Bull. Disas. Prev. Res. Inst., Kyoto Univ., Vol. 19, Part 3, No. 163, February, 1970

Forecasting of Atmospheric Stagnation in the Kyoto Basin

By Chotaro NAKAJIMA

(Manuscript received October 31, 1969)

Abstract

The Kyoto basin is surrounded on three sides by mountains about 300-500 m high. So, in winter, temperature inversion is apt to develop in this basin. Sea breezes do not come directly from the sea. In Kyoto, there are not such large factories; however the concentration of air pollution increases as much as that of a big industrial city, especially on winter mornings. We observed the temperature distribution in the vertical north-south cross-section in the Kyoto basin using thermister thermometer recorder mounted on a small plane. After analysing the vertical distributions of temperature and wind, we find that the difference between minimum temperatures on the top of Mt. Hiei and at the bed of the Kyoto basin is a good indicater of the air pollution in the Kyoto basin.

We examined the variation of the concentration of pollutants, the index of stability described above and the height of the 500 mb surface over Japan for winter days over two years. We found a high correlation between these elements. With these facts, we discussed the possibility of forecasting atmospheric stagnation in the Kyoto basin.

1. Introduction

Prevention of air pollution has been seriously considered in many cities of the world along with the development of modern industry. Control of the source of pollutants is the most essential and effective; however at the same time harmonious existence with industrial development is also important. Accordingly, from the economic point of view, it will be necessary to control it step by step based on climatic conditions. It will be necessary to forecast the air condition as the atmospheric potential for air pollution. This potential must indicate the degree of diffusion of the air pollutants.

The kinds of air pollution forecasting which are now investigated are short range (for several hours) and long range (for several days). As the example of the former case, there is a system-engineering method, which T. Takamatsu applied to forecasting air pollution in the Osaka District. And diffusion equations are mainly used. As the example of the later case, there is a study by M. E. Miller and a study by G. C. Holzworth; and this calls in question the large scale of forecasting climatic conditions which causes diffusion. Consequently, the problem is how to make ordinary weather forecasting agree with air pollution forecasting.

Here, we shall mainly discuss things from the latter point of view. Generally it is understood that the more diffusion decreases the more air pollution concentration increases; it is normal to forecast the case of low wind velocity and stable stratification as the climate condition of decreasing diffusion. This phenomenon occurs along with a larger scale of developed highs in weather charts. With cities which are located on the west coast of the continent, such as Los Angeles and Santiago de Chile, the behavior of the middle latitude high becomes a big factor. It is known that in the case of a city like London, the development of the blocking high becomes a big factor. However Japan is located close to the east coast of the Asian continent and is located in the frontal region which is between the Siberian High and Pacific High, and is also an island having complicated topography, being surrounded by the sea. Accordingly air pollution potential is controlled based on a small scale synoptic situation. Besides in this area, there is the effect of the local weather situation such as land and see breezes and the cold air lake of the basin.

The Kyoto basin is a basin which has a population of one million and is

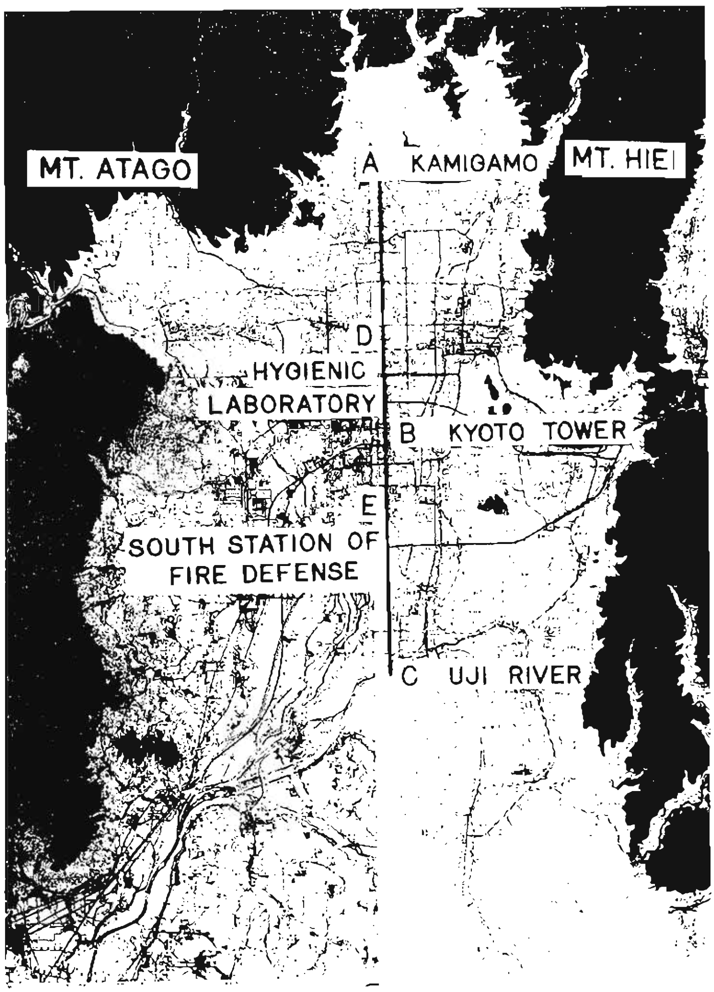

Fig. 1 Map of the Kyoto basin. Shaded area is the area 200 m higher than mean sea level. Thick straight line is the north-south flight course. A: North Point (Kamigamo) B: Kyoto Tower near Kyoto station C: South Point (Uji River) D: Hygienic Laboratory E: Fire Station.

around 10 km in diameter, surrounded on three sides by mountains about 300-500 m high, in the north, east and west directions respectively. In this basin the see breeze does not come in directly, and especially in winter it shows the typical characteristics of a basin. We shall describe the method of air pollution forecasting in the area where an inversion layer is apt to be found in winter.

