ON THE SPECTROMETER MEASUREMENTS OF COLUMN WATER VAPOR AMOUNT IN THE ANTARCTIC ATMOSPHERE

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Abstract: Spectral measurement of direct solar radiation was made by a spectrometer on the ground, and the total amount of water vapor was estimated. The result was 0.09 g/cm² at least in April and 0.16 g/cm² at most in December. In the present work, 0.9 μm near infrared absorption band of water vapor was measured in a rather low resolution and the total absorption was obtained. Using the relation of the water vapor amount and the total absorption (curve of growth), the water vapor amount was derived from the measured total absorption.

Uncertainties in the 100% transmission line and uncertainties in deriving the column amount of water vapor for the actual inhomogeneous distribution from the equivalent amount, resulted in errors. Since the measurement was made at Mizuho Station and there was no aerological data for comparison, the data of radiosonde flight at Syowa Station was compared. Efficiency of the present result and the method to obtain the column amount of water vapor were discussed.

1. Introduction

It is a matter of great interest to study the behavior of water vapor in the polar region. The problem of water vapor transportation is very important in the study of ablation and accumulation of snow cover, transportation of latent heat, and global circulation of water vapor. However, the observation of water vapor amount in the polar region especially inland, is accompanied by many difficulties, one from the extremely low temperature under which the measurements are made, and another from the fact that the absolute amounts of water vapor contained in the low temperature atmosphere are quite small.

At Mizuho Station, which is the second station of the Japanese Antarctic Research Expedition and is located in the highland on the antarctic glacial slope, 70°42'S, 44°20'E, 2230 m above sea level, some methods to measure the water vapor amount were tried by NISHIO (1978). An ordinary method with the Assman ventilated psychrometer was examined by Karl Fisher chemical method which was acknowledged to be accurate at extremely low temperatures. From the comparison of two methods, agreement was quite good within an experimental error above −20°C,

and the Assman psychrometer method was used throughout the routine measurements.

In this paper, a method was tried to measure the column amount of water vapor in the atmosphere by means of the remote measurement on the ground. The column amount of water vapor was estimated from the spectral measurements of the absorption of solar radiation by water vapor in 0.9 and 1.1 μm band regions. This kind of method had already been used in the early part of the 1900's as by Fowle (1912). Recently, the same method was used in order to observe atmospheric minor components such as NO_x, etc., by the measurement on the ground and also in order to observe stratospheric water vapor distribution by the measurement from aircraft and balloon (Murcray et al., 1960; Houghton and Seeley, 1960).

The present work was the first attempt of estimation of the column amount of water vapor at Mizuho Station. As there were no aerological data for comparison, discussion was made by comparing the diurnal variation of surface humidity with that of column value. And some verification was made by using the aerological data obtained at Syowa Station which is 300 km apart from Mizuho and located on the coast. Problems and merits of this method to observe water vapor amounts were also discussed.

2. Observational Method and Apparatus

Direct solar radiation was measured spectrally and total absorption W (equivalent width) of the near infrared H_2O band was derived as

$$W = \int_{\nu_1}^{\nu_2} [1 - T_\nu'] d\nu, \tag{1}$$

where ν is the wavenumber, T_ν' is the measured transmission function and ν_1 and ν_2 are the limit of the band. T_ν' is not the same as the real transmission function T_ν on account of finite resolution of the spectrometer, but if ν_1 and ν_2 were set in the region where absorption was 0, there is an approximate relation as

$$W \approx \int_{\nu_1}^{\nu_2} [1 - T_\nu] d\nu$$

$$= \int_{\nu_1}^{\nu_1} \left[1 - \exp\left(-\int_0^u k_\nu du \right) \right] d\nu, \tag{2}$$

where k_ν is the absorption coefficient at wavenumber ν. With the relation of eq. (2), namely the relation between absorber thickness u and the equivalent width W, the water vapor amount u can be derived from the measured equivalent width W. However, there exist some uncertainties in deriving true value of water vapor amount u, because the atmosphere is inhomogeneous and available information about the distribution of water vapor was scarce. In place of a real water vapor amount u for

