IDŐJÁRÁS

AZ ORSZÁGOS METEOROLÓGIAI SZOLGÁLAT FOLYÓIRATA

93. ÉVF. ★ 1. SZÁM ★ 1989. JANUÁR—FEBRUÁR

TARTALOM

CONTENTS

JOURNAL OF THE HUNGARIAN METEOROLOGICAL SERVICE

VOL. 93. ★ NO 1★ JANUARY—FEBRUARY 1989 ★ BUDAPEST

IDŐJÁRÁS

Az Országos Meteorológiai Szolgálat folyóirata
Journal of the Hungarian Meteorological Service

Felelős szerkesztő – Editor-in-Chief
MÉSZÁROS ERNŐ
Központi Légkörfizikai Intézet
1675 Budapest Pf. 39.
Telefon: 585-711

Műszaki szerkesztő – Technical Editor
SZABÓ ÉVA

Szerkesztőség: 1525 Budapest, Postafiók 38
Előfizetés: 1 évre 744 Ft. Megrendelhető: Az Országos Meteorológiai Szolgálat Pénzügyi Osztályán 1024 Budapest, Kitaibel Pál utca 1. Levélcím: 1525 Budapest, Pf. 38. Megjelenik kéthavonként.
Egyes szám ára: 124 Ft

Editorial Office: H – 1525 Budapest P. O. B. 38. This journal, published bimonthly, can be purchased from the distributor: KULTURA, H – 1389 Budapest, P. O. B. 149
The actual subscription rate is determined by the distributor

IDŐJÁRÁS

Az Országos Meteorológiai Szolgálat folyóirata. 93. évf. 1. szám. 1989. január – február
Journal of the Hungarian Meteorological Service. Vol. 93. No. 1. Jan – Feb 1989 Budapest.

Analysis of the release and spread of radiocaesium from Chernobyl*

H. M. ApSIMON and J. J. N. WILSON

Air Pollution Group, Mechanical Engineering Department, Imperial College, London, United Kingdom.

The aim of this paper is to simulate by means of an appropriate numerical model the ^{137}Cs deposition in Europe after the Chernobil accident. In the model the source strength, the meteorological situation and the deposition of radioactive materials are taken into consideration. On the basis of the results calculated the long-term effects of the deposition over Europe are discussed.

*

A csernobili balesetből származó radiocézium kibocsátásának és terjedésének analizise. A tanulmány célja a csernobili balesetből származó ^{137}Cs izotóp európai ülepedésének kiszámítása megfelelő numerikus modell segítségével. A modellben a szerzők figyelembe veszik a forrás erősségét, a meteorológiai helyzetet és a radioaktív anyagok légköri ülepedését. A kapott eredmények alapján megvizsgálják az ülepedés hosszú időléptékű várható hatásait.

1. Introduction

At 1.26 (local time) on 26 April 1986 a series of explosions occurred at the Chernobyl Unit – 4 nuclear reactor in the Ukraine, releasing radioactive material into the atmosphere. It took heroic efforts over the next ten days to control the release; meanwhile radionuclides travelled across the European continent and beyond. This paper describes work undertaken with a meteorological model, simulating the dispersal, to interpret what happened to the radioactivity released – in particular the ^{137}Cs which is the most important nuclide for long-termcontamination.

At the time of the accident at Chernobyl there was no recognised protocol for the monitoring and reporting of environmental radiological measurements. The International Atomic Energy Agency (IAEA) and World Health Organisation (WHO) were rapidly involved, the IAEA liaising with the USSR on the accident itself, and the WHO Regional Office for Europe quickly producing a report on 5 May 1986 and subsequently assembling radiological measurements from different countries. Two conventions have since been instituted through IAEA. The first is the Convention on Early Notification, which requires states

* This is a summary of a paper presented at the Institute for Atmospheric Physics in Budapest during a visit of Dr ApSimon in June 1988 as Chairman of the European Association for the Science of Air Pollution.

party to the Convention to notify directly, or through the IAEA, those states which may be physically affected in the event of an accident and provide information relevant to minimising the radiological consequences. Secondly there is a Convention on Mutual Assistance in the case of a nuclear accident or radiological emergency. Guidelines and arrangements in connection with these conventions are still under development through IAEA. Meanwhile individual states are revising their internal monitoring and communications for such situations.

The radiological data after Chernobyl were consequently extremely varied a wide range of units, types of measurement and measurement techniques were used. Attitudes of different countries also added to the distortion. Some tended to report peak activity, others indicated average levels, and yet others provided little information at all or issued official statements to the effect that there was no significant contimation. Subsequently the diversity of intervention levels for control of milk and other foodstuffs, even varying within individual countries, did little to clarify the actual levels of contamination.

To interpret the radiological data objectively, a computer simulation of the dispersal of material from Chernobyl in the atmosphere according to the meteorological conditions, has proved very useful. Such a model, called MESOS, had been developed at Imperial College to study hypothetical nuclear accidents in the context of risk analysis. This model uses routine meteorological observations reported by synoptic stations in the network of the World Meteorological Organisation (WMO), and these data were readily supplied by the UK Meteorological Office. Thus it is based on actual observations of the weather situation as it evolves rather than forecast situations.

The purpose of these model applications for this contract has been as follows.

i) to obtain an understanding of how air was circulating across Europe from Chernobyl, and use this as a framework for piecing together the measurements from different countries.

ii) to assess the quantities and variation in time of $^{137/134}Cs$ isotopes released and travelling beyond the frontiers of the USSR.

iii) to identify areas of Europe which were subject to precipitation during passage of the material, and were likely to have been subject to more severe contamination.

iv) providing a consistent picture emerged to estimate approximately the collective dose commitment to the European population outside the USSR as a consequence of the release.

2. The MESOS model

Before proceeding to analysis of the accident it is appropriate to give some details of the meteorological model, MESOS – II, which has been used. This is a Lagrangian trajectory model, simulating the release as a sequence of puffs whose advection, dilution and depletion are followed across the European map area. Puffs of activity are released at three hour intervals and tracked through a spatially and temporally evolving windfield. Dispersion and removal of activity from the puff are determined by reference to local conditions along the trajectory. A three hour release is assumed to be composed of a series of puffs which follow intermediate trajectories, leading to the exposure of the area between, as well as along, successive calculated trajectories. Releases lasting longer than three hours can be constructed from successive three hour releases. The model thus directly includes the large scale spreading of a release, due to synoptic scale divergence, which generally determines lateral dispersion during transport over long distances.

The evolving windfield is interpolated from standard surface pressure readings, corrected to 1000 mb, which are made every three hours at reporting stations in the worldwide WMO network. The pressure data is processed and stored on a 0.5° latitude by 1° longitude grid, spanning the area 10° W – 34° E and 38 – 62° N for the period of the Chernobyl accident.

Activity is deposited on the surface by both washout and rainout, throughout the depth of a puff and by dry deposition from the surface layers of a puff alone. Dry deposition in MESOS – II is represented by a nuclide dependent dry deposition velocity. The Chernobyl analyses have used values previously employed in MESOS – II; 0.003 $m.s^{-1}$ for ^{131} I, which was released in both gaseous and particulate forms and 0.001 $m.s^{-1}$ for the wholly particulate nuclides such as ^{134}Cs and ^{137}Cs.

Washout and rainout are represented by a simple washout model, whereby rainfall is assumed to scavenge the entire depth of the puff and give deposition at a rate which is a function of the rainfall rate (J) as follows:

$$\Lambda = \Lambda^{\circ} J^{0.8}$$

Λ° is the removal rate in rainfall of 1 mm hr^{-1}. Again values previously used in MESOS – II have been used for the washout coefficients; 0.00005 s^{-1} for both ^{131}I and the particulate nuclides. These washout coefficient and dry deposition velocities are consistent with observations which clearly show the geater importance of wet deposition in the ^{137}Cs deposition patterns. Thus, 5.0 mm of rain falling through a radioactive plume with an average concentration of either of the above nuclides of 1.0 $Bq.m^{-2}$ over a depth of 1000 metres, would yield approximately 0.9 $kBq.m^{-2}$ of deposited activity. The rainfall rate J is estimated from the present weather reports which form part of the three hourly data from each WMO reporting station, averaged over 1° latitude by 2° longitude cells. Consequently, the wet deposition pattern predicted by MESOS – II is only a broad guide to the areas likely to have experienced wet deposition and cannot give information on local variation in the wet deposition pattern.

Detailed descriptions of the model are given in *ApSimon et al.* (1985).

3. *Source terms*

Our earliest assessments using the MESOS model were presented at the Nuclear Installations Inspectorate in the UK on 21 May 1986, and have been reported elsewhere (*ApSimon et al.*, 1987). These results were also made available to international bodies such as WHO and IAEA. Apart from maps showing the daily spread of the cloud, they included estimates of the quantities of various nuclides released, which turned out to be in good agreement with figure subsequently presented at the IAEA in August 1986 when Soviet scientists gave a full account of the accident and its causes (*IAEA*, 1986). This agreement on source terms was perhaps surprisingly close, since the Soviet estimates were based on measurements within the USSR, and included coarse material settling close to the plant whereas our estimates were based on fitting radiological observations beyond the boundaries of the USSR to model simulations. Also initially we knew very little about the accident and could only deduce in broad terms that release had continued into the early days of May with a somewhat different nuclide composition.

Recently we have undertaken more detailed assessments of the source terms, and the results presented in the paper are based on these. *Table 1* illustra-

TABLE 1

Daily release patterns of ^{137}Cs from Chernobyl. a) Initial estimate derived from Soviet data. b) Revised estimate based on MESOS and measurements outside the U.S.S.R.

Day	*Release pattern a) Soviet data Bq/Day*	*b) Bq/Day*
21.00 25.04 – 21.00 26.04	$1.1.10^{16}$	$1.5.10^{16}$
21.00 26.04 – 21.00 27.04	$3.7.10^{15}$	$5.6.10^{15}$
21.00 27.04 – 21.00 28.04	$3.1.10^{15}$	$4.7.10^{15}$
21.00 28.04 – 21.00 29.04	$2.4.10^{15}$	Low
21.00 29.04 – 21.00 30.04	$1.9.10^{15}$	$3.8.10^{14}$
21.00 30.04 – 21.00 01.05	$1.9.10^{15}$	$7.7.10^{14}$
21.00 01.05 – 21.00 02.05	$3.7.10^{15}$	$1.1.10^{15}$
21.00 02.05 – 21.00 03.05	$4.8.10^{15}$	$1.9.10^{15}$
21.00 03.05 – 21.00 04.05	$6.7.10^{15}$	$2.7.10^{15}$
21.00 04.05 – 21.00 05.05	$7.4.10^{15}$	$3.0.10^{15}$
21.00 05.05 – 21.00 06.05	$1.1.10^{14}$	$1.1.10^{12}$
Total	$4.7.10^{16}$	$3.9.10^{16}$

tes how we have derived daily releases of particular nuclides for the case of ^{137}Cs. *Figure 1* is taken from the Soviet report (*IAEA*, 1986), and shows how the daily release of activity varied in response to the state of the reactor and the temperature of the core. The release was characterised by four stages as follows;

i) The mechanical discharge of dispersed radioactive fuel resulting from the explosion. The radionuclide composition of this part of the release corre-

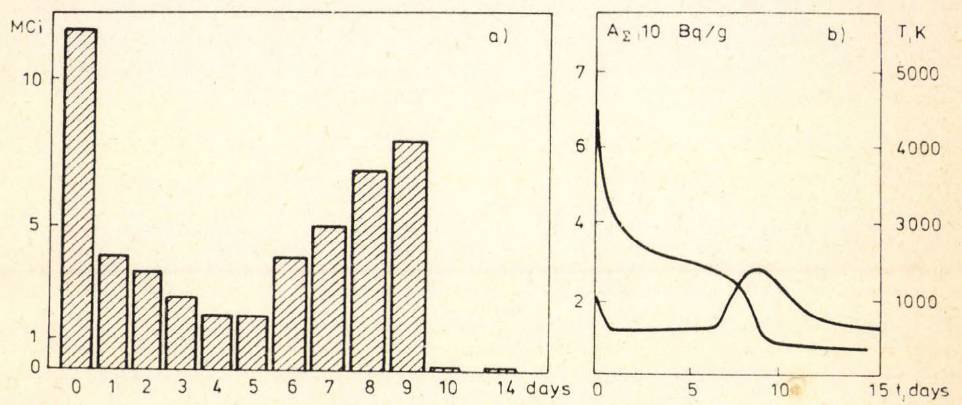


Fig. 1: a) Daily radioactive releases. *b)* Activity and temperature of the fuel after the accident

sponds approximately to the composition of fission products in the spent fuel, but enriched in volatile nuclides of iodine, tellurium and caesium.

ii) April 26th – May 2nd. The release rate declined as a result of covering the core with approximately 5000 tonnes of boron, lead, dolomite and sand in order to extinguish the fire in the graphite moderator. The radionuclide composition of the release during this stage was 'similar to the composition in the fuel' and included 'finely disperse fuel' released as a result of the fire.

iii) May 2nd – 5th. An 'increase in the power of the discharge occurred', driven by the buildup of decay heat in the now capped core. By May 5th, the core temperature was above 2000° C. Enhanced releases of iodine were observed from helicopter flights in the early part of this stage, however, the data are sparse. The increase in temperature during this stage must, however, have led to the migration up the core and subsequens release of less volatile nuclides, possibly attached to graphite aerosol.

iv) May 6th onwards. The release rate declined rapidly, following the construction of tunnels under the core, through which a nitrogen coolant was pumped. During this stage, the composition of the release resembled that of spent fuel.

The first column in Table 1 is based on the Soviet estimate of the total amount of ^{137}Cs released, and the premise that the variation in time matched that in Figure la. Our results based on fitting model simulations to radiological measurements of air concentrations of ^{137}Cs across Europe, are given in the second column; the total release is somewhat less than the Soviet estimate. This is consistent since we do not include enhanced local fall-out. Our estimates show the ^{137}Cs release rate is reduced relative to the overall release rate in the later days of the accident, when we find a higher proportion of $^{103/106}Ru$; this is to

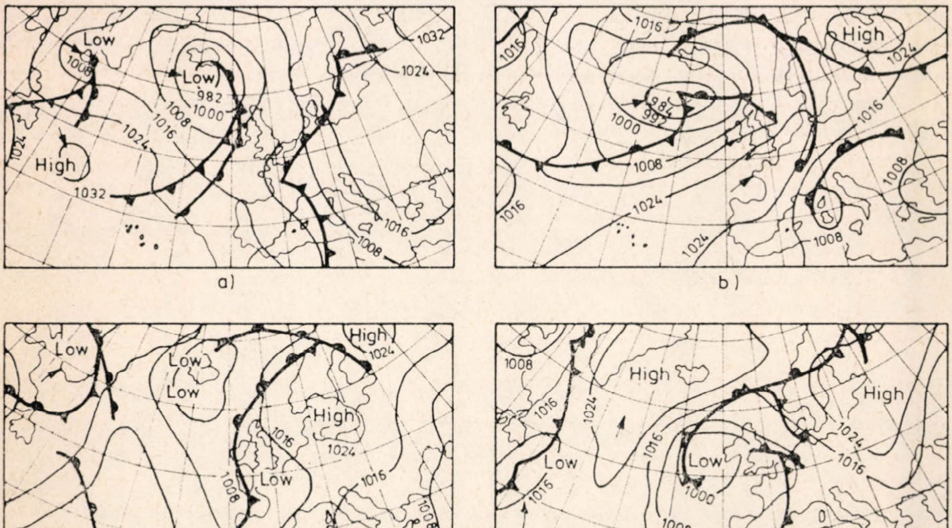


Fig. 2: Midday weather charts 26 April – 5 May 1986: *a)* Saturday 26 April 1986; *b)* Wednesday 30 April 1986; *c)* Friday 2 May 1986; *d)* Monday 5 May 1986

be expected with the higher core temperatures. Nevertheless the agreement between our estimates and those of Soviet scientists is good given the uncertainties.

4. The meteorological situation and the pattern of contamination across Europe

Figure 2 shows meteorological charts for selected days between 26 April and 5 May 1986, which give valuable insight into the pattern of transport and deposition across Europe.

Thus the early part of the release moved up into Scandinavia on 27 – 28 April, roughly parallel to the 1024 mbar isobar in Figure 2a, and passing close to the north-eastern corner of Poland as observed on Sunday evening. Precipitation and air concentrations were highly variable with some high values over southern Sweden and Norway. Some wet deposition in convective storms was also implied in the Ukraine and near Gomel, which was later partially evacuated. The MESOS results failed to predict the contamination over Finland, due to the wind-shear with height and the 3-dimensional nature of advection within the frontal system over Scandinavia.

On 29 April the release spread down southwards into Poland and East Germany, giving air concentrations over Poland of the order of 100 $Bq.m^{-3}$ of ^{131}I. This spreading persisted on 30 April, gradually clearing from Norway and Sweden, and by 1 May the cloud had thrust in a wedge across West Germany to the south of the ridge of high pressure pushing in from the Atlantic across the northern coast of Europe. At this point the cloud was almost splitting into two parts; one part blocked to the east by the anticyclone, and one part which flowed south of it. Air concentrations were higher in southern Germany than in the north, which like Denmark had escaped the radioactivity under the protection of the high pressure area which also pushed the cloud away from northern Poland. The calculated arrival times of the southern section of cloud are a few hours ahead of observations, and the subsequent western spread of the cloud towards Spain is slightly overestimated. There was a band of heavy rain giving high wet deposition over Bavaria and stretching over Switzerland into southern France. There was also further rain over Sweden.

Between 1 May and Friday 2 May the cloud spread much more extensively, reaching up behind the anticyclone towards the UK. The later part of the release now led to contamination over southern Europe. By Friday 2 May to Saturday 3 May the early part of the release had largely cleared away from the source regions and Poland, but the second peak of the release was moving towards Greece. Convective storms broke out over much of southern Europe from 1 – 3 May. Air now flowed northwards to the west of the anticyclone over Denmark, with a band of more polluted air from Austria to the north coast of FRG, and much of Britain within the cloud. Rain led to some relatively high values of deposition in Western Britain and then over Scotland on 3 – 4 May. Thereafter the air circled round a depression centred just to the west of Britain and was drawn northwards from Europe, with frontal systems precipitation over the North Sea (where a lot of the material was deposited) Denmark and Norway. Until this time Denmark had remained relatively free of the cloud. The remaining material affected the eastern half of Europe, gradually clearing away northwards from Greece to Scandinavia in generally dry weather. The airborne radiactivity had mostly cleared away from Europe by the end of the second week in May.

It appears that activity first entered Hungary on 29 April, from the north moving west, after being released from Chernobyl during 26 – 27 April, and reached Budapest by 30 April. By 1 May activity released on 29 April seems to have entered the country from the north and east on a more direct trajectory. Subsequently activity released between 29 April and 4 May gave rise to further exposure over Hungary. Thus levels were persistently elevated to various degrees from 29 April until 9 May. Because of exposure to different parts of the release nuclide specific data over Hungary could be quite revealing with respect to variations in the release pattern manifesting the higher ^{103}Ru/^{137}Cs ratios in the latter part of the release.

Figure 3 shows a map of the estimated deposition of ^{137}Cs across Europe based on MESOS – II simulations with the release pattern in column 2 of Table 1. It has been compared with deposition measurements; as expected it fails to predict contamination over Finland (where in the south some high levels were experienced as in Norway and Sweden), and overestimates the westward spread towards Spain. Nevertheless it picks out on a broad basis the regions of Europe which experienced higher deposition in rain systems. In practice the problems experienced across Europe in contamination of foodstuffs were associated with hot-spot areas where more intense precipitation scavenged the plume concentrating deposited $^{137/134}$Cs locally. In Scandinavia small areas with deposition in excess of 100 kBq.m^{-2} have been reported, and there are also high levels in parts of central and southern Europe, often exacerbated by orographic enhancement in mountainous regions.

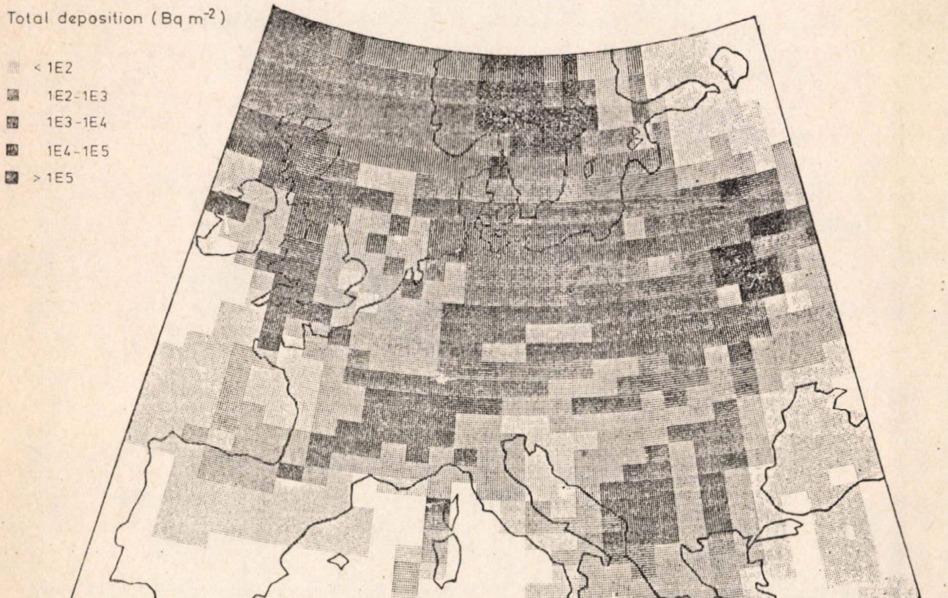


Fig. 3: Accumulated estimated deposition of Cs^{137} between 26. 4.86 and 15.5.86 from MESOS – I I simulation

Deposition of ^{137}Cs was often very closely correlated with rainfall patterns during passage of the release, and in some countries this has been used to deduce detailed deposition patterns. In the UK we have an advanced weather radar network giving detailed analysis of precipitation in space and time. We used this data to obtain a map of the estimated distribution of contamination over England and Wales, which gave very good agreement with measurements made on grass (*ApSimon et al.*, 1988). Obtaining the data to determine the exact time of passage of the radioactivity, which was crucial to the raincells intercepted, took a considerable time. However, there are now plans to make such capabilities operational at the UK Meteorological Office.

5. The long-term effects over Europe

The long-term contamination from Chernobyl over Europe is dominated by the deposited caesium isotopes, which are long-lived and persistent. The 1 mSv limit on dose commitment is therefore the relevant criterion.

Two modes of exposure are dominant for ^{137}Cs, the whole body external irradiation from the deposited material, and ingestion of the radionuclide. For external irradiation the shielding effect of buildings reduces the dose. Also deposition on smooth urban surfaces is generally considerably less than on soils and vegetation. *Charles et al*, 1982, (DOMESEMARC) give the effective whole-body dose over 50 years for an individual constantly outdoors following deposition of 1 $Bq.m^{-2}$ of ^{137}Cs on the soil as $1.2.10^{-7}$ Sieverts (Sv), and recommend an overall shielding factor of 0.5, which is very conservative for most urban populations. Doses resulting from ingestion of deposited ^{137}Cs depend on the particular foodstuffs and the manner in which they are contaminated by the deposition as discussed in the next section and hence on the dietary habits of the population, which vary considerably throughout Europe. Also not all food is locally grown. However estimates of doses resulting from ingestion, based on various shopping baskets (WHO meeting, June 1986) generally indicated a value for the dose commitment over 50 years for this exposure route which is very similar to that for ingestion. To this must be added the additional contribution from ^{137}Cs. The distribution of deposited ^{134}Cs is similar to that for ^{137}Cs, but the concentrations are almost exactly half as high, as has been systematically observed in air concentrations and used to distinguish fresh deposition of ^{134}Cs from Chernobyl from preexisting deposition from fall-out (in which ^{134}Cs was negligible). ^{134}Cs has a shorter half-life of 2 years and dose factors are slightly lower: for external irradiation the 50 year dose is $6.8.10^{-8}$ Sv per $Bq.m^{-2}$ deposited by comparison with the $1.2.10^{-7}$ Sv for ^{137}Cs. ^{134}Cs therefore adds about 30% to the dose commitment. This implies that where there is deposition of 5 $kBq.m^{-2}$ of ^{137}Cs the dose commitment to an individual is of the order of 1 mSv.

To obtain an approximate indication of the consequences of the Chernobyl accident for the European population, calculations were undertaken of the collective dose commitments due to the isotopes of $^{137/134}Cs$ using the dose factors given above and the deposition map calculated with the MESOS – II model, together with the population distribution. This of course makes no allowance for any reduction which may have resulted from the introduction of control measures. The resulting estimated collective dose commitment over 50 years for the European population outside the USSR amounted to 2.10^5 man.Sv. Averaged over the 550 million people included, this amounts to an average dose commitment per individual of 0.4 mSv. This corresponds to about 70% of the caesium isotopes released being deposited within the total map area shown in Figure 3, and an average deposition of 2 to 3 $kBq.m^{-2}$. To put this perspective the annual average dose due to natural sources of radiation (including radon) in the UK is 2.5 mSv with similar levels elsewhere in Europe, so that the average collective dose commitment from Chernobyl corresponds to about 2 months of such natural exposure. In hot-spots of local deposition individual doses may however be considerably higher.

6. Concluding comments

The accident at the Chernobyl nuclear power plant in the Ukraine on 26 April 1986 is the most serious civil nuclear accident in the world to date. A visit to Chernobyl in March 1986 with a party of scientists attending a SCOPE (Scientific Committee on Problems of the Environment) workshop in Moscow, clearly showed the huge and impressive effort which had been required to deal with the situation and restore the site with units ito 3 to an operational state again as well as entombing the damaged unit 4 under vast quantities of steel and concrete. Much can be learned from the Soviet experience. In particular, not just in the Ukraine but over Europe and beyond we can observe a great wealth of scientific information about the biogeochemical pathways of radionuclides through the environment. It was thus very welcome that at the VIIth General Assembly of SCOPE, which was held in Budapest during my visit to Hungary, a proposal put forward in Moscow in March for a SCOPE project on this topic was approved with full international collaboration.

