Impact of Antarctic Peninsula climate change on Galindez Island ice cap dynamics

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Abstract

Recent observations of the small ice cap of Galindez Island show significant changes since the 1950s. The mean annual temperature of the island has increased by over 2C° during the past 40 years to around -4°C. It is suggested that the ice cap has responded to regional climatic changes.

Observations of temperature show that the mean annual temperature has increased from around -5.8°C in the late 1940s to -3.0°C in the mid 1990s. A number of studies of the Galindez ice cap have been carried out during the period of occupation of the Faraday/Vernadsky station. The 1961 survey shows a reduced area enclosed by the fifty metre contour and this may reflect a recession following a very mild period in the late 1950s. The profiles show a significant reduction in height between the 1987 and 1995 surveys from around 3.4 metres at the top of the ice cap to around 0.8 metres close to the rocky outcrop.

The BAS surveys prior to 1987 show only small variation in the maximum height of the ice cap which was between 55 and 56 metres high. The most noticeable change to the ice cap has taken place in a bay opposite Wordie House. Here the ice rests on rock that is close to mean sea level and is hence affected by marine erosion at high tide. Although the bulk of the ice cap is receding, visual observation shows that the change is not uniform over the entire ice cap. Several studies have shown that significant environmental changes are taking place on Galindez Island.

The detailed geomorphology UAC survey of the Galindez ice cap based on the GPS and photogrammetric was started in 2002. The ice temperature measurements on different depth (temperature profiles) in comparison to historical BAS data are provided. The preliminary results of ice temperature measurements at 7 metres depth in September, 2003 gives - 4.4C, which has to approximately correspond to annual mean air temperature. The results of radio sounding observation of ice bulk thickness and bedrock shape undertaken in 1998 are discussed.

The precision GPS observations made by UAC enable to repeat the earliest BAS measurement of the Galindez ice cap fifty metres height contour, which were based on aerial photography and theodolite observations. The main objectives of the GPS and photogrammetric survey are producing the precision geodesic data for ice cap monitoring and the evolution model creation. The most recent photogrammetric survey shows the smallest area enclosed by the 50 metre contour with significant recession in all directions. The present observations taken together show a reduction in volume of around ten per cent of Galindez ice cap in eight years, suggesting that it will disappear within a century.

Introduction

The Argentine Islands are a small group of islands lying seven kilometers west of the Antarctic Peninsula at 65.15°S, 64.17°W. Argentine Islands ice caps are located in vicinity Graham Land Peninsula, sub-Antarctic and periglacial zone. Most of the islands of the group have small ice caps which form in the lea of exposed rocks at the north end, rise to a gentle summit and terminate at the southern end in a cliff, where the ice rests on rock near sea-level. The ice caps are symmetrical about an axis parallel to the prevailing wind, which is from around 020° (Fig. 1) [11].

