Vertical and Horizontal distribution of Ozone covering Kanagawa Prefecture, Japan

Shinji WAKAMATSU*
Toshiichi OKITA**

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Abstract

A series of measurements of ozone concentration and temperature up to an altitude of 1000 m were made in Kanagawa Prefecture using a helicopter. Various flight patterns were designed to provide appropriate data for determining both horizontal and vertical pollutant profiles. At altitudes below the zenith of sea breeze, high concentrations of ozone were observed and maximum ozone was detected under the inversion layer. This layer was formed in a three dimensional convergent area of wind. Observations made on a ferry boat across the Tokyo bay, showed that oxidant concentration was at a peak at the center of the bay under diverging conditions. Horizontal ozone profile at an altitude of 300 m showed a similar distribution to the ground level concentration of oxidants.

Introduction

The vertical distribution of ozone concentrations in the planetary boundary layer forms a basis of an investigation of the formation of photochemical oxidants. Lea[1] measured ozone profiles using ozonesondes on the coastal edge of the Oxnard Plain, 75 km west of downtown Los Angeles. The soundings showed that maximal ozone concentrations was detected above the base of low-level temperature inversion. Edinger et al.[2),3)], and Gloria et al.[4] made similar observations over Los Angeles Basin using aircraft. The results of these measurements showed that the maximum levels of photochemical oxidants occurred between the top and bottom of the temperature inversion. Miller et al.[5] observed that the oxidant concentration in the lowest few hundred meters rapidly increased when the inversion layer detorited. They also found high oxidant concentration at the crests of a wavy inversion layer. Miller et al.[6] measured the vertical distribution of total oxidants and temperature over Central Valley, Sierra Nevada foothills. They observed maximum total oxidant at the top of the inversion layer in the morning and the pollutants were transported following the upslope wind in the afternoon.

The results of these investigations indicate that the data obtained at the ground level station do not provide a firm basis for the explanation of the

* Department of Sanitary Engineering, Faculty of Engineering, Hokkaido University, Sapporo, Japan.
** Institute of Public Health, Shiroganedai Minatoku Tokyo, Japan.

mechanism of oxidant formation and thus a three dimensional survey is useful, although their data are still insufficient for the explanation of the vertical ozone profile.

One of the most important factors controlling the vertical distributions of ozone and other pollutants may be the vertical profile of temperature and winds and especially the vertical wind component would be significant. Vertical wind profiles have been measured by several investigators. Lyons and Olsson[7], Lyons and Cole[8] analyzing the lake and land breeze in the Chicago area ascertained the effect of Lake Michigan on the mesoscale pollution dispersion regimes.

According to their observations there was a well developed circulation which extended from about 15 km inland near the shore with a rather a strong vertical velocity of 1 m sec^{-1}. Angell et al.[9] observed the vertical motion over the Los Angeles basin using constant volume balloons (tetroons). The results to their measurement showed a very large oscillation of the tetroons in the daytime. Edinger[3] suggested that the photochemical oxidants moved up the heated mountain slope and stayed between the top and bottom of the temperature inversion.

In this study the vertical motion was calculated using divergent analysis from the data of multi-pibal flights and the relationship between the vertical ozone and temperature distributions was analyzed.

Observations

Kanagawa Prefecture and its vicinity are shown in Fig. 1. Here sea and land breeze occurs under a weak atmospheric pressure gradient and intense solar radiation. The sea breeze occurs at first on the southern and eastern

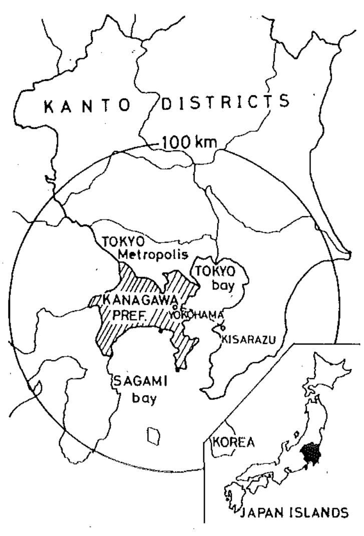

Fig. 1. Map of Kanagawa prefecture and its vicinity.

