A SIMPLE CLOUD-RADIATION STATISTICS AT MIZUHO STATION, ANTARCTICA

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Abstract: Cloud distribution characteristics at Mizuho Station, Antarctica are discussed. The transmittance of the direct solar radiation and downward longwave radiation are used as an index of clouds. The frequency of occurrence of the clear sky—1.0 transmittance, minimum extreme of downward longwave radiation—is very high throughout the year, which may be pronounced characteristics at inland stations. The direct solar beam transmittance is a good indicator of clouds in the sunlit season. The downward longwave radiation varies sensitively according to the cloud. The normalized emissivity defined from the longwave flux has a good correlation to the cloud amount, and is a good indicator of clouds throughout the year.

1. Introduction

Clouds are one of the most important features controlling the radiation budget and climate of the earth. In the Antarctic, clouds are especially a strong controlling factor of the surface radiation budget and hence of the temperature regime. It was found that clouds decrease the radiative cooling at almost any time throughout the year on the snow surface of inland of Antarctica. The decrease of the longwave radiative cooling was larger than the reduction of net shortwave (YAMANOUCHI and KAWAGUCHI, 1984).

The cloud information from the surface observation is limited so that there was no reliable global cloud climatology in the past. Recently, satellite data have come to be the powerful source of the information of cloud cover (HUGHES, 1984). However, the algorithm to detect cloud cover from the satellite data is not accomplished yet, and problems in comparing the satellite observation and surface observation are often discussed (*e.g.* HENDERSON-SELLERS *et al.*, 1981; WARREN *et al.*, 1981).

The present paper, as a preliminary work, discusses cloud distribution characteristics at Mizuho Station (70°42′S, 44°20′E) in Antarctica using radiation fluxes as an index of cloudiness. Formerly, THOMPSON and COX (1982) have derived the cloud climatology of thin clouds from the data of the direct beam irradiance obtained by the normal incidence pyrheliometer. Here, we derive the direct beam transmittance and also the amount of the downward longwave radiation. Frequency of occurrence of clear, cloudy and overcast sky is shown and compared with that of the conventional cloud observation by eye. Correlations between the shortwave transmittance and the longwave flux are discussed for each type of the sky. These data might be a strong help to the satellite cloud observation, since satellite observations are made from the radiation amount only. We cannot find any reports yet on the cloud climatology for the Japanese Antarctic Stations, except for the recent one by WADA (1985).

2. Data

Radiation data used in the present analysis were obtained during the POLEX-South observation at Mizuho Station, Antarctica in 1979 (YAMANOUCHI *et al.*, 1981a). Mizuho Station (70°42′S, 44°20′E) is located on the continental slope, about 250 km inland from the coast. The direct solar radiation was measured by the normal incidence pyrheliometer (EKO-MS52F). The downward longwave radiation flux was measured by Eppley PIR. Both were set at the height of 1.5 m above the snow surface. Measurements and calibration technique used are reported by YAMANOUCHI *et al.* (1981b) in detail. Data sampling was made once a minute. In the present paper, 30 min averages are used except where the 1 min data are given. Data of the surface-observed cloud amounts are derived from the Data Report (WADA *et al.*, 1980).

3. Longwave Radiation

Clouds have a strong effect on the downward longwave radiation. Overcast clouds give an increase of about 80 W/m² for middle or low clouds and about 40 W/m² for upper clouds (YAMANOUCHI and KAWAGUCHI, 1984). To see the relation between the cloud amount and the longwave radiation, the measured downward longwave flux averaged for 30 min is plotted against a cloud amount when the surface cloud observation was made (normally three times a day in 1979). Examples of winter three months, June, July and August, when the monthly average of the downward flux did not differ greatly, are shown in Fig. 1. The mean value of three months for the clear sky (cloud amount $n<1$) was 99 W/m² and for overcast with middle or low

