Greenland Ice Margin EXperiment (GIMEX)

GIMEX-91 Field Report

Institute for Marine and Atmospheric Research
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GIMEX-91 Field Report

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Cover: NOAA-10 image of Greenland, taken on July 25, 12:04 UT (AVHRR, Ch. 2). Note the dark band on the ice sheet in the study area, showing increased albedo due to accumulation of melt water at the surface (compare figure 5).
Courtesy Danish Meteorological Institute.

1. INTRODUCTION

GIMEX-91 (Greenland Ice Margin EXperiment) forms a part of the research project on *Land Ice and Sea-level Change*, carried out at the Institute for Marine and Atmospheric Research (formerly Institute of Meteorology and Oceanography), University of Utrecht. It is the second meteorological field experiment in the South-West of Greenland. The general aim of the project is to support modelling studies of the Greenland ice sheet in which physical processes determining the ablation are treated as explicitly as possible. Of particular interest is the relation between the radiation balance and clouds, the surface albedo, and the treatment of the turbulent fluxes. Other interesting points are the local circulation induced by the large thermal contrast between the warm tundra and the ice sheet, and the structure of the atmospheric boundary layer close to the ice margin.

In 1991 the field work has been carried out in close collaboration with two research teams of the Free University of Amsterdam and the University of Amsterdam. Besides, a close international collaboration exists with the Geological Survey of Greenland, The Eidgenossische Technische Hochschule in Zürich and the Alfred-Wegener Institut für Polar- und Meeresforschung.

The project is funded by the following bodies/institutions: the University of Utrecht, the Free University, the University of Amsterdam, the European Commission, NWO (the Netherlands Organization for Scientific Research), and VROM (the Ministry of Housing, Physical Planning and Environment).

2. LOGISTICS

Transportation of the equipment was partly determined by the previous expeditions carried out by our institute (referred to as GIMEX-90 and Arctowski-90/91). A part of the equipment (trucks, boat and camp gear) was stored in our container in Søndre Strømfjord during the winter

of 1990/1991. The meteorological instruments, used on King George Island (Antarctica) in the 90/91 Antarcic season, were sent by air to Søndre Strømfjord at the end of May.
The following scheme provide a synopses of the logistics.

time table

Sept.-Feb.		constructing an improved datalogger, maintenance of the meteorological instruments
March,	12	arrival of ship ORP "Arctowski" in Scheveningen transportation of equipment to Utrecht
March,	13-29	modification of the dataloggers, as well as fixing and calibration of the instruments
April,	4-24	field test of the equipment in Cabauw
April 24- May	3	packing of the equipment
May,	8	transport of 39 boxes to Søndre Strømfjord
May,	26	departure of group 1 (Boot, Van den Broeke, Duynkerke, Snellen)
May 28-June	9	installation of the camp and the meteo masts
June,	10	first day of complete measurements
July,	5	departure of group 2 (Portanger, Russell, Van de Wal)
July,	6/7	changing the guard
July,	31	last day of experiment
August,	23	transport of equipment by ship to Aalborg
September,	20	arrival of container in Utrecht

The same location as last year was used for the base camp. Since the team (5 persons) from the University of Amsterdam was living in the same camp, a large number of tents was erected (up to 12). Basically the same concept was used, one tent for living, one for cooking, one for the electronics, and, for each expedition member, one sleeping tent. The telex car was used as a small computer centre for data acquisition and data reduction. The other truck was extensively used for transportation of people, gas and food between the airport and the camp. In spite of the difficult terrain conditions, the 30 year old cars survived with only minor problems. Unfortunately the major road to the ice margin was damaged in the beginning of the field season by the heavy weight of the cars in combination with the water-saturated soil.

3. EQUIPMENT

Seven masts were erected along a line perpendicular to the ice edge, basically similar to last year's experiment. Two additional masts were installed for the audio- and data-communication. Based on the experience from last year, minor changes were made in the set up. Since mast 1 and mast 2 gave very similar results in 1990, it was decided to install mast 1 close to mast 3, but on the exposed top of the hill, overviewing the ice sheet margin. Mast 2, 3, 4, 5 and 6 were located at the same sites as during the GIMEX 90 expedition. To get a better reference for the balloon measurements, mast 7 was installed close to the balloon site. At this site bottom temperature was measured to a depth of 40 cm under the surface at six levels. Furthermore a few additional sensors were added at mast 4 (wind speed at 0.5 and 1 m and total radiation up and down). The complete set up is given in the following list and in figure 1.

Instrumentation:

Station 1:	temperature at 2 and 6 m:	ventilated Aandera 2775
	wind speed at 2 and 6 m:	Aandera 2740
	wind direction at 6 m:	Aandera 2750

