# GLOBAL PATTERN OF TEMPERATURE LAPSE RATE IN THE LOWER TROPOSPHERE—WITH SPECIAL REFERENCE TO THE ALTITUDE OF SNOW LINE

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## INTRODUCTION

The vertical differentiation of physical-bio-geographical phenomena is largely controlled by those of climatic elements, particularly of air temperature. Therefore, it serves to disclose the physical-bio-geographical implication in vertical sense to estimate air temperature in a given altitude.

A comprehensive survey of the temperature lapse rate of the earth (Bögel 1956, Lautensach and Bögel 1956) revealed its seasonal and regional characteristics, and was followed by a theoretical explanation (Hastenrath 1968). Bögel's results are based on the surface observation data which are considerably affected by the height and location of the station.

In this paper the gross characteristics of the global pattern of temperature lapse rate in the free atmosphere will be presented by using the aerological data for 214 stations of the earth. Then the 0°C heights estimated by these lapse rates will be compared to the altitudes of snow line.

## DATA AND METHOD

The data used here were obtained from Monthly Climatic Data for the World 1964 to 1968 and the aerological climatic table prepared by Flohn (Flohn 1961).

First, the monthly mean temperature lapse rates were calculated for both layers of 850/700 mb and 700/500 mb at 45 stations along the meridians 10°E, 140°E and 70°W. Then, the mean temperature lapse rates of the 850/500 mb layer for summer and winter were calculated and the 0°C height for summer were estimated. These results are demonstrated in several figures.

## RESULTS

The seasonal and latitudinal variations of 850/700 mb lapse rate are, in general, greater than that of 700/500 mb. The lapse rate of 850/700 mb layer ranges from 1.2° C/km to 9.6° C/km, while it ranges from 4.2° C/km to 8.3° C/km in the 700/500 mb layer. In the 850/700 mb layer the maximum lapse rate occurs during summer months in the northern hemisphere, particularly, being pronounced on the east coasts of Asia and North America. On the contrary, it appears during winter in the southern hemisphere excluding the Pacific space. The greatest annual range of lapse rate occurs in the continental parts of higher latitudes (Fig. 1a, Fig. 1b, Fig. 2a, Fig. 2b, Fig. 3a and Fig. 3b). The occurrence of the greatest lapse rate is caused by the small one during winter in higher latitudes and by the great one during summer in the subtropics. In part of these regions the annual range of lapse rate amounts to more than 3°C/km. For the 700/500 mb layer the similar regional and seasonal characteristics are recognized, but less sharply contrasted.

The frequency distribution of the average lapse rate for 850/500 mb during summer (July and August in the northern hemisphere, January and February in the southern hemisphere) is shown in Table 1. About 80 per cent of the samples concentrates within the narrow range from 5.1° C/km to 6.0° C/km. The arithmetic mean for 214 stations is 5.7° C/km. The global distribution of the lapse rate is represented in Fig. 4. From this, it is noted that the lapse rate is extraordinarily large in the subtropical deserts, while it is rather small, 4.5° C/km to 5.5°C/km, over the most parts of the Indian Ocean, the Pacific Ocean and the Arctic Sea. In the subtropical deserts the large rates more than 7.0° C/km occur, reaching the largest value 8.4° C/km at Colom Béchar in the Sahara.

**Table 1** Frequency distribution of average temperature lapse rate for summer months

| lapse rate °C/km | 4.1-4.5 | 4.6-5.0 | 5.1-5.5 | 5.6-6.0 | 6.1-6.5 | 6.6-7.0 | 7.1-7.5 | 7.6-8.0 | 8.1-8.5 |
|---|---|---|---|---|---|---|---|---|---|
| frequency | 1 | 16 | 80 | 80 | 16 | 11 | 6 | 1 | 3 |

On the other hand the lapse rates for 850/500 mb layer during winter (January and February in the northern hemisphere, July and August in the southern hemisphere) are, on the whole, smaller than those during summer. The frequency distribution is shown in Table 2. The largest value 7.2° C/km appears at New Delhi, whereas the smallest one 3.2° C/km at Seimchan in Siberia. The distribution pattern is rather similar to that during summer months, although it is accentuated by the smaller lapse rates on the east coasts of Asia and North America in higher latitudes.

