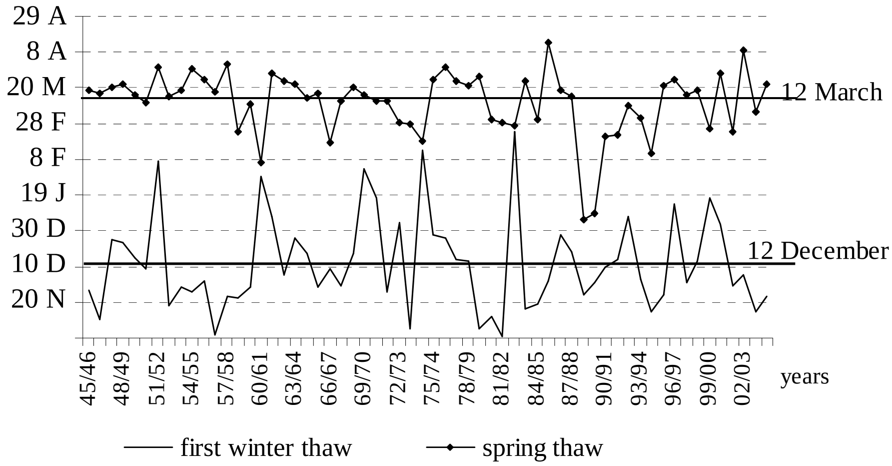


Fig. 1. Variability in dates of beginnings of winter and spring atmospheric thaw events. Years 1945/46-2004/05

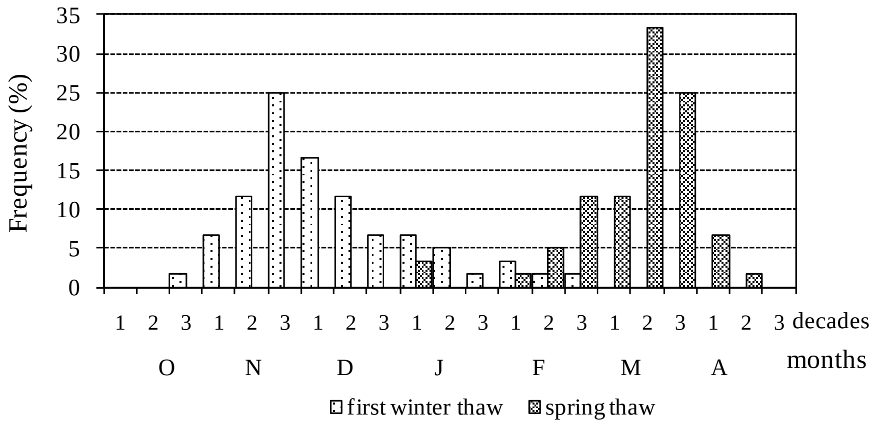


Fig. 2. Frequency (%) of beginnings of winter and spring atmospheric thaw events. Years 1945/46-2004/05

As is depicted in Figure 3, a clear increase in the frequencies of atmospheric thaws can be observed in the last ten days of November. During the calendar winter (December-March), the frequency of atmospheric thaws reaches at least 30%, whereas in the third ten-day period of December and in the first ten-day period of February, nearly a half of days belong to thaw days. A systematic increase in springtime thaw frequency can be observed with the beginning of February. In mid-March, every second day is a thaw day, whereas in the last ten-days of March, thaws occur more than 80% of time.

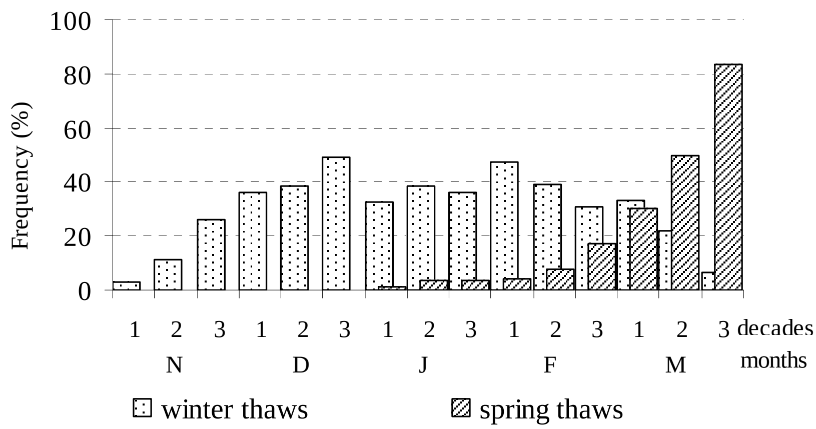


Fig. 3. Frequency (%) of winter and spring atmospheric thaw events by 10-day periods from November till March. Years 1945/46-2004/05

In the area of Bydgoszcz, atmospheric thaws are observed on 62 days, on average, i.e. during 51% of time between December and March (Fig. 4). During the calendar winter, the number of thaw days ranges from 12 to 14 and increases up to about 23 in March. Variability of a ten-day mean thaw intensity in December, January, and February is not high, from 2.4 to 2.7°C. It is not until springtime-thaw dominated March that temperature grows by 1°C to reach about 5°C in the third ten-day period of the month. The highest mean daily temperature recorded during thaw periods over the years 1945-2005 was three times as high as the average. Even in the coldest months of the year, i.e. in January and February, the maximum intensity of atmospheric thaws exceeded 9°C, and in the second ten-day period of January and the first one of February, temperature reached 11°C (Fig. 5).

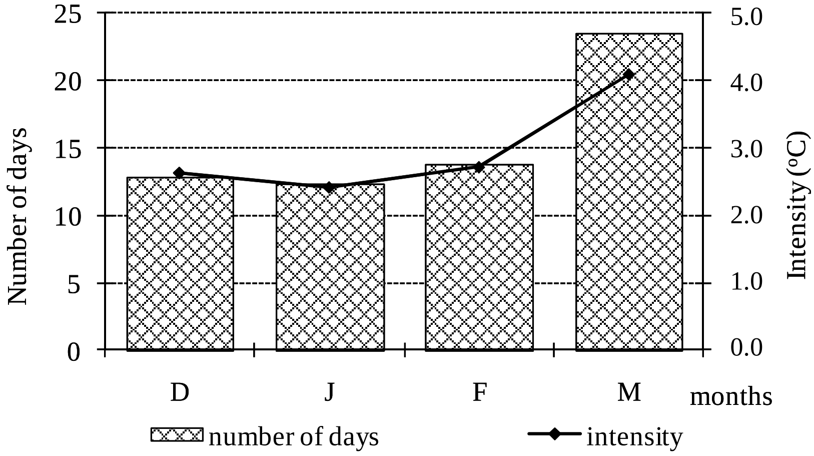


Fig. 4. Monthly mean number of days and intensity of atmospheric thaws. Years 1945/46-2004/05

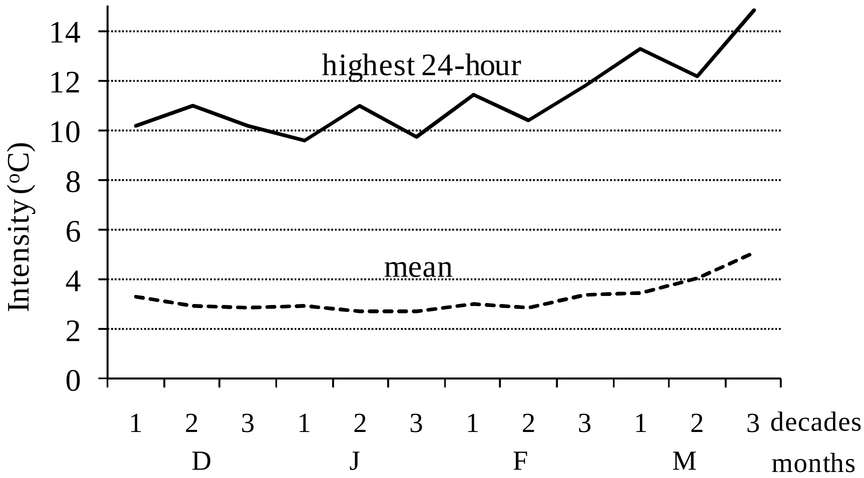


Fig. 5. Mean and maximum daily atmospheric thaw intensity by ten-days periods, from December till March. Years 1945/46-2004/05

The wide range of temperatures occurring during warmer winter days can also be concluded from the diagrams of the frequency of each range (Fig. 6). Their distributions during the calendar winter (December-March) are similar; the mean temperature usually remains within the range 0.1°C to 1.5°C, whereas the frequency of thaws of increasing intensity, from 1.6°C to 7.5°C, decreases in a very regular manner. During mid-winter thaws that still occur in March, on the other hand, the frequency of temperatures within the ranges 0.1°C to 6.0°C exhibits a considerably lower variability; much more often recorded are thaws of higher intensity, especially those exceeding 7.5°C. Such intensive winter thaws are noted in about 5% of cases over the entire wintertime, more frequently in February than in March, particularly those of the intensity exceeding 7.5°C.

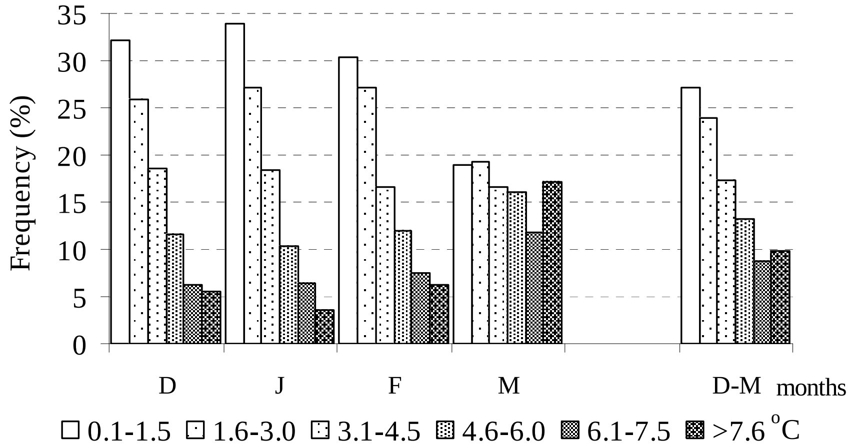


Fig. 6. Frequency (%) of winter atmospheric thaw periods by intensity class. Years 1945/46-2004/05

Duration of a thaw, besides intensity, is another important factor deciding whether its outcome can be of positive or negative character. On average, five periods of thaw are observed from November till March in Bydgoszcz and its vicinity; nearly half of this number are periods from 2 to 5 days long (Fig. 7), which is typical also for other regions of the country (Czarnecka 2005, 2009). Every winter, one thaw days sequence lasting either from 6 to 10 days or from 11 to 20 days is recorded, and every second winter on average we can observe a mid-winter thaw that lasts over 20 days. Intensity of a winter thaw increases with the duration of the effect. The intensity of the shortest thaws, lasting up to 5 days, is on average 2.2°C, during thaws of 11-20 days, mean temperatures are about 1°C higher, whereas that of the longest, more than 20-day thaw periods, is nearly twice as high as the intensity of the shortest periods of thaw (Fig. 7).

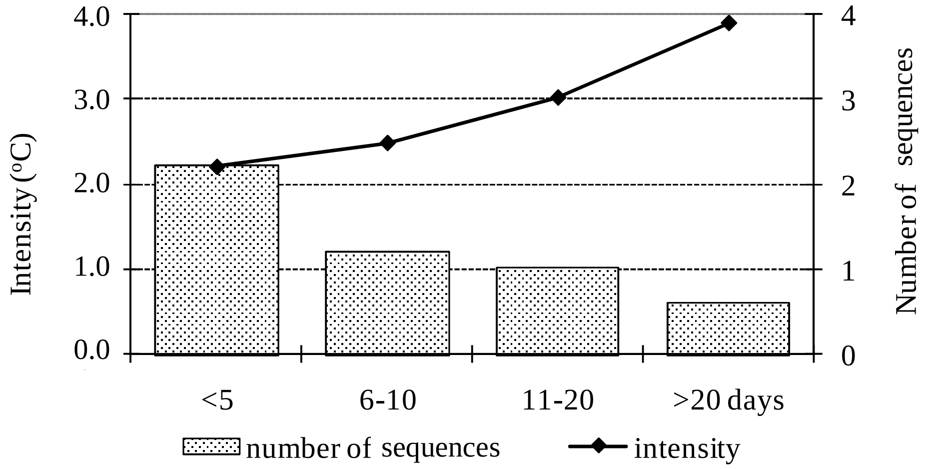


Fig. 7. Mean winter atmospheric thaw intensity in Poland from December till March by time periods. Years 1945/46-2004/05

Despite the fact that periods of thaws longer than 20 days are observed every second year, on average, thaws of such long duration are most frequent during nearly entire winter between December and March (Fig. 8). The third ten-day period of December and the second one of January are prominent in terms of mid-winter thaws longer than 20 days, as compared with thaws of shorter durations. The characteristic decrease in the frequencies of thaws recorded as 11-20 and >20 days long during the third ten-day period of January is accompanied by a distinct increase in the frequency of 6 to 10-day long thaws. An increased frequency of thaws occurring in the shortest sequences, up to 5 days, is observable in the second and third parts of January and the first part of February. An analysis of Figure 9 reveals that winter thaws, depending on their duration, in the second and third ten-day periods of December exhibit a low variability of intensity; on the other hand, the highest variability is characteristic for thaws recorded during the middle and last ten days of February. During the last ten days of March, intensity of thaws lasting over 20 days was about 6°C, whereas the mean temperature during the shortest thaws, as well as those lasting 11-20 days, did not exceed 1°C.

Over the years 1945-2005, the frequencies and intensities of atmospheric thaws in the area of Bydgoszcz exhibit an increasing trend line. However, a significant (usually at $\alpha = 0.1$) positive trend of both these phenomena was evident only for two months, steeper in March, more even in January, which is marked in Figures 10 and 11. The coefficient of determination for changes in the intensity of thaws was nearly twice higher in March (17.1%), whereas those of the linear trend for frequencies and intensities in January were similar.

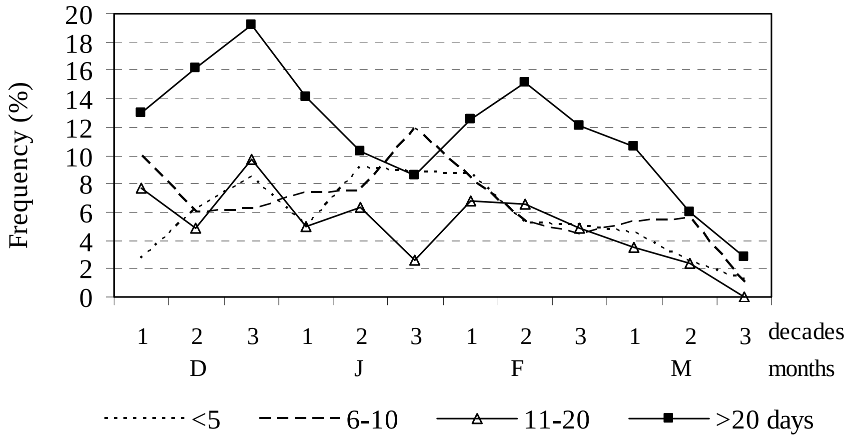


Fig. 8. Frequency (%) of winter thaw events by duration and ten-day periods from December till March. Years 1945/46-2004/05

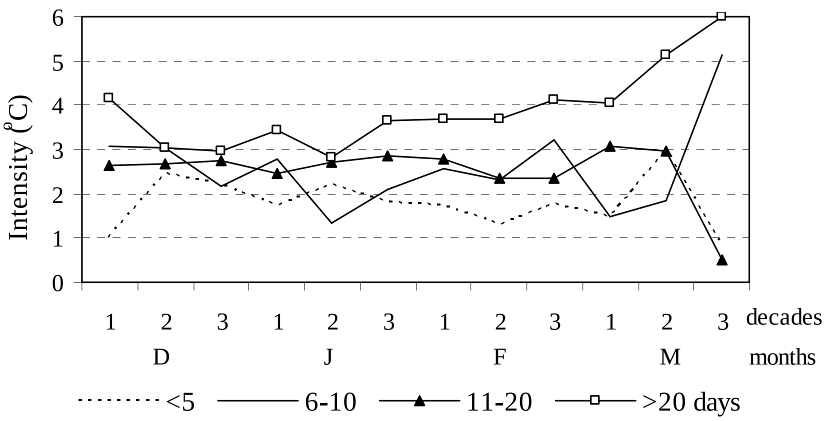
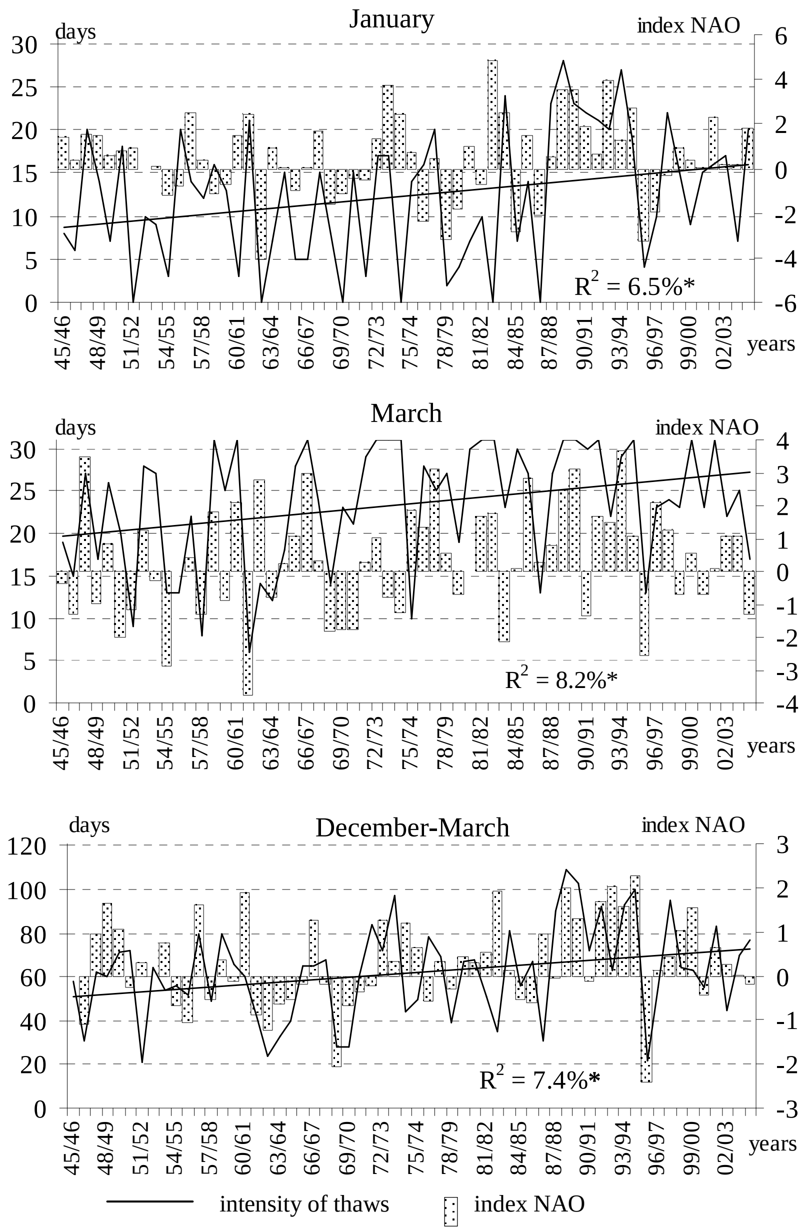
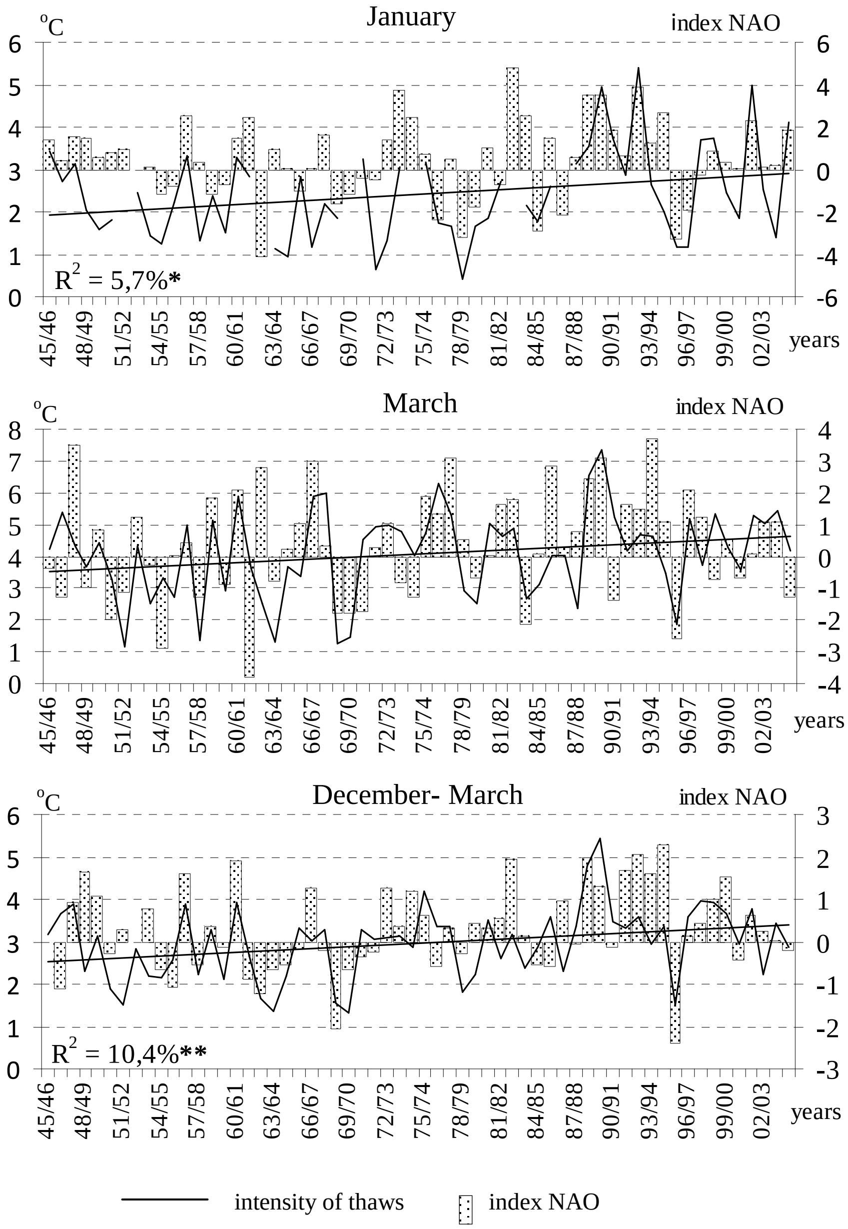


Fig. 9. Mean intensity of winter atmospheric thaw events by duration and ten-days periods from December till March. Years 1945/46-2004/05



R^2 – coefficient of determination for the linear trend of thaw days; * significant at $\alpha = 0.10$, **significant at $\alpha = 0.05$

Fig. 10. Variability of the number of days with atmospheric thaws and NAO index (Jones *et al.* 1997) during 1945/46-2004/05



R^2 – coefficient of determination for the linear trend of thaw days; * significant at $\alpha = 0.10$, **significant at $\alpha = 0.05$

Fig. 11. Variability of atmospheric thaw intensity and NAO index (Jones *et al*. 1997) during 1945/46-2004/05

In terms of the NAO index of Jones *et al.* (1997), the changes in the frequencies and intensities of atmospheric thaws during the period 1945-2004 shown in Figures 10 and 11 exhibit a circulatory pattern of the effect. Over the analysed sixty years, the periods of a positive NAO phase were usually accompanied by a larger number of thaw days of a higher intensity, which was particularly evident during the winters of 1988/89 through 1993/94; a positive NAO index (3 to 4), i.e. enhanced zone circulation, resulted in more than 20 days of thaws in January. Table 1 shows the results of an analysis of the NOA effect on thaws variability. Atmospheric circulation is a chief factor of thaws in January, February, and March; the intensity of thaws is most strongly affected by NAO in January, whereas in February circulation most strongly affects the frequency of thaws. The dates of spring thaws beginning were also explained by the effect of circulation, most strongly in February, less in January and March. In December, the circulation had little effect on thaws, except for some influence on its intensity. The relationship between the parameters of thaws and circulation conditions are stronger for the periods December-March compared to calendar winters (December-February).

Table 1. Coefficients of correlation between atmospheric thaws characteristics and NAO index (Jones *et al.* 1997) during 1945/46-2004/05

Characteristics of thaws	December	January	February	March	December-March	December-February
Beginning of spring thaw	–0.201	–0.415**	–0.494**	–0.324**	–0.628**	0.579**
Days with thaw	0.172	0.452**	0.680**	0.515**	0.569**	0.434**
Intensity	0.327*	0.620**	0.535**	0.512**	0.625**	0.426**

** significant at $\alpha = 0.01$; * at $\alpha = 0.05$.

CONCLUSIONS

1. In the area of Bydgoszcz, the first winter atmospheric thaw occurs most often during the last ten days of November and first ten days of December, whereas spring thaws usually start in the middle or end of March.

2. Atmospheric thaws occur in about 51% of days during December-March, including 43% of calendar winter days, slightly more often in February than in January.

3. The mean daily air temperature of a mid-winter warmer weather does not exceed 3°C in 60% of cases, with a few-percent higher frequency of the range 0.1-1.5°C. Thaws of the highest intensity, exceeding 7.5°C, usually occur in March; however, they were also observed during calendar winters with a frequency of 5%.

4. From December to March, five mid-winter thaws are observed on average; more than half of them last 2 to 5 days, however, a thaw longer than 20 days is observed every second year, on average.

5. The highest frequencies of mid-winter thaws lasting usually (most cases) 20 days or longer were observed during the last ten days of December. Such long mid-winter thaws prevail over shorter ones, also in the majority of ten-day periods during December to March.

6. The intensity of a thaw increases with its duration. The mean intensity of the shortest thaws (up to 5 days) was about 2°C, that of 11-20 day-long thaws increased to 3°C, whereas thaws lasting for more than 20 days reached 4°C.

7. Over the period 1945-2005, a rising trend in the intensity and frequency of thaws in January and March can be observed.

8. Atmospheric thaws are shaped by the circulation over the North Atlantic. The strongest relationship between thaw intensity and the North Atlantic Oscillation index (according to Jones *et al*. 1997), was observed in January, whereas that between the number of days and dates of spring thaws beginning was observable in February.

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10. THE INFLUENCE OF PRECIPITATION CONDITIONS ON THE CONCENTRATION OF SUSPENDED PARTICULATES PM10

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INTRODUCTION

In the group of meteorological elements shaping the spreading and dispersion of gas and particulates pollutants, an important role is played by precipitation conditions (Holst *et al.* 2008, Kasprzycki 1969, Rost *et al*. 2009, Walczewski, 1997, Velders and Matthijsen, 2009). However, their contribution to the cleaning of air is smaller than that of the dynamic elements determining the intensity of vertical and horizontal exchange of air (Czarnecka and Kalbarczyk 2008, Keary *et al*. 1998, Kulig 1981, Majewski *et al*. 2009). As Gawryś reports (1981), following Głowiak, about 30% of suspended particulates is removed from the air by the activity of electrostatic and gravitation forces and the remaining part is washed out by atmospheric precipitation. The cleaning role of precipitation as a main factor of the so called "wet deposition" or "wet stream", depends on many features of the phenomenon itself as well as the character of pollution. In the determination of washing out of pollutants by precipitation, in mathematical, deterministic models of their spreading, the following factors are taken into consideration: the character of precipitation, the time of duration, the intensity, the distribution of rain drops size and the speed of their fall as well as the type and chemical properties of pollutants and the diameter of aerosol particles (Głowiak *et al*. 1985, Juda and Chróściel 1974, Markiewicz 2004). The complexity of reasons determining the process of the washing out of pollutants and very large variability of ambient concentration as well as variability and discontinuity of precipitation cause that the qualitative evaluation of precipitation effectiveness is very difficult and even, in many deterministic models, it is determined, out of necessity, by means of only one parameter, namely, a washing out coefficient, approximated by analytical methods (Markiewicz 2004). A large limit in the description of the precipitation effect on variability of ambient concentration by means of statistical methods is the range and availability of standard measurements and observations of the phenomenon within the range of the IMGW (weather stations) network. They make it possible to carry out the analysis, mainly on the basis of decade (10 day periods) or monthly precipitation totals and frequency of their occurrence, and moreover, deriving mainly from a different location than that of the measurements of ambient concentration (Czarnecka *et al*. 2007, Czarnecka and Kalbarczyk 2008). Larger possibilities appeared in 2005 along with the start of a standardized system of monitoring the quality of air, the integral part of which is automatic, continuous registration of main meteorological elements, including atmospheric precipitation and an equally important thing, it is carried out in the place of the measurements of ambient concentration. For these reasons, the aim of this work was an attempt of statistical evaluation of precipitation effectiveness in removing suspended particulates PM10 as the pollutants most frequently disturbing the standards of the air quality in our country.

MATERIALS AND METHODS

The basic material consisted of average hourly concentrations of suspended particulates PM10 and the atmospheric precipitation totals over the years 2005-2007, registered within the frames of the system, monitoring the air quality, carried out by Voivodeship Inspectorates of Environmental Protection. Because not all immission stations functioning in individual towns have an identical range of the carried out measurements, the final choice of the materials constituting the basis of the description was decided according to the completeness of results embracing ambient concentration and atmospheric precipitation from the same location. This condition was satisfied only by seven stations situated in towns of central and southern parts of the country. Due to the observational gaps in the measurement series of immission or atmospheric precipitation in many selected stations, the final number of the basic series of hourly results amounted to about 156 thousand. All the stations represent an urban or suburban area of residential or residential and recreational character and are classified by Voivodeship Inspectorates of Environmental Protection as the stations of the urban background.

The basis for the analysis were hourly and daily values (mean or totals) according to seasons of the year or months, also considering the daytime and the time of night. It was assumed that independently of the season of the year, the daytime lasts from 7 am to 6 pm and the night – from 7 pm to 6 am according to the UTC. The amount of hourly and daily concentrations of suspended particulates PM 10 was assessed according to the alert and permissible levels listed in the Minister of Environmental Protection Regulation of 3 March 2008. Dz.U. nr 47 (Journal of Laws No 47). The influence of precipitation conditions on variability of the immission of suspended particulates PM10 was determined by the method of the regression analysis taking into consideration two levels of significance $\alpha = 0.05$ and $\alpha = 0.01$.

RESULTS AND DISCUSSION

In the years 2005-2007 average daily concentrations of suspended particulates, recorded in seven towns, selected for the analysis, varied from about 1 to 532 $\mu g \cdot m^{-3}$ and hourly averages – even up to 861 $\mu g\ m^{-3}$. The contribution of daily concentrations of above 50 $\mu g\ m^{-3}$, which, in accordance with the norm, can be exceeded with the frequency up to 35 days per year (Regulation ..., 2008), amounted to nearly 20% in the analysed three years. Although the largest amount of the immission of suspended particulates PM10 was characteristic of January 2006, the above mentioned permissible levels were also exceeded in 2005 and in 2007. Whereas the cases of exceeding an hour alert level amounting to 200 $\mu g\ m^{-3}$, was recorded only in 2006 (in the town of Radom in nine days) and once in 2007 in the town of Cieszyn. As Figure 1 shows, in nearly 50% of the cases, daily concentration of suspended particulates PM10 varied within the range of 10-30 $\mu g\ m^{-3}$, with a slight advantage of class 20-30 $\mu g\ m^{-3}$. Concentrations of above 100 $\mu g\ m^{-3}$ were recorded in about 3% of days.

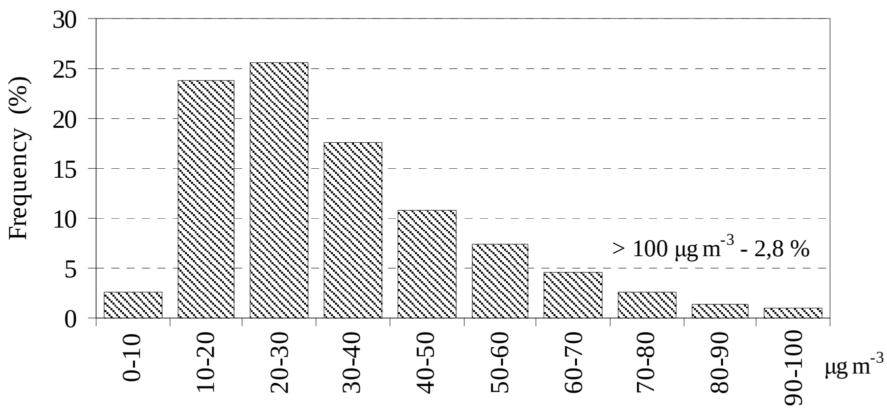

Fig. 1. Frequency of occurrence (%) of the recognized average daily classes of suspended particulates PM10 over the years 2005-2007

In the analysed three year series of daily data, the contribution of days without precipitation amounted to about 60 (Fig. 2). The smallest difference in the frequency of days with precipitation and without precipitation, about 13%, was characteristic of calendar summer, whereas in the remaining seasons of the year, the advantage of days without precipitation over the days with precipitation was considerably higher – in spring and autumn almost twice as large. In all the seasons of the year, precipitation occurred most often (in about 40% of cases) in individual days. Precipitation recorded in two successive days constituted half the number of cases of one day and the frequency of precipitation sequences longer than 4 days or more, did not exceed, on the whole, 10%. Precipitation lasting longer was recorded more often in spring, whereas less frequently in summer and autumn. In the years 2005-2007 precipitation recorded during the daytime (from 7 am to 6 pm) had a slight advantage over the night precipitation (7 pm – 8 am) and it was the largest in winter. A slight difference between the daytime and the time of night was also observed in respect of the precipitation amount average. Whereas contrastive conditions concerning the amount of precipitation occurred in summer and winter. During the calendar summer, mean hourly totals of precipitation, both those of the daytime and the night, amounted to about 1.4 mm and were more than twice as large as in winter (Fig. 2).

The introductory stage of the analysis aiming to show the effect of precipitation on the air pollution with suspended pollutants PM10 was the comparison of the amount of immission in series of days with and without precipitation. As the analysis of Figure 3 shows, average daily concentrations of suspended particulates PM10 not exceeding 20 $\mu g\ m^{-3}$ occurred equally often (those up to 10 $\mu g\ m^{-3}$ even more often) in days with precipitation as well as in days without precipitation. A washing out role of atmospheric precipitation began to be noticeable only at the concentrations of 20-30 $\mu g\ m^{-3}$, however, significantly clearer – starting from the daily immission exceeding 30 $\mu g\ m^{-3}$.

Whereas the largest daily concentrations of above 100 $\mu g\ m^{-3}$, occurred with the frequency of about 90% in days without atmospheric precipitation. The washing out role of the precipitation in relation to the air pollution with suspended particulates is also confirmed by the comparison of one hour concentrations occurring during precipitation which, depending on the station, were by 21 to 34 % smaller than those recorded in situations without precipitation (Fig. 4).

