A PRELIMINARY STUDY ON FOG AND COLD AIR LAKE IN JINGHONG AND MENGYANG BASINS, XISHUANGBANNA

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Abstract

Observations on fog and cold air lake were made in the Jinghong and Mengyang basins in the cold fog season and dry cool season of Xishuangbanna, 1986-87. The results showed some characteristic features on time-space structure and formation of fog and cold air lake.

1. Introduction

Xishuangbanna is located in the southwest of Yunnan Province is recognized as a part of the tropics. Its climate is, however, somehow different from that of other tropics because of its geographical environments. Owing to its position with higher latitude, Xishuangbanna is located on the north margin of the tropical climate regions. Furthermore, Xishuangbanna is inland, about 500km away from the nearest coast and there are many basins in this region. Therefore, the amplitudes of annual and diurnal variations of air temperature are very large.

These geographical environments produce the occurrences of typical local-climatological phenomena, that is, cold air lake and fog, under the stable weather conditions. Xishuangbanna has five seasons : 1) Rainy Season, 2) Cool Fog Season, 3) Cold Fog Season, 4) Dry, Cool Season and 5) Dry, Hot Season. The cool fog season is from the last ten-days of October to the last ten-days of November and the cold fog season from the first ten-days of December to the middle ten-days of February. In these seasons, frequent occurrences of fog are recorded at the meteorological observatories on the basin bottoms (Yoshino, 1986). Xishuangbanna is sometimes called as "Fog State" in China.

Greatly undulated topography with many big and small basins is one of the natural characteristics in Xishuangbanna. Therefore, the altitudinal zonations of land use are very distinct depending upon the local-climatological phenomena of each season.

In order to clarify the horizontal and vertical structure and the formation process of the fogs and the cold air lakes, a Japan-China cooperative study on fogs and cold air lakes in Xishuangbanna was undertaken in 1986. The meteorological observations were made during the periods from December 25, 1986 to January 15, 1987 and for February 12 to February 19, 1987.

2. Observation System

The observations, composed of the three parts, were carried out on the basin bottoms

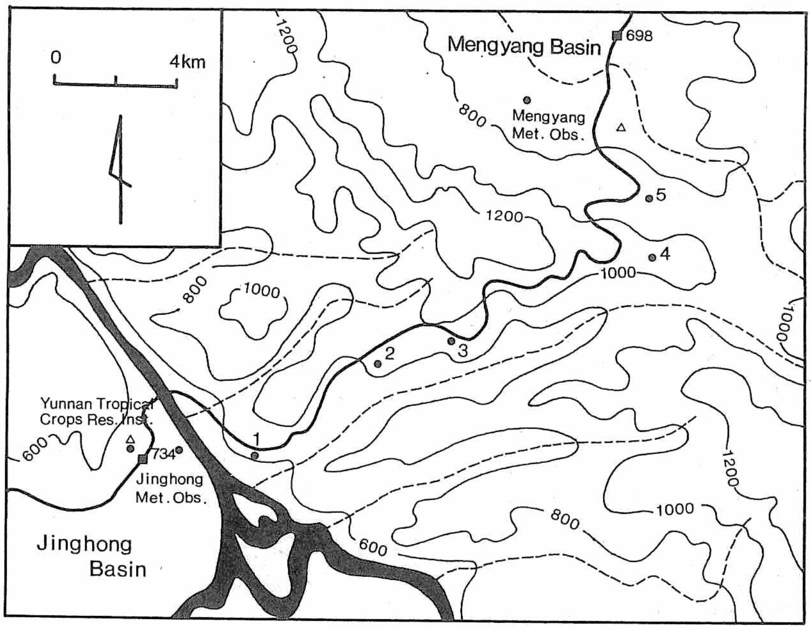

Fig. 1 Observation field and systems.
Broken line indicates a valley.

and slopes of Jinghong and Mengyang. Figure 1 shows the observation field and the observation systems.

i) Slope observation : five stations (black circles with a numeral) were set up on the slopes between the Jinghong and Mengyang basins. In these observation points together with the Jinghong and Mengyang Meteorological Observatories (JMO and MMO) air temperature, relative humidity, cloud amount and weather are recorded at intervals of three hours.

ii) Radio sonde observation : air temperature up to the height of 400m (sometimes up to 600m) above the basin bottoms was observed by a captive balloon at intervals of one hour in the mornings and evenings (triangle).

iii) Motor-car observation : from the Jinghong basin (milestone no. 734) to the Mengyang basin (no. 698), dry-bulb and wet-bulb temperature and visibility (in fog layer) were observed by a car equipped with a set of the instruments. The observations were made twice daily with staring time of 08h and 11h (Beijing Time).

3. Time-space distribution of fog

Figure 2 gives the composite variations of air temperature, relative humidity and cloud amount at the Jinghong Meteorological Observatory averaged for the period from Dec. 25, 1986 through Jan. 15, 1987. The large diurnal range of air temperature with more than 10°C and the high relative humidity at night time are remarkable. This figure also shows the rhythmical diurnal variation of cloud amount. The maximum appears at 08h and the minimum at 20h (Beijing time). Although the mean value is used in this figure, the value reaches to almost 10/10 at 08h. This rhythmical variation of cloud amount is associated with the high frequencies of occurrence of fog in the early morning.

The time-space distributions of fogs are examined from the results obtained by the slope observation. Figure 3 indicates the diurnal change of frequency of fog at each station during Dec. 25, 1986 to Jan. 15, 1987. The lower panel shows those on the bottom and the slope of the Jinghong basin. JMO has a height of 553m above sea level, ST. 1 on the slope 669m a. s. l. and ST. 4 : 1,132m a. s. l., respectively. Strictly speaking, MMO is located between the bottom and the slope in the Mengyang basin.

This figure shows two principal characteristics about the distributions of fogs. One is the difference of its appearances between the Jinghong and Mengyang basins and another is its altitudinal difference.

