Vol. 77 No.1 Spring 2004

GEOGRAPHIA POLONICA

GENERAL AND APPLIED CLIMATOLOGY: SELECTED ASPECTS

EDITORS:
MAGDALENA KUCHCIK and KRZYSZTOF BŁAŻEJCZYK

POLISH ACADEMY OF SCIENCES
INSTITUTE OF GEOGRAPHY AND SPATIAL ORGANIZATION

WARSZAWA

PUBLISHED by the Institute of Geography and Spatial Organization,
Polish Academy of Sciences, Warszawa, Poland.

EDITORIAL OFFICE:
Twarda 51/55, 00-818 Warszawa, Poland
Tel. (48 22) 6978-858, Fax (48 22) 620-62-21.

CONTRIBUTIONS and CORRESPONDENCE related to editorial matters
should be sent to the Editor: e.nowos@twarda.pan.pl

SUBSCRIPTION INFORMATION: Geographia Polonica (ISSN 0016-7282)
is published twice a year in Spring, and Autumn by the Institute of Geography
and Spatial Organization, Polish Academy of Sciences.

SUBSCRIPTION ORDERS for Geographia Polonica can be placed with:
ARS POLONA, Krakowskie Przedmieście 7; 00-068 Warszawa, Poland
(including single past and current issues)

ISSN 0016-7282

INFORMATION ON THE CONTENT (from 1964) and forthcoming issues are available at:
www.igipz.pan.pl/wydaw/home_pl.htm

GEOGRAPHIA POLONICA IS CURRENTLY ON LINE!
from vol. 75
The two latest issues (full text) are available at
www.igipz.pan.pl/wydaw/GPonline.htm

PREPARED FOR PRINT
by Małgorzata Cała
Department of Cartography and Geographic Information Systems,
Institute of Geography and Spatial Organization, Polish Academy of Sciences,
Twarda 51/55, 00-818 Warszawa, Poland

CONTENTS

ARTICLES

RESEARCH NOTES

BOOK REVIEWS

GEOGRAPHIA POLONICA, 77, 1, 5–7, Spring 2004
PL ISSN 0016–7282

EDITORIAL

MAGDALENA KUCHCIK and KRZYSZTOF BŁAŻEJCZYK

Institute of Geography and Spatial Organization, Polish Academy of Sciences
Twarda 51/55, 00-818 Warsaw
E-mail: mkuchcik@twarda.pan.pl, k.blaz@twarda.pan.pl

Climatology as a branch of geography seeks regularities to the spatial distribution of weather elements, and periodical changes in the states of the atmosphere. Climatologists thus use data and methods typical of climatology alongside other geographical methods and information. They benefit from methods specific to non-geographical sciences (e.g., physics, medicine, and biology) as well.

Temporal climatic research embraces a wide range of issues from the local micro- and topoclimate, through regional to global research. Since the 1990s climatic models and scenarios of global or regional climate changes have been the most popular research subject. Slightly less popular have been studies on atmospheric circulation and its seasonal anomalies and fluctuations, or changes of climate, as some climatologists say.

Another segment of climatology is concerned with the atmospheric environment and its influence on humans (the impact of weather on perceived temperature, mortality, morbidity, and accidents), which is to say bioclimatology. This focuses on the urban climate (as urban inhabitants are becoming more and more sensitive to the changes in thermal conditions, air pollution and noise), as well as on the possibilities for creating the most comfortable conditions for people. The results of these studies have great applied value in public health care, where they allow for the implementing of watch warning systems against dangerous atmospheric phenomena (e.g., heat waves), and secondly in architecture and urban planning.

Ever greater importance is being and will be assumed by the use of satellite images in analysing temporal states of the atmosphere, weather phenomena and surface temperature, as well as in evaluating spatial changes in climate.

Present-day climatological research there also retains a place for classical approaches, i.e. studies of the temporal and spatial distribution of meteorological elements and phenomena over long-time series and on different spatial scales.

In Poland, climatological studies are carried out in research and educational institutions. One of these is the Institute of Geography and Spatial Organization of the Polish Academy of Sciences (IGiPZ PAN) in Warsaw. Although the group of climatologists working there is very small, their research interests are wide. Four groups of research themes could be distinguished: fundamental studies on the boundary-layer heat and radiation balances, human bioclimatology with an emphasis on the climate-health relationship as well as the direct influence of meteorological stimuli on the human physiological response, urban climate studies, and topoclimatic studies involving field experiments and methods of topoclimatic mapping.

Climatological studies at the Polish Universities usually cover a wide range of topics. Nevertheless some specialisation could be observed. The Jagiellonian University in Kraków has gained significant experience in regard to climate change research. Many studies have been based around the city's meteorological records extending over an almost unique 200 years. Climate change is also studied at the Universities of Łódź, Warsaw and Wrocław, while research on the urban climate was undertaken at almost all Poland's universities, albeit as a special emphasis in Łódź, Warsaw, Wrocław, Gdańsk and Bydgoszcz.

Research on Poland's climate and that of Central Europe is carried out mainly at the universities of Poznań and Lublin, whereas the Silesian University in Katowice and the Nicolaus Copernicus University in Toruń specialize in synoptic climatology (the former) and the climate of polar regions both (the latter). Marine climatology and research on the sea-atmosphere relationship have been developing at Gdynia's Maritime Academy, and at Gdańsk University. The mountain climate is in turn mainly investigated in the Wrocław, Katowice and Kraków universities, as well as at IGiPZ PAN.

This short review points only to the main fields of climatological research in Poland. It could be noted that they correspond with the principal branches to the climatic studies carried out elsewhere. However, work in tropical climatology or on the El Nino Southern Oscillation (ENSO) is undertaken only exceptionally in Poland.

All the climatological research is capable of being assigned to either general or applied study. Among the seven papers making up the present volume, four fall within general climatology, three within the applied. The papers consider synoptic and regional climatology issues, climate change, the mountain climate, topoclimatology and bioclimatology.

The paper by D. Matuszko, R. Twardosz and K. Piotrowicz is based on the aforementioned meteorological records of Kraków, dating back to the end of the 18th century. This is one of the longest one-site series in Central Europe. Previous studies based on this series have reported changes in such meteorological elements as air temperature, precipitation and wind speed over the last hundred years. Only some of the changes are statistically significant. Most of them are well correlated with fluctuations in air circulation. The aim of the paper included here has been to study the relationships between cloudiness, temperature and precipitation. The results could be summarized as follows. The mean yearly air temperature has been rising steadily due to both natural and anthropogenic factors (global warming and urban development). Climatic warming in Kraków probably has resulted in the more frequent over recent decades of convective clouds, as well as showers, thunderstorms and hailstorms. No overall trend has been detected in the long-term series for total annual precipitation, as periods of high and low precipitation balanced each other.

Two papers of general climatology deal with mountain areas. M. Błaś and M. Sobik have been studying the distribution of fog frequency in the Carpathians in the years 1994-2000. As regards the annual number of foggy days the several factors that have appeared as influential include altitude of an observation point, its location relative to air circulation patterns and to the sea, elements of terrain morphology, and exposure to the prevailing winds. The great number of days with fog observed in the Carpathians suggests an important additional water flux through horizontal precipitation in this region. Horizontal precipitation could also play an important role in the deposition of pollutants here, as it does in the Sudetes.

The domain of topoclimatological research is exemplified by J. Baranowski's paper. The aim of this study has been to reveal heat exchange in the active layer in relation to soil, topography, plant cover and atmospheric conditions in a mountainous environment (exemplified by the Tatra Mountains). Very detailed field investigations have shown that features of an active surface such as conductivity in the soil, the density and height of plant cover, the substratum and the exposure and inclination of slopes have a major influence on the density of the energy flux in the active layer.

The study confirms the results of previous studies, to the effect that the occurrence and amount of precipitation influences energy flux as well.

The spatial and temporal regularities applying to thunderstorms constituted a research problem for L. Kolendowicz. The occurrence of thunderstorms in Poland appears to have been conditioned by the simultaneous presence of macro- scale atmospheric circulation and of local factors. The first element is responsible for the transport of moisture and heat energy, as well as for the movement of bar systems over Central Europe. The increasing frequency of numbers of days with thunderstorms, from 20 in the north of Poland to 30 in the south, could be related to the ever greater likelihood of the advection of subtropical air as one moves towards southern Poland. Local elements, e.g., relief, land cover or the distance to the Baltic Sea also influence the frequency of thunderstorms as well. The boundaries of the determined thunderstorm regions in fact correspond with the boundaries of geographical regions, suggesting that interregional differences in the frequency of thunderstorms are mainly conditioned by local features.

Much recent climatic research has been orientated towards the human being. The possibility of climate-related treatment (climatotherapy) at Polish health resorts is discussed by T. Kozłowska-Szczęsna and collaborators. The bioclimatic conditions of Poland's health resorts vary markedly in spatial as well as seasonal terms, thereby reflecting general climatic conditions as well as local factors such as relief, type of soil, vegetation cover, hydrology and land use. This variability creates great therapeutic opportunities and allows for a diversifying of the forms of recreation. The resorts of southern and south-eastern Poland favour diversified forms of climate-related treatment on a year- round basis, while heliotherapy and aerotherapy may be applied with success only in summer. Movement-based therapy prevails in the cool half-year.

K. Błażejczyk presents the results of experimental studies on an important part of the radiation balance in man human beings, i.e., absorption of solar radiation (ASR). The ASR was measured on a mannequin (used as an analogue model of man) in contrast to the majority of previous studies based on different analogue models such as the vertical cylinder or an ellipsoid. Four models for assessing ASR were proposed, depending on the kind of radiation data. The accuracy of the models was verified by direct measurements on human beings. The author presents the seasonal and geographical variation to the components of the radiation balance in the human being, as calculated for three stations representing the climatic conditions of northern, central and southern Poland.

Methods based on remote sensing data are presented by A.B. Adamczyk. Data from LANDSAT 5TM were used to analyse the variation in thermal energy in the Nara Region, Japan, on both the spatial and temporal (four- seasons) scales. The spatial difference in surface temperature varies with the type of land cover. The maximum average temperature occurs on a bare soil, the minimum in coniferous forest. Of special interest is the use of satellite images in the evaluation of seasonal changes in thermal conditions.

Noting this impressive variety, the editors would like to express the sincere hope that this collection of papers will allow the reader to acquaint him or herself, however briefly, with the kinds of climatological studies being conducted currently by Polish climatologists.

GEOGRAPHIA POLONICA, 77, 1, 9–17, Spring 2004
PL ISSN 0016–7282

RELATIONSHIPS BETWEEN CLOUDINESS, PRECIPITATION AND AIR TEMPERATURE

DOROTA MATUSZKO, ROBERT TWARDOSZ and KATARZYNA PIOTROWICZ

Institute of Geography and Spatial Management, Jagiellonian University
Grodzka 64, 31-044 Kraków, Poland
E-mail: d.matuszko@iphils.uj.edu.pl, r.twardosz@iphils.uj.edu.pl,
k.piotrowicz@iphils.uj.edu.pl

Abstract: The work described in this paper aimed at determining the relationship between air temperature, cloudiness and precipitation, based on the Cracow meteorological records. Meteorological data from the period 1901-2000 were used. The research was based on mean monthly temperature totals; the number of days with maximum temperatures above 10°C and above 25°C; annual and daily precipitation as well as the cloud cover and cloud type in three climatic observation terms. The mean yearly air temperature was found to show steady growth, induced by both natural and anthropogenic factors. Climatic warming in Cracow probably has resulted in the more frequent appearance of convective clouds, as well as intense showers, thunderstorms and hailstorms. On the other hand, the frequency of Stratus clouds and fog has been diminished which probably contributed to a reduction in the number of days with light precipitation. No overall trend has been detected in the long-term series for total annual precipitation, as periods of high and low precipitation balanced each other.

Key words: cloudiness, precipitation, air temperature, Cracow, Poland.

INTRODUCTION

An understanding of the recently prevailing world-wide thermal, nephologic and precipitation-related conditions is one of the paramount tasks of contemporary climatic research. Precipitation and air temperature are recognised by climatological literature as important indicators of a climatic change caused, among other factors, by the increasing carbon dioxide concentration in the atmosphere (Bradley et al. 1987). The development of global climate modelling requires precise information on cloud cover as input data, which assume *a piori* a certain value for cloudiness (Maleshko and Wetherald 1981). Nephologic observational data may also be used to verify cloud models.

In general the proportion of *Nimbostratus* (*Ns*) clouds that produce long, but non-intensive precipitation has been diminishing, giving way to the vertical-structure clouds *(Cb)* yielding short, shower precipitation (Kędziora 1995). When not intercepted by vegetation, such rainwater runs off rapidly on the surface or is collected by urban drainage systems. As a result, there is less evaporation, a lower content of vapour in the air and less overall precipitation. A likely cause of this change is the global warming during the 20th century. Since the end of the 19th century, the average annual temperature globally has clearly increased, by 0.3-0.6 deg (Folland et al. 1990; Houghton et al. 1996; Jones and Briffa 1992). However, the global warming effect is not distributed uniformly. The existence of zonal and regional variations is generally accepted, with some world regions even noting a drop in the temperature recorded (Stefanicki et al. 1998; Jones and Briffa 1992). Hence, a long-term series of data for a given site may prove crucial if past climatic conditions are to be understood. Knowledge of these conditions is the basis for any climatic forecasts. This is even more true for precipitation and cloud cover, as both are strongly affected by local conditions.

This paper aims to determine the relationships between air temperature, cloudiness and precipitation in Cracow, Poland, on the basis of a long-term homogenous series of meteorological observations. It is also a contribution to the discussion on feedback-relationships in the atmosphere.

MATERIALS AND METHODS

The research is based on daily meteorological measurements and observations carried out at the Meteorological Station of the Institute of Geography, Jagiellonian University, Cracow, during the years 1901-2000. The station is located in the Vistula river valley, in the city-centre botanical gardens (φ=50°04' N, λ=19°58' E, h=220 m a.s.l.). The series starts in May 1792 and is thus among the longest one-site measurement series in Central Europe. Until the beginning of the 20th century, the station was located outside the eastern city limits (Figure 1).

At the time, Cracow was a commercial, cultural and administrative centre with a very weak industrial function. Since the 18th century, the city had seen little spatial expansion, from 5 km^2 in 1792 to 8.9 km^2 in 1900, but its population had grown rapidly, from 10,100 in 1785 to 85,000 in 1900. Currently, the city has 751,000 inhabitants and an area of 327 km^2. Some economic and urban development took place between the First and Second World Wars, but the greatest spatial and functional change came after the WW II. To the east of the city, a heavy steel industry developed, together with the new neighbourhood of Nowa Huta providing housing and services.

The long duration and homogeneity of the data series, combined with the fact that air temperatures recorded in Cracow match those in other Central European weather stations (Kożuchowski et al. 1994), makes the Cracow meteorological station

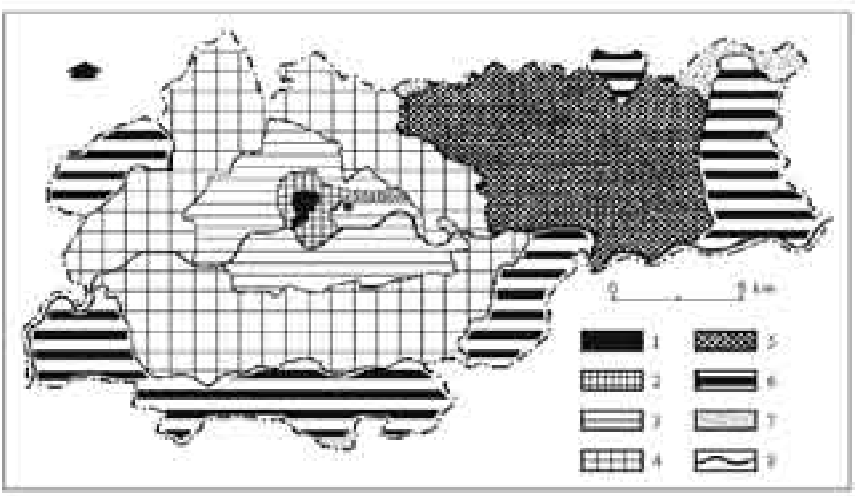


Figure 1. Urban development of the city of Cracow: 1—before 1792, 2—in 1792, 3—in the years 1909-1915, 4—in 1941, 5—in 1951, 6—in 1973, 7—in 1986, 8—Vistula river.

a good reference point for studies of Central European climatic evolution (Obrębska-Starklowa 1993). Additionally, during certain periods, there is also a good correlation with precipitation variability at other stations in this part of Europe (Twardosz 1996); great similarity has also been demonstrated between the patterns of cloud cover in Cracow and Prague (Matuszko 2001a), as well as in other parts of Europe (Henderson-Sellers 1986).

Only the 20th-century data were used in this paper, which takes advantage of the parallel measurements of air temperature and precipitation, as well as observations of cloud cover and type. The research considers mean monthly temperature; the number of days with maximum temperatures above 10°C and 25°C; annual and daily precipitation totals; mean monthly cloud cover and the type of clouds in three climatic observation terms.

RESULTS

On the basis of annual patterns for climatic elements in the period 1901-2000, temperature fluctuations have been shown to be interrelated with cloudiness values and with precipitation. There are two equal minimum values for mean annual cloud cover (Figure 2a), i.e., 57% in 1921 and in 1982; similarly, there are two equal maximum values of 78% in 1941 and 1952. At the beginning of the 20th century, a small decrease in cloud cover was noted, followed by an increase from 1906 up to the beginning of the 1940s, and then 20 years of consistently high values until 1961, when there was a downturn, eventually reversed at the beginning of the 1980s. Precipitation fluctuates via fairly regular periods of increase and decrease is the annual totals thereof (Figure 2b). There are two clear maxima (of nearly 1000 mm) in 1912 and 1966, and a minimum value (448 mm) in 1993. Very high precipitation totals were recorded at the beginning of the 20th century, in the 1960s and, following a period of very low precipitation, again from 1995 on. There has been an increase in extreme precipitation events, including the catastrophic rainfalls in the July of 1997 and 2001.

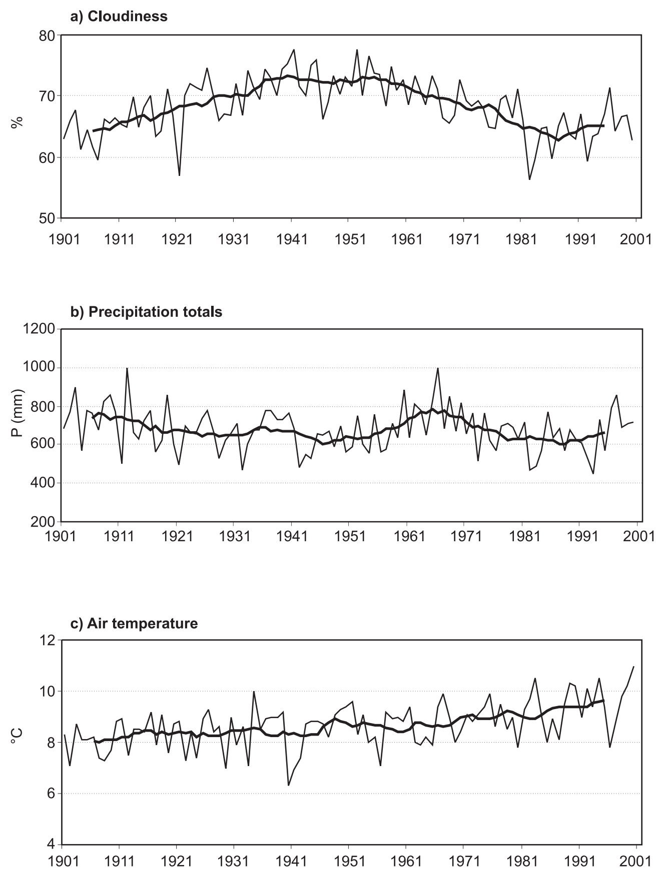


Figure 2. Multi-annual course of the annual values and 5-year moving averages of cloudiness (a), of precipitation totals (b) and of mean air temperature (c) in Cracow.

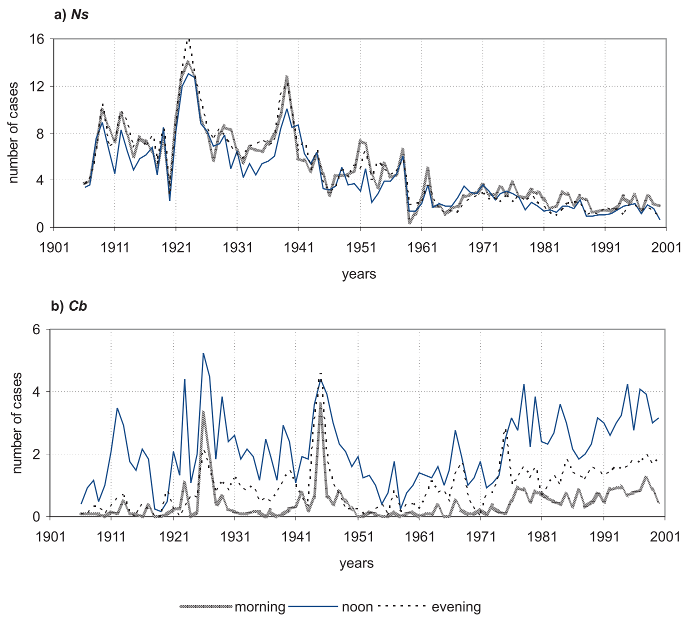


Figure 3. Multi-annual course of the frequency of the *Ns* and *Cb* clouds in Cracow

Neither cloud cover nor precipitation showed any clear-cut trend during the investigated period. In contrast, the mean air temperature displayed a significant upward trend from the beginning of the 20th century (Figure 2c). From 1983, there were as many as seven years in which the mean air temperature exceeded 10°C, with the year 2000 recording 11°C. 1940 turned out to be the coldest year of the series, with a mean annual temperature of 6.3°C.

A strong concordance between the cloud cover and precipitation since the 1960s has been related to the changing structure of cloud cover in Cracow, possibly caused by a warming effect (Figure 3). During the first half of the century, the cloud cover over the city included a sizeable proportion (30%) of stratus clouds (*St* and *Ns*), which then diminished, being replaced by convection clouds (Matuszko 2001b).

The large proportion of stratus clouds in Cracow during the period 1901-1950 was probably caused not only by the circulation factor, but also by the local conditions: the location of Cracow in the wet and poorly ventilated Vis-

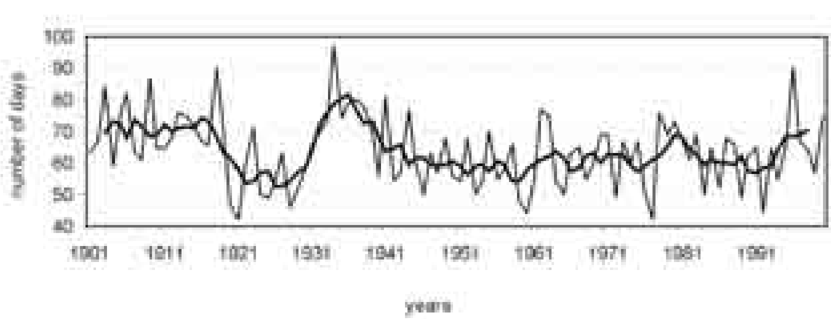


Figure 4. Multi-annual course of the annual values and 5-year moving averages of number of days with low precipitation (≤1 mm) in Cracow

tula valley combined with slow air exchange due to the inversion strata stagnant in the concave relief. After the Second World War, local marshlands were partly drained and the air became drier as a result of urbanisation and the emission of heated air to the atmosphere, all combining to limit the occurrence of low stratus clouds. Causing emissions of artificially-heated air and providing the vast concrete surfaces with a huge convection potential, intensive urbanisation was conductive to the development of the *Cu* and *Cb* clouds observed during the last 30 years (Matuszko 2001b).

The dominance of stratus clouds during the first half of the century correlates well with the high frequency of non-intensive precipitation. Indeed, at the beginning of the period and in the 1930s, there were a large number of days with very weak precipitation, at less than or equal to 1 mm (Figure 4). The same cloud structure explains a clear trend towards heavier cloud cover and falling totals for annual precipitation during the period 1901-1950. The non-intensive precipitation produced by the stratus-type clouds has a limited impact on annual totals.

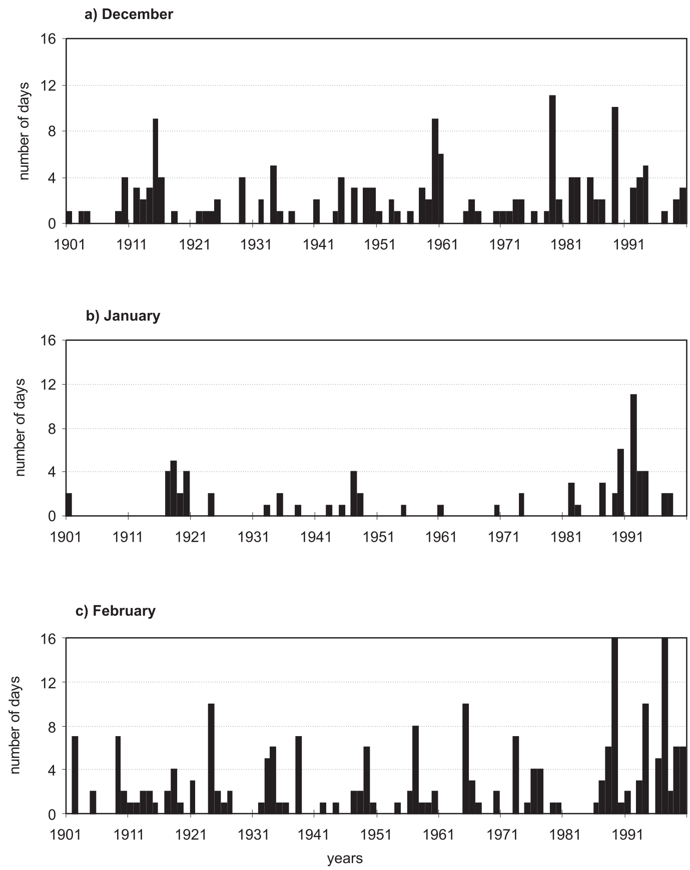


Figure 5. Multi-annual course of number of days with maximum air temperature above 10°C (t_{max}>10°C) in December, January and February in Cracow

Winter temperature has the strongest impact on mean annual temperature values (Trepińska 1997, 2000). Since the beginning of the 20th century, the number of days in December, January or February with a maximum temperature above 10°C has been rising (Figure 5). The largest increase in numbers of days with t_{max}>10°C was noted for February (up 2.4 days per 100 years). In the Februaries of 1989 and 1997, such days constituted more than 50% of the total, and this must have had an impact on other meteorological elements.

It was observed that, during the years 1966-2000, convection-type clouds and related thunderstorms tended to occur increasingly frequently during the cold half of the year (Figure 5), which should undoubtedly be associated with the growing proportion of very mild winter seasons (Piotrowicz 1996). During that period, thunderstorms occurred more frequently in March and April, and in summertime. According to the latest re-

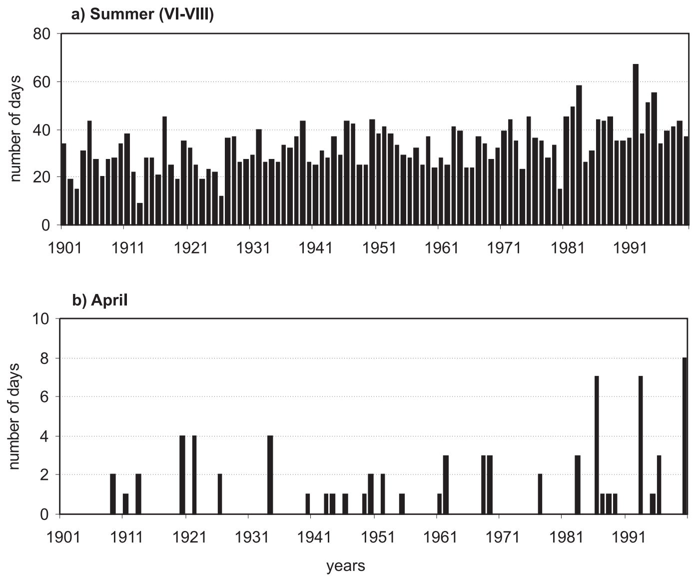


Figure 6. Multi-annual course of number of days with maximum air temperature above 25°C (t_{max}>25°C) in summer (June-August)—(a) and in April—(b) in Cracow.

search, the mean summer temperature has not only failed to show any upward trend, but actually went down in such a way as an apparent contradiction of global warming theory (Trepińska 1997, 2000). Nevertheless, the number of days with t_{max}>25°C during the 20th century's summer seasons rises (Figure 6) that contributes to increased temperature variability of that season. The number of days with t_{max}≥25°C increased in a month as early as April, which could explain the corresponding increase in days with *Cb* cloud or a thunderstorm during this month (Figure 7).

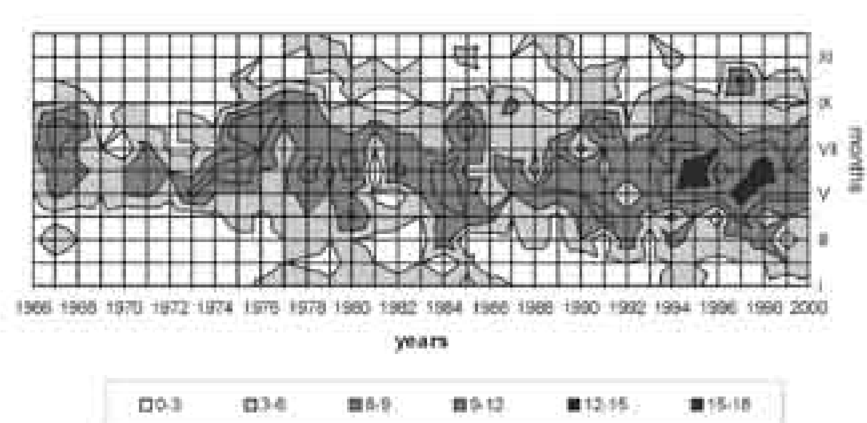


Figure 7. Annual course of the average monthly number of cases of Cb cloud (in the climatological terms) in Cracow in the years 1966-2000.

Atmospheric circulation compounded by human impact may be responsible for the change in the analysed meteorological elements. In southern Poland, air temperature is correlated with zonal circulation. Beginning from the 1970s, there has been an increase in air circulation from the west, which has contributed to a raising of air temperature that is particularly visible in wintertime (Niedźwiedź 1993). The cloudiness and annual precipitation totals revealed a stronger correlation with variability in the cyclonicity index (C) (Matuszko 2001b; Niedźwiedź 1993; Twardosz 1999). The close relationships between cloud cover and precipitation are best reflected in the cases of very heavy daily precipitation (>20 mm), which only occur at the rate of 3%, but account for as much as 21.9% of total annual precipitation (Twardosz 2000). The number of such days is responsible for 86% of the fluctuations in annual precipitation. Daily precipitation of such magnitude can almost only be produced by *Cb* and *Ns* clouds, and occurs most frequently in synoptic situations where there is cylconic trough (Bc), an advection from the north (Nc) or north-eastern advection (NEc) (Table 1).

Table 1. All cases of the very high daily precipitation (>60 mm) in Cracow (1901-2000)

Date	Daily precipitation totals (mm)	Genera of clouds	Synoptic situation *
19 June 1902	74.9	Ns	Nc
10 July 1903	67.8	Ns	Nc
2 June 1905	61.0	Cb	Ka
25 May 1912	83.9	Ns	NEc
16 April 1916	78.8	Ns	Nc
29 June 1925	65.2	Ns	Nc
20 August 1931	62.0	Cb	SWc
23 June 1946	77.1	Cb	Bc
8 July 1946	82.6	Cb	Bc
2 June 1955	63.4	Ns	Cc
21 June 1955	60.6	Ns	Bc
9 September 1963	99.0	Ns, Cb	Ec
29 May 1966	81.0	Ns	Nc
18 July 1970	85.2	Ns	Nc
13 June 1986	66.5	Cb	NEc
24 June 1989	79.0	Cb	Bc
5 July 1997	52.8	Ns, Cb	Bc

*Note: According to synoptic situations calendar by Niedźwiedź (2001).

Niedźwiedź distinguished 20 types of the synoptic weather situations using big letters to denominate direction of the air masses advection and indices 'a' and 'c' respectively for the anticyclonic and cyclonic barometric air pressure systems. Four situations named below are characterized by the lack of advection or changeable directions of the air inflow over area under investigation.

They are as follows: Ka—anticyclonic wedge, Cc—central cyclonic situation, Bc—cyclonic trough with different directions of the air masses advection.

CONCLUSIONS

The last century has seen, the mean annual air temperature in Cracow grow steadily, most likely as a consequence of both natural and human-induced factors. The warming of the Cracow climate may have contributed to the increased occurrence of low clouds caused by convection. The development of the *Cu* clouds followed by the *Cb* type often results in intensive occasional showers, thunderstorms and hailstorms, all of which have been increasingly frequent in recent years. It is worth noting that the increase in mean annual air temperature is mainly related to temperature in the winter months. In recent years the occurrence of *Cb* clouds and number of days with thunderstorms has also increased in this season.

Over the second half of the 20th century, the low occurrence of stratus clouds and of fogs, due to the dried air over the city, may have caused the reduction in the number of days with weak precipitation.

The long-term series reveals no overall trend for annual precipitation totals, as periods of high and low precipitation balanced each other.

Cloudiness and precipitation display the strongest statistical relationships with the cyclonicity index, while air temperature, particularly in winter months, is correlated with zonal circulation.

The existence of a feedback effect on the global scale intensifies an increase in air temperature (and in effect also evaporation), leads to an increase in cloud cover (stratus clouds) or to a boosted vertical cloud build-up (convection clouds), possibly combined with a drop in its horizontal development. The local features of Cracow would seem to attest to this hypothesis, thus confirming a view point that we are experiencing a shrinking in the proportion of stratus type clouds which produce long periods of precipitation of low intensity, in favour of vertically developed clouds yielding short rainstorms.

REFERENCES

Bradley R., Diaz H., Eischeid J., Jones P., Kelly P. and Goodess C., 1987, *Precipitation fluctuations over northern hemisphere land areas since the mid-19th century*, Science, 273, 171-175.

Folland C.K., Karl T.R. and Vinnikov K.Y., 1990, *Observed climate variations and change.* Climate change: the IPCC scientific assessment, Cambridge Univesity Press, 195-238.

Henderson-Sellers A., 1986, *Cloud changes in a warmer Europe*, Climatic Change, 8, 25—52.

Houghton J.T., Meira Filho L.G., Callander B.A., Harris N., Kattenberg A. and Maskell K., 1996, *Climate change 1995, The Science of Climate Change*, Cambridge University Press.

Jones P.D. and Briffa K.R., 1992, *Global surface air temperature variations during the twentieth century: Part 1, spatial, temporal and seasonal details*, The Holocene, 2, 165-179.

Kędziora A., 1995, *Prognoza zmian klimatycznych, Prognoza ostrzegawcza zmian środowiskowych warunków życia człowieka w Polsce na początku XXI wieku* (Climate changes prediction, Warning prediction of environmental living conditions' changes in Poland at the beginning of the 21st century), Zeszyty Naukowe Komitetu Człowiek i Środowisko, Instytut Ekologii PAN, 10, 97—132.

Kożuchowski K., Trepińska J. and Wibig J., 1994, *The air temperature in Cracow from 1826 to 1990: persistence, fluctuation and the urban effect*, International Journal of Climatology, 14, 1035-1049.

Maleshko V. P. and Wetherald R. T., 1981, *The effect of geographical cloud distribution on climate: A numerical experiment with an atmospheric general circulation model*, Journal of Geophysical Research, 86, 11995—12014.

Matuszko D., 2001a, *Porównanie stosunków nefologicznych w Krakowie i Pradze* (Comparison of nephological conditions in Cracow and Prague), Folia Geographica, ser. Geographica Physica, 31-32, 27-35.

Matuszko D., 2001b, *Long—term observation of cloud cover in Cracow (1792-1999)*. Geographia Polonica, 74, 41-56.

Niedźwiedź T., 1993, *Wieloletnia zmienność wskaźników cyrkulacji atmosfery nad Polską*

Południową (Multiannual variability of atmospheric circulation indices over Southern Poland) [in:] *Współczesne badania klimatologiczne* (Recent Polish climatological investigations in Poland and abroad), Krawczyk B. and Błażejczyk K., Conference Papers, IGiPZ PAN, 23, 7-18.

Niedźwiedź T., 2001, *Catalogue of synoptic situations in the upper Vistula river basin (1873-2000)*, Computer file.

Obrębska-Starklowa B., 1993, *The role of the climatological stations of the Jagiellonian University in Cracow in research on climatic conditions in Central Europe*, Zeszyty Naukowe UJ, Prace Geograficzne, 95, 17-23.

Piotrowicz K., 1996, *Thermal characterization of winters in the 20th century in Kraków*, Geographia Polonica, 67, 77-88.

Stefanicki G., Talkner P. and Weber R.O., 1998, *Frequency changes of weather types in the Alpine Region since 1945*, Theoretical and Applied Climatology, 60, 47-61.

Trepińska J. (ed.), 1997, *Wahania klimatu w Krakowie (1792-1995)* (Fluctuations of climate in Cracow 1792-1995), Kraków, Instytut Geografii UJ, 204 p.

Trepińska J., 2000, *Anomalie, cykle, trendy termiczne w klimatologii na przykładzie fluktuacji termicznych w Europie Środkowej w XIX i XX wieku* (Anomalies, cycles, thermic fluctuations in Central Europe during 19th and 20th), Acta Universitatis Nicolai Copernici, 106, 307-326.

Twardosz R., 1996, *Variabilité des précipitations atmosphériques en Europe Centrale pendant la période 1850-1995*, Publications de l'Association Internationale de Climatologie, 9, 520-527.

Twardosz, R., 1999, *Precipitation variability and tendency in Kraków for the period 1850-1997 related to circulation patterns*, Acta Geophysica Polonica, 1, 111-133.

Twardosz R., 2000, *Wieloletnia zmienność sum dobowych opadów w Krakowie w powiązaniu z sytuacjami synoptycznymi* (The long term variability of the daily precipitation in Cracow in relation to synoptic situations), Prace Geograficzne IG UJ, 105, 19-71.

