

IDŐJÁRÁS

QUARTERLY JOURNAL
OF THE HUNGARIAN METEOROLOGICAL SERVICE

CONTENTS

Editorial: Academician Rudolf Czelnai is 70	I
<i>Kirill Ya. Kondratyev</i> : Global climate change and the Kyoto Protocol	1
<i>Ágnes Mika, Ferenc Ács, András Horányi and Gábor Radnóti</i> : Sensitivity of the ALADIN weather prediction model to the changes of soil texture	39
<i>Kornélia Radics and Judit Bartholy</i> : Selected characteristics of wind climate and the potential use of wind energy in Hungary. Part II	59
<i>Mónika Lakatos and István Matyasovszky</i> : Specification of multivariate extremity in climatological data	75
News	87

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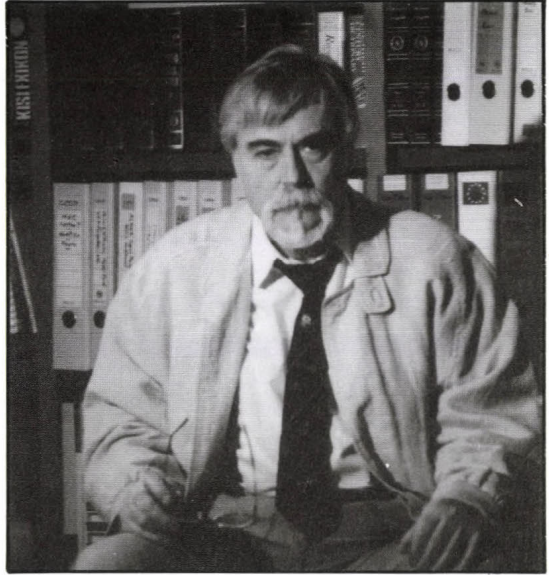
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Academician Rudolf Czelnai is 70

Academician Rudolf Czelnai celebrated his 70th birthday in May this year. Both me and the President of the Hungarian Meteorological Service, the publisher of Időjárás were thinking that this was an anniversary which should be noted in our Journal. Our feeling was strongly supported by the members of the Editorial Board.

The following is intended to be not just a traditional "laudation" of our highly honoured friend with exact details and dates of his extraordinary scientific career, rather some mixture of the previous and the portrait of the sympathetic personality as we all know him. I would like to wish Academician Rudolf Czelnai in the name of the whole Editorial Board long life full with happiness and successes in his future work for the benefit of our common challenge and mission: meteorology.

Indeed, one can say that Academician Czelnai is the most well-known Hungarian meteorologist all over the world, who gained abiding merits in the development of both domestic and global meteorology. During his scientific career which began in 1954, he achieved important results in very different fields of meteorology, extending almost to the whole range of our science from its theoretical aspects like optimum interpolation or climate research, to very practical ones such as the design and maintenance of instruments and observing systems. He is one of the rare personalities, who has always been interested in every part of meteorology, a person who can be called a "polihistor" in meteorology. He revealed outstanding talents also in university education of our science, and is the author of a number of excellent textbooks. The restitution of training of professional meteorologists in Hungary (at Budapest University) was initiated by him. In the late seventies he compiled the guidelines of a 5 years educational plan for this course which has not been changed in its main features since then, and even in our days is considered as one of the best in Europe.

He became President of the Hungarian Meteorological Service at a relatively young age in 1974. Under his ambitious and talented leadership the Service and meteorological science in Hungary in the whole passed through a little "golden age"; a relative optimum period, restricted, of course, by the large scale political environment of the communist regime. Inside the institution he changed the atmosphere to a more open and friendly one, and maintained a good balance between "theoretical" and "practical work" which was a delicate issue among the employees every time, especially under the communism. This was the basis of the almost unperturbed developments of these years. During the previous 30 years he was the first President who compiled a strategic plan for the HMS on decadal time-scale.

In external relations the main guidelines and outstanding features of his leadership were strong interdisciplinary co-operation with institutions and scientists representing Earth sciences other than meteorology inside Hungary, and lively everyday work contacts with meteorologists from many continents, with the World Meteorological Organisation in the first place. In this activities one could already recognize his extraordinary ability to build up and maintain long-term scientific co-operations and to co-ordinate the views and the work of scientific people from all parts of the world, which is one of the main strengths of his very open and very friendly personality.

It is not incidental, therefore, that he also made a bright career in the WMO serving at first as the Director of Scientific and Technical Programmes in the period 1981–1984, and then, as Assistant Secretary General of the WMO in the years 1985–1992. He supervised a number of global scientific programmes, but with the time going he became the supervisor of core administrative activities, such as technical co-operation of WMO countries, organization of WMO conferences, WMO publications, long-term planning, etc. After these successful, but weary-some years he retired from his position in the WMO, but did not at all retire from the science.

After returning to Hungary, he served for a short while as the President of the Scientific Council of the HMS, and now he plays a very active role in the life of the Hungarian Academy of Sciences. A presentation of Academician Czelnai is always an event for the Hungarian meteorological community. In this context—to explain the reason why people like his presentations—one has to emphasize the global nature and the far-reaching way of thinking which is so characteristic to him, in which he tries to synthesize and analyze the vast complexity of the surrounding world in order to give reasonable and useful answers to the most complicated questions of science and life.

Tamás Práger

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Global climate change and the Kyoto Protocol

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Abstract—In the context of the Third Report of the Intergovernmental Panel on Climate Change (IPCC–2001), failure of the 6th Conference of the FCCC (Framework Convention on Climate Change) parties, and preparations to the World Summit on Sustainable Development (“Rio+10”), the paper discusses unsoundness of the Kyoto Protocol recommendations on greenhouse gas emission reduction and far-fetched “flexible mechanisms” (including “emission trading”) of preventing dangerous changes of the global climate predicted for the 21st century. Analysis of the available observation data and uncertain results of the climate prediction by numerical modeling suggest the need for radically revising the FCCC and rejecting the Kyoto Protocol.

Key-words: global climate change, global warming, Framework Convention on Climate Change, Kyoto Protocol, greenhouse gases, World Summit on Sustainable Development, climate observations, climate modeling

1. Introduction

Recent decades have witnessed the world community’s unprecedented importance attached to climate change problems stirred up by mass media. This, undoubtedly, stimulated both scientific and applied developments through which further progress was achieved in understanding the causes of the present-day climate changes and the regular features in paleoclimate. However, we still need a better vision of climate changes in the future. The reliability of various scenarios and predictions of future climate changes remains doubtful (References). Various speculative exaggerations and apocalyptic prognoses of the men’s climatic impacts were, unfortunately, specifically attracting too much

attention. As a result, the climate change problem, conceptualized as human-induced global warming, became an acute geopolitical issue (*Bohmer-Christiansen*, 1999, 2000; *Hansen et al.*, 2000; *Houghton*, 2000, 2001; *Kondratyev*, 1992, 1998a, b, 2001, and many others). Paradoxically, Presidents and Prime Ministers in various countries (e.g., in the USA) enter into discussions on whether the Kyoto Protocol is to be treated as scientifically sound document (*From ...*, 2000). This situation is getting even more complicated, in particular, in the absence of sufficiently clear and uniform terminology. Without focusing on the very complex situation with climate definition (which deserves special discussion), we will remind, that the Kyoto Protocol defined the “climate change” as human-induced climate change. Anthropogenic impact on climate is beyond question, but the contribution made by anthropogenic factors into global climate formation still need to be convincingly assessed, and this is the main problem. In this situation, international documents analyzing the modern climate views unnecessarily apply the term “consensus” to their conclusions. Obviously, science progressed along the pathway of comparing various views and discussing, rather than voting, specific issues. In the climate case, this is dictated not only by the lack of precise definitions for terms being used but also by unclear and vague conceptual assessments for various aspects of climate problems.

The above-said is becoming of particular importance in the context of the World Summit on Sustainable Development to be held in Johannesburg (South African Republic) in September 2002. Unfortunately, the notion of “sustainable development” itself still needs an adequate definition, which is especially pertinent to the Russian version of this term. There is a good reason to believe that “Rio+10” conference will focus specifically on climate problems. In this connection, we will remind that the undeniable success of the Second UN Conference on Environment and Development (Rio de Janeiro, 1992), UNCED, and the Special Session of the UN General Assembly “Rio+5” which was held 5 years later (New York, 1997) consisted only in drawing attention of the Governments and the public to global change and sustainable development problems. Unfortunately, both these world forums were ill-prepared, as most clearly evidenced by their failure to elaborate the “Earth Charter” intended for formulating and substantiating the priorities; instead, a very amorphous and declarative “Rio Declaration” was adopted.

Today, the focus of discussion should be concentrated on three global environmental problems: (1) “global warming”— anthropogenically induced climate change; (2) fate of the ozone layer; and (3) closed nature of global biochemical cycles and the concept of biotic regulation of the environment. The primary importance of the third problem and the secondary significance of the two first-named ones were convincingly substantiated in scientific literature

(Gorshkov, 1990; Gorshkov et al., 2000; Kondratyev, 1990, 1992, 1997, 1998, 1999a, 2000, 2001a). A bitter paradox consists, however, in that despite all this, the UNCED documents show inadequate understanding of the fact that has crucial importance from conceptual viewpoint, namely the sequence of events: socioeconomic development under conditions of the population growth → anthropogenic impact on the biosphere → environmental implications of these impacts (climate, ozone, etc.).

Such misunderstanding advanced the “global warming” problem in the foreground, and this resulted in adoption of the International Framework Convention on Climate Change (FCCC). This is a rather inadequate and misleading document that unjustly treats developing countries; its focus—without good reason—is on anthropogenic origin of the observed global climate change and the recommended reductions of emission of greenhouse gases (GHGs), above all, carbon dioxide.

In December 1997, 160 countries participated in the Third Conference of the FCCC signatory-states, which was held in Kyoto (Japan). There, the possibility of implementing the required 5%—on the average—CO₂ emission reduction by the 2008–2012 period relative to the 1990-year level was the subject of prolonged heated debates. These debates and the so far lacking notable progress in CO₂ emission reduction clearly illustrate the absurd character of the Kyoto decisions. Global emissions tend to increase—not only in developing but also in industrial countries, including USA—and this trend will be preserved in the future. Naturally, the attitude of developing countries is dictated primarily by the highest priority for them, namely, rising the people’s living standard via industrial development rather than curtailment aimed at CO₂ emission reduction. However, specifically the latter item was the FCCC-signing condition laid down by the USA and other “golden billion” countries. The FCCC history is only one example illustrating the giant, primarily bureaucratic activity devouring hundreds of million dollars yearly. According to the GEF data as of July 30, 1998, 1.9 billion USD were assigned for 267 GEF projects (*Project ...*, 1998). In this context, it should be reminded that about 10 thousands participated in the Kyoto Conference only. The recent Hague Conference (November 2000) and Bonn Workshop (July 2001) had also large audiences and entailed large expenditures. The sums absorbed by these useless bureaucratic meetings could have been invested into development of science to a greater benefit of humankind (*Singer*, 1997, 1998).

One can think that the situation outlined stems from poor development of the scientific principles of global change problems. This conclusion is justified only in part, since as early as 1990 the key aspects of global environmental dynamics were discussed, e.g., in monographs (*Kondratyev*, 1990, 1998). *Gorshkov* (1990, 2000) advanced and substantiated the basic concept of biotic

regulation of the environment. *Kondratyev* (1990, 1992, 1998, 2001) demonstrated the fruitlessness of focusing on “greenhouse” aspect of global warming solely and drew attention to the need in studying the climatic system “atmosphere–ocean–land–ice cover–biosphere” taking into account the whole complex of feedbacks among its interactive components. The problem of global observation system was seriously analyzed (*Kondratyev* and *Varotsos*, 2000; *Goody*, 1998, 2001; *Goody et al.*, 2001; *Kondratyev* and *Cracknell*, 2001; *Reconciling ...*, 2000). Special attention is being given to atmospheric ozone variability.

In the problem of human-induced global climate changes, the main uncertainties stem from the following: (1) observation data are incomplete and insufficiently reliable not only for quantitative assessment of the anthropogenic component of the “global warming” but even for its scientifically substantiated identification; (2) uncertainties involved in accounting the climate-forming role of atmospheric aerosol and in introducing the so-called “flux correction” in numerical climate modeling can amount to tens or even 100 W/m² (*Kondratyev*, 1998, 1999), being much more significant than a potential ~ 4 W/m² enhancement of the atmospheric greenhouse effect due to the expected doubling of the atmospheric CO₂ concentration); (3) the results of numerical modeling of climate changes using relevant models differ and cannot be adequately verified; they cannot be used for reliable assessment of the “global warming”, because the results of such calculations depend on adjustment to observation data; and (4) even full accomplishment of the Kyoto Protocol recommendations can ensure only a negligible decrease in the annual average global average near-surface air temperature (SAT), no greater than several hundredth of a degree (*Wigley*, 1999). In this situation, the recommended greenhouse gas emission reductions make no sense, although their implementation can have far-reaching adverse socioeconomic consequences.

Recently, much attention has been given to analyzing the uncertainties (incompleteness) of numerical climate modeling. The major uncertainties, evidently, result from inadequate account of interactive processes in the “aerosol–clouds–radiation” system (*Kondratyev*, 1992, 1998, 2002). The fact that the most complex aspect of climate numerical modeling is taking into account the interactive biosphere dynamics is beyond question. This can be illustrated by two specific examples, which, certainly, only to a small extent reflect the complexity of the problem discussed.

For explaining the decrease in the daily variation of amplitude of the surface air temperature (DTR) by 3–5 K (which was observed during the period 1951–1993) owing to a more rapid rise of the minimal, compared to maximal, temperature, it was suggested that various factors, such as changes in the amount of clouds, water vapor and tropospheric aerosol content, as well as

turbulence and soil moisture should be taken into account. Positive trends in the three first-named factors could be responsible for a global radiation reduction in the daytime and enhancement of the atmospheric longwave radiation (LWD) in the nighttime. At the same time, changes in the turbulent mixing intensity and soil moisture could be responsible for variations of the heat- and moisture-exchange between the surface and the atmosphere, more substantially in the day than in the nighttime.

A fairly pronounced interactivity of the climate-forming processes and inadequate parameterization of them in climate models significantly complicate the task of assessing the contributions from various mechanisms to the DTR decrease. In this connection, *Collatz et al.* (2000) undertook numerical modeling on the response of the daily temperature variation of the vegetation-covered land surface to the changes in the external forcing and biophysical state of the vegetation cover. To this end, those authors used the SiB2 approximate land biosphere model at given meteorological conditions under various scenarios so as to simulate the likely impact of the interactive dynamics of the vegetation cover on the DTR.

The numerical modeling results showed that with increasing LWD the temperature of the air above the vegetation cover, T_m , tends to increase in the nighttime, thus decreasing the DTR. At the same time, changes in T_m or rise of $T_m + LWD$ (this is specifically the case for global warming conditions) favor increases both in the minimal and maximal temperatures making these factors of little importance for DTR. This response is due mainly to the influence of the daily variations of the aerodynamic stability and radiation balance.

Many of climate numerical modeling experiments utilize the global atmosphere circulation models (GCMs) coupled with land surface processes models (LSM). The results of these numerical experiments are essentially dependent on the specific features of interaction between the GCM and LSM models simulating the radiation, momentum, and energy exchanges between the surface and the atmosphere. Striving for covering the diversity of terrestrial ecosystems, LSM models became significantly complicated by introducing submodels, which take into account photosynthesis, vegetation cover dynamics, and biogeochemical cycles thus making the models radically more realistic.

Basing on the Simple Biosphere Model SiB (an LSM version), *Kim et al.* (2001) conducted various numerical modeling sensitivity experiments. They indicated the importance of not only the sensitivity of SiB to many of the morphological parameters of the vegetation cover but also of factors such as the sensitivity of transpiration of high vegetation cover to parameters characterizing the vegetation cover resistance. With improved SiB model those authors took into account the biogeochemical processes governing the water vapor, energy, and carbon dioxide exchange between the surface and the atmosphere.

The results of numerical modeling of the processes, occurring on a rice paddy test plot in Thailand (17°03'N, 99°42'E), using SiB2 and modified SiB2-Paddy models as coupled with mesometeorological model GAME-Tropics (GAME is the monsoon experiment in Asia conducted in the framework of the GEWEX global field experiment on energy and water cycles) were compared with the meteorological data derived in the rain season (September 1–6, 1999).

This comparison showed a good agreement between the results simulated with the two models of interest, on the one hand, and the observed daily variation of the radiation balance and the latent heat flux, on the other. The only exception was the latent heat flux simulated by the SiB2 model. The SiB2-Paddy simulations show a satisfactory agreement with the observed fluxes of latent heat and heat flux in soils, as well as of the carbon assimilation rate, but SiB2 simulations entail major systematic errors. After certain adjustment of the parameters, SiB-Paddy model provides fairly reliable values of the soil, water, and vegetation cover temperatures. The simulations of the radiation balance, as well as of the energy and water balances, latent heat fluxes, and carbon dioxide assimilation rate yielded fairly adequate results. This offers certain promises of adequate account of the biosphere as an interactive component of the climatic system.

De Rosnay et al. (2000) assessed the reliability of the parameterization schemes for the processes occurring on the land surface, which are utilized in general atmosphere circulation models (GCMs), from the viewpoint of agreement between the observed and the calculated annual average energy and water fluxes as dependent on the degree of detail in accounting the vertical structure of soil. The simulations evidence a fairly strong dependence of the fluxes on the vertical resolution. The 11-layer scheme of parameterization of the heat and water transfer in soil proves fairly adequate for a 1-mm-thick upper layer. The possibilities of realizing a scheme with this thin upper layer are unclear. *However, if one takes into account the fact that the horizontal resolution of GCMs is of the order of hundreds of kilometers, finding solution to this kind of problem requires further efforts.*

A major component of the problem of climate numerical modeling is a complex of issues related to the chemistry of atmosphere. It is a well-known fact, e.g., that the concentration field of such a greenhouse gas as tropospheric ozone (TO) under various conditions (city, region, and globe) is strongly affected by various short-lived minor gaseous components (MGCs)—ozone precursors—such as nitrogen oxides ($\text{NO}_x \equiv \text{NO} + \text{NO}_2$), methane (CH_4), as well as many organic compounds, hydrogen, and carbon monoxide (CO). Each MGC has its specific natural (biospheric) and anthropogenic sources.

Since TO is a greenhouse gas, the MGCs emitted can affect indirectly the atmospheric greenhouse effect formation via affecting the TO concentration

field. Also, MGCs-TO precursors affect the hydroxyl concentration field and, thereby, the oxidizing capacity of the troposphere. The hydroxyl concentration distribution in the troposphere, in turn, governs the life-time and, thereby, the global-scale concentration of methane.

All this is responsible for a complex interactivity of the processes responsible for both direct and indirect impacts on the formation of the atmospheric greenhouse effect. *Derwent et al.* (2001) described the global 3-D Lagrangian STOCHEM model which simulates chemical processes taking into account the MGCs transport. This model was used for simulating interconnected TO and methane concentration fields in case of emissions of short-lived precursors of tropospheric ozone such as CH₄, CO, NO_x, and hydrogen. In this case the radiative forcing (RF) of NO_x emissions varies with the emission location, be it near the surface or in upper troposphere, in Northern or Southern Hemisphere. For each short-lived MGC-TO precursor the global warming potential (GWP) was calculated using the data for the reaction between methane and tropospheric ozone under 100-year forcing. *The introduction of GWP means that RF due to emission of 1 Tg of an MGC was estimated (for a 100-year period) as equivalent (in RF) of carbon dioxide emission.* The combined impact of methane and TO led to the GWP of 23.3.

The simulations showed that indirect RF due to changes in the methane and TO content is significant for all the MGCs-TO precursors of interest. In the case of methane the RF is determined primarily by emissions of methane itself, while in the case of TO, by emission of all the MGCs-precursors, especially nitrogen oxides. The tropospheric ozone-induced indirect RF may be so large that MGCs-TO precursors will need to be ranked among the MGCs essential for assessing the likely climate changes and identifying preventive measures.

Despite USA President G. Bush's anti-Kyoto statements, many of the American newspapers of January 2001 published their articles under dramatically strained headings that informed their readers, e.g., about terrible warming predictions of scientists and about the threat of a global catastrophe in this century posed by the accelerating climate shift («Washington Post»), as well as about the Earth warming is generating a new danger signal («International Herald Tribune»), etc. This stemmed from the new climate change scenarios for the 21st century, which predict that the changes will be more significant than expected earlier. The Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC-2001) states that by the year 2100 the annual average global average surface air temperature (SAT) can increase by 5.8°C relative to the present time (IPCC, 2001) against only 3.5°C according to the estimate of five years' standing (IPCC, 1996).

Kerr (2001b) correctly noted that the widening range of the likely SAT rise compared to earlier estimates has even greater importance. This was not surprising, however, for many of experts in climate numerical modeling, as this field is still in its infancy and, also, numerical modeling has to rely on a limited amount of observation data (even for SAT the data series is about 100 years long only, being not globally complete).

Although the majority of experts tend to attribute the observed global warming to the GHG concentration growth, the range of possible climate change assessments has expanded rather than contracted in certain respects.

The main uncertainties in climate change assessment involve the following three aspects: (1) global warming detection from observation data; (2) global warming attribution to anthropogenic factors; and (3) future climate change prediction. *Kerr* believes (2001b) that owing to the new findings in the IPCC Report–2001, the range of uncertainty with respect to the two first-named aspects of the problem has contracted, but future climate predictions have become still less clear. The IPCC Report–2001 estimated the observed global warming at $0.6^{\circ}\pm 0.2^{\circ}\text{C}$ (at the statistical significance level of 95%), the warming during the recent 50 years being probably (by 66–90%) due to GHG concentration growth. One of the main factors responsible for uncertainties in climate numerical modeling is, as has been mentioned, inadequate account of the climate-forming role of atmospheric aerosols and clouds.

