WORKING PAPER

THE FORMATION OF STABLE COMPONENTS IN THE ATMOSPHERE DUE TO ENERGY PRODUCTION

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Foreword

This paper is devoted to the possibility of taking into account the pressures of human activity on the atmosphere. It was presented at the International Workshop Envrisk '88 "Energy and Environment: the European Perspective on Risk" organized by the Italian Commission for Nuclear and Alternative Energy Sources, May 1988.

THE FORMATION OF STABLE COMPONENTS IN THE ATMOSPHERE DUE TO ENERGY PRODUCTION

M. Antonovsky

The problem of the inter-relations between Man and Nature is a preoccupation of industrial societies. Moreover, the nature of the concern is not static over time, but may undergo rapid changes. Until recently, Man has played a relatively passive role in the Biosphere, influenced by, but not strongly influencing, its natural rhythms.

However, in recent centuries there has been a new "geological" phenomenon on the planet. For the first time, Man has become a large-scale geological "force" influencing Nature through threshold effects, surprises, discontinuities, risks, and catastrophical events (both slow and sudden).

Similar to ongoing research on the prediction of earthquakes, researchers are investigating such problems as climatic changes owing to the "greenhouse effect", the frequency of such disasters as Chernobyl or Bhopal, and how to prevent them. The hope exists that societies can respond to perceived ecological threats more easily than in the case of an earthquake. Even in such a catastrophic event as war, the current generation is much wiser than previous generations regarding the environmental risks entailed in such an event.

Now it is also known that there is a set of "life zones" or "life intervals" consisting of a narrow range of parameters necessary for life; for example, intervals i_k ($k=1,..,n$) of temperature, solar radiation, radioactivity, precipitation, pressure, concentrations of gases such as CO_2, SO_2, CO, NO_x, toxic materials, and so on.

For example, a decrease of solar radiation flow (or flux) by only a few percent would be sufficient to cause the freezing of a large fraction of the Earth's surface. An increase of this flux by several percent could cause the evaporation of most of the existing liquid water on the planet, and so on. Analogous consequences may arise if CO_2 concentrations decrease or increase, respectively. Moreover, many organisms could die owing to smaller variations of CO_2 in comparison with oscillations which could bring about climatic catastrophes.

The life intervals have been under threat many times in critical periods of geological history. If the probability p_k does not exceed the limits of the intervals i_k, with $k=1, \ldots, N$, then the probability p of the existence of life is:

$$p = p_1 \cdot p_2 \cdot p_3, \ldots, p_N$$

The value of p is a very small number. Nevertheless, life has existed in different forms for many millions of years. The significance of this fact is that on our planet there are some unique conditions that retain the oscillations of every "life interval" within an admissible limit. However, the activities of industrial societies are causing larger oscillations that may eventually lead to the parameters extending beyond the admissible limits.

For example, the current energy-production technologies are associated with impacts for each step of the production cycle, including mining, transport and use. Thus, the use of fuel, hydropower and atomic energy has local, regional and global impacts at different intervals of time. Local effects can become global problems if the number and distribution of small power stations is large. As the number of stations increases, the integrated impacts also increase, perhaps non-linearly. To take another extreme, a unique event such as the Chernobyl accident not only causes material damage, but also has enormous emotional, philisophical, scientific and social ramifications.

This event and the connected release of radioactivity into the environment have focused the interest of the international, scientific community on the meteorological aspects of transport of radionuclides and the mathematical modeling of processes by which radioactive materials contaminate the natural environment. This interest has already spawned an increased number of publications devoted to modeling the atmospheric transport of radionuclides and their fallout onto the surface after the accidents. These models can be used to assess the risk within the close vicinity of the nuclear power plant, and to recommend procedures by which populations within this area can be better protected from possible accidents in the future. (See for example, Izrael *et al.*, 1987; Dickerson *et al.*, 1986; Itogovyi doklad, 1986.)

Furthermore, even seemingly safe technologies such as hydropower merit greater attention in the future. Experience has shown that many undesirable consequences are caused by hydropower stations. These include: changes in the hydrological and biological structures of rivers, changes in local climate, immense damage to ecologically rich lands around rivers, and so on. For example, the artificial storage facilities for hydropower production often create a disequilibrium between the volume of water and geometry of the natural containment: the collapse of enormous quantities of soil from the banks and subsequent settling at the bottom of the water body can result in greatly reduced water depths and change the geometry (i.e. from a cup-like shape to a plate), the consequence being rapid eutrophication of a reservoir. The ecological consequences of the fossil use are well-known (Bolin 1987).

In order to make more precise assessments of the effect of anthropogenic activities on the environment, it is necessary to design an appropriate system of monitoring. The goal of such a system is to organize the stream of corresponding data in mathematical models in order to make predictions about the condition of the environment. Ecological theory has not yet completely succeeded in identifying the major quantitative mechanisms of stability of the natural ecosystem state, irrespective of the considerable efforts undertaken in this sphere. This means that we do not yet know exactly what the probable sources of instability are or might be, as a result of both conventional and new anthropogenic stresses on natural ecosystems and the biosphere as a whole. As a result, as noted above, we may face not only gradual ecological transformations but also a sudden loss of stability which may cause non-linear and surprising ecological effects. So, once more, the author wishes to stress that mathematical modeling is one of the most powerful and effective instruments available for investigating the complexity of problems mentioned above.

