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CONTENTS

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

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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

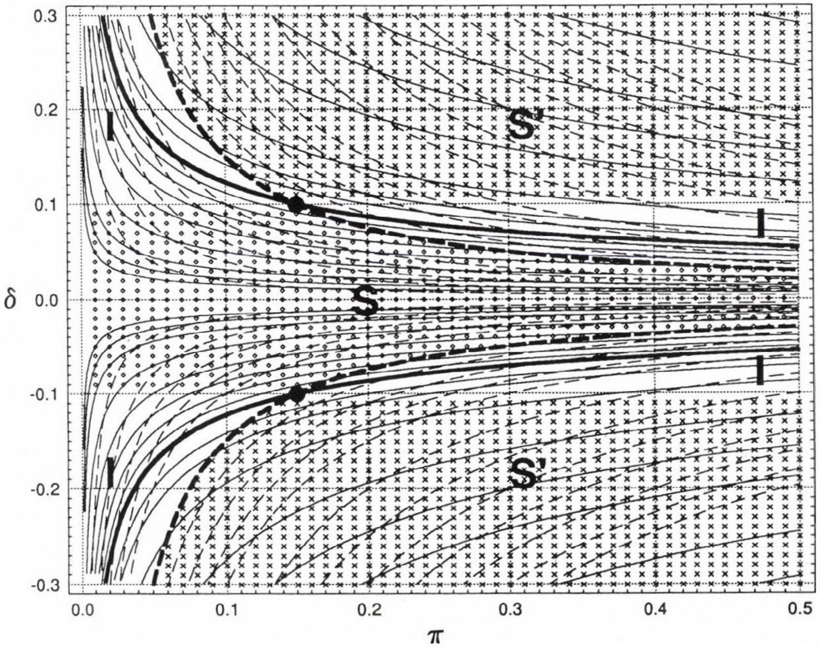

Fig. 1. Example of a sufficiency diagram (see Section 3.2). For a given reference system *A* (denoted by a large dot) the diagram identifies (i) the alternative systems *B* for which the reference system *A* is sufficient (diamonds, region denoted by *S*), (ii) the systems *B* that are sufficient for 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-

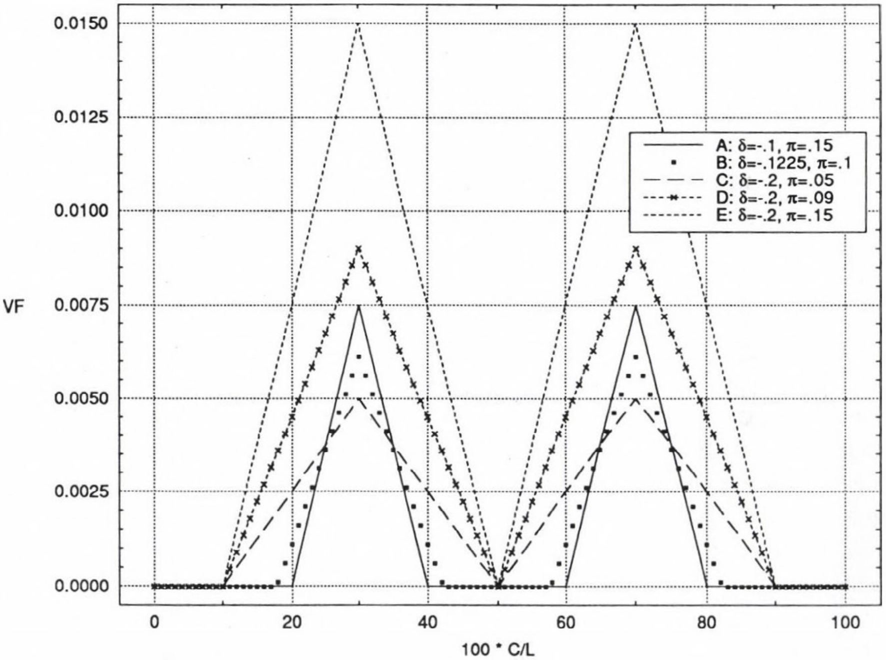

Fig. 2. The economic value VF of selected forecasting systems of the type considered in Section 3.2 as a function of the payoff structure parameterized through the cost-loss ratio C/L. Numerical values of the forecast quality parameters δ and π of the forecasting systems considered are indicated in the 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 (~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

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

The α_ι 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-

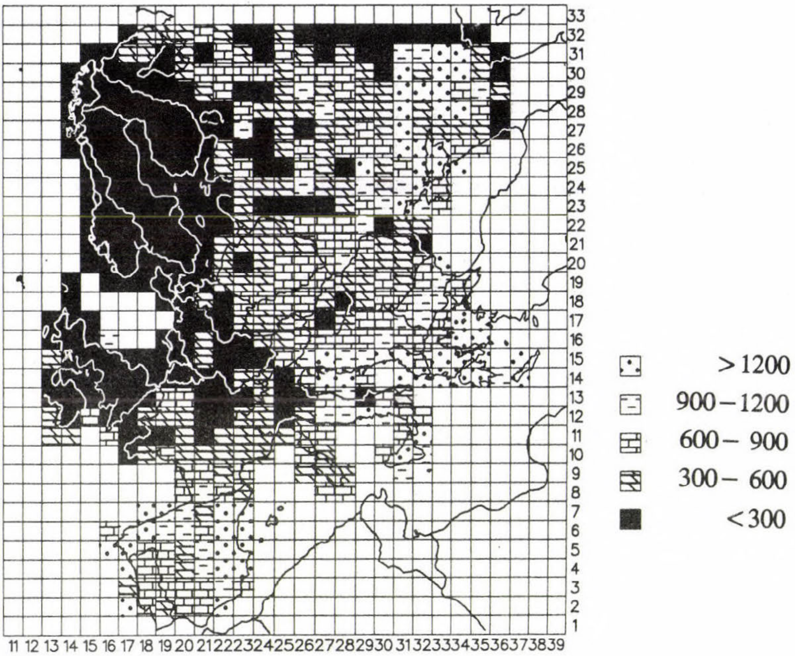

Fig. 1. Critical load map for deposition of sulphur expressed in H^+ [eq ha^{-1} y^{-1}] affording protection at the 1%ile level (including correction for the deposition of base cations)

