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Cooling of water and the overlying air by melting ice at Lagoon San Rafael in the northern Patagonia

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Abstract

Air and water temperatures were measured horizontally and/or vertically during the period from 24 to 27 November 1985, at Lagoon San Rafael in the northern Patagonia. Major findings are as follows :

1) Inversion of air temperature appeared in the layer below 50 to 80 m in height in the daytime.
2) Horizontal gradient of air temperature was large within the area with high number density of floating ice.
3) Water temperature decreased at both depths of one and five meters along the flow line of floating ice. Minimal value of air temperature was also observed along this line.

1. Introduction

On calm and fine days, mirage was often observed on Lagoon San Rafael during our stay (Oct. -Nov. 1985). Such an atmospheric phenomenon is due to a formation of temperature inversion of air, which is cooled strongly by contact with both floating ice and melt water on the lake.

Nakajima *et al.* (1985) measured water temperature and salinity in the lake. They pointed out that water near the lacustrine surface was cooled and diluted by melting ice. However, they could not draw a detailed horizontal map of the water temperature in the lake because of the small number of sampling points.

The purpose of the present work is to elucidate the cooling effect of floating ice on the lacustrine surface and on the overlying air both horizontally and vertically.

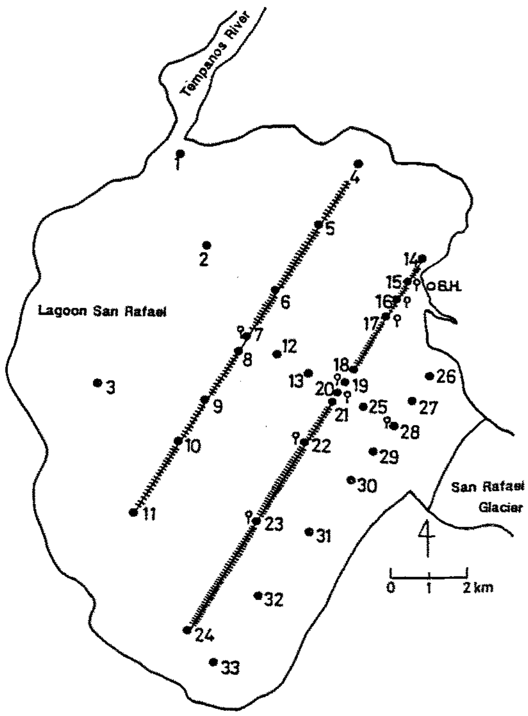

Fig. 1. Points of observation on Lagoon San Rafael. The symbol (♀) in the figure denotes the points at which air temperature was measured vertically. The symbol (++++) denotes a region where air temperature was measured with a constant interval of time on a moving shipboard.

2. Methods and points of observation

Figure 1 shows the points of the present observation, where water depth and both water and air tem-

Table 1. Summary of date, time and location of observation as well as comments on the location and the weather at that time.

Date & Time	Observational points & Comments
24 Nov. 1985	19 : Cloudy
11:36-11:56	19 : Cloudy
17:40-17:58	28 : Cloudy
19:29-19:47	28 : Fog and drizzle
25 Nov. 1985	
9:48-10:05	15 : Cloudy; Area with large number and size of floating ice
10:25-10:41	16 : Cloudy; Area with large number and small size of floating ice
11:10-11:25	17 : Cloudy; Area with small number and medium and small size of floating ice
12:47-13:02	20 : Cloudy; Area with small number and size of floating ice
14:00-14:15	22 : Cloudy
14:52-15:03	23 : Cloudy; Area with very small number and size of floating ice
16:45-18:33	4-11 : Cloudy
26 Nov. 1985	
9:58-15:10	26-33 : Clear sky
16:00-18:25	18, 21, 24 : Clear sky
27 Nov. 1985	
10:38-16:56	1, 2, 7, 12, 13, 19, 25, 28, 3 : Clear sky