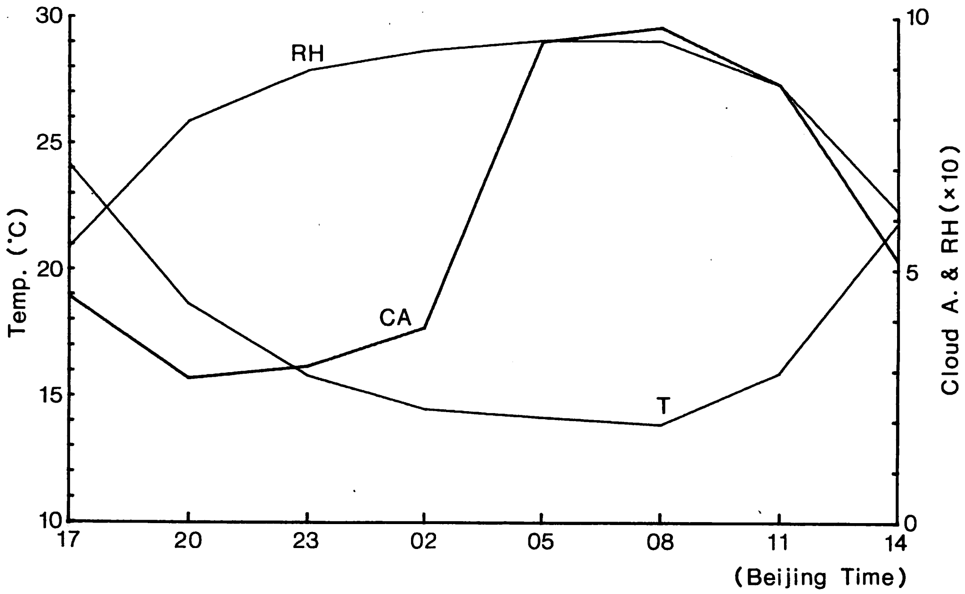

Fig. 2 Mean diurnal variations of air temperature, relative humidity and cloud amount at the Jinghong Meteorological Observatory during Dec. 25, 1986 to Jan. 15, 1987.

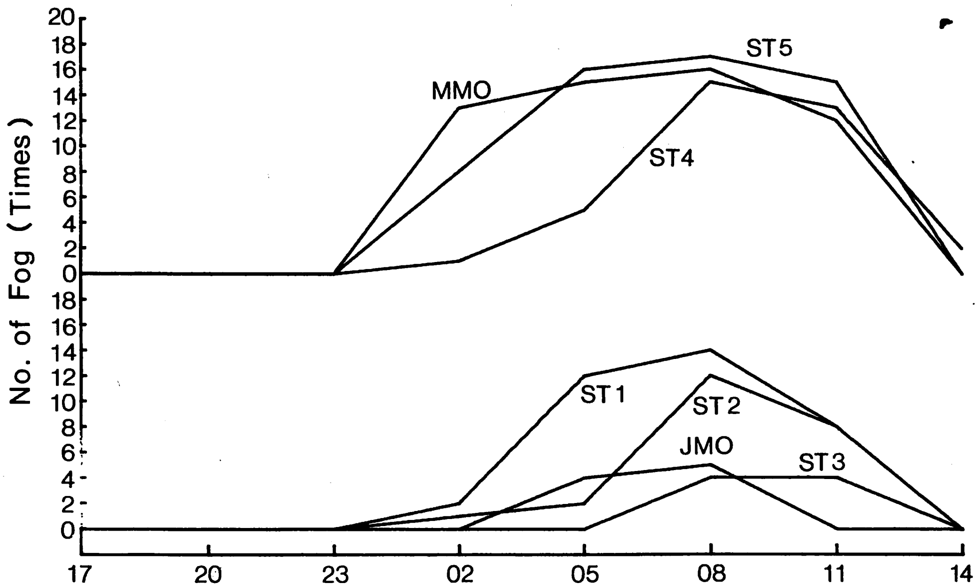

Fig. 3 Frequencies of occurrence of fog at stations along the slopes.

Fog appearance precedes in the Mengyang basin. On the basin bottom of Mengyang (MMO), fog appears already at 02h. Furthermore, the stations in the Mengyang basin have higher frequencies of occurrence of fogs than that in the Jinghong basin. The frequency at MMO counts 13 times at 02h, 15 times at 05h, 17 times at 08h and 12 times at 11h, while ST. 1 with the highest frequency of fog appearance on the Jinghong basin slope counts 2 times at 02h, 12 times at 05h, 14 times at 08h and 8 times at 11h. Number of times of the observation is 21 in all. This difference is frequency associated with the geographical environments, such as basin shape and basin size.

Fog appearance occurs in the lower part of the basins first and spreads toward the upper part with time lag. Abrupt increase of its frequencies is seen at ST. 2 (870m a.s.l.) and ST. 4 (1132m a.s.l.) at 08h. However, on the Jinghong basin slope, the stretch does not occur over ST. 2. The lowest appearance of fog is seen at ST. 3 (964m a.s.l.).

The motor-car observations give more detailed informations about the space distribution of fogs. Figure 4 shows the frequency of occurrence of fog and temperature anomalies from the space mean in this region by nine observations at 08h. T means air temperature and Td-Tw is temperature difference of dry-bulb minus wet-bulb. The axis of abscissa indicates the sequential number of mile stones from Kunming (unit : km) and their heights above sea level are shown in the lower part of this figure.

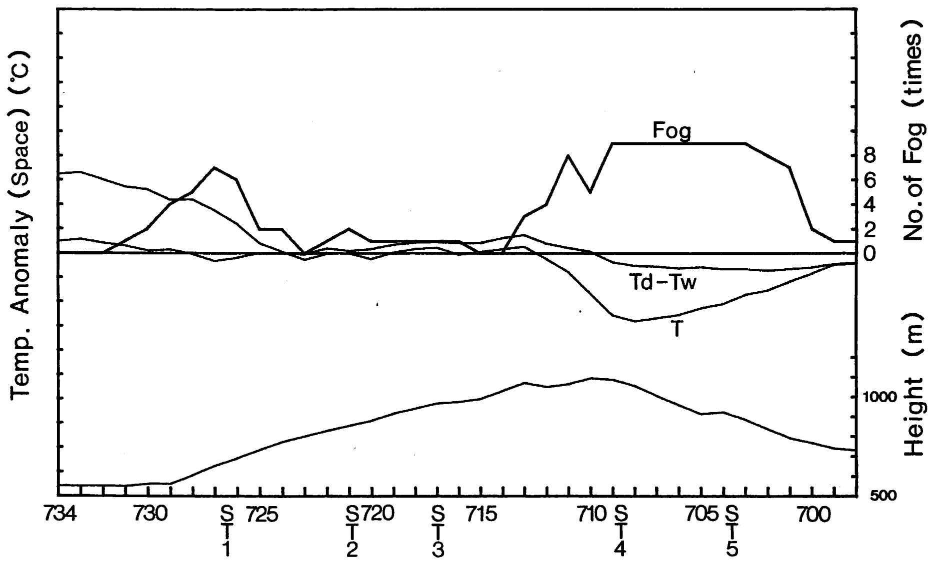

Fig. 4 Frequencies of occurrence of fog and temperature anomalies from space mean at 08h.

High frequency of fog appearance is seen along the slope of the Mengyang basin, where air temperature indicates negative anomaly from the space mean, except the basin bottom. On the other hand, only the area at the height of about 100m above the Jinghong basin bottom shows frequent appearance. Moisture is somehow high there, although the positive air temperature anomaly is predominant throughout the Jinghong basin slope. Another peak of its appearance is on the upper part of the slope. This suggests that the fog in the Mengyang basin sometimes runs over the pass.

