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Geophysics of Snow and Ice in Finland during the 1900s

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Abstract

In winter in Finland the land is covered by snow, fresh water bodies as well as the neighbouring areas of the Baltic Sea are covered by ice, and the ground is frozen. Snow and ice research is thus a natural field of geophysics in this country. The main topics have been the seasonal snow cover and sea ice. The research began well in the 1800s for practical monitoring purposes and for the sake of general interest in natural sciences. Until 1940 the activity was focused on the establishment and development of snow and ice monitoring systems. In 1950–1970 basic research questions began to arise as well as contacts to polar research formed. A major increase in the volume of research took place in the 1970s due to the expansion of the winter shipping in Finland and due to the general increase in human activity at high latitudes. During the last decade climate and environmental questions have become increasingly important which has created a wider activity in snow and ice research. Also a new generation with many new doctoral theses has come into the field which gives good promises for the future of snow and ice research in Finland.

1. Introduction

Snow and ice feature Finnish nature for more than half of the year and constitute a natural research field for environmental sciences. In general, the sphere of snow and ice – the cryosphere – is investigated in ecology, engineering, geography, and geophysics. There geophysics is further divided into the research of glaciers, seasonal snow cover, sea ice, lake ice and river ice, frozen ground, and atmospheric ice; these topics span through hydrology, oceanography and meteorology, and thus the knowledge of snow and ice is scattered to three different geophysical disciplines.

In Finland the regional climate is mild in summer and cold in winter when the polar front usually crosses the country. The average air temperature is below zero centigrade from three months in the south to six months the north. Finland belongs to the seasonal zone of the cryosphere: in winter the land is covered by snow, fresh water bodies as well as the neighbouring areas of the Baltic Sea are covered by ice, and the ground is frozen. Only minor all-year cryospheric components exist, small patches of permafrost and firn in northern Lapland.

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Snow and ice have always been a part of the everyday life in Finland. Therefore much practical knowledge has been accumulated about how to live in a snow and ice environment. Also practical problems have had a major motivating role for the research. It is clear that snow and ice monitoring systems developed early, starting in the 1800s (*Simojoki*, 1978); but it is less clear why it took long time, up to 1980s, before the snow and ice science had developed into a major discipline in Finland. One reason must be that there has been no formal snow and ice research organisation but the work has been scattered over several research institutes and university departments.

Snow monitoring for the management of watercourse areas has traditionally been the main background motivation for the snow research, and more recently the role of snow geophysics in winter ecology has become a new research field. Additional snow problems include skiing as well as other means of traffic on snow. Lake ice questions also involve ecology and traffic, and for river ice the main problems have been frazil ice in winter and ice jams in spring. Sea ice in the Baltic Sea has been a barrier to shipping, and by far most of the sea ice research in Finland has been connected to the winter shipping and marine construction in ice-covered seas. Snow and ice have also affected the cultural life some artists being inspired by the forms of frozen water and effects of freezing (Fig. 1).

Fig. 1. Nightfrost (Painting by Hugo Simberg, 1896), this theme was also a major geophysical question in Finland 100 years ago (e.g., *Jurva* , 1912).

Learned to live with the cold climate, Finnish snow and ice geophysicists have extended their research activities to cold regions outside Finland. This work has included glaciers in Svalbard and Antarctica and sea ice in the polar oceans. More official this became after Finland had joined the Antarctic Treaty in 1984 and after the Arctic Centre had been founded in Rovaniemi in 1992. Snow and ice scientists have been quite active in the Geophysical Society of Finland. The society also funded the first Finnish polar expedition for radio sounding experiments in Svalbard in summer 1937 (*Rossi*, 1975). The Finnish Ice Research Society was founded in 1990 with about 25 members from engineering and geophysics.

This article presents main lines of the history of snow and ice research in Finland during the 1900s. It is a continuation in its field to the excellent book of *Simojoki* (1978) on the history of geophysics in Finland in 1828–1918. The present study has a subjective bias since the authors have themselves contributed in snow and ice research for a good part of the period of the 1900s. Still such study is useful to presently active scientists as well as to history of science research in the future.

2. Construction of Observation Networks (1900–1940)

2.1 Snow and Ice Hydrology

In the meeting of the Finnish Geographical Society on 13 December 1890, it was proposed that snow depth should be measured in different parts of the country. In the following winter these observations were carried out at several stations, and also in the same winter the Central Meteorological Institute commenced snow observations at 20 sites. These two observation networks were integrated in 1909 under the Central Meteorological Institute, and then the total number of stations exceeded one hundred.

A pioneer in Finnish snow research was Ville Vihtori Korhonen (1885–1958). He examined largely snow mapping methods as well as snow accumulation in Finland and doctorated in snow science (*Korhonen*, 1915). In addition to the snow depth, the density was included to obtain the water equivalent of snow. The accuracy of these measurements was largely improved when V.V. Korhonen and G. Melander (1861–1938) constructed their snow sampler in the 1920s (Fig. 2); this sampler is still in use today. The Hydrographic Office, established in 1908, set up an extensive network of snow courses in 1935, designed by V.V. Korhonen. Each course was 4 km long, with snow depth measurement at 50-m intervals and snow density at 500-m intervals. The observation network greatly inspired Heikki Simojoki (1906–1991), a coming major character in Finnish snow and ice research.

