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COMPUTATION OF SO_2- LONG TERM CONCENTRATION IN THE VENETIAN AREA

by

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International Conference on Mathematical Models for Environment Problems - University of Southampton -

September 1975

Introduction

Many attempts have been made in the last two decades to simulate SO_2 concentration fields in areas affected both by industrial and urban emissions (Pooler 1961, Turner 1964, Shieh 1971, Calder 1971, Martin 1971, etc.). The models developed for such a purpose have proved to work well in situations in which the parameters affecting the dispersion were rather uniform over the whole area. In more complicated areas, on the contrary, further implementations of diffusion models up to now realized are needed in order to formulate a satisfactorily precise idea of their reliability as well as of their limits.

Venice and its surroundings are a typical example of an area in which the dispersion of the atmospheric pollutants is greatly affected by the non-uniformity of its geographic characteristics. In this area the presence of different types of adjacent surfaces (land, lagoon and Adriatic Sea, see fig. 1) induces a local circulation which interacts with the synoptic wind making it very difficult to identify the dispersion patterns of a pollutant.

On the other side the study of Air Pollution problem in Venice is made urgent by the damages that pollution causes to its priceless artistic patrimony.

In order to give a practical contribution to this problem an application of diffusion models is being carried out.

The problem was tackled by applying, as a preliminary attempt, a Gaussian type model, by which three-monthly average concentrations as well as the annual ones were simulated for the years 1973 and 1974. The obtained results are discussed in the present article.

Application of the model

Since the region under investigation shows the presence of a large industrial area (situated in the mainland) as well as three densely populated urban areas (Marghera and Mestre on the mainland, Venice on the islands at the center of the Lagoon, see fig. 1) both industrial and urban pollution must be taken into account in the model.

Data concerning industrial sources were taken from an inventory carried out by the Local Government in 1972 according to the National Law about Pollution promulgated in April 15th, 1971. Such an inventory showed the presence of 74 stacks with a total emission rate of 160000 tons/year and a range of heights from 10 to 120 m.
The knowledge of the average strength of sources introduces in the model computations a certain inaccuracy, which otherwise is somewhat reduced by the fact that long term averages are calculated.
The evaluation of the spatial distribution of domestic heating emissions was made on the basis of the last national general census, taken in 1972, which furnished a great mass of information not only about the distribution of the population but also about the state of buildings and their facilities (e.g. domestic heating plants).
For the 272 sections, in which the urban districts of the Venetian Area were subdivided, the consumptions of polluting fuels and therefore the yearly emissions of SO_2 were computed.
As for the definition of the emission rates (variable throughout the different periods of the year), it was achieved by using the concept of day/degree, defined as:

$$dd = T_b - \frac{\sum_{i}^{24} T_{h,i}}{24}$$

where T_b is the temperature at which heating starts and $T_{h,i}$ is the average hourly temperature at i-th hour of the day.
In Venice T_b is equal to 15,5 C. The total yearly emission was distributed over the whole "cold period", proportionally to the days/degree, as shown in fig. 2.
The above calculated fractions of the total yearly emission were then used to calculate the emission rates for each of the 272 above mentioned sections. Every area emission was finally introduced in the model as an equivalent constant strength point source, located in the barycenter of the corresponding section.

The height of the urban emissions, including plume rise, was estimated to be about 30 m in the historical center of Venice (whose buildings are generally old and low) and around 45 m. in the urban areas of the mainland, which have developed in the last three decades and show taller buildings. Meteorological data as well as SO_2-concentration data were supplied by the network that Tecneco installed in Venice by appointment of the Istituto Superiore di Sanità (Superior Institut for Health). It consists of one meteorological station situated in the historical center of Venice and of 24 monitoring sensors (fig. 1).
The meteorological station records on an hourly basis wind speed, wind direction according to the eight sectors of the wind rose, temperature, pressure, rainfall, humidity, cloudiness and fog. Concentration data recorded by the 24 monitoring sensors are transmitted to a small computer which elaborates the data and prints the hourly average values as well as daily statistics. Besides that, every time the 30 minutes average SO_2- concentration "standard" (.30 ppm) imposed by the Italian law is exceeded in a station the computer gives an alert. Since only 10 stations were regularly operating from February 1973, the model has been tested on the data recorded by them in the period February 1973 - January 1975. Anyway some results will also be given for the other operating sensors in the year 1974.

Diffusion equation

The equation used for the computation is the classical Gaussian plume formula (Pasquill 1962), written according to the modifications introduced by Martin (1971) and Calder (1971). For a single point source the concentration at a receptor point P is given by:

$$C_P = \frac{n}{\Pi^{3/2}} \frac{Q}{\sqrt{2}} \cdot \sum_{\substack{iw=1 \\ is=1 \\ it=1}}^{6,6,4} \frac{F(id,iw,is,it)}{U_{iw} D_P S_z(D_P,is)} \exp\left[\frac{-h^2(iw,is,it)}{2S_z^2(D_P,is)}\right]$$

where:

n	number of wind rose sectors (n=8, in our computation)
Q	source emission rate (Kg/s)
F (id,iw,is,it)	denotes the relative frequency of winds blowing into the given 45 - wind direction sector (id), for a given wind speed class (iw), atmospheric stability class (is) and temperature class (it).
U_{iw}	average wind speed for the iw - class at source height (m/s)
D_P	projection along the wind direction of the distance between the receptor point P and the point source
S_z	vertical standard deviation obtained from Gifford's plots (Slade, 1968) (m)
h	source effective height (m)

The above mentioned hourly meteorological data were used to determine the joint frequency distribution of meteorological conditions. As to wind speed the following six classes were used: 0—1,57, 1,57—3,14, 3,14—5,24, 5,24—8,38, 8,38—11 and greater than 11 m/s; the representative speed U_{iw} was computed as the arithmetic mean of the measured values belonging to the iw class. In order to take into account the variation of the wind speed with the height an esponential law was used, whose exponent was assumed equal to .25 for unstable and neutral classes and .5 for stable ones.