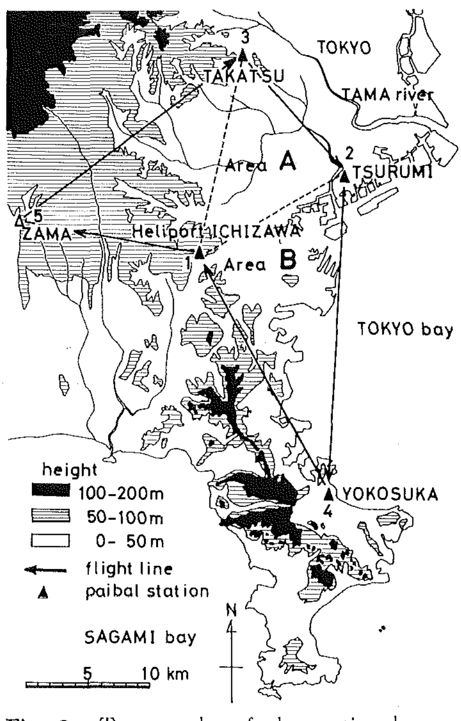

Fig. 2. Topography of observational area.

coasts in the morning and gradually penetrates into the interior of the land. Before noon the wind becomes stronger with its direction almost from the south but the wind weakens as it penetrates into the land and stagnation often occurs. Near the stagnant area oxidant concentration shows a tendency to have elevated values[10]. Topographical features of the south-eastern part of the Kanagawa Prefecture is shown in Fig. 2.

On July 17, 18 and 19 of 1973 the observations of vertical wind profile were made using pilot balloons, and measurements of total oxidants ozone and air temperature were made using an instrumented helicopter. A major effort was made to obtain the vertical ozone distribution up to about 1000 m on July 17 whereas on July 18 and 19 the horizontal distributions of ozone were observed on the helicopter. Ordinary single-theodolite pilot balloon observations were made at four stations (Ichizawa, Tsurumi, Takatsu and Yokosuka) as shown in Fig. 2. The vertical speed of the balloon was adjusted to 200 m min^{-1} in still air. A thermister (model ET-3AR, TAMAYA Co. LTD) loaded on the helicopter was used to measure the vertical temperature profile. The accuracy of this instrument is below 0.2°C and a response time of less than one second. Measurements of ozone were made with chemiluminescence ozone monitors (model GLX-11, DENKIKAGAKU KEIKI Co. LTD and model OX-21, KYOTO DENSHI Co. LTD). Both monitors have a sensitivity of below 1ppb and response time of less than one minute. These instruments were loaded on a helicopter to obtain vertical and horizontal ozone distributions. GX-2 KI analyzers (DENKIKAGAKU KEIKI Co. LTD) were used to record the ground level oxidant concentrations at 43 air monitoring stations in Kanagawa Prefecture.

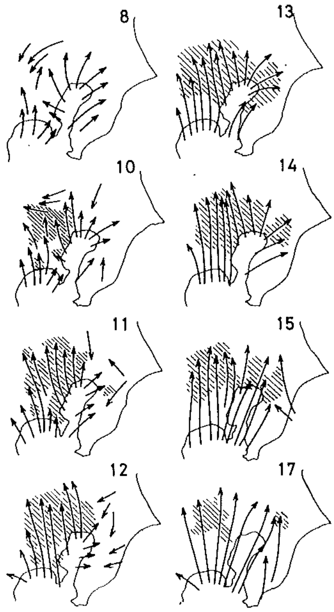

Fig. 3. Air flow pattern and distribution of oxidants near the ground on July 17, 1973. Hatched area indicates the area of more than 10 pphm of oxidants. Numerals in the figure are the time of observation in JST.

