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Annual course of superficial water temperature in the Ezcurra Inlet, King George Island, Antarctica

ABSTRACT: Temperature of superficial water in the Ezcurra Inlet was measured from March 1989 to February 1990, with a use of a mercurial thermometer with accuracy ±0.1°C. Temperature was measured usually once a month at selected points. Influence of various factors on temperature of superficial water was preliminarily analysed. Basing on these results, temperature distribution in the mentioned area was determined. Mean yearly temperatures for each station, average space temperatures on measurement days and mean yearly temperatures for the whole area of the Ezcurra Inlet were calculated.

Key words: Antarctica, South Shetland Islands, sea water temperature.

Introduction

Temperature is a main parameter of sea water and it is especially important in the case of a superficial layer. It depends on energy and mass exchange between sea and air (Garbalewski 1982, Dera 1983) and on other physical factors as heat advection caused by currents — including vertical mass mixing, turbulent mixing, *etc.* Precipitation influences temperature in a superficial layer of a sea. Rain warms water but hail and snow cool it. In a superficial layer of a sea, chemical and biological reactions proceed. Such internal factors also influence water temperature (Roll 1965).

Interaction between a sea surface and the air depends on radiation balance. The latter includes direct solar, sky, as well as reflected and effective sea surface radiation. Short wave radiation is absorbed in a superficial layer. If air temperature is lower than water temperature, a radiation stream flows upwards and in the opposite case — downwards. Exchange of radiation energy may create

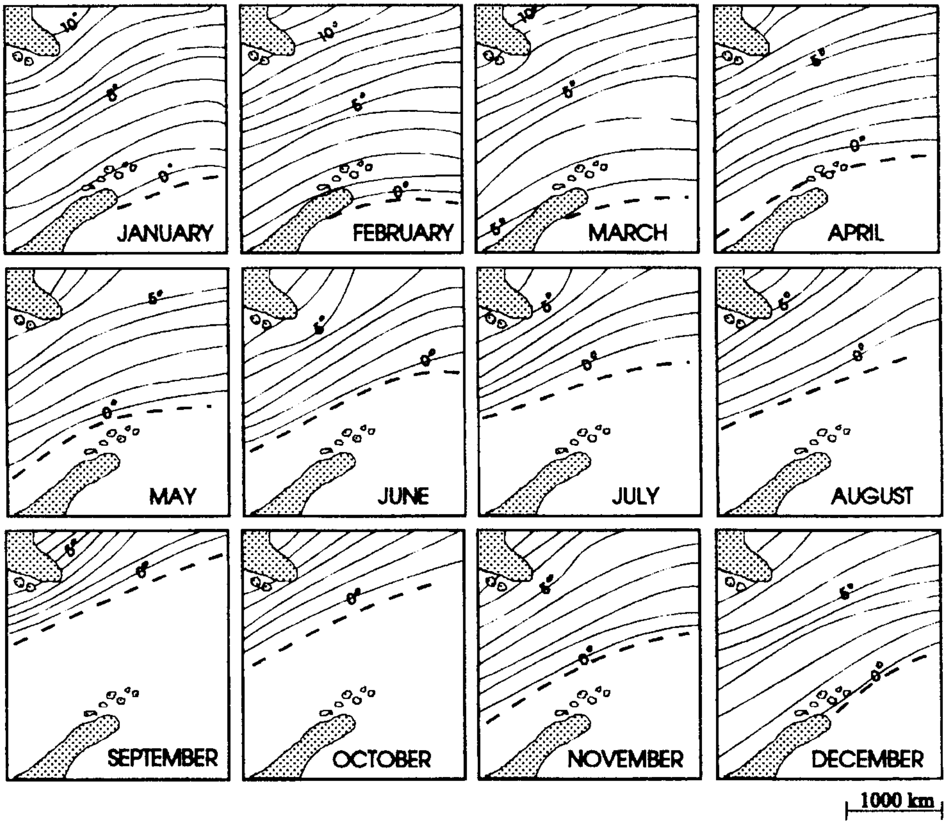

Fig. 1. Superficial water temperature in the Drake Passage and the Bransfield Strait in every month; marked is maximum extent of an ice field.

unstable vertical stratification which creates convection (Roll 1965). Heat exchange between a sea and the air occurs during evaporation, condensation and freezing of water (Roll 1965, Perry and Walker 1982, Monin and Krasickij 1985, Drihaut 1994).

Temperature at sea surface depends also on dynamic phenomena as currents, waves, tides, *etc.* Except for wind, air humidity and convection, many other factors influence also the temperature (Roll 1965, Monin and Krasickij 1985).

The paper presents results of measurements of superficial water temperature, collected from March 1989 to February 1990 in the Ezcurra Inlet.

Measurement area and methodology

The King George Island belongs to the South Shetland Islands. This archipelago is separated from the Antarctic Peninsula by the Bransfield Strait and from

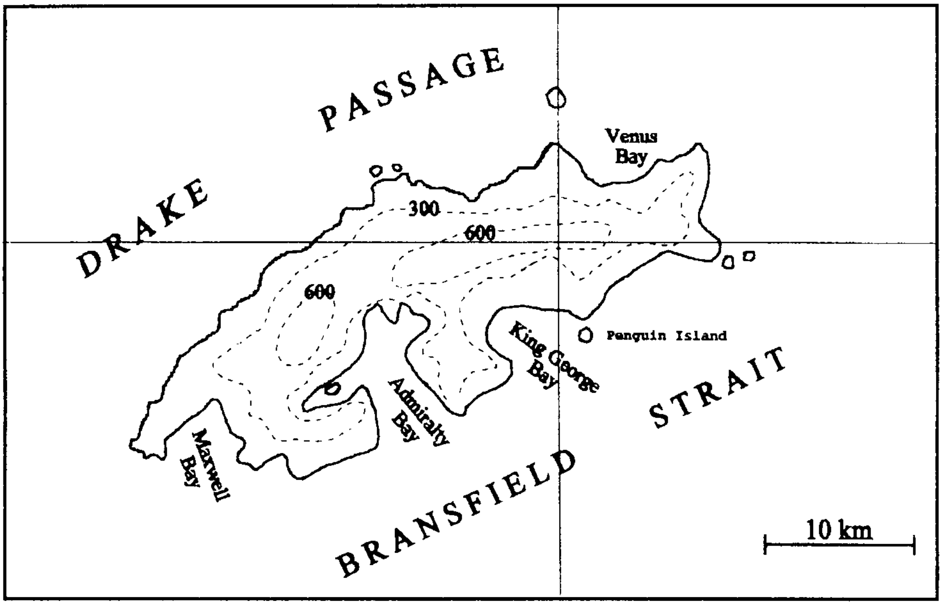

Fig. 2. King George Island.