However, one constraint may be the duration of time required to develop these models. History has shown that this time scale could be significant. For example, it took almost 2,000 years to evolve from the static mechanics of Archimedes to the dynamic mechanics of Newton, with the invention of differential and integral calculus. Prior to Newton, the arithmetic and geometry of Archimedes was insufficient to describe the relation between force and velocity. The challenge of today is to condense and organize the enormous accumulation of data and information into "usable" knowledge concerning the fundamental behavior of the biosphere. In this report the author briefly addresses some important questions. (See also, Izrael *et al.*, 1987; Alcamo *et al.*, (1987); Antonovsky *et al.*, 1983.)

First of all it is worth mentioning that in the last several decades there has been a rapid development in the number and sophistication of air-quality monitoring networks. This is true both nationally (including countries such as Canada, Great Britain, USSR, USA, and others) and internationally (including the ECE, European Monitoring and Evaluation Program (EMEP), the WHO Background Air Pollution Monitoring Network (BAPMON) and others (see WMOEP-VI/DOC8 (18.IV.1986)). These initiatives have lead to national and international projects for the development of extensive, environmental data bases, such as WDDES (IGV/ICA) - 1000 MB, NOAANET (NDAA / 60 MB, GRID/GEMS/UNEP/NASA) and several others.

The primary criteria in a monitoring system are a) the identification of the optimal number and disposition of the stations on a given landscape and b) the level of information obtained from the set of data gathered from the stations.

These criteria are fundamental but work counter to each other. Hence, a compromise must be reached.

The necessity of establishing a limited, spatially-organized network is mainly related to the high cost of constructing and operating monitoring stations. At the same time, the established network should, at a minimum, be sufficient to ensure that the most salient features of the deposition pattern under investigation are detected, i.e., the degree of information obtained should be adequate for the goals of the analysis. The data from such stations provides the analyst with a time string. However, if one were to consider this time series as merely a series of numbers, then the data would have no prognostic value. Rather, each of these numbers should be considered as a representative of some interval. The problem is to define the width of each of these intervals. The probability of containment of a data point within an interval is quite different than the probability of placement at one specific value.

In the following we attempt to demonstrate such an approach. Firstly, we describe the procedure for identifying statistically stable patterns in the time series of observations of background atmospheric pollutants (see Izrael, Antonovski et al., 1987). The data were collected as daily mean measurements of concentration of tropospheric sulfur dioxide and aerosol dust at five monitoring stations. These stations are as follows: Boroval (1976-1983), Berezina (1980-1983) and Repetek (1980-1983) in the USSR; two stations in Sweden and Norway, where corresponding data were collected to provide information on the long-term transport of these pollutants. In our approach we used well-developed statistical techniques and a special case of the main model law - two parameter logarithm - normal distribution (LN2). We also used the mixture of such distributions. The usual method for constructing multimodel distributions is to choose local models and apply a law of composition. These steps permit us to derive a global model based on a set of local models. Our local model is based on the normal law.

For construction of the multimodel law we applied the operation of composition of density functions $f_1(x)$ and $f_2(x)$:

$$f(x) = \pi_1 \varphi(\frac{a-x}{\sigma}) f_1(x) + \pi_2 \varphi(\frac{x-a}{\sigma}) f_2(x) ,$$

where π_1, π_2 are constant; a is a switch point between different laws washed by normal white noise with dispersion σ; $\varphi(t)$ is a distribution function of the normal law $N(0,1)$. It was shown that the model gives a good approximation of the empirical density of the seasonal series of observations with the value obtained for a sub-sample of 150 observations (see Izrael, Antonovski *et al.*, 1987).

So the problem of obtaining the stable statistical features of background contamination in the atmosphere is subdivided into two parts: the first is a decomposition of the seasonal series of observations in order to obtain an informative description of each season separately; the second is an investigation of such descriptions in order to derive stable statistical characteristics of the entire set of observations of the phenomenon.

The author would again stress that the main hypothesis of the investigation is that dispersion processes change one another in such a way that in the zone of influence of one process (near its mode) the "tails" of another are not observed.

Each seasonal series was subdivided into some set of intervals on the axis of logarithm of concentration. In terms of the model, it is possible to identify the i-th interval as an interval of the log concentration axis between the points $a_i + 3\sigma$ and $a_{i+1} - 3\sigma$, where a_i, $i = 1, \ldots, N$ are switch points (see above) and a_0 and a_{N+1} are the border points of the distribution.

Sequences are constructed by methods of classification where areas of groupings are established through a graph analysis of log concentration distribution functions with a remote linear trend. Thus we obtained a set of intervals of selective grouping, i.e., sample W in space J of all intervals of the log concentration axis. Defining the measure μ as the proximity of two intervals $I_1 = (\alpha_1, \beta_1)$, $I_2 = (\alpha_2, \beta_2)$:

$$\mu(I_1, I_2) = \frac{\min(\beta_1 \beta_2) - \max(\alpha_1, \alpha_2)}{\max(\beta_1, \beta_2) - \min(\alpha_1, \alpha_2)}$$

see that $-1 < \mu(I_1, I_2) \leq 1$, and if $\mu \geq 0$, then $\mu(I_1, I_2) = \frac{|I_1 \cap I_2|}{|I_1 \cup I_2|}$, where $|I|$ is the length of interval I.