the inhomogeneous atmosphere, an equivalent amount u_e, which is defined by the equation

$$u_e \equiv \int_0^u k_\nu(P, T)\,\mathrm{d}u/k_\nu(P_0, T_0)\,, \tag{3}$$

for the homogeneous paths, can be obtained directly from eq. (2), where P and T are the pressure and the temperature respectively, and suffix 0 indicates the standard value. By the aid of pressure scaling approximation u_e can be written as

$$u_e \approx \int_0^u \left(\frac{P}{P_0}\right)^n \mathrm{d}u\,, \tag{4}$$

where n is a scaling factor, which lies between 0 and 1. Then water vapor amount u can be obtained from the following equation if we had some information about the distribution of water vapor:

$$u_e = \int_0^u \left(\frac{P}{P_0}\right)^n \mathrm{d}u = A \cdot u\,. \tag{5}$$

Since we had no information about the distribution at the observational site (at Mizuho Station), the value of A in this work was derived from the average distribution of water vapor which was calculated from five distributions of relative humidity measured by radiosonde flight on typical clear days at Syowa Station in each season (Figs. 7, 8, 9). The values of A were obtained as 0.641, 0.630 and 0.645 for the cases of Figs. 7, 8 and 9 respectively with $n=0.8$. As this method is only an approximate one and may contain some uncertainties, a mean value of 0.64 was used in the analysis of the present study.

A spectrometer (spectro-pyrheliometer) of rather low resolution in a visible and near-infrared region with the diffraction grating was used for the spectral measurement of direct solar radiation. This spectrometer had been made by the 17th Japanese Antarctic Research Expedition for the measurement of turbidity in the Antarctic atmosphere. The properties of the same type of spectrometer had been described in the papers by MURAI et al. (1977, 1978). The wavelength range was between 0.3 μm and 2.0 μm, and the photomultiplier and the PbS cell were equipped as the detectors. In this study at using PbS as the detector, the mechanical slit width was set at 0.5 mm which led the spectral slit width to be about 3 nm around the wavelength of 1 μm, the sampling interval of spectrum was set at 1 nm, and the time needed for a scanning of the wavelength interval of 100 nm was about 3 min. Calibration of the wavelength was made by the emission line of a Hg-lamp and also by the absorption peaks of water vapor band, and accuracy and reproducibility of wavelength reading were within ± 2 nm. A quartz-halogen lamp which was supplied with 12 d.c. voltage was equipped as the reference lamp in order to correct the variation of sensitivity of the instrument output.

Fig. 1.   Spectrometer installed on the platform above the snow surface.

The main part of the instrument—optical system, detector and pre-amp—is mounted on the equatorial mounting with a photo-electric sun follower, so that the entrance slit is directly exposed to the solar beam. The equatorial with the spectrometer was set on the platform at the height of 3 m above the snow surface as shown in Fig. 1. Signal outputs were led to a laboratory beneath the snow surface where the main amplifier, the control unit and the recording system were set up. Digital data were recorded by the printer and analog data were also taken as monitor data.

3.   Results and Discussion

At Mizuho Station, the weather was bad, as katabatic wind of around 10 m/s was blowing continuously and drifting or blowing snow was prevailing. Even on clear days the measurement was often unreliable on account of heavy drifting snow, and reasonable data were obtained only on a few days in April and December.

