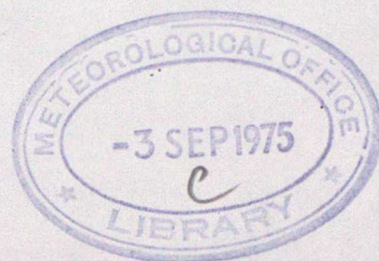


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Assessment of the accuracy of the scheme for predicting
high sulphur dioxide concentrations in London air during
the winter 1973 - 1974.

by

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ASSESSMENT OF THE ACCURACY OF THE SCHEME FOR PREDICTING HIGH SULPHUR DIOXIDE
CONCENTRATIONS IN LONDON AIR DURING THE WINTER 1973-74

Introduction

A scheme for the prediction of high concentrations of sulphur dioxide in London air was described in Turbulence and Diffusion Note No 19. (TDN 19). In order that the operational forecaster could use meteorological data readily available to him the scheme proposed was modified as follows:-

- (i) London Airport (Heathrow) meteorological data were to be used instead of Kew data.
- (ii) The "hours of calm" criterion was relaxed to include all hours when the mean wind fell below 5 kt.
- (iii) The minimum temperature up to midnight was replaced by the minimum temperature over the 24 hour period from 0900 hours to 0900 hours GMT.
- (iv) The effects of the daily mean wind direction were confined to winds from between 060 and 120 degrees, when estimated concentrations were increased by 50%.
- (v) The effect of daily mean wind speed was ignored.

The empirical formula for forecasting concentration in terms of the revised parameters is:-

$$C_{\text{est}} = 0.085 \left(1 + \frac{\delta_m}{6}\right) \left(1 - \frac{T-t}{28}\right) (5 \bar{C} + 4C_p) + 0.15 \bar{C}$$

where δ_m = 1 if mixing depth is low and 0 otherwise
T = minimum temperature 0900 hours to 0900 hours GMT
t = number of hours when mean wind falls below 5 kt
 \bar{C} = mean concentration
Cp = yesterday's concentration

Prior to October 1973 it was agreed with London Weather Centre (LWC) and the Medical Research Council (MRC) that forecast concentrations for the winter of 1973-74 should refer to an area typified by the site maintained by the MRC at St Bartholomew's Medical College, Charterhouse Square, London. This site is Finsbury 2 in the National Survey and is classified as being in a predominantly residential area with high-density housing interspersed with some industrial undertakings and surrounded by other built-up areas. Observations of the mean 24-hour concentration of sulphur dioxide are made at 2359 hours daily at this site and these measurements have been compared with the concentrations estimated by LWC. Mean concentrations were determined for this site for weekdays and weekends and showed that measured concentrations were reduced by 25% at weekends. Based on the preceding five year average winter concentration at the site, the mean concentration (\bar{C}) used in the above formula was $252 \mu\text{g}/\text{m}^3$ for weekdays and $190 \mu\text{g}/\text{m}^3$ for weekends. Using these values two nomograms were constructed, one for use during the week and the other for weekends and public holidays. (Fig 1).

Use of scheme

Forecasts of the expected mean concentration of sulphur dioxide over the period from 0900 hours to 0900 hours GMT were prepared by LWC at 1000 hours GMT daily. The forecast minimum temperature and expected number of hours of wind speed less than 5 kt during the next 24 hours were used. As yesterday's concentration (Cp) was not available it was derived from the forecast value for yesterday by substituting for the forecast values the actual minimum temperature

and number of hours of wind less than 5 kt at London Airport during the preceding forecast period and using the nomogram to find the value which should have been forecast. The expected height of the mixing depth was obtained from the rules given in Section 3 of TDN 19, cloud amount and wind speed being forecast for 2100 hours and 2400 hours GMT. Using this forecast data and the appropriate nomogram an estimated concentration was obtained. When this was greater than $500 \mu\text{g}/\text{m}^3$ a warning of high pollution was passed to the MRC. The forecast values were reviewed at 1600 hours and any amendment made to the estimated concentration.

Comparison of results

As the Finsbury 2 site gives daily values of concentration of sulphur dioxide it was decided to compare these with the forecast values. As the period measured, 0001-2359 hours, does not coincide with the forecast period, 0900-0900 hours, the value recorded at Finsbury at 2359 hours during the period of the forecast has been used. The following were compared with the actual value:-

- (i) The value forecast by London Weather Centre. Figure 2 shows the daily values.
- (ii) On some occasions significant errors in the estimated concentration had been made because the nomogram had been used incorrectly. Estimated concentrations were calculated on an Olivetti desk calculator using LWC forecast meteorological data and these compared with the actual value.
- (iii) Estimated concentrations were computed using the actual meteorological measurements from London Airport with C_p also derived from these measurements and compared with the actual value.
- (iv) Estimated concentrations derived as in (iii) but using the actual C_p instead of a forecast value. Figure 3 shows the daily values.