Received: March 2003
Revised: October 2003

GEOGRAPHIA POLONICA, 77, 1, 19–34, Spring 2004
PL ISSN 0016–7282

THE DISTRIBUTION OF FOG FREQUENCY IN THE CARPATHIANS

MAREK BŁAŚ and MIECZYSŁAW SOBIK

Department of Meteorology and Climatology,
University of Wrocław
Kosiby 8, 51-670 Wrocław, Poland
E-mail: blasm@meteo.uni.wroc.pl, sobik@meteo.uni.wroc.pl

Abstract: Altitude is one of the predominant factors which controls the annual number of days with fog (NDF). The second important factor influencing NDF is station location in regard to circulation patterns and distance from the sea. NDF depends also on terrain morphology at a given station site and in its wider neighbourhood, island-mountain of morphology or a position on the windward side of a larger massif. Special attention is paid to stations in convex landforms where orographic fog caused by the forced ascent of moist air occurs frequently. The large NDF (highest away from the Hercynian Mts) observed in the Carpathians suggest that this region is characterised by an important additional potential water flux in the form of horizontal precipitation. Depending on land use, this could play an important role in pollutant deposition, as it does in the Hercynian Mts.

Key words: fog frequency, fog deposition, fog distribution, fog-annual variations, Carpathians, mountain climatology.

INTRODUCTION

The aim of this study is to give a general description of fog frequency, as well as to indicate the potential role of pollutant deposition via fog in the environmental processes ongoing in the Carpathians. There is a lack of analysis regarding fog frequency on the scale of the Carpathian range as a whole, though the question was discussed in relation to the Polish part of the Western Carpathians by Hess (1965).

The authors of this study take advantage of synoptic details delivered by member countries of the World Meteorological Organization under an agreement provided for in the World Weather Watch contract. A database with information from over 8000 stations all over the World between 1994 and the present is available via the Internet (NCDC, 2000). The existence of fog, in at least one of the 8 synoptic hours (00, 03, 06, 09, 12, 15, 18, 21 UTC), is one of many information categories for which data are stored. The database called the Global Daily Summary includes the period 1994-2000 has been used to characterise the spatial distribution and annual variations in fog frequency in the Carpathians (34 stations). Only stations situated above 500 m a.s.l. with gaps in data below 25% were taken into consideration. The lacking data were completed separately in a given year, according to the following equation:

$$NDF = AD*365/ID$$

where:

NDF—annual number of days with fog;

AD—number of days with fog in an accessible data sequence;

ID—number of days with accessible data sequence.

Additionally, information about horizontal visibility (<1 km) from all visual observations was useful in showing the contribution made by whole-day fog. All of the stations were also divided into four groups as regards position within the type of landform. If any station is referred to in the further text, its name is followed by the station rank in Table 1.

FOG FREQUENCY IN EUROPEAN MOUNTAINS

The disintegrated body of Western Europe, W-E arrangement of major landforms and location in a zone of prevailing westerlies all suggest that oceanic air masses may readily penetrate a considerable part of the continent. The greater distance from the Atlantic Ocean and transformation of moist air masses as they pass over complex terrain contribute to a situation in which climate shows more distinctly continental features in Eastern and Southern, than in Western, Europe (Wallen 1977).

Figure 1 shows the geographical distribution of average annual fog frequency

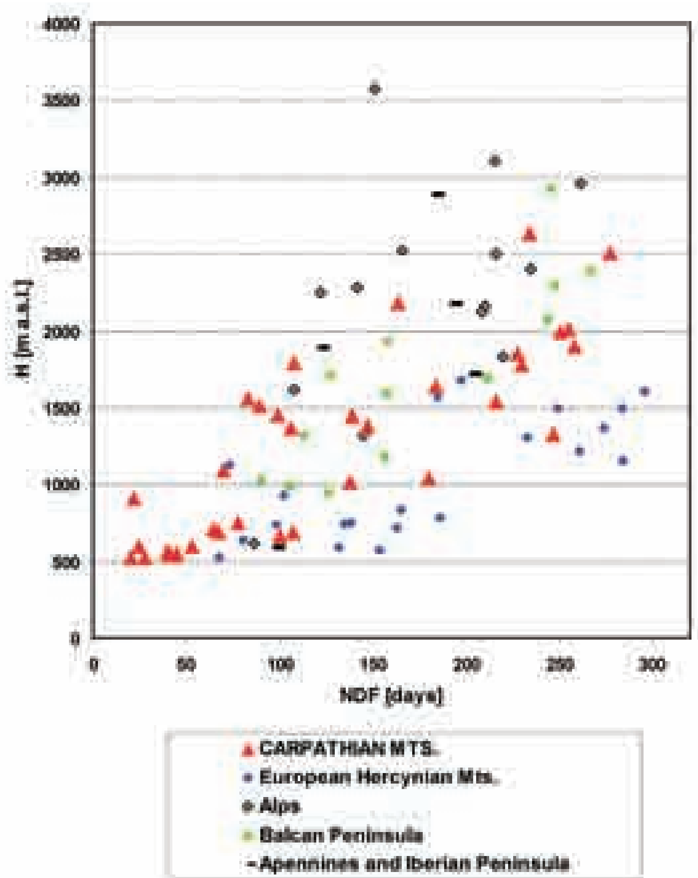


Figure 1. Regional distribution of annual fog frequency in European mountains.

Table 1. Mean annual NDF at montane meteorological observatories in Europe.

Explanations: NDF – number of days with fog; Hercynian European mountains – the zone of low and medium–height mountain ranges between the Massif Central and Ardennes in the west and the Świętokrzyskie (Holy Cross) Mts (Poland) in the east; EX – (exposed), mountain summit or ridge well exposed above the surrounding terrain; SC – (screened) mountain summit or ridge situated at a small distance from other summits of similar or greater altitude; SL – slope position, BN – basin landform position.

NR	STATIONS	φ(N)	λ(E)	NDF	H [m a.s.l.]	REGION (Figure 3)	TYPE OF LANDFORM (Figure 4)
1	2	3	4	5	6	7	8
1	Śnieżka	50°44′	15°44′	296	1602	European Hercynian Mts	EX
2	Brocken	51°48′	10°36′	284	1153	European Hercynian Mts	EX
3	Praded	50°04′	17°14′	284	1490	European Hercynian Mts	EX
4	Omu	45°27′	25°27′	277	2509	Southern Carpathians	EX
5	Szrenica	50°48′	15°31′	274	1364	European Hercynian Mts	EX
6	Botev	42°40′	24°50′	267	2389	Balkan Peninsula	EX
7	Zugspitze	47°25′	11°01′	262	2960	Alps	EX
8	Fichtelberg	50°26′	12°58′	261	1213	European Hercynian Mts	EX
9	Ceahlau Toaca	46°56′	25°55′	258	1898	Eastern Carpathians	EX
10	Chopok	48°56′	19°35′	255	2012	Western Carpathians	EX
11	Kasprowy Wierch	49°14′	19°59′	250	1989	Western Carpathians	SC
12	Feldberg	47°53′	8°00′	250	1493	European Hercynian Mts	EX
13	Czerni	42°35′	23°16′	248	2292	Balkan Peninsula	EX
14	Lysa Hora	49°33′	18°27′	247	1327	Western Carpathians	EX
15	Mussala	42°11′	23°35′	246	2927	Balkan Peninsula	EX
16	Bjelasnica	43°43′	18°16′	244	2067	Balkan Peninsula	SC
17	Grigna	45°57′	11°12′	235	2403	Alps	EX
18	Lomnicky Stit	49°12′	20°13′	235	2635	Western Carpathians	EX
19	Grosser Arber	49°05′	13°30′	233	1307	European Hercynian Mts	EX
20	Lacaut	45°49′	26°22′	230	1776	Eastern Carpathians	EX
21	Vladeasa	46°45′	22°48′	228	1848	Southern Carpathians	EX
22	Wendelstein	47°42′	12°01′	220	1832	Alps	EX
23	Saentis	47°15′	9°21′	216	2500	Alps	EX
24	Rarau	47°27′	25°34′	216	1541	Eastern Carpathians	SC
25	Sonnblick	47°03′	12°57′	215	3107	Alps	EX
26	Mourgash	42°50′	23°40′	212	1692	Balkan Peninsula	SC
27	Villacheralpe	46°36′	13°40′	210	2160	Alps	SC
28	Paganella	46°09′	11°02′	208	2125	Alps	SC
29	Monte Scuro	39°20′	16°20′	202	1720	Mediterranean zone *	EX
30	La Dole	46°26′	6°06′	197	1675	European Hercynian Mts	EX
31	Monte Cimone	44°12′	10°20′	192	2173	Mediterranean zone *	EX

1	2	3	4	5	6	7	8
32	Waldstein	50°08′	11°52′	186	786	European Hercynian Mts	SC
33	Aigoual	44°07′	3°35′	185	1565	European Hercynian Mts	EX
34	Cozia Pass	45°15′	24°15′	184	1640	Southern Carpathians	SC
35	Pic Du Midi	42°56′	0°20′	182	2883	Mediterranean zone *	EX
36	Crni Vrh	44°07′	21°57′	181	1039	Southern Carpathians	EX
37	Kredarica	46°23′	13°51′	166	2519	Alps	EX
38	Milesovka	50°33′	13°56′	165	836	European Hercynian Mts	EX
39	Tarcu	45°17′	22°32′	164	2180	Southern Carpathians	SC
40	Ślęża	50°53′	16°43′	163	718	European Hercynian Mts	EX
41	Snejanka	41°40′	24°41′	158	1930	Balkan Peninsula	SC
42	Zavizan	44°49′	14°59′	158	1594	Balkan Peninsula	EX
43	Smolyan	41°35′	24°41′	156	1180	Balkan Peninsula	SL
44	Elsenborn	50°28′	6°11′	154	570	European Hercynian Mts	EX
45	Jungfrau	46°33′	7°59′	151	3576	Alps	EX
46	Fundata	45°27′	25°18′	147	1380	Southern Carpathians	SC
47	Monte Brisbino	45°52′	9°01′	145	1319	Alps	EX
48	Guetsch	46°39′	8°37′	142	2284	Alps	SL
49	Piatra-gozna	45°05′	22°05′	139	1445	Southern Carpathians	SC
50	Cervena	49°47′	17°33′	138	750	European Hercynian Mts	EX
51	Kekesteto	47°52′	20°01′	138	1015	Western Carpathians	EX
52	Primda	49°40′	12°40′	135	45	European Hercynian Mts	SC
53	Święty Krzyż	50°51′	21°03′	132	90	European Hercynian Mts	EX
54	Kopaonik	43°17′	20°48′	127	713	Balkan Peninsula	SC
55	Lisca	46°04′	15°17′	126	41	Balkan Peninsula	EX
56	Patscherkofel	47°13′	11°28′	122	247	Alps	SC
57	Navacerrada	40°47′	4°01′	121	1888	Mediterranean zone *	SC
58	Lazaropole	41°53′	20°22′	114	1321	Balkan Peninsula	SL
59	Ineu	47°32′	24°53′	108	1792	Eastern Carpathians	SL
60	Feuerkogel	47°49′	13°44′	108	1621	Alps	SC
61	Toplita	46°55′	25°20′	107	689	Eastern Carpathians	BN
62	Strbske Pleso	49°07′	20°05′	106	1368	Western Carpathians	SL
63	Puntijarka	45°55′	15°58′	106	988	Balkan Peninsula	EX
64	Messtetten	48°11′	9°00′	102	930	European Hercynian Mts	EX
65	Miercurea	46°22′	25°44′	100	662	Eastern Carpathians	BN
66	Paltinis Sibiu	45°39′	23°55′	99	1454	Southern Carpathians	SL
67	Svratouch	49°44′	16°02′	99	737	European Hercynian Mts	SC
68	Portalegre	39°17′	7°25′ W	97	590	Mediterranean zone *	SL
69	Zlatibor	43°44′	19°43′	90	1029	Balkan Peninsula	SL
70	Sinaia	45°21′	25°33′	89	1510	Southern Carpathians	SL
71	Lunz	47°51′	15°00′	86	615	Alps	SL
72	Paring	45°23′	23°28′	83	1561	Southern Carpathians	SL
73	Wolfsegg	48°06′	13°41′	80	634	European Hercynian Mts	SL
74	Joseni	46°42′	25°30′	78	749	Eastern Carpathians	BN
75	Churanov	49°04′	13°37′	74	1126	European Hercynian Mts	SC

1	2	3	4	5	6	7	8
76	Predeal	45°30′	25°35′	70	1093	Southern Carpathians	SL
77	Kocelovice	49°28′	13°50′	68	522	European Hercynian Mts	SL
78	Liesek	49°22′	19°41′	67	692	Western Carpathians	BN
79	Intorsura	45°41′	26°01′	64	710	Eastern Carpathians	BN
80	Petrosani	45°25′	23°22′	53	599	Southern Carpathians	BN
81	Dudulesti	45°02′	24°32′	45	548	Southern Carpathians	SL
82	Braszov	45°38′	25°35′	41	538	Southern Carpathians	SL
83	Hvedin	46°52′	23°03′	40	561	Southern Carpathians	SL
84	Sfintu	45°52′	25°47′	28	525	Eastern Carpathians	SL
85	Cimpulung	45°16′	25°03′	24	600	Southern Carpathians	SL
86	Svermovo	48°51′	20°11′	22	906	Western Carpathians	SL
87	Odorhei	46°18′	25°18′	20	525	Eastern Carpathians	SL

* The 'Mediterranean zone' embraces here the Apennines and Iberian Peninsula mountains as they represent the same climatic zone.

versus altitude in the cases of 87 stations in the European mountains. Series' configurations indicate that altitude is one of the predominant factors which controls the annual number of days with fog (NDF). NDF increases with altitude, albeit with a moderate decrease in fog frequency being observed above a given level—about 2500 m a.s.l. in the Carpathians and 3000 m a.s.l. in the Alps (Błaś and Sobik 2000).

The following important factors influencing NDF are: exposure to advection of humid Atlantic air masses, proximity to the coast, the absence of competitors in the form of other mountains on the windward side and moderate altitude within the range 1000-1600 m a.s.l. This is the reason why the highest NDF on the European scale is to be observed in middle-sized Hercynian mountains (extending from the Massif Central via the Jura, Ardennes, Vosges, Black Forest, Bohemian Forest, Ore Mts, Harz and Sudetes). It is the highest Sudetic stations, i.e. Śnieżka [1—in Table 1], Praded [3], Szrenica [5] which join Brocken [2] in the Harz mountains in recording, where the largest number of foggy days per year (NDF) to be noted for the continental part of Europe (leaving aside Scandinavia and the British Isles): 296, 284, 274 and 284 days per year respectively (Table 1, Figure 2).

Why the highest fog frequency is typical for middle-sized European Hercynian mountains, as opposed to the much higher Alps, Carpathians or Balkan Mts, is something that calls for an explanation. Firstly, the highest stations like Jungfrau [45], Sonnblick [25], Zugspitze [7], Lomnicky Stit [18] or Mussala [15] are so high that they often protrude beyond the thin layer of low-level cloud. This is particularly characteristic for the colder half of a year during which the condensation level goes down, because of the seasonal decrease in solar radiation and predominant stable stratification with Stratus and Stratocumulus clouds reaching up to 2000 m a.s.l. (Figure 5). Secondly, the Alpine or Carpathian peaks of a height most favourable for fog formation (1500-2500 m a.s.l.) are often surrounded and screened by nearby higher massifs. A peripheral location on the windward side (taking into account the direction of atmospheric circulation) is particularly conducive to the presence of fog. Fog does not exist on the lee side where air subsides.

In the whole dataset the stations representing the island-mountain type of morphology are especially worthy of note, because of the highest fog frequency at their altitudes: Elsenborn [44] in Ardennes , Ślęża [40] in the Sudety Foreland, Waldstein [32] in the Ore Mts and Brocken [2] in the Harz.

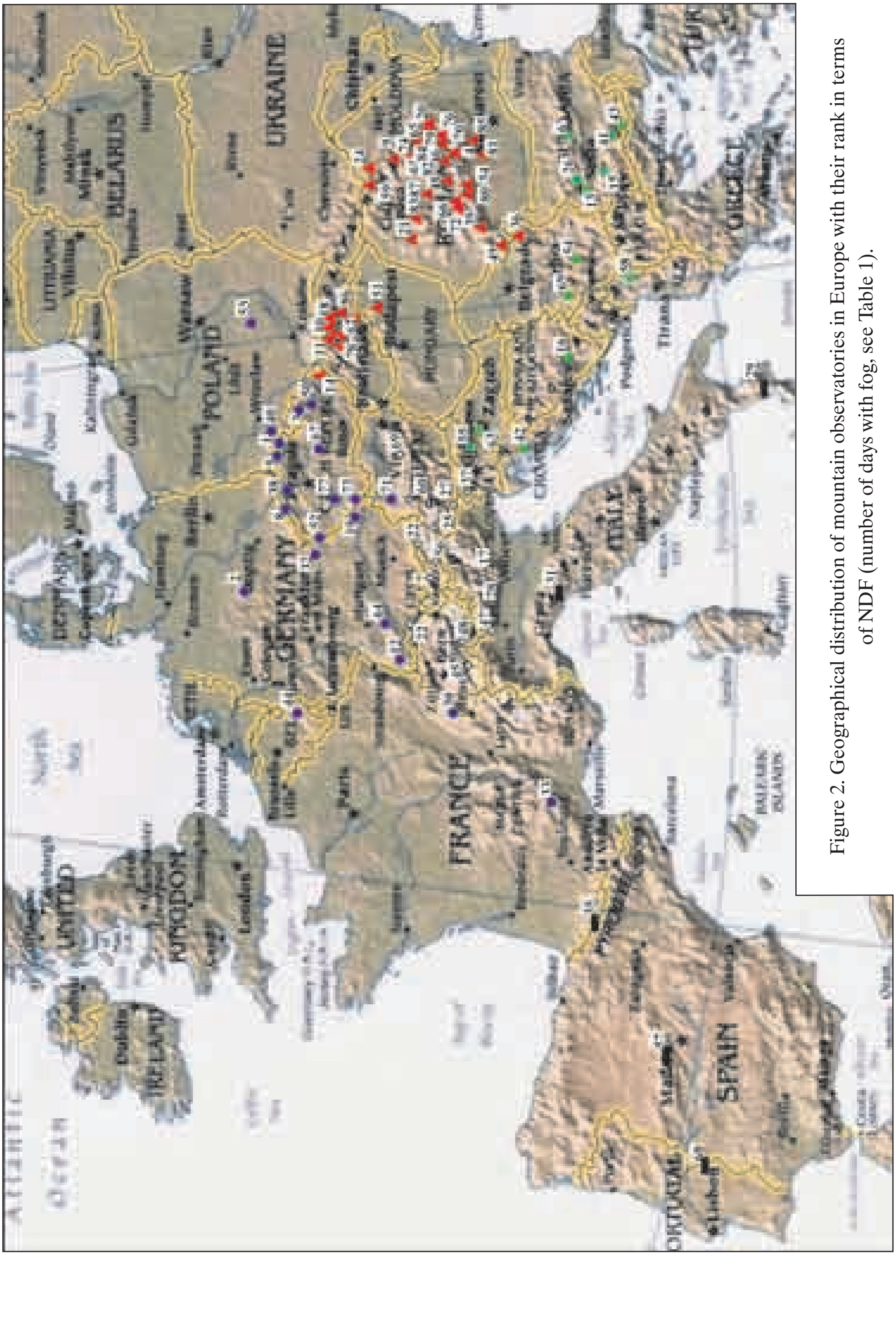


Figure 2. Geographical distribution of mountain observatories in Europe with their rank in terms of NDF (number of days with fog, see Table 1).

Owing to their isolated location, and independently of the air flow direction as a result of frequent airstream deformation due to topography, orographic fog is formed through the adiabatic cooling and the condensation of water vapour in the air ascending slopes.

NDF also depends on morphology at a given station, with orographic fog being formed by increasing relative height, and a position on the windward side of a larger massif. A good example of the role of these factors is seen at such mountain stations as Omu [4] and Ceahlau [9], that both have NDF of more than 250 per year (and more than in the Alps) despite their long distance from the Atlantic Ocean. Apart from that, important sources of atmospheric moisture for the Southern and Eastern Carpathians are the Black Sea and Mediterranean Sea. Additionally they are significantly exposed over the Wallachian Plain to the south, the Great Hungarian Plain to the west and the Moldavian Upland to the east. The same situation refers to the highest stations of the Balkan Peninsula, like Botev [6] and Mussala [15] (with 267 and 246 days with fog respectively). On one hand they are screened by the Dynaric Alps, reducing the intrusion of low-pressure systems of Mediterranean cyclogenesis, but on the other they are well--exposed in their eastern sector to the Black Sea and the Aegean.

Lower NDF, in comparison with the stations discussed above, is typical for the Mediterranean zone (Monte Scuro [29], Monte Cimone [31], Pic du Midi [35]). In spite of the great relative height and proximity to the Mediterranean Sea as an effective source of atmospheric water vapour, only wintertime is favourable for fog formation, because of the strong seasonality of cyclonic activity. During the warm half of a year a predominant influence of the subtropical high-pressure system concomitant with large-scale air subsidence is observed, which makes it difficult for air to ascend slopes and form orographic fog.

FACTORS CONTROLLING FOG FREQUENCY IN THE CARPATHIANS

REGIONAL DISTRIBUTION

NDF in the Carpathians varies across a wide range from 20 at Odorhei [87] to 277 at Omu [4] (Table 1, Figure 3). A clear relationship of NDF with altitude is visible, expressed by a Pearson's correlation coefficient equal to 0.68, while for the whole population of European data it is only 0.37.

The existing sources of data were divided into three groups according to their geographical position in the Western,

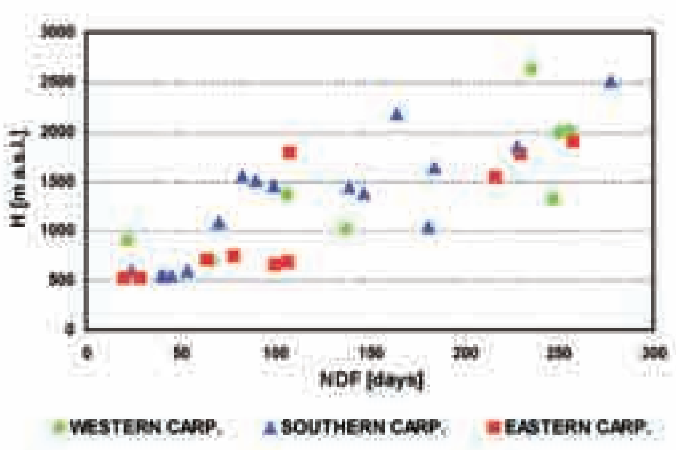


Figure 3. Distribution of annual fog frequency in the Carpathians.

Eastern and Southern Carpathians. Three stations from the Bihor Mts (Vladeasa [21] and Hvedin [83]) and the Eastern Serbian Ore Mountains (Crni Vrh [36]) were included within Southern Carpathians. In each of these three regions NDF is strongly dependent on altitude, with a correlation coefficient equal to 0.73 in the Eastern, 0.71 in the Western and 0.60 in the Southern Carpathians. NDF in all regions varies from less than 30 in the lower parts of mountains to more than 250 on mountain ridges (Figure3) which is very similar to the results obtained by Hess (1965).

THE INFLUENCE OF TOPOGRAPHY

Despite the distinct existing influence of altitude on NDF, it is possible to note stations at similar altitude which show very different NDF, e.g., at around 1000 m a.s.l. Svermovo [86], Predeal [76], Kekesteto [51], Crni Vrh [36] have NDF of 22, 70, 138 and 181 respectively, or at around 1800 m a.s.l. Ineu [59], Cozia [34], Lacaut [20] and Ceahlau Toaca [9] have NDF equal to 108, 184, 230 and 258. Furthermore, some individual groups of stations stand out from the whole population when relief is taken into account (Figure 4).

Stations situated at the bottom of valleys or valley-basins have relatively high NDF (53-107), poorly correlated with altitude (Pearson's coefficient = 0.06). A characteristic feature of this category is a very small annual number of days with fog lasting continuously for a whole day (from 0 to 3 days). The predominant type of fog in this group is a radiative one, which is formed at night but as a rule dissipates during the day.

The highest frequency of fog at any altitude is that to be observed on conspicuous convex landforms (called 'exposed peaks' in Figure 4), such as well-exposed summits and mountain ridges. NDF varies from 138 days per annum at Kekesteto [51] (1015 m a.s.l.) to 277 days at Omu [4] (2508 m a.s.l.). This category is also typical for its highest frequency of whole-day fog, with a maximum at Lacaut [20] of 75 days per year. Fog formed at such sites is most often of orographic origin, connected with the forced ascent of humid air on a windward slope. Similar features are also shown by stations on summits or ridges, which are more or less sheltered by other convex landforms situated in their vicinity—see the 'screened peak' group in Figure 4. In this case NDF is usually smaller than in the former group and the increase of NDF with height is comparably lower.

The last group of stations which can be distinguished by their landform is the 'slope'

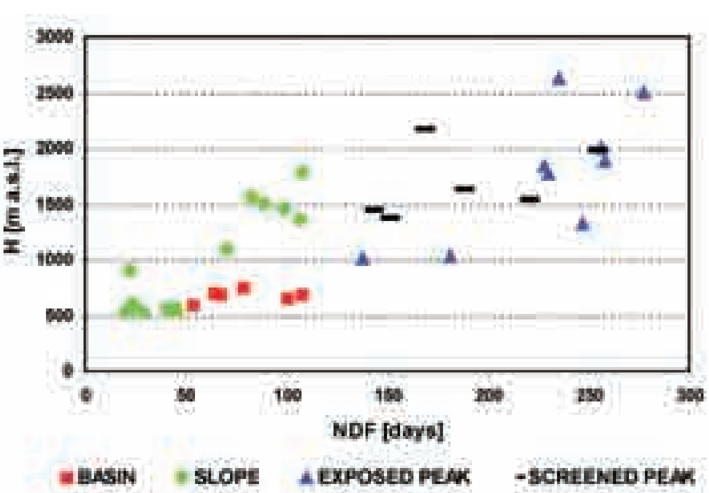


Figure 4. Annual fog frequency versus altitude with respect to landform category in the Carpathians.

category. The NDF varies in the range 20-108 and the lowest values in the whole database are observed in this category. This is the case at stations on the lower parts of slopes situated high enough above a valley bottom to extend beyond radiative fog, but lower than the level required for the orographic slope fog formed in ascending air. Above the last level, fog is only observed during circulation from selected sectors when a station is a windward one. Fog is not likely to form when an airmass comes from other directions and a descending airflow is observed. In any case, NDF correlates best with altitude in this category (Pearson's coefficient = 0.83).

ANNUAL VARIATIONS OF FOG FREQUENCY

Annual variation in NDF in the Carpathian stations may be grouped into 5 categories:

• Winter maximum frequency and summer minimum (below 1600-1700 m a.s.l., typical for convex landforms—Lysa Hora [14], Kekesteto [51] and Crni Vrh [36]; Figure 6, 8).

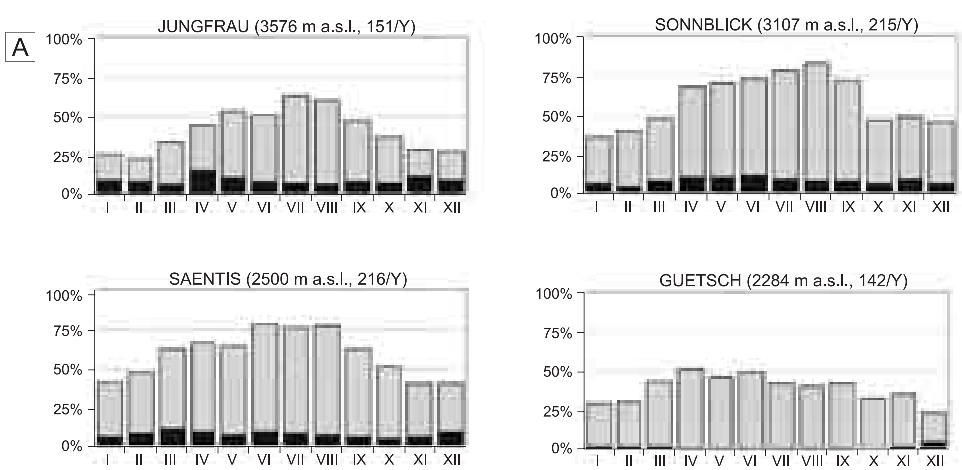
Such setting of extreme values is connected with air temperature changes during the year. In a cool half of a year thermal stability is predominant in the troposphere, and low-level clouds are formed. Such an annual distribution is also typical for slope position stations with the lowest NDF (Svermovo [86], Odorhei [87], Cimpulung [85], Hvedin [83], Dudulesti [81]; Figure 6, 7, 8). These are situated above the range of the radiation fog formed at the bottom of concave landforms while the base of frontal clouds seldom falls so low.

• Minimum in winter and maximum in summer (above 2300 m a.s.l.—Lomnicky Stit [18] and Omu [4]; Figure 6, 8). During the winter season such mountain stations are often higher than the low-level clouds typical during that part of year. The summer maximum of NDF in this group is caused by local thermal circulation up the warm slopes, which produces thick convective clouds with a base below mountaintops.

• Quasi-constant monthly frequencies (an intermediate zone at about 1800-2200 m a.s.l.—Chopok [10], Kasprowy Wierch [11]; Figure 6). In these cases the situation from the first and second categories compensate for each other in the annual cycle.

• August-October NDF maximum and March-May minimum (Miercurea Ciuc [65], Intorsura [79], Joseni [74], Petrosani [80] and Liesek [78]; Figs. 6, 7, 8). This corresponds to radiation fog, which is typical for concave landforms in the anticyclonic situations characteristic of the Carpathians, between August and October.

• Maximum frequency during spring and autumn (up to 1600-1700 m a.s.l.—Ceahlau [9], Lacaut [20], Rarau [24] and the Cozia Pass [34]; Figs. 7, 8). The double maximum



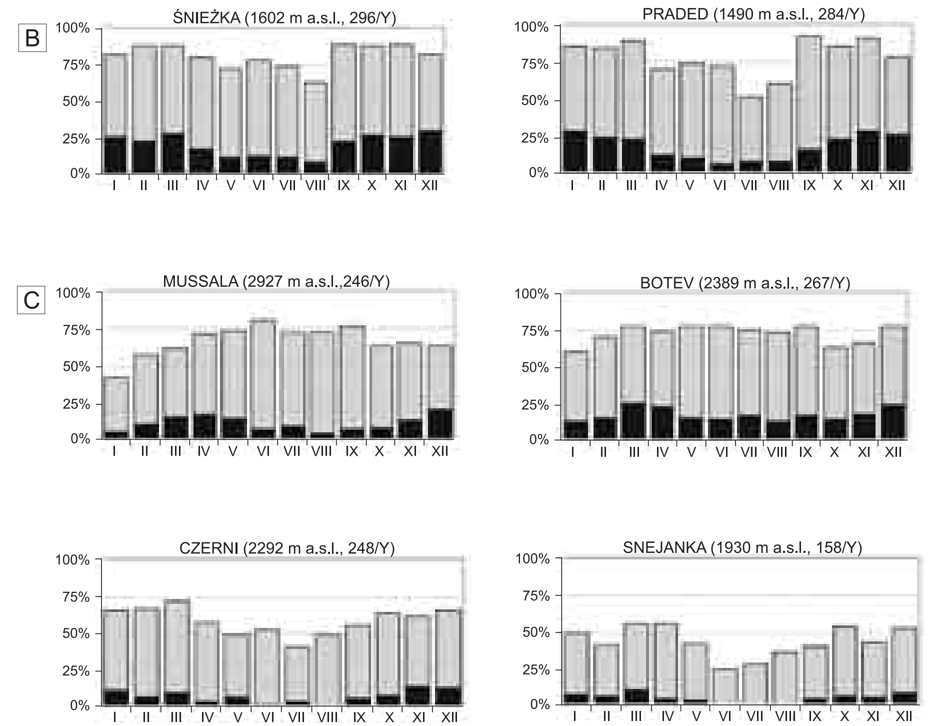


Figure 5. Annual variations of fog frequency (including contribution of whole-day fog—black bars) for selected stations in European massifs: A) Alps, B) European Hercynian Mts, C) Balkan Peninsula.

of fog frequency observed in the Eastern and Southern Carpathians occurs because of a more frequent seasonal cyclonic circulation of Mediterranean origin.

FOG IN ENVIRONMENTAL PROCESSES

Special attention in this study is paid to stations on convex landforms, at which orographic fog caused by the forced ascent of moist air occurs frequently. The analysed fog frequency can serve as an indicator of fog's potential importance in environmental processes. Direct fog-droplet deposition, called horizontal or fog precipitation, can make an important contribution to the hydrological input added to precipitation measured with standard raingauges (Ermich 1959; Ermich and Orlicz 1969, 1975; Ermich et al. 1967, 1972; Woźniak, 1984, 1991; Sobik and Migała 1993; Weathers et al. 1995;). Factors meteorological (fog frequency, wind speed, fog liquid water content) and morphological (relative height, type of landform) are responsible for the potential role of fog in total water flux. The type of land use (e.g., grass, forest and rock) conditions real fog deposition.

Chemical analyses confirm that fog samples are a few times more polluted than precipitation (Baron and Sobik 1995; Kmieć et al. 1995). This means that direct deposition of fog droplets onto vegetation can also make an important contribution to chemical input. At elevations higher than 800 m a.s.l. in the European Hercynian mountains, atmospheric deposition increases rapidly because of fog water input (Błaś 2001; Sobik et al. 1998). This is an important pathway by which

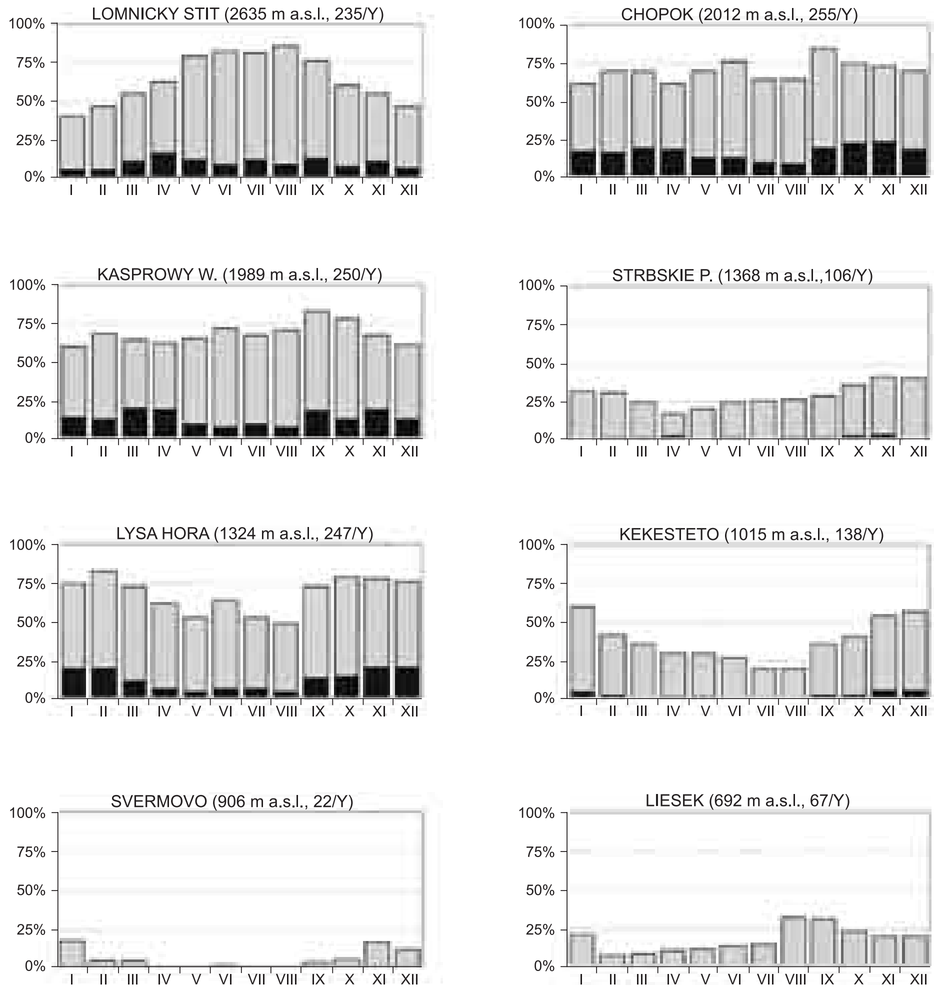


Figure 6. Annual variations of fog frequency (including contribution of whole-day fog—black bars) for selected stations in the Western Carpathians.

to explain the forest destruction observed especially in middle-sized mountains in Central Europe (the Sudetes, Ore Mts, Bohemian Forest, Harz, etc.).

Investigations indicate that the contribution of fog precipitation to total water flux and the pollutant deposition field show great spatial variability on the meso-, topo- and micro-scales. It is well known that, due to their long-range transport, atmospheric pollutants can affect distant regions even several hundred kilometres from pollution sources. This is partly the result of chemical liquid-phase transformations in clouds and water flux from the atmosphere to the ground in the form of precipitation, as well as of fog precipitation.

