Climatology

Innovative Research Strategies in a Dynamic Field

For a very long time meteorology has been a rather inconspicuous scientific field. The development of theories, methods and findings did not show a different pattern from most of the other fields of 'normal science.' Within the last two decades, however, this situation changed very much. The discovery of the ozone hole and of the global warming process were the two main topics which caused an enormous public awareness on climate research. Top scientific journals like *Nature* and *Science* published several relevant articles in the field with strong impact, far beyond the community of meteorology. An Intergovernmental Panel on Climate Change (IPCC) has been set up under the auspices of the World Meteorological Organization (WMO) and the United Nations Environment Program (UNEP). Since 1990, the panel publishes every five years a report (IPCC 1990) to access the most up-to-date research on global warming. The production of the report is organized as a combined effort of some 45 scientists, reviewed by hundreds of other researchers and 150 governments. The panel is "considered the most authoritative voice on global warming" (NYT Editor 2000). The global warming forecasts of climate scientists have been heavily debated, among scientists as well as politicians and the general public. The topic arrived at the front pages of news magazines. Especially the discussion about the anthropogenic factor in global warming has become one of the major scientific controversies in the 1990s. Thus, it is not astonishing that sociologists of science discovered climate change as an interesting 'object of study' (cf. Weingart, Engels, Pansegrau 2000). Climate research, in a way, combines various aspects that are of particular interest for science studies, in general:

- it is a highly interdisciplinary field, sharing knowledge of meteorology, (geo-) physics, atmospheric chemistry, biology, oceanography, environmental science, computer simulation, geoscience, etc.
- it is a highly dynamic, rapidly developing field, attracting much public funding

- it is basic science with an evident potential of application to the needs of mankind
- it stimulates a controversy in the arena between science, politics and the mass media

The notes of Aant Elzinga as a participant observer on climate research in Antartica offer insights into the complex dynamics of the research process in this field. With his article – partly analytic, partly impressionist – he takes the reader directly to the research front, right into the ice.

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Making Ice Talk: Notes from a Participant Observer on Climate Research in Antarctica

Aant Elzinga

Champagne on Ice

In the dark of the ice-cellar we opened the champagne bottles. The faces of our party of ten light up as cameras flash, and the ceiling becomes visible. The bottom-side of the plain plywood slabs above us are laid out on a series of wooden ribs stretched across a two-and-a-half meter deep chasm dug out in the snow. It is our ice laboratory; makes a hardly noticeable local dent, an anthropogenic singularity in the topography of the vast pristine expanse of a polar snowfield extending in all directions to the blue canopy of the polar horizon. Directly over our heads, over the plywood roof lies a plastic sheet. On top of that a decimetre of hand-shovelled loose snow provides insulation from the radiant sun which constantly circles about in the sky above 24 hours a day.

It is in the middle of January 1998. Outside at minus ten, with the sun directly overhead, it is relatively comfortable, but here inside the ice lab, our natural cooler, the temperature has to be kept below minus 20 degrees centigrade. Otherwise the ice cores we have been collecting will 'forget' their past (if they melt) or distort their d 18-Oxygen information when analysts back home put them to the isotope test in the refrigerated laboratories of climatological research centres, be it in Stockholm, Copenhagen, Utrecht or Grenoble.

So begin some notes made as a participant observer during the Swedish Antarctic Research Programme (SWEDARP) in the austral summer polar research season of 1997/98. The expedition landed on the sea-ice off the west coast of East Antarctica by the Weddell Sea far below the southern tip of Africa in mid-December 1997 and left again from the ice shelf near the same spot towards the end of February 1998. By that time we had collected three-and-a-half tons of ice cores. Since the thermostat and motor on our sledge-borne freezer container had become unreliable this valuable cargo was moved and loaded before anything else, ferried by helicopter over to the ship for immediate storage in a sturdier freezer. Then seven days sailing over stormy seas northward back to Cape Town, whereafter we took a plane, while the ice cores were transferred to another ship headed for Bremen, and thence to Stockholm for re-distribution to a number of European research centers. Considering the accumulating cost incurred it is no exaggeration to say that upon reaching its destinations the ice cargo was in fact worth half its price per gram in gold.

In order to convey some of the problems and tensions arising in an Antarctic expedition the present essay takes extracts *(in written style)* of reports from the field sent to the homepage of the Swedish Polar Research Secretariat, and interlaces these into the present account. The purpose is to sketch a few local epistemological, historical and geopolitical co-ordinates pertinent to international research on global climate change.

In Search of a Site for EPICA

The occasion for champagne in our natural ice chamber at the drilling site on Amundsenisen's high polar cap plateau January 1998 was to celebrate the ice drill just having taken up a core from 100 meters below the surface. One hundred meters here touches strata of annually accumulated snowfalls (precipitation) from 600 to 700 years ago. This is the age of the ice with which we spiked our precious drink that day. Before we were finished we would be breaking into the previous millennium, in as far as we finally stopped at 135 metres (equivalent to ca. 1,100 A.D.). Our location, baptised 'Camp Victoria' (after the Swedish Crown Princess), was 76° 00' S, 8° 03' W, i.e., deep into the interior of the territory called Dronning Maud Land (DML).

Much of the rationale for the Swedish expedition 1997/98 is related to the problem of global warming. The ice coring operation in particular is a contribution to a European project funded by the EC and co-ordinated through the European Science Foundation, viz., the European Project for Ice Coring in Antarctica (EPICA). EPICA is one of the success stories when it comes to placing Europe on the world scientific map (paleoclimatology) in competition with the US and Japanese. Our own operation in DML was only one of several pre-site surveys (Holmlund 1998: 37–45; Näslund 1998). A multinational team of ten persons was despatched from the Swedish base Wasa near the coast, through a broad string of jagged nunataks (mountain peaks sticking up through the ice cap) to Amundsenisen. It included Swedes, a Dutchman and Norwegians. A separate Dutch project with two other researchers and a technician stayed partway, at the little Swedish summer station Svea in the Heimefrontfjella mountain range, to study meteorological factors pertinent to climate change (Bintanja 1995 and 1999).