From the slope and the motor-car observations, a schematic model of the distribution of fog at 08h is obtained (Fig. 5). While the dense or moderate fog appears throughout the Mengyang basin slope except the basin bottom, the spatial distribution of fog is rather limited to the lower part of the slope in the Jinghong basin with the less or moderate grade. Fog scarcely appears in the range of 900-1050m a.s.l. on the Jinghong basin slope. Furthermore, this figure suggests that fog is not formed only by radiative cooling.

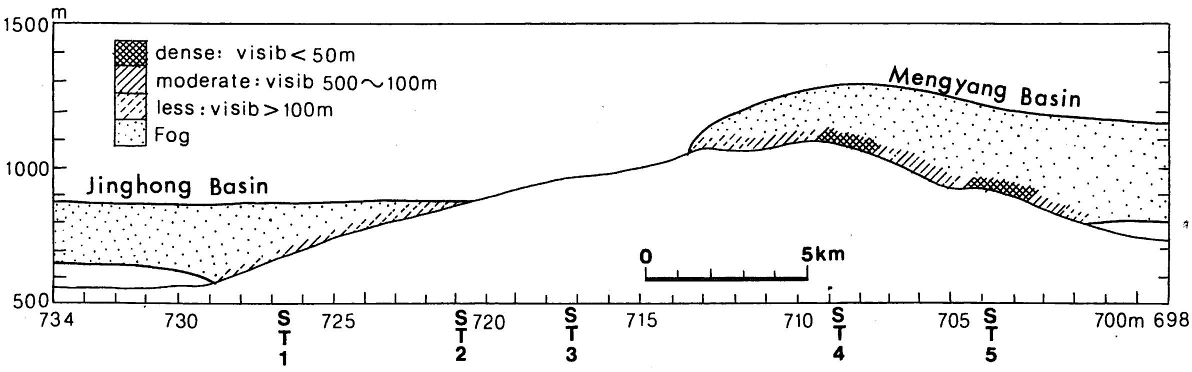

Fig. 5 Schematic view of distribution of fog at 08h.
dense : visibility <50m
moderate :visib. 50-100m
less : visib. >100m

4. Time change of cold air lake

Figure 6 shows the diurnal variation of the mean air temperature along the slopes of the Jinghong and Mengyang basins during the period for Dec. 25, 1987 to Jan. 15, 1987. The numeral on each profile shows the observation time (Beijing Time). The maximum temperature occurs in this region at 17h, because the local time is 1 hour 42 minutes later than the Beijing time.

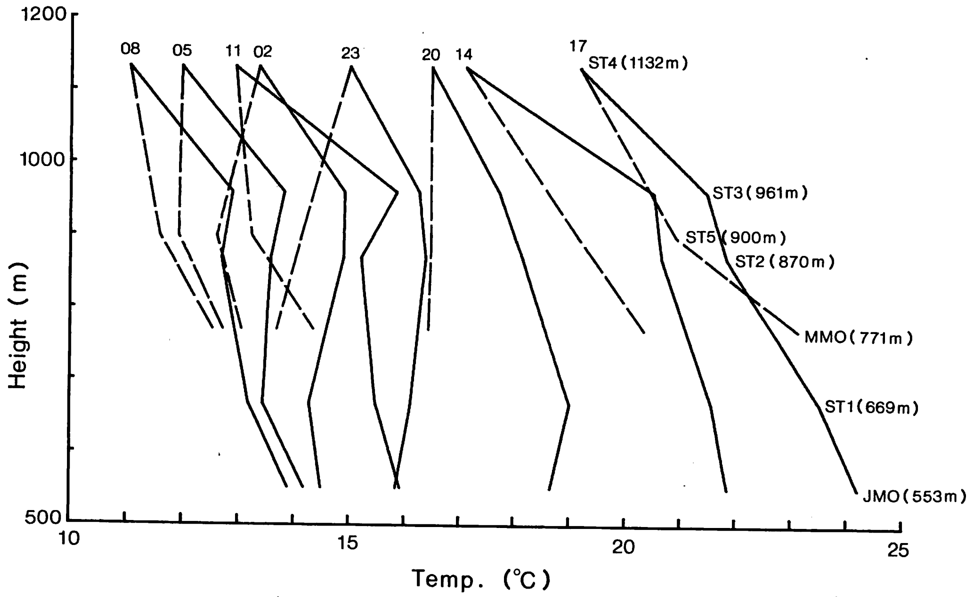

Fig. 6 Mean profiles of air temperature along the slopes of Jinghong basin (solid lines) and Mengyang basin (broken lines)

The profile at 17h shows a lapse rate of about 0.8°C/100m on the Jinghong basin slope. From 17h to 23h, the largest temperature fall occurs at MMO on the Mengyang basin bottom. As a result, sharp inversion of air temperature (cold air lake) is formed in the basin. The rate of temperature increase with height at 23h is about 0.5°C/100m on the Mengyang slope. The slope observation cannot give the height of top of the inversion layer between 20h and 05h. On the other hand, a relatively great temperature fall also occurs at JMO on the Jinghong basin bottom from 17h to 23h. The height of top of the inversion layer is about 100m above the basin bottom at 20h and goes up to 300m at 23h and 400m at 02h above the basin bottom.

From 02h to 08h, temperature fall on the basin bottoms becomes extremely slow and the inversion of air temperature disappears in the lowest layer of the slopes. However, the profiles suggest that the cold air still remains in the basins. The minimum temperature occurs at 08h at each station. The profile at 11h still shows the remnant of cold air in the basins. The lapse rate of air temperature is about 0.2°C/100m between JMO and ST. 2 at the time. An effect of the slope direction may be considered as well as other geographical environments on producing the difference of the profiles between the Jinghong and the Mengyang basin, since the Jinghong basin slope is faced to the south while the Mengyang basin slope is faced to the north.

The observations along the Jinghong basin slope suggests an existence of the thermal belt at ST. 3 (964m a.s.l. and about 400m above the basin bottom), where the relative high temperature is recorded between 23h and 14h. The relatively high temperature at day time may be due to the large amount of insolation under the no fog condition as shown in Figure 5. As a result, the greatest temperature rise is recorded there from 08h to 11h. An lapse rate of about 1°C/100m occurs between ST. 2 and ST. 3 at 11h. The previous observation made in this region in February 1983 also shows a similar thermal belt near the height of ST. 3 (Xishuangbanna weather study Group, 1983). These results suggest that at the height of ST. 3 on the Jinghong basin slope at least the temperature condition may be suitable for tropical agricultural land use.

