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Preliminary results of vertical ozone soundings at Wakkanai, Japan

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Abstract: In order to obtain better understanding of ozone change in northern Japan, soundings of vertical ozone profile by using an ECC type ozone sonde were conducted at Wakkanai (45.4°N, 141.7°E) in Hokkaido, the northernmost city of Japan, between 15th–24th February, 2001. Ten vertical profiles of ozone on consecutive ten days were obtained successfully. In this paper, the methods and results of the observations are shown.

1. Introduction

The ozone layer in the atmosphere plays an important role because it protects human beings and all life on Earth from UVB solar radiation. The ozone molecules in the stratosphere are formed in the upper stratosphere of lower latitudes and transported to the lower polar stratosphere through the atmospheric general circulation.

The Okhotsk Sea, the Aleutian Islands and Kamchatka Peninsula, which are located north of Japan, are regions where very high annual mean total ozone amounts have been observed (Japan Meteorological Agency, 2001) because these are the areas where ozone is transported and stored in the stratosphere.

To make sure how the ozone molecules are transported from the tropical upper stratosphere to these areas, it is necessary to have the vertical ozone profiles in these areas. However, there are not many reports on ozone profiles. Moreover, it is reported that large long term total ozone decreases in winter in these areas (World Meteorological Organization: WMO, 1998).

In order to grasp the actual state of the vertical ozone profile in these areas, ozone sonde observations using an Electrochemical Concentration Cell (ECC) type ozonesonde were carried out at Wakkanai (45.4°N, 141.7°E) in Hokkaido, the northernmost city of Japan, between 15th–24th February 2001.

This paper describes the instruments and procedures of the observations conducted at Wakkanai. The preliminary results are presented.

2. Observations

2.1. ECC ozonesonde

The ozonesondes used were type ECC ozonesondes produced by EN-SCI Corporation in the USA. A sensor of an ECC ozonesonde is a concentration cell composed of two half-cells, each of which consists of platinum electrode and Potassium Iodide solution (Komhyr, 1969). The concentrations of the solutions in the two cells are different. When one ozone molecule passes the half-cell containing sensing solution, two electrons flow in the cell's external circuit. The number of ozone molecules in the sampled air can be calculated from the measured sensor output current.

The sensor output current, pump temperature, motor current and battery voltage of an ECC ozonesonde are sent by cable to a Vaisala RS80-15 meteorological radiosonde. In addition, the signals of atmospheric pressure, relative humidity, and air temperature are simultaneously observed by a Vaisala meteorological radiosonde. These signals and the ECC ozonesonde signals are sent to a receiver on the ground on a 403 MHz radio carrier wave.

Before the flight, the ECC ozonesonde was prepared and stored in a flight box. The Vaisala radiosonde was connected and attached to the ECC ozonesonde in order to measure air temperature, atmospheric pressure and relative humidity. Then, observed data were transmitted to the ground station. The total weight of the ozonesonde and radiosonde with batteries is about 900 g. The ECC ozonesonde and radiosonde are generally flown with a rubber balloon.

Figure 1 shows how the ECC ozonesonde and the Vaisala RS80-15 meteorological radiosonde are connected to the balloon.

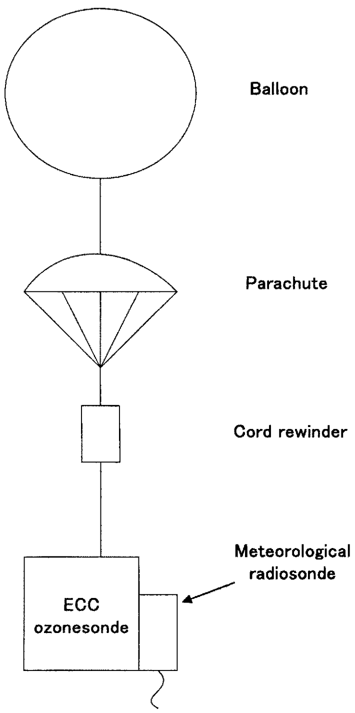

Fig. 1. The connection of ECC ozonesonde and radiosonde to the balloon just before the release.