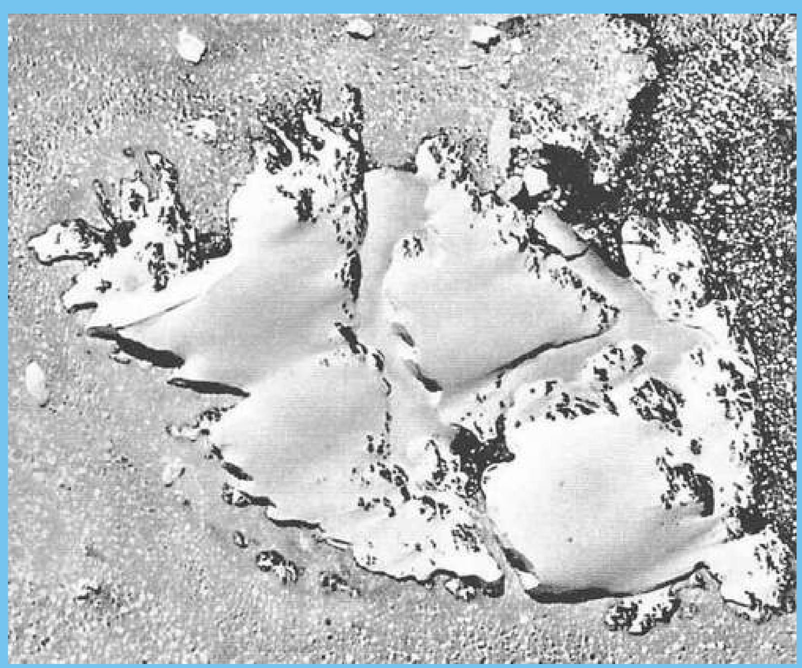

Fig.1. Arial photo of island group (by BAS: 26FID, 13000ft, 1956)

The former British Antarctic Survey Faraday station (since February,1996 the Ukrainian Antarctic Center Vernadsky station) is located at the western end of Galindez Island on Marina Point. The station was built in the 1950s and there is a continuous climatological record from the area since the late 1940s. Observations of temperature show that the mean annual temperature has increased from around -5.8°C in the late 1940s to -3.0°C in the mid 1990s, though warmer and cooler periods have occurred during this time. Minimum temperatures occurred in the late 1950s, with another cool period in the late 1970s and maximum temperatures have occurred in the 1980s, with another warm period in the early 1970s (Fig. 2).

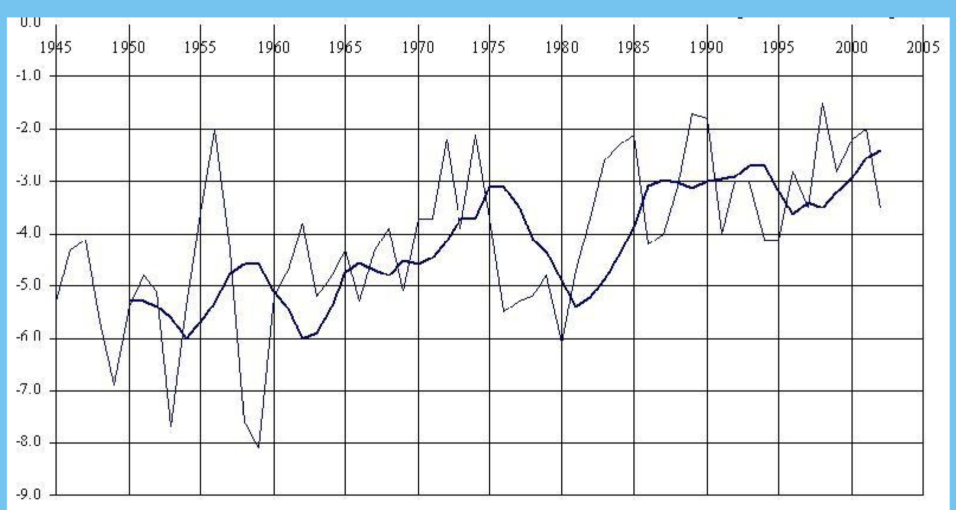

Fig. 2. Faraday/Vernadsky annual mean temperature 1947-2004

A number of studies of the Galindez ice cap have been carried out during the period of occupation of the station [1, 11, 8, 14]. In the 1960s Thomas and Sadler [8, 11] published reports on the mass budget of the ice cap which included details of the shape and size of the ice cap. Details included contour intervals and spot heights at the top of the ice cap. It was noted that apparent changes were taking place and therefore instituted an occasional program of simple survey work to quantify the changes. Three main types of measurement were introduced:

1) Measurement of the 50 metre contour.
2) Measurement of a profile of the top the ice cap along a fixed bearing.
3) Measurement of the bearing of the edge of the ice cliffs from fixed survey stations.