In the Kyoto basin, there are not such large factories; however the concentration of pollution occasionally increases as much as that of a big industrial city, especially on winter mornings. This is because of its bad climatic condition. Fig. 2 shows the annual change of concentration of SO_2 in Kyoto for 1964-1968. We can see in this figure the high concentration in winter. Fig. 3 shows the mean hourly variation of concentration of SO_2 in winter. The highest concentration occurs at about 10 JST, and the secondary high appears in the evening in Kyoto.

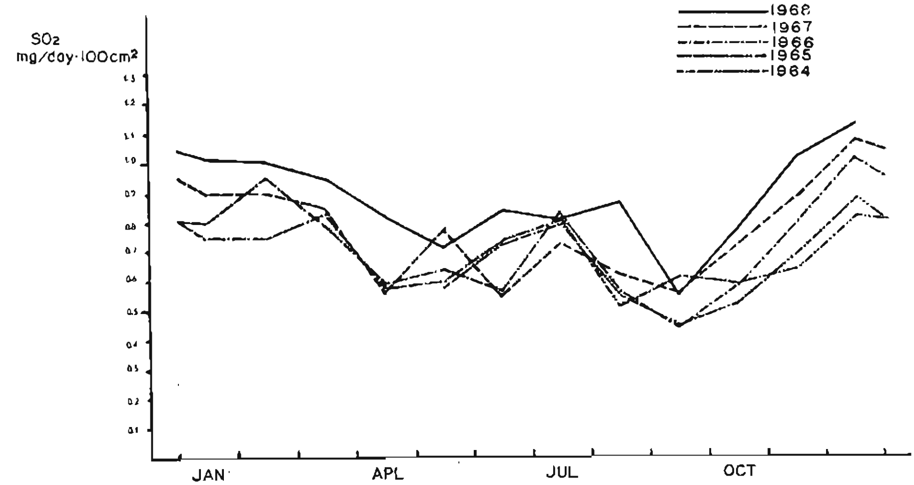

Fig. 2 Annual change of the concentration of SO_2 in Kyoto. (Mean of the values observed at 5 points).

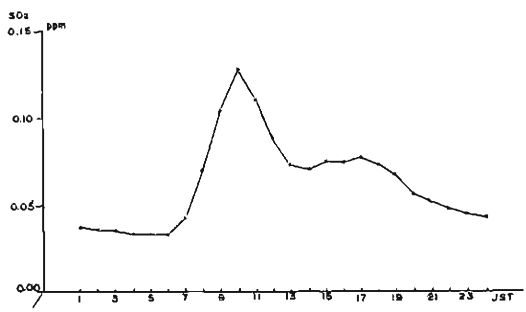

Fig. 3 Daily variation of the concentration of SO_2 in Kyoto. (Mean of the values observed at 5 points).

2. Inversion of Temperature Stratification

In order to know the actual condition of temperature inversion which occurs in the early morning in the Kyoto basin, we investigated the distributions of the vertical sectional distribution of temperature along a line lying from north to south in the centre of Kyoto city with a length of 15 km by using a small plane in the early morning of March 14, 1967. For our observation, we fitted a thermister thermometer with a white cylindrical cover on the prop of the main planes. We had the ventilation arranged naturally along the movement of our plane. We kept a record on the recorder in the plane.

The southern end of this basic line is 15 m above sea level, and the northern end is about 70 m above sea level, and the height difference is about 55 m for the 15 km horizontal length. We started at 6 : 48 from the southern point at a flight level of 100 m, with an upper flight level of 150 m at the half way mark, and passed the northern point at 6 : 58, and then turned round and started from the nothern point at 6 : 59 at a flight level of 200 m for the southern point. Finally, we arrived at the southern point at the 1000 m level at 7 : 50 and finished the first observation. We investigated the second time from 8 : 19. The schedule of our observation was as follows.

	First time	Second time
Flight level	Southern point : Northern point	Southern point : Northern point
100 m	6 : 48 ⟶ 6 : 58	8 : 19 ⟶ 8 : 28
200	7 : 08 ⟵ 6 : 59	8 : 38 ⟵ 8 : 29
300	7 : 09 ⟶ 7 : 18	8 : 40 ⟶ 8 : 48
500	7 : 28 ⟵ 7 : 20	8 : 58 ⟵ 8 : 50
700	7 : 30 ⟶ 7 : 39	9 : 00 ⟶ 9 : 08
1000	7 : 50 ⟵ 7 : 42	9 : 18 ⟵ 9 : 10

The day before our flight, the developed low passed the northern part of the Japan Sea and a cold front went down to the south over Kyoto at about ten.

The day of our observation was a fine day covered with the high, and the

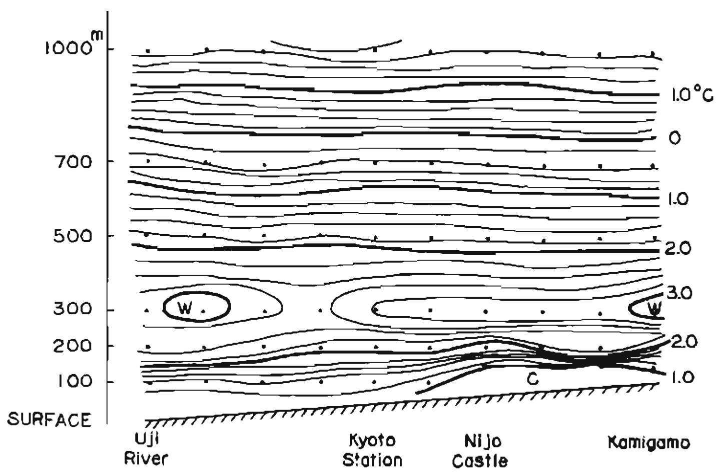

Fig. 4 N-S vertical temperature cross section in the Kyoto basin, observed from 6 : 48 to 7 : 42 Mar. 14, 1967.