Fig. 2. Mr. Oiva Urjankangas is weighing a snow sample with a Korhonen-Melander device in the 1970s (photograph by Esko Kuusisto).

Observations of the freezing and break-up of ice in lakes and rivers were commenced already in the 1830s, and in the beginning of the following century the data network expanded (e.g., *Johansson*, 1932). By far these are the longest hydrological time series in Finland; the longest one is the ice break-up in river Tornionjoki, from 1691, and the longest lake ice series is for Lake Kallavesi (from 1830). These data are now very valuable in climate change investigations. Regular ice thickness observations started in the 1910s, first in several lakes of the Kymijoki river basin.

Lake ice data observations were extensively analysed by H. Simojoki for his doctoral thesis (*Simojoki*, 1940). He examined, e.g., the delay from zero downcrossing of air temperature to freezing day and published a map showing the extremely late break-up date in 1867 followed by a famine in Finland. An interesting character in lake ice research was Aaro Hellaakoski, better known as a poet in Finland. He made investigations of shore ride-up of lake ice in Lake Saimaa (*Hellaakoski*, 1932).

An impressive scientist starting his career in the 1930s was Pentti Kaitera (1906–1985), who later became a professor in the Helsinki University of Technology. A particular military question to make floating ice thinner for defence purposes was solved by him by introducing the idea of pumping warm deep water; this idea was also patented later.

2.2 Baltic Sea

The ice cover of the brackish Baltic Sea is essentially a sea ice cover with small-scale structure of sea ice type and with drift ice fields. The ice cover has for long provided possibilities for overice traffic, fishing and seal hunting, but on the other hand the ice is a barrier to shipping. Since early 1800s time series records of the dates of freezing and ice break-up as well as the ice thickness have been collected (see *Leppäranta and Seinä*, 1985). The official start-up of the winter navigation dates back to 1877, when s/s Express opened the first all-year passenger ship route between Hanko and Stockholm.

Along with the development of the winter sea traffic a large set of coastal ice observation stations was founded (*Palosuo*, 1953). The immediate problem was then to establish a real-time reporting and charting system for the Baltic Sea ice conditions. The ice charting continued to be the principal motivation of the Baltic ice research during the first half of the 1900s (Fig. 3). The Finnish Institute of Marine Research was founded in 1918, and then the ice monitoring system was deeply revised by Gunnar Granqvist (1888–1965) and Risto Jurva (1888–1953). The latter became the pioneer of the Baltic Sea ice research, starting his research in 1920s in the Archipelago Sea (*Jurva*, 1925). He presented a cartographic system for the evolution of the ice conditions in his doctoral thesis (*Jurva*, 1937). The idea was that during each ice season certain consequent time-independent ice phases appear, and based on these phases the next change in the ice situation can be predicted. Also Jurva examined the ice climatology of the Baltic Sea and constructed a time series of the maximum annual ice extent of the Baltic Sea back to 1720. This time series has been very widely examined for climate research until presently. In the Second World War air raids of Helsinki by the Soviet air force, the home of R. Jurva was destroyed and with that much of his Baltic ice data material. The numbers of the ice extent time series seemed to disappear also, and the presentation closest to the original is found in graphical form in *Palosuo* (1953).

The ice seasons with interesting observations were documented in the report series of the Finnish Institute of Marine Research and serve now as excellent sources of information. Knowing the ice seasons in the warm winters in the 1930s is very useful in climate change investigations (e.g., *Granqvist*, 1930). An early effort was the organising of a Baltic Ice Week in 1938 to examine the ice mapping systems in all countries around the Baltic Sea (*Granqvist*, 1938). Aerial reconnaissance developed into a new ice charting method. Ice scientists were indeed enthusiastic of getting an aerial overview of the morphology and structure of drift ice fields from aerial photography. It is difficult to understand from our time, how large step in the understanding of drift ice resulted from the aerial observations.