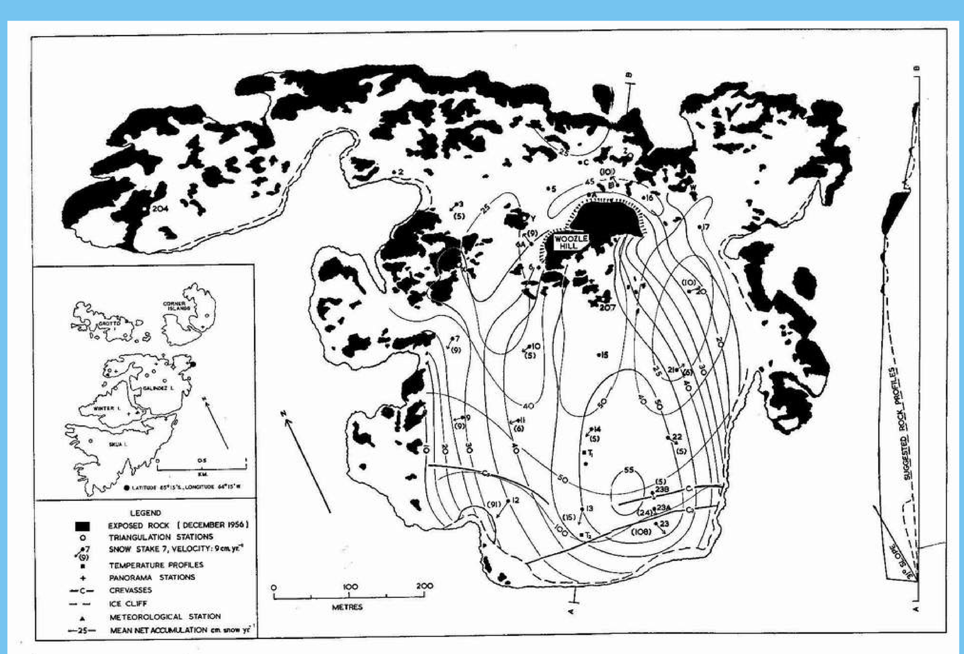

Fig. 3. Map of Galindez Island showing the 50-metres snow contour in March 1961 (by Thomas R.H., 1963 [11]).

Fifty metre contour

Survey station 207 is located on the highest exposed rocky outcrop on the island at a height of 51 meters. The top of the ice cap rises a little higher than this, making the fifty meters contour relatively easy to measure and was chosen for the present study. Ground based survey work at the south end of the island is prevented in most years by the presence of two large crevasses and the fringing ice cliffs.

The earliest measurement of the fifty meters contour is based on aerial photography carried out by Hunting Aero Surveys in December 1956 for the Directorate of Overseas Surveys. Thomas and Sadler made further survey in the 1960s in the course of glaciological studies. According to Thomas [11] researches the ice moves to southern-western direction, the velocity is 80 cm/year. The ice cap southern edge is separated of the ice cap body by the small crevasses series. Such positions are determined by the bedrock structure, the largest crevasses are opening on 100 cm/year.

From 1982 to 1996 the measurements were made using a theodolite set on the highest point of the ice cap and a levelling staff; distance being measured by tachymeter.

Prior to the 1995 survey all the studies show a similar position for the contour on the east side of the island, which is the direction of the prevailing wind. The positions of crevasses C_1 and C_2 also show little change, suggesting that they are tied to features in the bed-rock. Inspection of the western cliff tends to confirm this as there is a small inlet at sea-level just below the entrance to the crevasse. The overall position of the contour on the 56, 66 and 87 surveys is similar, although their appears to be a recession of the ice close to the exposed rock outcrop. The 1961 survey shows a reduced area enclosed by the fifty meters contour and this may reflect a recession following a very mild period in the late 1950s. The most recent survey shows the smallest area enclosed by the 50 meters contour with significant recession in all directions.

The profiles show a significant reduction in height between the 1961 and 1998 surveys from around 3.4 meters at the top of the ice cap to around 0.8 meters close to the rocky outcrop. The surveys prior to 1987 show only small variation in the maximum height of the ice cap, which was between 55 and 56 meters high. The most recent survey shows significant recession in all directions [Fig. 5].