Station 2:	temperature at 2 and 6 m:	ventilated Aandera 2775
	wind speed at 2 and 6 m:	Aandera 2740
	wind direction at 6 m:	Aandera 2750
Station 3:	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
	total radiation up and down at 1.5 m:	Aandera 2811
	wind speed at 6 m:	Aandera 2740
	wind direction at 6 m:	Aandera 2750
Station 4:	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
	total radiation up and down at 1.5 m:	Aandera 2811
	wind speed at 0.5, 1, 2 and 6 m:	Aandera 2740
	wind direction at 6 m:	Aandera 2750
Station 5:	temperature at 2 and 6 m:	ventilated Aandera 2775
	shortwave up and down at 1.5 m:	Kipp CM14
	wind speed at 2 and 6 m:	Aandera 2740
	wind direction at 6 m:	Aandera 2750
Station 6:	temperature at 2 and 6 m:	ventilated Aandera 2775
	shortwave up and down at 1.5 m:	Kipp CM14
	wind speed at 2 and 6 m:	Aandera 2740
	wind direction at 6 m:	Aandera 2750
Station 7:	temperature at 0.5 and 6 m:	ventilated Rotronic YA-100
	shortwave up and down at 1.5 m:	Kipp CM14
	wind speed at 6 m:	Aandera 2740
	wind direction at 6 m:	Aandera 2750
	temperature at -2, -5,-10, -18,-27,-41 cm	PT100-probes (with TA402W)

Some specifications of the sensors

sensor	type		range				precision
air temperature	Aandera	2775	-44	to	+49	°C	0.1
air temperature	Rotronic	YA-100	-20	to	+28	°C	0.05
bottom temperature							
humidity	Rotronic	YA-100	0	to	100	%	2
wind speed	Aandera	2740	0.2	to	60	m/s	0.2
wind direction	Aandera	2750	0	to	360	∞	4

sensor	type		spectral range				precision
pyranometer	Aandera	2811	300	to	2500	nm	3 W/m^2
pyranometer	Kipp	CM14	305	to	2800	nm	2 W/m^2
pyrradiometer	Aandera	2770	300	to	60000	nm	3 W/m^2

Number of sensors per station

	number of sensors	transmitting power (Watt)	distance to base camp (km)
station 1	5	0.5	1.0
station 2	5	0.5	5.8
station 3	12	0.5	0.2
station 4	15	5	2.6
station 5	7	5	7.3
station 6	7	20	38.8
station 7	12	0.5	0.1
total	63		

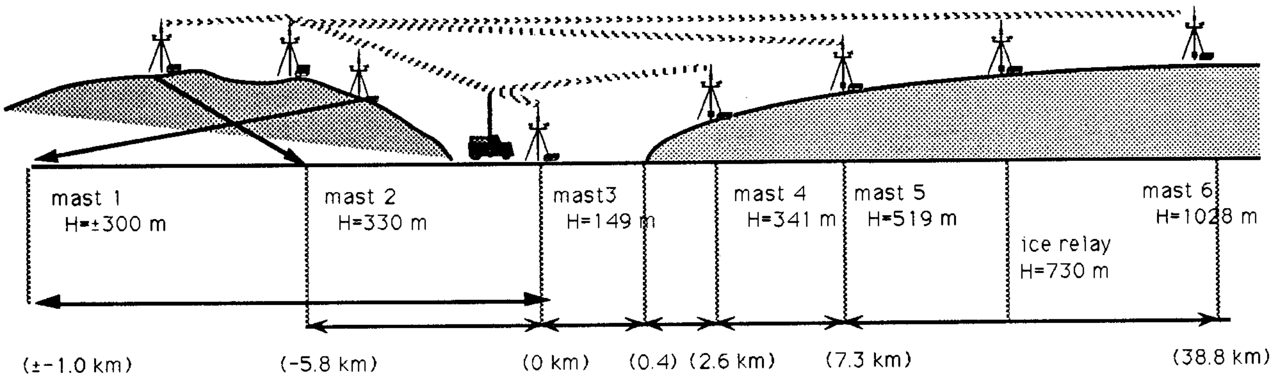


Figure 1. *The position of the masts along a line perpendicular to the ice edge near Søndre Strømfjord.*

A few remarks should be made concerning the set up. In spite of the longer measuring period, 51 days compared to 31 last year, the unguarded masts worked quite well during the whole period. Only the mast of the relay station on top of the mountain hill broke during a storm at the end of June. One day of data from mast 1 was lost due to eating of the electrical cables by snow rabbits. A problem encountered last year as well, but not properly solved. The applied construction for the ice masts consisting of four long beams with sharp pins at the end worked out fine again during a period with roughly 2.5 m of ablation, no adjustments were needed. Whether this will always be the case in an active zone like the ice margin in this area remains unclear. Crevasses, superglacial melt streams, and the development of irregularities can cause insurmountable problems for applying unguarded masts. Due to these processes the tilt of the relay station on the ice was about 15° by the end of the period.

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.

Data assimilation and data processing

The system of registration was telemetric (RIDAS, Radio Interfacing Data Acquisition). The sampling frequency for all sensors was 2 minutes most of the time. Due to bad data communication with station 6, sampling frequency was reduced to every 10 minutes during periods of bad weather. In addition to the sampling of the sensors, time, date, voltage of the battery, load current of the solar panel(s) and a dummy sensor value were also sampled.

