Environmental Meteorology

K. Grefen
J. Löbel
(editors)

KLUWER ACADEMIC PUBLISHERS

Environmental Meteorology

Proceedings of an International Symposium
held in Würzburg, F.R.G.
29 September - 1 October 1987

edited by

K. Grefen
and
J. Löbel

Verein Deutscher Ingenieure,
Kommission Reinhaltung der Luft,
Düsseldorf, F.R.G.

Kluwer Academic Publishers
Dordrecht / Boston / London

Library of Congress Cataloging in Publication Data

CIP

Environmental meteorology.

"The VDI Commission on Air Pollution Prevention--
in cooperation with the German Meteorological Society--
presents in this book the proceedings of the first
International Symposium on "Environmental Meteorology,"
held in Würzburg (West Germany) from 29 September to 1
October 1987"--Pref.
1. Air--Pollution--Meteorological aspects--
Congresses. I. Grefen, Klaus. II. Löbel, J.
III. VDI-Kommission Reinhaltung der Luft.
IV. Deutsche Meteorologische Gesellschaft.
V. International Sympsium on "Environmental Meteorology"
(1st : 1987 : Würzburg)
TD881.E58 1988 628.5'3 88-3078

ISBN 90-277-2697-3

Published by Kluwer Academic Publishers,
P.O. Box 17, 3300 AA Dordrecht, The Netherlands.

Kluwer Academic Publishers incorporates
the publishing programmes of
D. Reidel, Martinus Nijhoff, Dr W. Junk and MTP Press.

Sold and distributed in the U.S.A. and Canada
by Kluwer Academic Publishers,
101 Philip Drive, Norwell, MA 02061, U.S.A.

In all other countries, sold and distributed
by Kluwer Academic Publishers Group,
P.O. Box 322, 3300 AH Dordrecht, The Netherlands.

Printed in The Netherlands

PREFACE

The VDI Commission on Air Pollution Prevention - in cooperation with the German Meteorological Society - presents in this book the proceedings of the first International Symposium on "Environmental Meteorology", held in Würzburg (West Germany) from 29 September to 1 October 1987.

The primary goal was to get together scientists, experts of the meteorological services, specialists of environmental boards, and consulting engineers of the European countries. An equally important objective was to provide a bench mark document in the resulting proceedings publication.

The 1987 symposium shall start a series of symposia on all fields of environmental meteorology to be held once in three or four years in one of the European countries. We are full of hope to come to an intense cooperation with the national meteorological and environmental societies in the countries with this concern.

We like to express our sincere appreciation to the authors for their efforts and attention to the quality shown herein. The credit must be extended to the session Chairmen and to the advisory committee for the selection of the papers.

We think the book contributes substantially to a better understanding of meteorology being the link between emission and deposition of atmospheric pollutants.

Düsseldorf, November 1987

K. Grefen J. Löbel

CONTENTS

ADEQUATE METEOROLOGICAL MEASUREMENTS AS A PREREQUISITE FOR THE ASSESSMENT OF AIR POLLUTION

K. Höschele
Institut für Meteorologie und Klimaforschung
Universität Karlsruhe
D - 7500 Karlsruhe

ABSTRACT. The paper deals with meteorological measurements as a part of measuring programs for air pollutants. The importance of atmospheric conditions for the assessment of an air pollution situation is demonstrated by their influence on the various compartments of an air pollution system, comprising all stages from emission to effects. The main purpose of this review is a discussion of how to get representative data in various scales of time and space. A concluding survey contains various recommendations concerning the design of measuring programs.

