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Oceanography in Finland 1918–2000

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Abstract

Much of the marine science studied in the earlier part of the last century was follow up and development of the main original themes of Finnish study of the sea, which in addition to theoretical interest had also very practical aims. According to Heikki Simojoki (1978), the original themes were the studies of water level, studies of the ice and, the latest arrival, studies of the hydrography and structure of water masses. Simojoki presented a thorough analysis of the early stages of the history of oceanography until the dawn of Finnish independence in 1917. Since then, the development was strongly influenced by the institutions originating from earlier decades and, in particular, by persons already working in the field.

This study continues to follow the development of oceanography in thematic sequence. In several cases scientists have devoted to their main themes, much independent of work at other schools. There are many close ties to other geophysical studies, mainly to hydrology and meteorology. The author has dealt the overlapping themes more shortly. For practical reason earlier works are described in more detail, the value recent works remains to be evaluated later.

Background

Oceanographic research in contemporary Finland has three main roots. They all stem from basically scientific curiosity, but simultaneously they also have other practical aims in the background. The main roots, as described by *Heikki Simojoki* (1978) are the studies of water level, studies of the ice and, the latest arrival, studies of the hydrography and structure of water masses.

Dialogue on why the sea was escaping coastline was long a mystery and wild hypotheses on it were set in early 17th century. Still *André Celsius* (1743) considered that the amount of water in the Baltic Sea is diminishing and, consequently, the coastline is moving further from earlier position. It was not until 1765 that E.O. Runeberg first presented the idea that land may be rising instead. Ever since increasingly detailed studies on this phenomenon were conducted. The Finnish Society of Sciences established a set of regular observations for quantitative determination of land uplift in 1840's.

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By the end of 19th century, Finnish connections with the external word had increased to a level where marine transport also in wintertime became a must for the national economy. Earlier supply on season without ice cover only was insufficient and means were sought for extending the navigation season. During that time, the harbour of Hanko in the southernmost tip of Finland was the main point of export and import, but even during moderate winters there were several months during which the harbour was to be closed due to ice conditions. Obviously, there was considerable interest to find out what are the ice conditions determining possibilities for traffic.

Active interest in the study of the water body itself had to wait until the end of 19th century. There had been studies of temperature and salinity variations at different parts of southern Gulf of Bothnia, Gulf of Finland and northern Baltic Proper, but these were ephemeral and no systematic interest could be seen until 1890's. During that time, Finnish scientists attending in London Geographical Congress got to learn about initiative of Prof. Otto Pettersson of Sweden to arrange joint European studies of the seas in order to gain systematic knowledge for understanding variations of fisheries resources and the quality of the waters. Finnish scientists, in particular Professor of Applied Physics at the University of Helsinki, Theodor Homén saw this as an opportunity, not only to join study of a new field but also to show an independent action from that of the mainland Russia, which had plans to study mainly the Barents Sea.

Semi-permanent studies due to Homén's initiative started in 1898 by the decision of the Senate of Finland to give funds for the Finnish Society of Sciences for hydrographical and biological studies on the seas surrounding Finland. They were the nucleus of marine research in the country during the first half of the century. The funds made it possible to acquire staff for practical work as well as for scientific analysis. With the time of dawning independence, scientists were well trained for taking the responsibility of the forthcoming Institute of Marine Research. The institute started its operations on 1st January 1919. It had its administrative structure faithful to the main roots of earlier research as described above. The new director of the Institute was a physicist. For economical reasons hydrobiological studies carried out by the Society of Sciences remained in its auspices at the University and were not included in the Institute.

1. Water level

Problems in understanding the Baltic Sea water level variations stem back to 18th century. A thorough discussion of the earlier history is presented by *Simojoki* (1978). By the end of the 19th century some quantitative results on long time land uplift along the Finnish coastline were obtained thanks to the observation networks established and maintained by the Finnish Society of Sciences. In addition to tide poles and fixed watermarks along the coastline, continuously recording tide gauge had been established in Hanko 1887 and another in Helsinki 1904 (Fig. 1). *Eduard Blomqvist and Henrik Renqvist* (1914), in connection with the gargantuan work of the first precise levelling of

Finland, had estimated land uplift, mainly with tide pole time series of some 20 years. Their estimate was reconsidered by *Rolf Witting* (1918). With an exception of Hanko and Helsinki mentioned above, no other continuous records with higher time resolution were available. The results obtained on the basis of daily readings were subject to both air pressure variations as well as to wind set-up of the sea surface, factors well noted by those authors.

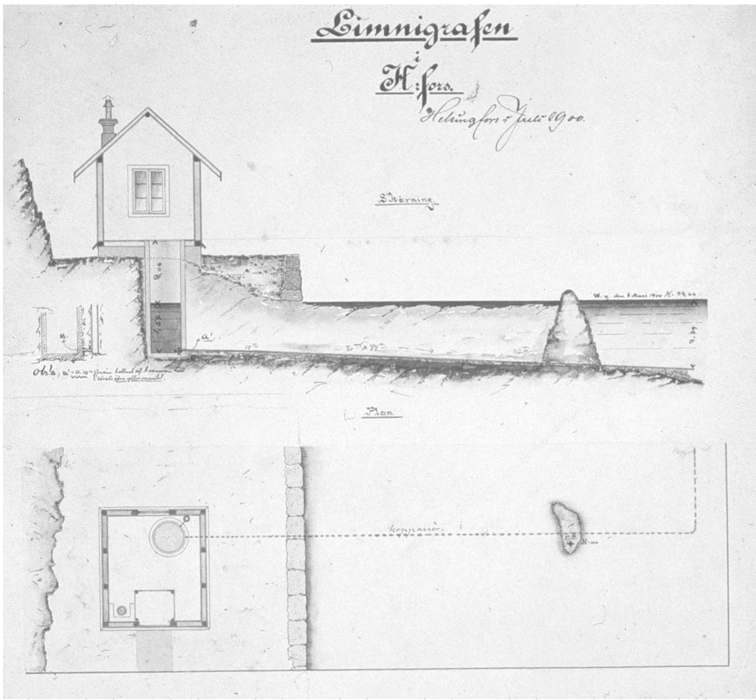

Fig. 1. Tide gauge of Helsinki, original construction plan.

When the Institute of Marine Research was established as a governmental research institute 19 November 1918, one of its main fields of study was the water level, as noted earlier. Witting, as the Director, was keenly interested in establishing a proper tide gauge network. From the beginning of 1919 another like minded scientist, Dr. Henrik Renqvist joined the Institute and was soon nominated as “thalassologist”, i.e. head of the Department of water level studies. He had earlier worked as a geodetist in the Supreme Board of Road and Waterway Construction with responsibility of precise levelling and water level observations. Renqvist realised that the needs of accuracy versus scale could best be solved with a special construction, which he designed jointly with Witting. The basic structure is an ordinary floater in the well connected with a horizontal circle of 1 m. circumference. It had pencils at 10 cm intervals, thus drawing a 1:1 graph of water level variations. (Fig. 2). For severe winter conditions, the cabin and well had to be isolated and heated to guarantee unfrozen operation all the year round. The construction of the network and building activity started immediately. During the period 1921–28 altogether 14 new recording tide gauges were built in Kemi, Oulu, Raahe, Pietarsaari, Vaasa, Kaskinen, Pori, Turku Degerby, Hamina, Viborg and Koivisto in the Baltic, Sortanlahti and Valamo in the

Lake Ladoga. Six of these became operational already in 1922. Still one station was added at Liinahamari in Petsamo, coast of the Barents Sea in 1930 and one at Rauma in 1932. The observational network was considered to be sufficient for both practical and scientific purposes.