Frequencies of calms were so low that it was decided to disregard them. Wind directions were grouped into 8 classes corresponding to the standard 8 compass directions (N,NE,....,NW).

Atmospheric stabilities were grouped into 6 classes, according to Pasquill's criteria. Finally, in order to take into account the influence of temperature on the plume rise, the following classes were intro-

duced: less than 0, 0—10, 10—20, and greater than 20°C; the representative temperature has been evaluated as the arithmetic mean of the measured values belonging to the it class.
The plume rise has been evaluated according to the Concawe formula (Détrie, 1969). Since no suitable information was available neither the height of the inversion layer nor the decay of SO_2 were introduced in the model.

Results

The monitoring stations were divided into three groups according to their geographical location. Figs. 3-4-5 show measured three-monthly average concentration as well as the calculated one for two stations chosen out of each group. Fig. 3 refers to sensors 6 - 30, located at the southern edge of the Industrial Area, while stations 10-29 (fig.4) are situated between the Industrial Area and the urban centers of Mestre and Marghera and finally fig. 5 shows the results for sensors 16 - 22 located in Mestre and in Venice respectively.
The model simulates fairly well the observed values for all the stations but 10 and 29. This is an expected result since the areas in which they are located show discontinuities (i.e. variations in surface roughness, and land-lagoon transition) greater than elsewhere. To this it must be added that they are very close to the strongest point sources and therefore much more affected by possible inaccuracies in the evaluation of their mutual locations.
All the results have been summarized in figs. 6-7, which also show the regression lines for 1973 and 1974 respectively. The correlation coefficients are .72 for the year 1973 and .8 for the year 1974.
The model was also used to calculate SO_2 - annual average concentration for the years 1973 and 1974; the relative results are plotted with the experimental ones in figs. 8-9. As it was expected, the model proved to give better results if the period of calculation was extended. The encouraging results obtained by applying the model

led to extend the calculations over the whole area of interest in order to get a visible description of the spatial distribution of the pollutant. This made it possible to draw the isolines of concentration, shown in figs. 10-11, for the periods June-August 1973 and December 1973-February 1974 respectively. By comparing the two maps a conclusion can easily be drawn that because of the local meteorological conditions (Runca and Zannetti, 1973), in summer SO_2 "keeps away" from the historical center, and concentrates itself near the industrial sources. In the winter, the different meteorology prevailing over the area as well as the presence of urban emissions causes a wider spread of the SO_2 and consequently raises the pollution level in the urban center of Venice.

Conclusions

The application of a gaussian-type model to compute long term SO_2- average concentration in Venice and its surroundings has been presented. Although it is difficult to describe the local meteorology, the choice of characterizing the atmospheric stabilities according to Pasquill's categories as well as the assumptions concerning height variation of the wind and the plume rise proved to be satisfactory. Since the obtained results showed that the seasonal patterns of SO_2- concentration can be described by the model, it has been used to illustrate the influence of seasonal climate on the SO_2 dispersion over the area and the contributions of urban and industrial emissions to the pollution level in the historical center of Venice. Improvements can be brought to the model by introducing in it a proper definition of the atmospheric stabilities on the basis of a more detailed knowledge of the local meteorology as well as by better defining the industrial emissions rates and locations. In such a way the model could become a valid tool for land planning purposes and for optimizing the monitoring network.

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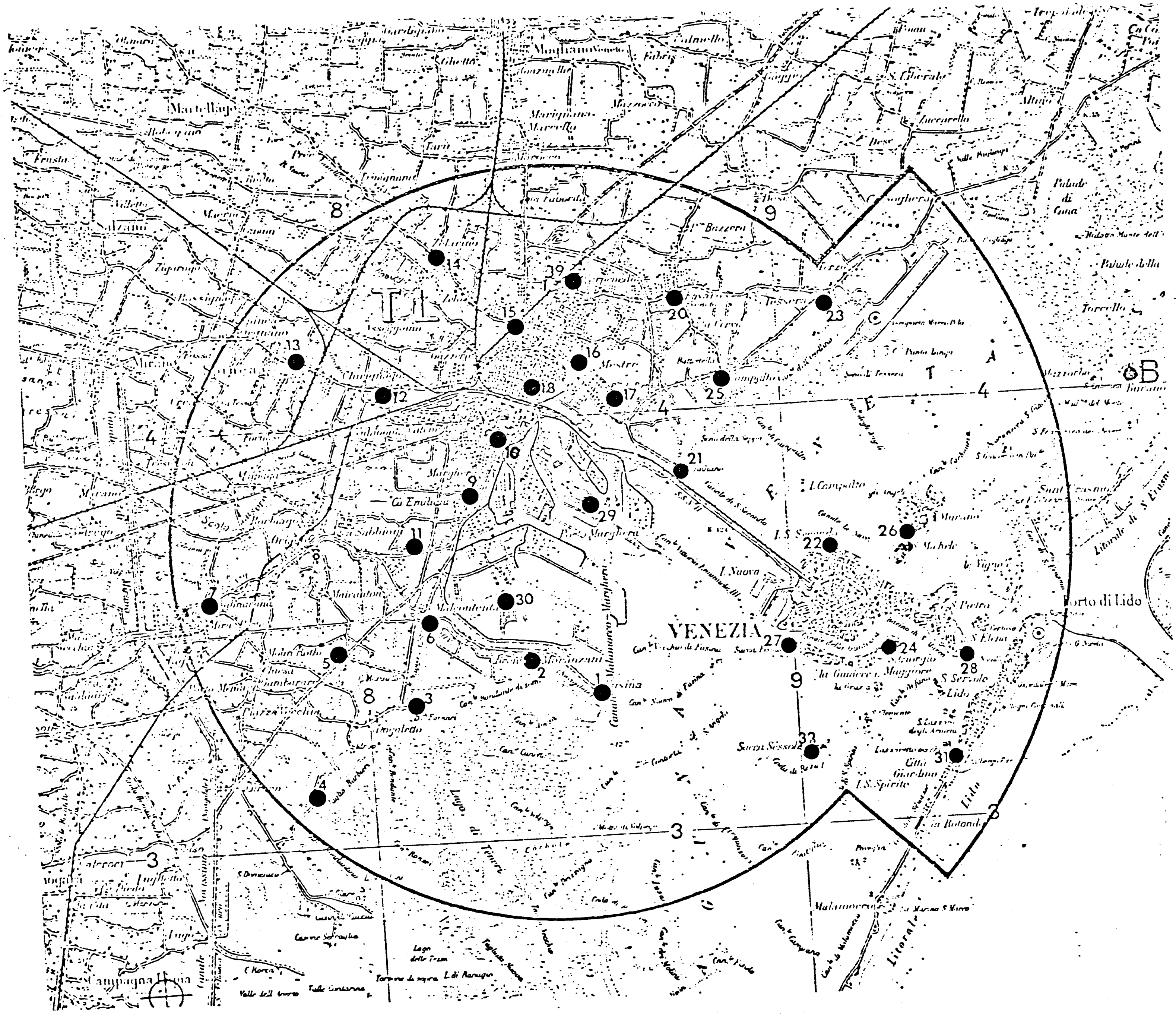