Unfortunately, the IPCC Report–2001 (*IPCC ...*, 2001) did not adequately assess the role of uncertainties in climate numerical modeling, and this specifically motivated the serious criticism towards the Report by many experts (*Han et al.*, 2000; *Kondratyev and Demirchian*, 2001; *Schrope*, 2001; *Singer*, 1997, 1998, 1999; *Soon et al.*, 2000; *Wojick*, 2001; *Woodcock*, 1999, 2000).

In the global change context, assessments of the present-day and the likely future global climate changes are undoubtedly of primary importance. Although the “global warming” concept is still dominating (as evidenced by the IPCC (Intergovernmental Panel on Climate Changes) Third Assessment Report (*IPCC ...*, 2001), new assessments should be treated as due only to mechanical development of the earlier speculations with a far-from-scientific motivation (as convincingly demonstrated by *Boehmer-Christiansen* (1999, 2000). The contradictions inherent in the climate assessments can be illustrated by radically opposite opinions expressed by two Candidates during the President election campaign in the USA (*From ...*, 2000). A. Gore has long been known as an ardent advocate of the “global warming” concept and the Kyoto Protocol, while G. Bush’s opinion can be characterized as follows. He rejects an environmental policy like that corresponding to the Kyoto Protocol, which would result in radical rise in prices for oil, oil products intended for district heating needs, natural gas, and electricity. President G. Bush believes that

such an agreement would expose the USA economy to strongly increased load without properly protecting it against undesirable climate changes. In G. Bush's opinion, the Kyoto Protocol is an inefficient and inadequate document which unjustly treats America, as it excludes from implementation of the Protocol recommendations 80% of the world, including such major population concentration centres as China and India. G. Bush assigns the primary importance to development of new environment friendly technologies and to the use of market mechanisms, including regulation-free electricity and natural gas markets, taxation, and "emission trading". In G. Bush's opinion, natural gas and nuclear energy will play important role in weakening the USA's perilous reliance on petroleum from abroad and in providing the USA with energy resources in the 21st century. While sharing this radical criticism toward the Kyoto Protocol (KP), we will note that G. Bush's opinion of the market mechanisms is specific to the USA, and in the case of "emission trading", disputable.

The unsoundness of the KP is even more clearly evident from the failure of the Sixth Conference of the Parties (COP-6), which was held on November 13–24, 2000, in Hague. It was attended by seven thousands representatives of 182 governments, 323 intergovernmental and non-governmental organizations, and 443 mass media titles. The Congressman J. Barton (Republican, Texas) said that if Bush won (which came true), his advice to Bush will be that USA reject the Kyoto Protocol and start negotiations aimed at setting the USA's economy free from unsound environmental restrictions. Barton said that what they saw at the COP-6 was an extremely useless exercise or making-things-up exercise, at the best. Therefore, in Barton's opinion, nothing from that week's discussion deserved a support by positive voting.

Interestingly—in this connection—the UNEP Executive Director K. Töpfer rejected the suggestion to treat nuclear energy as an important energy prospect, while the USA and Japan delegates in Hague expressed the readiness to support the funding of nuclear energy projects in developing countries with a view to reducing carbon dioxide atmospheric emissions.

An important feature of the Hague discussions was a certain confrontation between the USA and EC member-countries. These latter rejected the American suggestion on making use of various possibilities, including restoration of forests as carbon sink, in the carbon balance and required that the USA follow the general recommendations on carbon dioxide emission reduction (this view has changed later on to start "forest games").

One cannot qualify differently than absurd the recommendations of the COP-6.2 (second part of COP-6) Conference held in July, 2001 in Bonn. These recommendations introduced the notion of "certified emission reduction" (CER), that is, the recommended real emission reduction were replaced

by equivalent intensification of carbon sinks such as forests. This “innovation” permits Japan, Russia, and Canada to accumulate CERs owing to their forests. The absurd character of this recommendation is evident, above all, from the fact that the global carbon cycle problem is still far from solution (*Kondratyev and Demirchian, 2000*), which makes absolutely unrealistic any reliable assessment of the role of CER as a global climate-affecting factor. As to the intensively debated subject of the three “flexibility mechanisms”, namely, joint implementation, emission trading, and clean development mechanism (of technologies), these can be regarded as rhetorical only.

The Bonn recommendations received extremely contradictory opinions. On the one hand, *D. Kennedy* («Science» journal Editor) (2001) was distressed about “going it lonely” by President G. Bush and the USA and qualified the Bonn agreements as “breathing new life” into hopes for progress in solving the problem of global climate change. In *Sherman’s* (2001) opinion, the Kyoto Protocol, in spite of its clear drawbacks, should be regarded as an important milestone in the climate protection history. Sherman argues that the Kyoto Protocol will, probably, exceed any other international agreement, in its effect on the lives of all humans on this planet in the current century. Sherman believes that the success achieved in Bonn is a direct consequence of the dialogue and mutual understanding, as well as of the sense of reconciliation and compromise.

On the other hand, the opinion of a well-known scientist Dr. A. Agrawal [Chairman of the Centre for Science and Environment (India)] was absolutely different (http://www.cseindia.org/html/dte/dte.20010831/dte_edit.htm). To begin with, he said, that the Kyoto Emperor was no more wearing any clothes. Next, Dr. Agrawal characterized the Kyoto Protocol as a tiring and a fairly meaningless agreement on the climate change problem, which was agreed by the world within those two weeks. Dr. Agrawal said that huge scientific uncertainties in assessments of the greenhouse gas emission reduction efficiency made of the Kyoto compromise nothing more than a big shameful invention. This is not, however, surprising, in Dr. Agrawal’s opinion, because climate negotiations concern the economics rather than environmental problems, and each state does its best in protecting its right for environmental pollution. Exactly on the week of the euphoric declarations that the agreement achieved in Kyoto could save the world, the European Community decided to prolong for another 10 years the implementation of its subsidised programme for coal (the most polluting carbon fuel). Dr. Agrawal concluded his statement by saying that the Kyoto compromise would cost the whole world and everyone more than new clothes for the Emperor.

The main point in the global change problem is that while the global climate warming in the 20th century (especially, in its last quarter) is beyond

question, the factors responsible and quantitative estimates of their contributions into global climate change remain the subject of heated debates. This is even more pertinent to climate forecasts taking into account anthropogenic impacts. In this connection, it is symptomatic that the authors of the IPCC Report-2001 abandoned the “climate change” term defined in the FCCC as due to anthropogenic factors only and agreed upon an adequate definition which takes into account both natural and anthropogenic factors responsible for climate change. This correction to the “climate change” term makes senseless the Kyoto processes aimed at emission reduction for preventing undesirable changes because the climate constantly changes due to many factors. To supplement this, such change also contradicts the traditional definition of climate as the phenomenon characterized by 30-years-averaged values of its parameters. Now, we will turn to the question how the IPCC Third Assessment Report affected the views on the causes of climate changes.

2. Observation data

The variance of the present-day climate and climate change studies results primarily from inadequate completeness and quality of the available global archives of observation data. As known, climate can be characterized by numerous parameters such as surface and atmospheric air temperature and humidity, precipitation (liquid and solid); amount, lower and upper boundary altitude, microphysical and optical characteristics of clouds, radiation balance, and its components; microphysical and optical parameters of the atmospheric aerosol, chemical constituents of the atmosphere, and many others. At the same time, the empirical analysis of the climatic data is usually confined to the appeal to SAT observation data, because only in this case the observational series cover a time period of 100–150 years. However, even these series are far-from being homogeneous, which is particularly relevant to the global data file which is the main information source for the “global warming” concept substantiation. It should also be noted that the long-term variations of the annual average SAT rely mainly on imperfect observation data for the sea surface temperature (SST).

In the climate observation diagnostics, the focus must be on analyzing the climate variability, where not just averages but higher order moments are taken into account. Unfortunately, this approach has not been even attempted so far. The same is true of the internal correlation for the observational series. *McKittrick* (2001) analyzed the SAT long-term variations and showed that by subtracting the contribution to the temperature change within several recent decades made by internal correlation (i.e., climate system inertia) one reduces the temperature change virtually to zero. This points only to the fact that natu-

ral factors can affect the temperature, but the main problem still lies in singling out its anthropogenic component. The importance of this problem is dictated by the fact that specifically the global average SAT rise over the last 20–30 years serves the main argument in favor of the dominating anthropogenic contribution to the climate change.

2.1 Surface air temperature

One of the SAT observational series for the period since 1860 showed that the SAT annual average global average value increased by $0.6^{\circ}\pm 0.2^{\circ}\text{C}$. This by $\sim 0.1^{\circ}\text{C}$ exceeds the analogous value from the IPCC Report–1996 (see *Kondratyev*, 1999). The IPCC Report–2001 explains this increase by a higher SAT level over the 1995–2000 period. The observation data are indicative of a very strong spatiotemporal variability of the annual average SAT on the globe (such a variability is a cause of why reliable enough assessment of SAT uncertainties is impossible). For example, the global average SAT change suggests that the climate warming in the 20th century fell primarily on two time periods, namely, 1910–1945 and 1976–2000. Compared to Report–1996, the new version of the global average SAT change in the Northern Hemisphere excludes the warming period of ~ 900 –1200 and the cooling off period of 1550–1900. Only such a revolution in factology allows arguing that the climate warming in the Northern Hemisphere in the 20th century was the strongest over the last thousand of years with the 1990–2000 period as the warmest decade, and the year 1998 as the warmest year. Owing to specifically these arguments, an impression may be created that it is the marked increase in the CO_2 concentration over the last three decades that is specifically responsible for such extreme temperatures. By excluding these, not simulated by numerical models, it is obvious that one can achieve certain adequacy between the modeled and observed temperatures.

The IPCC Report–2001 makes no mention of the previously supposed climate warming enhancement in the Northern Hemisphere high latitudes as a characteristic feature of the human-induced global warming. However, the analysis of the SATs directly measured at the “North Pole” stations over a 30-year period (*Adamenko* and *Kondratyev*, 1999) and the dendroclimatic proxy data for the last 2–3 centuries shows the following. There was no warming enhancement in the Arctic region, and the temperature changes during the last century and recent decades exhibited major spatiotemporal non-homogeneity manifested as the simultaneous formation of climate warming and cooling off regions in the Arctic region (see also *Stafford et al.*, 2000).

Since the 1950s, with a more or less adequate aerological observational network, the trends for the global average SAT and lower troposphere tem-

perature have been almost identical (about $0.1^{\circ}\text{C}/10$ years (Angell, 1999, 2000a, b). According to the satellite-based microwave remote sensing data (over 1979–2000 period), the global average temperature of the lower tropospheric air increased by $\sim 0.036^{\circ}\text{C}/10$ years, i.e., significantly slower compared to SAT ($0.24^{\circ}\text{C}/10$ years). This difference is even more appreciable if one excludes the influence of the sharp temperature rise in 1998 due to the severe El Niño phenomenon. This is evidenced by low trends for the 1979–1997 period, namely, $0.012^{\circ}\text{C}/10$ years for the tropospheric air (that is, cooling according to the microwave remote sensing) and $0.158^{\circ}\text{C}/10$ years for SAT. There is no such a trend difference in the global circulation models that are the main IPCC instruments for understanding climate changes, and this casts serious doubts upon their capabilities. Controversial nature of existing temperature observation data has been convincingly analyzed by *Wojick* (2001).

Sonechkin (1998) has accomplished a study of self-similar and trend-like properties of hemispheric SAT time series as realizations of a fractional Brownian motion by means of the wavelet transform technique. The results obtained indicate a first evidence of a crossover scale that separated the obvious internally-induced, statistically stationary chaotic oscillations from the substantially longer, trend-like SAT variations, which origin is not clear and may be assumed to be extremely forced. The residual trend-like components reveal a single linear warming trend that was started at the beginning of the 20th century. The increment of this trend is equal to $0.59^{\circ}\text{C}/100$ years for both hemispheres. Later on *Sonechkin et al.* (1999) have demonstrated a very strong coupling between long-term SAT variations and Southern Oscillation dynamics. *Datsenko et al.* (2001) have applied similar approach to analyze seven seasonal early instrumental temperature series at various locations in Europe. They emphasized the crucial role of seasonality in the spatiotemporal structure of low-frequency SAT variability.

2.2 Snow and ice cover

These climate characteristics are treated by IPCC as important indirect global warming indicators. The Report says that there was a $\sim 10\%$ snow cover reduction since the late 1960s and a ~ 2 -week reduction of the annual lake and river ice cover in mid- and high-latitudes of the Northern Hemisphere in the 20th century. This was paralleled by retreating of the mountain glaciers in non-polar regions. Also, the Report states that the sea-ice cover in the Northern Hemisphere in spring and summer periods has reduced since the 1950s by 10–15%. It is highly probable that during the last decades (in end summer–early autumn periods) there was a $\sim 40\%$ thinning of the sea-ice cover period in the Arctic region, with a much less significant thinning in the winter period. Since

the 1970s, regular satellite observations have revealed no marked trends for ice cover either in the Arctic or Antarctic regions. Combined with insignificant temperature trends, this allows a conclusion that the ice thickness in the Arctic region is markedly influenced by the ocean currents and the North-Atlantic Oscillation (NAO) dynamics.

2.3 Surface level and heat content of the upper layer of the ocean

These characteristics are also important for IPCC in view of the serious concerns about global consequences of the World Ocean level rise. Because of exclusively fragmentary, intermittent, and unreliable measurement results available, the Report-2001 actually presents the calculation-corrected data. It states that the World Ocean level has risen by 0.1–0.2 m in the 20th century owing to thermal expansion of the sea water and land ice melting due to global warming. The Report says that in the 20th century the World Ocean level rising rate exceeded almost tenfold that over the last 3000 years. Since the 1950s, the ocean surface temperature rising has caused the heat content of the upper ocean layer to increase.

Levitus et al. (2001) analyzed the warming data for individual components of the climate system in the second half of the 20th century. These data were derived from the analysis of the increase in the heat content of the atmosphere and the ocean, as well as the heat consumed by melting of certain components of the cryosphere. The results suggested an increase in the heat content of the atmosphere and the ocean. Over the 1950–1990 period, the increase in the heat content of the 3-km-thick upper ocean level exceeded at least by an order of magnitude those for other components of the climate system. The increase in the heat content of the ocean observed in the 1955–1996 period was estimated at 18.2×10^{22} J, and that in the case of the atmosphere, at 6.6×10^{21} J only. As to latent heat due to phase transformations of water, these were estimated at 8.1×10^{21} J (decrease in the mass of terrestrial glaciers); 3.2×10^{21} J (sea ice cover reduction in Antarctica); 1.1×10^{21} J (melting of mountain glaciers); 4.6×10^{19} J (snow cover reduction in the Northern Hemisphere); and 2.4×10^{19} J (melting of permanent ice cover in the Arctic region).

Levitus et al. (2001) compared the observation data with the results of numerical modeling by the interactive model of the “atmosphere–ocean” system developed at the Geophysical Fluid Dynamics Laboratory (USA). This comparison took into account (1) the radiation effects due to the observed GHG concentration growth and changes in the sulphate aerosol in the atmosphere and extra-atmospheric insolation, as well as volcanic aerosol, and (2) only GHGs and sulphate aerosol. It was found that the observed heat content variations in the ocean can be primarily attributed to the GHG concentration

growth in the atmosphere, although one has to take into account a major uncertainty in assessing the radiative forcing due to sulphate aerosol and volcanic eruptions. The latter fact makes the work by *Levitus et al.* (2001) of insufficient reliability as regards human-induced warming identification. Those authors mentioned major variability of the heat content of the World Ocean from year to year and emphasized the following. They partially attributed the extremal warming of the World Ocean in the 1990s to the multidecadal warming of the Atlantic Ocean and Indian Ocean, as well as to the positive polarity of the possible biannual heat-content fluctuations of the Pacific Ocean. The observed variations of the heat content of the World Ocean can be related to the modes of hemispherical or global variability of the atmosphere from the ocean level to the stratosphere. Gaining insight into the nature of this kind of possible relations is of major importance for understanding the mechanisms governing the global climate.

As has been already mentioned, recent developments on identifying the human-induced climate changes were confined for the most part to analyzing comparatively long series of SAT data. Also, much more limited bodies of information on sea-ice cover variations, vertical temperature profiles (radiosonde data), and satellite microwave remote sensing results were analyzed. On the other hand, numerical modeling results suggest that more representative than SAT should be in this context the extremely scanty data on the amplitudes of the annual and daily temperature variations in winter.

Being the major component of the global climatic system, the World Ocean holds the priority in the variability analysis, especially after *Levitus et al.* (2001) revealed an increase in the heat content of the upper layer of all the oceans within the past 45 years. In this connection, *Barnett et al.* (2001) discussed the results obtained by comparing the numerical modeling and observation data for the heat content of the 3-km-thick upper layer of different oceans. The calculations utilized the "parallel" climate model (PCM) for the "atmosphere-ocean" interactive system (no flux adjustment) and five scenarios of the growth patterns for GHG concentration and sulphate aerosol content in the atmosphere.

The comparison showed that the calculated heat content anomalies (that is, deviations from the data corresponding to the control integration) did not differ from the observed values (for the 1950–1990 period), the statistical significance being at the level of 0.05. The only exception (in the global averaging case) was the data for the 1970s. In this case, the model does not simulate the heat content anomaly observed during this decade. On the whole, the probability of the fact that the heat content anomalies are due to natural variability of the climatic system does not exceed 5%. This makes realistic detection of the anthropogenic signal of the climate changes.

It should be noted, however, that oceans differ substantially in the nature of warming. A typical feature of the Atlantic Ocean (especially of its southern area) is an intensive vertical mixing and rapid propagation of the warming deep into the ocean. In other oceans this process has a much slower rate. The results obtained allow an important conclusion that climate models should simulate not only SAT but also ocean heat content variations. *Barnett et al.* (2001) pointed to certain weak points of the numerical modeling undertaken - in particular, that the natural climate variability was assessed basing on the control numerical modeling data only.

Cai and Whetton (2001) called attention to the fact that the enhancing effect of the “greenhouse” warming on the sea surface temperature (SST) field in the Pacific Ocean tropics can affect significantly the precipitation on the global scale in the future. Studies on these controversial problems with the use of both the observation and numerical modeling data yielded very different results. The climate warming during recent decades was similar in the spatial structure to the El Niño/Southern Oscillation (ENSO) phenomenon. In view of the lack of the data for such a structure over the entire century, it was suggested that the observed warming structure resulted from multidecadal natural climate variability rather than from the greenhouse forcing-induced change.

The first results of the numerical modeling with the use of interactive models of the “atmosphere–ocean” system showed that the warming structure characterized by a zonal SST gradient in the equatorial zone should be similar to El Niño, by contrast to certain theoretical studies which point to a similarity with La Niña. To settle this controversy, *Cai and Whetton* (2000) utilized for climate numerical modeling the interactive model developed at the Australian National Scientific Center (CSIRO Mark 2). They showed that the initially formed spatial structure of the warming is similar to La Niña (the strongest warming in extra-tropical latitudes for weak La Niña which is similar to the structure in tropics), which later on (after the 1960s) transformed to a structure similar to El Niño. Such results were yielded by three versions of numerical modeling (in addition to the control integration over 1000 years) with the GHG concentration growth in the atmosphere prescribed according to the observation data (1880–1990) and the IS92a scenario (1990–2100). These simulations did not take into account the influence of aerosol on climate formation.

The above-mentioned transformation of the spatial structure of the climate warming is due to warm extra-tropical waters that after deep submerging come through subtropics and reach the tropical zone where upwelling arises. This is specifically the reason for climate change. These results can be interpreted as confirming the conclusion that the warming having a characteristic El Niño-like spatial structure, which was observed over recent decades, is at least partly attributable to the human-induced enhancement of the atmospheric greenhouse effect. It was noted, however, that despite the similarity between

effect. It was noted, however, that despite the similarity between the observed and calculated warming structures, the observations carried out before the 1950s are less reliable. Also, conditions similar to La Niña were observed once again recently (in 1995–1996 and 1998–2000).

2.4 Other climate parameters

The observation data suggest a 0.5–1%/10 years precipitation enhancement in the 20th century in most of terrestrial regions in Northern Hemisphere mid- and high-latitudes. This was paralleled by approximately 0.3%/10 years precipitation reduction in most of the subtropical-latitude land regions which, however, weakened in the more recent years. As to the World Ocean, the lack of adequate observation data prevented revealing reliable precipitation trends. Since the middle 1970s, the most stable and intensive phenomena have been those of El Niño/Southern Oscillation (ENSO). Such ENSO dynamics was manifested in the features of the regional variations of SAT and precipitation in most of tropical and subtropical zones. The observation data on the intensity and occurrence of tropical and extra-tropical cyclones, as well as local storms, remain inadequate, which prevents revealing any clear trends (Grigoryev and Kondratyev, 2001).

2.5 Greenhouse gas and anthropogenic aerosol concentration in the atmosphere

The IPCC Report–2001 notes that since 1750 the carbon dioxide concentration in the atmosphere has increased by approximately one third and attained the highest level over the last 420 thousand years (possibly, over the last 20 million years), as evidenced by the borehole data. About two thirds of the CO₂ concentration increase over the last 20 years is accounted for fossil fuel burning emissions (the remainder resulted from deforestation and, to a lesser extent, from cement industry). Interestingly, by the end of 1999 the CO₂ emissions in the USA exceeded the 1990 level by 12%, which figure will further increase by another 10% by the year 2008 (Victor, 2001). At the same time, the Kyoto Protocol requires a 7% emission reduction by 2008 relative to the 1990 level, which implies a total emission reduction by ~25% (which is, certainly, absolutely impossible).

