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CALCULATIONS OF THE MEAN REGIONAL DISPERSION OF A RADIOACTIVE GAS EMITTED FROM A CONTINUOUS SOURCE

Christer Persson

DEPARTMENT OF METEOROLOGY
UNIVERSITY OF STOCKHOLM

INTERNATIONAL METEOROLOGICAL
INSTITUTE IN STOCKHOLM

DEPARTMENT OF METEOROLOGY
UNIVERSITY OF STOCKHOLM (MISU)

INTERNATIONAL METEOROLOGICAL
INSTITUTE IN STOCKHOLM (IMI)

Arrhenius Laboratory
Fack
S-104 05 STOCKHOLM, Sweden

Tel. 08/150160/2406

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ABSTRACT

The mean dispersion of a radioactive gas over distances of the order of 1000 kilometers is estimated with the aid of a statistical treatment of computed geostrophic trajectories and simplified vertical diffusion calculations based on the eddy diffusivity theory.

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CONTENTS

1 INTRODUCTION

In studies of atmospheric dispersion of radioactive matter emitted from a point source the main concern usually has been the determination of the concentration pattern in the immediate vicinity of the source, as a result of source characteristics and turbulent diffusion during different meteorological conditions.

In the present study, however, we shall try to estimate the mean seasonal dispersion over larger distances, of the order of 1 000 kilometers, and we shall thus be dealing with the problem of discribing the mean dispersion and decay of radioactive matter during several days after the emission. For this time-scale the most important factor that determines the character of the mean horizontal dispersion is the wind systems associated with the synoptic disturbances.

2 DESCRIPTION OF THE COMPUTATIONS

Atmospheric dispersion of pollution on the regional scale has been discussed in some detail by Bolin and Persson (1974) and in the following we apply the statistical method described there to estimate the mean dispersion of the radioactive gas ^{133}Xe (half-life 5.27 days) emitted from a point source. The emission is assumed to be continuous and constant at an effective chimney height of 100 m and the source strenght is put equal to 10^{19} relative units per year ($0.317 \cdot 10^{12}$ relative units per second). Except for the radioactive decay sink mechanisms such as dry deposition at the ground or scavenging by precipitation have been neglected, which of course is a valid assumption for an inert gas.

As in the report by Bolin and Persson (1974) we have assumed that the vertical and horizontal dispersion may be considered

as not statistically related to each other or to the emission. These assumptions are not in reality quite correct but permit us to separate the dispersion problem into two parts. The vertical diffusion can thus be calculated independently of the horizontal dispersion and the two calculations may then be combined to get the total three-dimensional dispersion.

As was stated in the introduction the mean horizontal dispersion essentially is due to the synoptic scale wind systems. We have therefore assumed, that by means of a statistical distribution of isobaric trajectories starting from a point in Southern Sweden, we can compute the mean horizontal dispersion of a radioactive gas emitted from this point. In the present computations the source has been assumed to be located outside Malmö (+), while the initiation point for the trajectories were situated close to Jönköping (*), see figure 1. However, the character of the mean regional dispersion certainly does not change appreciably between these two places. The trajectories were initiated every third day during the winter season (Oct - Mar) 1972-73 at the isobaric levels 1 000, 925 and 850 mb and every trajectory has been followed for 96 hours. We have used the geostrophic wind approximation for the levels 850 and 925 mb. At 1 000 mb the wind was assumed to be 2/3 of the geostrophic wind and directed 30° towards lower pressure. The errors in trajectory computations based on geostrophic wind approximation have been investigated by Henrikson (1971).