Results and Discussion

The weather condition on July 17, 18 and 19 were fairly typical in this season. A predominant northern Pacific high cell covered the Japanese archipelago and the pressure gradient was weak. The weather was fine and high extreams in temperature at ground level exceeded 30°C and the average wind velocity was below 3.0 m sec^{-1} as reported by the Yokohama Local Meteorological Observatory. Under these conditions, high concentrations of oxidants were observed in the sea breeze area. Therefore during these three days typical photochemical air pollution in the Kanagawa Prefecture was seen.

July 17

On July 17 a helicopter loaded with instruments made two flights starting at 0930 and 1330 JST. Each flight took off at the Ichizawa heliport, and the flight plan covered Zama, Takatsu, Tsurumi and Yokosuka at an altitude under 1000 m. Stream lines and oxidant concentration at ground level from 0800 to 1700 JST are shown in Fig. 3. A sea breeze began early in the morning both from the Tokyo and Sagami bays. Oxidant levels began to rise before noon near the coast and the area of high concentration gradually moved inland. The vertical distributions of wind observed by pilot balloons at four stations showed that the sea breeze top was at approximately 500–600 m and the mean wind velocity was 2–3 m sec^{-1} in the morning and 3–5 m sec^{-1} in the afternoon respectively. Before noon a high oxidant

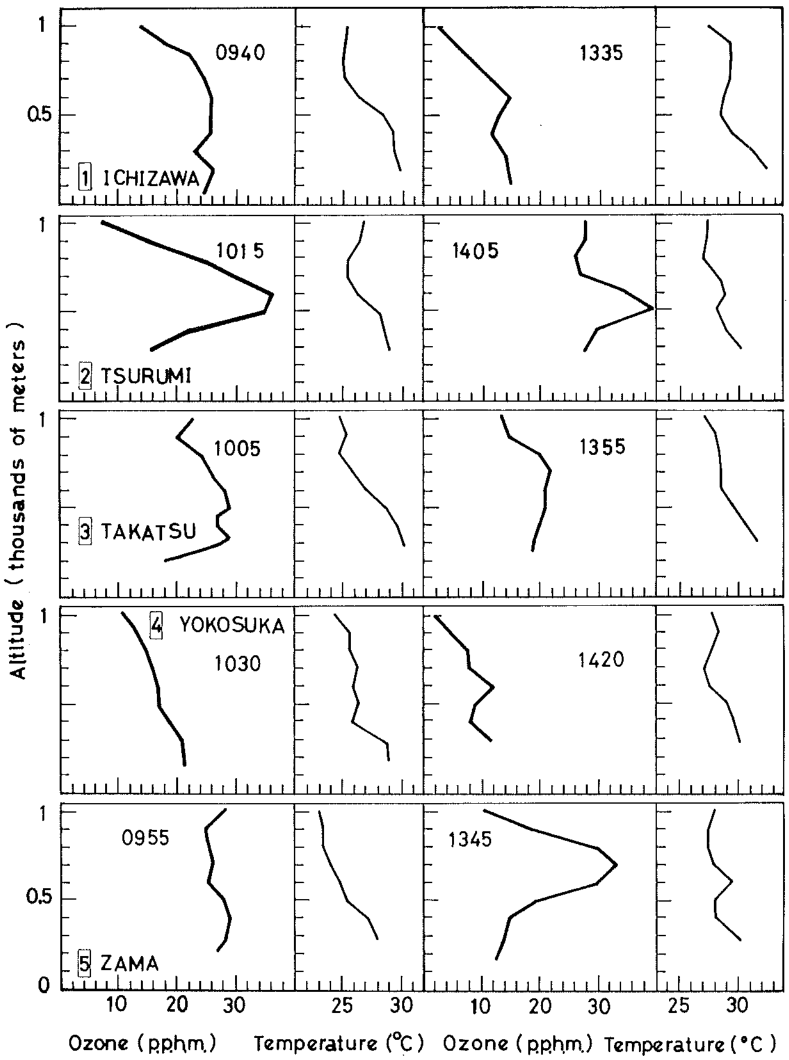

Fig. 4. Vertical distributions of ozone and air temperature on July 17, 1973. Numerals in the figure are the time of observations in JST.

