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Snow cover in the vicinity of *Arctowski* Station, King George Island, in winter 1991

ABSTRACT: Properties of a snow cover in the vicinity of *Arctowski* Station, King George Island (West Antarctica) were studied in 1991. Variations of snow quality and physical transformations were analysed against changes of atmospheric parameters, basing on water equivalent index and repeatable examination of snow pits. Essential dependence of snow cover distribution and snow structure from local climatic features and terrain morphology was found. Thawing occurs in the whole mass of snow, with its contribution of both liquid and gas water phases.

Key words: Antarctica, South Shetland Islands, snow cover.

Introduction

Physical and chemical investigations of snow take more and more place in the literature but a problem of local dispersion of a snow cover and small-scale changes caused by atmospheric agents are relatively poorly known. The matter of this process in high latitudes is well indicated, mainly during transition from a continuous to a discontinuous snow cover, and then to isolated patches of snow in summer. It has got significant impact on water circulation, transport of mineral matter, as well as relations of these factors to a substrate devoid of plants.

The research presented here, was initiated by the Dutch group (Bintanja *unpubl.*, Bintanja *et al., unpubl.*) and continued as the monitoring program of a snow cover during the 15th Polish Antarctic Expedition to *Arctowski* Station, King George Island, South Shetlands. Geographical position of the research area (Fig. 1) locates it in a zone of subpolar climate with strong maritime influence (Martyn 1985), where annual precipitation is over 500 mm and a snow cover

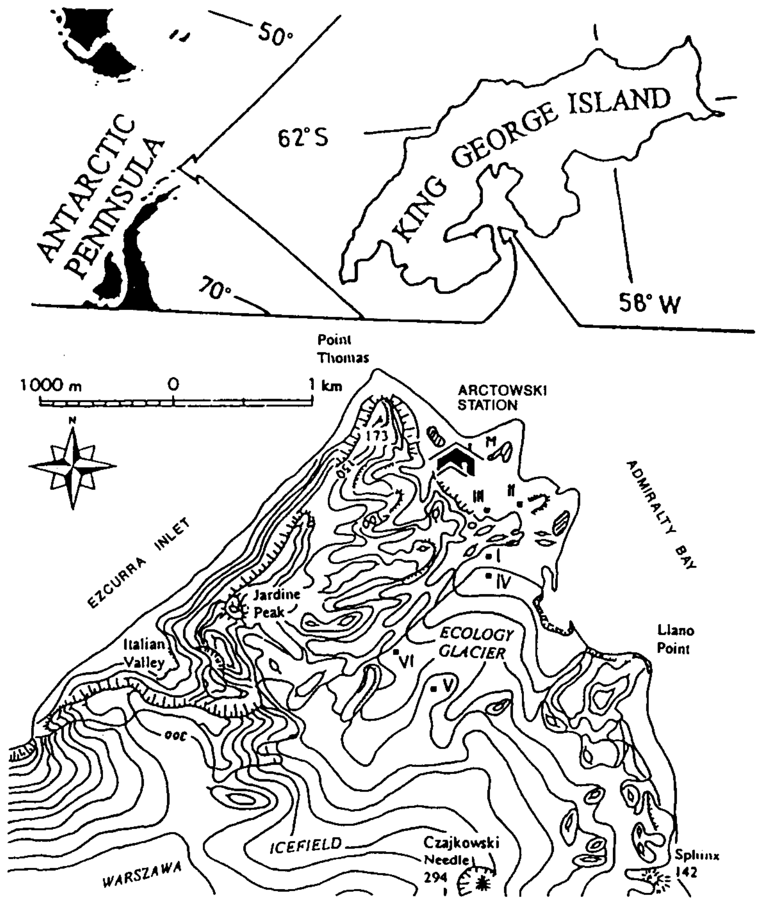

Fig. 1. Location of examined sites in the vicinity of the Polish Antarctic Station.
I–VI – location of snow pits, M – meteorological observatory.

occurs generally since April to the beginning of December. Observations were provided between April 15 and December 31, 1991, *i.e.* during the weather seasons III to VIII according to classification of Marsz (1992).