One of the original data in analog records are shown in Fig. 2. The upper part (a) is the record of the reference lamp and the lower part (b) is the record of solar radiation. The upper envelope of each record shows the measured spectrum, but the lower straight vertical line bears no meaning on the spectrum, which was a record when the shutter at the entrance slit was closed. Together with fine structures of absorption bands, large variations in outputs are seen in both spectra. These large variations are due to the variation of sensitivity of the instrument. In the case of
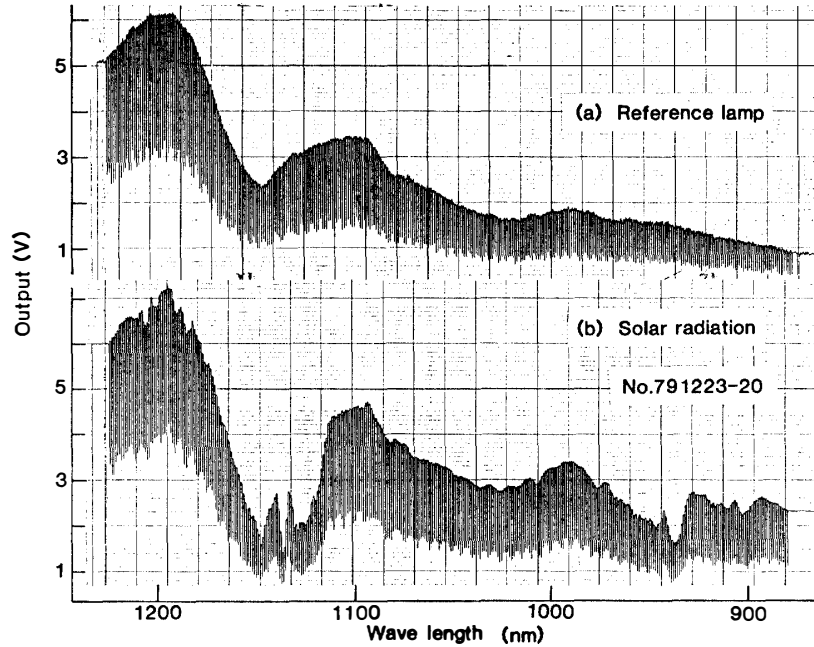
Fig. 2.   Analog records of the original spectra around 1 μm wave length obtained on December
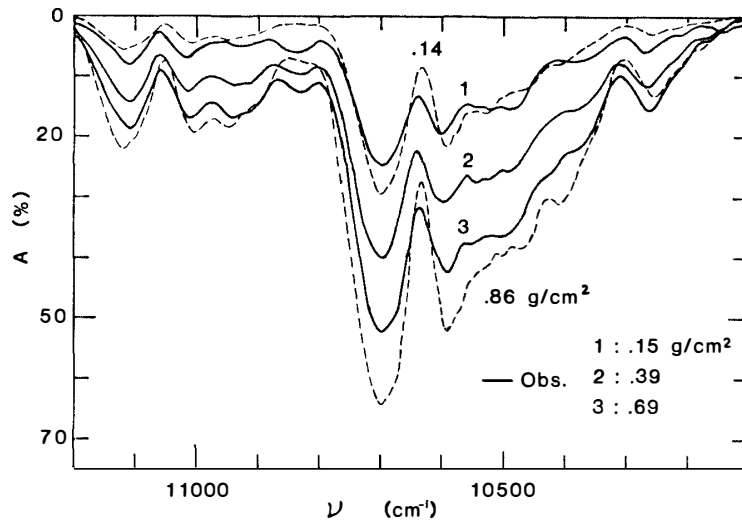23, 1979.   Ordinate indicates the relative output of the spectrometer.

Fig. 3.   Absorption spectra of the 0.9 μm water vapor band.   Solid lines represent the present
measurement on December 3, 1979 (1: No. 1, 2: No. 16, 3: No. 20), and broken lines
represent the experimental spectra after TANAKA and YAMANOUCHI (1981).   Numbers
indicate water vapor amounts.

