MERENTUTKIMUSLAITOKSEN JULKAISU
HAVSFORSKNINGSINSTITUTETS SKRIFT N:o 156

A TREATISE ON SEVERE ICE CONDITIONS IN THE CENTRAL BALTIC

BY

ERKKI PALOSUO

HELSINKI 1953 HELSINGFORS

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Helsinki 1953. Valtioneuvoston kirjapaino

CONTENTS.

PREFACE.

The basis of the present investigation was created by the aerial reconnaissance flights made during the severe winter of 1942 and preliminarily treated immediately after they were made. Only after the war did I have the opportunity of continuing the investigation started. I wish to express my deep gratitude to Professor RISTO JURVA, Ph. D, Director of the Institute of Marine Research, who has encouraged me in this investigation; he has followed its progress from the initial stages and given it continued support. In this connection I also wish to thank the departmental chiefs of the Institute, Dr. GUNNAR GRANQVIST, Ph. D., and Dr. HEIKKI SIMOJOKI, Ph. D., for the assistance and criticism offered during my work. I am also indebted to Professor ERIK PALMÉN, Ph. D., Dr. ILMO HELA, Ph. D., and Dr. EUGENIE LISITZIN, Ph. D., for valuable advice. I have had the opportunity of discussing the Ice Terminology employed with Dr. TERENCE ARMSTRONG, Ph. D., of the Scott Polar Research Institute (Cambridge), who has checked the manuscript for terminology.

For the results of the ice reconnaissance flights in Finland, particularly in the severe winter of 1942, I am indebted to the Officer Commanding the Air Force and all the air crew with whom I served. The other material obtained from Finland derives from the archives of the Institute of Marine Research and is based on the observations by lighthouse masters. As, due to war-time conditions, there have been no regular ships' reports I had to collect supplementary information from several cources. My thanks are due to the Board of Navigation and to all Finnish ship-owners who have readily placed at my disposal old ship's logs. In addition, I am very grateful to the icebreaker captains and the war-time masters of merchant vessels; they have personally gone through the log entries with me and in so doing recalled a great deal of important additional information on the then conditions.

For the collection of foreign material the author had the opportunity of visiting Sweden and Denmark. My respectful thanks are due to Commander Baron STELLAN HERMELIN, the Chief of the Central Office of the Swedish Government Icebreaking Service. Captain of the Swedish icebreaker »Ymer» in the winter of 1942, he has supplied me with detailed data on the events of that winter, illustrating them with sketch maps. I am also very grateful to Dr. C. J. ÖSTMAN, Ph. D., Mr. BERTIL RODHE, M. Sc., and

meteorologist Ole Nothberg of the Swedish Meteorological and Hydrological Institute in Stockholm, whose assistance made it possible for me to study their valuable observation material. I am indebted to the chief of the »Istjeneste» of Denmark, Commander R. Rosted, for his great assistance in obtaining material for me and for his co-operation in its preliminary treatment. My thanks are due to Dr. Franz Nusser, Ph. D., of the »Hydrographisches Institut» in Hamburg and Professor Joachim Blüthgen, Ph. D., of Erlangen University, who have readily answered my queries.

My wife, Mrs. Maini Palosuo, M. A., Mrs. Hilkka Kontiopää, M. A. (Helsinki) and Mr. L. A. Keyworth, M. A. (Cantab.) have helped with the translation and checking of the manuscript.

Merenkulun Säätiö (The Shipping Foundation) has granted me financial support in my work, for which I express my gratitude.

Helsinki, May 7, 1953.

