Glacio-Meteorological Investigations on Ecology Glacier, summer 90-91, King George Island, Antarctica

ARCTOWSKI-90/91 Field Report

Institute of Meteorology and Oceanography
University of Utrecht

The Netherlands Antarctic Expedition
King George Island, Arctowski Station,
December 1990-February 1991

Glacio-meteorological investigations on Ecology Glacier
Field Report

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1. INTRODUCTION

Ozone depletion, environmental pollution and global climate are all subjects of worldwide concern not only among scientists, but also among policymakers and public. Despite remoteness and extreme climate, part of the scientific effort to understand these and other global environmental issues is devoted to the Antarctic region. Today, scientists from 39 countries take part in a wide variety of research projects. Because of its geographical setting, the Netherlands are particularly vulnerable to the possible effects of global warming on sea level. The Antarctic ice sheet stores an amount of water equivalent to about 70 m of sea level, and small changes in its mass budget can thus have significant consequences.

It is generally accepted that in a warmer climate the total (surface) mass balance of the Antarctic ice sheet will increase, while that of the Greenland ice sheet will decrease. However, this does not apply to the subantarctic Islands, which are located in a relatively warm climate. Here, an increased melting and some runoff can be expected. Althoug the amount of ice may appear rather small, response times are short (comparable to mountain glaciers and other small ice caps at lower latitudes). An energy balance model of the snow/ice surface can be used to quantify the sensititivy of the subantarctic glaciers to climate change. Such a model requires input from field experiments, however. Notably, information on the relation between radiation balance and clouds, surface albedo, and turbulent transfer coefficients is needed.

In the framework of the Netherlands Antarctic Expedition (summer '91-'92) a glacio-meteorological experiment was carried out to facilitate a sensitivity study with an energy balance model. Although the duration of the experiment was rather short (31 days of full-scale measurements), useful information was obtained to make the application of an energy balance model to Ecology glacier possible.

The location of the measurements was selected for logistic reasons as the Netherlands Antarctic Expedition was housed at Arctowski Station (Poland). From there, the measuring sites on and near Ecology Glacier could be reached by feet.

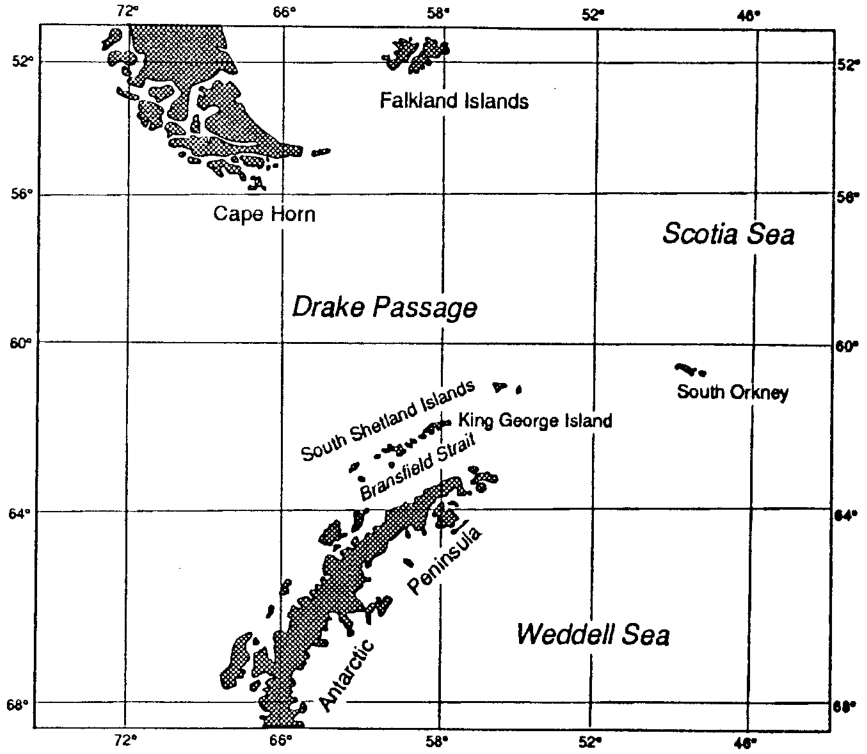
2. LOGISTICS

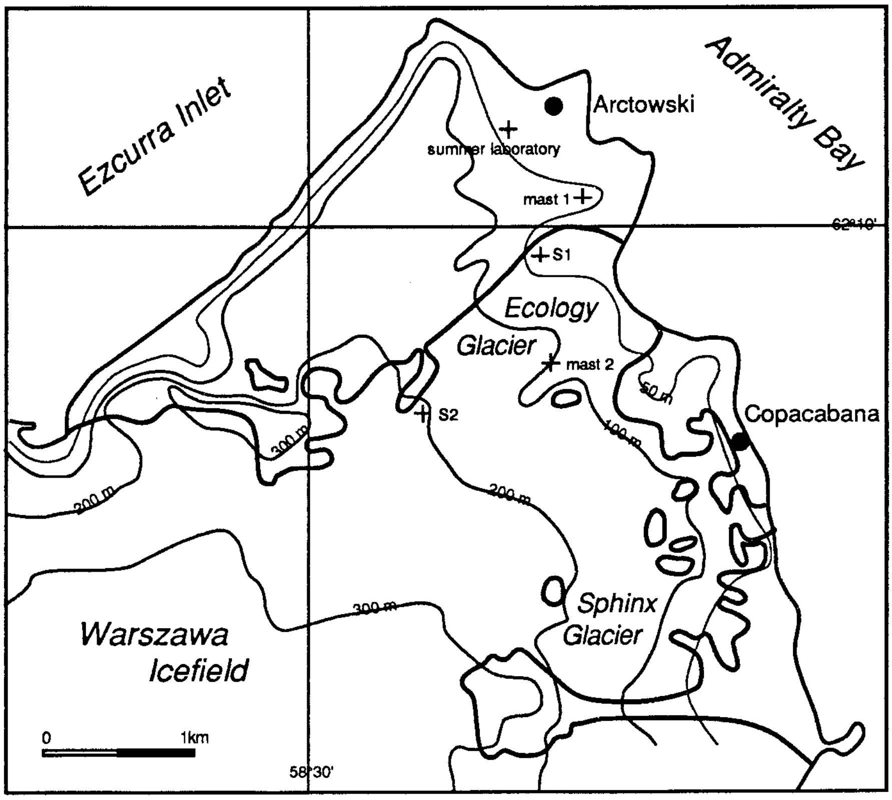
For the meteorological work the same equipment was used as in the Greenland Ice Margin Experiment (GIMEX) in 1990. The necessary equipment was sent back by plane from Søndre Strømfjord in Greenland to Amsterdam. Later it was put on board the Polish ship ORP "Arctowski", on her way to the Polish station on King George Island, one of the South Shetland Islands (geographical position: 62° S, 58° W).
Researchers of the institute travelled together with the other expedition members (a total of 22 under the leadership of Prof. dr. W. Wolff) by aeroplane to Punta Arenas, Chile. The Chilean Army took care of the transportation to Arctowski Station via their Antarctic station Teniente Marsh.