Figure 7 shows the diurnal variations of the profiles of saturation deficit along the slopes,

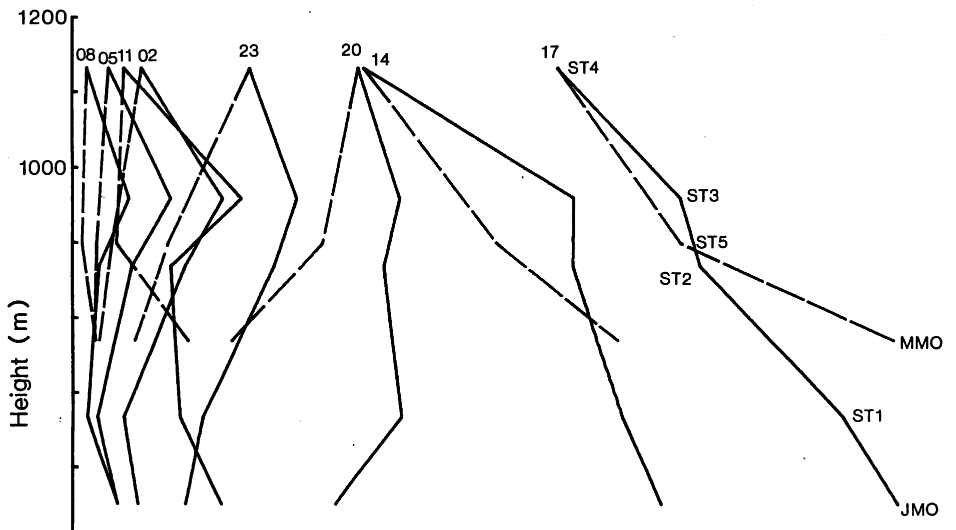

Fig. 7 Same as Fig. 6, but for saturation deficit along the slopes.

which is related to those of temperature and the distribution of fog. The Mengyang basin slope shows almost saturated condition between 05h and 08h. On the other hand, along the Jinghong basin slope, the same condition occurs only at ST. 1. At ST. 2 the saturation occurs only at 08h, and ST. 3, where fog appearance is scarce, is away from the saturation condition even at 08h.

5. Results of special observation

Special observation was made for two days within the first observation period, to clarify the characteristics of fogs and cold air lakes and the relationship between them in detail. Throughout the special observation period, the slope observation at intervals of one hour, the radio sonde observation through the night time and the motor-car observation of eleven times per day were carried out. It started at 17h Jan. 5, 1987 and resulted in success under the typical weather conditions of the cold fog season.

Figure 8 (a), (b) show the weather conditions at JMO from two days before the observation till two days after it. No rainfall was recorded, and the diurnal range of air

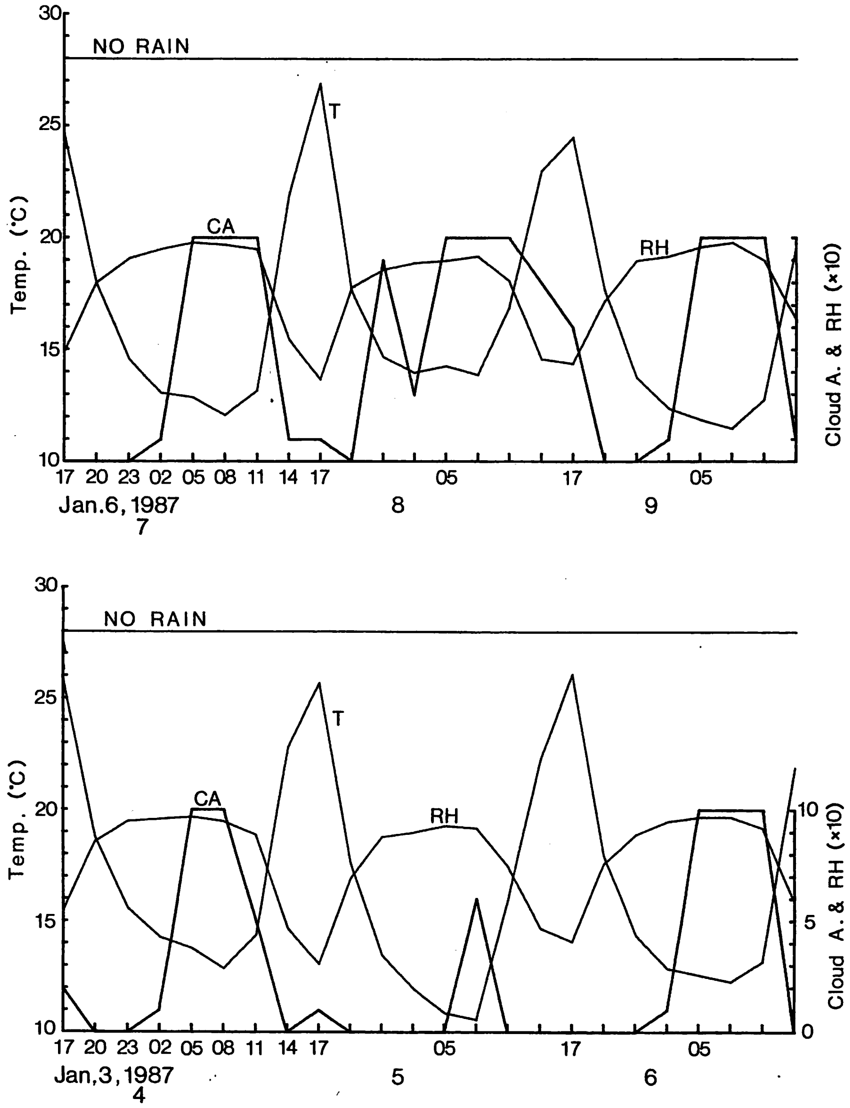

Fig. 8 Weather conditions at JMO from 17h Jan. 3 to 14h Jan. 9, 1987.

temperature there was about 15°C throughout this period. Under the stable weather conditions, the regular diurnal variation of cloud amount, which counts 10/10 between 05h and 11h and 0/10 in the afternoon, was predominant at JMO.

Figure 9 gives the diurnal variations of air temperature along the slopes during the special observation period. Heavy lines indicate air temperature at JMO and MMO on the basin bottoms. Abrupt temperature fall occurred on the basin bottoms at about the sunset time, and the lowest temperature in this observation field was recorded at MMO between 19h, Jan. 5 and 02h Jan. 6. Air temperature at JMO also showed the lowest in the Jinghong basin between 20h Jan. 5 and 02h Jan. 6. Therefore the sharp inversion layer of air temperature was rapidly formed after the sunset, particularly in the Mengyang basin. The temperature difference of 4.1°C, which means the increase rate of 1.1°C/100m, was recorded between MMO and ST. 4.

