Report 15

Limnological observations at Lagoon San Rafael and Elefantes Fjord

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Abstract. San Rafael Glacier flows into Lagoon San Rafael (area: about 130 km², depth: 50–90 m) and this lagoon is connected to Elefantes Fjord through River Tempanos.

The vertical distributions of water temperature and salinity and the water transparency, and the air temperature, wind direction and speed were observed on November 25–26, 1983. Continuous observations of the surface water temperature and the salinity were also made, at the fixd point near the northern coast of the Lagoon on November 23–29. The water was also sampled to estimate the concentration of chemical substances in the same largoon and fjold.

The process of mixing of glacier-melt water and sea water is analyzed. The vertical stability of the air layer flowing from the glacier over the cold lagoon is discussed relating to the appearance of mirages over this lagoon.

1. Introduction

Glaciological studies must be done not only on the ice-surfaces but also on the neighboring area. The climate around a glacier affects the growth and the shrinking of the glacier, and on the other hand, the glacier influences the atmosphere and water near the glacier. San Rafael Glacier is a temperate glacier due to the warm climate in this area, so it supplies much ice and melt water to the terminal lagoon. On the other hand, the tidal amplitude of the sea neighboring this lagoon is large and much salt is supplied to this lagoon by tidal mixing. The large amount of floating ice due to calving of the glacier also influences the lagoon. The temperature of the air flowing from the glacier is another important factor.

As seen in Figure 1, Glacier San Rafael flows from east to west, and flows into Lagoon San Rafael. The area of this lagoon is about 130 km² and the water depth is 50–90 m. This lagoon is connected to Elefantes Fjord (width about 10 km) through River Tempanos (width about 500 m and length about 10 km).

At the same time as our meteorological and hydrological observations, fish and zooplankton were collected by Akira Zama and collaborators. This collection has been analyzed by Akira Zama and Kazumasa Hirakawa and the results are reported in Reports 16 and 17.

2. Method of observations and results

The vertical distributions of water temperature and salinity and the water transparency,