Recent geodesy survey

Photogrammetry and GPS survey of small island ice caps in Antarctic Peninsula region within the framework of the GIS project for the Argentine Islands Archipelago has been started by Ukrainian Antarctic Centre in 2002. The main topic of recent research is monitoring of the ice caps changes and glaciers dynamics of Argentine Islands Archipelago in connection with the region climate changes. The changes of size, shape, and deformation, moving velocity and the edge position of ice caps on Argentine Islands Archipelago show the possibility to use the geodetic survey data of the ice cap for the regional climate variability study, and for the prognosis of the ice caps dynamic. The digital photogrammetry geodesy survey technology was introduced and three survey campaign were fulfilled in 2002, 2003, 2004 [13, 14, 16].

The survey gives the possibility to determine of the following parameters of the ice cap: the position of characteristic ice cap features, their position changes within observation period, the ice cap morphology and their morphometry characteristics, the data for ice volume changes estimation [13]. During the first campaign (2002) the measurements the coordinates of the survey point have been determined by the GPS in the static regime for the making more strict the centres location. In this way, the zero cycles of the ice survey have been made. The survey resulted the receiving in different time of the 12 stereo pairs as normal as deflected to the left (right) with the different focus distance (92 mm and 280 mm).

On the base of survey data the large-scale digital maps 1:2000 and 1:1,000 for Galindez Island were created (Fig . 4).

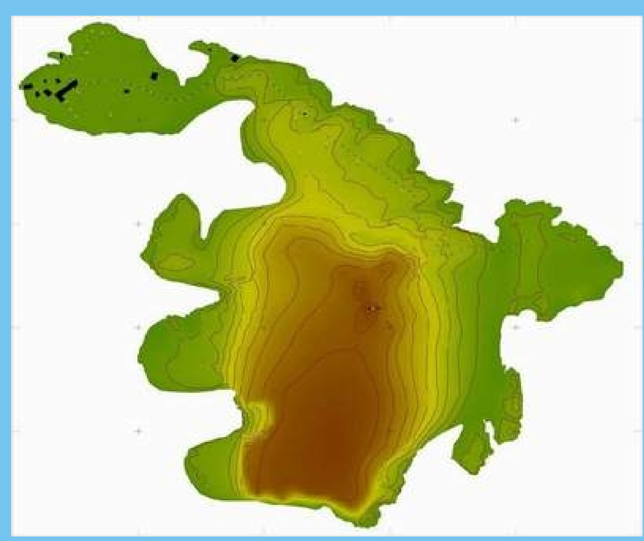

Fig. 4. The sketch of Galindez Island digital map created on the base of 2002-2003 photogrammetry survey. The height contour on top of the ice cap is 45 metres (by Glotov V., Chizhevsky V., 2004 [14])

Ice cap profile

A profile of the top of the cap cannot be obtained from the BAS surveys of 1956 and 1961, however the 1966 survey includes a number of spot heights. The two most recent surveys included a profile measurement from survey station 207 in the direction of the highest point of the ice cap using a levelling staff and tachymeter.
The comparison of the longitudinal profiles UAC survey and bedrock of the Galindez ice cap made in 1961, 1998 and 2002 (circles 2002, rhombs 1998, triangles -1961. The bedrock profiles are shown below: asterisks - by [11], squares by radiosoundings data [13]. Height in metres versus distance along ice cap (metres). The profiles of the top of the ice cap were schemed from the surveys of 1961, 1998, 2002 (Fig. 5).