concentration was detected covering the Kanagawa Prefecture. The vertical profiles of ozone concentration and temperature are shown in Fig. 4. In the morning at Yokosuka the concentration decreased with the altitude while at Zama, the concentration showed invariable throughout the layer. Over Ichizawa, Takatsu and Tsurumi areas maximal concentrations were observed between 500 and 600 m. This altitude was just below the height of the inversion layer. In the afternoon strong discontinuities in the vertical ozone distribution was observed above the base of the inversion layer.

The vertical distributions of horizontal divergence and vertical wind velocity were calculated from the pilot balloon data to obtain the relation between the vertical ozone profile and three dimensional structure of winds. Horizontal divergence Q and vertical velocity W_z are defined as,

$$Q=\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y} \tag{1}$$

where u and v are horizontal wind components at x and y directions respectively and,

$$W_z=-\frac{1}{\rho_h}\int_0^h \rho_z\left(\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}\right)dz \tag{2}$$

where z and ρ_z are the altitude from the ground level and air density respectively. Table 1 and Fig. 5 show the calculations and the areas A and B in Fig. 5 are as shown in Fig. 2.

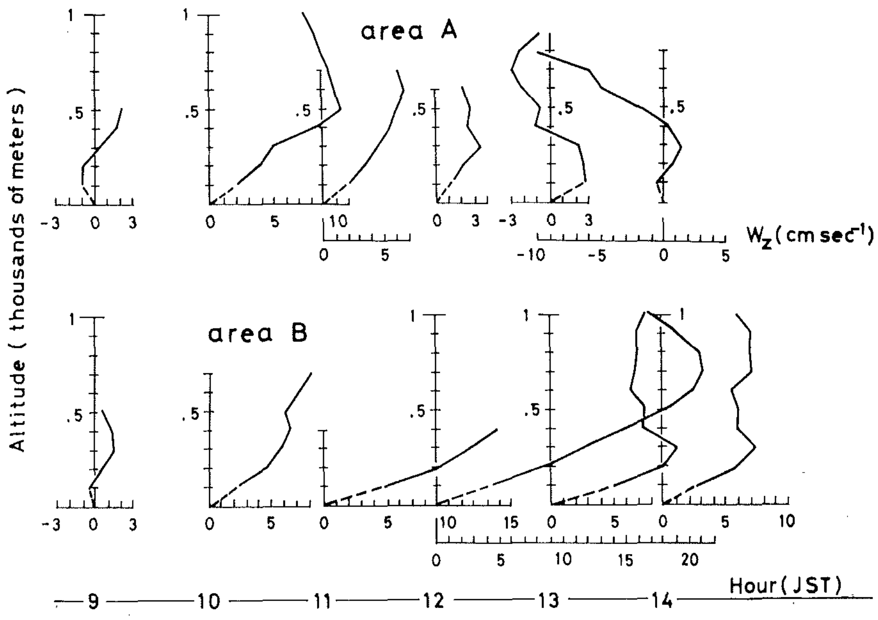

Fig. 5. Distribution of vertical velocity W_z on July 17, 1973.