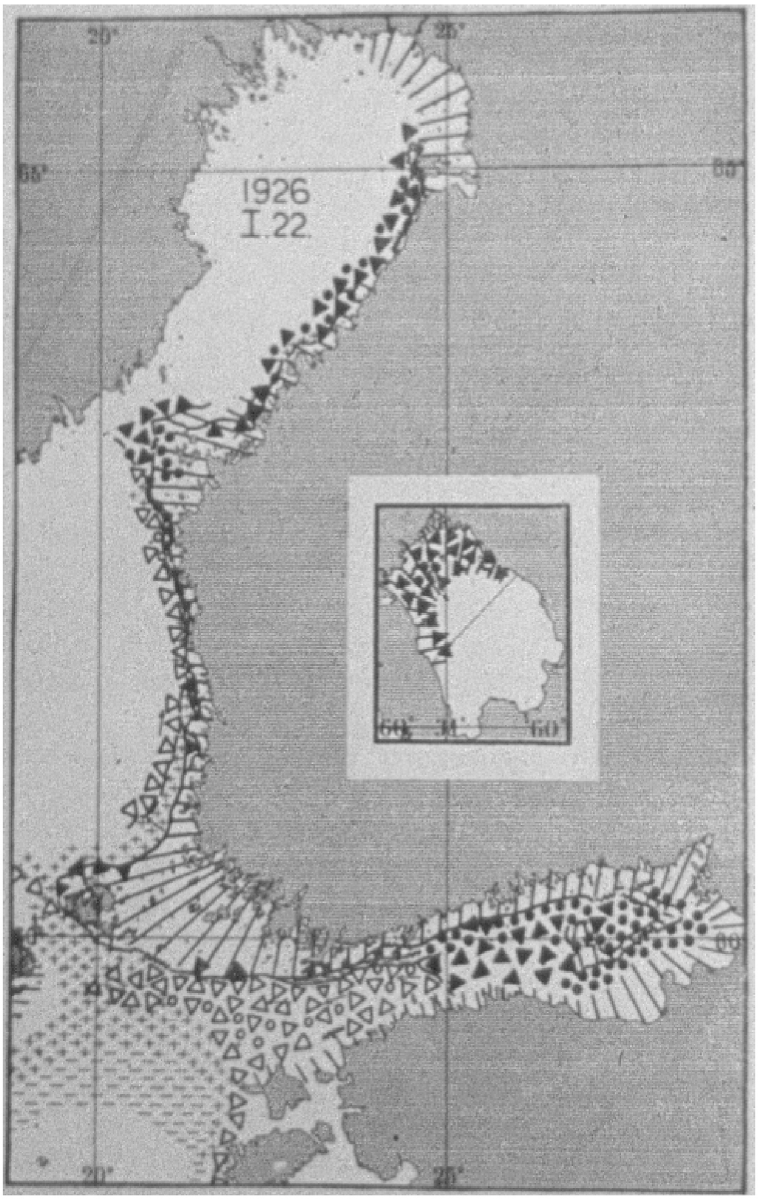

Fig. 3. Ice chart over the northern Baltic Sea from the 1920s (Source: Finnish Institute of Marine Research).

3. Deeper science develops (1940–1970)

3.1 Snow and ice hydrology

H. Simojoki made further investigations on the snow volume and started with work on snow physics. He worked with time evolution of snow density and snow stratigraphy (*Simojoki and Seppänen*, 1963). *Mustonen* (1965) also examined the water equivalent of snow.

Maunu Seppänen worked together with H. Simojoki with attention on effects of land surface topography on snow accumulation. He completed doctoral thesis on snow geophysics in Finland in 1961 (*Seppänen*, 1961), the topic was snow accumulation and snowmelt in a pine dominated forest. Seppänen also established a network of around 15 stake stations to give homogeneous time series of snow conditions in pine forests and in open fields (*Seppänen*, 1967).

Monitoring of the freezing and ice break-up as well as the ice thickness was continued by the Hydrological Office. A new feature was starting of the snow-ice observations by measuring the upward growth of the ice thickness using a stick frozen into the ice sheet. This system was most likely introduced by H. Simojoki. In the 1960s Erkki Palosuo (1912–) investigated the stratigraphy and crystal structure of the ice in Lake Sääksjärvi, southern Finland (*Palosuo*, 1965). Interestingly, the site was at the Nurmijärvi Geophysical Observatory and the field observer was Urmas Luosto, who later became the director of the Seismological Institute.

In the 1960s contacts to Canada were opened in lake ice research. Collaboration on the structure and stratigraphy of lake ice sheet began first with W. Adams, who later became a member of the Canadian parliament. In late 1960s Rene Ramseier spent one year in Finland to examine the crystal structure of lake ice with E. Palosuo. A particular question was the orientation of crystal c-axes in different types of lakes, with 60 lakes mapped in the study.

3.2 Baltic Sea

Jurva continued intensively his Baltic ice research. He examined the ice drift in the Gulf of Finland (*Jurva*, 1941) and examined further ice climatology (*Jurva*, 1952). The winters 1940 and 1942 during the World War II were very severe and the whole Baltic Sea froze over. Ice charting based on reconnaissance flights between Finland and Germany was performed by Air Force officer Erkki Palosuo (*Palosuo*, 1952), see Fig. 4. After the war, starting up with geophysics studies, he finished in 1953 his doctoral thesis, where he extended the cartographic system of *Jurva* (1937) to the severe ice seasons (*Palosuo*, 1953). Also *Palosuo* (1953) presented the first extensive description of the nature of the drift ice in the Baltic Sea.

Closer contacts to polar sea ice science started to grow in late 1950s. A particular occasion was the famous Conference on Arctic Sea Ice held in Easton, Maryland in February 1958 (*Arctic Sea Ice*, 1958). I. Hela and E. Palosuo, both from the Finnish Institute of Marine Research, took part in this conference and presented results from the Baltic winter studies. Also the International Geophysical Year 1957 opened international contacts to Finnish sea ice scientists.

Fig. 4. A photograph over Baltic sea ice fields taken in aerial reconnaissance flight in winter 1942 (*Palosuo*, 1953).

Research activities started to expand from the traditional mapping and climatology line. *Lisitzin* (1957) studied sea level variations during ice and ice-free periods showing the reducing influence of ice cover on sea surface slope.