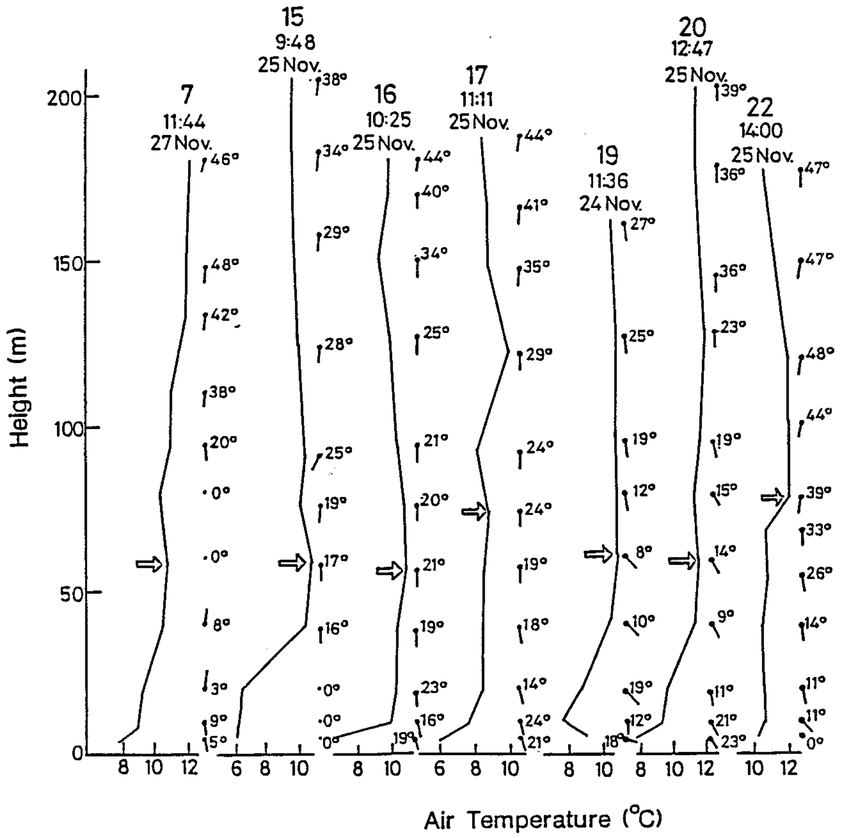

Fig. 2. Vertical profiles of air temperature. The number above each vertical profile means the point of observation. The top of the temperature inversion was indicated by an arrow.

peratures have been routinely monitored. The vertical profile of air temperature was obtained by using a radiosonde (Type RSII-80, Meisei Electric Co. Ltd., Japan) suspended from a balloon, which was moved up and down with a fishing rod. The map on water depth was reported by Nakajima *et al.* (1987) in this issue.

Table 1 summarizes the date, time and location of the observations and describes the location and weather at that time.

3. Results

Figure 2 shows the vertical profiles of air temperature. The air temperatures were measured at the levels where the lengths of string (L) connecting the radiosonde and the fishing rod were 5, 10, 20, 40, 60, 80, 100, 140, 180, 220 and 260 meters. Wind direction shown by the side of each height was estimated from the direction in which a balloon streamed with the wind. And each figure shown by the wind direction means the angle (θ) between the string and the vertical axis. Higher value of the slope means a higher wind velocity. The height (H) of each measuring point was approximated by an equation:

$$H = L\cos\theta$$

It was impossible to obtain vertical data of the air temperature when a wind vane set on the roof of the ship showed a velocity higher than 3 m/s.

We showed only the cases in which the highest measuring level was above 150 m in Fig. 2. It was observed that the top of the temperature inversion existed in an almost constant range from 50 to 80 m in height. Here, we defined the level as the lowest one at which a negative gradient of air temperature with height appeared. When wind blew from the glacier terminus, the air temperature had a tendency to be low.

It was impossible to know the horizontal patterns of air temperature all over the lacustrine surface, because variation of air temperature with time was much larger than that of water temperature. Instead, the horizontal gradient of air temperature (°C/km) between the nearest two points with time was obtained, *i.e.*, the difference in air temperature observed between the nearest two points (ΔT) was divided by the distance between them (R). Temperature change with time was thought to be small between these two points, since the time interval was less than ten

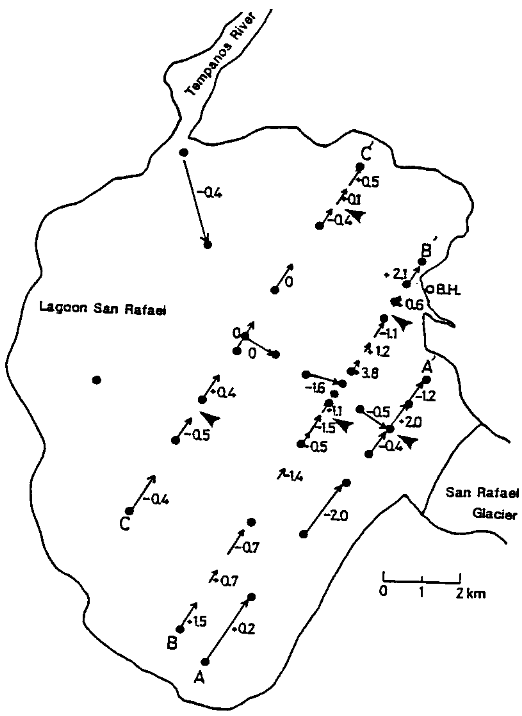

Fig. 3. Distribution of horizontal gradient of air temperature (°C/km) at a constant level (~1.5 m).