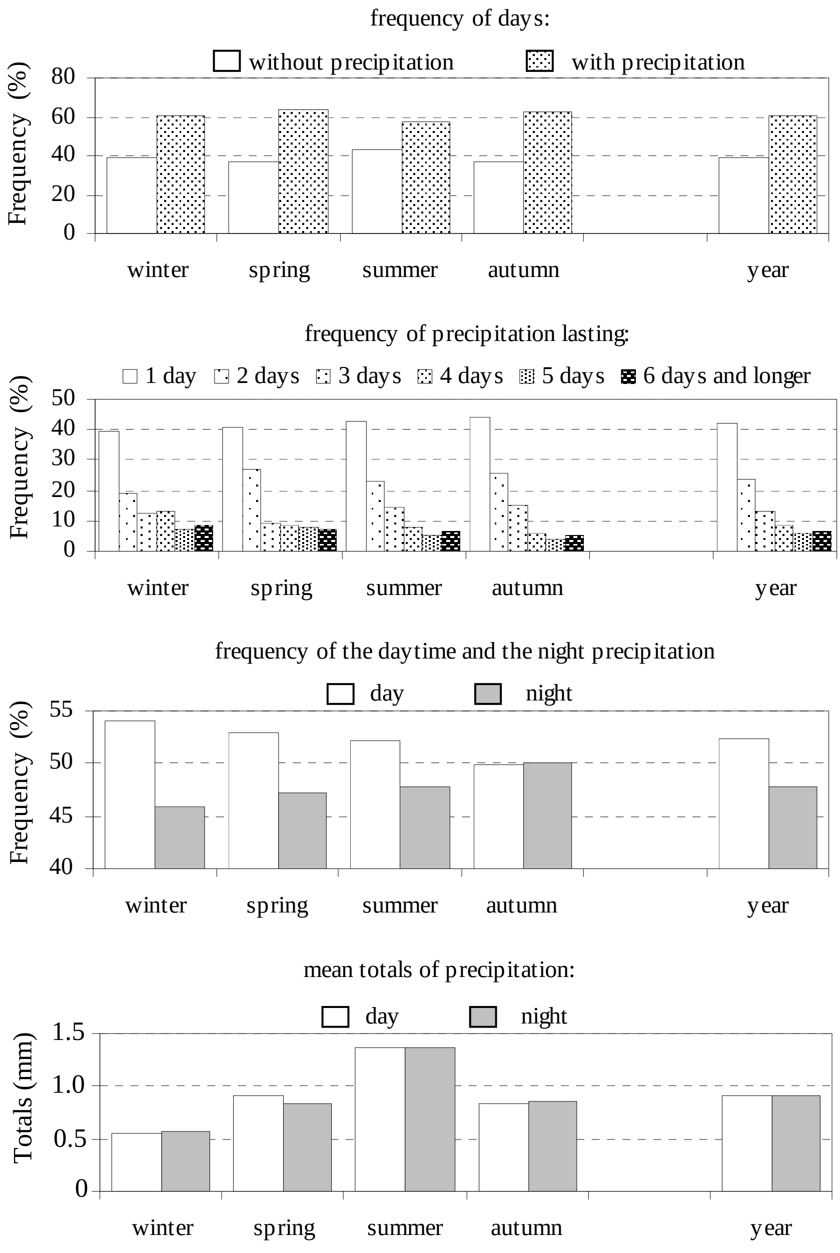

Fig. 2. Characteristics of the frequency of occurrence, the time of duration, the amount of precipitation according to seasons of year and periods of day over the years 2005-2005

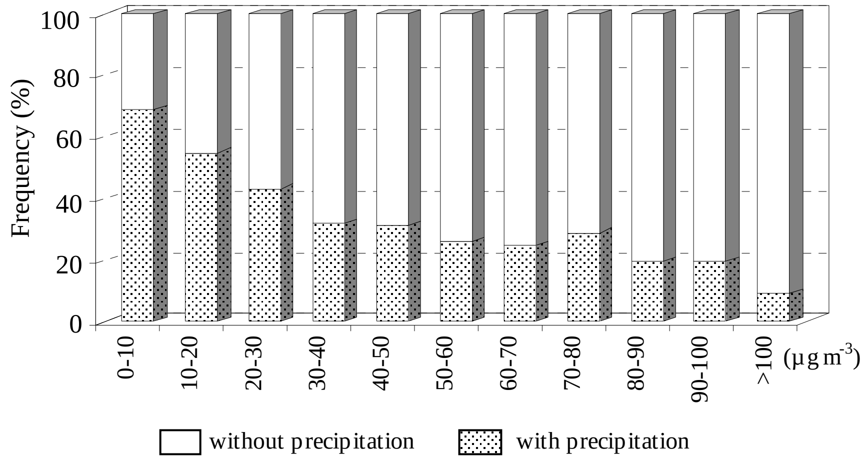

Fig. 3. Frequency of occurrence (%) of the recognized average daily classes of suspended particulates PM10 in the days with and without precipitation over the years 2005-2007

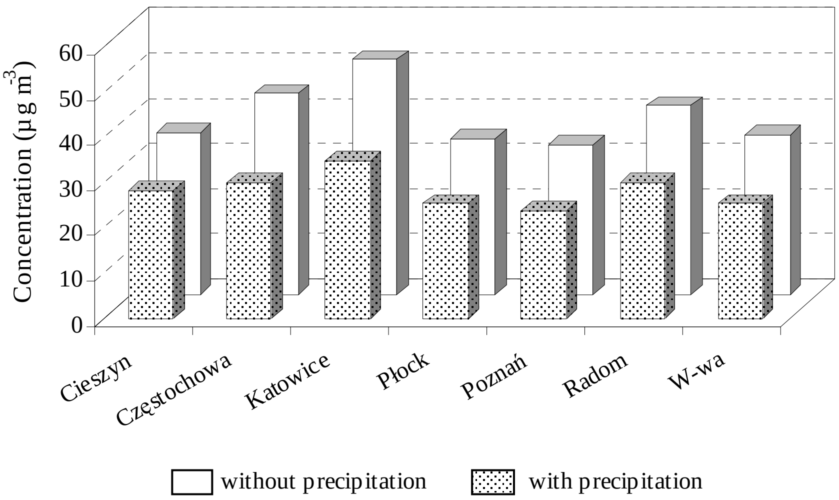

Fig. 4. Average hourly concentrations ($\mu g \cdot m^{-3}$) of suspended particulates PM10 over the years 2005-2007

However the difference between the concentration of suspended particulates in the days with precipitation and without precipitation depended on the season of the year (Fig. 5). In winter the immission of the suspended particulates in days of the occurrence of precipitation was by 36% smaller than in days without precipitation, whereas in summer – only by 13%. While in spring and autumn, the decrease in the concentration of particulates under the influence of precipitation was similar.

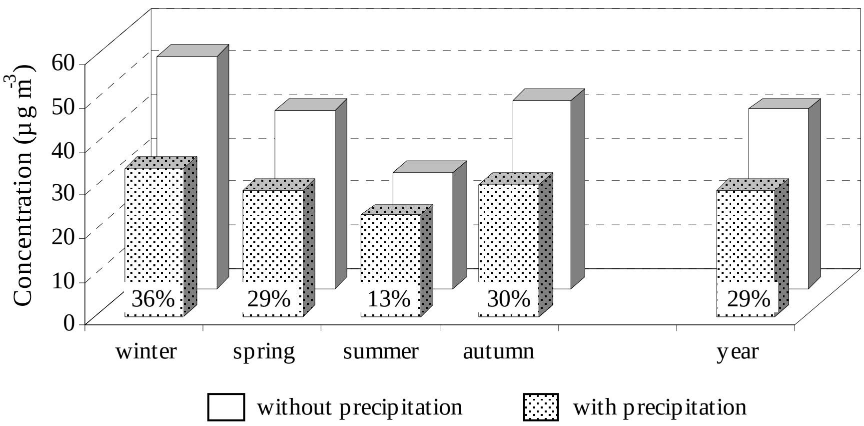

Fig. 5. Average daily concentrations (μg m^{-3}) of suspended particulates PM10 in the days with and without precipitation according to the seasons of year over the years 2005-2007

In all seasons of the year a larger decrease in the average immission of suspended particulates in series of days with precipitation, in comparison to series of days without precipitation, became noticeable in the time of night (Fig. 6), despite the fact that the frequency and the amount of night precipitation were similar like those of the daytime. A decrease in the immission during night precipitation as compared to the immission during the night without precipitation varied from 23% in summer to 42% in spring, whereas under the conditions of precipitation occurring in the daytime as compared to the immission in the days without precipitation – the decrease varied from 5% in summer to 34% in autumn.

The decrease in the concentration of suspended particulates PM10 under the influence of precipitation showed particularly large contrasts between the daytime and the time of night in summer.

The significance of precipitation as a factor of wet deposition of particulates pollutants is also confirmed by the results of the analysis of regression between average daily concentrations of particulates and daily totals of precipitation which turned out to be statistically significant for most of months and calendar seasons of the year. However, coefficients of determination, although significant at $\alpha = 0.01$, were very small and they did not exceed 5%. The influence of precipitation on variability of immission of particulates turned out to be insignificant, particularly in summer. Whereas the analysis of regression carried out in reference to the characteristic range of particulates concentrations, e.i. from 10 to 30 μg m^{-3}, and also the analysis limited exclusively to the series of days with precipitation, gave the results exclusively statistically insignificant.

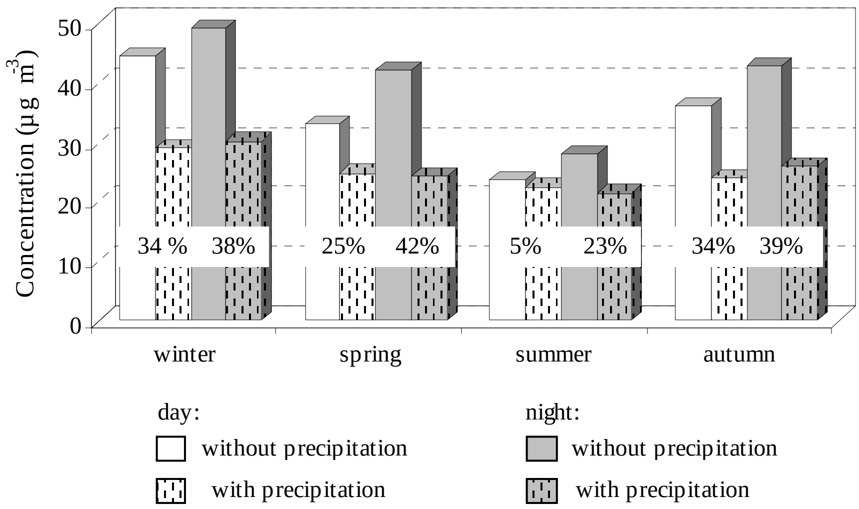

Fig. 6. Average daily concentrations (μg·m^{-3}) of suspended particulates PM10 in the days with and without precipitation in the daytime and in the night over the years 2005-2007

In order to provide the details to the evaluation of the role of precipitation as a factor of wet deposition, periods embracing the day before precipitation, the day or a sequence of days with precipitation and the day after precipitation were selected from the set of basic data. The sets selected in this way, included not only the cases of a decrease in the immission under the influence of precipitation (as compared to the immission on the day of preceding the precipitation), but also numerous situations in which an increase in the immission was recorded. This was also confirmed under the conditions observed in Warsaw (Majewski *et al*. 2009). Despite this, in all the seasons of the year, average daily concentrations of suspended particulates PM10 in the days of the occurrence of precipitation were by 11 to 29% smaller than the day before (Fig. 7). It means that a real decrease in the concentration of particulates on the day of the occurrence of precipitation, as compared to the day directly preceding precipitation, was smaller than it had been stated earlier (Fig. 5) on the basis of the comparison of the immission in the independent of one another, differing in number series of days with and without precipitation. Whereas, the smallest effectiveness of precipitation was confirmed in respect to the removal of particulates pollutants in summer, however a positive cleaning effect still maintained the following day. But in the remaining seasons of the year, the concentrations of particulates the next day after precipitation showed an increase, in spring even up to the level not much smaller than before its occurrence.

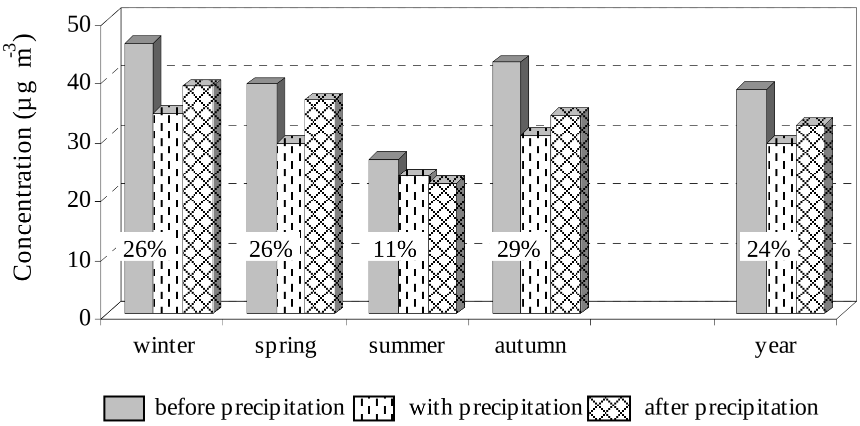

Fig. 7. Average daily concentrations (µg m^{-3}) of suspended particulates PM10 in the days before precipitation, with precipitation and after precipitation, over the years 2005-2007

The evaluation of the decrease in the immission of particulates under the influence of precipitation carried out for different combinations and ranges of its amount during a year, showed that the most effective was precipitation of the total from 8 to 20 mm, independently of the duration time (Fig. 8). It resulted in the largest reduction of the immission not only on the day of precipitation, but also still on the next day. A different comparative analysis of average daily concentrations of PM10 particulates in relation to the duration of precipitation, expressed by sequences of days, independently of its amount, also carried out for the whole year, indicates definitely the smallest effectiveness of one day precipitation (Fig. 9). A decrease in the concentration of particulates under the influence of longer lasting precipitation did not show very large differentiation in relation to the number of precipitation series, as it varied from 21 to 31% of the concentration recorded before the occurrence of precipitation period. The largest decrease in the immission was caused by precipitation occurring in five day sequences, but directly after them, like in the case of longer sequences (> 6 days), the concentrations showed a rapid increase.

Whereas the washing out effect of precipitation, still maintaining next day, became noticeable only at precipitation occurring in 4 successive days.

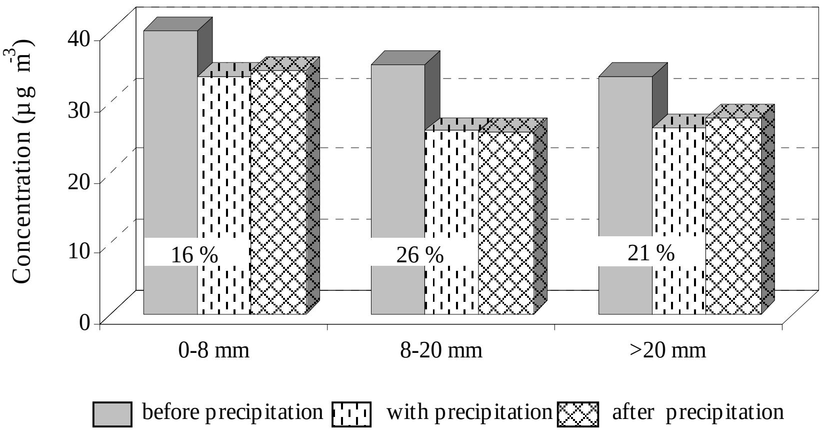

Fig. 8. Average daily concentrations (µg m^{-3}) of suspended particulates PM10 in the days before precipitation, with precipitation and after precipitation, according to the daily total of precipitation, over the years 2005-2007

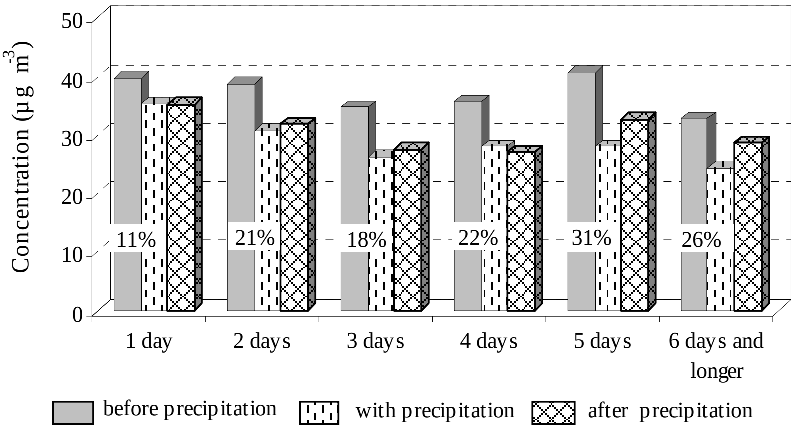

Fig. 9. Average daily concentrations (µg m^{-3}) of suspended particulates PM10 in the days before precipitation, with precipitation and after precipitation, in the series of precipitation of different length, over the years 2005-2007

The effectiveness of precipitation in removing particulates and gas pollutants depends not only on many features of the phenomenon itself, but it can be conditioned by their initial concentration. The differences observed in the effectiveness of precipitation can be conditioned by a clear daily and yearly structure of the particulates immission. In the analysed three year series of the data, the suspended particulates concentrations in winter amounted to about 40 μg m^{-3} and were twice as large as in summer, and in all the seasons of the year twice as large the imission was recorded in the night hours. A significant influence of the initial concentration on the effectiveness of washing out SO_2 was illustrated by the results of measurements made in the region of the power station in Turów. Rainfalls removed as much as 80% of SO_2 masses when its concentration amounted to 650 μg m^{-3} and only 40% at pollution 10 times smaller. With reference to NO_x the relationship was much less reliable and in the case of volatile particulates, it was statistically insignificant – Lisowski (1984).

The analysis of regression, carried out for all the seasons of the year, showed a statistically significant influence of the PM10 concentration in the day preceding the precipitation on the concentration of particulates not only in the days of its occurrence, but also on the first day after precipitation. For these reasons, continuing the statistical evaluation of the effectiveness of precipitation, the average daily concentration of particulates on the day of the occurrence of precipitation was taken into consideration. What is more, from the series analysed earlier, embracing the day preceding the precipitation, the day before precipitation, the day or days in which precipitation occurred and the day after precipitation, all the cases in which the concentrations of particulates increased despite the precipitation, were eliminated. The results of the analysis carried out both for different daily totals of precipitation and also for different concentrations of particulates are included in Table 1. In most cases the influence of the amount of precipitation on variability of the concentrations of suspended particulates PM10, including the concentrations before precipitation, turned out to be insignificant (Tab. 1). A statistically significant role of the amount of precipitation became noticeable mainly in the occurrence, with the intensity and the total of precipitation, additionally considering the amount of immission before the precipitation, gave in most periods of winter and spring, whereas it was insignificant in summer. The most significant results were obtained in regard to precipitation of the totals of up to 8 mm. The analysis carried out exclusively for this amount of precipitation, separately for the particulates concentrations >20 and > 30 μg m^{-3}, gave better results – in most cases statistically significant at $\alpha = 0.01$ (Tab. 2). However, the coefficients of partial determination did not exceed 10%. The daily precipitation of up to 8 mm had the largest influence on variability of the immission of particulates in autumn and winter, smaller in spring, whereas, once again its insignificant role was confirmed in summer.

Table 1. Coefficients of partial determination r^2 (%) defining the decrease in the average daily concentration of suspended particulates PM10 under the influence of different totals of precipitation, taking into account concentrations on the day before precipitation

Seasons	r^2/n	Total	< 8 mm	8-20 mm	> 20 mm
Spring	r^2	4.7*	6.7*	°	16.8*
	n	137	81	28	28
Summer	r^2	°	°	°	°
	n	159	86	45	28
Autumn	r^2	°	7.9**	°	°
	n	203	141	44	18
Winter	r^2	2.6*	7.3**	13,1**	°
	n	153	109	33	11
Year	r^2	1.1*	5.5**	°	°
	n	652	417	150	85

n – number of cases; ** significant at $\alpha = 0.01$; * at $\alpha = 0.05$; ° non-significant at $\alpha = 0.05$.

Table 2. Coefficients of partial determination r^2 (%) defining the decrease in the average daily concentration of suspended particulates PM10 under the influence of the totals of precipitation < 8 mm, taking into account concentrations on the day before precipitation

Seasons	r^2/n	Concentration before precipitation	
		> 20 μg m^{-3}	>30 μg m^{-3}
Spring	r^2	6.9*	8.5*
	n	78	61
Summer	r^2	°	°
	n	73	42
Autumn	r^2	8.4**	7.7**
	n	131	110
Winter	r^2	7.2**	9.0**
	n	101	83
Year	r^2	7.1**	8.4**
	n	283	148

n – number of cases; **significant at $\alpha = 0.01$; * at $\alpha = 0.05$; ° non-significant at $\alpha = 0.05$.

An attempt to evaluate the effectiveness of precipitation in removing particulates pollutants, requiring an analysis based on hourly values due to their intensity, was carried out on the example of Częstochowa. Correlation between a decrease in the immission of particulates under the influence of precipitation and its intensity turned out to be statistically insignificant. This is consistent with the results for Warsaw obtained by Majewski *et al*. (2009). Whereas the evaluation of the relationship between a decrease in the concentration of particulates in the hour ending the precipitation, as compared to the concentration in the hour before its periods (seasons of the year and periods of the day) the results statistically significant (Tab. 3). The discussed features of precipitation played a contradictory role in removing particulates pollutants, as the rising totals of precipitation caused a larger decrease in the immission, whereas the growth in the intensity of precipitation decreased the effectiveness of washing out. This is consistent with opinions on the larger effectiveness of long-lasting precipitation, particularly that of large totals (Głowiak *et al*. 1985, Kasprzycki 1969, Majewski *et al.* 2009, van der Wal and Janssen 2000), as opposed to occasional showers and storms, cleaning the air in a small degree and only for a short time. As Głowiak *et al.* (1985) report, the largest washing out activity take place in the drizzle, but only in relation to particulates of a larger aerodynamic diameter of grains, above 10 μm.

Table 3. Coefficients of partial determination r^2 (%) defining the decrease in the average hourly concentration of suspended particulates PM10 according to the intensity and the totals of precipitation, taking into account concentrations before precipitation, in Częstochowa over the years 2005-2007

Period	r^2 (%)		Number of cases
	Totals precipitation	Intensity	
Year	(+) 18.7**	(–) 14.4**	151
Day	(+) 8.9**	(–) 13.5**	71
Night	(+) 29.1**	(–) 21.6**	80
Spring	(+) 34.9**	°	25
Summer	(+) 11.9*	(–) 12.3*	40
Night	(+) 31.5**	(–) 36.8**	23
Autumn	°	°	30
Winter	(+) 36.5**	(–) 14.2*	47
Night	(+) 58.1**	(–) 26.8**	29

+/– positive/negative influence; ** significant at $\alpha = 0.01$; * at $\alpha = 0.05$; ° non-significant at $\alpha = 0.05$.

Values of the coefficients of partial determination, describing the contribution of the amount and intensity of precipitation to the explanation of variability of the particulates immission, taking their initial concentration into account, varied in a wide range from about 9 to 58% and the significance of both features of the phenomenon changed depending on the season of the year and the time of the day. In the scale of the whole year, the intensity of precipitation played a not much smaller role than its total, but in the daytime – distinctly larger, whereas in the time of the night – smaller. A particularly large influence of the precipitation intensity on the effectiveness of removing particulates pollutants and on the amount of immission was observed during the night in the calendar summer. During the night, both in summer and in winter, the effect of both discussed factors was clearly the largest.

Definitely better results of the analysis based on hourly values of the discussed variables, even only for one station, show much larger possibilities of demonstrating the washing out function of precipitation, depending on different features of the phenomenon. The results of continued studies will be presented in another description.

CONCLUSIONS

1. In the years 2005-2007, the average concentrations of suspended particulates PM10, recorded in series of hours and days with precipitation, were by 10 to 35% lower than the concentrations recorded before the phenomenon occurred.
2. Larger average differences between daily concentrations of PM10 particulates in the series with precipitation and the series without precipitation occurred in winter and in all the seasons in the night.
3. The smallest differences between daily concentrations of PM10 particulates in the series with precipitation and the series without precipitation were recorded in summer, but contrary to the remaining seasons, the washing out effect was sill maintained the following day.
4. In the scale of the whole year, the largest increase in the average immission of suspended particulates PM10 was caused by precipitation of the totals of 8 to 20 mm occurring both in individual days and in sequences of successive days and in reference to the duration time, by precipitation occurring in four day periods, independently of its amount.
5. Due to large variability of the concentrations of suspended particulates PM10, not only day by day, but also hour by hour, it seems necessary, while eva-

luating the washing out role of precipitation, to take into consideration the amount of the immission from the period (day or hour) before the precipitation.

6. Statistical evaluation of the effectiveness of atmospheric precipitation, carried out on the basis of daily data, made it possible to prove only a slight, positive effect of the increase in the precipitation amount on the reduction in the immission of suspended particulates in spring, autumn and winter. It particularly concerns the precipitation of the totals of up to 8 mm, and shows its insignificant role in summer.

7. The analysis of hourly values of both variables gives definitely larger possibilities to evaluate the washing out role of atmospheric precipitation, not only in respect if its amount, but also its intensity.

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11. SELECTED CHARACTERISTICS OF PRECIPITATION CONDITIONS OF THE NORTH-EASTERN POLAND IN THE YEARS 1951-2000

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INTRODUCTION

Precipitation is one of the most important factors determining the growth and yielding of plants and their amount and distribution have a significant effect on the agroclimate development (Dzieżyc 1989, Olechnowicz-Bobrowska 1970). The high spatial and temporal variability of precipitation has an unfavourable effect on satisfying the water requirements of plants. The area of north-eastern Poland is a region quite abundant in precipitation, but in some years, it proves unsatisfactory for crop plants. The excessive rainfall frequently occurring in this area also poses a threat to plant production (Atlas...2001, Koźmiński 1986, Szwejkowski *et al*. 2002, Woś 1999).

The aim of the study is to present temporal and spatial characteristics of the sequences of precipitation-free days, frequency of days with precipitation and the occurrence of deficiencies or excess of rainfall in the vegetation period (IV-IX) for the area of north-eastern Poland in the period of 1951-2000.

MATERIALS AND METHODS

On the basis of an analysis of 1951-2000 precipitation data from 11 stations (Białystok, Elbląg, Kętrzyn, Lidzbark Warmiński, Mikołajki, Mława, Myszyniec, Olsztyn, Ostrołęka, Prabuty and Suwałki) and weather posts of the Institute of Meteorology and Water Management (Banie Mazurskie, Białobrzegi, Brodnica) the following values were determined:

- the mean numbers of days with precipitation of ≥0.0 mm, ≥1.0 mm, ≥5.0 mm, ≥10.0 mm, ≥20.0 mm and ≥30.0 mm in the vegetation period (IV-IX);
- the mean numbers of precipitation-free sequences lasting ≥10, ≥15 and ≥20 days in individual months from April to September and in the entire vegetation period (IV-IX). While determining precipitation-free periods, it was assumed that the precipitation-free sequence lasting 10-15 was interrupted by one day with precipitation ≥1.5 mm or by two subsequent days

with the total amount of precipitation ≥1.5 mm, while precipitation-free sequences lasting longer than 15 and 20 days are interrupted by one day with precipitation ≥2.0 mm or two consecutive days with a total amount of precipitation ≥2.0 mm (Koźmiński 1986). A given precipitation-free sequence was included into the period under analysis when at least 60% of the days from this sequence occurred in this period. If 50% of days from the precipitation-free period fell on two subsequent months, the sequence was included into the second month;

- the frequency of precipitation deficiency or excess in the vegetation period (IV-IX), according to the Kaczorowska's criterion (1962).

In the area of north-eastern Poland, spatial diversity of the mean number of days with precipitation of ≥0.0 mm in the vegetation period (IV-IX) was presented graphically, by drawing maps with isolines every 5 days, for values ≥1.0 mm, ≥5.0 and ≥10.0 mm isolines were drawn every day, and for values ≥20.0 and ≥30.0 mm – every 0.1 of the day.

Maps presenting the mean frequency of precipitation-free sequences of ≥10, ≥15 and ≥20 days in the vegetation period were prepared by drawing isolines every 0.1, and for the frequency of vegetation periods with precipitation deficiency or excess according to the classification by Kaczorowska, isolines run every 2%.

All calculations were performed using the statistical software suite STATISTICA[1]. The SURFER application was used for analysing and graphically presenting the material[2].

RESULTS AND DISCUSSION

Number of days with precipitation

In the vegetation period (IV-IX), in the majority of the area under examination (Fig. 1a) the average number of days with precipitation ≥0.0 mm was 90-95. Higher values (over 95 days) occurred in its central part, including the Olsztyn Lakeland, the Great Mazurian Lakeland and the Elbląg Hills, the Suwałki Lakeland and the vicinities of Białystok; while the lowest (below 85 days) were found

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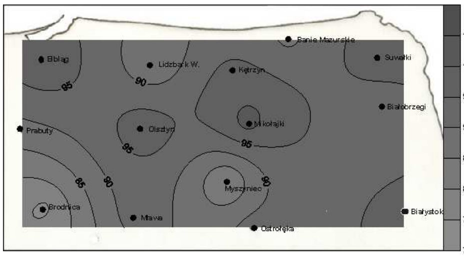
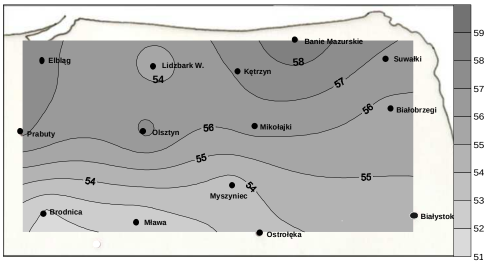
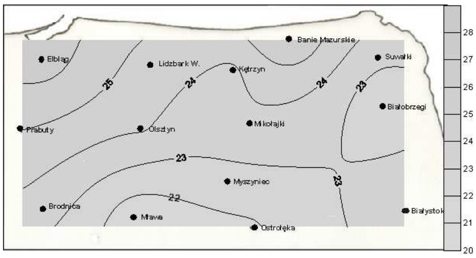
[1]StatSoft, Inc. (2007). STATISTICA (data analysis software system), version 8.0. www.statsoft.com.
[2]Surfer Version 8.05 – May 11 2004 Surface Mapping System 1993-2004 Golden Software, Inc. Serial Number WS – 075888-1983



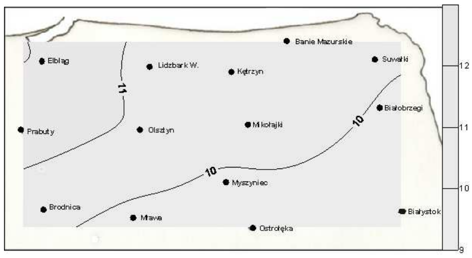
a) Numbers of days with precipitation ≥ 0.0 mm



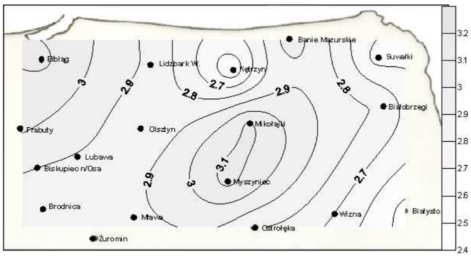
b) Numbers of days with precipitation ≥ 1.0 mm



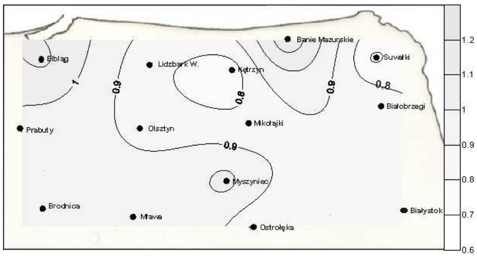
c) Numbers of days with precipitation ≥ 5.0 mm



d) Numbers of days with precipitation ≥ 10.0 mm



e) Numbers of days with precipitation ≥ 20.0 mm



f) Numbers of days with precipitation ≥ 30.0 mm

Fig. 1. Average of many years (1951-2000) numbers of days with precipitation ≥ 0.0 mm, ≥ 1.0 mm, ≥ 5.0 mm, ≥ 10.0 mm ≥ 20.0 mm and ≥ 30.0 mm in the vegetation period from April to September in north-eastern Poland

for the Chełmno-Dobrzyń Lakeland and the vicinity of Myszyniec. Isolines representing values of the mean number of days with daily precipitation of ≥ 1.0 mm (Fig.1b) generally ran latitudinally, and decreased from 56-58 days in the north of the area under analysis (except for the vicinity of Lidzbark Warmiński) to 52 days in the south. The mean numbers of days with daily precipitation exceeding ≥ 5.0 and ≥ 10.0 mm (Fig. 1cd) were the highest in the northern (>25 days) and the north-western (>11 days) part of the area under examination, generally decreasing southwards and south-westwards. On average, during the vegetation period in the most part of the area (Fig. 1e), 2.8-2.9 days with daily precipitation of ≥20.0 mm were recorded. More such days (3.0-3.1) fell for Elbląg Hills and the vicinities of Mikołajki and Myszyniec, and less (<2.7) – on Sępopol Lowlands and the zone along the western border of Poland, from Suwałki to Białystok. On average, days with daily precipitation ≥30.0 mm were scarce (0.7-1.1), while the values higher than 0.9 days concerned the vicinities of Banie Mazurskie and the western part of the region, while the lowest values (<0.9 days) concerned the eastern region (Fig. 1f).

The mean numbers of days with daily precipitation ≥0.0 mm in the vegetation period (IV-IX) calculated for the area of north-eastern Poland by Nowicka and Grabowska (1989) for the multi-year period of 1951-1970 were close to the values obtained in this study. The lowest values were recorded in Biskupiec, Giżycko, Ostróda and Myszyniec (77 days) and the highest (up to over 95 days) were in Kętrzyn, Olsztyn and Mikołajki. On average, during the compared multi-year periods, about 50% of days with low precipitation fell for a vegetation period. In addition, higher categories of precipitation were prevalent in summer months. In Poland during the vegetation period (IV-X), the average number of days with very poor precipitation (0.1-1.0 mm) is much higher in comparison to days with heavy precipitation (20.1-30.0 mm) (Olechnowicz-Bobrowska 1970).

Classification of precipitation according to Kaczorowska's criterion

During the vegetation periods (IV-IX) of the 1951-2000 multi-year period, (Fig. 2a), the average precipitation, according to Kaczorowska's classification, was the lowest (20-24%) in the western part of the examined area, i.e. between Elbląg and Brodnica. To the east of this zone, the course of isolines was meridional and their values regularly increased, accounting for 36-38% in the Great Mazurian Lakeland to 40-42% in Myszyniec and Ostrołęka. In eastern edges of the region, between Suwałki and Białystok, the mean frequencies of average precipitation in the vegetation periods were slightly lower and amounted to 34-36%. Spatial distribution of isolines representing percentage frequencies of dry and very dry vegetation periods was generally latitudinal, while their average values within these ranges were arranged otherwise (Fig. 2bc). Dry vegetation periods were most frequently recorded in the southern and the western part of the examined area (from 24% up to more than 26%), and least frequently (<18%) in its northern part, i.e. in the vicinities of Lidzbark Warmiński and from Banie Mazurskie to Białobrzegi. On the other hand, the highest frequencies

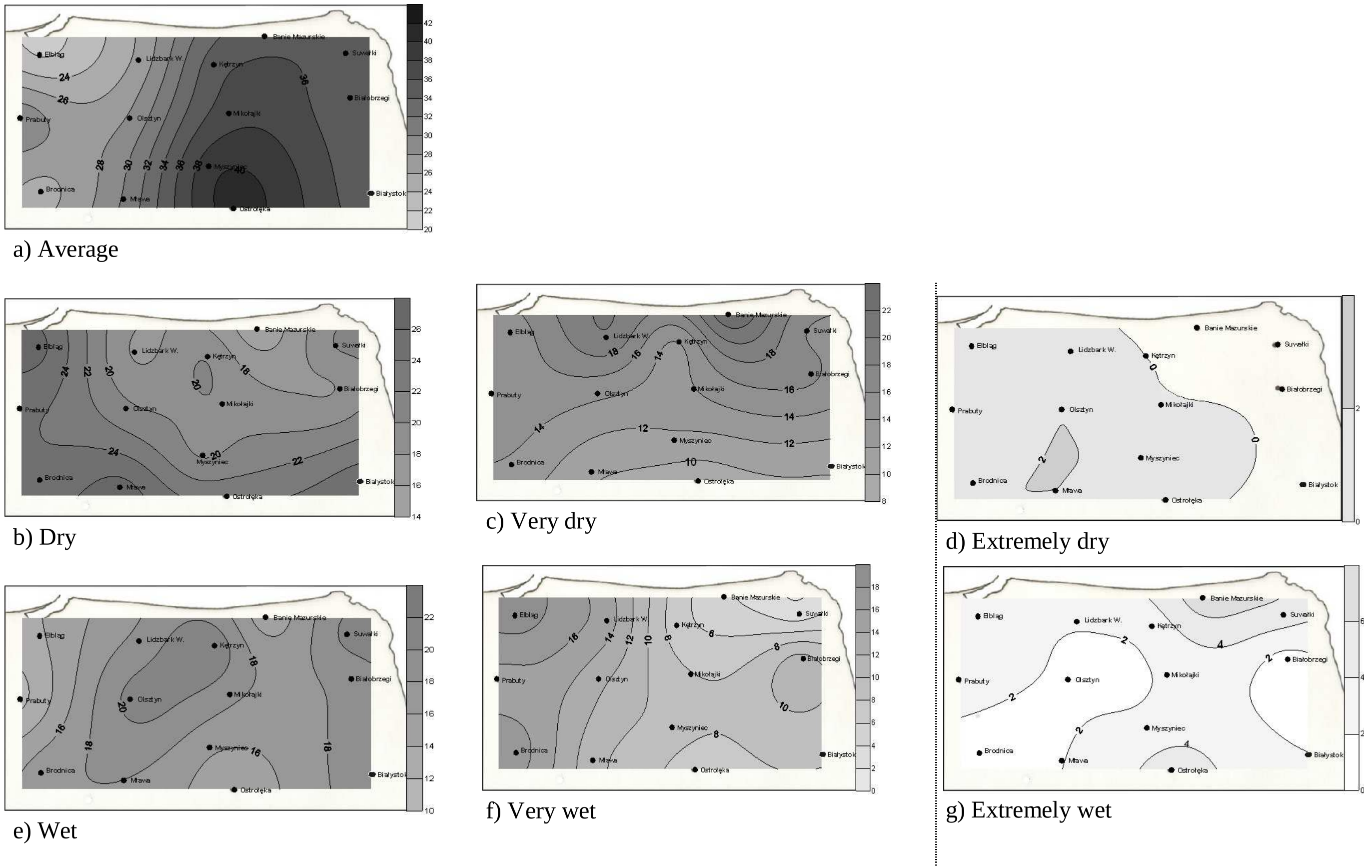


Fig. 2. Average frequency (%) of occurrence season of vegetation (IV-IX) with deficiencies and excess of precipitation according to the Kaczorowska's criterion in the north-eastern Poland in the years 1951-2000

of very dry vegetation periods (from 16% to >20%) were observed in these regions, and the lowest (<10%) was in its southern zone – from Mława to Białystok (Fig. 2c). In turn, extremely dry vegetation periods (Fig. 2d), of frequency below 2%, occurred in the majority of the region – in its western zone, while the highest values (>2%) were observed only between Olsztyn and Mława. Wet vegetation periods with frequency >20% were recorded in the region of Olsztyn and Kętrzyn and in the Suwałki Lakeland; and periods with frequency <16% were recorded in the western part of the analysed area and in the vicinity of Banie Mazurskie and Ostrołęka (Fig. 2e). The average frequencies of the very wet vegetation period in the strip from Elbląg in the north to Brodnica in the south amounted to 16-18%, and decreased eastwards (Fig. 2f). In the zone of rarely occurring (4-8%) very wet vegetation periods (from Banie Mazurskie and Suwałki in the north to Ostrołęka in the south), the highest frequencies (4-6%) of particularly wet vegetation periods were established (Fig. 2g). The characteristics of mean frequencies of vegetation periods with a deficiency or excess of precipitation, according to Kaczorowska's criterion, for some localities of north-eastern Poland and the 50-year period under examination, were presented in research by Banaszkiewicz and Grabowska (2009); Banaszkiewicz et al. (2009), and they concerned the Iława Lakeland and the Chełmno-Dobrzyń Lakeland, as well as the Narew Valley and the Biebrza Valley. A comparison of the assumed classification of precipitation in the vegetation period (IV-IX) in the Suwałki Lakeland in 1971-2000 and 1951-2000 revealed the occurrence of a similar frequency of average years in Suwałki (46%) in both multi-year periods, but a lower (22%) frequency of average vegetation periods in this locality in the 30-year period (Banaszkiewicz *et al*. 2007).