REFERENCES

ApSimon, H. M. Goddard A. J. H. and *Wrigley, J.* 1985: Long-range atmospheric dispersion of radio-isotopes- the MESOS model. *Atmos. Environ. 19,* 99 – 125.

ApSimon, H. M., Wilson J. J., Guirguis S. and *Stott, P.*, 1987. Assessment of the Chernobyl release in the immediate aftermath of the accident. *Nuclear Energy 26,* 295 – 301.

ApSimon, H. M. Simms, K. L. and *Collier, C. G.*, 1988: The use of weather radar in assessing deposition of radioactivity from Chernobyl across England and Wales: *Atmos. Environ.* 22., 1895 – 1900.

Charles, D., Crick M. J., Fell T. P. and *Greenhalgh J. R.*, 1982: DOSEMARC: The dosimetric module in the methodology for assessing the radiological consequences of saccidental releases. *Report NRPB – M74.* Published by HMSO.

IAEA, 1986: USSR State Committee on the Utilisation of Atomic Energy- The accident at the Chernobyl nuclear power plant and its consequences. *Proc. of IAEA experts meeting,* August 25 – 29 1986.

IDŐJÁRÁS

Az Országos Meteorológiai Szolgálat folyóirata. 93. évf. 1. szám. 1989. január–február
Journal of the Hungarian Meteorological Service. Vol. 93. No. 1. Jan–Feb 1989. Budapest

The case scenario approach to climate related impact analysis

MICHAEL A. GLANTZ

*National Center Atmospheric Research**
Boulder, Colorado, USA

This paper is concerned with how well society might be prepared for changes in climate variability and climate extremes as a result of the carbon dioxide/trace-gases-induced global warming. It presents the use and potential value of the "case scenarios" approach in identifying the ability of decisionmakers at various levels of society to respond to environmental changes at the regional level. This approach represents yet another way to assess the preparedness of societies to climate-related stress. Case scenarios are based on assessments of appropriate contemporary historical responses to climate-related environmental changes as analogues or surrogates for what might plausibly happen if a global warming occurs. Several case scenarios are briefly described. A detailed case study is presented based on the societal and environmental impacts of a set of four freeze events in a five-year period in the first half of the 1980s. This case scenario identifies societal strengths and weaknesses in the citrus growing region of the southeastern United States in coping with such unanticipated extreme meteorological events. This study also shows how adverse climate impacts in one country can change the country's ability to compete economically in the market place. It is hoped that the case scenario approach to climate impact assessments will be useful in other sectors and in other countries as well.

*

„Eset-szcenárió" megközelítés éghajlati vonatkozású hatásvizsgálatokhoz. A dolgozat célja annak elemzése, milyen jól tud a társadalom felkészülni a szén-dioxid és más nyomgázok okozta globális felmelegedés következtében létrejövő éghajlat-változásokra, ill. -szélsőségekre. Bemutatja az „eset-szcenárió" megközelítés használatát és potenciális értékét a döntéshozók tevékenységében a társadalom különböző szféráiban, hogy választ tudjanak adni a regionális méretű környezeti változásokra. E megközelítés mindenképpen új utat jelent annak felmérésére, mennyire készült fel a társadalom az éghajlat okozta stresszre. Az eset-szcenáriók lényege annak felderítése, hogy milyen megfelelő társadalmi visszahatások születtek a közelmúltban az éghajlati vonatkozású környezeti változásokra; ezeket analógiáknak tekintjük arra vonatkozóan, hogy valószínűleg mi történhetne, ha globális felmelegedés következne be. Részletes esettanulmányt mutatunk be, amely a 80-as évek első felében öt évből négyben előfordult fagykár társadalmi és környezeti hatásaival foglalkozik. Ez a tanulmány feltárja az USA délkeleti részének citrustermelő régióiban a társadalmi válasz erős és gyenge pontjait, amikor ilyen előre nem látott meteorológiai események fordulnak elő. A tanulmány azt is bemutatja, hogy az ártalmas éghajlati hatások milyen mértékben tudják megváltoztatni egy ország piacon való maradási képességét. Reméljük, hogy az éghajlati hatások felmérésére az ilyen eset-szcenárió megközelítések más ágazatokban és más országokban is hasznosnak bizonyulnak.

* The National Center for Atmospheric Research is sponsored by the National Science Foundation

Introduction

The purpose of this paper is twofold. First it is to discuss the use and potential value of what we call "case-scenarios" to identify the ability of societies (from the local to the international levels) to respond to low-grade, long-term environmental changes. We are most concerned with how well society might be prepared for changes in climate variability and climate extremes as a result of the CO_2/trace gas-induced global warming. The case-scenarios approach represents an attempt to develop yet another way to assess the preparedness of societies to climate-related stress. As opposed to the development of scenarios from atmospheric general circulation models (the development of societal impacts scenarios from the top down), the case-scenario approach is an attempt to develop such scenarios by using appropriate contemporary historical responses to climate-related problems as surrogates or analogues for what might feasibly happen in a warmer world (the development of societal impacts scenarios from the bottom up).

The second purpose of this paper (not necessarily unrelated to the first) is to present a multidisciplinary case study of the impacts of a set of freeze events on citrus production in the State of Florida (USA). This will serve to exemplify the kind of information that might be obtained in a typical climate impacts assessment. It is a shortened version of a longer more in-depth study on how climate can affect the economic competitiveness of a particular industry (*Miller* and *Glantz*, 1987). This case study also serves as yet another example of a case-scenario for the global warming section of the paper. The unusual repeated freezes in Florida in the early 1980s represent a plausible scenario of changes in frequency and intensity of extreme meteorological events that might accompany a CO_2/trace gas atmospheric warming.

The Carbon Dioxide issue and regional scenarios

There is a large collection of literature on the effects of carbon dioxide and other trace gases on global temperatures and ecosystems (e. g., *Bolin et al.*, 1986; *DOE*, 1985 a, b, c, d, 1986; *EPA*, 1983 a, b, 1984). Much of this work has been funded in the US by the Department of Energy (DOE). Originally, the DOE was charged with responsibility for societal impacts of CO_2-induced global warming but with a change in political administrations in the US in 1980, the DOE dropped its support for research into the societal aspects of CO_2 impacts. However, today there is a strong desire to focus attention on the societal and economic impacts of a global warming. Presently it is the US Environmental Protection Agency (EPA) that has the responsibility for assessing the societal impacts and policy aspects of a trace gases-induced global warming and the implications of those impacts for policy making. The problem is that there are still many uncertainties about the CO_2-induced warming that make studies of societal impacts of such a warming questionable. What, for example, does an average global warming mean to climate on a regional and local scale?

There has been considerable dependence in the past on scenario construction using General Circulation Models (GCMs) to determine regional-scale physical impacts. Yet, GCMs have not proven very reliable modeling precipitation and even temperature at the regional level. How useful to policymakers might such scenarios be for long-range planning purposes? While they may have some credibility (but not reliability) in scientific circles, they surely lack credibility in political circles because the policymakers do not have any experience in dealing with the kind of future worlds that the models suggest. Can this be remedied?

To complement the work of GCMs, we have undertaken an assessment of "case scenarios" that can be used as analogues of possible societal responses to the impacts of a trace gas-induced global warming. These cases contain actual societal responses to environmental changes that might provide us with some idea about how societies might respond to regional climatic changes. In a sense

Fig. 1.

these cases can serve as societal sensitivity studies that will show how well society is prepared to respond today to climate-related environmental problems. We look at two kinds of problems: long-term, low-grade but cumulative changes (e. g., sea level rise) and recurrent climate-related environmental changes (e. g., droughts). With regard to the latter at least two important concerns come to mind: changes in the frequency of occurrence of recurrent problems (i. e., increasing or decreasing) and changes in extremes (i. e., new records being set according to some standard, usually the historical record, or the lifetime of a structure such as a dam or reservoir).

It is important to note that how societies responded in the past may or may not provide a reliable guide as to how society might respond in the future to recurrent climate anomalies. For this reason, this approach may lack a degree of scientific credibility. Yet, they may have some credibility in political circles because they are based on recent experiences and policymakers will be able to relate to them, having had some experience, for example, dealing with the impacts of rising (or falling) lake levels on coastal communities, or dealing with the economic impacts of repeated freezes on citrus grove owners. In addition, such case scenarios could expose current strengths and weaknesses of existing institutions and processes in dealing with either long-term, low-grade cumulative environmental changes or with recurrent climate-related environmental changes, and thus can offer an opportunity for society to take into consideration appropriate adjustments.

For an assessment of case scenarios for North America, we have chosen to look at the following situations: metropolitan water supply (Northern Virginia) and drought, orange production (Florida) and freezes, the Mississippi River system and the impacts of high and low flow on navigation, coastal subsidence and sea level rise (Southern Louisiana), declining aquifers and agricultural adjustment (U. S. Great Plains), the rise in the level of the Great Lakes, the rise in the level of the Great Salt Lake (Utah), water supply management and drought (northern California) and the impact of an erroneous streamflow forecast on irrigated agriculture (Yakima, Washington). Only a few of these cases will be discussed here. Each case has its own contribution to make to our understanding of society's response to environmental change. The case studies are now in progress and the research findings (as well as the case-scenario's contributions to our understanding) are yet to be fully identified.

Specific Case-Scenarios: A few examples

Increasing levels of the North American Great Lakes. In the past few years levels of several of the North American Great Lakes *(Fig. 1.)* have been at or above record historical levels (*Cohen*, 1987; *Quinn*, 1985). There is no indication oen way or another whether this increase in levels will continue.

Previous extremely high lake levels were reached in 1974 and those have been matched or surpassed in the mid-1980s. Attention was drawn to the Great Lakes situation as a result of national media coverage of the damage that has resulted to communities bordering some of the lakes. In addition, Chicago's shorefront property had been damaged by high water as well as by wind-driven blocks of ice hurled into shorefront condominiums.

There has been considerable speculation recently about whether the increase in lake levels might be linked to the "greenhouse effect" resulting from the increase in the atmospheric content of the trace gases. This particular environmental change will be the focus of attention of the EPA's report to the US Congress early next year on the policy aspects of a carbon dioxide warming. If the CO_2 warming is taken seriously as a cause of increasing lake levels then it is assumed that these levels will remain high. In fact, with regard to a CO_2-induced warming it is believed that the level of the Great Lakes will go down, not up as they have been in the recent decades. Thus certain responses might be expected from organizations, agencies and political units (e. g., states, provinces, local communities, international commissions). A CO_2-induced warming will be a long-term, gradual but cumulative process. Several questions need to be explored. What kind of response should these various groups involved with different aspects of the Great Lakes system take? What kinds of preventive measures might be warranted, given that there is still considerable uncertainty about what such a warming might do to Great Lakes levels? Should those organizations allow the gradual changes to occur, and simply respond in an adaptive fashion to changes in lake level and associated problems such as coastal flooding or more severe storm surges? The Great Lakes are high now and have been high at previous times. Several questions might be investigated. How have societies bordering the Great Lakes dealt with sharp changes in lake levels in the past fifteen years? How have they responded in the past five years? Can we learn from such responses how societies in similar situations might respond to such climate-related environmental problems in the future? What does it tell us about how societies deal with incremental, low-grade cumulative environmental changes?

Rise in the Great Salt Lake. The U. S. Great Salt Lake is situated entirely within the State of Utah and is approximately 3,500 km². *(Fig. 2)*

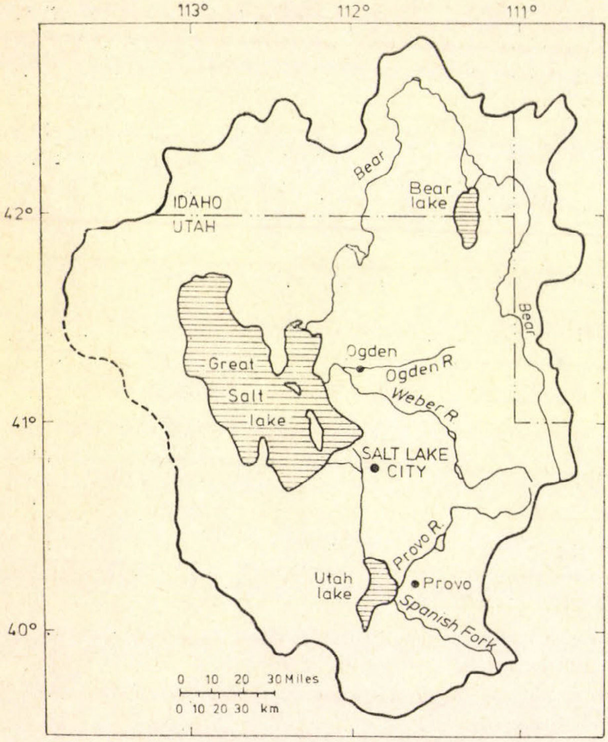


Fig. 2.

As of 1982, the level of the Great Salt Lake had reached its historic long-term average (1281) m), having rebounded from its historic low level in 1963 (1278 m). From the historic low of 1962 the levels continued to slowly rise until the early 1980s. Between September 1982 and June 1983, however, the level of the Great Salt Lake rose about 1.5 meters. The following year it had risen another 1.5 meters. There was little change in 1985. By 1986 it had risen yet another 1.2 meters, surpassing the previous historic high record set in 1873. The lake rose rapidly between 1982 and 1986, as a result of heavy precipitation in the fall and spring seasons. In June 1986 it had risen to its highest level ever recorded. Thre is uncertainty today about what direction the lake level will go in the near future.

Amidst all the speculation about why the lake level had risen as well as what society might do about it, political decisionmakers were prompted to action as a result of actual damages that resulted from the rising waters. The total damages have thus far been estimated to be over $300 million. Damage includes adverse impacts on industrial and mining activities along the lakeshore, destruction of agricultural land as well as wildlife refuges, railroad track beddings, highways, residential homes, employment prospects and so on. For example, rail lines had to be raised repeatedly in the mid-1980s in order to accomodate higher lake levels. In some areas the tracks can be raised no higher because the elevated beds cannot withstand the weight of the trains. In addition, the interstate highway (I−80) was also raised in this period but, for the same reasons, it cannot be further elevated. If the lake continues to rise, rail service to some parts of Utah will end. Also, some of the mining companies already adversely affected by rising lake levels have already closed down their lakefront operations and terminated the jobs of hundreds of employees.

According to *Morrisette* (1987), the State's response to the rising lake levels has been to "implement a set of incremental adjustments with each step being taken as a previous step became overwhelmed by the continuing rise of the lake level" (p. 94). The reason for the inability to cope with the impacts on the lake of a variable climate regime were related to two major causes: perceptions about the upper limits of the lake level (human time scales being different from natural time scales); rigidity in institutional arrangements for dealing with the levels of the Great Salt Lake. The State of Utah opted for building a pumping station at a cost of tens of millions of dollars to keep the lake level "safe" on the short-term. This solution was supported by some and opposed by others.

It appears that two views about future lake level rise were in competition with each other for support of decisionmakers: one view was that the lake had reached its highest level and therefore had to recede, the other view was that the past record provided little insight into the future. If climate was indeed changing, then there would be little value in placing a heavy reliance on the historical record. A controversy developed over how high could lake levels go and what lake level would be acceptable for planning for development around the lake. Contingencies were developed identifying what was believed to be the most likely high lake level (1283 m by the year 2025), the most likely low lake level (1278 m by 2010), and the more extreme but still possible high lake level (1284 m by 1998). More importantly, a planning level of 1286 m was identified as the most plausible high level (extreme event).

When lake levels in 1985 did not rise, some observers felt that the problem was over. This appear to be a common response to recurrent severe climate-related phenomena. It may be no more than wishful thinking; hoping that the problem will resolve itself. Also, decisionmakers do not want to put themselves in a position whereby they have authorized some costly mitigation measures, only to have the reasons for the measures evaporate. No one knows what the future holds in store for the Great Salt Lake.

What this case study tells us is how State decisionmakers have perceived lake levels and how they perceive future climate changes and their possible effects on lake levels. Current scientific speculation suggests that with a global warming the lake levels will decline, not increase. Perhaps this belief has reinforced Utah decisionmakers to opt for a short-term solution to rising lake levels and to hope that they made the right decision.

The Ogallala Aquifer Depletion in the US Great Plains. The Great Plains is considered to be part of the heartland for agricultural production in the United States. The aquifer underlies parts of eight states, from South Dakota to Texas *(Fig. 3.)*.

It is of variable saturated thickness with the thickest part being in Nebraska and the thinnest part being in the High Plains of Texas. Agriculture in the region is heavily dependent on the use of aquifer water for irrigation purposes.

The region itself produces principally corn, wheat, cotton and feed grains (sorghum). The region is drought prone with speculation about the periodicity of those droughts somehow being linked to 22-year sunspot cycles. Whether, such a relationship is found to exist, beyond a doubt, a myth has developed that a major drought hits the Great Plains every 20 years or so . . . and now we look and wait for them.

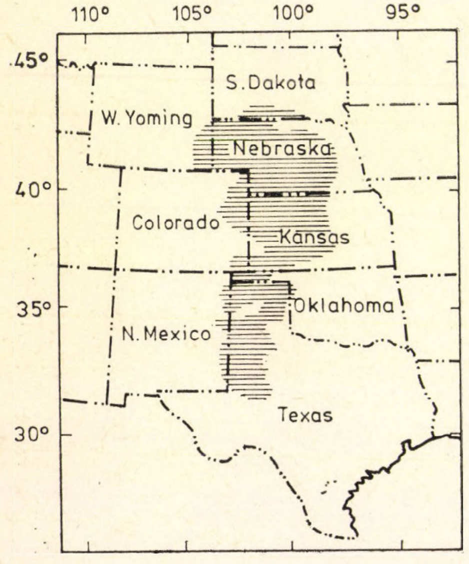


Fig. 3.

Droughts do return to the western part of the United States every so often and they have been of varying magnitude and impact. The droughts in the 1890s caused a great number of settlers to abandon their land in search of areas with less harsh climatic conditions. The worst of these droughts in intensity and in societal and environmental impacts took place in the mid-1930s, an era that is commonly referred to as the "dust bowl" days.

The spectre of a return of such prolonged and intense drought conditions is driving policymakers to take seriously scientific arguments about the regional effects of a global warming. Several models of a potential global warming suggest that the American Great Plains will become drier and soil moisture will become reduced. The models include output from general circulation models, historical and paleoecological reconstructions of the environment (regional climate and ecology) during the last warm epoch (the Altithermal about 4000 – 8000 years ago), and a reconstruction of midlatitude climate during the ten warmest Arctic summers this century (it is assumed that a one degree warming in the midlatitudes would mean a 3 – 4 degree warming in the polar region). There have even been scenarios constructed that "play out" the impacts of a 1930s type drought on a 1980s type economy in that region (*Bernard*, 1980; *Warrick*, 1984).

As the historical records show, each of the major droughts in the region has prompted decisionmakers from farmers to state governments to look for ways to buffer agricultural and other activities from the vagaries of climate, especially drought. Thus, during and following major droughts, there is a sharp increase in the number of wells constructed to tap the ground water. There seems to be little control over the exploitation of the aquifer. In fact, one could argue that for a long time the aquifer was seen as an unlimited resource. Yet the aquifer is not of homogeneous thickness or depth from the surface and is also more vulnerable to exploitation in some places than in others.

Driving the exploitation of the aquifer were favorable prices for agricultural production, cheap energy, available technology and, last but not least, recurrent droughts and dry spells throughout the region. However, some regions where the aquifer is thinnest (the High Plains of Texas) began to experience reduced availability of groundwater. The level of the aquifer had dropped to such an extent that it became more and more expensive to sink wells and required more energy to pump it out. With the depletion of the aquifer and with higher energy costs some farmers have reverted to dryland farming practices, shifted to crops with a lower dependence on water, or abandoned their land.

To take a look at the problem of a declining groundwater level, the US Congress authorized an $11 million study of the geology of the aquifer and the impacts of its depletion. Projections were made to the year 2020. In this report the climate of the region for the next 40 years was considered to be the same as the climate of the past several decades; that is, extremely favorable for agricultural production in the region. Such a view, of course, ignored all of the scientific discussion that has been taking place about the likely global warming as well as speculation about the regional impacts on the Great Plains of such a warming. The High Plains study looked at baseline projections (that is, the continuation of current policies and trends at all levels) and proposed five alternative water management strategies, two of which included intrastate and interstate water transportation. The proposal of extrapolating current policies and trends received much criticism when the study was evaluated (*NCAR*, 1985).

These two environmental problems – the actual, real problem of the drawdown of the Ogallala aquifer and the hypothesized, projected regional impacts of a global warming – should be looked at together rather than separately. Those studying each of these problems can learn from the research findings of the other. For example, how farmers in the Texas High Plains have responded to dwindling ground water supplies may shed light on how farmers in that region might respond to a change (perhaps associated with a trace gas-induced warming) in the frequency and intensity of droughts. How governments at all levels of society have responded to the long-term, low-grade but cumulative decline in ground water supply may present ideas on how best to deal with the long-term, low-grade but cumulative global warming associated with the burning of fossil fuels, the release of other trace gases, and deforestation. We have experience in dealing (or not dealing) with the aquifer's depletion, whereas we have little experience in dealing with an analogous (in several respects) problem of changes in precipitation in the American Great Plains. We can learn from societal responses to the depletion of the aquifer about how we might cope with an "atmospheric drying out" of the American Great Plains.

The aquifer depletion continues in many parts of the region and it is projected that after 2020 a groundwater "crisis" will emerge throughout the region. The global warming, if it continues, will become heightened by the early decades of the 21st century. These two adverse impacts on the water balance in the region (one actual and one potential) will converge, making a bad situation even worse.

As noted in the introduction, the following section represents both a case-scenario for the climate change issue discussed in the preceding section and a study of extreme events and societal responses to them.

The Florida Citrus Case Study. As a result of climatic factors, only a small portion of the world's agricultural land is suitable for the commercial production of high quality citrus. An even smaller portion is suitable for the profitable production of oranges intended for processing into frozen concentrated orange juice. The climate characteristics of the State of Florida were conducive for the state to become a major producer of oranges during the 19th century and the world's first major producer of frozen concentrated orange juice (FCOJ) in the mid-twentieth century. Citrus production in Florida has become a multibillion dollar industry.

The annual climatic patterns have allowed for profitable citrus production mainly in the central portion of the state. The geographic location of commercial citrus production has been limited in the southern part of the state by poorly drained soils and in the north by relatively high freeze probabilities. Even within the main citrus growing areas recurrent freezes can impose significant costs.

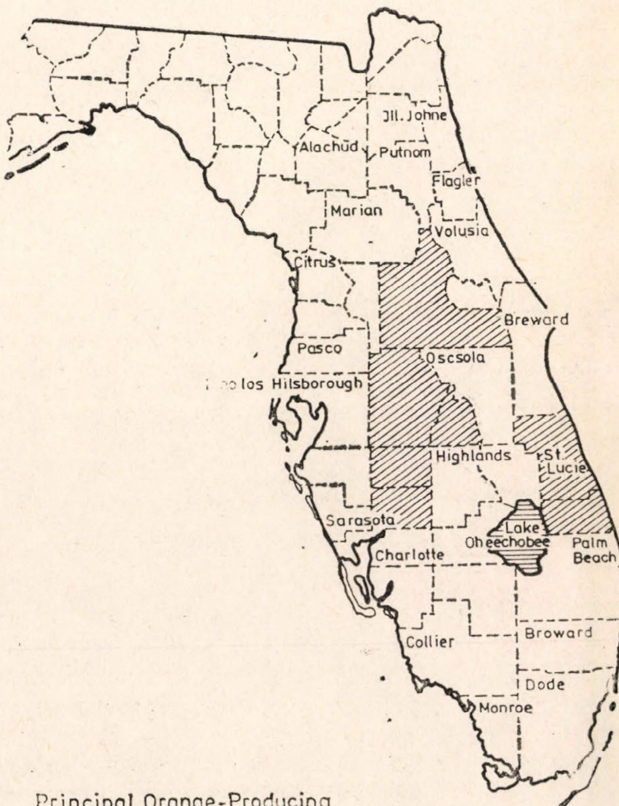
Between September 1980 and January 1986 the Florida citrus industry has suffered four major freezes. The most serious of these freezes (the third and fourth in the sequence) occurred in December 1983 and January 1985. Together, these two freezes are estimated to have killed approximately 40 percent of Florida's commercial citrus trees.

While Florida's citrus growers may have adjusted to the periodic occurrence of freeze damage, the set of freezes that began in 1980, as well as the devastating intensity of the 1983 and 1985 freezes, caught them by surprise. Such severe freeze damage had not been experienced for nearly a century.

The recent anomalous set of freezes has reinforced speculation about climate change. More than one writer has suggested that climate change is at the root of Florida's recent freezes. Chen, for example, reports that an apparent cooling trend can be discerned in Florida's minimum temperature records (*Chen*, 1984, 1985). Some observers questioned whether the citrus industry in Florida could recover. Moreover, if it recovers, what can it expect with regard to future climate variability and future climate extremes? Those who suggest a climate change, of course, represent only one view about why Florida's citrus region has been plagued by the recent series of damaging freezes. It is possible that freeze probabilities in Florida's orange growing areas *(Fig. 4a)* are high enough that this anomalous series of cold temperature events could have occurred even in the absence of a real climate change. In other situations, it has been shown that runs of extreme weather events can occur by chance with no change having necessarily occurred in the underlying probability distribution (*Glantz* and *Katz*, 1985).