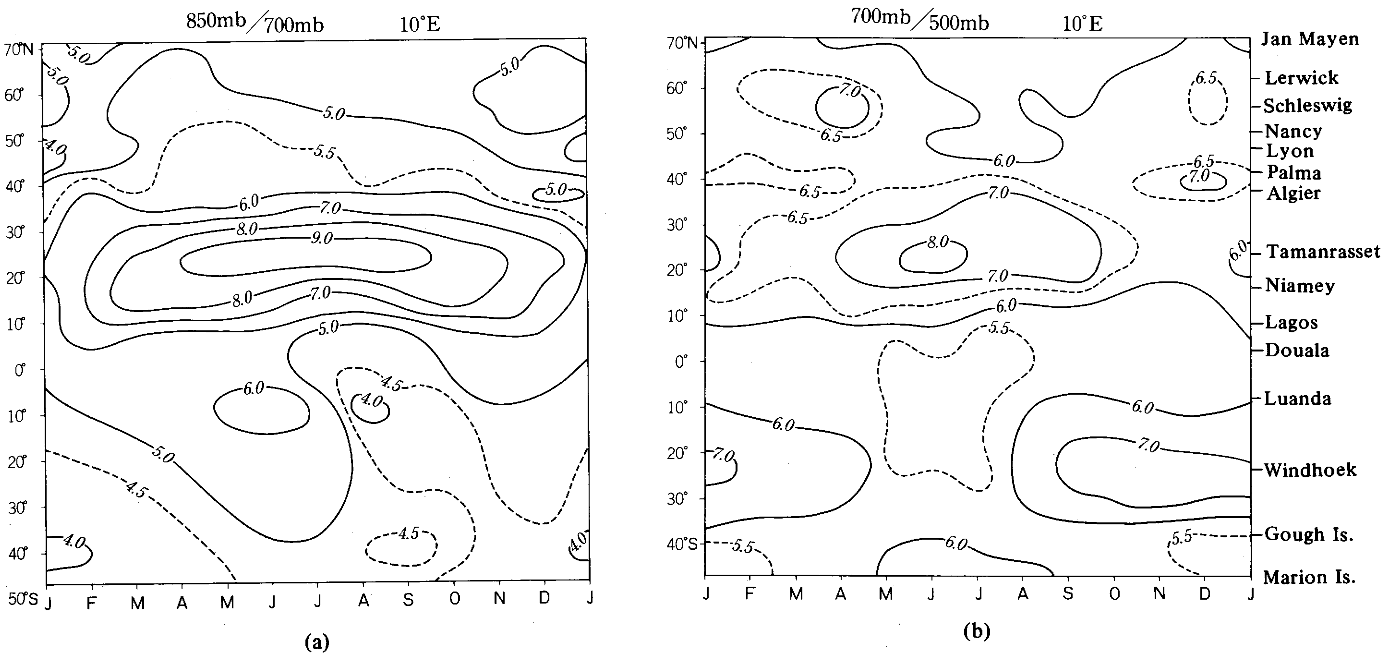


**Fig. 1** Seasonal variation of temperature lapse rate along 10°E (°C/km).
a: 850/700mb layer b: 700/500mb layer

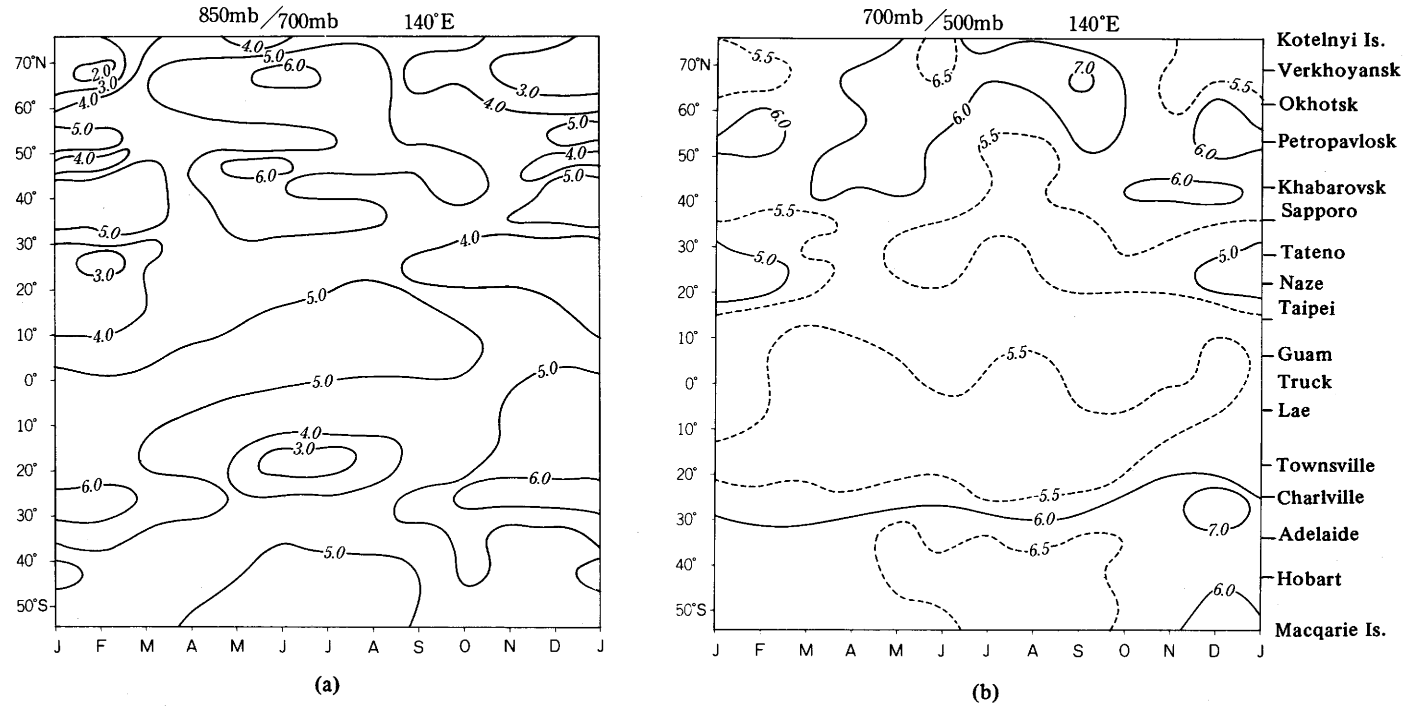


**Fig. 2** Seasonal variation of temperature lapse rate along 140°E (°C/km).
a: 850/700mb layer b: 700/500mb layer

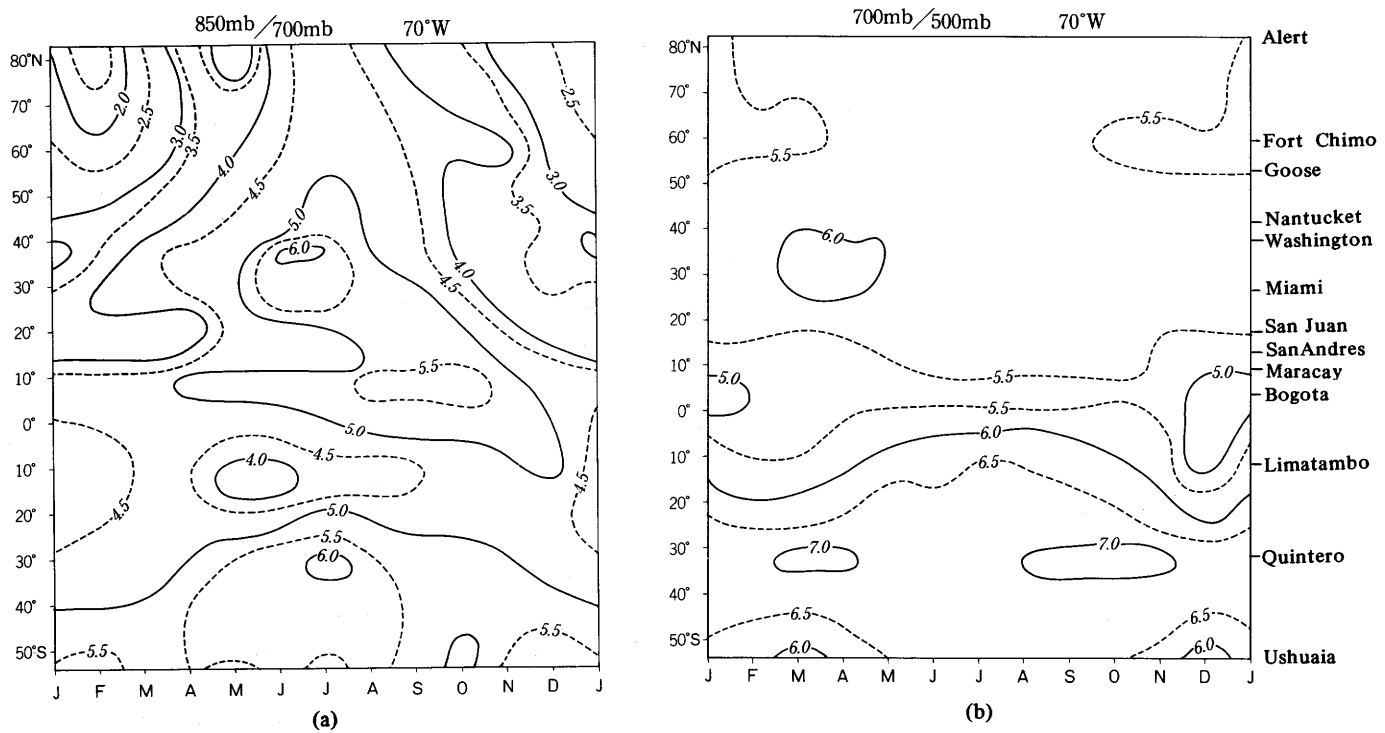


**Fig. 3** Seasonal variation of temperature lapse rate along 70°W (°C/km).
a: 850/700mb layer b: 700/500mb layer

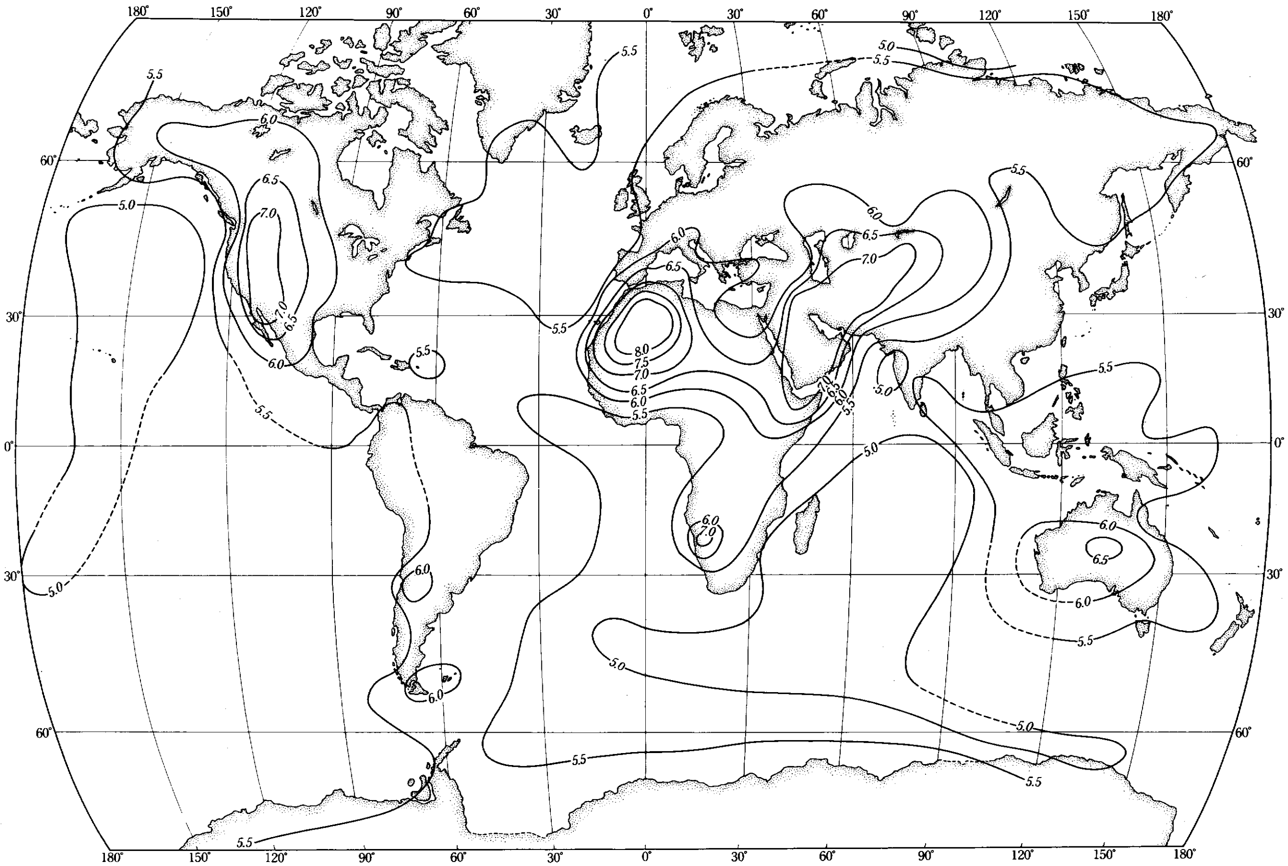