Using μ, we construct the algorithm for determining stable grouping intervals. So if we have three elements, π, $W \subset J$, a sample of intervals, and an interval I_0, then we can construct an estimating the extension of the interval I_0 as an interval of the statistical grouping of concentration.

1. Let $\mu_0 \in (0,1)$;
2. We construct section $S(I_0, \mu_0) = \{I_e, I_e \in W,\ l = 1, \ldots, L\}_k$ - the set of intervals arranged according to the sequence belonging to the cortage and where $\mu(I, I_0) > \mu_0$;
3. Using section $S(I_0, \mu_0) = \{I_e\}$ we construct matrix M with sizes $L \times L$ whose element (k, e) is equal to $\mu(I_k, I_e)$;
4. From matrix M we calculate the value $F_{W,\mu_0}(I_0)$ by the formula

$$F_{W,\mu_0}(I_0) = \frac{1}{L^2} \sum \gamma_{ke}\ \mu(I_k, I_e)$$

The functional $F = F_{W_0,\mu_0} : J \rightarrow R^1$, corresponding to each interval a number gives the estimation using sample W, and shows the extent to which this interval could be regarded as the interval of the statistical concentration grouping.

An interval I^* for which F_{W,μ_0} is maximum is called μ_0. The value μ_0 is defined to be stable for the interval I^* if

$$F_{W,\mu_0}(I^*) = F_{W,\mu_0 \pm\sigma}(I^*) ,$$

i.e., when a small variation of μ_0 does not change the value of the functional. Thus, a stable interval of statistical grouping for the given sample W is found, if m_0^*, μ_0^* and stable interval I^* are such that $F_{W,\mu_0^*}(I^*) > 1-\varepsilon$.

Tables 1 and 2 contain the results of the statistical analysis of the seasonal series of SO_2 and lead concentrations for the period 1982-1983, which illustrate the application of the suggested technique. For longer time periods see Table 3.

Columns contain interval sequences of selective grouping; rows contain sections corresponding to intervals of statistical grouping which are arranged according to their place on the axis of concentrations and observation areas. Let us illustrate the technique for establishing a stable interval (-0.74 - 1.5) using data from the Borovoye station.

Values of μ calculated for the corresponding seasonal sections 1-4 are as follows: 0.77, 0.75, 0.95, 0.86. Matrix M for this section is shown in Table 4. The stable interval of statistical grouping given in Table 2 has been calculated on the basis of all available data from the Borovoye station and, as one can see, differs but slightly from the interval calculated on the basis of data for 1982-1983.

Tables 2 and 3 illustrate the description of the whole data set in the form of an arranged set of stable intervals and sections corresponding to them. Let us describe examples of regularities revealed in the whole data base in terms of the obtained description.

A section is a set of intervals arranged on the axis of time according to seasons, which allows us to examine the dependence of the forming factor effect on seasons in observation areas. Thus, at the station in the Berezino Biological Reserve (see Table 2) SO_2 concentrations form four stable intervals and corresponding sections. As the table shows, the first and last intervals occur only in the summer and winter sections respectively. Intervals in between occur equally during all seasons. The tables contain data on the occurrence of the frequency of intervals in the warm and cold seasons (seasons designated by W and C). One can see that as far as lead is concerned, a clearly marked winter seasonal variation exists in the grouping interval for the highest concentration logarithms at Borovoye station, and in the Repetek Biological Reserve. As for SO_2, clearly marked summer seasonal and winter seasonal variations are displayed in Borovoye and Berezino Biological Reserve, while the station in the Repetek Biological Reserve reveals no difference in SO_2 behavior in summer or in winter in any section. Dust sections show no seasonal peculiarities at any station except for a very slight winter variation in Berezino Biological Reserve.

The discovered regularities could be used in the assessment of regional levels of background atmospheric pollution for removing the components of seasonal and anthropogenic effects.

A set of stable intervals for one station can be regarded as an informative description of all data obtained at this station. If we form, out of these sets (sequences) a base of intervals of statistically stable grouping, we can apply the above-described algorithms. The established intervals are statistically stable with regard to specific regional factors. An example to illustrate this method is the establishing of a stable interval for SO_2. Stable interval (-1.3: 1.5) defines the section as follows: combination of intervals (-1.3 -0.2), (-0.2, 1.4) for Borovoye sta-

Table 1: Determination of stable sections of logarithm intervals for SO_2 concentrations.