In the Jinghong basin the temperature difference of about 2°C continued between JMO and ST. 2 till 02h Jan. 6. The temperature fall on the basin bottoms became, however, extremely slow from the midnight, and as a result, the sharp inversion of air temperature disappeared in the lowest layer. On the other hand, a thermal belt was recognized clearly at ST. 3 on the Jinghong basin slope. The maximum temperature at ST. 3 along this slope

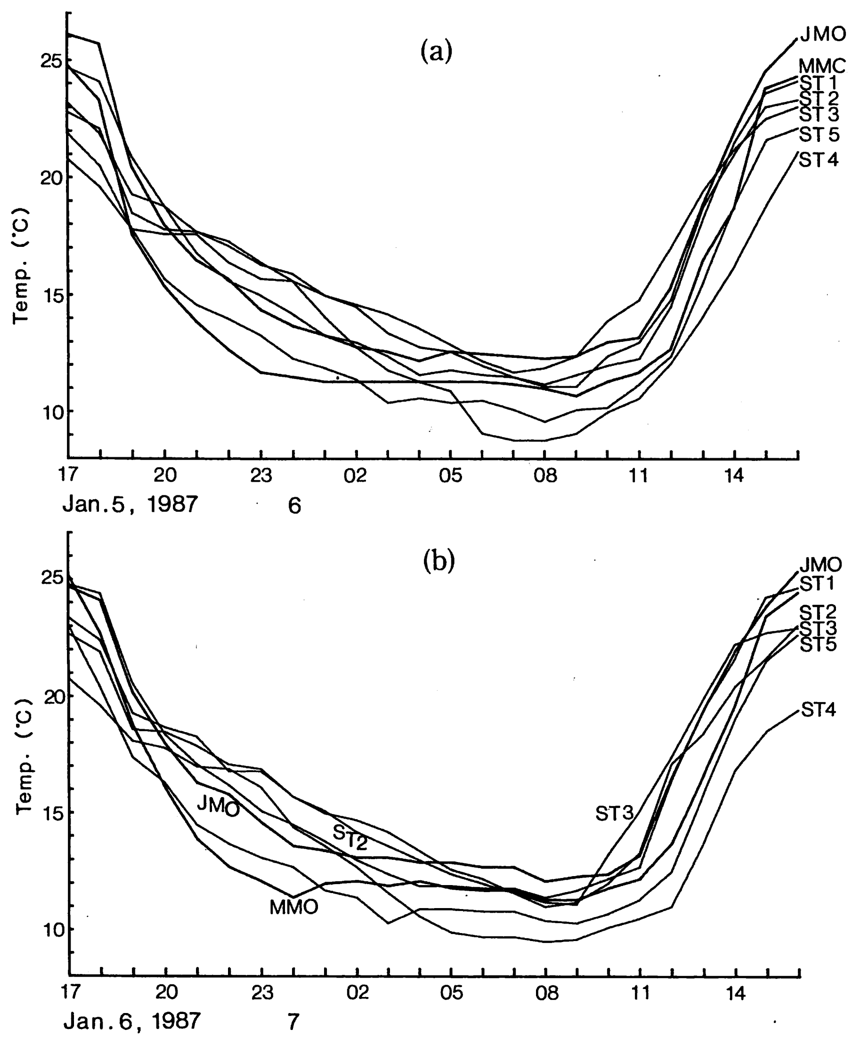

Fig. 9 Diurnal changes of air temperature at stations along the slopes during (a) Jan. 5 to Jan. 6 and (b) Jan. 6 to Jan. 7.

appeared between 02h and 05h between 09h and 13h of Jan. 6. The observation for Jan. 6 through 7 (Fig. 9(b)) also shows a similar feature on the development of cold air lake.

The result of the radiosonde observation through the night time at Yunnan Tropical Crops Research Institute (Jinghong) shows the more detailed features about the cold air lake over the Jinghong basin (Fig. 10). The inversion of air temperature first appeared at 19h Jan. 5 and gradually developed through the nighttime. The plural inversion layers of air temperature were recognized from 21h Jan. 5 till 03h Jan. 6. It can be considered that the axis of high temperature at a height of 350m-400m above the basin bottom corresponds to the thermal belt pointed out by the slope observations. Between 03h and 04h Jan. 6, the lowest inversion layer disappeared, and simultaneously the low temperature area appeared in the lower layer in the basin. Then the axis of low temperature moved upwards. It was located at a height of 300m above the basin bottom at 08h Jan. 6. If we refer to Figure 11, which indicates the diurnal variations of saturation deficit, JMO was almost in the saturation condition at 03h, and fog appeared at the Institute at 04h. Therefore it is assumed that the breakdown of the inversion layer in the lowest layer is mainly due to the strong long wave radiation from the fog layer and the effect of fog layer on the earth radiation. The formation of the relatively low temperature zone (refer to the thick dashed line in Fig. 10) may also be associated with the radiative cooling from the top of the fog layer. Figure 10 suggests, therefore, that the time evolution of the vertical temperature profile over the basin depends largely upon the appearance or nonappearance of fog in the basin.

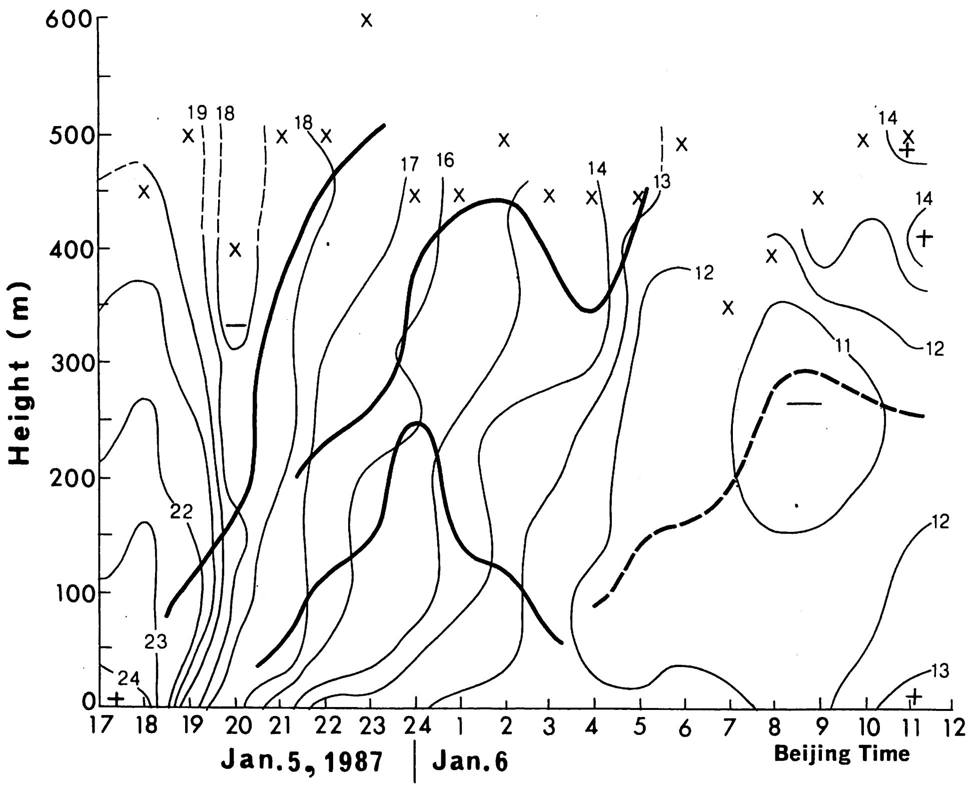

Fig. 10 Distribution of air temperature in the Jinghong basin by radio sonde observation.
Heavy solid line : top of inversion layer.
Heavy broken line : axis of low temperature area.
X : upper limit of observation.

