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EDITORIAL

*„Időjárás" (***Weather** *in English) is one of the oldest journals publishing papers in meteorology. Its first aim was to make known to Hungarian scientific community and public what was happening in the country and around the world in this field. For this reason, papers were published in the Hungarian language, in some cases even the proper Hungarian expressions for certain technical terms were introduced on the pages of this journal.*

After the second world war, it became even clearer than before that meteorology was an international science. Consequently, papers were also published in foreign languages prepared partly by foreign experts. The problem was that articles appeared mostly in Russian and German, and only relatively few in English. This was caused by the political situation at that time and also by the language knowledge of the older generation of meteorologists in this part of Europe. An important change was made in 1980 when it was decided to publish papers only in English and Hungarian. This was very necessary since in the meantime English became the leading international language in natural sciences including meteorology. On the other hand, a new generation was grown up for whom it was evident to speak and write in English.

Now, we want to make a further step in the direction of internationalism. Since the beginning of this year, all the papers will be published in English, although we will preserve the traditional Hungarian name of the journal. It is hoped that in this way we will create a really international quarterly forum promoting the east-west information exchange and facilitating the approach of eastern-central Europe to the western world.

It goes without saying that good manuscripts prepared in English are needed to realize this purpose. For this reason, all meteorologists and atmospheric scientists in East and West are encouraged to submit their papers to this old but renewed journal.

E. Mészáros Editor-in-Chief

IDŐJÁRÁS

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Development and application of a method for direct measurement of SO_2 fluxes

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(Manuscript received on 21 October 1991)

A simple method for direct measurements of SO_2 fluxes onto a surrogate surface has been developed. While employing a filter technique for the sampling itself, a chemiluminescence method was applied for the SO_2 analysis. Laboratory tests on the reliability of the sampling technique by means of a calibration chamber are reported. Some measurements of vertical SO_2 concentration and deposition profiles within forest areas are presented in order to demonstrate the applicability of the filter sampling technique developed. Deposition velocities ranging from 0.15 to 0.86 cm/s have been derived. The deposition velocity is not constant with height but depends on the ambient SO_2 concentration, which is strongly influenced by characteristics of turbulence and transport within forest areas.

Key-words: sulfur dioxide, dry deposition, forest pollution.

1. Introduction

The exchange of pollutants between the atmospheric boundary layer and any surface (vegetation, soil, water, materials) is controlled by transport mechanisms within the atmosphere as well as by adsorption and desorption processes at the surface (*Garland,* 1978). The dry deposition of trace constituents has to be considered as a very important cleansing mechanism for the atmosphere. Close to industrial sources the contribution of dry deposition to the total sulfur deposition rate is estimated up to 80 per cent (*Kuttler,* 1982).

1.1. Definition of the deposition velocity

The pollutant flux generally is described as being proportional to the referring concentration gradient. Assuming this gradient is directed vertically and the concentration of a pollutant disappears at any surface (*Flothmann,* 1982):

$$F \sim c(z) - c(z_0, \text{ whereby } c(z_0) = 0$$

leads to the simple relationship:

$$F \sim c(z)$$

respectively:

$$F = v_d \ c(z)$$

$c(z)$ = concentration of the pollutant at a given height z [$\mu g/m^3$]
F = pollutant flux [$\mu g/m^2$ s]
v_d = constant of proportionality, defined as deposition velocity [cm/s]

The deposition velocity depends on the effectiveness of the pollutant transfer, which is governed by the stability of the atmosphere and windspeed, as well as on the physical and chemical properties of the particular surface. Analogous to Ohm's law, a pollutant flux can be treated as counteracted by various transport resistances arranged in series (*Roth,* 1975):

$$r = r_t + r_l + r_s$$

r_t = turbulent transport resistance [s/cm]
r_l = diffusive transport resistance [s/cm]
r_s = surface resistance, determined by the special properties of the surface (e. g. pH, moisture conditions . . .)

The sum of r_t and r_l is defined as atmospheric resistance r_a. *Fig. 1* shows a scheme of the various transport resistances according to *Fowler* (1980).

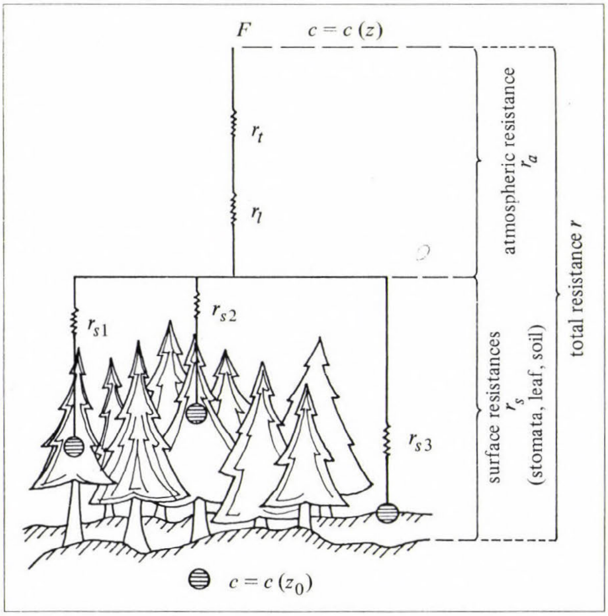


Fig. 1: Scheme of transport resistances (*Fowler,* 1980). F = pollutant flux, $c(z)$ = concentration of the pollutant at a given height z, $c(z_0)$ = concentration of the pollutant at any surface

The deposition velocity can be explained as the reciprocal of the overall transport resistance:

$$v_d(z) = (1/r) = (1/(r_a + r_s)) = (F/c(z)).$$

2. *Measuring method*

The measuring method for SO_2 applied in this investigation is based on the technique developed by *West* and *Gaeke* (1956). A 0.1 M sodium-tetrachloromercurate solution

($TCM - Na_2[HgCl_4]$) is used as absorber for SO_2. After absorption the SO_2 is converted into sulfite and fixed in a stable, nonvolatile disulfitomercurate complex. According to *WEST* and *GAEKE* TCM is assumed to be a perfect sink for SO_2. For the sampling procedure the „DELBAG Microsorban-98" filter material (47 mm dia.) seved as an appropriate surrogate surface.

The TCM impregnated filters were kept in customized filterholders allowing deposition fluxes to both sides of the filters and exposed for a defined period of time. Impregnation and analysis of the filters were performed using a chemiluminescence technique first introduced by *Stauff* and *Jaeschke* (1975) and by *Jaeschke* and *Stauff* (1978).

2.1. Analytical Method

The chemiluminescence technique is shortly summarized in this section.

The disulfitomercurate complex formed during the SO_2 sampling is generally stable. However, treating this complex with an acidic potassium permanganate solution (pH 2.5), dissociation occurs along with a chemiluminescence phenomenon indicating the oxidation of the free bisulfite ion to sulfate. The light yield of this process is proportional to the complexed SO_2 sample on the filter.

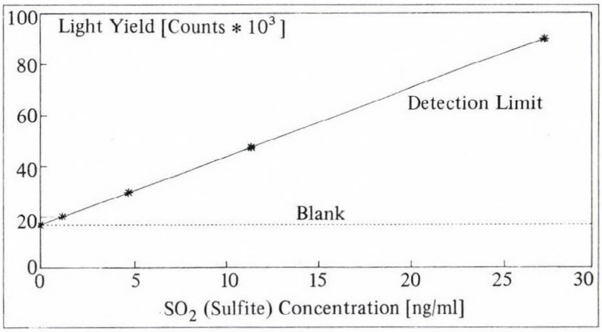


Fig. 2:
Typical calibration curve for the chemiluminescence technique. The average signal of blank samples is 17 918 counts (impulses). The detection limit, defined as blank counts plus 3σ standard deviation of the noise, is 22 428 counts, corresponding to 1.2 ng SO_2 (sulfite)/ml

To calibrate the chemiluminescence effect a standard sulfite solution is used diluted with TCM for stability purposes. A set of standards in the range 2–80 ng complexed SO_2 (sulfite)/ml is achieved by further dilution of the primary standard with 0.1 M TCM. Prior to any measurements the calibration of the chemiluminescence instrument took place (*Fig. 2*).

2.2. Filter sampling

In order to avoid contamination sealed filter holders were kept in an airtight box during transportation to any field site. *Fig. 3* shows exposed filter holders.

3. Laboratory experiments

Prior to any field experiments the applicability of the sampling method had to be verified. Therefore, various laboratory tests were undertaken using a calibration chamber to provide controlled and definite conditions (*Fig. 4*).

Ambient air, purified by means of an activated charcoal filter, was used to flush a vertical oriented glass tube (20 cm dia.) at a mean mass flow of about 100 l/min. Within the calibration chamber this carrier gas was homogenously mixed with controlled rates of 99.975 % pure SO_2. By using a flexible tension ring the filter holders containing the

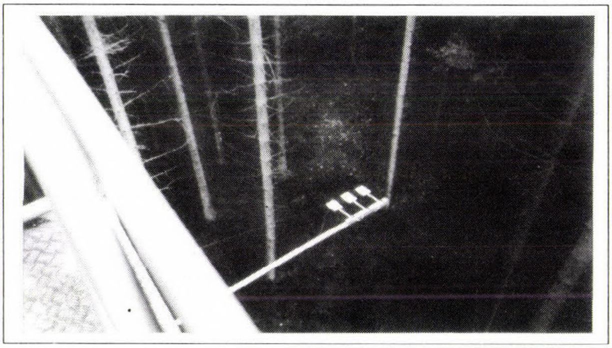


Fig. 3:
Exposed filter holders. The measurements preferably took place at different heights on specially equiped measuring

impregnated filters were exposed into the laminary SO_2 flow inside the glass tube. To adjust for different relative humidities any given fraction, up to the total amount of the purified airstream, was allowed to bypass through a set of four thermostated bubblers. SO_2 concent-

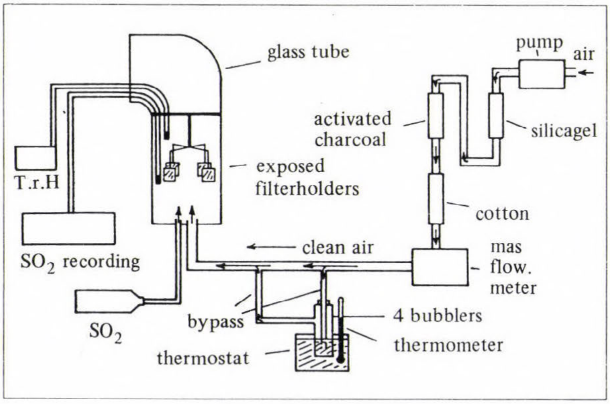


Fig. 4:
Scheme of the calibration chamber

ration, temperature and relative humidity within the glass tube were recorded continuously. Concerning the SO_2 deposition, the results of these investigations gave information on:

- the reproducibility of the sampling method;
- the dependence on the actual SO_2 concentration;
- the influence of temperature and relative humidity;
- the suitable exposure periods during field experiments.

With the exception of SO_2 concentration dependence, all results were normalized to a standard SO_2 concentration of 50 $\mu g/m^3$ to exclude the influence of different SO_2 concentration values during individual measurements.

By simultaneous exposition of four filters under identical conditions the reproducibility of the measurements has been examined (*Table 1*).

Table 1: Reproducibility (T = 24.7 °C, rH = 51 %, t = 50 min)

Filter ≠	Deposition rate [$\mu g/m^2$ s]	Deposition velocity (cm/s]
1	0.16	0.15
2	0.18	0.17
3	0.18	0.17
4	0.17	0.16

An average deposition rate of 0.17 ± 0.01 $\mu g/m^2$ s (± 5,6 % deviation) has been obtained, leading to a mean deposition velocity of 0.16 ± 0.01 cm/s (±5.9 % deviation). By repeating this experiment on different days, without changing the parameter settings, a maximum standard deviation of 23 per cent was obtained. Therefore one can expect the reproducibility to be better than at least 75 per cent.

Fig. 5 shows the SO_2 deposition rate versus the SO_2 concentration. All individual results of the several measurements have been plotted. The correlation coefficient from the linear regression is 0.96. Despite some scatter in the data, the linear relationship between SO_2 deposition and actual concentration could be verified.

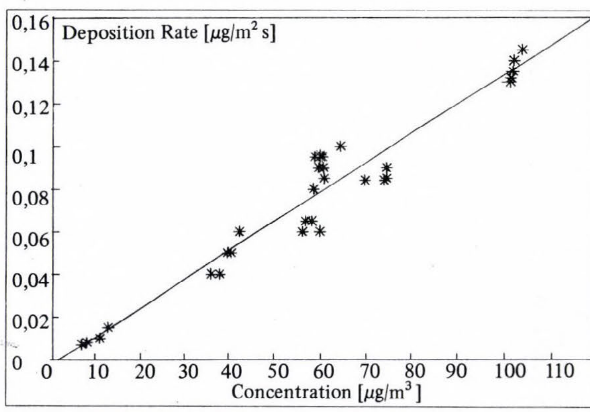


Fig. 5:
SO_2 deposition rate as function of SO_2 concentration. All individual results have been plotted

The relative humidity was varied over the range 33–94 % (T = 22.7°, t = 10–135 min). With regard to a correlation coefficient of 0.82 a significant dependence on the relative

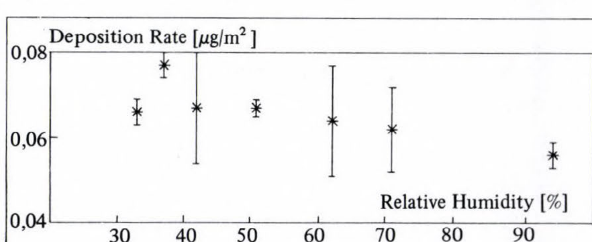


Fig. 6:
Influence of the relative humidity on the deposition rate in the range 33–94 %. $T = 22.7°C$, $t = 10–135$ min. The concentration has been normalized to 50 $\mu g/m^3$

humidity was not found (*Fig. 6*). In high relative humidity, however, the impregnated filters are prevented from untimely drying.

No temperature dependence within the range 19–27°C was observed. Due to technical restrictions it was not possible to extend the investigation towards lower temperatures. Applying a linear regression, a correlation coefficient of 0.7 was derived. Therefore, a significant dependence on temperature, within the temperature range investigated, may be discounted (*Fig. 7*).

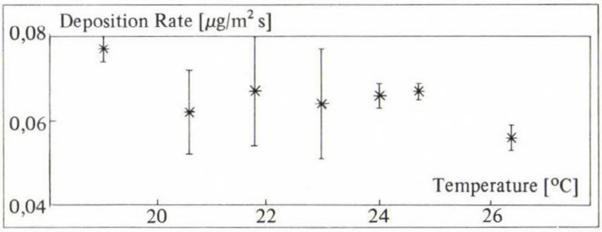


Fig. 7:
Influence of temperature on the deposition rate in the range 19–27°C. The concentration has been normalized to 50 µg/m³

Further data analysis was concerned with the relationship between SO_2 deposition and the exposure period. An additional generalization was achieved by defining five time classes (20, 40, 60, 80, 100 minutes) and combining data from different experiments falling within these classes. *Fig. 8* clearly shows a strong linear dependency of SO_2 deposition on exposure time as represented by a correlation coefficient of 0.99. The linearity over the total time scale also shows that the efficiency of the impregnated filters to absorb SO_2 remains unchanged at least up to 100 minutes.

However, during field experiments the exposure time is not recommended to exceed an average period of about 50–90 minutes to fulfill analytical demands at low atmospheric SO_2 concentrations and to prevent the filters from drying.

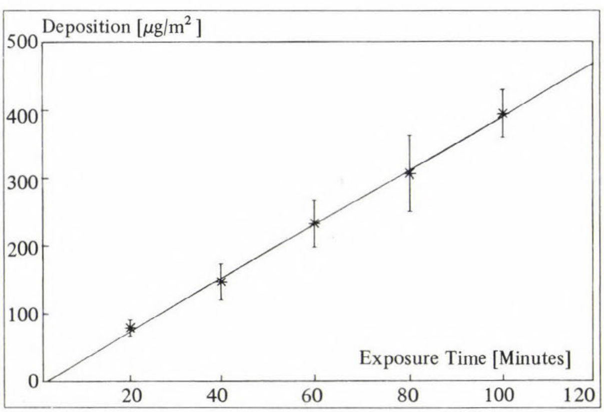


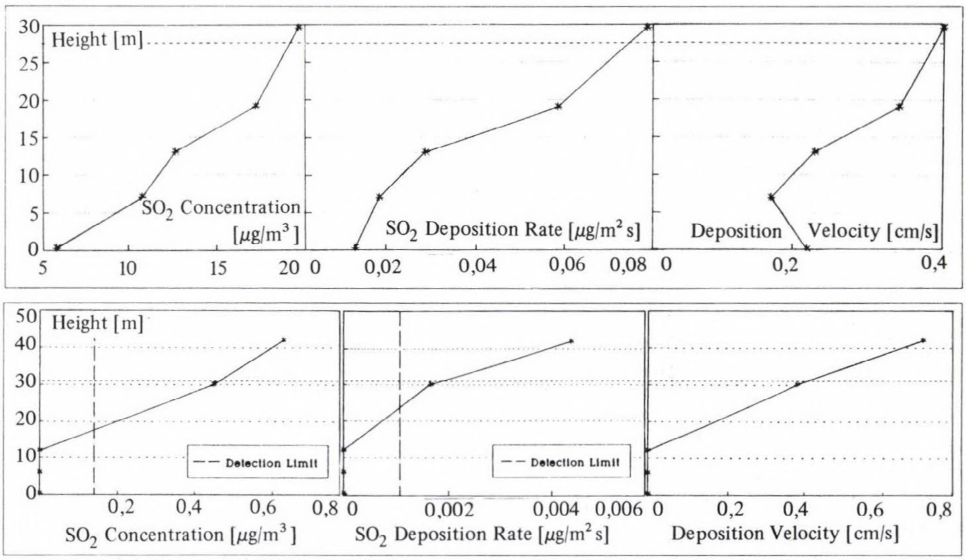
Fig. 8:
Deposition at different time classes (20, 40, 60, 80, 100 minutes). The concentration has been normalized to 50 µg/m³

Summarizing these results, the presented filter sampling method was applicable for field measurements.

4. Field measurements

Due to limitations of space, only a selection of field results are presented here. For detailed and complete information refer to *Fähnrich* (1990). All measurements took place at specially equiped measuring towers within forest areas at three different sites in the Federal Republic of Germany.

Tower a. (*Billtalhöhe/Königstein*) is located 20 km NW of Frankfurt/Main (520 m asl, height of the tower = 30 m, maintained by the *Hessische Landesanstalt für Umwelt*, spruce stand). Tower b. (*Göttinger Forst*) is located 5 km E of Göttingen (424 m asl, height of the tower = 43 m, maintained by the *Institut für Bioklimatologie* of the University of Göttingen, beech stand). Tower c. (*Nationalpark Bayerischer Wald*) is located 7 km NE of the small town Spiegelau and about 150 km NE of Munich (840 m asl, height of the tower = 52 m, maintained by the *Lehrstuhl für Bioklimatologie und Angewandte Meteorologie* of the University of Munich, spruce stand).



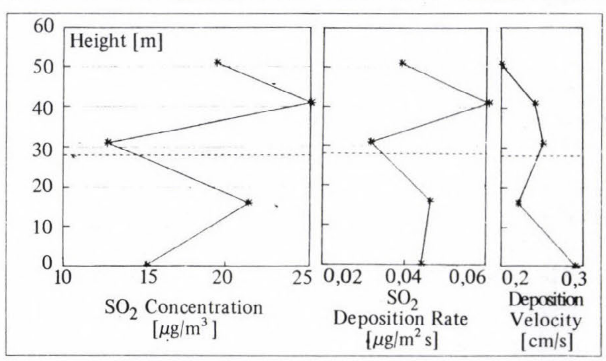


Fig. 9:
The results of SO2 concentration, deposition rate and corresponding deposition velocities are plotted versus the measuring levels. The dotted line represents the upper boundary of the forest stand. Values from different Towers.
a. Billtalhöhe/Königstein,
b. Göttinger Forst,
c. Nationalpark Bayerischer Wald..

Individual measurements of SO_2 deposition were performed at several levels of the measuring towers. During the deposition measurements samples to determine the actual SO_2 concentration in the respective levels were taken by means of an automated air sampling system. Details about this system are published elsewere (*Haunold* et al., 1986). Since this sampling procedure is also based on fixation of SO_2 by TCM and since furthermore, both kinds of samples were analyzed in the same way by the chemiluminescence technique, a very unique and comparable set of data is provided. Due to the reproducibility found during calibration chamber tests, the number of exposed filters was limited to two at each measuring level.

4.1. Results of the field measurements

The results of the measurements of SO_2 concentration and deposition rate and the calculated deposition velocities are plotted versus the several measuring levels in *Fig. 9 a., b., c.* The dotted lines represent the upper boundary of the forest stands.

Results of measurements which took place at the site *Billtalhöhe/Königstein* are illustrated in *Fig. 9. a.* Both SO_2 concentration and deposition rate show an increase with height. The mean rising rate of the concentration is 0.48 $\mu g/m^3$ per meter and 2.5 ng/m^2 s per meter for the deposition rate. The corresponding deposition velocities are lowest directly below the canopy. The higher values close to the ground and within the foliage region indicate a lower transport resistance.

The results of the measuring site *Göttinger Forst* are given in *Fig. 9. b.* Unstable weather conditions in combination with frequent rainfall led to a strong turbulent exchange of air masses which caused extremely low SO_2 concentrations, partly below the detection limit defined by the analytical procedure. The vertical profile of SO_2 concentration shows a strong decrease towards the soil surface, especially within the region below the canopy. High wind speeds up to 4.4 m/s above the forest stand led to an increase of the deposition velocity. Accordingly, only in the upper two measuring levels deposition rates could be estimated.

Fig. 9 c. represents the results of the site *Nationalpark Bayerischer Wald.* The vertical profiles of both SO_2 concentration and deposition rate show rather untypical behaviour without clearly directed gradients. Rather stable atmospheric conditions were dominant during this day. Due to the good correspondence between the profiles of concentration and deposition rate, the deposition velocity appeared to be constant, showing a slight decrease with height.

4.2. Discussion of the the results

The results found during field measurements indicate the strong influence of a forest stand formed by single plants. Very little reliable data are presently available on the characteristics of the plants as SO_2 sources and sinks. The interaction of gases with forest ecosystems, especially the input and output of gases during photosynthesis and respiration of the plants, needs further investigation.

The effectiveness of plants to act as a sink for SO_2 is also guided by the exchange of the gas through the stomata and cuticula of the plants (*Schaub* and *Knacker,* 1982). *Rennenberg* et al. (1990) reported about H_2S and even SO_2 emission from spruce trees under solar radiation. The lack of knowledge concerning the aerodynamical conditions within forest stands creates an additional problem and is a major restriction for a more detailed interpretation of the data.

The deposition velocity corresponds with the ratio of deposition rate and concentration at a given time and place. Higher values for the deposition velocity at constant ambient

SO_2 concentration indicate higher fluxes. It is obvious that forest stands are complex systems, without idealized behaviour of SO_2 concentration and deposition rates.

The simulation of deposition rates by means of simplified models is not applicable to forest stands. The preconditions (neutral stratification, logarithmic wind profile, soil as definite sink) are not given. The results of the field investigations show that a forest stand, in its entirety, acts as a sink for SO_2, to be classified in smaller subdivisions within the stand such as the foliage area or the soil area.

In general, the profiles of measured SO_2 concentration and deposition rate are very similar. Assuming the TCM impregnated filters are a perfect sink for SO_2, thus ensuring a constant absorption surface ($r_s = 0$), the deposition rate mainly depends on the ambient SO_2 concentration and on the atmospheric resistance. Due to the negligable surface resistance of the filters, a maximum rate of SO_2 absorption is reached. This is in contrast to natural surfaces, whose surface resistance will cause less absorption. The application of an identical absorption surface, however, provides a better chance to investigate atmospheric transport mechanisms.

A definite relationship between measured deposition rates and certain weather conditions has not been found. The turbulent exchange within forest stands is reduced compared to regions above the stand, so that very often the obtained concentration and deposition values refer to stagnant air masses. However, the results indicate that higher wind speeds cause higher fluxes and proportionally higher deposition velocities. Clearly directed and strictly proportional gradients of SO_2 concentration and deposition rate were not found. Due to this, the corresponding deposition velocities turned out not to be constant with height.

4.3. Comparison with other methods

Presently, no results of comparable measurements within forest areas are available. Measurements by means of common methods like eddy correlation or gradient method mostly are used only in one respectively two different levels above the surface. Unlike the filter technique described, these methods do not provide a direct measurements of the SO_2 flux.

Apart from that, theoretical gradient models concerning turbulent conditions within forest stands do not exist. So far, a comparison of the filter technique with other methods must be judged as rather limited. In spite of this, the comparison of the measured deposition rates reported here shows a good accordance with results of other techniques (*Table 2*).

Table 2: Comparison of the measured deposition rates with results of other authors

Deposition rate [$\mu g/m^2$ s]	**Surface**	**Method**	**Author (year)**
0.110	oak/hickory	eddy correlation	*Meyers/Baldocchi* (1988)
0.102	spruce, 1986	flux calculation	*Grosch* (1990)
0.112	spruce, 1987		
0.012–1.92	spruce	lab./wind tunnel	*Dollard* (1980)
0.045–2.22	pince		
0.011–0.26	birch		
-0.17–0.20	spruce/fir	eddy correlation	*McMillen* et al. (1987)
0.042 (min 0.0017, max 0.155)	impregnated filters	filter technique	*Fähnrich* (1990)

The deposition rates obtained by *Meyers/Baldocchi* and *Grosch* are not calculated for the whole leaf area but for 1 m^2 surface area.

5. Conclusion

According to the laboratory investigations, the developed filter sampling technique for direct SO_2 flux measurements showed the following advantages:

- reproducibility >75 per cent;
- lew detection limit;
- n significan influenc o temperature and relative humidity on the sampling method;
- short exposure periods.

The method has been successfully established for field measurements within forest areas. The SO_2 concentration and deposition profiles in the forest stands - especially within the crown regions - showed a rather unsteady behaviour indicating the influence of aerodynamical conditions within forest areas. There is no strong indication for anticipating an strict increase of SO_2 concentration and deposition rate with height. Therefore, the corresponding deposition velocities were not constant with height.

A strong dependence of the deposition rate on certain weather conditions could not be found. However, high wind speed effected high deposition velocities.

The obtained deposition rates of SO_2 are comparable with results of other techniques. Summarizing the results it can be stated that deposition rate and deposition velocity are strongly influenced by aerodynamical conditions within forest areas.

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IDŐJÁRÁS

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Energy production, economy and greenhouse gas emissions in Hungary[1]

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(Manuscript received on 14 October 1991; revised form on 22 January 1992)

The aim of this paper is to present the carbon dioxide, nitrous oxide and methane source strengths in Hungary. All the possible anthropogenic and biogenic sources are considered. The carbon dioxide cycle in the air over the country is also calculated. It is found that the quarter of the total carbon dioxide flux into the air (~ 100 $TgCyr^{-1}$) is due to energy production, while another quarter is liberated by the vegetation. The half of the carbon dioxide quantity is released by the soils. The sum of methane emissions is around 1 $TgCyr^{-1}$. It is dominated by human activities like natural gas production and solid waste treatment. On the other hand, the emission of nitrous oxide (18 $GgNyr^{-1}$ = 0.018 $TgNyr^{-1}$) is controlled by the release due to fertilizer use. In the paper the possibilities of the reduction of carbon dioxide, methane and nitrous oxide emissions are discussed.

Key words: Economy and air pollution, greenhouse gases, Hungary

1. Introduction

The composition of the atmosphere plays an important part in the control of climate on the Earth. This is caused by the fact that the transfer of short-wave solar and long-wave terrestrial radiations in the air is affected by atmospheric constituents. On the other hand, the composition is controlled by the material flows in nature, called the biogeochemical cycles. During geological times a natural equilibrium has been developed between atmospheric sources and sinks of different components leading to a constant composition.

This natural equilibrium is now jeopardized by human activities releasing a large amount of materials (pollutants) into the atmosphere. Fortunately, man is not able to modify the atmospheric concentration of main constituents (oxygen and nitrogen) owing to their huge quantities. However, the levels of so-called trace substances, giving less than 0.04 % of

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(1) Some parts of this paper are published as a chapter in the book entitled *Global Climate Change: Implications, Challenges and Mitigation Measures (Pennsylvania Academy of Sciences, Pennsylvania, U. S. A.)*

the volume of the dry air, can considerably be increased. The modification of the amount of gases (carbon dioxide, methane, nitrous oxides etc.) absorbing the thermal radiation emitted by the Earth's surface is dangerous in particular. The residence time of these greenhouse gases is relatively long (10–100 years) compared to the characteristic mixing time of the atmosphere. Consequently, they are well-mixed in the entire atmosphere causing world-wide problems like global warming.

This does not mean, however, that anthropogenic warming is solely a global issue. For solving this international problem all nations have to determine their greenhouse gas release and should study the possibilities of its mitigation measures. Moreover, the impacts of global warming in its area and to make all the feasible steps to avoid or reduce harmful effects.

The aim of this paper is to discuss the greenhouse gas emission (carbon dioxide, methane and nitrous oxide) for a small country, Hungary. Since greenhouse gas emissions are in close relation with energy production as well as with agricultural and industrial activities of a certain area, the economy of the country is also discussed in some detail. Finally, possibilities are proposed to reduce the emissions of the greenhouse gases discussed.

2. Carbon dioxide emission and budget

2.1. Biogenic sources

Carbon dioxide is the most important nutrient for plants, 90 % of their dry matter come from CO_2 fixed by photosynthesis (*Fung* et al., 1987). A part of carbon dioxide fixed is emitted by the plants by respiration. The release by respiration can be estimated on the basis of net primary production of the vegetation of different kinds (*Bolin* et al., 1977). If we assume that the total quantity of carbon assimilated is shared equally by net assimilation and respiration and consider the area of Hungary covered by different plants and forests, for the Hungarian CO_2 emission (expressed in C) by respiration of the vegetation a figure of 27.6 $Tgyr^{-1}$ is obtained. 70 % of this emission are due to the agriculture, that is related to human activities.

The respiration of man and animals also results in carbon dioxide emission. This emission can be determined by measurements of the CO_2 quantity exhaled by humans and different animals. The results of such measurements show that for mammals the CO_2 produced is proportional to the weight of the body. Taking into account the results of *Freeman* (1973) as well as the number of people and animals in Hungary we calculated a value of 2.4 $TgCyr^{-1}$ for this emission. The major part of this CO_2 source is caused by the respiration of man (28 %) and pigs (33 %). This latter is due to the importance of pigs in Hungarian animal husbandry (their number is 8.7 million).

Soil also provides an important biological carbon dioxide source. This source consists of three parts: microbiologial activity in soil, root respiration and decomposition of organic matter on the surface. In the literature empirical relationships can be found for estimation the strength of this complex source. These relationships are given for different vegetation types (*Fung* et al., 1987), including cultivated areas (*Hampicke,* 1980). Considering this information and the area of the vegetation cover of different types, the calculation results in a CO_2 emission between 38.6 and 47.7 $TgCyr^{-1}$. The uncertainty comes from the fact that a rather wide range of emission rate for agricultural soils (10–150 $gCm^{-2}yr^{-1}$) is given in the literature (e. g. *Hampicke,* 1980). On the basis of our calculations forests control the emission of CO_2 (73–90 %).

2.2. *Energy production and industry*

As it is well-known the combustion of fossil fuels is the most important world-wide anthropogenic carbon dioxide source. This emission depends on the quantity and carbon content of the fossil fuels used as well as on the fraction of carbon which can be oxidized (*Rotty,* 1987). For this reason the emission factors published in the literature are slightly different.

The first column of *Table 1* gives the energy produced in Hungary in 1987 by burning fossil fuels of different types. It should be noted that the sum of the values tabulated does not give the total energy use of the country. This is due to the fact that 110 PJ was produced in 1987 by a nuclear power plant, while an important quantity of electricity (106 PJ) was imported from the Soviet Union. The second column of the table shows the CO_2 emissions published by *Lévai* and *Mészáros,* 1989. It can be concluded that an important part of the total emission is caused by the use of solid fossil fuels (44 %). Taking into account the number of the population a value of 2.24 $tCyr^{-1}$ per capita can be calculated for Hungary. This is about two times more than the world average, but not too large compared to the values for developed countries (*Rotty,* 1987).

Table 1:
Hungarian energy structure and carbon dioxide emissions
(Lévai and Mészáros, 1989)

Fossil fuel	Energy (PJ)	Emission ($TgCyr^{-1}$)
Solid	359	10.5
Liquid	391	8.0
Gaseous	389	5.4
Total	1139	23.9

The Hungarian CO_2 emission per energy unit (17.5 MtC/EJ) is rather similar to the global mean value. Also, the Hungarian energy demand per capita (127 $GJyr^{-1}$) is acceptable considering the values for other countries. The problem is caused by the unefficient use of the energy produced. This is illustrated by the very high CO_2 emission per capita during the production of a value of one U. S. dollar. This figure is around 1000 $gCyr^{-1}$,which is considerably higher than the corresponding values for developed countries.

Finally, it is to be noted that cement industry and treatment of waste materials also emit carbon dioxide into the atmosphere. Calculations show, however, that for Hungary the strength of these sources can be neglected compared to the release during energy production (0.6 and 0.1 $TgCyr^{-1}$).

2.3. *Atmospheric budget*

As it was mentioned vegetation is a net carbon dioxide sink. Like CO_2 quantity released during respiration, the net sink can be determined on the basis of the mass of dry matter formed in plants (*Bolin* et al., 1977). Considering the appropriate data a value of 55.0 $TgCyr^{-1}$ is calculated for the country. A negligible sink is provided by the removal of CO_2 from the air by precipitation fall. Therefore this term (0.03 $TgCyr^{-1}$) is not considered in the following discussuion.

Table 2 summarizes the results of our study. One should say, however, that the figures given can be considered with some caution. While the error of the CO_2 emission by fossil fuel burning is not greater than ± 15 %, the uncertainty of other terms reaches probably ± 50 %. In spite of this problem it can be accepted on the basis of values tabulated, that atmospheric carbon dioxide budget is positive over Hungary: about two times more carbon is released than removed. This means that even if the energy production were entirely stopped, biogenic sources would produce more carbon dioxide than the quantity removed by the vegetation. Unfortunately, it is not possible to determine the role of man in the unbalance of biological sources. Agricultural activities produce an important amount of carbon dioxide at present, but we do not know the biogenic emission of this area before the beginning of intensive agriculture. Considering the fact, however, that an important part of the territory of the country was covered by forests about thousand years ago (the present forested area is only 17 %), one can speculate that deforestation has played some part in the development of the present situation.

Table 2: Atmospheric carbon dioxide budget over Hungary

	Sources ($TgCyr^{-1}$)	Sinks ($TgCyr^{-1}$)
Vegetation	27.6	55.0
Man and animals	2.4	
Soils	38.6 - 47.7	
Energy	23.9	
	92.5 - 101.6	55.0

3. Methane emission in Hungary

In the case of methane it is again very difficult to differentiate natural and anthropogenic sources. This means that even a large part of biological methane release is due to human activities.

Animal husbandry is one of these biological sources, which modifies considerably the emission of this gas. If we know the quantity of feedstuff consumed by ruminants their methane production can be calculated. In *Table 3* the input data necessary for this calculation as well as the results obtained are tabulated. It follows from this information, that sources in Hungary owing to ruminants emit into the air a CH_4–C quantity of 0.125 Tg per year. In spite of the fact that the Hungarian live-stock farming in this category of animals is dominated by sheeps, an important fraction of methane emission is caused by cows.

Table 3: Estimation of methane production from entertic fermentation of ruminants

Ruminants	Feed uptake (dry matter kg)[(1)]	CH_4 prod.(gCH_4/day per capita)[(2)]	Number of animals 10^3	CH_4 yield ($MgCyr^{-1}$)
Calves	2.8	64	214	3.8
Heifers	8.3	173	395	18.7
Cows	10.6	219	219	45.4
Beef cattles	13.0	266	266	26.3
Sheep	1.7	43	2337	27.5
Deer	3.0	68	55	1.1
Fallow deer	2.0	49	14	0.2
Roe deer	1.0	29	227	1.8
Moufflon	1.0	29	9	0.1
Total				124.9

[(1)] Kakuk and Schmidt, 1987 [(2)] Baintner, 1957

Under anaerobic conditions methane is also formed in soils mostly in marshy areas. Concerning human activities the most important global methane source of this kind is provided by paddy fields. The strength of this release depends on many factors as discussed by several authors (*Ehhalt*, 1985; *Holzapfel-Pschorn* and *Seiler*, 1986). These factors include the content of organic matter and temperature of soils as well as the physiological activity of the vegetation. Mathane emission can also be observed in the case of fresh waters, medows, forests and different cultivated lands. Calculations made on the basis of the information on emission factors available (*Ehhalt*, 1985; *Holzapfel-Pschorn* and *Seiler*, 1986) and of the areas of appropriate surfaces in Hungary show that the total methane emission from soils is between 0.05 and 0.1 $TgCyr^{-1}$.

The uncertainty of these figures makes it evident that the error of such calculations is at least a factor of 2. Due to the structure of the agriculture the emission from paddy fields is not too important in this country: it is less than about 0.02 $Tgyr^{-1}$ expressed in carbon. On the other hand, a rather large amount of CH_4 is released into the air by reeds, lakes, fish-ponds and water catchments. The upper limit of this emission is around 0.05 $TgCyr^{1}$.

Methane molecules are also released into the air from solid and liquid waste materials. In 1986 the total quantity of solid wastes in Hungary was equal to 18.5 10^6 m^3. According to *Bingemer* and *Crutzen* (1987) under anaerob circumstances about 80 % of the organic matter is transformed and results biogas, the 50 % of which is CH_4. Such conditions are created if the solid wastes are deposited in landfills or in open dumps. Taking into account this information and the composition of the waste quantity given above, a yearly methane formation of 0.189 TCg can be calculated. It can be assumed, however, that only a fraction (a value of 0.7 of this mass) (*Jager* and *Peters*, 1985) is released to the air, a CH_4-C emission of 0.132 $Tgyr^{-1}$ is obtained for this source strength.

For liquid waste materials similar calculations were carried out. In these calculations were carried out. In these calculations the organic dry matter content (0.3 kgm^{-3}) and biodegradability of 3 % of the wastes were taken into account. The results indicate that this methane source strength has an order of 10^{-3} $TgCyr^{-1}$, which can be neglected compared to the magnitude of other terms.

The main component of natural gas used for energy production is methane. Due to this fact during the mining and distribution of natural gases some methane quantity is released into the air. According to the literature (CONCAWE, 1986) and information given by the Hungarian Trust of Gas Industry methane release during mining is equal to 2 %. Since 86 % of natural gas exploited in Hungary (7.1 10^9 m^3) is CH_4 the loss in this way can easily be calculated. In Hungary an important part of natural gas (4.8 10^9 m^3 containing 90 % of CH_4) is imported from the Soviet Union in pipe- line systems. At the joining points of pipe-lines mainly in the case of low pressure system supplying houses about 3 % of the gas is lost (CONCAWE, 1986). This figure can also be applied for the transport of natural gas mined in Hungary. Taking into account all these values we calculate a total CH_4–C release of 0.234 $Tgyr^{-1}$.

Coal and lignite mining also provides a methane source since coals contain a certain amount of this gas. This amount is 5 m^3 per tons of coal on an avergage (*Ehhalt*, 1985), 50–100 % of this methane comes to the air during coal mining. For methane content of lignites we estimated the same value of 5 m^3/tons and assumed that 25–75 % of this methane is escaped into the air. The total quantities of coal and lignite exploited yearly in Hungary are 15.3 Mt and 7.0 Mt, repectively. This results in a CH_4 emission between 0.025 and 0.055 $TgCyr^{-1}$.

Considering the results discussed one can conclude that the total methane emission in Hungary is around 1 $TgCyr^{-1}$. About a quarter of this emission is due to natural gas production and distribution (see *Table 4*). It can also be stated that about 100 times more carbon dioxide-carbon is released into the air than carbon in methane form. This means that mitigation measures must be centered first of all on CO_2 emission. This conclusion is even valid if we take into account that for the same concentration increase methane is a more efficient greenhouse gas than carbon dioxide.

Table 4:
Details of Hungarian methane emission

Source type	Emission ($TgCyr^{-1}$)
Entertic fermentation of animals	0.125
Soils, water surfaces, marches etc.	0.054 – 0.093
Soild wastes	0.132
Natural gas production and distribution	0.234
Coal and lignite mining	0.025 – 0.055
Total	0.570 – 1.209

For the determination of atmospheric methane budget the sinks of this gas should be estimated. It is well known that methane does not have significant direct sinks, althought CH_4 uptake of some types of soils might be important. Methane is primarily removed by oxidation (OH radicals) in the troposphere. In the statosphere CH_4 is also oxydized by OH radicals and excited oxygen atoms and they play non-negligible role in the removal of chlorine containing hydrocarbons. Determination the yield of these processes is so uncertain, mainly for a small country like Hungary, that we did not undertake doing it.

4. Sources of nitrous oxide

Nitrous oxide is the most abundant nitrogen compound in the atmosphere. This greenhouse gas is formed in the soils by nitrification and denitrification. The most direct way of N_2O formation is the reduction of nitrate ions by hydrogen in gaseous and ionic form. However, nitrifying microorganisms also produce nitrous oxides during nitrification of ammonium and hydroxylamine, both coming from the decomposition of organic materials (*Brenner* and *Blackmer*, 1981). The emission from different soils treated with N-fertilizers in the form of ammonium sulfate or urea was significant in particular (*Breitenbeck* et al., 1980).

The release of N_2O from the soils not treated with fertilizers can be estimated on the basis of data of *Fenger* et al. (1990) giving the N_2O emissions for unit area of different soils. Using this procedure a value of 2.9 Gg of annual nitrogen emission is calculated for forests and grasslands in Hungary. On the other hand, in 1986 91.2 kg/ha N-fertilizers was used in the country. Taking into account the relationship between N_2O emission and the quantity of different N- fertilizers used (*Fenger* et al., 1990) the calculation results in a 12 $GgNyr^{-1}$ overall emission from Hungarian agricultural lands.

A certain amount of N_2O is also emitted from combustion sources during fossil fuel burning. Applying statistical information on the quality and quantity of different fossil fuels used in Hungary in 1986 as well as the emission factors proposed by *Fenger* et al. (1990) 1.4 $GgNyr^{-1}$ and 1.7 $GgNyr^{-1}$ are obtained for stationary and mobile sources, respectively.

The N_2O–N emissions from different Hungarian sources are summarized in *Table 5*. It can be seen that combustion sources emit only 17 % of the total emission.

However, if the N_2O–N quantity released from fertilizers is taken into account the anthropogenic fraction reaches 84 % of the total. This result must be considered with caution due to the uncertainties involved in the calculations. This is true in particular for soil emissions.

Table 5:
Total Hungarian N_2O emission in 1986 from different sources (expressed in $GgNyr^{-1}$)

Source type	**Emission**
Biological sources	
N-fertilized soils (agriculture)	11.9
Other soils	2.9
Combustion sources	
Stationary combustion	1.4
Mobile sources	1.7
Total	17.9

5. Possibilities of the reduction of man-made emissions

On the basis of the above discussion it is obvious that the main possibility of the reduction of the CO_2 emission in Hungary is the *energy saving* and *conservation.* Considering the value produced by the national economy the energy demand and consequently the quantity of carbon dioxide emitted are too high. There is no intention here to discuss in detail the possible ways of rational energy use. It is clear, however, that the transformation of the total economic system is needed. For this, however, an important capital investment and a good economic policy are necessary.

The CO_2 release into the atmosphere can also be reduced by the *diversification of energy sources.* This can be obtained by the application of sources with lower or zero specific emission like nuclear and hydroelectric power plants, electric energy import as well as geothermal and solar energy use. According to our experts (*Lévai* and *Mészáros,* 1989) it would be possible in 2010 to assure 80 % of the electric energy consumption of the country by nuclear energy. However, it is very probable that a large part of the population would be against this solution, not only because of the protection of the atmosphere but also because of the problems due to the storage of radioactive waste materials.

According to our calculations in the future among traditional fuels natural gas is preferred to coal: at the same energy production about 60 % of CO_2 are emitted into the atmosphere with using natural gas than in the case of coal (for further details see *Lévai* and *Mészáros,* 1989).

Possibility of the reduction of methane is unfortunately limited. It is well known that the largest changes of global and national CH_4 production are of anthropogenic origin. The increasing agricultural (raising cattles, growing rice etc.) and industrial activities represent the major sources of atmospheric methane. Thus, it is difficult to control or even reduce their strength. As it can be seen in *Table 4* natural gas production and distribution are the most important sources; mainly during the distribution a large amount of methane is released, which can be probably reduced by modernizing the pipi-line network. Another significant amount of methane is released by the wastes, its strength could be decreased by more reasonable utilization of wastes (municipal and agricultural) for biogas production in closed system.

Since nitrous oxide emissions are dominated by the application of nitrogen containing fertilizers, it is obvious that its release can be mitigated by a more rational and economic fertilizer use. It is necessary to find a compromise between ecological needs and agricultural production.

6. Conclusions

The Hungarian carbon dioxide emission due to the energy production can be reduced first of all by energy saving and conservation. On the other hand the release of methane can be mitigated by the production of biogas from waste materials and by modernization of pipe-line network of natural gas. For the decrease of nitrous oxide emission the rational use of fertilizers is obviously needed.

Since the water management, agriculture and forestry of this country are climate dependent, Hungary is very much interested in the climatic changes due to the increasing concentration of greenhouse gases, and it supports all international efforts aiming to reduce their unfavourable effects.

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Statistical mechanics of inviscid truncated models of two-dimensional incompressible flows

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In two-dimensional turbulence of the inviscid fluids the enstrophy is a conserved quantity in addition to energy if the wavenumber-space is continuous and isotropic. Accordingly, the absolute equilibria of the system can be described by two-parameter canonical distribution. This picture is valid in a spectrally truncated case, if the truncated Jacobian conserves the above mentioned quantities and satisfies the Liouville's theory of statistical physics.

In this paper the existence of the equilibrium solution is examined for the finite difference approximations to the vorticity equations. It is clear that the structure of aliased interactions has an important role.

The „temperature" parameters of equilibria in a spectrally truncated case is principally depending on the shape of the wavenumber-space. The „temperature" of the equilibria is one of the possible index-numbers describing the stability of the model. The accuracy of theoretical considerations has been verified by a simple finite difference model.

Key-words: two-dimensional turbulence, temperature of equilibrium, effects of phase errors and aliased interactions, canonical distribution.

1. Introduction

One of the fruitful lines of studying turbulence is the analysis of the power spectra of the kinetic energy. This problem has a long history of use in theoretical investigation of turbulence since the pioneering work of *Kolmogorov* (1941) and the newest research based on fractal geometry (*Jensen* et al., 1991; *Benzi* et al., 1990). It is well known that Kolmogorov's theory gives a qualitatively correct description of the main mechanism acting in the three dimensional turbulence at high Reynolds number, if the fluid is incompressible. In this case there is a cascade transfer of energy toward small scales where the dissipation is due to molecular friction.

The situation is quite different in two dimensions as firstly demonstrated by *Fjörtoft* (1953). It has been shown (*Kraichnan,* 1967) that the two-dimensional turbulence has two formal inertial ranges, $E(k) \sim \varepsilon^{2/3}k^{-5/3}$ and $E(k) \sim \eta^{2/3}k^{-3}$, where ε is the rate of cascade of kinetic energy per unit mass, η is the rate of cascade of enstrophy (enstrophy is the one-half squared vorticity) per unit mass. Some observational studies (*Kao* and *Wendell,* 1970; *Morel* and *Necco,* 1973) indicate that in the wavenumber range higher than $k = 10$, the energy spectrum approximately follows the power law of minus third.

The above described theory is valid if the turbulence is isotropic and homogeneous, thus the numerical integration of the model equations has an important role in the theoretical investigation of energy spectra. The dynamics of the three dimensional flow is governed by the existence of a single quadratic invariant: the total kinetic energy of the flow. A numerical truncated model flow evolves toward an equipartition of energy among all degrees of freedom. Hence, this flow has an $E(k) \sim k$ equilibrium spectrum if the turbulence is isotropic.

In contrast to three-dimensional flow, there are two inviscid constants of motion in the two-dimensional case. Namely, in addition to kinetic energy, enstrophy is an inviscid constant of motion. *Kraichnan* (1967) pointed out that according to the two-dimensional Navier-Stokes equation, the interaction of each triad of wavenumbers individually conserves both energy and squared vorticity.

Therefore, the truncated models conserve their total kinetic energy and enstrophy too, thus they have two-parameter equilibrium kinetic energy and enstrophy spectra (*Salmon* et al., 1976; *Kraichnan,* 1967, 1975) if the governing equation of the model satisfies the Liouville's theorem of statistical physics. In this generalized case the equilibrium distribu-tion can be described by the microcanonial distribution. Under the assumption that the system exhibits suitable ergodic properties, the expected energy spectra can be computed by long-term numerical experiments (*Basdevant* and *Sadourney,* 1975). When there is no significant excitation in the regions of wavenumber space where the modes are not dense, the canonical distribution can give a fairly accurate approximation to the spectrum (*Salmon* et al., 1976; *Kraichnan,* 1975) which is given by

$$E(k_i) = \frac{1}{2}(\alpha + \beta k^2_i)^{-1} \qquad (1)$$

where a and b are the solutions of

$$\frac{1}{2}\sum_i (\alpha + \beta k^2_i)^{-1} = E_0 \qquad (2)$$

and

$$\frac{1}{2}\sum_i k^2_i (\alpha + \beta k^2_i)^{-1} = Z_0 \qquad (3)$$

where E_0 and Z_0 are the initial total energy and enstrophy. In this way the equilibrum can be computed from the initial conditions. *Salmon* et al., (1976) have shown that there exists an unique solution of the above system of equations if $k^2_0 \leq k^2_1 \leq k^2_{max}$, where k_0 denotes the lowest (non-directional) wavenumber, k_{max} the upper cutoff or „grid" wavenumber used in the computational model, and $k^2_1 = Z_0/E_0$.

Bennet and *Haidvogel* (1983) studied the power spectra of the kinetic energy of slow-decaying two-dimensional turbulence in a low-resolution pseudospectral numerical model. The initial equilibrium energy spectra were determined by (1) for a given E_0 and Z_0. *Bennett* and *Middleton* (1983) solved the system of (2) and (3) for a finite difference approximation to the barotropic vorticity equation. However, a simplification was introduced in both cases, namely $dk = 1$ (where $dk = k_{i+1} - k_i$ if $k_0 \leq k_i \leq k_{max}$. Apparently this method could not take the current shape of the truncated wavenumber space into consideration.

