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QUARTERLY JOURNAL
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The radon and the natural atmospheric radioactive aerosol

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Abstract—The natural atmospheric radioactivity arises especially from radon 222 (of the ^{238}U decay series) and in a lesser way from radon 220 (thoron of the ^{232}Th decay series), both are noble and radioactive α emitter gas originating from the soil. Their short lived daughters like Po(RaA-ThA), Pb(RaB-ThB) and Bi(RaC-ThC) are attached to particles and make up the natural radioactivity of the atmospheric aerosol. By studying this latter, we can interpret various atmospheric phenomena, estimate the quantity of natural irradiation a given population may undertake and in a more theoretical way, control the correctness of some laws in aerosol physics and atmospheric electricity. The aim of the present review is to discuss the results of some studies made mostly in France to investigate radioactive aerosol particles in outdoor and indoor air.

Key words: radon, thoron, indoor and outdoor radioactivity, aerosol.

1. Radon and thoron concentrations in the air

The radon measurement technique is based on the double-filter method (Fontan, 1964). In our laboratory in Brest Tymen (1979) built an automated system by which radon concentration in air is evaluated each 30 minute. On an average, the radon concentration in the air has been found to be 4 Bqm^{-3} (0.13 pCiL^{-1}), while the thoron concentration is about 100 times less. In regions where the soil consists of granitic minerals (like, for example, around Brest in Western France), the concentration of radon is higher. Its average is equal to

13 Bqm⁻³, with considerable variations as a function of the origin of the air in which observations are carried out. Thus, mean radon concentration under sea influence is equal to 1 Bqm⁻³ (0.03 pCiL⁻¹), while it is 100 Bqm⁻³ (3 to 4 pCiL⁻¹) under local, continental conditions (*Renoux, 1987*). Measurements also show that radon concentration also depends on the hours of the day (see *Fig. 1*)

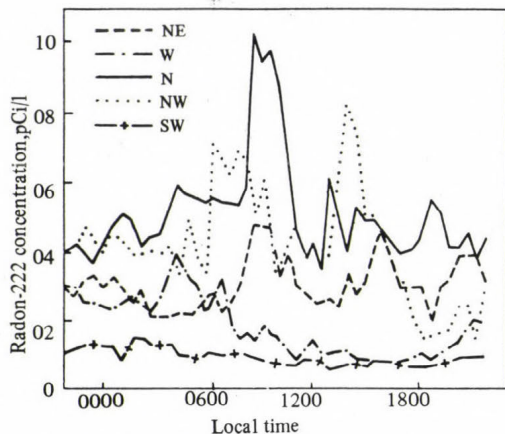


Fig. 1. Variation of the mean radon concentration (Bqm⁻³) as a function of the wind direction and time of the day

and season of the year. Among others, *Hayakawa (1985)* and *Ikebe (1988)* observed over Japan that in the surface air the levels of radon are lower in summer than in winter.

2. State of the radon 222 balance-short lived daughters

This is a fundamental parameter, when trying to estimate the natural radioactive aerosol concentration. The degree of equilibrium between radon and its daughters is defined as follows:

$$F_A = C_A/C_{Rn} \quad F_B = C_B/C_{Rn} \quad F_C = C_C/C_{Rn}$$

where C_A , C_B , C_C , C_{Rn} are the concentration of RaA(²¹⁸Po), RaB(²¹⁴Pb), RaC(²¹⁴Bi) and Rn respectively. A method developed by *Raabe and Wren (1969)* was used in Brest (*Renoux et al., 1980*) to estimate equilibrium

conditions. The results obtained are given in *Table 1*.

It appears that, on an average, the disequilibrium of radon progeny is important and highly depends on wind direction, particularly for RaA. It seems that F_A , F_B and F_C increase for winds blowing from the direction of areas where granitic soils are predominant. Concerning *Table 1* it should be noted that some authors discussed the RaC/RaB ratios in the atmosphere for testing different diffusion models (*Nakatani, 1975; Shapiro et al., 1978*). Their results are in good agreement with the French values tabulated.

Table 1. Average concentration (pCiL^{-1}) of radon and its daughters as a function of the wind direction. Values characterize the deviation from equilibrium

Wind direction	C_{Rn}	C_A	C_B	C_C	F_A	F_B	F_C
N	0.65	0.197	0.176	0.119	0.30	0.27	0.18
NW	0.330	0.165	0.135	0.094	0.50	0.49	0.28
W	0.11	0.066	0.029	0.021	0.58	0.26	0.19
SW	0.075	0.045	0.029	0.028	0.60	0.39	0.37
S	0.23	0.072	0.070	0.064	0.31	0.30	0.28
SE*	-	-	-	-	-	-	-
E	0.13	0.083	0.064	0.048	0.64	0.49	0.37
NE	0.26	0.134	0.102	0.083	0.52	0.39	0.32
Average	0.34	0.17	0.11	0.090	0.5	0.38	0.29
Average standard error	RaA: 37 %		RaB: 7.2 %		RaC: 14.9 %		

* Very few observations were carried out in the SE direction.

3. Ionic state of the radioactive aerosol developed from radon 222

There is a simple method to measure the small and large atmospheric radioactive (positive and negative) ions originating from radon 222. This is use of Zeleny tubes modified according to *Kawano (1957)* and *Renoux (1965)*. For example, the results obtained in Brest, France, by using this procedure (*Tymen,*

1979) are summarized in *Table 2* for particles with radius less than $2 \times 10^{-2} \mu\text{m}$.

Theory shows (*Bricard and Pradel, 1966*) that the ratio N_R^-/N_R^+ (where N_R^- represents the negative radioactive ions concentration, while N_R^+ is the

Table 2. Percentage of α -radioactivity carried by various categories of atmospheric ions

Positive small ions	Positive large ions	Negative large ions	Neutral nuclei
2 %	11 %	5 %	24 %

same for positive radioactive ions) is under the influence of the quantity Q/N^2 , where Q is the ionic air intensity, and N is the nuclei concentration. As the term Q controlled by the natural radioactivity varies very slightly, this ratio

Table 3. Proportions of radioactive nuclei according to various influences. In the table the relative ion concentrations are related to the total number concentration

	Maritime influence	Partial maritime influence	Urban influence	Paris
$N \cdot 10^{-4}$	1.7	1.7	4.6	10-15
N_R^+ (%)	7.7	10.1	12.6	7.9
N_R^- (%)	5.0	6.7	3.8	2.2
N_R^-/N_R^+	0.64	0.66	0.29	0.28

must therefore be much higher if N is lower. The results measured in Brest are shown in *Table 3* (first three columns), where the results obtained in Paris (*Renoux, 1965*) are listed (last column).

4. Size distribution of the natural atmospheric radioactive aerosol

There are different devices (Zeleny tubes, diffusion batteries, HEPA filters, cascade impactors), which make it possible to obtain the size distribution of the natural atmospheric radioactive aerosol (Renoux, 1965). Such measurements carried out in France (Tymen, 1979; Renoux, 1965) show that, on an average, 40 % of the natural atmospheric radioactivity is detected on particles with radius smaller than $2 \cdot 10^{-2} \mu\text{m}$. But in fact these are only average values which are not always appropriate because the size distributions vary as a function of the meteorological conditions. This is illustrated by the curves in Fig. 2, giving cumulative activities. In the figure two different types of behaviour can be seen; they are related to urban (NE, SE, S) and marine influ-

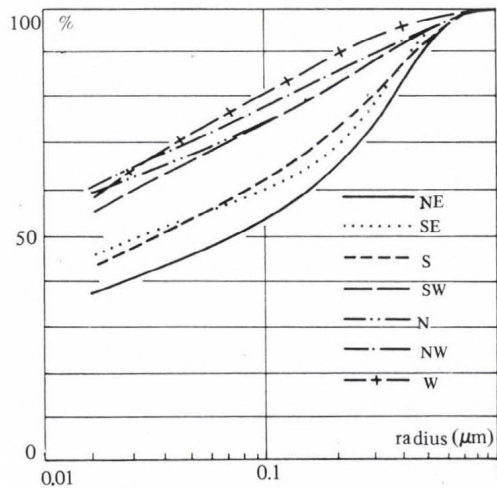


Fig. 2. Cumulative distribution of α activity from ^{222}Rn daughters according to wind direction

ences in Brest. In particular, it is established that, in some cases, radioactive aerosols with radius larger than $0.1 \mu\text{m}$, may reach 40 to 50 % of the total activity, which is in a good agreement with the characteristics of particles in the size range of $0.1\text{--}2 \mu\text{m}$ (Butor, 1981).

The formation of natural radioactive particles can be explained by the attachment of small radioactive ions on atmospheric aerosol particles. This can be proved by calculations based on the limiting sphere method (Tymen, 1978). In this theoretical method, we take into account the electric image of the diffusive ions, and the modification of the ion trajectory inside the limiting

sphere caused by the electric field of the stationary nuclei. The pre-existent aerosol size distribution is expressed with the help of three lognormal distributions for radii between $3 \cdot 10^{-3} \mu\text{m}$ and $3 \mu\text{m}$ (Butor, 1981; Tymen, 1978). Fig. 3 shows the results of such a calculation, carried out by a computer for two typical situations at the measuring site in Brest. As we see, the agreement between the theoretical curves and experimental points is good.

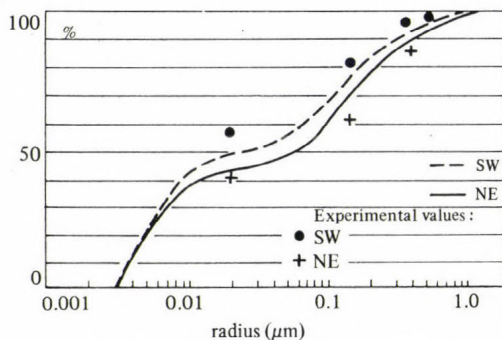


Fig. 3. Theoretical (curves) and experimental (points) distribution of α activity from ^{222}Rn daughters

All theoretical α activity curves obtained in Brest have an inflexion point between $0.01 \mu\text{m}$ and $0.1 \mu\text{m}$, which suggests a bimodal distribution of the total radioactivity in good agreement with the diffusion battery measurements of Sinclair *et al.* (1978).

5. The problem of radon and daughters indoors

Knowledge of radiation levels in buildings and living-houses is very important in the assessment of population exposures because most individuals spend a large part of their life indoors. Since about 1985, a lot of works have been made in different countries to estimate the level of radon and its daughters indoors (e.g. Rannou, 1988).

A few years ago a pilot study was conducted in France by the *Commissariat à l'Énergie Atomique* (C.E.A.) for the assessment of the potential indoor alpha energy due to radon products jointly with the survey of natural external human exposure. Inside this national survey, a specific study has been carried out in Brittany at the West of France by Tymen *et al.* (1987). In this study a median value of 101 Bqm^{-3} for ^{222}Rn indoor concentration has been found in

Finistère department and 120 Bqm⁻³ in Morbihan department. The values are significantly higher than the overall French average of 41 Bq⁻³ (Rannon, 1989). Generally, the annual indoor effective equivalent dose H_E due to the inhalation of radon daughters is about three times more than 1 mSV considered as a reference dose level in standard areas (UNSCEAR, 1982). In addition, 5 % of calculated H_E exceed 10 mSV (1 rem). The contribution of ²²⁰Rn daughters to total H_E is estimated to be 30 % on an average (Rannou, 1988), no marked correlation was found between ²²²Rn levels and γ dose exposure rates.

Table 4 gives the mean (arithmetic and geometric) concentrations indoors for ²²²Rn in different countries as published by Rannou and Tymen (1989).

Table 4. Mean indoor levels of ²²²Rn observed in various countries

Country	Arithmetic mean (Bq/m ³)	Geometric mean (Bq/m ³)	Number of observations
Belgium	50	41	79
Denmark	47	28	496
Finland	90	-	8150
France	115	41	3000
Ireland	-	53	498
Italy	-	27	500
The Netherlands	29	24	1000
Norway	80-100	-	1500
Great Britain	23	15	2309
Sweden	101	60	506
Switzerland	92	62	1851
U.S.A.	42- 60	34	817
Germany	49	40	5970

With the sudden awareness of the radon indoor's problem a new expansion of works in the field of natural atmospheric radioactivity is expected. Simultaneously with systematic measurements of the radon concentrations in different caves and localities it is necessary to conduct fundamental research under laboratory conditions to obtain a better understanding of the formation and behaviour of the radon progeny (Bondietty, 1989; Tymen et al., 1989). Generally two important physical parameters are used in lung dosimetry models to estimate radiation doses from inhaled Rn products. One of them is the activity median diameter of the "attached" natural radioactive aerosol and the other one is the "unattached" action of ²¹⁸Po (RaA) (Harley and Pasternak,

1982). The unattached fraction of Rn progeny consists of free molecular daughter atoms or ions possibly clustered with other molecules such as H₂O (i.e. an ultrafine particle of 0.5–3 nm in diameter), which differ significantly from daughter atoms “attached” particles in the preexisting ambient aerosol. Actually, the measurement of this unattached Rn fraction is the subject of extensive research (Tymen *et al.*, 1989; Harley and Pasternak, 1982; Hopke, 1989, 1990). For example, in a Japanese house Kojima and Abbe (1988) found unattached ²¹⁸Po(RaA) fractions between 0.078 and 0.21, and ²¹⁴Pb(RaB) fractions between 0.024 and 0.041. The rate of attachment of this unattached fraction is one of the key factors in the control of the behaviour of radon decay products. Recently, in 14 Finnish dwellings a wide range of rate values have been observed (Keskinen *et al.*, 1991) ranging between 5 to more than 300 h⁻¹ (high values are caused by occupant activities) with a median value of 18 h⁻¹, in a good agreement with the results of other authors (Porstendörfer *et al.*, 1987). Table 5 gives the indoor and outdoor exposure in France for the radon

Table 5. Internal exposures indoor and outdoor in France. PAE is the Potential Alpha Energy, while Co represents the Rn concentration

Internal exposure		Indoor	Outdoor
Rn 222 series	Co(Bq·m ⁻³)	41	6
	PAE (x·10 ⁻⁸ J·m ⁻³)	9.8	1.3
Rn 220 series	Co(Bq·m ⁻³)	18	0.2
	PAE (x·10 ⁻⁸ J·m ⁻³)	4.1	0.6

222 and 220 series (Rannou, 1987). In this table, PAE is the Potential Alpha Energy (the PAE concentration of any mixture of short-lived radon 222 or thoron 220 daughters in air is the sum of the potential alpha energy of all daughter atoms present per unit volume of air).

It can be seen that the internal exposure are 6–7 times higher indoor than outdoor. However, in spite of the existing epidemiologic surveys, it is difficult to make a general conclusion concerning the effective sanitary impact on the public (Renoux and Tymen, 1990). Therefore, it is important to initiate a field survey applying a rigorous case-control approach, which takes into count all the interacting factors. Actually, the European Community is supporting a project aiming to estimate the protection afforded by buildings against atmospheric radioactivity in aerosol form (Goddard *et al.*, 1989).

References

- Bondiatti, E.I., 1989: Growth dynamics of natural and anthropogenic radioactivity associated with ambient submicron aerosols. *20th Annual Meeting of the Fine Particle Society*. Boston, August 1989.
- Bricard, J. and Pradel, J., 1966: *Electric Charge and Radioactivity of Naturally Occurring Aerosols in Aerosol Science* (ed.: C.N. Davies). Pergamon Press, 87-109.
- Butor, J.F., 1981: Contribution to the study of the atmospheric aerosol in urban, maritime and oceanic areas. *Időjárás* 85, 117-125.
- Fontan, J., 1964: *Le dosage des radioéléments gazeux donnant des produits radioactifs de filiation*. Thèse d'Etat, Toulouse.
- Goddard, A.J.H., Mac Curtain, J. and Roed, J., 1989: Studies relating to the ingress of particulate radioactivity into and subsequent transport with dwellings. *20th Annual Meeting of the Fine Particle Society*. Boston, Aug 1989.
- Harley, H.H. and Pasternak, B.S., 1982: Environmental radon daughter alpha dose factors in a five-lobed human lung. *Health Phys.* 42, 789-799.
- Hayakawa, H., 1985: Radon concentration in cloud and rainfall rate dependency of short lived radon daughters in rain-water. *J. Nuclear Sci. and Technology* 22, 292-300.
- Hopke, P.K., 1989: The initial behaviour of ²¹⁸Po. *Indoor Air Environment Int.* 15, 299-308.
- Hopke, P.K., 1990: *A Critical Review of Measurements of the "Unattached" Fraction of Radon Decay Products*. Technical Report Series, U.S. Department of Energy.
- Ikebe, Y., Kojima, S. and Shimo, M., 1983: On the origin and transport of Rn-222 in the atmosphere. *Res. Lett. Atmos. Electr.* 3, 51-54.
- Kawano, M., 1957: *J. Meteorol. Soc. Japan*. Ser. 2, 35, N° 6.
- Keskinen, J., Lehtimäki, M. and Graeffe, G., 1991: Radon decay product attachment rates in dwellings. *J. Aerosol Sci.* 22, 765-777.
- Kojima, H. and Abe (S.), 1988: Measurement of the total and unattached radon daughters in a house. *Radiat. Prot. Dosim* 24, 241-244.
- Nakatani, S., 1975: *Characteristics of Natural Radioactivity Appearing in its Diurnal Variations*. Researches of the Electrotechnical Laboratory, Japan, Rep. N° 755.
- Porstendorfer, J., Reineking, A. and Becker, K.H., 1987: In *Radon and its Decay Products* (ed.: P.K. Hopke). Amer. Chemical Soc., Washington, 285-300.
- Raabe, O.G. and Wrenn, M.E., 1969: Analysis of the activity of radon daughter samples by weighted least squares. *Health Phys.* 17, 593-605.
- Rannou, A., 1987: *Contribution à l'étude du risque lié à la présence du radon 220 et du radon 222 dans l'atmosphère des habitations*. Thèse 3^{ème} cycle, Université de Brest.
- Rannou, A. and Tymen, G., 1989: Les résultats des campagnes de mesures du radon et facteurs explicatifs. In *Exposition au radon dans les habitations* (ed.: SFRP). Paris, 42-63.
- Rannou, A., 1988: *Le radon et ses risques dans les habitations*. R.G.N., N° 3, 238-244.