An overview of the activities is given below:

November, 2	departure of equipment with ship ORP "Arctowski" from the harbour of Scheveningen (the Netherlands)
December, 1-3	departure of Bintanja, Conrads and Portanger from Amsterdam, Schiphol; arrival few days later in Punta Arenas
December, 7	departure from Punta Arenas and arrival at Arctowski Station
December, 12	arrival of ship ORP "Arctowski"
December, 12/13	transport of equipment from ship to station
December, 15/16	installation of the two meteorological masts
December, 17	first day of experiment
December, 19	first launches with balloon
January, 16	last day of experiment
January, 17-22	packing of equipment
January, 23-25	transport of equipment to ship
January, 26	departure of ship ORP "Arctowski"
January, 29	arrival of participants in Ushuaia, Argentina
January, 31	departure from Ushuaia, and arrival in Amsterdam later, via Buenos Aires
March, 12	arrival of ship ORP "Arctowski" in Scheveningen transportation of equipment to Utrecht

At Arctowski Station close to the Ecology Glacier, one of the summer laboratories served as base camp. Two computers were installed, one of them serving as a data acquisition facility. Reliable power supply is essential for the whole experiment, so particular attention was paid to it. For this reason a no-break system was used.
On the north side of the garages the balloon system was installed. The balloon itself was taken back into the store-house after every launch. In a windy place like King George Island this is absolutely necessary if one does not want to spend too much helium in emptying the balloon and filling it again when gale conditions occurred. In fact, the tethered balloon system can only be used when wind speed does not exceed 10 m/s. However, on average there are about 205 days in a year when wind velocity does exceed 10 m/s! During the measuring period 14 out of 29 days were not suitable for balloon experiments. On the 7^{th} of January a balloon with radiosonde was lost due to an operational accident.
Because of a very crevassed area on the Ecology Glacier at higher elevations, transportation of equipment appeared only possible by helicopter support which, unfortunately, was not available. Therefore, it was decided not to install two extra masts at higher elevations as originally planned.





The outer part of the Antarctic Peninsula (upper map) and Arctowski Station and its surroundings (lower map). On the latter the positions of the two masts and the two mass balance measurement sites (S1 and S2) are shown.

View on Arctowski Station, Admiralty Bay and Bransfield Strait.

3. EQUIPMENT

Meteorological instruments on the masts

Two masts were erected. Mast 1, the 'land mast', on a snow-free ridge about 60 m above sea level and 500 m from the summer labs. This mast also served as a relay station to improve data-communication. Mast 2, the 'ice mast', was placed at a distance of about 1 km from the calving edge of Ecology Glacier at an elevation of 100 m. This was about 500 m from the edge of the glacier along an existing winter track. The set-up is shown in the map on page 3.

The instrumentation was as follows:

mast 1:	temperature at 0.5, 2 and 6 m:	ventilated Aanderaa 2775
	shortwave up and down at 1.5 m:	Kipp CM14
	wind speed at 2 and 6 m:	Aanderaa 2740
	wind direction at 6 m:	Aanderaa 2750
mast 2:	temperature at 0.5, 2 and 6 m:	ventilated Rotronic YA-100
	humidity at 0.5, 2 and 6 m:	ventilated Rotronic YA-100
	shortwave up and down at 1.5 m:	Kipp CM14
	shortwave up and down at 1.5 m:	Aanderaa 2811
	wind speed at 2 and 6 m:	Aanderaa 2740
	wind direction at 6 m:	Aanderaa 2750

Some specifications of the sensors:

sensor	type	range	unit	precision
air temperature	Aanderaa 2775	-44 to +49	°C	0.1
air temperature	Rotronic YA-100	-20 to +28	°C	0.1
humidity	Rotronic YA-100	0 to 100	%	2
wind speed	Aanderaa 2740	0.2 to 60	m/s	0.2
wind direction	Aanderaa 2750	0 to 360	deg	4

sensor	type	spectral range	precision
pyranometer	Aanderaa 2811	300 to 2500 nm	3 W/m2
pyranometer	Kipp CM14	305 to 2800 nm	2 W/m2

A count of the sensors:

	number of sensors	transmitting power (Watt)	distance to base camp (km)
Station1	8	0.5	0.5
Station2	13	5	1.5

Picture of the mast on Ecology Glacier

The use of unguarded masts in a region where melting rates are considerable (nearly 80 cm of water equivalent in the measuring period) poses some special problems. A construction fixed to the ice could be made, but this would imply large changes in the height of the sensors. This is undesirable, in particular since turbulent fluxes have to be calculated. Instead a construction was designed that stands freely on the ice surface. It consists of a regular aluminium mast, with four long legs at the base, making a small angle (10°) with the surface ('spider mast'). At the end of these legs sharp pins are attached to keep the construction in place. A mast of this type was tested in a field campaign on the Hintereisferner (summer 1989) and appeared to work well. It was then decided to use this design on Greenland as well. During GIMEX-90, the masts behaved in a satisfactory way. On Ecology Glacier, in the beginning of the measurement period a 'spider mast' mast was placed on a 1.2 m deep snow cover. This was equally successful. When the snow cover decreased, the snow-ice transition of the surface appeared to form no particular problem.