Regardless of the underlying cause or causes of this recent set of seemingly anomalous freeze events, the experience may have been sufficiently costly to convince many Florida citrus growers that freeze probabilities are significantly higher than they had previously assumed and may cavuse them to seek to minimize their risk of loss by resorting to one of a variety of measures. They may expand citrus planting into southern Florida. Citrus production has traditionally been limited in Florida's southern counties because the poorly drained soils in that region are in general unfavorable to citrus production. Such soils mean higher

a)



Principal Orange-Producing Regions in Florida

Fig. 4a.

land preparation costs, greater risks of disease and relatively lower yields. As another alternative they convert their land to other less risky uses. In many parts of Florida there is considerable enticement for orange grove owners to turn their land over to other uses. For example, Florida has one of the fastest growing populations in the nation, and groves could be converted by land developers into new communities. Other potential competing uses for land in Florida's traditional citrus growing areas include conversion into forest or pasture or into land suitable for the production of other fruits, nuts, or vegetables. These other investment alternatives might become more attractive following periods of severe freezes.

As long as the trees in a grove are alive and producing, its value in citrus production is likely to exceed its value in many alternative uses. Once the trees are dead, however, the value of that parcel of land falls dramatically, and the owner is faced with a radical change in the relative value of his land in alternative uses. It has been estimated that as much as 1/3 of the frozen-out citrus acreage will be put to other uses. At least 1/3, however, will be replanted. Those growers who do replant are generally following new practices including closer

Stipple = Major Orange-Producing Region in Brazil

Fig. 4b.

spacings, the installation of microsprinklers for cold protection, and the use of tree-wraps to protect the young trees from freeze damage. These practices provide greater cold protection for the young trees. Growers also hedge against freeze risks by planting a mix of early and late maturing varieties. While the early varieties face less risk of frost, they bring lower prices.

Until this decade, Florida growers were less vulnerable to financial losses from freezes, because when freezes adversely affected orange juice production, the resulting increase in price could compensate affected growers for some if not all of their loss. In addition, before 1962, Florida had virtually no competition as a supplier of FCOJ. Since the 1960s, Florida's output has been supplemented by a steadily increasing Brazilian FCOJ production. Today, the increased availability of Brazilian exports of FCOJ provides a ready substitute for shortfalls in Florida's production, thus the price of FCOJ has become fairly stable. Florida citrus growers can no longer count on sharp increases in prices for their oranges following a citrus-damaging freeze event.

The climate of Sao Paulo state in Brazil is especially suitable for the production of high quality oranges. *(Fig. 4b)* When in 1962 a severe tree-killing freeze occurred in Florida, the resulting rise in prices for oranges and especially for FCOJ caught the attention of entrepreneurs in Sao Paulo and stimulated the establishment of new orange groves and the development of modern, quality-controlled juice production techniques. Brazilian production has continued to expand since the 1960s. In fact, some American and multinational corporations involved in orange juice production have developed groves in Brazil as well in an attempt to minimize their financial vulnerability to the vagaries of climate.

Despite the stimulus that the 1962 freeze in Florida provided to Brazil to enter into the FCOJ industry, the role of subsequent Florida freezes in determining the rate of expansion of Brazilian FCOJ output is less clear. Steady growth in world demand, coupled with cost-saving technological innovations appear to have been the long-run driving forces behind this expansion. While there does appear to be a tendency for exports to increase in response to higher freeze-year prices, the strong underlying upward trend in output and exports suggests that the Brazilian FCOJ industry would have grown rapidly even in the absence of Florida's freezes. Although Brazilian producers have profited significantly from Florida's recent freezes, these windfall gains do not appear to have been the primary force (but a force none the less) behind the expansion of their citrus industry.

This does not mean that Florida's climate characteristics have not had an important role in its ability to compete economically with the Brazilian FCOJ industry. The pronenes of Florida's growing areas to freeze damage severely limits the ability of Florida's output to expand in response to growing world demand, while the possibility of freeze shocks results in potential windfall gains for other producers. The climate-induced instability of Florida's supply and the growing world demand have thus contributed to the creation of profitable opportunities for expanded Brazilian FCOJ production.

As for Florida's ability to continue and perhaps expand its key role in the global citrus economy, the recent freezes do not appear to have eliminated it. Rather, those freezes have reawakened Florida's citrus producers to the fact that they are involved in a climate-sensitive industry and have reminded them that the potential for freeze-related problems is never far away. This has sparked interest in developing hardier citrus varieties, more effective freeze protection methods, and better ways to hedge economically against freeze impacts to the industry.

Conclusion

There has been a sharp increase in interest in climate impact assessment in the United States, in Canada, in Germany, in Brazil and other nations in the past year or so. This has in large measure been due to growing concern among policymakers about the carbon dioxide issue. Their interest has also been reinforced by the attention that the impacts of the 1982–83 El Nino event (an atmospheric-oceanic phenomenon) had worldwide. Questions about how well society might be prepared for the yet unknown regional and local effects of a global warming have stimulated research into what might be called "prior" questions, that is, questions about how well today's societies are coping with long-term, low-grade cumulative environmental changes and with extreme meteorological events. Multidisciplinary climate impact assessments can provide useful knowledge to researchers as well as to policymakers about how societies might best deal with climate-related socioeconomic and environmental impacts. They can also provide information about which climate-related impacts people are most concerned.

REFERENCES

Bernard, H.W. Jr., 1980: *The Greenhouse Effect.* Ballinger Publishing Co., Cambridge, Massachusetts, USA.

Bolin, B., Döös, R. B., Jager, J. and *Warrick R. A.* (eds.), 1986: *The Greenhouse Effect, Climatic Change, and Ecosystems.* SCOPE 29. John Wiley & Sons., Chichester, England.

Chen, E., 1984: Long term climate trend. In *Cold Protection Guide*, Lake-Orange Extension Service, Central Florida Freeze Recovery Task Force, pp. 140 – 143. Institute of Food and Agricultural Sciences, Univesity of Florida, Gainesville, Florida, USA.

Chen, E., 1985: Minimum temperature change and freeze probabilities in Florida: 1925 – 1984. In *Cold Protection Guide*, 1985 Revision. Lake-Orange Extension Service, Central Florida Freeze Recovery Task Force, pp. S1 – S5. Institute of Food and Agricultural Sciences, University of Florida, Gainesville, Florida, USA.

Cohen, S. J., 1987: Influences of past and future climates on the Great Lakes region of North America. Submitted to *Water International.*

DOE (US Department of Energy), 1985a: *Carbon Dioxide and Climate: Summaries of Research in FY 1985.* DOE/ER – 0202/1. US Department of Energy, Washington, DC, USA.

DOE, 1985b: *Characterization of Information Requirements for Studies of CO_2. Effects: Water Resources, Agriculture, Fisheries, Forests and Human Health.* DOE/ER – 0236. US Department of Energy, Washington, DC, USA.

DOE, 1985c: *The Potential Climatic Effects of Increasing Carbon Dioxide.* DOE/ER – 0237. US Department of Energy, Washington, DC, USA.

DOE, 1985d: *Direct Effects of Increasing Carbon Dioxide on Vegetation.* DOE/ER – 0238. US Department of Energy, Washington, DC, USA.

DOE, 1986: *Carbon Dioxide and Climate: Summaries of Research in FY 1986.* DOE/ER – 0202/1. US Department of Energy, Washington, DC, USA.

EPA (*US* Environmental Protection Agency), 1983a: *Can We Delay a Greenhouse Warming?* Office of Policy Analysis, Office of Policy and Resources Management, Washington, DC, USA.

EPA, 1983b: *Projecting Future Sea Level Rise.* Office of Policy Analysis, Office of Policy and Resources Management, Washington, DC, USA.

EPA, 1984: *Potential Climatic Impacts of Increasing Atmospheric CO_2 with Emphasis on Water Availability and Hydrology in the United States.* Office of Policy Analysis, Office of Policy and Resources Management, Washington, DC, USA.

Glantz, M. H. and *Katz, R. W.*, 1985: Drought as a constraint in sub-Saharan Africa, *Ambio 14*, 334 – 339.

Miller, K. A. and *Glantz, M. H*, 1988: Climate and economic competitiveness: Florida freezes and the global citrus proscessing industry. *Clim. Change 12*, 135 – 164.

Morrisette, P., 1987: *Perception, Public Policy, and Societal Adjustment to Fluctuations in Climate: A Case of the Rising Level of the Great Salt Lake.* PhD Dissertation, University of Colorado, Boulder, Colorado, USA.

NCAR (National Center for Atmospheric Research), 1985: *Report of the Networkshop.* (Workshop organized by the Environmental and Societal Impacts Group, May 6 – 8, 1985. NCAR, Boulder, Colorado, USA).

Quinn, F., 1985: *Great Lake water levels.* Briefing conducted by the International Joint Commission. U. S. Army Corps of Engineers, North Central Division, Chicago, Illinois, USA, 1 – 24.

Warrick, R. A., 1984: The possible impacts on wheat production of a recurrence of the 1930s drought in the U. S. Great Plains. *Clim. Change 6*, No. 11, 5 – 26.

IDŐJÁRÁS

Az Országos Meteorológiai Szolgálat folyóirata. 93. évf. 1. szám. 1989. január – február
Journal of the Hungarian Meteorological Service. Vol. 93. No. 1. Jan – Feb 1989, Budapest

Statistics and decision making for extreme meteorological events

RICHARD W. KATZ

*Environmental and Societal Impacts Group National Center for Atmospheric Research**
Boulder, CO 80307 U.S.A.

Statistical methods appropriate for dealing with extreme meteorological events are reviewed. The statistical theory of extreme values and of records is contrasted with that for expected values. To demonstrate that means cannot simply be used as surrogates for extreme events in climate impact studies, an example is given of the nonlinear relationship between the likelihood of a particular extreme meteorological event and the mean for that variable. The inadequacy of standard statistical techniques that are employed to make inferences about climate variability is outlined, and alternative approaches are suggested. In estimating the probabilities of extreme meteorological events, the question arises of how long a historical record should be used. This issue is addressed from a decision-analytic viewpoint.

*

Szélsőséges meteorológiai események – statisztika és döntéshozatal. Áttekintjük a szélsőséges meteorológiai események kezelésére alkalmas statisztikai módszereket. Szembeállítjuk a szélsőértékeknek és a feljegyzéseknek, valamint a várható értékeknek a statisztikai elméletét. Annak illusztrálására, hogy az éghajlati hatáselemzésekben a szélsőséges eseményeket nem helyettesíthetjük egyszerűen az átlagokkal, példával mutatjuk be egy meghatározott szélsőséges meteorológiai állapot valószínűsége és e változó átlaga közötti nemlineáris kapcsolatot. Rámutatunk azoknak a standard statisztikai eljárásoknak az elégtelenségére, amelyekből következtetéseket szokás levonni a klíma változékonyságára, és helyettük alternatív megközelítéseket javasolunk. A szélsőséges meteorológiai események valószínűségeinek becslésénél felmerül a kérdés, hogy milyen hosszú legyen egy történelmi adatsor. Ezt a problémát döntésanalitikai szemszögből közelítjük meg.

Introduction

According to the dictionary, "extreme" weather conditions are defined as "exceeding the ordinary, usual, or expected." As is by now well recognized, extreme meteorological events play an important role in the manner in which climate affects society. Nevertheless, the ways in which climate (or changes in climate) is usually characterized rely on "expected" values (or averages). Further, most of the statistical methods that are employed either to estimate the likelihood of meteorological events or to make inferences about changes in climate are really designed for expected rather than extreme values.

* The National Center for Atmospheric Research is sponsored by the National Science Foundation.

In this paper, statistical methods appropriate for dealing with extreme meteorological events are reviewed. Specifically, the so-called statistical theory of extreme values and of records is discussed and contrasted with that for expected values. Problems that arise in attempting to apply this theory to meteorological data are examined. To demonstrate that means cannot simply be used as surrogates for extreme events in climate impact studies, an example is given of the nonlinear relationship between the likelihood of a particular extreme meteorological event and the mean for that variable. To draw any general conclusions about the probability of extreme events, information about the variability, not just the mean, of climate is necessary. The inadequacy of standard statistical techniques that are employed to make inferences about climate variability is outlined, and alternative approaches are suggested. Ultimately, information about climate is only of value insofar as it leads to a change in the actions taken by a decision maker. In estimating the probabilities of extreme meteorological events, the question arises of how long a historical record should be used. This issue is addressed from a decision-analytic viewpoint.

Extreme values and records

Theory of Extreme Values and Records. Besides their simplicity and convenience, there are some important theoretical reasons why averages play such a major role in applications of statistics. In particular, the Central Limit Theorem essentially states that for a wide range of possible shapes for the distribution of the individual observations, the distribution of their mean tends to the normal as the number of observations which are averaged increases. For instance, the distribution of daily precipitation amounts at a single site is known to be highly positively skewed. But as precipitation amounts are totaled over time and/or averaged over space, the distribution becomes less skewed and more nearly normal.

A parallel, if not completely analogous, theory exists for extreme values. Specifically, the distribution of the maximum (i. e., largest) value tends towards one of three possible distributions (termed Type I, Type II, and Type III extreme value distributions) as the number of observations increases. If the distribution of the individual observations has a relatively light right-hand tail (i. e., extremely large observations are sufficiently rare in occurrence), then the Type I extreme value distribution arises as the limiting distribution of the maximum. In fact, most of the distributions commonly fit to meteorological data do possess this property. *Figure 1* shows the probability density function for the Type I extreme value distribution. Note that this distribution has a substantial degree of positive skewness, quite unlike the normal distribution. The Type II extreme value distribution arises when the distribution of the individual observations has a relatively heavy right-hand tail, whereas the Type III extreme value distribution occurs when the individual observations have a distribution with a finite upper endpoint.

Just as the Central Limit Theorem can be employed to approximate the distribution of averages over large samples, extreme value theory can be applied to approximate the distribution of the maximum over large samples. However, the results concerning rate of convergence for extreme value theory are quite different in nature from those for the Central Limit Theorem. With averages, the normal approximation naturally is better if the distribution of the individual observations is close to normal and is worse if the distribution of the individual observations is far from normal (e. g., highly positively skewed). For example, since the distribution of daily mean temperature is nearly normal, the normal approximation is generally quite good for the distribution of monthly mean temperature. On the other hand, since the distribution of daily precipitation amounts is quite positively skewed, the distribution of monthly total precipitation is still somewhat positively skewed and the normal approximation is not very good.

Conversely, with the maximum, the most rapid rate of convergence to the Type I extreme value distribution occurs when the distribution of the individual

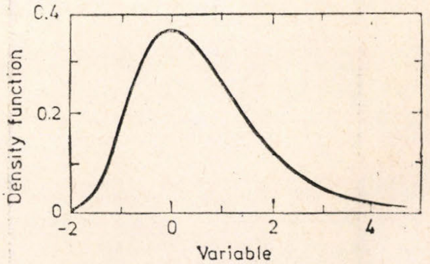


Fig. 1. Probability density function for Type I extreme value distribution.

observations is exponential shaped (in particular, positively skewed). When the distribution of the individual observations is normal or near normal, the rate of convergence of the distribution of the maximum to the Type I extreme value distribution is quite slow. Consequently, the maximum daily precipitation amount over a month might be well approximated by the Type I extreme value distribution, whereas the maximum daily mean temperature over a month would probably not be well approximated by this same distribution.

Besides the maximum, the theory of extreme values can be extended to the case of the minimum, the k^{th} largest (i. e., second largest, third largest, etc.) value, and the number of times a given threshold value is exceeded. Many meteorological time series possess a substantial degree of serial correlation. Nevertheless, extreme value theory still holds as long as the degree of dependence decreases at a fast enough rate (i. e., the correlation between observations taken at times that are relatively far apart must be sufficiently small). In fact, most stochastic processes employed to model the dependence of meteorological time series do satisfy this condition. Moreover, the extreme value theory approximations are the same as in the independent (uncorrelated) case, whereas the distribution of averages must be adjusted for the effects of dependence on the variability of time averages. See *Leadbetter et al.* (1983) or *Galambos* (1987) for a general review of the theory of extreme values.

Another way to consider extremes that is quite popular in meteorology is in terms of records. In other words, at what times in the previous history of observations were record-breaking maximums set (termed "record times") and what were the values of these record-breaking maximums (termed "record values"). For instance, it is interesting to speculate about whether the current frequency of occurrence of record-breaking weather is at a rate to be expected or is different enough from that expected to be indicative of a changing climate (in particular, perhaps a more variable climate).

Quite analogous to the theory of extreme values, there is a well-developed theory of records pioneered by *Rényi* (1962), among others. For example, there are results concerning the frequency of record breaking and concerning the distribution of the waiting times between consecutive records. In particular, the expected number of records set increases at a rate approximately proportional to the logarithm of the total number of observations. Moreover, although another record is always sure to eventually occur, the mean inter-record waiting time is infinite. See *Glick* (1978) for a review of the theory of records.

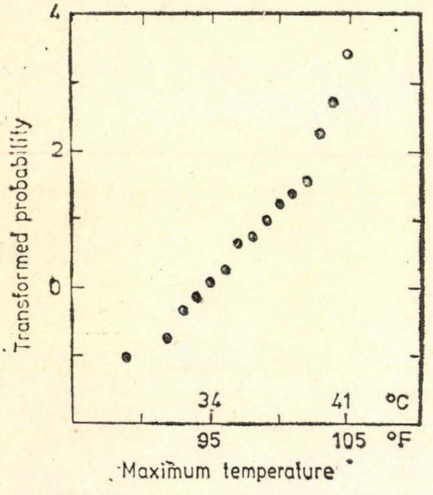


Fig. 2. Probability plot of Type I extreme value distribution for maximum monthly temperature at Des Moines, Iowa, 1948 – 1978. The degree to which the points fall along a straight line is indicative of how well the Type I extreme value distribution fits the data.

Applications to Meteorology. Much of the early development of extreme value theory was at least partially motivated by practical problems in the geophysical sciences [e. g., floods and related hydrological and meteorological processes (*Gumbel*, 1958)]. Consequently, numerous examples of applications to meteorology exist. Nearly all of the distributions fit to individual observations of meteorological data are in the "domain of attraction" of the Type I extreme value distribution (i. e., the limiting distribution of the maximum is the Type I extreme value). For instance, the normal distribution, commonly fit to temperature data (e. g., *Lehman*, 1984); the exponential, gamma, and lognormal distributions, commonly fit to precipitation data (*Todorovic* and *Woolhiser*, 1975; *Neyman* and *Scott*, 1967; and *Biondini*, 1976, respectively); and the Weibull distribution, commonly fit to wind speed data (e. g., *Conradsen et al.*, 1984), all are in the domain of attraction of the Type I extreme value distribution.

The extent to which the Type I extreme value distribution gives a satisfactory fit to the empirical (observed) distribution of the maximum value of meteorological data varies in practice. For instance, *Figure 2* provides an example of maximum monthly temperature in July at Des Moines, Iowa, for which the fit is not particularly good, especially in the right-hand tail fo the distribution. On the other hand, *Figure 3* shows the distribution of the monthly maximum of daily precipitation amounts at State College, Pennsylvania, an example for which the fit is relatively good.

The fact that many meteorological time series are autocorrelated does not necessarily invalidate the Type I extreme value distribution as an approximation for the maximum. For example, the type of stochastic processes usually employed to model the dependence of such variables as temperature (*Mearns et al.*, 1984) or wind speed (*Brown et al.*, 1984), known as autoregressive-moving average (ARMA) processes, still imply the Type I extreme value as the limiting distribution for the maximum. Moreover, a process chosen to model the dependence of daily precipitation amounts (called a "chain-dependent process") has also been shown to be in the domain of attraction of the Type I extreme value distribution (*Katz*, 1977a, b).

The effects of the annual cycle (i. e., non-identical distributions) on extreme value theory are much more complex than those of dependence. Some work has

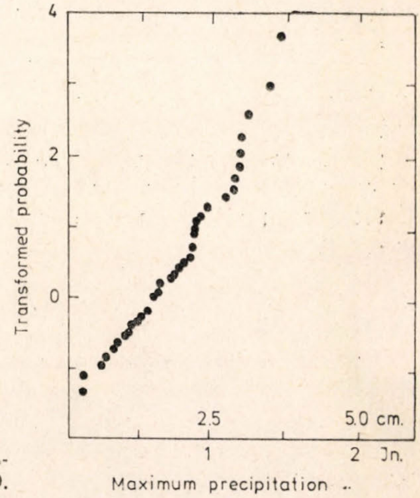


Fig. 3. Probability plot of Type I extreme value distribution for monthly maximum of daily precipitation amounts at State College, Pennsylvania, 1930 – 1969.

been done by *Horowitz* (1980) in the case of the maximum of hourly air pollution concentrations to take into account such nonstationarity. See *Tiago de Oliveria* (1986) and *Buishand* (1986) for reviews of extreme value theory that consider applications to meteorology.

In spite of the everyday citation of weather records, there has been surprisingly little application of the theory of records to meteorological problems. A few papers (*Hoyt*, 1981; *Reitan* and *Moran*, 1977) have dealt with statistical analysis of weather records, but little explicit use of the theory of records is made. Some obstacles to the successful application of this theory are present. For instance, some of the theoretical approximations are not particularly useful because of the slow rate of convergence. For example, the distribution of the number of records set is approximately normal, but this approximation is only relatively accurate for unrealistically large sample sizes. Moreover, some of the theoretical properties of records are dependent on the assumption of independent and identically distributed observations whereas, as mentioned earlier, meteorological time series typically possess autocorrelation and annual and diurnal cycles.

Glick (1978) does show that for both monthly total precipitation and monthly total hours of sunshine at Vancouver, British Columbia, the average number ob observed records is quite close to the theoretical expected number. As another example, consider the relatively long time series, 1820 – 1982, of annual mean temperature at Fort Snelling, Minnesota (*Baker et al.*, 1985, Table

II). Record maximums were set in the years 1820, 1821, 1822, 1825, 1830, 1833, 1846, and 1931, making a total of eight. This particular example illustrates how records are relatively easy to set near the beginning of a time series, but soon become quite difficult to break as the time series lengthens. An apparent dearth of records is evident over much of this time series (i. e., only one record set since 1846), at first glance perhaps suggesting a cooling trend or a decrease in variability. In fact, the total number of records set, eight, is actually greater than that expected (i. e., slightly less than six), under the assumption that annual mean temperatures are independent and identically distributed. For sake of comparison, the expected number of records set is about three for 10 observations, about five for 100 observations, and about 7 1/2 for 1,000 observations (*Glick*, 1978).

With regard to the issue of climate change, Glick observes that records are much more rare for weather data than for athletic performances (see also *Foster* and *Stuart*, 1954). In the case of athletics, it is clear that for various reasons (e. g., increased training) the probability distribution of performances is changing over time (*Ballerini* and *Resnick*, 1985; *Yang*, 1975). The evidence in favor of climate change is not nearly as strong, at least as seen in terms of its effects on records.

Means versus extremes

Most climate impact studies rely on changes in means of meteorological variables, such as temperature, to estimate potential climate impacts, including effects on agricultural production. However, extreme meteorological events, for example, a short period of abnormally high temperatures, can have a significant harmful effect on crop growth and final yield. Because the relationship between mean temperature and probabilities of extreme temperature events is inherently nonlinear, reliance on mean temperature changes essentially precludes any consideration of extreme temperature events when performing climate impact analysis. *Mearns et al.* (1984) illustrate, by concrete examples, the possibility that potential long-term changes in mean temperature may exert their principal impacts on the environment and society through changing probabilities of extreme events.

The extreme events that Mearns et al. choose to examine are geared toward agricultural concerns, particularly the effects of high temperatures on corn yields in the U. S. Corn Belt (midwestern U. S.). The results are discussed in terms of the probabilities of occurrence of these events, so as to reflect changing degrees of risk of crop damage associated with changes in mean temperature. Extreme temperature events for the month of July are selected, since it is the month when tasseling, a particularly temperature-sensitive phenological stage, most often occurs in the central U. S. Corn Belt. The threshold of 95°F (35 °C) is selected, because it represents the approximate midpoint of the range of high temperatures whose exceedance is commonly reported to be harmful to the corn crop during such a sensitive phenological stage.

Mearns et al. consider the following extreme temperature events:

(1) *Day event:* Maximum temperature on a given day in July equaling or exceeding 95 °F (35 °C).

(2) *Run event:* At least one run in the month consisting of at least five consecutive days equaling or exceeding 95 °F (35 °C).

(3) *Total event:* At least five days in the month (not necessarily consecutive) equaling or exceeding 95 °F (35 °C).

The run event is particularly important, because it is often argued that a run of hot days would be more harmful to a crop than several hot days interspersed with days that have somewhat lower maximum temperatures. A significant change in the probability of such runs could have a marked influence on the productivity and economics of the U. S. Corn Belt.