First data is stored locally at each mast, and after some time send in packets of 70 minutes' data to the receiving computer in the telex truck. In practise, a disturbance in the radio connection during up to 28 hours can be handled with this system without loosing data. Reduction of the sample interval to 10 minutes gives 5*28 hours local storage memory. The sequential accumulation of data from all the stations is done in a fully computer-steered procedure. On-line graphical display of the data enables quick adjustments of this procedure as well as a good physical insight in the on-going meteorological processes. In the morning the data of the previous day were reduced to 10 minute-, 30 minute- and hourly mean values, and simple energy balance calculations were done. Since calibration of the instruments has been done before, a complete "cleaned" and reduced data set was available a few hours after the last measurements. The complete data set, including balloon measurements (without back-ups), amounts roughly 100 Mb.

specification of the applied equipment:

- data loggers especially made RUU
- radio receiver, Kenwood TM431A/TH45
- radio-telemetry with Packet Radio, Protocol AX25, 1200 bits/s, 451 MHz
- computers, 2 x Mac Intosh IIcx, removable drives

The balloon measurements

In addition to the masts, a cable balloon system (with ADAS, Airborne Data Acquisition System) was used to measure wind, temperature and humidity profiles up to a height of 1000 m. A 11 m^3 balloon filled with helium was used.

specifications of the applied equipment:

balloon 1:	11.3 m^3, helium, type Airborne K-65, weight 7.3 kg.
balloon 2:	identical to balloon 1
cable:	2500 m Twaron, weight 1 g/m.
winch 1:	electric, 750 Watt, especially made
winch 2:	identical to winch 1

sonde 1: tethersonde
- air temperature
- wet bulb temperature
- wind speed
- wind direction
- pressure

sonde 2: tethersonde
- air temperature
- humidity from a carbon hygristor
- wind speed
- wind direction
- pressure

ADAS receiver operating at 404 MHz

The ADAS receiver samples 6 variables every 10 seconds: elapsed time, pressure, temperature, humidity, wind speed and wind direction. The ADAS sends the data to a Macintosh IIcx computer in the telex truck. Missing values and incomplete data strings are filtered by a simple computer program. The soundings were made every day at 07, 10, 13, 16, 19, 22, 01 and sometimes at 04 local time, subject to the condition that it was not raining and wind speed close to the surface at ± 6 m was not exceeding 10 m/s. In total approximately 220 ascents were made in 51 days. Until 18 July the measurements have been carried out with sonde 2 and balloon 1.

After the cable broke during the ascent of 16 LT, measurements were continued with sonde 1 and balloon 2.

Measurements of the soil temperature

To be able to calculate the heat flux in the tundra soil, temperatures were measured at several depths. Soil temperature was measured with the tempcontrol TA 402W by putting PT100-probes (length 40 cm) horizontally in the bottom at six different levels varying from 0 to 40 cm below the surface. Readings were done manually before and after each balloon ascent.

Mass balance measurements

The mass balance measurements were more successful this year, in spite of the fact that most stakes broke again during the winter. The crucial point in the stake measurements is finding the stakes. With help of GPS positioning, stakes could be found back, even if they were only visible for 15 cm above the ice surface at about 90 km from the ice margin! New stakes were drilled using a portable hot-water drill with a moderate drilling velocity of 6 m/30 minutes. The complete stake net was redrilled at the end of the summer with six meter long stakes, which will be measured at the end of the next melting season (August 1992).

Positioning and navigation

For navigation and positioning, two Magellan GPS NAV-1000 receivers were used. A larger number of satellites enabled use of the system during 23.5 hours a day in this area in the summer of 1991. By using the instruments in differential mode accurate positions (standard error of ± 10 m in the 3-dimensional mode) can be obtained. The first results of the displacement of the stakes are available now, since these measurements were carried out last year as well. The results are promising, as will be described in the next chapter.

Runoff measurements

To compare river discharge and ablation near the ice margin, runoff measurements were carried out. The measurements were done at the Sand Dune site in the Watson river 1.5 km to the west from the base camp. A pressure transducer was placed in a plastic pipe, and pressure and time were logged with a squirrel data logger every 10 minutes. To be able to convert pressure to discharge, velocity measurements were carried out during the whole period. All together 20 velocity cross-profiles were measured ranging from low discharge to peak discharge. Interesting were the irregular floods occurring close to the camp, caused by blocking of ice upstream from the camp site. Once ice blocks reached the terrace level and were deposited on the grass vegetation close to the balloon site. The data was downloaded once a week on a Macintosh Portable.

4. SOME PRELIMINARY RESULTS

It is of course impossible to give a full description of the results immediately after the experiment. Instead, a selection is presented to give a first impression of the data set. In some tables and figures, results from the previous experiment (GIMEX-90) will be presented for comparison.

Meteorological measurements

Figure 2 shows daily mean values of air temperature over the area with the warm tundra on one side and the cold ablation area (height ± 1000 masl) on the other side. The weather conditions were quite stable with only short periods of cold rainy weather. The total amount of rainfall was

43 mm (at base camp), which is roughly one third of the mean annual precipitation. The 27th of July gave 17 mm rainfall. The temperature at the different masts show the same general trend, although the amplitude of the changes from day to day are of cause different. The maximum temperature at mast 3 (2 m) was 18.2 °C on the 9th of July. The daily mean wind speed shows a less coherent structure between the different masts, see figure 3. A period of stormy weather gave 2-min average wind speeds of 25 m/s at mast 1 on the 29th of June.