TABLE 1 Horizontal divergence on July 17 in 10^{-4} sec^{-1}

A area

Altitude (m)	Hour (JST)							
	9	10	11	12	13	14	15	16
1000		0.88					0.85	
900		0.40			−1.64		2.36	
800		0.91			−0.45	3.28	−0.99	−6.67
700		0.54	0.47		0.69	1.75	−0.01	8.76
600		0.63	−0.50	0.46	1.46	3.08	−2.06	−1.76
500	−0.28	−1.40	−0.56	−0.11	−0.66	2.22	−0.67	2.37
400	−1.22	−3.57	−1.01	0.79	3.46	0.98	−1.48	−0.39
300	−1.48	−1.10	−0.85	−1.07	0.45	−0.81	−3.01	−0.41
200	−0.03	−2.02	−1.36	−0.86	0.24	−0.94	−1.08	−2.18
100	1.11	−2.00	−1.80	−1.29	−2.63	0.47	−1.62	−4.57

B area

2000						−0.53	0.56	2.41
1900						−0.26	3.60	2.21
1800						−0.35	1.12	2.80
1700						−0.55	0.43	−1.25
1600						0.37	0.43	0.02
1500						1.29	−0.97	3.87
1400						−0.35	−1.88	−5.35
1300						−1.17	−0.68	−0.63
1200						−1.47	−0.22	−0.61
1100						−1.53	0.28	−0.64
1000				2.48	−0.72	−2.25	−2.06	−1.15
900				2.15	0.16	−1.05	−0.43	−0.71
800				0.78	−0.20	0.40	−3.47	−10.09
700		−1.02		−0.37	−0.12	−1.76	−0.86	8.16
600		−1.12		−2.07	1.28	0.68	−0.86	−3.93
500	0.59	0.50		−3.03	−0.15	0.12	−0.18	−0.18
400	0.29	−0.58	−2.08	−3.00	3.67	1.46	0.54	1.66
300	−0.89	−1.09	−2.56	−3.19	−1.87	−1.61	−0.91	0.04
200	−0.97	−2.45	−4.36	−4.55	−3.98	−3.27	−2.46	−1.00
100	0.28	−2.34	−4.52	−4.41	−5.06	−2.57	−3.01	−3.51

The zone of negative divergence below 500 m denotes the area of sea breeze. In this negative zone the air gradually moved upward and on the contrary in positive areas it moved downward. The vertical wind velocity calculated by equation (2) show a stagnant area formed at an altitude of 400–700 m. In these areas high concentrations of ozone was observed. (c.f. Fig. 4)

Althrough no observation was made on the ozone profile above the sea breeze layer on July 17 several additional observations were performed in August 1973. On August 28, 1973 a predominant north Pacific high cell covered the Japanese islands and the weather was fine. The synoptic weather situation was similar to July 17, 1973. High level ozone was observed at an altitude between 800 and 900 m at Ichizawa. This altitude was almost coincident with the top of sea breeze layer. Fig 6 shows the observation up to 2000 m at Zama in the afternoon. Ozone concentrations decreased rapidly above the sea breeze layer.

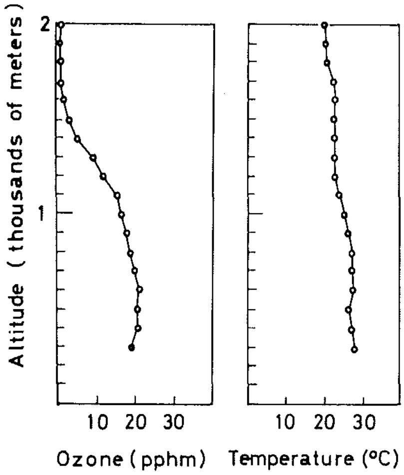

Fig. 6. Ozone distribution observed up to 2000 m at Zama between 1349 and 1358 JST on August 28, 1973.

July 18

On July 18 a north pacific high cell coverd Japanese islands and the weather was fine. A sea breeze from the Tokyo bay occurred at Yokosuka before 0900 JST and at Tsurumi 1000 JST respectively. But the air was stagnated at the central area of the prefecture. At noon the wind direction was almost from the south. Before noon oxidants increased at Yokosuka, Yokohama and Kawasaki districts and moved to the northern part[11]. Two helicopter flights were made beginning at 0930 and 1330 JST. Each flight began at Ichizawa and covered the Kanagawa Prefecture at a height of 300 m obtaining the horizontal profiles of ozone concentrations and temperature.

