Abstract

Vertical distribution of ozone at Japanese Antarctic station Syowa, 69°00′S, 39°35′E, was observed by means of carbon-iodine type chemical ozonesondes. Main purpose of this report is to give the results obtained by the soundings during the period from March 1966 to January 1967. Describing the data reduction method with some related problems, 28 vertical ozone distributions are given in ozonagrams and tables. A smoothed time-height cross section of ozone partial pressure is presented, with discussion on the seasonal characteristic ozone profiles and the ozone changes in each layer during the stratospheric sudden warming in 1966. Also, it is noted that the tropopauses are found 1–2 km above the level where ozone begins to increase upwards into the stratosphere.

1. Introduction

When the Japanese Antarctic station Syowa, 69°00′S, 39°35′E, was reopened, after four years of closure, in January 1966 by the 7th Japanese Antarctic Research Expedition team, observations of vertical distribution of ozone with ozonesondes were added to the total ozone measurements with a Dobson spectrophotometer. As observation by the optical ozonesonde is impossible during the polar night period, it is essential to use a chemical type ozonesonde. At the stage of preparation of the 7th JARE team, the titration type chemical ozonesonde (KOBAYASHI and TOYAMA, 1966a) was under development in Japan, and REGENER's chemiluminescence sondes and MAST's chemical sondes were already put to practical use in U.S.A. and other countries. But the titration type sondes required a troublesome treatment before each flight, and, so, another type of chemical ozonesonde was urgently developed. This new type of ozonesonde was a "carbon-iodine" type (KOBAYASHI and TOYAMA, 1966b) or named KC-type. After several test flights at Tateno Aerological Observatory in Japan, 49 sets of the sondes were transported to Syowa Station.

2. Outline of KC-65 Ozonesonde

The carbon-iodine ozonesonde was described in detail by KOBAYASHI and TOYAMA (1966b), but here the principle of ozone measurement and functions of the sonde are briefly given with Fig. 1.

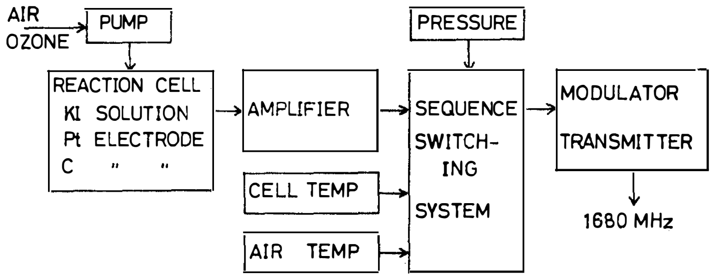

Fig. 1. Block diagram of the carbon-iodine ozonesonde KC-65.

The air involving ozone is pumped into the potassium iodide solution in the reaction cell through a capillary tube, and then the ozone reacts with the solution and liberates free iodine.

In KI solution : $2KI \leftrightarrows 2K^{+} + 2I^{-}$.

With ozone : $2I^{-} + O_3 + H_2O \rightarrow I_2 + O_2 + 2OH^{-}$.

The free iodine is reduced back to iodide by contact with the platinum gauze electrode.

At Pt electrode : $I_2 + 2e \rightarrow 2I^{-}$.

On the other hand, the reaction at the activated carbon electrode produces electrons.

At Carbon electrode : $2OH^{-} + C \rightarrow CO + H_2O + 2e$.

Accordingly, one ozone molecule produces a current of two electrons.

The reaction current i is amplified by a circuit and the output modulates the carrier frequency of 1680 MHz. The modulation frequency varies from 70 to 190 Hz depending on the change of the reaction current of 0 to 15 μA.

Besides the ozone detector mentioned above, there are two thermistors for the ambient temperature T_a and for the inside temperature T_c of the reaction cell. Through a switching system, each of signals i, T_a and T_c is transmitted for about 10 seconds one after another, and once every five cycles of the signals two standard marks 0 and S (about 8 μA) for the reaction current are inserted in place of T_a and T_c respectively. Thus the sequence of the signals becomes as follows :

$$i0S,\ iT_aT_c,\ iT_aT_c,\ iT_aT_c,\ iT_aT_c,\ i0S,\ iT_aT_c,\ldots\ldots\ldots\ldots\ldots$$

Also, an aneroid barometer switch shorts the output circuits of i, T_a or T_c at 17 pressure values, which are calibrated beforehand, transmitting 0 ohm reference for the thermistors as well as the pressure signals.

The two thermistors and the transmitter are those of the same specifications as the routine rawinsonde RS II-64 used at Syowa. The ozonesonde including power supply is enclosed by a Styrofoam box, except the thermistor for air temperature, and the aneroid switch, and hence the temperature T_c inside the reaction cell is kept almost above 0°C even in the cold stratosphere in polar winter.

3. Data Reduction

3.1. Basic formulas

When the pumping rate of air is denoted by V_c (ml/min) and the ozone density by ρ_{3c} (μg/m^3), where the suffix c means the values in the pump and detector cell system, the number of ozone molecules reacting in the cell per second is expressed by

$$N = \frac{V_c}{60} \cdot \rho_{3c} \cdot 10^{-12}/(7.97 \times 10^{-23}\ \text{g}),$$

where the denominator is the weight of one ozone molecule.

By the reaction described in Section 2, one ozone molecule produces a two-electron current, therefore the reaction current i (μA) is

$$i = 2eN \times 10^6, \qquad e = 1.602 \times 10^{-19}\ \text{coulomb}.$$

$$\rho_{3c} = 14.92 \times 10^3 \times i/V_c. \tag{1}$$

Now, denoting the volume of free air by V_a (ml/min), which is drawn into the pumping system per minute, the ambient temperature by T_a (°K), the temperature inside the reaction cell by T_c (°K), and the ozone density in the atmosphere by ρ_3,

$$V_a/T_a = V_c/T_c, \qquad \rho_3 V_a = \rho_{3c} V_c,$$

$$\therefore \quad \rho_3 = \rho_{3c} T_c/T_a = 14.92 \times 10^3 \times \frac{i}{V_c} \cdot \frac{T_c}{T_a}. \tag{2}$$

3.2. Derived formulas

After the computation of ρ_3, the following quantities are derived with the formulas given by GODSON (1962).

The ozone partial pressure P_3 (μmb) and the ozone mixing ratio r_3 (μg/g) are given by

$$P_3 = 1.732 \times 10^{-3} \times T_a \rho_3 = 25.84 \times i T_c/V_c, \tag{3}$$

$$r_3 = 1.657\ P_3/P, \tag{4}$$

where the denominator P (mb) is the ambient air pressure.

The integrated ozone amount $\Delta\Omega$ (matm-cm) between two altitude Z_1, Z_2 (km) or P_1, P_2 (mb) is given by

$$\Delta\Omega=0.04671\int_{Z_1}^{Z_2}\rho_3 dZ, \qquad (Z_1<Z_2), \tag{5}$$

$$=0.4761\int_{P_2}^{P_1} r_3 dP, \qquad (P_1>P_2), \tag{6}$$

$$=0.7890\int_{P_2}^{P_1} P_3 d\ln P=1.8167\int_{P_2}^{P_1} P_3 d\log P. \tag{7}$$

Note the difference between the two coefficients in eqs. (5) and (6).

In the eqs. (2) and (3), the reaction current i might be biased by a background current and the air flow rate V_c may change with the pumping efficiency at low pressures. These will be considered in the following sections.

3.3. Pumping efficiency at low pressures

According to KOBAYASHI and TOYAMA (1966 a, b), the pumping rate V_c at ambient pressure P(mb) is expressed empirically by

$$\frac{V_c}{V_o}=1-K\left(\frac{1}{P}-\frac{1}{1000}\right), \tag{8}$$

where V_o is the flow rate at 1000 mb, and K is a constant. Denoting the pressure at which V_c becomes 0 by P_s,

$$\frac{1}{K}=\frac{1}{P_s}-\frac{1}{1000}\fallingdotseq\frac{1}{P_s}, \qquad \therefore\ K=P_s \tag{9}$$

because P_s is usually smaller than 10 mb. That is, K may be determined empirically by ambient pressure P_s where the bubbling in the reaction cell stops.

This kind of experiment was performed with a pump and reaction cell block of the KC-65 ozonesonde which was spared for two years after it was manufactured. Instead of the reaction solution, Apiezon oil was used, which

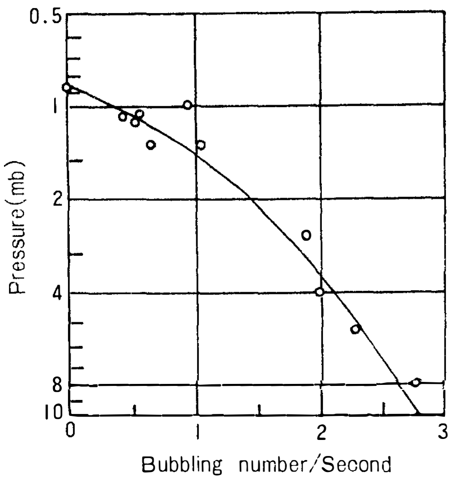

Fig. 2. Bubbling rate at low pressures, for the pump-reaction cell system of the KC-65 ozonesonde.

hardly boils even under low pressures. The result is shown in Fig. 2, and the bubbling stops at 0.87 mb. Taking into account the density difference between Apiezon oil and the reaction solution, K becomes 1.8 or nearly 2 mb.

According to the tests made immediately after the production of the ozonesondes for the use at Syowa Station, three bubbles per second, in average, were found at 5 mb. This seems to show a better efficiency than the result in Fig. 2. But, before the flights are made at Syowa Station, half a year to more than one year has lapsed since the pumps of ozonesondes were lubricated. So, the value $K=2$ mb was used in the computation.

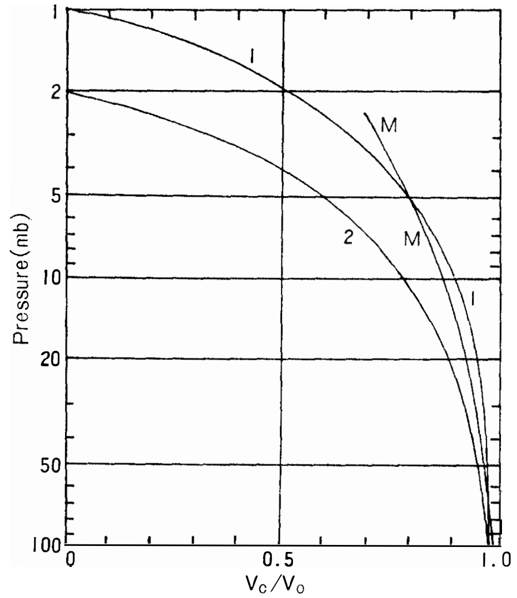

Fig. 3. Pumping efficiency at low pressures. V_0 and V_c are the flow rate at 1000 mb and Pmb respectively. Curves 1 and 2 are evaluated from eq. (8) for the cases of $K=1$ and $K=2$ mb respectively, and curve M is the flow-rate factors for MAST-BREWER sonde. Curve 2 was used in our computation.