> *24 Dec: One of the Hägglund tracked vehicles broke down on the way back from Svea to Wasa and had to be dragged / by the other / on a sledge. It was a broken axle that caused the mishap out in the field on Christmas Eve.*
>
> *26 Dec: The big question today is whether or not we can start the EPICA traverse earlier. The warm weather has put a stop to drilling / in the blue ice area / at Scharfenbergsbottnen.*
>
> *29 Dec: The work with organising the earlier departure for Svea and then onto the traverse on Amundsenisen is progressing smoothly. Today much of it has revolved around digging out and repairing a sleigh, fixing the windows and interior of an old living module that had filled with hard-packed snow, getting fuel needs sorted out for different legs of the trip, etc. Different functions in an expedition, scientific, logistical, medical, and finally, minimising the immediate environmental impact of our own presence on this continent – tend to pull in different directions. A clear-cut differentiation and definition of tasks and responsibilities is essential in this respect … Per Holmlund is continuing with the debugging of the radio echo equipment … After the delays in ice coring due to warm temperatures in the air / at Svea / now new problems have cropped up; technical difficulties with the drill requiring contact with Robert Mulvaney who is with the Halley (British Antarctic Survey) group that will be doing coring slightly south of our own EPICA-effort. Mulvaney has been involved with the redesign of the drill that is being used, and hopefully he can provide some advice on the current situation.*

In addition our expedition included environmental impact studies carried out by the Environmental Officer, who also remained at Svea, together with a photographer. British and German-led expeditions had further teams simultaneously working, respectively, at angles one degree of latitude south and one degree north of us, carrying out similar pre-site surveys. The eventual outcome of all these efforts were later subjected to scientific and logistical evaluations in order to determine where to situate a second leg of EPICA with deep-drilling down to 2 km starting in the year 2001.

The first leg of EPICA, at Dome Concordia (Dome C) far into the interior above the French station Dumont d'Urville is already into its third year. The climatic conditions at the two sites, Dome C and the future DML differ from each other. Dome C has less precipitation while DML receives more snow and hopefully will reveal important information about the 'signal' from changing past conditions over the Southern Atlantic. The latter is significant in discussions on changing ocean circulation regimes, coupling between northern and southern hemispheres, and the recent re-constructions of rapid climate change events at tail end of glacial periods (for a presentation of EPICA cf. Elzinga / Krueck 1999).

Epistemology: The Life and Purpose of Ice Cores in Shaping Climate Scenarios

Ice coring in Antarctica has had a dramatic impact on discussions regarding an enhanced greenhouse effect and uncertainty in projections of human-caused climate warming (cf. Street-Perrot / Robert 1994: 47–68; Graedel / Crutzen 1993: 223–229). This was especially after Claude Lorius and his French and Russian colleagues at the former Soviet research station Vostok in a most inaccessible place deep in the heart of Antarctica drilled a couple of kilometres into the icecap to bring up part of a "natural archive" (Lorius et al. 1985). Using ice of different ages, temperature trends can be built up. The now famous Vostok core was used to reconstruct a 160,000-year history of temperature variation, including a complete interglacial-glacial cycle (Jouzel et al. 1987; Legrand et al. 1988).

In their analysis the scientists claimed to 'see' warm temperatures in the interglacial period, about 120–130,000 years ago, and in the present interglacial of the past 10,000 years. Between these two periods, it is claimed, temperatures were more than 6° C colder than those experienced today. The analysis also points to temperature fluctuations in tandem with changes in volumes of greenhouse gases, CO_2 and methane, in trapped air over a period of 160,000 years. CO_2 content was found to be higher in interglacial periods, averaging around 260–280 parts per million (ppm), and lower during glacial times, averaging 190–200 ppm, and as low as 180 ppm. Note that it is now over 350 ppm. The methane content was 0.35 ppm during the glacial maximum, and about 0.65 ppm during the last 10,000 years until the nineteenth century. Now it is 1.7 ppm. Lorius et al. also did a climate sensitivity analysis and argued that the responsiveness of the climate system to the heat-trapping character of the greenhouse gases of the atmosphere is high (Lorius et al. 1990). They attributed about 5° C temperature difference between the last ice age and the interglacial period to the heat-trapping of greenhouse gases, and the rest to changes due to other causes. Furthermore they believe that the switches between ice ages and interglacials may have been triggered by the weak orbital variations (of the Earth around the Sun) and amplified by changes in greenhouse-gas concentrations.

Ice cores were thus enrolled as witnesses to tell us why we humans should be concerned about the enhanced greenhouse effect. In the late 1980s this spurred further deep drilling by several countries, and gave other ice coring efforts in Antarctica, including EPICA, considerable impetus.

Important studies of the transition from firn to ice in Antarctica were already made in the early 1950s by members of the Norwegian-British-Swedish Expedition who were the pioneers in DML (cf. below). At relatively shallow levels down to 60–80 m. the snow is consolidated as 'firn,' which is still porous, so that younger air seeps in from above. Below this, when the firn is further compressed and turns to pure ice the pores close, finally trapping the air. Therefore the trapped air to be analysed for greenhouse-gas and other telltale traces is younger than the ice that encloses it. Traditionally it has been assumed that in lengthy records the difference in age between the air and the ice that encloses it is not significant in constructing trends.

For mid- and high-latitude precipitation and mean annual temperature in polar regions there has thus been a simple formula according to which d 18-O regularly decreases by 1 per mil every time the temperature drops by 1.5° C when going across the ice-field, e.g., from coastal to Central Greenland. This relation has been used as a paleo-thermometer to translate information on changing 18-O isotope ratios at different depths into variations of temperature over time. Now the formula has been found to collapse for short periods of apparent rapid climate change recorded in the 'natural archive' of the Greenland ice sheet. As yet this has not affected interpretations of the Antarctic ice archive which appears to be less affected by seasonality, but it does call for caution in conceptual reconstructions of key correlations.

Recently, then, interpretative flexibility in the calibration of paleothermometers used to probe the ice record has become the subject of some discussion amongst leading scientists. This is in connection with the new problems thrown up by the apparent rapid fluctuations (so-called Dansgaard-Oerschger events after their 'discoverers') in ancient climates at crucial times in transitions from ice age to warmer interglacial periods. The last twenty years' traditional assumptions of fairly simple linear correlations between deuterium and oxygen-18 isotope ratios and atmospheric temperatures near polar plateaus at times of past precipitation are in cases of abrupt climate change being revised. To make sense of thermal anomalies, isotopic analysis of other gases (in this case 15N/14N and 40Ar/36Ar ratios) are now brought into play in much more sophisticated calculations that take into account differences between the age of the trapped air bubbles and the age of the surrounding ice matrix containing them.