Analyses of the ice stratigraphy, crystal structure and salinity commenced, with a new universal stage acquired in 1956. The field site was the fast ice in Helsinki between the mainland and the island Harakka. It was shown that the Baltic brackish ice is similar to sea ice, and further investigations in the north at Tornio showed that the transition from fresh water ice type to sea ice type occurs when the salinity of the water body is about 1 ppt (*Palosuo*, 1961). Ilmari Sala commenced ice strength investigations in the 1950s, with comparisons between the strengths of fresh water ice and sea ice. Experiments were also made with gravimeters on ice to map elastic waves travelling in the ice sheet and with pressure gauges to measure the pressure caused by moving ice (*Olkkonen and Palosuo*, 1957).

Sea ice ridges are the most striking feature in a sea ice landscape as well as being the main obstacle to winter shipping in the Baltic. It was therefore natural to build up an extensive field program on the structure of ridges (*Palosuo*, 1975). In late 1960s about 15 large ridges were mapped by photography and divers. The largest one, which was observed, had a 3.4-m sail and a 28-m keel.

Dr. Sulo Uusitalo (1920–1986) was a personality in Baltic Sea ice science. He worked in the Ice Service of the Finnish Institute of Marine Research in 1955–1977 and did serious research on the Baltic winter season in addition to the operational ice work. A notable result was a thermodynamic model, and he also utilised the model inversely to obtain the oceanic heat flux as a result (*Uusitalo*, 1973).

3.3 Polar snow and ice

Since the research trips of A.N. Nordenskiöld to the Arctic in late 1800s, polar snow and ice research was inactive in Finland until the International Geophysical Year 1957. Then Finnish scientists established a research base in Nordaustlandet, Svalbard (*Aro*, 1961). E. Palosuo joined there an international glacier group staying in the field camp for one year performing glacier surveys (Fig. 5). Palosuo analysed his data jointly with professor Valter Schytt from the University of Stockholm (*Palosuo*, 1985b). He also worked on a glacier in Sweden (*Eckerbom and Palosuo*, 1963) and in 1966 made a new trip to Nordaustlandet to continue his glacier research there.

Fig. 5. Nordaustlandet glacier expedition during International Geophysical Year 1957. Professor Erkki Palosuo (in front) loading Vessla vehicle for transportation of equipment.

4. Modern era (1970–2000)

4.1 Snow monitoring and science

Snow courses still constitute the basic network of snow surveys in Finland (*Perälä and Reuna*, 1990). Altogether the Finnish Environment Institute (FEI) maintains some 140 courses. On the basis of these observations, the water equivalent is first calculated for a 50-km grid over Finland and therefrom for various river basins. The data are used to monitor the volume of water in the snow cover for spring flood forecasting and for water management in power plants. Persistent studies on the snow climate of Finland were made by Reijo Solantie at FMI (e.g., *Solantie et al*. 1996).

Also investigations were started on the quality of snow and its impurity content (*Soveri and Peltonen*, 1996). Snow ecology has been investigated in particular in the University of Oulu (*Pruitt*, 1979; *Havas and Sulkava*, 1987).

Towards the end of the century more scientific geophysics of snow started to grow from the water resource monitoring. A snowmelt study in Lammi region, southern Finland was performed by *Kuusisto* (1973). Then two doctoral theses were defended. *Kuusisto* (1984) focused on the development of empirical snowmelt models, and *Vehviläinen* (1992) extended that work for operational application. Both these studies were closely connected to the snow monitoring programme at FEI.

Also connected to the monitoring, airborne and satellite remote sensing methods for the snow cover were under development. This work was made mainly by FEI with engineering groups from the Helsinki University of Technology and Technical Research Centre of Finland, VTT. Airborne gamma-ray spectrometry has been used in larger scale in the Kemijoki Basin since 1982 to map the water equivalent of snow. The method was developed and applied to Finnish conditions by Risto Kuittinen, who summarised this work in his PhD thesis in 1988 (*Kuittinen*, 1988).

Observation techniques for fine scale snow investigations were developed for the needs of applied research, in particular for the interpretation of remote sensing data. A snow fork was designed for the snow density and liquid water content measurement via the dielectric constant (*Denoth et al*., 1984), and Mr. Martti Toikka made this instrument into a commercial product. *Hyvärinen and Lammasniemi* (1987) presented an infrared measurement system of free-water content and grain size of snow. Methods were developed for snow photography by *Pihkala and Spring* (1985).

Skiing is a serious activity in Finland. In the 1970s, a branch of snow research initiated to examine the friction in skiing (*Palosuo*, 1985a). This work was commenced by E. Palosuo (Department of Geophysics, University of Helsinki) and later joined by E. Spring (Department of Physics, University of Helsinki). The research continued until 1990. A doctoral thesis was also prepared on the subject (*Lehtovaara*, 1989).