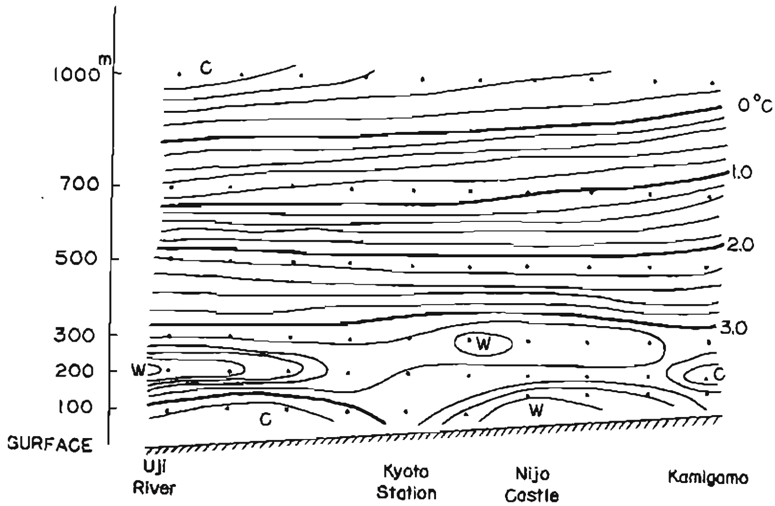

Fig. 5 Same as Fig. 4 but for 8:19 to 9:10.

center of the high was located north of Kyoto. On the morning of 14 th, at an altitude higher than about 300 m in Kyoto it blew the weak northwest wind and near the ground it was almost calm and blew a weak south wind. On the first flight, there was weak smog in the lower layer of the southern part. On the second flight the smog moved to the center of Kyoto and increased its thickness.

Fig. 4 and Fig. 5 show the result of this observation as a northsouth vertical

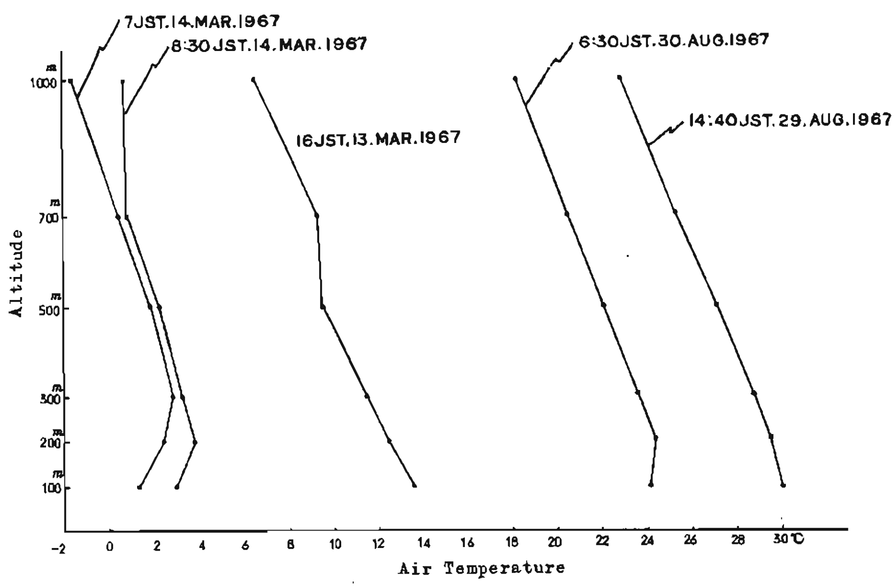

Fig. 6 Vertical distribution of the temperature in the Kyoto basin, observed in winter and summer (Mean values from Kyoto Station to Uji River).

cross section. It shows that the warmest layer exists at the height of 200-300 m and that below it is the inversion layer. This kind of observation was also made on the previous March 13 th at 16 : 00 after passing a cold front. At this time it blew the north west wind 7-10 m/sec., even on the surface. Our observation by flying was also made in the afternoon of August 29 th, 1968 and in the early morning of 30 th. Fig. 6 shows the vertical distribution of temperature in the winter and summer in Kyoto which is based on this information. This figure uses the mean temperature for the southern half of Kyoto at each level. The contrasts between winter and summer, in the early morning and in the afternoon are shown.

Thus in order to show statistically that the Kyoto basin is apt to develop an inversion layer, the comparison of the monthly mean lowest temperatures in winter time in Kyoto and Osaka is shown as follows. The coastal city of Osaka is 50 km from Kyoto.

	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.
Kyoto	11.8	5.9	1.3	−0.9	−0.5	1.9°C
Osaka	13.1	7.3	2.9	0.5	0.8	3.5°C

Near the top of Mt. Hiei (848.3 m) which is located on the east side of the Kyoto basin, climatic observations have been made for a long time. The difference between the daily lowest temperature at the top of this mountain and the daily lowest temperature at the bottom of the Kyoto basin is a good index for indicating the developing degree of the inversion layer. We named this the "Stability Index". Usually, this index takes a negative value, but on

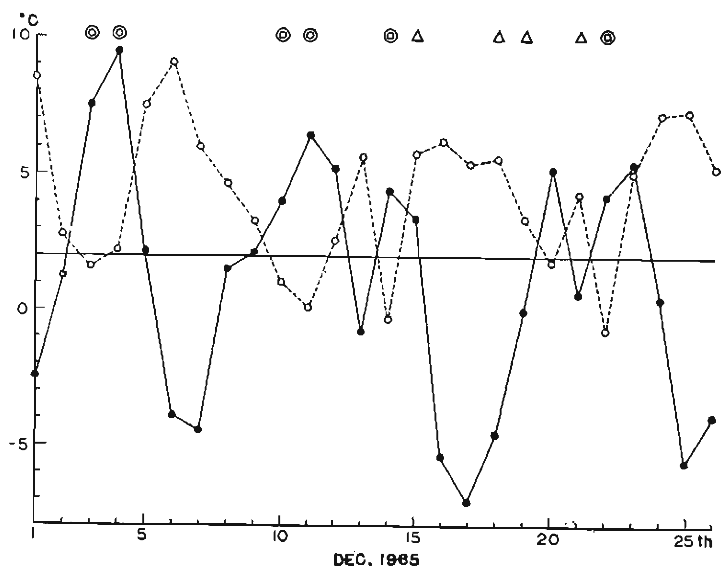

Fig. 7 Variation of "Statility index" (broken line) and the minimum temperature on the top of Mt. Hiei (848.3 m) (full line). But, stability index is shown in the opposite sense (For example, stability index −2°C is read as 2°C in temperature scale).

