TECHNICAL NOTE No. 188

APPLICATIONS OF METEOROLOGY TO ATMOSPHERIC POLLUTION PROBLEMS

by

D. J. Szepesi

CCl Rapporteur on Atmospheric Pollution

WMO - No. 672

Secretariat of the World Meteorological Organization - Geneva - Switzerland
The World Meteorological Organization (WMO), of which 160 States and Territories are Members, is a specialized agency of the United Nations.

It was created:
- To facilitate world-wide co-operation in the establishment of networks of stations for making meteorological observations as well as hydrological and other physical observations related to meteorology, and to promote the establishment and maintenance of centres charged with the provision of meteorological and related services;
- To promote the establishment and maintenance of systems for the rapid exchange of meteorological information;
- To promote standardization of meteorological and related observations and to ensure the uniform publication of observations and statistics;
- To further the application of meteorology to aviation, shipping, water problems, agriculture and other human activities;
- To promote activities in operational hydrology and to further close co-operation between Meteorological and Hydrological Services;
- To encourage research and training in meteorology and, as appropriate, in related fields, and to assist in co-ordinating the international aspects of such research and training.

The machinery of the Organization consists of the following bodies:

The World Meteorological Congress, the supreme body of the Organization, brings together the delegates of all Members once every four years to determine general policies for the fulfilment of the purposes of the Organization, to adopt Technical Regulations relating to international meteorological practice and to determine the WMO programme.

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FOREWORD

The importance of the role of meteorology in studying and coping with environmental pollution problems has long been recognized. Accordingly, due attention has been given to the subject within the World Meteorological Organization, where several technical commissions deal with relevant aspects of air pollution (with the Commission for Atmospheric Sciences acting as lead commission in atmospheric chemistry and air-pollution meteorology). The Executive Council Panel of Experts on Environmental Pollution co-ordinates activities in this field, including the collaboration of WMO with other agencies concerned.

An essential aspect of the activities referred to above is the preparation of publications. In particular, a number of WMO Technical Notes relating to atmospheric pollution have been published:

- **TN No. 114 (WMO-No. 274):** Meteorological factors in air pollution (1970);
- **TN No. 121 (WMO-No. 319):** Dispersion and forecasting of air pollution (1972);
- **TN No. 139 (WMO-No. 393):** Climatological aspects of the composition and pollution of the atmosphere (1974);
- **TN No. 170 (WMO-No. 550):** Meteorological and hydrological aspects of siting and operation of nuclear power plants. Volume I - Meteorological aspects (1985); Volume II - Hydrological aspects (1981);
- **TN No. 176 (WMO-No. 583):** Tropospheric chemistry and air pollution (1982);

In addition to these and other WMO publications, a number of technical documents concerning environmental pollution are issued, in particular in the Environmental Pollution Monitoring and Research Programme report series.

This Technical Note is based on a report submitted to the Commission for Climatology (CC1)* by Dr. D.J. Szepesi in his capacity as the Commission's Rapporteur on Atmospheric Pollution. It has been published on the recommendation of CC1, after the original report had been reviewed and commented on by several experts (including experts from CAS and CC1) and revised by the author, taking into account the comments received.

* The title of this Commission was "Commission for Special Applications of Meteorology and Climatology" (CoSAMC) between 1971 and 1979 and "Commission for Climatology and Applications of Meteorology" (CCAM) between 1979 and 1983.
By providing a concise overview of the various ways of applying meteorological data and knowledge to air-pollution problems, this publication may be of use to Meteorological Services in developing their activities in this field, and will also be of interest to users.

On behalf of the World Meteorological Organization, I should like to thank Dr Szepesi for the preparation of this review, and the experts who contributed by their comments and suggestions to the elaboration of the final form of this note, in particular Messrs B. Bringfelt, W. Klug, R.E. Munn, L.E. Olsson, R. Runca, H. Schirmer and D.B. Turner.

(G.O.P. Obasi)
Secretary-General
SUMMARY

The most significant development in air-pollution meteorology in the last decade took place in the field of modelling. However, while research-oriented numerical models made considerable progress, the quality and quantity of the meteorological data base to run them and the air-quality and precipitation-quality data base to validate them have not improved significantly.

In view of the above, the main goals of this publication are:

(a) To clarify the meteorological concept and factors of air- and precipitation-quality management on local, regional, continental and global scales;

(b) To define so-called background pollution, which is a major component of this management and of growing importance;

(c) To help promote, at the national level, the standardization of methods and parameters for regulatory-oriented estimations and the satisfactory monitoring of meteorological factors necessary for these models.

The experience gained in this field in the last decade has shown that national environmental organizations need the collaboration of experienced air-pollution meteorologists for the proper management of air resources to avoid the misinterpretation, misuse or possible mismanagement of the global atmosphere which serves as a repository for many tons of pollutants deposited daily in each community of the world.

The brief introductory chapter contains a summary of the main tasks in the application of meteorology to air-pollution problems. Monitoring, interpretation of data, forecasting of periods of high air-pollution potential, development of simulation techniques, preparation of a transmission data base, and assistance to air-quality planning are identified as principal tasks.

Chapter 2 discusses the basic ideas underlying the complex, interdisciplinary activity termed air-quality management. It describes the concept of background pollution, gives a historical review of the different systems of scales used to describe air-pollution processes, and suggests a system for general use. After a treatment of the estimation of background air and precipitation quality, the emission and transmission of air pollutants and the basic principles of air-quality measurements are briefly described.

Chapter 3 is devoted to the consideration of the meteorological station networks, observations and processed data needed for the operational evaluation of air pollution. The main sections in this chapter relate to wind measurement, atmospheric dispersion, mixing layer height, roughness length, removal and transformation processes, and the contents of the meteorological data base required for air-quality assessment.

A general discussion of the methods and models used to describe the transport and diffusion of air pollutants is given in Chapter 4.
SUMMARY

In the short closing chapter on organizational aspects, suggestions are made for ensuring a high degree of efficiency of the services provided by Meteorological Services to users in this field of application.

A list of references concludes the Technical Note.
RESUME

Ces dix dernières années, la modélisation a été le secteur de la météorologie de la pollution de l'air qui a progressé de la manière la plus marquante. Toutefois, si les modèles numériques axés vers la recherche ont été considérablement améliorés, il n'en va pas vraiment de même de la qualité et de l'importance de la base de données météorologiques utilisée pour ces modèles ni de la base de données sur la qualité de l'air et la qualité des précipitations permettant de les valider.

Ceci étant, la présente publication vise essentiellement :

a) à préciser la notion météorologique de gestion de la qualité de l'air et des précipitations à l'échelle locale, régionale, continentale et mondiale, ainsi que les facteurs météorologiques en jeu;

b) à définir ce qu'il est convenu d'appeler pollution de fond : il s'agit d'un élément essentiel de cette gestion dont l'importance va en s'accroissant;

c) à contribuer à promouvoir au niveau national la normalisation des méthodes et des paramètres utilisés pour les estimations effectuées en vue d'une réglementation et la surveillance satisfaisante des facteurs météorologiques nécessaires aux modèles.

L'expérience acquise dans ce domaine au cours des dix dernières années a montré que les organismes nationaux s'occupant de l'environnement avaient besoin de la collaboration de météorologistes spécialisés de la pollution de l'air, pour gérer comme il convient les ressources en air afin d'éviter toute interprétation erronée, mauvaise utilisation ou éventuellement mauvaise gestion des vastes possibilités qu'offre l'atmosphère du globe qui absorbe chaque jour des tonnes de polluants.

Le premier chapitre constitue un bref résumé des principales applications de la météorologie aux problèmes que soulève la pollution de l'air. Il s'agit essentiellement de la surveillance, de l'interprétation des données, de la prévision des périodes durant lesquelles le risque de pollution est élevé, de la mise au point de techniques de simulation, de la préparation d'une base de données sur la transmission et de l'assistance pour la planification de la qualité de l'air.

Le Chapitre 2 traite des idées fondamentales qui sous-tendent l'activité complexe et multidisciplinaire appelée gestion de la qualité de l'air. Il décrit la notion de pollution de fond, passe en revue l'historique des différents systèmes d'échelles utilisés pour décrire les processus de pollution de l'air et propose un système à usage général. L'étude estimative de la qualité de fond de l'air et des précipitations est suivie d'une brève description de l'émission et de la transmission des polluants de l'air et des principes fondamentaux de la mesure de la qualité de l'air.
Le Chapitre 3 est consacré à l'examen des réseaux de stations météorologiques, des données d'observation et des données traitées nécessaires à l'évaluation en exploitation de la pollution de l'air. Les principales sections de ce chapitre concernent la mesure des vents, la dispersion atmosphérique, l'altitude de la couche de mélange, la longueur de rugosité, les processus d'élimination et de transformation et le contenu de la base de données météorologiques nécessaire pour l'évaluation de la qualité de l'air.

Les méthodes et les modèles utilisés pour décrire le transport et la diffusion des polluants de l'air sont exposés de manière générale dans le chapitre 4.

Le bref chapitre de conclusion sur les aspects structuraux de la question propose aux Services météorologiques des moyens à mettre en œuvre pour assurer aux usagers une assistance très efficace dans ce domaine.

La Note technique se termine par une liste de références.
РЕЗЮМЕ

За последнее десятилетие наиболее значительные события в исследовании метеорологических аспектов загрязнения воздуха произошли в области моделирования. Однако в то время как численные модели, ориентированные на научные исследования, имели значительный прогресс, качество и количество баз метеорологических данных для введения в модели, а также база данных качества воздуха и осадков для валидации моделей значительно не улучшились.

С учетом сказанного выше основные задачи этой публикации следующие:

а) уточнить метеорологическую концепцию и факторы контроля качества воздуха и осадков в локальном, региональном, континентальном и глобальном масштабах;

б) дать определение так называемого фонового загрязнения, которое является основным компонентом этого контроля и важность которого возрастает;

в) оказать содействие проведению на национальном уровне стандартизации методов и параметров для оценок, ориентированных на регулирование качества воздуха и удовлетворительный мониторинг метеорологических факторов, необходимых для этих моделей.

Опыт, полученный в этой области за последнее десятилетие, показал, что национальным организациям, занимающимся вопросами окружающей среды, необходимо сотрудничать с метеорологами, специализирующимися в вопросах загрязнения воздуха, в целях правильного использования воздушных ресурсов, для того чтобы избежать неправильные интерпретации, использование или контроль глобальной атмосферы, которая является носителем многих тонн загрязняющих веществ, ежедневно выбрасываемых в атмосферу в каждой стране земного шара.

Краткая вводная глава содержит резюме основных задач по применению метеорологии к проблемам загрязнения воздуха. Мониторинг, интерпретация данных, прогноз периодов, способствующих достижению высокого уровня загрязнения воздуха, разработка методов моделирования, подготовка и передача баз данных, оказание помощи планированию качества воздуха определены в качестве основных задач.

В главе 2 обсуждаются основные положения комплексной, междисциплинарной деятельности, называемой управлением качеством воздуха. В главе
Представлена концепция фонового загрязнения, приводится исторический обзор различных систем масштабов, используемых для описания процессов загрязнения воздуха, и предлагается система для общего использования. После оценок фонового загрязнения воздуха и качества осадков кратко рассматриваются выброс и перенос загрязняющих воздух веществ и основные принципы измерения качества воздуха.

Глава 3 посвящена рассмотрению сетей метеорологических станций, наблюдений и обработанных данных, необходимых для оперативной оценки загрязнения воздуха. Основные разделы этой главы относятся к измерениям ветра, атмосферной дисперсии, высоте слоя перемешивания, шероховатости поверхности, процессам удаления и трансформации и базе метеорологических данных, необходимых для оценки качества воздуха.

Общее обсуждение методов и моделей, используемых для описания переноса и диффузии загрязняющих воздух веществ, приводится в главе 4.

В краткой заключительной главе по организационным аспектам сделаны предложения о том, каким образом метеорологические службы могут обеспечить высокую эффективность предоставляемого потребителю обслуживания в этой области применения.

В конце технической записи находится список использованной литературы.
RESUMEN

Ha sido en el campo de la elaboración de modelos donde se han alcan-
zado, durante el último decenio, los progresos más importantes en materia de
meteorología de la contaminación atmosférica. Por otra parte, aunque se rea-
izaron considerables progresos los modelos numéricos para la investigación,
o no así lo han hecho la calidad y cantidad de las bases de datos meteorológicos
utilizados para su empleo ni tampoco la base de datos sobre la calidad del
aire y de la precipitación.

En vista de lo que precede, la presente publicación se ha fijado los
objetivos principales siguientes:

a) aclarar el concepto y los factores meteorológicos de la gestión de la
calidad del aire y de la precipitación a escalas local, regional, continental y mundial;

b) definir la denominada contaminación de fondo, componente principal de
esta gestión, cuya importancia es cada vez mayor;

c) coadyuvar al fomento, a escala nacional, de la normalización de los
métodos y parámetros para realizar estimaciones acordes con lo esta-
blecido en las reglas y también al control satisfactorio de los fac-
tores meteorológicos necesarios para estos modelos.