KOMHYR and HARRIS (1965) reported the pump efficiency of MAST-BREWER ozonesonde. Their result is shown in Fig. 3, in comparison with the curves valuated by eq. (8) for the cases of $K=1$ and $K=2$ mb. Below 100 mb level in the atmosphere, the efficiency has no change practically. Above 5 mb level, the efficiency decreaces rapidly and may differ considerably with each pump.

3.4. Background current

Although the cause of background current is not known well, the current seems to depend on the degree of activity of the carbon electrode and on the time lapsed after the solution was poured into the detector cell.

The records of the background current at the beginning of bubbling before each flight showed 0.6 ± 0.4 μA in the average. But this value seems too large, because the background current at the beginning of air bubbling increases abruptly about 2–10 times as much the value before the bubbling, and then the background current with bubbling decreases gradually until it reaches a constant value which may be the true background current. The following may serve as an evidence for estimating the constant value.

Ozone reaction currents during the descent after the balloon burst were usually of the same order as in ascent, but with some time lag due to the faster descent. In one case, the background current recorded before the flight was 0.68 μA, but the current during the descent was almost constantly 0.2 μA. This might be interpreted as the real background current bacause the rubber film of the broken balloon covered presumably the air inlet tube.

Therefore, in computation of ozone amounts with eq. (2) or (3), one-third of the background current recorded before each flight was subtracted from the reaction current recorded during the ascent.

4. Flight Preparation and Selection of Reliable Data

4.1. Pre-flight treatment

The potassium iodide solution for the reaction with ozone was composed of the following chemicals.

Na_2HPO_4	:	5 g
KH_2PO_4	:	5
KBr	:	100
KI	:	0.2
H_2O	:	500 m*l*.

The solution was used after more than one week from the time it was prepared.

Each ozonesonde was checked, a few days before the flight, about the amplifier, transmitter, sequence switch system and barometer, and one electrode of the reaction cell was deposited with active carbon paste, and then the solution was supplied into the cell.

Immediately before the flight, the polyethylene inlet tube was conditioned by exposing it to ozone-rich air for about half an hour, the gain of the amplifier was re-adjusted and calibrated, and finally the background current with bubbling was recorded, while the flow rate of air sampling V_o was measured (about 400 m*l*/min).

4.2. Flights

The weight of a KC-65 ozonesonde including water activated batteries was about 2.5 kg and the ozonesonde was ascended by a 2 kg balloon with a net lift of about 3 kg. The balloon was inflated outdoors because the hut for inflating a 600 g balloon for routine sondes was not large enough for the 2 kg balloon, hence flights of ozonesondes were limited only on days when the surface wind speed was less than 2 or 3 m/s. (This situation has been improved since a new larger balloon hut was constructed in 1967.)

Among the 49 ozonesondes transported to Syowa Station, 3 ozonesondes were rejected due to faults in electric circuits, 2 showed no ozone change during the flights and 4 failed to reach the 100 mb level. From the remaining 40 flights,

Table 1. Ozonesonde soundings at Syowa, Mar. 1966 to Jan. 1967.

No.	Date			Highest level		Dobson ratio	No.	Date			Highest level		Dobson ratio
				Pres. (mb)	Height (gpm)						Pres. (mb)	Height (gpm)	
1	1966	Mar.	17	19.7	26928	1.126	15	1966	Aug.	23	54.4	17936	......
2		Apr.	12	27.3	23561	......	16			29	29.8	21088	......
3			20	26.2	23955	......	17		Sept.	6	30.4	21516	1.153
4			29	52.9	19338	......	18			19	15.5	25646	1.375
5		May	11	41.0	21098	......	19			27	52.0	18435	1.375
6			19	30.2	23033	......	20		Oct.	5	27.9	22356	1.165
7		June	2	22.0	24499	......	21			13	14.7	27149	1.158
8			6	48.6	19391	......	22			20	13.1	29302	1.301
9			18	60.6	17619	......	23			24	16.6	26840	1.538*
10			30	62.0	17638	......	24			30	14.9	27474	1.336
11		July	5	60.2	18065	......	25		Nov.	26	24.5	25681	1.453*
12			22	53.6	18218	......	26			29	23.1	26147	1.377
13		Aug.	5	33.6	20665	......	27		Dec.	12	29.0	24571	1.240
14			18	44.1	19180	......	28	1967	Jan.	11	23.9	26001	1.519*

* 1) *1966 Oct. 24 : Measurement of flow rate was uncertain, but this was covered by the correction with the Dobson ratio.*
2) *1966 Nov. 26 : Record of ozone reaction current was interpolated for 120 mb to 56 mb.*
3) *1967 Jan. 11 : Flight was made on the 26th day after depositting carbon paste and supplying solution into the detector cell.*

28 were selected as reliable soundings by the following criteria :

1) Maximum altitude reached should be higher than 70mb level,

2) "Dobson-ratio", which is explained in Section 4.3, should be less than 1.55.

Table 1 summarizes the 28 flights selected by these criteria, with the highest level reached and the Dobson-ratio.

The 70mb level in the first criterion might be too low at middle and low latitudes. But in the polar region, the maximum density of ozone is found usually near 100mb, and the mean maximum level of soundings lowers to 50mb in the winter season. Thus the 70mb was chosen as one of the criteria.

4.3. Dobson-ratio

The "Dobson-ratio" is the ratio of a total ozone amount measured by a Dobson spectrophotometer to a total ozone obtained by an ozonesonde. The former should be the value at the time closest to the latter. The latter is estimated by extrapolation assuming a constant mixing ratio above the highest level reached by the sounding.

The second criterion in Section 4.2 was chosen by the following reason. In 9 cases, which reached a level higher than 30mb and were judged as complete performance by the records of the sounding, the mean Dobson-ratio was 1.25 and the standard deviation σ of the ratio was 0.10. None of our cases at Syowa showed the ratio lass than 1.0 (Table 1). The ratios on MAST-type ozonesonde, as other examples, were 1.10 ± 0.12 at Boulder, Colorado (HERING and DÜTSCH, 1965) and 1.26 ± 0.11 at Christchurch, New Zealand (Ozone data for the world, 1965). Therefore, if the ratio was larger than 1.55 ($=1.25+3\sigma$), it was judged that the performance of the sounding was failed by some unknown causes which might be lowering of the sensitivity of the detector, the pumping efficiency or others.

When the Dobson-ratio was less than 1.55, this ratio was multiplied by the raw ozonesonde data at each level in order to adjust the total ozone amount estimated to that obtained by the Dobson spectrophotometer. By this correction, the ozone loss due to the intake system, 2–3% according to KOBAYASHI and TOYAMA (1966b), was also covered.

4.4. Winter data

For a period April through August, however, no Dobson value was obtained on account of the low solar altitudes or the polar night. Therefore, the raw ozonesonde data were not corrected.

This treatment might be supported by the fact that the mean total ozone amount measured by a Dobson spectrophotometer with the 'forcussed image method' was 309matm-cm in the same period at Roi Baudouin, 66°40′S, 24°19′E, the nearest station to Syowa (Fig. 5), and the total ozone amount estimated from the mean vertical distributon of the raw data of 15 soundings at Syowa for the winter period was 311, nearly corresponding to the former without correction.

But in these cases with no correction, the ozone loss due to the air intake system was not corrected either, and the true ozone values might be a few percent larger.

4.5. Accuracy

According to KOBAYASHI and TOYAMA (1966b), the exponential response time of the detector cell is 15–30 seconds, and the observational error of ozone partial pressure P_3 is less than 10 μmb. If we assume an increase of $\Delta P_3 = +10\ \mu$mb at 10mb and all levels below and an increase of mixing ratio $\Delta r_3 = +1.657 \mu g/g$ (corresponding to $\Delta P_3 = +10 \mu$mb at 10mb) above 10mb, then the increase of the total ozone would be 44matm-cm, which corresponds to 10–15% of total ozone values.

5. Results

5.1. Data presentation

Ozone amounts were computed at the levels for every minute in each flight, with the eqs. (2), (3), (4) and (7), substituting V_c of eq. (8) with $K=2.0$, taking the background current into account (Section 3.4), and then multiplied by the Dobson ratio (except for flights with no Dobon value from April to August). Finally, ozone values at standard levels, which were chosen at smaller intervals above 100 mb level, were interpolated from the values at every minute.

Ozone partial pressures thus computed and temperatures were tabulated in Annex, and those profiles were produced in ozonagrams (Figs. 10–19). The tropopause in each flight was chosen at the level where the temperature lapse rate becomes small somewhat abruptly, and it was marked with a small circle in the profiles of ozone and temperature.

Monthly means of ozone partial pressures at each standard level were calculated from the individual soundings in each month. But, in each of the months of March, December 1966 and January 1967, only one flight was made and the average of the three soundings altogether was taken as for summer season. These means were also tabulated in the Annex. Above 70 mb level, some soundings terminated at lower levels than other cases, hence the mean values up to 25 mb were estimated by extrapolation considering the upward tendency of ozone partial pressures and of mixing ratios.

5.2. Seasonal changes of ozone layer

The height-month cross-section of ozone partial pressure was constructed (Fig. 4), using bimonthly means calculated from each monthly mean. The mean tropopause in Fig. 4 was estimated from the monthly mean temperature profiles of routine soundings.

The layer of maximum partial pressure lies between 100 and 50 mb, or roughly between 15 and 20 km heights. In summer, except November, the layer of ozone maximum is higher than 60 mb (20 km), and in winter it is lowest at about 70–80 mb (16 km). This seasonal tendency is qualitatively the same as shown in the cross-sections of ozone densities reported by MacDowall and Smith (1962) on Halley Bay (75°31′S, 26°44′W) and by Wayant (1967) on the South Pole. The

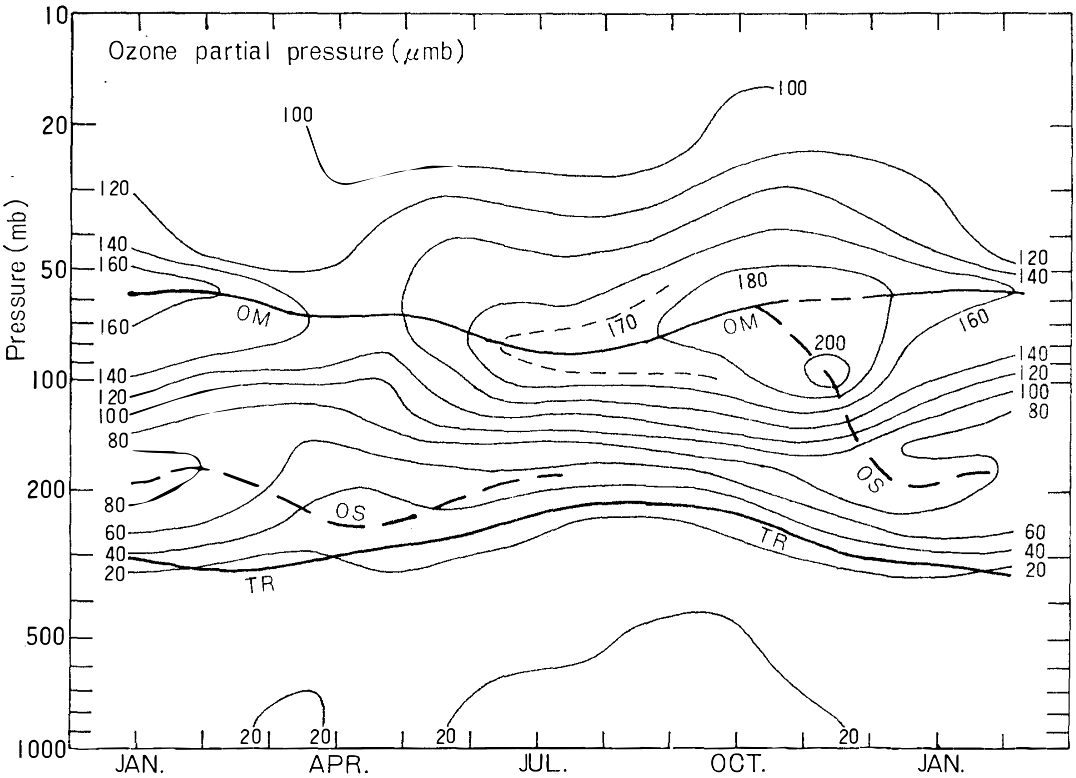

Fig. 4. Height-month cross-section of ozone partial pressures, at Syowa (69°00'S, 39°35'E), Mar. 1966 to Jan. 1967. OM: layer of ozone maximum. OS: layer of ozone secondary maximum and its trace. TR: tropopause level.

maximum values of ozone partial pressure increase from 130μmb in autumn to 180μmb in spring, and decrease after summer.