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

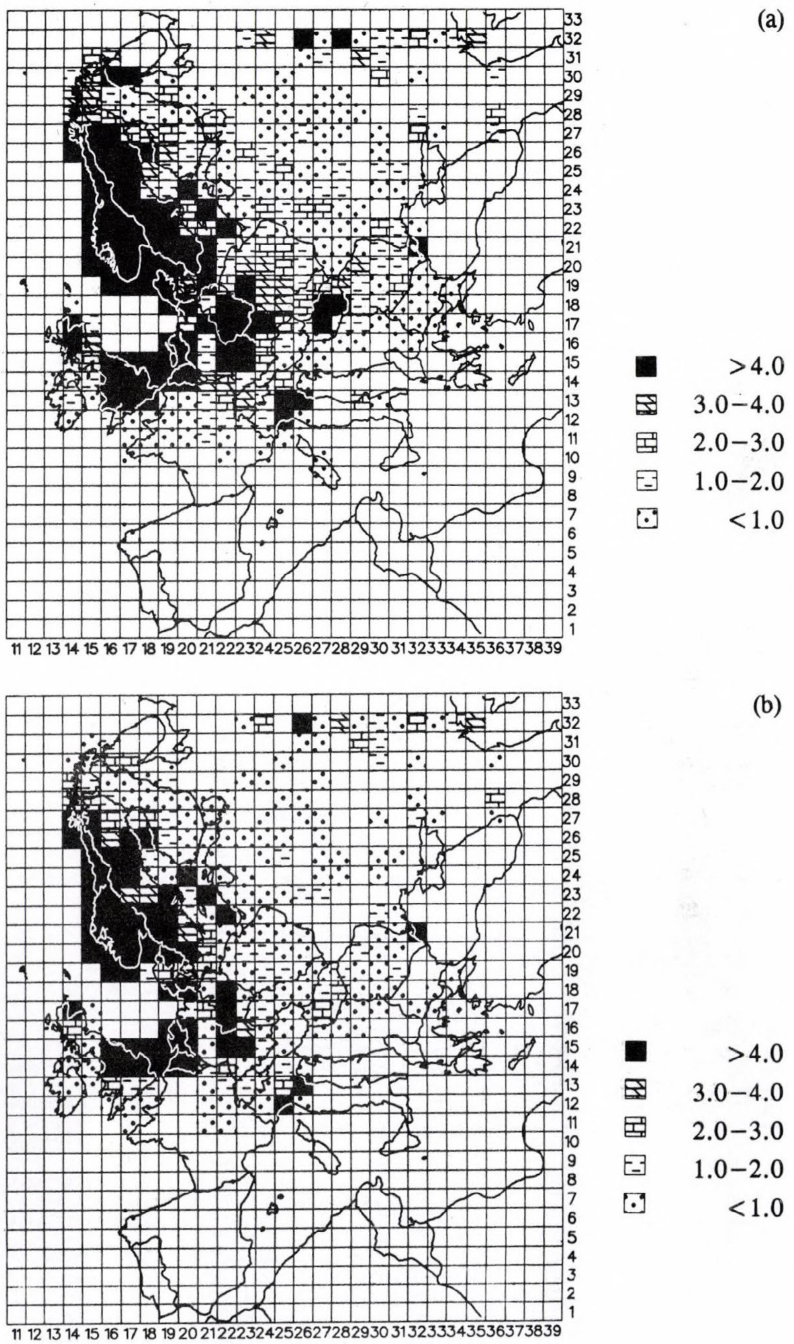

Fig. 2a, b. Maps of the damage function after different levels of expenditure in Europe of: (*a*) 0 and (*b*) 10 billion DM y^{-1} (DM: 1985 Deutsch Mark)

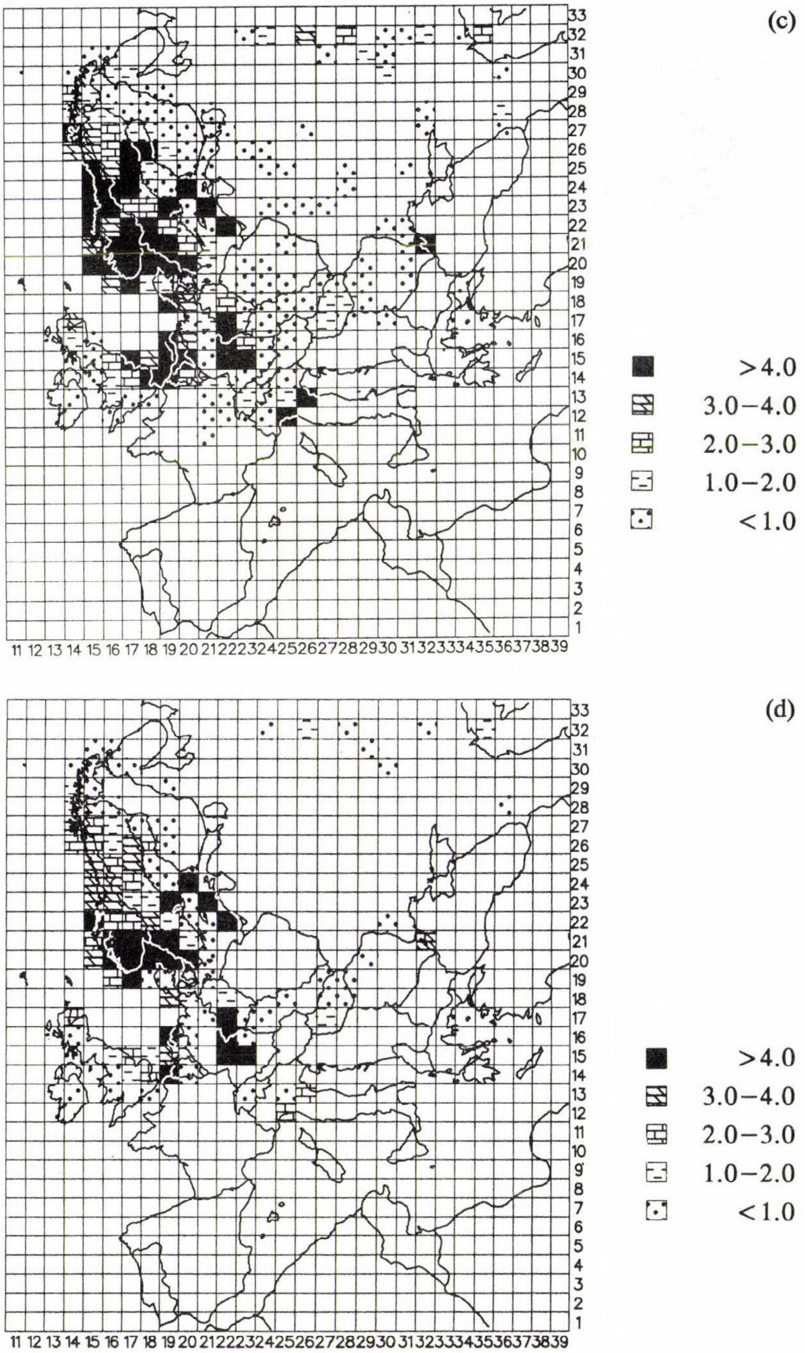

Fig. 2c, d. Maps of the damage function after different levels of expenditure in Europe of: (*c*) 20 and (*d*) 45 billion DM y^{-1} (DM: 1985 Deutsch Mark) where the level of expenditure is 20 billion DM y^{-1}. It is clear that countries in Southern Europe such as Greece and Portugal who are enlarging 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.