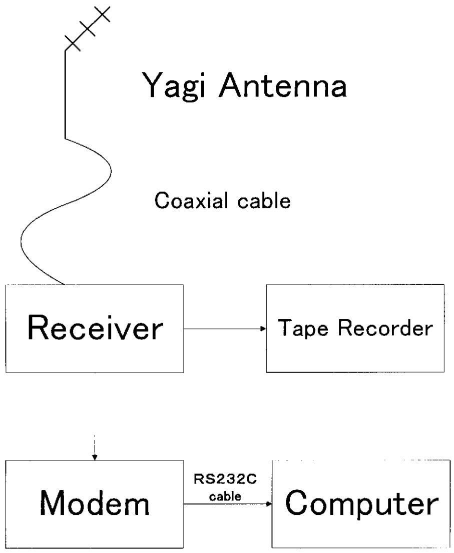

Fig. 2. Block diagram of the data acquisition system for ECC ozonesonde observation at ground station.

2.2. *Data acquisition system at ground station*

Figure 2 shows the configuration of the data acquisition system for an ECC ozonesonde observation. At first, the radio wave transmitted from a radiosonde which was attached to the ECC ozonesonde was received by a Yagi antenna and sent to the receiver through a cable. The receiver (IC-R8500, ICOM Inc.) extracted the signal from the 403 MHz radio wave and a 300 band modem demodulated the signal. The demodulated signal was sent to a computer (Dell Latitude 266) through an RS232C cable. The 'VO3' data acquisition software (EN-SCI Corporation, 1997a) on the computer reproduced the signals from the airborne ozonesonde and radiosonde. The computer displayed these values on the computer monitor every 1.2 s. In addition, the VO3 software calculated and displayed ozone partial pressures and other data on the computer monitor in real time. These data were recorded on a hard disk.

The low frequency signal output from the receiver was also sent to a cassette tape recorder connected to the receiver to record the output signal. The tape was to be used in case of a modem or computer failure on the ground.

The Yagi antenna was set on the roof of the building at the office of the Wakkanai District Meteorological Observatory. The antenna was connected to the receiver placed in the aerological operation room of the observatory.

2.3. *Preparation of ECC ozonesonde for the flight*

According to the ECC ozonesonde operation manual, the advanced preparation, check of overall sonde performance and charge of sensing solution should be carried out three days to one week prior to the flight. If there is a requirement to use the ECC ozonesonde on the same day or within 3 days, then we use the procedure written in

Section 2.4, 'Preparing and flying an ECC ozonesonde on the same day' of 'EN-SCI Corporation model KZ-ECC atmospheric ozone sounding system' published by EN- SCI Corporation (1997b).

On the day of the flight, in the morning we conducted preparations such as replacement of the sensing solution, passing ozone free air through sensor, and measurement of response time of the sensor. At about 1300 JST (Japanese Standard Time), we connected the ECC ozonesonde to a meteorological sonde and started to run the VO3 software. Then the flow rate of intake air and the background current were measured and input to the computer. At about 1500 JST, we started to fill the rubber balloon with hydrogen gas. In the final stage of preparation, we put an ECC ozonesonde into a flight box and attached the radiosonde to the ECC ozonesonde.

Before the flight, the ECC ozonesonde was placed in outdoor conditions to make sure that operation was normal. The VO3 software was operating in 'SURFACE OZONE' mode at this time.

2.4. Balloon flight and observations

When normal operation of the ozonesonde was confirmed, the VO3 software was switched to 'FLIGHT' mode. The ECC ozonesonde was then connected to a balloon with a parachute and a cord rewinder, as shown in Fig. 1. We launched the ozonesonde at around 1530 JST (see Fig. 3). After the launch, an antenna operator kept tracking the ozonesonde (see Fig. 4). We monitored the operation of the ozonesonde from the computer screen.

Table 1 shows the date and time of balloon release, ECC ozonesonde and meteorological radiosonde used, and also time and altitude when the ozonesonde reached its

Fig. 3. The release of an ECC ozonesonde at Wakkanai.

