

IDŐJÁRÁS

QUARTERLY JOURNAL
OF THE HUNGARIAN METEOROLOGICAL SERVICE

CONTENTS

<i>I. Szunyogh</i> : The dynamics of a shallow-water flow over topography. Part II. Numerical experiments	147
<i>S. F. Rajšić</i> and <i>Z. B. Vukmirović</i> : An application of multi-regression model for evaluation of precipitation chemistry	163
<i>A. Molnár</i> , <i>L. Makra</i> , <i>Chen Yaning</i> and <i>I. Borbély-Kiss</i> : Some data on the elemental composition of atmospheric aerosol particles in Xinjiang, NW China . . .	173
<i>L. Horváth</i> , <i>Gy. Baranka</i> and <i>E. Gy. Führer</i> : Decreasing concentration of air pollutants and the rate of dry and wet acidic deposition at the three forestry monitoring stations in Hungary	179
<i>I. Örményi</i> : An advanced traffic accident forecasting technique based on weather sensitivity of drivers	187
Book reviews	201
News	204
Contents of journal Atmospheric Environment Vol. 27A Nos. 8-12	206

IDŐJÁRÁS

Quarterly Journal of the Hungarian Meteorological Service

Editor-in-Chief
E. MÉSZÁROS

Editor
T. TÁNCZER

Technical Editor
Mrs. M. ANTAL

EDITORIAL BOARD

<i>ANTAL, E. (Budapest)</i>	<i>MAJOR, G. (Budapest)</i>
<i>BOTTENHEIM, J. (Downsview, Ont.)</i>	<i>MILOSHEV, G. (Sofia)</i>
<i>CZELNAI, R. (Budapest)</i>	<i>MÖLLER, D. (Berlin)</i>
<i>DÉVÉNYI, D. (Budapest)</i>	<i>PANCHEV, S. (Sofia)</i>
<i>DRÁGHICI, I. (Bucharest)</i>	<i>PRÁGER, T. (Budapest)</i>
<i>FARAGÓ, T. (Budapest)</i>	<i>PRETEL, J. (Prague)</i>
<i>FISHER, B. (London)</i>	<i>PRUPPACHER, H.R. (Mainz)</i>
<i>GEORGII, H.-W. (Frankfurt a. M.)</i>	<i>RÁKÓCZI, F. (Budapest)</i>
<i>GÖTZ, G. (Budapest)</i>	<i>RENOUX, A. (Paris-Créteil)</i>
<i>HAMAN, K. (Warsaw)</i>	<i>ŠAMAJ, F. (Bratislava)</i>
<i>HASZPRA, L. (Budapest)</i>	<i>SPÄNKUCH, D. (Potsdam)</i>
<i>IVÁNYI, Z. (Budapest)</i>	<i>STAROSOLSZKY, Ö. (Budapest)</i>
<i>KALNAY, E. (Washington, D.C.)</i>	<i>VARGA-HASZONITS, Z. (Budapest)</i>
<i>KOLB, H. (Vienna)</i>	<i>WILHITE, D.A. (Lincoln, NE)</i>
<i>KONDRATYEV, K.Ya. (St. Petersburg)</i>	<i>WIRTH, E. (Budapest)</i>

Editorial Office: P.O. Box 39, H-1675 Budapest

*Subscription from customers in Hungary should be sent to the
Financial Department of the Hungarian Meteorological Service
Kitabel Pál u. 1, 1024 Budapest.
The subscription rate is HUF 2000.*

*Abroad the journal can be purchased from the distributor:
KULTURA, P.O. Box 149, H-1389 Budapest.
The annual subscription rate is USD 56.*

IDŐJÁRÁS

Quarterly Journal of the Hungarian Meteorological Service
Vol. 97, No. 3, July–September 1993

The dynamics of a shallow-water flow over topography Part II. Numerical experiments

I. Szunyogh

*Department of Meteorology, Eötvös Loránd University,
Ludovika tér 2, H-1083 Budapest, Hungary*

Abstract—If a numerical approximation to the shallow-water system of equations conserves the total energy and the potential enstrophy, the purely rotational interactions will satisfy the Liouville theory of statistical physics. It means that in the absence of divergent vorticity forcing (energy flow from the divergent part to the rotational part of the kinetic energy), the rotational kinetic energy evolves toward a two-dimensional equilibrium. The divergent forcing is controlled by the conservation of potential enstrophy, thus the two-dimensional approximation well describes the temporary spectral distribution of the rotational kinetic energy. In order to examine the acting processes, numerical experiments were carried out by a well-known kinetic energy and potential enstrophy conserving scheme, which takes into consideration the effect of the bottom topography. The numerical model was integrated for sinusoidal-shaped, but different maximum-height topographies until the “energy catastrophe”.

In the presented experiments, the quasi-two-dimensional constraints cannot control the rotational kinetic energy of the wavenumbers higher than five. This fact leads to the “energy catastrophe”, which occurs when the divergent kinetic energy approaches an equipartition among the higher wavenumbers, and in this way, the time of the “energy catastrophe” is approximately independent of the height of the topography. These results show that the main cause of the energy catastrophe in a discretized Eulerian model is the restricted number of the potential vorticity type invariants in addition to the absence of the parametrization of the subgrid processes.

Key-words: Liouville theory, quasi-two-dimensional equilibrium of the rotational kinetic energy, equipartition of the divergent kinetic energy, energy catastrophe.

1. Introduction

In the first part of this paper (Szunyogh, 1993b, hereafter referred to as Part I) the quasi-two-dimensional behavior of the shallow-water flows has been examined from a theoretical point of view. It has been shown that the conservation of potential vorticity type invariants plays a principal role in the control of the vorticity type quantities. The most important invariant of this type

is the potential enstrophy, which provides the quasi-conservation of the enstrophy for properly chosen initial conditions. For these initial conditions in a given period of time the shallow-water flows possess quasi-two-dimensional features.

In Part I, it was supposed that the rotational kinetic energy evolves toward a two-dimensional equilibrium, which is determined by the temporary value of the rotational kinetic energy and the enstrophy. However, this consideration is valid only in the case when the purely rotational interactions satisfy the Liouville theory of statistical physics. It is well-known that the necessary condition in Liouville theory is satisfied in the continuous case (*Kraichnan, 1975*), but it is not straightforward in the case of the finite-difference equations. In *Section 2*, it will be shown that if a numerical scheme conserves the total energy and the potential enstrophy for a nondivergent shallow-water flow, the above condition is satisfied and considerations of Part I can be applied to numerical models. For the sake of more detailed examination of the acting processes, numerical experiments are carried out by a numerical scheme suggested by *Arakawa and Lamb (1981)*. This scheme conserves the total energy and the potential enstrophy even if the effects of the mass-divergence and the bottom topography are taken into account. The only problem is that higher moments of the potential vorticity are not conserved, or, in other words, the individual conservation of the potential vorticity is violated, but this is an avoidable error of Eulerian numerical schemes (*Szunyogh, 1993a*). The general description of the experiments is presented in *Section 3*, and the results are demonstrated in *Section 4*. Finally, *Section 5* summarizes the main conclusions of both parts of this paper.

2. How to choose the numerical scheme?

Eq. (Part I. 17.a) can be rewritten in the form

$$\frac{\partial \zeta}{\partial t} = \partial(\zeta + f, \Delta^{-1} \zeta) + DF, \quad (1)$$

where the term

$$DF = -(\zeta + f) \delta \quad (2)$$

is the divergent vorticity forcing. According to Eq. (1), in the absence of forcing ($DF=0$) the time evolution of the rotational kinetic energy is governed by the equation

$$\frac{\partial \zeta}{\partial t} = \partial(\zeta + f, \Delta^{-1} \zeta). \quad (3)$$

In the continuous case the spectral form of Eq. (3) satisfies the Liouville theory via the satisfaction of the necessary condition

$$\frac{\partial}{\partial \zeta_k} \left(\frac{\partial \zeta_k}{\partial t} \right) = 0, \quad (4)$$

for all k , where ζ_k denotes the components of the prognostical vector variable in the spectrally transformed Eq. (3) (for the exact definition of ζ_k see *Kraichnan, 1975; Basdevant and Sadourny, 1975*), and the rotational kinetic energy evolves toward a two-dimensional equilibrium. However, for discretized model equations the condition (4) is not satisfied automatically, and the important question arises whether it is possible to find a numerical scheme which satisfies the Liouville theory.

In the following, it is shown that the condition (4) is held if the applied finite-difference scheme conserves the rotational kinetic energy and the enstrophy for flows satisfying the condition $DF(t)=0$. Discretizing the Eq. (3) by a finite-difference scheme in the the first step, and transforming the discretized system of equations by a discrete Fourier transformation in the second step, the system of governing equations takes the form

$$\frac{\partial \zeta_i}{\partial t} = \sum_j \sum_k c_{i,j,k} K_j^{-2} \zeta_j \zeta_k, \quad i, j, k = 1, \dots, N^2 + 2N, \quad (5)$$

where the wavenumbers (sometimes referred to as pseudo-wavenumbers) K_j ($j=1, \dots, N^2+2N$) are defined by the eigenvalues K_j^2 of the finite-difference Laplacian, which is used for the approximation to term $\Delta^{-1}\zeta$, while the coefficients $c_{i,j,k}$, ($i, j, k=1, \dots, N^2+2N$) are depending on the numerical approximation applied to the two-dimensional Jacobian $\partial(\dots)$ (for further details see Appendix). In this way, the Liouville theory is satisfied if

$$\forall i, k \quad (i, k = 1, \dots, N^2 + 2N): c_{i,i,k} = 0, \quad (6.a)$$

$$\forall i, j \quad (i, j = 1, \dots, N^2 + 2N): c_{i,j,i} = 0. \quad (6.b)$$

Under the conditions

$$E_{rot} = \sum_{m=-N/2}^{N/2} \sum_{l=-N/2}^{N/2} (\nabla \Delta^{-1})_{m,l}^2 = const, \quad (7.a)$$

$$Z = \sum_{m=-N/2}^{N/2} \sum_{l=-N/2}^{N/2} \zeta_{m,l}^2 = const, \quad (7.b)$$

if $DF(t)=0$, the system of spectral Eq. (5) conserves both the rotational kinetic

energy and the enstrophy, since the quadratic quantities satisfy the following equalities:

$$\sum_{m=-N/2}^{N/2} \sum_{l=-N/2}^{N/2} (\nabla \Delta^{-1} \zeta)_{m,l}^2 = 2 \sum_{i=0}^{N^2+2N} (\nabla \Delta^{-1} \zeta)_i^2, \quad (8.a)$$

$$\sum_{m=-N/2}^{N/2} \sum_{l=-N/2}^{N/2} \zeta_{m,l}^2 = 2 \sum_{i=0}^{N^2+2N} \zeta_i^2, \quad (8.b)$$

where the rotational kinetic energy and enstrophy of the system of Eq. (5) are defined by the right-hand side of Eq. (8.a) and Eq. (8.b), respectively. However, the conditions (7.a) and (7.b) are held for a given system of discretized equations if and only if

$$\forall i, j, k \ (i, j, k = 1, \dots, N^2+2N): c_{i,j,k} = -c_{k,j,i}, \quad (9.a)$$

$$\forall i, j, k \ (i, j, k = 1, \dots, N^2+2N): c_{i,j,k} = -c_{i,k,j}, \quad (9.b)$$

respectively (Szunyogh, 1993a). From (9.a)

$$\forall i, j \ (i, j = 1, \dots, N^2+2N): c_{i,j,i} = -c_{i,j,i} = 0, \quad (10.a)$$

while from Eq. (9.b) and (10.a)

$$\forall i, k \ (i, k = 1, \dots, N^2+2N): c_{i,i,k} = -c_{i,k,i} = 0, \quad (10.b)$$

which implies that the condition (4) is satisfied according to (6.a) and (6.b).

When the numerical scheme conserves the total energy and the potential enstrophy for the whole system of shallow-water equations, the rotational kinetic energy and the enstrophy are conserved quantities for flows satisfying the condition $DF(t)=0$. Therefore, for these schemes the purely rotational interactions satisfy the Liouville theory and the rotational kinetic energy spectrum can change only as a result of the divergent vorticity forcing. However, it is worth to mention that the condition in the above presented statement is valid even for a much wider group of the numerical schemes than the group of the potential enstrophy and the total energy conserving schemes. On the other hand, the conservation of the potential enstrophy together with the conservation of the total circulation provide a realistic (continuous-type) control for the enstrophy via Eq. (Part I. 23).

Summarizing, a total circulation, potential enstrophy, and total energy conserving scheme is an optimal model to investigate the spectral energetics of

a shallow-water flow in the sense that it provides the quasi-conservation of enstrophy in addition to the satisfaction of the Liouville theory for the purely rotational interactions.

3. Numerical experiments

Numerical experiments were carried out by a finite-difference scheme which conserves the total energy, the circulation and the potential enstrophy (Arakawa and Lamb, 1981); therefore this model satisfies the optimum condition which was derived in the previous section. The domain used in numerical experiments is bounded by $x, y = 0$ km, and $x, y = 1920$ km, where cyclic boundary conditions are applied in both directions. The Coriolis parameter f is $10^{-4} s^{-1}$, and the acceleration of gravity g is $9.8 ms^{-2}$. The bottom topography is sinusoidal-shaped and generates divergent kinetic energy only at the wavenumber $K=1$. Experiments were carried out with three different maximum-height bottom topographies: $h_{smax} = 1$ km, 2 km, 3 km. The grid size in every experiments is $d=60$ km. The time derivative is approximated by leap-frog differencing and Heun scheme in the first and once in every 50 time steps, while the time interval is $\Delta t=1$ min. The initial condition is a uniform zonal current of 10 m/s with $h(x, y, t_0) = 5$ km height of the free surface. It should be mentioned that for these initial conditions $DF(t_0) = 0$, but $\partial DF / \partial t(t_0) \neq 0$.

In both three experiments, the governing equations were integrated until the "energy catastrophe", when the numerical invariance of the total energy and the potential enstrophy is violated. The computation has broken down after 6200, 6100, and 5700 steps for $h_{smax} = 1$ km, 2 km, and 3 km, respectively, as a consequence of overflow errors.

In order to compute the detailed spectral distribution of kinetic energy, the velocity field was splitting into its rotational and divergent parts \vec{v}_r , and \vec{v}_d . Computing double discrete Fourier transforms of \vec{v}_r , and \vec{v}_d , the rotational and divergent kinetic energy spectra may be evaluated by

$$E_{rot}(K) = \vec{v}_r^2(K), \quad (11.a)$$

$$E_{div}(K) = \vec{v}_d^2(K), \quad (11.b)$$

respectively, where the wavenumber K is defined by the eigenvalues of the finite-difference central Laplacian as

$$K^2(p, q) = (N/\pi)^2 (\sin^2[p\pi/N] + \sin^2[q\pi/N]). \quad (12)$$

In order to describe phase errors associated with Eq. (12), the number of modes in wavenumber bands of unit width related to Eq. (12) may be computed and

the result of this computation can be found elsewhere (Bennett and Middleton, 1983; Szunyogh, 1992).

On purpose to describe more accurately the spectral changes of energy, the energy of individual modes were summed in each wavenumber bands of unit width, thus figures of this paper show the so-called band-summed energy spectra. However, in the case of the spectral computations the time evolution of the energy is presented only for $h_{smax}=3$ km, because of the strong similarity to the other cases.

4. Results and discussion

The time evolution of kinetic energy (Fig. 1) shows periodic changes in the first 5000 timesteps, but, as it can be seen, the amplitude of the changes is a function of the maximum height of topography. However, in this first period, the frequency and the amplitude of the energy oscillation do not change for a given experiment and the numerical instability occurs accidentally in the model in all three cases. Control computations have shown that in the first period of the sudden energy increase the model could allow the conservation of total energy and potential enstrophy, thus these conservation laws were violated only in the last few timesteps as a result of the numerical instabilities.

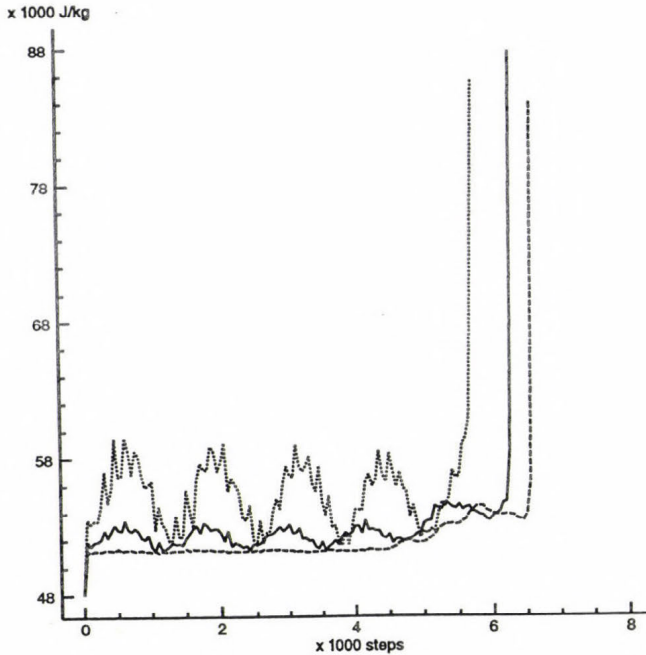


Fig. 1. Time evolution of the total kinetic energy for the different maximum height topographies (.....: $h_{smax}=3$ km, ———: $h_{smax}=2$ km, - - - - -: $h_{smax}=1$ km).

Examination of the time evolution of kinetic energy is a proper way to detect main energetical changes in the model, but in this way we cannot obtain information about the causes leading to the sudden increase of the kinetic energy. Therefore, for the sake of deeper understanding of acting processes, time evolution of the rotational and divergent parts of kinetic energy (Fig. 2, and Fig. 3) have been computed. It can be seen that the rotational kinetic energy shows the same periodic changes as the total kinetic energy, which is not surprising if we take into consideration that the rotational part of the kinetic energy is at least three orders of magnitude higher than the divergent part of the kinetic energy. On the other hand, the divergent part of the kinetic energy shows higher frequency changes and the strong increase is started about after 5000 timesteps. In addition, it can be stated that the time evolution of the different types of energy is very similar for the different height topographies. More accurately, although there are considerable differences between the amplitudes of changes, there are no significant differences between the frequencies and the times of the energy catastrophe.

According to the earlier theoretical considerations (Part I) it can be expected that the sudden rotational kinetic energy increase is started when the quasi-two-dimensionality of the flow is violated. Taking into account the above mentioned theoretical considerations, the best index parameter of the quasi-two-dimension-

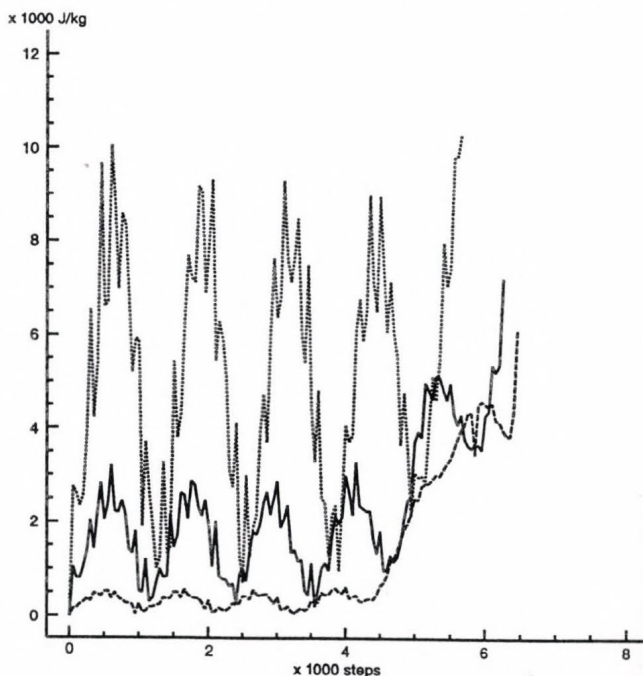


Fig. 2. Time evolution of the rotational part of the kinetic energy for different maximum height topographies. The meaning of the lines is the same as in Fig. 1.

ality is the average wavenumber whose time evolution is presented in Fig. 4. The model shows two-dimensional time evolution until the “energy catastrophe” since the average wavenumber remains under the value $K_1=2$, which defines an extremely stable “negative temperature” equilibrium for the spectral distribution of the rotational kinetic energy (Szunyogh, 1992). This means that the statistical mechanics of shallow-water flows are controlled by two-dimensional constraints, which provides extreme stability of the model in a statistical mechanical sense.