The following table gives the results of the comparisons.

| | Measured at MRC site Finsbury 2 | Predicted by LWC | Using forecast met data and desk calculator | Using post- facto met data and C_p forecast | Using post- facto met data and actual C_p |
|---|---------------------------------------|---------------------|--|--|--|
| Mean Concentration ($\mu\text{g}/\text{m}^3$) | 182 | 236 | 232 | 237 | 215 |
| S.D. | 94 | 99 | 89 | 82 | 77 |
| Correlation with actual | | 0.66 | 0.71 | 0.72 | 0.72 |
| Standard error ($\mu\text{g}/\text{m}^3$) | | 74 | 62 | 57 | 53 |

Table 1. Comparison of estimates of sulphur dioxide concentration with measured value at one site. October 1973 - March 1974.

Results obtained from the forecast scheme were also compared with a weighted mean daily concentration for 3 or 4 sites derived as in Section 4 of TDN 19. Two of the sites used in the original study, Kensington 4 and Hackney 2, no longer report. Two similar sites from the same localities, Kensington 8 and Hackney 7, were substituted and the mean daily concentrations for these plus London 17 and Deptford 3 were computed for the period October 1973 to March 1974. As previously, readings were not available for weekends and holidays. This mean concentration was compared with the estimated value obtained using post-facto meteorological data and a forecast C_p . The same value for \bar{C} was used as in the forecasts for Finsbury 2. The following table gives the result of this comparison and also the comparison of this forecast value and Finsbury 2 measurements for these occasions.

| | Measured at Finsbury 2 | Mean for 3 or 4 sites | Predicted using post-facto met data and forecast C_p |
|--|---------------------------|-----------------------------|---|
| <u>Period OCT-DEC</u> | | | |
| Mean ($\mu\text{g}/\text{m}^3$) | 234 | 279 | 263 |
| S.D. | 138 | 144 | 110 |
| Correlation with predicted value | 0.86 | 0.80 | |
| Correlation between Finsbury and 3 or 4 sites | 0.82 | | |
| <u>Period JAN-MAR</u> | | | |
| Mean ($\mu\text{g}/\text{m}^3$) | 182 | 184 | 244 |
| S.D. | 61 | 54 | 63 |
| Correlation with predicted value | 0.43 | 0.62 | |
| Correlation between Finsbury and 3 or 4 sites | 0.32 | | |
| <u>Period OCT-MAR</u> | | | |
| Mean ($\mu\text{g}/\text{m}^3$) | 208 | 232 | 253 |
| S.D. | 110 | 120 | 90 |
| Correlation with predicted value | 0.76 | 0.73 | |
| Correlation between Finsbury and 3 or 4 sites | 0.76 | | |

Table 2. Comparison of estimate of sulphur dioxide concentration with measured value at one site and mean of 3 or 4 sites. Weekdays only. Winter 1973-74. Total number of cases 94, 47 in each half of the winter.

Inherent error of scheme

Measurements at the London 17 site are made daily and these were compared with those for Finsbury 2 for the period October-December 1973. (Fig. 4). London 17 measurements cover the period from 1430 to 1430 hours whilst those for Finsbury 2 cover the period 0001 to 2359 hours. The correlation between the Finsbury 2 values read at 2359 hours and those at London 17 nine and a half hours earlier was 0.73; for those at London 17 fourteen and a half hours later it was 0.66. As the period used for the forecast scheme was 0900 to 0900 hours the time difference between the various concentrations was allowed for by using

the correlation between scheme-derived concentrations lagged in time. As forecasts were only done once a day this was for 24, 48 and 72 hours. A curve of correlation/time-lag is given at Fig. 5.

The error of the scheme was derived as follows:-

C = true average concentration over the city (unknown)
Period 0900 to 0900 hours

C_s = forecast concentration using scheme
Period 0900 to 0900 hours

C_F = measured concentration at Finsbury 2
Period 0001 to 2359 hours

C_L = measured concentration at London 17
Period 1430 to 1430 hours

C^* and C^{**} are the true average concentrations over periods 1430 to 1430 hours and 0001 to 2359 hours respectively.