Fig. 4. Tracking the ECC ozonesonde using a YAGI antenna on the roof of a building in Wakkanai.

Table 1. Summary of observations (observational date and time, serial numbers of ECC ozonesonde used and Vaisala meteorological radiosonde used, time and pressure at maximum height. The ending time is denoted in the last column).

Launching		ECC Ozonesonde	Vaisara R80-15	Time of Max.height	Pressure Of Max.height	Time of Observation stop
Date Month/date	Time (hh:mm:ss)			(hh:mm:ss)	(hPa)	(hh:mm:ss)
Feb. 15	15:30:00	2Z1250	914604305	17:09:15	4.16	17:22:00
Feb. 16	15:30:15	2Z1970	914604311	17:02:45	6.50	18:03:00
Feb. 17	15:29:00	2Z1253	48302504	17:07:30	4.81	17:49:30
Feb. 18	15:27:15	2Z1248	48302713	17:00:00	6.40	17:57:15
Feb. 19	15:30:15	2Z1965	48302501	17:08:45	5.03	18:18:15
Feb. 20	15:30:30	2Z1962	48302502	17:07:45	4.98	17:54:30
Feb. 21	15:30:15	2Z1964	914612301	17:01:15	9.83	18:03:15
Feb. 22	15:40:15	2Z1963	48302506	17:18:45	4.58	18:12:00
Feb. 2301	15:30:15	2Z1966	48302505	15:49:45	356.25	15:49:45
Feb. 2302	17:08:45	2Z1968	914612311	18:52:45	7.33	19:22:45
Feb. 24	15:51:00	2Z1967	48302710	17:38:00	3.80	17:50:45

highest point, and time when the observations ended. We continued the observations until the signals were no longer received.

3. Discussion of observational results

3.1. Correction to total ozone amount

Table 2 shows the total ozone amounts observed with a Dobson spectrophotometer at Sapporo (43.1°N, 141. 3°E) and those at Sapporo derived from TOMS (Total Ozone Mapping Spectrometer) data from 15th to 24th February 2001. It is seen in Table 2 that the total ozone amounts were compared with TOMS and Dobson spectrophotometer data on eight days. The mean values of total ozone amounts are 382.4 DU and 386.6 DU for Dobson spectrophotometer and TOMS data, respectively. It is found that the total ozone amount in TOMS data was 4.2 DU larger than that measured by the Dobson spectrophotometer in this period at Sapporo on average. After deriving a total ozone value from TOMS data at Wakkanai (45.4°N, 141.7°E), we subtract the difference of 4.2 DU from the TOMS total ozone amount in order to obtain the value correspond to Dobson total ozone amounts at Wakkanai.

3.2. Normalization of ECC ozonesonde data to TOMS total ozone

Table 2. Total ozone amounts measured from the Dobson spectrophotometer and from TOMS at Sapporo between 16th–24th February 2001.

Date	Dobson Total ozone (DU)	TOMS total ozone (DU)
Feb. 16	491.0	516.0
Feb. 17	438.0	431.6
Feb. 19	432.0	410.4
Feb. 20	327.0	344.8
Feb. 21	330.0	338.8
Feb. 22	341.0	367.0
Feb. 23	340.0	336.4
Feb. 24	360.0	348.0
Average	382.4	386.6

It is the general practice to normalize ozonesonde profile data to quasi simultaneously obtained Dobson spectrophotometer total ozone amount (EN-SCI Corporation, 1997b).

However, because Dobson spectrophotometer total ozone data were not available at Wakkanai, the results of ECC ozonesonde observation were normalized to the total ozone amounts 4.2 DU smaller than TOMS data at Wakkanai obtained by the method described above. Table 3 shows the total ozone amounts derived from TOMS data before and after the corrections were made, in addition to the total ozone amounts from the ECC ozonesonde obtained under the assumption of constant ozone mixing ratio

Table 3. Total ozone amounts from TOMS data at Wakkanai (1st column denotes the total ozone without correction and second column is for the total ozone with correction ; third column is for ozone from ECC ozonesonde) and the ratio of the 2nd column to the 3rd column (fourth column).