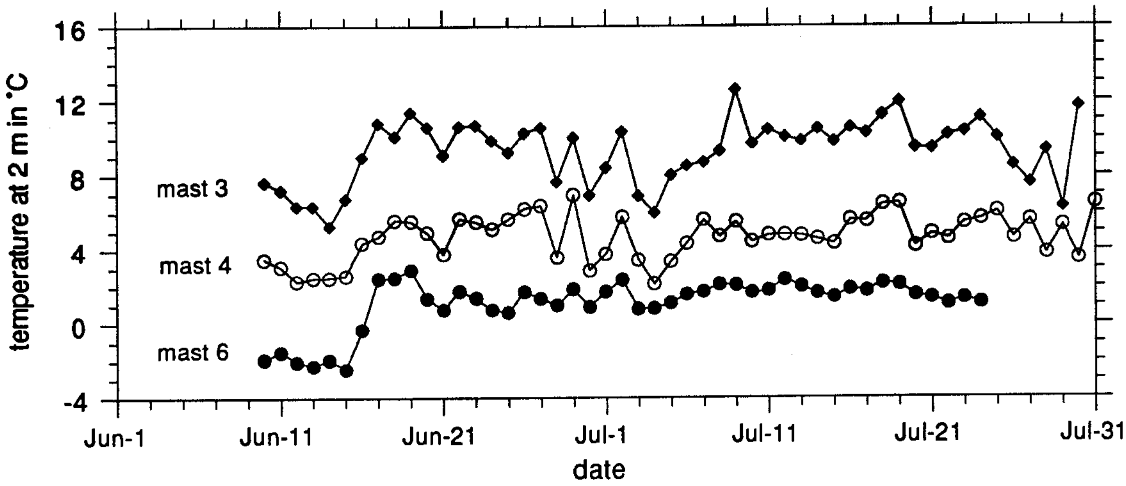


Figure 2. *Daily mean air temperature at 2 m, at mast 3, 4 and 6.*

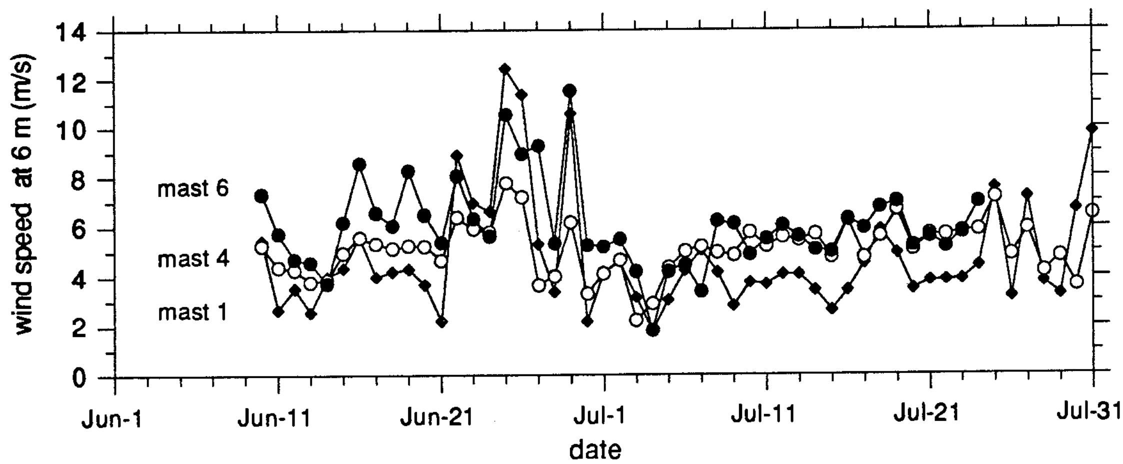


Figure 3. *daily mean wind speed at 6 m at masts 1, 4 and 6. The winds on the ice sheet are generally stronger.*

Table 1 shows a comparison of a few quantities measured at mast 4 in the summers of 1990 and 1991. It should be noted that the data from 1990 are mean values for the period 18th of July till the 17th of August. The data for 1991 are mean values for the period 10th of June till the 31rst of July. In spite of this it can be concluded that the summer of 1991 was colder and the wind speed was lower. The relative humidity above the ice seems to be rather constant in spite of the differences in temperature between both years. The net radiation on the other hand was considerably higher in 1991 (more sunshine). Altogether, this gave a larger amount of energy available for melting, and therefore a higher ablation rate.

Table 1: *Comparison between 1990 and 1991 measurements, mast 4.*

	1990	1991
dd 6 m (°N)	121	110
ff 6 m (m/s)	6.0	5.1
T 6 m (°C)	6.5	5.1
RH 6 m (%)	71	69
ff 2 m (m/s)	5.1	4.6
T 2 m (°C)	5.9	4.7
RH 2 m (%)	73	75
Q in (W/m^2)	172	262
Q net (W/m^2)	88	117
albedo	0.49	0.55

Mass balance measurements

Ablation was measured at 7 locations: masts 4, 5, 6, the ice relay and three additional sites (referred to as 7, 8 and 9) which are along the same transect higher on the ice sheet. The elevation of the stake locations runs from 340 to 1520 m.a.s.l.. As these places were not visited on exactly the same days, the duration of the period over which the ablation was measured differs somewhat. On each location 1 to 4 stake readings were carried out. Comparing the results of the different readings on one location shows only minor differences (< 5%). Figure 4 has been composed by converting all ablation data to yearly mean values for the different locations. In spite of the inaccuracy introduced by this conversion, a fairly good linear ablation gradient of 0.003 m w.e./m shows up, a value which corresponds well with other measurements in dry regions in Greenland. From this figure an equilibrium-line altitude of 1600 masl can be derived, which is rather high.
Comparing these results with the previous year reveals a lower ablation for this season, ± 4 m for mast 4 to ± 4.5 m for the previous season. It is impossible to explain this result because of the limited meteorological data available over the whole length of the ablation seasons 1990 and 1991. It should be recalled that the results, as mentioned in table 1, indicate a higher ablation rate in 1991. Hopefully the ablation measurements will be continued several years more to get a better insight in the interannual variation of the ablation.