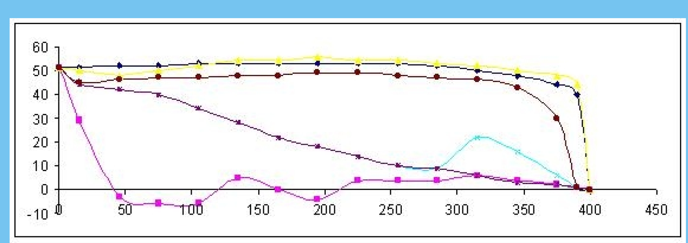

Fig. 5. The comparison of the longitudinal profiles survey and bedrock of the Galindez ice cap made in 1961, 1998 and 2002 (circles 2002, rhombs 1998, triangles -1961). The bedrock profiles are shown below: asterisks - by [11], squares by radiosounding data. Height in metres versus distance along ice cap (metres).

The ice cap soundings

The radio sounding research of the ice caps of the Galindez Island was carried up in January 1998 [5, 13, 14]. The main task was the measuring of the ice thickness. The radio sounding measurements was carried out for 31 points on the 4 profiles. The measures of the velocity of radio waves extending were realized with the using the method of the inclined sounding on the methodic common depth point. The measurement results are presented in the form of ice thick schemes and bedrock relief. The maximum thickness was about 57 metres. The 30 % of the ice bedrock is located under sea level (Fig. 3).

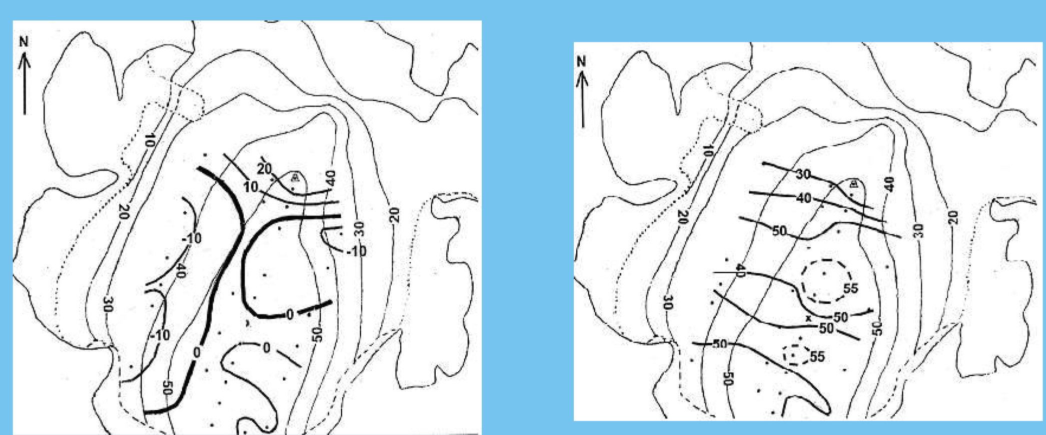

Fig. 6. The Galindez ice cap bedrock relief according to radiosounding data: bedrock relief (left), ice cap thickness (right) - bold lines [13].

The Galindez ice cap vertical electro-resonance sounding (ERS), which based on the processes of natural polarization of medium and spectral features of natural electric field under investigation objects, was provided in March 2004 [16, 17] (Fig. 7 and Fig. 8). The ice cap size and shape has changed significant since 1998.

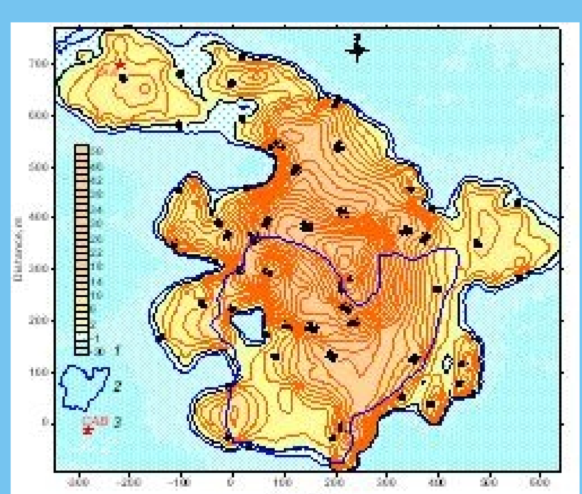

Fig. 7. The electro-resonance sounding sketch-map of Galindez Island surface: bedrock. (Reproduced with permission of the authors [16]).