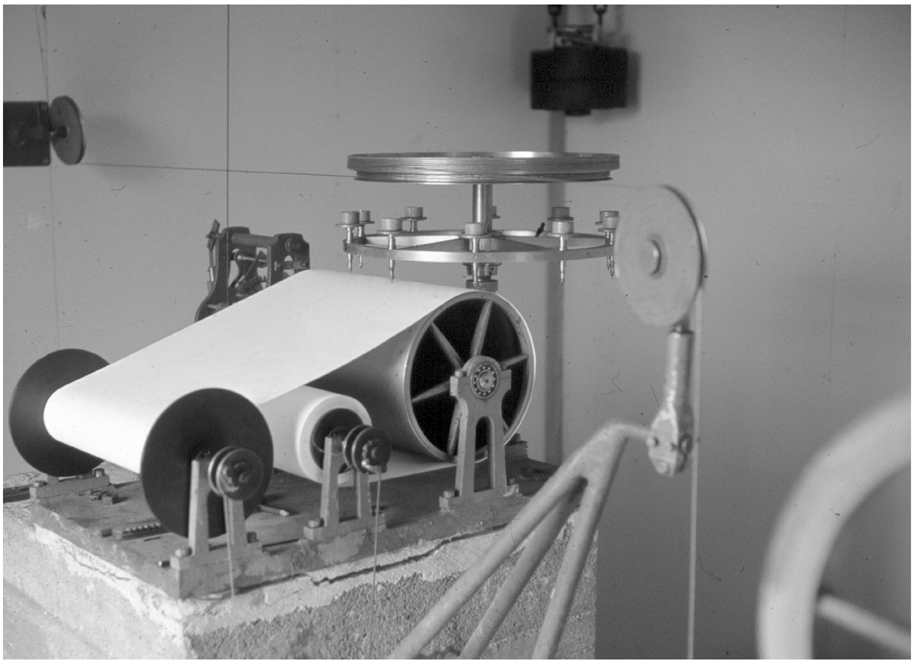

Fig. 2. Renqvist-Witting tide gauge, recording unit.

Today, having access to modern measurement techniques, it is hard to realise how crucial the new network was for science carried out in 1920's and 1930's. Developments in marine physics followed that in meteorology, so it was clear which role the pressure field inside the fluid had on the dynamics. Observations of sea currents, as well as determination of the dynamic effect of the wind stress was hard to arrange, thus water level served as a reliable measure for several kind of studies. The importance was augmented by the fact that the first precise levelling of Finland was carried out in 1889–1912 and its data for the reference level were available along the coastline. One can say that the establishment of this network was the most important single technical contribution to the Finnish marine physics, even greater than the construction of special research vessel in 1903. The network is still basically existent, with an exception of those lost to Soviet Union in the Second World War. For the others, minor reconstructions have been made due to arising needs in the development of harbours. On some sites the recording system has been moved by a few kilometres. Instrumentation has been modernised in 1970's and 1980's.

It is interesting to note that although the original idea of the construction was to serve both science and practical needs, the former got priority. This was shown by the fact that a number of harbours organised tide poles for water level observation service of seafarers. This was separate from the tide gauges described above and of lower accuracy as well. The Institute of Marine Research run the system and took care of twice a day delivery of water level information by broadcast. It was not until the end of 1980's that the two could be partly merged due to digitalisation of the observation system and remote automatic data transmission, as well as use of speech synthetizers on the tide gauges.

After the accurate and reliable observation network had been established, the information obtained for determining the land uplift increased quickly, and a number of improved estimates were published (*Hela*, 1953; *Lisitzin*, 1964; *Rossiter*, 1962; *Kääriäinen*, 1975; *Vermeer et al,* 1988). In the same connection the question of the steric height of the Baltic Sea was taken into consideration. Due to horizontal as well as vertical gradients of salinity, the density has both spatial and interseasonal variability. Consequently, the equilibrium level of the sea surface deviates from the geoid. *Witting* (1918) discussed this extremely nontrivial problem at length. The problem is simplified by the fact that the Baltic Sea does not have any permanent current system (no stable geostrophic adjustment), but complicated by the fact that the Baltic Sea basin is separated from the North Sea by a shallow sill and by the fact that between basins sills prevent free adjustment. Witting's calculations were based on salinity and temperature observations available from different parts of the Baltic Sea. He produced a map, which showed that the Kattegatt deviated by 10 cm from the geoid of the North Sea and the deviation increased to some 30 cm above the geoid at the northern end of the Gulf of Bothnia. There was a clear seasonal signal due to fresh water flux and the surface layer heating. Modern satellite determinations of geoid do not deviate significantly from that estimate.

In addition to the value for understanding recent crustal movements, these results served as a basis for the entire precise levelling system of Finland, they were used for various practical purposes such as design of harbours, waterways, bridges, other coastal constructions and reference for measuring the valuable surface area of real estate in expanding cities.

Already *Witting* (1918) discussed in detail the influence of wind and atmospheric pressure variations on the short time sea level variations. *Gabriel Hällström* (1842) debated this subject already in the previous century. He obviously was the first to consider that the influence of wind is equally important as the influence of atmospheric pressure. Before him, *Gissler* (1747) and *Schultén* (1806) had discussed the influence of atmospheric pressure, but considered the wind influence to be insignificant. Witting used water level recordings around the Baltic Sea combined with available meteorological information and gave a quantitative estimate of the influence of wind. According to him it was proportional to pressure gradient and some 75 degrees to the right of the pressure gradient. Altogether, he finds that the direct influence of wind is some 1.6 times the influence of pressure gradient. *Erik Palmén* (1932, 1936) developed a more general law, estimating the drag coefficient of wind on water surface. Palmén, as noted by *Eero Holopainen* (1985) had a magic skill to draw significant physical conclusions out of very limited amount of data. The values he obtained established a standard for the oceanographic literature of the first half of the century, often cited and used as best available estimates. This is due to the skills of the author and also due to the well functioning network, which enabled the studies.

When the mean sea level and its secular variation had been established, the question of water exchange with the North Sea arose. This problem, extremely nontrivial, has been approached by the Finnish oceanographers since Witting. The intensive tide gauge network enabled integration of the volume changes of the Baltic Sea. Similarly, the known salinities led already *Martin Knudsen* (1903) to present his diffusion equation on water exchange, and using the information of volumes, estimates were obtained of total water exchange. Witting obtained an estimate for total fresh water inflow to be on the average 467 km^3, a value which has been an unchanged base for water balance calculations ever since. *Ilmo Hela* (1944) carried out a thorough study of the water exchange with the North Sea. He determined water level variations both in the North Sea and in the Baltic Sea, analysed the results statistically, determined the seasonal cycle and determined the volume exchange rates in the Danish Sounds. According to Hela, the volume flux in the Sounds is not seldom of the order 100 000 to 200 000 m^3 per second, maximum values being some 400 000 m^3 per second. Interestingly, Hela provided a statistical map of sea level variation estimate from monthly average of the entire basin, showing the nodal region of the central northern Baltic. The water exchange has ever since played important role on the understanding of the behaviour of the Baltic Sea. References to it are found in a number of subsequent Finnish publications.

One conspicuous feature of the Baltic Sea water level variations is its periodic oscillations. The tides, although existent, play a very minor role except in a few locations in the archipelago. Instead, wind set up relaxes to periodic seiches oscillations with considerable amplitudes. This, in connection with the tides in the Gulf of Finland, had been studied already in 1911 by Witting, only a few years after the basic theoretical studies of *Chrystal* (1906). *Sten Stenij* in his classical papers (1930, 1932) studied the problem as a theoretical physics problem of eigenvalues. In these two papers Stenij solved the problem by integral equations for free, forced and resonant oscillations. He did not present any numerical solution in these papers. As a special case relevant to the Baltic Sea he considered 1-dimensional case, relevant to his later study on surges. This and other papers by Stenij were an example of his deep theoretical insight to the observed phenomena. He extended the interest, in particular in the 1930 paper to consider propagation of tidal waves in the ocean, work that was then timely all over the European research institutions.

Although the tides, in general, are insignificant tin the Baltic Sea, studies of tides were also carried out, in particular during the first decades. *Eugenie Lisitzin* (1943; 1944) calculated tidal values for both the Gulf of Bothnia and the Gulf of Finland. Despite of the small amplitude, the tides do influence navigation due to strong currents in the complicated straits of the archipelago, as she showed in a later paper (1967a). Lisitzin also calculated both annual and semi-annual tides for the both gulfs. The variation in amplitude and in the phase of the annual wave present some difficulty in interpreting these as really tidal waves, which she seemed to understand as well. For me, these may be rather taken as a practical harmonic analysis for interpreting the annual cycle of mean se level than as tidal wave. Another set of studies of tides originated due to the fact that Finland had for a period of more than 20 years a harbour in Liinahamari in the Barents Sea. As noted earlier, a tide gauge was established there in 1930 and forecasts of tides were made since 1936 (*Stenij*, 1937). This activity was continued until the Second World War.