**Fig. 4** Distribution of average lapse rate for 850/700mb layer during summer (July–Aug./Dec.–Jan.). unit: °C/km

**Table 2** Frequency distribution of average temperature lapse rate for winter months

| lapse rate °C/km | 3.1-3.5 | 3.6-4.0 | 4.1-4.5 | 4.6-5.0 | 5.1-5.5 | 5.6-6.0 | 6.1-6.5 | 6.6-7.0 | 7.1-7.5 |
|---|---|---|---|---|---|---|---|---|---|
| frequency | 2 | 4 | 26 | 29 | 46 | 52 | 39 | 5 | 1 |

## DISCUSSIONS

When the past and modern snow lines are referred to the term of air temperature, the vertical distribution of temperature is, in most cases, estimated by assuming the overall lapse rate as a definite rate between 5° C/km and 6° C/km. Since the regional differences in the lapse rate are marked as has been stated, we have to assume different values of lapse rate by regions.

Fig. 5 shows the 0° C heights during the summer season which were estimated in each station with different lapse rates. It can be easily observed that the maximum values of 0° C height appear in the Afro-Asiatic and North American subtropics. They amount to 5000m and more, which is partly 600m higher than those of the equtorial zone. The latitudinal distribution is also indicated in Fig. 6. In spite of the presence of larger longitudinal difference in height there can be noticed two maxima in the subtropics. This is due partly to the ascending motion in the lower troposphere of subtropics and partly to the considerable upward heat transfer from the earth's surface (Hastenrath 1968, Crutcher 1969).