an extremely stabilized stratospheric day, the value bacomes positive. The day having an index greater than $-2°C$ can be considered as a day on which an Inversion layer is developed. This is clear from Fig. 7. The abscissa of Fig. 7 shows the dates from December 1 st 1965 to 26 th, and the ordinate shows the above mentioned Stability Index. The dotted line shows the variation of the Index. The solid line shows the lowest temperature at the top of Mt. Hiei for reference. Double circles shows the day of the higher concentration of SO_2 in Kyoto, triangles shows the day on which the concentration of only suspended particulate is high. Examples of annual variation of days on which the Stability Index is greater than $-2°C$ is as follows:

1966								
Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
7	9	3	4	2	3	14	19	13
1967								
Jan.	Feb.	Mar.						
8	5	15						

3. The Characteristic of the Wind in the Kyoto Basin

In the Kyoto basin, the wind velocity is generally weak as compared with that of Osaka, which faces the sea. However, the wind both in Kyoto and Osaka is stronger in November and December than in January and February, when the temperature goes down to its lowest. This phenomenon is well equivalent to the distribution of days on which Instability Index is greater than $-2°C$.

Fig. 8 shows the results of measuring the wind velocity by a pilot balloon that were observed in the centre of the Kyoto basin from the evening of March 1 st, 1967 to the afternoon of 2 nd. One arrow feather corresponds to 1 m/sec.

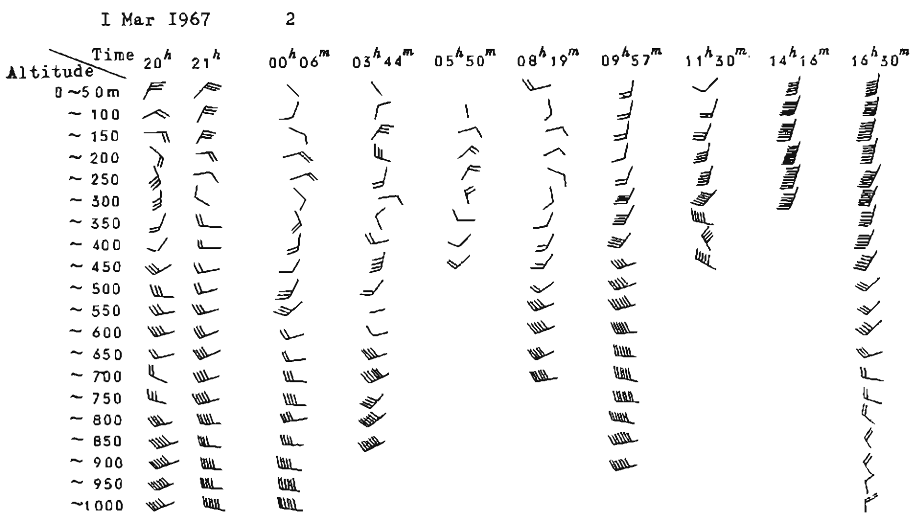

Fig. 8 Vertical distribution of the wind velocity observed at the municipal hospital near Kyoto Station. One barb indicates the wind speed of 1m/sec.

This day was a fine day covered with the moving high, and in the evening an inversion layer developed. However, as a low passed north of Kyoto in the evening of 2nd the south wind became strong. So, the SO_2 concentration became maximum not only in the morning but also in the afternoon an extreme value was produced by the south wind. We can presume from this example that there exists a complex relation between the wind near 1000 m and the wind at the bottom of the basin, which cannot be easily explained only by eddy friction. The distribution of the wind at the bottom of the basin on winter mornings is very complex because the wind is weak and the orographic effect is complicated.

4. Relalion between Air Pollution and Rainfall

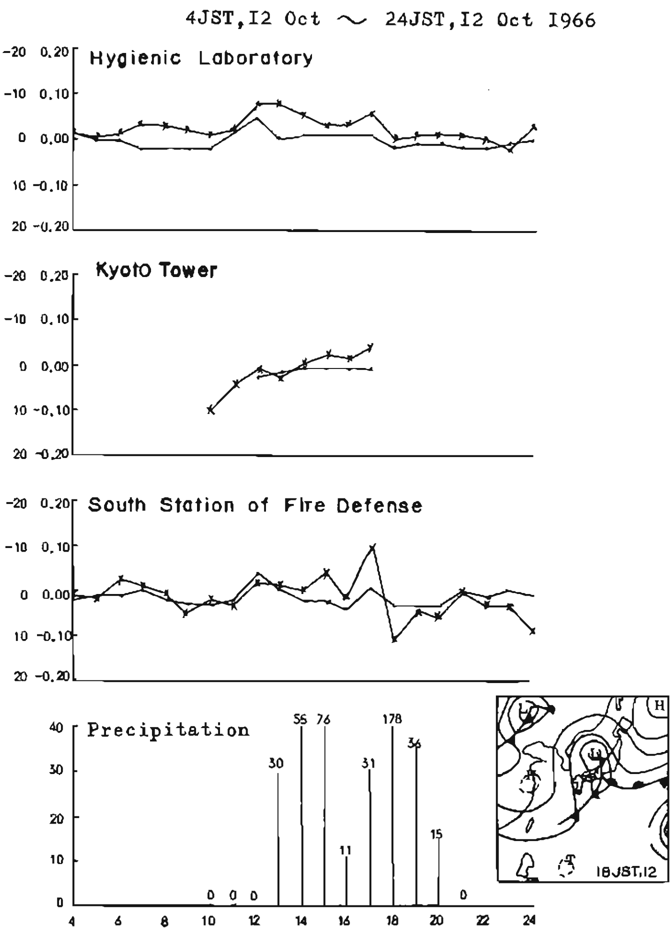

Fig. 9 Relation between the rainfall and the concentration of pollutants. The curves with dots indicate the daily variation of the SO_2 concentration (ppm), and the curves with crosses indicate the suspended particulate concentrations, (Transparency %). These values are indicated by the deviation from the monthly mean for each time. Hourly precipitation is shown by unit mm.