Observation stations	Warm season 1982	Cold season 1982-1983	Warm season 1983	Cold season 1983-1984	Stable intervals over the whole period of observations	Number of warm and cold seasons with corresponding stable intervals observed
1	2	3	4	5	6	7
Borovoye		-	(-2.0.-0.4)	-	-	5W1C
	(-1.4.-0.2)	-	-	-	-	7W1C
	(-0.2, 1.0)	(-0.5, 1.2)	(-0.4,-1.6)	(-0.5, 1.7)	(-0.2, 1.4)	7W1C
	(1.0, 1.8)	-	-	-	-	
	-	(1.1, 2.6)	-	(1.7, 3.2)	(1.3,-2.8)	8W1C
	-	(2.6, 4.0)	-	-	-	3W0C
Berezino	(-1.4,-0.3)	-	(-1.7.-0.2)	-	(-0.5.-0.3)	3W0C
biosphere	(0.1, 1.0)	(00.0, 0.8)	(-0.2, 1.0)	(0.2, 1.0)	(-0.1, 1.4)	4W3C
reserve	(1.0, 1.6)	(0.8, 1.5)	-	-	-	
	(1.6, 2.0)	(1.5, 2.5)	(1.0, 2.2)	(1.4, 1.8)	(1.4, 2.5)	4W3C
	-	-	-	(1.8, 2.8)	-	
		(2.5, 3.8)	-	(2.9, 4.0)	(2.8, 4.0)	4W0C
Repotek	(-2.3,-1.2)	(-2.2,-1.3)	(-2.0,-1.3)	(-1.8,-1.8)	(-2.1,-1.2)	3W3C
biosphere	(-1.2, 0.5)	(-1.2, 1.0)	(-1.2,-0.5)	(-0.8, 0.1)	(-1.2, 0.8)	4W3C
reserve	(0.5,-1.0)	-	(-0.5, 0.3)	-	-	
	-	(1.0, 2.3)	(0.3, 2.3)	(0.1, 2.3)	(0.6, 2.2)	2W2C

Table 2: Determination of stable sections of logarithm intervals for lead concentrations.

Observation stations	Warm season 1982	Cold season 1982-1983	Warm season 1983	Cold season 1983-1984	Stable intervals over the whole period of observations	Number of warm and cold seasons with corresponding stable intervals observed
1	2	3	4	5	6	7
Borovoye	-	(0.7, 1.6)	(0.0, 1.5)	-	(0.5, 1.5)	3W1C
	(1.0, 2.8)	(1.7, 2.3)	(1.5, 2.7)	-	(1.3, 2.5)	5W4C
	(2.8, 3.6)	(2.4, 3.2)	(2.7, 3.7)	-	(2.6, 3.8)	3W5C
	(3.6, 4.3)	(3.2, 3.6)	-	-	-	
	-	(3.7, 4.7)	-	-	(3.5, 4.5)	6W6C
Berezino biosphere	(0.6, 1.1)	(1.0, 1.7)	(1.0, 2.2)	(1.0, 1.7)	(0.9, 1.6)	3W3C
	(1.1, 2.1)	(1.7, 2.9)	(2.1, 2.5)	(1.8, 2.6)	(1.6, 2.8)	3W3C
	(2.1, 2.9)	-	(2.5, 3.3)	-	-	
	(3.0, 4.0)	(3.0, 3.7)	(3.3, 3.8)	(2.7, 3.5)	(3.0, 3.8)	2W3C
	-	(3.9, 4.3)	(3.8, 4.2)	-	(3.8, 4.2)	2W4C
Repetek biosphere reserve	(0.6, 1.6)	(0.6, 1.4)	(0.6, 1.3)	(0.8, 1.7)	(0.6, 1.4)	3W4C
	-	(2.5, 2.0)	(1.3, 1.7)	-	(1.4, 1.8)	2W2C
	(1.7, 2.3)	-	(1.8, 2.4)	(1.7, 2.2)	(1.8, 2.4)	2W2C
	-	-	-	(2.3, 2.7)	-	
	(2.4, 3.0)	(2.0, 3.2)	(2.4, 3.2)	(2.3, 2.7)	(2.3, 3.1)	2W4C
	(3.0, 3.5)	-	-	-	-	
	-	(3.3, 4.3)	-	(3.2, 4.3)	(3.3, 4.2)	0W4C

Table 3: Stable interval of statistical concentration grouping SO_2(mcg/m^2)

Berezina BR (3W,4C)			Borovoye (8W,8C)			Repetek BR (3W,4C)		
Interval	freq. (% of observation) –		interval	freq. (% of observation) –		interval	freq. (% of observation) –	
	W	C		W	C		W	C
0.22-0.8	3(14%)	0	0.1-0.33	5(23%)	1(16%)	0.05-0.1	1(18%)	2(4%)
0.9-4.0	3(79%)	4(21%)	0.25-0.8	7(27%)	1(20%)	0.12-0.3	3(26%)	4(21%)
4.0-12.0	3(10%)	4(53%)	0.8-4.0	7(68%)	7(38%)	0.3-1.0	3(26%)	4(44%)
16.0-54.0	0	4(29%)	4.0-16.0	1(17%)	8(54%)	1.0-2.7	3(27%)	2(22%)
			16.0-56.0	0	3(23%)	2.2-9.0	1(10%)	3(18%)
								Pb ng/m^3
2.7-5.5	3(16%)	3(13%)	1.5-4.5	4(17%)	1(10%)	1.8-4.5	2(14%)	3(26%)
5.5-18.0	3(60%)	4(50%)	4.5-12.0	8(47%)	6(23%)	4.5-6.7	3(30%)	2(14%)
18.0-45.0	3(23%)	4(27%)	12.0-40.0	8(39%)	7(59%)	6.7-12.0	3(45%)	2(62%)
45.0-59.0	1(7%)	2(15%)	40.0-56.0	3(6%)	5(30%)	12.0-24.0	3(29%)	3(33%)
57.0-100.0	0	1(10%)	59.0-100.0	0	2(17%)	24.0-57.0		4(9%)
								Dust ng/m^3
1.1-4.0	0	3(9%)	2.2-7.0	2(16%)	4(21%)			
3.3-9.0	3(7%)	1(35%)	4.5-24.0	8(32%)	7(55%)	13.0-36.0	3(32%)	4(15%)
7.0-27.0	3(30%)	4(41%)	24.0-56.0	8(67%)	7(29%)	36.0-59.0	3(31%)	4(50%)
27.0-57.0	3(54%)	4(45%)				59.0-100.0	3(37%)	3(30%)
54.0-75.0	1(20%)	3(11)%				90.0-160.0		2(14%)