absorption measurement at the surface, it is impossible to get the spectrum of 0
absorption—100% transmission line.   Therefore, the original measured absorption
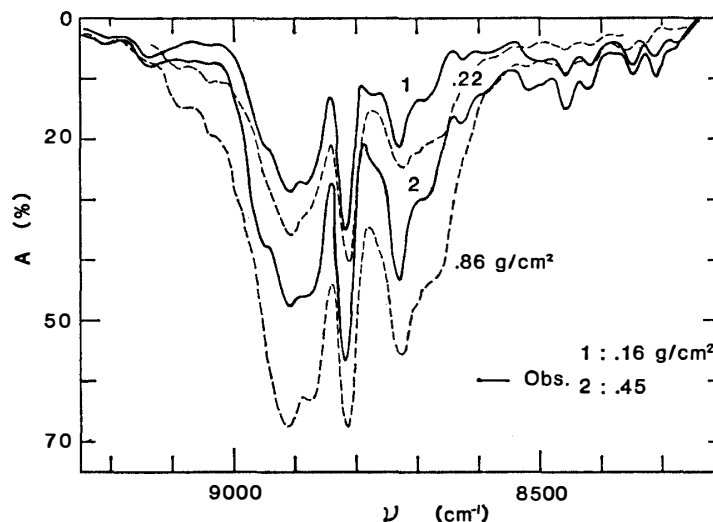spectrum of solar radiation was normalized by the spectrum of the reference lamp.

Fig. 4.   As in Fig. 3 but for the 1.1 μm band on December 23, 1979 (1: No. 1, 2: No. 16).

The output of the reference lamp was compared with the output of the standard lamp, which was calibrated at some typical wavelength, and the reference lamp was assumed to be constant or linear with wavelength of narrow intervals.   In the normalized spectrum, the 100% line was supposed to be straight, passing through the points where absorption was expected to be 0.

Solid lines in Figs. 3 and 4 are the examples of the finally obtained spectra of 0.9 and 1.1 μm bands, where abscissa indicates wavenumbers.   Spectra for some known water vapor amounts obtained from the laboratory experiment (TANAKA and YAMANOUCHI, 1981) are also drawn in the Figs. 3 and 4 by the broken lines.   For 0.9 μm band in Fig. 3, there are some discrepancies in the resolution between the experimental spectra and the present observed spectra, and uncertainties in wavenumber axis are seen, but as a whole, both spectra are consistent.   For 1.1 μm band in Fig. 4, resolutions of both measurements seem to be identical, but there are large discrepancies in the wing region between both spectra.   In the high wavenumber side wing between 9000 and 9100 cm^{-1}, absorption of the present observation is small, and on the other hand, in the low wavenumber side wing below 8600 cm^{-1}, absorption of the present observation is extremely large.   These inconsistencies in the wing absorption are due to the uncertainties of the 100% line in the present measurement of 1.1 μm band.   The uncertainties in the 100% line may be ascribed to the great variation of instrument sensitivity along the wavelength between 1.1 and 1.2 μm as seen in Fig. 2.   Errors would become large if 1.1 μm band was used in analyzing the water vapor amount in the atmosphere.   As for the other near infrared water vapor bands, absorption of 1.4 and 1.9 μm bands was strong and was saturated at the center of the band, and so these two bands were not effective to analyze the amount

Table 1. *Equivalent width of 0.9 μm band W and water vapor amount for each observational scan.*