Mearns et al. consider a *base case* in which the mean maximum temperature changes, while holding the variance constant; a *negative variance feedback case* in which the variance decreases as the mean increases; and a *positive variance feedback case* in which the variance increases as the mean increases. *Figure 4*

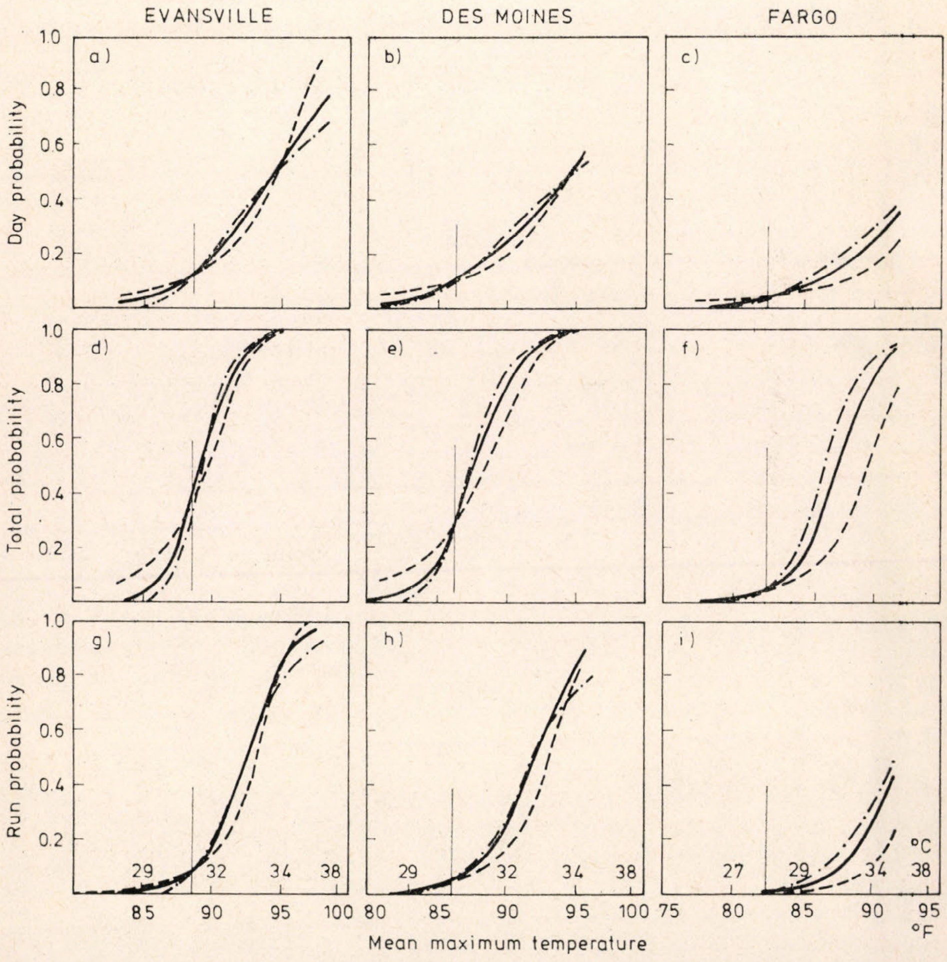


Fig. 4. Probability of day event, total event, and run event as a function of mean maximum temperature at Evansville, Des Moines, and Fargo for base case (solid line), negative variance feedback case (dashed line), and positive variance feedback case (dot-dashed line). Vertical lines indicate actual July mean maximum temperature for each station (Source: *Mearns et al.*, 1984, p. 1609).

shows the event probability curves as a function of the mean for these three locations; Evansville, Indiana, Des Moines, Iowa, and Fargo, North Dakota. As the mean increases, all the curves necessarily increase nonlinearly from an asymptotic lower limit of zero to an asymptotic upper limit of one.

These examples show that there can be practically significant shifts in the probability of extreme high-temperature events with seemingly little change in mean temperature. For instance, the likelihood of occurrence of the run event under a 3 °F (1.7 °C) increase in the mean, holding the variance constant, is about three times greater than under the current climate at Des Moines (a probability of 0.062 under current climate versus 0.206 in base case). Moreover, this probability changes even more if the variance is allowed to change simultaneously with the mean (a probability of 0.118 in negative variance feedback case and 0.232 in positive variance feedback case). It should be noted that Mearns et al. also consider the effects of changes in autocorrelation of the time series of daily maximum temperatures on the probabilities of extreme temperature events.

These changes in the probabilities of extreme high-temperature events could have important implications for crop yields, energy demand, and animal or human morbidity and mortality. Hence, such probability changes need to be taken into consideration in order to obtain realistic estimates of the impact of a climate change. These results have direct implications for climate modelers since they demonstrate the need to establish, not only what changes in mean temperatures are expected, but also what will happen to the variance.

Inferences about variability

Statistical analysis of climate data or of the output of climate experiments using general circulation models (GCMs) commonly has been concerned with the problem of estimating differences between location parameters (e. g., means or medians). To take into account the manner in which an atmospheric variable is distributed about a location parameter, differences between scale parameters (e. g., variances or interquartile ranges) also need to be estimated. In many applications, the potential impacts of changes in climate variability may be as great or greater than the impacts of any changes in climate means. Further, decisions concerning what strategy to take under a change in a climate mean cannot be made without an assumption about how climate variability would change. It is ordinarily assumed, by default, that the level of climate variability would remain the same. *Katz* (1988) considers in detail this question of how to make inferences about climate variability.

The problem of estimating changes in scale is more difficult than that of estimating changes in location, especially when working with real or simulated atmospheric time series. Because such time series are autocorrelated, the conventional definition of scale as simply the variance of a random variable has some drawbacks. In attempting to devise a meaningful definition of climate variability, several questions arise. Viewing a real or simulated time series for an atmospheric variable as a realization of a stochastic process, variability could refer to the variance of the process or to the variance of a time average of the process. If the data were generated by an independent process, then the time average variance would be directly proportional to the process variance. Because real or simulated atmospheric time series are autocorrelated, there is no simple relationship between the time average vairance and the process variance. Instead, the time average variance depends on the extent of the autocorrelation as well as on the process variance (e. g., *Jones*, 1975).

The concept of an underlying uncorrelated process is relied on in modeling the dependence over time of an atmospheric variable. Thus, it is natural to consider the variance of this underlying process, called the "innovation variance", as one alternative to the variance of the original process for representing climate variability. Roughly speaking, the innovation variance can be thought of as the variation of the process that still remains after variation attributed to past values of the process is removed. A definition of intrinsic variability based on "prewhitening" the data is advocated by *Katz* (1988). This approach requires fitting a parametric time series model, say a p^{th}-order autoregressive process (see *Katz* and *Skaggs*, 1981), to the data. Then the fitted model is used to obtain residuals that are approximately uncorrelated. The definition of climate variability refers to the variance of the corresponding theoretical errors (or innovations), for which the residuals are estimates.

A second problem arises because atmospheric variables, at best, have distributions that are only approximately normal in shape. Although tests for changes in means are not particularly dependent on the normality assumption, standard tests for changes in variance are extremely sensitive to departures from normality. In fact, *Box* (1953) has suggested that one particular test for equality of variances could be better used as a test for normal distributions. In another context, he has commented that making the standard test for equality of variances is "like putting to sea in a rowing boat to find out whether conditions are sufficiently calm for an ocean liner to leave port!" (*Box*, 1953, p. 333). Nevertheless, tests for changes in climate variability have relied on such procedures; for example, *Chervin* (1980) and *Hayashy* (1982) have applied the F-test for the equality of two variances to GCM simulated data.

In the case of an independent sample, several techniques have been proposed to correct for departures from the assumption of a normal distribution when making statistical inferences about variances. *Davis* (1977, 1979) has shown that some of these robust procedures for making inferences about variances still have the same asymptotic when applied to prewhitened data. With this theoretical justification, *Katz* (1988) applies one of the simplest of these so-called "robust" procedures to prewhitened simulated atmospheric data. This "standard error" technique involves an adjustment taking into account how the observed kurtosis ("peakedness" or "flatness") differs from that for the normal distribution. To demonstrate the application of this procedure, *Katz* (1988) uses daily mean temperature time series from GCM control runs, testing whether summer temperature variability differs from winter temperature variability. *Wilson* and *Mitchell* (1987) have also applied the same procedure to compare climate variability simulated by a GCM with observed climate variability.

Other more complex procedures, such as the so-called "jackknife" (*Miller*, 1968) or the "bootstrap" (*Efron*, 1982) could be used instead of the simple standard error technique. The jackknife involves systematically deleting data from the sample, say one value at a time, computing the statistic (e. g., the logarithm of the sample variance) for each subsample, and then combining the subsample statistics into one overall estimate. The bootstrap is based on a resampling scheme that differs slightly from that for the jackknife. Such procedures would be potentially more powerful in detecting changes in variability, but would require additional effort to implement.

Decision making

It is common practice to design for extreme geophysical phenomena by defining an event in terms of a threshold which is exceeded with a fixed small probability (e. g., 1% chance). For instance, flood plain regulations are often based on the socalled 100-year flood. But what is the rationale for such a procedure? The question of how rare event to design for is essentially a problem, in economics and falls within the realm of the field or decision theory. Moreover, there is the related issue of how best to estimate the probability of an extreme meteorological event (or equivalently, the extreme threshold corresponding to a fixed probability) from the available historical climate data base. Should a record that is as long as possible be relied on or should the relatively recent record be used? The first option would clearly produce the most precise probability estimates if the climate were not changing, whereas the second option would have the advantage of adjusting more rapidly to a possible climate change. The resolution of such an issue can again be based on a decision-analytic approach.

Decision analysis is concerned with the problem of how best to make decisions given the information available (generally imperfect) about events of interest. Formally, a decision maker (e. g., a farmer) is faced with the task of selecting an action to be taken from a set of possible actions (e. g., plant one type of crop or plant another type of crop). The economic consequences of these actions are dependent on events (e. g., drought or no drought) about which the decision maker has available some sort or information specifying their likelihood of occurrence. The decision maker needs a criterion for selecting the action to be taken. One such criterion is to choose the action having the greatest expected economic return (or more generally, maximum expected utility). Such expected returns are determined by weighting the possible consequences by the probabilities of occurrence of the corresponding events.

A review of decision analysis in the context of information about weather and climate is given by *Winkler* and *Murphy* (1985). This decision-analytic approach has been employed to determine the optimal actions to be prescribed for decision makers who have imperfect weather or climate forecasts available. For example, *Katz et al.* (1982) have studied the problem of an orchardist's decision concerning whether to protect fruit trees against possible damage due to extreme low temperatures given a forecast of the nightly minimum temperature. Further, *Brown et al.* (1986) have studied the problem of a farmer's decision concerning whether to plant spring wheat or to let the land lie fallow given a forecast of growing season precipitation.

The same type of methodological approach could be applied to the issue of how best to estimate the likelihood of extreme meteorological events. In theory, a decision maker could choose among different estimates of the probability of an extreme meteorological event on the basis of which estimation procedure leads to maximizing expected return. Although there have been calls for revising climate normals and other statistics to reflect the shorter, most recent time period in the light of possible climate change (*Todorov*, 1985), several examples suggest that this approach is not necessarily the best.

The West African Sahel has experienced a long run of dry years starting about 1970 (*Lamb*, 1982), whereas rainfall was abnormally high during the immediately preceding time period of the 1950s and 1960s *(Figure 5)*. Consequently, if in 1970 the rainfall normals had been based on a short time period (say, 1950 – 1970) rather than the entire record, these normals would have differed to an even greater extent from the rainfall actually observed during the 1970s and 1980s. Another example is the allocation of water in the Colorado River Basin in the United States. On the basis of a relatively short period of streamflow records, water rights were allocated between the upper and lower basins in 1922. A subsequent study (*Stockton* and *Jacoby*, 1976) reconstructed a longer historical record of streamflow using tree rings. This study established that the streamflow data on which the water compact is based constitutes a period of unusually high flow.

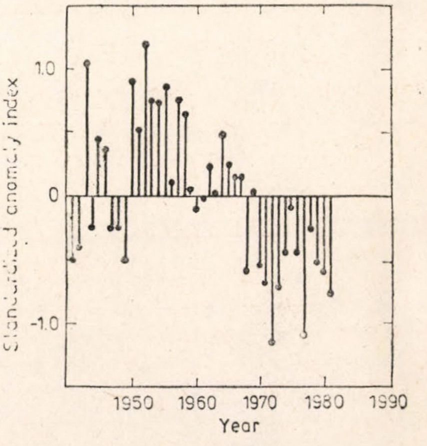


Fig. 5. Time series of Standardized Anomaly Index for West African Sahel based on April – October rainfall during 1941 – 1981 (Source: *Katz* and *Glantz*, 1986, p. 768).

Both of these examples suggest a fundamental quandary concerning the best way to estimate the likelihood of extreme meteorological events. On the one hand, if the climate is indeed changing, using a long prior record to estimate these probabilities would provide precise, but misleading, statistics. On the other hand, using a relatively short prior record would likely miss some of the natural climate variability and provide at best an imprecise estimate.

Concluding remarks

Difficulties in applying the theory of extreme values and of records to meteorological events have been reviewed. In particular, reasons have been given for the relative lack of attention devoted to certain aspects of this theory by meteorologists. The need to consider possible changes in the variability of climate, as well as changes in means, has been demonstrated by recourse to an example that deals with the likelihood of extreme high temperature events. Why it is inherently more difficult to draw statistical inferences about variances, than about means, is explained. It is suggested that a fundamental quandary concerning the best way to estimate the likelihood of extreme meteorological events can be resolved by relying on the theory of decision making.

Although the theory of extreme values is relatively well developed, it remains successfully integrate this theory with a realistic treatment of meteorological applications. Such an integration would be required in order to provide the most reliable, as possible, estimates of the likelihood of extreme meteorological events. It would also be helpful in attempts to detect changes in climate, as reflected by extremes.

Acknowledgments. I thank Barbara Brown, Kevin Keen, and Maria Krenz for their comments on a draft version of this manuscript.

REFERENCES

Baker, D. G., Watson, B. F. and *Skaggs, R. H.*, 1985: The Minnesota long-term temperature record. *Clim. Change. 7,* 225 – 236.

Ballerini, R. and *Resnick, S.*, 1985: Records from improving populations. *J. Appl. Probab. 22,* 487 – 502.

Biondini, R., 1976: Cloud motion and rainfall statistics. *J. Appl. Meteor. 15,* 205 – 224.

Box, G. E. P., 1953: Non-normality and tests on variances. *Biometrika 40,* 318 – 335.

Brown, B. G., Katz, R. W. and *Murphy A. H.* 1984: Time series models to simulate and forecast wind speed and wind power. *J. Clim. Appl. Meteor. 23,* 1184 – 1195.

Brown, B. G., Katz, R. W. and *Murphy A. H.* 1986: On the economic value of seasonal precipitation forecasts: The fallowing/planting problem. *Bull. Amer. Meteor. Soc. 67,* 833 – 841.

Buishand, T. A., 1986: Extreme value analysis of climatological data. *Third Int. Conf. Stat. Clim.* Austrian Society of Meteorology, Vienna, Austria, 145 – 158.

Chervin, R. M., 1980: On the simulation of climate and climate change with general circulation models. *J. Atmos. Sci. 37,* 1903 – 1913.

Conradsen, K., Nielsen, L. B. and *Prahm L. P.*, 1984: Review of Weibull statistics for estimation of wind speed distributions. *J. Clim. Appl. Meteor. 23,* 1173 – 1183.

Davis, W. W., 1977: Robust interval estimation of the innovation variance of an ARMA model. *Ann. Stat. 5,* 700 – 718.

Davis, W. W., 1979: Robust methods for detection of shifts of the innovation variance of a time series. *Technometrics. 21,* 313 – 320.

Efron, B., 1982: *The Jackknife, the Bootstrap and Other Resampling Plans.* Society for Industrial and Applied Mathematics, Philadelphia.

Foster, F. G. and *Stuart, A.* 1954: Distribution-free tests in time-series based on the breaking of records (with discussion). *J. Roy. Stat. Soc. Series B, 16,* 1 – 22.

Galambos, J., 1987: *The Asymptotic Theory of Extreme Order Statistics* (Second Edition). Krieger, Melbourne, Florida.

Glick, N., 1978: Breaking records and breaking boards. *Amer. Math. Mon. 85,* 2 – 26.

Gumbel, E. J., 1958: *Statistics of Extremes,* Columbia University Press, New York.

Hayashi, Y., 1982: Confidence intervals of a climatic signal. *J. Atmos. Sci. 39,* 1895 – 1905.

Horowitz, J., 1980: Extreme values from a nonstationary stochastic process: An application to air quality analysis. *Technometrics 22,* 469 – 478.

Hoyt, D. V., 1981: Weather "records" and climatic change. *Clim. Change. 3,* 243 – 249.

Jones, R. H., 1975: Estimating the variance of time averages. *J. Appl. Meteor. 14,* 159 – 163.

Katz, R. W., 1977a: Precipitation as a chain-dependent process. *J. Appl. Meteor. 16,* 671 – 676.

Katz, R. W., 1977b: An application of chain-dependent processes to meteorology. *J. Appl. Probab. 14,* 598 – 603.

Katz, R. W., 1988: Statistical procedures for making inferences about climate variability. *J. Clim.* (in press).

Katz, R. W. and *Glantz, M. H.*, 1986: Anatomy of a rainfall index. *Mon. Wea. Rev. 114,* 764 – 771.

Katz, R. W., Murphy, A. H. and *Winkler, R. L.*, 1982: Assessing the value of frost forecasts to orchardists: a dynamic decision-making approach. *J. Appl. Meteor. 21,* 518 – 531.

Katz, R. W. and *Skaggs, R. H.*, 1981: Ot the use of autoregressive-moving average processes to model meteorological time series. *Mon. Wea. Rev. 109,* 479 – 484.

Lamb, P. J., 1982: Persistence of Subsaharan drought. *Nature, 299,* 46 – 48.

Leadbetter, M. R., Lindgren, G. and *Rootzen, H.*, 1983: *Extremes and Related Properties of Random Sequences and Processes.* Springer-Verlag, New York.

Lehman, R. L., 1984: Errors in estimating monthly degree day normals by the fast method. *Bull. Amer. Meteor. Soc. 65,* 20 – 23.

Mearns, L. O., Katz, R. W. and *Schneider S. H.*, 1984: Extreme high-temperature events: Changes in their probabilities with changes in mean temperature. *J. Clim. Appl. Meteor. 23,* 1601 – 1613.
Miller, R. G., 1968: Jackknifing variances. *Ann. Math. Stat. 39*, 568 – 582.
Neyman, J., and *Scott, E. L.*, 1967: Some outstanding problems realiting to rain modification. *Proceeding Fifth Berkeley Symposium on Mathematical Statistics and Probability*, Vol. 5, University of California Press, 293 – 326.
Reitan, C. H., and *Moran, J. M.*, 1977: The probability of record daily low temperatures in winter. *Mon. Wea. Rev. 105,* 1442 – 1446.
Rényi, A., 1962: Theorie des elements saillants d'une suite d'observations. *Colloquium on Combinatorial Methods in Probability Theory.* Mathematics Institute, Aarhus University, Denmark, pp. 104 – 117.
Stockton, C. W., and *Jacoby, Jr., G. C.*, 1976: Long-term surface-water supply and streamflow trends in the upper Colorado River Basin. *Lake Powell Res. Proj. Bull. 18.* Research Applied to National Needs, National Science Foundation, Washington, D. C.
Tiago de Oliveira, J., 1986: Extreme values and meteorology. *Theoret. Appl. Clim. 37*, 184 – 193.
Todorov, A. V., 1985: Sahel: The changing rainfall regime and the "normals" used for its assessment *J. Clim. Appl. Meteor 24,* 97 – 107.
Todorović, P. and *Woolhiser, D. A.*, 1975: A stochastic model of n-day precipitation. *J. Appl. Meteor. 14,* 17 – 24.
Wilson, C. A. and *Mitchell, J. F. B.*, 1987: Simulated climate and CO_2-induced climate change over Western Europe. *Clim. Change 10,* 11 – 42.
Winkler, R. L. and *Murphy, A. H.*, 1985: Decision analysis. In *Probability, Statistics, and Decision Making in the Atmospheric Sciences* eds.: *Murphy, A. H.* and *Katz, R. W.*, Westview Press, Boulder, Colorado, 493 – 524.
Yang, M. C. K., 1975: On the distribution of the inter-record times in an increasing population. *J. Appl. Probab 12,* 148 – 154.

IDŐJÁRÁS

Az Országos Meteorológiai Szolgálat folyóirata, 93. évf. 1. szám. 1989. január – február
Journal of the Hungarian Meteorological Service, Vol. 93. No. 1. Jan – Feb 1989. Budapest

Elemental ratios related to selenium and vanadium as regional characteristics in atmospheric aerosols over Hungary

I. BORBÉLY-KISS, E. KOLTAY, and GY. SZABÓ
Institute of Nuclear Research, Hungarian Academy of Sciences, P.O. Box 51, H—4001 Debrecen, Hungary,

E. MÉSZÁROS
Institute for Atmospheric Physics, H—1675 Budapest, P. O. Bpx 39, Hungary

Samples of atmospheric aerosol particles collected at rural sites of Hungary were analyzed for 20 elements by proton-induced X-ray emission (PIXE) method. Selenium and vanadium related concentration data for selected trace elements sometimes used as elemental tracers in characterizing regional aerosols were deduced and compared with data from *Rahn* (1981, 1984) and *Dutkiewicz* (1987). Consclusions were drawn from these elemental ratios on the character and effect of regional aerosols.

*

Szelénre és vanadiumra vonatkoztatott elemarányok, mint a légköri aeroszolok regionális jellemzői Magyarország fölött. Magyarországi háttérterületeken gyűjtött légköri aeroszol részecske mintákat 20 elemre kiterjedő analízisnek vetettük alá, protongerjesztéses röntgenemisszió (PIXE) módszerrel. Meghatároztuk néhány nyomelem szelénre és vanádiumra vonatkoztatott koncentrációját, amelyeket gyakran alkalmaznak elemi nyomjelzőként a regionális aeroszolok vizsgálatában. Adatainkat összevetettük *Rahn* (1981, 1984) és *Dutkievwicz* (1987) hasonló adataival. Az elemi arányokból következtetéseket vontunk le a regionális aeroszol jellegére és hatására.

1. Introduction

The question of existence and tracer power of regional elemental characteristics in atmospheric aerosols has received increasing interest recently. A place--to-place variation of elemental ratios may be caused by the variation in characteristics of local industrial activity, transportation and structure of energy sources. The usefulness of elemental ratios in tracing long range transport of air masses is strongly influenced by the level of their stability against aging during transportation.

The investigation in this field is mainly done through systematic evaluation of data for trace element concentrations taken by different groups all over the world.

Pioneering work in finding reliable elemental signatures was made by groups in the United States. Thus, it was found by *Rahn* (1981) that elemental ratio of non crustal components Mn^* and V^* represents a regional fingerprints well applicable in searching for the possible sources of pollutant aerosols in the artic air. As deduced from existing elemental concentration data, different areas of the Northern Hemisphere are characterized by Mn^*/V^* ratios concentrated in the $Mn^* - V^*$ plane according to their geographic locations. In his work Rahn stressed that no data were found for his compilation from Middle and Eastern Europe. Some selenium related concentration ratios were checked by *Rahn* and *Lowenthal* (1984) as possible regional fingerprints. Frequency distribution curves taken at different sites were treated as possible tools for characterizing aerosols from different regions. The background station of the Hungarian Meteorological Service at K-Puszta was used as one of their sampling sites.

In a paper of *Dutkiewicz et al.* (1987) vanadium related concentration ratios were successfully used for characterizing aerosols from selected regions of USA with different structure of energy sources. As clearly indicated by their data vanadium and selenium related elemental ratios for some elements show order of magnitude differences between coal and oil combustion areas like Ohio River Valley and West Haverstraw, respectively.

In the above investigations concentration data have been obtained by using atomic absorption spectroscopy (AAS) and instrumental neutron activation analysis (INAA). Both methods provide excellent detection limits from 30 to 0.005 ng/m³ for a number of trace elements. However, special sample preparation needed for each element in the former case and the need of repeated measurements of delayed gamma-radiation within a period of a few months in the latter one makes the analytical procedure quite time consuming.

The aim of the present investigations was to contribute with local data to answering the question to what extent concentration ratios of selected pairs of trace elements are characteristic to aerosols originating from a specific geographic site.

2. Methodology

In the present work atmospheric aerosol samples were collected at rural sites of Hungary like K-Puszta and Farkasfa during a whole year in 1981/82. The samples were subjected to PIXE analysis. In a recent series started in autumn 1987 similar samples are being collected at K-Puszta aiming at a more complete investigation. The majority of the samples were taken at K-Puszta, which is located nearly at the center of Hungary between the rivers

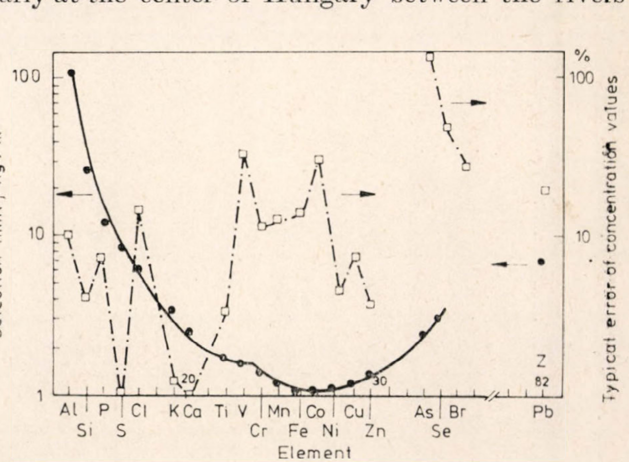


Fig. 1. Mimimum detection limits (solid line, left ordinate) and typical error (darhed line, right ordinate) of concentration data as the function of atomic numbers, as given by the computer evaluation of PIXE spectra, taken on aerosol samples.

Danube and Tisza, about 70 km SE of Budapest. The closest town of 100 000 inhabitants is about 10 km SE, and an steelmill is 50 km west of the station. The closest paved road with very low traffic density and the 5-E motorway are 3 and 5 km in NE, respectively. The whole area is slightly populated with small villages and farms. In order to average out possible effects from the immediate neighbourhood of the sampling site, use was made of samples taken at Farkasfa, which site is located at the western part of Hungary in the Őrség National Park, about 7 and 4.5 km from the Austrian and Yugoslavian borders, respectively. The closest towns with 50 000 and 250 000 inhabitants are in the distances 40 km E and 70 km W in Hungarian and Austrian territories, respectively. The closest road with moderate traffic density is 9 km in northern direction. Vienna and Budapest are 180 km NW and 250 km NE, respectively. The area is populated with small villages separated with hills and forests.

Integral sampling was performed using Nuclepore filters of 0.4 μm pore size, with 1.5 cm^2 exposed area. The sampling time was typically 24 hours with sampled air volume varying between 2 and 8 m^3.

The samples were subjected to PIXE analysis for obtaining elemental concentrations of the constituents of the samples.