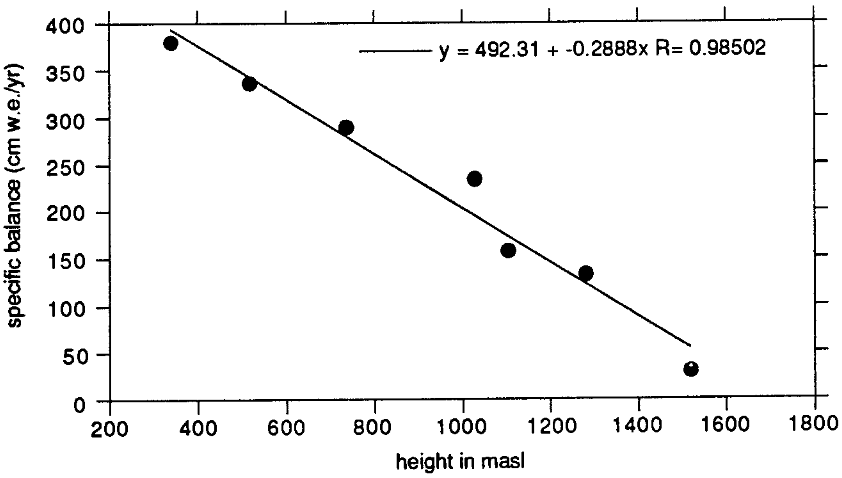


Figure 4. *Specific mass balance as a function of height over a area perpendicular to the ice edge near Søndre Strømfjord, covering the period ± 15 August 1990-15 August 1991.*

Surface albedo

One of the most interesting and important parameters in energy balance calculations for an ice surface is the albedo. This year reliable results were obtained from all our five stations with shortwave radiation sensors. Mast 3 and 7 located in the tundra show a constant albedo of 0.19 throughout the season. More striking is the surprising decrease in albedo at mast 6 during the season, a result resembling the observations on Alpine glaciers but in disagreement with our previous observation at the margin of the Greenland ice sheet last year. Comparing the albedo with the temperature measurements (figure 5) shows that the first decrease in the albedo seen at mast 4,5 and 6 after the 15th of June corresponds with a noticeable increase in the mean temperature. So it is likely that the increasing temperature results in more melt water at the surface. More meltwater at the surface reduces the albedo and a low albedo increases the absorbed energy for melt increasing the meltwater production, a positive feedback loop. Two days of cold weather, the 4th and the 5th of July, clearly show the opposite effect, namely, an increase in the albedo at the ice masts. Therefore it is not surprising that plotting temperature and albedo against each other gives a very high correlation, as shown in figure 6. As already noted in table 1, the albedo at mast 4 was significant higher this year than in 1990, 0.55 versus 0.49. This is in contrast with the negative correlation between albedo and temperature in figure 6, indicating a decrease in the albedo of 0.013 at mast 4 for an increase of 1 °C. An attempt to explain variations in albedo by the variations in cloud conditions failed. Plotting the incoming radiation as a measure for the cloud cover, versus the albedo resulted in a random scatter plot. But an interesting result is obtained when the albedo is plotted versus the calculated ablation, as considered in the next paragraph. The negative relation between meltwater production and albedo, as indicated in figure 7, proves once more that water on the surface is the dominant parameter which explains variations in albedo at one location.