La experiencia adquirida en esta esfera en el pasado decenio ha reve-
lado que las organizaciones que se ocupan de cuestiones medioambientales en
los países necesitan la colaboración de meteorólogos experimentados de la
contaminación atmosférica para realizar una gestión adecuada de los recursos
atmosféricos con objeto de evitar la mala interpretación, utilización o posi-
ble mala gestión de las vastas capacidades de la atmósfera mundial, en la que
se almacenan tantas toneladas de contaminantes que desechar diariamente cada
comunidad del mundo.

El capítulo de introducción contiene un breve resumen de las princi-
pales actividades de aplicación de la meteorología a la solución de los pro-
blesmas que plantea la contaminación atmosférica. Estas son el control, la
interpretación de los datos, la predicción de los periodos de grandes posibi-
lidades de contaminación atmosférica, la elaboración de técnicas de simula-
ción, la preparación de una base de datos para la transmisión, y la asistencia
da la planificación de la calidad del aire.

En el Capítulo 2 se discuten las ideas fundamentales sobre las que
reposa esta compleja e interdisciplinaria actividad denominada gestión de la
calidad del aire. En él se describe el concepto de contaminación de fondo, se
hace un examen histórico de los diferentes sistemas de escalas utilizados para
describir los procesos de contaminación atmosférica y se sugiere un sistema de
utilización general. Después de estudiar la estimación de la calidad gene-
ral del aire y de la precipitación, se describen brevemente la emisión y
transmisión de contaminantes atmosféricos y los principios básicos para reali-
zar mediciones de la calidad del aire.
El Capítulo 3 se dedica al examen de las redes de estaciones meteorológicas, así como de las observaciones y datos procesados necesarios para realizar una evaluación operativa de la contaminación atmosférica. Las principales secciones de este capítulo tratan de las mediciones del viento, la dispersión atmosférica, la altura de la capa de mezcla, la longitud de la rugosidad, los procesos de eliminación y transformación y el contenido de la base de datos meteorológicos necesaria para evaluar la calidad del aire.

En el Capítulo 4 se presenta una discusión general de los métodos y modelos utilizados para describir el transporte y difusión de contaminantes atmosféricos.

En el breve capítulo final consagrado a los aspectos de organización, se formulas sugerencias sobre el modo en que los Servicios Meteorológicos podrían esforzarse por asegurar un alto nivel de eficiencia de los servicios que proporcionan a los usuarios en este campo de aplicación.

La nota técnica contiene al final una lista de referencias.
CHAPTER 1

THE ROLE OF AIR-POLLUTION METEOROLOGY

The main tasks of air pollution meteorology can be summarized as follows:

(a) Monitoring, by which is meant the participation in air-pollution surveys to ensure (Munn, 1976):

- The minimum number of sampling stations required for each pollutant, bearing in mind the objectives of the study;
- The siting of individual sampling stations in order to obtain representative "readings";
- The minimum number of samples that must be taken at each station to obtain representative air-pollution statistics;

(b) Interpretation of data:

- Provision and interpretation of climatological diffusion data;
- Analysis of air-quality surveillance data with respect to meteorological conditions;

(c) Forecasting periods of high air-pollution potential for dynamic air-quality management programmes;

(d) Development of meteorological simulation techniques:

- Development of atmospheric dispersion models useful for air-quality management, with a description of the possibilities and limitations of the models - now that simple but useful models have been completed, a new generation of more complex models can be worked out, which usually will require more detailed information;

(e) Preparation of a transmission data base:

- Preparation of transmission input data (joint frequencies or time series) by meteorological preprocessing programs on the basis of data of one- to five-year observations, in view of the wide scale and consistent application of existing simulation techniques;

(f) Air-quality planning:

- Assistance to air-quality planners in the compilation of emission inventories "understandable" to meteorological simulation models;
- Interpretation of the relationship between proposed or existing emission standards and ambient air-quality standards;

- Evaluation of the effectiveness of individual control or abatement measures for a polluting source or a complex of sources;

- Assistance to air-quality planners or managers in applying meteorological simulation models on urban, regional or country-wide scales for the development of control schemes or abatement strategies yielding the optimum cost/benefit ratio (McCormick, 1970).
CHAPTER 2

AIR-QUALITY MANAGEMENT

2.1 INTRODUCTION

Air-quality management is an interdisciplinary field requiring the collaboration of meteorologists, chemists, engineers, health officials, ecologists, land-use planners, sociologists and economists (Munn, 1976).

The ultimate objective of the collaboration is generally the abatement of atmospheric pollution. Theoretical solutions to the problem may appear simple: to eliminate or to control all significant pollution sources. The practical application of such solutions is extremely difficult, however, since the economic cost of radical changes in fuel usage, energy-conversion systems, waste-disposal methods, and modes of transportation may be prohibitive.

The atmosphere must continue to serve as a repository for the many tons of pollutants which must be disposed of daily in each community. What is needed therefore is a national basis for determining the degree of constraints necessary to achieve satisfactory air and precipitation quality. This involves estimating the maximum rate of pollution discharge compatible with the natural diluting and removal capacity of the atmosphere to meet air- and precipitation-quality (ecological) norms.

Obviously, some form of compromise must be reached in which the aforementioned dual role of the atmosphere is optimized. The desirable end product of previous studies should be the development of an air-resource management plan. Such a plan requires a high degree of understanding of the fundamental mechanisms involved in the phenomenon of air pollution.

There are two basic components in an air-resource management plan. Firstly, a clear definition of the air-pollution problem and, secondly, a technique for determining the optimum type and degree of control which would ensure the desired air and precipitation quality.

The task of defining the problem can be facilitated by the use of the systems analytical approach (Table I), which provides a basis for understanding the role and significance of the principal factors in atmospheric pollution, and the manner in which they interact.

An orderly appraisal of the principles and procedures of the meteorological (transmission) subsystem must include considerations of the larger one, the total air-quality management system, shown in a modified flowchart (Rossano, 1976) (see Table I). The main responsibilities of collaborating sciences for the subsystems on different scales are shown in the lower part of the table.

As stated above, while the total air-quality management needs the collaboration of different branches of science, the leading role for co-ordinating the tasks in the different subsystems is variable. On the local scale, for example, public health officials are responsible for setting up
CHAPTER 2

air-quality criteria (subsystem 11), while preparing ecological criteria for regional, continental and global scales is mainly the task for ecologists and/or meteorologists.

2.2 BACKGROUND POLLUTION

In dealing with the transmission of air pollution, different terms like background pollution, background and non-background modes, local, regional and global background pollution, very-long-range, long-range, interregional, medium-range and short-range pollution transports are used, often not in a consistent way, and even their scales in time and space are not defined in quantitative terms. It seems necessary to make a synthesis of these terms, collecting them in an overall framework and assigning them scales in a consistent way.

This is necessary for elaborating the transmission subsystem of air-quality management programmes on different scales, ranging from local to global. Such air-quality management programmes on different scales should be based on the knowledge of the present state of the environment, the trends of its change. ecological criteria and standards, budget studies of natural and anthropogenic trace constituents and on transmission models.

2.2.1 Historical aspects

The concept of background pollution, which was created in the 1960s, is developing from one of a "climatological-administrative" character to one of a "synoptic-operational" character, shown in a concise form in Table II.

The basic goal of the "climatological-administrative" background concept was to collect reliable data on the anthropogenic effects on the atmosphere and to make global climate studies.

Later, the programme was extended to provide data for studies of air-surface interchange and transport within and between regimes, but these developments did not fit properly into the original framework.

On the other hand, "synoptic-operational" concepts were developed on the national and continental levels, which were characterized by many contradictory elements as far as goals, terminology and scales are concerned.

A way out of this situation was to transform the earlier climatological concept into a "synoptic-operational" one which, at the same time, kept all the positive elements of the earlier system and ensured the continuation of the ongoing WMO programme to achieve long series of air- and precipitation-quality data. On the other hand, only a "synoptic-operational" system and modelling based on it are capable of making a distinction between natural, short-lived and long-lived anthropogenic atmospheric trace constituents, which is the basic aim of the whole exercise.

2.2.2 Scales of air-pollution dispersion processes

First of all, it is necessary to define air-pollution processes (or regimes). Considering their transport, dispersion, removal, transformation, emission and air-quality conditions, air-pollution processes are integer and persistent atmospheric mechanisms, which evolve across characteristic stages in time and space.
TABLE I

Total air-quality management system

Subsystems of management

<table>
<thead>
<tr>
<th>Subsystems of management</th>
<th>Principal factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emission standards (10)</td>
<td>Emission (1)</td>
</tr>
<tr>
<td>Air-quality and ecological criterion (11)</td>
<td>Emission survey (6)</td>
</tr>
<tr>
<td>Air-pollution control activities (15)</td>
<td>Meteorological survey (6)</td>
</tr>
<tr>
<td>Air-quality and ecological standards (12)</td>
<td>Air-and precipitation quality survey (7)</td>
</tr>
<tr>
<td>Air-quality planning (13)</td>
<td>Air-pollution effects survey (8)</td>
</tr>
<tr>
<td>Air-quality forecasting (14)</td>
<td>Air-pollution effects (4)</td>
</tr>
<tr>
<td></td>
<td>Economic and political indicators (9)</td>
</tr>
</tbody>
</table>

Pollution scales

<table>
<thead>
<tr>
<th>Pollution scales</th>
<th>Main responsibilities of collaborating sciences</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sub-systems</td>
<td>Local (site-specific, urban)</td>
</tr>
<tr>
<td>1</td>
<td>T</td>
</tr>
<tr>
<td>2</td>
<td>M</td>
</tr>
<tr>
<td>3</td>
<td>H</td>
</tr>
<tr>
<td>4</td>
<td>H,E,T</td>
</tr>
<tr>
<td>5</td>
<td>T</td>
</tr>
<tr>
<td>6</td>
<td>M</td>
</tr>
<tr>
<td>7</td>
<td>H</td>
</tr>
<tr>
<td>8</td>
<td>H</td>
</tr>
<tr>
<td>9</td>
<td>T</td>
</tr>
<tr>
<td>10</td>
<td>T</td>
</tr>
<tr>
<td>11</td>
<td>H</td>
</tr>
<tr>
<td>12</td>
<td>H,M,T</td>
</tr>
<tr>
<td>13</td>
<td>M,T</td>
</tr>
<tr>
<td>14</td>
<td>M</td>
</tr>
<tr>
<td>15</td>
<td>T</td>
</tr>
</tbody>
</table>

Legend: E = ecology; H = health; M = meteorology; T = technical sciences
## TABLE II

### History of air-pollution scales

<table>
<thead>
<tr>
<th>LOCAL</th>
<th>REGIONAL</th>
<th>GLOBAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>WHO:</td>
<td>Objectives</td>
<td>Determine anthropogenic</td>
</tr>
<tr>
<td>1969</td>
<td>Protect human health</td>
<td>effect on atmosphere</td>
</tr>
</tbody>
</table>

### Overall scales

<table>
<thead>
<tr>
<th>WHO</th>
<th>IMPACT LEVEL (WHO)</th>
<th>BACKGROUND LEVEL (WHO)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WHO:</td>
<td>Regional Nov. 1976-1978</td>
<td>Regional with extended programme</td>
</tr>
</tbody>
</table>

#### Climatological scales

<table>
<thead>
<tr>
<th>WHO</th>
<th>REGIONAL</th>
<th>EXTENDED PROGRAMME</th>
<th>GLOBAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>1976</td>
<td>(a) Long-term changes in</td>
<td>(a) Transport and deposition</td>
<td>(a) Global inventories and</td>
</tr>
<tr>
<td></td>
<td>atmospheric composition due to</td>
<td>of potentially harmful</td>
<td>their trends for climate</td>
</tr>
<tr>
<td></td>
<td>changes in regional land use</td>
<td>substances;</td>
<td>studies;</td>
</tr>
<tr>
<td></td>
<td>practices and man-</td>
<td>(b) Global latitudinal</td>
<td></td>
</tr>
<tr>
<td></td>
<td>induced activities;</td>
<td>transport for global</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(b) Air-surface exchange</td>
<td>biogeophysical modelling.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>and atmospheric transport within</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>regimes characterized by</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>significant man-made influences.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Operational scales

<table>
<thead>
<tr>
<th>Rossi et al. (1976)</th>
<th>LOCAL</th>
<th>REGIONAL</th>
<th>STATE-WIDE</th>
<th>CONTINENTAL</th>
<th>GLOBAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hyd. et al. (1978)</td>
<td>MICRO-</td>
<td>SYNOPTIC</td>
<td>0-10 km</td>
<td>1 000 km</td>
<td>Planetary</td>
</tr>
<tr>
<td></td>
<td>URBAN</td>
<td></td>
<td>10-100 km</td>
<td></td>
<td>&gt; 1 000 km</td>
</tr>
<tr>
<td>Smith (1977)</td>
<td>SHORT</td>
<td>SUBREGIONAL</td>
<td>REGIONAL</td>
<td>LONG-RANGE</td>
<td></td>
</tr>
<tr>
<td></td>
<td>RANGE</td>
<td>AQCR</td>
<td>STATES</td>
<td>STATES</td>
<td></td>
</tr>
<tr>
<td></td>
<td>50 km</td>
<td>50-200 km</td>
<td>200-500 km</td>
<td>&gt; 500 km</td>
<td></td>
</tr>
</tbody>
</table>

### New scales

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>LOCAL</th>
<th>REGIONAL</th>
<th>CONTINENTAL</th>
<th>HEMISPHERIC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site-specific</td>
<td>Urban</td>
<td>Medium range</td>
<td>Long range</td>
<td>Very long range</td>
</tr>
</tbody>
</table>

| Upwind range from receptor (km) | 0-5 | 5-100 | 100-300 | 300-3 000 | > 3 000 |
| Sampling height (m) | 2-600 | 2-1 000 | 2-1 500 | 2-3 000 | 2-10 000 |

*AQCR = Air quality control region*
Meteorological and climatological scales were reviewed by Yoshino (1975) and are shown in Figure 1, a close inspection of which reveals that considerable disagreement exists regarding the identified phenomena and their scales. Besides, air-pollution processes must be identified by their pollution and meteorological aspects. On the basis of these considerations, it can be concluded that air-pollution processes should not be classified according to purely meteorological characteristics only.