Table 4: Similarity matrix for the section of interval (-0.2 - 1.5)

	-0.2, 1.8	-0.5, 1.2	-0.4, 1.6	-0.5, 1.7
- 0.2, 1.8	1	0.6	0.8	0.8
- 0.5, 1.2		1	0.7	0.8
- 0.4, 1.6			1	0.9
- 0.5, 1.7		F ≈ 0.8		1

tion; combination of intervals (-1.5, -0.3), (-0.1, 1.4) for Berezina station; intervals (-1.2, 0.8) and (0.6, 2.2) for Repetek station.

It follows, for quality considerations, that background concentration levels should possess different kinds of stability. The regional background pollution level is characterized by stability in time; hemispheric level - by stability in time and space, etc. Therefore, stable grouping intervals suggested for the description of samples are statistical data interpreted as characteristics for background concentration levels.

The following section of the report presents an integral estimation of the impact of the energy system on some model territories, and summarizes the results of research work on ecological-economic modeling carried out in *Natural Environment* and the Climate Monitoring Laboratory Goskomgidromet and USSR Academy of Sciences in the period 1979-1987, embodied as as multigoal, automized system (MARS) (see Antonovsky and Litvin, 1987). This is a decision support system for protecting the atmosphere from pollution at the level of mesoscale regions or cities: two corresponding modifications of the program exist.

Management decisions on decreasing atmospheric pollutions are made in practice at the corresponding administration territorial level, i.e., an economic region, a territorial-production complex, a republic, a separate state and so on. Such a territorial scale corresponds to the notions of a mesoscale region. One can consider a city as an elementary territorial administrative level.

Currently, management aims of activities that pollute the atmosphere are not simple. On the other hand, it is impossible to formulate an "ideal" criterion to estimate the state of the lower atmosphere. Besides, management tasks in cities and mesoscale regions have their concrete features (peculiarities) that define the use of different models for the calculation of criterion indexes.

Cities and mesoscale regions, as a rule, contain hundreds or even thousands of sources of atmospheric pollutants. To decrease the pollution of the lower layers of the atmosphere, various concrete pollution-control measures can be enacted at each of the sources. Each measure may have a different result in controlling pollution. Hence, practical decisions for which measures to implement require information as to their relative effectiveness.

The MARS program is capable of providing this information for stationary sources. A mesoscale region and a city are exemplified in MARS by a regular grid with a step/pitch from 0.5 km to 10 km (usually 1 cm for a city and 10 km for a region). On such a grid for each screen cell there is information on the economic damage as a result of atmospheric pollution (scattering), and the pollutant distribution parameter in the atmosphere.

Principally different approaches to modeling pollutant distribution are used for cities and regions.

Maximum surface layer atmosphere concentrations of pollutants are calculated for cities according to the bearing and velocity of wind on the basis of the analytic solution of atmospheric diffusions under the bound limits corresponding to 20-30 minute averaging of meteorological parameters. Such a situation corresponds to unfavorable weather conditions which are relatively common recorded during a year.

The chosen time interval of averaging and low velocity of wind serve to minimize the effects on a model territory/city. Thus, calculations to minimize the indices of pollutant concentration patterns may lead to a possible realization of the criteria for decreasing emissions and economic damage in cities.

Deposition of sulfur, as well as evaluation of the potential hazard for coniferous forests, are calculated for mesoscale regions.

Each model index is an additive one; that is, for in any calculated point it is qualified by the covering of emittent-affected zones. These zones are not equally distributed since the distances over which pollutants are dispersed differ greatly. This differentiation becomes apparent if calculated values are compared with limiting values.

Thus, to make cost-effective decisions in the field of atmospheric protection in the absence of ideal criteria, it is necessary to analyze the range complex of indices and partake in the art of interpretation of the results.

MARS is a powerful tool for analyzing the effectiveness of pollution control measures. It contains a compiled data bank for making all possible (permissible) sets, and optimizing discrete atmospheric protection strategies. The exhaustive search of a large number of variants becomes possible thanks to the use of dynamic programming models and a functional diagram for distributing the expenditures.