The dispersion parameters, cf Bolin and Persson (1974), S (standard vector deviation) and $|\overline{r(t) - r(\tau)}|$ (distance between the centre of gravity of the trajectory end points (at time t) and the point of initiation (at time τ)) have thus been determined for times up to 96 h. The half-life of ^{133}Xe is, however, appreciably longer (5.27 days), which

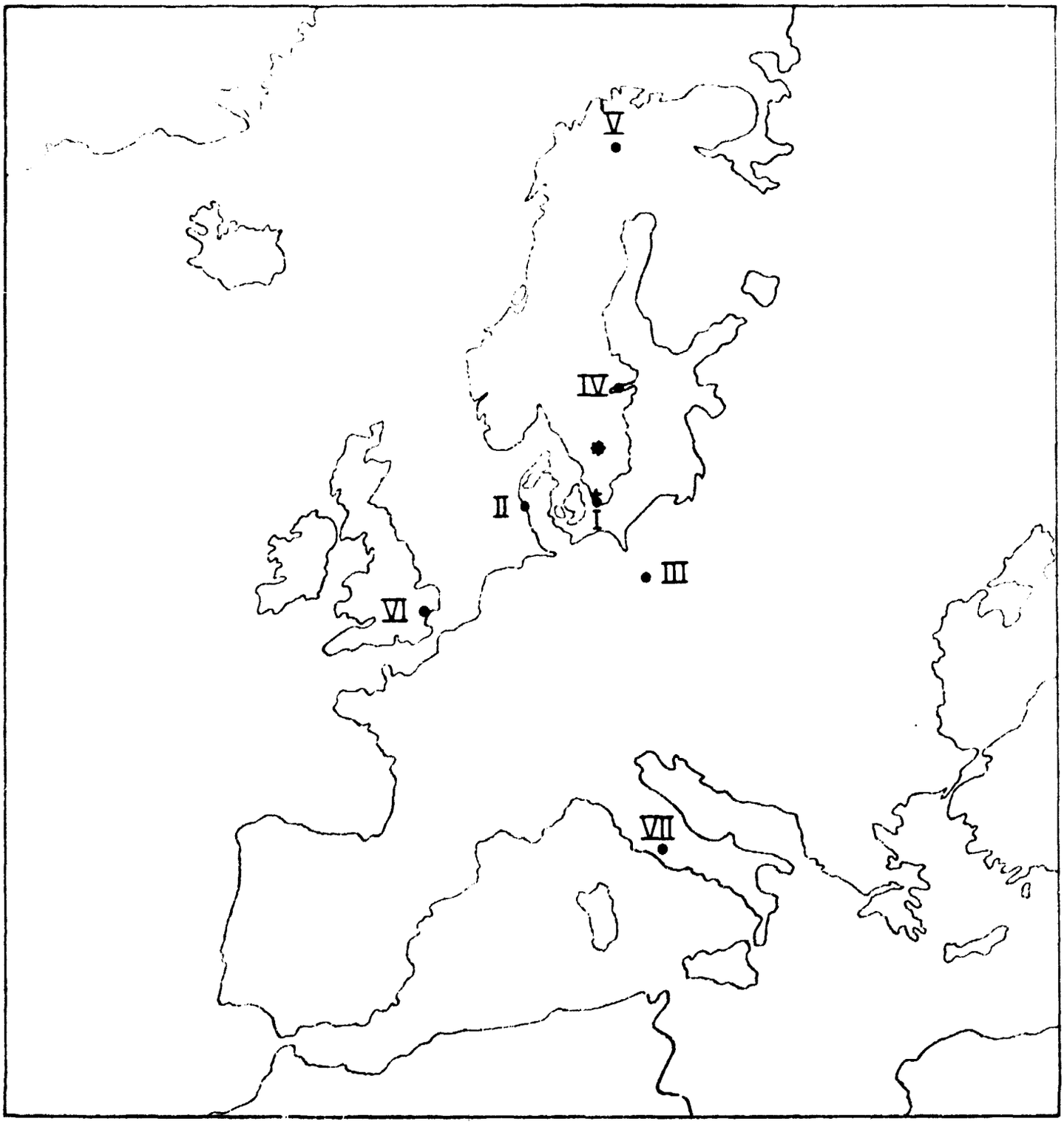

Fig. 1 The initiation point for the trajectories is indicated by ⁎ and the position of the source by +. The dots