Data assimilation

The system of registration was telemetric (RIDAS, Radio Interfacing Data Acquisition System). The sampling frequency for all sensors is 2 minutes; to this time, date, voltage of battery, load current of solar panel, and a dummy sensor are added.
First data are stored locally at the mast, and after some time send in packets to the receiving station in the laboratory. In practice, a disturbance in the radio connection during up to 28 hours can be handled with this system without loosing data. The sequential accumulation of data from all the stations is done in a fully computer-steered procedure. The total volume of physical data per day (excluding the cable balloon) amounts to about 21000 numbers.
Further equipment/specifications:

radio receiver, Kenwood TM431A/TH45
radio-telemetry with Packet Radio, Protocol AX25, 1200 bit/s, 451 MHz
computers: 2 x MacIntosh IIcx, removable drives.

Each mast has its own power unit (for ventilation of the temperature sensor and local computer/ transmitter), consisting of a solar panel (Siemens, 12 Watt) in combination with a regular battery, and a lithium battery to overcome periods with extremely low insolation.

The balloon

In addition to the masts, a cable-balloon system (with ADAS, Airborne Data Acquisition System) was used to obtain wind, temperature and humidity profiles up to a height of 1200 m. A 11.3 m^3 balloon was used, requiring one and a half bottle of helium for one filling. Some specifications:

- 11.3 m^3 balloon, helium, type Airborne K-65, weight 7.3 kg
- cable: 2000 m Twaron, 1 g/m.
- winch: electric, 750 Watt, especially made
- sonde 1: tethersonde
    - air temperature
    - wet-bulb temperature
    - wind speed
    - wind direction
    - pressure
- sonde 2: tethersonde
    - air temperature
    - relative humidity from a carbon hygristor
    - wind speed
    - wind direction
    - pressure

- data assimilation: ADAS (Atmospheric Data Acquisition System).

  The ground station is a basic ADAS-receiver, which receives six variables by telemetry: elapsed time, pressure, temperature, wet-bulb temperature or relative humidity, wind speed, wind direction. The ADAS then sends the data to a Macintoch IIcx computer in the laboratory. The operating frequency is 404 MHz.

Soundings were made three times a day at 09, 15, 21 hour local time, subject to the condition that it was not raining and wind speed at the surface was not exceeding 10 m/s. In total, 23 ascents were made in 29 days.

Mass balance measurements

During the course of the measuring period several density-depth and temperature-depth profiles were measured at two locations on the snow-covered Ecology Glacier. Density was measured by inserting a small stainless steel cylinder (diameter 5.1 cm, length 24.3 cm, volume 500 cm^3) horizontally into the snow from a snow pit. Snow temperature was measured with the Tempcontrol TA 402W by putting PT100-probes (length 40 cm) horizontally in the snow deck. Furthermore, when the snow cover became thinner and eventually disappeared, ablation stake measurements were performed. Along the existing wintertrack across Ecology Glacier snow-depth measurements were made.

Picture of measurements in the snow deck on Ecology Glacier.

4. SOME PRELIMINARY RESULTS

We have obtained a complete data-set for the period from the 17th of December 1990 until the 16th of January 1991. In the same period the Polish meteorologists performed the regular synoptic observations. Here we present some results, to give a first impression of the local meteorological conditions in relation to the ablation process.

Meteorological measurements

The weather at Arctowski is varying on a timescale of a few days or less. Short periods of sunny weather and periods with low cloud cover and precipitation succeed each other rapidly. Figure 1 shows the daily mean air temperature (2 m) at mast 1 and mast 2. Mean values are listed in the table.

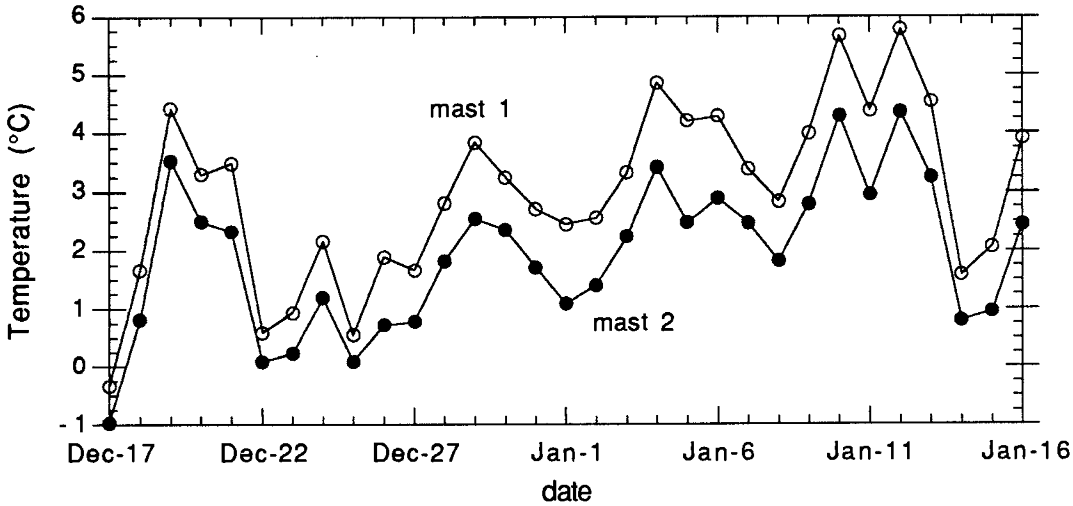


Figure 1. Daily mean air temperature (2 m) at mast 1 and mast 2.