The slope observations show that almost saturated air came into existence at MMO at 23h Jan. 5 (Fig. 11(a)). The formation of saturated air preceded in the Mengyang basin, and it was completed throughout the basin slope at 03h Jan. 6. On the Jinghong basin slope, this condition appeared first at ST. 1 at 03h and then at JMO at 04h Jan. 6. ST. 3 was away from the condition throughout the period. Sudden but slight increases of saturation deficit at 06h and 10h of Jan. 6 at MMO may be considered as observational noises.

Figure 12 shows the time sequences of appearance of fog along the slope during the period. A count of level 1 denotes the appearance of fog. Following the formation of saturated air, fog appeared first at MMO at 02h, which is followed by the Jinghong basin slope. At JMO, it occurred at 04h but disappeared soon associated with the change of the vertical temperature distribution above the basin, as shown in Fig. 10. The fog at ST. 1 appeared at

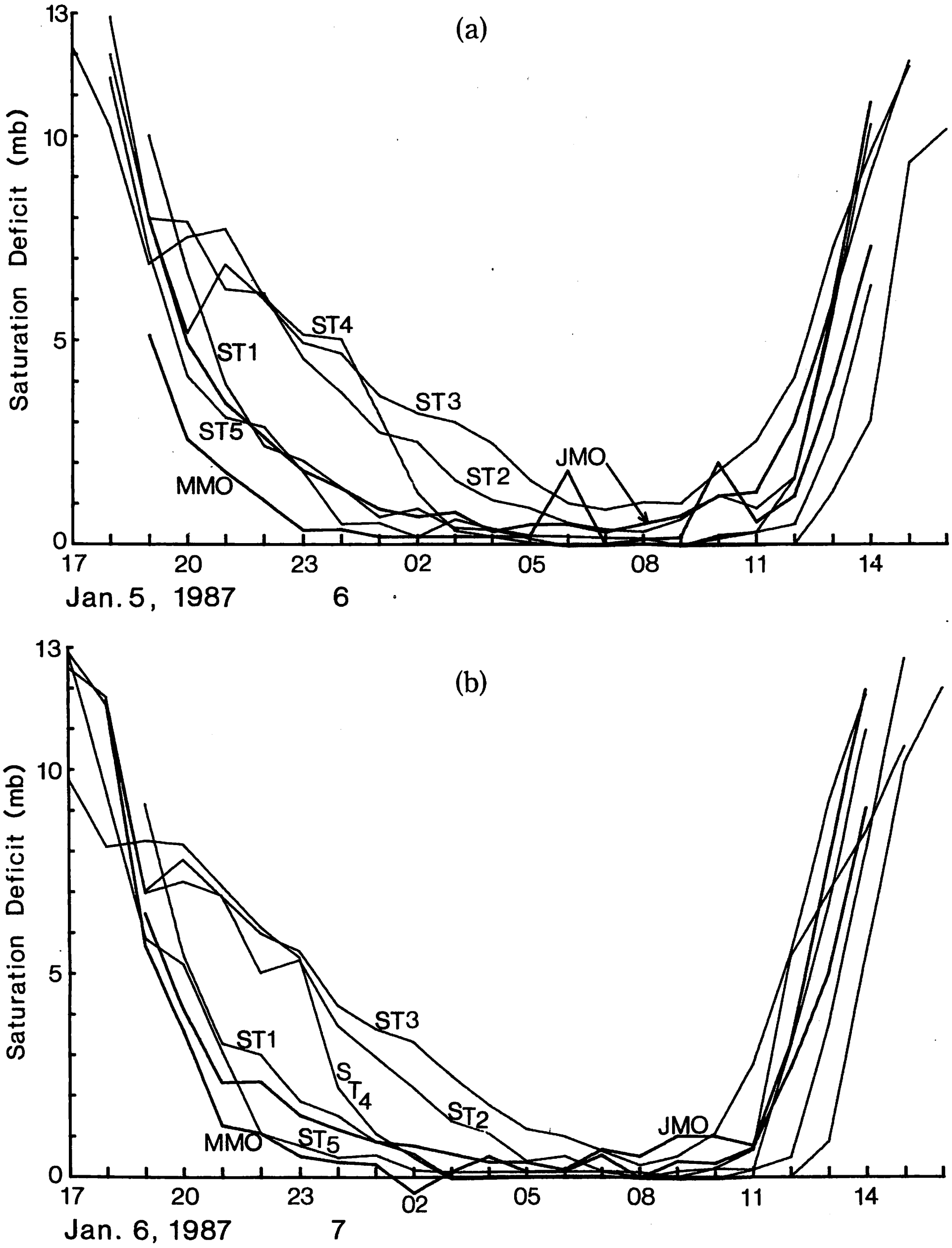

Fig. 11 Diurnal changes of saturation deficit at stations along the slopes during the day of (a) Jan. 5 to Jan. 6, (b) Jan. 6 to Jan. 7.

04h and continued for six hours. The fog on the upper part of the Jinghong basin slope (ST. 4) appeared at later time than the lower part and its duration is also short. It did not appear at ST. 3. The result of the motor-car observations shows similar time-space characteristics of fog formation along the slopes.

Another interesting phenomenom shown in this figure is a diurnal change of wind at ST. 4. The SW wind was blowing there till 23h Jan. 5, but the wind direction changed to NE after the calm period. The NE wind continued till 15h Jan. 6. This diurnal change of wind at ST. 4 is clearly detected even through the routine observation at intervals of three hours from Dec. 25, 1986 to Jan. 15, 1987. It is noteworthy that the timing of wind direction change to NE corresponds to the fog appearance and the temperature fall there (Fig. 9). This suggests that the fog there is advected from the Mengyang basin associated with the local or regional scale mountain-valley wind system.