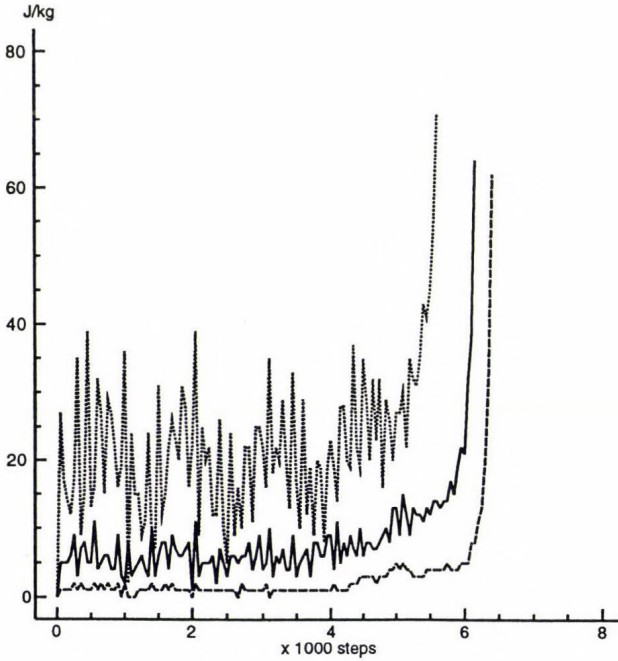


Fig. 3. Time evolution of the divergent part of the kinetic energy for the different maximum height topographies. The meaning of the lines is the same as in Fig. 1.

Since the applied numerical scheme provides the conservation of the the enstrophy and rotational kinetic energy in the absence of the divergent processes, purely rotational interactions cannot change the average wavenumber. In other words, the only effect which can produce an increase of the average wavenumber is the divergent vorticity forcing. More accurately, this forcing can increase the average wavenumber if it produces rotational kinetic energy at wavenumbers higher than the temporal average wavenumber of the flow. More specifically, average wavenumber changes are governed by spectral characteristics of the term $DF(t)$. In the presented experiments, at the first step the term $DF(t)$ is zero due to the initial conditions, thus there is no rotational

kinetic energy forcing. However, beginning with the next step the forcing term differs from zero since the topography necessarily produces divergence according to Eq. (Part I.17.b). The term $DF(t)$ is nonlinear as it can be seen from Eq. (2), therefore it can exchange the rotational and the divergent kinetic energy between different scales of rotational and divergent motions. It means that the divergent motion of a given wavenumber can produce rotational motions which is related to a higher wavenumber than the divergent process itself. This statement is valid only in the presence of rotational motions in the flow which can be described by wavenumbers higher than zero. In the presented

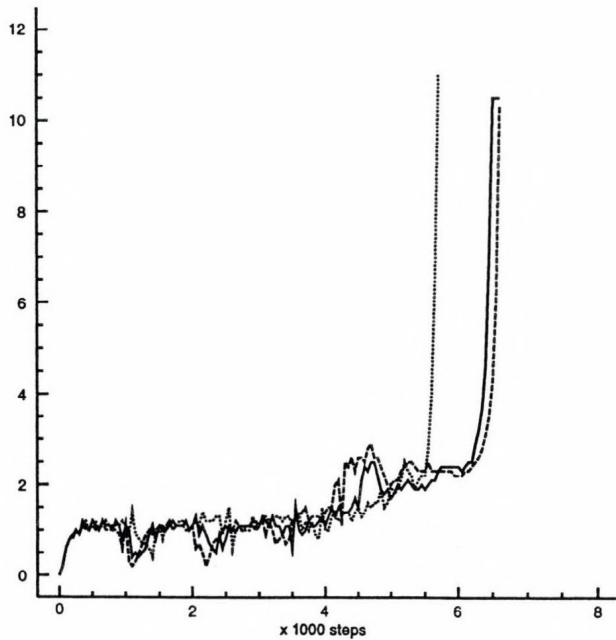


Fig. 4. Time evolution of the average wavenumber for the different height topographies.
The meaning of the lines is the same as in Fig. 1.

experiments, the initial forcing occurs at the wavenumber $K=1$ (due to the spectral characteristics of the topography), while there are no rotational motions associated with wavenumbers higher than zero (due to the initial conditions for the velocity components). In this way, the rotational energy is forced under the wavenumber two. Unfortunately, this is true only in the first few steps since, as it was stated in Part I, the divergent kinetic energy evolves toward an equipartition among the wavenumber modes. It follows that the divergent kinetic energy flows to the higher wavenumbers independently of the wavenumber, where the divergent energy is fed into the model. The validity of

these ideas has been verified for our experiments (Fig. 5). In the first period, the divergent kinetic energy has only one spectral maximum near the wavenumber $K=1$, which is the scale of the orographical forcing. The divergent kinetic energy flows to the higher wavenumbers and a secondary spectral maximum is built up at the ninth wavenumber band. It indicates that the divergent kinetic energy is approaching to the equipartition at the higher wavenumbers since, as a consequence of the phase errors, the number of wavenumber modes is the highest in the ninth wavenumber band (Szunyogh, 1992). After 5700 timesteps (in the immediate vicinity of the energy catastrophe) the divergent kinetic energy is distributed equipartitionally at the wavenumbers higher than $K=5$, and the secondary maximum appears at the scale of the orographical forcing.

As a result of the above described process, rotational kinetic energy is forced at the higher wavenumbers. In order to investigate this process quantitatively, time evolution of the rotational kinetic energy has been computed

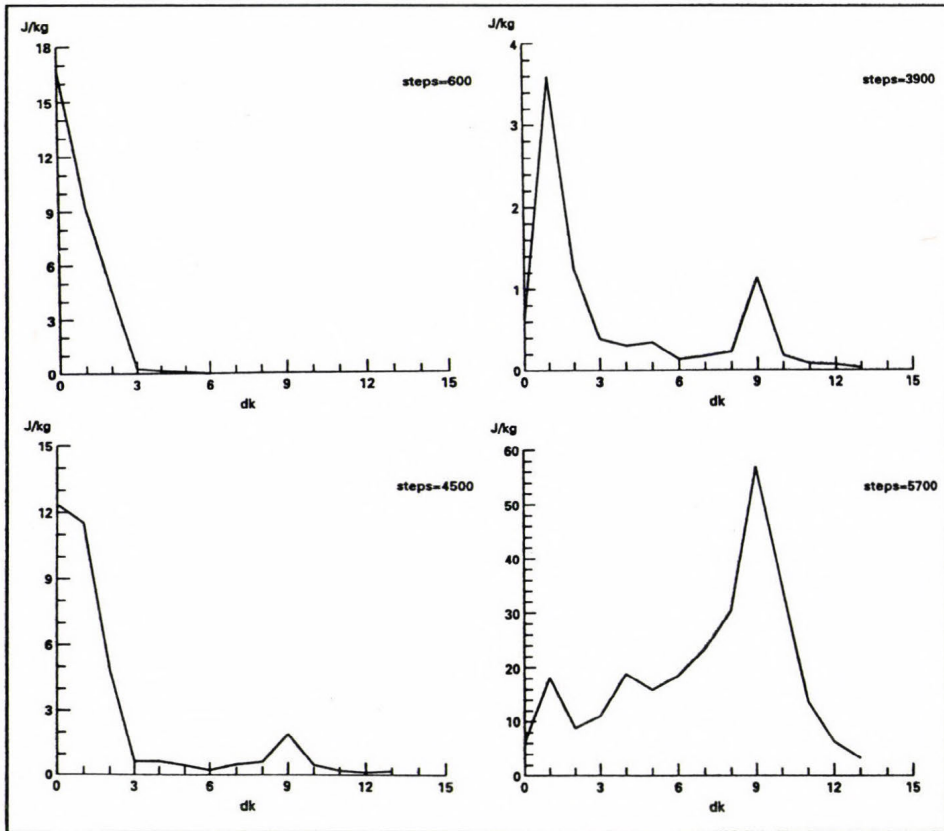


Fig. 5. Spectral distribution of the divergent kinetic energy for timesteps, when the kinetic energy is extremely high. The parameter $h_{smax}=3$ km.

for each wavenumber band and the results are presented in *Fig. 6* for some selected wavenumber bands. Since the magnitude of the divergence (or divergent energy) is much less than the magnitude of the rotational kinetic energy, rotational kinetic energy of the higher wavenumbers is very low and practically negligible in the first period but, as it can be seen, the invariance of the average wavenumber (which is the strongest two-dimensional constraint) has no influence on the rotational kinetic energy of the wavenumbers higher than $K=5$. After the well-balanced first period the rotational kinetic energy of the higher wavenumbers starts to increase suddenly as a consequence of the strongly nonlocal (and so extremely effective) two-dimensional rotational interactions. At the end, the sudden rotational kinetic energy increase leads to the "energy catastrophe". It should be mentioned that the fastest kinetic energy increase can be observed in the ninth wavenumber band due to the highest number of the wavenumber modes. This fact confirms the statement that phase errors and aliased interactions (which amplify the effects of the phase errors) play an important role in statistical mechanics (or, in other words, in the spectral energetics) of the finite-difference models of the atmosphere.

5. Conclusions

It has been shown that the Eulerian shallow-water system of equations shows quasi-two-dimensional behavior as a consequence of the conservation of potential enstrophy and total circulation. Validity of the theoretical considerations has been verified by numerical experiments. The applied numerical scheme is optimal for investigating the spectral energetics of the shallow-water system in the sense that it provides the conservation of the potential enstrophy, the total circulation and satisfies the Liouville theory for purely rotational interactions. The experiments have revealed that the time of the "energy catastrophe" is closely independent of the maximum height of the topography. This fact indicates that the principal cause of the energy catastrophe is the development of the unstable energy distribution, while the amplitude of the energy oscillation plays only a secondary role. This means that the shape of the topography plays a more important role in the development of the numerical instabilities than the height of the topography. In the first period of the model integration the spectral characteristics of the topography play a predominant role in the spectral distribution of divergent kinetic energy. However, after this first period (in the presented experiments after 5000 timesteps) the shape of the divergent kinetic energy spectrum becomes independent of the spectral characteristics of the initial conditions and this fact necessarily leads to "energy catastrophe".

The presented results are in a good accordance with the well-known fact that long-term numerical integrations of the shallow-water equations require the control of the high-frequency divergent perturbations (by normal-mode initial-

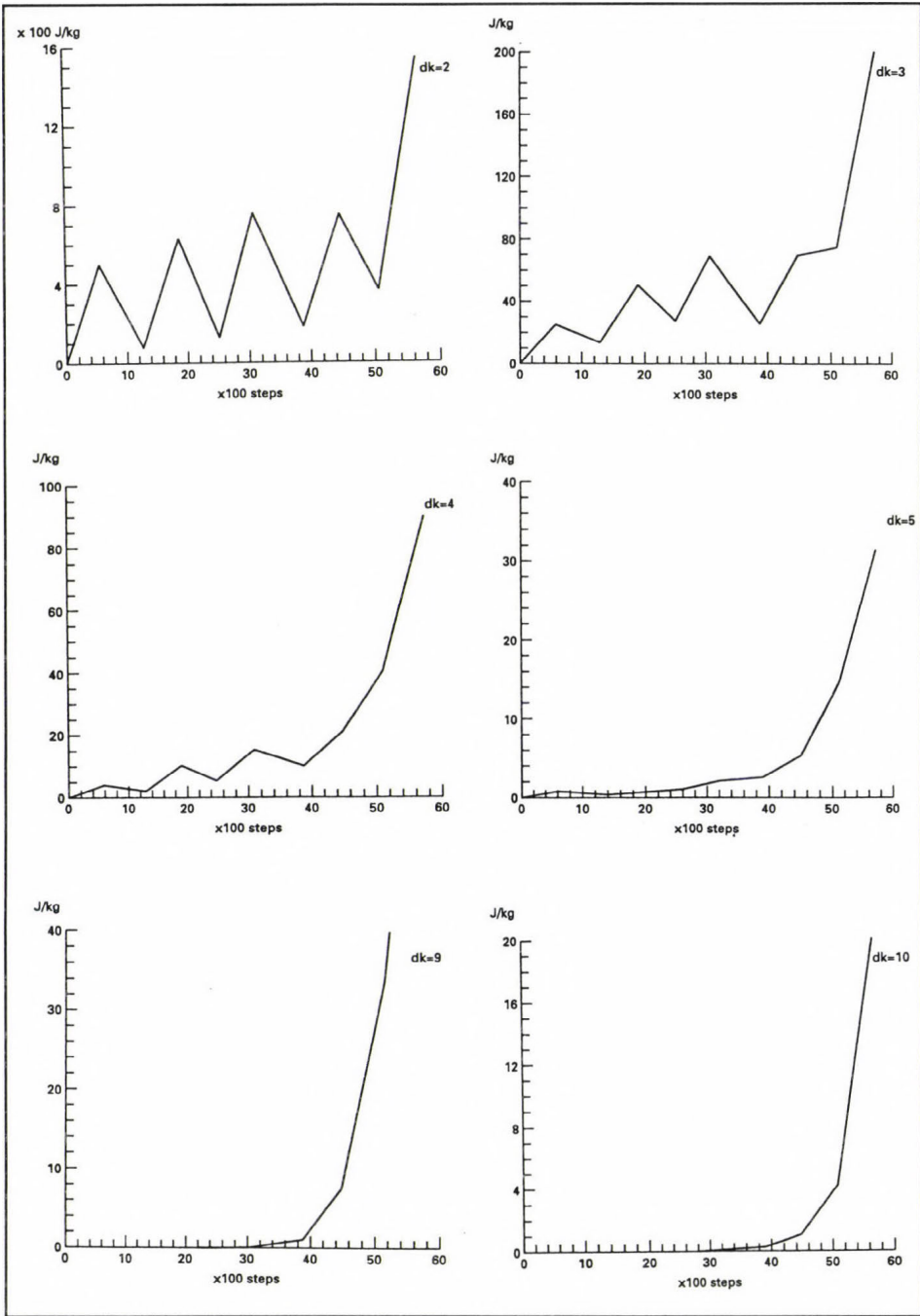


Fig. 6. Time evolution of the rotational kinetic energy for some selected wavenumber bands dk .
The parameter $h_{smax}=3$ km.

ization or with the introduction of artificial viscosity). However, it must be stated that the absence of realistic parametrization of the subgrid physical processes is not the only cause of the existence of uncontrolled high-frequency perturbations as it is considered in many papers. Namely, discretization of the Eulerian fluid dynamical equations necessarily restricts the infinite number of the independent potential vorticity type invariants (the infinite number of the independent constraints) to one or two invariants. In other words, taking into consideration the relation between the vorticity-type integral (Casimir) invariants in the Eulerian form of the equations and the individual invariants in the Lagrangian form of the equations (Shepherd, 1990), discretizations of the Eulerian equations necessarily violate the individual conservation laws. For instance, in the presented experiments the conservation of total circulation and potential enstrophy could not control the disturbances whose spatial frequency was higher than $K=5$.

Finally, the above considerations call the attention to danger of the method trying to describe the long-term behavior of the atmosphere on the basis of numerical experiments, which are carried out by extremely low-resolution numerical models. These models are discretized, strongly truncated Eulerian models which are really far from the simulated continuous physics with individual conservation laws. In addition, the spectral energetics of these models cannot be controlled by two-dimensional constraints since do not possess statistical mechanical equilibrium states because of the strongly limited number of interactions.

References

- Arakawa, A. and Lamb, R.V., 1981: A potential enstrophy and energy conserving scheme for the shallow water equations. *Mon. Wea. Rev.* 109, 18-36.
- Basdevant, C. and Sadourny, R., 1975: Ergodic properties of inviscid truncated models of two-dimensional incompressible flows. *J. Fluid Mech.* 69, 673-688.
- Bennett, A.F. and Middleton, J.F., 1983: Statistical mechanics of a finite-difference approximation to the barotropic vorticity equation. *Quart. J. Roy. Meteorol. Soc.* 109, 795-808.
- Kraichnan, R.H., 1975: Statistical dynamics of two-dimensional flow. *J. Fluid Mech.* 67, 155-175.
- Shepherd, T.G., 1990: Symmetries, conservation laws, and Hamiltonian structure in geophysical fluid dynamics. *Adv. Geophys.* 32, 287-338.
- Szunyogh, I., 1992: Statistical mechanics of inviscid truncated models of two-dimensional incompressible flows. *Időjárás* 96, 22-31.
- Szunyogh, I., 1993a: Finite-dimensional quasi-Hamiltonian structure in simple model equations. *Meteorol. Atmos. Phys.* 52, 49-57.
- Szunyogh, I., 1993b: The dynamics of a shallow-water flow over topography. Part I. Theory. *Időjárás* 97, 73-85.

APPENDIX

Using an arbitrary finite-difference scheme to discretize Eq. (3) the model equations can be written as

$$\frac{\partial \zeta_{l,m}}{\partial t} = \partial_{l,m}(\zeta + f, \Delta^{-1} \zeta), \quad -N/2 \leq l, m \leq N/2, \quad (\text{A.1})$$

where l and m denote the position of the gridpoints in each direction, and $\partial_{l,m}(\cdot, \cdot)$ is the finite-difference approximation to the two-dimensional Jacobian. On the finite-difference grid the two-dimensional discrete Fourier transformation is defined by

$$\zeta_{p,q} = \frac{1}{(N+1)^2} \sum_{m=-N/2}^{N/2} \sum_{l=-N/2}^{N/2} \zeta_{m,l} e^{i(pm+ql)}, \quad (\text{A.2})$$

where the spectral coefficients $\zeta_{p,q}$ satisfy the following relation:

$$\zeta_{m,l} = \sum_{p=-N/2}^{N/2} \sum_{q=-N/2}^{N/2} \zeta_{p,q} e^{-i(pm+ql)}. \quad (\text{A.3})$$

Taking into account Eq. (A.2) and Eq. (A.3), the system of complex spectral equation is

$$\frac{\partial \zeta_{p,q}}{\partial t} = \partial_{p,q}(\zeta + f, \Delta^{-1} \zeta), \quad (\text{A.4})$$

where $\partial_{p,q}(\cdot, \cdot)$ is the spectrally transformed form of the finite-difference Laplacian $\partial_{l,m}(\cdot, \cdot)$. Using the conservation of total circulation and the assumption $f = \text{const}$, the variable $\zeta_{0,0}$ becomes independent of time, thus it can be removed from the prognostical vector variable. Moreover, since the grid values are real, the spectral coefficients satisfy the relation

$$\zeta_{p,q} = \zeta_{-p,-q}^*, \quad (\text{A.5})$$

where the star denotes the complex conjugate. It means that only $N^2 + 2N$ variables are independent of the $2(N+1)^2$ prognostical variables in Eq. (4). According to this fact a new vector variable can be introduced, whose components are defined by the following index transformation:

$$\begin{aligned} \zeta_{P,Q} &:= \text{Re}(\zeta_{p,q}) = \text{Re}(\zeta_{-p,-q}), \\ \zeta_{P',Q'} &:= \text{Im}(\zeta_{p,q}) = -\text{Im}(\zeta_{-p,-q}), \\ -N/2 \leq P \leq N/2; \quad 0 \leq Q \leq N/2. \end{aligned}$$

$$(\zeta_1, \zeta_2, \dots, \zeta_{N^2+2N}) = (\zeta_{-N/2,0}, \dots, \zeta_{N/2,N/2}, \zeta_{-N/2',0}, \dots, \zeta_{N/2',N/2'}). \quad (\text{A.6})$$

Using this notation, Eq. (A.4) takes the form

$$\frac{\partial \zeta_i}{\partial t} = \sum_{j=1} \sum_{k=1} c_{i,j,k} K_j^{-2} \zeta_j \zeta_k, \quad i, j, k = 1, \dots, N^2 + 2N, \quad (\text{A.7})$$

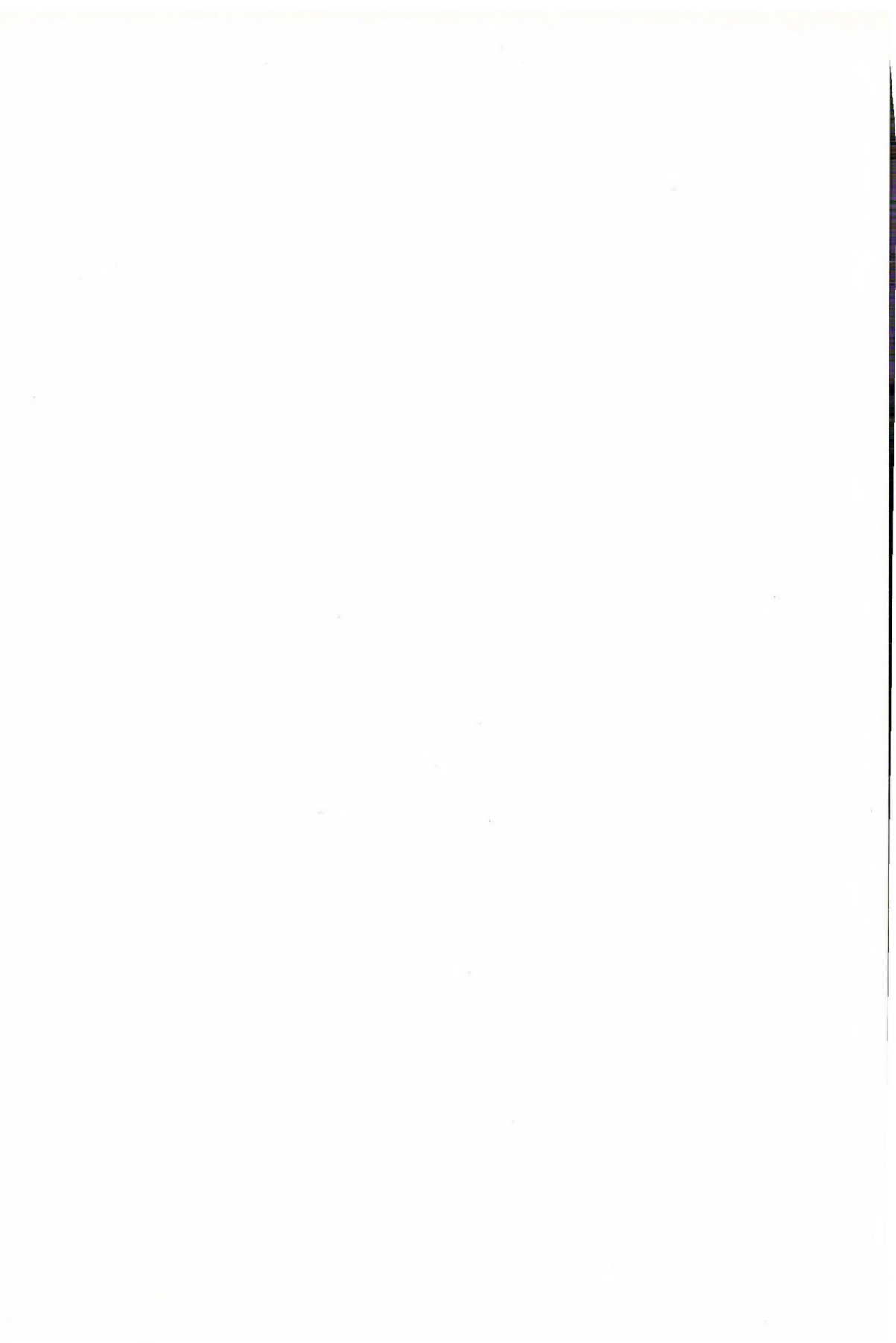
where $K_j^2 = K^2(p, q)$ are the eigenvalues of the finite difference Laplacian $\Delta_{m,l}^2$ and the coefficients $c_{i,j,k}$ are defined by $\partial_{p,q}(\cdot, \cdot)$.