4.2 Lakes and rivers

The present network of freezing and ice break-up observations of the Finnish Environment Institute constitutes about 150 sites while ice thickness is observed at 40 sites. Apart from the monitoring, lake ice research has been limited. The lake ice problem has been considered more or less solved. Ice climatology of Finnish lakes has been summarised by *Kuusisto* (1994). Geographers did work on the coastal effects of thermal expansion of lake ice (e.g., *Alestalo and Häikiö*, 1979). In river ice problems serious research would have been desired, but due to limited manpower in the field, river ice is still waiting for its first PhD in Finland.

A particular lake ice bearing capacity question arose when Finlandia Ski Marathons were commenced in 1970s. The start of the marathon was made in Lake Katumajärvi at Hämeenlinna, and the ice was then loaded with people and trucks. As a curiosity, in winter 1980 the danger was pointed out by president Kekkonen and the immediate consequence was the invitation of an ice scientist to the lake. A method to strengthen the ice by pumping lake water into the snow cover was developed (*Palosuo*, 1982).

Integration of geophysics into research of our environment has caused a new start in fresh water ice research in the 1990s. Time series data have been collected from Lake Pääjärvi, Lammi, and impurities within ice have mapped in several lakes of varying water quality (*Leppäranta et al*., 1998).

4.3 Baltic Sea

During the last thirty years the knowledge of the geophysics of the Baltic ice has much deepened and widened and the human input has increased many-fold. A strong kick-off to this research was the establishment of the Finnish–Swedish Winter Navigation Research Board in 1970, motivated by the aim to keep all the main harbours of Finland and Sweden open through the winter including the northern Bay of Bothnia. Resources were provided in particular for research on ice climatology, ice mapping, ice forecasting, and ice forces. This research program gained also international recognition (*Weeks*, 1998).

A Baltic ice data bank was constructed based on the good quality material available since the beginning of 1960s in collaboration between Finland and Sweden. This was then utilised for a statistical ice atlas (*SMHI and FIMR*, 1982), which is the only Baltic ice atlas with detailed information from drift ice fields and which has been the basic reference for 20 years. In 1982 the first prediction on the effect of the climatic change on the future Baltic sea ice extent was made (*Makkonen et al*., 1982).

Finnish geographers have particularly examined the coastal effects of sea ice motion. In the Bay of Bothnia, *Alestalo and Häikiö* (1973) mapped one shore ride-up case and *Alestalo et al.* (1986) reported of the highest (15 m) measured coastal grounded ridge in the Baltic.

Baltic ice mapping experienced a major methodological improvement with satellite remote sensing. Occasional images were obtained in 1970s, and the first satellite image receiving station was purchased by the Finnish Institute of Marine Research (FIMR) in 1981 for the NOAA satellites.

To aid real-time planning of icebreaker operations, development of a short-term (days) ice forecasting system was considered necessary. Several ice dynamics experiments were performed in 1975–1979 in the Bay of Bothnia, and mathematical models were developed for the ice dynamics (*Leppäranta*, 1981a, b). An operational ice forecasting system was tested in 1976 becoming a routine a year later (*Leppäranta*, 1977); this was probably the first ice forecasting system in the world based on a numerical model. Also atmospheric boundary-layer studies were made above Baltic ice fields for better understanding of the wind stress on ice pack (*Joffre*, 1984). The intensive period of ice dynamics studies was close to the period when the famous AIDJEX (Arctic Ice Dynamics Joint Experiment) programme was performed in the Beaufort Sea (1970–1978).

Fig. 6. Ice dynamics experiment in the Bay of Bothnia, winter 1978 (photograph by Matti Leppäranta).

In 1980s a large sea ice geophysics group (5–8 scientists) grew in the FIMR. The main themes were sea ice dynamics and forecasting, sea ice morphology, and sea ice remote sensing. A series of field experiments was performed in 1985–1992. The investigations included sea ice crystal structure (*Kosloff*, 1992). Work in sea ice ridges was restarted to continue the work of Palosuo 20 years earlier.

An extensive drilling program was carried through to map the internal structure of ice ridges in 1987–1989. Based on the ridge data a doctoral thesis work was finished by *Paula Kankaanpää* (1998) who later became the director of the Arctic Centre in Rovaniemi. Ice ridging was much examined in the Baltic Sea for the practical shipping application. A specific opening was the performance of full scale loading tests with sea ice ridges in the Baltic Sea (*Leppäranta and Hakala*, 1992).

A new research area opened in remote sensing when airborne and spaceborne microwave methods became available. An extensive experiment program BEPERS-BEERS (Bothnian Experiment in Preparation for ERS-1 – Baltic Experiment for ERS-1) was performed in the Baltic Sea in collaboration between Finland, Germany and Sweden in 1987–1994. The focus was to examine the use of the ERS-1 satellite Synthetic Aperture Radar (SAR) in the Baltic, including a preparatory phase with airborne SARs (*Askne et al*., 1992). In this research program, *Manninen* (1996) prepared a doctoral thesis on radar backscatter modelling, also based on field observations. Technical questions in remote sensing of snow and ice, basically microwave methods were widely examined by the Space Research Laboratory of the Helsinki University of Technology.

ERS-1 was launched in 1991, and its applicability for ice mapping in the Baltic became finally tested in 1992. With very positive outcome, satellite SARs have now become a routine tool in ice charting.