- Renoux, A., 1965: *Etude des ions radioactifs de l'air*. Thèse 5.199.4555, Fac. Sc. Paris. Rapport CEA R 2771.
- Renoux, A., Tymen, G., Le Gac, J. and Madeleine, G., 1980: Study of the ^{222}Rn shortlived daughter disequilibrium in a mixed maritime and continental atmosphere near granitic soils. *Health Phys.* 39, 291-298.
- Renoux, A., 1987: Natural atmospheric radioactivity and radioactive aerosol. The problem of radon 222 and daughters indoors. *J. Aerosol Sci.* 18, 677-680.
- Renoux, A. and Tymen, G., 1990: Le radon dose-effet. *Pollution Atmosphérique* N° 126, 167-177.
- Shapiro, M.H., Kosowski, R. and Jones, A.D., 1978: Radon series disequilibrium in Southern California coastal air. *J. Geophys. Res.* 83, 929-933.
- Sinclair, D., George, A.C. and Knutson, E.O., 1978: *Assessment of Airborne Radioactivity*. Amer. Nuclear Soc., Proceeding Series.
- Tymen, G., 1978: Distribution of natural radioactivity attached to atmospheric aerosol particles. *J. Environ Sci. Health A13*, 803-815.
- Tymen, G., 1979: *Répartition granulométrique de l'aérosol naturel et des particules radioactives issues du radon, en atmosphère maritime et urbaine peu polluée*. Thèse d'Etat, Brest.
- Tymen, G., El Moussaoui, B. and Renoux, A., 1989: Modelling and experimental study on time evolution of radon daughters size distribution. *20th Annual Meeting of the Fine Particle Society*. Boston, August 1989.
- Tymen, G., Mouden, A., Renouard, H. and Rannou, A., 1987: Assessment of indoor exposure to inhaled ^{222}Rn and ^{220}Rn daughters in granitic areas located at the west of France. *American Industrial Hygiene Conference*, Montréal.
- UNSCEAR, 1982: *Ionizing Radiation: Sources and Biological Effects*. United Nations Ed.

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Total deposition and budgets of heavy metals over Eastern Europe

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Abstract—In recent years there has been an increased interest in trace metals in the atmosphere and the environmental effects of their deposition. This is to large extent because heavy metals can accumulate in the biosphere and may be toxic to living systems. On the basis of IIASA's TRACE model, the total (wet plus dry) deposition of As, Cd, Pb and Zn has been estimated for Eastern Europe. These are annual averages for rural areas, and relate to the situation in Europe in the mid-1980s. The maximum deposition value is $3.5 \text{ mg m}^{-2} \text{ yr}^{-1}$ for As, $1.5 \text{ mg m}^{-2} \text{ yr}^{-1}$ for Cd and $50 \text{ mg m}^{-2} \text{ yr}^{-1}$ for Zn. All these maxima occur in Southern Poland. The highest total deposition of Pb ($15.0\text{--}20.0 \text{ mg m}^{-2} \text{ yr}^{-1}$) has been computed for Western Czechoslovakia and also for Southern Poland. Deposition levels throughout most of Eastern Europe are at least one or two orders of magnitude greater than observed in remote parts of the world.

The annual average concentration of metals in some rural areas are lower, but within a factor of two of drinking water guidelines. This is cause for concern because some short-term concentrations are almost assuredly much higher than the annual average.

Because of long-range transport, there is a very significant transboundary exchange of heavy metals within Eastern Europe. As with acid-causing pollutants, the problem of heavy metals contamination in the region depends on the reduction of this transboundary pollution.

Key words: atmospheric deposition, heavy metals, Eastern Europe.

1. Introduction

Since the middle of this century, energy generation, industrial production and transportation have caused serious environmental contamination by trace elements including heavy metals. The rate of contamination can vary from place to place as a function of source densities and intensities of heavy metals flux as well as meteorological conditions. Aerosols containing heavy metals can also be transported far away from their sources by advection before being deposited.

The TRACE model developed at IIASA (*Alcamo et al.*, 1992; *Bartnicki and Alcamo*, 1992) focuses on European-scale emission, transport and deposition of four heavy metals: As, Cd, Pb and Zn. These metals are particularly important because of their toxicity and/or ability to accumulate in the natural environment. On the basis of TRACE model calculations, this paper presents calculations of total deposition, concentration in precipitation and budgets of heavy metals in Eastern Europe. An attempt has also been made to estimate the effects of the most intensive regional sources in Eastern Europe on the deposition of As, Cd and Zn in the surrounding countries.

2. Modeling deposition processes of heavy metals

The main sources of As, Cd and Zn in the lower atmosphere over Eastern Europe are power plants, metallurgical plants and other large industrial facilities. For Pb, a main source is also motor vehicles (*Pacyna and Münch*, 1988). These metals are emitted to the atmosphere either as volatile gases or very fine particles and usually disperse and mix fairly quickly into the lower atmosphere. Within a few minutes or hours the emitted gases condense into or adhere onto fine particles, in the size range of 0.1 to 10 μm in diameter. Particles of this size are too fine to effectively settle, and too coarse to be deposited by diffusion. Hence, they can be transported hundreds or more kilometers from their sources before gradually being removed from the atmosphere by dry or wet deposition. Particles are continuously deposited onto soil, vegetation, lakes and other surfaces by gravitational settling and diffusion. This is called "dry deposition". Particles containing heavy metals are also swept from the air by precipitation as it falls to earth or are incorporated into cloud droplets and later fall to earth as these cloud droplets are collected by precipitation. This process is called "wet deposition". The TRACE model represents these processes in a simple way for all Europe.

The model relies on long-term average meteorological data as input, and computes the long-term average levels of heavy metals in the atmosphere. Details are presented in *Alcamo et al.* (1992); here we only briefly review its main features.

The calculation procedure of the model is divided into two steps. First, the loss of pollutant from a parcel of air as it travels from a source to a receptor is represented by a simple loss term. This equation gives the air concentration of a pollutant at a receptor located R distance downwind from a source:

$$c(x_r, y_r; x_e, y_e) = \beta \frac{E(x_e, y_e)}{R} (1 - \alpha) e^{(k_d + k_w)t^*}, \quad (1)$$

where c is the air concentration at the receptor due to a single emission source; (x_r, y_r) is the receptor position; (x_e, y_e) is the emission source position; E is the amount of emissions at the source; R is the distance between source and receptor, i.e. $R = \sqrt{(x_r - x_e)^2 + (y_r - y_e)^2}$; α is the local deposition coefficient; k_d and k_w are the first order loss coefficients, in units of inverse time, which reflect the loss of mass from the air parcel by dry and wet deposition, respectively; and t^* is the time of travel between sources and receptors. The factor β is derived by assuming mass conservation and is given by:

$$\beta = [2\pi h k \cdot A]^{-1}, \quad (2)$$

where h = mixing height, $k = k_d + k_w$, and A is given by

$$A = k_1 e^{k_1 \frac{b^2}{4a}} \int_{\frac{b}{2a}}^{\frac{b}{2a} + \bar{x}} e^{-k_1 a y^2} dy + k_2 e^{k_2 \frac{b^2}{4a}} \left(\int_0^{\infty} e^{-k_2 a y^2} dy - \int_0^{\bar{x} + \frac{b}{2a}} e^{-k_2 a y^2} dy \right),$$

in which $y = x + \frac{b}{2a}$. The variable \bar{x} is equal to $\frac{\delta x}{\sqrt{\pi}}$ in which δx is the model grid size. The constants a and b in this equation are estimated from a relationship between geographic distance and transport time described in *Alcamo et al.* (1992).

The total concentration, $c(x_r, y_r)$, at the receptor is computed from the sum of contributions coming from all emission sources, weighted according to the frequency of backward trajectories, $F(s)$, coming from a particular sector, s :

$$c(x_r, y_r) = \sum_{s=1}^8 F(s) c_s(x_r, y_r). \quad (3)$$

In the second step of the calculation, wet and dry deposition of the pollutant at the receptor is computed from the air concentration. Wet deposition d_w , is computed with a scavenging ratio:

$$d_w = c(x_r, y_r) \cdot W_q \cdot P, \quad (4)$$

where W_q is the scavenging ratio, i.e. the ratio of the concentration of heavy metals in precipitation to their concentration in air and P is the precipitation intensity. Despite the simplicity of this approach, it nevertheless takes into account the amount of precipitation at a particular location, which accounts for much of the spatial variability of wet deposition.

Dry deposition is computed from:

$$d_d = c(x_r, y_r) \cdot v_d. \quad (5)$$

The dry deposition velocity v_d is computed with the semi-empirical model of *Sehmel* (1980). This deposition model is based on wind-tunnel experiments and theoretical removal rates via Brownian diffusion and gravitational settling. Dry deposition velocities are computed as a function of particle size (D), surface roughness (z_o) and friction velocity (u_*). The advantage of using this model over assigning deposition velocities *a priori* is that it provides an independent basis for estimating the spatial variation of dry deposition velocity in Europe as a function of "local" meteorological conditions (as indicated by u_* and z_o). Also, the necessary friction velocity and surface roughness data are available on a European grid.

Disadvantages of this model are that it is based partly on empirical wind tunnel measurements and that it requires as input the characteristic size of metal particles in the atmosphere, which is obviously difficult to estimate for all Europe.

We use an assumed particle size distribution for heavy metals to compute a size-weighted v_d :

$$v_d = \sum_{i=1}^n v_d(D_i, u_*, z_o) f(D_i), \quad (6)$$

where $v_d(D_i, u_*, z_o)$ is taken from the curves presented in *Sehmel* (1980). Data for u_* and z_o were obtained on a European grid with a spatial resolution of 150x150 km² from the EMEP Synthesizing Center West (*J. Saltbones*, personal communication).

The variable $f(D_i)$ is the fraction of mass with diameter D_i . For these data we have provisionally used the Mediterranean measurements by *Dulac et al.* (1989) to represent Southern European conditions. To represent Northern European conditions, we use particle data measured in Norway by *Cornille et al.* (1991). These data were used because (1) they cover relatively long periods of measurement (3 to 12 months) rather than only short field campaigns; (2) they were collected at several sites and represent a wide geographical area rather than a single station; (3) the measurement sites were probably not significantly affected by local sources but nevertheless were influenced by distant anthropogenic sources. These characteristics are consistent with the assumptions of the TRACE model.

The model was tested with air concentrations and wet deposition data measured at several sites in Europe between 1978 and 1985 (*Alcamo et al.*, 1991). Because of uncertainty of data from Eastern Europe, only measurements from Western Europe (with one exception) were used for testing. This is an unfortunate situation since it would be obviously more desirable to test the model's accuracy in Eastern Europe by comparing it with data from this region. On the other hand, it is known from other studies that emissions of heavy metals from Eastern Europe significantly affect measured levels of heavy metals in Northern and Western Europe (see, e.g. *Pacyna et al.*, 1984). Hence, the agreement of model calculations with measurements in these areas provide some validation of calculations in Eastern Europe itself. As to the results of model testing—in general, it was found that model calculations agree fairly well with As and Pb data, but underestimate Cd and Zn data. After sensitivity analysis of the TRACE model it was concluded that this underestimation may be due to either underestimated emissions or measurement contamination before 1985 which could have resulted in extreme overestimation of measurements (*Alcamo et al.*, 1992).

The only observations from Eastern Europe used to test the model were Cd and Pb data measured at the EMEP station K-Pusztá in Central Hungary (46° 58' N, 19° 35' E) (*Table 1*). Model results at this station were similar to results at Western European stations in that model calculations were within a factor of

two of Pb measurements, and underestimated Cd measurements.

Table 1. Model calculations versus measurements at K-puszta in Hungary

Constituent	Years	Calculated		Measured	
		Mean	Range	Mean	Range
Pb air concentration ($\mu\text{g m}^{-3}$)	1981-85	28.95	23.40-35.23	56.6	45.10-71.9
Pb wet deposition ($\text{mg m}^{-2} \text{yr}^{-1}$)	1983-85	5.44	4.11- 6.32	6.68	5.03- 7.69
Cd air concentration ($\mu\text{g m}^{-3}$)	1981-85	0.31	0.28- 0.36	1.21	1.03- 1.50
Cd wet deposition ($\text{mg m}^{-2} \text{yr}^{-1}$)	1984-85	0.095	0.09- 0.10	0.63	0.55- 0.71

3. Long term deposition of heavy metals

The annual total deposition of heavy metals is an important indicator of their long-term impact on the environment because many metals are known to gradually accumulate in lake and river sediments, in forest soils and in vegetation (Ottar *et al.*, 1989). Despite the fact that heavy metals contamination can lead to many environmental impacts, not much work has been devoted to quantifying a threshold deposition level above which the natural environment is adversely affected. To this point, only damage threshold levels for sulfur and nitrogen deposition have been recommended in Europe (see, e.g. Sverdrup *et al.*, 1990).

Figs. 1(a) through (d) present the computed total deposition (wet plus dry) of heavy metals for Eastern Europe. These maps are based on 1985 meteorological data such as precipitation and wind direction because reliable meteorological data are available for this year for all Europe. Emissions data are from 1982 for As, Cd and Zn, and 1985 for Pb because these were the most recent data available for gridded emissions covering all of Europe. Hence, these maps present the situation in Europe as of the mid-1980s.