Proton induced X-ray emission process reviewed in a recent paper of *Koltay* (1988) offers a fast, non-destructive and reliable multielemental microanalytical method. As shown in *Fig. 1* it gives detections limits between 100 to 1 ng/m^3 smoothly varying for elements between aluminium and lead. The limitation set by detection limits higher than those in AAS and INAA methods is much compensated by the speed of deducing a consistent set of absolute concen-

TABLE 1.

Results of PIXE analysis on 1981/82 aerosol samples. $\langle C\rangle$ = average concentrations (ng/m^3), σ = geometric standard deviations, E_f = enrichment factors related to titanium

Element	Year			Winter			Summer		
	$\langle C\rangle_y$	σ	E_f	$\langle C\rangle_w$	σ	E_f^w	$\langle C\rangle_s$	σ	E_f^s
Al	291	(2.3)	0.60	232	(2.0)	0.61	317	(2.4)	0.56
Si	703	(2.3)	0.38	491	(2.1)	0.35	838	(2.3)	0.40
P	169	(1.9)	40.2	144	(1.9)	44.5	183	(1.9)	37.8
S	1940	(1.8)	1940	1682	(1.9)	2184	1970	(2.3)	1712
Cl	16.8	(2.4)	28	16.5	(2.4)	35.7	17.1	(2.3)	24.7
K	230	(1.8)	2.15	214	(1.7)	2.6	240	(1.9)	1.9
Ca	368	(2.3)	2.3	246	(2.2)	2.0	458	(2.2)	2.5
Ti	20	(2.3)	≡1	15.4	(2.3)	≡1	23	(2.2)	≡1
V	3.85	(1.7)	8.9	4.4	(1.7)	14.7	3.0	(1.8)	6.8
Cr	11.6	(1.6)	38.7	10.8	(1.4)	46.7	12.2	(1.7)	35.3
Mn	11.4	(1.9)	2.85	10.57	(1.9)	3.45	12	(1.8)	2.6
Fe	267	(2)	1.1	228	(1.9)	1.2	291	(2)	1.0
Co	1.45	(1.8)	9.35	1.03	(1.5)	8.7	1.6	(1.9)	9.1
Ni	1.42	(1.8)	5.55	1.79	(1.7)	9.1	1.2	(1.8)	4.2
Cu	7.50	(1.9)	34.5	7.63	(2.0)	45	7.5	(1.8)	29.5
Zn	36.4	(2.1)	151.7	42.8	(1.8)	232	34	(2.2)	123
As	4.0	(2.1)	645	5.4	(2.1)	1129	2.8	(1.8)	387
Se	1.35	(2.1)	4218	1.0	(1.9)	4062	1.5	(2.1)	4000
Br	–	–	–	–	–	–	4.2	(1.9)	379
Pb	34.8	(1.9)	756	36.4	(1.7)	1016	33.7	(2.0)	634

tration data for all the constituents of the sample above $Z \approx 12$ from a single X-ray spectrum emitted under proton bombardment. The concentrations of elemental constituents Al, Si, P, S, Cl, K, Ca, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Se, Br and Pb were deduced from the computer evaluation of the spectra. The results of the earlier set of measurements were treated in detail in the paper of *Borbély – Kiss et at* (1988). As an illustration the geometric year by, winter and summer concentration average data for the observed elements are gathered in *Table 1* together with the respective geometric standard deviations and titanium related enrichment factors. In the series of present measurements similar data are being collected with the same technique. At present, the data from 1987/88 include contribution only from the summer half – year. Both data sets were recently subjected to a re-evaluation in terms of regional signatures aiming at a direct comparison with the results obtained by the groups of *Rahn* (1981, 1984) and *Dutkiewicz* (1987).

3. *Results and conclusions*

The results obtained from the evaluation of both sets of experimental results can be presented as follows.

- The few ng/m^3 detection limits of PIXE compared to the low concentration level of selenium in aerosols results in a high error in absolute selenium concentration. However, the reliability of selenium related signature values is enhanced by the fact, that they are deduced from a consistent set of elemental concentrations obtained from a single irradiation of the sample. Better accuracy is achieved for vanadium related signature values. This means, that PIXE turned out to be an effective tool for the investigation of regional signatures in aerosol samples.
- Our measured values contribute to information from Eastern Europe and consequently to the worldwide material published in this field; such data were not available earlier.
- The compilation of widespread Mn^*/V^* data mentioned above and their comparison with those obtained in the Artic led *Rahn* (1981) to the conclusion, that artic air has been influenced by a previously unrecognized

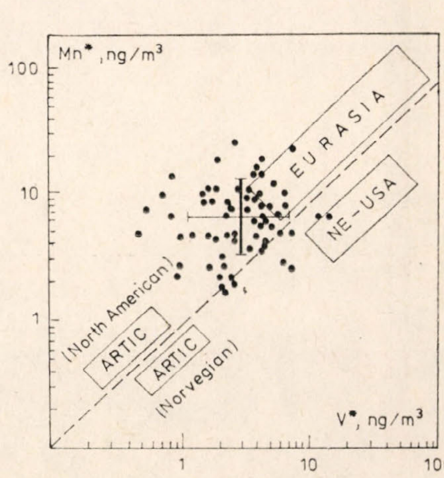


Fig. 2. Mn* – V* scatter diagram taken from the paper of *Rahn* (1981) completed with the 1981/82 data obtained in this work

precursor with a very high Mn^*/V^* ratio – probably higher than all Eurasian data published earlier – transported from an eastern European region. In this respect, the presentation of Hungarian data seems to be very important. In *Fig. 2* the Mn^*/V^* scatter diagram taken from *Rahn*'s paper (1981) is completed with measured points from our 1981/82 data set. The scatter of experimental data covers a broad interval of Mn^*/V^* ratio, the centroid representing the geometric means of Mn^* and V^* concentrations is close to the signature value 2.0 ± 0.5 found as western European average. These data together with our frequency distribution histograms for elemental ratios were treated in the paper *Borbély-Kiss et al.* (1988) as an argument against a strong regional contribution to the artic pollution aerosols.

– Three sets of frequency distribution histograms for selenium related regional signatures measured on samples from Hungarian sampling sites are compared in *Fig. 3*. The first curves were measured by *Rahn et al.* (1984) with INAA method on samples collected during fall and winter 1981/82, second and third curves were measured by us with PIXE method, during a whole year in 1981/82 and during summer half of the years 1987/88. Differences

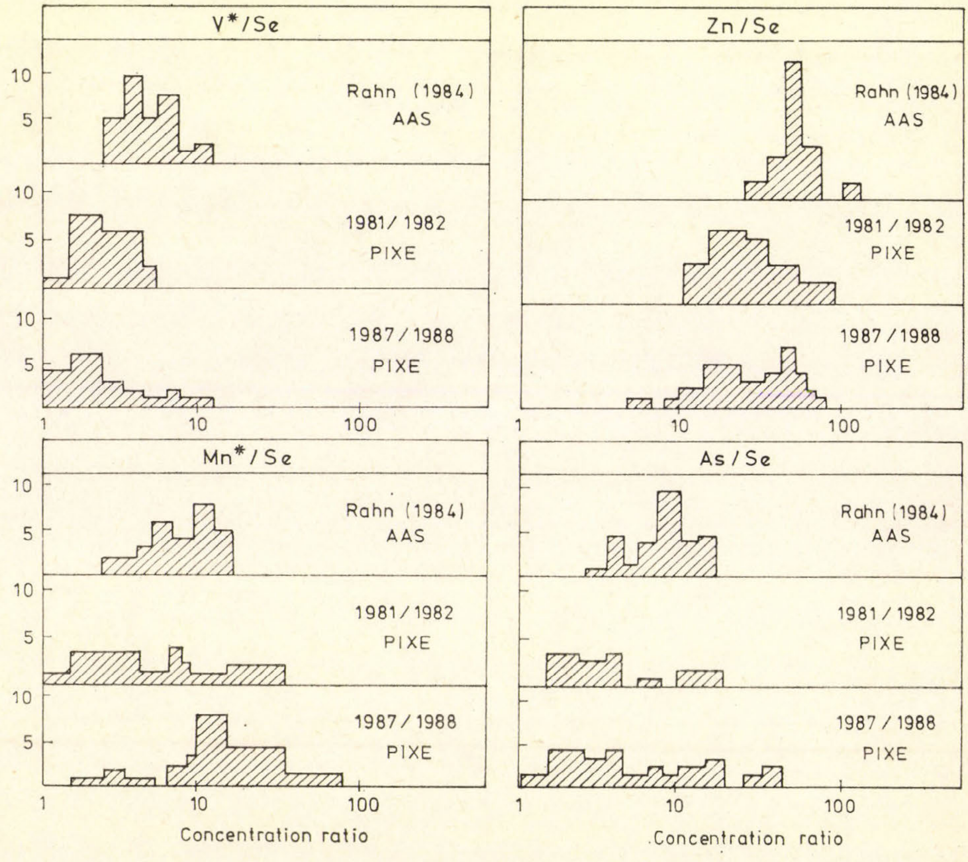


Fig. 3. Frequency distribution histograms for selenium related elemental signatures in samples collected at Hungarian remote sites (the ordinate gives the number of cases).

TABLE 2

Selenium related geometric mean elemental signatures and geometric standard deviations in aerosol samples from Hungarian sampling sites

Tracer	Present work		Rahn, 1984
	1981/82 year	1987/88 summer	1982 winter data
	average		
V*/Se	2.29(1.7)	2.62(3.3)	5.20(1.3)
Mn*/Se	4.90(2.4)	8.70(2.5)	8.90(1.8)
Zn/Se	30.0 (1.7)	30.15(2.1)	48.0 (1.1)
As/Se	4.60(2.1)	5.58(2.8)	8.90(1.4)

in the shapes may be caused by three reasons, namely by systematic errors in the used analytical methods, by seasonal effects and long-term variation of regional elemental ratios. The similarity in curve shapes is still convinc-

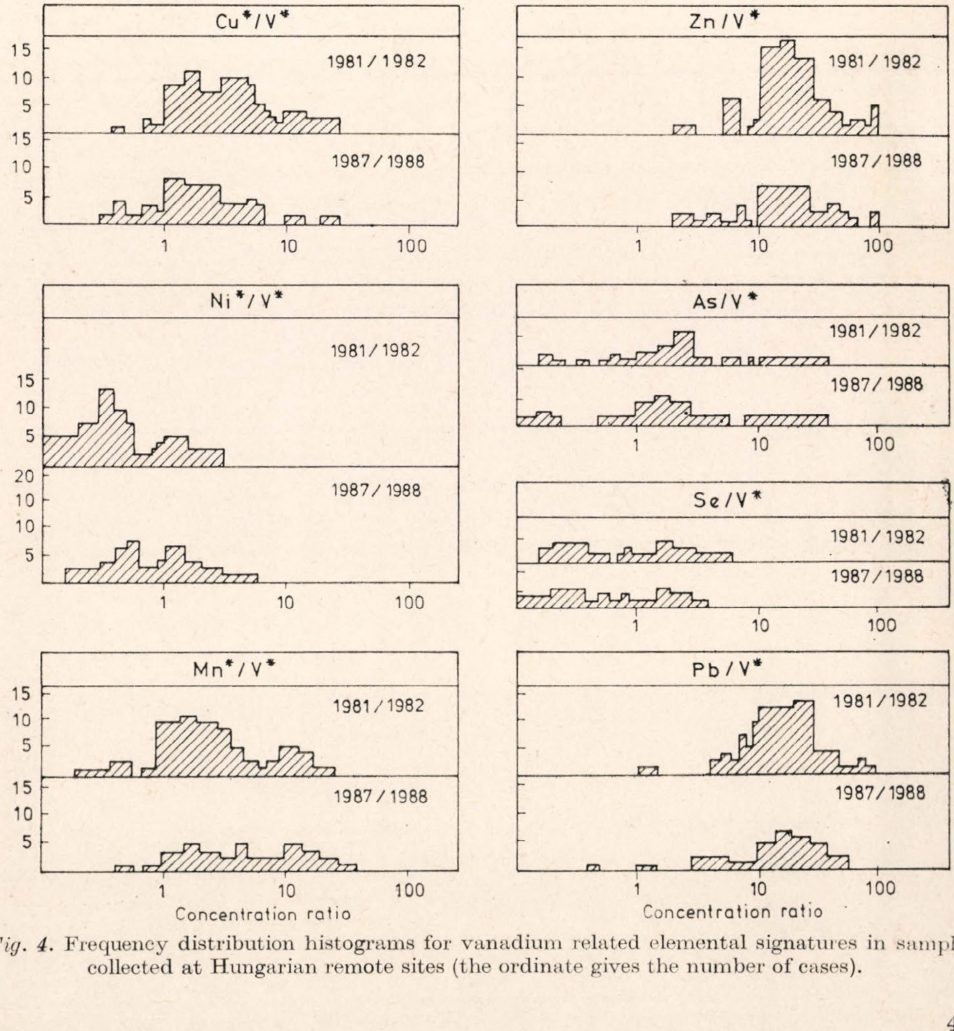


Fig. 4. Frequency distribution histograms for vanadium related elemental signatures in sample collected at Hungarian remote sites (the ordinate gives the number of cases).

ing. Geometric mean values and mean geometric standard deviations are compared in *Table 2*. While there appears a systematic difference between PIXE and AAS data, the combined methodical, seasonal and long term variation effects are within geometrical standard deviation.

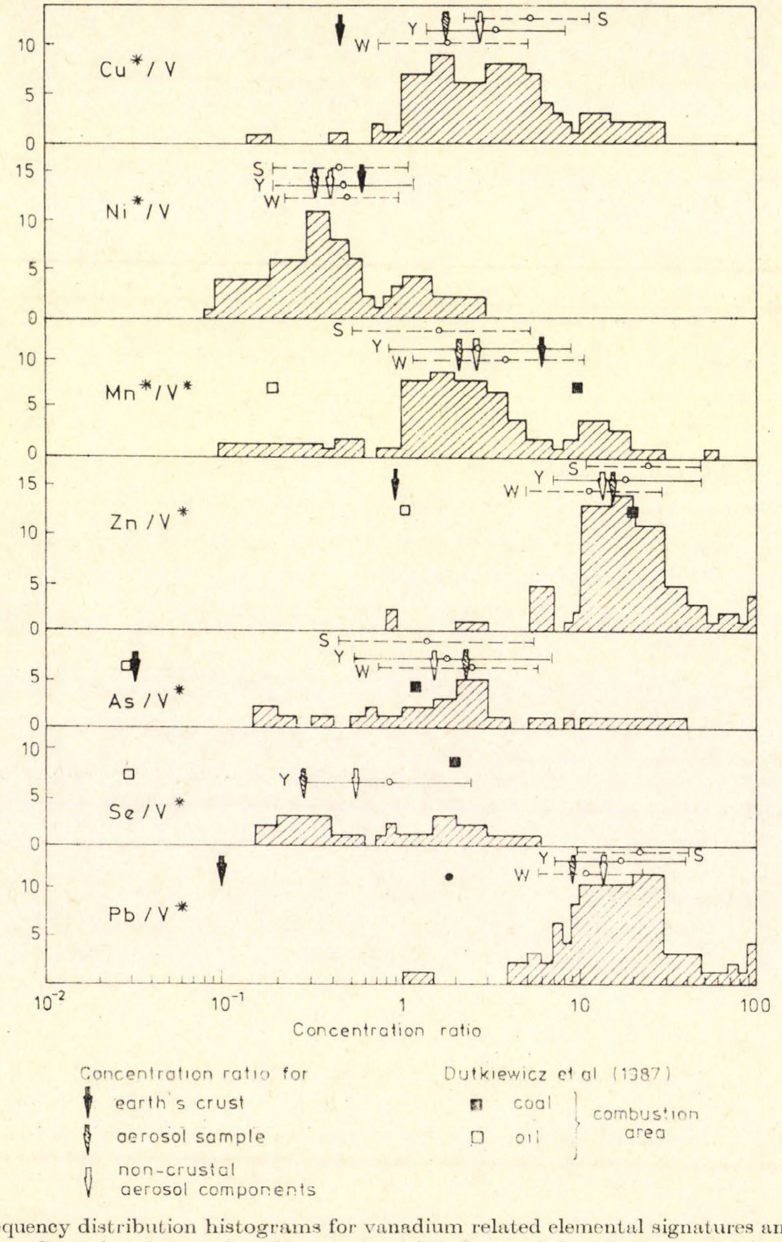


Fig. 5. Frequency distribution histograms for vanadium related elemental signatures and seasonal average data. Crustal and aerosol ratios together with corrected data for non-crustal contribution are indicated by arrows according to the notations shown in the inset. Typical US data for coal combustion (ORV) and oil combustion (WHS) areae taken from the paper of *Dutkiewicz et al* (1987) are shown by full and empty squares, respectively (the ordinate givel the number of cases).

- The same test has been performed for vanadium related regional elemental ratios; frequency distribution histograms for our old and new data sets have been compared. Complete agreement can be observed between the respective histograms in *Fig. 4*.
- Frequency distribution histograms for vanadium related regional signatures constructed from data set of the whole year 1981/82 are shown in *Fig. 5*. Seasonal behaviour is shown by average data points and standard deviation bars with notations *Y* (year), *W* (winter) and *S* (summer). The sensitivity of a selected elemental ratio for antropogenic sources is related to its difference between crust samples and sampled aerosols, and an additional effect is due to the correction for non-crustal components in the aerosol. The corresponding values are shown in the figure with full, hatched and empty arrows, respectively. Average aerosol concentration ratios for elements 1 and 2 are given as

$$(C_1/C_2)_{\mathrm{aer}} = (F_1/F_2) \cdot (C_1/C_2)_{\mathrm{soil}},$$

where F are the enrichment factors calculated on the basis of titanium as purely crustal constituent. Non-crustal concentrations are given as

$$C^*_{1,\,\mathrm{aer}} = C_{1,\,\mathrm{aer}} - C_{\mathrm{Ti},\,\mathrm{aer}}(C_1/C_{\mathrm{Ti}})_{\mathrm{soil}}.$$

A wide variation was found by *Dutkiewicz* (1987) in the above parameters for geographic regions in USA predominantly characterized by coal-fired

TABLES 3

Vanadium related geometric mean elemental signatures and geometric standard deviations in Hungarian aerosol samples from sampling sites and from US sites of different combustion character (ORV = Ohio River Valley, coal combustion area, WHS = West Haverstraw, oil combustion area)

Tracer	Present work			Dutkiewicz et al. (1987)	
	1981/82		1987/88	1987	
	year	winter summer	summer	ORV, coal	WHS, oil
	average			combustion area	
Mn*/V*	2.72(3.2)	3.70(3.2) 1.63(3.2)	3.84(3.2)	10.0 (2.3)	0.22(2.0)
Ni*/V*	0.46(2.3)	0.48(2.0) 0.45(2.5)	0.96(2.4)	–	–
Cu*/V*	3.39(2.6)	1.93(2.7) 5.01(2.0)	1.70(2.5)	–	–
Zn/V*	17.60(2.7)	11.60(2.6) 23.40(2.4)	12.50(2.9)	26.0 (1.9)	1.00(2.4)
As/V*	1.78(3.5)	2.38(3.8) 1.43(3.9)	1.31(3.7)	1.20(1.7)	0.03(4.1)
Se/V*	0.83(3.0)	– –	0.53(2.7)	2.30(1.6)	0.03(2.1)
Pb/V*	16.90(2.4)	11.50(2.2) 21.80(2.4)	14.32(3.2)	–	–

and oil-fired power plants, their corresponding signature values are shown here by empty and full squares, respectively. From a direct comparison with our histograms we found that the signatures in Hungary reflect the predominance of coal combustion character of the aerosols. The case on Mn^*/V^* is less convincing, the limitations of Mn^*/V^* as a tracer have beer treated in detail by *Husain et al.* (1984). Geometric mean data for ouf measurements are given in *Table 3* together with those from *Dutkiewicz et al.* determined for the Ohio River Valley (ORV) and West Haverstraw (WHS). There is a general agreement between Hungarian data and ORV data for the ratios indicated. Our results show much similarity with Ohio River Valley data from *Shaw* and *Paur* (1983), as well as with French data for Gardanne (*Grimaldi et al.*, 1988).

Our results are in full accordance with the structure of energy sources in Hungary; the contribution of coal fired electric power plants to the total electric power generated in the country by non-nuclear power stations amounts to 52% while oil fired plants contribute 11% only. The third component of 37% represents the capacity of natural gas combustion stations with insignificant emission of vanadium. No corresponding data were found in the literature for the ratios Cu^*/V^*, Ni^*/V^* and Pb/V^*. Elemental signatures Pb/V^* may be of importance in measurements on environmental effects of car exhaust. Lead as general pollution element might also be considered for the denominator in a new set of elemental tracers.

The applicability of elemental signatures in tracing air masses is strongly influenced by their stability against aging during long range transport. This effect sometimes checked through their variation as a function of transport distance (on a scale of a few hundred kilometers) is a subject of our present investigations. We try to deduce some conclusions in this respect from the analysis of size distribution curves for the respective pairs of elements.

REFERENCES

Borbély-Kiss, I., Haszpra, L., Koltay, E., László, S., Mészáros, Á., Mészáros, E. and *Szabó, Gy.*, 1988: Elemental concentrations and regional signatures in atmospheric aerosols over Hungary. *Physica Scripta 37*, 299–304.

Dutkiewicz, V. A., Parekh, P. P. and *Husain, L.*, 1987: An evaluation of regional elemental signatures relevant to the Northeastern United States. *Atmos. Environ. 21*, 1033–1044.

Grimaldi, F., Gonezo, F., Viala, A., Mola, P., Muls, E. and *Bresson, H.*, 1988: Etudes dela qualité der l'air à l'intérieur de locaux d'habitation et de locaux scolaires dans la région de Gardanne (Bouches-du-Rhône). *Pollution Atmosphérique N°. 118*, 147–151.

Husain, L., Webber, J. S., Canelli, E., Dutkiewicz, V. A. and *Halstead, J. A.*, 1984: Mn/V ratio as a tracer of aerosol sulfate transport. *Atmos. Environ. 18*, 1059–1071.

Koltay, E., 1988: Particle induced X-ray emission: basic principles, intrumentation and interdisciplinary applications. In *X-ray spectroscopy in atomic and solid state physics* (eds.: *J. G. Ferreira* and *M. T. Ramos*). NATO Advanced Study Institute series. Plenum Publishing Corporation, New York.

Rahn, K. A., 1981: The Mn/V ratio as a tracer of large-scale sources of pollution aerosols for the Artic. *Atmos. Environ, 15*, 1457–1464.

Rahn, K. A. and *Lowenthal, D. H.*, 1984: Elemental tracers of distant regional pollution aerosols. *Science 223*, 132–139.

Shaw, R. W. and *Paur, R. J.*, 1983: Composition of aerosol particles collected at rural sites in the Ohio River Valley. *Atmos. Environ. 17*, 2031–2044.

IDŐJÁRÁS

Az Országos Meteorológiai Szolgálat folyóirata, 93. évf. 1. szám, 1989. január – február
Journal of the Hungarian Meteorological Service, Vol. 93. No. 1. Jan – Feb 1989 Budapest

Drought indices in meteorology

T. FARAGÓ, E. KOZMA and CS. NEMES

Central Meteorological Institute,
H—1525 BUDAPEST P.O.B. 38. Hungary

Proper quantification of drought events is required for either their comparative spatial and temporal evaluation or for relevant predictability studies. Drought indices appear to be the simplest tools in drought analysis. The objective of this paper is to collect more or less "popular" indices, and to compare them as to their theoretical and numerical effectivness. Indices are classified into four groups: precipitation indices, supply/demand (water balance) indices, soil moisture indices, and "recursive" indices. For each group, a few typical expressions are given and analyzed for their performance and comparability. Some empirical relations are established among the different indices. Those indices proved to be of highest utility in the delineation of meteorologically determined droughts which possess "memory" that is which actual values depend also on preceding values of the related meteorological elements. Such indices are the soil moisture, and Bhalme – Mooley or Palmer indices. Results are illustrated for.some.recent.drought.events.in Hungary.

*

Aszályindexek a meteorológiában. Mind az aszályos időszakok területi és időbeli összehasonlításához, mind előrejelezhetőségüknek vizsgálatához szükséges e jelenségek megfelelő számszerűsítése. Az aszályok vizsgálatának a legegyszerűbb eszközei a különféle indexek. E tanulmány célja a többé-kevésbé ismert aszályindexek összehasonlítása mind az elméleti, mind a számszerűsíthető hatékonyságuk szempontjából. Az indexeket négy típusba soroltuk: csapadékindexek, vízmérleg-indexek, talajnedvességi indexek, és „rekurzív" indexek. Minden egyes csoport néhány főbb indexének alkalmazhatóságát, illetve az indexek összefüggéseit elemeztük. A meteorológiailag meghatározott aszályok leírásában azon indexek bizonyultak a leghatékonyabbnak, amelyeknek bizonyos „memóriája" van, azaz aktuális értékük a megelőző időszak meteorológiai elemeinek az alakulásától is függ. Ilyen index a relatív talajnedvesség, a Bhalme – Mooley és a Palmer-index. Az eredményeket az elmúlt évek konkrét adataival illusztráljuk Magyarország különböző területeire vonatkozóan.

1. Introduction

"There is a strong desire to develope indices for all factors in nature and society.... If it is properly formulated, if its limitations are recognized ... then an index can be very useful. Its misuse and misinterpretation, however, may lead to the development of policies that are inappropriate for combatting environmental and societal effects of droughts. In particular, there should not be an overreliance on any single index to monitor droughts." (Katz and Glantz, 1986; p. 770)

Among the extreme meteorological events, droughts are possibly the most slowly developing, often have the longest duration, and probably are the least predictable of all atmospheric hazards. Due to these characteristics, particularly their temporal character, droughts cannot be compared with other weather and climate extremes such as floods, hurricanes, lightening hail, cold, winter stroms, frosts or windstroms, which also significantly contribute to a nation's annual loss due to weather (*Riebsame et al.*, 1986). Because of their peculiar character, droughts deserve great scientific investigation. The problem involves a large number and variety of definitions, indicators, indices and methods of evaluation. As a consequence, almost all agrometeorologists, climatologists and agronomists engaged in this field have their own time series, methods and conclusions about the characteristics of drought episodes, even for the same regions.