Fig. 1 Venetian Area - Dots indicate the location of the SO_2 monitoring stations (2,6,9,10,16,17,22,24,29,30 were operating since Feb. '73)

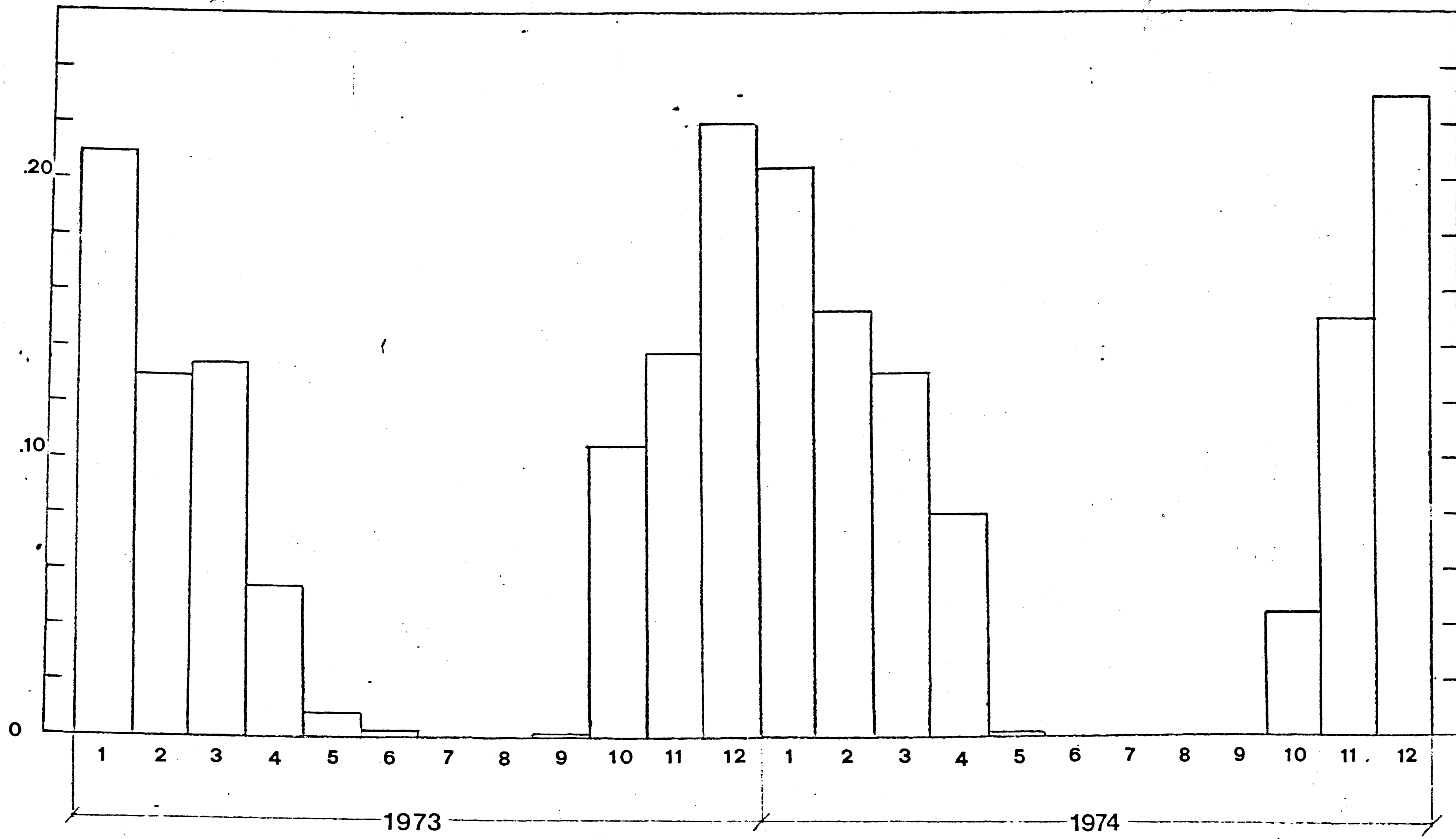
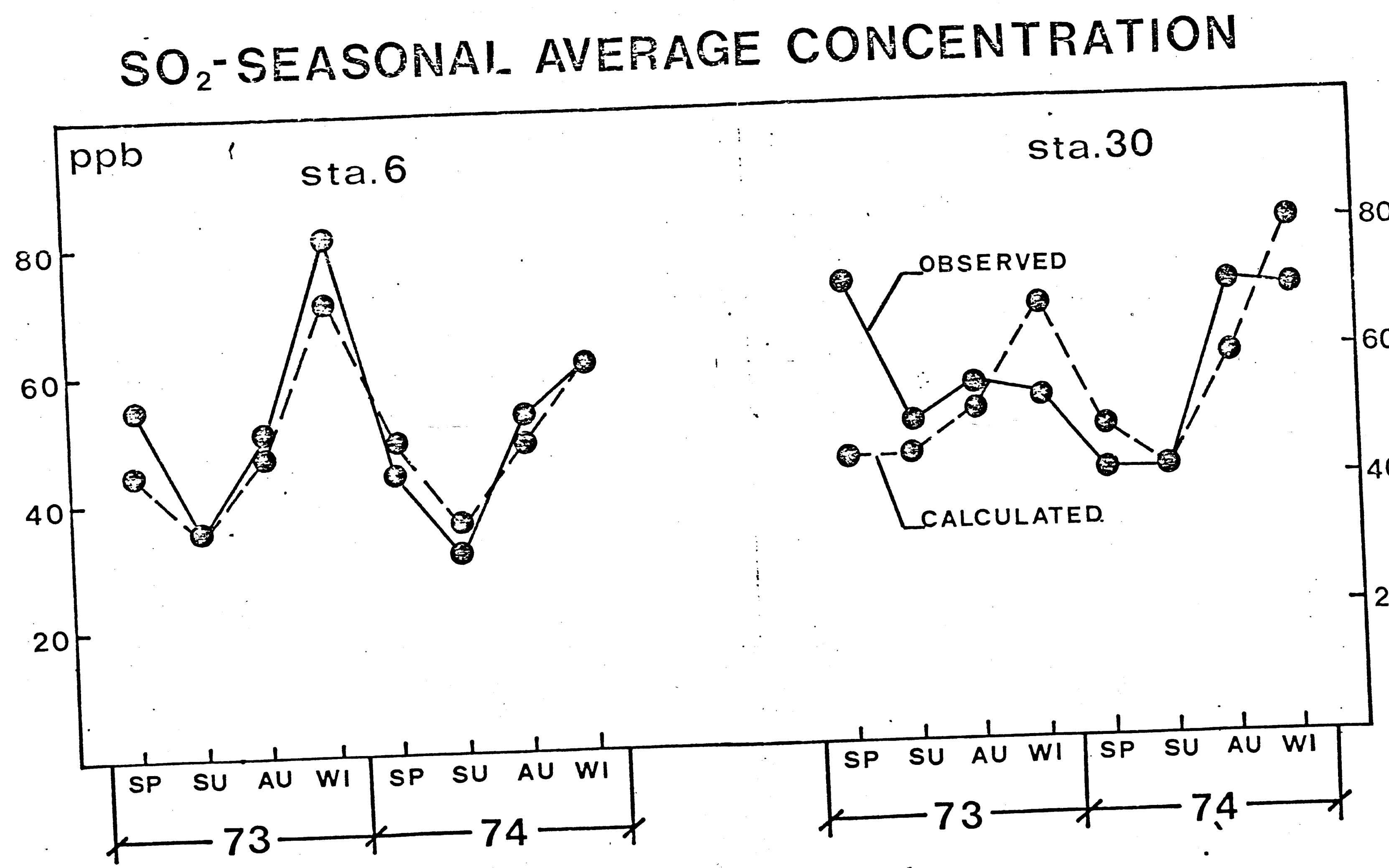