South America by the Drake Passage (Dietrich and Ulrich 1968). A strong current of the West Wind Drift, which is an important temperature-creative factor in this area, flows through both straits. Water temperature in both straits varies from 1–2°C in January to below 0°C in April. From May to November, a sea around the South Shetland Islands is covered by ice. Extent of ice during every month is presented (Fig. 1). Mean of several-years air temperature in this area varies from 1°C in January to -12°C in July. Average yearly precipitation equals to 568 mm at the Deception Island, and 817–819 mm in a middle part of the Drake Passage. Precipitation at the South Shetland Islands exceeds 30 mm each month (Atlas okeanov 1977, Rakusa-Suszczewski and Kwarecki 1987).

Temperature of a superficial water in the Drake Passage and the Bransfield Strait is not much different during successive months (Fig. 1). The West Wind Drift which transports 55–75 × 10^6 m^3/s of water, influences significantly the temperature of a coastal water near the South Shetland Islands. This current decreases water temperature in spring and increases it in autumn. Ice cover and sea temperature depend on inflow of solar energy.

Temperature was measured in the presented area (Fig. 2), *e.g.* in the Admiralty Bay and along the coast of the Bransfield Strait. Water in the Admiralty Bay was examined gradually as it is a vast area. Temperature of the whole Ezcurra Inlet was examined during a day. This area was examined on March 2 and 29, May 23, July 25, September 30, November 7 and 28, December 15 in 1989 and on January 6, 18 and 26 in 1990. Because of ice cover, no investigation

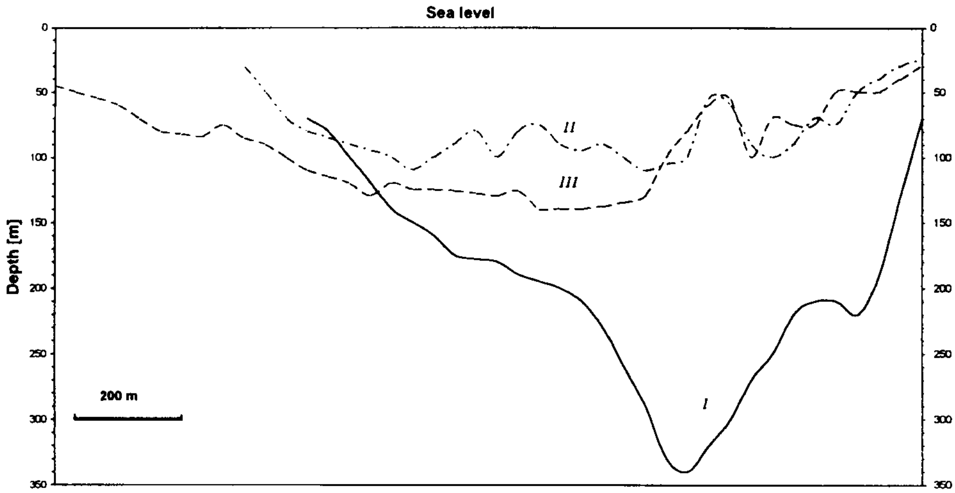

Fig. 3. Ezcurra Inlet; marked are profiles I–III.

was done in April, June and August. Such measurement was performed more systematically, if the weather was favourable and no ice cover occurred.

Temperature was measured with a mercurial thermometer of ±0.1°C accuracy. Water samples were collected at the measurement stations (*cf.* Fig. 3), from a superficial layer to 0.5 m depth with a use of a plastic container, hanging on a rope (Gurgul, Stochmal and Szymczak 1994).

Factors influencing temperature of superficial water

The Ezcurra Inlet is a southwestern branch of the Admiralty Bay. It is a deep, concave form, sea bottom of which has a diversified topography. Water circulation in the fiord and its exchange between the fiord and the Admiralty Bay is dependent on its topography.

There is a water exchange between the Bransfield Strait and the Admiralty Bay, and between the Admiralty Bay and the Ezcurra Inlet during the whole year. Inflow of water from the Bransfield Strait is possible at southeastern, southern and southwestern winds. Water from the strait cools water in the bay in spring and warms it in autumn. When winds from the above-mentioned directions occur, icebergs and ice fields flow in. Melting of ice cools water in the bay. This phenomenon was observed in April 1989. A few to several dozen of icebergs flowed each day into the bay. At northwestern, northern and western winds, water and icebergs flew out from the bay to the Bransfield Strait.

Exchange of water between the Bransfield Strait and the Admiralty Bay is also influenced by tides. The most intensive exchange is caused by syzygy tides.

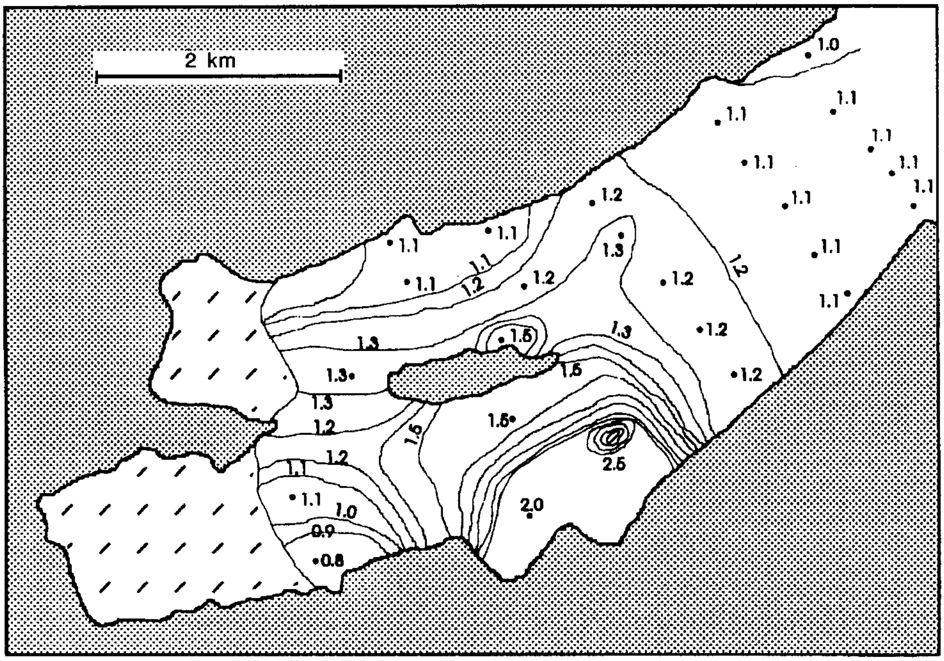

Fig. 4. Profiles of a bottom of the Ezcurra Inlet, along which samples of water were collected.