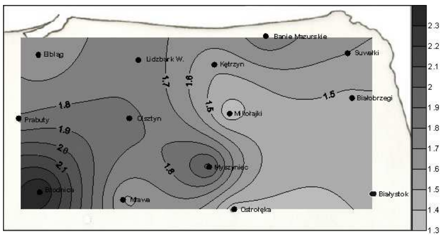
Precipitation-free sequences

An analysis of the occurrence of precipitation-free periods lasting ≥10 days in subsequent months of vegetation (Tab.1) demonstrated that they occurred most frequently in April, May and September (0.2-0.5), and slightly less often in other months. Precipitation-free sequences lasting ≥15 days were also typically recorded in these months. No precipitation-free periods lasting ≥20 days in June and July were found for any of the localities under examination, while such periods occurred with the mean frequency of 0.1 in other months of the multi-year period under analysis.

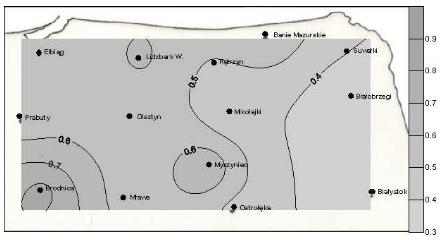
Table 1. Average of many years (1951-2000) numbers of non-precipitation day sequences lasting ≥10, ≥15 and ≥20 days in the particular month from April to September in the vegetation period (IV-IX) in the north-eastern Poland in the years 1951-2000

Station	IV			V			VI			VII			VIII			IX		
	> 10	>15	>20	> 10	>15	>20	> 10	>15	>20	> 10	>15	>20	> 10	>15	>20	> 10	>15	>20
Banie Maz.	0.5	0.2	0.1	0.3	0.1	0.0	0.3	0.1	0.0	0.3	0.1	0.0	0.3	0.1	0.0	0.2	0.1	0.0
Białobrzegi	0.2	0.1	0.0	0.2	0.0	0.0	0.2	0.0	0.0	0.2	0.1	0.0	0.3	0.1	0.0	0.3	0.1	0.0
Białystok	0.2	0.0	0.0	0.2	0.1	0.0	0.2	0.0	0.0	0.2	0.1	0.0	0.3	0.1	0.0	0.3	0.1	0.0
Brodnica	0.4	0.2	0.0	0.5	0.1	0.0	0.3	0.1	0.0	0.3	0.1	0.0	0.4	0.1	0.0	0.5	0.2	0.1
Elbląg	0.3	0.1	0.0	0.4	0.1	0.0	0.2	0.0	0.0	0.3	0.1	0.0	0.3	0.1	0.0	0.2	0.1	0.0
Kętrzyn	0.3	0.1	0.0	0.3	0.0	0.0	0.3	0.1	0.0	0.2	0.0	0.0	0.2	0.1	0.0	0.3	0.1	0.0
Lidzbark Warm.	0.3	0.1	0.1	0.4	0.1	0.0	0.2	0.1	0.0	0.3	0.1	0.0	0.3	0.1	0.0	0.3	0.1	0.0
Mikołajki	0.3	0.1	0.0	0.3	0.1	0.0	0.2	0.0	0.0	0.1	0.1	0.0	0.2	0.1	0.0	0.2	0.1	0.0
Mława	0.3	0.1	0.0	0.3	0.1	0.0	0.2	0.0	0.0	0.2	0.1	0.0	0.2	0.1	0.1	0.3	0.1	0.0
Myszyniec	0.4	0.2	0.1	0.4	0.1	0.1	0.3	0.1	0.0	0.3	0.1	0.0	0.3	0.0	0.0	0.4	0.2	0.1
Olsztyn	0.3	0.1	0.0	0.4	0.0	0.0	0.3	0.1	0.0	0.2	0.1	0.0	0.3	0.1	0.0	0.3	0.1	0.0
Ostrołęka	0.3	0.1	0.0	0.2	0.0	0.0	0.2	0.1	0.0	0.2	0.1	0.0	0.2	0.1	0.0	0.3	0.1	0.1
Prabuty	0.3	0.1	0.0	0.4	0.0	0.0	0.3	0.1	0.0	0.2	0.1	0.0	0.3	0.1	0.0	0.4	0.1	0.0
Suwałki	0.2	0.0	0.0	0.3	0.1	0.0	0.2	0.1	0.0	0.3	0.1	0.0	0.4	0.0	0.0	0.3	0.1	0.0

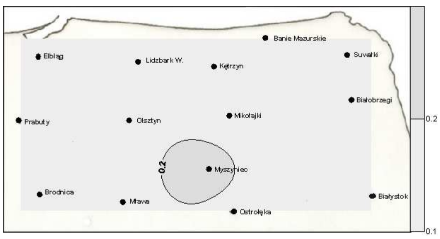
In the vegetation periods (IV-IX), in 1951-2000, as illustrated in Figure 3a, the mean number of precipitation-free sequences ≥10 days was the lowest in the south-eastern part of the examined region (the Land of the Great Mazurian Lakes, the Narew Valley and the Biebrza Valley, as well as Białystok Upland) amounting to 1.3-1.6. Values of 1.8-1.9 concerned the Iława Lakeland and the Olsztyn Lakeland. Their higher number (>2) was established in the Chełmno-Dobrzyń Lakeland and in the Kurpie Plains. The spatial distribution of the frequency of precipitation-free sequences lasting ≥15 days was similar to the distribution of ten-day sequences, but their number was lower, accounting for 0.3-0.4 in the eastern borders of the region (vicinities of Suwałki, Białobrzegi and Białystok) and from 0.6-0.7 in the Kurpie Plains to 0.7-0.8 in the Chełmno-Dobrzyń Lakeland (Fig. 3b). The mean number of precipitation-free sequences (0.2) lasting ≥20 days was established only in the vicinity of Myszyniec (Fig. 3c); while in the remaining area of north-eastern Poland this value ranged from <0.2 to 0.1. The threat of the occurrence of precipitation-free sequences of all categories under examination (≥10, ≥15 and ≥20 days) was the highest in the vicinity of Myszyniec, while of those lasting ≥10 and ≥15 was in the area around Brodnica.



a) ≥10 days



b) ≥15 days



c) ≥20 days

Fig. 3. Average of many years (1951-2000) numbers of non-precipitation day sequences lasting ≥10, ≥15 and ≥20 days in the vegetation period from April to September in the north-eastern Poland in the years 1951-2000

The mean number of precipitation-free sequences of ≥10 and ≥15 days in the entire vegetation period (IV-IX) was lower in the 50-year period analysed in this study, 1951-2000, than in the period of 1951-1970 (Nowicka, Grabowska 1989) in Lidzbark Warmiński, Olsztyn, Kętrzyn and Mikołajki. In the case of sequences lasting ≥20 days, this number was the same in Lidzbark Warmiński and higher in Olsztyn, while lower in Kętrzyn and Mikołajki. The comparison also showed that the number of sequences of all categories under examination was lower in Białobrzegi, Elbląg, Kętrzyn, Lidzbark Warmiński, Mikołajki, Myszyniec, Olsztyn, Prabuty and in Suwałki in the 50-year period of 1951-2000 than in the period of 1971-2000 (Banaszkiewicz *et al*. 2004, 2007).

CONCLUSIONS

An analysis of selected precipitation indicators calculated for north-eastern Poland for 1951-2000 made it possible to formulate the following conclusions:

1. Isolines representing the spatial distribution of the mean number of days with precipitation of ≥1.0 and ≥5.0 mm in the vegetation period (IV-IX) revealed a similar and generally latitudinal arrangement; values of the mean number of days with precipitation in these categories decreased from the north to the south (≥1.0 mm) and from the north-west to the south-east (≥5.0 mm).
2. The frequencies of dry and very dry vegetation periods and very wet and particularly wet vegetation periods (according to Kaczorowska's classification) were reversed, i.e. a more frequent occurrence of very dry periods was found for the areas with the lowest frequency of dry vegetation periods (the northern part of the region under examination). On the other hand, the most frequent occurrence of particularly wet periods was observed in the areas where the frequency of very wet vegetation periods was low (in the strip from Banie Mazurskie and Suwałki in the north to Ostrołęka in the south).
3. The spatial distributions of the frequency of precipitation-free sequences lasting ≥10 and ≥15 days in the vegetation period (IV-IX) were similar: they occurred most frequently in the south-western part of the area under examination and least frequently in the south-eastern part. The threat of precipitation-free sequences of all categories under examination (≥10, ≥15 and ≥20 days) was the highest in the vicinity of Myszyniec, while of those lasting ≥10 and ≥15 was in the region of Brodnica.
4. In the areas with the lowest number of days with low precipitation (≥1.0 and ≥5.0 mm) and at the same time, with the most frequent occurrence of dry vegetation periods (selected according to Kaczorowska's classification) i.e. in the

western and south-western part of the region, precipitation-free sequences of all categories under analysis (≥10, ≥15 and ≥20 days) were recorded most frequently.

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12. STABILITY OF THE ZONAL FLOW IN THE EURO-ATLANTIC REGION (1971-2006)

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INTRODUCTION

The dominant feature of the air flow over the European continent are recurrent shifts between the regime of intensive western flow and the zonal flow breakdown which often coincides with the marked dominance of the meridional circulation patterns. The aim of the research was to identify the main features of variability and the assessment of stability of the zonal flow over the European continent in the temporal coverage comprising 36 years (1971-2006) The variability of the indices of zonal flow was also utilized as a point of reference of the relative vorticity field evolution that is directly linked with the processes of cyclogenesis and cyclolysis over the area of research.

METHODS AND DATA

The source material comprised (see the list below) meteorological variables (daily averages) acquired from NCEP/NCAR Reanalysis (Kalnay 1996). The spatial coverage was the Euro-Atlantic region extending from 40°W to 40°E and 35°N and 75°N. The isobaric level for the analysis was 1000 hPa.

Used variables:

- wind vector components (uwnd – zonal, vwnd – meridional) – both variables served as a input for the relative vorticity calculations,
- geopotential heights (at 1000 hPa) that were utilized in the procedure of zonal index calculations.

Zonal flow intensity (ZI – zonal index) can be interpreted as a measure of average slope of the isobaric surface and as such the measure of the horizontal pressure gradient responsible for zonal wind vector component. It can be expressed with the following formula.

$$\mathrm{ZI(1000\ hPa)} = \mathrm{HGT(1000\ hPa)}_{35^{o}\mathrm{N}} - \mathrm{HGT(1000\ hPa)}_{65^{o}\mathrm{N}} \qquad (1)$$

where: HGT(1000hPa)35°N/65°N – standardized values of average 1000 hPa isobaric height at parallels or their fragments 35°N i 65°N (Li 2003)

High values of the ZI indicate strong zonal air flow in the troposphere. However, it should be noted that in lower troposphere high intensity of zonal flow should not be connected with the zonal flow *per se*. It should be rather connected with the intensification of processes leading to cyclogenesis. Low values of ZI over Europe at low levels of troposphere determine the occurrence of meridional macro-forms of atmospheric circulation and this might result in the development of anticyclones (blockades) which divert the usual paths of storms moving towards the eastern parts of the continent.

In mid and upper troposphere values of ZI reflect the level of deformation of zonal flow in the form of Rossby waves which are a natural effect of the existence of thermal gradient between the tropics an polar areas together with the rotation of the Earth. those are visible in the pressure field and air flow as waves in mid and upper troposphere. Depending on the number of waves, usually 4-6 waves around the hemisphere, we experience either strong zonal flow (small number of waves) or its breakdown (higher number of waves).

The influence of Rossby waves in upper troposphere on the course of the processes in the lower part of this strata of the atmosphere is prominent and is marked by the steering of the processes of divergence and convergence in the lower strata together with marked zones of convergence and divergence in upper strata (Olivier 1987). Rossby Waves carry the centres of vorticity with its maximum values in troughs and minimum in ridges.

Relative vorticity of the airflow can be expressed with the following formula:

$$rot\vec{v} = \frac{\partial v}{\partial x} + \frac{\partial u}{\partial y} \tag{2}$$

where: rot $\vec{v}$ – relative vorticity, u – zonal wind component, v – meridional wind component, x, y – coordinates (axis x towards east, axis y towards north) (Zwieriew 1965).

Relative vorticity (rot $\vec{v}$) is the measure of intensity and the direction of spin of the air around vertical axis perpendicular to the plane over which the rotation occurs. (Olivier 1987) In mid-latitudes vorticity together with the divergence of the airflow play a significant role in the generation of the disturbances in the air flow (Bauer 1995).

RESULTS

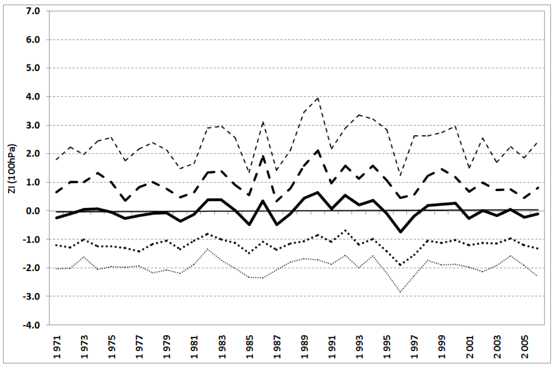
The analysis of the multiannual course of ZI revealed (Fig. 1) that the analysed period can be divided into couple of sub-periods. For the average values years 1971-1980 can be describes as relatively stable with respect to ZI variability. Period 1981-1989 witnessed a significant imbalance in the state of zonal flow which was marked by the changes in the circulation regimes at the year-to-year basis. Next, in the 90-ties visible prevalence of zonal flow dominated until 1996 when the deep minimum of ZI values was noted (lowest values in the whole analysed period).

Starting from 1997 the variability of ZI was strongly limited and the prevalence of negative annual values was also noted after 2000. When taking the basic statistical features into consideration the changes in variability are apparent especially for the extreme values. Extremely low values of ZI (10^{th} percentile) do not exhibit significant change whereas for upper extremes (75^{th} & 90^{th} percentile) which indicate substantial zonal flow intensity one can distinguish a major variability. Additionally the period 1971-1990 aside being the one with greatest variability of annual extremes is characterised with positive trend.

Early 90-ties bring a marked change in the direction of evolution of the state of the air flow system in analysed region. In general 80-ties and 90-ties were the period when significant variability of ZI was noted whereas the beginning of the XXI century brought dramatic decrease in the range of recorded ZI values. Years 2005 and 2006 were characterised by the increase in the range of variability when both percentile 10^{th} & 90^{th} moved towards extremes which indicates the return of the higher polarization of zonal flow characteristics after the relative stabilisation of the zonal flow in the beginning of XXI century.

Analysis in a seasonal scale reveals major differences in the course of ZI values. Winter is characterised with the highest variability with average values between -1(1979, 1996) up to 3 (1989, 1995). During analysed 36 years there were only 6 winters with the negative average values of ZI. Maximum ZI values were noted in the period 1988-1995 after which there was a marked decrease in 1996 which was followed by equally rapid return to strong zonal flow in the following year. From the beginning of the XXI century there is a gradual decrease of values of ZI in winter.

Spring is a perfect example of the prevalence of zonal flow breakdown conditions during the whole analysed period. There are only four years (1986, 1990, 1992 & 1994) when the values of ZI were positive. in the first part of the period significant variability of spring ZI was noted with the maximum in mid 90-ties. After 1996 minimum ($ZI \approx -2.0$) there was an increase to the value of -0.5. Interesting feature of ZI variability since the end 90-ties (1998) until 2004 is the reduction of its inter-annual variability and the values of ZI were practically constant. This period is also characterised by diminished inter-seasonal variability. Values noted in 2005 and 2006 might indicate the end of the stability period lasting from 1998.



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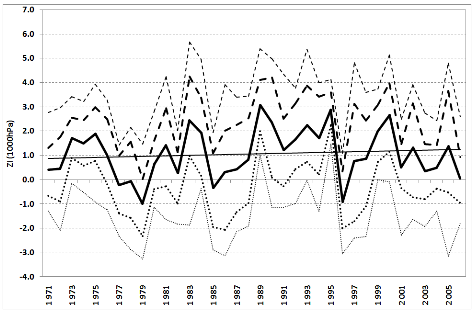

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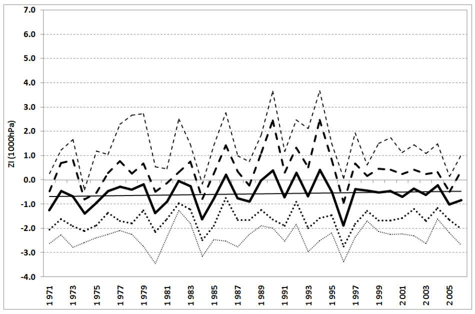
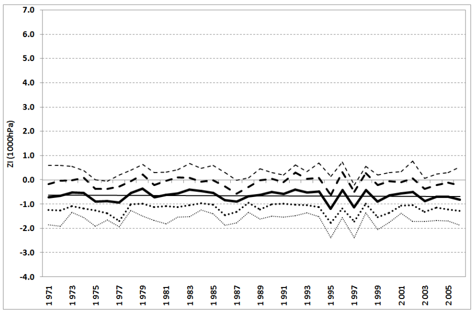
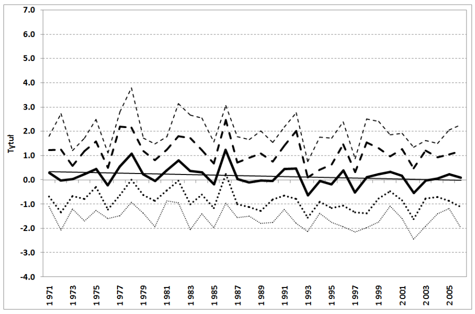


MAM



JJA



SON

Fig. 1. Course of basic statistics of $ZI_{1000hPa,}$(1971-2006); JD – annual, DJF – winter, MAM – spring, JJA – summer, SON – autumn; bold solid line – average, light dotted line – 10^{th} percentile, bold dotted line – 25^{th} percentile, bold dashed line – 75^{th} percentile, light dashed line – 90^{th} percentile

Summer in comparison with other seasons is characterised by the lowest variability with stable and low values of ZI (averages between – 1 and 0). There is however a marked increase in variability in the mid 90-ties. There is also slight increase in the summer intra-seasonal variability in the beginning of XXI century.

There is a higher variability of ZI values in autumn than it was the case in summer. One can recognize gradual decrease of ZI and whereas in the period 1971-1988 average values of ZI were above zero there is a prevalence of negative ones since the beginning of 90-ties.

On the basis of features of multiannual ZI variability analysed above one can identify significant change which occurred in the beginning of 90-ties which is not only apparent for average values but even more visible for ZI extremes (especially 75th and 90th percentile). This sub-period is also characterised by different direction of the climate system evolution (with respect to zonal flow characteristics) (Tab. 1).

Table 1. Trend equation coefficients ZI 1000 hPa (annual & seasonal) (x10^{-3} year^{-1}) for selected subperiods

Season/Statistics	Period	ZI_{p10}	ZI_{p25}	$ZI_{average}$	ZI_{p75}	ZI_{p90}
YEAR	1971-2006	–1.11	0.05	1.97	0.38	7.97
	1990-2006	–9.79	–9.82	–30.71	–54.79	–73.12
DJF	1971-2006	–0.65	4.18	11.06	19.24	21.91
	1990-2006	–85.65	–62.80	–83.24	–99.63	–86.35
MAM	1971-2006	6.46	4.53	6.42	8.98	2.41
	1990-2006	7.83	4.92	–38.43	–91.62	–113.38
JJA	1971-2006	–3.25	–1.91	–1.72	–0.82	–1.22
	1990-2006	–12.16	–9.37	–12.83	–16.09	–1.63
SON	1971-2006	–12.34	–12.06	–10.42	–11.13	–11.42
	1990-2006	0.34	0.63	–0.20	4.80	2.52

In the case of annual averages of ZI the scale of changes is significant as from slightly increasing values at rate $1.97 \cdot 10^{-3}$ y^{-1} (1971-2006) in the last 17 years of analysis there was an evident decrease in zonal flow intensity over the area of research ($-30.7 \cdot 10^{-3}$ y^{-1}). This value is accompanied by negative trend for 10th percentile and positive for 90th. This might serve as an indicator of an overall ZI variability increase (range). The change of 25th percentile is not so prominent as in the case of average values. The highest change occurred for 90th and 75th percentile ($-54.8 \cdot 10^{-3}$ y^{-1} and $-73.1 \cdot 10^{-3}$ y^{-1} respectively).

Seasonal variability of the trend coefficients points to winter and spring as the seasons during which the changes were most prominent (1990-2006). In winter in the case of average values the pace of changes is 8 times faster than during the whole analysed period with mutual reverse of direction of change. Similar differences were noted for extreme values (75th and 90th percentile). Other statistics for winter season reveal relatively homogenous decrease of ZI values in the last 17 years.

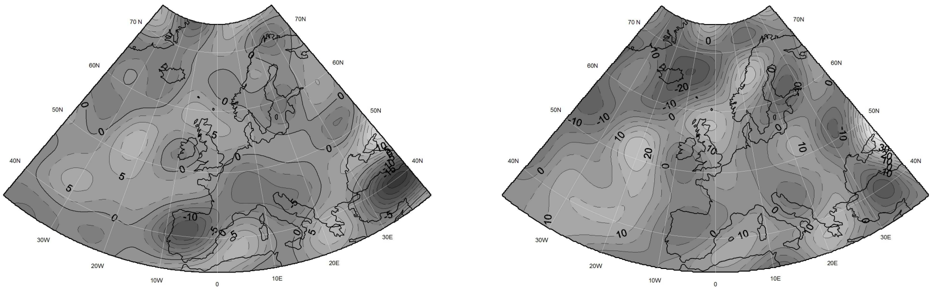
In spring the changes in the circulation regimes are greater than those noted in winter. For 75th & 90th percentiles there is also a change in the direction of evolution. Simultaneously the intensity of changes is greater than in the period 1971-2006. In general, spring is characterised by the significant decrease of variability in the period 1990-2006.

In summer the changes despite being visible are not as dramatic as it was in the case of spring and winter. There is also no change in the direction of trend but only increase of the change pace. What is interesting the pace of changes of 90th percentile of ZI changes only slightly. In autumn there is an overall drop in for all ZI characteristics (1971-2006). Years 1990-2006 reveal a slight decrease in average values ($-0.2 \cdot 10^{-3}$ y^{-1}) and increase for other characteristics (highest for 75th and 90th percentile).

The variability of ZI describing the state of the airflow system is not without influence on the field of airflow characteristics – relative vorticity. As it can be seen (Fig. 2) spatial variability of the values of trend coefficients of relative vorticity is dissimilarly shaped when distinct periods, identified in ZI variability analysis, are taken into consideration.

For the period 1971-2006 (annual averages) the majority of the area in the foreground of European continent is characterised by slightly positive values of trend coefficients which indicates the increase of cyclonic airflow. Small area over Great Britain and an area south of Greenland covering Island and parts of the North Atlantic is characterised by the decrease of the cyclonicity of airflow.

Over the majority of continent the decrease of the relative vorticity is noted and minimum values of $\mathrm{rot}\,\vec{v}$ trend coefficients are recorded over Iberian Peninsula. The trend analysis for 1990-2006 reveals distinct increase in spatial variability of trend coefficients The range of values is nearly $50 \cdot 10^{-8}$ s^{-1} y^{-1} whereas for 1971-1990 it is only $25 \cdot 10^{-8}$ s^{-1} y^{-1}.



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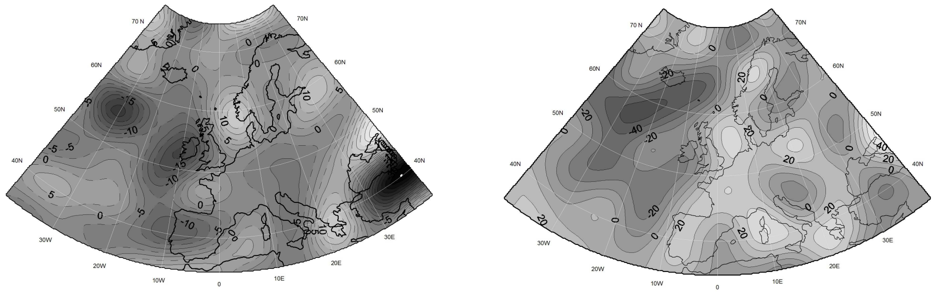

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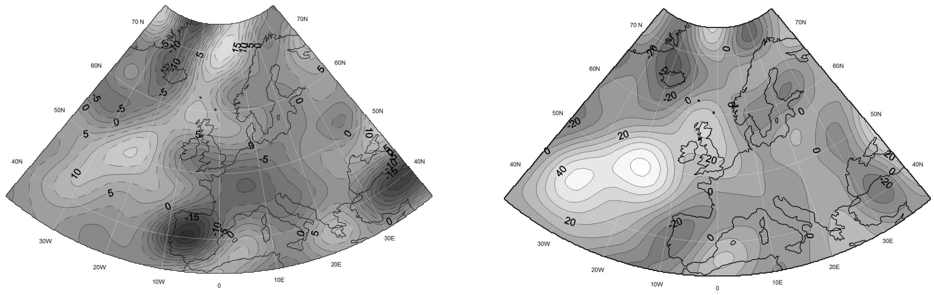

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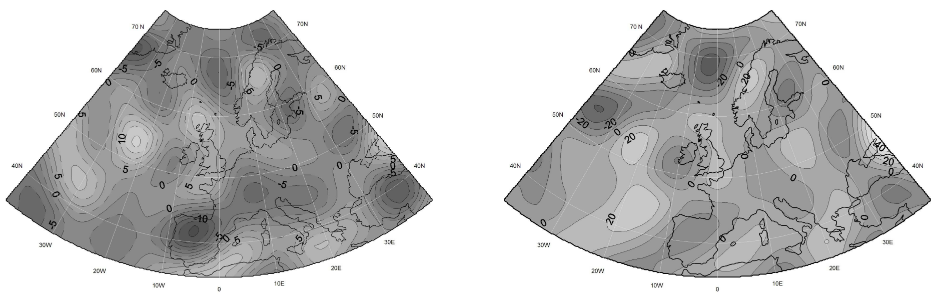

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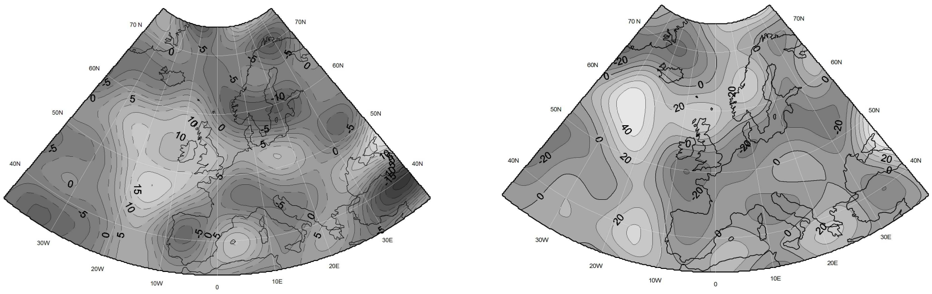

SON

Fig. 2. Relative vorticity trend coefficients (x10^{-8} s^{-1} y^{-1}) for selected periods:1971-2006 – left panel, 1990-2006 – right panel. The rest of the indicators as in Figure 1.

There is a distinct deepening of the minimum values near Island where the trend coefficients fall below $-30 \cdot 10^{-8}$ s^{-1} y^{-1} which indicates even higher decrease in cyclonicity in this area. Marked area of the increase of vorticity in the south-western part of the area of research denotes the tendency to level the differences in the manner of airflow in the region. There are also marked increases of relative vorticity west of Scandinavian Peninsula which might confirm recent ideas of the shift in atmospheric centres of action in North Atlantic (Hilmer 2001).

Seasonal analysis of relative vorticity trend coefficients spatial variability confirms the change in the evolution of the airflow system over the analysed region. In winter there is a significant shift of the centres of action over the area of research. in the case 1971-2006 period two major areas of the relative vorticity decrease are apparent in the foreground of the continent.

1990-2006 reveals one well developed centre of relative vorticity decrease in the foreground of the continent. Coastline of Europe delimits the range of this area relatively well and the interior is dominated by the increase of $\mathrm{rot}\,\vec{v}$. The scale of this increase does not match the decrease pace in the foreground of the continent (they are twice as small).

As it was mentioned before, spring is a peculiar season of the year during which values of ZI are low and the general picture of the airflow might be described with the dominance of meridional circulation. What is interesting period 1990-2006 there is a marked decrease of vorticity near Island which is accompanied by the increase south of this area. The sub-period does not go far from the whole analysed period however there is a deepening of tendencies recorded in 1971-2006.

This is significantly pronounced in the south-western part of the research area where the increases of relative vorticity (in the area usually connected with the anticyclonal airflow) is twice as fast as in the whole period. Also, near Island there is a area of decrease of relative vorticity.

In summer (1971-2006) there is a high spatial variability of the tendencies of the relative vorticity field. In the foreground of the continent marked semi-isolated areas with significant increase are present. One could risk the statement that those are the remnants of the vast vorticity increase area recorded in spring.

In autumn the direction of the vorticity field evolution indicates an apparent increase of $\mathrm{rot}\,\vec{v}$ in the foreground of the continent with the values exceeding $15\cdot10^{-8}\,s^{-1}y^{-1}$ west of Biscay Bay. The areas of $\mathrm{rot}\,\vec{v}$ decrease cover Southern Baltic Sea and southern part of the continent. Comparison with the selected period (1990-2006) reveals the westward shift of the areas of $\mathrm{rot}\,\vec{v}$ increase and the existence of apparent centre of vorticity increase south of Island with the trend coefficients values over $40\cdot10^{-8}\,s^{-1}y^{-1}$. The areas of significant drop of $\mathrm{rot}\,\vec{v}$ coincide with the coastline of the continent and stretch from the Iberian Peninsula through Biscay Bay, La Manche and further east across Southern Baltic.

CONCLUSION

Introductory analysis of the stability in the course of the zonal air flow index in the Euro-Atlantic region (1971-2006) showed significant changes in the absolute values as well as tendencies of statistical characteristics. It is most apparent in the first years of XXI century when the year-to-year variability of ZI was strongly limited. There was also a significant change in trend direction since the 90-ties. Values of trend coefficients of ZI were calculated for the sub-period 1990-2006 (with later comparison with 1971-2006). The values of relative vorticity tendencies were also calculated for the same periods. The analysis revealed significant changes in the relative vorticity field evolution. It can be expected that the changes in circulation regimes represented by the macroscale input (zonal circulation index) will substantially modify the shape of the airflow field in the regional scale and this might be followed – in the longer time scale – by the change of climatic conditions of the area of research.

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13. EVALUATION OF ATMOSPHERIC INSTABILITY INDICES FOR STORM PREDICTION IN NORTHERN POLAND

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INTRODUCTION

Storms are phenomena affecting many aspects of human life. One of the method of storm prediction is the assessment of atmospheric instability on the base of wide range of instability indices. These parameters indicate whether or not the conditions are favourable for storm development. Proper prediction of occurrence of storms is significant for protection of society against its consequences.

Bąkowski and Bielec-Bąkowska (2005) described conditions of occurrence of some atmospheric hazards like storms, heavy snow and strong wind in Poland using some of instability indices. The same authors (Bielec-Bąkowska and Bąkowski 2006) analyzed instability indices during convective phenomena occurrence in Warsaw.

Evaluation of instability indices as a tool for prediction of thunderstorms and showers in Greece was performanced by Marinaki *et al.* (2006). Deme *et al*. (2002) analysed 65 thermodynamical and dynamical indices for prediction of daily rain amount in Dakar.

The main aim of this study is to describe four instability indices: CAPE, LIFT, KI and TTI to investigate the relationship between atmospheric instability and storm occurrence at two meteorological stations located in Northern Poland: Szczecin and Suwałki.

INSTABILITY INDICES

Atmospheric instability is a condition where the atmosphere is unstable and the weather is subject to a high degree of variability through distance and time. In unstable conditions, a lifted parcel of air will be warmer than the surrounding air at altitude, less dense and prone to rise freely. There are two basic forms of atmospheric instability: convective instability and dynamic instability. Under convective instability the rise of warm air leads to the development of clouds, precipitation is very possible as well as convective storms. Dynamic instability occurs through the horizontal movement of air and the physical forces such as the Coriolis force and pressure gradient force. Dynamic lifting and mixing produces cloud, precipitation and storms.

Convective Available Potential Energy (CAPE) is a measure of the amount of energy available for convection. CAPE is directly related to the maximum potential vertical speed within an updraft; thus, higher values indicate greater potential for severe weather (Tab. 1). CAPE is represented on an upper air sounding by the area enclosed between the environmental temperature profile and the path of a rising air parcel, over the layer within which the latter is warmer than the former. This area often is called positive area. The index can be obtained from the formula:

$$CAPE = g\int_{zLFC}^{zEL} \left(\frac{T_{(vp)} - T_{(ve)}}{T_{ve}}\right) dz \qquad (1)$$

where: g – gravity force;
LFC – level of free convection;
EL – equilibrium level;
T_{vp} – virtual temperature of lifted parcel;
T_{ve} – virtual temperature of the environment;
z – altitude.

Table 1. Atmosphere instability on the base of CAPE index (Bąkowski 2005)

CAPE (J kg^{-1})	Instability
0-999	slightly unstable
1000-2500	moderately unstable
2500-4000	highly unstable
> 4000	extremely unstable

High CAPE means storms will build vertically very quickly. The updraft speed depends on the CAPE environment. As CAPE increases (especially above 2500 J kg^{-1}) the hail potential increases. An intense updraft often produces an intense downdraft since an intense updraft will condense out a large amount of moisture. Isolated regions of very heavy rain are expected when storms form in a large or extreme CAPE environment. Storms will only form and the CAPE actualized if the low level capping inversion is broken.

Lifted Index (LIFT) is a measure of atmospheric instability in the atmosfere up to 500 millibars. It is defined as a rising parcel's temperature when it reaches the 500 millibars level, subtracted from the actual temperature of the environmental air at 500 mbar.

$$LIFT = T_{500} - T_L \tag{2}$$

where: T_{500} – actual temperature of the environment at 500 mb;
T_L – temperature of a parcel lifted at 5000 mb.

If the Lifted Index is a large negative number, then the parcel will be much warmer than its surroundings, and will continue to rise. Thunderstorms are fueled by strong rising air, thus the Lifted Index is a good measurement of the atmosphere's potential to produce severe thunderstorms (Tab. 2).

Table 2. Atmosphere instability on the base of LIFT index (Bąkowski 2005)

LIFT (°C)	instability	thunderstorm probability
0 to +3	mostly stable conditions	thunderstorms unlikely
0 to –3	slightly unstable	thunderstorms possible
–3 to –6	unstable	thunderstorms probable
–6 to –9	highly unstable	severe thunderstorms possible
< –9	extremely unstable	violent thunderstorms, tornadoes possible

The LIFT only assesses instability in one level of the troposphere. This index should be used only for warm season convection. LIFT is most relevant in the warm sector of a mid-latitude cyclone or in a barotropic troposphere. LIFT is worthless when a shallow polar air mass moves into the boundary layer and is usually worthless for forecasting winter precipitation.