The maximum temperature at mast 1 (2 m) was almost 8 °C on the 10th of January. The mean temperatures for the whole period are 3.0 °C and 1.9 °C for mast 1 and mast 2, respectively. The 10-year averaged December and January temperatures at Arctowski Station (1.6 °C and 2.2 °C respectively) show that the measurements took place in a relatively warm period. Relatively cold days were the 17th of December (after an even colder period), the 22th, 23th and 25th of December and the 14th and 15th of January. Warm days were the 10th and 12th of January.

	mast 1	*mast 2*
mean temperature at 0.5 m (°C)	3.3	1.5
mean temperature at 2 m (°C)	3.0	1.9
mean temperature at 6 m (°C)	2.9	2.8
wind speed at 2 m (m/s)	6.7	4.8
wind speed at 6 m (m/s)	6.9	5.7
shortwave down (W/m^2)	-	224.9
shortwave up (W/m^2)	-	154.6

Values of measured meteorological elements, averaged over the measuring period (31 days)

A characteristic feature of the subantarctic climate are periods with relatively strong, gusty, predominantly westerly winds. Also periods with winds from the east occur, transporting cold air from the Weddell Sea region to the South Shetland Islands. This is a relatively calm, laminar flow of cold air. Figure 2 shows the daily mean wind speed at mast 1 (6 m). Winds at Arctowski are highly variable in space and time, caused by the steep hills near Arctowski. Highest wind speeds occurred on the 23th of December and on the 10th of January when a short, intense gale took place (wind speeds up to 28.6 m/s occurred on the 10th of January). The mean wind speed at mast 1 (6 m) was 6.9 m/s.

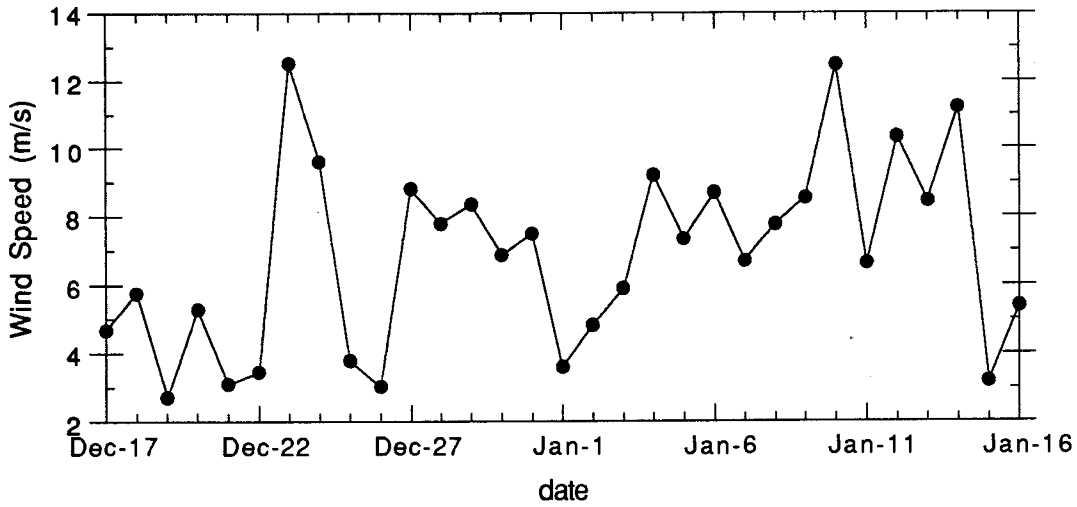


Figure 2. Daily mean wind speed (6 m) at mast 1.

In determining the total mass balance of a glacier or ice cap with an energy/mass balance model, the temperature lapse rate is an important input parameter [2]. The lapse rates calculated by linear fits to the 23 balloon soundings are shown in figure 3. In general, the deviation from a linear temperature profile is small. Only twice an inversion was observed (December 21 and January 16). The overall mean lapse rate was -6.2 K/km.

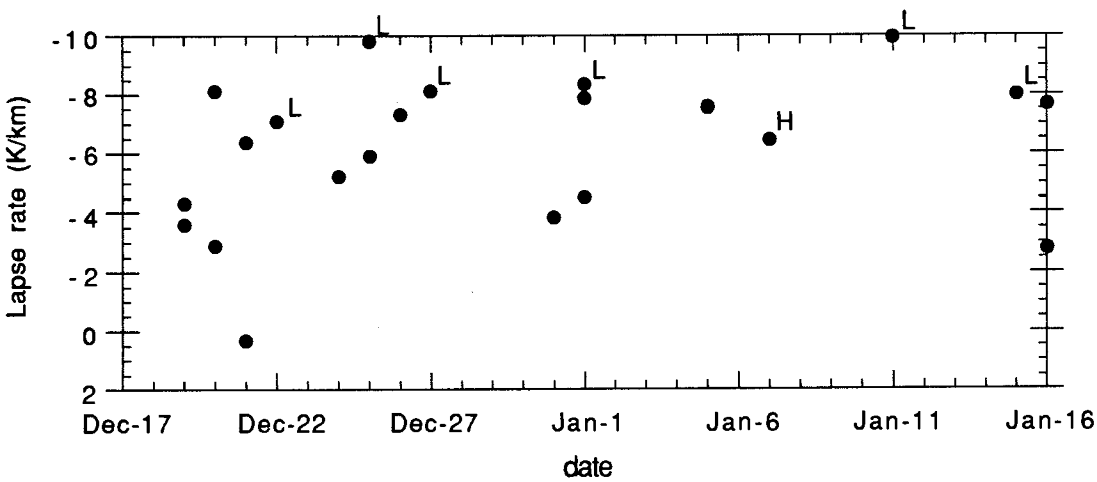


Figure 3. Lapse rates calculated from the 23 soundings. Results from low soundings (maximum height 400 m) are indicated by L and from a high sounding (maximum height 5000 m) by H.

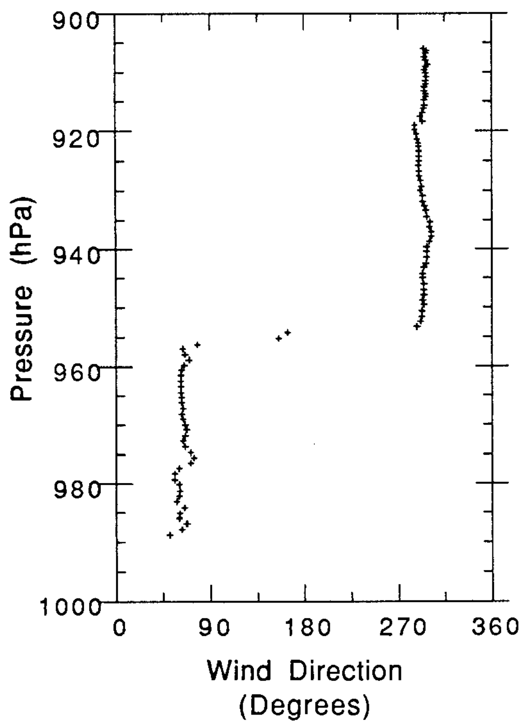


Figure 4 a) Wind direction profile on the 21^{st} of December, 21:00 LT.