The As deposition pattern shows two peaks—one in the southern part of Poland and one in Eastern Yugoslavia (Fig. 1a). The maximum deposition value is around $3.5 \text{ mg m}^{-2} \text{yr}^{-1}$ in Poland. The local maximum is over $2.0 \text{ mg m}^{-2} \text{yr}^{-1}$

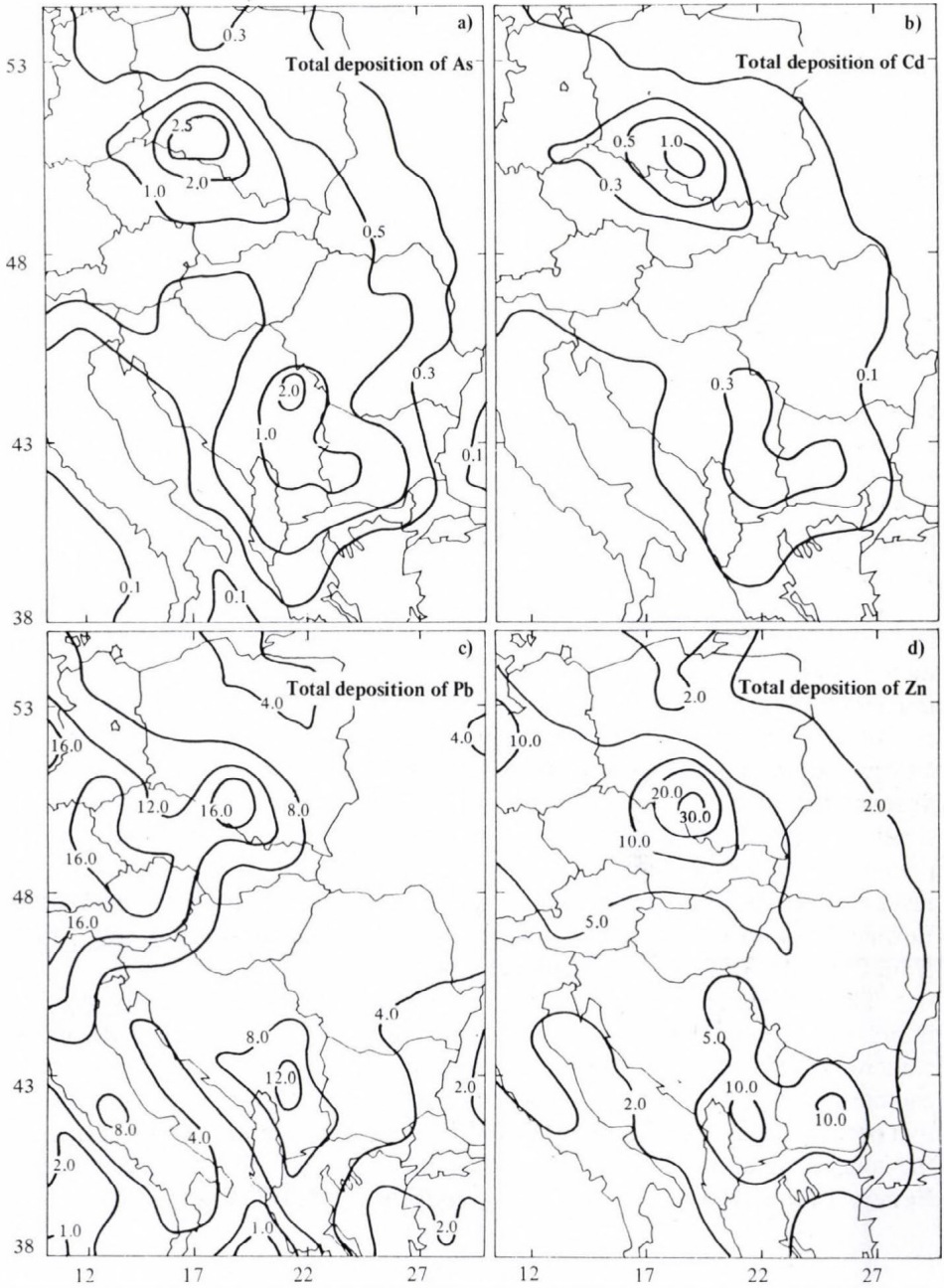


Fig. 1. Total (wet plus dry) annual deposition of heavy metals, mid-1980s: (a) arsenic, (b) cadmium, (c) lead, (d) zinc. Units: $\text{mg m}^{-2} \text{yr}^{-1}$.

in Yugoslavia. Moving towards the edge of the continent total deposition of around $0.1 \text{ mg m}^{-2} \text{ yr}^{-1}$ is reached. It can be seen from this figure that total arsenic deposition remains relatively high ($2.0\text{--}3.0 \text{ mg m}^{-2} \text{ yr}^{-1}$) even at a distance of more than 100 km from the peak areas. The lowest As total deposition values can be seen in Hungary and Romania.

Although, as noted above, the threshold levels of As and other metals are not known, we can at least compare their computed magnitude in Europe with their levels in remote parts of the world (Antarctica, South Pacific, and similarly remote areas). Arsenic deposition, for example, ranges from 0.01 to $0.20 \text{ mg m}^{-2} \text{ yr}^{-1}$ in remote areas (Lahmann *et al.*, 1986). This is exceeded by one or two magnitudes throughout most of Europe (Fig. 1a).

The Cd pattern shows one high and several lower peaks in Eastern Europe (Fig. 1b). As for arsenic, the high peak occurs in South Poland and the lower peaks in the central part of Bulgaria and south-eastern part of Yugoslavia. The maximum of total Cd deposition is around $1.5 \text{ mg m}^{-2} \text{ yr}^{-1}$ in Poland and $0.4\text{--}0.5 \text{ mg m}^{-2} \text{ yr}^{-1}$ in Yugoslavia and Bulgaria. These levels may be compared to the range of 0.006 to $0.229 \text{ mg m}^{-2} \text{ yr}^{-1}$ for remote areas (Lahmann *et al.*, 1986).

The pattern of Pb (Fig. 1c) is different from the other metals because Pb has a different emission profile. Sources of Pb are relatively well distributed motor vehicles, while As, Cd and Zn come mostly from point sources in industrialized areas. It is also to be taken into consideration that the removal rate of Pb is less than for the other metals so Pb on the average travels further and can be deposited over a wider area with lower maxima. Highest total deposition of Pb has been computed for the western part of Czechoslovakia and South Poland ($15.0\text{--}20.0 \text{ mg m}^{-2} \text{ yr}^{-1}$). It can be assumed—regarding the prevailing wind directions over this part of Europe—that this relatively high level of deposition is caused by the higher emission densities in the Western European countries. Deposition levels of Pb in remote areas of the world range from 0.026 to $3.65 \text{ mg m}^{-2} \text{ yr}^{-1}$ (Lahmann *et al.*, 1986).

The deposition pattern of Zn (Fig. 1d) is very similar to that of As. This is not surprising taking into consideration that a major source of As is zinc smelting. Differences are only in the absolute values of total deposition. In the southern part of Poland it reaches $50 \text{ mg m}^{-2} \text{ yr}^{-1}$. In Bulgaria and Yugoslavia two peaks can be detected by the TRACE model calculations. Over these areas the total deposition of Zn is $10.0\text{--}15.0 \text{ mg m}^{-2} \text{ yr}^{-1}$. On the other part of Eastern Europe the value of total Zn deposition is $2.0\text{--}7.0 \text{ mg m}^{-2} \text{ yr}^{-1}$.

4. Concentration of heavy metals in precipitation

Because rainwater is used directly or indirectly as a source of drinking water in Eastern European rural areas, the concentration of metals in precipita-

tion is important to public health. Since the monitoring of these elements in precipitation is very scattered in Eastern Europe, the only possibility to estimate their concentration for the whole area of Eastern Europe is through model computation. Using the TRACE model, the concentrations of As, Cd, Pb and Zn have been calculated on the basis of wet deposition calculations (also by TRACE model) and annual precipitation data over the EMEP grid system. Results of these computations are presented *Fig. 2*. For reference, we present some recommended international guidelines for these substances in drinking water (*Table 2*).

Table 2. Examples of guidelines for heavy metals in drinking water

Metal	$\mu\text{g/l}$	Institution
As	50	World Health Organization ^a
	50	European Community ^b
	10	Rhine Basin Association - Category "A" ^c
	50	Rhine Basin Association - Category "B" ^c
Cd	5	World Health Organization ^a
	5	European Community ^b
	1	Rhine Basin Association - Category "A" ^c
	5	Rhine Basin Association - Category "B" ^c
Pb	50	World Health Organization ^a
	50	European Community ^b
	30	Rhine Basin Association - Category "A" ^c
	50	Rhine Basin Association - Category "B" ^c
Zn	500	Rhine Basin Association - Category "A" ^c
	1000	Rhine Basin Association - Category "B" ^c

^a WHO (1984) Guidelines for Drinking-Water Quality. Vol. 1. Recommendations. WHO: Geneva

^b EC Directive 80/778/EEC (1980)

^c Internationale Arbeitsgemeinschaft der Wasserwerke im Rhein einzugsgbiet (1987). Rheinbericht '86/ '87. Water supplies in Category "A" do not require special treatment before being used for drinking water; Category "B" requires physical/chemical treatment

In general, the patterns of concentration in precipitation (*Fig. 2*) are similar to total deposition patterns (*Fig. 1*). However, deposition patterns have somewhat stronger spatial gradients because "local" deposition is quite high in the vicinity of strong sources.

In the case of As (*Fig. 2a*), two large areas with local maxima can be spotted. The first one is in South Poland-North Czechoslovakia with a maximum over $2.0 \mu\text{g l}^{-1}$. In the surroundings of this area a circle with a radius

of around 300–400 km can be detected where the As concentration in precipitation is 1.0–2.0 $\mu\text{g l}^{-1}$. This area covers practically the whole territory of

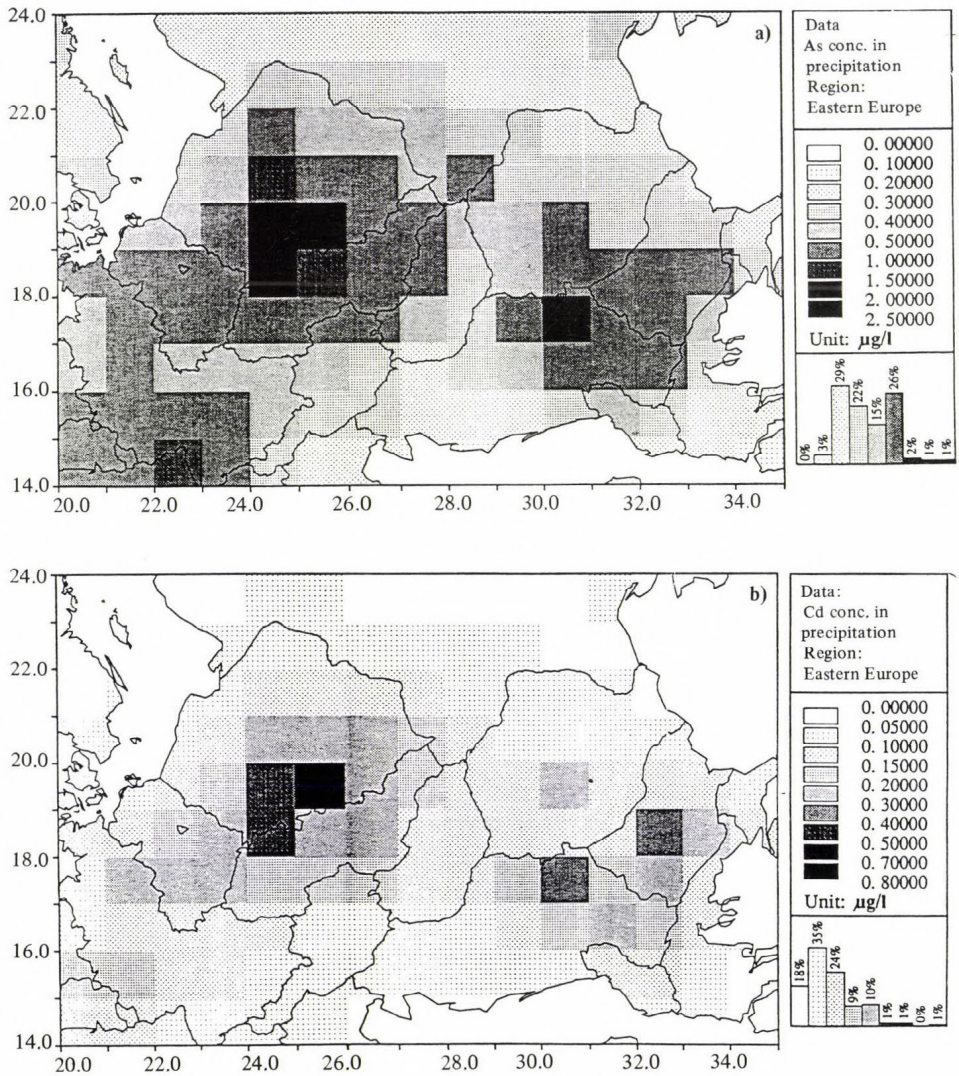


Fig. 2a, b. Annual average concentration of arsenic (a) and cadmium (b) in precipitation, mid-1980s

Czechoslovakia and the southern and central part of Poland. A lower local maximum is situated around the Bulgarian–Romanian–Yugoslavian border. A

peak of near $2.0 \mu\text{g l}^{-1}$ occurs in Yugoslavia. Towards the edge of the continent the As concentration in precipitation decreases to around $0.1 \mu\text{g l}^{-1}$.

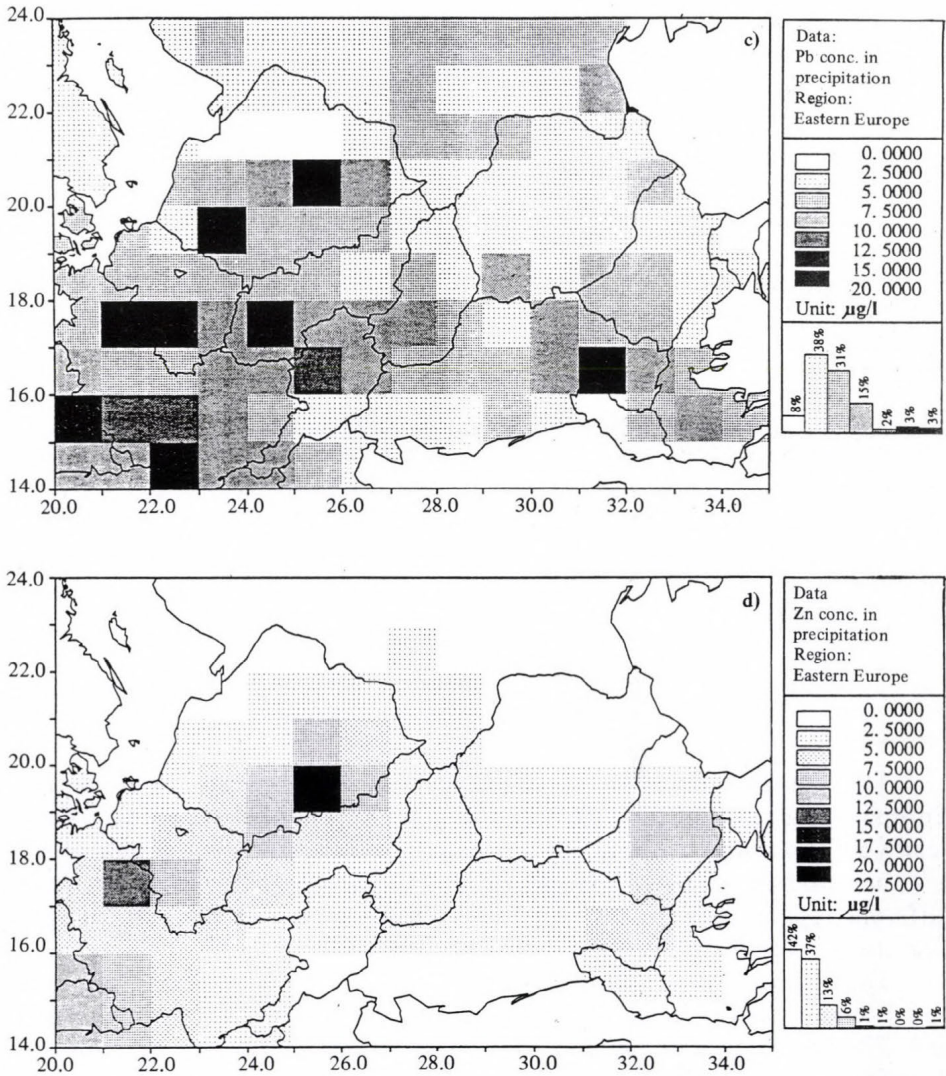


Fig. 2c, d. Annual average concentration of lead (c) and zinc (d) in precipitation, mid-1980s

The Cd pattern (Fig. 2b) shows one considerable peak in Poland (over $0.7 \mu\text{g l}^{-1}$) and two others in Bulgaria and Yugoslavia ($0.3\text{--}0.4 \mu\text{g l}^{-1}$). In the

central part of Eastern Europe (Hungary, north-western part of Romania) the Cd concentration in precipitation is 0.1–0.2 $\mu\text{g l}^{-1}$. On the northern part and Adriatic coast of Yugoslavia the Cd concentration is below 0.1 $\mu\text{g l}^{-1}$. In North Czechoslovakia the Cd concentration is 0.2–0.4 $\mu\text{g l}^{-1}$ partly due to the effect of south Polish sources.

The pattern of Pb—as it was indicated when presenting the total deposition maps—is different from the other metals. Pb concentration in precipitation over 15.0 $\mu\text{g l}^{-1}$ can be seen in certain parts of Poland. In other regions of Eastern Europe it varies between 2.5 and 15.0 $\mu\text{g l}^{-1}$ (Fig. 2c).

The maximum Zn concentration (Fig. 2d) in precipitation has been computed also for South Poland. Its value is over 20.0 $\mu\text{g l}^{-1}$. A smaller maximum in Bulgaria can also be detected (around 10.0 $\mu\text{g l}^{-1}$). For the remainder of Eastern Europe Zn concentration of 2.0–5.0 $\mu\text{g l}^{-1}$ has been calculated.

On one hand it can be seen that computed levels of all elements are below the drinking water guidelines presented in Table 2. On the other hand, the concentration of these elements are within an order of magnitude of these guidelines in the maxima regions, and in some case within a factor of 2 of these guidelines. This is of importance because over short periods of time these concentrations can be much higher than the annual average.

5. Atmospheric budgets of heavy metals for Eastern European countries

The emission densities of heavy metals vary considerably in Eastern Europe. As a result of this, total deposition of heavy metals in a country with relatively low emission density can be highly affected by other countries with a higher emission density. It is possible to estimate the relative contribution of different regions in Europe to the total deposition of each Eastern European country only on the basis of model computations.

The results of these computations—separately for each country and heavy metal—are presented in Table 3 through 6. It was computed that both Bulgaria and Poland emit twice as much arsenic as they receive in the form of deposition. Yugoslavia also “exports” more arsenic than it receives.