Errata—In Part I (Szunyogh, 1993b) of this work equations (17.b) and (20.b) were incorrectly given by the author. In a correct way they are

$$\frac{\partial \delta}{\partial t} = \vec{k} \nabla \times (\zeta + f) \vec{v} - \Delta \left(\Phi + \frac{\vec{v}^2}{2} \right), \quad (\text{17.b})$$

and

$$\frac{\partial}{\partial t} E_{\kappa} = \vec{v}_{\kappa} \nabla \Delta^{-1} \frac{\partial \delta}{\partial t} = f(\vec{v}_{\psi}, \vec{v}_{\kappa}, \Phi). \quad (\text{20.b})$$



IDŐJÁRÁS

Quarterly Journal of the Hungarian Meteorological Service
Vol. 97, No. 3, July–September 1993

An application of multiregression model for evaluation of precipitation chemistry

S. F. Rajšić and Z. B. Vukmirović

*Institute of Physics,
Pregrevica 118, 11080 Belgrade-Zemun, Yugoslavia*

(Manuscript received 7 May 1993; in final form 13 September 1993)

Abstract—Using the five-year data sets for stations from EMEP network of the former Yugoslavia, the multiregression model is successfully applied for evaluation of basic relations relevant for precipitation chemistry. Such type of supervising pollutant transmission in the lower troposphere is appropriate for national monitoring and should be recommended to non-developed countries. A meritorious estimate of exported and imported amounts of pollutants, as well as regional and local contributions, could be established in the episodes with precipitation by applications of the proposed multiregression model with stepwise variable selection.

Key-words: precipitation chemistry, multi-variable regression, EMEP network.

1. Introduction

On the basis of detailed analysis of multi-year data sets for precipitation using a multiregression model (*Prat et al.*, 1983), the authors of this work have applied successfully this method to available data sets from the sites in Yugoslavia (*Vukmirović*, 1983; *Rajšić*, 1991) and Belgium (*Rajšić et al.*, 1991). In the last attempt (*Rajšić*, 1991) a more sophisticated model has been used in which a stepwise variable selection is provided. Besides, an original method for “missing values” is developed and applied, thus improving available data base.

A measuring project according to the Cooperative Programme for the Monitoring and Evaluation of the Long-Range Transmission of Air Pollutants in Europe (EMEP) was implemented on Puntijarka station in 1977 (*Table 1*). In the following years other stations also began to operate. The last station included in EMEP network was Kamenički Vis (1983). Being in Serbia, this station is of particular interest for this work, so that first complete five-year

data sets in the period of 1984–1988 are chosen for analysis. 24-h precipitation samples were taken at the indicated stations (Table 1) and transported to the Central Laboratory of the Federal Hydrometeorological Institute in Belgrade. Sampling and chemical analysis were in accordance with the methodology established by EMEP (EMEP, 1977).

Table 1. Basic data for EMEP stations of the former Yugoslavia

Station	Coordinates		Altitude amsl (m)
	λ	φ	
Mašun (Slovenia)	14°22'	45°39'	1026
Puntijarka (Croatia)	15°58'	45°54'	988
Zavižan (Croatia)	14°59'	44°49'	1599
Kamenički V. (Serbia)	21°57'	43°24'	813
Ivan Sedlo (Bosnia- Herzegovina)	18°02'	43°46'	970
Lazaropolje (Macedonia)	20°42'	41°32'	1332

The aim of this work is to evaluate basic relations of microconstituents in precipitation and therefore to determine the common issues of the network. Also, it is important to point out the diversity of each station located in areas with different natural and anthropogenic precursor sources of microconstituents in precipitations.

2. Experimental procedure

Sampling was organized in non-automated devices in the intervals of 24 hours by 07 to 07 of next day. Only at Ivan Sedlo station in the last year (1988) an automated sampler "ERNI" (Swiss) was applied. Every day samplers were cleaned by rinsing with distilled water.

Precipitation samples collected are filtered into polyethylene bottles and maintained at cold dark place prior to the transport to the Central Laboratory.

A brief listing of analytical methods applied for measuring microconstituents is given as follows. Acidity of precipitations is measured by a pH-meter named "Radiometer", which is calibrated by buffers from the manufacturer in the range from 4.01 to 7.00 at temperature of 25°C. The accuracy is

$\pm 1\%$. Sulphate ions are determined by turbidimetric method on 400 nm. The sensitivity is 0.05 mg S l^{-1} . Nitrate ions are analyzed by spectrophotometric n-(1-naphthyl)ethylenediamine method (Griess's method) on 520 nm. The sensitivity threshold is 0.02 mg N l^{-1} . Spectrophotometric mercury thiocyanate method is used for chloride determination. The sensitivity threshold is $0.05 \text{ mg Cl l}^{-1}$. For ammonia, spectrophotometric indophenol method is applied with sensitivity threshold of 0.04 mg N l^{-1} .

Alkaline metals (Na and K) as well as alkaline-earth metals (Ca and Mg) are determined by atomic absorption method. The sensitivity threshold for all microconstituents was approximately 0.02 mg l^{-1} .

Obtained weighted average concentrations, expressed as amount of relevant microconstituent in mg l^{-1} , as well as a number of samples, in the period 1984–1988, are presented in Table 2.

Data sets are very representative for detailed statistical analysis. The most mineralized precipitations are those of Kamenički Vis. Of particular concern is high concentration of sulphates and nitrates. At the same station maximum number of days (67) with precipitations of $\text{pH} \leq 4.5$ has been found in the observed period. Then, Zavižan and Puntijarka follow and at the end Lazaropolje with only 6 days.

Table 2. Weighted average concentrations in mg l^{-1} (1984–1988)

Station	No. of samples	SO ₄ -S	NO ₃ -N	Cl	NH ₄ -N	Ca	Mg	Na	K
Mašun	511	0.88	0.39	1.47	0.27	1.03	0.30	0.59	0.25
Puntijarka	631	1.63	0.45	1.38	0.45	1.25	0.45	0.60	0.54
Zavižan	736	1.47	0.75	2.02	0.43	1.84	0.49	1.04	0.45
Kam. Vis	546	3.47	1.50	1.46	0.71	2.08	0.48	1.87	0.51
Ivan Sedlo	537	1.40	0.30	1.80	0.19	0.65	1.11	2.34	0.17
Lazaropolje	570	1.68	0.34	2.00	0.46	1.43	0.49	1.17	0.57

Statistical analysis is performed on AMSTRAD PC with 8087 coprocessor. The standard programmes: STATGRAF, QUATRO and STEPFOR for regression analysis are used. In addition to algorithm in procedure of regression, an original algorithm for iterative calculation of "missing values" is developed for the purposes of this work. Sometimes, the quantity of collected precipitation is not satisfactory for complete analysis or may be the analysis is unsuccessful, so that the calculation of "missing values" by model improves data bases (Rajšić, 1991). Using this model data base for all stations increased, approximately, from 10% to 30%.

The principal characteristic of chosen multiregression model is the stepwise variable selection which provides test of significancy of involved variables in each step. The procedure runs from zero independent variable and in every next step one variable is added. Previously tested variable may be insignificant in any next step. In this case it is automatically rejected from further study.

3. Results and discussion

The simplest multiregression model is that with one dependent variable (X_1) and two independent variables (X_2 and X_3):

$$X_1 = a_1 + a_2X_2 + a_3X_3,$$

for which the correlation coefficient, R , can be expressed as:

$$R_{1,23} = \sqrt{\frac{r_{12}^2 + r_{13}^2 - 2r_{12}r_{13}r_{23}}{1 - r_{23}^2}},$$

where r represents the coefficients of linear correlation and indices show corresponding pairs of variables.

The correlation matrices of linear correlation coefficients are presented in *Table 3*. The relations selected by proposed model are given in *Table 4*. Besides, the principal microconstituents significancy test is performed for correlation with precipitation height (mm). Poor negative correlation is found mostly for dilution effect, except at Kamenički Vis, where precipitations were the most mineralized. No good correlation of H^+ -ion with other ions is found, while the situation becomes better when pH has been introduced. The similar conclusion concerning H^+ has been found for Hungary (*Horváth and Mészáros, 1984*). Nevertheless, correlations for both forms are presented in *Table 4*.

As can be seen, better correlations are found for Cl (*Table 3 and 4*), then for SO_4^{2-} and NO_3^- . Chloride ions might be of natural origin (NaCl), but SO_4^{2-} and NO_3^- are the indicators of strong acid presence in the lower troposphere.

Taking into consideration the continental background concentrations (*Szepesi and Fekete, 1987*) and the results of the analysis of meteorological factors influence (*Rajšič, 1991*), one may conclude that acid precipitations at Kamenički Vis are not only transported from Western Europe, but that a contribution from short-regional scale is also significant. Probably, industrial sources in Kosovo as well as Bor mining and smelting basin influence the elevated acidity and relatively higher concentrations of sulphate and nitrate

Table 3. Correlation matrices for EMEP network of the former Yugoslavia in the period 1984–1988

	mm	pH	SO ₄ -S	NO ₃ -N	NH ₄ -N	Na	Mg	Ca	Cl	K	H ⁺
Mašun											
mm	1.00	-0.09	-0.31	-0.18	-0.26	-0.17	-0.21	-0.23	-0.18	-0.17	-0.04
pH	-0.09	1.00	0.20	0.16	0.08	0.20	0.25	0.34	0.15	0.18	-0.66
SO ₄ -S	-0.31	0.20	1.00	0.45	0.50	0.21	0.36	0.39	0.36	0.21	0.01
NO ₃ -N	-0.18	0.16	0.45	1.00	0.23	0.22	0.34	0.33	0.26	0.31	-0.03
NH ₄ -N	-0.26	0.08	0.50	0.23	1.00	0.16	0.13	0.21	0.17	0.24	0.05
Na	-0.17	0.20	0.21	0.22	0.16	1.00	0.22	0.25	0.67	0.77	-0.07
Mg	-0.21	0.25	0.36	0.34	0.13	0.22	1.00	0.62	0.21	0.24	-0.13
Ca	-0.23	0.34	0.39	0.33	0.21	0.25	0.62	1.00	0.25	0.32	-0.12
Cl	-0.18	0.15	0.36	0.26	0.17	0.67	0.21	0.25	1.00	0.42	-0.01
K	-0.17	0.18	0.21	0.31	0.24	0.77	0.24	0.32	0.42	1.00	-0.05
H ⁺	-0.04	-0.66	0.01	-0.03	0.05	-0.07	-0.13	-0.12	-0.01	-0.05	1.00
Puntijarka											
mm	1.00	-0.14	-0.24	-0.19	-0.24	-0.22	-0.19	-0.26	-0.30	-0.23	-0.00
pH	-0.14	1.00	0.19	0.04	0.26	0.05	0.30	0.36	0.28	0.36	-0.66
SO ₄ -S	-0.24	0.19	1.00	0.44	0.52	0.25	0.34	0.49	0.52	0.46	0.03
NO ₃ -N	-0.19	0.04	0.44	1.00	0.17	0.39	0.28	0.30	0.31	0.22	0.04
NH ₄ -N	-0.24	0.26	0.52	0.17	1.00	0.20	0.23	0.36	0.49	0.45	0.00
Na	-0.22	0.05	0.25	0.39	0.20	1.00	0.29	0.28	0.39	0.25	0.01
Mg	-0.19	0.30	0.34	0.28	0.23	0.29	1.00	0.55	0.28	0.41	-0.09
Ca	-0.26	0.36	0.49	0.30	0.36	0.28	0.55	1.00	0.46	0.41	-0.09
Cl	-0.30	0.28	0.52	0.31	0.49	0.39	0.28	0.46	1.00	0.65	-0.09
K	-0.23	0.36	0.46	0.22	0.45	0.25	0.41	0.41	0.65	1.00	-0.12
H ⁺	-0.00	-0.66	0.03	0.04	0.00	0.01	-0.09	-0.09	-0.09	-0.12	1.00
Zavižan											
mm	1.00	0.01	-0.25	-0.18	-0.19	-0.19	-0.21	-0.20	-0.22	-0.21	-0.07
pH	0.01	1.00	-0.07	-0.07	-0.18	0.13	0.22	0.31	0.12	0.13	-0.64
SO ₄ -S	-0.25	-0.07	1.00	0.47	0.64	0.34	0.31	0.57	0.42	0.49	0.26
NO ₃ -N	-0.18	-0.07	0.47	1.00	0.27	0.37	0.20	0.41	0.29	0.32	0.23
NH ₄ -N	-0.19	-0.18	0.64	0.27	1.00	0.18	0.14	0.21	0.21	0.32	0.31
Na	-0.19	0.13	0.34	0.37	0.18	1.00	0.15	0.33	0.67	0.31	0.01
Mg	-0.21	0.22	0.31	0.20	0.14	0.15	1.00	0.47	0.19	0.23	-0.08
Ca	-0.20	0.31	0.57	0.41	0.21	0.33	0.47	1.00	0.40	0.46	-0.06
Cl	-0.22	0.12	0.42	0.29	0.21	0.67	0.19	0.40	1.00	0.45	0.05
K	-0.21	0.13	0.49	0.32	0.32	0.31	0.23	0.46	0.45	1.00	0.01
H ⁺	-0.07	-0.64	0.26	0.23	0.31	0.01	-0.08	-0.06	0.05	0.01	1.00

Continued Table 3

	mm	pH	SO ₄ -S	NO ₃ -N	NH ₄ -N	Na	Mg	Ca	Cl	K	H ⁺
Kamenički Vis											
mm	1.00	-0.10	-0.41	-0.29	-0.29	-0.13	-0.26	-0.39	-0.33	-0.35	-0.06
pH	-0.10	1.00	0.13	-0.02	0.11	-0.13	0.17	0.24	0.07	0.28	-0.56
SO ₄ -S	-0.41	0.13	1.00	0.37	0.42	0.09	0.37	0.55	0.50	0.57	0.08
NO ₃ -N	-0.29	-0.02	0.37	1.00	0.06	0.01	0.36	0.61	0.14	0.25	0.10
NH ₄ -N	-0.29	0.11	0.42	0.06	1.00	-0.04	0.20	0.09	0.17	0.23	0.12
Na	-0.13	-0.13	0.09	0.01	-0.04	1.00	0.00	0.13	0.57	0.23	0.05
Mg	-0.26	0.17	0.37	0.36	0.20	0.00	1.00	0.38	0.14	0.30	-0.02
Ca	-0.39	0.24	0.55	0.61	0.09	0.13	0.38	1.00	0.32	0.45	-0.02
Cl	-0.33	0.07	0.50	0.14	0.17	0.59	0.14	0.32	1.00	0.70	0.05
K	-0.35	0.28	0.57	0.25	0.23	0.23	0.30	0.45	0.70	1.00	-0.03
H ⁺	-0.06	-0.56	0.08	0.10	0.12	0.05	-0.02	-0.02	0.05	-0.03	1.00
Ivan Sedlo											
mm	1.00	0.03	-0.03	-0.07	-0.03	-0.01	-0.05	-0.07	-0.01	-0.06	-0.03
pH	0.03	1.00	-0.02	0.01	0.15	-0.08	-0.10	0.33	0.03	0.17	-0.71
SO ₄ -S	-0.03	-0.02	1.00	0.10	0.37	0.07	0.18	0.18	0.03	0.09	0.11
NO ₃ -N	-0.07	0.01	0.10	1.00	-0.01	-0.03	-0.03	0.66	0.13	0.27	0.01
NH ₄ -N	-0.03	0.15	0.37	-0.01	1.00	-0.05	-0.07	0.01	0.04	0.09	-0.06
Na	-0.01	-0.08	0.07	-0.03	-0.05	1.00	-0.10	0.00	0.43	0.06	-0.00
Mg	-0.05	-0.10	0.18	-0.03	-0.07	-0.10	1.00	0.12	-0.13	0.16	0.20
Ca	-0.07	0.33	0.18	0.66	0.01	0.00	0.12	1.00	0.29	0.64	-0.12
Cl	-0.01	0.03	0.03	0.13	0.04	0.43	-0.13	0.29	1.00	0.30	-0.04
K	-0.06	0.17	0.09	0.27	0.09	0.06	0.16	0.64	0.30	1.00	-0.07
H ⁺	-0.03	-0.71	0.11	0.01	-0.06	-0.00	0.20	-0.12	-0.04	-0.07	1.00
Lazaropolje											
mm	1.00	-0.09	-0.24	-0.12	-0.17	-0.06	-0.14	-0.25	-0.16	-0.21	-0.06
pH	-0.09	1.00	0.14	0.00	0.32	-0.04	-0.06	0.25	0.17	0.24	-0.65
SO ₄ -S	-0.24	0.14	1.00	0.39	0.46	0.06	0.37	0.68	0.49	0.77	0.10
NO ₃ -N	-0.12	0.00	0.39	1.00	0.04	-0.01	0.09	0.29	0.09	0.37	0.09
NH ₄ -N	-0.17	0.32	0.46	0.04	1.00	0.02	0.02	0.30	0.35	0.49	-0.06
Na	-0.06	-0.04	0.06	-0.01	0.02	1.00	0.01	0.05	0.59	0.20	0.02
Mg	-0.14	-0.06	0.37	0.09	0.02	0.01	1.00	0.51	0.12	0.22	0.16
Ca	-0.25	0.25	0.68	0.29	0.30	0.05	0.51	1.00	0.37	0.58	0.01
Cl	-0.16	0.17	0.49	0.09	0.35	0.59	0.12	0.37	1.00	0.55	-0.10
K	-0.21	0.24	0.77	0.37	0.49	0.20	0.22	0.58	0.55	1.00	-0.02
H ⁺	-0.06	-0.65	0.10	0.09	-0.06	0.02	0.16	0.01	-0.10	-0.02	1.00

Table 4. Relations of microconstituents in precipitations from EMEP network of the former Yugoslavia in the period 1984–1988