The tropopause is found at the level where the ozone partial pressure is about 20–30μmb, and highest in winter and lowest in summer. The upward increase of ozone partial pressure starts usually at 1–2km below the tropopause (Section 5.5).

The maximum ozone partial pressure in November to December, after the spring stratospheric warming with maximum total ozone, is about 200μmb and the level of it lowers to 100mb (16km) abruptly from the general tendency (Fig. 4). This lowering of the ozone maximum seems to continue to the tongue at 200mb in January, broadening the ozone layer and giving a secondary maximum in the lower stratosphere. This secondary maximum appears intermittently until July, becoming weaker gradually.

Table 2 shows the yearly mean of fractional ozone amounts in several layers. Very roughly speaking, half of the total ozone amount exists below (or above) the 50mb level (20km in height).

Fig. 5 shows the seasonal change of total ozone amounts measured by the Dobson spectrophotometer at Syowa. For comparison and to know the winter

Table 2. Fractional ozone amount in each layer, yearly mean at Syowa.

Layer (mb)	Surf.-400	400-200	200-100	100-50	50-25	Above 25	Total
Ozone (matm-cm)	13	16	53	88	70	85	325
(%)	4	5	16	27	22	26	100

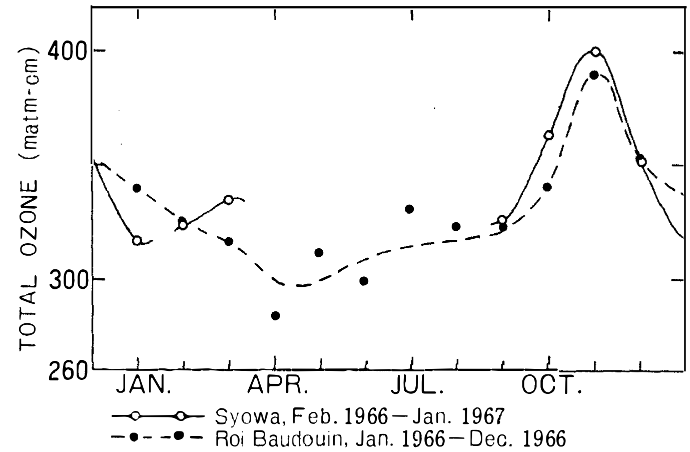

Fig. 5. Seasonal changes of total ozone amount at Syowa and Roi Baudouin.

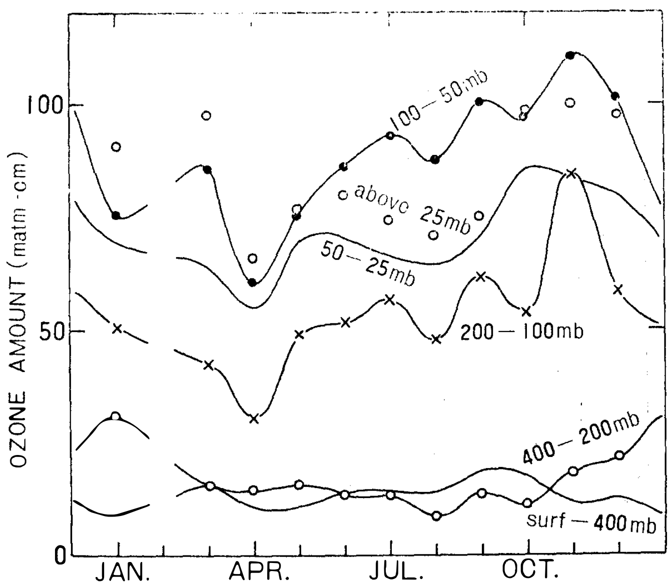

Fig. 6. Seasonal changes of ozone amount in each layer of surface-400mb, 400-200mb, 200-100mb, 100-50mb, 50-25mb and above 25mb, at Syowa.

ozone amount, the total ozone at Roi Baudouin measured with the "forcussed method" was also shown.

The changes of ozone amount in each layer are shown in Fig. 6, in which the ozone amount above the 25mb level is estimated by the assumption of constant mixing ratio. The dips in April in Fig. 6 correspond to such tendency as shown in Fig. 5. The ozone amounts at 200–100 mb and 100–50 mb levels increase through winter. The sharp increase of total ozone from September to November (Fig. 5) is due first to the ozone increase above 50 mb, and then to the increase at 200–50 mb levels (Fig. 6). This is shown more clearly in Table 3 and Fig. 7. That is, the ozone increase begins above the level of maximum ozone partial pressure in September to October, and then it shifts downwards to the lower stratosphere in October to November. In the same period, the temperature

Table 3. Monthly increase of ozone (matm-cm) in each layer, at Syowa.

	Sept. to Oct.	Oct. to Nov.	Nov. to Dec.	Dec. to Jan.
Above 25 mb	+23	+ 2	− 3	− 8
25 - 50	+15	− 2	− 4	−10
50 - 100	− 3	+13	− 9	−26
100 - 200	− 8	+31	−25	− 8
200 - 400	− 2	+ 7	+ 4	+ 9
400 - surf.	− 1	− 6	+ 1	− 4
Total	+24	+45	−36	−47

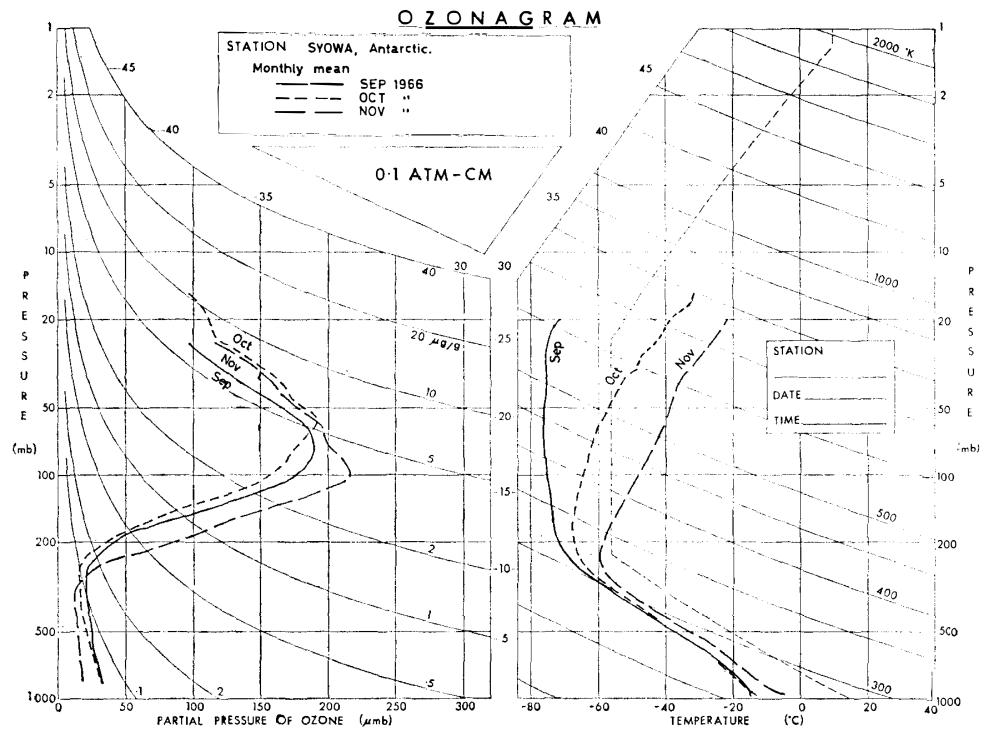

Fig. 7. Monthly mean profiles of ozone partial pressure and temperature in spring at Syowa. Ozone increase during the stratospheric warming period begins above 60 mb level and then shifts downwards.

at 20mb increases from −70°C to −20°C (Fig. 7). In November to January, the ozone increase is limited around the tropopause height (Table 3 and Fig. 6). The major decrease of total ozone (Fig. 5) in November to January occurs first below the level of maximum ozone partial pressure and then above it (Table 3), gradually broadening the ozone layer through autumn.

5.3. Representative mean profiles of ozone and temperature

Fig. 8 presents the mean vertical profiles of ozone partial pressures and of temperatures for summer-autumn, winter and spring. The temperature profiles, which are averages of the routine radiosonde observations, show distinct contrasts with one another.

The summer-autumn temperature has a sharp negative lapse rate just above the tropopause and is nearly constant vertically (around −40°C) throughout the stratosphere. Corresponding to this, the summer-autumn ozone profile has a clear secondary maximum around 200mb.

The winter temperature decreases upwards even above the tropopause, and the tropopause is less significant. The level of maximum ozone partial pressure lowers to 70–80mb (16km) and the secondary maximum diminishes in the mean.

The spring temperature profile has a negative lapse rate throughout the stratosphere, but in the troposphere it is nearly the same as in winter. Ozone

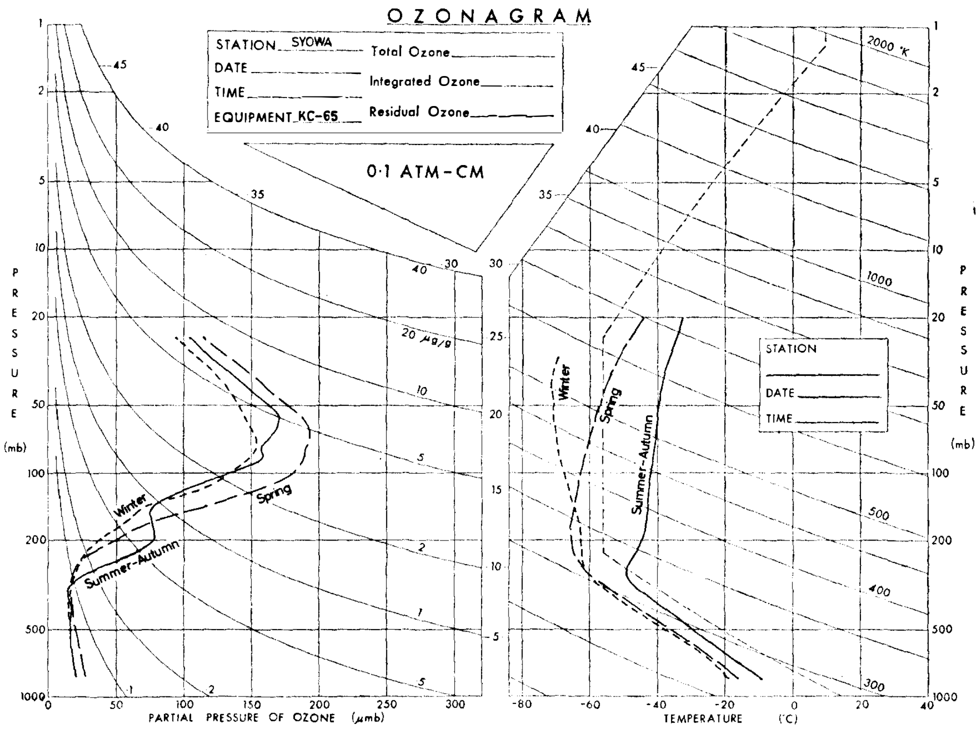

Fig. 8. Mean profiles of ozone partial pressure and temperature at Syowa, for summer-autumn (Dec. to Mar.), winter (Apr. to Aug.) and spring (Sept. to Nov.).