According to the IPCC Report–2001, both the World Ocean and land act now as global sinks of CO₂. In the ocean case, this is due to chemical and biological processes, and in the land case, to enhanced “fertilization” of vegetation due to increasing CO₂ and nitrogen concentrations, as well as to changing land use patterns. The IPCC’s approaches to carbon cycle remained virtu-

ally identical to those in early 1990s, although Report-2001 devoted to this problem a special chapter. From the very beginning, the IPCC was wrong in estimating the forest and land use processes, taking the fossil fuel burning and deforestation as the main sources of CO₂ emissions. In attempts to close the carbon cycle by balance calculations they introduced an undefined “fertilization sink” term which obscures the carbon cycle problem. Emissions due to “carbon burning” by humans when breathing were excluded as a CO₂ source. According to *Wigley* (1998, 1999), about 135 kg of carbon in a year; for 6 billion people this makes about 0.8 Gt, and this is much greater than the cement industry emission which is a “must” in all the Report versions. As shown by *Kondratyev and Demirchian* (2000), an additional, beyond 270 ppm, anthropogenic increase in the CO₂ concentration in parts per million K_a linearly varies with the global population size. According to this dependence, the current CO₂ concentration in the atmosphere can be parameterized as $K \sim 270 + K_a = 270 + 15P$, where P is the population size (in billion). For example, the concentration K of the atmospheric carbon dioxide in the year 2000, when the population size was about 6.1 billion, is equal to $K \sim 270 + 15 \times 6.1 = 361.5$ ppm. This value differs by only 2.2% from that obtained at the Mauna Loa observatory, namely, 369.7 ppm. This inaccuracy is comparable with those for P and K values. When related to the K_a - P linear dependence, the carbon cycle model not only more adequately simulates the processes observed in the carbon cycle, but also (which is more important) more accurately links the forecasted future CO₂ concentration to the only variable, i.e., the population size. For example, basing on this relationship, one can expect that the carbon dioxide concentration in the atmosphere will rise by the year 2100 (with the predicted population size in 2100 of 12 billion) to $K_a = 15 \times 12 = 180$ and $K \sim 270 + 180 = 450$ ppm.

The fact that the CO₂ concentration growth in the 21st century will be due mainly to human activity is beyond question. Basing on the model data, the Report states that the biosphere and ocean will be gradually losing their importance as the concentration rise barrier. In this connection, the Report-2001 presents a probable range of the CO₂ concentrations by the end of century, namely, 540–970 ppm against the pre-industrial and present-day levels of 280 and 369.7 ppm, respectively. The carbon cycle models listed in the Report-2001 assign the primary role in the oceanic sink of carbon to diffusion and chemical processes occurring in water. These models do not take proper account of the processes due to carbon dioxide transport by ocean currents, which is especially relevant to cold water formation regions. Such factors make the carbon dioxide absorbing capability look more optimistic. This is also evidenced by increase in the oceanic sink as stated in the Report. Land use, whose pattern and intensity are governed by the aggregate economic ac-

tivity, can create sinks for carbon. Likewise, deforestation does not necessarily decrease the sink. By making some of the Amazonian large forests a region of zero sink-source carbon balance, one can achieve some positive results. The same role was assigned to lumber industry complexes in the former USSR, where logging was paralleled by creating new forest plantation whose sink significantly increased in time. These and other features of the economic activity make a decisive contribution to the established linear dependence between the increase in the human-induced CO_2 concentration in the atmosphere (K_a) and the population size. The observations and modeling showed that the per capita carbon emissions reached a maximum level by the end of the past century, whereupon they began to decline, which is quite natural in the context of the world economic development situation. It should be noted that the emission declined naturally, not responding to any administrative measures like those recommended by the Kyoto Protocol. All this makes unlikely the forecasts of carbon dioxide concentration above 450–460 ppm.

Since 1750 (indirect data), the atmospheric methane concentration has increased by a factor of 2.5, and now it tends to increase. The annual growth rate of the CH_4 concentration decreased virtually to zero, exhibiting a greater variability in the 1990s compared to the 1980s. Since 1750, the nitrous oxide concentration has increased by 16%. Through implementing the Montreal Protocol recommendations and follow-up measures, the concentrations of a number of halocarbons, acting both as GHGs and ozone-depleting gases, either increased at a lower rate or began to decline. On the other hand, there was a rapid growth of the concentrations of their substitutes and of some other synthetic compounds (e.g., perfluorocarbons PFCs and sulfur hexafluoride SF_6). As to other greenhouse gases, their concentrations expected for the year 2001 widely vary. For example, some experts believe that the tropospheric ozone as a greenhouse gas can become equal in the contribution to methane and will also be important in deteriorating the air quality over the most of the Northern Hemisphere.

The estimated radiative forcing (RF), which characterizes the enhancement of the greenhouse effect in the atmosphere and is due to the concentration growth of the atmospheric mix of minor gaseous components (MGCs), is proved to be 2.42 W/m^2 , into which various minor gaseous components such as CO_2 , CH_4 , halocarbons, and N_2O contributed with 1.46, 0.48, 0.33, and 0.15 W/m^2 , respectively. The decrease in the total ozone concentration observed in the two recent decades could result in a negative RF of -0.15 W/m^2 , which can decline to zero during the present century provided efficient ozone layer-protecting measures be taken. The increase in the tropospheric ozone concentration since 1750 (by approximately one third) could lead to a positive RF about of 0.33 W/m^2 .

Since publication of the IPCC Report–1996, many changes have been made to assess RF as due not only to the previously considered sulphate aerosol but also to other aerosol types. This concerns especially carbon (soot) aerosol which strongly absorbs solar radiation, as well as organic, sea salt and mineral aerosol. Major spatiotemporal variability of the aerosol content in the atmosphere and of its properties significantly complicates assessing the aerosol impact on the climate (*Kondratyev, 1999*). An example to this can be found in the “alternative strategy” proposed by *Hansen et al. (2000)*. These authors assumed the approximate mutual compensation of the climate warming via the CO₂ concentration growth and cooling due to anthropogenic sulphate aerosol. In this situation, more importance is assigned to anthropogenic methane emissions (mainly due to rice paddies) and carbon (absorbing) aerosol. Being acceptable at least for the reason of making unnecessary the Kyoto Protocol, this new strategy—unfortunately—creates a broad scope for political games, now around methane and carbon aerosol.

Another climate-forming factor to be taken into account is the extra-atmospheric solar radiation change. The contribution from this factor to RF over the period since 1750 could have been approximately 20% of that from CO₂, due mainly to enhancement of extra-atmospheric insolation in the second half of the 20th century (the 11-year insolation cycle is important to be taken into account). The fact that the IPCC Report–2001 neglects the phase of the Middle Ages warming and the Little Ice Age indicates that climate experts are still far from understanding the possible mechanisms of enhancement of the solar activity impact on the climate (*Haigh, 2000; Kondratyev, 1998*).

3. Results and reliability of numerical climate modeling

The problem of numerical modeling was analyzed in detail in, e.g., *Bengtsson, 1999; Houghton, 2000, 2001; Kondratyev, 1998, 1999; Schlesinger and Andronova, 2000, 2001; The greenhouse ..., 1999* and many others. Here, we will restrict ourselves to brief comments. The progress in improving the completeness of numerical models of climate which take into account interactively all the components of the climatic system “atmosphere–hydrosphere–cryosphere–biosphere” is beyond question. The interactive simulation of the global carbon cycle in climate models has been started at last. The extreme complexity of climate models and numerous empirical parameterization schemes they utilize for parameterization of various processes hinder assessment of the adequacy of these models, especially from the viewpoint of future climate prediction. This was specifically responsible for very schematic, contradictory, and unconvincing attempts to compare numerical modeling results and observation data.

One is forced to accept the fact that despite all the improvements made, the models in question do not adequately describe the reality. The major drawback of these models is that their adequacy is quantitatively unverifiable. Moreover, the more detailed the simulation of the reality, the more unattainable task of overcoming this drawback in view of the stochastic nature of the processes and models. This makes unconvincing the conclusions concerning, e.g., the long-term change of the annual average global average SAT over the recent 150 years. If, according to the IPCC Report-1996, the observed and calculated (taking into account the CO₂, and sulphate aerosol concentration growth) SAT variations agree well, one has to attach more attention to the methane and carbon aerosol, as proposed by *Hansen et al.* (2000). Unfortunately, in both cases the conclusions rest upon arbitrary opinions, and the agreement between the models and observations is achieved in reality by nothing more than forced fitting. Also, a meaningful comparison of the theory with observations requires consideration of the regional climate changes (not only SAT) and not only average values of the climate parameters but also their variability characterized by higher-order moments. An indication of a necessity to further improve coupled climate models is the controversial conclusion concerning the fate of thermohaline circulation (THC) under conditions of global warming. Due to *Gent* (2001), there will be no THC changes under conditions of global warming. An unsolved problem is the "warming commitment" discussed by *Wetherald et al.* (2001).

According to *Charlson et al.* (2000), anthropogenic aerosols strongly affect the cloud albedo, and the assessment of the global average forcing showed that these values are of the same order of magnitude (though with opposite sign) as those due to GHGs. *Recent studies show that the aerosol forcing can even exceed the predictions.*

The Achilles hill of climate models is parameterization of the biosphere dynamics (*Gorshkov et al.*, 2000; *Kondratyev*, 1998; *Zhang et al.*, 2001). In this context, fairly many numerical experiments were carried out previously with the aim to elucidate how deforestation affects the Amazon river basin. These experiments showed that total deforestation (replacement of rainforest by grass cover) will result in reduction of evaporation from the surface and precipitation, though in a simultaneous rise in the surface temperature. This will be responsible for a rise of SAT within 0.3–3°C. Such changes are due mainly to increase in the surface albedo and decrease in soil moisture. This will cause a decrease in the energy and water vapor fluxes to the atmosphere, a moisture convection decay and latent heat release which, in turn, will be responsible for a decline in the atmosphere warming. This will have a dual effect on the atmosphere circulation: (1) changes in the ascending and descending air flows in tropics and subtropics (Hadley circulation cells) and (2) changes in the

planetary wave generation conditions (Rossby waves) propagating from tropics to mid-latitudes.

To elucidate in more detail how deforestation affects the atmosphere circulation and climate, *Gedney and Valdes (2000)* carried out numerical experiments on simulating the present-day (“reference”) climate and total deforestation conditions for the Amazonian region. To this end they took advantage of a 19-level spectral (T42) general atmosphere circulation model. Deforestation should change the following climate-forming parameters: albedo (13.1→17.7%); roughness (2.65→0.2 m); vegetation cover share (0.95→0.85); leaf area index (4.9→1.9); minimal vegetation cover resistance (150–200 s/m); root zone depth (1.5→1.0 m). All this will change the soil type as well. Numerical modeling revealed statistically significant variations of precipitation in winter period in the north-east area of the Atlantic Ocean, which result from deforestation and propagate further eastwards, toward Western Europe. Such variations are due to changes in large-scale atmosphere circulation in mid- and high-latitudes. Simulation of such variations using the simple model confirmed that they are due to planetary wave propagation. This suggests that the results revealing the interrelation between the processes occurring in the deforestation region and in North Atlantic and Western Europe are independent of the model chosen, with the variation range corresponding to the assessed human-induced climate changes due to increase in the CO₂ and aerosol concentration.

Zhang et al. (2001) carried out a significantly more extensive numerical modeling of the climate implications of tropical deforestation under progressing “greenhouse” warming due to the CO₂ concentration doubling. Those authors utilized the global climate model CCM1-Oz developed at the National Center for Atmospheric Research (USA). Calculations suggest a major decline of evapotranspiration (by ~180 mm/year) and precipitation (by ~312 mm/year), as well as a SAT increase by 3.0 K in the Amazonian region. Similar, though less pronounced changes are observed in South-East Asia (precipitation reduction by 172 mm/year and warming by 2.1 K). Even less pronounced changes are observed in Africa (precipitation increase by 25 mm/year). Energy balance assessments showed that the climate warming is due not only to greenhouse effect enhancement but also to deforestation-induced decrease in evapotranspiration. Statistically significant climate changes are observed in mid-latitudes as well.

The IPCC Report–1996 contains a conclusion that was subject to heated debate, namely, that the balance of evidence suggests a discernible human impact on global climate. Also, the report states that the “anthropogenic signal” is already manifested against the natural climate variability background. The IPCC Report–2001 (*IPCC ...*, 2001) states that detection and attribution studies regularly indicate the presence of the anthropogenic signal in the climate observation data for the last 35–55 years. The nature-induced impacts could play

a role in the warming observed in the first half of the 20th century, but they cannot explain the warming in the second half of the century. This report also indicates, however, that the reconstruction of the climate for the last 1000 years, as well as model estimates demonstrate low probability of that the observed climate changes in the second half of the 20th century could be of completely natural origin. Also, the report emphasizes the high uncertainty of the quantitative estimates for human-induced warming, especially as regards contributions of various warming factors (this holds above all for clouds and atmospheric aerosol). The judgements and conclusions mentioned are so evidently conflicting and unconvincing that we leave them without comments. Certainly, the leading role in substantiating the future climate predictions should belong to integrated models describing the dynamics of the interaction between the socioeconomic development and the nature (Kondratyev, 1999; Prinn et al., 1999; *The Atmospheric ...*, 1998; Victor, 2001). It remains to be seen, however, how realistic the forecasts can be, based on such models with their extraordinary complexity and inadequate input information. It seems likely that at least in the not so distant future integral models will serve for preparing very schematic scenarios only. An important advantage of such models is that they show the regional climate change pattern. However, this pattern (whose adequacy is doubtful) can be obtained only after multiple simulation of climate changes on the global scale, which is very problematic.

New data suggest that with a 1% annual growth of the CO₂ concentration under various scenarios of the economy development and various aerosol compositions, the global average annual average SAT increase during the period 1990–2100 will be 1.4–4.8°C against 1–3.5°C from the IPCC Report–1996. In this connection it is symptomatic that with improving the models and increasing their number, the divergence of this process deepened rather than contracted. Importantly, the SAT values calculated in terms of various models for the same scenario of MGC emissions were virtually identical to those with the same model for various scenarios. As to regional climate predictions, they are still statistically unreliable. However, one can, probably, hold as reliable the conclusion that in many terrestrial regions the warming will be faster than on the global scale, especially, in high-latitudes during the cold half-year. The most substantial (~40% in excess of the global average value) was the calculated climate warming in northern region of Northern America, as well as in the Northern and Central Asia. By contrast, the summer warming in South and South-East Asia and in southern regions of Southern America and the winter warming should be weaker than the global average warming. Numerical modeling data are indicative of the forthcoming enhancement of the water content of the atmosphere as well as precipitation. In particular, there can be precipitation enhancement in Northern Hemisphere mid- and high-latitudes, as well as

in Antarctica in winter. This conclusion is of special importance in the glacier dynamics context. For low latitudes, depending on the MGC emission scenario chosen, both precipitation enhancement and reduction is probable.

Responding to great interest to possible anomalous events, the *IPCC Report (2001)* gives prognostic estimates as correlated with the recent observation data (*Table 1*). This problem has been discussed by *Karl et al. (1999)* and *Grigoryev and Kondratyev (2001)*. The deficient observational data and unreliable results of numerical modeling make the conclusions in the table fairly vague.

Table 1. Observed and predicted anomalous weather and climate changes

Phenomenon	Observations (second half of the 20th century)	Forecast (2050–2100)
Abnormal temperature maxima and number of unusually hot days	Almost all terrestrial regions	Revealed by the majority of models
Enhanced heat index	Many of terrestrial regions	
Abnormally intensive precipitation	Many of Northern Hemisphere mid- and high-latitude regions	
Abnormally high temperature minima and decrease in the number of cold days	Almost all terrestrial regions	Possible, taking into account increase in minimal temperatures
Decrease in the number of frost days		
Decrease in the daily temperature amplitude	Many of terrestrial regions	Almost all models
Summer continent dehydration	Selected regions	
Maximal wind enhancement in tropical cyclones	Not observed, but the number of case studies is scarce	Selected models
Enhancement of medium and maximal precipitation in tropical cyclones	Insufficient data	

Calculations of human-induced (“green-house”) climate changes evidence a possible weakening in the future of thermohaline circulation (THC) in Northern Hemisphere oceans. However, even models revealing such a weakening still reflect the preserved “greenhouse” warming in Europe. It is still unclear

whether the THC collapse can be irreversible and which threshold conditions correspond to this kind of collapse. None of the available models predicts complete cease of THC within the next 60 years.

Numerical modeling of the “global warming” process suggests that there must be further snow and sea ice cover reduction in Northern Hemisphere. Further retreat of glaciers (except for Greenland and Antarctic, including Western Antarctic, ice sheet) is expected in the 20th century. With the given scenarios of the greenhouse gas concentration growth over the 1990–2100 period, the World Ocean level can rise within 0.14–0.8 m (~0.47 on the average), which exceeds 2–4-fold the ocean level rise rate in the 20th century.

IPCC believes that the anthropogenic impact on the global climate will be preserved for a long time, and this will determine the following specific features of the corresponding processes:

- Carbon dioxide emissions have durable impact on the atmospheric CO₂ concentration. Even within several no-emission centuries the fraction of carbon dioxide retained in the atmosphere can reach 20–30% of the total emission level;
- The supposed stabilization of the atmospheric CO₂ concentration requires significant reduction of the carbon dioxide emissions, as well as a more significant decrease in emissions of other greenhouse gases;
- After stabilization of the CO₂ concentration level the global average SAT will also continue to grow for hundreds of years owing to the giant thermal inertia of the ocean (this concerns only 15–25% of the whole increase);
- The ocean level and ice sheets will continue to respond to previous climate changes during thousands of years after the climate stabilization. Model calculations show that in case of warming of 5.5°C, the World Ocean level can rise (owing to the Greenland ice melting) by 3 m within 1000 years. Modern dynamics models for the Western Antarctic ice sheet suggest that the melting can be responsible for the ocean level rising within 3 m during 1000 years, but one should take into account the fact that the possible long-term dynamics of the Western Antarctica cryosphere has not been properly studied.

The conclusions concerning the currently observed and, especially, the likely future climate changes are very uncertain. This concerns both the diagnostics of the present-time dynamics of climate, its simulation models and numerical modeling results. According to the *IPCC Report (2001)*, the priority should be assigned to developments along the following eight directions:

- To stop further degradation of the conventional meteorological observation network;

- To continue research on global climate diagnostics with the aim to obtain long series of observation data with a higher spatio-temporal resolution;
- To attain more adequate understanding of the interaction between the components of the ocean climatic system (including deep-lying layers) in their interaction with the atmosphere;
- To reach more realistic understanding of the long-term climate variability;
- To apply the “ensemble” approach in numerical modeling of global climate in the probabilistic estimation context;
- To develop the integral totality (“hierarchy”) of global and regional models, with a special attention to numerical modeling of regional impacts and extreme changes;
- To substantiate interactive physicobiological climate models and socio-economic development models with the aim to analyze the environment–society interaction dynamics.

This should be supplemented, in particular, by the following:

- For understanding the regular features of the present-day climate, paleoclimatic investigations are essential, especially on sudden—within comparatively short time periods—changes (*Kondratyev, 1998, 1999; Kukla, 2000*);
- Intensive satellite-based remote sensing studies have not yet provided an adequate global information required for climatic system diagnostics, because the existing satellite-based and conventional observation system operate in a far- from-optimum regime. Despite many efforts to and major progress in development of the Global Climate Observation System (GCOS), Global Ocean Observation System (GOOS), Global Terrestrial Observation System (GTOS), and (at a later time) Integrated Global Observation System (IGOS), the task of optimizing the global observation system still remains to be solved. We still need to realize that along with accumulation of long homogeneous observation data series required for climate system diagnostics there is also a need in problem-driven (“focused”) observational experiments. These latter will address problems such as global carbon cycle, anthropogenic impact on the stratospheric and tropospheric ozone, the dynamics of the processes occurring in the “aerosol–clouds–radiation” system, biotic regulation of the environment etc. (*Goody et al., 2001; Kondratyev and Cracknell, 1998; Kondratyev, 1999*);
- The IPCC documents vaguely estimate the levels of anthropogenic impact on global climate. *Reilly et al. (2000)* correctly explain this situation primarily by the lack of quantitative estimates for the uncertainty of the results obtained (this is the case for, e.g., expected rise of SAT by 1.4–5.8°C). Clearly, in such situation the decision-making on environmental policy (e.g., in the case of Kyoto Protocol) relies on views lacking a

icy (e.g., in the case of Kyoto Protocol) relies on views lacking a serious scientific substantiation (see *Soon et al.*, 2000). In this connection, a question arises as to whether predictions for the year 2100 make sense in view of the fact that the prospects for the global socioeconomic development cannot be predicted. The only possible answer to this question suggests itself: One can only prepare entirely conditional scenarios relying on which the political decision-making would be unwise and even fraught with danger. This is even more pertinent to regional scenarios, which have specific of practical interest, rather than global average estimates which can be likened to the "hospital average temperature". Naturally, we cannot accept the attempts by *Allen et al.* (2001) to excuse the lack of quantitative estimates of uncertainties—especially by pleading the fact that in 1990 the IPCC was pressed to make a statement attributing the observed climate changes to anthropogenic impact—on grounds that otherwise it might have been done by anybody else. The opinion by *Wigley and Raper* (2001) defending the IPCC Report–2001 conclusions also cannot be regarded as convincing evidence.

4. Conclusion

The main conclusion following from discussion of the IPCC Reports which have been used to substantiate the need in the entire process of adoption and realization of the Kyoto Protocol is that they are unsuitable as decision-making bases. The gaining insight into characteristic features of the present-day climate system dynamics and especially assessing the likely climate changes in the future are seriously complicated by the lack of reliable estimates of the contribution made by anthropogenic factors to the present-day climate change. We clearly realize that human-induced enhancement of the atmospheric greenhouse effect due to GHGs concentration growth in the atmosphere should be responsible for certain changes in the global climate. But no use of this fact for creating panic and for solving political problems can be tolerated. Unfortunately, many of the leading figures in the IPCC act in accordance with specifically this principle.

