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INSTITUTE OF GEOGRAPHY AND SPATIAL ORGANIZATION

GEOGRAPHIA POLONICA

62

GLOBAL CHANGE: POLISH PERSPECTIVES

EDITED BY
LESZEK STARKEL & MAŁGORZATA GUTRY-KORYCKA

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INSTITUTE OF GEOGRAPHY
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POLISH NATIONAL COMMITTEE
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FOREWORD

The shrinkage of the natural resources (water, biomass, soil and mineral resources), environmental pollution and discernible climatic changes due to the greenhouse effect have for many years been the object of numerous national research programmes aimed at getting to know the mechanisms of changes as well as predicting the effects of change for the environment and economy.

At the turn of 1985 and 1986 the Committee for the International Programme of Global Research on Changes in Geosphere and Biosphere (IGBP — Global Change) was established. The programme is being carried out in the decade 1991-2000 under a Core Projects and the related programmes. Its purpose is a "description and comprehension of the interaction of man-caused physical, chemical and biological processes controlling the transformation of matter and energy over the entire terrestrial globe".

The Polish National Committee IGBP — Global Change was established at the end of 1989 at the Presidium of the Polish Academy of Sciences.

In 1993 the decision was taken to publish a new series to present the national achievements summarising the research work in this field. The series might be a forum for scientific discussion and presentation of the achievements of Polish science in global research. Establishing a separate publication was not easy. The proceedings of the conference "Global Environmental Change — a Challenge to Humanity" were published as a separate issue of the periodical Kosmos Vol. 42, No. 1 (218).

Thanks to the kindness of the Board of Directors of the Institute of Geography and Spatial Organization of the Polish Academy of Sciences, we are introducing a new publication "Global Change: Polish Perspectives" to be issued within the framework of the periodical "Geographia Polonica" appearing since 1964. We expect to publish one or two issues yearly.

The new series will be supported by the Polish National Committee IGBP — Global Change of the PAS, whose appointed members form a separate editorial board of the series. Each issue will consist of two parts: the first — comprising the reviewing and summarizing articles, as well as papers presenting the advance in researches carried out in Poland and second — including reports on the organizational activity of the IGBP National Committee and on its contacts with foreign institutions, as well as presentation of research programmes and proceedings of scientific meetings.

The issues will present the state of knowledge and results of Polish research, both included in and related to the IGBP Core Projects.

This volume, the first issue in the new series comprises 7 articles:

Z. Bednarz, T. Niedźwiedź, B. Obrębska-Starkel, Z. Olecki, J. Trepińska: *Natural and anthropogenic fluctuations and trends of climate change in Southern Poland.* The article summerizes multidisciplinary studies of

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climatologists and dendrologists of Cracow on climatic changes in Southern Poland related to the World Climate Research Programme (WCRP).

M. Gutry-Korycka, P. Werner and B. Jakubiak in their article on *Generation of time series of the meteorological values in changing climatic conditions* present an original approach to the simulation of hydrometeorological sequences indispensable for modelling hydrological processes adapting the GCM scenarios models of climatic change to Polish conditions on various spatio-temporal scales.

The next three articles discuss the contribution of Cracow physicists to the Core Project: International Global Atmospheric Chemistry (IGAC).

The article *Measurements of concentration of the trace gases active in the greenhouse effect* by J. Lasa, G. Drozdowicz and J. Śliwka is devoted to the original methodology of the application of a detector to the measurement of concentration of the greenhouse gases causing the greenhouse effect.

The second article, entitled *Evolution of isotopic composition and concentration of atmospheric CO_2 as a result of anthropogenic influences* by T. Kuc and M. Zimnoch, presents the Polish investigations on the CO_2 content in the atmosphere by referring to the global scale.

The third article, entitled *Measurement of atmospheric radioactivity in Cracow* by T. Florkowski, J. Grabczak and K. Różański, presents the results of the measurement of radioactivity in the atmosphere in Cracow.

R.B. Zeidler of the Institute of Hydro-Engineering of the PAS in article *Polish Baltic coast: changes, hazards and management* gives a survey of the research relative to the Core Project Land-Ocean Interactions in the Coastal Zone (LOICZ), analyzing the effects of the water level of the Baltic in various aspects.

The next paper, entitled *Biochemical studies in the Ratanica forest catchment* by K. Grodzińska, presents the results of investigation of water cycle in the forest basin — concerning to biogeochemical cycle.

The chronicle and the survey of the scientific and organizational activity of the IGBP Committee constitute the second part of the issue, comprising reports on national conferences, symposia, seminars and meetings of the working groups organized by the Polish National Committee IGBP — Global Change, which shows its organizational and coordinating activity (Appendix 1).

The project of Poland's membership in the EUROSTART illustrates the international links ensuring contacts with the Core Projects and organizational activity of the IGBP (Appendix 2).

The materials presented in this issue are the first report on the contribution of Polish science to the solution of tasks of the IGBP research projects.

I am indebted to all the Authors and to the editorial board for their help in launching the series.

Thanks are also due to the Editorial Board of "Geographia Polonica" for making the columns of their publication available to the series "Global Change: Polish Perspectives". The issue is appearing thanks to a special subsidy of the Committee for Scientific Research.

Leszek Starkel — Editor
Chairman of the Polish
National Committee IGBP — Global Change
Polish Academy of Sciences

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NATURAL AND ANTHROPOGENIC FLUCTUATIONS AND TRENDS OF CLIMATE CHANGE IN SOUTHERN POLAND

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ABSTRACT: Climatic changes in Southern Poland, including the Carpathian Mountains are shown in regional and local scale. There are discussed: changeability of the circulation indices during the winter season and fluctuations of the air temperatures based on the instrumental observations in the mountain stations. The influence of climate is referred to the secular changes in the width of tree rings in Tatra Mountains and the thermal feelings of human body. Local changes of the radiation inflows are characteristic features of developing urbanization.

KEY WORDS: Climate change, circulation indices, air temperature, sunshine duration, precipitation, long-term instrumental observations, Carpathian Mountains, dendroclimatological data, thermal sensibility of human body, transparence of atmosphere.

INTRODUCTION

Instrumental observations of climate elements have been carried out in Southern Poland since about 200 years. They enable to characterize climate changes in Central Europe from causal point of view and to present statistical variability of climate components as well as of long-term trends of their courses. Series of meteorological observations together with dendrochronological data from the Tatras and from the Carpathian valleys make it possible to follow air temperature changes during the last 250 years, showing the character of thermal conditions in the last phase of the Little Ice Age (1741-1850) and processes of global warming. Actinometric research developing in this region since the 60s reveal direct causes of human activity, which influence directly the natural climate, causing changes in solar radiation.

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CHANGES OF CLIMATE IN SOUTHERN POLAND

One of the important factors causing the climatic change in Southern Poland is the atmospheric circulation. Its influence is most distinct in winter.

The changeability of the circulation indices in winter was calculated according to the Murray and Lewis method (Murray and Lewis 1966), on the basis of circulation types frequencies for the years 1873/74-1991/92. The western zonal circulation index (modified progression index P), southern meridional circulation index S and cyclonicity index C were taken into account.

The long-term fluctuations of these indices, especially of P index (Fig. 1) and complex index P + S + C (Fig. 2) are similar to the variability of winter temperatures in Krakow (Fig. 3). It means that atmospheric circulation factor has a much greater influence on climate than anthropogenic one. However, the increase of winter temperatures by about 2 K has been observed since 1940. During the last 35 years, 7 mild winters and only one severe one (1962/63) were observed. Another period of mild winters existed between 1909 and 1925 (5 mild winters). Six severe winters were recorded between 1929 and 1963, and other three before 1893.

The influence of the Atlantic Ocean on the climate of Poland is connected with the circulation changes. The difference of temperature between summer and winter can be a good measure of continentality and oceanity (Fig. 4)

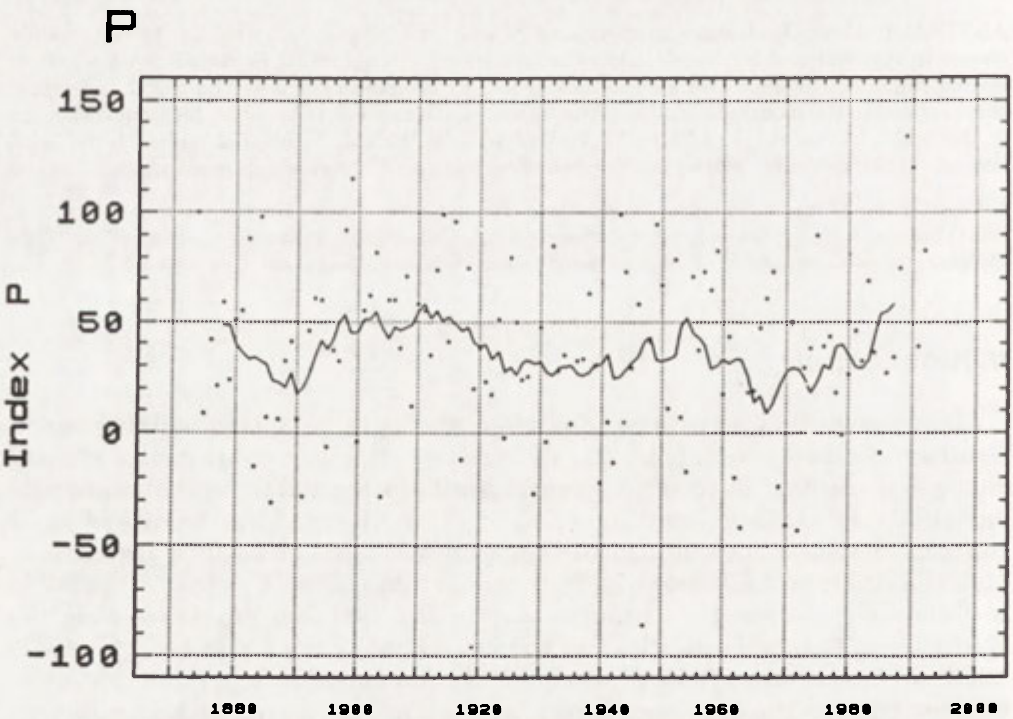

Fig. 1. Progression index for winters in Southern Poland (11-year running means)

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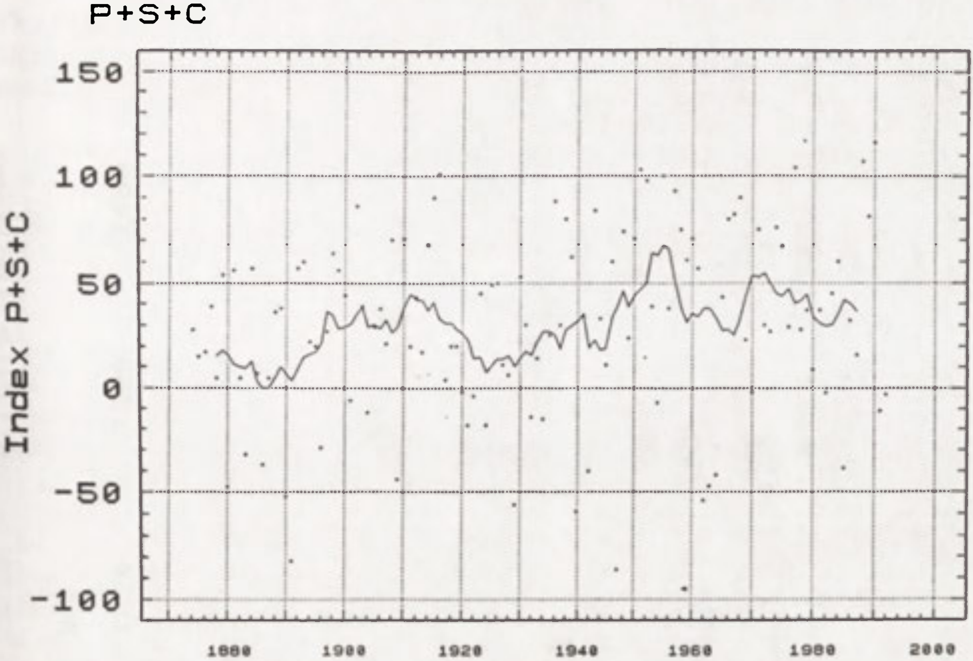

Fig. 2. Complex circulation index (P + S+ C) for winters in Southern Poland (11-year running means)

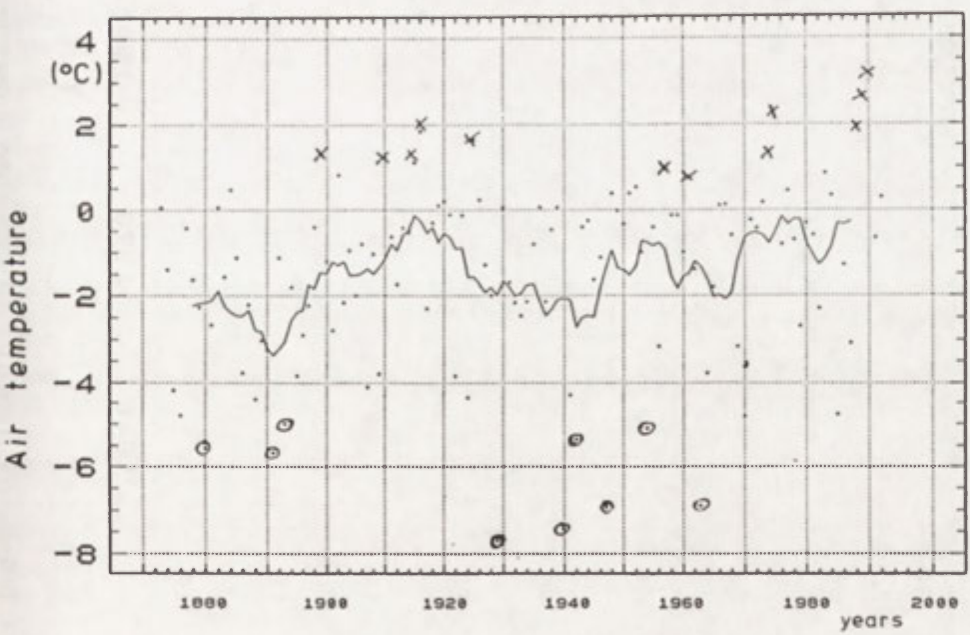

Fig. 3. 11-year running means of winter air temperature in Cracow
× — mild winters (mean of winter months < 1°C), o — severe winters (mean of winter months < -5°C)

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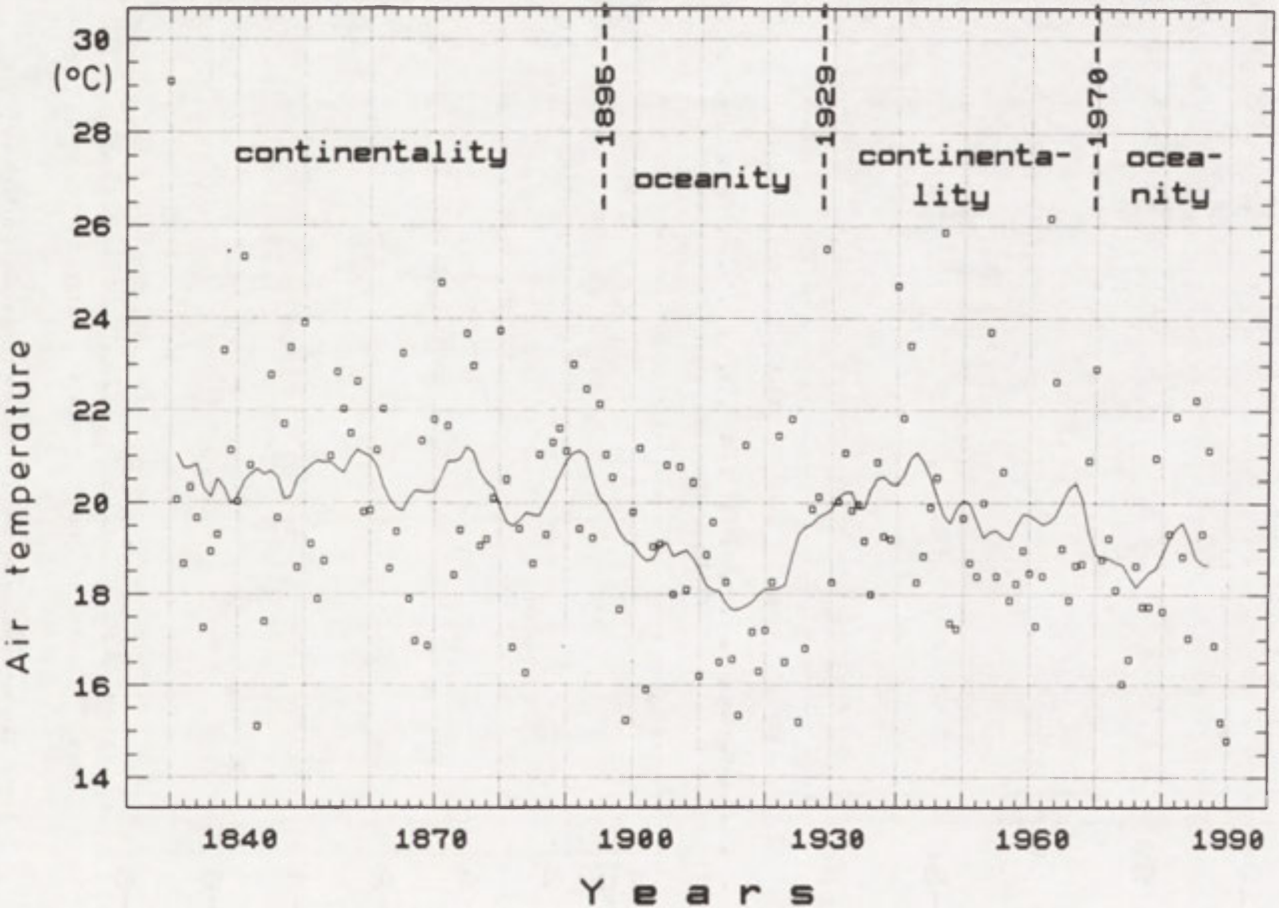

Fig. 4. Difference of winter and summer temperatures 10-year running means 1826-1990; continental influence; oceanic influence
(Cracow-Jagellonian University)

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The following periods can be distinguished for Kraków in the years 1826-1992: 1826-1895 continental influences, 1895-1929 oceanic influences, 1929-1970 continental influences, and 1970-1992 oceanic influences.

THERMAL TRENDS AND FLUCTUATIONS IN SOUTHERN POLAND IN 19TH AND 20TH CENTURY

Thermal trends in southern Poland have the same direction as the ones in Central Europe. However, the intensity of the fluctuations is different. The analysis of air temperature course in this area was based mainly on the series of air temperature measurements carried out in Cracow, continuously since 1826. Other stations have shorter periods, usually no longer than 100 years.

In the 19th century, the influence of the nearest surroundings of the meteorological station was rather constant, because the city developed slowly. The influence of urban and industrial development on changes in thermal fluctuations has been already noted since the 20s, and particularly since the 50s. It has been ascertained that this influence is particularly seen in the course of the mean minimum temperature, which has increased by 1.4°C since the beginning of measurements, while the real mean has increased by 1.0°C. These values refer to mean annual temperatures.

In the second quarter of the 19th century, the annual means had the lowest values. The years 1829-1838 were the coldest ones, with mean temperature of 7.3°C. Strong upward trend occurred in the last quarter of the 19th century; it was present in Western and Central Europe. It was then that the contemporary period of warming started and it has lasted up till now with some exceptions in the 40s (Fig. 5). In the latest years the intensity of fluctuations increased as well, but the overall upward trend of temperature still persists. In the years 1981-1990 mean annual temperature exceeded 10°C three times (in 1983, 1989 and 1990).

The series of air temperature measurements from Zakopane in Tatra Mountains (beginning in 1896) shows similar trends, but the intensity of changes is smaller. As far as summer is concerned, there is even a downward trend of temperature (Fig. 6). In Cracow, mean temperatures of winter months and November increased most of all. Thermal trends of winter months in 19th century had divergent directions and in 20th century were consistent throughout many years (Trepińska 1984).

Apart from natural thermal trends and fluctuations there are also influences of city climate, estimated at about 0.3-0.6°C. Thermal fluctuations in cities can be increased by such values. Moreover, the greater the altitude, the less changeable the temperature.

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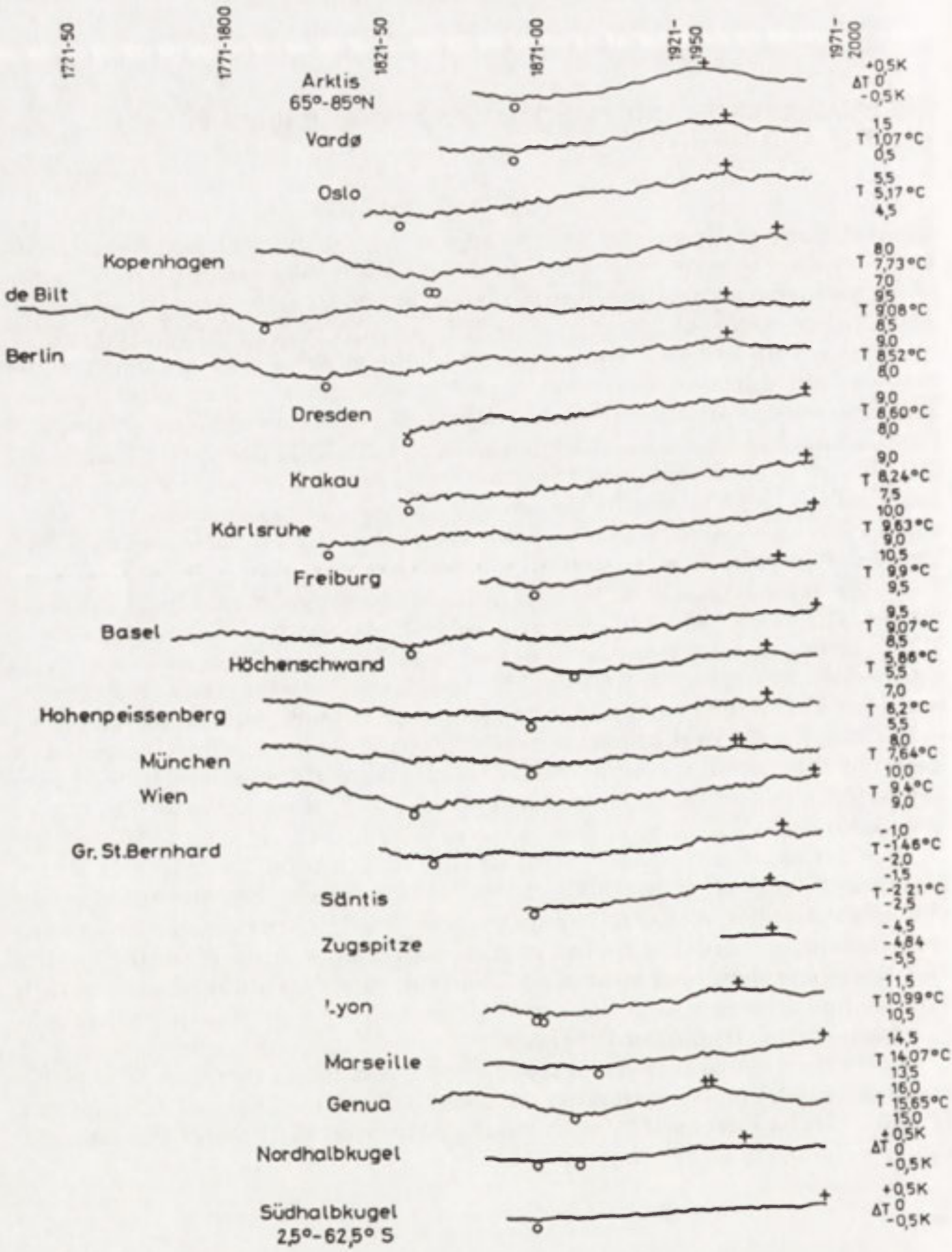

Fig. 5. Contemporary warming in Northern hemisphere, according to H. v. Rudloff (1991)

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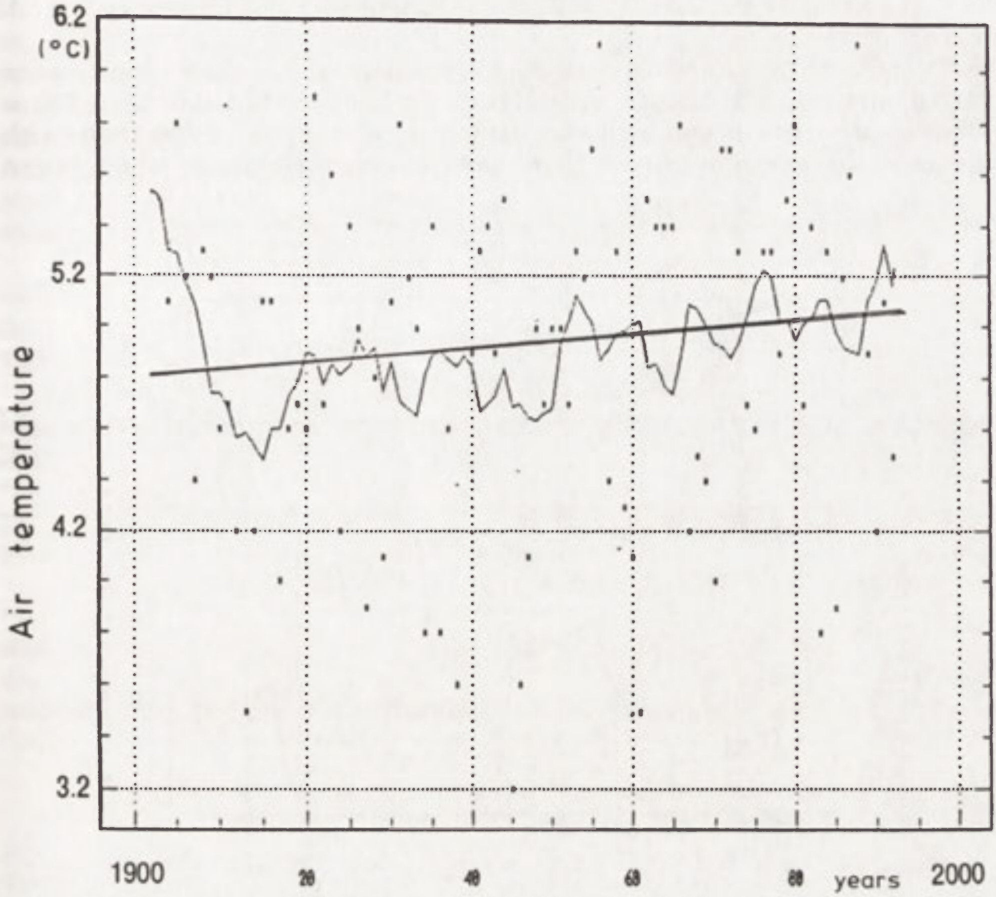

Fig. 6. 11-year running means of annual air temperature in Zakopane

LONG-TERM TRENDS OF CHANGES IN AIR TEMPERATURE, SUNSHINE DURATION AND PRECIPITATION IN VERTICAL PROFILE ON THE CARPATHIANS

It is difficult to find long series of climatological observations for the areas, where the influence of anthropogenic factor can be excluded. Data from the mountains fit best to such conditions. Air temperature changes in the Tatras may be characterized starting from 1951 for the stations at Hala Gąsienicowa (1520 m) and at Kasprowy Wierch (1991 m) and from 1910 for Zakopane (844 m). It results from the curves of 10-year running means (Fig. 7) that the period of cooling occurred in higher parts of the mountains in 1973-1984 which is much later than it did in Cracow (221 m), where it occurred in 1952-1968. Distinct upward trend of temperature appeared in the Tatras only after 1984 (Niedźwiedź 1992). The variability of thermal conditions diminishes with the increase in altitude. The oscillations of 10-year means reached 0.6°C in Cracow,

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0.4°C in Zakopane and only 0.2°C at Hala Gąsienicowa and Kasprowy Wierch in the years 1951-1990.

Precipitation measurements in the Carpathians and in their vicinity were started relatively late. The longest series for Cracow was started in 1849. Three relatively dry periods can be distinguished since that time: 1850-1890 (with minimum precipitation around 1946) and contemporary period which began

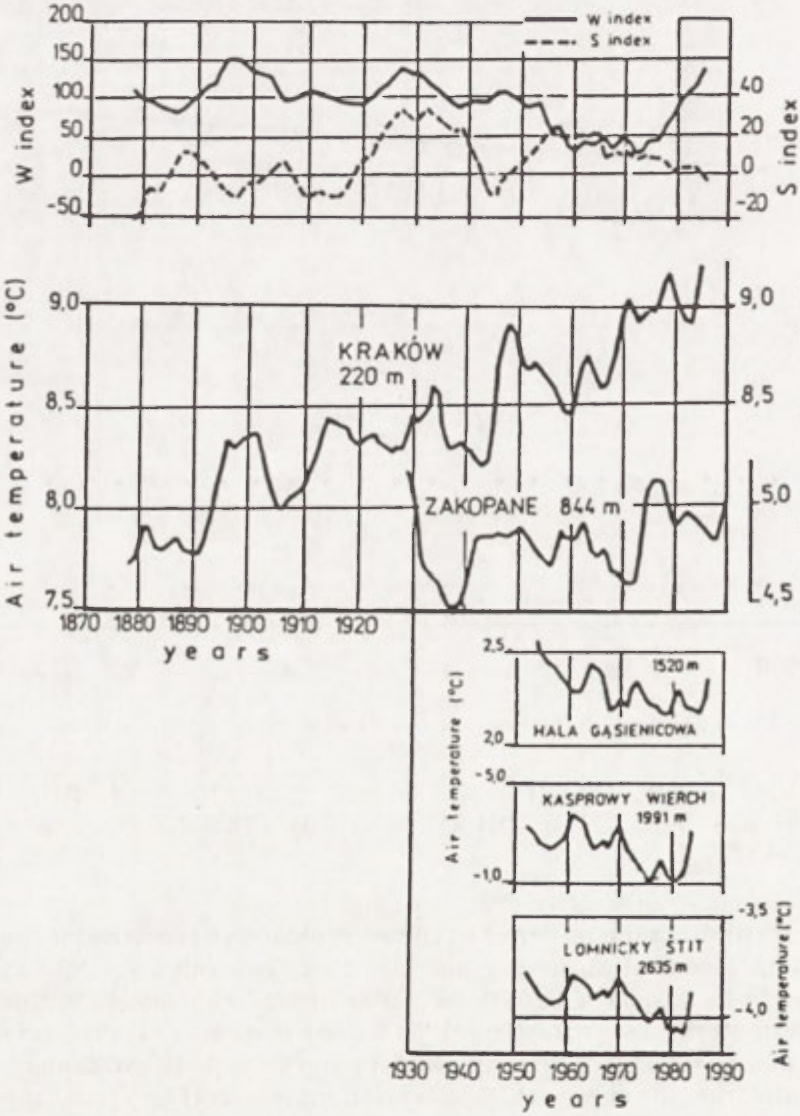

Fig. 7. Changes of annual characteristics of atmospheric circulation and annual averages of air temperature in the Tatra Mountains and Cracow (the curves are smoothed by 10-year running means). High values of the W-index indicate greater frequency of western air flow from the Atlantic Ocean. Positive values of S-index indicate the predominance of Southern air flow over Northern air flow

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in 1975 and lasts up till now. Wet periods occurred in 1867-1919 (with maximum in 1900-1909) and in 1955-1974. The present trend towards dry and warm years seems to be quite stable. The oscillations of precipitation decrease with altitude. The range of oscillations reached 20% of the highest 10-years mean of precipitation totals in Cracow and 17% in Zakopane (in 1901-1990), 14% at Hala Gąsienicowa and only 10% at Kasprowy Wierch (the last two stations have data only for the period 1951-1990). The increase in altitude attenuates the intensity of fluctuations and increase in precipitation amount.

Sunshine duration is an important climatic element informing about the influence of solar factor. Series of heliographic measurements for Cracow come from 1859-1990, for Zakopane from 1924-1990, for Hala Gąsienicowa from 1951-1990 and for Kasprowy Wierch from 1947-1990.

Sunshine duration in Cracow has downward trend, although means of total hours with sunshine were higher in the 60s and 80s of the 19th century and in the 40s of the 20th century than long-term mean value. The downward trend of sunshine duration lasted generally till 1977. The decrease was large, mean annual sunshine duration decreased by 430 hours in the period of 30 years. The increase in sunshine duration has been observed since 1978.

Changes of sunshine duration in the Tatras in the last 40 years are worth mentioning. Minimum sunshine duration total occurred at Hala Gąsienicowa and at Kasprowy Wierch in 1976, i. e. in the similar period as in Cracow. The decrease in sunshine duration was observed in the whole Carpathian area and was not caused only by local factors. The increase of sunshine duration since 1976 is also common of the whole area.

RECONSTRUCTION OF THERMAL AND PRECIPITATION CONDITIONS IN THE TATRA MOUNTAINS ON THE BASIS OF DENDROCLIMATOLOGICAL DATA

Annual rings of long-living trees can supply interesting information about climate changes in the past (Fritts 1976). The most suitable for that purpose are the trees from the zone of timberline. The main climatic factor limiting the thickness of their annual rings is low air temperature during short growing season (Tranquillini 1979, Schweingruber 1983). In the case on stone pine (*Pinus cembra* L.) from the Polish Tatras, the dependence of annual rings thickness on mean air temperature of June and July for the period of years from 1911 to 1965 can be represented by the correlation coefficient $r_{xy} = 0.772 \pm 0.052$ and similarity coefficient of 80% (Bednarz 1984). Large totals of precipitation during the growing season, influencing the decrease in air temperature, limit the growth of tree rings. Exact dependence of annual rings thickness of stone pine (y) upon mean monthly air temperature of June and July (x), described by the linear regression equation $x = 8.13 + 0.202y$, enabled the reconstruction of thermal conditions in these months since 1741 (Fig. 8).

The analysis of the curve representing the changeability of air temperature of June and July in the past indicates the existence of a few periods of deep

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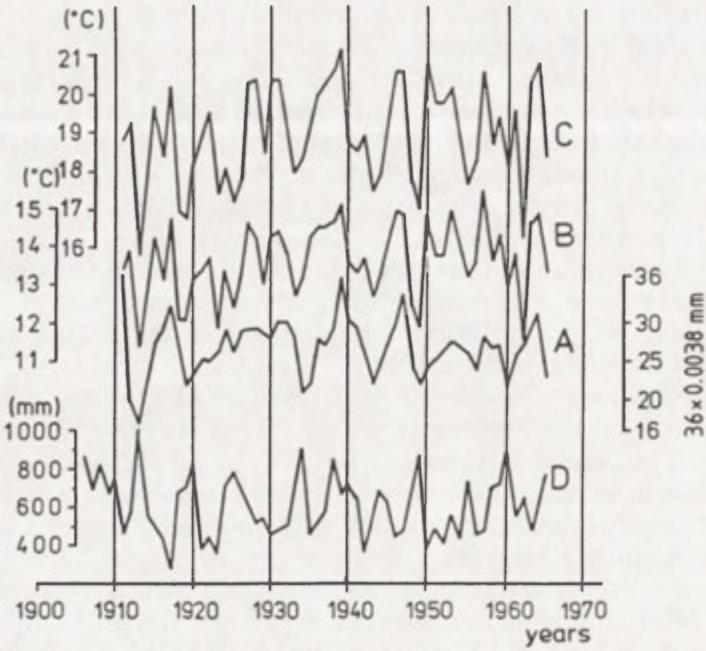

Fig. 8. Comparison of mean thickness of annual rings of stone pine (A) in the Tatras with mean air temperature in June and July (B), mean maximum air temperature (C) and precipitation total in May-August (D) in Zakopane

thermal depressions. Information from the years 1740-1850 is particularly interesting, because there is little meteorological data for that period. The first distinct period of cooling occurred in the Tatras in the years 1740-1750 (Fig. 9). Analogical phenomenon was observed in the Alps (Eckstein, Aniol 1981). The years 1741-1747 were the coldest in both these mountain ranges. The consequence of this phenomenon in the Alps was the increase in the size of glaciers (Messerli et al. 1978). The next period of coolness occurred in the years 1760-1773. It was even more distinct in the Alps.

The third and longest cool period, called the last episode of the Little Ice Age occurred in the Tatras and the Alps in the first half of the 19th century. It was characterized by the occurrence of many unusually cold and humid years. It was reflected in unusually thin annual rings of stone pine. The year 1816 stands out among the cold years and is called "the year without summer" by climatologist (Stommel, Stommel 1979). The years 1806-1811, 1815, 1817-1829, 1835-1845 were also wery cold and humid (Bednarz, Trepińska 1992). Violent processes of glacial expansion occurred in the Alps during these exceptionally cold periods. The last episode of Little Ice Age influenced the social and economical situation in Poland especially in 1815 and 1816. The press informed of food shortages, price rises and weather anomalies (Sadowski 1980). For example, a newspaper "Gazeta Lwowska" from 1816 reported that "In the information on this year's harvest received from Biala on October 13, 1816, we read that for over 30 years the inhabitants have not remembered such

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bad weather conditions. From autumn 1815 rains have not stopped up to the present day, except for a few weeks of better weather from the end of August to the middle of September".

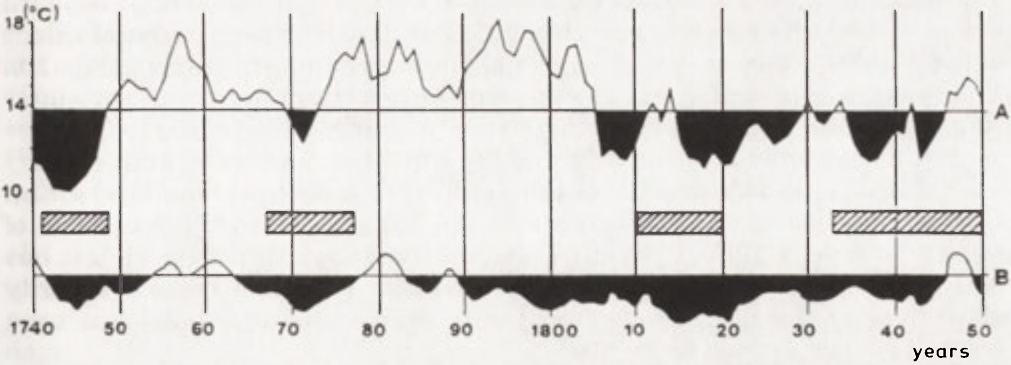

Fig. 9. Cooling in the first half of the 19th century (the last episode of the Little Ice Age) in the Tatras, reconstructed on the basis of the analysis of the thickness of annual rings of stone pine (*Pinus cembra* L.)
A — Oscillations of mean air temperature in the Tatras in June and July 1740-1850;
B — Dendroclimatological reconstruction of air temperature in the Alps in summer (Eckstein, Aniol 1981). Periods of increased glacial activity are marked with rectangles

Many climatologist claim that one of likely causes of cooling in the first half of 19th century was the increase in volcanic activity (Lamb 1970, Budyko 1971; Kelly, Sear 1984). Particular attention is paid to the eruption of Tambora volcano in April 1815, said to be "the largest and deadliest volcanic eruption in recorded history" (Slothers 1984). The eruption of Katmai volcano in Alaska in 1912 confirms this hypothesis. The transparency of atmosphere dropped after this eruption from 0.77 to 0.56 (Kalitin 1938). Such state was maintained for two following years, causing huge reduction of direct solar radiation intensity. As a consequence, sudden decrease in thickness of annual rings and wood density occurred in large area of Europe, especially in the zone of timberline in the Tatras and the Alps (Schweingruber et al. 1979, Bednarz 1984).

CHANGES IN THERMAL SENSIBILITY OF HUMAN BODY IN WINTER IN THE 20TH CENTURY

As it was revealed by many investigations, the variability of air temperature in winter depends mainly on circulation conditions and cycles of Sun activity. Thermal feelings of a man in winter may be described by Osokin's S index of weather severity. Values of this index for winters of 20th century are determined by the influence of air temperature in 77% and by the influence of wind velocity in 20% (Obrębska-Starklowa 1990). It is an important advantage od the S index, that it takes the influence of air temperature amplitude into

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account and thereby reflects the influence of air masses incoming from various source areas.

The average value of S index for winters in the 20th century amounted to 1.33 in Cracow, which means that winters were "slightly severe". Standard deviation of the S index was equal to 0.225. Trends in long-term course of values of the S index can be read on the basis of 10-year running means S_{10} (Fig. 10). They have reverse course to that of 10-years means of air temperature in winter (Fig. 3) and are related to the occurrence of macrotypes according to Girs.

In can be stated that the first and the second decade of the 20th century were characterized by small deviations of S indes value from long-term mean. Distinct increase in S_{10} value began in the 20s and lasted till the period of severe winters (S>1.90) in the 40s. Constant trend towards milder winters has been observed since that time with the exception of slight increase in severity of winters in the 60s. The series of very mild winters (S<0.95) has been occurring since the end of the 80s.