In Romania the emission and total deposition of As are approximately balanced. In Hungary, Czechoslovakia and Albania the deposition exceeds the emission, i.e., they are net As importers. The effects of the high emission densities in Poland and Bulgaria can be detected as high contribution from Eastern Europe to the total deposition over Czechoslovakia, Hungary and Romania, Albania, respectively.

The situation for Cd is similar in some ways to As. Poland and Bulgaria

are the most important “net Cd exporters” in Eastern Europe. The Cd emissions of Yugoslavia are also very high compared to its total deposition. Over Hungary, Czechoslovakia and Albania, the Cd deposition is far below Cd emissions. The contribution of Hungarian sources to the total deposition over

Table 3. Arsenic-annual emissions (1982) and deposition (mid-1980s)

Country	Emitted (t yr ⁻¹)	Deposition (t yr ⁻¹)	Average flux (kg km ⁻² yr ⁻¹)
Albania	17.2	22.2	0.77
Bulgaria	146.9	73.7	0.66
Czechoslovakia	93.7	160.0	1.25
Hungary	16.1	52.1	0.56
Poland	591.3	281.0	0.90
Romania	116.2	113.5	0.48
Yugoslavia	272.0	206.3	0.81

Hungary has also been estimated by a simple trajectory model (Bozó and Horváth, 1992). There is a very good agreement between the two different calculations since the relative contribution estimated is around 10 % for both cases.

Table 4. Cadmium-annual emissions (1982) and deposition (mid-1980s)

Country	Emitted (t yr ⁻¹)	Deposition (t yr ⁻¹)	Average flux (kg km ⁻² yr ⁻¹)
Albania	0.70	7.03	0.24
Bulgaria	65.50	29.24	0.26
Czechoslovakia	21.60	43.19	0.34
Hungary	4.40	16.15	0.17
Poland	180.40	89.31	0.28
Romania	43.40	39.53	0.17
Yugoslavia	85.80	60.49	0.23

Pb budgets for the Eastern European countries are much more balanced than they are for As and Cd. Poland, and Bulgaria have turned out to be “net Pb exporters”. In the case of Bulgaria the ratio of Pb emission/Pb deposition is around 2. This is the highest value in Eastern Europe.

As expected, the Zn pattern is very similar to that of As. The most important “net exporters” are Poland and Bulgaria. Total deposition of Zn over

Czechoslovakia, Hungary and Albania is much lower than their Zn emission.

If we divide the total deposition to each country by the area of the country we obtain the average annual flux of these metals (last column in Tables 3 through 6). These values are much more similar between countries than the

Table 5. Lead-annual emissions (1982) and deposition (mid-1980s)

Country	Emitted (t yr ⁻¹)	Deposition (t yr ⁻¹)	Average flux (kg km ⁻² yr ⁻¹)
Albania	136.3	201.5	7.00
Bulgaria	1569.2	674.8	6.08
Czechoslovakia	1151.0	1752.6	13.70
Hungary	596.9	727.1	7.81
Poland	2956.3	2508.5	8.02
Romania	1154.6	1382.4	5.83
Yugoslavia	1961.9	2281.0	8.92

values of total deposition. Whereas total deposition varies by up to a factor of ten between countries, flux differs only by a factor of two. Czechoslovakia receives the largest flux of all metals, and Poland has the second largest flux of all metals except Pb.

Table 6. Zinc-annual emissions (1982) and deposition (mid-1980s)

Country	Emitted (t yr ⁻¹)	Deposition (t yr ⁻¹)	Average flux (kg km ⁻² yr ⁻¹)
Albania	36.8	183.3	6.38
Bulgaria	1760.8	760.8	6.86
Czechoslovakia	755.9	1189.8	9.30
Hungary	199.3	451.7	4.86
Poland	4040.1	2233.2	7.14
Romania	716.6	818.3	3.45
Yugoslavia	1958.8	1412.6	5.52

In Fig. 3 we present the estimated origin of the heavy metals flux to each country broken down according to contributions from (1) the country itself, (2) Western Europe, (3) other Eastern European countries. The contribution from

other Eastern countries is significant for As, Cd and Zn flux, ranging from 12 to 83 % of the total flux to different countries (Figs. 3a, b, d). The contribution of emissions from Western Europe to these metals is relatively minor (20 %

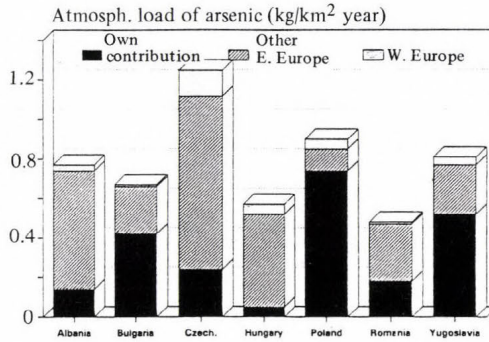


Fig. 3a. Country budgets of arsenic for various Eastern European countries

or less of the total flux). The situation for Pb is different from the other metals. Because of the high Pb emissions in Western Europe in the mid-1980s, the West contributed significantly to the Pb flux to Eastern European countries

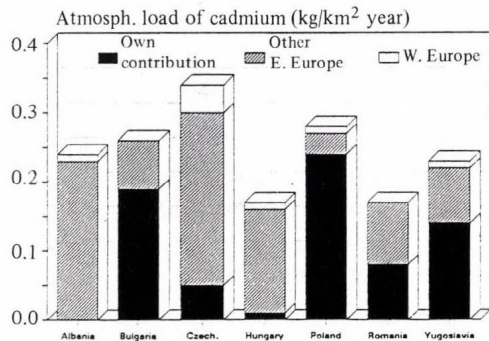


Fig. 3b. Country budgets of cadmium for various Eastern European countries

(Fig. 3c). In the case of Poland and Czechoslovakia, the West contributed more to Pb flux to these countries than was contributed by their Eastern European neighbours.

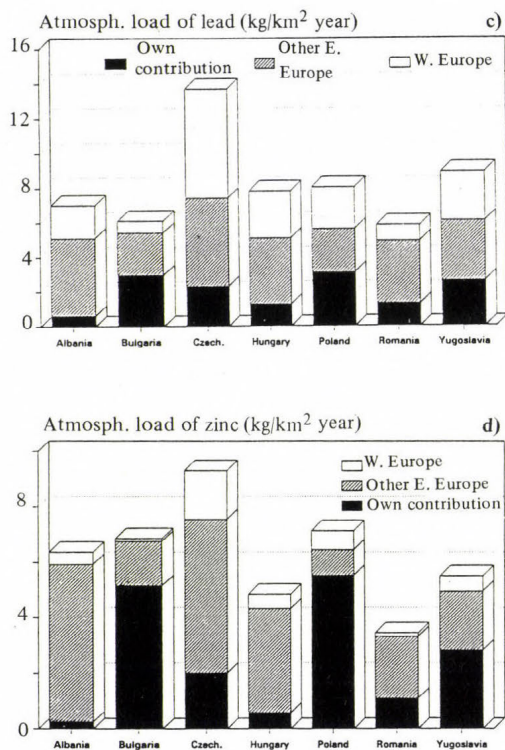


Fig. 3c, d. Country budgets of lead (c) and zinc (d) for various Eastern European countries

6. Effects of sources with high emission densities to the deposition in surrounding countries

Since the particles containing heavy metals can travel long distances after being emitted, the deposition of heavy metals in rural areas is greatly affected by emissions hundreds of kilometers away. On the basis of TRACE model calculations, it was also possible to estimate the effects of these sources on the deposition heavy metals in the surrounding countries. As an example, we compute the effects of southern Polish sources on wet deposition of As, Cd and Zn (Figs. 4a, b, c). It is not surprising that near the sources—approximately in 150–200 km distance—the contribution of the emitters to the wet deposition of As, Cd and Zn is over 80 %. Over the northern part of Czechoslovakia the

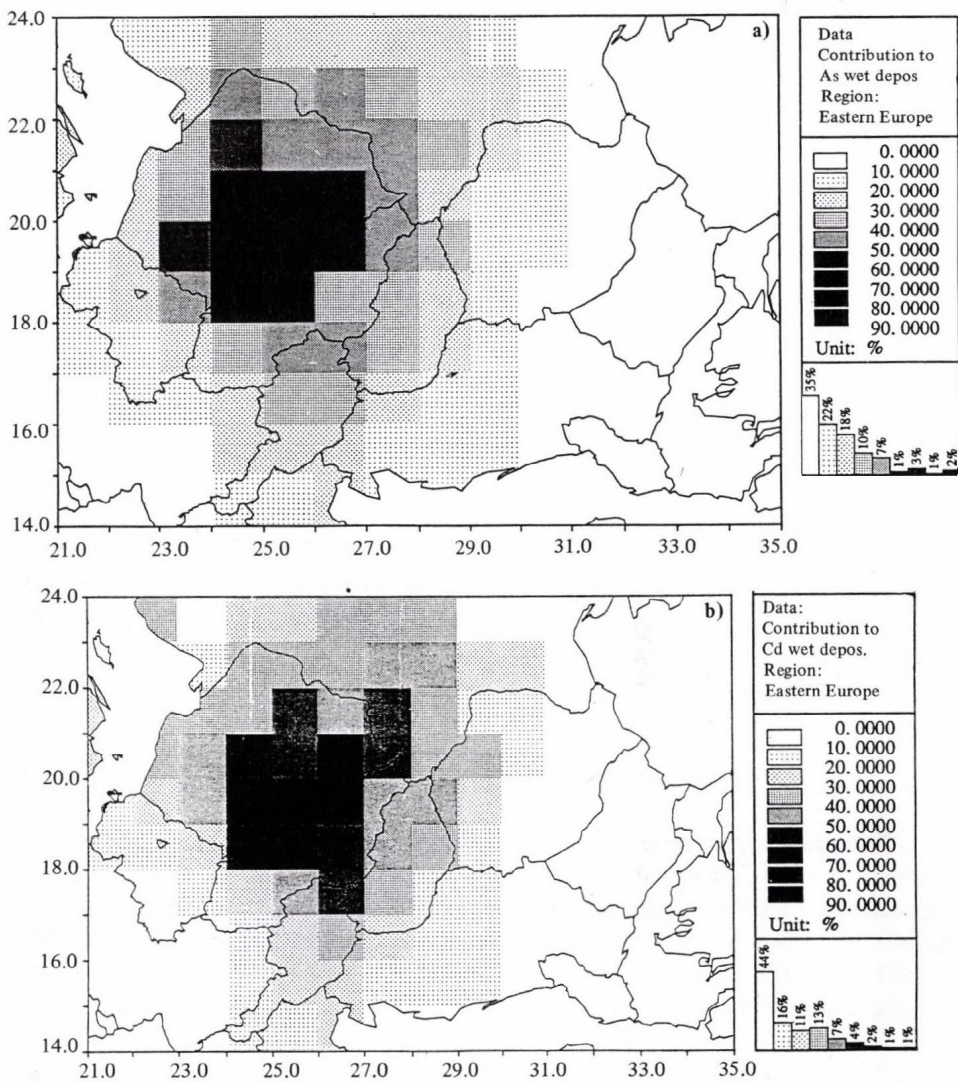


Fig. 4a, b. Contribution of southern Polish sources to wet deposition of arsenic (a) and cadmium (b) in Central and Eastern Europe

contribution of these sources to the wet deposition pattern of As, Cd and Zn is also very high. Moving towards Hungary and Yugoslavia, the contribution decreases to 30–40 %. It can also be seen in Fig. 4 that the prevailing western winds in Europe cause a higher contribution to wet deposition moving eastward from the sources.

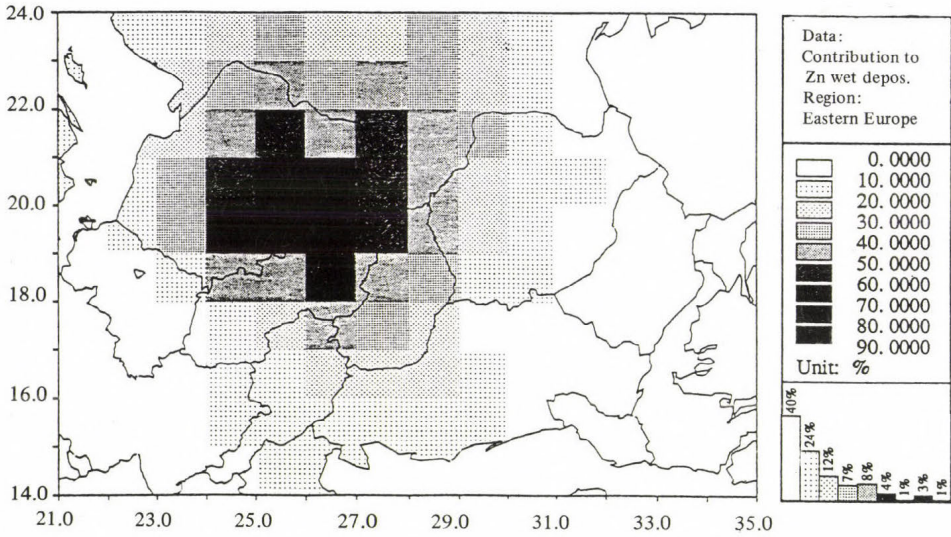


Fig. 4c. Contribution of southern Polish sources to wet deposition of zinc in Central and Eastern Europe

7. Summary and conclusions

This paper presents estimates of the background contamination of rural areas in Eastern Europe due to the atmospheric load of heavy metals (As, Cd, Pb and Zn). This contamination occurs because particles containing heavy metals travel long distances from their sources in industrial areas. The TRACE model quantifies this long range transport, and has been used in this paper to estimate annual average levels of heavy metals in Eastern Europe in the mid-1980s (the only period with reliable emissions data).

We compute that peak levels of heavy metals deposition in Eastern Europe occur in Southern Poland and Eastern Yugoslavia. Deposition levels of heavy metals throughout most of rural Eastern Europe exceed levels in remote areas of the world by one or two orders of magnitude. The long term consequences of this load on ecosystems in Eastern Europe should be examined.

High concentrations of heavy metals in precipitation occur, as expected, where the highest deposition occurs. However, the spatial pattern of concentration in precipitation in Eastern Europe is not quite the same as the pattern of deposition-spatial gradients of deposition are stronger because "local" deposition is very high where emissions are strong.

Although the computed concentrations of As, Cd, Pb and Zn in precipita-

tion are below drinking water guidelines, they approach within a factor of two of these guidelines in some areas. This is of concern because it is likely that short-term concentrations are much higher than the computed annual averages.

Some countries are "net exporters" of As, Cd, Zn (Bulgaria, Poland and Yugoslavia), whereas other countries are "net importers" (Albania, Czechoslovakia and Hungary). The situation is different for Pb, because lead originates largely from well-distributed vehicles, whereas the other metals originate primarily from concentrated industrial sources. Hence, the emissions and deposition of Pb are more closely balanced for Eastern European countries, with the exception of Bulgaria and Poland who are net exporters of Pb.

The origin of the load of heavy metals to Eastern European countries was also investigated. Western Europe contributes 20 % or less to the loads of arsenic, cadmium and zinc, but was a significant contributor to the load of Pb in the mid-1980s. Now, however, Western Europe's adoption of lead-free petrol has resulted in lower emissions in Western Europe and a smaller absolute contribution to the Pb load in Eastern Europe.

Other Eastern European countries contribute a substantial percentage of the atmospheric load to their Eastern European neighbours. In the case of arsenic, this contribution ranges from 12 % for Poland to 83 % for Hungary. There is also a significant transboundary exchange of Cd, Pb, and Zn within Eastern Europe.

Summing up, although the deposition of heavy metals is very severe in industrial areas near to sources, a great amount of these heavy metals travel beyond borders and contribute to air pollution problems in neighbouring countries. As with acid-causing pollutants, the problem of heavy metals contamination in Eastern Europe depends on a reduction of transboundary pollution in the region.

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References

Alcamo, J., Bartnicki, J. and Olendrzynski, K., 1992: Computing heavy metals in Europe's atmosphere. Part I: Model development and testing. *Atmos. Environ.* (in press).

Bartnicki, J. and Alcamo, J., 1992: Computing heavy metals in Europe's atmosphere. Part II: Maps of air concentration and deposition. *Atmos. Environ.* (submitted).