Their heights as well as the ones of neap tides in the Admiralty Bay in February 1978 and in January 1979 (Catewicz and Kowalik 1984, Rakusa-Suszczewski 1992) were equal to:

$2(M_2 + S_2) = 1.58$ m, $2(M_2 + S_2) = 1.42$ m,

$2(K_1 + O_1) = 1.23$ m, $2(K_1 + O_1) = 1.30$ m,

accordingly.

Maximum difference between sea levels was equal to 2 m in February 1978. Tides influence water mixing in a coastal zone. It results in almost stabile water temperature in the upper sea layer (to several metres depth).

Water flowing into the Admiralty Bay, branches out into two parts. One of them flows northwards and the other — westwards (Ezcurra Inlet). Shape of the fiord bottom influences water discharge and its inflow to the fiord. Relief of a sea bottom was determined along the profiles with an echo sounder of the cutter *Słoń Morski* (Figs 3–4). The profile I was located along the line A–E (Fig. 3). In a southern part of the bay, its bottom goes down very quickly, thus creating a narrow shelf at depth of 180–190 m. Farther on, the bottom still drops down to a depth of 320–330 m (at about one third of the fiord width). From this point, the bottom goes up towards the northern shore. The profile II (along the line F–J) is slightly waving. A deepest part of the fiord along this profile equals to about 130 m. The profile III extends along the line K–O. In the northern part of the fiord, the bottom goes down slowly to a depth of 130–140 m, but it is waving at a southern shore. Different depths in this part of the fiord are equal to 90 m. Such bottom shape influences significantly water circulation in the Ezcurra Inlet and all the same, a temperature field in the region.

The most intensive exchange between the Bransfield Strait and the Admiralty Bay occurs at winds from SE, S, SW (inflow) and NW, N and NE (outflow). Frequencies of winds from these directions are equal to 9.1%, 6.3%, 27.7% and 12.9%, 9.8%, 5.2% respectively (Rakusa-Suszczewski 1992). Most frequent winds come from the south, influence water circulation and water temperature in the Bransfield Strait. Temperature of superficial water in the Ezcurra Inlet depends on wind direction and velocity. The warmest winds come from the northwest and north, and the coolest from the east and southeast (Styszyńska 1990). Wind velocity influences the rate of evaporation and rending of water droplets from crests of waves. These processes decrease temperature of a superficial layer. In summer, winds from the southwest, west and northwest are the most frequent. Their average velocity varies from 6.2 to 11.2 m/s (Newton 1972, Dubov 1974, Philips 1977, Garbalewski 1982).

Air temperature plays an important role in thermodynamic processes at sea--air boundary. Heat exchange between the above-mentioned media can be determined on the basis of measurements of air temperature at the *Arctowski's* Station in 1978–87 (Kowalik and Wielbińska 1989, Rakusa-Suszczewski 1992). Very cold winters occurred in this area, *e.g.* in 1986, when the Admiralty Bay was covered by sea ice for 5 months and ice was as much as 3 m thick. The winter 1989 was the mildest one — the Admiralty Bay was covered by sea ice during a short period only and investigations could be continued.

Solar radiation reaches a southern shore of the Ezcurra Inlet. Therefore, this shore was snow- and ice-free from January to April 1989 and from November 1989 to February 1990 (Fig. 3). A southern shore of the fiord is steep from the Point Thomas to the Herve Cove. Similar situation occurs in the whole southwestern part of the fiord. Shores inclined at 60–90° receive solar radiation and are warmed. They radiate and make water in the fiord warmer. Small bays, *e.g.* the Herve Cove or the Mansimet Cove create niches, where complex thermal processes are due to repeatedly reflected light. The Dera Icefall and the Rosciszewski Icefall reflect solar radiation towards the shores of the bay. Rising air temperature makes glacier melt- and freshwater streams flow out from under the glaciers. Fresh- and seawater mix turbulently at mouths of streams and intensive thermal processes occur there. Thermal processes near a northern shore of the fiord are completely different. These shores are covered by glaciers (Emerald Icefall), which collapse to the fiord from the altitude of 400–500 m (Birkenmajer 1987). These shores are rarely insolated during the Antarctic summer. Different insolation of shores results in varying temperatures of land and water. During summer, glaciers are rended on the northern shore and icefields are common there.

Except for molecular processes, biochemical and other ones influence temperature of superficial water.

Temperature changes of superficial water

Measurements of temperature of superficial water in the Excurra Inlet started on March 2, 1989. There were no clouds in the sky in the morning. During the day, a cloud cover increased to overcast. Wind was light. Water temperature was over 0°C all over the Ezcurra Inlet (Fig. 5). The lowest temperature was noted in the western part of the fiord and was equal to 0.9°C. The Golden Cave Bay and the Cardozo Cave Bay were covered by ice. The temperature varied from 1.0°C to 1.3°C over most of the area. It was higher between the Dufayel Island and the southern shore only, and equal to 1.5–2.5°C.

Temperature of superficial water decreased until March 29, particularly in the western part of the fiord. It was due to glacier impact (Fig. 6). In this part of the fiord, water temperature varied from 0.8 to 1.5°C. There were abundant rainfalls in March. Glacial and rainwater entered the fiord. It influenced significantly temperature of superficial water. Temperature in the middle and eastern part of the fiord remained almost unchanged or increased at 0.1–0.2°C.

In April, the air cooled down rapidly — there were ten odd degrees below 0°C. Simultaneously icebergs flew into the Admiralty Bay at winds from southeast and south, and filled a considerable part of the bay. Melting of ice decreased water temperature in the fiord.

There was a big wind-storm, velocity of which reached 15–23 m/s on May 22. It mixed a superficial water. Winds from northern directions pushed out icebergs from the bay and brought warmer and humid air. Water temperature decreased from the Bransfield Strait inwards the bay. It was equal from -0.2 to -0.3°C in the Bransfield Strait, -0.4°C at the Demay Point (bay mouth) and from -0.4 to -0.5°C in a middle part of the bay and in the Ezcurra Inlet (Fig. 7).

In June the air cooled down. It snowed and the Admiralty Bay was frozen. The air temperature rised at the beginning of July. Winds from northern directions removed an icefield from the bay. Studies of water temperature in the Admiralty Bay and the Ezcurra Inlet were started on July 25, 1989. The temperature varied from -0.8°C to -0.9°C (Fig. 8), and the highest water temperature was noted near the southern shore.

At the end of September, water temperature in the fiord slightly increased (Fig. 9). It was due to inflow of solar energy and winds from the north. Temperature of the whole superficial water in the fiord varied from -0.7°C to -0.9°C. The highest one was noted at the southern shore and decreased towards the northern shore.