Jean Jouzel, who currently heads the overall organisation of EPICA, summarises:

> In using this/the aforementioned traditional/relation as a paleothermometer, researchers have assumed that the present-day spatial relation does not change with time; that is, spatial and temporal slopes are assumed to be similar. Simple models show that this assumption holds only if such factors as the evaporative origin and the seasonality of precipitation remain unchanged between different climates, which is not at all guaranteed. These limitations have long been recognised and examined through simple and complex isotopic models (Jouzel 1999: 910).

Surprisingly the more sophisticated analysis also seems to lend itself to what may be rhetorical overtones in a debate regarding the relative neglect of climatological studies that have a different geopolitical frame of reference. In concluding his review of the revised analysis of events punctuating the glacial period 14,650 years ago, and the rapid onset of warming, Jouzel says, "this finding constitutes a breakthrough which will be extremely useful for deciphering mechanisms of abrupt climate changes and already suggests a North Atlantic rather than a tropical trigger for the climate event" (Jouzel 1999: 911).

There is much here to warrant a closer study of the social epistemology of paleothermometry in European laboratories. However that is not the purpose of the present account. Instead I want to home in on the study of life in the (ice-)field, the stage before the laboratory and gas analysis. It is the stage in which ice goes over from having been a facet of nature in its own-right to becoming an object-for-us, to be interrogated by humans, i.e. as ice-'core.' In as far as it is forcefully pulled up in cylindrical lengths of a given diameter, the 'recovery' as it is called – of the ice core – is essentially a human effort, depending for its success on costly logistics. It is also constrained in practice in the field by attention to factors both of human safety and environmental protection.

Life in the (Ice-)Field

While our expedition was meant to facilitate a future probe of the time-scale by which ice ages are measured, time-wise we ourselves were also situated at the front end of a long chain of complicated scientific events and processes (Sigg et al. 1994). The task of the team was to bring up ice cores, to coax and transport the objects to be interrogated to the laboratories back home. In this context ice is far from being a passive or malleable entity; it is capricious and puts up plenty of resistance. Lots of things 'go wrong' in the field; trial and error is a prevalent factor in many different dimensions of an expedition.

Other programmes inserted in an expedition also vie for due time promised participants, sometimes in bilateral agreements with groups of scientists in other countries, which may cut into time or create haste for the coring operation. The constraints, both natural and human are many.

Work in the field precedes the complicated process whereby chemical analysis of ice samples and air trapped in bubbles in the Antarctic ice is used to reconstruct past climate trends on our planet. Glaciological field-work is only one facet of climate-related research that takes place in the world today. It is time consuming, sometimes adventurous, and less visible than the more dramatic statements made by the gas analysts or computer modelers. But the trend analysts for their work need the materials that the humbler field workers make available. It is the stuff from which ultimately are constructed proxy accounts of parallel changes in atmospheric temperature and greenhouse gases as represented in elegant graphs published by leading scientific periodicals. By itself ours was not the kind of laboratory work that results in agenda-setting papers in *Nature* or *Science*; it only linked into these via the more sophisticated analysis back home.

On the other hand an expedition is no longer what it used to be in the old days. High tech has also made its entry in the field, with the domination of logistics now by sophisticated artificial life support systems on which the Antarctic researcher must rely. For example, there are no longer any dogs around, they are prohibited as an environmental hazard factor on Antarctica because they may infect seals with a contagious disease. Transportation instead involves light snowmobiles that can draw sledges, but also much heavier track vehicles than the old wartime weasels. Base stations are modern, sometimes with solar panels to generate electricity. Helicopters are the rule, and regular contact may be maintained with neighbouring stations by scheduled radio transmissions, and with persons and agencies back home via both satellite telephone and e-mail. Some of the rugged edge nevertheless remains, making fieldwork quite different from laboratory life.

In the history of southern polar science the development of new technologies has always played a key role, as have economic and political interests. These contingencies carry institutional motives (Elzinga/Bohlin 1993). Today overt economic motives relating to resource exploitation have been pressed back by monitoring of the environment and efforts to tease out anthropogenic from natural factors of climate change. At the same time national prestige and politics as motive factors remain and receive considerable play in the formation of Antarctic research agendas. To appreciate this and other contextual aspects it becomes relevant to consider some historical background.

Science as Politics and Politics as Science in the AT-Regime

The Antarctic continent is roughly the size of the US and Mexico taken together. Extremely inhospitable for human habitation, the continent has not witnessed the regular kind of colonisation whereby Western nations gained a foothold elsewhere on the globe. As a rule a group of humans wanting to spend some time there have to bring with them their own artificial life support system. Except for certain coastal regions where some explorers have managed to survive in primitive stone huts and used seals and penguins for meat, fire and lighting the wicks of their oil lamps, everything needed to keep alive and move about has to be brought in from afar.

> *30 Dec: Packing is the big issue today, with departure on New Years day creeping ever closer. Per's scientific equipment in five or six boxes of varying sizes does not take up as much room compared to all the other stuff needed to support our presence and movement on and across the vast rigorous icy stretches. Antarctica is a craving continent. It levels out everything before it, reducing to a common denominator of cold and sluggishness. Water freezes, metal cracks, bodies and machines slow down and strain. Counteracting this requires lots and lots of energy, in various forms. Ninety eight percent of this has to be brought in from other continents: solar electricity from our solar panels on the house and sledge-based living modules is an important exception … Packing just now for the three-week EPICA-effort in the interior has involved loading and securing: heavy equipment, spare parts, 2 snowmobiles with small sledges, 390 kg liquified petroleum gas for various heating needs, 30 barrels of diesel fuel (200 kg / barrel) for the two Hägglund vehicles (to be replenished by 10 further barrels during stopover at the Svea station), and 10 gasoline drums for the snowmobiles. In addition to this go 8 barrels of diesel fuel for the Icelandic jeeps / i. e., oversized Toyota Cruisers with huge deflatable tires to increase traction in loose snow; this was the first time these were tested these as terrain-going vehicles in Antarctica.*
>
> *Quality also counts in producing heat and converting energy under extreme circumstances (jet A-1 fuel for -50 degrees C, Arctic diesel for down to -35 or -40, and environmental diesel fuel when the atmospheric temperature is above -20 degrees; all this has to be planned to fit changing conditions during different legs of the EPICA-effort).*

During the optimistic 1950s there were visions of setting up mining settlements inside the ice, lit by electricity coming from nuclear reactors. However such scenarios never got beyond the free fantasies of science fiction and popular mechanics magazines.