The main purposes here are to discuss in detail the canonical distribution of truncated models of two-dimensional incompressible flows, and the solution of (2) and (3) without the above mentioned simplification.

2. *The existence of the equilibrium solution*

The vorticity equation of two-dimensional flows is

$$\partial\omega/\partial t = J(\omega, \psi) \tag{4}$$

where J is the Jacobian and the streamfunction ψ is related to the vorticity ω by

$$\Delta\psi = \omega. \tag{5}$$

This system of equations can be written in truncated spectral form if all fields are assumed to be periodic in each direction. Let $\Psi(k, t)$ be the Fourier series of $\Psi(x, t)$, thus the governing equation (*Basdevant* and *Sadourney*, 1975) becomes

$$\frac{\partial}{\partial t}\Psi(k, t) + \sum_{p+q=k} \frac{P^2}{K^2} a(p, q)\Psi(p, t)\Psi(q, t) = 0. \tag{6}$$

In this equation $a(p, q)$ is depending on the choice of the truncated Jacobian, P and K are pseudo-wavenumbers. It has been shown (*Basdevant* and *Sadourney*, 1975) that (6) satisfies the Liouville's theorem if

$$a(p, q) = 0 \qquad \text{when } p = 0 \qquad \text{or} \qquad q = 0.$$

If a finite difference approximation is applied to the system of (4) and (5), (6) becomes

$$\frac{\partial}{\partial t}\Psi(p, q) = \sum_{r=-1}^{1} \sum_{s=-1}^{1} \sum_{a+c=p+rN} \sum_{b+d=q+sM} k^2_{ab} k^{-2}_{cd} A_{abcd}\Psi(a, b)\Psi(c, d), \tag{7}$$

where $\Psi(p, q)$ is the double discrete Fourier transform of the discretized streamfunction, N and M are the numbers os gridpoints in x and y direction respectively. The pseudo- wavenumber $k(p, q)$ and the function A_{abcd} are depending on the choice of the approximation to the Laplacian and Jacobian. The summations over the integers r and s with values -1 and 1 express the effect of the aliased interactions (*Orszag*, 1971). It is clear that (7) satisfies the Liouville's theorem if

$$A_{abcd} = 0 \text{ when } a = p, b = q \text{ or } c = p, d = q.$$

In addition, the finite difference Jacobian obviously has to conserve the total energy and enstrophy. If a numerical method satisfies the above conditions, the examination of the statistical mechanical properties of the model is possible.

3. The „temperature" of equlibria

The canonical distribution is related to a thermal equilibrium ensemble with α playing the role of inverse temperature and β acting as a thermodynamic potential for enstrophy (*Kraichnan,* 1975). The „temperature" of the equlibrium solution is negative if one of the above parameters is below zero. *Fox* and *Ország* (1973) pointed out that the only qualitative difference between positive and negative temperature equilibria is the possible existence of a maximum of $E\,(k)$ within the interval $k_{min} \leq k < k_1$, if the wavenumber space is continuous.

The situation is quite different in a discretized case because the shape of the equilibrium spectra is strongly depending on the pseudo-wavenumber space.

Equations (2) and (3) exhibit three regimes of equilibria, distinguished by the value of $k^2{}_1$. In the energy-equipartition state $\beta = 0$ thus

$$k^2{}_1 = k^2{}_b = (NM)^{-1} \sum_i^{NM} k^2{}_i \qquad (8)$$

while in the enstrophy-equipartition state $\alpha = 0$

$$k^2{}_1 = k^2{}_a = NM \sum_i^{NM} k^{-2}{}_i \qquad (9)$$

The regimes are then

$$k^2{}_0 < k^2{}_1 < k^2{}_a \qquad \beta > 0, \ -\beta k^2{}_0 < \alpha < 0; \qquad (10)$$

$$k^2{}_a < k^2{}_1 < k^2{}_b \qquad \alpha > 0, \quad \beta > 0; \qquad (11)$$

$$k^2{}_b < k^2{}_1 < k_{max} \qquad \alpha > 0, \ -\alpha < \beta k^2{}_{max} < 0. \qquad (12)$$

It follows that the „temperature" of equilibrium is depending not only on k_0, k_1 and k_{max} (which is valid if the k space is continouos) but on the choice of the pseudo-wavenumbers too, according to the truncated Laplacian. As a main result, if a finite difference method is applied, the effects of phase errors influence the „temperature" of the equilibrium solution.

4. Numerical method for the computation of α and β

The system of (2) and (3) can not be solved by a classical Newton's method, because there are some problems with the accurate choie of initial values for the iteration. It means that an „individual" method has to be applied. The equations (2) and (3) are partial derivatives of

$$f\,(\alpha, \beta) = \frac{1}{2} \sum_i \ln\,(\alpha + \beta k^2{}_i) \qquad (13)$$

thus the numerical solution of system of equations can be attributed to the finding the extremum of the

$$P(\alpha, \beta) = f(\alpha, \beta) - E_0\alpha - Z_0\beta \tag{14}$$

potential function. This is a resolvable problem for the BASF-Hitachi computer of the Hungarian Meteorological Service. The only difficulty is to choose the interval including the extremum. However, by taking (10), (11) and (12) into account, a computationally efficient method could be designed. If the solution is in a negative temperature regime, the values of α nad β must be computed more precisely, else in the wavenumber region, which contains the predominant part of the energy, the spectrum becomes reasonably deformed. This is indeed a strong constraint in the case of negative α.

5. Numerical experiments

The applied numerical model was suggested by *Bennett* and *Middleton* (1983). They have pointed out that (7) satisfies the Liouville's theorem if the Jacobian is approximated by the Arakawa's nine-point scheme. Therefore, the equlibrum spectra can be estimated by the canonical distribution.

All fields were assumed to be periodic in both x and y directions with periods of $D = 11\ 200$ km. The spatial derivatives were approximated by centred finite differences on the grid, where $N = M = 32$. In this way $h = DN^{-1}$ and $(x_m, y_l) = (mh, lh)$, $-N/2 \leq m$, $1 < N/2$. According to the second-order five- point scheme approximated to the Laplacian in equation (5), the pseudo-wavenumber is

$$k(p, q) = 2N\,[\sin^2(\pi p/N) + \sin^2(\pi q/N)]^{1/2}. \tag{15}$$

The number of modes in wavenumber bands of unit width for both (15) and the $k(p, q) = (p^2 + q^2)^{1/2}$ space (which is valid in a pseudospectral case) is shown in *Fig. 1*. In this figure, the straight line has a slope of 2π, according to the isotropic continous wavenumer space.

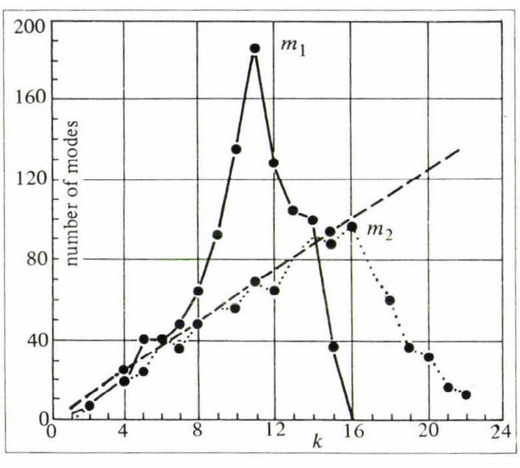

Fig. 1:
Number of modes in the wavenumber bands of unit width for finite difference modes (solid line) and the truncated spectral modes (dotted line). Straight line shows the number of modes in the isotropic continuous case.

The values of k_o, k_a, k_b and k_{max} were determined for the second-order five-point scheme and the pseudo-spectral representation with some different N (*Table 1*). It is clear that k_o, k_a, k_b and k_{max} are lower in the finite difference approximation compared to the pseudospectral case. The wavenumbers separating the wavenumber ranges are increasing functions of N. The main difference between the two representations is the lower „grid" (or upper cutoff) wavenumber in case of the finite difference approximation. Summing up, the applied finite difference method leads to a narrower negative β range.

Table 1:
Comparison of the equilibrium regimes concerning the different representations

(The first value belongs to the finite difference representation, the second value belongs to the truncated spectral representation)

N	k_0		k_a		k_b		k_{max}	
16	00.0	1.4	3.6	3.9	5.1	6.5	7.2	11.3
32	00.0	1.4	6.6	7.0	10.2	13.1	14.4	22.6
64	00.0	1.4	12.1	12.8	20.4	26.1	28.8	45.3
128	00.0	1.4	22.5	23.6	40.7	52.2	57.6	90.5

Table 2 contains the parameters of the experiments. The initial geopotential field (Experiment 1) was defined by

Table 2:
Parameters of the experiments

Experiment	Resolution	Time steps
1	32 x 32	0
2	64 x 64	0
3	32 x 32	75
4	32 x 32	150

Experiment	E_0	Z_0	α	β	k_1
1	210.4859	6454.62	-0.02748	0.04052	5.5
2	290.027	34785.30	-0.06478	0.11826	10.9
3	845.378	88559.80	0.62640	-0.00020	10.2
4	845.378	88559.80	0.62640	-0.00020	10.2

$$\Phi_{m,l} = 5500 - 300\,[\sin^2(2m\Pi/15) + \sin^2(2l\Pi/15)] \text{ if } -8 \leq m, l \leq 7 \tag{16}$$

$$\Phi_{m,l} = 5500 \text{ if } -16 \leq m, l \leq -9 \text{ or } 8 \leq m, l \leq 15$$

It must be emphasized that this geopotential field is not an example of the real atmosphere; the purpose of our experiments is to demonstrate the extent to which the appearence of energy spectra depends upon the temperature of equilibria. It can be easily shown that (16) determines an equilibrium state. Therefore it is possible to discuss the errors of the expected equilibrum spectra computed by (1), (2) and (3).

The band-summed equilibrium spectra and the the spectra defined by canonical distribution are shown is *Fig. 2*, while the band-averaged specta are demonstrated in *Fig. 3*. For the computation, all fields were transformed to a $2\pi \times 2\pi$ domain, thus in the figures the values of energy have to be multiplied by $(D/2\pi)^2$ to obtain the results in *kJ* units. It can be seen that according to the theoretical considerations the canonical distribution gives a more accurate estimation of the equilibrium spectra, except in a wavenumber range where the modes are not dense.

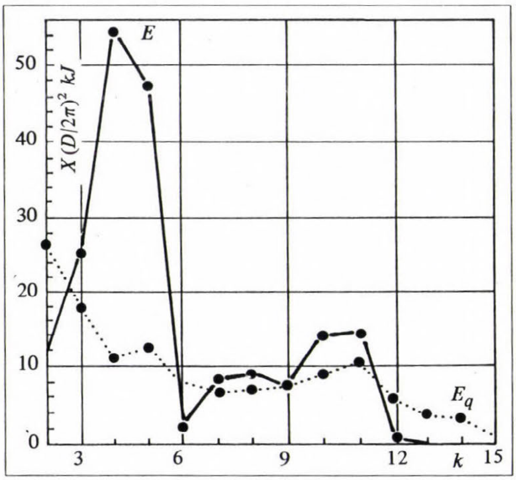

Fig. 2:
Band-summed energy spectra of the model (solid line) and the band-summed equlibrium energy spectra based on the canonical distribution (dotted line) in the Experiment 1.

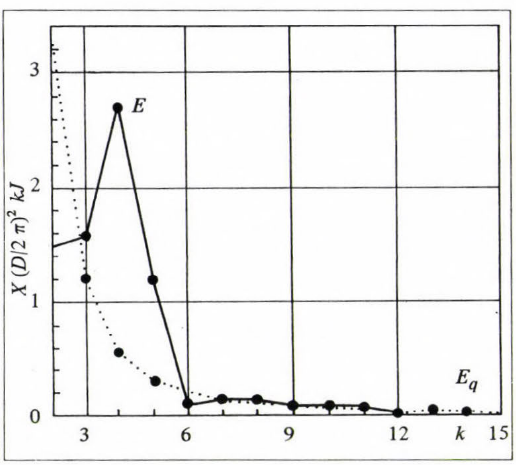

Fig. 3:
Band-averaged energy spectra of the model (solid line) and the band- averaged equilibrium energy spectra based on the canonical distribution (dotted line) in Experiment 1.

Transforming the (16) geopotential field to a $N = 64 \times 64$ grid, the total energy, enstrophy and k_1 are increasing, while the negative α involves the weakest decreasing. However, the increasing resolution does not change dramatically the temperature of equilibria.

For the time-depending experiments (Experiment 3 and 4) the initial field was created by the perturbation of (16) with a Gaussian white noise, when the expected value was 80. The initial band-summed energy spectra and the equilibrium spectra of the form (1) are shown in *Fig. 4*. It can be seen that the region of lower wavenumbers has an energy surplus in proportion to the equilibrium spectra, while in the higher wavenumbers there is a deficit of energy.

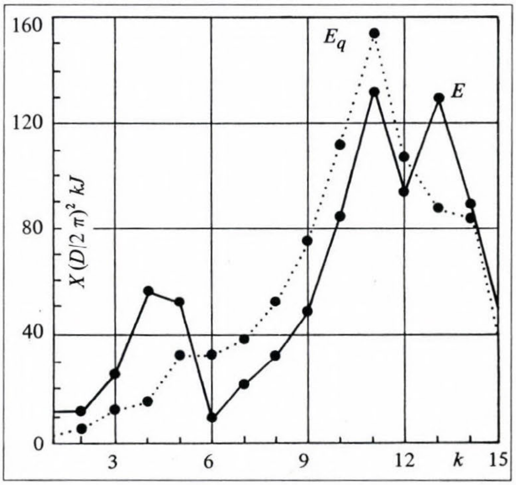

Fig. 4:
Initial band-summed energy spectrum in Experiment 3 and Experiment 4. (Lines mean the same as in Fig. 3.)

As a result of the perturbation, the equilibrium temperature belongs to the negative β regime. In Experiment 3 and 4 the time integration of equation (4) completed by leap-frog scheme and Euler forward scheme in the first time step. A time step of $\Delta t = 5$ minutes was used according to the Courant-Friedrichs-Lewy condition, while in the first step $\Delta t = 2.5$ minutes was applied in order to decrease the errors of the Euler's scheme.

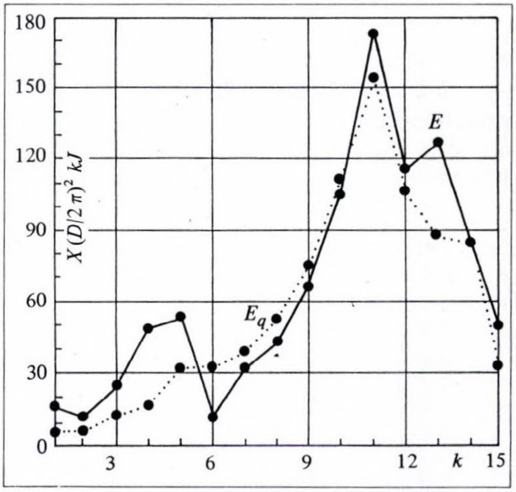

Fig. 5:
Band-summed energy spectrum after 75 time steps in Experiment 3. (Lines mean the same as in Fig. 3.)

Figs 5 and *6* show the energy spectra after 75 and 150 time steps, respectively. It is evident that the energy spectrum is in the neighbourhood of the equilibria in the region of higher wavenumbers, while in the lower wavenumbers the spectra advanced to the equlibrium spectra. Meanwhile, the integration was stable, and the total energy and enstrophy did not increase significantly. In consequence of the increasing energy of higher wavenumbers,

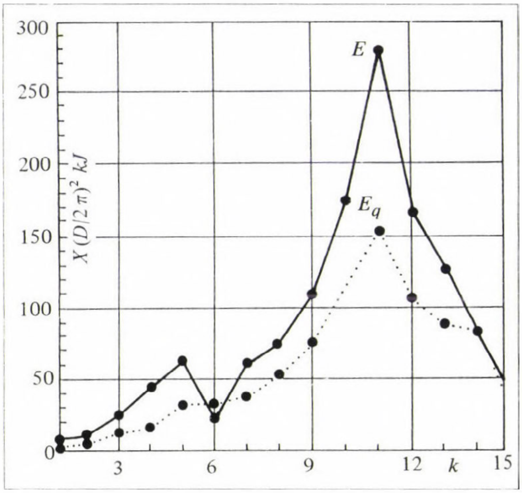

Fig. 6:
Band-summed energy spectrum after 150 time steps in Experiment 4.
(Lines mean the same as in Fig. 3.)

the model became less and less stable and the energy surplus was distributed proportionally to the number of modes after 150 time steps. This means that the negative β states, which are very stable in respect of the enstrophy, are significantly unstable in the numerical modelling.

6. Concluding remarks

The numerical method developed in Section 4 is suitable for the accurate computation of the equilibrium solution. In this way, the initial conditions of the equilibrum experiments can be designed with the knowledge of E_0 and Z_0, following the procedure of *Bennett* and *Haidvogel* (1983). One of the possible continuations of this work is to repeat the experiments of *Bennett* and *Haidvogel* (1983), and *Bennett* and *Middleton* (1983) using the above mentioned more accurate method. Nevertheless, it seems to be more interesting to use it in a more up-to-date high-resolution (at least 515^2) turbulence model.

The theory of two-dimensional equlibrium flows can be extended to shallow-water equation where the enstrophy is subjected to the constraint of the absolute potential-enstrophy. Some numerical experiments with a finite difference approximation to a shallow-water model will be shown in a subsequent paper.

List of symbols

k – nondirectional wavenumber;
ε – rate of cascade of kinetic energy per unit mass;
η – rate of cascade of enstrophy per unit mass;
E_0 – initial total energy;
Z_0 – initial total enstrophy;
α, β – parameters of the equilibrium solution;

ψ – stramfunction;

ω – two-dimensional vorticity;

Ψ – Fourier series and Fourier transform of ψ;

k_0 – k_{min};

x_m, y_i – gridpoints;

N, M – numbers of gridpoints in each direction;

Φ – geopotential field;

D – extension of the model-area in both direction.

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Problems in potato irrigation using the scheduler plant stress monitor

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Invetigation on irrigation scheduling based on infrared thermometry and soil moisture measurements were carried out at Keszthely, Hungary, during the 1989 growing season. The microclimate of irrigated plots changed during the growing season and became more sensitive to plant diseases. Decreased leaf area and early defoliation of irrigated potatoes resulted in lowered final yields. This negative effect drew our attention to the importance of plant protection when using the „Scheduler" Plant Stress Monitor in irrigation timing. There were no significant differences between the „Scheduler" and conventional irrigation systems, but the „Scheduler" method used less water.

Key-words: irrigation, soil moisture, potato.

1. Introduction

Scheduling irrigation using surface temperature measurements is based upon the assumption that when water becomes limiting, transpiration reduces and temperature increases. However, real water status of plants depends on other environmental factors such as air temperature, vapour pressure and wind speed. The basis of using infrared thermometry in irrigaton scheduling was developed by *Fuchs* and *Tanner* (1966), *Idso* et al. (1981) and *Jackson* et al. (1981). As a result of wide range investigations in plant physiology and meteorology the „scheduler" system was developed by Standard Oil Engineered Materials Company, these modern technologies in agriculture and computer science take the guesswork out of irrigation. The monitor automatically measures crop and air temperatures, global radiation and humidity, then the 64 K microprocessor analysing the data detects plant stress long before it is apparent to the eye. After field sampling, the data are transferred to an IBM PC/AT computer.

As *Stark* and *Wright* (1985) reported, foliage temperature measurements cannot be used effectively in schedule irrigation for potatoes, because of the high sensitivity of plants to environmental factors. Our purpose was to verify the validity of the „Scheduler" under Hungarian climatic conditions in irrigated potato trials. Potato is a suitable crop for such investigations since it is relatively sensitive to water stress.

2. *Theoretical consideration*

The ability of substances to reflect, absorb and transmit radiation varies considerably, thus providing a method of extracting information about substances (*Jackson* et al., 1980). The infra-thermometer recieves reflected radiation from the canopy in a direction within the field of view of the instrument. The amount of reflected radiation, which depends on surface temperature, can be expressed using the Stefan-Boltzmann law. The different type of the plant water stress indices are calculated from various environmental factors which influence the plant- water relationship. One of the most popular indices is the CWSI, the Crop Water Stress Index (*Jackson,* 1982) and this is used in construction of the „Scheduler Plant Stress Monitor".

3. *Material and methods*

Investigation was carried out with potatoes at the Potato Research Institute of Pannon University of Keszthely, during the 1989 growing season. The soil of experimental field is a Ramann type brown forest soil.

Agronomic procedures

Before ploughing (in September 1988) 50 kg ha^{-1} phosphorus, and 250 kg h^{-1} potassioum fertilizers, and at planting, 175 kg ha^{-1} nitrogen fertilizer were applied. The potato cultivar Desiree was planted with a plant density of 50 000 ha^{-1} on the 7th April, and immidiately hilled. The control of weeds was carried out by spraying Patoran Special before emergence, later on Sencor was used. Diseases were controlled by weekly spraying of pesticides and fungicides, but twice weekly when it was necessary.

Irrigation

A NADIR drop irrigation system was used, dropping elements were spaced every 50 cm. The plastic tubes were placed directly on the rows before emergence. Three different water treatments were used:

- natural rainfall only;
- irrigation using the „Scheduler" insturctions;
- irrigation by measuring the soil moisture.

Scheduler description

The „Scheduler" Plant Stress Monitor determines the most important meteorological elemets that effect the transpiration. It works quickly, it takes four samples every second. In our experiment we took 30–40 samples in each of the treatments and the measurements were replicated three times. The instrument sees an oval shaped area. The size of this area depends on how far the target is from the user and how far the instrument is above the canopy. In our case the sampled area was 1000 cm^2.

To get correct results the „Scheduler" must be aimed at sunlit leaves. The insolation must be stable, between 11.00 and 15.00 hours. Another contributing factor is the wind speed. Wind speed was determined at 1 m above the plant stand. Measurements were taken daily, except for cloudy and rainy days.

The field moisture capacity and the wilting point of the soil are important factors in irrigation. When soil moisture fell near the wilting point, the amount of water required to bring the soil moisture to 60–65 percent of field capacity was added by irrigation. Soil samples were taken from the root zone of plants of a border row twice weekly, and the soil moisture was determined gravimetrically.

Phenological observations and leaf-area measurements using LI–3000 type leaf-area-meter were performed during the growing season. At the end of the vegetative period the yield of plots (25 m^2) was determined.

4. Results and discussion

The weather in 1989 growing season was rainy and humid. The average air temperature during the measuring period was very close to the climatic normal. The amount of raifall was 18.5 percent higher than that of the earlier 15 year mean. The summer – except June – was wet, the rate of precipitation was 74.5 percent of the averages.

As there was no significant difference between the results concerning microclimate and plant morphology of the two differently irrigated treatments, only the results received with irrigation by „Scheduler" instructions are given.

The microclimate of plants may be affected by irrigation. The measured air temperature – 1 m above the canopy – as a result of higher water supply was lower in irrigated plants compared to the air temperature during control treatment (*Fig. 1.a*). The difference in air temperature between the two different water level treatments was not always high, but it could effect the intensity of physiological processes, mainly transpiration and photosynthesis.

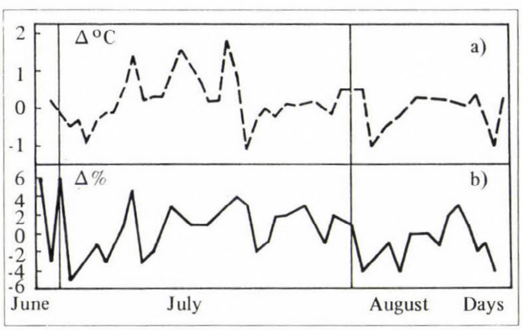

Fig. 1:
Difference in air temperature
(a) and relative humidity
(b) between irrigated and non-irrigated treatments

In July, the irrigation increased the relative humidity of the air (*Fig. 1.b*). In August, when the leaf-area-index (LAI) of irrigated plots decreased rapidly due to plant diseases the difference in relative humidity of the two different water levels ceased. Although the quantity of change in elements of microclimate was not high, they may effect physiological processes and the appearance of different plant diseases.

The seasonal variations of the water stress indices measured and of those corrected by wind speed were also investigated (*Fig. 2*). The influence of wind speed on the measured index was determined studying the relationship between wind speed and stress index by regression analysis. The relationship between the two elements was linear ($y = 1.11x + 0.27$; $r = 0.99$).

The whole research period was divided into two parts. In the first part of the measuring period – until the end of July – both the irrigated and non-irrigated plant stands were healthy. From the beginning of August in irrigated treatments we had problems with plant diseases, and for this reason the stress index values for August were studied separately.

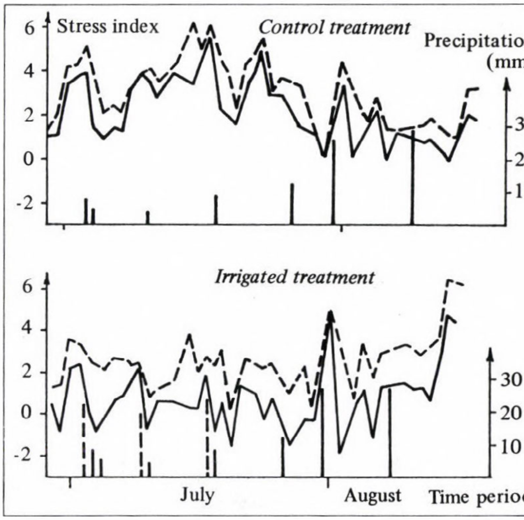

Fig. 2:
Measured (continuous line) and corrected (broken line) stress indices during 1989 growing season. The broken vertical lines are the amounts of irrigation water

Wind speed measured at higher levels above the canopy resulted in a larger difference in corrected stress indices. The influence of convective cooling on the index of control plants was lower than that of the irrigated treatment.

In July the difference in corrected stress index between control and irrigated plots was 1.15. The irrigated canopy had 11.5 percent higher transpiration rate than the non-irrigated control.

In the second half of investigation the change in microclimate of irrigated potatoes resulted in the appearance of different plant diseases, and this caused changes in physiological processes and the timing of phenological phases (*Table 1*).

Table 1:
Phenological phases (days from planting) of potato in control and irrigated conditions

Treatment	Planting date	Emergence	Flowering	Maturation	Harvesting
Control	07.04	29	66	165	183
Irrigated	07.04	29	68	147	174

Different plant diseases decreased the length of the vegetative period of irrigated potato through defoliation. The longer the time period of vegetation, the higher the possibility of producing more photosynthates. Larger leaf areas increase the difference in dry matter production (*Fig. 3*). In spite of the usual plant protection, Colorado beetles attacked irrigated potatoes on 1st August. Irrigation resulted in a special leaf texture, that favoured the spreading of Colorado beetles. The insect damage caused a 12.5 percent decrease in LAI and increased the possibility of attack of plant diseases. At the same time the change in LAI of control plants was zero. Unfortunately, the weather conditions in August (high air humidity) were good for other microbes, mainly for the Early blight fungus. *Caligari* and *Nachmias* (1988) also reported that potatoes with normal disease control cannot be protected from infection of Early blight.

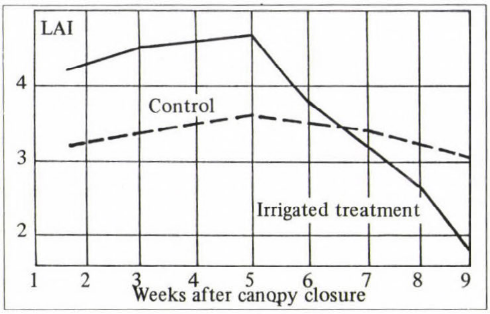

Fig. 3:
The leaf-area-indes (LAI) values during 1989 after canopy closure

The best parameter for predicting the appearance of plant disease is the change in plant temperature and crop-air temperature difference (*Fig. 4*). In August the difference in crop and air temperature of irrigated potatoes increased drastically. The same was observed for stress indices. As a result of insect damage the LAI of irrigated potatoes decreased. The stress indices were 4.2 and 2.0 for irrigated and control plants, respectively (10 August – 16 August).

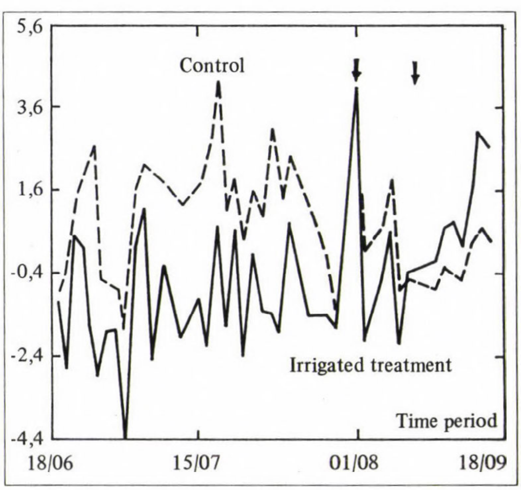

Fig. 4:
Seasonal variation of plant-air temperature difference

Change in the microclimate of irrigated potatoes made the attack of plant diseases possible. Decreased assimilatory surface and length of flowering and maturity time resulted in lowered yields. No significant difference in yield was observed between irrigation methods used in spite of the fact that amount of irrigation water was different in the two treatments.

Potatoes irrigated by „Scheduler" instructions used up 48.8 percent less water than the plants irrigated with monitoring the soil moisture in the field.

On the basis of these investigations we can conclude that under Hungarian climatic conditions changes in microclimate are important in plant protection of irrigated potato crop.

Acknowledgement

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Variation of sun-shine duration in Bulgaria

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Variability of the annual and monthly sun-shine duration for 21 meteorological stations in Bulgaria were analysed. Varying sun-shine duration tendencies were found using an integral difference curve method. Trend analysis was carried out using visual estimation of smoothed time curve and fitted 8-order polynomial. To identify the trend character of the climatic data the Spearman rank correlation test was used.

Key-words: sun radiation, climate change, Bulgaria.

1. Introduction

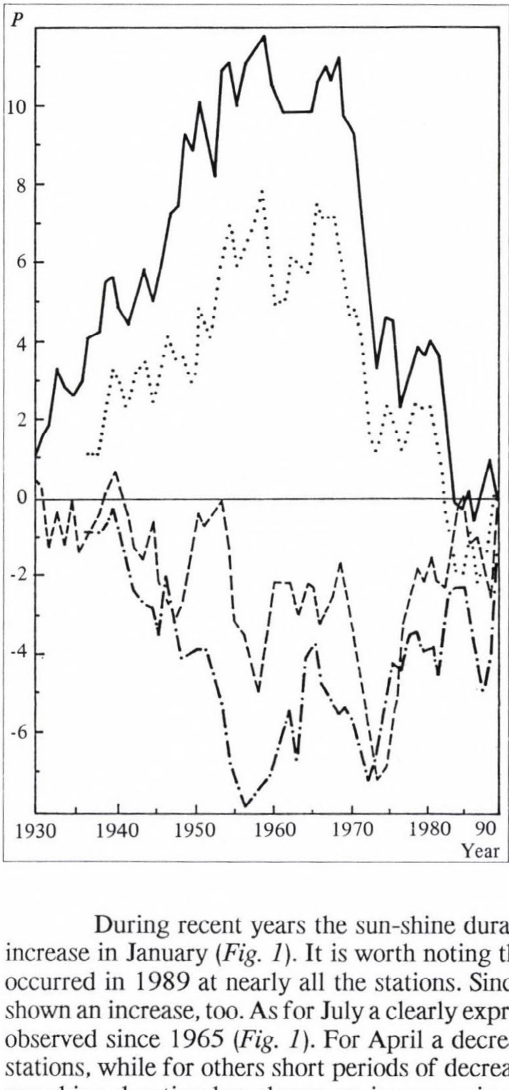
Industrialization exerts an increasing influence on the natural course of climatic changes. Fears of unfavorable change in climate, caused by human activity has led to many climate change studies. The temporal and spatial changes of the sun-shine duration due to either the natural processes in the atmosphere or human activity are one of the characteristic features of climate change.

Variation in sun-shine duration data, were analysed for 21 climatic stations in Bulgaria. Three stations were located on mountain peaks – Musala (2925 m), Cherni vrah (2286 m) Murgash (1687 m). The period studied was from 1938 to 1990. The records of sun-shine duration for the months of January, April, July and October as well as annual values were analysed.

2. Analysis and Results

The variations of both the annual and monthly sun-shine duration from year to year are so large that any trends could be obscured. To dampen the high-frequency interannual variation and to identify the trends in the monthly and annual records, both graphical and statistical approaches were used.

To define the occurrence of high or low sun-shine duration more clearly, the method of the integral difference curves was used (*Battalow*, 1968; *Drozdov* and *Grigorieva*, 1971). The same method has been used before by *Lingova* and *Ivancheva* (1983) to study the variation of sun-shine duration up to 1975. In present analysis the emphasis was placed on the existence of trends in subsequent years.



P is computed as follows:

$$P = \frac{\sum_i (K_i - 1)}{C_v}$$

where $K_i = \frac{Q_i}{Q}$ and $C_v = \frac{\bar{Q}}{\sigma}$

Q_i – sun-shine duration for i-th year,
Q – mean sun-shine duration,
σ – mean square deviation

Fig. 1:
Integral difference curves of sun-shine duration

During recent years the sun-shine duration record has shown a tendency towards increase in January (*Fig. 1*). It is worth noting that the highest value of sun-shine duration occurred in 1989 at nearly all the stations. Since 1967 sun-shine duration in October has shown an increase, too. As for July a clearly expressed decrease in sun-shine duration can be observed since 1965 (*Fig. 1*). For April a decreasing tendency was found for some of the stations, while for others short periods of decreasing and increasing alternated. The annual sun-shine duration has shown an increase since 1970 for most of the stations, while in isolated stations showed a decrease (*Fig. 2*).

The time-series of sun-shine duration was smoothed by overlapping the 9-year weighted mean. The series were fitted with an 8-order polynomial. (*Fig. 3*). These methods eliminated random and short-term fluctuations. These series showed a generally oscillatory character with increases and decreases during the shorter-term period. The most pronounced feature of this curves is the significant above-average July and annual sun-shine duration about 1950. The other outstanding feature is the significant below-average sun-shine duration in July about 1970 and in January about 1954. Note the similarity between the various sun-shine duration records at different stations in particular months. However, the magnitudes of the trends are smaller than the interannual variations of the sun-shine duration records.

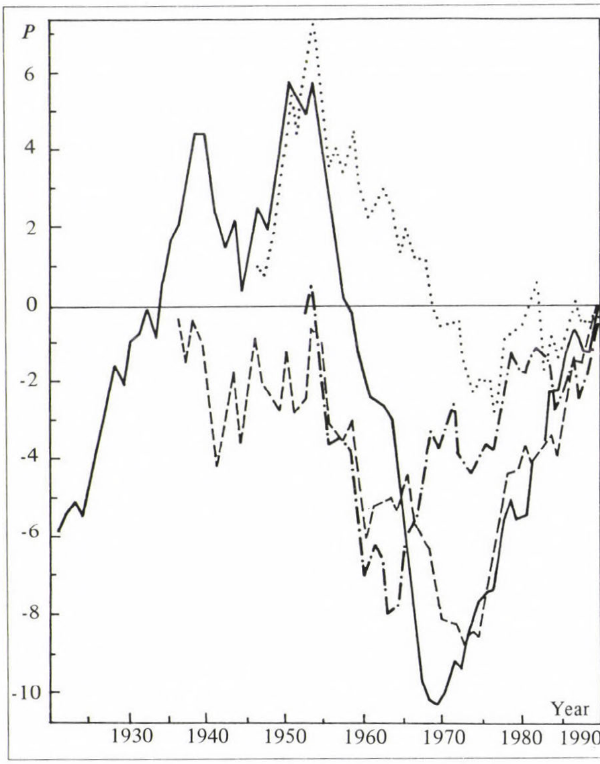


Fig. 2:
Integral difference curves of annual sun-shine duration

Because the visual examination of the smoothed curves is very subjective, an objective statistical method was used to further investigated the trends in sun-shine duration.

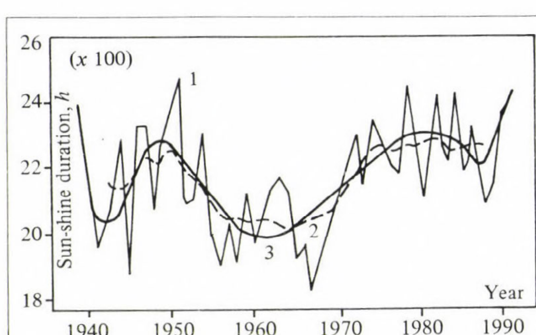


Fig. 3:
The time series of sun-shine duration at Obr. Chiflik
1: original series;
2: the 9-year weighted moving average;
3: the fitted 8-order polynomial

The presence of some form of trend in climatological data may be examined by the Spearman rank statistics *r* (*WMO,* 1966; 1990) which is computed as follows:

$$r = 1 - \frac{6 \sum_{i=1} d^{-}_i}{N(N^2 - 1)},$$

where $d_i = m_i - i$, m_i is a rank of the i-th member in the series and N is the size of a sample.

Using this statistics, the trend analysis for each station and month is applied for the period 1938–1990. In general the trends are positive in January and negative in July. Also trends in annual sun-shine duration differ between stations.

The value of r was tested for significance by solving for t in the equation

$$t = r\sqrt{\frac{N-2}{i-r}}$$

and compared with the two-tailed 95 % probability points of „Student's" t with $(N - 2)$ degrees of freedom. Since most of the computed t lies within these limits, the presence of trend in these data in the last 50 years can not be substantiated.

3. Conculusion

There is a great variability in the course of sun-shine duration for the different months and that is why a common trend cannot be observed. The trends in the series was an oscillatory. In winter sun-shine duration increases and in summer it decreases in the last years. This trend, however, is not significant at most of the stations. It also agrees with the evaluation of the temperature conditions of the recent years in Bulgaria (*Koleva* and *Iotova*, 1990).

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LITERATURE

RAMBLER, M. B., MARGULIS, L. and FESTER, R. (Editors): **Global Ecology. Towards a Science of the Biosphere.** Academic Press, Inc. London, 1989. 12 + 204 pages, 30 figures, 17 tables

Including the editors, 18 authors contributed in writing this comprehensive book, among others J. E. Lovelock and L. Margulis prominent representatives of Gaia hypothesis.

One of the greatest scientific challenges of our age is to understand the fundamental nature of the system that supports life on our planet. In this system biological, chemical and physical processes interact in such manner that the biosphere has existed since millions of years while its development, transformation has taken place, morever it has contributed actively to the transformation of its enviroment.

The book provides review of this complicated chain of various mechanisms in six chapters. The title of the first chapter is „Gaia and geognosy". The term geognosy denotes a new science, which considers the Earth not only as a planet, but along with its hydrosphere and biosphere it exhibits a combined system. One of the simpliest model of this system is the „daisy world", with white and black flowers controlling the planetary temperature, is also presented in this chapter.

The further chapters give analysis of various types of ecosystems, the cycles of transport of chemical elements within the Earth-atmosphere system, the photochemistry of biogenic gazes, the methods of remote sensing, and the human responsibility in influencing the composition of the atmosphere. Finally two appendixes are added to the book: the first provides a dictionary of therminology, the second presents the goal and function of GERO (Global Environmental Research Organization).

G. Koppány

CHRONICLE

Formation of the Commission on Environmental Science of the Hungarian Academy of Sciences

In the last years it has become evident that human activities modify the different media of our environment: atmosphere, hydrosphere, pedosphere etc. Since environmental conditions have made the development of human economy and society possible, man jeopardizes in this way his own future. To avoid problems we have to learn that natural resources are not illimited and we must live in harmony with nature. In other words we have to create the conditons of the so-called sustainable development which preserves the environment for future generations.

It goes without saying that, among other things, scientific research is needed to elaborate the strategy of sustainable development. We have to know in more detail environmental processes we are modifying and possible effects of modifications. Briefly, the study of the interaction of man and his environment is an obvious research purpose. It is evident that research can not be done solely by one branch of classical sciences. Considering the classification of sciences, environmental science is interdisciplinary in nature. The cooperation of many scientific fields is needed to fill the requirements.

By recognizing the importance of the subject, the General Assembly of the Hungarian Academy of Sciences held in 1991 made a resolution to form a Commission on Environmental Science under the auspice of its Presidium. It was also decided that membership of the Commission should consist of scientists delegated by different departments of the Academy due to the complexity of the problem.

During its first meeting on September 26, 1991 the Commission discussed its terms of references. It was concluded that the aim of the Commission is to coordinate and evaluate basic research being carried out in Hungary by environmental scientists. Members agreed that for obtaining this aim the continuous survey of results received by the scientific community all over the world is necessary. Members accepted to propose for assent to the Presidium the following points as basic purposes of the Commission:

a) Discussion and evaluation of Hungarian scientific conceptions in environmental science;

b) Selection of new research areas and methodologies;

c) Discussion of scientific research carried out in different institutions;

d) Elaboration of propositions for environmental education at different levels; working out the general concepts of the education;

e) Survey of the state of environment in the country; elaboration of the scientific bases of environmental protection;

f) Evaluation of non-governmental international relations;

g) Promotion of the publication of environmental issues including the information of the public;

h) Coordination of the work of environmental committees of the departments of the Academy.

It was emphasized by the members that it would be useful to look for contact with other similar commissions abroad taking into account the international character of environmental science. The importance of such world-wide projects as the International Geosphere-Biosphere Programme was stressed in particular.

E. Mészáros

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Volume 26A Number 3 1992

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IDŐJÁRÁS

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The radon and the natural atmospheric radioactive aerosol

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(Manuscript received 27 December 1991; in revised form 12 March 1992)

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 interprete 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 (*Fontàn*, 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*)

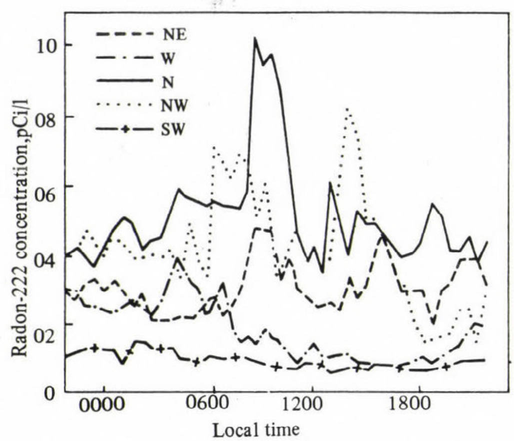

Fig. 1. Variation of the mean radon concentration (Bqm^{-3}) as a function of the wind direction and time of the day

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:

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

where C_A, C_B, C_C, C_{Rn} are the concentration of RaA(^{218}Po), RaB(^{214}Pb), RaC(^{214}Bi) 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 $2x10^{-2}$ μm.

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 $2 \cdot 10^{-2}$ μm. 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 influences in Brest. In particular, it is established that, in some cases, radioactive aerosols with radius larger than 0.1 μm, 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 0.1–2 μm (*Butor*, 1981).

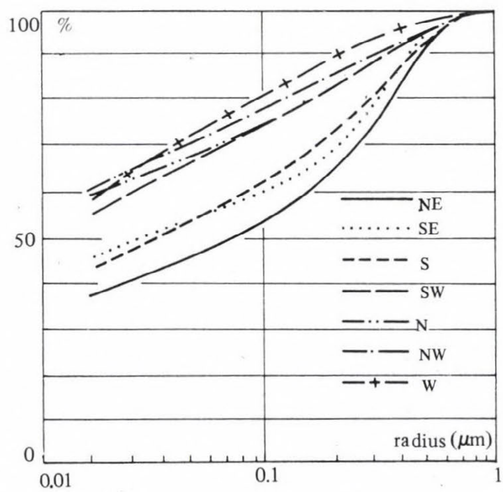

Fig. 2. Cumulative distribution of α activity from ^{222}Rn daughters according to wind direction

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-existant aerosol size distribution is expressed with the help of three lognormal distributions for radii between $3 \cdot 10^{-3}$ μm and 3 μm (*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.

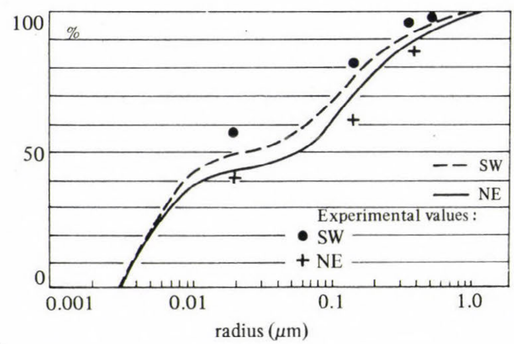

Fig. 3. Theoretical (curves) and experimental (points) distribution of α activity from ^{222}Rn daughters

All theoretical α activity curves obtained in Brest have an inflexion point between 0.01 μm and 0.1 μm, 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 ^{220}Rn daughters to total H_E is estimated to be 30 % on an average (*Rannou,* 1988), no marked correlation was found between ^{222}Rn levels and γ dose exposure rates.

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

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

Country	Arithmetic mean (Bq/m³)	Geometric mean (Bq/m³)	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 ^{218}Po (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 H_2O (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 ^{218}Po(RaA) fractions between 0.078 and 0.21, and ^{214}Pb(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($Bq\cdot m^{-3}$)	41	6
	PAE ($x\cdot 10^{-8}$ $J\cdot m^{-3}$)	9.8	1.3
Rn 220 series	Co($Bq\cdot m^{-3}$)	18	0.2
	PAE ($x\cdot 10^{-8}$ $J\cdot m^{-3}$)	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).