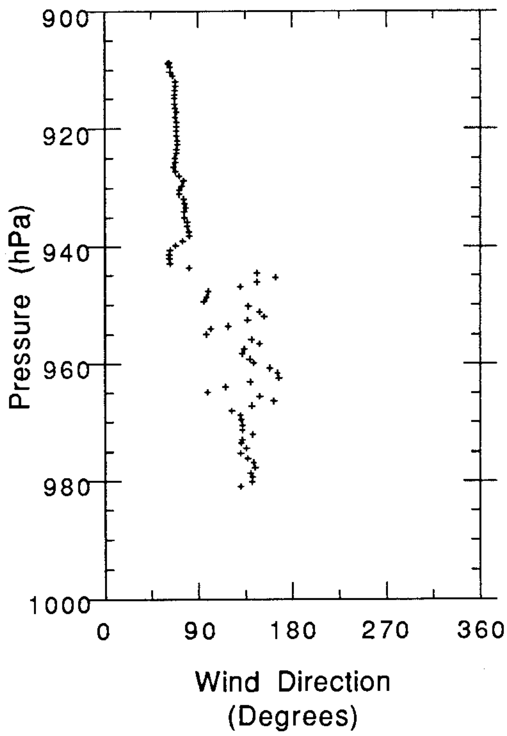


Figure 4 b) Wind direction profile on the 25^{th} of December, 09:00 LT.

Figure 4a shows a very interesting sounding. A large scale westerly wind in the upper layer is present above approximately 350 m and in the lower layer winds from the east prevail. The temperature and wind speed profiles show no discontinuity at the same height. At the same time, the Russian station Bellingshausen, situated at the south-west side of King George Island, reported westerly winds at all heights. This feature is caused by the special location of Arctowski Station at King George Island, see figure 5.

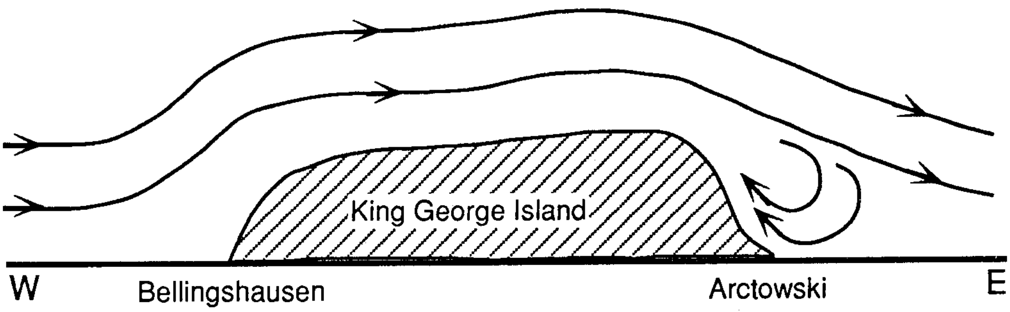


Figure 5. Wind structure around King George Island in case of a strong westerly wind.

Arctowski is situated in the lee side of the island. As a result, sometimes a lee rotor develops when there is a westerly wind across the island. Other effects of the topographic conditions on King George Island are the formation of orographic clouds (mainly *Altocumulus Lenticularis*)

and the lower mean cloudiness at Arctowski (6.2 oct) as compared to that of Bellingshausen (7.1 oct).
Figure 4b shows a sounding of the 25th of December. Up to 910 hPa there is wind from easterly directions. This type of profile occurs only in relatively cold periods (the 17th, 22nd and 25th of December, the 1st and 15th of January). In these situations, wind speeds are usually low.

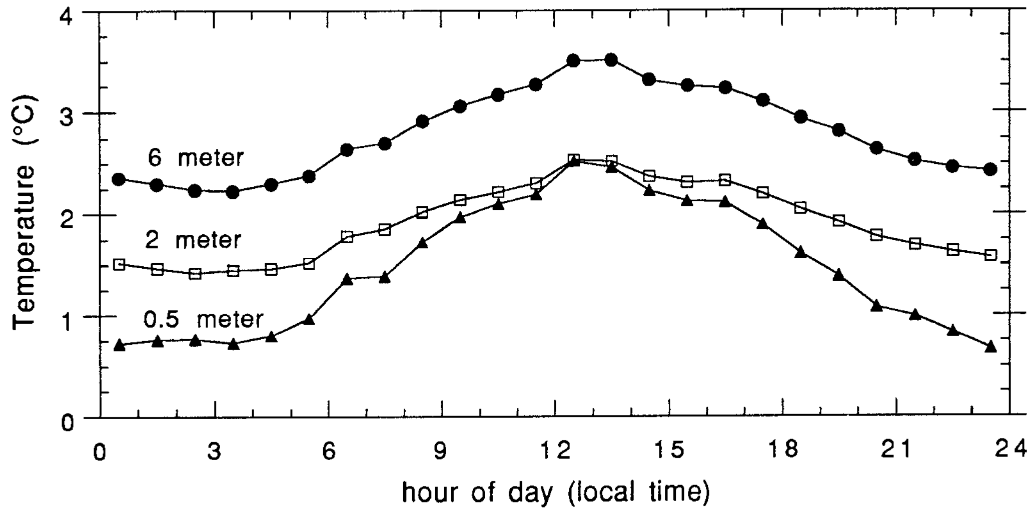


Figure 6. Mean daily cycle of the temperature at mast 2. The time of maximum solar elevation is 12:52 LT.