In 1990s sea ice investigations still widened. New thermodynamic models were developed (*Saloranta*, 2000; *Launiainen and Bin*, 1999). In particular Saloranta's work included a proper treatment of snow metamorphism with snow ice formation from slush on ice. Work on sea ice sediments was also commenced (*Granskog*, 1998). Theoretical work on the morphology of sea ice was commenced by M. Lensu (*Lensu*, 1998).

Along with large interdisciplinary programs such as BASYS (Baltic Sea System Study) connections of ice geophysics research to ecology and protection of the Baltic have been increasing. A particular question for the Baltic Sea is oil combatting, because of the ice season and because of the vulnerability of the shallow and semi-enclosed sea itself. After an oil tanker accident in winter, the behaviour of oil in ice covered sea was examined by *Palosuo et al*. (1982). Baltic sea ice ecological investigations were commenced in Finland in the 1980s. Ice biota was studied by *Huttunen and Niemi* (1986) and by *Ikävalko* (1997).

Sea ice scientists outside the Baltic Sea region took part in some of the field programs which was very valuable at least from the point of view of the Baltic ice science. The structure and physical properties of ice were examined by *Weeks et al.* (1990), *Lewis et al.* (1993) performed studies of the surface topography of the Baltic ice by a laser profilometer, and *Zhang* (2000) has worked on numerical modeling of sea ice dynamics. The Baltic SAR remote sensing studies were joined by several polar sea ice scientists. In particular, with similar basins in the seasonal sea ice zone, co-operative efforts have been very fruitful (*Wu and Leppäranta*, 1990; *Shirasawa and Leppäranta*, 1996).

4.4 Polar snow and ice

In the 1980s polar snow and ice science began rapid development in Finland. The first landmark was the participation in the Swedish expedition Ymer-80 to the Eurasian sector of the Arctic, July – September 1980. E. Palosuo and M. Leppäranta examined the small-scale properties and thickness of sea ice as well as sea ice ridges during the expedition (*Leppäranta and Palosuo*, 1987), and H. Österholm joined a glacier study group in Nordaustlandet. M. Leppäranta also participated in the MIZEX (Marginal Ice Zone Experiment) program in the Greenland Sea, 1983–1984 (*Leppäranta and Hibler*, 1987). Good collaboration with Sweden realised then in the continuation of participation in Swedish Arctic expeditions Oden-91 and Arctic-96 (*Eicken et al.*, 1995). Due to increasing activities in both polar regions, the Polar Committee was founded in Finland and for public relation purposes also a book about Finnish polar research was published by the Ministry of Trade and Industry (*Heinonen*, 1989).

Also in 1980, a Soviet–Finnish "Arctic project" commenced with the final aim to utilise the oil and gas resources of the Eurasian continental shelf of the Arctic. After the "oil crisis" and approaching 1980s it was believed that offshore drilling and transportation of oil and natural gas in the Arctic would soon become profitable. The need of safe and economic technology for such operations created a boom in ice research and engineering. This was particularly visible in Finland due to its existing technology in building icebreakers and the extensive clearing trade and technological co-operation with the Soviet Union. Also, at the time, the Finnish government started to allow, and partly force, its research institutions to operate on a commercial basis. This created a need to abandon purely scientific arguments in directing research and to find research money where it was around. Later due to the development of oil price the economical goal shifted longer ahead of time.

The Arctic project produced a lot of ice mechanics studies (see chapter 5). The first wind tunnel in the world for sea spray icing experiments was constructed at the Finnish Institute of Marine Research (Fig. 7). Atmospheric ice accretion work was commenced by L. Makkonen in Finland leading to a doctoral thesis in this field (*Makkonen*, 1985). Icing of ships was also examined by *Makkonen* (1987, 1989). Atmospheric icing studies (see *Makkonen*, 2000) found a new application in Finland when Kemijoki Ltd started in the late 1980s to develop arctic wind energy. Consequently, a numerical model of wind turbine was developed (*Finstad and Makkonen*, 1996) and utilised in the design of an ice prevention system for operational wind turbines.

In 1992 Arctic Centre was opened in Rovaniemi, including a small research institute and an exhibition centre. The second director was a German sea ice scientist Manfred Lange who commenced sea ice program there but did not stay there long. A British glaciologist, Dr. John C. Moore, moved to the Arctic Centre in 1993, and since then he has had a major role in Finnish snow and ice research starting new glacier research projects with Finnish young students included.

In 1984 Finland signed the AntarcticTreaty which includes a general duty to do research in Antarctic regions. Consequently, a summer station Aboa was designed and constructed by VTT during an expedition directed by O.-P. Nordlund in January 1989. The station is located on the Basen plateau 130 km inland from the ice edge on the coast of the Weddell Sea (Fig. 8). Several snow and ice scientists have taken part in the Antarctic research, first of all the research group of J. Launiainen with members from the Finnish Institute of Marine Research and Department of Geophysics of the University of Helsinki (e.g., *Vihma and Launiainen*, 1993). *Vihma* (1995) presented doctoral thesis including Antarctic sea ice investigations.