Erkki Palosuo

5°
10°
15°
E
20°
25°
30°
65°
60°
55°
BOTHNIAN BAY
GULF OF BOTHNIA
BOTHNIAN SEA
ARCHIPELAGO SEA
ÅLAND SEA
GULF OF FINLAND
SKAGERAK
KATTEGAT
BELTS
ÖRESUND
CENTRAL BALTIC
GULF OF RIGA
AJOS
RAAHE
ULKOKALLA
VALASSAARET
VAASA
SÄLGRUND
MÄNTYLUOTO
RAUMA
AGO
FINNGRUNDET
GÄVLE
ÖRSKAR
ÖREGRUND
SALSKAR
MARKET
KUMLINGE
NAANTALI
TURKU
LÖHM
KÖKAR
UTÖ
LÅGSKAR
BOGSKÄR
SÖDERARM
SVENSKA HÖGARNE
STOCKHOLM
SANDHAMN
LANDSORT
HÄVRINGE
KOPPARSTENARNE
GOTSKA SANDÖN
FÅRÖ
STENKYRKEHUK
VISBY
VÄSTERVIK
ÖLANDS NORRA UDDE
HÖGBY
HOBURG
KALMAR
KAPPELUDDEN
ÖLANDS SÖDRA UDDE
UTKLIPPAN
HANÖ
SIMRISHAMN
SANDHAMMAREN
CHRISTIANSÖ
HAMMEREN
HAMINA
KOTKA
TAMMIO
HAAPASAARI
PELLINKI
HELSINKI
HARMAJA
BARÖSUND
HANKO
JUSARÖ
RUSSARÖ
BENGTSKAR
NAISSAAR
TALLINN
OSMUSSAAR
PALDISKI
TAHKUNA
RISTNA
VILSANDI
RIGA
(LIBAU)
(MEMEL)
(BRÜSTERORT)
(RIXHÖFT)
(HELA)
(KÖNIGSBERG)
GDYNIA
(DANZIG)
(JERSHÖFT)
(KOLBERG)
(SWINEMÜNDE)
(STETTIN)
GULLMARFJORDEN
GÖTEBORG
SKAGEN
SKIVE
RINKØBING
ÆBELTOFT
HJELM
HELSINGØR
HÄLSINGBORG
VEN
VEJLE
KØBENHAVN
FALSTERBO
TRELLEBORG
HELNÆS
NAKSKOV
MØEN
GEDSER
ARKONA
SASSNITZ
FEHMARN
DARSSERORT
WARNEMÜNDE
LÜBECK
WISMAR
HAMBURG

Figure 1.

ICE TERMINOLOGY.

1. The present treatise employs the ice terms recommended by the *Commission for Maritime Meteorology* (1952). However, the author wishes to make the following comments:

In the Baltic region ice forms during the winter only; it develops and decays in the course of the winter. Hence, instead of w i n t e r-i c e we can simply say i c e. The i c e w i n t e r 1 9 4 2 refers to the ice winter 1941/42.

DEVELOPMENT AND DECAY.

The initial freezing in calm and even in windy frosty weather takes the form of an »oil»- or »film»-like ice on the sea surface (Picture 1, *Istjänsten i Finland* 1937; *cf.* HERDMAN 1953). The »i c e f i l m» is thin, its dimension expressable in millimetres. This accounts for its great elasticity. Thicker ice can retain a certain degree of flexibility but as a rule is easily broken up by wind or swell. Hence the term i c e-r i n d (thickness less than 5 cm) is too comprehensive to be used for this initial phase of freezing as a separate phase.

The term n e w i c e as employed by the author refers to newly developed ice, one or two nights old. The use of the term y o u n g i c e (newly formed ice, thickness 5 cm to 15 cm) is more common in the Arctic and Antarctic seas than in the Baltic. Even with persisting frost it is several days in the Baltic region before a more considerable thickness is reached (JOHNSON 1943). The best equivalent to the term »young ice» in the Baltic region is perhaps the designation employed in the early winter: Swedish »blåis», Finnish »sinijää». In English this term, »blue ice», refers the oldest and hardest from of glacier ice; it is distinguished by a slightly bluish or greenish color. In the Baltic area the clear part of ice is called in Swedish »kärnis», in Finnish »teräsjää».

FORMS OF FAST ICE.