Leaving aside the role of the mountain barrier as a whole, some local effects in topoclimatic scale are also clearly visible. In mountainous terrain a substantial proportion of annual rainfall originates from orographic fog/cloud, due to the 'seeder-feeder' effect (Bergeron 1965). Measurements indicate that, in the Sudetes, as compared with the surrounding lowland, the 'seeder-feeder' ef-

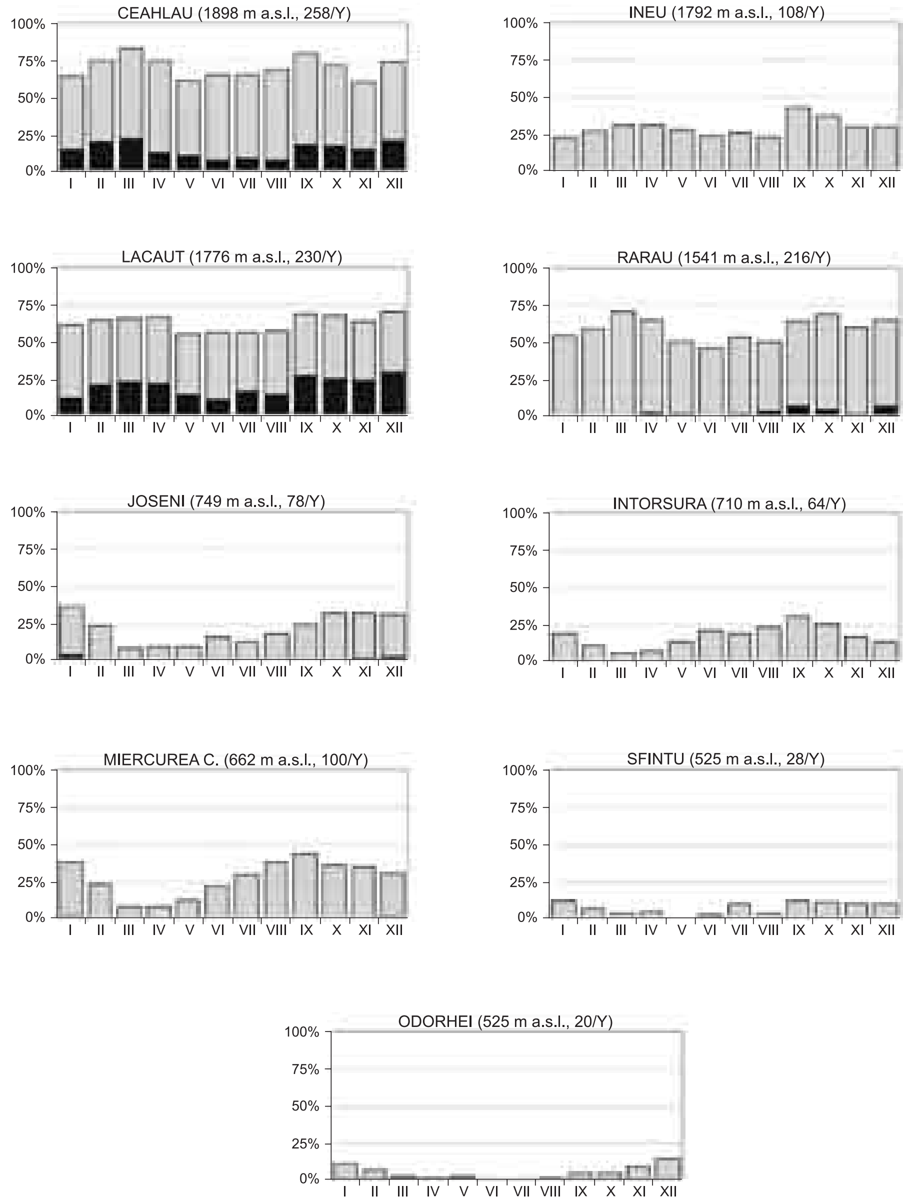
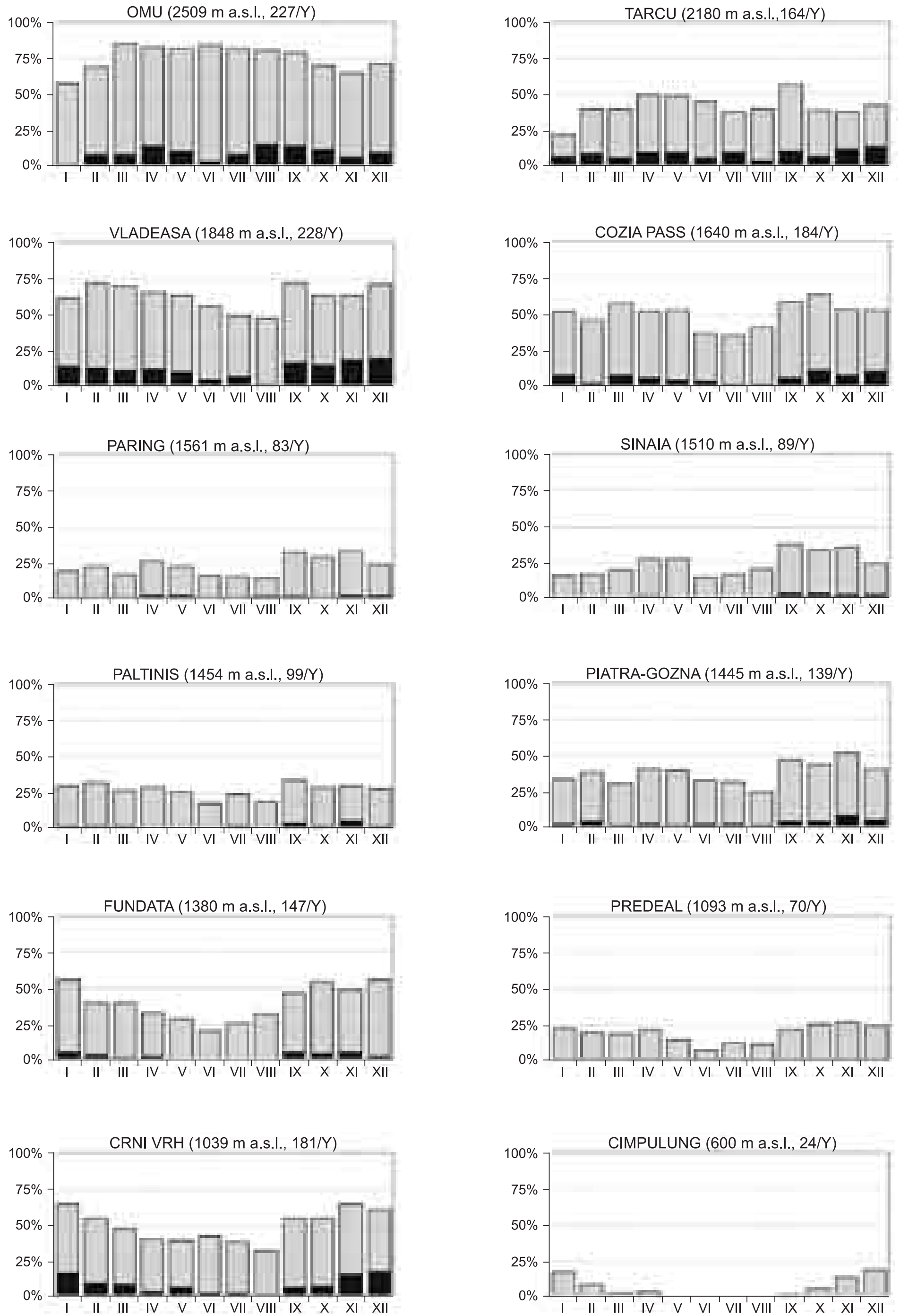


Figure 7. Annual variations of fog frequency (including contribution of whole-day fog—black bars) for selected stations in the Eastern Carpathians.

fect is typically accompanied by a doubling in rainfall enhancement and tripling of pollutant deposition (Dore et al. 1999).

Land use expressed by roughness is the most important factor responsible for the huge differentiation in fog precipitation and pollutant deposition on a local/micro scale (Błaś 2001; Lovett 1984; Lovett and Kinsman 1990; Lovett et al. 1982; Sobik et al. 1998; Weathers et al. 1995). The greatest throughfall is measured near an edge of a forest stand, with a steady decrease as one


OMU (2509 m a.s.l., 227/Y)
TARCU (2180 m a.s.l.,164/Y)
VLADEASA (1848 m a.s.l., 228/Y)
COZIA PASS (1640 m a.s.l., 184/Y)
PARING (1561 m a.s.l., 83/Y)
SINAIA (1510 m a.s.l., 89/Y)
PALTINIS (1454 m a.s.l., 99/Y)
PIATRA-GOZNA (1445 m a.s.l., 139/Y)
FUNDATA (1380 m a.s.l., 147/Y)
PREDEAL (1093 m a.s.l., 70/Y)
CRNI VRH (1039 m a.s.l., 181/Y)
CIMPULUNG (600 m a.s.l., 24/Y)
100%
75%
50%
25%
0%
I II III IV V VI VII VIII IX X XI XII

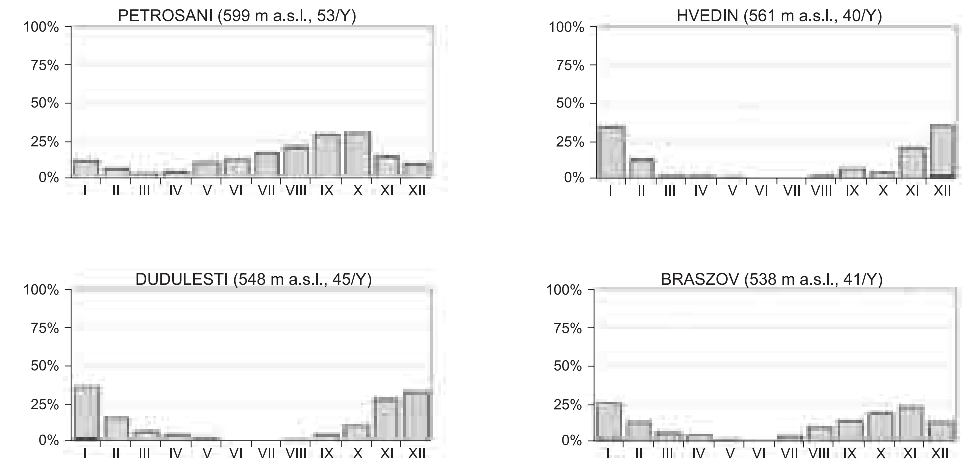


Figure 8. Annual variations of fog frequency (including contribution of whole-day fog – black bars) for selected stations in the Southern Carpathians.

passes inside the forest. This phenomenon is thus defined as on 'edge effect.' Trees on the edge of a forest stand are well exposed to the wind and may collect more fog water than trees inside the forest, which screen each other. The high value for throughfall at the edge of forest—due to the efficient capture of both cloud droplets and precipitation—is clear, when wind direction is consistent with the aspect of the edge of the forest. The efficiency of fog/cloud-droplet deposition varies in relation to the size and amplification of the receptor surface (rocks, grass, dwarf pine, forest). In mountainous areas, vegetation makes an important contribution to hydrological inputs, particularly in forested areas where the vegetation efficiently cleans out fog droplets. Taking height and surface area index (SAI) into consideration, the highest efficiency of horizontal precipitation is typical for spruce trees (Sobik et al. 1998; Zimmermann and Zimmermann 2002). In the Sudety mountains (were fog frequency exceeds 250 days year^{-1}), the role of fog precipitation in total water flux and pollutant wet deposition could be greater than the role of precipitation under the trees at the edge of a spruce forest stand well exposed to westerly circulation. The highest values of fog precipitation (over 2000 mm year^{-1}) were recorded at the edge of a forest stand in the Izerskie Mts (westernmost orographic barrier of the Sudetes), with values only around one-third as high 40-50 metres inside the forest (750 mm year^{-1}; Błaś 2001). These results obtained from mountainous areas situated relatively close to the area of interest indicate that similar phenomena may also apply to the Carpathians.

CONCLUSIONS

There are several controlling factors as regards the annual number of days with fog (NDF). The predominant one is altitude particularly in case of convex landforms. The second important factor influencing NDF is station location relative to circulation patterns and distance from the sea. NDF also depends on terrain morphology at a given station site and in its wider neighbourhood, relative height, island-mountain morphology and position on the windward or leeward side of a larger massif.

Special attention in this study is also paid to stations on convex landforms where orographic fog caused by the forced ascent of moist air occurs frequently. The analysed fog frequency can serve as an indicator of fog's potential importance in environmental processes.

REFERENCES

Baron H. and Sobik M., 1995, *Rola osadów atmosferycznych w zakwaszaniu środowiska przyrodniczego wierzchowiny Karkonoszy* (The function of precipitation in acidifacation of upper parts of the Karkonosze Mts) (English sumary), Acta Universitas Wratislavensis, Prace Instytutu Geograficznego, Seria C. Meteorologia i Klimatologia II, 1705, 59-73.

Bergeron T., 1965, *On the low-level redistribution of atmospheric water caused by orography*, Proceedings of the International Conference on Cloud Physics, Tokyo, May 1965, 96-100.

Błaś M. and Sobik M., 2000, *Mgła w Karkonoszach i wybranych masywach góskich Europy* (Fog in Giant Mts and selected European massifs) (English summary), Opera Corcontica, 2000, 35-46.

Błaś M., 2001, *Rola mgły w przychodzie wody i mokrej depozycji zanieczyszczeń w Sudetach* (The role of fog in water flux and wet deposition of pollutants in the Sudetes), unpublished Ph.D. Thesis, University of Wrocław.

Dore A.J., Sobik M. and Migała K., 1999, *Patterns of precipitation and pollutant deposition by rain and snow in the western Sudete Mountains, Poland*, Atmospheric Environment, 33, 3301-3312.

Ermich K., 1959, *Metody badań nad osadami z mgły w lasach górskich* (Methods of research on horizontal precipitation in montane forests), Ekologia Polska, B, 5 (4), 313-322.

Ermich K., Bednarz Z. and Feliksik E., 1967, *Wstępne badania nad osadami z mgły w Karpackim obszarze leśnym* (Preliminary results of studies on horizontal precipitation in Carpathian forested area), Problemy Zagospodarowania Ziem Górskich, 3 (16), 123-142.

Ermich K., Bednarz Z. and Feliksik E., 1972, *Badania nad ilością osadów z mgły w Beskidzie Małym, Sądeckim i w Gorcach* (Studies on volume of horizontal precipitation in Beskid Mały Mts, Beskid Sądecki Mts and Gorce Mts), Problemy Zagospodarowania Ziem Górskich, 10, 173-193.

Ermich K. and Orlicz M., 1969, *Ilości wody dostarczane przez osady z mgły na Kasprowym Wierchu w Tatrach* (Volume of horizontal precipitation on Kasprowy Wierch Mt. in the Tatra Mts), Problemy Zagospodarowania Ziem Górskich, 5, 155-182.

Ermich K., and Orlicz M., 1975, *Osady mgielne na Kasprowym Wierchu w Tatrach* (Horizontal precipitation on Kasprowy Wierch in the Tatra Mts), Problemy Zagospodarowania Ziem Górskich, 14, 81-115.

Hess M., 1965, Mgła (Fog), [in:] *Piętra klimatyczne w Polskich Karpatach Zachodnich* (Vertical climatic zones in the Polish Western Carpathians), Zeszyty Naukowe UJ, Prace Geograficzne, 11, 195-198.

Kmieć G., Kacperczyk K., Zwoździak A. and Zwoździak J., 1995, *Acid pollutants in air and precipitation/deposition in the Sudeten Mountains*, Poland, Water, Air and Soil Pollution, 85, 2131-2136.

Lovett G.M., 1984, *Rates and mechanisms of cloud water deposition to a subalpine balsam fir forest*, Atmospheric Environment, 18, 361-371.

Lovett G.M. and Kinsman J., 1990, *Atmospheric deposition to high-elevation systems*, Atmospheric Environment, 24, 2767-2786.

Lovett G.M., Reiners W.A. and Olson R.K., 1982, *Cloud droplet deposition in subalpine balsam fir forest: hydrological and chemical inputs*, Reprint Series, 218, 1303-1304.

NCDC, 2000, *Global Daily Summary*, National Climatic Data Center, http://www.ncdc.noaa.gov./

Sobik M. and Migała K., 1993, *The role of cloudwater and fog deposits on the water budget in the Karkonosze (Giant) Mountains*, Alpex regional Bulletin, Swiss Meteorological Institute, 21, 13-15.

Sobik M., Błaś M. and Quiel F., 1998, *Udział osadów mgielnych w przychodzie wody z atmosfery i depozycji zanieczyszczeń w lasach Sudetów Zachodnich* (Contribution of fog precipitation in water flux and pollutant deposition in montane ecosystems, Western Sudetes, Poland), (English sumary), [in:]Geologiczne Problemy Karkonoszy

(Geoecological problems of the Karkonosze Mountains), Proceedings of scientific session, 15-18.X.1997, Poznań, 151-162.

Wallen C.C., 1977, *Climates of Central and Southern Europe*, [in:] Landsberg H.E., (ed.), *World survey of climatology*, Volume 6, World Meteorological Organization, Geneva.

Weathers K.C., Lovett G.M. and Likens G.E., 1995, *Cloud deposition to a spruce forest edge*, Atmospheric Environment, 29(6), 665-672.

Woźniak Z., 1984, *Metoda wyznaczania przychodu wody z mgły w górskiej zlewni zalesionej* (A method of estimation of water flux from fog into a forested montane catchment), unpublished Ph.D. Thesis, Institute of Meteorology and Water Management, Wrocław-Warszawa.

Woźniak Z., 1991, *Osady z mgły w Sudetach (znaczenie osadów i sposób pomiaru przychodu wody z mgły)* (Horizontal precipitation from fog in the Sudetes: the role of horizontal precipitation and measurement methods), Prace Krakowskiego Towarzystwa Naukowego, 53, 24-34.

Zimmermann L. and Zimmermann F., 2002, *Fog deposition to Norway Spruce stands at high-elevation sites in the Eastern Erzgebirge (Germany)*, Journal of Hydrology, 256, 166-175.

Received: March 2003
Revised: October 2003

GEOGRAPHIA POLONICA, 77, 1, 35–44, Spring 2004
PL ISSN 0016–7282

ENERGY EXCHANGE IN AN ACTIVE LAYER IN THE KOCIOŁ KASPROWY (TATRA MOUNTAINS)

JAROSŁAW BARANOWSKI
Institute of Geography and Spatial Organization, Polish Academy of Sciences,
Twarda 51/55, 00-818, Warszawa, Poland
E-mail: j.bar@twarda.pan.pl

Abstract: The studies were done between 8th and 20th August 1998, in an area extending between 1820 and 1880 m a.s.l. (located in the altitudinal zone of alpine vegetation). The study location named Kocioł Kasprowy is the corrie on the upper part of the slope. The magnitude of the heat flux in the active layer was measured with a heat flux sensor of diameter 5 cm, placed on special stands close to the soil surface. The research showed that factors other than incident solar radiation having a major influence on the size of the energy flux flowing through the active layer are site exposure and inclination. The work confirmed that the frequency of occurrence and amount of precipitation influences energy conductivity in soil markedly, and hence also the size of the heat flux.

Key words: Tatra Mountains, heat flux, active layer.

INTRODUCTION

Physical features of the substratum, relief, vegetation cover, water relations and soil type all generate climatic differentiation on the local scale, shaping the exchange of heat between the active surface and the atmosphere. The atmosphere layer near ground is generated by the upper part of plant and soil matter, while heat exchange is achieved in the active layer comprising the near-ground air layer, the biosphere and the anthroposphere (Paszyński et al. 1999). The active layer plays host to a vertical flow of energy by way of radiation, turbulence, phase transitions of water, the molecular conductivity of heat and photosynthesis. Of great significance to the development of plants is the spectral range of solar radiation. The infra-red represents c. 45-50% of global solar radiation, the visible 45%, and the ultra-violet only 5-9%. However, it is the latter, especially UV-A and UV-B (at 0.28-0.4 μm) that are the most active biologically (Kozłowska-Szczęsna and Błażejczyk 1998). The development of plants is very much conditioned by the retention of an energy equilibrium. Short-wave radiation is subject to the greatest diffusion, such that electromagnetic radiation of wavelengths below 280 nm does not reach the Earth's surface. In mountains, where the atmospheric layer is thinner than in the lowlands, a greater proportion of the short-wave (ultra-violet and blue-light) radiation does get through. Furthermore, in a geographical environment like the Tatra Mountains which has a high degree of naturalness, any quantitative determination of the heat flux in the active layer with a certain type of vegetation cover allows for an insight into the exchange of energy under different plant associations. Familiarity with the energy exchange, as well as the physical and thermal properties of the substratum, relief and energetic requirements of plants, are prerequisites if the linkage between plants and the other elements of the natural environment is to be better understood.

It is under the influence of such a diverse active surface that the exchange of energy is shaped. The literature includes many publications dealing with the impact of different types of active surfaces on the heat balance (Ajzenštat 1967, Borzenkowa 1967, Kostin 1970). One of the factors which influences the structure of the heat balance is the heat flux flowed through the active layer. Studies have been done on the heat flux since the mid 20th century, though an intensification of study followed the introduction of heat flux sensors as a means of measurement in the active layer and an alternative to indirect methods. The main centres involved themselves in such work have been in Western Europe and the USA, with the more relevant publications in the field being Halliwell and Rouse (1987), Gerhardt (1957), Monteith (1958), Miller (1981), Kilmer (1982), Oke (1978), Philip (1961) and many others.

The aim of the study described here has been to determine the size of the heat flux passing through the active layer, and the relationship between the flux magnitude and the type of vegetation cover; as well as to identity of the main factors conditioning energy exchange in the study area.

The research concerning heat flux is being done mainly in the ground. There are not many articles describing this subject of active layer.

CHARACTERISTICS OF THE STUDY AREA

The studies were done between 8th and 20th August 1998, in an area extending between 1820 and 1880 m a.s.l. (thus located in the altitudinal zone of alpine vegetation, Figure 1). The study location named Kocioł Kasprowy is the corrie on the upper part of the slope.

Measurements were made on south-east and north-east facing slopes, with the soils present thereupon being classed as mineral, carbonate-free and weakly-developed, i.e., in the initial stage of development. The firm rocky substratum is overlain by organic matter weakly combined with rock waste that has mainly arisen through weathering. The colour of the soil is black-brown (Degórski 1999), reflecting the considerable accumulation of organic matter in the face of the very slow processes of humification and mineralization. The soil organic matter content was found to vary between 30% on the upper parts of slopes and 50% in the lower parts. Soils are in the main cryogenic (lithosols) soils or typical rankers, with the former supporting a mossy form of *Oreochlo distichae-Juncetum* alpine grassland, or else the wood-rush *Luzula spadicea*, as well as a moist grassland community *Luzuletum Spadiceae* and an association with reedgrass *Calamagrostietotum villosae tatricum*. The cryogenic soils are most often present where there is enhanced erosion of all kinds, and are characterized by a marked dynamic of contemporary soil processes. Podsolic rankers are in turn the soils on which an association with bilberry *Vaccinietum myrtilli* is present, or else a further variant of the aforementioned alpine grassland *Oreochlo distichae-Juncetum trifidi typicum*, in the form with *Vaccinium myrtillus.*

A CHARACTERISATION OF WEATHER CONDITIONS DURING THE MEASUREMENT PERIOD

The weather in the measurement period was characterized by a quiet high pressure system area with mean daily air temperature of 11.0°C in the Kocioł Kasprowy and 10.9°C on the Kasprowy Wierch summit. The mean level of cloud cover was 50%, varying between 45% in the morning and 70% at midday (with the main cloud types being Cu and Cb convection clouds, as well as Ci clouds).

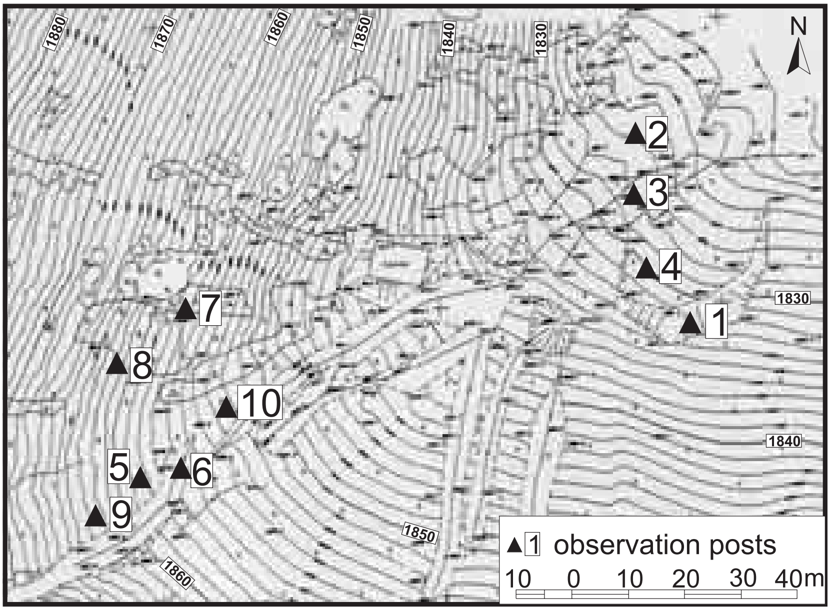


Figure 1. Location of points for the measurement of heat exchange in the active layer
Profile A: Lower part of the Kasprowy Corrie: 1—'stony' site, 2—'gully' site I, 3—'bank' site, 4—'moss' site. Profile B: Upper part of the Kasprowy Corrie: 5—'flattening' site, 6—'gully' site II, 7—'bilberry' site, 8—'rush' site, 9—'woodrush' site, 10—'snow bed' site.

There were only 5 days with precipitation during the period, including 3 on which rain fell in trace quantities of less than 1 mm. August 13th was characterized by a precipitation of 7.0 mm, and August 18th by 3.1 mm. Relative air humidity varied between 40 and 90%. The wind speeds noted over short periods did not normally exceed 3 ms^{-1} and only being greater occasionally (attaining 7 ms^{-1} on August 9th and 13th).

MEASUREMENTS

The magnitude of the heat flux in the active layer was measured with a heat flux sensor of diameter 5 cm, placed on special stands close to the soil surface. The sensor plate was aligned with the slope in such a way that its lower surface was just above the soil, while the upper one was situated in the root zone. In the case of measuring points from which vegetation cover was absent, or at which it was very limited, the upper part of the sensor remained uncover. The influx of energy to the upper side of the sensor plate was associated with the solar and thermal radiation of the atmosphere, as modified by plant cover (and the type, density and height thereof). The influx of energy from below in turn depended on the thermal conductivity of the soil, as related to its structure, thickness and formation. The variable density of the heat flux is proportional to the difference in potentials generated by the thermopile, as a result of differences between the upper and lower plate surfaces.

Measurements of the energy flux in the active layer were made automatically over 24-hour periods in two profiles (A and B) in the lower and upper parts of the Kocioł Kasprowy. In total, ten measuring points were put in place. The period of field research also coincided with operations at two meteorological stations, in the Kocioł Kasprowy and Hala Gąsienicowa clearing, at which air temperature, wind speed and solar radiation were measured. Cloud cover, the state of the solar disc and wind direction were also noted. The locations of measuring points and profiles are presented in Figure 1.

RESULTS

Analysis of materials collected in the course of fieldwork indicates that the main factors conditioning the heat flux density in the active layer at the different sites—apart from meteorological conditions—are the exposure and gradient of the slope and the vegetation cover.

The south-east-facing Profile B had totals for the daily heat flux (at between 200 KJ m^{-2} and 5000 KJ m^{-2}) that were greater than in the north-east-facing Profile A (where values ranged from 100 KJ m^{-2} to 2500 KJ m^{-2}).

The highest daily sums of the heat flux in Profile A were those observed at a point situated on the 'stony' scree-slope (Figure 2). This reflected the physical properties of the rock of this substratum, which was heated relatively rapidly and characterized by effective conductivity of thermal energy. The other points on Profile A had total values for the 24-hour heat flux in the range 0 to 800 KJ m^{-2}, though they tended to be rather higher on overcast days at the 'bank' site, and on cloud free days at the 'gully I' site. This phenomenon was probably associated with the type of active layer. Although the points were separated by the

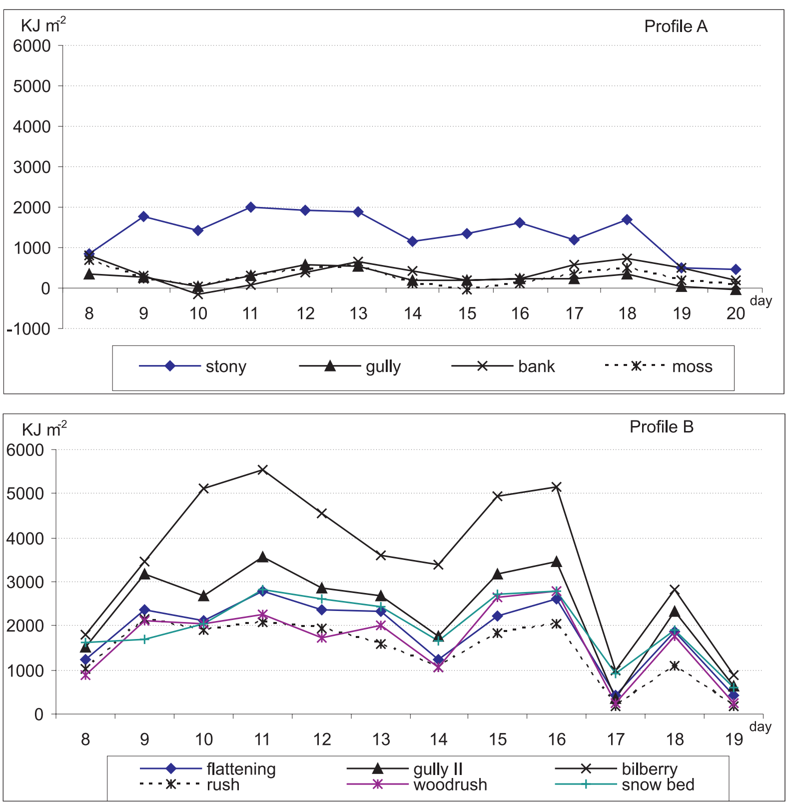


Figure 2. 24-hours totals of heat flux inside active layer at several days of August 1998.

maximum distance (of 7 m), the ‘gully’ I site was overgrown with dense grass, while the underlying substratum had a limited amount of litter to serve as an insulator for the flux of heat flowing up from below. The ‘bank’ site was characterized by a surface that was formed from fine rubble and gravel, and free of vegetation, what allowed a large amount of energy from the atmosphere to reach the land surface.

The highest observed 24-hour totals of the heat flux along Profile B were those of the bilberry community on a 30° south-east facing slope. This site had favourable solar conditions, as reflected in the high values for the 24-hour heat flux as well as the plant species present. Alongside a low (20 cm) scrub of bilberry there was a dryness- and warmth-loving grassy vegetation of the *Oreochloo distichae-Juncetum trifidi* association. On cloud-free, the daily sums of heat flux was of as much as 5500 KJ m^{-2} as compared to between 1000 and 3000 KJ m^{-2} on overcast days.

A somewhat lower value for the 24-hour heat flux was measured on the fresh erosive surface (at the ‘gully’ II site) which characterized a 25° north-east-facing slope. Values attained on clear days were of 3000 KJ m^{-2}, while those of overcast days were of 1000 KJ m^{-2}. There were thus no more major differences to be associated with cloudiness, as was the case with Profile A. The lack of a vegetation cover did, however, increase the intensity of the heat flux penetrating the active layer—especially on clear and calm days.

The lowest daily sums of the heat flux on clear days was reported from the SE-facing slope overgrown with three-leaved rush, as well as the slope site of NE exposure featuring *Luzula spadicea*. Very similar values were obtained for the grassy ‘snow bed’ and within the soil on the small level area of the NE-facing slope characterized by soil creep (the ‘flattening’ site). The differences in 24-hour energy totals reported for the active layer on cloud-free and overcast days were limited (of 1000 KJ m^{-2}).

The very similar 24-hour values noted from the ‘flattening’, *Luzula* and ‘snow bed’ sites reflect the similar exposure, and hence similar insulation conditions. Furthermore, the greater soil moisture at these points (as compared with the bilberry patch and fresh erosion surface), increased the thermal conductivity on the slope, and hence the density of the flux from the substratum. With greater soil moisture, thermal conductivity increases, but only to a certain threshold value, above which any greater degree of humidity has no impact on conductivity (Adamenko 1979 after Paszyński et al. 1994)

The limited variability of the daily sums of the heat flux—as observed at all measuring points in the final study period (17-19 August) were caused by a high level of cloud cover (80-100%), which limited the influx of direct solar radiation.

In analyzing 24-hour course of the heat flux in the active layer it is necessary to bear in mind its short-term density and the direction of flow. In general, during a day the heat flux incoming mainly from solar radiation is being transferred via the active layer into the soil. The reverse situation applies at night; as the heat flux is directed from the deeper soil layers towards the active layer, and then through that layer, from which it radiates out into the atmosphere. This is mainly dependent on radiative relationships—of which the role in overall net radiation is considerable—being capable of accounting for about 50% of the total (Skoczek 1994).

On Profile A, the maximum 24-hour heat flux density was present around 13.00, as the Sun was at its highest point. For the stony and grassy sites it was then of 100-130 W m^{-2}. Elsewhere the values attained were of between 10 and 40 W m^{-2}. Figure 3 presents the hourly totals for the heat flux on a cloud-free day (11.8.1998) and a overcast one (19.8.1998). On Profile A, sunny days were associated with values of as large as 50 to 500 KJ m^{-2}, while overcast days had maxima in the range 0 to 300 KJ m^{-2}.

On Profile B, the maximum 24-hour heat flux density was characteristic of the hours 10.00-11.00, though there were sometimes (rather lower) secondary maxima at 13.00.The flux density was greater by some 150 W m^{-2} than that measured along Profile

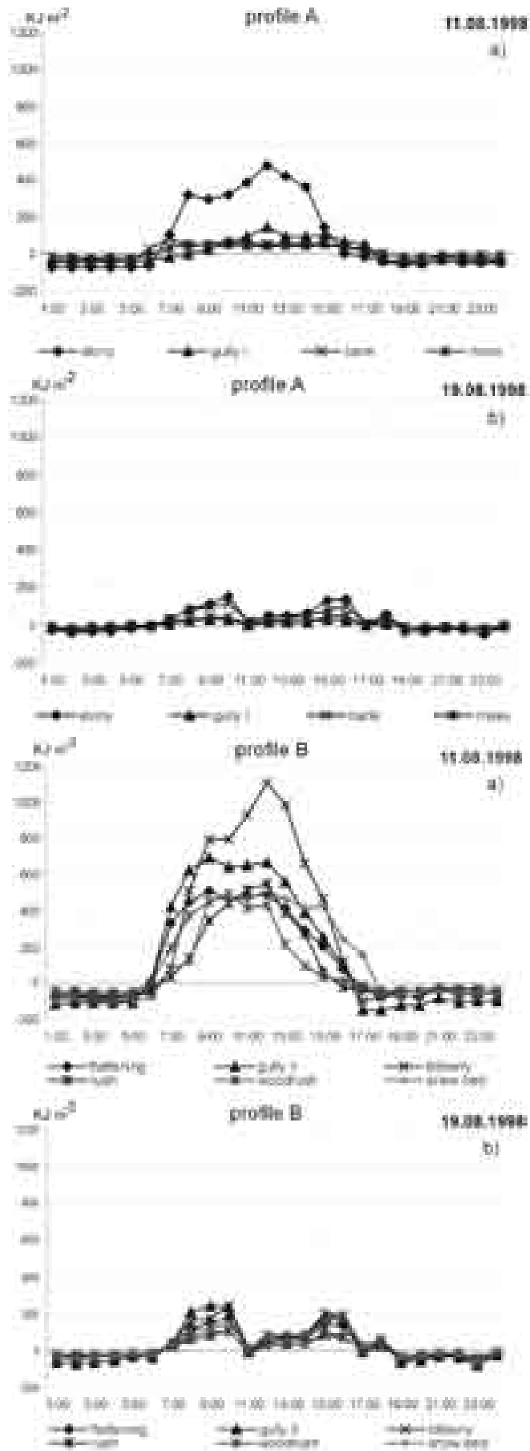


Figure 3. Hourly totals of heat flux during sunny (a) and cloudy (b) days.

A, on account of the favourable solar conditions. The first maximum resulted from the situation of the measurement points on the east- and south-east-facing slope, as around 11.00 the angle of the incident rays of the sun in relation to the incline of the slope was of almost 90°. The second maximum coincided with the Sun's attainment of its highest elevation in the sky. On overcast days there was no distinct 24-hour maximum in the heat flux density, with the maximum value achieved being of approximately 400 W m^{-2} (Figure 4). In contrast, on clear days the overall intensity of solar radiation with the sun at its highest was of 1000 W m^{-2}.

ferent sites on the two profiles. Bearing in mind the hourly heat-flux totals for the two profiles, the differences were small (of 0-10 KJ m^{-2}). At clear, dry nights the differences could be of as much as 100 KJ m^{-2}.

Figure 5 presents the moment at which the heat flux changes direction in relation to the active layer, beginning to penetrate into the soil. The bars marked on the diagram show the periods during which the heat flux was directed from the active surface towards the soil. Also marked are the times at which the change in the direction of the flow occurred in the morning and evening. The course noted for these points in the

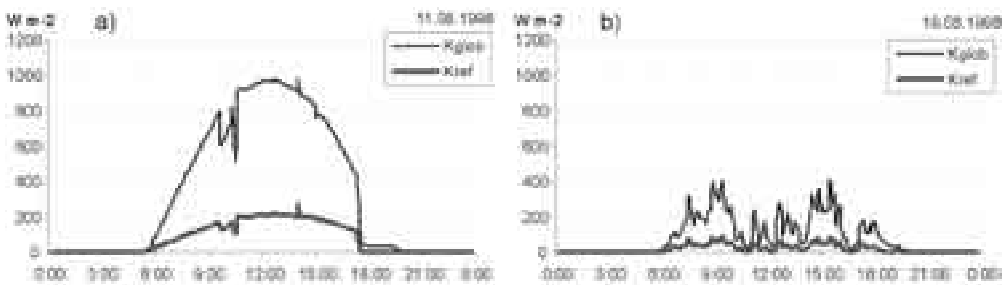


Figure 4. Daily course of global solar radiation and reflected solar radiation during sunny (a) and cloudy (b) days.

The highest heat flux densities observed for the active layer were those characteristic of the 'bilberry' site between August 9th and 11th; at which time the midday values were in the range c. 250-300 W m^{-2}. Rather lower values (around 220 W m^{-2}) were measured in the fresh erosive surface (the 'gully' II site).