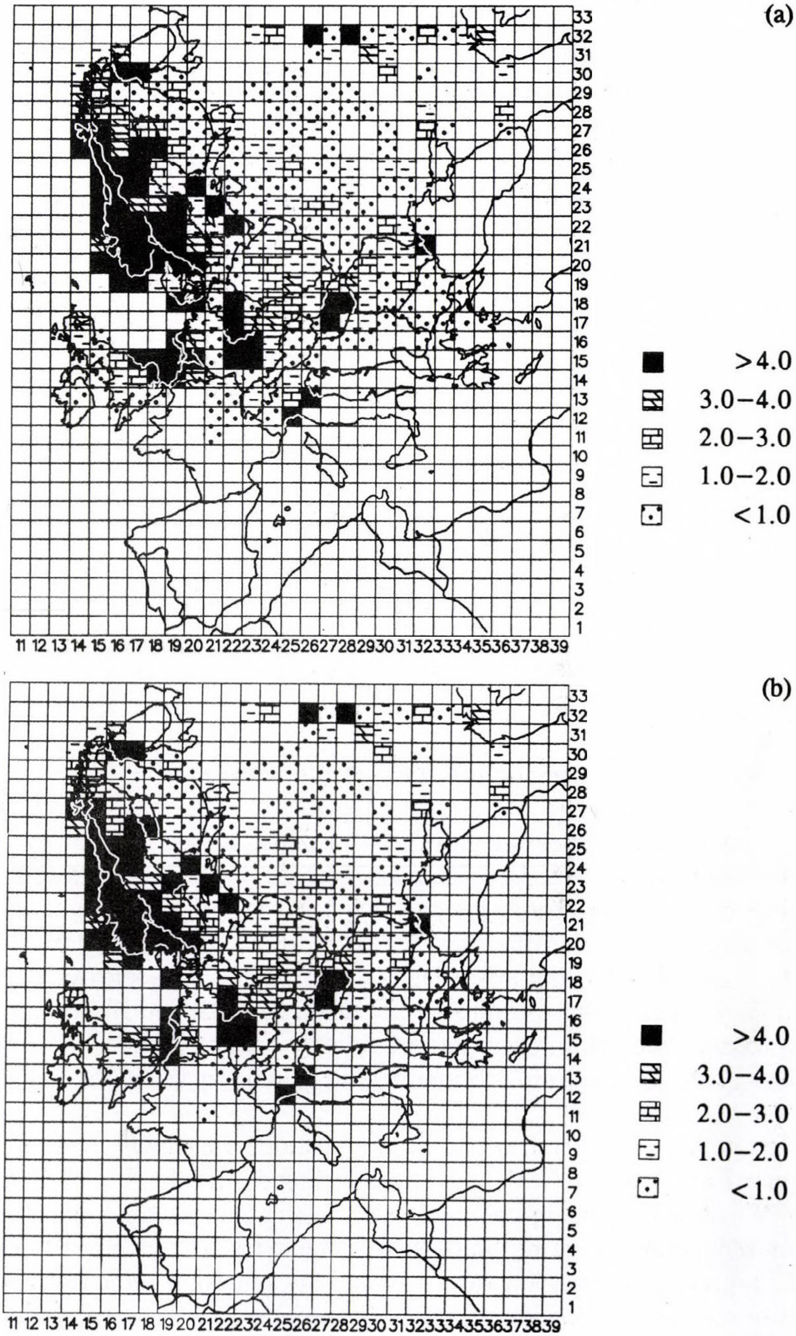

Fig. 3. Maps of the damage function corresponding to optimised expenditure levels of: (*a*) 9.2 and (*b*) 20 billion DM y^{-1} in Western Europe alone (DM: 1985 Deutsch Mark)

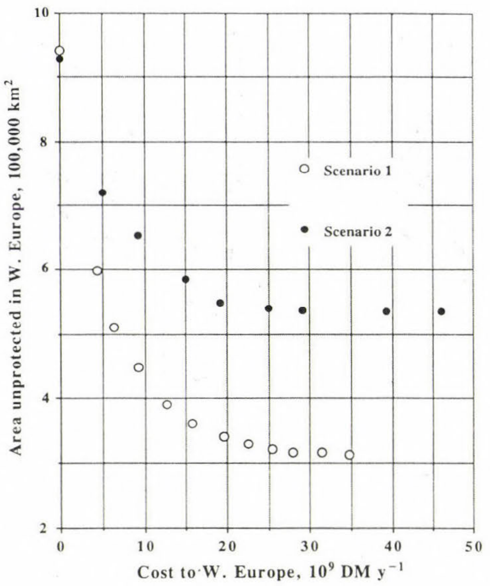

Fig. 4. The relationship between the area unprotected in Western Europe and expenditure for the case when Eastern Europe does participate (scenario 1), and when it does not (scenario 2)

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.

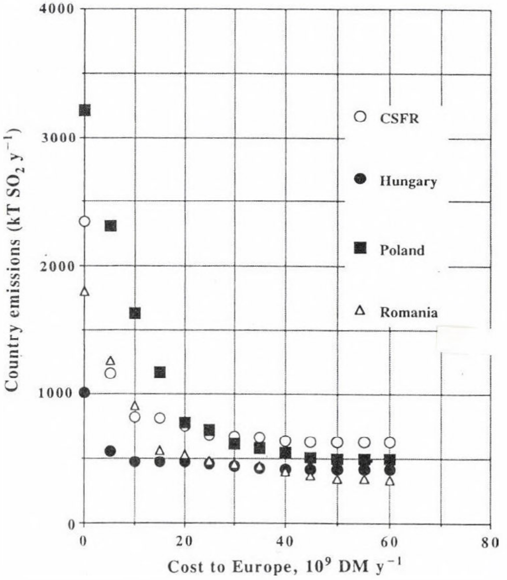

Fig. 5a. ASAM (*A*batement *S*trategies *A*ssessment *M*odel) strategy for emission reductions in some eastern European countries when all countries participate in a scheme targeting all 1% CCE critical loads