2.2.2.1 Time and space scales

The determination of time scales from the model-application point of view depends on the effects of the pollutant, the regulatory standards, and the variability of emissions and meteorological conditions (Drake et al., 1979): odour and taste perception are nearly instantaneous, possible acute toxic effects on humans and animals occur over periods of hours, and chronic effects occur over seasons and years. Regulatory standards are usually closely related to the time scales of expected effects. Emission variability in meteorological conditions depends on turbulence, passing thunderstorms and weather fronts, and stationary air masses.

The time and space resolution of an air-quality model (AQM) and its ability to forecast are no better than the corresponding characteristics of the meteorological input data. Table III shows the relationship between time and space scales of atmospheric phenomena and scales of meteorological flow models (Drake et al., 1979). The characteristic length $L$ is $1/4$ of the wavelength $\lambda$ and the time scale $\tau$ is $1/4$ of the period $P$ of the dominant disturbance producing the atmospheric phenomena.

Because of computational requirements, atmospheric models using physical fluid dynamics equations cannot span scales beyond a factor of about 50, as with AQMs. For the seven categories listed in Table II, $L_{\min}$ and $L_{\max}$ represent the minimum and maximum length scales of the phenomena in question, while the finite difference grid size is $L_{\min}/2$. Since $L_{\max}$ equals 50 $L_{\min}$, we have 100 grid spaces in each horizontal direction.

Models with length scales less than global or hemispheric require time-dependent lateral boundary conditions so that features with $L_{\max}/4$ scales are properly resolved. This limitation on the scales spanned by atmospheric models implies that a user can expect broad coverage or detailed interaction, but not both. Boundary conditions must always be specified, while sub-grid-scale processes must always be parameterized.

2.2.2.2 New system of air-pollution dispersion scales

In the last two decades, air pollution problems have appeared on more scales than were listed among the conventional UN or meteorological scales, i.e. local, regional and global. The resolution requirements for these scales and the ground-level concentration of the most common air pollutants differ roughly by one order of magnitude depending on the scale of the pollution process. An outline of the new system of scales is shown in Table II.
<table>
<thead>
<tr>
<th>Author</th>
<th>Scale Range</th>
<th>Site-Specific</th>
<th>Urban</th>
<th>Regional</th>
<th>Continental</th>
<th>Hemispheric or Global</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hall (1955)</td>
<td>0.5-10</td>
<td>micro</td>
<td>meso</td>
<td>macro</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flohn (1959)</td>
<td>0.001-0.1</td>
<td>micro</td>
<td>local</td>
<td>meso</td>
<td>regional</td>
<td>macro</td>
</tr>
<tr>
<td>Takahashi (1969)</td>
<td>&lt;10</td>
<td>micro</td>
<td>meso</td>
<td>macro</td>
<td>synoptic</td>
<td></td>
</tr>
<tr>
<td>Yoshino (1961)</td>
<td>&lt;0.1</td>
<td>micro</td>
<td>local</td>
<td>meso</td>
<td>macro</td>
<td></td>
</tr>
<tr>
<td>Mason (1970)</td>
<td>0.1-1</td>
<td>micro</td>
<td>convective</td>
<td>meso</td>
<td>synoptic</td>
<td>planetary</td>
</tr>
</tbody>
</table>

Air pollution scales:
- **local**: 0.1 - 1
- **urban**: 1 - 10
- **regional**: 10 - 100
- **continental**: 100 - 1000
- **hemispheric or global**: 1000 - 10000

**Figure 1** - Meteorological, climatological and air-pollution scales
### TABLE III

Atmospheric scales: model scope, characteristic length and time scales of phenomena (from Drake et al., 1979)

<table>
<thead>
<tr>
<th>Atmospheric scales</th>
<th>Model</th>
<th>Length</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>grid (km)</td>
<td>$L_{\text{min}}$ (km)</td>
<td>$L_{\text{max}}$ (km)</td>
</tr>
<tr>
<td>Global</td>
<td>400</td>
<td>800</td>
<td>40 000</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hemispheric</td>
<td>200</td>
<td>400</td>
<td>20 000</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Continental</td>
<td>100</td>
<td>200</td>
<td>10 000</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Regional</td>
<td>20</td>
<td>40</td>
<td>2 000</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Local</td>
<td>1</td>
<td>2</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Convective</td>
<td>0.04</td>
<td>0.08</td>
<td>4.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Turbulent</td>
<td>0.01</td>
<td>0.02</td>
<td>1.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
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</tbody>
</table>

A scheme of the present system of evaluating air-pollution processes is shown in Figure 2. The basic idea of this system is the following:

(a) The scale system of background pollution is receptor-oriented and pollution processes are defined as a function of upwind distances from the receptor;

(b) At the same time, polluting effects of individual air-pollution processes are apparently source-oriented, as long as their time-dependent integrity remains;
(c) Background pollution from a larger-scale pollution process is superimposed on the polluting effect of the smaller-scale process, e.g. the continental background plus the regional polluting effect give the regional background pollution, etc;

(d) Receptor points for the measurement of concentration levels caused by a pollution process of a given scale should be located so as to ensure that they are not affected by other (smaller-scale) processes, e.g. continental-level pollutant concentration can be measured at a certain point if pollution processes of regional, urban and local scales are lacking at a distance of 200 km around the receptor;

(e) Mean concentrations of anthropogenic species show a variation of roughly two orders of magnitude from the local to the global level;

(f) The density of emission at different scales of pollution processes varies considerably. From local to global scales it differs by several orders of magnitude.

Having discussed the general features of air-pollution processes in the previous paragraph, we shall describe them on the basis of their source, scale and background characteristics. The downwind range of an air-pollution process (e.g. continental scale) depends on the existence of smaller-scale processes. If such a smaller-scale process (e.g. urban-scale process) between the continental-scale process and the receptor does not exist, the lower end of the continental-scale air-pollution process coincides with the receptor point (0 km).

As Figure 2 clearly shows, "local-scale" comprises site-specific and urban-scale polluting processes.

Site-specific pollution originates from low-level individual point, line or area sources. At this scale, the density of emission is highest because anthropogenic emission is concentrated on a limited area. The polluting effect of the site-specific scale air-pollution process can be easily distinguished within some 100 m, maximum 5 km, downwind of the source from the background pollution of a larger-scale process. Site-specific pollution is considered allowable if it meets short- and long-term air-quality standards based on health and economic considerations.

Urban-scale pollution originates from multiple area, line and point sources. This is the scale where the pollution process of an industrial area also belongs. The distinction of urban-scale pollution from site-specific and regional-scale processes is justified by the fact that this is the only scale where the highest density of anthropogenic emission can be found relatively homogeneously on a large area. The horizontal scale of urban-pollution processes ranges up to 100 km from the upper limit of the site-specific process, depending on the extent of the settlement or industrial area investigated. Generally, its characteristic range is 20 km. The urban-scale polluting effect superimposed on the regional background pollution should not exceed short- and long-term air-quality standards based also on health and economic considerations.
Figure 2 - Scheme of the present system of evaluating air-pollution processes
Regional-scale pollution originates from area, high point and composite high sources (urban plumes). The length scale of regional pollution processes was the topic of many discussions in past years.

Smith (1973) suggested that the horizontal dimensions of an area which we call a region may lie between limits set by two meteorological properties. The lower limit is given by the horizontal distance beyond which the ground level concentrations are significantly affected by the depth of the mixing layer. During the daytime, this is typically of the order of 20 km downwind from the source area. The upper limit is given by the typical length over which meteorological parameters are relatively uniform.

Bingemer (1977) found that the polluting effects (creation of sulphur dioxide and particulate sulphate) of intense source areas could not be separated from the continental background pollution beyond a downwind distance of 200 or 300 km.

According to Schirmer's view (personal communication), the regional scale is appropriately defined by a range whose lower limit is characterized by the dominating influence of the mixing layer and the upper limit by an assimilation of the meteorological parameters.

It is generally agreed that the duration and distance within which the integrity of a polluted air mass is conserved depends on its initial volume and meteorological conditions. These are generally valid for power plant and urban plumes on a regional scale. It seems reasonable, therefore, to use for regional studies the upwind length scale ranging from several tens of kilometres measured from the receptor point generally to 200 or maximum 300 km, depending on the homogeneity of the area investigated.

The regional nature of many air-pollution problems (episodes and photochemical smog occurring at the regional level) generally indicates that the problem should be tackled at that level, this principle being recognized in the designation of official air-quality control regions in some countries. Air-quality standards on the regional level have to be established, therefore, to avoid excess abatement costs in neighbouring areas.

National (countrywide) considerations could also be an important part of the overall air-quality management programme although state boundaries do not correspond to the air-pollution pattern (Rossano and Thielke, 1976).

Continental-scale pollution originates from regional-level composite high sources (regional plumes). The horizontal scale of continental processes is from several hundreds to 3,000 km, where a characteristic range is 2,000 km. The polluting effect of continental-scale processes superimposes on the hemispheric background pollution, which includes mostly natural and long-lived anthropogenic components.

Continental-scale considerations are important where air pollution may be transported from one country to another and create problems of international proportions.

The concentration of anthropogenic trace constituents is considered permissible as long as it does not cause detrimental acidification of soil and freshwater ecosystems in a considerable part of the continent. In continental-scale studies, the role of the natural and long-lived components
(originating from other continents) of global background trace constituents should be further clarified.

Hemispheric- or global-scale pollution originates from continental-scale composite high sources (continental plumes). The average density of emission is the lowest at global-scale pollution processes. The horizontal scale of global pollution processes is beyond 2 000 - 3 000 km.

Global considerations include such factors as the balance between sources and sinks and the evaluation of the effects that might possibly result from imbalance. For international energy policy decisions based on climate impact studies, it is necessary to know whether the global level of radiatively active substances (e.g. CO₂ and fine particles) in the Earth's atmosphere is increasing and, if so, at what rate.

2.2.3 Definition of background pollution

2.2.3.1 Background air quality

Ideally, the fate of atmospheric trace constituents could be best studied by using a global-scale transmission model which comprises smaller-scale submodels and takes into account the input of all natural and man-made sources, the three-dimensional and time-dependent transport, dispersion, removal and transformation mechanism of the trace constituents with proper resolution.

It is well known that the state-of-the-art is far behind the requirements in all respects and, though modelling techniques have reached a certain level of success, the general applicability is not satisfactory.

To investigate smaller-scale, mostly anthropogenic air-pollution processes, the alternatives for researchers and air-quality managers are either to neglect the polluting effect resulting from large-scale processes or to take it into account as background-pollution. This means that the need to define and use the background-pollution concept and values will exist until satisfactory global-scale modelling is developed. Though the Global Tropospheric Chemistry Programme (NAS, 1984) and the EUROPICA (1986) programme hold certain promises for the long-term realization of such global-scale modelling, this could take many years. For simpler studies, when complicated modelling is not feasible, practical solutions can and will be achieved only by making similar drastic simplifications as outlined above.

For the sake of general definition of background pollution on different scales, a drastic simplification of the complex atmospheric pollutant transmission as "pollution processes" was necessary.

The present concept of air-pollution processes helps in generalizing that of background pollution (Szepesi, 1974; 1980): air pollution originating from a larger-scale pollution process around or outside a more intense but smaller-scale process is called background pollution. The pollutant concentrations originating from the larger-scale process are superimposed on the more intense effect of the smaller-scale process. By following this principle, global, hemispheric, continental and regional background pollution can be defined.