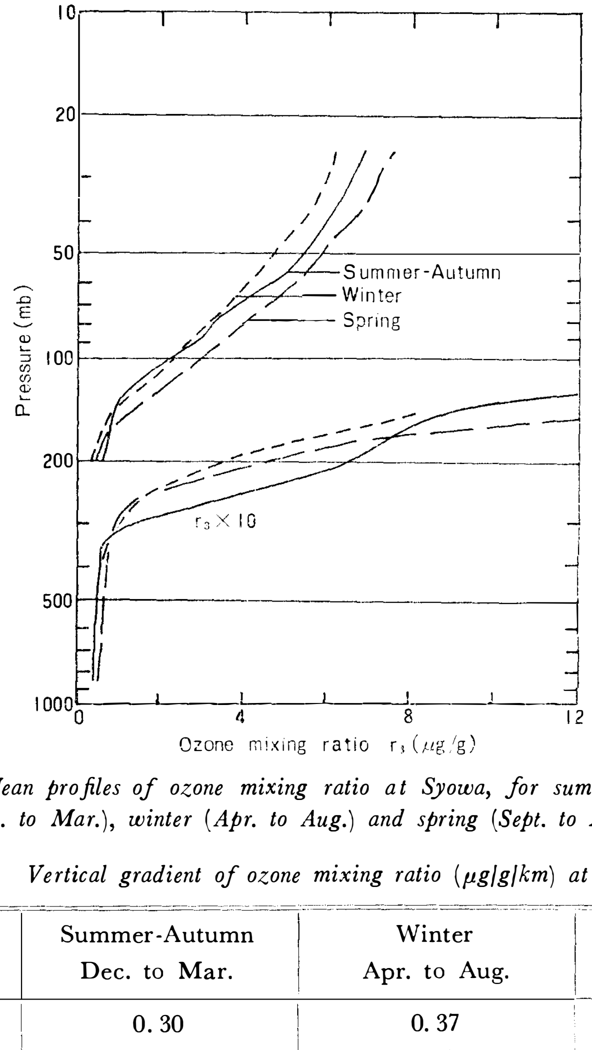

Fig. 9. Mean profiles of ozone mixing ratio at Syowa, for summer-autumn (Dec. to Mar.), winter (Apr. to Aug.) and spring (Sept. to Nov.).

Table 4. Vertical gradient of ozone mixing ratio (μg/g/km) at Syowa.

	Summer-Autumn Dec. to Mar.	Winter Apr. to Aug.	Spring Sept. to Nov.
25 - 50 mb	0.30	0.37	0.39
50 - 100	0.66	0.57	0.65
100 - 200	0.35	0.45	0.60
200 - 400	0.126	0.062	0.087
400 - 850	0.005	0.004	0.003

profile shows an increase in the entire stratosphere.

Fig. 9 is the vertical profiles of ozone mixing ratio for the different seasons. The mixing ratio in the stratosphere increases upwards steadily and the level of maximum mixing ratio does not appear up to 25 mb (25 km). But the vertical gradient of ozone mixing ratio, as shown in Table 4, has a maximum of 0.5–0.7 μg/g/km in the 50–100 mb layer, above which it tends to decrease.

In the case of summer-autumn in Fig. 9, if the constant mixing ratio is assumed above the 25 mb level, the total ozone becomes 326 matm-cm, and if extrapolated to 7.5 μg/g at 10 mb and the constant mixing ratio is assumed above 10 mb, then the total is 334 matm-cm, the difference being 2.5% and smaller than the sounding error (Section 4.5).

In the troposphere, the vertical gradient of ozone mixing ratio is about 0.003–0.005 μg/g/km (Table 4). Assuming that this gradient is ascribed only to vertical diffusion, the downward flux F of ozone is expressed as :

$$F = A\frac{dr_3}{dH} \tag{10}$$

where A is the Austausch coefficient and dH is the height difference. The ozone flux F is assumed to be 0.1 μg/m²s, as taken by JUNGE (1962) according to REGENER's experiment (1957). Then the Austausch coefficient in the troposphere becomes :

$$A = 250\,\mathrm{g/cm \cdot s}.$$

5.4. Individual profiles of ozone and temperature

This section describes characteristic features of the profiles of ozone partial pressure and temperature for individual soundings.

In April (Fig. 10), the ozone profiles had the secondary maxima around 200–300 mb, and the major maxima were rather small.

On May 11th (Fig. 11), the ozone profile had a trace of the secondary maximum around 300 mb, corresponding to the negative lapse rate of temperature above the tropopause, but on May 19th it ascended to 200mb.

The ozone values of June 2nd (Fig. 12) was abnormally large, but this might correspond to the warm stratospheric temperature of about −60°C, while the mean for June was −70.1°C at 100 mb.

Three other cases in June and the case on July 5th (Fig. 13) were the soundings during the polar night. Although the tropopauses were less determinable, the ozone partial pressures showed a distinct increase above the tropopauses, making weak secondary maxima around 200mb.

The two soundings in July (Fig. 13) showed very similar ozone values above the 150mb level, although the stratospheric temperatures were much different each other.

After July 22nd through August, September and October (Figs. 14–16), the ozone partial pressures in the lower stratosphere increased linearly upwards up to 100mb, except the case of August 18th when there was a dull secondary maximum corresponding to the sharp secondary tropopause at 150mb.

In September (Fig. 15), the soundings reached higher levels and an indication of stratospheric warming appeared from the upper stratosphere, but ozone increase which might be accompanied by the warming was not yet clearly shown.

The stratospheric sudden warming in 1966 commenced over the coastal stations in the Indian Ocean sector such as Roi Baudouin and Syowa, and the ozone soundings in October caught this phenomenon. The 50mb temperature increased from −62.1°C on October 14th to −33.9°C on October 20th, and the total ozone measured by the Dobson spectrophotometer increased from 337 to 454matm-cm in the same period. The soundings on October 13th and 20th (Fig. 16) showed remarkable increases of ozone and temperature above the 100mb

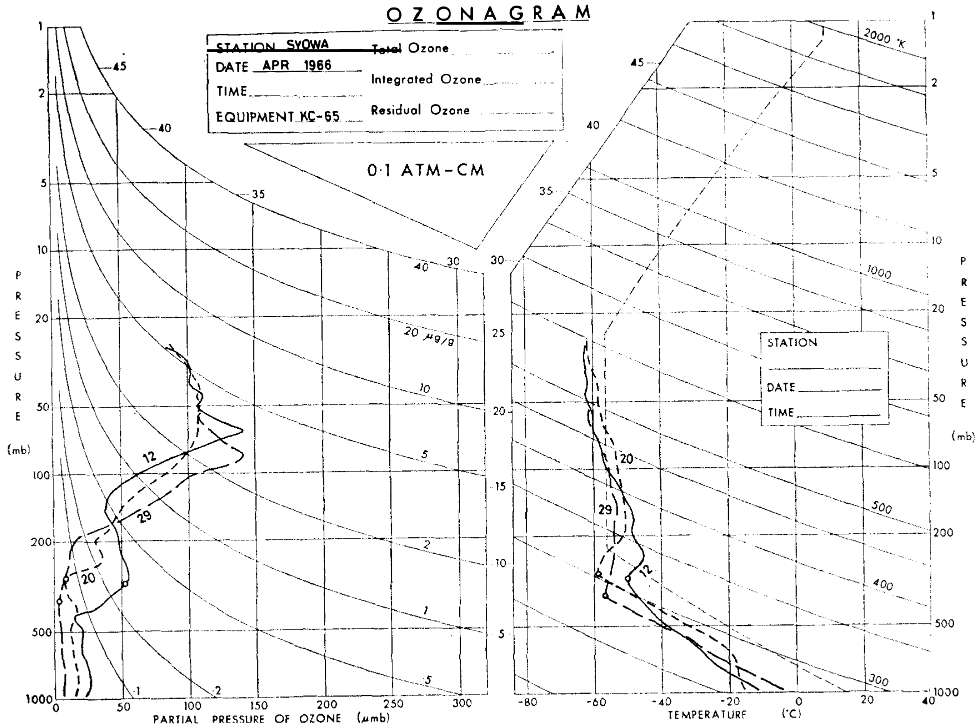

Fig. 10.

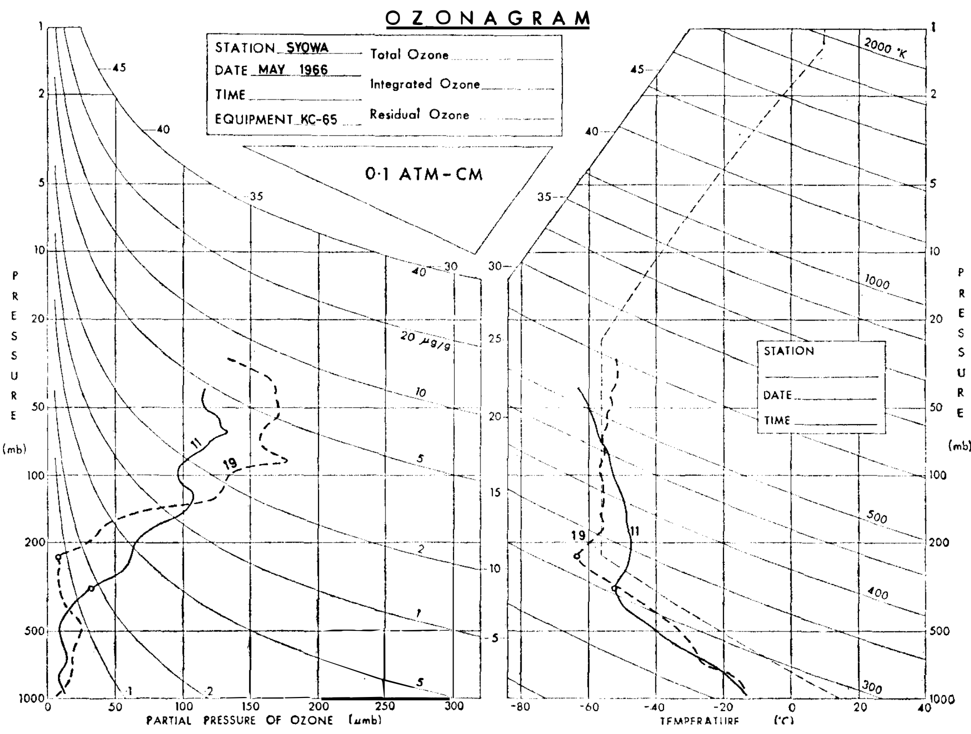

Fig. 11.