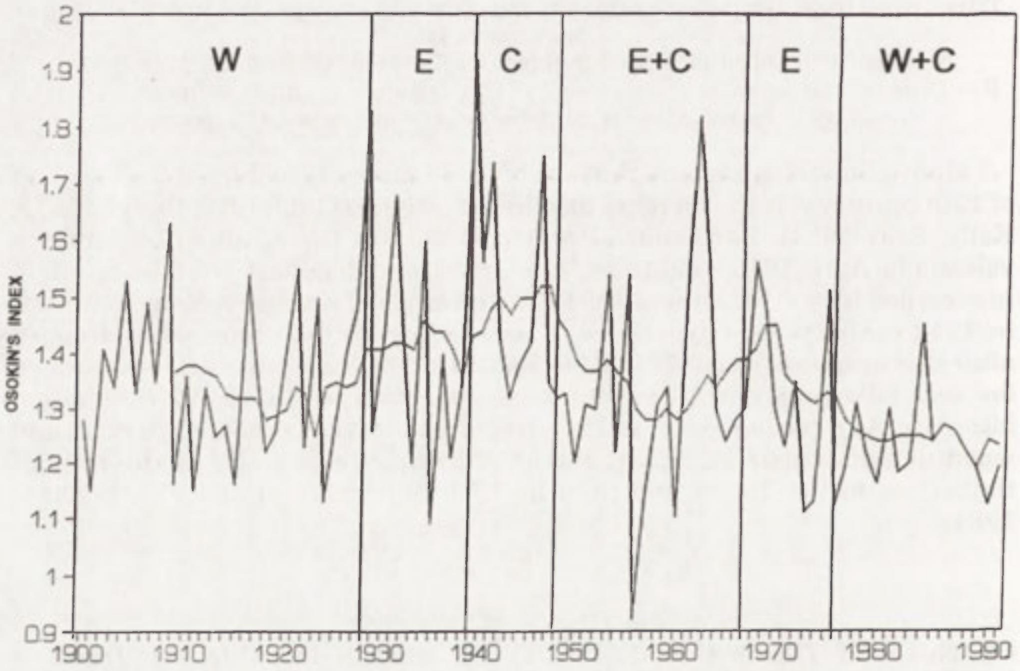

Fig. 10. Changes in thermal sensibility in winters of the 20th century
period of zonal circulation W in 1990-1928; period of eastern meridional circulation E in 1929-1939; period of southern meridional circulation C in 1940-1948; period of mixed circulation E + C in 1949-1967; period of eastern meridional circulation E in 1968-1976; period of mixed circulation W + C since 1977.
Osokin's index of winter climate severity (S): <1.0 — mild winters; 1.0-2.0 — slightly severe winters; 2.1-3.0 — moderately severe winters; 3.1-4.0 — severe winters; 4.1-5.0 — very severe winters; 5.1-7.0 — unusually severe winters; > 7.1 — extremely severe winters

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CHANGES IN TRANSPARENCY OF ATMOSPHERE AND SOLAR RADIATION CAUSED BY URBAN DEVELOPMENT

Results of measurements carried out by cloudless weather in 1968-1985 were used to characterize the influence of anthropogenic factors upon the transparency of atmosphere and the components of radiation balance (Olecki 1986, 1992; Hess, Olecki 1990). They were carried out under conditions of severely polluted atmosphere in the centre of Cracow (φ = 50°53', λ = 19°56', Hs = 206 m) and for comparison in the area away from the urban and industrial influences in Gaik-Brzezowa (φ = 49° 52', λ = 20°04', Hs = 260 m).

Mean monthly indices of atmosphere transparency reduced to the same elevation of the Sun above the horizon of 30° oscillate between 0.78 in winter to 0.58 in summer in the surroundings of Cracow where there is no anthropopression (Fig. 11). Values higher than 0.70 are the most commo in for winter days. They amount to 80% of all measurements in December, 10% of which are values higher than 0.80. The transparency of atmosphere in summer is lower; 65% of the measurements are the values lower than 0.65.

Mean monthly transparency indices in the polluted air of Cracow oscillate from about 0.50 to 0.72 in the same period (Fig. 12) without having a regular yearly course. They have a distinct downward trend, especially in the latest years of the discussed period. 75% of measurements are the values between 0.50 and 0.70, only 16% exceed 0.70 and 7.5% are the values below 0.50. There are 7-9% of summer measurements that amount to values below 0.40.

Transparency of atmosphere in Cracow in the whole period 1968-1985 generally lower than in the areas without urban influence (Fig. 13). Differences in atmosphere transparency between the city and its surroundings increase.

Lower transparency of atmosphere in the city makes the intensity of direct solar radiation 30-40% lower in winter and 10-15% lower in summer in comparison to area outside the city (Fig.14). Diffused radiation does not make up for the loss in solar energy income caused in this way. As a result, global radiation in the city is 10-25% lower than outside it.

Atmosphere pollution in the city, changed properties of earth surface, emission of vast amounts of artificial heat cause better energetic balance in the city. Higher air temperatures in the city are caused by that fact.

CONCLUSIONS

The presented characteristics of climate changes in the period of instrumental measurements in Southern Poland allows to put forward some questions dealing with reconstruction of climatic conditions in the past and their forecasting in the nearest decades. These questions are as follows:

1. How is the natural changeability of circulation factors, which make a background for human activity factors, formed?

2. What is the accuracy of reconstruction of climate changes in Southern

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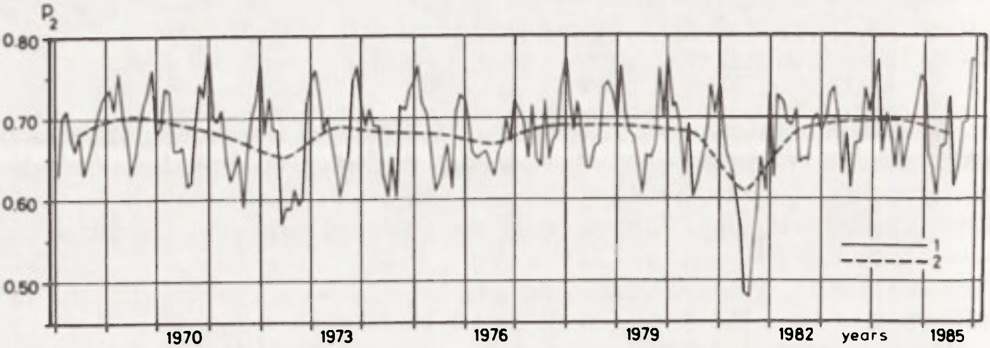

Fig. 11. Mean monthly (1) and annual (2) values of the atmosphere transparency coefficients (p_2) under cloudless weather conditions at Gaik-Brzezowa

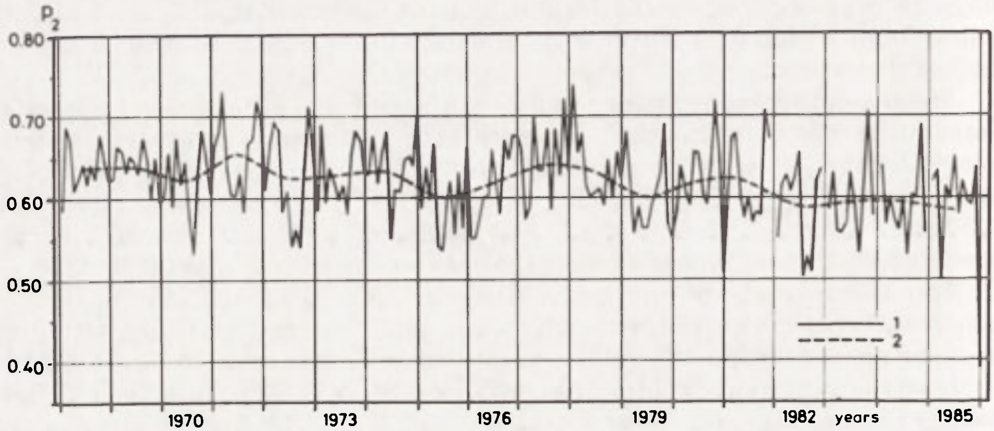

Fig. 12. Mean monthly (1) and annual (2) values of atmosphere transparency coefficients (P_2) under cloudless weather conditions in Cracow

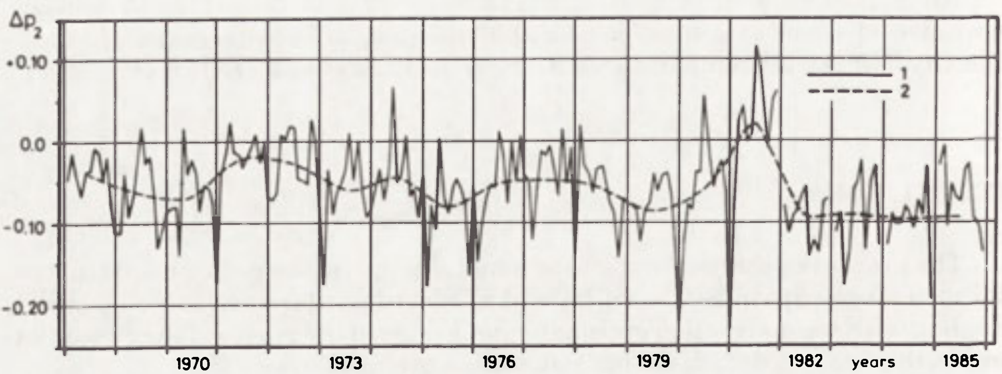

Fig. 13. Differences between mean monthly (1) and annual (2) values of the atmosphere transparency coefficients (Δp_2) under cloudless weather conditions in Cracow and at Gaik-Brzezowa

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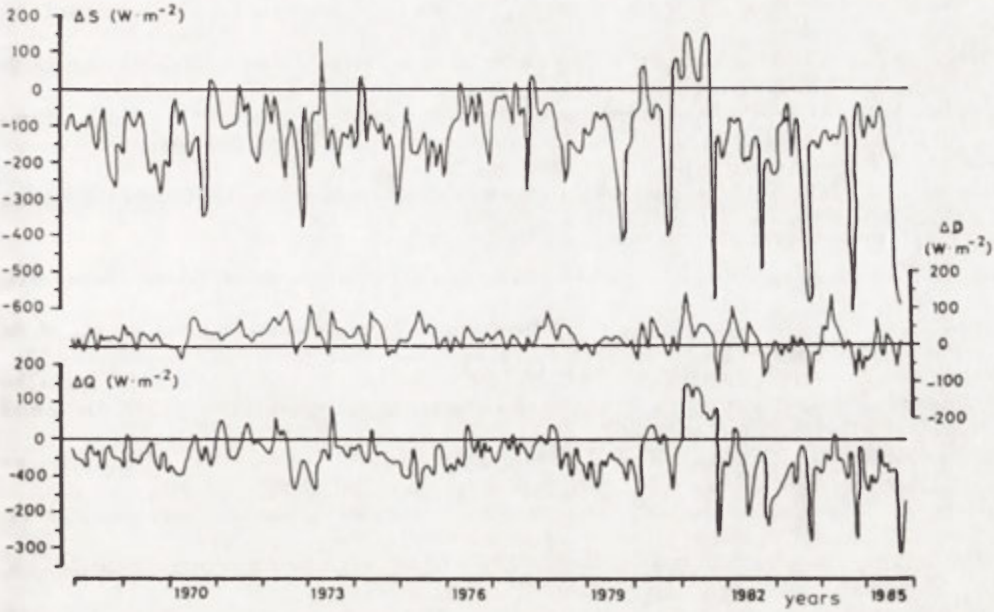

Fig. 14. Differences in the intensity of the direct radiation (ΔS), diffused radiation (ΔD) and the global radiation (ΔQ) between Kraków and Gaik-Brzezowa during cloudless weather at noon

Poland before the period of instrumental measurement, using proxy data e.g. dendroclimatological data?

3. How great is the importance and share of natural and anthropogenic factors in forming the set of climatic elements such as air temperature, precipitation and sunshine duration, which influence the ecosystem and the conditions of human life?

It is needed to study following periods to be able to answer the last question:

— period of increase in air temperature and concurrent increase in sunshine duration and decrease in precipitation totals in the 80s of the 20th century;

— period of decrease in air temperature and concurrent decrease in sunshine duration and large totals of annual precipitation totals in the years 1955-1975.

It is also necessary to study farther the climatic conditions at the end of the Little Ice Age and in the period of global warming of climate to determine how changes in intensity of climatic factors influence the natural environment and human activity.

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GENERATION OF TIME SERIES OF THE METEOROLOGICAL VALUES IN CHANGING CLIMATIC CONDITIONS

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ABSTRACT: The authors discuss the average air temperature and mean precipitation amounts in long-term and short — time variability. This research may be a starting point for combining GCM's models (GFDL and GISS) used to forecast spatial distribution of climatic changes in hydrological models on the territory of Poland.

Methods of grid simulation using 90-year and 30-year sequences provide sufficient statistical material for a relatively precise estimation. Authors presented stochastic generation of meteorological data in others time step (daily, monthly and yearly) by Markov chain.

KEY WORDS: scenarios of global climate change; GCM models application (GFDL, GISS); generation of meteorological data (air temperature, precipitation); Markov chains application.

INTRODUCTION

Changes in the course of global geophysical processes may affect the size and time schedule of the elements of the hydrological cycle in a catchment. Water balance, which constitutes a quantitative approach to this cycle in the scale of the particular catchments, is highly sensitive to global changes of the air temperature and precipitation that determine the vertical and horizontal water exchange.

Using uncertain scenarios of changes that regard a global climatic warming as the main reason for unstationary circulation of water in a catchment, a simulation of the mean annual values of fields of the air temperature and precipitation over the territory of Poland was done. It constitutes the chief reference to the values of global changes to which the elements of water cycle will be subjected.

Thus, the field of the air temperature was generated out on the basis of average values for 30 years (1951-1980) from 58 meteorological gauges (Materials for the Climatological Atlas 1989), and in order to generate a field of precipitation, average yearly values of total precipitation for 90 years (1891-1980) from 57 gauges were used (Chrzanowski 1988).

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A construction of the method of generating daily sequences of the air temperature and precipitation in a point, i.e. the location of a meteorological station, cames from empirical values and data combined from the following components: an annual signal, as well as stationary annual, monthly and daily anomalies (Jakubiak 1990).

The method of generation was applied to the 30-year (between 1961 and 1990) sequence of daily values of the air temperature and precipitation at meteorological station — Brwinów (near Warsaw).

GENERATION OF NORMAL VALUES OF THE AIR TEMPERATURE AND PRECIPITATION WITH ASSUMED SCENARIOS OF CLIMATIC CHANGES

Sensitivity of catchment to climatic changes is most often considered in relation to changes of radiation balance whose index is the air temperature, and to changes in humidity balance essentially dependent on atmospheric precipitation.

Models of global changes of climate developed in recent years particularly in the USA and Great Britain permit a creation of scenarios of changes based precisely on these meteorological elements.

In the Division of Water Resources of the Institute of Geophisics of the Polish Academy of Sciences prof. Z. Kaczmarek[1] has been conducting a research for several years aimed at adaptation and verification of some chosen climatic scenarios within the territory of Poland.

Research on the influence of climatic changes on the course of meteorological elements, on runoff and evapotranspiration in particular, is being carried out twofold.

The first approach consists of a simulation of hydrological processes by using physically justified mathematical models of catchments and assumptive scenarios of changes of meteorological elements; the second is aimed at defining a degree of sensitivity of the particular processes of the hydrological cycle to climatic warming due to the greenhouse effect.

In this research, which is the first step to combine climatic and hydrological elements, two scenarios were chosen corresponding to double concentration of CO_2 in the atmosphere worked out for Europe according to global models of circulation GCM (General Circulation Model): GFDL model (Geophysical Fluid Dynamic Laboratory) and GISS model (Goddard Institute for Space Studies).

Results for these models for the region of Central Europe were obtained from the National Center for Atmospheric Research (NCAR) in Boulder, USA, version of the model before 1989 (Scenariusze... 1992).

Both global GCM models realize scenarios of climatic changes which envisage increase in the air temperature as well as in atmospheric precipitation.

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[1] The authors wish to thank prof. Z. Kaczmarek for supplying them with the scenarios of climatic changes according to the GFDL and GISS models.

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Output data from global models appear in the form of files each of them with the scenarios of climatic changes according to the GFDL and GISS models of values of temperature and precipitation corresponding in the nodes of the net to data along scenario 0 ($1 \times CO_2$) that is to natural conditions and data resulting from a doubled value ($2 \times CO_2$). At that, in the case of temperature, increase in the air temperature was taken into consideration ($+\Delta t$), while in the case of precipitation the relation of precipitation in accordance with scenario 0 and scenario ($2 \times CO_2$) was used.

Numerical values of assumed climatic changes were defined in nodes of the geographical grid of separation 1 degree of latitude by 1 degree of longitude, (i.e. $\approx$ 80 km $\times$ 80 km).

Central Europe as a region has an area limited by 45 degrees and 55 degrees of latitude N and by 10 degrees and 25 degrees of geographical longitude E was adopted. The region of Europe distinguished, going beyond Poland's territory, was divided into 150 unit entry files of dispatching 1 degree of latitude by 1 degree of longitude. To carry out the so-called down-scaling of climate information from GCM models in the territory of Poland, several numerical procedures ought to be applied.

The map of Poland scaled 1:3 mln in quasi-stereographical secant projection in the system type of GUGiK 1980 (Grygorenko 1985) was used as a base map. Transformation of the geographical system into the system of regular (Cartesian) coordinates was made using the ADS procedure in the set of the programme PC ARC/INFO. The base of meteorological data was created using the programme Dbase IV. From this data base the values of geographical location of climatological stations were generated using procedure PROJECT which permits a transformation to quasi-stereographical projection. Next, using procedure TRANSFORM the location of stations was transformed into the system of cartographical coordinates.

The SURFER package was chosen for interpolation and presentation of the results obtained.

As an interpolation net for the spatial model of climatological elements a square grid of dimension of cells 2 $\times$ 2 mm on the same scale as the base map was used (in fact, the dimension of the field (cell) of interpolation amounted to 6 km $\times$ 6 km). In the interpolation the area outside the contour of Poland was "covered up".

The method of kriging for spatial interpolation was applied to construct the field of the air temperature.

The method of kriging is based on the assumption that the expected value is equal to the difference $[z(x) - z(x + h)^2]$, where $z(x)$ is the value of a meteorological variable at the station, while h indicates the distance between the stations.

The method of kriging is confined to estimation of ordinates (z) in the nodes of the grid on the basis of values of the measuring points. The method assumes that the mean value of errors during estimation amounts to 0, while the variance is the least possible. For interpolation of precipitation the method of reverse distances between climatological gauges was used (Tański 1990).

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Interpolation procedures permitted the creation of simulation maps in the two-dimensional form of isopleths (isohiets and isoterms). (Figs. 1, 2, 3 and 11, 12, 13) and three-dimensional block diagrams representing the spatial distribution of chosen meteorological elements in Poland's territory (Figs. 4 to 9).

Numerical and graphical areas obtained made it also possible to construct charts representing the relation of the numerical value of the meteorological element to the area limited by the isoline of the same value as the above-mentioned isoline. Curves of total annual precipitation distribution illustrate the share of Poland's territory (in per cent) enclosed between the successive isohiets or isoterms of mean annual values of the air temperature (Figs. 10 and 14).

Each successive stage of the graphical analysis of fields of meteorological elements was referred to scenario 0 (under the existing meteorological conditions) and to two global models GFDL and GISS, which permit a simulation of changes of meteorological elements according to the scenario of double increase of CO_2 contents.

The disadvantage of the acquired simulation is the fact that the realized grid model takes into consideration mathematical but not geographical interpolation; therefore in the areas with high gradients of meteorological elements, especially

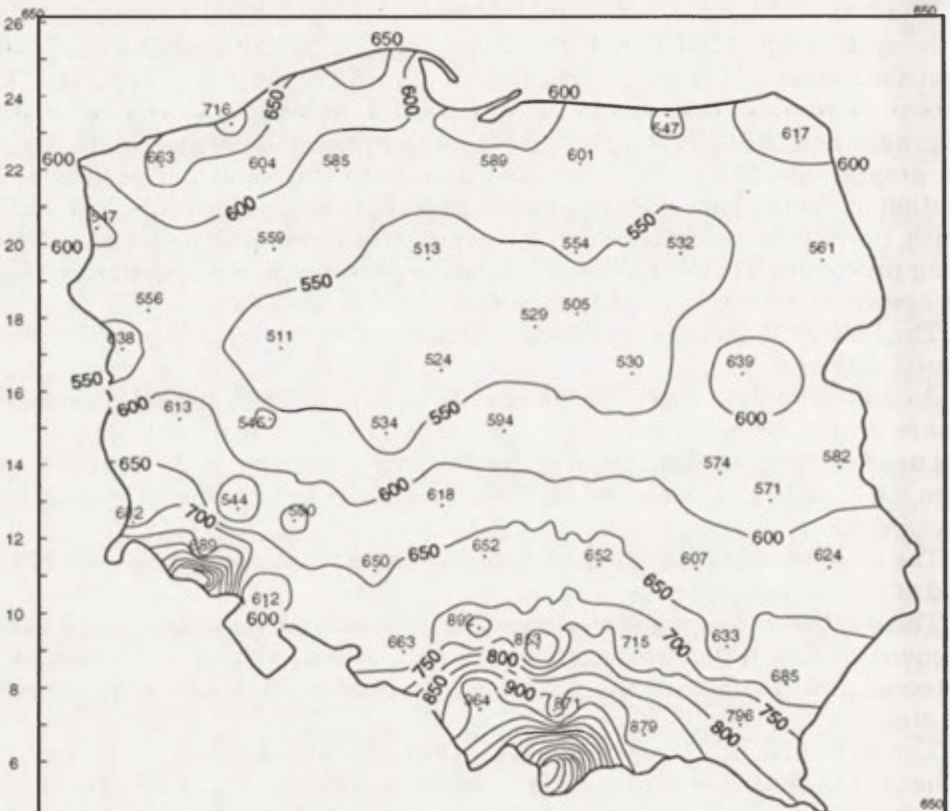

Fig. 1. Normal precipitation in (mm) in (1891-1980), scenario 0

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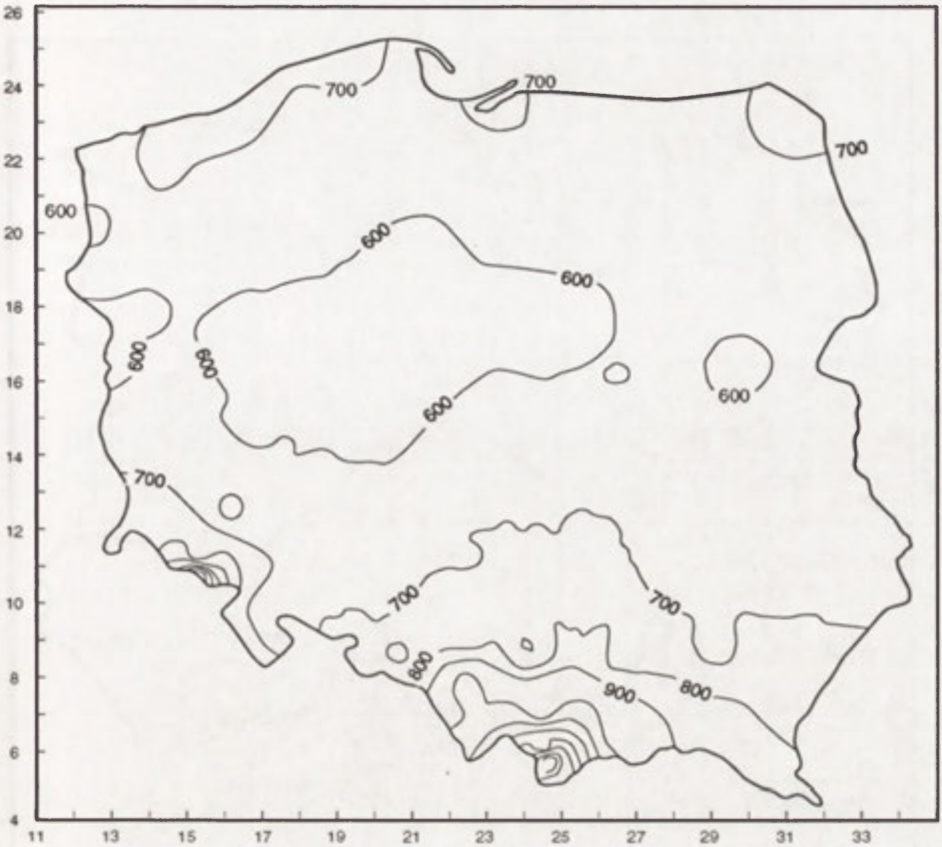

Fig. 2. Generation of normal precipitation in (mm), scenario ($2 \times CO_2$) — according to GFDL model

in the mountains and in uplands, there may be great differences between the empirical values and those obtained from linear interpolation. Thus deviations will appear on areas of small density of the measuring stations.

Graphical and numerical areas obtained will be the starting point for the search of the method of constructing of transition to sub-scaling models indispensable for realization of changes of water circulation due to climatic warming in the mezo- and macro-scale system.

The input data for simulation models according to scenarios of changes of the air temperature and precipitation (monthly, half-yearly and yearly) obtained from GISS and GFDL models and introduced into the hydrological model of a catchment slightly differ. The above-mentioned scenarios of climatic changes envisage the increase in the air temperature on the ground level by about 4°C and the increase in precipitation over most of the whole year by 10 mm (except for September).

In the GISS model the increase of precipitation ranges from 1.1 mm to 13.2 mm, while the GFDL model expects the increase of precipitation to be slightly below 10 mm, with the exception of August, when the increase is >30 mm, and

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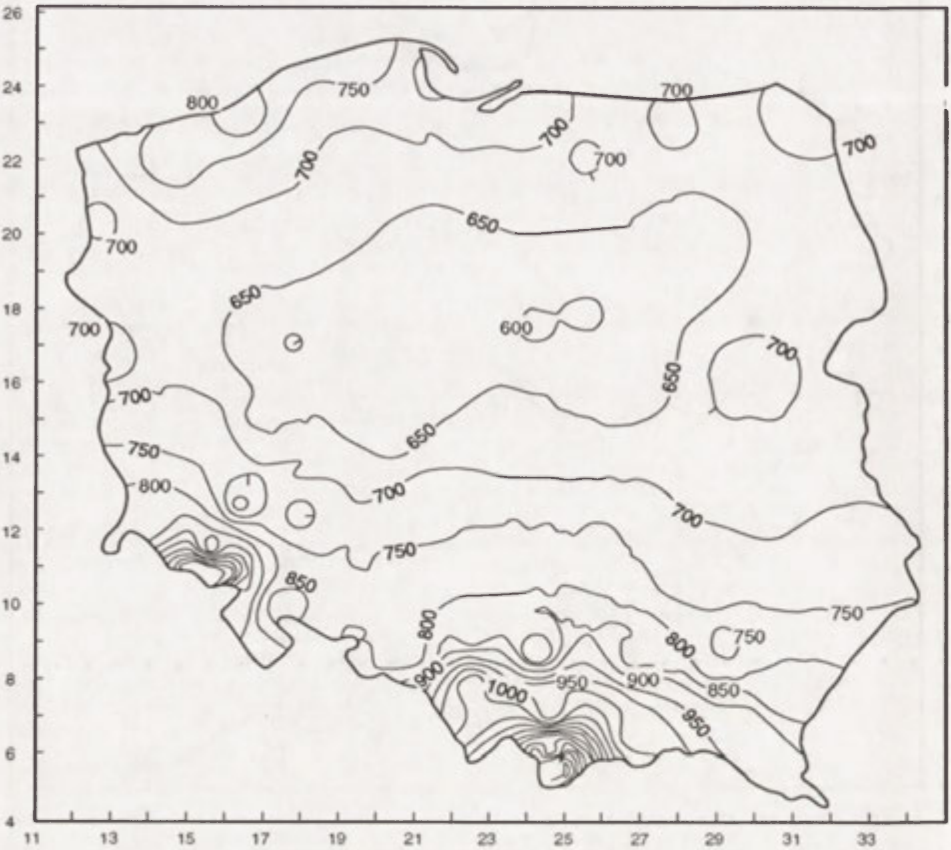

Fig. 3. Generation of normal precipitation in (mm), scenario (2 × CO_2) — according to GISS model

June, September and October, when precipitation decreases = 5 mm (Ozga-Zielinska 1992).

The interpolated fields of changes of the air temperature and atmospheric precipitation in relation to normal real precipitation and simulated precipitation provided grounds for estimation of differences in values of these elements obtained from global models GISS and GFDL.

Differences between the areal average of the annual value of the precipitation total (half of the area of Poland) in natural conditions amount to 639 mm, according to the GISS model they will reach 749 mm, while according to the GFDL model annual precipitation is expected to amount to 655 mm (Fig. 10).

Over half of Poland's territory the value of the air temperature in natural conditions amounts to 7.7°C, while according to the scenario of doubled CO_2 contents in the GISS model it will amount to 10.5°C, while in the GFDL model it will reach 11.9°C (Fig. 14).

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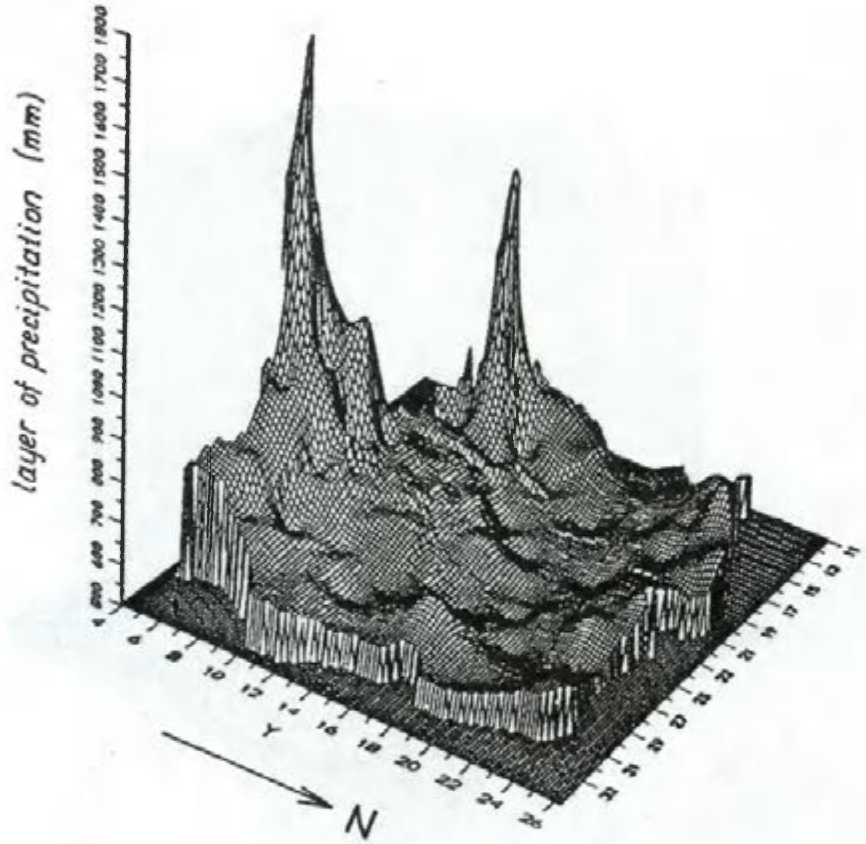

Fig. 4. Three-dimensional distribution of normal precipitation in (mm), in 1891-1980, scenario 0

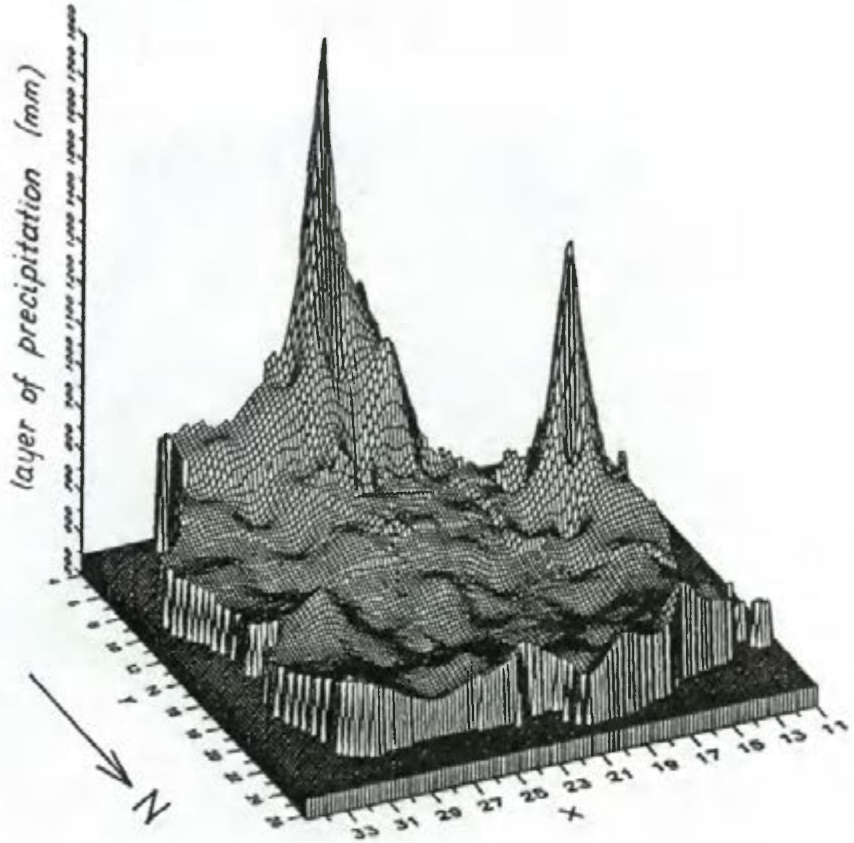

Fig. 5. Three-dimensional distribution of normal precipitation in (mm), scenario ($2 \times CO_2$) — according GFDL model

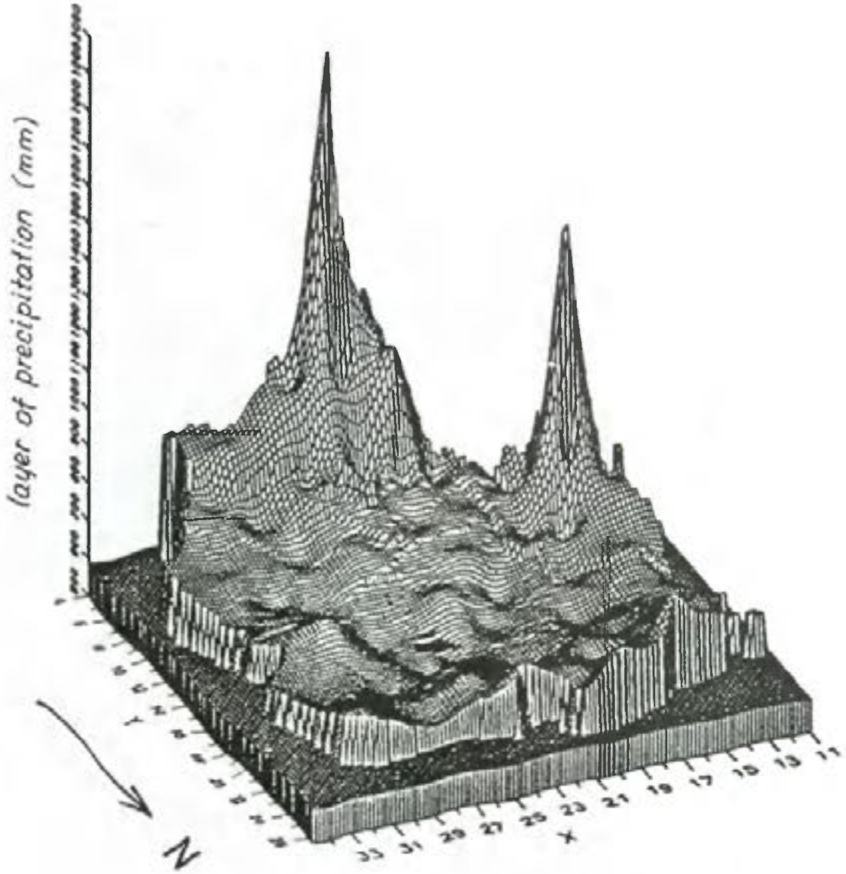

Fig. 6. Three-dimensional distribution of precipitation in (mm), scenario ($2 \times CO_2$) — according GISS model

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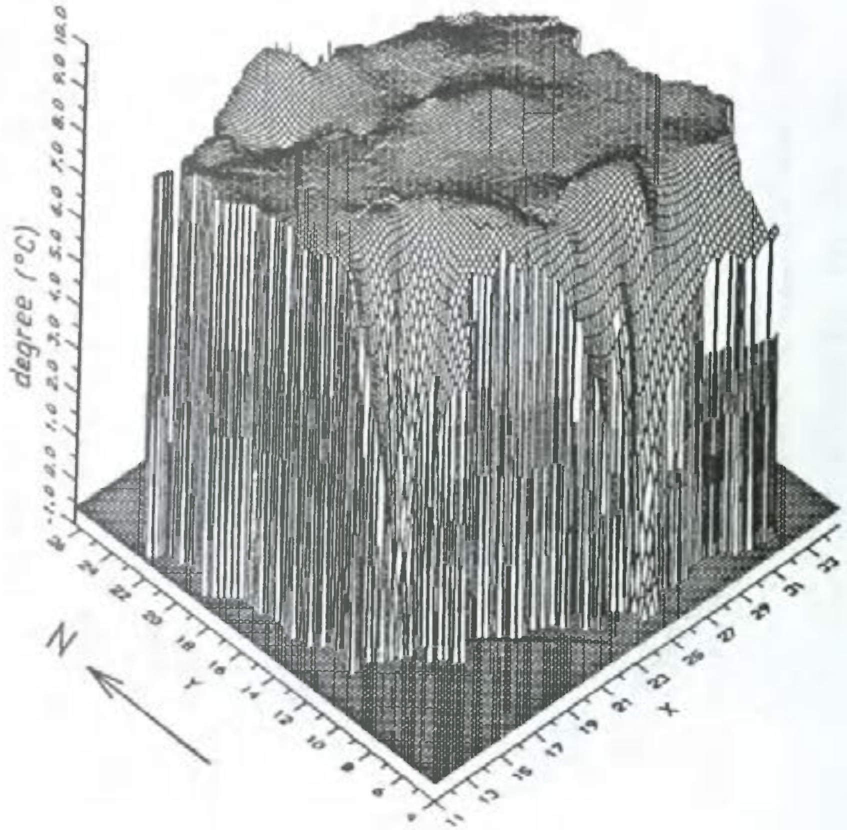

F g. 7. Three-dimensional distribution of the average air temperature (1951-1980), scenario 0

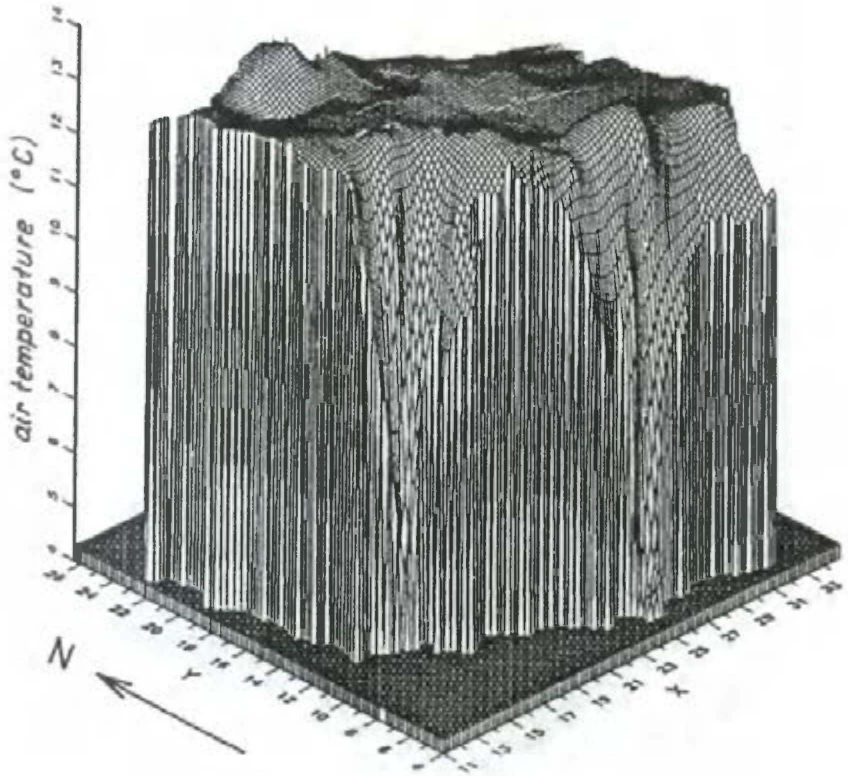

Fig. 8. Three-dimensional distribution of the average air temperature, scenario ($2 \times CO_2$) — according to GFDL model

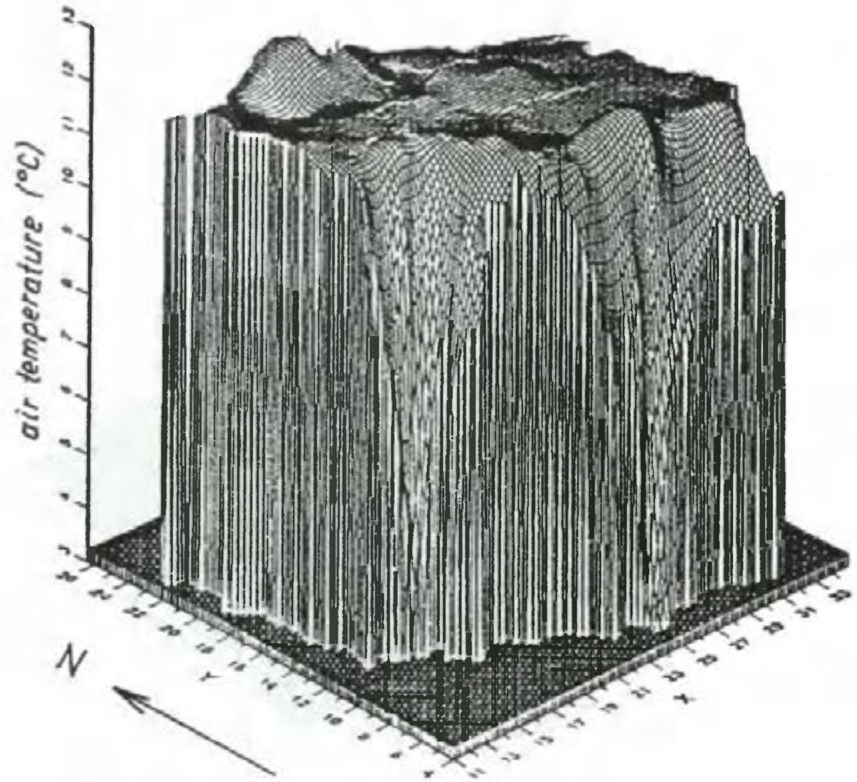

Fig. 9. Three-dimensional distribution of the average air temperature, scenario ($2 \times CO_2$) — according to GISS model

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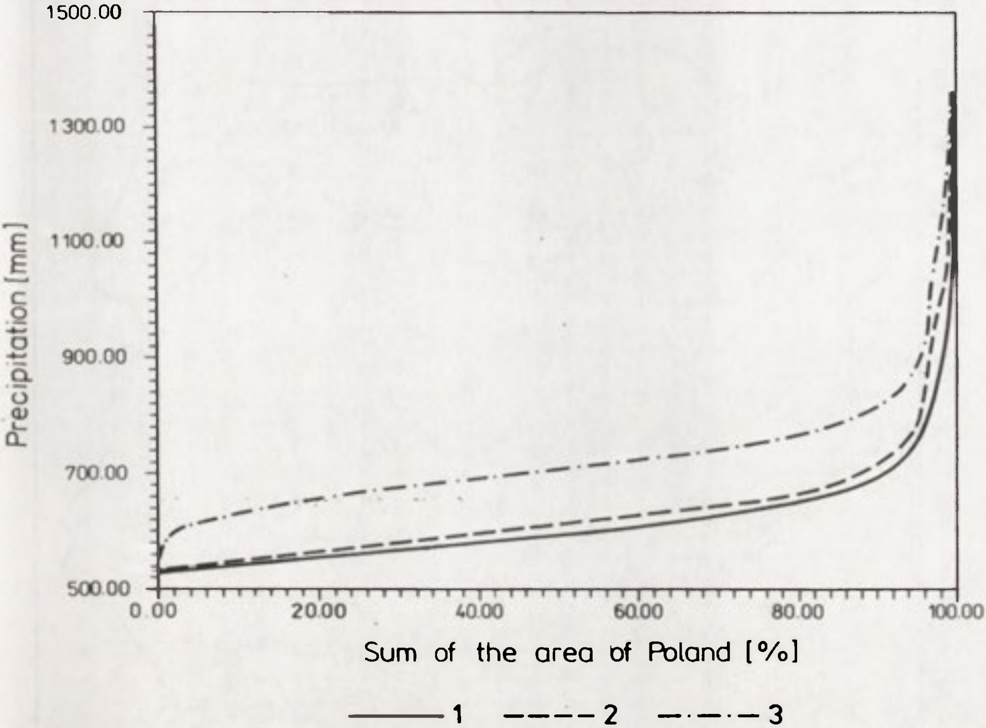

Fig. 10. Areal distribution in Poland in (%) of normal precipitation
1 — period 1891-1980 (scenario 0); 2 — generation according to GFDL (scenario (2 × CO_2) model); 3 — generation according to GISS (scenario (2 × CO_2) model)

METHOD OF GENERATING THE DAILY SEQUENCES OF AIR TEMPERATURE AND PRECIPITATION VALUES WITH GIVEN STATISTICAL PROPERTIES

An analysis of the time series of meteorological elements observed in the points shows that each measurement constitutes a sum of several different components. Some of them are deterministic, while others can be regarded as the effect of the stochastic process. Construction of the method generating the sequences of mean daily values of the air temperature stemmed from estimation — according to the measurement data — of the following components: annual signal, daily stationary anomalies, monthly stationary anomalies and yearly stationary anomalies.