Date	Ser. No.	LT	sin h	W (cm^{-1})	u_e(g/cm^2) (slant path)	u_e(g/cm^2) (column)	u(g/cm^2) (column)
1979							
Dec. 2	2	2010	0.180	198.1	0.546	0.0983	0.154
	3	2025	0.164	202.8	0.571	0.0936	0.146
	4	2050	0.140	218.9	0.659	0.0923	0.144
	6	2145	0.102	251.7	0.858	0.0875	0.137
	7	2200	0.085	258.9	0.905	0.0765	0.120
	8	2220	0.076	274.4	1.010	0.0767	0.120
	10	2235	0.067	286.1	1.100	0.0732	0.114
	11	2300	0.058	303.9	1.243	0.0716	0.112
Dec. 3	1	1040	0.647	90.3	0.154	0.0996	0.156
	2	1100	0.653	86.1	0.143	0.0934	0.146
	4	1130	0.659	88.1	0.148	0.0957	0.150
	5	1220	0.658	86.2	0.144	0.0948	0.148
	6	1305	0.639	87.0	0.146	0.0933	0.146
	10	1505	0.560	97.5	0.172	0.0963	0.150
	11	1555	0.503	102.6	0.185	0.0931	0.145
	12	1635	0.458	106.5	0.196	0.0898	0.140
	14	1700	0.428	98.6	0.175	0.0749	0.117
	15	1745	0.365	131.1	0.275	0.100	0.156
	16	1930	0.229	163.5	0.394	0.0902	0.141
	17	1950	0.207	176.1	0.445	0.0921	0.144
	18	2025	0.162	190.1	0.506	0.0820	0.128
	19	2100	0.133	206.0	0.588	0.0782	0.122
	20	2135	0.104	223.3	0.685	0.0712	0.111
Dec. 23	1	1400	0.639	96.0	0.168	0.107	0.167
	2	1425	0.623	95.4	0.167	0.104	0.163
	9	1545	0.546	96.4	0.169	0.0923	0.144
	10	1650	0.469	110.9	0.209	0.0980	0.153
	11	1705	0.443	109.9	0.206	0.0913	0.143
	12	1740	0.398	121.4	0.242	0.0963	0.150
	13	1915	0.281	155.0	0.361	0.101	0.158
	14	1930	0.262	161.0	0.385	0.101	0.158
	16	2010	0.217	183.9	0.478	0.104	0.163
	17	2025	0.200	188.9	0.500	0.100	0.156
	20	2100	0.164	210.1	0.610	0.100	0.156
	21	2120	0.144	220.1	0.666	0.0959	0.150
	22	2135	0.132	229.1	0.719	0.0949	0.148
Apr. 6	2	1430	0.163	184.6	0.481	0.078	0.122
	8	1610	0.058	285.4	1.094	0.063	0.098

of water vapor. On the other hand, absorption of 0.7 and 0.8 μm bands was too weak with a small amount of water vapor which exists in the optical path in an inland part of Antarctica like Mizuho Station. Hereafter, in this study only the results of 0.9 μm band are used in the analysis.

Equivalent widths calculated from each measurement are listed in Table 1 with date and time of the measurements and relative airmass at the time. From the equivalent witdh W, the equivalent amount of water vapor u_e was derived by using the curve of growth as shown in Fig. 5 (TANAKA and YAMANOUCHI, 1981). As mentioned
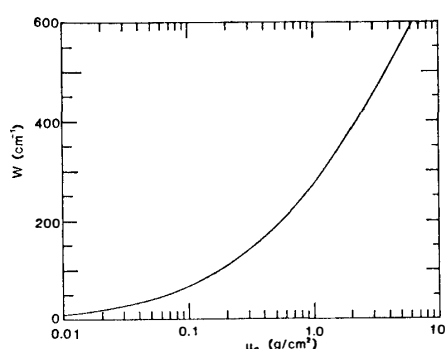
Fig. 5.   Equivalent width W for the 0.9 μm water vapor band for the water vapor amount u_e (after TANAKA and YAMANOUCHI, 1981).