Under the circumstances science became a surrogate for colonisation. The Antarctic Treaty (AT) statutes stipulate that in order to join in and have a right of presence a country has to display substantial research in the region. This used to be interpreted as meaning that one had to establish and maintain a research station. In recent times however it has been enough to rent facilities (e. g., the Polish station Arctowsky, after the collapse of the Cold War when hard currency was needed) or conduct good quality marine research off ships in the coastal waters. The Swedish station established in the late 1980s was directly motivated by the desire to enter the Antarctic Club before 1991 when the Treaty was up for possible revision and – it was anticipated – the door might be shut, thereby excluding potential new members.

Science is thus the vehicle whereby nations manifest their presence and their right to participate in the management of Antarctic affairs at a supra-national level. The AT is a viable regime *outside* the UN-system.[1] Although it has been contested both by Third World countries and NGOs, the Treaty has hitherto stood the test of time and periodic turbulence especially in the wake of the oil crisis of the 1970s, when several Third World nations were taken on board. This helped break up the compact Western colonial configuration, while taking some of the sting out of the opposition. Within the framework of the AT science has a dual role; apart from importance in its own right in advancing knowledge, science has symbolic clout in a geopolitical arena, therewith serving a continuation of politics by other means (Elzinga 1993).

As already indicated, the accent during the past ten years has come to lie on environment and environmental protection. Since 1991 there is a special Environmental Protocol which is linked to the Antarctic Treaty. It placed a moratorium on all minerals exploitation for fifty years, and specific rules have been worked out to govern Environmental Impact Assessment procedures to which all activities – with science and tourism as most prominent – in Antarctica have to be subjected. Ultimate responsibility for living up to these rules remains with national authorities in the countries from which expeditions originate, and there is no supranational controlling body. Observance of the principles laid down is voluntary; peer pressures and a system of mutual inspection play an important role.

One of the key concepts is 'minor and transitory impact.' This draws a line of demarcation between projects that do not need *further ex ante* impact assessment (i. e., projects that are expected to give less than minor or transitory impacts), and those (anticipating more than minor or transitory impact) that do require more thorough or comprehensive evaluations before being approved. Here exists a lot of interpretative flexibility – what is minor, and what is transitory impact? Another question is, what about cumulative effects of human activities in Antarctica? This is another domain where conflict and tensions may emerge during the course of an expedition.

> *30 Dec continued: Finally, security of life and limb of all individuals plays in; therefore on top of it all we carry 8 barrels of helicopter fuel – which we hope we don't need to use – for possible emergency medical and rescue operations. Foresight, indeed, has many dimensions, all of which become amplified under Antarctic conditions.*
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> *Our doctor, Krister Ekblad led the packing of food for people: roughly 600 portions of 1 kg food and drink per person per day for three weeks, plus an extra week thrown in 'just in case.' We have to plan for an average intake, he says, of 4,000–5,000 calories/person/day, which is about double the normal consumption even for a hard working person back home. His explanation is that we must make provisions to burn at least 2,000/person/day extra to beat the cold, which drains us of our heat.*
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> *Some of what we are leaving in the glacier down the hill from the base station, stached away in a crevasse provided by mother Nature; the crevasse has now been recruited as an 'actant.'*
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> *For the participant observer such conflicts and tensions can also be used to explore the dynamics of research in the field. Here four aspects stand out in the identification and assessment of environmental impacts, or risk calculation: (1) cultural variability due to researchers' affiliation with different scientific disciplines (variation over disciplines like geology, glaciology, biology, atmospheric physics, etc.); (2) task differentiation within, say, an expedition (functional differentiation: researcher, construction worker, mechanic, helicopter pilot, doctor, driver, logistics and environmental officers, etc.); (3) generational differences, with younger researchers on the average attributing relatively greater importance to environmental ambitions; (4) what country a researcher comes from, in as far as this may bring in differences in the entrenchment of environmental consciousness in the cultures of different countries (cultural variation between countries) (Elzinga 1999 and 1998). The last point*

opens up for new tensions, also at the policy level between countries that are party to the Antarctic Treaty.

2 Jan: Good news was that the faulty bearing in the ice coring drill was reparable. Tomas filed and polished it, and with Freyr's help got the expensive sophisticated machine back onto its legs. This was crucial since the success of the EPICA-traverse hinges largely on this piece of equipment which is Dutch-owned but shared for mutual scientific benefit in a European context. The second day of the year ended with a late (midnite chili con carne and pasta) dinner for 14 hungry persons … Since meat was solidly frozen it had to be hacked into small pieces. Here a large knife and a crow bar were useful instruments.

Historical: Seven Pie-Like Sectors

Seven countries historically claim the right to have a special position in that they at various times put forward and documented territorial claims. That is why some maps of Antarctica show a series of pie-like sectors, all but one of which meet at a common point at the geographic South Pole. (The Norwegian slice does not go all the way down to the Pole, since this would give precedence to a sectoral definition that other countries like the former USSR might have used to substantiate their claim to Spitsbergen in the northern hemisphere). The text of the AT neither recognises nor denies these national claims. Thus it provides a *modus vivendi* where the use of the continent foregrounds science and other peaceful activities.

The Norwegians for their part base their claim to DML on Antarctic exploration during their period of prowess as a whaling nation. In the 1920s when the price of oil was rising, Britain was fearful of the depletion of whales in her sector and refused to issue further permits in the Falklands Dependency regions where most whales were hunted 1904–1914. Norwegians developed new technology, which allowed them to process whale meat entirely offshore on ships at sea (so-called pelagic whaling).[2] Thus they neither needed to pay tax to the British, nor subject to controls. They also looked for and opened new hunting grounds. The southern ends of the Atlantic and Indian oceans, just off the Antarctic coastal ice, were found to be particularly rich regions. In the course of these activities the dominant Norwegian firm, led by Lars Christensen, also sponsored survey mapping of the coastline and inland (e. g., Hjalmar Riiser-Larsen 1929/30; Viggo Wideröe 1936/37; cf. Bogen 1957).

In all Christensen financed no less than nine Norwegian Antarctic Expeditions from 1927 to 1937; in his own report he points to three of these as yielding important scientific contributions (Christensen 1938). Using the newly available technique of airplanes and aerial photography a lot of territory was covered, revealing interesting new features. Christensen himself notes a feature that could fascinate anyone interested in the coming and going of ice ages: on Ingrid Christensen Land (named after his wife),

> A curious phenomenon in the mountains on this part of the coast was a great quantity of small fresh water lakes up in the mountains, quite open and without a sign of ice on the water or around the edges of them (Christensen 1938: 9).