Daily values of total precipitation are subject to variations in space as well as in time, while the nearby measuring points and neighbouring time intervals show a significant degree of similarity. Probabilistic models are an appropriate method permitting a study of both variability and correlation between daily precipitation totals. They are useful for description of meteorological processes in the function of several significant parameters and they are indispensable for drawing proper statistical conclusions about meteorological data.

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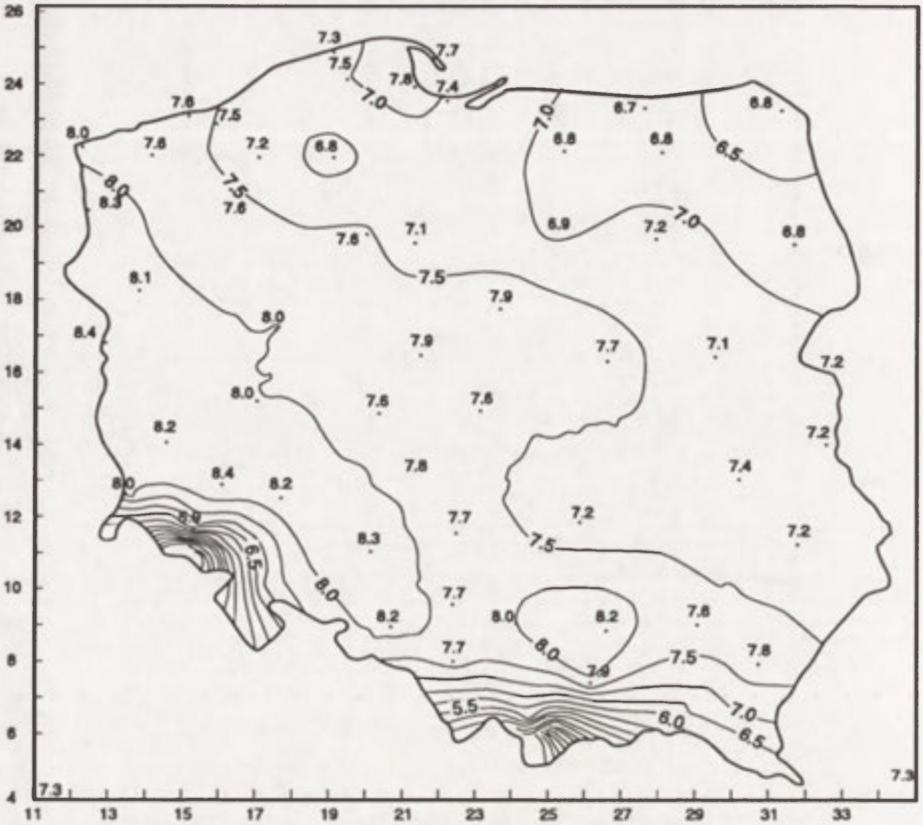

Fig. 11. The average air temperature in (°C) in (1951- 1980), scenario 0

The first probabilistic models were used by K.R. Gabriel and J. Neumann (1962) in the Markov chain of the first order for mathematical description of daily precipitation in Tel Aviv. Generalization of the model of daily precipitation as the function of two variables describing its occurrence as well its daily amount was formulated by P. Todorovic, D.A. Wolhiser (1975) and R. Katz (1985).

The most interesting results related similar to the modelling of probability of occurrence of daily precipitation totals in Poland were presented by E. Kupczyk (1980).

MODELLING OF TIME SEQUENCES OF THE AIR TEMPERATURE AND DAILY PRECIPITATION TOTALS

The research methodology worked out by B. Jakubiak (1990) was used, which in the case of continuous meteorological elements yielded satisfactory results. Due to long empirical sequences (30 years of daily data) during adaptation, changes were made in the way of estimation of the annual signal.

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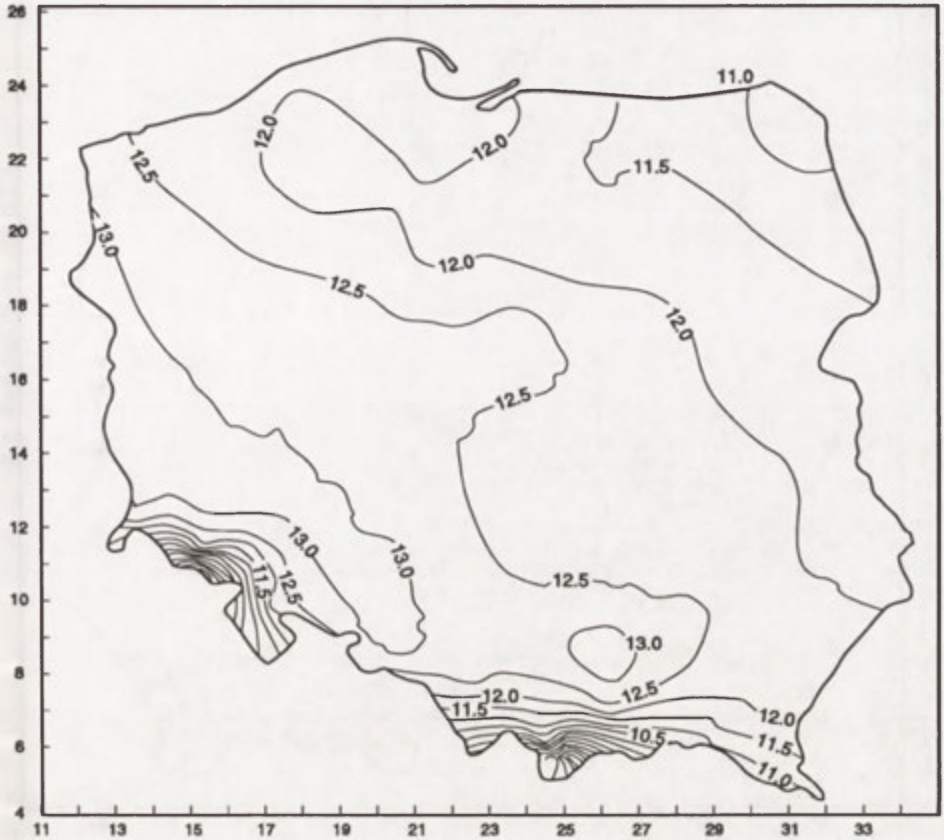

Fig. 12. Generation of the average air temperature in (°C), scenario ($2 \times CO_2$) — according to GFDL model

For this description, ortogonal polynomials were used, whose coefficients were estimated by using the method of the least squares. Normalization of an independent variable to a range <-2,2> was made. The ortogonal polynomials obtained in this way were transformed, having chosen an adequate degree of the polynomial, to the form being a polynomial function of re-scaled independent variable, which highly facilitated its application for the simulation model. Finnaly, after the analysis of errors of approximation, the polynomial of the 9th degree was used to describe the annual signal.

ESTIMATION OF PARAMETERS OF THE MODEL OF AUTOREGRESSION OF THE SECOND ORDER: THEORETICAL ASSUMPTIONS

The model of autoregression of the second order for the process of the zero mean takes the form:

$$x(t) = a_1 x(t-1) + a_2 x(t-2) + \epsilon(t) \tag{1}$$

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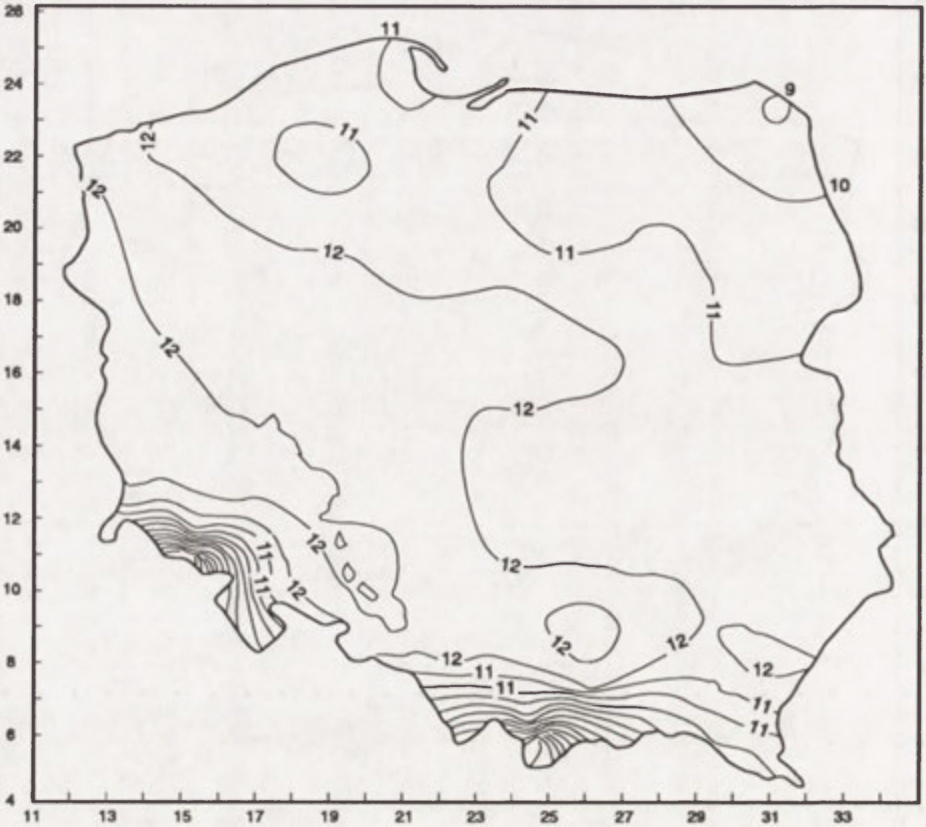

Fig. 13. Generation of the average air temperature in (°C), scenario (2 x CO_2) — according to GISS model

expressing linear regression with data in previous time steps. Errors ϵ (t) have a zero mean, do not show correlation and have variance σ_{ϵ}^{2}. For data n of observation x_1, x_2 ...x_n the values of lag-time may form an ordinary regression equation

$$y = X\beta + \epsilon \tag{2}$$

where:

$$y = \begin{Bmatrix} x_3 \\ x_4 \\ \cdot \\ \cdot \\ x_n \end{Bmatrix} \quad X = \begin{Bmatrix} x_2 & x_1 \\ x_3 & x_2 \\ \cdot & \cdot \\ \cdot & \cdot \\ x_{n-1} & x_{n-2} \end{Bmatrix} \quad \beta = \begin{Bmatrix} a_1 \\ a_2 \end{Bmatrix} \quad \epsilon = \begin{Bmatrix} \epsilon_3 \\ \epsilon_4 \\ \cdot \\ \cdot \\ \epsilon_n \end{Bmatrix}$$

Coefficients of regression estimated by the method of the least squares are the solution of normal equations

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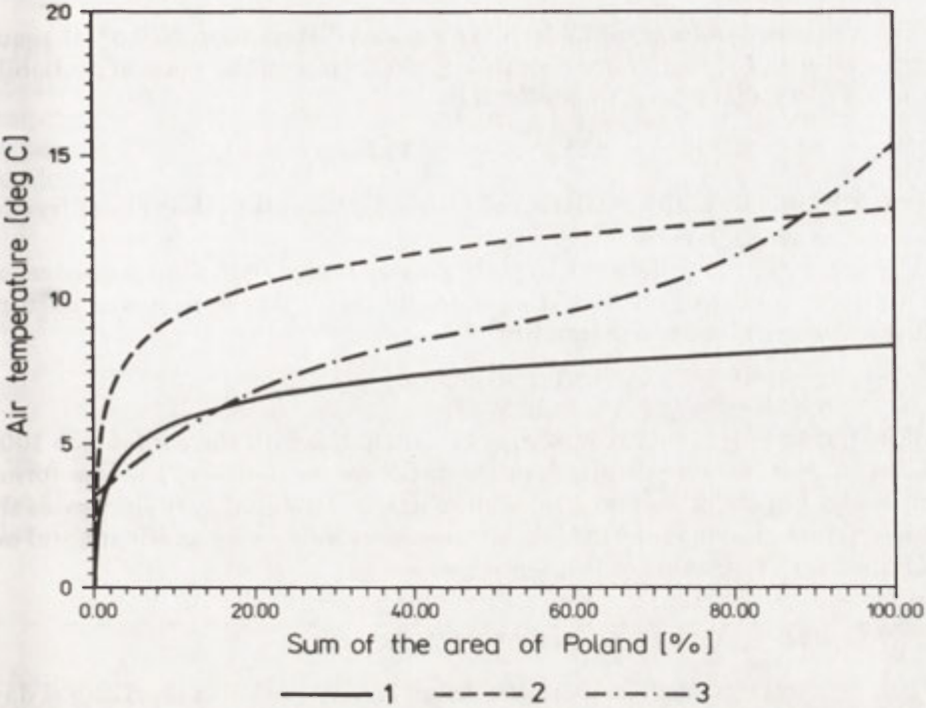

Fig. 14. Areal distribution of the average air temperature in Poland in (%)
1 — period 1951-1980 (scenario 0); 2 — generation according to GFDL (scenario 2 × CO_2) model; 3 — generation according to GISS (scenario 2 × CO_2) model; axis x — the sum of area in Poland covered by the given isopleth (%); axis y — avearge year air temperature in (°C)

$$\left(X^T X\right) b = X^T y \qquad \text{or} \qquad b = \begin{Bmatrix} a_1 \\ a_2 \end{Bmatrix} = \left(X^T X\right)^{-1} X^T y\,.$$

The matrix of co-variance of estimated coefficients of auto-regression is as follows:

$$\text{cov}(b) = \sigma^2 \left(X^T X\right)^{-1} \tag{3}$$

and σ_ε^2 may be estimated from the residual sum of squares

$$\sigma_\varepsilon^2 = (y - Xb)^T (y - Xb)/(n - 5)\,. \tag{4}$$

The number of degrees of freedom the denominator amounts to n-5 because in the equation of the second order two first points in the sequence of observation are lost for the forecast, two subsequent degrees of freedom should be subtracted to define coefficients, and one for the removal of the mean from the sample.

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THE TESTING OF HYPOTHESES

From the assumption that $\epsilon(t)$ has a normal distribution $N(0,\sigma_\epsilon^2)$ it results that the ellipsoid of confidence containing 100 (1 - α)% of the mass of probability in the area of parameters X is defined by

$$(\beta - b)^T (X^T X)(\beta - b) < \sigma_\epsilon^2 F(2, n-5, \alpha) \qquad (5)$$

where: $F(n_1, n_2; \alpha)$ is the statistics of Fisher for n_1 and n_2 degrees of freedom at the significance level α.

Using the expression (5) the hypothesis was tested that time sequences *x(t)* are a purely random process of the white noise. To this end, it was assumed that β = 0, which leads to inequality

$$\lambda = b^T (X^T X)\, b / \sigma_\epsilon^2 < F(2, n-5, \alpha)\,. \qquad (6)$$

If inequality (6) is satisfied, it may be concluded with the confidence 100(1-α)% that β = 0, which permits a presentation of sequence $x(t)$ in the form of white noise. On the other hand, non-satisfaction of inequality (6) indicates that the model tested — model AR(1) or AR(2) respectively — is significant and may be applied for simulation of the sequence.

MODELLING OF DAILY PRECIPITATION TOTALS

The research focused on a certain fragmentary period comprising n days. Each day was ascribed stochastic variable J_k being able to take only two values: 0 if precipitation did not occur that day, and 1 if it did occur. If N_n indicates the number of precipitation days in the n-day period, then

$$N_n = \sum_{k=1}^{n} J_k \,. \qquad (7)$$

Stochastic variable N_n may take values from interval $(0,n)$. At the same time X_m indicates a daily precipitation total on the m-th day with precipitation (it should be noticed that the m-th precipitation day may be any day following the m-1 day of the chosen period). According to these definitions, precipitation total $S(n)$ in the n-day period equals

$$S(n) = \sum_{m=0}^{N_n} X_m \qquad (8)$$

It results from the above that

$$P\{S(n) = 0)\} = P\{J_1 = 0\,,\ J_2 = 0, \ldots J_n = 0\} \qquad (9)$$

as well as

$$P\{S(n) > 0\} = 1 - P\{S(n) = 0\} \qquad (10)$$

Thus $S(n)$ is a stochastic process with a discrete parameter.

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DEFINITION OF THE PROCESS

The probabilistic model of daily precipitation totals may be considered as a special case of the chain of dependent processes: conditional occurrence of precipitation on the day under consideration according to the state of precipitation on m antecendent days as well as the amount of precipitation on the day considered:

$$\left\{J_k \mid J_{k-1}, J_{k-2}, \ldots J_{k-m}, X_k\right\}$$

It was assumed that J_k creates the process of Markov of the m-th order. Such an assumption indicates that J_k satisfies condition

$$P\left\{J_k = j \mid J_0, J_1, \ldots J_{k-2}, J_{k-1} = i\right\} = P\left\{J_k = j \mid J_{k-1}, J_{k-2}, \ldots J_{k-m} = i\right\} \quad i, j = 0, 1 \quad k = 1, 2 \ldots n \tag{11}$$

The significance of accepting of the model of the Markov chain of the first, second and third order was tested. In the case of the Markov chain of the first order J_{k+1} satisfies condition

$$P\left\{J_{k+1} = j \mid J_0, J_1, \ldots J_{k-1}, J_k = i\right\} = P\left\{J_{k+1} = j \mid J_k = i\right\} \quad i, j = 0, 1 \quad k = 1, 2 \ldots \tag{12}$$

Expression (12) indicates that for the data of the previous states of the process $J_1, \ldots J_{k-1}$ and the current state J_k the conditional distribution of the future state J_{k+1} directly depends only on J_k. Condition (12) is called the Markov property.

If the J_k-th process is stationary, the course of this dependence may be shown by investigating the shape of the auto-correlation function:

$$r_m = \text{cov}\left(J_k, J_{k+m}\right) / \text{var}(J_k) . \tag{13}$$

Probabilities defined by (12) are called transition probabilities. If these probabilities are independent of n, the Markov chain has a stationary transition probabilities. The research considered only chains with stationary transition probabilities. Let us mark the transition probability by p_{ij}

$$P_{ij} = P\left\{J_{k+1} = j \mid J_k = i\right\} . \tag{14}$$

Let $P = (P_{ij})$ indicate the matrix of probability of transition of dimensions 2×2. From the definition of transition of probabilities it results that

$$\sum_{j=0}^{1} P_{ij} = 1, \quad i = 0, 1 \tag{15}$$

Such a square matrix P comprising non-negative elements and having sums of rows equal to 1 is called a stochastic matrix. If we mark the initial distribution of the process by $\Gamma_i = P\left\{J_1 = i\right\}$, $i = 0, 1$, then

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$$\sum_{j=0}^{1} \Gamma_j = 1 \tag{16}$$

The of transition matrix P and vector of initial probabilities Γ wholy define the probabilistic structure of the Markov chain. The Markov property of equation (6) may be easily generalized to illustrate the situation in which conditional probability of occurrence of the subsequent state of process J_{k+1}, given the previous states $J_1 ... J_k$ depends only on m of the last states J_k, J_{k-1},... J_{k-m+1}, $m \geq 1$. Especially the Markov chain of the m-th order satisfies equation

$$P\{J_{k+1} = j_{k+1} \mid J_1 = j_1, \dots J_{k-m+1} = j_{k-m+1}, \dots J_k = j_k\} = \\ = P\{J_{k+1} = j_{k+1} \mid J_{k-m+1} = j_{k-m+1}, \dots J_k = j_k\} \tag{17}$$

for all the states $j_1 ... j_{k+1}$ as well as for $k = m, m+1, ...$

NUMBER OF PRECIPITATION DAYS

If we assume that the occurrence of antecedent precipitation is independent, the process will be described by the binomial distribution. Due to bonds in the Markov chain an exact expression according to this distribution is much more complicated. It is easier to calculate distribution of probability of occurrence of precipitation days from recurrency formulae.

Let us mark the initial state of the process directly preceding the n-day period by J_0. Let us determine probabilities

$$W(j;n) = Pr\{N = j\}, \quad W_0(j;n) = Pr\{N = j \mid J_0 = 0\} \\ W_1(j;n = Pr\{N = j \mid J_0 = 1\} \\ j = 0, 1, \dots n \tag{18}$$

Making $W(j;n)$ dependent on whether the initial day J_0 is a precipitation day or not we will obtain

$$W(j;n) = W_0(j;n) + W_1(j;n)\,. \tag{19}$$

Recurrency formulae for $W_0(j; n)$ and $W_1(j; n)$ are obtained from making these probabilities dependent on the state of day J_1

$$W_0(j;n) = P_{00}\, W_0(j; n-1) + P_{01} W_1(j-1; n-1) \tag{20}$$

$$W_1(j;n) = P_{10}\, W_0(j; n-1) + P_{11}\, W_1(j-1; n-1) \\ j = 0, 1, \dots n \qquad n = 1, 2, \dots \tag{21}$$

with initial conditions: $W_0(0;0) = W_1(0;0) = 1$
and convention that $W_0(n; n-1) = W_1(-1; n-1) = 0$.

For the given matrix of transition probabilities P and vector of initial probability Γ, W_0(j; n) and W_1(1; n) may be calculated in a recurrency way from dependences (20) and (21) inserting $j = 0,1,...n$; $n = 1,2,...$ Then $W(j; n)$ may be defined from $W_0(j;n)$ and $W_1(j;n)$ using equation (19).

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GENERALIZATION OF THE MARKOV PROCESSES

Elaboration of the model permitting to fit to daily precipitation totals demands generalization of the model of the Markov chain. It was assumed that the process of precipitation consists of a stochastic process of two random variables which depends on the chain of events (J_{k-1}, X_k), k= 1, 2... Variable J_k describes the occurrence of precipitation while variable X_k its amount.

Let us assume that process J_k satisfies condition (12), thus creating a binary (for two states) Markov chain of the first order. Let us mark the precipitation amount in the k-th day by X_k and let us assume that process X_m: m = 1, 2... has the following properties

(i) distribution X_m depends on J_{m-1},

(ii) variables X_m are conditionally independent, given the J_m-th process.
Both conditions should be understood in the term of probabilities as

$$P\{X_k < x \mid J_0, X_1, \dots J_{k-2}, X_{k-1}, J_{k-1} = i\} = P\{X_k < x \mid J_{k-1} = i\}, x \geq 0 \quad (22)$$

We may specially define conditional functions of distribution

$$F_i(x) = P\{X_k < \mid J_{k-1} = i, J_k = 1\}, \quad i = 0, 1. \quad (23)$$

Property (i) indicates that in the case of the given precipitation day, its amount has been chosen from distribution Fo or from distribution F_1 depending on whether the antecedent day was a precipitation day or not. Property (ii) indicates that precipitation totals on the successive days are conditionally independent. The first attempts, like those of P. Todorovic and D.A. Woolhiser (1975) were confined to a special case of the process of the Markov chain, assuming that $F_0 = F_1$ and that their common distribution is being described by an exponential function.

DAILY PRECIPITATION TOTAL: CHOICE OF A MATHEMATICAL MODEL

Let us assume that we have a sample n of successive observations J_1, $J_2, \dots J_n$. We will make a test of the relation of probability, given the zero hypothesis, that the sequence is described by the Markov chain of the k-th order and given the alternative hypothesis that it is the chain of the k+1-th order. Let us mark the maximum likelihood function for the k-th Markov chain by M_k $(J_1, \dots J_2, \dots J_n)$

$$M_k(J_1, J_2 \dots J_n) = \prod_{i_1, \dots i_{k+1}} P_{i_1, \dots, i_{k+1}}^{n_{i_1 \dots i_{k+1}}} \quad (24)$$

where

$$P_{i_1, \dots, i_{k+1}} = \frac{n_{i_1 \dots i_{k+1}}}{\sum_{i_{k+1}=0}^{1} n_{i_1 \dots i_{k+1}}} \qquad \sum_{i_{k+1}=0}^{1} n_{i_1 \dots i_{k+1}} > 0 \quad (25)$$

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is an estimation of transition probabilities by the method of the maximum likelihood. The likelihood ratio test statistic for k-th order versus $(k + 1)$-th order Markov chain is

$$\pi_{k,k+1} = 2\ln\Gamma_{k,k+1} \tag{26}$$

where

$$\Gamma_{k,k+1} = \frac{M_k(J_1, J_2 \dots J_n)}{M_{k+1}(J_1, J_2 \dots J_n)} \tag{27}$$

Given the zero hypothesis that the Markov chain is of the k-th order, statistics (26) has an approximate distribution chi-square with the number of degrees of freedom defined by the formula

$$df = (s^{k+1} - s^k)(s - 1) \tag{28}$$

RESULTS OF SIMULATION OF ATMOSPHERIC PRECIPITATION

In meteorological research the assumption of stationary transition probabilities of between the particular states is often reasonable when the research is confined to the period permitting elimination of the annual course. That is why the method was realized with regard to months. For description of the occurrence of precipitation days in a month, the model of the Markov chain of the first order was used. Parameters of the model were determined from the observation data regarding daily precipitation amounts at Brwinów from thirty years (1961-1990). In each month the matrix of transition probabilities for the particular states (equation 12) was defined. Tables 1, 2, 3 shows examples of the matrix for the Markov chain of the first order from January and July. Then, distributions of probability of the occurrence in the month of precipitation days from 1 to 31 days from recurrency formulae were determined.

TABLE 1. Transition probabilities for the Markov chain of the first order (0 denotes a day without precipitation, $i = 1$ designates a precipitation day)

Previous state	Current state							
	January				July			
	0		1		0		1	
	a	b	a	b	a	b	a	b
0	.719	.695	.281	.305	.698	.693	.302	.307
1	.367	.339	.633	.661	.416	.420	.584	.580

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TABLE 2. Transition probabilities for the Markov chain of the second order; 0 denotes a day without precipitation; 1 denotes for a precipitation day

Previous state	Current state							
	January				July			
	1		0		1		0	
	a	b	a	b	a	b	a	b
00	.741	.717	.259	.283	.694	.701	.306	.299
01	.385	.338	.615	.662	.480	.459	.520	.541
10	.688	.664	.313	.336	.683	.665	.317	.335
11	.373	.359	.627	.641	.355	.382	.645	.618

TABLE 3. Transition probabilities for the Markov chain of the third order; 0 indicates a day without precipitation; 1 denotes a precipitation day

Previous state	Current state							
	January				July			
	0		1		0		1	
	a	b	a	b	a	b	a	b
000	.771	.746	.229	.254	.702	.697	.298	.303
001	.375	.347	.625	.653	.464	.461	.536	.539
010	.694	.674	.306	.326	.702	.686	.298	.314
011	.321	.366	.679	.634	.434	.429	.566	.571
100	.677	.667	.323	.333	.686	.735	.314	.265
101	.414	.319	.586	.681	.516	.471	.484	.529
110	.684	.656	.316	.344	.673	.651	.327	.349
111	.408	.357	.592	.643	.320	.358	.680	.642

Figure 19 illustrates the distribution of total number of precipitation days in the first decades of January, April, July and October, defined according to the parameters of the Markov chain model of the first order. In the first decades of January and October 5 precipitation days are most likely to occur, in the first decade of July — 4 precipitation days, and in the first decade of April — 3 or 4 precipitation days. It is characteristic that this distribution is moving towards a smaller number of precipitation days. For example, in January probability of the occurrence of only two precipitation days within a decade is greater than probability of the occurrence of 8 precipitation days.

The process of simulation of the occurrence of precipitation within a month was carried out. For each month an estimation of significance of the order of the Markov chain was made, assuming the zero-hypothesis that the sequence is described by the Markov chain of the k-th order as opposed to the alternative hypothesis that this is the chain of the $k + 1$-th order. Table 1 includes matrixes of transition probabilities corresponding to selected months for the Markov chain of the first, second and third order. Results obtained from the 20-year sample (1961-1980) were marked with letter a, while the results obtained from the 30-year sample (1961-1990) were marked with letter b).

Simulation of values of daily precipitation amounts was made on the assumption that these values are independent, while their distribution may

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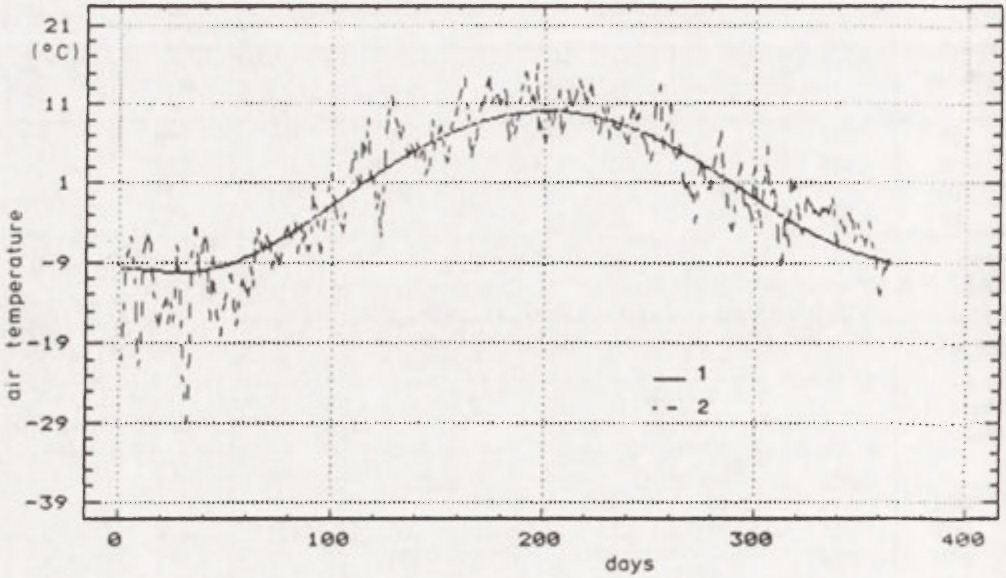

Fig. 15. Observed values of deviations of daily values of the air temperature at Brwinów
1 — annual course; 2 — deviations

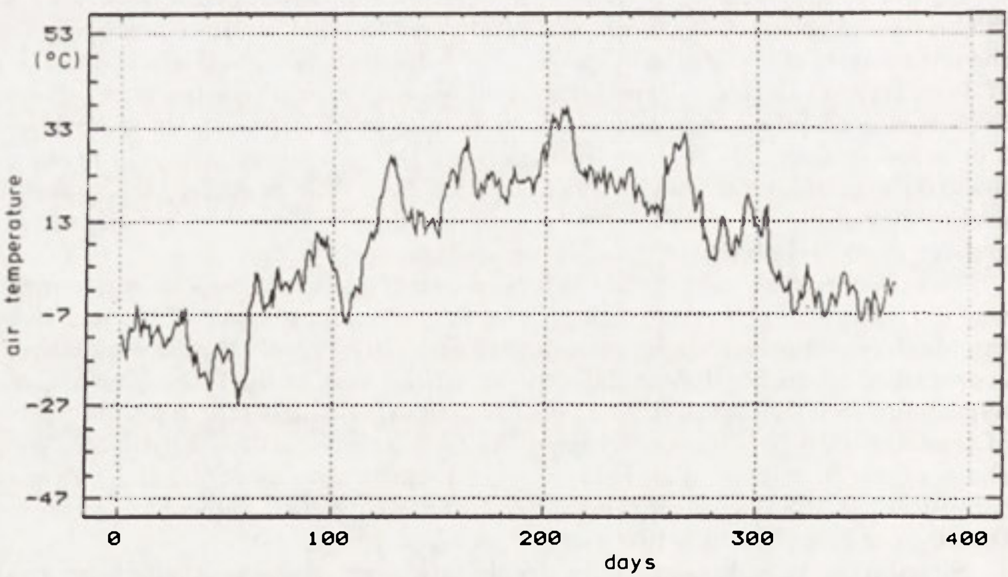

Fig. 16. Simulated annual course of the air temperature at Brwinów

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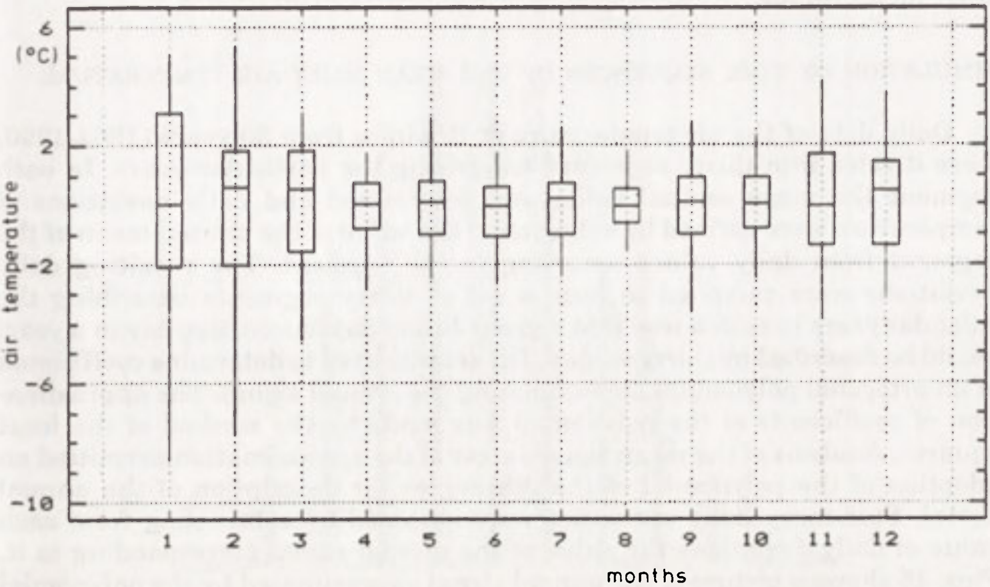

Fig. 17. Observed stationary anomalies of monthly air temperature at Brwinów in the years 1961-1990

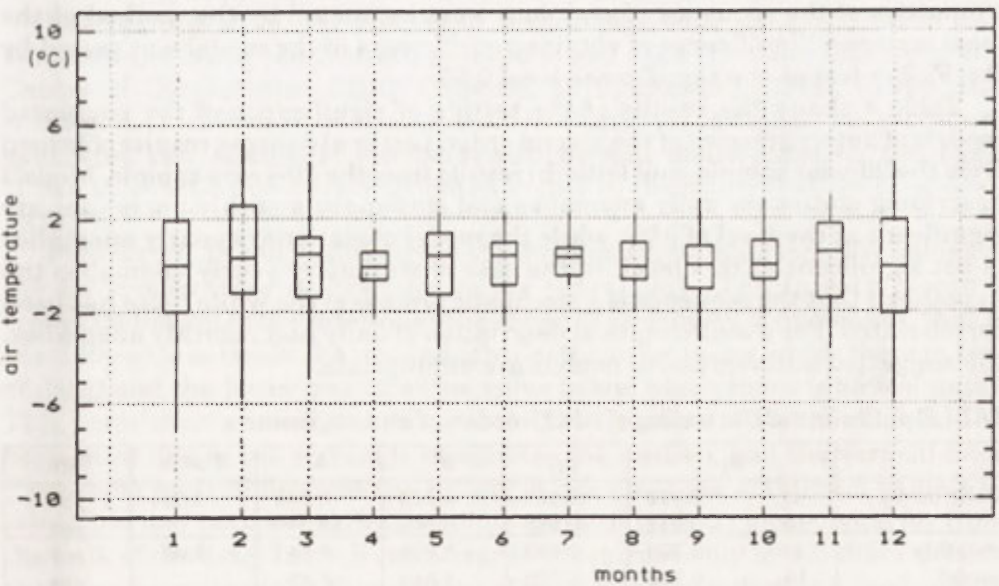

Fig. 18. Simulated stationary anomalies of monthly air temperature at Brwinów in the years 1961-1990

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be approximated by the exponential function. Parameters of distribution were estimated separately for each month and modified by the assumed changes of their mean values.

SIMULATION OF TIME SEQUENCES OF THE MEAN DAILY AIR TEMPERATURE

Daily data of the air temperature at Brwinów from 30 years (1961-1990) were divided into thirty segments comprising the particular years. In each segment the mean annual value was determined and daily deviations of temperature were defined by subtracting the value of the annual mean of the segment from daily values occurring in the segment. The resulting daily deviations were compiled to form a set of thirty segments describing the calendar years in such a way that a given Julian day (successive day in a year) would be described by thirty values. The set was used to determine coefficients of an ortogonal polynomial approximating the annual signal. The approximation of coefficients of the polynomial was made by the method of the least squares. Analysis of the mean square error of the approximation permitted an adoption of the polynomial of the 9th degree for description of the annual signal. Stationary daily anomalies were obtained by subtracting from each value of daily deviations the value of the annual signal corresponding to it. Figs. 15 shows a picture of the annual signal approximated by the polynomial of the 9th degree with superimposed daily deviations of air temperature from the 1970 average.

Parameters of the respective autoregression model capable of generating stationary sequences of anomalies with statistical properties similar to the properties of the sequence of real data were estimated by the method of the least squares. Significance of obtained coefficients of the model was tested by the Fisher test at the significance level 0.05.

Table 4 shows the results of the testing of significance of the suggested models of autoregression of the second order. Letter a) denotes results obtained from the 20-year sample, and letter b) results from the 30-years sample. Models describing stationary daily anomalies and stationary monthly anomalies are significant at the level of 95%, while the model of stationary yearly anomalies is not significant at this level. In the case of stationary yearly anomalies the hypothesis that the sequence is a stochastic process of the white noise has been corroborated. For a mathematical description of daily and monthly anomalies, the suggested autoregressive models are appropriate.

TABLE 4. Results of the testing of AR(2) models of air temperature

		β_1	β_2	σ^2	λ	F 95%	Sign.
daily model	a)	0.912	-0.155	5.923	6.286	2.99	yes
	b)	0.981	-0.059	6.666	33.283		yes
monthly model	a)	0.108	0.038	3.619	4.34	3.02	yes
	b)	0.176	-0.070	3.840	5.89		yes
annual model	a)	0.203	-0.385	0.000	1.50	3.68	no
	b)	0.206	-0.120	0.000	0.61		no

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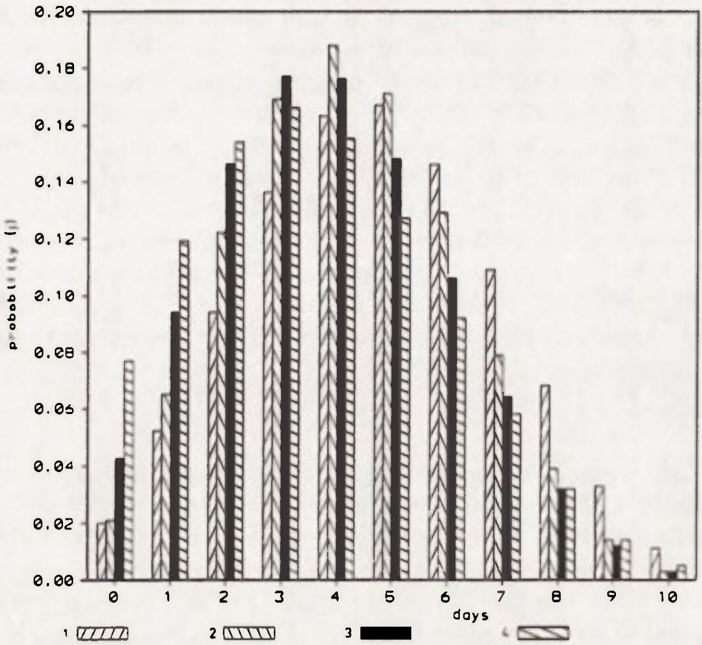

Fig. 19. Probability of occurrence of (j) precipitation days in the decade periods at Brwinów
1 — January; 2 — July; 3 — April; 4 — October

For realization of the process of white noise with the given mean and standard deviation the Normco procedure was used from the Library of the Centre of Computation CERN (Downie, 1978; Hagberg, 1979). In the case of the given mean and correlation coefficient between variables, the procedure generates two stochastic numbers with normal distribution on the basis of two stochastic numbers distributed evenly in the interval <0,1> (Zieliński, 1979).