Drought is considered as one of the man's worst enemies *(WMO*, 1975), because of its potential to continue for a long time over a large area and to have long-lasting effects. It expresses some sort of imbalance, arising from either extraordinary climatic variations or human activities (overconsumption of water, overgrazing and soil erosion, migration of population to places with insufficient water resources etc.). This dual character of the drought concept is stressed by *Kraus* (1977, p. 1009) who states that "by definition droughts are anomalies-deviations from a rainfall regime to which people, plants and animals have adapted as the local norm."

In spite of its special character (severity, recurrence, spatial pattern), societies – even those that are regularly affected by this hazard – fail to effectively adapt themselves to this adverse phenomenon. One of the typical causes is the short-mindedness: "with a return to above-mean rainfall levels, interest in dealing with the chronic (Sahelian) problems (revealed by the drought) will dissipate" *(Glantz and Katz*, 1977; Lamb, 1982). Moreover, adjustment is rather costly and the cost/loss ratio can hardly be assessed. Similar problems repeated during the recent drought incidences in sub-Saharan Africa *(Glantz and Katz*, 1985). As regards our region, we note that a new research program has been initiated recently in Hungary, following a four-year period of drought (1983–86) in various regions of the country. Of course, the main purpose of investigations of droughts, be of regional or large-scale extension, is the development of forecasting methods. In this relation, only some success can be mentioned, e.g., for the subtropical area, which is based on the El Niño – Southern Oscillation (ENSO-) related processes *(Bhalme et. al.*, 1983; *Bell*, 1986).

From a scientific point of view, the concept of drought is ambiguous. Some of the reasons for this problem are: (1) the water/moisture deficit may occur in the atmosphere, in water basins, in the hydrosphere, in the soil in accordance with the multistate and multiphase character of the water cycle; (2) the complexity of causes leading to a particular form of drought; (3) the regionally relative nature of drought (i.e., its significance depending on the local water supply/demand relations); and (4) the differential effects of water/moisture shortages on various natural and socioeconomic processes.

It is obvious that any form of drought originates from precipitation deficits, and that all other aspects of droughts are related to these inadequate precipitation amounts. But, a hydrological drought can occur even if anomalous rainfall was observed in the distant catchment area of the rivers. This emphasizes the need for the complex analysis of the areal and temporal characteristics ordifferent forms of drought. Moreover, while there are special disciplinary fequirements in drought investigations, the various approaches to and the related definitions of drought may not be separated. As *Wilhite and Glantz* (1985, p. 6) note: "Although it is useful to compartmentalize the various views of drought, the boundary separating these views is often vague." Not even the concept of meteorological drought can be isolated and analyzed in a ,,pure" form; it is closely related to the incidence of hydrological, agricultural and other droughts. Varga-Haszonits (1985) also points out the differences and similarities among the approaches of various scientists to droughts. Thus, the meteorological analysis should encompass the extended idea of meteorologically determined droughts.

Our goal was to collect a set of "popular" indices for droughts for a few months or longer, and to compare their theoretical and practical advantages, limitations, interrelations, and numerical effectiveness. These investigations showed only limited agreement among the drought/moisture indices. Actually, that agreement is a direct consequence of both the relative nature of drought and the related specific characteristics of all droughts and indices. It has been revealed that the highest performance can be achieved by such recursive indices as for instance, the Palmer-index. In areas, where soil moisture measurements or its reasonably good estimations are available, the respective (soil drought) indices are more advantageous.

The analysis concerns the meteorological and the "meteorologically determined" droughts. More exact estimations could be made by means of more specific (e.g., plant-specific) indicators of moisture deficiency, taking into account the particular timing and regional extent of water demand during the consecutive developmental stages of plants of plants or for different forms of socioeconomic activities.

2. Drought definitions and the introduction of indices

There are many conceptual definitions of drought in the scientific literature. Quite a few of these definitions have been reviewed by *Wilhite and Glantz* (1985), by *Andreeva and Sazonov* (1987), *Girskaya and Sazonov* (1979) and by the WMO (1975), but according to the authors of the first work (see also *Sadowski*, 1984 and *Bagrov*, 1986) the lack of a precise (and objective) definition of drought can be an obstacle to understanding this phenomenon.

Meteorological drought is often identified with atmospheric drought and defined simply with below mean precipitation amounts, sometimes combined with parameters of air temperature, humidity and wind velocity. This type of apparently oversimplified definition is reported by *Sadowski* (1984): "Atmospheric drought, with rainfall deficit in comparison to normal values." Similarly, *Bell* (1986) notes: "drought... is the unfulfillment of expected rainfall." As a matter of fact, the general term drought is not identical to precipitation deficit, but rather it is usually the consequence of below-normal precipitation *(Oladipo*, 1985). These attributes have been quantified in a more general drought definition given in WMO (1986, p. 2) that relates all other forms of drought to the precipitation deficit: "Drought is by definition a sustained, regionally extensive, deficiency in precipitation... All other definitions of drought are related to the effect or impact of below normal precipitation on agriculture, water resources, social and economic activities." More precisely, atmospheric drought is a *state* of the atmosphere (not an instantaneous but an integrated state for a longer period of time) that results in less than average (for that peirod) precipitation amounts and/or below normal atmospheric humidity. Other authors extend the concept of meteorological drought to soil droughts. Indeed, the soil moisture balance is closely connected to the atmospheric processes in terms of recharge into and loss water from the surface layer of the soil. Thus, the low precipitation, high temperatures and consequently low air humidity may cause the soil to dry out. Nevertheless, soil drought is a specicif form of this phenomenon, which is closely but not exclusively controlled by meteorological processes.

Agricultural drought occurs when the available soil moisture is inadequate to meet the evaporative demand by crops. This deficiency may result either from an unusually low moisture supply or an unusually high moisture demand (WMO, 1975). For its numerical analysis, all the abovementioned parameters of the atmospheric and the soil dryness/wetness can be used, though relevant agrometeorological studies must be plant-specific. Some compromise can be achieved if the meteorological approach is refined to account for the plant-specific time period (vulnerable stages of plant development in regard to the water availability), or the depth of the actual root zone in the case of soil moisture evaluations.

Hydrological drought refers to a period of below-normal streamflow and depleted reservoir storage, and it can also be treated as a meteorologically determined phenomenon. A similar definition is given by *Das* (1983). From a meteorological standpoint, the snow accumulations in the catchment areas, the runoff term in the surface water balance, or the potential evaporation for a specific case are of significance.

For scientific analysis, the different types of droughts are usually quantified. For this purpuse various indices are introduced.

In the past, the concept of dryness/wetness was primarily developed for studies of the geographical distribution of climates, or the determination of climate zones. Numerical indicators of moisture availability introduced for the characterization of climatic zones are termed "aridity indices". Aridity expresses a relatively permanent state of climate. Drought is a "shorter-term" phenomenon. Moreover, drought means a moisture deficit relative to the local (climatically and ecologically/socially established) average moisture balance. Therefore, aridity indices must be used with proper care for drought studies. In other words, the intensities of drought incidence in various parts of the world can be compared only if the corresponding anomalies are normalized in relation to local expected conditions. Indices have been specially developed for drought analysis. Various indices are used, depending on the purpose of an investigation (whether persistence, intensity or recurrence is in question) or on the availability of meteorological data.

The above mentioned disciplinary aspects of drought studies also affect the choice and the utility of indices. From a meteorological standpoint, the different types of droughts can be delineated by means of meteorological parameters in a wider sense (parameters of the state of the atmosphere, "in itself", and those which have significant effects on the agricultural or hydrological water balance through evaporation or evapotranspiration, and, in turn, through available soil moisture amounts or levels in water reservoirs, etc.).

3. Drought indices

3.1. Indices of cumulative precipitation anomalies. All forms of drought are related to some antecedent and relative precipitation amounts for a time period lasting from a month (or less) to years. But drought may occur well after this anomalous precipitation period. For example, agricultural drought may well be the consequence of a rainfall shortage during the previous autumn or winter. Therefore, the simplest measures of drought severity only account for precipitation characteristics.

Precipitation index (AI): $\Delta P = P - \mu(P)$(mm), (1)

where P denotes the monthly (or longer-time) precipitation amount and $\mu(P)$ is its "normal" (or mean) value. This index is an appropriate variable for the analysis of the precipitation fluctuations at a single station. Kane and Trivedi (1986) investigated long series of precipitation anomalies for different sites to reveal significant periodicities.

Deviation of the actual amount from normal is applied to drought/flood identification by many authors. *Glantz and Katz* (1985) used $(\sum_1^M \Delta P_m)/M$, the average of these anomalies for stations, as a regional index in the analysis of drought for Sub-Saharan Africa. *Adámyné and Csomor* (1986) retained only the signs of station anomalies to determine the regional extent of drought episodes, depending on which sign was most prevalent for different regions in Hungary.

It goes without saying that the anomalies for nonhomogeneous regions or larger areas with different climatic conditions are not comparable. To avoid this problem, either relative amounts, or standardized values should be used. The relative value is used in two forms:

Relative precipitation amount (rP): $P/\mu(P)$ ($\times 100\%$), (2)

Relative anomaly index (rAI): $[P-\mu(P)]/\mu(P)$ ($\times 100\%$). (3)

The rP-index is an indicator of drought if its value is less than some established threshold level, e.g., 75% on an annual basis, or 60% for a particular month. The use of other, slightly different levels was also suggested in *WMO* (1975). *Bunting* et al. (1976) have analyzed the long-term series of monthly and annual area-averaged rP-values to test the hypotheses of the existence of trends and periodicities for the Sahelian region. For a recent world-wide drought assessment (*WMO*, 1986), the following criterion was applied: annual $rP < 60\%$ for more than two consecutive years (combined with an additional condition that the area affected must be 50% or more of the region).

Standardized anomaly index (SAI):

$$P' = [P-\mu(P)]/\sigma(P), \tag{4}$$

where $\sigma(P)$ is the standard devition of P. A very detailed analysis of SAI was accomplished by *Katz and Glantz* (1986). It proved aeffective for the delineation of regional precipitation anomalies because of the reasonable comparability of station SAI-values. For a single station, the usual probability levels can be applied to choose particular threshold values in accordance with the hypothetical distribution of SAI (Gamma or Gaussian distribution for longer periods of time provide a good statistical fit). The variance of a regional (average) index depends on the number of stations and their correlations.

Kraus (1977) applied area-averaged SAI on an annual basis for two monsoonal (African and Indian) regions to reveal persistence in the occurrence of rainfall anomalies. This hypothesis was later refuted by *Katz* (1978). *Nicholson* (1979) returned to the same problem and *Lamb* (1982, 1983) also intensively used this index for the Sub-Saharan area. *Bhalme and Mooley* (1980) introduced the rainfall anomaly index, weighted by the reciprocal of coefficient of variation, which is actually equivalent to the SAI multiplied by $\mu(P)$.

R o o y a n o m a l y i n d e x (RAI): $3P\ [h-\mu(P)]$, if $P>0$ (5)

$-3P/\ [l-\mu(P)]$, otherwise,

where h = mean of ten highest P-values and l = mean of ten lowest P-values, within the sample. For RAI, nine abnormality classes were given *(Oladipo,* 1985), ranging from extremely wet to extremely dry classes.

Similary for the standardization of station precipitation anomalies, an analogous procedure can be suggested for a sequence of monthly amounts:

A v e r a g e SAI (ASAI): $[\sum_1^K \Delta(P_k)/\sigma(P_k)]/K$. (6)

3.2. Other indices of atmospheric drought. The water vapor saturation deficit is commonly used for the characterization of atmospheric drought, although the temporal scale for similar analyses is usually much shorter than a month *(Pasechniuk and Sennikov,* 1983; *Levitt,* 1958):

S a t u r a t i o n d e f i c i t: $d = E_s - E = E_s\,(1-\varrho)$ (hPa), (7)

where ϱ is the relative humidity, E is the vapour pressure, and E_s is the saturated vapour pressure. Threshold values for the identification of atmospheric dryness for a shorter period, the "sukhovei" are: $20-29$ hPa = weak, $30-39$ hPa = moderate, $40-49$ hPa = intense, >50 hPa = very intense.

Dry conditions of longer time intervals can be described with the number of days of at least mild dryness. *Pasechniuk and Sennikov* (1983) have shown the strong correlation between this dryness measure and the precipitation amount during the growing season (correlation coefficient reached between $0.7-0.8$). Air temperature and wind can also play important roles in the formation of severe atmospheric dry situations.

3.3. "Supply/demand" indices based on the water balance. Precipitation is the dominant form of water supply for the soil water balance. It is evident that for a more precise delineation of drought conditions, the "demand" side of this balance must also be considered. Water demand is usually expressed through the potential evaporation or, as a simplest approximation, the average temperature of the analyzed period. Maximum evaporation can be assessed from the radiation balance, too.

L a n g' s r a i n f a l l i n d e x (LI): P/T (mm/°C), (8)

where T is the mean air temperature for the given monthly (or longer) period.

d e M a r t o n n e a r i d i t y i n d e x (dMI);

$12P/(T+10)$, the monthly index (mm/°C) (9)

$P/(T+10)$, the annual index.

Originally, LI and dMI were developed as aridity indices, although they can be used for the detection of drought episodes (*WMO,* 1975). *Chowdhury* and *Hussain* (1983) apply dMI for aridity analysis (the select arid areas with annual dMI <20) and choose a different criterion for drought studies.

S e l y a n i n o v' s h y d r o t h e r m a l c o e f f i c i e n t (SHC):

$P/(\sum_{t>10\,°C} t/10)$ (mm/°C), (10)

where t denotes the consecutive daily mean air temperatures. This index (known also as HTC) is often employed for agrometeorological investigations *(Sapozhnikova,* 1958; *Sinicina* et al., 1973; *Ajtay,* 1977.) The established threshold values for drought (and aridity) classification are: $0.4-0.7$ = very dry, $0{,}7-1.0$ = dry, $1.0-1.3$ = insufficiently wet, >1.3 = wet. A simpler criterion is recommended in WMO (1975) for drought indentification, namely, SCH < 0.5. SCH can be directly formulated for monthly values (*Bagrov*, 1983) in the form P/(3T).

Thornthwaite Index (WMO, 1975): $1.65[P/(T+12.2)]^{10/9}$ (11)

Ped's Drought Index (PDI1) $\Delta T/\sigma(T)-\Delta P/\sigma(P)$. (12)

Bagrov (1983) transformed PDI1 into a wetness index to demonstrate the limitations of this index (and the SHC) for yield estimation. Recently, the statistical properties of the original PDI1 index were investigated (*Bagrov*, 1986). The simple criterion of drought, namely, the validity of inequality of PDI1 > 2, is appropriate only when the independence of T and P is assumed for a single month. If these requirements are not satisfied, the threshold value should be modified: (1) for a K-month period, the $2/\sqrt{K}$ threshold value is the proper choice; (2) the actual dispersion of the index for a single month equals $2(1-r)$, where r is the correlation between T and P.

It was mentioned above that the temperature in these indices simply substitutes for the more complex potential evaporation term. A few indices incorporate PE explicitly.

Potential water deficit: $PE-P$, (mm) (13)

Potential evapotranspiration ratio: PE/P. (14)

Moisture availability index (MAI): P/PE. (15)

Biswas and Khambete (1983) used MAI for climate potential assessment for crop production in the arid zone of India. It is believed that the same levels of MAI values can be used for meteorological drought evaluation: ≤ 0.3 = very dry, >0.3 = classification depends on the relative length of time units with MAI > 0.3 within the vegetation period.

Dryness ratio: $(R/L)/P$, (16)

where R is the surface radiatoin balance. This ratio is primarily a measure of dryness or wetness that is commonly used for defining climatological regions (*Péczely*, 1979).

Finally, let us consider indices with ET instead of the precipitation amount (ET stands for the actual evapotranspiration). These indices more closely express the drought/flood conditions from the agricultural (or hydrological) perspective. The relation of these two indicators of water supply can also be evaluated by means of the Thornthwaite moisture index, $(P/ET-1)\times 100\%$.

Relative evapotranspiration: ET/PE (100%). (17)

This index was used by, among others, *Patel et al.* (1986) for agricultural drought classification in relation to crop yield estimation.

Bowen ratio: $(R-L\times ET)/(L\times ET)=(R/L)/ET-1$. (18)

This ratio expresses the relation of the heat flux to turbulent eddies in the boundary layer to that part of the radiation balance which is used for evaporation (*Hare*, 1983).

3.4. Soil moisture indices.

Relative soil moisture content: W/AWC ($\times$100%). (19)

with W and AWC denoting the actual soil moisture and the available (or disponsible) water capacity for a fixed soil depth (e.g., the upper 1-meter layer or the root zone for a given plant).

Besides this well-known ratio, an extended form of Ped's drought index incorporates the standardized value of the soil moisture amount *(Davidov and Ped,* 1983):

Ped's drought index, (PDI2):

$$\Delta T/\sigma(T) - \Delta P/\sigma(P) - \Delta W/\sigma(W), \tag{20}$$

3.5. „Recursive" indices. Indices describing the moisture conditions for a relatively long time period through the integrated values of the related meteorological elements provide only a rough picture of the potentially adverse conditions within this period. It is thought that above al the cumulative effect of prolonged moisture deficits (month by month) should be properly expressed. For this purpose "recursive indices" are formulated. The simplest way to do so is to consider the progression of the accumulation of precipitation anomalies, which is expressed by the "residual mass curve" introduced by *Foley (WMO,* 1975).

Foley's cumulative anomaly index (FAI):

$$FAI_1 = \Delta P_1, \; FAI_k = FAI_{k-1} + \Delta P_k \text{ for the } k\text{th month.} \tag{21}$$

For the comparability of FAI-values of various stations and periods, normalization can be made, $\sum_1^K[\Delta P_k/\widetilde{P}]/K$, where $\widetilde{P}$ is the annual precipitation amount for the given station.

Bhalme and Mooley (1980) defined a "recursive" drought/flood index based on monthly precipitation amounts. Conceptually, this index (the BMDI) can be considered as an essentially simplified version of the well-known PDSI, the Palmer Drought Index *(Palmer,* 1965).

Bhalme-Mooley Drought Index (BMDI):

$$i_0 = 0; \; i_k = c_1 i_{k-1} + (SAI)_k/c_2 \text{ monthly index} \tag{22}$$

$$\text{BMDI} = (\textstyle\sum_1^K i_k)/K \text{ for a period of } K \text{ months.}$$

The coefficients were derived for Indian observations: $c_1 = 0.5$ and $c_2 = 0.4855$. The regional extent of drought is expressed as a Drought Area Index, being defined as the percentage of area with averaged BMDI value below a certain negative threshold *(Das,* 1983). Coefficients in the BMDI formula were recalculated using data from Nebraska for the growing season, April-September *(Oladipo,* 1985): $c_1 = 0.452$ and $c_2 = 0.4267$. Slight variations appeared for a larger data base observations in the interior plains of North America: $c_1 = 0.548$ and $c_2 = 0.4267$ *(Oladipo,* 1986).

Palmer Drought Severity Index, (PDSI). The PDSI is based on the thorough analysis of the elements of surface water balance and on the comparison of their actual values to their climatically or physically attainable (potential) values *($ET \sim PE$* for the evapotranspiration, $W \sim AWC$ to estimate soil moisture amount, etc.).

A particular locality can be characterized by the ratios of the averages of the actual and potential values for all constituents in the water balance: α = ratio of averages of *ET* and *PE*, β = ratio of averages of actual and potential recharge, γ = the same ratio for the runoff, δ = the same ratio for the moisture loss, where the recharge and the loss express the change of the moisture content in the root zone of soil with opposite signs (i.e., negative changes assigned to the loss term). For a particular month, the "expected" value of the precipitation, or the value "climatically appropriate for existing conditions," the "CAFEC value" (a term introduced by Palmer) is calculated from the water balance equation: $\hat{P} = \alpha\, PE + \beta\, PR + \gamma\, PRO - \delta\, PL$, where PE, PR, PRO and PL are the potential values of evaporation, recharge, runoff and loss for that month, respectively. The deviation of the actual P from its CAFEC value weighted by a climatic factor (valid for the month and the area) provides a moisture anomaly index, $Z = K\,(P - \hat{P})$.

The so-called final PDSI is derived by a recursive equation:

$$PDSI_k = PDSI_{k-1} + Z_k/3 - 0.103\ PDSI_{k-1}. \tag{23}$$

The initialization depends on criteria for determining and ending times of wet and dry periods. Palmer scaled his index in accordance with a prescribed set of categories, which was recently adopted for the derivation of the BMDI: < -4.0 = extreme drought, $(-4, -3)$ = severe drought, $(-3, -2)$ = moderate drought, $(-2, -1)$ = mild drought, $(-1, +1)$ = near normal, and similar categories of slightly, moderately, very wet and extremely wet periods. The growing season can be characterized with the average PDSI values for the corresponding months.

PDSI is rather popular because of its quasi-invariance under different changes in climatic conditions for different regions (*Wilhite*, 1983; *Hecht*, 1983; *Karl*, 1983; *Oladipo*, 1985; *Rao et al.*, 1986).

4. *Some properties and limitations*

To evaluate the abnormality of P, the precipitation amount for a particular time period (month, season, etc.), this value must be interpreted in terms of its empirical probability distribution. For this purpose, either certain levels (thresholds) are used, such as the record amount (P_{min}, P_{max}); the lowest decile (P_{ld}), quartile (P_{lq}), median; or some "integrated" measures of dispersion of the distribution, e.g., the standard deviation, the mean absolute deviation, the average of the ten lowest values in a record; or the mean (expected) value of the distribution may also be mentioned among these characteristics.

Keeping in mind that the regional extent of a drought episode is commonly determined by mapping the individual index values or calculating areal averages, the values should be standardized first. This means transforming the original values into $P' = [P - \mu(P)]/d(P)$, where $d(P)$ denotes some general measure of dispersion. Typical examples of such a standardization use one of the above thresholds values, as in the case of indices defined by (3), (4) and (5): $\mu(P)$ for rAI, $\sigma(P)$ for SAI or $[l(P) - \mu(P)]/3$ for RAI. Such a procedure is performed to eliminate regional differences in local climates, or, in other words, to archieve regional comparability of various meteorological stations. Implicity, one would also expect that standardized indices for different areas (stations) ought to quantify drought events with similar socioeconomic (agricultural, hydrological, etc.) impacts in nearly identical ways. For the evaluation of the consequences, it can be assumed that the natural ecosystems and societies have adjusted to the "surrounding" local or regional climate and other environmental conditions (*Palmer*, 1965; *WMO*, 1986).

Among the precipitation-based indices, the rAI has a formally different character because its normalizing term $[\mu(P)]$ is not a measure of dispersion. This problem is partly solved using the finding reported by *Katz* and *Glantz* (1986), who have shown that for the Sahelian area the mean and standard deviation of precipitation amounts are closely related: the rainfall variability (for the April – October period) tended to increase. A similar statistical relationship takes place in Hungary (*Figure 1*). This approximate linear proportionality between the mean and standard deviation has a more general basis. Supposing that the monthly precipitation amounts obey the gamma distribution with the density function, $f(P) = P^{\gamma-1} \exp(-P/\beta)/[\beta^{\gamma}\Gamma(\gamma)]$, where β, γ are the scale and shape parameters, respectively, the expected value equals $\beta\gamma$, while the standard deviation is $\beta\sqrt{\gamma}$. If for the case of two stations only the means differ, $\mu(P_1) = c\,\mu(P_2)$ (i.e., their density functions are of the same form with identical shape parameters), then the relations between the scale parameters and the two standard deviations are given by $\beta_2 = \mu(P_2)/\gamma = c\mu(P_1)/\gamma = c\beta_1$, $\sigma_2 = \beta_2\sqrt{\gamma} = c\beta_1\sqrt{\gamma} = c\sigma_1$. Instead of this linear relationship, *Drozdov* (1956) came to a slightly different formula, $\sigma^2(P) = \alpha\mu^2(P) + k\mu(P)$, which again leads approximately to the previous result if the second term is small. For very dry regions, the ratio $\sigma(P)/\mu(P)$ differs considerably from a constant and significantly increases with decreasing $\mu(P)$. Based on this relationship, a nearly equal performance can be assumed for all the "standardized". rainfall indices. In particular, for an individual station, after the actual precipitation (for the given period) is classified (compared with a threshold value C), say $P<C$, then all other simple moisture anomaly indices determine a corresponding class on a different scale (different units according to the transformation definition of the index); that is, $SAI < C/\sigma(P)$, $rP < C/\mu(P)+1$, $\mathrm{rAI} < C/\mu(P)$, etc.

In spite of the advantageous properties described above, these indices do not meet the more rigorous requirements concerning the independence of the distribution of regional indices from any changes in the set of individual stations. Katz and Glantz (1986) noted that the average of local SAI values for M stations has a variance $1/M$ for uncorrelated and equally distributed data. For rAI, a similar expression takes place: var $[\Sigma_1^M(\mathrm{rAI})]/M] = \sigma^2(P)/\mu^2(P)/M$.

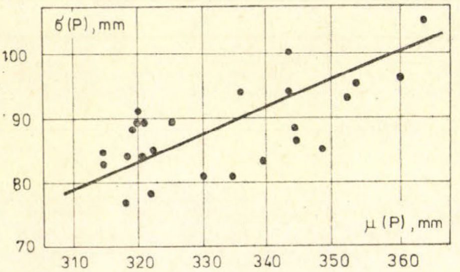


Fig. 1. Relationship between μ(P) and σ(P) based on 80 years averages for 25 meteorological stations in the Hungarian Great Plane (precipitation amounts for the growing season: Apr – Sept)

All indices treated above characterize the precipitation anomaly of a period of K months as a whole, neglecting the time dependence of the monthly anomalies during that period.