1. INTRODUCTION

Concentrations of air pollutants, as a measure for ambient air quality, vary in space and time over one ore two orders of magnitude in the range of $\mu g/m^3$, with periods from the time resolution of measuring instruments in the range of minutes or seconds up to years. On the other hand the concentrations of water vapor, a typical meteorological element, in the higher range of g/m^3, have much smaller variations in space and time, typical are 10 % of the daily mean. The primary reason for the irregular behaviour of pollutants is the uneven distribution and changing activity of sources, in combination with the varying meteorological conditions for the distribution, the transformation and the removal of substances, emitted into the atmosphere. The widely adopted conception, restricting the role of meteorology to transport and diffusion of gases and particles, is too simple and incomplete. A more thorough analysis reveals, that atmospheric conditions control all stages and branches of a pollutants way from sources to sinks (Figure 1).

2. AIR QUALITY SYSTEM, THE ROLE OF METEOROLOGY

Starting with sources: how far are emissions dependent on meteorological conditions? If we consider emissions released near the ground, say below 20 or 50 m - these are mainly responsible for local pollution

K. Grefen and J. Löbel (eds.), Environmental Meteorology, 1–8.

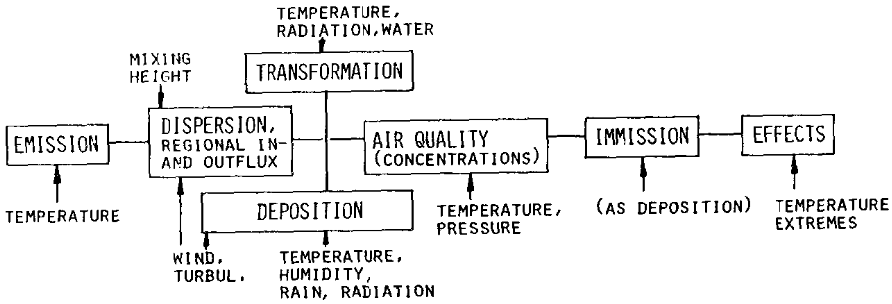

Figure 1. Air Quality System, Compartments with some Relevant Meteorological Conditions.

in cities - the prevailing sources are 'road traffic' and 'space heating'. As a whole the emissions of these two groups of sources have about the same importance. The bulk of sulfur dioxide from these two source groups (90 - 95 %) is due to domestic heating, but this is equalled by nitrogen oxides, carbon monoxide and hydrocarbons with a larger contribution of road traffic (typical are 60 - 90 % of emissions near the ground). As for particulate emissions the relation is about 50:50. All these relations depend on the kind of heating systems in use and on the specific emissions of motor cars.

It is a well known fact that the consumption of fuel for space heating over a certain period may be assessed very well by a measure like 'heating degree days', based on mean daily ambient temperatures. As a consequence, a large portion of emissions into the lower layers of the urban atmosphere increases linearly with mean temperatures falling beneath for instance 15 °C. For single days the estimation of fuel consumption may be improved by additional meteorological parameters as wind velocity, rain, humidity and solar radiation. Even emissions from road traffic may be increased in severe cold weather because of lower temperatures in engines and exhaust systems and reduced velocities on roads, covered with ice or snow. Under very heavy winter conditions motorists may switch over to public transportation and so reduce car emissions. An accurate emission inventory for a case study has to allow for these modifications of source activities by changing atmospheric conditions.

After leaving the source pollutants will be distributed in the atmosphere. Transport and diffusion are governed by the wind field and its turbulent components up to a distance from the source, relevant for dispersion. The volume, available for dispersion, may be limited in height by an inversion layer, preventing further vertical turbulent transports. In an extremely simplified box model for area sources concentrations are inversely proportional to the product of the mean wind speed and the height of a layer with turbulent mixing. Small values of wind speed result in very large values of concentration. This is one simple reason for the extreme skewness of frequency distributions for observed concentration values and the resulting difficulties with arithmetic means of concentrations. For the linkage between source activities on the one side and concentration fields on the other side, wether observed or calculated, we need representative data for the turbulent wind field, possibly with complementary data of thermal stratification, interacting with turbulence.