	(a)	(b)	(c)	(d)
Observational date	Total ozone from TOMS (without correction) (DU)	Total ozone from TOMS (with correction) (DU)	Total ozone from ECC ozonesonde (DU)	Ratio of column (b) to column (c)
Feb. 15	497.8	493.6	530.6	0.930
Feb. 16	491.4	487.2	483.8	1.007
Feb. 17	424.6	420.4	437.1	0.962
Feb. 18	377.8	373.6	388.3	0.962
Feb. 19	417.0	412.8	438.2	0.942
Feb. 20	395.8	391.6	361.7	1.083
Feb. 21	356.9	352.7	393.8	0.896
Feb. 22	431.0	426.8	433.5	0.985
Feb. 23	360.4	356.2	325.7	1.094
Feb. 24	393.0	388.8	420.8	0.924

above the height at which the balloon burst. Table 3 also shows the ratios of the corrected TOMS total ozone amounts to ECC ozonesonde total ozone at Wakkanai. By multiplying this ratio by the ozone partial pressure, we can normalize the ozonesonde profile data to the corrected TOMS total ozone. Then the total ozone from the ozonesonde profile data will be equal to the corrected TOMS total ozone.

3.3. *Vertical profiles of ozone and air temperature at Wakkanai*

Figure 5 shows the vertical profiles of ozone partial pressure and air temperature observed at Wakkanai between 15th–24th February 2001. The ozone profiles are normalized by the method described above. These figures show that most of the maximum peaks are between 100 and 50 hPa. The daily variation is small in the troposphere below 300 hPa, though it is large between 200 hPa and 10 hPa in the stratosphere. Large laminae are seen at around the 125 hPa level from 21st–24th February 2001. These phenomena are also observed during the descending phase (not shown in this paper). Similar ozone profiles were observed by Tomikawa *et al.* (2002).

3.4. *Daily variation of total ozone amounts at Wakkanai*

Figure 6 shows the daily variation of corrected total ozone amounts with TOMS data from 1st–28th in February 2001 at Wakkanai. As seen in column (b) of Table 3, total ozone amounts at Wakkanai show a daily variation between 350 DU and 500 DU. Figure 6 also shows that the second maximum value and the minimum value of total ozone amounts of February 2001 were observed between 15th–24th February 2001 (shown by dots with circles).

3.5. Classification of the vertical profiles of ozone and air temperature

In order to know the distribution of ozone changes at which altitude occurred, we classified the ozone distributions into three classifications, which are denoted as class L (total ozone amount is larger than or equal to 450 DU), class M (total ozone amount between 450 DU and 400 DU) and class S (total ozone amount is lesser than 400 DU). Table 4 shows the classifications of ozone into three classes. The mean vertical profiles