Fig. 2 Histogram of domestic heating emissions distribution throughout the years 1973 and 1974.



SO2-SEASONAL AVERAGE CONCENTRATION
ppb
sta.6
sta.30
OBSERVED
CALCULATED
80
60
40
20
SP SU AU WI SP SU AU WI
73
74

Fig.3

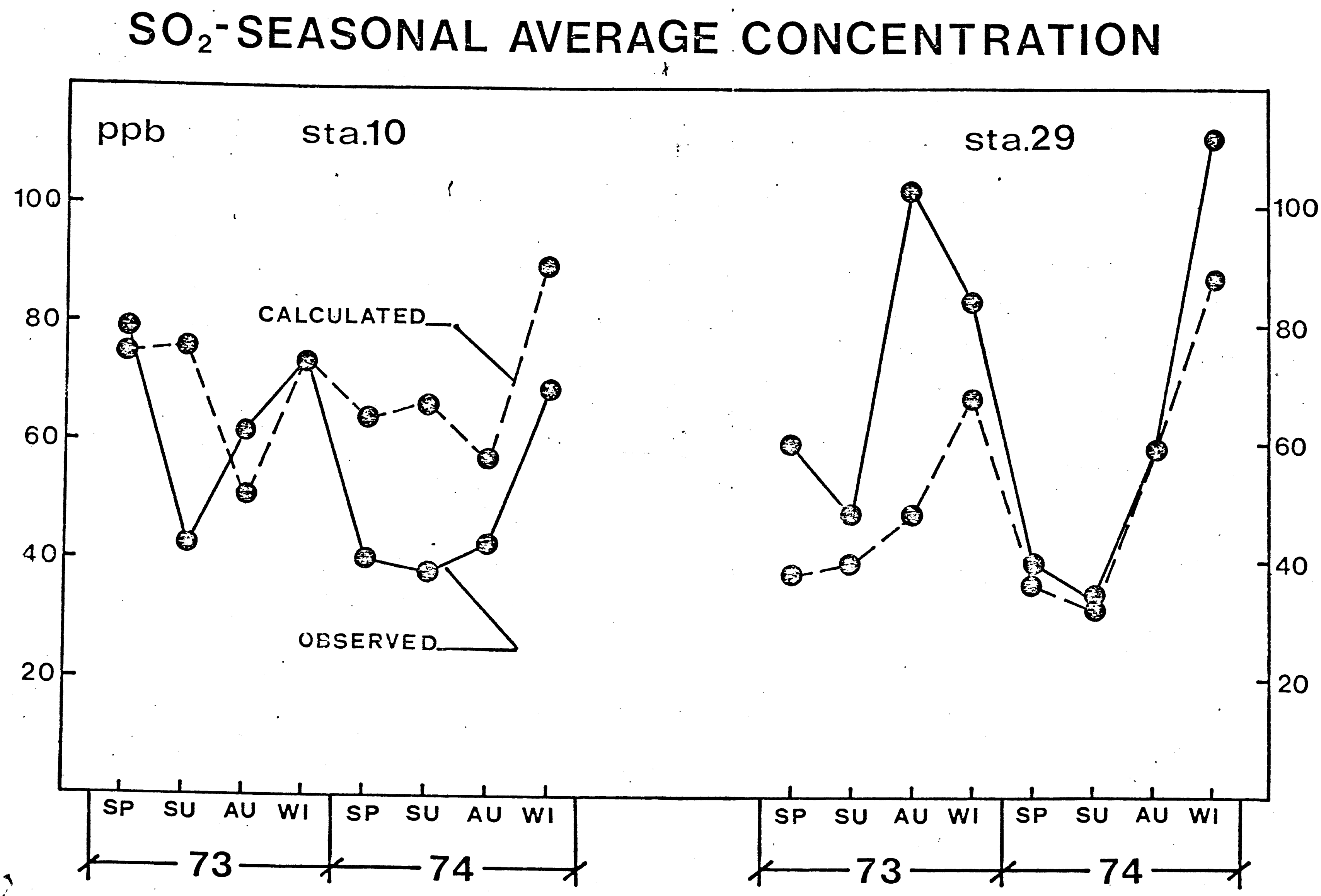

SO$_2$-SEASONAL AVERAGE CONCENTRATION
ppb
sta.10