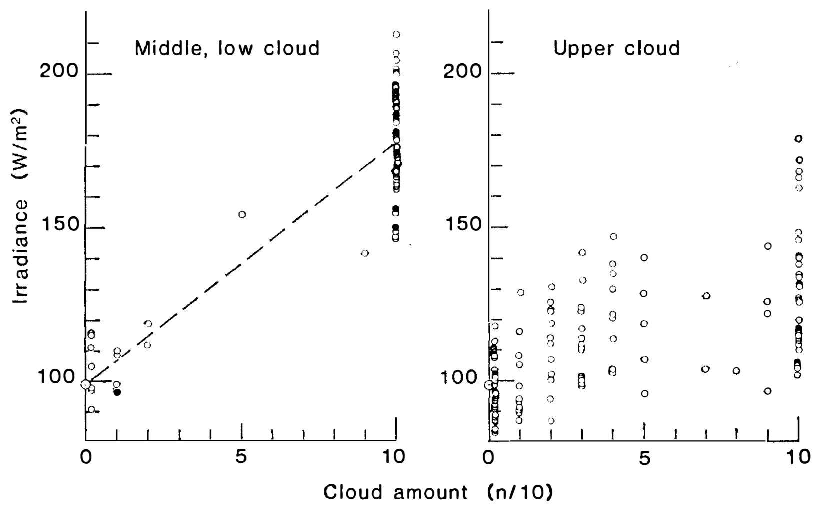

Fig. 1. Downward longwave radiation (30 min average) against cloud amount for three times a day when the surface cloud observation was made in June, July and August, 1979. Points corresponding to the cloud amount 0⁺ are plotted on n=0.25. Large circle with dot indicates an average for clear sky and dashed line is an average relation.

cloud ($n=10$) was 178 W/m^2 (since Mizuho Station is located at 2230 m height, clouds were scarcely observed as "low cloud"). However, the points scatter greatly, especially for upper clouds. An interesting thing is that the occurrence of low or middle clouds with cloud amount less than 9 is very scarce, while there are many cases of upper clouds with cloud amount less than 9. This is partly reasonable, since upper clouds and liable to be broken just as cirrus, and low or middle clouds are liable to be stratiform. On the other hand, this is partly doubtful. Even for middle or low clouds, partial clouds are liable to be misinterpreted as upper clouds. Cloud observation at the surface by eye is rather subjective and erroneous. Especially in the dark season, observation is less reliable.

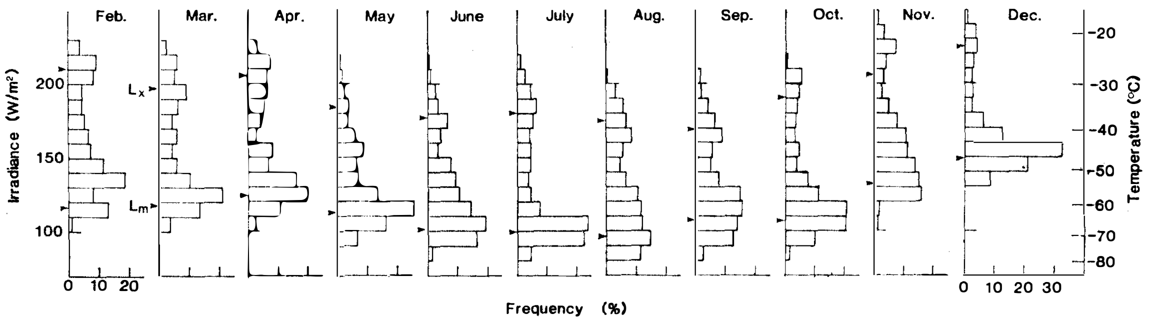

Fig. 2. Frequency occurrence of downward longwave radiation for each month in 1979. Arrows on each ordinate indicate L_x (mean value for overcast with middle or low cloud) and L_m (mean for clear sky), respectively.

In order to see how the downward longwave flux is distributed, frequency of its occurrence is derived for each month in Fig. 2. We have to notice the distribution profile. For most of months, the frequency curve shows dual peak. One peak is around the clear sky mean ($n<1$) L_m and another is around the mean value for the overcast sky ($n=10$, middle or low cloud) L_x, indicated by arrows in the figure, respectively. The way and degree of concentration are different among months. For May and December, most occurrences concentrate around L_m, and almost no peak exists for L_x. Monthly means of surface-observed cloud amount are 3.5 and 4.2, respectively, for these two months, which are still lower values at Mizuho Station. Clear sky is predominant in these two months. For February, March and April, patterns are different and a quite large peak exists around L_x. The rate of concentration is not so high for this peak as for the peak around L_m. Surface-observed cloud amounts are as large as 6.5, 6.3 and 5.7, respectively, for these three months. Variations of cloud effect and cloudiness is well displayed in these frequency distribution curves.