- Bozó, L. and Horváth, Z., 1992: Atmospheric concentration and budget of lead and cadmium over Hungary. *Ambio* 21, 324-326.
- Cornille, P., Maenhart, W. and Pacyna J., 1991: PIXE analysis of size-fractionated aerosol samples collected at Birkenes during spring 1987. *Nucl. Instr. Meth. Phys. Res.* (in press).
- Dulac, F., Buat-Ménard, P., Ezat, U., Melki, S. and Bergametti, G., 1989: Atmospheric input of trace metals to the Western Mediterranean: Uncertainties in modelling dry deposition from cascade impactor data. *Tellus* 41 B, 362-378.
- Lahmann, E., Munari, S., Amicarelli, V. and Abbaticchio, P., 1986: Heavy metals: identification of air quality and environmental problems in the European Community. Vol. 1 EUR 10678. CEC: Brussels.
- Ottar, B., Lindberg, S.E., Voldner, E., Lindquist, O., Meyer, R., Semb, A., Steiness, E. and Watt, J., 1989: Special topics concerning interactions of heavy metals with the environment. In *Control and Fate of Atmospheric Trace Metals* (eds.: J.M. Pacyna and B. Ottar). Kluwer Academic Publishers, 365-372.
- Pacyna, J. and Münch, J., 1988: *Atmospheric Emissions of Arsenic, Cadmium, Mercury and Zinc in Europe in 1982*. Norwegian Institute for Air Research, NILU OR: 17.
- Pacyna, J., Semb, A. and Hanssen, J.E., 1984: Emission and long-range transport of trace elements in Europe. *Tellus* 36B, 163-178.
- Sehmel, G.A., 1980: Particle and gas dry deposition: a review. *Atmos. Environ.* 14, 983-1011.
- Sverdrup, H., de Vries, W. and Henriksen, A., 1990: *Mapping Critical Loads*. Nordic Council. NORD 1990.

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Isobaric and isentropic objective analysis of meteorological fields for regional and continental scale trajectories

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Abstract—An isobaric and isentropic objective analysis method is presented using data from European rawinsonde stations or regional fine-mesh grid forecasts from Bracknell. Three dimensional fine-mesh analyses of meteorological fields are performed applying biharmonic and cubic spline interpolation. Trajectory methods which are suitable to calculate the transport of moisture and air pollution in isobaric and isentropic coordinate system are tested. The results are presented in a case-study. The forward isobaric trajectories are operationally used on a local PC network in the short range forecastings and the backward trajectories are operatively calculated for the investigation of air pollution on BASF main frame computer.

Key words: air trajectories, objective analysis, meteorological fields.

1. Introduction

The questions how pollutants, aerosol or radioactive particles spread in the atmosphere belong to those meteorological problems which are of the particular social interest because of their importance in the quantitative precipitation forecast or environmental protection.

To answer these questions there are several possible ways. One can solve e.g. the system of equations describing transport processes. In this approach the fields of the quantities being of interest can be derived analogously with those occurring in any numerical weather forecasting problem. As another way of description, the transport process can be considered in a Lagrangian manner, i.e. one solves the problem by computing the trajectories of atmospheric particles, which transport and conserve some properties.

In this paper this latter approach is followed. Trajectories are usually derived along isobaric surfaces even though synoptic scale processes are accompanied by significant vertical motions. Therefore it is advantageous to introduce an isentropic coordinate-system since during adiabatic processes atmospheric particles move along isentropic surfaces.

By the use of TEMP telegrams of European radiosounding station and the grid forecasts of Bracknell (UKMO) up to 36 hours, meteorological elements are interpolated to an isentropic and an isobaric grid network and then experiments are carried out on different trajectory models.

2. *Isentropic analysis*

Nowadays isentropic analysis is widely applied in numerical weather prediction on very short range or nowcasting systems. Isentropic trajectories are used for the calculation of the transport of air pollution and for forecasting of rainfall quantity.

Namias (1939) and his co-workers started to examine the isentropic (constant potential temperature) fields in 1935. In 1939 they published meteorological fields with height contours, windspeed and moisture values of isentropic levels.

Isentropic coordinates have an advantage to the isobaric coordinates because in adiabatic motion the air parcel remains on the constant coordinate surface. In this way the trajectories can be calculated quite easily (*Danielsen*, 1961; *Petersen and Uccellini*, 1979). A further advantage—as shown by *Shapiro and Hastings* (1979)—is that isentropic surfaces are nearly parallel to the frontal layers, so they produce smaller gradients than isobaric ones, which cross through the frontal layers. In spite of these advantages the isentropic analysis has not been used for a long time in operational meteorological practice. Recently isentropic objective analysis is used (*Benjamin*, 1987) in the Regional Operative Forecasting System (PROFS) in the USA. Besides the evident and actual meso-meteorological applications the isentropic analysis has an important role in studying large scale atmospheric processes. For the above mentioned goals the fields of the potential vorticity are used (*Ertel*, 1942; *Hoskins et al.*, 1985; *Eliassen*, 1987). Developing and surviving of blocking patterns are studied by *Crum and Stevens* (1988).

In order to study these processes, the traditional meteorological information (in measurement points) or forecasted meteorological parameters (in grid points) are required. The interpolation methods are applied for fine-mesh analysis of these data.

3. Biharmonic and cubic spline interpolation

For the analysis of meteorological fields and calculation of trajectories, it is necessary to know the values of these fields in rectangular grid network. Because of the practical applications two different map projections are used. *Fig. 1* shows the grid network of rawinsonde stations on the stereographical map projection, which is used in short range forecasting. In studying the air pollution in regional and continental scale we use the so called EMEP map projection (*Fig. 2*). On both maps equidistant grid network is used with $\Delta s = 150$ km grid length.

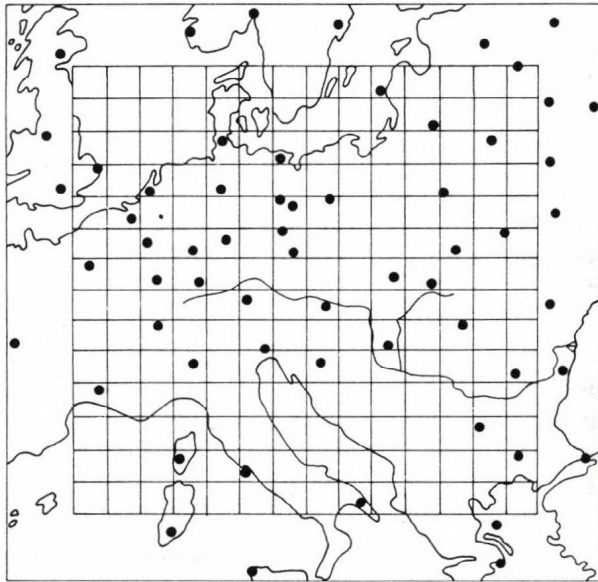


Fig. 1. The grid network on the stereographic weather map

In isobaric coordinate system only horizontal interpolation is needed, but in the isentropic case the vertical interpolation is also used. A summary is given how to determine the meteorological elements in gridpoints of an isentropic system from rawinsonde data.

The data of rawinsonde stations are used. Rawinsonde station which are situated outside the domain are used in order to be accurate at the edge at domain. The potential temperature of pressure levels is calculated using the part A and B of the TEMP telegrams. The height, temperature, horizontal wind

components and relative humidity in the given gridpoints are determined by applying cubic spline interpolation in vertical direction (*Horváth and Práger, 1985*). In the next step on every isentropic surface ($\Theta = \text{const}$) the meteorological parameters are calculated applying biharmonic spline interpolation (*Dévényi et al., 1988*).

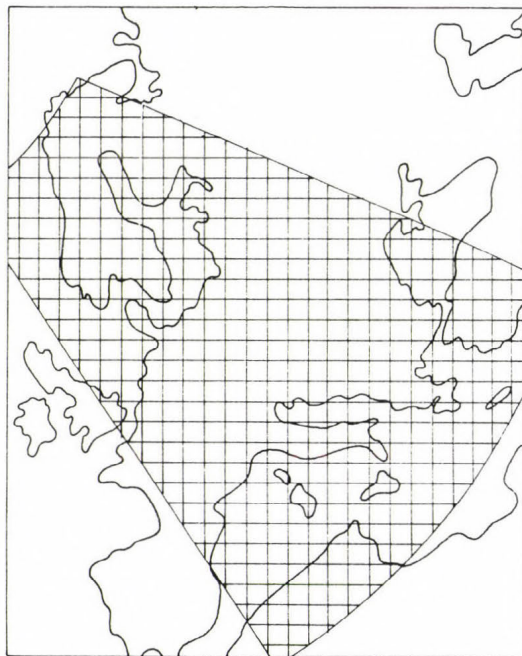


Fig. 2. The EMEP grid network

Biharmonic spline interpolation is the special case of the more general multiharmonic splines. The interpolated value at any point of the territory is calculated by superposition of the impact of every measurement points, so the spatial structure of the meteorological field is well described. In 2 dimensions the biharmonic spline may be derived from conditions

$$\int_{\Omega} (\sigma_{xx}^2 + 2\sigma_{xy}^2 + \sigma_{yy}^2) \delta\Omega = \min_{w_2^2}, \quad (1)$$

where w_2^2 means the class of twice continuously differentiable functions. In any

point the interpolated value can be determined from the equation

$$\sigma(x,y) = \sum_{i=1}^N \frac{1}{2} \lambda_i r_i^2 \ln r_i^2 + \nu_{00} + \nu_{10}x + \nu_{01}y, \quad (2)$$

where N is the number of measurement points, r is the distance between the interpolated point at the i measurement point, and $\lambda_i, \nu_{00}, \nu_{10}, \nu_{01}$ are the spline coefficients.

The spline coefficients are determined by solving the following linear equation system:

$$\begin{bmatrix} 0 & a_{12} & \dots & a_{1N} & 1 & x_1 & y_1 \\ a_{21} & 0 & \dots & a_{2N} & 1 & x_2 & y_2 \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ a_{NI} & 0 & \dots & a_{NN} & 1 & x_N & y_N \\ 1 & 1 & \dots & 1 & 0 & 0 & 0 \\ x_1 & x_2 & \dots & x_N & 0 & 0 & 0 \\ y_1 & y_2 & \dots & y_N & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} \lambda_1 \\ \lambda_2 \\ \cdot \\ \cdot \\ \cdot \\ \lambda_N \\ \lambda_{00} \\ \lambda_{10} \\ \lambda_{01} \end{bmatrix} = \begin{bmatrix} m_1 \\ m_2 \\ \cdot \\ \cdot \\ \cdot \\ m_N \\ 0 \\ 0 \\ 0 \end{bmatrix} \quad (3)$$

where m is the value of the i measurement point, $a_{ij}=a_{ji}=R \ln R$, and R is the distance between the i and j measurement points. Note, if the measurement and grid network is fixed, then inversion of the matrix of Eq. (3) has been done only once, and after that the spline coefficients can be calculated by multiplying this matrix by the right hand side vector, so in that case we can save computation time.

4. Trajectory methods

In meteorological practise it is often necessary to calculate the path of the air parcel. At the beginning the trajectories were originated by subjective

graphical methods (Pettersen, 1956; Danielsen, 1961; Szepesi, 1978). Later objective computer methods were developed, which are useful for the calculation of many simultaneous trajectories. The other way of developing is the use of isentropic trajectory methods, which are more adequate for the atmospheric motions (Danielsen, 1961; Petersen and Uccellini, 1979).

We must mention the activity of Iványi and Mersich (1984) who calculated the climatological trajectories for 2 and 4 days on the 850 hPa isobaric surface in three Hungarian background air pollution measurement stations, and they indicated the main European source territories.

Nowadays in the international practice wide range of methods are applied. The choice among these methods depends on the task and the technical possibility. The simple isobaric trajectory methods are suitable for statistical investigations (Heffter and Taylor, 1975; Harris, 1982; Miller et al., 1987). In the early 60-s Danielsen (1961) proved that the isobaric and isentropic trajectories diverge from each other in the case of strong temperature advection. Iterative probe trajectories were constructed from the conservative conditions of three quantities (potential temperature, total energy and a kinematic variable). In the dynamic method of Petersen and Uccellini (1979) the inviscid motion equation is integrated by Adams-Bashford scheme. Therefore with this method some problem of Danielsen method can be avoided.

In our investigations the forward and backward trajectories were computed on isobaric and isentropic coordinate systems as well. In both coordinate system implicit kinematic method is used. In the isentropic system the dynamic method of Petersen and Uccellini is also applied.

Our methods will be shortly presented below. In the dynamic method the positions of air parcels are defined on the basis of Ψ Montgomery potential and wind field. On the Θ isentropic surfaces the Montgomery stream function is calculated from the p pressure and the Φ geopotential

$$\Psi = \Phi + c_p \left(\frac{p}{p_0} \right)^\kappa \Theta,$$

where $c_p = 1005 \text{ J kg}^{-1} \text{ K}^{-1}$, $\kappa = 0,286$, $p_0 = 1000 \text{ hPa}$.

The acceleration of air parcels is calculated from

$$a_x^n = - \frac{\Delta \Psi^n}{\Delta x} + f v^n \quad (4)$$

$$a_y^n = - \frac{\Delta \Psi^n}{\Delta y} - f u^n. \quad (5)$$

The velocity is derived from using Adams-Bashford scheme

$$u^{n+1} = u^n + \Delta t (3a_x^{n+1} - a_x^{n-1})/2 \quad (6)$$

$$v^{n+1} = v^n + \Delta t (3a_y^{n+1} - a_y^{n-1})/2 \quad (7)$$

except the first time-step when

$$u^1 = u^0 + a_x^0 \Delta t \quad (8)$$

$$v^1 = v^0 + a_y^0 \Delta t. \quad (9)$$

The n . endpoint of trajectory is calculated from

$$x^{n+1} = x^n + \Delta t (u^n + u^{n+1})/2 \quad (10)$$

$$y^{n+1} = y^n + \Delta t (v^n + v^{n+1})/2. \quad (11)$$

The isentropic streamfunction is linearly interpolated in time. The value of the Δt time step is arbitrarily chosen to conserve the stability of the scheme. The dynamical method presented above can be applied in isobaric coordinate system, but in the momentum equation we have to use the gradient of geopotential instead of the gradient isentropic stream function. In the case of longer time period (greater than 24 h) it is recommended to use the kinematic method allowing greater time steps (1–3 h). The construction of this iterative kinematic methods is shown in *Fig. 3*. The starting point of the n . part of trajectories is denoted by P_0 , and the ending point is denoted by P_E . The coordinates of P_E ending point is calculated the following

$$P_1 = P_0 + \Delta t \frac{dp_0^n}{dt} \quad (12)$$

$$P_2 = P_1 + \Delta t \frac{dp_1^{n+1}}{dt} \quad (13)$$

$$P_3 = (p_0 + P_2)/2 \quad (14)$$

$$P_E = P_0 + \left(\frac{dp_0^n}{dt} + \frac{dp_3^{n+1}}{dt} \right). \quad (15)$$

The values of $\frac{dp}{dt}$ velocities are interpolated from gridpoint by using r^{-2} weight functions.

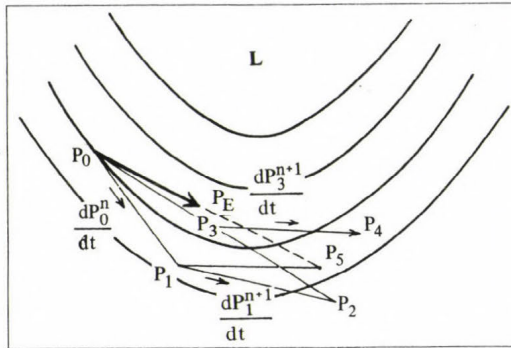


Fig. 3. Method of the iterative kinematical trajectory

5. Results

A fine-mesh analysis and trajectory method was developed in isobaric and isentropic systems. During the analysis we used the part A and B of rawinsonde data. Fine mesh grid from Bracknell (UKMO) is used with $\Delta\phi = \Delta\lambda = 2.5^\circ$ gridlength and $\Delta t = 6$ h timestep. Analysis of height, temperature, relative humidity and windspeed and wind direction fields are used and besides them some derivative fields (vertical temperature gradient, potential vorticity, etc.) are also calculated. Arbitrary vertical cross-sections can be used. The trajectories are calculated in the gridpoint of EMEP network if air pollution is monitored, and in centre of 18 water basin of Danube and Tisza if rainfall is forecasted. The position of air parcels can be traced forward and backward in time. The main points of our task are summarized in *Table 1*. The subpoints can be combined together.

The application of this method is showed in a case study. In April 1989 a strong cold front arrived coming from the north of the Carpathian-basin.

Table 1. Summary of the task

-
1. Database:
 - a) TEMP telegram of European rawinsonde stations (part A, B)
 - b) analysis and forecast field of fine mesh grid from Bracknell (UKMO)
 2. Map projection:
 - a) stereographical map for the synoptical practise
 - b) EMEP map projection for investigation of air pollution on continental scale
 3. Coordinate system:
 - a) isobaric (x,y,p)
 - b) isentropic (x,y, Θ)
 4. Method of calculation of trajectory:
 - a) kinematical
 - b) dynamical
 5. Direction and duration of trajectory:
 - a) forward — between 12, 96 h
 - b) backward — between 12, 96 h
 6. Computer background:
 - a) BASF 7/63 (main frame)
 - b) IBM PC/AT
-

A lot of intensive showers and thunderstorms indicated the arrival of cold front in the northern part of Hungary. The following day the cold air mass overflowed the whole country. Cooling was especially strong in the lower layers. In Central Europe a strong horizontal contrast developed which is shown on the isentropic maps (*Fig. 4*). Development of this cold front can be seen on the north-south isentropic vertical cross section (*Fig. 5*) at 12.00 UTC on 2 April 1989.