Interesting is the daily course of the temperature at different heights at mast 2, averaged for the whole measuring period, as can be seen in figure 6. Mean temperature amplitudes are 1.3 °C (6 m), 1.1 °C (2 m) and 1.8 °C (0.5 m). The formation of a relatively warm layer near the surface of the glacier is striking. This happened only during calm, sunny periods, suggesting that a combination of absorption of short-wave radiation in the very moist lower layer and the absence of a turbulent sensible heat flux to the surface is the cause of this heating. It ends when either wind speed is increasing or insolation is decreasing. Then cooling occurs through an increasing downward turbulent sensible heat flux or a negative radiation balance of this lower layer (the net outgoing longwave radiation is positive). By this mechanism, the surface gains a 'delayed' amount of additional energy at the end of the day.

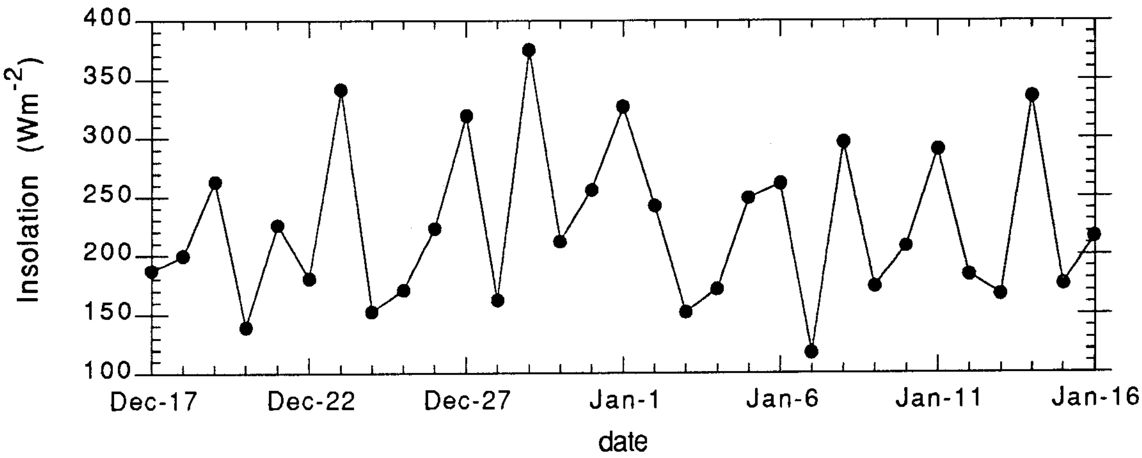


Figure 7. Daily mean insolation at mast 2.

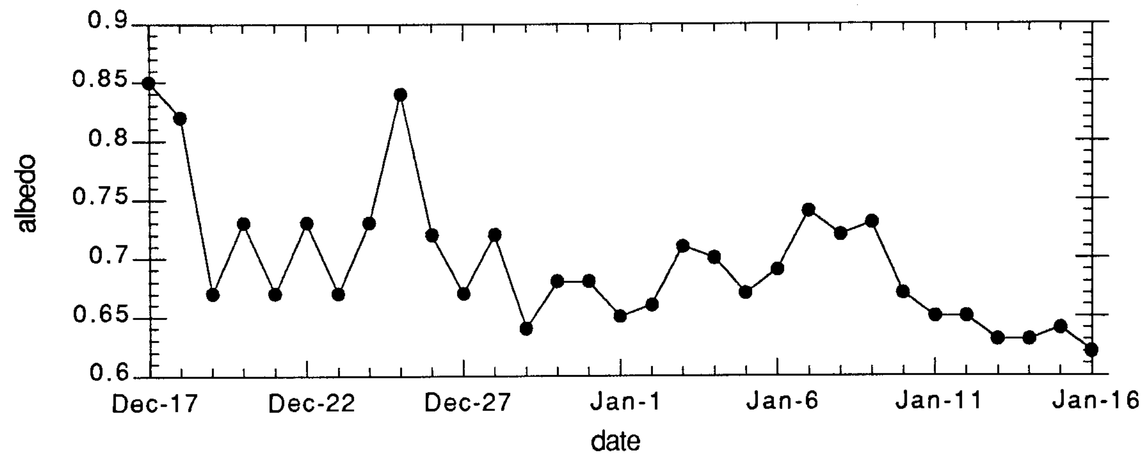


Figure 8. Daily mean albedo at mast 2.

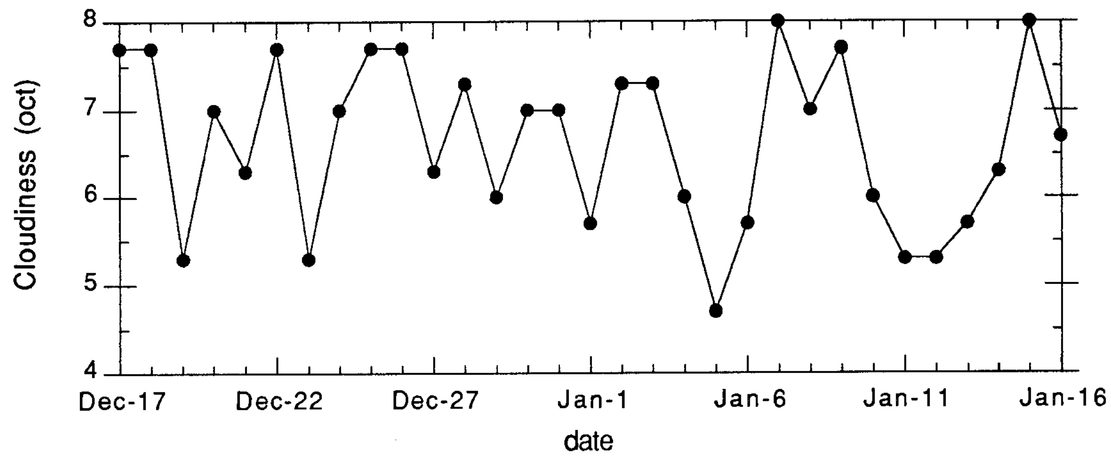


Figure 9. Daily mean cloudiness.

The value of the albedo is very important for the energy balance of a glacier's surface and therefore for the ablation [3]. The albedo depends strongly on the type of surface. Melting snow, which was the surface type for most of the measuring period at mast 2, has a clear-sky albedo of 0.65 – 0.70. Figure 7, 8 and 9 give an impression of the high variability of the daily mean insolation, albedo and cloudiness.