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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 mg m^{-2} yr^{-1} for As, 1.5 mg m^{-2} yr^{-1} for Cd and 50 mg m^{-2} yr^{-1} for Zn. All these maxima occur in Southern Poland. The highest total deposition of Pb (15.0–20.0 mg m^{-2} 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:

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

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:

$$\beta = [2\pi hk \cdot A]^{-1}, \tag{2}$$

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:

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

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:

$$d_w = c\,(x_r,y_r)\cdot W_q \cdot P, \tag{4}$$

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:

$$d_d = c\,(x_r,y_r)\cdot v_d. \tag{5}$$

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 characteristics 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:

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

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 km^2 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–Puszta 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 ($\mu g\ m^{-3}$)	1981-85	28.95	23.40-35.23	56.6	45.10-71.9
Pb wet deposition ($mg\ m^{-2}\ yr^{-1}$)	1983-85	5.44	4.11- 6.32	6.68	5.03- 7.69
Cd air concentration ($\mu g\ m^{-3}$)	1981-85	0.31	0.28- 0.36	1.21	1.03- 1.50
Cd wet deposition ($mg\ m^{-2}\ yr^{-1}$)	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 mg m^{-2} yr^{-1} in Poland. The local maximum is over 2.0 mg m^{-2} yr^{-1}

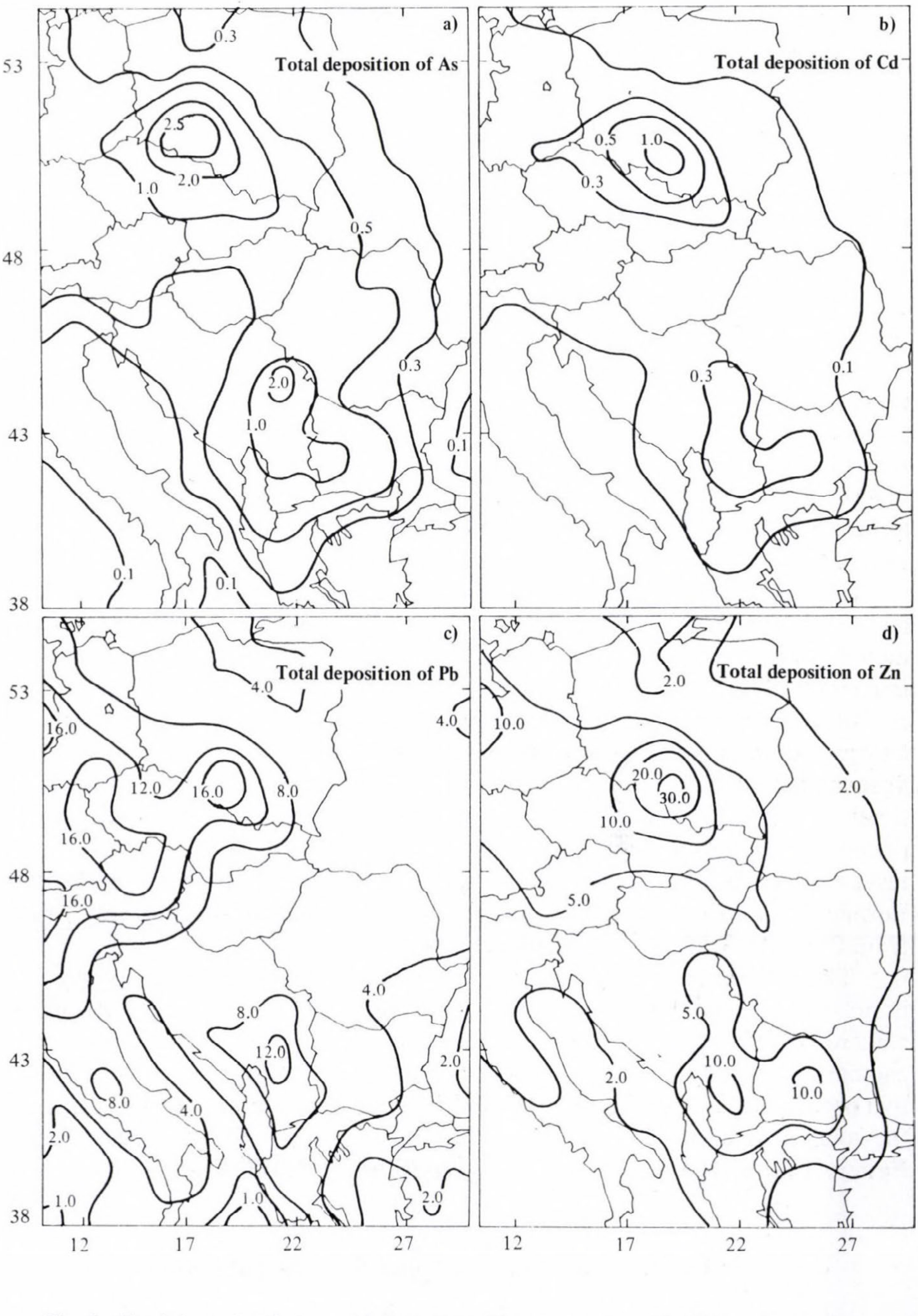


Fig. 1. Total (wet plus dry) annual deposition of heavy metals, mid-1980s: (a) arsenic, (b) cadmium, (c) lead, (d) zinc. Units: mg m^{-2} yr^{-1}.

in Yugoslavia. Moving towards the edge of the continent total deposition of around 0.1 mg m^{-2} yr^{-1} is reached. It can be seen from this figure that total arsenic deposition remains relatively high (2.0–3.0 mg m^{-2} 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 mg m^{-2} 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 mg m^{-2} yr^{-1} in Poland and 0.4–0.5 mg m^{-2} yr^{-1} in Yugoslavia and Bulgaria. These levels may be compared to the range of 0.006 to 0.229 mg m^{-2} 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 (15.0–20.0) mg m^{-2} 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 m^{-2} 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 mg m^{-2} 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 10.0–15.0 mg m^{-2} yr^{-1}. On the other part of Eastern Europe the value of total Zn deposition is 2.0–7.0 mg m^{-2} 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 precipitation 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	μg/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 einzugsgebiet (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 $\mu g\ l^{-1}$. 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 $\mu g\ l^{-1}$. This area covers practically the whole territory of

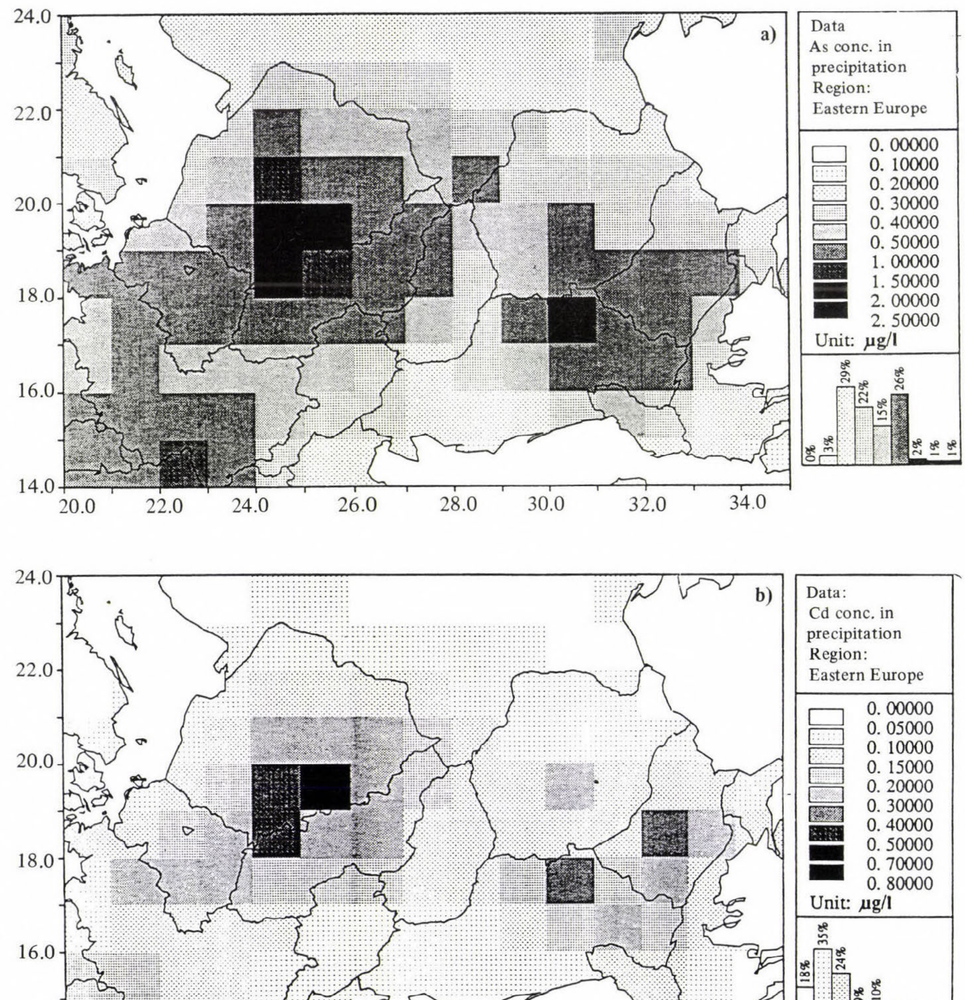


Fig. 2a, b. Annual average concentration of arsenic (a) and cadmium (b) in precipitation, mid-1980s

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

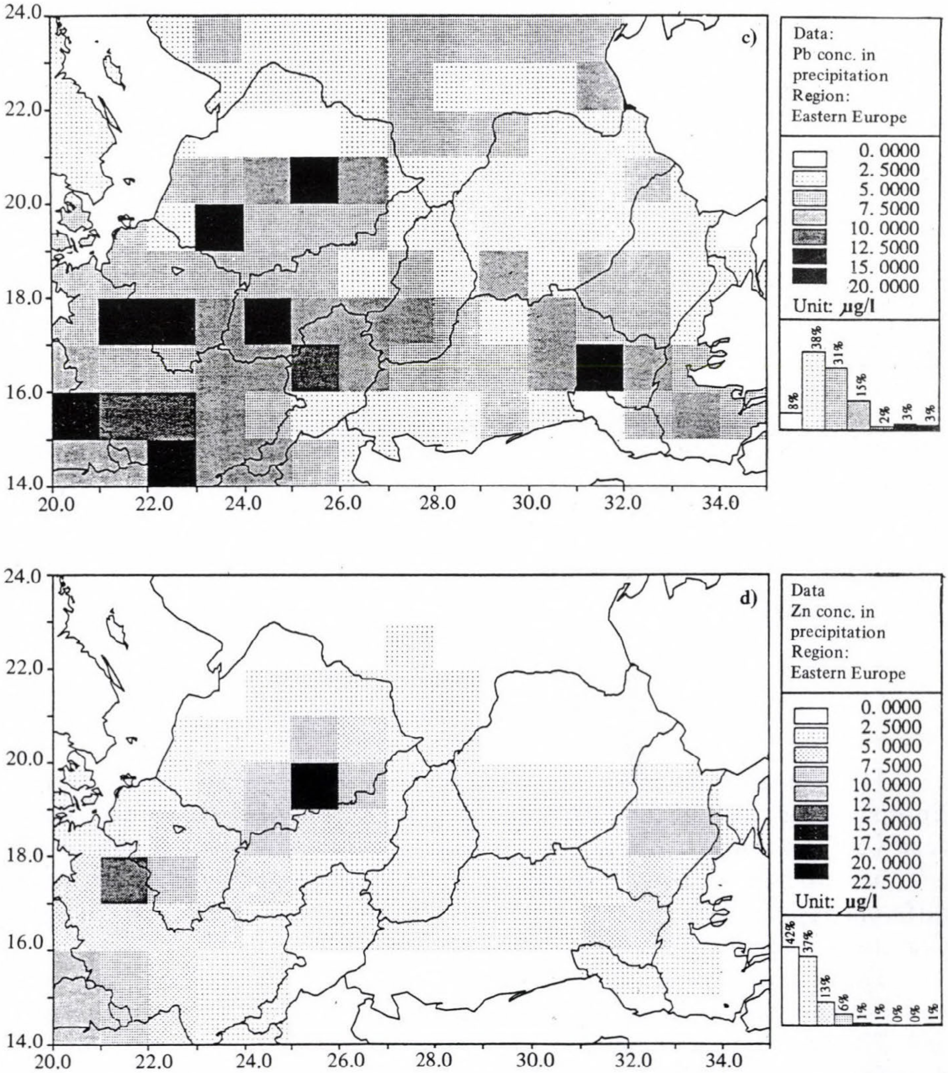


Fig. 2c, d. Annual average concentration of lead (c) and zinc (d) in precipitation, mid-1980s

The Cd pattern (Fig. 2b) shows one considerable peak in Poland (over 0.7 $\mu g\ l^{-1}$) and two others in Bulgaria and Yugoslavia (0.3–0.4 $\mu g\ l^{-1}$). In the central part of Eastern Europe (Hungary, north-western part of Romania) the Cd concentration in precipitation is 0.1–0.2 $\mu g\ l^{-1}$. On the northern part and Adriatic coast of Yugoslavia the Cd concentration is below 0.1 $\mu g\ l^{-1}$. In North Czechoslovakia the Cd concentration is 0.2–0.4 $\mu g\ l^{-1}$ 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 $\mu g\ l^{-1}$ can be seen in certain parts of Poland. In other regions of Eastern Europe it varies between 2.5 and 15.0 $\mu g\ l^{-1}$ (Fig. 2c).

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

County	Emitted ($t\ yr^{-1}$)	Deposition ($t\ yr^{-1}$)	Average flux ($kg\ km^{-2}yr^{-}$)
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 %

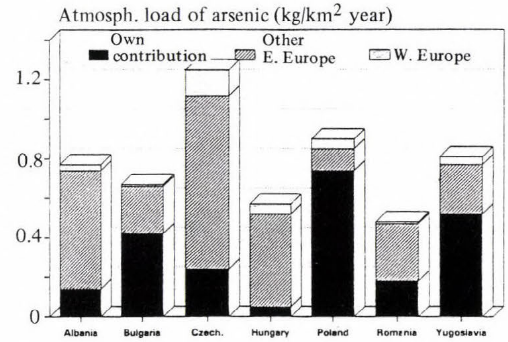


Fig. 3a. Country budgets of arsenic for various Eastern European countries

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

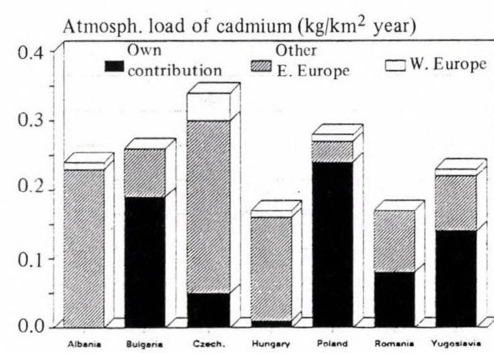
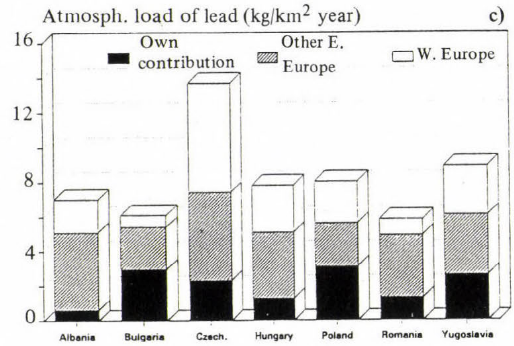


Fig. 3b. Country budgets of cadmium for various Eastern European countries

(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.



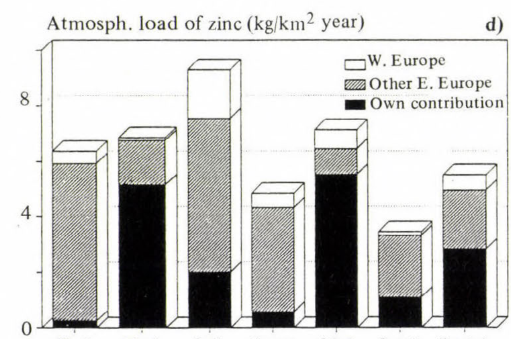


Fig. 3c, d. Country budgets of lead (c) and zinc (d) for various Eastern European countries

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

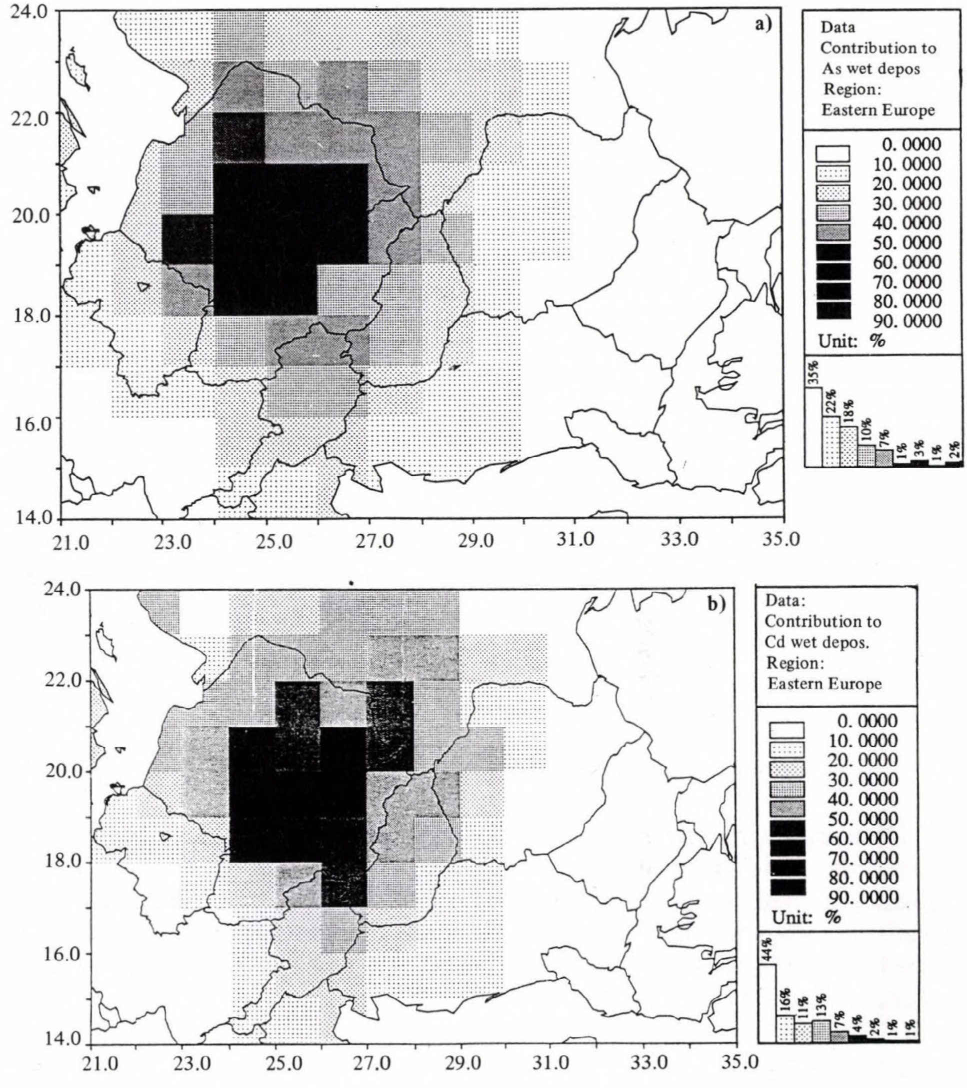


Fig. 4a, b. Contribution of southern Polish sources to wet deposition of arsenic (a) and cadmium (b) in Central and Eastern Europe

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.

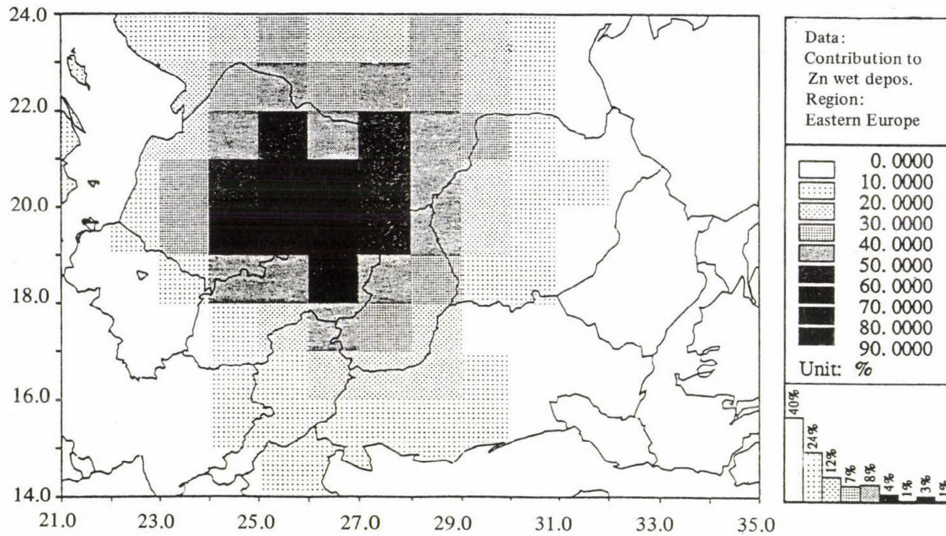


Fig. 4c. Contribution of southern Polish sources to wet deposition of zinc in Central and Eastern Europe

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 precipitation 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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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 radiosonding 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 *Uccelini*, 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.

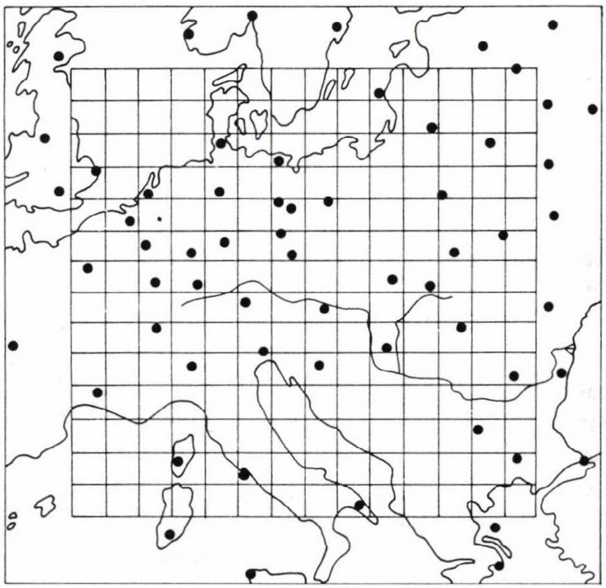

Fig. 1. The grid network on the stereographic weather map

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 (Θ=const) the meteorological parameters are calculated applying biharmonic spline interpolation (*Dévényi et al.*, 1988).

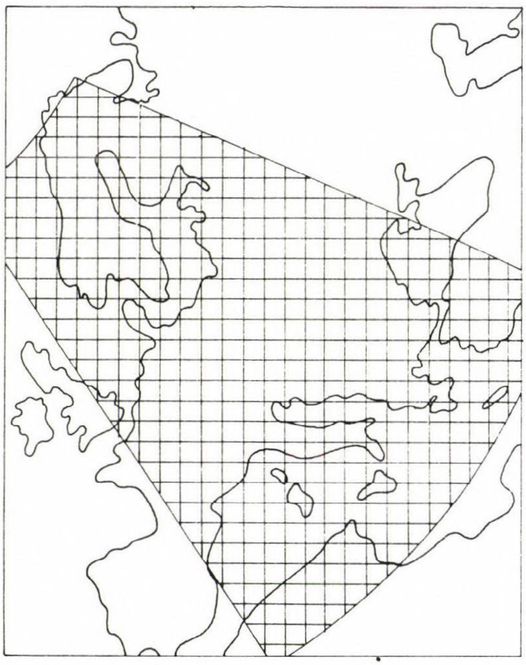

Fig. 2. The EMEP grid network

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

$$\int_{\Omega} \left(\sigma_{xx}^2 + 2\sigma_{xy}^2 + \sigma_{yy}^2\right) \delta\Omega = \min_{W_2^2}, \qquad (1)$$

where W_2^2 means the class of twice continuously differentiable functions. In any point the interpolated value can be determined from the equation

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

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

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

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

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 calculeted 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 *Uccelini,* 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 *Uccelini* (1979) the inviscide 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 Uccelini 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

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

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

The acceleration of air parcels is calculated from

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

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

The velocity is derived from using Adams-Bashford scheme

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

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

except the first time-step when

$$u^1 = u^0 + a_x^0 \, \Delta t \tag{8}$$

$$v^1 = v^0 + a_y^0 \, \Delta t. \tag{9}$$

The *n.* endpoint of trajectory is calculated from

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

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

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_O, and the ending point is denoted by P_E. The coordinates of P_E ending point is calculated the following

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

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

$$P_3 = \left(p_0 + P_2\right)/2 \tag{14}$$

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

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

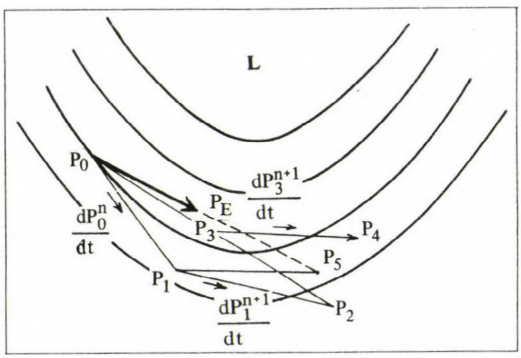

Fig. 3. Method of the iterative kinematical trajectory

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 $\Delta\phi=\Delta\lambda=2.5°$ 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.

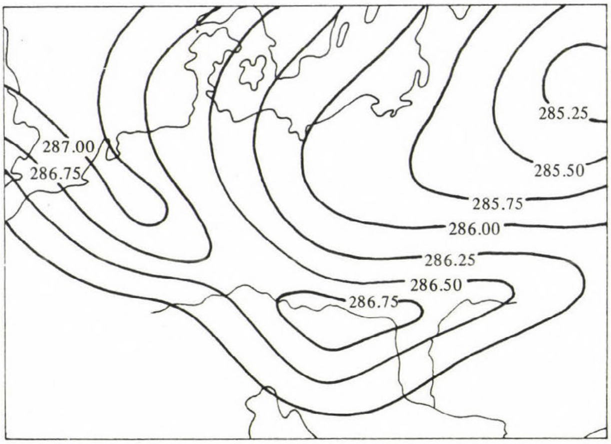

Fig. 4. Field of the isentropic stream function on the 285 K level (unit in 10^3 m^2 s^{-2})
00 UTC 01 April 1989 and 12 UTC 02 April 1989

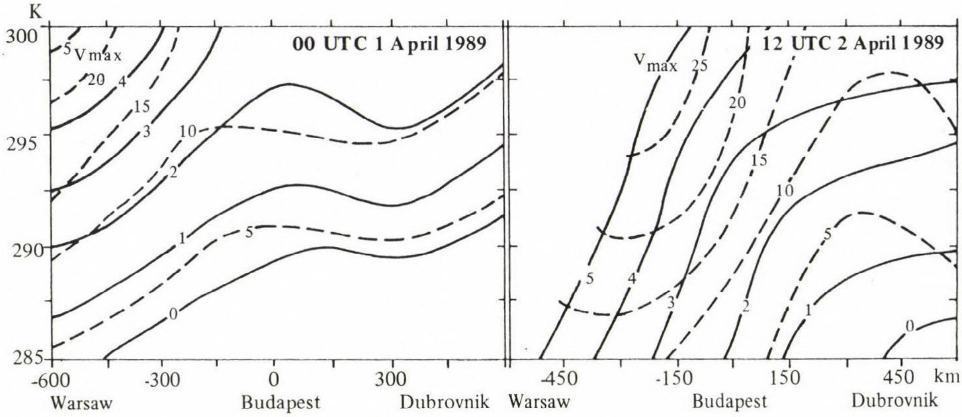

Fig. 5. North-south vertical isentropic cross section between the 285 and 300 K isentropic levels
00 UTC 01 April 1989 and 12 UTC 02 April 1989

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

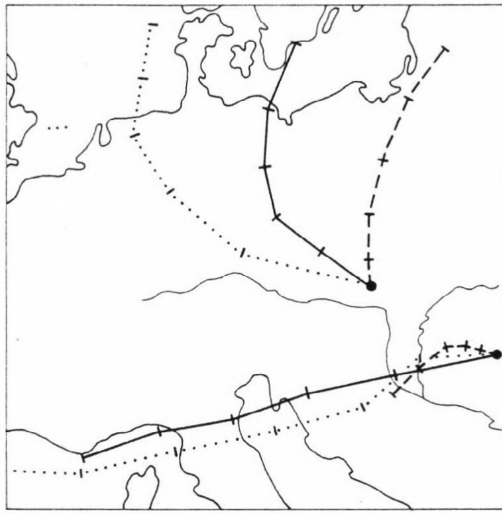

Fig. 6. 30 h backward trajectories on 850 (dashed), 700 (solid) and 500 hPa (dotted) 12 UTC 02 April 1989

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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

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

the zonal equation of motion

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

and the meridional equation of motion

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

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

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

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

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

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

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

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

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

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

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:

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

$$- \frac{f}{S}\frac{\delta}{\delta p}\left(\frac{\delta\omega}{\delta y}\frac{\delta u}{\delta p} - \frac{\delta\omega}{\delta x}\frac{\delta v}{\delta p}\right) - \frac{R}{S}\frac{\nabla^2 Q}{C_p P}, \qquad (4)$$

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

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

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

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

and the thermodynamic energy equation is

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

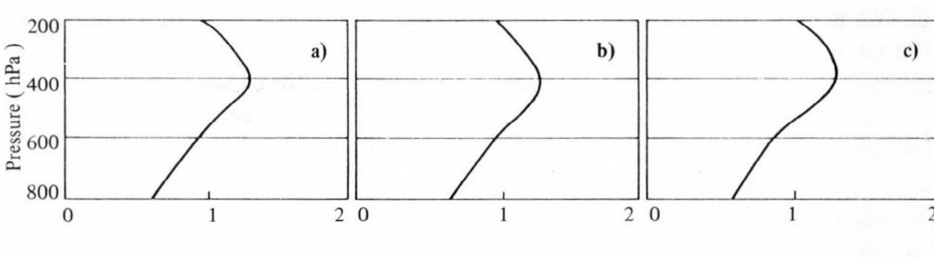
where $$S = -\frac{\alpha}{\Theta}\frac{\delta \Theta}{\delta P}.$$

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/deg^2

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.

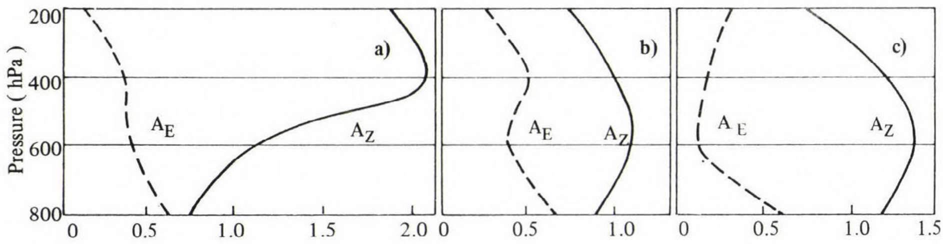


Fig. 2a–c. Vertical distribution of A_Z and A_E on 5th, 6th and 7th July 1979, 12 GMT respectively. Unit: 10^2 erg/cm²/hPa

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 Tibetian 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 Tibetian 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.

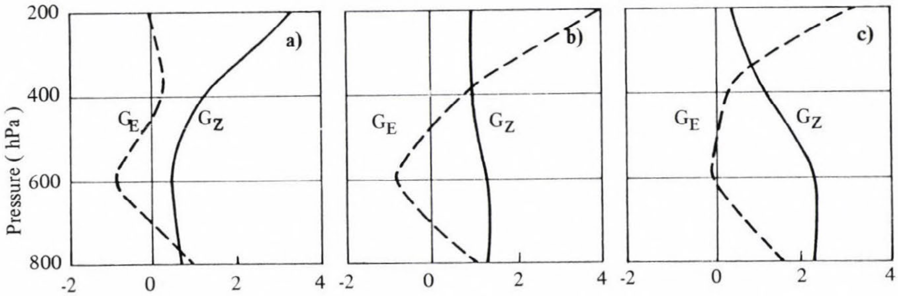
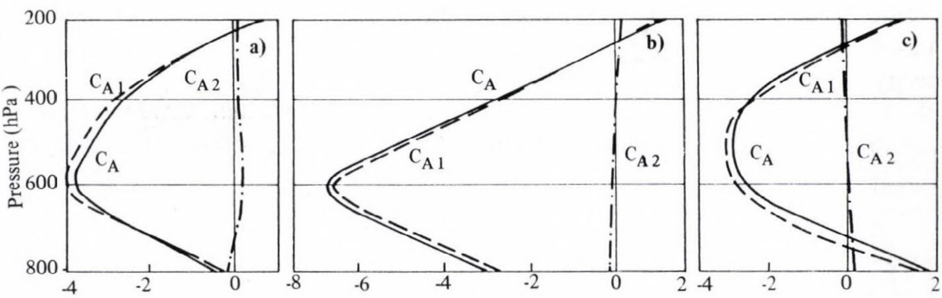


Fig. 3a-c. Vertical·distribution of G_z and G_E on 5th, 6th and 7th July 1979, 12 GMT respectively. Unit: 10^{-3} erg/cm²/sec/hPa

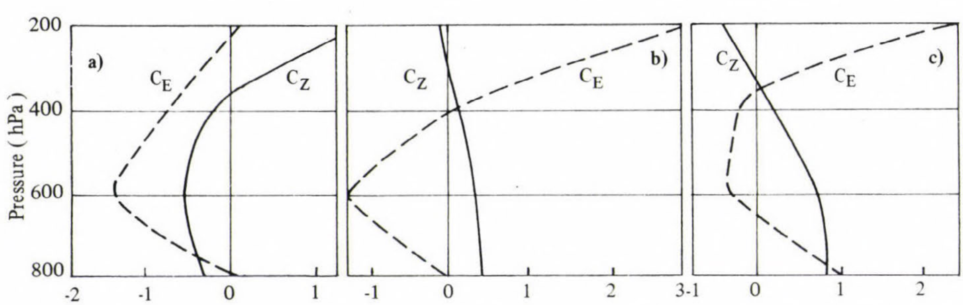


Figs. 4a-c. Vertical distribution of C_A with its components on 5th, 6th and 7th July 1979, 12 GMT respectively. Unit 10^{-4} erg/cm²/sec/hPa

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/cm^2/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.

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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

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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 exists?	Management: Former	Management: Present	Management: Future
Local urban	0-20	Contaminating subs.	Health	Y	Y	↓	↓	↓
Regional	20-200	Cont. subs. and pot. acid. subs.	Health and ecology	Y N	Y 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	$(1.6+1.2)10^9$	$7.4x10^7$	-	$0.8x10^6$
	Lead	$(4.5+0.3)10^5$	$2.2x10^4$	$9.0x10^4$	$6.2x10^2$
	Cadmium	$(7.3+0.8)10^3$	-	$1.1x10^3$	4.4
	TSP	$(0.2+3.7)10^9$	$9.2x10^6$	-	$4.5x10^5$
Potential acidifying subs.	Sulfur dioxide	$(1.6+1.3)10^8$	$2.5x10^7$	$4.5x10^7$	$1.4x10^6$
	Nitrogen dioxide	$(8.0+8.9)10^7$	$2.2x10^7$	$1.9x10^7$	$2.6x10^5$
	NM VOC	$(0.8+4.6)10^8$	$(2.2+3.5)10^7$	$(2.2+1.8)10^7$	$2.3x10^5$
	Ammonia	$1.7x10^8$	-	$9.0x10^6$	$1.5x10^5$
Greenhouse gases	Carbon dioxide (C)	$(5.3+1.6)10^9$	$1.2x10^9$	$2.0x10^9$	$2.7x10^7$
	CFC-11 CFC-12	$7.7x10^5$	-	-	$5.5x10^3$
	Methane	$(1.8+3.5)10^8$	-	-	$5.3x10^6$
	N_2O	$(1.4+5.9)10^6$	-	-	$9.5x10^3$

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.

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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 hypothetic 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

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Application of nonlinear dynamics in atmospheric sciences Part I. Theoretical background

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(Manuscript received 17 June 1992; in final form 5 September 1992)

Abstract—When studying the physical processes that are essential for an understanding of the transient behaviour of the atmosphere (the weather) and the steady-state behaviour of the climatic system (the climate), we are dealing with enormously complex geophysical systems. In order to discover the inherent behavioural characteristics of these systems, it is advantageous to perform qualitative analysis of low-order models which are highly simplified versions of reality. The theory of dynamical systems, emanating from a series of numerical experimentation carried out with low-order models, has led to some findings that, as some researchers claim, are revolutionary in scientific thought. With the intention of reviewing the applicability in meteorology of dynamical systems theory, and especially the results of nonlinear dynamics, a modified version of the concept of climate is suggested and a survey of the theoretical aspects is presented. Examples of the application of nonlinear dynamics in various fields of atmospheric sciences will be given in the second part of this paper.

Key-words: geophysical fluid, dynamical system, attractor, basin of attraction, chaos.

1. Introduction

The earth's atmosphere should be considered as a *geophysical fluid*, i.e. a planetary scale medium whose dynamical properties are determined mainly by two factors: *(a)* the important role played by the Coriolis force and gravitational force, and *(b)* the shallowness of the medium (the great horizontal extent of the atmosphere relative to its vertical extent). These factors distinguish the atmosphere from general fluids and make it unique in the field of fluid dynamics. Further determinant characteristics of this geophysical fluid include *(c)* nonlinearity, primarily due to advection, which cannot be removed by any transformation of the independent and dependent variables, *(d)* thermal forcing by differential solar heating, and *(e)* frictional dissipation due to the viscosity of the fluid during molecular and large-scale motion. As a consequence of nonlinearity, the atmosphere is a *complicated hydrodynamical system*. The effects of advection, the most prominent nonlinear term in the governing equations, cannot be removed by linearization, because this procedure simply replaces the product of two unknown quantities by the product of an unknown and a known. Due to solar heating and friction, the atmosphere is a *forced dissipative system*; it acts as a kind of heat engine, continually converting heat into mechanical energy, which is in turn converted back to heat by dissipation. In order that a fluid shall be able to convert heat into mechanical energy by circular processes without any progressive change of state of the fluid, it is necessary that the possible thermodynamical states of each fluid particle form a two-dimensional manifold, at least. This is the case for atmospheric air, where two variables of state, e.g. pressure and density, are free to vary independently under the influence of heat sources. In other words, thermodynamic activity or "convection" is an important ultimate driving mechanism of the system, and probably the only one of real significance. Finally, the atmosphere constitutes a *bounded system*, because the increase of its total energy due to thermal forcing will be stopped by dissipation if the energy exceeds a certain value (*Ghil* and *Childress*, 1987; *Yang*, 1991).

Thermal forcing and frictional dissipation are comparatively slow effects which do not *directly* lead to such rapid changes as are usually seen on weather maps in disturbed regions. In such areas we can assume that the rapid change is either a result of a redistribution of pre-existing kinetic energy, or of a release of available potential energy; heat sources and friction are secondary effects which can have only modifying influence during such a short span of time. One may therefore assume that the changes during a limited time interval from a given initial state will take place almost as if the motion were adiabatic and frictionless (*Eliassen* and *Kleinschmidt*, 1957). On the other hand, heat sources and friction are of vital importance for explanation of how the initial state with its supply of releasable energy was created. The theory of adiabatic and frictionless motion is no longer adequate to explain changes over more extended periods of time than the characteristic time scale of the transient behaviour of the atmosphere, i.e. the life cycle of extratropical disturbances which control variations of weather. As the time span which we are concerned becomes longer and longer, atmospheric processes become more and more affected by the behaviour of the terrestrial spheres adjacent to the atmosphere: the oceans, the land surface, the world's ice masses and snow deposits, and the biomass. On climatic time scales, these spheres are linked together in such a way that an anomaly in one part of the ensemble can trigger a series of changes in other variables. We are therefore faced with a *coupled geophysical system* which presents the scientist with an extraordinarily complex physical as well as chemical and biological problem.

In order to achieve the necessary quantitative understanding of the mechanisms that are responsible for the changes in the state of the atmosphere on different time scales (i.e., for the variations of weather and climate), the most useful and comprehensive way to follow is the construction of models. These models are mathematical representations of the basic physical laws which govern the system's behaviour. The particular equations express the time derivative of each relevant variable in terms of the instantaneous overall state of the system and its environment; that is, they possess a form which renders them suitable for stepwise numerical integration. Therefore, the problem of both weather change and climatic change can be treated as a well-defined mathematical problem. A prerequisite of such a treatment is, however, the existence of exact, mathematically interpretable definitions of the basic meteorological notions. We shall consider this matter in Section 2.

Atmospheric processes, as we have seen, should be looked upon as manifestations of an extraordinarily complex geophysical system. Consequently, models developed for adequately simulating its real processes are necessarily complicated, too. A typical example can be found in weather forecasting practice where the complexity of the global models tends to grow commensurately with the capacity of supercomputers. The computational effort needed to handle models in which the number of variables is of the order of 10^5 is, however, prohibitive for most pure research. Faced with the necessity of reducing the resolution of their equations, some meteorologists have turned to low-order models, where the number of degrees of freedom of the system has been reduced even below ten.

Low-order models are systems of ordinary differential equations which have been simplified by extreme reduction of the number of dependent variables (*Lorenz*, 1960, 1982, 1987). The usual procedure of constructing low-order models is to transform the original partial differential equations into spectral form. This is done by expressing the field of each dependent variable as a series of orthogonal functions, such as multiple Fourier series or spherical harmonics, and letting the coefficients in these series be the variables in an infinite system of ordinary differential equations. This system is then truncated by discarding all but a finite number of variables and equations. Usually the retained variables are the coefficients of the orthogonal functions of largest spatial scale, although selective truncation is sometimes also used.

When we introduce low-order models, nothing beyond correct *qualitative* agreement with reality is to be expected. Our hope is that instead of the details of the processes, *the essential behavioural characteristics* of the fluid can be adequately and faithfully modelled by such reasonably small-dimensional systems of appropriately chosen models.

Low-order models are examples of dynamical systems. A *dynamical system* is a way of describing the passage in time of all points of a given space (*Hirsch* and *Smale*, 1974). This space could be thought of, for example, as the space of states of some physical system. It was the time evolution of state in an extremely simple autonomous dynamical system constructed by *Lorenz* (1963) which led him to realize that deterministic systems can behave chaotically. This means they act in such a complicated way one cannot predict exactly what they will do in the future—the best one can do is to make probabilistic statements about them.

Chaos can be thought of as deterministic randomness—"deterministic" because it arises from intrinsic causes and not from some external noise, and "randomness" referring to irregular, unpredictable behaviour. Chaos theory can be applied in almost every field of science, and—according to some scientists—it has fundamentally changed our view of the world by forcing us to face our limitations. *Kurt Gödel* proved that any mathematical system of interest is incomplete—there will always be questions that can be asked but not answered in any particular logical system. "Chaos is, in a sense, Gödel's child,"—said *Joseph Ford*, a U.S. physicist, in an interview to *Science* (*Pool*, 1989)—because chaos theory proves that there are physical questions that cannot be answered.

A concise introduction to dynamical systems is given in Section 3. Examples of dynamical systems analysis in the field of atmospheric sciences will be presented in Part II of this paper.

2. *Definitions*

Regarding the two most fundamental concepts of meteorology, the following definitions are proposed. *Weather* is the instantaneous physical state of the atmosphere. The continually changing weather (i.e. the continuous time evolution of the atmosphere) is portrayed by the chronological succession of the physical states. We believe that there is no problem with this statement: as far as we know, no one has ever proposed a definition which was essentially different from the one given above.

The history of the concept of climate is much more complex. We do not intend, however, to enumerate here all the various definitions which have been suggested for climate. The new *WMO Vocabulary* has climate as "the manifestations of weather over a particular area and for a particular period of time". This definition may be interpreted by saying that *climate* is the ensemble of all the physical states of the atmosphere which occurred over a particular area within a suitably specified time period in the past (or will occur in the future).

This version of the definition of climate has several practical advantages:

(a) The climate as a concept is not intermixed with the method by which this concept is (or can be) characterized. In other words, we advise a clear distinction between the climate itself and the different statistical properties

(mean values, variances and co-variances, probabilities of extreme events, *etc.*) which we use for describing the climate.

(b) The definition does not identify the climate with any of the processes which are (or can be) responsible for its variations or change.

(c) The definition does not attach the climate to any prescribed time span. We are not convinced that it is a mandatory requirement to make as precise as possible the dividing line between weather and climate. Of course, if we select a time interval which is too short (e.g., shorter than, say, the characteristic life time of the large-scale disturbances in the middle latitude westerlies) then "climatic" variations become indistinguishable from the transient behaviour of the atmosphere as manifested in the continuously changing weather. The other extreme should also be excluded: when an infinite time span is selected, climatic change and prediction become meaningless concepts. Between these two extremities there appears to be no unique answer to the question of an appropriate length for the time period: climates defined in terms of widely differing time spans all constitute different aspects of the problem.

The properties outlined above are necessary conditions for the tractability of the climatic problem, if we intend to use mathematical means.

The definition of climate, in the form we have put it, is a strictly *meteorological* version of the solution of the problem—and, as such, it is not necessarily the best version. When we are investigating the physical processes which are responsible for the variations of climate, we have to make a clear distinction between an *internal* system and a set of forcing influences (or boundary conditions of the system) that can be considered as *external* causes of a change in the ensemble of states of the system. Over time scales of months and seasons, the atmosphere is the sole component of this internal system, because the processes of all the terrestrial spheres surrounding it can be treated as parts of the external driving mechanisms, which are acting as surface boundary conditions that are independent of the processes within the atmosphere. For example, an anomalous sea-surface temperature or the unusual extent of continental snow cover should be considered as potential external causes of the climate variability, because they can induce anomalies in the monthly or seasonal mean temperatures of the atmosphere. When the time scales of interest extend over years and decades, however, the atmosphere *and* the ocean should be considered *together* as internal components of the system, since on these time spans a mutual coupling develops among the specific variables of the two spheres. For even longer periods, the surface lithosphere, the cryosphere and the biomass should also be treated as portions of the internal system. This system is called the *climatic system*. On the other hand, different extraterrestrial processes (like solar activity, or changes in the earth-sun orbital geometry) and terrestrial processes (like changes in the configuration of the earth's crust, volcanic activity, or the various anthropogenic influences) which can obviously alter the ensemble of states of the climatic system, act always as *external forcing mechanisms* with no regard to the time scales we have selected.

The chain of thought described above is a part of the theory of *external causation* of climatic change, and the necessary response to modifications in the external conditions is called *forced variation* of climate. The logical outcome of the facts now summarized is twofold: first, the climate is *not* a unique notion, and second, it is *not* a simple meteorological concept. The climate should be defined in terms of an ensemble of the physical states of *all* the spheres which form the internal climatic system. Consequently, the definition of climate as an ensemble of the physical states of solely the atmosphere (which is of course the central component of the climatic system) is valid only for the monthly and seasonal time scales. For more extended time spans, variables like sea-surface temperature, or the extent of sea-ice have exactly the same right to become members of the internal state ensemble as air temperature or any other atmospheric state variables. Therefore, the concept of climate should be looked upon as a function of the time span which we intend to investigate, and, moreover, as a *geophysical* term rather than barely a meteorological one.

The extended version of the interpretation of climate may be a somewhat unfamiliar concept, and the following argument might be advanced against it. Interactions or feedback mechanisms among the diverse variables of the internal system act as internal controls of the climatic system. These complex nonlinear interactions can therefore be considered as *internal causation* of climatic change, and as these processes take place independently of any modifications in the external conditions, climatic variations due to these internal mechanisms are called *free* (*Lorenz*, 1976, 1979). Regarding the efficiency of these internal controls, *Robock* (1978) has shown that with no external forcing, internal processes alone can produce Northern Hemisphere temperature fluctuations as large as those observed for the past 100 years.

By introducing the concept of internally caused free climatic change, the extension of the meaning of climate beyond the atmosphere becomes a senseless action. On the other hand, within the *deterministic theories* of climatic change, it is compulsory to make a clear distinction between cause and effect, and *all* of the state variables of some system are assumed to be dependent on the control parameters of the system. *Dynamical systems analysis* is a deterministic approach to the problem, and the following parts of this paper will shed more light on the logic of the wider interpretation of climate.

3. Dynamical systems

In mathematical terminology a set of *n* ordinary differential equations in *n* time-dependent variables

$$dx_i/dt = f_i\,(x_j,\, u_k) \qquad \begin{aligned} i, j &= 1, 2, \ldots, n \\ k &= 1, 2, \ldots, m \end{aligned} \qquad (1)$$

constitutes an *nth-order dynamical system*, where $x_i(t)$ are state variables of the system at time t, f_i is the ith component of the field vector of the system, and u_k are control parameters of the system. Because the governing equations do not contain terms corresponding to random forces, (1) is a *deterministic system*. If the field vector does not explicitly depend upon time, as in Eq. (1), then the dynamical system is said to be *autonomous*. The dynamical system in which the field vector depends explicitly on time is called *nonautonomous*. If there exists a $T>0$ such that $f_i(x_j, t)=f_i(x_j, t+T)$ for all x_i and all t, the nonautonomous system is said to be *time-periodic* with period T. An nth-order time-periodic nonautonomous system can always be converted to an $(n+1)$th-order autonomous system by appending an extra state variable $x_{i+1}=2\pi t/T$. A nonautonomous system that is not time-periodic can also be converted to an autonomous system with any $T>0$; however, the system will necessarily be unbounded ($x_{i+1}\rightarrow\infty$ as $t\rightarrow\infty$) and many of the results from autonomous dynamical systems theory about asymptotic behaviour will not apply.

The number of independent variables needed to specify the state of a system or, equivalently, the number of independent state variables needed to describe the dynamics of the system equals the number of *degrees of freedom* of the system. Thus, the dynamical system (1) has n degrees of freedom. It is convenient to treat the x_i independent variables of this system as coordinates in an n-dimensional abstract space called *phase space* (or *state space*). A particular state of the system then becomes a *point* in phase space, while a particular time-dependent solution of Eq. (1) becomes a *trajectory* (or *orbit*).

The basic goal of dynamical systems theory is to investigate the ultimate fate of all trajectories of the system, or, in other words, to understand the asymptotic consolidated behaviour of a given system as $t\rightarrow\infty$. We follow with some further definitions (*Schewe* and *Gollub*, 1985; *Parker* and *Chua*, 1987).

Steady-state refers to the asymptotic behaviour of the system as $t\rightarrow\infty$. Dynamical systems theory requires that the steady state be bounded. The difference between a solution of Eq. (1) and the steady state of the system is called the *transient*. A point P is a *limit point* of x_i if, for every neighbourhood U of P, the trajectory repeatedly enters U as $t\rightarrow\infty$. The set of all limit points of x_i is called the *limit set* $L(x_i)$ of x_i. A limit set L is *attracting* if there exists an open neighbourhood U of L such as $L(x_i)=L$ for all x_i which are elements of U. Attracting limit sets are also called *attractors*. The *basin of attraction* of an attractor is defined as the union of all such neighbourhoods U. Every trajectory starting in the basin tends toward the attractor as $t\rightarrow\infty$.

Attracting limit sets are of special interest since the existence of nonattracting limit sets cannot be observed in real physical systems. Attracting limit sets appear as geometrical objects in the phase space toward which the system's trajectories converge in the course of time. Therefore, these limit sets are useful for categorizing the types of steady-state behaviour.

There are many possible ultimate fates (i.e. types of attractors) in a given dynamical system. Classical types of steady-state behaviour include constant solutions (stationary states) of Eq. (1) which appear in the phase space as single equilibrium points (*fixed-point attractors*); periodic solutions of Eq. (1) whose phase portraits become closed orbits (called *limit cycles*); and quasi-periodic solutions of Eq. (1) when the trajectories loop around the surface of a *torus* and eventually fill that surface (i.e., attractors are in these cases no longer single trajectories). In general, the trajectory of a quasi-periodic solution with two base frequencies lies on a two-torus; a quasi-periodic solution with base dimension p possesses an attracting limit set that occupies the surface of a p-torus.

The dynamical system (1) is *linear* if $f_i(x_j)$ is linear. In a stable linear system, there is only one attracting limit set; hence, the steady-state behaviour is independent of the initial condition. In a typical *nonlinear system*, however, there can be several attractors, each with a different basin of attraction. In these cases the initial condition determines in which attracting limit set the system eventually settles.

Nonlinear systems have always played an important role in the study of natural phenomena, but the last decade has seen a heightened interest in nonlinear systems research. This increased interest is mainly due to the recent discovery of *strange behaviour* of extremely simple autonomous dynamical systems: the surprising fact that even a well-defined *deterministic* dynamical system can exhibit an irregular, *apparently random*, "chaotic" steady state. Such a *deterministic nonperiodic behaviour* is caused by the inherent unstable nature of a nonlinear system with respect to small disturbances, as opposed to *noise*, which is the *random nonperiodic behaviour* of a system resulting from a stochastic driving force.

There is no generally accepted definition of *chaos*. From a practical point of view, it can be defined as none of the classical types of limit sets enumerated above, which are simple geometrical objects or, in mathematical terms, smooth topological submanifolds of the available phase space. The attracting limit set for a chaotic behaviour is not a topological manifold and does not have integer space dimension, but consists of an infinite complex of manifolds. An arbitrary straight line intersects the *chaotic attractor* (or *strange attractor*) of an irregular dynamical system in a Cantor set, which is an uncountably infinite set whose points are all separated by continua. Such formations, having noninteger dimensions, were invented (or at any rate clearly formalized) by *Mandelbrot* (1977) and are referred to as *fractals*.

Another property of chaotic systems is *sensitive dependence on initial conditions:* given two different initial conditions arbitrarily close to one another, the trajectories emanating from these points diverge at a rate characteristic of the system until, for all practical purposes, they are uncorrelated. Therefore, no matter how precisely the initial condition is known, the long-term behaviour of a chaotic system can never be predicted.

When the dynamical system is an *atmospheric model*, the weather becomes a point in its phase space. As the state of the atmosphere varies in accordance with the governing equations, it traces out an orbit which is the phase portrait of the changing weather. The steady-state behaviour of the atmosphere, i.e. the geometrical object in the phase space toward which the trajectory converges in the course of time, is an attracting limit set of points. It is this ensemble of states which we look upon as constituting the climate; or, more precisely, the climate which is in equilibrium with the control parameters (external conditions).

When the dynamical system is a model of the *climatic system* consisting of the atmosphere and of the appropriately selected adjacent terrestrial spheres, then the phase space of this system is spanned by all of the independent state variables involved. Therefore, each point in this space represents a state of the climatic system at a given instant (the "weather" of the system), and a trajectory gives a visualization of the evolution of the system. The steady-state (i.e. equilibrium climate) of the climatic system appears in the phase space as the attractor of the system. Note that the coordinates of this phase space are meteorological as well as non-meteorological state variables.

Points on the attractor represent those states which are compatible with the climate. Rarely visited parts of the attractor represent extreme instantaneous states. Physically unrealistic states are not on the attractor. The existence of more than one attractor of the system implies the existence of several metastable climates, and the stability of the prevailing climate can be characterized by the extent of the respective basin of attraction. To know that the system is in the basin of attraction of a metastable equilibrium is to know that it will remain for a time. To know that the system is in a state of transition is to know that it will change more rapidly and be less predictable. Climate itself becomes a question of distributions among possible attracting limit sets, and climatic change a matter of how the altered external influences (modifications in the control parameters of the system) lead to altered distribution of the attractors and their basins (cf. *Charney* and *DeVore*, 1979).