minutes. Figure 3 shows that ΔT was obtained by subtracting the temperature at the arrow tail from that at the head. The horizontal pattern of floating ice, which was taken from an airplane of LADECO (Linea Aerea Del Cobre) on 29 November 1985, is shown in Fig. 4. This pattern did not change very much during the present observation (24 to 27 Nov.).

No completely accurate value of R was obtained, since the locations of the observational points were identified from the surrounding landscape. However, it was found that zones with a large horizontal gradient of air temperature corresponded to the areas with high floating ice density. The thick arrows in Fig. 3 show the minimal air temperature sites which were found during the observation of air temperature along the lines A-A', B-B' and C-C'. One or two such sites existed around the center of the glacier terminus along the line A-A' and along both lines B-B' and C-C', respectively. The minimal air temperature, which appeared in the southern part of C-C', was not caused by the cooling effect of melting ice because this region is adjacent to the area where the water temperature is high (see Figs. 5a and 5b).

Figures 5a and 5b show the patterns of water temperature at 1 and 5 m in depth, respectively. The

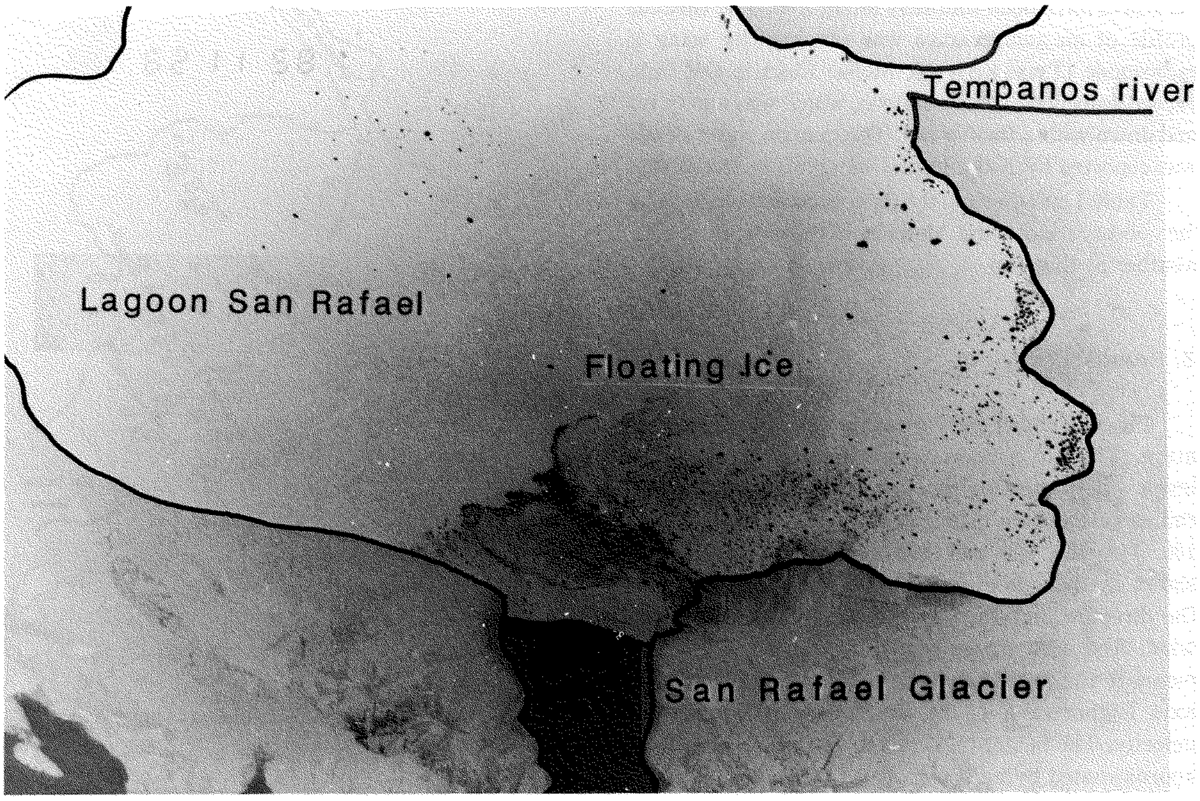

Fig. 4. A picture of Lagoon San rafael taken from an airplane of LADECO in 29 Nov. 1985.