In the Baltic region the f a s t i c e is level; in its most typical form it is encountered in the vicinity of the coasts, in the inner and even outer archipelago regions. Laying off the coasts or between islands it forms the f a s t i c e f r i n g e (which has a width) typical of the Baltic (JURVA 1937).

The fast ice edge (which has no width) is the line limiting the extent of the fast ice, normally on the seaward side.

In calm cold weather level new ice can also develop out in the open sea; on growing sufficiently thick it is similar to level fast ice in quality. Only after it is set in motion by wind etc. does the ice on the open sea undergo various mechanical changes (breaking, pressure) resulting in the sea ice assuming a form different from the level fast ice of the archipelago.

Later on during the winter after the ice in the zone of the outer archipelago or in the open sea outside the archipelago has frozen over and become immobile, it also can be taken as fast ice. The author will show later the existence of an »extended fast ice fringe» of this type.

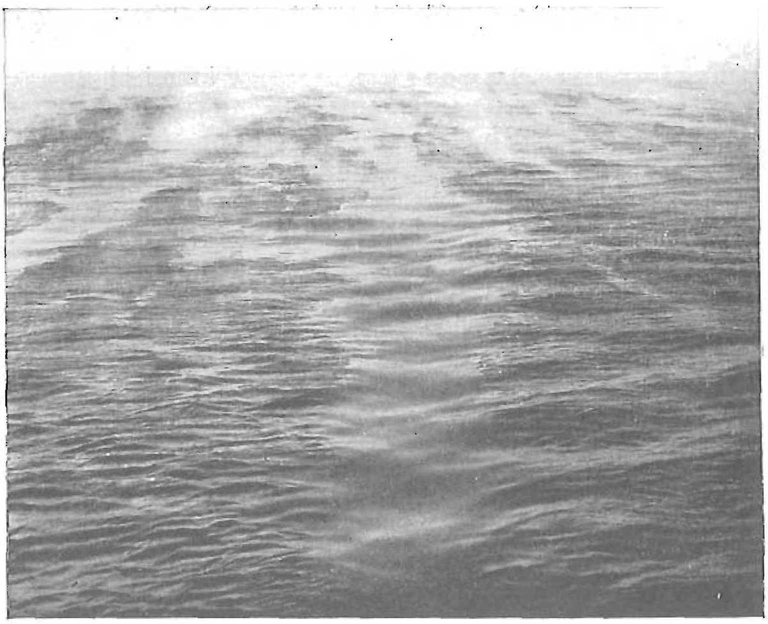
DRIFT ICE.

Drift ice in the Baltic refers to broken ice, either drifting or susceptible to drift, which as a rule is level. The term pack ice in English covers »a mass of floating (heavy) pieces of ice» but in Swedish means »pressured ice» only. Hence to avoid confusion the term »pack ice» has not been used.

The designation drift ice becomes properly applicable when the thickness of the ice reaches approx. 10 cm; thinner broken ice can be called e. g. drifting new ice.

In the Baltic region drift ice in the open sea is seldom more than 50 cm thick; apart from in the Bothnian Bay, it occurs in extremely severe winters only. When level drift ice approaching the above thickness is encountered in the open sea it is in the majority of cases formed from several layers of thin ice rafted on top of one another. For instance, in the Bothnian Bay region JURVA has found rafting of 8 layers even. Level drift ice remaining 50 cm or a little thicker does not create the same obstacle to navigation as the »drift ice» in the Arctic and Antarctic Oceans; in the Baltic ice-breakers go through the drift ice field. Hence the »closeness» of the drift ice here has not the same significance as in the Arctic and Antarctic Oceans. For the term very open (ice cover, 1/8—2/8), open (3/8—5/8), close (6/8—7/8) and very close (practically 8/8) are substituted the more general terms unbroken and scattered. The terms heavy and easy are used to indicate the degree of difficulty for navigation.