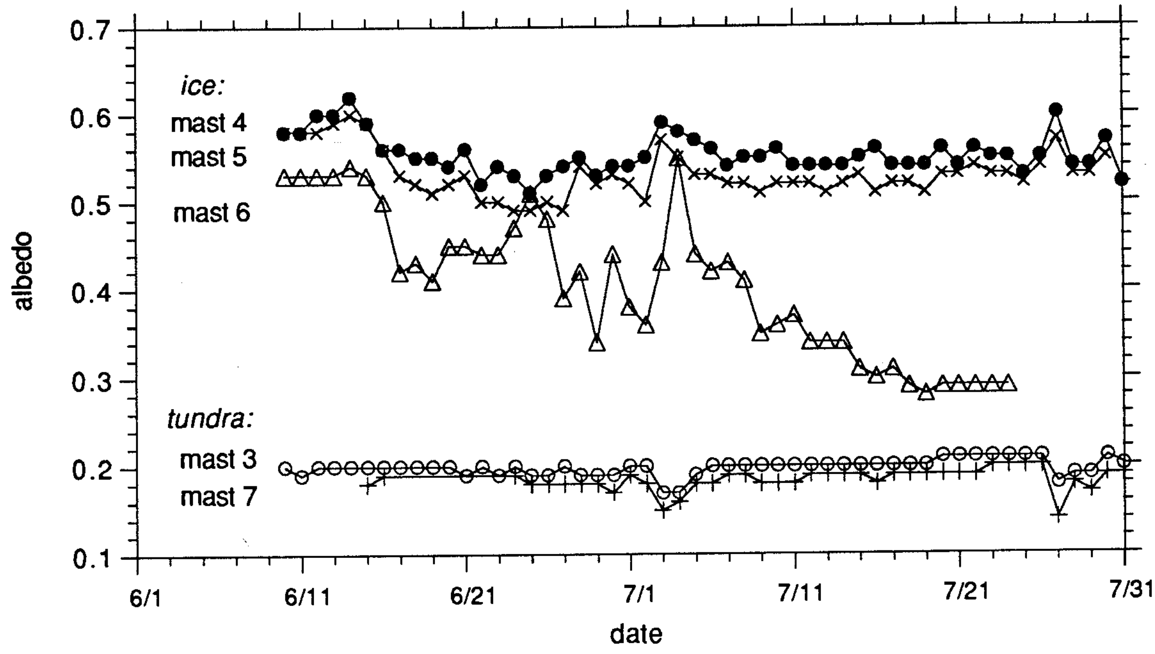
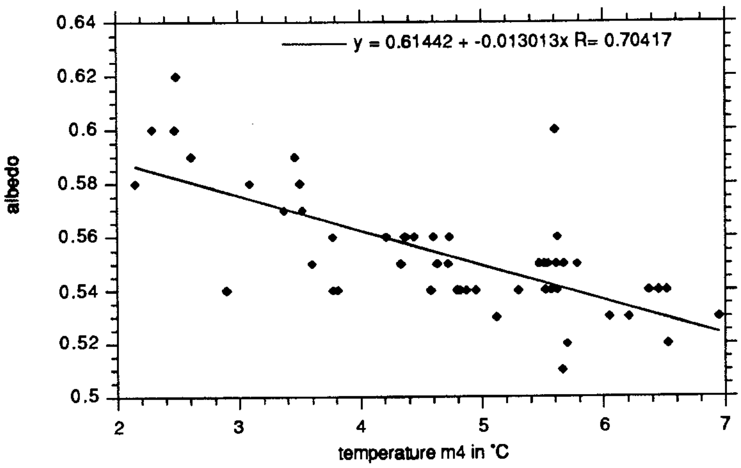
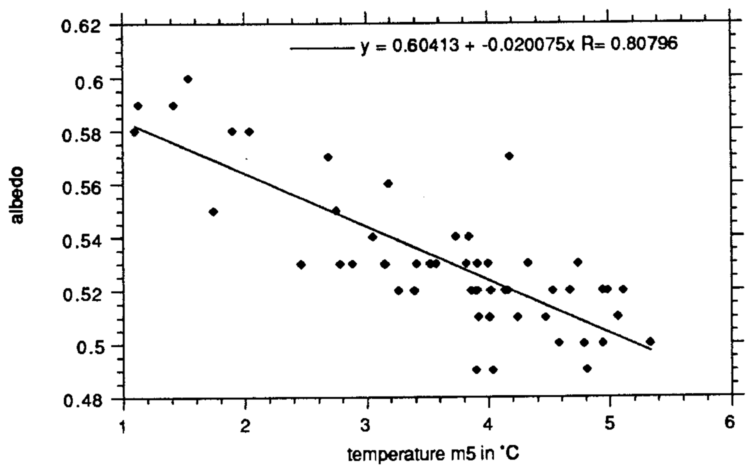


Figure 5. *Daily mean albedo as measured at the masts 3,4,5,6 and 7. Remarkable is the decreasing albedo at mast 6 and the relatively high albedo at mast 4 and mast 5.*





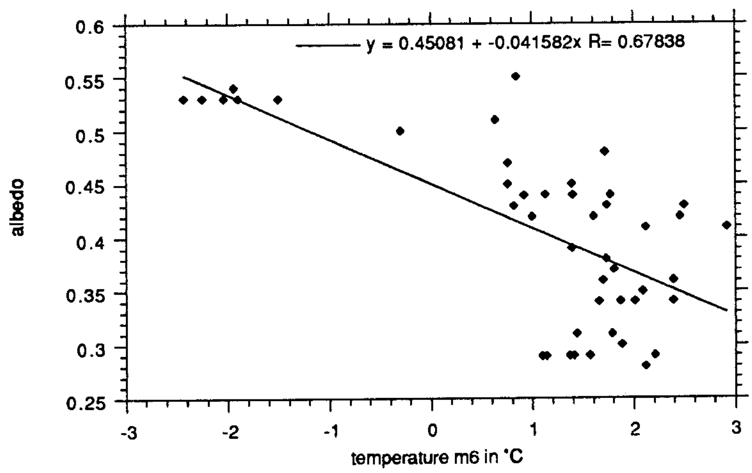


Figure 6. *Daily mean albedo versus temperature at 2 m for mast 4, mast 5 and mast 6.*

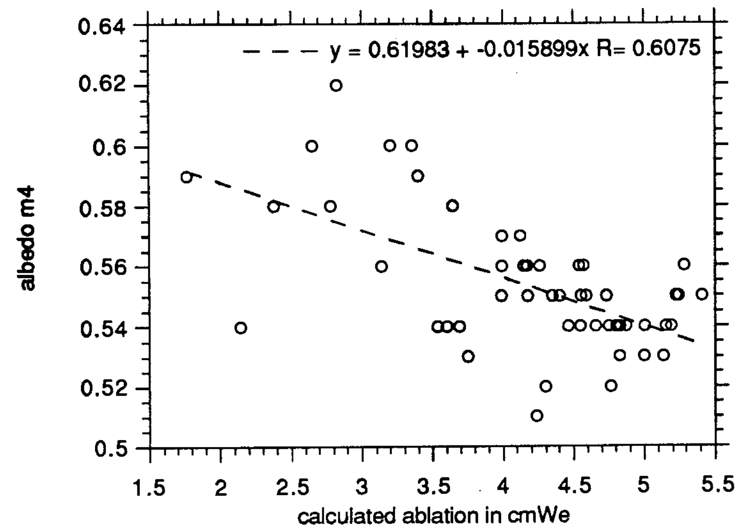


Figure 7. *Daily mean albedo plotted against the calculated ablation according to a simple energy balance model. The figure shows a decreasing albedo if the ablation increases, indicating the lowering of the albedo of ice due to the presence of water at the surface.*