Methods and data

A meteorological observatory registered in the World Meteorological Organization (No. 89052) was founded at the *Arctowski* Station in 1978. All observations in 1978–89 were collected in agreement with standards of the World Meteorological Organization. Starting from 1990, observations were reduced to three basic measurements a day, supplied by continuous and automatic record of data (Zwoliński 1992). Air temperature, relative humidity, wind speed, wind direction in 8

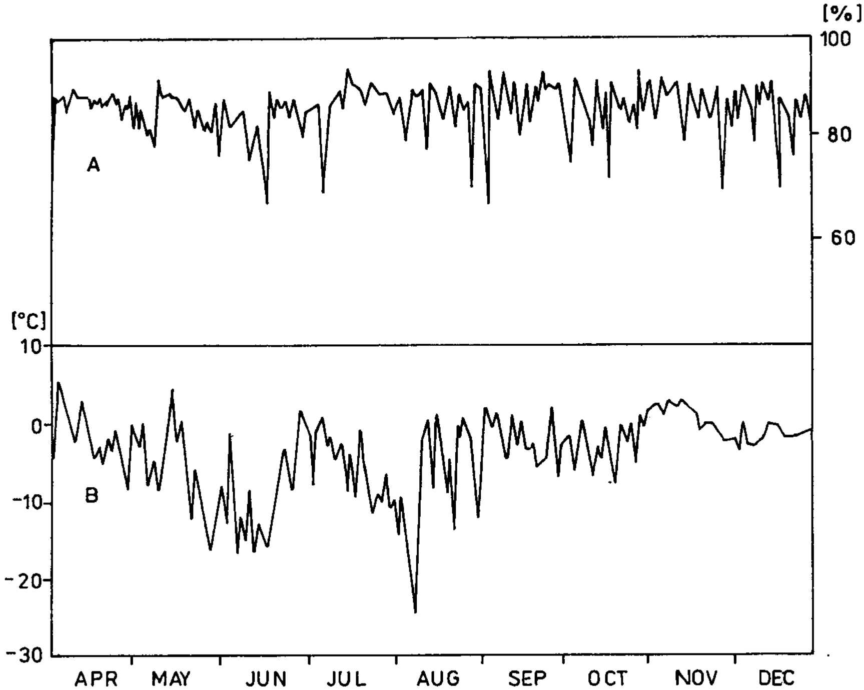

Fig. 2. Daily mean relative humidity (A) and temperature (B) at the *Arctowski* Station in winter 1991.

sectors, type and quantity of precipitation were the measured parameters. In terms of occurrence of the uniform snow cover, its depth and water equivalent to calculate mean snow density in the profile were observed (Figs 2–5).

Since the late winter (morphogenetic season after Marsz *unpubl.*), *i.e.* September to the end of 1991, recurrent observations of a snow profile in excavations to a mineral substrate (Fig. 1, Pl. 1) were undertaken. Measurements were based on the USA-CRREL standard set (Gray and Male 1981) which contains metal tubes to collect snow samples, balance to determination of density, durometer to evaluate the hardness index and thermometers.[1] Thickness, bed succession, structure and quality of snow and contact between succeeding layers were controlled at walls of a snow pit. Actual weather conditions during measurements were observed as well as temperature, density and hardness index at different depths below a snow surface (Figs 7–8). Samples were furthermore transported to the laboratory, where electric conductivity of melted snow was performed. In this part, the material includes twelve excavations at six sites done once, twice or three times.

[1] The snow investigation set was hired from the Chilean Antarctic Station *Marsh*; the authors are grateful to Mr. Hector Barrientos Para, the base commanding officer.

Discussion of results

The research period with a continuous snow cover lasted 260 days in 1991. It was characterized by mean daily temperatures between -25 and 5°C, and relative humidity of 65–91% (Fig. 2A, B). Mean temperature of the whole interval was equal to -3.6°C but even during the coldest month, temperatures above 0°C were noted. High relative humidity (mean 85.8%), drops below 80% in single cases only. Softer weather conditions start at the end of October (beginning of the ablation season). In November, warming up and flattening of other climatic parameter curves is indicative.