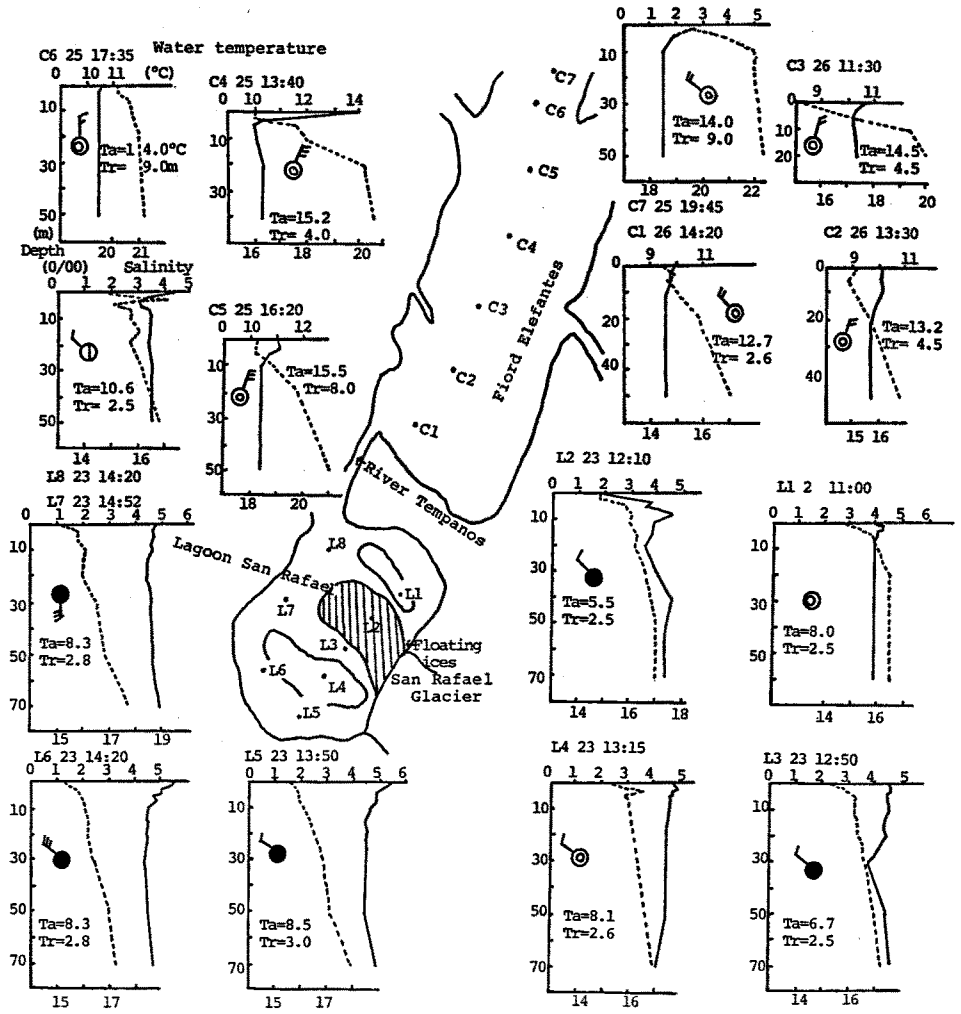

Fig. 1. Positions of stations L1–L8 in the lagoon and stations C1–C7 in fjord, and the dates of observations. Vertical distributions of water temperature (solid lines) and salinities (broken lines), and air temperatures (Ta), transparencies of water (Tr), wind speeds and directions and cloud amounts are also shown for each station. One barb showing wind speed corresponds to 1 m/s. Symbol ● shows rain and ◎ shows cloud amount of 80% or more.

and the air temperature, wind direction and speed were observed at 8 points in Lagoon San Rafael and 7 points along Elefantes Fjord on November 25–26, 1983. Also the surface water temperature and salinity were observed at a fixed point (point L1 in Fig. 1) near the northern coast of the lagoon on November 23–29. Sampling of the water (about 2 m under the water surface) at the same points was also done for chemical analysis.

Water temperature, salinity and transparency were lower in the lagoon (3.8–6.8°C, 14.3–18.8‰, 2.5–3.0 m) than in the fjord (9.6–11.9°C, 20.6–29.8‰, 2.5–9.0 m), due to the influence of cooling and dilution by melt water and supply of small sand particles from the glacier. Figure 1 shows the points of observation, vertical profiles of the water temperature and salinity, surface water temperature (Ta), transparency (Tr), wind direction and velocity

and cloud amount. Figure 2 shows a time-depth cross section of lake temperature and salinity at the fixed station (L1). In this figure, the variability of temperature and salinity can be seen. For example, high-salinity water (>18‰) penetrated into the layer below 10 m depth at Station L1 on November 25.

The surface salinity was about 14‰ on November 23–25 and then increased to 17‰ on November 29. The surface water temperature was about 5°C on November 23–25, increased to 7°C and decreased to 5°C again on November 29.

In spite of these variations, the general features in this lagoon can be described using Figure 1. In the area with much floating ice (such as station L2), water surface temperature is very low (1–2°C) with low salinity due to the ice melting, whereas it is about 8–9°C in the area without floating ices. However, in the deep water, the temperature (3.5–5°C) and salinity (16–17‰) are relatively uniform in the lagoon even under floating ice.

On the other hand, the vertical distribution of salinity along the fjord indicates that large gradients existed vertically at Station C3 and horizontally from Station C2 to Station C3 on November 25–26, as seen in Figure 3. From this profile, it is noted that low-salinity water