Although tidal prediction is not necessary in the Baltic, water level variability due to meteorological disturbances is considerable. Long period records indicate in the nodal region (Åland islands) variability of 170 cm, at the end of the Gulf of Bothnia 325 cm and at Hamina, Gulf of Finland 275 cm. The range is much larger in St. Petersburg, which is located at a funnel type end of the shallow bay. It is therefore natural that one recurring issue in Finnish studies of the 1920's to 1950's was the wind set up. After Witting, in particular *Palmén* (1932; 1936) analysed water level data and found a relation quadratic to wind velocity and inversely proportional to water depth, which was used widely by subsequent authors. Mostly the results were used to estimate a stationary response to wind. However, the most conspicuous exception was the analysis of *Stenij* (1936) of the big flood of Leningrad in 1924. In this particular case the water level rose 369 cm above mean sea level, causing tremendous damage. Stenij's analysis led to conclusion that the flood was caused by a number of coincident factors, such as: high water level in the entire Baltic Sea, the propagation of the atmospheric low along the axis parallel of the Gulf of Finland in such a way that wind direction was parallel to the Gulf, propagation velocity of the low close to the velocity of free barotropic water wave and, finally, occurrence of secondary oscillation simultaneously with the above coincidence.

Today the estimation of water level variations are no more a high priority scientific problem, forecasting and analysis are a part of numerical modelling work carried out at the institutions. The open boundary condition towards the North Sea is removed by extending the models westwards, giving thus reliable exchange estimates for the Baltic Sea.

While majority of Finnish studies on water level focused on the Baltic Sea, the knowledge was used widely also outside the home waters. Both Hela and Lisitzin had close contacts with scientists working on similar problems in other parts of the world. This is seen in the publications of Lisitzin on the water level variations of Brest and the Mediterranean (e.g. *Lisitzin*, 1958), in close interest of *Rossiter* (1962) in the land upheaval and mean sea level of the Baltic Sea and, in particular in a number of publications of Lisitzin on the global mean sea level. All this culminated in her contract to publish a book on the global mean sea level (*Lisitzin*, 1974). This volume considers the full range of sea level problems from eustatic rise to determination of geoid to tidal variations and tsunamis. The contents very much reflects the wishes of the publisher who had taken the initiative and invited her to write the book. It does also give a considerable synthesis of her earlier works.

2. Sea ice

Studies of sea ice have a separate paper in this volume. Therefore, detailed discussion on ice studies is not given here. Some aspects related to sea ice have to be mentioned, as they deal with the very complex interaction of atmosphere and ocean in the presence of ice cover.

The role of sea ice on the layer beneath has many influences. It decouples the air sea interaction, thus isolating the layer beneath from further mixing and cooling. As a wide, slab-like field, it also has different response to atmospheric forcing from the open areas. One classical example of this is the study of *Lisitzin* (1957, 1967b) on the influence of the ice cover on water level fluctuations. She used selected stationary situations in the Gulf of Bothnia, when wind was blowing along the basin. She compared the values obtained for the numerical coefficient of the water level inclination equation, which can, in the Gulf of Bothnia be reduced to less than half during a severe ice cover. In another paper she discusses the influence of ice in general noting, among others, that in the White Sea tidal amplitudes in the winter can be reduced by 50 %.

Jouko Launiainen and his team have analysed the interaction of atmosphere and the sea in the presence of sea ice. This work has been carried out in various contexts, partly as an effort to improve operational models for the Baltic Sea, as a part of Finnish Antarctic programme to estimate the heat budget of the Weddell Sea, and as a part of the international BALTEX program in cooperation with many other EU partners (*Launiainen and Vihma*, 1994; *Vihma and Launiainen*, 1993). Their studies have resulted in improved models of heat exchange in winter conditions with heterogeneous interfaces, in improvements of ice drift and thermodynamic models and, in particular based on long term cooperation with other scientists working on the Weddell Sea region, to improved parametrisation of sub-grid scale phenomena in numerical models *Vihma* (1995).

3. Hydrography

By definition, hydrography can be interpreted as the study of physical oceanography at large, or just study of the properties of the seawater and its distribution in time and space. My choice of definition is the latter. Partly because this to a great extent describes a complete set of activities in Finland, partly because other aspects of physical oceanography are better described as chapters of their own.

As described in extenso by *Simojoki* (1978), the end of 19th century was an active starting period of hydrographical studies. In addition to opening a new field of research it also served other national purposes by Professor Theodor Homén and Fisheries Inspector Oscar Nordqvist (*Simojoki*, 1978; *Mälkki*, 1990). As a consequence, by the time of independence Finland had an extensive set of coastal stations where temperature and salinity profiles were measured regularly. Moreover, the availability of a research vessel enabled wider studies of hydrographical variations around the entire Baltic Sea. For practical reasons, the activities were limited to the northern Baltic and the Gulf of Finland and the Gulf of Bothnia. By that time the people in charge had no difficulties in obtaining observers for the coastal stations. A network of light vessels was in operation, pilots and lighthouse managers were eager to do observations even if the payment was marginal, and the entire archipelago was inhabited enabling recruitment of competent observers. It is no wonder that during that time the number of observers of hydrography, water level at tide poles and ice conditions in wintertime was truly extensive. On many later studies, not only in Finland, the era from 1899 to 1960, when the population of archipelago started diminishing, has been recorded as truly fruitful in producing unique Baltic Sea data sets, on which long term variation of the climate can be studied.

Witting (1910a, 1912, 1918) was the first to make use of this hydrographical data. The Geographical Society of Finland published an extensive Atlas of Finland (1910), in which also conditions on the Baltic Sea were included. In addition to the maps and diagrams presented, the Atlas contained a comprehensive explanation book, in which Witting wrote a 78 page description of the information available on particular maps, with a more concise French text for non-native readers. This text more or less summarises the state of art by that time. One may say that it to a certain extent also reflects his view on what has to be studied, thus describing the future agenda of the institute to come. Quite a number of Witting's later publications reflect the ideas and studies presented in this text, including the 1912 publication on hydrography and his main work, the 1918 publication on water level problems. The 1910 Atlas of Finland also served as an example for a similar work published in 1960 and, to a certain extent, to a much wider series of atlases published in 1976 to 1992. In all of these subsequent atlases, a special description of the Baltic Sea was included. The maps were not just explanatory notes on data for the public, much new material was collected and data files processed in order to obtain a synthesis of the results, as in the case of the first atlas.

The coastal hydrographic station network, as described by *Simojoki* (1978) was expanded during the first decade of the 20th century mainly due to the work of Gunnar Granqvist. When the FIMR was established, he became the first "thalassologist" of combined ice and oceanography department. His keen interest in the observation network continued well until his retirement. Regular inspections and guidance to the observers both encouraged them in their work and guaranteed the quality of the observations. The results were used by many authors already in 1930's in a study of the seasonal and interdecadal variation of temperature and salinity along the Finnish coast, in a number of other studies of the FIMR; and recently in 1982 by Launiainen and Koljonen as well as in 1992 by Alenius and Haapala. All these recent studies relate to aperiodic changes in the hydrography of the Baltic Sea. These studies would have been impossible without the standard observations network.

The Baltic Sea structure is determined by three main factors: fresh water input from rivers, salt water input from the Kattegat region and the internal processes determined by atmospheric and solar forcing, as modified and steered by the very complicated topography. If simplified, the bulk of the Baltic Proper can be divided in four layers. The uppermost two are in connection with the atmosphere in winter, when convection extends to the bottom of winter mixed layer, forming the upper level of halocline. In summer, the second layer is isolated from atmospheric influence due to solar heating and formation of the seasonal thermocline. The origin of the cool, low saline layer, although found already by Mohn in 1875, was first explained by *Oscar Nordqvist* (1888) and ever since formed a good reference for the severity of the winter. Below these layers, which have low salinity and are also strongly influenced by river inflow, lies the main halocline and respective bottom layer. Its temperature is higher than that above, determined mainly by the ambient temperature during the time of its inflow through the Danish Sounds. Salinity in this layer varies but remains dependent on salinity of inflow water and mixing conditions in Arkona basin. In cases of extreme inflow, a fourth layer forms in the deeper parts of the main basin. One of the basic concerns of Otto Pettersson, when he invited people to discuss continuous joint studies in 1898 had been that the bottom layer of the Baltic Sea sometimes turned anoxic (without the influence of man!), calling for concern of both scientists and fishery people. No wonder, the structure and development of salinity and layering of the Baltic Sea water masses remained a main concern of also Finnish scientists during the entire 20th century. *Hela* (1950) considered the inflow of Kattegatt to be one of the reasons in herring abundance fluctuations, thus connecting the climatic factors to the fisheries in a modern way. The global atmospheric temperature has increased during the last century. As a consequence, one might assume that the Baltic Sea has become warmer, The long time series now available reveal, however, that there has been no significant increase in the temperature of the Baltic Sea (*Alenius and Haapala*, 1992).