Figs. 10-19. Vertical profiles of ozone partial pressure and temperature of individual soundings. The number beside a profile indicates the date of the sounding, and the small circle shows the tropopause.

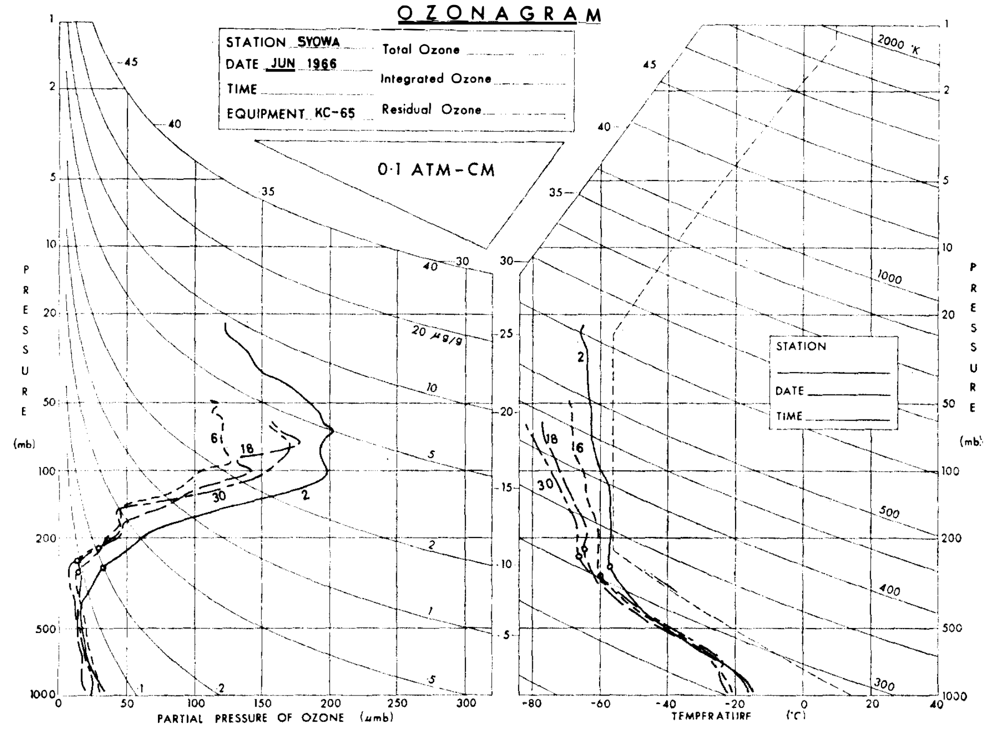
OZONAGRAM
STATION SYOWA
DATE JUN 1966
TIME
EQUIPMENT KC-65
Total Ozone
Integrated Ozone
Residual Ozone
0·1 ATM-CM
PRESSURE (mb)
PARTIAL PRESSURE OF OZONE (μmb)
TEMPERATURE (°C)
2000 °K
STATION
DATE
TIME

Fig. 12.

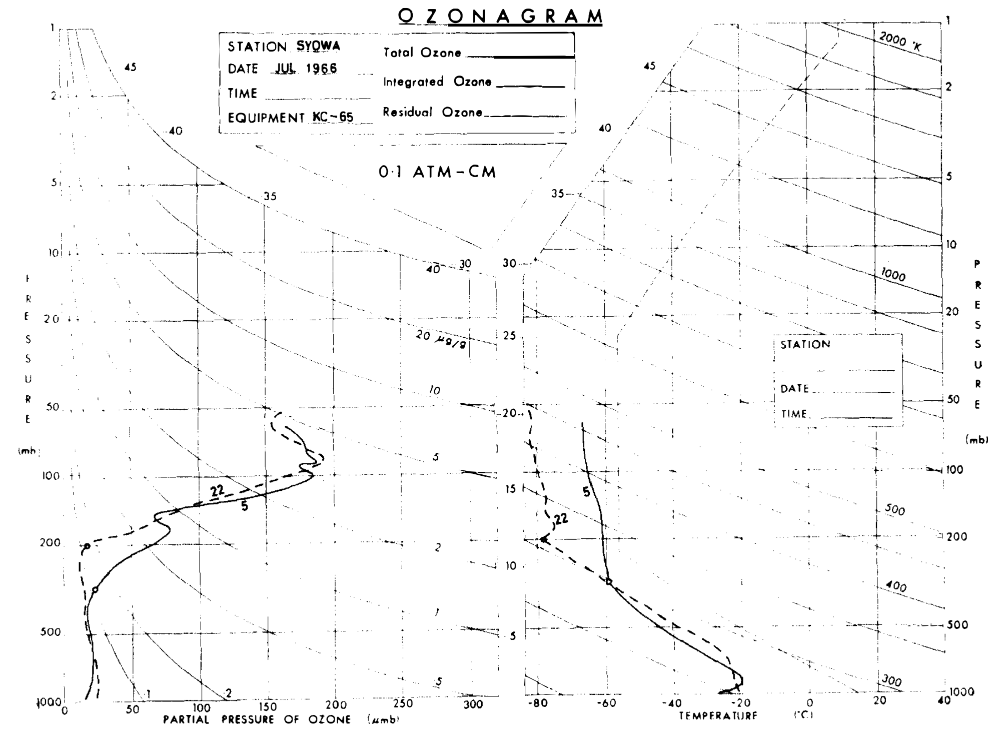
OZONAGRAM
STATION SYOWA
DATE JUL 1966
TIME
EQUIPMENT KC-65
Total Ozone
Integrated Ozone
Residual Ozone
0·1 ATM-CM
PRESSURE (mb)
PARTIAL PRESSURE OF OZONE (μmb)
TEMPERATURE (°C)
2000 °K
STATION
DATE
TIME

Fig. 13.

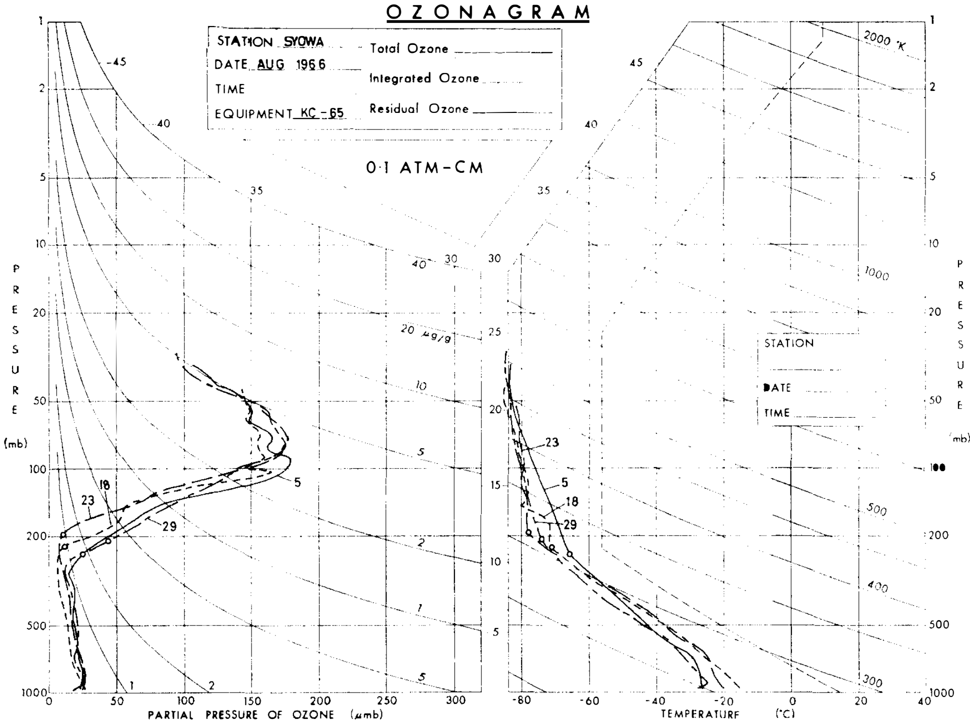
OZONAGRAM
STATION SYOWA
DATE AUG 1966
TIME
EQUIPMENT KC-65
Total Ozone
Integrated Ozone
Residual Ozone
0·1 ATM-CM
PRESSURE (mb)
PARTIAL PRESSURE OF OZONE (μmb)
TEMPERATURE (°C)
STATION
DATE
TIME

Fig. 14.

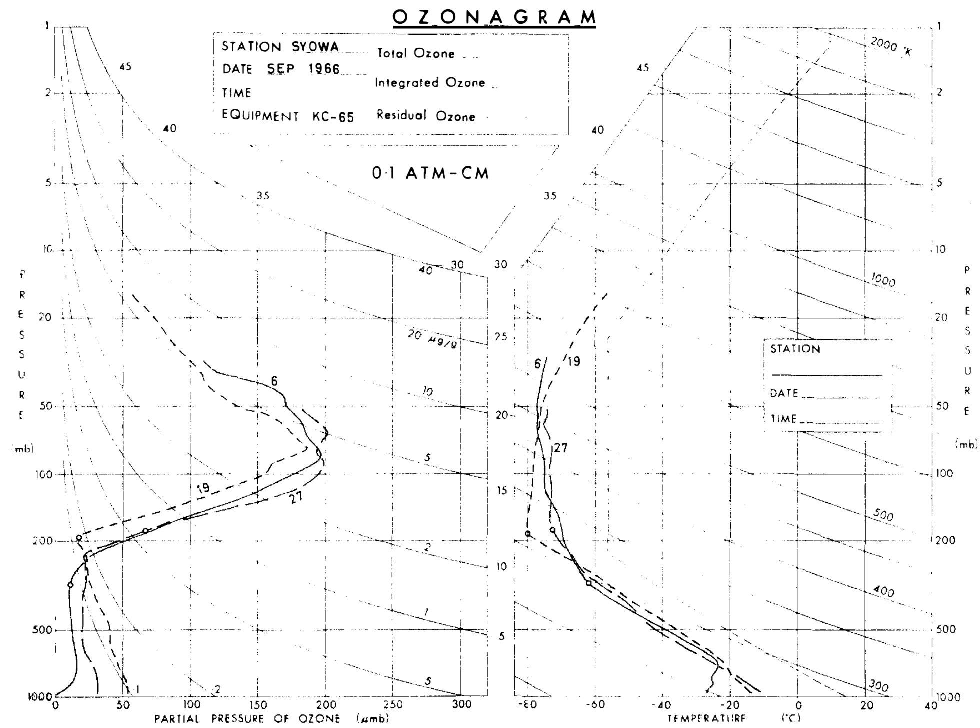
OZONAGRAM
STATION SYOWA
DATE SEP 1966
TIME
EQUIPMENT KC-65
Total Ozone
Integrated Ozone
Residual Ozone
0·1 ATM-CM
PRESSURE (mb)
PARTIAL PRESSURE OF OZONE (μmb)
TEMPERATURE (°C)
STATION
DATE
TIME

Fig. 15.