Dispersion analysis of wind velocity and direction (Fig. 3), based on readings every hour, indicates quite a smooth course of wind velocity. A mean daily wind speed does not exceed 20 m/s. These merits correspond to the blizzard snowfall effects. Such situation appeared during southern and southwestern circulation of polar origin. Extreme conditions with wind speed over 40 or even 60 m/s are connected with foehn-like air movements from the north and west. These foehns carry rainfalls and warming-ups. In general, wind velocity indicates wide differentiation and gustiness with calm periods from 5 to 20% per month (Fig. 3B). A comprehensive chart of wind directions (Fig. 3C) does not indicate distinct monthly specifications. Rare wind directions dominate occasionally *e.g.* in April when 20% of winds blew from N and SE. In fact, the only rule is a weak participation of the northeastern winds during all the months.

Wind speed and direction are the main agents in development and transformation of a snow cover. The main snowfall occurred during the first half of the observation period (from April to August), when the southwestern circulation predominates. Large amount of snow could not be accumulated in connection with the substrate and was blown out into the water of the bay. If the bay is frozen, snow is drifted on its northern side. In the open field on the Keller Peninsula, near the Brazilian Base *Ferraz* (Viela *personal commun.*), or in the Maxwell Bay, the Korean *Sejong* Station (Lee, Kim D.H. and Kim Y. 1990), a snow depth surpassed 2 m. At the same time, it was 1 m thick only at the *Arctowski* Station. These specific conditions occur in the vicinity of the Polish station while in other areas, a speed of the southern wind never exceeds 40 m/s. Such blizzard-like winds are the most productive for a snow cover. Snow is deposited in morphologically favourable sites only, like hollows or lee slopes. Its accumulation is mainly the effect of a horizontal aeolian transport. A snowfall itself, a total of which in the discussed period was equal to 137.4 mm, does not describe well a depth of a snow cover. Most of a snow mass is lost in the bay, which was frozen between the end of June and the mid-September only. Record of precipitation with a use of the standard Hellman's pluviometer (Fig. 4A, B), seems to be a signal of a snowfall than a real value. Analysis of a snow depth in the open field of a meteorological observatory seems to be more

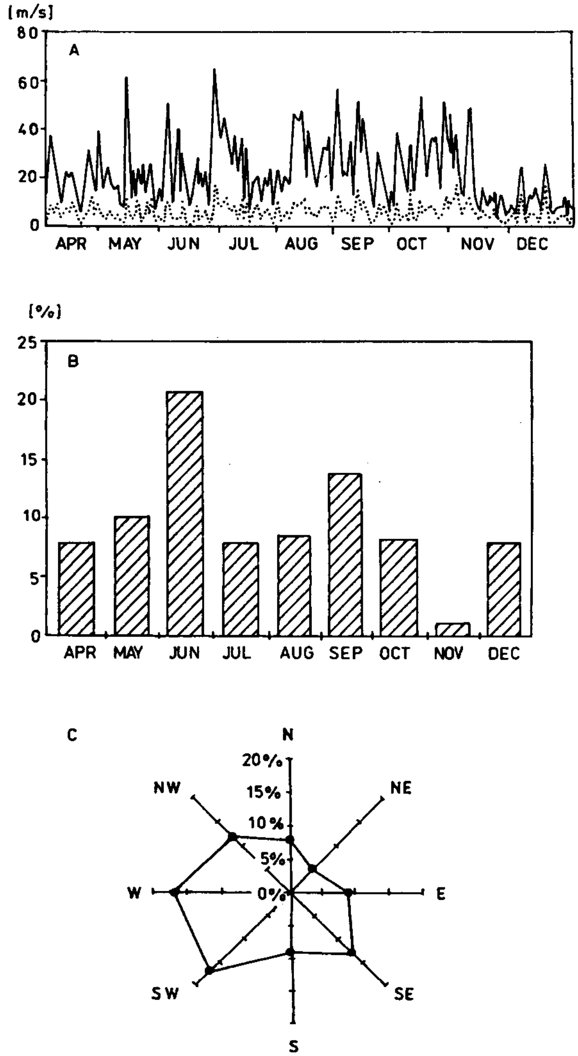

Fig. 3. Wind 2 m above the ground in the vicinity of the *Arctowski* Station. A – wind speed (daily mean – dotted, daily maximum – solid), B – calm periods per month, C – frequency of wind directions.