4. Shortwave Radiation

The solar radiation is depleted by clouds. Transmittance of the solar radiation is shown in Fig. 3 for example. The ratio of the direct solar radiation $I(h)$ against the extraterrestrial solar radiation I_0 ($=1353$ W/m^2) is shown in (a). According to the extinction by the atmosphere, transmittance depends on the path length, *i.e.*, solar

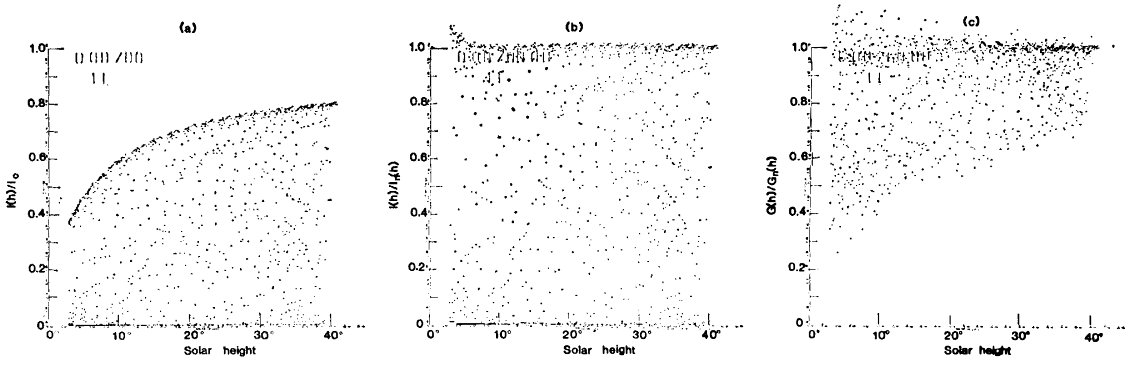

Fig. 3. Transmittance of the solar radiation against solar elevation angle h for November 1979. a) Ratio of the direct solar radiation $I(h)$ to the extraterrestrial radiation I_0, b) ratio of $I(h)$ to the normal clear sky direct radiation I_n and c) ratio of the global solar radiation $G(h)$ to the normal clear sky global radiation $G_n(h)$.

elevation angle. In (b) to eliminate roughly the elevation angle dependence and to see the effect only of clouds, transmittance is derived as the ratio of $I(h)$ to the average normal clear sky direct solar radiation $I_n(h)$ determined by YAMANOUCHI (1983).

$$T_r = I(h)/I_n(h). \tag{1}$$

Though the actual value of $I_n(h)$ has some variations according to the sky condition, the average value is given as a simple function of h. For the purpose of cloud detection we do not need high precisions. Though the observation by the pyrheliometer is made only for a narrow field of view (aperture angle of 4°), statistical data for a long time interval, such as 30 min, one day or one month, are considered to represent the cloud condition of the whole sky even in the case of broken clouds. The ratio of the global solar radiation $G(h)$ to the normal clear sky global radiation $G_n(h)$ (YAMANOUCHI, 1983) is also shown in (c). Data points concentrate near the upper extreme, which correspond to the clear sky, in (a), (b) and (c). In (a) and (b), the points around the abscissa are of thick clouds, and other points lying between two extremes are of thin clouds or of averages of partial cloud (which is not uniform within a sensor's field of view or within the sampling time). THOMPSON and COX (1982) discussed these intermediate values to examine the variation of occurrence/thickness of thin clouds. In (c) the points lie in the upper half of the figure. The depletion of the global radiation by clouds cannot be very large even for the thickest cloud on account of multiple reflection between the cloud and the snow surface (YAMANOUCHI, 1983). This type of ratio is not much useful to distinguish the cloud type.

The relation between the shortwave transmittance and the cloud amount was also examined just as done in Fig. 1 for the longwave flux. For the overcast by middle or low clouds the transmittance is 0; however, for the upper clouds the relation is varied largely. Even for the overcast, the transmittance ranges from 0 to 0.9.