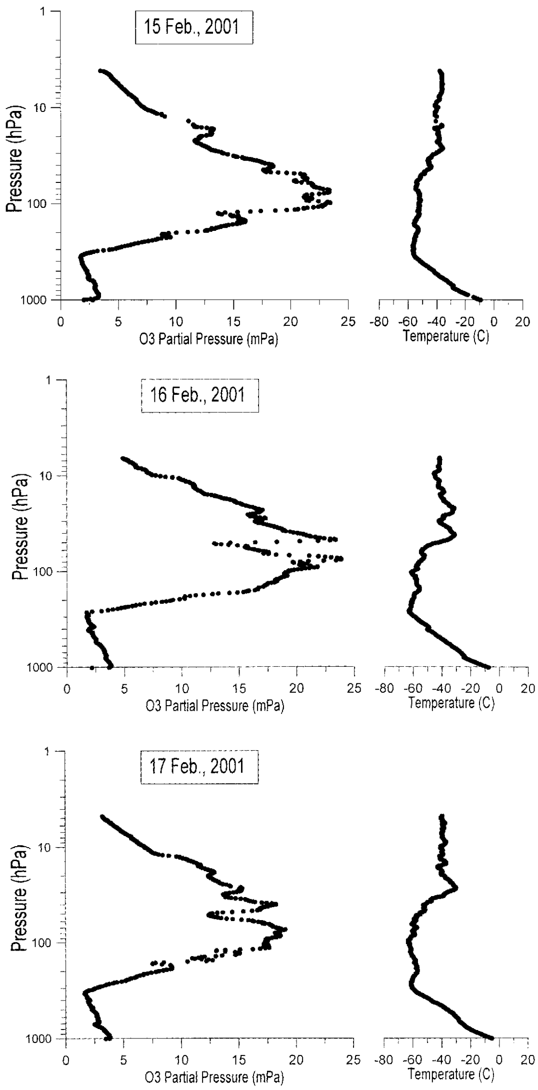

Fig. 5. Vertical distributions of ozone partial pressure and air temperature observed at Wakkanai on 15th–24th February 2001. On 23rd February, two ECC ozonesondes were released. The day numbers of 2301 Feb. and 2302 Feb. correspond to the ones in Table 1.

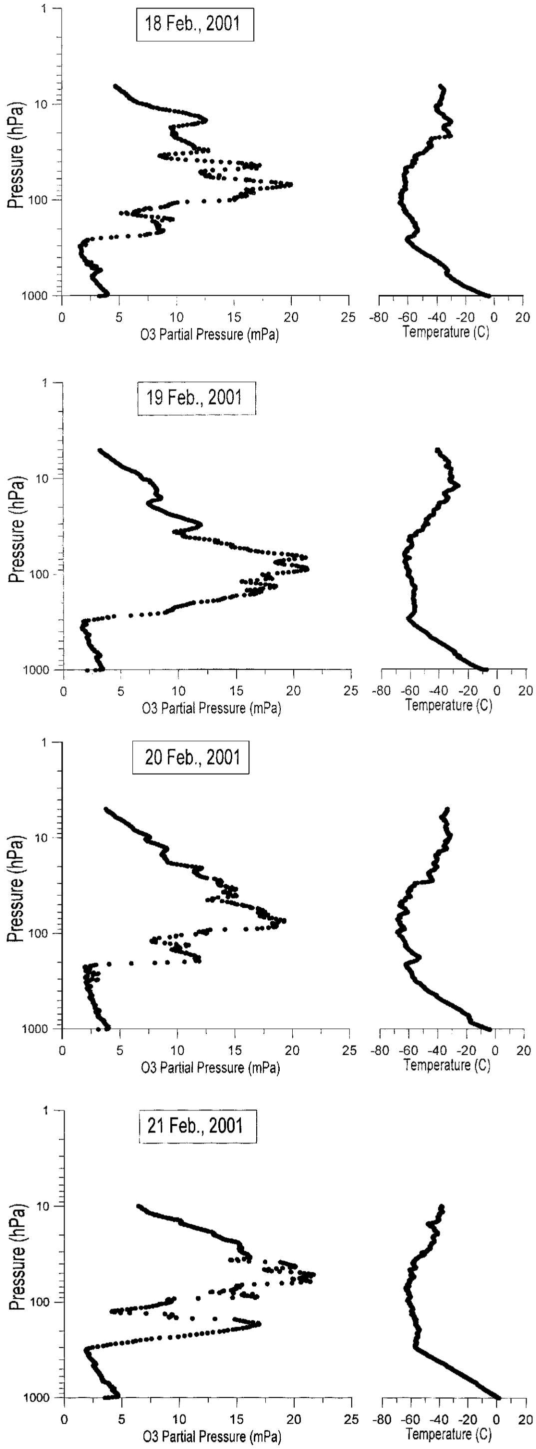

Fig 5. Continued.