Station	Principal relation	Correlation coefficient
Mašun		
	$\text{pH} = 5.57 + 0.08\text{Na} + 0.11\text{Ca}$	R=0.36
	$\text{H}^+ = 9.18 - 3.69\text{Mg}$	R=0.13
	$\text{SO}_4^{2-} = 0.32 + 1.75\text{NH}_4 + 0.56\text{Mg} + 0.15\text{Ca}$	R=0.60
	$\text{NO}_3^- = 0.01 + 0.47\text{NH}_4 + 0.55\text{Mg} + 0.09\text{Ca} + 0.31\text{K}$	R=0.44
	$\text{Cl}^- = 0.86 + 0.28\text{NH}_4 + 1.07\text{Na} + 0.08\text{Ca} - 0.43\text{K}$	R=0.70
Puntijarka		
	$\text{pH} = 5.62 + 0.10\text{Mg} + 0.09\text{Ca} + 0.17\text{K} - 0.05\text{NO}_3$	R=0.46
	$\text{H}^+ = 7.60 - 0.93\text{Ca} - 2.25\text{K} + 1.19\text{SO}_4$	R=0.18
	$\text{SO}_4^{2-} = 0.47 + 1.12\text{NH}_4 + 0.35\text{Ca} + 0.44\text{K} + 0.01\text{H}$	R=0.66
	$\text{NO}_3^- = 0.02 + 0.49\text{Na} + 0.28\text{Mg} + 0.16\text{Ca}$	R=0.47
	$\text{Cl}^- = 0.82 + 0.38\text{NH}_4 + 0.21\text{Na} - 0.17\text{Mg} + 0.13\text{Ca} + 0.54\text{K}$	R=0.75
Zavižan		
	$\text{pH} = 5.85 - 0.10\text{SO}_4 - 0.05\text{NO}_3 - 0.16\text{NH}_4 + 0.05\text{Na} + 0.09\text{Mg} + 0.11\text{Ca} + 0.09\text{K}$	R=0.50
	$\text{H}^+ = 4.48 + 2.98\text{SO}_4 + 1.90\text{NO}_3 + 7.76\text{NH}_4 - 1.04\text{Na} - 2.21\text{Mg} - 1.82\text{Ca} - 0.55\text{K}$	R=0.45
	$\text{SO}_4^{2-} = -0.09 + 1.82\text{NH}_4 + 0.10\text{Na} + 0.29\text{Ca} + 0.33\text{K} + 0.01\text{H}$	R=0.80
	$\text{NO}_3^- = -0.43 + 0.36\text{NH}_4 + 0.34\text{Na} + 0.27\text{Ca} + 0.27\text{K} + 0.03\text{H}$	R=0.55
	$\text{Cl}^- = 1.20 + 0.54\text{Na} + 0.07\text{Ca} + 0.47\text{K}$	R=0.72
Kamenički Vis		
	$\text{pH} = 5.56 - 0.04\text{Na} + 0.09\text{Mg} + 0.09\text{Ca} + 0.22\text{K} - 0.04\text{SO}_4 - 0.07\text{NO}_3$	R=0.47
	$\text{H}^+ = 10.50 + 8.57\text{NH}_4 - 1.91\text{Ca} + 2.20\text{NO}_3$	R=0.19
	$\text{SO}_4^{2-} = 0.96 + 1.42\text{NH}_4 + 0.29\text{Mg} + 0.32\text{Ca} + 0.90\text{K} + 0.01\text{H}$	R=0.74
	$\text{NO}_3^- = -0.65 + 0.53\text{Mg} + 0.61\text{Ca} + 0.01\text{H}$	R=0.65
	$\text{Cl}^- = 0.83 + 0.18\text{NH}_4 + 0.18\text{Na} + 0.86\text{K}$	R=0.83
Ivan Sedlo		
	$\text{pH} = 5.64 - 0.10\text{SO}_4 - 0.44\text{NO}_3 + 0.36\text{NH}_4 - 0.18\text{Mg} + 0.36\text{Ca} - 0.08\text{Cl} - 0.14\text{K}$	R=0.52
	$\text{H}^+ = 6.51 + 1.87\text{SO}_4 + 3.45\text{NO}_3 - 3.07\text{NH}_4 + 4.32\text{Mg} - 2.38\text{Ca}$	R=0.32
	$\text{SO}_4^{2-} = 0.68 + 0.01\text{H} + 1.01\text{NH}_4 + 0.02\text{Na} + 0.29\text{Mg} + 0.16\text{Ca} - 0.16\text{K}$	R=0.49
	$\text{NO}_3^- = -0.12 + 0.01\text{H} - 0.13\text{Mg} + 0.39\text{Ca} - 0.21\text{K}$	R=0.71
	$\text{Cl}^- = 1.47 + 0.07\text{Na} - 0.24\text{Mg} + 0.12\text{Ca} + 0.23\text{K}$	R=0.55
Lazaropolje		
	$\text{pH} = 5.96 + 0.24\text{NH}_4 - 0.03\text{Na} - 0.10\text{Mg} + 0.13\text{Ca} + 0.09\text{K} - 8\text{SO}_4 + 0.05\text{Cl}$	R=0.45
	$\text{H}^+ = 2.88 + 0.31\text{Na} + 1.00\text{Mg} - 0.64\text{Ca} + 0.63\text{SO}_4 - 0.96\text{Cl}$	R=0.29
	$\text{SO}_4^{2-} = -0.08 + 0.51\text{NH}_4 - 0.05\text{Na} + 0.22\text{Mg} + 0.49\text{Ca} + 1.34\text{K} + 0.04\text{H}$	R=0.84
	$\text{NO}_3^- = 0.20 - 0.34\text{NH}_4 - 0.03\text{Na} + 0.07\text{Ca} + 0.46\text{K} + 0.02\text{H}$	R=0.44
	$\text{Cl}^- = 1.08 + 0.43\text{NH}_4 + 0.27\text{Na} + 0.13\text{Ca} + 0.50\text{K} - 0.03\text{H}$	R=0.77

ions at this site. This is very important for the estimate of transboundary pollutant transport in the lower troposphere. The more complex analysis has shown that only 34% of $\text{SO}_4^{2-}\text{-S}$ at Kamenički Vis is originated from the import (Rajšić, 1991), the rest is from emitters in Serbia. A more detailed analysis will be published.

Very good correlations are found between anions observed and some cations like Na^+ and K^+ . The best correlation with the highest contents is at Mašun and Zavižan (close to the seaside) indicating thus the influence of sea spray on NaCl and KCl contents in precipitations.

However, the best correlation for both linear and multi-regressions is found for SO_4^{2-} and NH_4^+ ions at all stations. The presence of $(\text{NH}_4)\text{HSO}_4$ or $(\text{NH}_4)_2\text{SO}_4$ confirms the intensive processes of transformation of SO_2 into H_2SO_4 and partially or completely neutralization of sulphuric acid with ammonia. Ammonia could be released by natural and anthropogenic sources. These results indicate the territory of the former Yugoslavia as a field of strong SO_2 emission originating from foreign and own sources.

The model is very appropriate for describing precipitation chemistry. In a situation without communication with other countries, precipitations reflect both behavior of neighbors and ourselves.

Finally, one network for precipitation chemistry under high-professional control is not so expensive, but offers very useful information for strategies of sustainable development and participation in the international activities for abatements of SO_2 and NO_x emissions.

4. Conclusion

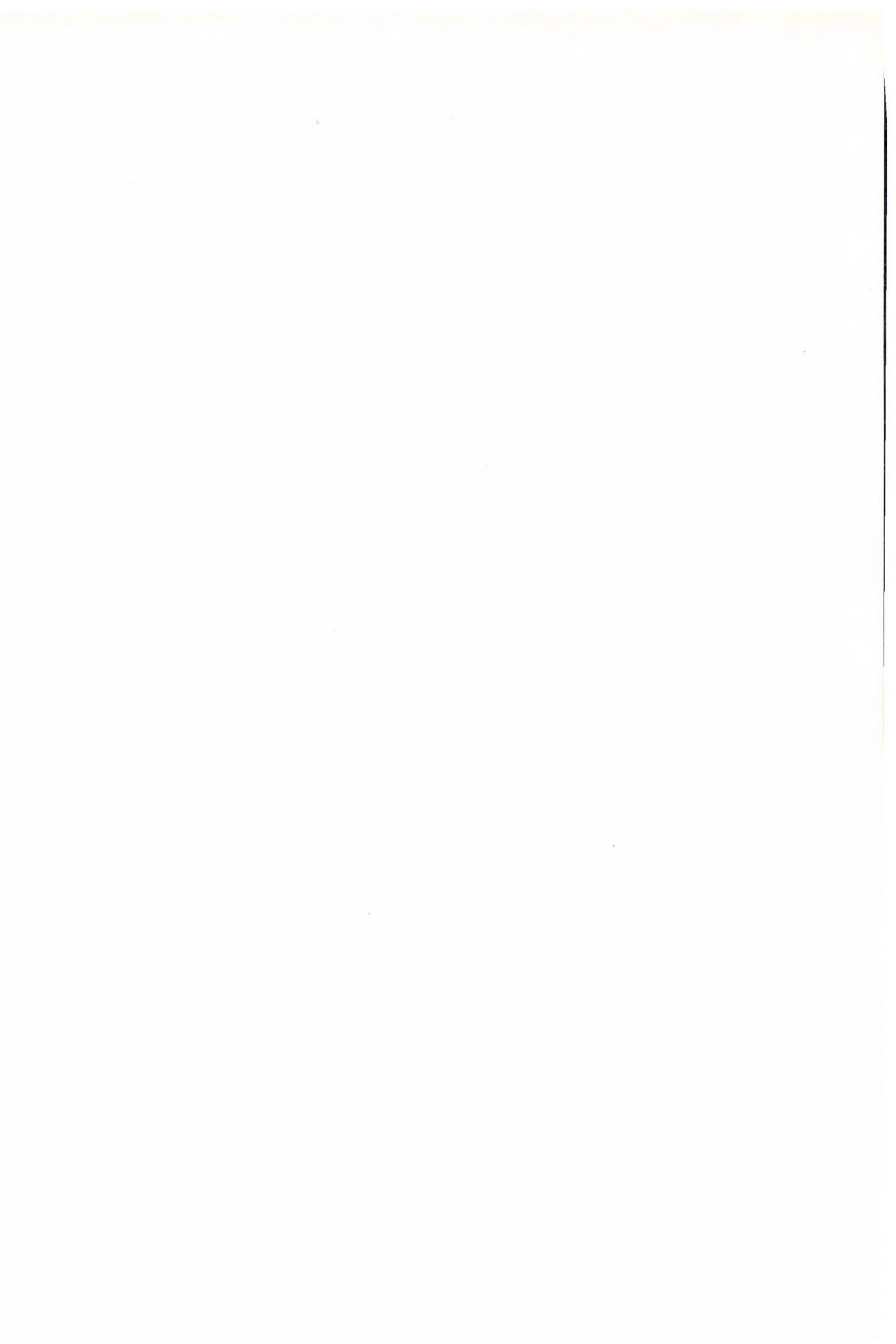
On the basis of the obtained results, the following conclusions may be underlined:

- Multiregression with stepwise variable selection is recommended for describing diversity of sites included in one network with the same purpose.
- Application of the proposed multiregression model for precipitation chemistry provides very useful information on transformation and transport of atmospheric microconstituents relevant for environmental protection.
- This type of analysis is necessary in the network of a non-developed country for which an organization of automated monitoring of gaseous pollutants-precursors of acid rains, is too expensive.

Acknowledgements—The authors are very grateful to the *Federal Hydrometeorological Institute* for providing data bases from EMEP network of the former Yugoslavia. Also, the authors appreciate financial support received from the *Ministry of Science and Technology of the Republic of Serbia*. The particular acknowledgements of valuable help in development of the programme for “missing values” is given to *Ljubomir Rajšić*.

References

- EMEP, 1977: *Manual for Sampling and Chemical Analysis*. EMEP/CHEM. 3.77, NILU, Lillestrøm.
- Horváth, L. and Mészáros, E., 1984: The composition and acidity of precipitation in Hungary. *Atmos. Environ.* 18, 1843-1847.
- Prat, G.C., Coscio, M., Gardner, D.W., Chenone, B.I. and Krupa, S.V., 1983: An analysis of the chemical properties of rain in Minnesota. *Atmos. Environ.* 17, 347-355.
- Rajšić, S., 1991: *Consistency of Physico-Chemical Parameters for Transmission of Pollutant in the Troposphere*. Doc. Dissert., University of Belgrade, Faculty of Science, Belgrade.
- Rajšić, S., Otten, P. and Van Grieken, R., 1991: Chemical composition of rain water in Antwerp, Belgium. *Environ. Techn.* 12, 257-261.
- Szepesi, D.J. and Fekete, K.E., 1987: Background levels of air and precipitation quality for Europe. *Atmos. Environ.* 21, 1623-1630.
- Vukmirović, Z.B., 1983: An application of regression model for determination of the precipitation acidity origin (Serbian). *Zaštita atmosfere* 11, 1-5.



IDŐJÁRÁS

Quarterly Journal of the Hungarian Meteorological Service
Vol. 97, No. 3, July–September 1993

Some data on the elemental composition of atmospheric aerosol particles in Xinjiang, NW China

A. Molnár¹, L. Makra², Chen Yaning³ and I. Borbély-Kiss⁴

¹ Department of Analytical Chemistry, University of Veszprém,
P.O. Box 158, H-8201 Veszprém, Hungary

² Department of Climatology, University of Szeged,
Egyetem u. 2, H-6722 Szeged, Hungary

³ Xinjiang Institute of Geography, Chinese Academy of Sciences,
Urumqi, Xinjiang, China

⁴ Institute of Nuclear Research,

P.O. Box 51, H-4001 Debrecen, Hungary

(Manuscript received 1 July 1993; in final form 31 August 1993)

Abstract—Six aerosol samples were collected in the air over arid areas of NW China during a Hungarian expedition in 1990. The samples collected were analyzed by the PIXE method. The results of the analyses are presented and discussed.

Key-words: elemental composition of aerosol particles, PIXE, China.

1. Introduction

The elemental composition of atmospheric aerosol particles has been studied widely during the last two decades (e.g. *Mészáros*, 1991). This is due to the importance of such measurements for estimating the environmental impact of the particles on local, regional and global scales. Among other things, samplings in the atmosphere far from human influences were carried out under oceanic and continental conditions to investigate the global cycle of aerosols. In spite of these efforts (e.g. *Penkett et al.*, 1979; *Adams et al.*, 1983; *Morales et al.*, 1990; *Winchester et al.*, 1981) the chemical composition of aerosol particles over continents like Africa, South America and Asia is not well understood.

Thus, few information are available from the aerosol in the air over the vast inner regions of China (*Winchester and Wang*, 1989). Further, concentration data from an area near the Great Wall (*Winchester et al.*, 1981) and from

Huangshan mountain (Eastern China, *Xu et al.*, 1991) can also be found in the open literature.

The aim of this paper is to present the results of the analysis of aerosol samples collected in the air over Xinjiang, NW area of China (Central Asia).

2. Sampling

Aerosol samples were collected by means of Nuclepore polycarbonate filters with 0.4 μm pore size. The sampling time was 4–6 hours in the afternoon, during which 3–4 m^3 of air were sampled. The geographical position and characteristics of the sampling sites are given in *Table 1*. Generally speaking,

Table 1. Date of sampling and geographical position and description of sampling sites

Sample No.	Date	H (m)	φ ($^{\circ}\text{N}$)	λ ($^{\circ}\text{E}$)	Site description
1	17 June	1290	44 $^{\circ}$ 20'	84 $^{\circ}$ 50'	N slope of Tiensan (steppe)
2	18 June	420	44 $^{\circ}$ 50'	86 $^{\circ}$ 10'	Dzungaria (steppe)
3	19 June	0	42 $^{\circ}$ 30'	88 $^{\circ}$ 45'	Turfani basin (desert)
4	20 June	865	40 $^{\circ}$ 55'	86 $^{\circ}$ 20'	Takla-Makan (desert)
5	21 June	1255	42 $^{\circ}$ 20'	83 $^{\circ}$ 00'	Tiensan (mountain desert)
6	22 June	1950	43 $^{\circ}$ 50'	88 $^{\circ}$ 07'	E Tiensan (semi-arid)

each site was far from located areas, the distance from the nearest large city (Urumqi, with population of 1 million) varied between 100–400 km. The electric current necessary for the function of the pump was supplied by an electric generator. The exhaust gases from the generator were conducted downwind with a tube. After sampling the filters were placed in small plexiglass boxes sealed carefully. The filters remained in these boxes until their analysis by PIXE in Hungary.

3. Results and discussion

The results of the analyses of samples are summarized in *Table 2*, where the absolute concentrations as well as the enrichment factors are given. These latter data were calculated relative to aluminum by using average crustal fractions reported by *Mason* (1966).

One can see from the numbers listed that elements like silicon, sulfur, calcium and iron were found in a relatively high concentration. While silicon, calcium and iron have enrichment factors below about 10 proving their soil origin, sulfur is enriched considerably at all sites indicating its formation either by gas-to-particle conversion or by the disintegration of the surface, the sulfur

Table 2. Concentration (x: ngm^{-3}) and enrichment factor (EF) of different elements in the atmospheric aerosol over the regions of NW China

Element	Sample 1		Sample 2		Sample 3		Sample 4		Sample 5		Sample 6	
	x	EF	x	EF	x	EF	x	EF	x	EF	x	EF
Al	66.8	1	82.7	1	195.5	1	991.6	1	152.9	1	162.2	1
Si	222.9	0.79	259.3	0.74	711.8	0.86	4752	1.1	656.4	1.0	851.2	1.2
P	<6.3		<5.1		<5.9		<9.6		<5.9		<5.1	
S	115.5	824	120.5	694	163.6	398	619.6	298	123.0	383	177.5	521
Cl	76.5	954	50.9	513	77.1	329	666.2	560	56.2	306	58.7	276
K	69.5	4.7	54.1	3.0	173.9	4.0	1326	6.0	139.2	4.1	164.6	4.6
Ca	133.1	6.0	186.6	6.7	473.6	7.3	5231	15.8	668.5	13.1	478.8	8.8
Ti	7.65	2.8	6.37	1.9	21.1	2.6	150.0	3.7	24.0	3.8	28.7	4.3
V	<1.2		<1.0		<1.3		4.24	5.5	<1.3		1.3	10.3
Cr	7.31	177	5.40	105	8.18	67.5	24.4	39.6	6.89	72.7	7.99	79.5
Mn	1.19	2.1	1.44	2.1	5.65	3.5	25.2	3.1	3.23	2.5	4.44	3.3
Fe	126.3	3.7	113.5	2.7	348.4	3.5	1884	3.7	315.5	4.0	374.9	4.5
Co	<2.1		<1.8		<3.2		33.6	106.6	3.85	79.2	<3.1	
Ni	<0.9		0.68	15.1	1.86	17.6	19.1	35.6	1.12	13.5	0.99	11.2
Cu	<0.7		0.89	21.7	0.98	10.1	7.78	15.6	1.38	18.2	1.35	16.7
Zn	<0.9		1.65	40.2	3.52	36.3	25.9	52.6	2.49	32.8	2.17	27.0
As	<3.2		<1.7		<2.0		13.5	1099	2.66	1400	1.32	656
Pb	9.49	1478	<5.9		<5.5				<7.6		<5.7	

content of which is very different in this area from the average crustal composition reported by *Mason* (1966). Besides, the concentration of aluminum and potassium is also high. They also originate from the Earth crust. The concentration of the elements of soil origin is important in particular for sample of number 4. This is understandable since sampling was carried out in this case under desertic conditions when the air was very dusty.

The case of chlorine should be mentioned separately. Its concentration level is very significant in spite of the fact that oceanic influences can practically be excluded. In addition, the Cl enrichment factor is between 300 and 900 similar to that of sulfur. It is proposed with caution that this is due to the fact that soils are rather salty and several lakes contain a lot of sodium chloride in the regions considered. Anyway, similar results were obtained in Sudan, Africa (*Penkett et al.*, 1979). Penkett and his coworkers attributed this finding to the disintegration of salt flats and to the evaporation of rainwater leaving a salt rich layer.

The concentration of some notorious pollutants like lead, zinc, copper and vanadium is generally low. Even, the enrichment factor of zinc, copper and vanadium has a magnitude of ten which indicates that they are at least partly of crustal origin. On the other hand, chromium was found in a concentration similar to that measured over Hungary (*Molnár et al.*, 1993). Also, this element was enriched like in the air over industrial areas. Thus, it cannot be ruled out that Cr level reflects the effect of the city Urumqi, where iron smelting is an important human activity. It is also possible, however, that chromium is of crustal origin (*Nriagu*, 1989) and its concentration in soils of this area is higher than the average (see *Mason*, 1966). This latter hypothesis is supported by the fact that the highest chromium concentration was found over the Takla-Makan desert.

It should be also noted that no clear changes in concentration are found if we consider our data as a function of the altitude above the sea level. This seems to indicate that the effects of the underlying surface are practically independent of the height for a vast region. However, much more measurements would be necessary to obtain a clear vertical pattern.