Oceanographic, meteorological and biological studies were also promoted, mostly in the interest of the whaling industry, but also of interest to scientists more generally. The Norwegian Whaler's Insurance Association used the material to produce comprehensive maps of the coastline. As empirical benchmarks in historical time some of the results of these studies are still of value today, including for computer simulation modeling, when comparing changes in the annual extent of sea ice in connection climate research.

When it comes to the emphasis on climate research there are further historical events that deserve attention in the present account. It is interesting here to highlight an often forgotten historical line from the situation sixty and fifty years ago to the efforts we see today, at least in DML. Indeed, the question of climate change was already being addressed the first time the interior of Dronning Maud Land was mapped. This is something that has fallen into obscurity and is worth recalling today when the term 'global warming' is on so many lips.

From Neu-Schwabenland to Dronning Maud Land: Norway Beats Germany

On many Antarctic maps one will find the name Neu-Schwabenland. This is in honour of the catapult ship used by a German expedition to Antarctica 1938/39. To this day the names of the the expedition leader

Ritscher, the ship's captain Kottas and the two Lufthansa pilots, their flying boats, as well as a number of other older German names are still attached to some prominent features of the map of the larger territory called Dronning Maud Land.

Presently the German Neuymayer research station is also located on the coast in this area, while the former DDR station Georg Foster is now dismantled. During the past couple of decades German researchers have added a layer of new names to commemorate colleagues and modern sponsors, although East Germans came to reject the older names introduced by Ritscher's expedition, preferring the later Norwegian names. Naming in Antarctica can be a rather political business, even out in the field. For example, even today names attached to new sites are carefully chosen to signal honorific deference in scientific or political credibility cycles, or simply in the hope of enhancing future funding opportunities from research councils and enrolling private sponsors.

When German aviation ultimately returned to the area in the 1983/84 season with ski-equipped aircraft it was during the third post-IGY (International Geophysical Year) expedition. Even then the German pre-war expedition was a significant marker in geographical space and time.

The Schwabenland expedition in January/February 1939 carried out what at that time was to be the most systematic and extensive aerial photogrammetry yet undertaken anywhere. This expedition, led by Captain Alfred Ritscher, made use of a catapult ship Schwabenland which belonged to Deutsche Lufthansa. Previously it was stationed in the Azores as a landing and servicing platform for flying boats of a Dornier-Wal type on the German airmail route between Europe and South America.[3] Two of these planes, together with their veteran Lufthansa postal route pilots (who were used to landing in choppy waters) were taken along – the planes could be catapulted off the ship to reach flying speed in a matter of a few seconds, and after completing their mission they could be scooped up out of the sea with the help of a crane. This technology, never tried in the Antarctic before, was fairly successful, helped by the luck of good weather.

The German Antarctic Expedition 1938/39 was not only or primarily concerned with science. Its origins lay with Nazi-Germany's Big Power intent to participate in the continued division of Antarctica into spheres of interest and to secure German whaler's interests whose oil production was important for both industry and an expansive military machine on the brink of starting a second world war. Thus it was not only a matter of mapping the region, but also to lay the basis for claims to sovereignty, which was not at all unusual – several other countries, including the US, had been doing the same thing. In this particular area however it was only Norway that was the contender.

In order to substantiate possible sovereignty claims and annexation the German planes on their reconnaissance missions were also given the task of throwing out small javelins which stuck into the ice sheet below – this trick had been tested in the Alps. The metal arrows had small zwastikas in their tails, insignia to mark the nationality of the claim. These were supposed to be hurled down every 30 km along lines criss-crossing in a broad grid to mark out the territory.[4] There was no time to waste because it was well known that Norway also intended to lay claim to the same territory.

As it turned out the Norwegians, through their own intelligence sources in Berlin were already alerted to the secret German expedition that left Hamburg late 1938. Consequently their monarch proclaimed sovereignty over a still larger portion of this previously unclaimed territory. It is eight times the size of Norway itself, stretched on both sides of the zero meridian from 20° W to 45° E, and is named Dronning Maud Land in honour of the Norwegian queen at that time. The date was 14 January 1939, just five days before the Schwabenland reached the ice-edge of the Antarctic coast.

Glaciology from the Air: Oases in a Desert of Ice?

The scientific or technical content of the German effort using photo mapping as a basis to lay a claim to a large slice of Antarctica was more successful than the underlying political objective. In the span of fifteen days seven sorties were made over the Antarctic ice sheet and coastal mountain ranges to cover a large geometric grid. A vast number of aerial photographs were taken, useful for stereoscopic analysis and subsequent mapping, reaching into the interior as far as 800 km south of the coast (to ca 74° S lat.) (Ritscher 1942).[5]

Scientists who were aware of this work during or shortly after the Second World War were impressed. For example, the Swedish geologist J.G. Andersson who had been in Antarctica at the turn of the century wrote in 1945:

The cartographic result of these seven inland flights was simply unique. An until then completely unknown sector of the Antarctic coastline between 11.5° W lat. and 20° E lat., as well as the interior terrain to a breadth of 300 km had been mapped in a way that signified a great advance for knowledge of the South Pole continent (Andersson 1945: 416).[6]

The only trouble was that this airborne mapping was unconnected to ground surveys that could have provided astronomical positioning as triangular points, so-called 'ground truth.' Thus the maps hung in the air as it were. Estimates of elevation above sea-level of nunatak peaks had been grossly exaggerated, usually being out by 1,000 m., and the elevation (above sea level) ascribed to the polar plateau was 1,500 m. too high. Excepting a few features, later ground expeditions found it impossible to connect landmarks they saw to the photogrammetric maps.[7] Consequently a lot of the German names were later rejected by the Norwegians when they produced new maps over the region in the 1950s. It was not until 1986 that some understanding was gained of the German maps. This was in a Ph. D. thesis whose author used maps from the Maudheim expedition and recent satellite images to reset the aircraft position from which each of the German photographs was taken (Brunk 1986; cf. Swithenbank 1999: 233, note 4).