This generalized concept of background pollution is in agreement with the local-scale practical approaches described in recent US publications.
2.2.3.2 Background precipitation quality

The concept of background pollution is applicable not only to air but to precipitation quality as well. For this, a distinction has to be made between sub-cloud and in-cloud transport and scavenging processes. Namely, pollutants having escaped from the mixing layer to the free atmosphere are transported as continental, hemispheric and later as global background pollution and are ultimately removed - mostly by precipitation - to the surface, superimposing on the effect of smaller-scale local pollution processes. This background pollution, originating from larger-scale polluting processes, includes both natural and trace constituents and anthropogenic ones, originating from very-long-range transport.

Current views on this subject were well expressed at the ECE/EMEP session in 1983 as follows:

"The biggest deficiency of the models is the treatment of cloud development and rainfall which involves taking air pollution up to heights several times the conventionally assumed mixing depth (1 km) and then raining some of it in oxidized form. The remaining material presumably stays above the mixing layer during the next dry spell and is thereby isolated from deposition at the ground in a region where solar radiation levels are higher than near the ground. The next rain event will bring some more of this material out, and so on. This train of thinking inevitably introduces mechanisms whereby all emissions, natural and man-made, travel appreciably longer distances (very long-range transport) than considered hitherto by existing models and would explain also the composition of rain in remote parts like the Pacific and Indian Oceans."

Based on the above reasoning, it was assumed that a multi-parameter regression analysis of long-term measured data is capable of making a distinction between contributions from sub-cloud and in-cloud scavenging processes. Therefore, the following regression equation was used for sulphur species:

\[
D = \lambda_1 P C_1 + \lambda_2 P C_2 + \lambda_3 P C_3
\]

(1)

where:

\(D\) (mg \((SO_4^2-S)\) \(m^{-2} y^{-1}\)) = yearly total of sulphur wet deposition*;

\(\lambda_1\) mg \((SO_4^2-S)\) \(1^{-1}/\mu g \((SO_2-S)\) \(m^{-3}\) = scavenging ratio of sulphur dioxide expressed as \(S_1\) in the sub-cloud layer;

\(P\) (mm \(y^{-1}\)) = yearly precipitation total at a receptor point;

\(C_1\) (\(\mu g \((SO_4-S)\) \(m^{-3}\)) = average concentration of sulphur dioxide in the sub-cloud layer (practically the mixing layer) originating mostly from regional-scale anthropogenic sources;

\(\lambda_2\) (mg \((SO_4^2-S)\) \(1^{-1}/\mu g \((SO_4^2-S)\) \(m^{-3}\) = scavenging ratio of particulate sulphate in the sub-cloud layer;

* \((SO_4-S)\) and \((SO_2-S)\) indicate that the sulphur content is expressed in terms of \(S\) and not as \(SO_4\) or \(SO_2\)
\( C_2 (\mu g (SO_4^-S) \ m^{-3}) \) = average concentration of particulate sulphate in the sub-cloud layer (practically the mixing layer) originating mostly from regional-scale anthropogenic sources;

\( \lambda_3 (\text{mg} \ S \ \text{l}^{-1}/\mu g \ S \ \text{m}^{-3}) \) = scavenging ratio of sulphur species in the zone of cloud formation; and

\( C_3 (\mu g \ S \ \text{m}^{-3}) \) = average concentration of sulphur species in the layer of cloud formation (practically the mixing layer) originating mostly from natural and distant (continental- and hemispheric-scale) anthropogenic sources.

The third term of equation (1) helps to interpret the background contribution of wet deposition. If this term is divided by the yearly and areal (i.e. regional) average precipitation total \( P \) (mm yr\(^{-1}\)):

\[
\frac{\lambda_3 \ P \ C_3}{P} = b_w
\]

it gives the in-cloud background precipitation quality in mg l\(^{-1}\) originating for a larger scale (i.e. continental) air-pollution process.

In practical applications, the consideration of both sub-cloud background-air quality and in-cloud background-precipitation quality is necessary. This will be shown through a simple example: for a regional-scale acid-rain model, the estimated polluting effect of regional-scale anthropogenic sources has to be increased by the continental-scale sub-cloud background air-quality contribution. According to the model simulation, this will be scavenged by raindrops which have already attained in-cloud continental-background composition before entering the mixing layer.

2.2.3.3 Results of regresional analysis

The regression equation (1) is also useful for estimating background-precipitation quality values for regions and continents.

Such regresional analyses of sulphur and nitrogen species data were carried out for the central European region bordered by 10°W-30°E longitudes and 35°N-70°N latitudes and for continental Europe. For the multiregressive analyses the territorial distribution of five-yearly (1978-1982) average data measured in the EMEP network were used for sulphur (sulphur dioxide, particulate sulphate and precipitation sulphate) and for nitrogen (nitrogen dioxide and precipitation nitrate) species (Popovics and Szepesi, 1986). Using the smoothed patterns of the different species, air- and precipitation-quality data were read at each of 55 (or 260) grid points over central Europe. Emission-density data for sulphur and nitrogen oxides and precipitation totals were also read at the same grid points. For the co-located points, multiregressive relationships were analysed. Major findings of the regresional analyses are shown in Table IV.

A high correlation was found by multiregressive analyses of precipitation quality, gaseous and particulate species data. This is clearly shown by the statistics given in Table IV. In these cases, reliable background values were analysed (supplied by [24], [32], [2], [14], [27].
[41], [4] and [16]) which served as basic data for the composition of Figure 3*. For continental Europe, a higher correlation was found than for the central part. The relationships were poorer for northern Europe and even more so for southern Europe, supposedly because of the sparsity of measurement data.

When the relationship between air- or precipitation-quality data and emission-density data was analysed, a poorer correlation and too-high background values were found.

2.2.3.4 Background pollution data

After defining the background pollution on different scales, the continental and hemispheric areal averages of measured concentration data and background values given by regression analysis of measured and estimated data will be compared and assessed here. Most of these data were used for budget studies or simulation models.

2.2.3.5 Reported background data

In 1960, Junge reported that rainwater concentration data seemed to indicate that the excess $\text{SO}_4^{2-}$ concentration over land - even in remote unpolluted areas - was higher than over the oceans. The lowest values from the USA, Europe, and elsewhere were 0.73 mg S $\text{l}^{-1}$ (disregarding the coastal and polar regions) compared with 0.166 mg S $\text{l}^{-1}$ [33] over the oceans. He concluded that it was unlikely that all the excess continental $\text{SO}_4^{2-}$ in rain was industrial sulphur. Junge used this latter value as a natural background for the correction of the sulphur balance of the USA.

Based on similar reasoning, Rodhe and Grandell (1972) found a background value of 0.25 g (SO$_4^{2-}$-S) m$^{-2}$ y$^{-1}$ [37] for northern Europe.

An assessment of the background pollution of natural origin was carried out by Rasmussen (1975). He found that, for atmospheric sulphur, the natural component was dominant over the anthropogenic part. Assuming $1 - 1.5 \times 10^{14}$ g S y$^{-1}$ natural sulphur emission and $5 \times 10^{17}$ 1 y$^{-1}$ precipitation total for the globe (an oversimplified method) gives 0.2 mg (SO$_4^{2-}$-S) $\text{l}^{-1}$ [44] average background sulphate of natural origin in precipitation. This is equivalent to 0.2 g (SO$_4^{2-}$-S) m$^{-2}$ y$^{-1}$ average rate of wet deposition. The overestimation of Rasmussen seems due mostly to a neglect of the considerable effect of dry deposition. A more realistic value of about 0.1 mg (SO$_4^{2-}$-S) $\text{l}^{-1}$ might be found if the effect of dry deposition were considered.

In 1975, Eliassen and Saltbones carried out empirical investigations to determine the total background (natural + anthropogenic) sulphate concentration of precipitation for Europe. A background sulphate value of 0.2 mg (SO$_4^{2-}$-S) $\text{l}^{-1}$ [38] was found from sources which were not identified by the model applied for the greater part of Europe.

*Note: For the figures appearing in square brackets here and in the subsequent sections 2.1.3 and 2.1.4, see legend to Table IV on page 17.
TABLE IV
Relationship of air- and precipitation-quality data for sulphur species

(Correlation coefficients are: \( r \) for precipitation sulphate and sulphur dioxide or particulate sulphate; \( R \) for the left and right sides of equation (1) in paragraph 2.2.3.2.)

<table>
<thead>
<tr>
<th>Area</th>
<th>Sulphate in precipitation</th>
<th>Sulphur dioxide</th>
<th>Particulate sulphate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mg S l(^{-1})</td>
<td>µg S m(^{-3})</td>
<td>µg S m(^{-3})</td>
</tr>
<tr>
<td></td>
<td>( \bar{\text{SO}_4} )  ( \sigma ) ( R )</td>
<td>( \text{SO}_2 )  ( \sigma ) ( r )</td>
<td>( \bar{\text{SO}_4} )  ( \zeta ) ( r )</td>
</tr>
<tr>
<td>Central Europe</td>
<td>1.67 [24] 0.65 0.73 HB + CZPE 0.385 [32]</td>
<td>6.55 [2] 2.83 0.58</td>
<td>2.54 [14] 0.92 0.72</td>
</tr>
<tr>
<td>Europe</td>
<td>1.06 [27] 0.67 0.88 HB</td>
<td>4.05 [4] 2.88 0.84</td>
<td>1.64 [16] 0.97 0.85</td>
</tr>
</tbody>
</table>

Figure 3 - Contribution from background pollution of sulphur and nitrogen species (for the figures in square brackets, see the legend to Table IV on page 17)
Nyberg (1977) carried out precipitation-quality measurements on weather ships. He found that, for air masses transported from North America, the sulphate content of precipitation was 0.2 - 0.62 mg (SO₄²⁻-S) l⁻¹ [39] while, for air transported from the Azores, the concentration was 0.1 mg (SO₄²⁻-S) l⁻¹ [43]. Because the average sulphate concentration of precipitation over the northern part of Scandinavia was 0.33 mg (SO₄²⁻-S) l⁻¹, Nyberg concluded that a considerable part was originating from North America.

For the OECD (1977) programme on long-range transport of air pollutants based on regression analysis of measured precipitation sulphate and particulate sulphate concentration data, Eliassen and Saltbones (1982) reported a sulphate background value of 0.266 mg S l⁻¹ [34] for northern Europe, 0.4 mg S l⁻¹ [31] for continental Europe and 0.66 mg S l⁻¹ [29] for Central Europe.

For a newer model version (Eliassen and Saltbones, 1982) the background concentration was taken as 0.155 mg (SO₄²⁻-S) l⁻¹ [40] compared to 0.4 mg (SO₄²⁻-S) l⁻¹ in the routine model. Partly due to this different treatment of the "background" sulphur, the total deposition in the individual countries of Europe is reduced by between 6 and 34 per cent and the values in the "indeterminate" column of the budget tables increased.

Recent results from Canada, (P.W. Summers, Atmospheric Environment Service, personal communication, 1985) demonstrate that the concept of background is dependent upon proximity to oceans, underlying surface characteristics and proximity to sources of anthropogenic emissions. North of 60°N, remote from oceans, prairie dust and pollution sources, typical precipitation sulphur concentrations are 0.17 - 0.33 mg (SO₄²⁻-S) l⁻¹ and wet depositions are 0.03 - 0.1 g (SO₄²⁻-S) m⁻² y⁻¹ (Barrie and Hales, 1984). On the Canadian Pacific coast, excess sulfur concentrations are in the range 0.02 - 0.05 mg (SO₄²⁻-S) l⁻¹ and with an annual precipitation of 150-400 cm, wet deposition ranges from 0.07 to 0.13 g (SO₄²⁻-S) m⁻² y⁻¹. Background values for eastern Canada associated with westerly and northerly flows are also in the range of 0.07 - 0.13 g (SO₄²⁻-S) m⁻² y⁻¹. A recent review of excess precipitation sulphate concentrations over the North Atlantic Ocean yielded values in the range of 0.10 to 0.13 mg (SO₄²⁻-S) l⁻¹ (Whelpdale et al., 1985).

As far as trace species concentrations in air are concerned, de Bary and Junge in 1963 reported that stations in Iceland and the northern part of Scandinavia indicated an SO₂ background level over the North Atlantic of about 1.5-2.0 μg S m⁻³ [6] in summer and 3-4 μg S m⁻³ [7] in winter, with a seasonal variation very similar to that of the polluted areas.

The OECD study in 1977 reported that measured concentrations were higher than the estimated ones by 0.75 - 1.00 μg S m⁻³ [8] for sulphur dioxide and by 0.33 - 0.5 μg S m⁻³ [18] for particulate sulphate.