means that the dispersion also after 96 h should be considered. Attempts have therefore been made to estimate S and $\overline{|r(t) - r(\tau)|}$ for longer times. When the correlation coefficient R falls to zero, which according to Bolin and Persson (1974) happens after 70-90 hours, the standard vector deviation S is proportional to $\sqrt{t-\tau}$ (cf also Durst et al (1959)), which permits us to estimate S reasonably well for some period of time after 96 h. We have determined $\overline{|r(t) - r(\tau)|}$ by extrapolation of $(r_x(t) - r_x(\tau))$ and $(r_y(t) - r_y(\tau))$, but this probably gives rather uncertain results. We have, however, in the present study used those extrapolated values up to 10 days after the emission time (see figure 2 and 3). The horizontal dispersion has, except for this extension in time, been calculated in the same way as by Bolin and Persson (1974), thus assuming a Gaussian distribution of the trajectory end points around the mean wind.

The vertical diffusion was treated in a very simplified way with the aid of an eddy diffusion approach. The following equation has been used.

$$\frac{\partial Q}{\partial t} = \frac{\partial}{\partial z}\left(D \frac{\partial Q}{\partial z}\right) - \beta \cdot Q \qquad (2.1)$$

where

$$D = k u_* z \quad \text{for} \quad z_0 \leq z \leq H$$

$$D = k u_* H \quad \text{for} \quad H \leq z$$

and with the notations

k = von Karman's constant
u_* = the friction velocity
z_0 = the roughness length
β = the decay constant