The results of the observations are shown in Fig. 7. The distribution of divergence is calculated by equation (1). Negative values were detected below the altitude of 500 m. These zones denote the area of sea breeze. Under converging conditions below the altitude of 500 m polluted air gradually moved upward and high concentrated ozone layers probably formed at the stagnant layer by a similar mechanism to that on July 17. At an altitude of 300 m a high concentration was observed to

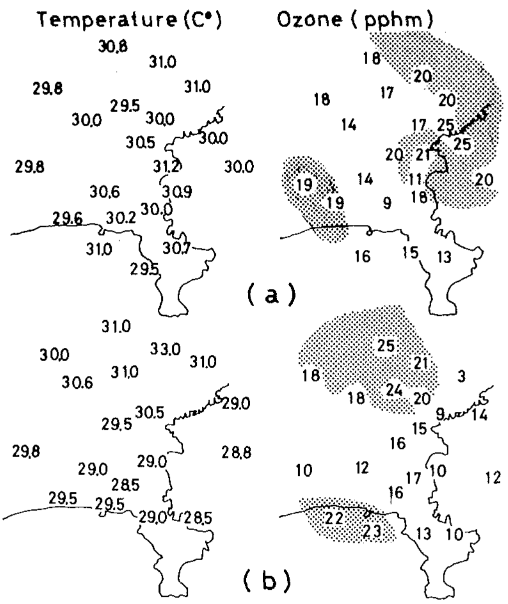

Fig. 7. Horizontal distribution of ozone concentration and temperature at the altitude of 300 m on July 18, 1973. Fig. (a) and (b) are observed at 0940–1106 and 1324–1439 JST respectively.

west and east ward of the prefecture in the morning and to the south and northern area in the afternoon. This tendency was also observed in most ground level concentration distributions of oxidants.

July 19

On July 19 an anticyclone was situated at the northern part of Japanese islands. At 0900 JST the wind was in a northerly direction and then varied to an easterly direction. Sea breeze from the Sagami bay occurred at noon and the weather changed to fine. The top of the sea breeze was nearly 500 m high. By the calculation of divergence a negative value was detected below an altitude of 500 m[12]. The air temperature was relatively low and ozone concentration was not so high. The horizontal ozone and temperature profiles at an altitude of 300 m are as shown in Fig. 8. Two helicopter flights were made in a similar manner to that of July 18. Before noon the ozone concentration both at ground level and 300 m was high. In the afternoon at 300 m, a high concentration was detected in the northern part of the prefecture. Near the ground high concentration was observed at the northern part and on the coast of the Sagami bay. High ozone concentrations at the coast remained until 1800 JST.

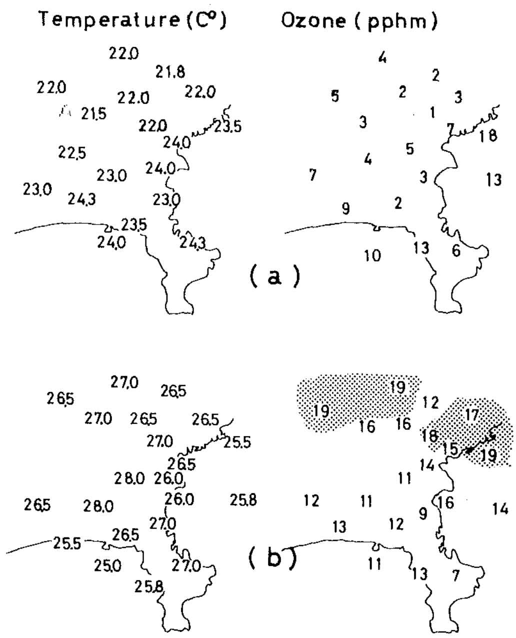

Fig. 8. Horizontal distribution of ozone concentration and temperature at the altitude of 300 m on July 19, 1973. Fig. (a) and (b) are observed at 0935–1106 and 1327–JST respectively.