Immediately after release into the atmosphere and parallel to dispersion primary pollutants are exposed to physical and chemical transformations. An example for very fast transformations, resulting in a very short 'life time' of minutes is the oxidation of NO to NO_2. Decisive for reaction or transformation rates are, besides the concentrations of participating substances, meteorological parameters as solar radiation for photochemical reactions, or the existence of liquid water for reactions in cloud or fog droplets. Besides this temperature has a rather large effect on rates of bimolecular reactions or rates of disintegration of single molecules. As for solar radiation, the photolytic reaction rates depend on the irradiation of a volume of gas or a sphere from all directions and not on the radiation striking a horizontal plane surface, we normally measure as 'global radiation'. For a sphere an increasing solar zenith angle will only reduce radiation intensity by an elongated path through the atmosphere, the so-called air mass. In the case of global radiation there is an additional reduction by the changing incident angle. So the irradiance changes less with growing solar zenith angles up to about 50^{o}, it depends on the albedo of the ground and on the height above ground or above sea level.

Transformation or decomposition of a certain pollutant will limit its lifetime in the atmosphere, such it is one process contributing to the removal of pollution, but possibly it is at the same time a source for secondary pollutants. For the atmosphere of a given region or for a limited airshed a transport to neighbouring regions or to higher levels may be regarded as another process of removal, but this output from one region will be an input for another region or atmospheric layer. The genuine processes of removal from the air are dry and wet deposition at the ground. It is obvious, that for the precipitation-related process of scavenging, resulting in wet deposition, parameters as cloud and precipitation droplet spectra and rain intensity as well as duration are of interest. Especially the role of vegetation in dry deposition makes it more difficult, to quantify the depletion of pollutants at the lower limit of the atmosphere. Present or past weather events, responsible for the condition of vegetation and soil, for instance wetness or opening of stomata, play a role. So deposition velocities change under the combined effects of rain, evaporation, radiation, temperature. Another essential meteorological parameter controlling deposition velocity is wind speed and turbulence.

A result of all processes described until now, from source emission to deposition is ambient air quality as another compartment in the air pollution system. Monitoring concentration fields as a measure for air quality is in many investigations the first step into the matter, because air quality and its control is in the focus of general interest. This paper also started from this point with a view on changing concentrations. Meteorological parameters play a role at this stage as well, especially for the comparison of measurements of gaseous pollutants in different heights. Temperature and pressure are needed for calibration of instruments and for the conversion of units, for instance mixing ratios of molecule numbers or volumes (in ppm or ppb) in mass per volume (mg or $\mu g/m^3$). The same is true for comparing measured data with the set points of pollution control, the air quality standards.

The last compartments in this systems approach are the immission and the effects of air quality or the impact on receptors like humans, animals, plants, soil, water, materials or the effects in the atmosphere itself (reduction of visibility, attenuation of radiation, promotion of fog formation). The transfer of pollutants to receptors is on the one side a removal or deposition process, but here the primary interest lies in the effects on receptors. Compared with soil, water and vegetation man will play a poor role in removing pollutants, but concerning impact man is in the centre of interest and effects on other receptors are considered as impairment of man's environment. Obviously the same atmospheric parameters as in the deposition process contribute to the variable impact on receptors for a given ambient air quality situation or concentration field. For soil, vegetation or materials we have already mentioned these parameters, which control the mass transfer to the receptor or the poisoning dosage. In addition, the effect of the same dosage may be changed in living organisms by meteorological conditions as extreme heat or cold. For man the transfer of pollutants to skin or eyes is governed by the rules of deposition too. The transfer to lungs by active breathing will depend mainly on activity or metabolic rate; meteorological conditions will normally play a minor role, except for extreme conditions. An example: the same concentration in units of mass per volume will result in an about 20 % higher dosage in 2000 m height than in sea level, for the same activity.