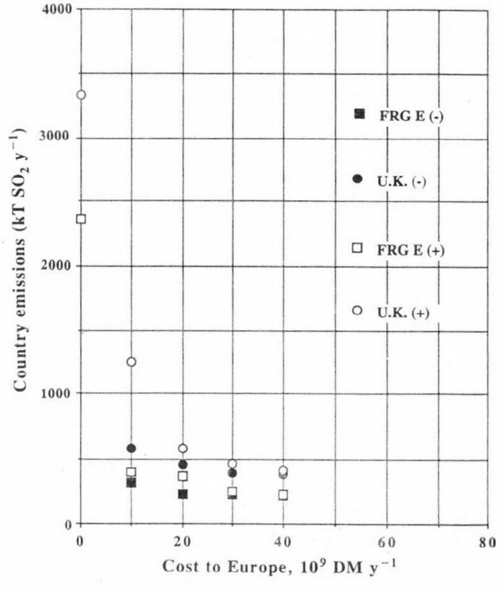

Fig. 5b. ASAM strategy for emissions reductions in the UK and the former East Germany (denoted as FRG E), with (+) of without (-) the participation of the Eastern European countries

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 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.

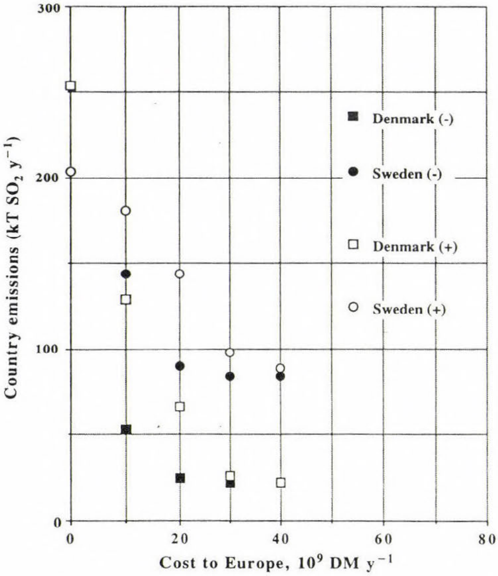

Fig. 5c. As 5b for Denmark and Sweden

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.

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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.

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

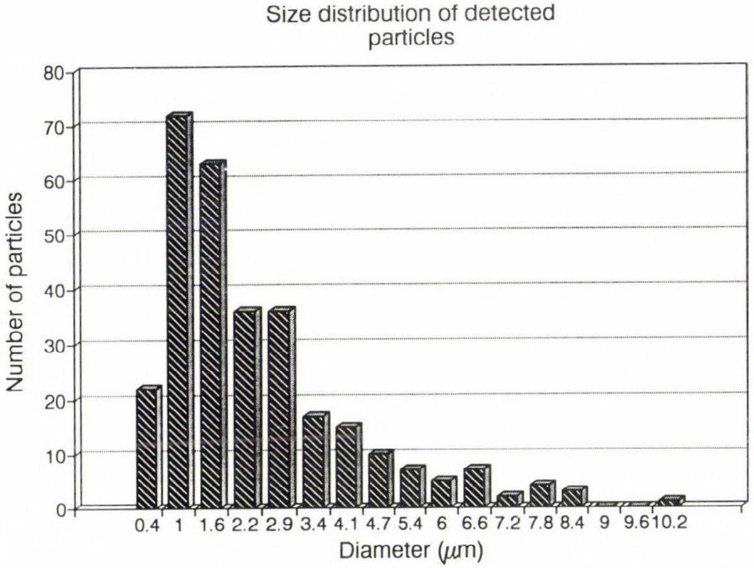

Fig. 1. Size distribution of aerosol samples taken on April 1 when the mean temperature was 19°C and the number of sunny hours was 11

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.

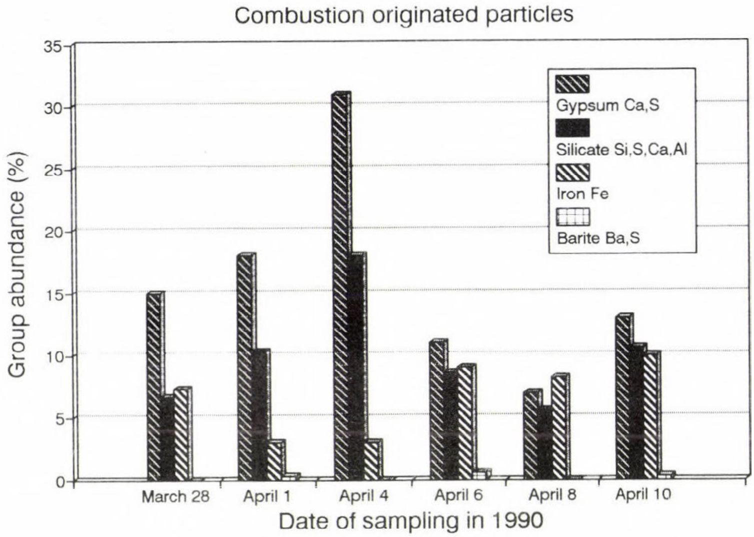

Fig. 2a. Group abundances (in %) of combustion originated particles in the K-puszta

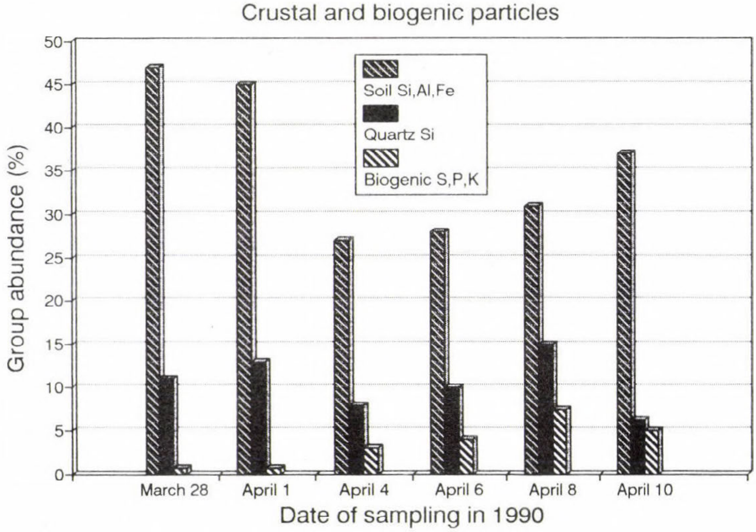

Fig. 2b. Group abundances of crustal and biogenic particles in the K-puszta campaign

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	Shape
	%	Mg	Al	Si	P	S	Cl	K	Ca	Ti	Mn	Fe	Ni	Zn	As	Br	Sn	Ba	Pb	(micron)	factor
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.