We investigate whether the rainfall in the Kyoto basin rolls the clarification of air pollution. For our investigation we investigate the comparison with the rainfall variation and SO_2 concentration and suspended particulate which is observed by automatic measurement at three places, Kyoto South Fire Station, Kyoto Tower and Kyoto Hygienic Laboratory concerning all the days of daily rainfall over 2 mm from April to December 1966. Fig. 9-11 are the examples. The axis of the abscissa is time. SO_2 concentration is shown by unit ppm and the suspended particulate is shown by the transparency rate (%). Moreover, these values are shown as the deviation value from the monthly average value at every time. So the effect of normal daily variation is eliminated.

Fig. 9 is the example when it rained more than 450 mm in 10 hours on October 12 th 1966 in the Kyoto basin; in this case, the cleaning effect by precipitation is not so distinct. Fig. 10 is the example of December 15 th 1966, and there existed two lows in the north and the south of Kyoto on the weather chart,

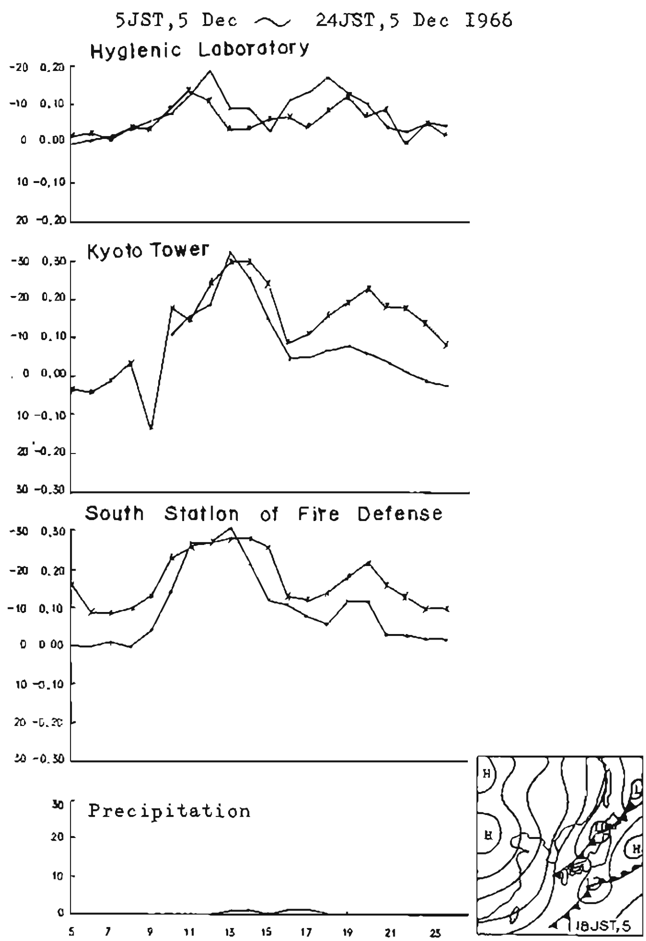

Fig. 10 Same as Fig. 9 but for another weather condition.

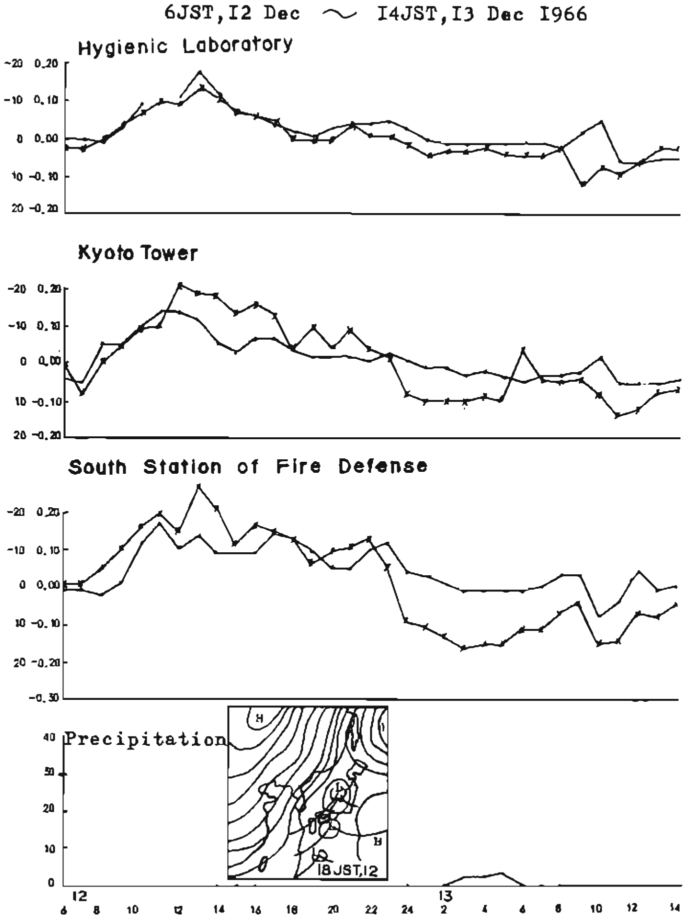

Fig. 11 Same as Fig. 9 but for another weather condition.

and there was light rain in the afternoon. This kind of weather pattern is the pattern where the concentration of pollutant becomes very high; and on this day it indicates a considerably high concentration. The clarification by the rainfall is scarcely seen and, on the contrary, the element of preventing the diffusion of pollutants strongly appears. Fig. 11 is the example of 12 to 13 December 1966 when the weather pattern changes to the winter type after passing a low. At the time of passing of the low, the pollutant concentration goes up high because of the same reason for the above example, but after passing the cold front which accompanies the light shower on the early morning of 13th, the air becomes remarkably clear because the wind becomes strong and a fresh current is introduced.