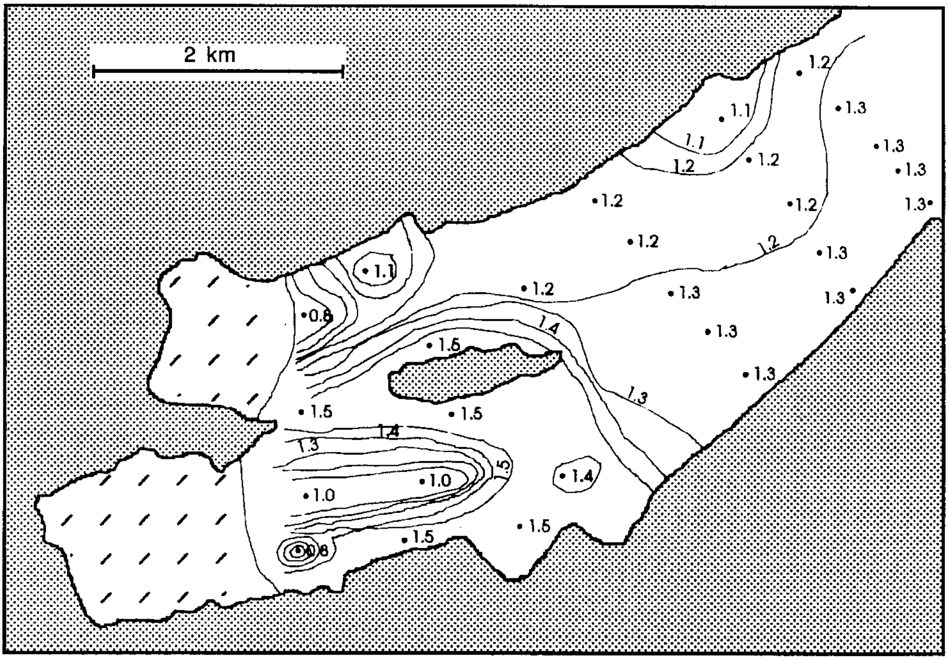

Fig. 5. Temperature of superficial water in the Ezcurra Inlet on March 2, 1989.

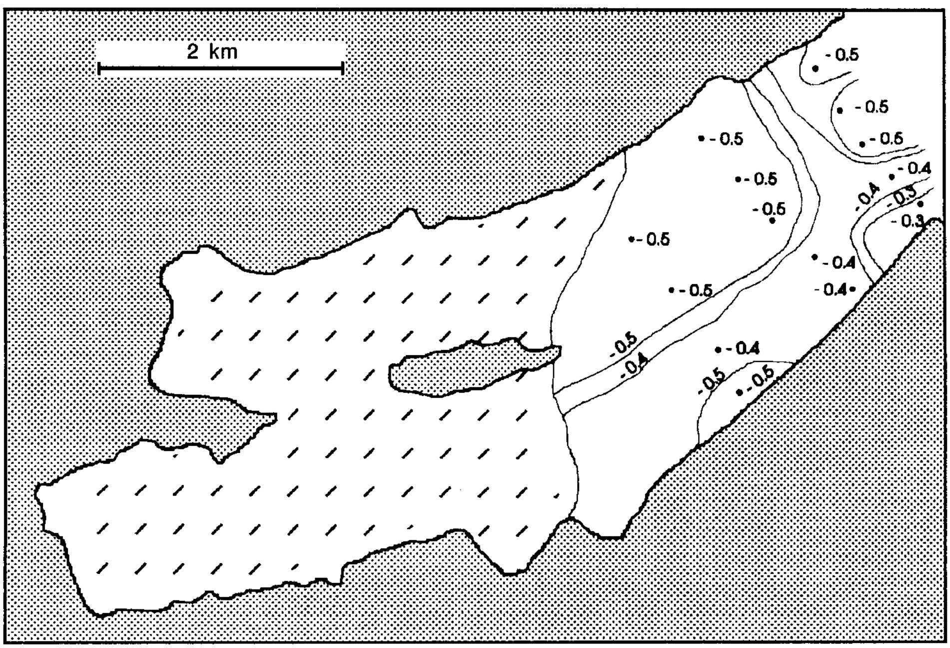

Fig. 6. Temperature of superficial water in the Ezcurra Inlet on March 29, 1989.

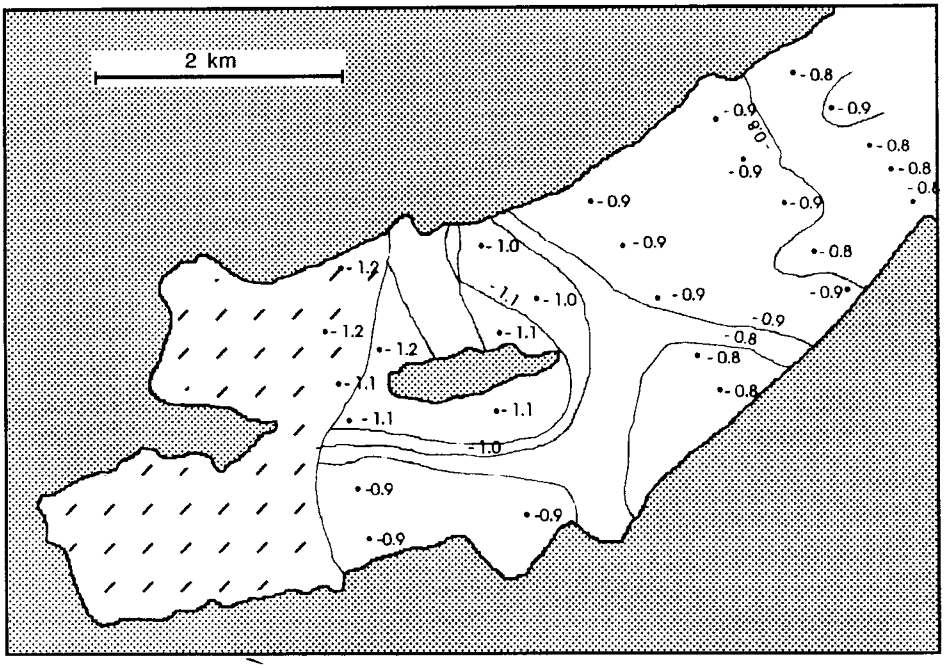

Fig. 7. Temperature of superficial water in the Ezcurra Inlet on May 23, 1989.