While sea level gives an indication of the surface stress, the internal structure of the water masses determines its internal structure of currents. These baroclinic currents tend to have slower time scales than the barotropic ones, enabling their structure to be determined by means of hydrography. Standard procedures followed by oceanographers in the early 20th century focused (and still do!) on determination of dynamics by the geostrophic calculations, partly because of lack of other means. This practice was also followed in Finland after the First World War. A classical example of the outcome of these studies is the paper by *Erik Palmén and Erkki Laurila* (1938). The study was a thorough analysis of the influence of a single storm on the entire system of the northern Baltic. In an interview in 1991 Laurila told to the present author the story of that paper, to some extent typical for the work on those days' Finnish marine research. He worked at the FIMR on a short contract and had been carrying out standard summer cruise when a storm rose. After the storm the cruise was continued as planned with sections across the Gulf of Finland, with data, which he as a non-oceanographer found very interesting. Palmén visited his office after the cruise, saw his graphs and suggested production of a joint paper, with full analysis of the meteorological as well as oceanographic conditions. The paper, analysed well by two skilful scientists, became a classic due to its findings and was cited in textbooks decades afterwards.

4. Air sea interaction

The early studies on atmosphere – ocean interaction in Finland relate, as described above, to the determination of wind setup and wind stress in general, based to a very big extent on available meteorological observations and water levels on the coastline. When the comprehensive coastal observation network was established, meteorological observations became a standard in the lighthouses and the light vessels as well. In addition to wind observations, other meteorological measurements provided the scientists with data, which enabled them to estimate characteristics of air – sea interaction. The heat exchange of the Baltic Sea with the atmosphere was treated by both purely oceanographic and purely meteorological observations. *Heikki Simojoki* (1946) calculated the heat exchange of the Northern Baltic using temperature and salinity observations done on a lighthouse. These regular measurements enabled him to estimate the heat content variability during the year. He estimated the role of advection mainly from variations of salinity in the measurement profile. In other papers *Simojoki* (1948, 1949) treated the meteorological data for estimation of the evaporation and precipitation in the Baltic Sea. This problem has been relevant to the study of the Baltic Sea over the entire 20th century, mainly because its close connection to the freshwater budget of the sea area, but also because its close connection to the atmospheric exchange processes. In addition to Simojoki, *Hela* (1951) and *Palmén* (1963) treated the heat budget problem as well. *Ilmo Hela* (1951) made a careful determination of evaporation on the basis of Finngrundet lightship meteorological and hydrographical data. While the approach of Hela was a classical one, based on known exchange equations and careful determination of exchange coefficients on the basis of data, the approach of Palmén was entirely different and led him to provide a benchmark paper on the request of WMO on determination of evaporation. Palmén considered the moisture flux in the atmosphere and determined the evaporation minus precipitation value from the moisture flux divergence using aerological observations along the coastline of the Baltic Sea. He obtained reliable results despite of the sparse number of aerological stations. The method, often referred afterwards with his name, has proven to be valuable tool in estimation of water and energy budgets on wide range of regions where the observation network is insufficient for direct determination of moisture flux. Today, it is a standard tool in numerical model hindcast and analysis of data.

Heat convection as well as vertical diffusion was determined by a variety of scientists, most of them using the standard technique of bulk aerodynamic equations. The Baltic Sea research flourished by the middle of the 20th century of similar equations with slightly deviating numerical coefficients, giving results which fitted with data on some location. It was not until the 1980´s that this was in basic research replaced by a more sound approach, where the stability of the overlying atmosphere was taken into account using Monin-Obuchov length scale as the non-dimensional variable. Using the concept of stability, it can be easily explained why the numerical constants of the bulk equations deviate from each other: the climatological stability conditions vary from place to place and, without taking into consideration the local stability climate arguments can easily be raised. The determination of Monin-Obuchov scale required advanced instrumentation for obtaining the boundary layer profile, or to determine cross covariances for turbulent fluxes. The approach was applied earlier on land fields but over wavy surfaces, in particular over salty water bodies, additional complications slowed the progress. The involvement of Finnish scientists in these studies came from the need to estimate the fate of heated cooling water when the first atomic energy power plant was planned. In this connection, an observation tower was built both on the Hästholm bay off Loviisa, as well as on a nearby tower on land. The studies, carried out by *Launiainen* (1979) led to a new track in Finnish study of air-sea interaction.

The problem of behaviour of the atmospheric planetary boundary layer became a marine research topic due to its close connection with the marine weather forecasts. These studies, both theoretical and experimental (*Joffre*, 1979, 1982) went hand in hand with simultaneous studies of sea ice field dynamics, with a joint aim to not only provide prime science but also improvement in marine weather forecasting.

When FIMR was established in 1918, its structure was divided into three departments. Water level had a department of its own, physical oceanography and ice studies were combined into one department, and the third department was for chemical oceanography. To which extent this reflects the availability of competent scientists is unknown to the present author. Anyway, chemical oceanography has ever since been one of the strongholds of Finnish marine research. The scientist chosen for the "thalassologist" of the Department of Chemical Oceanography was Kurt Buch. He had been earlier a member of the Society of Sciences team and became later Professor of Chemistry in Abo Akademi University and later in Helsinki. One of his main interests during his entire career was the carbonate cycle. The gas exchange between the atmosphere and the sea, in particular the question of the change of atmospheric carbon dioxide (*Buch*, 1939a, 1939b, 1949, 1960a, 1960b, 1960c) got his main attention. He did not only consider the chemical balances in the Baltic Sea but extended his studies to the Atlantic Ocean and the Arctic Ocean as well. His conclusions, based on his own measurements as well as those of other scientists was that the atmospheric carbon dioxide increase had been some 10 % during the first decades of the century. He pointed out that the consequent heating is strongest in the northern regions, leading to the increase in atmospheric temperatures. His conclusion was that it would be beneficial for the climate of the northern regions. In view of the recent interest in climate change, Kurt Buch was truly a forerunner in these gas exchange studies. Interest in his studies has risen again, and during the recent years projects have started to continue this work.

Kurt Buch did also, jointly with Erik Eriksson from Sweden, establish the first Scandinavian network for collection of dry deposition from the atmosphere. Buch operated the network on Finnish side in the beginning. When he became professor at the Åbo Akademi University, Dr. Folke Koroleff from FIMR took the responsibility. The network was later merged to the activities of FMI air quality net.

In connection with study of energy and momentum exchange with the sea, *Sergei Kitaigorodskii and Pentti Mälkki* (1979) visited also the gas exchange problem. Their approach was to determine parametrisation of gas exchange theoretically by determining the equivalent of viscous sublayer for diffusion of gases through the interface.

The most visible form of air-sea interaction, wind-generated waves, became a focus of marine research in Finland in the beginning of the 1970's, mainly because of active interest in marine transport and shipbuilding. Also the development of new reliable instruments made it possible to start collecting data on waves, which in the Baltic Sea had earlier been only visually determined. Active data collection, jointly by FIMR and the Helsinki University of Technology, began in 1972 and continued on these lines for a period of some 10 years.

It soon became obvious that, besides collecting data, theoretical and experimental work was needed. The studies begun by focusing on the specific wave modelling problems in the Baltic Sea, but it turned out that the Baltic Sea is in fact better suited for studying wave growth than e.g. the North Sea, where swell from the Atlantic Ocean complicates the interpretation of results. In 1976 and 1979 fetch-limited wave growth was measured in nearly ideal meteorological conditions in the Bothnian Sea. Among the results was conclusive evidence (*Kahma*, 1981) that the spectrum of fetch-limited wind waves is wind-dependent also in the saturated part and therefore does not follow the *Phillips* (1958) law.

The results lead the responsible scientist, Kimmo Kahma, to establish at an early stage working relations with leading laboratories and scientist in the field. To note a few outcomes of this activity: a series of papers on the mechanism of wave development and on enhanced dissipation by wave breaking at the sea surface layer (*Agrawall et al*. 1992).

5. Sea currents, diffusivity

Sea currents have always been on the focus of marine scientists. Here, like in the development of physics in general, the developments in theory and experimentation follow each other closely. Finnish scientists belonged from the very beginning to the larger community of Scandinavian researchers, with names such as Bjerknes, Nansen, Ekman, Helland Hansen and others. No wonder, they were well informed on the most recent developments and were eager to develop the science on their own initiative. Process studies on sea current in the modern sense begun early in the last century. The first Finnish scientist in this field was Witting, after him the studies were continued by others. In order to determine profiles of currents, Witting constructed an advanced current meter, which on the contrast to other meters of that period, recorded current variations in real time on a special form (*Witting*, 1910b, 1923, 1932). Movements of the observation platform (ship) were recorded in relation to a floating buoy. The instrument was used in a number of studies, e.g. in a joint ICES study of currents in 1931. The meter recorded the complicated current structure both in time and space. It revealed strong shear layers ("layers of kinematic transition"). This instrumentation could not, however, be used for long periods of time and, therefore, the tide gauge network, as described above, became one of the main instruments also in the determination of water movements.