K Index (KI) is a measure of the thunderstorm potential (Tab. 3) based on vertical temperature lapse rate, moisture content of the lower atmosphere, and the vertical extent of the moist laser:

$$KI = (T_{850} - T_{500}) + Td_{850} - (T_{700} - Td_{700}) \tag{3}$$

where: T_{850} – temperature in Celsius at 850 mb,
T_{500} – temperature in Celsius at 500 mb,
Td_{850} – dew point in Celsius at 850 mb,

T_{700} – temperature in Celsius at 700 mb,
Td_{700} – dewpoint in Celsius at 700 mb.

The temperature difference between 850 mb and 500 mb is used to parameterize the vertical temperature lapse rate. The 850 dew point provides information on the moisture content of the lower atmosphere. The vertical extent of the moist layer is represented by the difference of the 700 mb temperature and 700 mb dew point. This is called the 700 mb temperature-dew point depression.

Table 3. Probability of thunderstorm occurrence on the base of KI (Bąkowski 2005)

KI (°C)	Probability of thunderstorm (%)
< 15	0
15-20	< 20
21-25	20-40
26-30	40-60
31-35	60-80
36-40	80-90
> 40	close to 100

The KI has proved useful in indicating the probability of air mass thunderstorms.

Total-Totals Index (TTI) is a stability index and severe weather forecast tool:

$$TTI = (T_{850} - T_{500}) + (Td_{850} - T_{500}) \quad (4)$$

where: T_{850} – temperature in Celsius at 850 mb,
T_{500} - temperature in Celsius at 500 mb,
Td_{850} – dewpoint in Celsius at 850 mb.

The Total-Totals Index is the arithmetic sum of two other indices: the Vertical Totals Index (temperature at 850 mb minus temperature at 500 mb) and the Cross Totals Index (dew point at 850 mb minus temperature at 500 mb). As with all stability indices there are no magic threshold values, but in general, values of less than 50 or greater than 55 are considered weak and strong indicators, respectively, of potential severe storm development (Tab. 4).

Table 4. Convection phenomena occurrence on the base of TTI (Lelątko and Ziemiański 2004)

TTI (°C)	convection phenomena
≤ 43	thunderstorms unlikely
44-45	likely thunderstorms
46-49	isolated severe storms
50-55	widely scattered severe
≥ 56	scattered severe storms

TTI may not pick up a capping inversion that prevents storms from developing. Index will be too stable if a layer of moisture is just under the 850 mb level.

Vertical Total Index may be very high and contributes to causing a high TTI even when moisture is lacking. Index will be too unstable in these situations. TTI works best for flat areas in low to moderate elevations. Does not work for high elevations.

METHODS

Instability indices from two Polish upper air stations (Łeba nad Legionowo) and one German station (Greifswald) are utilized in this study (Fig. 1). Four months with the highest number of storms in Szczecin and Suwałki are examined based on the 00.00 and 12.00 UTC radiosonde data during the period 1981-2000. The exception is Greifswald where sounding data are available from 1992.

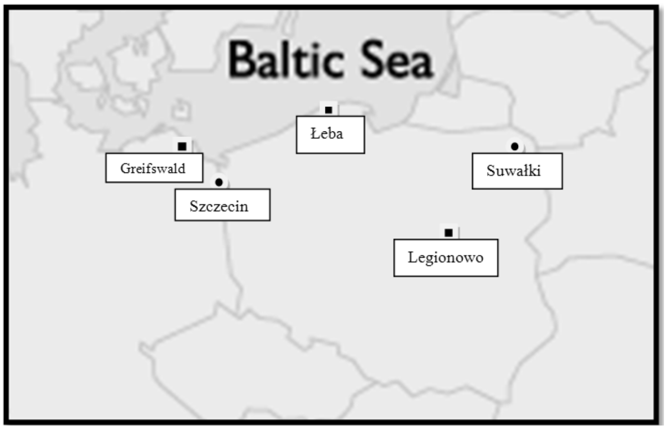

Fig. 1. Location of upper air station and meteorological stations

Four described above instability indices were chosen to divide their value range into two distinctive classes in which a storm event is either forecasted or not forecasted:

- Convective Available Potential Energy (CAPE),
- Lifted Index (LIFT),
- K Index (KI),
- Totals Totals Index (TTI).

Although meteorologists assume that indices listed above indicate moderate or very strong instability when CAPE > 999 J kg^{-1}, LIFT ≤ –3, KI > 25, TTI > 45, the threshold values may vary according to local conditions of particular meteorological station (Lelątko and Ziemiański 2004).

Meteorological stations give the observed information of yes or no event. The objective of this study is to investigate which index and where is the most appropriate for instability monitoring as well as to improve the thresholds value accuracy at meteorological station. To achieve this aim the consistency table (Tab. 5) is constructed.

Table 5. Consistency table (Marinaki *et al*. 2006)

Forecast/Observed	Yes	No	Total
Yes	a	b	a + b
No	c	d	c + d
Total	a + c	b + d	a + b + c + d

According to Table 5 Yule Index (consistency index) is applied given by equation:

$$Y = \frac{(ad - bc)}{\sqrt{[(a+b)(b+d)(a+c)(c+d)]}} \qquad (5)$$

The Yule index values range from –1 to 1 where 1 means the best consistency, 0 means no consistency and –1 means conversed consistency. The Yule index was calculated for each pair of upper air station and meteorological station.

RESULTS

Mean annual number of stormy days at investigated stations vary from 17 in Szczecin to over 20 on Suwałki (Tab. 6). In Szczecin storms may occur on every month of the year but the highest probability of storm occurrence appears in both meteorological stations from May to August. Mean monthly number of days with storm in Szczecin does not exceed 4 while in Suwałki achieves values higher than 5, specially in June and July.

The results of research of CAPE threshold indicate that its value for both meteorological stations in almost all analysed months is much lower than previously assumed (Tab. 7) and is higher or equal to 300 J kg^{-1}. It means that storms may be predicted even if the convection intensity is weak (Lelatko and Ziemiański 2004).

The best upper air station for storm prediction in Suwałki is Legionowo (the exception is May, for this month CAPE derived from upper air sounding in Łeba carried out at 00.00 UTC is better). In the case of storm prediction for Szczecin the best upper air stations differ in months.

Table 6. Mean annual and monthly number of stormy days in Szczecin and Suwałki, 1981-2000

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Szczecin	0.2	0.2	0.2	1.0	3.6	3.5	3.8	2.7	1.5	0.3	0.2	0.1	17.0
Suwałki	0.0	0.0	0.2	0.8	4.3	5.5	5.1	3.5	1.2	0.2	0.1	0.0	20.6

Table 7. Evaluation of **CAPE** for storm prediction in Northern Poland stations

	00.00 UTC	May	Jun	Jul	Aug
Szczecin	Threshold	≥300	≥300	≥1000	≥300
	Yule Index	0.10	0.17	0.17	0.12
	Upper Air Station	Łeba	Greifswald	Łeba	Legionowo
Suwałki	Threshold	≥300	≥300	≥300	≥300
	Yule Index	0.09	0.13	0.25	0.16
	Upper Air Station	Łeba	Legionowo	Legionowo	Legionowo
	12.00 UTC	May	Jun	Jul	Aug
Szczecin	Threshold	≥300	≥300	≥300	≥300
	Yule Index	0.19	0.51	0.32	0.14
	Upper Air Station	Legionowo	Greifswald	Greifswald	Legionowo
Suwałki	Threshold	≥300	≥300	≥300	≥300
	Yule Index	0.29	0.37	0.36	0.27
	Upper Air Station	Legionowo	Legionowo	Legionowo	Legionowo

The threshold values of Lifted Index enabling storm prediction in Szczecin and Suwałki vary but usually are lower in July and August (Tab. 8). For Suwałki the best prediction of storms is derived from upper air soundings carried out in Legionowo. Storms in Szczecin should be predicted on the base of Lifted Index from different upper air stations depending on the month one investigate.

Table 8. Evaluation of **LIFT Index** for storm prediction in Northern Poland stations

	00.00 UTC	May	Jun	Jul	Aug
Szczecin	Threshold	< 0	< 0	<-3	< -1
	Yule Index	0.17	0.32	0.20	0.12
	Upper Air Station	Łeba	Greifswald	Łeba	Łeba/ Legionowo
Suwałki	Threshold	< 0	< 0	< 0	< 0
	Yule Index	0.20	0.21	0.29	0.21
	Upper Air Station	Legionowo	Legionowo	Legionowo	Legionowo
	12.00 UTC	May	Jun	Jul	Aug
Szczecin	Threshold	< 0	< 0	< -1	< -1
	Yule Index	0.19	0.52	0.38	0.16
	Upper Air Station	Łeba/ Legionowo	Greifswald	Greifswald	Legionowo
Suwałki	Threshold	< 0	< 0	< -1	< -1
	Yule Index	0.39	0.34	0.41	0.27
	Upper Air Station	Legionowo	Legionowo	Legionowo	Legionowo

The threshold values of K Index predicting storm in both meteorological stations vary according to the month (Tab. 9). The best upper air station for storm prediction on the base of K Index in Szczecin is Greifswald while prediction of storms in Suwałki should be made on the base of upper air soundings from Legionowo or Łeba.

Application of Total Total Index for storm prediction shows that in case of Szczecin the best station for storm forecast is Greifswald and in case of Suwałki – Legionowo (Tab. 10). The threshold values of Total Total Index enabling storm prediction is in almost all months not lower than 45 for both meteorological stations.

Table 9. Evaluation of **K Index** for storm prediction in Northern Poland stations

	00.00 UTC	May	Jun	Jul	Aug
Szczecin	Threshold	≥ 25	≥ 25	≥ 25	≥ 25
	Yule Index	0.31	0.29	0.13	0.16
	Upper Air Station	Greifswald	Greifswald	Greifswald	Greifswald
Suwałki	Threshold	≥ 25	≥ 30	≥ 30	≥ 25
	Yule Index	0.31	0.29	0.25	0.22
	Upper Air Station	Łeba	Legionowo	Legionowo	Łeba/ Legionowo
	12.00 UTC	May	Jun	Jul	Aug
Szczecin	Threshold	≥ 20	≥ 30	≥ 25	≥ 30
	Yule Index	0.40	0.39	0.36	0.25
	Upper Air Station	Greifswald	Greifswald	Greifswald	Łeba
Suwałki	Threshold	≥ 25	≥ 25	≥ 30	≥ 20
	Yule Index	0.40	0.38	0.32	0.19
	Upper Air Station	Łeba	Legionowo	Legionowo	Łeba/ Greifswald

Table 10. Evaluation of **TTI** for storm prediction in Northern Poland stations

	00.00 UTC	May	Jun	Jul	Aug
Szczecin	Threshold	≥45	≥45	≥43	≥45
	Yule Index	0.31	0.28	0.19	0.16
	Upper Air Station	Greifswald	Greifswald	Greifswald	Greifswald
Suwałki	Threshold	≥45	≥45	≥45	≥45
	Yule Index	0.24	0.26	0.23	0.20
	Upper Air Station	Legionowo	Legionowo	Legionowo	Legionowo
	12.00 UTC	May	Jun	Jul	Aug
Szczecin	Threshold	≥45	≥45	≥45	≥45
	Yule Index	0.36	0.36	0.28	0.22
	Upper Air Station	Greifswald	Greifswald	Greifswald	Greifswald
Suwałki	Threshold	≥45	≥45	≥45	≥45
	Yule Index	0.24	0.29	0.29	0.26
	Upper Air Station	Legionowo	Legionowo	Legionowo	Legionowo

CONCLUSIONS

In this study, four instability indices were tested to improve storm prediction in Northern Poland. The author tried to find one threshold and upper air station that fits better to Yule criterion. The conclusions are:

1. The best upper air station for storm forecast in Suwałki is Legionowo, for Szczecin it is Greifswald or in some months Łeba.
2. 12.00 UTC atmospheric soundings represent connective phenomena better than 00.00 UTC soundings.
3. Threshold values for each analysed instability index differ according to month, especially K index.
4. K Index seems to be the best instability predictor, especially when utilised for storm forecast. This conclusion refers to both meteorological stations located in Northern Poland.

An ideal index should delineate space-time domains in which the forecast event occurs and outside which the forecast event does not occur. This is hard to achieve when conditional probability of storm occurrence in moderate or large instability conditions rarely exceeds 50% (Bielec-Bąkowska and Bąkowski 2006). Thus when forecasting storms and other convective phenomena several instability indices should be analysed together. The results of this investigation may be useful in this process.

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14. EDDY COVARIANCE METHOD IN MICROMETEOROLOGICAL RESEARCH REGARDING MASS AND ENERGY EXCHANGE WITHIN THE BOUNDARY LAYER

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INTRODUCTION

During the past thirty years there has been a breakthrough in the research regarding mass and energy exchange between the atmosphere and surfaces of various ecosystems. It was a result of an enormous technical progress in the area of measurement as well as gathering and processing data. This progress contributed to creating completely new measuring tools such as quick gas analyzers and anemometers. The access to these tools made it possible to apply Eddy Covariance method in micrometeorological research on a large scale (Eddy Covariance, EC). This method allows the researchers to deal with the issues of global changes to establish the dynamics of CO_2 and H_2O exchange between ecosystems and the atmosphere. Such research helps to understand how the increasing concentration of greenhouse gases, air pollution and changing meteorological conditions influence or may influence, the intensity of the exchange of both mass and energy, which takes place on the surfaces of various ecosystems (Olejnik 1988, Olejnik and Kędziora 1991). This research lays rational bases for creating likely projections of future fate of these ecosystems. These scenarios give rational arguments when making decisions regarding the management of natural resources and climate protection.

The task undertaken by many scientists during past years was to gather as many data as possible as far as the fluxes of CO_2, H_2O and sensible heat exchanged by various land ecosystems and the atmosphere are concerned. These data are indispensable for parametrization of various mathematical models adjusted to the local scale (Olejnik *et al*. 2001a and 2001b, Owen *et al*. 2007), which allow for different scenarios of climate change (IPCC 2007).

Because of the innovative character of the measurement technique which is Eddy Covariance method, this method is still being improved. It causes some difficulty in finding methodology that would be uniform in every respect. General assumptions of the methodology are uniform, however there are many aspects, such as some improvements or data quality tests which are frequent subject of disputes published in professional magazines.

The authors of the following study want to present their point of view regarding the application of the Eddy Covariance method. The applied methodology is based on many years of theoretical studies and over eight years of experience in using Eddy Covariance method.

EDDY COVARIANCE METHOD

Micrometeorological measurements

Micometeorology is a branch of science which focuses on the part of the atmosphere which is close to the earth surface and which has direct contact with it. This surface is often called active (Kędziora 1999). It is from several to a dozen or so kilometers high (Aurela 2005) and it is known as the boundary layer (Stull 1988). It is defined as a part of the troposphere, which, after a several-hour time distance, influences directly the earth surface and the other way round. The interaction between the active surface and the boundary layer is based most of all on two phenomena which occur in the air: the influence of rarefied air and the friction that takes place between the earth surface and horizontally moving air, both these phenomena cause eddies in the air, the so called turbulence. These movements are the main mechanism of flux of the energy and matter (e.g. water steam, carbon dioxide), between the active surface and the atmosphere.

In the lower level of the boundary layer the fluxes of mass and energy fluctuate inconspicuously with height. This layer is about 10% of the height of the whole boundary layer (Aurela 2005) and is called the developed boundary layer (Kędziora 1999) or the surface boundary layer (Baldocchi 2003). The tools for measuring mass and energy fluxes, in the case of every method used, must be located exactly in this layer, if we want to obtain representative results. This issue was discussed more broadly in the next chapter.

Eddy Covariance method (Eddy Covariance, EC) is the one that has been particularly well developed among all the measurement methods applied to assess mass and energy flux between the active surface and the atmosphere. This method has been known for a long time since the creator of its theoretical bases is thought to be Sir O. Reynolds (Baldocchi 2003, Reynolds 1895). However, high technical requirements of this method caused that many attempts to implement it were not satisfying or limited to the measurement of the flux of sensible heat (H) (e.g. Swinbank 1951). Only the current developments in computer science and miniaturization of spectroscopic techniques allowed using Eddy Covariance method in field research to measure mass and energy fluxes.

The first successful attempt to apply EC method during continuous, all-year-round measurements of the CO_2 and H_2O exchange was made only about 20 years ago at Harvard University (Wofsy *et al.* 1993). For the past 20 years EC technique has been widely implemented, particularly in the USA, and also in Canada and other countries in the Western Europe. This intense research accelerated the development of the EC method and led to its widespread implementation by more and more research teams all over the world.

The EC technique has been successfully used by many researchers investigating the exchange of carbon dioxide and heat balance of various active surfaces such as e.g.: an oak forest in Tennessee (Baldocchi and Meyers 1991), aspen boreal forest in Canada (Black *et al*. 1996, 2000), subpolar ecosystems in Sweden and Finland (Aurela 2005), farming areas (Józefczyk 2005), peat bog (Urbaniak 2006), a forest in Poland (Urbaniak *et al*. 2010).

Eddy Covariance method

In order to illustrate in a simple way what underlies the steady state mass and energy fluxes in a well-developed boundary layer it can be compared to a container full of water which is simultaneously dripping out and poured into the container. It is obvious that in order to maintain the steady level of water in the container the incoming and outgoing flux must me the same. Thus, it is enough to measure one of them in order to obtain the value of the other. In other words if we want to measure e.g. CO_2 flux exchanged between the ecosystem and the atmosphere, it is sufficient to measure the flux in any point of the developed boundary layer where the value of this flux does not fluctuate with height and at a certain time. The law of conservation of mass applies here (Aurela 2005, Baldocchi 2003, Stull 1988).

Mathematical notation of the mass conservation law for carbon dioxide fluxes can be presented as in the formula 1 (Baldocchi 2003). It states as follows: the sum of the changes in the carbon dioxide concentration ρ_s averaged in time t (expression I) and horizontal advection (expression II) and vertical mass flux (expression III), are balanced by the sum of divergence of carbon dioxide flux in the following directions: longitudinal (x) latitudinal (y) (expression IV) and vertical

(z) (expression V), as well as by biological source of carbon dioxide (S_B) (expression VI) and soil respiration (expression VII):

$$\underbrace{\frac{\partial \overline{\rho_s}}{\partial t}}_{I} \underbrace{+ \bar{u}\frac{\partial \overline{\rho_s}}{\partial x} + \bar{v}\frac{\partial \overline{\rho_s}}{\partial y}}_{II} \underbrace{+ \bar{w}\frac{\partial \overline{\rho_s}}{\partial z}}_{III} = -\left[\underbrace{\frac{\partial F_y}{\partial y} + \frac{\partial F_x}{\partial x}}_{IV} + \underbrace{\frac{\partial F_z}{\partial z}}_{V} \underbrace{+ S_B(x,y,z)}_{VI} \underbrace{- F_z(0)}_{VII} \right] \qquad (1)$$

In the equation 1, $\bar{u}, \bar{v}$ and $\bar{w}$ are the components of the wind velocity vector averaged in certain time, in the directions x, y and z respectively.

The EC technique requires some introductory assumptions to obtain representative estimated values of the fluxes. The stationarity of the measured fluxes (the quantity of the flux does not fluctuate with time) as well as the homogeneity of the surface over which the measurements are conducted are assumed (the problem will be discussed more broadly further. In such ideal conditions the value of I expression from the equation 1 equals zero (it is the so called storage). Additionally, in flat, horizontal, uniform area, the horizontal adequacy equals zero and might be neglected (expression II). It is also known that the average speed of the vertical component of wind velocity vector is very small, which leads to the possible assumption that vertical mass flux can be equated to zero (expression III). Given such conditions the horizontal divergences of the flux, $\partial F_x / \partial x$ and $\partial F_y / \partial y$ in the expression IV equal zero. Assuming the above, the equation of mass and energy conservation (equation 1) is simplified to the balance between the vertical divergence of carbon dioxide flux (expression V), and its biological source S_B, (expression VI) and soil source (expression VII). Hence the equation 1 can be expressed in the following way:

$$\frac{\partial F_z}{\partial z} = -S_B + F_z(0) \qquad (2)$$

By the integration of the equation 2 in relation to the height, one obtains the equation combining the average density of the vertical flux, measured at a certain height over the plant surface $F_z(h)$, with the net quantity of the density of the mass fluxes which come in and out from the layer of soil lying beneath $F_z(0)$ and the vegetative layer:

$$F_z(h) = F_z(0) - \int_0^h S_B(z)\, dz \qquad (3)$$

In practice using the equation 3 and the Eddy Covariance method (EC), it has become possible to estimate the net flux of any scalar quantity (not only CO_2), exchanged between the active surface and the atmosphere (Baldocchi 2003, Baldocchi *et al*. 2001a).

As it has been mentioned before, some turbulences moving the air up or down occur in the surface boundary layer. Trace gases such as carbon dioxide are moved together with the air. Applying sensors which react appropriately fast and which are required by the EC method, enabled measurements of the direction and velocity of these air turbulences and together with them the concentration of gases. Thanks to an extremely short time constant of the sensors used in this method, measurements at a rate of several readings per second became possible (Fig. 1), and the most frequent applied rates of data sampling are in the range of 10 to 20 Hz.

Such rate of sampling it is makes it possible to measure high-frequency changes occurring in the density of gases under research, as well as air temperature and wind velocity (e.g. Anderson 1984, Baldocchi *et al*. 2001b). With such fast measurement rate it becomes viable to calculate total net flux of any scalar quantity (e.g. mass or energy) using the equation proposed by Swibank (Swinbank 1951):

$$F = \overline{w \cdot \rho} \tag{4}$$

where:
F – flux of scalar quantity (energy (W m^{-2}) or mass (μmol m^{-2} s^{-1})),
w – vertical component of wind velocity vector (m s^{-1}),
ρ – scalar quantity (temperatura (K) for energy or density of the substance (μmol m^{-3}) for gases),
$\overline{}$ –this symbol denotes the average quanity in time.

One of the crucial issues when applying the Eddy Covariance method is the averaging time of the obtained results of measurements. Too short averaging time leads to understating the energy or mass flux. It stems from the fact that the changes in the studied parameters moved by bigger turbulence eddies, having the diameter of several to several dozen meters, are not measured because the time of their passing through the sensor is longer than the averaging time. On the other hand, too long averaging time of the measured data often fails to meet the requirement criteria of the flux stationarity (e.g. too big fluctuations in temperature) and averages the measured fluxes in too long period of time. Most authors of the studies devoted to mass and energy exchange are interested in the dynamics of fluctuations of particular fluxes during the day, not in their average from several hours of measurement or daily average. Taking the above into consideration and accounting for the experience acquired so far by many researchers using the EC method, the suggested time after which the measurements should be averaged fluctuates between 30 and 60 minutes (Aubinet *et al*. 2000). Only in the specific cases it is prolonged to several hours. Such specific case is nighttime, when the turbulence weakens, and the surface boundary layer is dominated by big eddies.

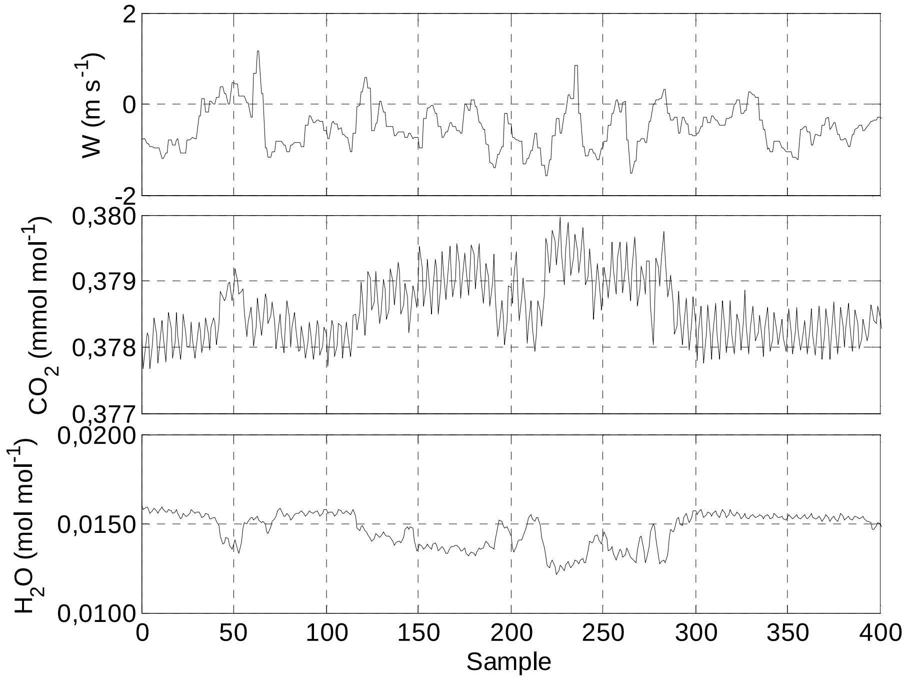

Fig. 1. Hypothetical course of the vertical component of wind velocity vector (upper graph), carbon dioxide concentration (middle graph), water vapor concentration (lower graph), in the ten-second measurement conducted at the frequency of 40 Hz. (On the basis of own measurements)

In practice the above mentioned fluxes are calculated by means of a modified formula 4. Modification means here conducting the so called Reynolds decomposition (Araya 1988, Baldocchi *et al*. 1999, Reynolds 1895) which assumes that at any moment during the averaging time period, fluctuations of the vertical component of wind velocity vector (w) can be described as a sum of averaged w ($\overline{w}$) and instant deviation from w (w’). This idea is illustrated by Figure 2, whereas mathematical notation has been presented in the formula 5.

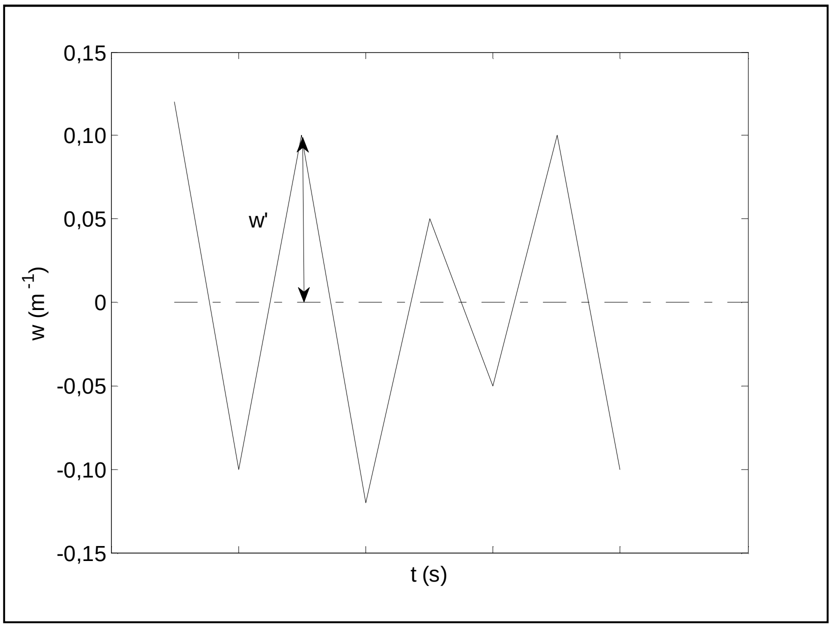

Fig. 2. Reynolds Decomposition for the vertical component of wind velocity (w). red polygonal chain symbolizes measurement signal. Black dashed line shows a certain average in time (t) from the measured values. Vertical arrowhead line shows aberration from the average (w').

$$w = \overline{w} + w' \tag{5}$$

where:

w – instant quantity of the vertical component of wind velocity vector (m s^{-2}),

$\overline{w}$ – average quantity of the vertical component of wind velocity vector (m s^{-2}),

w' – instant fluctuation of the vertical component of wind velocity vector from the average quantity (m s^{-2}).

Similar operations can be done for the scalar quantity (e.g. CO_2, H_2O or T), which later on are substituted in the formula 4 and the following is obtained:

$$\begin{aligned} F &= \overline{(\overline{w} + w')(\overline{\rho} + \rho')} = \overline{(\overline{w}\,\overline{\rho} + \overline{w}\,\rho' + w'\,\overline{\rho} + w'\,\rho')} = \\ &= \underbrace{\overline{w}\;\overline{\rho}}_{I} + \underbrace{\overline{w}\;\overline{\rho'}}_{II} + \underbrace{\overline{w'}\;\overline{\rho}}_{III} + \underbrace{\overline{w'\rho'}}_{IV} \end{aligned} \tag{6}$$

Since, as it stems from calculations, the average quantity of the fluctuations from the average from each data sample equals 0 ($\sum \overline{w'} = 0, \sum \overline{\rho'} = 0$), thus the expressions II and III in the equation 6 equal 0 and the formula is simplified as follows:

$$F = \underbrace{\overline{w}\overline{\rho}}_{I} + \underbrace{\overline{w'\rho'}}_{II} \qquad (7)$$

As follows from the equation 7 total vertical flux of each scalar quantity is the sum of the average vertical of mass flux (part I) and turbulence flux (part II) (Moncrieff *et al.* 1997, Webb et al. 1980). The second part of the equation 7 is nothing else but the covariance of the vertical component of wind velocity vector and the scalar quantity whose flux we are interested in – hence the name of the measurement method. This part determines the average value of the product of momentary fluctuations of the vertical component of wind velocity vector and scalar quantity from their average and describes turbulent exchange of mass and energy between the active surface and the atmosphere. The first part of the equation 7 is the so called mass flux caused by horizontal, not zero, component of wind velocity. As it has been mentioned earlier, the biggest part of total mass and energy exchange between the active surface and the atmosphere occurs thanks to turbulence. However ignoring mass flux in estimating these fluxes is in some cases a source of serious mistakes, e.g. indication of CO_2 absorption by the surfaces completely devoid of vegetation. Explanation of this problem is described in further text.

Eddy Covariance method in practice

Correction of flux quantity due to air density changes

Flux measurements with the application of the Eddy Covariance method are based on the measurements of fluctuations of the vertical component of wind velocity vector and scalar quantity fluctuations such as air temperature, carbon dioxide concentration or water vapor (Baldocchi 2003).

Currently the measuring kit used for Eddy Covariance method consists of two basic tools: ultrasound anemometer and spectrometric gas analyzer. The first can be used to measure the fluctuations of the vertical component of wind velocity vector and air temperature ((m s^{-1}) and (°C) respectively), whereas the latter fluctuations of water vapor and carbon dioxide concentrations expressed in mol density units (mmol m^{-3}). Unfortunately the measurement results expressed in this unit are the source of difficulty when it comes to calculating gas fluxes, because the changes in mol density occur not only as a result of increasing or decreasing the number of molecules of these gases in a density unit but are also a result of fluctuation in temperature, pressure and humidity of air as it occurs in the free atmosphere (Baldocchi 2003).

Additionally, the fluctuations of the atmospheric air resulting from the temperature changes and water vapor concentration changes can be the reason that the average quantity of the vertical wind velocity does not equal zero ($\overline{w}$, in the equation 7). For example a situation can be considered in which we have a positive value of sensible heat flux (H). The part of air going upwards is in this case warmer and has lower density that the air simultaneously going downwards. If we assume that the amount of the mass exchanged between two levels of the surface boundary layer is the same, then an average quantity $\overline{w}$, which is above zero must occur. However, this quantity is small, about 1 mm s^{-1} and currently none of the widely used anemometers is able to measure it.

Additionally, it should be mentioned that the average concentration of carbon dioxide in the atmospheric air is so small that its fluctuations do not influence the change in air density. Therefore, the flux of CO_2, related to the average vertical component of wind velocity, is impossible to be estimated by means of the formula 7. In practice instead of using mol density units to calculate CO_2 and H_2O fluxes, the so called mixing ratio is used, or the above mentioned ratios are considered in more extended formulas which are described and explained below.

Taking the above into consideration, Webb and his team (Webb *et al*. 1980) proposed two ways of calculating the fluxes of carbon dioxide and water vapor. Both ways are correct and the results obtained when using them are quite similar. The authors base on two assumptions. Firstly, the average vertical wind velocity may play an important role and secondly, vertical flux of dry air equals zero:

$$\overline{w\rho_a} = 0 \tag{8}$$

The first assumption was empirically proved by Leuning and his coworkers (Leuning *et al.* 1982). They measured carbon dioxide fluxes over flat dry field completely devoid of vegetation. After calculating CO_2 flux from the formula 7, it turned out that it is directed towards the active surface (similarly as during photosynthesis which was impossible to occur in this case). Whereas the quantities of CO_2 flux calculated by means of assumptions and formulas suggested by Webb and his co-workers (Webb *et al*. 1980) were close to 0. Thus, the assumptions suggested by this team of researchers and described below proved right.

Basing on the two given assumptions Webb *et al*. (1980) introduced the following formulas:

– for calculating CO_2 flux

$$F_c = \bar{\rho}_a \overline{w' s'} \tag{9}$$

where:

F_c – CO_2 flux (g m^{-2} s^{-1}),1
$\bar{\rho}_a$ – averege density of dry air (g m^{-3}),
w'– fluctuation of the component of vertical wind velocity (m s^{-1}),
s' – fluctuation of mixing ratio CO2 (g g^{-1}), s = ρ_c/ρ_a, where ρ_c stands for CO_2 density in dry air (g m^{-3}).

– for calculating H_2O flux:

$$E = \bar{\rho}_a \overline{w' r'} \tag{10}$$

where :

E – flux of H_2O (g m^{-2} s^{-2}),
r' – fluctuation of mixing ratio H_2O (g g^{-1}), r = $\rho\tilde{v}\rho_a$, where ρ_c stands for H_2O density in dry air (g m^{-3}).

When applying the formulas 9 and 10 to calculate CO_2 and H_2O fluxes high-rate data regarding the ratios of mixing of both gases are required. Sometimes obtaining such data is hard because the measurements of air temperature fluctuations conducted exactly in the place of measuring of CO_2 and H_2O density fluctuations are needed in order to calculate them. In practice high-rate temperature measurements are obtained by using an ultrasound anemometer which is distant from a gas analyzer by about 40-50 cm. This can have a negative impact on the quality of measurements, particularly when they are conducted over less rough surfaces where small turbulent eddies dominate. Then a problem arises if the temperature measured this way is the temperature of the air passing simultaneously through the gas analyzer? Additional difficulty in applying the formulas 9 and 10

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[1]In order to receive carbon dioxide flux in mol units (mol m^{-2} s^{-1}) the obtained result should be divided by molecular mass of CO_2, m_c = 44.01 g mol^{-1}.
[2]In order to present the quantity of water vapor flux in energy units, the obtained result flux to be multiplied by latent heat of water evaporation L = 2448 J g^{-1}.

is the necessity of conducting high-rate measurements of air pressure, therefore these formulas are applied very cautiously.

Next set of formulas for calculating CO_2 and H_2O fluxes proposed by Webb and co-workers (Webb *et al*. 1980), bases on the relation between molecular masses of air and water vapor. These formulas can be denoted as follows:

– for calculating CO_2 fluxes:

$$F_c = \overline{w'\rho'_c} + \frac{m_a}{m_v}\frac{\bar{\rho}_c}{\bar{\rho}_a}\overline{w'\rho'_v} + \left(1 + \frac{\bar{\rho}_v m_a}{\bar{\rho}_a m_v}\right)\frac{\bar{\rho}_c}{\bar{T}}\overline{w'T'} \tag{11}$$

where:

w' – fluctuation the component of vertical wind velocity (m s^{-1}),
ρ_c – density of carbon dioxide in dry air (g m^{-3}),
ρ_c' – fluctuation of carbon dioxide density (g m^{-3}),
ρ_α – dry air density (g m^{-3}),
ρ_v – water vapor density in dry air (g m^{-3}),
m_α – molecular air mass (g mol^{-1}),
m_v – molecular water vapor mass (g mol^{-1}),
T – air temperature (K),
T' – air temperature fluctuation (K).

– for calculating H_2O fluxes:

$$E = \left(1 + \frac{m_a}{m_v}\frac{\bar{\rho}_v}{\bar{\rho}_a}\right)\left(\overline{w'\rho'_v} + \frac{\bar{\rho}_v}{\bar{T}}\overline{w'T'}\right) \tag{12}$$

where:

E – water vapor flux density (g m^{-2} s^{-1}).

In the case of sensible heat the formula is expressed as follows:

$$H = c_p\bar{\rho}\,\overline{w'T'} \tag{13}$$

where:

H – heat flux quantity (W m^{-2}),
$\bar{\rho}$ – average air density ($\rho_c + \rho_a$) (g m^{-3}),
c_p – specific heat of air at constant volume (J g^{-1} K^{-1}),
T' – temperature fluctuations (K).

The above formulas 11, 12 and are most frequently used in the Eddy Covariance method, particularly when using an open-path analyzer. Applying the formulas 9 and 10 for calculating CO_2 and H_2O fluxes gives almost identical results, however it requires a calculation, or better a measurement of the mixing ratio of both gases.