A refined (and more effective) approach is performed in the simplest way with the use of the sequence of accumulated anomalies (or the elements of the "residual mass curve"): ΔP_1, $\Delta P_1 + \Delta P_2$, ..., $\sum_1^K \Delta P_k$ (WMO, 1975). However, the precipitation anomalies for different months produce different impacts; thus the amounts of the natural water supply should be compared with the "established" water demand for the particular time period. This means that it is more reasonable to use the standardized precipitation values so that we can introduce the series of cumulative monthly standardized anomalies, $\sum_1^k \Delta P_j/\sigma)P_j)$, or, for a period of K months, the average of monthly values: $\mathrm{ASAI} = \sum_1^K[\Delta P_k/\sigma(P_k)]/K$.

Among the indices based on the precipitation term, the BMDI defined by *Bhalme and Mooley* (1986) appears to be a unique example reflecting the development of a dry episode through a "recursive" definition: $i_k = c_1 i_{k-1} + [\Delta P_k/\sigma(P_k)]/c_2$, $\mathrm{BMDI} = (\sum_1^K i_k)/K$. The BMDI for a given period can be expressed in the form ($c_2' = 1/c^2$, $P' = \Delta P/\sigma(\sigma P)$:

$$i_k = c_1 i_{k-1} + c_2' P_k' = c_2'(c_1^{k-1}P_1' + c_1^{k-2}P_2' + \dots + P_k') = c_2' \sum_1^k c_1^{k-j} P_j',$$

$$\mathrm{BMDI} = \sum_1^K i_k/K = c_2'[(1 + c_1 + c_1^2 + \dots + c_1^{K-1})P_1' +$$

$$+ (1 + c_1 + c_1^2 + \dots + c_1^{K-2})P_2' + \dots + P_K'].$$

Obviously, the "weights" for previous months are gradually reduced with increasing values of K (the length of the period): $(1 + c_1 + c_1^2 + \dots + c_1^{K-1})/K \to 0$.

However, the "weight" of the first month increases with respect to that of the last month, so that their ratio tends from an initial value of 1 to 2 as K increases, which is possibly an unreasonable property.

One question remains: is the "recursive index" more straightforward than the "directly" determined indices (like SAI or rP) for the identification of drought episodes. Of the latter indices, the ASAI corrected by a factor of c_2' is "closest" to the BMDI because both are based on consecutive SAI values of months within a given period. (The correction by c_2' results in the equality of ASAI and BMDI for the first month). As a matter of course, an ASAI-type moisture index contains more information on the precipitation "history" of the period than any other index of the total precipitation anomaly for the whole time interval. Let us consider, for example, the SAI-value corrected by the $\sqrt{K}$ factor ($P = \sum_1^K P_k$):

$$\frac{1}{\sqrt{K}} SAI(K) = \frac{1}{\sqrt{K}} \Delta P/\delta(P) = \frac{1}{\sqrt{K}} \sum_1^K P_k' \frac{\sqrt{K}\sigma(P_k)}{\sigma(P)}.$$

Thus, for uncorrelated consecutive P_k-values:

$$SAI(K)/\sqrt{K} = \sum_1^K P_k'/K = ASAI(K).$$

But these assumptions are usually not valid; as illustrated in *Table 1* for three Hungarian stations (from an 80-year observation period; $K = 6$).

TABLE 1

Ratio of standard deviations of precipitation amounts for sequence of months and for the whole period

$\sqrt{K}\sigma(P_k)/\sigma(P)$	Apr	May	Jun	Jul	Aug	Sept
Baja	0.78	1.15	1.07	0.95	1.04	0.98
Kalocsa	0.77	0.97	1.15	1.03	0.97	0.89
Nyíregyháza	0.66	0.82	1.05	0.97	0.97	0.84

Let us introduce two periods lasting for K months (e.g., two growing seasons) so that all months are "normal" with zero SAI values, except for the first and last month:

$1: SAI_1 = -2, \Delta P_2 = 0, \ldots, \Delta P_{K-1}, \Delta P_K = 0$

$2: \Delta P_1 = 0, \Delta P_2, \ldots, \Delta P_{K-1} = 0, SAI_K = -2.$

The index of total anomaly is independent of the time when the single anomalous month occurred. Therefore, for both periods we obtain the same value: $ASAI' = c_2' ASAI = c_2'(-2/K)$, while the BMDI values are significantly different: $BMDI_1 = c_2'(-2/K)[(1-c_1^k)/(1-c_1)]$, $BMDI_2 = c_2'(-2/K)$. Obviously, the two indices coincide only when the precipitation deficit takes place during the last month of the period, $ASAI' = BMDI_2$. In this case, $BMDI_2 = -0.7$ (provided $K = 6$), which characterizes a near-normal period. With respect to the former period, the consecutive BMDI values are as follows: -4.0 (extreme drought), -3.0 (severe drought), ..., at last for the sixth month, -1.3 (mild drought). Thus, the "recursive" index reflects the fact that the precipitation anomalies during the given period have their agricultural or hydrological impacts mainly on the water balance of the soil. That is why these effects are delayed and smoothed.

Similar "recursive" indices can be deduced in another, and possibly more natural, way. The effects of serial precipitation anomalies accumulate as a soil moisture deficit (surplus) or a particular state of a plant. The simplest soil moisture balance can be given by $W_k = W_{k-1} - ET_k + P_k$, where W denotes the available (disponsable) soil moisture. A soil moisture deficit index can be formulated, for instance, with the following equation: $\tilde{i}_k = (W_k - AWC)\eta, = 4/AWC$, which gives -4 for the driest situation, $W = 0$, like PDSI or *BMDI*. Substituting a simple paramererization scheme for the actual evaporation (*Faragó*, 1985), a BMDI type recursive index is defined, which depends only on the monthly precipitation amounts: $\tilde{i}_k = \tilde{i}_{k-1} - \varepsilon W_{k-1} + P_k = a\,\tilde{i}_{k-1} + bP'_k + c$ where $a = 1-\varepsilon$, $b = \sigma(P_k)$, $c = \eta\mu(P_k) - 4\varepsilon$.

Indices based exclusively on precipitation provide a simplified insight into the drought phenomenon. Actually, it is a supply/demand problem. For an agriculturist, the water demand refers to the amount of water for evapotranspiration (*ET*). Because data for *ET* are not routinely collected, temperature-based expressions are used for the estimation of the potential evaporation (*PE*); for instance (*Antal*, 1968): $PE = 0.74\ (E_s - E)^{0.7}(1+aT)^{4.8}$. (mm/day; $a = 1/273$). If the purpose of quantification is the determination of climatological or agroecological regions in a general sense, then the radiation balance is used for the (potential) demand estimation.

The water supply/demand balance is expressed either in the form of a ratio or as a difference, e.g.:

	Lange's LI	Selyaninov's SHC	Ped's PDI1	Pot. water deficit	Dryness ratio
Supply:	P	P	$\Delta P/\sigma(P)$	P	P
Demand:	T	$\Sigma t/10$	$\Delta T/\sigma(T)$	PE	R/L

There is only a slight relationship between the precipitation-based and the balance-type indices. *Bagrov* (1986) has analyzed the statistical properties of Ped's index. Besides the estimation of the expected recurrence time of drought, the statistical distribution of this index was also investigated.

This distribution is close to normal (Gaussian) with zero mean and dispersion $\sigma(PDI1) = 2(1-r)$, where r denotes the correlation coefficient between T and P (for a single month). During the summer season, this coefficient is usually slightly below zero. Bagrov's conclusions probably hold for other locations at middle latitudes and definitely have a physical background (through the cloud-insolation coupling and the cooling effects of precipitation). For a Hungarian station, Baja, we obtained the empirical value $r = r\,(P, T) = -0.2$. This gives some basis for connecting the "P-based" and "supply/demand" indices (at least for the summer or growing season) in drought idenfification, however, the later indices evidently include more information for the analysis of meteorologically determined hydrological or agricultural droughts.

Most straightforward indices incorporate the elements of the soil moisture balance. The most sophisticated of those indices is the rather popular Palmer Drought Severity Index (PDSI). Despite its regular computation in some countries, no attempt has been yet made to adopt it in Hungary. Despite of its advantageous properties, even the PDSI cannot be considered universa Raol.

and Subramaniam (1986) refer to a severe drought event in the Indian subcontinent during 1918 for which Bhalme and Mooley showed the unreliability of the PDSI; to correct this problem, they recalculated Palmer's coefficients. *Oladipo-* (1985) demonstrated the nearly comparable performance of simple precipitation based indices, such as Roy's RAI and, to an even greater extent, the BMDI and PDSI for the purposes of single-station analyses.

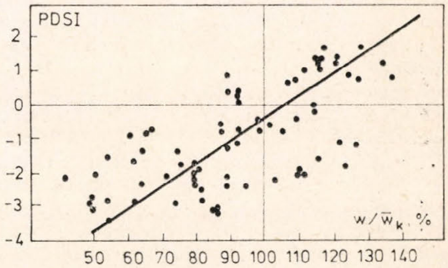


Fig. 2. PDSI versus relative soil moisture content divided by its normal value (%) for the corresponding month. The sample consists of all months of years 1981 – 86 for station Baja. The coefficient of correlation: $r = 0.66$

The PDSI is a "recursive" index, and is related by definition to the soil moisture balance in the way shown above. If the "established" water supply/demand regime for a given region is identified with the long-term average of the relative (available) soil moisture w then we may expect a good relationship between PDSI and the deviations of w from its normal, or their ratio. The latter is depicted in *Figure 2* for the station of Baja in Hungary. Fitting a linear regression between these variables provides a coefficient of correlation 0.66 for monthly values from the period 1981 – 86.

5. *Illustration of the performances of some indices*

We have analyzed the general aspects of the performance and comparability of different drought (moisture) indices in the previous section. We now summarize some results of the numerical studies. All calculations were based on Hungarian data series of precipitation, air temperature and soil moisture measurements.

TABLE

Drought indices in the growing season, Baja (1975 – 1986)

Year	rP%	RAI	SAI	SHC (mm/°C)	PDI1	PE/P	ET/P	ET/PE (%)	W/AWC (%)	BMDI	PDSI
1975	143	2.7	1.3	1.5	−1.6	1.3	0.9	70	90	2.5	3.0
1976	80	−1.7	−0.8	0.9	−0.1	2.5	1.4	56	59	−1.4	−0.2
1977	78	−1.9	−0.9	0.9	−0.1	2.6	1.5	57	60	−1.5	−0.8
1978	95	−0.4	−0.2	1.1	−1.7	1.9	1.2	65	72	−0.1	0.7
1979	81	−1.6	−0.8	0.9	0.6	2.6	1.5	58	53	−1.1	−0.7
1980	98	−0.1	−0.1	1.2	−2.0	1.8	1.2	64	69	0.3	0.5
1981	93	−0.6	−0.3	1.0	0.2	2.2	1.4	64	67	−0.8	−0.0
1982	85	−1.3	−0.6	0.9	0.9	2.4	1.5	63	62	−0.9	−0.1
1983	93	−0.6	−0.3	0.9	1.3	2.5	1.2	48	38	−0.9	−2.7
1984	88	−1.1	−0.5	1.0	−1.0	2.1	1.2	62	65	−0.8	−2.3
1985	78	−1.9	−0.9	0.9	−0.1	2.4	1.5	62	72	−1.2	−1.5
1986	97	−0.3	−0.1	1.0	0.0	2.1	1.4	68	75	−0.1	0.2
Drought	(50; 70]	(−3.0; −2.0]	(−1.0; −0.6]	[0.7 1.0)	(1.5; 2.0]	[2.5; 3.5)	[1.4; 1.9)	45; 55)	[40; 50)	(−4.0; −2.0]	(−4.0; −2.0]
Extreme drought	≤50	≤−3.0	≤−1.0	<0.7	>2.0	≥3.5	≥1.9	<45	<40	≤−4.0	≤−4.

First, the relatively long-term series (1901 – 1986) of various indices were compared for a single meteorological station Baja located in the SW-part of the Hungarian Great Plain. As an illustration, *Table 2* summarizes the values of several indices calculated for the period 1975 – 1986. Apparently, the rainfall amount during the last eleven growing seasons were more or less anomalous according to most indices. Even this short period exhibits the occasionally considerable difference in the performance of drought indices. The growing season of 1983 was exceptional in accordance with the values of indices possessing with "memory". Though the rainfall amount was near normal (rP = 93%) during this period, the values of W/AWC and PDSI (38% and −2.7, respectively) are the smallest for this years, which is a consequence of the precipition deficit of the previous months. Such properties of these indices are very important, especially when we compare their values for growing seasons. During these months, most areas in Hungary receive only about 60 percent of the annual totals (for instance, at Baja it is 58 percent); therefore, the preseason precipitation during the winter months has a very importent role in the water balance of soils. We note *(Table 2)* approximetely parallel runs of rAI and SAI, that for the recursive indices BMDI and PDSI, and to a less extent, for the relative soil moisture (W/AWC) and PDSI. (The latter is most evident for the extremely dry events, i.e. for the extremely small values of these indices.)

More detailed investigations of the drought episods have been made for the years 1983 and 1986, including the analysis of spatial distribution of the index values. In 1983, the drought period started on the Great Plain in the previous winter and lasted through the spring and summer seasons. In Transdanubia the previous winter was wet, and this accumulated wetness in the soil was enough to sustain good moisture storage during the following spring. The summer was very dry in this part of Hungary, as it is shown by the soil moisture index W/AWC *(Fig. 3)* according to which an extreme drought incidence is indicated in the GreatPlain area. The potential evapotranspiration ratio (PE/P) gives a much milder classification even for the longer period of the whole vegetation season. Most values of this index do not exceed the threshold 3.5, i.e. a value that separates the classes of "drought" and "extreme drought" events. Such a contradictionary behaviour of these indices is a trivial consequence of their properties. The soil moisture balance and the related index express in a certain way even the below normal-normal moisture conditions of the preceding (winter) period that was characteristic for the most part of the Great Plain (just in contrary to he situation in the Transdanubian area).

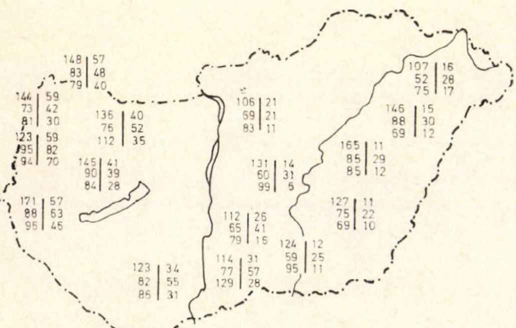


Fig. 3. Spatial distribution of some indices characterizing the 1983 growing season:

rp for previous winter	rp in Apr – Sept
rp for previous spring	PE/P in Apr–Sept
rp for previous summer	W/AWC in June – Aug

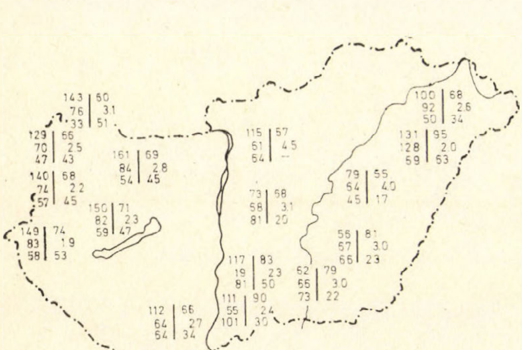


Fig. 4. Values of some indices characterizing the 1986 growing season:

rp for previous winter	rp for autumn
rp for previous spring	W/AWC in Jul – Sept
rp for previous summer	W/AWC in October

The character of the drought during the 1986 growing season was different to some extent because the previous winter season and the summer as well were considerably wetter in the whole country (*Fig. 4*). However the autumn brought about an extremely dry period throughout the Eastern part of the country, as well as in the E–SE part of Transdanubia.

6. *Conclusions*

Summarizing the main results of the above comparison, we have found some similarities among the different types of drought indices. Apparently, the precipitation indices possess similar features when applied to individual stations, yet some standardization is needed before determining regional indices. There is a much weaker connection between the precipitation indices and the balance-type expressions, and even less of a connection with the recursive indices. Therefore, it seems impossible to reduce the existing multitude of drought (moisture) indices to a single one. At the same time, for the delineation of meteorologically determined droughts, those indices that possess "memory" (the soil moisture indices and the recursive indices) are of highest utility.

Authors are grateful to Mr. *A. Kiss* and Mr. *L. Danicska* for programming and computational works, and our special thanks are also due to Mrs. *M. Krenz* for her editorial help.

REFERENCES

Adámyné K. E., Csomor M., 1986: Seasonal precipitation amounts in Hungary. Met. Service, Budapest (manuscript; in Hungarian).

Ajtay Á., 1977: Agroclimatological conditions of potato production in Hungary. Kis. Kiadv. 41, Met. Service, Budapest (in Hungarian).

Andreeva, L. K., B. I. Sazonov, 1987: Comparison of dryness indices. Tr. GGO, No. 513, 83–88. (in Russian).

Antal E., 1968: A new method for estimation of potential evapotranspiration. Hiv. Kiadv. XXXIV, Met. Service, Budapest, 414–423. (in Hungarian) .

Antal E., Kozmáné T. E., 1980: Climatological method for estimation of areal evaporation. *Időjárás, 76*, 83–92. (in Hungarian).

Bagrov, N. A., 1983: On the meteorological index of yields. *Meteor. Gidrol. 11*, 92–99 (in Russian).

Bagrov, N. A., 1986: On drought frequency. *Meteor. Gidrol. 12*, 43–48. (in Russian).

Bell, A., 1986: El Nino, and prospects for drought prediction. ECOS, *49*, 12–18.

Bhalme, H. N., D. A. Mooley, 1980: Large-scale drought/floods and monsoon circulation. *Mon. Wea. Rev.* 108, 1197–1211.

Bhalme, H. N. et al., 1983: Fluctuations in the drought/flood are over India and relationships with the Southern Oscillation. *Mon. Wea. Rev. 111*, 86–94.

Biswas, B. C., N. N. Kahmbete, 1983: Climatic potential for crop production at some stations in arid zone of India. *Mausam, 34*, 1, 77–80.

Buchinskii, I. E., 1976: *Droughts and dry spells.* Gidrometizdat, Leningrad. (in Russian).

Bunting, A. Z. et al., 1976: Rainfall trends in the West African Sahel. Q. *J. Roy. Met. Soc. 102*, 59–64.

Chowdhury, M. H. R., M. A. Hussian, 1983: On the aridity and drought conditions of Bangladesh. *Mausam. 34*,.1., 71–76.

Das, P. K., 1983: Droughts and famines in India – A historical perspective. *Mausam* 34, 2., 123–130.

Davidov, N. I., D. A. Ped, 1983: The state-of-the-art and perspectives for drought studying and forecasting in the USSR. *Meteorol. Gidrol., 5*, 26–30. (in Russian).

Drozdov, O. A., 1956: Fundamentals of climatological analysis of meteorological observonatis Leningrad Univ. (in Russian).

Faragó T., 1985: Soil moisture content: estimation of its probability distribution. *J. Clim. Appl. Meteor.*, 371–376.

Girskaya, E. K., B. I. Sazonov, E. I. Kropp, 1979: Indices of meteorological droughts. Tr. GGO. No. 403. 14–21. (in Russian).

Glantz, M. H., R. W. Katz, 1977: When drought is a drought? *Nature, 267*, 192 – 193.
Glantz, M. H., 1982: Consequences and responsibilities in drought forecasting: the case of Yakima, 1977. *Water Resour. Res. 18*, 1, 3 – 13.
Glantz, M. H. et al., 1985: Cultivating agriculturally marginal lands: drought follows the plow. *Ambio 14/6*, 334 – 339.
Glantz, M. H., R. W. Katz, 1985: Drought as a constraint to development in Sub-Saharan Africa. Manuscipt, Nat. Center for Atm. Res. *31*, 41 – 85/4.
Hare, F. K., 1983: Climate and desertification. WCP – 44, WMO, Geneva.
Hecht, A. D., 1983: Drought in the Great Plains: History of societal response. *J. Clim. Appl. Meteor. 22*,.51 – 56.
Kane, R. P., N. B. Trivedli, 1986: Are droughts predictable? *Clim. Change 8*, 209 – 223.
Karl, T. R., 1983: Some spatial characteristics of drought duration in the United States. *J. Clim. Appl. Meteor.* 1356 – 1366.
Katz, R. W., 1978: Persistence of Subtropical African droughts. *Mon. Wea. Rev. 106*, 1017 – 1021.
Katz, R. W., M. H. Glantz, 1986: Anatomy of a rainfall index. *Mon. Wea. Rev. 114*, 764 – 777.
Kraus, E. B., 1977: Subtropical drought and cross-equatorial energy transports. *Mon. Wea. Rev. 105*, 1009 – 1018.
Lamb, P. J., 1982: Persistence of Sub-Saharan drought. *Nature, 299*, 46 – 47.
Lamb, P. J., 1983: Sub-Saharan rainfall update for 1982: continued drought. *J. Clim. 3*, 419 – 422.
Levitt, J., 1958: Frost, drought and heat resistance. *Protoplasmatologia 8*/6).
Namias, J., 1983: Some causes of United States drought. *J. Clim. Appl. Metreo. 22*, 30 – 39.
Nicholson, S, E., 1979: Revised rainfall series for the West Africal subtropics, *Mon. Wea. Rev. 107*, 620 – 623.
Obasi, G. O. P., 1984: Drought in Africa. WCP Newsletter, 6 – 1 – 2.
Oladipo, E. O., 1985: A comparative performance analysis of three meteorological drought indices. *J. Clim.*, 655 – 664.
Oladipo, E. O., 1986: Spatial patterns of drought in the interior plains of North America. *J. Clim., 6*,495 – 513.
Palmer, W. C., 1965: *Meteorological drought.* U. S. Weather Bureau, Res. Paper, No. 45.
Panofsky H. A., G. W. Brier., 1958: Some applications of statistics to meteorology, Univ. Park., Penns.
Pasechniuk, L. E., V. A. Sennikov., 1983: Agroclimatological assessment of "suhkovei" and the yield of the spring wheat. Gidrometeoizdat, Leningrad., (in Russian) .
Patel, S. R., et al., 1986: Crop yields as influenced by agricultural drought. A water balance approach. *Mausam 3*, 341 – 342.
Péczely Gy., 1979: *Climatology.* Tankönyvkiadó Budapest (in Hungarian).
Rao, A. S., A. R. Subramaniam, 1986: An analysis of droughts in Maharashtra by a modified Palmer's approach, *Mausam 3*, 341 – 342.
Riebsame, W. E. et al., 1986: The social burden of weather and climate hazards. *Bull. Amer. Met. Soc. 67*, 11, 1378 – 1388.
Sadowski, M. J., 1984: Climatological premises of soil drought forecasting. *J. Clim., 4*, 637 – 643.
Saphoznikova, S. A., 1958: Agroclimatological zones of Ukraine. Tr. UNIGI, (Ukr. State. Sci. Inst.) *14*, 3 – 9,. (in Russian).
Sinicina, H. I., et al., 1973: Agroclimatology. Gidrometizdat, Leningrad/in Russian).
Subramaniam, A. R., A. V. Rao, 1983: Agricultural droughts at Peddapuram, East Godavari district, Andhra Pradesh. *Mausam 34*, 4, 439 – 442.
Waggoner, P. E. et al., 1965: Agricultural meteorology. Met. Monographs, *6*, 28.
Varga-Haszonits, Z., 1983: Agroclimatology and agrometeorological forecasting. Met. Service, Budapest.
Varga-Haszonits, Z., 1985: Meteorological information and agricultural decisions. Proc. Conf. on "The climatic potential...", Met. Service, Budapest, 97 – 140.
Wilhite, D. A., 1983: Government response to drought in the United States: with particular reference to the Great Plains. *J. Clim. Appl. Metcor. 22*, 40 – 50.
Wilhite, D. A., M. H. Glantz, 1985: Understanding the drought phenomenon: the role of definitions. *Water Intern. 10*, 111 – 120.
WMO, 1975: Drought and agriculture. WMO Techn. Note. No. 138.
WMO, 1986: Report on drought and countries affected by drought during 1974 – 1985. WCP – 118· WMO,Geneva.

A SZOCIALISTA ORSZÁGOK METEOROLÓGIAI/HIDROMETEOROLÓGIAI KONFERENCIÁJA BUKARESTBEN

A szocialista országok meteorológiai/hidrometeorológiai szolgálatainak szokásos, 2 évenkénti vezetői konferenciájára 1988 októberében, Bukarestben került sor. Az immár 20. alkalommal összeült konferencián a 7 európai és 4 Európán kívüli ország képviseletében résztvevő 57 delegátusa között a Magyar Népköztársaság öttagú – dr. *Ambrózy* Pálné (OMSZ), *Dévényi* Dezső és *Kassai* Béla (KEI), illetve *Nagy* Sándor (HM) összetételű – küldöttségét *Barát* József, az OMSZ elnöke vezette.

A konferencia első, okt. 5-től 8-ig tartott, ún. előkészítő szakaszát a két bizottság, nevezetesen a tudományos kutatások koordinálásával, valamint a távközlési és egyéb kérdésekkel foglalkozó munkája, míg a második szakaszt okt. 9-től 15-ig a tulajdonképpeni Vezetői Konferencia plenáris ülései jelentették. A konferencia a szolgálatok szinte minden nemzeti és nemzetközi tevékenységét áttekintő kérdéseket 12 pontba sűrítve, 26 ajánlást dolgozott ki. Ezek sorából természetesen itt csak a legfontosabb tárgykörűekre térünk ki.

A Konferencia megállapította, hogy a szinoptikusok munkahelyének automatizálása területén szorosabb együttműködés kívánatos a meteorológiai szolgálatok között. Ezért megbízta a *Számítástechnikai és Automatizálási Munkacsoportját*, hogy az automatizált szinoptikus munkahelyek technikai eszközeire és a technológiákra egységes követelményrendszert dolgozzon ki; folytassa az információ feldolgozó rendszer koncepciójának kidolgozását egy prognosztikai szupercentrum előkészítésére.