Figures 17, 18 show statistics of observed and simulated monthly values of the air temperature at Brwinów in the years 1961-1990. In each month a rectangle indicates the inter-quantile range of variability of anomalies, that is the difference between the upper quantile (the value below which there is 75% of data) and the lower quantile (the value below which there is 25% of data). This permits an immediate estimation of the situation of 50% of all data. The horizontal line in the rectangle designates the median, and the vertical lines (branches) protruding from the rectangle run up to the extremum values: — minimum and maximum. Single points mark untypical values, lying far from the bulk of the data. In such cases branches protrude only by 1.5 times outside the inter-quantile range. Comparison of the two charts indicates a good quality of monthly simulation of anomalies of temperature because the basic properties of the observation data are sufficiently conspicuous in the simulated data.

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Estimation of stationary annual anomalies was also made. Their range of changeability is very small: from -0.0354 to +0.0225 (°C), so that practically they are evenly distributed around null. Stationary annual anomalies were simulated as white noise with the zero mean.

Fig. 16 shows the ultimate result of simulation, where the annual course of the air temperature at Brwinów is expressed as the sum of a yearly signal as well as stationary annual, monthly and daily anomalies. The models of autoregression applied are consistent with daily, monthly and annual time scales and may be used to create artificial but wholly real times series of the air temperature and precipitation reconstructing selected statistical properties of the observation data. The change of selected properties of the entire population permits a generation of sequences of meteorological sequences corresponding to climatic conditions different from the current ones.

CONCLUSIONS

Climate is described according to the statistics of meteorological phenomena observed over the period of at least 30 years.

Research on the time and spatial structure of the natural fields of the air temperature and precipitation (scenario 0) has satisfied this requirement.

This research was methodical and cognitive and it may be a starting point for combination of global models GCM used to forecast climatic changes with hydrological models. It paved the way for development of global models for the nodes of a regular grid on a smaller scale. The stochastic methods applied permitted a determination of the local spatial structure of daily meteorological elements coupled with large-scale information.

Methods of simulation using 90-year and 30-year sequences are sufficient statistical material for a relatively precise estimation, and as a matter of fact direction of changes of meteorological fields constituting inputs to the hydrological model of a catchment.

Daily and monthly anomalies of air temperature at observing point were generated by the models of autoregression identified on the basis of observation values. Annual air temperature anomalies were simulated by a generator of the white noise, while the annual course was approximated from empirical data by a polynomial of the 9th degree.

Some change to the earlier version of a scheme were introduced, mainly by applying the averaging process before estimation the coefficients of a polynomial, which, to be equivalent to previous formula of a root squares, is able to work with much longer time series without any lost of a accuracy of results.

The probabilistic model of daily precipitation totals was derived according to a generalized model of the Markov chain describing a stochastic process of two random variables: occurrence of precipitation and its daily total. The process of occurrence of daily precipitation was simulated by the auto- regression model of the first order (probability of occurrence of precipitation on the current day depends only on the state of precipitation on an previous day). The precipitation total was determined from the exponential distribution. The

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mean monthly total of precipitation from many years was the parameter of the simulation model. The process of simulation was considered as positively completed when many years' means from the simulated data approximated the observed many years' means.

The models used provide appropriate methods for generating daily sequences of the air temperature and precipitation with given statistical properties.

Both approaches to simulation of fields of meteorological variables in long and short time intervals will be applied to combine global models with large-scale and small-scale models, given the scenarios of climatic changes.

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MEASUREMENTS OF CONCENTRATION OF THE TRACE GASES ACTIVE IN THE GREENHOUSE EFFECT

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ABSTRACT: In the paper the gas chromatograph for the tropospheric measurements of the trace gases active in the greenhouse effect and the ozone layer destruction are described. For the measurements of the CO, CH_4 and CO_2 an automatic gas chromatograph was constructed. For the CFCs monitoring the gas chromatographic system realizing the enrichment procedure of the air sample is presented. The construction and the operation of the photoemission electron capture type detector is described. This detector was developed for the stratospheric measurements of the CFCs "in situ".

KEY WORDS: greenhouse effect, measurements of trace gases in the stratosphere.

INTRODUCTION

The forecast concerning the increase of the greenhouse effect and the depletion of Earth's ozone layer affect the measurements of concentration of the trace gases participated in these processes. The gases which should be measured are: carbon dioxide, methan and chlorofluorocarbons (CFCs), particularly freons.

The investigations of the influence of the CFCs emitted to the troposphere on the ozone concentration in the stratosphere, the construction of the mathematical models describing the physico-chemical processes in stratosphere in the global scale are based on the measurements of concentration of the all components participating in these processes and their changes in the long time period.

The reliability of the prognosis concerning the stratospheric ozone depletion is connected with reliable concentration measurements of the CFCs and the other compounds which affect the ozone layer (Protecting the Earth's... 1989). The investigations of possible increase in the greenhouse effect in the global scale require the systematic measurements of the CO_2 and CH_4 concentration in troposphere over the industrial regions and in the "clean" zones. These kind of the measurements are performed by means of the gas chromatography.

In the Laboratory of Environmental Physics of the Institute of Nuclear Physics in Cracow and in the Faculty of Physics and Nuclear Techniques the

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University of Mining and Metallurgy in Cracow, the concentration of the trace gases is measured since many years. At present, the concentration measurements of the CO, CO_2, CH_4, CFCs in Cracow and the CFCs in Maków Podhalański are carried out.

In the laboratories mentioned above the new electron capture detector (ECD) based on the electron photoemission process for the gas chromatograph to the stratospheric measurements of the CFCs was destined, because the detector EC equipped with the ^{63}Ni source can not be used in the balloon expeditions.

MEASUREMENTS OF THE CO, CH_4 AND CO_2

The special automated gas chromatograph for the measurement of concentration of the above mentioned gases was constructed (analogical as was used by Schmidt (1992) in Heidelberg). In Figure 1 the scheme of this gas chromatograph is presented. In the future this gas chromatograph will be used as one link of the chain stations for measuring the long distance distributions of the pollutions.

CONSTRUCTION AND OPERATION OF THE GAS CHROMATOGRAPH

In the thermostat (T) (Fig.1) there is the gas chromatographic column (K) packed with Carboxen 1000 (made by Supelco). This column allows for the separation of the CO, CH_4 and CO_2 in one analysis. The CO and CO_2 are converted to the CH_4 on the Ni catalyst is placed in the oven (KAT). The gases are detected by means of the FID detector (DET). The detector signal is measured by the electrometer (EL) connected to the computer (KOM). The computer steers the work of the electromagnetic valves (Z1) and (Z2). The (Z1) valve allows to supply the injector (D) by the sample of the examined air (S) or by the standard mixture (SM) containing the CO_2 and CH_4 in the nitrogen tank under the pressure. The air flowing through the injector is caused by the pump (P). The injector is equipped with 2 ccm sample loop (PD). The air sample is introduced to the gas chromatographic column by the injector system in the time intervals regulated by the computer. The sample injection system is the pneumatic type and the extra pressed air steers it by means of the valve (Z2).

SELECTION OF THE CATALYST TEMPERATURE

The concentration of the methane and the carbon dioxide in the air is about 2 and 300 ppm respectively. The registration of the detector signal for two compounds on the one chromatogram needs the change in the range of the electrometer. For the range of the electrometer giving the peak height for the CO_2 on the full scale, the peak for the CH_4 is very small and it would be projected by the computer with the bad precision. The temperature of the

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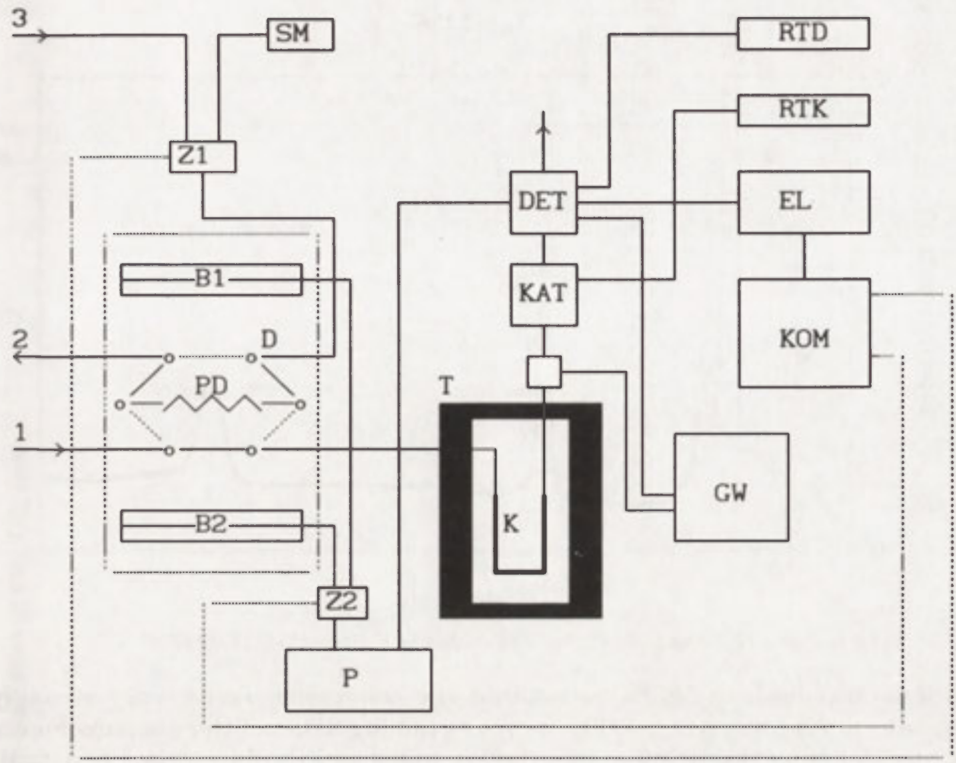

Fig. 1. The scheme of the automatic gas chromatograph for measurement of concentration of the CO, CH_4, and CO_2 in the air
1 — the inlet of the carrier gas, 2 — the outlet of the air sample (or standard mixture), 3 — the inlet of the air sample, D — the pneumatic injector, PD — the sample loop, T — the thermostatic oven, K — the chromatografic column, KAT — the nickel catalyst, DET — the detector, P — the pump, PS — the bottle with the standard mixture, Z1, Z2 — the electromagnetic valves, RTD — the regulator of the detector temperature, RTK — the regulator of the catalyst temperature, EL — the electrometer, KOM — the computer, GW — the hydrogen generator, B1, B2 — the injector control systems

catalyst was decreased to 532°K for have same precision in scanning area of both peaks. At this temperature the conversion factor for CO_2 to CH_4 is 0.01% and the heights of the both peaks are the same. In Figure 2 the example of the air sample analysis in these conditions is presented.

PRECISION OF THE MEASUREMENTS

The temperature of the chromatographic column thermostat, the oven of the FID and of the catalyst is regulated with precision ± 1°K. This precision is too low to have the measurements of concentration with precision equal 1%. The decrease in the catalyst temperature from 686°K (at which the conversion

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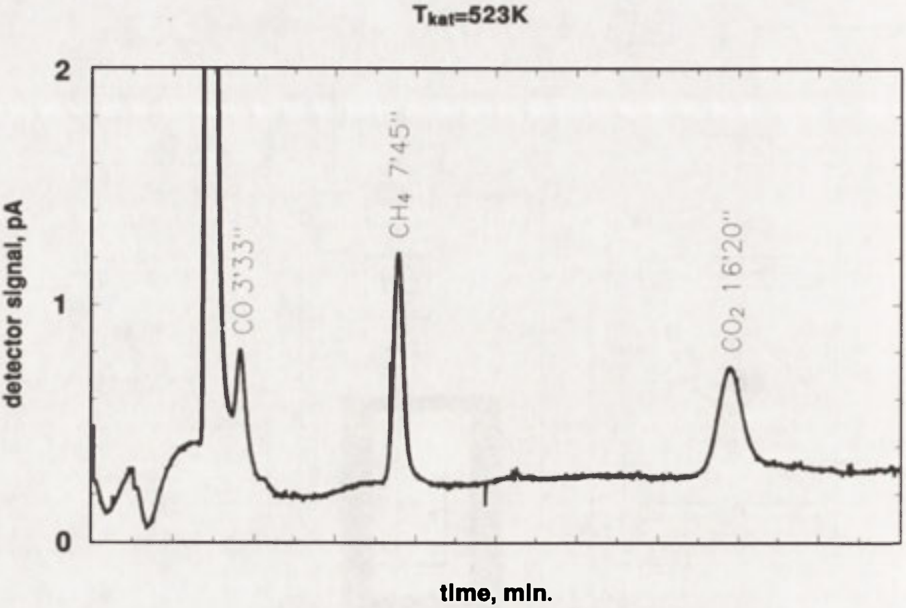

Fig. 2. The example of the air analysis in Cracow (3- 9.IX.1993)

factor is maximal) to 523°K cause that the conversion factor very strongly depends on the temperature. For increase the precision of the measurements the block of the catalyst oven has the big mass and the large time constant. The change of the catalyst temperature in time is slow and allow to make two analysis of the air sample and one of the standard mixture sample in the same temperature. The computer calculates the area of the peaks for these two analysis and compares it with area for standard mixture. In this way the precision of the measurements depends only on the precision of the standard mixture.

In Figure 3 the example of change in concentration of the CO, CH_4 and CO_2 in Cracow is presented.

TECHNICAL DATA OF THE GAS CHROMATOGRAPH

Chromatographic column:	
material	steel
lenght	15 ft
internal diameter	1/8"
temperature	350°K
Carrier gas	nitrogen
flow rate	40 ccm/min.
Detector	FID
temperature	373°K
air flow rate	600 ccm/min.

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Catalyst	niclum oxide
mass	80 mg
temperature	523°K
hydrogen flow rate	55 ccm/min.
Sample volume	2 ccm
Standard mixture	CH_4 and CO_2 in nitrogen
concentration of CH_4	3.37 ppm ±0.2 ppm
concentration of CO_2	165 ppm ± 10 ppm

(This part of work was accomplished as a part of grant no 6.0704.91.01 from the Committee for Scientific Research)

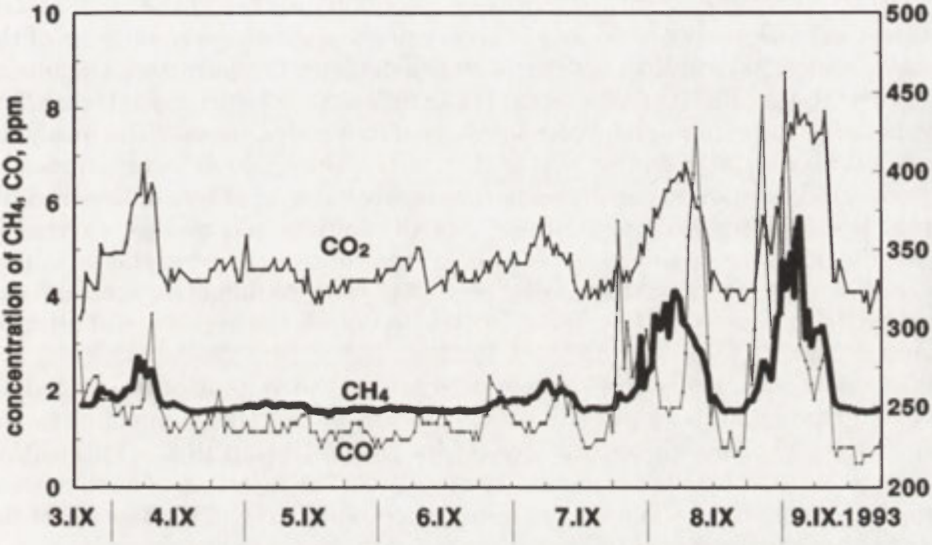

Fig. 3. The long time change in the concentrations of the CO, CH_4 and CO_2 in Cracow

MEASUREMENTS OF THE CFCs IN THE TROPOSPHERE

The concentrations of the CFCs and the other compounds influencing Earth's ozone layer are in the range from ppm to ppt. The gas chromatograph equipped with the electron capture type detector allows for the direct measurements of concentrations of these components in the troposphere. This method is commonly used for the monitoring of the CFCs in many stations on Earth.

The very low detectability level of the CFCs and the halogenated compounds by the EC detector causes many problems with the quantity of the measurements. The reliability of the concentrations measurements on ppt level depends on the reliability of the calibration methods. For this reason many methods were developed for preparing the calibrations standard mixtures as well as the special analytical techniques managements to optimization of the analysis and its precision in the long time. How many problems there are with analysis of the CFCs on the ppt level we can see in the work of

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Rasmussen and Khall (1981) which presented results of the interlaboratory measurements of the same mixture of the air sample.

At present the two methods are used for the measurements of the CFCs in the air. The first is based on the direct analysis of 1 to 5 ml of the air sample and the calculation of the CFCs compounds masses on the base of the coulometric effect in the ECD. In the second method the air sample, volume from 100 to 1000 ml is enriched on the trap to concentrations about the ng level. The calibration of the detector signal can be done by means of the permeation standard or by the gases mixture containing the CFCs on the ng level.

The first method was examined by Lasa and al. (1978), Lasa (1990), Lasa and Śliwka (1991), Śliwka and Lasa (1992). On the base of these examinations it was stated that the calibration measurements by means of the coulometric effect in the ECD are possible only in a very precisely defined conditions of the detector work. This conditions depend on the detector temperature, the purity of the carrier gas and the parameters of the pulses supplying the detector. The accordance of the coulometric measurements, in which a mass of the analyzed compound is calculated from a loss of the electric charge in detector caused by the compound, cannot be verified experimentally because of lack of the credible standards on the ppt level. In spite of that the coulometric method is used in the monitoring stations because in this system of the analysis the automatization of the gas chromatograph is very easy. The coulometric method was tested by Rasmussen and Lovelock (1983) by a very large exponential dilution system.

When using the method of sample enrichment the volume of the tested air must be great enough to get the concentration of the CFCs injected to the chromatographic column on the level of its concentration in the calibration mixture or emitted by the permeability standard. The injection of such a great concentrations to the ECD needs to lessen their sensitivity. This system of the CFCs analysis is described below.

DESCRIPTION OF THE MEASURING SYSTEM

Lasa and Rosiek (1992) give a review of the actual analytical methods used for analysis of the CFCs in the air. A very interesting system was developed in Institute of Chemistry of Atmosphere, Jülich, Germany. This system allow for the simultaneous monitoring of the CFCs and the hydrocarbon in the air. Three detectors: PID, ECD and FID, connected in line allow the identification of some compounds of the sample. The authors of this paper used the simplified version of this system worked out for the analysis of the CFCs in the air only.

In Figure 4 a scheme of the measured system is presented. The system consists of the 10-way valve (V_{10}), the chromatographic columns (K1) and (K2). The column (K2) is connected to the detector (ECD) (made in the Institute of Nuclear Physics and Techniques, Academy of Mining and Metallurgy, Cracow). The detector is supplied with the pulse voltage from the generator (GI). The detector signal is measured by the electrometer (EL) and recorded by the

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recorder (R). The sample loop (SL) filled with glass pellets is joined to the valve (V_0) (connections 3 and 4). Also the reservoir (V), the system of the valves (Z1), (Z2), (Z3), (Z4), the pump (P) and the pipette (Pip) with the analyzed air are connected to the valve (V_{10}). The additional gas (AG) is installed between the column (K2) and the detector to diminish the time constant of the detector.

OPERATION OF THE SYSTEM

In the state presented in Figure 4, the carrier gas (CG) flows through the column (K2) and the detector (ECD). In the column (K1) a "back flash" is realized, that means that by this column the carrier gas flows in the opposite direction than during the analytical process. After opening the valves (Z1), (Z2), (Z3), (Z5) and putting the pump on, the reservoir (V) and all the gas connections are pumped out. In the same time the sample loop is heated to 500°K.

After activation of the sample loop the compounds of the air sample can be adsorbed in it. For this purpose the valves (Z1), (Z2), (Z3) are closed and the pump is off. The sample loop is put into the liquid nitrogen, next the valves (Z1), (Z3) and the valves on the pipette are open. The reservoir (V) suck the air from the pipette through the sample loop. The piezo-manometer (M) installed on the reservoir (V) indicates the change in pressure and allows to determine the air volume passed by the sample loop. The resistance of the sample loop cause that the 100 ccm of air is transported during 5 minutes. Such a long time allow for a very good determination of the sample volume.

The next step is the injection of the sample to the chromatographic column. For this purpose the values (Z1), (Z3), and the valves on the pipette are closed. The liquid nitrogen is taken of from the sample loop and the sample loop is heated by the electric current to 550°K in the time 30 s. In this time the compounds of the sample are desorpted from the glass pellets and after turning the ten way valve (V_{10}) they are introduced to the chromatographic column. In this position of the ten way valve (V_{10}) the columns (K1) and (K2) are connected in series.

In Figure 5 the example of the analysis of the air sample from Cracow is presented. We can see that in the air four kinds of freons are present and other halogenated compounds.

TECHNICAL DATA OF THE CHROMATGRAPH AND THE CONDITIONS OF THE ANALYSIS

Chromatographic columns:	
packing	n-Octane on Porasil C (80/100 mesh)
dimensions	K1: 2m K2: 8 m
internal diameter	2 mm

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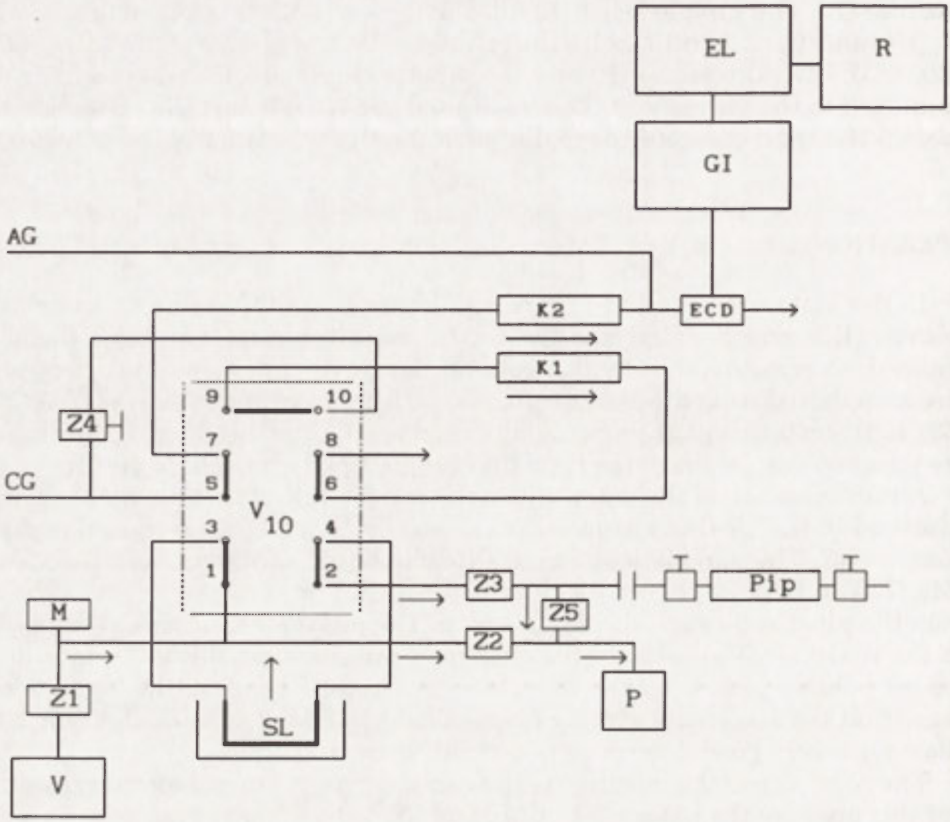

Fig. 4. The scheme of the gas chromatograph for the CFCs concentration measurement in the troposphere (explanations in the text)

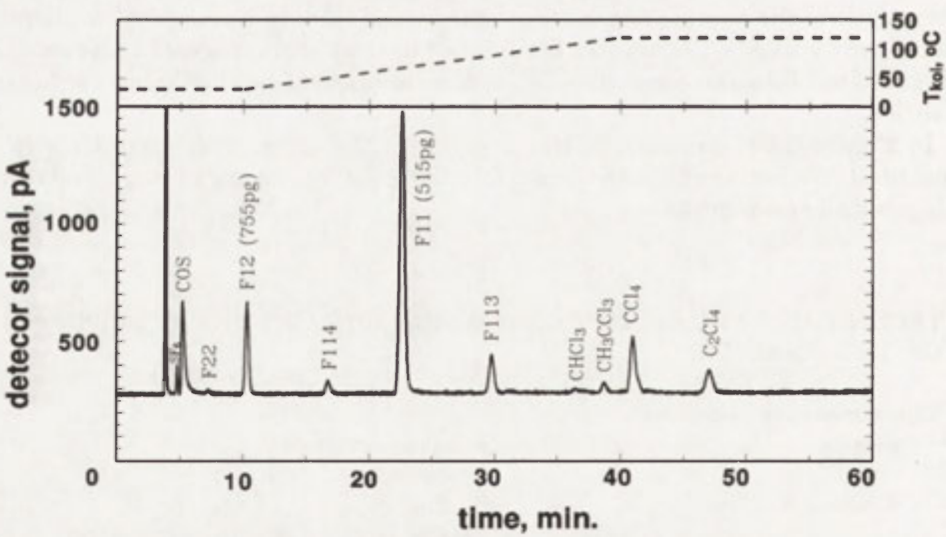

Fig. 5. The example of the analysis of the CFCs in Cracow

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Column temperature: programmable	10 min. at 30°C
	then to 120°C at 2°C/min
	40 min. at. 120°C
Carrier gas:	N_2 (0_2 < 1 ppm)
carier gas flow rate	20 ml/min.
make up gas flow rate	40 ml/min.
Detector	ECD
detector temperature	523°K
detector standing current	3.2×10^{-9}A
detector supply voltage:	pulse
time of pulse	9 μs
repetition time	80 μs
Electrometer range	1.5×10^{-9}A
noise amplitude	3×10^{-12} A
Detectability level:	
Freon F-11	5×10^{-15}g
Freon F-12	9×10^{-15}g

(for the 300 ml sample volume and for the detector supplied with the pulse repetition time equal 2560 μs).

This part of work was accomplished as a part of grant no 6.0405.91.01 from the Committee for Scientific Research.

PHOTOEMISSION ELECTRON CAPTURE DETECTOR

The freon F-12 has a very high depletion potential of the ozone layer and it is chemically stable. For this reasons the measurements of its concentration in the troposphere and the stratosphere are very important. At Earth's surface the concentrations of the F-12 is about 500 ppt, but in the stratosphere the several ppt only. In Figure 6 the dependence of the freon F-12 concentration on the altitude is presented. The measurement of the freon F-12 concentration "in situ" in the stratosphere is very difficult because the use of enrichment method is impossible.

This problem is proposed to be solved by:

a) the injection of very large air sample to the chromatographic column,

b) to develop a new type of the EC detector with a high sensitivity.

Ad a) After many experiments it was established that it is possible to increase the air sample by correctly constructed sample loop and others pneumatic parts of the gas chromatograph and in such a way the dispersion of the freon peak is diminished. The analytical system was tested on sample volume equal up to 200 ccm. For such a sample the peak volume of the freon F-12 was very good separated from the peak of the CO_2, freon F-11 and H_2O.

Ad b) In the photoemission EC detector a UV lamp is a source of the electrons. The external surface of the lamp is covered by 150 Å thick layer of gold. The electrons are emitted under the influence of the UV radiation from the gold layer. The electrons are captured by the molecules of the analyzed sample what gives as the result a signal of the detector in the measuring circuit.

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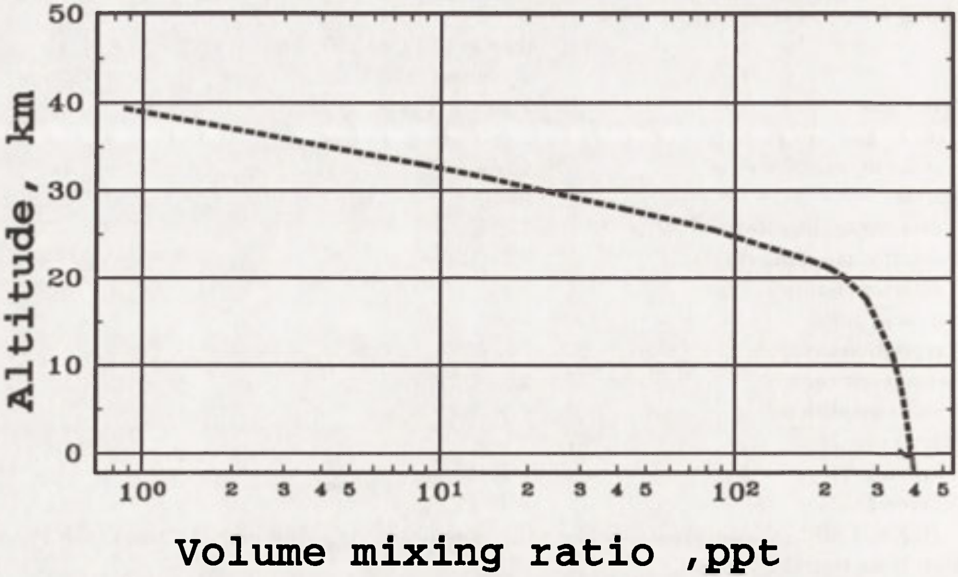

Fig. 6. The dependence of the freon F-12 concentration on the altitude

The detectability level of the detector is determined by the fluctuation of the UV lamp current. To diminish the detectability level for the CFCs in the measuring circuit the electronic registration and the signal filtration was applied. In Figure 7 the scheme of the supply system and the signal measuring system is presented.

In Figure 8 the example of the air sample with 200 ppt of the freon F-12 is shown. Figure 8a presents the detector response without the electronic filtration, Figure 8b presents the fluctuation of the UV lamp current and Figure 8c the detector response with the electronic filtration. The electronic filtration system was developed by Rosiek (1993).

In Figure 9 the dependence of the detector response on the mass of the freon F-12 is presented.

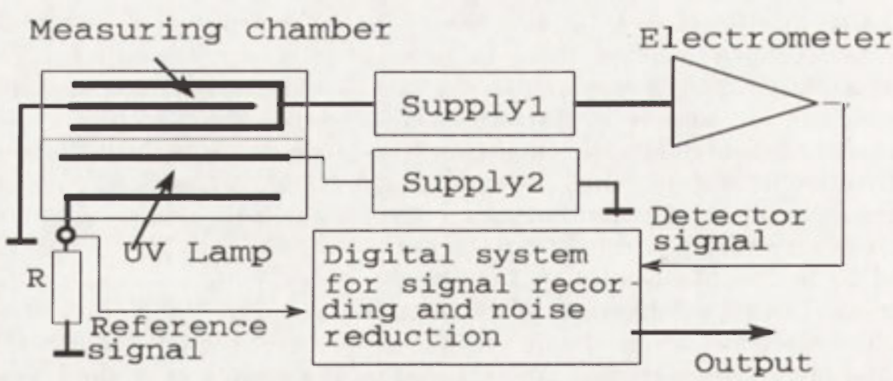

Fig. 7. The scheme of the measured circuit of the photoemission electron capture detector

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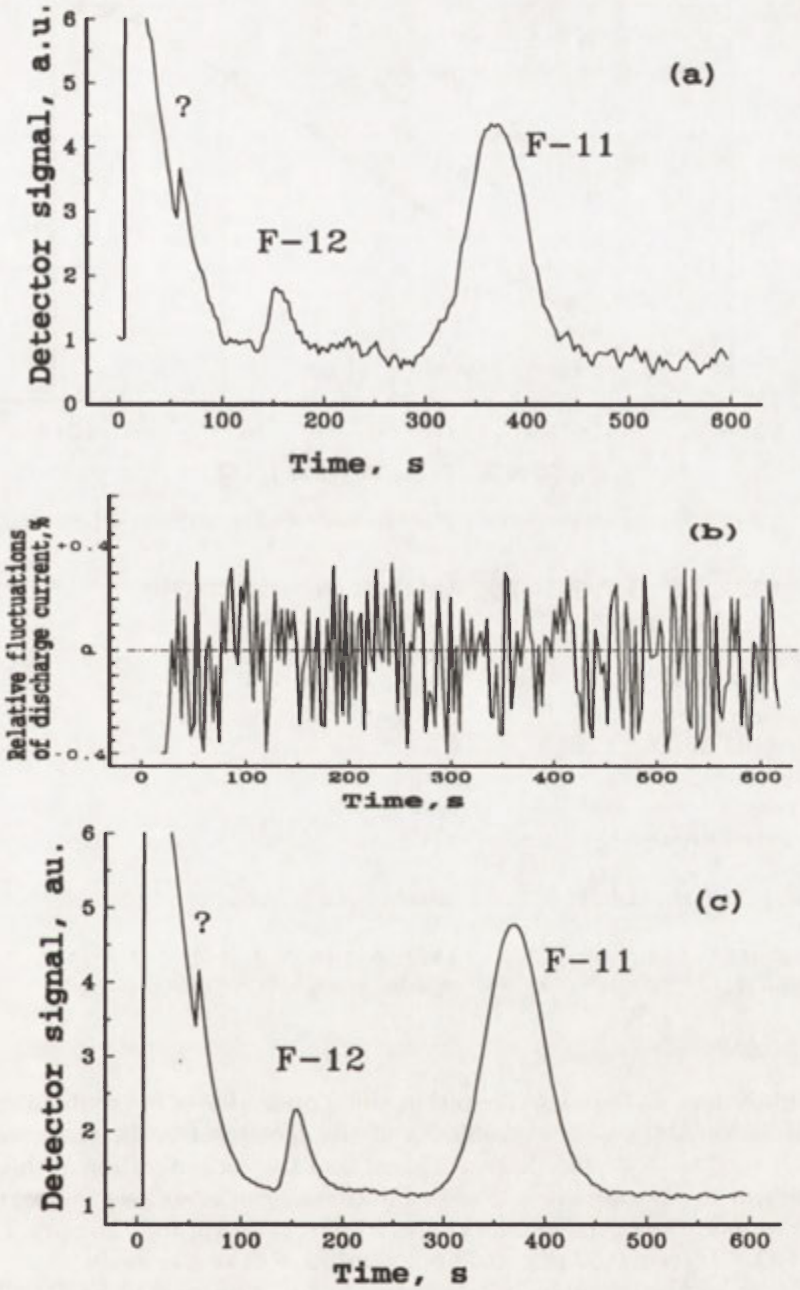

Fig. 8. The example of the analyze of the air sample with 200 ppt of the freon F-12
a — response of the detector without the electronic filtration, b — fluctuation of UV lamp current, c — response of detector with the electronic filtration

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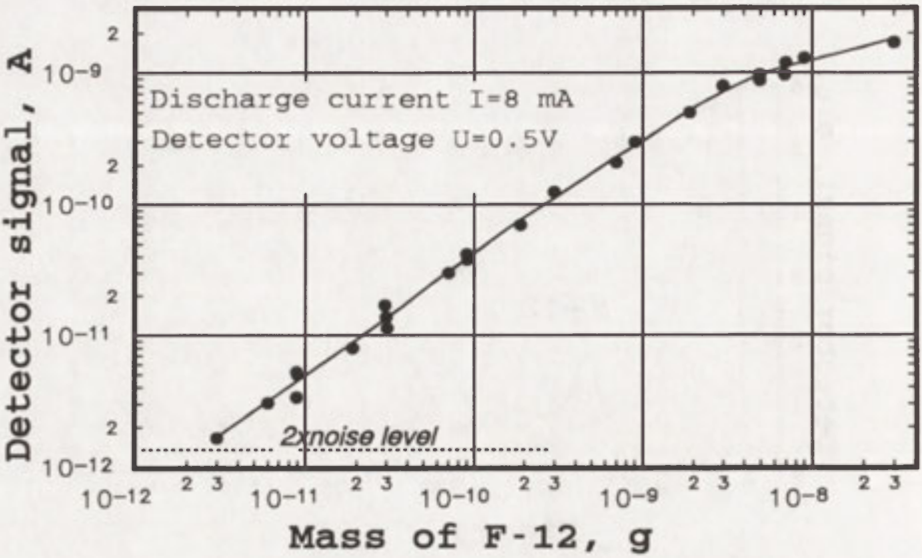

Fig. 9. The dependence of the photoemission electron capture detector on the mass of the freon F-12

PARAMETERS OF THE PHOTOEMISSION EC DETECTOR

Carrier gas:	nitrogen or argon
Volume of the detector:	1.2 ccm
Photoemission current:	$(1{+}{-}3) \times 10^{-10}$A
Voltage supplied detector	0.5 V
Detectability level for freon F-12	3×10^{-12}g
Dynamic range	1000
Maximal temperature work	423°K
UV lamp:	
Current	15 mA
Power	3 W
Time of life	4000 h
Emission layer	Pt + Au, 150 Å

CONCLUSIONS

The analytical methods presented in this paper allows for realization of the continual concentration measurements of the gases active in the greenhouse effect. From our measurements it is evident that the concentration of these gases measured in the atmosphere of Polish Southern area is subject for permament daily oscilations around the middle values which are 325 ppm, 1.25 ppm, 1.75 ppm for CO_2, CO, CH_4 and 0.52 ppb, 0.30 ppb for F12, F11 respectively.

The described photoemission electron capture detector (PhECD) allows for concentration measurements of large parts of freons in troposphere and also it may be useful for balloon experiments in the lower stratosphere up to 25 km height.

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EVOLUTION OF ISOTOPIC COMPOSITION AND CONCENTRATION OF ATMOSPHERIC CO_2 AS RESULT OF ANTHROPOGENIC INFLUENCES

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ABSTRACT: Systematic investigations of the isotopic composition in atmospheric CO_2 and its concentration in Cracow urban area have been carried on at the Environmental Physics Department, Faculty of Physics and Nuclear Techniques. Continuous sampling at biweekly intervals was supplemented by series of samples representing four-hour periods. Comparison with the similar researches from the other world reference stations enabled estimation of the anthropogenic changes in one of the most degraded region of Poland. Besides this our observations indicate that world isotopic trends noticed by "clean" stations are also registered in Cracow.
Concentration of the atmospheric CO_2 in Cracow along the last ten years is almost constant reaching very high value: 372.5 ppmv if compared with the station at Mauna Loa, Hawaii (ca. 345 ppmv), and does not indicate the remarkable increasing tendency. One can explain this situation by constant level or even decrease in total volume of the burned fossil fuels in Poland, and neighbouring countries.

KEY WORDS: fossil fuels, radiocarbon, CO_2 concentration, stable isotopes

INTRODUCTION

Carbon and oxygen, which are the basic elements composing living matter, due to the different isotopic fractionation associated with formation of organic and inorganic compounds, show characteristic isotopic composition determined by the type of chemical compound, and physical processes controlling the reaction.

Carbon on the earth is represented by 3 isotopes: 2 stable, and 1 radioactive of masses: 12, 13, and 14, respectively. The most abundant is ^{12}C, about 100 times more than ^{13}C while the natural atmospheric concentration of ^{14}C is negligible small: ca. 1 atom per 10^{10} atoms of carbon. However, ^{14}C permanently produced in the upper part of atmosphere by secondary cosmic radiation shows concentration which can be measured with accuracy better than 1%.

From the only stable isotopes of oxygen present in the environment two of masses 18 and 16 are of measurement significance. The concentration ratio of these two isotopes is used in numerous investigations as a proxy indicator of natural processes in ecosystems.

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An isotope composition of the atmospheric CO_2 is a potential source of information about the origin of this gas, contribution of different components, and in many cases specifies processes associated with natural circulation of carbon in the environment.

Investigations of atmospheric CO_2 concentration gained in recent years world-wide significance since the observed global warming was linked with a greenhouse effect of the anthropogenic origin. Thus the isotopic measurements became an important part of study over the CO_2 sources, sinks, flux, and other parameters used in the circulation models.

ANTHROPOGENIC CHANGES IN CARBON ISOTOPE COMPOSITION AND THE CO_2 CONCENTRATION

Anthropogenic disturbances and their influences on ecosystems have been a metter of intensive studies in world-leading research institutions since about twenty years. Investigations of the environmental isotopes of carbon, and oxygen became recently one of the important part in global and regional studies over ecosystems.

RADIOCARBON

^{14}C present in terrestrial organic matter and "young" inorganic carbon compounds decays with $T_{1/2} = 5730$ years. This figure determines concentration of radiocarbon as function of time since "closing of the system" i.e. the moment of breaking down an exchange (direct and indirect) of carbon with atmospheric CO_2.

During the recent thousands years, as it was documented by numerous investigators (Damon et al. 1966; Pearson et al. 1986, Stuiver and Braziunas 1989), natural production of ^{14}C has not been constant. Observed fluctuations of radiocarbon concentration in the atmosphere is presented in Fig. 1. Long scale natural changes are small if compared with the nuclear weapon tests in early 60-ties which doubled the atmospheric ^{14}C concentration in the northern hemisphere. During the next decades the mixing processes caused exponential decrease, however, up today the former (before tests) level has not been reached, and the lowering tendency is still observed.

The modern industrial era which started in the mid XIX century caused remarkable changes in the natural environment, mainly in the northern hemisphere. Fast increasing demand of energy has resulted in a parallelly increasing exploitation of fossil fuels originating from geological deposits, and thus free from the ^{14}C isotope. CO_2 produced in burning process and released to the atmosphere lowers the ^{14}C concentration in the environment. Since early studies of Suess (1955) this effect has been investigated both in global, and regional scale (Vogel and Uhlitzsch 1975; Tans et al. 1979; Awsiuk and Pazdur 1986; Kuc 1989).