Understating of the covariance quantity by spatial separation of the sensors

Although the sizes and shapes of two main sensors used for the Eddy Covariance method (anemometer and gas analyzer) are adjusted so that they only minimally interfere with turbulence of the air going through them, at present it is impossible to sample the same portion of air simultaneously by both sensors. The distance between the sensors is about 0.4 m and shortening it may lead to serious interference in the air turbulence (the influence of one sensor on the other). The necessity of keeping spatial distance between the two main tools in the Eddy Covariance method poses another problem for researchers connected with calculations of gas fluxes. Depending on wind velocity the same portion of air is sampled by both sensors with a certain shift in time (at higher wind velocity this time is shortened). Moore noticed (Moore 1986) that calculated covariance e.g. $\overline{w'\rho_c'}$, is sometimes understated because the examined portion of the air passes first through one sensor and after a while through the other. This situation

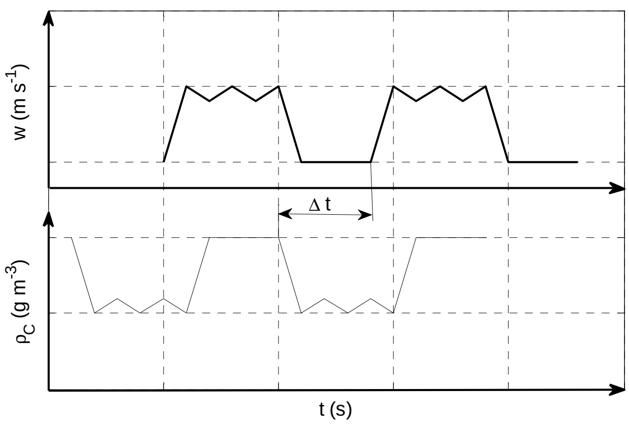

Fig. 3. A diagram illustrating the idea of moving measurement series against one another in order to obtain maximum covariance. Symbol Δt means the movement in time of data population „ρ_c" against population „w", which is necessary to be introduced

causes that the covariance from both sensors calculated directly from the spectrums of the obtained data is understated, particularly at low wind velocity. The problem was solved by moving the measurement series in relation to each other to the right or to the left, depending on the wind direction (the wind direction determines which of the measuring tools will sample the air first) (Fig. 3). The movement of me asurement series in time occurs automatically by means of special software.

Measurement series are moved in relation to one another until the highest quantity of their covariance is obtained. And this maximum covariance is used to calculate fluxes of gases exchanged between the active surface and the atmosphere.

Understatement of the flux quantities during windless nights

When conducting measurements in the surface boundary layer the meteorological conditions are not always perfect for using the Eddy Covariance method. Then during gas fluxes measurements the emphasis is placed on these elements of the equation 1 which usually come close to zero (I, II, III and IV). This problem occurs most often at nighttime when the wind velocity drops dramatically (Katul *et al.* 2004, Lee *et al.* 1996). Under the circumstances, correct assessments of mass and energy fluxes, and particularly CO_2 flux become especially difficult. It is because during windless nights turbulent mixing drops down or becomes still. Carbon dioxide which is a product of both soil and vegetation respiration being heavier than air gathers in the space between the vegetative layer and the sensors located a few meters above this layer. Additionally, when the measurements are conducted in the area with a significant tilt, carbon dioxide may slide on the surface of the ground as a result of gravitation and will not be noticed by the measuring tools at all (Paw *et al*. 2000). The situation is slightly better when the measuring tools are located over flat surfaces. After a windless night when the wind grows in the morning and turbulence together with it, the sudden and momentary surge in CO_2 flux is observed (Aurela 2005, Massman and Lee 2002). For such reasons, scientists applying the Eddy Covariance method often observe understatement in the quantity of the night carbon dioxide flux (Black *et al*. 1996, 2000, Lindroth *et al.* 1998, Valentini *et al*. 2000). Currently the most widespread practice, which makes solving this problem possible is the so called filtering of night measurements. This procedure is based on analyzying one of the parameters which describes the current conditions of turbulent exchange in the atmosphere. This parameter is the so called friction velocity (u*).

The formula to calculate friction velocity can be expressed as follows (O&A RUA User Manual 2004):

$$u* = \sqrt{\overline{l'w'}(2\sin^2\Phi - 1) + (\overline{l'}^2 - \overline{w'}^2)\sin\Phi\cos\Phi} \qquad (14)$$

where:

$u*$ – friction velocity (m s^{-1}),
l' – fluctuations in the horizontal wind velocity (x, y) (m s^{-1}),
w' – fluctuation´ s in the vertical wind velocity (m s^{-1}),
Φ – angle of tilting of the wind vector against the verhorizontaltical surface (°).
The quantities w´ and l´ are measured by an ultrasound anemometer.

A certain threshold quantity of the friction velocity is assumed below which the Eddy Covariance method cannot be used. The measurements conducted at times when u* quantity is too low (lack of self-sufficient turbulence) are rejected from the data collections of calculated mass and energy fluxes treating them as inaccurate. The gaps created this way in the collected data of given fluxes e.g. CO_2 (night respiration), are filled with the quantities calculated on the basis of experimental functions. One of the frequently used is the empirical relation between the quantity of respiration and the surface or air temperature (Lloyd and Taylor 1994). Some authors bridge the gaps in the data collections of given CO_2 fluxes by substituting the quantities of fluxes measured during windy nights over the same ecosystem in similar meteorological conditions (this data may come from several nights preceding or following the windless night) (Józefczyk 2005).

Critical quantity of the friction velocity, above which the flux quantities of carbon dioxide obtained by means of the Eddy Covariance method can be assumed as correct is not a universal value and depends on the roughness of the surface and meteorological conditions, in the light of many publications, this quantity is within the range of 0.1 to 0.6 m s^{-1} (e.g. Baldocchi 2003). One of the methods of calculating the threshold quantity of friction velocity characteristic for a given ecosystem is the analysis of a graph illustrating the correlation between CO_2 flux and friction velocity (F_c = f(u*)) (Massman and Lee 2002, Black *et al*. 1996, Lindroth *et al*. 1998, Aubinet *et al*. 2000, Falge *et al*. 2001). Using data from a longer measurement series one can obtain the following correlation (F_c = f(u*)), and the graph created in this way may illustrate for which u* value the quantity of the flux ceases to grow (it ceases to depend on u*). However, this visual method for finding minimal u* value which allows using the Eddy Covariance method is relatively subjective and may hamper comparing the results of CO_2 fluxes measurements conducted over various ecosystems. Therefore, Gu and his co-workers (Gu *et al*. 2005) suggested statistical and, to a certain extent, universal method of calculating threshold quantity of friction velocity ($u*_{th}$), above which the Eddy Covariance method can be used preserving the proper quality of carbon dioxide measurements. This method is based on international search for $u*_{th}$. quantity. At first u* quantities are assigned to F_c quantities measured at the same time (these are exclusively nighttime measurements). Subsequently the measured quantities of F_c fluxes are normalized by means of the quantities of this flux calculated using one of the empirical models of respiration (e.g. Lloyd and Taylor 1994). Thus, the created sample from the data of normalized quantities of carbon dioxide flux is ranked in the growing manner. Next step is to create two samples from the data created in this way.

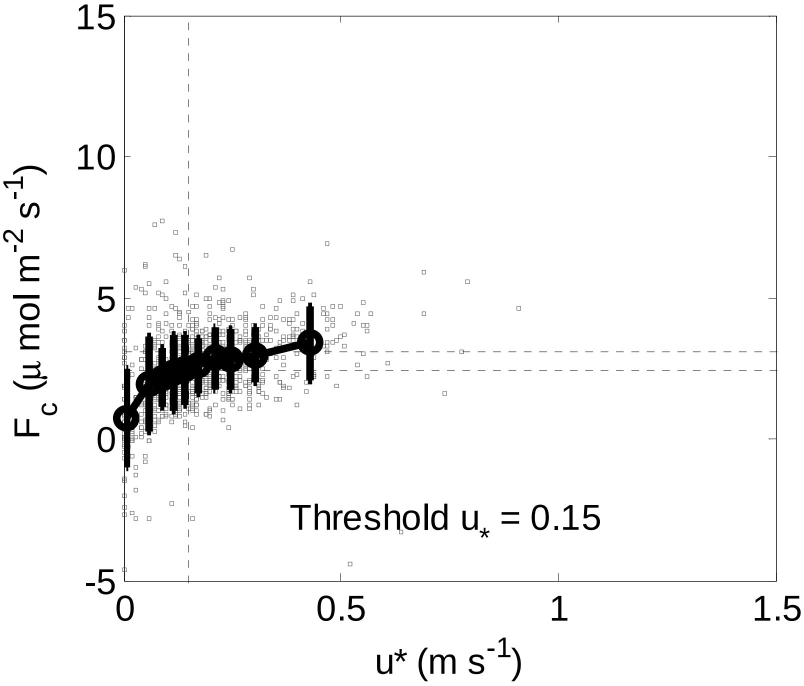

Fig. 4. The dependence of the quantity of F_c flux measured at night in Rzecin on the friction velocity (u*), for the months from June to August 2004. The upper dotted line shows the average F_c quantity calculated on the basis of the quantities measured above u* = 0.15 m s^{-1}.Lower line shows F_c quantity at the threshold quantity of u*

The first sample is the so called 'moving window' containing certain segment from all quantities of normalized F_c fluxes The other sample consists of all quantities in a given database and it is the so called 'referential sample'. Another step is comparing the averages from both samples, which is done by means of t – test of zero hypothesis: H0: Fm ≥ Fr, where Fm stands for an average from a 'moving window', and Fr an average from the referential sample. If zero hypothesis is not confirmed, the 'moving window' is moved higher and the values above it are excluded from the referential sample. 'Moving window' is moved along the referential sample until zero hypothesis is confirmed or to the last element of the referential sample. If zero hypothesis has been confirmed, a median from u* quantities ascribed to normalized flux quantities in the 'moving window' is calculated. This is the threshold quantity of the friction velocity ($u*_{th}$), above which the Eddy Covariance method gives accurate results.

Figure 4 presents hypothetical graph illustrating the dependence of carbon dioxide flux (F_c) on friction velocity (u*).

Rotation of coordinate system

Theoretical assumptions for the Eddy Covariance method project locating an ultrasound anemometer over a horizontal flat area, geopotentially perpendicularly. In practice these requirements are very difficult to meet. Most often the measurements are conducted on smaller or bigger slopes, rarely can we also ensure ideally vertically located sensor, which may tilt from the vertical line with time and with the changes of meteorological conditions. It results in registration of a non-zero average of the vertical component of wind velocity vector (during a half-an-hour averaging period $\overline{w}$ should equal 0). This problem is solved by rotation of the coordinate system of the anemometer, by applying an appropriate computer program so that the projections of vector resultants of wind velocity on both axes (one vertical z and one horizontal y) of the rotated coordinate system equaled 0. Most often the so called double rotation around the vertical ax z is used and thus, obtaining $\overline{v} = 0$ and around y ax, thus obtaining $\overline{w} = 0$. The rotation is conducted at every averaging time e.g. 30 min. In some works one can come across the so called triple rotation (one additional around a new ax z→z'), as a result of which a zero value of the product: $\overline{u'v'} = 0$ is obtained (i.e. horizontal covariances of the horizontal components of wind velocity vector u and v) (Aurela 2005, Baldocchi *et al.* 1998, Massman and Lee 2002, Tanner and Thurtell 1969). Such procedure conducted by a computer program used for calculating mass and energy fluxes, solves the problem of non-zero quantity of the vertical component of wind velocity vector measured by the anemometer.

Spatial representation of mass and energy fluxes

Besides technical problems presented above connected with using the Eddy Covariance method, and being quite easy to solve by applying certain procedures in the calculating software, there is still one crucial problem about using the Eddy Covariance method in field conditions. This problem involves proper location of the measuring tower in the studied ecosystem and proper adjustment of the height at which the sensors applied in the Eddy Covariance method are located. Ideal solution would be placing the measuring tower in the middle of a very big homogenous area and these sensors should be placed quite high above the active surface so that the signal registered by them was characteristic for the surface of the studied ecosystem. On one hand, the higher the sensors are placed the better characteristics of the studied area is obtained from the averaged measuring signal. On the other hand, however, it involves higher requirements in terms of the size of the studied area (when the sensors are located high above the active surface the fetch may reach hundreds of meters or kilometers). In natural conditions these requirements are difficult to fulfill because it is hard to find several hundred hectares of a homogenous and flat area, especially in the European, often patchy, structure of land use. A solution to this problem might be placing the sensors lower above the active surface which pertains the risk of obtaining results which will not be representative for the whole studied area (these sensors 'see' the signal from too small a surface), and simultaneously they are too close to a boundary atmospheric layer which is not fully developed in terms of turbulence. For these reasons before making a decision regarding the location of measurement tower and its height, the researchers often conduct an analysis of the examined area considering its aerodynamic conditions. In order to do this they use mathematical models simulating the distribution of measuring signals in various meteorological conditions and at various quantities of energy fluxes exchanged between the studied ecosystem and the atmosphere.

As it has been mentioned, the measurements conducted at a certain height over the active surface should be representative for a given area. Because the measurements are rarely conducted in the ideal conditions described above, over vast flat areas it is necessary to estimate the spatial representation of measured quantities. The probable source of air sample which passes through the measuring sensors is estimated (or the way through which the air reached the sensor). This allows to assess to what extent the measured values are related to the studied active surface and are representative (Schmid 2002). Model studies showed that the area of the field around the sensor from which the subsequent air samples are taken assumes the shape of a footprint. Therefore, in international literature it is called 'footprint' (Finn *et al*. 1996, Gash 1986, Leclerc and Thurtell 1990, Józefaczyk 2005). Size and shape of the footprint depend on the height of placing the sensors over the active surface, its aerodynamic characteristics (roughness and leaves), and on the current dynamic properties of the atmosphere (velocity, wind direction and the state of thermodynamic balance of the atmosphere).

There are several methods of estimating the size of the footprint which can be divided into two groups:

(1) Analytical solutions of two-dimensional equation of adequacy-diffusion (Horst 2001, Horst and Weil 1992, Kormann and Meixner 2001, Pasquill 1972, Schmid 1994, Schuepp *et al*. 1990).

(2) three-dimensional stochastic model of Lagrangian dispersion (reverse trajectories) (Flesch 1996, Kljun *et al*. 2002, 2003, Leclerc and Thurtell 1990).

The first group of methods proposing analytical solutions, despite its elegance and cohesion has certain limitations caused by the inability to use them among vegetation. The second group of methods, Lagrangian stochastic models is more versatile and may be used within the complexes of various surfaces, as well as over them. These methods in many cases describe the processes of diffusion in a better way; however, it is necessary to remember that such a single simulation in certain conditions does not account for any gradual changes in the properties of the studied ecosystem (e.g. plant growth). Basically, both vertical dispersion (by turbulence) and horizontal going along the wind direction (by horizontal adequacy) is in this method simulated numerically by calculating Lagrangian trajectories for hundreds thousands of "marked" air samples (Józefczyk 2005, Leclerc *et al*. 2003). Figure 5 illustrates an example of a simulated three-dimensional view of a footprint obtained by means of Lagrangian stochastic model.

The footprint changes in size with time. It depends mostly on the wind direction and velocity. So its estimation should be conducted for various conditions. It is particularly important for the measurements conducted on small areas and in the places where the measuring system was installed on the border between two surfaces (e.g. an arable field and a meadow). After conducting the measurements in a certain area it is possible to define more accurately the area footprint, in relation to what has been presented in Figure 5. In order to do this, the analytical model of Kormann and Meixner was used (Kormann and Meixner 2001), which gives very close results to the stochastic model of reversed Lagrangian trajectories, over a vegetative surface, and is much simpler to be applied (Kljun *et al*. 2003). Hypothetical results are illustrated in Figure 6.

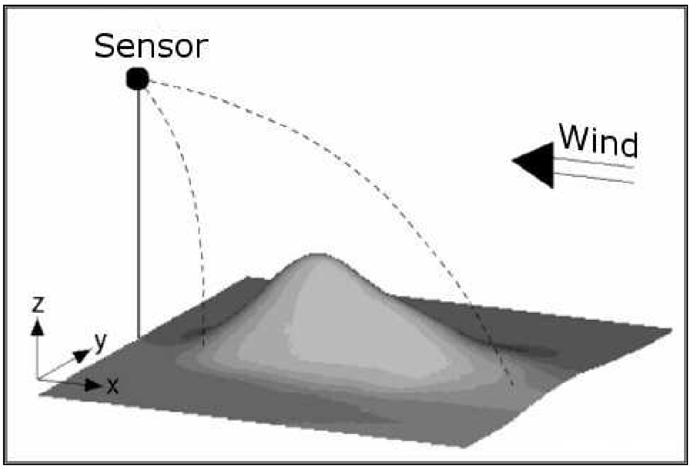

Fig. 5. Three-dimensional picture of the footprint obtained by means of Lagrangian stochastic model (dotted lines symbolize the boundaries of the atmosphere part which contains the trajectories of air which reaches the sensor) (Kljun *et al.* 2002)

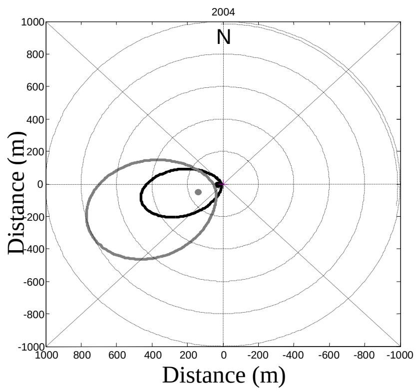

Fig. 6. Estimated footprint areas for 2004 by means of analytical method. Grey ellipse shows night-time (windless periods), black one – daytime conditions with good turbulence). Grey point and a black point indicate the place of the highest influence on the measuring kit, for nights and days respectively. The sensor is located on the crossing of the lines in the middle of the map. Data gathered from April to September were used for the analysis

Results and discussion

The Eddy Covariance method is very simple in its theoretical assumptions, however, as it has been presented above, in order to obtain a good quality of measured fluxes you have to conduct an array of activities – tests and corrections (e.g. Foken and Wichura 1996). There are many descriptions of the methods of application of the Eddy Covariance method in literature (e.g. Lee *et al*. 2004). It is known that a part of activities which aim at correcting the calculations are justified only in certain situations and in others they may increase either the systematic or accidental mistakes. An example is removing a trend from the measurement series (detrending) in order to filter the data so that long-term trends in fluctuations of the measured parameters can be eliminated (Gash and Culf 1996, Rannik and Vesala 1999). It is useful e.g. when these long-term fluctuations follow the slow changes of the characteristics (float) of the sensor. However, this technique has few followers among the users of the Eddy Covariance method because it influences the measuring signal the same way as a high-pass filter does. It means that it removes from the measurement series a part of low rate samplings which contribute to the calculated fluxes (Rannik and Vesala 1999).

This study presents the strategy of handling the data obtained by means of the Eddy Covariance method, which was adopted in the Meteorology Department of the University of Life sciences in Poznań.

One of the most intriguing questions asked by scientists using the EC method is as follows: what influence do all these corrections have on the flux quantity described in other studies? Will simplifying the calculation procedure have a significant negative impact on the quality of the measured fluxes? Will adopting this particular method of processing measurement data reflect in a better way the actual quantities of the studied fluxes?

In order to answer the questions the exemplary results obtained from the EC measurement system located over a peat bog in Rzecin (Chojnicki *et al*. 2007) are presented below. Further considerations used the calculations required for the estimation of CO_2 flux. As shown in the formula11 the quantity of CO_2 turbulent flux stems mostly from the quantity of the vertical component of wind velocity vector and concentration of this gas. Therefore, Figures 7, 8 and 9. illustrate the results of the covariance calculations for the vertical component of wind velocity vector and CO_2 for one day (30th June 2004), and not for the flux only. These covariances were calculated by using the same measurement series but different ‘strategies’ of calculations were used, according to the description given above.

Figure 7 shows the influence which the moving of the measurement series against each other has on the quantity of the flux.

Figure 7 shows the influence of the moving of the measurement series against each other has on the quantity of the flux. The moving procedure generally has very little influence on the quantities of the obtained fluxes, although this influence is more conspicuous during the day than at night. This reaction of the covariance does not surprise. At night the wind velocity is smaller thus, the turbulence in the atmosphere is smaller too. The course of fluctuations of the measured parameters 'smoothes' and as a result the moving of measurement series does not influence the covariance quantity, despite the fact that the time needed for one portion of air to get from one instrument to another is longer than during the day.

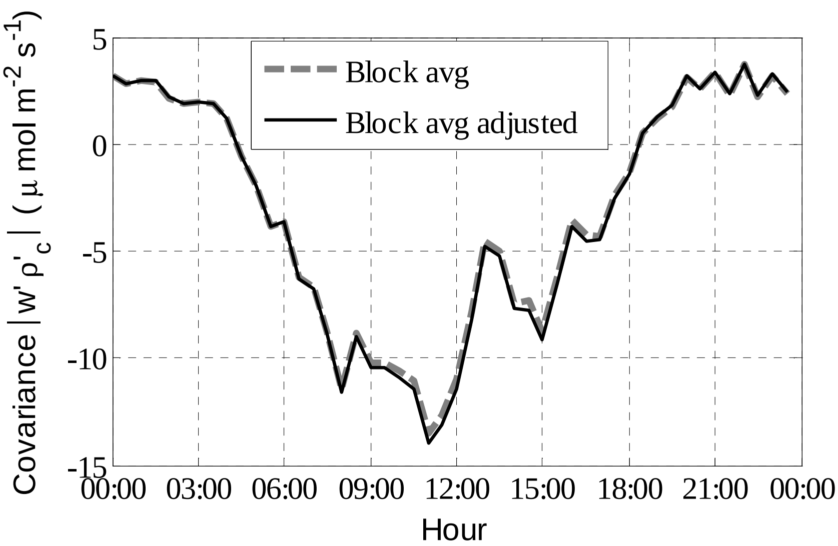

Fig. 7. Comparison of $\overline{w'\rho_c'}$ covariances calculated on the basis of unprocessed measurement data (Block avg.)and after their moving in order to find the biggest quantity (Block avg. adjusted)

Despite these small differences between the covariance quantities $\overline{w'\rho_c'}$ calculated with and without moving of the measurement series, it is important to note that it may influence the flux quantity over a longer period of time. It is very important when we want to obtain an accurate assessment of the exchange balance of a given gas between the studied ecosystem and the atmosphere.

Moving the measurement series against each other causes a slight modification in the covariance quantity. The measurement series rotation procedure has a slightly bigger impact on the obtained quantities. Figure 8**.**a presents daily course of covariances calculated on the basis of the unprocessed measurement data and after moving measurement series and triple rotation.

This time the differences are more conspicuous both at night and at daytime. Each correction is conducted every time in subsequent half-an-hour periods. We can observe that sometimes half-an-hour period quantities calculated without corrections are the same as those calculated after corrections and sometimes they are distinctively different. It means that for every half-an-hour period for which the flux is averaged, there are different correction quantities. Factors influencing such changes in the corrections are mostly connected with the velocity and direction of wind. They occur because it is very hard to place the measurement system over an ideally flat and horizontal area of the ecosystem. Most often the measurement is conducted over a slightly inclined area. In such conditions the air moving above the ground does not move ideally horizontally against the gravitation field. Depending on wind direction it may slightly go downwards or upwards. It leads to occurring an additional vertical vector of wind velocity. It disturbs the measurement causing overstating or understating of the quantity of the measured flux. The procedure of rotation of measuring series allows correcting these interferences.

Probably this situation occurred in a measuring station in Rzecin when the wind blows at the angle of ~70°, which corresponds to East-Northeast (ENE) direction. This hypothesis seems to be confirmed by the course of wind velocity and direction presented in Figure 8.b. When the wind blows exactly from this direction the quantity of correction increases after using the rotation. The given example does not indicate any impact of wind velocity on the quantity of the rotating correction. It confirms that the rotation is sensitive to the interaction between the anemometer – and its vertical position – inclination of the terrain and wind direction. Whereas wind direction and thus, the quantity of the turbulence does not influence the quantity of the correction.

Despite the fact that the corrections discussed above do not modify the studied fluxes in the way that would be the same for every single averaging time (e.g. half an hour), the general trend showing the correlation between covariances calculated on the basis of the unprocessed and corrected data. This correlation was presented in Figure 9.

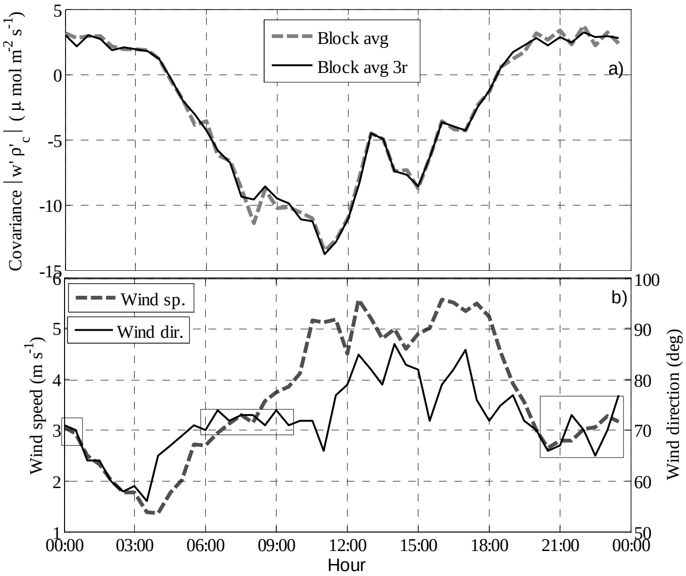

Fig. 8. Comparison of $\overline{w'\rho_c'}$ covariances calculated on the basis of unprocessed measurement data (Block avg.) and after using the moving of measurement series and triple rotation (Block avg. Adjusted 3r)(a), the course of wind velocity and direction (b)

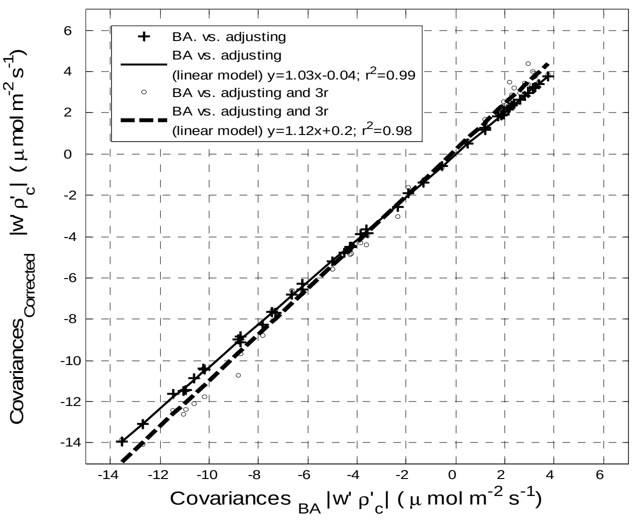

Fig. 9. Comparison of the influence of moving the measurement series (BA vs. adjusting) and triple rotation together with moving series (BA vs. adjusting and 3r) on the quantity of covariance

Each of the discussed corrections increases the quantity of covariance (Fig. 9). It can be claimed that in the studied case only the moving of the measurement series causes the increase of this flux by about 3% (the regression coefficient equal 1.03). Additional, triple rotation increases the covariance quantity significantly by 12% (the regression coefficient equal 1.12). However, the fact of tilting the lines at a bigger angle than 45° from the X ax is the most important for users of the covariant systems. Most of these systems are used to assess mass and energy fluxes in a longer time period e.g. during several years or several seasons at least. It means that within this time period such situations occur when the measured fluxes will be both positive and negative. It will cause that the effect of increasing the flux as a result of correction might be ignored or will be dramatically reduced. The question arises: why make such complex calculations? The answer can be given also in figure 9. We can see that both lines do not cross the coordinate system in point 0. First of them, illustrating the correlation between the unprocessed data and data after the moving, crosses the Y ax in point –0.04. It means that using this correction moves zero quantity of the net CO_2 flux exchange downwards. It will cause that on average net CO_2 flux calculated in the longer period will be lower that if it was calculated without the correction. More confusing is a fact that after using the triple rotation 0 quantity moves in the opposite direction and equals +0.2. Thus summing up the fluxes calculated after correction of moving the measurement series and rotations in the long run will return more of CO_2 assimilated by the studied ecosystem than using covariances calculated without these corrections. The question arises if the discussed corrections really improve the obtained results or the contrary? Their use is logically justified and confirmed by other researchers e.g. (Moore 1986) or (McMillen 1988).

As it has been presented above even using a given correction or neglecting it may influence the calculation results. However, there is another important issue which should be considered when calculating the fluxes using the Eddy Covariance method. Webb Paerman and Leuning in their work (1980) presented two approaches towards calculating CO_2 fluxes. This work leads to the conclusion that both formulas are correct and should bring the same results. Figure 10 presents the correlation between the fluxes calculated using the formula 9 and 11. As we can see in the enclosed figure, the results differ from each other slightly. In the circumstances, high determination ratio r^2 = 0.99 is not satisfying because one could expect the value r^2 = 1. A question arises what accounts for these differences? The answer should be found in the imperfection of the measurement system. The data presented in the Figure 10. come from the measurement system equipped with a gas analyzer with an open measuring path. It measures the amount of CO_2 in the air expressed in mol units of this gas in a given volume of air. This method of calculating CO_2 amount in the air is sensitive to air temperature changes, atmospheric pressure changes and the amount of water vapor in the air. Thus, in order to find out the real, absolute quantity of CO_2 these parameters must be measured too, which allows obtaining the real CO_2 mixing ratio in dry air, which can be used to calculate the flux of this gas. The necessity of high-rate measurement of air temperature and atmospheric pressure means that we need to have the proper equipment with a short time constant. It is difficult in practice even in relation to temperature. Using microthermocouples enables to measure temperature fluctuations, not its absolute quantity. In the case of pressure it is even more difficult. In most cases thus, average quantities of temperature and pressure are used for a given integration period in which CO_2 flux is calculated. In such a situation it is easier to use the formula 11 instead of 9.

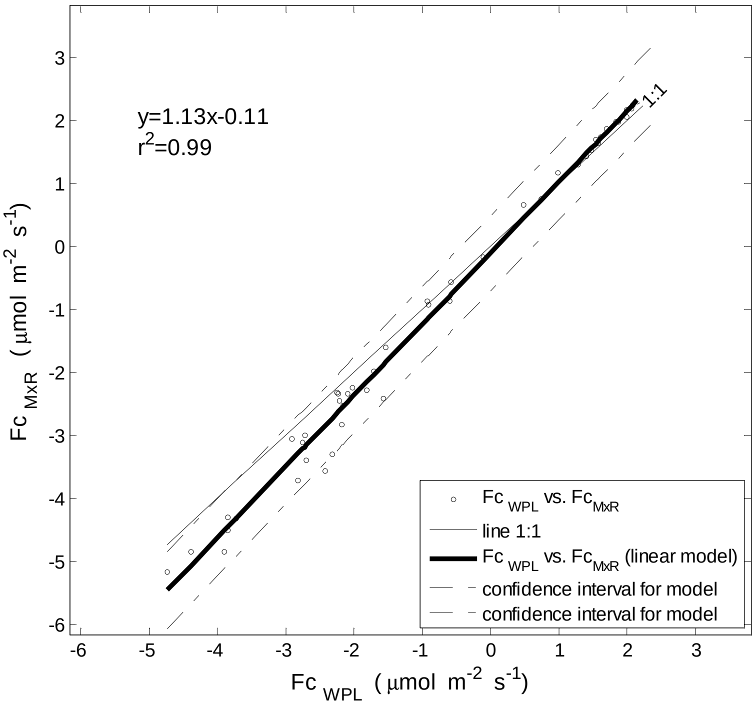

Fig. 10. Comparison of CO_2 fluxes calculated by using the formulas 11 (Fc_{WPL}) and 9 (Fc_{MxR})

As the above analysis indicates the use of formulas may influence the obtained quantity although theoretically they should bring identical results, however using slightly differently processed input data may lead to obtaining different results. The aim of the current study is not to issue an arbitrary statement regarding the calculation process but rather indicate a problem of lack of one standard of calculations. It partly stems from lack of equipment standard and the differences resulting from the fact as far as the unprocessed data are concerned, and partly it stems from various approaches of different researchers.

CONCLUSIONS

1. The Eddy Covariance method is currently the best tool used to estimate matter and energy flux exchanged between the between the active surface and the atmosphere. Its usefulness has been confirmed by many researchers. However, each user should be aware of its limitations and the necessity of introducing a number of tests and corrections improving the assessment of the measured fluxes quantity.
2. Particular corrections conducted on the gathered data may amount to a dozen or so percent of the quantity of the measured flux and their application is to a large extent dependent on the type of the equipment used and the surface over which the system has been placed.

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15. THE INFLUENCE OF PLUVIAL CONDITIONS ON SPRUCE FOREST STANDS STABILITY IN BESKID ŚLĄSKI MTS.*

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INTRODUCTION

Beskid Śląski is characterized by a compact spatial layout and together with Beskid Żywiecki Massif is an important element of the climate barriers in this part of Europe. Clear climatic vertical zonality and asymmetry are clearity a result of variation of elevation, exposure and slope angle. The land cover is also an important geographic factor that has influence on the climate. The forest stands cover an area of 390 square kilometers of this region. The effect of the impact of these factors is a local climate system in valleys, on slopes, ridges and hills. The results obtained in recent years indicate the changes in the distribution of some pluvial climate parameters. This is evidenced by the difference between current indexes and the climatic norm for this region (Feliksik and Durło 2004). Particularly important for the climate regime is also changes on the land surface connected with the process of spruce stands dieback. The soil of the large area of moderately cold and moderately warm climatic zones was exposed. This may modify the current parameters of the heat and water balance. These processes seem to be so significant that it is possible to change the existing topoclimatic conditions in some parts of the massif. Recognition and understanding of this occurrences and their course in the future are an important elements of spatial planning and management of natural resources.

Both foresters and researchers are unanimous in the fact that modification of the pluvial conditions, which occurred in recent years, may have contributed to the loss of stability of spruce forest stands in this region. However, the research results so far don't give a clear answer (Wilczyński and Feliksik 2005, Durło 2010a, 2010b). It seems that the outcomes of this study bring us closer to solving this problem. These investigations are very important from the viewpoint of forest management. The aim of this study was the characterize the multiannual variabili-

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ty of precipitation in the area of lower subalpine zone in the Beskid Śląski. Research hypothesis assumes that the uneven and irregular supply of water to the active surface is a reason to disturbances in the spruce forest stands in Beskid Śląski.

MATERIAL AND METHODS

The material for the analysis carried out at 26 meteorological stations and posts of the Beskid Śląski area (Tab. 1). The study used the following materials: climatological newspapers, precipitation newspapers, monthly lists of meteorological observations, precipitation year-books, pluviograms and collections of electronic REGCM3 database from years 1948-2008 for Central Europe. Most stations are operating under the observation and measurement IMGW network in the area of Beskid Śląski. The Jaworzynka meteorological station belongs to the Wisła Forests Inspectorate. The station in Ustroń City is one of the Polish State Environmental Protection Inspectorate network. The outposts are located across the physical-geographical unit in the full range of altitude (Fig. 1). Fourteen stations are situated within the concave terrain forms, the other on the convex. Full, uniform, fifty years old sequence of data was collected at 5 stations, in other cases the series were shorter about for a dozen of years. The shortcomings include the late nineties and early years of this century. Deficiencies resulting from the reorganization of observation network and change method of measures. Incomplete sequences are supplemented in accordance with the methodology contained in the papers (Pruchnicki 1995, Peterson and Easterling 1994, Tuomenvirta 2001, Wijngaard et all 2003, Gonzales-Rouco et all 2001). The statistical analysis of results was performed using STATISTICA 9.0 (StatSoft, Inc. (2007). STATISTICA (Data Analysis Software System, Version 9.0).

The analysis of pluvial climate in Beskid Śląski was conducted in several respects. The first one concerns the precipitation conditions forming during the past fifty years, based on the historical record of information about the course, distribution and intensity of precipitation. The second aspect relates to the identification of hazards that may cause a disturbance of water balance of forest ecosystems within the lower subalpine zone forest. We used standard statistical-mathematical methods for the calculations of precipitation indices (Pruchnicki 1980). The distribution of Jedliński vegetation index, Sielianinow's and De Martonne's index also Kaczorowska's moisture index was analyzed (Feliksik and Durło 2004). The classification of irregularity index of precipitation *Wn* (1) according to the criteria in Tables 2.

Table 1. The characteristic of meteorological stations in Beskid Śląski Mts.