reliable (Fig. 4C). A cycle of deposition, transformation and ablation of a snow cover is well indicated there. One of the most important factors that modifies snow properties, is the rainfall coming with warming-up of the air mass. Highest rainfall is also the effect of mixing with sea water, suspended in the air by northern winds. It is confirmed by high electric conductivity of these samples. In an extreme situation, at the end of June when a big snowfall occurred, a rainfall followed by a drop of temperature was denoted. It gave a layer of ice,

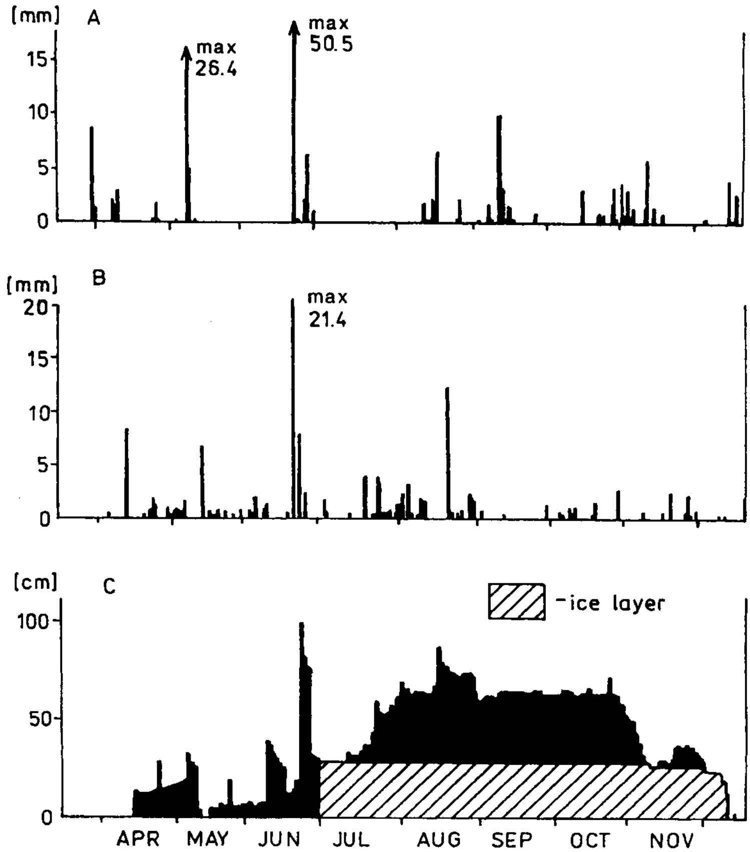

Fig. 4. Precipitation: A – rain, and B – snow, C – snow cover thickness, observed at the *Arctowski* Station.

up to 30 cm thick, on flat or slightly inclined surfaces. This ice reached long-cristalline structure before the end of winter. Similar ascends of superimposed ice, without a phase of granular firn as expression of singular or seasonal ice layer lifting (Jonsson and Hansson 1990), took place on the surface of a glacier. It has not been higher than 10–15 cm and fast ablation at the beginning of summer destroyed it rapidly.

Water equivalent expresses changes in a snow cover under atmospheric conditions. It allows to estimate a mean snow density in the profile (Fig. 5). The water equivalent was determined every five days, according to the instructions for the meteorological observatories (Janiszewski 1988). Varying density shows an increasing trend, but its lowerings are due to a fresh impact of snow. Such changes between 0.3–0.5 g/cm^3 are the mean in the profiles. Jania (1993) gives density merits from 0.01 to 0.8 g/cm^3, so they are quite high here according to saturation and migration of water in the cover. This is conformable to observa-

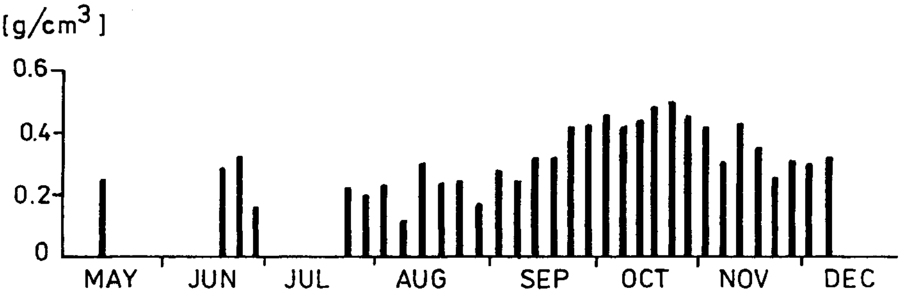

Fig. 5. Snow density on a flat surface of the floodplain at the station, in water equivalent per five-day intervals.

tions of Noble (1965) in the same region and Pereyma (1981) in the Hornsund area of Spitsbergen. Such density is characteristic for regions with sudden advections of humid and warm air mass and strong winds.