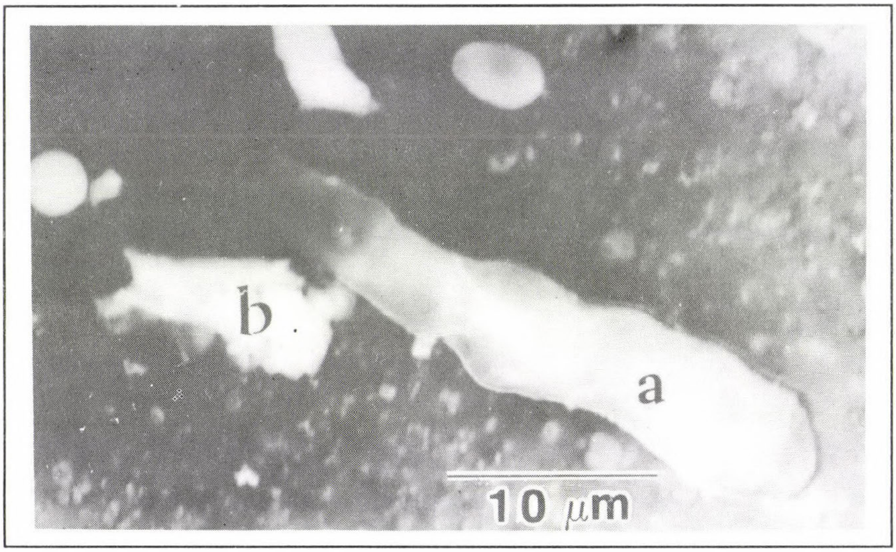

Fig. 3. Electron micro graph of aerosol sample taken at K-puszta, (*a*) biological object, (*b*) soil particle

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,

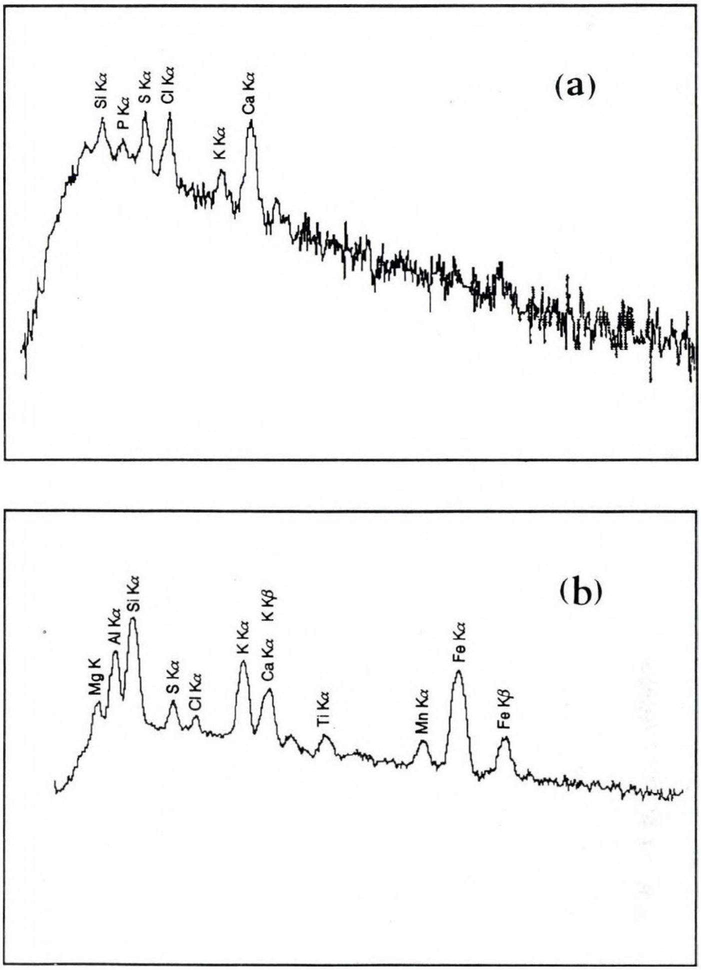

Fig. 4. X-ray spectra on logarithmic scale of aerosol particles presented in Fig 3, (*a*) biological object, (*b*) soil particle

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

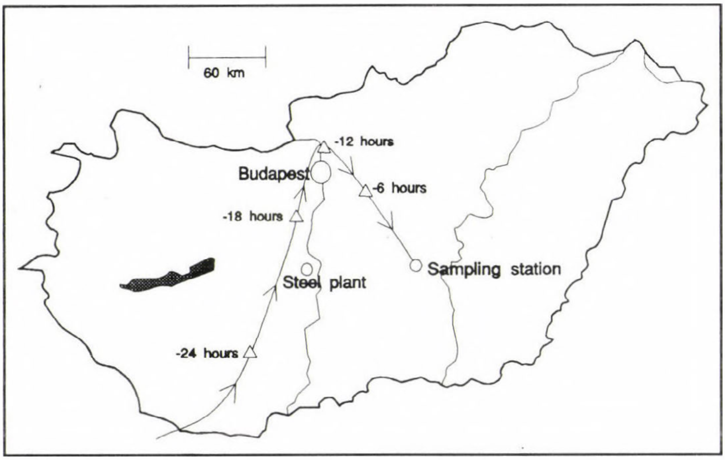

Fig. 5. Trajectory of air cell at 850 hPa on April 6, 1992

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.

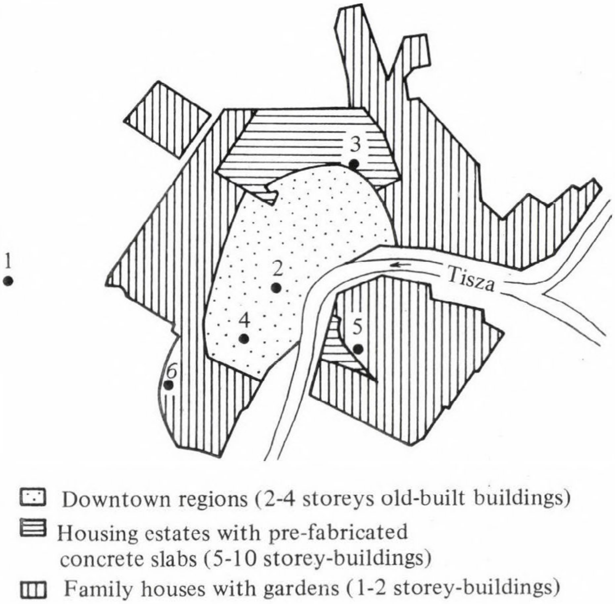

Fig. 1. The morphological types of Szeged and the used stations: 1. Aerological Observatory, 2. Restaurant of Napsugár, 3. Víztorony square, 4. Ady square, 5. Hospital for Children, 6. Department of Agriculture, Juhász Gy. Ped. Col.