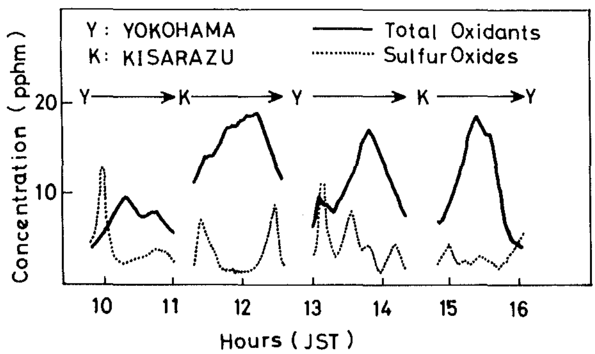

Fig. 9. Distributions of oxidants and sulfur oxides observed on a ferry boat between Yokohama and Kisarazu on August 9, 1971.

Observation from a ferry boat (August 9, 1971)

Fig. 9 shows the data obtained on board a ferry-boat between Yokohama and Kisarazu. The ship course is as shown in Fig. 1. It can be readily noted that sulfur oxides, a primary pollutant had higher concentrations near the coast in comparison with that at the center of the Tokyo bay whereas the oxidant had a peak concentration at the center of the Tokyo bay. The ground level air flow patterns on August 9, 1971 are shown in Fig. 10. The mechanism underlying these profiles would be that a layer of high ozone level descended to the sea level under the diverging conditions caused by the sea breeze over the Tokyo bay.

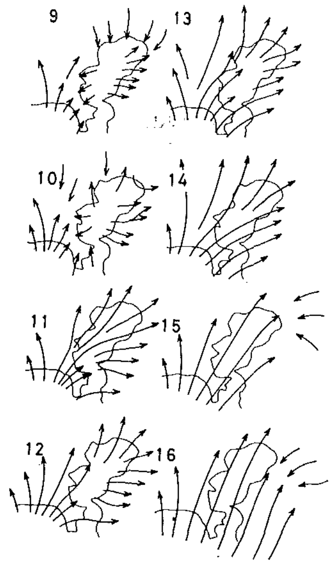

Fig. 10. Air flow pattern near the ground on August 9, 1971. Numerals in the figure are the time of observations in JST.

Discussion and Conclusions

Data obtained using a helicopter and pilot balloons over the Kanagawa Prefecture on July 17, 18 and 19 in 1973 were analyzed together with the ferry-boat data on August 9, 1971. The results are summarized as follows;

Vertical ozone distributions are influenced by the vertical wind and temperature profiles. In general maximum ozone concentrations are found at the stagnant zone of vertical wind which is detected by the calculation of divergence and the altitude of this zone was approximately between 500 and 700 m. This zone is below the top of sea breeze and the base of the temperature inversion.

The mechanism underlying these distributions may be summarized as follows. The primary pollutants emitted from the sources near the ground are gradually elevated in the convering zone of the sea breeze and remain in the stagnant zone. Under sufficient solar radiation the primary pollutants in the stagnant area gives rise to the secondary pollutants by photochemical reactions. Below the base of temperature inversion where dense smog is often formed the radiation diminishes and thus the photochemical reactions also diminished. In addition in the lower region of the atmosphere the higher level of primary pollutants readily destructs ozone. For these reasons the vertical profile of ozone has a peak at an altitude between 500 and 700 m. On compensating for the air ascending in sea-breeze layer over the land a down flow was observed over the bay which carries high oxidants to the sea surface.

In a horizontal survey at an altitude of 300 m a high ozone concentration was observed at first near the coast in the morning and was transported to the northern part of the prefecture following the movement of the sea breeze inland. This tendency is also found in the ground level concentration of oxidants. Above the sea breeze layer the ozone concentration decreased rapidly with height.

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