4. Concluding remarks

The new concept of "deterministic randomness" has given birth to a rapidly developing interdisciplinary field of research called *nonlinear dynamics*. Chaos, also referred to as strange behaviour, is currently one of the most exciting topics in nonlinear systems analysis. We are convinced that the application of also referred to as strange behaviour, is currently one of the most exciting topics in nonlinear systems analysis. We are convinced that the application of this approach in atmospheric sciences has already led to a better understanding of the variability and predictability of synoptic and climatic processes. Part II of this paper is aimed at demonstrating this progress with the hope that it will encourage some readers to explore deeper the yet unknown possibilities.

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The history of the DAR^{3}E weather forecasting workstation

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Abstract—DAR^{3}E is a weather forecasting workstation developed for operational use. It is the culmination of a series of prototypes developed at the Forecast Systems Laboratory. Its purpose is to better understand requirements for next-generation workstations in U.S. National Weather Service forecast offices. In this paper we describe how lessons learned from each prototype influenced the characteristics, functional requirements, and design of the subsequent workstation. We address issues of data integration, access, animation and presentation and workstation performance. We discuss how these factors influenced the evolutionary system-design process for an operational forecasting setting.

Key-words: operational weather service, PROFS, combined analysis.

1. Introduction

DAR^{3}E is part of a risk reduction effort for modernization of the United States National Weather Service (NWS) field operations. The history of DAR^{3}E begins at the laboratories of the Program for Regional Observing and Forecasting Services (PROFS).

PROFS is now part of the National Oceanic and Atmospheric Administration (NOAA) Forecast Systems Laboratory (FSL). As described by *MacDonald* (1984), it was founded in 1980 with the mandate to improve operational weather services by researching, developing, testing and transferring scientific and technological advances. Within a year, PROFS had begun to develop and

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test interactive meteorological workstations. In the ensuing decade, PROFS gained considerable expertise by developing over a dozen different workstations.

During this same period, the NWS was developing plans for modernizing and restructuring its field operations. The technological components of this modernization include an advanced Doppler weather radar network (NEXRAD), an automated surface sensing network (ASOS), next generation geostationary orbiting satellite sensors (Goes-NEXT), and a system (AWIPS-90) to process, integrate, display, and support forecaster interaction with these new and existing data sets.

As a result of the need of the NWS to better understand the requirements for AWIPS-90 (Advanced Weather Interactive Processing System for the 1990s) and the growing experience in the advanced workstation area within PROFS, a cooperative agreement was reached between these two NOAA elements in 1984. Through this agreement, PROFS would develop a functional prototype of AWIPS-90 and place it in an operational NWS environment for comprehensive analysis and evaluation. The operational environment was the Denver, Colorado Weather Service Forecast Office (WSFO). The project became known as DAR^{3}E (Denver AWIPS-90 Risk Reduction and Requirements Evaluation).

Experience gained from this and subsequent collaborative risk reduction activities has profoundly influenced both the understanding of requirements and subsequent specifications for AWIPS-90. AWIPS-90 will be developed by private industry beginning as early as next calendar year.

2. *Overview*

The domain of most of the PROFS workstations has been operational weather forecasting. In this presentation, we will briefly review a few key, early workstations that significantly influenced DAR^{3}E. We will describe how lessons learned from each iteration influenced the characteristics, functional requirements, and design of the each subsequent workstation and ultimately, AWIPS-90. We address issues of data integration, access, animation presentation and workstation performance. We discuss how these factors forced the evolutionary system-design process for an operational forecasting setting. (An overview of the systems built between 1981 and the present is shown in *Appendix A*.)

Data integration was the principal factor which originally drove the design of the early PROFS workstations and continues to affect design decisions today. Integration of the wide variety of data and products to be available to NWS operational forecasters by the mid-1990s has also been one of the primary objectives of the AWIPS-90 effort. Currently, in NWS field offices, several sensing systems have dedicated display devices, requiring the forecaster to shift attention among systems. In addition, each system may present data on different map projections and for different spatial and temporal scales. Mental integration of these multiple data sets is difficult. Such data segregation will no longer be acceptable in the data-rich AWIPS-90 era.

Animation was another of the original design drivers for PROFS workstations. Animation of meteorological data over time is critical to the rapid extraction of information. The default method of viewing products on PROFS' workstations has been to view a time series as a "film loop". When a product is selected for viewing by the forecaster, the most recent instances of that product are loaded into the display memory for immediate animation. To facilitate rapid access to multiple frames, graphics and images are stored in a "display ready" form.

Performance is a critical factor for supporting severe weather forecasting and warning functions. In 1981, the first PROFS workstation could retrieve and display ("load") a single 512x512 pixel image in about 40 seconds. Forecasters using this system unanimously agreed that this was too slow. The 1982 system improved this loading speed by a factor of six. Forecasters still felt the system was too slow. Today's DARE-II system can load images at greater than 10 frames per second (400 times faster than the first PROFS system) and graphics at about 1 frame per second. Yet, one of the most frequent comments about DARE-II is that the system should be faster, especially during severe weather.

Workstation performance has a significant impact on Forecaster Inquiry Time, defined by *MacDonald* (1985) as the time required by the forecaster to review all of the products necessary to make the correct forecast or warning decision. This becomes increasingly important as the volume of data rises dramatically in the forecast office of the future.

Data access is accomplished via menu selection for all workstations but the very first. The organization of items within menus was driven in part by the goal of data integration. User interfaces were designed to encourage a systematic approach to forecasting with products and functions grouped in a way that is meteorologically logical. For example, products are grouped by geographic scale rather than by type. This organization is based on the empirical observation that forecasters can best comprehend atmospheric phenomena by beginning with the large planetary-scale and progressing to the small mesoscale as described in *Bullock et al.* (1988) and depicted in *Fig. 1*. To achieve true integration, products grouped in each scale must have similar temporal and spatial resolutions. As subsequent systems grew in functionality and number of products, PROFS endeavored to provide the forecaster with increasingly quick, easy, and utilitarian access to functions and products.

Data presentation characteristics have been chosen to maximize forecaster understanding of represented atmospheric and weather phenomena in minimal time and with minimal effort. This implies user control over aspects of the data

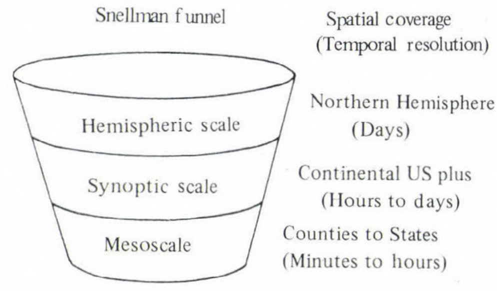

Fig. 1. Snellman funnel approach to weather forecasting

display including choice of graphic overlays on images, image combinations, color table selection, map background selection, zoom, pan, and animation.

3. *History*

The PROFS system design methodology is to iteratively build systems to test the efficacy of combinations of data sets for making mesoscale forecasts. The results of evaluating these systems then serve as useful input to the designers of next-generation weather-forecasting systems. In this brief history we emphasize issues raised in the overview as they pertain to the systems named POWS (1981), POWS82, POWS83, RT85, DAR^{3}E (1986), and DARE-II (1989).

3.1 POWS—1981

POWS is the original *P*ROFS *O*perational *W*orkstation. During the first year of PROPS, funding emphasis was placed on development of the Exploratory Development Facility, a networked computer system for data ingest and generation of display-ready products. This facility has grown over the years and is described by *Brown* (1983), *Grote* (1985), and *Mandics* (1986). It will not be further discussed here.

As described by *Beran* and *MacDonald* (1981), the emphasis for the 1981 system was on determining which combinations of products are most useful for mesoscale forecasting. Given computer-hardware costs and the need for real-time access to data, designers recognized that POWS should focus on providing diagnostic and simple prognostic information rather than locally-generated model output. Although we are approaching the ability to provide local-model output, this focus is still the case today.

After a review of existing interactive systems in research environments, PROFS developers recognized that an operational environment required a tailored, direct approach to product selection. The initial command-line oriented interface emphasized direct selection of the few available products, with no hierarchical organization superimposed.

Details of POWS and POWS82 are presented by *Reynolds* (1983). During development of POWS, it was recognized that satellite images required re-mapping to minimize navigation and viewing-angle errors. Formal evaluation and informal feedback showed that increased temporal resolution is required for mesoscale convective forecasting and that data assimilation and objective techniques required improvement.

As described by *Leserman* (1991; unpublished manuscript), weather forecasting imposes a high cognitive load. Under stringent time constraints, the forecaster must (1) access, view, and assimilate data from a variety of sources and in an assortment of forms; (2) formulate hypotheses for the progression of atmospheric conditions; and (3) compose and issue a spectrum of forecasts. A major insight, resulting from evaluation of the original POWS and reflected in the design of all subsequent systems, was the importance of system ease-of-learning and ease-of-use to mitigate this cognitive load.

3.2 POWS82—1982

Intended to address the ease-of-learning and ease-of-use issues, the major modification in the 1982 system was the introduction of a menu to replace the command-line user-interface. This menu, displayed on a color graphics terminal, was populated with "buttons" that could be selected with a light pen. The buttons were grouped into fixed regions of the menu called panes. (A schematic of pane organization is shown in *Fig. 2.*) Selection of a button with the light pen would invoke the presentation of a particular product, control some aspect of the display such as animation speed, or cause the contents of another pane to be modified.

POWS82 introduced hierarchical organization of products based upon the Snellman funnel approach, depicted in Fig. 1. One pane was dedicated to product selection and contained all the product-selection buttons for a single meteorological scale. Another pane contained buttons for selection of one of the four POWS82 scales. These scale-buttons were used to control the contents of the product-selection pane. Yet another pane contained animation control buttons for speed, first frame dwell, and so on. In POWS82 the product selection pane doubled as a region to display text products. This was very inconvenient and in POWS83 an additional screen was added to the workstation for text product display.

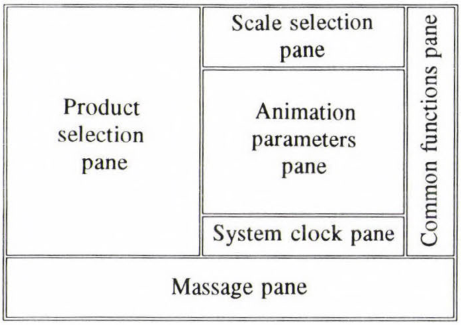

Fig. 2. Schematic of menu pane organization for early workstation

The POWS82 menu simplified data access and the control of data presentation. The organization of buttons on the menu superimposed structure on the forecast process by making it easy to step through meteorological scales. Difficulties were related to poor performance of the light-pen, slow system response, and lack of feedback. For example, once the user selected a product button, it would take several seconds to begin to load that product to the display. In the interim, the user would wonder whether a valid light-pen "hit" had occurred and might re-select the button, thereby re-initiating the load process.

3.3 POWS83—1983

It was recognized that less-than-superlative performance would continue to be the norm because of hardware availability and costs, the large size of image products, and processing requirements. Therefore, in 1983 a special-purpose User Interface Management System (UIMS) was developed to address feedback requirements and other human factors issues. As described by *Leserman* (1991), this UIMS would serve as the platform for the user-interface for POWS83 and subsequent systems including RT85 and the first DAR^3E workstation. Using the UIMS, menus for subsequent systems would be specified using a graphical editor for creation and location of menu panes and buttons. Some workstations were built using the UIMS editor only—not a new line of code was written.

All user-feedback was handled within the UIMS software component. For example, when a product-selection button was selected, it would immediately change color and shape, informing the user that a valid hit had occurred. Then, during the process of loading the product from mass storage to display memory, the product-selection button would flash. When the load was complete, the button would stop flashing but retain the shape and color associated with selection. As reported by *Schlatter et al.* (1985), most forecasters became comfortable with this new user interface within an hour.

In POWS83, the somewhat unreliable light pen was abandoned in favor of a touch screen. The touch screen was more reliable, but not sufficiently so. Also, forecasters working normal shifts found use of the touch screen to be physically fatiguing.

A well-received addition in POWS83 was the "green" time that appeared next to each product selection button. Each such four character time-string is automatically updated to display the observation time of the most recent instance of a product to arrive in the database. Green times serve as a highly visible product notification and inventory mechanism and are still in use in current workstations.

The hierarchy imposed on menu item organization (beginning in 1982) allowed buttons for many products and functions to be available within limited screen space. As the number of products, functions, and applications increased in subsequent systems, the hierarchy got deeper. As this happened, specific buttons became harder for the user to locate. Therefore, menus starting with POWS83 were organized to minimize the depth of the hierarchy. The POWS83 touch-screen interface to the manus imposed a limit on the minimum button size. In later workstations a mouse replaced the touch screen, allowing a smaller button target. Thus, more buttons could fit on the screen and a shallow hierarchy was preserved, even with an increasing number of buttons.

Sluggish workstation response was still a problem in POWS83. Improvements were needed in the speed of image and graphic product loading and in the redraw rate for menu panes.

3.4 RT85—1985

The RT85 system introduced two major changes from previous systems. First, the touch screen was replaced with a mouse for the selection of products and functions. Also, a second meteorological product display was added to the workstation. Both changes had profound affect on workstation use and both remain through the current DARE-II realization.

Mouse. The use of the mouse as the menu selection device was immediately accepted by all users as a significant improvement over all previous selection methods. It was easy to master and not tiring to use. More importantly, it accommodated more buttons per menu-hierarchy level as described above. This was important because of a growing product set and the addition of duplicate controls for the second meteorological display.

Display controls. Unfortunately, the duplication of display controls within a single menu created confusion for the user of the workstation. Because the product-selection buttons were not also duplicated, the user needed to first select a button indicating the destination display of the next product selection. Pre-selection of the display-destination button was frequently omitted because the user's attention was focused on the forecasting task, not on control of the workstation. The irritating result was that products were often unintentionally loaded to the wrong display, possibly forcing unintended erasure of previously loaded products.

For example, a forecaster might load an 8-frame satellite-image color table, changing the color of overlays, setting the loop rate, zooming in for detail, and so on. The forecaster might then decide to compare this data with, for example, the latest Doppler radar reflectivity image loop on display number two. We observed that the typical forecaster selection sequence was as follows: decide which product to look at next, locate its button on the menu, and select it. Since, in this sequence, the display-destination was not explicitly changed, the Doppler product selection would replace the carefully adjusted contents of display number one.

This problem created a high level of user frustration and, surprisingly, it did not diminish substantially with user experience. Furthermore, the problem was exacerbated in heat-of-battle situations, when it could be least afforded. The problem was so acute that it became a design driver for subsequent systems. It was reduced in DAR^{3}E by changing the "load order", that is, product-button selection did not directly load the product as in previous workstations. Rather, after product selection the forecaster was required to explicitly select the appropriate display and that subsequent action caused all selected products to be loaded. Although this revised procedure reduced user frustration, it increased the number of step in the load process. Elimination of this new problem became a design driver for DARE-II.

3.5 DAR^{3}E—1986-1989

The design of the first DAR^{3}E system was based on the RT85 system. However, the purpose and objectives of DAR^{3}E were significantly different from any previous PROFS workstation. The purpose was to develop a prototypical AWIPS-90 workstation based on a set of functional requirements developed by the NWS. The primary objectives were 1) to fully support the public forecast function at the Denver, Colorado WSFO (Weather Service Forecast Office) and 2) to provide insight into AWIPS-90 design and performance requirements along with associated NWS modernization transition issues. Installed in the Denver WSFO in the fall of 1986, DAR^{3}E physically replaced the existing, operational, "AFOS" console which supported the public forecast function. DAR^{3}E then supported that function for three years.

DAR^{3}E introduced into an operational environment for the first time, many of the advanced data sets planned for the modernized NWS. This included a suite of radar products from NCAR's 10-cm CP-2 Doppler. The CP-2 data were processed to simulate a subset of products that would eventually be provided to NWS offices by NEXRAD.

Deployment in an operational setting demanded more stringent requirements for system reliability and functionality. Data sets had to be produced continuously to support around-the-clock operations. DAR^{3}E was not a summertime, daytime operation as were most previous PROFS exercises which had focused exclusively on short-range (0-12 hour) forecasts and warnings for a limited area (Eastern Colorado). The Denver WSFO has a much longer period and larger area of forecast and warning responsibility. All data and functions required to support this responsibility, but which were not in RT85, were added to this system. Three new product scales and hundreds of new products were added, including a full suite of operational text and graphic products. A new text workstation was developed to complement the graphic/image workstation. Although a significant enhancement, this new text workstation will not be discussed here.

Data access. Graphic products will play an increasingly important role in modern forecasting. The number of graphics available on DAR^{3}E increased by an order of magnitude over RT85, to more than 400. By the AWIPS-90 era this number will increase by more than another order of magnitude. Existing methods of graphic product selection were not adequate to allow the user to view a fraction of the available graphics in the time allowed for the forecast formulation process. More effective data access and display methods were needed. DAR^{3}E introduced the first effort to improve access to graphics through a concept called "family graphics".

A graphics family is a group of related graphic fields combined for easy access and presentation. For example, one family might contain several fields from a single numerical model. Families were implemented as an 8-frame animation-loop of 8-bit images with each field embedded as a single bit plane. Thus, up to 64 individual graphic fields (including the map background) could be rapidly loaded with a single button selection. An easy means to independently toggle the visibility of each field allowed the forecaster to view, in animation, any combination of the fields which made up that family. Several families of graphics were automatically generated with DAR^{3}E, including single-model and model-comparison families. *Heideman et al.* (1989) report that this new method of data access proved to be one of the most popular features of the DAR^{3}E system, especially during non-convective periods.

Display controls. For improved workstation interaction, DAR^{3}E introduced a specially designed keypad-and-trackball input-device called a "trackpad". Each graphic/image display had a dedicated trackpad. This was considered a significant improvement over previous interactive methods because it allowed the forecaster to control the data display (e.g., zoom, toggle overlays, and step through frames) without removing eyes or attention from the display. A victim of its own success, the trackpad suffered wear from very heavy use and was soon replaced by a strengthened version.

Data presentation tradeoffs. Animation was enhanced in DAR^{3}E by providing loops of up to 32 frames in length on each display. However, in order to achieve this new capability, we faced an interesting data-presentation dilemma. This involved tradeoffs of loop length, workstation performance, and data resolution. Understanding this dilemma requires a brief description of the hardware used and our allocation scheme for display hardware resources.

The two graphic/image displays of DAR^{3}E were controlled by a single graphics device, with display memory organized as 32 bit planes of 1024 by 1024 pixels. Each graphics/image display was assigned 16 of these 32 planes. This memory resource was automatically allocated, but depended on the loop length and product requests of the user. For example, if the selected loop length for a display was 4 frames, then, each frame being 512 by 512 pixels and each pixel being 8 bits "deep", 8 bit planes of that display would be allocated to each of the 4 frames. Four more bit planes for that display would be reserved for the map background and up to three one-bit-deep graphical overlays. The last 4 planes were not used in 4-frame mode.

Table 1 shows how bit planes were allocated for loops of 4, 8, 16 and 32 frames. For 8 and 32 frame loops, addition of the map background and graphic overlays degraded the image in the number of bits available per pixel. This is equivalent to a reduction in the depicted precision of the data value for each pixel. For 16 and 32 frame loops, the spatial resolution was also reduced, from 512x512 to 256x256, quadrupling the areal coverage of each pixel. Thus, resolution of images in 32 frame loops was degraded in both spatial and pre-

Table 1. Allocation of display memory for RT85

Bit plane	4 frame loop	8 frame loop	16 frame loop	32 frame loop
1	512x512 image	512x512 image	256x256 image	256x256 image
2	"	"	"	"
3	"	"	"	"
4	"	"	"	"
5	"	degrading overlay 3	"	degrading overlay 3
6	"	degrading overlay 2	"	degrading overlay 2
7	"	degrading overlay 1	"	degrading overlay 1
8	"	degrading map background	"	degrading map background
9	graphic overlay 3	512x512 image	graphic overlay 3	256x256 image
10	graphic overlay 2	"	graphic overlay 2	"
11	graphic overlay 1	"	graphic overlay 1	"
12	map background	"	map background	"
13	unused	degrading overlay 3	unused	degrading overlay 3
14	"	degrading overlay 2	unused	degrading overlay 2
15	"	degrading overlay 1	"	degrading overlay 1
16	"	degrading map background	"	degrading map background

cision dimensions. An 8 or 32 frame image loop with three overlays resulted in severely degraded imagery. The tradeoff resulted in inconsistent presentation of products—a situation we were trying to avoid.

In addition to product resolution degradation, frame loading speeds had not been increased from previous systems. It could take over two minutes to simply load a 32 frame loop, a very high cost for operational forecasting. Despite the degradation problem, the most frequently selected loop length was 8 frames because it could be loaded relatively quickly (in about 30 seconds) and because it retained the full 512x512 spatial resolution. Loop lengths greater than 8 frames were infrequently used. Thirty-two frame loops with overlays were almost never used. This design tradeoff of display memory resources became an issue again with DARE-II.

3.6 DARE-II–1989-present

DAR^3E was replaced at the Denver WSFO in the fall of 1989 by the next generation system, DARE-II. The DARE-II development represented a dramatic departure from the previous PROFS workstation iterations. First, it involved a complete redesign and re-implementation, dropping the User Interface Management System (UIMS) software developed with POWS83. It incorporated a new hardware platform, independence of the two image/graphic displays, and a new user interface with menus overlaying each image/graphic display. Second, DARE-II was not just a new workstation, but a complete meteorological system with multiple workstations, data ingest and data storage subsystems, and distributed processing on its own independent local area network (LAN).

DARE-II was built for continued support to the NWS modernization risk reduction activities. The primary purpose was to move the Denver WSFO closer to an AWIPS-equipped office to allow the NWS to better understand and prepare for operational and transitional issues associated with modernization. When installed in the Denver WSFO, it completely replaced the original DAR^3E, as well as all other consoles supporting office functions.

Performance. Performance of the original DAR^3E workstation at Denver was minimally acceptable, especially during severe weather. Therefore, as described by *Bullock* and *Walts* (1991), performance considerations drove many of the design decisions for DARE-II. To enhance performance, each DARE-II workstation has a dedicated host processor, and each image/graphic display has a dedicated display processor. This provided true workstation and screen independence which was also a critical factor for reliability.

In addition, each animation workstation has a local, dedicated, high-performance image disk on which all (several thousand) current satellite and radar images are stored. Image frames of 512x512 resolution can be retrieved from this local disk at a rate of up to 30 images per second. Benefits of this architecture are speed and reduction of traffic on the LAN. Additionally, it allows for "graceful degradation" since the only penalty for a complete failure of an image disk is in performance, not functionality. Thus, the distributed nature of the DARE-II architecture, with redundant processors for each critical function, ensures both high reliability and performance during critical weather situations.

Data access. As a result of the product selection problems described above and because of the large increase in the number of products with (over 10,000 total), the DARE-II user interface was completely redesigned. The most apparent change is that menus are no longer on a dedicated display, but are fully integrated as an overlay on each meteorological display. The visibility of the menu overlay may to toggled with a press of a mouse-button. This presentation of menus simplifies the product-selection process and clarifies feedback regarding the display state.

The new menu system is displayed within moveable, overlapping windows, not the fixed panes of previous systems. Thus, although the new menus maintain the hierarchical approach, the user, is free to "tear-away" components from the location of original display. Components that are so "torn" and relocated, remain on the screen, even when higher levels of the hierarchy are removed. This allows the forecaster to tailor the menus for personal preference or a particular forecasting scenario such that there is always direct access to frequently requested products. It also allows forecasters to monitor the receipt of products of interest via the product arrival ("green") times that are displayed within each product button and updated dynamically upon receipt of a new version. In severe weather situations, forecasters can watch for receipt of a critical product and then, with a single mouse click, load that product into the display in seconds.

Another important data access feature of DARE-II involves the concept of "bundles". The state of a graphics/image display at any time is called a bundle. It includes loaded products and their attributes (e.g., loop length and color table). A dynamic "recall list" stores the last 10 bundles for each display. Any bundle from that list may be re-displayed with a single button selection. Static bundle lists (called procedures) may be constructed by the forecaster for recall at any time. As the forecaster steps through one of these procedure lists, the most recent products for each bundle will be loaded to the display. Procedures may be constructed for a variety of weather events, seasons, or personal preferences.

The DARE-II user interface also includes an improved matrix-menu for selection of display-ready graphic products and generation of graphics for gridded fields. This matrix menu is user-tailorable, allowing selection of models, levels, and fields. Within the tailored menu, shortcuts are provided for loading comparative animation sequences.

4. Summary and conclusions

Interactive, real-time, meteorological workstations have come a long way during the last decade—from workstations with very limited functions, limited data sets, and cumbersome user interfaces to the modern workstations of today. The keys to modern workstation design include full integration of data sets, a functionally efficient user interface, high system reliability, and overall system performance (speed, speed, and more speed).

Through the iterative process from POWS82 to DARE-II, PROFS has worked very closely with the operational meteorological community. Feedback from operational forecasters performing real forecasting and warning tasks in real time provided the basis for changes to each subsequent system.

Many of the lessons learned during this process have been incorporated into the specifications for the AWIPS-90 systems which will be developed by private industry for the NWS.

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APPENDIX A PROFS/FSL meteorological workstations

System Season of first use *# of products*	Primary use(s) and evaluation techniques.
POWS Fall 1981 *~15 products*	Controlled exercise using canned data sets made available in simulated real time. Informal feedback from test subjects.
POWS82 Summer 1983 *~25 products*	Re-implementation of POWS with improved user interface.
POWS83 Summer 1983 *~100 products*	Three month, real-time, summer-season, controlled exercise conducted by research and professional forecasters to evaluate system and data for convective weather.
MERIT Fall 1983 *~1,000 products*	Evaluation of techniques for least fuel-consumption routing of aircraft considering the weather and atmospheric scenarios.
Hi-Res Radar Test Winter 1983-84 *~8 products*	Evaluation of the efficacy of high resolution radar data sets.
Cool Season Test Winter 1983-84 *~100 products*	Controlled exercise to test the efficacy of data sets oriented to winter weather scenarios.
ARTCC System Summer 1984 *~100 products*	Two year operational evaluation by the staff meteorologist at the Denver Federal Aviation Administration (FAA) Air Route Traffic Control Center (ARTCC).
RT85 Summer 1985 *~400 products*	Second, more extensive, three month, real-time, controlled, summer-season exercise.
DAR^{3}E Fall 1986 *~2,000 products*	Three year operational validation by the Public Forecaster in the Denver National Weather Service (NWS) Forecast Office to evaluate the system as part of a risk reduction effort for next generation NWS forecast office technology.
POWER Spring 1987 *~400 products*	(1) Intended as an affordable system for research meteorologists. (2) Spring-season exercise at the National Severe Storms Laboratory in Norman, OK.

SERS Summer 1987 *~400 products*	(1) National Center for Atmospheric Research test at Stapleton International Airport for wind-shear detection. (2) Installed for teaching at Colorado State University. (3) Rotated through National Weather Service offices for training.
Joint Ice Center Summer 1989 *~200 products*	Operational use by Ice Analysts at the Navy/NOAA Joint Ice Center. Hardcopy output faxed to ships.
DARE-II Fall 1989 *~10,000 products*	Functional prototype of AWIPS-90 system supporting all functions in the Denver, Colorado Weather Service Forecast Office (WSFO). In January 1991, a second DARE-II system was installed in the Norman, Oklahoma WSFO to validate infrastructure to support a modernized NWS.
PC System 1990 *~2000 products*	Low-cost implementation of operational meteorological workstation with much of the functionality of DARE-II.

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A combined bispectral cloud analysis using digital data from MOS-1

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Abstract—It is aimed to determine cloud amounts and types by satellite information. The study has been performed using visible and infrared band digital images taken over Europe on July 26, 1988 by Japanese satellite MOS-1. It is decided by using threshold values based on histograms of signal intensities whether a pixel is cloudy or cloud-free. The cloud amounts are estimated for a square network of 25 pixels x 25 pixels (area of approximately 2500 km^2). We investigate at what degree the cloud amounts computed from the visible and the infrared images coincide. In 68 per cent of the cases the difference is within ± 10 per cent. The cloud types are defined for a square network of 5 pixels x 5 pixels, with spatial resolution of about 100 km^2 by simultaneous use of the visible and infrared images and a coherence test carried out in the infrared image. Altogether 15 cloud types are differentiated. The cloud analysis discovered that the frontal cloud band over Ukraine was inactive and the Balkan Peninsula was covered by convective clouds with various development, the most mature element of which was a meso-scale convective complex (MCC) over the Southern Carpathians.

Key-words: cloud analysis, satellite, MOS-1.

1. Introduction

Correct knowledge of the cloud field is of principal importance for both the weather forecasting and climate studies. However, the conventional ground observations can give information about only 10-20 per cent of the cloud coverage. On global scale the only feasible way for acquiring homogeneous data on clouds in spatial and temporal continuity is to exploit satellite data. In order to infer reliable climatological characteristics of the cloud field on global scale *International Satellite Cloud Climatology Project* (ISCCP) was created in which the prime data source was considered to be satellite information. For characterizing the cloud field, cloud amounts, types are used and as new parameters the cloud top temperature (height) and optical thickness are introduced.

Satellite data on clouds are provided by imagery in visible and infrared bands. It is decided by various techniques whether a given pixel is cloud-free or cloudy (and to what extent). In the framework of the ISCCP nine cloud classification methods were developed (*WMO/ICSU,* 1984). Most of the methods is bispectral, based on simultaneous use of visible and infrared images. The simplest decision model is the so-called threshold technique in which a pixel is assumed to be cloud-free or cloudy by only count value (threshold value). In more complicated approaches the results of model computations are already incorporated. The analyses aiming at the exactness require application of correction with respect to sun- and satellite-zenith angle variations. Of the attempts the methods based on brightness histograms are capable of finding natural clusters in the cloud field. A further possibility for cloud detection is a coherence test made in the infrared images.

In the last decade the satellite cloud studies in Hungary were conducted in three ways. First, digitized analog images were used as in work carried out in common with the Institute for Computer Technics (*Tänczer* and *Hegedűs,* 1980, 1981) and in the paper published by the Meteorological Department of Eötvös Loránd University (*Császár,* 1988). Second, visual evaluation of analog images was performed for establishing climatological characteristics of the cloud coverage Europe (*Tänczer,* 1988). The third way is the up to date approach, cloud investigation by using digital satellite information. Since the digital satellite receiving station has been installed in the near past so far only such studies could be performed which were based on data set received by other meteorological services. Of these we should mention our method developed for determining cloud amounts in METEOSAT visible images (*Tänczer et al.,* 1988, 1989) and the present work itself.

2. *Analysis of the cloud field*

2.1 Data base

Digital data from Japanese satellite MOS-1 were acquired by financial support of the National Committee for Technology Development in Hungary. This satellite, among others, takes imagery in visible spectrum with resolution of 900 m, in infrared spectrum (11 μm) and water vapor absorption band (6,3 μm) with resolution of 2.7 km. Though the images mainly exhibit cloud-free areas a narrow part of one image on July 26, 1988 at 9.34 UTC is covered by pretty variable clouds. It was aimed to accomplish an automatic, objective analysis of the cloud field at that time on computer. The fact that only case was the object of the study, however, restricted possibilities of the work. The used pictorial sector included a part of Eastern Europe (*Fig. 1*) and consisted of 350 lines and 590 coloumns. (For displaying the area on TV monitor the image was turned away by ninety degrees.) To enlarge the reliability and the quality of the graphic analysis the image data were averaged for subwindows of 5 pixels x 5 pixels. In such a way the investigational area was reduced to 70x118=8260 pixels with resolution of approximately $8x12 \approx 100$ km^2.

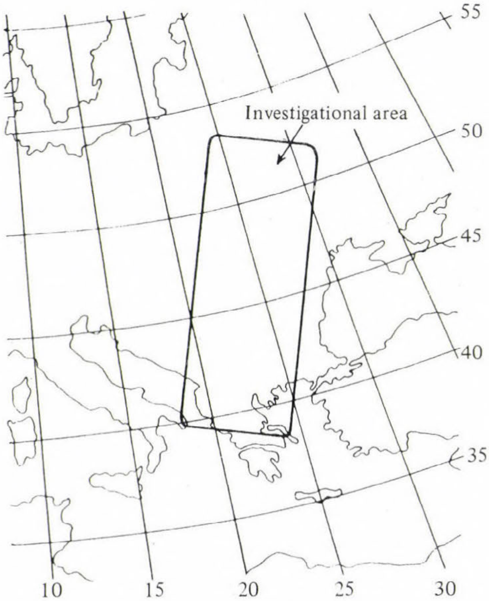


Fig. 1. Location of the investigational area

2.2 Definition of cloudy areas

In the cloud analysis a bispectral approach was chosen. It may be expected that this technique yields significantly better results than if either visible or infrared images are only used. As known in the visible spectrum the brightness of clouds is depending on the illumination and the albedo, and the latter is related, first of all, to the cloud thickness. At the same time, in the infrared images the brightness of clouds is mainly determined by cloud top temperatures (heights).

The definition of cloudy pixels and the separation of clouds with respect to their thickness (albedo) and height (top temperature) have been based on histograms of signal intensities which are shown in *Figs. 2* and *3*, respectively. We endeavoured to assume the threshold values on the basis of the frequency distribution as far as it could be done. The relatively large extent of the investigational area and inside that the variation of meteorological conditions (mainly the thermal state of the atmosphere) prevented the appearance of regular clusters. Corrections (with respect to changes of sun elevation, satellite zenith angle and temperature conditions) and division of the area onto subdomains needed in such studies were not made because of their complexity. The

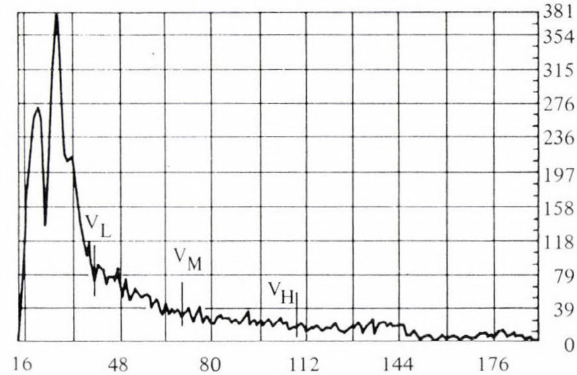


Fig. 2. Frequency distribution of signal intensities in the visible image indicating the threshold values (V_L, V_M, V_H) separating clouds of different levels

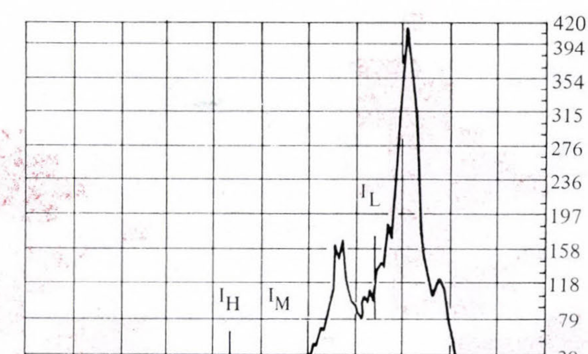


Fig. 3. Frequency distribution of signal intensities in the infrared image indicating the threshold values (I_L, I_M, I_H) separating clouds of different levels

surface albedo could not also determined by searching the minimum value in its time series. This step would have allowed for estimation of the subpixel cloud cover which was disregarded in the study. In view of these eliminations the model presented may be considered as a first approximation to the problem. However, the advantage that it can be rapidly realized enables to use in the operational work as well. After some considerations (taking into account the ground-based surface temperatures in the infrared image and the necessity of accordance of cloudy pixel numbers in both the images), the threshold values of cloudy pixels were assumed to be $V_L=38$ in the visible image and $I_L=151$ in the infrared image. Consequently, pixels were judged as cloudy where condition $V_L>38$ or $I_L<151$ was fulfilled. The thresholds are marked in Figs. 2 and 3.

2.3 Determination of cloud amounts

It is reasonable that cloud amounts be determined in accordance with ground-based observations. Therefore the cloud amounts were produced for nonoverlapping boxes of 25 pixels x 25 pixels (approximately 40x60 km). Thus the erroneous definition of one pixel is included in the estimated cloud amount with weight of only 0.0016. To display results, assuming 25 per cent intervals (0-25, 26-50, 51-75 and 76-100), four categories were differentiated as earlier used in conventional nephanalyses. Maps of cloud amounts obtained from visible and infrared data are depicted in *Figs. 4a* and *b*, respectively.

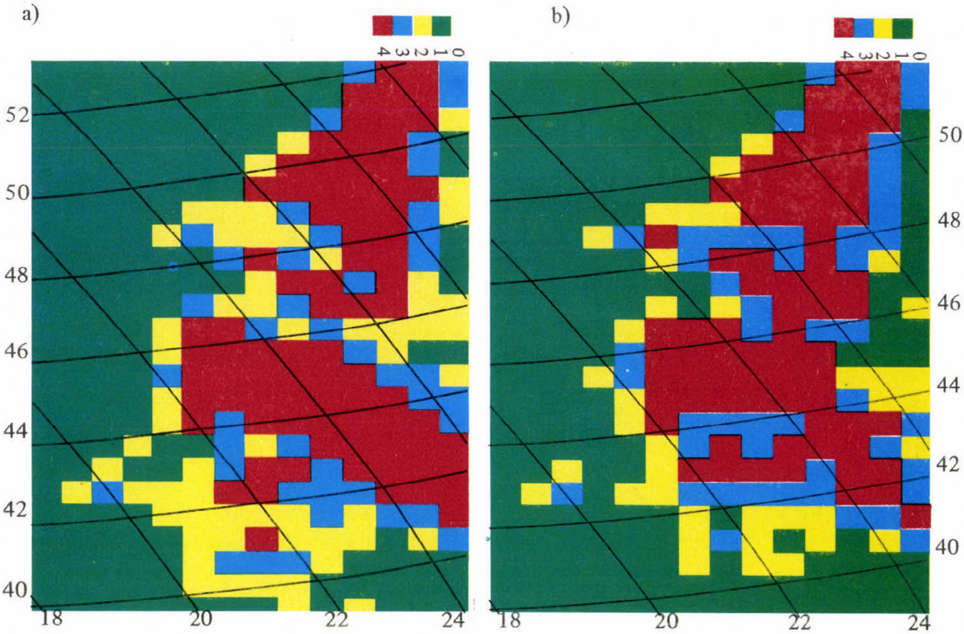


Fig. 4. Cloud amounts expressed in percentage, based on the visible image *(a)*, and infrared image *(b)*, MOS-1 on July 26, 1988 at 9.34 UTC. 1: 0-25, 2: 26-50, 3: 51-75, 4: 76-100. A picture element covers an area of about 2,500 km²

The agreement between the two fields is conspicuous. Two large continuous covered areas are observed: (1) in the upper right part and (2) in the middle-lower right part of the images. The former area is associated with a cold front whereas the latter is related to a well developed convective activity and a mesoscale convective complex (MCC) within that. In the bispectral analysis only those pixels are used to assume to be cloudy which are supported by both the threshold values. In the present paper such restriction was not made in order to take the measure of the agreement between the two fields. The result of the comparison is illustrated in *Table 1.*

Table 1. Frequency distribution of the difference of cloud amounts computed from visible and infrared data (N_V - N_I) in terms of pixel numbers (n) and percentage of cases (p)

	<-50	-50 - -31	-30 - -11	-10 - +10	+11 - +30	+31 - +50	>50
n	0	75	800	5655	1505	225	0
p	0	1	10	68	18	3	0

In 68 per cent of cases the difference is below ± 10 per cent but already 96 per cent is found within limits of ± 30 per cent and no case exceeding ± 50 per cent occurs. In the visible image the cloud amounts are somewhat greater than in the infrared one. This fact can be explained by an assumption that the threshold value I_L in the infrared image indicates clear skies in the southern territories at occurrence of low clouds because of the higher temperature of the lower troposphere. Later, when studying the vertical stratification of the cloudiness we shall be convinced of reality of the assumption. Pixels with greater cloud amounts in the infrared image occur mainly in mountainous regions (due to the lower surface temperatures).

2.4 Definition of cloud types

Analysis of cloud types was implemented for the 8260 pixels (i.e. with resolution of about 100 km^2). The most marked separation was expected with respect to cloud heights (temperatures). In the histogram of the infrared image (Fig. 3) we assumed those threshold values empirically which separated the low, medium and high clouds (I_M=128 and I_H=102). On the basis of these values we studied the stratification of clouds with the height which has been shown in *Fig. 5a.* It can be seen that the cloud field mainly consists of low clouds but in the central (over Southern Carpathians) and lower part (over Macedonia) of the image cumulonimbi with high vertical extension are found.

Analogously to the infrared image the brightness values of the cloudy areas in the visible image were separated into three categories (assuming thresholds of V_M=68 and V_H=108). In *Fig. 5b* the separation of clouds with respect to their albedo (thickness to a good approximation) may be observed. It can be established that the thickness of the clouds compared to the cloud top temperature indicates a more definite variability. Along the axis of the cloud band, in the upper part of the image, the cloudiness is thicker than in its edges while the cold clouds in the central and lower part of the image verify the pres-

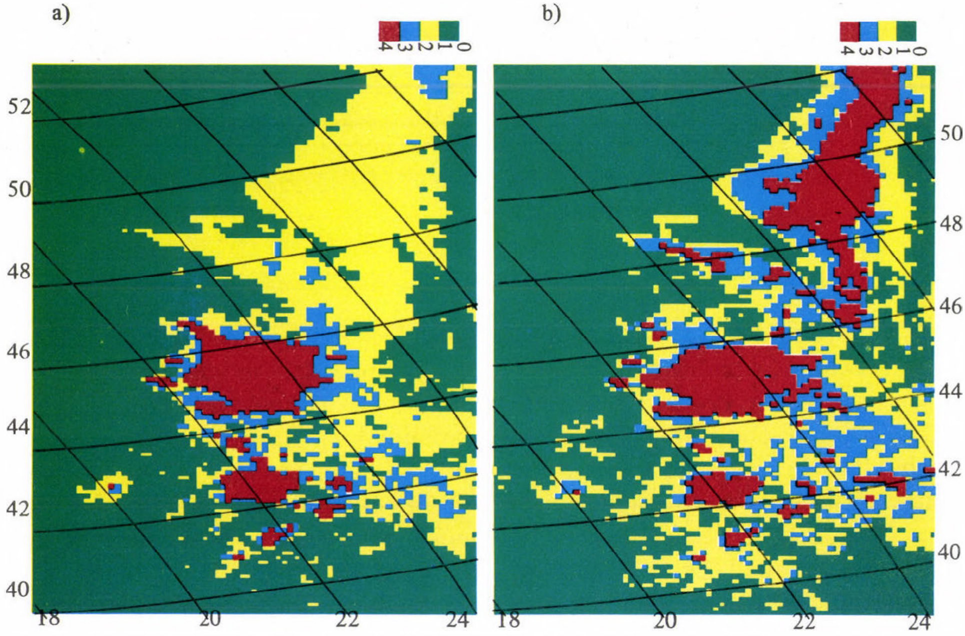


Fig. 5. Images separated into brightness categories, MOS-1 on July 26, 1988 at 9.34 UTC *(a)* infrared image, 1: ground surface, 2: low cloudiness, 3: medium cloudiness, 4: high cloudiness; *(b)* visible image, 1: ground surface, 2: thin clouds, 3: medium thick clouds, 4: very thick clouds. A picture element covers an area of about 100 km^2

ence of cumulonimbi there. After combining the visible and infrared data the pixels may be classified into sixteen boxes defined by the threshold values. The frequency distribution of signal intensities within the boxes is shown in *Table 2*.

The dark warm area are located in the left lower part of the table whereas the very bright cold clouds in the right upper part of the image. The area covered by different categories can be easily estimated, e.g. the area of clear skies amounts about 450,000 km^2 while that of cumulonimbi is approximately

Table 2. Bispectral frequency distribution of signal intensities

IR				
	0	21	85	330
102				
	0	111	199	100
128				
	186	955	702	391
151				
	4542	634	4	0
	38	68	108	VIS

33,000 km^2. It is noteworthy that the frequency in the left lower corner (dark, cold area) and in the right upper one is practically zero.

We intended to complete the analysis of cloud types by a coherence test, computing root mean squares (rms) of signal intensities for 5 pixels x 5 pixels subwindows. It is expected that areas with high coherence (low rms) would correspond to clear skies and those with low coherence (high rms) to cloudy areas. In addition, within the cloudy area a difference in the rms values should exist in dependence on that if there stratiform, cumuliform or multilayered cloudiness is present. The frequency distribution of rms is illustrated in *Fig. 6a* for the visible image and in *Fig. 6b* for the infrared image. It is conspicuous that the rms values scatter in a greater interval in the visible image than in the infrared one. This fact may be explained mainly by the presence of shadows in

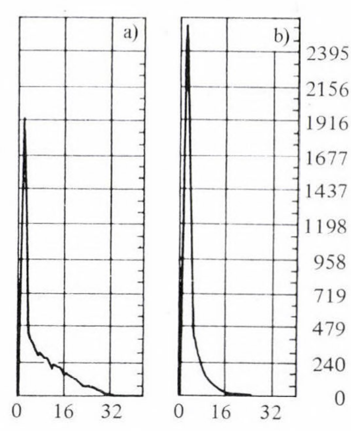


Fig. 6. Frequency distribution of rms values of signal intensities *(a)* in the visible image, *(b)* in the infrared image

the visible image. For this reason the rms values in the infrared image were only used in the analysis such as in the original method by *Coakley* and *Bretherton* (1982). The coherence test was then made in such a way that after separating the cloudy and cloud-free pixels on the basis of the visible image we differentiated domains with low and high values of rms. The separating threshold value of rms was assumed to be $\sigma_k = 3$. The result of this test is depicted in *Fig. 7.*

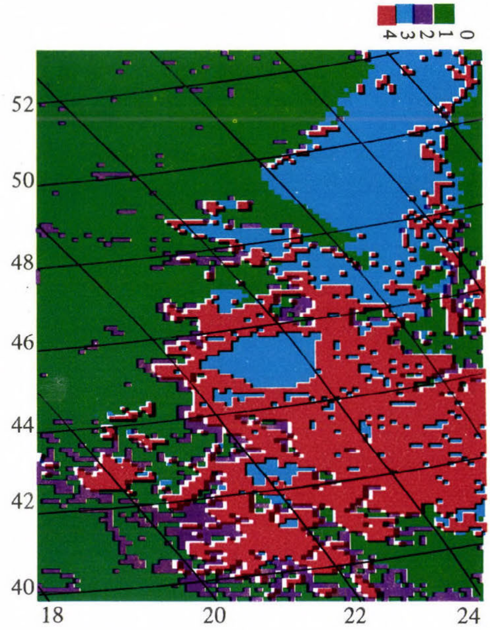


Fig. 7. Roughness of the infrared image, based on a coherence test, showing the distribution of rms (σ) values, MOS-1 on July 26, 1988 at 9.34 UTC. 1: ground surface with $\sigma \leq 3$, 2: ground surface with $\sigma > 3$, 3: cloudiness with $\sigma \leq 3$ (one-layered stratiform clouds), 4: cloudiness with $\sigma > 3$ (cumuliform or multi-layered clouds)

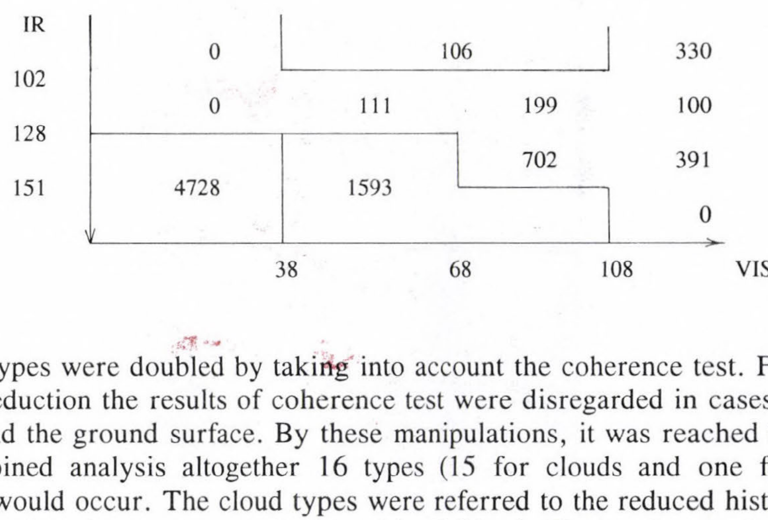
Fig. 7 clearly demonstrates that the low rms values may be attributed to cloud-free areas. There are excepts for regions of the mountains and the seaside. It looks well that the frontal cloud band basically consists of stratiform cloudiness and over the Balkan Peninsula there are cumuliform clouds. It is interesting that the coherence test assigned the MCC to be stratiform. This fact may be explained by the mature stage of the cloud system, i.e. by reaching the tropopause and stretching on it. The horizontal extent with diameter of about 200 km is large enough to give low rms values.

2.5 Combined cloud analysis

The combined cloud analysis was carried out on the basis of brightness values of the visible and infrared images and of the coherence test. As in both the images four categories were differentiated existence of 32 cloud and surface types would be theoretically expected. In the displaying technique, because of our printing equipment, however, only 16 colors might be used, therefore the number of the types had to be reduced significantly.

The reduction was made on the basis of practical consideration with reliance on Table 2. Of 16 categories three are fully lacking, therefore they may be eliminated. Two categories of cold brightness temperatures and low frequency (representing Ci clouds) are supposed that may be joined. Two categories of low albedo (evidently cloud-free areas) are considered to be one type as well. In our opinion it is also acceptable to combine the two categories of less bright, low level cloudiness (lower two lines of the second coloumn), and even to supplement it with the category of the lower line implying only four cases. The reduced bispectral frequency distribution prepared in such a way is shown in *Table 3*.

Table 3. Reduced bispectral frequency distribution of signal intensities



The types were doubled by taking into account the coherence test. For the further reduction the results of coherence test were disregarded in cases of Ci clouds and the ground surface. By these manipulations, it was reached that in the combined analysis altogether 16 types (15 for clouds and one for the surface) would occur. The cloud types were referred to the reduced histogram and rms values in the manner indicated in *Table 4*. Finally the result of the combined cloud analysis is presented in *Fig. 8*.