Electric conductivity of precipitating water (Fig. 6) acts on a primary mineralization and determines chemical properties of a snow cover during its formation. If electric conductivity of a snow cover and a snowfall are compared, then one can realize that mineral content is transported dry by winds. In snow samples, a mineralization over 30 µS was detected, while in rain water the values of 500 µS are common.

Data from the snow pits created a second group of results. First site (I) was established in a marginal zone of the Ecology Glacier, in an elongated depression 30 m wide and 5 m deep, located between north-south oriented longitudinal morainic ridges. Snow is deposited on a till surface, with large boulders and devoid of plants (Pl. 1, Fig. 1). Inclination of the area favours drainage of infiltration water. During observation period of 88 days, a maximum depth of the snow cover reached 160 cm. Six snow layers were distinguished in a syn-

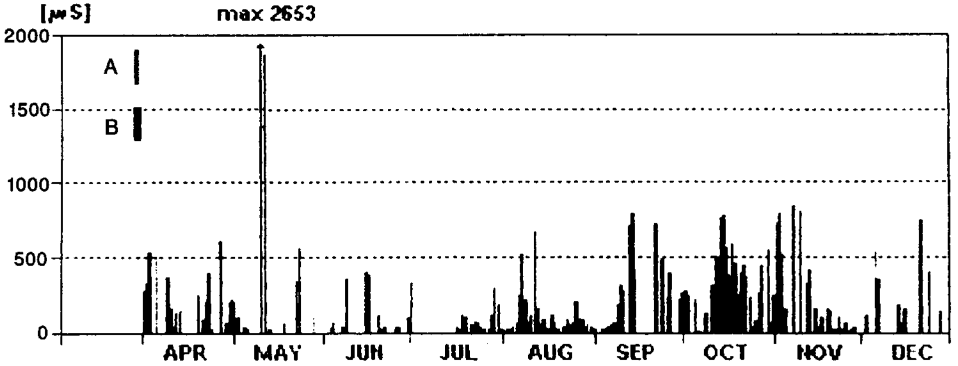

Fig. 6. Electric conductivity of precipitation.
A – days with rainfall, B – days with snowfall.