Then:

$C_s = C + C'_s$ where C'_s = the error of the scheme

$C_L = \frac{\bar{C}_L}{\bar{C}} C^* + C'_L$ where C'_L is the inherent "error" of the London 17 measurement

$C_F = \frac{\bar{C}_F}{\bar{C}} C^{**} + C'_F$ is that for Finsbury 2

Also $C^* - \bar{C} = r^* (C - \bar{C}) + C^{**}$ where r^* is the appropriate time correlation and similarly for C^{**}

$$a^2 \equiv \overline{(C_L - C_s)^2} = \sigma_c^2 \left[1 - 2r^* \frac{\bar{C}_L}{\bar{C}} + \frac{\bar{C}_L^2}{\bar{C}^2} \right] + (\bar{C}_L - \bar{C})^2 + \overline{C_L'^2} + \overline{C_s'^2}$$

$$b^2 \equiv \overline{(C_F - C_s)^2} = \sigma_c^2 \left[1 - 2r^{**} \frac{\bar{C}_F}{\bar{C}} + \frac{\bar{C}_F^2}{\bar{C}^2} \right] + (\bar{C}_F - \bar{C})^2 + \overline{C_F'^2} + \overline{C_s'^2}$$

$$c^2 \equiv \overline{(C_L - C_F)^2} = \sigma_c^2 \left[\frac{\bar{C}_L^2}{\bar{C}^2} - 2r^{***} \frac{\bar{C}_L \bar{C}_F}{\bar{C}^2} + \frac{\bar{C}_F^2}{\bar{C}^2} \right] + (\bar{C}_L - \bar{C}_F)^2 + \overline{C_L'^2} + \overline{C_F'^2}$$

where $\begin{cases} \bar{C} = \bar{C}_s \\ \sigma_c^2 = \overline{C_s^2} - \bar{C}_s^2 + \overline{C_s'^2} \end{cases}$
 r^*, r^{**}, r^{***} are estimated from the correlation curve

The equations are solved for $\overline{C_s'^2}$ by forming $c^2 - a^2 - b^2$, eliminating unknown $\overline{C_L'^2}$ and $\overline{C_F'^2}$. This gave an inherent error, $\sqrt{\overline{C_s'^2}} \approx 45 \mu\text{g}/\text{m}^3 \pm 5$

A similar calculation was made using the forecast value, the Finsbury 2 value and the mean of 3 or 4 sites for the occasions during the period October 1973 to January 1974 when these were available. This gave an inherent error of $\approx 53 \mu\text{g}/\text{m}^3$.

Analysis of errors

For the period October 1973 to March 1974 the errors derived from the various estimates of concentration and that measured at a single site, Finsbury 2, are:

| | $\mu\text{g}/\text{m}^3$ |
|--|--------------------------|
| Error in average concentration | 50 |
| In addition | |
| Error in forecasting meteorological data | 20 |
| Error in incorrect use of nomogram | 40 |
| "Error" of single site | 25 |
| Error from differences in 24-hour period | 25 |
| Error inherent in scheme | 45 |
| Total error | 74 |

Figure 6 indicates the effects of errors in forecasting meteorological parameters.