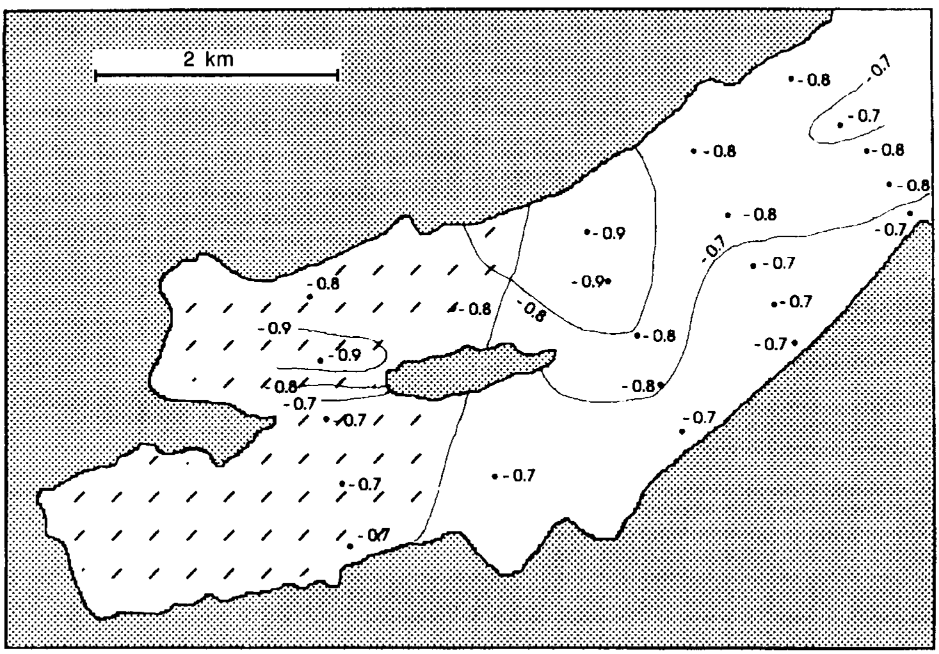

Fig. 8. Temperature of superficial water in the Ezcurra Inlet on July 25, 1989.

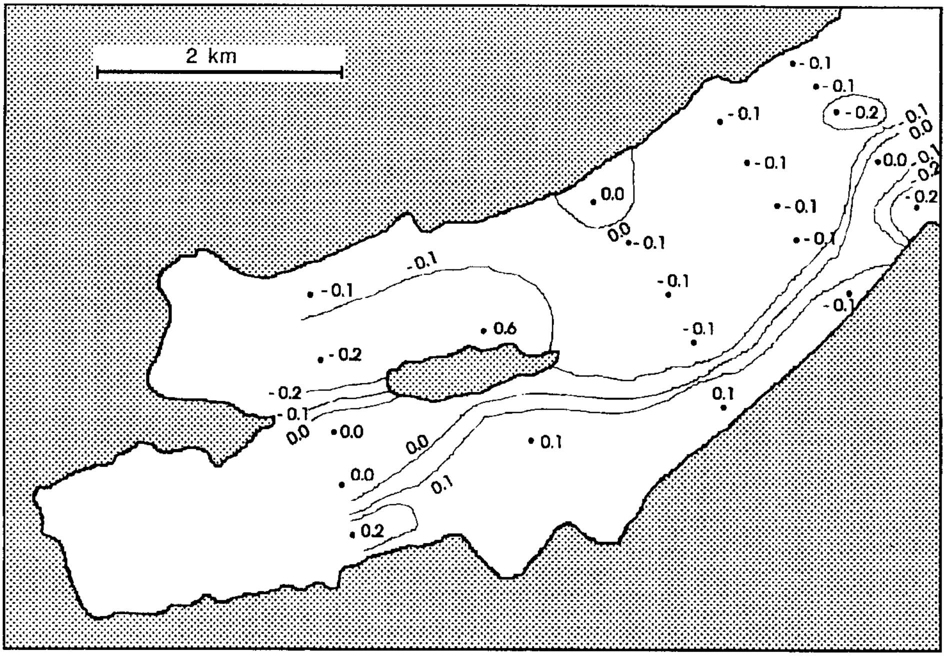

Fig. 9. Temperature of superficial water in the Ezcurra Inlet on September 30, 1989.

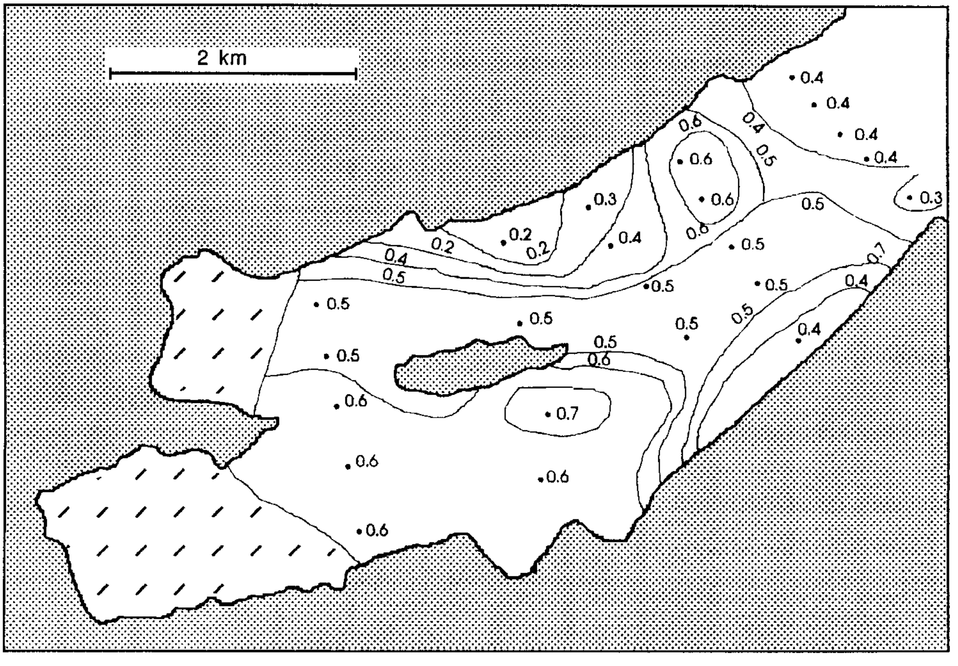

Fig. 10. Temperature of superficial water in the Ezcurra Inlet on November 7, 1989.