Frequency distributions of the transmittance of the direct solar radiation T_r are shown in Fig. 4 for the sunlit five months. Variations of the frequency affected by clouds are clearly seen. For any month, transmittance of 1.0 for the clear sky or 0 for the thick overcast has the highest frequency, and intermediate transmittance is

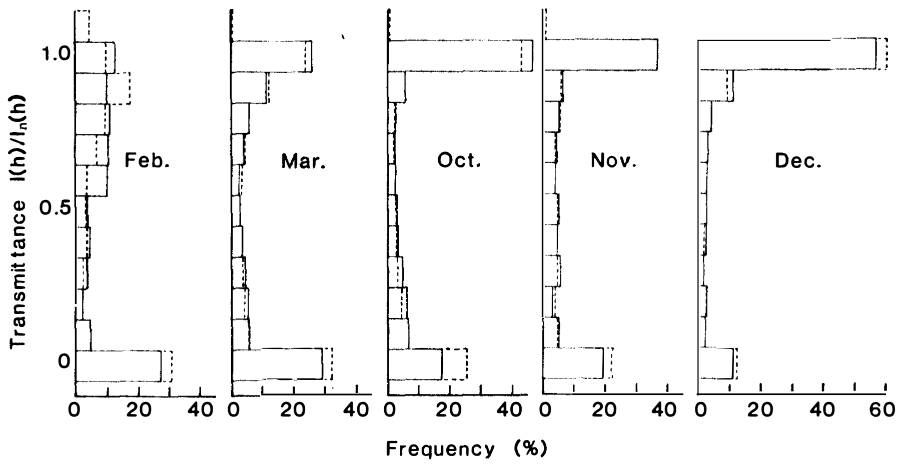

Fig. 4. Frequency of occurrence of transmittance of direct solar radiation T_r for the sunlit five months. Solid lines are for 30 min mean and dotted lines are for 1 min data.

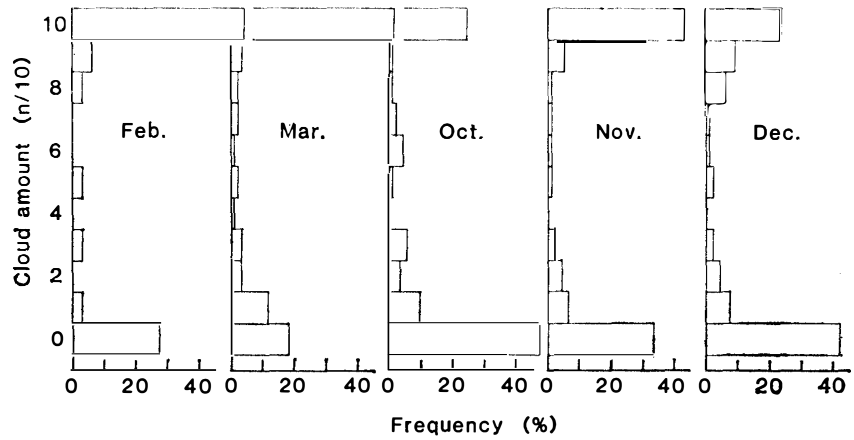

Fig. 5. Frequency of occurrence of conventional cloud amount observed at the surface by eye for five months in 1979.

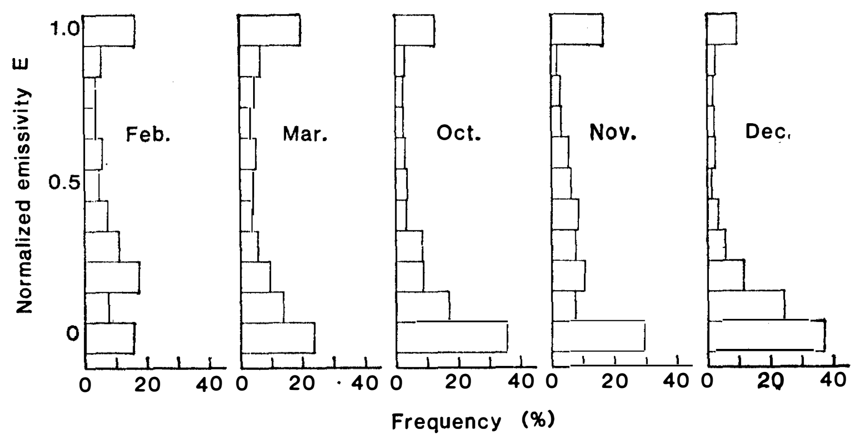

Fig. 6. Frequency of occurrence of normalized emissivity for five months in 1979.

low in frequency. Profile of frequency distribution is different from month to month. Clear sky has high frequency in October and December and cloudy sky has high frequency in February and March. Anyway, high concentration for the clear sky—1.0 transmittance—is noticeable, and this is a pronounced characteristic at inland stations of Antarctica.