However, production of ^{14}C in nuclear power reactors acts in opposite way

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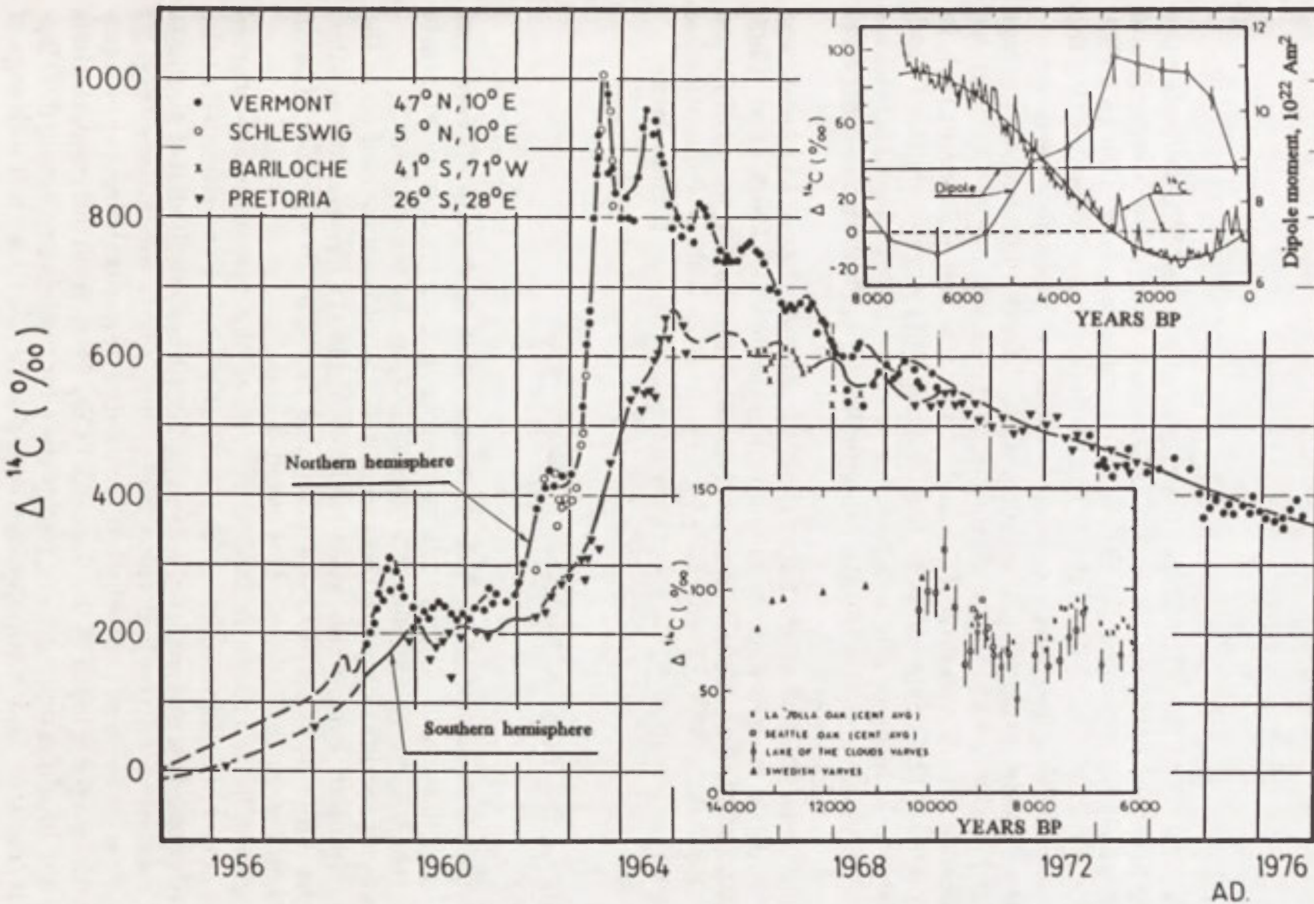

Fig.1. Changes of the atmospheric ^{14}C concentration as result of the nuclear weapon tests (after Levin et al. 1980). In the upper corner: fluctuations caused by changes of the earth magnetic field (Damon et al. 1989). In the lower corner: reconstructed $\Delta^{14}C$ values on basis of the fossil oaks and lake sediments (Stuiver et al. 1986)

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to the Suess effect, but these releases are ca. two orders on magnitude smaller than from fossil fuels (Otlet et al. 1992), and are noticed in a close vicinity of power stations (Loosli and Oeschger 1989; Hertelendi at al. 1989).

ISOTOPE ^{13}C

Concentration of the ^{13}C isotope, usually expressed as $\delta^{13}C$ following the generally accepted notation (Craig 1957) is different for various organic and inorganic compounds present in the terrestrial environment (Deines 1980). Exchange of carbon usually in form of CO_2 between "boxes" representing the characteristic $\delta^{13}C$ values leads to changes which can be easily measured.

Carbon dioxide produced while combustion of fossil fuels has an average value of the $\delta^{13}C$ lower ca. 16‰ with respect to the atmospheric CO_2, however, this difference depends on type of the fuel, or contribution of different fuels in case of mixture. The same refers to the contemporary organic matter (wood, peat coal) which decomposing in a natural way, and burned by men releases CO_2 of different $\delta^{13}C$ value to the atmosphere. Intensity of this process depends upon climate and season.

The anthropogenic modification of the $\delta^{13}C$ value in the environment, was studied by direct measurements in the atmospheric CO_2 (Mook et al. 1983; Friedli et al. 1987; Kuc 1989), and recorded in organic matter, mainly in wood (Freyer and Belacy 1983; Leavitt and Long 1986) providing a quantitative information on depletion of ^{13}C concentration in global, and regional scale.

ATMOSPHERIC CO_2 CONCENTRATION

A simple consequence of increasing consumption of fossil fuels from one side, and global-scale disturbances in land covers i.e. clearing of tropical forests from the other, is increasing concentration of CO_2 in the atmosphere.

Permanent monitoring since the end of 1950' s has been carried on in the Mauna Loa station, Hawaii (Bacastow and Keeling 1981), however, many other projects in different countries have been also aimed at this problem (Levin 1987; Tanaka et al. 1987) during the recent decade.

The tropospheric concentration of CO_2 since the measurement started indicates permanent increase (secular trend) which has been estimated at the reference Mauna Loa station to ca. 1.2 ppmv/a in 1956-1989 (Boden et al. 1990). In 1989 concentration reached value 352 ppmv, Yearly oscillations (Fig. 2.) point to a seasonal component which is modulated by natural biogenic processes and anthropogenic input of the fossil fuel CO_2. Data from different stations spread over the globe deliver basic parameters for models predicting development of terrestrial, and marine ecosystems closely linked with the change of climate.

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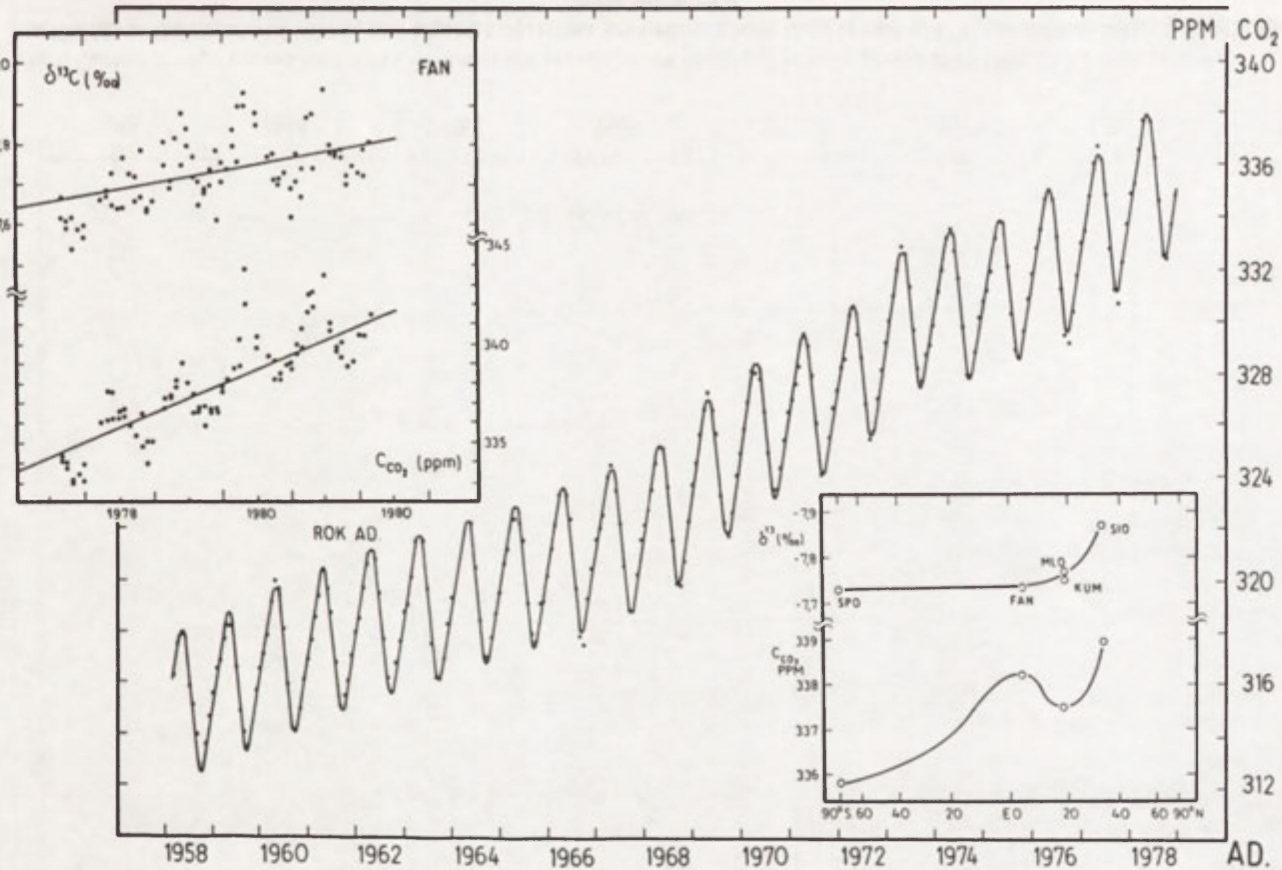

Fig.2. Atmospheric CO_2 concentration on Mauna Loa, Hawaii (19.5°N, 155.6°W), points represent monthly average values (Bacastow and Keeling, 1981). In the upper corner: atmospheric CO_2 concentration and $\delta^{13}C$ on Fanning Island (3.9°N, 159.3°W). In the lower corner: seasonally adjusted atmospheric CO_2 concentration and $\delta^{13}C$ in 01.01.1980 (Mook et al. 1983). SPO — south pole; FAN — Fanning Island; MLO — Mauna Loa; KUM — Cape Kumukahi, Hawaii, SIO — La Jolla, California

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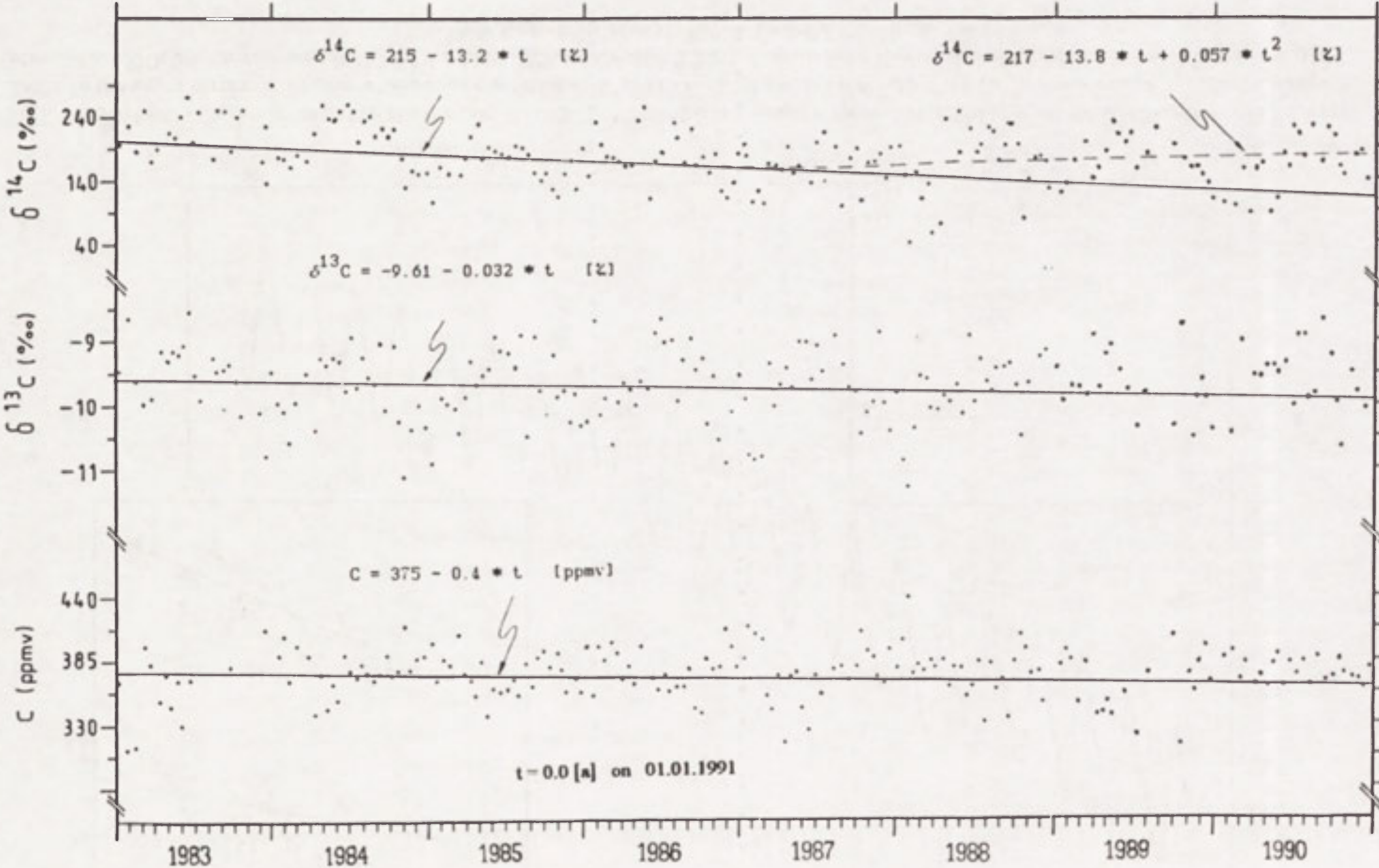

Fig.3. Carbon isotope composition and CO_2 concentration at Cracow sampling point in period 1983-1990. Solid lines represent regression line fittings to the measured values, and adjacent equations are written above. Only in case of $\delta^{14}C$ one obtains better fitting to the second order polynomial

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OBSERVED ISOTOPIC COMPOSITION, AND CONCENTRATION OF CO_2 IN CRACOW REGION

Cracow, an urban agglomeration with about 1 milion inhabitants is mostly influenced by pollutants coming from the west — the Silesian district distanced 60-100 km — where numerous coal mines are located with associated heavy industry. Discharges from local sources (electric and heating power stations, factories) are of similar magnitude. Sampling point located on a roof of the Institute, a separate building, bordering recreation, and sport grounds isolated from local chimney discharges is representative for the town area.

Measurement results obtained so far (Kuc 1991) as a continous record of biweekly averaged values, and presented in Fig. 3 confirms general trends, and seasonal variations observed in foreign global stations, however, absolute values are remarkable different.

Radiocarbon record from the reference stations, where local anthropogenic changes are negligible (as on Jungfraujoch, Leven at al. 1989) compared with the results from Cracow sampling point enables to calculate contribution of CO_2 originating from fossil fuels (fossil fuel component). Monthly average in 1989-1990 are presented in Fig. 4, and compared with data for Heidelberg, Germany (Levin et al. 1989). Fossil component in Cracow is systematically higher ca. 5-17 ppmv than for Heidelberg showing the same seasonal dependence.

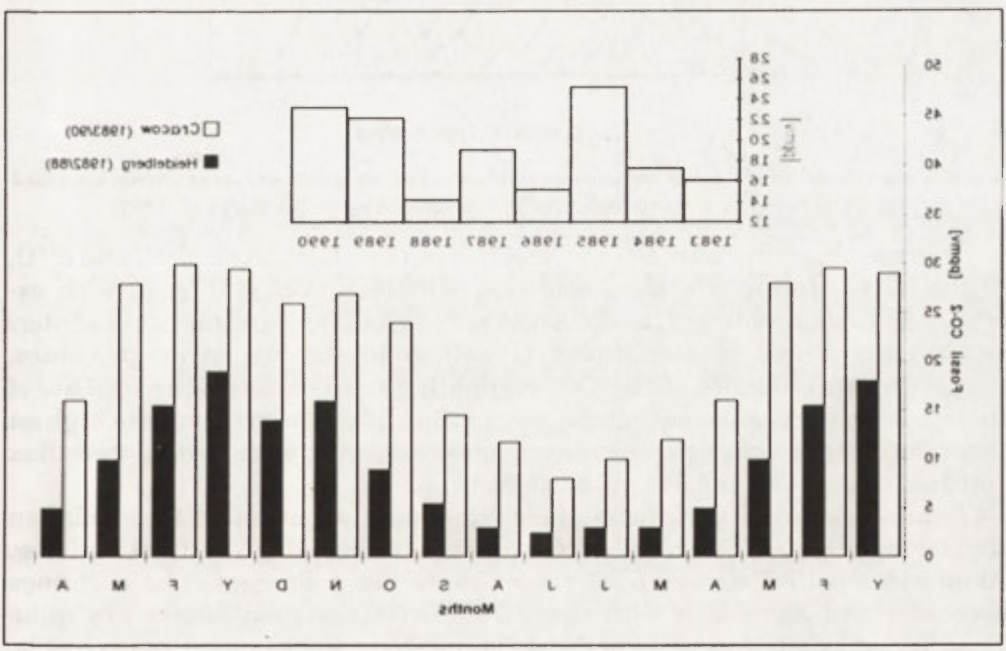

Fig.4. The fossil fuel component at Cracow and Heidelberg (Levin et al. 1989) sampling points. The upper curve presents yearly average values for Cracow

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The calculated mean value of fossil fuel component for the whole period is 19.5 ppmv, and subtracting this figure from the mean CO_2 concentration (372.5 ppmv) one obtains 353 ppmv as typical for "clean air" in Europe. The same value was reported as mean in 1985 for Garmisch-Partenkirchen, Germany (Boden et al. 1990).

Atmospheric concentration of CO_2 in Cracow indicates rather constant value for 1989-1990 (Fig. 3), however, the absolute values are ca. 20 ppmv higher than in European "clean air". This fact can explain lack of the globally observed increasing tendency both for lower (Boden et al. 1990), and higher altitudes reported by Tanaka et al. (1987) for Japan (Fig. 5).

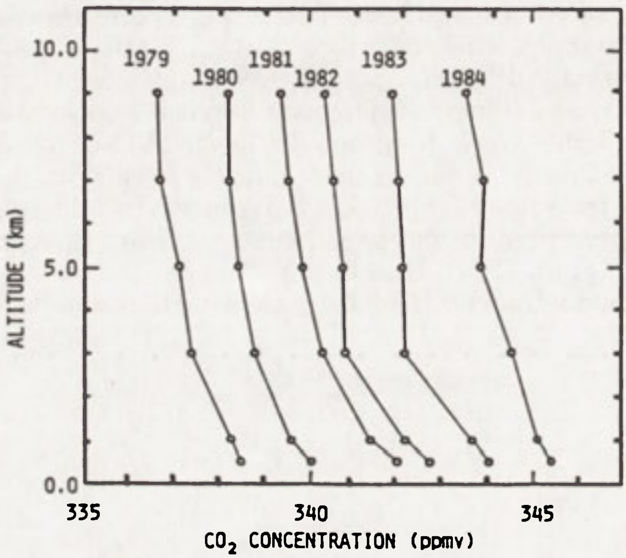

Fig.5. Vertical profiles of annual mean concentrations of atmospheric CO_2 over Japan, obtained from the best fit curves to measured values (according to Tanaka et al. 1987)

Diurnal observations of the CO_2 isotopic compositions, both $\delta^{13}C$, and $\delta^{18}O$, in the lower atmosphere show characteristic fluctuations (Fig. 6) with extremes falling at midnight, and noon. A seasonal difference (summer–winter) is well pronounced in amplitudes as well as in absolute, average values, suggesting an influence of the CO_2 originating from various sources. One of them is biogenic component coming from soil respiration, creating the highest flux to atmosphere in summer season, and competing with assimilation flux which is also most intensive at the same time.

Summer, diurnal variations are predominantly controlled by insolation (light) intensity, and temperature gradient inducing vertical mixing. Amplitudes both $\delta^{13}C$ and $\delta^{18}O$ reflect these rapid changes. The exchange processes and associated with them isotope fractionation effects are quite complex, and simple answers of the still remaining questions are not possible. However, more details could be available after further, extended field experiments.

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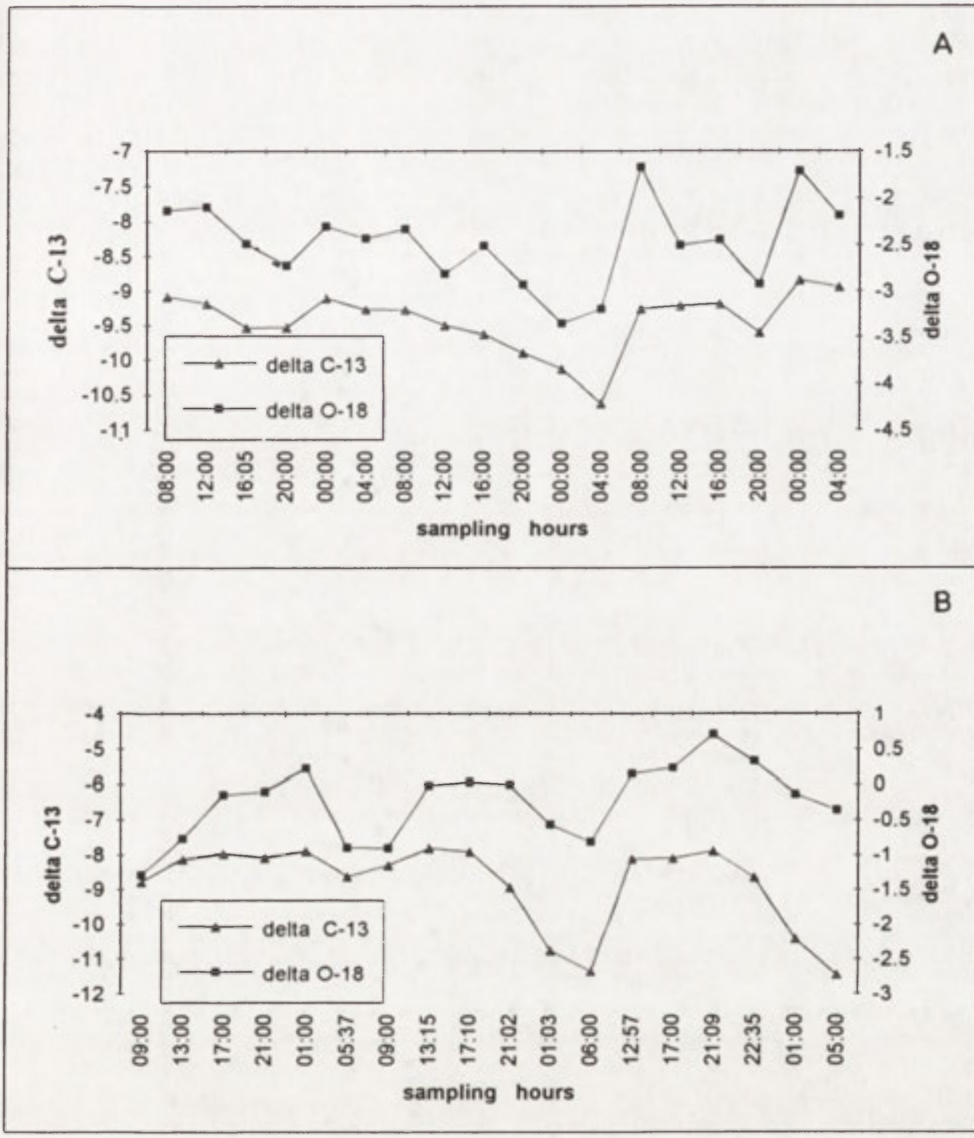

Fig. 6. Diurnal profile of the CO_2 stable isotope composition in Cracow
A — sampling point taken in winter (10-13.12.1992), B — summer (07-10.07.1992), about 15 m above ground level

CONCLUSIONS

Investigations of the isotopic composition in the atmospheric CO_2 provide useful, quantitative information on local, and global anthropogenic changes resulting from the fossil fuel combustion.

The calculated mean value of fossil fuel component at the Cracow sampling

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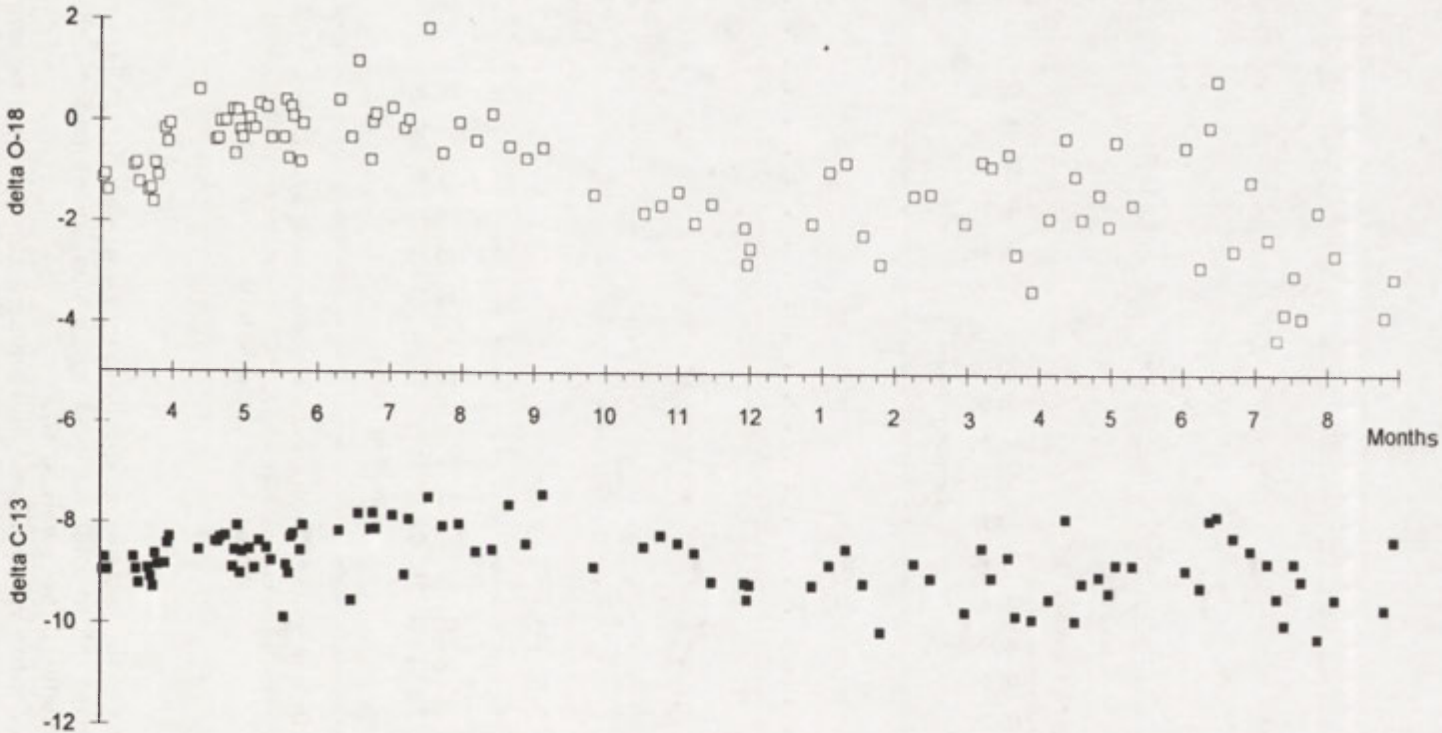

Fig. 7. Seasonal profile of the stable isotope composition in atmospheric CO_2 (III-IX 1992)

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point for period 1983-1990 is ca. 19.5 ppmv, being 2.2 times higher than in Heidelberg, Germany, however, the atmospheric CO_2 concentration in recent years in Cracow is almost constant, not following the global trend.

Observations of diurnal, and seasonal changes (Fig. 7) offer the information about the biological activity, and soil respiration, the causes influencing the CO_2 concentration over investigated area. These effects can be compared with the man-induced disturbances.

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MEASUREMENT OF ATMOSPHERIC RADIOACTIVITY IN CRACOW

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ABSTRACT: Radioactivity of several components of atmosphere in Cracow is measured continuously or periodicaly in the framework of international cooperation. The paper describes some results of measurement of tritium, ^{222}Rn, ^{85}Kr and others.

KEY WORDS: atmosphere, radioactive components, measurement, tritium, ^{222}Rn, ^{85}Kr.

INTRODUCTION

Radioactive components of the atmosphere originate from natural sources like ^{222}Rn or are introduced by men's activity (nuclear tests in the atmosphere, nuclear industry). Whereas the radioactivity caused by nuclear tests (phased out practicaly in 1962) decreases, the radioacitivity released by nuclear installations increases with time. The release takes place in normal operation or in nuclear accidents like Chernobyl case.

Measurements of radioactive components of the atmosphere help in understanding on-going processes and transport of the radioactivity over continents. Some measurements in Cracow are performed continuously (e.g. tritium) other periodicaly. Atmospheric tritium data together with stable isotope composition of atmospheric precipitation are passed to the International Atomic Energy Agency data bank collecting data from over 100 meterological stations in the world. These data periodicaly published thus creating an important basis for investigations in the field of hydrology, meteorology etc. Other measurements are carried out in the framework of international cooperation projects.

TRITIUM IN PRECIPITATION

Precipitation samples collected monthly in the meteorological station in Cracow are analysed for tritium concentration since 1975. Figure 1 shows the temporal record of tritium in Cracow precipitation. For comparison the record for Vienna is also shown indicating excellent correllation between these stations. Single peaks in 1975 in Vienna and in 1978 in Cracow indicate the

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instantaneous discharge of tritium in nuclear reactor fuel reprocessing plants in Russia or in Western Europe. The detailed analysis of meteorological situation at this time allows for identification of the tritium source. As seen in Figure 1 there is a systematic decrease in tritium content in precipitation. Seasonal variations are due to seasonal injections of tritium to the atmosphere from the stratosphere where tritium was deposited during atmospheric nuclear tests. Tritium content is expressed in tritium units (T.U.): one T.U. being the isotope ratio of hydrogen to tritium equal 10^{18}. Half-life of tritium is 12.43 years.

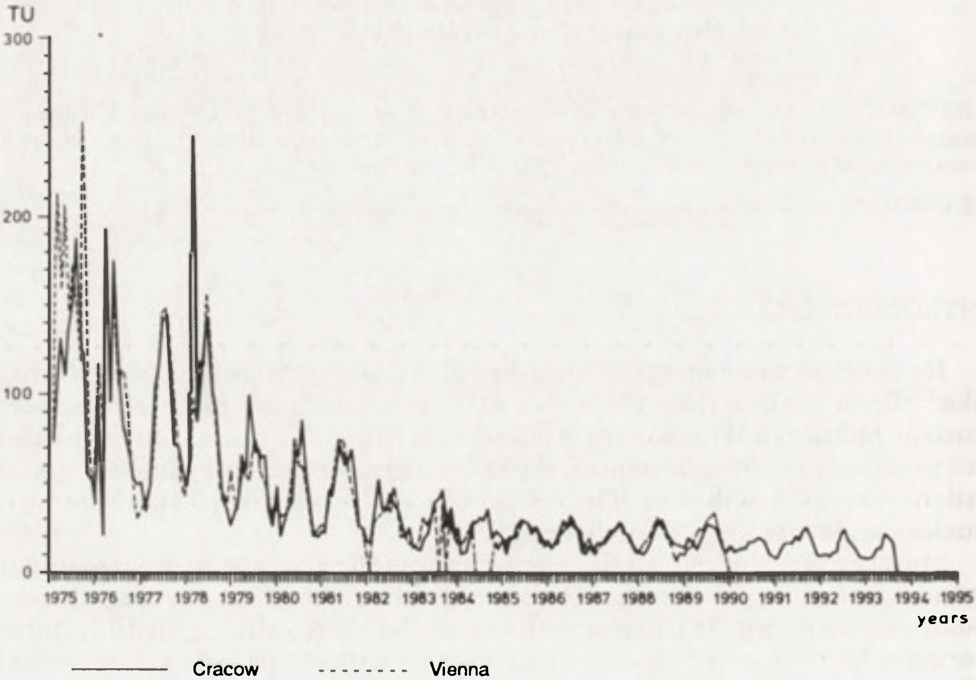

Fig. 1. Tritium in precipitation (Cracow, Vienna)

TRITIUM IN THE ATMOSPHERIC WATER VAPOUR

Measurement of tritium in the atmospheric water vapour close to the earth surface is carried out from 1988 in the weekly system in the framework of international cooperation of several institutes in Central Europe (Vienna, Budapest, Zagreb, Sofia and others). Purpose of this study is the monitoring of tritium discharges from nuclear power stations and early signalizing of possible accidents. Figure 2 shows the last 3.5 years record of weekly atmospheric water vapour samples together with the tritium in precipitation data in this period of time. The tritium content in water vapour is, in general, slightly higher than tritium content in precipitation in the same period.

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KRYPTON-85 IN THE ATMOSPHERE

^{85}Kr (half-life 10.7 years) in the atmosphere comes from gas discharges from the nuclear installations (nuclear power stations and fuel reprocessing plants). Its concentration in the atmosphere steadily increases. During years 1977-85 ^{85}Kr atmospheric concentration was measured in Cracow in the framework of international cooperation with institutes in Freiburg, Madrid and Miami. Figures 3 and 4 show the measurement data (Weiss et al. 1986, 1986a). The purpose of the study was the investigation of the global circulation of krypton and checking the possibility of determination of the time and place of the ^{85}Kr emission from the nuclear installations. Figure 5 shows the increase of ^{85}Kr atmospheric concentration in Cracow according to the elaborated model. Measured values for several years are also shown.

SHORT-TIME MEASUREMENTS

After Chernobyl accident ^{85}Kr, ^{133}Xe and ^{131}I were measured in the Cracow atmoshere. Figure 6 shows the increase of ^{85}Kr and ^{133}Xe activity during few days after the accident (Florkowski et al. 1987).

RADON-222 IN THE ATMOSPHERE

^{222}Rn (half-life 3.8 days) originated from the ^{238}U radioactive series present in the soil and rock diffuses to the atmosphere and takes part in the atmospheric transport. The decay products of radon are isotopes of heavy metals which soon after their production become attached to the atmospheric aerosols and particles. They fall down to the earth and make possible dating e.g. lake sediments (^{210}Pb method). Measurement of atmospheric radon content helps in understanding the transport of air masses from the ocean over the continent. Monitoring of radon has started in July 1981 and is continued for two years. Figure 7 shows the record of minimum daily values of radon activity which are best suited for further comparison between distant sampling points. The minimum values represent radon concentrations from higher levels of the atmosphere not influenced by diurnal fluctuations. Figure 8 illustrates the daily variations of radon content in Cracow (highest and average variations). The systematic difference between Heidelberg (Germany) and Cracow was analyzed for selected periods with well defined meteorological situation (western circulation). Figure 9 shows the comparison of monthly average values for sampling stations in Heidelberg (8°42'E), Waldhof (10°43'E), Platform in the North Sea (7°10'E) and Cracow (19°E) taken from Volpp (1984). One can see the systematic increase of radon content from west to east (continental effect). Figure 10 compares the radon activity in Cracow and Heidelberg for June 1983. During the same meteorological situation the day and night variations in Cracow are much higher and the minimum values are similar. The possible explanation for higher diurnal difference in Cracow is the night temperature inversion due to low wind velocity. In winter the local radon flux from the soil is much smaller (frozen soil and snow cover).