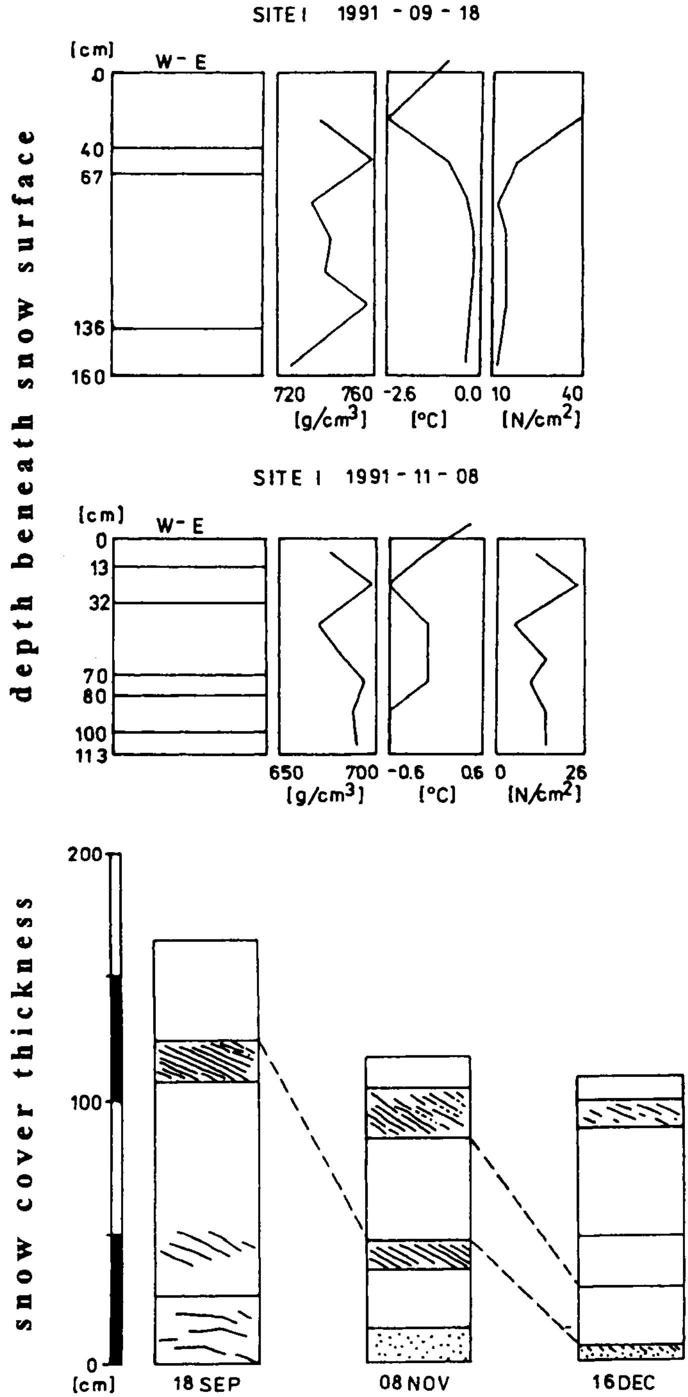

Fig. 7. Site I: varying snow thickness and physical parameters.

thetic profile. A following development of a snow cover results from the analysis of its transformation (Fig. 7). At first, four layers are desribed. Higher compaction and density is observed in strata with large- and small-scale cross-bedding, smoothly underlined by ice surfaces. Distinct borders of layers are ice laminae up to 1 cm thick, filled occasionally with mineral and plant detritus. Second image presents vast similarity in structure and density of three lower beds. They have 36% of initial height. Changes of density are not radical during the observation period. Variation of density due to loading with water is equal to about 2–3% only. However, the lowermost bed is transformed into a snow-water mixture, with temperature of 0°C. The bottom layer which is 30 cm thick, collects water from cover drainage as a sponge.

The site II was located at the foot of a northern slope of a rocky ridge, covered with a morainic material. A hill is 55 m high and permits eminent rate of snow deposition. Thickness of the cover reached 2 m at the beginning of November. Three observations at intervals of 39 and 36 days were done (Fig. 8). The exposition enabled simple correlation of a snow depth, with predomination of the southwestern winds in September and October (30% of all wind directions during these months). Structure of the cover is much more complicated there. In terms of fast ablation (southern exposition) and absence of key horizons, the minimum coefficient like in the previous case should be applied. Dynamics of accumulation (110 cm) is in the level of about 50%. Structural transformations in particular layers are not visible for macroscopic examination, but variation of physical parameters in apparently uniform strata can be observed.

Other sites located in a more open area did not indicate so thick accumulation series (Pl. 1, Fig. 2). Ice occurs commonly at the base. Such covers are more compact, with a high hardness index and density, as well as typical cross-bedding when deposited on mineral slopes. Morphology of the surrounding area has big influence on directions of air streams. At large exposed surfaces (*e.g.* on glaciers), a wind effect is not adjusted by obstacles. Snow particles are in a permanent horizontal movement and stratification is absent. A thin snow cover has been developed during fall events of calm periods (Pl. 2).

Conclusions

Starting from the very beginning, a character of initial substrate is not of great significance for transformation in a snow cover. First snowfall unifies bedrock in plain as a flat surface. Humidity and friction index of solid rock, moraine, tundra or ice, means less than morphology of the area or character and distribution of obstacles versus dominant atmospheric circulation. Probability of quiet snow cover accumulation connected with snowfall is equal to about 0.15, under