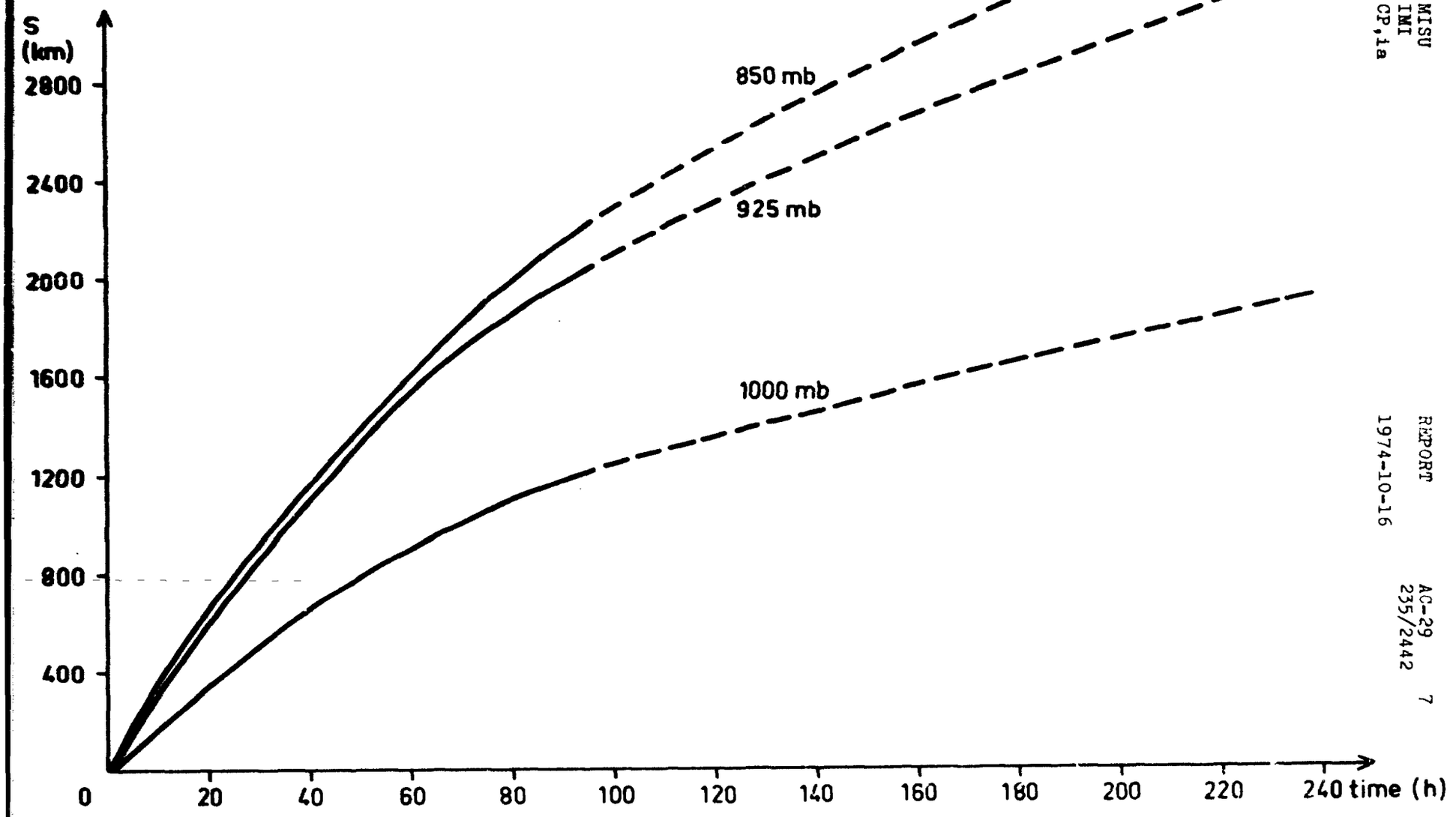

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Fig. 2 Relation between standard vector deviation S and time as used in the dispersion calculations (cf the text).