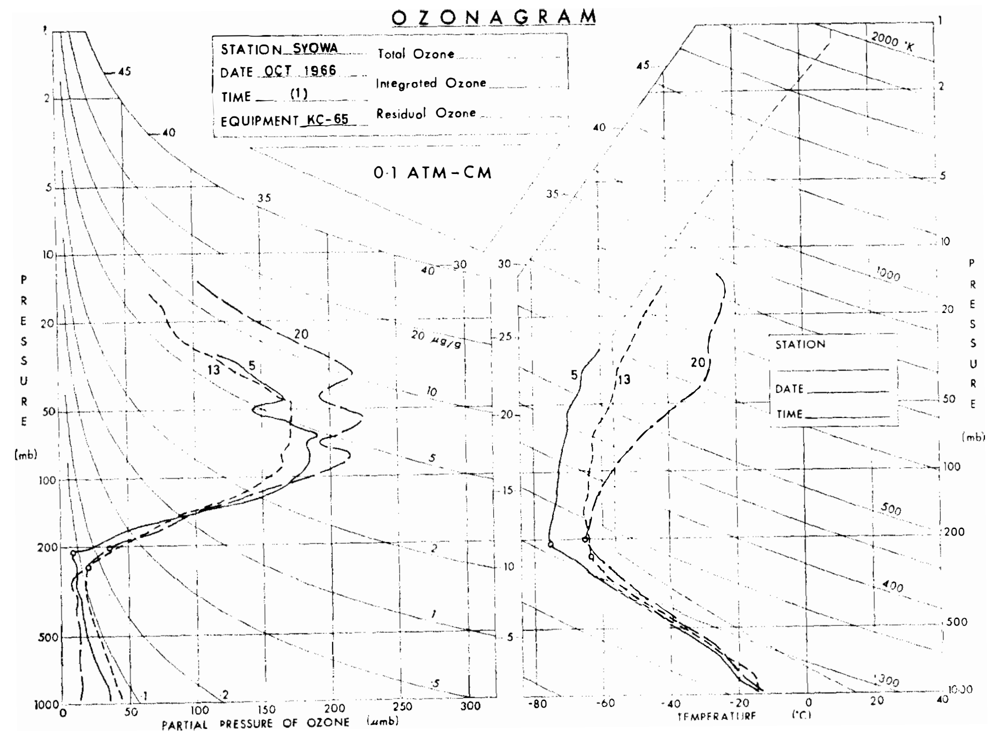
OZONAGRAM
STATION SYOWA
DATE OCT 1966
TIME (1)
EQUIPMENT KC-65
Total Ozone
Integrated Ozone
Residual Ozone
0·1 ATM-CM
PRESSURE (mb)
PARTIAL PRESSURE OF OZONE (μmb)
TEMPERATURE (°C)
STATION
DATE
TIME

Fig. 16.

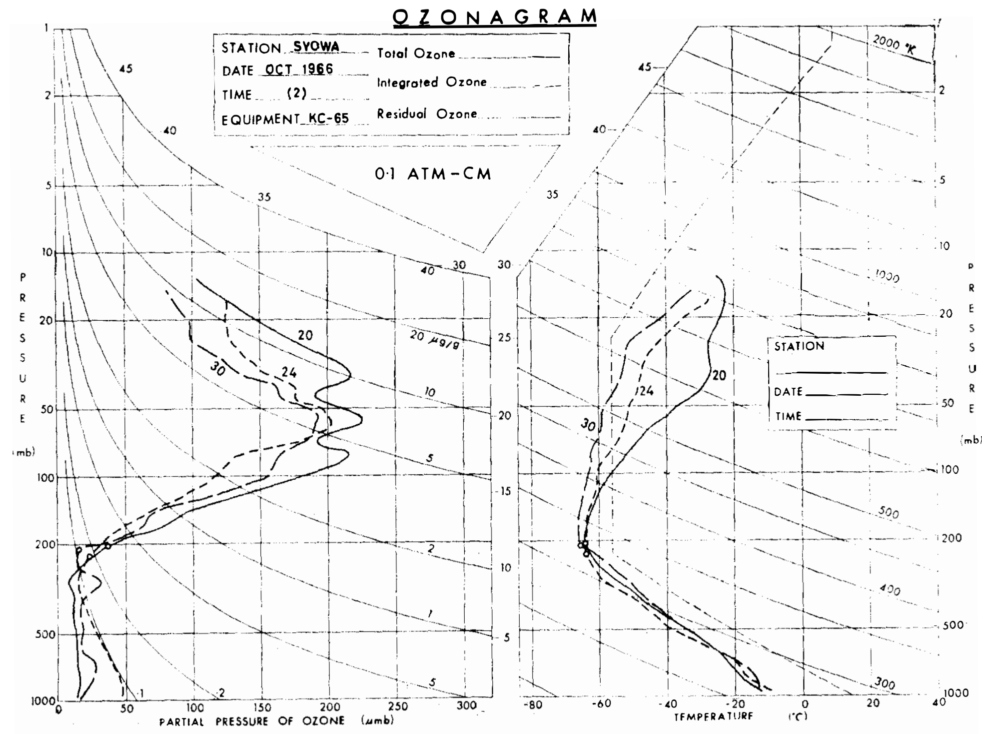
OZONAGRAM
STATION SYOWA
DATE OCT 1966
TIME (2)
EQUIPMENT KC-65
Total Ozone
Integrated Ozone
Residual Ozone
0·1 ATM-CM
PRESSURE (mb)
PARTIAL PRESSURE OF OZONE (μmb)
TEMPERATURE (°C)
STATION
DATE
TIME

Fig. 17.

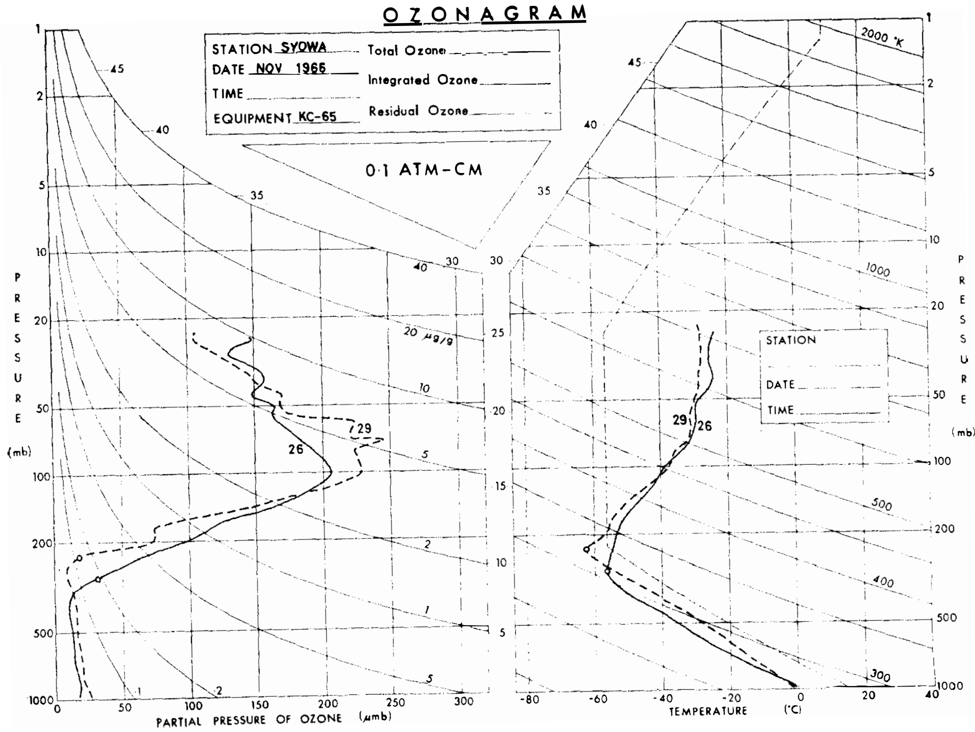

Fig. 18.

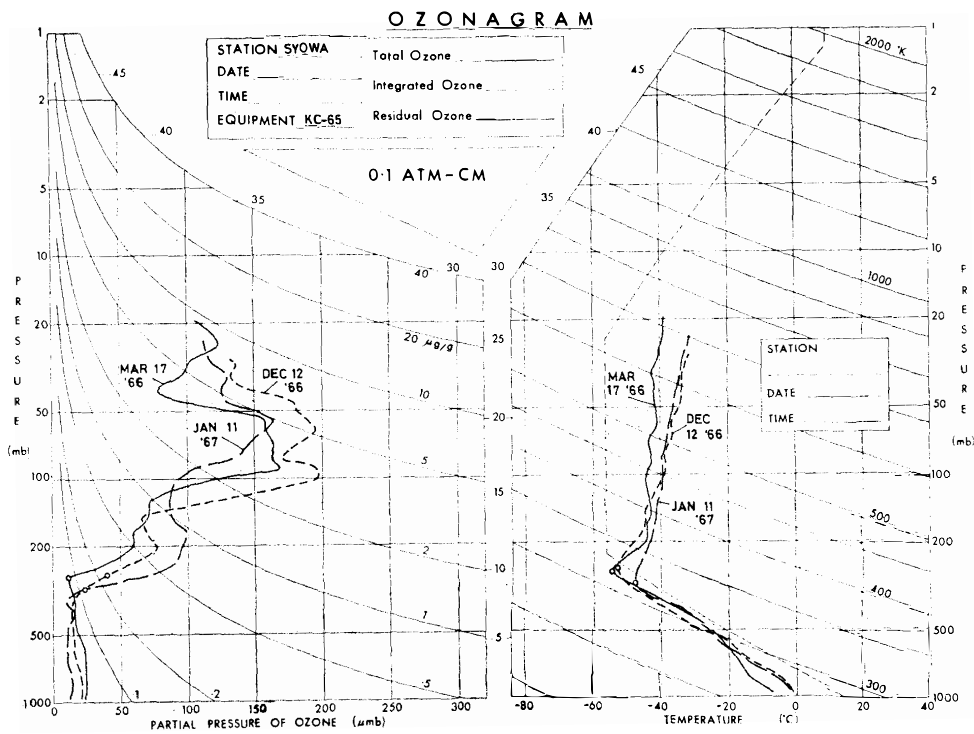

Fig. 19.

level, but the profiles below 100mb on both days were not changed essentially.

On October 26th, the 50mb temperature dropped to −56.4°C and the total ozone to 333matm-cm. In this period (Fig. 17), the ozone decrease occurred throughout the stratosphere. After that, the 50mb temperature and total ozone increased gradually to the maxima of about −25°C and 450matm-cm in late November. In this period (Figs. 17–18), the warming and ozone increase continued in the lower stratosphere below 60mb.

After midsummer to autumn (Fig. 19), the profiles of ozone partial pressures were rather irregular with very large secondary maxima in the lower stratosphere.

These ozone profiles and changes must be investigated more precisely particularly with wind data.