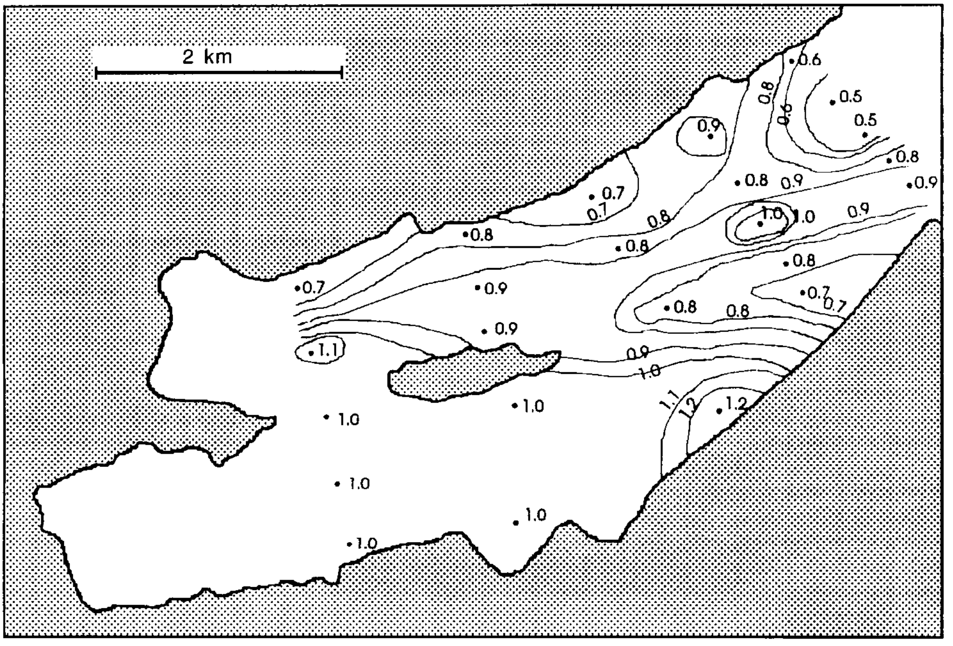

Fig. 11. Temperature of superficial water in the Ezcurra Inlet on November 28, 1989.

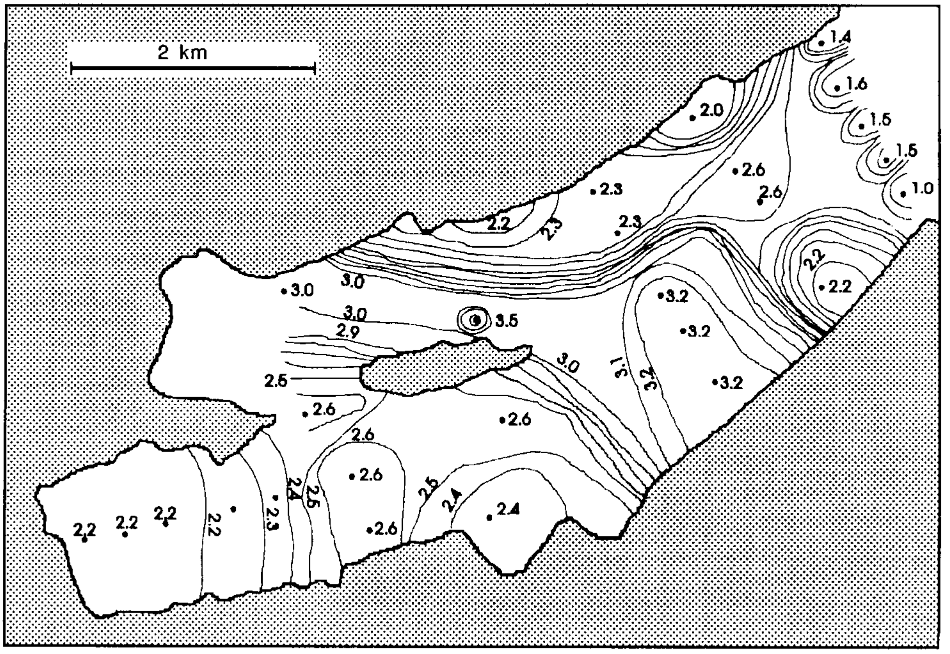

Fig. 12. Temperature of superficial water in the Ezcurra Inlet on December 15, 1989.

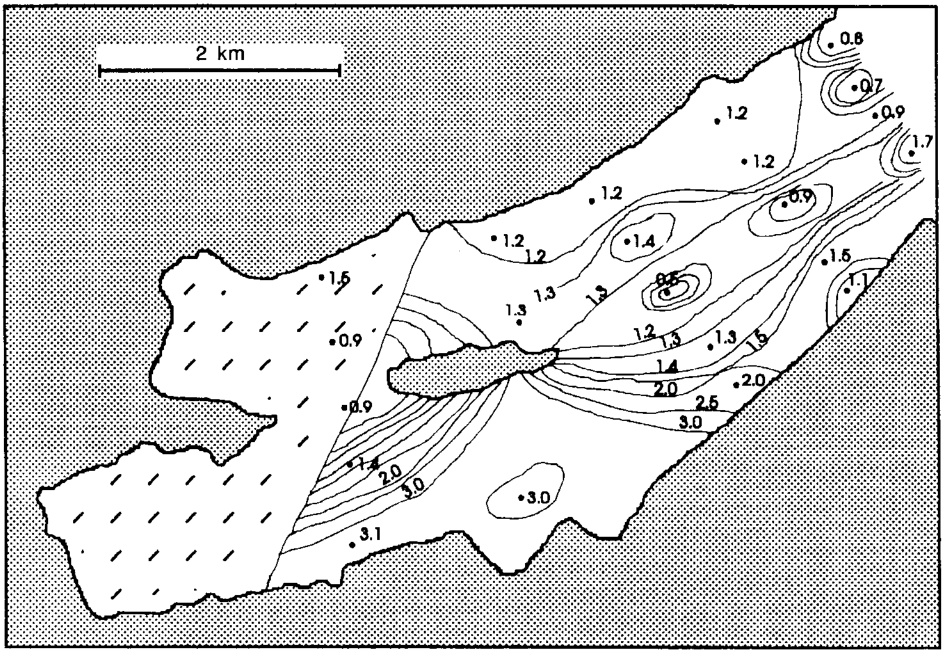

Fig. 13. Temperature of superficial water in the Ezcurra Inlet on January 6, 1990.