It is possible to work out optimal strategies in MARS for each of the criteria with the use of two kinds of economic expenditure: capital and discounted ones; that is, comparing expenditure and results of diverse economic processes. These two types of expenditures reflect the resource part of the index of effectiveness of atmospheric protection activities.

The application of MARS requires a relatively small data bank, consisting of two parts: a) information on natural climatic features of the territory, and parameters of emission sources and; b) information on technology to reduce emission sources. The first part of the data bank is well established. Its preparation does not cause any difficulties or require much time. The second part of the data bank supposes a designed study of possible technological measures for reducing effluents at the sources. For this it is also necessary to generalize analogues for other cities/regions. It should be stressed that MARS, in this respect, gives minimum opportunities to create a data base of atmosphere protection measures in cities, republics, states and so on.

Proposed models, algorithms, and package programs were multilaterally examined and are used in the USSR to base strategies of atmosphere protection in cities and regions. Located in the territory of a region (which could be chosen from cities, industrial centers, territorial-production complexes, administrative regions, republics) are, as a rule, several thousand sources, each contributing to the pollution of the lower atmosphere. To control that pollution level it is necessary, within the framework of atmosphere monitoring, to perform various actions which are characterized by different efficiencies:

$$W_m = E_m / R_m,\ m \in M_i,\ i \in I \qquad (*)$$

where R_m - the volume of expenses e.g., investments, overall needed for the realization of m - action;

M_i - the series of actions technically permissible for i - source;

I - the set of air pollution sources in the region.

The effect from m-action linked directly with a source is determined as a difference:

$$E_m = E_m^{(1)} - E_m^{(2)} \tag{1.2}$$

Component $E_m^{(1)}$ is a basic (before the realization of m-action) share of a certain source in the lower atmosphere pollution level, and $E_m^{(2)}$ is a share of the source after the realization of m-action which could be defined as atmospheric protection if $E_m^{(1)} > E_m^{(2)}$.

The volume of atmospheric protection resources is limited:

$$\Sigma R_m \leq R, m \in M_i, i \in I$$

and for every limit R^* the corresponding optimum program can be found:

$$W = \Sigma W_m \rightarrow \max, R = R^*, m \in M_i, i \in I \qquad (**)$$

The reverse setting of a problem, reflecting the achievement of a desired state of the atmosphere W^* is also possible:

$$R = \sum R_m \rightarrow min, \quad W = W^*, \quad m \in M_i, \quad i \in I \qquad (***)$$

The succession of the optimum programs with the monotonously increasing W efficiency values, and the all-permissible R resource consumption determines the function of the efficiency of the atmospheric protection actions in the region. The synthesis of the function is necessary for calculating the amount of resources used for the protection of the atmosphere. The optimum function of the efficiency of atmospheric protection activities in a region is the final product of calculations done through MARS.

The MARS permits the obtaining of efficiency functions of the atmospheric protection activities on five types of criteria ($E_m^{(1)}$ and $E_m^{(2)}$ calculation methods), including the analysis of the two kinds of expenses (investments and total*). Each of the criteria may be interpreted depending on the goals of the analysis. The results of the calculations on the criteria chosen represent the solution of the practical problems in atmospheric protective from pollution.

The MARS has two modifications designated for calculations on a level of an industrial center or a city (MARS-1, and on the level of a meso-scale region (MARS-2). Those modifications differ one from another by the composition of an initial data base, by model blocks of pollutant dissipation in the atmosphere, and by sets

* The total expenses could be calculated using one of the known methods of commensuration of diverse economic expenditures directed at the realization of an atmospheric protection action; e.g., $P = C + EK$, where C = expenses on exploitation for one industrial cycle (1-year), K = investments realized during several industrial cycles, and E = norm of the investments efficiency.

of criteria for the efficiency of atmospheric protection actions.

Calculations using MARS require no special knowledge in mathematical modeling or computers. However, at the same time, MARS provides good possibilities for environmental managing based on assessment, monitoring, and control of an air basin pollution level.

An assessment of a pollution level includes the following:

a) Mapping of pollutant discharge.

b) Calculation of a structure of economic damage for each of the sources and pollutants.

c) Mapping of economic damage.

d) Calculation of fields of pollutant maximum concentrations under normal unfavorable conditions (MARS-1).

e) Calculation of mean annual sulfur compounds concentrations (MARS-2).

f) Calculation of mean annual sulfur compounds dry deposition over a region (MARS-2).

g) Calculation of mean annual wet deposition of sulfur compounds over a region (MARS-2).

h) Calculation of mean annual values of sulfur exportation out a region of eight sectors and of total exportation (MARS-2).

i) Calculation of indices of potential damage to coniferous forests of a region from total sulfur deposition (MARS-2).

j) Mapping of sulfur concentrations and deposition and of indices of potential damage to coniferous forests (MARS-2).