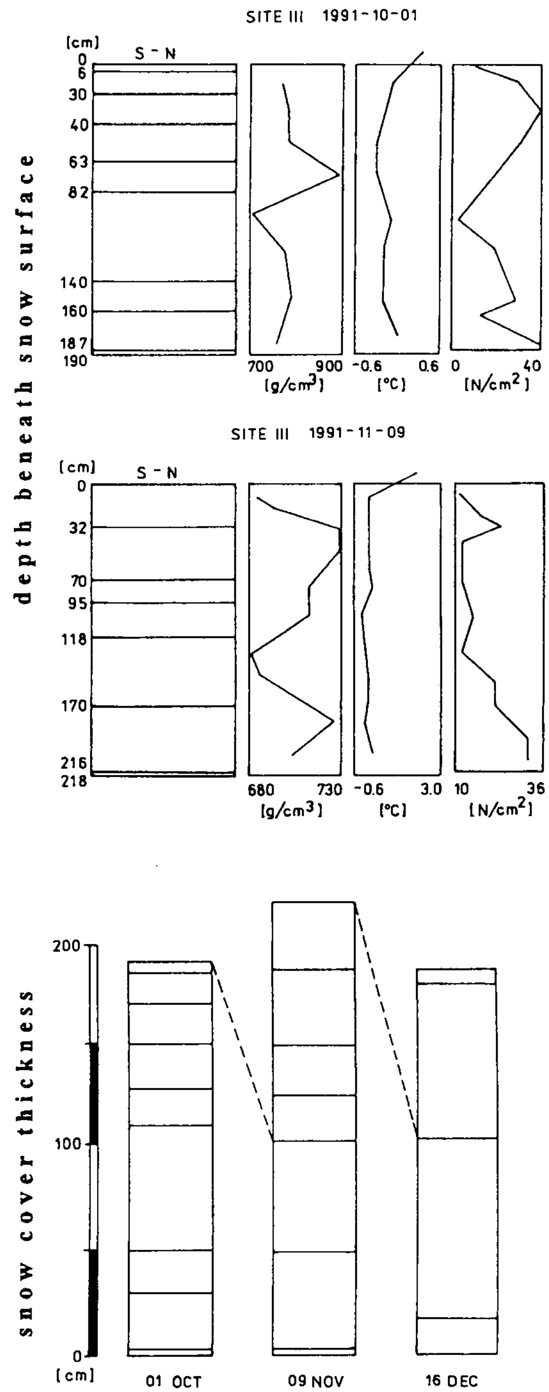

Fig. 8. Site III: varying snow thickness and physical parameters.

assumption that at wind speed over 5 m/s the fresh snow cannot retain in its primary position.

According to different types of ablation (Kłapa 1968) in a described zone, the effective snow melting is a consequence of several processes. The most dynamic decrease of snow mass is connected with a fhn circulation. High temperature, rainfall and strong wind allow melting as well as evaporation and sublimation that produce water vapour. Saturation of water in the snow cover causes rise of solar ablation due to lower albedo. Coexistence of these three phases of water at time of ablation, results not only in surficial thawing but in wastage of a whole volume. Snow recrystalization in normal pressure does not result in any important changes of density. Such conditions favour development of wide structures, in which water and vapour can penetrate easily. Common vertical corrosion channels that control water ingress (Kłapa 1968), were observed at the end of the ablation period. In deeper layers inactive to accidental, daily changes of atmospheric conditions and therefore independent of air temperature, snow melts also in temperatures below 0°C (Kühn 1987). Large dispersal of surficial values, in contrast with stable conditions deeper, produces depth hoar layer which seems to be hanged 5–10 mm over the rest of snow. It was also described by Kłapa (1968) and Colebeck (1989). No influence of air temperature variation is noted already 20 cm below a snow surface, leading to mass release according to a total energetic budget of a snow cover.