sta.29
CALCULATED
OBSERVED
100
80
60
40
20
SP SU AU WI SP SU AU WI
73
74

Fig. 4

SO_2-SEASONAL AVERAGE CONCENTRATION

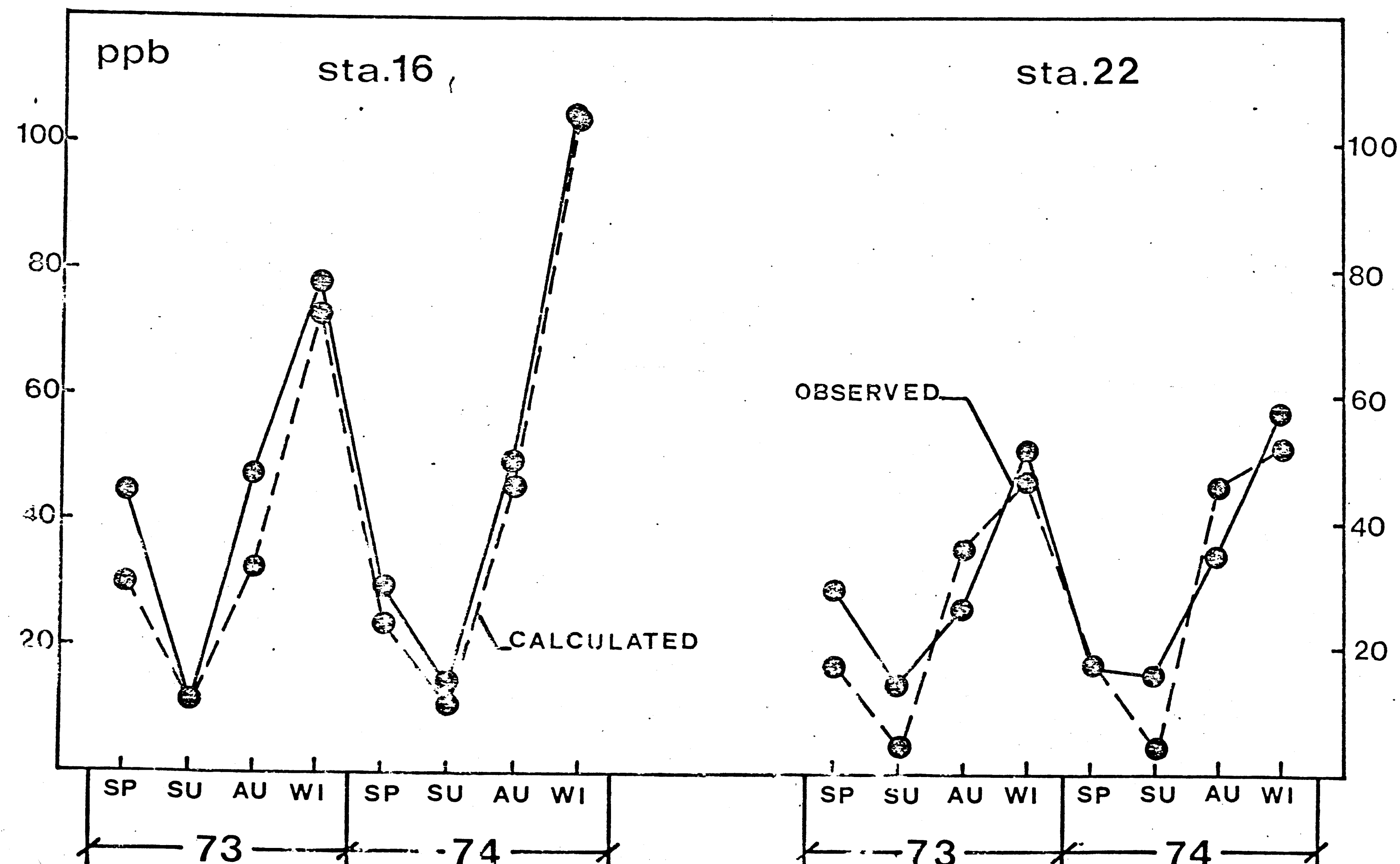


Fig.5

Fig. 6 Regression line of observed versus calculated average SO_2 concentration (ppb) for three-monthly periods from Feb. '73 to Jan. '74.