Based on the combined analysis, the following features of the cloud field can be ascertained. Over West Ukraine cloud system of a weak, inactive cold front extended only in the lower troposphere was situated. In the middle part of the cloud band the cloudiness is thicker than in its edges (the cloud band is vertically thinner at its eastern side). In the northern part of the band a Ns with

Table 4. Cloud types assigned on the basis of the combined analysis (see Table 3). On the left (right) side types with high (low) coherence are found

$\sigma \leq 3$

IR ↓ / VIS →			
0	Ci		Mature expanded Cb
0	As trans	As op	Ns
Ground surface	Fog or thin St	St	Thick St
			0

$\sigma > 3$

IR ↓ / VIS →			
0	Ci		Devel-oping Cb
0	Ac	Multi-layered Ac	Less develop-ed Cb
Ground surface	Cu or Sc	Cu cong	Well dev. Cu cong
			0

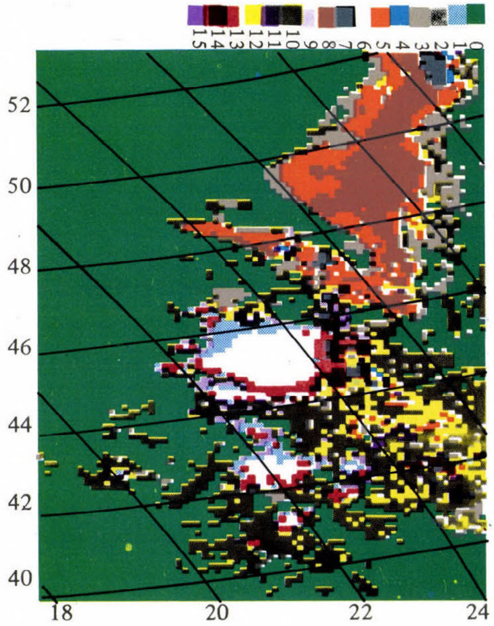


Fig. 8. Combined bispectral analysis of the cloud field, MOS-1 on July 26, 1988 at 9.34 UTC. 0: ground surface, 1: Cirrus, 2: Altostratus translucidus, 3: Stratus (thin) or fog, 4: Altostratus opacus, 5: Stratus (medium thick), 6: Cumulonimbus (well-developed and expanded), 7: Nimbostratus (precipitating cloud), 8: Stratus (thick), 9: Altocumulus, 10: Cumulus and/or Stratocumulus, 11: Multi-layered cloudiness (mainly Altocumulus), 12: Cumulus congestus, 13: Cumulonimbus (developing) or its edges, 14: Cumulonimbus (less-developed), 15: Cumulus congestus (well-developed). A picture element covers an area of about 100 km^2

a smaller horizontal extent formed from which, on the basis of the 12 UTC synoptic map, it rained. The presence of the extended MCC over Southern Carpathians and scattered thunderstorm activity over Balkan seems to be proved. Cb anvils being identifiable in the images indicate strong northward upper winds in this region which are verified by upper wind measurements. At the same time, in the southern side of cumulonimbi very steep "cloud-wall" is found (i.e. the cloud thickness and top height are growing very quickly). Over the Rumanian Plain and Bulgaria convective activity with variable intensity is observed. The northeastern section of the Carpathians is covered by almost continuous St cloudiness with variable thickness.

It was intended to verify the cloud analysis presented here but for the lack of 09 UTC synoptic data (not archived in the services) we had to disregarded the possibility of the verification. In view of the significant transformation of the cloud field, 06 and 12 UTC data might not used for the purpose of verification.

3. Conclusions

The paper aimed to analyse the cloud field in detail. In order to define cloudy areas threshold technique was employed. The cloud types were identified by both bispectral histograms of signal intensities and coherence test. The clouds were classified into 15 types. Owing to numerous neglects the results may be considered as a first approximation. The relative simplicity and rapidness of the method, however, suggest its operational applicability. The objective verification is disregarded because of the lack of simultaneous observational data but the near 06 and 12 UTC synoptic charts verify the reality of the presented cloud analysis.

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Changes in precipitation data at Belgrade

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Abstract—A probabilistic model is proposed for determining the occurrence of climatic changes on the basic of precipitation data. This model is a generalization of the commonly used Markov chain model used to estimate the variance within the group. The procedure is illustrated by using data of Belgrade, Serbia, for the fall seasons from 1951 to 1980.

Key-words: precipitation, climatic changes, Belgrade.

1. Introduction

The Markov chain model for the daily occurrence of precipitation has achieved widespread use. However, in the literature there are no models for the daily amount of precipitation which employ this Markov chain model as part of the process.

The probabilistic model for the daily amounts of precipitation which will be considered is itself a special case of a so-called chain-dependent process or sequence of random variables defined on a Markov chain (*Katz,* 1974). While the model does introduce dependence into the precipitation process through the dependence of the Markov chain, it is still simple enough to apply for computation purposes. For example, the distribution of the total amount of precipitation in n days (n=1, 2, ...) can be readily calculated.

Two properties of precipitation data which may be of greater importance in determining whether significant climatic variations have occurred are the variance and the persistence. Knowledge of these two properties of past precipitation amounts would help set bounds on predictions of future precipitation. However, for the analysis of agricultural and public water demand, it can be argued that precipitation variability over time is at least as important as changes in the simple precipitation mean. Considering these implications, a more meaningful determination of climatic change may result from the investigation of the variance of precipitation (*Englehart* and *Douglas*, 1985). So, *Eidsvik* (1980) used Akaike's method for model identification to identify Markov chain models for simple transformation of daily precipitation. Also, the series of daily precipitation amounts, described as a chain-dependent process, could be used together with the simplified water balance equation (*Faragó*, 1985) to examine the probability distribution of soil moisture by recurrence formulas.

To determine a more accurate estimate of the within group (daily) variability of precipitation data, a model which allows for dependence must first be fitted to the daily data. So a first-order autoregressive [AR(1)] model has been fitted to climatic data (*Leith,* 1973). Using precipitation data, the AR(1) model assumes that the amount of precipitation falling on day n is a function of the amount of precipitation falling on day n-1 plus a random component. A more accurate description of this dependence is that the amount of precipitation falling on day n depends only on whether the previous k days were wet or dry. The generalization of the Markov chain as proposed by *Katz* (1977a) fits this description. From Katz's model, an estimate of the group-to-group variability under the null hypothesis can be obtained, which allows for dependence.

2. *Definition of process in the model*

The model for daily precipitation developed by *Katz* (1977a) considers the process $\{(X_n, J_n)$: $n\ldots$, -1, 0, 1, ...$\}$, where X_n is the amount of rainfall on day n=1, 2, ..., while J_n denotes the rainfall pattern (wet or dry) for days n, n-1, ..., n-k+1. Let H_i be equal to 1 on a day i with precipitation and to zero on other days. Then $J_n = \sum_{i=1}^{k-1} H_{n-1} 2^i$. It is assumed that $\{J_n\}$ forms a Markov chain with states $\{0, 1, \ldots, 2^k\text{-}1\}$. For example, if k=2, then J_n can be 0, 1, 2 and 3. The rainfall pattern can best be discerned by writing the value in base two. Thus, $2=10_2$ and so $J_n=2$ indicates that there was rain on day n-1 and no rain on day n. Similarly, if k=3 and $J_n=6=110_2$ there was rain on days n-2 and n-1, but not on day n.

Let $\mathbf{P}=(P_{ij})$ be the matrix of transition probabilities, i.e. $P_{ij}=P[J_n=j \mid J_{n-1}=i]$. Each row and column of $\mathbf{P}$ contains at most two nonzero elements and the rows sum to 1. For example, if k=2 and i=2, then only P_{20} and P_{21} can be nonzero, as other transitions are not possible. $P_{23}>0$ implies the possibility of a transition from rain on day n-2 and no rain on the day n-1 to rain on days n-1 and n and $P_{22}>0$ also requires both no rain and rain on day n-1.

Let $\mathbf{\Pi'}=(\Pi_0, \Pi_1, ..., \Pi_2k_{-1})$ be the vector of stationary probabilities ($\mathbf{\Pi'P}=\mathbf{\Pi'}$ and its elements sum to 1). The $\{X_n\}$ process is assumed to be independent, given the $\{J_n\}$ process. In particular, the probability distribution of rainfall on day n depends only on J_n and J_{n-1}. That is

$$F_{ij}(x) = P[X_n \leq x \mid ... X_{n-2}, X_{n-1} ..., J_{n-2}, J_{n-1} = i, J_n = j]$$

$$= P[X_n \leq x \mid J_{n-1} = i, J_n = j].$$

It is assumed that observations begin with X_1 and that the process is in its stationary condition on day 0 (i.e. $P[J_0=i]=\Pi i$).

Katz (1977b) obtained

$$\mu = E[X_n] = \sum_{i,j} \Pi_i P_{ij} \mu_{ij},$$

and

$$\sigma^2 = Var[X_n] = \sum_{i,j} \Pi_i P_{ij} m_{ij} - \mu^2,$$

where

$$\mu_{ij} = E[X_n \mid J_{n-1} = i, \quad J_n = j],$$

and

$$m_{ij} = E[X_n^2 \mid J_{n-1} = i, \quad J_n = j].$$

Let $S_r = X_1 + ... X_r$. Then, as r goes to infinity, the distribution of $(S_r - r\mu)/\gamma(r)^{1/2}$ converges to the standard normal distribution, where $\gamma^2=\sigma_2+2\mathbf{\Pi'Q}\ (\mathbf{Z'}\text{-}\mathbf{F})\ \mathbf{Qe}$. The matrix $\mathbf{Q}=(P_i\ \mu_{ij})$, $\mathbf{e}$ is a column of unit vector, $\mathbf{F}=\mathbf{e\Pi'}$, and $\mathbf{Z'}=[\mathbf{I}\text{-}(\mathbf{P}\text{-}\mathbf{F})]^{-1}$.

3. Numerical example to determine variability and climatic change

Temporal and spatial precipitation variations have been studied by many climatologists, but most investigations of those topics have been primarily concerned with delineating specific areas and time periods affected by abnormal precipitation amounts. In many of these studies, mean precipitation amounts for months, season or years were compared to determine whether significant precipitation variations occurred during the period of record. Trends, periodicities and abrupt changes in mean precipitation amounts were sought, which would conform respective changes in hypothesized causal factors, such as sunspots and circulation regimes.

To investigate climatic change with regard to precipitation, it is necessary to know how much of the year-to-year variation is due to day-to-day variability. This may be expressed by the variance components model (*Graybill*, 1961) $X_{st}=\mu+a_s+b_{st}$, where $s=1, \ldots, n$ is the year and $t=1, \ldots, m$ is the day of the year. Here the subscripts s and t are replacing the single subscript n used in the previous section, so that days can be identified with the appropriate year. The a_s and b_{st} are random variables with zero mean and variances σ_a^2 and σ_b^2. The null hypothesis of no change from year to year is equivalent to $\sigma_a^2 = 0$. To test this hypothesis, the variance of the annual averages is estimated by

$$\sum_{s=1}^{n} (Z - Z_s)^2 / (n - 1),$$

where

$$Z = \left(\sum_{t=1}^{m} X_{st}\right) / m$$

and

$$Z_s = \left(\sum_{s-1}^{n} Z\right) / n$$

is compared to a similar estimate based on observations during the year, by assuming that the null hypothesis is true. If the variables X_{st} are independent, and b_{st} has normal distribution, then the denominator is $\sum_{s,t} (X_{st} - Z) / mn(m-1)$ and the ratio has an F distribution with n-1 and $n(m$-1) degrees of freedom under null hypothesis.

In the case of dependence, the analysis can still be performed. The denominator must be replaced by an estimate of

$$Var\,(Z) = Var\left(\sum_{t=1}^{m} X_{st} / m\right) = \frac{1}{m^2}\; Var\left(\sum_{t=1}^{m} X_{st}\right).$$

Under the null hypothesis, the value of X_{st} does not depend on s and, therefore, an estimate of $Var\left(\sum_{t=1}^{m} X_{st}\right)$ using data from all years is valid. Using the model of Section 2, an estimate of $Var\left(\sum_{t=1}^{m} X_{st}\right)$ is given by $\gamma_2 m$ and so $Var(Z)$ may be estimated by γ^2/m. The appropriate test is then $\chi^2 = m\sum_{s=1}^{n}(Z-Z_s)^2/\gamma^2$ and, under null hypothesis, it will have a chi-square distribution with n-1 degrees of freedom (as $m \to \infty$). The large sample sizes encountered in these investigations make it reasonable to assume that γ_2 is known (not random).

As numerical example, daily rainfall data for Belgrade are collected for the months of September, October and November from 1951 through 1980. The transition probabilities are assumed to be stable from day to day and from year to year. It is also assumed that the amount of precipitation on a given day does not depend on the amount of precipitation sampled on the previous day (or days, if $k>1$). Following *Katz* (1977a), the correlation coefficients of the natural logarithmus of precipitation amounts are calculated. All of them are found to be near zero (0.18 for first order and 0.13, 0.11 and 0.16 for the three second order cases 001, 101, and 111) which indicates no significant dependence.

Table 1 gives the relevant estimated quantities for the model with independence and for the models with one and two-day dependence. The first two models yield chi-square values that are clearly significant. However, the Schwarz Bayesian Criterion (*Schwarz,* 1978) indicates that the appropriate model involves 2-day dependence *(Table 2)*. With this model, the significance vanishes because the extra variance is accounted for in the model.

The exact distribution of the daily total amount of precipitation data $S_r = \sum_{i=1}^{r} X_i, (r=1,2,...)$ for Belgrade has also been computed. It has been assumed that the amounts of precipitation on consecutive days are conditionally independent. Recurrence relations for computing the distribution of S_r can be used. Conditioning on J_0 yields

$$H_n(x) = \lambda_0 H_n(x;0) + \lambda_1 H_n(x;1),$$

and further conditioning on J_1 yields

$$H_n(x;0) = P_{00} H_{n-1}(x;0) + P_{01} F_0(x) * H_{n-1}(x;1),$$

$$H_n(x;1) = P_{10} H_{n-1}(x;0) + P_{11} F_1(x) * H_{n-1}(x;1).$$

Here, $n=1, 2, \ldots$, with initial conditions $H_0(x;0)=H_0(x;1)=1$, and the asterisk denotes the convolution operator. In this case, it has been assumed that F_0 and F_1 have a common scale parameter of 6.14 mm. *Fig. 1a* illustrates the resulting

Table 1. Analysis of precipitation data for Belgrade

	Independence	One-day dependence	Two-day dependence
Transition probabilities (those not given are 0)		$P_{00}=1-P_{01}=0.79$ $P_{10}=1-P_{11}=0.40$	$P_{00}=1-P_{01}=0.83$ $P_{12}=1-P_{13}=0.41$ $P_{20}=1-P_{21}=0.59$ $P_{32}=1-P_{33}=0.37$
Stationary probabilities	$P(\text{rain})=0.33$	$\Pi_0=0.78$ $\Pi_1=0.33$	$\Pi_0=0.61$ $\Pi_1=\Pi_2=0.15$ $\Pi_3=0.18$
Conditional means (mm) (those not given are 0)	$\mu_1=6.01$	$\mu_{01}=4.10$	$\mu_{01}=4.11$ $\mu_{13}=6.67$ $\mu_{21}=5.15$ $\mu_{22}=8.33$
Conditional second moments (mm^2) (those not given are 0)	$m_1=99.81$	$m_{01}=50.01$ $m_{11}=127.08$	$m_{01}=58.18$ $m_{13}=91.58$ $m_{21}=59.13$ $m_{33}=153.11$
Unconditional mean (μ)	1.37	1.40	1.41
Unconditional variance (σ^2)	28.01	28.25	30.14
Variance of seasonal averages (γ^2)	28.01	30.15	39.58
Chi-square (28 df)*	73.51	57.18	40.13
p-value	0.002	0.01	0.09

*Chi-square $= 29 \sum_{s=1}^{29} (Z - Z_s)^2 / \gamma_2 = 1693.68/\gamma^2$

Table 2. The order of dependence estimated

Order (k)	SBS (k)
0	298.21
1	-18.14
2	-49.64
3	-38.98

density functions for $S_r > 0$ and selected values of r. It can be shown that the sum of a chain dependent process is asymptotically normally distributed. Expressions for asymptotic mean and variance for the distribution function $F_i(i=0,1)$ are given by *Katz* (1977b) and have been discussed previously in Section 2.

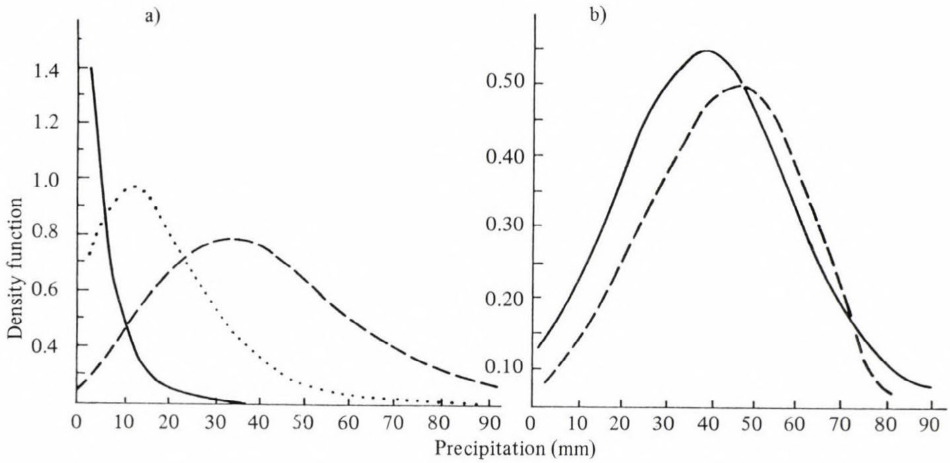

Fig. 1. Distribution of the total amount of precipitation in r days: *(a)* exact distribution for $r=1$ (solid), 10 (dotted), and 20 (dashed) and *(b)* exact and asymptotic distribution for $r=20$, exact distribution (solid), asymptotic distribution (dashed)

Using this expressions, the asymptotic normal distribution has parameters $\mu=2.11$ mm and $\sigma^2=27.24$ mm^2. While from Fig. 1a the convergence of the exact distribution to the normal distribution with increasing r is evident, *Fig. 1b* indicates that a sample size of 20 is not large enough for an accurate approximation.

4. Conclusions and plans

A probabilistic model, representing the sequence of daily amounts of precipitation, has been considered. The key assumptions required for the application of this process are that

- the sequence of daily amounts of precipitation constitutes a Markov chain, and
- the amounts of precipitation on consecutive wet days are conditionally independent.

This process might be used to characterize, in a climatological sense, a precipitation sequence in terms of a few parameters which take into account the day-to-day dependence of precipitation.

The analysis of variance approach will be used to determine whether the seasonal precipitation of 32 Serbian stations have changed during the 30-year period (1951-1980). For those stations where no change is found, the variance estimated by using the Katz model will be interpreted as the amount of variability that can be expected within an unchanging climate. For those stations where change is found, upper-air circulation data will be investigated to determine relationships between precipitation variability and circulation variability.

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Understanding the human environment: a new challenge for scientific research[1]

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Abstract—The aim of this paper is to summarize main environmental problems human race is facing. It is concluded that research has to be intensified in the field of environmental science for understanding in more detail the relationship between human activities and natural environment. This is obviously needed to elaborate future strategies for environmental protection.

Key-words: global and regional changes, environmental science, environmental protection.

1. Introduction

The planet-Earth has a unique environment in the Solar System. These special environmental properties are due to the presence of life. Some billion years ago the size of the Earth and its position in the Solar System rendered the formation of life possible. Owing to these cosmic characteristics hydrogen did not escape from the planet into the space but it remained imbedded in water molecules. Atmospheric composition and temperature as well as ultraviolet radiations coming from the Sun created favourable conditions for the formation of organic materials in shallow waters. The process initiated in this way led to the development of plants and animals and finally to birth of a thinking species, man, who is able to understand the near and far environment and to produce

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energy and goods necessary for his life. However, during the history his activities have become an important factor in the control of the environment which jeopardizes the conditions which have made his economic and social development possible.

2. *Our past environment*

After its formation life did not only suffer environmental conditions, but it became an active factor in the control of the environment. Environmental conditions modified the biosphere, but, on the other hand, living species made an effort to stabilize the environment for the sake of their own survival. For this reason *Lovelock* (1988) proposed that the Earth is a giant living system, the state of which is far from physio-chemical equilibrium. Without going into details of the debate about this idea we note that it is really not unbelievable that the relatively stable conditions during geological times, which have never endangered the life as a whole, have been related in some way to the control capacity of the biosphere. Even such events as the cosmic catastrophe of 60 million years ago leading to the extinction of dinosaurs did not put at risk the existence of the biosphere. This event catastrophic for the dinosaurs made the spread of an other family of vertebrates—the mammals—possible, which was determinant in the formation of human species.

Environmental changes in the past were very slow processes compared to the duration of human life. Ice ages built up over a period of about hundred thousand years, and terminated in a shorter time of about ten thousand years. The last glaciation reached its maximum approximately twenty thousand years ago and came to an end about ten thousand years ago. The higher, stable temperature formed since that time has been very favourable for the development of the activity of mankind. Man began the clearing of forests, the use of wood and built towns which led to local and regional changes in the environment. However, these environment changes were negligible considering the planet as a whole. This situation changed drastically about two hundred years ago when, instead of using energy offered by nature (e.g. energy of animals, wind and water courses), man started to produce energy by burning fossil fuels mined from the Earth's interior. Due to this new energy industry has developed in a spectacular way and life conditions have been substantially improved. A new philosophy has become widespread according to which man is an absolute master of nature. In conformity of this philosophy human society has expected from science to make such discoveries which improve the efficiency of industry, agriculture and transportation.

3. *Present changes: environment and human activities*

Both the spread of agricultural production mentioned above and the industrial revolution of two hundred years ago led to the rapid growth of population (see *Fig. 1*). During the last two centuries this has reached such a level that human activities necessary for food, energy and industrial supply of the population have become an important factor in the control of the environment of the entire planet. Thus, man alters the surface, builds cities and towns by producing an artificial physical environment. Waste materials formed during his activities are

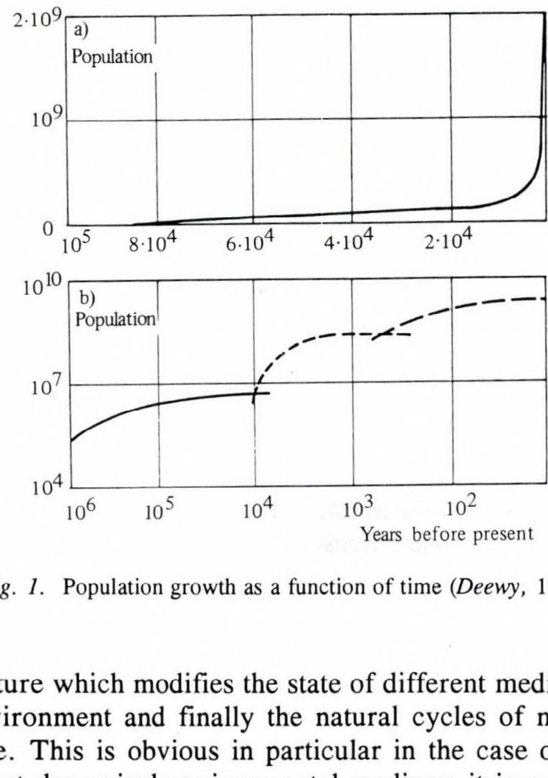

Fig. 1. Population growth as a function of time (*Deewy,* 1960)

released into nature which modifies the state of different media (air, soil, water etc.) of the environment and finally the natural cycles of materials which is essential for life. This is obvious in particular in the case of the atmosphere which is the most dynamical environmental medium: it is polluted already on a global scale. This is very dangerous because air pollutants modify the climate affecting the physical and chemical state of other media, too.

The most serious environmental problem is caused by the combustion of fossil fuels. *Fig. 2* shows the temporal variation of the emission of carbon dioxide into the atmosphere as a function of time. Carbon dioxide is one of the most important greenhouse gases which means that its molecules in the air do not alter the transfer of solar radiation, but absorb the longwave heat radiation emitted by the surface of the planet. Consequently, the increase of CO_2

concentration is followed by the warming of climate. Moreover, during the burning of fossil fuels several other substances are emitted into the atmosphere. Coals, oils and also natural gases contain several materials (sulfur, nitrogen, toxic metals) which, after their emission increase the acidity and micro-elemental content of atmospheric precipitation. The anthropogenic modification of chemical composition of atmospheric depositions influences the chemical processes of surface waters and soils, the life of terrestrial and aquatic ecosystems and finally it creates changes in food-chain.

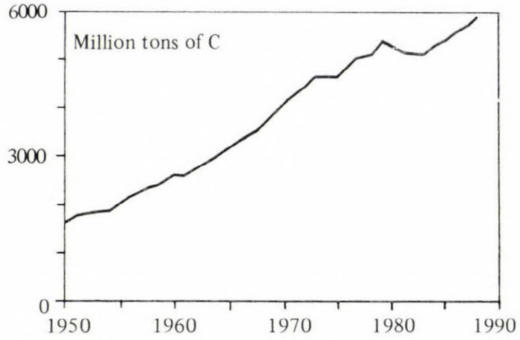

Fig. 2. Anthropogenic emissions of carbon dioxide into the atmosphere in terms of metric tons as a function of years (*Boden et al.*, 1990)

A major part of energy produced by burning fossil fuels is used by industry and domestic consumers. Industry emits further pollutants (e.g. toxic metals and gases) into the air, but also "produces" a lot of solid and liquid wastes which, if their treatment is not sufficient, poison soils and waters. This is intensified by the production of domestic wastes the mass of which can be even greater than the quantity of industrial refuses. The annual waste production of the world is around 1 Pg (1 Pg$=10^{15}$ g$=$1 billion metric tons) at present.

Table 1 gives the carbon dioxide emission due to energy production and deforestation as well as the sum of industrial and domestic waste production expressed in decaying organic carbon (this is about 20 % of the total mass). For comparison, the dry matter production of the biosphere and the CO_2 emission of terrestrial plants are also tabulated. One can see that the anthropogenic carbon dioxide emission is only 7 % of the biogenic continental release. In spite of this fact carbon dioxide emission owing to human activities has serious consequences since about the half the CO_2 quantity emitted remains in the air which intensifies the atmospheric greenhouse. Generally speaking, anthropogenic effects disturb the material cycles which are closed under natural conditions. This interrupts the material equilibrium of different media of the environment. Data tabulated also make it evident that the carbon dioxide quantity emitted into the atmosphere exceeds the mass of solid and liquid wastes produced emphasizing the importance of our effects on the composition of the atmosphere.

Table 1. Annual dry matter production of the plant carbon dioxide emission of continental biosphere and the quantity of some forms of pollution, all expressed in $Pgyr^{-1}$ of carbon equivalents

Dry matter production	118	(*SIPRI*, 1980)
Biological CO_2 emission	100	(*IPCC*, 1990)
Anthropogenic CO_2 emission	7	(*IPCC*, 1990)
Industrial wastes	0.03	(*Bingemer* and *Crutzen*, 1987)
Domestic wastes	0.20	(*Bingemer* and *Crutzen*, 1987)

Notes: Anthropogenic CO_2 emission also contains the release due to deforestation.
SIPRI: Stockholm International Peace Research Institute
IPCC: International Panel on Climate Change

The most dangerous class of global pollutants emitted by chemical industry consists of different chlorofluorocarbons called the freons. These substances do not affect human health, and are not flammable, but in the near-surface air they contribute to greenhouse effects. Further, in higher air layers chlorofluorocarbons are destroyed by ultraviolet radiations and chlorine species created in this way remove ozone molecules from the air which protect the biosphere from lethal short-wave radiations. Thus, it is accepted by experts that the ozone hole formed over Antarctica during spring months is the consequence of the release of these materials. Even, it is very probable that the atmospheric ozone content decrease of about 1 % per year observed by satellites over the midlatitudes of the Northern Hemisphere is caused by freons (*Stolarski et al.*, 1991).

On the other hand atmospheric pollutants like nitrogen oxides and different hydrocarbons released mainly in exhaust gases of cars and vehicles increase the ozone concentration in the air near the surface. The ozone molecules formed by chemical reactions of these substances intensify on local and regional scales the oxidation capacity of the air and consequently the transformation of some gaseous pollutants (sulfur dioxide, nitrogen dioxide) into acids. At the same time carbon monoxide, also emitted during transport, decreases the concentration of oxidants on a global scale, disturbing natural chemical processes in the atmosphere. An other dangerous pollutant emitted by automotive sources is lead, the annual emission of which (*Nriagu,* 1989) exceeds the value of 0.3 Tg (1 Tg=10^{12} g=1 million tons).

The increase of the number of population necessitates the improvement of worldwide food production. Accordingly during last times the extension of agricultural areas has increased considerably. In 1860 it was 0.6×10^9 hectars (1 hectar=10^4 m^2), while the present figure is around 1.5×10^9 hectars. Parallel to the increase of agricultural territories, the extension of regions devastated by erosion has also increased. It is estimated that the erosion moves annually a soil mass of 100 Pg (*Richards*, 1988). In the time being the annual increase of areas used for agricultural production is 10^7 hectars, while the loss due to soil degradation reaches the value of 6×10^6 hectars (*FAO,* 1981). Mainly in more developed countries the quantity of fertilizers used is very important. In some countries (The Netherlands, Belgium, Germany) the fertilizer mass dispersed annually on 1 hectar exceeds the value of 300 kg (*FAO,* 1989). The use of fertilizers consisting mostly of nitrogen, phosphorus and potassium, beside favourable temporary effects on the production, is followed by the increase of the nitrate and acid concentration of soils which results in the decrease of the productivity on a longer time scale. Moreover, fertilizers contain in traces a lot of substances, which can rise the concentration of certain elements in soils above the toxic levels. Finally, the use of fertilizers modifies nitrification and denitrification processes in soils which promotes the release of gaseous nitrous oxide into the atmosphere. Since nitrous oxide plays an essential role in the removal of ozone in the high atmosphere, the increase of its emission rate may pose a threat to the protecting ozone layer. In addition to this, since nitrous oxide molecules absorb the heat radiation, the increase of its concentration level in the atmosphere makes the atmospheric greenhouse more efficient. Fortunately, the present natural nitrous oxide emission exceeds the strength of anthropogenic release.

In developed countries the increase of nitrate concentration of drinking water is caused by fertilizer use. In contrast, in developing countries the lack of the cleaning of sewage water is the main factor in the process. It is estimated that 75 % of the population in developing countries does not get at healthy drinking water and 25 thousand persons die each day because of poisoning due to the consumption of polluted water.

Rice production is an important part of the world agriculture. It is accompanied by the inundation with water of large areas which results in increased methane emission into the atmosphere. Methane is formed by the decay of organic matters under anaerobic conditions. It takes part in the control of oxygen level and greenhouse properties of the atmosphere. According to the analysis of air bubbles imbedded in Antarctic ice samples taken at different depths (*Khalil* and *Rasmussen*, 1989) the methane concentration in the air in the sixteenth century was less than the half of the present figure of 1.7 ppm (ppm: parts per million). It should be noted that animal husbandry also increases the methane concentration in the atmosphere since during enteric fermentation in the intestines of animals a rather large amount of methane is formed. The area on the Earth surface used for animal husbandry is equal to $3.1 x 10^9$ hectars at present (*FAO,* 1981). From this waste territory, beside methane, an important quantity of ammonia is released which plays an essential role in the control of the acidification of the environment. On the other hand, extensive animal husbandry concentrated on small areas produces a large amount of manure which, among other things, can increase the nitrate content of soils and surface waters. Generally speaking, the pollution of surface waters endangers the quality of rivers and it modifies finally the composition of waters and sediments reaching the oceans. Data gained in the Global Environmental Monitoring System of United Nations show than in more than 50 % of rivers in Europe the nitrate-nitrogen concentration is higher than 5 mgL^{-1}, which is the half of the water quality standard accepted by the World Health Organization. In several rivers the nitrate-nitrogen concentration exceeds the value of 20 mgL^{-1}.

Both plant production and animal husbandry alter the number of species of plants and animals, as well as their spatial distribution. This leads to the decrease of natural genetic biodiversity. In turn, other human effects like deforestation, desertification and pollution contribute to the decrease of the variability of different species. This causes obviously the inversible degradation of the biosphere since it cannot be regenerated.

Table 2 summarizes the above discussion from the point of view of the atmosphere. Data tabulated indicate that the strength of global anthropogenic emissions of different gases, except for carbon dioxide nitrous oxide and hydrocarbons, reach or exceed the rate of natural biogenic emissions which leads to important environmental consequences as will be discussed further in the next paragraph.

4. The future of our environment: the great challenge

During last decades it has become evident that we pollute the environment not only in the vicinity of pollution sources. It is now clear that we produce serious regional and continental problems (e.g. acidification of the environment) and the main dangers are created by world-wide global pollution which can disturb the natural environmental equilibrium, e.g. the stable climate system of the planet.

Global climate changes are due first of all to the emission of greenhouse gases. As it was mentioned, these gases absorb the heat emitted by the Earth

Table 2. Global emissions of pollutant gases of global importance (Tg yr^{-1}), ratio of anthropogenic sources to global sources (%) and environmental effects of the emissions (*Mészáros*, 1992)

Gas	Main sources	Emission	%	Effects
Carbon dioxide	Energy production	25 000	7	Greenhouse
Carbon monoxide	Transport	1 000	90	Oxidant capacity
Methane	Rice, animals	300	70	Greenhouse
Nitrous oxide	Fertilizers	1	6	Greenhouse
Sulfur dioxide	Energy production	150	70	Acidification
Nitrogen monoxide	Transport	60	70	Acidification, oxidant capacity
Ammonia	Animals husbandry	25	50	Acidification
Hydrocarbons	Transport	90	10	Oxidant capacity
Freons	Coolants, propellants	1	100	Ozone hole, greenhouse

surface. Consequently, the rise of their concentration leads to warming of the planet. Considering the complexity of processes determining climate, the forecasting of the warming is not an easy task. For this purposes climate models are applied which contain with different complexity the mathematical description of physical and chemical processes governing climate. These models have to be further improved mainly concerning the ocean-atmosphere coupling and the effects of clouds. Moreover, the estimation of regional changes is very difficult with present models owing to their large spatial resolution. The estimation of the possible future concentration of different gases is also uncertain since it depends on the future structure of industry and agriculture.

The curves *Fig. 3* give the magnitude of the warming as a function of time. The figure also represents the uncertainly of forecasting by the interval of calculations based on different estimates. One can see that in 2100 our climate will possibly warmer by 4 °C on the average. The probable value of warming will be somewhere between 3 °C and 6 °C. This indicates a very fast climate change which has never occurred during geological times. Calculations also show that the warming will be more significant near the poles of the Earth and over continental areas. Owing to the re-distribution of the temperature the quantity of precipitation will be altered. According to model runs it seems to be probable that the precipitation amount will be higher near the poles and lower over North America and Europe. This means that water supply of soils will be worse than at present which will influence the conditions of agriculture and water management. Briefly, we will spoil those climatic conditions which have made the economic and social development during the last ten thousand years possible. In addition to this, owing the warming, the level of seas and oceans will rise (see *Fig. 4*), which threatens with inundation several countries and costal areas.

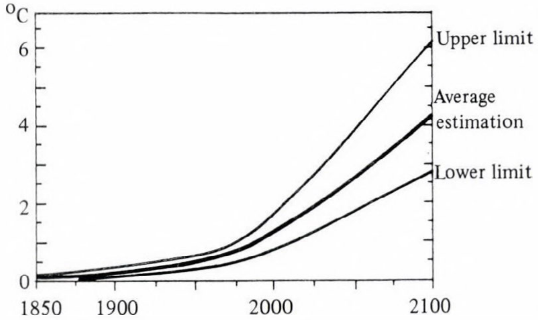

Fig. 3. Increase of the global average temperature relative to the value for 1850 owing to the emission of greenhouse gases into the atmosphere (*IPCC,* 1990)

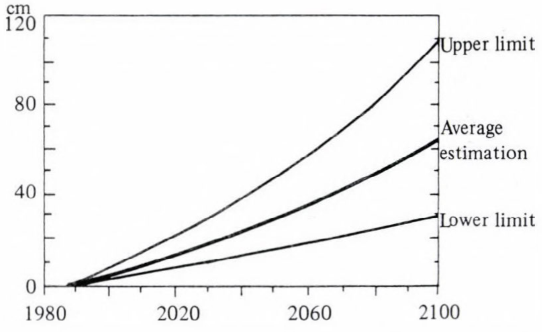

Fig. 4. Rise of the sea level caused by global warming presented in the previous figure (*IPCC,* 1990)

It can be concluded that human race faces a great challenge. A new era begins which will be different from those happened during our history. In the future the determining factor of human development will be the relationship between environment and human activities. Man has to conduct his economic activity in harmony with environment. We have to find the roads of the so-called *sustainable development* which makes certain the future of coming generations. We must develop such an economic life which eliminates practically the pollution endangering human health, reduces the degradation of the quality of air, water and soil and, last but not least, excludes the possibility of irreversible global changes. It goes without saying that this aim can be reached only by close international cooperation and by solving economic and political problems which cause inequalities among different parts of the world. It is hoped the UN Conference entitled "Environment and Development" which will be held in Rio de Janeiro, this year, will be the first step in this direction. At the same time, research workers dealing with nature, society and economics should elaborate the scientific bases of sustainable development by doing complex investigations.

5. Science and environment: the birth of a new scientific discipline

For laying the foundation of sustainable development much more research is needed. Further basic research should be conducted to understand physical, chemical and biological laws governing the huge energy and material flow in nature. Before investigating the consequences of human activities, the understanding of the natural mechanism of different environmental media is indispensable.

For the study of the interrelation between man and environment by *environmental science* a new scientific approach in unavoidable, beside reproducible laboratory experiments giving the same results under identical coordinations, much more variable field observations are necessary. On the other hand, we have to disregard common classification of sciences since environmental science is very complex and it needs the active cooperation of several classical disciplines. We should learn that nature is one complex entity and it does not bother about the classification of phenomena invented by man. Thus, if we study the material flows in nature, called the biogeochemical cycles, the borders between earth and biological sciences are entirely disappeared and we have to apply the methods of physics and chemistry and combine the results in up-to-date mathematical models. Further, if we include the effects of energy production, industry and agriculture into the study we cannot avoid the use the methods of economics and sociology. It is evident that we do not expect that one scientist be an expert in all these questions. But it is absolutely necessary that environmental scientists be equipped with such a conception which permits them to comprehend the results of other disciplines. Briefly, for doing environmental investigation research workers with a wide intellectual horizon are claimed.

To understand the aim of environmental science the relation and difference between this new discipline and environmental protection should be stressed. As *Fig. 5* shows the effects of human activities on the environment are studied

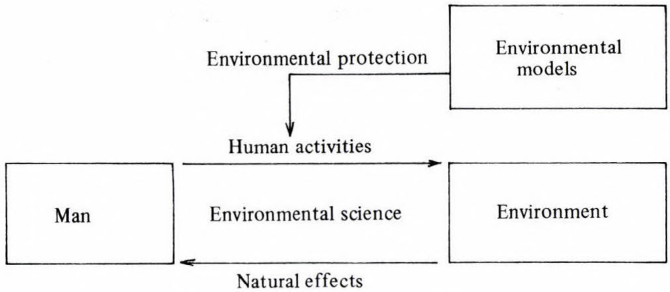

Fig. 5. Representation of the role of environmental science and environmental protection/strategy according to *Jörgensen* and *Johnson* (1981)

by environmental science. Scientists estimate, by means of mathematical models, environmental modifications as a function of the parameters of human activities. These models make it possible to calculate the maximum intensity of a certain activity which permits to hold the effects below a predetermined level. On the basis of this result the technical methods and strategies as well as the legal regulation of environmental protection can be elaborated. Thus, environmental protection is a technical and/or legal action which is based on the results of environmental science aiming to understand the mechanism of nature: environmental protection is unimaginable without environmental research.

This conclusion has been drawn in many countries. Several environmental research institutes and university departments have been organized recently. The importance of the question has also been recognized by the Hungarian Academy of Sciences. This is proved, among other things, by the choice of the scientific topic of the present assembly. However, further efforts are needed to initiate and strengthen environmental research and education. Hungarian science has to join relevant international research programs organized to study environmental questions of global and continental scales. On the other hand Hungarian scientific community has to contribute in a more effective way to the improvement of the state of the environment in our country.

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BOOK REVIEW

K. Ya. Kondratyev (ed.): **Aerosol and Climate** (in Russian). Gidrometeoizdat, Leningrad, 1991. pp. 541.

It is well documented that the composition of the Earth's atmosphere is changing owing to the release of different pollutants into the air. These changes in composition are very dangerous since, among other things, they can lead to climate modifications. This is true in particular when so-called greenhouse gases are emitted which absorb the heat radiation of the surface. The effects of such emissions on climate are estimated by rather sophisticated mathematical models containing physical and chemical laws governing climate. One of the greatest problems of these models in due to the inadequate consideration of the role of atmospheric aerosol particles and their interaction with water vapor during cloud formation.

For this reason all publications dealing with this question rather neglected are appreciated. The present volume was prepared in agreement with the resolution of a Joint Soviet-American Commission aiming to cooperate in the field of environmental science. Accordingly, the chapters were written by Russian and American authors. Owing to the re-writing of American names in Cyrillic letters, their identification is sometimes difficult. It is also a pity that the authors' affiliations are not given. The reviewer hopes, however, that this fascinating book will also be published in English, with the arrangement of this formal problem.

The book contains following chapters (the authors are not given: to avoid unappropriate wording):

(1) Methods of the experimental determination of microphysical characteristics of atmospheric aerosols
(2) Aerosols of surface origin
(3) Oceanic aerosol
(4) Secondary aerosols, aerosols formed *in situ*
(5) Anthropogenic aerosols
(6) Stratospheric aerosols
(7) Atmospheric aerosol models
(8) Radiation properties of clouds
(9) Influence of aerosols on radiation transfer
(10) Climatic effects of aerosols.

It follows from these topics, and from the length of the book that practically all the problems relative to the properties of aerosol particles and to climate-aerosol relationship are treated in this book. Each chapter is followed by a reference list containing many publications in Russian and English. The combination of results on the atmospheric aerosol published in these two languages makes the volume rather unique in this field. However, the presentation of the characteristics of cloud condensation nuclei is missing, as in many textbooks on the subject. This is regrettable since the structure of clouds, so essential in the control of albedo (as this is stressed in detail in the present volume), depends on the number and nature of cloud condensation nuclei. The reviewer believes that if we discuss the properties of the aerosol and clouds, and their climatic effects the processes leading to the growth of particles into cloud elements including nucleation processes should be at least outlined. Generally speaking, the study of cloud condensation and ice nuclei has been a bit neglected during last years.

Data and information presented are correct and scientifically well-founded. On the other hand, the concept of their discussion obviously reflects the ideas of the author(s) of the chapters. It should be considered, however, that exactly these differences in views of scientists give reasons for the publication of several books on the same subject.

Finally, it is tempting to compare the present volume with the book of G.A. d'Almeida and P. Koepke also published in 1991 by the Deepak Publishing Company ("Atmospheric Aerosols; Global Climatology and Radiative Characteristics") in Hampton, Virginia, U.S.A. First, in the book edited by Kondratyev much more information on the chemical and physical properties of atmospheric aerosol particles is presented including the stratospheric aerosol layer. Further, in the chapters dealing with these topics much more papers are referenced than in the other book. The volume of d'Almeida and Koepke, on the other hand, contains more data tabulated in a clear, well-arranged way. Thus, both books have their own merits, however, their use can be slightly different.

In summary, in the volume reviewed the reader can find a lot of correct information. Consequently, it can be recommended for those research workers and students who are interested in the subject and can cope with the Russian language.

E. Mészáros

NEWS

Annual General Meeting of Academia Europaea in Budapest, 1992

Academia Europaea was created in 1988. The Foundation Meeting was held in Cambridge (U.K.) with the participation of several well-known scientists, mostly from the western part of Europe who elected *Prof. A. Burgen*, the famous English pharmacologist, as their first President. The founding of the *Academia* was one of the responses to the consciousness of Europe as a cultural entity. As its scope states: "The *Academia Europaea* is an international, non-governmental, non-profit making, charitable unincorporated association of individual scholars, having as its objective the promotion of education, learning and research." The activity of Academia includes all kinds of sciences from humanities to technology. Its work is divided in Subject groups, one of them concerns the atmosphere and is called Global Climatology.

One of the first aims of the *Academia* was to invite as members scientists from Eastern Europe to form a body which is really continent-wide. Thus, among other nations, Hungarian research workers have also been elected which has made the active participation of Hungary possible. Even in Heidelberg (Germany) at its third Annual General Meeting (1991) *Á. Csurgay*, Vice Secretary-General of the Hungarian Academy of Sciences, was elected as member of the Council of the *Academia*. At the same meeting *D. Kosáry,* the President of the Hungarian Academy of Sciences, invited the *Academia* to hold its fourth General Meeting in Budapest, Hungary. This invitation was unanimously accepted.

The fourth Annual General Meeting was organized between 17 June and 19 June, 1992 in the Congress Hall of the Hungarian Academy of Sciences and in the Gellért Hotel, both in Budapest. The conference began with Subject Group Meetings, including the meeting of the group named Earth and Marine Sciences the work of which is in close connection with meteorology (the Subject Group General Climatology did not hold a meeting). The General Meeting was formally opened after 2 o'clock on June 17. After a business meeting related the organization of the *Academia* the general introductory lecture (called Erasmus lecture) was presented by the famous Hungarian economist, *J. Kornai* with the title "The evolution from planned to market economies". The very actual presentation was followed by a lively discussion.

Scientific lectures were divided into five symposia:

I. History of the rights of minority groups
II. The future of museums

III. Modern views on biological evolution
IV. The image of science
V. The role of the oceans and lakes in ecological balances.

The chairman of the first symposium was *D. Kosáry* who presented his ideas in a lecture entitled "Nation and state of East-Central Europe". From meteorological point of view the symposium V should be mentioned which the chairmanship of *P. Lassere* (France) discussed under several up-to-date atmospheric problems like oceanic sulfate particle production and oxygen formation.

During the last afternoon (19 June) an interesting round table discussion was held in Martonvásár in the Agricultural Research Institute of the Hungarian Academy of Science. The aim of the discussion, chaired by *E. Duursma* (The Netherlands), was to continue the debate of Symposium V, including the fate and ecological problems of two Hungarian lakes: Lake Balaton and Lake Velence. The program in Martonvásár was closed by a Beethoven concert to the memory of this great European compositor who visited several times the castle of this Hungarian village.

Finally, the last event of this very successful Annual General Meeting was the meeting of the Council. Among other things it was decided that the next general Meeting of the *Academia* will be organized in Uppsala, Sweden next year.

E. Mészáros

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

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Short Communication

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NOTES TO CONTRIBUTORS

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IDŐJÁRÁS

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On the relationship between the quality and value of weather and climate forecasting systems

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(Manuscript received 25 September 1992; in final form 20 January 1993)

Abstract—This paper is concerned with the relationship between the scientific quality and the economic value of forecasts produced by weather and climate forecasting systems. Forecast quality is inherently a multidimensional concept, since it is fully described only by the joint distribution of forecasts and observations. Aspects of forecast quality such as bias and accuracy are usually measured by computing one-dimensional scores based on this joint distribution. Forecast value generally depends in a complex way on forecast quality in its full dimensionality.

Quality/value relationships are considered here both in general and in the context of specific decision-making situations. The sufficiency relation is used to explore and illustrate the ordinal nature of these relationships. In particular, it is shown that improvements in accuracy (an aspect of quality) do not necessarily imply an increase in value. The value-related implications of the sufficiency relation are demonstrated explicitly by comparing the economic value of prototypical climate forecasting systems in a standard decision-making problem. This binary relation is also used to describe the conditions under which a monotonic quality/value relationship exists for a prototypical climate forecasting system.

Recent studies of quality/value relationships in prototypical and real-world situations are briefly reviewed. These studies include situations involving both static and dynamic decision-making models. The general properties of quality/value relationships in these situations are described.

The need for further studies of quality/value relationships, both in general and in specific contexts, is emphasized. Some implications of these relationships for the development of a coherent methodology for forecast evaluation are discussed.

Key-words: Forecast quality, forecast value, quality/value relationships, sufficiency relation, forecast evaluation/verification, aspects/measures of forecasting performance.

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1. Introduction

The value of weather and climate forecasts is difficult to assess, whether these assessments are based on *prescriptive* studies of the ways in which the forecasts should be used or *descriptive* studies of the ways in which they actually are used. Both prescriptive and descriptive studies involve modeling and analyzing weather/climate-information-sensitive decision-making problems; the former are concerned with identifying the decisions that are optimal according to some prescriptive theory, whereas the latter are concerned with reproducing the decisions that are actually made by the users of the forecasts (see *Katz* and *Murphy*, 1993; *Stewart et al.*, 1984; *Winkler* and *Murphy*, 1985). Regardless of which approach is taken, neither forecasters nor users generally possess the appropriate training or the necessary experience to undertake such studies.

For these (and other) reasons, forecasters and users frequently use measures of various aspects of forecast quality as surrogates for measures of value. For example, it is frequently assumed, either explicitly or implicitly, that increases in forecast accuracy (which is an aspect of quality; see Section 2.1) necessarily lead to increases in forecast value. However, it is relatively easy to show that this assumption is, in general, *not* correct (see Section 2.3). What then is the nature of the relationship between forecast quality (and its various aspects) and forecast value? What general properties do quality/value relationships possess and what (if any) other properties do such relationships exhibit in specific decision-making problems? Under what conditions can increases in quality be unambiguously assumed to lead to increases in value?

These (and other related) questions have been addressed in a variety of recent studies related to the value of weather and climate forecasts in general and quality/value relationships for such forecasts in particular. The purposes of this paper are to describe the basic concepts and methods underlying the assessment of quality/value relationships, to summarize the results of recent studies investigating these relationships, and to discuss the methodological and practical implications of these results. In order to restrict the scope of this review to manageable proportions, attention is focused on quality/value relationships in contexts in which a prescriptive approach is taken to forecast-value assessment.

In Section 2 some basic definitions and concepts regarding forecast quality and forecast value are introduced. The implications of these basic considerations for quality/value relationships are also briefly discussed. Section 3 considers quality/value relationships in general, with particular reference to the sufficiency relation. First, this binary relation is defined and its properties are discussed, and then an example illustrating its application is presented. This section also summarizes recent studies involving the application of the sufficiency relation—and other closely related evaluation methodologies—to weather and climate forecasts. Section 4 describes recent work related to the study of quality/value relationships in the context of specific decision-making problems, including applications involving both prototypical and real-world situations. Section 5 contains a discussion of (i) some implications of currently available results regarding quality/value relationships for the practice of forecast verification; (ii) major deficiencies in the current state of knowledge regarding quality/value relationships; and (iii) important issues that should be addressed in future studies of these relationships.

2. *Forecast quality and forecast value: Basic definitions and concepts*

2.1 Forecast quality

The quality of forecasts produced by a forecasting system can be defined as the totality of statistical characteristics embodied by the joint distribution of forecasts and observations, $p(f, x)$, where f and x denote the forecasts and the observations, respectively (see *Murphy* and *Winkler*, 1987). This bivariate distribution contains all of the nontime-dependent information required to describe forecast quality *completely*. If the parameters characterizing the joint distribution are assumed to be time-independent, then these parameters can be estimated from a single realization of the verification process extending over time. However, if the time-dependent behavior of forecast quality is also of interest, then it is necessary to consider the trivariate distribution $p(f, x, t)$ in which t denotes time. In this case multiple realizations are needed to estimate the parameters constituting the trivariate distribution. We restrict our attention here to the time-independent, single-realization case.