The mean albedo is equal to 0.69. Until the 11th of January the variability of the albedo can be completely attributed to variations in cloud cover ([4], [5]). At high latitudes, cloud cover tends to increase the mean zenith angle of incoming solar radiation (because diffuse radiation has a larger share) and thereby to decrease the albedo. Moreover, clouds change the spectral composition of the radiation. They cause a shift to the visible part of the spectrum where the albedo of snow is relatively high. In this way, clouds increase the snow albedo. It is obvious from figure 7,8 and 9 that the spectrum-shift is the most important factor. After the 11th of January the snow deck disappeared, leaving only ice and patches of snow. Consequently the albedo dropped to 0.63 or less. Then, a much lower variability of the albedo was observed.

Ablation measurements and calculations

Ablation was measured at 3 locations (see map): at mast 2 (elevation 100 m), at S1 (Ecology Glacier, border; elevation 35 m) and at S2 (elevation 200 m). At S2 two density-depth profiles were measured, which are shown in figure 10. As usual, during the melting season the thickness of the snow deck decreases while the density increases. Approximately half of the

melted upper layers of snow penetrated downward as meltwater and froze in the lower layer or stayed there as liquid water. The other half penetrated through the snow deck and reached the temperate ice where it ran off.
At mast 2 density-depth profiles were measured, and when the snow cover thinned and eventually disappeared, ice-stake measurements were carried out. In figure 11 two of the measured density-depth profiles are shown. The mean column density seems to remain fairly constant during the melting period, while the snow depth decreases. In figure 10b the lowermost layer (thickness = 13 cm, density = 880 kgm^{-3}) is not shown as the densification of this layer seemed to be caused mainly by the horizontal inflow of meltwater. Otherwise, a serious underestimation of melting would be made. The snow depth measurements support this view. Table 1 summarizes the ablation rates for the three measuring sites.

location	elevation (m)	period (days)	ablation (cm w.e. day^{-1})	pdd (K)	ddf (cm w.e. $K^{-1}day^{-1}$)
mast 2	100	32	2.3	60.3	1.2
S1	35	7	5.6	21.8	1.5
S2	200	19	0.8	33.8	0.4

Table 1. Measured ablation rates. Values of pdd are calculated from mast 2 temperatures and the lapse rate.

At S1 a very high ablation is measured, which is caused by an extremely low albedo associated with morainic material covering the glacier (the albedo ranges from 0.08 to 0.25 according to differences in the time of day, cloudiness and surface conditions). At S2 the albedo is somewhat higher than at mast 2. Therefore, the degree-day factor (ddf) decreases with height due to increasing albedo and the ablation-delaying effect of a thick snow pack (storage of melt water).

The measured snow temperature appeared to be always 0 °C throughout the column. The apparent constancy of the density at mast 2 provides an additional possibility to calculate ablation from snow depth measurements. The results, together with ablation measurements at S1 and S2, are shown in figure 12.

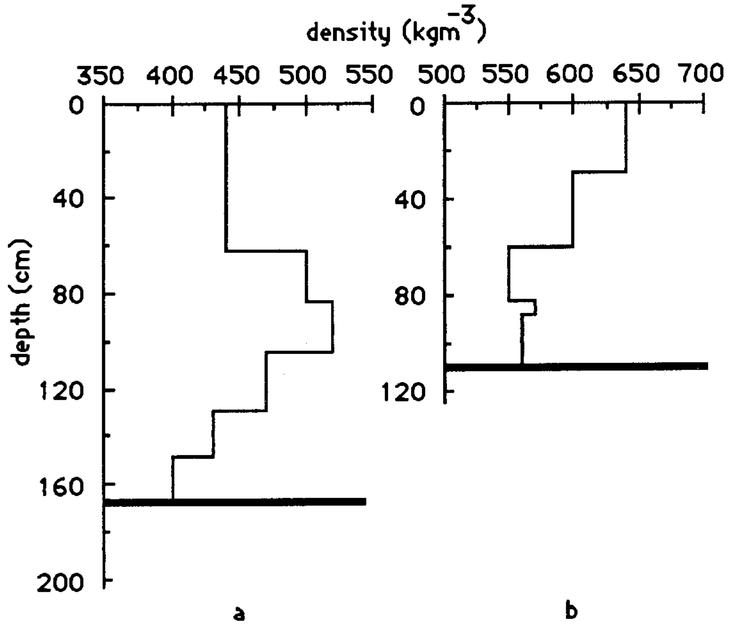


Figure 10. Density–depth profiles at S2. a) December 28, 12:00 LT. b) January 15, 12:00 LT.

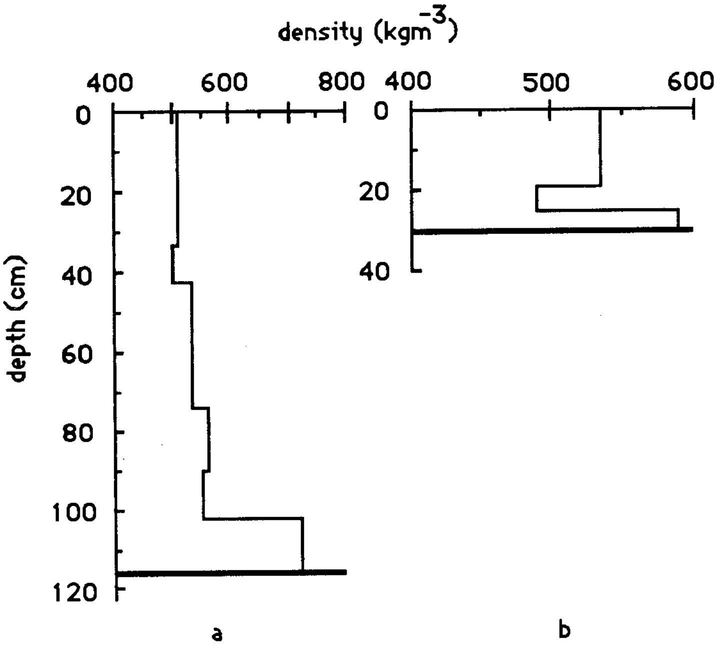


Figure 11. Density–depth profiles at S1. a) December 16, 15:00 LT. b) January 10, 12:00 LT.