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:

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

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).

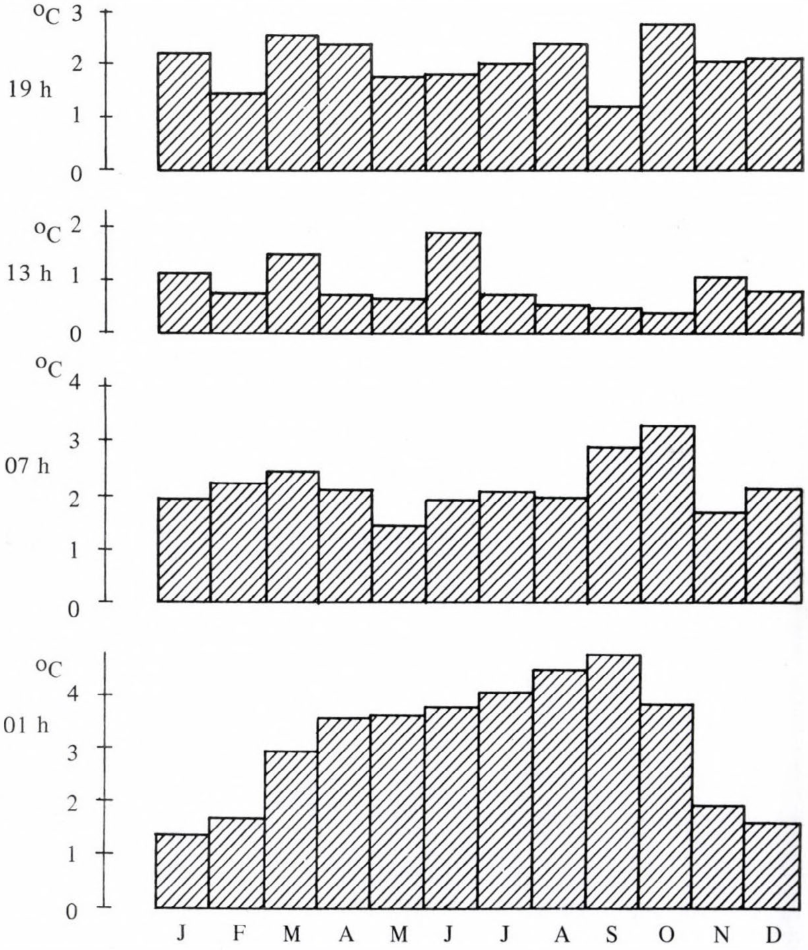

Fig. 2a. The annual variation of temperature surplus of the Station 2 (1978–80)

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

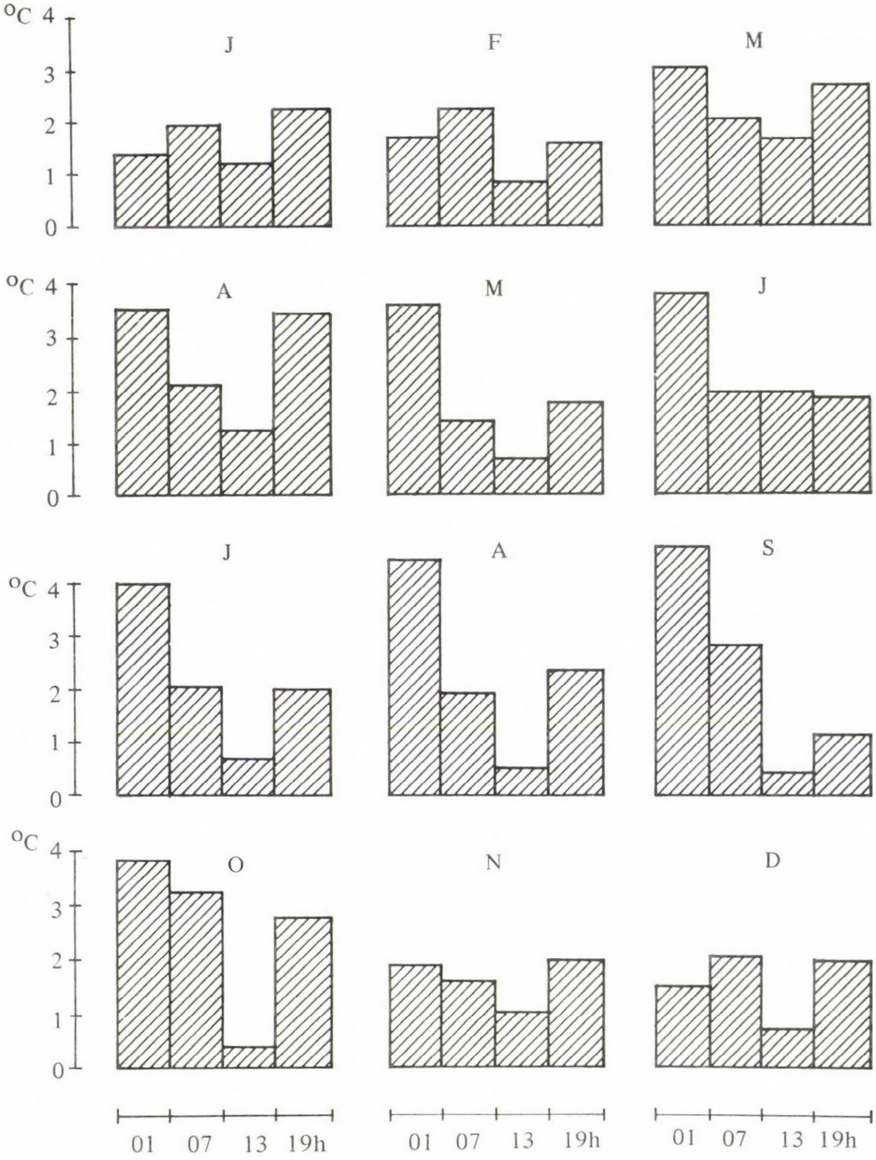

Fig. 2b. The diurnal variation of temperature surplus of the Station 2 (1978–80)

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.