Forecast quality is inherently multidimensional in nature, in the sense that more than one number generally is required to reconstruct the basic bivariate distribution. For example, it takes $3(=2\text{x}2-1)$ numbers to reconstruct $p(f, x)$ in dichotomous situations involving nonprobabilistic forecasts and it takes $21(=11\text{x}2-1)$ numbers to reconstruct $p(f, x)$ in dichotomous situations involving probabilistic forecasts with 11 distinct probability values. Dimensionality (in this sense) is a fundamental characteristic of forecast verification problems (*Murphy*, 1991).

The multidimensional nature of forecast quality also can be understood from a different (but closely related) perspective. Forecast quality can be shown to consist of several different aspects, including bias, accuracy, skill, reliability, sharpness, resolution, and discrimination (*Murphy* and *Winkler*, 1987). Some aspects of quality can be defined in terms of the joint distribution itself. For example, accuracy relates to the overall correspondence between individual pairs of forecasts and observations, as reflected by $p(f, x)$. Other aspects relate to conditional and/or marginal distributions that can be obtained by factoring the basic joint distribution. For example, reliability relates to the conditional distributions of the observations given the forecasts, $p(x|f)$, and discrimination relates to the conditional distributions of the forecasts given the observations, $p(f|x)$.

These considerations suggest that traditional methods of forecast verification, in which forecast quality is characterized by one or two measures of overall performance (e.g., a mean square error, a correlation coefficient, a skill score) are inadequate. Specifically, traditional methods generally do not respect the true dimensionality of verification problems and, as a result, they are quite likely to overlook—or at least to measure inadequately and/or incompletely—various aspects of forecast quality. The nature and extent of these deficiencies depend on several factors, including the severity of the reduction in dimensionality, the properties of the verification methods themselves, and the statistical characteristics of the verification data sample (i.e., the matching pairs of forecasts and observations).

Comparative verification—which is concerned with the comparison of the quality of two or more forecasting systems—suffers from many of these same deficiencies. As presently practiced, it is also based largely on a few measures of overall performance such as mean square errors, (anomaly) correlation coefficients, and skill scores. As in the case of evaluating a single forecasting system, in order to assess the relative quality of different forecasting systems it is necessary to consider quality in its full dimensionality. In particular, the conditional and marginal distributions associated with the respective joint distributions must be evaluated—and compared—in order to make definitive statements regarding all aspects of relative forecast quality.

2.2 Forecast value

Forecasts possess no intrinsic value; instead, they acquire value through their use by weather/climate-information-sensitive decision makers. In the context of the prescriptive approach to decision making and assessing the value of forecasts, the basic determinants of forecast value are: (i) the alternatives (or admissible actions) available to the decision maker; (ii) the payoff structure associated with the decision-making problem; (iii) the quality of the information on which decisions are based in the absence of forecasts; and (iv) the quality of the forecasts themselves (see *Hilton*, 1981). If the alternatives available to the decision maker change (e.g., an action is added or deleted), the decision-making problem itself is changed, and such a change generally leads to changes in payoff structure and forecast value.

The payoff structure specifies a loss or gain for each possible combination of alternative and event (in this paper, it is assumed that the events are defined exclusively in terms of weather and/or climate variables). These losses or gains can be expressed in many different ways; for example, in terms of monetary losses/gains, lives lost/saved, etc. Here we assume that all losses or gains are expressed in monetary terms and that these monetary payoffs reflect the true worth of these outcomes to the decision maker. In addition, it is assumed that the decision maker chooses the alternative that minimizes (maximizes) his/her expected loss (gain). In effect, these assumptions imply that the decision maker's utility function is linear in monetary payoff (see *Clemen,* 1991; *Raiffa,* 1968; *Winkler* and *Murphy,* 1985).

Determinants (iii) and (iv), taken together, indicate that forecast value depends on both the quality of the forecasts and the quality of the information on which decisions are based in the absence of the forecasts. In particular, if the quality of the forecasts is such that the user makes the same decisions with and without the forecasts, then the forecasts are of no value. It should be noted that the assumption that the decision maker possesses a *linear* utility function simplifies the assessment of forecast value. Under this assumption, the value of the forecasts is simply the difference between the user's expected payoffs when his/her decisions are made with and without the forecasts.

It is also important to recognize that forecast value in general depends on forecast quality in its full dimensionality. That is, in order to assess the value of forecasts, the joint distribution $p(f, x)$ (or the components of one of its basic factorizations) must be known. In the prescriptive approach, expressions for forecast value usually involve the conditional distributions of the observations given the forecasts, $p(x|f)$, and the marginal distribution of the forecasts, $p(f)$ (e.g., *Winkler et al.*, 1983; *Murphy,* 1985).

2.3 Implications for quality/value relationships

Since forecast quality is inherently multidimensional in nature and forecast value depends *(inter alia)* on forecast quality in its full dimensionality, the relationship between forecast quality and forecast value is necessarily complex. In addition, the prescriptive approach to decision making itself, in which the decision maker (under the linear utility assumption) chooses the alternative that minimizes (maximizes) his/her expected loss (gain), dictates that this relationship is inherently nonlinear (e.g., *Katz* and *Murphy,* 1990).

It is in general true that forecast value increases as forecast quality (in its full dimensionality) increases. However, the multidimensional nature of forecast quality implies that increases or decreases in *aspects* of quality (e.g., accuracy) do not necessarily imply concurrent increases or decreases in value. For example, *Murphy* and *Ehrendorfer* (1987) have shown that increases in forecast accuracy can actually result in decreases in forecast value. Such quality/value reversals can occur when one-dimensional scores that measure particular aspects of quality are used as surrogates for multidimensional measures of quality itself. In such situations, changes in the basic characteristics of the underlying joint distribution of forecasts and observations can lead to a better one-dimensional score at the same time that they prescribe that a user take courses of action that lead to less desirable outcomes. In fact, these reversals can occur whenever the dimensionality of forecast quality is reduced in an arbitrary manner (i.e., in a manner that fails to take into account the user's decision-making problem). Only in those situations in which forecast quality is one-dimensional does a one-to-one monotonic relationship exist between forecast accuracy (which is then equivalent to forecast quality) and forecast value.

In order to investigate in greater detail the relationship between quality and value, it is therefore quite natural to identify the conditions that a joint distribution $p(f,x)$ must satisfy in order that increases in quality lead unambiguously to increases in value. These conditions are embodied by the sufficiency relation (*Blackwell,* 1953; *DeGroot* and *Fienberg,* 1986), which explicitly accounts for the multidimensional nature of forecast quality. The applicability of this binary relation in the context of comparative evaluation of weather and climate forecasting systems has been explored in several recent studies (see Section 3). In view of the potential importance of the sufficiency relation as a means of inferring the general nature of quality/value relationships, it is considered in some detail in the following section.

3. Quality/value relationships in general: the sufficiency relation

3.1 Description of the sufficiency relation

In the context of comparative evaluation, the sufficiency relation accounts for the multidimensional nature of forecast quality by considering the joint distributions of forecasts and observations for the two forecasting systems of interest. This multidimensional comparison establishes whether or not system *A* is *sufficient* for system *B*. In brief, system *A* is sufficient for system *B* if *B*'s joint distribution (or the components of a factorization thereof) can be obtained through a stochastic transformation of *A*'s joint distribution (for a formal definition, see *Ehrendorfer* and *Murphy,* 1992). The stochastic transformation represents an auxiliary randomization that introduces uncertainty into *B*'s forecasts that is not present in *A*'s forecasts.

The conditions for the existence of a stochastic transformation are rather stringent. In any case, given that system *A* is shown to be sufficient for system *B*, two important consequences follow: (i) *A*'s forecasts are of higher quality than *B*'s forecasts; and (ii) *A*'s forecasts possess greater value than *B*'s forecasts independent of any reference to a specific user (or payoff structure). Thus, if sufficiency can be established (which is not always possible; see below), this relation orders the forecasting systems in terms of both quality (in *all* its aspects) and value. It is evident, then, that the sufficiency relation is a potentially useful tool in investigating the general nature of the relationship between forecast quality and forecast value.

It is important to understand that the sufficiency relation establishes only a quasi-order on forecasting systems. That is, it is not always possible to show that system A is sufficient for system B (or vice versa); in such cases, no stochastic transformation exists and the two systems are said to be *insufficient* for each other. The frequency with which—and the conditions under which—insufficiency is encountered in the real world are issues of considerable practical importance and warrant careful investigation.

3.2 Application of the sufficiency relation: an example

In order to illustrate the use of the sufficiency relation as a means of investigating quality/value relationships, we consider here an application involving the comparative evaluation of prototypical climate forecasting systems (for a detailed discussion of this application, see *Ehrendorfer* and *Murphy,* 1992). These systems produce probabilistic forecasts of below-normal, near-normal, and above-normal climate conditions (e.g., average temperature over a 30-day period), where the three anomaly categories are defined in such a way that their historical climatological probabilities are 0.3, 0.4, and 0.3, respectively.

The systems are prototypical in the sense that certain simplifying assumptions are made that lead to an evaluation problem that involves only two parameters. First, these systems are restricted to using only three possible forecasts—namely, f_1, f_2, and f_3—each of which specifies a coherent set of probabilities for the three above-mentioned climate conditions. Further, in this three-by-three situation (three climate conditions or events, three possible forecasts) the quality of the forecasts produced by these systems is assumed to be completely described by only two parameters, denoted here by δ and π. (Note that a three-by-three situation requires, in general, specification of six parameters to describe quality completely, given the climatological probabilities.) This description is achieved by setting the conditional probabilities of occurrence of the three events given f_1, f_2, and f_3 equal to $(0.3-\delta, 0.4, 0.3+\delta)$, $(0.3, 0.4, 0.3)$, and $(0.3+\delta, 0.4, 0.3-\delta)$, respectively. Thus, for example, the probability of occurrence of below-normal conditions given that forecast f_3 is issued is equal to $0.3+\delta$. The second parameter π specifies the frequency of use of forecast f_1 (and f_3), implying that f_2 is used with a relative frequency of $1-2\pi$. Note that specification of the values of these parameters, together with the climatological probabilities, permits reconstruction of the full joint probability distribution. Further, this relatively simple and highly symmetric structure makes it possible to display the forecasting systems of interest in a two-dimensional diagram.

To facilitate interpretation, it may be assumed that the forecasts are reliable, in the sense that the probabilities specified by the forecasts are identical to the conditional probabilities described above. In this case, for example, for a forecasting system characterized by $\delta = -0.1$, the first entry in the forecast f_3 is equal to 0.2, which is also the relative frequency of occurrence of below-normal temperatures given that f_3 is issued (see previous paragraph). Under the assumption of perfect reliability, f_1 and f_3 are referred to as below-normal and above-normal forecasts, respectively, whereas f_2 is simply a climatological forecast.

In the framework of these forecasting systems, application of the sufficiency relation yields a separation of the two-dimensional parameter space into three different kinds of regions: (i) region S containing the systems B for which the given reference system A is sufficient; (ii) region S' containing the systems B that are sufficient for the reference system A; and (iii) region I containing the systems B that are insufficient for the system A. An example of a particular *sufficiency diagram* is shown in *Fig. 1*. In this case, reference system A, indicated in this figure by a large dot, possesses the parameter values $\delta = -0.10$ and $\pi = 0.15$. From this diagram it is evident that an alternative system B is sufficient for system A if it uses more extreme non-climatological forecasts than A (expressed through larger values of δ). However, this result holds only if π^B is at least as large as π^A; that is, the more extreme non-climatological forecast must be used by system B with a frequency that is at least as large as the frequency of use of the non-climatological forecast by system A. Otherwise, δ^B must become substantially larger as π^B decreases. Still, to a limited degree, smaller π^B can be offset by larger (in absolute value) δ^B. However, the converse does not hold; if δ^B is smaller than δ^A, it can be seen from Fig. 1 that such a deficiency cannot be offset even by values of π^B much larger than π^A.

In order to illustrate the implications of the sufficiency relation for the relationship between the quality and value of the prototypical forecasting systems under consideration here, isopleths of the expected ranked probability score (ERPS; solid lines) as well as of the value of the forecasts (VF; dashed lines) are included in the diagram. Note that both types of isopleths are drawn at unequal intervals for the numerical values of ERPS (VF) of 0.25, 0.30, 0.35, 0.372, 0.39, 0.405, 0.41025, 0.412, 0.414, 0.415, 0.416, 0.417, 0.418, 0.419, 0.4196, 0.4198, 0.4199 (0.001, 0.002, 0.003, 0.004, 0.005, 0.0075, 0.009, 0.011, 0.013, 0.015, 0.020, 0.025, 0.030, 0.035, 0.040, 0.045, 0.049), with increasing (decreasing) numerical values from the lower-right and upper-right corners toward the middle of the diagram (these isopleths are symmetric about the horizontal line $\delta = 0$). The ERPS (for the original definition of the RPS, see

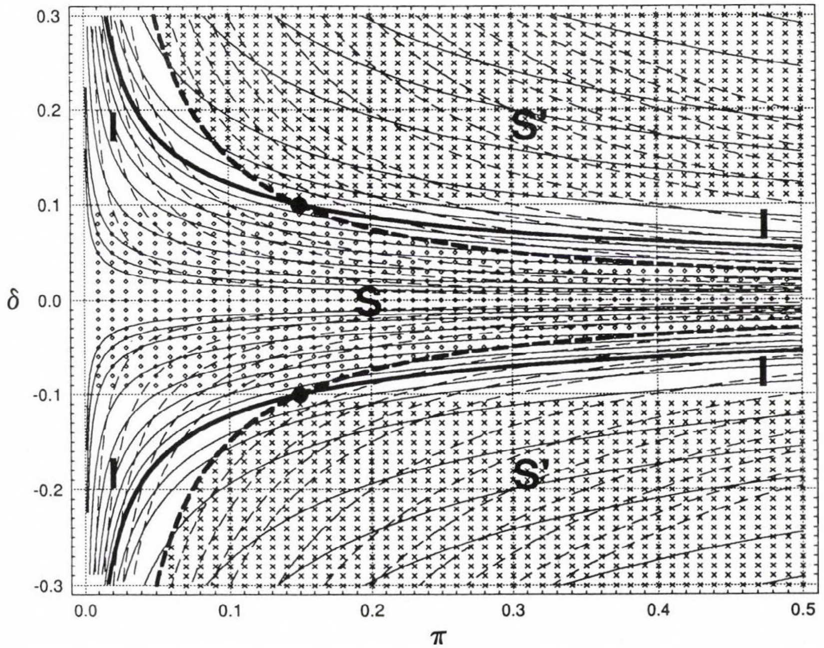

Fig. 1. Example of a sufficiency diagram (see Section 3.2). For a given reference system *A* (denoted by a large dot) the diagram identifies (i) the alternative systems *B* for which the reference system *A* is sufficient (diamonds, region denoted by *S*), (ii) the systems *B* that are sufficient for the system *A* (crosses, region denoted by *S*'), and (iii) the systems *B* that are insufficient for the system *A* (blank region denoted by *I*). The identification of the regions shown is achieved through explicit application of the sufficiency relation. Lines included in the diagram are isopleths of ERPS (solid) and VF (dashed; assessed as described in Section 3.2 for $C/L=0.3$). The bold isopleths denote the ERPS and VF of the reference system; namely, ERPS=0.414 and VF=0.0075. For additional details, as well as the numerical values of the isopleths plotted, see Section 3.2.

Epstein, 1969) is chosen to serve as a representative one-dimensional measure of forecast accuracy, a particular aspect of quality (see Section 2.1). Forecast value is assessed within the framework of the prototypical decision-making problem considered by *Murphy* (1985); in this problem, three possible alternatives (protective actions) are available to the decision maker (see also Section 4.1). In the context of Fig. 1, the basic expense matrix—describing the expenses (payoff structure) associated with various combinations of actions and events (see also Section 2.2)—is modeled through a single parameter, the cost-loss ratio *C/L.* Here this ratio takes on the value 0.3, indicating that the cost of complete protection against adverse conditions is 30% of the total unprotected loss.

From the general discussion of the implications of the sufficiency relation for forecast quality (see Section 3.1), the results in Fig. 1 are clear; all systems lying in S' possess better expected scores than that of the reference system. This result reveals that the ERPS is to some degree consistent with the results derived from the sufficiency relation, in the sense that a better score can never be achieved by a system B for which system A is sufficient (i.e., the ERPS-isopleths are convex curves in this diagram). However, it is also evident that at least one aspect of quality is ignored if only the score itself is considered; it is impossible to infer from the ERPS alone whether B is superior to A in all aspects of quality (i.e., is sufficient for A) or is merely insufficient for A. This deficiency of the ERPS—common to all one-dimensional scores in such situations—results from the fact that ERPS-isopleths exist that traverse both regions S' and I.

Considering the VF-isopleths, it is evident that higher quality (as indicated by larger values of δ and π) implies greater value since the VF-isopleths also are convex curves. Thus, sufficiency implies higher quality as well as greater value (see also Section 3.1). The shape of the VF-isopleth plotted for VF=0.0075 (i.e., the VF of the reference system A) is rather remarkable. Obviously, this isopleth represents the boundary between region I and regions S' (for $\pi \leq \pi^A = 0.15$) and S (for $\pi \geq \pi^A = 0.15$). The unique nature of this isopleth can be further interpreted as follows: consider an alternative system B with the same value of VF as the reference system A. Then, a marginal improvement in the quality of B will lead to a system that is sufficient for A (given that δ^B is larger than δ^A; otherwise, the improved system is merely insufficient for A). Note that this property does not hold for systems B that possess the same ERPS as the reference system A; that is, marginal improvements in quality when both systems exhibit the same ERPS will *not* lead to a sufficient system, since the ERPS-isopleth of the reference system does not represent a boundary in the sufficiency diagram.

Next, examining the behavior of the ERPS-isopleths and the VF-isopleths together reveals the reason that a multi-valued relationship exists between ERPS and VF in this simple example. Specifically, the two sets of isopleths intersect; for example, while following a solid curve (i.e., holding accuracy constant) a number of dashed curves are encountered (i.e., value is changing). The multi-valued nature of the accuracy/value relationship admits the possibility of accuracy/value reversals; that is, a better score may be associated with a decrease in value. For example, consider following a dashed curve from a point (e.g., in S' where both isopleths intersect toward the next intersection (i.e., ERPS improves while VF is held constant) and then following a solid curve toward the next intersection (i.e., ERPS is held constant while VF decreases). This path describes an accuracy/value reversal, because an improved score is associated with a decrease in value. However, it can also be seen from Fig. 1 that if the multidimensional nature of quality is considered in the sense that an increase in quality is denoted by increasing (or holding constant) both δ and π

(and not increasing one and decreasing the other as in the case of an accuracy/value reversal), then such an increase is *always* accompanied by greater value due to the convexity of the VF-isopleths.

In Fig. 1 the implications of the sufficiency relation for forecast value have been considered for a specific class of users (i.e., those users for whom the three-action, three-event cost-loss ratio decision-making model is appropriate with $C/L=0.3$). As a further illustration of the implications of the sufficiency relation for the value of the forecasting systems under consideration here, VF is presented for a larger class of users (i.e., C/L is allowed to vary) in *Fig. 2*. In this case, the VF of five selected forecasting systems is shown as a function of C/L. The parameters determining the quality of these systems (their respective positions in the sufficiency diagram) are indicated in the figure leg-

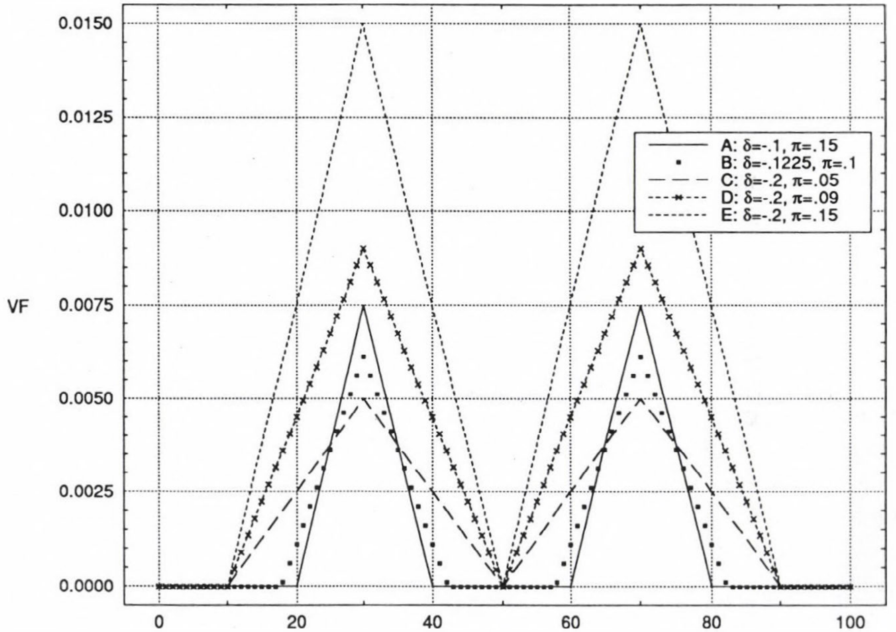

Fig. 2. The economic value VF of selected forecasting systems of the type considered in Section 3.2 as a function of the payoff structure parameterized through the cost-loss ratio C/L. Numerical values of the forecast quality parameters δ and π of the forecasting systems considered are indicated in the box (inset). Systems A, B, and C were chosen in such a way that they are insufficient for each other, whereas systems D and E are sufficient for the reference system A (see Fig. 1). Note that the relative magnitude of VF for the insufficient systems depends on the specific payoff structure identified through the numerical value of C/L, whereas systems D and E have larger values of VF than system A over the entire range of C/L (since they have been found to be sufficient for A).

end. Specifically, the reference system A is considered as well as a system B that is insufficient for A, but possesses the same value of the ERPS. Further, a second insufficient system C is included with a better ERPS than system A. Finally, two systems, D and E, are considered both of which are sufficient for the reference system A, where system D possesses the property of using more extreme forecasts less often (i.e., $|\delta^D| > |\delta^A|$, but $\pi^D < \pi^A$). Since system E uses more extreme forecasts more often than system A (i.e., $|\delta^E| > |\delta^A|$, and $\pi^E > \pi^A$), the former is obviously sufficient for the latter (see also Fig. 1).

First, considering $C/L=0.3$ in Fig. 2 (recall that $C/L=0.3$ was chosen to compute VF in Fig. 1), it can be seen that for this specific payoff structure the reference system A possesses a larger value of VF (namely, 0.0075) than the systems B and C both of which are insufficient for A. However, the VF of system A is substantially smaller than the VF of systems D and E both of which are sufficient for A (namely, 0.009 and 0.015, respectively). Second, from the perspective of different users (identified by different numerical values of the cost-loss ratio), it can be seen from Fig. 2 that systems that are sufficient for system A always possess larger values of VF than A regardless of the specific payoff structure (i.e., C/L) under consideration. This fact illustrates one of the powerful consequences of being able to show that one forecasting system is sufficient for another forecasting system. Third, it is also evident from Fig. 2 that, in the case of insufficient systems (e.g., B and C), the answer to the question of whether one system is more valuable than another system depends on the specific value of the cost-loss ratio. For example, for a user with $C/L=0.2$ the VF of system B is larger than the VF of system A (0.001127 versus 0.0), with the opposite relationship holding for $C/L=0.3$ (0.0075 versus 0.006127). This result illustrates clearly the interpretation that can be given to insufficient systems; namely, if two systems are insufficient for each other, then the payoff structure of the user determines which system is more valuable. That is, relative to the reference system, the alternative system is necessarily of greater value for some users and less value for other users.

3.3 Review of recent applications of the sufficiency relation

The sufficiency relation – originally developed in the context of the comparison of statistical experiments by *Blackwell* (1951, 1953) – was introduced into the forecasting literature by *DeGroot* and *Fienberg* (1982, 1983, 1986). It was employed first in the meteorological literature by *Ehrendorfer* and *Murphy* (1988) who explored its application to primitive probabilistic forecasting systems. They showed that it is possible to identify conditions that basic aspects of quality (i.e., elements of the joint distribution) must satisfy in order to ensure that one forecasting system is sufficient for another forecasting system. In addition, they verified that if A's forecasts are sufficient for B's forecasts in such a context, the value of the former is greater than that of the latter irrespective of the user's payoff structure.

The sufficiency relation has been formulated in a different manner by *Krzysztofowicz* and *Long* (1991a), based on a theorem presented by *Blackwell* and *Girshick* (1954). They identified a forecast sufficiency characteristic (FSC) which employs simple conditions based on inequalities to determine whether one forecasting system is sufficient for another forecasting system. This approach offers advantages over the direct application of the definition of sufficiency, in that it avoids an explicit search for stochastic transformations. The fact that the search for stochastic transformations becomes increasingly laborious as the dimensionality of the joint distribution increases makes an approach based on the FSC particularly attractive. However, it should be noted that the FSC approach—as currently formulated—is applicable only in situations involving dichotomous events.

Comparative evaluation of objective and subjective precipitation probability forecasts has been undertaken using FSCs by *Murphy* and *Ye* (1990a). For these highly competitive forecasts, they found that the respective FSCs seldom satisfied the conditions for sufficiency. Situations that might be characterized as "almost sufficient" were found on numerous occasions, but considerable care must be exercised in drawing conclusions regarding relative quality and relative value in such situations. *Krzysztofowicz* and *Long* (1991b) also applied FSCs to comparative evaluation of precipitation probability forecasts, but they modeled the predictive probabilities using beta distributions (instead of using empirical relative frequencies). The use of beta distributions tends to smooth the empirical data, and the authors found that the conditions for sufficiency were satisfied in most situations with smoothed data.

Recently, *Krzysztofowicz* (1992) used the sufficiency relation as a basis for formulating a measure of forecast skill called the Bayesian correlation score (BSC). The BSC allows direct inferences regarding sufficiency when comparing two forecasting systems. This measure is based on the assumptions that the joint distribution of forecasts and observations is bivariate normal and that the forecasts are unbiased overall. Under these conditions, the BSC represents a one-dimensional measure of forecasting performance that incorporates all relevant aspects of forecast quality. This study demonstrates the importance of the sufficiency relation as a theoretical framework within which it may be possible to develop particularly appropriate verification measures for specific applications.

4. Quality/value relationships in specific situations

The relationship between the quality and value of weather and climate forecasts has been investigated in a variety of specific situations. Two general types of weather/climate-information-sensitive decision-making problems can be identified: (i) prototypical situations; and (ii) real-world situations. The former represent idealized decision-making problems, whereas the latter represent specific decision-making problems that actually arise in the real world. Most studies of quality/value relationships in these situations have been based on a prescriptive, decision-analytic approach to decision making and assessing the value of information (see *Katz* and *Murphy*, 1993; *Winkler* and *Murphy*, 1985). In implementing this approach, simplifying assumptions are frequently made about various features of the underlying decision-making problems. These assumptions relate to such features as the structure of the problem (e.g., static or dynamic in the sense that past decisions do not or do affect future decisions), the alternatives available to the decision maker, the weather/climate events, the payoff structure (e.g., costs, losses), the format and number of distinct forecasts, and the decision criterion. This section briefly reviews a representative set of studies of quality/value relationships in prototypical (Section 4.1) and real-world (Section 4.2) contexts.

4.1 Prototypical situations

The most widely studied prototypical decision-making problem is the well-known cost-loss ratio situation (e.g., *Thompson*, 1962; *Murphy*, 1977). Relationships between forecast quality and forecast value in static versions of this problem have been investigated by *Chen et al.* (1987), *Katz* and *Murphy* (1987), *Murphy* (1985), *Murphy* and *Ehrendorfer* (1987), and *Murphy* and *Ye* (1990b). Moreover, quality/value relationships in dynamic versions of the cost-loss ratio situation have been explored by *Katz* and *Murphy* (1990) and *Murphy et al.* (1985). Recently, studies of the latter type have been extended to include autocorrelated forecasts and/or observations (*Epstein* and *Murphy*, 1988; *Katz,* 1992, 1993; *Wilks,* 1991).

Two important characteristics of quality/value relationships identified in such studies are: (i) their inherent nonlinearity and (ii) their multi-valued nature when quality is not measured in its full dimensionality. With regard to the nonlinearity of the quality/value relationship, the latter is often characterized by the existence of a quality threshold below which forecasts are of no value (see also Section 3.2). Above the quality threshold, value generally increases as a nonlinear function of increasing quality. It is also interesting to note that the quality/value "curve" is frequently convex, in the sense that the *sensitivity* of forecast value to changes in forecast quality increases as quality improves.

Quality/value relationships become multi-valued when the multidimensional nature of quality is not respected (e.g., when quality is measured in terms of a one-dimensional measure of accuracy). In such circumstances, as illustrated in Section 3.2, reversals can occur in the usual accuracy/value relationship, in the sense that (for example) value can decrease as accuracy increases for at least some users. In a different vein, inclusion of the autocorrelation in forecasts and/or observations frequently – but not always – reduces the value of forecasts, but it does not alter the above-mentioned general characteristics of quality/value relationships.

Other idealized situations include the generic choice-of-crop problem investigated by *Winkler et al.* (1983) and the so-called continuous (or Gaussian) decision-making problem considered by *Gandin et al.* (1992). Quality/value relationships in these situations have not been subjected to the same intensive study as that directed towards these relationships in the cost-loss ratio situation.

4.2 Real-world situations

Prescriptive studies of the value of weather/climate forecasts – and quality/value relationships – in real-world situations involve the formulation of models that prescribe the user's decision-making and information-processing procedures. For example, the so-called "impact functions" that translate the effects of weather/climate variables into economic or other payoffs to the user must be specified. In addition, statistical models are frequently used to characterize the quality of the forecasts under consideration. Considerable effort is frequently required (in the areas of data acquisition and analysis, as well as in model development and refinement) to ensure that these models represent reasonably realistic descriptions of the relevant procedures and relationships.

Most real-world studies of quality/value relationships have been conducted within the framework of agricultural decision-making problems. For example, studies of static agricultural problems include the haying/pasturing situation (*Wilks* and *Murphy,* 1985) and a specific choice-of-crop problem (*Wilks* and *Murphy,* 1986). Dynamic decision-analytic studies in this vein include the corn-production problem (*Sonka et al.*, 1986, 1987), the fruit-frost problem (*Katz et al.,* 1982), the fallowing-planting problem (*Brown et al.,* 1986; *Katz et al.,* 1987), and the harvest-scheduling problem (*Wilks et al.,* 1993).

With regard to quality/value relationships, the results of the real-world studies support the conclusion that these relationships are inherently nonlinear. Moreover, most of these studies reveal the existence of quality thresholds below which the forecasts are of no value. With regard to forecast value itself, studies involving short-range weather forecasts indicate that such forecasts can be of considerable value, achieving 50% of the value of perfect forecasts in some cases (e.g., *Katz et al.,* 1982). On the other hand, current long-range forecasts appear to be of relatively little value overall, although even modest improvements in quality could lead to significant increases in their value in some contexts (e.g., *Brown et al.,* 1986; *Wilks* and *Murphy*, 1985). Moreover, these results also demonstrate that, above the quality threshold, the relationship between forecast quality and forecast value is generally nonlinear.

5. *Discussion and conclusion*

The scientific quality of forecasting systems is inherently a multidimensional concept. To measure forecast quality in its full dimensionality, it is generally necessary to consider the joint distribution of forecasts and observations (or the conditional and marginal distributions associated with the factorizations of this joint distribution; see Section 2.1). Thus, one-dimensional verification scores that measure a particular aspect of quality, such as accuracy or skill, are generally incapable of adequately describing all potentially relevant characteristics of forecasting performance.

Forecasting systems acquire economic value through the use of the forecasts by decision makers involved in weather/climate-information-sensitive decision-making problems. The determinants of forecast value in such contexts include both characteristics of the decision-making problems and characteristics of the information available to—and used by—the decision maker (see Section 2.2). In particular, forecast value is strongly related to forecast quality.

The present paper has focused on various aspects of the relationship between forecast quality and forecast value. This relationship is complex—and inherently nonlinear—in nature (see Section 2.3 as well as Sections 3 and 4). In particular, it is not possible to infer forecast value from forecast quality (or vice versa). Moreover, the relationship between one-dimensional verification scores, as measures of specific aspects of forecast quality, and forecast value is generally multi-valued in the sense that forecast value can be specified only within certain limits given a particular numerical score. Quality and value necessarily stand in a one-to-one monotonic relationship only in those situations in which forecast quality is one-dimensional (even in these situations this relationship is usually nonlinear).

The multidimensional nature of forecast quality—together with the complex nature of the relationship between forecast quality and forecast value—possesses important implications for various practices related to forecast evaluation. These practices arise in situations involving both quality/value relationships in general (i.e., ordinal relationships) as well as quality/value relationships in specific situations (i.e., relationships between the magnitude of changes in quality and the magnitude of changes in value). In the case of ordinal relationships, the foremost implication relates to the current practice—which results from the fact that forecasters are seldom in a position to assess forecast value directly—of automatically assuming that forecasts that achieve a better score (e.g., more accurate forecasts) are also more useful (i.e., of greater value). This practice is clearly inappropriate and potentially misleading; the multi-valued nature of accuracy/value relationships implies that increases in accuracy may result in decreases in value for some users. Without specific knowledge of users' payoff functions, it is not possible to ascertain whether users subject to such quality/value reversals represent a significant or relatively insignificant segment of the overall user population.

In the case of situations in which the relationship between the magnitude of a change in quality and the magnitude of a change in value is of interest, it is important to distinguish between the nature of the results that can be obtained from prototypical and real-world studies. Since prototypical studies generally do not relate to any specific weather/climate-information-sensitive decision-making problem, they can at best provide estimates of forecast value only in relative terms. For example, such estimates might specify the value of the forecasts relative to the value of perfect forecasts. Only real-world studies of forecast value—and quality/value relationships—can provide information regarding the magnitudes of changes in forecast-value estimates. This fact underlines the important role that such real-world studies inevitably play in any comprehensive evaluation of weather or climate forecasts.

Although studies conducted to date have provided valuable insights into quality/value relationships, both in general and in specific situations, these relationships obviously warrant further investigation. First, a methodological framework is needed within which quality/value relationships can be studied in a systematic and coherent manner. The sufficiency relation would appear to represent an integral part of any such framework, since it naturally accounts for the multidimensional nature of forecast quality. However, it would be useful to "extend" this framework to allow for the possibility of investigating ordinal quality/value relationships in situations in which users of concern possess a specific class of payoff functions and/or in which the joint distribution of forecasts and observations can be described by a relatively small set of verification measures. Moreover, in those situations in which individual aspects of quality (e.g., accuracy, skill) possess a multi-valued relationship with value, it would be useful to try to describe the general characteristics of these accuracy/value "envelopes" and to identify the conditions that must be satisfied by the joint distribution of forecasts and observations to ensure that the quality/value relationships of interest possess certain desirable properties (e.g., single-valuedness and monotonicity).

Such studies—when supplemented by representative investigations of forecast value and quality/value relationships in the real world—should provide valuable results and insights into various issues of practical importance. For example, it may be possible to identify certain groups of users which possess less complex quality/value relationships or for whom one-to-one monotonic quality/value relationships exist under less restrictive conditions. These studies may also lead to the identification of essential aspects of forecast quality in various contexts, in the sense that these aspects summarize effectively all of the relevant information contained in the basic joint distribution. Moreover, the formulation of a coherent framework for studies of quality/value relationships—and the results of these methodological and practical studies—should be quite valuable in the continuing effort to develop more appropriate verification methods. Thus, it is evident that studies of quality/value relationships represent an integral part of a coherent approach to the problem of evaluating the forecasts produced by weather and climate forecasting systems.

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Abatement strategies for sulphur dioxide, and analysis of the role of emissions from Central and Eastern Europe

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Abstract—To assist in the current development of new protocols on reductions in emissions of sulphur and nitrogen species, the *Abatement Strategies Assessment Model*, ASAM, has been developed to derive and assess effective schemes for reducing acidification across Europe. In accordance with the agreement of 34 countries within the *UN Economic Commission for Europe* in May 1991, we have taken into account critical loads reflecting the capacity of different ecosystems to sustain deposition of acidic species. In this paper the ASAM model is applied to illustrate how the benefits of sulphur dioxide emissions reductions can be maximised relative to the effort invested, and the importance of action in particular regions of Europe.

Key-words: Sulphur dioxide, emission control, acid deposition, critical loads, integrated assessment modelling, transboundary pollution.

1. Introduction

The agreement by many European countries to reduce emissions by 30% relative to those in 1980, by the year 1993, has been insufficient to solve the problems of acidification in Europe. The damage to forests, fresh waters and other sensitive ecosystems is increasing, and stronger action is now required. To this end the *UN Economic Commission for Europe*, UNECE, is working on development of new protocols for SO_x and NO_x. This paper describes some of the work undertaken for the *Task Force on Integrated Assessment Modelling*, TFIAM, in this context.

To analyse different possibilities for SO_2 abatement strategies for Europe we have developed the *Abatement Strategy Assessment Model*, ASAM. This model combines information on present and future emissions in each country, the atmospheric transport between countries as represented by modelling studies within EMEP (*European Monitoring and Evaluation Program*), maps of critical loads as sustainable annual rates of deposition of sulphur across Europe, and information on costs of reducing the projected emissions for each country which grow progressively more expensive as the stringency of control increases.

It can readily be shown with the ASAM model that a uniform reduction of emissions throughout Europe is not a cost-effective way of controlling acidification. A far more beneficial approach is to invest in reducing those emissions which contribute most to the excess deposition, particularly in sensitive areas; this means stricter control of sources close to or upwind of such regions. However this results in very different levels of effort and expenditure in different countries (*Derwent*, 1988).

2. *The ASAM model*

The ASAM model has been described in some detail in a previous paper (*ApSimon et al.*, 1992), together with sensitivity studies to parameterization of the long-range transport modelling and year-to-year meteorological variability. Hence only a brief summary will be given here.

The geographical distribution of emissions is prescribed on a grid spanning Europe with grid squares of the order of 150 by 150 km, using data provided by EMEP, and based on official submissions from each country. Projected unconstrained emissions of SO_2 if there were no control measures imposed are based on estimates supplied by IIASA from data on future energy use projections up to the year 2000 (*Amman* and *Sorensen,* 1991). Emission reduction calculations may take as their starting point these unconstrained emissions; or they may start from the current position (1990) as in this paper, or from current plans of different countries to reduce emissions to see what additional measures are required.

To examine the deposition due to this initial source distribution, and estimate how it would change as a result of a reduction at a source in any given grid-square, requires source-receptor matrices. These define the annual deposition (e.g. in g m^{-2} y^{-1} of S) in each "receptor" square per unit annual emission of sulphur from each square with emissions. These have been derived from calculations undertaken within EMEP by the Norwegian Meteorological Institute with a *Lagrangian model* of atmospheric transport across Europe (*Iversen et al.*, 1991). This model follows the history of columns of air along trajectories culminating at each grid-point at 6 hourly intervals; along each trajectory the emissions into the puff column are distinguished according to their origin, so that the contribution from different source countries to deposition at the receptor at the end-point of the trajectory can be calculated separately. Calculations have been undertaken spanning 5 years to smooth out year-to-year variations in meteorology, and the average over these years has been used in the results presented here. (The effect of variability between years is investigated in *ApSimon et al.*, 1992.)

A complication is that a portion of the deposition is "unattributable"; that is it cannot be traced back with certainty to an origin in a particular country. The EMEP centre has systematically reduced this portion by considering contributions to it—for example from marine regions and ships: but a part of it is due to circulation of material leaked into the free troposphere, where its range is effectively global. Even though the unattributable contribution is small, typically of the order of 0.1 g m^{-2} y^{-1}, this is not insignificant for some sensitive areas where it can amount to some 30% or more of the critical load. This was illustrated by applying ASAM with and without the unattributable deposition included (*ApSimon et al.*, 1991). However on the basis that the unattributable deposition is effectively from global scale circulation, a proportion ($\sim$ 1/3rd) is attributed to North American emissions for which a 50% reduction is planned: the rest is reduced in proportion to European emissions as a whole.

As mentioned below with respect to critical loads, similar problems arise with respect to the neutralising effect of deposition of base cations. These tend to be higher in southern parts of Europe where Saharan dusts and suspended soil particles contribute calcium and magnesium in sufficient quantities to counteract the acidic species, and is one of the reasons why Southern Europe is less susceptible to problems of acidification. A map of base cation deposition has been prepared by the EMEP *Synthesizing Centre West* at NILU, using measurements within the EMEP station network, and can be incorporated as a neutralising factor adding to the critical loads. However fly-ash from brown coals can contribute quite large amounts of base cations, and where this has not been controlled in the past, improved emission control may also modify the base cation deposition pattern in the future. This is likely to be more important for Central and Eastern European countries, but as yet there is insufficient information to treat these emissions in more detail. However they should be borne in mind in assessing the uncertainties in the effectiveness of control strategies.

The critical loads represent the capacity of the environment to receive deposition of sulphur without adverse effects. They have been defined across Europe according to specifications set by experts in a special task force of the UN ECE on mapping, and compiled at the *Coordinating Centre on Effects* (CCE) at RIVM in the Netherlands (*CCE,* 1991). The CCE have derived separate maps for sulphur and nitrogen. These correspond to different levels of protection, represented by the maximum percentage of ecosystems in each grid square which may not be protected by the assigned critical load. Thus the 1%ile map depicts levels of deposition which will protect all but the most sensitive 1% of ecosystems in that grid-square. Inevitably the critical load maps are somewhat simplified, and cannot fully allow for systematic spatial variations within grid cells which may be correlated with deposition—for example orographic effects: these effects are not represented in the modelling of the source–receptor matrices either.

The possible ways in which sulphur emissions may be controlled include changing to low sulphur coal, or to other energy sources such as nuclear power or gas; controlling emissions by such means as flue-gas desulphurisation or limestone injection; or reducing energy requirements. Some of these are very dependent on other aspects of energy policy, but it can be argued that if emissions can be reduced to a given level by a limited selection of methods such as end-of pipe technologies, then equivalent reductions can be achieved at the same or even lower cost if additional options are included. In the calculations presented in this paper we have used national cost curves for each country provided by IIASA (private communication), without allowing for energy efficiency improvements or switches to non-fossil fuels. These indicate costs increasing more and more sharply as the emission reductions implemented increase, until further abatement becomes prohibitively expensive.

3. Weighting functions and the Best Economic Environmental Pathway

The approach used to derive economically and environmentally effective emission reductions is referred to as the *Best Economic Environmental Pathway*, BEEP. It is based on the assumption that environmental improvements will be achieved as a result of successive steps during a specified time period; and that at each step it is desirable to maximise the ratio of the benefit, in terms of reduction of deposition towards specified target loads or critical loads, to the associated cost. ASAM thus produces a sequence of emission reductions at selected emitters, with deposition converging towards desired levels as a function of the cumulative cost.

Thus suppose that there is an overall fund to spend from. For each emitter there are successively more expensive options per ton of sulphur dioxide removed. At each step the sources are scanned to identify the COST of the cheapest option not yet implemented for each emitter, and simultaneously the associated BENEFIT of the corresponding reduction. The benefit of a reduction for source **i** reflects the corresponding change in deposition at any receptor **j**, ΔD_{ij}, and what contribution this can make to reducing any excess of current deposition, D_j, at that location over the target deposition T_j. This excess is termed the exceedance

$$BENEFIT\ (emitter\ i) = \Sigma_j\ \alpha_i\, \beta_{ij}\, F\{\Delta D_{ij},\ \max(0: D_j - T_j)\}.$$

The α_i and β_{ij} are weighting functions built in to the model. They can, for example, be used to put more emphasis on sensitive areas and reflect damage, or to weight susceptible areas where the exceedance is particularly large. Successive steps are implemented until the target loads are attained or the maximum expenditure allowed is exhausted. Maps of the deposition, and its exceedance over the target loads may be produced at specified intervals in the cumulative expenditure.

The BEEP approach has the advantage that it shows clearly how the benefit to cost ratio changes with increasing expenditure, and how closely environmental goals are being reached. Thus it is evident if unreasonably large expenditures are implied to reduce deposition by negligible amounts of one or two centigrammes per square metre in certain difficult areas. More sophisticated linear optimisation techniques (such as those used in the RAINS (*Amman et al.*, 1991) and CASM (*Chadwick* and *Kuylenstierna,* 1989; *SEI,* 1991 models), concentrate on obtaining just an optimised "best solution" strategy to meet specified target deposition maps exactly; but do not differentiate the relative importance of the emission reductions implemented within the scheme selected.

4. Scenario analysis

As an illustration of the application of ASAM to derive effective strategies for control of acidification, we shall consider a situation starting from current emissions in the year 1990, and aiming to reduce deposition of sulphur as far as possible towards the 1%ile critical load map for sulphur deposition. A map of the latter as derived by the *Coordinating Centre for Effects* at RIVM in the Netherlands, and adjusted for base cation deposition, is shown in *Fig. 1*. The 1%ile level provides a relatively ambitious target, endeavouring to protect all but the most sensitive 1% of ecosystems in each grid square.

In the calculations presented here we have taken account of the fact that the same level of excess deposition, say 0.3 g of sulphur per m^2 per year, is far more serious on a sensitive area, with a critical load also perhaps as low as 0.3 $gSm^{-2}y^{-1}$, than on a less sensitive area with a critical load of say 3 $g\ S\ m^{-2}\ y^{-1}$. Thus, although we have minimized the straight exceedance and have used a uniform weighting function, we have analysed the environmental effects in terms of a function more indicative of potential damage. Ideally this requires dose-response relationships which may be quite complex; but we have adopted a relatively simple relationship where the damage (*D*) function for any grid-square is defined as

$$D = Exceedance/(\Delta + CL),$$

where the *exceedance* reflects the deposition of sulphur in excess of the critical load, *CL*, and is zero when this is achieved; and Δ is a small quantity, comparable with natural levels of sulphur deposition and other small uncontroll-

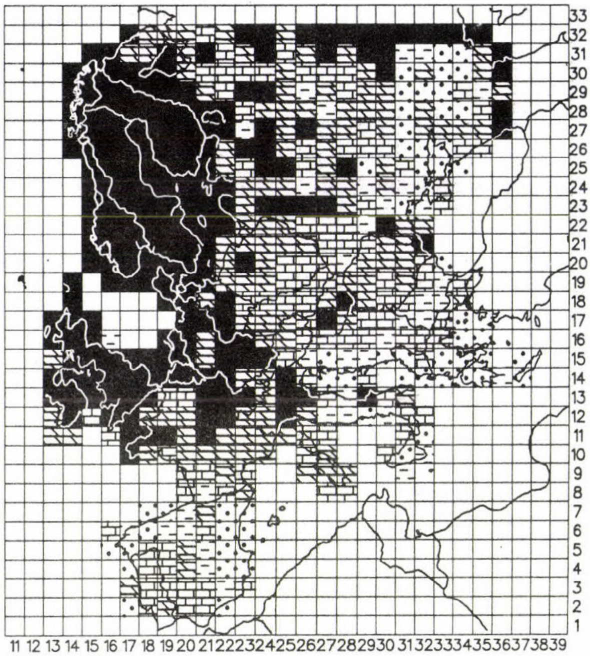

Fig. 1. Critical load map for deposition of sulphur expressed in H^+ [eq ha^{-1} y^{-1}] affording protection at the 1%ile level (including correction for the deposition of base cations)

able contributions, which normalises the damage function when critical loads for anthropogenic emissions are near zero. In the results presented here Δ is taken as 20 H^+ eq ha^{-1} y^{-1}.

Fig. 2a shows a map of the damage function initially with the pattern of emissions as in 1990. In *Figs. 2b, 2c* and *2d*, emission reductions have been introduced to optimise reductions in total exceedance across Europe up to different levels of cumulative cost; viz 10, 20 and 45 billion (10^9) Deutsch Marks per year in the three cases; this is scenario 1. It can be seen that there is substantial improvement as a result of the first 10 and 20 billion DM y^{-1}, but that thereafter there is a relatively modest improvement with an additional 25 billion DM y^{-1} compared with the first 20 billion. At such high expenditure the benefits of further reductions are purely marginal (also see Fig. 4 below). This demonstrates how the benefit to cost ratio of introducing additional emission control decreases with successively higher levels of cumulative expenditure. There is a clear priority for the most effective steps to be taken first in order to protect the areas most susceptible to damage. It is also evident that complete protection at such a stringent level as the 1%ile critical load is not achievable.