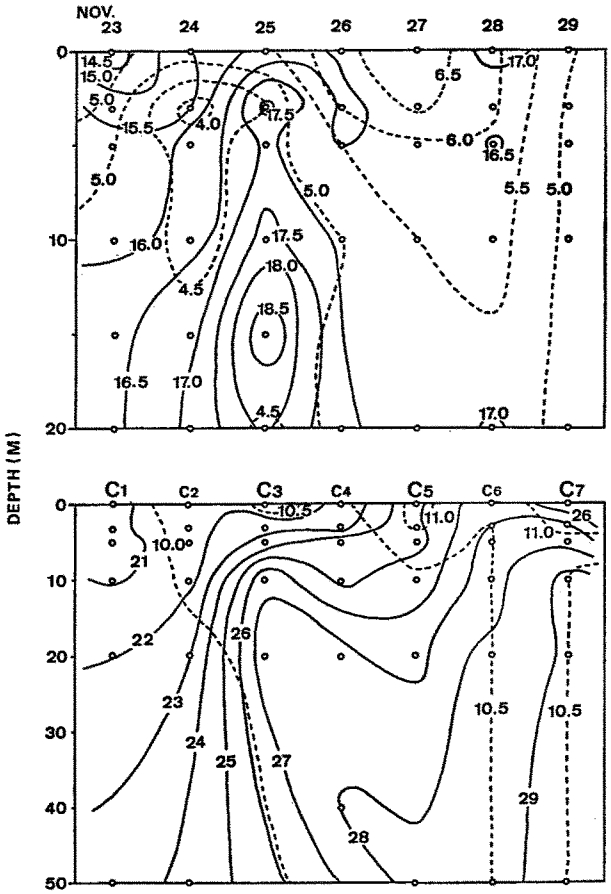

Fig. 2 (upper). Isopleths of water temperature (broken line: °C) and salinity (solid line: ‰) at Station L1 in Lagoon san Rafael during November 23–29, 1983.
Fig. 3 (lower). Vertical distribution of temperature and salinity in Elefantes Fjord on November 25–26, 1983.

extended to the upper layer of Stations C2 to C3, and formed therein the front through contacting high-salinity water extending upward from the deep layer. The renewal of the surface layer of lagoon water appears to be largely dependent on a tidal cycle which controls the inflow and outflow of fjord water through the narrow channel.

Observation of the amount of flow through the River Tempanos was tried. The width of the river is about 500 m and the mean depth is 30 m near the lagoon. The observation was made on November 25. At 16 h 50 min (about 2 hours after the lowest tide), current veloci-