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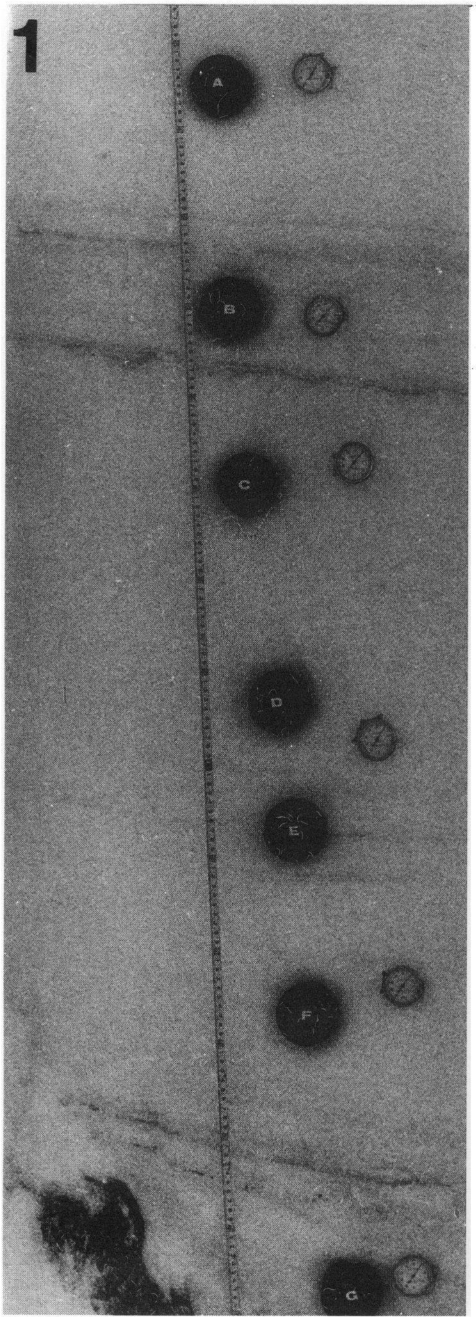
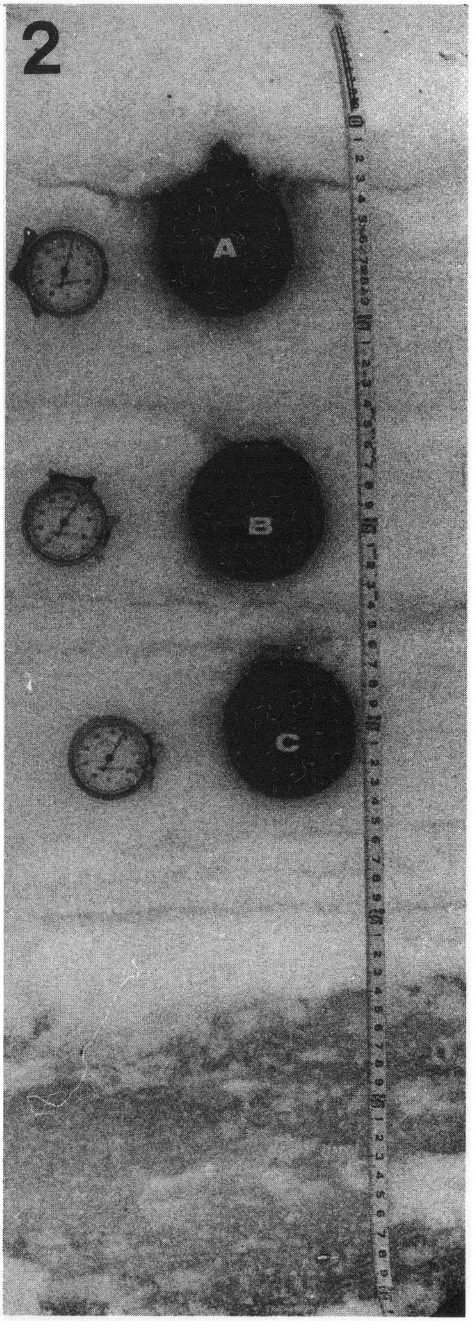
Streszczenie

Podczas XV Wyprawy Antarktycznej Instytutu Ekologii Polskiej Akademii Nauk na Wyspę Króla Jerzego w 1991 roku, prowadzono obserwacje pokrywy śnieżnej w okolicach stacji im. H. Arctowskiego (fig. 1). Zmienność cech fizyko-chemicznych śniegu badano na tle warunków atmosferycznych, w oparciu o pomiary równoważnika wodno-śniegowego (fig. 2–6), a także w profilu pionowym, poprzez powtarzalnie wykonywane wkopy (fig. 7–8; pl. 1). Stwierdzono zasadniczą zależność rozkładu pokrywy śnieżnej i jej struktury od lokalnych cech klimatu oraz morfologii terenu (pl. 2). Ablacja odbywa się w całej masie śniegu przy udziale zarówno ciekłej jak i gazowej fazy wody występującej w pokrywie.





1. Snow cover profile at the site I with thermometers and sampling containers.
2. Profile of snow at the site II with ice layer at the base.

Patches of snow at the surface of the Ecology Glacier at the end of ablation season (January 1992).