Conclusions

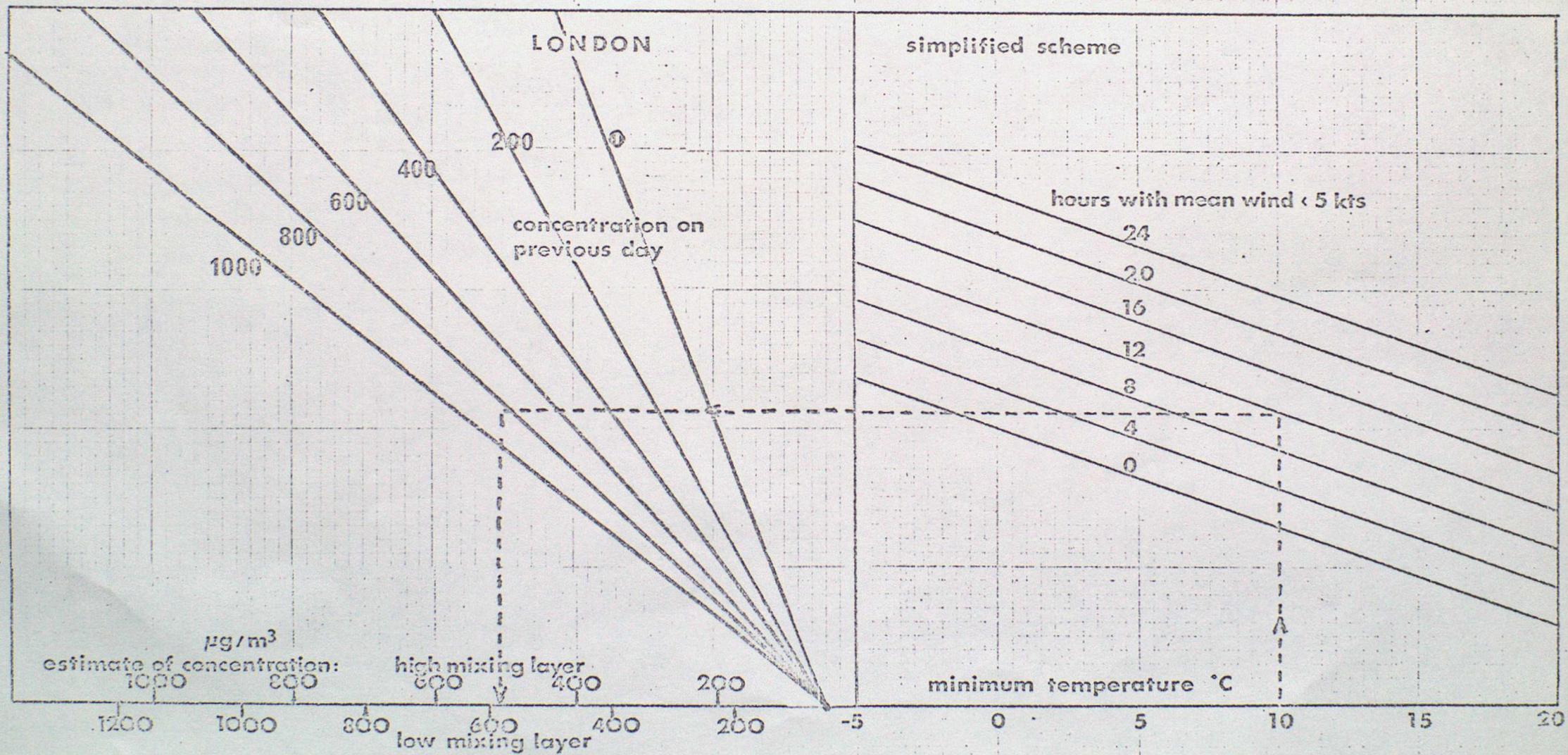
The emission pattern for the winter 1973-74 cannot be regarded as normal because from mid-December industrial output was affected by a national fuel shortage. For several weeks many industrial undertakings were working for only three days per week and even after the end of this restriction on the 8 March the normal winter emission pattern was unlikely to have been fully restored. In December 1973, although the mean minimum temperature was less than in December 1972 and the number of hours of wind less than 5 kt was greater, the mean sulphur dioxide concentration at Finsbury 2 was 40% lower than in December 1972. Over the whole winter the mean concentration was 33% lower than the mean of the previous five winters for this site. Bearing this in mind, forecast concentrations issued by LWC are in good agreement with actual values measured. Although weather conditions from 30 December to 1 January were conducive to higher levels of pollution than were observed many firms had remained on holiday throughout the Christmas week. The consistent differences between forecast and actual concentrations during the second half of February and early March can also be attributed to the abnormal emission pattern.

Two points which may be considered for the further improvement of the scheme are:-

- (i) that a desk calculator be used to compute the estimated emission values instead of using a nomogram;
- (ii) that yesterday's concentration should be available at the time the forecast is made.