The information for decision-making regarding the monitoring and control of atmosphere pollution is provided by:

a) Analysis of efficiency of initial atmosphere protection efforts.

b) Analysis of efficiency of all permissible series of the atmosphere protection efforts.

c) Calculation of an optimum efficiency function.

d) Plotting of an optimum function.

e) Establishing an optimum series of the atmospheric protection actions in accordance with (**) or (***).

f) Determination of permissible waste norms for sources in accordance with the optimum series.

g) Calculation of complete expenses for the optimum series of actions.

h) Determination of an expedient amount of expenses for the atmosphere protection efforts in a region.

i) Determination of the effect of a range of regional sources on coniferous forests (an index of damage for coniferous forests from deposition of sulfur compounds) (MARS-2).

The MARS, run on a personal computer of IBM-PC-AT class, analyzes the effect of 1,000 large sources emitting seven different pollutants in the air basin of a city or a meso-scale region, presented by a regular grid 50 x 50 with a step (space) from 0.5km up to 10km, correspondingly.

The MARS structure contains 34 blocks.

1. Block of organization, following the development of data bank.
2. Bank of environmental and climatic characteristics.
3. Bank of parameters of stationary atmospheric pollution sources.
4. Block for modeling structure and spatial distribution of economic damage due to atmospheric pollution.
5. Assessments of economic damage for each of the sources and the pollutants.
6. Spatial distribution of economic damage for each of the pollutants and total.
7. Block for modeling of the dissipation of pollutants in the atmosphere over a city or an industrial center.
8. Pollutant concentration fields over a city or an industrial center.
9. Block for modeling of sulfur compound concentrations, dry and wet deposition for a mesoscale region, and sulfur exportation.
10. SO_2 concentration field.
11. SO_4^{2-} concentration field.
12. SO_2 dry deposition field.
13. SO_4^{2-} dry deposition field.
14. SO_2 wet deposition field.
15. SO_4^{2-} wet deposition field.
16. Deposition field of total sulfur compounds.
17. Assessments of sulfur exportation out of a region on eight sectors and of total exportation.
18. Block for modeling the index of potential damage to coniferous forests in a region due to total deposition of sulfur compounds.
19. Spatial distribution of the index of potential damage to coniferous forests.
20. Block for modeling parameters of initial atmosphere protection actions.
21. Bank of initial atmosphere protection actions.
22. Block of expenses mode selection.
23. Block of selection criterion of the efficiency of atmospheric protection efforts.
24. Block of organization of the bank of actions efficient enough for selected mode of expenses and criterion.
25. Bank of actions efficient for selected mode of expenses and criterion.
26. Block for modeling of permissible technological chains for decreasing wastes from sources, and for analysis of their efficiency for a selected mode of expenses and criterion.
27. Efficient series of actions for each of the sources (initial information for an optimization model).
28. Block for modeling the optimum strategies of the atmospheric protection efforts.
29. Information on parameters of the optimum strategy.
30. Block of selection the specific optimum strategy.
31. Block of organization of the series of the atmospheric protection actions corresponding to the optimum strategy selected.

32. The optimum strategy for achieving a predetermined norm of the air basin state.
33. The optimum strategy for distribution of expenses of atmospheric protection actions with a predetermined limit of resource.
34. Block of listing of the register.

Apparently, at present there is no "ideal" index for E_m effect determination and therefore there is no "ideal" efficiency of m-action for the atmospheric protection. That is why, depending on the aim of the atmospheric protection strategy, the calculated assessments of effect used in MARS could be divided into five types.

The first type is based on the calculation of the emitted mass of one or several pollutants. Comparison of pollutants included in the effect index could be done by the coefficients of toxicity (reverse value to the maximum allowable concentration). In that case, the efficiency of an action is the reduction of emitted mass per unit of expenses. This index is simple and convenient and there now exists a developed data base for its usage. However, the effect of pollution sources is determined, not only by the amount of pollutants entering the lower atmosphere, but also by the peculiarities of pollutant dissipation in the atmosphere and, therefore, by the structure of recipients suffering from adverse pollutants.

Those moments could be considered while using the index of the second type, namely, of the economic damage from pollution of the lower layer of the atmosphere (Antonovski, Litvin, 1987):

$$Y = \gamma \times \sigma \times f \times M$$

where

Y - the economic damage (roubles/year);

γ - the specific economic damage (roubles/comparison ton), average for the USSR is $\gamma = 2.4$;

σ - the dimensionless value characterizing the structure of recipients located in the zone of a source of active pollution ($0.05 \leq \sigma \leq 30$);

f - the dimensionless correction for the mode of the dissipation of a pollutant in the atmosphere, to be dependent on the active height of a source, mean annual wind velocity, and rate of admixture disposition ($I \leq f \leq 10$).

For the organized sources (stacks of height $h < 10m$) the zone of an active pollution is presented by a circle with a center in a point of a source location and with a radius of 50 h, but for $h \geq 10m$ the zone is a ring formed by radiuses $R_{inner} = 2\varphi h$, $R_{outer} = 20\varphi h$, where φ is a dimensionless correction for a plume raising:

$$\varphi = 1 + \frac{\Delta T}{75}$$

where ΔT is the drop in temperature between the mouth of a source and the ambient atmosphere (mean annual temperature).

The given mass of pollutants emitted from a source (comparison ton/year):

$$M = \sum_{j=1}^{N} A_j \times M_j$$

where M_j = the mass of an annual emission of j-pollutant (ton/year).