Table 1 gives an indication of the magnitude of emission reductions and corresponding costs in each country, corresponding to the situation in Fig. 2c

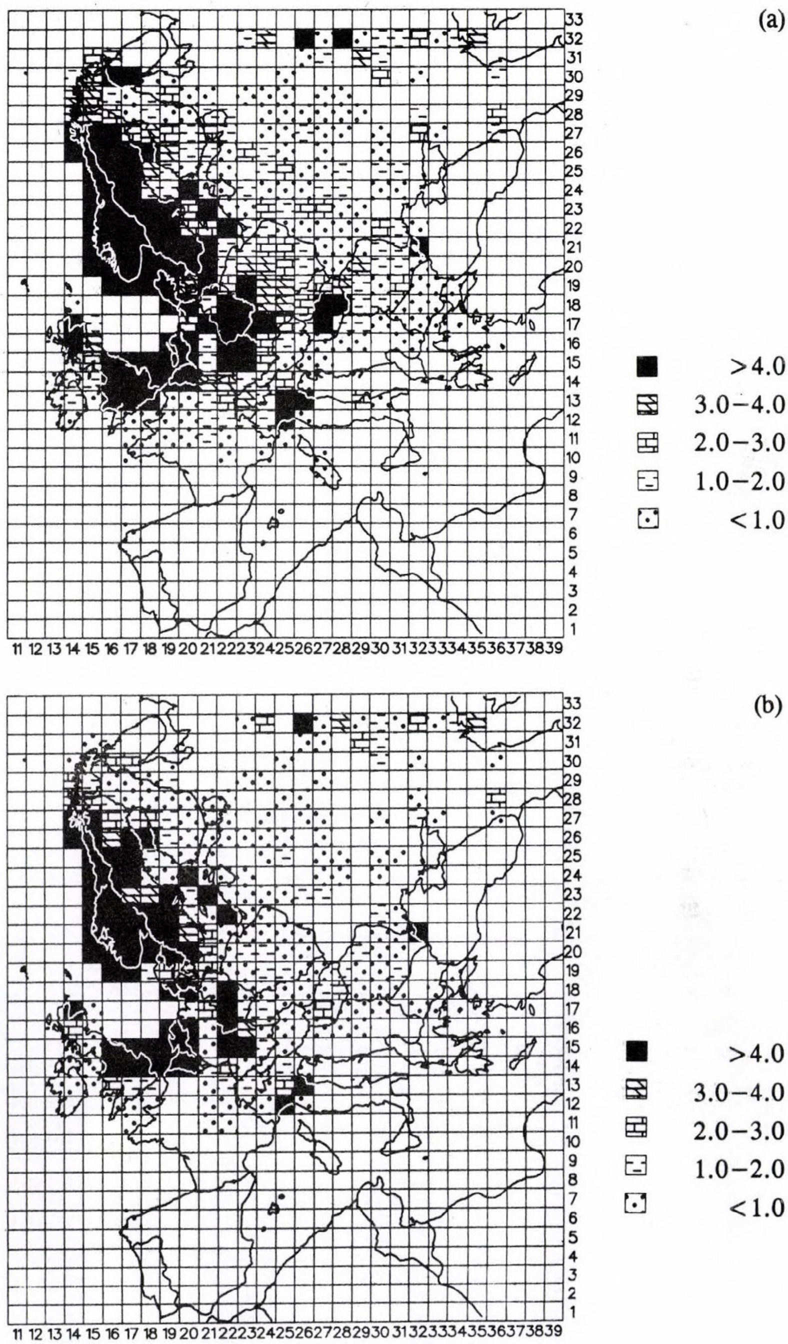

Fig. *2a, b.* Maps of the damage function after different levels of expenditure in Europe of: (*a*) 0 and (*b*) 10 billion DM y^{-1} (DM: 1985 Deutsch Mark)

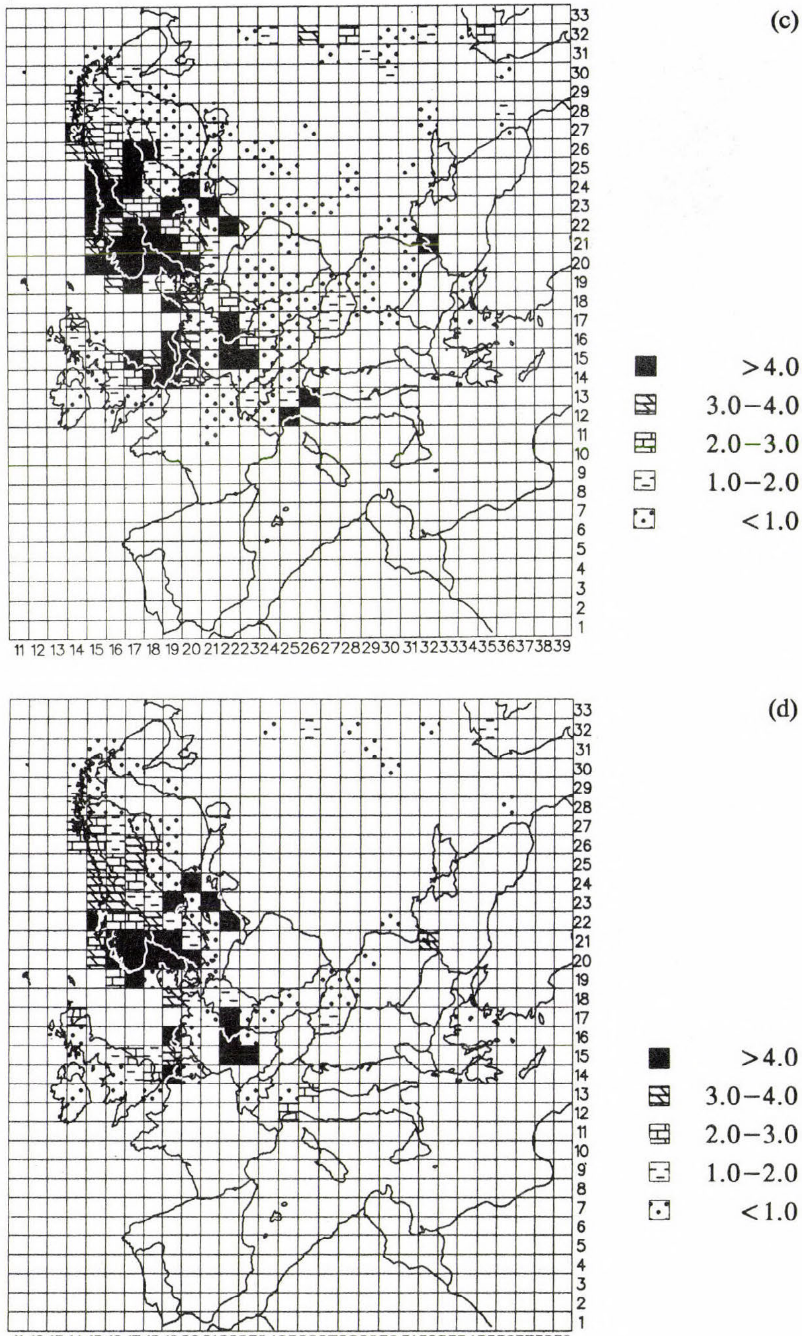

Fig. 2c, d. Maps of the damage function after different levels of expenditure in Europe of: (*c*) 20 and (*d*) 45 billion DM y^{-1} (DM: 1985 Deutsch Mark) where the level of expenditure is 20 billion DM y^{-1}. It is clear that countries in Southern Europe such as Greece and Portugal who are enlarging their industrial base, need to take relatively little action; the same holds for countries that have already taken major steps to reduce their sulphur emissions, such as Austria and Switzerland. At the other end of the scale big reductions are required in Poland, the U.K., Czechoslovakia, Germany; and a considerable effort in several of the other countries too.

Table 1. Emission reductions and costs for scenario 1 in which all countries participate and all targets are included. Total cost level is 20 billion Deutsch Marks (DM) per year

Country	Cost (million DM y^{-1})	SO_2 emission (ktonnes y^{-1}) After abatement	In 1980
Albania	0	50	101
Austria	0	99	329
Belgium	478	214	821
Bulgaria	226	576	1014
C.S.F.R.	1488	757	3100
Denmark	363	66	444
Finland	144	156	570
France	573	730	3492
F.R.G East	1466	367	5005
F.R.G. West	1333	632	3147
Greece	5	495	517
Hungary	345	476	1617
Eire	30	143	209
Italy	1127	1257	3840
Luxembourg	10	7	18
Netherlands	210	177	462
Norway	27	45	136
Poland	3346	781	3852
Portugal	0	212	263
Romania	1105	535	1693
Spain	125	2014	3107
Sweden	130	144	494
Switzerland	10	56	126
Turkey	54	2818	860
U.K.	3153	582	4831
Yugoslavia	764	989	1188
Kola/Karelia	381	238	900
St. Petersburg	229	100	650
Baltic Republics	378	167	593
Byelorussia	349	240	736
Ukraine	1096	1241	3764
Moldavia	82	60	156
Rest of U.S.S.R.	1017	4718	6001

We can now examine how this situation (scenario 1) is altered if Central and Eastern European countries are not able to reduce their emissions, and in addition Western European countries work only towards achieving critical loads in Western Europe, and ignore Central and Eastern Europe-scenario 2. Thus in *Figs. 3a* and *3b* only Western European countries emissions (including the former East Germany) are reduced in accordance with protection of their combined territory; and emissions in Albania, Bulgaria, Czechoslovakia, Hungary, Poland, Romania, Yugoslavia and Kola-Karelia, St. Petersburg, the Baltic Republics, Byelorussia, Ukraine, Moldavia, and the European part of the C.I.S remain fixed at their 1990 levels (although emissions in some of these countries have decreased temporarily since 1990 with the large changes which have taken place).

The expenditure in Western Europe in Fig. 2c was 9.2 billion DM y^{-1}, just under half the total expenditure of 20 billion DM y^{-1}. Therefore in deriving Fig. 3a this same amount has been invested in reducing emissions in western Europe. It can be seen that the resulting map of damage looks very much worse than in Fig. 2c. Even when the whole 20 billion DM y^{-1} spent in the case of Fig. 2c is allocated to emission reductions in Western Europe, the map of damage remains very much worse, as is illustrated in Fig. 3b; in fact there is little improvement compared with Fig. 3a. This is because the most effective emission reductions have already taken place within the first 10 billion DM y^{-1} of this expenditure in Western Europe, and beyond this point improvements are largely cosmetic. This clearly illustrates that what can be achieved by reducing emissions in the Western European countries alone is very limited, and that effective action on acidification requires a similar level of investment in Central and Eastern Europe.

This is further illustrated in *Fig. 4*, in which we have estimated the total area which is still unprotected in Western Europe at different levels of expenditure, for the two scenarios – with and without emission reductions of sulphur dioxide in Central and Eastern Europe. The ordinate indicates the total area of Western Europe (in square kilometres) over which the deposition still exceeds the critical loads, allowing for the distribution of areas with different sensitivities in each grid square. This again illustrates how this area reduces sharply in the first stages of expenditure as the priority sources for reduction are controlled, and the curves level off as expenditure increases. It clearly shows the difference in what can be achieved with and without action to control emissions in Central and Eastern Europe. Again it indicates how it is not possible for Western Europe alone to solve the problem of acidification.

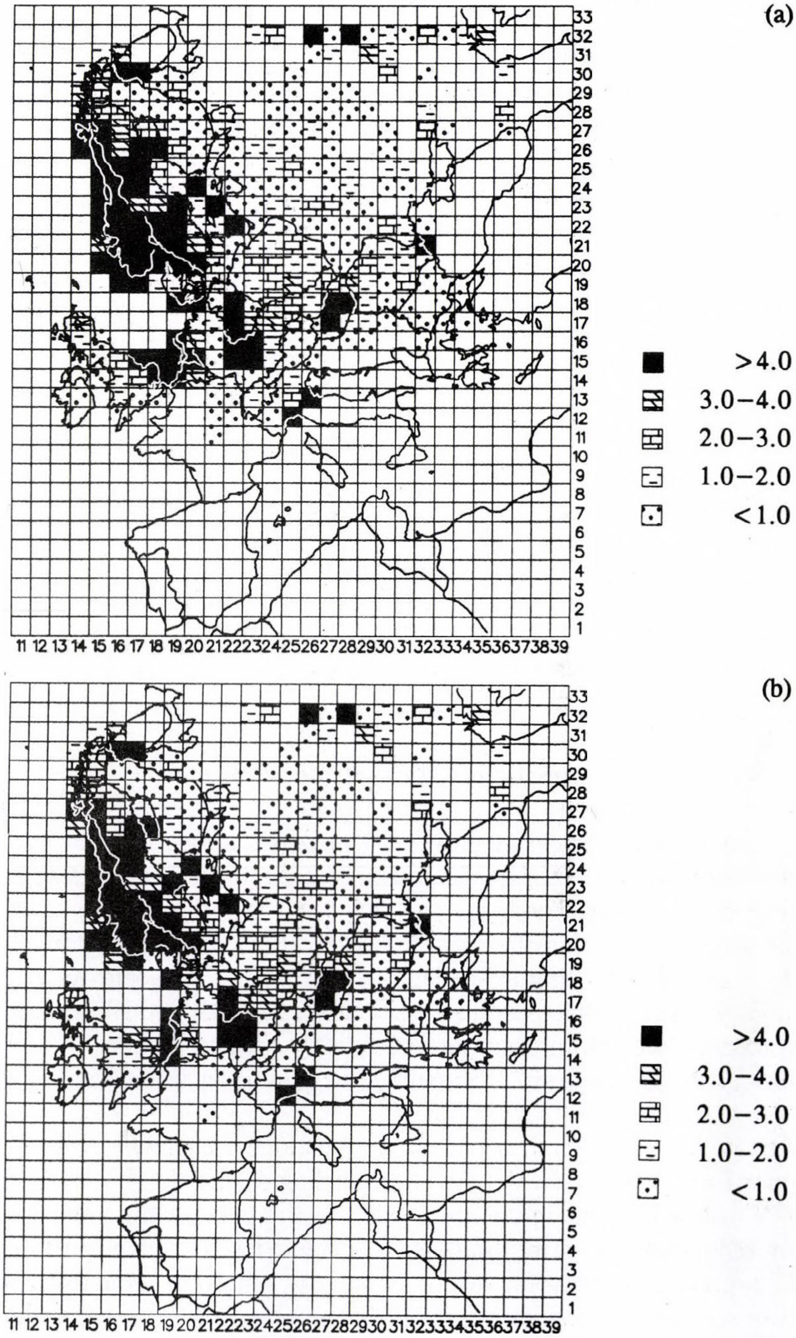

Fig. 3. Maps of the damage function corresponding to optimised expenditure levels of: (*a*) 9.2 and (*b*) 20 billion DM y^{-1} in Western Europe alone (DM: 1985 Deutsch Mark)

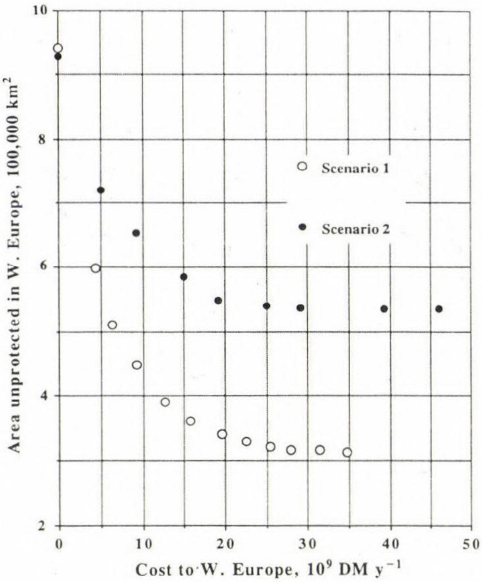

Fig. 4. The relationship between the area unprotected in Western Europe and expenditure for the case when Eastern Europe does participate (scenario 1), and when it does not (scenario 2)

5. Implications for individual countries

To examine this further we have analysed the effort implied in different countries in the two scenarios. Thus in *Figs. 5a* to *5c* the emissions of SO_2 remaining in individual countries are indicated at different stages of overall effort or expenditure, for the two scenarios. Fig. 5a shows how emissions would be reduced according to scenario 1 in Poland, Czechoslovakia, Romania and Hungary. Clearly these countries are making a large contribution within the improvements indicated in Figs. 2a to 2c. In the second scenario of course, the emissions of these countries are assumed to remain at their starting values in 1990.

In Fig. 5b the corresponding emission reductions are shown for the UK, and the former East Germany which has been included with the rest of Germany as part of Western Europe in this analysis. Again a large amount of effort in emission reduction is required in these two countries. However particularly for the UK, a greater priority for larger immediate emission reductions would be implied in scenario 2. Fig. 5c shows the same effect on emission reductions in Denmark and Sweden, with a particularly stringent emission control indicated for Denmark in scenario 2. Other countries in N.W. Europe follow a similar pattern, depending on the degree to which they have already reduced their emissions.

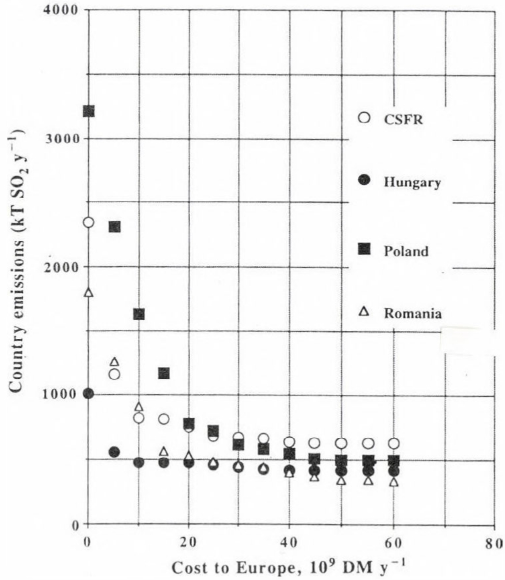

Fig. 5a. ASAM (*A*batement *S*trategies *A*ssessment *M*odel) strategy for emission reductions in some eastern European countries when all countries participate in a scheme targeting all 1% CCE critical loads

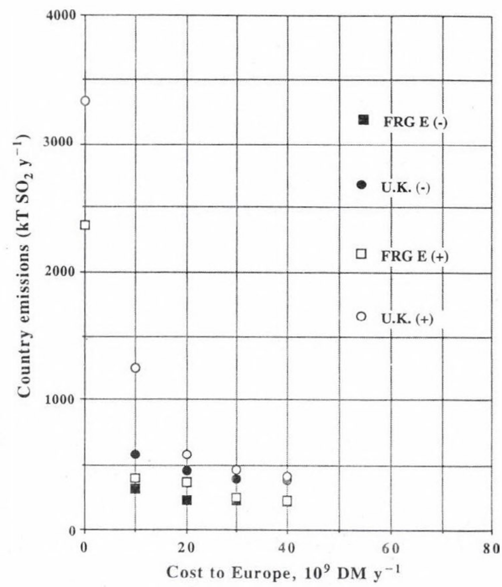

Fig. 5b. ASAM strategy for emissions reductions in the UK and the former East Germany (denoted as FRG E), with (+) of without (-) the participation of the Eastern European countries

Since acidification is far more of a problem in Northern Europe, than in Southern Europe, where soils are generally less sensitive and rain has more alkaline constituents from Saharan dusts etc, the emission reductions required

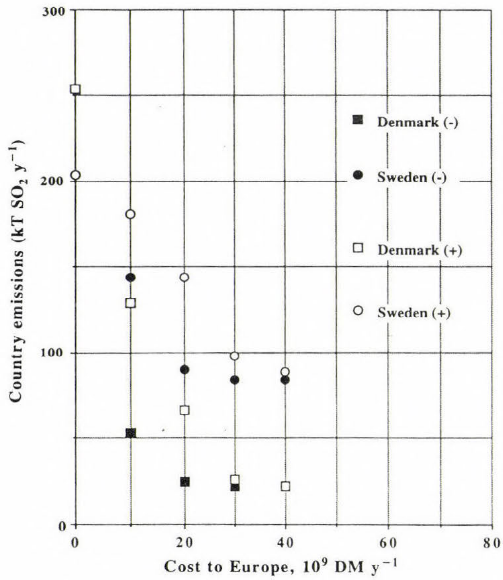

Fig. 5c. As 5b for Denmark and Sweden

in Southern Europe are less. Thus a similar investigation of the implications of non-participation of Southern European countries in SO_2 emission reductions, shows that they make relatively little difference; except where protection of relatively small sensitive areas in those countries is involved, which can largely be solved by local action.

6. *Summary and conclusions*

In this paper the application of integrated assessment to effective control of sulphur dioxide emissions to reduce problems of acidification in Europe has been illustrated. In particular two scenarios have been compared, in which in the first emission reductions have been optimised over the whole of Europe, and in the second the implications if emissions in Central and Eastern Europe were to remain equivalent to 1990 levels have been investigated. Some reduction in emissions has already taken place with recent changes in these countries, but these are modest compared with the reductions really required to combat acidification effectively. It is clear that emission reductions in Western Europe alone are insufficient to protect sensitive areas within this part of Europe; and that it is far more cost-effective to invest in emission reductions across the whole of Europe. This also helps to solve more local pollution problems in Central and Eastern Europe.

Acknowledgements – We should like to acknowledge the support of the *UK Department of the Environment* and the *Commission of the European Communities* in this work; and the cooperation from the *Norwegian Meteorological Institute*, responsible for the modelling of transboundary transport of acidifying pollutants within the *European Monitoring and Evaluation Programme*, EMEP. We are also grateful to the *Coordinating Centre on Effects at RIVM in the Netherlands* for providing the critical loads data, and to the *International Institute for Applied Systems Analysis* for making their estimates of the costs of sulphur dioxide control in the different countries available; and for the benefit of discussion with colleagues from these and other organisations.

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IDŐJÁRÁS

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Single particle analysis of Hungarian background aerosol

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Abstract—Source apportionment of air particulate matter was performed in order to determine the possible sources of atmospheric solid pollutants. Hitherto these studies were mostly based on bulk composition measurements of the aerosol. The method of single particle analysis (using automated electron microprobe analysis) was introduced to study "background" aerosol samples from K-puszta. Most particles were found to be of anthropogenic origin, like fossil fuel burning and steel smelters. The classified particle groups were related to the corresponding air cell trajectories.

Key-words: Single particle analysis, electron microprobe, background aerosol.

1. Introduction

Hitherto source estimation of atmospheric particulate matter using receptor models has mostly been based on bulk composition measurements of the aerosol. Source profiles, i.e. the concentrations of several elements for air particulate matter originating from one source, can be deduced from the receptor data using a number of multivariate techniques among which the chemical mass balance method. The application is limited by the large number of observations that must be made for each of the variables. Often an elaborated sample preparation is necessary for fractionating the sample into several sub samples, according to the density, particle diameter or other relevant properties. Often this may result in poorly resolved source characteristics.

On the other hand, methods for single particle analysis provide direct information on chemical composition and morphology for each individual particle. In case of sufficient lateral resolution and chemical sensitivity, this enables even a size fractionation on the basis of some measured or derived parameters, as well as a separation of chemically different particle groups.

Automated electron probe X-ray micro analysis (EPMA) has sufficient spatial resolution (0.1 – 0.3 μm) to detect individual particles, and it has successfully been used to classify atmospheric aerosol particles from urban, remote, continental and marine areas, or suspension particles in the water of estuaries and seas (*Xhoffer et al.*, 1992). Such method was never before used to analyze aerosol samples from the area of Eastern Europe. In previous work only fly ash particles originating from this geographical area were studied by EPMA single particle analysis (*Török et al.*, 1990). The emitted stack fly ash particles were classified into several chemically and morphologically different groups. The EPMA automatic particle recognition and characterization system is capable to detect automatically particles greater than 0.1 – 0.3 μm and elements heavier than Na. The measurement data of summer and winter sampling showed that, in the particle size range between 0.3 and 2 μm, two types of unexpected groups are present. One group has a high barium content and the other group consists of calcium sulphate particles with high arsenic content. This arsenic is supposed to be on the surface of the particles due to the condensation in the cooled stack gas.

The aim of the present work is to find the relative abundance of the particle types originating from different sources at a background monitoring station (K-puszta) in the middle of the Great Hungarian Plain. For some samples the corresponding air trajectories were calculated and were related to the results of the source profiling data.

In earlier work, the bulk chemical composition of aerosol sampled at this station has been measured by using wet chemical and PIXE methods. Bulk and size-fractioned samples analyzed by the PIXE method were used for source apportionment with multivariate statistical analysis (*Borbély-Kiss et al.*, 1990, 1991).

2. *Materials and methods*

2.1 Sampling

Six samples were taken in the spring of 1990 at the sampling site, which is located nearly at the centre of Hungary between the rivers Danube and Tisza, about 70 km south-east of Budapest. The closest town of 100 000 inhabitants, namely Kecskemét, is about 10 km SE, and a ferrous metallurgy plant is located at 50 km from the station. The closest paved road (with very low traffic density) is at least 5 km away. The station is situated in a clearing in a forest consisting of deciduous and coniferous trees.

Sampling was performed at 2 m above ground level using Nuclepore filters of 0.4 μm pore size, with 1.5 cm^2 exposed area. The sampling time was 24 h and the sample volume varied between 3 and 8 m^3.

2.2 EPMA

The aerosol loaded filters were measured by a JEOL 733 Superprobe equipped with a Tracor Northern (Middleton, USA) particle recognition and characterization program (PRC) that facilitates a fully automated analysis on a preset number of particles. For X-ray micro analysis, 25 keV and 1 nA operating conditions were used. The PRC system operates in the following way. As the beam scans across the field of interest, a particle is considered as detected when the digitized backscatter signal exceeds a preset threshold value. The coordinates of the contour points are determined and additional information such as particle diameter, perimeter and shape factor ($\text{perimeter}^2/4\pi \times \text{area}$) are calculated. Energy dispersive X-ray spectra are collected for 30 seconds with the electron beam scanning over the particles. In each sample about 300 particles were measured. Measurement data were stored on magnetic tape for "off-line"data processing on a VAX 11/780. The large data sets contain for each particle: net characteristic X-ray intensities for 18 elements, diameter and shape factor of the particle. Classification of the particles was carried out by hierarchical cluster analysis (*Van Espen,* 1984) based on the Ward's error sum strategy, that has previously been proved to be the most advantageous procedure for environmental applications (*Bernard* and *Van Grieken,* 1992). A second hierarchical clustering was performed on the average composition data of the samples and resulted in a set of training vectors (centroids) that are relevant for the campaign. Finally a nearest centroid sorting is used to classify all particles from one campaign according to their distances from the centroids of the clusters. The method of *Forgy* (1965) minimizes the sum of squares of the distances to the centroids for a fixed number of clusters. This procedure results in an average composition data set for each sampling site and in the abundances of the particle groups in each sample.

3. Results and discussion

As mentioned above, particles greater than 0.1 μm are detected in automatic analysis. Size distribution curves of particles detected by EPMA in all samples were measured[1]. The size distribution curves of the particles showed that 80 % of the detected particles is smaller than 3 μm; they have a long residence time. As an example, *Fig. 1* shows the size distribution curve related to a dry day.

[1] Note that those graphs are not necessarily equivalent with the size distribution of all particles in the air.

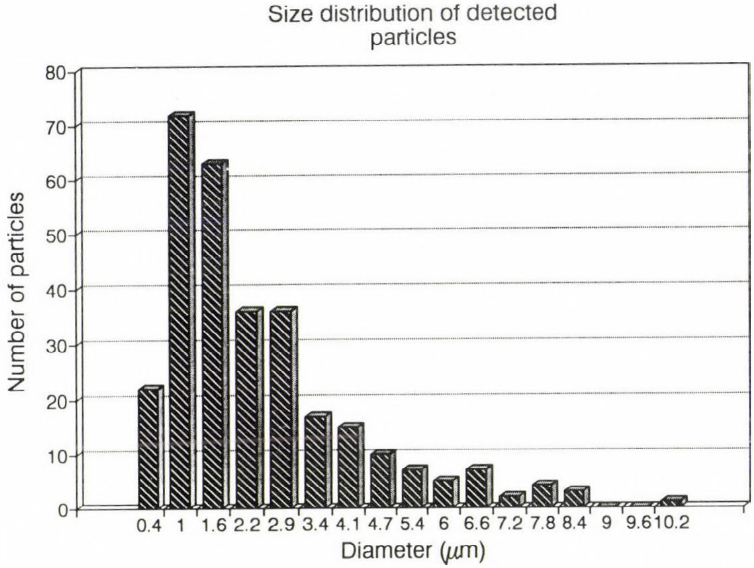

Fig. 1. Size distribution of aerosol samples taken on April 1 when the mean temperature was 19°C and the number of sunny hours was 11

The chemical speciation of the particles is based on the net X-ray intensities that gives rise to the assignment of the particles to different particle types. However, particle groups of various origin might have very similar EPMA spectra due to the low sensitivity for trace components. E.g. alumina-silicate particles might be soil dust as well as fly ash particles. The higher sulphur content and the typically round shaped morphology of the latter may be an indication for fossil fuel burning.

Table 1 gives an overview of the major particle types found in the 1990 sampling campaign. Hierarchical clustering of the chemical and morphological data of the individual samples showed that a major fraction of the particles (>0.3 μm) detected during this sampling period were of anthropogenic origin, mainly from power stations and metallurgical emissions. *Fig. 2* shows relative abundances obtained by non-hierarchical clustering of the entire data set. This classification gives the relative abundances of each particle group in the samples. The abundances of particle groups classified as combustion originated are presented in *Fig. 2a*, and those identified as crustal and biogenic are presented in *Fig. 2b*. Due to the size of the data set (1800×20 variables) non-hierarchical clustering was applied. This procedure, of course, results in slightly different particle classes compared to those obtained by hierarchical clustering. This gives rise to some dissimilarity with groups found for one particular day as presented in *Table 2*.

Table 1. Particle groups in background aerosol sampled in April-May 1990 in K-puszta as detected by EPMA

Particle type	Major components detected by EPMA	Diameter (μm)	Shape factor
Industrial			
Silicate	Si, Al, S, Ca	2.6	1.7
Gypsum	Ca, S, Si	2.3	1.8
Iron-rich	Fe, Si, S	1.5	1.5
Pyrite	Fe, S, Si	0.8	1.7
Metals	Al or Ti or As		
Crustal and biogenic			
Silicate	Si, Al, K, Fe	2.7	2.6
Quartz	Si	1.5	2.3
Limestone	Ca	1.7	2.5
Biological	S, P, K	2.6	2.5
Sulphate	S	0.8	1.7
Traffic	Pb, Cl, Br	0.6	1.3

Gypsum is very common in fly ash since often lime is added to reduce gaseous sulphur emission. In some Hungarian power stations (Ajka) alkaline lignite with high Ca content (*Rausch et al.,* 1988) is burned. These type of particles, however, might have various other sources as well (*Van Borm,* 1989).

As mentioned above, silicate particles of industrial origin are different in composition and shape from the soil silicates. They can originate from any type of coal burning. Their abundance did not depend significantly on the wind direction. Very few particles were observed with a relatively high V and Ni content which would indicate oil fired power station as aerosol emission source.

The Fe-rich particles might originate from various sources like steel plants, corrosion and coal burning. The abundance of this group depended on the wind direction. The same holds for the Fe- and S-rich particles, i.e. the pyrite group.

Barite type particles were observed occasionally at lower abundances. The same type of particles were found in the stack flyash from the Borsod power plant (*Török et al.,* 1992).

Soil dust silicates of Fig. 2b have a rectangular or irregular shape with a shape factor of 1.6–2.7. Their Na, Mg and K content is usually higher than that of the fly ash silicates. However, if the measured data have higher statistical error the distinction between the two groups is very difficult. The measurement conditions can be improved if detectors of higher efficiency are used for the low energy (<3keV) region.

Quartz was present in all samples but the limestone particle group was only occasionally observed.

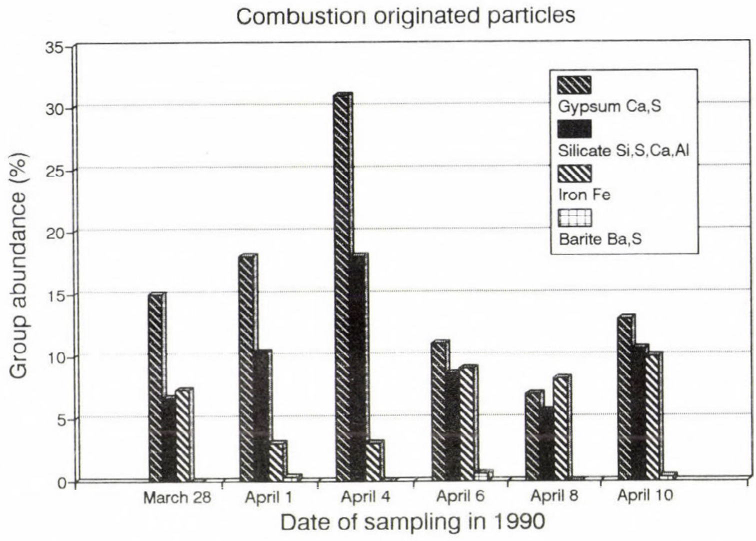

Fig. 2a. Group abundances (in %) of combustion originated particles in the K-puszta

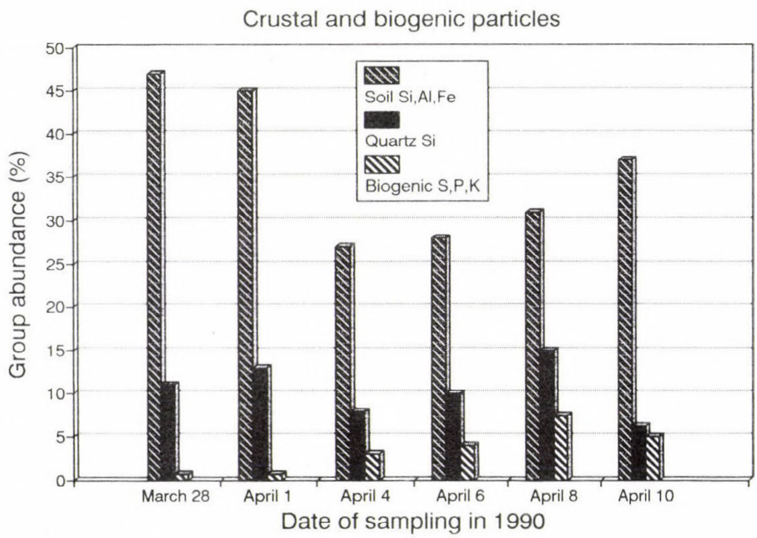

Fig. 2b. Group abundances of crustal and biogenic particles in the K-puszta campaign

Morphological visualization showed that the samples contained numerous biological particles. A similar observation was reported more than a decade ago by *Mészáros* (1977). Since the sampling period was very early spring, very few plants were blooming and hardly any pollen was observed. Many biological

Number	Abundance %	Relative X-ray intensities																		Diameter (micron)	Shape factor
		Mg	Al	Si	P	S	Cl	K	Ca	Ti	Mn	Fe	Ni	Zn	As	Br	Sn	Ba	Pb		
1	27.0	0.1	21.0	59.0	-	5.0	-	7.0	2.0	0.3	-	6.0	-	-	-	-	-	-	0.1	2.6	2.7
2	20.3	-	0.1	2.9	0.2	5.6	0.1	-	0.7	0.3	0.4	84.0	-	-	-	-	-	-	-	1.5	1.6
3	15.0	0.7	14.0	33.0	0.3	12.0	0.1	2.4	14.0	2.5	-	13.0	-	-	-	-	1.4	0.8	-	2.4	3.2
4	13.0	1.3	2.2	5.4	1.7	34.0	0.2	0.3	46.0	0.2	0.6	6.2	-	-	-	-	-	-	1.2	2.3	2.5
5	7.3	-	-	96.0	-	2.6	-	0.6	0.2	0.1	-	0.7	-	-	-	-	-	-	-	2.5	3.1
6	4.7	-	1.3	14.0	-	19.0	2.1	1.7	-	0.5	1.9	54.0	3.8	1.0	-	-	-	1.1	-	1.2	1.6
7	4.7	-	19.0	-	-	5.3	18.0	12.0	-	-	-	-	-	-	9.1	8.4	-	8.3	20.0	1.0	1.4
8	4.0	1.3	-	-	2.8	91.0	-	2.7	-	-	-	-	-	-	2.2	-	-	-	-	0.8	1.5
9	2.7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100.0	0.9	1.5
10	1.3	-	1.3	11.0	-	-	-	-	-	74.0	1.6	8.9	-	-	-	-	-	-	-	2.1	2.2

Table 2. Results of EMEP classification obtained on aerosol sample taken on April 6
(The daily mean temperature was 19°C and 1 mm rain fell)

particles were fibres and waxes of 5–30 μm. *Fig. 3* shows two large aerosol particles among other smaller particles and *Fig. 4a* and *4b* present the X-ray spectra of these large particles. It can be seen that biological particles give characteristic X-ray spectra with relative low intensity on a high Bremsstrahlung background. Since the backscattered electron signal of these particles is not significantly above the preset backscattered electron threshold, detection in automatic measurement is not very efficient.

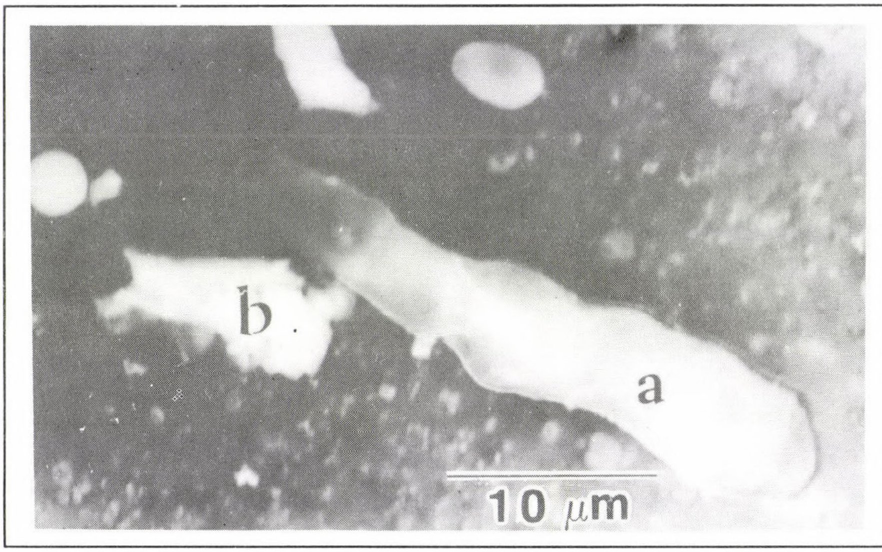

Fig. 3. Electron micro graph of aerosol sample taken at K-puszta, (*a*) biological object, (*b*) soil particle

For two sampling dates, the trajectory of the air mass at 850 hPa was also calculated. One of them, presented in *Fig. 5*, shows the trajectory of the air cell taken on April 6. Each point of this trajectory corresponds to 6 hours. It is obvious from the figure that the air was transported over the Adriatic Sea and spent longer periods in industrial areas of Hungary and the urban region of Budapest.

The different particle groups obtained for this sample are tabulated in Table 2. This sample was one out of the two that contained some halogen-rich particles. The first group is presumably soil silicate. The second group could originate among others from a steel plant laying at about 50 km from the sampling site (see Fig. 5). The third group is fly ash silicate that is rich in Ca and S.

The fourth group is the above mentioned calcium sulphate group. Groups #2,

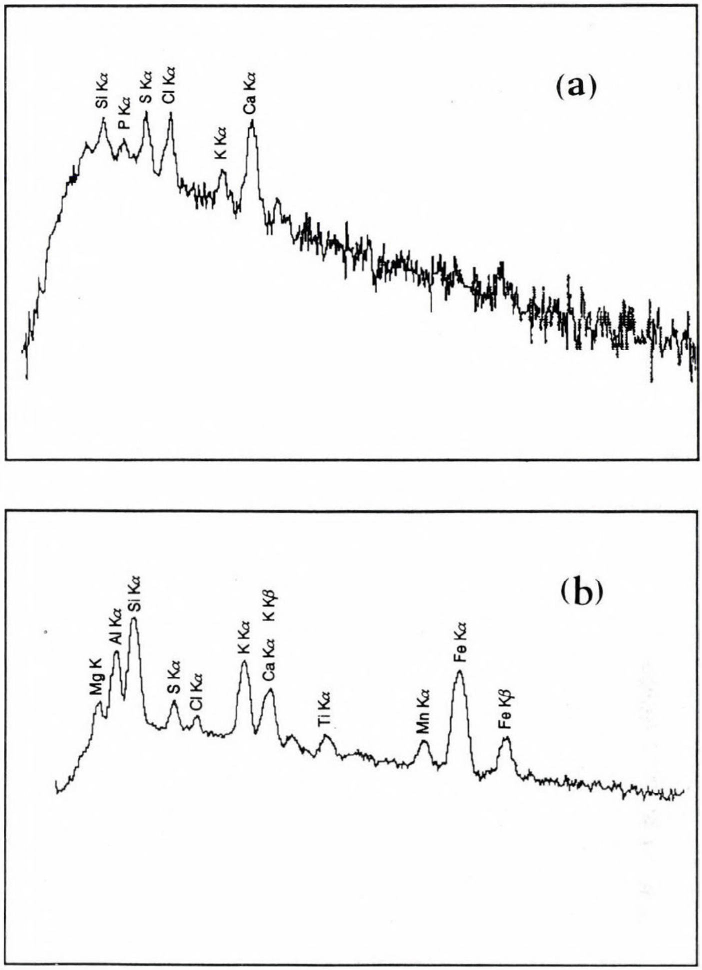

Fig. 4. X-ray spectra on logarithmic scale of aerosol particles presented in Fig 3, (*a*) biological object, (*b*) soil particle

3 and 4 might originate from the northern industrialized region of Hungary. The fifth group is quartz usually present in all samples at the same abundance (around 10%); however, this group can be observed in coal fly ash as well. This group is followed by the usual iron- and sulphur-rich group #7 that might originate from various sources; steel and non-ferrous plants, steel smelters and coal burning. In this sample the secondarily formed sulphate particles were also detected in group #8. Since the detection of particles is under automatic control, very small aerosol particle groups, about a few tenth of micron, are not always observed. Moreover, in view of the energy deposited by the electron beam in

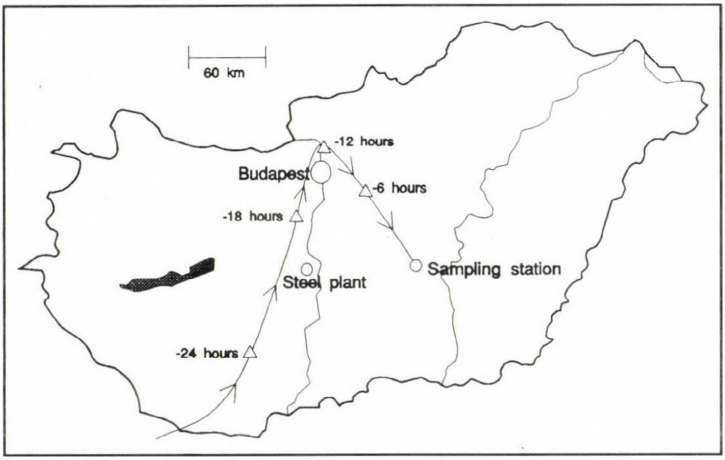

Fig. 5. Trajectory of air cell at 850 hPa on April 6, 1992

the EPMA and the vacuum condition, unstable components will disappear. For these reasons the secondary $(NH_4)_2 SO_4$ particles are not detected as abundant as they are present in the aerosol. Since the sampling stage was far from a paved road the presence of automobile exhaust particles was not significant. Two types of such particles were observed i.e., those containing exclusively Pb as inorganic component (group #9) or particles with high Cl, Br and Pb signals (group #7). The last group is Ti-rich; it is not significant and its presence indicates weak or distant sources. This group was usually observed when the air cell originated from the South.

4. Conclusion

Most particles of the Hungarian background aerosol (in the 0.3 – 20 μm size range) are of anthropogenic origin. Since the method is based on the determination of inorganic macro components the identification of particle groups of similar composition can be dubious. For such particles the morphological parameters and the trace components can improve the distinction. The comparison of the classified particle groups and the corresponding air parcel trajectories indicated that the source identification is reasonable for anthropogenic sources. In the future the sensitive PIXE method will be applied for aerosol trace analysis to further identify the aerosol samples collected at the same site.

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Diurnal and annual variation of the urban temperature surplus in Szeged, Hungary

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Abstract—This paper examines the temperature increasing effect originating from the climate modification effects of the city *Szeged* situated on a plain territory of Hungary.

It can be stated that there is a correspondence between the measure of the increase of temperature and the urban morphological type. The data used here were obtained from several stations representing the different built-up areas of the city. The examination is based on the differences of monthly temperature means between the given stations and the reference-station at all observation times.

The temperature surplus of the urban heat island sometimes exceeds even 4°C and its maximum is in early autumn during the evening.

Key-words: Urban climate, temperature surplus, Szeged.

1. Introduction

By establishing cities mankind has strongly modified natural surfaces. Since the albedo as well as the heat- and waterbalance depend more or less on the quality of surfaces these modifications have led to changes in meteorological elements, mainly temperature and humidity. The anthropogenic heat emission and the air pollution emitted in gaseous and aerosol phases in the territory of cities are of great importance as well. Due to these factors, specific local climate develops in the cities which in many respects, differs from the climate free from anthropogenic effects.

In bigger cities the climate changes are more obvious. However, modification can be observed even in the case of medium size cities (*Oke,* 1973, 1979; *Nkemdirim* and *Truch,* 1978; *Park,* 1987). This fact explains why much more attention should be paid to the climate modification effects from the mid 70's in Szeged. Research covering this topic was initiated by the Department of Climatology of Szeged University. Only small part of the enormous quantity of data received at that time has been processed (*Károssy* and *Gyarmati,* 1980; *Pelle,* 1983; *Unger,* 1992). This paper aims to reduce this deficiency.

Due to the powerful development of Szeged during the last 15 years, the explored features of the city climate have become much more remarkable until now.

2. The investigated area, data and methods

Szeged is situated in the south-east and the lowest plain (69 m a.s.l.) territory of Hungary, free of orographical effects. Thus its geographical situation is favourable to have relatively undisturbed city climate. The number of the inhabitants of the city counted up to 175000 in the investigeted term, in 1978 (*Sindely,* 1978). Thus it is considered to be a city of medium size, the temperature surplus of which can be shown comparing to its surroundings.

The research of urban climate in Szeged was begun in 1974 by cross section measurements, comparison between climates of different housing estates. Afterwards a station network was established where in 10 microclimatological stations measurements were taken between 1977 and 1980. Air temperature, humidity, maximum and minimum temperature and precipitation were measured. With possibilities taken into consideration, the stations represented several types of built-up areas of the city. Each station had a thermometer shelter with an Assmann-type psychrometer, minimum- and maximum thermometers inside and a pluviometer outside. The measurements were taken, at some stations 4-times, at other stations 3-times a day, by observers.

The present research used the data of the five stations, which were most characteristic from urban climatological points of view (*Zsiga,* 1983; *Pelle,* 1983). The reference-station was the Aerological Observatory which is situated outside the city, near the Airport. Its location is free of urban climatic effects and here the north-west wind prevails. *Fig. 1* illustrates the location of stations and the morphological types of the city.

The Station 2 was set up at the city centre influenced freshly by climate modification effects of the town, at a paved square bounded by more storeys building. The Station 3 was set up at a new housing estate with 5-10 storeys buildings built by prefabricated concrete slabs. The Station 4 was set up beside the 3 storey building of the University—in this way it represented the climate of streets with more storeys buildings built by traditional architectural technics. The Station 5 was set up at the grovy garden of the Children's Hospital bounded by busy streets. The Station 6 was set up at the suburb.

The measurements were taken at the first four stations four times a day (01, 07, 13 and 19, Central European Time), while at the last two stations three times (07, 13 and 19, CET). In this way, the investigation of data of the Stations 2, 3 and 4 provides a more comprehensive picture about the diurnal variation of the temperature surplus in the city than the investigation of the data of the Stations 5 and 6.

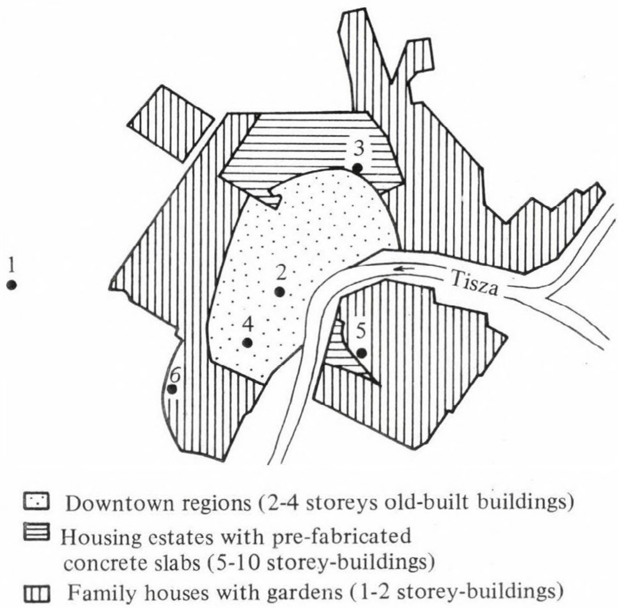

Fig. 1. The morphological types of Szeged and the used stations: 1. Aerological Observatory, 2. Restaurant of Napsugár, 3. Víztorony square, 4. Ady square, 5. Hospital for Children, 6. Department of Agriculture, Juhász Gy. Ped. Col.

The observations were taken during the whole year only from 1978 to 1980, therefore, the data of these 3 years were used in the examinations. The monthly and annual mean air temperatures were determined for each station at different observation times and then the differences of means from the corresponding mean values of the reference-station were examined.

On the basis of these differences, the annual variation of the temperature surplus can be drawn at the given observation times, while the monthly differences show the diurnal variation of the temperature surplus of the given month at several observation times. According to the different morphological types, the temperature increasing effect can be noticed on the basis of density of the built-up areas.

The examinations, mentioned above, suggest the average intensity of the city heat island known already in the literature (*Oke,* 1973, 1979; *Park,* 1987). It is denoted as ΔT_{u-r} and it provides the temperature difference between the city "core" (supposedly the warmest area of the city) and the reference-station in its surroundings.

As the examinations of other cities revealed (*Oke,* 1979, 1982), the maximum temperature difference occurs 3–4 hours after sunset. In the recent case, it means that almost throughout the year, the maximum difference can be expected between 19 and 01, because of the fixed observation times. The maximum temperature difference develops under clear and calm weather conditions and its value can be estimated by two different equations in the case of Europe. These equations depend on the population of the cities:

$$max\ \Delta T_{u-r} = 2.01 \log P - 4.06 \ (°C) \qquad (Oke,\ 1973)$$
$$max\ \Delta T_{u-r} = 1.92 \log P - 3.46 \ (°C) \qquad (Park,\ 1987),$$

where P is the population of the city.

On the basis of the first equation, this maximum difference in Szeged is 6.48°C, while on the basis of the second one it is 6.65°C (which do not significantly differ from each other).

3. *Results and conclusions*

Let's consider the temperature differences of the Station 2 representing the inner city (*Table 1*).

Table 1. The average temperature surplus of the Station 2 (°C)

Month	01h	07h	13h	19h	Month	01h	07h	13h	19h
Jan	1.35	1.93	1.13	2.83	Jul	4.03	2.03	0.70	2.00
Feb	1.63	2.20	0.73	1.50	Aug	4.50	1.97	0.53	2.40
Mar	2.93	2.43	1.50	2.60	Sep	4.77	2.87	0.43	1.20
Apr	3.53	2.10	0.70	2.40	Oct	3.83	3.30	0.33	2.80
May	3.60	1.40	0.67	1.77	Nov	1.93	1.67	1.03	2.03
Jun	3.73	1.90	1.90	1.80	Dec	1.60	2.13	0.77	2.10
					Year	3.12	2.16	0.87	2.12

By means of these data, the diagram of the temperature surplus can be drawn at all observation times and by months (*Fig. 2*). The figure shows that at 01 considerable temperature surplus can be pointed out which exceeds even 4°C in July, August and September. Since the data of the 01 observation is after the expected time of maximum difference, the value of September (4.77°C) shows good correspondence with the data received from the equations, mentioned above. The temperature differences are above 2 °C during the greatest part of the year, while the smallest (but above 1 °C) values are in the winter months from November to February.

The former fact can be explained by strong longwave heat emission originating from the surface after sunset, caused by the great daily input of solar radiation in summer. On the other hand, the latter fact can be explained by the weak longwave heat emission, caused by small daily input of solar radiation in winter, which can be counterbalanced by strong evening space heating only to a smaller extent.