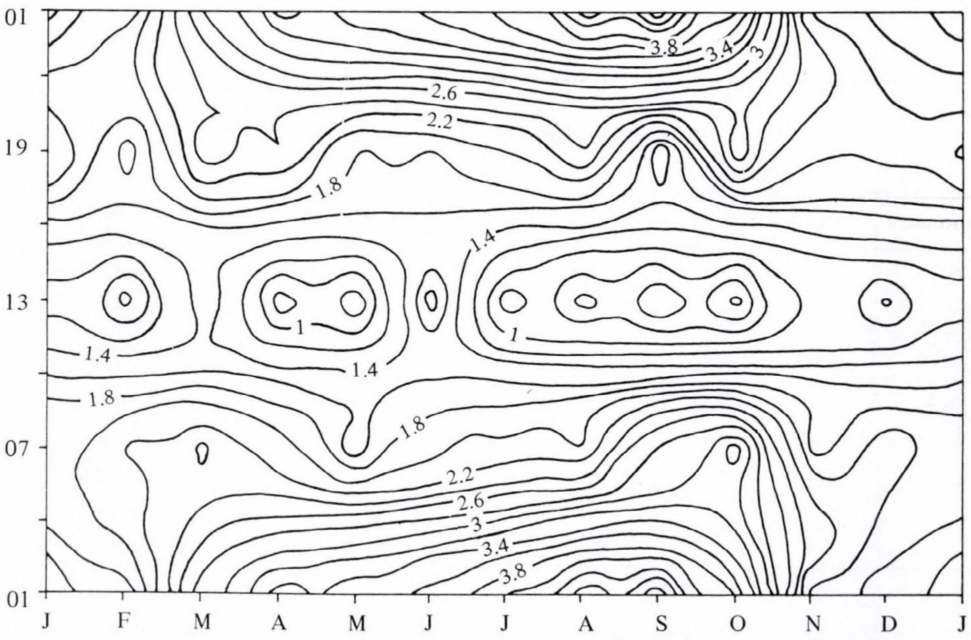

Fig. 3. The isopletes of the temperature surplus of the Station 2 (1978 – 80)

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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(Manuscript received 22 May 1992; in final form 8 January 1993)

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 Consumption 10^3 t	Coal S%	Fuel-oil Consumption 10^3 t	Fuel-oil S%	Mean S%	Mean calorific value (kcal/kg)
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.

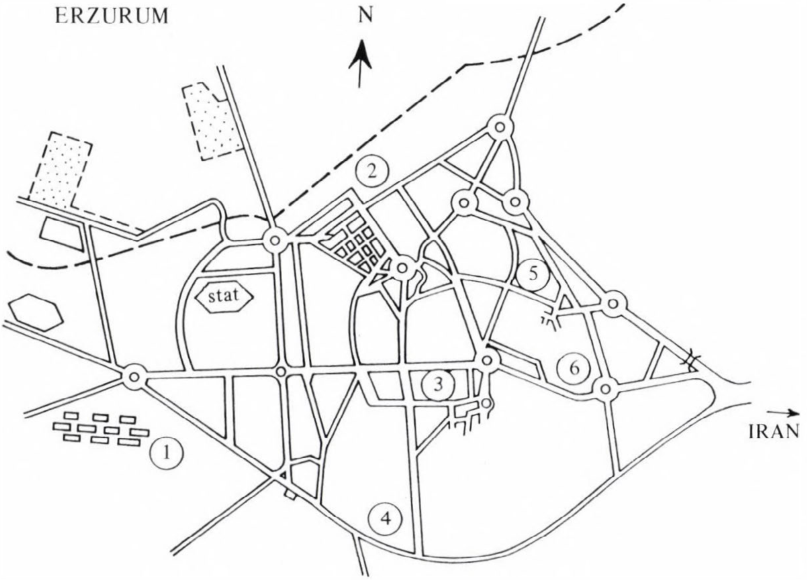

Fig. 1. Location of the measurement stations in city: 1. Atatürk University, 2. Railway Station, 3. Governor's Old Office, 4. Environmental Health Department, 5. 12 Mart Primary School, 6. Aziziye Primary School

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:

$$A_0 = \frac{(U \cdot P \cdot A \cdot T_h / V)}{K\left(1 - \dfrac{a_4}{V}\right)} , \qquad A_1 = \frac{U \cdot P \cdot A / V}{K\left(1 - \dfrac{a_4}{V}\right)} , \tag{12}$$

$$A_2 = \frac{a_2 / V}{\left(1 - \dfrac{a_4}{V}\right)} , \qquad A_3 = \frac{a_3 / V}{\left(1 - \dfrac{a_4}{V}\right)} , \tag{13}$$

$$A_4 = \frac{1}{\left(1 - \dfrac{a_4}{V}\right)} . \tag{14}$$

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:

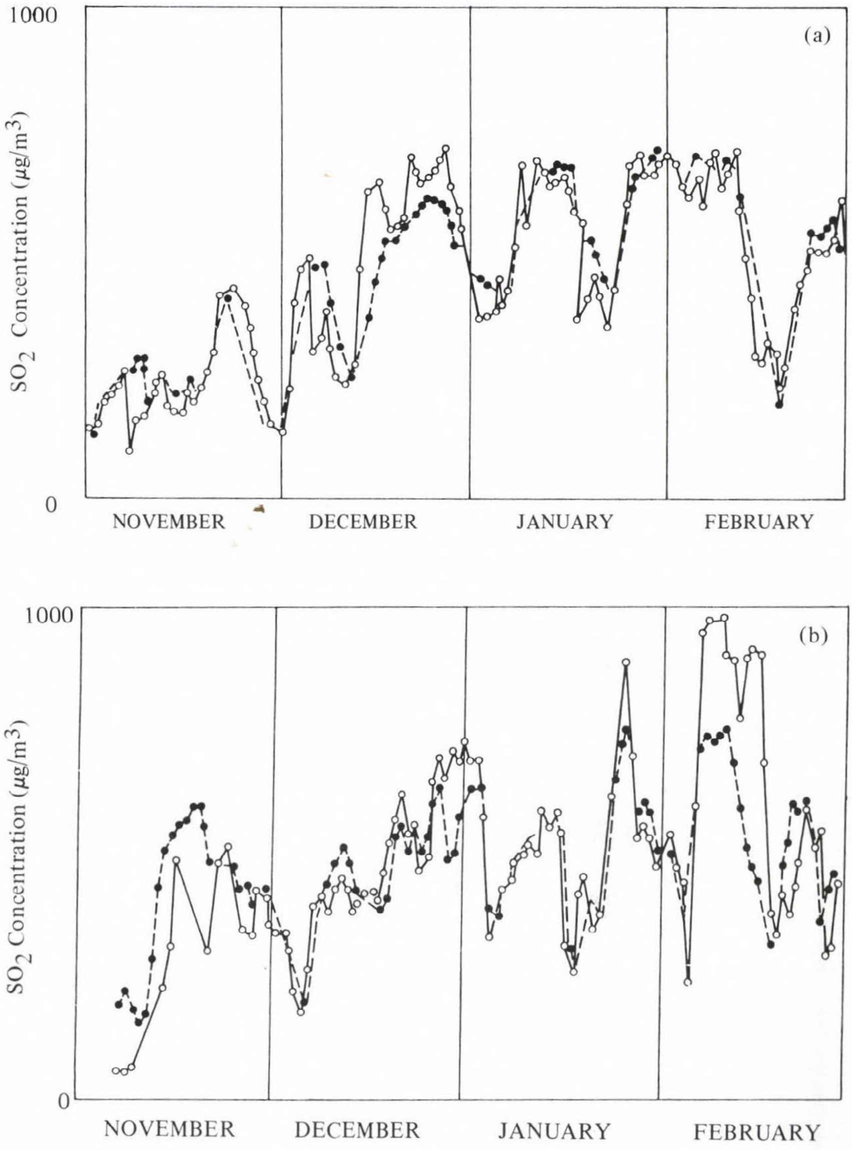

Fig. 2a, b. Measured and calculated daily SO_2 mean concentration for winter seasons (*a*) 1989–90, (*b*) 1990–91 (—o— observed, —●— model)

- 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

$$t_{1/2} = \frac{\ln 2}{(a_4/V)} . \tag{15}$$

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).

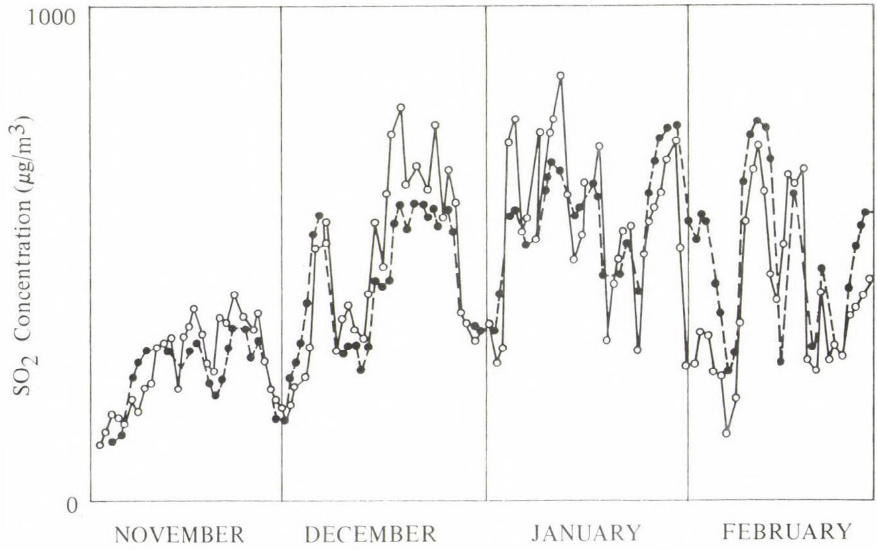

Fig. 2c. Measured and calculated daily SO_2 mean concentration for winter season 1991–92, (—○— observed, —●— model)

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 intergovernmental 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 interdepartmental 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

an international journal

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

Volume 26A Number 11 1992

Volume 26A Number 12 1992

Fifth International Conference on Indoor Air Quality and
Climate Indoor Air 90: *Characterization of Indoor Air*

A. Cavallo, K. Gadsby and *T.A. Reddy:* Use of natural basement ventilation to control radon in single family dwellings, 2251-2256.

Volume 26A Number 13 1992

H. Kaupp and *G. Umlauf:* Atmospheric gas-particle partitioning of organic compounds: comparison of sampling methods, 2259-2267.

S.N. Pandis, R.A. Harley, G.R. Cass and *J.H. Seinfeld:* Secondary organic aerosol formation and transport, 2269-2282.

T.K. Hinkley: Variation of rock-forming metals in subannual increments of modern Greenland snow, 2283-2293.

N. Coichev, K. Bal Reddy and *R. van Eldik:* The synergistic effect of manganese (II) in the sulfite-induced autoxidation of metal ions and complexes in aqueous solution, 2295-2300.

J.N. Cape, K.J. Hargreaves, R. Storeton-West, D. Fowler, R.N. Colvile, T.W. Choularton and *M.W. Gallagher:* Nitrite in orographic cloud as an indicator of nitrous acid in rural air, 2301-2307.

G.J.H. Roelofs: On the drop and aerosol size dependence of aqueous sulfate formation in a continental cumulus cloud, 2309-2321.

M.P. Olson, J.W. Bottenheim and *K.K. Oikawa:* Nitrogen sources-receptor matrices and model results for eastern Canada, 2323-2340.

D.H. Lowenthal, J.C. Chow, J.G. Watson, G.R. Neuroth, R.B. Robbins, B.P. Shafritz and *R.J. Countess:* The effects of collinearity on the ability to determine aerosol contributions from diesel- and gasoline-powered vehicles using the Chemical Mass Balance model, 2341-2351.

E.O. Edney, S.F. Cheek, D.C. Stiles and *E.W. Corse:* Field study investigations of the impact of shape, size and orientation on dry deposition induced corrosion of galvanized steel, 2353-2363.

J.C.S. Chang and *Z. Guo:* Modeling of the fast organic emissions from a wood-finishing product—floor wax, 2365-2370.

R.P. Wayne, C.E. Canosa-Mas, A.C. Heard and *A.D. Parr:* On discrepancies between different laboratory measurements of kinetic parameters for the reaction of the hydroxyl radical with halocarbons, 2371-2379.

R.M. Harrison, D.B. Nedwell and *M.T. Shabbeer:* Factor influencing the atmospheric flux of reduced sulphur compounds from North Sea inter-tidal areas, 2381-2387.

A.-M. N. Kitto and *R.M. Harrison:* Processes affecting concentrations of aerosol strong acidity at sites in eastern England, 2389-2399.

H.A. Bridgman: Evaluating rainwater contamination and sources in southeast Australia using factor analysis, 2401-2412.

H. Kaplan and *N. Dinar:* A stochastic model for the dispersion of a non-passive scalar in a turbulent field, 2413-2423.

Technical Notes

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

The purpose of *Időjárás* is to publish papers in the field of theoretical and applied meteorology. These may be reports on new results of scientific investigations, critical review articles summarizing current problems in certain subject, or shorter contributions dealing with a specific question. Authors may be of any nationality but papers are published only in English.

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* * *

The manuscript should meet the following formal requirements:

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