4. Comparison with other data

It is attempted to compare our data with those of *Penkett et al.* (1979) and *Annegarn et al.* (1983) gained in China, Sudan and Namibia, respectively. These results are of great value since they are based on samplings done *in situ* under desertic conditions. Data tabulated indicate (see *Table 3*) that in Sudan, when winds blow from the Sahara, the concentrations of different elements are very high and they are in general agreement with our results for Takla-Makan (sample No. 4, see *Table 2*). On the other hand, data published for Namibia agree rather well with our other results. This obviously means that aerosol composition is a function of the extension of the desertic area as well as of the

Table 3. Concentration of different elements in atmospheric aerosol particles in Sudan during Sahara wind (Penkett et al., 1979) and in the Namib desert (Annegarn et al., 1983). The values are expressed in ngm^{-3}

Element	Al	Fe	Ca	K	S	Cl	Cu	V	Ti	Mn	Zn	Cr
Sudan	3030	2996	<1000	-	767	970	49	9	-	35	31	1
Namibia	-	246	425	94	264	616	<0.8	3	22	4	~1	2

meteorological conditions during sampling. We emphasize again that at each desertic site chlorine in the aerosol particles has a higher level than sulfur. Finally, chromium concentrations over NW China are surprisingly high, mainly over the Takla-Makan desert.

References

- Adams, F., Van Espen, P. and Maenhaut, W., 1983: Aerosol composition at Chacaltaya, Bolivia, as determined by size-fractionated sampling. *Atmos. Environ.* 17, 1521-1536.
- Annegarn, H.J., Van Grieken, R.E., Bibby, D.M. and Von Blottnitz, F., 1983: Background aerosol composition in the Namib desert, South West Africa (Namibia). *Atmos. Environ.* 17, 2045-2053.
- Mason, B., 1966: *Principles of Geochemistry*. Wiley, New York.
- Mészáros, E., 1991: The atmospheric aerosol. In *Atmospheric Particles and Nuclei* (G. Götz, E. Mészáros and G. Vali). Akadémiai Kiadó, Budapest, 17-84.
- Molnár, A., Mészáros, E., Bozó, L., Borbély-Kiss, I., Koltay, E. and Szabó, Gy., 1993: Elemental composition of atmospheric aerosol particles under different conditions in Hungary. *Atmos. Environ.* (accepted for publication).
- Morales, J.A., Hermoso, M., Serrano, J. and Sanhueza E., 1990: Trace elements in the Venezuelan savannah atmosphere during dry and wet periods, with and without vegetation burning. *Atmos. Environ.* 24A, 407-414.
- Nriagu, J.O., 1989: A global assessment of natural sources of atmospheric trace metals. *Nature* 338, 47-49.
- Penkett, S.A., Atkins, D.H.F. and Unsworth, M.H., 1979: Chemical composition of the ambient aerosol in the Sudan Gezira. *Tellus* 31, 295-307.
- Xu, J., Hu, H. and Zhou, J., 1991: Model study of atmospheric aerosols in some typical places of China. *J. Aerosol Sci.* 22, S625-S628.
- Winchester, J.W., Lü Weixiu, Ren Lixin and Wang Mingxing, 1981: Fine and coarse aerosol composition from a rural area in North China. *Atmos. Environ.* 15, 933-937.
- Winchester, J.W. and Wang, M.-X., 1989: Acid-base balance in aerosol components of the Asia-Pacific region. *Tellus* 41B, 323-337.

IDŐJÁRÁS

Quarterly Journal of the Hungarian Meteorological Service
Vol. 97, No. 3, July–September 1993

Decreasing concentration of air pollutants and the rate of dry and wet acidic deposition at the three forestry monitoring stations in Hungary

L. Horváth¹, Gy. Baranka¹ and E. Gy. Führer²

¹ Institute for Atmospheric Physics,
P.O. Box 39, H-1675 Budapest, Hungary

² Forest Research Institute,
Frankel Leó u. 44, H-1023 Budapest, Hungary

(Manuscript received 29 March 1993; in final form 23 August 1993)

Abstract—Concentration and dry+wet deposition of acidic atmospheric pollutants were determined in three Hungarian forestry monitoring stations between 1988 and 1992. Concentration of most important acidic compounds (sulfur and nitrogen dioxide) does not reach the critical level therefore forest decline as consequence of direct effects (foliar uptake through stomata) may be excluded. Total (dry+wet) deposition of acidic pollutants are $187 \text{ mg H}^+ \text{ m}^{-2} \text{ yr}^{-1}$ as an average of 3 stations. The acidic load at Hungarian forestry stations frequently exceeds the critical value recommended by international organizations. Though concentration and deposition of atmospheric acidic compounds has considerably decreased in the recent years, further monitoring of acid deposition in forests is necessary because the accumulation effects of acid load to forest soil.

Key-words: forest decline, acid deposition, critical load.

1. Introduction

Forest decline occurring in some North American and Central European forests during the recent decades is attributed to anthropogenic air pollution and acidic deposition according to some authors.

Harmful effect of air pollution on forest health may be direct and/or indirect. In the case of direct impact, air pollutants through stomata initiate biochemical processes resulting in toxic effects, e.g. radical pathology. Deposition can affect the leaves directly, mostly if the leaves are destructed by some oxidants (O_3 , H_2O_2).

Indirect effect of acidic substances appears in the long term acidification of forest soil. In Hungary the opinions differ concerning the primary cause of forest decline. *Stefanovits* (1986) pointed out that the pH of some Hungarian forest soil has decreased by 0.4–1.9 unit during 20–30 years as a consequence of deposition and accumulation of acidic pollutants.

In the country serious problems in sessile oak forests mostly in the northern area of Hungary have been observed. According to *Jakucs* (1986) mostly the indirect effect of acidic deposition is responsible for decline of sessile oaks. On the other hand the majority of foresters and ecologists believes that forest damages are as the consequence of different biotic and abiotic effects.

Phenomena above mentioned, i.e. acidification of forest soils, forest decline, furthermore the fact that Hungary belongs to moderately polluted countries in Europe (*Horváth*, 1989a) support the need for continuous monitoring of the rate and trend of atmospheric acidic deposition in Hungarian forests.

For these reasons Forest Research Institute and Institute for Atmospheric Physics of Hungarian Meteorological Service have started a monitoring program in 1988 at three forestry monitoring stations. Preliminary results for the stations has been reported elsewhere (e.g. *Horváth* and *Führer*, 1991; *Führer* and *Horváth*, 1992). The aim of this paper is to summarize the results of the first five years of the monitoring program (1988–1992).

It should be mentioned here that beside acidic compounds there is an other important group of compounds which can be responsible for forest damages, namely the photooxidants (ozone) and free radicals generating by the reaction between ozone and alkenes (*Möller*, 1988). Modeling and monitoring the effect of photooxidants on forest are the subject of one of our research projects.

The aims of this paper are to calculate the concentration and deposition of acidic compounds for forests and compare them with standards and recommendations. By this comparison we can make an attempt to decide, if the acidic components may influence the forest health in Hungary.

2. Measuring program of the monitoring stations

The three forestry monitoring stations are located in pine forests at the west and the middle of Hungary (Farkasfa: $\varphi=45^{\circ}55'$, $\lambda=16^{\circ}18'$, $H=312$ m and K-pusztá: $\varphi=46^{\circ}58'$, $\lambda=19^{\circ}33'$, $H=126$ m, respectively) as well as in the Mátra-Mountains, north-east of Hungary (Nyírjes: $\varphi=47^{\circ}54'$, $\lambda=19^{\circ}58'$, $H=560$ m).

Forestry stations were located on openings in the forest. The generally recommended siting criteria (approximately 50 m distance from forest edge)

are fulfilled at Nyírjes and Farkasfa stations. At K-puszta station the 10 m height sampling tube is located above the canopy so the canopy influences can be practically neglected.

Sampling and measuring program of the three stations involves the determination of the daily 24h average of the most important acidic gaseous pollutants including sulfur dioxide, nitrogen dioxide, nitric acid and ammonia and chemical composition of aerosol particles (ammonium, sulfate and nitrate). Chemical composition of precipitation is also measured on the basis of monthly wet-only sampling. In this paper concentrations of ammonium, sulfate and nitrate measured in the program are reported. Dry and wet deposition rates has been calculated by use of concentrations measured in the air or in the precipitation water and of the dry deposition velocity (cm s^{-1}) or the precipitation rate ($\text{L m}^{-2} \text{mo}^{-1}$). Detailed description of sampling and analytical methods including the estimated average dry deposition velocities can be found e.g. in *Horváth* (1989a) or *Pais and Horváth* (1990). From practical point of view concentration of nitric acid gas and the chemical composition of aerosol particles have been determined only at two stations (K-puszta, Nyírjes). Concentration of ammonia gas is measured only at the K-puszta station.

In this paper only the acidic deposition is discussed. Acid deposition rate was calculated as described in *Horváth* (1989a) and *MSZ* (1988). It can be respected as the upper limit of acidity. Basic compounds (mainly soil-derived HCO_3^- ions in the large aerosol fraction) due to their short lifetime have great spatial concentration variability (*Horváth*, 1981). Therefore, instead of uncertain net (acidic and alkaline) deposition we prefer to use the term of possible highest rate of acid deposition.

Beside chemical measurements main meteorological parameters including air temperature and humidity, wind direction and velocity have also been continuously monitored.

It should be noted that Nyírjes station was burnt down in July, 1992 because of a forest fire. For this reason only the first half year of 1992 was taken into account during the calculation.

3. Results

3.1 Concentration of air pollutants

As it was mentioned above direct effects of acidic air pollutants are related to their high atmospheric concentrations. The exact determination of the "dangerous" level of pollutants is impossible. There are different approaches to estimate the air quality standards for forest ecological systems. According to *WHO* (1985) the harmful level of sulfur dioxide and nitrogen

dioxide for forests (for the two most important air pollutants from the point of view of acidification) is $30 \mu\text{g m}^{-3}$ as a yearly average. These figures correspond to Hungarian standards determined for "particularly protected" areas (MSZ, 1990). Proposed critical loads for forests are 20 and $30 \mu\text{g m}^{-3}$ as a yearly average for sulfur dioxide and nitrogen dioxide, respectively (Várallyay et al., 1992).

Yearly averages for sulfur dioxide and nitrogen dioxide as well as the variation of mean monthly values can be seen in Fig. 1. According to Fig. 1

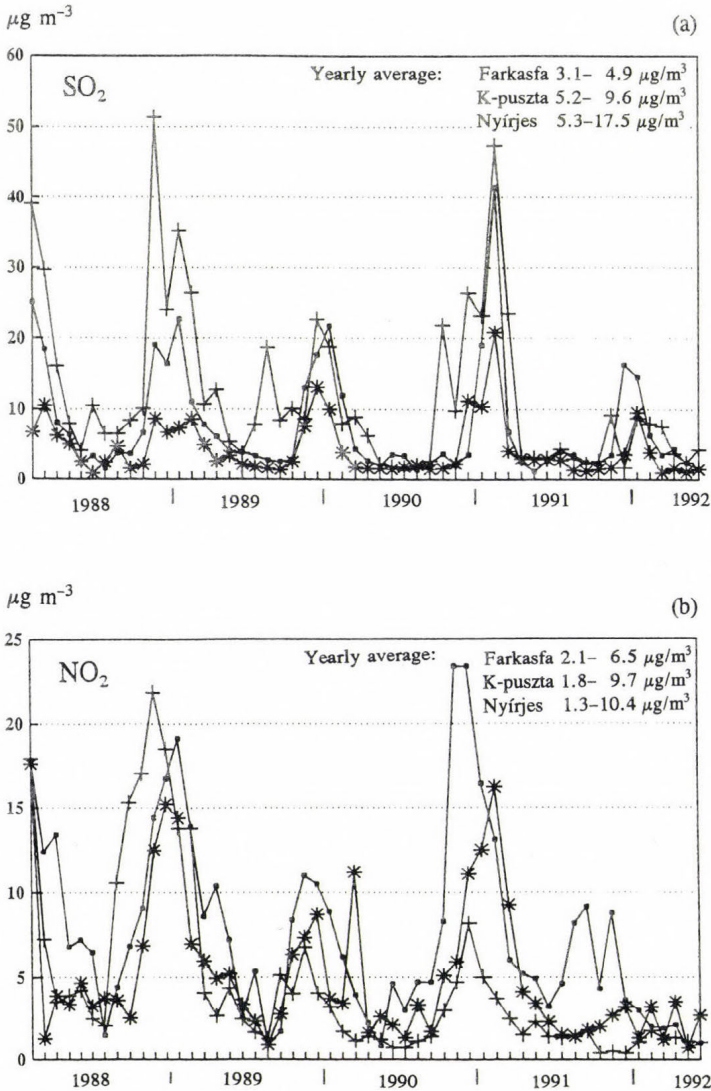


Fig. 1. Variation of the mean monthly concentration of sulfur dioxide (a) and nitrogen dioxide (b) (K-pusztá —, Nyírjes +, Farkasfa *).

yearly mean values of pollutants do not reach the harmful level. A west-east increase can be observed in the concentration of sulfur and nitrogen dioxides. Further important information is that higher sulfur dioxide and nitrogen dioxide levels occur during the winter half-year, out of the vegetation period. For deciduous forests the foliar uptake of gases is possible only during the vegetation period (practically during summer half-year, April–November). In the case of coniferous forest the uptake of sulfur and nitrogen dioxide is minimized in the winter half-year because of the closed stage of the stomata. It means that direct effect of acidic air pollution can be probably excluded.

Concentration of other acidic pollutants does not comparable to that of sulfur and nitrogen dioxide. The level of nitric acid which is the third most important pollutant beside sulfur and nitrogen dioxide does not reach the $2.0 \mu\text{g m}^{-3}$ as an average.

3.2 Deposition of air pollutants

In contrast with high atmospheric level of pollutants dry and wet deposition of acidic substances (sulfur and nitrogen compounds) may affect the forest health by indirect processes through accumulation in the forest soil. The rate of dry, wet and total (dry+wet) acidic deposition was determined by the method described in MSZ (1988) and Horváth (1989b) (Table 1). Deposition of sulfur and nitrogen compounds was expressed in hydrogen ion equivalents. The average rate of total deposition (for the period of 1988–92 as an average of 3 station) is $187 \text{ mg H}^+ \text{ m}^{-2} \text{ yr}^{-1}$. The share of dry and wet deposition is approximately the same. However, in the summer half-year the

Table 1. Dry (d), wet (w) and total (t) acidic deposition at forestry monitoring stations expressed in $\text{mg H}^+ \text{ m}^{-2} \frac{1}{2} \text{ yr}^{-1}$ and $\text{mg H}^+ \text{ m}^{-2} \text{ yr}^{-1}$ units

Name of station	Period	1988			1989			1990			1991			1992			Mean		
		d	w	t	d	w	t	d	w	t	d	w	t	d	w	t	d	w	t
K-pusztá	Year	111	85	196	107	99	206	88	73	161	99	85	184	67	49	116	94	78	172
	Winter	81	35	116	76	28	104	64	34	98	67	32	99	43	16	59	66	29	95
	Summer	30	50	80	31	71	102	24	39	63	32	53	85	24	33	57	28	49	77
Nyírjes	Year	165	163	328	129	141	270	90	125	215	86	105	191	57	60	117	105	119	224
	Winter	81	35	116	76	28	104	64	34	98	64	32	96	34	31	65	64	32	96
	Summer	84	128	212	53	113	166	26	91	117	22	73	95	23	29	52	41	87	129
Farkasfa	Year	72	93	165	78	107	185	66	124	190	67	81	148	55	75	130	68	96	164
	Winter	47	39	86	55	14	69	46	56	102	43	30	73	32	26	58	45	33	78
	Summer	25	54	79	23	93	116	20	68	88	24	51	75	23	49	72	23	63	86
Mean of stations	Year	116	114	230	104	116	220	81	107	188	84	90	174	60	61	121	89	98	187
	Winter	70	36	106	69	23	92	58	41	99	58	31	89	37	24	61	58	32	90
	Summer	46	78	124	36	92	128	23	66	89	26	59	85	23	37	60	31	66	97

wet, in winter half-year the dry deposition dominates (Fig. 2). While dry deposition has a winter, wet deposition has a summer peak. Consequently, there is no expressed annual variation in the total deposition.

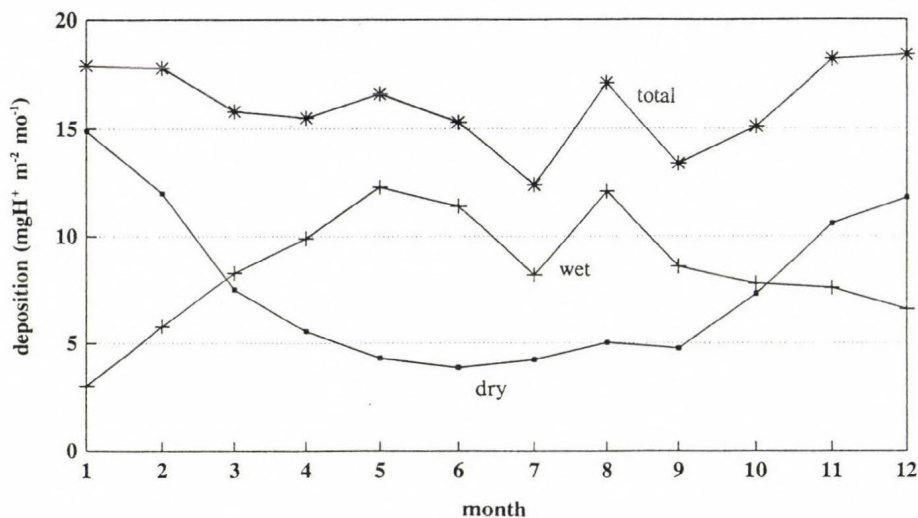


Fig. 2. Annual variation of dry, wet and total acidic deposition as an average measured at the three forestry monitoring stations (1988–1992).

The ratio of sulfur to nitrogen compounds in the total deposition is 42 and 58%. The relative importance of sulfur compounds is continuously decreased from 46% to 36% during the 5 years. It is in agreement with our earlier results (Horváth, 1989a) suggesting that N/S ratio is increasing in the acidic deposition.

The average yearly acidic depositions of Farkasfa and K-pusztá stations are similar, 164 and 172 mg H⁺ m⁻² yr⁻¹, which can be regarded as a “background” acid deposition for Hungary. For Nyírjes station the acidic deposition is higher, 224 mg H⁺ m⁻² yr⁻¹ indicating local pollution effect.

The yearly deposition figures for the 3 stations generally do not exceed the proposed critical load for Hungary. It is established total acid deposition is 280 mg H⁺ m⁻² yr⁻¹ (Várallyay *et al.*, 1992). It can be seen from Table 1 that exceedance of the critical load occurred only in 1988 at Nyírjes station.

According to the recommendation of UN and ECE (RIVM, 1991), Hungary is divided into different grids according to sensibility of the given area. The critical loads for the 4 different areas for Hungary are 20–50; 50–100; 100–200 and >200 mg H⁺ m⁻² yr⁻¹. Lowest figures are generally determined for western and northern part of Hungary. Taking into consideration these recommendations we can see that in the majority of the cases the critical load is exceeded.

3.3 Trends in concentration and deposition

As Fig. 1 and Table 1 suggest, concentration of the most important acidic compounds (sulfur and nitrogen dioxide) as well as total (dry+wet) deposition of pollutants have decreased during the 5 years of investigation. It is probably due to reduced sulfur and nitrogen emission in Hungary and in the neighbouring countries as a consequence of change in economical structure of East European region. Roughly, the atmospheric level of pollutants and the rate of acidic deposition have reached to the half of the value measured in 1988 as Fig. 3 illustrates.

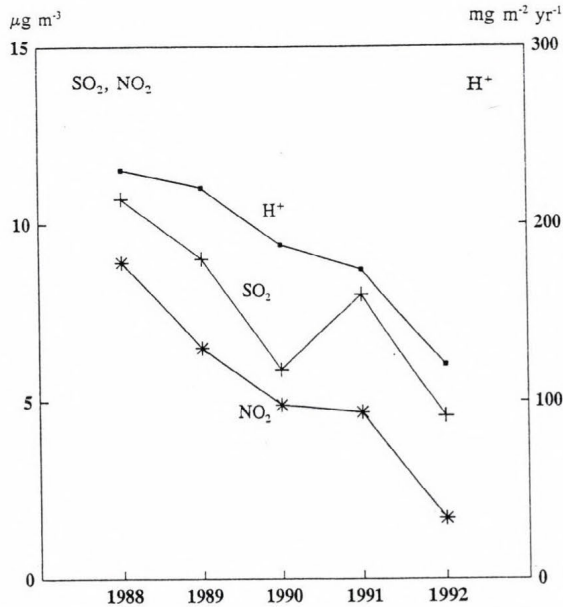


Fig. 3. Variation of the concentration of sulfur dioxide and the nitrogen dioxide and the rate of total acidic deposition at forestry stations.

This fortunate tendency suggests that we can not probably face the danger of direct forest decline in the near future caused by increased level of pollutants. In spite of the decreasing deposition rate the critical loads recommended by international organizations are frequently exceeded. For this reason the continuous monitoring of acid deposition is needed for the effects of pollution may accumulate in the forest soil (e.g. accumulation of nitrogen loading, mobilization of heavy metals, decrease of buffer capacity against acid stress) causing long term indirect damages in forests.

Furthermore, other types of pollution (e.g. high level of photochemical oxidants, including ozone), also responsible for forest decline, should be included into the study.