Energy balance calculations

The meteorological measurements can be used to calculate the ablation. Without giving the details and problems with these calculations, a few preliminary results will be presented. Figure 8 shows calculated and measured ablation at mast 4 as a function of time. The measured ablation is slightly higher (7.5%) than the calculated ablation. This is a reasonable result considering the uncertainties in the calculations and the measurements themselves. Because ablation measurements are available roughly each 5 days, a more detailed comparison can be presented.

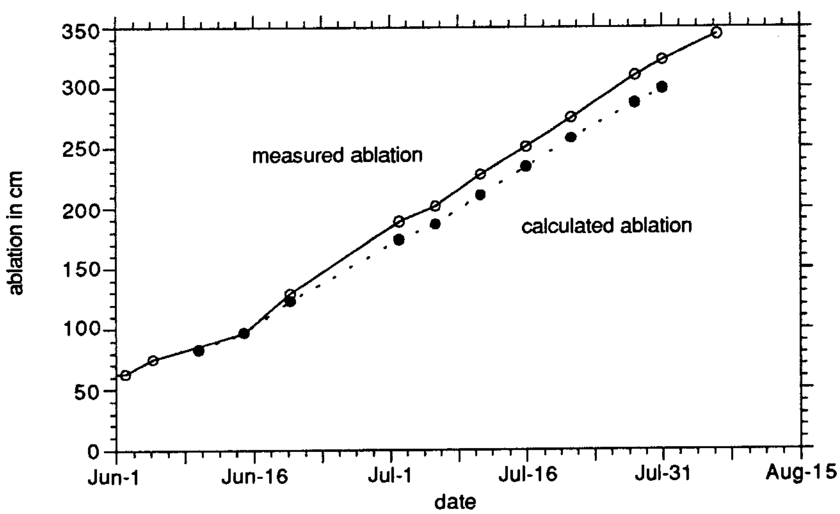


Figure 8. *The measured and calculated ablation as a function of time. On 15 June both curves are equal by definition. The mean difference between the calculated and measured amounts 7.5%.*

In Figure 9 the calculated ablation is compared with the measured ablation during short time intervals. During three periods (15-20 June, 20 June-2 July and 21-28 July) a considerable discrepancy between the calculated and measured ablation occurs. Looking at the different components of the energy balance per period does not reveal an obvious shortcoming in the calculations (i.e. no systematic error in one of the terms in the energy balance equation). Further attention will be paid to this point in the near future.

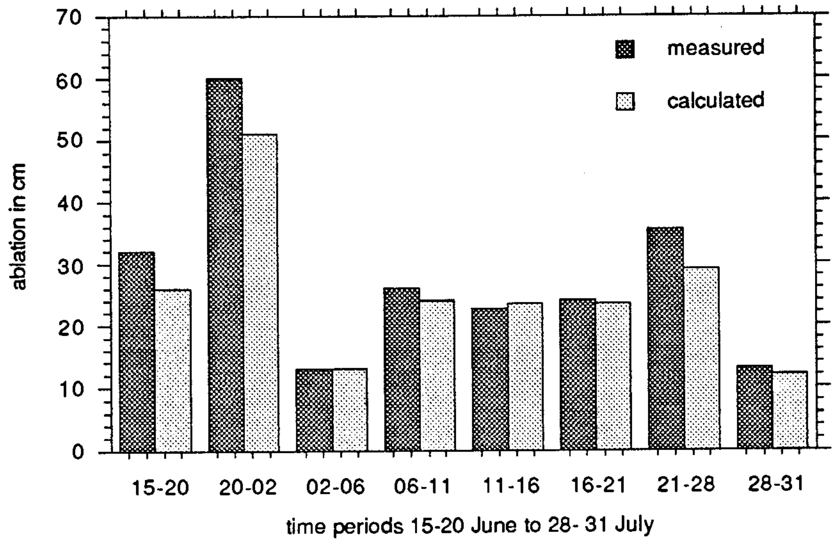


Figure 9. *A Comparison between the measured and calculated ablation per period.*

Discharge measurements

The discharge can be considered as a third additional source of information on the measured and calculated ablation, because most of the water is superglacial melt water. Complicating factors are the precipitation, subglacial and englacial water, travel time of the water, and the inaccurately defined catchment area. Nevertheless interesting results are obtained with a simple water flow model forced by the energy available for melting. Figure 10 shows a comparison between the measured and the calculated discharge in the Watson river. The trends in both curves is in rather good agreement, although the measured discharge varies more than the calculated discharge. Refinement of the model and the energy balance calculations may reduce the differences slightly in near future.