In order to discuss the relation between 0° C height and snow line, Fig. 7 is prepared. Here both categories of 0° C height are represented in comparison with the altitude of snow line. As was discussed by Leopold (Leopold 1951), the close correspondence of the profile of average 0° C height for two summer months is apparent in lower latitudes. However, the difference between them increases with latitude. According to the recent research on the mass balance of the glacier (Hoinkes 1971), the determining parameter to the glacial behavior is the summer temperature index from May to September in mid-latitudes. For this reason the average 0° C heights from May to October/November to April are also indicated in Fig. 7. They are more closely related to the altitudes of snow line than in the case of the temperature for two summer months.

From these facts, the higher altitude of snow line in the subtropics can be primarily explained by the temperature characteristics in latitudinal pattern, although it would be emphasized in some degree by small quantities of precipitation.

In the palaeoclimatic researches of the last ice age, the depression of the snow line has been converted with a definite overall temperature lapse rate to the lowering of average temperature. At the present, it is difficult to reconstruct the regional pattern of the temperature lapse rate in the past climate. However, it is doubtless that there was considerable difference in the temperature lapse rate of the globe, as seen at the present time. As a result, it is recommended to adopt 7–8°C/km as the lapse rate in the subtropical portions of the continents and 4–5°C/km in the marine climates of middle- and higher latitudes during the last ice age.