in the preceding section, the value A of eq. (5) was obtained as 0.64 from the temperature and pressure distributions in Figs. 7 to 9. Then the column water vapor amount u was obtained as listed in the 7th column of the table. Experimental uncertainties were estimated to be $\pm 10\%$ from the uncertainties of the equivalent width measurement. The values ranged from 0.1 to 0.16 g/cm^2 for December and 0.09 to 0.12 for April. As there were no aerological data at Mizuho Station in 1979, no direct information was available on the water vapor amount to compare and verify the present results. In spite of indirect information, daily variation of water vapor pressure at the surface (1.5 m height) was compared with the variation of column amount u in Fig. 6. Water vapor pressure was derived from the dew-point measurement made with the hygrometer of impedance type which was compiled by WADA et al. (1981). Water vapor pressures for three days when the present observation was made are listed in Table 2, together with air temperatures. Results of December 3 are shown in Fig. 6. The surface water vapor pressure increases from 0.36 mb at 04 LT to 0.78 mb at 14 LT and again decreases to 0.34 mb. In the upper part of the figure, the column water vapor amount is roughly constant, about 0.14 g/cm^2, till 20 LT and then it decreases to 0.11 g/cm^2. It is difficult to ascertain whether this variation in the column amount is the reflection of real variation or only an experimental error, but the variation of the column amount seems to have the similar tendency to the variation of the surface water vapor pressure.

Another verification was made by the aerological data obtained by radiosonde
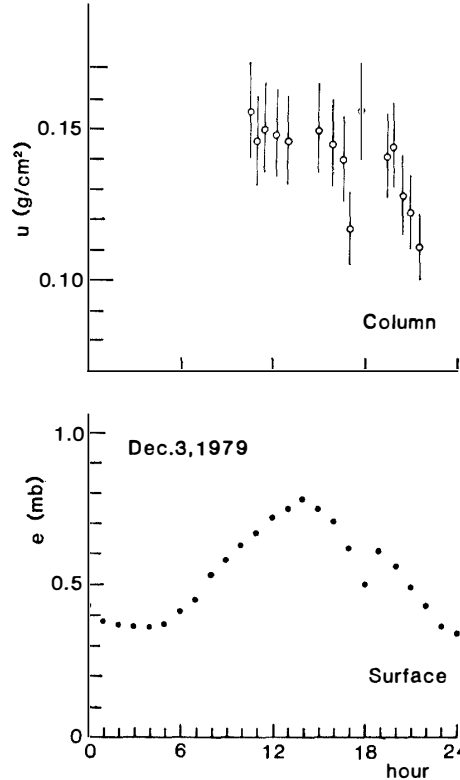
Fig. 6. Comparison of diurnal variation of the surface water vapor pressure and the column water vapor amount for December 3, 1979. Vertical lines in the upper figure show the experimental uncertainties.

Table 2. Air temperature, water vapor pressure and relative humidity at the suface of Mizuho Station, 1979.

Hour	Dec. 2			Dec. 3			Dec. 23		
	T_{air} (°C)	e(mb)	Relative humidity (%)	T_{air} (°C)	e(mb)	Relative humidity (%)	T_{air} (°C)	e(mb)	Relative humidity (%)
00	−27.8	0.38	61	−28.3	0.43	72	−21.0	0.67	58
03	−29.6	0.33	62	−30.1	0.36	72	−23.0	0.57	59
06	−26.6	0.37	53	−27.5	0.41	64	−21.1	0.63	55
09	−27.7	0.52	83	−21.7	0.58	54	−17.9	0.79	67
12	−17.8	0.73	48	−18.8	0.72	52	−15.2	0.99	53
15	−14.4	0.73	36	−14.8	0.75	39	−13.9	1.07	51
18	−13.0	0.75	33	−12.0	0.50	20	−14.6	1.02	52
21	−18.2	0.61	42	−23.2	0.49	52	−18.1	0.80	54
24				−27.6	0.34	53	−21.6	0.58	53

flown at Syowa Station (JAPAN METEOROLOGICAL AGENCY, 1981). On the radiosonde, measurements of relative humidity were made by carbon hygrometer. Because Mizuho Station is about 300 km apart from Syowa Station, this verification was also