Both Profiles A and B had totals for the hourly heat flux assuming positive values in the day and negative ones at night. An exception to this rule was provided by the 24-hour courses of radiation sums at the 'moss' site on Profile A. There, on 12, 13 and 18 August 1998, the positive values noted on the latter two dates were the result of rainfall that had taken place during the day (7 mm fell on 13 August, 3.1 mm on 18th). These days were also characterized by much more limited differences in heat flux values between different sites on the two profiles.

diagram allow it to be determined that the penetration of energy into the soil began at a different time at each of the sites. On Profile A such an event took place between 05.20 and 07.30; while the positive flux ended before 18.00, though was dependent on the type of weather and of substratum. The change in direction happened much earlier on clear than overcast days, while the situation was the reverse in the evening, with cloud-free days seeing a much earlier onset of the soil's release of heat to the atmosphere. For example, on August 11th the surface overgrown with bilberry was characterized by a change in the value of the heat flux from negative to positive around 06:00, while the change in the reverse direction happened at 15.45. On the overcast 17th August, in contrast, the morning transition via zero to a positive

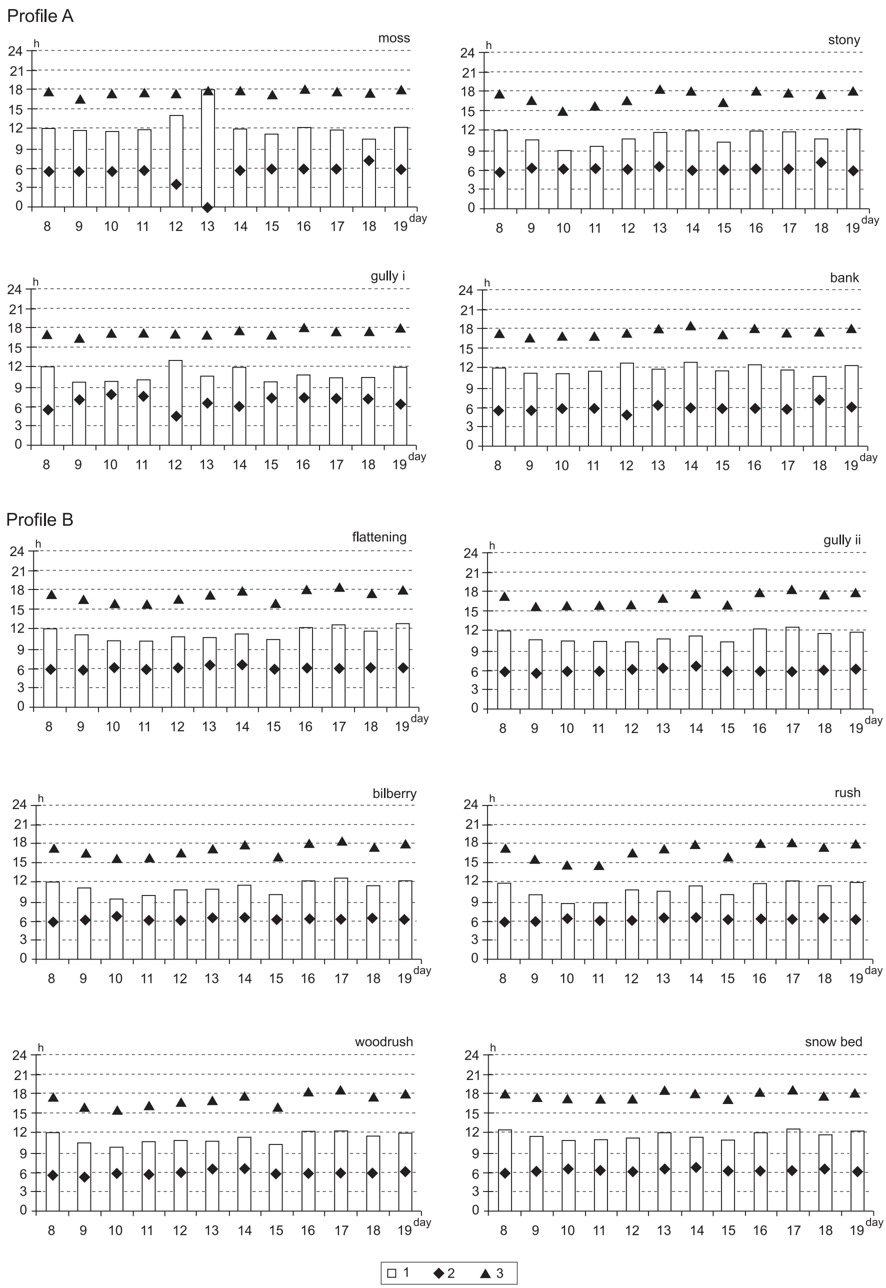


Figure 5. Characteristic of heat flux inside active layer several measurement point in the period 8-11 August 1998.
1—total time of positive heat flux
2—the time of the changes of heat flux in the morning
3—the time of the changes of heat flux in the evening

value took place at 05.55, while the evening switchover came as late as at 18.25. Such differences are of major significance for all processes ongoing in the active layer which use heat energy. The earliest warming of the substratum began on the 'bank' surface of fine gravel and rubble, as well as on that overgrown by a think carpet of dense moss. The latest change of direction to a positive flux was noted at the bottom of the erosive gully, while the earliest change back to the negative (entailing the release of heat from the soil) occurred on the 'stony' scree-slope, and the latest at the 'moss' site. The longest-lasting transfer of energy from the surface into the active layer was thus characteristic of the 'moss' site, and the shortest of the aforementioned erosive gully heavily overgrown with grass, but also featuring stones. The mean duration of a positive-value flux was 12h 24' at the 'moss' site, and 10h 47' at 'gully' I, reflecting a maximal difference of approximately 1.5 hours.

On Profile B, positive heat flux values were noted between 06.00 and 18.00 on average, albeit with the earliest being characteristic of the fresh erosion surface (the 'gully' II site), and the latest among the bilberry on the grassy 'snow bed'. The shortest duration for a heat flux to the substratum was the 10h 45' noted at the site overgrown with *Juncus trifidus*, and the longest the 11h 34' at the grassy 'snow bed'. The evening change of direction of the flux from positive to negative occurred earliest at the 'rush' site (on average at 17.01 during the study period). The corresponding time at the 'snow bed' came at 17.45.

Bearing in mind the period of energy absorption by the substratum, it was possible to note large differences between different days at different study sites. These mainly reflected differing weather conditions. The mean duration of the energy absorption (when the ground surface absorbs the solar radiation) was shorter at most sites on clear days than on overcast ones. This is a result of the fact that the considerable heating of a rather dry substratum is followed by a rapid re-release of energy to the atmosphere as soon as the inflow of direct sunlight ceases. As a consequence the longest period of the transfer of energy into the soil was noted on overcast days following rain, as was observed at most points on Profile A on August 13th and 14th. Greater soil moisture induced by rainfall in those days created good conditions for the penetration of heat into that soil. On Profile B, the shortest time over which the flux assumed positive values was observed on August 10th and 11th, sunny days with limited cloud cover. In turn, the longest period of heating of the active layer over 24 hours was to be seen at most of the sites during the overcast days of August 16, 17 and 19 (August 18th and 19th had rain). When days with the longest period of positive heat-flux values are considered, the difference between Profiles A and B is seen to reflect the differing nature of the substratum and variability in plant cover. The measuring sites on Profile A had tall grassy vegetation, stony ground or moss, while Profile B sites mainly had substrata supporting dry-loving vegetation, thereby attesting to the lesser soil moisture and less favourable water retention capacity. Of greater importance than rainfall in this case was the longer period of cloudy weather, with a limited influx of solar radiation.

CONCLUSIONS

Analysis of heat exchange in the active layer of the Kocioł Kasprowy in the Tatra Mountains—as based on the results of direct measurement of heat flux density—pointed to the considerable variation of this aspect in relation to soil conditions, topography, plant cover and atmospheric conditions.

The research showed that factors other than incident solar radiation having a major influence on the size of the energy flux flowing through the active layer are site exposure and inclination. The work also confirmed that the frequency of occurrence and amount of precipitation influences energy conductivity in soil markedly, and hence also the size of the heat flux.

On the small study site around the Kasprowy Wierch summit, there were marked differences in energy balance, manifesting themselves in the different values for the heat flux passing through the active layer. This attests to a close interdependence between components of the environment and energy conditions in the active layer. The amount of the heat flux also depends on the thickness of the active layer itself. In the case of plant communities with a well-developed root zone and limited moisture there is a hindering of the flow of energy through the layer. The air there serves as an insulator for the heat flux. Much greater spatial differentiation of the heat flux was observed during clear days than overcast ones. Moreover, the direction to the flow of energy was dependent, not only weather conditions, but also on the type of vegetation and soil moisture.

REFERENCES:

Ajzenštat B.A., 1967, *Teplovoj balans i mikroklimat vlaznych gornych dolin* (Heat balance and microclimate of wet mountain valleys), SANIGMI, Trudy GGO (Glawnaja Geofiziczeskaja Obserwatoria), 35/50, Leningrad.

Borzenkova I.I., 1967, *Nekotorye osobennosti teplovogo balansa v rajone juznogo sklona Zangezurskogo chrebta* (Some features of heat balance of the south slope of Zangezursky ridge), Trudy GGO (Glawnaja Geofiziczeskaja Obserwatoria), 193 Leningrad, 47-52.

Degórski M., 1999, *Zróżnicowanie pokrywy glebowej pięter wysokogórskich w bezwęglanowych rejonach Tatr Polskich* (Differentiation of soil cover in high-mountain zones of the non-carbonate areas of Poland's Tatra Mountains), Prace Geograficzne, 174, 25-36.

Halliwell D.H. and Rouse W.R., 1987, *Soil heat flux in permafrost characteristics and accuracy of measurement,* Journal of Climatology, Royal Society of Meteorology, 7, 6, November, December, 1-14.

Kilmer V.J., 1982, *Handbook of soils and climate in agriculture,* CRC Press Inc., Boca Raton, Florida, 445 p.

Kostin S.I., 1970, *Radiacionnyj, teplovoj i vodnyj balans pocvenno-rostitelnych provincji centralno-cernozemnoj polosy* (Radiation, heat and water balances of the central tchernozem region), Trudy GGO (Glawnaja Geofiziczeskaja Obserwatoria), 263 Leningrad, 89-106.

Kozłowska-Szczęsna T. and Błażejczyk K., 1998, *Promieniowanie słoneczne i jego wpływ na organizm człowieka* (The influence of solar radiation on a human organism), Balneologia Polska, tom 40, 1-2, 130-141.

Miller D.H., 1981, *Energy at the surface of the Earth,* Academic Press, New York, London, Sydney, San Francisco, 516 p.

Monteith J.L., 1958, *The heat balance of soil beneath crops*, Arid Zone Research, Climatology and Microclimatology, Proceedings Canberra Symposium, UNESCO, 123-128.

Oke T.R., 1987, *Boundary layer climates*, Methuen, London and New York, 435 p.

Paszyński J., Konstantinova T.S., Boloban J. and Krawczyk B., 1994, *Przestrzenna i czasowa zmienność składników bilansu cieplnego w terenie o pagórkowatej rzeźbie* (Spatial and temporal variations of the components of a heat balance in a hilly area), Zeszyty IGiPZ PAN, 26, 5-19.

Philip J.R., 1961, *The theory of heat flux meters*, Journal of Geophysical Research, 66, 2, 571-579.

Skoczek J., 1994, *Struktura bilansu cieplnego powierzchni pola czarnoziemu (na przykładzie Mołdawii)* (The structure of haplic chernozem heat balance (a case study of Moldova), Zeszyty IGiPZ PAN, 26, 21-40.

Received: April 2003
Revised: September 2003

GEOGRAPHIA POLONICA, 77, 1, 45–61, Spring 2004
PL ISSN 0016–7282

THE MAIN FEATURES OF BIOCLIMATIC CONDITIONS AT POLISH HEALTH RESORTS

TERESA KOZŁOWSKA-SZCZĘSNA, BARBARA KRAWCZYK
and KRZYSZTOF BŁAŻEJCZYK
Institute of Geography and Spatial Organization, Polish Academy of Sciences,
Twarda 51/55, 00-818, Warszawa, Poland
E-mail: klimat@twarda.pan.pl, b.kraw@twarda.pan.pl,
k.blaz@twarda.pan.pl

Abstract: Climate-related treatment is one form of therapy at health resorts that bases itself around the use of natural climatic attributes. In the light of this, the aim of the present studies has been to analyse the bioclimatic conditions at different Polish health resorts, with a view to the available curative resources of the climate being determined, along with the opportunities for the different forms of climatotherapy to be taken advantage of.

Key words: bioclimate, climatotherapy, health resorts, Poland.

INTRODUCTION*

Health-resort treatment resembles all of medicine in being in essence a product of the period from the Renaissance onwards. The author of the first work on spas to be published in Poland was thus Wojciech Oczko (1537-1600), Court Physician to King Stefan Batory, who has been dubbed the father of Polish balneology. Nevertheless, the first traces of the use of mineral waters—obtained from Western Poland—extend back into prehistory. Thus wooden water intakes from springs have been found in Szczawno (Sudetes). In the Mediaeval period (12th century) the curative properties of water were known in Cieplice Śląskie and Lądek (Sudetes). In the 16th century the next 11 spas were established. The period 1921-1938 saw 36 health resorts of different kinds operating in Poland (Leszczycki 1939). As of today there are 43 health resorts in Poland constituted by law (Figure 1), along with several other localities that have the necessary resources and environmental attributes to sustain engagement in curative and recreational activity.

The aim of the present study is to characterise the bioclimate of health resorts in the different bioclimatic regions of Poland, and to assess the suitability of their biothermal conditions for climatotherapy.

MATERIALS AND METHODS

In describing the bioclimate of the resorts meteorological data from the years 1971-1990 were used. Daily and mean values for the following meteorological elements were taken into consideration: sunshine duration,

* The text is an extract from the monography „Bioklimat uzdrowisk polskich i możliwości jego wykorzystania w lecznictwie' published in Polish in Monografie Instytut Geografii i Przestrzennego Zagospodarowania PAN 3, 611 p.

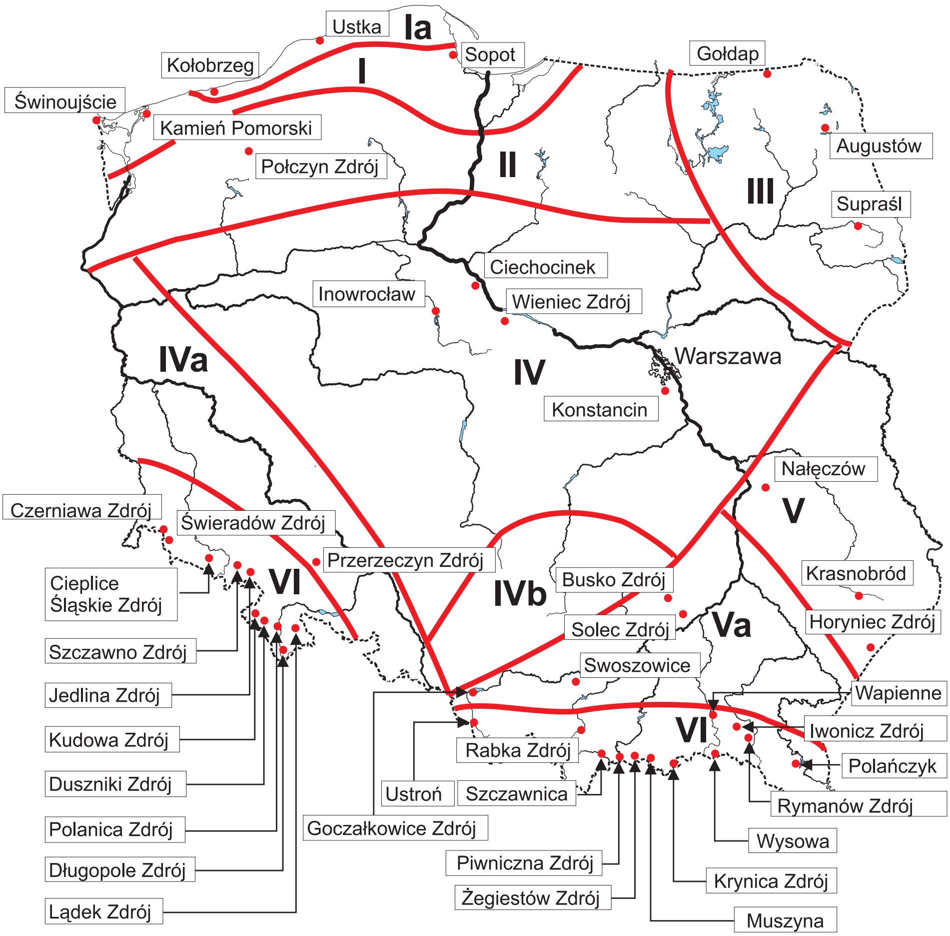


Figure 1. Distribution of health resorts in Poland (2002)
I-VI—bioclimatic regions (after Kozłowska-Szczęsna 1997)
I—coastal region under greatest influence from the Baltic Sea, Ia—the most stimulatory sub-region, II—lakeland region with less extreme bioclimatic conditions than in I, III—north-eastern region (the warmest way from the mountains), IV—central region with typical bioclimatic conditions, IVa—sub-region of limited stimulatory power, IVb—sub-region of relatively powerful stimuli (mainly associated with air pollution), V—south-eastern region (the warmest), Va—sub-region with enhanced thermal stimuli, VI—foothills and mountains region with highly differentiated bioclimatic conditions and strong stimuli.

cloudiness, air temperature and humidity, precipitation, storms, fog, snow cover and wind. These data were also used to calculate the Heat Load index (*HL*).

The work took in all 43 Polish health resorts (Figure 1). The special attention was paid to the data obtained at 12 UTC, since these are taken to best characterise the time of day at which people are in the open air most often in the temperate latitudes. The mean long-term values for meteorological elements were related to standards for

Central European resorts accepted in the field of human bioclimatology (Kozłowska-Szczęsna et al. 1997). Use was also made of the classification of resorts in different physico-geographical conditions as devised by T. Kozłowska-Szczęsna (1984):

- coastal health resorts;
- lowland resorts (at altitudes below 300 m a.s.l.)—taken to include the plain, valley, mid-forest and lakeside categories;
- foothills resorts (at 300-500 m a.s.l.) and mountain resorts (between 500 and 700 m a.s.l.), the latter taken to comprise the ridge, slope, valley, valley-slope and lakeside categories;
- high mountain resorts (at altitudes of over 700 m a.s.l.).

The bioclimatic typology of Poland was also applied in the analysis (Kozłowska-Szczęsna 1987, 1997, Kozłowska-Szczęsna et al. 1997).

To assess solar radiation stimuli, the measure of sunshine duration in health resorts was taken i.e., the number of hours during which the Sun's rays reach the ground. This was set against standards for Central European health resorts—1500 hours of sunshine per year (cf. 1350 for recreational sites). In the description of the solar conditions of health resorts reference was also made to data from the years 1951-1975 (Kuczmarski 1990).

The basis for the determination of thermal conditions in health resorts was constituted by:

- mean daily air temperature and the mean for 12 UTC (in °C),
- the absolute maximum (t_{max}) and minimum (t_{min}) air temperatures (in °C),
- the absolute amplitude of air temperature (in °C),
- the number of 'summer' days (i.e., with mean daily air temperature ≥ 15°C).

The frequency of occurrence of strong thermal stimuli was assessed on the basis of the number of days with characteristic threshold values for air temperature: hot days ($t_{max} \geq 25.0$°C), frosty days ($t_{min} \leq -10.0$°C), very hot days ($t_{max} \geq 30.0$°C), very frosty days ($t_{max} \leq -10.0$°C).

Air humidity was estimated on the basis of the relative humidity (*RH*) of the air as noted at midday observation term. The following scale for perceived relative air humidity was adopted (Kozłowska-Szczęsna et al. 1997): dry air—$RH \leq 55\%$, moderately dry air—*RH* of 56-70%, moderately humid air—*RH* of 71-85%, very humid air—$RH > 85\%$. Another measure used in determining humidity conditions was a water vapour pressure $e \geq 18.8$ hPa. Such humidity conditions are perceived as sultry.

The annual precipitation totals and number of days with precipitation (rainy days) with daily total ≥ 0.1 mm were also considered. They were compared with the standard for health resorts, which is of 183 days with precipitation per year. Account was also taken of precipitation totals in the warm and cool halves of the year (respectively May-October and November-April).

Consideration was given to the frequency of some atmospheric phenomena: fog, snow cover and storms. Particularly noteworthy among these phenomena are fogs—considered negative from the bioclimatic point of view since they limit the income of solar radiation and favour the retention in air of particulate and gaseous pollutants. In accordance with the norm adopted, the mean number of days with fog in a health resort should not exceed 50 in the period October-March and 15 in April-September.

The assessment of wind conditions was based around wind speed (v) at 12 UTC recorded at 10-20 m above the ground. The following scale to assess wind conditions was used: calm (v of 0-1 m s^{-1}), slight wind (v of 1-4 m s^{-1}), moderate wind (v of 4-8 m s^{-1}), strong wind (v over 8 m s^{-1}). The number of cases of strong wind (exceeded 8 m s^{-1} at 12 UTC) was also noted.

Analysis of air pollution took in those pollutants whose concentrations are defined by Polish sanitary standards. An Order of the Minister of Environmental Protection of 1998 brought in the following permissible mean daily values for the concentrations of air pollutants in areas enjoying health-resort protection: particulate matter (PM_{10})—40 μg m^{-3}, sulphur dioxide—30 μg m^{-3}, nitrogen dioxide—25 μg m^{-3}.

Biothermal conditions were considered to reflect the response on human beings of the thermal stimuli that shape subjectively received sensations of warmth as well as the level of the actual heat load of an organism. Thus biothermal conditions were evaluated with the use of the Heat Load (*HL*) index, as based on the human heat balance. The calculations applied the MENEX model of man-environment heat exchange (Błażejczyk 1993, 2001). The general equation for heat balance takes the following form:

$$M + R + C + L + E + Res = S$$

The inputs of heat to an organism are the metabolic heat production (M) and the solar radiation absorbed by man (R). The elimination of heat to the environment takes place by: the turbulent exchange of sensible heat (convection—C), long-wave emission (radiation—L), the turbulent exchange of latent heat (evaporation—E), breathing (respiration—Res).

The net heat storage (S) is a balance of heat gains and heat losses from a human body. At particular moments of the day S may assume negative or positive values, attesting to a failure to balance heat exchange, as a result of a prevalence of heat losses from the organism over heat gains, or else of gains over losses. This may lead to the steady cooling of the organism (a negative balance) or to its heating (with a positive balance). All of the components of the heat balance equation are expressed in W m^{-2}.

The *HL* index (non-dimensional) takes account of the influence of net heat storage (S), absorbed solar radiation (R) and heat loss by evaporation (E) on the heat loading of an organism. The Heat Load index allows for the determination of heat or cold stresses of varying intensity. *HL* was calculated (for 12 UTC on each day of the 1971-1990 period) with the use of the following formulas (Błażejczyk 2004):

—at $S < 0$ W m^{-2} and $E \geq -50$ W m^{-2}

$$HL = [(S+1000)/1000]^{[5/(1+R)]}$$

—at $S \geq 0$ W m^{-2} and $E \geq -50$ W m^{-2}

$$HL = [(S+1000)/1000]^{[2-1/(1+R)]}$$

—at $S < 0$ W m^{-2} and $E < -50$ W m^{-2}

$$HL = (E/-50)\,[(S+1000)/1000]^{[5/(1+R)]}$$

—at $S \geq 0$ W m^{-2} and $E < -50$ W m^{-2}

$$HL = (E/-50)\,[(S+1000)/1000]^{[2-1/(1+R)]}$$

where all coefficients and constants are expressed in W m^{-2}.

The Heat Load index was applied to assess the suitability of local biometeorological conditions for various forms of climatotherapy, i.e., heliotherapy (sunbathing), aerotherapy ('airbathing') and kinesitherapy (movement in the open air). For each form of climatotherapy there were defined the following levels of physiological parameters:

—during heliotherapy a person stands in a sunny place (M=70 W m^{-2}) and is dressed in light summer clothing with thermal insulation of 0.5 clo* (light shoes, thin trousers or skirt and short-sleeved shirt or blouse),

—during aerotherapy a person is in the standing posture (M = 70 W m^{-2}) and is dressed in normal summer clothing with insulation of 1.55 clo (shoes and socks, long woollen trousers, a shirt and sweater or jacket),

—during mild kinesitherapy a person moves at a speed of about 3.5 km h^{-1}, or engages in less intensive physical exercise (M = 120 W m^{-2}), is dressed in normal light summer clothing (with insulation of 1.55 clo),

—during intensive kinesitherapy (intensive movement in the open air), a person moves at a speed of about 5 km h^{-1}, engaging in exercise of considerable intensity or involving him/herself in action games (M=170 W m^{-2}), is dressed in normal light summer clothing (with insulation of 1.55 clo).

Adopting constant values for physiological parameters (metabolic heat production, constant skin temperature equal to 32°C in the months May-October and 30°C in the period November-April), as well as constant values for clothing insulation, it becomes possible to estimate the influence of meteorological elements on biothermal conditions.

Biothermal conditions prevalent through

* clo—unit of thermal clothing insulation; 1 clo = 0,155°C m^2 W^{-1}

the year in given health resorts may be determined as:

—soft, when they favour to keep the thermal equilibrium in most people, including elderly and ill;

—hardening, if they activate thermoregulation and endurance mechanisms in an organism (such that they necessitate medical supervision when they involve children, elderly or those who are ill and making use of climatotherapy procedures);

—loading, in as much as they can bring about major disturbances to an organism's heat system, including among those who are young and fit.

Particular *HL* values denote different degrees of heat load and different types of biothermal conditions:

HL	Perceived load	Biothermal conditions
0.821-0.975	Slight cold stress	soft
0.976-1.025	Thermoneutral conditions	
1.026-1.180	Slight warm stress	
0.250-0.820	Great cold stress	hardening
1.181-1.750	Great hot stress	
< 0.250	Extreme cold stress	loading
>1.750	Extreme hot stress	

The frequency of soft, hardening and loading conditions in successive decades of the year provided a basis upon which to assess their suitability for the different forms of climatotherapy (Figure 2). If the frequency of soft conditions regarding aerotherapy or kinesitherapy exceeded 50% of the days in particular decades, the situation was termed 'suitable without limitations'. Analogously, if—at a given place—more than half of decade were characterised by loading conditions, the period was regarded as 'unsuitable' for the given form of climate therapy. The remaining situations were treated as 'suitable with limitations'.

Somewhat different criteria were applied in assessing the suitability of biothermal conditions for heliotherapy. In this case, the recognition of decade under consideration as suitable without limitations required nothing more than that 30% of days should have thermoneutral or very limited cold or heat stress conditions around midday (*HL* = 0.931-1.185). In the case of the aforementioned form of climatotherapy, the differentiation to criteria applied in the assessment of biothermal conditions reflects the fact that sunbathing is generally undertaken in places sheltered from the wind, and not therefore represented by meteorological stations.

GENERAL CHARACTERISTIC OF THE HEALTH RESORT BIOCLIMATE

At the present study the main features of bioclimate of particular bioclimatic regions of Poland are pointed. The Table 1 contains the essential bioclimatic characteristics of selected health resorts.

IN THE COASTAL REGION (I and Ia), the mostly exposed to influences from the Baltic Sea 5 health resorts are located (Figure 1). In this region Poland's highest mean annual values of sunshine duration are noted (from 1540 in the western to 1640 hours per year in the central and eastern parts of the seashore) that markedly exceed the norm for Central European health resorts. Through the year, the highest values of sunshine duration are present at the end of spring , c.240-250 hours in May. The most favourable solar conditions persist between May and August. The mean annual values of air temperature varies from 7.9 to 8.3°C, while the means for midday are in the range of 9.3-10.3°C. The absolute amplitudes of air temperature (52-55°C) are much lower than observed in the north-eastern region (70°C).

Table 1. Mean annual values of meteorological elements (selected health resorts)

HEALTH RESORT	Region I					Region II	Region III	
	Świnoujście	Kamień Pomorski	Kołobrzeg	Ustka	Sopot	Połczyn Zdrój	Gołdap	Supraśl
Sunshine duration (hours)	1578.0	1543.4	1639.3	1641.7	1641.5	1508.0	1581.2	1584.7
Cloudiness at 12 UTC (%)	65	68	72	68	71	71	72	66
Mean daily temperature (°C)	8.3	8.2	8.1	7.9	8.2	7.4	6.5	6.7
Mean temperature at 12 UTC (°C)	10.1	10.3	9.9	9.5	9.3	9.9	9.2	-
Absolute max. temperature (°C)	33.3	33.6	33.9	33.9	33.4	34.1	32.5	33.4
Absolute min. temperature (°C)	-20.4	-20.0	-20.2	-20.7	-18.5	-28.8	-31.0	-35.4
Number of summer days (mean daily temp. ≥15.0 °C)	78.1	80.8	74.8	69.1	80.0	69.6	68.2	-
Number of hot days (max. temp. ≥25°C)	14.3	20.1	13.3	13.5	7.0	21.4	21.8	25.5
Number of very hot days (max. temp. ≥30.0°C)	2.0	2.9	2.0	2.0	0.2	2.2	1.7	1.6
Number of frosty days (min. temp. ≤-10.0°C)	5.5	8.2	6.4	6.5	4.6	13.8	24.2	-
Number of very frosty days (max. temp. ≤-10.0°C)	0.3	0.5	0.4	0.2	0.4	0.9	4.3	4.0
Air humidity at 12 UTC (%)	86	71	83	84	72.3	70	-	-
Number of sultry days	12.4	9.7	6.5	6.7	9.1	5.6	-	-
Precipitation totals (mm)	516	623	665	702	492	628	646	655
Number of days with precipitation ≥ 0.1 mm	169.1	163.9	181.4	179.0	173.5	158.4	160.4	170.9
Number of days with storm	15.6	7.2	17.5	15.9	13.2	10.0	8.7	15.8
Number of days with fog	42.3	37.7	50.5	34.3	46.6	35.4	67.4	60.3
Number of days with snow cover	43.3	38.6	40.3	53.1	48.3	52.9	75.4	83.1
Mean wind speed (v) at 12 UTC (m s^{-1})	4.8	4.3	3.8	4.3	5.3	3.5	4.2	2.9
Calms (%)	2.8	8.8	3.4	0.2	4.7	15.2	4.8	14.2
Number of cases of strong wind ($v \geq 8$ m s^{-1}) at 12 UTC	47.6	37.7	14.6	28.6	72.6	26.0	38.3	-

HEALTH RESORT	Region IV			Region V			
	Inowrocław	Ciechocinek	Wieniec Zdrój	Busko Zdrój	Goczałkowice Zdrój	Swoszowice-Kraków	Nałęczów
Sunshine duration (hours)	1599.0	1494.1	1408.8	1521.0	1466.3	1390.8	1593.3
Cloudiness at 12 UTC (%)	69	70	60	69	63	73	69
Mean daily temperature (°C)	8.1	8.3	7.6	7.4	8.1	8.3	7.4
Mean temperature at 12 UTC (°C)	11.0	11.4	10.9	10.5	11.1	11.4	10.8
Absolute max. temperature (°C)	35.4	35.5	33.7	33.7	33.5	34.4	33.0
Absolute min. temperature (°C)	-28.6	-30.3	-24.5	-29.5	-27.0	-28.2	-36.9
Number of summer days (mean daily temp. ≥15.0 °C)	91.7	94.1	83.1	82.3	88.3	91.4	78.8
Number of hot days (max. temp. ≥25°C)	34.2	42.3	37.3	30.6	31.7	37.8	32.7
Number of very hot days (max. temp. ≥30.0°C)	4.9	7.1	5.4	2.4	2.5	4.6	3.5
Number of frosty days (min. temp. ≤-10.0°C)	14.8	14.0	16.0	20.7	15.4	15.6	20.6
Number of very frosty days (max. temp. ≤-10.0°C)	2.1	1.5	0.8	2.0	1.5	1.6	2.0
Air humidity at 12 UTC (%)	69	67	69	70	69	69	69
Number of sultry days	12.7	12.3	13.3	17.2	11.2	13.8	19.0
Precipitation totals (mm)	509	561	519	544	781	733	540
Number of days with precipitation ≥ 0.1 mm	150.2	153.3	131.4	138.0	174.4	158.6	154.7
Number of days with storm	12.4	15.7	7.2	-	23.4	27.6	20.1
Number of days with fog	40.5	39.6	39.7	48.3	56.3	117.8	22.7
Number of days with snow cover	53.0	45.3	46.2	58.1	52.6	68.0	63.9
Mean wind speed (v) at 12 UTC (m s^{-1})	3.2	3.3	2.2	3.8	2.5	2.5	3.4
Calms (%)	1.3	10.1	18.1	2.1	25.5	1.7	28.3
Number of cases of strong wind ($v \geq 8$ m s^{-1}) at 12 UTC	14.6	17.9	2.1	33.2	10.6	9.0	24.0

HEALTH RESORT	Region VI (Sudeten Mts)							
	Świeradów Zdrój	Cieplice Śląskie Zdrój	Szczawno Zdrój	Kudowa Zdrój	Duszniki Zdrój	Polanica Zdrój	Długopole Zdrój	Lądek Zdrój
Sunshine duration (hours)	1465.2	1465.2	1465.2	1440.0	1547.4	1547.4	1547.4	1547.4
Cloudiness at 12 UTC (%)	63	70	68	69	69	68	62	69
Mean daily temperature (°C)	6.9	7.4	7.4	7.1	6.1	7.2	7.2	7.1
Mean temperature at 12 UTC (°C)	9.1	10.8	9.8	9.6	8.8	10.3	10.0	10.0
Absolute max. temperature (°C)	33.9	35.2	34.9	35.2	36.0	34.9	34.6	34.2
Absolute min. temperature (°C)	-25.6	-30.3	-26.9	-28.0	-28.2	-26.2	-29.7	-26.1
Number of summer days (mean daily temp. ≥15.0 °C)	57.3	64.9	66.6	68.7	52.5	64.7	64.9	61.9
Number of hot days (max. temp. ≥25°C)	10.5	24.3	18.4	23.7	13.9	23.2	18.3	20.4
Number of very hot days (max. temp. ≥30.0°C)	0.5	2.4	1.3	2.4	0.6	1.9	0.8	1.4
Number of frosty days (min. temp. ≤-10.0°C)	12.2	20.6	13.4	18.4	19.9	14.7	15.2	15.6
Number of very frosty days (max. temp. ≤-10.0°C)	1.6	1.1	1.4	1.3	3.3	1.2	1.4	1.3
Air humidity at 12 UTC (%)	69	-	66	69	71	67	65	69
Number of sultry days	3.3	-	4.4	8.4	4.7	6.7	5.1	7.1
Precipitation totals (mm)	1175	613	656	618	807	699	812	824
Number of days with precipitation ≥ 0.1 mm	203.3	163.5	180.9	168.1	177.0	174.4	173.2	180
Number of days with storm	19.1	15.8	19.2	13.1	14.2	21.9	20.2	16.2
Number of days with fog	24.6	29.5	20.3	24.5	27.5	40.8	82.1	38.6
Number of days with snow cover	92.4	53.9	51.1	60.1	76.5	57.5	63.7	75.6
Mean wind speed (v) at 12 UTC (m s^{-1})	3.1	3.5	3.4	2.1	2.8	2.7	3.9	2.4
Calms (%)	22.1	32.1	16.6	27.6	36.4	24.9	8.9	29.3
Number of cases of strong wind ($v \geq 8$ m s^{-1}) at 12 UTC	33.4	28.4	16.6	5.2	8.3	21.3	44.9	11.9

HEALTH RESORT	Region VI (Carpathians)							
	Ustroń	Rabka Zdrój	Szczawnica	Żegiestów Zdrój	Muszyna	Krynica Zdrój	Wysowa	Iwonicz
Sunshine duration (hours)	1423.5	1494.3	-	1153.9	1338.5	1444.0	-	1254.9
Cloudiness at 12 UTC (%)	66	59	63	66	67	66	68	73
Mean daily temperature (°C)	7.0	6.5	6.5	6.3	6.2	5.8	5.7	7.1
Mean temperature at 12 UTC (°C)	10.5	10.3	10.2	10.2	10.4	9.6	8.9	9.4
Absolute max. temperature (°C)	32.9	34.1	33.8	32.5	31.6	30.8	31.4	31.2
Absolute min. temperature (°C)	-28.2	-29.8	-28.5	-33.1	-34.2	-29.9	-29.8	-24.7
Number of summer days (mean daily temp. ≥15.0 °C)	65.1	60.0	57.9	59.3	56.1	48.8	53.9	75.2
Number of hot days (max. temp. ≥25°C)	25.2	27.0	21.6	25.3	25.1	16.8	13.2	15.4
Number of very hot days (max. temp. ≥30.0°C)	1.2	1.9	1.1	1.3	1.1	0.5	0.0	0.3
Number of frosty days (min. temp. ≤-10.0°C)	19.8	25.3	26.4	28.0	31.2	28.6	30.2	14.7
Number of very frosty days (max. temp. ≤-10.0°C)	1.3	1.2	1.6	1.7	1.7	1.8	2.6	2.1
Air humidity at 12 UTC (%)	-	68	64	64	64	66	70	69
Number of sultry days	-	8.1	7.4	13.2	9.0	9.7	8.5	8.1
Precipitation totals (mm)	1165.0	894	832	797	736	819	823	858
Number of days with precipitation ≥ 0.1 mm	191.7	180.4	173.8	179.7	170.6	185.6	192.4	164.8
Number of days with storm	16.2	17.6	22.2	19.7	22.6	20.0	19.4	21.3
Number of days with fog	54.4	72.4	62.4	-	75.7	86.2	45.6	81.7
Number of days with snow cover	83.7	96.9	93.5	89.6	95.7	104.1	107.5	91.9
Mean wind speed (v) at 12 UTC ($m\ s^{-1}$)	2.7	1.3	2.1	1.9	1.8	1.1	4.1	2.6
Calms (%)	29.4	48.0	23.9	47.4	51.2	65.1	12.2	27.8
Number of cases of strong wind ($v \geq 8\ m\ s^{-1}$) at 12 UTC	5.6	2.7	8.2	0.4	3.1	0.6	25.6	21.0

On the middle stretch of coast, the thermal conditions are slightly more severe than those noted either further west or east.

The coastal health resorts are humid or very humid in character. Only in Kamień Pomorski from March to September and in Sopot between July and September moderately dry air prevails. Annual precipitation totals range between 400 and 700 mm. A feature of the precipitation totals is the small prevalence of the precipitation noted in the warm half of the year over that noted in the cool half-year. The relevant ratios are 59:41% in Kołobrzeg and 57:43% in Ustka. In the eastern part of the coast an influence of the continental climate makes itself felt, and in the western one the influence of maritime climate is observed. The aforementioned ratio is of 65:35% and 53:47%, respectively. Snow cover is much more short-lived than in the south or east of Poland (40-50 days yearly).

The wind directions in the coastal health resorts are determined by general circulation factors. There is a prevalence of NW, W and SW winds. In Sopot the share taken by SE wind is also considerable. The mean annual wind speed is of c. 5 m s^{-1}, with relatively rare periods of calm. Compared with the inland parts of Poland, coastal health resorts have twice as many days with strong winds around midday (30-70 days yearly). A specific feature of the seashore health resorts is the presence of marine aerosols in the air as well as the sea breezes. The breezes bring with them a marked cooling following on from a period of warming—something that is not favourable to the heat and water balance of the human organism. In general the concentrations of the main pollutant substances in the atmosphere are much below the sanitary standards. Only in Sopot in several years the air pollution by sulphur dioxide and nitrogen dioxide was significant.