Another set of data became available when the coastal stations on lightships started doing regular observations of water temperature and salinity, meteorology and current variations several times a day starting in the summer of 1907. The observation method was relatively simple: a wooden and iron cross, which was tied on rope with markings which enabled determination of its velocity from a moored vessel. Compass was used for determination of current direction. By floaters and weights the depth of the cross could be arranged according to needs, this enabled the scientists also to obtain information on current variability with depth. The first results of this system of observations was used by Witting when he determined wind setup and produced data sets for the first Atlas of Finland on circulation in the Baltic Sea. The most cited contribution using this data is, however, due to *Palmén* (1930). He compiled the full set of data from a five year period and, on the basis of this, presented a map of the surface circulation of the northern Baltic Sea and it gulfs, giving also on the basis of measurements a figure for the stability of the currents in the map. According to this map the overall circulation is cyclonic, due to prevailing wind conditions and Coriolis effect, but the stability of the currents is low because of considerable variability of the meteorological conditions. The resultant circulation can thus be considered as a residual, which is only a fragment of the currents induced by the wind. In other papers Palmén determined the wind stress on the sea as a quadratic dependence, and showed that the surface current also increased proportional to the wind velocity. Observations from different lightships gave different least square estimates, which did not in practice deviate much from each other. Palmén himself and many other authors used for simplicity the linear dependence found for Finngrundet in the open Bothnian.

In a study of similar light vessel observations *Hela* (1952) analysed the circulation of the Gulf of Finland, dividing it to drift and permanent current. Nor surprisingly, he found a strong influence of the coastline, which he quantified. He also found a linear dependence for current velocity to wind on the Finnish side, a different one on the Estonian side of the Gulf.

One of the dominant periodic motions of the Baltic Sea is its inertial motions. After the first analysis of the phenomenon by Swedish scientists Gustafsson and Kullenberg in 1936, a joint Baltic study was established in 1939 in the southern Baltic Sea. Four vessels, one from Sweden, one from Finland, one from Germany and one from Latvia measured currents in the southern Baltic on expedition of eight days. The coming WW2 interrupted a detailed study of the full data set. However, *Börje Kullenberg and Ilmo Hela* (1942) made an analysis of the currents, compared the results with existing theories and noted both the spatial damping due to coastline and temporal decay. Although the outcome would not today justify a similar effort, on its time the study was both an indication of strong ties among the Baltic scientists and of common will to understand the then relatively unknown phenomenon.

The latter half of 1960's brought a new wave in marine instrumentation. Due to increased naval activities in the cold war era, emphasis was laid on development of reliable current meters for hydrographical as well as submarine operation purposes. These instruments became commercially available and soon formed a standard tool for study of the seas. In most cases they were acquired for large regional studies done for industry, city, port and maritime authorities. Although the availability was limited, the instruments were used for research as well. An example of this kind of use large data sets of current measurements was that of *Mälkki* (1975). He analysed coastal fluxes of momentum and energy from a long data set of 14 current meters in a polygon of four moorings. The data originated from coastal region off island of Landsort south of Stockholm. The geometry of moorings enabled him to determine energy transfer between principal components and mean and fluctuating motion. He also considered the old problem of inertial currents and analysed its generation mechanism, propagation and decay. Once the motion is set up by either sudden impulse or cessation of atmospheric forcing, energy is distributed to near inertial frequencies by dissipation, which he showed to vary within narrow limits for three separate sources: those which Kullenberg and Hela had analysed, the decay of seiches analysed from tide gauge data and from the current mooring array.

The co-operation of Scandinavian marine physicists, in the framework of Nordic Council for physical oceanography, brought a wide set of joint activities also into the Baltic Sea. Current variability studies were carried out to continue the analysis started in the Swedish coast. These studies revealed the structure of the coastal currents and have provided valuable data for other studies. Another venue of joint large scale studies was provided later on in the organisation of the Gulf of Bothnia year in 1991 and a similar Gulf of Finland year in 1996. The earlier, carefully designed by an interdisciplinary scientific team resulted in interesting results, presented in a number of bilateral seminars and later published in international journals. Still much of the data obtained during this bilateral program waits for analysis, they have been used in connection of modelling studies. The latter, with a main emphasis on practical results for operational actions was scientifically less successful, although producing a number of publications.

Already in 1920's there was a considerable concern on the pollution of the waters around Helsinki. The FIMR was asked for an estimate on the situation and its development. Typical to Witting who carried out the study, the report he provided (1933a) did not only give practical estimates on the dispersion, mixing and dilution of waste output but also led him to study the mixing process itself (1933a, b). As pointed out by *Akira Okubo* (1974), he did actually provide the Richardson diffusion equation independent of Richardson. Richardson had presented the law in 1926 for atmosphere, and Witting was the first one to publish the same for the marine environment. The fact that he was unaware of Richardson's results and that his work did not come better known before the WW2, is presumably due to the fact that Witting left science for a decade approximately at the same time and did not reveal his results in international conferences any more.

Simojoki (1946) and *Hela* (1966) studied further the vertical mixing both using the annual cycle of the heat and salinity profiles in the fixed stations. Horizontal mixing was object of practical interest in connection of the waste water problems of industrial waste disposal (*Hela and Voipio*, 1960) and discussion on waste problems of the City of Helsinki in 1960's (*Niemistö et al*. 1968) and led to massive experiments with Rhodamine B. The main contribution of these studies was not as much theoretical as combination of the theoretical understanding to environmental conditions determined by local climate.

6. Instrumentation

As pointed out earlier, one of the reasons for development in the very beginning has been the production of proper instrumentation for measurements and analysis. When tide gauge observations were begun, the available commercial instruments soon proved to be insufficient and a new construction was designed for Helsinki already in 1904. Similarly, an entirely new, reliable design was found necessary in the establishment of the coastal tide gauge network in the early 1920's. Other kinds of instruments were developed as well: the Witting current meter (design originally 1910); graphical instrument for harmonic analyses, which were done in large amounts for the study of annual cycles, tides and other periodicities; and as the most complicated one an automatic reader of the tide gauge recordings, designed by Stenij in 1933. As described earlier, the recording instrument utilised a circular disk and coloured pencils at 10 cm intervals, its readings were often tedious to read if variations of water level were large.

One of the instruments which have remained practically unknown was the bathythermograph designed by Laurila. He himself described the development in an interview as follows: "In 1937 I had the responsibility to carry out time consuming and dull observations of sea temperature with reversing thermometers. So I started to wonder whether these could be done more elegantly. After a while I designed a bimetal arm, which moved in one direction due to temperature change and in another direction due to pressure change in the cylinder, in which it was connected. Recording was made on soft wax surface.” It proved to be useful during the time of its use in the late 1930’s. This innovation disappeared from the inventories and minds of scientists rather soon while its American successor, invented again by US navy during WW2, remained one of the basic instruments for decades.

No instrument is better than its maker can do. One of the benefits for scientists during the era of mechanical instruments was the existence of fine mechanic workshop, established first for the Society of Sciences. It became later Government fine mechanic workshop, and in 1945 a laboratory of the State Technical Research Centre, on the initiative of Erkki Laurila (*Sario*, 1974). The short history booklet of this workshop indicates that it truly had a considerable impact on all branches of geophysics on time when you had the choice: leave it undone or construct a special instrument for it.

A chapter of instrumentation would be insufficient without mentioning something about research vessels used. They, simultaneously, give a glimpse on the relationship of marine science to other players in the marine field. The research vessels of FIMR are the main subject of this discussion. A shorter note is made on other, usually smaller Finnish vessels.