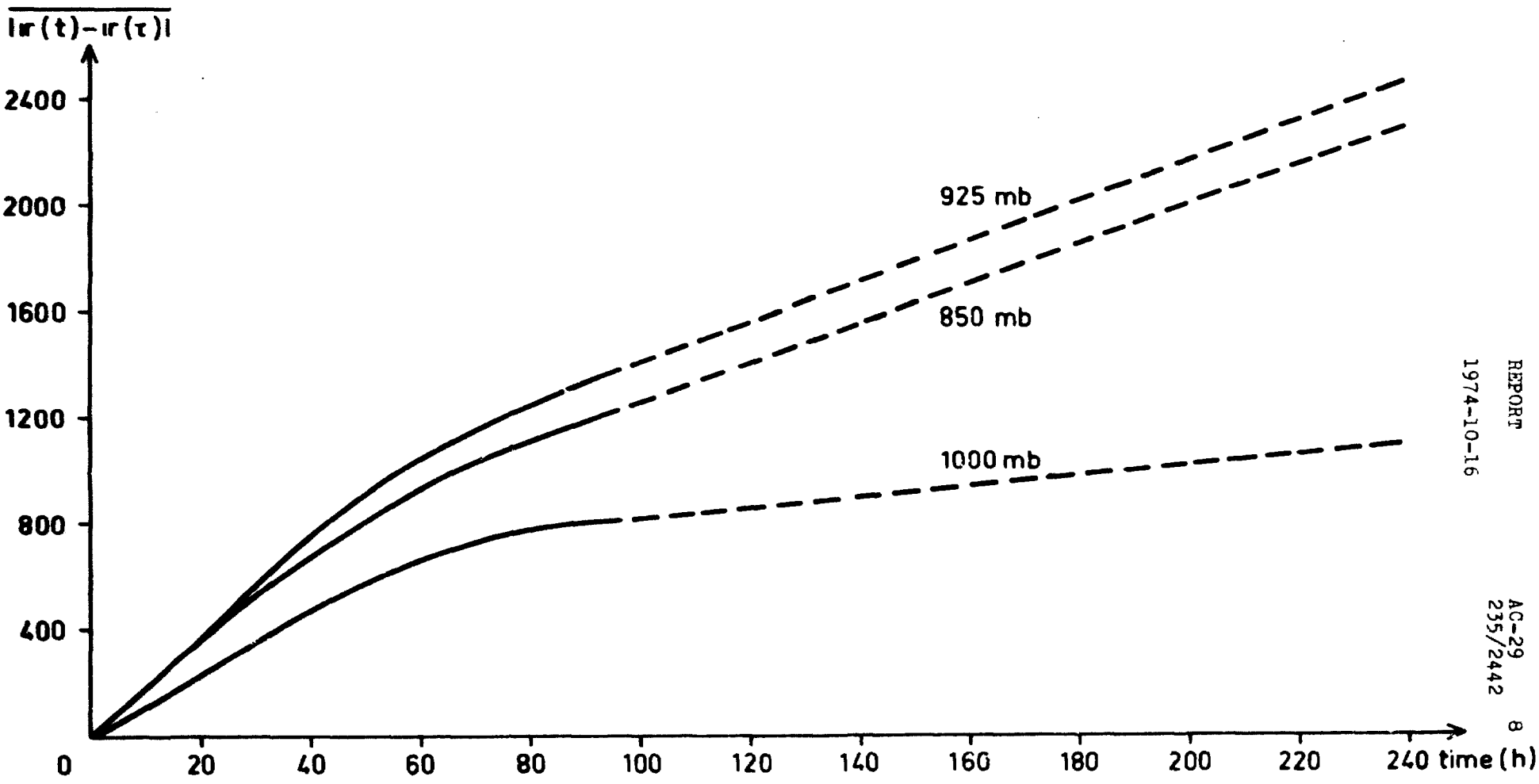

Fig. 3 Relation between $\overline{|r(t) - r(\tau)|}$ and time $t-\tau$ as used in the dispersion calculations (of the text).

We have assumed a meteorological situation characterized by $u_* = 0.30$ m sec^{-1}, which means a wind speed of 4 m sec^{-1} at the height 10 m if $z_o = 3$ cm. H was put equal to 85 m, which implies an eddy diffusivity of 10 m^2 sec^{-1} above that level, which is a rather large value, probably larger than the average during winter.

The vertical diffusion certainly varies very much with the meteorological conditions and it is of course not possible to describe it with the aid of eq 2.1 and just one value for u_* and not consider the influence of the stratification. The influence of i.e. convection and inversions has thus not been dealt with.

3 RESULTS

The mean three-dimensional concentration distribution has been obtained through combining the horizontal and the vertical dispersion calculations as mentioned in the previous section. The mean concentration pattern over Europe, referring to a height of 10 m above the ground, is presented in figure 4. The computed mean concentration profiles for a number of different places in Europe (see figure 1) are given in figure 5. Point I is situated about 35 km southwest of the source. However, depending on the computation method used, we cannot expect a detailed resolution in the concentration pattern close to the source. The concentration values for point I should rather be regarded as a kind of mean value over an area surrounding this point.

In the results presented here we have only considered the dispersion of the radioactive gas during the first 10 days after the time of emission. However, still about 33 % of the emitted ^{133}Xe is left in the atmosphere after 10 days, since the half-life of the gas is 5.27 days. This part of