From the result of investigating the 66 rainy days, clarification by rainfall does not appear so much clearly. On the contrary, it is shown that with weather which causes light rain pollution is apt to occur. In the case where the north wind becomes strong after passing the cold front, the air is cleared.

5. Forecasting Air Pollution in the Kyoto Basin

The forecasting of air pollution is divided into forecasting the drainage source and forecasting the atmospheric air pollution potential. The former is controled by the active degree of factories and the amount of traffic; here we shall not describe this. The atmospheric potential differs according to the geographic location and topography. In general, for instance in the case of London or Los Angeles, this potential is related to the considerably large scale of the atmospheric pattern and its variation is very loose.

However in the case of Japan, the season when air pollution is apt to occur is the winter and, besides winter, when the Siberian continental high is weaker than the ordinary winter and when a front exists near Japan. In such a case the weather is apt to vary and it is rate for the same potential to continue for more than 10 days.

In Fig. 12, four surface weather maps for the days with high concentrations of pollutant in Kyoto are shown. As shown in these figures, Japan is not covered by a strong large high, but also by a weak moving high. In many such cases, the low approaches western Japan. On these days, the temperature is relatively higher than that of usual days. This fact is shown also in Fig. 7 indicating the variation of the minimum temperature on the top of Mt. Hiei. When the temperature of free air is relatively high and no cloud exists at night as in this case, strong inversion develops in the basin by radiation cooling. Kyoto is not directly affected by sea breezes and is favourable for the developement of a cold air lake, so the inversion is apt to develop in Kyoto rather than in Osaka or Kobe. For this reason, it is important to forecast the minimum temperature on the top of Mt. Hiei and cloudiness at night time in order to

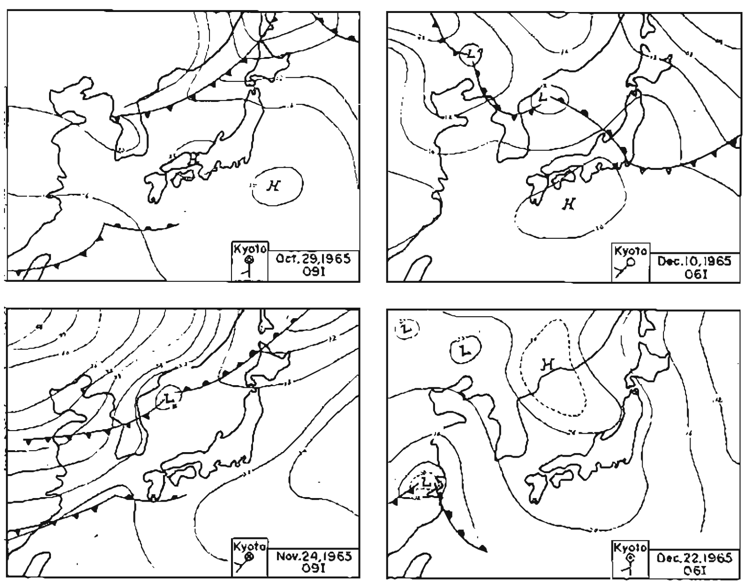

Fig. 12 Surface weather maps favourable for the high concentration of pollutants.

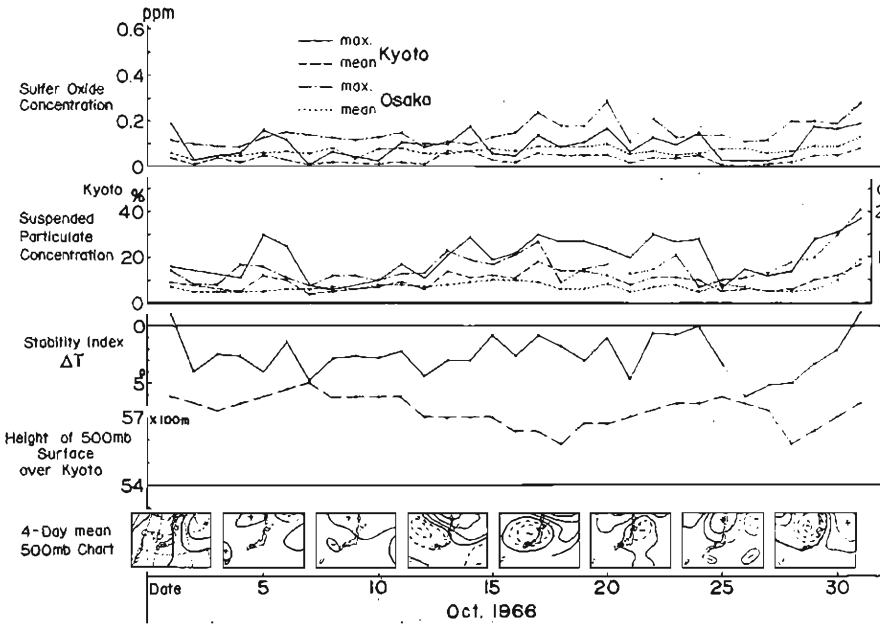

Fig. 13 Variation of the concentration of pollutants, stability index, height of 500 mb surface over Kyoto and 4-day mean 500 mb chart (deviation from the normal) in Oct. 1966.