The backward isobaric trajectories (*Fig. 6*) indicate that the wind became stronger and its direction turned from north to west in higher levels.

Forecasted isobaric backward trajectories on 850, 700 and 500 hPa for the centre of 18 water basin of Danube and Tisza are calculated operationally twice a day in the local area network of Central Institute for Weather Forecasting. Trajectories and wind vectors which show the temperature advection are visualized on the screen of the PC. The duration of trajectories is 18 and 30 hours. Parametrized cloudiness fields showing the forecasted cloud patterns are also visualized.

96 hour backward trajectories on the 850, 700 and 500 hPa are calculated

for K-puszta (background air pollution station) every day in the BASF 7/63 main frame computer.

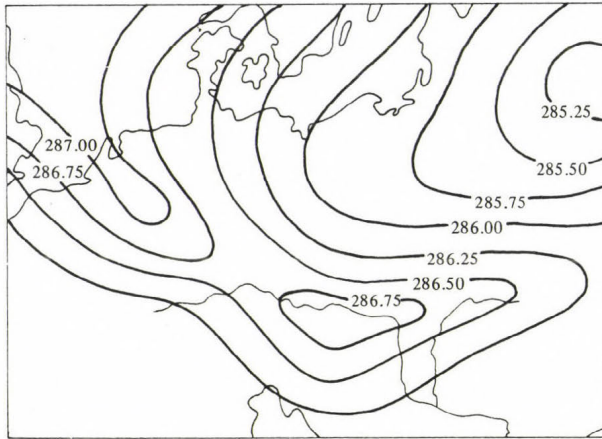


Fig. 4. Field of the isentropic stream function on the 285 K level (unit in $10^3 \text{ m}^2 \text{ s}^{-2}$)
00 UTC 01 April 1989 and 12 UTC 02 April 1989

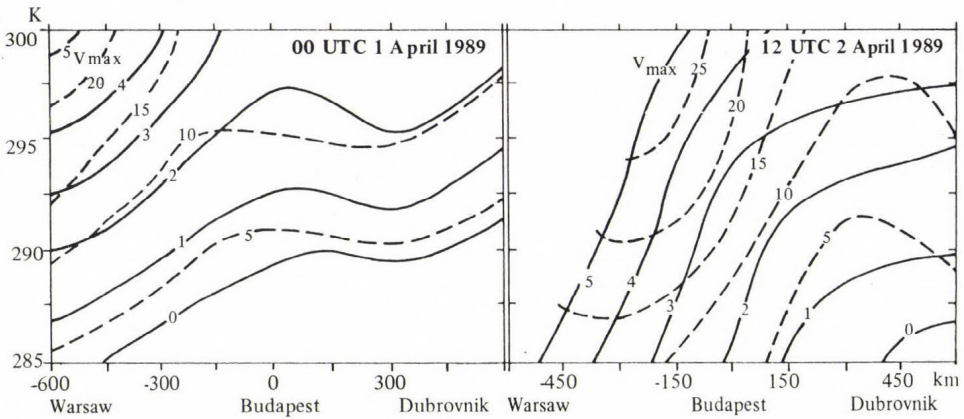


Fig. 5. North-south vertical isentropic cross section between the 285 and 300 K isentropic levels
00 UTC 01 April 1989 and 12 UTC 02 April 1989

The isentropic cross section and trajectories are used for the investigation of special weather condition (heavy rain or strong cold front).

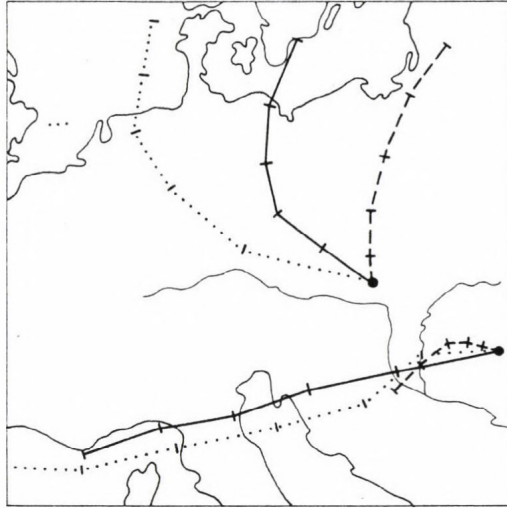


Fig. 6. 30 h backward trajectories on 850 (dashed), 700 (solid) and 500 hPa (dotted) 12 UTC 02 April 1989

References

- Benjamin, S. G., 1987: An isentropic meso-scale analyses system. *IUGG Symposium on Mesoscale Analyses and Forecasting, Incorporating Nowcasting*. Vancouver.
- Brummer, R., 1987: An isentropic coordinate model used in mesoscale data assimilation system. *IUGG Symposium on Mesoscale Analyses and Forecasting, Incorporating Nowcasting*. Vancouver, 561-564.
- Crum, F. X. and Stevens, D. E., 1988: A case study of atmospheric blocking using isentropic analysis. *Mon. Wea. Rev.* 116, 223-241.
- Danielsen, E. F., 1961: Trajectories: isobaric, isentropic and actual. *J. Meteorol.* 18, 479-486.
- Dévényi, D., Ihász, I. and Sipos, Gy., 1988: Common objective analyses of satellite and traditional meteorological information. *Symposium on Using Satellite Measurements in Modelling and Forecasting of Atmospheric Phenomena*. Prague, 174-179.
- Dutton, J. A., 1987: *The Ceaseless Wind*. Mc Graw-Hill, New York.
- Eliassen, A., 1987: Entropy coordinates in atmospheric dynamics. *Z. Meteorol.* 37, 1-11.

- Ertel, H., 1942: Ein neuer hydrodynamischer Wirbelsatz. *Meteorol. Zeitsch.* 59, 277.
- Harris, J. M., 1982: The GMCC atmospheric trajectory program. *NOAA Technical Memorandum ERL ARL-116*.
- Heffter, J. L. and Taylor, A. D., 1975: Trajectory model - Part I. A regional-continental scale transport, diffusion and deposition model. *NOAA Technical Memorandum ERL ARL-50*.
- Horváth, Á. and Práger, T., 1985: Study of the dynamics and predictability of squall-line (in Hungarian). *Időjárás* 89, 141-160.
- Hoskins, B. J., Mc Intyre, M.E. and Robertson, A. W., 1985: On the use and significance of isentropic potential vorticity maps. *Quart. J. Roy. Meteorol. Soc.* 111, 877-946.
- Iványi, Zs. and Mersich, I., 1984: A climatological analysis of two and four day backward trajectories. *Időjárás* 88, 145-153.
- Miller, J. M., Martin, D. and Strauss B., 1987: A comparison of results from two trajectory models used to produce flow climatologies to the Western Mediterranean. *NOAA Technical Report Memorandum ERL ARL-151*.
- Namias, J., 1939: The use of isentropic analyses in short term forecasting. *J. Aeronaut. Sci.* 6, 295-298.
- Sandwell, D. T., 1987: Biharmonic spline interpolation of GEOS-3 and SEASAT altimeter data. *Geophys. Res. Lett.* 14, 139-142.
- Petersen, R. A. and Uccellini L. W., 1979: The computation of isentropic atmospheric trajectories using a "discrete model" formulation. *Mon. Wea. Rev.* 107, 566-574.
- Pettersen, S., 1956: *Weather Analyses and Forecasting*. Vol. I, McGraw-Hill, 428.
- Szepesi D., 1978: Transmission of sulfur dioxide on local, regional and continental scale. *Atmos. Environ.* 12, 529-535.

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Study of available potential energy of a depression pattern in the region of Bay of Bengal

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Abstract—Generation, conversion and transformation of available potential energy have been computed for a depression over the Indian monsoon region using *MONEX* data. Balanced wind is used for the computation of vertical motion field by solving omega equation. It is observed that generation of zonal and eddy available potential energy generally increases during the life cycle of the depression. The eddy available potential energy acts as a source of eddy kinetic energy as well as zonal available potential energy.

Key words: potential energy, monsoon, Bengal depression.

1. Introduction

Essentially the differential heating of land and ocean in summer is responsible for the intensification and the weakening of the monsoon circulation. Over the past two decades it has been of general interest for diagnosing the observed behaviour of cyclone over a region to evaluate the energy budget. Tremendous work has already been carried out by several investigators in the budget analysis over the Indian region (*Keshavamurty and Awade, 1970; Singh et al., 1980; Desai, 1986; Masters and Kung, 1986*). The bulk of the published works in this field have dealt only with particular components of the energy budget. The most commonly described components have been those contained in the kinetic energy budget while the diabatic generation and transformation of available potential energy have been a subject of interest over the Indian monsoon region. *Rajamani and Kulkarni (1986)* and *Gupta and Mandal (1987)* studied the energy terms and conversion between zonal available potential

energy and eddy available potential energy during the life cycle of the depression.

In this paper an attempt has been made to present the energetics analysis of a depression that formed over the Bay of Bengal during *MONEX* 1979, at a grid resolution of 1.875 deg lat/long which has never been attempted in the past over the Indian monsoon region. Since omega computations have been performed using the balanced wind which is the rotational component only, the results may have wide variations as during the depression period, the divergent part of the wind may be equally effective. The purpose of the study is to see how closely the balanced wind resembles to the actual one as is generally known to all. *Saha and Saha* (1988) discussed the thermal budget of this depression recently.

2. Energy equations

The basic equations used in deriving the formulae for various forms of energy and their transformations based on *Lorenz's* (1955) formulation are the first law of thermodynamics

$$\frac{\delta \Theta}{\delta t} + \frac{u \delta \Theta}{a \cos \phi \delta \lambda} + \frac{v \delta \Theta}{a \delta \phi} + \frac{\omega \delta \Theta}{\delta p} = \frac{Q}{C_p} \left(\frac{\bar{\Theta}}{\bar{T}} \right), \quad (1)$$

the zonal equation of motion

$$\frac{\delta u}{\delta t} + \frac{u \delta u}{a \cos \phi \delta \lambda} + \frac{v \delta u}{a \delta \phi} + \frac{\omega \delta u}{\delta p} = v \left(f + \frac{u \tan \phi}{a} \right) - \frac{1}{a \cos \phi} \frac{\delta \Phi}{\delta \lambda}, \quad (2)$$

and the meridional equation of motion

$$\frac{\delta v}{\delta t} + \frac{u \delta v}{a \cos \phi \delta \lambda} + \frac{v \delta v}{a \delta \phi} + \frac{\omega \delta v}{\delta p} = -u \left(f + \frac{u \tan \phi}{a} \right) - \frac{\delta \Phi}{a \delta \phi}. \quad (3)$$

Splitting up u , v and Θ fields into zonal mean and perturbation, *Lorenz's* equations, neglecting the boundary terms, frictional terms etc., for the rates of change A_Z and A_E may be written as

$$\frac{\delta A_Z}{\delta t} = -C_Z - C_A + G_Z$$

$$\frac{\delta A_E}{\delta t} = -C_E + C_A + G_E.$$

Terms appearing in these equations are defined as

$$A_Z = \frac{1}{2} \int_M \gamma [T]''^2 dM$$

$$A_E = \frac{1}{2} \int_M \gamma [T^{*2}] dM$$

$$G_Z = \int_M \frac{\gamma}{C_p} [T]'' [Q]'' dM$$

$$G_E = \int_M \frac{\gamma}{C_p} [T^* Q^*] dM$$

$$C_Z = - \int_M [\omega]'' [\alpha]'' dM$$

$$C_E = \int_M [\omega^* \alpha^*] dM$$

$$C_A = - \int_M \gamma [V^* T^*] \frac{\delta [T]}{a \delta \phi} dM - \int_M \gamma \left(\frac{T}{\Theta} \right) [\omega^* T^*]'' \frac{\delta}{\delta p} [\Theta]'' dM$$

$$\gamma = \frac{-R}{\delta \bar{\Theta}} \frac{1}{p} \left(\frac{P_0}{p} \right)^{R/C_p},$$

where γ is the stability factor (*Holopainen, 1970*).

Energy integrals are denoted as follows

$$[X] = \frac{1}{(\lambda_2 - \lambda_1)} \int_{\lambda_1}^{\lambda_2} X d\lambda$$

$$\bar{X} = \frac{1}{A} \int_{\lambda_1}^{\lambda_2} \int_{\phi_1}^{\phi_2} X d\lambda d\phi,$$

where A is the area considered and X is any arbitrary function, and

$$X = [X] + X^* = X'' + \bar{X},$$

$$[X]'' = [X] - \bar{X}.$$

3. Synoptic situation and data

The monsoon depression of 5–8 July 1979 occurred during the summer *MONEX* field program and was uniquely well observed, especially by numerous drop wind sondes from research aircrafts over the Bay (*WMO, 1981*). Its motion and behaviour appear to be typical. During the first few days of July 1979 there was weak evidence of a westward moving upper level through over southeast Asia, apparently acting as a predecessor of the depression as *Saha et al. (1981)* found to be typical.

On 3 July, the aircraft and land based upper wind observations defined a trough oriented northeast-southwest (*Sanders, 1984*) from the central part of the Bay of Bengal to Central Burma. This trough had little vertical slope, being elevated toward the west over the Bay and perhaps toward the east near the coast. A weak cyclonic circulation center was apparent on 5 July near the Burmese Coast at 850 hPa and over the Bay some 250 km to the southwest at 500 hPa. The trough containing the centre now sloped toward the west north of the centre and toward the east south of it. By the next day the circulation had strengthened markedly at 850 hPa as well as at 500 hPa surface with the centre still sloping toward the southwest. A slow west-south-westward displacement of the system had begun at a rate of about 2 ms^{-1} . On 7 July there was some

further intensification and the beginning of the separation of a lower tropospheric centre, moving westward at 3 ms^{-1} from the mid tropospheric centre, which had progressed west-south-westward at 4 ms^{-1} . Warner (1984) also found a south-westward tilt of the centre with elevation on this day. On the 8th, the system crossed the coast and on 9th weakened over the Indian Peninsula. The 850 hPa centre moved north-westward, while at 500 hPa the direction of the motion was westward. At both levels the speed was about 5 ms^{-1} , so as to produce a substantial vertical tilt.

As part of FGGE level-III b data base, special grid point data sets for 12 GMT at 1.875° lat/long grid resolution were obtained from European Centre for Medium Range Weather Forecasts for the Indian monsoon region bounded by 9.4° to 30°N and 69.4° to 101.3°E at 100 hPa, 300 hPa, 500 hPa, 700 hPa, 850 hPa and 1000 hPa surfaces for the period 4-8 July 1979. A cubic interpolation technique was applied, to interpolate the grid point data to the 900 hPa surface using the wind data for 100 hPa, 300 hPa, 500 hPa, 700 hPa, 850 hPa and 1000 hPa surfaces, thus resulting into input fields at 100 hPa, 300 hPa, 500 hPa, 700 hPa and 900 hPa surfaces.

4. Method of computation

The ECMWF analysis of u , v fields have been used to solve the nonlinear reverse balance equation (Singh and Singh, 1990) including the Jacobian and beta terms for the calculation of geopotential and, the solenoidal windfields u_ψ and v_ψ at 100 hPa, 300 hPa, 500 hPa, 700 hPa and 900 hPa surfaces. These are considered as input fields for solving the omega equation as written below:

$$\nabla^2 \omega + \frac{f^2}{S} \frac{\delta^2 \omega}{\delta p^2} = \frac{1}{S} \left(\frac{\delta}{\delta p} J(\Phi, \eta) + \frac{1}{f} \nabla^2 J \left(\Phi, -\frac{\delta \Phi}{\delta p} \right) \right) - \frac{f}{S} \frac{\delta}{\delta p} \left(\xi \frac{\delta \omega}{\delta p} - \omega \frac{\delta \xi}{\delta p} \right) - \frac{f}{S} \frac{\delta}{\delta p} \left(\frac{\delta \omega}{\delta y} \frac{\delta u}{\delta p} - \frac{\delta \omega}{\delta x} \frac{\delta v}{\delta p} \right) - \frac{R}{S} \frac{\nabla^2 Q}{C_p P}, \quad (4)$$

where some of the terms in the equation have been omitted. This equation can further be decomposed as

$$\nabla^2 \omega_1 + \frac{f^2}{S} \frac{\delta^2 \omega_1}{\delta p^2} = \frac{1}{S} \left(\frac{\delta}{\delta p} J(\Phi, \eta) + \frac{1}{f} \nabla^2 J \left(\Phi, -\frac{\delta \Phi}{\delta p} \right) \right) \quad (5)$$

$$\nabla^2 \omega_2 + \frac{f^2}{S} \frac{\delta^2 \omega_2}{\delta p^2} = -\frac{f}{S} \frac{\delta}{\delta p} \left(\left(\xi \frac{\delta \omega}{\delta p} - \omega \frac{\delta \xi}{\delta p} \right) + \left(\frac{\delta \omega}{\delta y} \frac{\delta u}{\delta p} - \frac{\delta \omega}{\delta x} \frac{\delta v}{\delta p} \right) \right) \quad (6)$$

$$\nabla^2 \omega_3 + \frac{f^2}{S} \frac{\delta^2 \omega_3}{\delta p^2} = -\frac{R}{S} \frac{\nabla^2 Q}{C_p P} \quad (7)$$

and the thermodynamic energy equation is

$$\frac{\delta}{\delta t} \left(-\frac{\delta \Phi}{\delta p} \right) + \vec{V} \cdot \nabla \left(-\frac{\delta \Phi}{\delta p} \right) - (\omega_1 + \omega_2 + \omega_3) S = -\frac{RQ}{C_p P}, \quad (8)$$

where

$$S = -\frac{\alpha}{\Theta} \frac{\delta \Theta}{\delta P}.$$

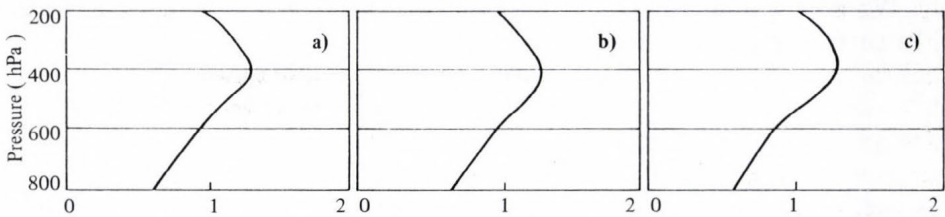
At the very first stage, Eq. (5) has been solved to get the adiabatic vertical velocity ω_a . This term was substituted as a guess value to calculate the forcings of Eq. (6) and relaxed to get ω_2 . Further ω_a was modified as $\omega_a = \omega_1 + \omega_2$. With this ω_a the forcing of Eq. (6) was evaluated and further relaxed to get new value for ω_2 . This new ω_2 was compared with the earlier one and iteration was repeated so as to reduce the difference between the final ω_2 and the preceding one to be under the tolerance limit of one per cent.