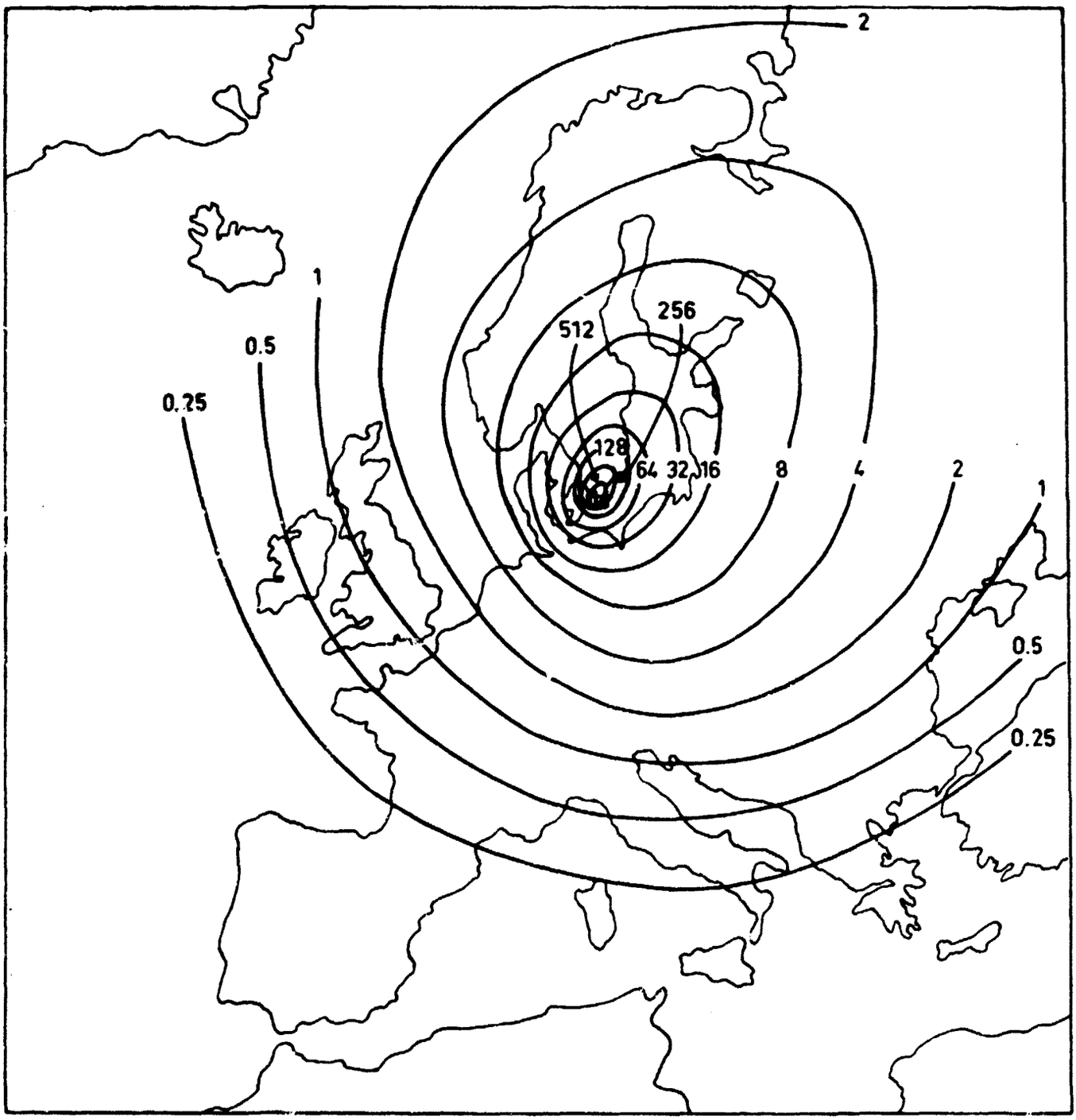

Fig. 4 Computed mean value of the concentration pattern (units per m^3) at a height of 10 m. The emission is assumed to be continuous from a point source located at +. The horizontal dispersion has been computed with the aid of trajectories at the levels 1000 mb, 925 mb and 850 mb initiated over Southern Sweden during the winter 1972-73. The emission is assumed to be 10^{19} relative units per year. Halflife = 5.27 days. Only dispersion during the first 10 days after the time of emission has been taken into consideration.