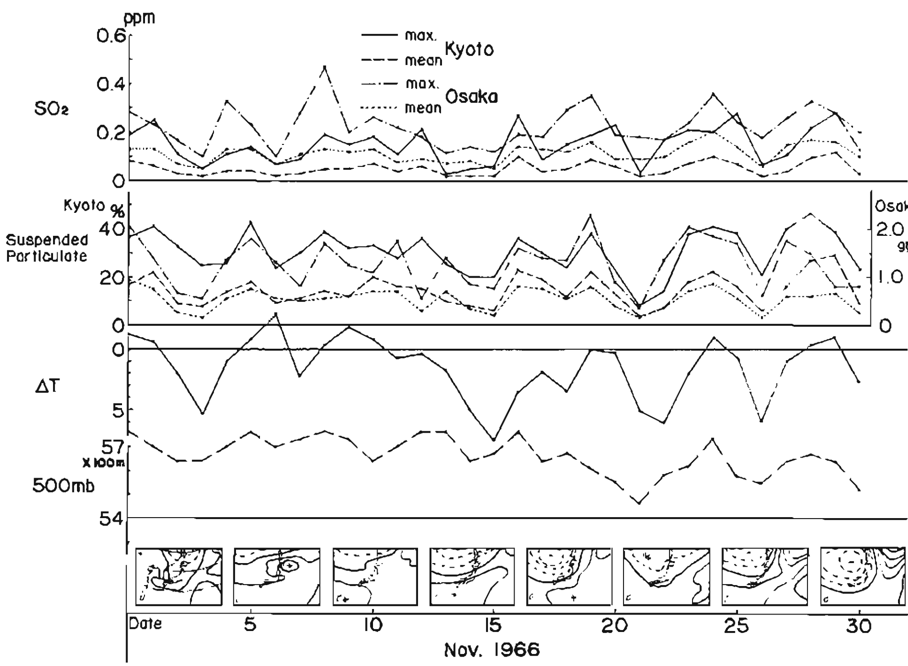

Fig. 14 Same as Fig. 13 but for Nov. 1966.

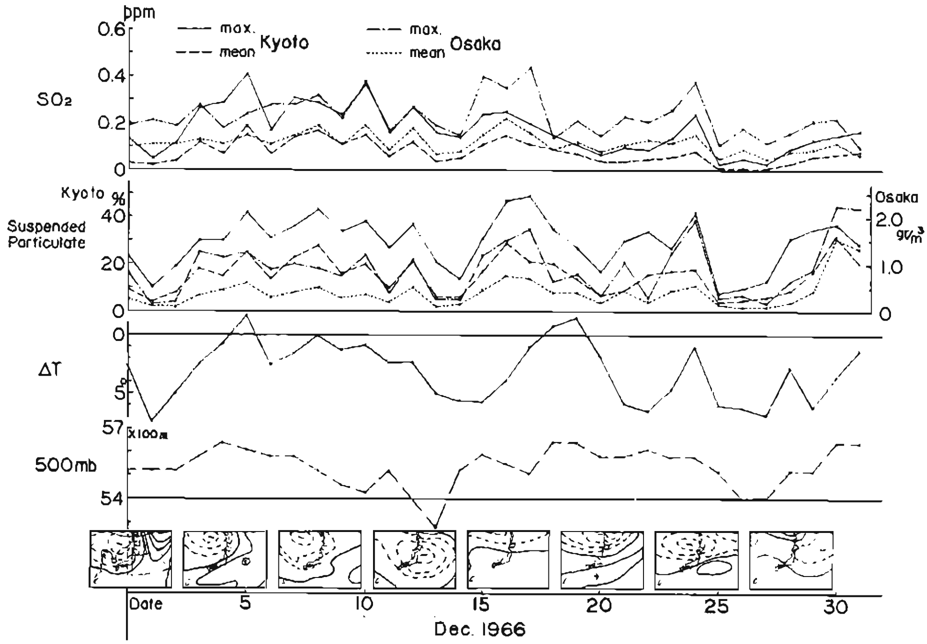

Fig. 15 Same as Fig. 13 but for Dec. 1966.

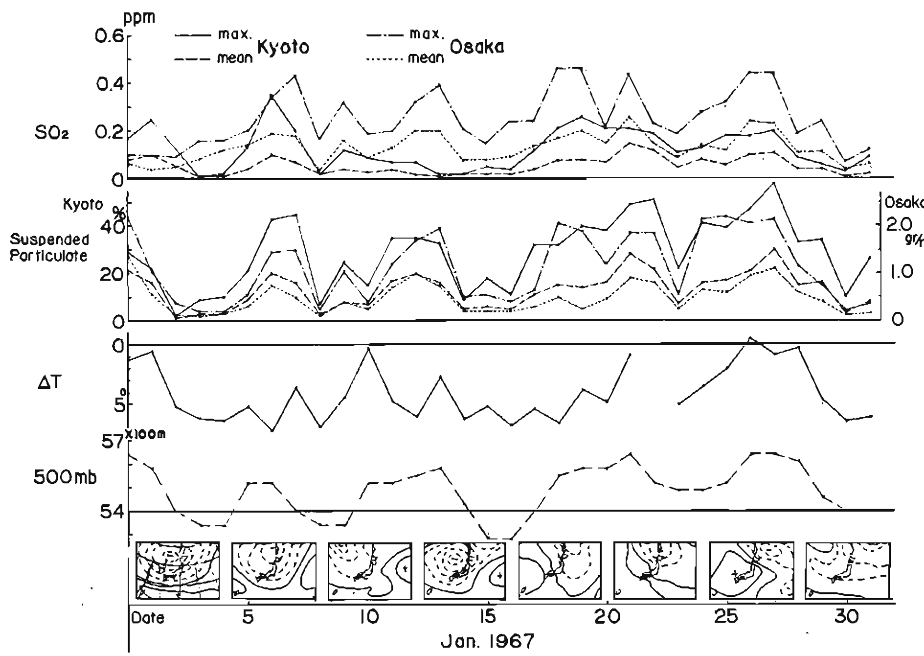

Fig. 16 Same as Fig. 13 but for Jan. 1967.