Coefficient of relative potency of a pollutant:

$$A_j = a_j \alpha_j \delta_j \lambda_j \beta_j$$

where a_j = an index of relative danger of a pollutant inhaled by a human; α_j = the correction for probability of a pollutant accumulating in environmental compartments, in food chains, and pollutant intake into humans by any means other than inhalation; δ_j = the correction for a pollutant effect on various recipients other than humans; λ_j = the correction for probable secondary discharge of a pollutant into the atmosphere; β_j = the correction for probable formation of secondary pollutants which are more dangerous than an initial pollutant. A_j values for the most frequently occurring pollutants are calculated in Antonovsky and Litvin (1987) and lie within the limits of 1 to 12×10^5. While using the index of the second type the efficiency appears to prevent economic damage per unit of expense.

The suggested method for calculating economic damage is addressed to particular sources, and based on emission accounting. Therefore, it keeps the advantages of the indices of the first type. However, the effect on recipients is considered in the nearest vicinity of a source (the zone of the active pollution).

The research results show that pollutants may be transported over long distances, and transformed and deposited on the underlying surface, thus affecting various recipients far beyond the limits of the active pollution zone. The calculation of the atmospheric deposition (indices of the third type) is of special importance when the size of a region is on the order of several hundred kilometers. In that case, the decrease in total deposition per unit of expenses is the criterion of the efficiency. The fourth type of indice is sulfur exportation out of a region's limit (total or directional). This type of indice is of particular interest for analyzing the effect of a particular region's pollution sources on bordering regions. It can be also used for facilitating decision-making regarding the implementation of the Convention on Transboundary Transport of sulfur compounds. It can also be used for linking the results obtained through MARS-2 with the models of transboundary transport. The special meso-scale models of transportation, transformation and deposition of atmospheric pollutants are used for calculating the indices of the third and fourth types.

The fifth type of indice is based on the comparison of the maximum lower atmospheric pollutant concentrations to their maximum allowance values, calculated for so-called normal unfavorable meteorological conditions.* This indice is most important for urban territories where the major recipient is population. If there are other recipients sensitive to the pollution of the territory of a city, it is necessary to compare the concentrations to the maximum allowable values for those recipients (secondary norms), but we must bear in mind that such a base of standards is currently not sufficiently developed.

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* The normal unfavorable meteorological conditions presuppose the non-stable stratification of the atmosphere and occur rather frequently during a year. Assume that a decrease in maximum pollutant concentrations to the level of the maximum allowable concentrations would provide the mean daily maximum allowance concentrations, whereas the reverse premise is not correct. That is why the criterion of minimization of "the maximum pollutant concentrations" indices is realized in MARS-1.

The model of an admixture dissipation in the atmosphere was modified for the purpose of calculating the maximum pollutant concentrations in the surface layer over urban territories under normal unfavorable conditions. The peculiarity of the modification is a considerable reduction of time needed for calculation, which is most important when using that block in optimization blocks of MARS-1 complex. When using the indices of the fifth type, the efficiency of actions is evaluated by the decrease of the index of pollutant concentrations per unit of expense. The corresponding index is decreased per unit of expenses. The corresponding index is determined for those elements of the regular grid where the exceeding of the calculated concentrations over the maximum allowable ones exists:

$$q_i = \sum_i \sum_k C_j^{(i,k)} / P_j \,, \quad \text{for} \quad \forall C_j^{(i,k)} > P_j$$

where q_j = the index of calculated maximum concentrations of the j2- pollutant (the sum of excesses of maximum occasional allowable concentrations in a city);

$C_j^{(i,k)}$ = the maximum calculated concentration of j - pollutant in (i,k) raster element of a regular grid presenting a city;

P_j = the maximum occasional allowable concentration of j-pollutant in the atmosphere over a settlement.

The state of an air basin over a city could be considered satisfactory when:

$$q_j \leq 1 \quad \text{for} \quad \forall_j \qquad (*')$$

The general index of an air basin pollutant for several pollutants over a city*:

$$Q = \sum_j q_j \,.$$

At the same time, for reaching the satisfactory state of an air basin of a city for several pollutants simultaneously, a more strict condition in comparison to (*') should be carried out:

$$Q \leq 1$$

There is a possibility in MARS to produce additional efficiency criteria such as (*) under different methods of E_m calculation, if any of the five indices listed above are used. The simplest "dose-effect" model permitting calculation of the index of potential damage from sulfur compounds to coniferous forests of a region could serve as an example of such an additional criterion, illustrating the expediency of the use of MARS in order to protect the atmosphere from pollution.

Also worth mentioning is the IIASA Regional Acidification Information and Simulation (RAINS) model, which is recognized by the ECE as a major prediction model to be used in future discussions with respect to going beyond the 30% sulfur emission protocol. This model was developed by the Acid Rain Project of IIASA's Environmental Program, and is a set of computer models that can be used to evaluate the abatement policies of acidification in Europe. The Project tries as much as possible to use existing models and adapts them as a bridge between scientists and modelers. The major user of this work is expected to be the Executive Body of the Convention on Long Range Transboundary Air Pollution which was established in

* For a group of pollutants having the property of summarizing their effect.

1979.

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