A felhasználók számára készülő éghajlati információk minőségének és tartalmának javítása érdekében a Vezetői Konferencia megbízta *Klimatológiai Munkacsoportját*, hogy az egyes szolgálatoknál folyó fejlesztési munkákat figyelembe véve, készítsen ajánlást az adatfeldolgozás technikai eszközeinek és módszereinek fejlesztésére.

A környezetvédelmi témák tárgyalásánál a Szovjetunió Hidrometeorológiai Szolgálata bejelentette, hogy a balesetekből származó veszélyes radioaktív, kémiai stb. szennyezőanyagok terjedésének követésére és előrejelzésére a Szovjetunióban specializált meteorológiai központot hoznak létre.

A Konferencia megvitatta azokat a kutatási eredményeket, amelyek az INTERKOZMOSZ keretében a *Kozmikus Meteorológiai Állandó Munkacsoport* és a *Távérzékelési Állandó Munkacsoport* irányításával folynak. A Konferencia támogatja a *Távszondázási Munkacsoport* javaslatát regionális együttműködés létrehozására a Kárpát-térség országai (Csehszlovákia, Magyarország, Lengyelország, Szovjetunió, Románia) között a környezet állapotának figyelemmel kísérésére, és az időjárás analízisének és előrejelzésének javítására távérzékelési adatok segítségével. A műholdas információk szélesebb körű bevezetéséhez az operatív prognosztikai gyakorlatba, a Vezetői Konferencia megbízta a *Szinoptikus és Repülésmeteorológiai Munkacsoportját*, hogy az INTERKOZMOSZ *Kozmikus Meteorológiai Munkacsoportjával* dolgozzák ki 1989–1990-ben a szocialista országok meteorológiai/hidrometeorológiai szolgálatainak közös kutatási tematikáját a kozmikus meteorológia területén.

A Vezetői Konferencia megvizsgálta a hidrometeorológiai műszerek kifejlesztésének, szabványosításának, egységesítésének, gyártásának és a szocialista országok műszerellátottságának helyzetét. Hangsúlyozta, hogy törekedni kell az automata mérőműszerek egységesítésére, mérési, adatfeldolgozási folyamatok komplex automatizálására, valamint a légkör alsó rétegének korszerű eszközökkel (pl. SODAR) történő szondázására. A Vezetői Konferencia ismételten megállapította, hogy nincs megnyugtatóan megoldva a KGST-n belül a meteorológiai műszerek sorozatgyártása.

A Konferencia megállapította, hogy a szocialista országok távközlési rendszerének fejlesztése tendenciájában megfelelő, a meteorológiai/hidrometeorológiai szolgálatok együttműködését azonban akadályozza egy-egy meteorológiai távközlési központ kapacitáshiánya. Jelen helyzetben nincs lehetőség a rendelkezésre álló megfigyelési adatok és feldolgozott információk cseréjének igényelt bővítésére, de a szocialista országok többsége nem férhet hozzá a Meteorológiai Világszolgálat biztosította új típusú információkhoz sem, mert ezek eléréséhez nemcsak a távközlési utak átviteli sebességének növelésére, de új átviteli eljárások bevezetésére is szükség lenne.

A Vezetői Konferencia keretében a közös tudományos kutatásokat a *Tudományos Konzultatív Bizottság* koordinálja. Az 1986–1990 közötti periódusban 9 főirányban (amelyek felölelik a meteorológia legfontosabb területeit) összesen 12 kutatási téma kidolgozása folyik. A magyar meteorológiai szolgálat a 12 téma közül jelenleg 10 végrehajtásában vesz részt.

A Vezetői Konferencia megtárgyalta a meteorológiai és hidrometeorológiai szolgálatok sokoldalú együttműködésének perspektíváit: nevezetesen a jelenlegi koordináción túlmutató kooperációs lehetőségeket, illetve a közös operatív és/vagy tudományos kollektívák (intézetek, munkacsoportok, laboratóriumok stb.) jövőbeni létrehozásának szükségességét. Ezen elvek alapján a Vezetői Konferencia úgy döntött, hogy ideiglenes szakértői munkacsoportot hoz létre egy olyan egyezmény kidolgozására, amely a jövőben lehetővé teszi a magasabb együttműködési formák alkalmazását is. Az egyezménnyel a jelenlegi Vezetői Konferencia helyett *a szocialista országok meteorológiai/hidrometeorológiai szolgálatainak szervezete* jön létre, amely szervezet azonban független marad a KGST-től és jellegében hasonló lenne az INTERKOZMOSZ együttműködéshez. A létre jövő szervezetben a meteorológiai/hidrometeorológiai szolgálatokat ugyanazok a személyek képviselnék, mint akik jelenleg a szolgálatok WMO képviselői. Egy szakértői csoport azt a feladatot kapta a Vezetői Konferenciától, hogy olyan egyezmény tervezetét készítse el, amely – figyelembe véve az egyes szolgálatok speciális nemzeti státuszát – megfelelő módon számol egy ilyen szervezet létrehozásának nemzetközi jogi, államigazgatási, anyagi stb. kihatásaival, ugyanakkor lehetőséget biztosít az együttműködés magasabb formáinak az alkalmazására is. A tervek szerint az egyezmény aláírására a XXI. Vezetői Konferencián 1990-ben kerül sor.

A Vezetői Konferencia megtárgyalta a szoojet hidrometeorológiai szolgálat javaslatát egy közös hosszútávú előre jelző központ létrehozásáról, amelynek megállapítására kb. 10 éves időtartamban lehet számítani. Ugyanakkor várható, hogy a kutatási munkák már korábban kb. 2–3 év múlva megindulnak.

A Vezető Konferencia következő ülésére 1990 őszén Kubában kerül sor.

Ambrózyné Mohácsi M.

A WMO HIDROLÓGIAI BIZOTTSÁGÁNAK CHy NYOLCADIK ÜLÉSE

A WMO CHy 1988. október 24-e és november 4-e között tartotta nyolcadik ülését Genfben. Az ülésszakon 71 ország és 13 nemzetközi szervezet képviseltette magát, mintegy 150 küldöttel. Magyarországról dr. *Antal* Emánuel az OMSZ elnökhelyettese és dr. *Starosolvszky* Ödön a VITUKI Hidraulikai Intézetének igazgatója vett részt a Bizottság ülésén. Az ülésszak 22 napirendi pontjának megtárgyalásához 22 dokumentum és 14 információs anyag készült, amit kb. 30 műszaki jelentés egészített ki, mintegy 1200 oldal terjedelemben.

A Bizottság megvitatta többek között a CHy hosszútávú tervét, különös tekintettel a Hidrológiai Operatív Többfeladatú Alprogramra (HOMS). Foglalkozott a hidrológiai szolgálatokkal és hálózatokkal, a hidrológiai adatok gyűjtésével, továbbításával, az adatfeldolgozás, tárolás, visszakeresés és terjesztés kérdésével, ill. a hidrológiai előrejelzésekkel és modellkészítéssel. Nagy hangsúlyt fektettek a kiadványok, a rendezvények, az oktatás és a képzés terén felmerülő problémák megoldására, továbbá a műszaki együttműködésre és a különböző projektekre.

Az ülésen a vártnál is nagyobb támogatásra talált Finnország és Magyarország együttes javaslata (20-as dokumentum) a tavak és tározók hidrológiájának fejlesztésére, illetve Csehszlovákia és Magyarország (21-es dokumentum) a városi hidrológia fejlesztésére tett javaslata. E javaslatokhoz számos támogató hozzászólás hangzott el, aminek eredményeként a két téma bekerült a Bizottság programjába.

Az elmúlt négy éves aktív elnöki munkája alapján a várakozásnak megfelelően dr. *Starosolszky* Ödönt, a VITUKI Hidraulikai Intézetének igazgatóját egyhangúlag újraválasztották. Így a WMO Hidrológiai Bizottságának ismét magyar elnöke lesz az 1988–1992-es periódusban. Az elnököt is újraválasztották Allan *Hall* ausztrál hidrológus személyében.

A soron következő négy évre a Bizottság figyelembe vette a WMO hosszútávú tervét, valamint az UNESCO/WMO Konferencia (Genf, 1987) ajánlásait, továbbá a Brundtlandt jelentést és az ENSZ 1990-ben induló természeti, katasztrófa elhárítási dekádjának tervezett anyagát. Egyértelmű, hogy így erősödtek a környezeti kapcsolat és a katasztrófa elhárítás szempontjai.

A Bizottság ülésén kirajzolódott, hogy tovább kell folytatni a vízrajzi munka fejlesztését, figyelembe véve az utóbbi években bekövetkezett változásokat a műszerezésben és a számítástechnikában Erősíteni kell a veszélyek elhárítása, megelőzése vagy csökkentése érdekében folytatott tevékenységet (árvíz előrejelzése, aszály, váratlan vízszennyezés stb.). Kiemelték a delegátusok az éghajlatváltozás vízgazdálkodási hatásainak becslésére szolgáló módszerek fejlesztésének szükségességét.

A jövőben tovább erősödik a hidrológiai szolgálatok szervezeti, anyagi, működési problémái iránti érdeklődés és a problémák megoldása iránti érzékenység. Növekszik a felhasználói szemléletű hidrológiai munka iránti igény. A jövendő feladatokat érintő, valamint az egyes nemzetközi szervezetekkel való együttműködésről szóló magyar hozzászólás kedvező fogadtatásra talált.

A Hidrológiai Bizottság ülése során másfél napot fordítottak egy *tudományos konferenciára*, amelynek témája a „vészhelyzetek hidrológiája" volt. A konferencián a szélsőséges árvizek és aszálykárok hidrológiai problémáival 8 előadás foglalkozott. A baleseti vízszennyezés hidrológiai következményeit 6, a vulkán-kitörések hidrológiai következményeit pedig 3 előadás mutatta be. A földrengések, a föld- és kőcsuszamlás hidrológiai hatásait 4 előadásban taglalták, rendkívül érdekes kőlavináról fölvett film kíséretében. Végül a természetben, így a hazánkban is gyakrabban előforduló gátés árvédelmi töltésszakadás hidrológiai következményeivel 3 előadó foglalkozott. Ez a tudományos konferencia elsősorban arra mutatott rá, hogy a vízzel kapcsolatos katasztrófák mennyire sokoldalúak és hogy észlelésük, előrejelzésük kétségtelenül oly nehéz feladat, amelyre a WMO Hidrológiai Bizottságának megfelelő iránymutatást kell adnia.

A tudományos konferenciának külön jelentőséget adott az, hogy az ENSZ 1990-ben *természeti katasztrófa csökkentési dekádot* indít. A WMO Hidrológiai Bizottsága részéről ez a másfél napos konferencia ennek előkészítését és megalapozását szolgálta. A tudományos konferencián részt vett dr. *Bakonyi* Péter (VITUKI) egy előadással és *Takács* Ágnes (KEI) is, aki hozzászólásában radaros mérések és a mennyiségi csapadékelőrejelzések alkalmazásának fontosságát hangsúlyozta.

Antal E.

A KÖZPONTI LÉGKÖRFIZIKAI INTÉZET AZ EUREKA PROGRAMBAN

Az EUREKA programot 1985. július 17-én jelentették be Párizsban. A program célja az volt, hogy a fejlett technika-technológia területén a vállalatok és kutatóintézetek szorosabb kapcsolata révén növelje az európai tőkés országok iparának, gazdaságának versenyképességét a világpiacon. Mivel az ipari tevékenység és a technológia-fejlesztés elképzelhetetlen a környezeti hatások számbavétele nélkül, az EUREKA-ba egy környezeti kutató programot is belefoglaltak, amely a EUROTRAC *(EUROpean experiment on TRAnsport and transformation of environmentally relevant trace Constituents in the troposphere over Europe)* nevet kapta.

A EUROTRAC egy olyan közös európai környezeti program, amely az emberi tevékenységnek az Európa feletti troposzféra kémiai összetételére gyakorolt hatásait vizsgálja. Ebben a vizsgálatban külön hangsúlyt kap a természetes és antropogén eredetű anyagok légköri terjedése és átalakulása, valamint légkörből való kikerülése. Elsősorban azokról az anyagokról van szó, amelyeknek jelentős a befolyásuk a környezetre, például a savas anyagokról és az oxidánsokról, illetve az ezek képződésében szerepet játszó anyagokról. A EUROTRAC fő célja, hogy bővítse ismereteinket a légköri folyamatokról, a légkör és a bioszféra közötti kapcsolatról, tudományos alapokat adjon a környezetgazdálkodással kapcsolatos politikai döntésekhez és elősegítse a környezetünk állapotának megfigyelésére szolgáló érzékeny műszerek kifejlesztését. A program interdiszciplináris jellegének megfelelően a munkában a legkülönbözőbb szakterületek művelői működnek együtt.

A EUROTRAC Nemzetközi Végrehajtó Bizottsága eddig 11 fő kutatási témát fogadott el. Az Országos Meteorológiai Szolgálat Központi Légkörfizikai Intézete (tudomásunk szerint az egyetlen olyan magyar intézmény, amely részt vesz az EUREKA programban) ezek közül kettőben vesz részt. Az egyik a TOR *(Troposhperic Ozone Research)*, amely a troposzférikus ózonnal kapcsolatos kutatásokat fogja össze. A probléma lényege, hogy ma Európában az átlagos felszínközeli ózon-koncentráció kétszerese a 100 évvel ezelőttinek és jelenleg is évente 1–2%-kal nő. Gyakran alakulnak ki fotokémiai szmog-helyzetek, amelyeket, többek között, a magas ózon-koncentráció jellemez.

A TOR program az ózon keletkezésének és terjedésének elméleti és kísérleti vizsgálatát tekinti fő feladatának. Felszíni, repülőgépes és magaslégköri léggömbös mérések tartoznak a programba, valamint elméleti kutatások, matematikai modellek, amelyek megkísérlik leírni az ózon és egyéb oxidánsok keletkezésének folyamatát és légköri terjedését különböző környezeti feltételek mellett.

A Központi Légkörfizikai Intézet Levegőkémiai osztálya mind a mérési, mind a modellezési feladatokban részt vesz. Mivel Európa alapvetően a nyugatias légáramlások övezetében helyezkedik el, a k-pusztai regionális háttérállomáson végzett mérések közel 300 km-rel növelik meg azt az utat, amelyen a szennyezett levegőben lezajló átalakulások nyomon-követhetők.

A másik kutatási téma a BIATEX *(BIosphere/ATmosphere EXchange)*, amely a bioszféra és a légkör kapcsolatával foglalkozik. A bioszféra a légköri nyomanyagok forrása és nyelője is lehet. Befolyásolja a légkör kémiai összetételét és ezen keresztül hatást gyakorol az oxidánsképződésre, a savasodásra, sőt közvetve a Föld éghajlatára is. A BIATEX egyrészt a bioszférából a légkörbe kerülő, illetve a légkörből a bioszférába jutó anyagok összetételével és mennyiségével, másrészt a kibocsátásért és az elnyelésért felelős folyamatok vizsgálatával foglalkozik. A program méréseket, műszer- és módszerfejlesztést, valamint elméleti kutatásokat tartalmaz.

A Központi Légkörfizikai Intézet Levegőkémiai osztályán régóta folyik a gázok és aeroszol részecskék kiülepedésének vizsgálata. A BIATEX keretében elsősorban a nitrogénvegyületekkel foglalkozunk. Folytatódnak az 1987-ben megkezdett repülőgépes koncentrációprofil mérések és sor kerül a nitrogén-vegyületek légkör és bioszféra közötti fluxusának mérésére is. Sajnos, a BIATEX közös, nemzetközi terepmérésein való részvételünk pénzügyi okok miatt kétséges.

Haszpra L

A XX. ALP-I METEOROLÓGIAI NEMZETKÖZI KONFERENCIA

1988 szeptember 18 és 25 között zajlott le Sestolában, az Észak-Appeninek 1020 m tszf-i magasságban fekvő kis hegyi üdülőhelyén. A konferencia rendezését az Itáliai Meteorológiai Szolgálat vállalta magára, több intézmény anyagi támogatásával.

A konferencia valóban nemzetközi jellegű volt. A külföldiek többsége az Alp-i országokból érkezett, de más európai országokból, sőt más kontinensekről is érkeztek meteorológusok, akik előadásaikkal, hozzászólásaikkal gazdagították a konferenciát.

Az előadások tematikáját az alábbiak szerint csoportosították: 1) általános klimatológia és statisztika; 2) általános szinoptikus meteorológia, beleértve az analízist, előrejelzést, továbbá esettanulmányokat; 3) hó-glaciológia, hidrometeorológia; 4) numerikus modellezés, objektív előrejelzés, ilyen jellegű esettanulmányok; ebben a témakörben hallhattunk az Alpex-eredményeket értékelő, továbbá a planetáris határréteg, kérdéseivel foglalkozó előadásokat is; 5) mezoskálájú rendszerek, nowcasting, s a hozzá kapcsolódó megfigyelési módszerek és berendezések; 6) levegőszennyezés, ill. levegőminőség, sugárzás- és energiaproblémák; 7) hegyvidéki meteorológia, hegyvidéki éghajlati környezet és emberi tevékenység, továbbá biometeorológiai kérdések köre.

Az előadások számát tekintve az 1., a 4. és az 5. témakör volt a leggazdagabb. Az előadások nagy többsége a szakmai igényesség jegyében végzett munkáról tanuskodott, ugyancsak igényesen elkészített szemléltetőanyag, vetített ábrák, diafilmek által kísérve. Az olasz rendezőgárda mind szakmai, mind technikai tekintetben zökkenőmentessé tette az előadások bonyolítását. Négynyelvű szinkrontolmács segítségével mind az előadottak, mind nyomukban a vita, sokszor örvendetesen élénk eszmecsere jól követhető volt.

Az 5) témakörben magyar részről a *Bodolainé Jakus* Emma – *Vissy* Károly: "Untersuchung des Einflusses der Alpen auf die heftigen Sturme herforrufenden Gewitter, in Ungarn, unter Einbeziehung von Satelliten Daten" c előadás hangzott el. Előadója, Vissy Károly olyan speciális időjárási helyzetet demonstrált, amely fölöttébb kedvez a Kárpát-medencében, ismétlődő instabilitási vonalak kialakulásának, de amelynek létrejöttében az Alpoknak blokkoló szerepe van. Az Alpok közelségének a Balaton körzete időjárására gyakorolt hatása adott indokot arra, hogy *Böjti* Béla a magával hozott poszter és színes videofilm segítségével ismertetőt adjon a Siófoki Obszervatórium viharjelző szolgálatáról. E színes bemutató jólesően oldotta az összetettebb kutatások eredményeit komoly figyelemmel követő hallgatóság fáradtságát.

A konferencia szervezői lehetővé tették, hogy a résztvevők kis létszámú csoportokban megtekintsék a Monte Cimene (2165 m tszf) csúcsán működő obszervatóriumot, ahol a hagyományos meteorológiai megfigyeléseken túl légköri ózon és légköri CO_2 mérést is folytatnak.

Az Alp-i konferenciára szánt dolgozatok többségéről a szerzők kétnyelvű összefoglalót küldtek a szervező bizottságnak, a kötetbe foglalt összefoglalókat valamennyi résztvevő megkapta, ezzel is könnyebbé vált az előadások követése.

A konferencián több, nemzetközileg elismert szaktekintély mellett sok fiatal kolléga is résztvett, akiknek a dinamizmusa, jó szakmai fölkészültsége élénk eszmecserékkel, az egyes problémák többszempontú megvilágításával a konferencia szakmai eredményességét növelte. A konferencia nemzetközi jellegét emelte ki az a tény is, hogy a megnyitón résztvett G.O.P *Obasi*, a WMO főtitkára is.

A szakmai rendezésen túl a Sestola-i helyi, továbbá a Modana-i tartományi idegenforgalmi hivatal munkatársai nagy gyakorlattal, gondossággal sokat tettek azért, hogy a vendégek jól érezzék magukat. Szép orgonahangversenyt és a helyi férfikórus előadását hallgatva győződhettünk meg arról, hogy Olaszország ma is a zene művelésének szeretetében él.

Adámyné Koflanovits E.

SZERZŐINK FIGYELMÉBE

Az IDŐJÁRÁS célja az elméleti és alkalmazott meteorológia tárgykörébe tartozó tanulmányok publikálása. A tanulmányok új kutatási eredményeket tartalmazó beszámolók, illetve adott szakterület időszerű kérdéseit összefoglaló kritikai szemlecikkek lehetnek. A közlés nyelve: magyar vagy angol. A kettes sortávolsággal gépelt kéziratok két példányban küldendők be a következő címre: **Időjárás Szerkesztősége 1525 Budapest, Pf. 38.**

A kéziratokat a szerkesztőbizottság lektoráltatja. A lektor nevét a szerzővel nem közöljük. A kéziratnak a következő formai igényeket kell kielégítenie:

Címrész: Tartalmazza a tanulmány címét, a szerző(k) nevét, munkahelyét és ez utóbbi pontos címét.

Összefoglalás: Külön oldalakon, magyar és angol nyelven, tartalmazza a kutatás célját, módszerét és a kapott eredményeket.

Szövegrész: Alcímekkel értelemszerűen fejezetekre tagolandó.

Irodalmi hivatkozások: Szövegben a hivatkozás tartalmazza a szerző(k) nevét aláhúzva és a publikálás évét. Pl. egyetlen szerző esetén: *Róna* (1909), vagy ha a szerző neve a szövegbe nem illeszthető be: *(Róna,* 1909); két szerző esetén: *Gamow* és *Cleveland* (1973); több szerző esetén: *Bacsó* et al., (1953). Ha adott szerzők ugyanazon évben publikált több cikkére hivatkozunk, akkor az évszámhoz *a, b* stb. betűket írunk. Az irodalom felsorolása a **cikk végén a** szerző(k) neve szerinti betűrendben történik. Folyóirat esetén: szerző(k) neve, évszám, a cikk címe, a folyóirat neve, kötetszám, kezdő és befejező oldalszám. Pl.: *Dési, F.*, 1955: A meteorológiai kutatás időszerű kérdései. *Időjárás 57*, 65–70. Könyv esetén: Szerző(k) neve, évszám, könyvcím, kiadó, megjelenés helye. Pl. *Junge, C. E.*, 1963: *Air chemistry and radioactivity*. Academic Press, New York and London.

Ábrák: A kézirat első példányához az ábrákat pausz- vagy mm-papíron, a másodikhoz az eredeti ábrák másolatát kell csatolni. Az ábrák aláírásait külön lapon kell mellékelni. Fényképek fekete-fehér színben, fényes, kontrasztos minőségben nyújthatók be.

Táblázatok: A táblázatokat arab számozással, szövegükkel együtt, külön lapon kell mellékelni.

Matematikai formulák és jelölések: A nem latin betűket és kézzel írott jeleket a margón ceruzával írt magyarázattal kell ellátni.

A szerzők megjelent tanulmányukért tiszteletdíjat és térítésmentesen 30 db **különlenyomatot** kapnak. Több különlenyomat a szerző költségére a kézirat elküldésével egyidejűleg rendelhető.

NOTES TO THE AUTHORS

The purpose of IDŐJÁRÁS is to publish papers in the field of theoretical and applied meteorology. These may be reports on new results of scientific investigations or critical review articles summarizing current problems in certain subject. Authors may be of any nationality but papers are published only in Hungarian or English. Two copiees of the manuscripts, typed with double space, should be sent to the **Editorial Office of Időjárás.** Address: **Budapest, P. O. B. 38. H-1525, Hungary.**

Papers will be subjected to constructive criticism by unidentified referees.

The manuscript should meet the following formal requirements:

Title: Should contain the title of the paper, the name(s) of the author(s) with indication of the name and address of employment.

Abstract: Should contain the aim, method and conclusions of the scientific investigation on a separate page.

References: The text citation should contain the name(s) of the author(s) underlined and the year of publication. In case of one author: *Róna* (1909), or of the name of the author cannot be fitted into the text: *(Róna,* 1909); in case of two authors: *Gamow* and *Cleveland* (1973); there are more than two authors: *Bacsó* et al. (1953). When referring to several papers published in the same year by the same author, the year of publication should be followed by letters, *a, b* etc. At the end of the paper the list of references should be arranged alphabetically. For an article: the name(s) of author(s), year, title of article, name of journal, volume number, pages. E. g. *Dési, F.* 1955: Current problems of meteorological research. *Időjárás 57*, 65–70. For a book: the name(s) of author(s), year, title of book, publisher, place of publication. E. g. *Junge, C. E.*, 1963: *Air chemistry and radioactivity*. Academic Press, New York and London.

Figurens: Should be prepared entirely in black India ink upon transparent paper and be attached to the first copy of the manuscript; a copy of the original figures should be attached to the second manuscript copy. The legends of figures should be given on a separate sheet. Photographs of good quality may be provided in black and white.

Tables: Should be marked by Arab numbers and provided on separate sheets together with relevant captions.

Mathematical formulas and symbols: Non-Latin letters and hand-written marks should be explained by making marginal notes in pencil.

Authors are receiving 30 **reprints** free of charge. Additional reprints may be ordered at the authors expense when submitting the manuscript.

AZ ORSZÁGOS METEOROLÓGIAI SZOLGÁLAT FOLYÓIRATA

A szerkesztésért felel: dr. Mészáros Ernő
Szerkesztőség: 1024 Budapest, Kitaibel Pál utca 1.
Levélcím: 1525 Budapest, Pf. 38. Tel.: 353-500
Kiadja a Pallas Lap- és Könyvkiadó Vállalat, Budapest VII., Lenin körút 9—11. Telefon: 221-285
Levélcím: 1906 Budapest, Pf. 223
Felelős kiadó: Siklósi Norbert vezérigazgató
88.1976., Állami Nyomda, Budapest
Felelős vezető: Mihalek Sándor igazgató

INDEX: 26 361

HU ISSN 0324—6329