Further areal average values of measured concentration data of sulphur and nitrogen oxides reported by Georgii (1978) [3], Granat et al. (1976) [11, 21, 42] and Mézáros (1978) [3, 15] are also presented in Table V. Values underlined are considered representative areal average concentrations on different scales, and are also taken as background values relative to smaller-scale processes (see Table V and Figure 3).
**TABLE V**

Reported background concentration values of sulphur species in air

(The legend to the figures in square brackets is given in Table IV. Underlined values were used to draw Figure 3.)

<table>
<thead>
<tr>
<th>Scale</th>
<th>Location</th>
<th>Sulphur dioxide $\mu g$ S m$^{-3}$</th>
<th>Particulate sulphate $\mu g$ S m$^{-3}$</th>
<th>Precipitation sulphate mg S l$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Local-urban</td>
<td>Budapest</td>
<td>30.0 [0]</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Regional</td>
<td>Rural Hungary</td>
<td>6.8 [1]</td>
<td>2.95 [13]</td>
<td>2.0 [23]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4.0-10.0 [3]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hemispheric</td>
<td>Northern hemisphere</td>
<td>1.25 [9]</td>
<td>0.8 [19]</td>
<td>0.157 [41]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.3-1.5 [5], 0.75-1.0 [8], 1.5-2.0 [6], 3.0-4.0 [7]</td>
<td>0.3-1.0 [17], 0.33-0.5 [18]</td>
<td>0.07-0.13 [36], 0.155 [40], 0.166 [33], 0.2 [38], 0.2-0.62 [39], 0.25 [37], 0.286 [34], 0.27 [35]</td>
</tr>
<tr>
<td>Global</td>
<td></td>
<td>0.7 [12], 0.5-1.7 [11]</td>
<td>0.3 [22]</td>
<td>0.1 [45]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.5 [10], 0.5-1.7 [11]</td>
<td>0.1-0.5 [20.21]</td>
<td>0.04 [42], 0.1 [43.58], 0.20 [44]</td>
</tr>
</tbody>
</table>
2.2.4 Contribution of background pollution

For the assessment of the background contribution to the measurable air and precipitation quality on different scales, a simple logical scheme shown in Figure 3 was constructed. For the elaboration of this scheme, the following data were used:

- Reported areal average concentration data on urban [0, 46], regional [1, 13, 23, 47, 52], continental [9, 19] and global [12, 22, 45] scales:

- Extrapolated values for the global scale [51, 57]:

- Calculated areal average concentrations on regional [2, 14, 24, 48, 53] and continental [4, 16, 27, 49, 54] scales:

- Hemispheric background data given by multiregressional analyses [41];

- Extrapolated data from the European continent to the North Atlantic based on five years of EMEP data [50, 56]; and

- Hemispheric background data increased by the continental zone polluting effect (CZPE) for the central part of the continent [32].

By plotting and analysing these data as relative concentration contributions in Figure 3, the following conclusions may be drawn:

- 69 per cent of the average sulphur-dioxide concentration over Europe originates from continental-scale anthropogenic sources;

- Only 18 per cent of the anthropogenic sulphur emission (22.5 Mt S y\(^{-1}\) is wet deposited over a considerable part of the European continent (west of longitude 30°E);

- 15 per cent of the average precipitation sulphate over Europe comes from the hemispheric background. If not all the sources over the whole continent are considered, the hemispheric background concentration should be increased by the polluting effect of the continental zone (CZPE) which was left out of the modelling. This increased hemispheric background value for the previously defined grid over Europe is 0.385 mg (SO\(_4\)-S) \(^{-1}\) (see value [32]);

- 63 per cent of the average nitrogen-dioxide concentration over Europe originates from continental-scale anthropogenic sources;

- 11 per cent of the average precipitation nitrate over Europe comes from the hemispheric background, which is similar to the contribution of precipitation sulphate. It is recommended to repeat this multiregressional analysis for nitrogen species when longer records of reliable particulate nitrate and nitric acid gas data are available.

For air-resources management, if the major part of the anthropogenic sources over the European continent are duly considered, the following
hemispheric background values should be taken into account: 1.250 μg (SO\textsubscript{2}-S) m\textsuperscript{-3}, 0.800 μg (SO\textsubscript{4}²-S) m\textsuperscript{-3}, 0.157 mg (SO\textsubscript{4}²-S) l\textsuperscript{-1} and 0.04 mg (NO\textsubscript{3}-N) l\textsuperscript{-1}.

2.2.5 Practical evaluation of background pollution

For the preparation of emission-control strategies, assessment of the current air- and precipitation-quality levels and identification of the major pollutant contributors are necessary. The contribution from the background pollution means the initial condition from which the control strategy of the emission on a certain area or region has to start. The measured or calculated value of background pollution includes contributions from natural sources and distant non-identified anthropogenic sources. While, for local-scale impact-level assessments, continental- or regional-scale background pollution contributes only 10-20 per cent of the measurable average concentration for continental-scale simulation, the role of the hemispheric background is greater (30-70 per cent). In other words, the importance of background pollution increases from the local to the continental scales.

The necessity to establish a practical means for the evaluation of the background concentration emerged in many countries. Instead of reviewing all these efforts, it will be shown here how the background pollution concept was commented in one country, i.e. the USA.

Between 1977 and 1980, the US Environmental Protection Agency (USEPA) held a series of public meetings for the purpose of presenting its draft Guideline on Air Quality Models and receiving comments from interested experts. The stated aim of the Guideline was to promote consistency, if not uniformity, in the application of air-quality models (AMS, 1981).

Comments were received on a wide range of topics, including one on which EPA specifically solicited advice:

"How are background air-quality data best determined?"

A number of commentators offered specific suggestions for determining background pollution.

In response to EPA's questions, there were about 40 comments on the best methods of determining background concentrations. Several commentators requested that the meaning of the term "background" should be clarified. The participants showed a marked preference for background or baseline air-pollution concentration data to be determined by an analysis of air-quality measurements. However, many of these same participants also recognized that modelling would be valuable as a means of extrapolating or interpolating between concentrations measured at monitoring stations.

One commentator mentioned the special problems associated with determining background in the presence of existing sources. He pointed out the danger that, without a very well-calibrated model for a particular source, it might be concluded that too much background would be removed if emissions from that particular source were reduced or eliminated. He also wondered how the background value should be determined for emission reductions in evaluating the prevention of significant deterioration.
A number of commentators offered specific suggestions for determining background: one suggested that background was stability-dependent and another suggested that there was a dependence on wind speed such that a curve of background versus wind speed should be used to estimate the background concentration applicable to a given modelled increment prediction. Several others suggested the use of pollution wind roses. Six commentators suggested that, if an actual sequence of meteorology was used in the modelling, the corresponding sequences of measured air-quality data should be used as background values.

There were 20 comments on various aspects of determining "background". One commentator pointed out that the procedure required by the Guideline now seemed to consist of a concentration estimate for the source of the question plus modelled concentrations from other identified sources in the neighbourhood plus non-specific background. He suggested that if this was the EPA requirement, it should be stated more explicitly in section 2.2 of the Guideline. As to the length of record of background data, another commentator recommended that a two-year period of monitored data should be used to establish background, unless there were recent known emission changes.

EPA suggested that, in the case of areas with a few well-known sources but not urban areas, background concentrations could be determined by using modelling to remove the effect of the known sources. Two State agencies commented on this procedure. One requested more guidance on how to remove the influence of existing sources. The other agency suggested that this procedure would not be required because the adjustment of background was subject to all the uncertainties of basic modelling. This agency suggested the use of upwind monitors instead. Another State agency requested further guidance on EPA's phrase "similar meteorological conditions". One commentator suggested that the procedures were literally not workable in some cases, while two other commentators suggested alternative procedures. Yet another State agency indicated agreement with the procedure suggested in the proposed revised Guideline for determining background by averaging monitor values when the winds are blowing in a way that the monitor is not impacted by the source in question. A meteorological consultant suggested that periods when the wind speed is less than 2.2 m s^{-1} should be eliminated when determining background. There were several comments on the use of multisource modelling to establish background.

2.2.5.1 Background pollution for continental- and regional-scale modelling

The methods of evaluating short-term and long-term average background data are different. Daily average background values can be evaluated, for example, in the following way: for regional-scale modelling, the continental-scale background has to be considered. This contribution includes continental-scale polluting effect and hemispheric background pollution. The former part can be easily estimated along air trajectories or simply as a sector average along the mean wind direction using sector average emission density, wind speed, washout conditions, etc.

This continental-scale polluting effect has to be added to the hemispheric-scale background effect taken from long-term measured data (see Table V).
Chapter 2

Half-yearly or annual average background values might be evaluated in two ways. One method is when the sector values are averaged according to wind statistics. The second alternative is shown by a practical example. To estimate the continental-scale yearly mean background concentration, all the concentration data measured under background conditions available for that continent must be averaged. If three to five years' average data are plotted, the smoothed pattern analysed and data read at grid points and averaged again for the whole territory, further improvement could be gained. This latter method was used to estimate average data for Table IV.

Climatic variability might have a significant inter-annual effect on the amount and spatial distribution of background pollution. This variability may increase as consideration proceeds from larger- (e.g. global) to smaller- (regional) scale pollution processes.

2.2.5.2 Background Air Quality for Site-Specific Applications

To satisfy the need for consistent practical applications, the US Environmental Protection Agency published a Guideline on Air Quality Models (EPA-450/2-78-27).

Section 5.4 of this Guideline states the following:

"To adequately assess the significance of the air quality impact of a source, background concentrations must be considered. Background air quality relevant to a given source includes those pollutant concentrations due to natural sources and distant, unidentified sources of anthropogenic pollution. For example, it is commonly assumed that the annual mean background concentration of particulate matter is 30-40 μg m⁻³ over much of eastern USA. Typically, air-quality data are used to establish background concentrations in the vicinity of the source under consideration. However, where the source is not isolated, it may be necessary to use a multisource model to establish the impact of all other nearby sources during dispersion conditions conducive to high concentrations.

If the point source is truly isolated and not affected by other readily identified man-made sources, two options for determining background concentrations from air-quality data are available. The preferable option is to use air-quality data collected in the vicinity of the source to determine mean background concentrations for the averaging times of interest when the point source itself is not impacting on the monitor. The second option applies when no monitors are located in the vicinity of the source. In that case, average measured concentrations from a "regional background pollution" site can be used to establish a background concentration.

For the first option it is a relatively straightforward effort to identify an annual average background from the available air quality data. For shorter averaging times, background concentrations are determined by the following procedure. First, meteorological conditions are identified for the day and similar days when the highest, second-highest, etc. estimated concentration due to the source occurs. Then the average background concentration on days with similar meteorological conditions is determined from air-quality measurements. The background for each hour is assumed to be an average of hourly concentrations measured at sites outside of a 90° sector downwind of the source. The one-hour concentrations are then averaged to obtain the background concentration for the averaging time of concern."
If air-quality data from a local monitoring network are not available, then monitored data from a "regional background pollution" site may be used for the second option. Such a site should characterize air quality across a broad area, including that in which the source is located. The technique of characterizing meteorological conditions and determining associated background concentrations can then be employed.

If a small number of other identifiable sources are located nearby, the impact of these sources should be specifically determined. The background concentration due to natural or distance sources can be determined using procedures already described. The impact of the nearby sources must be assumed for locations where interactions between the effluents of the point source under consideration and those of nearby sources can occur. Significant locations include (a) the area of maximum impact of the point source, (b) the area of maximum impact of nearby sources, and (c) the area where all sources combine to cause maximum impact. It may be necessary to identify these locations through a trial-and-error analysis.

If the point source is located in or near an urban multisource area, there are several possibilities for estimating the impact of all other sources. If a comprehensive air-monitoring network is available, it may be possible to rely entirely on the measured data. It is necessary for the network to include monitors judiciously located so as to measure air quality at the locations of the point source's maximum impact and locations of the highest concentrations in the area. If the point source is not yet operating, its calculated impact can be added to these measured concentrations. If the source already exists and is contributing to the measured concentrations, its calculated contribution should be subtracted from the measured values to estimate the concentration caused by other man-made sources and by background.

If the monitored data are inadequate for such an analysis, then multi-source models can be used to establish the impact of all other sources. These models should be used for appropriate pollutants and averaging times to identify concentrations at the times and locations of maximum point source impact. The times and locations of maximum impact due to all other sources must also be identified. If a model is not available for the appropriate averaging times, statistical techniques can be used with an appropriate model to extrapolate from one averaging time to another. All statements in this paragraph regarding the data requirements and validity of air-quality models are applicable to analyses of this type.

For control strategy evaluations, the impact of growth on area-wide emissions and on concentrations caused by nearby sources should also be considered for the next 10-20 year period. To determine concentrations in future years, existing air quality should be proportionately adjusted by the anticipated percentage change in emissions in the vicinity of individual monitoring sites. However, for new source reviews, changes in existing air quality should generally be considered for the period prior to the start-up date of the source."