As described by *Simojoki* (1978), the first research vessel for Finland was built in 1903 (Fig. 3), on the basis of the influence of Oscar Nordqvist. It served well until the end of 1930’s. S/S Nautilus was used for all expeditions (Fig. 4). Nordqvist himself was fisheries inspector, so the use of the vessel was dual: for basic marine research and for fishery studies. She was used until 1938, next year a passenger vessel with name Aranda (from Latin verb *arare* – plough). She was used one season only, WW2 started in the late summer 1939 and, after the war, Aranda had to be given to Soviet Union as a part of war indemnity. The FIMR remained without a vessel until 1953, when a passenger vessel with name Aranda was built for winter traffic between Turku on mainland and Mariehamn on Åland islands. Granqvist was actively involved in the building project from the very beginning, he designed the use of the vessel in summer season so that passenger lounges were transformed to laboratories, and sampling was enabled both from the fore deck (heavy coring, e.g. geological piston corer) and in the midships. Aranda was subsequently used until 1988, i.e. 35 years. During this period, some changes were made. First, entry during IGY into Barents Sea (Fig. 5) was only possible after closing some low level entries and making other minor changes. A more substantial rebuilding was made in 1976 when the vessel was transferred entirely to a research vessel to be used all the year round. Main reason for this was that the archipelago winter traffic got a new vessel into use. Second major change was made in 1983 when all the engines had to be replaced by new ones, spare parts for 30 years old diesel engines did not simply exist.

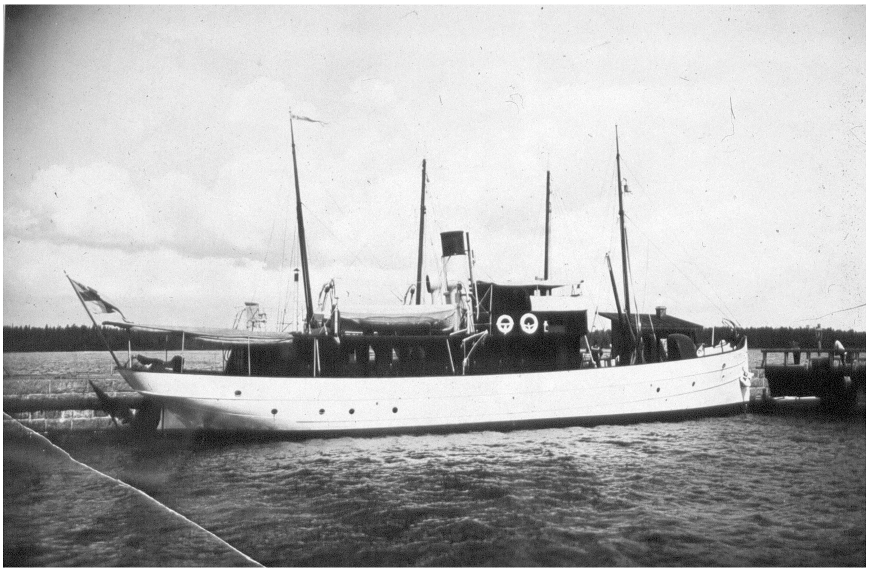

Fig. 3. S/S Nautilus in 1903.

Fig. 4. Water sampling at S/S Nautilus in 1920’s.

Fig. 5. Waiting for entry to Longyearbyen on board R/V Aranda (II) in 1957. Drs. Folke Koroleff (left) and Aarno Voipio (photo: Ilmo Hela).

Already in the beginning of 1980's intention was to build a new research vessel, due to weaknesses of the old construction: contamination level was high, air conditioning could not be built to satisfy needs of modern analytics, vibrations of the hull prevented use of computers and delicate instruments in general and, for the purpose of winter studies the hull and power supply were not satisfactory. This plan came finally into reality with a new vessel, third by name Aranda (Fig. 6). She was constructed in 1988–89, and also fortified to ice class Super A1 with extra strength for Antarctic waters. In design of this new vessel, FIMR team, led by Lauri Niemistö, was able to use all the experience gained earlier in the cooperation with Finnish shipyards on research vessel construction. The outcome is truly good.

Fig. 6. R/V Aranda (III) at work in pack ice field. Helicopter landing on the front deck, light mast folded down.

It is interesting to compare some of the statistics of the above vessels described above. Table gives basic statistics, in which we can observe the growth, according the needs, of the vessel size and performance capacity. New things necessitated this growth, such as ice operations capability, need for increased operation radius and need for bigger interdisciplinary teams on board.

Name	**Years**	**Length (m)**	**Power (kW)**	**Crew**	**Scientists**
Nautilus	1903–1938	30	239	12–13	8
Aranda	1939	46	368		
Aranda II	1954–1988	53	970	20	19
Aranda III	1989–	59	3200	12–14	25

Finnish universities, by traditions, have operated mainly in the archipealgo regions, their research vessel needs have been mainly satisfied by boats less than 20 m. long. In cases their research interest has focused into open sea they have either participated into FIMR cruises or cruises of other research institutions.

As mentioned above Aranda has, since 1954 been capable for multipurpose research. She was used, in addition to classical oceanography, in gravimetric, meteorological, fisheries and geological studies in different seas. Other research institutions, however, have used other vessels for their purposes, often modified from platforms originally constructed for other purposes. Thus Geological Survey of Finland has used an earlier archipelago ferry, R/V Geola for coring in the archipelago and Finnish Environment Institute a small vessel R/V Muikku constructed originally for archipelago hydrographical soundings and modified for lake research. The institutes mentioned have used these vessels in studies of bottom structure and environmental quality of the northern Baltic Sean and in the archipelago. A common feature of these vessels is that they cannot be used for marine research in the open sea in difficult weather conditions.

7. Optics

The colour of the sea has been a subject of studies in oceanography for more than a century. Its importance stems from the fact that it is simultaneously an indication of extra substances in suspension, indictor of contamination, determinant of the light penetration and thus limiting factor for light absorption and primary production. One of the very early instruments for finding quantitative data was the Secchi disc, a white horizontal disc which is lowered down until it is no more visible. It gives a simple value of the light penetration, which can be calibrated to a range of optical properties. Observations using this instrument and using photometric determination of light absorption were made since 1910 during the cruises of the Society of Sciences hydrographical unit. After the war they were continued by FIMR until 1939. The activity resumed in 1970’s. Witting, as the initiator analysed the first result in his 1912 paper on hydrography. *Lisitzin* (1938) made an in depth analysis of the available material, determining mean “Secchi depth” for all observation sites around the northern Baltic Sea. Witting revisited the problem again by after he returned to science from politics in 1944. The in depth analysis on light in the sea, which mainly focused on determination of light absorption remained his last publication (*Witting*, 1944).

The interest in determining simple means for monitoring eutrophication brought the Secchi disc observations to a renewed focus in 1980’s. *Launiainen et al.* (1989) did comparisons of earlier optical observations with more recent ones and concluded that the “Secchi depth” had during the decades reduced all over the Baltic, on the average more than 3 meters.

8. Modelling of the dynamics

Geophysical studies have always aimed at quantification. To cite Lord Kelvin: “if you cannot quantify it, you do not understand it.” From the very beginning of marine science activities, quantification was one of the main themes in studies of water level variations, current variability, hydrography. Purely qualitative descriptions were and are necessary, but their role has been continuously diminishing. From the very beginning, quantification, or in other words analytical modelling was a standard tool in Finnish oceanography. It can be seen in Witting’s and Stenij’s analysis of periodical movements, Palmén’s determination of stresses, wind setup and currents, to mention a few. Analytical modelling is at its best a tool, which gives a deep insight in the physics of the process studied. Numerical modelling can be seen at its worst as a black box where data is transferred and the outcome resembles something familiar but it is impossible to say why. Analytical modelling has its limitations, as the work of *Stenij* (1932) indicates: there are no numerical results, which can be verified with data since one has to simplify the conditions in order to obtain equations, which can be solved. This dilemma has remained in oceanography and meteorology. The only solution is to try to obtain best sides of both.

When computers became available for geoscientists, it did not last long before they were used for numerical models of marine dynamics. *Hansen* (1956) made first models for the North Sea and established a new tradition in Hamburg University. The first one in Finland to apply the new tool was *Sulo Uusitalo* (1960), who studied the response of the sea on stationary atmospheric forcing. Modelling has always been time consuming, even with modern tools and programming languages, but Uusitalo did the programming by machine and assembler languages. Bearing in mind the sophistication of computers then available, the study was in the forefront on numerical modelling of its time. He subsequently continued with studies of the influence of variable wind on the barotropic current.

After Uusitalo, Olli Jokinen developed numerical models for the Gulf of Bothnia. The first Finnish oceanographer to produce a higher resolution numerical model for currents and water level variations of the entire Baltic Sea was *Sirpa Häkkinen* (1980). She, like Uusitalo, checked the validity of her Baltic Sea model using tide gauge data in the basins, obtaining values corresponding to reality. She developed a model with open boundary in the Danish Straits, atmospheric forcing from geostrophic wind with two different parametrisation schemes and spline interpolation. In test runs the model produced reliable water level variations for all tide gauges. Häkkinen has continued oceanographic modelling ever since, mainly for the Arctic regions and ocean-ice marginal zones after moving to USA.