After these iteration, the revised estimate for $\omega_a = \omega_1 + \omega_2$ is used as initial guess for the vertical velocity ω and the thermodynamic Eq. (8) has been solved to estimate the diabatic heating rates. This heating rate has been further used to solve Eq. (7) for ω_3 which was added in $\omega = \omega_a + \omega_3$. This revised ω was further used to calculate diabatic heating rates through Eq. (8) using the new ω_3 , obtained from Eq. (7). We have now two subsequent sets of ω_3 fields. If the difference between these two ω_3 fields is less than one per cent of its normal value at each grid point, it is considered to be the acceptable omega field otherwise iteration is performed to reduce the deviations between the final ω_3 and the preceding one to be under the tolerance limit of one per cent of its

characteristics value at each grid point. These ω_1 , ω_2 and ω_3 were added to get the final total vertical velocity ω at each grid point at 200 hPa, 400 hPa, 600 hPa and 800 hPa surfaces. The geopotential values at 100 hPa, 300 hPa, 500 hPa, 700 hPa and 900 hPa surfaces obtained from the numerical solution of the balance equation (Singh and Singh, 1990) were used to get the temperature fields at 200 hPa, 400 hPa, 600 hPa and 800 hPa surfaces using the hydrostatic balance and the equation of state. These temperatures, wind and the vertical velocity values were used to solve the thermodynamic energy equation for diabatic heating rates. The vertical velocity (ω), temperature, diabatic heating and the wind fields at 200 hPa, 400 hPa, 600 hPa and 800 hPa surfaces were further used over the area of computation to calculate A_Z , A_E , γ , G_Z , G_E , C_Z , C_E and different components of C_A for the period 5–7 July 1979.

5. Results and discussion

Figs. 1a-c show the vertical distribution of γ on 5th, 6th and 7th July 1979 respectively, which is a measure of eddy activities in the atmosphere. We note the maximum value of γ at about 400 hPa surface indicating that over the Indian monsoon region, the 400 hPa surface being more active in eddies. Smagorinsky (1963) and Baker et al. (1977) also observed the maximum value of γ to be at 400 hPa surface. Since it is the areal mean, thus a depression over the Bay of Bengal has no influence upon the distribution of γ during the life cycle of the depression.



Figs. 1a-c. Vertical distribution of areal mean stability factor (γ) on 5th, 6th and 7th July 1979, 12 GMT respectively. Unit: 10^5 erg/gm/deg²

Figs. 2a-c show the vertical distribution of zonal (A_Z) and eddy (A_E)

available potential energy on 5th, 6th and 7th July 1979, respectively. We note that the vertical distribution of A_Z is similar to that of γ on 5th July. However, on 6th and 7th the maximum of A_Z was at lower level i.e. at 600 hPa and its magnitude has also been reduced as compared to A_Z on 5th July due to the presence of a depression at the Bay of Bengal. The eddy available potential energy is always less than A_Z . On the 7th July there is substantial drop in the magnitude of A_E at 600 hPa. It seems that the substantial increase in A_Z at 600 hPa is due to the decrease in A_E at that level on 7th July indicating that the eddies at 600 hPa transfer the potential energy to its zonal form i.e. of the basic flow.

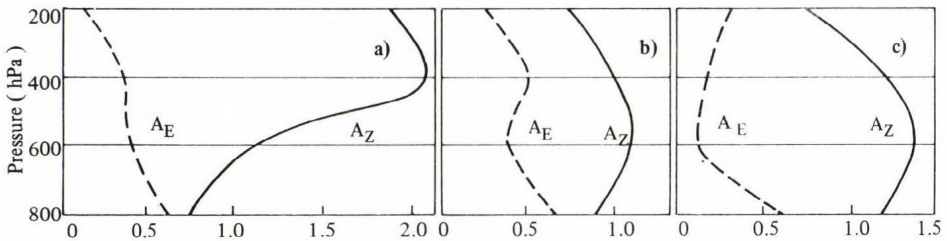


Fig. 2a-c. Vertical distribution of A_Z and A_E on 5th, 6th and 7th July 1979, 12 GMT respectively. Unit: 10^2 erg/cm²/hPa

Figs. 3a-c show the vertical distribution of zonal (G_Z) and eddy (G_E) generation of available potential energy on 5th, 6th and 7th July 1979, respectively. We note that the eddy destruction of A_Z is the most intense at about the 600 hPa surface and gradually decreases in its magnitude from 5th to 7th July. The destruction of eddy available potential energy is observed between 500 and 700 hPa surfaces only. However, the zonal form of the available potential energy always shows a net generation being maximum on 5th July at 200 hPa, which shifts to the lower surfaces from 600 to 800 hPa on 6th and 7th July. The zonal as well as eddy generation gradually increases in its magnitude from 5th to 7th July in the lower tropospheric layer and seems to be due to the presence of the depression over the Bay of Bengal. However, above the 400 hPa surface the increase in magnitude of the A_E generation from 5th to 7th seems to be due to the extreme northward shifting of the trough of westerlies over Tibetan Plateau in the upper troposphere. As westerlies move from higher latitudes to the Indian Continent in the mid and upper troposphere cold air intrusion cools the warm tropical air. Shifting of the cold westerlies trough to Tibetan Plateau causes the

warm tropical air over India to warm up further. Thus with the heated and cold air masses the resulting stratification of the atmospheric temperature field enhances the eddy generation of available potential energy.

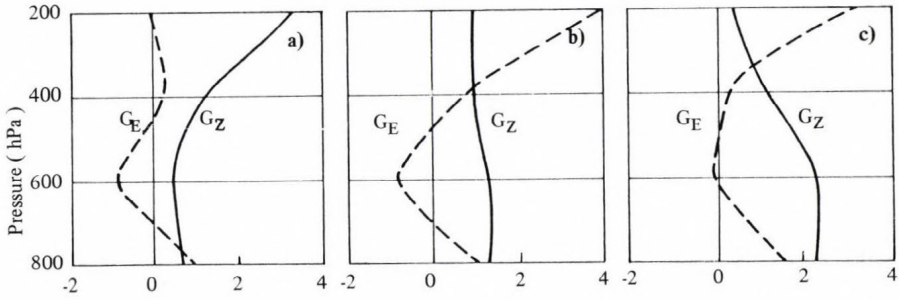
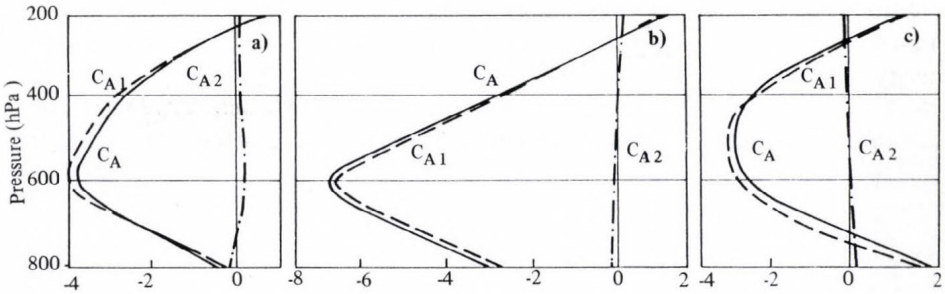


Fig. 3a-c. Vertical distribution of G_z and G_E on 5th, 6th and 7th July 1979, 12 GMT respectively. Unit: 10^{-3} erg/cm²/sec/hPa



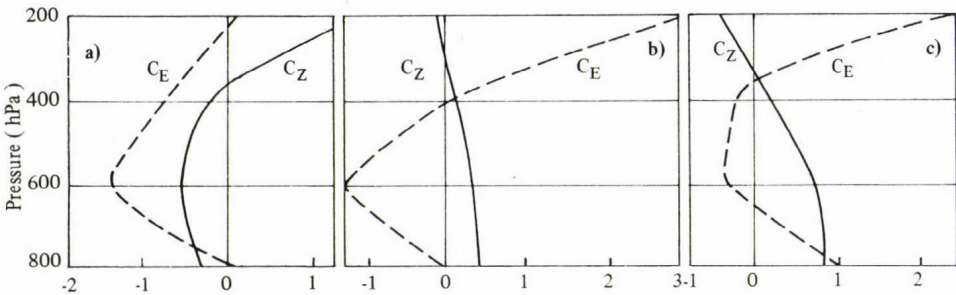
Figs. 4a-c. Vertical distribution of C_A with its components on 5th, 6th and 7th July 1979, 12 GMT respectively. Unit 10^{-4} erg/cm²/sec/hPa

Figs. 4a-c show the vertical distribution of transformation of zonal available potential energy to eddy available potential energy (C_A) on 5th, 6th and 7th July 1979, respectively. It consists of two terms, namely C_{A1} and C_{A2} . The C_{A1} term represents the transformation of zonal available potential energy to eddy available potential energy due to meridional horizontal transport of sensible heat

parallel with the temperature gradient over the region. Whereas C_{A2} expresses the transformation from zonal to eddy available potential energy due to vertical transport of sensible heat over the region of computation. We note that in general C_{A2} is almost negligible at each level in the vertical as compared with C_{A1} . Thus, we can safely neglect the second term for the computation of C_A . *Desai* (1986) computed C_A over the Indian monsoon region with the presumption that C_{A2} is negligible as compared to C_{A1} and observed a positive value of C_A . It indicated that in the beginning of monsoon epoch there was a transformation from zonal to eddy available potential energy due to horizontal meridional transport of sensible heat along the thermal gradient.

The profiles in *Fig. 4* show that in the investigated period there is a reverse transformation identified with negative values of C_A and maximum of this transformation lies at about 600 hPa which shifts to 500 hPa on 7th July with the weakening of the depression over the Bay of Bengal. In the upper troposphere the transformation term is positive above 300 hPa surface throughout the period of depression. However, during the active period, transformation of A_E to A_Z is predominant in the lower and middle troposphere. *Keshavamurty* (1973) also observed that the mean meridional circulation gets changed over the Indian region during the monsoon season.

Figs. 5a-c show the vertical distribution of zonal (C_Z) and eddy (C_E) conversion of available potential energy to kinetic energy on 5th, 6th and 7th July 1979, respectively. We note that there was a conversion from zonal available potential energy to zonal kinetic energy above the 400 hPa surface on 5th July and below it the opposite process took place i.e. transformation of zonal kinetic energy to zonal available potential energy. This gets changed on 6th and 7th July below 400 hPa surface to a reverse distribution with the conversion of zonal available potential energy to zonal kinetic energy under the 400 hPa surface.



Figs. 5a-c. Vertical distribution of C_Z and C_E on 5th, 6th and 7th July 1979, 12 GMT respectively. Unit: 10^{-3} erg/cm²/sec/hPa

The conversion from eddy available potential energy to kinetic energy on 5th July had a negative maximum at 600 hPa and from 800 to 200 hPa the eddy kinetic energy is acting as a source of eddy available potential energy. On the subsequent two days, i.e. on 6 and 7 July, the region of negative conversion in the middle troposphere gets decreased and above 400 hPa and below 650 hPa it changed to a positive value indicating that the conversion becomes from eddy available potential energy to eddy kinetic energy which is the usual direction of conversion.

It is noteworthy that in the middle troposphere a conversion of eddy available potential energy to zonal available potential energy took place for which the eddy kinetic energy was acting as source in the C_E conversion.

Our case-study partially completes the results of earlier analyses of the dynamics of monsoon depressions in the following aspects:

- in the lower troposphere the zonal as well as eddy generation of available potential energy increases due to the presence of the depression over the Bay of Bengal, however, in the upper troposphere, the northward shifting of upper level westerlies trough causes the generation of eddy available potential energy;
- the eddy available potential energy gets transformed in the zonal form throughout the lower and middle troposphere with a maximum at about 600 hPa surface during the depression period;
- prior to the formation of the depression, the eddy kinetic energy act as a source to eddy available potential energy. This is changed due to the presence of the depression over Bay of Bengal and eddy available potential energy act as a source to eddy kinetic energy during the life cycle of the depression.

Acknowledgement—Financial support provided by Council of Scientific and Industrial Research, New Delhi to one of the authors (RKS) is gratefully acknowledged.

List of symbols

λ, ϕ	— longitude, latitude
p	— pressure
u, v	— eastward and northward components of wind
u_ψ, v_ψ	— eastward and northward components of solenoidal wind
ω	— dp/dt , vertical velocity
Φ	— geopotential (gZ)
T	— temperature

θ	— potential temperature
dM	— increment of mass
a	— radius of earth
f	— Coriolis parameter
R	— gas constant
C_p	— specific heat at constant pressure
Q	— diabatic heating rate per unit mass
α	— specific volume
S	— static stability parameter
A_z, A_E	— zonal and eddy components of available potential energy
G_z, G_E	— zonal and eddy generation of available potential energy
C_z, C_E	— zonal and eddy conversion of available potential energy to kinetic energy
C_A	— transformation from zonal to eddy available potential energy
γ	— stability factor
ξ	— vertical component of relative vorticity
η	— vertical component of absolute vorticity
J	— Jacobian operator
g	— acceleration due to gravity

References

- Baker, E.W., Kung, E.C. and Sommerville, C.J.R., 1977:* Energetics diagnosis of the NCAR general circulation model. *Mon. Wea. Rev.* 105, 1384-1401.
- Deasai, D.S., 1986:* Study of energetics in strong and break monsoon. *Mausam* 37, 365-367.
- Gupta, S.C. and Mandal, G.S., 1987:* Behaviour of kinetic energy generation function during a western disturbance in May 1982. *Mausam* 38, 97-102.
- Holopainen, E.O., 1970:* An observational study of the energy balance of the stationary disturbances in the atmosphere. *Quart. J. Roy. Meteorol. Soc.* 96, 626-644.
- Keshavamurty, R.N., 1973:* *On the maintenance of the mean Indian southwest monsoon circulation and the structure and energetics of monsoon disturbances.* Ph. D. thesis, Mysore University, India.
- Keshavamurty, R.N. and Awade, S.T., 1970:* On the maintenance of the mean monsoon through over North India. *Mon. Wea. Rev.* 98, 315-319.
- Lorenz, E.N., 1955:* Available potential energy and the maintenance of the general circulation. *Tellus* 7, 157-167.
- Masters, S.E. and Kung, E.C., 1986:* An energetics analysis of cyclonic development in the Asian winter monsoon. *J. Meteorol. Soc. Japan* 64, 35-51.
- Rajamani, S. and Kulkarni, J.R., 1986:* On some energy aspects of the monsoon depression during its life cycle. *Mausam* 37, 9-16.
- Saha, K.R. and Saha, S., 1988:* Thermal budget of a monsoon depression in the Bay of Bengal during FGGE-MONEX-1979. *Mon. Wea. Rev.* 116, 342-354.
- Saha, K.R., Sanders, F. and Shukla, J., 1981:* Westward moving predecessors of monsoon depressions. *Mon. Wea. Rev.* 109, 330-343.