The vertical electric-resonance sounding method is based on the effect of the polarization of geoelectrical inhomogeneities of a geological section in the Earth's natural quasi-stationary electric field. This field can be presented as a wave packet of electromagnetic oscillations. Half of the length of the packet's wave is corresponding to a depth of the bedding of a polarized body's upper boundary. Identifying and studying these electromagnetic oscillations enables to evaluate the depth range of an anomalous electromagnetic body's bedding [16].

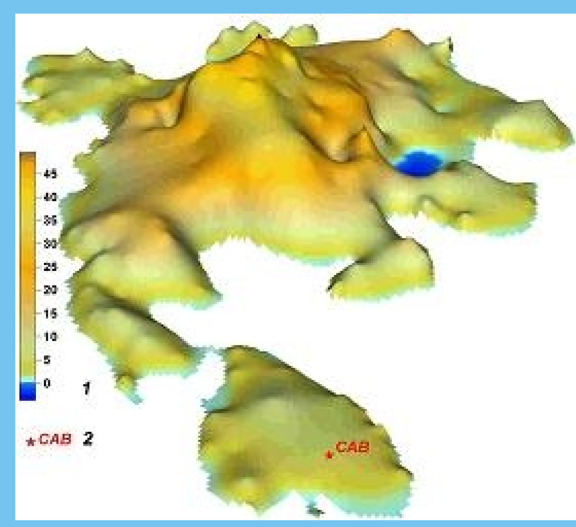

Fig. 8. 3D model of Galindez Island surface based on ERS soundings: bedrock. (Reproduced with permission of the authors [16]).

Shape changes of the west part of ice cap

The most noticeable change to the ice cap has taken place in a bay opposite Wordie hut. Here the ice rests on rock that is close to mean sea level and is hence affected by marine erosion at high tide. Observations of the sea temperature have been made at the tide gauge site since 1973, though records until 1989 are rather patchy.

The seawater temperature anomaly to +4.2°C (and to +5.0°C in open water area) was observed during the 2000-2001 summer season (Fig. 9) [9]. Presumably the conditions of high atmosphere temperature, high insolation level and calm weather were the cause of the seawater temperature increasing. The seawater temperature trend includes the three maximums: +3.5°C for the last decade of December; +5.0°C during January/February; +2.5°C for the first part of March. At the 20 m depth the positive seawater temperature was registered 10-15 days later then at the surface, and at 30 m - 35 days later. The heating of seawater covered all seawater thickness to 35 m depth. At the beginning of March the highest seawater temperature +2.3°C was registered at the depth of 30 m. The southern-western ice cap part lies under the sea level and the unique water temperature (from +1 to +5°C, 2000) were recorded during last 5 years possible the degradation velocity could increase (Fig. 10) [7].

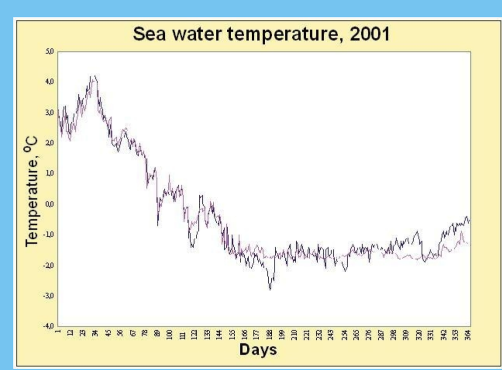

Fig. 9. The seawater temperature anomaly.