LAKELAND REGION (II) has milder bioclimatic conditions than Region I and Ia. Only one lowland lakeshore health resort (Połczyn) is located here. The annual sunshine duration is c. 1510 hours. The highest monthly totals (200-230 hours) are noted from May to August, while the lowest values (24-36 hours) occur between November and January. The mean annual air temperature is of 7.4°C (10°C for the midday). The amplitude of temperature is of 63°C. While the mean annual relative humidity of the air points to moderately dry air, the highest *RH* values are noted between October and February and the lowest ones—in May. Precipitation totals are of c. 630 mm, with 59% of this coming in the warm and 41% in the cool half year. The number of rainy days a year is below the health resort standard. The greatest number of rainy days is noted in November and the smallest one—in February and April. In both the October-March and April-September periods, the respective number of foggy days do not exceed the standards adopted for health resorts. Snow cover lasts for 53 days a year, as in the coastal region.

W and SW winds prevail through the year. Calm conditions are more frequent than in the seashore (15.2%). Wind speed is also lower than by the sea, at 3.5 m s^{-1}. In recent years the mean 24-hour concentrations of sulphur dioxide and nitrogen dioxide have not exceeded the values in force for areas of health-resort protection. The same is true for levels of respirable particulate matter.

NORTH-EASTERN REGION (III) is Poland's coldest away from the mountains. It includes the 3 lowland health resorts: mid forest (Supraśl) and mid forest-and-lakeside (Augustów, Gołdap). The characteristic features are a relatively high sunshine duration (> 1580 hours yearly, 240 hours in May), the country's lowest values for air temperature (mean annual of 6.0-6.7°C and midday of 9.0-9.2°C), great amplitudes of air temperature (70°C) and a long period with snow cover (75-96 days a year). There is about 30 summer days and 10 hot days fewer than in the central and south-eastern regions.

Annual precipitation totals range from 510 to 546 mm; warm half-year precipitation accounts for 63-64% of the annual totals. The number of rainy days is below the health resort standard. However, foggy days are relatively frequent (> 60 a year) and the standard for health resorts is not exceeded in the October-March period only. As throughout Poland, NW, W and SW winds are noted most frequently. Calm states account for between 5 and 14% in a year. Strong winds occur mostly in autumn and winter. Air pollution is not a source of disquiet in the health resorts under consideration; all the sanitary standards are not exceeded.

THE CENTRAL REGION (IV, IVa, IVb) is characterised by bioclimatic conditions typical of Poland. It has 5 lowland health resorts. 2 of them is located in valleys (Ciechocinek, Przerzeczyn), 2 are mid-forest (Wieniec, Konstancin) and 1 is on a plain (Inowrocław). Only in Inowrocław and Konstancin the annual sunshine duration is sufficient for climatic treatments (1570-1600 hours). At other resorts the values of sunshine duration are within the standards for recreational localities. In the May-August period sunshine totals are favourable for applying heliotherapy. Mean annual values of air temperature range between 7.6°C and 8.3°C (c. 11°C around midday). The temperature amplitudes reach 58-66°C, with the peak value characterising Ciechocinek. This locality also has the greatest in Poland number of summer, hot and very hot days.

The relative humidity is in the range of moderately dry air almost all over the year (excluding May only, with dry air). The annual precipitation totals are relatively low (509-596 mm). Most of rainfalls occur in the warm half year (64-68%). The numbers of rainy days and of foggy days are below the health resort standards. Snow cover is observed only during 42-46 days a year. Beside NW, W and SW winds prevailing at some localities S, SE or N winds are also relatively frequent. The number of calms is the greatest (18%) in mid-forest health resorts and the smallest (1%) at the elevated plains. The same relations concern wind speed. All the health resorts of the central bioclimatic region are characterised by air pollution readings that fall within permissible limits for areas enjoying health-resort protection.

SOUTH-EASTERN REGION (V, Va) is the warmest in Poland. It includes 7 lowland health resorts: 2 valley-situated (Krasnobród, Swoszowice), 4 plain-situated (Busko, Solec, Nałęczów, Horyniec) and 1 lakeshore (Goczałkowice). The annual totals of sunshine duration are of 1500-1590 hours. The mean annual values of air temperature range from 7.0°C to 8.0°C (10.5°C to 11.0°C for midday hours). Temperature amplitudes are 60-70 °C. The greatest number of frosty days (c. 40) is characteristic for eastern part of the region and the smallest one (15) for its western part.

As in Central region the annual relative humidity points to moderately dry air. Precipitation totals range from 540 mm to 780 mm. 58-71% of precipitation falls in warm half-year. In none of the resorts does the number of rainy days exceed the standard (138-174 a year). The number of foggy days is very differentiated (from 23 up to 118). The health resort standards of foggy days are exceeded in Swoszowice throughout the year, while in Busko and Goczałkowice between April and September. Snow cover persists longest in Horyniec (102 days a year) and for the shortest period in Goczałkowice (just 53 days).

There is a prevalence of NW, W and SW winds with considerable frequency of E, SE and S winds. In the resorts in question, the midday hours are ones of slight winds. Only in spring are moderate winds to be noted. The greatest number of calm situations is noted in Horyniec (36%) and the smallest one—in Busko and Swoszowice (2%). Except in Swoszowice, air pollutants are not present at concentrations exceeding the standards set for areas under health-resort protection. In the case of Swoszowice, the proximity of Kraków ensures that the air is of poor quality.

The greatest number of health resorts is located in FOOTHILLS AND MOUNTAINS REGION (VI). Bioclimatic conditions vary markedly, mainly in relation to relief and altitude. The mountains and foothills resorts are characterised by specific bioclimatic conditions. Atmospheric pressure and oxygen concentration decline with altitude, while direct solar radiation (including biologically-active UV) increases in intensity. Föhn-type winds are worthy of note, since they heat and dry the air, as well as they provoke abrupt changes in air pressure—as a stimulus impacting negatively upon people's mental state and wellbeing. The region has 22 health resorts (12 in the Carpathians and 10 in the Sudetes).

The solar conditions are differentiated depended on health resort location. At the narrow valleys the annual sunshine duration do not exceed 1350 hours. However, at ridges and wide valleys sunshine duration is sufficient for heliotherapy. In general, there is less sunny hours in the Carpathian than in Sudetic health resorts. Also mean annual air temperature is lower in the Carpathians (5.7°C-7.1°C) than in the Sudetes. (6.9°C--7.4°C). Temperature amplitudes in the Sudetic resorts range from 60°C to 66°C, while the corresponding range for the Carpathians is between 56°C and 66°C. Valley and valley-slope resorts are prone to major monthly and annual contrasts in air temperature, though this is more marked in the Carpathians than in the Sudetes .

Most health resorts of this region have moderately dry air (*RH* of 56-70%). From November to February, the air humidity ranges between 71 and 85% (moderately humid air). Only in a couple of the Carpathian resorts in April and May *RH* do not exceed 55% (dry air). Annual precipitation totals range from 807 mm to 1175 mm in the foothills resorts, and from 613 mm to 1165 mm in the mountains ones. Overall, the Sudetic health resorts have slightly higher precipitation totals than the Carpathian ones. Most of precipitation is noted in the warm half-year (56-68%). The number of rainy days is rather higher in the Sudetes than in the Carpathians. Number of foggy days ranges between 20 (Szczawno) and 86 (Krynica). Foggy days are noticeably more frequent in the Carpathian than in Sudetic health resorts. The adopted standard for foggy days in the warm months (April-September) is exceeded in 8 of the Carpathian and in 1 Sudetic resort. Snow cover lasts longer in the Carpathians (83-108 days) than in the Sudetes. (51-92 days a year).

All of the health resorts witness a prevalence of winds from the western sector, though southerly winds are also noticeable, as E wind in the Carpathians. In the Sudetes, calms are recorded on about 9-36%, and in the Carpathians—from 12% to over 50%. The mean wind speed ranges from 1.2 to 4.0 m s^{-1} (slight winds). Only in Wysowa v is a little greater, with moderate winds being reported on average. The number of days with strong winds varies markedly from 10 to 45. Air pollution, especially, sulphur dioxide and nitrogen dioxide is not a problem in most of the resorts. However, the permitted concentration of NO_2 has been exceeded in some years in Cieplice, Lądek and Ustroń.

THE SUITABILITY OF BIOTHERMAL CONDITIONS FOR CLIMATOTHERAPY

The concept of biothermal conditions should be taken to encompass a set of meteorological factors impacting upon the human body and inducing various adaptive (thermoregulatory) reactions in regard to the surroundings. The three types of biothermal conditions identified (soft, hardening and loading) allowed for the determination of the lengths of periods of differing degrees of suitability (i.e., suitable, suitable with limitations and unsuitable), in the cases of heliotherapy, aerotherapy and kinesitherapy (therapy involving movement). The basic period adopted was a decade.

The study made use of 7 health resorts located in different bioclimatic regions representative of different physico-geographical conditions in Poland (Kozłowska-Szczęsna et al. 2002). Ustka (3 m a.s.l.) is a coastal health resort in the coastal region (Ia), with a highly stimulating climate subject to influences from the Baltic Sea. In turn, the largest, central, bioclimatic region (IV) has conditions that might be termed typical of the country. It is represented by Ciechocinek (at 40-46 m a.s.l.), a lowland (valley) health resort. Region V (south-eastern Poland) is the country's warmest. It includes Nałęczów (at

180-200 m a.s.l.), which is a lowland (plain) resort. In turn, the foothills and mountain region (VI)—as characterised by a high variability of bioclimatic conditions and a major stimulatory influence—was represented by two Carpathian health resorts: Iwonicz Zdrój (at 380-450 m a.s.l.), as a valley-slope resort in the foothills, and Krynica Zdrój (at 560-620 m a.s.l.) as a mountain valley health resort. There were also two resorts in the Sudetes included on the list: Lądek Zdrój (at 450-500 m a.s.l.)—a valley-slope resort in the foothills, and Duszniki Zdrój (at c. 550 m a.s.l.), as a mountain valley-slope resort.

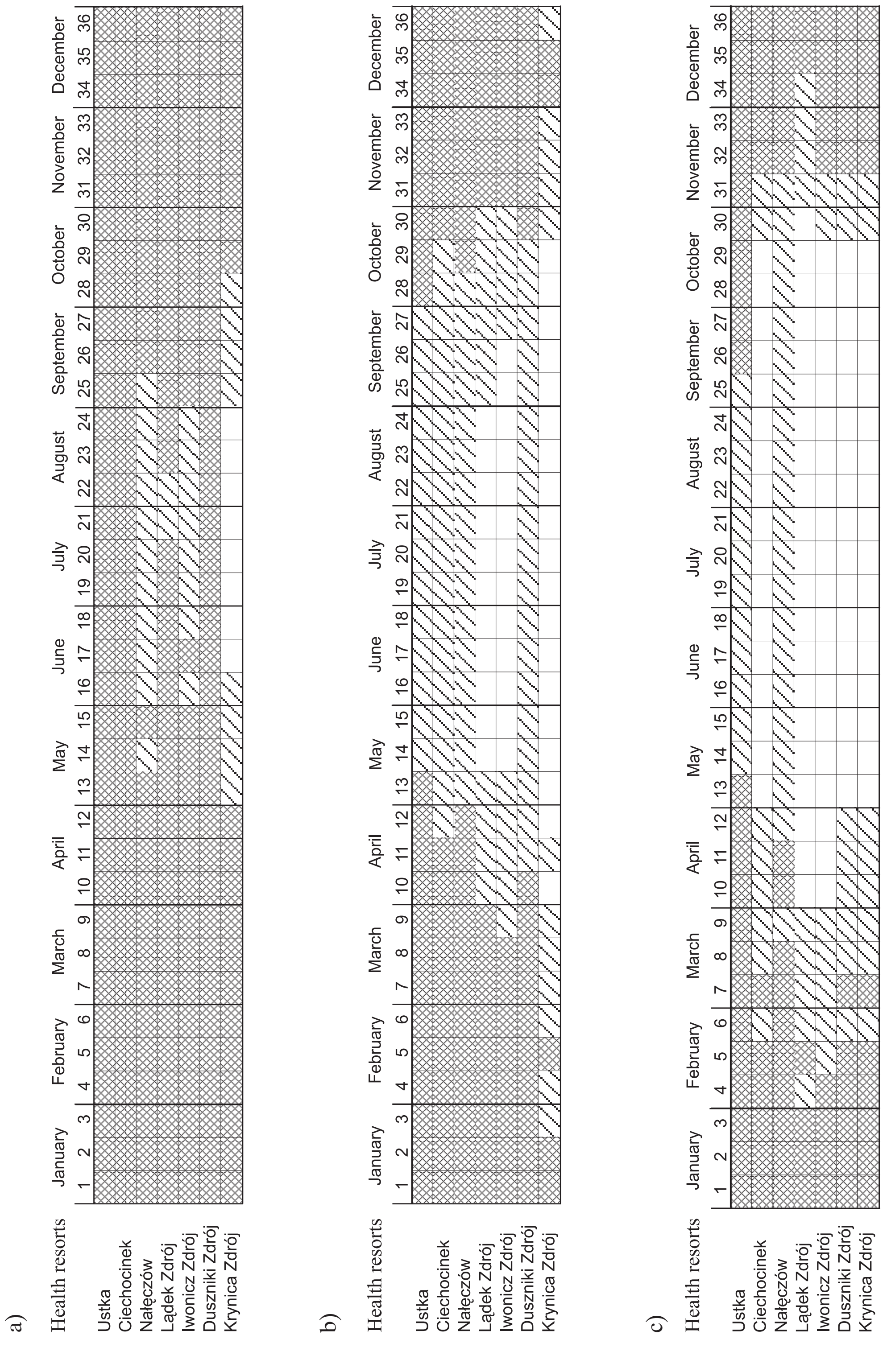
HELIOTHERAPY

The climatic conditions of the southern Baltic shore prevent Ustka from meeting the adopted criteria for heliotherapy-friendly biothermal conditions at any time of year (Figure 2a). What this means is that on most (more than 70%) of the days of the year—the summer period inclusive—conditions are unsuitable (loading) for this form of therapy, in spite of the large amounts of sunshine. This reflects the fact that the air temperature is relatively low (not exceeding 20°C on average around midday, even in July and August), and the wind speed high (at c. 4.0 m s^{-1}). In such conditions, the heat loss from a body clothed to a insulation of 0.5 clo imposes major or very major cold stress on a body, even that of a young and fit person. Only between the last third of June and the end of the middle third of August are hardening biothermal conditions present around 7-12% of the time in region I of the coastal bioclimate. In this case, the heliotherapy activates thermoregulation mechanisms in the body.

A similar pattern is observed in the central bioclimatic region (IV), which takes in lowlands and is represented by Ciechocinek. Throughout the year, there is no 10-day period in which conditions suitable for heliotherapy without limitations pertain for more than 30% of the time. Only in the first and middle decades of August do soft biothermal conditions attain at least a 10% frequency, while the period in which bracing conditions apply 10-20% of the time extends from the last third of May to the middle third of August. During this time, loading biothermal conditions unsuitable for heliotherapy account for 70-85% of the days in a given 10-day period.

In the south-eastern bioclimatic region (V), represented by Nałęczów, the suitability of biothermal conditions for heliotherapy is rather greater than in the two aforementioned regions. Conditions suitable for heliotherapy without limitations are experienced more than 30% of the time almost uninterruptedly between the second third of May and the first third of September. Limitations in regard to heliotherapy result from the quite high (over 25%) frequency of marked or very marked heat stress to be noted in the warm half of the year (Krawczyk 2001).

In the mountain and foothills health resorts of bioclimatic region VI, the suitability of local biothermal conditions for heliotherapy is varied, and dependent not only on altitude, but also on local relief, including the topographic orientation of mountain valleys. Thus, in Lądek Zdrój, a valley-slope resort in the foothills of the Sudetes, a 30% frequency of biothermal conditions suitable for heliotherapy with limitations is present in only two decades in late July and early August. Better conditions are present in Iwonicz Zdrój (a Carpathian foothills resort in valley-slope conditions), because the same degree of suitability is observed for a much longer period—i.e., from the first decade of June to the last decade in August. In the valley-slope mountain resort of Duszniki Zdrój, the period from the end of June to the second decade of August has conditions of restricted suitability for heliotherapy only 12-14% of the time, with these being unsuitable in the remainder of cases (c. 80%). Among the 7 health resorts analysed it is Krynica that offers the best conditions for heliotherapy. This valley resort of the Carpathians has the lowest average wind speed and the longest period of suitability for heliotherapy—lasting from the beginning of May to the first decade of October, with a period of no-limitations lasting from the middle third of June to the end of August.


a)
b)
c)
Health resorts
Ustka
Ciechocinek
Nałęczów
Lądek Zdrój
Iwonicz Zdrój
Duszniki Zdrój
Krynica Zdrój
January
February
March
April
May
June
July
August
September
October
November
December
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36

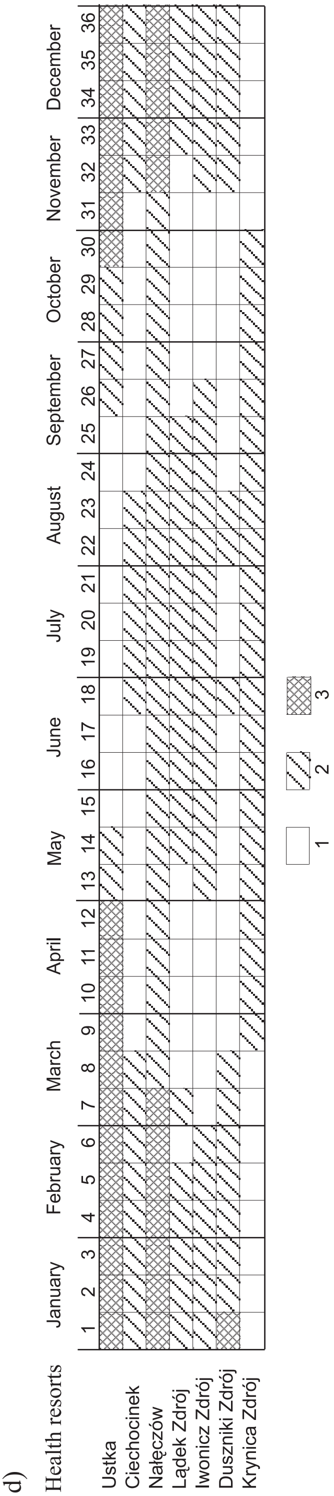


Figure 2. Suitability of biothermal conditions for: a) heliotherapy, b) aerotherapy, c) mild kinesitherapy, d) intensive kinesitherapy (at 12 UTC, 1971-1990)
1—conditions suitable without limitations, 2—conditions suitable with limitations, 3—unsuitable conditions,
1-36—decades of the year.

AEROTHERAPY

In Poland, biothermal conditions for this form of treatment (Figure 2b) are rather more suitable than those for heliotherapy. This is first and foremost a reflection of the fact that clothing with greater insulation can readily be used. Along the middle part of the coast (e.g., in Ustka), conditions suitable for aerotherapy without limitations pertain between the second decade of May and the end of September.

On the Polish lowland, in turn—as at Ciechocinek—the period in question is as much as a month longer. However, the best conditions of all for this form of therapy are those characterising the foothills and mountains health resorts, where suitability without limitations—in the form of soft biothermal conditions favourable to keep the thermal equilibrium of an organism in most people—are present at least 50% of the time in mid May (at Lądek and Iwonicz) and last until September. Rather poorer conditions for aerotherapy (suitability with limitations) apply to Duszniki, where the air temperature around midday is lower than in any of the other resorts of the Sudeten foothills, at 17-19°C in summer.

Among the mountain and foothills health resorts, the one with the longest period of suitability for aerotherapy both with and without limitations is Krynica. Due to the limited (c. 1 m s^{-1}) wind speeds in its valley location, the unreservedly suitable conditions arise in April and continue through to the middle of October. The criterion of suitability with limitations extends the useful period here back into March and forward into November. Indeed, there are even certain decades in winter where such favourable conditions arise.

MILD KINESITHERAPY

Where a person is expected to move about in the field at a speed of around 3.5 km h^{-1}, or engage in physical exercise of moderate intensity, the picture of biothermal conditions in given health resorts changes markedly. The metabolic heat production by a person greater than in the standing posture ensures that the frequency with which soft or hardening biothermal conditions are noted in given decades increases, while the period over which this form of climatotherapy is either suitable without limitations or suitable with limitations is much longer. In the middle part of the Baltic coast (Ustka) it stretches from May to September (Figure 2c), while in the lowlands (Ciechocinek) it runs from March to October.

In south-eastern Poland (Nałęczów), in contrast, conditions suitable with limitations arise as late as in April, but then continue to November. The best conditions for the pursuit of mild climatotherapy are present in foothills and mountain areas. There the period suitable without limitations runs from April or May to the second decade in October. However, if certain limitations are taken note of (in regard to children, elderly and the sick people whose climatotherapy takes place under medical supervision), the period may be extended from the end of February through to the beginning of November.

INTENSIVE KINESITHERAPY

When it comes to this kind of therapy, i.e., movement in the field at a speed of about 5 km h^{-1}, or physical exercise of greater intensity, the heat flux generated by metabolic processes rises to 170 W m^{-2}. This ensures that conditions unsuitable for this form of climatotherapy are either altogether absent, or else appear only in the November-February period (Nałęczów), and between the last third of October and the end of April (Ustka).

The specifics to the biothermal conditions pertaining during intensive kinesitherapy ensure more limited suitability of the summer months. The large amounts of metabolic heat combine with the relatively high air temperature observed at the above time to subject the organism to considerable thermoregulatory loads (Błażejczyk 2002, Krawczyk 2001). Biothermal conditions are hardening at this time, such that for all of the studied health resorts except Ustka and Duszniki, the spring-summer period is characterised by conditions that are suitable with limitations where intensive kinesitherapy is concerned (Figure 2d). These last uninterruptedly from the last third of May through to the first decade of September. Such a state of affairs is particularly visible in the case of Krynica. Where the Polish health resorts are concerned, the most favourable biothermal conditions for intensive kinesitherapy are those noted usually in spring (March-April) and autumn (September-October). An exception here is Krynica, where the limited movement of air ensures unreservedly suitable conditions for intensive therapy via movement even in winter. In turn, at Ustka, the most favourable conditions persist from the last third of May to the first decade of September, while in Duszniki the comparable period lasts from April to October.

CONCLUSIONS

The bioclimatic conditions of Poland's health resorts vary markedly from place to place and season to season, in reflection of both the general climatic conditions typical for Poland as a whole, and such local factors as relief, type of soil, vegetation cover, water relations and land use. This creates considerable therapeutic opportunities and allows advantage to be taken of various forms of recreation.

From the point of view of solar conditions, the health resorts of northern Poland stand out. Nevertheless, the major heat load of an organism brought about by strong winds and a relatively low air temperature ensure that the most favourable form of climatotherapy is that involving movement. Furthermore, the winter period is not favourable to the full use of climate therapy in the health resorts of northern Poland.

The resorts of the south and the south-east regions have conditions favouring various forms of climate-related treatment throughout the year. While heliotherapy and aerotherapy may be applied with success in summer, precipitation may impose certain limitations at this time of the year. In contrast, in the cool half-year, movement-based therapy of varying intensities may be applied. Valuable bioclimatic features are extended in time into winter, thanks to the long periods for which a snow cover lies.

REFERENCES

Błażejczyk K., 1993, *Wymiana ciepła pomiędzy człowiekiem a otoczeniem w różnych warunkach środowiska geograficznego* (Heat exchange between man and his surroundings in different kinds of geographical environment), Prace Geograficzne 159, 123 p.

Błażejczyk K., 2001, *Bilans cieplny człowieka jako narzędzie badań bioklimatycznych* (Human heat balance as a tool of bioclimatic research), Przegląd Geograficzny 73, 4, 535-554.

Błażejczyk K., 2002, *Znaczenie czynników cyrkulacyjnych i lokalnych w kształtowaniu klimatu i bioklimatu aglomeracji warszawskiej* (The influence of air circulation and local factors on climate and bioclimate of Warsaw agglomeration), Dokumentacja Geograficzna 26, 160 p.

Błażejczyk K., 2004, *Bioklimatyczne uwarunkowania rekreacji i turystyki w Polsce* (Bioclimatic principles of recreation and tourism in Poland), Prace Geograficzne, 192, 270 p.

Kozłowska-Szczęsna T., 1984, *Les conditions bioclimatiques en tant que base d' evaluation du milieu géographique des stations de cure polonaises*, Geographia Polonica 49, 129-138.

Kozłowska-Szczęsna T., 1987, *Types of bioclimate in Poland*, Geographia Polonica 53, 138-140.

Kozłowska-Szczęsna T., 1997, Zasoby lecznicze uzdrowisk w Polsce (Treatment resources of health resorts in Poland), Balneologia Polska 39, 1-2, 122-133.

Kozłowska-Szczęsna T., Błażejczyk K. and Krawczyk B., 1997, *Bioklimatologia człowieka. Metody i ich zastosowanie w badaniach bioklimatu Polski* (Human Bioclimatology—methods and applications), Monografie 1, Instytut Geografii i Przestrzennego Zagospodarowania PAN, Warszawa, 200 p.

Kozłowska-Szczęsna T., Błażejczyk K., Krawczyk B. and Limanówka D., 2002, *Bioklimat uzdrowisk polskich i możliwości jego wykorzystania w lecznictwie* (The bioclimate of Polish health resorts and the opportunities for its use in treatment), Monografie 3, Instytut Geografii i Przestrzennego Zagospodarowania, PAN, Warszawa, 611 p.

Krawczyk B., 2001, *Ryzyko wystapienia stresu ciepła w wybranych uzdrowiskach polskich* (The heat stress hazard in the selected health resorts), Balneologia Polska 43, 1-2, 88-93.

Kuczmarski M., 1990, *Usłonecznienie Polski i jego przydatność dla helioterapii* (The sunshine duration in Poland and its significance for heliotherapeutic purposes), Dokumentacja Geograficzna 4, Instytut Geografii i Przestrzennego Zagospodarowania PAN, 69 p.

Leszczycki S., 1939, *Uzdrowiska Polski ich rozmieszczenie oraz rozwój w latach 1921-1939* (Die Bäder—und Kurorte in Poland und die Kurgästebewegung im Jahre 1921-1938), Komunikaty Studium Turyzmu UJ w Krakowie, 21, 16 p.

Received: April 2003
Revised: September 2003

GEOGRAPHIA POLONICA, 77, 1, 63–76, Spring 2004
PL ISSN 0016–7282

RADIATION BALANCE IN MAN IN VARIOUS METEOROLOGICAL AND GEOGRAPHICAL CONDITIONS

KRZYSZTOF BŁAŻEJCZYK
Institute of Geography and Spatial Organization, Polish Academy of Sciences, Warsaw
and Institute of Geography, Bydgoszcz University, Poland
E-mail: k.blaz@twarda.pan.pl

Abstract: Solar radiation is a very important factor influencing human beings, in that it plays a significant role in the human heat balance. Bioclimatic and thermophysiological research makes use of various ways by which to assess absorbed solar radiation (ASR), as an essential part of the radiation balance in man (Q). Previous research based either on theoretical considerations or on experimental studies has used different analogue models of the human being as either a vertical cylinder or on ellipsoid. The present paper discusses the results of experimental studies on solar radiation absorption with absorbed fractions of solar radiation being measured on a mannequin. Depending on the kind of radiation data, three models were proposed for assessing ASR. The accuracy of the models was verified by direct measurements made on subjects.

Key words: absorbed solar radiation, radiation balance of humans, skin temperature.

INTRODUCTION

In climatology and human heat-balance research two kinds of radiation are considered: solar (i.e. short wave) with a wavelength of 0.1-4.0 μm and thermal (i.e. long-wave) with a wavelength of 4.1-50.0 μm. Solar radiation is divided into three ranges: ultraviolet (<0.4 μm), day-light (0.4-0.76 μm) and infrared (>0.76 μm) (Błażejczyk 1998a, Błażejczyk et al. 1993). Each range of radiation has its specific biological activity. UV radiation has bactericidal properties; it also produces vitamin D_3 and burning of the skin surface. Day-light radiation is a source of human visual and mental impressions. However infrared beams have thermal features (Błażejczyk 1998a, Clark and Edholm 1985, Kozłowska-Szczęsna and Błażejczyk 1998). Long-wave radiation is emitted by any body and its intensity depends on the temperature of the radiating surface (Błażejczyk 1993, 1994).

In bioclimatic and thermophysiological research the human heat balance and its components are considered very frequently as basic characteristics of organism functioning and of human well being. They also indicate people's satisfaction or dissatisfaction with the outdoor climate. Radiation balance is an essential component of human-environment heat exchange. In this area special attention should be paid to absorbed solar radiation (Błażejczyk 1996, 1998b, 2000, Błażejczyk et al. 1999, 2000, Matzarakis et al. 2000). The general equation for the radiation balance of man (Q, W m^{-2}) has the following form:

$$Q = R + L, \qquad (1)$$

where: R—absorbed solar radiation (W m^{-2}), L—net long-wave radiation in man (W m^{-2}).

The net long-wave radiation is a balance of heat exchange by thermal radiation between human body and the atmosphere, as well as between the human body and the ground, as follows:

$$L = (0.5\,Lg + 0.5\,La - Ls)\,Irc \quad (2)$$
$$Lg = 5.5\,10^{-8}\,(273 + Tg)^4, \quad (3)$$
$$La = 5.5\,10^{-8}\,(273 + t)^4\,(0.82 - 0.25\,10^{(-0.094\,vp)}), \quad (4)$$
$$Ls = 5.39\,10^{-8}\,(273 + Tsk)^4, \quad (5)$$

where: *Tg*—ground temperature (°C), *Tsk*—skin temperature (°C), *vp*—vapour pressure (hPa), *Irc*—the coefficient reducing heat transfer due to clothing:

$$Irc = hc'/(hc' + hc + 21.55\,10^{-8}\,T^3) \quad (6)$$
$$hc = (0.013\,ap - 0.04\,t - 0.503)\,(v + v')^{0.5} \quad (7)$$
$$hc' = (0.013\,ap - 0.04\,t - 0.503)\times$$
$$\times 0.53/\{Icl\ [1 - 0.27\,(v + v')^{0.4}]\} \quad (8)$$

where: *T*—air temperature (K), *t*—air temperature (°C), *v*—wind speed (m s^{-1}), *v'*—body motion (m s^{-1}), *Icl*—clothing insulation (clo).

Outdoors, during daylight hours, the *L* intensity varies over rather a narrow range and the main component of the radiation balance is absorbed solar radiation (ASR). In the human heat–balance models ASR is considered in various ways, with different measures of solar geometry being used (Figure 1). A review of methods used to express absorbed solar radiation is given by Błażejczyk et al. (1993) and Underwood and Ward (1966). However, a majority of previous studies have been based on theoretical relationships between solar geometry and absorption of solar energy, while only a few have been derived from experimental approaches, as in Krys and Brown (1990) and Błażejczyk et al. (1998). In the first experiment a vertical cylinder was used as an analogue model of a human being and in the second an ellipsoid. Both geometrical analogues give only a general approximation of the human body.

In practical applications of the human heat balance, ASR, is considered a function of solar radiation fluxes that are: direct (*Kdir*), diffuse (*Kdif*) and reflected from the ground (*Kref*). The general equation for absorbed solar radiation (*R*) has the form:

$$R = (\beta dir\,Kdir + \beta dif\,Kdif + \beta ref\,Kref)\,\alpha Cl \quad (9)$$

where: *β*—absorption coefficients defining doses of particular solar fluxes (*Kdir, Kdif, Kref*) absorbed by man, *α*—a parameter related to skin reflectance, and *Cl*—a parameter expressing thermal insulation of clothing.

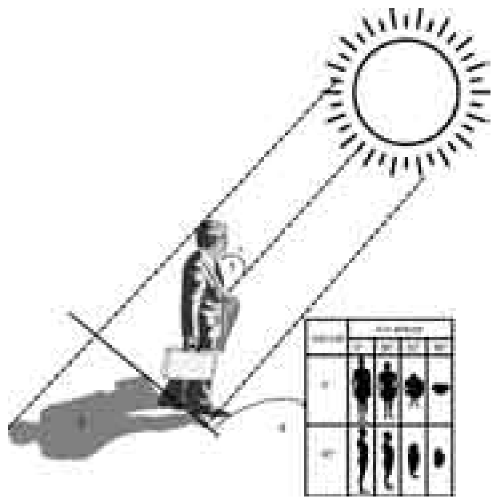


Figure 1. Parameters of solar geometry used in assessing absorbed solar radiation: 1—trigonometric function (e.g. Budyko and Cycenko 1960, Blazejczyk 1994, Krys and Brown 1990), 2—area of body shade cast on ground (Terjung and Louie 1971), 3—ratio of body area receiving solar beams (Breckenridge and Goldman 1971), 4—projected area (Underwood and Ward 1966).

The aim of this paper is to present the results of studies dealing with the absorption of solar radiation by a mannequin model and by a human being outdoors. The new models for assessing absorbed solar radiation are considered and their applicability discussed, along with that the whole radiation balance in human beings.

METHODS

The absorption of solar radiation were studied on both, a mannequin and subjects. The mannequin was used as a geometrical analogue model of a human being. Five series of measurements were made: in July 1995, October 1995, July 1996, July 1997 and August 1997. Research stations of the Institute of Geography and Spatial Organization of the Polish Academy of Sciences in Borowa Góra (35 km NE of Warsaw) and Hala Gąsienicowa (in the Tatra Mts) were the sites of field experiments.

The absorbed dose of solar radiation was derived from direct measurements of dry heat exchange observed on the surfaces of the mannequin (*DHm*) and subjects bodies (*DH*). *DHm* and *DH* values were measured using special, elastic heat flux plates with a diameter of 40 mm. Sensors were attached to the forehead, forearm, palm, chest, back, thigh and lower leg (Figure 2). At the same places the skin temperature of subjects and surface temperature of the mannequin were measured to control heat exchange by long-wave radiation (*Lm* for the mannequin and *Ls* for subjects). Heat loss by convection (*Cm*) was obtained from direct measurements made on the mannequin with the use of a heat flux plate covered by a lupollen dome. The *Cm* value has assumed to be similar for subjects.

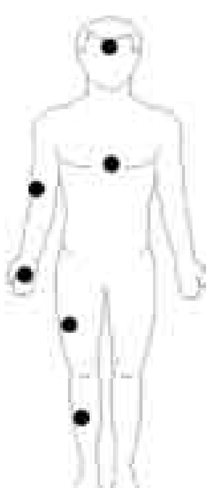


Fig. 2. Measurement points of dry heat exchange and surface/ skin temperature; the seventh point was on the back

Beside physiological parameters, meteorological elements, i.e. air and ground surface temperatures, wind speed, relative air humidity, vapour pressure were measured along with solar radiation (global, direct, diffuse and reflected) and long wave radiation (of the sky and of the ground). The data were registered automatically as 1 minute averages.

The absorbed solar radiation of the mannequin (*Rm*) and of subjects (*R*) were extracted from dry heat exchange as follows:

$$Rm = DHm - Lm - Cm \text{ and} \quad (10)$$

$$R = DH - Ls - Cm - M \quad (11)$$

where: *M* is metabolic heat production at subject (W m^{-2}) calculated for individual subjects using Schofield's equations (Schofield 1985). *Ls* and *Lm* were calculated using equation (5).

In the first part of the studies *β* coefficients were defined on the basis of measurements carried out on the mannequin. In operational use, solar radiation intensity is measured on the horizontal plane and *β* coefficients are used for its re-calculation for the human body surface. In the second part of the experiment, climatic and physiological measurements were made, and used in the validation of numerical models of absorbed solar radiation derived from the first, 'mannequin' part of investigations.

The STATGRAPHICS Plus, v. 1 software package was used to find statistical relationships between solar radiation intensity on the horizontal plane and that absorbed by the mannequin body, as well as for validation of ASR models.

RESULTS

Absorption of solar radiation depends on several factors: the intensity and structure of solar radiation, the Sun altitude (*h*), ground albedo, body-to-Sun orientation and insulating power and colour of clothing and skin. With a clear sky, global radiation increases in line with the Sun's elevation and can reach

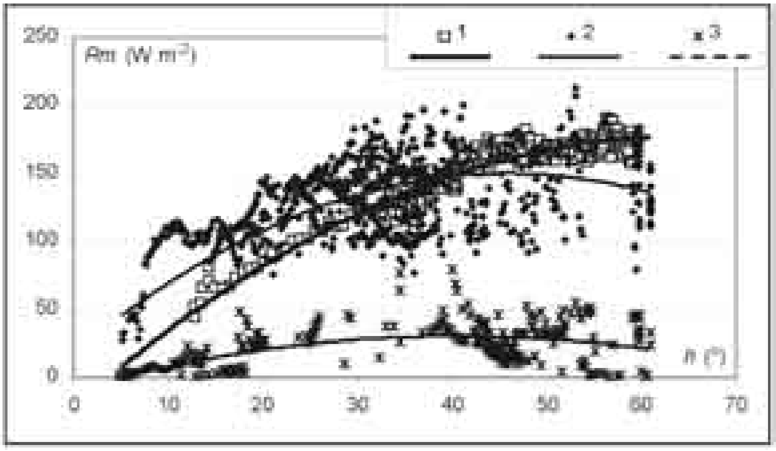


Figure 3. Solar radiation absorbed by a mannequin (*Rm*) at different Sun altitude (*h*) and various cluod scenarios: 1—clear sky, 2—cloudiness of 20-50%, 3—overcast sky.

an intensity of 1100-1200 W m^{-2}. Where ASR was concerned the highest values were observed at a solar elevation of about 55°; the regression line for ASR is very well correlated with *h* (r=0.98). However, in cloudy conditions (*N*=20-50%), the relationship between ASR and *h* is a little weaker than in a clear sky (r=0.85), and the greatest absorption of solar radiation occurs at Sun altitude of 30-60°. At a low solar angle (*h*<35°) ASR was bigger in cloudy than in clear–sky conditions. This is probably caused by diffuse radiation generated by reflections of solar beams from cloud cover (Figure 3). Similar relationships between ASR and solar angle were observed when using the ellipsoid, as another analogue model of man (Błażejczyk 1993, Błażejczyk et al. 1998).