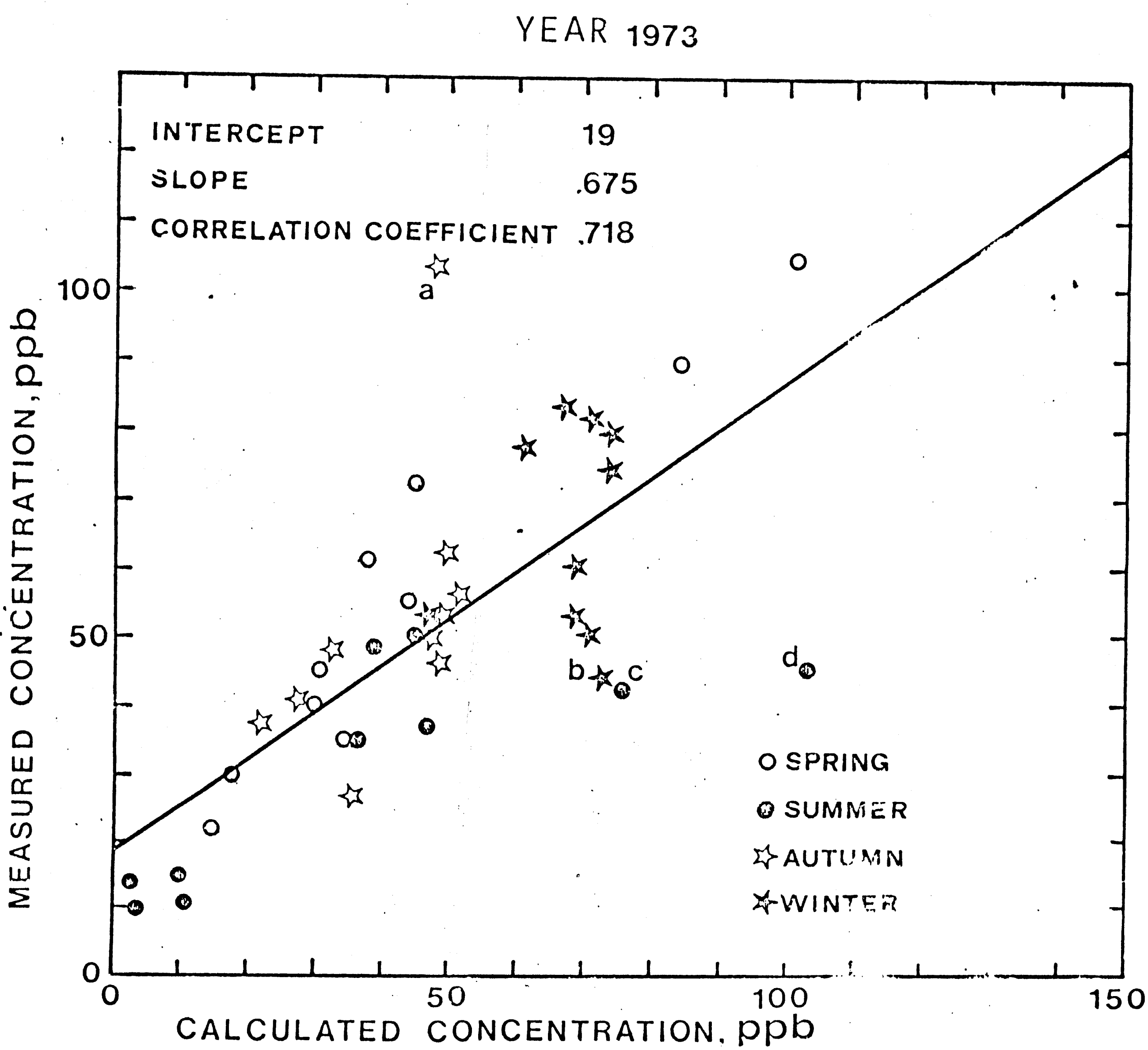
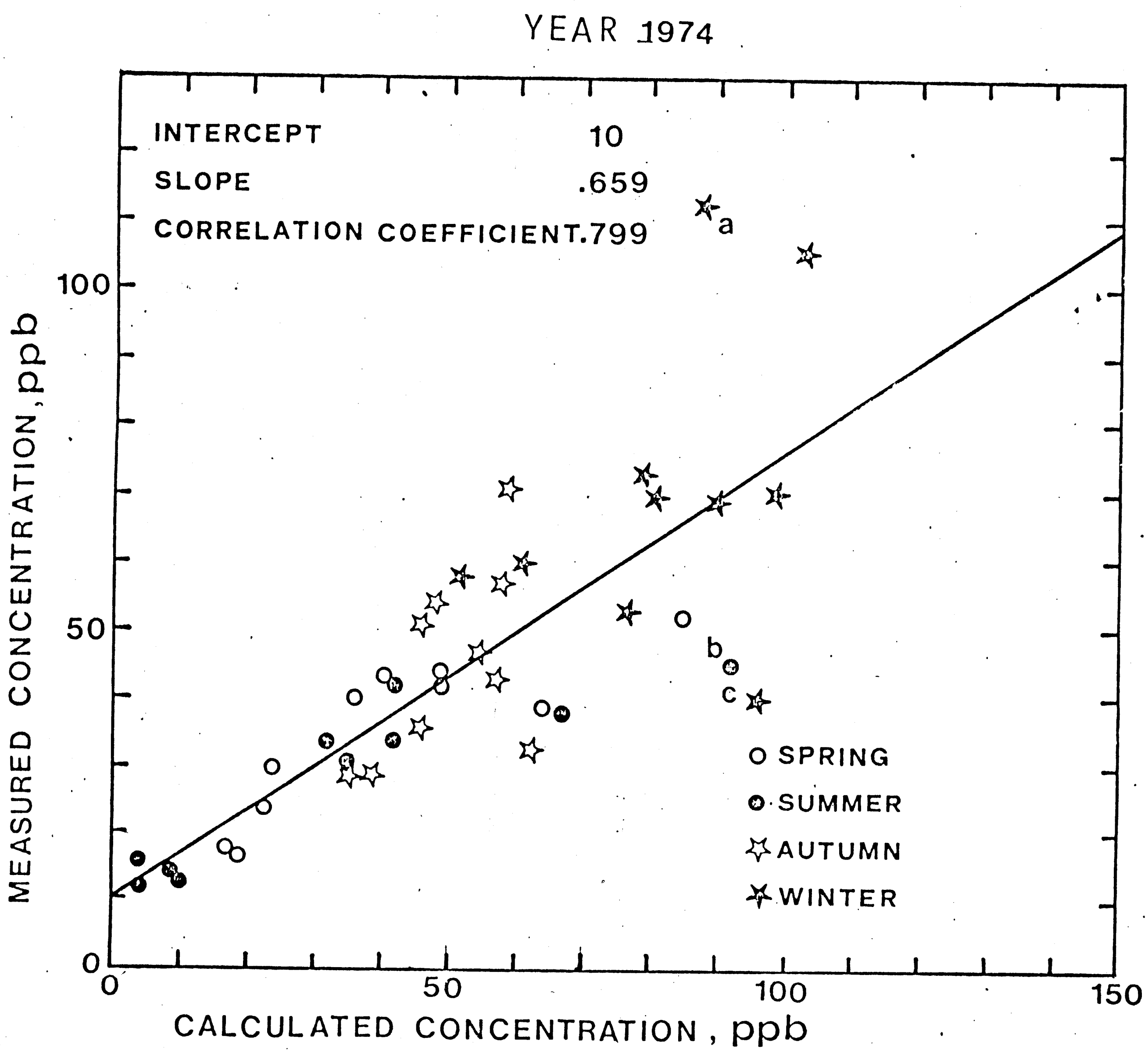