The above mentioned models contained at the time of their creation the state of art for barotropic fluctuations, in particular in the modelling of water level. Water level is a function of forcing and current divergence, thus verification of models requires information of model versus observed currents, to be more specific, including baroclinic variations of the currents. Applied to the entire season, the boundary processes in thermocline and halocline have to be taken into account, as well as heat exchange with the atmosphere. Thus the comprehensive modelling of the Baltic Sea has developed slowly, not the least due to the problems involved with the water exchange with the North Sea. The determining parameter for the scale of motions, Rossby radius, is of the order of a few kilometres only, thus eddy resolving models require for the Baltic Sea considerable computer capacity. A way of simplifying the modelling of internal structure of the water mass tried by Rein Tamsalu and Pentti Mälkki (*Mälkki and Tamsalu*, 1985; *Tamsalu and Mälkki*, 1987) is to parametrise the layer structure (in their case by self similarity). Models with self-similarity parametrisation have been utilised ever since. Verification has been sought in sets of current mooring experiments carried out by Finnish scientists. Another set of verification has been the determination of statistical resultant of the current field in the seas around Finland and comparing that figure with the results of Palmén (*Myrberg*, 1991). Myrberg also made a comprehensive comparison of different numerical models of the Gulf of Finland (*Myrberg*, 1998).

Numerical modelling for study of scenarios, in particular for applications has become a standard tool in oceanography. Although the processes are highly non-linear and thus the forecasting skill has strict limits it has developed during the last decades in many fields. One of the good examples is the modelling of waves. The archipelago on the northern coasts of the Baltic Sea with its thousands of large and small islands is a challenge for wave modelling and wave theories. Studies were undertaken to settle between alternative theories and their applicability to predicting the waves influenced by the archipelago. The studies led to development of wave growth diagrams, parametric hindcasting models and, as a consequence of the tragic accident of M/B Estonia in 1994 to operational information and forecasting system. The more general wave prediction model, which was outcome of close European co-operation, became available once the meteorological forecasting grid was fine enough. At the same time, the exchange between wind and waves got entirely new understanding. Coupled atmospheric-wave models were implemented in the Baltic Sea in 1996 and will become operational in 2001. Experimental studies of the wind-wave coupling revealed the invalidity of Monin-Obuchov scaling in the atmospheric boundary layer in the presence of significant swell (*Drennan*, *et al*., 1999; *Smedmann*, *et al*., 1999).

9. Out of the Baltic Sea

Earlier chapters do already give a glimpse of the wider international scope of the Finnish marine research beyond the Baltic Sea. This is partly because of the nature of the studies – process oriented, be they focusing on wind stress, turbulent diffusion, air-sea interface or chemical exchanges. Partly also the studies of Finnish scientists focused on geographical regions other than the Baltic Sea. Examples presented above are again the Atlantic carbon dioxide balance, mean sea level in the Mediterranean and global ocean.

Some of the scopes not mentioned yet are connected with participation either in international programmes or studies done while Finnish scientist worked abroad for longer times. Erik Palmén, while visiting USA produced a couple of important papers, one jointly with R.B. Montgomery on equatorial counter current (*Montgomery*, 1940), one with W. Munk on the mechanism of the Antarctic Circumpolar Current (1951). Ilmo Hela worked long times abroad, partly in USA, partly in IAEA in Monaco. During these visits he published a number of papers on Gulf Stream, Florida current and western Atlantic, during his stay in Monaco focus was on Mediterranean problems.

Another activity leading to international problems was participation in global programs. The first major effort was the International Geophysical Year 1957–1958, when Finnish expedition participated in the work on Barents Sea. The activities, in more detail described by *Hela* (1959) consisted on hydrographical, chemistry, geological and gravimetric work in the Barents Sea as well as building the camp for Scandinavian scientists in Spitsbergen. This expedition was the first one carried out with a Finnish research vessel outside the Baltic Sea, it thus established a new opening in participation on international programs. The expedition was successful but was not, mainly due to economical reasons, followed by other Atlantic expeditions until the end of 1980's.

Nordic Council for Physical Oceanography was for decades a natural forum for cooperation. Funded by Nordic Council of Ministers, it enabled young graduate students to work in other countries' institutions and the institutions to establish, on marginal extra expenses, joint research programs. Also many Finnish students used this opportunity in the 1970's and 1980's. Further Atlantic activities were implemented in connection with the work program of Nordic Council for Physical Oceanography, leading to a specific program called Nordic WOCE. In this program, which was implemented in early 1990's, the Finnish share was air-sea interaction studies in the Faroe – Shetland region.

Finland joined in the Antarctic Treaty in 1984. This implied research activity of the member country, to be carried on national platforms. Having considered various alternatives, the responsible authorities decided that major expeditions be carried out using the new research vessel, which was to be constructed in 1988–89. After this decision, a number of new focuses came into Finnish oceanography. During the operational tests of the new R/V Aranda, physical studies in the North Atlantic started an active co-operation with other Scandinavian scientists in the Denmark Strait area. These led later on into participation in a larger joint European program, funded partly by the European Union. In this programme the Finnish contribution is the study of the hydrography of Denmark Strait region and participation in the determination of overflow of the Strait by a multi year array of current moorings.

The first Finnish large scale expedition into Antarctic waters, led by the author of this article, had a very wide science program. The reasoning was to enable a wide range of Finnish scientists to start working on Antarctic problems. In marine sciences it included, among others, studies of sea ice, currents and hydrography of the Weddell Sea upper layer, as well as air-sea interaction studies, which continued almost without to the end of the century. Field studies included all basic marine sciences, much of the emphasis was on biological and physical oceanography. The expedition established lively contacts with other European teams. This led in particular to improved observing and modelling programs of the region's mass and heat balance. Results of these have been discussed in previous chapters.

10. Pioneering

A large number of activities in Finnish oceanography have directly or indirectly led to developments in other fields. In 1927 FIMR started – first in the Baltic Sea region

– testing echo sounding for improvement of efficiency of its own work. The British made echo sounder proved to be useful but, according to anecdotal fiction, the authorities responsible for sea charting were not convinced of the usefulness of this new method. The need for reliable delivery of information is another area where innovative approach has led to practical results. The Baltic ice code, used since the international agreement in 1925 was to a great extent based on Finnish ice code. Decades later, when long wave radio transmission of facsimile maps had ceased, FIMR started sending maps by NMT network, an effort which required solving of many technical problems. This was entirely new for the developers of the Nordic Mobile Telephone system, but became subsequently widely accepted in mobile information transmission. A third area where Finnish marine research has contributed to new technical designs is building of research vessels. Due to long practice, compact design of ergonomic and effective working facilities for research ships active in cold seas was easy task when Finnish shipyards requested for advice in 1970's and 1980's. During that period, those shipyards produced tens of high quality research vessels.

11. Co-operative programs

Marine research needs for developing a wide range of co-operative research campaigns, like other geophysical sciences. The study of 4-dimensional fields of motion requires measurement arrangements, which most often exceed national possibilities. Unlike meteorology, fixed observational networks do not usually exist, and the dimensions of the key dynamic indicator, the Rossby radius of deformation is one decade smaller than in meteorology. During the last century, international campaigns were organised in oceanography after IGY by several organisations. Finnish marine scientists were active on these, in particular on those organised in the Baltic Sea (International Council for the Exploration of the Sea and Baltic Oceanographers), partly also on regions outside the Baltic.

The largest Baltic programme implemented was the Baltic Year in 1968, which resulted in a comprehensive observation database of all regions and all seasons. The program lasted for an entire year with carefully planned participation of all Baltic countries all over the basin. Much of what is known about the development of stagnation in conditions of poor water exchange with the North Sea results of the observations made during the Baltic Year. Similar, but more limited in space or time were bilateral programmes of the study of the Gulf of Bothnia (1991) and Gulf of Finland (1998), discussed earlier in Chapter 6. In a certain way these were forerunners of later large programmes funded within EU framework.

12. Personalia

Any description of Finnish oceanography during the past century would be only partial without short description of the key players. I limit in this summary to those who were active in the earlier half of the century or who are no more in active scientific work. It is not surprising that many of the names mentioned below also appear in other parts of this volume, I therefore leave their contribution to a short remark.