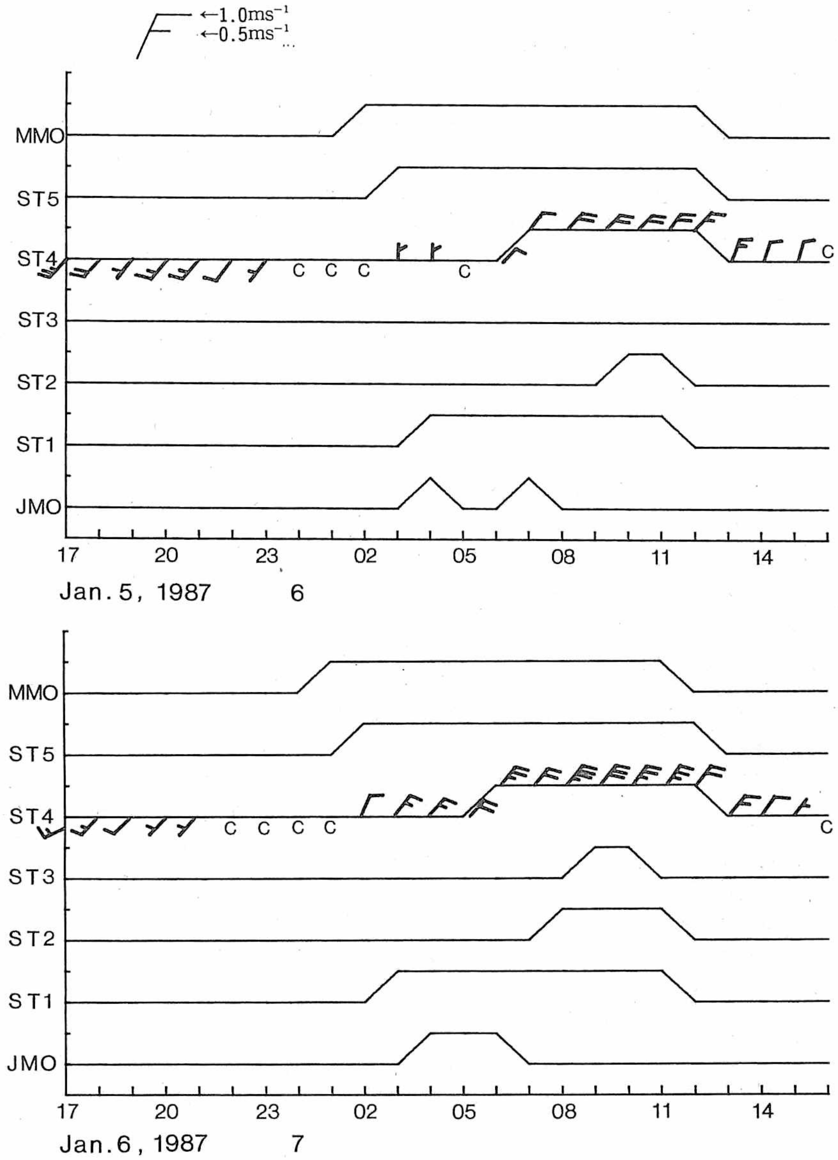

Fig. 12 Distribution of fog occurrence along the slopes during the day of (a) Jan. 5 to Jan. 6 and (b) Jan. 6 to Jan. 7.
A full-barb (half-barb) of winddirection shaft denotes $1.0 m \cdot s^{-1}$ ($0.5 m \cdot s^{-1}$) and C denotes calm condition.

The similar features on the formation and disappearance of cold air lake and fog layer are noted from 17h Jan. 6 to 17h Jan. 7 through the slope, radio sonde and motor-car observations.

6. Seasonal change of fog and cold air lake

In Xishuangbanna, the dry, cool season starts from the last ten-days of February. Therefore a result of our observation from Feb. 12 to 19, 1987 may show different characteristics on fog and cold air lake from that in the cold, fog season.

Figure 13 gives the frequencies of occurrence of fog at each station along the slopes from Feb. 12 to 19. A striking contrast between Figs. 13 and 3 is that fog appearance is restricted in lower part of the slopes in this period.

The mean diurnal variations of air temperature profile along the slopes during this period (Fig. 14(a)) also suggest that the condition of cold air lake formation is different from that in December and January. The magnitude of diurnal range of air temperature is larger throughout the slopes in this period. In particular, large temperature fall occurs in the lower part of the slopes in the night time, and the temperature difference between MMO and ST. 4 reaches to 4.7°C at 23h, which is equal to the rate of about 1.3°C/100m. In the same way, the temperature difference of 2.7°C (the rate of about 0.9°C/100m) is recorded between JMO and ST. 2 at 23h. The sharp inversion layers of air temperature is seen on the slopes even at 11h. However, the diurnal variations of vertical profiles of saturation deficit (Fig. 14(b)) show that the saturated condition appears only at about 8h on the Jinghong basin slope but relatively longer period (from 23h to 11h) on the Mengyang basin slope, which corresponds well to the period of fog appearance (Fig. 13).

7. Conclusion

The purpose of our study is to clarify the time-space characteristics and formation processes of fog layer and cold air lakes and also to comment on the interrelationship between these two in the mountainous region of Xishuangbanna. The screen, radio sonde and motor-car observations were made on the bottoms and the slopes of the Jinghong and Mengyang basins during Dec. 25, 1986 to Jan. 15, 1987 and Feb. 12 to 19, 1987. The results obtained through these observations are as follows:

1) Cold air lakes develop well in these two basins. However, the degree of development is different between the two basins. The fog formation precedes in the Mengyang basin, and the rate of air temperature increase in the inversion layer is greater there. The thermal belt on the slope is clearly seen at ST. 3 at a height of about 400m above the Jinghong basin bottom through the night and morning.

2) Fog appears frequently in the basins in the morning. However, it is restricted in the lower layer of the slope in the Jinghong basin, while it occurs throughout the slope in the Mengyang basin. Fog duration is longer in the Mengyang basin and in the lower part of the basin slope.