For understanding how realistic the climate predictions are, verification of the model adequacy to the currently observed climate changes and paleoclimate dynamics (based on indirect data) has crucial importance. As to the use of modern observation data, the situation seems fairly paradoxical: Such verification is virtually confined to averaged temperatures, while it is evident that one needs all other kinds of information. The paradox consists in that satellite observations provide a giant excess of nonsystematized data, which is paralleled

by the already mentioned degradation of the conventional (in situ) observation network.

Verification of global climate models by comparing the numerical modeling and observation data is an extremely complex task. It has been solved most often by comparing long series of data on the annual average global average SAT, which virtually always yielded the same conclusion (despite substantial—sometimes cardinal—distinctions in accounting climate-forming processes), namely, that calculations agree on the whole with observations. Another feature characteristic of these developments is a conclusion—not adequately substantiated scientifically—of a major (or even dominating) contribution from anthropogenic factors (above all, greenhouse effect) to climate formation. Clearly, this approach to model verification cannot be taken seriously, because (1) modern climate models are still imperfect from the viewpoint of interactive account of the biospheric processes, “aerosol–clouds–radiation” interaction, and many other factors, and (2) the only long-term (100–150-year-long) SAT observation series available is far from being adequate from the viewpoint of calculating annual average global average SAT (not to mention other climate parameters).

Recent developments under GCOS, GOOS, GTOS, and IGOS programmes are undoubtedly useful, but they still do not substantiate the optimal global observation system (this question was discussed in detail in monographs (Kondratyev, 1998; Kondratyev and Cracknell, 1998), and in more recent years, by Goody *et al.* (2001)). This is primarily explained by imperfect climate models intended as the conceptual basis for observation planning to be further improved following the refinement of the models. In this connection we should emphasize the need in analyzing the *divergences* disclosing specific “weak points” of models rather than in making illusory statements treating global climate models as fairly realistic. Clearly, the focus of consideration should be not only on SAT but on the *totality* of the climate parameters. The primary attention should be given to model’s simulation of climate changes (including at least second-order moments).

Paleo data indicate that in the geological past there were strong and sometimes very rapid climate changes. *Alverson et al.* (2000) noted, for example, that the ocean level changed by over 100 m, the stable changing rate being over 1 m within 1000 years. Such changes significantly exceed the supposed human-induced changes corresponding to the doubling of the atmospheric CO₂ concentration, which shows that any concerns about anthropogenic impact on the climate are unjustified. The problem consists not so much in forecasting in detail the climate of the future as in analyzing how sensitive is the modern society and its infrastructures to the likely climate changes. It is worth to mention that for many countries, including Russia and the USA (see *Kondratyev,*

2001), the forecasted warming means advantages rather than danger. In this connection, paleo data are of a greater value for climate prediction than numerical modeling-based schematic scenarios.

As to climate predictions and the atmospheric greenhouse emission reduction recommended by the Kyoto Protocol, the former is clearly need to be interpreted as schematic scenario and the latter, correspondingly, as having no real grounds. This suggests an acute need in revising the Framework Convention on Climate Change (before "Rio + 10") and rejecting unjustified and non-realistic recommendations contained in the Kyoto Protocol that pose threats to socioeconomic development. The collapse of the 6th Hague Conference of the FCCC signatory-countries (November, 2000) suggests that these costly conferences are fruitless and the global climate change problem needs a serious scientific discussion without domination of adepts of "global warming" concept. The real situation consists in that greenhouse emissions continue to increase, and this trend will be preserved, in particular, in the USA, and all the reasonings on the importance of "flexible market mechanisms", "emission trading", etc. are purely rhetorical.

The current status of the climate theory by no means receives only optimistic assessments. In this connection it will be appropriate to mention opinions of American experts (see *Shackley et al.*, 1998). For example, North from Texas University finds it difficult to judge whether climate models have improved over the recent 5 years and believes that the uncertainties are still as large as 20 years ago. Stone from Massachusetts Institute of Technology thinks that the major uncertainties in predictions of present-day climate changes have not decreased at all. Charlson from Washington State University believes that one would be wrong in thinking that one understands the climate. In Kerr's opinion, the information contained in the *IPCC Report (2001)* substantially reduces the uncertainty in solving the problem of detecting the "anthropogenic signal" for climate and supports the conclusion that global climate changes have anthropogenic origin but, at the same time, not only decreases but even extends the range of uncertainties in climate predictions. *Gutzler* from New-Mexico State University says that it seems to him that the solution to the "anthropogenic signal" detection problem has *almost* been found. According to *IPCC Report-2001*, the warming observed during the recent 50 years is, probably (by 66–90%), due *for the most part* to the GHG concentration growth. In this connection, it should be noted that the problem of quantitative estimation of what is "almost" and what is "for the most part" remains to be solved. These vague formulations clearly reflect the degree of uncertainty of the climate numerical modeling results.

Very much to the point was the remark by *Soros (2000)* that at the present time the CO₂ emissions are about 16% above of those in 1990 in the USA, 6% in

the European Community member-countries, 5% in Japan, and 24% in Australia. Thus, in the 1990s there was a rise, rather than stabilization, of atmospheric emissions of carbon dioxide. Also, there is no evidence to suggest any serious emission reduction efforts (the CO₂ emission reduction in Germany and Great Britain have nothing to do with the Kyoto recommendations). *Soros* (2000) was right in voicing a concern about the credibility gap to the Kyoto Protocol and the clear lack of prospect for its ratification by the leading industrial countries.

Tol (2000) mentioned with a good reason that one must not be under misunderstanding that without fossil fuel the world will be like a paradise. Though attractive on small scales, renewable energy sources have unclear prospects on large scales. The limitations of, e.g., hydro energy and wind energy became evident. All this reflects the undoubted truth that one needs to search ways of further development of civilization and to substantiate an adequate environmental policy in the context of the dynamics of the “society–nature” interactive system. Finding solution to this problem will require unprecedented cooperative efforts by experts in natural and social sciences.

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Sensitivity of the ALADIN weather prediction model to the changes of soil texture

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Abstract—The sensitivity of ALADIN's forecasts to the changes of soil texture is evaluated. In the experiments different ALADIN versions and soil texture databases are applied. Three ALADIN versions are tested: the 1-dimensional ALADIN, ALADIN with dynamical adaptation, and ALADIN with data assimilation. Two soil texture databases are used: a global soil map and a more detailed Hungarian soil texture map. 48-hour forecasts are analysed. Among forecast variables, the superficial soil water content and the 2m air temperature are chosen. The main results are as follows: the superficial soil water content and the 2m temperature differences increased with increasing soil texture differences. In the case of maximum sensitivity, they reached 2.5 kg m⁻² and 4.4°C, respectively. The sensitivity was most pronounced for ALADIN with data assimilation.

Key-words: soil texture, superficial soil water content, 2m air temperature, ALADIN limited area model, data assimilation

1. Introduction

The state of the atmosphere is determined in a great extent by surface conditions, via transfer processes of momentum, heat and moisture in the soil–vegetation–atmosphere system (Pitman *et al.*, 1999; Kabat, 1998; Betts and Ball, 1996). Recognising the importance of these interactions, land surface schemes have been developed for use in numerical weather prediction models. The fluxes of momentum, heat and moisture are determined by the properties of the surface, mostly by albedo, roughness length and soil hydraulic

properties. Over ground, the latter parameter depends considerably on the soil texture. For weather prediction purposes, the basic soil properties are usually defined in global datasets, like the FAO (Food and Agricultural Organisation) digital soil map of the world (FAO, 1988).

So far the sensitivity of land surface schemes to the changes of soil texture was investigated using fictitious soil texture data and analysing the changes of near surface fluxes. The sensitivity proved to be strong (Pitman, 1994), especially on climatological scale and it appeared in the annual variation of latent and sensible heat fluxes (Irannejad and Shao, 1998). The sensitivity on a short (several days) time scale was also investigated by Mihailovic *et al.* (1992).

In this paper, the sensitivity of the ALADIN mesoscale limited area numerical weather prediction model to the choice of the soil texture database is analysed. ALADIN's land surface module is ISBA (Interactions Soil Biosphere Atmosphere), a well known and widely tested PILPS (Project for Intercomparison of Land Surface Parameterization Schemes) model (Noilhan and Planton, 1989). The attention is paid to the changes of state variables: the superficial soil water content and the 2m air temperature. In contrary to the previous studies, the experiments are performed using real databases. These databases are the Webb *et al.* (1991) global database and the Hungarian soil texture map.

2. Models

The sensitivity experiments are performed using three versions of the ALADIN mesoscale limited area numerical weather prediction model. They are the operational version of the ALADIN model (using dynamical adaptation), ALADIN using data assimilation, and the one dimensional version of ALADIN, the Single Column Model (SCM). In this chapter a short description of each model version is given along with a short presentation of the ISBA land-surface scheme.

The ALADIN (Aire Limitee Adaptation Dynamique developement InterNational) numerical weather prediction model (Horányi *et al.*, 1996) was developed in the scope of an international collaboration led by Météo France. It is a spectral limited area model. The Hungarian version of the model, ALADIN/HU operates at the limit of the hydrostatic assumption typically at a resolution of 8 km. The model is run at the Hungarian Meteorological Service (HMS) twice a day (using 00 and 12 UTC data). It can make reasonably good short range predictions (up to 48 hours) for the territory of the Carpathian Basin. The lateral boundary conditions for the Hungarian model are taken from the regional ALADIN/LACE model (Brožková, 2001) and the transition

between them is made by relaxation, which means the inclusion of a transition zone between the two model domains (Davies, 1976). The initial conditions are computed from the regional model's analysis fields via horizontal and vertical interpolation. The initial conditions do not include any new information compared to the regional model (ALADIN/LACE), but during the integration at a higher resolution the model is "adapting" to the high resolution surface characteristics. This is the so-called dynamical adaptation.

Objective analysis schemes (optimum interpolation (OI) and 3DVAR) have also been developed for ALADIN to provide the possibility to run the model in data assimilation mode rather than dynamical adaptation. Within the data assimilation cycle the model integration is performed for six hour periods, and in every sixth hour the model state is corrected with observational data. Starting from this modified state, the model is integrated for the next six hours, when new data are used, and so on. In the experiments presented in this paper, the OI scheme (Gandin, 1963) is used and only synoptic surface observations are assimilated.

The 3D operational ALADIN model has a 1D version, called Single Column Model (SCM) (Piriou *et al.*, 1999). With SCM the ALADIN physical parameterization package can be run in an interactive environment, allowing easier understanding and validation of the package. The SCM can be run in two ways: in free mode and in a forced way, when the dynamical forcing (advection terms, adiabatic term from temperature equation, and baroclinic term from wind equation), and the semi-implicit scheme are provided by the 3D model, since these two operators are unavailable in SCM. In forced mode it is possible to replay in an interactive mode the predictions done at a given point of the 3D run, which allows the investigation of the physical package and the observation of the role of dynamic forcings in the forecasts. The free mode run is not designed for prognostic purposes, it can be used for testing the parameterization schemes. The scope of this paper is to observe what effect the altered soil texture has on the temperature and moisture characteristics of the boundary layer. For this purpose the free mode run seems to be the most convenient one. In this case only the initialization of the model is needed (in forced mode boundary conditions from the 3D model are required), which is done by using the 3D model state over a given grid point.

In each model version the air-surface interactions are described by the ISBA land-surface scheme. For a detailed description see Noilhan and Planton (1989) and Noilhan and Mahfouf (1996). The description of the changes made during the implementation in the ALADIN model can be found in Giard and Bazile (2000). The ISBA scheme describes the exchanges of heat and water between the low-level atmosphere, the vegetation and the soil. It has seven prognostic variables: the surface temperature, the deep soil temperature, the

interception water content (the water stored on the leaves), the liquid and frozen part of superficial soil water content (corresponding to a very thin layer of 1cm), and the liquid and the frozen part of the total soil water content.

In ISBA the sand and clay fractions have an effect in controlling the moisture and heat transfer processes through determining the soil thermic and hydraulic coefficients. Hereafter the effect of the soil texture on the soil water content and the 2m temperature is described.

In ISBA the soil water content is computed using the force restore model (Noilhan and Mahfouf, 1996). Its basic concept is the division of the total soil layer into two parts. The thin surface layer (1 cm thick in ISBA) reacts rapidly on atmospheric demands, while the total soil layer, which includes the surface layer too, (with variable depths, roughly from 10 cm for stony areas to 3 m for forests, always including the root zone) makes its contribution on a longer time scale.

The water income for the surface layer is represented by the precipitation, the water dripping down from the leaves (the runoff from the interception reservoir), and the melting of snow and ice. The surface layer loses water through evaporation from the bare ground, runoff, freezing of water, and diffusion of water in the ground. The incomes for the total soil layer water content are the same as for the surface layer. The losses are represented by the bare ground evaporation, transpiration, gravitational drainage, and freezing of water (Giard and Bazile, 2000; Gerard, 2000).

As seen above, all transpiration originates from the deep reservoir, where the roots are situated. Runoff begins when the water content exceeds the saturation value. When the deep soil water content reaches the field capacity, a gravitational drain appears at the bottom.

The sand and clay fractions play their role through three so-called hydraulic coefficients. The first of them appears in the surface layer water content equation. It increases when the soil dries (when hydraulic conductivity is decreasing), thus regulating the amount of incoming water absorbed by the surface layer and its contribution to evaporation. The second coefficient characterizes the speed by which the water profile returns to the equilibrium profile. It increases with hydraulic conductivity and plays part in the formulation of the water diffusion in the ground. The third coefficient is present in the deep layer water content equation, in the formulation of gravitational drainage and it characterizes the speed by which the water profile is relaxed to the field capacity. For the surface and deep soil layer water content equations and for the exact formulation of the hydraulic coefficients see Appendix A.

The 2m temperature is not a prognostic variable, it is interpolated from the surface temperature and the temperature of the lowest model layer. The soil texture has an effect on the 2m temperature through the surface

temperature equation (for detailed formulation see Appendix B). The surface temperature is computed from the energy budget of the following fluxes: surface net radiative energy flux, surface sensible and latent heat fluxes, heat flux between surface and deep ground, snow melting flux and surface freezing flux. A thermic coefficient determines the rate of change of soil temperature with respect to contributing fluxes.

3. Databases

In the operational version of ALADIN the sand and clay fractions used as input data in ISBA are taken from a global database, constructed by *Webb et al.* (1991). In order to show the sensitivity of ALADIN to the soil texture changes, a new database, a Hungarian soil texture map was implemented in the model. In the following section a short description of the two databases is given, followed by the description of the computation of sand and clay fractions based on the Hungarian database and of the differences between the two databases.

3.1 The global database

The Webb et al. database is a standardized global data set of soil horizon thicknesses and textures, compiled from the FAO/UNESCO Soil Map of the World, Vols. 2–10 (1971–81). The very heterogeneous high resolution data were transformed into representative homogeneous information at a much lower resolution. This digital map, with a resolution of 1°, comprises 106 soil types, grouped in 26 major soil units. The textural classes refer to the upper 30 cm of the dominant soil and they reflect the relative proportions of clay (fraction less than 0.002 mm), silt (0.002–0.05 mm), and sand (0.05–2 mm) in the soil. The fraction sizes are in accordance with the USDA classification. Three major textural classes are recognised: coarse, medium and fine. The coarse textures are: sands, loamy sands and sandy loams with less than 18% clay and more than 65% sand. The medium class comprises sandy loams, loams, sandy clay loams, silt loams, silt, silty clay loams, and clay loams with less than 35% clay and less than 65% sand. And finally the fine textures are: clays, silty clays, sandy clays and clay loams, with more than 35% clay. The soil texture and soil depth data can be obtained directly from the database for the ARPEGE/ALADIN model grid.

3.2 The Hungarian database

The Hungarian database is a 1:100.000 scale soil texture map, constructed by the Soil and Agrochemical Research Centre of the Hungarian Academy of

Sciences (HAS). The simplified version of the map can be found in *Várallyay et al.* (1980). The map uses seven soil texture types: sand, sandy loam, loam, clay loam, clay, peat, and coarse fragments. The fraction size limits slightly differ from the limits used in the USDA classification. They are 2–0.02 mm for sand, 0.02–0.002 mm for loam and less than 0.002 mm for clay.

3.3 Computation of sand and clay fractions from the Hungarian database

The computation of sand and clay fractions is performed on the base of the map presented in *Várallyay et al.* (1980). First, the relative coverages of soil texture types are determined for each grid surface. After this, the sand and clay fractions are defined according to the following equations:

$$CF(\%) = CCo RCCo + CMe RCMe + CFi RCFi, \quad (1)$$

$$SF(\%) = SCo RCCo + SMe RCMe + SFi RCFi, \quad (2)$$

where CF and SF are the clay and sand fractions in percent; CCo , CMe , CFi and SCo , SMe , SFi are the clay and sand fractions of the coarse, medium and fine soils in percent, and $RCCo$, $RCMe$ and $RCFi$ are the relative coverages of the coarse, medium and fine soils, respectively. In this study the $CCo=3\%$, $CMe=19\%$, $CFi=58\%$ and $SCo=92\%$, $SMe=43\%$, $SFi=22\%$ values are used, according to those used at Météo France.

Finally, the $RCCo$, $RCMe$ and $RCFi$ parameters are derived as follows:

$$RCCo = RCSa + RCSaCl, \quad (3)$$

$$RCMe = RCLo, \quad (4)$$

$$RCFi = RCCILo + RCCI, \quad (5)$$

where $RCSa$, $RCSaCl$, $RCLo$, $RCCILo$, $RCCI$ are the relative coverages of sand, sandy clay, loam, clay loam, and clay respectively. The sand and clay fractions are not estimated when the grid surface contained peat or coarse fragments.

3.4 Differences between the databases

The differences between the databases are caused first of all by the different resolutions, but also by the fact that there is a difference in the fraction limits used by the two maps. This latter difference is neglected during the computation of sand and clay fractions. On the other hand the parameteriza-

tions used in constructing the data sets are the same, so the differences between the sand and clay fractions can only originate from the differences of the input data (texture and relative coverage).

3.4.1 Clay fraction differences

The largest absolute differences between the two soil texture maps occur in the northeastern part of Hungary (*Fig. 1*). The clay fractions derived from the Webb et al. soil map are about 30% larger than the fractions calculated from the Hungarian database. In some places the differences even exceed 50%. Relatively large (more than 20%) differences can be observed in the north-western part of the country, with the larger values sometimes in the global and sometimes in the HAS database. In the area between rivers Danube and Tisza the Hungarian database contains the larger values, the difference is about 20%. In the south-western part of Hungary the two soil maps are in good agreement, with differences mainly below 20%.

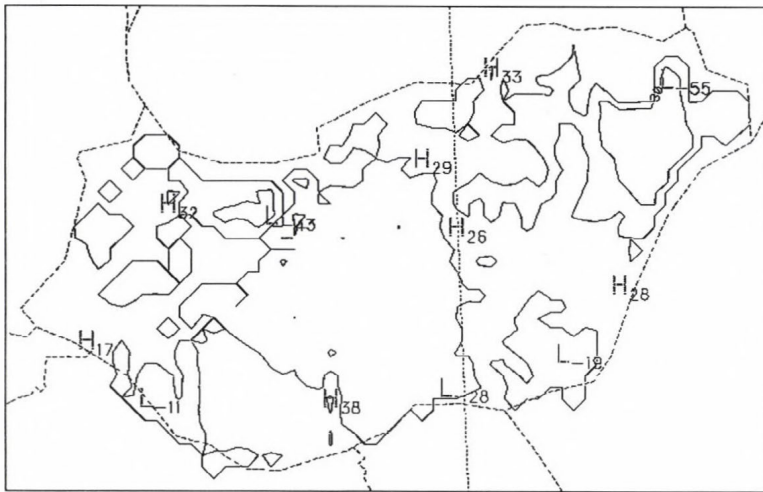


Fig. 1. Clay fraction differences in percent between the global and the Hungarian databases in Hungary (H - high, L - low).

3.4.2 Sand fraction differences

The largest absolute sand fraction differences can be seen in the northeastern part (*Fig. 2*) of the country. Here the Hungarian soil map contains the larger values and the differences exceed 60%, in some places even 70%. In the

western part of the country there are larger values in the Hungarian database, the differences are mainly 30%, but in some places they exceed 60%. In the area between rivers Danube and Tisza the differences are about 30%, with higher values in the Hungarian database. In the southern territory the differences are more than 20%, with larger values in the global database. The sand fractions derived from the two soil maps are in a good accordance in the area to the East of river Tisza except the northeastern part, and in the centre of Transdanubia.

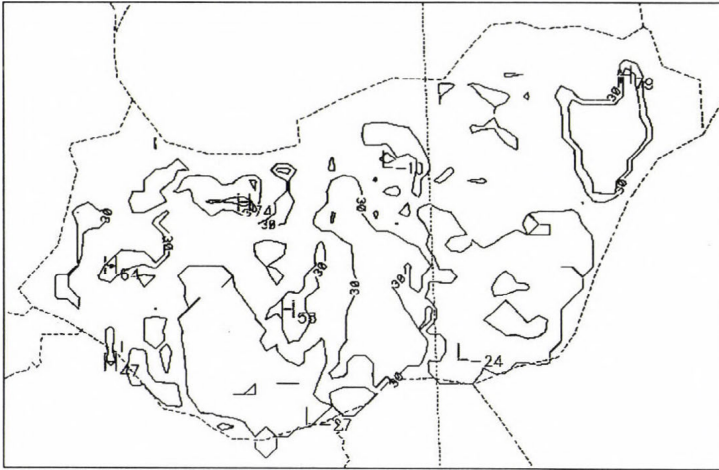


Fig. 2. Sand fraction differences in percent between the global and the Hungarian databases in Hungary (H - high, L - low).

4. Sensitivity tests

Sensitivity experiments are performed with all three versions of ALADIN (presented above). In the following chapter the results obtained from the SCM, operational ALADIN, and ALADIN with data assimilation scheme are presented. The investigated parameters are the superficial soil water content and the 2m temperature.