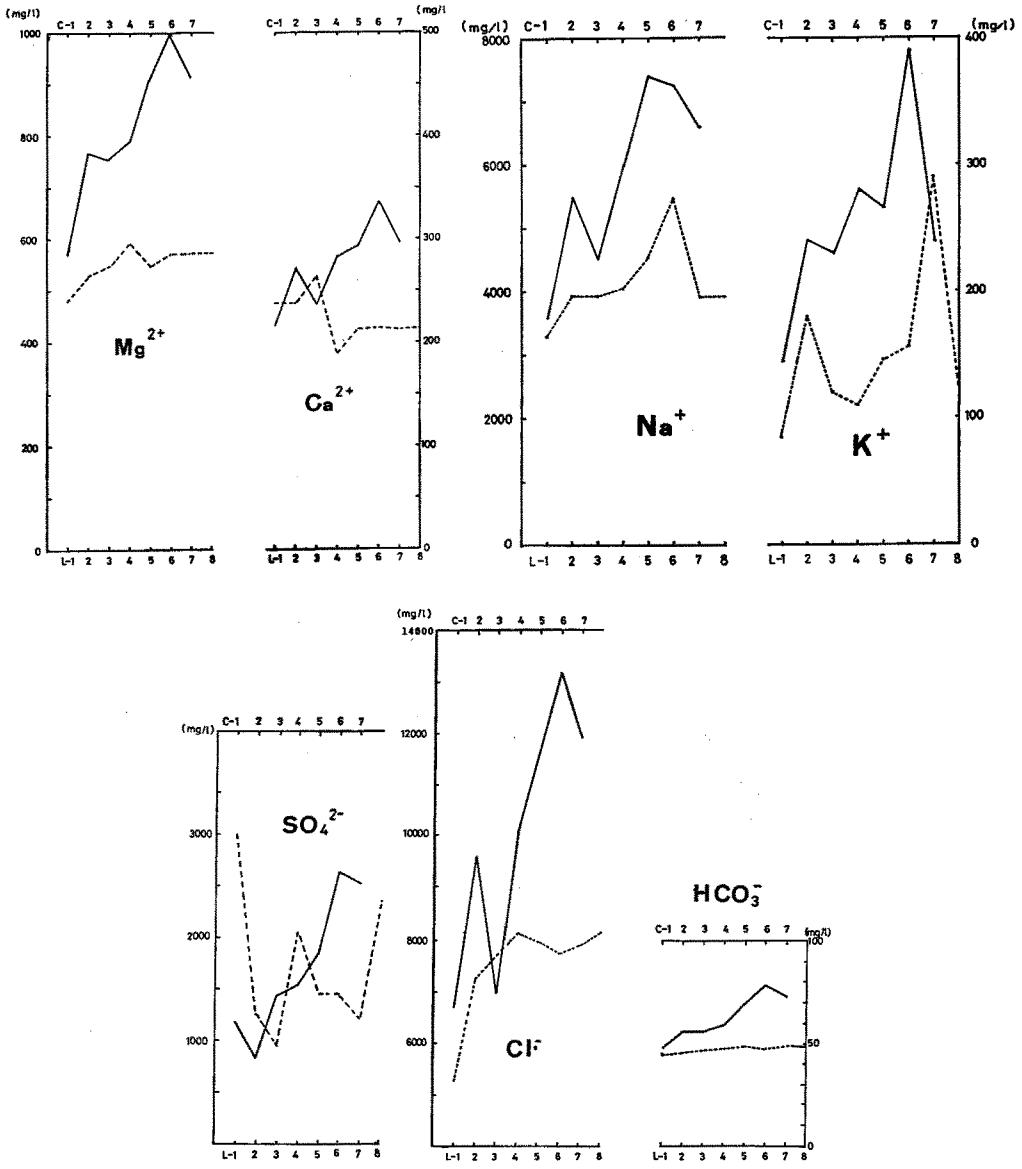

Fig. 4. Distribution of the values of the concentration of chemical substances at 8 points in Lagoon San Rafael (broken lines) and at 7 points in Elefantes Fjord (solid lines).

ties were 1.15 m/s (surface), 0.7 m/s (1 m depth) and 0.5 m/s (2–4 m depth) near the eastern coast. The river current was irregular and high speed. However, the observations in the middle and near the western coast of the river were impossible due to danger from floating ice and due to irregularity relating to large eddies.

We also collected water samples to find the concentration of chemical substances (Na^+, K^+, Ca^{2+}, Mg^{2+}, soluble-SiO_2, Cl^-, HCO_3^-, SO_4^{2-}, NO_2^--N, NO_3^--N). The results (Fig. 4) show the effect of mixing of sea water and glacier melt water. All of the chemical substances increased in concentration from the terminus of the glacier to the open sea.

The air temperature over the lake was 5.5°C at 12 h 10 min on November 23 at station L2 among the floating ice and 8.0°C (11 h 00 min, St. L1), 6.7°C (12h 50 min, St. L3), 8.1°C (13 h 15 min, St. L4), 8.5°C (13 h 50 min, St. L5), 8.3°C (14 h 20 min, St. L6), 8.3°C (14 h 52 min, St. L7), and 10.6°C (15 h 20 min, St. L8). These values were about 5°C higher than the surface water temperature. The wind speed in the layer near the cold surface water was 1–3 m/s and the wind direction was mainly north-westerly as seen in Figure 1.

3. Discussion

In late November, 1983, cyclones often appeared near this area and the weather was mostly rainy. So, the present data in the lagoon and fjord can be assumed as normal for this season. Figure 5 shows an IR image of Lagoon San Rafael and Elefantes Fjord. From this photograph, we can see the areas with floating ice from the glaciers not only in the lagoon but also in the fjord. By the melting of this ice, the temperature and salinity of the water near the floating ice will decrease. The distribution of floating ice will also change according to the wind over the water surface. Then, the distribution of temperature and salinity of the surface water may also be variable according to the weather conditions and tidal phase.