5.5. Ozone increase through tropopause level

As shown in the ozonagrams (Figs. 10–19), the upward increase of ozone partial pressure begins usually at a level below the tropopause which is indicated with a small circle. Here the author defines "ozone-pause" as the level at which the ozone partial pressure starts to increase upwards into the stratosphere. In practice, the ozone-pause is selected out of the data for every minute in each flight, as the level of minimum ozone partial pressure nearest to the tropopause.

Table 5. Frequency distribution of ΔH=tropopause height − "ozone-pause" height, at Syowa.

ΔH (km)	0.00 —0.49	0.5. —0.99	1.00 —1.49	1.50 —1.99	2.00 —2.49	2.50 —2.99	3.00 —3.49	Total
Number of cases	7	6	5	3	5	1	1	28

The height differences between the tropopause and the ozone-pause are tabulated in Table 5. The upward increase of ozone layer starts always, at Syowa, below the tropopause. The height differences are mostly (93% of the cases) less than 2.5km, and the mean difference is 1.25km. This value is larger than the value (less than 0.5km except one case in 16 soundings at Halley Bay) reported by MacDowall and Smith (1962).

Acknowledgments

The author expresses his sincere thanks to the people who supported this task. Dr. J. KOBAYASHI and Mr. Y. TOYAMA of Meteorological Research Institute, Japan Meteorological Agency, developed the carbon-iodine type ozonesonde and instructed the author in treatment of the sondes. At Syowa Station, two meteorologists, Mr. Z. SEINO and Mr. K. ISHIDA of J. M. A., and other members of the 7th Japanese Antarctic Research Expedition led by Dr. A. MUTO, collaborated in the ozonesonde flights and encouraged the author. Mr. Y. MORITA, the former chief of the Antarctic Observation Office, J. M. A., encouraged the task and Mr. T. SUZUKI and other staff of the Aerological Section, J. M. A., helped in the data reduction. This first success of the practical soundings using Japanese chemical ozonesondes owes to those mentioned above.

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(*Manuscript received January 20, 1969*)

ANNEX

This annex gives the tables of ozone partial pressures and air temperatures at selected pressure levels for individual ozone soundings and for monthly or seasonal means during the period from March 1966 to January 1967 at Syowa Station (69°00′S, 39°35′E), Japanese Antarctic Station. The ozonesonde was KC-65, carbon-iodine type.

Explanation of the tables :

DATE : 2 digits stand for each of year, month and day of observation (*e. g.* 660317 means March 17th, 1966).

TIME : 2 digits stand for each of local standard hour (=GMT+3hours) and minute of balloon release (*e. g.* 1055 means 10h55m).

TOTO3 : Total ozone amount (matm-cm) obtained by the Dobson spectrophotometer.

DOBR : Dobson ratio (ratio of TOTO3 to the total ozone estimated from raw data of the ozone sounding).

INTO3 : Integrated ozone amount (matm-cm) below the highest level of the sounding.

P : Atmospheric pressure (mb).

T : Air temperature (0.1°C), negative sign omitted and, if positive, plus sign added.

P3 : Ozone partial pressure (0.1 μmb for individual sounding and μmb for mean).

Special levels :

SURF : Surface level, 15m above mean sea level.

O3PSE : Ozone-pause, at which P3 starts to increase upwards into the stratosphere.

TRPSE : Tropopause level.

O3MAX : Level of maximum P3.

MINP : Minimum pressure, that is, highest level of the sounding.

Each sign of the special levels is followed by the pressure value of P and, underneath, the velues of T and P3 at that level. The values of INTO3 and P3 were corrected by multiplying raw ozone data by the value of DOBR, except for winter data without Dobson value.

In the tables of monthly means, INTO3 is the total ozone amount estimated from the mean vertical distribution of ozone on the assumption that the mixing ratio is constant above 25mb level, and T is the monthly average of daily routine soundings. T in ( ) is estimated from the ozone soundings in the month and P3 in ( ) is extrapolated taking into account the upward tendencies of ozone partial pressure and mixing ratio of the individual soundings. Seasonal means were calculated from the monthly means.

DATE	660317		660412		660420		660429	
TIME	1055		1810		1756		1752	
TOTO3	323		......		......		......	
DOBR	1. 126		......		......		......	
INTO3	238. 0		176. 7		158. 1		105. 7	
P	T	P3	T	P3	T	P3	T	P3
850	132	248	190	266	174	167	117	065
700	175	239	263	230	183	148	237	061
600	205	234	316	200	235	136	303	040
500	258	187	387	198	320	115	396	050
400	358	165	456	306	441	169	534	030
350	435	139	486	421	505	086	562	052
300	506	122	493	535	571	076	553	068
250	520	341	450	509	573	349	535	107
200	442	589	488	469	511	299	535	139
175	439	597	484	463	504	416	533	340
150	429	681	495	394	504	460	527	595
125	436	720	518	413	516	597	547	818
100	444	1250	562	630	525	815	549	1027
90	423	1669	572	781	532	922	560	1337
80	428	1619	577	968	530	990	577	1384
70	431	1629	597	1238	548	1055	594	1257
60	410	1583	600	1305	573	1071	606	1114
55	410	1576	602	1192	578	1070	614	1072
50	416	1317	611	1072	583	1090		
45	417	979	623	1113	583	1070		
40	414	791	617	1012	588	1080		
35	423	948	625	1017	606	1023		
30	402	1008	628	973	614	932		
25	393	1235						
20	385	1107						
17. 5								
15. 0								
12. 5								
10. 0								
Special levels	SURF	982. 4	SURF	981. 4	SURF	985. 7	SURF	983. 8
	063	243	116	213	156	154	035	074
	O3PSE	274. 9	O3PSE	435. 1	O3PSE	309. 3	O3PSE	366. 0
	547	109	440	141	561	071	567	025
	TRPSE	274. 9	TRPSE	309. 5	TRPSE	290. 2	TRPSE	366. 0
	547	109	500	524	582	081	567	025
	O3MAX	92. 2	O3MAX	64. 6	O3MAX	42. 4	O3MAX	84. 8
	423	1671	598	1401	585	1099	568	1405
	MINP	19. 7	MINP	27. 3	MINP	26. 2	MINP	52. 9
	384	1077	619	827	615	859	611	1086

DATE	660511		660519		660602		660606	
TIME	1816		1200		1833		1145	
TOTO3	......		......		......		......	
DOBR	......		......		......		......	
INTO3	168.8		214.6		313.6		133.9	
P	T	P3	T	P3	T	P3	T	P3
850	170	092	157	147	174	276	227	277
700	252	128	272	170	272	207	266	249
600	325	114	297	187	329	187	322	199
500	399	078	338	242	409	166	408	199
400	497	159	427	130	484	164	503	137
350	520	239	478	089	521	222	551	132
300	514	408	551	068	552	289	592	131
250	485	579	624	076	576	419	603	262
200	477	654	598	313	568	616	603	357
175	487	773	555	391	570	873	608	454
150	490	956	569	605	572	1213	626	453
125	503	1075	560	1244	571	1758	640	850
100	529	953	570	1343	600	1983	656	1064
90	536	982	563	1550	607	1945	669	1270
80	545	1101	555	1646	616	1923	681	1225
70	570	1206	564	1562	624	1980	679	1195
60	580	1274	547	1612	629	1945	684	1214
55	591	1244	552	1692	625	1918	682	1128
50	602	1145	533	1696	626	1862	686	1191
45	614	1136	538	1679	633	1768		
40			526	1681	635	1654		
35			516	1577	638	1468		
30					625	1398		
25					658	1251		
20								
17.5								
15.0								
12.5								
10.0								
Special levels	SURF	985.3	SURF	995.3	SURF	983.3	SURF	993.7
	132	121	128	060	149	332	207	307
	O3PSE	497.0	O3PSE	293.3	O3PSE	447.8	O3PSE	316.9
	402	075	561	067	452	156	578	128
	TRPSE	323.6	TRPSE	236.5	TRPSE	268.5	TRPSE	294.1
	524	313	639	072	572	317	597	133
	O3MAX	64.8	O3MAX	88.1	O3MAX	66.0	O3MAX	93.0
	577	1318	562	1758	625	2023	663	1276
	MINP	41.0	MINP	30.2	MINP	22.0	MINP	48.6
	630	1172	521	1317	648	1230	690	1106

DATE TIME TOTO3 DOBR INTO3	660618 1759 .... 134.7		660630 1752 .... 127.6		660705 1753 .... 166.4		660722 1807 .... 159.6	
P	T	P3	T	P3	T	P3	T	P3
850	179	172	243	249	205	191	227	244
700	260	176	233	211	289	213	235	221
600	328	146	308	182	365	198	295	205
500	424	129	392	135	447	187	385	173
400	526	144	487	113	528	167	494	140
350	579	130	546	092	566	182	554	145
300	617	168	604	082	595	246	615	127
250	641	180	659	139	606	379	693	108
200	640	473	665	408	608	654	778	175
175	646	467	671	478	607	790	749	507
150	671	735	687	437	616	669	777	732
125	690	969	710	1110	634	1398	775	1154
100	720	1425	743	1526	653	1837	795	1680
90	731	1314	765	1236	655	1753	802	1896
80	750	1660	783	1708	656	1796	812	1861
70	768	1701	805	1671	658	1759	824	1657
60							812	1527
55							818	1584
50								
45								
40								
35								
30								
25								
20								
17.5								
15.0								
12.5								
10.0								
Special levels	SURF	970.4	SURF	999.1	SURF	994.7	SURF	998.4
	159	200	218	239	266	141	207	238
	O3PSE	269.7	O3PSE	275.3	O3PSE	441.9	O3PSE	246.8
	634	115	641	072	492	157	698	106
	TRPSE	225.2	TRPSE	245.4	TRPSE	316.5	TRPSE	199.0
	648	303	662	167	589	218	780	177
	O3MAX	74.7	O3MAX	79.8	O3MAX	87.8	O3MAX	85.6
	759	1789	784	1710	658	1886	809	1920
	MINP	60.6	MINP	62.0	MINP	60.2	MINP	53.6
	771	1577	821	1558	665	1629	820	1619

DATE TIME TOTO3 DOBR INTO3	660805 1815 .... 209.8		660818 1755 .... 159.6		660823 1803 .... 138.2		660829 1812 .... 214.9	
P	T	P3	T	P3	T	P3	T	P3
850	274	252	195	206	236	260	276	264
700	297	222	262	156	254	216	322	166
600	371	207	307	155	313	192	363	207
500	432	175	380	134	379	174	436	205
400	506	175	482	086	461	146	548	178
350	544	183	546	070	535	132	589	161
300	601	150	615	056	620	102	642	110
250	653	217	686	063	685	078	699	119
200	686	427	720	292	772	100	746	492
175	696	596	724	503	787	201	757	661
150	716	795	803	539	782	542	774	829
125	739	1355	782	953	796	798	785	1126
100	761	1746	799	1417	795	1390	804	1380
90	772	1776	803	1590	802	1668	801	1625
80	785	1614	816	1532	806	1721	820	1744
70	801	1645	824	1555	807	1731	830	1707
60	818	1484	836	1460	808	1669	834	1643
55	822	1499	840	1488	814	1581	835	1631
50	829	1430	858	1458			833	1508
45	834	1380	854	1430			833	1321
40	841	1188					844	1134
35	840	1085					848	987
30							843	972
25								
20								
17.5								
15.0								
12.5								
10.0								
Special levels	SURF 268 O3PSE 606 TRPSE 660 O3MAX 774 MINP 835	972.4 230 296.3 145 242.4 241 89.3 1783 33.6 1051	SURF 150 O3PSE 682 TRPSE 723 O3MAX 796 MINP 853	981.3 268 253.7 062 220.7 110 103.6 1646 44.1 1433	SURF 206 O3PSE 738 TRPSE 781 O3MAX 802 MINP 814	974.0 247 222.3 062 191.9 109 74.3 1757 54.4 1578	SURF 279 O3PSE 666 TRPSE 747 O3MAX 823 MINP 843	977.6 163 281.1 095 205.6 442 75.0 1753 29.8 967