An important role in solar radiation absorption is played by direct Sun beams. This can be seen when ASR is compared regarding subjects stood in sunny places and those shaded by trees. Both absorbed solar radiation and skin temperature were considerably higher during exposure to the Sun than in shadow. The biggest differences were observed at an intensity of global radiation of 500-600 W m^{-2}, which corresponds with

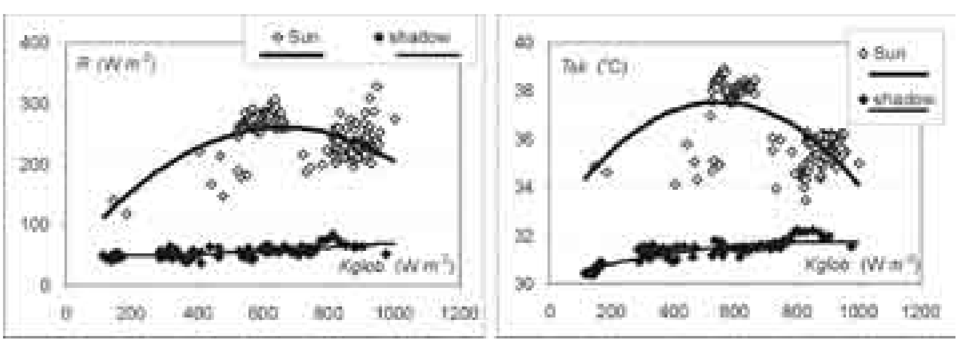


Figure 4. Absorbed solar radiation (*R*) and skin temperature (*Tsk*) in subjects during Sun and shadow exposition at various intensity of global solar radiation (*Kglob*).

a Sun elevation of 30-35° (Figure 4). Decreasing of R and consequently reduction of *Tsk* in high *Kglob* values are an effect of solar angle. *Kglob* >600 W m^{-2}, occurs at Sun altitudes >35°. At the same h values solar angle observed on the human body decreases and both, absorbed solar radiation (R) and skin temperature (*Tsk*) decrease as well.

The next factor which influences absorbed solar radiation is clothing. Two characteristics of clothing should be considered: thermal insulation (*Icl*) and albedo (*ac*). Insulation depends on the thickness and kind of clothing and albedo on the colour of fabric. The measurements made on the mannequin furnishes an example as to how clothing insulation influences ASR. Under clothing—with an insulation of 0.8 clo and albedo of 30%—*Rm* was up to 60% lower then on the nude mannequin. The biggest differences in *Rm* were observed at a global radiation of 400-500 W m^{-2}, which corresponds with a Sun elevation of about 30° (Figure 5).

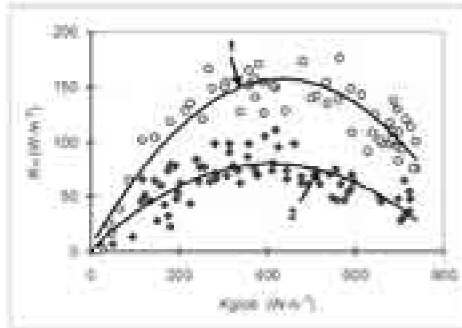


Figure 5. Solar radiation absorbed by nude (1) and clothed (2) mannequin; thermal insulation of clothing is 0.8 clo and its albedo is 30%.

The influence of clothing colour on ASR was tested on both the mannequin and on subjects. On a mannequin the physical process of the absorption of solar radiation is clearly observed. Under black clothing *Rm* was 50-100 W m^{-2} higher than under white. The difference in surface temperature was of 10-15°C. Where subjects are concerned it is not only the physical processes but also the physiological responses of an organism to radiation stimuli that play an important role. The R values were 50-100 W m^{-2} higher under black than under white clothing, as with the mannequin. However the response in skin temperature was different from that

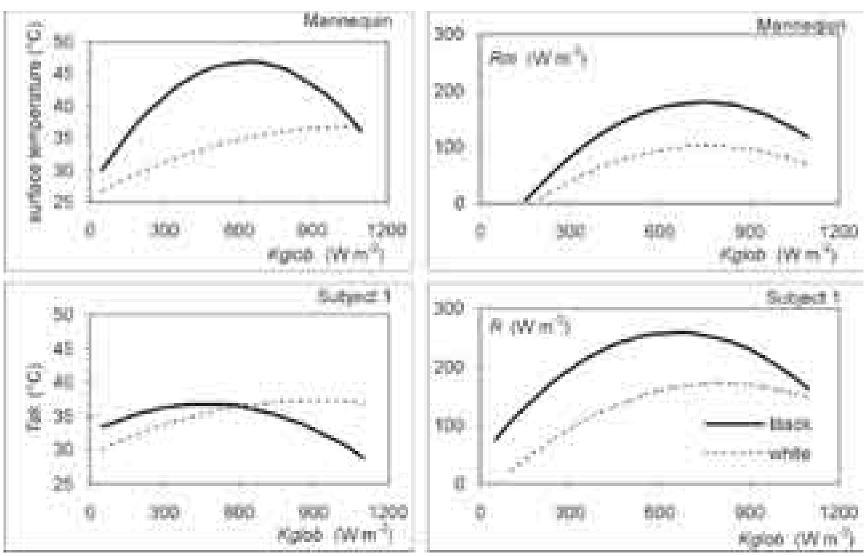


Figure 6. Relationships between intensity of global solar radiation (*Kglob*) and skin temperature (*Tsk*) and absorbed solar radiation (R) in a subject, as well as between *Kglob* and *Rm* values and surface temperature of a mannequin under black and white clothing (by Blazejczyk et al. 1999).

of the mannequin surface. At Sun altitude of <25-30°, *Tsk* under black clothing rises due to an increase in *Kglob*. This is manifested in activation of sweat glands and in the evaporation of sweat which caused a significant decrease in *Tsk* (Fanger 1972). Under white clothing, the skin surface heating was not so intensive, and subjects reported considerably lesser sweating than under the black. Thus skin cooling by evaporation was relatively limited and at a high *Kglob* skin temperature under black clothing was 2-3°C lower than under a white textile (Figure 6).

The main purpose of the research was to find the absorption coefficients which allow for a recalculation of the intensity of particular solar fluxes measured at meteorological stations (on a horizontal plane) to the radiation values absorbed by man. The results of experimental studies carried out on the mannequin provide information as to the coefficients of absorption (β). In general, β coefficients depend on the Sun altitude. For direct radiation β has two forms: at $h<5°$ βdir has a positive trend, and at $h \geq 5°$ βdir decreases due to an increase in the Sun's elevation, in line with an exponential function. For the sum of diffuse and reflected radiation one linear function of the β coefficient was found (Figure 7).

In the practice at meteorological sta-

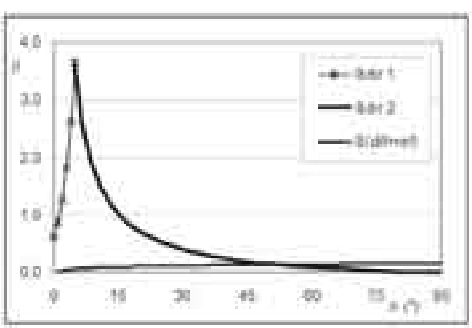


Figure 7. Absorption coefficient (β) at various Sun altitude (h) for particular fluxes of solar radiation (direct– dir, diffuse—dif, reflected—ref): βdir 1—at h <5° (r=0.682, n=76), βdir 2—at h >5° (r=0.869, n=2509), β(dif+ref)—for the sum of diffuse and reflected radiation (r=0.899, n=95).

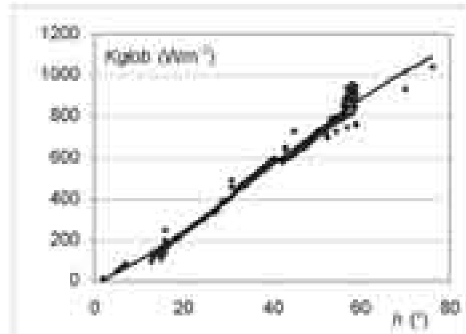


Figure 8. Relationships between Sun altitude (h) and global solar radiation (*Kglob*) under clear sky conditions (r=0.99, n=285, p=0.01).

tions it is most often global solar radiation alone that is measured. Thus, relationships between *Kglob* and absorbed solar radiation (*Rm*) were also studied. It was found that both, *Kglob* and *Rm* depended on cloudiness. The proportion of actual *Kglob* and potential level of global solar radiation under clear sky (*Kt*) was used as a relative measure of cloud cover. The equation for the calculation of *Kt* was derived from the measurements carried out in Poland and in Vietnam (Figure 8). The *Kt* equation has the form:

$$Kt = -0.0015\,h^3 + 0.1796\,h^2 + 9.6375\,h - 1.9 \qquad (12)$$

Absorption of solar radiation by a mannequin was studied as a function of global solar radiation at various combinations of Sun altitude and *Kglob*/*Kt* ratio. Several relationships were found. The correlation coefficients of the regression lines varied from 0.567 up to 0.943 (Figure 9).

The relationships between solar radiation intensity, Sun altitude and absorbed solar radiation were studied both, on the mannequin and on subjects. The results were used to elaborate new, numerical models of absorption of solar radiation by man.

NUMERICAL MODELS OF ABSORBED SOLAR RADIATION

On the basis of the β coefficients derived from the studies reported, the absorbed solar radiation (R) can be assessed in four dif-

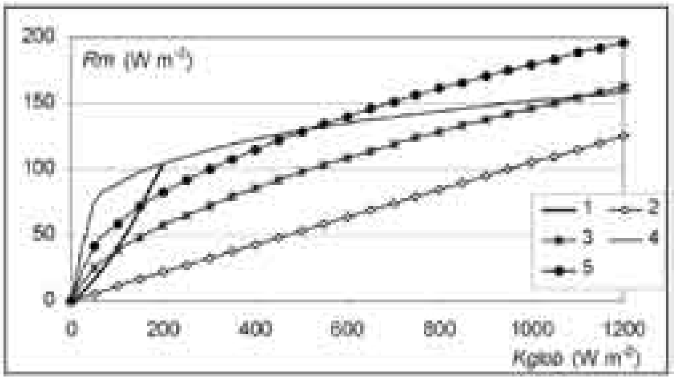


Figure 9. Solar radiation absorbed by a mannequin (*Rm*) as a function of global solar radiation (*Kglob*) at various combinations of Sun altitude and *Kglob*/*Kt* ratio:
1—at $h<12°$ (r=0.912, n=289), 2—at $h>12°$ and *Kglob*/*Kt* <0.8 (r=0.943, n=1648), 3—at $h>12°$ and *Kglob*/*Kt* of 0.8-1.05 (r=0.745, n=396), 4—at $h>12°$ and *Kglob*/*Kt* of 1.05-1.2 (r=0.567, n=0.274), 5—at $h>12°$ and *Kglob*/*Kt* >1.2 (r=0.741, n=720).

ferent ways, depending on the type of input radiation data.

When we use measured data of separate solar radiation fluxes the **SolDir** or **SolGlob** models can be applied. The **SolDir** model can be used when we have data of direct (*Kdir*) as well as diffuse (*Kdif*) and reflected (*Kref*) solar radiation fluxes. Depending on the Sun's elevation (*h*), absorbed solar radiation is calculated as follows:

—for $h \leq 5°$

$$R = [1.4\, Kdir\, e^{(-0.51\, +\, 0.368\, h)} + (Kdif + Kref)\times \times(0.0018 + 0.0462\, \mathrm{Ln}\, h)]\,(1 - 0.01\, ac)\, Irc \quad (13)$$

—or for $h > 5°$

$$R = [Kdir\,(26.34/h - 0.329) + (Kdir + Kref)\times \times(0.0018 + 0.0462\, \mathrm{Ln}\, h)]\,(1 - 0.01\, ac)\, Irc \quad (14)$$

where: *ac*—the albedo of the skin and/or clothing (%), *h*—the Sun's altitude (degree), *Irc*—coefficient reducing heat transfer due to clothing (see equations 6, 7, 8).

At a majority of meteorological stations only global solar radiation (*Kglob*=*Kdir*+ +*Kdif*) is measured. In this case we can use the **SolGlob** model to assess absorbed solar radiation. The equations have various forms depending on solar elevation (*h*) and *Kglob*/*Kt* ratios:

—for $h \leq 12°$,

$$R = (0.0014\, Kglob^2 + 0.476\, Kglob - 3.8)\times \times(1 - 0.01\, ac)\, Irc \quad (15)$$

—for $h > 12°$ and *Kglob*/*Kt* ratio ≤ 0.8

$$R = 0.2467\, Kglob^{0.9763}\,(1 - 0.01\, ac)\, Irc \quad (16)$$

—for $h > 12°$ and *Kglob*/*Kt* ratio of more than 0.8 up to 1.05

$$R = 3.6922\, Kglob^{0.5842}\,(1 - 0.01\, ac)\, Irc \quad (17)$$

—for $h > 12°$ and *Kglob*/*Kt* ratio of more than 1.05 up to 1.2

$$R = 43.426\, Kglob^{0.2326}\,(1 - 0.01\, ac)\, Irc \quad (18)$$

—for $h > 12°$ and *Kglob*/*Kt* ratio more than 1.2

$$R = 8.9281\, Kglob^{0.4861}\,(1 - 0.01\, ac)\, Irc. \quad (19)$$

It is relatively frequent for us not to have any data on solar radiation intensity at our disposal. In such situations, the relationships between absorbed solar radiation and Sun altitude at various cloudiness levels were analysed (Figure 10). Several regression equations with correlation coefficients

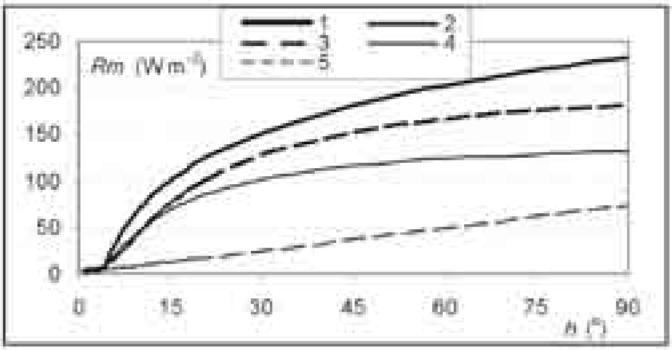


Figure 10. Solar radiation absorbed by a mannequin (*Rm*) at various Sun altitude (*h*) and cloudiness scenarios:
1—at $h \leq 4°$ (r=0.46, n=73), 2—at $h > 4°$ and *N* of 0-20% (r=0.896, n=432), 3—at $h > 4°$ and *N* of 21-50% (r=0.925, n=671), 4—at $h > 4°$ and *N* of 51-80% (r=0.806, n=991), 5—at $h > 4°$ and $N > 80\%$ (r=0.838, n=950).

r>0.8 and a standard error of estimation of ±9% were found.

These equations are the numerical form of the **SolAlt** model which can be used when we have at our disposal data on the amount of cloud cover only:

—for $h \leq 4°$

$$R = (1.642 + 0.254\, h)^2 (1 - 0.01\, ac)\, Irc \quad (20)$$

—for $h > 4°$ and $N \leq 20\%$

$$R = (103.573\, \mathrm{Ln}\, h - 140.6)(1 - 0.01\, ac)\, Irc \quad (21)$$

—for $h > 4°$ and $N = 21\text{-}50\%$

$$R = 1.4\, e^{(5.383 - 16.072/h)} (1 - 0.01\, ac)\, Irc \quad (22)$$

—for $h > 4°$ and $N = 51\text{-}80\%$

$$R = 1.4\, e^{(5.012 - 11.805/h)} (1 - 0.01\, ac)\, Irc \quad (23)$$

—for $h > 4°$ and $N > 80\%$ as well as for shaded sites

$$R = 0.9506\, h^{1.039} (1 - 0.01\, ac)\, Irc. \quad (24)$$

In some applications (e.g. the Klima-Michel Model of Jendritzky 1990, the IREQ

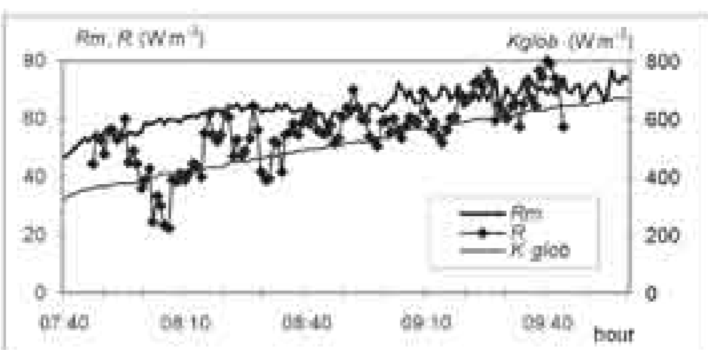


Figure 11. Values of solar radiation absorbed by mannequin (*Rm*) and by subject (*R*) during 2-hours exposition at sunny day, for the comparison global solar radiation (*Kglob*) is plotted, Borowa Góra, 14 July 1997.

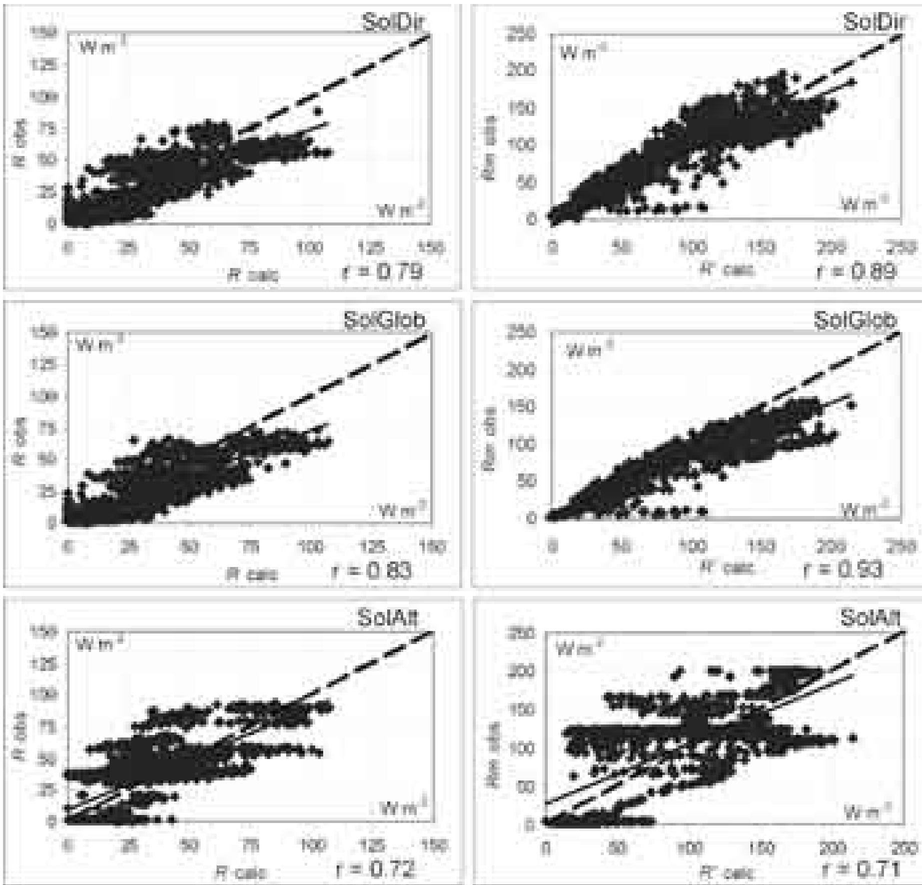


Figure 12. Relationships between measured values of absorbed solar radiation and those calculated with the aid of **SolDir**, **SolGlob** and **SolAlt** models: *R* obs—measured on clothed subjects, *Rm* obs—measured on a nude mannequin, *R* calc—calculated under clothing, *R'* calc—calculated without clothing; regression line is solid, identity line is dotted, r—coefficient of correlation.

model of Holmér 1988 or MEMI model of Höppe 1984), the so-called mean radiant temperature (*Mrt*) is used as a measure of the radiation impacts of an environment on man. In this case the *R* value can be calculated using the following formula:

$$R = \{[5.39\ 10^{-8}\ (273 + Mrt)^4] - [5.39\ 10^{-8}\ (273 + Ta)^4]\}\ Irc. \qquad (24)$$

VALIDATION OF THE MODELS

As was referred to above, the absorption of solar radiation was measured on both the mannequin and on subjects. The results of measurements made on subjects were used in the validation of those derived from the ‘mannequin’ part of the studies. There are two difficulties that were verified: 1) how *R* and *Rm* values correspond to each other, 2) how accurate are the *R* values calculated with the use of **SolDir**, **SolGlob** and **SolAlt** models, in comparison to measured ones.

Analysis of *R* and *Rm* values measured simultaneously shows that they are very similar. The differences reach 10-15% and are caused mainly by evaporation processes occurred at subjects’ skin. This effected short-term fluctuations of skin temperature and of heat flux as measured by heat flux sensors. However, the concordance between R and Rm values seems sufficient to provide that the mannequin model offers a good representation of the geometrical proportions of the human body (Figure 11). Thus **SolDir**, **SolGlob** and **SolAlt** models can be used in human heat-balance research.

The next step in validation was to compare values of absorbed solar radiation measured on clothed subjects (R obs) as well as on a nude mannequin (Rm obs). The calculations were made including the clothing factor (R calc)—when considering subjects—and without the clothing factor (R' calc)—when considering the mannequin. The set of independent data (n=1518) was used in this purpose.

The results point to a significant correlation between values of absorbed solar radiation measured on subjects and calculated ones. The highest correlation coefficients (r=0.83) were obtained for the **SolGlob** model and a slightly weaker r value (0.79) for the **SolDir** model. The weakest relationships (r=0.72) were for the **SolAlt** model. We can also notice better relationships obtained for the mannequin then for subjects; the correlation coefficients between Rm and R' values were 0.93, 0.89 and 0.71 respectively (Figure 12).

Taking into consideration all the statistical analysis it seems that the **SolDir** and **SolGlob** models provide a good approximation of absorbed solar radiation in humans. The smallest differences in average values between R obs and R calc were observed with the **SolDir** model: -3.6 W m^{-2} (-9.9%) for subjects and -4.9 W m^{-2} (-5.4%) for the mannequin. With the **SolGlob** model the same differences were -8.3 W m^{-2} (-22.3%) and -17.6 W m^{-2} (-19.4%), respectively. The maximal values of R calc were different from R obs of -17 W m^{-2} (-16.2%) for **SolDir** and -34 W m^{-2} (-31.8%) for **SolGlob** model. Similar proportions were noted for Rm obs and R' calc maximal values. The **SolAlt** model gives the weakest approximation of absorbed solar radiation. The mean error to the R estimation does not exceed ±5 W m^{-2}. However, extremal differences varied within the range ±50 W m^{-2} for subjects and ±150 W m^{-2} for the mannequin.

Figure 13. Location of meteorological stations used in the studies.

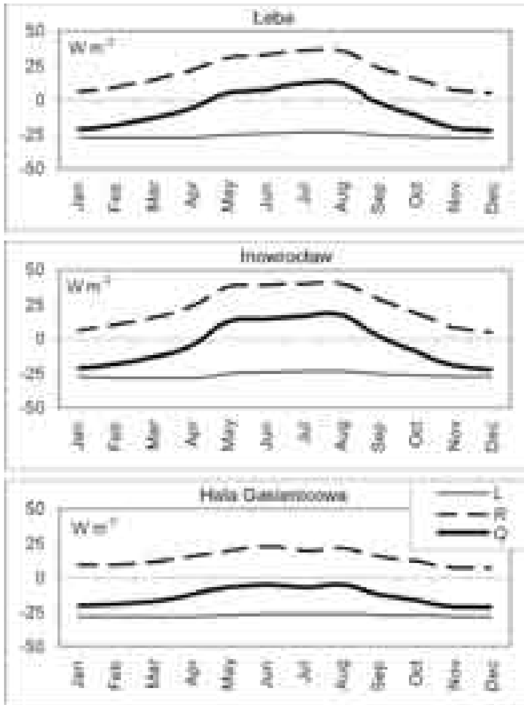


Figure 14. Annual course of the components of the radiation balance in man in selected regions in Poland, 1961-1980; *L*—net long-wave radiation, *R*—absorbed solar radiation, *Q*—radiation balance of man.

APPLICATION OF THE MODEL

The models proposed were used in various applications, e.g. for the assessment of the bioclimatic conditions of Polish health resorts (Kozłowska-Szczęsna et al. 2002) and in the evaluation of bioclimatic conditions for the needs of recreation in Warsaw agglomeration (Błażejczyk 2002). In the present study the model discussed in the paper was used to characterise the geographical distribution of the components to the human radiation balance in Poland. Three meteorological stations was chosen: Łeba—on the Baltic seashore, Inowrocław—in central Poland and Hala Gąsienicowa—a mountain station in the Tatras (south Poland) (Figure 13). The meteorological data from the period 1961-1980 were used in the calculations. Absorbed solar radiation in man was assessed using the **SolAlt** model. Net long-wave radiation was calculated using equations (2-8), and the radiation balance in man using equation (1).

No geographical and seasonal differentiation in net long-wave radiation in man is observed. Averaged *L* values vary from about -23 W m^{-2} in the summer to about -30 W m^{-2} in the winter. Absorbed solar radiation is significantly differentiated. The greatest *R* values are observed in the central part of Poland (Inowrocław); they vary from 5 W m^{-2} in the winter to about 40 W m^{-2} in the summer. Slightly lower is the absorbed solar radiation on the Baltic seashore (Łeba), 5 and 36 W m^{-2}, respectively. In southern Poland *R* values are the lowest, especially in the summer (up to 22 W m^{-2}). However, during the winter months the mountainous region of Poland has slightly better solar conditions then central and northern areas (Figure 14).

A relatively stable heat loss by long-wave radiation ensures that absorbed solar radia-

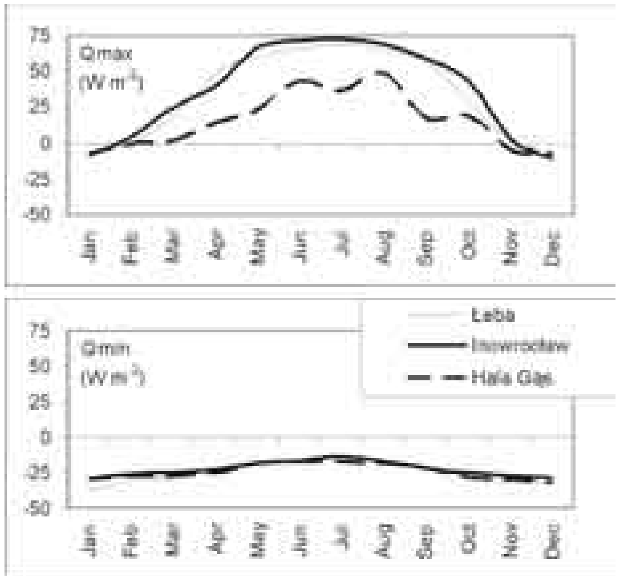


Figure 15. Maximal (*Q*max) and minimal (*Q*min) values of radiation balance in man in the chosen regions of Poland.

tion is the most important component of radiation balance in man (*Q*). In northern and central Poland *Q* varies—on average—from -22 W m^{-2} in the winter to about 15 W m^{-2} in the summer. Positive mean values of *Q* are observed from May to August. In the mountains, heat loss by radiation occurs during whole the year.

When analysing extreme values for the radiation balance in man we note than only in the winter is *Q*max negative. From March to November we can find meteorological conditions which lead to a net income of heat by radiation. The highest, positive *Q*max values, reach 70-73 W m^{-2} in central and northern Poland and 50 W m^{-2} in the Tatra Mts. In the latter area, maximal values for radiation balance are lowest during the whole year. However, minimal *Q* intensity is not differentiated spatially and seasonally (Figure 15).

CONCLUSIONS

When derived from experimental research carried out outdoors using analogue models of people (mannequins) and live subjects, numerical models of absorbed radiation would seem to give a good approximation of radiation balance in man.

The new models presented in the paper provide realistic values for absorbed solar radiation. They can be incorporated into the various models of human heat balance and be used in a range of weather and geographical conditions.

REFERENCES

Błażejczyk K., 1993, *Wymiana ciepła pomiędzy człowiekiem a otoczeniem w różnych warunkach środowiska geograficznego* (Heat exchange between man and his surroundings in different kinds of geographical environment), Prace Geograficzne IGiPZ PAN, 159.

Błażejczyk K., 1994, *New climatological-and-physiological model of the human heat balance outdoor (MENEX) and its applications in bioclimatological studies in different scales,*. Zeszyty IGiPZ PAN, 28: 27-58.

Błażejczyk K., 1996, *Assessment of solar radiation absorbed by man based on simple meteorological parameters,* [in:] Y. Shapiro, D.S. Moran and Y. Epstein (eds) Environmental ergonomics, Recent progress and new frontiers. Freund Publ. House, Ltd., London and Tel Aviv: 190-193.

Błażejczyk K., 1998a, *Promieniowanie słoneczne a gospodarka cieplna organizmu człowieka* (Solar radiation and human heat balance), Zeszyty IGiPZ PAN, Nr 51.

Błażejczyk K., 1998b, *Solar radiation and cold tolerance* [in:] I. Holmér and K. Kuklane (eds) Problems with cold work, Proceedings from an international symposium held in Stockholm, Sweden, Grand Hotel Salstjööbaden, Nov. 16-20, 1997, Arbete och Hälsa, 18: 111-113.

Błażejczyk K., 2000, *Absorption of solar radiation by man* [in:] J. Werner and M. Hexamer (eds), Environmental ergonomics IX, ICEE Rurh 2000, Medical Faculty, Ruhr-University Bochum, Bochum, Germany, Aachen, Shaker Verlag: 43-46.

Błażejczyk K., 2002, *Znaczenie czynników cyrkulacyjnych i lokalnych w kształtowaniu klimatu i bioklimatu aglomeracji warszawskiej* (Influence of air circulation and local factors on climate and bioclimate of Warsaw agglomeration), Dokumentacja Geograficzna, 26, 153p.

Błażejczyk K., Nilsson H. and Holmér I., 1993, *Solar heat load on man (Review of different methods of estimation)*. International Journal of Biometeorology, 37, 3, 125-132.

Błażejczyk K., Holmér I. and Nilsson H. 1998, *Absorption of solar radiation by an ellipsoid sensor simulated the human body,* Applied Human Sciences, 17 (6), 267-273.

Błażejczyk K., Tokura H., Bortkiewicz A., Kato M. and Szymczak W., 1999, *Thermoregulatory and circulatory reactions in subjects exposed to the sun and wearing white and black clothin.* [in:] J.A. Hodgdon, J.H. Heaney and M.J. Buono (eds), Environmental Ergonomics VIII, Int. Series on Environmental Ergonomics, vol. 1, Naval Health Research Center, San Diego State University, 177-181.

Błażejczyk K., Tokura H., Bortkiewicz A. and Szymczak W., 2000*, Solar radiation and thermal physiology in man* [in:] R.J. de Dear, J.D. Kalma, T.R. Oke and A. Auliciems (eds) Biometeorology and urban climatology at the turn of millennium, Selected papers from the ICB-ICUC'99 Conference (Sydney, 8-12 Nov. 1999), WCASP-50, WMO/TD No. 1026, World Meteorological Organization, Geneva, 267-271.

Breckenridge J.R. and Goldman R.F. 1977, *Effect of clothing on bodily resistance against meteorological stimuli* [in:] S.W. Tromp (ed.), Progress in human biometeorology, II, 194-208.

Budyko M.I and Cycenko G.V., 1960, *Klimaticeskie faktory teplooscuscenija celoveka* (Climatic factors and thermal sensations in man) (in Russian), Izvestia Akademii Nauk SSR, Geografia, 3, 3-11.

Clark R.P. and Edholm O.G., 1985, *Man and his thermal environment,* E.Arnold Ltd., London.

Fanger P.O., 1972, *Thermal comfort*, Technical Academy Press, Copenhagen.

Holmér I., 1988, *Assessment of cold stress in terms of required clothing insulation – IREQ*, International Journal of Industrial Ergonomics, 3, 159-166.

Höppe P., 1984, *Die Energiebilanz des Menschen, München Universitäts Schriften, Fachbereich Physic*, Wissenschaftliche Mitteilungen, 49.

Jendritzky G., 1990, *Bioklimatische Bewertungsgrundlage der Räume am Beispiel von mesoskaligen Bioklimakarte* [in:] H. Schirmer (ed.), Methodik zur räumlichen Bewertung der thermischen Komponente im Bioklima des Menschen, Akademie der Räumforshung und Landesplanung, Hannover, 114, 7-69.

Kozłowska-Szczęsna T. and Błażejczyk K., 1998, *Promieniowanie słoneczne i jego wpływ na organizm człowieka* (Solar radiation and its influence on man), Balneologia Polska, 40, 1-2, 130-141.

Kozłowska-Szczęsna T., Błażejczyk K., Krawczyk B. and Limanówka D., 2002, *Bioklimat uzdrowisk polskich* (Bioclimate of the Polish health resorts), Monografie IGiPZ PAN, 3.

Krys S.A. and Brown R.D., 1990, *Radiation absorbed by a vertical cylinder in complex outdoor environments under clear sky conditions*, International Journal of Biometeorology, 34, 69-75.

Matzarakis A., Rutz F. and Mayer H., 2000, *Estimation and calculation of the mean radiant temperature within urban structures* [in:] R.J. de Dear, J.D. Kalma, T.R. Oke and A. Auliciems (eds) Biometeorology and urban climatology at the turn of millennium, WCASP-50, WMO/TD No. 1026, World Meteorological Organization, Geneva, 273-278.

Schofield W.N., 1985, *Predicting basal metabolic rate, new standards and review of previous works*, Human Nutrition: Clinical Nutrition., 39 C, suppl. 1, 5-41.

Terjung W.H. and Louie S.S-F., 1971, *Potential solar radiation climates of man*, Annales of Association of American Geographers, 61, 3, 481-500.

Underwood C.R. and Ward E.J., 1966, *The solar radiation area of man,* Ergonomics, 9, 2, 155-168.

Received: February 2003

GEOGRAPHIA POLONICA, 77, 1, 77–88, Spring 2004
PL ISSN 0016–7282

VARIATION IN ACTIVE SURFACE TEMPERATURE IN THE NARA REGION OF JAPAN

ANNA BEATA ADAMCZYK
Institute of Geography and Spatial Organization, Polish Academy of Sciences, Warsaw
Twarda 51/55, 00-818, Warszawa, Poland
E-mail: a.badam@twarda.pan.pl

Abstract: A continuous variation of thermal energy, presented as air temperature, is registered by a ground-based network. However, an insufficient number of stations does not allow for the presentation of the spatial distribution of these values on the meso or micro scales. For this reason data recorded by a satellite sensor were used to analyse the variation in thermal energy on both spatial and temporal scales. Five satellite images were selected to represent seasons of the year and the thermal conditions of these days were validated. Apart from in August they presented typical thermal conditions for the month, thereby allowing the relation between different types of land cover and surface temperature in satellite acquisition time to be analysed.

Key words: air temperature, surface temperature, satellite data, type of land cover.

INTRODUCTION

The thermal energy flux emitted from an active surface and the resulting temperature are the most important variables in many studies. These elements create the actual weather and in consequence climatic conditions. Knowledge of the spatial distribution of temperature and its variation is therefore of basic importance in climatology and meteorology. The most popular method for receiving temperature data is a ground meteorological station network. The distances between these stations are optimal for a global study, but there are not enough for studies on the topo- and microclimatological scales. Consequently we have to use average data obtained from a few stations in a selected region.

Another method to obtain thermal data is remote sensing data acquisition. The advantage of this method is that we receive the most accurate data from every surface we want.

The energy radiated from a surface is a function of the temperature of that surface and its emissivity. Therefore, in a region with a mosaic land cover type its differentiation has a significant effect on the variability of surface and air temperature. This can be presented using the remote sensing method. The distribution of thermal energy results from natural features and human activities, such that for example: fields, houses and factories affecting its change (Adamczyk et al. 1999; Adamczyk 2002). It is important to know what causes the change in thermal energy and how these changes proceed.

In analysing seasonal variation in surface temperature, five satellite images were used. The Landsat earth resources satellite systems provide near global coverage of the earth's surface on a regular and predictable basis (Richards 1993). The Sun's synchronous orbit ensures that the satellite views the same point of the surface at the same local time at predicted intervals. This allows for a comparison of radiation changes over the sixteen-day cycle. The Thematic Mapper (TM) is one of two Landsat5 sensors. It has seven wavelengths with a 30-meter (band 1-5, 7) and 120-meter (band 6) spatial resolution. In this analysis all seven bands were used.

Image data recorded by the TM sensor on the satellite contains the signature of the object and the effect of the atmosphere. Path radiance was estimated from Rayleigh scattering which is represented by an inverse fourth power function of the wavelength. Path radiance was subtracted from the radiance observed by the satellite, and in this way reduced reflectance was obtained. The seasonal change in solar zenith angle and changing distance between the earth and the sun affect the radiance measured by the sensor. However, these effects were eliminated through the transformation of reduced reflectance into spectral reduced albedo.

To analyse temperature variation of an active surface it is necessary to classify different types of land cover. In this paper the classification was made using the Pattern Decomposition Method (PDM), as developed at the Department of Information and Computer Science, Nara Women's University. The PDM is an analytical method based on a linear spectral mixing of ground objects for multidimensional satellite data (Muramatsu et al. 2000, Adamczyk 2003). In this method the reduced albedo value for each pixel in an image is decomposed into three components using the three standard spectral shape patterns as follows:

$$Ai \rightarrow CwPiw + CvPiv + CsPis$$

Cw, Cv, Cs are decomposition coefficients for a water shape pattern, vegetation shape pattern and soil shape pattern, respectively. These three decomposition coefficients are found using the least-squares method and include two types of information. First is the characteristic of the shapes of the spectral response pattern and second the original reduced albedo value. The former information was used to determine the classification of land cover.

RESULTS

AIR TEMPERATURE

To analyse seasonal variation in thermal energy, five satellite images of the Nara Region of Japan were used. The days of acquisition were 27 June 1987, 18 November 1987, 22 February 1988, and 26 April 1988 at a local time of approximately 10:00. On 4 August 1995 the local time of acquisition was 9:30. The satellite TM sensor collects a datum once every 16 days. This represents thermal energy existing only at the extracted time of the given day. In the case of our analysis these are five mornings over the year. Thus to evaluate thermal conditions on analysed days they were compared with the typical monthly thermal conditions.