| | Measured at Finsbury 2 | Predicted by LWC | Using forecast met. data and desk calculator | Using post-facto met. data and C _p forecast | Using post-facto met. data and actual C _p |
|--|---------------------------|---------------------|---|--|--|
| Mean Concentration (μgm^{-3}) | 182 | 236 | 232 | 237 | 215 |
| S.D. | 94 | 99 | 89 | 82 | 77 |
| Correlation with actual | | 0.66 | 0.71 | 0.72 | 0.72 |
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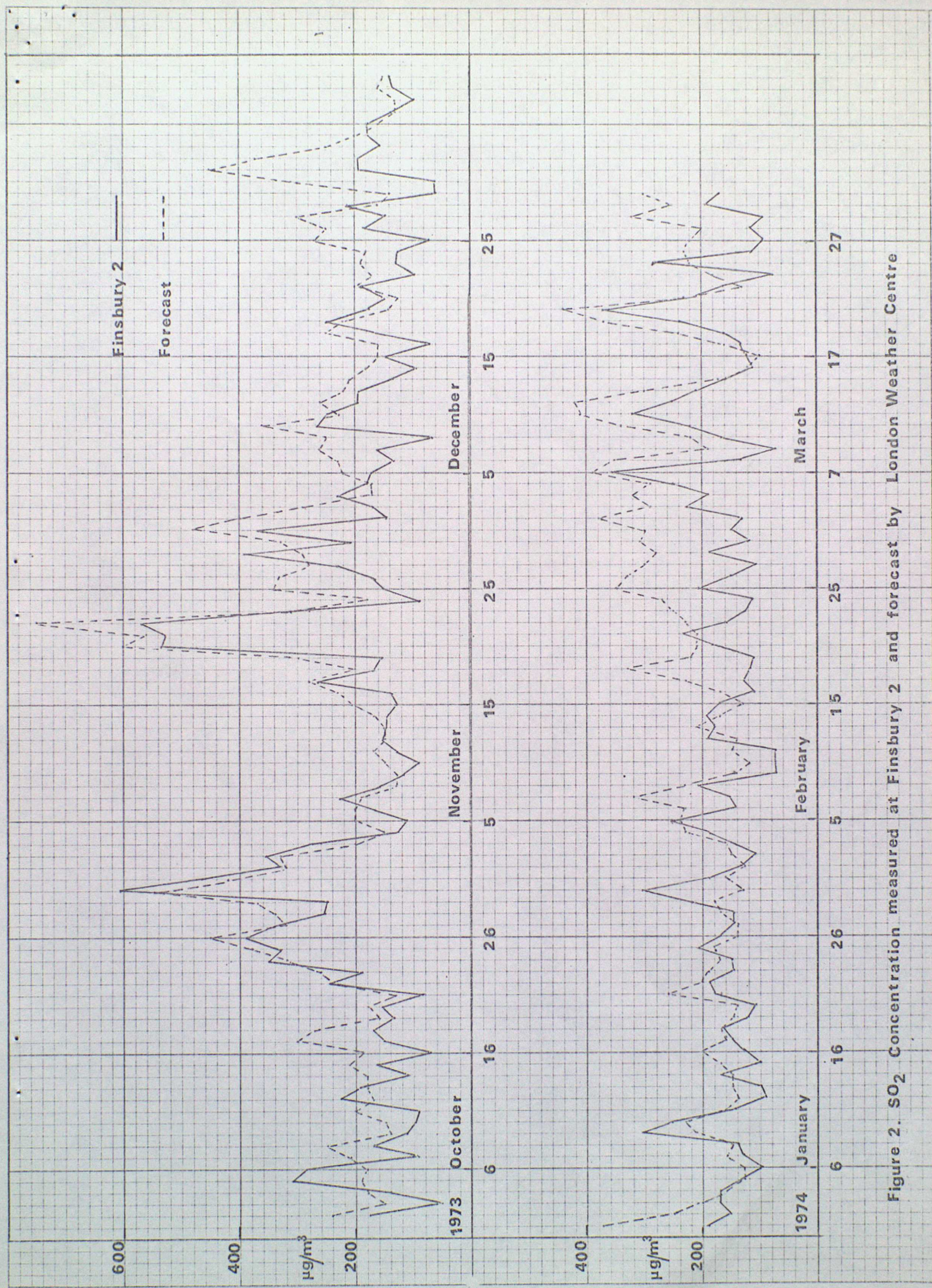


Figure 2. SO₂ Concentration measured at Finsbury 2 and forecast by London Weather Centre