Acknowledgements—This work has been supported by *Hungarian Academy of Sciences* as an OTKA project, contract number: 341.

References

- Führer, E.Gy. und Horváth, L., 1992: Saure deposition in Ungarn. *Agrokémia és Talajtan* 41, 90-101.
- Horváth, L., 1981: Chemical composition of precipitation water in Hungary (in Hungarian). *Időjárás* 85, 201-212.
- Horváth, L., 1989a: Measurement of atmospheric acid deposition in Hungary (in Hungarian). *OMSZ Kisebb Kiadványai*, No. 65, Budapest.
- Horváth, L., 1989b: Measurement of acid deposition in Hungary. In *Acid Deposition, Sources, Effects and Controls* (ed.: J.W.S. Longhurst). British Library Technical Communications, Letchworth.
- Horváth, L. and Führer, E.Gy., 1991: Acid deposition in forest ecosystems. In *Proceedings "Expertentagung Waldschadenforschung im östlichen Mitteleuropa und in Bayern"*, GSF-Bericht 24/91.
- Jakucs, P., 1986: The impact of atmospheric acidification on living organisms (in Hungarian). *Időjárás* 90, 150-158.
- Möller, D., 1988: Production of free radicals by an ozone-alkene reaction—A possible factor in the new-type forest decline? *Atmos. Environ.* 22, 2607-2611.
- MSZ, 1988: Determination of atmospheric acid deposition (Hungarian Standard). MSZ 21860.
- MSZ, 1990: Requirements of cleanness of ambient air (Hungarian Standard). MSZ 21854.
- Pais, I. and Horváth, L., 1990: Atmospheric acidic deposition and its environmental effect in Hungary. In *Advances in Environmental Science* (ed.: D.C. Adriano). University of Georgia, USA.
- Stefanovits, P., 1986: A few new data on soil acidification (in Hungarian). *Magyar Tudomány* 93, 339-341.
- Várallyay, Gy., Fekete-Nárai, K., Führer, E., Gopcsa, E., Haszpra, L. and Várkonyi, T., 1992: *System for Rural Air Quality Standards*. Proposal for provision of law. Institute for Environmental Management, Budapest, Hungary, (manuscript).
- RIVM, 1991: Mapping critical loads for Europe. *CCE Technical Report* No. 1. National Institute of Public Health and Environmental Protection, Bilthoven, The Netherlands.
- WHO, 1985: *Air Quality Guidelines—Ecological Effects of Air Pollutants*. World Health Organization ICP/CEH 902/m 71 (S), 29 July, 1985.

IDŐJÁRÁS

*Quarterly Journal of the Hungarian Meteorological Service
Vol. 97, No. 3, July–September 1993*

An advanced traffic accident forecasting technique based on weather sensitivity of drivers

I. Örményi

*National Institute for Rheumatics and Physiotherapy,
Laboratory for Electrobiometeorology,
Frankel Leó u. 25/27, H-1023 Budapest, Hungary*

(Manuscript received 5 May 1993; in final form 2 August 1993)

Abstract—Data of 2130 accidents made by the drivers of Budapest Post Office between 1978 and 1983 are studied based on weather and geophysical factors. The weather sensitivity of individuals who caused the accidents was classified into 7 subtypes. Provable significant differences were found between the accidents made by warm and cold front sensitive on 24 hour, monthly and seasonal basis. Significantly higher number of accidents was made by weather sensitive car drivers during stationary fronts. Among air masses in the higher level of the troposphere the subtropical and the arctic air masses affect mostly the warm and cold front sensitive drivers. The effect of the variations in the geomagnetic activity with different types of weather sensitivity can also be proved. In geomagnetic storms the warm front sensitive and in severe geomagnetic storms the mixed front sensitive make more accidents. The above findings are very useful for medical meteorological and accident forecast provided that the weather sensitivity of individuals is known.

Key-words: traffic accidents effects of fronts and air masses, geomagnetic activity, individual weather sensitivity.

1. Introduction

The meteorological and cosmic effects on traffic and industrial accidents have been investigated since 1965 in Budapest. The influence of fronts, air masses near to the ground and in the higher level of the troposphere, solar flares and variations in the geometric activity were examined (Örményi, 1972a, 1977, 1978). There seems to be no relation (at last in Budapest) between the ordinary meteorological elements (phenomen such as fog) like humidity, barometric tendency, temperature and the accidents. The start of precipitation involves risk of accident, especially in winter time in view of the icy conditions (Örményi, 1970). The efficiency of meteorological elements on traffic acting in

a metropolitan area versus the road transport in country may be entirely different because of the variation infrastructure (WMO, 1990).

Experiences obtained in the road accidents' forecast show that the type of weather sensitivity of car drivers in the accident should also be taken into account (Örményi, 1972b, 1990).

2. Material and method

The accidents made by the car drivers of the Budapest Post Office between 1978 and 1983 were used to the statistical data processing. 2130 accidents made by 2011 male and 119 female car drivers of age between 18 and 60 were registered. The type of weather sensitivity was established by means of a questionnaire (Örményi, 1972c, 1990) prepared by the collaborators of the Psychological Laboratory of the Hungarian Post. The questionnaire was compiled based on the work of Curry (1948) and standardised on a Hungarian population of more than 26,000 (see Appendix). The answers to questions on the ergotropic working phase (E) are divided by the values of trophotropic working phase (T) of the human organism. On the basis of these quotients in Table 1, three types of warm front sensitivity, two types of mixed front sensitivity and three types of cold front sensitivity are differentiated. In this paper all mixed sensitive car drivers are considered as one group. On the other hand, this typology is, at the same time, suitable for the establishment of the sensitivity to geophysical factors, among others the solar activity. The role of geophysical factors was proved at accidents occurred in chemical industry in Nyergesújfalu and Budapest between 1969 and 1973 (Örményi, 1986).

Different types of front and air masses were used in the investigation based on Berkes' classification (1961) as well as macrosynoptic types determined by Péczely (1957) for the Carpathian Basin. The list of meteorological elements

Table 1. Distribution of various geophysical biotypes (GBT), according to E/T quotients

Geophysical biotypes		Intervallum E/T quotients	Frequency distribution %
Cold front type sensitive 3	C ₃	0.01 - 0.43	1.3
Cold front type sensitive 2	C ₂	0.44 - 0.68	9.7
Cold front type sensitive 1	C ₁	0.69 - 0.88	22.4
Mixed cold front type sensitive	M _c	0.89 - 0.99	13.1
Mixed warm front type sensitive	M _w	1.00 - 1.08	15.5
Warm front type sensitive 1	W ₁	1.09 - 1.28	17.8
Warm front type sensitive 2	W ₂	1.29 - 1.88	17.2
Warm front type sensitive 3	W ₃	1.89 - 49.00	3.0

were compiled in the Laboratory for Electrobiometeorology of the National Institute of Rheumatics and Physiotherapy using the data of the National Meteorological Service. The influence of the solar activity was related to the variations in the geomagnetic activity by means of the *Bartha-Berkes* classification (*Berkes*, 1970) so as it is shown in *Table 2*. The daily elongation of the horizontal component of geomagnetic activity (characteristic number) was taken into account in the classification. The data were obtained from the Geomagnetic Observatory Tihany. *Bernoulli's* method (*Jessel*, 1954) and *Schelling's* (1937, 1940) "n" and "T" tests were used in the data processing. Significant values were considered at least $P=0.05$.

Table 2. Corresponding values of geomagnetic variations according to *Bartha's* and *Berkes's* classifications and K_p values

Characteristic number	Range of daily elongation in H-component, expressed in nT	Corresponding limit value of K_p max during a day
0	0 - 30	0 - 2°
1	30 - 60	2 ⁺ - 3 ⁺
2	60 - 100	4 ⁻ - 5°
3	100 - 160	5 ⁺ - 6 ⁺
4	160 - 210	7 ⁻ - 8 ⁻
5	210 -	8° - 9°

Periodical effects such as 24 hours rhythms as well as the weekly and annual effects all were taken into account. The distribution of types of weather sensitivity (geophysical biotypes = GBT) in the accidents was the following: 132 of W_3 type (6.2%); 314 of W_2 type (14.7%); 301 type of W_1 type (14.1%); 503 of M type (23.6%); 478 of C_1 type (22.4%); 353 of C_2 type (16.6) and 49 of C_3 type (2.4%). Consequently, in the accidents 35% of the drivers belonged to warm front sensitive, 23.6% to mixed front sensitive and 41.4% to cold front sensitive.

3. Results

3.1 Distributions of the accidents with respect to types of weather sensitivity

Fig. 1 shows 24 hours rhythms of accidents made by individuals of different weather sensitivity. In the lower part of the figure all cases are specified. The peak in accidents was at 11.00 a.m. and the second peak at 2.00 p.m., a minimum at 10.00 p.m. and a second minimum at 4.00 a.m. As there was less accidents with sub-types, therefore, instead of seven only the three main types of weather sensitivity were used. In the upper part of *Fig. 1*. 24 hour rhythms of the accidents of warm front sensitive (W), in the middle part those of mixed front sensitive (M) and in the lower part those of cold front (C) are given. The

number of accidents caused by warm front sensitive usually has opposite trend against those done by cold front sensitive (correlation coefficient $r = -0.68 \pm 0.11$).

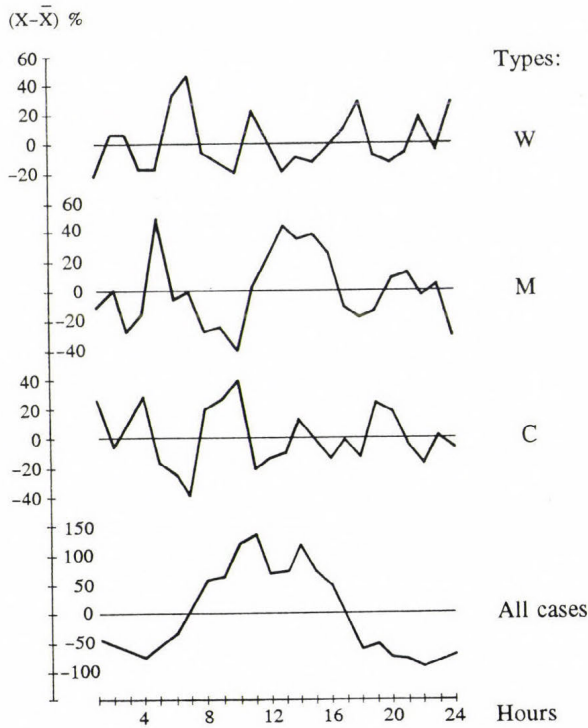


Fig. 1. Daily rhythm of traffic accidents made by various GBT. On the vertical axis deviations from the mean of cases are presented in percentage.

The weekly rhythm was also monitored which is illustrated in *Table 3*. The decrease on weekend may be explained by the reduced traffic in Budapest. On the other hand, there is no significant difference in the distribution of the accidents caused by the three types of weather sensitivity (warm, cold, mixed).

Table 3. The number of accidents on each day of the week and their deviation from the mean ($X - \bar{X}$)

	Mon	Tue	Wed	Thur	Fri	Sat	Sun
Number of cases	329	388	365	352	405	191	100
$(X - \bar{X}) \%$	8	28	20	16	33	-37	-68

The study of distribution was also performed on monthly scale (*Table 4*). The high number of accidents in the first three months of the year is related to winter weather conditions (icy roads, weak visibility etc.).

Table 4. The monthly distribution of accidents and the deviations from the average ($\bar{X}-\bar{X}$)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Okt	Nov	Dec
Number of cases	230	198	213	173	172	175	168	150	178	186	142	145
($\bar{X}-\bar{X}$) %	30	12	20	-3	-3	-1	-6	-16	0	5	-20	-18

Fig. 2 shows the annual rhythms of accidents (deviations from the mean) for the three types of weather sensitivity in percentage. The compilation of the figure is similar to that of Fig. 1. The values of smoothed curves are plotted by dotted lines. The number of accidents caused of warm front sensitive also shows a trend opposite to that of accidents done by cold front sensitive. The correlation coefficient between the two series is $r = -0.70 \pm 0.14$. The same correlation is $r = -0.84 \pm 0.085$ for smoothed values, indicating a close but opposite relation between the two curves.

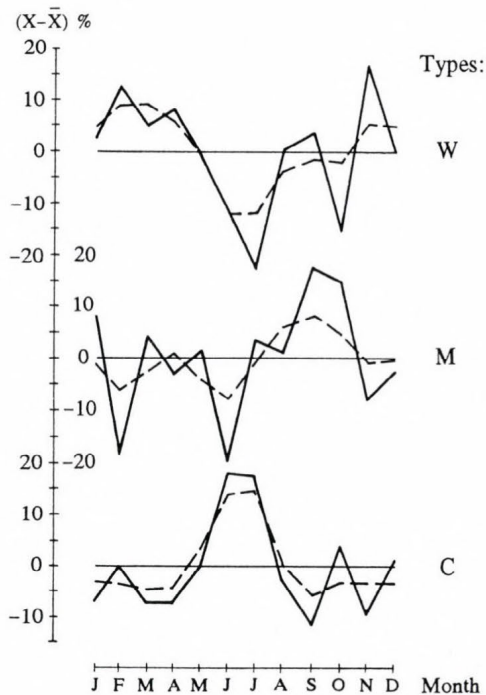


Fig. 2. Annual variations of traffic accidents made by various GBT.

Fig. 3 shows the seasonal distribution of accidents made by different types of weather sensitivity. Data of warm front sensitive are displayed in the upper part, of mixed front sensitive in the middle and cold front sensitive in the lower

part of the figure. The figure also verifies that accidents caused by warm front sensitive (W) and cold front sensitive (C) show an opposite trend and the correlation coefficient is very high, $r = -0.95 \pm 0.048$.

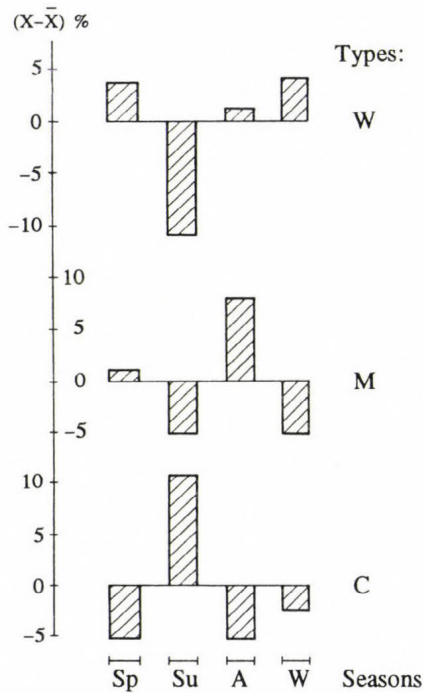


Fig. 3. Seasonal variations of traffic accidents made by various GBT (3 types).

Warm front sensitive make the highest number of accidents in winter and spring, mixed front sensitive in autumn and cold front sensitive in summer. Result of the seasonal statistics of accidents are shown in Table 5.

Table 5. The seasonal distribution of all accidents (No.) and their deviations from the mean $(X-\bar{X})$

Season	No.	$(X-\bar{X}) \%$
Spring	558	5
Summer	493	-8
Autumn	506	-5
Winter	573	8

3.2 The effect of different weather types

Result of significancy test based on the correlation between prevailing weather conditions in the time of car accidents and types weather sensitivity are found in *Table 6*. In compilation of this table all the seven subtypes of weather sensitivity are used.

Table 6. Results of significancy test based on the correlation between prevailing weather conditions in the time of car accidents and types of weather sensitivity. The underlined numbers indicate the significant results on the level of $p=0.05$

Types of fronts	Types of weather sensitivity													
	W ₃		W ₂		W ₁		M		C ₁		C ₂		C ₃	
	d/s	N	d/s	N	d/s	N	d/s	N	d/s	N	d/s	N	d/s	N
W	-1.13	2	<u>2.69</u>	16	1.16	13	<u>4.06</u>	31	1.89	21	0.19	11	-0.19	2
W _h	1.49	8	1.38	18	<u>2.21</u>	18	1.52	24	1.43	22	1.45	17	-1.67	0
O _w	1.23	4	1.87	4	0.09	2	-0.02	3	<u>1.99</u>	6	1.41	4	<u>2.37</u>	2
W _u	1.25	4	<u>2.27</u>	9	1.42	8	<u>4.53</u>	8	<u>2.55</u>	14	1.16	8	0.16	1
C	-0.92	4	-1.26	8	<u>-2.74</u>	4	-1.38	16	-1.71	13	-0.28	14	0.37	4
C _h	0.08	8	-1.48	10	-1.12	13	-1.26	22	<u>-2.68</u>	13	-0.75	16	-1.14	2
O _c	-1.18	0	0.7	4	0.5	4	-0.48	4	0.13	5	-1.35	1	0.31	1
I	-1.21	4	-1.14	10	-1.05	12	-0.40	24	-0.31	22	<u>2.21</u>	26	-1.53	1
O _{or}	<u>4.11</u>	3	1.49	2	5.68	6	-0.31	1	<u>4.35</u>	6	<u>2.22</u>	3	1.71	1
S _{ww}	1.85	4	<u>4.79</u>	12	<u>5.89</u>	15	<u>3.66</u>	15	<u>4.47</u>	16	0.94	6	-0.96	0
S _{cc}	<u>6.31</u>	12	1.49	8	<u>3.34</u>	13	<u>2.83</u>	17	1.81	13	<u>6.75</u>	22	<u>5.09</u>	7
S _{wc}	<u>2.49</u>	6	0.23	5	<u>3.55</u>	13	<u>3.06</u>	17	0.54	22	<u>2.36</u>	11	<u>4.37</u>	6
S _{cw}	<u>3.05</u>	5	1.44	5	<u>5.03</u>	16	1.69	8	1.69	8	1.51	6	0.29	1
D	-0.76	2	-1.06	4	-1.67	3	<u>-2.39</u>	4	-0.67	9	-1.87	3	0.9	3
S	-1.43	1	<u>2.24</u>	13	0.67	10	0.21	14	<u>2.04</u>	14	-0.29	8	0.02	22
D _c	-1.35	0	-1.91	0	<u>-2.03</u>	0	-1.01	4	-1.63	2	-1.15	2	0.06	1
Front nil	<u>-3.41</u>	2	<u>-4.53</u>	5	<u>-4.55</u>	7	<u>-5.38</u>	14	<u>-5.23</u>	12	<u>-5.26</u>	5	<u>-2.08</u>	2

The upper part of the table shows the statistical analysis of accidents made by individuals of different weather sensitivity during warm front situations: in the first line during surface warm front (W), in the second line during upper warm front (W_h), in the third line during a warm occluded front (O_w) and in the fourth line during unstable warm front (W_u). Types of weather sensitivity are indicated in columns of the table. The ratio Δ/σ is the difference between the expected mean and the actual number of accidents divided by the standard deviation. The number of accidents (N) is also given. The numbers of accidents made by various subtypes of warm front sensitive are different. The number of accidents made by subtypes C₂ and C₃ of cold front sensitive is very low. The ratio for accidents made by C₃ during an occluded warm front is high, but

the number of cases is low. It is typical that W_2 , M and C_1 react strongly to different warm fronts passage.

The second part of the table shows accidents made during different cold fronts. Statistical analysis for surface cold fronts (C) is given in the first line, for upper cold fronts (C_h) in the second line, for cold occluded fronts in the third line (O_c), for line of instability in the fourth line (I), and for orographic occlusion fronts (O_{or}), typical to the Carpathian Basin, in the fifth line. The most efficient situation is the orographic occlusion front since four types of weather sensitivity react strongly to it. The speed of the frontal passage is usually so that their biological effects are felt for three or four hours, except for the case of orographic occlusion.

The third part of the table shows the effects of stationary fronts. The effect of a stationary front that arrives and leaves as warm front (S_{ww}) is given in the first line, if it arrives and leaves as a cold front (S_{cc}) in the second line, if it arrives as a warm front and leaves as a cold front (S_{wc}) in the third line, if it arrives as a cold front and leaves as a warm front (S_{cw}) in the fourth line. In these weather conditions different types of weather sensitivity make significantly more accidents than under other situations. S_{cc} situation the W_3 types made much more accidents than expected. But, as it turned out latter it was a consequence of common effect of several factors (like air masses in the higher level of the troposphere, geomagnetic activity). After eliminating extremes the number of accidents is not significantly higher.

The last part of the table shows four situations: subsidence (D) in general in the upper first line, destroying high pressure system (S) accompanied by following falling barometric tendency in the second line, descending motion between two cold front (D_c) in the third line and non frontal conditions (Front Nil) in the fourth line. The table shows that in nil frontal conditions none of the types of weather sensitivity are inclined to make accidents. But during destroying high pressure system the risk of accidents is obviously high for W_2 and C_1 .

3.3 *The effect of the air masses*

Hereafter the influence of biologically efficient air masses near to the ground and in the higher level of the troposphere is outlined.