patterns in both figures are similar to each other, *i.e.*, the water temperature is relatively low in the areas with floating ice. Melting water rushes out from the bottom of the glacier terminus, which leads to the formation of carved ice that is pushed offshore rapidly. Therefore, the floating ice area with a high number density is formed offshore rather than near the glacier terminus as seen in Fig. 4. As indicated in the patterns of floating ice depicted in Fig. 4 and in those of water temperature shown in Figs. 5a and 5b, the main flow line of floating ice exists along the line between the glacier terminus and the estuarine area of the Tempanos River. Among the pieces of floating ice observed in the area with high density, some of the small ones move easily and keep melting with the stream. Figure 3 depicts the minimal values of air temperature along the lines B-B' and C-C' existing in the flow line.

Figure 6 shows the horizontal pattern of differential water temperature in which values at 5 m in depth were subtracted from those at 1 m in depth. The shaded area in the figure is the region where water temperature at 1 m in depth is lower than that at 5 m. In this region melting ice has a greater cooling effect on the temperature of lacustrine surface water than the heating effect by both the overlying air and solar radiation. Comparing the two results in Figs. 3 and 6, the shaded area corresponds well with the region with high number density of floating ice and with the minimal air temperature. Further, a comparison between the two results in Figs. 5 and 6 indicates that the area also corresponds well with the area in which lowering of water temperature occurred. In the northern and southern corner of the lake, water temperature at 1 m in depth is especially higher than that at 5 m in depth. This is probably caused by the strong warming by warm air blowing in from the lakeside and/or by advection of warm water from the lakeside.

4. Concluding remarks

Air and water temperatures were measured horizontally and/or vertically during the period from 24 to 27 November 1985 at Lagoon San Rafael. Major findings are as follows :