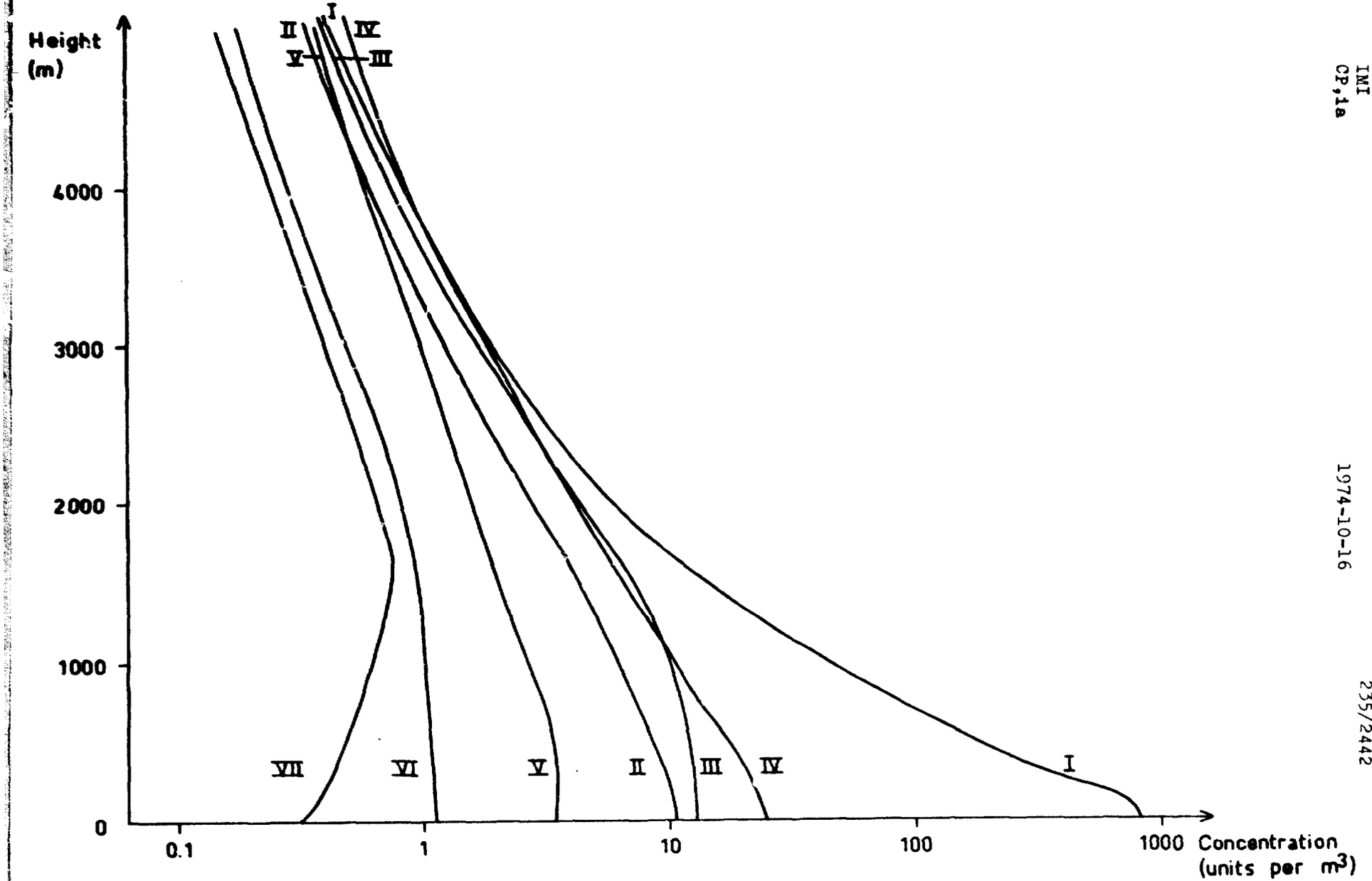

Fig. 5 Calculated vertical mean concentration profiles for seven points located as shown in figure 1.

the emission will - regarded as a mean value over a season - be dispersed rather evenly over a very wide area. This "additional concentration" is probably of the order of 0.5 to 1 relative unit per m^3 in most of the lower troposphere over a large part of Europe. But the "additional concentration" might be somewhat larger in the east and north-east parts depending on the westerly to south-westerly mean winds. We have, however, not included this "additional concentration", in the results presented. Besides, it is very important to be aware of the fact that the results given only refer to the mean concentration during a rather long period of time (a season or more). The dispersion pattern in a specified situation usually is very much different from the results presented.

The assumption about the statistical independence between the vertical and the horizontal dispersion, the simplified discription of the vertical diffusion and the extrapolation of $\overline{|r(t) - r(\tau)|}$ and S might cause rather considerable uncertainty in the computations. Therefore the obtained results should just be regarded as a first approximative picture of the regional concentration distribution.

4 ACKNOWLEDGEMENTS

I appreciate helpful discussions with professor Bert Bolin. The trajectories were computed by state meteorologist Ann-Beate Henrikson at the Swedish Meteorological and Hydrological Institute.

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