All the above discussions are made with the 30 min average data. Since 30 min may be too long for a particle cloud to be observed as constant, 1 min data are also used. Frequency distributions of 1 min data are indicated in Fig. 4 by dotted lines. Shorter time intervals are supposed to result in low frequency of the intermediate transmittance and high frequency of the 1 and 0 transmittance. Although Fig. 4 indicates this tendency, the difference between the 1 min data and the 30 min mean data is not so large as expected. Some increase is seen for the 0 transmittance and a slight decrease for the intermediate transmittance.

5. Relation of Radiation to Cloud Amount

Frequency distributions of the conventional cloud amount observed at the surface are shown in Fig. 5 to compare with Fig. 4. The highest frequency for the overcast in February, March and November, the highest frequency for the clear and the second high for the overcast in October and December, and very low frequency for the intermediate sky conditions are common for both figures.

In order to compare with these two figures, frequency distributions for the downward longwave flux are rewritten using the normalized emissivity

$$E=\frac{L_d-L_m}{L_x-L_m}, \tag{2}$$

in Fig. 6. Most of E is between 0 to 1. E which exceeds 1.05 is included in the region $0.95<E\leq 1.05$, and E which is under -0.05 is included in $-0.05<E\leq 0.05$. These frequency distributions correlate highly with those in Fig. 4.

Table 1. Correlation coefficients of frequencies of occurrence of the cloud amount (n), longwave normalized emissivity (E) and shortwave transmittance (T_r) in 1979.

	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
n–E	0.62	0.77	0.75	0.90	0.74	0.83	0.81	0.86	0.98	0.80	0.78
n–T_r	0.86	0.90							0.96	0.86	0.92
E–T_r	0.80	0.95							0.93	0.94	0.89

Correlation coefficients among frequencies of occurrence of the cloud amount (n: 0 to 10), longwave normalized emissivity (E: 0 to 1) and shortwave transmittance (T_r: 1 to 0) for each month are shown in Table 1. High correlations are seen especially between cloud amount and transmittance. Variations of frequency for E from 0 to 1 are well simulated by those for T_r from 1 to 0, and are similar to those for cloud amount from 0 to 10.

Overall variations of cloud amounts, shortwave transmittance and normalized emissivity of longwave flux are shown for each month in Fig. 7. The shortwave trans-

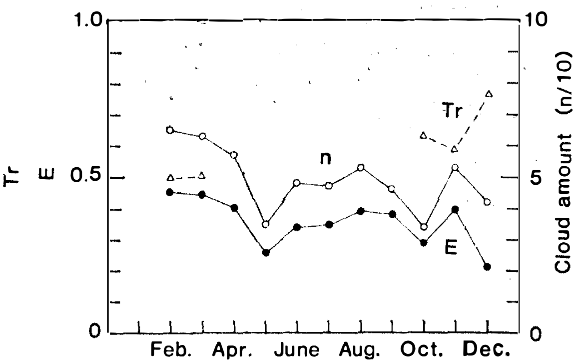

Fig. 7. Annual variation of monthly mean cloud amount n obtained by conventional surface observation, shortwave transmittance T_r and longwave normalized emissivity E in 1979.