The revised version of the former definition given by the EPA in 1985 said:

"Background concentrations are an essential part of the total air quality concentration to be considered in determining source impacts. Background air quality includes pollutant concentrations due to: (1) natural sources; (2) nearby sources other than the
one(s) currently under consideration; and (3) unidentified sources. Typically, air quality data should be used to establish background concentrations in the vicinity of the sources under consideration."

On the basis of this, it can be concluded that, for the assessment of the effects of local-, regional- and continental-scale anthropogenic emissions, the contribution of the background air and precipitation quality must always be clarified and taken into account properly.

2.3 EMISSION

As has been mentioned previously, the main goal of defining the new system of evaluating air-pollution processes is to establish a practical means for the simplified management of air quality: in other words, to create a general concept of air-quality management on different scales.

For the rational management of natural clean-air resources, a knowledge of factors characterizing the sources, transmissions and air quality is necessary in a spatial and temporal resolution suited to the scale of the pollution process.

2.3.1 Sources of trace constituents

On a global scale, the trace constituents of the atmosphere originate mainly from natural sources. The anthropogenic contribution is considerable only in Europe and in the north-eastern part of the USA.

The main types of anthropogenic emitters are point source and area source.

Point sources are pollution emitters, whose plumes are not influenced (downwashed) by mechanical turbulence induced by the surrounding buildings and, therefore, the natural diluting and transporting power of the atmosphere can be effective during a greater part of the year. Mostly, high chimneys of power plants, district heating stations and industrial plants are considered as point sources.

Area sources are polluting objects which emit through low chimneys or stacks, generally in the vicinity of the roof level of the surrounding buildings. Pollutants originating from an area source are subjected to mechanical turbulence induced by the surrounding buildings and thus an initial intense mixing occurs following their discharge. Mostly industrial plants, city blocks etc. are considered as area sources, while their ventilation openings, low stacks and chimneys are too numerous to be treated separately.

2.3.2 Emission inventory

Knowledge of the pollutants, types of source and their emission rates is fundamental to the study and control of air pollution. The systematic collection and collation of detailed information concerning the air-pollution emissions in a given area are referred to as an "emission inventory". An inventory should contain as much information as possible on the types of source as well as their contribution to air pollution in terms of the
composition of emissions and the rates of discharge of individual pollutants. This should be supplemented with information on the number and geographical distribution of high point sources. The inventory should be kept up to date. Although man-made sources of pollution should receive most attention, the contribution made by natural sources must also be taken into account (Rossano, 1976).

While the compilation of an emission inventory is not the task of an air-pollution meteorologist, he should, however, make sure that the compiled information of emissions is in terms readily applicable to simulation models.

For many purposes, a rough estimation of emission is already useful. The resolution requirements of emission inventories are scale-dependent. Characteristic square grids in km$^2$ units are 0.25 - 4.0 for local scale and 16-625 for regional scale.

2.4 TRANSMISSION OF AIR POLLUTANTS

Pollutants emitted into the atmosphere are influenced by environmental factors such as wind, precipitation, solar radiation, temperature, humidity, other gaseous pollutants and aerosols. Under the influence of the above factors, their concentration and residence times in the atmosphere vary considerably.

The simultaneous effects of transport, dispersion, removal and transformation mechanisms on pollutants are called transmission of air pollutants. The priorities of the main factors of transmission for pollution processes on different scales are shown in Table VI.

On the basis of Table VI, it can be concluded that, as the scale of pollution processes varies, the relative importance of factors of transmission changes:

(a) Mixing-layer height, relatively unimportant for urban models, becomes increasingly important in evaluating the growth of the urban plume;

(b) Tall stacks, of great use in controlling urban air pollution are much less effective in altering air quality on regional scales from 100 to 300 km;

(c) Land-use planning, of limited effectiveness in controlling the transport of pollutants on an urban scale, is of vastly increased importance in regional air-quality planning;

(d) For a large source, the maximum ground-level concentration by that source is the limiting consideration. Secondary pollutants such as sulphate particles and ozone may be important at larger distances from the source. For regional air-quality planning, the cumulative effect of large urban sources can be pronounced if they are aligned parallel to regional wind trajectories;

(e) The effect of turbulent dispersion should be taken into account only for local- and regional-scale studies;
(f) As the direction of air transport has first priority on most scales, it would be recommended to study and clarify the effect of fluctuations of the general circulation on air- and precipitation-quality trends.

**TABLE VI**

Priorities of the main factors of transmission for pollution processes on different scales

<table>
<thead>
<tr>
<th>Priorities</th>
<th>Local</th>
<th>Regional 100-300 km</th>
<th>Continental 300-3 000 km</th>
<th>Hemispheric or global &gt;3 000 km</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Site-specific 0-5 km</td>
<td>Urban 5-100 km</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>D</td>
<td>D</td>
<td>D</td>
<td>D</td>
</tr>
<tr>
<td>2</td>
<td>H_p</td>
<td>U</td>
<td>Z</td>
<td>Z</td>
</tr>
<tr>
<td>3</td>
<td>U</td>
<td>τ_d</td>
<td>τ_w</td>
<td>τ_d</td>
</tr>
<tr>
<td>4</td>
<td>σ</td>
<td>Z</td>
<td>τ</td>
<td>U</td>
</tr>
<tr>
<td>5</td>
<td>Z</td>
<td>τ</td>
<td>τ</td>
<td>τ</td>
</tr>
<tr>
<td>6</td>
<td>τ_d</td>
<td>τ_w</td>
<td>U</td>
<td>-</td>
</tr>
<tr>
<td>7</td>
<td>τ_w</td>
<td>σ</td>
<td>H_p</td>
<td>-</td>
</tr>
<tr>
<td>8</td>
<td>τ</td>
<td>H_a</td>
<td>σ</td>
<td>-</td>
</tr>
</tbody>
</table>

**Legend:**
- D = Direction of air transport;
- U = Wind speed;
- τ_d = Dry deposition (wind speed, surface roughness);
- τ_w = Wet deposition (duration and intensity of precipitation);
- τ = Transformation (solar radiation, temperature, relative humidity);
- σ = Dispersion;
- Z = Mixing layer height; and
- H = Effective height of point and area sources.

2.5 AIR-QUALITY CHARACTERISTICS

Air-quality aspects of air-pollution processes are characterized by the maximum polluting effect (maximum concentration), the background (design background) pollution and air-quality standards.

The main objective of the air-quality investigation is to estimate the maximum polluting effect of a source or pollution process which generally develops during certain meteorological conditions. The polluting effect of the process superimposes on the background pollution originating from a higher-order pollution process.
The main characteristics of air-quality measurements depend on the scale of the pollution process. The respective siting criteria, number of stations and period of investigation are shown in Table VII. On this basis, it can be concluded that the polluting effect of an air-pollution process can best be measured at a receptor point if no smaller-scale process exists around it over a distance d (see Table VII).

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Site-specific</th>
<th>Urban</th>
<th>Regional</th>
<th>Continental</th>
<th>Hemi-spheric or global</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Range</strong> &lt;br&gt; Characteristic Maximum (km)</td>
<td>2</td>
<td>20</td>
<td>200</td>
<td>2 000</td>
<td>&gt;2 000</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>100</td>
<td>300</td>
<td>3 000</td>
<td>&gt;3 000</td>
</tr>
<tr>
<td><strong>Siting criteria</strong> &lt;br&gt; Distance of local sources d = x_{max}</td>
<td>d&gt;0.1</td>
<td>d&gt;60</td>
<td>d&gt;100</td>
<td>d&gt;500</td>
<td></td>
</tr>
<tr>
<td><strong>Number of stations</strong></td>
<td>&gt;1</td>
<td>5-50/city</td>
<td>100/region</td>
<td>50-80/continent</td>
<td>8-10</td>
</tr>
<tr>
<td><strong>Period of investigation</strong></td>
<td>Few days</td>
<td>1-5/years</td>
<td>Continuous</td>
<td>Continuous</td>
<td>Continuous</td>
</tr>
<tr>
<td><strong>Air- and precipitation-quality standard</strong></td>
<td>Health and economic considerations</td>
<td>MAINLY BASED ON</td>
<td>The need to avoid:</td>
<td>Excess abatement costs in other areas</td>
<td>Detrimental effects on fauna and flora</td>
</tr>
</tbody>
</table>

* indicates the upwind distance of the source area from the receptor.
The representativeness of the receptor point can be checked by correlating the measured and calculated concentration values for that point, originating from different-scale pollution processes. The locality is properly selected if the highest correlation results in the respective pollution process.

As has been done for air-quality standards which are valid for local- and urban-scale pollution processes, air- and precipitation-quality criteria and standards should also be established for regional-, continental- and global-scale pollution processes. As a first idea, certain objectives are shown in Table VII.
CHAPTER 3

MeteOROLOGICAL INFORMATION, NETWORK AND DATA-PROCESSING
REQUIREMENTS IN ROUTINE MONITORING OF AIR POLLUTION

3.1 INTRODUCTION

Here we shall be concerned mostly with those meteorological variables and parameters that can be derived from conventional observations such as are commonly made by national Meteorological Services throughout the world (meteorological surface and upper-air observations). Although these data are generally reliable and readily available, they usually require special processing and interpretation (Holzworth, 1974). Often, it is necessary to interpolate these data (e.g. stability parameter on the basis of cloudiness, wind and surface temperature data) in space and time.

3.2 METEOROLOGICAL NETWORKS

To validate air-pollution dispersion models, air-quality and meteorological monitoring is necessary. While there is no necessity to co-locate meteorological and air-quality instrumentation, it may be convenient to do so, provided the network density is sufficient. Since meteorological instruments are relatively inexpensive, it is advisable to include wind, temperature, and moisture measurements at all sites. For local-scale studies, turbulence measurements at three to five sites are desired for areas characterized by different surface roughnesses and particular thermal characteristics. A network of two to four sites to measure wind and temperature aloft is also necessary. The fixed network has to be supplemented during special studies by both mobile and temporary samplers (Szepesi, 1976).

As far as meteorological surveillance is concerned, the following criteria were formulated by Pooler (1974):

(a) For meteorological measurements, specific site criteria are based on the geometry of the surrounding area, rather than pollutant sources;

(b) For wind measurement there should be no significant obstruction to the airflow higher than one-tenth of the distance to the obstruction from the point of measurement;

(c) For vertical temperature difference measurement, local topographical depression should not be chosen for sites.

Measurement of turbulence by a fast-response directional vane in the horizontal or vertical directions is very important, mostly for complex terrain situations. Over level terrain, mostly wind and temperature profile measurements are used to determine the rate of turbulence. For areas influenced by terrain, field measurements of one to five years are necessary.
CHAPTER 3

3.3 WIND

In current models, it is of primary importance that the entire wind field should be used rather than a single-station observation in order to account for the effect of transport. This factor has the highest priority among all parameters in simulating local, urban, regional and continental pollution processes.

Starting speeds of anemometers and wind direction vanes greater than 0.5 m s\(^{-1}\) (often 2-3 m s\(^{-1}\)) will result in anomalous occurrences of "calms" and cause serious limitations in validating urban simulation models.

Calculated concentrations are inversely proportional to wind speeds when pollutant decay is negligible. Decay acts to reduce the "sensitivity" to wind speed. Calculated concentrations are insensitive to changes in the wind-profile power-law exponent: maximum changes in calculated concentrations were 10 per cent when the exponent was changed from 0.15 to 0.30.

Small changes in wind direction (e.g. 3° azimuth) may result in extremely "sensitive" effects for short-term single-station concentrations. Short-term concentration estimates are thus dependent on accurate wind-direction estimates.

3.4 ATMOSPHERIC DISPERSION

The second main factor of atmospheric transmission is dispersion. Parameters of the turbulent dispersion must characterize the temporal variations and spatial distributions of the non-steady-state changes of dispersion conditions. For different pollution processes and types of source, the dispersion parameters must represent also the relevant depth of the atmosphere in which the mechanism of dispersion takes place.

Dispersion coefficients are estimated from atmospheric stability classes by using a qualitative relationship. These stability classes can be determined by evaluating (a) commonly available wind speed, cloudiness and radiation data, or (b) temperature lapse rate and (c) wind direction fluctuation data. Availability of basic climatological diffusion data representative for a larger area will permit interpolation of stability.

The stability classes attributed to Pasquill (1962) have been used widely, largely because they can be determined readily from unsophisticated meteorological data. The determination of the Pasquill classes has been made more objective by Turner (1969), who specified the classes according to a net radiation index and wind speed.

Atmospheric stability determinations are often made by analysis of the vertical temperature structure as measured on meteorological towers or by the synoptic upper-air observations of national Meteorological Services. For the simplification of complicated temperature profiles, the use of the average lapse rate for the lower 300 or 600 m layer is recommended (Szepesi, 1964; Popovics and Szepesi, 1970).
Stability classes can be obtained from standard deviations of horizontal or vertical wind-direction fluctuations. Climatological data on horizontal wind-direction range may be obtained rather easily from continuous wind recordings; the usefulness of such data is greatly enhanced by their relationship to the Pasquill stability classes.