4.1 Experiments with the SCM

The aim of the experiments conducted with the Single Column Model is to get an idea about the sensitivity of the ALADIN surface physical package to the soil texture during a long integration period.

The model integration is performed for a ten day period, above the grid point with the largest differences between the two databases ($\varphi=48.15^\circ\text{N}$; $\lambda=20.89^\circ\text{E}$). According to the Webb et al. database, in this grid point there is 15% sand and 53% clay, while the Hungarian soil map contains 91% sand and 3% clay. The initial profiles for SCM are computed from the results of the 3D runs. The experiments are performed in free mode, no forcing from the 3D model is supplied into SCM. In these experiments the emphasis is placed on the study of land surface—air interactions and not on the exactness of forecasts. Two model runs are done, starting from the May 22, 1999 and the June 14, 1999 profiles. Due to the fact that the two model runs led to very similar conclusions, only the results of the model integration starting from the June 14, 1999 profile are presented.

The soil water content changes are as expected (Fig. 3). The water content curve of the more sandy soil of the Hungarian database is always below the curve representing the results obtained with the global database according to the bigger water conductivity of sand. On the sandy soil a sudden drying can be observed at the beginning of the period as the water content is adapting to the new soil texture. The differences between the results range from 0.6 kg m^{-2} to 1.7 kg m^{-2} .

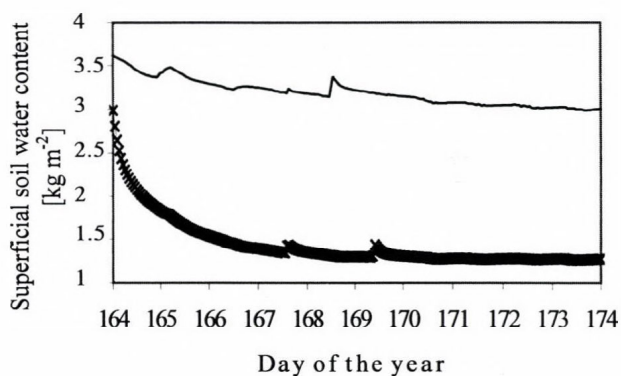


Fig. 3. Soil water content changes in the integration period of ten days. The solid line and the crosses represent the results obtained by the global and the Hungarian databases, respectively.

In the integration period of ten days the greatest difference between the 2m temperatures obtained by the different model runs is 0.8°C . This appears on the fourth day of integration period (Fig. 4). The results are in line with the soil texture. Above the sandy soil the temperature maxima are always higher than in the case of the clayey soil. The largest daily temperature oscillations

can be observed above the more sandy soil (the maximum variation here is 6.8°C, while above the clayey soil it is somewhat lower: 6.5°C). The explanation of this phenomenon is the bigger soil water content of the clayey soil, which leads to greater latent heat fluxes, thus moderating the temperature rise during daytime and reducing cooling at night.

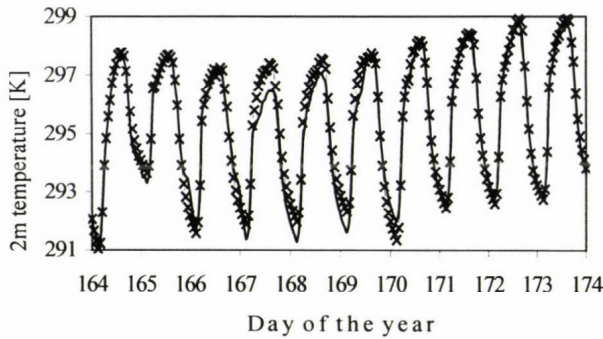


Fig. 4. 2m air temperature changes in the integration period of ten days. The solid line and the crosses represent the results obtained by the global and the Hungarian databases, respectively.

4.2 Experiments with the 3D ALADIN model

Three types of experiments are performed with different versions of the 3D ALADIN model. First, the operational model is run using fictitious soil texture data. In one case this means 100% clay and 0% sand and in the other 100% sand and 0% clay over the whole domain. This highly hypothetical situation is studied in order to get a picture about the maximum sensitivity of ALADIN to the soil texture. Second, experiments are performed with the operational ALADIN, using the two real databases described above. Finally, sensitivity tests are done with the global and the Hungarian databases, using surface data assimilation cycle in ALADIN.

The impact of soil texture on soil water content and especially on 2m temperature is expected to be small. There are lots of effects which can suppress the link between the soil texture and 2m temperature, like precipitation (the convective precipitation is very sensitive to any change of parameters), strong advection, snow cover on the ground, etc. In order to be able to demonstrate the impact, those grid points are investigated for which the effect can be expected to be maximal. Thus four synoptic stations are selected for which the differences between the two databases are the largest. For list of stations see *Table 1*.

One can expect the effect of soil texture on soil water content and 2m temperature to be maximal in such a situation when a wet soil is exposed to a large amount of radiation. Thus, such periods are chosen, based on the daily weather reports, when during the first 24 hours there is precipitation, which is followed by sunshine in the next 24-hour period. Three model runs are done with all model versions using different input data, selected according to the previous criteria. Unfortunately, the forecasts differ from the situation described in the daily weather reports. They predict rain for the last 24 hours too. The results regarding the sensitivity of the model to the databases are similar, so only the 48 hour forecast starting with initial data of the June 14, 1999 is presented.

Table 1. Sand and clay fraction data in percent for the four selected synoptic stations

WMO Nr.	Station name	Latitude	Longitude	Sand fraction		Clay fraction	
				Global	Hungarian	Global	Hungarian
12786	Záhony	48.40°N	22.17°E	21	92	47	3
12815	Mosonmagyaróvár	47.88°N	17.28°E	32	67	35	14
12843	Budapest, Lőrinc	47.43°N	19.18°E	44	72	25	9
12892	Napkor	47.97°N	21.88°E	29	83	34	6

4.2.1 Sensitivity tests with the operational model using fictitious soil texture data

First, the experiments are performed with fictitious soil texture data in order to get a picture about the maximum sensitivity of ALADIN. Two extreme cases are investigated: 100% clay and 100% sand on the whole model domain, respectively. Model runs are performed only with ALADIN using dynamical adaptation. The usage of data assimilation would have led to completely distorted results, due to the fact that information carried by the observations are inconsistent with the fictitious texture data. The model integration is performed for the same period for which the experiments with the real databases are carried out.

The model forecasts predict rain for all four stations. The amount of precipitation during the 48-hour integration time on the sandy soil is between 2.2–6.0 mm, while for the clayey soil between 0.2–3.8 mm. The values are larger above the sandy soil for all stations.

The results for the water content of the surface soil layer can be seen in Fig. 5. The results are as it can be expected on the base of soil texture. The water content of the clayey soil is always higher than that of the sandy soil, in spite of the higher amount of precipitation above the sandy soil. The results show well the great water conductivity of sand. The differences between the results range from 0.1 to 1.6 kg m⁻².

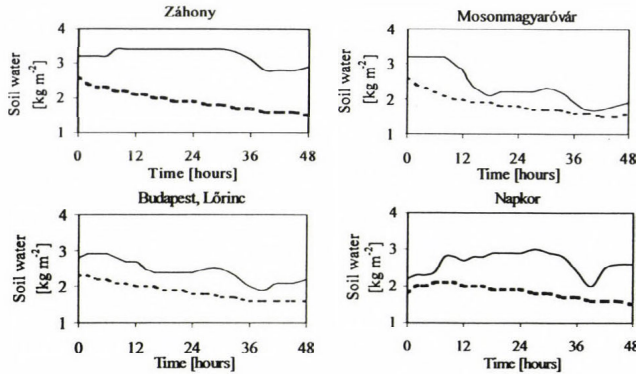


Fig. 5. Soil water content changes in the surface layer in the integration period of June 14–15, 1999. The solid and dotted lines represent the results obtained by the 100% clay, 0% sand and the 0% clay, 100% sand fractions, respectively.

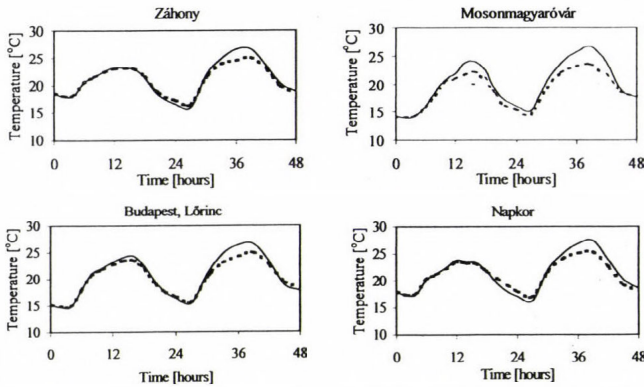


Fig. 6. 2m temperature changes in the integration period of June 14–15, 1999. The solid and dotted lines represent the results obtained with the 100% clay, 0% sand and the 0% clay, 100% sand fractions, respectively.

For 2m temperature predictions see Fig. 6. An unusual result can be observed in the figures, namely that the temperature maxima are higher above

the clayey than above the sandy soil (one could expect the maxima to be higher over sand). The explanation of this surprising result is that above the sandy soil there is a bigger amount of precipitation by 1.6–3.8 mm than above the clayey soil. This increased amount of precipitation can lead to a bigger air moisture content, and thus to a reduced 2m temperature. The differences between the results range from 0 to 3.2°C.

4.2.2 Sensitivity tests with the operational model using real databases

Forecasts with the operational model can be done up to 48 hours, because operationally we have boundary conditions only until that period. In lack of data assimilation the initial soil water content and the initial 2m temperature are not balanced, since they originate from the regional model's analysis fields, which are computed using the global data. The effect of soil texture on the 2m temperature is not as direct as in the case of soil water content (see Appendices A and B), thus one can expect that the 48-hour integration period will not be long enough to allow the occurrence of significant differences between the 2m temperatures computed with the different databases. That's why the experiments were performed using surface data assimilation too.

In the following part the forecasts of superficial soil water content and 2m temperature are presented for the four selected stations.

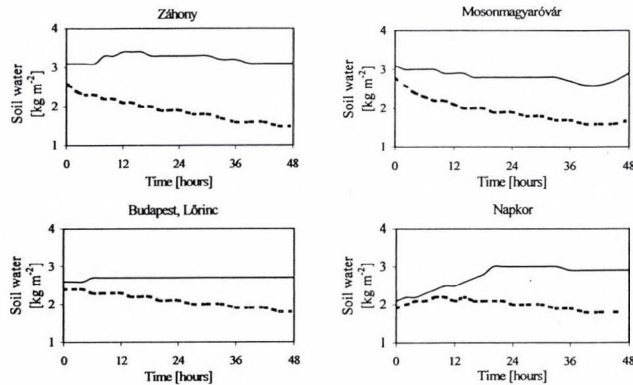


Fig. 7. Soil water content changes in the surface layer in the integration period of 14-15 June, 1999. The solid and dotted lines represent the results obtained by the global and the Hungarian databases, respectively.

The changes of water content of the surface soil layer can be seen in Fig. 7. The soil water content values of the clayey soil of the global database are always higher than those of the sandy soil (by 0.1–1.6 kg m⁻²), because of the

higher hydraulic conductivity of sand. An almost continuous drying of the sandy soil can be observed in spite of the rain (the model gave an amount of precipitation of 1.7–4.5 mm/48 hours for all five stations), while the water content of the clayey soil sometimes increases and sometimes decreases. The differences between the two curves are in general increasing during the integration period for all stations.

The results of 2m temperature forecasts obtained from the model runs with the two databases can be seen in Fig. 8. According to the expectations, the differences between the results are very low, mainly below 0.5°C due to the inconsistency between the values of initial water content and temperature, and the new soil texture. The greatest difference occurred at Záhony: 0.9°C.

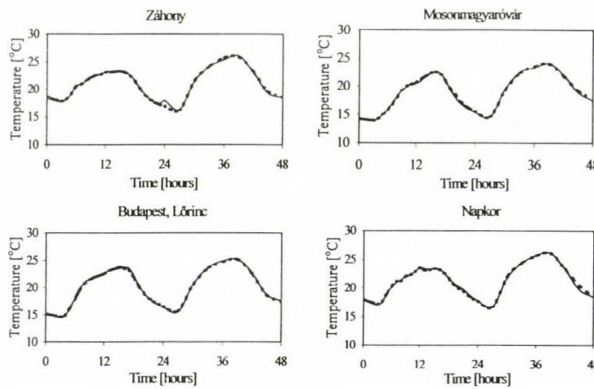


Fig. 8. 2m temperature changes in the integration period of 14–15 June, 1999. The solid and dotted lines represent the results obtained by the global and the Hungarian databases, respectively.

4.2.3 Sensitivity tests with ALADIN using data assimilation

As seen above, the 48-hour integration period is not long enough to demonstrate the effect of soil texture on the 2m temperature, due to the inconsistency between the initial water content and the new soil texture. By using data assimilation we expect greater differences between the results. The data assimilation scheme is run over a three-day period, the model state being corrected with the synoptic data every sixth hour. Afterwards a 48-hour forecast is done. The results for soil water content and 2m temperature are presented below.

The soil water content values can be seen in Fig. 9. The differences between the initial soil water contents have increased compared to the results of the operational model runs, from 0.2–0.5 kg m⁻² to 1.2–2.2 kg m⁻². Due to

the use of the data assimilation, the initial water content is consistent with the texture type. The results are as expected, the water content of the sandy soil is always less than that of the clayey soil. The maximum difference is 2.5 kg m^{-2} .

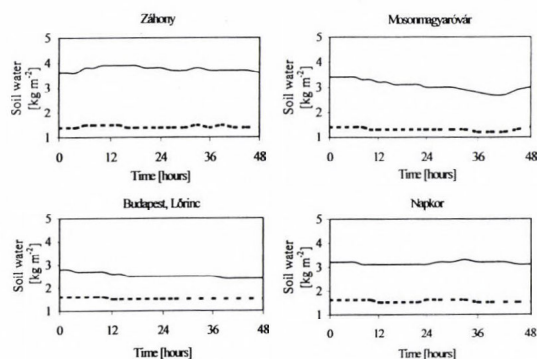


Fig. 9. Soil water content changes of the surface layer in the integration period of 14-15 June, 1999. The solid and dotted lines represent the results obtained by the global and the Hungarian databases, respectively.

The results for the 2m temperature can be seen in Fig. 10. The differences between the results for the two stations where the amount of precipitation exceeded 3.5 mm (Záhony and Napkor) are low. The maximum difference is 0.8°C . This fact illustrates well, how the effect of soil texture on the 2m temperature can be suppressed by precipitation. For the two remaining stations (with less than 3 mm rain) the differences were larger compared to the results of the operational model runs. The maximum difference was 4.4°C .

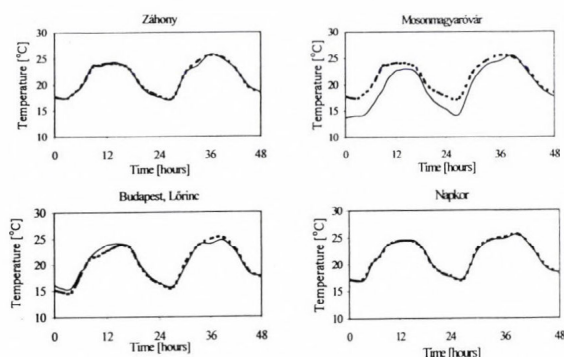


Fig. 10. 2m temperature changes in the integration period of 14-15 June, 1999. The solid and dotted lines represent the results obtained with the global and the Hungarian databases, respectively.

5. Conclusions

The subject of this study was to evaluate the sensitivity of the ALADIN mesoscale numerical weather prediction model to the variation of the soil texture. The sensitivity tests were performed with three versions of ALADIN. They were the one dimensional version of ALADIN, the operational model using dynamical adaptation, and ALADIN with data assimilation. Soil texture data were taken from two databases: the Webb et al. global database and a Hungarian soil texture map. Forecasts were done with all three model versions using the different soil texture data. The sensitivity of soil water content (in the surface layer) and 2m temperature predictions to the changes of soil texture were evaluated in four selected grid points, where the differences between the databases were the largest.

Experiments with SCM were performed for a ten day period. During this time the maximum difference between the soil water contents was 1.7 kg m^{-2} while that for the 2m temperature was 0.8°C .

The operational model was run with fictitious soil texture data first, which meant 0% clay and 100% sand in one case and 100% clay and 0% sand in the other case. The soil water content of the clayey soil was always higher than that of the sandy soil, due to the higher water conductivity of sand. The largest difference was 1.6 kg m^{-2} . In contrast with the expectations, the temperature maxima were higher above the clayey soil, what was caused by the higher amount of precipitation above sand. The maximum difference between the predicted 2m temperatures was 3.2°C .

During the experiments with the operational model using the real databases, the soil water content of the more sandy soil was always less than that of the clayey soil, according to the previous expectations. The largest difference was 1.6 kg m^{-2} . The differences between the predicted 2m temperatures were small, they remained mainly below 0.5°C , with a maximum of 0.9°C , due to the inconsistency between the initial water content, 2m temperature, and the new soil texture.

In order to start the 48-hour forecast from initial conditions consistent with the soil texture, and thus to be able to demonstrate the effect of soil texture on the 2m temperature, a data assimilation cycle was used. The differences between the initial water contents have grown from $0.2\text{--}0.5 \text{ kg m}^{-2}$ to $1.2\text{--}2.2 \text{ kg m}^{-2}$ compared to the results of the operational model runs, due to the use of data assimilation. During the 48-hour integration the greatest difference between the soil water contents was 2.5 kg m^{-2} . The largest difference between the predicted 2m temperatures was 4.4°C . Here it has to be mentioned, that this value is an overestimation of the real sensitivity, due to the fact, that in the data assimilation system no updating of the soil prognostic

variables was included. The use of the same 2m data to constrain the surface would have brought the results somewhat closer.

The differences between the 2m temperatures were larger with increasing texture differences (compare the results of operational model runs with real and fictitious data). The use of data assimilation adjusted the initial conditions to the soil texture, hence the differences between the soil water contents and 2m temperatures grew even larger. The situation considered here wasn't ideal for showing the maximum sensitivity of ALADIN to the soil texture, since the forecasts gave precipitation instead of sunshine for the second 24-hour period. Under ideal circumstances (wet ground exposed to strong radiation) the sensitivity may even prove to be larger.

Further research on this topic should be taken into consideration, running the model with data assimilation and evaluating the results over a long time period. They may even be compared with synoptic data to see whether the forecasts on average can be improved by using a detailed Hungarian soil texture map.

APPENDIX A

Computation of the soil water content

The prognostic equations for the soil water contents of the two layers are the following:

$$\frac{\partial W_s}{\partial t} = \delta_{land} \left[C_1 \left(P_g + F_{evg} + F_{ror} + F_n \right) - F_{wsp} - F_{ros} - F_{si} \right],$$

$$\frac{\partial W_p}{\partial t} = \delta_{land} \left[\left(P_g + F_{evg} + F_{ror} + F_n \right) + F_{tr} - F_{rop} - F_{pi} - F_{si} \right],$$

where

- W_s – superficial liquid soil water content,
- W_p – total liquid soil water content,
- δ_{land} – land fraction within the grid box (1 or 0),
- P_g – precipitation flux at the ground,
- F_{evg} – bare ground evaporation flux,
- F_n – snow melting flux,
- F_{si} – surface freezing flux,
- F_{pi} – deep freezing flux,
- F_{ror} – runoff from the interception reservoir,
- F_{ros} – runoff from the surface reservoir,
- F_{rop} – gravitational drainage (at the bottom of the deep reservoir),
- F_{wsp} – water diffusion in the ground.

Hydraulic coefficients

The C_1 coefficient increases when the soil dries, as hydraulic conductivity is then reduced:

$$C_1 = C_{1sat} \left(\frac{W_{sat}}{W_s} \right)^{\frac{b}{2} + 1},$$
$$C_{1sat} = (5.58 \times CLAY + 84.88) \times 10^{-2},$$
$$w_{sat} = (-1.08 \times SAND + 494.305) \times 10^{-3},$$
$$b = 0.137 \times CLAY + 3.501.$$

The C_2 coefficient characterises the speed by which the water profile returns to the equilibrium profile. It increases with hydraulic conductivity and participates in the formulation of the water diffusion in the ground:

$$F_{wsp} = \frac{C_2}{\tau} (W_s - W_{seq}),$$
$$C_2 = C_{2ref} \frac{F_{Sp}}{1 - F_{Sp} + \varepsilon},$$
$$C_{2ref} = 13.815 \times CLAY^{0.954}.$$

The C_3 coefficient is present in the formulation of gravitational drainage and it characterises the speed by which the water profile is relaxed to the field capacity:

$$F_{rop} = \frac{C_3}{\tau} \max(0, W_p - W_{fc}),$$
$$C_3 = 5.3275 \times CLAY^{-1.043}.$$

Denotation of symbols:

$SAND$ – sand fraction in percentage,

$CLAY$ – clay fraction in percentage,

W_{sa} – water content at saturation,

W_{seq} – superficial water content at equilibrium between gravity and capillarity forces,

τ – the 1 day period (86,400 seconds),

F_{Sp} – the saturated part of the soil,

ε – a small value limiting C_2 at saturation,

W_{fc} – field capacity.