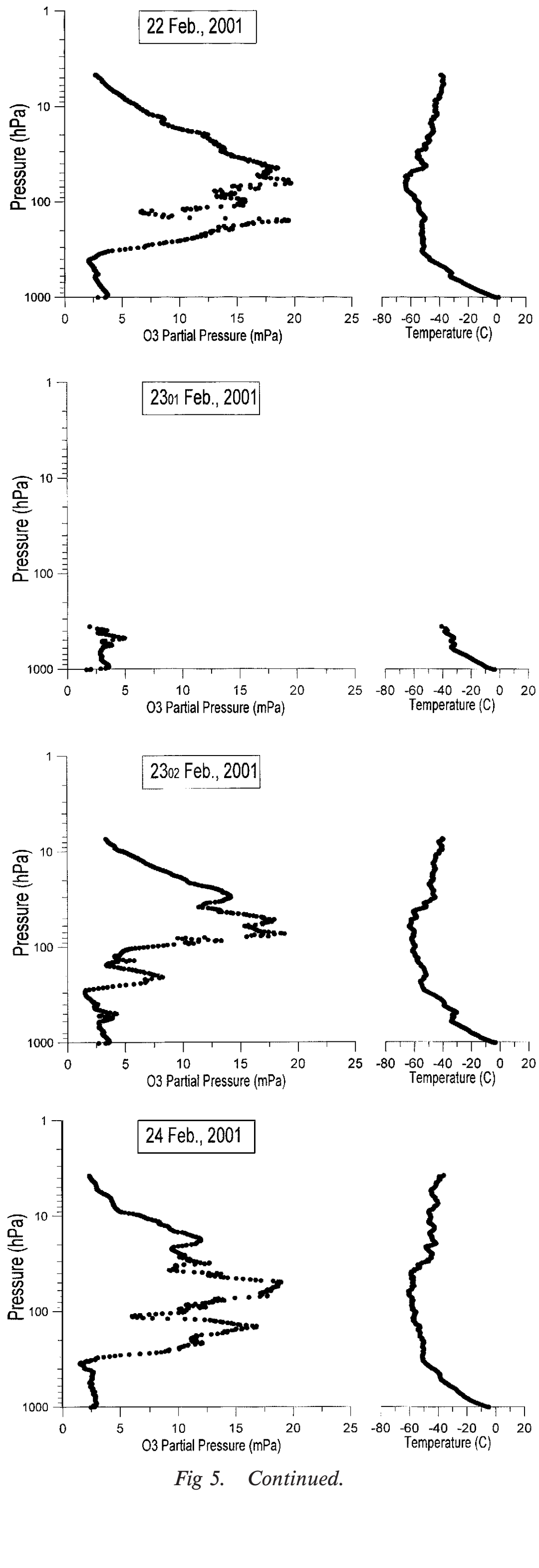

Fig 5. Continued.

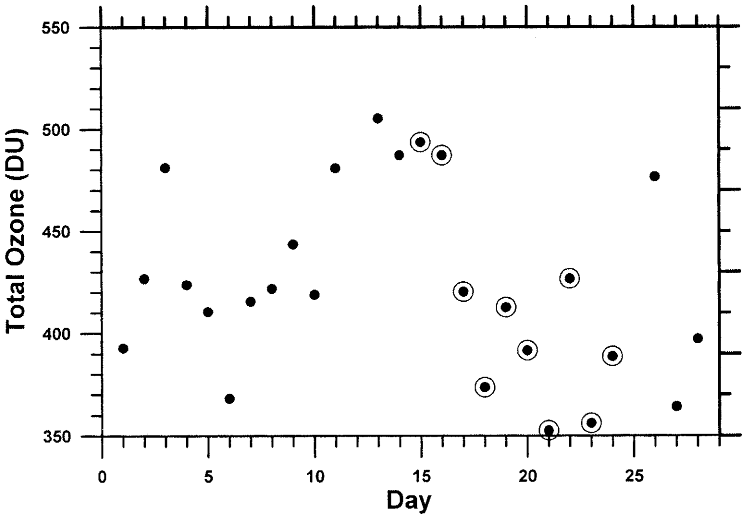

Fig. 6. Daily variations of corrected total ozone amounts at Wakkanai between 1st–28th February 2001. The horizontal axis shows day number in February. The dots with circles show the value of corrected total ozone in the period between 15th–24th February 2001.

Table 4. Classification of the days into three classes : class L (total ozone amount≧450 DU), class M (total ozone amount between 400 DU and 450 DU) and class S (total ozone amount<400 DU).