To validate the information on thermal

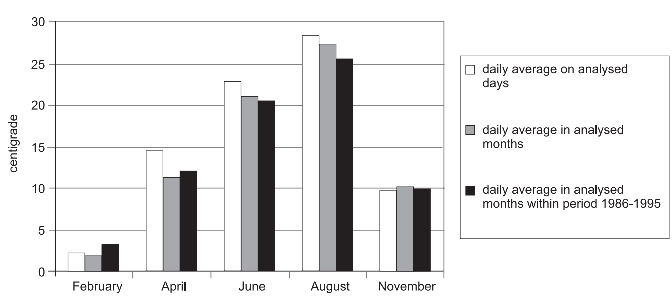


Figure 1. Seasonal variation of air temperature.

energy acquired by the satellite TM sensor, air temperature from ground measurement is given. The Automated Meteorological Data Acquisition System (AMeDAS) provides measurement of air temperature throughout the day. The information is given each hour over 24 hours (24 records per day). Daily air temperature on selected days, monthly air temperature and average daily air temperature from the year 1986 to the year 1995 (hereinafter called the average daily air temperature) were calculated (Figure 1).

In February, April, June and August, the daily air temperature was higher than the monthly air temperature, in November it was lower. However, as the standard deviation calculated for average monthly temperature shows, these differences are negligible (Table 1).

Weather conditions change according to the season but natural causes or human activity modify this change from year to year. 10 years is the optimal period in calculating average air temperature including the phenomenon mentioned above. The comparison of daily air temperature and average daily air temperature over 10 years showed that for April, June and August the daily air temperature was higher than the latter, while in February it was lower. This temperature was the same in November as in the other months. However, the standard deviation for the average daily air temperature was higher than or the same as for February, April, June and November. The exception was August during which the daily air temperature was greater than the standard deviation. This naturally indicated that only one day, 4 August 1995, had unusual, exceptionally hot, thermal conditions in the analysed period.

Mean daily temperature is a very useful variable in climatological studies. The standard mean daily air temperature is calculated from the whole day and contains both the maximum temperature of the day and the

Table 1. Standard deviation and difference between selected and average temperature for months. The value of the solar radiation coefficient is greater than 8 when the Sun operates for more than 50 min in an hour.

	February	April	June	August	November
Standard deviation of monthly air temperature	1.8	3.2	2.3	1.3	2.8
Difference between daily and monthly air temperature (°C).	0.3	3.2	1.8	0.9	-0.4
Standard deviation of daily air temperature over period 1986-1995	2.8	3.3	2.2	1.7	3.2
Difference between daily air temperature and that over period 1986-1995 (°C).	-1.0	2.4	2.2	2.8	-0.2
Standard deviation of air temperature in satellite acquisition time over period 1986-1995	2.9	3.7	2.7	1.4	2.9
Difference between air temperature in satellite acquisition time and that over period 1986-1995 (°C).	-1.6	3.6	1.8	3.1	0.6
Standard deviation of air temperature in satellite acquisition time when coefficient of solar radiation>8	2.9	3.7	2.4	2.0	3.4
Difference between air temperature in satellite acquisition time when coefficient of solar radiation>8 and that over period 1986-1995 (°C).	-1.8	2.8	0.0	2.1	0.4

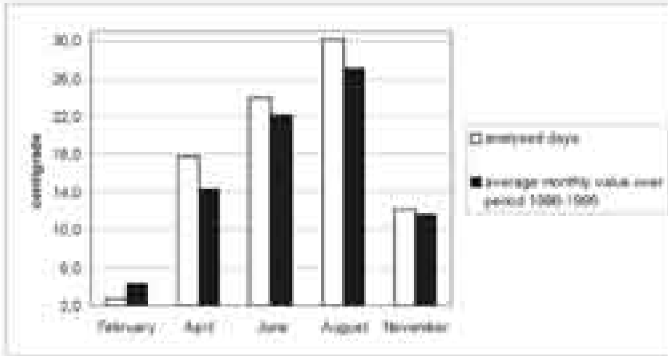


Figure 2. Seasonal variation in air temperature in satellite acquisition time.

minimum temperature of the night. But the temperature calculated from satellite data presented the hourly temperature—at 10 a.m. local time. The difference between mean daily temperature and temperature measured at the time of satellite data collection varied from 0.5°C in February to 3.1°C in April. This is the reason why mean daily temperature cannot be used to validate surface temperature measured by satellite at its observation time.

Instead of mean daily temperature the air temperature measured at the time of satellite data collection for each selected day will be considered. This type of temperature will hereinafter be called the satellite air temperature. This was analysed for selected days and in the period from 1986 to 1995 (Figure 2). For April, June, August and November the satellite air temperature was higher than that over the 10 years. A difference of over 3°C occurred in April and August. The minimum difference (of less than 1°C) could be observed in November. Regardless of such a big distinction (3°C), in April, February, June and November the satellite air temperature is typical for these months (Table 1). The only exception was the day in August, being much warmer than usual.

Weather conditions comprise many elements of which air temperature is only one. Solar radiation is the main source of thermal energy. Consequently, the value of

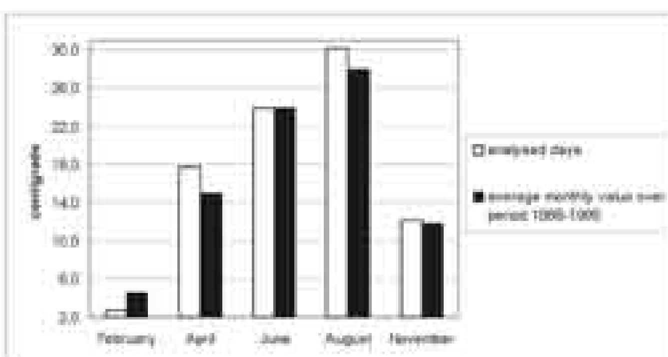


Figure 3. Seasonal variation in air temperature in satellite acquisition time when coefficient of solar radiation >8

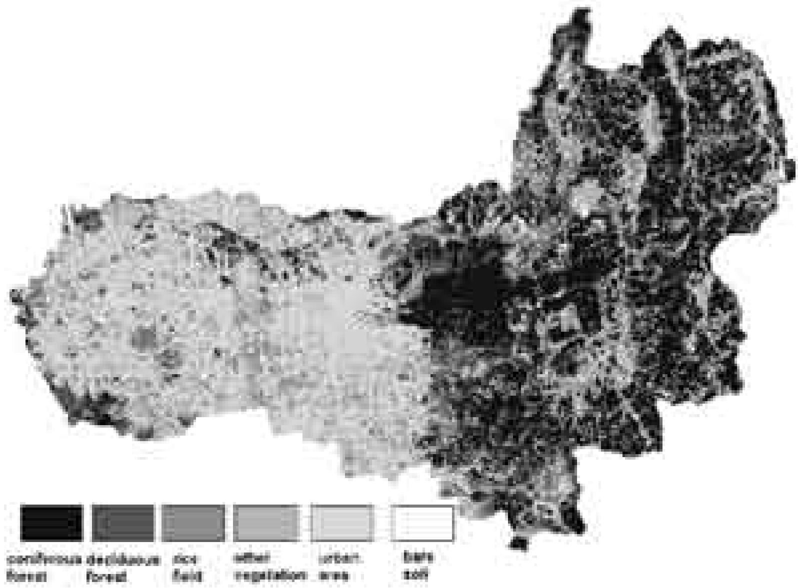


Figure 4. Classification of land cover in Nara City Region.

temperature varies with the duration of solar radiation, which is measured by AMeDAS stations as well as air temperature. Results were presented as a coefficient on a scale from 0 to 10: where 10 means that solar radiation reaches the surface continuously over 1 hour without any disturbance such as clouds. This is indirect information about cloudiness. Satellite images used for this analysis were taken when the weather was almost without clouds. Therefore, the satellite air temperature was only extracted with a solar radiation coefficient of more than 8. The days that exemplified these selected values were analysed as shown in Figure 3. In April, June, August and November the satellite air temperature for these days was higher than that over 10 years. In February it was lower. As in the previous calculation, this difference was negligible according to the standard deviation calculated for average satellite air temperature over 10 years for the days in question (Table 1).

The conclusion is that thermal conditions on the selected days in February, April, June and November were typical for the respective month. On 4 August 1995 thermal conditions were warmer. On the basis of these observations monthly thermal conditions will be considered using the above mentioned samples of thermal conditions.

CLASSIFICATION OF LAND COVER

Satellite data provide information about thermal energy from different kinds of active surface. The seven sorts of surface were distinguished: water, urban area, bare soil, deciduous forest, coniferous forest, paddy field and other vegetation such as grass or vegetable and tea plantations. It is supposed that these types of surface affect temperature changes over the year significantly.

Classification of land cover was achieved in the following manner. Since correction of geometric distortion was necessary to analyse more than one image, we co-registered the five satellite images mentioned in the previous section using the affine transformation equation with a set of control points. Next, the PDM was applied and spectral characteristics for types of land cover obtained. Next, different types of land cover were distinguished from the four satellite images of 26 April 1988, 22 February 1988,

Figure 5. Topographic map of Nara City Region.

27 June 1987 and 18 November 1987. Within the acquisition time of these images (over one year), the position of land cover types should be the same. Next, we matched the suitable types of land cover from four images. After that seven types of land cover for four satellite images were given.

The satellite image of 4 August 1995 was registered eight years after the previous one. Thus a new classification following investigation of spectral characteristics for the seven types of land cover mentioned previously, and for this particular satellite image was created. Finally, a classification into seven categories of land cover for the complete set of five satellite images was established (Figure 4).

According to this classification the Nara Region can be divided into western and eastern parts. The first is a low, flat area (Figure 5), which implies intensive human activities and, hence a concentration of urban areas and also a large expanse of rice fields. The western part contains 88% of the total urban areas in the Nara Region.

In the eastern part of the Nara Region the dominant category of land cover is forest, especially coniferous forest. This area has a diversified land configuration with a number of hills and valleys. Hence the main category of land cover is forest, situated on the slopes of hills and mountain ranges. Other types of land cover such as urban areas or rice fields are located along the river and valleys.

To make sure that the final classification was correct it was compared with a detailed digital land cover map. The Geographical Survey Institute created this map for the year 1985. The pixel size of the land cover map is 10 meters and the pixel size of the satellite image 30 meters. In order to make both the land cover map and the satellite data, uniform 3×3 neighbouring pixels of the land cover map were assumed to be 1 pixel. If the specified type of land cover occupies a maximum number of 3×3 neighbouring pixels, all of them are recognised as this specified type of land cover. The comparison result of the final classification and digital land cover map is shown in Table 2.

Considering the difference between the pixel sizes, the year of observation and the types of land cover, the result of the satellite data classification agreed with the land cover map, except as regards water. Water areas were not therefore taken into consideration in the following analysis.

VARIATION IN TEMPERATURE OF AN ACTIVE SURFACE

Variation in surface temperature was analysed using data from five satellite images. As considered in the previous section, thermal conditions on these days were typical for the analysed months in the period 1986-1995. This confirms the fact that each individual day can represent monthly thermal conditions irrespective of the year.

Table 2. Confrontation of satellite image class data and detailed land use data obtained by Geographical Survey Institute for 1985.

Class	Area (km^2)		Difference of area	
	satellite image	land use map	%	km^2
rice field	26.00	27.15	4.2	1.15
other vegetation	133.86	130.50	2.6	3.36
water	0.75	3.54	78.8	2.79
non vegetation area	49.54	49.03	1.0	0.51
				Σ 7.81 (3.7% of total area)
total	210.15	210.22	0.03	0.07

Surface temperature was calculated using satellite data. Satellite brightness temperature was transformed to surface temperature in line with the types of the surrounding area. The satellite resolution for thermal energy is 120×120 meters (pixel), and surface temperature was calculated for an area of this size using the Stefan-Boltzmann law of the form:

$$Ts = Tb^{*}\varepsilon^{-1/4}.$$

where: Ts—surface temperature, ε—emissivity of different type of land cover, Tb—brightness temperature acquired from satellite image.

The term surface temperature (Ts) in this case means the temperature calculated from the energy flux registered on a satellite or in space. This temperature is suitable for the layer in which energy exchanges take place. There is a canopy of forest, city or concrete pavement. In meteorological studies two types of temperature are measured by ground-based observation. The first is air temperature measured 2 m above the ground, with the thermometer sheltered to avoid direct solar radiation. Second is temperature measured on the ground. The altitude corresponding to surface temperature level above the ground depends on the field of view of the satellite sensor. This altitude can be over 15 meters in the case of a forest, or a few centimeters above the ground in the case of grassland.

The transformation of satellite data provides another thermal characteristic—the temperature of an active surface (Ts). This is an important index of heat exchange between an active surface and the atmosphere and plays the main role in forming air temperature. Using this method we obtain values of Ts in each pixel. The average value of the temperature of an active surface from the whole Nara region changes with the seasonal variation in incoming solar radiation. As shown in Figure 6, the maximum average Ts occurs in June (25.6°C), which represents the summer conditions of the year, and a minimum in February (2.1°C) representing winter conditions. A very small difference between the average value in June and August, of only 0.8°C, was noticed.

The maximum average Ts was in June, whereas the maximum value of air temperature occurred in August. In spite of warmer than typical thermal conditions on 4 August 1995, the temperature of the active surface was higher in June by 3°C.

The difference between maximum and minimum surface temperature in the day indicates a range for energy change depending on topographical conditions, including land cover differentiation. For the investigated period, the smallest difference was for summer conditions (7.5°C in August) and the biggest for winter conditions (28.4°C in February). In summer the Sun's elevation is higher than in winter, hence more incoming solar radiation reaches the horizontal

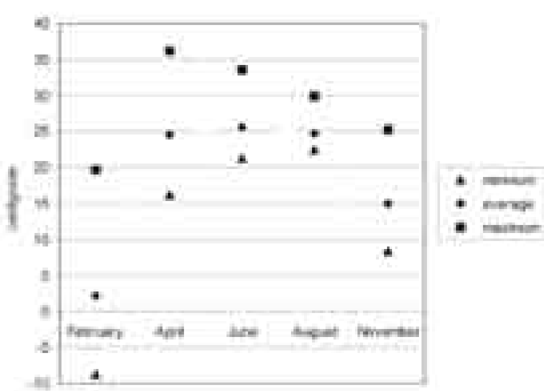


Figure 6. Seasonal change of surface temperature.

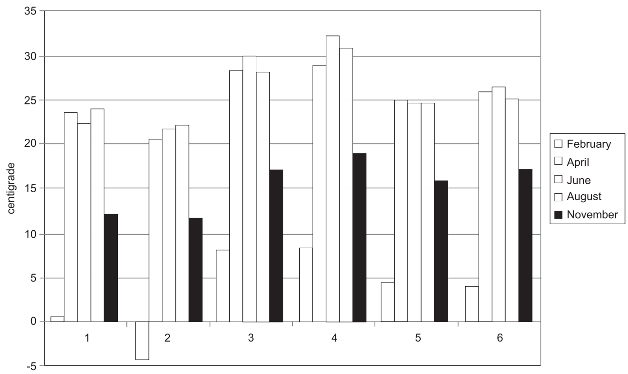


Figure 7. Average surface temperature in each category.

surface, causing a reduction in differences among the types of land cover. In winter most of the valleys and mountain slopes are in the shade, due to the Sun's low elevation, such that their surface temperature is very low, whereas the Ts of urban areas at that time is very high. It is clearly visible for the industrial region, with an additional, artificial source of energy.

The minimum Ts was observed in February in the eastern part of Nara Region, along the mountain range covered by forest with an elevation of over 500 m above sea level. In this place a relatively very low value of surface temperature occurred all year. The maximum Ts was registered in April, in the industrial area of the western part of Nara Region. This area had a very high value of surface temperature throughout the year.

The spatial distribution of active surface temperature depends on the type of land cover. As was mentioned before, Nara Region was classified according to six types of land cover. Generally the vegetation area that constitutes 76% of total area is situated mostly in the eastern part of Nara Region. The urban area occupying 23% is in turn concentrated in the western part. This disproportion in the distribution of the two main types of land cover results in the western part being significantly warmer than the eastern part during all the year.

The average surface temperature for selected land cover is as shown in Figure 7. For all the investigated months, it was forests that had the lowest value of average Ts. Forests, especially coniferous forests covering the shady slopes of the mountains and located at high altitude, significantly reduce the value of Ts. As could be observed, the deciduous forests appeared to have a relatively warmer signature than the coniferous forests. In February and April, deciduous forests are leafless and in these months the difference

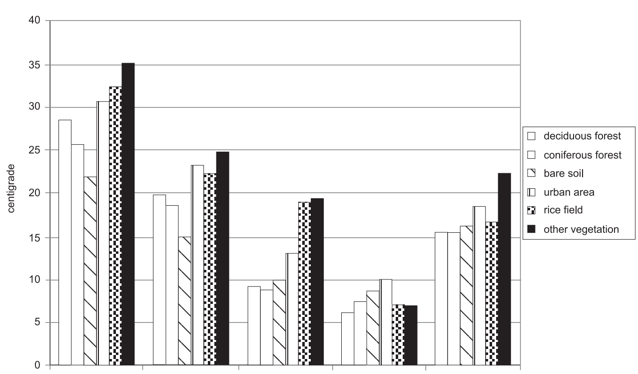


Figure 8. Differences between maximum and minimum surface temperature.

between these two types of forests in the region was the biggest over the year (4.8°C and 3.0°C respectively). In June and August foliage absorbs thermal energy, so that this difference was very small (0.7°C and 1.8°C respectively). In November the difference was smaller than the error of measurement. The urban areas had the highest value of surface temperature throughout the year, and the bare soil a slightly lower one.

The difference between maximum and minimum surface temperature is as shown in Figure 8. Ts varied with the class of land cover. In February, April, June and November, the biggest dispersion of the Ts value was registered for other vegetation (35.1°C and 24.8°C 19.3°C and 22.2°C respectively). This type of land cover comprises miscellaneous kinds of agriculture, and their location is near the urban area, as well as shaded mountain valleys. It is for these reasons that we could observe such a big disproportion in thermal radiation from it.

The smallest disproportion was registered in the most homogeneous types of land cover. In February and April this was bare soil (21.9°C and 14.9°C respectively) but in June and November—coniferous forests (5.7°C and 15.4°C respectively). The structure of coniferous forests is the same through the year, but due to their contrasted localisation (a high mountain and near a flat urban area) in Nara Region, this type of land cover had a bigger Ts difference than bare soil.

In August, the differentiation of Ts was modified. The smallest change was noted for deciduous forests (6.1°C) and a significant distinction between deciduous and coniferous forests (1.2°C) was thus observed. The biggest variation in the Ts value was in the urban area (10.0°C).

Similarities among all analysed images were as follows:

- The western part of Nara Region was distinctly warmer than the eastern.
- The forests and ponds had a significantly cooler signature than other types of land cover. Therefore, they were clearly visible in all the investigated months.
- The industrial area, closest to the southern boundary of Nara Region, was the warmest place.

The biggest city of Nara Region is Nara Town which comprises a compact settlement surrounded by parks and forests on the eastern side and residential districts consisting of houses and blocks on the others. In February and November the contiguous settlement area was cooler than the surrounding residential districts. At that time the surface temperature in the Nara Town area was lower than the Ts in agricultural areas such as rice fields or grassland. In April, June and August, the urban area indicated significantly higher Ts than the other types of land cover. As for Nara Town, in these months there were no differences between contiguous settlement and residential districts.

CONCLUSIONS

To analyse variation in thermal energy on both spatial and temporal scales, five satellite images representing seasons of the year were selected (27 June 1987, 18 November 1987, 22 February 1988, 26 April 1988 and 4 August 1995). The thermal conditions on selected days, apart from in August, were typical for the respective month (August 4th 1995 was warmer than average).

The average value of temperature changes with the seasonal variation in incoming solar radiation. Variation in both air and surface temperature were at a minimum in February and at maxima in August as regards air temperature and in June as regards surface temperature. The difference between maximum and minimum values of Ts on the day indicates the range of the energy changes depending on topographical features, including differentiation of land cover. For the investigated period, the smallest difference was in August and the greatest in February.

To understand the role of surface in forming the Ts, a classification of land cover was made and validated with a map of land cover. This was based on ground measurement. Except for water, the types of surface agreed significantly with the land cover map. They were therefore used to evaluate the role of different types of surface in Ts changes. The maximum average value of Ts occurs in the bare soil and the minimum in the coniferous forests. The spatial difference in Ts for types of surface varies with the class of land cover. Generally, this dispersion is high for short-stature vegetation. The only exception occurred in August, when the highest disproportion in Ts was noted for urban areas. Altitude also plays a very important role where Ts dispersion is concerned. The reason why the most homogeneous type of land cover- coniferous forest—revealed major differences between maximum and minimum surface temperature is that it covers the slopes of hills at a maximum elevation of over 1000 meters situated in the eastern part of the Nara region, as well as a flat area at an elevation of 100 meters in the western part.

The conclusion is that spatial variability of the surface temperature value is significantly greater in the western part of Nara Region than in eastern. The former is mainly covered by urban areas. Two kinds of urban area were distinguished in Nara Town. The first was compact settlement in the centre of the town. The second the residential districts consisting of houses and blocks of flats encountered in the compact settlement. In February and November the contiguous compact settlement was cooler than the residential districts. In both February and November the surface temperature in Nara Town was lower than in the agriculture areas such as rice fields or grassland. In April, June and August urban areas were significantly warmer than the other types of land cover.

In this analysis thermal energy was converted into surface temperature. The surface temperature describes thermal conditions on the level at which energy exchange takes place, which means that the altitude of a measured site varies depending on the kind of land cover. Interpretation of the results of analysed surface temperature from satellite data must therefore be carried out very carefully.

ACKNOWLEDGEMENTS

This paper was completed as part of a Japanese Government Scholarship. The author gratefully thanks Professor N. Fujiwara and Dr K. Muramatsu from the Department of Information and Computer Sciences Nara Women's University for their support and help in providing satellite images. Copyright by Department of Information and Computer Sciences, Nara Women's University.

REFERENCES

AdamczykA.B., 2003, *Analiza warunków termicznych metodą teledetekcji (na przykładzie okolic Nara w Japonii)* (Use of remote sensing data in the analysis of thermal conditions at Nara City Region, Japan), [in:] Błażejczyk K., Krawczyk B. and Kuchcik M. (eds) *Postępy w badaniach klimatycznych i bioklimatycznych* (Progress in climatic and bioclimatic research), 117-129.

Adamczyk A.B., 2002, *Mapa odchyleń temperatury promieniowania wykonana na podstawie zdjęcia satelitarnego* (Map of brightness temperature changes) [in]: K. Błażejczyk, *Znaczenie czynników cyrkulacyjnych i lokalnych w kształtowaniu klimatu i bioklimatu aglomeracji warszawskiej* (Influence of air circulation and local factors on climate and bioclimate of Warsaw agglomeration), Dokumentacja Geograficzna, 26, 151-154.

Adamczyk A.B., Muramatsu K. and Fujiwara N., 1999, *Seasonal variation of thermal energy of surface in Nara City*, Proceedings of the 27th Conference of the Remote Sensing Society of Japan, Kumamoto, Japan, 121-124.

Muramatsu K., Furumi S., Fujiwara N., Hayashi A., Daigo M. and Ochiai F., 2000, *Pattern Decomposition Method in the albedo space for LANDSAT TM and MSS data analysis*, International Journal of Remote Sensing vol. 21, 119—99.

Richards J. A., 1993, *Remote Sensing Digital Image Analysis: An Introduction*, New York: Springer-Verlag

Received: June 2003
Revised: September 2003

GEOGRAPHIA POLONICA, 77, 1, 89–95, Spring 2004
PL ISSN 0016–7282

RESEARCH NOTES

THUNDERSTORM SEASONS AND REGIONS IN POLAND

LESZEK KOLENDOWICZ
Institute of Physical Geography and Environmental Planning
Adam Mickiewicz University
ul. Fredry 10, 61-701 Poznań, Poland
E-mail: leszko@amu.edu.pl

Abstract: Taking into consideration the similarity to annual courses characteristic of the number of days with thunderstorms at Polish synoptic stations, an attempt has been made to determine potential seasons of thunderstorm days per year. The stations were also capable of being grouped such that Poland could be divided into five thunderstorm regions. Differences in the thunderstorm activity characteristics of particular stations and thunderstorm regions are connected with both the circulation of the atmosphere and such local conditions, as relief, land cover or the influence of the Baltic Sea on the coast.

Key words: thunderstorm seasons, thunderstorm regions.

INTRODUCTION

Analysis of thunderstorm occurrence in Poland reveals spatial differentiation to frequencies, as well as the great similarity of annual course characteristics. Previous studies have also shown that thunderstorm become more frequent as one moves from the north to the south of Poland (Stopa 1962; Atlas…1990). In the annual courses for the number of thunderstorm days at particular synoptic stations in north-western Poland it is possible to distinguish seasons characterized by particular intensities of thunderstorm activity (Kolendowicz 1996).

The aims of the research described here have thus been: to distinguish potential seasons of thunderstorm activity in Poland within the annual courses for the number of days with thunderstorms; to group synoptic stations with similar annual courses for the number of days with thunderstorms and to divide the territory of Poland into five regions with a specified characterization of thunderstorm activity.

DATA AND METHODS

The research is based on daily meteorological data from the years 1969-1998 concerning the occurrence of thunderstorms at 50 Polish synoptic stations of the IMGW (Institute of Meteorology and Water Management) (Figure 1).

To distinguish thunderstorm seasons within the year a division was made using a modification of the method which had been used by the author in regard to north-western Poland (Kolendowicz 1996). In the research, a division of the year into pentads was used together with a five-pentad moving average. The initial and final dates for particular periods were established on

Figure 1. Location of synoptic stations.

the basis of the transitions noted for the five-pentad moving averages for days with thunderstorms per year through respective liminal values. As a result, the year was divided into four seasons of thunderstorm activity on the basis of the following liminal values and names of particular seasons were assumed:

A—The season of growing thunderstorm activity—the five-pentad moving average is equal to or greater than 0.07 and smaller than or equal to the sum of the mean value and standard deviation for a given station.

B—The season of maximal thunderstorm activity—comprising pentads in which values of the five-pentad moving average are greater than the sum of the mean value and standard deviation for a given station.

C—The season of declining thunderstorm activity—where the five-pentad moving average is equal to or greater than 0.07 and smaller than or equal to the sum of the mean value and standard deviation for a given station.

D—The season of random thunderstorm activity—with values for the five-pentad moving average lower than 0.07 (corresponding with fewer than two days with thunderstorm per pentad over thirty years).

The similarity of the characteristics noted for the annual courses of numbers of thunderstorm days in some regions of Poland constituted the basis for the grouping of stations. Specifically courses for particular pentads of the year in the period 1969-1998 were grouped using the Ward method. The grouping had 49 stages and resulted in a division of the area of Poland into five regions of different thunderstorm activity. The result after the 46th grouping seemed the most interesting, being characterized by a rapid growth of binding distance in relation to the binding stages.

RESULTS

At all synoptic stations the beginning of a year is characterized by random thunderstorm activity. However, from April the number of days with thunderstorm increases quickly. From May to August the frequency and variability of occurrence of thunderstorm days are highest. The summer period is characterized by a noticeably greater number of thunderstorm days as one moves from the north to the south in Poland. Once the summer period is over, the number of thunderstorm days is abruptly lower, as, from the second half of October to the end of the year, days with thunderstorm occur very seldom. Diagrams for chosen stations are as given in Figure 2.

The analysis of initial dates for thunderstorm seasons and of the durations thereof at particular synoptic stations leads to a conclusion that the season of random thunderstorm activity is the longest. At the majority of stations it lasts 150-180 days per year. It was longer only in Gdańsk (200 days) and

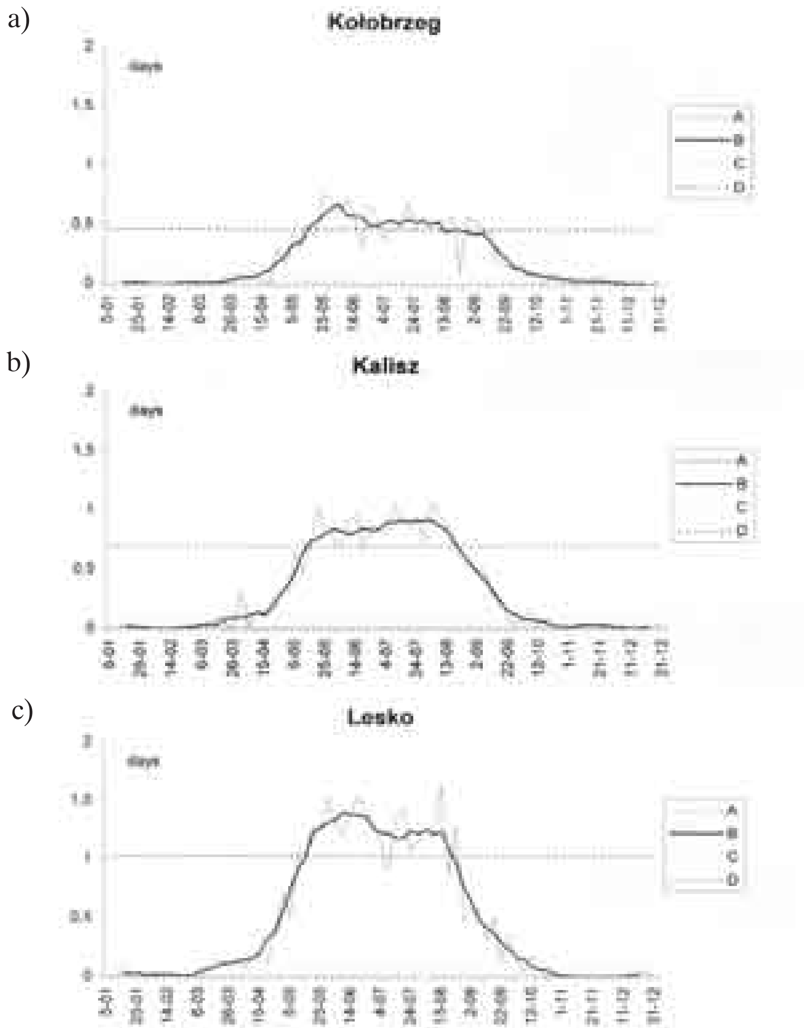


Figure 2. Thunderstorm days in Kołobrzeg, Kalisz, and Lesko, 1969-1998. Annual course of mean number of days with thunderstorms in pentads per year (A), five-pentad movable mean (B), the value of 0.07 corresponding with days with thunderstorm in a pentad (C), sum of the mean value and the standard deviation of the movable five-pentad mean (D).

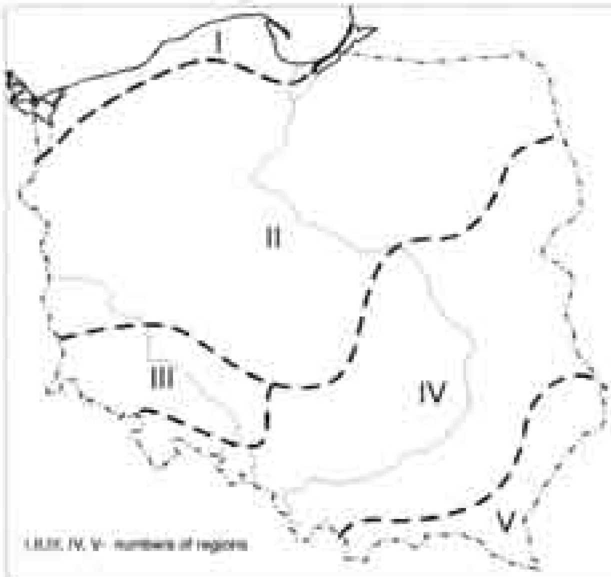


Figure 3. Thunderstorm regions in Poland.

shorter only in Ustka (140 days), Warszawa (130 days) and Katowice (145 days). This season begins in virtually all of Poland between 28 September and 27 October. It comes later only in the Warsaw Basin (after 7 November) and on the central part of the Baltic coast (after 17 November).

The season of the spring increase in growing thunderstorm activity begins earliest on the Silesian Upland (on 25 January) and southern part of the Kraków-Częstochowa Upland (2 March), and in the Bieszczady Mountains (7 March). It is in the latter that it lasts longest (over 60 days). The season starts latest on the Baltic coast and in the eastern part of the Pomeranian Lakeland. On the Baltic coast the season is also the shortest, as it varies in length from 25 days in Gdańsk to 35 days in Świnoujście and Szczecin.

The season of maximal thunderstorm activity is the second longest period after the season of random activity. It begins between 11 and 20 May at the majority of stations, and varies in length from 45 days in Chojnice to over 100 days on the central part of the Baltic coast. At most stations the number of days in this season fluctuates between 50 and 60 per year.

The autumn season of declining thunderstorm activity begins at most stations between 14 and 23 August. It comes earlier in Zamość, Chojnice and Gdańsk (on 9 August), and later on the central part of the Baltic coast (8 September). Its duration at most stations is from 45 to 65 days. Only in Ustka, Warszawa and Koszalin is it longer, lasting respectively 75, 85 and 90 days per year.

Grouping based on an assumption that a single station cannot form a separate region resulted in the division of Poland into regions characterized by different features of thunderstorm activity in the year (Figure 3).

Region I (5 stations) comprises the northern part of Poland from the Szczecin Lowland via Pobrzeże Słowińskie to the Vistula Delta. The region is characterized by the smallest number of days with thunderstorm per year (averaging between 12.3 in Gdańsk and 17.3 in Szczecin). The season of growing thunderstorm activity begins latest in this region (on 11 April) and is shortest (at around 31 days). The season of random thunderstorm activity is relatively long.

Region II (18 stations) covers the Pomeranian Lakeland, Mazurian Lakeland, Wielkopolska Lakeland and Wielkopolska Lowland. There are 18.5—23 days with thunderstorm per year here.

Region III (5 stations) covers the Silesian Lowland and western part of the Sudetes and Foreland. In this region the number of days with thunderstorm varies between 23.5 and 26 per year.

Region IV (15 stations) comprises the Mazovian Lowland, along with the Podlasie Lowland, the Małopolska Upland excluding Roztocze, the Sandomierz Upland and the western part of the Podkarpacie plus the eastern part of the Sudets and Foreland. In this region, the average number of days with thunderstorm per year varies from 24.8 to 29.2.

Region V (5 stations) covers the central and eastern part of the Carpathians and Foothills as well as Roztocze. At particular stations there are 30.6—33.8 days with thunderstorm per year.

The results of averaging the initial dates of particular thunderstorm seasons and their durations are presented in Tables 1 and 2. There is a noticeable delay as regards the initial date of the season of growing thunderstorm activity in the north and center in relation to the south of Poland. This season begins on 22 March in Regions III, IV and V, but five days later in Region II and with a twenty-day delay in Region I (on 11 April). Initial dates of the seasons of maximal thunderstorm activity and declining thunderstorm activity are similar throughout Poland and the differences are of less than five days. The average duration of these seasons is also similar at particular stations, with differences not being bigger than 10 days. The season of random thunderstorm activity begins latest in the north of Poland—in Region I. It lasts longer here than in the other regions, though the differences concerning both average initial dates and duration times are of not more than 10 days over the area of the whole country.

Table 1. Average initial dates of thunderstorm activity seasons in particular thunderstorm regions of Poland, 1969-1998. A—Season of growth in thunderstorm activity, B—Season of maximal thunderstorm activity, C—Season of falling thunderstorm activity, D—Season of random thunderstorm activity.

	A	B	C	D
R I	11.04	11.05	19.08	18.10
R II	27.03	16.05	19.08	13.10
R III	22.03	11.05	19.08	8.10
R IV	22.03	16.05	14.08	8.10
R V	22.03	16.05	19.08	13.10

Table 2. Average length (days) of thunderstorm activity seasons in particular thunderstorm regions of Poland 1969-1998. A, B, C, D as in Table 1.

	A	B	C	D
R I	31	101	57	176
R II	47	95	56	167
R III	50	98	48	169
R IV	53	93	55	164
R V	52	95	54	164

CONCLUSIONS AND DISCUSSION

To date the issue of thunderstorms and the courses to the number of days with them over Poland have been studied considering days and five- or ten-day periods as well as monthly periods (Arendt 1919, Gockel 1925, Stopa 1962, Kolendowicz 1996). An example of research from the USA is the work of Neumann (1971), where a 15-day moving average value for each day of the year was used. Pelz (1977) assigned mean values for each day of the year. A division into pentads was applied to present the frequency of occurrence of the first and last thunderstorm day in the year. Schüepp (1980) used a division of the year into months.

In this research, Neumann's method and the division of a year into pentads were considered and tested at a chosen station. The division of the year into pentads together with a five-pentad moving average allowed for the identification of dates of particular thunderstorm seasons, though the results were very similar.

Taking into consideration synoptic conditions leading to the occurrence of thunderstorms (Stopa 1964, 1966), as well as the growing probability of a thunderstorm together at successively higher mean daily air temperature (Kolendowicz 1998), it may be assumed that the cooling effect of the Baltic Sea in the spring and summer (Woś 1999) as manifested in northern Poland may bring about a decrease in frequency of thunderstorm days in this area, as well as a delay in the occurrence of the season of growing thunderstorm activity. In autumn, however, the Baltic Sea, being a warming element, may delay the onset of the season of random thunderstorm activity in this region.

It should be noted that the occurrence of a thunderstorm is conditioned by the simultaneous presence of two elements: macro scale atmospheric circulation and local factors. The first element (Barnes, Newton 1985) is responsible for a transport of moisture and heat energy as well as for the movement of bar systems over the area of Europe, the Mediterranean Basin and the eastern part of the Atlantic Ocean (Walker 1992, Kolendowicz 1998). The growing frequency of days with thunderstorms from 20 in the north to 30 in the south of Poland may be related to the growing frequency of occurrence of warm masses of tropical air over the southern part of Poland. The importance of local elements connected with interaction with the surface was reflected by Schaefer et al. (1985) and Gassman et al. (1983). The division of Poland into thunderstorm-prone regions presented in the current research—though based on different initial data—is similar to the one given by Stopa (1962). The boundaries of the determined regions correspond with the main boundaries of geographical regions. Thus the differences between the regions are also conditioned by local conditions connected with the land surface.

REFERENCES

Atlas klimatyczny elementów i zjawisk szkodliwych dla rolnictwa w Polsce (Atlas of climatic elements and phenomena hazardous for Polish agriculture), Instytut Uprawy, Nawożenia i Gleboznawstwa w Puławach, AR w Szczecinie. Puławy,1990.