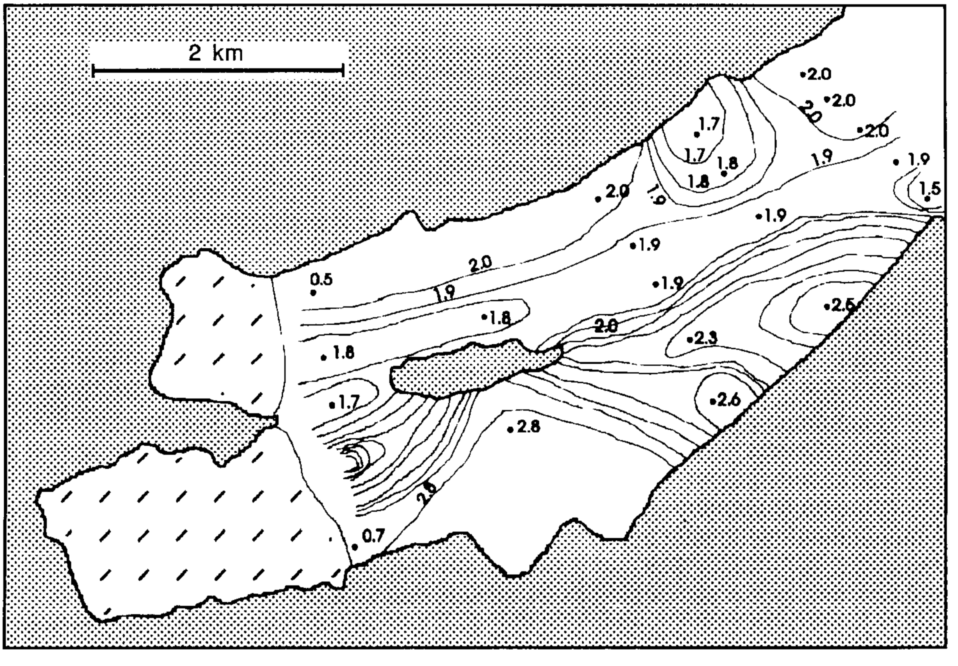

Fig. 14. Temperature of superficial water in the Ezcurra Inlet on January 18, 1990.

During the first 10 days of October, a lot of ice-pack and icebergs were transported into the bay by winds from southern directions. Most of the Admiralty Bay was covered by sea ice. At the end of October, some ice was removed from the bay. Solar radiation increased temperature of superficial water (Fig. 10). The lowest temperature occurred at mouth of the fiord and in its western part. Mixing of water was noted at the fiord mouth, therefore temperature varied from 0°C to -0.2°C. Change in temperature from -0.2°C to 0.2°C was due to ice melting in the western part of the fiord and therefore, superficial water between the Dufayel Island and the southern shore of the fiord got warmer. Temperature of superficial water in other parts of the fiord was equal to -0.1°C.

Several sunny days in November resulted in rise of temperature of superficial water. There was overcast and showers on November 28 (Fig. 11). The wind was week. Water temperature in the whole Ezcurra Inlet was over 0°C. The lowest temperature was noted near a northern shore and the highest one between the Dufayel Island and a southern shore of the fiord.

Further rise of temperature of superficial water occurred at the beginning of December. Measurements were carried out on December 15. It was a cloudy day without wind. The lowest temperature (0.5°C) was noted at the fiord mouth (Fig. 12). It was due to inflow of water from the Bransfield Strait. The temperature increased towards the western part of the fiord and reached 1.1°C at the Dufayel Island. The highest temperature occurred near a southern shore, at the Italian Village.

There was overcast and no wind on January 6, 1990. The temperature increased significantly (Fig. 13). Numerous glaciers broke out. Pieces of ice rended from glaciers, drifted southeasterly, creating a streaky icefield. The lowest water temperature was measured at the fiord mouth (1.6°C). The temperature was below 2°C in places where ice melted at northern and western shores. The highest temperature of superficial water (3.5°C) was observed to the north from the Dufayel Island and in a mid-southern part of the fiord (over 3°C).

Water temperature was measured again two weeks later (Fig. 14). The water temperature changes significantly from place to place, especially in the western part of the fiord where difference between the lowest (0.9°C) and the highest (3°C) temperature equals to 2.1°C. Considerable change in temperature occurs also at the fiord mouth. Temperature of a superficial water dropped almost everywhere, except for the area between the Dufayel Island and a southern shore.

On January 26, 1990 (Fig. 15), an overcast occurred and it was drizzling. Water temperature in the Ezcurra Inlet was similar as during a preceding season. Few days before measurements, the weather was sunny and the water got warmer. Highest variation of temperature (from 1.2°C to 2.8°C) was observed in a southwestern part of the fiord. Water temperature between the Dufayel Island and a southern shore dropped slightly. The highest temperature during most of the year was noted in this very area. Supposedly, either warm rocks at

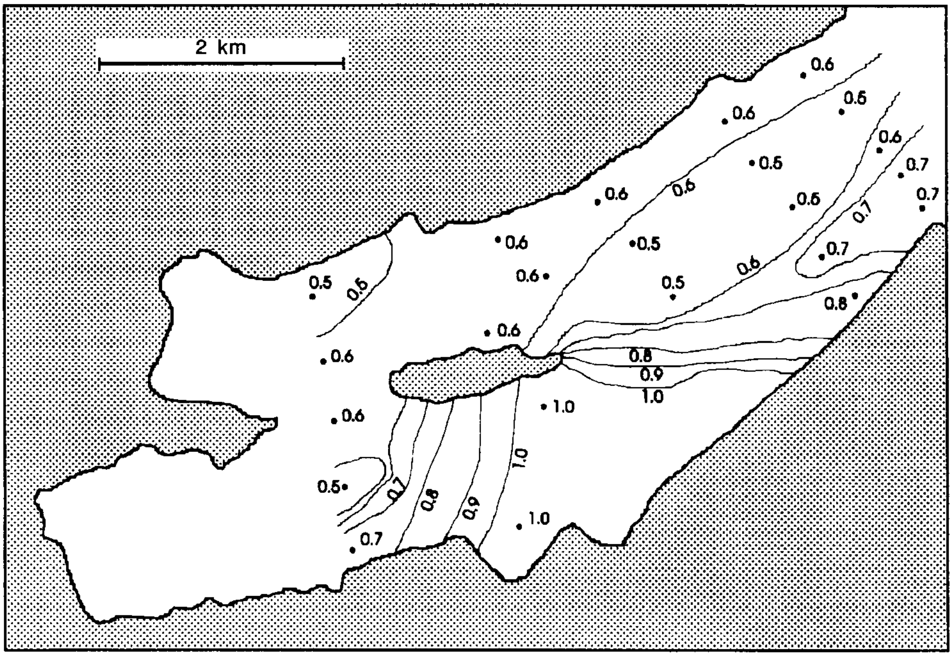

Fig. 15. Temperature of superficial water in the Ezcurra Inlet on January 26, 1990.

a southern shore of the fiord make surface water warmer or there is a heat emission from a bottom of the fiord.

Mean temperatures for the station, the mouth and the fiord were calculated on the basis of the collected data. 25 measurement stations were selected and temperature was measured 11 times at every one of them. Mean daily temperature for the fiord was calculated according to the equation:

$$\overline{T}_i = \frac{1}{25} \sum_{j=1}^{25} T_{ij} \tag{1}$$

where T_{ij} — temperature at the 'j' station on the 'i' measurement day. Mean daily water temperature $\overline{T}_i$ was below 0°C from May to November 1989 (Fig. 16).