- Sanders, F.*, 1984: Quasi-geostrophic diagnosis of the monsoon depression of 5-8 July 1979. *J. Atmos. Sci.* *41*, 538-552.
- Singh, U.S. and Singh, R.K.*, 1990: Solution of the balance equation over the Indian Monsoon region. *Proc. Indian Nat. Sci. Acad.* *56A*, 55-62.
- Singh, S.S., Kulkarni, A.A. and Bandyopadhyay, A.*, 1980: The kinetic energy budget of monsoon circulation over the Indian region during ISMEX-1973. *PAGEOPH* *119*, 16-23.
- Smagorinsky, J.*, 1963: General circulation experiments with the primitive equations: I. The basic experiment. *Mon. Wea. Rev.* *91*, 99-164.
- Warner, C.*, 1984: Core structure of a Bay of Bengal monsoon depression. *Mon. Wea. Rev.* *112*, 137-152.
- WMO*, 1981: Summer Monex field phase Report. *FGGE Operations Report 8*, 179.
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IDŐJÁRÁS

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Future air resources management – A realistic approach

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Abstract—This paper is directed to environmental engineers and scientists who are familiar with air quality management regulations and are interested to know how present day practices might grow step by step to a multi-level air resources management (A.R.M.) system in the coming decades. The management system proposed here is a simple but a quasi-closed one. Present day regulations and precautionary measures are compared to a future multi-level A.R.M. system.

Key words: air resources management; local, regional, continental and global scales; criteria and standards.

Former air quality management—as it is known—was based on the requirement to meet local scale health standards. The same types of regulations are valid presently too. Rate of emission is allowable if health standards are met. In some countries allowable regional emission density values and in principle national emission totals are determining factors. It is expected that future multi-level A.R.M. should meet relevant criteria and standards shown by *Tables 1, 2 and 3.*

Taking into account the immense costs of emission abatement the following questions should be answered:

- Is the presently available information base (air quality, emission) reliable enough?
- Are the methods statistically validated?
- Are priorities established by cost/benefit and risk analyses?

While for local and regional scales the management system has been practically elaborated this is not the case for continental and global scales.

For the preparation of the multi-level A.R.M. system climatological and

Table 1. Characteristics of multi-level air resources management

Scales	Allowable emission totals	Criteria, standards
Global	Continental	Climatic change
Continental	National	Target and critical levels and deposition
Regional	Emission density	Health and ecological
Local and urban	Rate of emission	Health

Table 2. Features of air resources management

Scale, km	Signif. pollutant	Risk involved	Air quality norm exists?	Allowable emission density	Management		
					F o r m e r t	P r e s e n t	F u t u r e
Local urban 0-20	Contaminating subs.	Health	Y	Y	↓	↓	
Regional 20-200	Cont. subs. and pot. acid. subs.	Health and ecology	Y	Y			
			N	N			↓
Continental 200-2000	Pot. acidifying subs.	Ecology	N	N		↑	↑
Global > 2000	Greenhouse gases	Climate change	N	N			

chemical aspects should be jointly considered. Chemical forcing functions should encompass contaminating substances, potentially acidifying species and greenhouse gases. Estimated emissions of these pollutants for 1985 are shown in *Table 4*.

Table 3. Environmental norms and standards

Health	Short and long term norms and standards
Ecology	Critical and target levels, deposition loads
Climate	Detectable, significant change in climate and its anomalies

Instead of the present day air quality management which is based for each pollutant on separate considerations, future multi-level A.R.M. should be based on a more comprehensive expectation i.e. to meet air resources criteria and standards (atmospheric ecological norms) relevant for local, regional, continental and global scales. This new management system is much more complex than the present day local scale air quality permission system. Simple extension of local scale management practice is improper for the elaboration of regional, continental and global scale A.R.M. systems.

The main features of a multi-level A.R.M. system is shown by *Table 2* and *3*. Almost each element of this future system exist presently in a certain preliminary form. However, interrelationships are not fully clarified. Risk factors, cost/benefit relationships have not been analysed. Dose/response relationships, criteria and standards have not been established. Total global costs of the different scenarios have not been assessed.

It looks evident that to establish realistic air resources priorities for different scales some system-analytical approach mentioned here could not be avoided. A realistic, quantitative assessment can:

- increase the credibility and clarify the risk of possible future air resources catastrophes,
- establish more solid base for preparing international air resources management agreements,
- focus on the white spots of our knowledge from the view of A.R.M.,
- promote the development of scientifically-technically based A.R.M. practices.

In order to make the new A.R.M. system for environmental engineers in their daily work applicable, management techniques for different scales should

Table 4. Estimated pollutant emission (1985)

	t/a	Global (anth. + biogen.)	North America	Europe	Hungary
Contaminating substances	Carbon monoxide	$(1.6+1.2)10^9$	7.4×10^7	-	0.8×10^6
	Lead	$(4.5+0.3)10^5$	2.2×10^4	9.0×10^4	6.2×10^2
	Cadmium	$(7.3+0.8)10^3$	-	1.1×10^3	4.4
	TSP	$(0.2+3.7)10^9$	9.2×10^6	-	4.5×10^5
Potential acidifying subs.	Sulfur dioxide	$(1.6+1.3)10^8$	2.5×10^7	4.5×10^7	1.4×10^6
	Nitrogen dioxide	$(8.0+8.9)10^7$	2.2×10^7	1.9×10^7	2.6×10^5
	NM VOC	$(0.8+4.6)10^8$	$(2.2+3.5)10^7$	$(2.2+1.8)10^7$	2.3×10^5
	Ammonia	1.7×10^8	-	9.0×10^6	1.5×10^5
Greenhouse gases	Carbon dioxide (C)	$(5.3+1.6)10^9$	1.2×10^9	2.0×10^9	2.7×10^7
	CFC-11	7.7×10^5	-	-	5.5×10^3
	CFC-12				
	Methane	$(1.8+3.5)10^8$	-	-	5.3×10^6
	N ₂ O	$(1.4+5.9)10^6$	-	-	9.5×10^3

be put on the same footing. Based on these ideas easily applicable, unified methodology is necessary to carry out baseline assessment, impact analyses, planning and management. The methodology should be based on measured representative background values, validated models, agreed criteria and standards and emission density norms. For multi-level air resources standards each new major source should meet local regional, continental and global emission density norms where natural sources are also considered. No abatement strategy on any scale should be based on the assumption that the target levels and loads be lower than the measured background values. On the basis of this short discussion one can conclude as follows.

A.R.M. in near future will encompass contaminating substances, potentially acidifying species and greenhouse gases.

Global, continental, regional and local standards should be met separately.

However, dose/effect relationships for global and continental scale phenomena are not yet understood to furnish sound information for decision-making.

Current scientific-technical efforts are inadequate to establish a sound multi-level A.R.M. system, compared to the immense costs of emission abatement involved.

For the development of a new A.R.M. system priorities should be based on risk and cost/benefit analyses carried out for all scales. For such analyses the total social costs involved should be taken into account. A.R.M. goals could be approached only on a medium or long term scale, step by step.

To put A.R.M. on a quantitative footing elaboration of dose/response relationships, norms and standards and background levels are inevitably important preconditions.

In contrary to the considerable hardness to assess expected costs and risks involved, this could not mean that it is better not to touch this problem. This could qualify the correctness of our environmental approach. Only in case when cost aspects are realistically considered can be expected that sooner or later A.R.M. is proceeding from an fully open system to a quasi-closed one. Only such system can also reveal the white spots in our environmental knowledge.

The ideas mentioned here are mostly evidences put in a system analytical frame. Further researches and development on these is possible perhaps as a multi-national joint effort.

References

Szepesi, D., 1987: Application of meteorology to atmospheric pollution problems. World Meteorol. Org., *Technical Note No. 188*, WMO-No. 672, Geneva.

Szepesi, D., 1989: *Compendium of Regulatory Air Quality Simulation Models*. Akadémiai Kiadó, Budapest.

BOOK REVIEW

Götz, G., Mészáros, E. and Vali, G.: **Atmospheric Particles and Nuclei.** Akadémiai Kiadó, Budapest, 1991. 274 pages.

The General Assembly of the International Association of Meteorology and Atmospheric Physics (IAMAP) which took place in Vienna, Austria, in August 1991, revealed a new and stronger interest towards the area of problems concerning atmospheric aerosol and condensation nuclei (CN), originated, first of all, from the fresh results of research in the climate-forming role of aerosol (see e.g. the works of one of the present reviewers; Kondratyev: *The "Aerosol-Clouds-Climate" Interactions*, which are under publication). For example, the new idea of gas-phase reactions of dimethylsulfide (DMS) transformation, generated by sea algae and emitted to the atmosphere, put forward by E. Mészáros, R. Charlson et al. provoked a considerable resonance. The assessments available reveal that CN, which are products of reactions of this kind, influence the processes of cloud formation and thus are capable of causing changes in the Earth's radiation budget which are opposite in sign to the enhancement of the greenhouse effect of the atmosphere and comparable with the latter in value. Several papers presented at the IAMAP Assembly were devoted to similar estimations relevant to gas-phase reactions with the participation of sulphur dioxide. The field experiments carried out about 20 years ago within the framework of the CAENEX Program have revealed the presence of a strong impact of anthropogenic aerosol on the radiative properties of clouds. The longterm program of Soviet-American cooperation whose completion was marked by the publication of joint monograph *Aerosol and Climate* (edited by K. Ya. Kondratyev and published by Gidrometeoizdat in Leningrad, 1991) was aimed, above all, at the integration and generalization of the available data on the climate-forming contribution of aerosol.

Considering the above-said, it is quite natural, of course, that three most prominent experts in the field of aerosol and CN research, G. Götz, E. Mészáros (Hungary) and G. Vali (U.S.A.) have written a monograph which is doubtless a substantial and most timely book, and a review of which is offered here.

The authors have been successful in discussing, in a rigid and logical enough form, in their modest-volume (274 pages) book, a number of complicated and sophisticated problems of the physics and chemistry of atmospheric aerosol, its role in the phase transformations of water and the formation of climate. The monograph is intended as a manual for students and young professionals in the sphere of meteorology and environmental protection. Therefore, it mainly deals with those results in atmospheric aerosol studies that have been definitely established and generally recognized. The book also considers the processes of aerosol transformation.

Concise as it is, the book presents most interesting and practically useful data borrowed from various sources and analyzed from a different point of view, at a new angle. Thus, for instance, a comparison of the estimates of the power of various global aerosol sources performed in the chapter *Atmospheric Aerosol* (E. Mészáros) between the data published in 1971 and G. Prospero's results of 1984, has brought about the conclusion that, for the most part, these estimates are approximate and underestimated. A distinct tendency towards the enhancement of the power of natural aerosol sources is observed which is probably due to the impact of human economic activity.

Data on the chemical composition of atmospheric aerosol presented in the book are very useful. In our opinion, however, the monograph would have gained considerably if the authors had used a wider range of Soviet studies which have not been adequately reflected. The choice of material used by the authors reveals in rather a "polarized" manner their own notions of the physics and chemistry of atmospheric aerosol, as well as their own scientific interests.

The chapter *Cloud Condensation Nuclei* (E. Mészáros) offers material which is extremely important for understanding the role of chemico-physical properties of CN in the processes of formation of clouds and precipitation, and consequently, in the formation of climate. Special emphasis here is put on the role of sulphate particles which to a great extent reflects the impact of anthropogenic factors. It is shown that the condensation properties of particles vary markedly with height. Of great interest are the observational data and their interpretation presented in the chapter discussed. The last section of the chapter is devoted to a brief outlined of the results of studies of the influence of artificial condensation nuclei on clouds (both CN introduced to obtain a certain effect, and those formed from ejections into the atmosphere of various pollutants are examined). Special attention is drawn to the works of Chagnon who found out the effect of large industrial complexes on the amount of precipitation in their vicinity. However, the author offers no assessment of these results.

The chapter *Nucleation of Ice* (G. Vali) occupies just a little less space than the largest one *Atmospheric Aerosol*. It presents ample concrete experimental material encompassing the results of laboratory studies of ice formation processes under artificially regulated and controlled conditions, as well as the results of investigations of the natural of natural ice formation nuclei and processes of in situ ice formation.

In overcooled clouds, the possibility of the presence of ice crystals and their rapid growth into precipitation elements is determined by the presence of natural condensation nuclei. If they are insufficient in amount to initiate the process of precipitation formation, clouds can be seeded artificially by nuclei suitable for stimulation of the process of precipitation formation.

A large section of the chapter deals with the problem of artificial impact on clouds of coolers and aerosols of different nature, in particular, of silver iodide. The material is outlined mostly in a descriptive manner, but this weak point is compensated by ample bibliography presented.

The final chapter *Aerosols and Climate* (G. Götz), devoted to the analysis of the effect of aerosol particles on the atmospheric radiation budget, is based, in a traditional way, on the description of the effects of strato- and tropospheric aerosols. Very interesting here are the estimates of the influence of the albedo of stratospheric clouds of various optical density on the temperature decrease in the near-ground air layer. In the context of numerical modeling of the impact of aerosol on climate, some estimates are given which have been obtained by making use of models of different complexity. Possible effects of volcanic eruptions and a hypothetical nuclear war on climate are briefly discussed, as well as the aerosol anthropo- and biogenic (DMS) impacts on the radiative properties of clouds. Regrettably, the author of this chapter is apparently completely unaware of numerous Soviet relevant publications, including those published in English (for example, K. Ya. Kondratyev: *Climate Shocks: Natural and Anthropogenic*. Wiley & Sons, New York et al., 1988, 296 p).

The Appendices to the monograph can also be most useful. The first two Appendices consider the fundamentals of the theory of nuclei formation and droplets growth, the third one offers a scheme of calculations of radiative transfer in the atmosphere, and the final one presents the terminology employed in the book.

In conclusion, one can only emphasize again that the book reviewed is a substantial piece of work written by prominent experts in the field, and the reader can certainly derive from it a lot of valuable knowledge.

L. S. Ivlev and K. Ya. Kondratyev

NEWS

General Assembly of the Hungarian Academy of Sciences, 1992

The Hungarian Academy of Sciences (HAS) held its 152th General Assembly between 4 and 8 May 1992. This Assembly was an important step in the history of the Academy since it was organized after essential modifications in academic life in accordance with political changes in the country. As the President of HAS, *D. Kosáry* stated in his inauguration speech during the last two years the structure of HAS has become more democratic, much more people are involved in the scientific committees, the work of the Secretarial is reorganized and simplified and the new directors of the scientific research institutes of HAS are nominated according to an open application system. At the same time HAS has made all possible steps to preserve the level of scientific research and qualification. Concerning this latter issue HAS proposed a new form of collaboration with universities which are also under renewing. For scientific qualification two degrees of doctorship are recommended, both under the auspices of a joint commission formed by experts delegated by HAS and universities. HAS believes that two degrees are necessary for assuring the high level of science and education. The first degree would be equivalent with the PhD of western universities, while the second one would promote the appropriate choice of full professors and HAS members.

In his statement *L. Mádl*, Minister of State charged with scientific affairs noted that the Commission of Science Policy of the Hungarian Government ratified this qualification system. Among other things he stressed that the Government does not plan any new ministry for research since it considers HAS as the trustee of the scientific affairs of the country including the coordination of the work of research institutes. It was also mentioned that the Government accepted a new act concerning HAS, which will be submitted to the Parliament together with other acts like the Act for Education. According to the new act HAS will be an independent self-governing body with its own properties and not a state organization.

I. Láng, the Secretary-General of HAS reported about the activity of research institutes working in the frame of HAS. He evaluated the results

obtained on the basis of the number of publications and the citation index of papers published. His evaluation shows that the research activity of HAS' institutes is good if we compare the results with those of other countries with similar GNP. This is a very satisfactory achievement, he said, taking into account the financial restrictions during the last years.

The second important aspects of the General Assembly of HAS in 1992 was that, for the first time, the main topics chosen by the Presidium for discussion was environmental science. The introductory lecture for this discussion was delivered by *E. Mészáros*, President of the Commission for Environmental Sciences of the Presidium. The lecturer summarized the past, present and future relationship between man and Earth's environment. He also outlined the aims and purposes of environmental science in connection with environmental protection. During the Assembly a conference of one day was organized by the commission mentioned to evaluate the present state of different media of the environment in Hungary as well as the strategy necessary for its improvement.

In addition to this conference, several sections of HAS held meetings on various problems of environmental science and protection. Thus, the environmental aspects of energy production and transportation, the role of chemical science in environmental research, and the cycle of microelements in different geospheres were treated in detail. It was concluded that HAS has to increase its activity concerning environmental science considering the importance of this field for the well-being of future generations of mankind. The need for the introduction of environmental education into the program of schools and universities was also emphasized by many participants.

A unique event of the General Assembly was the formation of the Academy for Literature and Fine Arts. This Academy wearing the name of *I. Széchenyi*, the great Hungarian thinker of the last century, will be operated under the umbrella of HAS. In this way the old traditions are restored and the two different aspects of the understanding of life and nature can be discussed together in close cooperation and friendship.

E. Mészáros

ATMOSPHERIC ENVIRONMENT

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