No.	Localization	Altitude m a.s.l.	Geographical coordinates	Landform
1	Barania Góra	1120	49.36 N 19.00 E	Convex
2	Bielsko Biała	398	49.48 N 19.00 E	Concave
3	Brenna	350	49.45 N 18.52 E	Concave
4	Brenna Leśnica	420	49.43 N 18.54 E	Concave
5	Czantoria	852	49.41 N 18.49 E	Convex
6	Goleszów	350	49.44 N 18.45 E	Concave
7	Górki Wielkie	325	49.46 N 18.51 E	Concave
8	Istebna Kubalonka	780	49.36 N 18.54 E	Convex
9	Istebna Stecówka	750	49.35 N 18.57 E	Convex
10	Istebna Zaolzie	580	49.34 N 18.56 E	Concave
11	Młoda Góra	820	49.35 N 18.52 E	Convex
12	Jaworzynka	675	49.32 N 18.55 E	Convex
13	Koniaków	740	49.33 N 18.58 E	Convex
14	Lipowa	530	49.40 N 19.05 E	Concave
15	Klimczok	1010	49.44 N 19.00 E	Convex
16	Milówka	445	49.34 N 19.05 E	Concave
17	Nowy Dwór	380	49.39 N 19.10 E	Concave
18	Skrzyczne	1240	49.41 N 19.02 E	Convex
19	Szczyrk	520	49.43 N 19.02 E	Concave
20	Ustroń Centrum	410	49.43 N 18.49 E	Concave
21	Ustroń Równica	650	49.43 N 18.51 E	Convex
22	Wapienica	390	49.48 N 18.59 E	Concave
23	Wisła Centrum	430	49.39 N 18.52 E	Concave
24	Wisła Głębce	480	49.38 N 18.53 E	Concave
25	Wisła Malinka	685	49.39 N 18.59 E	Convex
26	Zwardoń	690	49.30 N 18.59 E	Convex

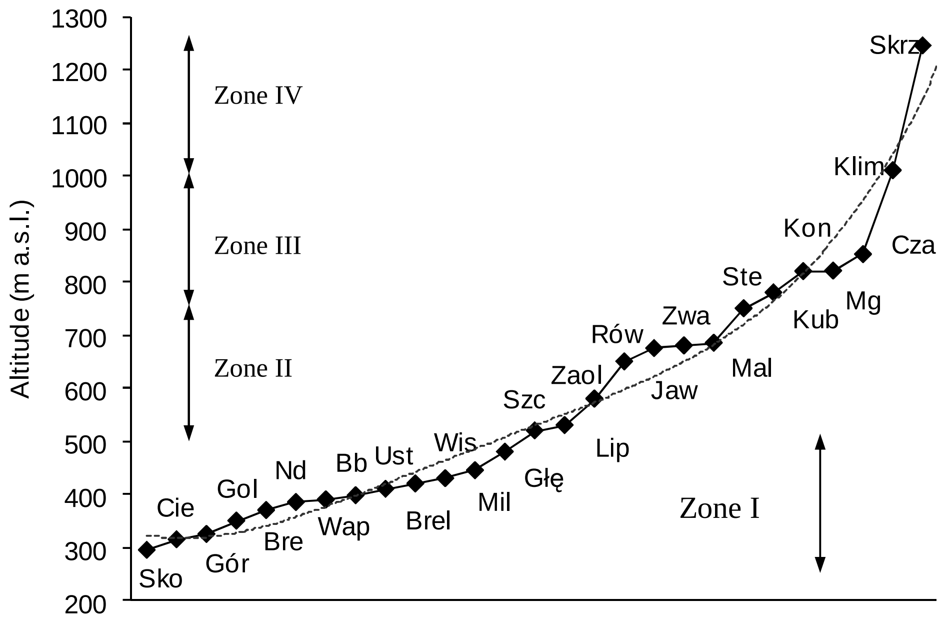

Fig. 1. The hypsometrical profile of meteorological stations localization in Beskid Śląski Mts.

Table 2. The classification of precipitation irregular index W_n

Class (%)	Type of distribution	The degree of precipitation irregularities
0-20	Regularity distribution	1
21-40	Moderate irregularity	2
41-60	Mean irregularity	3
61-80	Great irregularity	4
81-100	High irregularity	5
>100	Extremely high irregularity	6

$$W_n = \frac{\sum_{i=1}^{i=12} (P_{Ri} - 0{,}0833 \cdot P_{Rr})}{P_{Rr}} \cdot 100 \qquad (1)$$

where: P_{Rr} – yearly sum of precipitation (mm); P_{Ri} – monthly sum of precipitation (mm)

RESULTS

The mean annual sum of precipitation (1957-2006) in the Beskid Śląski was 1200 mm with a deviation of 160 mm. The biggest amount of rainfall was usually in July. The lowest values of monthly totals were of February and March 65 mm (Fig. 2). The highest rainfall zone was summit part of Wiślański massif. The least rainfall is in the south-eastern part of the Beskid Śląski massif near Rajcza, Węgierska Górka and Milówka City. The average ratio of the total rainfall of winter to summer is 57%. It was the largest in hilltop of massif, the smallest was in the valleys and at the lower parts of the slopes. The monthly precipitation totals in the Beskid Śląski has a gamma distribution with parameters c = 3.15 and b = 34.28. There are mostly monthly rainfalls in the range from 50 to 100 mm on the study area. The median distribution of precipitation in the Beskid Śląski was 99 mm.

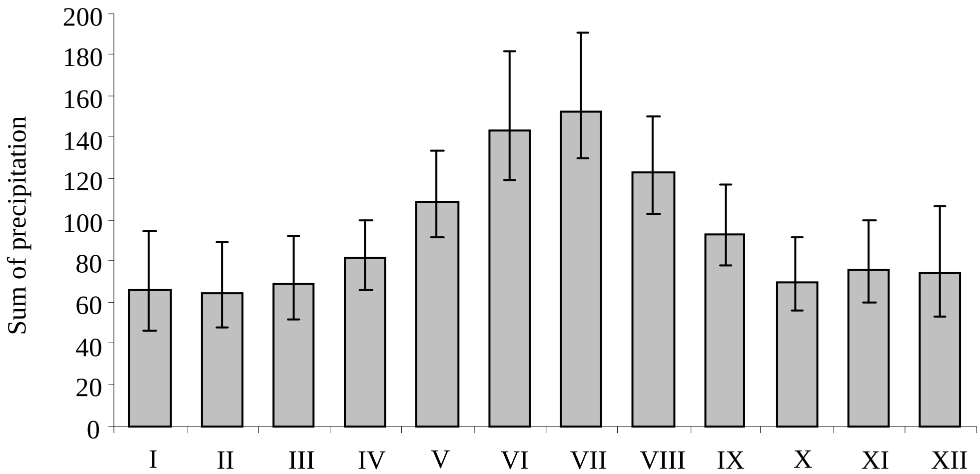

Fig. 2. The monthly average of sum of precipitation in 1957-2008 period in Beskid Śląski Mts.

The pluvial conditions in the past two decades have slightly modified in relation to historical data. The variance of precipitation decreased. The winter to summer precipitation ratio increased by about 10%. Total precipitation has decreased in the warm part of the year, this reduce is mainly observed in June and July. The course of multiannual precipitation sum didn't show any tendency. Directional regression factor equation is 0.63, standard error of estimation amounts to 180, while the coefficient of determination R^2 equal to 0.0 at $p < 0.71$. Number of days with precipitation during the year is similar to that in the previous years, and now stands at 198 with a deviation of 17 days. Number of days with precipitation during the growing season shows no significant trend. Jedliński vegetation coefficient averages 15.6 with a deviation of 3.7 and, like other indicators does not show a significant trend. Sielianinov index remains at an average of 6.0 with a deviation of 1.2. De Martonne'a ratio reaches a value of 9.5 with an average deviation of 4.0 which corresponds to the average conditions in the Western Carpathians. Characteristics of moisture year, based on the Kaczorowska classification, indicate the dominance of the "average year". One quarter of all cases was dry years while 18% were wet years. The annual rainfall of less than 75% of normal rainfall doesn't occur, but there were a few years with the rainfall above 126% of "normal pluvial year". Results of Kaczorowska index variability didn't appear significant changes in his distribution in recent years. In the search of potential threats from pluvial climate, irregularity precipitation index was interesting (Fig. 3). The average of its value was 41%, which according to the classification criteria means the "average irregularities". The results of trends analysis indicates a clearly negative tendency with a coefficient b = –0.107 with an error of 0.08 and insignificant correlation coefficient R = 0.18 (Fig. 3). The ratio of the standard error of estimation and the average of series was 0.22.

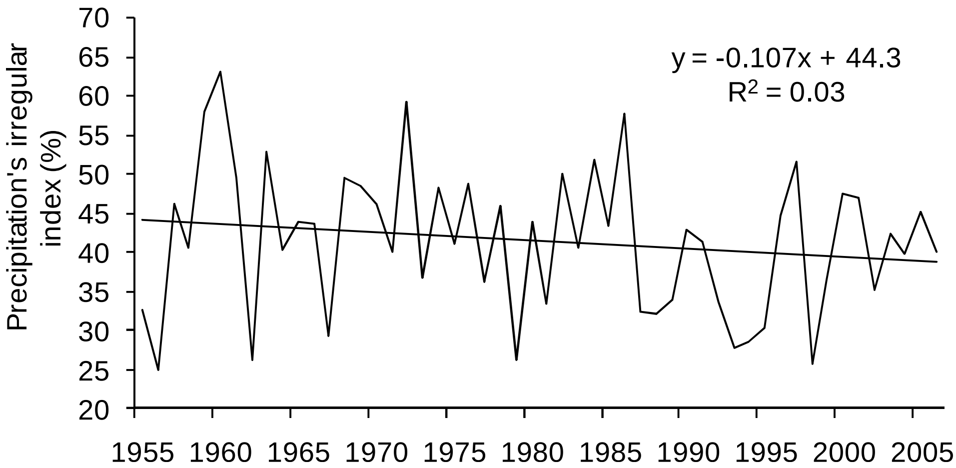

Fig. 3. Multiannual course of precipitation irregular index W_n with trend line in Beskid Śląski Mts.

The formation of annual increment in spruce begins about a month after the start of the growing season usually. In the Beskid Śląski region that point of time is about 20 May. Increment culminates after 30-40 days, about the third decade of June. By the end of July, sometimes even in early August, this process continually slows down, and it ends at the first decade of August. Therefore, most important for the growth of this species, is the sum of precipitation during from May to July quarter. The results of the distribution analysis of the total rainfall in the months showed the statistically insignificant negative trend of precipitation in May and July. In June the directional coefficient b = –0.97 was significant at $p < 0.05$. The "clarity index" of this model was only 0.34 and indicating low quality prediction and forecasting is impossible based on the regression equation. Total precipitation in May has evolved several times the standard deviation in both the positive and negative in the last two decades (Fig. 4). In June there were significantly more likely to decline relative to the average of many years, most often highlighted as one of the decade from 1988 to 1997. In this respect July is unique, because through 20 consecutive years, with one exception that is 1980, the yearly sum was lower than climate pluvial norm for this month (Fig. 5).

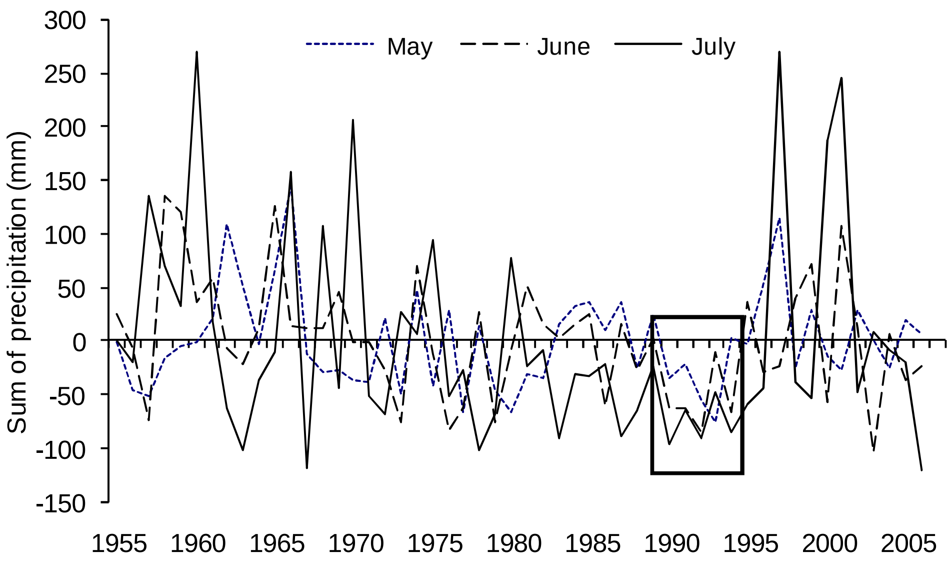

Fig. 4. The absolute deviation form multiannual average sum of precipitation in May, June and July in Beskid Śląski Mts.

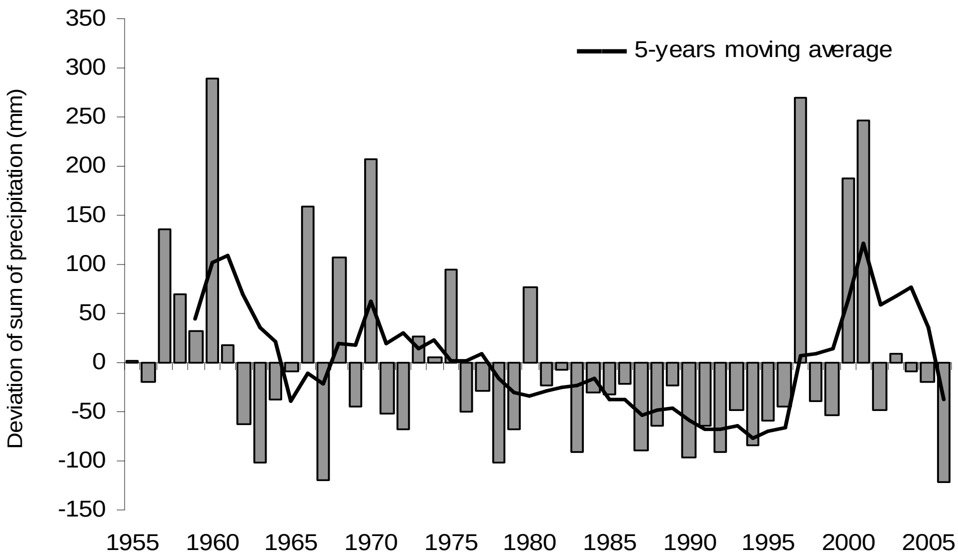

Fig. 5. The absolute deviation form multiannual average sum of precipitation in July with trend line (5 years moving average) in Beskid Śląski Mts.

Complementing this disadvantage was the fact that during the period from 1990 to 1996, indicators of rainfall in three consecutive months: May June and July were lower than the multiannual average (Fig. 4). Deficiencies were respectively 23% in May, 26% in June and 42% in July.

DISCUSSION

Meteorological phenomena occurring in recent years in the southern part of Poland arouse a growing interest in forestry. Although the occurrence of these phenomena is subject to natural processes in the atmosphere, the risk of their impact tend to be harmful to forests. Currently the average pluvial climate conditions in the Beskid Śląski Mts. are a bit different from the historical data, and these differences are noticeable mainly in the phenomena of precipitation during the summer. The exceptional period in that sense was finishing decade. Perceptible reduction is seen primarily in yearly rainfall in favor of precipitation during the winter. Although the modification of the distribution of annual rainfall increases the amount and frequency of their occurrence in the winter from the hydrological point of view it seems to be beneficial, provided that the rate of disappear of the snow cover will be spread over at least period of one month, which would translate meaning better during spring retention. In view of the demand of subalpine forests zone to atmospheric moisture, and soil during the last part of spring and early summer, this has signaled a change over the long run may be disadvantageous. Reasons for doing so bring the results of research on climate water balance. They show that in the past two decades the frequency of months with negative climatic water balance has significantly increased, among them stands out in May. If the above proposals will correspond to the results of this work, then it is considered that the boundaries of favorable growth conditions in the Beskid Śląski spruce will include only an area above 800 meters. This means that the range of the spruce in the Western Beskids may in future be subject to substantial modification. Presented in this paper the trends of irregular rainfall index despite the poor quality of the model. This suggests that pluvial conditions will improve in the coming years. Paradoxically, however, this trend does not necessarily prove to be beneficial for water management of forest ecosystems. The average perennial value of the irregularity index of 41% is far from an ideal distribution of precipitation, with the ideal which is optimal for growth of coniferous trees in the pluvio-nival area. Based on a climatological norm, this index should not exceed 20%, although this option doesn't give a hundred per cent guarantee optimal incremental rhythm. It therefore appears that no amount of rainfall, which reaches the soil throughout the year but the timing and frequency in which it is registered on the forest canopy, will play a decisive role in shaping the water balance of forest ecosystems in this climatic zone. Confirmation of this hypothesis can be proved through dendroclimatic studies conducted in this area for several years, as well as the studies on the rainfall interception at the spruce which stands in the Beskid Śląski Mts.

CONCLUSIONS

1. Disruption in the functioning of spruce stands in Beskid Śląski could be due to shortage of rainfall during the formation of annual growth, mainly by reducing the amount of rainfall in July, over the past 20 years.

2. Shortages of precipitation in the next three crucial months for the growth of spruce of the lower subalpine forest zone, was one of the causes of weakening of the stands.

3. With the same amount of precipitation during the growing season, positive growth of trees is done, when the precipitation is uniformly supplied to the forest canopy.

4. The irregularity rainfall index *Wn* proved to be very little precise indicator of the disturbance in pluvial regime in the Beskid Śląski Mts.

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16. VERIFICATION OF DATA QUALITY FROM AUTOMATIC WEATHER STATIONS

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INTRODUCTION

One of the crucial elements of most meteorological and climatic research is gathering measurement data. Independently of the parameters that the data involve they should be thoroughly examined in terms of quality. Gathering data from automatic measurement stations is conducted by reading them from the sensors and recording them in the memory or sending them to databases. However, not always the procedure of gathering data from AWS (Automatic Weather Station) is conducted entirely properly. Various mistakes occur in data sets during measurements. They occur regardless if the measurements are conducted manually or by means of AWS. These mistakes may be caused by different technical factors including faulty functioning of the sensors or wrong transmission and recording of the data in databases. Incorrect quantities significantly decrease the quality of the collected data. It entails reduction of the significance of the obtained figures for further research and analyses. In order to eliminate wrong values the procedure of quality control is applied (QC).

A lot of data are gathered during measurements. These are millions of figures which translate into gigabytes of hard disc volume. Therefore, creating a clear system of QC is indispensable. Many unreliable research results which were obtained by applying incorrect values received directly from weather stations can be eliminated thanks to clear QC procedures. QC procedures are applied not only in meteorology but in all branches of science where numerical data are collected. When the number of the values obtained from automatic stations is high and requires quality control similar criteria can be applied. Only the threshold values should be adjusted depending on the discipline they come from. It streamlines the further procedure of data processing and eliminates mistakes from the beginning of the calculation process.

Data verification indicates the mistakes which occur in the data set i.e. aberrations from the assumed values. As it has been mentioned earlier the mistakes occurring in the data set may be caused by both faulty functioning of the measuring instruments as well as wrong service of the systems which conduct the measurements. In the case of weather stations they might be also caused by lack of their regular maintenance (Shafer *et al*. 1999). Regular service of the station, calibration of the sensors and maintaining the equipment in good condition ensure better quality of the obtained data. They increase the chance of unfailing and reliable work of measurement stations.

Four criteria of quality control analysis are accepted (WMO, 2004) in order to conduct a proper QC of meteorological data. First is the test of data set in terms of its reliability. It consists in conducting the estimate whether each value from the analyzed set fits in the real range of values which may occur in a certain place and time (season of the year). Incorrect data can be eliminated by such reference of meteorological data gathered from the automatic station to specific climatic conditions in the place where the station is located. Another criterion is internal cohesion analysis. It accounts for discovering and elimination of single data records which are internally incoherent. The criterion consists of several conditions which have to be met in order to qualify the measured quantities as correct ones. For example when the wind velocity is zero then it is impossible to determine its direction. Thus, if there is any quantity recorded in the base then it must be qualified as wrong. Another criterion is comparing the differences of a given quantity of a meteorological parameter with the preceding and subsequent quantity (looking at the measurement order). The fourth criterion applied for quality control is comparing sums of the differences between the neighboring quantities within one meteorological parameter, according to the formula presented in the next part of the study.

Such filtering of the data gives the possibility of exact indication and later elimination of the mistakes. Thereby, it guarantees selecting correct values and obtaining high quality data set. High quality data are an excellent basis for further calculations and analyses in which the mistake caused by wrong input data will be eliminated.

DATA QUALITY CONTROL

In the following work quality control was conducted on data sets from meteorological recorders in four automatic weather stations. These station are working in the area of Wielkopolska in the following sites: Wieszczyczyn, Rzecin, Stare Miasto, Złotniki. The stations conduct continuous measurements. The following parameters are measured: temperature, relative air humidity, speed and direction of wind, precipitation, atmospheric pressure and solar radiation (total radiation). The verified data come from the period of 2005 to 2007. The recorder memory contains mean values for the period of 10 minutes. The readings of the sensors are conducted more often but a mean value of every parameter is calculated every 10 minutes and it is stored in the memory, and later on sent to station supervision system by a mobile telephone connection. Thus, altogether 52560 figures are recorded for one meteorological element during the period of 12 months. To sum up, meteorological elements which are measured by AWS give over 7 mln quantities annually. Each of the meteorological elements undergoes quality control according to the above mentioned criteria.

Describing the information in the introduction in greater detail, the data were analyzed according to the following criteria:

- reliability test which involves estimation whether each figure from the analyzed data set fits in the real range of values possible to occur in a certain place and time (season of the year),
- checking the internal cohesion of the data set (mutual exclusion of the values of certain parameters whose simultaneous occurrence is logically contradictory. E.g. it is impossible that precipitation may occur when there are no clouds, such a situation indicates that at least one of the parameters is wrong),
- comparing the differences between a certain quantity of meteorological element with the preceding and subsequent quantity (looking at the order of measurements), considering a specific threshold value of the difference between the neighboring readings,
- comparing the sums of the differences (formula 1 recommended by WMO) between the neighboring values (according to the measurement order).

First QC criterion is a reliability test. Meteorological parameters' values show a great deal of changeability both daily and seasonal. Thus, various thresholds and value ranges should be accepted because of this changeability depending on the time and period of time in which the measurements were conducted. Considering climatic conditions and season of the year it can be determined if the measured values fit in the possible ranges. Mean daily value and the range of values created on the basis of a measured quantity plus/minus the threshold (Fiebrich and Crawford 2001) should be taken into consideration in the applied criteria. This test allows indicating big mistakes and sudden surges of quantities. The above method is used to mark the data which exceed possible occurring quantities established on the basis of means and daily changeability in a given area. If mean daily value does not fit in the range: quantity plus/minus threshold, then it should be qualified as wrong. This method should be used for testing data reliability for meteorological elements presented in table 1 (Shafer *et al*. 1999, Fiebrich and Crawford 2001).

Table 1. Threshold values characteristic for the climate of Wielkopolska region

Meteorological element	Unit	+/– threshold
Air temperature at 2 m	^{o}C	25
Soil temperature at 5 cm	^{o}C	10
Dew point temperature	^{o}C	25
Pressure	hPa	30
Relative humidity of air	%	30

When analyzing meteorological elements which are characterized by a great changeability in a short period of time (rainfall, wind speed and direction, radiation) the following range for actual values was established. Respective meteorological elements together with accepted ranges have been presented in Table 2 (Shafer *et al*. 1999, Fiebrich and Crawford 2001).

Table 2. Quantity ranges which should cover the measurement results characteristic for the climate of Wielkopolska region

Meteorological element	Unit	Range
Rainfall	Mm	0-50
Wind speed	M s^{-1}	0-50
Wind direction	^{o}Compass	0-360
Solar radiation	W m^{-2}	0-1200

When the values do not fit in the given range they are qualified as inconsistent data and are not used for further calculations and analyses.

Another criterion is checking internal cohesion, i.e. checking whether measured quantities of meteorological elements do not exclude each other. Conditions of this criterion are always the same independently of the place and season of measurements (WMO 2004). This solution allows finding irregularity when the measurement quantity indicates rainfall without clouds or solar radiation with total overcast. When conducting a verification it is necessary to consider logical regularity of the occurrence of particular weather phenomena. It is supposed to eliminate the measurements which are mutually exclusive. This procedure is conducted on the data from the same period but for various parameters. They are the basis for establishing incorrect data. The assumptions can be divided into two groups. The first includes conditions which when unfulfilled make one of the two elements suspicious. The second group includes conditions which when unfulfilled make both elements suspicious.

When the following conditions are not fulfilled then one of the meteorological elements is suspicious:

- dew point temperature ≤ air temperature 2 m,
- wind speed = 0 then wind direction = "lack of wind direction",
- wind speed ≠ 0 then wind direction ≠ "lack of wind direction",
- wind gust ≥ wind velocity.

When the following conditions are not fulfilled then both of the meteorological elements are suspicious:
(only for mean values from the measurement period no longer than 10minutes - WMO 2004):

- cloudiness = 0 and rainfall = 0,
- cloudiness = 0 and period of precipitation = 0,
- cloudiness = ∞ and period of sun radiation = 0,
- period of sun radiation > 0 and sun radiation > 0,
- quantity of precipitation = 0 and time of precipitation = 0.

Another criterion which is used to verify the measurement data is the comparison of the differences between the analyzed quantity of one meteorological element with the preceding and subsequent quantity. They are conducted in order to detect unnaturally high increase in values. If the difference is higher than threshold they are qualified as incorrect data. Threshold values which are used differ depending on the length of the period in which the measurement is conducted.

Two threshold values should be used. When the lower value is exceeded the data are qualified as suspicious and when the higher value is exceeded they are qualified as incorrect therefore, they should not be used for further calculations and analyses. The applied threshold values are presented in table 3 (WMO 2004).

Table 3. Threshold values applied to compare the current values with neighboring ones

Meteorological element	Unit	Threshold for suspicious	Threshold for incorrect
Air temperature at 2 m	^oC	3	5
Soil temperature at 5 cm	^oC	0,5	1
Dew point temperature	^oC	2	4
Pressure	HPa	0,5	2
Relative humidity of air	%	10	15
Solar radiation	Wm^{-2}	800	1000

The criterion comparing the sums of the differences analyses the results of three consecutive measurements W_1, W_2, W_3, where the tested value is W_2. Formula used for such test is taken from WMO report (2004):

$$(W_2 - W_1) + (W_2 - W_3) \leq 4\sigma \quad (1)$$

where: σ – standard deviation.

Standard deviation value is determined on the basis of thirty consecutive measurements, fourteen preceding and fifteen subsequent to W_2 , considering also W_2 value. The comparison of differences was conducted according to formula 1, for the following meteorological data: temperature at the height of 2 meters, soil temperature at the depth of 5 centimeters, dew point temperature, precipitation quantity, wind velocity, atmospheric pressure and relative air humidity. In case of wind direction it is too changeable to be tested according to the method mentioned above. All measurements which do not fulfill the condition are qualified as suspicious.

After quality analysis the data selected on the basis of the criteria mentioned above are assigned to one of fur following categories (Shafer *et al.* 1999):

- proper value (the value which fulfills all criteria used in QC),
- suspicious value – when at least one criterion is not fulfilled ,
- incorrect value (when the reliability test is negative and when the criterion of comparing of the differences of the analyzed quantity of a certain meteorological element with preceding and subsequent quantities is not fulfilled),
- lack of data.

RESULTS OF DATA QUALITY ANALYSIS

The conducted quality analysis involves the measurements for the period of 2005-2007. These measurements were gathered in one data set and its analysis has been conducted. Figures 1 to 5 present the percentage of suspicious and incorrect values selected by applying the above mentioned criteria of qualitative analysis of the data from AWS, 0.1% corresponds to 631 values of suspicious/incorrect data.

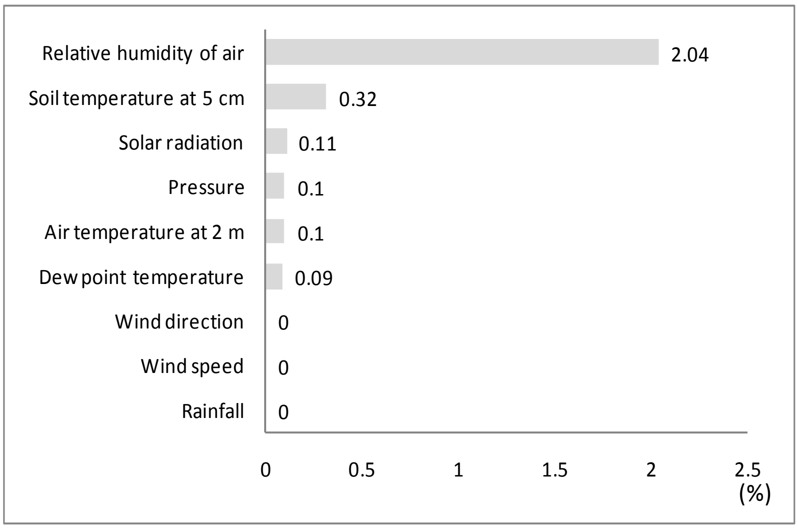

Fig. 1. The percentage of incorrect results which were found after conducting data reliability test for all controlled stations in the period of 2005-2007

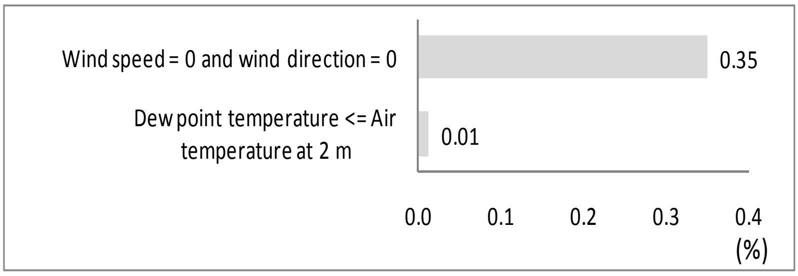

Fig. 2. The percentage of incorrect results which were found after conducting internal coherence test for all controlled stations for the period of 2005-2007

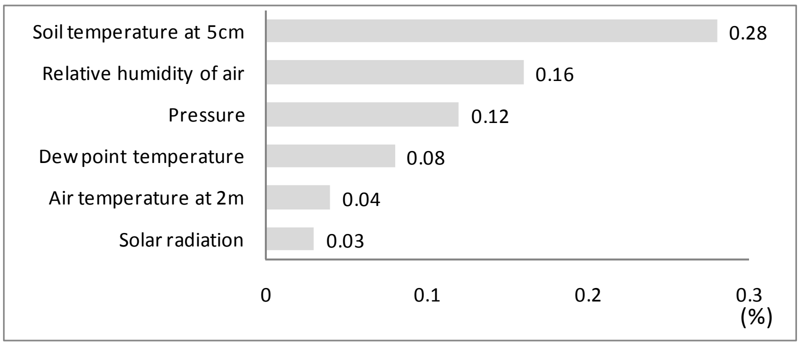

Fig. 3. The percentage of suspicious results found after comparing the differences and using lower threshold values (Tab. 3), for all controlled stations in the period of 2005-2007

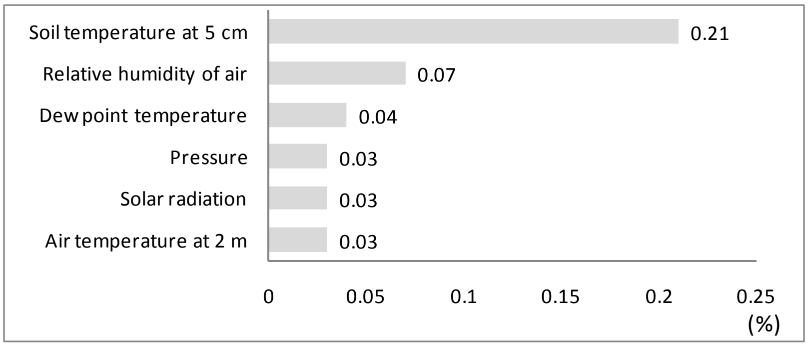

Fig. 4. The percentage of incorrect results found after comparing the differences and using lower threshold values (Tab. 3), for all controlled stations in the period of 2005-2007

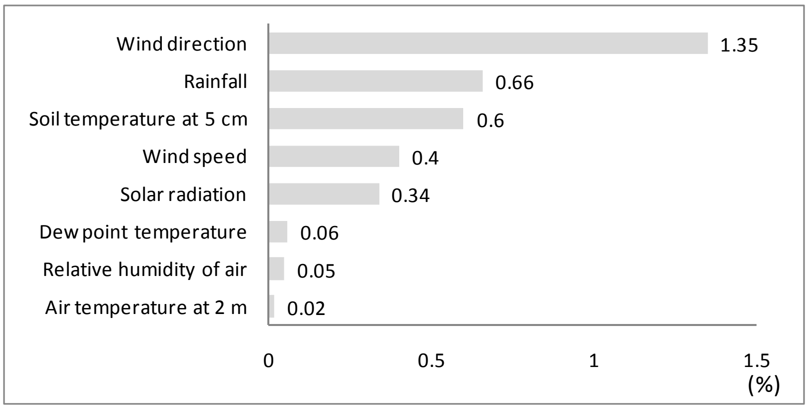

Fig. 5. The percentage of suspicious results which were found after comparing sums of the differences using formula 1 for all controlled stations in the period of 2005-2007

ANALYSIS OF THE RESULTS

The results of data quality control carried out by applying the first criterion where the results of measurements were compared with threshold values and ranges of parameter values which are characteristic for the climate in Wielkopolska region are presented in Figure 1. The biggest numbers of data contradictory to this criterion were found in the measurements of relative air humidity – 2.04% from the whole data set, 0.32% were recorded for soil temperature measurements which can stem from high failure frequency of the sensors used here. The number of mistakes oscillating around 0.1% was found in the results of solar radiation, pressure, air temperature and dew point temperature measurements. The set containing results of wind speed and direction and rainfall measurements did not contain any incorrect values according to this criterion.

Figure 2 presents the results of the application of internal cohesion criterion. Two interrelations were analyzed here. First interrelation that should occur is the lack of wind direction marking when the wind speed is zero, the second is the air temperature which is bigger or equals the dew point temperature. The first interrelation does not occur in the case of 0.35 % of all wind direction and speed measurements. Whereas the second condition is not met in the case of only 0.01% of the data set.

The results of comparing the differences by using lower threshold values in the third QC criterion are presented in Figure 3. The results obtained by using higher threshold values for the same criterion are presented in Figure 4. The values presented in Figures 3 and 4 explicitly indicate that the measurements of solar radiation and air temperature are of the best quality. Both when using the lower and the higher threshold values the number of selected data does not change significantly and ranges between 0.03% and 0.04%. Such results indicate very good quality of the measurements of these two meteorological elements. Results of soil temperature at 5cm contain many mistakes. When applying lower threshold values it is 0.28% when applying higher it is 0.2%. Such results were probably obtained because of high failure frequency of the sensors.

Figure 5 presents the results of comparison of sums of differences using formula 1 (WMO 2004). The fewest mistakes namely 0.01% and 0.02% were found for the measurement results of pressure and air temperature respectively.

FILLING THE GAPS AFTER QUALITY CONTROL

After data quality verification and removal of the incorrect values the gaps which have been thus created should be filled. This procedure is usually conducted by either using a linear or block method.

Linear method uses only the existing extreme values and there have to be minimum three correct results of measurements at each edge of the gap. The trend of fluctuations between extreme figures is used to establish the missing values.

Block method relies on filling the gap on the basis of a similar sequence of values found in another period of time or coming from another AWS. If the data set used for filling the gap comes from another meteorological station then a regression equation must be determined. Two sequences of values from the same periods of time from two AWS stations are needed to do this. They create the basis for determining the linear regression equation. The precision of this kind of gap filling remains questionable, however in some cases it is a necessity since the data set must be continuous, e.g. in model studies.

Linear method is used when the missing data sequence is no longer than 90 minutes. In the case of bigger gaps the data are filled by means of block method. However, using block method is not always correct. While completing the data it is necessary to bear in mind that daily parameter variations as well as many other feedbacks occur which have not been discussed here as the issue is rather complex.

CONCLUSIONS

1. The conducted quality analysis determines which measurement results of meteorological elements are the highest and which are the lowest quality. It can be concluded that the lowest quality data are obtained from the devices recording measurements of soil temperature. The highest percentage of suspicious/incorrect values are found in these data as a result of comparing the differences by using both the lower and the higher threshold values
2. The smallest number of incorrect data is found among the results of air temperature and pressure measurements. In the case of none of the applied criteria they do not exceed 0.12% which is a very good result.
3. One should also remember about the periodical visual observation of the data and sensor calibration. Periodical calibration improves the functioning of automatic measurement stations. This procedure decreases the failure frequency

to a big extent. Following the rules of automatic quality control as well as periodical control of automatic measurement stations one can be sure that the incorrect values will be excluded.

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17. AIR TEMPERATURE AND PRECIPITATION IN THE LASY RYCHTALSKIE FOREST PROMOTION COMPLEX

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INTRODUCTION

The study is based results of studies on marshy areas of the Lasy Rychtalskie Forest Promotion Complex. The main objective of this study (working hypothesis) was to indicate that adverse climatic changes, primarily decreasing precipitation, may result in the ombrogenic marshes becoming degraded within less than 100 years. Forest marshes do not usually cover large areas, but they are areas increasing biodiversity of adjacent ecosystems. The study presents air temperatures and atmospheric precipitation at the Siemianice Forest Experimental Station in the multiannual period of 1975-2006 and in detail in an average year of 2005. Based on these analyses instability of ombrogenic marshes in that area was indicated.