Because simulation models are very sensitive to the dispersion coefficient, which in turn depends on the stability conditions, there is an urgent need to establish commonly accepted procedures for the estimation of atmospheric stability.

Under conditions which do not involve low (e.g. 100 m) mixing heights, calculated short-term concentrations were shown to vary by a factor of 3 to 10 or more when the diffusion parameters varied from the Pasquill Class E to the McElroy-Pooler Class I. This large sensitivity indicates the need for measurements of atmospheric conditions which are clearly related to differences in diffusion conditions (i.e. values of $\sigma_z$).

An NCAQ workshop (1979) summarized the current thinking on stability and plume spread as follows:

Direct measurements of vertical profiles of wind, temperature and turbulence, which are representative of the actual plume environment, are preferable to indirect characterizations. Direct measurements of horizontal wind-direction variability may be incorporated in Pasquill's procedure (1976) for estimating crosswind spread.

3.5 MIXING-LAYER HEIGHT

Mixing layers may be maintained convectively by surface heating or mechanically by wind-generated turbulent mixing. A mixing layer is classified as either convective or mechanical, when one or the other mechanism is dominant. When both mechanisms are active, the buoyancy-driven mixing layer usually dominates (Drake et al., 1979).

The convective layer height should be measured routinely by a monostatic sodar with vertical beam. Objective rules have been developed to assist the operators in evaluating $h_c$, and automatic and pattern-recognition methods are under development. Sodar resolution is about 10 m, and the useful range varies from 50 to 1 000 m. The sampling time constant is typically 10 s. Convective mixing-layer heights derived from sodar and radiosonde profiles generally agree with 50 m.

When the mixing-layer height exceeds the range of the sodar system, other methods are available. Aircraft equipped with a fast-response temperature sensor readily provide temperature profiles to greater heights. Tethersondes may be used in moderate-to-light wind conditions where they are not an aviation hazard. A slow-rise radiosonde balloon may be used when tracked by double theodolite observations. These tracked balloons also provide data on winds aloft.

Bistatic sodar can be used to derive the mechanically mixed layer height in the stable boundary layer. But the method is of limited value because the characteristic value lies between 0 and 200 m, while the minimum range of the technique is 50 m. The mechanically mixed layer height is best determined from temperature or velocity turbulence data from an instrumented tower, supported by sodar.
3.6 ROUGHNESS LENGTH

The roughness length, $z_0$, at a site may be derived from wind-speed profile data under neutral atmospheric conditions or estimated from a description of surrounding surface features. Once estimated, the roughness length may be assumed to be fixed. Consequently, only a limited record of wind profile data is needed (Drake et al., 1979).

If $z_0$ is to be derived from wind-profile data over relatively flat, homogeneous terrain, wind measurements should be made at three heights between 2 and 20 m, preferably with 5 per cent wind-speed accuracy, 10 s response time, 30 s sample averaging time and one-hour sampling duration. If, however, the surface is patchy, with large and varied roughness elements, so that it is difficult to determine the proper instrument heights, $z_0$ can be estimated indirectly and $z_0$ values should depend upon wind direction. The estimate should take into account the size and distribution of roughness elements. Fortunately, dispersion modelling is not very sensitive to $z_0$. It is adequate to estimate $z_0$ within a factor of two.

3.7 REMOval AND TRANSFORMATION PROCESSES

A given atmospheric pollutant can be removed by precipitation scavenging, dry deposition, chemical transformations and radioactive decay. On the other hand, during periods of high wind speed, material on the ground may be resuspended and atmospheric concentrations increased. These processes are governed by meteorological factors such as temperature, humidity, wind and turbulence, solar radiation, precipitation rates, raindrop-size distribution, precipitation-charge distribution and snow and cloud morphology and source characteristics such as buoyancy, stack aerodynamics, orographic effects and multiplume interactions (Drake et al., 1979).

For short-lived pollutants, the effect of atmospheric transformation and removal processes must be taken into account for which a general decay term can be used. With longer downwind distances, the effect increases. For instance, highly significant effects are computed for locations 30 km downwind of the centre of an urban area when comparing a no decay assumption with a 30-minute half-life assumption. Concentrations with no decay were 50 times greater than concentrations with decay.

For regional- and larger-scale pollution processes, this overall factor of decay can be subdivided into partial terms of dry deposition, wet deposition and transformation during low and high humidity conditions. In doing so, the time intervals during which the respective transformation or removal mechanisms are effective can be evaluated using hourly synoptic data, and must be fully taken into account in the transmission model (Szepesi, 1981).

To investigate long-lived pollutants, contributions from the higher-order pollution processes must be taken into account.

3.8 EFFECTIVE HEIGHT OF POLLUTANT RELEASE

The height of the emission point on the local scale is an important factor to exploit the natural diluting capability of the atmosphere. Recently, M.E. Smith (1975) reported that a conversion from low to high stacks
(80 m to 250 m) had resulted in markedly reduced ground-level concentrations, especially within a 5 km radius. At large distances, however, a higher chimney might lead to higher concentrations of secondary pollutants, e.g. sulphate particles.

For point sources, the effective height is generally a "sensitive input" - less sensitive, however, if vertical diffusion is strong.

On the basis of comparisons between concentrations calculated using a single height for area-source emissions, and concentrations calculated using a spectrum of heights, it is concluded that, for simulation of the polluting effect of area sources, the effective height is not a "sensitive" input.

3.9 VARIATIONS IN EMISSION RATES

Since the emission algorithms are based on heating degree-day values, unseasonable temperatures or sudden changes in air temperature will result in corresponding systematic errors of predicted short-term concentrations at all locations for a short lag period, until the adjustment in space-heating operations occurs. Over a long-term period, errors in short-term concentrations due to differences between actual and estimated emission rates tend to be balanced in the combined frequency distribution of short-term concentrations for several locations.

3.10 LONG-TERM ESTIMATIONS

Errors in long-term model inputs will include the sensitivity effects summarized above for short-term concentrations. Over a long time, however, the random errors tend to compensate each other. This is the reason why long-term concentration calculations averaged over several locations are generally found to be in agreement with observed concentrations. Systematic errors which can effect long-term concentrations may arise from the spatial variability of emissions, the selection of the vertical diffusion parameter, the pollutant half-life, wind speed and mixing-height data.

3.11 METEOROLOGICAL (TRANSMISSION) DATA BASE (NCAQ, 1979)

Meteorological data are a primary input to air-quality models but they could also be a principal source of uncertainty and inaccuracy in estimating pollutant concentrations. The main source of surface meteorological data used for most air-quality assessments are the principal stations of national Meteorological Services. Relatively few in number, these stations are usually located at major airports and the principal measurements made are low-level (generally less than 10 m above the surface) observations of wind speed, wind direction, temperature, humidity and parameters such as cloud cover used in an indirect determination of atmospheric stability. National Meteorological Services are also the source of routine upper-air meteorological data based on radiosondes released generally twice a day. Radiosondes provide measurements of wind speed, wind direction, temperature and humidity at various elevations above the surface. The data-collection programmes at these stations are designed primarily to provide information for weather forecasting and aircraft operations, not air-quality assessments. Consequently, the locations of the stations and the types and heights of measurements are not the most relevant for the air-quality assessments required by national air-quality management programmes, thereby adding to the uncertainties and inaccuracies of model calculations.
The currently available surface and upper-air meteorological measurement programmes therefore need to be improved considerably to support the dispersion modelling required by national air-quality management. Examples of improvements include the following:

(a) Hourly averages of standard deviation of horizontal wind direction (sigma-theta) at a height of 10 m (requiring the use of a sensitive wind vane);

(b) Hourly averages of wind speed and direction at a height of 10 m;

(c) Hourly average temperature gradient over a suitable height interval (from surface to a height of 1 km);

(d) Maintenance of all hourly data in a form compatible with a computer compilation.

Besides these, the collection of on-site data at major pollution sources is strongly encouraged as being much more representative of local conditions and thereby reducing greatly the reliance on the sparse network of principal stations.

Multiple stations should be used to represent wind and stability fields over the region of interest. Upper-air or tower data should be used where possible to obtain more representative data for elevated releases.

It is essential to use the same transmission data base both for evaluating baseline conditions and assessing the expected plant or emission growth impacts.

In areas where airflow has considerable spatial variability (e.g. sea breeze, valley flow, drainage winds or other flows influenced by terrain), spatial analyses for local circulation patterns are recommended and, when available data are insufficient, the use of a terrain-dominated wind-flow model could generate a wind field for subsequent use with an air-quality model.

A systematic procedure for data logging is necessary at national weather stations to eliminate the representation of nearly instantaneous values as hourly averages. Methods are also needed to fill in missing data.

In the past, models were designed to accept available data. Model development should now concentrate on the use of data that are required to accomplish the task in hand. The concept is that model requirements should establish what data are collected and where, rather than that data availability should dictate input.

The meteorological data base could also serve as a tool for work relating to the interpretation and extrapolation of long-term pollution trends, and to identify whether such trends are caused by changes in emissions and/or by secular fluctuations in weather patterns.

The establishment of a meteorological data base at any realistic level is well within the reach of contemporary modelling techniques. Before implementation, modellers should agree on the type and quality of data needed. One extreme in disseminating a large data base would be to copy tapes for every user's installation; the opposite extreme in implementing a large
common data base would be that of the large computer and multiple remote terminals (Ruff, 1974).

3.12 FORECASTING AIR POLLUTION (Munn and Berlyand, 1975; Berlyand, 1980)

Forecast requirements can be roughly categorized by space-time scales. On the local scale, dispersion formulae can be applied. On the urban scale, local circulations become very important, specially during large-scale atmospheric stagnation situations. On the regional scale, forecast requirements primarily depend on meteorological variables (light wind and subsidence inversions associated with warm core stagnating anticyclones). It is anticipated that, over the next few years, a combination of numerical prediction models and statistical and subjective techniques will predominate in local and urban forecasting practices.

Atmospheric stagnation and air-pollution potential have been defined by Holzworth (1969), Sonkin (1968) and Bezoglaja (1968). The pollution-potential concept was extended to a relative dilution index by Holzworth (1974) in a very general way to include the effects of variable urban dimensions, mixing height and average wind speed.
CHAPTER 4

METHODS AND MODELS

4.1 INTRODUCTION

The fundamental provisions of national air-pollution control regulations require the establishment of a link between emissions from a source and the resultant impacts (in the form of pollutant concentration) at a receptor some distance away. Transmission models provide the link between source and receptor by simulating the complex physical and chemical processes affecting a pollutant during its transport. Transmission models can be used to calculate emission limitations and have been the subject of considerable controversy, since results therefrom have been the basis for decisions affecting the cost of emission controls for a source for the location of a facility. The role of modelling in implementing the objectives of clean-air legislation, therefore, is coming under increased scrutiny.

The following comments have been made about the accuracy and limitations of air-quality modelling (NCAQ, 1979):

Modelling is a developing science which is improving as a result of considerable research and development activity. In practical applications, however, model accuracy is limited by operational constraints such as the time and resources available and the need for regulatory consistency and reproducibility of model predictions. These constraints often lead to the use of less-than-optimal (state-of-the-art) models.

The accuracy of the calculated pollutant concentration of any air-quality model is affected by the following factors:

- Uncertainties in the simulation of complex physical and chemical processes;
- Uncertainties or inaccuracies in emission inventory data used as input to the model;
- Uncertainties in the quality or representativeness of the meteorological data used as input to the model;
- Limited applicability of the model to situations other than the particular one for which it was developed and validated.

Overall model accuracy can only be discussed in the context of a specific application. Certain types of model applications are inherently more accurate than others. For example:

- Relative versus absolute application: using a model as a predictive tool to project differences between two or more alternatives is inherently more accurate than attempting to calculate an absolute number;
• Magnitude versus location: models generally predict the magnitude of a concentration more accurately than the precise location of that magnitude because of inaccuracies in the meteorological fields used by the models;

• Field versus point: the accuracy of predicting an area of all points above a certain concentration (i.e. within a particular concentration isopleth) is better than the accuracy of predicting the concentration at a particular point;

• Long-term versus short-term estimates: the accuracy of calculated annual average concentrations is better than calculated "worst-case", one-, three- or twenty-four hour concentrations because a mean value can be more accurately determined than extreme values.

To the extent possible, some indication of the expected accuracy of a calculated concentration should be routinely provided with the calculated value for consideration in the decision-making process. For rational and informed decisions to be made, the results of air-quality models, including uncertainties, should be kept in their proper perspective.

Models are excellent predictive tools within the limits of the conditions for which they were developed. They are the only predictive tools available for use in the process to implement present clean-air regulations. As the range of model applications expands, it is the responsibility of the decision-makers to promote model development and validation accordingly, rather than endorse continued reliance on clearly inappropriate models.

The need for regulatory consistency and the limitations of resources which act as constraints on model development and application are generally recognized. Nevertheless, these constraints should not be used as excuses to apply a model to a clearly inappropriate situation.