indirect. In Figs. 7 to 9, the average temperature and water vapor distributions obtained by 5 flights on clear days early in April and December are shown respectively. Together with the average value, the maximum and minimum values of
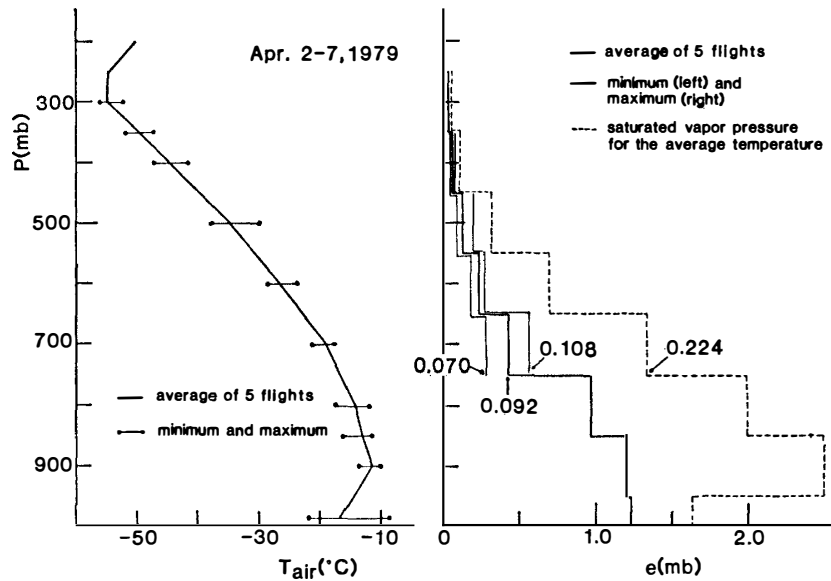

Fig. 7. Distributions of temperature and water vapor pressure obtained from 5 radiosonde flights at Syowa Station on clear days between April 2 to 7, 1979. Numbers in the figure show the column water vapor amounts above 750 mb level (in g/cm²).
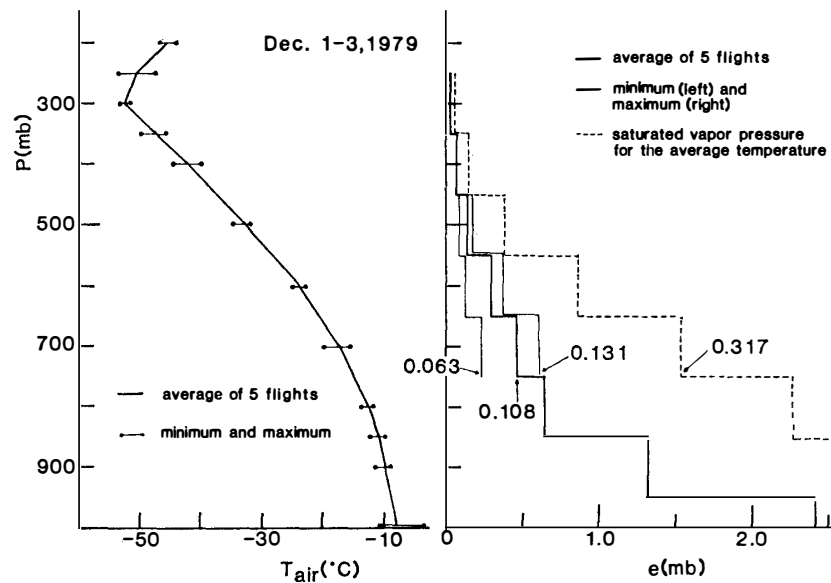