Forests and marshes in climatic changes aspect

One of the most significant problems in contemporary climatology of climate warming. Although not confirmed beyond any doubt, still numerous factors indicate climate change within the recent, relatively short period of time. Opinions presented in literature on the subject vary considerably – from extreme positions, forecasting disastrous effects in many regions worldwide to the claim that "the problem of climate change has been exaggerated against all proportions" (Klemes 1993).

Primary elements of climate, i.e. air temperature and precipitation, undergo natural changes over time. These are diurnal, season, annual and multi-annual fluctuations, caused mainly by the Earth's revolution, the rotation of the Earth around the Sun as well as changes in solar activity (with estimated intervals of 11, 22, 35, 90 and 180 years) (Boryczka 1993, Miler and Miler 2005, Petit *et al*. 1999, Woś 1994).

In the last 200 years temperature and precipitation additionally undergo anthropogenic changes, resulting from an increased content of atmospheric dust (absorption of solar radiation), condensation nuclei of water vapour and greenhouse gases (the greenhouse effect in the atmosphere), or other forms of human activity (drainage, considerable urbanization, etc.).

While natural factors of climate change exhibit periodical (cyclic) changes, the anthropogenic factor of climate change is characterized by a constant change trend, i.e. the linear trend. Thus, short-term time trends of climate change depend on cyclicity of natural factors, an increase in atmospheric pollution and an unmeasurable factor connected with randomness.

It is remarkable that if there were no greenhouse effect at all the mean temperature of the Earth's surface would be $-18^{o}C$ (Kundzewicz 2007 by IPCC – The Intergovernmental Panel of Climate Change).

Climate change in some regions of Poland may lead to a reduction of wetlands, further drop of ground water table and intensified extinction of species connected with wetlands. Deep transformations are expected to occur in the composition and health condition of stands. Differences between evolutionarily developed adaptations of Polish tree ecotypes to the climate we have had to date and to new climatic, hydrological and edaphic conditions will intensify. Among other things, we need to focus here on riparian forests (Tomiałojć 1995). In studies concerning the role of forest cover in the water balance of catchments some authors stressed considerable retention capacity of forested areas. This capacity influences an increased total runoff from catchments with higher forest cover in dry years and its reduction in wet years, as well as increased runoff in summer half-years and its reduction in winter half-years (Kosturkiewicz 1976, Ostrowski 1965, Tyszka 1995).

In studies on catchments with different degrees of forest cover Miler *et al*. (1999) showed high retention capacity of catchments with a higher forest cover. This is evidenced by very uniform courses of monthly flows and relatively limited monthly changes in retention.

Also in long-term studies conducted by the Department of Water Management, the Forestry Research Institute, under conditions found in lowland catchments a stabilizing effect of forest cover may be observed on water runoff from the area of the catchments, mainly a reduction of its uneven distribution (Sienkiewicz *et al*. 1995).

Many foreign authors found a reduction of mean and maximum flows from forest catchments in relation to unforested catchments in the summer period (Calder 1992, Cassie *et al*. 2002, Fahey 1994, Gush *et al*. 2002, Harr 1967, Harr *et al*. 1979, Helvey 1980, Jones and Swanson 2001, Keppeler 1986, 1998, Keppeler and Ziemer 1990, Swanson and Hillman 1977, Swif and Swank 1981).

Sustainable water management thanks to its supply in adequate amounts, quality and time should promote permanent, sustainable development of a multipurpose forest economy, biodiversity of species and landscape types, preservation of valuable specimens of flora and fauna as well as habitats (Ciepielowski 1999a). When trying to care for water resources we need to take into consideration water requirements of the forest site, not only pertaining to the overall amount of water available to plants, but also the adaptation of its supply to the annual and multiannual cycles of vegetation development, as well as maintenance of adequate water fertility, sufficient to meet nutrient requirements (Ciepielowski 2004).

The need for water retention may be assessed by:

- Observations of stands,
- Observation of trends in changes of ground water tables (a rapid lowering of the water table in the vegetation season and maintenance of such ground water table over a longer time period, inadequate for the forest site type, constitutes an indicator of transformation capacity of ecosystems),
- Observation of trends in changes of water resources in water reservoirs and marshes,
- Analysis of changes of retention in the water balance of a hydrographic unit (Ciepielowski 1999b).

When talking of small water retention in forests, both in the quantitative and qualitative aspects (autopurification of waters), it needs to be remembered that its primary role is not to accumulate usable water reserves (adequate for direct economic use), but to change site water content, to raise ground water table and change the microclimate. For this purpose a more important role is played by the total area of even very shallow water bodies, than a bigger volume of water, contained e.g. in one reservoir (Ciepielowski *et al.* 1995). This means that from the nature point of view for an increase in the internal water cycle it is more advantageous to have a bigger number of small water bodies than one big reservoir (Kędziora 1995).

Until recent times forest hydro-amelioration was conducted only in excessively wet sites. At present we may observe the problem of lowering ground water tables, resulting in a deterioration of water relations, as well as the disappearance of marshes. The primary goal of water retention is to stop the degradation of water relations threatening the stability of forests. Water retention in forests should contribute to an increased moisture content of sites in accordance with the forest site type, enhanced biodiversity, limitation of erosion processes and alleviation of consequences of climate change. The goal of retention is also to satisfy water requirements of animals and birds, to provide water for forest control, to supply water for forest nurseries, farms, fish farming and to enhance recreation value of forests (Ciepielowski 1999b). At least a partial restoration of previous water conditions in forests would initiate mechanisms of slow self-regulation of species composition of phytocenoses and diversification of the forest environment. At each stage of forest economy we may undertake various activities aiming at an improvement of water relations. Their goal should be first of all to restore in the forest ecosystems an adequate role of moist and swampy sites (Ciepielowski *et al*. 2000).

The indispensable role of marshes in the natural environment may not be underestimated. Thus it is crucial to maintain their natural or semi-natural condition. For this purpose it is necessary nationwide to:

- Counteract excessive or unjustified outflow of water from such areas,
- No longer regulate rivers or smaller watercourses,
- Rationally use water resources,
- Reduce the application of mineral fertilizers and crop protection products in the immediate vicinity of marshes,
- Maintain or restore extensive use of semi-natural ecosystems,
- Cease afforestation of valuable non-forest marshes,
- Reduce the exploitation of gyttja and peat (digging peat only for therapeutic purposes),
- Counteract fragmentation of marshes at the stage of spatial management planning,
- Incorporate protection of marshes into spatial planning processes and cover "live" march ecosystems with legal protection (www.gis-mokradla.info...).

MATERIAL AND METHODS

After a detailed analysis of materials collected from forest divisions, site inspections, analysis of large-scale maps (1:10 000), etc. three experimental plots were selected for detailed studies, i.e. microcatchments, which are situated so that they are almost completely located on forest marshy areas (comprising 8.58, 30.61 and 32.00 ha). This was the crucial point of the experiment, since the aim, among other things, was to estimate runoff from such areas. When we discuss ombrogenic marshes we mean marshes which origin (water supply) is connected with atmospheric precipitation, differently than in case of flow valley marshes. The soils in the catchments are formed from sands (catchment no. 1) or sands and silts (catchments nos. 2 and 3). (Forest Management Plans for the Antonin Forest Division and the Siemianice Experimental Forest Division – Operat …).

In the microcatchments an observation bore-holes were made. Work on each of them was completed at the drilling to the ground water table. In the bore holes, PCV pipes with a diameter of 50 mm were placed. From the top wells were sealed with a PCV cork to prevent possible contamination from getting into the pipe. These wells represented three location variants: in watershed areas, in slopes and in valleys of the catchments.

In 2004 systematic field studies were initiated, including e.g. measurements of ground water levels (51 wells) and measurements of water stages in watercourses (3 Thomson triangular weirs) as well as periodical analyses of water quality.

Ground water levels were measured once a week and the recorded result was read accurate to ±0.5 cm. The area of each microcatchment was drained by a ditch collecting and discharging water from the analysed plots. Water gauging stations were established on all ditches in the profiles closing the catchments. Water depth in the ditches was measured once a week and the readings were accurate to ±0.5 cm.

In the summers of 2005 and 2006, due to a considerable lowering of ground water tables, deeper foundation of wells was necessary.

Weather conditions were evaluated in the period of the study on the basis of data from the Siemianice Station, situated in the central part of the Lasy Rychtalskie Forest Promotional Complex, where measurements have been taken since 1975. Experimental Station at Siemianice is located at the seat of the Siemianice Experimental Forest Division. Coordinates of the station are 51^{o}11’ (N) and 18°09’ (E). The station is located at an altitude of 182 m a.s.l.

The analysis included the hydrological year of 2004/2005, which in terms of total precipitation (514.5 mm) and mean annual temperature (8.6^{o}C) may be considered as average, since deviations of the above values do not exceed 10% respective means.

Individual components of resource balance were as follows: precipitation based on standard measurements Hellmann’s rain gauge (on above named station), evapotranspiration was calculated according to Konstantinow, runoff based on water stages at weirs, change in retention was estimated based on changes in ground water stages in wells (Miler *et al.* 2004-2007, 2005).

Water balances were developed for forest ombrogenic marshes based on hydrometeorological measurements conducted within this study (Miler *et al*. 2004-2007, 2005).

The Lasy Rychtalskie Forest Promotion Complex

Forest Promotion Complexes (FPC) were created to promote persistently balanced forest management and natural reserves in the forests. These are functional areas of particular ecological, educational and social significance (Ustawa z dn. 28 września 1991 o lasach). The Lasy Rychtalskie Forest Promotion Complex was created 1 July 1996 by the Director General of State Forests by precept No 18 of Promotion Forest Complexes. It is comprised of the forests belonging to two forest divisions of Regional Directorate of the State Forests in Poznań: Forest division Antonin and Forest division Syców, along with Forest Experimental Institution Siemianice, which is a unit of Agricultural University of Poznań.

The Lasy Rychtalskie Forest Promotion Complex (LRFPC) takes its name from its location within the Rychtal working circle of the Syców forest division. The total area of LRFPC is 47904.08 ha, with 19847.38 ha of forest division Antonin, 22139,61 ha of forest division Syców, and 5917.09 ha of Forest Experimental Institution Siemianice.

Production value of the forests in LRFPC equals as follows: average stands resources are 166 $m^3 ha^{-1}$ in forest division Antonin, 192 $m^3 ha^{-1}$ in forest division Syców, and 293 $m^3 ha^{-1}$ in Forest Experimental Institution Siemianice. The average age of the stands is between 48 in Antonin and 62 in Siemianice. It is 56 in Syców.

Forest division Antonin consist of three working circles: Antonin, Świeca and Moja Wola, with 23 forest districts. The whole division is situated within Wielkopolskie voivodeship, the powiat Ostrzeszów (Mikstat and Ostrzeszów gmina) and Ostrów (Odolany, Przygodzice and Sośnie gmina).

According to the natural and forest regionalization the area of the Inspectorate is placed mainly in III (Wielkopolsko-Pomorskie)Region, District 9 of the Kotlina Żmigrodzko-Grabowska; only south-east part of the range Antonin belongs to V (Silesia) Region, 2 District of Wroclaw . In the geomorphologic sense the Inspectorate is situated in the proglacial Barycko-Głogowska valley, Odolanowska Valley. Flat marshy river valleys with wet habitats are the main features of the landscape. Podzol soils of river sand origin, consisting of loose and clay sand, often with the high level of ground water predominate in the division. In the lower areas and along watercourses and reservoirs soils of organic origin (muck and peat of various level of mineralization) have a significant share in the soil structure. Wet habitats, which are under direct influence of ground water occupy 34.1% of the division's area.

The climate is transitional between the climate of lowlands and the climate of uplands. The average annual temperature ranges between 7°C and 8°C. The annual precipitation reaches 500-600 mm. Vegetation season lasts 210-217 days.

The Antonin forest division has the highest level of woodiness in RDLP Poznań – the forests cover nearly 49% of the area. The most abundant species in the area is Scots pine.

The rivers of Złotnica, Polska Woda, Młyńska Woda and Meresznica flow into the river Barycza catchments. From the south east to the north west there flows the river Litwin along which there is a number of huge fish ponds. In many places forests border with the ponds, where the water level at the time of fish breeding is higher than the surrounding ground level. It causes leaking through the causeways and flooding the forests. This takes place most often in the spring. (Kondracki 1994, Operat Urządzenia Gospodarstwa Leśnego dla Nadleśnictwa Antonin opracowany na okres 01.01.1994 -31.12.2003).

Forest division Syców consist of four working circles: Rychtal, Bralin, Syców and Międzybórz with 20 forest districts, Gaszowice nursery and the Stefan Białobok forest arboretum. Syców and Międzybórz forest districts are situated in the dolnośląskie voivodship , whereas the Bralin and Rychtal districts in the wielkopolskie voivodship. The division covers the area of three powiat (ostrzeszowski and kępiński in the wielkopolskie voivodship and oleśnicki in the dolnośląskie voivodship) 13 gmina and 3 towns.

The natural conditions in the division are diverse. According to the natural and forest regionalization the north-west part of the division is situated in III (Wielkopolsko-Pomorskie)Region, District 9 of the Kotlina Żmigrodzko-Grabowska. The rest belongs to V (Silesia) Region, 2 District of Wroclaw .

Podzolic and mainly cryptopodzolic soils dominate in the Syców forest division. Brown soils are found insularly and in the lower areas black soils mainly.
Considerable morphological diversity of the area has its strong influence on the climate. According to the research conducted for Rychtal Forests the average temperature in the hottest month, which is July, reaches 19^{o}C, and the coldest, January, 1.5^{o}C. What is characteristic is the drop of the temperatures mainly in May. The average annual precipitation ranges between 500 and 600 mm. The precipitation in the summer months makes 65% of the annual precipitation. In the area of Wzgórza Osterzeszowskie you can notice some characteristics for continental climate. Vegetation season exceeds 210 days.

The most abundant species in the area is Scots pine, which occupies 86.8% of the area of the division. The next common species is oak, which along with maple, elm and ash occupy 5.3% of the forest area.

The area of the division is situated mainly in the catchments of the Odra river and its tributary Widawa. There is evident watershed of the rivers Prosna and

Barycza in the Bralin district, and the sources of the Studnica river in the Rychtal district. It is worth noticing that it is meagre in watercourses and reservoirs. There are no lakes in the area. (Kondracki 1994, Opera Urządzenia Gospodarstwa Leśnego dla Nadleśnictwa Syców opracowany na okres 01.01.2000-31.12.2009).

Forest Experimental Institution (FEI) Siemianice is divided into two working circles: Laski and Wołczyn, with 7 forest districts. FEI Siemianice is situated on the border of three voivodships: wielkopolskie, opolskie and łódzkie, in powiats of Kępno, Wieruszów and Kluczborg. FEI Siemianice, nursery Dobrygość and Experimental Industrial Plant (sawmill) in Laski are the parts of the FEI. According to the natural and forest regionalization the north-west part of the Inspectorate is situated in V (Silesia) Region, 2 District of Wroclaw .

Brown soils dominate in the whole Inspectorate taking 31.2% of the area.

The average annual temperature ranges between 6.4^{o}C and 7.6^{o}C. The average annual precipitation ranges between 400 and 500 mm. Vegetation season is 210 days on average.

In the FEI Siemianice the species of the stands are most varied with pine occupying 63.5% of the forest area, oak 12.3% and alder 8.6%.

The area of the division is plain, in the Laski District it gently rises southwards, and in the Wołczyn District it rises northwards. Most of the area is situated in the catchments of the Prosna River, which is a tributary of the Warta River. Only the southern part of the Wołczyn District lies within the catchments of the Odra River. Watercourses Janica, Niesób (Samica), Pomianka, Partwa flow into the Prosna River. Strumień Wołczyński and Struga, which flow into the Stobrawa River – a tributary of the Odra River, flow across Wołczyn District. There are no natural reservoirs in the area of the division. (Kondracki 1994, Operat Urządzenia Gospodarstwa Leśnego dla Nadleśnictwa Siemianice opracowany na okres 01.01.1994-31.12.2003).

The characteristic of the habitat conditions in The Lasy Rychtalskie Forest Promotion Complex. In general forest habitats take up 57%, coniferous forest habitats 37.5% and upland habitats 5.5% of the area of the LRFPC. Fresh coniferous forest is in the majority in the Antonin division. In the divisions of Syców and Siemianice fresh mixed forests dominate. Riverine forest is least common in the whole area.

The wet habitats, boggy coniferous forest (Bb), boggy mixed coniferous forest (BMb), boggy mixed forest (LMb), alder swamp forest (Ol), ash-alder swamp forest (OlJ), and riparian forest (Lł), which are under the influence of ground waters take up adequately: 1.2% (239.22 ha) in the Antonin division, 1% (220.85 ha) in the Syców division, and 6.34% (374.93 ha) in the FEI Siemianice.

The definitions of marshlands vary in different sources. All the water and land-water ecosystems are considered marshlands (the definition accepted by the Ramsar convention). What is characteristic for marshlands is presence of water, unique types of wetland soils and the plants adapted to wet soils.

It is assumed that the term marshland will refer to forest areas and ecosystems excessively wetted and which should initially include areas classified in stands descriptions as boggy coniferous forest (Bb), boggy mixed coniferous forest (BMb), boggy mixed forest (LMb), alder swamp forest (Ol), ash-alder swamp forest (OlJ), and riparian forest (Lł).

Bogs take 221.10 ha in the Antonin division. In the districts of Mariak, Jarnostaw, Możdżanów, and Sośnie in the Moja Wola working circle in particular there are seasonal problems with the humidity of the ground.
In the forest division Syców 24.98 ha of bogs have been marked. The problem of excessive wetness of the area is of little economical and natural importance.
In the FEI Siemianice there is only 2.30 ha of bogs. However about 20% of the soils in the area (Disricts of Laski, Marianka, Ciecierzyn and Unieszów) is under significant influence of ground waters.

RESULTS AND DISCUSSION

Air temperature

Mean diurnal air temperatures were calculated as arithmetic means from measurements taken at 00, 06, 12 and 18 hours of Polish time.

Maximum mean daily temperature of 28.2^{o}C was recorded on 30 July 2005. Minimum mean daily temperature was observed on 6 February 2005 (–13.0^{o}C) (23 January 2006 it was as low as –26.6^{o}C).

The frequencies of days characteristic in terms of temperatures were analyzed. The biggest group comprised warm days, while the smallest group consisted of very frosty days. There were 83 days other than those characterized above (with daily temperatures within the 0^{o}C-15^{o}C range) in the hydrological year of 2005 and their distribution in individual months is presented in Tables 1 and 2.

The highest mean monthly air temperature in 2005 was recorded in July (20°C). The lowest mean monthly temperature was found in February (–4.7^{o}C).

The biggest monthly range of temperatures was recorded in May (20.8^{o}C). The smallest temperature range (6.5^{o}C) was observed in December.

Table 1. The number of days characteristic in terms of temperatures at the meteorological station at Siemianice in the hydrological year of 2005

Division of days characteristic in terms of temperatures	Number of days characteristic in terms of temperatures in hydrological year 2005	
Very frosty maximum diurnal air temperature below -10°C	February – 1	Σ 1
Frosty maximum diurnal air temperature below 0°C	November – 6 December – 14 January – 14 February – 22 March – 12	Σ 68
Cool minimum diurnal air temperature below 0°C	November – 7 December – 11 January – 7 February – 4 March – 13 April – 8 May – 1 October – 3	Σ 54
Warm maximum diurnal air temperature above 15°C	April – 15 May – 13 June – 14 July – 14 August – 20 September – 18 October – 12 November – 1	Σ 107
Hot maximum diurnal air temperature above 25°C	May – 3 June – 8 July – 13 August – 11 September – 9	Σ 44
Very hot maximum diurnal air temperature above 30°C	May – 3 June – 1 July – 4	Σ 8

Table 2. The number of days with diurnal air temperatures ranging from 0°C to 15°C at the Siemianice weather station in individual months of the hydrological year

Year \ Month	XI	XII	I	II	III	IV	V	VI	VII	VIII	IX	X
	Number of days with diurnal air temperatures in the 0-5°C range											
2005	16	6	10	1	6	7	11	7	0	0	3	16

Temperature thresholds (apparent values of temperatures), determined by the mean daily air temperature in climatology, constitute the basis for the identification of thermal seasons of the year (Farat 2004). Mean dates marking the beginning of thermal seasons of the year and their mean duration for the area of the Siemianice Experimental Station are presented in Table 3.

Mean annual air temperatures from the analyzed multiannual period (1975 - 2006) indicate an upward trend. Mean air temperature from these years was 8.9^{o}C (Figure 1). In terms of temperatures the hydrological year of 2005 (with a mean temperature of 8^{o}C) may be considered as average, due to the deviation from the average of less than 10%.

Table 3. Mean dates marking the beginning of thermal seasons of the year and mean duration of seasons (the author's study based on Lorenc 2005)

Thermal seasons of the year	Thermal thresholds	Mean dates of beginning of thermal season of year	Mean duration of thermal season of year
Early spring	$0°C \leq T_{diurnal\ mean} < 5°C$	15 II-20 II	35-40
Spring	$5°C \leq T_{diurnal\ mean} < 10°C$	20 III-30 III	30-35
Early summer	$10°C \leq T_{diurnal\ mean} < 15°C$	25 IV-30 IV	35-40
Summer	$T_{diurnal\ mean} \geq 15°C$	30 V-5 VI	90-100
Late summer	$10°C \leq T_{diurnal\ mean} < 15°C$	30 VIII-10 IX	20-35
Autumn	$5°C \leq T_{diurnal\ mean} < 10°C$	5 X-10 X	20-30
Early winter	$0°C \leq T_{diurnal\ mean} < 5°C$	5 XI-10 XI	40-50
Winter	$T_{diurnal\ mean} < 0°C$	15 XII-25 XII	50-60

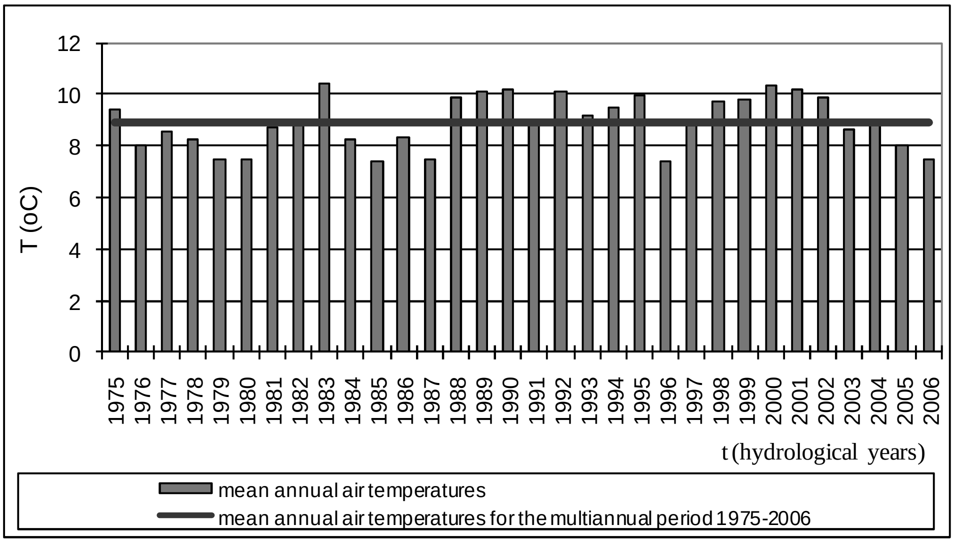

Fig. 1. Mean annual air temperatures and mean annual air temperatures for the multiannual period 1975-2006 (hydrological years) at the meteorological station at Siemianice

The trend of mean annual air temperature at Siemianice is positive (+0.027^{o}C/year). This dependence was not statistically significant at the usually assumed level of significance $\alpha = 0.05$ – Figure 2.

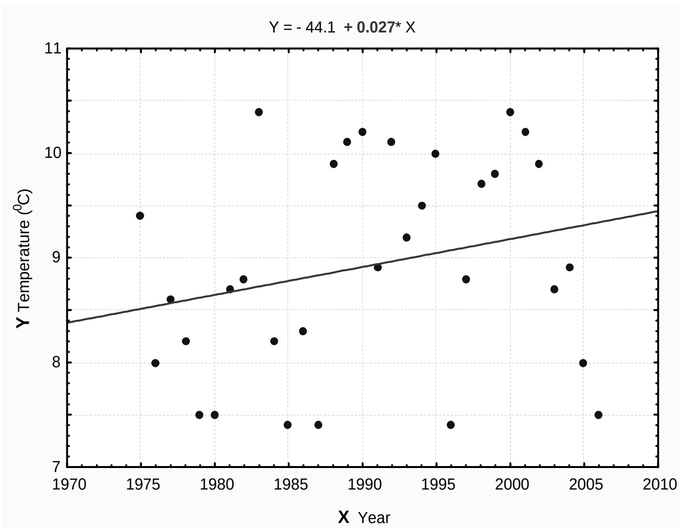

Fig. 2. Trend for mean annual air temperatures at Siemianice in the years of 1975-2006

Atmospheric precipitation

Data on the amount of precipitation during plant vegetation is of practical importance for agriculture, horticulture and forestry. Assuming arbitrarily that the vegetation season is the period from the beginning of April to the end of October precipitation total in that time interval in the hydrological year of 2005 was 303.2 mm, which accounted for 58.93% of annual precipitation.

In the hydrological year of 2005 there were five relatively long precipitation-free periods (longer than 10 days). All these periods took place during the vegetation season. These breaks amounted to 17 days (April), 13 (June), 15 (July), 11 (August) and 15 days (September).

The total number of days with precipitation in the hydrological year of 2005 was 136. The month with the most abundant precipitation (15 days and more) was January (17 days). The lowest number of days (5 days and fewer) with precipitation was recorded in October (5 days).

When analyzing the percentage of days with precipitation with a specific threshold value (Tab. 4) it may be stated that the biggest number of such days was recorded for precipitation with a threshold value $P \geq 1.0$ mm. In the hydrological year of 2005 they accounted for approx. 57% total number of days with precipitation. The next considerable number of days was observed for precipitation with a threshold value $P \geq 0.1$ mm, which in that year amounted to approx. 32% total number of days with precipitation. The lowest number of days was found for precipitation with a threshold value $P \geq 20$ mm. It accounted for 1.5% total number of days with precipitation for that year.

The highest monthly total precipitation levels were recorded for the hydrological year of 2005 in November (74.6 mm) and May (89.8 mm). In turn, the lowest value of monthly precipitation total was recorded in October (7.9 mm).

When analyzing daily sums of precipitation in individual months the most significant difference (above 20 mm) between the highest daily precipitation total and the lowest daily precipitation total occurred in May (21.3 mm) and August (20.2 mm). The smallest variation (below 5 mm) in the amounts of daily precipitation totals from a given month was recorded in October (4.6).

Annual precipitation totals from the analyzed multiannual period (1975-2006) showed a downward trend. Mean precipitation total from these years was 565.7 mm (Fig. 3). In terms of moisture content the hydrological year of 2005 (with precipitation total of 514.5 mm) in view of the mean sum from the multiannual period we may consider this year as average. Moisture level characteristics of such a year indicates a slight, i.e. lower than 10%, deviation from annual precipitation value from the mean for the multiannual period.

The trend of annual precipitation totals at Siemianice was negative (–1.573 mm year^{-1}). However, similarly as for air temperatures, this dependence is not statistically significant at the commonly assumed significance level $\alpha = 0.05$ (Fig. 4).

Table 4. The number of days with precipitation with specific threshold value at the Siemianice weather station in the hydrological year of 2005

Period	Threshold value of precipitation				Total (mm)
	$P \geq 0.1$ mm	$P \geq 1.0$ mm	$P \geq 10$ mm	$P \geq 20$ mm	
November	0	11	3	0	14
December	2	7	0	0	9
January	7	9	1	0	17
February	2	11	0	0	13
March	3	7	0	0	10
April	3	2	1	0	6
May	2	10	1	1	14
June	6	5	1	0	12
July	6	5	3	0	14
August	6	6	1	1	14
September	4	3	1	0	8
October	3	2	0	0	5
Winter half-year	17	47	5	0	69
Summer half-year	27	31	7	2	67
Hydrological year 2005	44	78	12	2	136

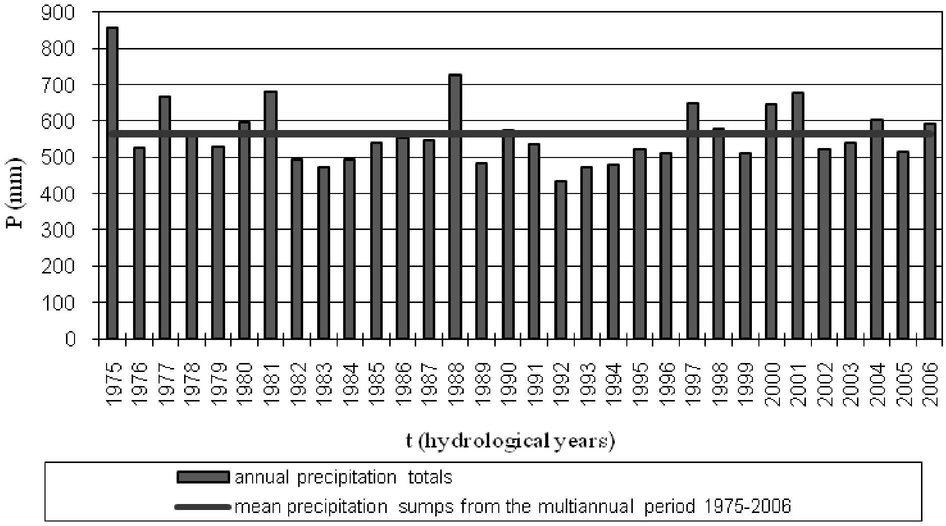

Fig. 3. Annual precipitation totals and mean precipitation sums at the meteorological station at Siemianice from the multiannual period 1975-2006 (hydrological yeras)

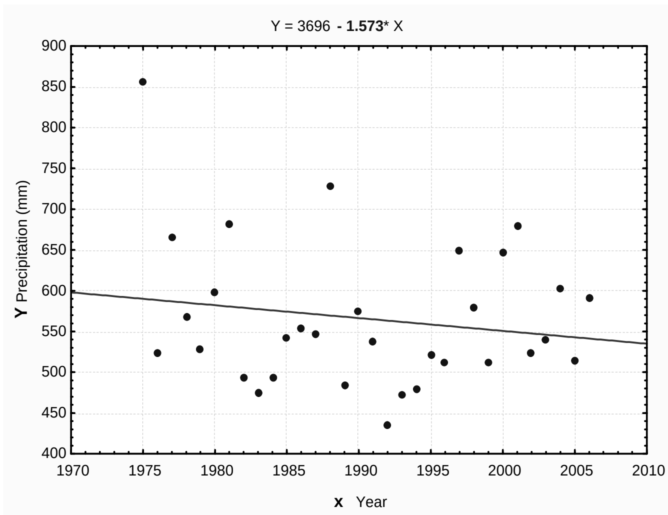

Fig. 4. The trend of annual precipitation totals at Siemianice in the years 1975-2006

The presented climatogram for Siemianice was prepared for the multiannual period of 1975-2006 – Figure 5 (Krysztofiak 2008).

In Table 5 there is a short review of atmospheric phenomena and mean annual days number with the particular phenomena.

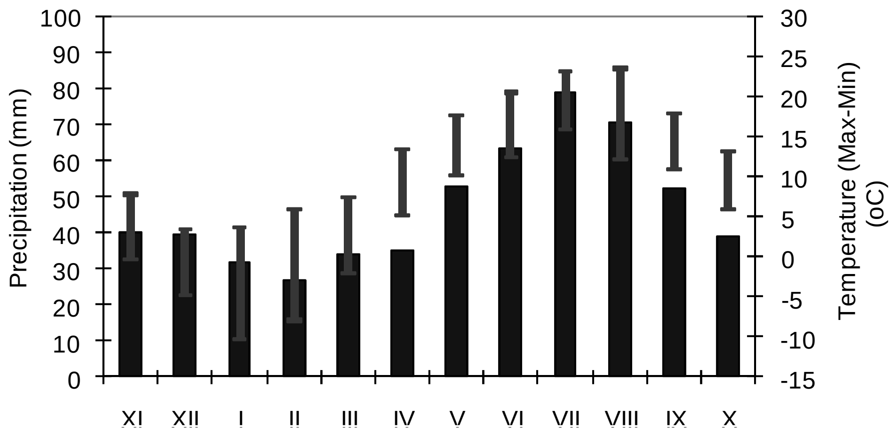

Fig. 5. A climatogram for Siemianice (1975-2006)

Table 5. Mean annual days number with particular atmospheric phenomena on the area of Forest Experimental Station Siemianice (*the author's study based on* (Lorenc 2005)

Atmospheric phenomena	Mean annual days number with the phenomena
Storm	22-24
Hail	2-4
Dew	160-180
Nebulosity	300-320
Fog	50-60
Snowfall	40-50
Snowstorm	0-5
Hoarfrost	60-70
White-frost	4-8
Sleet	0-6
Atmospherci muddiness	40-70

Water balance

Annual components of a balanced water balance for forest ombrogenic marshes (2004/2005) are as follows: precipitation total of 534.6 mm, evaporation of 509.1 mm, runoff of 20.5 mm and retention change of +5.0 mm.

Estimated time trends – annual changes for annual precipitation totals and mean annual air temperatures, as it was described above, amount to –1.573 mm and +0.027°C, respectively.

The positive annual trend of mean annual temperatures will obviously stimulate an increase in evapotranspiration, but this depends on many factors, e.g. on water availability. Thus in the forecast of water relations in the investigated areas it may be assumed that evapotranspiration will not undergo significant changes. Runoff from the analyzed marshy areas is so slight (4%) that its changes may be considered negligible in forecasts.

Thus the forecast concerning changes in water relations in forest ombrogenic marshes (the Lasy Rychtalskie Forest Promotion Complex), expressed by changes in groundwater levels, may be based on the negative annual trend for annual precipitation (–1.573 mm year^{-1}).

If we assume that significant changes in marshy ecosystems are going to occur when the mean groundwater level will drop by approx. 50 cm (50% present mean groundwater status), as a result of decreasing annual precipitation totals, it may be estimated that it will take place after approx. 100 years. At the above assumptions and soil porosity in the aquifer of 34%, after 100 years decreasing precipitation results in a lowering of groundwater table by a mean 46.3cm.

If we extended the observation series at Siemianice, e.g. by the correlation with the series of observations taken for precipitation in Wrocław (the Lasy Rychtalskie Forest Promotion Complex is located at a distance of approx. 40 km), where observations have been recorded since 1860, the calculated trend of annual precipitation totals would be only –8.8 mm (100 years)$^{-1}$.

Obviously the 100 years mentioned above is an estimate. However, it corresponds to the order of magnitude in relation to the period, after which such changes in water relations are possible in these marshy areas that they would change their character and cease to be excessively moist sites.

CONCLUSIONS

1. Marshy ecosystems in the Lasy Rychtalskie Forest Promotion Complex, valuable from the point of view of biodiversity, are going to be threatened in the near future by water deficit, resulting from an adverse climatic change. It may be estimated that after approx. 100 years the forest sites, presently classified as ombrogenic marshes, may be overdried.
2. Pragmatically speaking it should be attempted to completely stop the runoff of water from these areas. This will somewhat slow down the overdrying process, but retention of slight runoff from these areas (approx. 4% total annual precipitation) in a longer period of time will not be able to stop the degradation of marshes.

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18. SUMMARY

The first chapter presents the outline of the history of the meteorological network in the 19th century in the southern Polish Kingdom which was denominated Galicia by the Austrian invaders. The second half of the 18th century was characterized by extensive development of new branches of science in Europe. New instruments for measuring weather elements, such as mercury barometers and thermometers appeared. Unfortunately, political events in the Polish Kingdom namely three consecutive partitions impeded the development of science. In spite of the fact the new meteorological stations were founded, first in Warsaw in 1779, and later in Krakow in 1792. Professor Jan Śniadecki – a famous mathematician and astronomer, the first head of the Astronomical Observatory of the Jagiellonian University in Krakow began to gather records of instrumental and visual observations in 1792. The meteorological network in Galicia was founded in 1865 by the Physiographic Committee and its Meteorological Section. The Astronomical Observatory in Krakow was its central institution. The Committee published Materials for the Climatography of Galicia, from 1867 to 1914. They are a very rich assemble of used frequently in meteorological research.

Solar radiation is the principal source of energy for atmospheric processes. Therefore, it is one of the key climate forcing agents. Next (II) chapter attempts to outline the history of heliographic and actinometric observations in the area of present-day Poland from their onset until the World War II. The first regular measurements of insolation began in Kraków in 1883. The measurements were also started early in such locations as Wrocław, Warsaw, Kołobrzeg and on Mt. Śnieżka. Before the World War I, and thus before the State Meteorological Institute (PIM) was established, measurements of insolation were also carried out (with frequent breaks) at a number of other stations. A rapid growth of the heliographic network can be observed after the end of the World War I. Systematic actinometric measurements were started in Warsaw in 1900. Besides Warsaw, regular measurements of insolation were carried out in a few other few places, e.g. in Silesia and on the coast. Some short series of measurements were collected for a few locations in the centre of the country as well. Actinometric measurements were also performed in the mountains. Initially, these comprises a short series between a few days and a few months, however longer series are available for Zakopane (1935-1938) and Mt. Kasprowy Wierch (1938-1939).