Fig. 4 shows the effect of maritime arctic air masses (mA) and continental arctic air masses (cA) near the ground (subscript GL) and in the higher level of the troposphere (subscript H). The effect of maritime and continental air masses near to the ground are given in the upper two graphs and the influence of the maritime and continental air masses in the higher level of the troposphere in the lower two graphs. The probable error ($P=0.05$) is also plotted. Air masses near the ground have no particular influence except for W_3 , when the air is coming from the higher level of the troposphere. Contrary to these in the

case of air masses in the higher layer of the troposphere the mixed and some cold front sensitive are inclined to make accidents.

Fig. 5 shows the influence of subtropical air masses coming into the Carpathian Basin. mT is the abbreviation of subtropical air masses from the Azores and m'T the subtropical air masses from the Mediterranean. The sudden arrival of subtropical air masses in the higher level of the troposphere is indexed by 1 (mT₁ and m'T₁, respectively). From Fig. 5 follows that the number of accidents and the level of significance are much lower for cold front sensitive than expected. However, a sudden subtropical air flow from the Azores mT₁ is most reacted by W₃ then W₂ and W₁ and finally by M. The

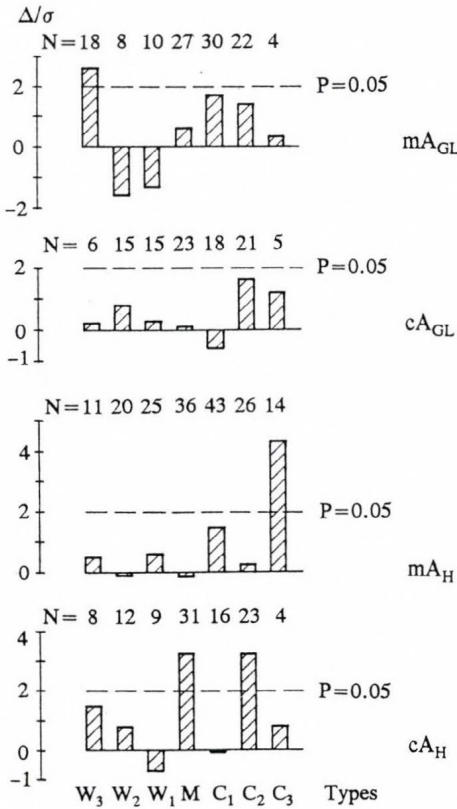


Fig. 4. Influence of arctic air masses near the ground (subscript GL) and higher level of the troposphere (subscript H) on road accidents made by various GBT. On the vertical axis the difference between the expected mean and actual number of accidents divided by standard deviation is depicted. N is the number of accidents.

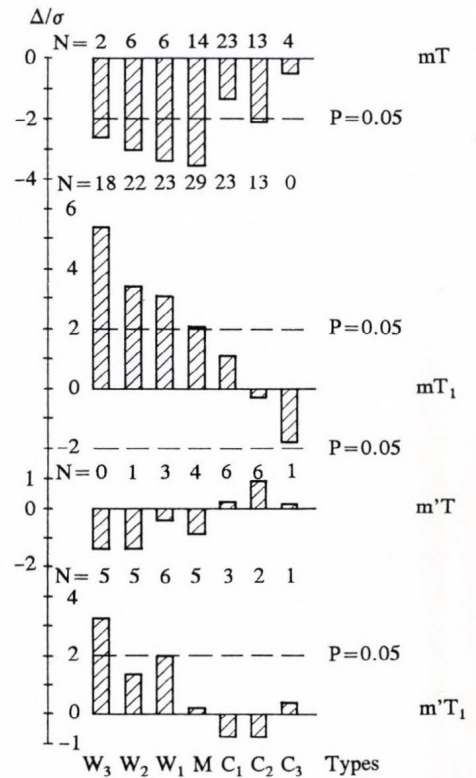


Fig. 5. Road accidents made by various GBT in the case of intrusion of subtropical air masses in the higher levels of the troposphere. The meaning of the vertical axis agrees with that of Fig. 4. Subscript 1 refers to arrival of sudden arrival of air masses. N is the number of accidents.

influence of a sudden $m'T_1$ air flow is not as significant although W_3 and W_1 make sensibly more accidents.

The influence of macrosynoptical types are not dealt with here because they are peculiar to the Carpathian area. Nevertheless, there are such types of weather sensitivity who are liable to make accident in significantly higher number even in high pressure system and it confirms the findings with the destroying high pressure system.

3.4 Influence of solar activity

The influence of solar activity was related to the variation of the geomagnetic activity (Örményi and Majer-Hock, 1991). The key day ("0" day) is the day of the geomagnetic activity. In Fig. 6a accident for characteristic numbers $Ch=2$ and $Ch=3$ and in Fig. 6b those for characteristic numbers $Ch=4$ and $Ch=5$ are shown within ± 3 days of the geomagnetic activity in question. In this case three types of weather sensitivity together were taken into account. From the figure it is concluded that the number of accidents made by warm front sensitive decreased significantly on the key day ($Ch=2$) just like the total number of accidents. In the lower part of the figure it can be seen that the number of accidents increased significantly on the key day ($Ch=3$). There is a remarkable increase in the accidents made by warm front sensitive as well. The number is accidents also increases two days after the storm.

In the cases of $Ch=4$ there is a significant increase in the accidents caused warm sensitive one day after storm (left side of Fig. 6b). The number of accidents made by mixed front sensitive increases significantly two days before storm, probably because a severe geomagnetic storm is usually preceded by an increased geomagnetic activity. Finally, in a very severe geomagnetic storm ($Ch=5$), there is a nearly significant increase in the accidents made by mixed front sensitive whereas the total number of accidents made by cold front sensitive decreased on the key day (right side of Fig. 6b).

4. Conclusions

From the investigations it is concluded that the number of industrial and traffic accidents increases during front passages. According to our experiences in many cases as a result of correct weather forecast, the number of accidents could be decreased by 25 to 35%. To improve the method the type of weather sensitivity (geophysical biotypes) has to be determined. A study was made on car drivers if the Budapest Post Office in which circumstances of 2130 accidents were examined.

There was sensible differences among the 24 hours, monthly and seasonal distributions of effects especially for warm and cold front sensitive. There is an opposite relationship between the accidents made by warm and cold front sensi-

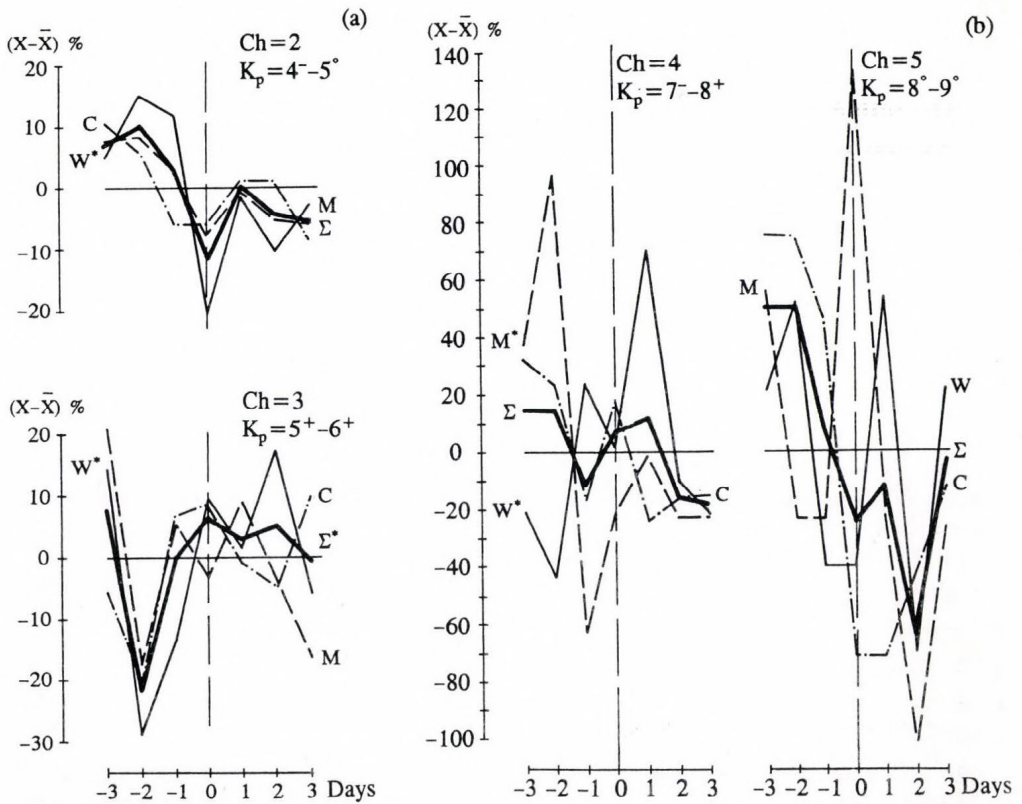


Fig. 6. Road accidents of various GBT as a function of geomagnetic characteristic numbers (Ch) in cases of Ch=2 and 3 (a) and in cases of Ch=4 and 5 (b). The curves show deviations from the mean of accidents in percentage. Denotations: W (solid line)—warm front sensitive, C (dashed line)—cold front sensitive, M (dot-dash line)—mixed front sensitive, Σ (bold line)—all data; asterisks denote significant variations.

tive in the monthly and seasonal distribution. The highest number of accidents are made by weather sensitive individuals during stationary fronts and not in short time front passages. It is remarkable that different subtypes of warm front sensitive react significantly but not in the same way to subtropical air masses coming in the higher level of troposphere, when the actual temperature is by 6 or 8 degrees higher than the average temperature calculated for the suitable period. In the case of cold front sensitive the average temperature is by 6 or 8 degrees lower than the average for arctic air masses in the higher level of troposphere. In these case the number of accidents is significantly higher.

The effect of solar activity can be proved by numerous accidents made in disturbed geomagnetic activity (Ch=2) and in geomagnetic storms (Ch=3). Individuals of different weather sensitivity do not react to them in same way. Warm front sensitive make more accidents in storms Ch=3, 4. Mixed front sensitive react to most severe geomagnetic storms (Ch=5).

The above findings help to make the accident more efficient and lead to a lower number of accidents. *The types of weather sensitivity can be determined in a couple of minutes and as a result an individual weather forecast valid to specific types of weather sensitivity may be issued.*

Acknowledgements—The author wishes to express his thanks to Mrs. Jolan Majer-Hock for her technical assistance.

References

- Berkes, Z., 1961: Luftmassen und Fronttypen im Karpatenbecken. *Időjárás* 65, 289-293.
- Berkes, Z., 1970: Cosmic effects in the lower atmosphere (in Hungarian). *Publications of the 10th Section of the Hungarian Academy of Sciences* 3, 131-157, Budapest.
- Curry, M., 1948: *Bioklimatik*. American Research Institute, Riederau, Ammersee.
- Jessel, U., 1954: Bemerkung zur medizinisch-meteorologischen Statistik. *Med. Med. Hefte* 9, 7-20.
- Örményi, I., 1970: Influence of weather and solar activity on the insurance of the traffic (in Hungarian). *Review of Home Affairs* 8, 61-72.
- Örményi, I., 1972a: Possible effect of ELF Atmospherics of 3 cps range on traffic accidents in a metropolitan area in Hungary. *Biometeorology* 5, 93-94.
- Örményi, I., 1972b: A random sample test to determine the possible distribution of weather sensitive human subjects in Hungary. *Biometeorology* 5, 94-95.
- Örményi, I., 1972c: Questionary method for determination of weather sensitivity (in Hungarian). *Ergonomia* 5, 156-165.
- Örményi, I., 1977: Bases of medical-meteorological forecast of industrial and traffic accidents in Budapest. *Cahiers de Médecine du Travail* XIV, 243-246.
- Örményi, I., 1978: Modification effect of solar activity on reliability of the forecasts of traffic accidents. *Cycles* 29, 37-41.
- Örményi, I., 1986: The needs and applications of forecasting of geoactive solar activity for human reactions. Solar terrestrial prediction. *Proc. of a Workshop of Meudon*, France, Publ. of Air Force Geophys. Lab. 601-605.
- Örményi, I., 1990: Variation of weather sensitivity (Geophysical Biotypology) over 40 years among representative population of Budapest. *Proc. Symposium of Human Biometeorology*, Strbské Pleso, 288-296.
- Örményi, I. and Majer-Hock, J., 1991: Alteration of geomagnetic activity during traffic accidents caused by car drivers of various geophysical biotypes. *Proc. of IAGA, XX. Assembly*, Wien, p. 632.
- Péczely, G., 1957: Grosswetterlagen in Ungarn. *Kleinere Veröffentlichungen der Zentralanstalt für Meteorologie*. No. 30, Budapest.
- Schelling, H., 1937: Zur statistischen Beurteilung des Erfolges von Schutzimpfung. *Klin. Wschr.* 16, 1691-1692.
- Schelling, H., 1940: *Arbeiten aus dem Staatlichen Institut für experimentelle Therapie u. dem Forschungsinstitut für Chemotherapie*. Frankfurt, No. 39.
- WMO, 1990: *Economic and social benefits of meteorological and hydrological services*. No. 733, Geneva.

APPENDIX

Questionnaire to the determination of the weather sensitivity

Name..... Birth's place.....

Date of birth.....Month.....Day.....Hours.....

Note! It is in your interest, that on the basis of this questionnaire we should get a correct reference. Please answer to it candidly. There are four possibilities to your reply. Kindly fill out the squares on the right with one of the 4 following numbers corresponding to your preference

- 1 if you prefer the question of group 1
- 2 if you prefer the question of group 2
- 3 if both of them seem not to apply to you
- 4 if you prefer both of them

Group 1 of questions (E)

1. Are you of a hot temper?
2. Are you exhausted by excitements?
3. Can you take quickly decisions?
4. Do you easily blush?
5. Are you sociable?
6. Are you vivid, irritated?
7. Are you talkative?
8. Are you often in high spirits?
9. Can you learn easily by heart?
10. Do you feel yourself well in a cool (Northern) wind?
11. Do you feel yourself uncomfortable in a warm (Southern) wind?
12. Do you suffer from warm air?
13. Do you tolerate well cold air?
14. Don't you like to take a sunbath?
15. Are you not disturbed by draught?
16. Do you tolerate a hot day badly?
17. Do you prefer a coll sleeping room in winter?
18. Do you feel low before a thunderstorm?
19. Do you sweat to much?
20. Do you like to make excursions or to cultivate some sport?
21. Can you stand for a long time?
22. Are you in a better general condition after taking a rest?

Group 2 of questions (T)

- Are you of a quiet temper?
- Can you easily tolerate excitements?
- Are you cool in your decisions?
- Do you blush rarely?
- Are you not sociable?
- Are you slow to rouse?
- Are you tongue-tied?
- Are you often moody?
- Do you slowly learn by memory?
- Do you feel yourself uncomfortable in a cool (Northern) wind?
- Do you feel yourself well in a warm (Southern) wind?
- Do you tolerate well warm air?
- Do you suffer from cold air?
- Do you like to take a sunbath?
- Do you suffer from aerophobia?
- Do you tolerate a hot day well?
- Do you prefer a heated sleeping room in winter?
- Do you feel low during or after a thunderstorm?
- Do you sweat little?
- Do you not like to make excursion or to cultivate some sport?
- You can't stand for a long time?
- Are you in a better general condition after moving?

- | | |
|--|--|
| 23. Do you like to swing? | You don't endure swinging? |
| 24. Do you prefer to sleep on a high pillow? | Do you prefer to sleep on a low pillow? |
| 25. Are you disturbed by noise during sleep? | You are not disturbed by noise during sleep? |
| 26. Do you dream little? | Do you dream frequently? |
| 27. Do you wake up frequently in the night? | You do not often wake up in the night? |
| 28. Do you need little sleep?
(less than 8 hours) | Do you need much sleep?
(more than 8 hours) |
| 29. Are you fit immediately after waking up? | You are still tired after waking up? |
| 30. Do you feel better in the morning? | Do you feel better in the evening? |
| 31. Do you prefer to wear an open suit or shirt? | You prefer to wear a closed suit or shirt? |
| 32. Do you wake up early in the morning? | Do you wake up later on? |
| 33. Do you have sensitive eyes against light? | Your eyes are not sensitive against light? |
| 34. Do you have short sighted eyes? | Do you have long sighted eyes? |
| 35. Are your arms and legs generally warm? | Are your arms and legs generally cold? |
| 36. Do you have your illness with a high fever (over 38°C)? | Do you have your illness with a low fever (below 38°C)? |
| 37. Do you have a quick recovery after an illness? | Do you have a slow recovery after an illness? |
| 38. Are you susceptible to an acute disease with fever? | You are susceptible to an acute disease without fever? |
| 39. Do you tolerate pains badly? | Do you tolerate pains easily? |
| 40. Do you have a strong menstruation? | Do you have a weak menses? |
| 41. Do you have pains during menses? | Do you have pains after menses? |
| 42. Do you prefer heavy work for a short time? | Do you prefer easier work for a long time? |
| 43. Do you have a good appetite? | Do you have a bad appetite? |
| 44. Are you not fastidious about your food? | You are not fastidious about your food? |
| 45. Do you prefer meat? | Do you prefer fruit or vegetables? |
| 46. Do you like your food salted and spiced? | You don't like your food salted and spiced? |
| 47. Are you sensitive to smells? | You are not sensitive to smells? |
| 48. Can you hardly fall asleep after taking coffee in the evening? | You are able to sleep easily after having had coffee in the evening? |
| 49. Do you tolerate alcohol well? | Do you tolerate alcohol badly? |
| 50. Do you prefer milk or tea? | Do you prefer tea or milk? |

Date.....

1. Number of the answers in group 1.....

2. Number of the answers in group 2.....

$\frac{E}{T}$:.....

Type:.....

BOOK REVIEWS

J.R. Holton: An Introduction to Dynamic Meteorology. Third Edition. International Geophysics Series, Vol. 23. Academic Press, San Diego, 1992, 511 pages.

First two editions of *An Introduction to Dynamic Meteorology* have served as a standard basic textbook of dynamic meteorology for generations of meteorologists. The classical work of *Professor Holton* provided a bridge to the pioneers of the dynamic meteorological research in the fifties and the sixties. First edition was published in 1972 and 7 years later, it was followed by the second, revised version.

About 13 years have been elapsed since second edition of the widely respected textbook was published. During that period, a number of significant advances have been made in our understanding of a variety of atmospheric phenomena, ranging from the introduction of the so-called Q-vector formalism for diagnosing vertical motion in extratropical weather systems to the role of sea surface temperature anomalies in low-frequency variability. The new edition reflects the advances made in these fields and others, while providing a systematic treatment of the fundamental laws governing the atmospheric motion.

The third edition contains about fifty percent new material, including many new figures, while much of the previous materials has been revised and reorganized.

In Chapters 1–4, the author provides a systematic development of the basic conservation laws. Except for a short section on surface pressure tendency in Chapter 3 and a section on the baroclinic potential vorticity in Chapter 4, the first four chapters remain the same as in the second edition.

Chapter 5 about the planetary boundary layer (PBL) has been rewritten in order to incorporate sections on the boundary layer turbulent kinetic energy budget and the mixed layer model of the PBL.

In Chapter 6 the quasi-geostrophic system of equations is developed and it is demonstrated how they can be used to diagnose synoptic-scale motions at middle latitudes. Excellent physical interpretation of quasi-geostrophic potential vorticity and its relation to Ertel's potential vorticity are given. The mechanisms responsible for vertical motion in quasi-geostrophic systems are examined using two approaches: the classical omega equation, which was discussed in the second edition, and the Q-vector form of the omega equation, which represents an important new addition to this chapter. A brief new section on the ageostrophic circulation in synoptic systems is also presented.

An introduction to the linear wave theory is given in Chapter 7. Chapter 8 is devoted to the formulation and solution of the baroclinic instability problem. A new section includes a derivation of the Rayleigh necessary condition for instability. The basic kinematics and dynamics of mesoscale circulation systems are presented in Chapter 9. This material is a new addition to the book with topics in the kinematics of frontogenesis, semi-geostrophic theory, symmetric instability, mountain waves, cumulus convection, convective storms and dynamics of hurricanes.

An introduction to the theory of the general circulation of the atmosphere is given in Chapter 10. The following chapter is addressed to the structure and dynamics of equatorial circulations. A linear, inviscid shallow-water model on an equatorial plane is used to derive the dispersion relations and structures of equatorial Kelvin, Rossby-gravity and Rossby waves.

The dynamics of vertically propagating planetary waves are treated and their importance in sudden stratospheric warmings is discussed in Chapter 12. Discussion of the quasi-biennial oscillation and several aspects of the ozone layer are given in the last sections of the chapter. The final chapter contains new material on numerical modelling and weather prediction.

Holton's *An Introduction to Dynamic Meteorology* will continue to serve as the cornerstone for education at undergraduate and graduate levels and also provides references for researchers in the atmospheric sciences.