Date	Total ozone with correction (DU)	Class
Feb. 15	493.6	L
Feb. 16	487.2	L
Feb. 17	420.4	M
Feb. 18	373.6	S
Feb. 19	412.8	M
Feb. 20	391.6	S
Feb. 21	352.7	S
Feb. 22	426.8	M
Feb. 23	356.2	S
Feb. 24	388.8	S

of ozone partial pressure for three classifications are shown in Fig. 7. The figure indicates that the ozone below 200 hPa for three classes has similar vertical profiles. The ozone partial pressure for the L class at altitudes higher than 200 hPa is generally larger than those for the M and S classes. The mean values of ozone in the M and S classes have exhibited similar profiles below 200 hPa and higher than 70 hPa. There are distinct differences for ozone profiles that are observed in the M and S classes between 200 hPa and 70 hPa.

Figure 8 shows the mean vertical profiles of air temperature observed by ECC ozonesonde for three classifications. Mean air temperature in the L class shows a lower

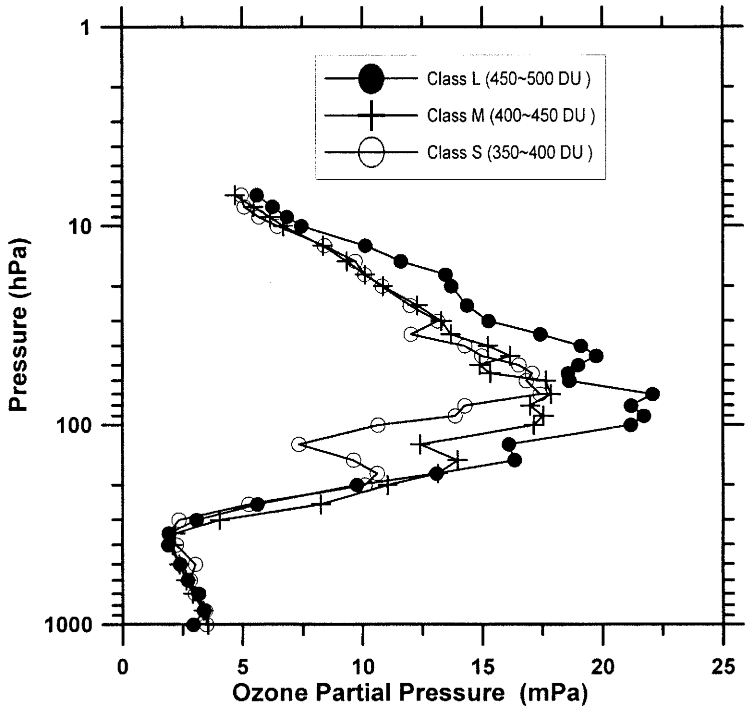

Fig. 7. Mean vertical profiles of ozone partial pressure at Wakkanai for L, M and S classes.

temperature than the M and S classes below 150 hPa. Also, mean air temperature of the L class is higher than that in the M and S classes between 150 hPa and 20 hPa. The temperature in the M class is lower than that in the S class below 150 hPa. The temperature in the M class is slightly higher than that in the S class between 150 hPa and 20 hPa. The temperatures for these classes are similar at altitudes higher than 20 hPa. The temperature difference between the L and S classes is maximum at 40 hPa and minimum (negative) at 400 hPa.

We conclude that the total ozone amount is large when air temperatures in the lower stratosphere between 150 hPa and 20 hPa is high and vice versa. Similar correlations were also reported at Syowa Station (69.0°S, 39.6°E) in the Antarctic (Chubachi, 1993).

3.6. Correlation between 400 hPa and 40 hPa temperatures

Figure 9 shows the measured temperatures at 2030 JST for 400 hPa and 40 hPa levels and for the period 1st–24th February 2001, which are obtained from the routine upper air observation at Wakkanai District Meteorological Observatory. There is a strong negative correlation between these two values. Therefore it is estimated that there is a possible negative correlation between total ozone amounts and air temperatures in the troposphere (400 hPa). Actually, negative correlation ($r = -0.85$) between total ozone amounts and air temperatures at 400 hPa was seen.