3. GATHERING METEOROLOGICAL AND CLIMATOLOGICAL DATA

There is no basic difference between meteorological or climatological observations or data but we may distinguish the application of these data in mainly meteorological or climatological aimed studies. As a typical example for the first kind appear single episodes of acute pollution as the accidental release of toxic gases. Forecasting the path and dispersion of released toxicants needs actual and prognostic informations about the state of the atmosphere. In most cases however, studies in air pollution problems will have a statistical character, the aim is a probalitistic prediction. Even examining pollution episodes as a consequence of extreme weather conditions, as smog periods, has not the purpose to give a detailed reconstruction of a certain case. This is only needed for the description and classification of samples of past cases, for an extraction of common properties and relevant preconditions with the aim to take better precautions for the future. The bulk of air pollution monitoring systems is organized to make measurements in a quasi climatological time scale and to render informations about air quality over periods of typically one year.

Reliable meteorological measurements require as much diligence as measurements of pollutants; the expenditure necessary for every single parameter at any point is often underestimated. Therefore one of the first steps in developing a measuring program for air pollutants has to be to prepare an inventory of already existing meteorological observations in the survey area and to make sure, that the data will be available for the provided purpose. This is not only for saving additional surplus measurements: long time series of existing observations are a useful and scarcely replaceable means to normalize new observations over short periods by a regression analysis between parallel measurements.

Observations at single stations are very small samples in space of parameters with a high spatial variability. A random choice of sites for a station would transfer this variability as uncertainty of the observation results concerning conclusions for other sites. A way out would be to install a great number of stations in a regular or irregular network. Our knowledge of reasons for variations of atmospheric conditions in space enables us to reduce this uncertainty to a large extent in a less expensive way: the random sample is replaced by a representative sample, at a station with standardized environmental conditions.

The more our knowledge of the reasons for spatial variations of air pollutants is growing, the more we could dispense with monitoring networks and work with representative stations as in climatology. One danger however is, that our models, explaining the variations, are incomplete or wrong for the given situation.

A network of representative stations, together with topographic data, as height above sea level, exposition to sun radiation or prevailing winds, land use and vegetation cover, enable us to draw or to calculate and plot climate maps with a much higher, perhaps up to one order of magnitude better resolution that we could with respect to the grid size. Nevertheless the distances between stations of the meteorological services are too large, to cover the needs of air pollution climatology. In the southern hilly part of the Federal Republic of Germany climate stations have a distance of 20 - 25 km, a map of 1:1 000 000 with picture elements of 2 km in nature, corresponding with 2 mm on the map, will cover an area of about 400 km x 500 km in the upper mesoscale, Southern Germany for instance. Many air pollutant problems however belong mainly to the local or microscale, below an extent of 20 km down to some meters, for the dispersion from single stacks or from a highway.

Another problem is that reaching this high resolution above an irregular topography is possible with some climatological elements as temperature, but not as easy for the direction of surface wind, the most decisive parameter for dispersion of pollutants in the local and microscale.

The next step, after making an inventory of existing meteorological observing stations is therefore a careful examination of the survey area on topographic maps and on up-to-date aerial phorographs. Slopes, valleys and escarpments indicate the possibility of mesoscale wind systems with a change of direction in a daily course. Inspections of typical sites during a critical time of the day will help to decide, if further investigations or additional measurements are needed. Using the knowledge from existing investigations about similar topographic features we choose a place, representative for the range of the respective mesoscale wind system and manage to get along with only one or few stations.

For microscale pollution studies around buildings we mainly refer to wind measurements above roof tops. The correlation with air motion between obstacles can be derived from existing examples of results calculated with numerical models or from wind tunnel experiments. For verification one or two low level measuring points are helpful.