Mean yearly water temperature at selected stations was calculated according to the relation:

$$\overline{T}_j = \frac{1}{11} \sum_{i=1}^{11} T_{ij} \tag{2}$$

where T_{ij} — temperature at the 'j' station on the 'i' measurement day (Fig. 17). The lowest mean temperature (0.5°C) was noted in a middle and western part of

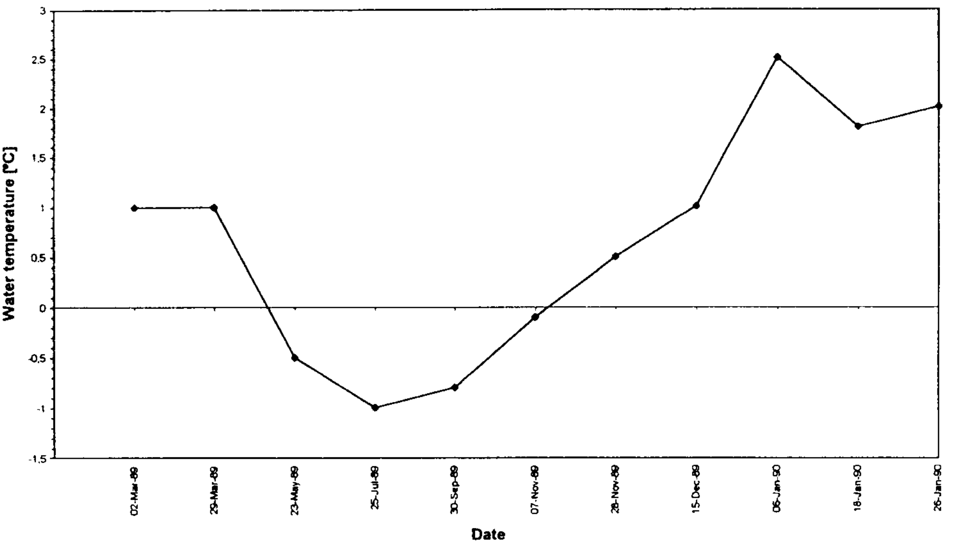

Fig. 16. Annual variation of mean temperature of superficial water in the Ezcurra Inlet.

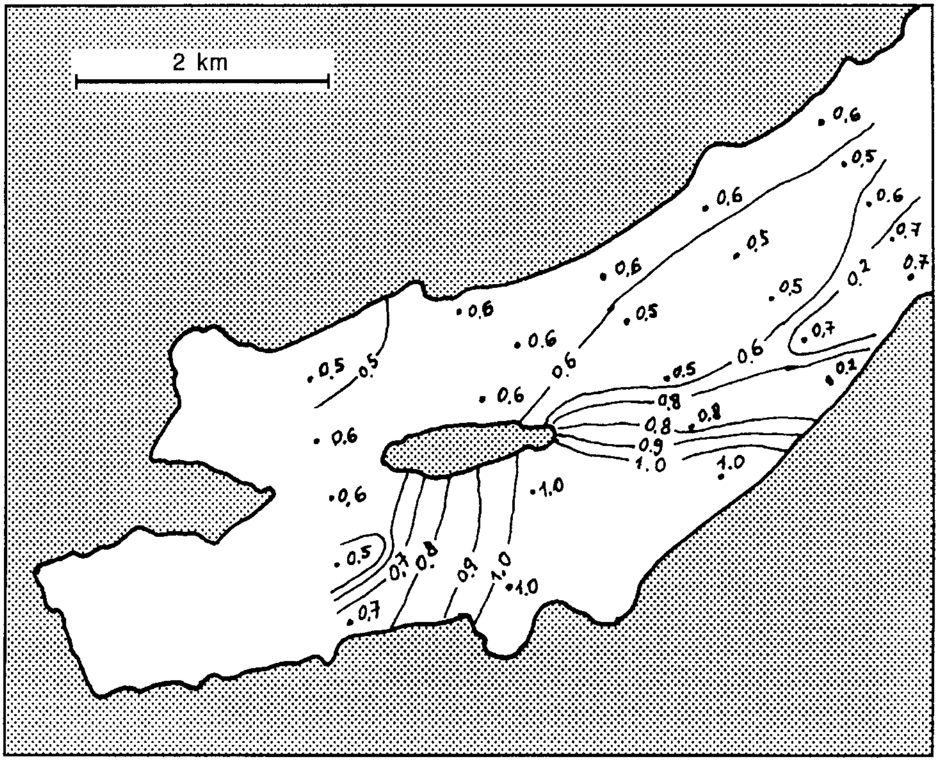

Fig. 17. Mean temperature of superficial water in the Ezcurra Inlet.

the fiord. The highest one was equal to 1°C and was observed between the Dufayel Island and a southern shore.

The average temperature for the whole measurement season and for the entire fiord was equal to:

$$\bar{T}_i = \frac{1}{11 \cdot 25} \sum_{i=1}^{11} \sum_{j=1}^{25} T_{ij} = 0.41^{\circ}C \qquad (3)$$

then it was over 0°C. Such result is due to the mild winter 1989 at the King George Island.

Final remarks

Studies of a superficial water temperature in the Ezcurra Inlet start examination of thermal processes in this area. Temperature measurements enable determination of its changes in the fiord, in time and the temperature gradient. Inflow of solar energy was examined during the mentioned season. Simultaneous measurements of inflow of solar energy and changes of temperature determined correlation between these physical processes, water temperature dependent on solar radiation dose and components of heat balance for the Admiralty Bay.

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Streszczenie

Na podstawie danych z literatury przedstawiono temperaturę w wodach otaczających Wyspę Króla Jerzego, tj. w cieśninach Drake'a i Bransfielda (fig. 1). W okresie od marca 1989 do lutego 1990 roku badano temperaturę wody powierzchniowej na obszarze Zatoki Admiralicji (fig. 2) oraz fiordu Ezcurra (fig. 3). Pomiary wykonano przy pomocy termometru rtęciowego z dokładnością ±0,1°C — każdorazowo na 25 stacjach — w dniach: 2 i 29 marca, 23 maja, 25 lipca, 30 września, 7 i 28 listopada oraz 15 grudnia 1989 roku, a także 6, 18 i 26 stycznia 1990 roku. Na podstawie pomiarów opracowano mapki rozkładów temperatury w fiordzie w poszczególnych dniach (fig. 5–15). Wyznaczono również sezonowe zmiany średniej temperatury akwenu (fig. 16) oraz sporządzono mapkę rozkładu przestrzennego średniej temperatury rocznej dla poszczególnych punktów pomiarowych (fig. 17). Przeprowadzona została wstępna analiza wpływu różnych czynników na temperaturę wody powierzchniowej w Zatoce Admiralicji i fiordzie Ezcurra. Wymiana wód między fiordem Ezcurra a Zatoką Admiralicji wpływa również na kształtowanie się temperatury w obu akwenach. Zależy ona m. in. od zmian głębokości fiordu (fig. 4) oraz od dopływu energii słonecznej.