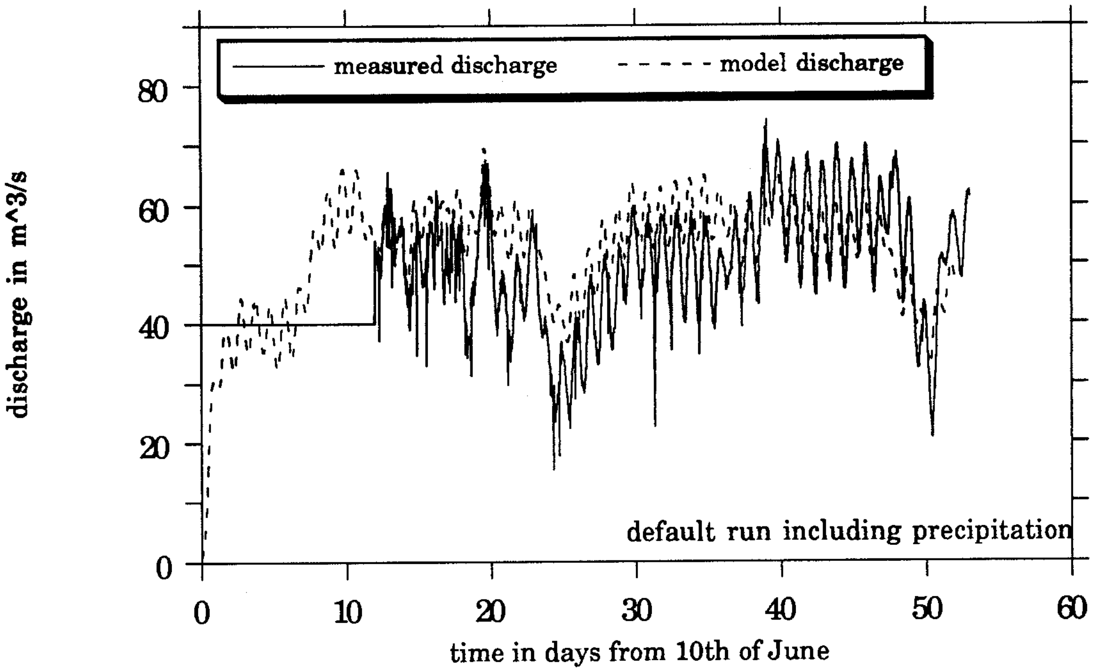


Figure 10.*The measured discharge in comparison with the model discharge as a function of time.*

GPS measurements

Although the differential GPS measurements are not directly linked to the meteorological work described in the previous paragraphs some attention will be given to it here. The results of the displacement of the stakes in time will be used for comparison with future modelling of the ice flow. Already this year some useful results were obtained. Table 2 shows annual velocities for the different locations. Because the base is a fixed point, its displacement of 16 m over one year, gives an indication on the the accuracy of the results, which is in agreement with the technical specifications of the instruments. The highest velocities were measured at the relay station on the ice, in the most crevassed area, more towards the ice margin velocities are lowering slightly as expected. In disagreement with the theoretical expectation (zero horizontal velocity at the ice divide ± 300 km from the edge), is the high velocity found at station 9. No explanation can be given at this stage and further measurements should clearify this point.

Table 2. *Results of the differential GPS measurements for all the ice stations.*

station	velocity in m/y
station 4	119
station 5	118
relay station	129
station 6	96
station 7	90
station 8	90
station 9	118

5. CONCLUSIONS

The detailed meteorological fieldwork has finished successfully with GIMEX-90 and GIMEX-91. Most of the interpretation, modelling and writing still remains to be done. Concluding remarks are therefore rather preliminary. But it is worthwhile to state a number of conclusions based on the knowledge obtained so far.

Equipment and experimental set-up:

- The especially developed dataloggers worked sufficiently well.
- RIDAS works well; much of the data handling has been done at the base camp during the fieldwork.
- The balloon data are of good quality, and many ascents were made. The system is very vulnerable and a spare balloon and spare winch are certainly necessary to obtain measurements during a period of almost two months.
- Breaking of the ablation stakes is difficult to prevent. This can be solved satisfactory by an accurate positioning system, like GPS.

Preliminary results:

- The gradient in the specific balance is in agreement with other measurements in South-West Greenland.
- The observed equilibrium-line altitude of 1600 m is significantly higher than the averaged equilibrium line altitude used in the literature.
- The annual ablation rate in the ice margin has been slightly lower than in the previous summer.
- Lowering of the albedo during the ablation season might occur on Greenland as well.
- The surface albedo is clearly dependent on the amount of water at the ice surface.
- The surface heat flux in the tundra can be very high, up to about 300 W/m^2.
- The catchment area of the Watson river is small, no contribution from water originating from the higher ablation area reaches the proglacial river.
- The mean albedo for ice measured at mast 4 and mast 5 is extremely high for an ice surface.
- The energy used for melting at mast 4 is partitioned as follows: absorption of shortwave radiation (75%), sensible heat flux (25%), longwave radiation and the latent heat flux can be neglected.

6. PARTICIPANTS

group 1: P. Duynkerke (field leader)
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H. Snellen (technician)
M. van de Broeke (student)

group 2: R. van de Wal (field leader)
M. Portanger (technician)
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General project leader: J. Oerlemans
General logistic manager: L. Conrads

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H. Langedijk, Electronical Assistance, N. Kuipers.
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