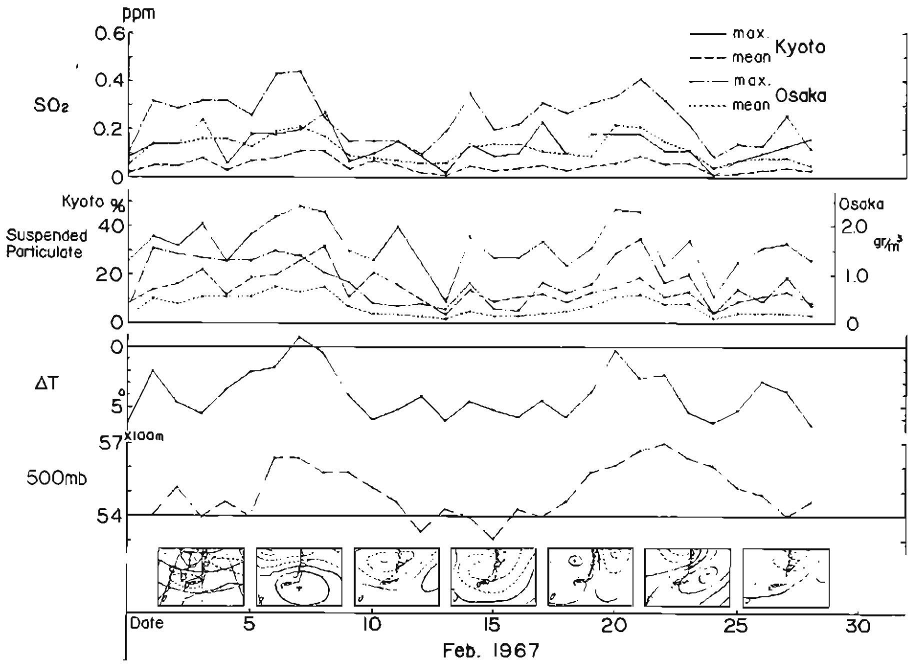

Fig. 17 Same as Fig. 13 but for Feb. 1967.

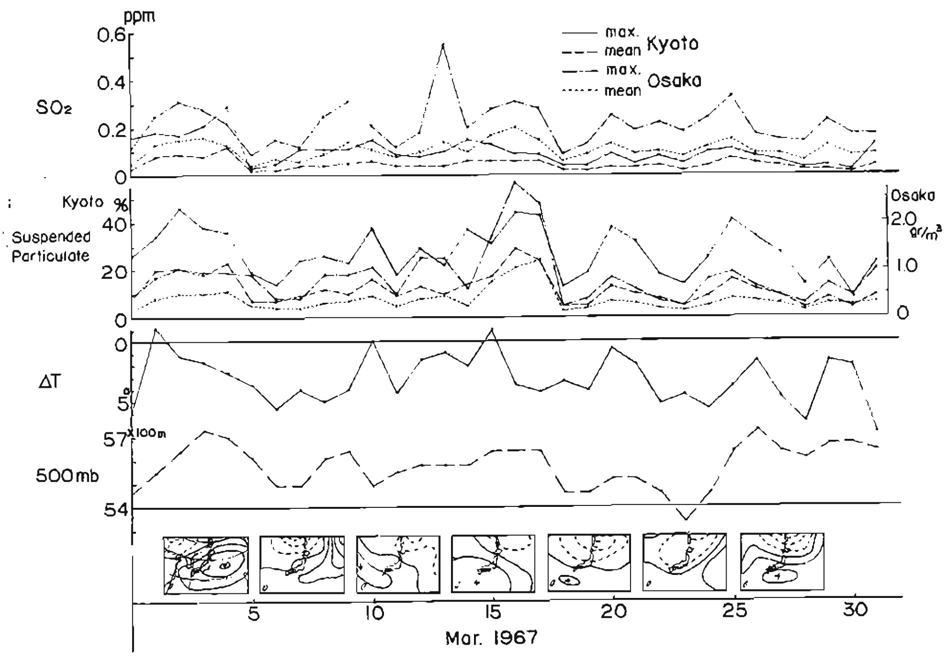

Fig. 18 Same as Fig. 13 but for Mar. 1967.

forecast the air pollution in the Kyoto basin. This is the forecasting of atmospheric potential for air pollution.

The final purpose of forecasting air pollution is so as to prevent it. For actual work to prevent air pollution, several or 10 days forecasting is hoped for. For the preparation of such prolonged forecasting, the work shown in Fig. 13-18 is done. Two winter seasons are analysed, but here the first half for Oct. 1966-Mar. 1967 is shown. In each figure, the top curve shows the daily mean and maximum concentration observed at the Hygienic Laboratories in Kyoto and Osaka. Secondly, the concentration of the suspended particulates observed at the same places are shown. However, in the case of Kyoto the values are shown as transparency rate (%), but in the case of Osaka the values are shown by the unit gr/m. Thirdly, the stability index (the difference between the minimum temperatures at the top of Mt. Hiei and at the Kyoto meteorological observatory at the bottom of the basin) (full line). Fourthly, the height of 500 mb surface over Kyoto for 21 JST (unit m, broken line). Finally, the charts shown in these figures are the 4-day mean 500 mb height patterns, but for the deviations from the normal. In mid winter, generally, the negative deviation area over Japan indicates the strong wind winter type (corresponding to weak air pollution), and the positive deviation area over Japan indicates the warm winter type (corresponding to strong air pollution). So we must examine whether all the curves in these figures vary in the same phase. After this examination, we concluded that the phase of the variation of all the curves is relatively similar from November to the following February. The results are not so good for October of March. So for the mid winter we can forecast the atmospheric potential for the air pollution if we can obtain the deviation chart of 4-day mean 500 mb pattern as the progno-chart.

Acknowledgements

The authors are much indebted to the members of the applied climatology research section of the Disaster Prevention Research Institute and the members of the Hygienic Bureau of Kyoto City for their cooporation in making the observations.

References

1) Botteger, C. M. and H. J. Smith : The Nashville Daily Air Pollution Forecast, Monthly Weather Rev. Vol. 89, 1961, pp. 477-481.
2) Holzworth, G. C. : A Study of Air Pollution Potential for the Western United States. J. Appl. Met., 1, 1962, pp. 366-382.
3) Niemeyer, L. E. : Forecasting air Pollution Potential, Monthly Weather Rev. Vol. 88, 1960, pp. 88-96.
4) Osaka District Met. Obs : Air Pollution in Osaka, 1968.
5) Stern, A. C. : Air Pollution, 1968.
6) Takamatsu, T. : Computer Control System for Air Pollution. 4th Congress of the IFAC, Poland, 1969.