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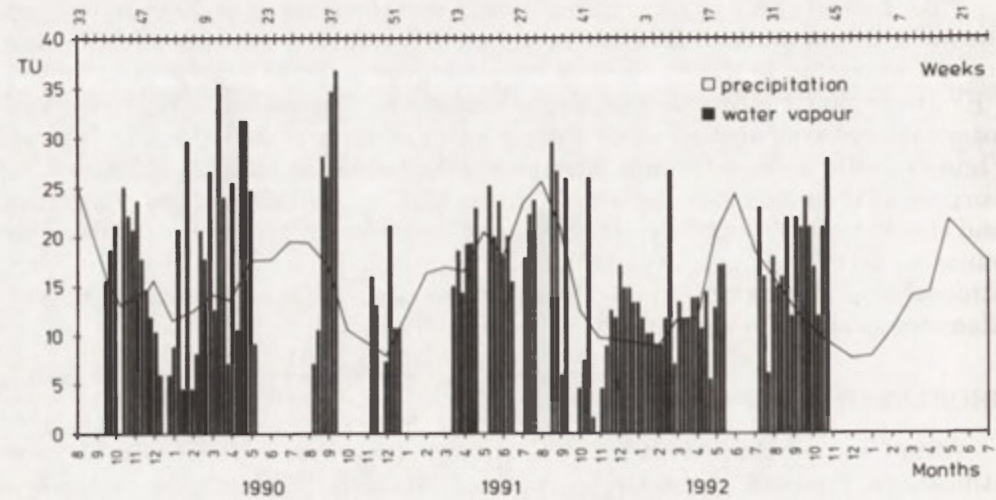

Fig. 2. Tritium in atmospheric water vapour (Cracow)

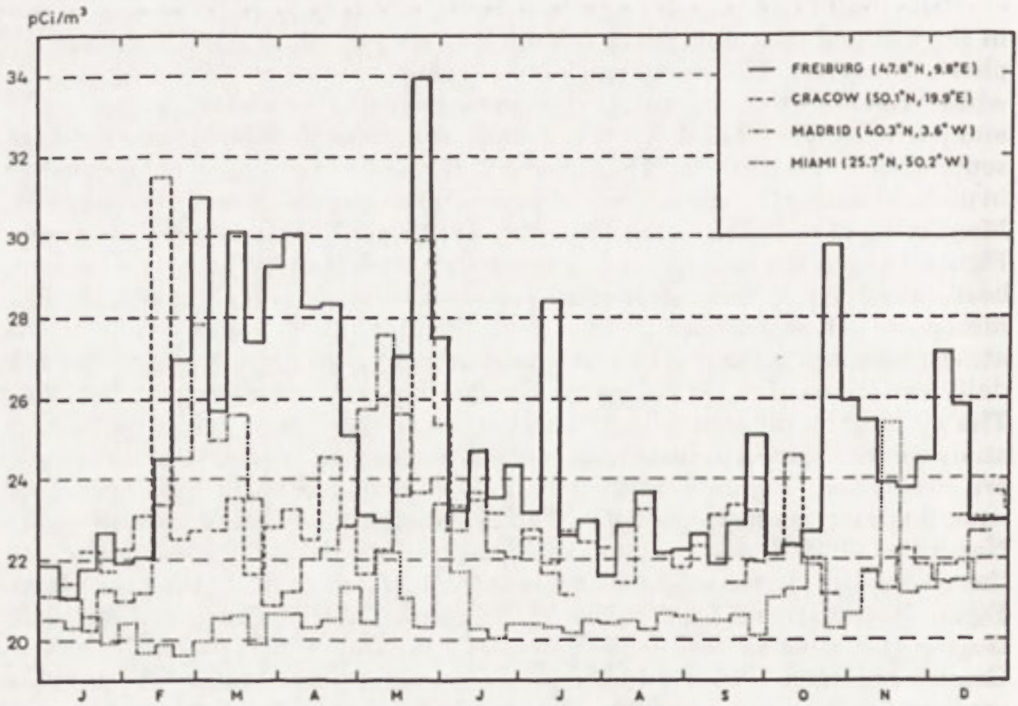

Fig. 3. ^{85}Kr acitivity of weekly composite samples of the nearground air in 1984 collected at the stations: Freiburg, Cracow, Madrid

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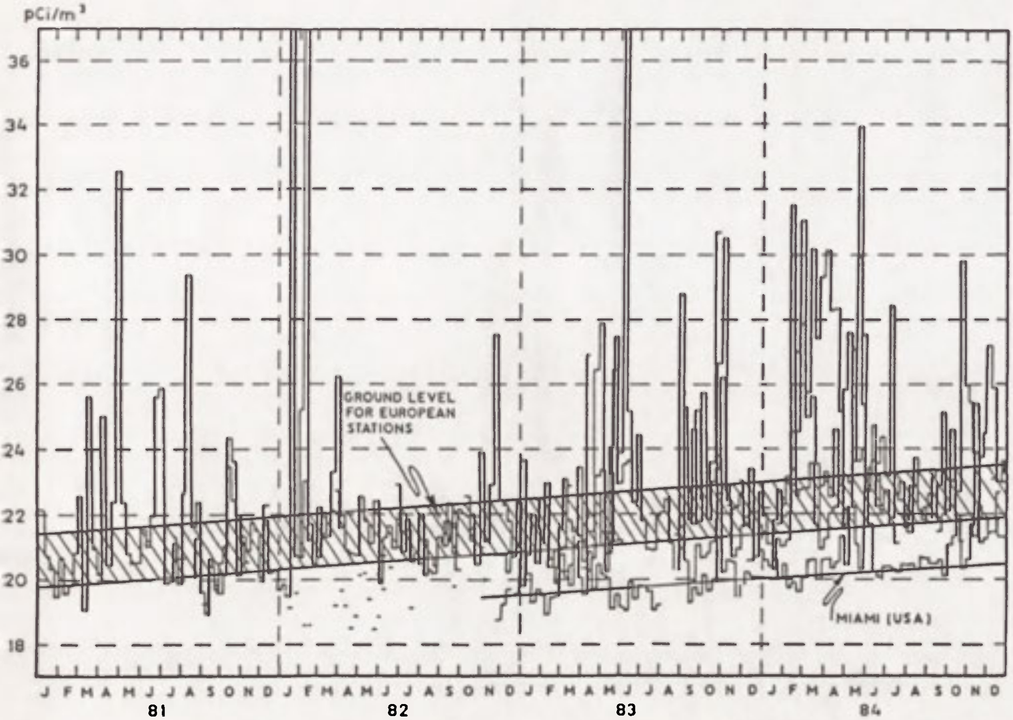

Fig. 4. ^{85}Kr activity of weekly composite samples collected at the stations: Freiburg, Madrid, Cracow and Miami. Hatched area represents the European ^{85}Kr baseline; straight line indicates the corresponding baseline at the Miami station

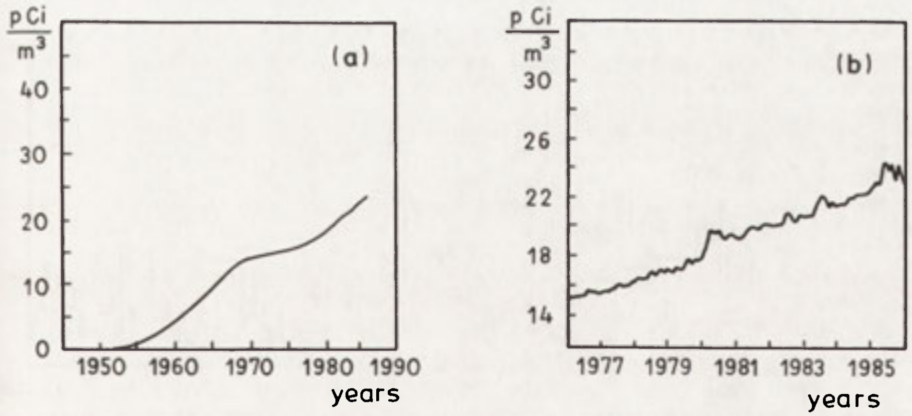

Fig. 5. Increase of ^{85}Kr atmospheric concentration in Cracow
a — mathematical modelling simulated, b — measured

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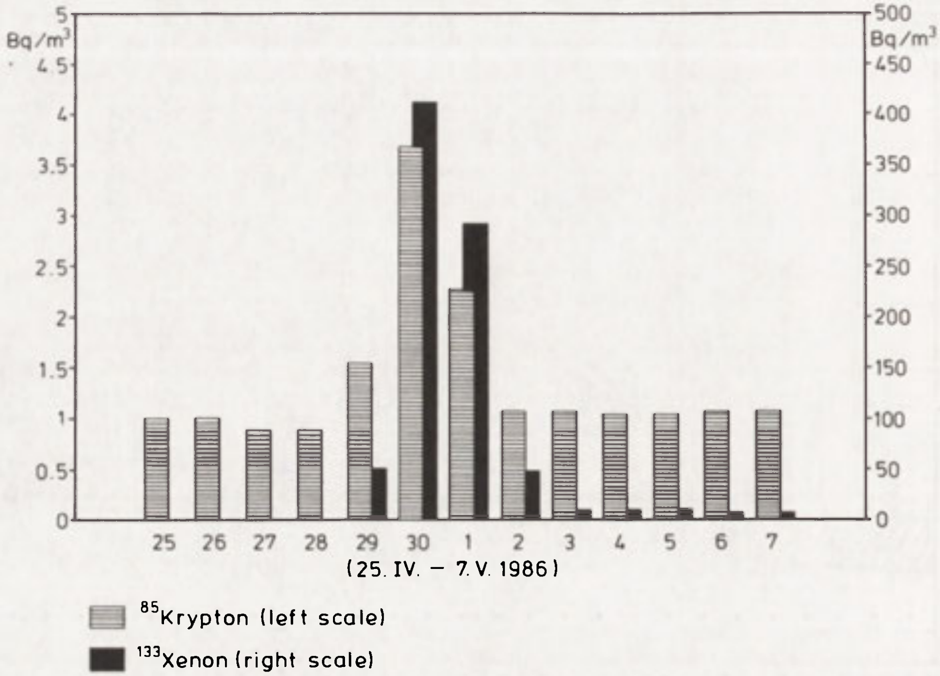

Fig. 6. ^{85}Kr and ^{133}Xe in Cracow after Chernobyl accident

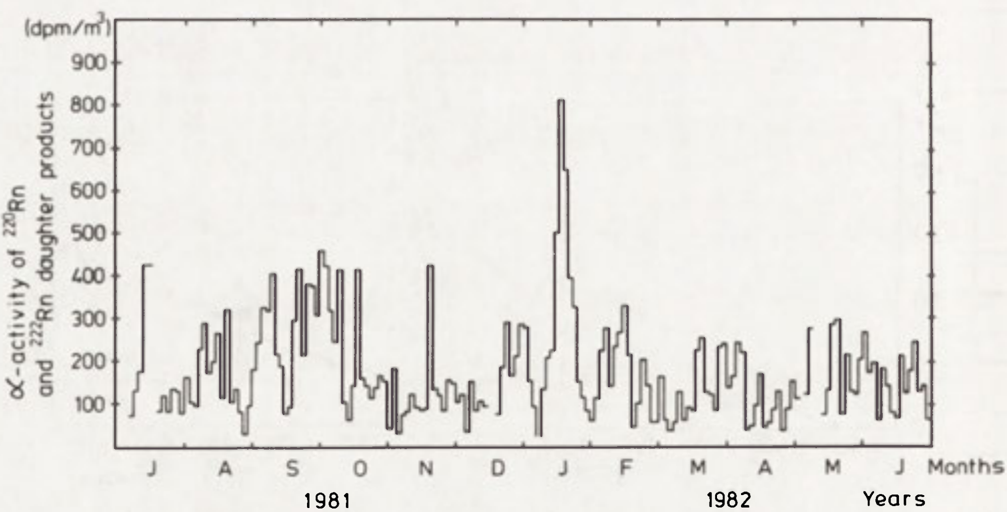

Fig. 7. Record of minimum daily radon and daughter content in Cracow

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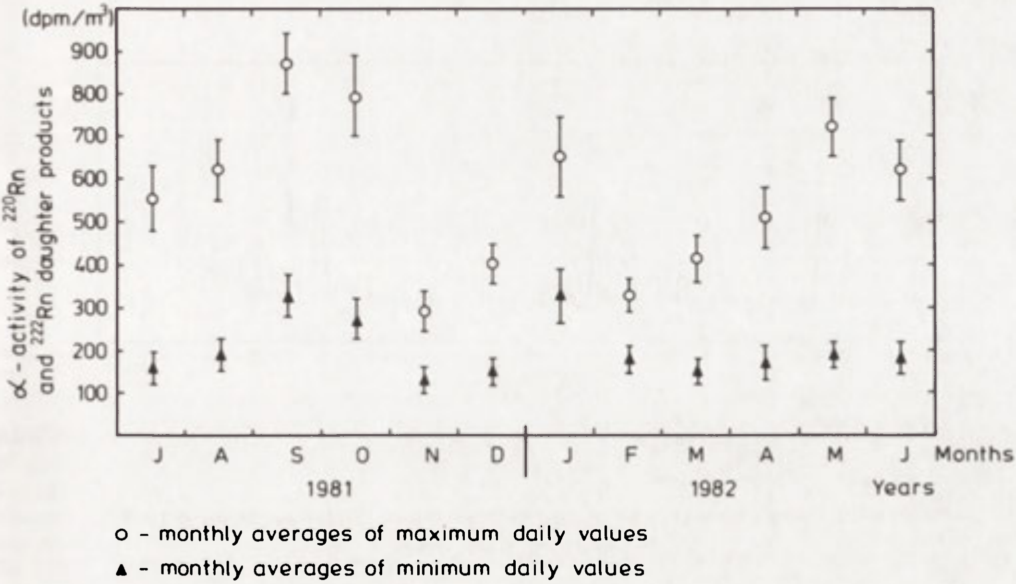

Fig. 8. Daily variations of radon content in Cracow (highest and average) and daughter products

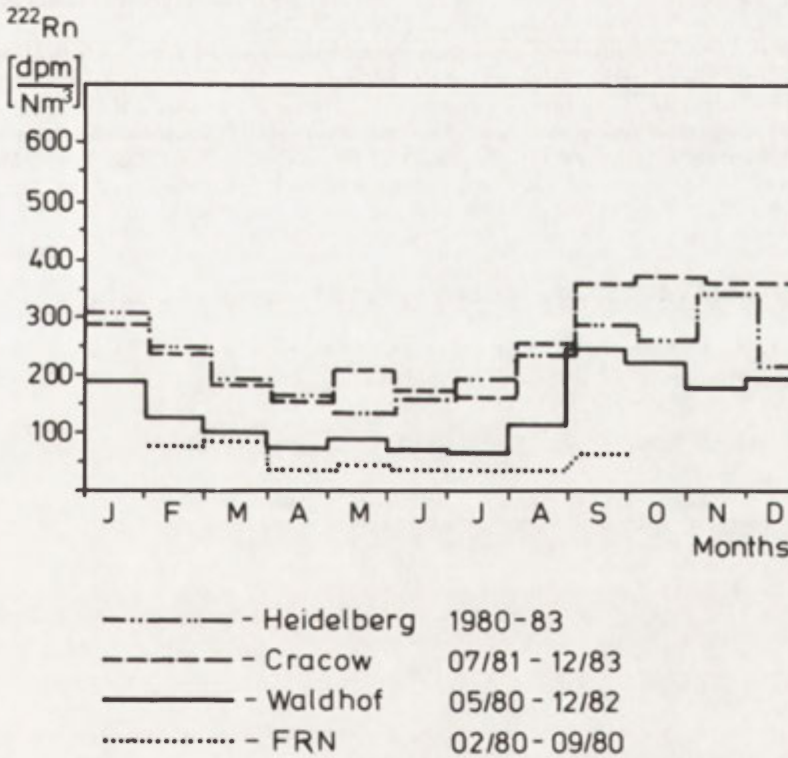

Fig. 9. Comparison of monthly average radon values in four stations

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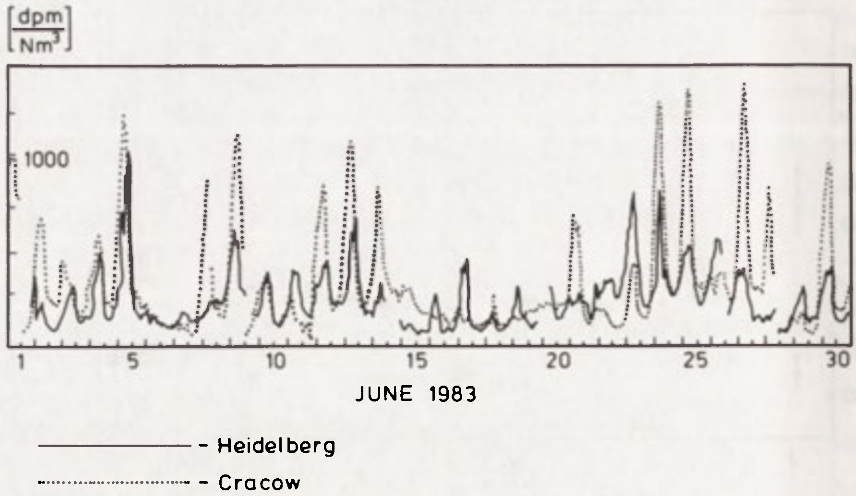

Fig. 10. Comparison of radon record in Cracow and Heidelberg in June 1983 (according Volpp 1984)

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POLISH BALTIC COAST: CHANGES, HAZARDS AND MANAGEMENT

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ABSTRACT: It is widely taken for granted that the climate is changing worldwide, partly on account of anthropogenic effects. The impact on Polish coast of the accelerated sea level rise (ASLR) due to the intensifying greenhouse effect has been tackled under IPCC auspices (Zeidler 1992). Regional climate change for the Baltic Sea is discussed first, with particular emphasis on recent findings for sea level (mean and extrema) and storm intensity. Examination of trends and statistical distributions for sea level datasets, revised and updated for the Polish coast, has partly confirmed some earlier conclusions drawn for mean sea level showing a trend about 20 cm per 100 years. For the maximum sea levels the rising trend is about two times smaller. More thought is being given to the general problem of land (primarily arable) degradation due to extended landward penetration of sea water due to ASLR. Long-term coastline change is analysed on the basis of routine topographic and bathymetric data collected at the PAS Institute of Hydro-Engineering IBW PAN Coastal Research Station, situated some 75 km from Gdansk. Following that analysis, we are postulating a large-scale model basing on conservation laws for sediment volume, the shore profile equilibrium (the Dean profile), dispersion terms between coastal cells, and linkage between wave energy dissipation and shore transformation. Assessment of coast vulnerability to ASLR (Zeidler 1992) has been summarized to identify the potential hazards. The Polish "Study Area" under IPCC 'Common Methodology' has been defined as the area within which the physical effects of the accelerated sea level rise (ASLR) over the next century could be felt. The inland boundaiy of the study area was chosen as the + 2.5 mm contour. In summary, the area endangered under ASLR1 and ASLR2 is very substantial — 2230 km^2 both flooded permanently and at risk (flooded periodically). The area losses under ASLR1 and ASLR2 are respectively 672 and 948 km^2. The length of roads flooded is 400 km and 564 km in the two cases, in addition to 35 and 126 km of railways, 300 and 415 km of primary power lines, and 26 bridges. The population to be evacuated in advance amounts to 142,690 (urban) and 92,150 (rural), thus 234,840 in total. Various protection techniques are proposed to avoid loss of land. Flood protection in the Lower Vistula River has been described in a comprehensive monograph published by IBW PAN (Makowski 1993).

KEY WORDS: climate change; sea level rise; shore protection; coastal management; Poland's coast vulnerability to sea level rise.

IMPLICATIONS OF CLIMATE CHANGE FOR THE BALTIC COAST

POLISH COAST

The Baltic Sea coast forms Poland's borders along 500 km. The Baltic is a shallow, almost land-locked sea. Its salinity is low, barely 7-8 ppth in the Polish coastal zone.

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Polands' coastline forms two major gulfs — the Pomeranian Gulf and the Gulf of Gdańsk, and two lagoon-type bodies connected with the sea by narrow straits: the Szczecin Bay and the Vistula Bay. Thus two major estuarine systems occur on the Polish coast — of the Odra River on the west and the Vistula River in the eastern part, about 700 and 850 km^2 in size. A substantial part of the Vistula Delta, the Zuławy, is a depression reaching almost 2 m below sea level.

The Polish coast consists of two basic types — dunes and barrier beaches, and cliffs. The former occupy most of the coast while cliffs stretch along less than 100 km. Coastal bariers between the sea and lakes are well developed in the central and eastern parts of the coast. The Hel Peninsula is a unique spit system separating the Gulf of Gdańsk from open sea. Because of its intensive erosion and multifarious importance, it has become a subject of concern to both Polish and international authorities.

GLOBAL CLIMATE CHANGE

It is widely taken for granted that the climate is changing worldwide, partly on account of anthropogenic effects.

The Earth's environment, shaped by geologic, physical, chemical, biological and other processes, and their powerful interactions, changes with time over different time scales. Natural phenomena, such as variation of the Earth's orbit, changes in the amount of radiation from the Sun, the horizontal and vertical movement of continents and mountain building processes, are responsible for long periods of slow progressive change interspersed with short periods of rapid change, exposed in the Earth's history by the use of various techniques (including paleodating).

We are also aware that human activities, which have always had a local effect on the inironment, are becoming felt on global scale, as the world population increases and the demand for more resources builds up. Hence the natural phenomena become accelerated. The greenhouse effect is a good example. The natural jacket of greenhouse gases (primarily CO_2, water vapour, CH_4, N_2O, ozone and CFCs) passes more solar radiation to the Earth than that reflected and produced by the Earth, thus keeping the Earth warmer by aproximately 33°C than without the greenhouse effect. The latter is accelerated because of the intensified production of the greenhouse gases by industry and other human activities.

The global warming has the most direct effect on the world ocean by thermal expansion of sea water due to higher temperatures and melting of ice and snow cover. Superimposed on these phenomena are changes in global atmospheric circulation, precipitation etc. together with numerous land-ocean interactions. On the continents alone, the water flowing towards the ocean will be affected by atmospheric changes and the land-atmosphere interactions. The modelling of all these interacting phenomena (and many other physical, biological etc. ones involved) is extremely complex, particularly in the shelf and coastal zones, where all factors of atmospheric, hydrographic and terrestrial origin play

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important role. It is attempted within numerous scientific programmes, such as LOICZ IGBP, but hopes for immediate solutions and reliable software packages seem premature.

Accelerated sea level rise (ASLR) due to the intensifying greenhouse effect has been tackled under IPCC auspices. As depicted in Figure 1, the projected ASLR is much faster than the changes experienced over last 100 years. The IPCC 1992 Supplement did not revise the 1990 Report's estimate shown in Figure 1, although some scientists raise doubts about the predicted magnitudes.

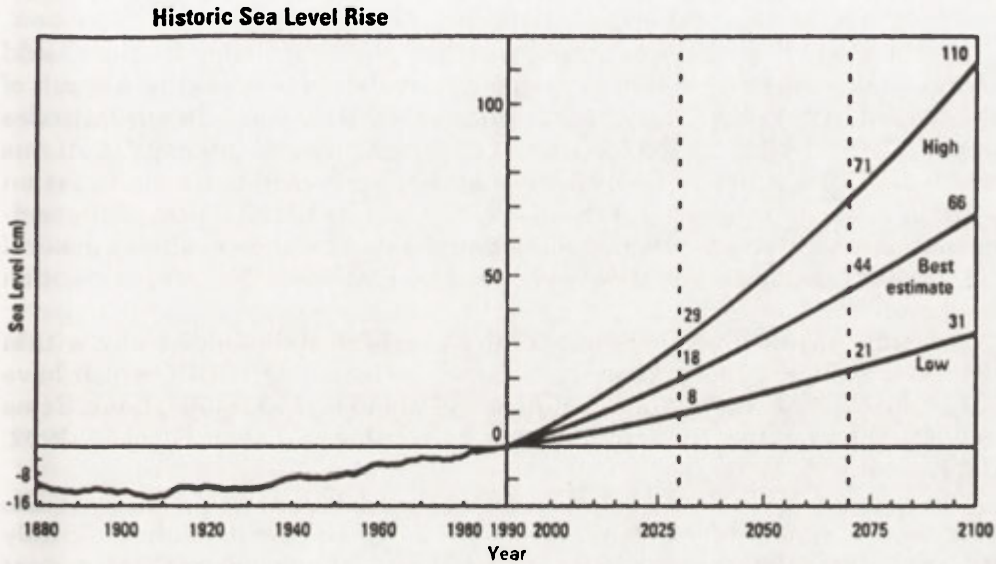

Fig. 1. Sea level rise as predicted by IPCC in case no measures are taken to counter the emission of greenhouse gases (Scenario A "Business as usual"), according toT.P. Barnett (1988)

REGIONAL CLIMATE CHANGE: THE BALTIC SEA

For the Baltic Sea, the possible changes in precipitation, evaporation, transpiration, and their uncountable outcomes, are all not amenable to ready prediction, either. However, one can focus attention on the most likely and conspicuous outcome of such change — the sea level rise. One can also resort to the belief of some researchers, climatologists in particular, who broadly assume that the world's air temperature can rise by some 4°C in 100 years, and that Poland will be no exception to this general rule. What is less proved, and remains to be examined in detail, one may claim that the intensity of storms will increase, say by 10% in the coming century. All this data is speculative to a considerable degree; hence a lot of research is badly needed to support or reject such statements. This paper refers to some recent studies throwing light on the topic.

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In 1992 the Author headed a Polish-Dutch team who completed Case Study Report on Vulnerability (VA) to ASLR (Zeidler 1992) outlining the application to Poland of the IPCC (RSWG) Common Methodology and providing an overview of climate change and its implications, together with response strategies. No other effects of climate change but ASLR have been considered in the study, although possible positive effects were mentioned such as (1) deepening of navigable waters; (2) renewal of biological life; (3) flushing of dead zones etc.

A few important aspects of the coastal zone vulnerability and management identified under that programme have been continued since the completion of the Study Report, and are outlined and commented on in the paper.

In the Study Report, it was anticipated that "the forthcoming studies should concentrate on the patterns of atmospheric circulation to appear as a result of the Greenhouse Effect. The intensification of westerly winds in our latitudes might be responsible for the increase in the frequency and intensity of storms in the Baltic Sea. In addition, the new atmospheric conditions can cause an intensification of the inflow of the North Sea waters to the Baltic, a phenomenon that contributes to renewal of the Baltic water, its higher salinity, general rise of sea level, and a variety of surge and oscillation modes, just to mention the few effects".

About the same time, there have been a couple of studies under way, within various Polish and international programmes (including IGBP), which have shed more light on the change of climate in Poland and its implications. Some new findings for the Baltic region can be emphasized (see: Global... 1992, Contemporary... 1993).

At present there is no reliable climate model that would forecast the long-term variability for Poland. Hence the research postulates in the Study Report (Zeidler 1992) remain in force. Global circulation models (GCM) are not yet powerful enough to yield a reliable prediction of climate change in Poland, let alone the Baltic coast. Nonetheless, some GCM have been employed by Polish researchers.

Inter alia, A. Olecka's (1993) study has been aimed at creating future climate scenarios for Poland, relating to doubling (preindustrial times as reference) of carbon dioxide concentration in the atmosphere. A. Olecka claims that the most probable predicted regional distribution of climatic variables is based on GISS GCM output data for six grid points situated inside and around Poland. Fifty two Polish synoptic stations yield monthly averaged surface temperature and precipitation for intercomparison. Third-order polynomial interpolation, multiple regression and empirical orthogonal functions have been used to evaluate the anticipated changes in temperature and precipitation related to CO_2 doubling. The results obtained from GISS modelling and the synoptic stations are different as to magnitude and spatial distribution. The common finding consists in the likely increase in the mean annual temperature to 10-13°C and warmer winters (-1 to 5°C in January). Precipitation will grow even twice as much and can exceed 1000 mm in some regions.

The above conclusions are controversial, and by no means widely shared by

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other researchers. Instead, it is believed that none of the available GCM (such as GISS, GFDL, UKMO and OSU) satisfies the necessary preconditions for aplication to regional climate change forecast, encompassing adequate spatial and temporal resolution, coupling of models for atmospheric and oceanic circulation, time-dependent increase in greenhouse gases etc. Brazdil (1993), who presents examples of computations for Central Europe (Czech and Slovak Republics) subject to CO_2 doubling indicates that air temperature can increase by 2°C in spring and 2.5°C in winter about the year 2030. An increase in precipitation is expected in winter, spring and summer and throughout the year in the two countries, while in Slovakia the precipitation can fall in autumn and its change in summer is difficult to predict unambiguously, thus remaining uncertain.

Important the Baltic conditions is not only precipitation but also water discharge from the catchment basin affected by the climate change. In the context of Brazdil's (1993) conclusions based on GCM M. Lapin (1993) employed other tools (the Zubenok — Budyko method) to calculate the water balance elements for Slovakia, basing on the measured series for precipitation, relative air humidity and snow cover. M.Lapin exposes falling trends in precipitation over the next 35 years, accompanied by a significant rise in potential evapotranspiration, dropping humidity, soil moisture and snow cover, all due to 1-2°C warming.

With respect to the effect of climate change on water resources, Z. Kaczmarek (1992) expresses doubts if the available statistical data can provide sufficient proof for trends in precipitation and/or river discharge, such as those already existing for the air temperature resulting from the greenhouse effect. Nonparametric Kruskal-Wallis and Mann tests employed for 176 discharge series from all continents displayed various trends, even for rivers within the same geographic zones (Kaczmarek 1992).

Hence it becomes inviting to harness general circulation models (GCM) for simulation of hydrological processes. Two models, GFDL and GISS, applied to the Polish conditions under various weather scenarios, have provided results which, although contradictory at places, can be summarized as a slight decrease in total catchment discharge, especially in central Poland, lowering of low water stages, and substantial changes in the seasonal course of water budget elements, together with general perceptible soil moisture deficit throughout the vegetation period (Kaczmarek 1992).

As a slightly secondary issue one can ascertain that, despite the temperature growth due to the accelerated greenhouse effect and the elongation of the vegetation period, the crops can remain at the present level, depending on the availability of water (Ryszkowski 1992); this in turn controlling the soil conditions, affecting the sediment discharge to the sea etc.

Similar conclusions for Poland's water balance are repeated by Kaczmarek (1993). First of all, he does not believe that the available GCM are accurate enough to underpin regional impact assessments and water budget studies. Kaczmarek's climate change scenarios have been based on NCAR data (September 1989) and two GCM (GISS and GFDL) for air temperature and

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precipitation. A stochastic water budget model CLIRUN was operated for various input data stemming from GCM, and calibrated for river basins (31 stations for the years 1951-1990 and mean monthly discharge data for 22 river basins). Potential evapotranspiration was calculated by the Budyko method, and effective precipitation and snow melting were modelled independently. The results have been summarized as follows (Kaczmarek 1993):

(a) Depending on the climate scenario and the region, the annual runoff may decrease or increase; actual evaporation increases in both GISS and GFDL in all regions;

(b) In the draught period (usually August to October) runoff values and catchment water storage decrease for both scenarios over most area; runoff fall can be very substantial in Poland's Central Lowlands;

(c) Runoff is more sensitive to changes in precipitation than to temperature rise; the highest sensitivity is observed in regions with low values of the runoff coefficient;

(d) Because of changes in snow accumulation processes in warmer environment, shifts in spring floods might be experienced, but flood volumes are not likely to change much.

It may be tacitly assumed that the climatic conditions over Central Europe is changing along similar lines. Hence, in the light of the findings for Poland, Bohemia and Slovakia, it can be anticipated that the drainage area for the entire Baltic Sea will suffer from increasing water deficit. This might bring about a falling component of the long-term sea-level trend. On the other hand, precipitation and evaporation are expected to undergo serious seasonal changes. Taking into account the general patterns of water exchange between the North and Baltic Seas, with substantial intrusion (into the Baltic) during winter and predominance of outflow (due to precipitation and runoff surplus) in summer, one can venture a hypothesis that sea level rise in the Baltic will be more pronounced in the winter than in the summer. This would agree with quite a widespread conviction that extreme events will become more conspicuous in the wake of global warming.

SOME BALTIC CLIMATE CHANGE PROGRAMMES UNDER WAY

The programme "Climate in the Baltic Sea Basin" involves Poland's researchers under WMO auspices. Tentative findings basing on the analysis of meteorological data for the years 1961-1990 encompass an intensifying trend in the anticlockwise circulation of air masses (except for low pressure-gradient situations). Temperature and precipitation for the same period are now compared versus their counterparts for 150 years (Miętus 1993).

Another programme titled "Local atmospheric circulation index for identification of hazardous meteorological and hydrologic processes in the Polish Baltic coast zone" aims at identification of the coupling between the atmospheric circulation and sea water levels. The "North Atlantic Climatologic Dataset" programme managed by the Danish Meteorological Institute will soon be fully operational. One of the striking features exposed so far for the

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Polish surface waters (at Świnoujście) was a decrease in water temperature, correlating with an increase in air temperature; a finding certainly requiring further verification.

RECENT FINDINGS FOR SEA LEVEL (MEAN AND EXTREMA) AND STORM INTENSITY

In our 1992 VA study, for "open sea" we have ascribed the flooding probability to the exceedance probability of storm surge-induced sea levels. The Pearson Type III distribution fitted to the maximum annual water levels measured at Gdańsk (from 1886 to 1975, Majewski 1990) was employed to produce the required exceedance curve. The 100-year design water level can be approximated as 650 (i.e. 1.5 m above MSL) while its counterpart for the return period of 1000 years is about 680 (i.e. 1.8 m). This solved the problem for our Areas 2 and 3 (central coast). The situation is obviously different for river and lagoon flooding scenarios (our Areas 1 and 4). Although we have derived some tentative figures and adopted definitions, more thought must be given to rigorous derivation of the respective flooding frequencies.

Recent examination of trends and statistical distributions in sea level data sets, revised and updated for the Polish coast, has partly confirmed some earlier conclusions drawn for mean sea level and exposed new findings for *extremum* sea levels. The following trends have been established for ten Polish tide gauge stations (Dziadziuszko 1992), see Table 1.

TABLE 1

Station	Mean sea level 1951-1985	Growth rate (mm/yr)
Trzebież	504.8	2.0
Świnoujście	497.1	1.4
Kołobrzeg	498.1	0.8
Ustka	499.9	2.0
Łeba	500.1	1.5
Władysławowo	499.5	1.7
Hel	501.4	1.7
Gdynia	502.9	2.2
Gdańsk-Nowy Port	504.0	2.9
Tolkmicko	502.2	1.5

Note: Tide gauge zero = 500 NN_{55} (Amsterdam) = 508 H_r (Kronshtat)

These trends should be looked at in longer time scales, such as those dealt with by Z. Dziadziuszko and T. Jednorał (1988) for Świnoujście (from 1811), Kołobrzeg (from 1867), Ustka (from 1901) and Gdańsk (from 1886), always to 1985. The multi-yearly mean sea level for those periods assumes the following values Świnoujście — 491.1 cm ±0.3 cm, Kołobrzeg — 494.0 cm ±0.4 cm, Ustka — 497.9 cm ±0.5 cm, Gdańsk-Nowy Port — 500.1 cm ±0.5 cm.

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Figure 2 illustrates the clear growth rate. That trend can be described by the following gradients: Świnoujście — +0.7 ± 0.1 mm/yr, Kołobrzeg — +1.1 ± ± 0.1 mm/yr, Ustka — +0.2 ±0.2 mm/yr, Gdańsk–Nowy Port — +1.2 ±0.2 mm/yr.

Longer components can be discriminated by data smoothing and filtering, such as visible in Figure 3.

Annual sea level maxima (ASLM) constitute the most recent contribution to the knowledge of the Polish Baltic hydrology (Wróblewski 1993). The measured raw data are illustrated in Figure 4. The difficulties encountered in their analysis encompass the absence of a constant discretization step, unknown statistical independence, and the inherent trends and periodicities. The

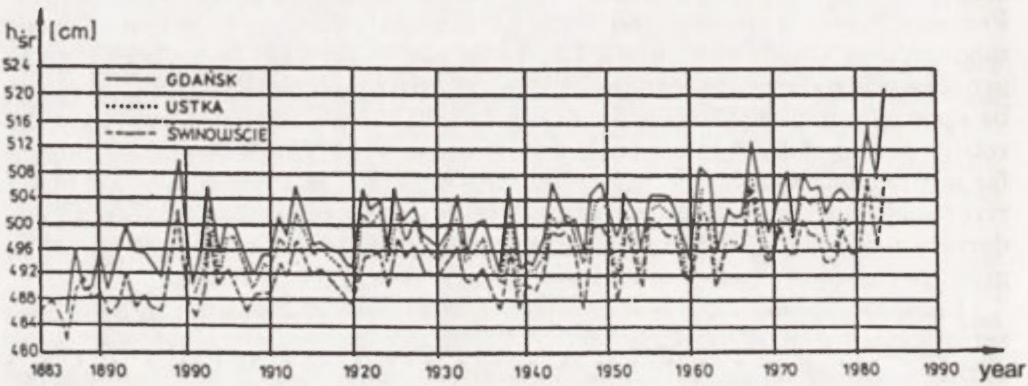

Fig. 2. Mean yearly sea levels at three Polish Baltic stations (Dziadziuszko end Jednorał 1988)

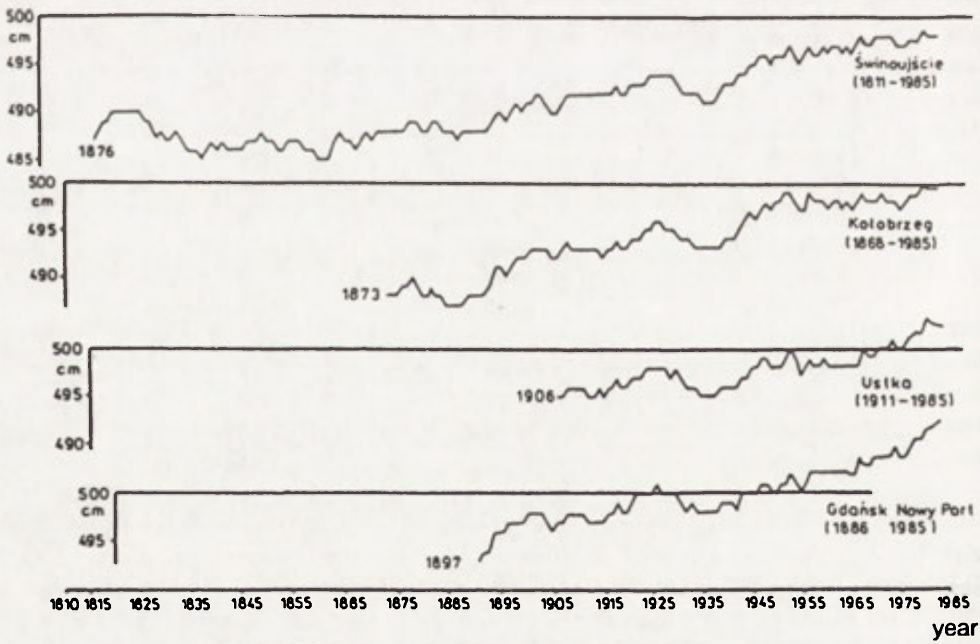

Figure 3. 11-year consecutive sliding mean sea levels (Dziadziuszko end Jednorał 1988)

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ASLM trends have been assumed linear (checked by nonparametric Mann-Kendal testing at 95%) and have been found to approach 0.5 mm/yr at Świnoujście, 0.7 mm/yr at Kołobrzeg and 1.73 mm/yr in Gdańsk. Hamming windowing (better than maximum likelihood in this case) displayed significant periodicities about 8, 5-6 and 3 years. Bartlett testing confirmed the data independence for Gdańsk but not for the other stations. Seasonal occurrence of the maxima is obvious — 74% of all ASLM occurred between November and February, these months encompassing all ASLM with 10-% exceedance and 91% of 25-% exceedance (remaining 9% in October and March).

The probability of ASLM exceedance P(h) basing on the Gumbel distribution reads as follows in Table 2.

Figure 5 shows the exceedance values in the graphical form.

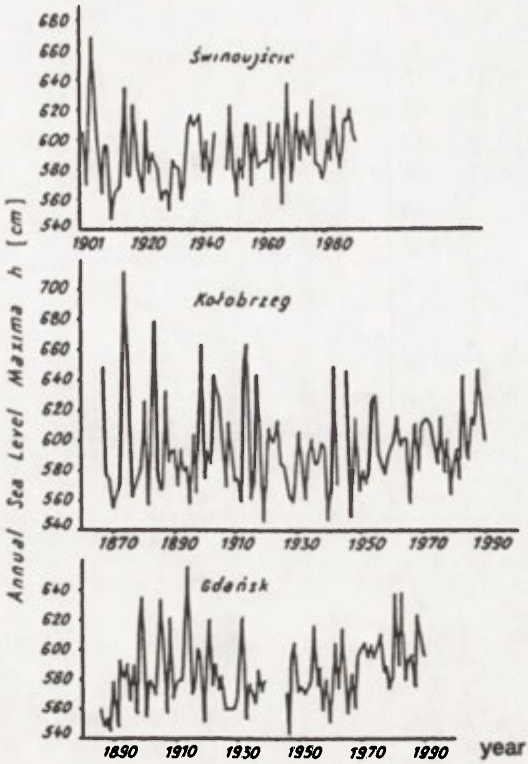

Figure 4. ASLM at Świnoujście, Kołobrzeg and Gdańsk (Wróblewski 1993)

Another interesting research objective attacked now by the author and his associates consists in description of the correlation matrices for joint sea level and wave height events under storm conditions observed and hindcast along the Polish Baltic. This programme is to end in two years, and is hoped to be fruitful both scientifically and practically (design of coastal and maritime structures basing on more than just one storm parameter such as sea level).

Table 2

Probability P, %	99	90	80	70	60	50	40	30
T (years)	1.01	1.11	1.25	1.43	1.61	2.0	2.50	3.33
Świnoujście (cm)	548	561	568	573	579	584	590	597
Kołobrzeg (cm)	540	556	564	571	577	583	590	598
Gdańsk (cm)	538	551	558	563	568	573	579	585
Probability P, %	20	10	5	2	1	0.5	0.2	0.1
T (years)	5.0	10	20	50	100	200	500	1000
Świnoujście (cm)	605	620	633	652	665	678	695	706
Kołobrzeg (cm)	609	625	642	664	680	696	717	733
Gdańsk (cm)	594	608	621	639	651	664	681	694

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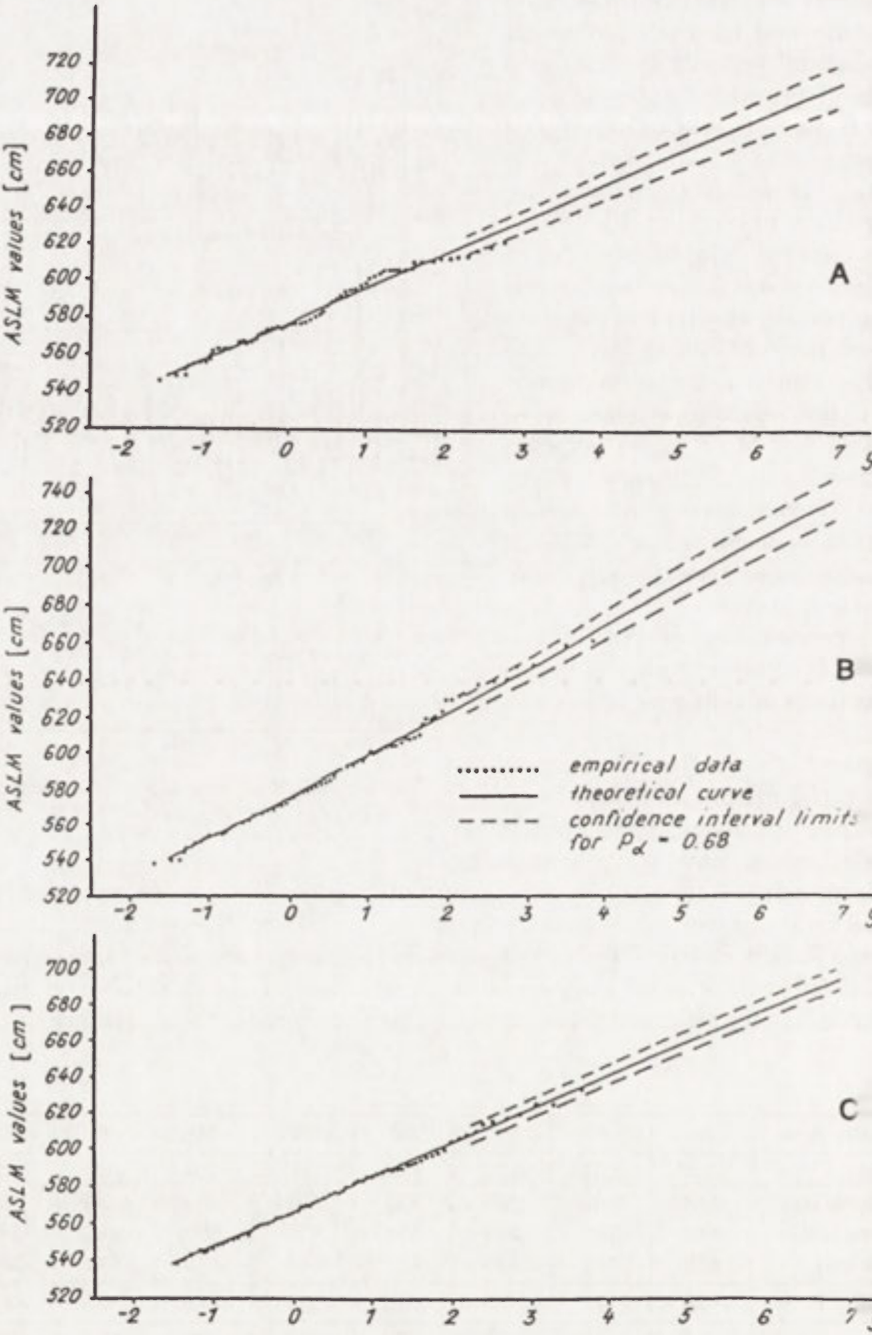

Figure 5. ASLM exceedance curves fitting the Gumbel distribution (Wróblewski 1993)
A — Świnoujście, B — Kołobrzeg, C — Gdańsk

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CHANGING SALINITY

As regards salinity, in the Study Report we have provided some estimates of the twofold effect of the sea: (1) on estuaries, lakes, rivers and other surface waters; (2) on shallow subsurface waters. From our inquiry it was concluded that salinity intrusion on and below water surface was negligible altogether. However, it was stated that "one problem that might arise due to ASLR consists in possible penetration of sea water to the wells supplying water to the cities of Gdańsk, Gdynia and perhaps Szczecin".

More thought has been given to the general problem of land (primarily arable) degradation under a recent programme led by the Author. G. Kohno and M. Nishigaki's (1982) equations for unsteady groundwater flow in the coastal zone have been adopted to analyse the penetration of sea water into coastal subsurface aquifers (Zaradny 1993). Ghyben-Herzberg's, Bear-Dagan's and other solutions for steady state follow as partial cases. The formulation is used as a starting point for evaluation of the soil-water conditions in terms of the following factors:

— extended landward penetration of sea water due to ASLR;
— change in the chemical and physical properties of soil;
— change in soil water potential and plant suction potential;
— effect on the phenomena of germination, root growth, plant metabolism etc.

Inter alia, the rise of groundwater level can bring about both positive and negative effects, depending on the water stage before ASLR, type of crop etc. Rising groundwater table causes a higher contribution of the capillary rise in the plant water budget. Rising groundwater table, coupled with higher yield from wells, expands in turn the area of sea water penetration. Adequate coastal management should incorporate as high as possible groundwater table gradients. As to the plant suction potential, it can deteriorate in time due to accumulation of salt in the root zone. The effect of ASLR on germination is largely perceptible in young plants (thus endangering dune stabilization etc.). Many other aspects are expected to emerge as a result of the study under way.