3–4 Jan: After a late awakening to recoup our energies, the wagon train took off at 1 PM, preceded by Lars and Mart on snowmobiles to reconnaissance the leads; they were followed by the two Icelandic jeeps. The SANAE people / from the South African station / indicated they would come by, so Pelle stayed behind waiting to be picked up by helicopter to guide our guests to the field – this would also give him a chance to check the tricky Kibergdalen pass from the air … The German Schwabenland aerial surveys in the late thirties apparently did not reach south of Kirwangweggen (which had been called Neumayer Steilwand). Heimefrontfjella became an important discovery for the Norwegians, who attached the names of their freedom fighters and leaders of the anti-nazi resistance and clandestine guerilla operations ('Heimefront') to mountain peaks, nunataks and valleys here. Geography and cartography can be very political. Now even the maps compiled by the Institut für Angewandte Geodäsie in Frankfurt / Main uses names like XU-fjella, *KK-dalen (wartime code names of the resistance), Pionerflaket, or Mathiesenskaget just to our left in Sivorgsfjella.*

… Tomorrow comes the struggle up to it, up the slope and past the crevasses (50–100 metres deep) which close in from both sides leaving only a small safe passage (ca 100 metres broad) between Sivorgsfjella and Tottanfjella. Getting stuck in a crevasse is not only dangerous, it would also probably delay us a whole day with unloading, salvaging, reloading and rerouting through a new lead.

The Ritscher-report nevertheless had repercussions that were to be significant for post-war climatologists.[8]

One who perused the Ritscher-report in detail was Hans W:son Ahlman, the Swedish glaciologist, professor at Stockholm University until 1950 and thereafter Swedish ambassador to Norway. Ahlman was particularly interested in the small snow and ice free areas he saw, like islands in an alpine type mountain landscape 300–400 km from the coast. Much of his life he had studied glacier retreat in the Arctic. The question now was whether these 'oases', as he called them, represented a similar trend in the southern hemisphere, in which case one had to do with a 'global' climate change, past or present. He wrote:

As far as I am aware, these conditions are the first more certain indications in interior Antarctica of a relatively late warm period, even if one does not know the chronology. However there is nothing that tells against the assumption that it constitutes something similar to the post-glacial warm period on other parts of the globe (Ahlman 1944: 651).

In a later paper on the subject he wrote:

As far as I know, there is no other area on the earth where one can find, as one does here / in the Schwabenland photographic data / local glaciers in the domain of inland ice, sensitive and reacting to the climatic factors that determine their destiny (Ahlman 1948: 247).

[And,] it is possible here to get an answer to the question whether or not the recent history of glaciers and climate, and therewith climate fluctuations, also include the Antarctic (Ahlman 1948: 249);

in other words, whether or not the 'fluctuations' are global.

NBSX and the Issue of Global Climate Change as Perceived 1948

The pictures taken by the Schwabenland expedition and its accompanying report inspired Ahlman to work towards organising an Antarctic expedition in hopes of gaining first hand knowledge of the area and to determine whether or not the glaciers there were waning. He was interested in making the ice talk at close range.

The ultimate outcome of his efforts was the Norwegian-British-Swedish Expedition of 1949–1951, also called the Maudheim expedition, and sometimes NBSX. He worked intensively and lobbied leading scientists and politicians for four years to get it launched. It was his last great project, predicated on the belief that there might be global characteristics of the climate warming problem (at the time it was referred to as *climate improvement*) (Kirwan et al. 1949: 11–13; Ahlman 1948). It was largely Norwegian financed but included fourteen men from five nations in the overwintering party. At the time it was recognized as "representing an entirely new venture in international scientific co-operation" (*Cambridge News* 14 Feb 1949; Illingworth 1949). Later it was referred to as a precursor and exemplar for the International Geophysical Year 1957/58 (Crary 1962, cited in Swithenbank 1999: 227), which in turn lay the groundwork for a viable vehicle for a supra-national regime, the AT, in which science makes up much of the glue (cf. above).

The speculation regarding snow and ice-free oases with lakes in a desert of ice was used to interest a wider public and in fund raising for the NBSX. This led to amplification in the daily press, where there was talk of a long lost civilisation in the Antarctic (*Stockholms Tidning* 6 Dec 1948). Some papers referred to an 'Antarctic Shangri La', and the 'oasis mystery'. A Minnesota newspaper is reported to have picked up a *Times* of London interview with a member of the organizing committee L.P. Kirwan and credited him with the discovery of Beduin encampments, date palms and camels at the South Pole.[9]

> *6 Jan: The interesting thing with the landscape under the ice in this region is that it tells us something about the origins of the ice many millions of years ago … What we see on the radar screen is a landscape that has lain there deep-frozen and undisturbed for more than 10 million years … When we turn back to where the wagon-train is we find that it has come to halt – one of the Hägglund*

track-vehicles has a gearbox ceased up … After much discussion two of party of ten were sent back to Wasa to fetch spare parts, 600 km altogether, there and back again by snowmobile … An advance party of five was sent on with the jeeps to the drill site at 76° S, 8° W to start getting up smaller cores of firn, so as not to lose too much time.

7 Jan: Work with replacing the gearbox in the axle done and the train got on its way again by 7 PM.

15 Jan: Different tasks proceeded largely according to plan. An attempt to obtain a 20 metre firn core however almost cost us the smaller drill when it got stuck at the infamous risk zone at 16 metres. Antifreeze sloshed in the hole and a strong crane on the track vehicle saved the day … The larger drill reached down to 111 metres, but the big event was passing the 100 m. mark on the 14th, which was celebrated with champagne.

The theory of a retreating polar ice cap due to global warming was picked up by many writers at the time, and seems to have influenced others with an Antarctic science ambition. Finn Ronne, for example, the leader of a privately sponsored expedition to Graham Land 1947–1948, in his book *Antarctic Conquest* (1949) states boldly:

The retreat of the ice that they / Darlington and Latady flying over George VI Sound 1947 /, and which I already observed in our local glacier, we found characteristic wherever we went. A similar shrinkage of glaciers and ice barriers has been noticed in the Arctic, which points to a gradual warming of the earth's climate. If this process ever gets to the point of melting the Greenland and Antarctic icecaps completely, the water thus released will so raise the sea level that all the world's seaports will have to move miles inland. However, since such changes would take hundreds of thousands of years, it's nothing for us to worry about (Ronne 1949: 67).

It should be added here that Graham Land is the British name for part of the Antarctic Peninsula facing South America. It is a region in the close vicinity of oceans and therefore more sensitive to recent climatic fluctuations than are regions in the continental interior. Retreating glaciers and collapse of parts of ice-shelves around the Peninsula are an issue of considerable concern today.