Fig. 7 Regression line of observed versus calculated average SO_2 concentration (ppb) for three-monthly periods from Feb. '74 to Jan. '75.



SO_2 - ANNUAL AVERAGE CONCENTRATION 1973

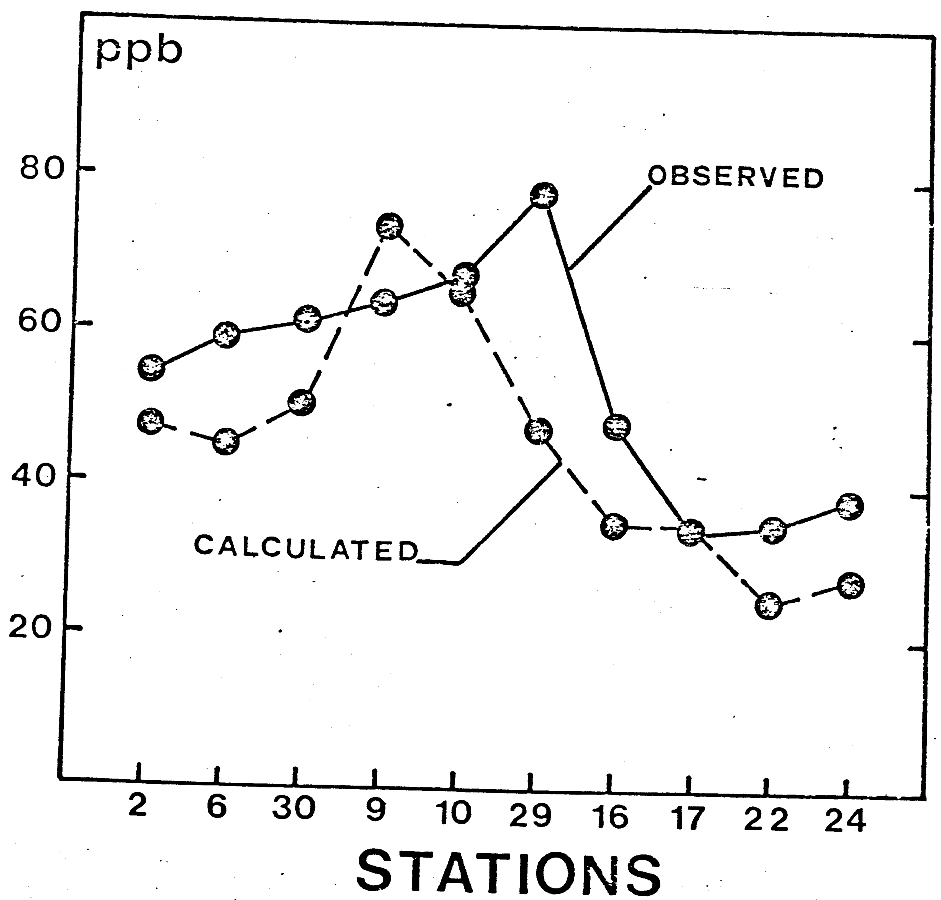


Fig.8

SO_2 - ANNUAL AVERAGE CONCENTRATION 1974

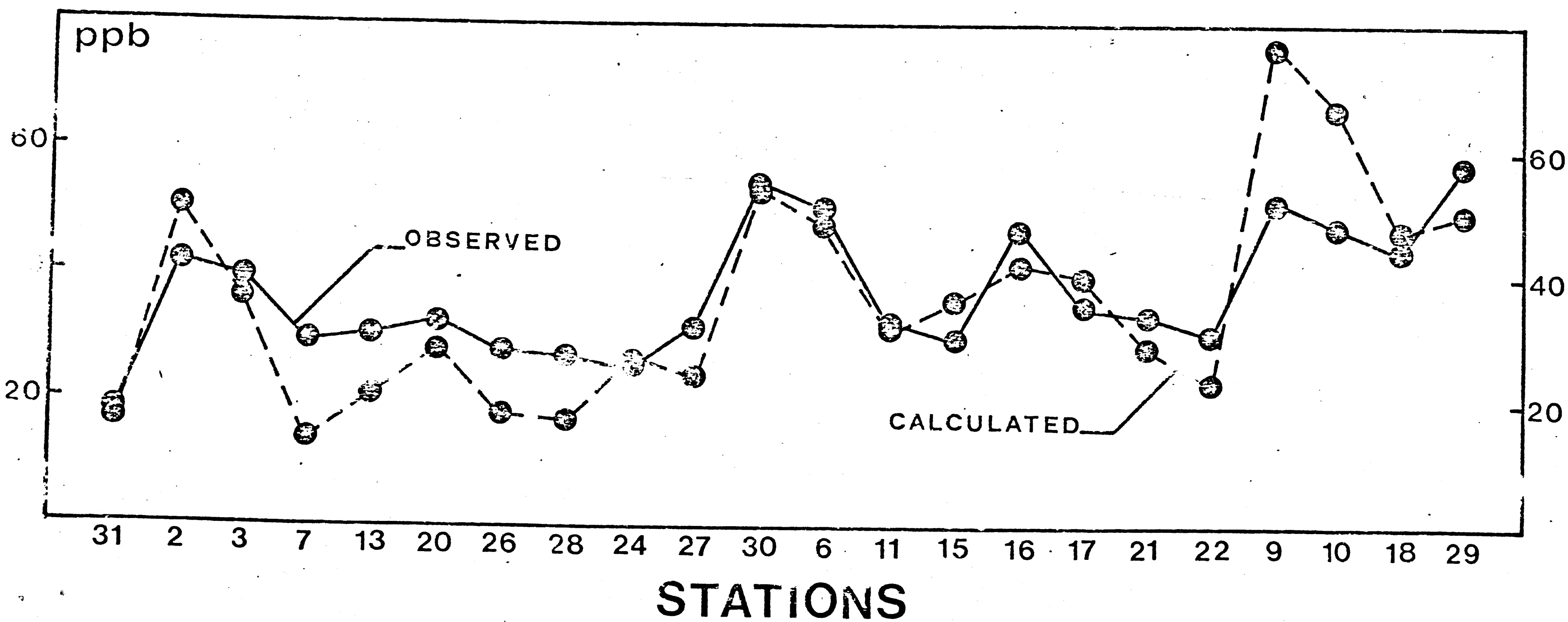


Fig.9

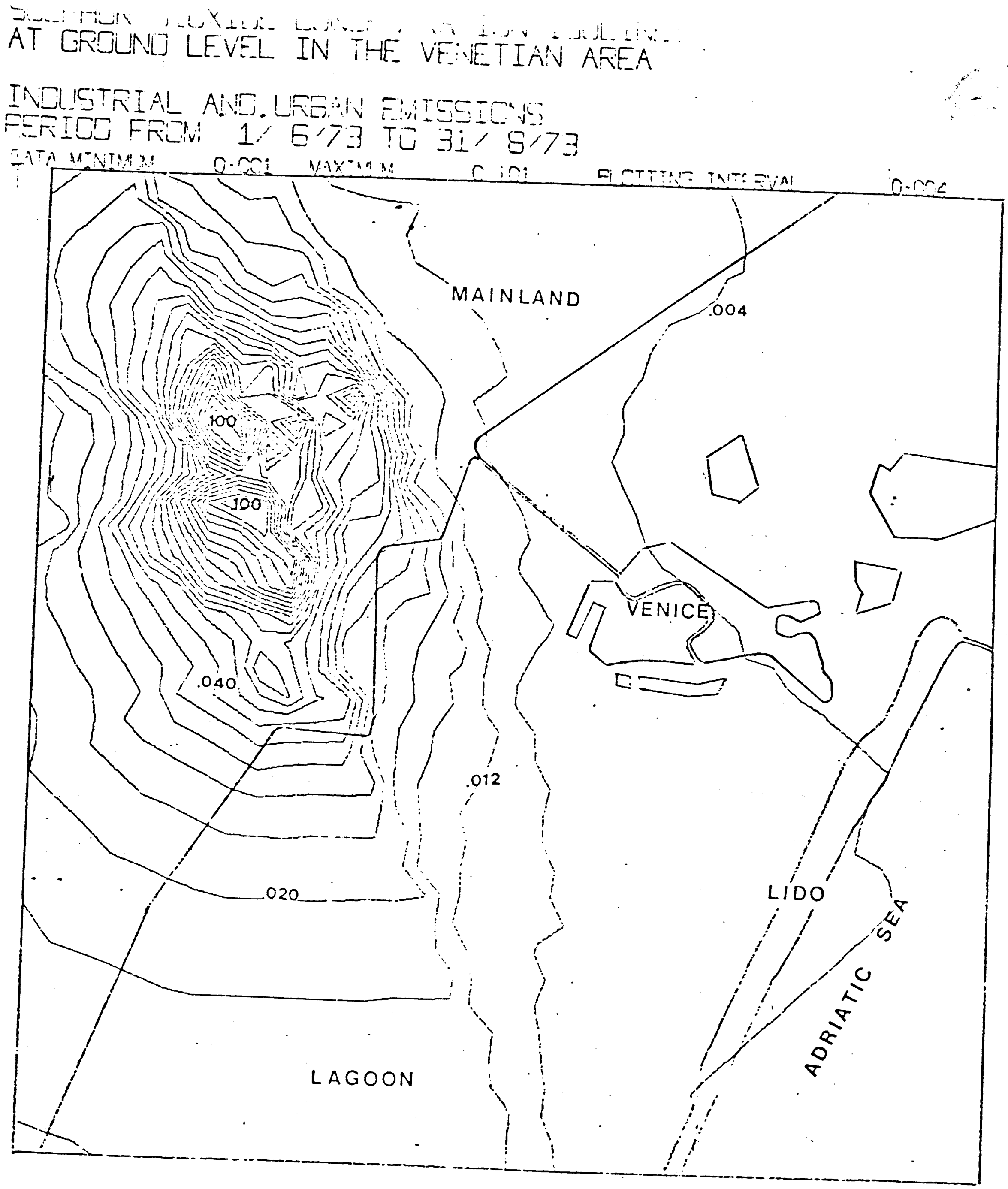


Fig. 10 Concentration values are in ppm.