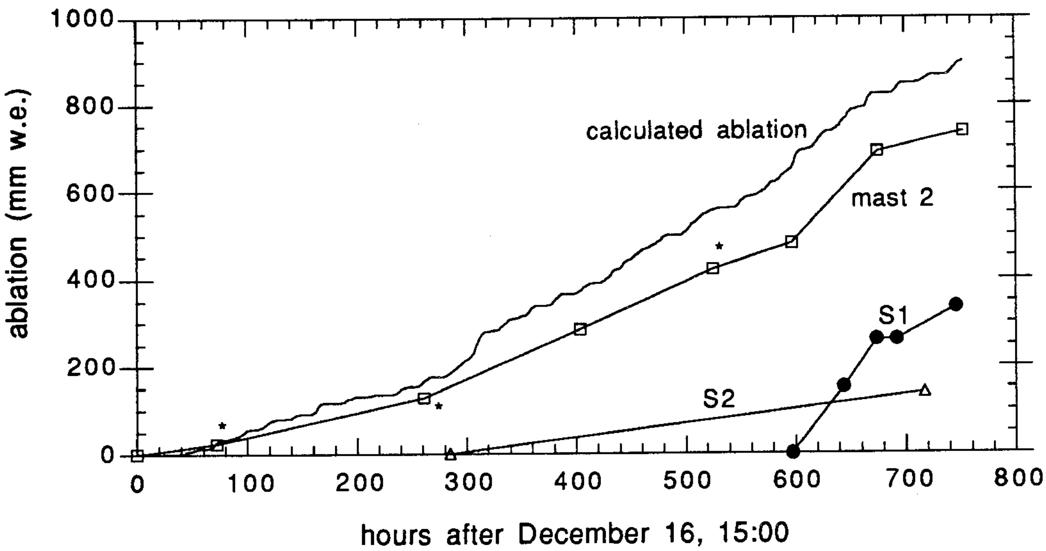


Figure 12. Measured cumulative ablation for S1 and S2 together with the measured and calculated ablation for mast 2. Results with an asterisk are calculated from snow depth measurements. For explanation of E1 and E2, see text.

To compare the measured ablation with calculations, the long wave radiation and the turbulent fluxes have to be determined. For the incoming long wave radiation, a radiation model has been used. The most important input parameters are: temperature, humidity, lapse rate, cloudiness and cloud base height. For the outgoing longwave radiation it was assumed that the surface radiates as a black body with temperature T_S.

In calculating the turbulent fluxes the Monin-Obhukov similarity theory was used, taking into account the influence of stratification. Input parameters: temperature (0.5 m and surface), humidity (0.5 m and surface), wind speed (2 m) and the surface roughness lengths for momentum, heat and moisture. The values of the surface roughness lenghts may be not constant during the measuring period because of the changing surface of the glacier. Nevertheless, constant values are taken for the whole period: 1 mm (momentum) and 1 cm (heat and moisture).
Part of the available energy at the surface is used for heating of the snow deck by refreezing of melt water (and conduction). Therefore, a model was constructed which calculates the temperature profile in the snow deck (similar to the model of Greuell and Oerlemans, 1986).

The result is shown in figure 12. The calculated cumulative ablation is much higher then the measured ablation, especially after the 29th of December when a relatively short, intense gale with high temperatures occured, causing an increase of the calculated ablation. Variation of the surface roughness lengths can change the turbulent fluxes and, therefore, the total ablation considerably.
To get insight in the relative importance of the three major contributors to ablation at mast 2 we set the total energy balance at 100%. Then, the gain of energy by absorption of short wave radiation is 75% and by the turbulent fluxes 35%. The net emission of long wave radiation causes a loss of energy of 10%.
In spite of the fact that ablation at King George Island occurs throughout the whole year (even in winter periods), ablation measurements performed by the Polish meteorologists in February and March 1991 show that in this period main ablation took place within two months, from about the 20th of December until the 20th of February. Therefore, the measuring period covered nearly half of the effective ablation period.

5. CONCLUSIONS

A list of conclusions and points of interest:

Equipment and experimental set-up:

* Power supply with solar panels at the masts is satisfactory for summer experiments. Snowdrift may cause problems.
* RIDAS works well; much of the data handling has been done in the summer laboratory during the experiment.
* The balloon data are of good quality, but only a small number of ascents were made. This is a direct consequence of the bad weather conditions in this region.
* Snow–density measurements are quite easy to perform, 5 density-depth profiles could be made.
* Ablation stake holes were successfully made by hand–drilling (although only two stakes were placed).
* Snow–temperature measurements encountered some technical difficulties. The equipment turned out to be sensitive to moisture. Further testing should be carried out.

Preliminary results:

* Weather at King George Island is variable on a few days time scale, due to the rapid eastward movement of low pressure systems around Antarctica.
* The mean temperature (2 m) is 3.0 °C at mast 1 and 1.9 °C at mast 2.
* The wind direction is predominantly west although short periods of wind from the east occur. Mean wind speed is 6.9 m/s.
* The mean lapse rate, obtained from the balloon soundings, is equal to -6.2 K/km.
* The topography of King George Island causes significant mesoscale phenomena: turbulence around the island, lee rotors, gravity wave formation and large variations in cloudiness.
* In a thin layer above the glacier warming occurs during windless, sunny periods, affecting the glaciers surface energy balance.

* The mean albedo is 0.69 at mast 2. Albedo variations are mainly caused by fluctuations in cloudiness.
* Measured ablation is high at lower elevations and decreases rapidly with height due to an increasing surface albedo and snow depth.
* Ablation is low compared to the Greenland ice margin due to a higher albedo and much lower temperatures.
* The energy used for melting at mast 2 is partitioned as follows: absorption of short wave radiation (+75%), turbulent heat fluxes (+35%) and the emission of long wave radiation (-10%).

6. PARTICIPANTS

L. Conrads (field leader)
M. Portanger (technician)
R. Bintanja (Ph.D. student)

General project leader: J. Oerlemans
General expedition leader: L. Conrads

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