APPENDIX B

Computation of the 2m temperature

The starting equations are the equations for moisture and dry static energy (the sum of enthalpy and geopotential):

$$\begin{aligned} q(z) &= q_s + \alpha_h(z)(q_L - q_s), \\ s(z) &= s_s + \alpha_h(z)(s_L - s_s), \\ s(z) &= c_p T(z) + \phi(z), \\ c_p(q) &= c_{pa} + (c_{pv} - c_{pa})q. \end{aligned}$$

From these the following equation can be derived for the temperature in the z height:

The prognostic equation for the surface temperature is the following:

$$T(z) = \frac{c_p(q_s)T_s + (\phi_s - \phi(z)) + \alpha_h(z) [c_p(q_L)T_L - c_p(q_s)T_s + (\phi_L - \phi_s)]}{c_p(q(z))},$$

$$\frac{\partial T_s}{\partial t} = \delta_{land} C_T (Q_R + Q_{sens} + Q_{lat} - F_{sp} - L_f(F_n - F_{si})).$$

The thermic coefficient for bare ground can be expressed as:

$$C_G = C_{Gsat} (F_{Sp})^{-\frac{b \ln 10}{2}},$$

$$C_{Gsat} = -1.5571 \cdot 10^{-8} \cdot SAND - 1.441 \cdot 10^{-8} \cdot CLAY + 4.70217 \cdot 10^{-6}.$$

For vegetation alone it has a constant value (C_V).

The C_T thermic coefficient for the whole ground-vegetation system can be obtained by weighting the previous contributions by the bare ground and vegetation fractions:

$$C_T = \left[(1 - veg) \frac{1}{C_G} + veg \frac{1}{C_V} \right]^{-1},$$

where

- q – specific humidity,
- s – dry static energy,
- $c_p(q)$ – isobaric specific heat of the wet air as a function of specific humidity,
- c_{pa} – isobaric specific heat for dry air,
- c_{pv} – isobaric specific heat for water vapour,
- T – temperature,
- ϕ – geopotential,
- s – index for the surface,

- L – index for the middle of the lowest model layer,
 z – height,
 α_h – coefficient depending on the atmospheric stability (on the Richardson number),
 $f_h(z)$ – coefficient depending on the atmospheric stability (on the Richardson number),
 Q_R – surface net radiative energy flux,
 Q_{sens} – surface sensible heat flux,
 Q_{lat} – surface latent heat flux,
 F_{sp} – heat flux between surface and deep ground,
 L_f – melting heat,
 veg – vegetation fraction.

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IDŐJÁRÁS

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Selected characteristics of wind climate and the potential use of wind energy in Hungary. Part II

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Abstract—Renewable energy resources including especially wind energy are considered important energy sources. Since the early 80's several research projects have investigated new technologies worldwide, others have built wind field models and dealt with the optimal siting of wind power stations. This work is to clarify the possibilities of wind energy utilization in Hungary. In the second part of the paper, first, 20th century wind climate in the country is summarized analysing and comparing wind data of five different sources. Wind profile is analysed using multilevel wind measurements (from 10 m to 115 m) at the Hegyhátsál area. Significant differences are found in wind speed frequency distributions of vertical levels during the year. A case study is carried out using a mesoscale wind model for surroundings of Hegyhátsál (41 km × 41 km) in order to estimate horizontal and vertical cross sections of wind power fields. Height of a given available wind power level is mapped for larger areas (100 km × 100 km) over Trans-Danubia and over the Great Hungarian Plain demonstrating the importance of siting wind power stations.

Key-words: renewable energy resources, wind energy, wind climate, wind profile, statistical time series analysis, wind field modeling

1. Introduction

Conversion of renewable energy is considered a key issue that plays an important role in the life of inhabitants of our planet. Apart from a negligible period relative to historical time scales, renewable energy provided the only energy resources accessible to mankind. Continuously increasing energy need and energy use of human settlements stem from hundreds of years ago, so it is

a persistent problem starting long before the last century (Gipe, 1995). Structure of these complex processes and their interrelations are presented in Fig. 1. The upper part of the figure (using data from Sørensen, 2000) shows the trend of the average rate of energy conversion per capita on a logarithmic time scale, extending backwards from year 1990. Furthermore, it indicates the estimated variation in energy use with dotted and dashed lines representing societies using the largest and the smallest energy amounts, respectively. For the more recent period, data from Darmstadter et al. (1971) and the European Commission (1997) are included. The lower part of the figure presents the dramatically increasing population rate and the quantity of burnt fossil fuel having definitely similar trends.

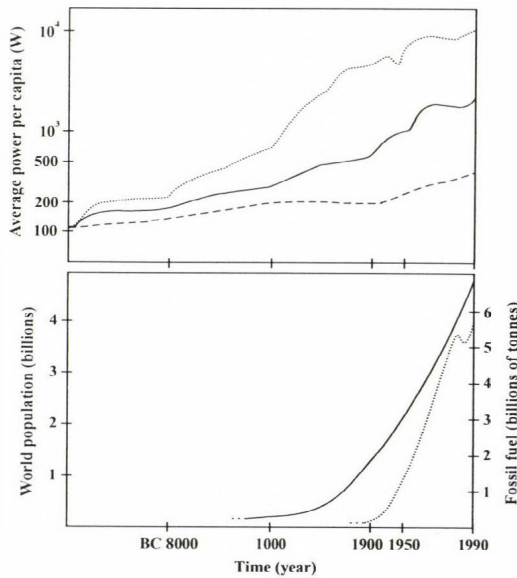


Fig. 1. Trend of the average rate of energy conversion per capita on a logarithmic time scale (up). The estimated variation in energy usage is shown with the dotted and dashed lines representing societies using the largest and the smallest energy amounts, respectively. The dramatically increasing population rate (solid line) and the quantity of the burnt fossil fuel of the world (dotted line) are also indicated (down). (Sources: Sørensen, 2000; Darmstadter et al., 1971; the European Commission, 1997.)

During the entire history of mankind, difference between societies with the highest and the lowest energy consumption has never been so high as nowadays. Increasing energy use of the last millennium is partly due to the

shift in population distribution towards higher latitudes, and to overall increased energy demand (space heating, hot water, lighting, refrigerating, transportation, etc.). Development in the last century is dominated by the energy consumption of the industrialized countries. Evidently, people living in well-organized and mostly urbanized societies use the largest energy amounts.

The difference between the most and the least developed regions of the world, considering energy use as well as infrastructural conditions, seems to continue to widen. Further development of the industrialized part of the world is extremely important because of its dominant share of the total energy used. However, the key factors of the near future trends depend on the other and larger part of the world now using very little energy: whether it will continue to do so or it will increase its energy use.

From a long-term point of view it is suggested that man must base his energy use partly on renewable energy resources. Consequently, there is an urgent need to expand the currently limited technological capacity aimed at utilization of renewable energy, and make such energy conversion technologies more viable than they are at present.

The main purpose of this research project was to consider and review the utilization of potential wind resources of Hungary. In the second part of the paper, first, wind climatologies for Hungary are reviewed, summarizing the results published by several authors in the last century. Then, results of wind profile measurements are presented. Based on the observed time series, errors of wind profile fitting are estimated. Finally, model simulations of wind field are provided to characterize possible wind energy utilization in selected regions of Hungary.

2. *Wind climate*

Nowadays, there is a growing and identified interest to erect wind turbines in order to substitute traditional or environmentally pollutant energy resources. Optimal siting of wind power stations requires the knowledge of detailed topography and wind climate of the studied region. Since climate change can be an important factor as well, wind climate variations of Hungary has been analysed for the last century. Wind climatological data from all available sources have been collected (several authors studied various time periods using sometimes irregular units such as Beaufort scale). For this analysis from the viewpoint of wind energy utilization, the best climate indicators would be the wind climate tables (*Troen and Petersen, 1989; Bartholy and Radics, 2001*). However, measurements that can satisfy the requirements of climatological diagrams are unavailable from the earlier decades of the last century. Therefore, spatial distribution of mean wind speed can be presented summariz-

ing all available information. Selected and corrected data sets have been re-drawn and nine of them are presented in Fig. 2, 3, and 4. Difficulties arose in the comparison because the various sources apply different averaging periods (annual, semi-annual, and monthly averages) and different measuring networks.

Fig. 2 shows the spatial distribution of annual mean wind speed over the country determined from wind observations in 1901–1930. This map was transformed from a similar one (*Bacsó*, 1959) which was given in Beaufort force. For a ten-year-long period (1931–40) *Bacsó et al.* (1953) gave a more detailed semi-annual map-pair for summer and winter half-year (Fig. 3) using data of much more stations than in Fig. 2.

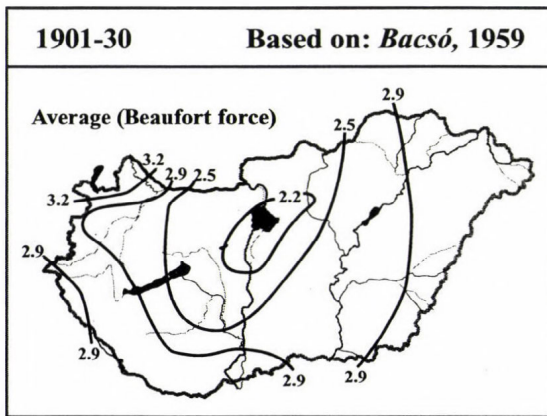


Fig. 2. Spatial distribution of annually averaged wind speed over Hungary.

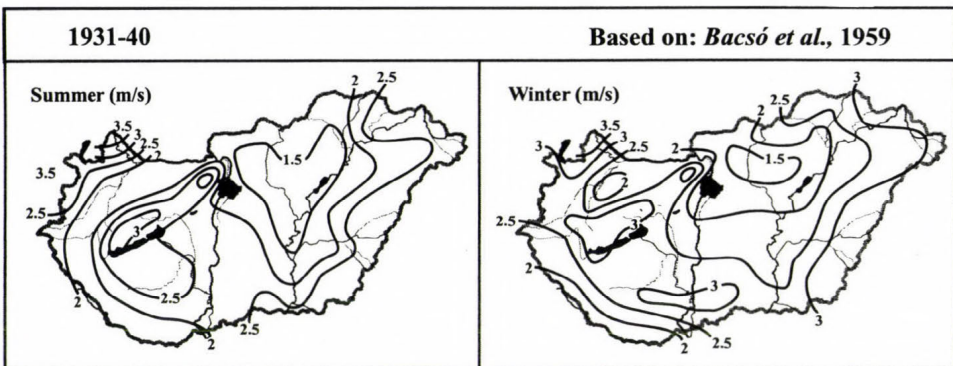


Fig. 3. Spatial distribution of averaged wind speed for winter and summer half-years over Hungary.

Wind energy utilization is the most critical in transition seasons where annual maximum and minimum values occur. Generally, April (in some region March) is the windiest month in the country, while October can be characterized by large spatial variability over different regions of Hungary. Therefore, for the second half of the 20th century—when more observations are available—we chose April and October to represent wind climate. Fig. 4A, B, and C show monthly mean wind speed in April and October for the periods of 1958–1962, 1968–1972, and 1950–1980, respectively (*Kakas, 1967; Tar, 1991; Pécsi, 1989*).

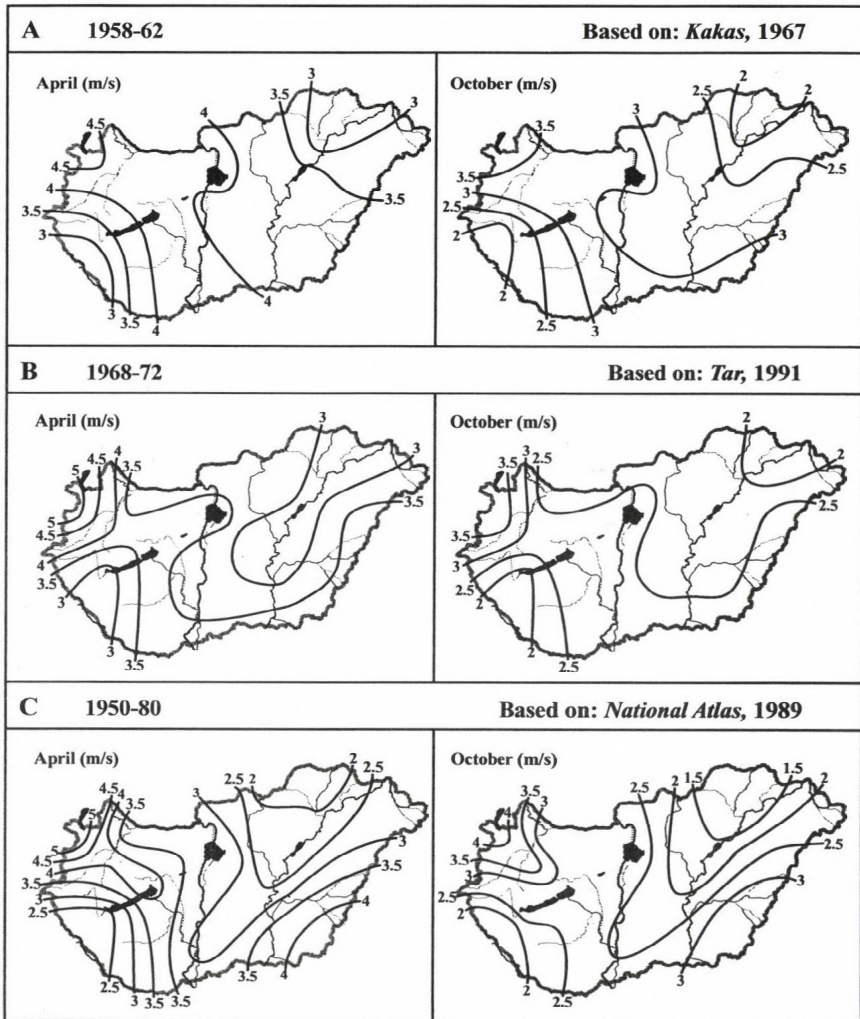


Fig. 4. Monthly wind speed averages of April and October for three different time intervals.

As a summary of Fig. 2, 3, and 4 the following can be drawn. Maximum wind speed values occur in the northwestern corner of the country (around the Dévényi-gate). In general, two minimum wind speed centers appear on the maps, one in the southwestern and the other in the north, northeastern part of Hungary. Average values in Trans-Danubia are higher than in the eastern part of the country. Although, maximum and minimum centers do not show annual moving, values are higher, and the range between the maximum and minimum values are getting also somewhat higher in spring (April) than in autumn (October). Based on the analysed wind speed data no significant changes can be observed during the 20th century, nevertheless for selected areas and shorter periods significant trend was found (Tar *et al.*, 2001).

Because of the inhomogeneity of time series, the changes in measuring techniques and instruments, several replacements of measuring stations and their changing surroundings, the above summary obviously includes some uncertainties. Despite all these factors, it is very unlikely that significant trend would stay hidden in this analysis.

3. Wind profile

Collaborating with the AEROCARB EU-5 framework project (Haszpra *et al.*, 2001), we had the opportunity to carry out wind profile measurements near the village Hegyhátsál, at a site of the northwestern part of Hungary (46.96°N, 16.65°E). Wind speed and wind direction have been observed at four levels from the end of September 1994 (Bartholy and Radics, 2000) on a 117 m tall TV and radio transmitter tower. The measuring station lays at 248 m above sea level, and surrounded mainly by agricultural fields and forest patches. As shown in Fig. 5, the lower part of the tower (56 m) is a 7.75 m diameter cylinder where measurements are recorded at 48 m height in both south and north direction. On the upper cylindrical part (1.82 m diameter) measurements are performed at 82 and 115 m height in north direction. The tower is also a NOAA/CMDL (National Oceanic and Atmospheric Administration/Climate Monitoring and Diagnostics Laboratory) global air sampling network site. In addition, carbon dioxide mixing ratios are continuously monitored, and the atmosphere-surface exchange of CO₂ is measured by eddy covariance (Haszpra *et al.*, 2001).

First, data set of the lowest measuring point (near surface) was analysed. The instrument is placed at 10 m above ground and 70 m away from the tower with the intention to exclude as much as possible shelter effects of the tower. The well-known annual cycle of wind speed can be recognized in the observed data. April is the windiest month in Hegyhátsál area, and October is the least

windy month of the year, as the Hungarian wind climate can be characterized in general. Therefore, relative wind speed frequencies of these months are presented in Fig 6. The first columns represent the relative frequencies of wind calm periods that are relatively low compared to some other regions of Hungary. Certainly, calm periods appear much more frequently in October (9.3%) than in April (5.0%). In both months the most frequent wind speed values are in the 0–4 m s⁻¹ interval. However, wind speed values above the average in April occur more often than in October.

Fig. 5. Structure of the wind profile at the measuring station Hegyhátsál.

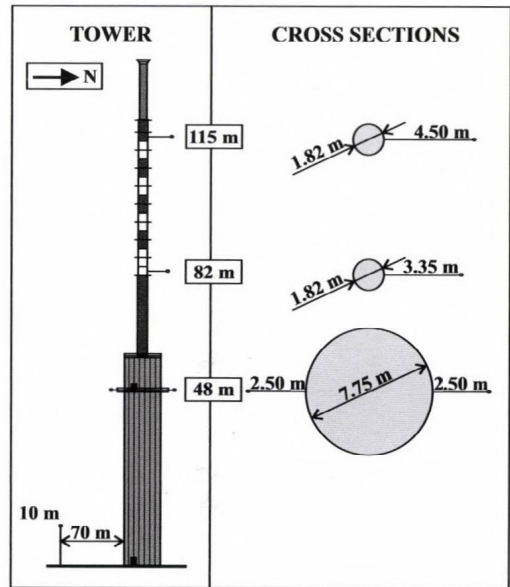
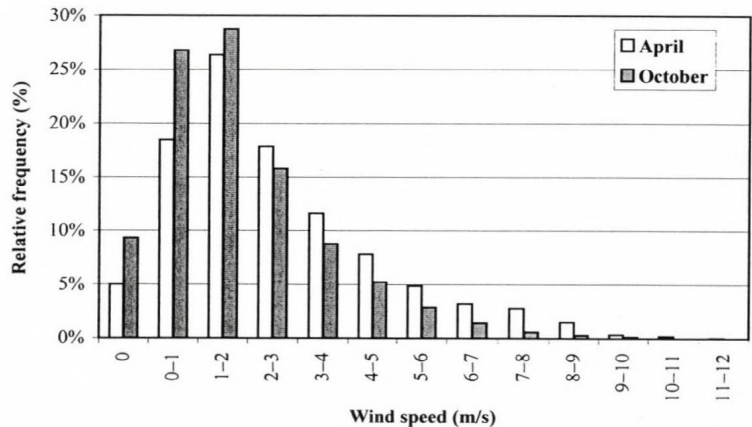


Fig. 6. Frequency distributions of wind speed for April and October at station Hegyhátsál.



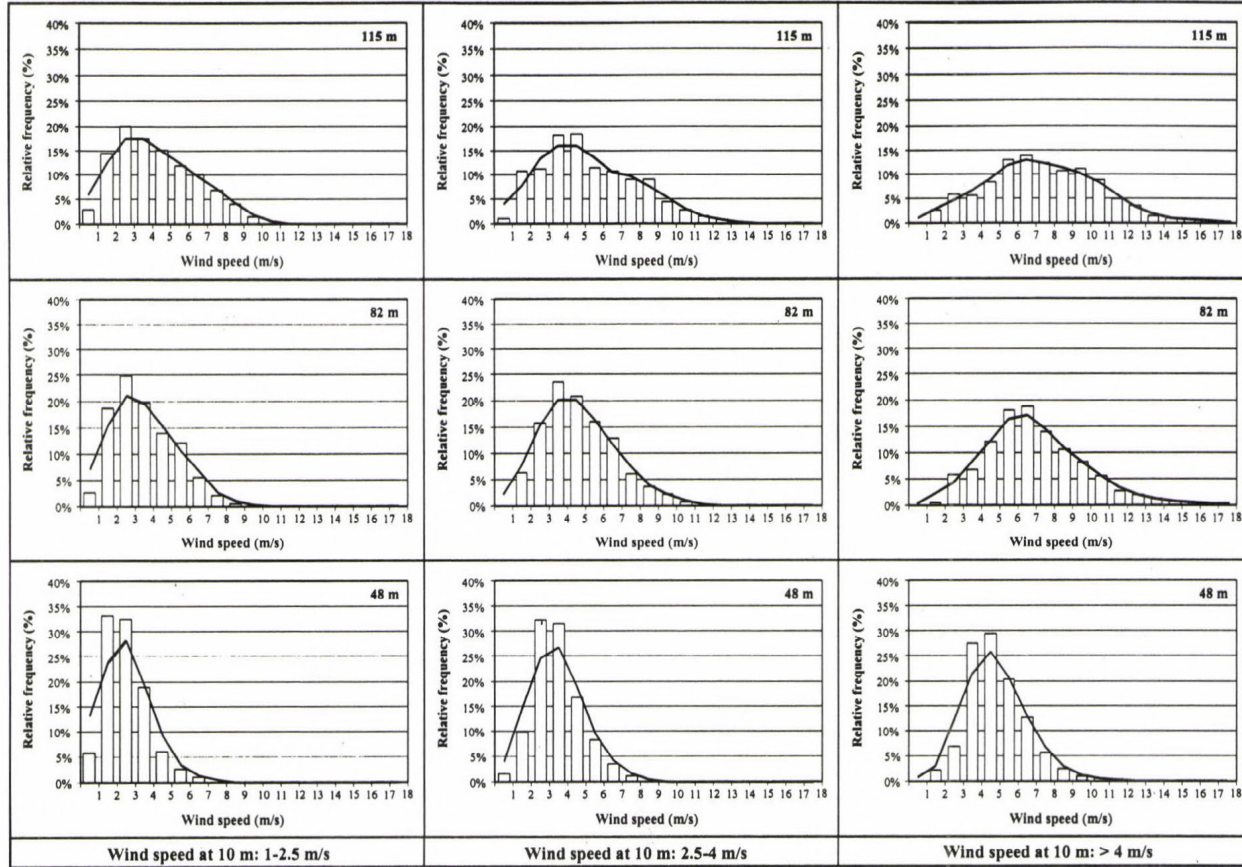


Fig. 7. Relative frequencies of wind speed observed at three levels in April using the tercile classification of April near surface data. Smoothing (running means) is indicated by solid lines.

Multilevel wind speed measuring experiments on towers are suitable to estimate the vertical profiles of wind speed. Although our data set includes errors coming from the shelter and wind field perturbation effects of the specially shaped tower, detailed profile analysis and profile fitting can provide appropriate information about the vertical structure of the flow.