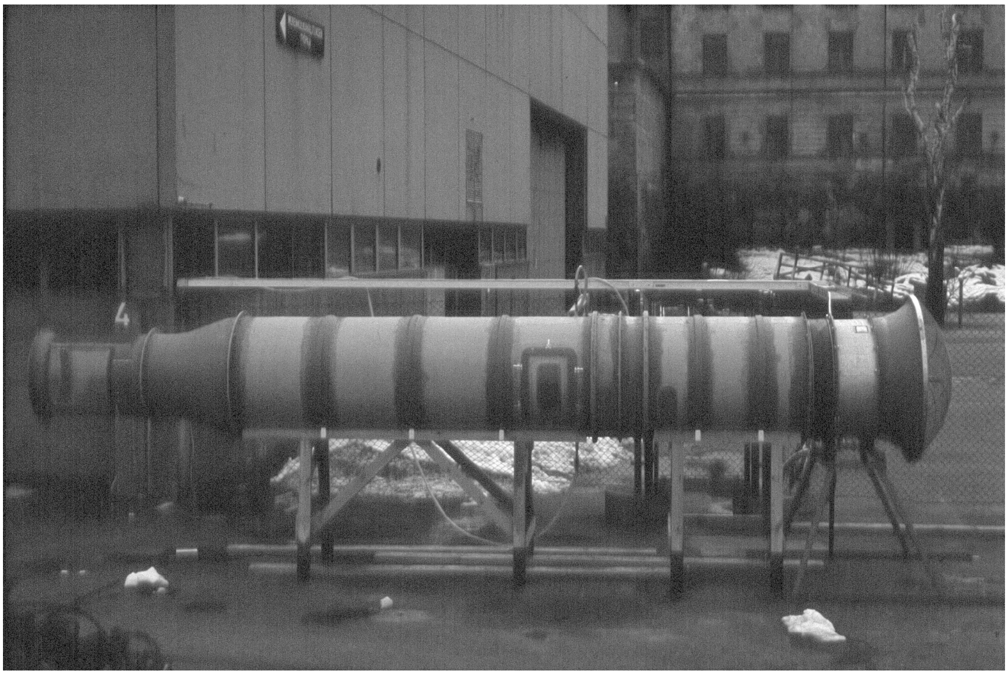

Fig. 7. Wind tunnel of FIMR for ice accretion experiments (courtesy of Lasse Makkonen).

Fig. 8. The Finnish Antarctic station Aboa (courtesy of VTT).

5. Ice engineering

Many practical ice and snow problems in Finland have always called for engineering solutions. These have been based on traditional knowledge and surprisingly little systematic ice and snow engineering research was made prior to the 1970s. Perhaps this was due to that Finnish people must have, for generations, coped with ice and snow as a part of everyday life that it was hard for them to believe that something new could be found by research. When Finland started to change from a rural society to an industrialised nation, new kind of ice problems arose. The main Finnish ”ice related” industry, ship building, did not, however, require much detailed research on ice but the design was mainly based on full scale ship trials and some ice pressure measurements.

Following the destruction of the Kemi sea marker by ice, an extensive measurement programme was commenced in 1970s on mechanical properties of ice aiming to study ice forces on ships and fixed structures (*Enkvist*, 1972; *Määttänen*, 1975, 1987; *Varsta*, 1983; *Tuhkuri*, 1996). Full-scale field work was done by *Määttänen* (1975, 1986) studying ice forces on the Kemi I lighthouse (Fig. 9). He also developed a well-known dynamic ice-structure interaction model (*Määttänen*, 1979).

Fig. 9. Kemi I lighthouse in drift ice field (courtesy of VTT).

Significant contributions were made also in other studies of ice-structure interactio (*Eranti*, 1992; *Tuhkuri,* 1995; *Kärnä et al*., 1999), adhesion of ice (*Oksanen*, 1983; *Makkonen and Lehmus*, 1987). A widely used power line icing model was developed by *Makkonen* (1984a).

One goal in the engineering research was to find scaling relations between the ice in nature and the ice used in small-scale ships-in-ice tests at the Wärtsilä Ship Yards (later Masa-Yards, then later Kværner-Masa-Yards) model ice tank established in 1969. Much practical research was made in this ice tank and a special formula was developed for making the tank ice. For a while the ice tank of the Wärtsilä Arctic Research Centre was the biggest of the kind in the world.

The arctic ice engineering boom of the 1980s affected above all the Laboratory of Structural Engineering and the Ship Laboratory of the Technical Research Centre of Finland (VTT), the Helsinki University of Technology, and the Wärtsilä Shipyard. All these organisations possessed ice tanks for small-scale modelling of ice forces on ships and offshore structures. Other Finnish shipyards and some other research organisations were then involved in the research as well. Almost twenty Ph.D. theses were prepared on ice engineering and mechanics.

By the end of 1980s the Finnish government withdrew from its role as the main funding source of Arctic engineering research. It also became evident that the planned large scale offshore operations in the Arctic would not be seen in the near future partly due to the uncertain political situation in Russia after the collapse of the Soviet Union. The companies' interest in funding ice research thus disappeared also. Many researchers in the field found other jobs and by the end of the century e.g. many Arctic research facilities were demolished at VTT, including the ice tank and Finland's first cold room built for ice research in 1964 at Betonimiehenkuja 3, Otaniemi. Later a decision was also made to demolish the Kværner-Masa-Yards (Wärtsilä) Arctic Research Centre and its ice tank.