3) From the special observation, it is shown that the vertical temperature profile above the basin changes largely affected by fog appearance. The inversion of air temperature in the lowest layer disappears in the early morning because of the fog formation, and at the

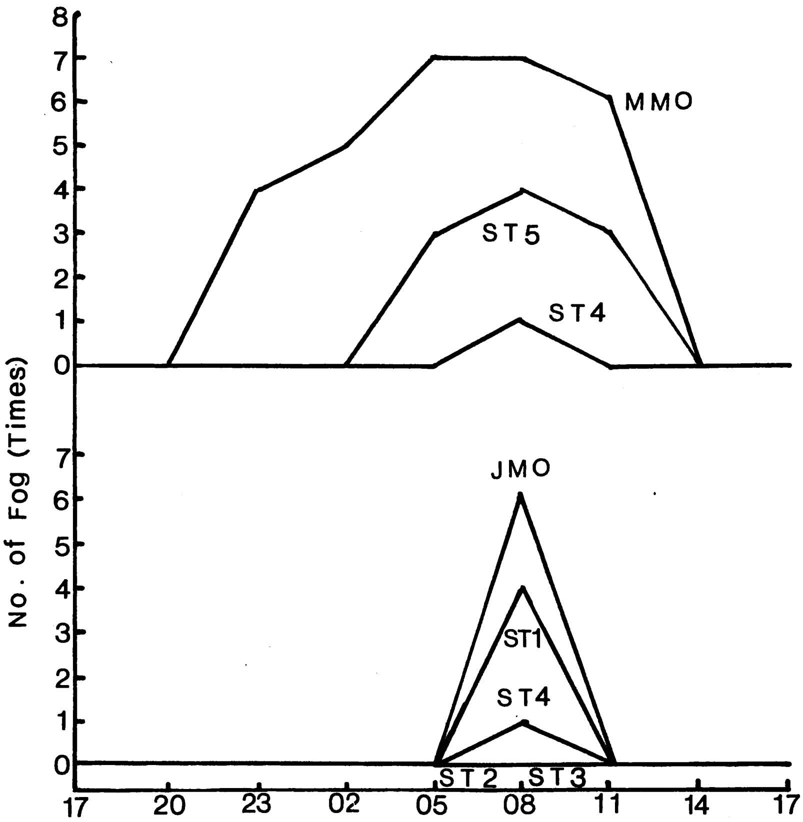

Fig 13 Frequencies of fog occurrence of fog during Feb. 12 through 1987.

same time, the low temperature appears in the lower layer in the basin. The drastic change of wind direction occurs at ST. 4 associated with the temperature fall and fog appearance there. This might indicate a useful information about the mechanism of fog formation.

4) The observation during Feb. 12 to 19, 1987 shows somewhat different features on the local-climatological phenomena. Fog appearance is restricted in the lower layer in the basins, and the duration of fog appearance in a day is shorter than that during December through January. These features are also evidenced by the diurnal variations of air temperature and saturation deficit along the basin slopes.

The results summarized above strongly suggest that the effects of local topographical environments, such as the basin shape, the basin size and the slope direction, are important for the formation of fog and cold air lake over the Jinghong and Mengyang basins. Therefore, the more detailed observations on the local-climatological phenomena should be made under various topographical environments including the comparison of several slope directions in the basin for the further study. Furthermore, a study on the synoptic weather condition of fog and cold air lake formation should also be carried out from the standpoint of regional climatology.

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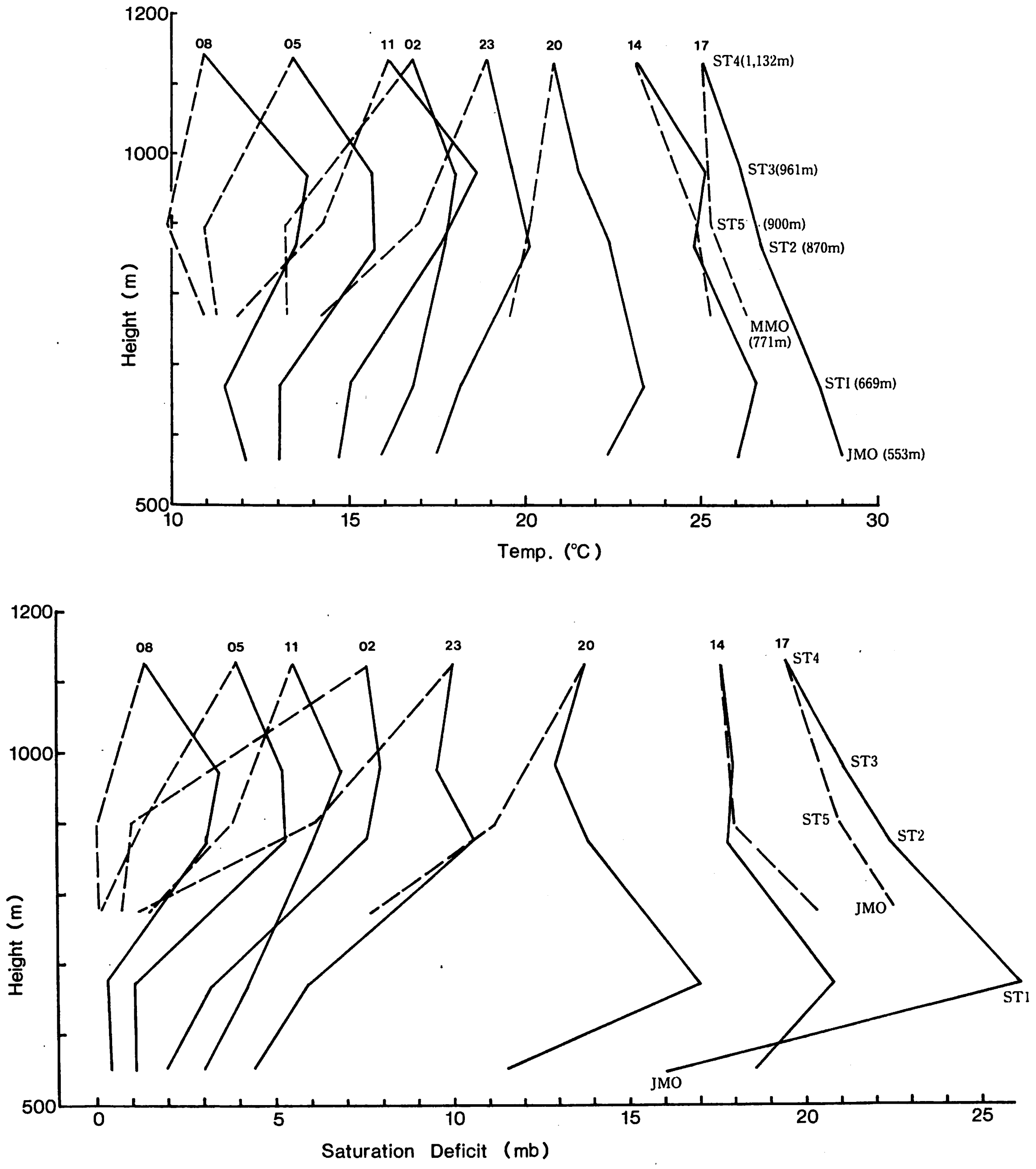

Fig. 14 Mean profiles of (a) air temperature and (b) saturation deficit during Feb. 12 through 19, 1987 along the slope of Jinghong basin (solid lines) and Mengyang basin (broken lines).

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