Six-year-long (1995–2000) database measured at four levels was analysed. Classification of wind speed values is based on the near surface time series (observed at 10 m). Periods with wind speed less than 1 m s^{-1} were excluded from the analysis having no significant effect in wind energy production. After determining the tercile values (2.5 m s^{-1} and 4 m s^{-1}) of wind speed time series in April near the surface, ranked data was divided into three groups with equal number of observations (33.3% of data in each group). *Fig. 7* shows the frequency distributions of observations from the higher measuring levels (48, 82, and 115 m) based on the near surface wind speed classification described above. Also the smoothed curves of the distributions are indicated in the figure (where the running mean technique were applied for all consecutive wind speed classes). In order to compare the selected two months, the same threshold values (terciles of April) were used for October leading to an asymmetric distribution (46.9%, 31.8%, and 21.3%, respectively). *Fig. 8* represents the relative frequencies of the above-defined categories in case of October.

In spite of the unequal distribution of the groups of October data, relative frequencies remain smaller than in case of April. However, large differences cannot be observed between April and October wind climate conditions at higher levels. As height and wind speed increase, the range of wind speed frequencies is getting larger resulting in larger errors in wind profile estimation.

4. Wind field estimations

Before estimating extractable wind power or siting wind power stations, it is necessary to map the spatially continuous wind fields. Such maps can be obtained solely by using wind models. The WAsP model (*Mortensen et al.*, 1993) developed at Risø National Laboratory, Roskilde, Denmark has been selected for this reason. It is a linear spectral model for near neutral boundary layer flow over complex terrain. The model can be used to analyse raw time series and estimate the wind climate at any site using digitized topographical, roughness, and shelter maps.

In order to verify the WAsP model for selected regions of Hungary, input data measured at Hegyhátsál at 10 m height have been used to model the wind

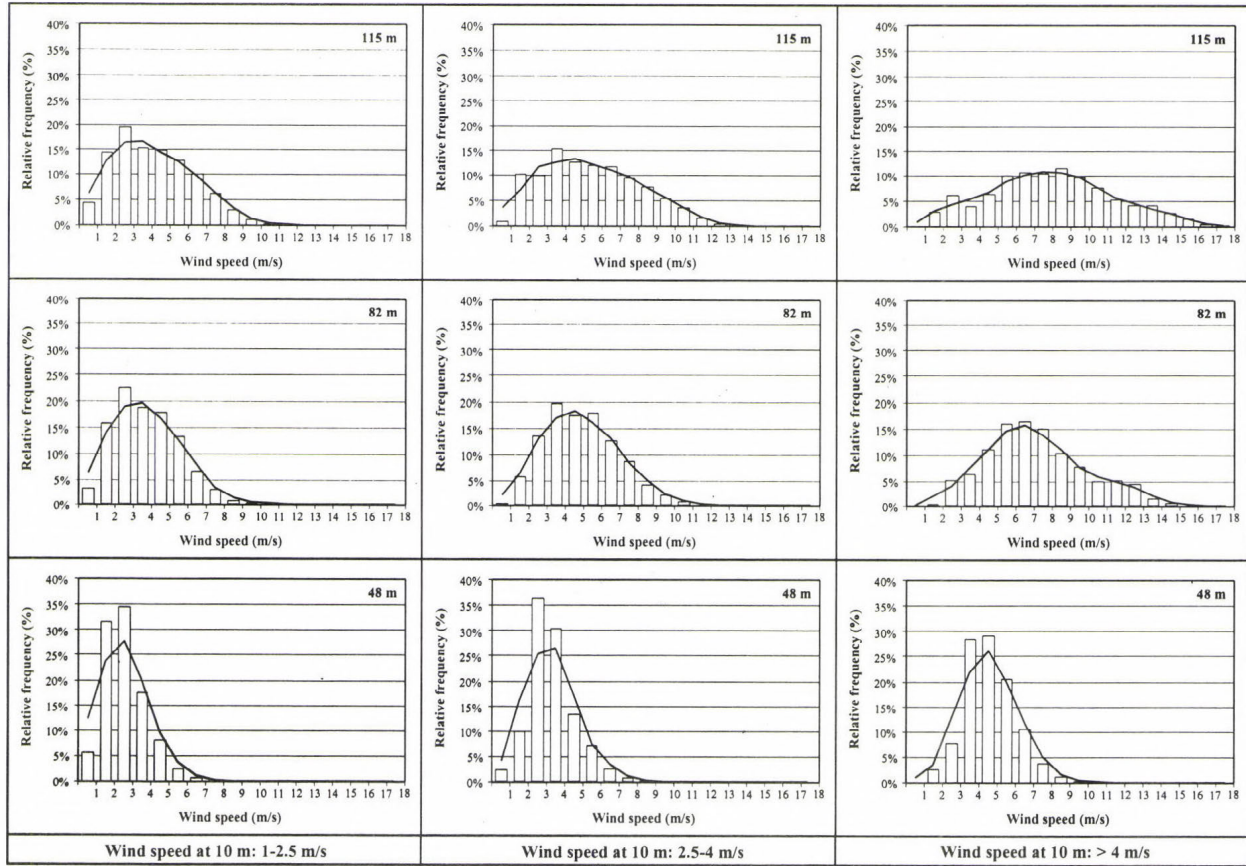


Fig. 8. Relative frequencies of wind speed observed at three levels in October using the tercile classification of April near surface data. Smoothing (running means) is indicated by solid lines.

field over the hilly terrain of 41 km × 41 km area. The topography has been included in WAsP as a height-contour map using 25 m isolines. Roughness length has been set to 1 m, 0.5 m, and 0.1 m for forests and cities, villages and orchards, and shrublands or grasslands, respectively. In case of water bodies, 0.001 m has been chosen. Effects of every obstacle near the station have been taken into consideration. We did not find considerable differences between measured and simulated values; consequently, topography of the hilly terrain does not generate remarkable model errors. Since orography of Hungary does not show large variability in elevation above the sea level, our preliminary results suggest that the WAsP model will provide reasonable output fields (Bartholy and Radics, 2001). Therefore, it is possible to extrapolate wind data of Hegyhátsál simulating mean flow over the surroundings.

After including the orographical characteristics of Hungary into the WAsP model, measured wind data were extrapolated horizontally and vertically. In Fig. 9 a case study for the Hegyhátsál area is presented. First, mean wind speed field was simulated for a 41 km × 41 km area around the measuring place at 18 m height. The model run was based on the fine resolution digital terrain model (DTM 1000) and on the measured wind speed at 10 m height (Fig. 9, top). Then, available wind power fields were estimated and mapped for 18 and 50 m heights, respectively (Fig. 9, middle and bottom). The simulated mean wind speed values, as well as, the topography are in good agreement with the structure of the mean wind power field. Consequently, the case study demonstrates strong dependence on height and topography. Even at siting wind power station with 50 m rotor axis height, the available wind power has 80–130% variability (comparing to the wind power value of Hegyhátsál) depending on terrain modification.

Figs. 10 and 11 present the vertical cross-sections (longitudinal and latitudinal, respectively) of available wind power fields resulted from simulations using the WAsP model. On both diagrams the vertical structure of wind power fields in Hegyhátsál area can be recognized through the run of the 50, 100, 150 and 200 W m⁻² isolines. This kind of figures can provide useful hints in case of siting wind power stations, but three-dimensional information would be the best tool over a larger area.

Results of two case studies are presented in Fig. 12, where height and structure of a given wind power level (180 W m⁻² was selected based on the results of Fig. 9) are mapped for a Trans-Danubian and a Great Hungarian Plain sector (100 km × 100 km each). The upper part of the figure is centred to Pápa (47.36°N, 17.49°E), and the lower part to Kecskemét (46.92°N, 19.75°E). Height of the selected wind power level was calculated by the WAsP model using ten-year-long database of the above mentioned stations.

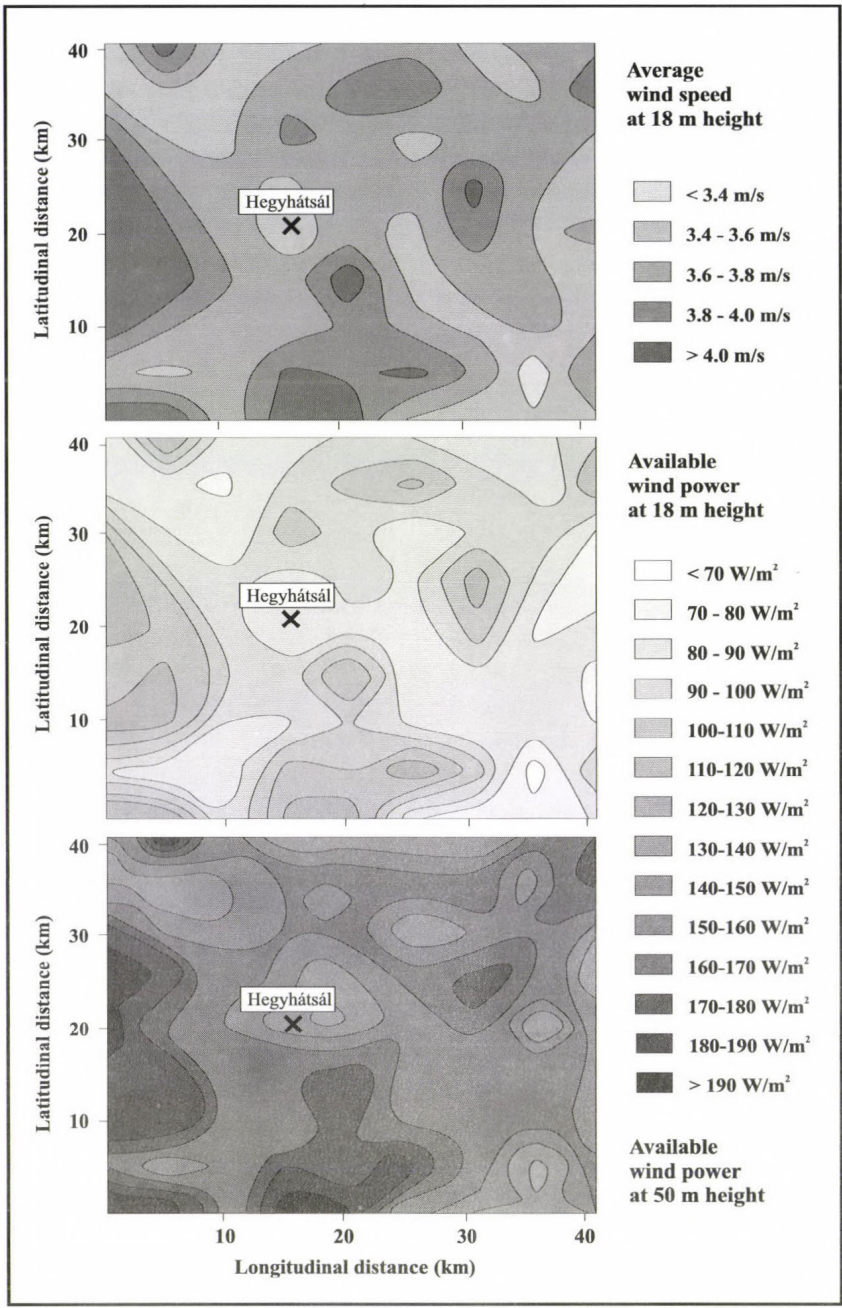


Fig. 9. Average wind speed and available wind power values at different levels around station Hegyhátsál.

Considerable spatial differences are present at both areas (maximum values: 60–70 m, minimum values: 8–10 m) that can be explained partly by topography and roughness, and partly by basic flow patterns of the region. Effects of the complex orography of the Pápa region (including foothills of the Alps, Mountain Bakony, etc.) result in somewhat more variable structure of isolines than the flat terrain of the Kecskemét region (Great Hungarian Plain). The northwestern-southeastern axis dividing the higher and lower height values on the Kecskemét map has good correspondence with the structure of wind climates presented in Figs. 2–4. This type of maps can support the optimal siting of wind power stations. However, the optimal solution would be to construct a map of the entire country using data observed at many more stations and considering more detailed digital terrain models.

Fig. 10. Latitudinal (N-S) vertical cross-section of mean flow demonstrating wind power isolines around station Hegyhátsál.

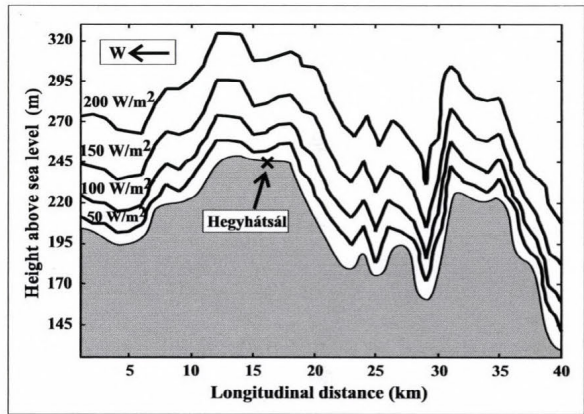
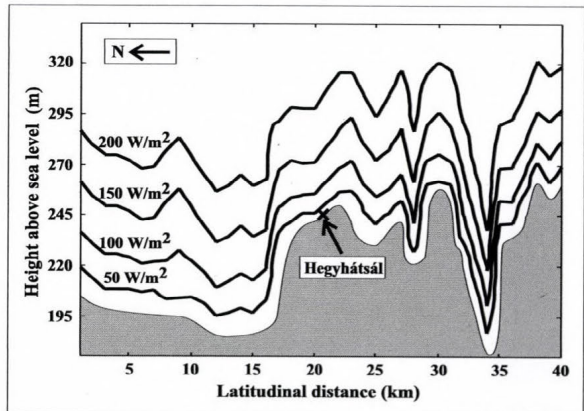


Fig. 11. Longitudinal (W-E) vertical cross-section of mean flow demonstrating wind power isolines around station Hegyhátsál.



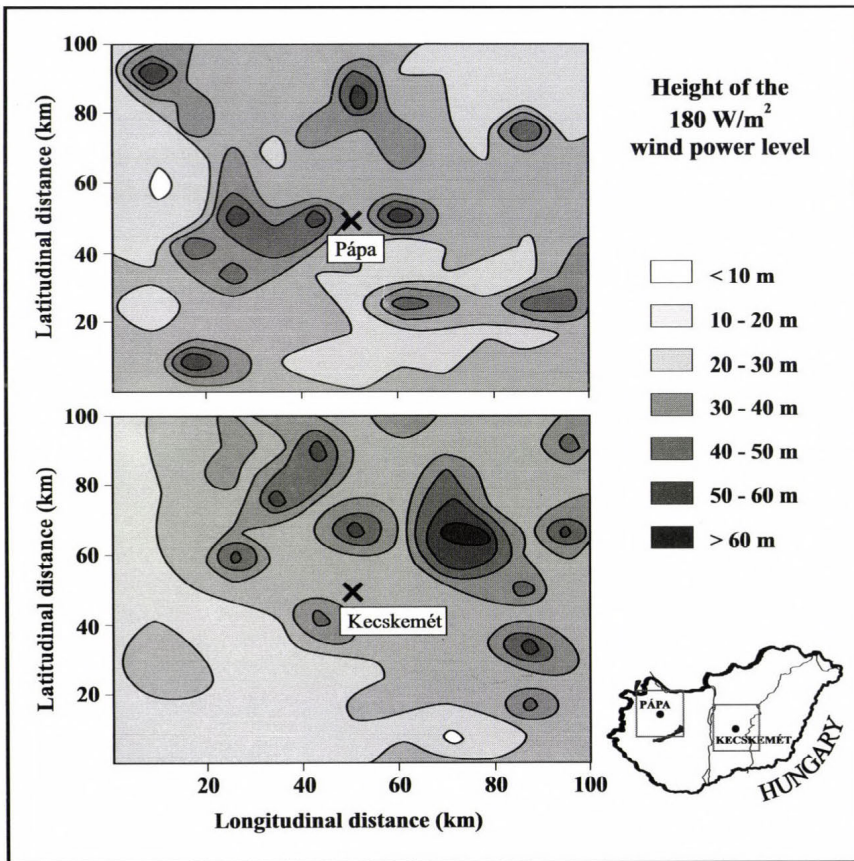


Fig. 12. The height and the structure of 180 W m^{-2} wind power level over Trans-Danubia (up) and the Hungarian Great Plain (down).

5. Conclusions

For wind energy utilization purposes, the second part of the paper begins with summarizing the wind climate information of the 20th century. Maximum wind speed values occur in the northwestern corner of the country, while minimum centers appear in the southwestern and in the north, northeastern part of the country. Although, these centers do not have annual moving, the analysis of transition seasons show that wind speed values are higher, and the range between the monthly extremes is getting also somewhat higher in April than in October. In spite of different error sources (inhomogeneity of data, changes in

observation techniques and measuring instruments, replacements and changing surroundings of measuring stations, etc.), the last century do not show significant changes or variations in mean regional flows.

Wind profile measurements and data analysis was carried out on Hegyhátsál TV transmitter tower, where multilevel wind speed time series are available from the 1994–2000 period. Selecting the windiest (April) and the least windy (October) months of the year, wind speed frequency distributions was analysed. Case classification was based on truncated tercile values of near surface (10 m) data of April. Using the same terciles for October, leading to an asymmetric distribution of group members (46.9%, 31.8%, and 21.3%, respectively), relative frequencies remain smaller than in April. Larger differences can be observed near the surface that seems to become smaller at higher levels.

Instead of discrete estimations of available wind power, we present horizontal and vertical cross-sections of average wind speed and available wind power isosurfaces around Hegyhátsál (41 km × 41 km) using the WASP model. Three-dimensional maps provide more information, where height of the 180 W m⁻² wind power surface is presented for a 100 km × 100 km area of Trans-Danubia and the Great Hungarian Plain. In order to have a complete overview of available wind power of the entire country, further model simulations are necessary using more detailed digital terrain models and wind data from denser measuring network. In the future this type of maps may support the optimal siting of wind power stations in Hungary.

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Specification of multivariate extremity in climatological data

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Abstract—A methodology is presented to determine extreme regions of multivariate climatological data. The term extreme is defined as events having small probabilities at the tails of an underlying probability density function. The traditional parametric procedure to estimate the density does not guarantee that such a model fits the data satisfactorily in areas representing rare events. Therefore, a nonparametric approach is proposed which does not restrict the possible form of the density. Two examples, namely dangerous apparent temperatures and icing conditions are discussed to illustrate the methodology.

Key-words: extremes, multivariate data, kernel density estimator, apparent temperature, icing

1. Introduction

The term “extremes” can be defined in several ways. These include tools such as the average returning period of an occurrence arising from small probabilities, number of exceedances of high or low thresholds, duration below or above these thresholds, and many other choices. These characteristics are closely related to the probability distribution of maximum or minimum of a variable during a specific period. Theory of extreme distributions based on asymptotic formula is well-developed for univariate data (*Gumbel*, 1958; *Leadbetter* et al., 1983). In multivariate case, similar results are available when maxima or minima are considered in every component of multidimensional variables (*Tawn*, 1990). However, special attention is frequently

dedicated to states of multidimensional variables, which are not necessarily extremes in every or even in one dimension, but these states may be called extremes as vectors, because they drastically deviate from the “usual” state.

Therefore, the term extreme is now defined as events having small probabilities at the tails of an underlying probability density function. Consider a multivariate random variable with probability density function $f(x)$. For any ε satisfying $0 < \varepsilon < 1$ an extreme set $T = T(\varepsilon)$ is defined as

$$T : \{x; f(x) < c\} < \varepsilon, \quad \int_T f(x) dx = \varepsilon, \tag{1}$$

where $c = c(\varepsilon)$ (Fig. 1). When the analytical form of f is known, the solution of problem Eq. (1) is straightforward. The traditional procedure for estimating f is the parametric approach, which consists of equipping a prespecified family of density functions with a finite set of parameters. The task is then to estimate these parameters using a sample of data. However, there is no guarantee that such a model fits the data satisfactorily in areas representing rare events, although customary tests do not reject the model.

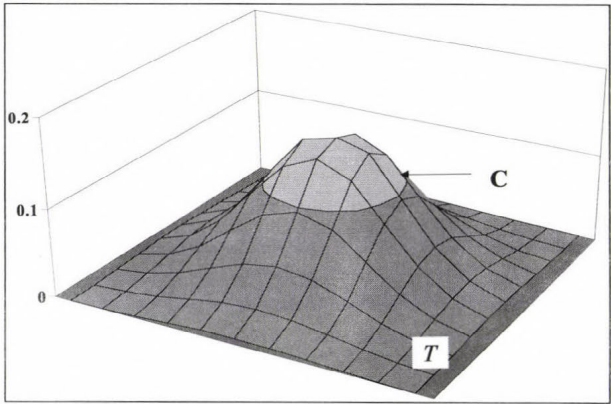


Fig. 1. The extreme set, T , specified by C in two dimensions (see Eq. (1) for explanation).

The present paper proposes another procedure, namely the nonparametric approach to estimate f . The technique does not restrict the possible form of the density function, the estimate is obtained directly from data. In the rest of the paper, Section 2 introduces the methodology to obtain extreme sets with a nonparametric estimator. Two examples for the two-dimensional case are discussed in Section 3.

2. Methodology

2.1 Concept

The idea of nonparametric estimation of univariate probability density functions was introduced by *Rosenblatt* (1956) and *Parzen* (1962). The so-called kernel density estimate $\hat{f}(x)$ from a sample x_1, x_2, \dots, x_n is given by

$$\hat{f}(x) = \frac{1}{nb} \sum_{i=1}^n K\left(\frac{x-x_i}{b}\right), \quad (2)$$

where $K(z)$ is a kernel function satisfying certain properties to provide an appropriate estimate of $f(x)$. An example of appropriate kernel functions is in Eq. (10). Note that Eq. (2) is a sum of elementary densities

$$\frac{1}{nb} K\left(\frac{x-x_i}{b}\right) \quad (3)$$

over sample elements, and the bandwidth b controls how well these elementary densities centre around the observations (*Fig. 2*).