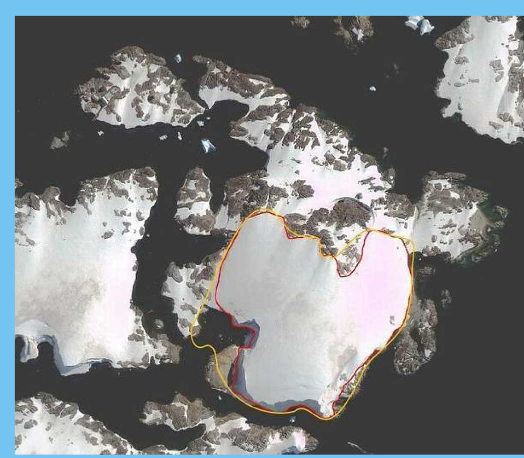

Fig. 10. Galindez ice cap boundaries: December 1961 and January 2004.

The photogrammetry shows considerable reducing of the ice cap west part between 2002 and 2004 (Fig. 10, 11). The ice cap changes have spatial inhomogeneity.

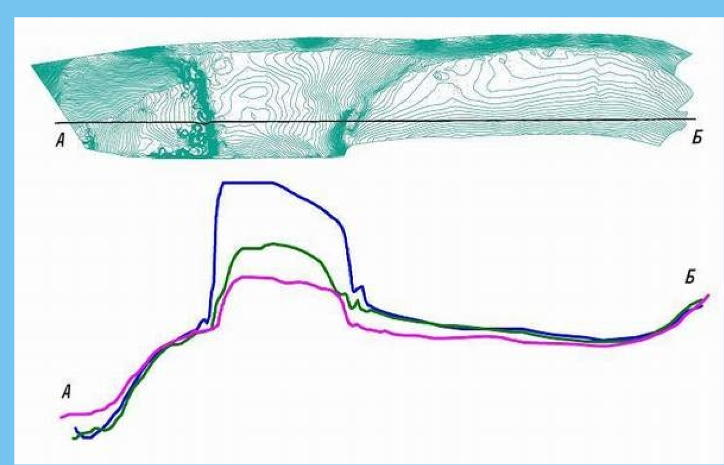

Fig. 11. The decreasing of west side of the Galindez ice cap during 2002 -2004 is equal ~ 50 000 m^3 (total volume approx 2 000 000 m^3)

Discussion and conclusion

Although the bulk of the ice cap is receding, visual observation shows that the change is not uniform over the entire ice cap. Some areas have receded more than others, and a few areas have actually increased in ice cover; for example the narrow isthmus between Marina Point and Galindez Island melted out completely in 1986, but was covered with ice some two metres thick in 1995, albeit crossed by two small crevasses. Local observation suggests that the major factor in governing accumulation is the direction of the wind during major snowfalls, particularly the first snowfalls of each winter. Most ablation takes place in the summer during periods of heavy rain and strong winds when the temperature is around 5°C.

Several studies have shown that significant environmental changes are taking place on Galindez Island. King has shown that the mean annual temperature has increased by 2.5 °C since 1947 and has linked mean winter temperature with regional sea-ice extent [4]. Colwell has examined the overall climate of the island and found evidence for an increase in the ratio between rainfall and snowfall since 1956. These effects will act to decrease the amount of seasonal snow cover and lead to changes in the relict ice cap [2]. Lewis-Smith has found that Deschampsia Antarctica and Colabanthus Quitensis are increasing in abundance on the island (though this author found no additional sites of Colabanthus despite extensive searches in 1995) [3].The researches for 1940-1985 were shown that the small ice caps Argentine Islands Archipelago are relicts of ice shelves and the their sizes are changing constant but this changes aren't homogeneous [8, 11, 13]. The photogrammetry survey and GPS measurements are used for researches of the changing of the sizes, shape and the position of the ice cap edge is influenced of the rapid warming in Antarctic Peninsula region. These measurements show that major recession of the cliffs is taking place. The largest recession has taken place on the western and eastern parts [13, 14].

The present observations taken together show a reduction in volume of around several percent of Galindez ice cap in eight years, suggesting that it will disappear within a century. Consequently the permanent ice caps monitoring of the Argentine Islands would be provided.

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