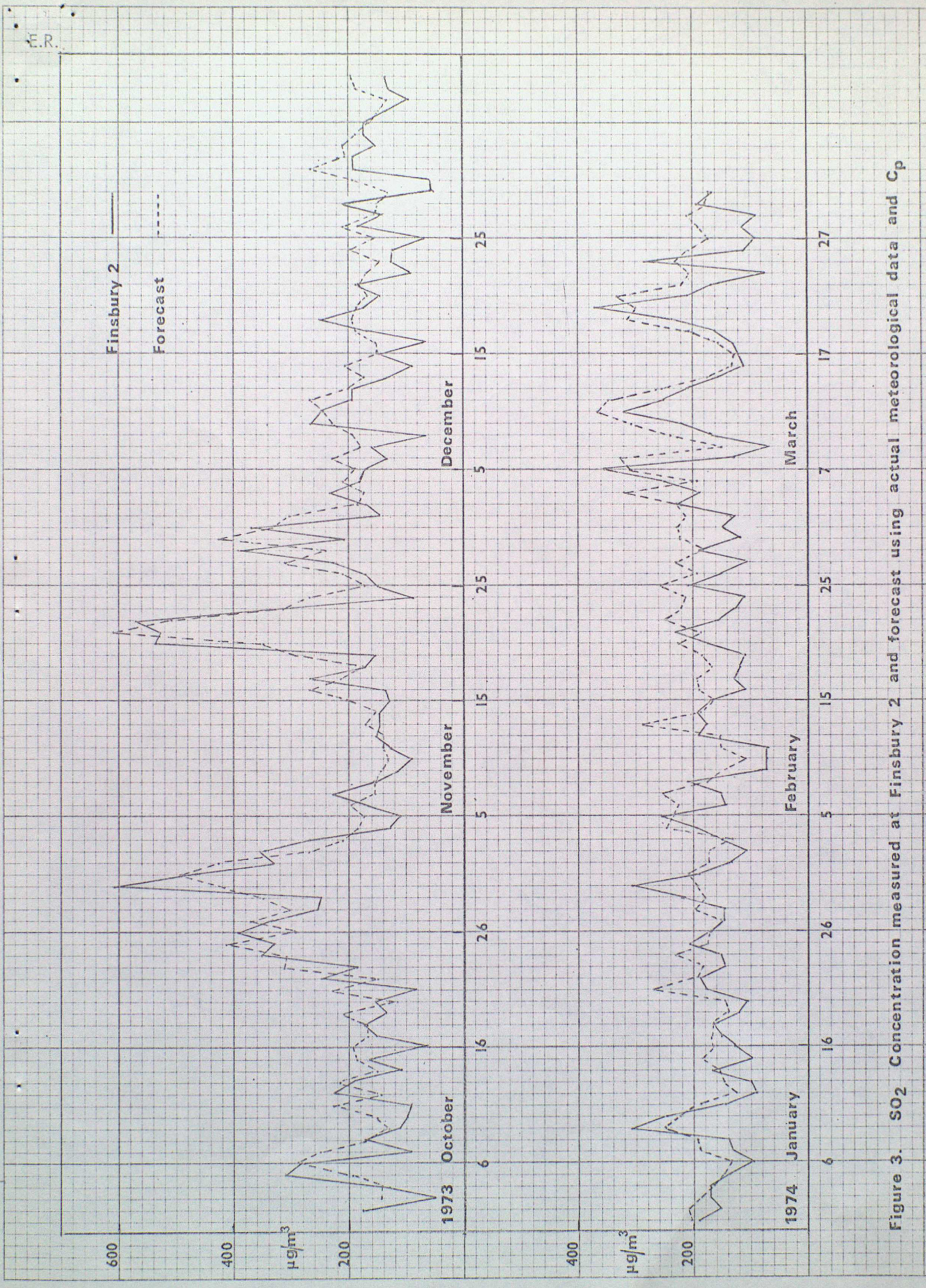
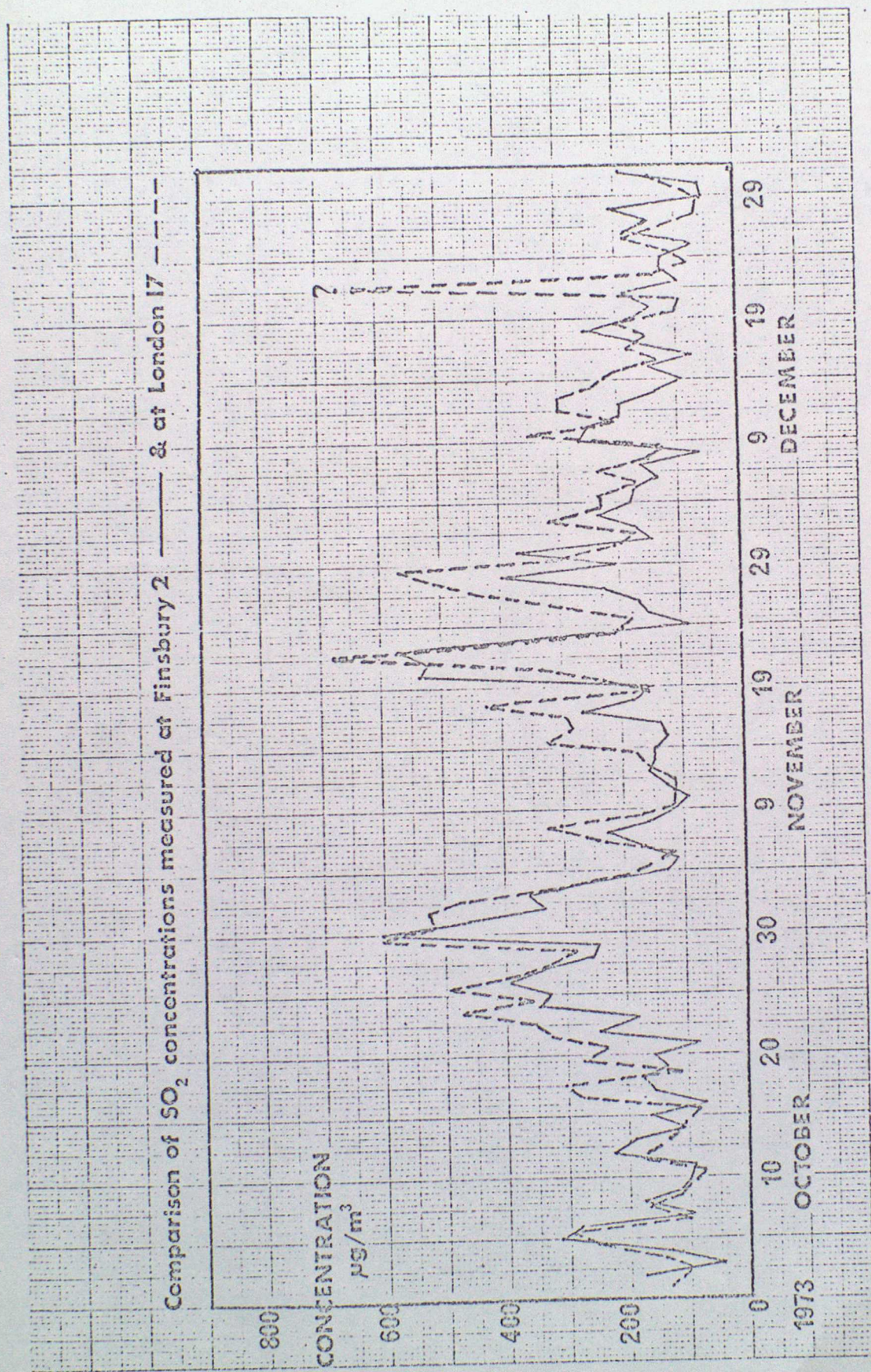