Fig. 8. As in Fig. 7 but on clear days between December 1 to 3, 1979.
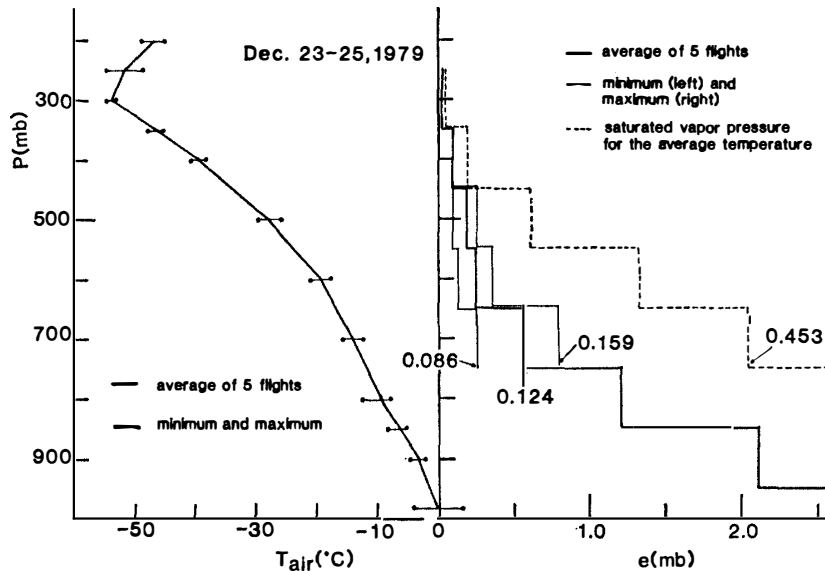
Fig. 9.   As in Fig. 7 but on clear days between December 23 to 25, 1979.

water vapor pressure in 5 flights are plotted and also the saturated vapor pressure for the average temperature distribution is drawn by broken line. Because Mizuho Station is located at the height of 2230 m above sea level and the average surface pressure is near 750 mb, total column amounts of water vapor existed above 750 mb level were calculated for each distribution of water vapor, and are given in Figs. 7, 8 and 9. The average column amount for April was 0.092 g/cm², 0.108 g/cm² for the early part of December and 0.124 g/cm² for the middle to late December. Column amounts obtained by the spectral measurements at Mizuho Station (Table 1) lie in the range between the average value and around the maximum value of the aerological data. It is inferred that values from the aerological data are rather small, because humidity is larger near the snow surface than in the upper part, and if the snow surface was at the level of 750 mb the column amount might be larger. Consequently, the column amounts from the spectral measurements are consistent with the aerological values measured at Syowa Station. It was difficult to verify diurnal variation of the column water vapor amount from the data of radiosonde, because radiosonde was flown only twice a day at 03 LT and 15 LT.

4. Concluding Remarks

The column amount of water vapor at Mizuho Station in summer was about 0.15 g/cm², and some diurnal variation was observed. From the discussion in the preceding section, the column amounts obtained in the present study seem to be reasonable. However, there still exist some problems in the present method. It is

difficult to isolate strictly the absorption by water vapor from the solar spectrum on account of extinction by scattering and non-selective absorption. The 100% line in the present study was drawn only approximately. There is also another approximation in the present method to derive the real amount of water vapor u from the equivalent amount u_e. But without any information about the distribution of water vapor, it is difficult to obtain a precise relation between u and u_e. Because of the low resolution of the spectrometer, observation was restricted to the column amount. With a high resolution infrared spectrometer, not only the column amount but the distribution of water vapor might be observed. Judging from the strength of the absorption band and the amount of water vapor in the Antarctic atmosphere, 0.9 and 1.1 μm regions would be appropriate for the column amount observation from the ground.

In the present work, observations were made only on a few days, when the meteorological condition varied little. It is necessary to carry out another observation in the place where aerological data are available and to verify the applicability of the present method to various conditions, especially at low temperatures.

As one of the remote sensing techniques of the atmospheric study, it might be valuable to make more observations with the present method and to derive seasonal variation or difference from place to place of the column amount of water vapor. The present method is also related to the remote measurement of the column water vapor amount from satellites.

A spectral measurement from aircraft will be another subject. The column amount and the distribution of water vapor in the upper atmosphere will be obtain by measuring the direct solar radiation, and by measuring the reflected solar radiation from the snow surface, the column amount in the lower atmosphere between the surface and the aircraft can also be derived with the aid of the previously obtained values.

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