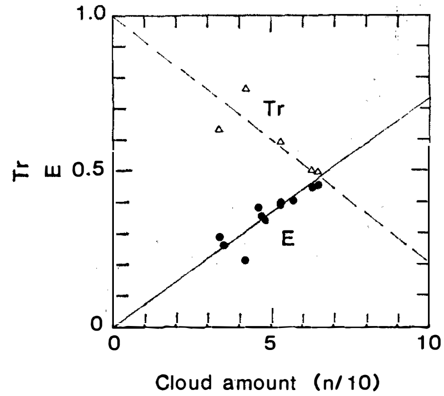

Fig. 8. Scatter diagram of monthly mean shortwave transmittance T_r and longwave normalized emissivity E against cloud amount n for 1979.

mittance has an inverse correlation with cloud amounts. Though the correction for the solar zenith angle was already conducted, the zenith angle dependence in the cloud layer still remains. The transmittance near the polar night is liable to be lower and that near the summer solstice is liable to be higher, if the cloud is the same. The variation of longwave normalized emissivity corresponds quite good to the variation of cloud amounts.

In order to see the correlation again, a scatter diagram is made as shown in Fig. 8. The cloud amount and the shortwave transmittance show an inverse correlation, and a very high correlation is seen between the longwave normalized emissivity and the cloud amount. The best fit relation is

$$E=0.073n. \tag{3}$$

The proportional coefficient is smaller than 0.1, which means that clouds are composed of not only low or middle clouds but also of upper clouds in average. This figure clarifies that the longwave normalized emissivity is a very good indicator of cloud amounts throughout an year, irrespective of noon or night.

6. Longwave and Shortwave Radiation

In order to see the effect of clouds in both the shortwave and longwave radiation simultaneously, a two-dimensional histogram of the shortwave direct transmittance and the downward longwave flux is made. Figure 9 shows an example of two-dimensional histograms for November. The dense crowd of points in the right-hand side of the figure around $T_r \approx 1.0$ corresponds to the clear sky. The points on the ordinate at high longwave radiation correspond to the thick overcast. The points for partial clouds or thin clouds are distributed between these two extremes.

Though the points scatter widely in this figure for a month, those for the particular day when the cloud type does not differ greatly lie on a line. These lines show a steep slope in the case of thick clouds and a gentle slope for thin clouds. This type of two-

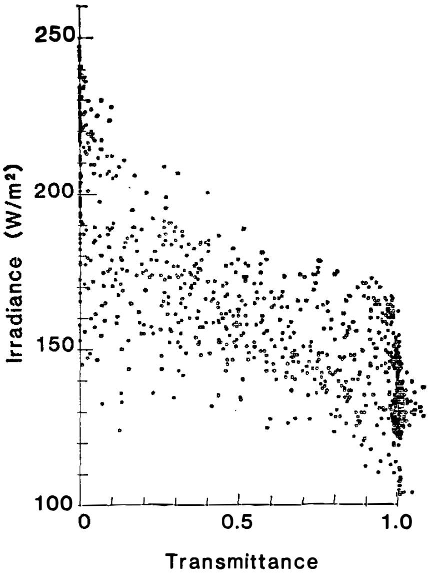

Fig. 9. Two-dimensional histogram of shortwave transmittance and downward longwave radiation for November 1979.

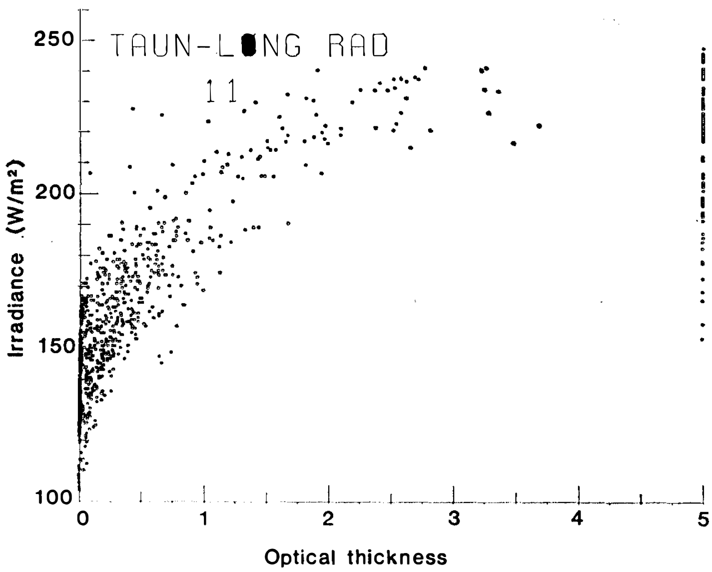

Fig. 10. Two-dimensional histogram of shortwave optical thickness and downward longwave radiation for November 1979. Points of $\tau>5$ are plotted at $\tau=5$.

dimensional histogram is convenient to examine thin and partial clouds; however, it is not sensitive to the difference of thick clouds.