DATE	660906		660919		660927		661005	
TIME	1153		1144		1759		1758	
TOTO3	332		314		350		342	
DOBR	1.153		1.375		1.375		1.165	
INTO3	245.9		268.4		205.7		249.6	

P	T	P3	T	P3	T	P3	T	P3
850	255	128	186	524	161	315	212	334
700	236	148	227	458	265	273	256	271
600	307	139	284	408	336	205	301	220
500	398	119	363	397	423	193	385	192
400	516	108	461	330	495	203	489	166
350	582	111	525	293	552	198	550	141
300	627	121	578	245	618	233	624	108
250	663	216	668	240	657	219	684	119
200	696	530	772	180	703	491	757	251
175	701	771	798	346	729	700	756	474
150	713	1089	798	744	736	1129	743	930
125	746	1458	789	1115	726	1657	731	1492
100	751	1768	786	1545	734	1952	726	1754
90	752	1925	785	1607	731	1998	724	1825
80	755	1946	781	1796	727	1934	717	1835
70	764	1891	771	1805	736	1983	703	1812
60	769	1811	767	1689	753	1976	696	1769
55	767	1789	767	1586	738	1892	699	1628
50	773	1710	757	1359			685	1415
45	764	1705	751	1231			666	1666
40	756	1577	732	1116			657	1574
35	752	1191	707	1076			649	1430
30			686	973			611	1299
25			658	838				
20			621	729				
17.5			592	671				
15.0								
12.5								
10.0								

Special levels	SURF	978.4	SURF	974.7	SURF	969.9	SURF	983.4
	265	005	135	537	105	311	147	358
	O3PSE	340.2	O3PSE	198.2	O3PSE	233.9	O3PSE	226.3
	595	106	775	178	679	211	728	098
	TRPSE	316.9	TRPSE	185.0	TRPSE	181.4	TRPSE	212.4
	617	112	798	179	726	677	758	103
	O3MAX	87.2	O3MAX	77.1	O3MAX	65.0	O3MAX	66.0
	753	1964	783	1863	741	2012	693	1917
	MINP	30.4	MINP	15.5	MINP	52.0	MINP	27.9
	742	1092	558	579	741	1829	601	117.1

DATE	661013		661020		661024		661030	
TIME	1129		1755		1753		1752	
TOTO3	344		454		392		350	
DOBR	1. 158		1. 301		1. 538		1. 336	
INTO3	290. 3		372. 8		293. 1		286. 2	
P	T	P3	T	P3	T	P3	T	P3
850	151	407	182	160	163	465	140	244
700	228	361	229	142	204	396	204	279
600	280	320	278	141	286	354	280	164
500	367	270	356	127	390	265	354	177
400	474	208	451	107	471	206	435	156
350	529	190	496	123	531	157	482	192
300	584	190	562	083	597	140	517	319
250	630	199	608	194	629	193	581	142
200	644	455	648	410	646	316	664	356
175	650	641	637	711	642	447	665	616
150	656	851	625	914	633	631	660	688
125	640	1262	606	1297	612	917	649	1100
100	635	1541	566	1824	610	1170	630	1551
90	630	1648	543	2054	598	1241	626	1592
80	625	1632	506	2158	567	1361	628	1625
70	624	1698	479	1924	545	1785	605	1834
60	604	1701	427	2180	526	2017	591	1899
55	588	1710	398	2262	517	2009	595	1918
50	574	1707	361	2108	515	1956	584	1848
45	565	1643	315	1913	498	1763	563	1645
40	558	1537	294	1980	485	1758	552	1623
35	548	1336	271	2178	473	1536	531	1344
30	528	1175	274	2024	458	1402	525	1202
25	499	929	272	1762	413	1281	507	994
20	472	809	239	1479	348	1228	410	956
17. 5	444	779	230	1319	280	1257	370	879
15. 0	414	694	222	1162			324	814
12. 5								
10. 0								
Special levels	SURF	960. 3	SURF	974. 1	SURF	968. 6	SURF	994. 1
	146	436	123	144	096	473	135	156
	O3PSE	287. 0	O3PSE	301. 3	O3PSE	299. 8	O3PSE	223. 8
	598	187	561	082	597	140	624	142
	TRPSE	247. 0	TRPSE	202. 4	TRPSE	230. 7	TRPSE	209. 0
	633	200	650	378	644	236	658	150
	O3MAX	45. 7	O3MAX	55. 1	O3MAX	55. 5	O3MAX	54. 9
	568	1719	399	2264	517	2026	595	1919
	MINP	14. 7	MINP	13. 1	MINP	16. 6	MINP	14. 9
	414	681	252	1029	275	1253	324	808

DATE	661126		661129		661212		670111	
TIME	1149		1815		1159		1725	
TOTO3	421		388		366		330	
DOBR	1. 453		1. 377		1. 240		1. 519	
INTO3	305. 6		304. 3		262. 0		240. 6	
P	T	P3	T	P3	T	P3	T	P3
850	102	173	082	214	044	209	049	135
700	197	137	154	192	147	177	148	109
600	278	134	209	181	187	159	215	098
500	356	115	282	165	294	149	298	099
400	470	087	383	157	393	136	351	158
350	533	108	452	134	456	144	441	107
300	567	246	526	102	505	264	478	360
250	557	564	615	091	521	508	464	869
200	533	989	574	731	473	782	431	973
175	522	1160	555	733	448	702	420	991
150	479	1522	521	1293	445	651	416	894
125	431	1859	451	1853	422	1203	406	860
100	389	2038	378	2293	387	1953	391	916
90	357	2008	369	2262	383	1946	401	1063
80	318	1921	329	2230	383	1685	390	1374
70	309	1814	310	2191	364	1804	380	1458
60	298	1680	316	2228	363	1935	374	1559
55	299	1618	309	1758	360	1905	355	1631
50	291	1634	303	1680	347	1813	360	1514
45	259	1478	291	1695	337	1785	364	1305
40	245	1553	289	1533	337	1473	344	1263
35	251	1540	284	1416	334	1319	339	1306
30	254	1314	278	1255	319	1356	338	1192
25	239	1476	284	1051			315	1141
20								
17. 5								
15. 0								
12. 5								
10. 0								
Special levels	SURF	989. 8	SURF	994. 1	SURF	987. 8	SURF	987. 9
	002	156	016	258	008	208	009	119
	O3PSE	400. 7	O3PSE	269. 4	O3PSE	368. 8	O3PSE	358. 5
	469	086	578	091	431	138	430	093
	TRPSE	292. 2	TRPSE	232. 8	TRPSE	265. 1	TRPSE	310. 4
	569	311	629	185	530	402	478	232
	O3MAX	102. 7	O3MAX	72. 5	O3MAX	87. 2	O3MAX	54. 4
	392	2042	315	2441	381	1960	352	1642
	MINP	24. 5	MINP	23. 1	MINP	29. 0	MINP	23. 9
	240	1463	289	1061	315	1319	312	1133

DATE TIME TOTO3 DOBR INTO3	Mean for Apr. 1966 …… …… 235		Mean for May 1966 …… …… 296		Mean for June 1966 …… …… 313		Mean for July 1966 …… …… 316	
P	T	P3	T	P3	T	P3	T	P3
850	144	17	154	13	211	25	218	22
700	218	15	223	15	268	21	254	22
600	279	13	284	15	336	18	321	20
500	359	12	363	16	416	16	399	18
400	448	17	460	15	512	14	497	16
350	501	19	514	17	564	14	555	17
300	550	23	557	24	613	17	613	19
250	538	32	570	33	641	25	672	25
200	507	30	561	48	640	47	715	42
175	504	41	559	58	644	57	720	65
150	509	48	558	79	653	71	732	70
125	519	61	570	116	676	117	745	128
100	532	83	582	115	701	150	769	176
90		101		127		144		183
80		111		138		163		183
70	558	119	607	139	740	164	799	171
60		116		144		158		158
55		111		147		153		(153)
50	568	108	624	143	746	153	796	(148)
45		109		141		(147)		(139)
40	572	105	640	(140)	756	(137)	807	(130)
35		102		(132)		(127)		(120)
30	547	95	672	(115)	766	(115)	……	(109)
25		(83)		(97)		(100)		(94)
20								
17.5								
15.0								
12.5								
10.0								

DATE TIME TOTO3 DOBR INTO3	Mean for Aug. 1966 293		Mean for Sept. 1966 326 339		Mean for Oct. 1966 363 363		Mean for Nov. 1966 400 408	
P	T	P3	T	P3	T	P3	T	P3
850	235	25	175	32	183	32	124	19
700	284	19	238	29	244	29	198	17
600	305	19	302	25	303	24	257	16
500	416	17	384	24	383	21	334	14
400	514	15	486	21	479	17	437	13
350	585	14	547	20	535	16	497	12
300	631	11	612	20	596	17	556	18
250	691	12	675	23	650	17	593	33
200	734	33	725	40	675	36	584	86
175	747	49	735	61	677	58	567	95
150	758	68	741	99	671	80	544	141
125	773	106	745	141	663	121	517	186
100	789	149	756	176	646	157	476	217
90		167		184		167		214
80		165		189		172		208
70	809	166	762	189	614	181	417	208
60		156		183		191		196
55		155		176		191		(188)
50	808	147	759	(164)	569	181	387	(180)
45		138		(153)		171		(170)
40	813	(126)	752	(140)	537	169	363	(162)
35		(116)		(127)		157		(152)
30	788	(103)	767	(110)	(479)	142	301	(139)
25		(90)		(95)		119		127
20			712	......	(390)	112	215	......
17.5						106		
15.0						(95)		
12.5								
10.0								

DATE TIME TOTO3 DOBR INTO3	Mean for Mar., Dec. 1966 and Jan. 1967		Mean for Apr.-Aug. 1966		Mean for Sept.-Nov. 1966	
P	T*	P3	T	P3	T	P3
850	095	20	192	20	161	28
700	175	18	249	18	227	25
600	235	16	305	17	287	22
500	304	15	391	16	367	20
400	398	16	486	15	467	17
350	452	13	544	16	526	16
300	492	25	593	19	588	18
250	484	57	622	25	639	24
200	445	78	631	40	661	54
175	434	76	635	54	660	71
150	431	74	642	67	652	107
125	425	93	657	106	642	149
100	418	137	675	135	626	183
90		156		144		188
80		156		152		190
70	404	163	703	152	598	193
60		170		146		190
55		170		144		185
50	396	(162)	708	140	572	175
45		(152)		135		165
40	389	(143)	717	128	551	157
35		(132)		119		145
30	362	119	693	107	516	130
25		(103)		93		114
20	326	......			439	......
17.5						
15.0						
12.5						
10.0						

* *Mean including Feb. 1966.*