Differences in modelling assumptions should be resolved through timely scientific exchanges. Present regulatory mechanisms for approval of models could be based on established model-performance criteria and therefore made easier, more timely and more consistent.

The most appropriate uses of air-quality models for air-quality management and regulatory applications are for:

• Estimation of the impacts of changing source strength and as a planning tool to monitor strength;

• Comparison of the relative effects of various control-strategy scenarios.

Models can also be used as adjuncts to monitoring programmes. Existing long-range transmission models are also useful as analytical tools for estimating the impacts of sources in one area to distant territories.

As indicated previously, an appropriate application of a model depends on the availability of accurate emission inventories, the understanding of the physical and chemical processes, the quality and representativeness of the meteorological data, and the validation of the model for a given situation.
When these conditions are not all satisfied, models may still be used with caution to provide useful information to the decision-maker. In these cases, however, a model should not be used as the only determinant in a pass/fail exercise for making decisions regarding air-quality management and regulation. Models cannot replace rational and informed decision-making, nor should they be used as the sole determinants in marginal attainment/non-attainment situations.

Dispersion modelling alone will not result in either accurate characterization of the sources responsible for long-term ambient concentrations of total suspended particles (TSP) or a correct identification of appropriate control strategies for TSP because of major contributions from fugitive emissions. Detailed filter analyses and micro-inventories may be preferable to models to identify major sources of TSP in areas of dominant contributions of fugitive emissions to TSP concentrations. Such specialized analysis must be built into models before the latter can be used as regulatory tools for evaluating alternative strategies.

It is recommended to study the following air-quality management alternatives to lessen the reliance on modelling in questionable or uncertain circumstances:

- Emission-density zoning;*
- Emission and technological standards to replace ambient standards for particulate matter (fugitive emissions) and secondary pollutant precursors.

4.2 PHYSICAL MODELLING

Wind tunnels are widely used for studying aerodynamic effects around buildings. When winds are strong, atmospheric stratification is near-neutral and, in these conditions, scale modelling has been notably successful in solving or preventing downwash problems. The horizontal dimensions of prototypes are generally of the order of a few kilometres and a scaling ratio of about 1:12 000 is often used (Munn, 1976).

Even in the most advanced meteorological wind tunnels (only two or three exist in the world), an essential difficulty arises from the rather thin boundary layer that is generated. With a view to studying the differences in the resulting turbulent fields, meaningful tests could be to model 1 x 1 km squares within a city. Simulations of a whole city with its heat-island seem still beyond present capabilities (Fox, 1974 (b)).

The inability of wind tunnels to simulate a wide range of atmospheric stability conditions and problems with effects of averaging times is a problem. In some cases, wind-tunnel results are more accurate than results obtained from models. However, there are few generic wind-tunnel studies which incorporate simultaneous measurements of concentration fields and wind-flow fields.

* Emission-density zoning is a regulatory system in which the maximum legal rate of emissions of air pollutants from any given area is limited by the size of the area and its zoning classification.
At a recent workshop (NCAQ, 1979) it was concluded that:

- The ratio of exit velocity to wind speed \((w/u)\) was an important factor in evaluating entrainment into the cavity;

- Experience at different sites suggested that the critical value of \((w/u)\) varied with geometry;

- Time-lapse photography showed that entrainment into cavity was intermittent;

- Wind-tunnel experiments could only simulate a limited range of atmospheric stability, while field experiments had difficulty in documenting a wide range of downwash conditions (due to time, budget, and logistic constraints) and, therefore, both approaches should be used.

4.3 METEOROLOGICAL MODELLING

A complete model which simulates atmospheric transmission considers four phenomena affecting pollutants in the atmosphere: transport, dispersion, transformation and removal. Some models account for transformation and removal as decay by using the half-life of the pollutant.

The difficult task of summarizing all the existing interesting but complicated simulation models will not be attempted here. Instead of this, reference is made to the work of Koch and Thayer (1971), whose sensitivity findings have been summarized above.

On the basis of a WMO questionnaire on practical air-quality models, a thorough assessment was undertaken, the results of which are being published (Szepesi, 1987).

4.4 REGIONAL-SCALE MODELLING

When the contribution from large-scale pollution processes is considerable, an estimation of regional- and continental-scale transmission becomes an indispensable part of any local-scale modelling effort. The effects of regional-scale transmission can be manifested as acid deposition, visibility degradation and non-attainment of air quality standards far downwind from the original source.

The following recommendations can be given for possible inclusion in the regional studies to be performed at each site:

- More extensive regional modelling should be included with the other modelling efforts to define the source-receptor "areas of influence" downwind of the selected study regions. For sulphur oxides, these distances are expected to be about 1,000 km. Such modelling efforts should also be applied to assess pollutant inflow to the study region;

- Provisions for linear chemical kinetics and depositions within the models previously applied to the regions should be included. Results computed by original and modified models to assess local effects of reaction and deposition phenomena should be compared;
• Modelling for SO$_2$ conversion and oxidant formation should be combined as much as possible to achieve optimal cost-effectiveness of transmission simulation;

• The modelling programme should be used to take advantage of the diagnostic application of modelling results to obtain areal averages of deposition and conversion parameters;

• According to the conclusions reached by a recent workshop on long-range transmission (Modeling experts, 1976), some improvement could be achieved by incorporating known dry-deposition rates as a function of location and season. Wet deposition of SO$_2$ and sulphate could also be incorporated in the general decay term or as a discontinuous process; this, however, requires knowledge of the areal extent and the duration of precipitation with a time resolution of six hours. This approach may be capable of simulating the actual deposition which, in turn, can be compared with measurements on an event basis;

• The current approach used to incorporate the chemical transformation of SO$_2$ to SO$_4$$_2$ using decay time, is adequate in the present models for long-term averages only. Further refinements will require the inclusion of reactions with other relevant substances, concentration measurements of these substances, and the compilation of source inventories for these materials. Improved short-term modelling will be needed to improve long-term statistics;

• Such an approach makes it possible to prepare country-wide transmission models to check the environmental impact of alternative national abatement policies, taking into account the effect of long-range transmission.

The following simple characteristics of regional-scale transmission can be applied (NCAQ, 1979):

• The decay rate of SO$_2$ on an annual average basis is about 1 per cent and includes heterogeneous and homogeneous reactions and ground depositions;

• On a short-term basis the decay rate will vary significantly (to a maximum of about 15 per cent per hour), depending upon the time of day and meteorological conditions;

• The residence times for SO$_2$ and SO$_4$$_2$ are one day and three to five days, respectively. The corresponding distance scales for SO$_2$ and SO$_4$$_2$ are approximately 500 km and 1 000 - 2 000 km, respectively;

• The sulphate problem is a regional- and continental-scale phenomenon and synoptic-scale meteorological features must be considered in predicting ambient SO$_4$$_2$ concentrations. SO$_4$$_2$ significantly contributes to ambient total suspended particle (TSP) concentrations. In the regional studies, therefore, care should be taken for background TSP in the region;
Data suggest that the residence time of SO$_4$ increases with the height of the plume. This indicates that while tall stacks reduce ambient ground-level SO$_4$ concentrations, they also might increase SO$_4$ loading downwind.

4.5 APPLICATION OF MODELS

The ultimate goal of developing and validating transmission models for different scales of pollution processes is to assess the environmental impact of energy development or the pollution-abatement policies which allow control authorities to set realistic local and regional permissible levels. A model must therefore be practical in terms of pollution control and requires routinely available transmission data.

The development of emission, transmission and air-quality submodels must be a balanced effort because, generally, the weakest link determines the value of the whole model. Complex models have not yet been developed to the point of achieving a balance between the various components (Fox, 1974 (b)).

Two types of air-quality simulation model are currently used in urban areas, namely the multiple-source Gaussian diffusion model, which uses a single wind speed in addition to stability and mixing-height data, and more complex mass balance models requiring a set of data on wind velocity and direction as well as on the boundary-layer structure. The complex models are required to calculate short-term concentrations of reactive pollutants and concentrations during episodal conditions (Fox, 1974 (a)).

In the present advanced stage of modelling techniques, the establishment of teleprocessing networks makes current air-quality simulation models available to users. The models involved should be in the form of computer programs accessible to remote users' terminals and connected to a central computer facility by regular telephone lines.

The following two types of model should be available:

- Climatological transmission models, i.e. long-term (seasonal and annual) models to calculate sulphur dioxide and particulate levels emitted from point and area sources for urban and regional areas;
- Short-term urban transmission models to calculate the contribution of fossil fuel combustion from transportation to the carbon monoxide levels.

The use of these models by remote terminals requires only a minimum of programming knowledge. Some models can be executed "on-line" by the user himself who, interactively, enters the control parameters specific to his own problem (e.g. source strength, stack height, etc.) (Turner, 1973).

4.6 RELIABILITY OF MODELS

A simple number representing the accuracy of a specific model could not be given because the accuracy is dependent on the model application and the accuracy and representativeness of the input data. It is important to understand the relative contribution of errors in meteorology, emissions, and
model physics to the total error in the model output. Whilst a substantial amount of validation information exists in the literature, it has nonetheless been pointed out that these data are limited in scope. Validation studies are usually carried out with small data bases (e.g. two weeks). Instrumentation for comprehensive validation studies is generally not intended for long periods. The scope of validation studies is often limited to one location.

4.7 REGULATORY USE OF MODELS

Findings of recent assessment (NCAQ) on the use of models in the regulatory process can be summarized as follows:

Models are useful as analytical tools but results therefrom should be used as the sole criterion in a regulatory decision only when the difference between model prediction and the standard is greater than the error associated with the application of the model.

It is considered that, on the national level, regulatory bodies should promote the consistent application or even the standardization of the following specific features of air-quality models:

- Appropriate methodologies for determining short-term (3-24 hours) and annual average concentrations;

- Appropriate plume-spread parameters based on source height (e.g. elevated or ground-level) and source location (e.g. urban or rural);

- Use of stability-typing schemes or direct determination of plume-spread parameters;

- Corrections of adjustment for topographical features;

- Type, quality and length of record of meteorological data used as input to models;

- Plume-rise formulation and effective stack-height determinations;

- Characterization of wake entrainment from buildings and vents; and

- Significance of removal and transformation processes in estimates of downwind concentrations.
CHAPTER 5

ORGANIZATIONAL ASPECTS

The interest of WMO in air-pollution matters originally arose in view of special requirements for studies on climatic change but the relevance of activities in this field to a large number of environmental problems was soon recognized. The interest of the Organization in environmental aspects is apparent in its present policy as can be seen from the number of panels, working groups and rapporteurs on air pollution and related topics. In establishing its policy regarding the atmospheric aspects of environmental pollution, WMO must pay due regard both to its own objectives and, to ensure maximum efficiency, to organizational developments at the level of its Members. These developments require direct input of information from the transmission (transport, dispersion, removal and transformation of pollutants in the atmosphere) sub-system to the total air-resource management system, which means a logical, direct collaboration between national Meteorological Services or modellers on the one hand, and national Services in charge of air-quality management on the other.

To reach this goal, it is of paramount importance for national Meteorological Services to be represented in national environmental policy-making bodies. This position should ensure that the main aspects relating to transmission are taken into account correctly (e.g. the effect of different weather parameters such as temperature, wind speed, etc., on air-quality trends, the superimposed effect of different types of source and pollution process, the different diluting capabilities of various types of source etc.).

Other tasks which the national Meteorological Services could usefully incorporate in their activities would be:

- To establish effective air-quality and meteorological surveillance systems in collaboration with monitoring agencies;

- To help national air-quality planners or managers in preparing emission inventories for cities, employing standard procedures to ensure that the output of inventories is readily usable in meteorological simulation models;

- To participate in national programmes for the development of air-quality standards (health, meteorological and technical organizations);

- To bring together model developers and air-quality managers to exchange ideas, discuss users' needs and demonstrate modelling techniques;

- To standardize modelling techniques mostly on the national level for specific air-quality management application, as well as to give consideration to methods for the efficient dissemination of such models to all users;
• To arrange for relevant transmission data for modelling purposes to be available in an evaluated and processed form;

• To proceed to transmission measurements in cities and industrial areas over periods of one to five years.

The communication gap between modeller and user is a serious one and needs to be bridged. The erroneous use of current models through unsuitable application, the lack of understanding of the importance of meteorological parameters, the need for more sophisticated and accurate urban and regional models and the fact that the user needs answers immediately are factors which have made for poor results and which have frequently led to questionable policy decisions in environmental management.

Many modellers wish to look upon their work as a continuing research endeavour, rather than develop a dynamic tool for application in air-quality management programmes. Because the confidence limits of the output are not set, users tend to mistrust the modelling, considering it a black art rather than engineering (Jones, 1973).

The communication gap between modeller and user can be reduced by convening modeller-user meetings, by making the modeller responsible for his predictions and by ensuring that he is prepared to state accuracy limits.
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