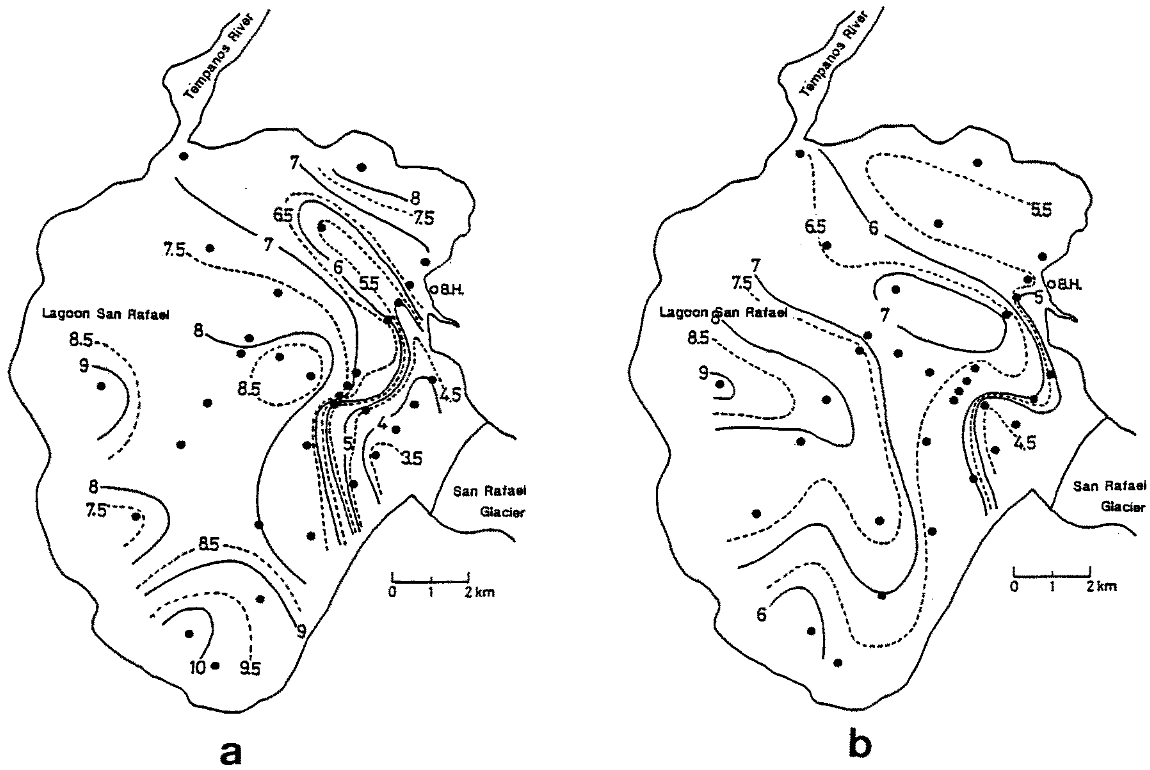

Fig. 5. Horizontal pattern of water temperature (°C) at 1 m (a) and 5 m (b) in depth.

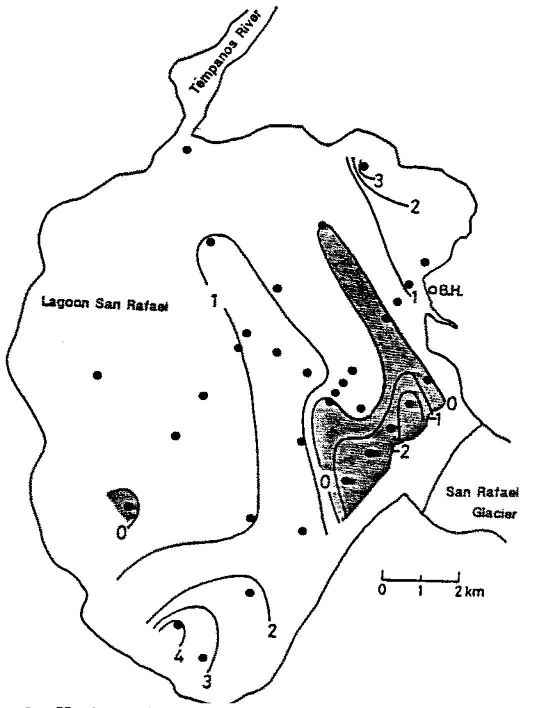

Fig. 6. Horizontal pattern of difference in water temperature (°C) between 1 and 5 m in depth. The region where water temperature at 1 m depth is lower than that at 5 m in depth is shaded.

Inversion of air temperature appeared in the layer below the level of 50 to 80 m. When wind blew from the glacier terminus, air temperature had a tendency to be low. Air temperature was low near and in the floating ice area. Horizontal gradient of air temperature was large within the area with high number density of floating ice. Water temperature decreased at both depths of 1 and 5 m along the flow line of floating ice. Minimal value of air temperature was also observed along this line.

Vertical profiles of air temperature were obtained only in daytime. In the evening, the mirage disappeared; therefore, the vertical and horizontal patterns of water and air temperature were expected to show daily variation. Wind speed and direction were closely related, especially to the vertical profile of air temperature. Further studies of the horizontal distribution of wind speed and direction will be undertaken in the future.

Acknowledgments

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Resumen

Enfriamiento del agua y del aire por encima debido al derretimiento de hielo en Laguna San Rafael, Patagonia

En días despejados con viento calmo desde Octubre a Noviembre de 1985 hemos observado a menudo espejismos en la Laguna San Rafael. Dicho fenómeno se debe a la formación de una capa de inversión térmica que es fuertemente enfriada por el contacto con hielo flotante y agua de derretimento sobre la Laguna. El objetivo de este trabajo es estudiar el efecto del enfriamiento del hielo flotante sobre la superficie lacustre y el aire por encima, tanto horizontal como verticalmente.

Se obtuvo un perfil vertical de la temperatura del aire (Fig. 2) por medio de una radiosonda suspendida a un globo cuya posición vertical se pudo variar con una caña de pescar. Se observó una inversión de temperatura del aire en la capa inferior al nivel de 50 a 80 m. Cuando el viento provenía del frente del glaciar la temperatura del aire era generalmente baja.

A medida que disminuyó la distancia hacia la superficie del hielo flotante la temperatura del aire disminuyó. Dentro de la zona con gran densidad de hielo flotante el gradiente horizontal de la temperatura del aire era elevado (Fig. 3). La temperatura del agua mostró valores bajos a profundidades de 1 y 5 m a lo largo de la línea de flujo de hielo flotante (Fig. 5), siendo menor la temperatura a 1 m (Fig. 6). Solamente a lo largo de esta línea de flujo el agua de derretimiento tiene un efecto térmico más importante que la radiación solar y el aire sobreyacente en la temperatura de la superficie de agua lacustre.