With the aid of international networking, academic funding and a new source of research funds – the European Union – ice engineering research in Finland survived, however. In fact, due to the long term nature of basic research, many fruits of the arctic ice engineering boom of the 1980s became ripe only after the peak of financing was over.

A renown ice friction theory with a quantitative ice friction model was developed in early 1980s (*Oksanen and Keinonen*, 1982; *Oksanen* 1983). *Makkonen* (1988) constructed the first icicle growth model, and *Santaoja* (1990) modelled ice deformations. In 1990s ice research was made also at the Department of Physics, University of Helsinki as related to nucleation of clouds (e.g. *Bogdan* 1997). A new theory of the phase change equilibrium of the ice/water system was proposed by *Makkonen* (1997) explaining the regelation and surface premelting of ice as well as the density maximum of water in a new way.

Research was also made at VTT in construction using ice and snow and in winter sports. Reviews of the ice engineering research funded by the Finnish government in 1980s are presented in *Määttänen* (1987) and *Enkvist and Eranti* (1990).

5. Education and conferences

In spite of severe impacts of winter on human safety and economy there has been no university chair in Finland assigned to ice and snow research. Ice and snow subjects were lectured at the University of Helsinki and Helsinki University of Technology. The geophysics chair has been held by ice and snow scientists: H. Simojoki (1967–1972), E. Palosuo (1972–1977) and M. Leppäranta (1992–) in the University of Helsinki, which eventually resulted in very active ice and snow education culminating in a Graduate School of Snow and Ice (1999–). In 1990s also two professorships at Helsinki University of Technology were held by scientists with a background in ice research (M. Määttänen in the strength of materials and K. Riska, in arctic shipbuilding). In 1990s advanced study institutes have been held on snow and ice science in Finland.

Several university positions were opened in Rovaniemi following the establishment of the Arctic Centre as a part of the University of Lapland in 1992. This had initially little impact on education, however, since there is no faculty of science in that university. While the establishment of the Arctic Centre increased the volume and internationality of glaciological research in Finland, it was seen by many as a prime example of poor science organising on political arguments.

Of some help in increasing co-operation and information exchange in Finland has been the Finnish Ice Research Society that was established in 1990. During the first ten years of activity M. Määttänen, M. Leppäranta and L. Makkonen have acted as the presidents of the society. In the International Glaciological Society the Finnish correspondents have been E. Palosuo, M. Seppälä and M. Leppäranta, and L. Makkonen was also a member of the Council in 1988–1995.

Several international conferences on ice and snow and related subjects have been organised in Finland but only since the 1980s. The most important of them have been IAHR (International Association for Hydraulic Research) Symposium on Ice in 1990 and International Glaciological Society (IGS) Symposium on Applied Ice and Snow Research in 1993. IGS Nordic Branch meetings have held in Finland in 1995 and 1999. A series of Baltic Sea ice climate workshops was initiated in Finland in 1993 (*Haapala and Leppäranta*, 1993). Also POAC (Port and Ocean Engineering under Arctic Conditions) conferences were held in 1983 and 1999, and four international symposia on wind power in icing conditions were organised in 1990s. Textbooks have been produced by Finnish ice researchers (*Eranti and Lee*, 1986; *Makkonen*, 1984b, 1994; *Leppäranta*, 1998).

6. Conclusions

A brief report has been presented on the history of geophysical research of snow and ice in Finland during the 1900s. In winter in Finland the land is covered by snow, fresh water bodies as well as the neighbouring areas of the Baltic Sea are covered by ice, and the ground is frozen. Snow and ice research is thus a natural field of geophysics in this country. However, no particular snow and ice research institute has existed in Finland, which may be the main reason why the research was scattered and occasional in the time before 1970s.

The main topics have been the seasonal snow cover and sea ice. The research began well in the 1800s for practical monitoring purposes and for the sake of general interest in natural sciences. Until 1940 the activity was focused on the establishment and development of snow and monitoring systems. In 1950–1970 basic research questions began to arise as well as contacts to polar research formed. A major increase in the volume of research took place in the 1970s due to the expansion of the winter shipping in Finland and due to the general increase in human activity in high latitudes.

In late 1900s different branches of geophysics were finding each other again, after a few decades when the branches much examined their very own problems. Interfacing sea ice science, sea ice drift information was required by geodesists making gravimeter measurements from drifting ice in the Gulf of Bothnia.

During the last decade climate and environmental questions have become increasingly important which has created a wider activity in snow and ice research. Also research projects have started where geophysics and engineering interact much more in snow and ice research (e.g., *Tuhkuri et al*., 1999). A new generation with many new doctoral theses have come into the field. These theses include backscatter modelling for microwave remote sensing (*Manninen*, 1996), sea ice ridges (*Kankaanpää*, 1997), sea ice ecology (*Ikävalko*, 1997), and sea ice dynamics (*Haapala*, 2000; *Uotila*, 2000; *Zhang*, 2000). All this gives good promises for the future of snow and ice research in Finland.

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