The area of the lake is about 130 km^2 and the mean depth is about 70 m, so the total water

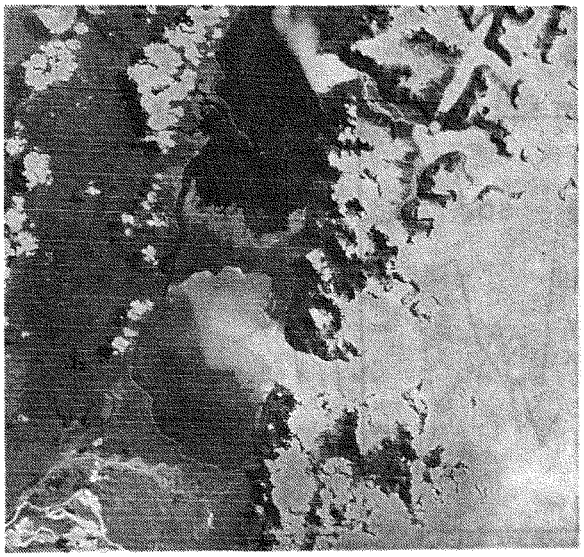

Fig. 5. Infra-red images of the area surrounding Lagoon San Rafael by LANDSAT on January 22, 1979.

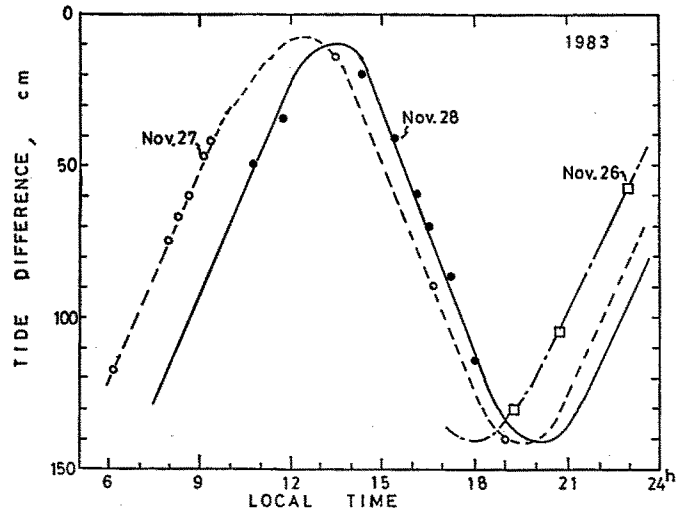

Fig. 6. Tidal oscillation observed at the northern coast of Lagoon San Rafael on November 26–28, 1983.

mass of the lagoon is estimated to be about 1×10^{10} tons. The cross sectional area of San Rafael Glacier at terminus is about 3000 m × 100 m = $3 \times 10^5 m^2$, and the mean velocity of the glacier movement is about 10 m/day. If we suppose that the amount of water mass draining through the glacier is about the same as the amount of discharging ice mass, the supply of water from the glacier to the lagoon can be estimated to be roughly 6×10^6 ton/day. The amplitude of the tide on November 26–28 in this lagoon was about 1.3 m as seen in Figure 6, so the mass transport through River Tempanos in 12 hours was estimated as 1.3 m × 130 $km^2 = 2 \times 10^8 m^3$. This is much larger than the water supply from the glacier. However, the net supply of salinity due to the tidal mixing is difficult to estimate.

We sometimes saw mirages over the water surface of Lagoon San Rafael. The complicated vertical temperature distribution in the lowest atmospheric layer will be established between the warmer air (10–15°C) and the air just above the cold water (5–8°C). This vertical temperature gradient may be the cause of the mirage.

Resumen. Observaciones limnológicas en la Laguna San Rafael y el Fiordo Elefantes

El Glaciar San Rafael descarga hacia la Laguna San Rafael (área cercana a 130 km^2 y profundidad de 50 a 90 m), estando unida esta última con el Fiordo Elefantes (de un ancho aproximado de 10 km) a través del Río Témpanos (ancho cercano a 500 m y unos 10 km de largo).

