ON DENSITY OF PRECIPITATION CHEMISTRY NETWORKS

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Abstract. Using Scandinavian precipitation chemistry data the dependence of the accuracy of the interpolation and areal averaging of \( \text{SO}_4^{2-} \), \( \text{NO}_3^- \), \( \text{NH}_4^+ \), and \( \text{Ca}^{2+} \) contents of precipitation water on the density of the network and on the size of the area considered is studied. On the basis of the results obtained the density of networks operating with a given accuracy can be determined as a function of the area. As an example the density of the networks determining the annual and monthly areal \( \text{SO}_4^{2-} \) deposition as well as the point values of the monthly \( \text{SO}_4^{2-} \) concentration with an accuracy of 10\%, 25\%, and 30\%, respectively, is calculated. The accuracy provided by such networks for other components in precipitation water is also studied.

1. Introduction

In the last decades the air pollution has become a global phenomenon. Man modifies the chemical composition of the atmosphere not only in the vicinity of the cities and factories; but man-made constituents can also be identified far away from the site of human activities. The global pollution of the atmosphere can influence the radiation balance of the Earth, the processes of the precipitation formation and the chemical composition of precipitation water. Changes in the chemical composition of air and precipitation water and the modifications in the climate can touch the whole biosphere involving the man and his environment and might be sources of several economical and political problems. Therefore, studying this so-called background air pollution is one of the most important tasks of air chemistry.

During the formation and fall of precipitation a part of the trace constituents being in the air gets into the precipitation water. The chemical composition of precipitation water characterizes well the quantity of trace constituents (aerosol particles, water--soluble gases) contained in the troposphere. Precipitation chemistry measurements are also needed for budget calculations and long-range transport modelling. Therefore, the program of each type of monitoring stations involves precipitation chemistry measurements. However, there is hardly any information, what network densities are necessary for different purposes. There are only a few works dealing with the density of precipitation chemistry networks (e.g. Karol and Myatch, 1972; Granat, 1975a, b; Finkelstein and Seilkop, 1981). Papers cited above describe different methods but contain hardly any recommendations for the network density.

In our investigation we deal with the regional (50–500 km) background air pollution. Using a mathematical-statistical method we study the accuracy of the precipitation chemistry networks of different densities and estimate the necessary density of the networks. Some preliminary results of this investigation are already published in the journal of the Hungarian Meteorological Service (Haszpra, 1980; 1981; 1983).

2. Mathematical Method

The basic principle of network planning methods is the following: the meteorological network covering a given area has to make possible to determine the value of the meteorological element for any point or any part of the area with the required accuracy. In other words, the error of the interpolation for any point or that of the areal averaging for any part of the area must not exceed the maximum value permitted by the investigations.

The error of the interpolation and that of the areal averaging strongly depends on the methods used. In our investigation such methods are chosen that the interpolation (averaging) error characterized by the mean quadratic deviation between the interpolated (averaged) value and the real one should be minimum. These methods are called optimum interpolation and optimum averaging and reviewed in the appendix on the basis of Gandin's and Kagan's works (Gandin, 1965; Kagan, 1967).

For a given area the interpolation and averaging error depend on the location and number of stations. In the mathematical modelling the real networks can be regarded as such in which the stations are located at any point of the area with the same probability. In such a case for a given number of stations the mean interpolation (averaging) error \( \overline{E} \) can be determined by the 2N-fold integral of the error function \( E(x_1, y_1, \ldots x_N, y_N) \):

\[
\overline{E}^2 = \frac{1}{S^N} \int \cdots \int_{(S)} E^2(x_1, y_1, \ldots x_N, y_N) \, dx_1 \, dy_1 \ldots dx_N \, dy_N,
\]

where \( N \) is the number of stations, \( S \) is the size of the area, while \( x_i \) and \( y_i \) are the co-ordinates of the \( i \)-th station.

Since the relation between \( E^2 \) and the number of stations as well as the station co-ordinates is very complicated, the value of the above integral is calculated numerically by a simple Monte Carlo method: The co-ordinates of the stations are produced by a random number generator, supposing that the stations can be located at any point of the area with the same probability. Then \( E^2 \) is calculated for the station configuration produced in the mentioned way. This procedure is repeated in \( n \) cases and the obtained error values are averaged estimating the value of \( \overline{E}^2 \):

\[
\overline{E}^2_n = \frac{1}{n} \sum_{i=1}^{n} E_i^2.
\]

With increasing \( n \) \( \overline{E}^2_n \) stochastically converges to the expected value of the interpolation (averaging) error \( \overline{E}^2 \).

By means of this method it can be determined, how accurate interpolation (averaging) can be made on an average by assuming a given number of stations located randomly in a given area. Then the basic question of the network planning can be answered: how many stations are necessary on an average for a given area to reach a prescribed accuracy.