LONG-TERM COASTLINE CHANGE

Routine topographic and bathymetric data have been collected at the Institute of Hydro-Engineering PAS Coastal Research Station, situated in Lubiatowo on the Polish coast of the Baltic Sea some 80 km from Gdańsk. Along with parameters of wind, waves, currents and other hydrologic factors, topographic features have been measured since 1983 on a 2.7-km beach and nearshore zone extending some 800 m from shoreline. The beach profiles have been arranged every 100 m. The first systematic and mutually-compatible records of beach and shore topography date back to 1964, and echosoundings plus tachimetry are continued every four weeks.

In addition to Lubiatowo, a few other sites have also been made available to Institute of Hydro-Engineering staff, such as Bulgarian Black Sea or

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Senegalese coast off St. Louis, not to mention the cartographic material for Poland's coastal units such as Hel Peninsula. Hence we have insight into a considerable bulk of a reliable field database stretching over a reasonably long span of time. This data set encompasses mostly sandy beaches, and partly cohesive beds. It has been used for various research purposes. At present we focus attention on its use to model the large-scale coastal behaviour (Pruszak and Zeidler 1993).

The concept of beach and shore equilibrium has been analyzed as to whether it can be applied to large-scale modelling. Coastal climate has been quantified with respect to the controlling factors in various time scales. Characteristic beach and shore features are discriminated as to their weight in the measurement and prediction of coastal changes. It is generally concluded that small-scale modelling concepts can be extended to large scale only under exceptional conditions.

We are postulating a large-scale model based on conservation laws for sediment volume, the shore profile equilibrium (the Dean profile), dispersion terms between coastal cells, and linkage between wave energy dissipation and shore transformation. Superimposed on the Dean profile, identified with the first eigenfunction, are sand bars, with geometrical properties (distance, spacing, height, volume, shape etc.) specified on the basis of the available field data. Hence the coastal cell (control volume) is delimited by different kinds of shore profiles (such as cliff or partial erosion, erosion or accretion in terms of the coefficient A in the Dean profile etc.) along shore, and described by the superposition of shore profile features in the cross-shore direction. The testing of the sensitivity of the model to various parameters is based on the shoreline migration measured.

ASSESSMENT OF COAST VULNERABILITY TO ASLR

BOUNDARY CONDITIONS

This short chapter is added to familiarize the Reader, interested in both changing hydrology and coastal habitats, with potential evolution of Poland's coastal zone due to climate change, or ASLR in particular. This summary is based on the study dealing with Poland's vulnerability to sea level rise (Zeidler 1992) mentioned earlier in this paper.

The Polish "Study Area" has been defined as the area within which the physical effects of the accelerated sea level rise (ASLR) over the next century could be felt. The inland boundary of the study area was chosen as the +2.5 m contour.

No other effects of climate but ASLR have been considered in the study.

Out of the total length of the Polish coastline, the "open sea" coast is almost exactly 500 km (of which 72 km on both sides of the Hel Peninsula), while the banks of the Szczecin Bay measure about 240 km, and those of the Vistula Bay about 100 km.

Because of their distinct features, four major Areas have been distinguished: the Odra Estuary (Area 1), western dunes and barrier beaches

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(Area 2), central-east dunes and barrier beaches with the Hel Peninsula (Area 3), and the Vistula Delta (Area 4). Area 1 includes the agglomeration of Szczecin (and Świnoujście), while Area 4 encompasses the three-city complex of Gdańsk, Sopot and Gdynia, to gether with Elbląg (Table 3).

Table 3

Area	Description	Length, km	Surface area, km^2
1	W border to River Rega[1]	320	595
2	River Rega to Łeba	170	244
3	Łeba to N Gdynia	160	173
4	Gdynia to E Border	190	1217

[1] West of Kołobrzeg

The division into three impact zones permitted a convenient distinction through the study area cross-section within which flooding probablitites could be assessed: (I) between 0.0 m and +0.3 m MSL contours: (II) between +0.3 m and +1.0 m MSL; (III) between +1.0 m and +2.5 m MSL.

The data collected from maps, reports, computations, studies and other sources (e.g. land-use, socio-economic etc.) were entered pertaining to each of the impact zones separately in working tables. Flooded areas (i.e. areas 'lost') could then be readily deduced as zone I at ASLR1 (30 cm/100 yrs) and zones I+II at ASLR2 (1 cm/yr), while the area at risk was defined as II+III at ASLR1 and III at ASLR2.

For the purposes of assessment, the following habitats have been distinguished: coastal waters, beaches and dunes, forests, lagoons and barrier lakes, rivers and estuaries, and swamps/bogs. Coastal forests display the highest biodiversity among all coastal habitats.

THE EXTENT OF VULNERABILITY FOR THE "NO MEASURES" OPTION

The extent of inundation and population hazards in our study area are visible in Tables 4 and 5.

The impact zones between contour lines 0-0.3 m, 0.3-1 m., and 1-2.5 m cover respectively 845, 883 and 476 km^2, thus 2204 km^2 in total, in addition to 30 km^2 of beaches and dunes likely to dissapear as a result of ASLR2 (and some 10 km^2 due to ASLR1).

The principal ASLR impact in the Odra estuary will consist in inundation extending at ASLR2 up to River Rurzyca (695 km). Polder dykes have crests about 1.5-2 m above MWL. At higher stages most polder dykes will be overtopped. The inundated polders will include those of Międzyodrze (between East and West Odra), around the Szczecin Bay, Świna and Dziwna. Equally endangered by flooding are urban areas of Szczecin (primarily Dąbie), Świnoujście, Trzebież and other towns. Indirect effects encompass damage to sewerage and other infrastructure. Parts of the ports of Szczecin, Świnoujście and Police are also vulnerable. The impact zones I and II within Area 1 measure in total 163.8 and 496.6 km^2, respectively.

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Table 4. Distribution of land-use categories in impact zones I, II and III; area in hectares, length in kilometres

Impact Zone I - 0.0-0.3 m										
Area	AH	AL	AO	F	W	U	I	R	NR	RD/LR/TL/NT/B
1	90	11,955	2,635	1415	30	40				30/25/41////
2		30	400						430	
3		130	40							
4	64,870	130	1,685		352	130	150			291/108/302/29/6/
Total	64,960	12,245	4,760	1,415	382	170	150		430	321/133/343/29/6/
Total Impact Zone I Surface Area = 84,512 ha										
Impact Zones I + II - 0.0-1.0 m										
1	297	34,338	5,435	7,290	550	640	505	35		70/89/74/15/1/17
2		11,100	995	2,745	110	90			465	27/11/30/1/1/4
3		11,531	118	24	17	5	8	12		6/8/7/2///
4	86,910	1,930	2,265	1,260	2,590	705	430	95	275	428/179/415/61/65/26
Total	87,207	58,899	8,813	11,319	3,267	1,440	943	142	740	531/287/525/79/66/47
Total Impact Zones I+II Surface Area = 172,770 ha										
Impact Zone III - 1.0-2.5 m										
1		7,935	145	1,690			300			36/9/35/6/2/4
2		5,380		2,315	370					36/7/5/3/1//
3		3,210		330	155	85		730		28/10/7/11///
4	21,520	200		795	1,215	815	370			97/12/60/8/9//
Total	21,520	16,725	145	5,130	1,740	900	670	730		197/38/107/28/11/5
Total Impact Zone III Surface Area = 47,560 ha										

Notes: Land-use categories: AH — high agriculture; AL — low agriculture; AO — land out-of-use; F — forests; W — rural; U — urban; I — industry (including ports); R — recreation; NR — national reserves; RD — roads; LR — local roads; TL — power transmission lines; RL — railways; NT — narrow-track railways; B — bridges

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Table 5. Population of the Study Area

Area	Zone	Urban	Rural	Total
1	I (0-0.3 m)	1,630	3,450	5,080
	II (0.3-1.0 m)	21,080	9,630	30,710
	III (1-2.5 m)	28,960	2,940	31,900
2	I	0	270	270
	II	1,210	4,580	5,790
	III	870	2,880	3,750
3	I	0	110	110
	II	740	9,310	10,050
	III	1,550	2,490	4,040
4	I	9,590	25,810	35,400
	II	40,980	17,650	58,630
	III	36,080	13,030	49,110
Total		142,690	92,150	234,840

All Polish coastal polders, arranged in eight complexes of 243 polders measuring 183,557 hectares will be at stake.

In Areas 2 and 3, narrow coastal barriers between the sea and low-lying lakes (much as lagoons or embayments in other areas) could erode, making the hinterland widely accessible to sea water. The higher levels attained by storm surges in ASLR scenarios will destroy foredunes and erode barrier islands and spits. The lowered barriers will then be susceptible to storm washover. The lakes will grow more saline.

Słowiński National Park and Łeba dune field, a memorable natural landscape, special enough to be included on UNESCO's list of the world's Biosphere Reserves, are endangered as well. The Hel Peninsula, a fairly unique spit formation separating the Gulf of Gdańsk is most vulnerable, and will become a smaller island if no protective measures are applied.

Gdańsk, Szczecin, Świnoujście and Gdynia ports are all flooded and at risk, though to different degree. For instance, the industry of Gdańsk (ports included) occupies 430 and 330 hectares in impact zones I+II and III, respectively. In addition, Gdańsk is now a lively industrial, scientific and cultural centre of northern Poland. The endangered urban areas of Gdańsk cover 450 and 680 ha in the same zones. Full prevention measures should be taken to avoid any loss of this valuable and historical piece of our study area.

One should point out the importance of ports and several shipyards in Gdańsk, Gdynia and Szczecin, the industrial hinterland, such as oil refinery linked to oil terminal in Gdańsk in Area 4, and the Lower Odra power plant and the large chemical plant and port at Police in Area 1, the architecture, historical, and cultural values of old cities, primarily Gdańsk in Area 4, and numerous roads and railways, in addition to other infrastructure.

The Vistula Delta covers an area of 2,320 km^2 with major cities of Gdańsk, Elbląg and Malbork. Its polder area occupies 180,000 hectares (0.6% of the land

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area of Poland). Most of its depressions and lowland will be damaged. The dikes already built will be too low for the new hydrological conditions, especially ASLR2. They have been designed to stay under water not longer than a couple of days. In summary, the area losses under ASLR1 and ASLR2 are very heavy — 672 km^2 (80% of all Area 1-4) and 948 km^2 (55%) respectively. The length of roads flooded is 400 km and 564 km in the two cases, in addition to 35 and 126 km of railways, 300 and 415 km of primary power lines, and 26 bridges.

Enhanced shoreline erosion and shore retreat has been analyzed by the use of field data, Bruun computations and numerical models such as P. Vellinga (1984), D.L. Kriebel and R.G. Dean (1984, 1985). All results point to a figure exceeding 150 m of shoreline and dune retreat in the course of 100 years of ASLR2 scenario. The counterpart for ASLR1 can be estimated at 50 m per 100 years.

Hence the impact zones between contour lines 0-0.3 m, 0.3-1 m. and 1-2.5 m cover respectively 845, 883 and 476 km^2, thus 2204 km^2 in total, in addition to 30 km^2 of beaches and dunes likely to dissapear as a result of ASLR2 (and some 10 km^2 due to ASLR1).

OUTLINE OF THE FULL PROTECTION OPTION

In the Study Report, the "full protection" response strategy was defined as "the implementation of all feasible protection measures to minimize losses of any coastal land or values".

Described in the report (Section 7.2) are various protection techniques adopted, while Section 7.3 provides an overview of specific subareas and the solutions proposed to secure their protection. In the latter, we began with identification of specific systems on the "inland" side first, followed by an examination of our protection strategy along the entire "open sea" coast, scanned kilometre by kilometre, from east to west.

We have examined the suitability of various methods for the diversified environments. From that variety of possible coastal defence measures we have chosen dykes, seawalls, offshore breakwaters, artificial beach nourishment and land elevation, in addition to local land abandonment. Many structures are new, and some existing structures are proposed for reconstruction and adaptation to new ASLR conditions.

Inter alia, full protection of the Odra estuary means preservation of the polders on peripheries of the estuary. 107 and 280 km of new dykes must be constructed in Area 4 under ASLR1 and ASLR2, respectively; the lengths of adapted dykes are 243 and 324 km. In Areas 2 and 3, new polders require new facilities such as pump stations, drainage and other infrastructure. In our concept of Hel Peninsula protection we have largely adopted the viewpoint of Polish and Dutch experts, and rely mostly on artificial nourishment. In Area 4, it seems imperative to keep the present agricultural use of the Vistula Delta (much as the lower Odra Valley), especially in the polder areas.

Hence full protection of Żuławy polders at ASLR2 requires a bulk adaptation of the existing dykes and the construction of some new dykes and storm

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and flood prevention facilities. At ASLR2, one should construct 52 km of new dykes and adapt 647 km of those presently in use. Under ASLR1, the respective numbers are 13 and 600 km.

The adaptation should encompass river dykes on Żuławy, frontline dykes on the Vistula Bay, lower dykes around Lake Drużno, and river dykes along Rivers Szkarpawa and Nogat, and Kanał Jagielloński, which make up the navigation route between Gdańsk and Elbląg. The Vistula dykes should be adapted on some 35 km from the mouth upstream. Other rivers will require new dykes, in addition to the adapted ones.

The storm barrier at the entrance of River Tuga should be virtually redesigned in view of ASLR2, and other river gates must be considered to keep storm surges away from the delta.

Additional protection should also be secured on polders around the Vistula Bay (at Krynica Morska, Przebrno, Kadyny, Tolkmicko and Pasłęka).

Shore protection schemes for specific areas are outlined in the Study Report, together with an overview of port adaptation works; the total length of berths is 57.4 km.

Future investigations are still deemed necessary as continuation of this stage of VA studies, quite limited due to time constraints.

FLOOD PROTECTION IN THE LOWER VISTULA RIVER

A comprehensive monography (Makowski 1993) has just been published at the Author's institut, as a result of an extensive database and literature review, supported by retrieval of historical material from Polish and foreign archives. The monograph provides all available details of the planning, design, construction, damage, maintenance and repair of dykes in the Vistula Delta. Analysis of seepage and groundwater conditions, subsidence and erosion, together with the mechanisms of dyke breaching and the past scenarios of flooding, gives an invaluable bulk of information permitting better planning and management at present; and has been welcome by planners, designers,managers, environmentalists and engineers with utmost attention.

CONCLUDING REMARKS

Since the paper is a review of various aspects concerning the implications of climate change within the coastal area, no clear-cut conclusions but very few basic ones can be postulated. First of all, the hazards of considerable losses of land and property, if not casualties and life toll, are substantial in terms of Poland's GNP. Protection is less costly but still amounts to high proportions of GNP (or might be estimated as one-fifth of Poland's foreign debt). Those hazards should be taken as seriously as the accelerated sea level rise (ASLR) and the greenhouse effect itself, a phenomenon quite commonly accepted worldwide. Secondly, measures preventing the environmental impact of ASLR

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and counteracting the losses should be taken as early as possible. Any unnecessary delay might prove both more costly than at present and disastrous to the fragile coastal environment subjected to irreversible change.

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BIOGEOCHEMICAL STUDIES IN THE RATANICA FOREST CATCHMENT (WIELICZKA FOOTHILLS, S POLAND)

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ABSTRACT: Biogeochemical and bioindication studies in the beech-pine forest catchment exposed to the moderate, but chronic industrial emissions in southern Poland were described. Balance of nutrients and pollutants was calculated, forest damage using plant indicators was estimated. All data show that the forest in the Ratanica catchment is deteriorated.

KEY WORDS: nutrient and polutant cycling, forest catchment, air pollution, forest health monitoring, bioindicators.

INTRODUCTION

Forest decline over increasingly large areas of Europe has given an impetus to more intense ecological investigations in forest ecosystems. Damage to forests is caused by various factors. However, industrial pollution seems to be the primary cause of the suffering of not only forests affected by heavy gas and dust emission but also those situated far from large agglomerations exposed to low level but long-lasting pollution. Such forests have now become the object of investigations carried out by numerous scientific teams, acting often within the framework of joint international programmes.

In order to find out the causes of forest damages experimental investigations in various types of chambers with controlled dosage of pollutants, as well as biogeochemical field studies on the cycling of elements in the ecosystems are conducted. The most useful object for biogeochemical studies are small hermetic catchments (Hornung et al. 1990; Kostrzewski, Stach 1992; Černy 1993). The Ratanica catchment is an example of such a catchment. It is situated some 40 km south of Cracow, near a large water retention reservoir at Dobczyce. It has been exposed to the moderate but chronic industrial emissions for more than 40 years.

In the forest part of the Ratanica catchment, biogeochemical investigations have been conducted for the past three years. They are carried out under several projects of the Committee for Scientific Research, supervised by K. Grodzińska (W. Szafer Institute of Botany, Polish Academy of Sciences), and by R. Laskowski (Department of Ecosystem Studies, Jagellonian University). At the same time, they form part of the Joint Polish-Swedish Research Programme

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in the field of the effects of air pollution on forests, and within this programme they are carried out under two projects: "Deposition and biogeochemical run-off investigations" and "Air pollution and monitoring of forest health".

These biogeochemical investigations were preceeded in the Ratanica valley by botanical and ecological team work (Grodzinska and Weiner, in press).

CHARACTERISTICS OF THE RATANICA CATCHMENT

The Ratanica stream, a tributary of the mountain Raba river, lies at the Carpathian Foothills (49°51'N, 20°02'E) (Gilewska 1991) (Fig. 1). Its catchment covers an area of some 242 ha, the forest catchment covering 88 ha). Its highest point is elevated of 424 m above sea level, while its lowest point lies at 270 m above sea level. It is charaterized by flat ridges and fairly steep slopes intersected by deep gullies. Its bedrock is formed by the Carpathian flysh (Istebna series), covered in the lower parts of the valley by the quasi-loess Quaternary formations (Aleksandrowicz 1991). The soils of the Ratanica catchment are usually composed of podsolized brown, acid brown and leached brown soils (Adamczyk et al. 1989). The average annual precipitation amounts

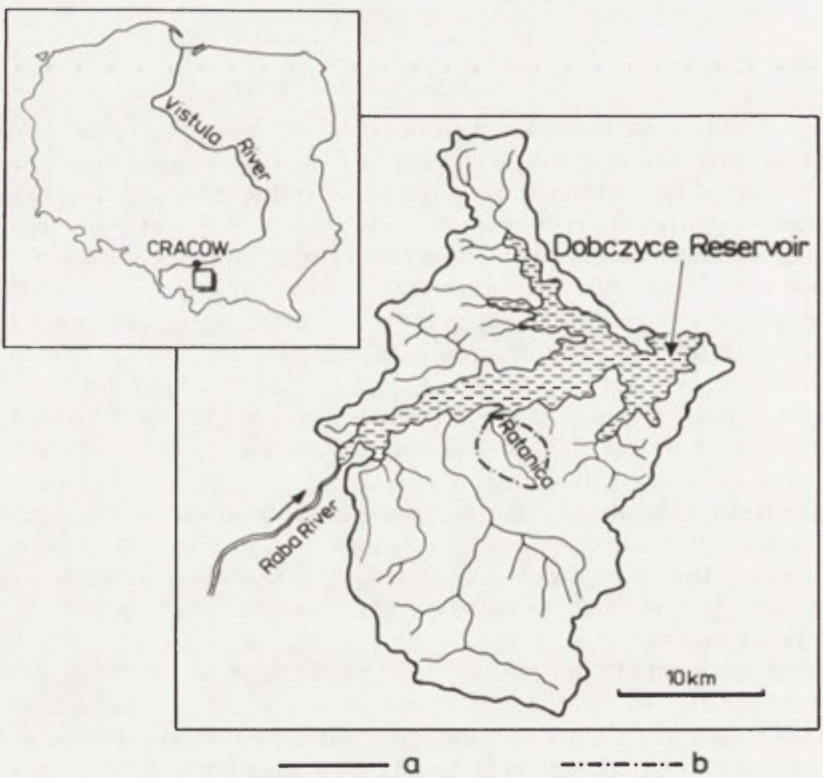

Fig. 1. Location of the Ratanica catchment
a — watershed of Dobczyce reservoir basin, b — Ratanica catchment

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to some 820 mm in the lower part of the catchment and to some 900 mm in its upper part. The annual air temperature averages 7.5°, and the vegetation period totals 218 days (Suliński, Kucza, in press). Vegetation is typical of the Carpathian Foothills. The upper part of the catchment is covered by beech and pine woods, sometimes having the admixture of larch trees. These forests are of anthropogenic character. The age of trees ranges from 40 to 80 years, the oldest classes being rarely found. The lower parts of the Ratanica catchment are occupied by meadows and fields, which are usually intensively fertilized (Różański, in press).

THE EXTENT OF INVESTIGATIONS IN THE RATANICA CATCHMENT

The purpose of the investigations was to estimate the amount of the inflow of biogenic matter and pollutants to the forest ecosystem (input), their accumulation in the ecosystem as well as their outlow from the ecosystem (output). These investigations will permit a determination of the actual pollution load of the ecosystem and an assessment of the disturbance in its functioning.

The fieldwork is concentrated on beech and pine woods on three transects intersecting horizontally the entire catchment and comprising 29 measuring sites, as well as on a permanent plot (0.25 ha) with 15 measuring sites (Fig. 2).

The research studies include: measurement of concentration of SO_2, NO_2 and suspended dust particles, meteorological measurement (atmospheric precipitation, air temperature, wind velocity), measurement of the amount and chemical composition of precipitation (bulk precipitation, throughfall, stemflow), measurement of the amount and chemical composition of soil water, measurement of the amount and chemical composition of stream water, measurement of the amount of biomass and chemical composition of litterfall, as well as determination of the actual condition of the catchment forest by use of plant indicators.

The concentration of pollutants in the air, meteorological measurement as well as the amount of outflow from the catchment are being constantly recorded. Precipitation and stream water are collected every two weeks throughout the year, while soil water and litterfall at monthly intervals.

In the samples collected, concentration of SO_4, NO_3, NH_4, PO_4, Cl, K, Na, Mg, Ca, Mn, Zn, Cu, Pb, Cd and pH, as well as electrolytic conductivity are determined.

The measurements are made using atomic absorption spectrophotometer (AAS Varian BQ 20), emission spectrometer (Flapho 4), ion chromatograph (Dionex 100), pH-meters and conductometer.

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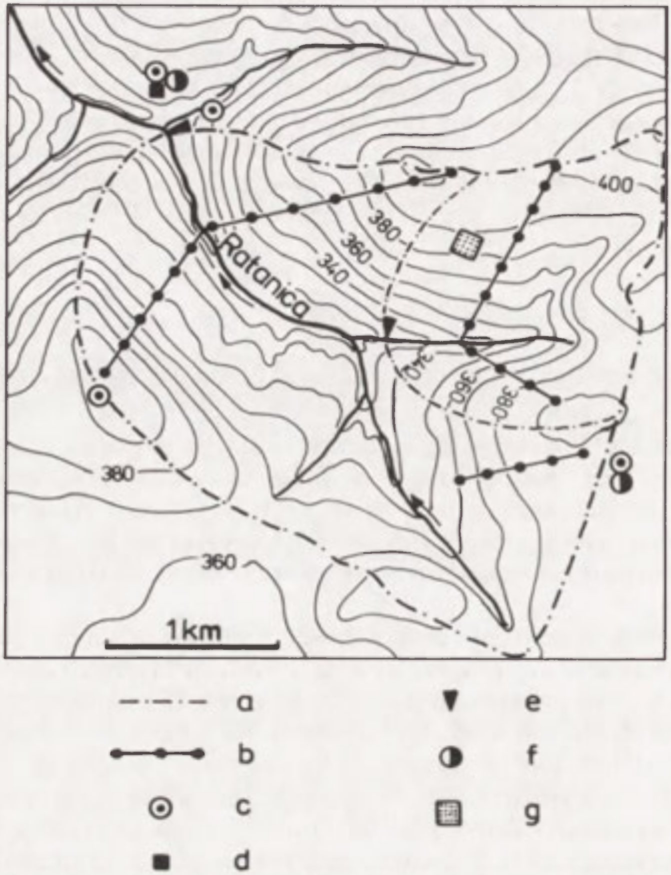

Fig. 1. Ratanica forest catchment
a — borders of the catchment and sub-catchment, b — transects with measurement sites (throughfall, litterfall, soil water), c — bulk precipitation, d — station of measurement of concentration of SO_2, NO_2 and suspended dust particles, e — weir, f — meteorological station, g — permanent plot

RESULTS OF BIOGEOCHEMICAL INVESTIGATIONS

The SO_2 concentration in the air during the two years under investigation averaged 27 $\mu g.g^{-3}$, NO_2 concentration 9.6 $\mu g.m^{-3}$, and the concentration of dust particles averaged 23 $\mu g.m^{-3}$. The value of these gases and dust showed a great daily and monthly variability, the highest values being recorded in the winter season. It is worth noting that the level of all the above-mentioned pollutants decreased in 1992 as compared to 1991 (Szarek et al. 1993).

The pH of precipitation in the Ratanica catchment is acid (pH about 4.5). The pH during the two years under investigation was 4.45 in the case of bulk precipitation, 4.76 for throughfall, and 4.05 for stemflow (beeches). The pH

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reaction of all kinds of precipitation varies in time, its lowest values being recorded in the winter.

The pH of the stream water is neutral or alkaline; its average value during the two analyzed years amounted to 7.71 and ranged from 6.75 to 8.32.

The ecosystem is supplied with a large amount of sulphur (about 30 kg × ha^{-1} × $year^{-1}$), and nitrogen (>20 kg × ha^{-1} × $year^{-1}$), as well as of chlorine (18 kg) and of heavy metals — Zn, Cu, Pb, Cd (about 2 kg).

The balance of nutrients and pollutants calculated for two years (1991-1992) showed negative values for sulphur, chlorine, sodium, magnesium and calcium, slightly positive for phosphorus, manganese, potassium and nitrogen, while highly positive for zinc, lead, cadmium and copper, as well as for hydrogen ions. This indicates a progressing acidification of the catchment, which is partiularly dangerous in view of the high accumulation of heavy metals in soil.

The investigations on the cycling of elements in the ecosystems must be carried on during many years to obtain the formula of the functioning of those ecosystems and to predict the effects of long-lasting inflow of pollutants. Two years studies within the Ratanica catchment, under different meteorological conditions, gave a preliminary assessment of biogeochemical cycles. Therefore the work will be continued during the subsequent three years (1994-1996).

RESULTS OF BIOINDICATION STUDIES

The level of pollution of the forest ecosystem in the Ratanica catchment was also determined using several sensitive plant indicators (Grodzińska 1993).

The concentration of heavy metals (Zn, Fe, Cr, Cd, Pb) in the moss (*Pleurozium schreberi*) in the Ratanica valley is 3-4 times higher than in the relatively clean north-eastern area of Poland. The concentration of total sulphur in pine needles (*Pinus silvestris*) in the area under investigation is much higher than the value 1300 $\mu g.g^{-1}$ regarded as a toxic level (Linzon et al. 1979). Damage to pine needles determined by the scanning microscope is considerable at Ratanica. According to the five grade scale worked out by Huttunen and Leine (1963), it represents the 3rd or 4th degree of degradation of the wax layer of the needles. According to J. Lesiński (oral information), the pine trees in the Ratanica valley has the shape of the crown and branches changed and the age of its needles is often limited to 2 years. The flora of lichen in the Ratanica forest is poor and it lacks species sensitive to industrial pollution (J. Kiszka, oral information).

CONCLUSION

Biogeochemical and bioindication data show that the forest in the Ratanica catchment is affected by the moderate but chronic industrial emissions. Poor outflow of polutants — mainly of ions of heavy metals and hydrogen ions — is likely to impair seriouly the funcions of this forest ecosystem.

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POLISH NATIONAL COMMITTEE OF IGBP — GLOBAL CHANGE: STRUCTURE AND ACTIVITIES

ORGANIZATIONAL STATUS AND MEMBERSHIP

Polish National Committee of IGBP (PNC-IGBP) is affiliated with Presidium of the Polish Academy of Sciences (PAS). The Committee consists of 33 members representing various scientific disciplines including representatives of human sciences related to ISSC Project — Human Dimensions. The following list of members and committee authorities have been approved for cadence 1993-1996 by the Presidium of PAS on October 18th, 1993:

Leszek Starkel (Chairman), *Zdzisław Kaczmarek* (Vice-Chairman),
Małgorzata Gutry-Korycka (Scientific Secretary).
Members:
Roman Andrzejewski, Marek Baranowski, Krzysztof Birkenmajer, Włodzimierz Bojarski, Alicja Breymeyer, Zbyszko Chojnicki, Kazimierz Dobrowolski, Ryszard Domański, Czesław Druet, Tadeusz Florkowski, Stefan Godzik, Krystyna Grodzińska, Andrzej Kędziora, Piotr Korcelli, Krzysztof Korzeniewski, Andrzej Kostrzewski, Stefan Kozłowski, Krzysztof Kożuchowski, Zbigniew Kundzewicz, Edward Radwański, Stanisław Rakusa-Suszczewski, Magdalena Ralska-Jasiewiczowa, Karol Rotnicki, Andrzej Różkowski, Kazimierz Rykowski, Lech Ryszkowski, Maciej Sadowski, Andrzej Szujecki, Jacek Walczewski, Ryszard B. Zeidler (detailed personal information — Appendix 1).

The PNC-IGBP activities are focused on international IGBP Core Projects. There are some programmes not yet officialy included in international cooperation, and some new projects are planned (list of Polish projects — Appendix 2).

In frame of PNC-IGBP activities no working groups, regional sub-committees or problem groups have been distinguished.

The topics corresponding to Core Projects are treated in Poland either as separate national grants realised under the leadership of given scholar by a working team consisting of persons from one or more institutions, or as the team realising the direct agreement with the foreign institution. Almost all the themes in progress are related in subject though not formally with IGBP-Global Change. Many constitute an integral part of the programmes: IPCC, IHP UNESCO, MAB UNESCO, SCOPE, WCRP-WMO, GEWEX-BALTEX, UNEP, INQUA etc. (Appendix 3).

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FINANCIAL TERMS

PNC-IGBP was financed till 1993 of the means of PAS in amount sufficient only to cover the costs of meetings and administrative expenses. The additional support, mainly for editing purposes, came from PAS special budget and National Fund for Environmental Protection and Water Management.

In 1993, the Polish Committee for Scientific Research (CSR) has approved the funds to meet the needs of administrative and publishing activities of PNC-IGBP. The funds of CSR which were already used for the National Research Project of IGBP-Global Change (IGBP-GC) in years 1991-1993, will support this project in the future, in form of individually assigned research grants. Besides, chosen research projects are sponsored by foreign institutions (USA, Sweden) under the direct agrements.

CONFRERENCE AND MEETINGS IN 1993

Global warming and contemporary climatic changes in Poland; the conference organized by PNC-IGBP and Szczecin University in Szczecin, May 31st – June 1st. It consisted of six sessions: Paleogeography, climatic models and scenarios; Climatic models, temperature changes, methodology; Temperature changes, anthropogenic influences, solar radiation and sunshine; Water balance, sea level, environmental changes; Hydrography of Baltic Sea, atmospheric circulation, climate and biosphere and great poster session (for relation see page 112).

In 1993 four scientific meetings and one international seminar have taken place:

Plant indicator and monitoring of air pollution effects on forest; the meeting of Polish-American working group organized by Institute of Botany of PAS and Jagellonian University in Mogilany; May 5-6th.

Air pollution and forests; the meeting of Polish-Swedish working group organized by Institute of Botany of PAS in Cracow; May 17-18th.

Water pollution in coastal zone of Baltic Sea, Puck and Gdańsk Bays in comparison to pollution in coastal zone in Atlantic Ocean and Mediterranean Sea in France; Polish-French seminar in Hel Maritime Research Station; September 12-15th (see page 114).

Forest ecosystems in front of climatic change; the meeting organized by Forest Faculty of Agricultural Academy in Warsaw, held in Białowieża; October, 18-20th.

Poland's contribution to IGBP-Global Change Programme on oceanographic investigations; the symposium organized by Institute of Oceanography of Gdańsk University, Committee for Sea Research and PNC-IGBP in Sopot; November, 16th (see page 116).

RECENT PUBLICATIONS

Proceedings of Conference on *Global Environmental Changes — a Challange for Humanity,* Cracow, 22-23 October, 1992, Kosmos, v. 42, no 1 (218), Warszawa 1993 (in Polish).

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Proceedings of International Conference on *Global Warming and Contemporary Climatic Changes in Poland,* Szczecin, 31 May 1993, Szczecin 1993 (in Polish).

Proceedings of Vth Symposium on *Forest Ecosystems in Front of Climatic Changes,* Białowieża, 18-20 October 1993, Białowieża (in print).

Newsletter No 1 — Global Change new informative bulletin of PNC-IGBP, first issue in March, 1994.

PNC-IGBP prepares currently new series of publications entitled *Global Change*: Polish Perspectives including the results of Polish investigations related to IGBP Core Projects and PNC-IGBP programme. This publication: Geographia Polonica 62 is the first volume of this series.

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Małgorzata Gutry-Korycka

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CHRONICLE OF PNC — IGBP

GLOBAL ENVIRONMENTAL CHANGES — A CHALLENGE FOR HUMANITY (Cracow, 22-23 September 1992)

Some 100 scholars representing the most important scientific intitutes in Poland met in Cracow to discuss causes and effects of global climatic change. The Conference was organized by the National Committee IGBP — Global Change of the Polish Academy of Sciences and Arts in Cracow, the Ministry of Environmental Protection, Natural Resources and Forestry, as well as the Scientific Committee "Man and Environment" of the PAS.

Man's interference into the natural environment has led to significant climatic changes on a regional scale and a global warming of the Earth is now expected to occur.

Disappearance of the ozone layer leading to the warming of the atmosphere disturbs the water and energy circulation on the continents and in the oceans. The rate of this disturbance and its effects are manifold, therefore they are investigated by the various sicentific disciplines.

At the Cracow Conference, various aspects of the expected climatic changes and their effects were presented. Against a background of global change the analysis was also made of changes of the main climatic elements and of the entire Poland's natural environment in order to answer the question: are we endangered by the warming of climate and what might be its effects?

The Conference was attended by sholars representing many disciplines dealing with environmental research, including broadly conceived geophysics, physics, geology, geography, ecology, agriculture, history and psychology.

14 papers were presented at the plenary sessions, including 11 papers read by the participants and 8 contributions on posters.

The Conference was opened by its chief organizer, L. Starkel, chairman of the PNC — IGBP — Global Change. This was followed by the speaches of the host, deputy chairman of the Polish Academy of Sciences and Arts, A. Bielański, and Vice-President of the PAS and its Scientific Secretary L. Kuźnicki.

The major resolutions of the *Rio declaration on environment and development (versus) the beginning of post-industrial era* were presented by S. Kozłowski, chairman of the Advisory Committee for Ecology at the Presidential Office of the Republic of Poland and Chairman of the Scientific Committee "Man and Environment" of the PAS. S. Kozłowski discussed such concepts as the Earth's ecosystem, sustained development, and other problems related to

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sovereign right of each state to utilize the natural resources, and to implement its own environmental policy to achieve respective guarantees for natural development.

The research on the previous geological eras aimed at finding similarities to the present-day violent changes of climate and natural environment were presented in the paper *Global change of the environment in the past* by L. Starkel of the Institute of Geography and Spatial Organization of the PAS.

On the basis of climatic change on the Earth in the past conclusions can be drawn on possible shifts in climatic and vegetation zones on the Earth due to global increase in temperature and precipitation. It is possible to reconstruct the rate of climatic changes in the past through the investigation of glacial cores, laminated lake and marine sediments, as well as tree-rings increments.

On the other hand, the investigations of climatic extremes in the past, e.g. great floods or low pressure allow us to get to know threshold values impairing the stability of ecosystems and determine the length of the period indispensable for the geosystem to come back to the equilibrium. Of special importance is the determination of differences in mechanism of changes of geosystems in natural conditions prior to man's interference and changes due to anthropopressure.

The relationship between the natural resources and the history of society from the historical viewpoint was presented by J. Topolski of the Institute of History of the Adam Mickiewicz University in Poznań. The author distinguished three periods of social development from the point of view of cultural evolution of utilization of the environment and characterized them: (1) the period from the beginning of the industrial revolution (till the end of the 18th century); (2) the period of the industrial revolution lasting until the 20th century; (3) post-industrial age, i.e. modern development of production and use of information systems. The author analyzed the evolution of man's mentality directed towards exploitation of the natural environment without considering the ensuing global results. J. Topolski stated that man was for a long time quite careless about using both direct and indirect natural resources (renewable and non-renewable alike), but also in destroying those resources by secondary impact on the natural environment.

Changes in gas structure of the atmosphere and energy output as the chief causes of the greenhouse effect were discussed by T. Florkowski of the Institute of Physics and Nuclear Technique of the Academy of Mining and Metallurgy in Cracow. The latest world research, i.e. the analysis of the air bubbles in glacial cores show that the CO_2 concentration in the atmosphere has currently been highest over the past 160 thousand years. The following gases have the largest share in the greenhouse effect: carbon dioxide CO_2 (50%), methane (20%), as well as carbon oxide, nitric oxides, sulphur dioxide, freon and ozone. Global energy output in the world comes mainly from the combustion of oil (37.6%), coal (30.5%) and gas (19.9%).

In the discussion, W. Bojarski, author of the report on the state of energy output in Poland and emission of pollutants to the atmosphere drew the attention to the need for changing energy sources conducive to the emission of greenhouse gases.

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International and political aspects of climatic change were briefly outlined from the geopolitical viewpoint by M. Sadowski of the IMiWM in Warsaw. The author focused on the principles of climatic convention and pledge of Poland's government to stabilize CO_2 and methane emission till the year 2000 at 1988 level.

The greenhouse effect (versus) climatic change was presented by B. Obrębska-Starkel of the Institute of Geography of the Jagellonian University. According to the estimates, due to the greenhouse effect global air temperature has risen from 0.3 to 0.6°C over the past 100 years. Mathematical models of global climatic change assuming double CO_2 concentration relative to 260-280 p.p.m. in 1850 and predicting temperature increase within the limits 1.9-5.2°C allow to predict the future of the Earth's climate. According to B. Obrębska-Starkel, it is still actual to ask how to identify the signal of intensified greenhouse effect, what is its consequence and what is the information noise stemming from simulataneous operation of natural and anthropogenic factors.

The ozone in the stratosphere and toposphere as well as the mechanisms determining quantitative changes of this extremely important protective greenhouse gas were discussed by A. Dziewulska-Łosiowa of the Institute of Geophysics, PAS in Warsaw. Changes in ozone content in the troposphere and stratosphere were related to thermal processes, volcanic outbursts and increasing amount of greenhouse gases. The recent years, saw not only the growing area of the ozone hole over the Antarctic and Greenland, but also a very slow decline of total ozone contents in the winter at higher and medium latitudes of the Northern Hemisphere.

In his paper *World water resources endangered*, Z. Kaczmarek of the Institute of Geophysics of the PAS expressed the opinion that the relationship of water requirements and resources on the entire globe are advantageous, but their spatial and time distribution is not concomittant with the demographic and political structure and the needs. Tension and hazards in water economy are entirely regional and cannot be solved by use of global strategy.

The sensitivity of the hydrosphere (water circulation) to global climatic change can be investigated by statistical methods using the assumed scenarios.

The hitherto investigations assumed the stationary character of hydrological process within a fixed time interval. However, Z. Kaczmarek stresses that caution is needed in inferring and forecasting hydrological changes due to climatic change because of a large margin of uncertainty.

The next three papers dealt with the response of land ecosystems, such as forests, single species, biocenoses (A. Breyemeyer of the Institute of Geography and Spatial Organization, PAS), lakes (A. Hilbricht-Ilkowska, Institute of Ecology, PAS), and agricultural areas (L. Ryszkowski and A. Kędziora, Department of Research on Agricultural and Forest Environment, Polish Academy of Sciences, Poznań) to the warming of climate.

The thermo-micstic regime of lake ecosystems of Northern and Eastern Europe is particularly sensitive to global climatic change. They may be evaluated from the viewpoint of water quality, speeding up of entrophization,

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biotic diversity and the rate of evolution of lakes bound up with the changes of hydrological conditions.

A very important effect of the climatic warming will be the displacement of natural zones in the direction of the poles. The ecosystems displaced will be exposed to danger of losing the species which will not have time to adapt themselves to changing environmental conditions. The relationship between the greenhouse effect and changes in agriculture may be very well marked. Although the extension of the vegetation period (up to 10 months) and increase of stenothermal crops may be regarded as advantageous, the scenarios show that the decline of the precipitation totals, recession and withdrawal of snow cover are likely to cause more frequent humidity shortage in soils, which in turn leads to lower yields of crops. This will be followed by changes in alimentation of the rivers and increasing number of pests (Ryszkowski, Kędziora).

Z. Rotnicki of the Institute of Quaternary Research, the Adam Mickiewicz University of Poznań, presented the problem of "*The increase in the ocean level and its effects*". The rise of the ocean level will lead to increased coastal erosion and transgression of salty water into the areas of exceptionally good soils, high population density and economic importance. The author presented hydrologic and geomorphological consequences, as well as socio-economic effects, illustrated by examples from the Baltic coast.

The two last papers dealt — with "*socio-economic dimension of exhaustion of natural resources and environmental degradation*" (R. Domański, Institute of Spatial Economy, Academy of Economics, Poznań) and "man's psychic response to global environmental change" (A. Biela, Chair of Experimental Psychology, Catholic University of Lublin). So far, the knowledge on these topics is still negligible.

The discussion was dominated by two opposing opinions expressed by the advocates and opponents of the impact of global climatic change. The need was emphasized to carry out interdisciplinary investigations in the field of global cause of climatic change and its effects, as well as the need for their co-ordination in the particular countries. It was also stressed that the state of research on the mechanism of global warming and its effects are imperfect and statistical methods and mathematical models are marked by a great margin of uncertainty.

The materials distributed during the Conference in Cracow were published thanks tot he Fund for Environmental Protection and Water Economy at the Ministry of Environmental Protection, Natural Resources and Forestry. The proceedings of the Conference were published in a separate issue of the periodical Kosmos Vol. 42, No.1 (218), 1993.