Figure 3. SO_2 Concentration measured at Finsbury 2 and forecast using actual meteorological data and C_p



— Figure 4 Finsbury 2 and London 17 SO₂ concentrations

CORRELATION between scheme-derived
concentrations lagged in time.

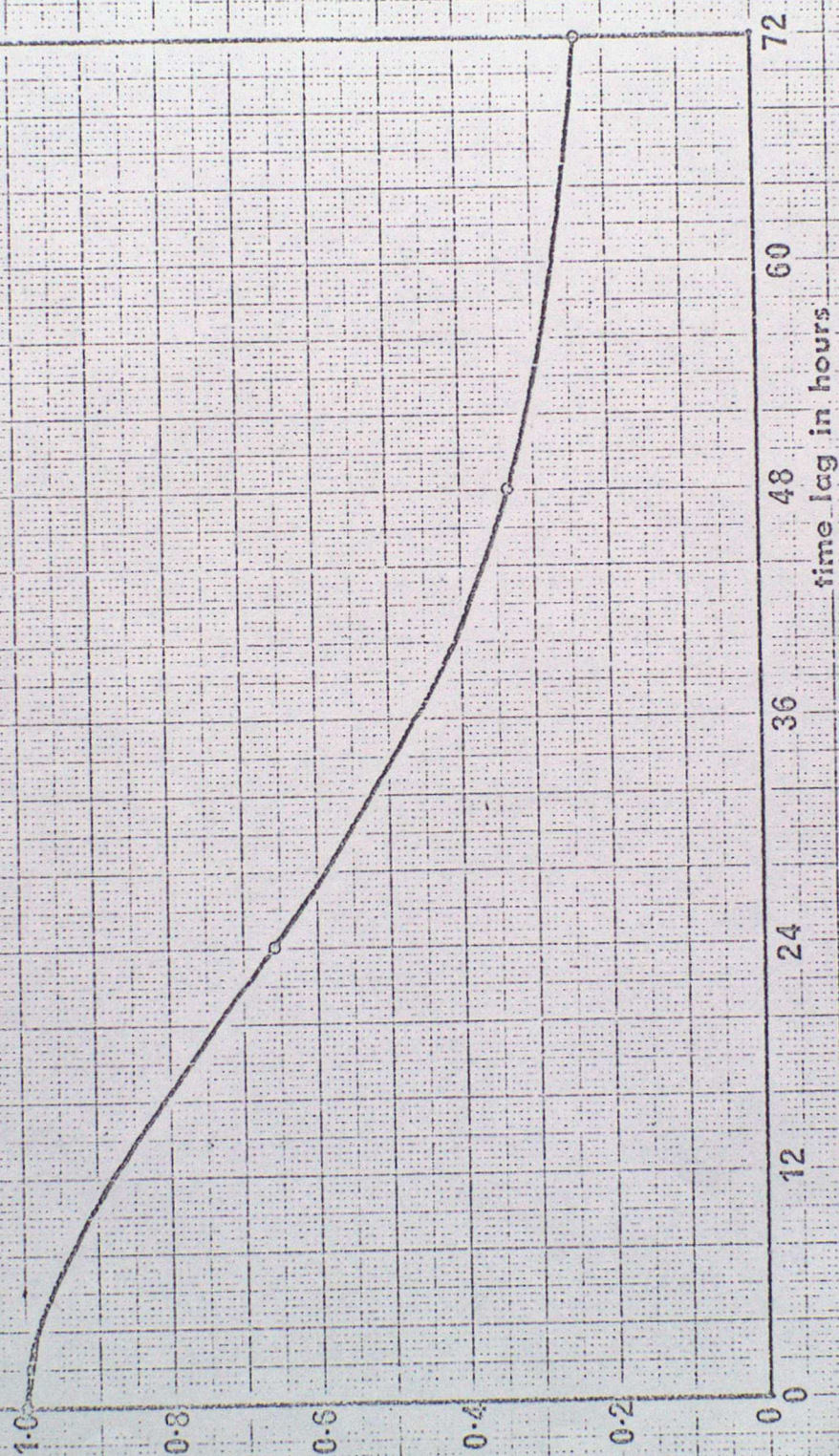