Meteorologists and oceanographers were also taking an interest in theories of climatic fluctuations (Wallén 1950). At a scientific meeting in Copenhagen in Oct 1948, the following resolution was taken:

Having considered a number of lectures on climatic fluctuations the International Council for the Exploration of the Sea recommends that these important and far-reaching problems ought to be more closely investigated and that these investigations might be adequately supported by Governments in different countries (Ahlman 1948: 241).

Not everyone accepted Ahlman's speculations. One's disciplinary affiliation might make a difference. The geologist J.G. Andersson, already cited, vented his scepticism early on regarding the 'oasis'-theory of a polar icecap thaw, or fossil lakes from a past climatic period. Having studied the same pictures from the Schwabenland expedition he wrote, in 1945, how the alpine lakes around certain nunataks like the dramatic Wolhthat-massif can also be interpreted in a different way.

… the situation tallies well with the notion developed by some southpole explorers, that in the vicinity of dark cliffs local snow melts and therewith follows the creation of melt water lakes, which quite naturally often appear to be ice-covered, perhaps with some holes where the water finds its way under the ice. Thus I do not think one needs to regard these lakes as fossil lakes as professor Ahlman has sought to interpret them (Andersson 1945: 436).

Some Results of the Maudheim Expedition 1949/52

Ahlman's original plan had been to have the Maudheim expedition land near the zero meridian to set up a station on the coast from which glaciologists and geologists could make their way inland to the dramatic areas photographed by the Germans, especially the Wolhthat-massif. Sea-ice conditions and currents however made this impossible, and the party ended up quite a bit westerly, at Kap Norvegia on a bay known to Norwegian whalers. This was early February 1950: The wintering party were quickly unloaded with all their gear; they were to spend two full years a ways up on the ice-shelf which was about 200 metres thick, floating on the water, and moving up and down with the tide like on a hinge.

The expedition members included meteorologists, glaciologists, a dog-handler and a cook, a medical officer, plus the expedition leader John Giaever.[10] Inland transportation over the ice sheet was by Weasels (war-surplus tracked vehicles), and two teams of dogs to pull sledges, the latter being the mode used for travel furthest into the interior. It was a challenging time, a multinational group doing research where none had set a foot before them. It was also adventurous, with crevasses, terrible winds and whiteouts. Three members in a group of four drowned when they got disoriented during a whiteout near the base-camp Maudheim and inadvertently drove one of the weasels over the ice-shelf into the cold sea; the fourth was rescued after spending 11 hours alone on an ice-floe. Another person got a stone splinter in his eye during geological field work and eventually had to have his eye removed by amateur surgery in an improvised operating theatre set up in the base-camp hut, instructed from afar over the wireless by a medical authority back in Sweden.

Carbon monoxide poisoning from the exhaust fumes of the engine on the Canadian Longyear 'Straitline' rock drill used for ice coring in a separate shanty, as well as poor ventilation in the main house almost got to some of the others. Still at the end of the two years the group were able to bring out some important results. It was the first time anyone had drilled and recovered a 100-metre ice core in Antarctica (it was from the ice-shelf by the wintering base, where most of the time was spent in core drilling and in examining the cores obtained). As the senior glaciologist of the expedition, Valter Schytt wrote: "Here was an opportunity to study for the first time the processes by which snow is altered to ice in a climatic region where melt water plays no part in the metamorphosis" (Schytt 1953). Snow density studies, together with the surveyor's leveling work and some other parameters were also used to calculate fairly accurately the depth of the ice in the ice shelf. The result agreed with the outcome of seismic soundings, which were used to verify it (the value found was 180–190 metres – cf. also Robin 1953).

A profile of the bedrock underneath the ice sheet was made on the basis of seismic soundings along a 600 km traverse from the coast into the interior, showing a maximum depth of the ice field in some places 2,600 metres; this was another first (Robin 1956). Finally, Valter Schytt lay to rest his mentor's (Ahlman's) notion of possible glacier retreat in Antarctica. Charles Swithenbank (1999) discusses what they saw in the field just after New Year 1951. This was after they had reached the nunatak they recognised from the German maps, named after one of the flying boats.

Passat was made of diorite sill material and it too had a big wind-scoop, but here the moat held water. There was one lake 20 by 150 metres and it appeared to be about half a metre deep … clinging to the bedrock surfaces … luxuriant mats of green, long-haired moss in sheltered spots. Here, we realised was an Antarctic oasis (Swithenbank 1999: 148).

The lichens clung to the rock right down to the snow-level. Schytt knew that even in warmer climates lichens might take many decades to migrate. If the ice surface were retreating then a band of lichen-free rock would be found an appreciable distance above the snow-level. Since this was not the case one could infer that there was no glacial retreat in the region.

16 Jan: Jon, Aant and Freyr continued to drill small firn cores and Lars Karlöf began analysing them. Lars is measuring the snow's electrical conductivity which varies with the snow's density and the origins of the airmass. The seasonal variation in these parameters can be used to distinguish different years and also the yearly precipitation. The results he is getting are very interesting. They can be interpreted in a way that makes 'our' site an excellent one for future deep core drilling since the precipitation is relatively high and therefore it gives the high time resolution needed to be able to make good comparative studies with the ice core results from the inland ice of Greenland.

The next day they went to explore Boreas, named after the other German flying boat. There it was the same story: lichens and moss in abundance.

On that morning, in other words, we established the fact that the general recession of the glaciers in the north had no direct counterpart in the inland ice of Dronning Maud Land … Not until much later could we also state that the inland ice itself was not increasing (Swithenbank 1999: 150).

The ice had told its story, and it was a falsification of a hypothesis that had already started to get entrenched in some circles and – through the media – in popular imagination.

Before the wintering party was taken home by the *Norsel* in February 1952, some Swedish planes the ship had brought along were used to do extensive reconnaissance flights into the interior. Thanks to clear weather they were able to photograph almost half the area previously covered by the German expedition 12 years earlier. This new aerial photo-survey, together with ground information and maps made by the wintering party during their two years of field-work laid the basis for a revision of maps of the region. The later Norwegian maps threw out a number of German names since the features of the landmarks to which they attached could not be identified. This was also the case for the range of nunataks where the Swedish station Wasa was established in 1989. The German name Kraul Berge (after the name of the Schwabenland's ice navigator, Otto Kraul) still appears on certain countries' maps (e.g., a French one), but on the Norwegian map it is called Vestfjella (Westerly Range), and the Swedes call the nunatak on which their station is placed, Basen in Vestfjella.