The aim of the third chapter is to show the results of regular temperature and air pressure measurements conducted by David von Grebner in Wrocław from

1710 to 1721. This series is the oldest surviving measurement series available in Poland. They were conducted at various times however the most systematic ones are those taken just after sunrise. The following work presents the results of the analyses using morning temperature records. David von Grebner used Thermometrum Academiae Florentinae for the temperature measurements with its 180 degree scale. The air temperature in Wrocław in the observation period was probably colder than today. The analyses show a very high frequency of temperatures lower than -20.0 in Florentine scale. In the study period the mean annual temperature reveals a growing tendency. Rough comparison of the annual measurement periods of 1710-1720 and 1970 and 1981 showed some similarities between the courses of measurements however, reliable comparison of temperature values between historical and present-day periods is difficult due to conversion problems from the scale used on the Florentine thermometer in Wrocław to the scales used in contemporary thermometers.

The next chapter presents the results of a comparison between the ten-day period values of relative air humidity and saturation deficit obtained from standard (manual) station and automatic station in Agro- and Hydrometeorology Wroclaw-Swojec Observatory of Wroclaw University of Environmental and Life Sciences for the period 2000-2009. The data for 2009 were used to verify calculated regression equations. Standard measurement of air humidity was accomplished by August psychrometer which was placed in the meteorological screen, 2 meters above the ground and by means of daily thermohygrograph. Saturation deficit mean daily values were calculated from three terminal measurements (7, 13, 19 CET) and relative air humidity from four terminal measurements (1, 7, 13, 19 CET). Mean daily values of two analyzed humidity indicators according to automatic station Campbell Sci. Ltd. (CR23X) were calculated from all 24 hourly values.

In the fifth chapter the following material from the weather station in Ustka gathered during the period from April to September over the years 1986-2005 was used: 24-hour period values of air temperature, relative humidity of air, wind speed and atmospheric pressure and a number of days with precipitation >0.1 mm and >1.0 mm and the state of the sky. Apart from this, a decade of real sunshine over the years 1986-2000 was taken into account. The number of days of the following meteorological conditions was determined: comfort days (t_{max} 18-23^{o}C), warm days (t_{max} >25^{o}C), very hot days (t_{max} >30^{o}C), days with 24-hour period of amplitude of air temperature >8^{o} and >12^{o}C, days with 24-hour period of relative humidity of air >85 and >95%, days with pressure changing every 24 hours within the values of >8 and >12 hPa, days with precipitation >0.1and >1.0 mm in 24-

hour period and with wind speed of >8 and >10 $m \cdot s^{-1}$. In the second part of the study, the bioclimatic indexes such as subjective temperature index STI, heat load of organism HL, predicted insulation of clothing Iclp and weather evaluation index WEI for the needs of recreation and tourism were taken into consideration. In the region of Ustka the dominating type of weather is warm weather (37% of days of the whole half-year period), then cool weather (31%), comfort days occur in 25%, and days with cold and hot weather – in 4 and 3%, respectively. Throughout the whole warm half-year period, the weather conditions in the region of Ustka are favourable for sunbathing if clothing of suitable insulation is worn, and in May the conditions are even very favourable. However, in this month, a low temperature of air is a limiting factor. In April, the moderately favourable weather occurs every three days on average and sporadically it is unfavourable. Similar weather conditions pervade for sunbathing. The bioclimatic conditions in the region of Ustka make it possible to lengthen the most intensive touristic season which lasts at present from mid-June to August, for about 45 days, i.e. from mid-May to mid-September.

Previous research has shown that the thermal heat island in Warsaw is a frequent phenomenon but it does not occur every day. The goal of the sixth chapter was to determine the intensity of the urban heat island and its variability in the course of the day and night in conditions of light and heavy cloudiness. The study used meteorological data from automatic measurement stations made accessible by *the Provincial Inspectorate* for *Environmental Protection* (WIOŚ), collected in the period from 01.09.2003 to 31.12.2008 at four urban background stations in Warsaw, one in Piastów and at the regional background station in Legionowo, located beyond the range of influence of the Warsaw agglomeration. Information on a degree of cloudiness comes from observations conducted at the Warsaw University of Life Sciences (SGGW) meteorological station and from daily meteorological bulletins of the Institute of *Meteorology* and Water Management (IMGW). On the basis of the data, differences in air temperature between particular stations and the station in Legionowo were determined. The differences enabled determination of the intensity and time of the occurrence of the urban heat island. Frequency distributions of the differences were also carried out and the development and disappearance of the island at different times of day and night were graphically presented, taking into consideration seasons of the year. The phenomenon of an urban heat island appears both in the case of assumed cloudless days ($N \leq 2$) and cloudy days ($N > 6$). On the analysed days the highest intensity of the urban heat island was recorded in the heart of the city centre

(Krucza Street and Niepodległości Avenue). On cloudless days the intensity of the heat island was considerably higher than the intensity on cloudy days.

The study presented in the next (VII) chapter involved daily mean air temperatures measured at 200 cm above the ground level, recorded by the meteorological station in the city of Bydgoszcz, Poland, between November and March 1946-2005. An atmospheric thaw event was defined as a period of two or more days with a mean daily temperature above 0°C that followed at least a three-day long period of a mean daily temperature below 0°C. Duration of winter thaws was expressed as a total number of days in the thaw, as well as sequences of up to 5, 6-10, 11-20, and more than 20 consecutive days of thaw, however, only in relation to winter seasons. Thaw intensity was described as mean daily air temperatures during thaw days within the winter thaw periods, as well as the frequency of the following temperature ranges: 0.1-1.5, 1.6-3.0, 3.1-4.5, 4.6-6.0, 6.1-7.5, and >7.6^{o}C. A statistically significant increase in frequency and intensity of thaws in January and March was found for the period 1946-2005. It was demonstrated that both frequency and intensity of thaws, as well as the onset of spring thaw periods, was determined by atmospheric circulation in January, February, and March.

In chapter eight the study was based on average and hourly concentrations of suspended particulates (PM10) over the years 2005-2007 recorded by seven measurement stations functioning within the range of the system monitoring the air quality (National Inspectorate of Environmental Protection). It was stated that during the years 2005-2007, the average concentrations of suspended PM10 particulates, recorded in series of hours and days with precipitation, were by 10 to 35% lower, depending on the season of the year and the day, than the concentrations recorded before the phenomenon occurred. However, a slight statistically significant effect was proved only in reference to the amount of precipitation, taking into account the concentration of PM10 particulates before precipitation. The lowest effectiveness was characteristic for the precipitation in summer, but contrary to the remaining seasons of the year, its positive effect in reducing the immission of particulates was still observed the next day after precipitation. The example of Częstochowa demonstrated that an analysis of hourly values of both variables gives definitely larger possibilities to evaluate the washing out role of precipitation, not only in respect if its amount, but also its intensity.

Next chapter presents selected characteristics concerning precipitation conditions of the north-eastern Poland. The study is based on twenty-four-hour data originating from 14 stations and posts of the Institute of Meteorology and Water Management between 1951-2000. The research included analysis of the frequency of vegetation periods (IV-IX) with deficiencies or excess of precipitation according to Kaczorowska's criterion. The frequency of precipitation-free periods (lasting ≥10, ≥15 and ≥20 days) was calculated for individual months of the vegetation period from April to September, and for the entire vegetation period, as well as the average number of days with precipitation ≥0.0 mm, ≥1.0 mm, ≥5.0 mm, ≥10.0 mm, ≥20.0 mm and ≥30.0 mm in the vegetation period (IV-IX). Additionally, a spatial diversification of selected precipitation indicators in the vegetation period in the examined area is presented. It was found that precipitation-free sequences of all analysed categories (≥10, ≥15 and ≥20 days) most frequently appeared in the areas of the lowest number of days with low precipitation (≥1.0 and ≥5.0 mm) and at the same time of the most frequent occurrence of dry vegetation periods (selected according to the classification presented by Kaczorowska), i.e. in the western and the south-western parts of the region.

The study in the tenth chapter presents the comparison between two methods (objective and subjective) of atmospheric circulation classification. The comparison of the two methods indicated some discrepancies stemming from the differences in typological procedure, the quality of data sources and various layouts of baric systems. The objective method is partly based on Jenkinson and Collison method. The degree of adaptation of the objective method to subjective method of classification of atmospheric circulation were checked by means of a comparison of daily circulation types in both methods on a given day and analyses of synoptic situations. Moreover, selected meteorological parameters during particular circulation types in both methods were also analyzed. The comparisons show that both methods in many cases give different results of classification of synoptic situations. This discrepancy results from different methodologies of determination of atmospheric circulation types in both methods.

The purpose of the eleventh chapter is to examine the relative impact of North Atlantic Oscilation (NAO) on the atmospheric instability over Europe and to compare it with the influence of other circulation patterns such as: East Atlantic Pattern (EA) and Scandinavia Pattern (SCAND). The investigation is based on selected instability indices such as: Vertical Total (VT), Total Totals (TTI), KI index (KI) and Convective Available Potential Energy (CAPE) using the radio sounding measurement from 41 European stations taken at 00UTC over 1993-2007. To examine the influence of different circulation patterns on the instability is based on correlation coefficient calculated for monthly average from May to August. Results show positive values of correlation coefficient between TTI and KI indices and NAO circulation type over southern Europe in July and August, and negative correlation over the Scandinavian Peninsula and over the zone from Ireland to Poland. The strongest relationship is observed between selected instability indices and SCAND index over northern and central Europe.

Four instability indices: CAPE, LIFT, KI, TTI are described and the potential of these indices in storm prediction is examined for the area of Northern Poland. The analysis in the next (XII) chapter is based on upper air sounding data from Łeba, Legionowo, and Greifswald and storm data from meteorological stations in Szczecin and Suwałki regions for the period 1981-2000. The analysis revealed that the best upper air station for storm forecast in Suwałki region is Legionowo whereas for Szczecin it is Greifswald or Łeba. 12.00 UTC atmospheric soundings represent convective phenomena better than 00.00 UTC soundings. Threshold values for each analyzed instability index differ according to a month and K Index seems to be the best instability predictor, especially when it comes to storm forecast.

Thirteenth chapter presents results of research concerning the analysis of the Arctic Oscillation (AO) variability in the period of 1971-2006. AO daily data allowed the recognition of the period of distinct features in AO course. The usage of daily AO values enabled the analysis of other statistical characteristics, namely extremes. The selected sub-periods in the AO course serve as a point of reference for the analysis of relative vorticity field evolution in the Euro-Atlantic region. The analysis revealed major differences in the course of AO and its characteristics as well as substantial shifts in the relative vorticity field.

Eddy covariance method is currently the main tool used to measure mass and energy flux exchange between various ecosystems and the atmosphere. The XIV chapter presents the principles of the method as well as the strategy of data management in the case of the data obtained from the measuring system used by the Meteorology Department of the University of Life sciences in Poznań. Subsequent steps of the procedure were described in detail and their influence on the obtained results was presented in the charts.

The fifteenth chapter presents the results of climatological elaboration of pluvial conditions in Beskid Śląski Mts. The data come from measurements from the years 1957-2008 which were collected at 26 meteorological stations and posts situated in Beskid Śląski region. The aim of this study was evaluation of the rainfall changeability on spruce stand stability in Beskid Śląski lower subalpine forest zone. The multiannual average rainfall indices showed no significant change. Total precipitation has decreased in the warm part of the year, this decrease is mainly observed in June and July. Total precipitation in May several times evolved the standard deviation, both positive and negative, in the last two decades. In June there were significantly more likely to decline relative to the average of many years, most often highlighted as one of the decade from 1988 to 1997. In this respect July is unique, because through 20 consecutive years, with one exception that is 1980, the yearly sum of precipitation was lower than climate pluvial norm for this month. Complementing this disadvantage was the fact that during the period from 1990 to 1996, indicators of rainfall in three consecutive months: May June and July were lower than the multiannual average.

Field studies presented in the next (XVI) chapter were carried out on marshland areas in the Promotion Forest Complex Rychtalskie Forest. Marshland areas are characterized by very large water storage capacities. Weather conditions in the study period were evaluated on the basis of data from the Siemianice Station, where measurements have been taken since 1975. The analysis involved the hydrological year of 2004/2005, which in terms of total precipitation (514.5 mm) and mean annual temperature (8.6^{o}C) may be considered as average, since deviations of the above values do not exceed 10% from the respective means. The trend of mean annual air temperatures is positive (+0.027^{o}C year^{-1}). The trend of total annual precipitation is negative (–1.573 mm year^{-1}). Total annual outflow is relatively small – about 4% of the total annual precipitation and it occurs only in winter half-year and in May. Ground water levels lie shallow, about 1 m under the surface area. The forecast of water condition change in the investigated areas, expressed by ground water changes, was based on negative trend of precipitation. It has been assumed that, essential changes on marshland area ecosystems will occur, when average ground water levels come down by about 50% of the present state. It has been estimated that it will happen after around 100 years.

Chapter seventeen discusses the principles of data quality monitoring for the meteorological data obtained from automatic measurement stations. The analyses used the data from the years 2005-2007 which were obtained in four automatic measurement stations located in Wielkopolska region. WMO guidelines applied to conduct their qualitative analysis were adopted to the climatic conditions of the site in which the monitored meteorological station operates. The results indicate that even regularly serviced measurement stations are not capable of maintaining absolute continuity and reliability of measurements. Thus, independently of the method of measurement there are some information gaps in the collected data which should be filled applying proper methods also described in this chapter.

Keywords: meteorological observations in Galicia, history of the meteorological network in Galicia, early heliographic and actinometric measurements, meteorological measurements by David von Grebner, early instrumental observa-

tions in Wrocław (Breslau), Florentine thermometer, historical climatology, automatic weather station (AWS), Ustka region, bioclimatic indices, forms of activity, urban heat island, urban climate, winter and spring thaws, precipitation totals, precipitation periods, precipitations in north-eastern Poland, atmospheric circulation classification, instability indices, convection, tele-connections, atmospheric instability, NAO index, storm, Convectively Available Potential Energy , Total Index, K Index, Lifted Index, Arctic Oscillation variability, atmospheric circulation variability, airflow vorticity, eddy covariance method, measure mass and energy flux exchange, pluvial conditions in Beskid Śląski, water balances of marshland areas, forecast of ground water levels changes

19. STRESZCZENIE

Rozdział pierwszy monografii przedstawia zarys historii sieci meteorologicznej w XIX wieku w południowej części Królestwa Polskiego, którą zaborca austriacki nazwał Galicją. Druga połowa XVIII wieku odznaczyła się w Europie znacznym rozwojem nowych gałęzi nauk. Pojawiły się nowe instrumenty do pomiarów elementów pogody jak rtęciowe barometry i termometry. Niestety, polityczne wypadki w Królestwie Polskim – trzy rozbiory ziem polskich zahamowały rozwój nauk. Mimo to były zakładane nowe stacje meteorologiczne, najpierw w Warszawie w 1779, nieco później w Krakowie, w 1792. Sławny matematyk i astronom, profesor Jan Śniadecki, pierwszy dyrektor Obserwatorium Astronomicznego Uniwersytetu Jagiellońskiego rozpoczął zapisy instrumentalne i wizualne w 1792. Sieć meteorologiczna w Galicji została założona w 1865 przez Komisję Fizjograficzną i jej Sekcję Meteorologiczną w 1865 r. Centralą tej sieci było Obserwatorium Astronomiczne UJ. Komisja Fizjograficzna wydawała roczniki pt. Materiały do klimatografii Galicji w latach 1867-1914. Zawierają one bogaty materiał obserwacyjny wykorzystywany w badaniach klimatologicznych.

Promieniowanie słoneczne to podstawowe źródło energii dla procesów zachodzących w atmosferze. Dzięki temu jest ono jednym z głównych czynników kształtujących klimat. W rozdziale drugim przedstawiono historię obserwacji heliograficznych i aktynometrycznych dla obszaru dzisiejszej Polski od ich rozpoczęcia aż do wybuchu II wojny światowej. Pierwsze regularne pomiary usłonecznienia rozpoczęto w 1883 roku w Krakowie. Bardzo wcześnie pomiary zaczęto wykonywać także m.in. we Wrocławiu, Warszawie, Kołobrzegu i na Śnieżce. Przed I wojną światową, a więc przed utworzeniem Państwowego Instytutu Meteorologicznego pomiary usłonecznienia (często z przerwami) prowadzono także na wielu innych stacjach. Intensywny rozwój sieci heliograficznej nastąpił po zakończeniu I wojny światowej. Systematyczne pomiary aktynometryczne zostały zapoczątkowane w 1900 roku w Warszawie przez W. Gorczyńskiego. Poza Warszawą regularne pomiary promieniowania słonecznego prowadzone były w niewielu miejscach, m.in. na wybrzeżu i na Śląsku. Krótkie serie pomiarowe zgromadzono m.in. dla kilku punktów w centrum kraju. Pomiary aktynometryczne prowadzono również w obszarach górskich. Początkowo były to krótkie serie obejmujące pojedyncze dni do kilku miesięcy, natomiast dłuższe serie pomiarowe zebrano dla Zakopanego (1935-1938) i Kasprowego Wierchu (1938-1939).

Rozdział trzeci poświęcono analizie wrocławskiej serii pomiarowej Davida von Grebnera, która jest najstarszą znaną serią pomiarową w Polsce. Pomiary obejmowały ciśnienie atmosferyczne oraz temperaturę powietrza. Były one wykonywane w latach 1710-1721, w różnych terminach, jednak z największą systematycznością tuż po wschodzie słońca. W niniejszym opracowaniu zostały przedstawione wyniki analiz wykorzystujące dane pomiarów temperatury powietrza z terminu porannego. Do pomiarów termometrycznych David von Grebner wykorzystał Termometr Florentyński ze skalą 180-stopniową. Temperatura powietrza we Wrocławiu w analizowanym okresie była prawdopodobnie niższa niż obecnie. Analizy pokazują że bardzo często temperatura spadała poniżej –20,0 stopni skali Florentyńskiej. W analizowanym okresie temperatura wykazywała tendencję wzrostową. Pobieżne porównanie cech przebiegów rocznych dla okresów 1710-1721 oraz 1970-1981 wykazało współbieżność obu przebiegów z minimum w styczniu i maksimum w lipcu, jednak porównania takie są bardzo trudne z uwagi na problemy z konwersją skali używanej w termometrach Florentyńskich na skale używaną współcześnie. Trwają prace nad bardziej szczegółowym porównaniem serii z XVIII w. z warunkami termicznymi panującymi obecnie.

Celem badań przedstawionych w kolejnym rozdziale było porównanie dekadowych wartości wilgotności względnej i niedosytu wilgotności powietrza uzyskanych dwoma metodami w Obserwatorium Agro- i Hydrometeorologii UP Wrocław-Swojec w okresie 2000-2009. Dane z roku 2009 posłużyły do weryfikacji uzyskanych równań regresji liniowej. Standardowe (klasyczne) pomiary warunków wilgotnościowych powietrza wykonano za pomocą psychrometru Augusta umieszczonego w klatce meteorologicznej na wysokości 2 m nad glebą oraz według rejestracji termohigrografu dobowego. Średnią dobową wartość niedosytu wilgotności powietrza obliczano z trzech terminów (godz. 7, 13 i 19 CET)(, natomiast wilgotności względnej z czterech (godz. 1, 7, 13 i 19 CET). Średnie dobowe obu wskaźników wilgotności według automatycznej stacji meteorologicznej typu Campbell obliczano na podstawie wszystkich 24 wartości godzinnych.

W rozdziale piątym analizowano dobowe wartości temperatury powietrza, wilgotności względnej powietrza, prędkości wiatru, ciśnienia atmosferycznego oraz liczbę dni z opadem >0,1 mm i >1,0 mm i zachmurzenia z okresu kwiecień-wrzesień, ze stacji w Ustce, za lata 1986-2005. Poza tym zebrano dekadowe usłonecznienie rzeczywiste za lata 1976-2000. Określono liczbę dni komfortowych (t_{max} 18-23^{o}C), gorących (t_{max} >25^{o}C), upalnych (t_{max} >30^{o}C), z dobową amplitudą temperatury powietrza >8^{o} i >12^{o}C, dobową wilgotnością względną powietrza >85 i >95%, z różnicą ciśnienia z doby na dobę >8 i >12 hPa, z opadem >0,1 i >1,0 mm na dobę i prędkością wiatru >8 i >10 $m \cdot s^{-1}$. W drugiej części pracy wykorzystano wskaźniki bioklimatyczne jak: temperaturę odczuwalną STI, obciążenie cieplne organizmu HL, przewidywaną izolacyjność odzieży Iclp oraz wskaźnik oceny pogody WEI dla potrzeb rekreacji i turystyki. W rejonie Ustki dominującym typem pogody jest pogoda ciepła (37% dni całego półrocza), a następnie chłodna (31%), dni komfortowe występują w 25%, a dni z pogodą zimną i gorącą – odpowiednio w 4 i 3%. Przez całe półrocze ciepłe panują w rejonie Ustki warunki pogodowe korzystne dla kąpieli słonecznych, przy zastosowaniu odzieży o odpowiedniej izolacyjności, a w maju nawet bardzo korzystne, jednakże w tym miesiącu czynnikiem ograniczającym jest niska temperatura powietrza. W kwietniu, średnio co trzeci dzień, występuje pogoda umiarkowanie korzystna i sporadycznie niekorzystna. Podobne warunki pogodowe panują dla kąpieli powietrznych. Najlepsze warunki termonentralne występują w lipcu i sierpniu – średnio co drugi dzień. Natomiast pewną uciążliwość dla różnych form spędzania wolnego czasu stanowią dni z opadem, których najwięcej jest w drugiej dekadzie lipca i trzeciej sierpnia. Występujące w rejonie Ustki warunki bioklimatyczne umożliwiają wydłużenie najbardziej intensywnego sezonu turystycznego, trwającego obecnie od połowy czerwca do sierpnia o około 45 dni tj. od połowy maja do połowy września.

Dotychczasowe badania wykazały, że termiczna wyspa ciepła w Warszawie jest częstym zjawiskiem, ale nie występuje codziennie. Celem badań przedstawionych w rozdziale szóstym monografii było określenie intensywności MWC oraz jej zmienności w ciągu doby w warunkach małego i dużego zachmurzenia. W opracowaniu wykorzystano dane meteorologiczne pochodzące z automatycznych stacji pomiarowych, udostępnione przez WIOŚ, zgromadzone w okresie 01.09.2003-31.12.2008r. na czterech stacjach tła miejskiego w Warszawie, jednej w Piastowie oraz na stacji tła regionalnego w Legionowie zlokalizowanej poza zasięgiem wpływu aglomeracji warszawskiej. Informacje o wielkości zachmurzenia pochodzą z obserwacji prowadzonych na stacji meteorologicznej SGGW oraz codziennych biuletynów meteorologicznych IMGW. Na podstawie danych określono różnice temperatury powietrza między poszczególnymi stacjami a stacją w Legionowie pozwalające na określenie intensywności i czasu występowania wyspy ciepła. Sporządzono także rozkłady częstości tych różnic oraz graficznie zobrazowano rozwój i zanik wyspy w różnych porach doby z uwzględnieniem pór roku. Zjawisko wyspy ciepła zaznacza się zarówno w przypadku przyjętych dni pogodnych ($N \leq 2$) jak i pochmurnych ($N \geq 6$). W analizowanych dniach największą intensywność MWC notowano w ścisłym centrum miasta (Krucza i Al. Niepodległości). W dni pogodne intensywność wyspy ciepła była wyraźnie wyższa od notowanej w dni pochmurne.

W rozdziale siódmym scharakteryzowano częstości i intensywności odwilży atmosferycznych w rejonie Bydgoszczy, z uwzględnieniem wieloletniej tendencji zjawiska. Podstawę analiz stanowiły średnie dobowe wartości temperatury powietrza z wysokości 200 cm n.p.g. z okresu od listopada do marca w latach 1946-2005 r. ze stacji IMUZ w Bydgoszczy. Odwilże atmosferyczne opracowano jako co najmniej dwudniowe ciągi, w których średnia temperatura dobowa wzrastała powyżej $0^{o}C$, występujące po przynajmniej trzydniowym okresie ze średnią dobową poniżej $0^{o}C$. Uwzględniono podział na odwilże zimowe, po których notowano jeszcze nawroty termicznej zimy oraz wiosenne, kończące zimę i prowadzące do trwałego wzrostu temperatury powyżej $0^{o}C$. Czas trwania odwilży atmosferycznych w sezonie zimowym wyrażono za pomocą ogólnej liczby dni odwilżowych, a także nieprzerwanych ciągów liczących do 5, od 6 do 10, 11 do 20 i ponad 20 dni, ale wyłącznie w odniesieniu do odwilży zimowych. Intensywność odwilży określono za pomocą średnich dekadowych wartości temperatury powietrza w dniach odwilżowych, w przyjętych okresach z odwilżą zimową, a także częstości występowania następujących zakresów temperatury: 0,1-1,5, 1,6-3,0, 3,1-4,5, 4,6-6,0, 6,1-7,5 i >7,6^{o}C. W latach 1945-2005 zaznaczył się statystycznie istotny wzrost częstości występowania i intensywności odwilży w styczniu i w marcu. Stwierdzono, że częstość i intensywność odwilży atmosferycznych a także początek odwilży wiosennych determinuje cyrkulacja atmosferyczna w styczniu, lutym i marcu.

Podstawę opracowania w kolejnym (VIII) rozdziale stanowiły średnie godzinne stężenia pyłu zawieszonego PM10 oraz sumy opadów atmosferycznych z lat 2005-2007, rejestrowane przez siedem stacji pomiarowych, funkcjonujących w ramach systemu monitoringu jakości powietrza PIOŚ. Stwierdzono, że latach 2005-2007, średnie stężenia pyłu zawieszonego PM10 rejestrowane w seriach godzin i dni z opadem były, w zależności od pory roku i doby, od około 10 do 35% mniejsze w porównaniu do stężeń rejestrowanych przed wystąpieniem zjawiska. Jednak statystycznie istotny, nieduży wpływ udowodniono wyłącznie w odniesieniu do wysokości opadów, przy jednoczesnym uwzględnieniu stężenia pyłu PM10 przed wystąpieniem opadu. Najmniejszą efektywnością charakteryzowały się opady w okresie letnim, ale w przeciwieństwie do pozostałych pór roku, ich pozytywny skutek w zmniejszeniu imisji pyłu, zaznaczał się także jeszcze następnego dnia po opadzie. Na przykładzie Częstochowy wykazano, że zdecydowanie większe możliwości oceny oczyszczającej roli opadów atmosferycznych, nie tylko ze względu na ich wysokość, ale także ich natężenie, daje analiza godzinnych wartości obu zmiennych.

W rozdziale dziewiątym przedstawiono wybrane charakterystyki dotyczące warunków opadowych Polski północno-wschodniej. Opracowanie oparto na dobowych danych z 14 stacji i posterunków IMGW z lat 1951-2000. Dokonano analizy częstości występowania okresu wegetacyjnego (IV-IX) z niedoborem lub nadmiarem opadu wg kryterium Kaczorowskiej. Wyliczono częstość występowania okresów bezopadowych (trwających ≥10, ≥15 i ≥20 dni) w poszczególnych miesiącach okresu wegetacyjnego od kwietnia do września. Przedstawiono też zróżnicowanie przestrzenne wybranych wskaźników opadowych w okresie wegetacyjnym na badanym obszarze. Stwierdzono, że ciągi bezopadowe wszystkich badanych kategorii (≥10, ≥15 i ≥20 dni) najczęściej pojawiały się na obszarach o najmniejszej ilości dni z niskimi opadami (≥1,0 i ≥5,0 mm) a zarazem najczęstszym występowaniu suchych okresów wegetacyjnych (wydzielonych wg klasyfikacji Kaczorowskiej), tj. w zachodniej i południowo-zachodniej części regionu.

Celem badań prezentowanych w rozdziale dziesiątym jest porównanie klasyfikacji cyrkulacji atmosferycznej za pomocą subiektywnej metody Osuchowskiej-Klein z obiektywną metodą Jenkinsona i Collisona, bazującą w głównej mierze na wirowości ścięcia oraz wietrze geostroficznym. Porównanie dopasowania klasyfikacji obiektywnej do subiektywnej wykazało rozbieżności wynikające głównie z różnic w procedurze typologicznej, z jakości źródeł danych oraz odmiennego położenia układów barycznych sterujących cyrkulacją atmosferyczną podczas niektórych typów cyrkulacji. Stopień dopasowania obu metod klasyfikacji cyrkulacji atmosferycznej oceniono na podstawie frekwencji poszczególnych typów cyrkulacji wyznaczonych metodą subiektywną podczas typów wydzielonych metodą obiektywną, porównania map wzorcowych typów cyrkulacji wykorzystywanych w metodzie subiektywnej z mapami średniego rozkładu ciśnienia atmosferycznego opracowanymi dla poszczególnych typów cyrkulacji w metodzie obiektywnej oraz analizy rocznego rozkładu usłonecznienia, temperatury powietrza, wilgotności powietrza i opadu atmosferycznego.

W rozdziale jedenastym przedstawiono wpływ wybranych typów cyrkulacji na chwiejność atmosfery nad Europą. Do określenia stanu chwiejności zastosowano wybrane wskaźniki niestabilności (np.: VT, KI, TTI, CAPE), wykorzystując wyniki badań 41 europejskich stacji radiosondażowych reprezentujących warunki aerologiczne o godzinie 00UTC w latach 1993-2007. Wpływ typów cyrkulacji na chwiejność atmosfery badano wykorzystując współczynniki korelacji wyznaczane na podstawie średnich miesięcznych wartości od maja do sierpnia. Wyniki pokazują pozytywne wartości korelacji pomiędzy wskaźnikami TTI, KI i NAO nad południową Europą w lipcu i sierpniu i ujemną korelację nad Skandynawią oraz strefą od Irlandii do Polski. Najsilniejszy związek jest obserwowany pomiędzy wybranymi wskaźnikami niestabilności oraz indeksem SCAND nad północną i centralną Europą.

W rozdziale dwunastym monografii analizowano możliwości określenie prawdopodobieństwa pojawienia się w Polsce Północnej burz w warunkach wystąpienia chwiejności atmosfery identyfikowanej za pomocą czterech wskaźników niestabilności: CAPE, LIFT, KI, TTI. Analizę przeprowadzono z wykorzystaniem metod statystycznych dla okresu 1981-2000 na podstawie danych z sondaży aerologicznych pochodzących ze stacji Łeba, Legionowo i Greifswald oraz danych o wystąpieniu burz na stacjach w Szczecinie i Suwałkach. Wykazano że dla Suwałk lepszą stacją prognostyczną jest Legionowo, a dla Szczecina Łeba lub Greifswald. Sondaż z 12.00 UTC reprezentuje lepiej zjawiska konwekcji w atmosferze niż z godziny 00.00 UTC. Wartości progowe dla każdego z indeksów różnią się zgodnie z miesiącami, indeks K wydaje się być najlepszym predyktorem niestabilności, szczególnie w zakresie prognozowania burz.

W kolejnym rozdziale zaprezentowano wyniki badań analizy zmienności wartości indeksów cyrkulacji AO/NAM – Oscylacji Arktycznej w latach 1971-2006, charakteryzującej system przepływu powietrza w skali hemisferycznej. Dobowe dane AO pozwoliły na rozpoznanie okresów wyraźnych zmienności AO oraz wykonanie dodatkowych analiz statystycznych. Wybrane podokresy w zmienności AO posłużyły jako punkty referencyjne do analizy ewolucji względnej wirowości pola w regionie Euro-Atlantyckim. Analizy pokazują główne różnice w tendencjach i charakterystykach AO takie jak wyraźne przesunięcie wirowości pola.

W rozdziale czternastym omówiono metodę kowariancji wirów, która jest obecnie głównym narzędziem służącym do pomiaru strumieni materii i energii wymienianych pomiędzy różnymi ekosystemami a atmosferą. W materiale przedstawiono podstawy tej metody oraz strategię postępowania z danymi uzyskanymi z systemu pomiarowego jaką stosuje się w Katedrze Meteorologii Uniwersytetu Przyrodniczego w Poznaniu. Poszczególne kroki postępowania opisane zostały szczegółowo, a ich wpływ na uzyskane wyniki przedstawione graficzne.

Rozdział piętnasty zawiera wyniki opracowania wieloletniej zmienności warunków opadowych na obszarze Beskidu Śląskiego. Dane do opracowania pochodziły z okresu 1957-2008, z 26 stacji i posterunków meteorologicznych zlokalizowanych na badanym obszarze. Celem badań była ocena wpływu wieloletniej zmienności opadu atmosferycznego na stabilność drzewostanów świerkowych w reglu dolnym Beskidu Śląskiego. Ustalono, iż średnia wieloletnia suma opadu nie wykazywała wyraźnego trendu w badanym okresie. Zaobserwowano wyraźną obniżkę sumy opadu w ciepłej części roku, głównie w czerwcu i w lipcu. Wciągu ostatnich dwóch dekad opady w maju kilkukrotnie odbiegały od średniej o wartość odchylenia standardowego zarówno na plus jak i minus. Unikalny pod tym względem okazał się lipiec, gdyż w okresie 20 kolejnych lat, z wyjątkiem 1980 roku, suma opadu w tym miesiącu był niższa od przeciętnej z wielolecia. Szczególny pod tym względem był okres między 1990 a 1996. W tym czasie, suma opadu w trzech kolejnych miesiącach, maju, czerwcu i lipcu, była wyraźnie niższa od średniej wieloletniej.

Rozdział szesnasty bazuje na wynikach badań na obszarach mokradłowych Leśnego Kompleksu Promocyjnego Lasy Rychtalskie. Ocenę warunków meteorologicznych przeprowadzono na podstawie danych ze stacji Siemianice (pomiary prowadzone są od 1975 roku). Jako przeciętny przyjęto rok hydrologiczny 2004/2005 (Psuma rocz. = 514,5 mm, $T_{śr.\ rocz.}$ = 8,6^{o}C). Odchylenia tych wartości od wartości przeciętnych dla wielolecia 1975-2006 są mniejsze niż 10%. Trend średniej rocznej temperatury powietrza w Siemianicach jest dodatni (+0,027^{o}C·rok^{-1}). Natomiast trend sum rocznych opadów atmosferycznych w Siemianicach jest ujemny (–1,573 mm·rok^{-1}). Całkowity roczny odpływ jest względnie niski – około 4 % opadów i zachodzi głównie w zimowej połowie roku, oraz w maju. Poziom wody gruntowej jest niski i wynosi około 1 m poniżej poziomu gruntu. Prognozy warunków wilgotnościowych na badanym obszarze zmieniają się, szczególnie w wyniku zmian wody gruntowej, w konsekwencji negatywnego trendu opadów. Istotne zmiany w ekosystemach mokradłowych zachodzą, gdy średni poziom wód gruntowych spada o około 50 cm (50% obecnego średniego stanu wód gruntowych). Można szacować, że nastąpi to po około 100 latach.

W rozdziale siedemnastym omówiono zasady kontroli jakości danych meteorologicznych pochodzących z automatycznych stacji pomiarowych. Do wykonania analiz wykorzystano dane z lat 2005-2007 pochodzące z czterech automatycznych stacji pomiarowych, rozlokowanych na terenie Wielkopolski. Do ich analizy jakościowej zastosowano wytyczne WMO, dostosowane do warunków klimatycznych miejsca pracy kontrolowanej stacji. Uzyskane wyniki pokazują, że nawet regularnie serwisowane stacje pomiarowe nie są w stanie zapewnić absolutnej ciągłości i pełnej rzetelności pomiarów. Zatem niezależnie od sposobu prowadzenia pomiarów zdarzają się luki w danych, które należy wypełnić wykorzystując odpowiednie metody, również opisane w niniejszym rozdziale.

Słowa kluczowe: obserwacje meteorologiczne w Galicji, historia sieci meteorologicznych w Galicji, wczesne pomiary heliograficzne i aktynometryczne, pomiary meteorologiczne Dawida von Grebnera, wczesne obserwacje instrumentalne we Wrocławiu (Breslau), termometr Florentyński, historia klimatologii, automatyczne stacje pomiarowe (AWS), region Ustki, wskaźniki bioklimatyczne, formy aktywności ludzkiej, miejska wyspa ciepła, klimat miasta, zimowe i wiosenne odwilże, opady całkowite, okresy opadowe, opady w północno-wschodniej Polsce, klasyfikacja cyrkulacji atmosferycznej, wskaźniki niestabilności, konwekcja, niestabilność atmosfery, wskaźnik NAO, burza, potencjalnie dostępna energia konwekcji, wskaźnik K, wskaźnik unoszenia, zmienność cyrkulacji arktycznej, zmienność cyrkulacji atmosferycznej, wirowość pola, metoda kowariancji zawirowań, pomiary wymiany masy i energii, kondycja opadowa Beskidu Śląskiego, bilans wodny obszarów bagiennych, prognozowanie zmian poziomu wody gruntowej, analiza jakości danych meteorologicznych.