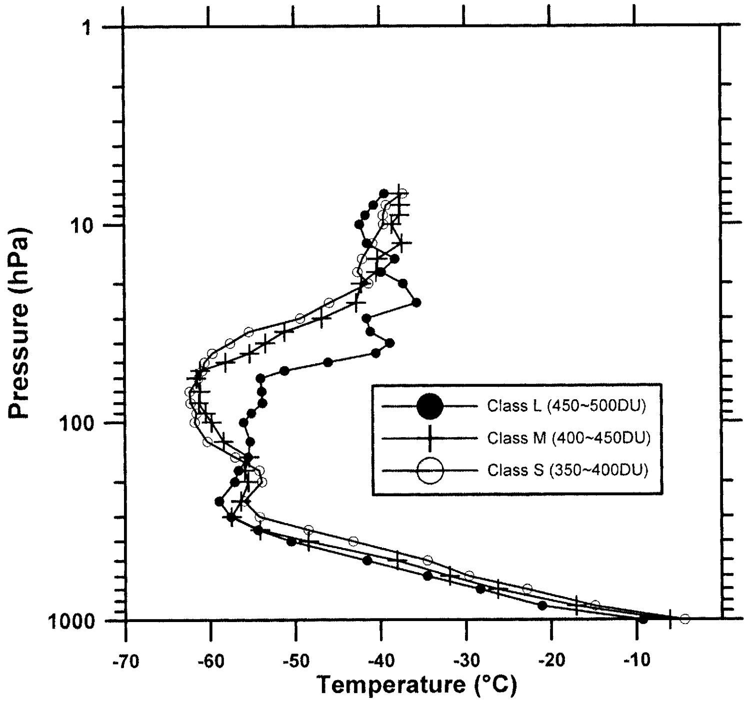

Fig. 8. Mean vertical profiles of air temperature at Wakkanai for L, M and S classes.

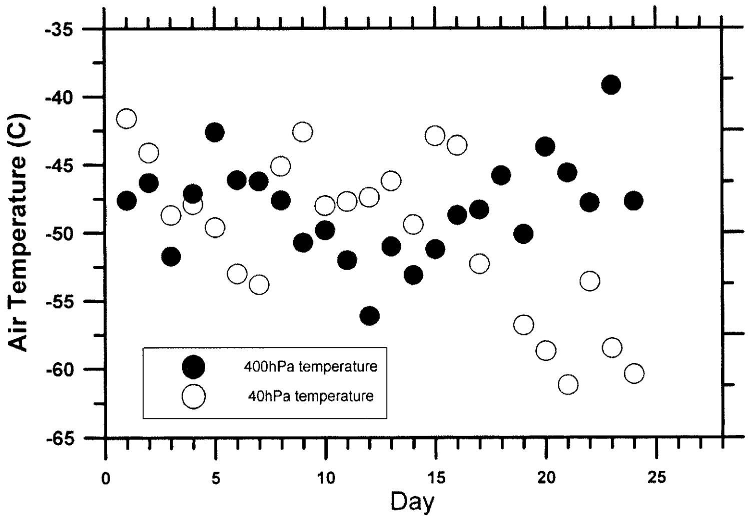

Fig. 9. Air Temperatures at 400 hPa and 40 hPa levels between 1st–24th February 2001.

4. Conclusions

Observations of vertical profiles of ozone partial pressures by ECC ozonesonde were carried out at Wakkanai, Hokkaido between 15th–24th of February 2001. The observed data were normalized to the TOMS total ozone amounts because the total ozone amounts with Dobson spectrophotometer were not measured at Wakkanai. The maximum TOMS total ozone was 494 DU and the minimum value was 353 DU at Wakkanai in the observation period. The differences among the ozone vertical profiles were small below 200 hPa, though distinct differences were observed at altitude higher than 200 hPa. The differences were also seen in vertical distributions of air temperatures. There were strong positive correlations between the total ozone amounts and the air temperatures at the 40 hPa level in the stratosphere, and negative correlations between total ozone amounts and air temperatures at 400 hPa in the troposphere.

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