Małgorzata Gutry-Korycka

CONTEMPORARY CLIMATIC CHANGES (CCC) CONFERENCE
(Szczecin 31 May – 1 June 1993)

On May 31st-June 1st 1993, the conference on contemporary climatic changes in Poland in relation to global warming ("CCC" — Conference) was

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arranged in the University of Szczecin. The University (Institute of Marine Sciences, Department of Climatology) and the Polish National Committee for IGBP — Global Change have taken share to organize it.

Conference sessions were held in the ancient Castle of Pommerian Princes in Szczecin. Szczecin city as well as the Ministry of Environmental Protection and the Ministry of National Education provided financial support for organizers of the conference.

More than 80 experts and scientists from 8 European countries and from Israel had been interested to take part in the meeting. The programme of the CCC — Conference included 43 scientific lectures and contributions on posters. They represented various studies carried out to estimate the impact of climatic changes on Nature in the past and in the future.

Espacially, scenarios of the possible changes in climate conditions due to global growth of the greenhouse effect were estimated.

The specific objectives of the Conference were consequently: paleogeographic studies, climate scenarios and models, natural and anthropogenic factors of climate changes, analysis of climatological time series, sea level changes and hydrographical conditions in the Baltic Sea.

It is worth mentioning that, amongst other papers, some of them contain valid aspects for understanding of temporal and spatial patterns of climate. For example, in the lecture by L. Starkel (Institute of Geography and Spatial Organization PAS, Cracow) the variations of extreme events have been considered on the basis of geological records. It has been proved that high frequency of extremes or their rapid decline may start a general change of climate. This statement matters much for monitoring of contemporary weather events and anomalies.

The inertial motion of the Sun has been considered as a very possible origin of the variability of solar activity and long-term climate changes (I. Charvatowa, J. Strestik, Czech Academy of Sciences, Prague). For the next decade, chaotic motion of the Sun, decrease in solar activity and decreasing "natural" tendency of air temperatures were discussed.

On the other hand, B. I. Sazonov (Main Geophysical Observatory, St. Petersburg) explained the rise of winter temperatures in Northern Europe on the basis of specific position of the greatest planets in 1989-1993.

An attempt at creation future climate scenarios related to CO_2 doubling has been presented in the paper by A. Olecka (Institute of Environmental Protection, Warsaw). Scenarios for temperature changes in the Northern Europe were the topic of paper by G. Wójcik, K. Marciniak and R. Przybylak (N. Copernicus University, Toruń).

The proceedings of the CCC — Conference have been published by the Publishing House of Szczecin University. The set containe 20 contributions in Polish with English abstracts.

Krzysztof Kożuchowski

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POLISH-FRENCH SEMINAR ON OCEANOLOGY
(Hel Peninsula, 12-15 September 1993)

First Polish-French seminar on oceanology in Hel Marine Station, in September 12-15, 1993 was organized by the Institute of Oceanography, Gdańsk University.

27 oceanographers participated: from France (9), Japan (1) and Poland (17).

Seminar was opened by the director of Oceanography Institute of Gdansk University, chairman of the Polish National Committee on Sea Research, and member of the Global Change Polish National Committee — IGBP K. Korzeniewski.

Programme was thematically divided into 2 sessions.

The first session involved geology, hydrological and hydrochemical conditions in Puck Bay Area and the Gulf of Gdansk.

H. Jankowska described lithology of pre-Quaternary bedrock as well as Quaternary bottom sediments of Puck Bay. On this ground, the author detaily presented distribution of bottom sediments, their mineral composition, water and organic matter content of the deposits.

L. Fałkowska & J. Bolalek (Inst. of Oceanography, Gdańsk University) presented the spatial and temporal variation of phosphates, nitrates and ammonium levels in the Gulf of Gdansk.

Result of studies on the organic carbon concentrations and oxidative--reduction potentials of bottom water and uppermost layers of the bottom sediments from the Puck Bay were demonstreted by J. Pempkowiak (Inst. of Oceanology, PAS).

"Hydrochemical fate of selected elements in Southern Baltic ecosystems" presented P. Szefler (Medical Academy Gdansk). The author showed different methodological approaches to statistical assessments. Therefore on the basis of the geochemical factors, local contamination by heavy metals in Gdansk Bay was identified.

General papers referred to biological aspects of sea water.

Detail characteristics of microphytobenthos of Puck Bay and their sesonal variations was described by M. Witak.

General description of the Baltic zooplancton was presented by M.I. Żmijewska, L. Bielecka, K. Blachowiak-Samołyk as well as projected investigations over the seasonal succesion and identified variation in the composition, abundance, biomass, age distribution in the zooplankton, as dependent on an environment.

The most essential changes of species structure were obeserved in the biocenosis of Puck Bay by M. Wolowicz (Inst. of Oceanography, Gdańsk Univ.). Changes concerned to: paucity of the species composition of zoobenthos groups with a simultaneous increase in biomass flow of energy through the ecosystem, towards biofiltrators constituting a blind ling in the trophic chain.

K.S. Skora & M.R. Sapota from Institute of Oceanography, University of Gdansk discussed problems of changes in the proportion of ichthyofauna species of Puck Bay.

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This may produce great changes in fito and zoobenthos communities an in consequence changes in spawning areas for many fishes and food basis.

Results of teledetection experiment in Central Baltic Sea-pool e.g. transformation of data from NOAA-S satellite and direct measurements of sea surface temperature were presented by D. Balicki (Inst. Oceanology PAS). Accuracy of satellite data are less than 1°C so they seem to be usefull for preparing distribution of sea surface temperature on the maps.

Possibilites of using the AVHRR data for solving some oceanographycal problems like:

— investigation of the phenomenon of coastal upwelling,

— identification of sources and examining the spreading of pollutants from the land sources in the coastal area,

— water circulationin the surface layer of the sea,

— verification of the numerical models of water circulation,

— monitoring of the extent and intensity of phytoplankton blooming,

— investigation of sea-ice phenomena. The examples of interpretation of satellite images of Baltic were also presented by A. Krężel (Inst. of Oceanography, Gdansk Univ.).

During the second session five French reports have been presented and devoted generally to oceanographic problems of the Mediterranean Sea and the Atlantic Ocean.

Results of surveys for dissolved herbicides concentration caried out in the Rhone delta and drainage canals of Atlantic coast zone were presented by J. Tronczyński (IFREMER/ Nantes).

R. Gaudy from Centre d'Oceanologie de Marseille, described environmental factors upon the Berre lagoon ecosystem, rising due to physical and chemical conditions by natural (river floods, storms) and anthropic events (functioning of electric plants, irrigation needs) — were demonstrated.

H. Masse from Centre d'Oceanologie de Marrseille presented programme National d'Oceanologie Cotiere (PNOC) which aspire to be the French contribution to the core project Land-Ocean Interaction in the Coastal Zone (LOICZ). Then topics of ongoing research in the Mediterranean Sea and biological cycles in the Guld of Lion.

P. Queffeulou (IFREMER/ Brest) presented an overview of the ERS-1 satellite mission in the term of sensors and orbit and showed the potential impact of the ERS-1 data on studies of wind, waves and sea-ice.

Mr Legrand (IFREMER/DITI) has presented, on example of oceanographic studies, the efforts made to transpose the laboratory methods into direct measurements on the ground. Monitoring is another important objective in which levels and trends of natural phenomena are the main interest. In this case the methods of measurements which are chosen should be well established and validated.

Krzysztof Korzeniewski

Text by Joanna Szczęsna according to Polish-French Seminar Programme and abstracts of papers.

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THE NATIONAL SYMPOSIUM OF MARINE CORE PROJECTS OF THE IGBP
(Sopot, 16 November, 1993)

The all-Polish scientific symposium was held in Sopot with the view of surveying the achievements of the Polish research institutes in the domain of investigations carried out under marine IGBP Core Projects. The Symposium was organized by the Institute of Oceanology of the Polish Academy of Sciences in Sopot, with the participation of the Institute of Oceanography of Gdansk University, as well as of the Institute Hydro-engineering of the Polish Academy of Sciences in Oliwa. Its topics were sponsored by the programme commission established by the Committee for the Sea Investigation of the Polish Academy of Sciences.

The topics of the symposium dealt with marine issues concentrated in three core projects of the IGBP:

— Core Project *LOICZ (Land-Ocean Interaction and the Coastal Zone)*, which presented the results of investigations carried out by the Polish research institutes on the changes of the Baltic environment and its coastal zone;

— Core Project *JGOFS (Joint Global Ocean Flux Study)*, which groups the problems of the mass and heat exchange between the ocean and the atmosphere;

— Core Project *GOEZS (Global Ocean Euphotic Zone Study)*, concerning the light and solar energy transmission in the sea upper layer, as well as photosynthesis and biological primary production occurring in this layer.

The most widely represented were the investigations carried under the Core Project *LOICZ*. The results were presented as two groups of problems: global changes in the Baltic environment and changes occurring in its coastal zone. In the first group the results of investigations on the following issues were presented:

— possibilities of evaluation of climatic changes in view of acoustic tomography of the ocean;

— variability of the index of local air masses circulation over the Baltic Sea;

— relationship between climatic oscillations and states of the Baltic glacies-covering;

— variability of salinity of the Baltic water, stemming from forecasts of changes of the Earth's climate;

— tendencies in long-term changeability of the state of concentration of biogenic compounds and oxygen relations in the Baltic Sea environment;

— long-term changes of the hydrological regime in the area of the southern Baltic;

— importance of the anthropogenic component in overall balance of inflow of vestigial minerals to the Baltic Sea;

— directions of biocenotic changes in the Baltic ecosystem.

The second group of problems of the LOICZ, concerning changes occurring in the Baltic Sea coastal zone, presented the results of investigations chiefly related to development of the southern coastal zone of the Baltic Sea and

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variability of its contact area. The results of investigations in this field contributed to greater knowledge of:

— geological aspects of formation of the Polish Baltic coastal zone;

— long-term tendencies in changing coastal line (evaluation of the estimates of changeability);

— impact of change of atmospheric circulation on fluctuation of the state (levels) of water in the coastal zone;

— growth trends and probabilistic characteristics of the high sea water level near the coast of the southern Baltic Sea;

— sensitivity of the Polish shoreline of the Baltic Sea to the accelerated sea water level (greenhouse effect);

— possibility of semi-empirical modelling and simulation of a large-scale variability of the sea coast as well as processes of abrasion of beaches and dunes;

— possibility of prediction of the impact of intrusion of salty waters into the ground on environmental degradation.

Under the JGOFS Core Project the papers were presented discussing the results of the investigations concerning:

— impact of atmospheric circulation on the changing amount of the stream of chemical substances flowing from the atmosphere to the sea;

— production and transport of marigenic aerosols in the southern profile over the Atlantic;

— characteristics of the sea aerosol stream in the seaside zone;

— process of aerosol mass, heat and humidity exchange in the shoreline atmospheric layer;

— micro-biological transformation of organic substance in the surface micro-layer of the sea;

— lidaric method of inwestigation of characteristics of the aerosol layer over the sea.

In the Core Project GOEZS the papers analyzed the results of investigations carried out at present by the Polish research teams on:

— changeability of influx on solar energy onto the surface of the Southern Baltic;

— long-term variability in overall primary production of the Baltic;

— investigations on the state of chlorophyll concentration in the Baltic water using a radiometric method;

— mathematical modelling and simulation of photosynthetical productivity of the ocean based on remote sensing methods satellite data;

— mathematical modelling and simulation of the processes of vertical changeability of phyto-plancton concentration in the euphotic layer of the sea.

During the symposium the working meeting of the Core Projects group of the Committee for the Sea Investigation, Polish Academy of Sciences, was held with the participation of the chairman of the Polish Committee of the IGBP, L. Starkel. The participants discussed the problem of continuation of investigations carried out by the Polish oceanographic institutes under the marine core projects IGBP. As a result, the decision was made to separate these topics from the general research plans of the following posts: Institute of

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Oceanology of the PAS, Institute of Oceanography of the University of Gdańsk, Institute of Hydroengineering PAS, as well as other intitutes, as a marine Core Projects — comprising the topics of the LOICZ, JGOFS and GOEZS. Coordination of the activities related to this task was entrusted to K. Korzeniewski (IO-UG), in the domain of the LOICZ regarding the changes of the state of the sea environment, as well as the problems tackled by the JGOFS, to R. Zeidler (IH-PAS), in the field of the LOICZ problems, relative to coastal processes, to A. Zieliński (IO-PAS) in the field of the GOEZS. Besides, the need was emphasized to extend LOICZ topics by including ecological problems. Also the staff of the co-ordinating body was enlarged. Its members are currently: Cz. Druet, chair, K. Korzeniewski (IO-UG-JGOFS and LOICZ (open sea), R. Zeidler — LOICZ (coastal zone), A. Zieliński — GOEZS, M. Pliński (IO-UG) — LOICZ (ecology), E. Mojski (Institute of Geology — Division of Sea Geology — LOICZ (geology).

Czesław Druet

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MEETING OF THE EUROPEAN NATIONAL COMMITTEES FOR IGBP — GLOBAL CHANGE

EUROPEAN RESEARCH NETWORK OF THE IGBP — EUROSTART
Amsterdam, Brussels 4-9 June 1993

In Brussels the meeting was held by the chairman of the National Committees for the IGBP on the co-operation with the European Community convened by the Centre for Scientific Cooperation of the 12th Division for Science, Research and Development of the Commission of European Community (CEC). The meeting was chaired by the General Director, J.P. Contzen. It was attended by the representatives of 19 countries.

The meeting was held to discuss the mechanisms of co- operation between European countries and programmes of the European Community concerning environmental change, concentrated in the ENRICH programme (European Network of Research in Global Change). The programme would ensure exchange of information and at the same time coordinate the hitherto undertakings of the CEC, relative to crucial problems of the IGBP, such as MEDIAS, EIPO and TEPO. Each year considerable means (ca 150 thousand ECU) would be allocated for this research. At the same time, the ENRICH might be a platform for co-operation between the Community countries, EFTA and Central and East European countries, as well ensure conveyance of information to politicians and economists. The discussion showed that European co-operation is a must both due to the need for obtaining a uniform picture of changes in the whole Europe and for presentation of mechanisms of global change.

It seems particularly interesting to us that the Central and East European countries were asked to enter this cooperation.

There are currently real prospects for joining the existing research topics in connection with the resolution of the 12th Division of the CEC of the beginning of May 1993. Unfortunately, there is not much time and the issue must be approved by the co-ordinator of the given topic and submitted by 2nd July, 1993. It is also possible to join the newly submitted topics, which does not preclude the chance in the future. However, the co-ordinator must be a researcher from Western Europe (the member country of the Community).

On 7-8 June, 1993 the advisory meeting of experts was held in Amsterdam to discuss the **European Research Network of the IGBP programme (the so-called European START)**, organized by the IGBP Committee of the Dutch Royal Academy of Sciences and Arts jointly with the National Institute of

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Health and Environmental Protection (RIUM), with consultation from the IGBP national committees of the Russian Federation, Germany and Poland. The meeting was attended, apart from the delegates from 20 countries, by: the secretary general of the IGBP programme, J. Marks, secretary of the START programme, T. Rosswall, delegates of the IGBP crucial problems, of the CEC and of the HDP Programme — Human Dimensions Programme.

Poland was represented, apart from L. Starkel the chairman of PNC — IGBP, by A. Kędziora. The sessions were chaired by R.M. van Aalst, deputy director of the RIUM.

In addition to introductory speeches to discussion, presenting the views of the countries inspiring the meeting (U.M. Kotlyakov, H.J. Bolle), of the START secretariat (T. Rosswall) creating regional centres for co-operation and the initiative of the European Community (J.P. Contzen), a general discussion of the objectives and forms of co-operation was held. The discussion took place partly in the working groups focusing on the crucial problems of the IGBP. The participants emphasized Europe's unique location, the best state of reconnoitring of the problems due to the existing long-lasting measurement series, ongoing rapid changes of land use and irreversible environmental degradation in many industrial centres.

The need was emphasized to concentrate in Europe on problems of environmental change over the past centuries (prior and during the industrial revolution), impact of growing greenhouse effect on the state of ecological catastrophe in industrial regions and in coastal zones. Unfortunately, no decisions were made in this field because the group of the participants was considered as insufficient. Also the forms of co-operation proposed did not satisfy other participants. The motion to create a new co-ordinating body for Europe (a council and a secretariat) was not passed.

The long list of postulates prepared by the Conference Secretariat was not adopted either.

But in the afternoon of 8 June the motions prepared by the Commission elected by the delegates of countries were adopted as a resolution.

THE ASSUMPTIONS OF EUROSTART

1. Introduction

1.1. It is assumed as advisable to establish the EURO-START to implement the IGBP programme.

1.2. Europe is distinguished among other regions by high concentration and history of research, well-developed mechanisms of co-operation and co-ordination, specificity of many problems, increasing prospects for co-operation between the East and the West, and possibilities of scientific co-operation with Africa.

1.3. EURO-START ought to develop on the basis of the existing structures and after identification of the needs.

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1.4. The participants of the meeting do not have a mandate to determine details of co-operation, but they postulate the main directions of activity.

2. Directions of activity

2.1. To make the survey of the scope of research on global change and the related structures in European countries.

2.2. To determine the main scientific needs for the EURO-START, indispensable for accomplishment of crucial problems of the IGBP (e.g. new mega-projects, data banks, network of research sites, social initiatives).

2.3. To determine the attitude to other programmes, such as HDP, ENRICH etc.

2.4. To identify development mechanisms, distinguishing the role of the national IGBP programmes, crucial problems, European Community etc.

2.5. To draw attention to co-operation of the West with the East and with Africa.

2.6. To extend consultation with research communities through regional or thematic symposia.

2.7. To organize a conference on goals and scope of co-operation under the EURO-START.

It was resolved that this programme will be co-ordinated by a small team including representatives of IGBP, HDP, EC, National Committees (2-3) and non-affiliated persons.

The meeting on European co-operation was therefore an important step forward, despite the lack of agreement in many details. It also gave an opportunity to exchange information on the national structures supervising the research work carried out under the IGBP. Poland's situation is very difficult. Despite its considerable potential, it lacks overall co-ordination, funds to be assigned both for researches and costs of maintenance of the secretariat of the National Committee and for publication of the materials.

On 9 June, A. Kędziora got acquainted with the research programme of the Dutch Institute (RIUM), and L. Starkel with the work on paleohydrology of the Geologocal Service in Haarlem.

For Polish research projects related to IGBP — Global Change and EURO-START see Appendix 2.

Leszek Starkel

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APPENDIX 1

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Walczewski Jacek (meteorology) Institute of Meteorology and Water Management, P. Borowego Str. 9, 30-960 Kraków, tel. 11-92-08

Zeidler Ryszard B. (civil engineering) Institute of Hydroengineering, PAS, Kościerska Str. 7, 80-953 Gdańsk, tel. 52-20-11, fax: (48-58) 52-42-11, tlx: 0512845

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APPENDIX 2

POLISH IGBP — GLOBAL CHANGE STUDIES RELATED TO EUROSTART PROJECT

RESEARCH TOPICS

The Polish National Committee of IGBP-Global Change has identified the following research topics as of overriding importance for European development, able to be incorporated in IGBP-Core Projects.

Name of topic related to Eurostart	Leaders and leading institutions working in this field
Biospheric Aspects of the Hydrological Cycle – BAHC	
Impact of non-stationarity of global geophysical processes on Polish water resources. Grant of CSR no. 9-S602—047-03 related closely to WCRP-GEWEX, projects A2 and B3 of World Climate Programme – Water, Country Study (in. coop. with USA).	prof. ZDZISŁAW KACZMAREK Institute of Geophysics PAS Ks. Janusza Str. 63, 01-452 Warszawa Coop. Institute of Meteorology and Water Management, Warszawa.
Influence of global climate changes on hydrological cycle in the selected catchments. Grant of CSR no.66-273-9102 related to IHP UNESCO "Friend Project".	prof. MAŁGORZATA GUTRY-KORYCKA Division of Hydrology, Faculty of Geography and Regional Studies, University of Warsaw Krakowskie Przedmieście Str. 30, 00-927 Warszawa Coop.: Institute of Meteorology and Water Management, Warszawa, Division of Hydrology, A. Mickiewicz University, Poznań
Complex evaluation of drought risk in Wielkopolska region. Grant of CSR no.4-S-401-055-04.	prof. ANDRZEJ KĘDZIORA, prof. ZBIGNIEW KUNDZEWICZ Departament of Agricultural and Forestry Research PAS Bukowska Str. 19, 60-809 Poznań
Global Change and Terrestial Ecosystems – GCTE	
Inflow deposition and runoff of the biogens and industrial pollution in the forest ecosystem. Grant of the CSR.	prof. KRYSTYNA GRODZINSKA Institute of Botany PAS Lubicz Str. 46, 31-512 Kraków Coop.: Institute of Ecology, Jagellonian University, Royal Swedish Academy, Swedish Agricultural Academy, Polish-American Project – US Department

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of Agriculture, Forest Service, Massachusets University, Bowling Green State University – Ohio, Michigan University.

Deposition and budget of pollutants and mineral in nutrients in forest ecosystem along a pollution and climate gradient.
Grant no. 324/DN/93 of the Ministry of Environment, Natural Resources and Forestry.

prof. STEFAN GODZIK
Institute of Ecology of Industrial Regions
Kossutha Str. 6; 40-833 Katowice
Coop. Swedish Agricultural Academy.

Ecological management of agricultural landscape (energy flow and matter cycling).
Grant of CSR no. 6-074-91-01.
Dissipation of mineral-organic copmounds leached from cultivated fields.
Grant of CSR no. 6-P-205-077-04 related to MAB – Land Use Changes,
SCOPE Project Phosphorus cycle.

prof. LECH RYSZKOWSKI,
prof. I. ŻYCZYŃSKA-BAŁONIAK
Department of Agricultural and Forestry Research PAS
Bukowska Str. 19; 60-804 Poznań

Causes, course and effects of degradation of forests in the Sudetes Mts, and ways of their recultivation.

prof. KAZIMIERZ RYKOWSKI
Forestry Research Institute
Bitwy Warszawskiej 1920 Str. 3,
00-973 Warszawa
Coop. with Sweden.

Transformation of energy and matter transfer in the young morainic landscapes.
Grant of the CSR.

prof. ANDRZEJ KOSTRZEWSKI
Institute of Quaternary Research,
A. Mickiewicz University
Fredry Str. 10, 60-701 Poznań

Monitoring of ionic exchange in the air-water-plant-soil-system at Diabla Góra station (Borecka Forest, North Poland) connected with International Program of Integrated Monitoring.

prof. A. OSTROWSKA
Institute of Environmental Protection
Krucza Str. 5/11, 00-548 Warszawa

The influence of global climatic change on forest ecosystems.
Grant of CSR.

prof. KAZIMIERZ RYKOWSKI
Forestry Research Institute
Bitwy Warszawskiej 1920 Str. 3,
00-973 Warszawa

The carbon balance of Polish ecosystems.

prof. KAZIMIERZ RYKOWSKI
Forestry Research Institute
Bitwy Warszawskiej 1920 Str. 3;
00-973 Warszawa

International Global Atmospheric Chemistry – IGAC

Anthropogenic influence to the variations of stable and radioactive isotopes in the atmosphere.
Grant of CSR no. 6-0704-91-01.

prof. TADEUSZ FLORKOWSKI
Faculty of Physics and Nuclear Techniques,
Academy of Mining and Metallurgy
Mickewicz Av. 30, 30-059 Kraków

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Isotope variations of carbon dioxide and methane in Cracow.

prof. TADEUSZ FLORKOWSKI
Faculty of Physics and Nuclear Techniques, Academy of Mining and Metalurgy
Mickewicz Av. 30, 30-059 Kraków
Coop. with Intetrnational Atomic Energy Agency in Vienna.

Measurements of trace gases in the atmosphere-greenhouse effect.
Grant of CSR.

assoc.prof. JAN LASA
Institute of Nuclear Physics
Radzikowskiego Str. 152, 31-342 Kraków
Coop. Oak Ridge Natural Laboratory.

Balance of the greenhouse gases on the Polish Territory and methods of their limitation in the atmosphere.
Grant of CSR.

prof. WŁODZIMIERZ BOJARSKI
Institute of Fundamental Technological Research Świętokrzyska Str. 21; 00-049 Warszawa

Application of remote sensing methods of collecting the informations about layer of mixing in the atmosphere.
Grant of CSR.

prof. JACEK WALCZEWSKI
Institute of Meteorology and Water Management Section Cracow
Borowego 14; 30-215 Kraków

Land-Ocean Interactions in the Coastal Zone – LOICZ

Exchange and transformation of nutrients and CO_2 in marine contact zones: atmosphere-water and water-sediments.
Grant of CSR no. 6P-202-012-04.

prof. KRZYSZTOF KORZENIEWSKI
Institute of Oceanography, Gdańsk University
Piłsudskiego Av. 46, 81-378 Gdynia
Coop.: Institute of Oceanology PAS – Sopot, Pedagogical University – Słupsk, Department of Analitical Chemistry Medical Academy, IFRAMER – France.

Sediment dynamics in water media.

prof. RYSZARD B. ZEIDLER
Institute of Hydroengineering, PAS
Kościerska Str. 7, 80-953 Gdańsk

Dynamics of Polish Baltic coast with reference to sea level rise.
Grant of CSR no. 6-P202-004-04, close relation to IPCC and LOICZ.

prof. RYSZARD B. ZEIDLER
Institute of Hydroengineering, PAS
Kościerska Str. 7, 80-953 Gdańsk
Coop.: Institute of Oceanology PAS, Delft Hydraulics, Netherlands.

Physical processes in the tideles estuariesand aspects of their numerical modelling.
Close connection with LOICZ.

assoc. prof. E. JASIŃSKA,
assoc. prof. W. ROBAKIEWICZ
Institute of Hydroengineering, PAS
Kościerska Str. 7, 80-953 Gdańsk
Coop.: University of Hamburg, HYDROMOD Germany, Delft Hydraulics, Netherlands.

Geological and morphodynamical investigation of coastal zone of Pomeranian Bay and Szczecin Lagoon.
Grant of Ministry of Education no. 129/E-340/S/94.

prof. S. MUSIELAK
Szczecin University
Felczaka Str. 3a, 71-412 Szczecin

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Past Global Changes — PAGES

Record of environmental and climatic changes in the varved lakesediments during the Late Glacial and Holocene.
Close connection with stream 1 and 2 of PAGES
Grant of CSR no. 6-0252-91-01.

prof. MAGDALENA RALSKA-JASIEWICZOWA
Institute of Botany PAS
Lubicz Str. 46, 31-512 Kraków
coop.: Institute of Geography and Spatial Organization PAS
Institute of Geology PAS,
Radiocarbon Laboratory,
Silesian Polytechnic – Gliwice,
Institute of Physics and Nuclear Techniques
Academy of Mining and Metallurgy – Cracow,
Institute of Botany and Institute of Geography – Toruń University,
Archeological-Ethnograhical Museum – Łódź,
Centre des Faibles Radioactivity CNRS – Gif-sur-Yvette,
Hugo de Vries Laboratory – University of Amsterdam,
Deptartment of Geology – Lund University.

Paleohydrological changes in the South Poland river valleys during last 20 ka and their relation to global climate changes.
Grant of the CSR no. 6-0783-91-01. Coop. with INQUA Commission on Global Paleohydrology.

prof. LESZEK STARKEL
Institute of Geography and Spatial Organization PAS
Św. Jana Str. 22, 31-018 Kraków
Coop. Faculty of Geology – Academy of Mining and Metallurgy – Cracow.

Paleohydrological changes in the river valleys of the North and Central Poland during last 150 ka and the global environmental change.
Grant of the CSR.

prof. KAROL ROTNICKI
Institute of Quaternary Research A. Mickiewicz University
Fredry Str.10, 61-701 Poznań

Deglaciation of the NW Poland conditions of transformation of geosystem (20-10 ka BP).
Grant of the CSR.

prof. STEFAN KOZARSKI
Institute of Quaternary Research
A. Mickiewicz University,
Fredry Str.10, 61-701 Poznań

Stratigraphy and paleogeographic conditions of loess accumulation in Central Europe.
Grant of the CSR.

prof. HENRYK MARUSZCZAK
Department of Geography – Curie-Skłodowska University,
Akademicka Str.19, 20-033 Lublin

Methods of isotopic chronometry and their application in geology and archeology.
Grant of the CSR.

prof. M. F. PAZDUR
Institute of Physics, Silesian Polytechnic
Krzywoustego Str. 2, 44-100 Gliwice

Land-Use/Cover Change – LUCC

Land use changes and ecosystems in conditions of expected greenhouse effect (project under organization).

Institute of Geography and Spatial Organization PAS:
Dept. of Agricultural Geography
(prof. ROMAN SZCZĘSNY),

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	Dept.of Geoecology (prof. ALICJA BREYMEYER), Dept.of Geomorphology and Hydrology in Cracow (prof. LESZEK STARKEL).

Global Ocean Euphotic Zone Studies – GOEZS

Investigation and modelling of the interactions of solar radiation and the marine environment.	dr T. KRÓL Institute of Oceanology PAS Powstańców Warszawy Str. 55, 81-712 Sopot Coop.: Institute of Oceanography Gdańsk University, Institute of Oceanology AS Russia – Moscow, IFREMER–France.
Investigation and modelling of fine structures of hydrophysical fields and its influence on the plankton concentration.	prof. A. ZIELIŃSKI Institute of Oceanology PAS Powstańców Warszawy Str. 55, 81-712 Sopot, Coop.: Institute of Oceanography Gdańsk University, Institute of Oceanology AS Russia – Moscow, Institut fuer Meereskunde–Hamburg, IFREMER – France.
Introduction of satellite methods to monitor the Baltic Sea environment.	prof. J. OLSZEWSKI Institute of Oceanology PAS Powstańców Warszawy Str. 55, 81-712 Sopot Coop.: Institute of Oceanography Gdańsk University, ISPRA – Italy, IFREMER – France.
Investigation and modelling of energy input through photosynthesis into the marine eco-sytem.	dr B. WOŹNIAK Institute of Oceanology PAS Powstańców Warszawy Str. 55, 81-712 Sopot Coop.: Lomonosov University – Moscow, Institute of Oceanology AS Russia–Moscow, ISPRA – Italy, IFREMER – France.

Human Dimensions of Global Environmental Change – HDP

Ecologically sustainable development of cities and regions (project under organization).	prof. RYSZARD DOMAŃSKI Chair of Spatial and Environmental Economy – Economical Academy – Poznań Niepodległości Ave. 10, 60-967 Poznań Coop.: Institute of Geography and Spatial Organization PAS, Institute of Socio-Economic Geography A. Mickiewicz University, Faculty of Economical Sciences – Warsaw University.

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General climatic (projects)

Scenarios of climatic change and relationship with sources of energy and economy closely connected with WCRP and IPCC.
Grant of CSR.

prof. MACIEJ SADOWSKI
Institute of Environmental Protection
– Climate Protection Center
Kolektorska Str. 4, 01-628 Warszawa
Coop. various research institutes.

Contemporary climatic tendencies in N-Poland and in Baltic Region.
Grant of Ministry of Education
No 129E-341/3/93.

prof. KRZYSZTOF KOŻUCHOWSKI
Institute of Oceanology Szczecin University
Felczaka Str. 3a, 71-412 Szczecin

Changes of the topoclimates in the mountain valleys in conditions of rising anthropopressure (including greenhouse effect).
Grant of CSR.

prof. BARBARA OBRĘBSKA-STARKEL
Institute of Geography Jagellonian University
Grodzka Str. 64, 31-144 Kraków
Coop. Cracow branch of the Institute
of Meteorology and Water Management.

TRAINING ACTIVITIES

In Poland the following capacity for EUROSTART training activities exsists:

Small courses for evaluation of heat balance, groundwater chemistry and ecological management of agricultural landscape (related to GCTE).
Research Centre for Agricultural and Forest Environment Studies
Bukowska Str. 19, 60-804 Poznań

Training in field of sediment dynamics, exchange of nutrients etc. (related to LOICZ).
Institute of Hydro-Engineering PAS
Kościerska Str. 7, 80-953 Gdańsk

Institute of Oceanology PAS
Powstańców Warszawy Str. 55, 81-712 Sopot

MONITORING AND DATA MANAGEMENT

In Poland the following institutions have capacity for basic monitoring and data management:

Institute of Meteorology and Water Management,
ul. Podleśna str. 61, 01-673 Warszawa
(mainly for climatic parameters, surface waters and shallow groundwaters)

Institute of Pedology and Soil Cultivation,
osada Pałacowa, 24-100 Puławy

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State Geological Survey,
Rakowiecka str. 4, 00-975 Warszawa
(*mainly for groundwaters)*

State Inspection of Environmental Protection
subordinated to Ministry of Environment Protection, Natural Resources and Forestry,
Wawelska 52/54, 02-067 Warszawa
(various monitoring directions)

Besides of these institutional programmes the new projects of complex monitoring will be introduced:

Integrated monitoring of energy exchange and circulation of matter in selected catchment basins (providing data of 10-12 field stations) — coordinated by prof. A. Kostrzewski.
Institute of Quaternary Research
Adam Mickiewicz University
Fredry Str. 10, Poznań

Two other programmes are subsequently under preparation i.e.:
Monitoring of earth surface focused on industrial pollution in the forest ecosystems.

Monitoring of living resources.

Especially the integrated monitoring realised at the research stations should be the area of close European cooperation supported by BAHC, GCTE as well as by EUROSTART and ENRICH.

MATHEMATICAL MODELLING

In Poland exist several teams prepared for modelling activities. They realise studies of mesoscale modelling of climatological, hydrological and oceanological processes. Among them a team for modelling *carbon budgets of forest ecosystems* is developing in:
Forest Research Institute
Bitwy Warszawskiej 1920 Str. Warszawa

SYNTHESIS

Impact of global changes on the geoecosystems is interesting to various teams led by members of PNC-IGBP.

SOCIAL AND POLICY PROGRAMMES

In Poland there are two leading institutions connected with social and policy-related initiatives which might be of interest for EUROSTART:

- Committee „Man and Environment"
  Polish Academy of Sciences
  Palac Kultury i Nauki, Warszawa
  (realising policy-related studies on the greenhouse effect)

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- Committee „Poland in 21st Century”
  Polish Academy of Sciences
  Pałac Kultury i Nauki, Warszawa

POLISH COUNTRY STUDY

The separate large research programme (Polish Country Study) is developed in cooperation with United States of America and focused on *Strategies of GHG's emission reduction and adaptation of Polish society and economy to the changed climate.*

Project manager: prof. MACIEJ SADOWSKI
Climate Protection Centre
Institute of Environmental Protection
Ministry of Environmental Protection, Natural Resources and Forestry
Kolektorska Str. 4, 01-628 Warszawa

The project consists of following study items:

A steering and coordinating process to perform country study with a computerized system to generate adoption and mitigation strategies E. Radwański).

Energy oriented strategies of CO_2 emission reduction based on macroeconomic scenarios of the Polish economy development by the year 2010 (T. Lis).

Elaboration of a mathematical model of the GHG'S emission reduction strategy for electricity and heat energy subsectors (E. Hille)

Strategy of development to enable GHG'S emission reduction (S. Pasierb).

Strategies of the Polish Egriculture under forthcoming greenhouse effect (E. Nalborczyk).

Development of biomas conversion methods for alternative fuels production (J. Pabis).

Working out a strategy and technology of exploitation the renewable energy sources in Poland (J. Tymiński).

A development startegy for the Polish forestry to improve CO_2 balance of forest ecosystems (W. Gliński).

Elaboration of the programme to reduce GHG'S emission from the transport sector: development of the detailed workplan (W. Suchorzewski).

Elaboration of the GHG'S emissions reduction strategies in the municipal sector (P. Skowroński).

Legal and economical aspects of proposed GHG'S emission reduction strategies in Polish economy (J. Żurek).

Strategy of Polish water resources management in face of climatic change (Z. Kaczmarek).

Coastal zone management and defense for Poland's coastal segment most vulnerable to climate change in scale of decades and centuries (R. B. Zeilder).

Management of the project and final report preparation (M. Sadowski).

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APPENDIX 3

ACRONYMS

AGCM	Atmospheric General Circulation Model
BAHC	Biospheric Aspects of the Hydrological Cycle (IGBP Core Project)
BALTEX	Baltic Sea Experiment
CCC	Contemporary Climate Changes Conference
CSR	Committee for Scientific Research
FRIEND/UNESCO	Flow Regimes International Experimental Network Data
GAIM	Global Analysis, Interpretation, and Modelling (IGBP TASK TEAM)
GCIP GEWEX	Continental-Scale International Project
GCM	General Circulation Model
GCOS	Global Climate Observation System
GCSS GEWEX	Cloud System Study
GCTE	Global Change and Terrestrial Ecosystems (IGBP Core Project)
GEWEX	Global Environment Water Experiment
GOEZS	Global Ocean Euphotic Zone Studies (IGBP Core Project)
GRID	Global Resources Information Database
HDP	Human Dimensions of Global Environmental Change
IAHS	International Association of Hydrological Sciences
IGAC	International Global Atmospheric Chemistry (IGBP Core Project)
IGBP	International Geosphere-Biosphere Programme,
IGBP-DIS	Data and Information System (IGBP Framework Activity)
ICSU	International Council of Scientific Unions,
IHP UNESCO	International Hydrological Programme
INQUA	International Quaternary Association
IPCC	Intergovernmental Panel on Climate Change (WMO/UNEP)
ISLSCP	International Satellite Land-Surface Climatology Project (part of GEWEX)
JGOFS	Joint Global Ocean Study Project (IGBP Core Project)
LOICZ	Land-Ocean Interactions in the Coastal Zone (IGBP Core Project)
LUCC	Land-Use/Cover Change (IGBP Core Project)
MAB	Man and the Biosphere (UNESCO)
NOAA	National Oceanic and Atmospheric Administration
PAGES	Past Global Changes (IGBP Core Project)
PAS	Polish Academy of Sciences
PCS	Polish Country Study (cooperation with USA)
PILPS	Project for Intercomparison of Land Surface Scheme (of GCIP project of GEWEX)
PNC-IGBP	Polish National Committee of IGBP
SIEP	State Inspection of Environmental Protection (PIOS)
START	Global Change System Analysis, Research and Training (IGBP/WCRP/HDP)
SCOPE	Science Cooperation Environment Council
UNEP	United Nations Environment Programme
UNESCO	United Nations Education, Scientific and Cultural Organization
WCRP	Word Climate Research Programme
WMO	World Meteorological Organization

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INSTRUCTIONS TO AUTHORS

International Geosphere–Biosphere Programme IGBP — Global Change serial publication is designed to provide a forum for presentation and discussion of the internationally recognized problems related to world environmental change including disturbed climatic variability resulting from human and physical dynamics.

In addition there is also a place for Polish National Committee IGBP and international corresponding organizations Chronicle of activities and research cooperation.

Submission. Submit to the Editor on address given. The manuscript in duplicate must be typewritten in English or French, double-spaced (abstract and references triple-spaced) on one side only of International Standard Size A4 paper with a lefthand margin of 40 mm.

All articles are reviewed and they are expected to be original and not yet published elsewhere unless in other languages than stated above. Authors are responsible for submitting accurately typed manuscripts.

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Presentation. Manuscript should be arranged in the following order of presentation. First sheet: title, author (authors) name, affiliation, full postal address, telephone, fax numbers. Same refers to all co-authors, if appropriate. Second sheet: Abstract of 100 words, Key words, 3-10. Subsequent sheets: Introduction, the text, conclusion (conclusions). Then on separate sheets: number one — acknowledgement (if desired); number two — notes; number three — references.

Appendixes, tables, figures, captions to illustrations should be also given on separate sheets. Words or text passages should not be underlined.

Do not use indents. For paragraphs enter a line space. The main text may be organized in sections under approporiate heading without numerals.

All measurements should be given in metric units. Authors are expected to write as concisely as possible and avoid footnotes whenever possible.

References should be listed triple-spaced in one alphabetical sequence at the end of the text. Write name of author (authors), initials, date of publication in round brackets (), the publisher and place of publication. If applicable, indicate pages reffered to. Names of journals, in italics, abbreviated in accordance with International List of Abbreviations.

References should be indicated in text by giving, in parenthesis, the author's name followed by the data of the paper or book, as (Smith 1992).

Refering to the author in the text indicate initial and name, then data of publication in brackets. Use the form (Smith at al. 1994) where there are more than two autors, but list all authors in the references. Definite quotations should state the source and page number; i.g. (Smith 1994:58). Notes should be refered to by superscript letters.

Figures (e.g. all maps. graphs, diagrams, drawings in black and white colour, by laser printer or clear drawings in Indian ink on transparent paper) should be numered and prepared on separate sheets. Their position should be indicated in the text.

Equations and mathematical formulas-symbols used must be clearly explained. Axes should be clearly described, use only units and abbreviations approved by International List.

All illustrations — photographs and figures, submitted in duplicate — must be in a form suitable for reproduction, camera-ready. They exact drawn lines and clear symbols should allow for size reduction, if required, in print. Axes should be clearly described use only units and abbreviations approved by International List.

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Measurement units to be used in text and diagrams

	Abbreviation
time: years, days, hours, seconds	a(ka), d, h, s
rates	a^{-1}, d^{-1}, h^{-1}, s^{-1} (not 1/h)
depth	mm, m
distance	m, km
area	m^2
volume	m^3, Ml
discharge	m^3s^{-1}
pressure	hPa (not mb)
weight	g, kg
density	g m^{-3}, kg m^{-3}
temperature	°C
power	W
radiation	W m^{2}
angle	°
latidude, longitude	6°15' N etc
altitude	m
decimals	0.1 (not 0,1)
numbers	1 000 (not 1,000)
spaces between units in a series	g m^{-3} (not gm^{-3})

No full stop/period after abbreviations and no brackets around units on graphs e.g. precipitation mm
Multiples of units are normally restricted to steps of thousand, and fractions to steps of a thousand:

Fraction	Abbreviation		Multiple	Abbreviation	
10^{-3}	milli	m	10^3	kilo	k
10^{-6}	micro	μ	10^6	mega	M
10^{-9}	nano	n	10^9	giga	G

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