Gy. Gyuró

T.E. Graedel and P.J. Crutzen: Atmospheric Change; An Earth System Perspective. W.H. Freeman and Company, New York, 1993. 446 pages, hardback with tables, figures and coloured pictures and illustration. Price: 48,22 U.S. dollars.

It is now well documented that human activities modify the Earth environment on different scales. The modifications are serious in particular in the case of the atmosphere which plays an essential role in the control of biogeochemical cycles and climate. One can speculate that atmospheric changes will lead to important alteration of the Earth system.

In spite of the importance of the problem relatively few books are devoted to the subject. Thus, the present book of the two famous atmospheric scientists has been really badly-needed. Briefly speaking, their volume is an excellent and very clear summary of this field, in spite of the fact that it is a bit difficult to decide whether the authors aim was to write about atmospheric changes or the entire Earth system. This is not an important question, however, since the atmosphere is in a close relationship with other media of our planet.

It is a great advantage of the book that each chapter is completed with exercises and a list for further reading, which makes it very useful for beginners and students. In addition to this, a glossary of the most important expressions and an index can be found at the end of the volume.

As the writers inform the readers in the preface and introduction, five chapters (2-6) at their book discuss generally the basic topics in Earth system science. These chapters include the brief description of the driving forces of the planet, the dynamics and radiation balance of the atmosphere as well as our principal ideas about aerosols, hydrosols and water cycle. This first part is followed by the description of chemical principles applied in Earth system science (Chapter 7), while the next two chapters are devoted to the chemistry of the atmosphere and aquatic systems. Then, four chapters (10-13) describe our knowledge of the histories of climate and chemistry on the basis of up-to-date information gained by different techniques including the ice core record. Chapters 14 and 15 present in a didactic way the budgets and cycles of different constituents as well as the numerical models used in environmental chemistry; Chapters 16-18 discuss possible future climates on different time scale. Finally, the book is closed by a chapter on change and sustainability. In this last chapter, among other things it is concluded that "On very long time scales, the planet will surely become incapable of sustaining life as a consequence of the increasing solar radiation. Whether that time scale is of any interest, however, may or may not turn out to be under humanity's control. As a people, we are causing stresses to the biospheric system beyond all previous experience, and hoping that a surprise that cannot be managed is not waiting in the wings."

In summary, the reviewers believes that this thoughtful book should be used in each schools and at all universities, where the aim is to explain to students, the future generation, what to do "to minimize in every way possible the stresses on our planet".

E. Mészáros

NEWS

“Harmony with Nature” ISES Solar World Congress

The International Solar Energy Society (ISES) is a worldwide nonprofit organization dedicated to the advancement of the utilization of solar energy. Founded in 1954, the Society has members in more than 90 of the world's countries. In each second year, some part of the Society's members and non-member experts meet regularly on the Solar World Congresses. In 1993 the host of this congress was the Hungarian Section of the ISES, the congress took place in Budapest, between August 23–27. The next meeting will be in Harare, Zimbabwe in September of 1995.

“Harmony with Nature” has been selected as general title of the recent congress, to emphasize the fact, that the solar energy as renewable energy does not pollute the environment. In the distant future, its role will be deterministic in the sustainable development of the humankind.

The Budapest congress was organised in co-operation with the following International Organizations:

Comission of European Communities
European Parliament
EUROSOLAR
International Energy Agency
International Energy Foundation
International Atomic Energy Agency
World Bank
World Resources Institute and
several United Nations Organizations.

World Meteorological Organization was represented by a Hungarian expert.

The sponsors of the meeting were several Hungarian ministries, as well several foreign ministries and agencies.

The program of the congress was composed from exhibitions and several types of meeting as plenary sessions, committee meetings, board meeting, working group meetings, seminars, forums, workshops, honour and special sessions and technical sessions. The topics connected to the meteorology were presented on oral and poster technical sessions. Contrary to the previous congresses, where 15–20 meteorological papers were presented, in this year more than 60 abstracts have been accepted in the field of meteorology and

radiation measurements. (The full number of the abstract accepted for all of the technical sessions exceeded 1200.)

The overwhelming part of the meteorology related papers dealt with the utilization of meteorological solar radiation measurements for the purposes of solar energy users. Several statistical and theoretical models were presented to drive radiation parameters for those places where radiation measurements do not exist or the time series are not long enough to calculate climatological characteristics. Interesting instrument developments might result in more precise or less expensive radiation data. This way this meeting is the largest regular scientific meeting of the solar radiation measuring experts. The meteorologists must pay more attention to the ISES meetings.

The scientific proceedings of the Budapest Solar World Congress will be published in eight volumes, namely:

- I. Energy Policy, Environment, Education
- II. Radiation, Meteorology, Fundamentals
- III. Photovoltaics
- IV. Solar Thermal
- V. Active Systems
- VI. Passive Systems
- VII. Solar Architecture
- VIII. Biomass, Agriculture, Wind Energy.

As it is seen from the above list, the ISES congresses are mainly technical in their nature, but the meteorology (including solar radiation data and instruments) plays a founding role in the solar energy utilization activity.

G. Major

ATMOSPHERIC ENVIRONMENT

an international journal

To promote the distribution of Atmospheric Environment *Időjárás* publishes regularly the *contents* of this important journal. For further information the interested reader is asked to contact *Dr. P. Brimblecombe*, School for Environmental Sciences, University of East Anglia, Norwich NR 7TJ, U.K.

Volume 27A Number 8 1993

Fourth International Conference on Carbonaceous Particles in the Atmosphere

- H. Puxbaum* and *T. Novakov*: Introduction, 1167.
- P.J. Sheridan*, *R.C. Schnell*, *J.D. Kahl*, *J.F. Boatman* and *D.M. Garvey*: Microanalysis of the aerosol collected over south-central New Mexico during the ALIVE field experiment, May–December 1989, 1169–1183.
- J.C. Chow*, *J.G. Watson*, *L.C. Pritchett*, *W.R. Pierson*, *C.A. Frazier* and *R.G. Purcell*: The DRI thermal/optical reflectance carbon analysis system: description, evaluation and applications in U.S. air quality studies, 1185–1201.
- C. Liousse*, *H. Cachier* and *S.G. Jennings*: Optical and thermal measurements of black carbon aerosol content in different environments: variation of the specific attenuation cross-section, σ , 1203–1211.
- D.J. Eatough*, *A. Wadsworth*, *D.A. Eatough*, *J.W. Crawford*, *L.D. Hansen* and *E.A. Lewis*: A multiple-system, multi-channel diffusion denuder sampler for the determination of fineparticulate organic material in the atmosphere, 1213–1219.
- K. Ruoss*, *R. Dlugi*, *C. Weigl* and *G. Hänel*: Intercomparison of different aethalometers with an absorption technique: laboratory calibrations and field measurements, 1221–1228.
- S.G. Jennings*, *F.M. McGovern* and *W.F. Cooke*: Carbon mass concentration measurements at Mace Head, on the west coast of Ireland, 1229–1239.
- E. Schultz*: Size-fractionated measurement of coarse black carbon particles in deposition samples, 1241–1249.
- A. Leonardi*, *H. Burtscher* and *H.C. Siegmann*: Size-dependent measurement of aerosol photoemission from particles in diesel exhaust, 1251–1254.
- H. Burtscher*, *D. Matter* and *H.C. Siegmann*: Measurement of size distribution and photoelectric activity of particles in a gas diffusion flame, 1255–1259.
- P. Ciccioli*, *A. Cecinato*, *R. Cabella*, *E. Brancaleoni* and *P. Buttin*: The contribution of gas-phase reactions to the nitroarene fraction of molecular weight 247 present in carbon particles sampled in an urban area of northern Italy, 1261–1270.

- C. Helsper, W. Mölter, F. Löffler, C. Wadenpohl, S. Kaufmann and G. Wenninger*: Investigations of a new aerosol generator for the production of carbon aggregate particles, 1271-1275.
- J.E. Penner, H. Eddleman and T. Novakov*: Towards the development of a global inventory for black carbon emissions, 1277-1295.
- J.A. Rau and M.A.K. Khalil*: Anthropogenic contributions to the carbonaceous content of aerosols over the Pacific Ocean, 1297-1307.
- W.F. Rogge, M.A. Mazurek, L.M. Hildemann, G.R. Cass and B.R.T. Simoneit*: Quantification of urban organic aerosols at a molecular level: identification, abundance and seasonal variation, 1309-1330.
- C. Sabbioni and G. Zappia*: Characterization of particles emitted by domestic heating units fueled by distilled oil, 1331-1338.
- T.V. Nunes and C.A. Pio*: Carbonaceous aerosols in industrial and coastal atmospheres, 1339-1346.
- M. Bizjak, R. Cigler A.D.A. Hansen and V. Hudnik*: Diurnal concentrations of black carbon and some other air pollutants in Ljubljana, Slovenia, 1347-1350.
- Y.J. Kim, J.F. Boatman, R.L. Gunter, D.L. Wellman and S.W. Wilkison*: Vertical distribution of atmospheric aerosol size distribution over south-central New Mexico, 1351-1362.
- R.L. Gunter, A.D.A. Hansen, J.F. Boatman, B.A. Bodhaine, R.C. Schnell and D.M. Garvey*: Airborne measurements of aerosol optical properties over south-central New Mexico, 1363-1368.
- R.S. Hamilton and T.A. Mansfield*: The soiling of materials in the ambient atmosphere, 1369-1374.
- J.P. Lodge Jr*: Summary Lecture, 1375.

Volume 27A Number 9 1993

- J.-P. Tuovinen, T. Laurila, H. Lättilä, A. Ryaboshapko, P. Brukhanov and S. Korolev*: Impact of the sulphur dioxide sources in the Kola Peninsula on air quality in northernmost Europe, 1379-1395.
- P.G. Simmonds, D.M. Cunnold, G.J. Dollard, T.J. Davies, A. McCulloch and R.G. Derwent*: Evidence of the phase-out of CFC use in Europe over the period 1987-1990, 1397-1407.
- I. Grgič, V. Hidnik, M. Bizjak and J. Levec*: Aqueous S(IV) oxidation—III. Catalytic effect of soot particles, 1409-1416.
- J.L. Gras*: Condensation nucleus size distribution at Mawson, Antarctica: seasonal cycle, 1417-1425.
- J.L. Gras*: Condensation nucleus size distribution at Mawson, Antarctica: microphysics and chemistry, 1427-1434.
- N. Dombrowski, E.A. Fomeny, D.B. Ingham and Y.D. Qi*: Modelling of flow characteristics within deposition gauges under blowout conditions, 1435-1442.

- D. Anfossi, E. Ferrero, G. Brusasca, A. Marzorati and G. Tinarelli*: A simple way of computing buoyant plume rise in Lagrangian stochastic dispersion models, 1443-1451.
- C.K. Laird and S.A. Sloan*: Nitrous oxide emissions from U.K. power stations, 1453-1457.
- S. Grinshpun, K. Willeke and S. Kalatoor*: A general equation for aerosol aspiration by thin-walled sampling probes in calm and moving air, 1459-1470.
- E.J. Palen, D.T. Allen, S.N. Pandis, S. Paulson, J.H. Seinfeld and R.C. Flagan*: Fourier Transform Infrared analysis of aerosol formed in the photooxidation of 1-octene, 1471-1477.
- P. Zannetti, I. Tombach, S. Cvencek and W. Balson*: Calculation of visual range improvements from SO₂ emission controls—II. An application to the eastern United States, 1479-1490.
- S.R. Hanna and J.C. Chang*: Hybrid plume dispersion model (HPDM) improvements and testing at three field sites, 1491-1508.
- H. Sakugawa and I.R. Kaplan*: Comparison of H₂O₂ and O₃ content in atmospheric samples in the San Bernardino Mountains, southern California, 1509-1515.

Volume 27A Number 10 1993

- G. Christakos and G.A. Thesing*: The intrinsic random field model in the study of sulfate deposition processes, 1521-1540.
- S.A. Young, D.R. Cutten, M.J. Lynch and J.E. Davies*: Lidar-derived variations in the backscatter-to-extinction ratio in Southern Hemisphere coastal maritime aerosols, 1541-1551.
- R. Sequeira*: On the large-scale impact of arid dust on precipitation chemistry of the continental Northern Hemisphere, 1553-1565.
- L. Giusti, Y.-L. Yang, C.N. Hewitt, J. Hamilton-Taylor and W. Davison*: The solubility and partitioning of atmospherically derived trace metals in artificals and natural waters: a review, 1567-1578.
- P. Hurley and W. Physick*: Lagrangian particle modelling of buoyant point sources: plume rise and entrapment under convective conditions, 1579-1584.
- V.E. Cachorro, A.M. De Frutos and M.J. Gonzalez*: Analysis of the relationships between Junge size distribution and Ångström α turbidity parameters from spectral measurement of atmospheric aerosol extinction, 1585-1591.
- X.Q. Zhang, P.H. McMurry, S.V. Hering and G.S. Casuccio*: Mixing characteristics and water content of submicron aerosols measured in Los Angeles and at the Grand Canyon, 1593-1607.
- A. Greenburg, J.-H. Lwo, T.B. Atherholt, R. Rosen, T. Hartman, J. Butler and J. Louis*: Bioassay-directed fractionation of organic compounds associated with airborne particulate matter: an interseasonal study, 1609-1626.

Volume 27A Number 11 1993

- P.K. Koutsenogii, N.S. Bufetov, V.I. Drozdova, V.L. Golobkova, T.V. Khodger, K.P. Koutzenogii, V.I. Makarov, V.A. Obolkin and V.L. Potemkin:* Ion composition of atmospheric aerosol near Lake Baikal, 1629-1633.
- S. Husted:* An open chamber technique for determination of methane emission from stored livestock manure, 1635-1642
- C.V. Raiyani, S.H. Shah, N.M. Desai, K. Venkaiah, J.S. Patel, D.J. Parikh and S.K. Kashyap:* Characterization and problems of indoor pollution due to cooking stove smoke, 1643-1655.
- G. Sharf, M. Peleg, M. Livnat and M. Luria:* Plume rise measurements from large point sources in Israel, 1657-1663.
- M. Andretta, R. Bianconi, W. Flospergher and M. Tamponi:* The MRBT model: an analytical dispersion model in a finite mixing layer. Sensitivity analysis and validation against tracer measurements, 1665-1672.
- B. Lamb, D. Gay, H. Westberg and T. Pierce:* A biogenic hydrocarbon emission inventory for the U.S.A. using a simple forest canopy model, 1673-1690.
- S. Lal, S. Venkataramani and B.H. Subbaraya:* Methane flux measurements from paddy fields in the tropical Indian region, 1691-1694.
- P.E. Perros:* Large-scale distribution of hydrogen peroxide from aircraft measurements during the TROPOZ II experiment, 1695-1708.
- R.C. MacDonald and R. Fall:* Detection of substantial emissions of methanol from plants to the atmosphere, 1709-1713.
- G. Devitofrancesco, F. Benvenuti, M. Biserni and C. Conte:* Study on utilization of piezoelectricity in the determination of quartz in respirable dust, 1715-1719.
- A. Febo, C. Perrino and M. Cortiello:* A denuder technique for the measurement of nitous acid in urban atmospheres, 1721-1728.
- J.A.K. Simmons and A.H. Knap:* The impact of leaded to unleaded gasoline conversion on the oceanic island of Bermuda, 1729-1733.
- Ji Xueli, Jiang Dahe, Fei Simei, Yuan Hui, He Pinjing, Ye Boming, Lei Zhongliang and Feng Chang:* Road dust emission inventory for the metropolitan area of Shanghai city, 1735-1741.
- J.L. Philips, R. Field, M. Goldstone, G.L. Reynolds, J.N. Lester and R. Perry:* Relationships between indoor and outdoor air quality in four naturally ventilated offices in the United Kingdom, 1743-1753.
- C.L. Blanchard and K.A. Tonnessen:* Precipitation-chemistry measurements from the California Acid Deposition Monitoring Program, 1985-1990, 1755-1763.
- J.R. Brook, P.J. Samson and S. Sillman:* The relationship between upwind SO₂ emissions and SO₄²⁻ concentrations in precipitation at six sites in the eastern U.S.A., 1765-1779.

Volume 27A Number 12 1993

- H.M. Cartwright and S. P. Harris*: Analysis of the distribution of airborne pollution using genetic algorithms, 1783-1791.
- J.-M. Giovannoni*: Modeling of SO₂, Pb and Cd atmospheric deposition over a one-year period, 1793-1808.
- F. Flatøy*: Balanced wind in advanced advection schemes when species with long lifetimes are transported, 1809-1819.
- E. Ganor, Z. Levin and D. Pardess*: Determining the acidity and chemical composition of fog, haze and cloud droplets in Israel, 1821-1832.
- E.D. Suttie and E.W. Wolff*: The local deposition of heavy metal emissions from point sources in Antarctica, 1833-1841.
- R.F. Harrington, A.W. Gertler, D. Grosjean and P. Amar*: Formic acid and acetic acid in the western Sierra Nevada, California, 1843-1849.
- U. Bartell, U. Hofmann, R. Hofmann, B. Kreuzburg, M.O. Andreae and J. Kesselmeier*: COS and H₂S fluxes over a wet meadow in relation to photosynthetic activity: an analysis of measurements made on 6 September 1990, 1851-1864.
- Xu-Liang Cao and C.N. Hewitt*: Evaluation of Tenax-GR absorbent for the passive sampling of volatile organic compounds at low concentrations, 1865-1872.
- K. Fuhrer, A. Neftel, M. Anclin and V. Maggi*: Continuous measurements of hydrogen peroxide, formaldehyde, calcium and ammonium concentrations along the new GRIP ice core from Summit, central Greenland, 1873-1880.
- U. Baltensperger, M. Schwikowski, H.W. Gäggeler, D.T. Jost, J. Beer, U. Siegenthaler, D. Wagenbach, H.J. Hofmann and H.A. Synal*: Transfer of atmospheric constituents into an Alpine snow field, 1881-1890.
- P. Ciccioli, E. Brancaleoni, M. Frattoni, A. Cecinato and A. Brachetti*: Ubiquitous occurrence of semi-volatile carbonyl compounds in tropospheric samples and their possible sources, 1891-1901.
- W.R. Cofer III, J.S. Levine, E.L. Winstead, B.J. Stocks, D.R. Cahoon and J.P. Pinto*: Trace gas emissions from tropical biomass fires: Yucatan Peninsula, Mexico, 1903-1907.
- J.M. Miller, J.L. Moody, J.M. Harris and A. Gaudry*: A 10-year trajectory flow climatology for Amsterdam Island, 1980-1989, 1909-1916.
- J.L. McElroy and T.B. Smith*: Creation and fate of ozone layers aloft in Southern California, 1917-1929.
- Short Communication**
- G. Vleugels, R. Dewolfs and R. Van Grieken*: On the memory effect of limestone for air pollution, 1931-1934.

NOTES TO CONTRIBUTORS

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, critical review articles summarizing current problems in certain subject, or shorter contributions dealing with a specific question. Authors may be of any nationality but papers are published only in English.

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 names(s) of the author(s) with indication of the name and address of employment.

The title should be followed by an *abstract* containing the aim, method and conclusions of the scientific investigation. After the abstract, the *key-words* of the content of the paper must be given.

Three copies of the manuscript, typed with double space, should be sent to the Editor-in-Chief: *P.O. Box 39, H-1675 Budapest, Hungary.*

References: The text citation should contain the name(s) of the author(s) in Italic letter or underlined and the year of publication. In case of one author: *Miller (1989)*, or if the name of the author cannot be fitted into the text: *(Miller, 1989)*; in the case of two authors: *Gamov and Cleveland (1973)*; if there are more than two authors: *Smith et al. (1990)*. 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) in Italics or underlined, year, title of article, name of journal,

volume number (the latter two in Italics or underlined) and pages. E.g. *Nathan, K. K., 1986: A note on the relationship between photosynthetically active radiation and cloud amount. Időjárás 90, 10-13.* For a book: the name(s) of author(s), year, title of the book (all in Italics or underlined with except of the year), publisher and place of publication. E.g. *Junge, C. E., 1963: Air Chemistry and Radioactivity.* Academic Press, New York and London.

Figures should be prepared entirely in black India ink upon transparent paper or copied by a good quality copier. A series of figures should be attached to each copy of the manuscript. 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 Arabic numbers and provided on separate sheets together with relevant captions. In one table the column number is maximum 13 if possible. One column should not contain more than five characters.

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

The final text should be submitted both in manuscript form and on *diskette*. Use standard 3.5" or 5.25" DOS formatted diskettes for this purpose. The following word processors are supported: WordPerfect 5.1, WordPerfect for Windows 5.1, Microsoft Word 5.5, Microsoft Word for Windows 2.0. In all other cases the preferred text format is ASCII.

* * *

Authors receive 30 *reprints* free of charge. Additional reprints may be ordered at the authors' expense when sending back the proofs to the Editorial Office.

Published by the Hungarian Meteorological Service

Budapest, Hungary

INDEX: 26 361

HU ISSN 0324-6329