Coming to DML almost fifty years later in search of a site for EPICA, our expedition found the same rugged landscape the members of the Maudheim expedition had reported. Physical conditions and landmarks reminded us of their stories. On the other hand we came with an entirely different artificial life support system, which meant that some of our logistical and other problems also were different.

> *16 Jan ctd.: The radar programme has not gone as well so we have had to make some changes in three respects in hopes of solving our dilemma – one of these is a huge excavation shaft 2.5 metres deep near the drill site in order to study the annual snow layers in more detail.*
>
> *18 Jan: (Temperatures by this time were reaching -39° C at night). Packing and ready to get back … Temperature measurements in the drill holes appear to be more complicated than we had expected … Maybe they reflect irregularities in the snow's accumulation pattern upstream from the drilling site. This would disqualify the region for a future deep drilling operation and complicate interpretation of our own 136 metre long core.*

Concluding Remarks: Constraints and Negotiations Around Research in the Field

From the field notes one can see that some things have changed and others remain the same; 'the ice' is still a capricious and demanding partner in the act of research in Antarctica. One has to make constant improvisations to overcome difficulties put in the way by Nature and the wear and tear of an expedition.

Our major setback was the failure of the radar. This triggered a controversy over responsibility: Was it those in charge of logistics who should have seen to it that a power generator unit did not produce disruptive 'peaks' in the electrical current serving the radar unit, or lay the fault with the scientists for not testing the equipment sufficiently back home, or for failing to define more specific parameters for operating conditions? The problem was never resolved. It was compensated in part by falling back on more traditional methods of snow stratification analysis in the field.

We see here how research in Antarctica is not constrained by Nature alone. Certainly, if it is too warm during a given period, and ice core drilling fails because of this, or if instruments break down, one may have to reschedule/re-negotiate scientific work plans. This brings into play at least three sides of a *triangle of action and reaction* where research activities are constrained by what may be called the human dimension, played out in *logistics*, concern for protecting the *environment*, as well as *health and safety* (Elzinga 1998 and 1999). Within this framework for science in action, strong components of negotiation reduce degrees of freedom in research work.

Apart from logistics and human safety, in recent years more and more emphasis has also been placed on EIA and monitoring. Primary considerations in the triangle constraining the free play of the researcher in field-work thus pertain to personal safety, the material and technical conditions of logistical support systems, and today also the obligation to take into account the impact of what one does to the environment. Social studies of science here can contribute to deeper insights into the complex dynamics of the research process. This is particularly significant when it comes to environmental impact analysis.

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Notes

1 To date 44 nations have agreed to the AT, but only 27 are Consultative Parties (full members), i. e., the ones who actually control the decision-making process.

2 It has been estimated that from 1905 to 1937 Norway caught 430,935 whales in Antarctic waters (Burke 1994; 30, note 7 to Ch 7).

3 The airline advertised a 4-day Berlin-to-Rio airmail service; pictures of the catapult system can be found in Burke (1994: 150–156; also see Grieson 1964: 493–498).

4 On the map that was produced, spots with arrows are specially marked. American, British, South African and German scientists on later expeditions have used metal detectors to try and find the arrows, but without success. One story has it that the navigator or photographer in the plane simply threw out all the arrows in one spot to get it done with (Robert Headland, Scott Polar Research Institute, Cambridge – private communication).

5 Ritscher's entire report consists of two parts, a report of the expedition and its results, and a selection of illustrations with commentary in a separate folder; some of the pictures are colour tainted and paper spectacles with blue and rose tinted mica are included in the inside cover of the second report, providing the reader with a stereoscopic gaze. In all 11,600 photographs were taken, and the ones developed were 18x18 cm. For an early review see Andersson (1945: 403–420); Fagerholm (1944) also reprints some of the photographs. Fagerholm notes how aerial photogrammetry was spurred by military interests, and very advanced in

the reconnaisance by Italy prior to the bombing of Abbysinia in the mid-1930s.

6 Andersson was so impressed by the German effort that he gave a detailed account of the Schwabenland expedition, both in the first edition of his book (1945), and again in the second edition (*Sydpolens Hjältar* 1954), which is expanded to include a brief account of the Maudheim expedition. A Norwegian in the early 1940s recognizes the German contributions, but points out that Norwegian aerial photography had already mapped quite a bit of territory earlier, and that Norway occupied Dronning Maud Land since 1939 (Aagaard 1944).

7 Moreover they only had the published photographs at their disposal. Ahlman apparently met with Ritscher after the war, only to learn that the bulk of the photographic material had been lost, buried during the war in the ruins of the Deutsche Seewartes House (National Hydrological Office) in Hamburg (cf. Ahlman 1948: 216).

8 A second volume (Ritscher 1958) was published during the International Geophysical Year (IGY) 1957/58 with hydrographical, oceanographic and biological papers, and a substantial introduction by H.P. Kosack who used material from the BNSX expedition 1949/52 to correct several errors and reinterpret some of the German maps. Kosack later wrote a comprehensive encyclopaedic work (Kosack 1967). The Norwegian Bogen criticizes Kosack from a politico-ideological perspective (Bogen 1957).

9 Reported in *New York Herald Tribune* 21 April 1949; *Christian Science Monitor* in its earlier account 4 April 1949 notes that Kirwan also envisioned prospects of industry and possible extraction of mineral resources, including uranium deposits. A later report by Kirwan appears in *Times of London* 19 Nov 1949.

10 Giaever's expedition report is in Norwegian, in book form (Giaever 1952). It was translated immediately translated into Swedish (Giaever/Schytt 1952), and then English (Giaever 1954). Note that the Swedish edition carries the glaciologist Valter Schytt's name as co-author. Charles Swithenbank's recent book (1999) gives a detailed personal account of the NBSX. He was the youngest member of the expedition, going as Schytt's assistant. Swithenbank's book, published fifty years after the expedition's commencement, has a full list of the scientific publications, and it

is a mine of much other information concerning the state of the art research at the time. A broader historical perspective, all too brief though, may be found in Fogg (1992). It covers early history of glaciology (pp. 269–274), seismic survey (pp. 264–266), with a picture of the bottom profile made over Dronning Maud Land, and it discusses the ice coring to derive climate historic records (pp. 274–279).

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