The temperature difference is the smallest at 13 and it cannot be noticed at all in September and October (0.5 °C). In the winter months, it is around 1 °C, while it is the greatest in June (almost 2 °C).

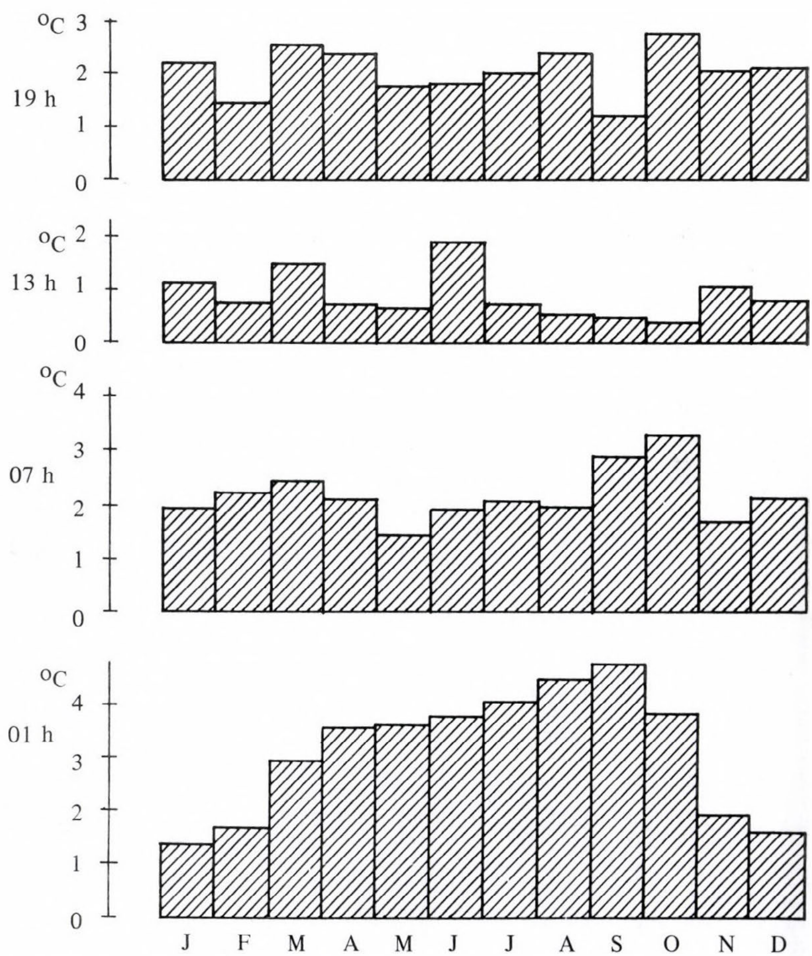

Fig. 2a. The annual variation of temperature surplus of the Station 2 (1978–80)

The temperature differences at 07 and 19 are almost the same during the year, they are about 2 °C.

The diurnal variation of the monthly mean temperature surplus shows characteristic feature from March to November (except June). It decreases typically from the maximum of 01 till 13, then it increases till 19. The values

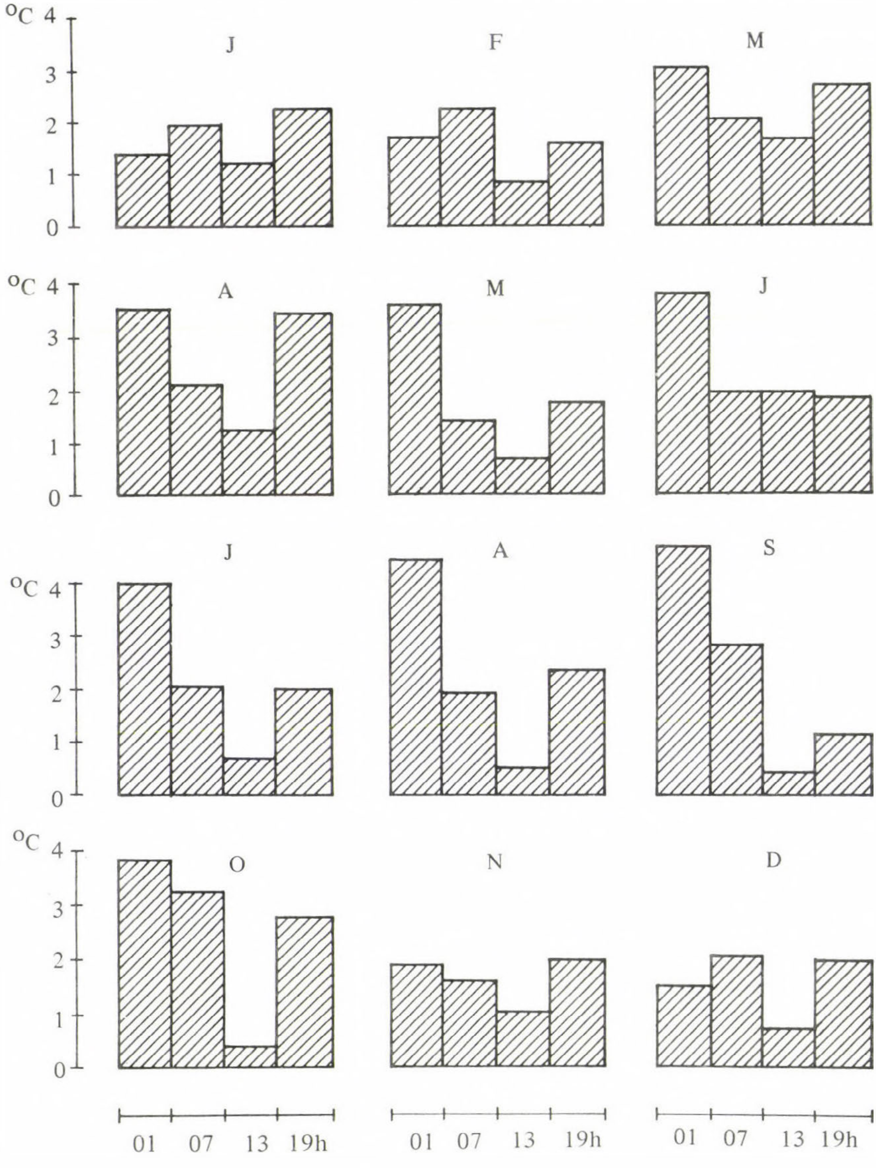

Fig. 2b. The diurnal variation of temperature surplus of the Station 2 (1978–80)

at 19 are lower than the ones at 01. The maximum at 01 reflects the heat reproduction of the solar radiation's absorption of the previous day, which decreases obviously by the morning. However, the temperature difference at 07 is considerable enough, which is in connection with the fact, that the energy of the morning solar radiation is used by the evaporation of dew in the surrounding country, while in the inner city because of the missing or less dew, it is used by the heating of the air. The minimum at 13 can be explained by the influence of the convection, advection and cloud development getting stronger and by the rural surface getting dry and well heated by that time.

In the winter months, on the basis of the results, mentioned above, the maximum of the temperature surplus can be observed not at 01, but in the morning or in the evening, while the minimum can be found at 13 similarly to the rest of the year.

The diagrams of the Fig. 2 are summarized in a figure by the help of isoplates (*Fig. 3*). Using the Fig. 3 with the consideration of the formerly mentioned restrictions, it can be seen how warmer the inner city is as compared to its surroundings, that means, how intensive the heat island is at any month and at any time of the year.

As the Station 2 is situated in the inner city and supposedly it represents the area of the heat island in the best way, so the results for this station were interpreted in the most detailed way.

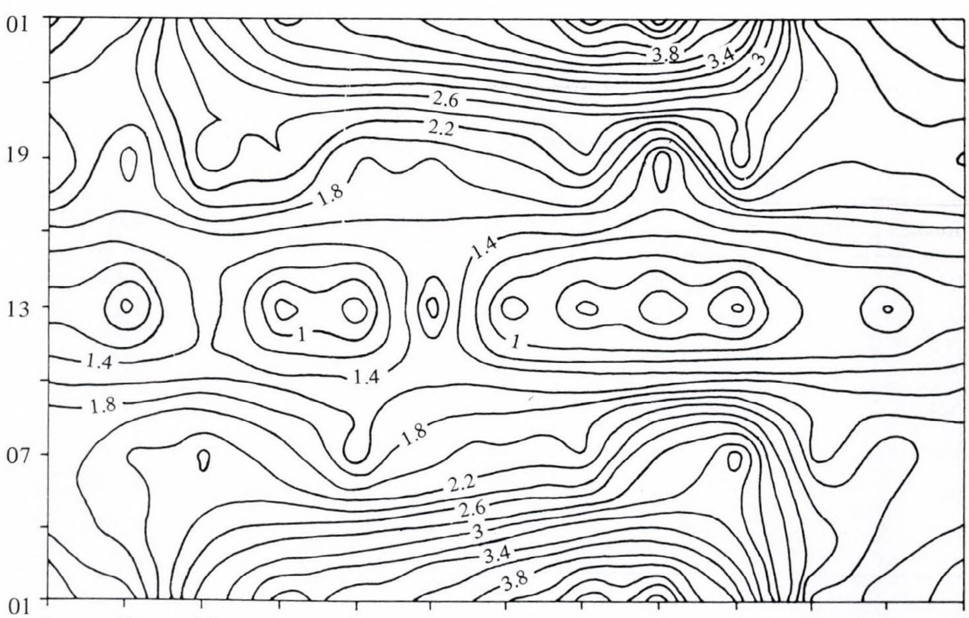

Fig. 3. The isopletes of the temperature surplus of the Station 2 (1978–80)

The examination concerning the next four stations is not so detailed, however, it can be stated that apart from a few monthly means of difference of the Station 6, all the other differences are positive (although not to the same extent as in the inner city). This unambigously proves that it is warmer in the city than in its surroundings. The Station 6 is situated in the outskirts, therefore, it cannot be said to be a representative city station.

In the case of the Station 3 and 4 the values of the temperature surplus are summarized in tables (*Table 2* and *3*). On the basis of these data isoplates, showing clearly the annual and diurnal variation of temperature surplus, which are similar to the Fig. 3, can be constructed.

Table 2. The average temperature surplus of the Station 3 (°C)

Month	01h	07h	13h	19h	Month	01h	07h	13h	19h
Jan	0.90	0.93	0.57	0.80	Jul	2.77	1.30	1.00	0.70
Feb	0.20	1.07	0.57	1.17	Aug	2.53	1.23	0.20	0.90
Mar	1.85	1.53	0.87	1.47	Sep	2.95	1.85	0.77	1.93
Apr	1.95	1.30	0.63	1.27	Oct	2.15	1.87	0.53	1.77
May	2.00	0.77	0.70	0.70	Nov	0.80	0.77	0.77	1.13
Jun	2.35	1.03	1.10	0.93	Dec	1.10	1.13	0.53	1.10
					Year	1.80	1.39	0.69	1.16

Table 3. The average temperature surplus of the Station 4 (°C)

Month	01h	07h	13h	19h	Month	01h	07h	13h	19h
Jan	1.23	1.33	0.73	1.40	Jul	1.90	1.73	1.17	0.73
Feb	1.10	1.25	0.65	1.05	Aug	2.10	0.53	1.53	0.90
Mar	0.90	1.15	0.25	1.15	Sep	2.07	1.30	1.20	1.10
Apr	1.25	0.70	0.90	0.80	Oct	1.77	2.13	0.57	1.20
May	1.47	0.57	1.40	0.67	Nov	0.05	0.95	0.30	0.60
Jun	1.67	0.40	1.70	0.43	Dec	0.70	1.15	0.40	0.70
					Year	1.35	1.10	0.90	0.89

In the case of the Station 5 and 6 the tables are given, isoplates cannot be drawn precisely on the basis of the data from only three observation times (*Table 4*).

As the tables and figures show, the temperature surplus is the greatest at 01—with maximum in summer and autumn—, considerably in the case of Station 3 situated in housing estate with pre-fabricated concrete slabs.

Table 4. The average temperature surplus of the Station 5 and 6 (°C)

	Station 5			Station 6		
Month	07h	13h	19h	07h	13h	19h
Jan	0.67	0.47	1.57	0.07	0.17	−0.23
Feb	0.63	0.47	0.60	0.30	0.27	−0.17
Mar	1.10	0.67	0.90	0.70	0.23	0.40
Apr	0.67	0.70	0.80	0.73	0.33	0.60
May	0.37	0.43	0.47	0.27	0.47	0.73
Jun	0.07	0.70	0.43	0.13	0.53	0.40
Jul	0.40	0.23	0.70	0.27	0.20	0.23
Aug	0.70	0.20	0.10	0.33	0.33	0.67
Sep	1.17	0.20	1.63	0.70	0.07	1.00
Oct	1.53	0.50	1.30	0.63	−0.13	0.30
Nov	0.90	0.87	1.13	−0.07	−0.07	−0.07
Dec	0.97	0.83	1.03	0.03	−0.10	−0.37
Year	0.76	0.52	0.89	0.34	0.19	0.28

The differences at 01 and at the other observation times can be said to be more moderate than the ones in the inner city in the following decreasing order:

Station 3: 5—10-storey buildings with concrete slabs,

Station 4: untight built-up inner city,

Station 5: border between family houses and 5—10-storey buildings with concrete slabs,

Station 6: outskirts.

It can be stated for all stations, that the size of the temperature surplus is reflected adequately by the density of the given built-up area, moreover, the minimum of the temperature surplus is at 13, in each case.

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A simple mass-balance model for air pollution

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Abstract—A simple mass-balance model is developed and tested using SO_2 and meteorological data obtained during 1989–1992 winter seasons in *Erzurum*, Turkey. Agreement between observed and estimated data was found very satisfactory with a correlation coefficient greater than 0.95.

Key-words: Air pollution, mass-balance model, mathematical modeling.

1. Introduction

For mathematical modeling of air pollution, mainly two different approaches have been used (*Seinfeld,* 1975; *Einar et al.*, 1978):

- Statistical dispersion models (*Gauss type*) calculate the possible pollutant concentrations. Model parameters are fitted by regression analysis of long-term data.
- Mechanistic dispersion models, developed by applying continuity equation to pollutant concentration, include the effects of all dynamic processes and use data relating to emission, meteorology and atmosphere chemistry.

These models are usually very complicated and impractical to be applied especially in area of complex topography. So, simple air quality models based on emission and meteorological data are proposed (*Inger,* 1985; *Topçu et al.*, 1992). In this study a simple mass-balance model is developed and tested with data obtained in *Erzurum*, Turkey.

Erzurum city center is situated on a plateau, 1950 m from sea level, surrounded by mountains in the east, south and the north. It lies in the NE–NW direction, on an area about 20 km long, 5 km width. Altitude difference between upper and lower limits of the city is approximately 200 m. The yearly average temperature is 6°C, while average temperature of winter season from November to March is approximately −10°C (see later Table 2).

This severe climate and unfavorable geomorphology and topography of the city cause serious air pollution problems. As no important industrial establishment exists in the city, the major source of pollutant is domestic heating. For this purpose various qualities of fuel including coke, lignite and fuel oil are consumed (*Table 1*). Mean SO_2 concentration of winter season increased rapidly from 265 $\mu g/m^3$ to 514 $\mu g/m^3$ in recent 3 years due to rapid enlargement of the city (*Table 2*). So, forecasting of air pollution in near future by means of this model is of vital importance.

Table 1. Fuel consumption and fuel characteristics of three winter seasons

Year	Coal		Fuel-oil		Mean S%	Mean calorific value (kcal/kg)
	Consumption 10^3 t	S%	Consumption 10^3 t	S%		
1989–90	323	1–3.75	100	2.5	2.0	6577
1990–91	315	1–3.75	165	2.5	2.1	7076
1991–92	390	1–4.4	170	2.5	2.1	7240

Table 2. Mean SO_2 and meteorological data of three winter seasons

Year	SO_2 ($\mu g\ m^{-3}$)	T (°C)	R ($m\ s^{-1}$)	P (mm)
1989–90	265	−10.2	1.5	0.38
1990–91	488	−9.5	1.3	0.42
1991–92	514	−10.6	1.2	0.32

2. *Observations*

2.1 *Meteorological data*

Daily meteorological data consisting of wind speed (ms^{-1}), temperature (°C) and precipitation (mm) were obtained from department of meteorology in

Erzurum as 7 hour average values. In the model the arithmetic mean of these hourly averages was used.

2.2 SO_2 *data*

SO_2 data were collected at six stations located at various points by considering the topography of the city (*Fig. 1*). Pollutants measurements have been made by *Environment Problems Research Center* since 1979. SO_2 analysis is made by absorption of SO_2 in H_2O_2 and later by acidimetric titration. Daily average SO_2 concentration is calculated as a arithmetic means of values obtained from these six stations.

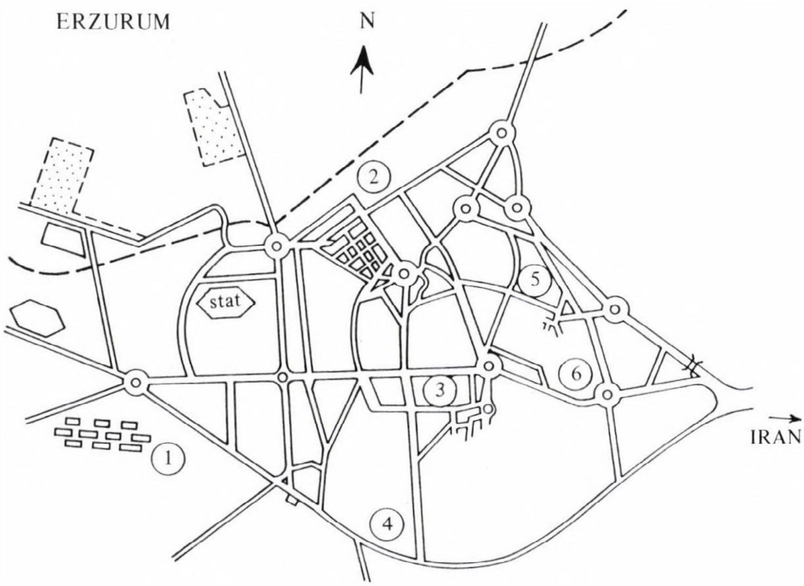

Fig. 1. Location of the measurement stations in city: 1. Atatürk University, 2. Railway Station, 3. Governor's Old Office, 4. Environmental Health Department, 5. 12 Mart Primary School, 6. Aziziye Primary School

3. *Mass-balance model*

Various assumptions which have been made while model developing, can be summarized as follows:

- *Erzurum* may be seen as an area source since there is no important industrial area to be considered as a point source. Thus, the sulfur dioxide and particle emission are only due to domestic heating.

- In setting the sulfur mass-balance, a control air volume is taken over the city. All the inputs and outputs of pollutant occur in this control volume. Outputs of SO_2 are caused by wind, precipitation, diffusion, chemical reaction and adsorption.
- The outflow of pollutant from the control volume is proportional to wind speed. The wind blowing in every direction carries out SO_2 at equal amount from this volume regardless of wind direction.
- Removal rate by precipitation, mainly as snow, is proportional to precipitation rate.
- SO_2 reacts with H_2O_2 and OH (formed from O_3 and H_2O vapor) via liquid and gaseous phase reactions, respectively. These reactions form H_2SO_4 and metal sulfates which are deposited onto the soil, plants, water sources, and building surfaces, etc. The global reaction rate and also the deposition rate is first order with respect to total sulfur concentration.
- SO_2 leaves also the control volume by thermal molecular and eddy diffusion. It is known that at superadiabatic conditions vertical thermal diffusion is stimulated, but at stable condition, it is restrained. It is to be noted in this respect that during winter season in *Erzurum* an inversion layer is observed nearly all days. So, removal by thermal diffusion may be neglected. Meanwhile removal by eddy and molecular diffusion is proportional to pollutant concentration.

In view of these assumptions, various inputs and output terms for mass balance equation are the followings:

$$\text{Daily pollutant input} = \propto \cdot S \cdot F, \tag{1}$$

where F is the daily fuel consumption and S is the mean pollutant content of various fuels. On the other hand, the heat supplied for domestic heating by burning fuels, Q, may be given as

$$Q = F \cdot K, \tag{2}$$

K is mean calorific value of various fuels. This heat supplies steady-state heat losses and are given by the heat transfer equation:

$$Q = U \cdot A \cdot \Delta T, \tag{3}$$

where U is mean overall heat transfer coefficient of building materials, A is the total heat transfer area of all the buildings in city; $\Delta T = T_h - T$, where T is the daily air temperature, while T_h is the temperature inside the house. By combining Eqs. (1, 2) and (3):

$$\text{Daily SO}_2 \text{ input} = \propto \frac{U \cdot S}{K} A(T_h - T) \tag{4}$$

or

$$\text{Daily SO}_2 \text{ input} = a_0 - a_1 T, \tag{5}$$

$$\text{where } a_0 = \frac{U \cdot S \cdot A \cdot T_h}{K} \quad \text{and} \quad a_1 = \frac{U \cdot S \cdot A}{K}.$$

For the output terms the following equalities may be written:

$$\text{Output rate by the wind} = a_2 \cdot W, \tag{6}$$

$$\text{Removal rate by the precipitation} = a_3 \cdot P. \tag{7}$$

As the removal by eddy diffusion, chemical reaction and adsorption are assumed proportional to pollutant concentration, C, these three terms may be combined to give:

$$\text{Removal rate deposition chemical reaction, eddy diffusion} = a_4 \cdot C. \tag{8}$$

a_2, a_3, and a_4 in Eqs. (6)−(8) are proportionality constants. On the other hand, accumulation of pollutant in the control volume V is given as,

$$V(\mathrm{d}C/\mathrm{d}t) = \sum \text{Inputs} - \sum \text{Outputs}. \tag{9}$$

By combining Eqs. (5,6,7,8) with Eq. (9) one obtains

$$V(\mathrm{d}C/\mathrm{d}t) = a_0 - a_1 T - a_2 W - a_3 P - a_4 C. \tag{10}$$

If differential term $\mathrm{d}C/\mathrm{d}t$ is approximated by a difference term $\Delta C/\Delta t$, where $\Delta C = C_j - C_{j-1}$ and Δt is equal to 1 day, a suitable arrangement of Eq. (10) gives

$$C_j = A_0 - A_1 T - A_2 W - A_3 P + A_4 C_{j-1}, \tag{11}$$

where j denotes the actual day and $j-1$ the previous day.

The following relations may be written for model parameters from A_0 to A_4:

$$A_0 = \frac{(U \cdot P \cdot A \cdot T_h / V)}{K\left(1 - \frac{a_4}{V}\right)}, \qquad A_1 = \frac{U \cdot P \cdot A / V}{K\left(1 - \frac{a_4}{V}\right)}, \tag{12}$$

$$A_2 = \frac{a_2 / V}{\left(1 - \frac{a_4}{V}\right)}, \qquad A_3 = \frac{a_3 / V}{\left(1 - \frac{a_4}{V}\right)}, \tag{13}$$

$$A_4 = \frac{1}{\left(1 - \frac{a_4}{V}\right)}. \tag{14}$$

4. Application of the model to data

To obtain best-fit values of model parameters, linear regression analysis was performed with SO_2, particles and meteorological data of 3 years. The results are shown in *Table 3* with corresponding data number and correlation coefficient for 3 years separately. The mean standard deviation between model predictions and measured SO_2 values is 30 $\mu g/m^3$. These statistical considerations support that this simple model is sufficiently reliable for predicting pollutant concentration.

Table 3. Model parameters and multiple correlation coefficient R

Year	A_0	A_1	A_2	A_3	A_4	R	Data number
1989–90	105	4.4	22	4.4	0.76	0.97	43
1990–91	233	7.0	24.8	4.3	0.49	0.97	48
1991–92	181	10.8	20.8	4.4	0.43	0.95	72

The validity of the model is also shown in *Figs. 2a-c*. When model parameters of 1991–92 winter season are compared the following conclusions may be drawn:

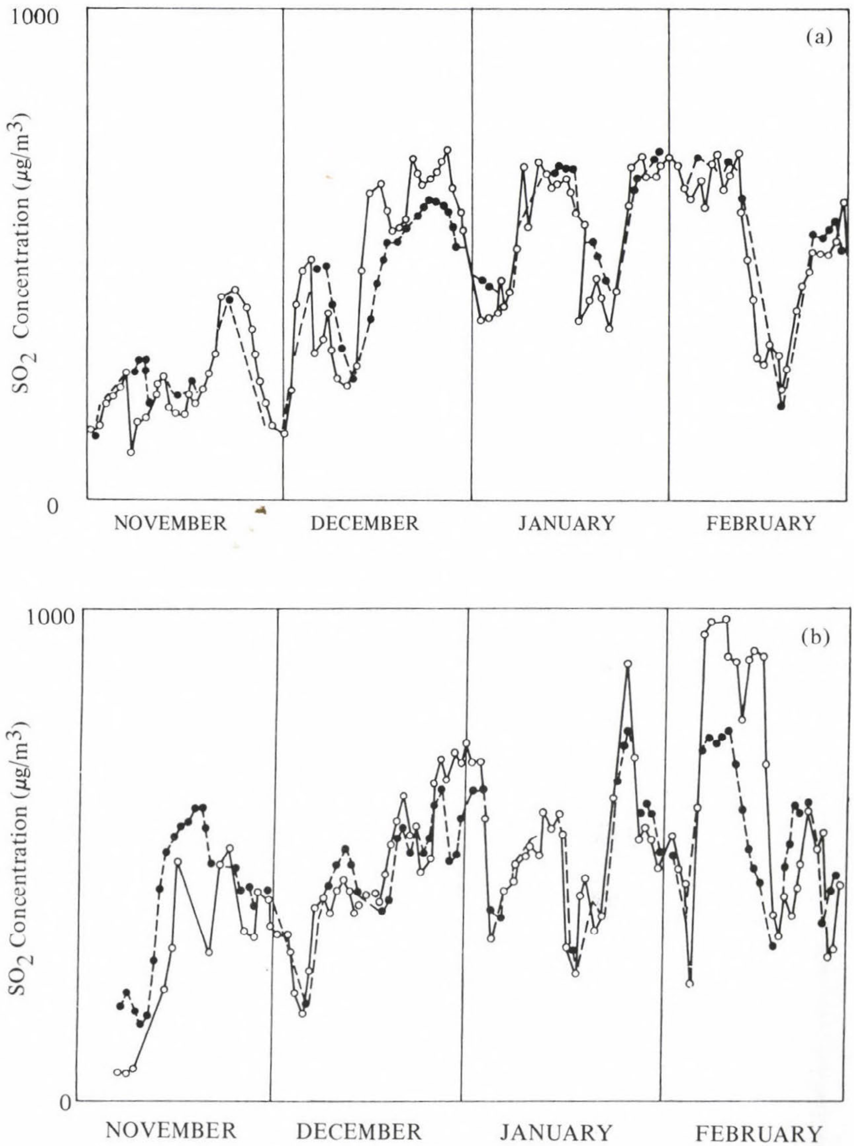

Fig. 2a, b. Measured and calculated daily SO_2 mean concentration for winter seasons (*a*) 1989–90, (*b*) 1990–91 (—o— observed, —●— model)

– Wind parameters, A_2, are nearly equal for three years, with mean value equal to 22.5 and 8.1 for SO_2 and particles, respectively. The same conclusion is also valid for precipitation parameter, A_3, with mean value equal to 4.4 and 1.9.

- Model parameters A_0 and A_1 change significantly in years. From relationship (12) one can see that $A_0/A_1 = T_h$ (°C). This ratio is calculated as 23.9, 33 and 17 for 3 years (Table 3) with mean equal to 24.7°C.
- Model parameter A_4 is related to removal by chemical reaction, deposition and eddy diffusion which is assumed to be first order with respect to SO_2 concentration (see Eq. 8). For the half-life of SO_2 the following relation may be deduced

$$t_{1/2} = \frac{\ln 2}{(a_4/V)} . \qquad (15)$$

The mean A_4 value of three year is 0.56. By means of Eq. (14) (a_4/V) is calculated as 0.44 and by Eq. (15) $t_{1/2}$ is found equal to 1.5 day. This result is consistent with that given in literature (*Patterson et al.*, 1981).

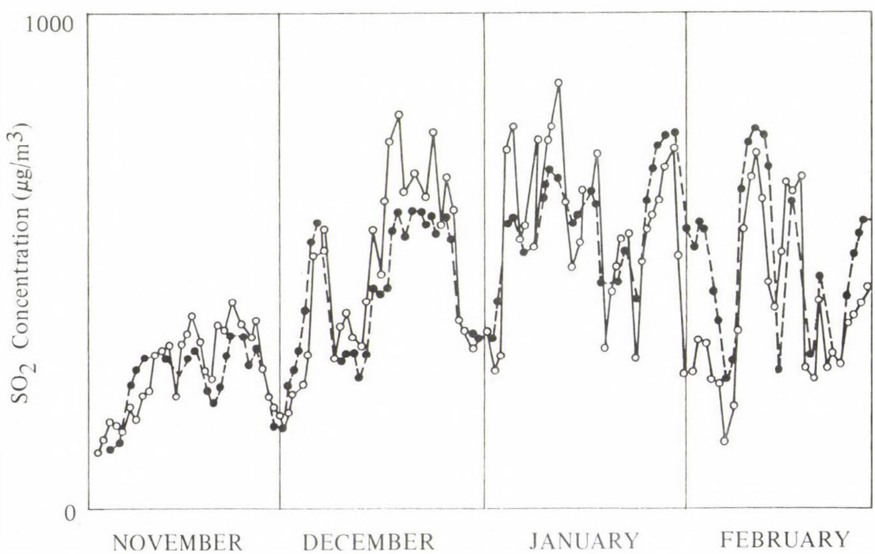

Fig. 2c. Measured and calculated daily SO_2 mean concentration for winter season 1991–92, (—o— observed, —•— model)

5. Conclusion

A simple mass-balance model was developed using SO_2 and meteorological data obtained during three winter seasons in *Erzurum*. This model explains satisfactorily SO_2 and particle concentration levels. Stepwise regression analysis showed that the most effective parameters on actual pollutant concentration are the previous days' pollutant concentration and temperature, these two parameters explain more than 90% of data. When averages SO_2 and meteorological data are used, the relative output rate of SO_2 by wind is 24 $\mu g/m^3$ per day and 150 $\mu g/m^3$ per day by chemical reaction and deposition. It is clear that snow is not as effective as rain in cleaning the atmosphere. In *Erzurum*, during winter season, the wind speed is low and the topography of the city prevents the wind to decrease pollutant concentration. When Figs. 2a-b are examined, it is seen that the model underpredicts some SO_2 data belonging to days at which severe inversion was is observed. So, terms taking into account these phenomena more elaborately may be inserted into the model. Also the model must be tested by independent dataset.

Acknowledgements—We are grateful to *A. Yaylali* for his help on getting meteorological and SO_2 data.

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BOOK REVIEW

J. Lovelock: ***Healing Gaia; Practical Medicine for the Planet.*** Harmony Books, New York, 1991. 192 pages, hardback with tables and coloured pictures and illustrations. Price: 25 U.S. dollars.

J. Lovelock, the creator of the Gaia theory published again a fascinating book, in which he exposes in a clear and elegant way his philosophy about the planet Earth, about life and science. He forwards his ideas concerning the self-regulating capacity of the Earth-biosphere system (Gaia) and puts into a new perspective his views on climate regulation. He proposes, as a kind of planet physiologist, a treatment for the anthropogenic illness (the people plague) of the planet which can be followed with a close cooperation with Gaia.

According to him established science today is reductionist and it does not work with the whole system, it deals "...with separated parts of the planet divided arbitrarily into the biosphere, the atmosphere, the lithosphere, and the hydrosphere. These are not real divisions of the Earth, they are spheres of influence inhabited by academic scientists". The "bottom-up" view of present scientific investigation aiming to understand the details of a unique entity should be replaced/completed by holistic "top-down" view regarding the planet as a whole. Since in spite of the existance of the so-called "big science" organized research is slow and since we do not know well how the world works, an immediate empirical planetary medicine is needed to heal world-wide maladies. This medicine is based on the idea that Gaia is a huge living organism like a redwood tree, the 97 % of which is dead. However, both the redwood tree and the Earth with its thin biosphere are alive, that is they are such bounded systems which are open to a flux of energy and matter, and are able to keep their internal conditions constant, despite changing external conditions.

I think that for the readers of this journal Chapter 7 of the volume can be recommended in particular. This chapter entitled *Physiology and climate regulation* contains a new original concept about climate and biospheric climate control. As it is known, the luminosity of the Sun, like in the case of any star, increases continuously. The biosphere compensates this increase, as Lovelock postulates by the regulation of the cycles of greenhouse gases, e.g. carbon dioxide. Consequently the concentration of carbon dioxide is much lower presently than before the formation of life. This regulation worked well until about 2 million years ago and earlier this date the Earth was free of ice since that time cold and warm periods have occurred alternately: the climate has become more perturbed, which probably indicates a crisis in climate control, a senescence of the system. Since ice ages are much longer than warmer periods. Lovelock argues that they may be considered the normal comfortable states of the planet. During glaciations less carbon dioxide remains in the air owing to land glaciers which lower the sea level. Under these conditions large areas, mostly in Equatorial regions are dry which results in a denser flora consuming carbon dioxide. However, the system is unstable and small additional flux of heat (due e.g. to variations of the Earth orbit around the Sun) produces a fever of Gaia. In other words each interglacial is a planetary illness. Unfortunately, human species, the product of the present fever, releases further greenhouse gases into the atmosphere which makes the problem more acute.

Since the Sun grows even hotter, it can be calculated that after about 100 million years a zero carbon dioxide abundance will be necessary to keep the temperature at present levels. The question is: what will happen if the present regulation system will be uneffective. One possibility is that a new biospheric climate control mechanism will form, e.g. by generating more stable clouds by algal emissions of sulfur gases which produce cloud condensation nuclei. An other possibility is that a new, hotter climate regime will born, creating optimum conditions for plantes pumping down carbon dioxide. Of course, these possibilities are in the realm of pure speculation. It seems to be certain, however, that we are acting now against our planet, against Gaia. This is very dangerous since, as Lovelock states, "The rules of Gaia are that organisms that adversely affect their environment do not long survive. We humans would do well to remember this." The empirical solution is to cut back the emission of greenhouse gases by avoiding freon leakage from refrigerators and air-conditioners, by gathering pollutants from efficient power plants for further use and last but not least by placing more value on our forest. On the other hand the understanding of the Earth by correct scientific research is also obviously needed.

The reviewer hopes that even this short discussion makes appetite to the reader to order this excellent book or to look for it in a library. It is believed that even for those who do not agree entirely with the Gaia theory the reading of this volume will be exciting since it generates thoughts about our planet and life and about the ways how Nature does operate.

E. Mészáros

NEWS

The Thirteenth International Conference on Nucleation and Atmospheric Aerosols

The *Thirteenth International Conference on Nucleation and Atmospheric Aerosols* was held between 24 and 28 August 1992. This series of conferences is regularly organized by the *Committee on Nucleation and Atmospheric Aerosols of the International Commission on Clouds and Precipitation* of IAMAP (*International Association for Meteorology and Atmospheric Physics*). The present meeting was located at the University of Utah in Salt Lake City (Utah, U.S.A.) and hosted by *Professor N. Fukuta*. It was opened by the lieutenant governor of Utah (*W. Val Oveson*) and by the president of the university (*A.K. Smith*). *N. Fukuta* and *P.E. Wagner* (Austria, chairman of the organizing committee) also addressed the participants (their number was around 120).

The lectures, oral or poster, were divided into four broad areas of specialization:

(1) Fundamental processes of nucleation (5 sessions, 3 invited review papers).
(2) Cloud droplet nucleation in the atmosphere (4 sessions, 2 invited review papers).
(3) Ice nucleation in the atmosphere (4 sessions, 1 invited review paper).
(4) Formation, characteristics, and climatological effects of atmospheric aerosols (7 sessions, 4 invited papers).

The papers were published before the conference on a hard-cover book by the A. Deepak Publishing Co. The proceedings were available for all registered participants at the beginning of the meeting.

The scope of the conference was rather wide. Laboratory works on nucleation process were presented together with model calculations on cloud development and long-range transport of aerosol particles in the atmosphere. At the same time it was a pity that relatively few papers were devoted to the climatic effects of aerosol particles as well as to the possible control of climate by aerosol particles of natural or anthropogenic origin. The original aim of this series was to provide an international forum for scientists working in the field of cloud droplet and ice crystal formation. At that time (in the fifties when this series was started) the practical aim of this kind of research was to understand cloud formation to be able to modify natural processes by artificial nuclei dispersed *intentionally* into the clouds (e.g. to enhance the precipitation amount). However, we are living now in an era when one of the main goals of atmospheric research is to estimate *inadvertent* anthropogenic effects on climate, in particular on clouds. It is also clear that this can be only done by clarifying how Nature produces clouds without human modifications.

It goes without saying that this general statement is not a criticism of the present conference. It was excellently organized and several interesting papers were presented. Also during the breaks of sessions fascinating discussions were held among participants. And everybody enjoyed the excellent campus of the University of Utah, the wonderful landscape of the Salt Lake Valley and the nice weather. The above statement is rather a proposition for the future: it would be desirable to include the scientific community dealing with the problem mentioned into the work of coming conferences of this long, historical series.

E. Mészáros

Scientific Days '92 on Meteorology

The Hungarian meteorologists celebrated the *International Space Year* (ISY) at a conference entitled *Satellite Meteorology* which was organized by the *Meteorological Scientific Commission of the Hungarian Academy of Sciences* together with the *Hungarian Meteorological Service* on 19-2O November 1992.

In addition to the 35th anniversary of launching the first artificial earth satellite, *Sputnik I.*, two national satellite meteorological events have also given occasion for celebration, namely the reception of APT from meteorological satellites started in the Hungarian Meteorological Service 25 years ago, and a digital receiving station which was installed this year.

The morning session of the first day was chaired by *Prof. E. Mészáros*. In this opening lecture *(Hungarian space research applications)* G. Tófalvi, Director in Charge of the Hungarian Space Agancy, positively considered the space research activity made so far in the framework of the *Intercosmos Organization*. He expressed his hope to form closer relations with the western space agencies, and introduced the new order of finance and organization form of the Hungarian space research.

T. Tänczer outlined recent results of the satellite meteorology. Particularly, the attention was called to global climatic trends regarding the cloudiness, temperature, precipitation and ozone content revealed by means of satellite data.

G. Bálint summarized the hydrological aspects of remote sensing. It has been proved that in most tasks the complex use of data originating from different sources can result in solution.

Another paper (by *J. Mika et al.*) aimed at improving the climatic representativity of short period satellite data series. The basic assumption is the application of a partial period in which the frequency occurrence of macrosynoptic situations is in accordance with the average one of a long period.

D. Dévényi et al. presented a method for incorporating satellite sounding data into the four-dimensional data assimilation system.The method is based on robust filtration and spline interpolation. In the investigated cases the inclusion of satellite data improved the analysis of the temperature and geopotential fields.

In the afternoon session, *Prof. R. Czelnai* was the chairman, and the papers were devoted to radiation meteorology aspects and direct hydrological applications of remote sensing.

G. Major reviewed the results of the radiation balance of the Earth-atmosphere system achieved by satellite measurements. In addition,he referred to the role of spectral radiation measurements playing in the vertical sounding of the atmosphere at present and in the future.

Co-authors *I. László, F. Miskolczi* and *R. Pinker* (working now in the USA) have made an attempt to produce radiation data on the basis of global cloud information acquired in the Intenational Satellite Cloud Climatology Project. With reliance on radiation transfer models, a method was developed for computing the direct, diffuse, global and photosyntetically active radiations on the entire globe.

A. Rimóczi-Paál gave information about the investigations of radiation balance evaluated from METEOSAT images. She has used empirical relationships, radiosounding data on vertical profile of the temperature and air humidity as well as radiation transfer model.

G. Szász and *V. Zilinyi* have studied the dependence of spectral albedo on the soil composition using field measurements.The results allow for determining the soil types from remote sensing data.

V. Vadász and *M. Potyok* analysed the relation between temperatures both evaluated from satellite infrared data and measured in the thermometer screen at the ground surface. It has been pointed out that the vegetation index plays a determining role in the formation of the relation.

The afternoon session was closed by three papers in hydrological topics. The first paper (by *B. Licsko*) summarized the applications of water management by remote sensing (river and lake management, flood protection, plain, hilly region and settlement management.). The second paper (by *J. Sass*) drew attention to mapping possibilities by remote sensing. The developed method enables to indentify numerous species of plants. The third paper (*G. Varga* and *F. Szilágyi*) introduced a procedure for estimating the leafgreen content and suspended matter concentration of ground waters. The research has been based on both LANDSAT and SPOT observations and remote sensing data from aircrafts.

On the second day the presentations were devoted to weather analysis and prognosis by satellite information and some actual meteorological problems.

I. Csiszár presented paper on the use of temperature, humidity, geopotential and ozone data derived from TOVS measurements by NOAA as supplement information in the meteorological 3-dimensional analysis.

E. Fejes has performed objective, bispectral analysis of the cloud field based on digital images from METEOSAT. In addition, she has analysed the connection of the frontal cloud bands with the thermal front parameters.

J. Kerényi has studied the development of cumulonimbi by means of albedo and cloud-top temperature maps. She managed to find relation between the two satellite cloud parameters and the rainfall intensity.

F. Dombai et al. presented a technical system developed for combined analysis of digital radar and satellite data. The system works at Nyiregyháza and provides rainfall intensity estimation in every 5 minutes.

Finally, concerning some actual meteorological problems, *T. Pálvölgyi* analysed the role of volcanic activity and stratospheric ozone depletion in the large-scale warming. Furthermore, *J. Mika* and *C. Nemes* searched for the effect of the eruption of Mt. Pinatubo on the climatic anomalies in Hungary.

The two-days session was closed by an information about the most outstanding event of ISY, the COSPAR meeting at Washington D.C., presented by the chairman of the session, *G. Major*. In that meeting, the Hungarian meteorologists delivered 7 presentations.

The *Meteorological Scientific Days* were worthy of the ISY, the two anniversaries. The participants of the session could listen to good reviews about the activity in the field of satellite meteorolgy and hydrology in Hungary. It has been proved that these scientific fields keep level with the progression as far as possible. This fact may warrant the effective relationship and successful cooperation with the western space agencies.

T. Tänczer

United Nations Conference on Environment and Development: towards sustainable coexistence with nature

The Conference, most often referred to as the UNCED was held in Rio de Janeiro during 3-14 June 1992. It has been the greatest event in history of the United Nations since its foundation at least as concerns its level and number of participants, visitors and press people. Almost all States of the world, members of the UN were presented at this event, the national delegations were headed by high-level politicians, state leaders, and altogether it was attended by about 30000 participants, observers and visitors.

The event was opened on 3 June 1992 by *Boutros Boutros-Ghali*, the Secretary-General of the United Nations, and such prominent persons addressed that ceremony as *Fernando Collor de Mello*, the President of Brazil who had been elected as the Chairman of the UNCED, *Maurice Strong*, the Secretary-General of the Conference who had that key position already twenty years before at the Stockholm Conference, *Carl Gustav XVI*, the King of Sweden, *Gro Harlem Brundtland*, the prime-minister of Norway and the head of the famous World Commission on Environment and Development, and *Mario Soares*, the head of the Portuguese government.

What might be even more important for the scientific community and especially for the natural scientists, this UN-Conference—at least at its outset—was not devoted to the recurring problems of peace and war or matters of tensions between and coexistence of nations but the global issues of the relation between man and the ambient environment. It is a consequence of recognition that certain human impacts on environment have reached global level and can lead to irreversible changes, that the ability of ecosystems and societal systems to adjust to external changes is limited, that the degradation of natural resources in many instances has become the potentially critical factor in stability or limiting factor of further development of socioeconomic systems.

The Conference was held just twenty years after the Stockholm Conference on Human Environment and it was convened according to a UN General Assembly resolution adopted in 1988. A special *Preparatory Committee* (PrepCom) was established in 1990 and simultaneously, two intergovernmental negotiating committees started to discuss conventions on protection of the Earth's climate and biodiversity.

As mentioned before, during the recent decades it became evident that certain human activities could lead to rapid degradation of or possibly irreversible changes in natural systems. As a consequence, the key objective of the international negotiations on all related issues was to achieve the sustainable development, that is to maintain the proper and fragile balance between the increasing human demands on one side and the stability of environmental conditions and the conservation/renewal of the finite natural resources on the other side. The need for this approach was already explicitly expressed in those recommendations of the World Commission on Environment and Development which were published in 1987 in its famous publication entitled "Our common future".

The first part of the UNCED was held by 11 June 1992 and its programme was played on two distinct scenes and in two sharply different manners.

The high level plenary meeting "on the front scene" was attended by the members of the governmental delegations commonly headed by ministers for foreign affairs or for environment who briefly presented the main features of their national economies, the state of environment and the national positions on the Conference and its objectives. There were no disputes, no open confrontations, but high diplomacy, political declarations and applauds at these elegant, "green tie" sessions.

As a contrast to it, on the back scene, the atmosphere was hot in the eight working groups and the Main Committee. The experts attempted to find compromises and to finish those conference documents during these nine days which had been discussed, drafted and had not been finalized for almost two years of negotiations since the first meeting of the PrepCom in 1990. There were profoundly opposing views, differing national positions about the chapters and parts which concerned problems of atmosphere (the stratospheric ozone layer, the transboundary air pollution, the increasing greenhouse effect), energy conservation, freshwater resources, biodiversity and biotechnology, protection of forests, transfer of environmentally sound technology, financial mechanisms in general and the financial supports for the developing countries, in particular. These discussions and efforts lasted by the last moments and thereafter, the delegates worked even during the last night and finalized the documents just before the highest level second part of the Conference.

The *Earth Summit* was held on 12-13 June with the participation of 110 heads of states (64 presidents, 46 prime ministers and 8 vice-president). The world leaders in their addresses expressed the increasing concern about the state of global environment, the common but differentiated responsibility of the nations and the need for more effective international cooperation to cope with these problems.

Formally, the UNCED succeeded in passing five documents.

The *Rio Declaration* is a list of basic principles on the human rights for safe and healthy environmental conditions, the common responsibility of States for the state of the Earth environment, for the use of natural resources and the environmental protection. The real and precious substance of the initially planned *Earth Charter* was almost lost despite the long process of discussions in the PrepCom and despite having an almost accomplished draft text by the last round of PrepCom sessions. As a matter of fact, the Rio Declaration is a filtered, simplified, reduced version of the Charter.

The *Agenda-21* is a 40 chapter 800 page document which describes all recent, significant environmental and related socio-economic problems and the necessary actions to solve those by and during the 21th century in collaboration of the nations. From a general standpoint, these comprehensive actions would serve to achieve the sustainable development on all scales, for all nations taking into account the sensitivity of natural systems, the various interests and rights coupled with the terms of intra- and intergenerational equity.

The *Forest Principles* is a set of most important guidelines and conditions to conserve the world's forests, to stop the accelerating deforestation process, to switch to more careful forest management. There was a lasting and tense dispute among the various groups of country delegations during the negotiating process to outline or even to drop the idea of a convention on world's forests protection and the Principles are just the "soft" outcome of seeking the compromises.

At last, the *Framework Convention on Climate Change* and the *Convention on Biological Diversity* were actually finalized by the respective inter-governmental committees before the UNCED and these new international treaties were opened for signature during the Conference.

In parallel to the UNCED, the nongovernmental environmental organizations arranged for their own alternative meeting, the *Global Forum* in the Brazilian megapolis. It was a lively gathering of hundreds of organizations from all parts of the world and their representatives continued the pressure on high-level policy-makers even on the spot of the UNCED to achieve more concrete agreements "*to save the Earth*".

The Hungarian participation in the UNCED was prepared by the inter-departmental National Committee. The head of delegation in Rio de Janeiro was *Sándor K. Keresztes*, the minister for environment and regional policy; *Dr. Árpád Göncz*, the president of the Republic of Hungary headed the delegation in the days of the Earth Summit. Members of the delegation were inter alia *Dr. Tamás Katona*, state secretary of the Ministry for Foreign Affairs, *Dr. Nándor Rott*, head of the Parliament Committee for Environment, *Dr. István Láng*, the Secretary-General of the Hungarian Academy of Sciences and more than ten representatives of various ministries, experts, NGO-members. The delegation took part in the mostly simultaneous plenary meetings and sessions of the Main Committee and the eight working groups. *Dr. Göncz* signed both conventions during the Earth Summit, on 13 June 1992.

Two "green books" have been published in Hungary by the National Committee in relation with the UN-Conference. The "Hungary's National Report to UNCED" summarized the features of the state of environment in accordance with a PrepCom recommendation. Later on, "The UNCED: facts and data" published at the end of 1992 gave a brief overview of the history, events and documents of the Conference together with a presentation of principles from the Rio Declaration and an indicative list of the national follow-up tasks.

The Conference should be critically evaluated, however, it ought to be considered as a very important milestone on the long road to adequate public awareness on the environmental problems, sustainable use of natural resources and the environmentally conscious management of economic activities, societal development. The compromises achieved during the negotiations primarily reflect the present state of different interests between the groups of developing and developed countries. Nevertheless, messages of the Conference will obviously be long-lasting. It seems to be just the starting point for a hopefully extending and productive international cooperation to better understand the increasing load on natural systems and their vulnerability, to halt the human practices with adverse and possibly irreversible environmental impacts, to cope with the population explosion and the accelerating growth of demands for the natural resources, to reduce the hazardous emissions from the industrial and other economic activities.

For the coordination of these efforts, new UN institutional mechanisms were also formulated and recommended by the Conference. The 47th General Assembly has just passed the resolution on establishing the ministerial level Commission on Sustainable Development and considering the relation and possible restructuring of all environment-oriented activities under the aegis of the United Nations. According to these provisions, the global environmental issues and their relations with the questions of socio-economic development and international cooperation will be regularly reviewed by the highest level UN-forum in the future.

At national level, relevant long-term environment policies and programmes should be elaborated in accordance with the Agenda-21 and the two conventions beside those commitments which should be accomplished under these conventions after their ratifications and entry into force. In context of the atmospheric issues, these documents reinforce the importance of relevant monitoring systems, data analysis for detection of possible changes in state of the climate system on various scales, identification of the causes and assessment of the impacts of these changes and the international and interdisciplinary cooperation in finding the adequate response policies.

T. Faragó

ATMOSPHERIC ENVIRONMENT

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Volume 26A Number 11 1992

Review Article

General Papers

Volume 26A Number 12 1992

Fifth International Conference on Indoor Air Quality and Climate Indoor Air 90: *Characterization of Indoor Air*

Volume 26A Number 13 1992

Volume 26A Number 14 1992

Technical Note

Volume 26A Number 15 1992

Third International Conference on Atmospheric Sciences and Application to Air Quality

Abstract

General Papers

Short Communication

NOTES TO CONTRIBUTORS

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* * *

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