The key and dominant character of the first two, almost three decades was undoubtedly **Rolf Witting** (1879–1944). His role in the establishment of the solid foundation has been thoroughly described by *Simojoki* (1978) his personal character similarly by *Lisitzin* (1978). Both knew him personally, I therefore limit myself to a few comments only. Witting acted in oceanography since 1902, with basic education on physics, mathematics and astronomy. By the time of the establishment of FIMR, he had already made himself well known as competent marine scientists with good intuition, thorough analysis and careful experimentation. In addition, he was known to be a good organiser. This made him an evident candidate for the directorship and, unfortunately for science, due to his thorough memoranda on administrative matters a good candidate for Parliament and later to Government. Witting was willing to look at applications, like the pollution problem around Helsinki, but his approach was through basic science, as the above mentioned case of turbulent diffusion indicates.

Erik Palmén (1898–1985), as stated by Lisitzin, was in some respects an entirely opposite personality in comparison with Witting, focusing all his life entirely for science. His major contributions are described in the chapters of meteorology. His time in FIMR ranged from 1922 to 1947. Last eight years of this time he was the Director of the Institute. A substantial part of his early meteorological publications were written during that period. His major contributions to oceanography were at his time fundamental, as mentioned above. Some of his later works on ocean dynamics, in particular the one on ACC has been frequently cited still recently.

Many of the "builders" of the FIMR, such as Sten Stenij (1900–1985), Henrik Renqvist (1883–1953), Heikki Simojoki (1906–1990) and Kurt Buch (1881–1967) continued their career in other branches of science: Buch as professor of chemistry in Åbo Akademi and University of Helsinki; Stenij as professor of mechanics in and later as rector of the Technical University of Helsinki; Renqvist and later Simojoki as the director of Hydrological Office. Erkki Laurila (1913–1998), mentioned above in Chapter 3, worked on oceanography only a short interval. His main field was theoretical physics, after an early stay in the FIMR, he made his main career at the Technical University of Helsinki and later as Academician at the first Academy of Finland.

Gunnar Granqvist (1888–1965) joined early the oceanographic team of Finnish Society of Sciences, acted later as "thalassologist" at FIMR and as Deputy and Acting Director. He worked at the Institute a period of 42 years, the longest fidelity record so far, maybe forever. His main contribution to oceanography is the well organised permanent observational network, its quality control and maintenance, careful administration and, after WW2 the design of research vessel Aranda in 1953.

Risto Jurva (1888–1953) was the person who developed ice research in Finland. He created the ice service for navigation in FIMR, as well as foundation of the study of ice conditions in the seas around Finland. He joined the Institute in 1919, worked there in different capacities, during the period 1947 to 1953 as the director. His PhD thesis (1937) dealt with ice conditions, already in this work can be seen his approach of describing the development of ice winter at different phases, starting with the freezing of coastline and bays, ending with a full ice cover over the sea, then retreating again. Use of this phase development gave the ice service an opportunity to compensate for lacking data as well as to make a short term forecast. His major work, to be published in 1940's was to a great extent destroyed in the bombings of Helsinki in February 1944. After this, his interest became directed on different directions in versatile ways, he was a popular lecturer, opponent of several PhD dissertations, worked on long term climatology, was active in establishing scientific societies and, as a hobby, developed seismology at the University of Helsinki.

Ilmo Hela (1915–1976) described himself his entering to oceanography as a kind of accident. As a student, he went to study meteorology at the University of Hamburg, but since the Institute of Oceanography was closer to his dormitory than the respective meteorological one, he continued with oceanography. This anecdote was characteristic to him: versatile mind with odd stories, if necessary. Hela was quick in learning new things, effective in his work and a good organiser. He joined the FIMR in 1941 and, despite of military service in WW2, completed his PhD thesis on water level variations in the Baltic Sea in 1944. His main works in Finland focused on water level variations, hydrography and current fluctuations in the Baltic Sea. His contribution to world oceanography comes from his stays as professor in University of Miami and director of IAEA Institute on radioactivity in Monaco. Hela was the director of FIMR during the period of 1954 to 1975. During this period, his talents were used in many national and international duties, among others as member or secretary of several committees in Finnish science administration, as general secretary of IAPO and vice president of the International Council for the Exploration of the Sea; and as the member of UNESCO Executive Council. Ilmo Hela used his international connections for promoting Finnish marine science by organising younger scientists possibilities for working abroad. He also made substantial initiatives for international cooperation. Conferences of Baltic Oceanographers during the time of tense political confrontations in the Baltic Sea region were his initiative, he thus enabled the scientific discussion to go on despite of other difficulties in communications. These conferences were for many younger scientist first international contacts during the time when attending conferences was not as commonplace as today.

Eugenie Lisitzin (1905–1989) was the first female scientist in Finland to defend her PhD thesis in physics. She joined the FIMR in 1933 and worked almost entire her carried until 1972 on water level problems. Her main focus was first the determination of mean sea level and its secular change for the Baltic Sea, she applied the extensive water level data to many connected problems, like determination of water exchange of different basins by using volume fluctuations, on determination of tidal fluctuations of the Baltic Sea, determination of the influence of ice cover on water level fluctuations, to mention a few. At relatively early stage she became interested in determination of the mean sea level of the world ocean. Like in the questions of the Baltic Sea water level analyses, she became a renown expert on this field and was invited to write an extensive monograph on the topic.

Erkki Palosuo: see *Leppäranta et al.*, this issue.

Sulo Uusitalo (1920–1986) was a mathematician by education. He joined FIMR in 1956. While working mainly on ice problems and ice service, he visited International Meteorological Institute in Stockholm in 1958 to study possibilities for making numerical forecasts on water level fluctuations of the Baltic Sea. This, to a certain way, led him to the lifelong activities on numerical modelling, referred above. He, like Risto Jurva, can be characterized as a perfectionist, working thoroughly on the problem at hand, developing a computer program, ice map or ice report, all with the same devotion. Despite of the main focus of modelling, his interest ranged to a wide number of topics in physical oceanography.

13. Concluding remarks

During the latter half of the last century, marine research technology developed enormously. New kinds of instrumentation as well as development of powerful computers enabled research not foreseen before the WW2. The science of oceanography has simultaneously developed to the same theoretical level as its sister science meteorology. Interaction between these two sciences is intimate. Many of the old problems dealt with Finnish oceanographers earlier have lost their actuality or have been included in more complex ones. There are many examples of these. Evaporation is treated as a part of coupled air sea interaction (e.g. *Vihma et al*., 1991), and instead of models for waves or ice drift coupled models are developed. In these models interaction is real, not only influence of atmospheric forcing. Internal dynamics of the sea are intimately connected with models of the dynamics. Process studies and analyses of hydrography serve as test material for better parametrizing of the models (e.g. *Alenius et al*., 1998). Production of an ice report or ice chart for the aid of navigation includes complex receipt of satellite pictures, their classification and final transmission to customers (e.g. *Similä and Karvonen*, 1999).

In Finland, the total volume of marine research has increased with accelerating pace. If we e.g. compare the number of Ph.D. theses, the production during the last three decades is much larger than during the previous seven, yielding a rate, which is threefold as compared with the previous decades. Still the approach has been much the same: main part of the basic research aims at establishing basis for development of services. No wonder, main part of basic research is still made in research institutions. Opening to wider marine community in the form of working with non-Baltic problems was nothing new, as the above examples show. What has changed is that this has become a regular part of Finnish oceanography, not only production of occasional papers during visits to other laboratories. This is partly due to more intensive mobility of scientists, partly due to joining new treaties (Antarctic Treaty, EU Science programme).

The history of science is history of scientists, much less history of organisations. In the case of Finnish oceanography, the scientists have mainly been working on one single institution, the FIMR. This has its traditional reasoning, due to the size of the country, its small population and the emphasis marine issues have for the Finnish society. *Lisitzin* (1978) has reviewed the first fifty years of FIMR. Reader is referred to her summary of the Institute's activities. Although basic research is the main topic of this article, one may easily notice from the above that practical objectives have very much directed also the strategies of research. It has been the intention of the research at all occasions that good applications can only arise from good basic science. This tradition was set on the first decades of the century by those responsible, in particular Rolf Witting. Many of the examples above indicate that. This emphasis has also enabled the scientific and application people to collaborate closely, very much like the meteorological community of the Bergen school. Needless to say, there was also an intimate relationship with this counterpart.

The spectrum of topics studied in Finnish oceanography is wide but not complete. Many important fields have not been studied, many of the fields have been subject to limited interest of a few studies or a single researcher only. That is necessarily the case in a small community. It has not been possible to refer to even major part of all the hundreds of papers produced during the decades. Rather, the intention of the author has been to give the reader a review of broad lines and trends of study, and highlight some of the important results. The focus of the above summary is very much on the earlier decades of the last century, with less analysis on the recent studies. The spectrum of research has widened, deepened and become more international. An objective analysis of the results can be only obtained in the years to come.

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