Another kind of two-dimensional histogram is examined. The ordinate represents the downward longwave radiation as in Fig. 9. The abscissa indicates the broadband optical thickness (only provisional) of clouds defined as

$$\tau = -\frac{1}{\operatorname{cosec} h} \ln \frac{I(h)}{I_n(h)} \,. \tag{4}$$

Figure 10 shows an example for November. The points for the clear sky and thin cloud concentrate around the ordinate and the points for thick overcast are distributed in a rather wide area. This type of figure is sensitive to the variation of thick clouds. Some typical examples of the figure for a particular day are listed in Fig. 11. The

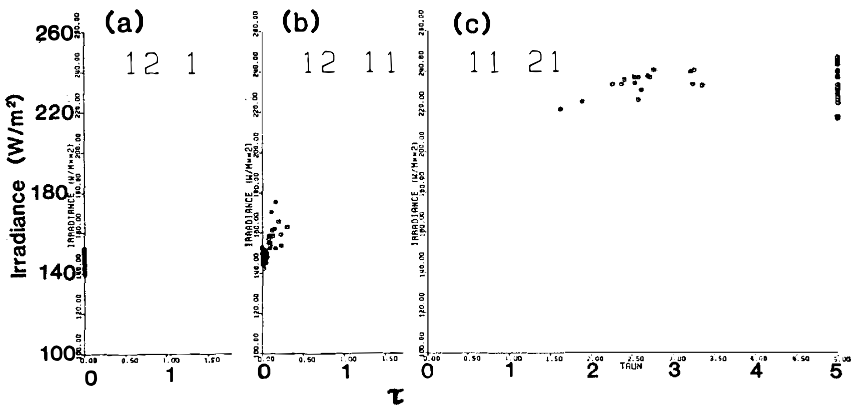

Fig. 11. Scattergram of shortwave optical thickness and downward longwave flux for clear sky (a), upper cloud (b) and middle or low cloud (c).

points for the clear sky lie on the ordinate as seen in (a). (b) is for the day when Ci distributes for the whole day. Even in the case of overcast, the points for Ci lie in the region of $\tau < 0.5$. On the day of 10As (c), the points are distributed in the region of $\tau > 1.5$ and large amount of L_d. From the distribution profile, cloud effect on the radiation budget can be suspected. In the first order discussion the optical thickness τ represents the cloud liquid/ice water content and the downward longwave flux L_d represents the cloud base temperature and emissivity.

7. Conclusion

The radiation amount observed at the surface has a useful information about the cloud lying above. Though the radiation and the cloud cannot be related one to one, they are in a good relation in the statistical meaning. The direct solar beam transmittance is a good indicator of the cloud in the sunlit season. The downward longwave radiation flux also varies sensitively according to the cloud. The normalized emissivity defined in the present paper highly correlates to the cloud amount, and may be the most powerful and simple indicator of the cloud amount which can be used in the daytime and at night, throughout the year.

Cloud distribution characteristics are examined from these cloud indices. At Mizuho Station, the frequency of occurrence of the clear sky, with 1.0 transmittance and the minimum extreme of the downward radiation, is extremely high throughout the year. This high occurrence of clear skies is common at inland stations. Also, the frequency of occurrence of the overcast ($n=10$), with transmittance 0 and normalized emissivity 1, is high. The frequency of occurrence of intermediate cloud amount is very small. The high occurrence of the clear sky and overcast has also been reported over the land in winter by HENDERSON-SELLERS (1978). For this kind of discussion, the use of only the average "cloud amount" is not suitable.

Cloud amounts obtained by the conventional meteorological observation are subjective and liable to be erroneous, especially in the dark night and by non professional observers. In examining the radiation budget or radiative effect of clouds, the radiation amount itself is more useful than the conventional "cloud amount." So, without making cloud analysis, the climatological distribution of radiative properties of clouds is directly obtained and minor climatic changes can be detected. Long-range monitoring of the radiation amount as an information of clouds is to be made in the future. The measurement of the longwave radiation flux may be most suitable for detecting cloud amounts at the automatic weather station in the Antarctic.

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