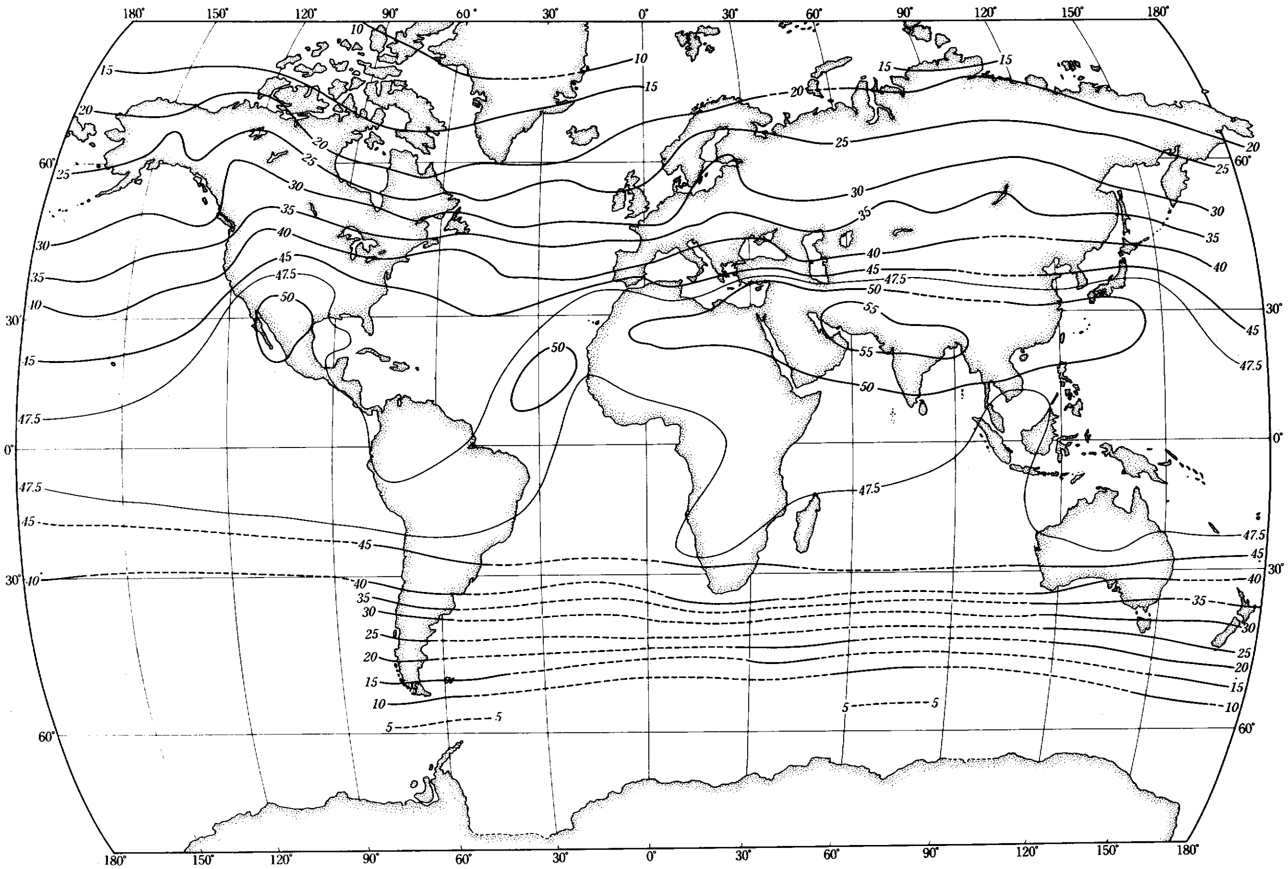

Fig. 5 Distribution of average 0°C height during summer. unit: 100m.

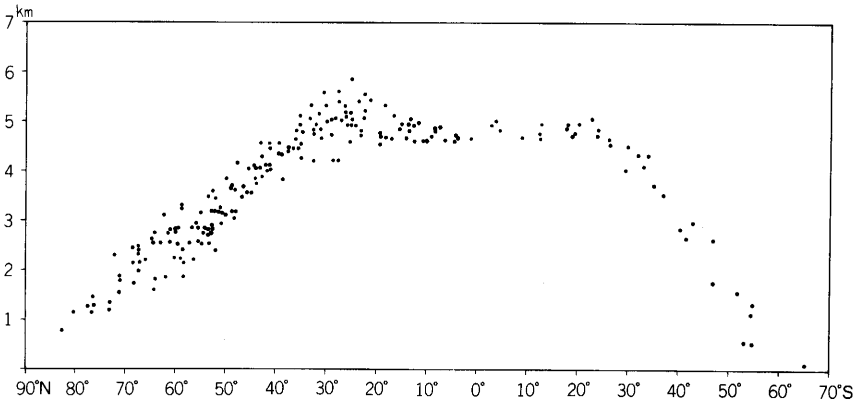


**Fig. 6** Latitudinal distribution of average 0°C height during summer.

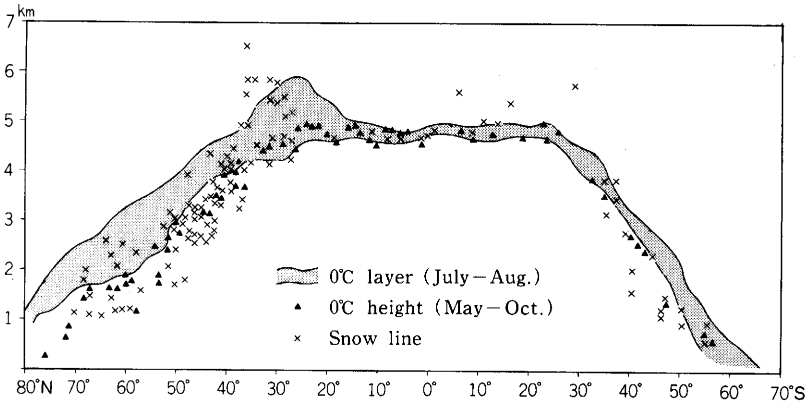


**Fig. 7** Relation between snow line and average 0°C height during summer. (The data of snow line based on Hermes 1955)

If one assumes 5°C/km as the overall lapse rate on the glove in the past, it may produce misleading results; the lowering of the temperature due to the snow line depression of 1000 m may be underestimated by 2–3°C in the subtropics, and may be overestimated by 1°C in the marine climates of middle- and higher latitudes.

The author wishes to dedicate this paper to Professor Dr. Jogyo Takeuchi of Waseda University in honor of the seventieth anniversary of his birthday.

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