Figure.5. Correlation between scheme - derived concentrations lagged in time

ERRORS IN FORECASTING METEOROLOGICAL PARAMETERS

2 in every 3 lie within
the ± 50 concentration
error bands

ΔH : hours of wind < 5 kts

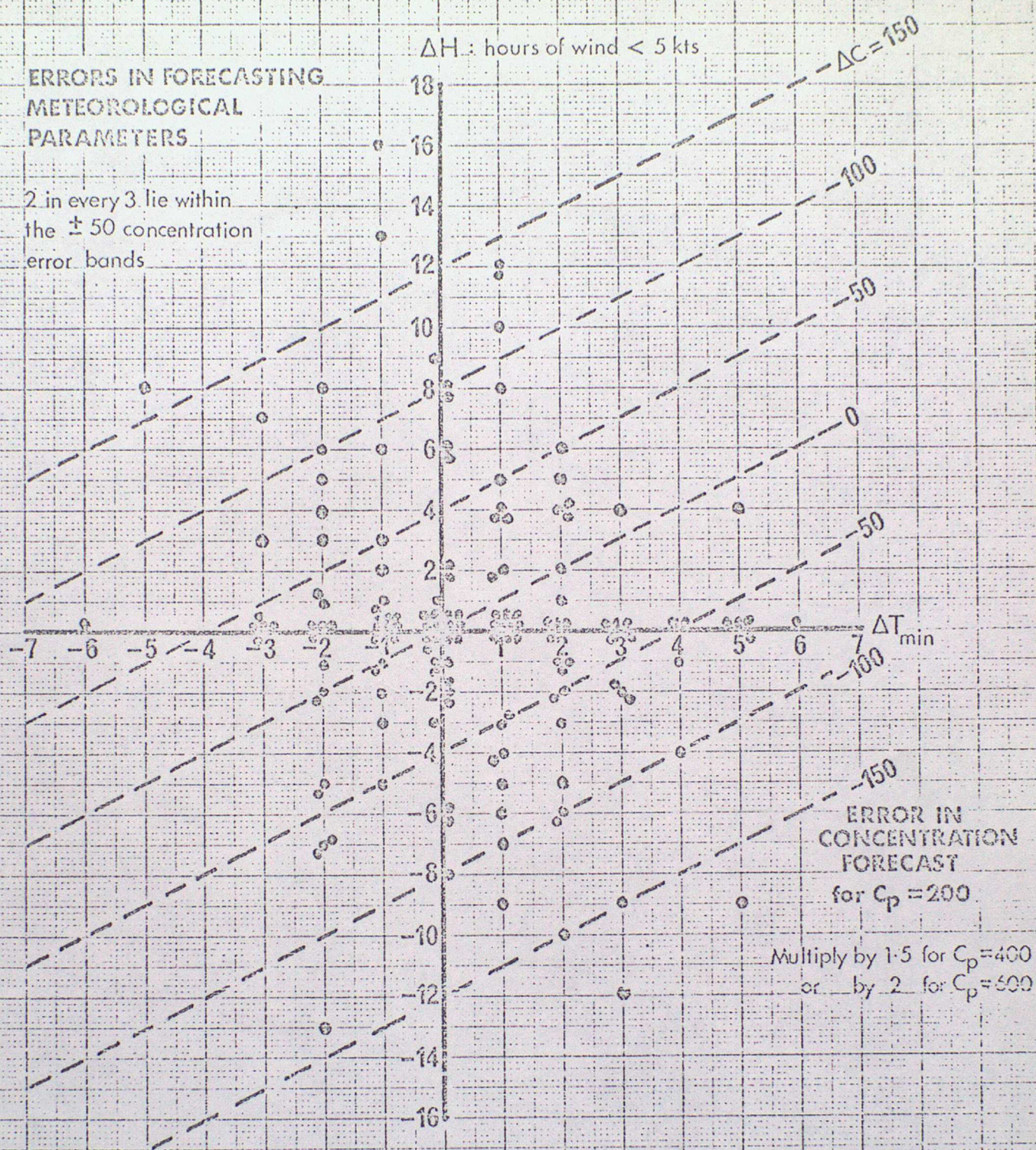


Figure.6. Errors in forecasting meteorological parameters