Arendt Th., 1919, *Ergebnisse der Gewitter-Beobachtungen in den Jahren 1916, 1917, 1918*, Berlin, Behrend & Co.

Barnes S.N. and Newton C.W., 1985, *Thunderstorm in the synoptic setting*, [in:] E.Kessler (ed.), *Thunderstorm morphology and dynamics*, University of Oklahoma Press, 75-112.

Gassman F., Haschke D. and Rudin F., 1983, *Moeglichkeiten antropogener Veraenderungen der Gewittertaetigkeit*, EIR-Bericht Nr. 500, Würenlinger, November.

Gockel A., 1925, *Das Gewitter*, PDV Berlin Bonn.

Kolendowicz L., 1996, *Burze na obszarze Polski Północno-Zachodniej w świetle częstości występowania różnych typów cyrkulacji atmosfery* (Thunderstorms in the area of North-Western Poland in different types of atmospheric circulation), Zeszyty Instytutu Geografii i Przestrzennego Zagospodarowania, PAN. 39, Warszawa,109 p.

Kolendowicz L., 1998, *Zjawiska burzowe w Polsce a warunki synoptyczne* (Thunderstorms in Poland and synoptical coditions), Bogucki Wydawnictwo Naukowe, Poznań.

Neumann C.J., 1971, *The thunderstorm forecasting system at the Kennedy Space Center*, Journal of Applied Meteorology, Vol.10, October, 921--936.

Pelz J., 1977, *Die Gewitter in Berliner Raum*, Met. Abh., Neue Folge Serie A, Monographien, Band 1 Heft 3, Berlin.

Schaefer J.T., Hoxit L.R. and Chappell C.F., 1985, *Thunderstorms and their mesoscale enviroment*, [in:] E.Kessler (ed.), *Thunderstorm morphology and dynamics*, University of Oklahoma Press, 113-132.

Schüepp M., 1980, *Gewitter und Hagel*, Klimatologie der Schweiz, Heft 25/K, 48 p.

Stopa M., 1962, Burze w Polsce, Prace Geograficzne 34, Instytut Geografii, PAN,Warszawa 109-183.

Stopa M., 1964, *Warunki meteorologiczne sprzyjające powstawaniu burz w różnych masach powietrza*, Przegląd Geofizyczny 9, 1, 67-75.

Stopa M., 1966, *Prawdopodobieństwo występowania burz w niektórych regionach geograficznych Polski*, Przegląd Geofizyczny 1, Warszawa, 45-55.

Walker A., 1992, *Grossräumige Austauschprozesse der Atmosphäre als Ursache von Starkgewittern*, Phisische Geographie, 35, Zürich.

Woś A., 1999, *Klimat Polski*, Wydawnictwo Naukowe PWN, Warszawa, 302 p.

Received: April 2003
Revised: September 2003

GEOGRAPHIA POLONICA, 77, 1, 97–108, Spring 2004
PL ISSN 0016–7282

BOOK REVIEWS

Weather and Transportation in Canada, edited by Jean Andrey and Christopher Knapper, Department of Geography Publication Series, University of Waterloo, 2003, 289 pp.—Magdalena Kuchcik

The book brings together eight articles on the relationship between the weather or climate and transportation (transport, as it would be termed in British English). However, the scope of the problems discussed in this book is broader than the title suggests. The authors, Canadian climatologists in the majority, also consider the economic costs of disrupted mobility, new technologies of watch warning systems, drivers' perception of risk, etc. The articles are arranged into three thematic groups: weather and road safety, snow-related mobility challenges and disruptions.

Although the Canadian transportation system is qualified as one of the best on a world scale, traffic injures are the major cause of death among 1-to 44 year-old Canadians, and are responsible for 16 percent of all injury admissions to the acute care hospitals wards. Moreover, 21% of collisions resulting in injury and 18% of fatal collisions occur during inclement weather (intensive rainfall, snowfall, drifting snow or fog) that usually results in insufficient visibility. These factors are considered to be a direct or indirect cause of accidents in a majority of studies. The human factors of accidents, such as the effects of sunlight glare or of barometric pressure and/or heat stress on the psychophysical state of drivers, are in contrast dealt with only rarely.

One reason to conduct so many studies on the impact of weather on the transportation risk in highly motorized countries like Canada or the USA is a natural desire to save human life. Another reason is, however, economic, i.e., to reduce the financial losses provoked by traffic accidents. In Canada, one-third of traffic injures are attributed to bad weather, costing $700 million annually. Additionally, the half of property-damage collisions attributable to weather conditions are estimated to cost c. $400 million. Thus, a majority of the studies aimed at improving weather transportation systems for drivers seek to to mitigate the weather-related crash risk.

The volume's first paper, by Jean Andrey, Brian N. Mills and Jessica Vandermolen, reviews more than 40 empirical studies, conducted mostly in Canada, on weather-related crash risk and the role of weather information. Although the majority of Canadians are satisfied with the amount of weather information they are receiving and the accuracy of weather forecasts, as well as recognizing the elevated risk associated with freezing rain, blowing snow or fog, the crash risk is still highly elevated during slippery road conditions, etc. This implies that drivers care little about the weather. Unfortunately, drivers usually believe in their ability to handle most of the traffic situations arising in unfavourable weather conditions. A warning system thus needs to aim at enhancing risk perception, improving hazard detection and advising drivers. Considerable interest is directed towards the design and implementation of intelligent transportation systems (ITS), which would provide technological solutions to improve mobility, promote economic efficiency, reduce energy use and emissions of gases and increase safety on the road.

Two papers in the book report the results of precise scientific research on weather-related transportation issues. The first of these studies was led by Jean Andrey and Christopher Knapper, the second by Jeffrey Suggett. Of particular importance would seem to be the former study, which was based on a detailed questionnaire as to how drivers perceive and respond to changes in the driving environment (including weather). Irrespective of their age, educational level, employment status and the various environmental factors listed in the survey, the questioned drivers (n=446) all identified freezing rain as the second most important hazard factor (after alcohol). Fog, snow, a slippery road or glare were perceived as factors of moderate severity, while rain and high winds were thought even less hazardous. As regards the adjustments made in the face of weather hazards, more than 70% of motorists referred to reducing speed, but only one-third reported increasing concentration, while less than 10% spoke of the distance to the preceding vehicle. These findings are of a particular concern in the light of behavioural studies pointing to a lack of attention as a significant source of accidents caused by drivers. However, a high rate of weather-related collisions attests to the insufficiency of these adjustments made.

Conducting an empirical study on the weather-related crash risk in Regina, Saskachewan (in six-hour periods), Jeffrey Suggett found that the relative collision risk varies from 1.47 (for n=116) during rain, through 2.11 (for n=128) during a snowfall to 2.46 (for n=16) during mixed precipitation (the standard for dry weather being 1.0). The relative injury risk indices were of 1.42, 1.68 and 3.20 respectively. Thus, the collision risk is high for mixed-precipitation days as well as for several days following snowfall, due to snowy mud remaining on the road. Interestingly, wet roads seem to pose no particular threat to drivers.

Of great importance in increasing road safety in wintertime—especially in northern countries—is road maintenance. Traditional methods of clearing the road surface of snow and ice involve plowing, salting and sanding. The new technologies use road weather sensors to measure visibility, road surface temperature and weather elements, to provide thermal maps of road segments as well as road weather prediction models. These new technologies aim at improving road safety and reducing the cost of winter road maintenance. In 1998, these costs exceeded $1.3 billion in Canada and $2 billion in the USA, as an important budgetary expense for the respective governments (paper by Brenda Jones). Surprisingly, even in Canada there is no public agency or government department to engage in the systematic collection of winter road maintenance data on a regular basis. Clearly, such information would help in improving budgetary planning.

Notwithstanding the important expenditures on road maintenance, such a phenomenon as heavy snowfall in an urban area has been almost neglected in natural-hazard studies, as compared with floods, earthquakes, hurricanes or even avalanches. Thus, it is not surprising that impediments to the mobility of people, goods and services are thought to be the main result of heavy snowfall, and deaths or injures are rarely reported. The only exception was the January 1999 Toronto snow emergency (described in detail by a trio of climatologists: Brian N. Mills, Jeffrey Suggett and Lisa Wenger). The January 1999 snowfall in Toronto was considered the most severe winter weather episode in Canada since the beginning of the 20th century. In that January, downtown Toronto received over 118 cm of snow during the month and the depth of the snow cover reached 65 cm. Several snow storms and high winds yielded snow drifting and a high windchill. A large increase in the number of heart attacks among people shoveling snow was stated by the Emergency Services. Fortunately, injury collisions declined in those days due to a reduced mobility of inhabitants. The snow emergency interfered with air, road and rail transportation activity, entertainment, some kinds of manufacturing output, the distribution of goods and services, etc. However, other businesses (e.g., hotels, car and roof repair services or winter clothing shops) reported increasing revenues. In general, however, this period of extreme severe weather cost the city over $70million.

The next problem discussed in the book, by David Morvin and Max S. Perchanok, concerns the deicing by salt showing a steady and worldwide increase. In Canada alone, 4,750,000 tonnes of NaCl were used for deicing in winter 1997/98. 'Regrettably because of high release around storage and snow-disposal sites and through runoff and splash from road surfaces into soil, watercourses and water bodies, inorganic chloride road salt impacts the aquatic environment, plants and animals.' Historical surveys conducted by the Salt Institute show that the usage of salt during severe winters has grown since 1960, three to four fold depending on the province. Data presented in that study could be of assistance in defining the risk of environmental contamination by road salt in Canada, and provide input for models simulating the movement or dispersal of salt in the environment surrounding roads, and stimulate similar searches in other countries.

The last two papers concentrate on the interaction between the greenhouse gases emitted by means of transportation and the weather system, and on the impact that climate change exerts on transportation. Estimates made within the context of the United Nations Framework Convention on Climate Change suggest that transportation is responsible for 27% of global greenhouse gas (GHG) emission, just after the power industries producing 36% of GHG. While Canada may not contribute much to the world's totals for GHG (1.8%), Canada's 22 tonnes of GHG per capita (used more for moving people than for moving goods) leaves its people among the most 'fecund emitters', just after the United States of America at 25 tonnes, and far above the former Soviet Union at 16 tonnes. In his paper, Clarence Woudsma discusses several solutions as to how to reduce the gap between projected growing transportation emissions and the Kyoto Protocol, e.g., the use of alternative-fuel vehicles, a broader implementation of the Intelligent Transportation Systems improving transport system efficiency (and indirectly air quality), and changes in lifestyle (e.g. cycling instead of driving to work).

The most interesting paper from the climatic point of view would seemto be that by Jean Andrey and Brian N. Mills, who offer a critical summary of climate sensitivities of the transport system (road, air and marine), as well as presenting implications of climate change, as documented or predicted. In the face of climatic warming, especially in the northern and western regions of Canada, several issues have been raised, e.g., a geographical expansion of frequent freeze-thaw cycles that could accelerate road deterioration and a shortening of the ice-road season. Less-harsh winters are likely to result in savings, due to reduced route maintenance costs and salt corrosion-related damage to vehicles. However, summer heat would lead to increased pavement damage; and greater use of air conditioning in vehicles (which increase fuel consumption). Sea level rise would damage marine infrastructure, bridges, rail lines, airports etc. However, a warmer climate would bring a net benefit to the Canadian economy: rail infrastructure in the northern Canada would be spared, sea-level would rise, allowing for the entrance of larger ships with more cargo, fuel consumption by aircraft would likely decrease thanks to stratospheric cooling, etc. The paper presents some examples of adaptation of transport to weather and climate-change scenarios, as well as some recommendations for future studies. The authors' critical attitude towards Intergovernmental Panel on Climate Change statements and scenarios should be underlined. For example, to the following citation from the IPCC: 'Recent impact studies covering transportation refer only to developed countries such as Canada… [and]… generally analyze only direct impacts of climate on infrastructure and operations, the authors added comment that even statements about the studies in the developed world are often based on limited evidence and the last report of the IPCC contains even fewer references to potential transportation-related impacts and sensitivities.'

Weather and Transportation would seem especially valuable for academics and practitioners interested in studying the mutual influence of these elements. Meteorologists responsible for creating weather information systems would also find the book useful. Although there are many scattered publications as well as unpublished expert reports on the mutual impact of weather and transportation, the reviewed collection of papers is worth bringing forward to a larger audience on account of its uniqueness, conciseness and comprehensiveness. The fact that the book is based on Canadian examples does not restrict its value to Canada alone, the problems discussed being universal and the proposed solutions adaptable elsewhere.

And last but not least, the reviewer is pleasantly surprised to find some references to Polish authors—something that is rarely noted in the Western geographical literature.

Like any book, Weather and Transportation provokes some critical remarks. A thorough reader would notice the shortcomings in the presentation of methods used in analyzing the data and a rather popular manner of describing the problems treated in this book. As a bioclimatologist, I wonder why such a large group of people dealing with weather and transportation relationship would not have responded to the challenge of defining the human factors on the road, including e.g., physical responses to acute weather changes or meteorotropism among drivers. This should not have been neglected when 60-70 percent of all accidents on the road occurred during fine weather and were due to driver error.

Magdalena Kuchcik
Institute of Geography and Spatial Organization
mkuchcik@twarda.pan.pl

Spatial Dynamics of Mediterranean Coastal Regions. An International HDP-oriented Research, Vol. 1: The North-Eastern Mediterranean, Vol. 2: The Mediterranean Island-states and Maghreb Countries, Pàtron editore, Bologna, 2002, edited by Berardo Cori and Enrica Lemmi—Niels B. Groth

COASTALIZATION OF MEDITERRANEAN COUNTRIES

One may argue that coastal regions are peripheral, situated as they often are on national borders. However, coastal regions have also been centres of overseas trade and trade-related industries. If one adds to this the development of mass tourism and second home settlements after the Second World War, it could be argued that coastal areas are at the centre of development rather than on the periphery. Due to the competition for land generated by overlapping interests of land-use and the vulnerability of natural assets in coastal areas, politicians and spatial planners have shown a special interest in the development of coastal regions.

As an example, one could mention the cooperation that took place among the countries around the Baltic Sea just after the fall of the Iron Curtain. They agreed to prepare a joint vision for spatial development and an Agenda 21 for the entire Baltic Sea Region. One of the first follow-up actions was the preparation of joint guidelines for the planning of the coastal zone around the Baltic Sea.

Another example is a study of spatial development that addressed the Mediterranean Coastal Regions, a project conducted by geographers from Italy, Albania, Greece, Tunisia, Algeria and Germany. At the initiative of Adalberto Vallea and the Pisa Geographical School, the research group conducted an analysis of the Spatial Dynamics of Mediterranean Coastal Regions.

The analysis deals with the growth, change and pressures that have characterized the spatial evolution of the coastal belt of Mediterranean countries over the last few decades. 14 separate case-studies deal with the Adriatic coastal regions of Italy, Croatia and Albania, the coastal regions of Greece and Mediterranean Turkey, Tunisia and the coastal regions of Algeria and Morocco and the islands of Cyprus and Malta.

The project received financial support from the Italian National Research Council and from the Italian Ministry of Universities and Scientific Research and Technology. The research project was initiated early in the 1990s and issued its report in 2002 in two volumes, edited by Berardo Cori and Enrica Lemmi.

Within a common thematic framework, each of the 14 case-studies tells its own separate story, thoroughly revealing the peculiarities of its part of the coastline. However, the case studies also demonstrate that in most Mediterranean countries, coastal regions share the same destiny of becoming the locus of development. Urbanization, mass tourism, second home settlements, road centre development, industrialization and more recent restructuring of industry are taking place within the coastal regions, along with congestion, urban sprawl, competition for land and environmental hazards. Taken together, these developmental changes are called coastalization.

However, common trends and individual peculiarities of coastalization are only tacitly present in the report, since the reader looks in vain for an introduction, a summary and conclusions. Only a brief preface informs the reader that an introductory essay was published elsewhere.

All the case studies reveal the land-use pressures and conflicts in the coastal regions, usually at the expense of the inland regions. It is emphasised that, in some of the former colonial countries the coastalization was initiated long ago, during the colonial era. Thus, in Tunisia and Morocco, the colonial rulers gave priority to the harbour cities. After independence, coastalization was given a new momentum as in most of the other Mediterranean countries by industrialisation and mass tourism. Just one example shows the overall impact of coastalization: In Tunisia 5.7 million people are living within a 20,000 km^2 coastal region, whereas 3.3 million people live in the 150,000 km^2 inland region. The coastal region contains 80% of industrial areas and 90% of hotel accommodation.

Throughout the Mediterranean region, tourism is seen as an important stimulus for economic development. However, tourism also impoverishes landscapes and poses environmental threats. Thus, Greece is facing the problems of tourist saturation, it is argued. The natural vegetation and the productive landscape have gradually changed into an aesthetic landscape with a predominantly decorative character. This ‘artificialization’ of the coastal environment calls for specific programmes for balancing promotion and protection at the same time. Therefore, a Carrying Capacity Assessment was conducted in the central-eastern part of Rhodes as a first step in launching such a programme more generally. However, efforts to implement development control based on the assessment encountered strong resistance; the local economy is now based especially on tourism.

In coastal regions, the urban system has usually developed according to different but coexisting economies, e.g., one driven by industrial development and one by tourism. In northern Adriatic Italy, an urban system of high-order services pivoting on the provincial capitals coexists with a ‘seaside tourist area’ stretching uninterruptedly along the whole coastal arc and based on hotel tourism and second-home tourism. In Greece, the urban system is characterized by an urban hierarchy of a few important old centres at the higher level accompanied by a recent and enormous fragmentation at the base. The authors of the Greek study emphasise that the urbanization process has not just been characterized by a shift back from the growth of the metropolitan areas to the smaller and medium-sized cities. Rather, new forms of urbanization have emerged, driven by recreational and tourist functions located outside, more or less independently of the former urban hierarchies.

The development of tourism has taken

different points of departure. In the European countries, especially in Italy, hotel tourism in the 1930s represented the start. Later, domestic needs for a second home and campsite tourism developed, ending up with recent mass-tourism based on tourist resorts. In the former socialist countries, e.g., Croatia, formerly part of the Federal Republic of Yugoslavia, the factories almost always directly managed the structures intended for their employees' holidays during the socialist period. This situation has now changed, and tourism has become an economic force in itself. This new economy is, however, monitored with a lack of local influence, due to an extremely centralized institutional structure established after independence.

In Turkey, the exploitation of the economic potential of tourism was the motivation for adopting Western-style tourism. As in most Islamic countries, religious-cultural and peasant-nomad traditions formerly played a significant role in organizing leisure time. This situation first changed by governmental initiatives. In 1953, a law for tourism promotion was passed with the purpose of bringing Turkish workers up to a more regular and co-ordinated 'Western-style' holiday behaviour, in order to avoid the heavy losses incurred from individual vacation leave from work. Subsequently, the real birth of modern mass tourism took place after 1982, when the second 'law for tourism promotion' was passed in order to attract foreign investment and compete with the more developed Mediterranean holiday destinations in Italy, Spain and France, as well as Tunisia and Greece.

A crucial issue for several case studies is how industrialization takes place. On the one hand, large-scale industrialization is needed for regional development and promoted by national programs. On the other hand, industrialization based on endogenous endowments and local control is accorded high priority by the researchers. The Italian studies reveal both kind of industrialization. In the Marches a decentralized production structure was established, made up by small businesses, artisan enterprises, separate departments and work carried out at home. This kind of structure, referred to as industrial zone or 'system area', allows for lower costs, flexibility and competitiveness. However, it also poses serious limitations such as reduced levels of production, weak direct contacts with financial markets and subordination from purchasing centres. The Bari area, south of the Marches, was characterized by the presence of a substantial base of small and medium-sized industrial activities. They formed the legacy of entrepreneurial experience and 'industrial culture' which later contributed to extensive episodes of industrial growth during the 1960s, facilitated by national regional development programmes, rather than by local initiatives.

The authors note that the large-scale industrialization of the Bari area showed a pronounced division of labour between the industrial centres. Moreover, the high level of specialization did not create any complementary bonds between the centres. This observation runs contrary to recent assumptions and political aspirations that the functional and economic division of labour between centres has created a sound basis for complementary urban relations and, hence, for the development of polycentrism, a core concept of the EU spatial development policies. The Bari case study is thus a useful case study within the current research agenda on polycentrism. The argument of the Bari study is that the larger companies, as operational units of national and multinational companies, produce effects and functional bonds which go beyond the local level and integrate on the national scale. The companies do not seek out contact with the potential of the regional economy but establish themselves as independent 'islands' in technical, financial and commercial terms.

Also in Tunisia, industrialization was characterised by large-scale industrialization and a top-down process. After independence, Tunisia planned to break away from the French system and to relaunch the various economic sectors. Particular attention was given to the industrial sector. In the early 1970s, Tunisia experienced a phase of industrialization by big industry set up mainly by the state and almost always financed by public capital and private investment from abroad, especially the Arab countries. In 1981, however, the government encouraged Tunisian companies to produce consumer goods for the local markets. As a result, there has been a more recent growth of small and medium-sized businesses, many of which have formed partnerships in order to obtain a patent or share an international brand name.

The concern for local influence on development is very pronounced in the Croatian study. The authors observe that the dynamics that affected the Croatian coastal belt are almost exclusively of external origin. During the 1950s and 1960s, the driving force was the Federal Yugoslav Government. It gave priority to strategic sectors, such as shipbuilding and energy industries. Little room was left open for local administrators. This situation has not been modified with the independence of Croatia, as an extremely centralized institutional structure has been adopted. The authors argue that lack of local influence and disorganization of the local administrations, the change in population and the decline of traditional activities have all made autonomous paths of development nearly impossible.

Local influence on development varies among the Mediterranean countries. Thus, the Turkish study observes that the dominance of the governmental administration on local development contrasts with the states of the north-western Mediterranean (Spain, France and Italy). In the latter countries, spatial change dynamics are generally controlled at the lowest level of the administrative hierarchy. However, the authors observe that governmental control in Turkey is often only insufficiently perceived by the national administration, partly due to the relative independent behaviour of sectoral administrations.

It is obvious that the Mediterranean countries offer great opportunities for comparing and learning about administrative principles and political monitoring of regional development in countries with different cultural and political backgrounds. The case of Cyprus is of special interest due to the parallel developments created by two different political regimes following the partitioning of Cyprus, in 1974, into Greek and Turkish sectors. In the Greek sector, further development of industry and especially tourism took place, whereas the development of the Turkish part occurred at a much slower pace. Being located under the same climatic, cultural and environmental conditions, the diversification of the development in the two sectors is a showcase of achievements obtained by different political-administrative regimes.

The question of local influence has a special relevance to the former colonial states. They are challenged not just by new external forces in the era of globalization but also by the trauma of colonialism. Thus, the case-study of Morocco interprets the impacts of recent international policies for sustainable development as a return to the period of colonial territorialization. It was during colonial times that the inland located centres of the former caravan trade at the foot of the Atlas Mountains, were replaced by the European driven commercial and colonial exploitation of the coastal strip along the Atlantic Ocean. Once set in motion, the coastalisation continued even after the independence and the reunification of Morocco. The recent adoption of the ‘sustainability’ concept by international organisations has deeply affected relations between Morocco and international funding agencies as well as the national development policies for the coastal strip. Large French and other European companies were invited to take over crucial infrastructure development projects, e.g., public water management. In the long run, the promotion of intervention strategies in the name of sustainability induced by the outer world is characterised by the penetration of sectoral policies without effective evaluation of the local opportunities or impacts.

The 14 case studies reveal interesting observations dealing with specific Mediterranean issues. However, the case studies also show development trends and policy-making of more general interest, since the coastal regions are arenas of social and geographical development. Unfortunately, the report is not guided by any editorial contributions. And this is my main objection to the report. Without any overall organizing framework, the individual case studies do not form a report. Rather, the case studies form an annex to a report that has yet to be written. I strongly recommend completing the task by editing a joint summary report. The purpose of such a summary report would be to show which spatial trends and policies are jointly shared by the Mediterranean countries and which are not. We still need to know whether the Mediterranean countries share common challenges and a common future. Only one case study—the Algerian—asks for policy measures to be taken jointly by the Mediterranean countries. It is regrettable that no comparative research based on the case studies has been conducted. The reader must show an inordinate amount of enthusiasm to read all the case studies. Yet this does not compensate for missing comparative information; we are at the mercy of the individual research interests of the authors. To establish a common platform for a comparative understanding is a job for the editor.

If a joint report were to be prepared, I would recommend improving several maps and adding new ones. No map of the entire Mediterranean region is included in the present report. Thus, it is difficult to obtain a brief overview of e.g., those coastal regions included in the project and those not included. The title does not indicate that only a part of the Mediterranean coastal regions are included in the study. Thus, not included are the western coast of Italy, and the coastal regions of France, Spain, Libya, Egypt, Israel and Syria. Further, several maps in the present report are of poor quality, in some instances, names referred to in the text are missing. In other cases, legends are missing.

I would also recommend including a brief introduction to the current state of research within the relevant fields. As a minimum, some introduction to the HDP research programme is needed. This programme is referred to as the most important frame of reference for the case studies, yet the reader is told nothing about the programme.

These case studies are valuable contributions to our knowledge about the spatial dynamics of the Mediterranean coastal regions in particular and to our knowledge about spatial development in general. However, we should expect more than individual contributions from a joint effort of so many skilled researchers.

Niels Boje Groth
Senior Researcher
Danish Centre for Forest, Landscape and Planning
nbg@kvl.dk

Irregular Migration. The Dilemmas Of Transnational Mobility, edited by Bill Jordan and Franck Düvell, 2002, Edward Elgar, Cheltenham, UK, 284 pp. —Izabella Koryś.

This book from Bill Jordan and Franck Düvell is a very remarkable publication for at least three reasons.

Firstly, irregular migrations—although accounting for a substantial share of current migration flows—have rarely become the subject of systematic scientific research (their irregular character is one of the major obstacles that preclude reliable and trustworthy measurement and examination of this phenomenon).

Secondly, Jordan and Düvell attempt to identify structural factors that determine the continuous inflow of irregular migrants to rich Western countries. In examining the complex grid of factors determining international migration flows, the authors refer to economic theory, globalization processes, common resources and the dilemmas of distributive justice in the welfare-state. Beside the thorough description and examination of migration processes currently ongoing, the authors raise questions as to principles of wealth redistribution between rich and poor countries and limitations on personal freedom to improve one's own situation regardless of the deterioration in well-being of others. These kinds of questions are worth asking, even if proposed answers remain unsatisfactory.

Thirdly, the theoretical framework here is neatly associated with empirical findings. Empirical evidence is based on in-depth interviews conducted with irregular migrants recruited from three ethnic groups: Brazilians, Turks (of Turkish and Kurdish origin) and Poles. Nothwithstanding the substantial volume of Polish emigration, groups of Polish migrants are rarely examined by external observers, thus any evidence of this kind deserves much attention.

The book is divided into three parts. The first one, entitled *Mobility and its regulation*, presents the theoretical framework employed by the authors to analyse irregular migrations (chapter 1: 'Irregular migration and mobility in economic theory'). Further, it depicts the legal regulations that were imposed in the EU countries to limit the inflow of so called 'economic' migrants and to secure benefits and privileges for primary sector workers (chapter 2: 'Mobility and migration in the European Union). The third chapter ('Irregular migration, labour markets and social protection') reconstructs the gradual shift from a 'zero migration' to a 'migration management' doctrine that is presently taking place in British government immigration policy. The second part *The UK as a case study* is based on in-depth interviews. It analyses pull and push factors that attract irregular migrants to Great Britain (chapter 4: 'Why they come'), as well as describes strategies developed by migrants to enter the U.K., pass strict border controls and adapt to the conditions of the host society (chapter 5:'How they survive'). The scope and form of support offered to migrants by legally established migrants' organizations in the U.K. is analysed in chapter 6 ('The role of support organisation'). In the third part *The response of the receiving society*, the narratives of irregular migrants from the previous part are confronted with the views and opinions of the 'opposite side' i.e., experts dealing with irregular migrants in their professional activities (chapter 7: 'Internal controls and enforcement: immigration authorities and the Police'), as well as NGOs' and social service workers (chapter 8: 'Irregular migration and the public services'). Chapter 9: 'Recruitment of labour from abroad' analyses the situation of regular migrants, i.e., Indian workers recruited within the UK work permit scheme. The final chapter 'In search of global justice' presents the authors' opinions on desirable developments in migration policy.

According to Jordan and Düvell, irregular migration, defined broadly as 'crossing borders without proper authority or violating conditions for entering another country (p.15)', should not be treated as a marginal and temporal effect of any low efficiency of border controls. It should rather be seen as an inherent part of the 'new international economy', closely linked to globalization. In terms of global economy, international migration (including the irregular forms thereof) is another form of labour mobility, which itself is regarded as a key element in the achievement of efficient allocations of resources through markets. The main incentives that stimulate migration flows are global and regional inequalities of income—a potential migrant estimates costs and benefits of moving to alternative locations, and migrates where expected discounted net returns are greatest over projected working lives. In the U.K. the authorities are tough on border controls, but migrants are left alone once they have passed through the immigration office. This is extremely attractive to migrants from various locations who appreciate the wide range of jobs available, with the risk of being expelled relatively lower than in other European countries (e.g., Germany). The constant supply of a migrant labour force is regarded as an influential factor stimulating the national economy and increasing the competitive potential of enterprises. What is also significant—migrant workers employed in the secondary sector of the labour market are easily dispensed with any costs, and are thus the first to bear the consequences of economic fluctuations.

If a migrant labour force is so beneficial, why do developed countries then limit the terms of entry to their territories, in effect producing irregular migrants, instead of granting them access to such absorptive labour markets? (Although it is trivial, one may say that there would be no irregular migrants without border controls and restrictions of entry). Jordan and Düvell shed light on this paradox that stems from an unavoidable conflict between the maximization of individual utility (i.e., movement to a more propitious milieu) and the distributive justice of collective resorts. On the one hand, the freedom to choose in which community to live and work is a key principle in both liberal theories of political justice and economics of labour markets. We all feel pity for people that are so desperate to reach the 'promised land' of rich western countries that they take the risk of being suffocated, drawned or injured while being trafficked. On the other hand, however, political units (like contemporary states) are 'territorial' in their nature and attempt to, (in fact are expected to) 'develop their land to its most efficient productive capacity, and to optimise distributions between members of their communities' (p.8). As the authors conclude, 'the presence of irregular migrants from the Second and Third Worlds in affluent First World countries exposes an unresolved issue, since economic theory and the economics of production and exchange know no boundaries or borders, while the economics of welfare is about distributions among finite membership groups'(p.9). The opposition between the individual freedom to improve own situation by migration to another political unit, and the right of a political community to limit the access to (at least some) common resources for community members results solely in growing numbers of irregular migrants in Western Europe. As Jordan and Düvell explain bluntly, irregular status automatically excludes migrants from most of the social benefits available to citizens of rich countries. Thus imposition of strict regulations prohibiting immigrants from legal employment and simultaneous silent acceptance of their presence in the U.K is in fact an efficient strategy for eating one's cake and having it—the demand for the labour force is supplied without any expenses on allowances, unemployment and social benefits, etc. to which legal migrants are entitled to. An analogous mechanism is present in other European countries like Germany (towards Polish migrants) as well as in Poland (towards migrants from the former USSR that are employed in exactly those jobs which Polish migrants usually take in Western countries, i.e., agriculture, construction, nursery and house-keeping).

Interestingly enough, the actual status quo differs from the EU principles on migration policy. 'In the EU, migration was for almost 30 years seen as one of the negative factors—the threat of competing away the protected wages and conditions of European workers, and of crowding and degrading their welfare and environmental systems' (p. 51). In the U.K., in line with the 'zero migration' doctrine, all immigrants (except refugees who should be offered help for reasons of human solidarity) were regarded as undesirable intruders scrounging for social benefits and 'living on taxpayers' expense'. As a result, the asylum-seeking procedure was frequently abused, as it served as a channel to enter British territory. The outcome of that policy was the opposite to the expected: economic migrants are widely accepted by British society. What is more, they are even clandestinely employed by Home Office officers (p.104)! Authors were surprised that 'irregular migrants from Brazil, Poland and Turkey, most unable to speak any English, were able to get work within days of arriving in the country, mainly behind the scenes in restaurants, cafes, and fast-food outlets, in textile 'sweatshops', or in work renovating wealthy people's houses. Far from encountering resistance and hostility, these arrivals were welcomed as a supply of cheap labour for such work, and found it rather easy to conceal themselves among the city's minority ethnic populations'(p.32). It emerges that the main victims of abuse and physical violence from the local population are recognized refugees and asylum-seekers, who are treated as rivals for state-owned apartments, occupations and other forms of social protection provided to the 'poorest white'.

In the second and third parts of the book, the theoretical framework developed in the first is illustrated with findings and quotes from in-depth interviews conducted with irregular migrants (25 interviews for each migrant group). Apart from migrants, officials from the Police and Home Offices were also interviewed, as were NGO workers, etc. (unfortunately the authors have not given any information as to the number and timing of these interviews).

The conducting of in-depth interviews with irregular migrants is something that always poses a serious methodological challenge. Irregular migrants are 'invisible', according to official statistics and databases (especially if they were smuggled into the country illegally), because they neither register nor pay taxes. As a consequence, selection and recruitment of interviewees is very difficult and troublesome. In addition, the people involved are usually distrustful of researchers and rarely go into details answering questions or spontaneously share opinions and feelings. The language barrier creates another difficulty, since with rare exceptions, irregular migrants seldom possess sufficient language skills to enable them to express freely in a foreign language and verbalise reflections, emotions and beliefs.

Jordan and Düvell resolved these difficulties by assigning in-depth interviews to co-workers from studied ethnic groups or at least speaking their language. In line with Jordan's research experience, the questions on the subject of irregular migration were to be asked 'in a neutral way that allowed interviewers to contextualise it in their accounts' (p. 95), while 'the objective of the interviews was to produce accounts of immigration experiences in which the significance of irregular activity could be understood' (p. 95-96). A snowball method (by which interviews are arranged through contacts of the previous interviewee) was used to contact irregular migrants. Although this method of recruitment is regarded as the only feasible way to interrogate such an inaccessible category of respondents, conclusions that are drawn from the findings on an representative sample might be slightly biased or incomplete, much like Jordan and Düvell's findings on Polish migrants residing in London.

According to the authors, all Poles coming to London do this purely for economic reasons: 'Although travel, tourism and sightseeing were mentioned by 8 of 25 (interviewees), either as reasons for paying a first brief visit to the UK before coming to work, or as secondary motives for their journeys from Poland, in none of these is it sustained beyond the first page of the interview transcript, except in the case of one woman (…). All the rest gave straightforward workers' accounts, in which it was taken for granted that the UK offered wages and employment that was absent in Poland' (p. 102). In Jordan and Düvell's view, Polish irregular migrants flooding into the UK belong to 'members of the avant-garde in global capitalist relations—advocates of open borders (without 'mental residues' of the communist system) who pioneered the outer limits of labour-market flexibility and personal insecurity, insisting on taking their chances against global market forces without any shelter from collective organisations, government regulation or the rights of citizenship' (p. 90). Unlike the Poles, Brazilians arrive in London driven either by 'traveller's accounts of leaving Brazil, emphasizing personal growth and development'(p.101), or by a motivation to 'gain knowledge or experience that would be valuable to them in the Brazilian economy on their return' (p. 101). Some migrants mentioned 'earning, and the opportunity to save for the future', but unfortunately the authors give no information as to how these accounts are spread among irregular Brazilian migrants. Migrants of Turkish/Kurdish origin seem also to come to England for other than purely materialistic reasons. 'Only two out of 25 interviewees gave economic reasons for leaving Turkey' (109), whereas '11 of 25 mentioned language (either existing ability or desire to learn English) as a reason for choosing the U.K and the same number gave the fact that they had relatives or friends there'. Several men who spent time in other countries have learnt about the situation of asylum seekers in the UK, yet (as the authors proudly proclaim) 'what influenced their choice was political and personal freedom, not the economic situation or the availability of benefits' (s. 109).

The question without answer is whether the accounts and motivations of irregular migrants would differ if the interviews were conducted by different persons. In Jordan and Düvell's study Brazilians interviews were made by a 'Brazilian doctor doing a postgraduate degree in complementary health studies' (s. 96); Turkish respondents (beside those contacted through „family and friendship networks") were recruited in Turkish/Kurdish advice centres, community centres and cultural centres. Interviews with Polish migrants were conducted by a Pole 'who graduated in Poland, came to London to visit her brother, met and married her husband from the Turkish/Kurdish community and now works as an interpreter in a health service' and luckily 'was able to use her networks to make contact with and recruit the group o Polish workers' (p. 97). But if she had married a Jew (and let's say she had been a poet or a jazz musician), 'one of the most unexpected findings' of the study—'that Polish immigrants were extensively employed in Turkish-owned enterprises' (p. 92)—would most probably still have remained undiscovered. Instead of that, the authors would have reported on the strong ties linking Jewish entrepreneurs with Polish workers, also a fact, but something that has not been mentioned in the book. Maybe she would also have come across young Poles who arrived in London to learn English or experience personal growth in London's boheme circles.

It is thus quite probable that the interviewers have themselves become an element of the context influencing 'accounts' of irregular migrants. Of course I'm not going to deny the existence of either 'structural' differences that shape the self-perception of a persecuted Kurdish activist who cannot return to homeland and Polish economic migrants that often leave Poland to accumulate money for purchasing desirable consumer goods, nor neglect the mechanism of self-selection that attracts the mainstream of Brazilian economic migrants to the US rather than the UK. As a result Brazilians who choose London must do this for some reason beyond the purely economic. Due to the same mechanism of self-selection, Poles who migrate to Rio de Janeiro or Mexico City for sure differ from those migrating to London or Berlin. Unfortunately the authors lightly passed over the main limitation of qualitative methods, that conclusions drawn from a small and unrepresentative sample serve mainly in exemplification and should not be automatically extrapolated to an entire population, especially when a population is heterogeneous as where irregular migrants flood into 'global cities' as focal points of the 'new international economy'.

What should be emphasised strongly is that the whole book is very interesting (especially the second part, which reconstructs the daily life of irregular migrants in London and is exceptionally picturesque and exciting). Beyond this, it is also a grave and comprehensive input into the British and European public debate on the principles of migration policy.

Izabela Koryś
Central European Forum
for Migration Research
Institute of Geography and Spatial
Organization
ikorys@iom.int