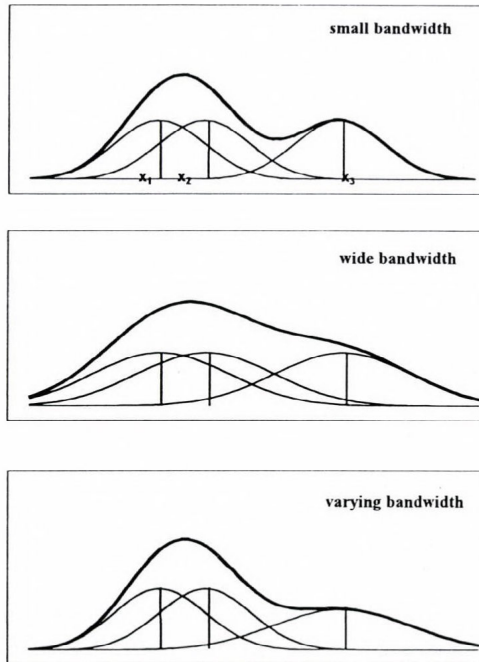


Fig. 2. Role of different bandwidth (b in Eq. (2) and others) choices.

A possibility for choosing the kernel is that $K(z)$ itself is a density function because $K(z)$ is required to integrate to unity. $K(z)$ with support $[-1,1]$ ($K(z)_{[-1,1]}$) is called kernel of order k if the condition

$$\int_{-1}^1 K(z)z^j dz = \begin{cases} 1, & j=0 \\ 0, & 0 < j < k \end{cases} \quad (4)$$

is satisfied.

Under $n \rightarrow \infty; b \rightarrow 0; nb \rightarrow \infty$, Eq. (2) provides an asymptotically unbiased and consistent estimate of $f(x)$ with asymptotic mean square error (MSE)

$$MSE(x) = E\left[(\hat{f}(x) - f(x))^2\right] = u^2(x) + v^2(x), \quad (5)$$

where the asymptotic bias is equal to

$$u(x) = E[\hat{f}(x) - f(x)] = B \frac{h^k}{k!} f^{(k)}(x), \quad (6)$$

and the asymptotic variance is

$$v^2(x) = Var[\hat{f}(x)] = E\left[(\hat{f}(x) - E[\hat{f}(x)])^2\right] = \frac{V}{nb} f(x), \quad (7)$$

while

$$B = \int_{-1}^1 K(z)z^k dz, \quad V = \int_{-1}^1 K^2(z)dz. \quad (8)$$

Symbol E denotes the expectation, and $f^{(k)}(x)$ is the k th derivative which is assumed to be finite. The dependence of the MSE on the density and its k th derivative, the kernel, and the bandwidth is clearly shown by Eqs. (5) to (8). The bias Eq. (6) is higher in areas where $f^{(k)}(x)$ is higher, and the variance Eq. (7) is higher where $f(x)$ is large. The bias term penalizes oversmoothing, and the variance term penalizes undersmoothing. Thus, an optimal bandwidth that recognizes this trade-off must exist. The optimal b minimizing Eq. (5) is

$$b_{opt}(x) = \left(\frac{f(x)V}{(f^{(k)})^2 n B^2} \right)^{1/(2k+1)}, \quad (9)$$

and the convergence rate of $\hat{f}(x)$ to $f(x)$ is proportional to $n^{-2k/(2k+1)}$.

Eq. (9) cannot directly be used in practice because it needs the knowledge of $f(x)$. The bandwidth, therefore, should be estimated from the sample. One could think that the choice of b is not a difficult problem by using the bandwidth which delivers, in some sense, a best fit to the sample available,

while the choice of k and K seems to be quite arbitrary. However, the situation is just the contrary. A class of optimal kernel functions is known, and several simulation and real data studies suggest that a small variability in k does not considerably affect the resulting density. Generally, a small value of k , say $k=2$ can be chosen. In contrast, the bandwidth choice has a great importance.

The selection of kernels is based on asymptotic properties Eqs. (6) and (7). Kernel functions minimizing the asymptotic variance Eq. (7) can be found in Gasser *et al.* (1985). For instance, for $k=2$ and $k=4$, the kernel is $K(z)=1/2_{[-1,1]}$ and $3/8(3-5z^2)_{[-1,1]}$, respectively. One of the most frequently used kernels is

$$K(z) = \frac{3}{4}(1-z^2)_{[-1,1]} \quad (10)$$

having smallest MSE among kernels with $k=2$.

The above functions, however, may be used just in the case when $f(x)$ is defined on the interval $(-\infty, \infty)$, unless the kernels are modified near the endpoints. Müller (1991) has developed a very general formulation to have kernels for any $x \in (m, M)$ and M for any k , where (m, M) denotes the support of $f(x)$. Let $K_+(q, z)$ and $K_-(q, z)$ be functions with support $[0, 1] \times [-1, q]$ and $[0, 1] \times [-q, 1]$, respectively and with some smoothing requirements (Müller, 1991). Then, kernels at a point x are given by

$$K_x = \begin{cases} K_+(1, z), & m+b \leq x \leq M-b \\ K_+((x-m)/b, z), & 0 \leq x < m+b \\ K_-((M-x)/b, z), & M-b < x \leq M \end{cases}, \quad (11)$$

where $K_-(q, x) = K_+(q, -x)$. Eqs. (6) and (7) to calculate asymptotic bias and variance are essentially held, but now B and V depend on q . The boundary kernel Eq. (11) corresponding to Eq. (10) is

$$K_+(q, z) = 6(1+z)(q-z) \frac{1}{(1+q)^3} \left[1 + 5 \left(\frac{1-q}{1+q} \right)^2 + 10 \frac{1-q}{(1+q)^2} z \right]. \quad (12)$$

A natural choice of the bandwidth is to minimize the integrated mean square error

$$\int_m^M (\hat{f}(x) - f(x))^2 dx, \quad (13)$$

which is estimated by the so-called least square cross-validation (LSCV)

$$1/n \sum_{i=1}^n \hat{f}^2(x_i) - 2/n \sum_{i=1}^n \hat{f}_i(x_i), \quad (14)$$

where $\hat{f}_i(x_i)$ is a cross-validated estimate, i.e., an estimate Eq. (2) but with x_i omitted.

The methodology outlined above has serious limitations. Specifically, \hat{b} obtained with the minimization of Eq. (14) is selected globally while Eq. (9) clearly shows the necessity of locally varying bandwidths. The use of local bandwidth $b(x)$ is, however, not practical because the resulting curve does not necessarily integrate to unity. Additionally, the estimated density function may behave poorly at tail areas of the real density, which is crucial when just extremes are in question. In order to remove these difficulties, Eq. (2) is modified according to *Abramson* (1982) as

$$\hat{f}(x) = \frac{1}{nh} \sum_{i=1}^n f(x_i)^{1/2} K\left(\frac{x-x_i}{h} f(x_i)^{1/2}\right). \quad (15)$$

The usefulness of local bandwidths $b(x_i) = hf(x_i)^{-q}$, $q > 0$ obvious, because many sample elements are available where the density function is large, but few observations come from flat regions of the underlying density (see Fig. 2). Such a choice therefore, makes the importance of sample elements more uniform. The exponent $q=1/2$ is optimal in the sense that it eliminates the asymptotic bias of the estimate. The unknown values $f(x_i)$ in Eq. (15) are substituted by their initial estimates $\check{f}(x_i)$ obtained with a global bandwidth. The parameter h is chosen as to minimize

$$1/n \sum_{i=1}^n \hat{f}^2(x_i) - 2/n \sum_{i=1}^n \hat{f}(x_i), \quad (16)$$

where \hat{f} corresponds to Eq. (15) with cross-validated $\check{f}_i(x_i)$ initial estimates.

2.2 Estimation of multivariate densities

Taking a sample $\mathbf{x}_1, \mathbf{x}_2, \dots, \mathbf{x}_n$ for a p -dimensional random vector, the Parzen-Rosenblatt estimator is given by

$$\hat{f}(\mathbf{x}) = \frac{1}{n|\mathbf{B}|} \sum_{i=1}^n K_p(\mathbf{B}^{-1}(\mathbf{x} - \mathbf{x}_i)), \quad (17)$$

where \mathbf{B} represents the bandwidth matrix and $|\mathbf{B}|$ denotes its determinant. The p -dimensional kernel function defined on $S = [-1, 1]^p = [-1, 1] \times [-1, 1] \times \dots \times [-1, 1]$ satisfies

$$\int_S z_1^{j_1} \dots z_p^{j_p} K_p(\mathbf{z}) d\mathbf{z} = \begin{cases} 1, & \sum_{i=1}^p j_i = 0 \\ 0, & 0 < \sum_{i=1}^p j_i < k \end{cases} \quad (18)$$

for every $j_1, j_2, \dots, j_n \geq 0$. A simple choice to specify the estimator is to use products of one-dimensional kernels with the same bandwidth in every dimension resulting in the same amount of smoothing in different directions of coordinates. This choice is not favorable when the variance of the components differs substantially. Therefore, a much more reliable estimate can be obtained by different bandwidths for different directions as

$$\hat{f}(\mathbf{x}) = \frac{1}{nb^p} \sum_{i=1}^n \left[\prod_{j=1}^p \frac{1}{\sigma_j} K\left(\frac{\mathbf{x}_j - \mathbf{x}_{ij}}{b\sigma_j}\right) \right], \quad (19)$$

where j refers to j th component of the vector and σ denotes standard deviation.

The Abramson estimator Eq. (15) in multivariate case becomes

$$\hat{f}(\mathbf{x}) = \frac{1}{nh} \sum_{i=1}^n f(\mathbf{x}_i)^{p/2} K_p\left(\frac{(\mathbf{x} - \mathbf{x}_i)f(\mathbf{x}_i)^{1/2}}{h}\right). \quad (20)$$

Comparing Eqs. (19) and (20), the final form will be

$$\hat{f}(\mathbf{x}) = \frac{1}{nh^p} \sum_{i=1}^n f(\mathbf{x}_i)^{p/2} \left[\prod_{j=1}^p \frac{1}{\sigma_j} K\left(\frac{\mathbf{x}_j - \mathbf{x}_{ij}}{h\sigma_j} f(\mathbf{x}_i)^{1/2}\right) \right]. \quad (21)$$

3. Examples

Daily temperature and relative humidity data observed in Budapest, Hungary, 12 UTC from 1961 to 1990 have been analysed in January and July. The aim is to quantify the probability of extreme warm and dry or extreme cold and wet conditions.

The Abramson density estimator Eq. (21) has been used for this purpose. Since the relative humidity is close to but never larger than 100%, the boundary kernel Eq. (12) has been used at the right boundary. First an initial estimate Eq. (2) was produced with $b=0.58$ for summer and with $b=0.63$ for winter. These global bandwidths were chosen by minimizing Eq. (14) (see Fig. 3). Substituting these initial estimates into Eq. (16), the optimal h is 0.046 for summer and 0.059 for winter.

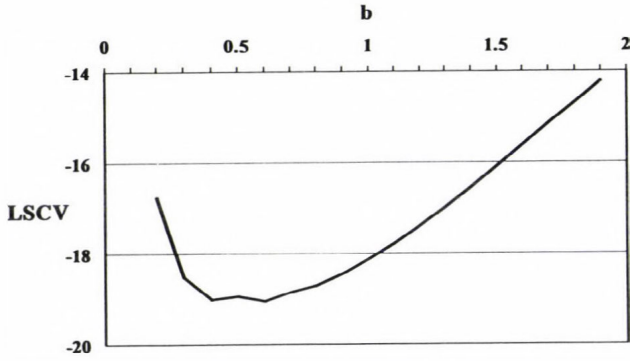


Fig. 3. Quantity of least square cross-validation (LSCV) in case of temperature and relative humidity for July.

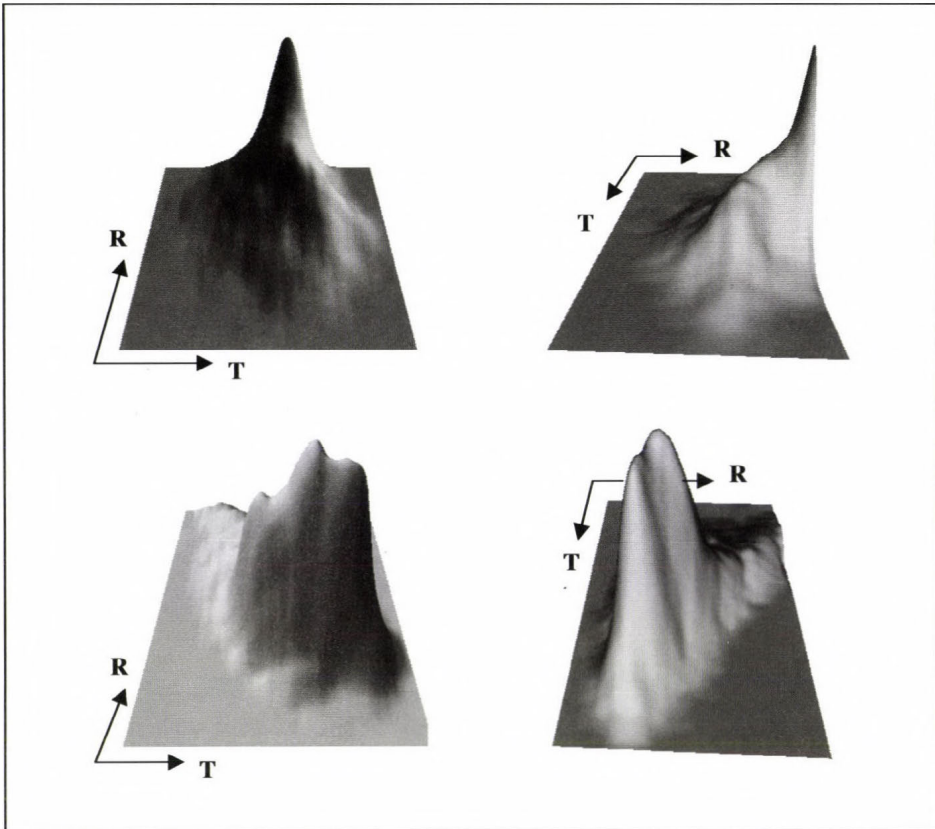


Fig. 4. Two dimensional probability density function of temperature ($T [^{\circ}\text{C}]$) and relative humidity ($R [\%]$) for winter (top) and summer (bottom), as seen from two orthogonal view-points.

Fig. 4 shows the estimated densities from two directions. In summer, the density has a fine structure with a wide maximum area scattered by three local peaks. The main maximum (25.7°C, 45%) does not correspond to average conditions since the means calculated from data are 24.6°C and 49% for temperature and relative humidity, respectively. The difference between the maximum and mean is due to the asymmetry of the density. One of the local peaks is related to cooler and wetter (frequently rainy) days, while the second local peak reflects hot and dry conditions associated with air masses from Sahara. Also, the density has a long tail toward low temperatures and high relative humidities meaning a considerably larger chance for cool and wet conditions than for warm and dry situations. The air is frequently almost saturated in winter. Therefore large values of the density are located at 100% along the temperature axis. The peak is located at (0.15°C, 100%), while the means calculated from data are 0°C and 77% suggesting a substantial asymmetry of the probability distribution of relative humidity.

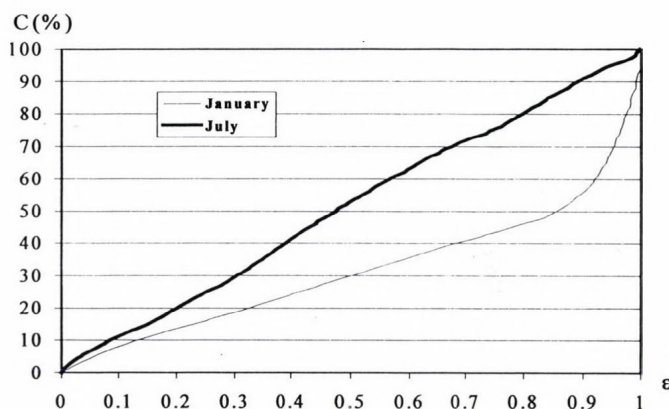


Fig. 5. The relationship between c and ε .

In order to obtain extreme sets $T(\varepsilon)$, the relationship $c=c(\varepsilon)$ has to be established. It can be done by a numerical approximation to the integral in Eq. (1). Cutting the surface of the density function with a horizontal plain at different percentage of the maximum c_{max} of the density, the volume under the dark surface in Fig. 1 gives the probability ε . Correspondence between ε and c/c_{max} is shown in Fig. 5. The curve for January has a larger slope indicating that the density is less concentrated than in summer.

Under normal conditions, temperature and humidity are the most important elements influencing comfort. A special index based on human

physiology was developed to measure of what hot weather feels “like” to the average person. The degree of heat stress may vary with age, health and body characteristics. This index is determined by the actual air temperature and relative humidity, and is called apparent temperature (Quayle and Doehring, 1981). Counterparts of areas surrounded by curves in Fig. 6 define the domains $T(\varepsilon)$ for different probabilities ε . The relationship of air temperature and relative humidity to apparent temperature is also shown here according to four danger categories. The probability of having critical temperature and humidity can be calculated by integrating the density function over the area where corresponding apparent temperatures exceed the critical value of an actual danger category. For instance, if the apparent temperature exceeds 26.6°C (80°F), fatigue is possible with prolonged exposure and physical activity. Under the climate of Budapest, the probability of such an event is 0.249. The probability of events with apparent temperatures exceeding 32.3°C (90°F) is quite small, namely 0.027 in our region. The remaining danger categories when apparent temperature is higher than 40.5°C (105°F) and 54.4°C (105°F) have negligible probabilities.

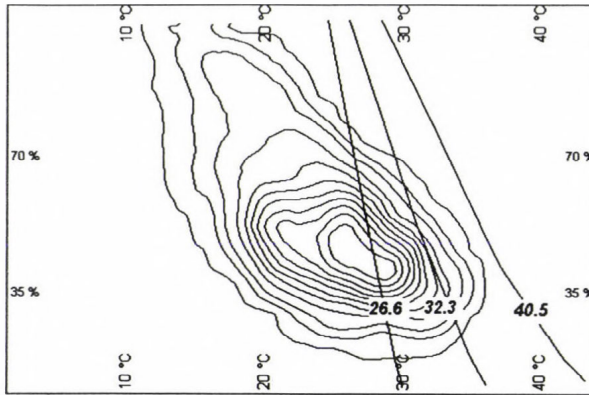


Fig. 6. The heat stress categories defined by the apparent temperatures on probability density function of temperature and relative humidity for July.

There is a chance for icing when the air is close to the saturation and the actual temperature is below zero (Mika et al., 1995). This area is approximately represented by rectangles according to 90% and 95% relative humidities (Fig. 7). Relative frequency of such cases calculated directly from data is 0.126 and 0.062, while integration of the density in Fig. 7 gives 0.146 and 0.076.

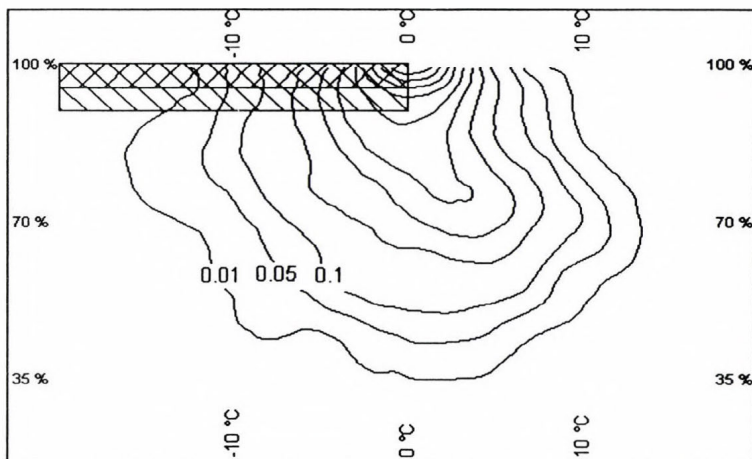


Fig. 7. Conditions preferable for ice formation on probability density function of temperature and relative humidity for January.

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NEWS

Dr. Iván Mersich winner of a 2001. Dennis Gabor Prize

This highly distinctive prize was established by the NOVOFER Foundation for recognizing outstanding achievements in the field of science and technology. It is given every year to a small number of carefully selected individuals. In the last year one of the seven winners of the prize was *Dr. Iván Mersich*, President of the Hungarian Meteorological Service. The distinction was conferred on him on the 10th of December, 2001 at a solemn ceremony in the presence of many of his friends and colleagues.

The eponym of the prize does not need much introduction. Dennis Gabor—winner of the 1951. Nobel Prize in physics—and been one of the outstanding scientists and innovators of Hungarian origine who substantially contributed to the creation of modern technology. The prize carrying his name was established in 1989. Since that time it was bestowed upon altogether 87 Hungarians and 6 individuals from abroad.

Dr. Iván Mersich is the head of the Hungarian Meteorological Service since the beginning of 1991. Consequently, his term included a particularly difficult period of transition. Under the preceding socialist (planned economy) regime the Meteorological Service had to be—necessarily—a rather inflated autarchic organization quite similar to all other institutions of the Soviet Bloc. From that state this organization had to be radically transformed to become a much leaner, yet more efficient, high-tech service which fits into the array of modern European national meteorological services. Today we may confidently say that the target is achieved and that Dr. Mersich definitely deserves credit for this achievement. The prize was given to him in recognition of his creative, innovative approach to his job and also in appreciation of his untiring drive to get things done.

The Hungarian meteorological community is deeply honoured by the fact that among the excellent individuals, selected from the broadest range of professions, now there is a meteorologist, who deserved this prize and the distinction that goes with it.

R. Czelnai

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