Parallel with the growing horizontal scale there is a slowly increasing height of the atmospheric layer, relevant for the dispersion of pollutants. At the small scale end the height of sources above ground plays a role too. For meteorological parameters as temperature, humidity, wind velocity and direction, the autocorrelation in space increases too with height, the small scale properties of the surface loose their influence more and more. This justifies large distances as 200 km in central Europe between soundings in the free atmosphere; the gaps can be filled by interpolation methods. An approximation to the wind at the base of the free air is the geostrophic wind, calculated from pressure data of synoptic stations. This geostrophic level, about 1,5 km above ground, is relevant for dispersion in the upper mesoscale, over more than 200 km horizontal distance. For the lower mesoscale (< 20 km) it is possible to calculate wind fields for the boundary layer with a numerical model, using the geostrophic wind and topography data. In Session 4 Dr. Adrian, Karlsruhe, will present results of a wind climatology with a 5 km distance of grid points.

4. SURVEY AND CONCLUSIONS

The guidelines VDI 3786 contain a comprehensive compilation of instructions for standard meteorological measurements, concerning air pollution: wind, temperature, humidity, radiation and precipitation at surface stations, as well as aerological measurements with free and tethered balloons. They deal with measuring methods, instruments, installation and site selection, calibration, maintenance and evaluation in detail; but only in a general way or very little with the necessity and the form of a measuring program. Not yet available is a guideline for more modern methods, competing with standard profile measurements, as SODAR. The possible use of such a system has to be examined, replacing a meteorological tower, especially for short term measurements in connection with dispersion problems in the lower mesoscale. If large scale pollution studies use aircraft measurements for monitoring pollutants in higher levels, these often are combined with meteorological measurements of temperature, humidity, turbulence, thus completing the results of upper air soundings from ground stations.

Some more remarks have to be made, concerning the measuring of meteorological elements as described in the guidelines. Ambient air temperature and humidity is in many cases with enough precision available from existing stations. Temperature profiles at towers demand a rather high effort for the accuracy needed for the assessment of thermal stratification. For the determination of stability classes this can be replaced by measuring vertical wind fluctuations in one height. Solar radiation, in the time scale of hours or days, does not change very much over large horizontal distances. On the other hand poor maintenance will produce considerable deviations. If possible the data from an existing meteorological station should be used. We have already mentioned, that the reference for radiation in photochemistry is a sphere, not a horizontal plane. Radiation balance is a basic quantity in boundary layer meteorology, but not recommendable as a means for the determination of stability classes.

Finally summing up we recommend

- to adjust the frequency and accuracy of measurements to the demands of resolution in time and space and to feasibility

- to consider the application of remote sensing methods

- to use the existing knowledge for the selection of representative sites for measuring points and representative terms for measuring periods

- to combine results from field observations with data from model calculations or wind tunnel experiments

- to couple short term measurements (about for instance 6 month or 1 year) with existing long time series of observations (10 or 30 years) and/or

- to relate results of a short time series with dominating large scale weather patterns and transform for a normal long time frequency distribution of these patterns.

REFERENCES

Finlayson-Pitts, B.J., and Pitts, J.N., 1986: Atmospheric Chemistry, Fundamentals and Experimental Techniques. J. Wiley, New York

Höschele, K., 1974: 'Die Repräsentanz zeitlicher Stichproben einiger für Immissionsbetrachtungen wesentlicher meteorologischer Größen'. Meteorol. Rdsch. 27, 5-10

Nester, K. and Hübschmann, W., 1985: 'Anwendung klimatologischer Daten bei der Ermittlung der Umweltbelastung durch Großemittenten'. promet 1'85, 6-13

Verein Deutscher Ingenieure (VDI): Meteorological Measurements concerning Questions of Air pollution

Part 2, 1980: Wind
Part 3, 1985: Air Temperature
Part 4, 1985: Air Humidity
Part 5, 1986: Global radiation, direct solar radiation and net total radiation
Part 6, 1983: Turbidity of ground-level Atmosphere, Standard visibility
Part 7, 1985: Precipitation
Part 8, 1987: Aerological Measurements

Weber, E. (ed), 1982: Air Pollution, Assessment Methodology and Modelling. Plenum Press, New York

Yoshino, M.M., 1975: Climate in a Small Area, an Introduction to Local Meteorology. University of Tokio Press