Se observó la distribución vertical de la temperatura del agua, la salinidad y transparencia del agua, temperatura del aire, dirección y velocidad del viento en Noviembre 25 y 26 de 1983. Se hizo también una observación contínua de la temperatura del agua en superficie y la salinidad en un punto fijo cercano a la costa norte de la laguna desde el 23 al 29 de Noviembre.

A fines de Noviembre de 1983 aparecieron con frecuencia ciclones cerca de esta área y la condición del tiempo era principalmente lluviosa. Los resultados de observaciones contínuas

en el punto fijo muestran que la salinidad del día 23 al 25 era cercana al $14^0/_{00}$ y luego aumentó al $17^0/_{00}$ el 29 de Noviembre. La temperatura en superficie fue cercana a 4 °C desde el día 23 al 25, aumentó a 7°C y bajó a 6°C el día 29.

La temperatura del aire de la corriente catabática en el Glaciar San Rafael (SE, 2–4 m/s) fue alrededor de 10°C y era más cálida que la temperatura del agua en superficie (cercana a 5.5°C), por lo tanto soplaba sobre la capa de aire frío debido a su flotabilidad. La velocidad del viento en la capa fría cerca de la superficie fue del NW, 1–3 m/s, que es en sentido opuesto al viento catabático.

La temperatura del agua en superficie fue de 1–2°C en la zona con témpanos flotantes, mientras que era cercana a 8–9°C en la zona sin témpanos flotantes. Si la distribución de los témpanos flotantes cambia, entonces la distribución de temperatura del aire y del agua también cambia. La distribución vertical de la temperatura del agua era prácticamente uniforme, con un valor de 3,5–5°C incluso bajo los témpanos flotantes.

En el Fiordo Elefantes, al norte de la laguna, la temperatura del agua en superficie y la del aire aumentaron en la parte norte, siendo la del agua cercana a 10°C y la del aire cercana a 15°C en un punto a unos 20 km al norte del extremo sur del fiordo.

La salinidad en la Laguna San Rafael fue de $17–18^0/_{00}$ en la capa más profunda y cerca de $15–16^0/_{00}$ en la capa superficial. En el Fiordo Elefantes, la salinidad en superficie cambiaba de acuerdo a la descarga de pequenõs cursos de agua en ambos márgenes, pero la salinidad en capas profundas fue mayor en el sector norte, y alcanzó cerca de un $20^0/_{00}$ en un punto situado a 20 km del extremo sur. La transparencia fue de 2–3 m en la Laguna San Rafael y cerca de 4–9 m en el Fiordo Elefantes.

El área de la laguna es cercana a 130 km^2 y la profundidad media es de unos 70 m, por lo tanto la masa total de agua en la laguna se estima cercana a 1×10^{10} ton. El área transversal del Glaciar San Rafael es alrededor de $3.000\ m \times 100\ m = 3 \times 10^5 m^2$, y la velocidad media del movimiento del glaciar es cercana a 10 m/d. Si suponemos que la cantidad de masa de agua que se descarga a través del glaciar es aproximadamente igual a la cantidad de hielo que fluye, el aporte de agua desde el glaciar hacia la Laguna puede ser estimada a grosso modo como igual a 6×10^6 ton/d. La amplitud de la marea a fines de Noviembre fue cercana a 1,3 m; entonces la masa de agua que fluye por el Río Témpanos en 12 h fue estimada como $1{,}3\ m \times 130\ km^2 = 2 \times 10^8 m^3$. Esto es mucho mayor que el aporte de agua del glaciar.

El ancho del Río Témpanos cerca de la laguna es cercano a 50 m, con una profundidad media de unos 30 m. La dirección y velocidad del flujo de agua en este lugar era variable, pero la velocidad media fue aproximadamente igual a 0,5–1,0 m/s.

Se observó también la concentracíon de sustancias químicas (%) en el agua. El fenómeno óptico que aparecía sobre los témpanos flotantes en la laguna como producto de perfiles verticales complicados de temperatura sobre la superficie de agua también fue observado.