When the open spaces between floes of drift ice are covered by new ice an unbroken ice field forms, i.e. frozen solid. After the ice has grown sufficiently thick it remains, in certain sea regions at least, such as the eastern part of the Gulf of Finland, very nearly immobile for a long time. Insofar as this ice field is not anchored to the islands or shallows and can move slightly with cracks and lanes resulting it cannot be considered as part of the fast ice fringe.



Picture 1. »Ice-film.» (Off Hanko in winter of 1929. Institute of Marine Research photo, *Istjänsten i Finland* 1937).

If a solid-frozen drift ice field is pressed against the coasts it usually breaks up. If again a frozen drift ice field moves outward from the coast, and has not been under pressure, a lane parallel with the coast is formed but the field itself remains practically unbroken. If therefore in such a field the floes are large (over 20 km across) and no wide lanes are present the author has considered it as still frozen solid until it is further broken up.

PRESSURED ICE.

After the ice of the open sea starts drifting cracks appear and pressure occurs. The first degree of pressure, with the ice still thin, is the rafting or piling-up of thin ice (within each band the pieces have »dovetailed» one into another, Picture 23), in the course of which the drifting ice field remains level. Elevations in a thicker ice field or floe, usually snow-covered, caused by two or more bodies of ice being pressed together, result in pressured ice (often immobile and pressure no longer being applied). This pressured ice often assumes ridge-like formations with fairly extensive intermediate level areas (Pictures 12—14). Sometimes, particularly off the fast ice fringe, successive pressured ice ridges are so dense that a uniform uneven zone is formed. According to some earlier measurements the heaped ice masses in the open sea attain a thickness of some 2—4 m, closer to the coast a thickness of some 4—6 m (MAKAROV 1901).

2. LIST OF THE ICE TERMS EMPLOYED.

English	Swedish	Finnish
belt	drivisband	ajojäävyö
(blue ice)	kärnis	teräsjää
»bridge of fast ice»	»fastisbrygga»	kiintojääsilta
broken ice	bruten is	rikkoutunut jää
channel	ränna	uoma
crack	spricka	halkeama
drift ice	drivis	ajojää
fast ice	fast is	kiintojää
fast ice edge	fastisrand	kiintojään reuna
fast ice fringe	fastisbräm	kiintojääreunus
fragile ice	porös is	hauras (kevät-)jää
heavy ice	svår is, grov is	paksu, vaikeakulkuinen jää
hummocked ice	isupptorning, isröse	ahtojääröykkiö
ice cake	isbit	jääteli
»ice-film», (»ice scum»)	ishinna	jääkalvo
ice floe	isflak	jäälautta
ice rind	isskorpa	jääkuori
lane	råk	railo
level ice	slät is	tasainen jää
loose ice	lös is	irtojää
new ice	nybildad is	uusi jää
open water	öppet vatten	avovesi
opening	öppning	aukko
pancake ice	tallriksis	lautasjää, »jääkukka»
piling-up of thin ice	tunn is skjuter	päällekkäin ajautuminen
pressured ice	packis	ahtojää
pressured ridge	packisvall	ahtojääharjanne
pressure of ice	ispressning	jäänpuristus
rafted ice	hopskjuten is	kokoon ajautunut jää
scattered ice	spridd is	hajajää
sludge, slush	sörja	sohjo
strips	strängar, »rator»	(sohjo-)viiruja

I. MATERIAL.

A. SURVEY OF ICE OBSERVATION MATERIAL PRIOR TO THE 1920's.

3. Notes on severe ice winters have been preserved from very early times, but the information on ice conditions of the open sea during such winters is occasional in character. It is contained in descriptions of journeys over the ice, e.g. from Denmark by sledge to the Wendish towns of Lübeck, Wismar etc. In the severe winter of 1323, for instance, the ice on this stretch is reported to have been strong enough for real inns to be set up on the ice (SPEERSCHNEIDER 1915). Later on regular trans-ice traffic was organized at certain points; on the Belts of Denmark it was run by the so-called ice-boats and in 1633 on the Åland Sea by »postrotarne» (i.e. groups of farms in Eckerö (Finnish) and Väddö (Swedish) which took turns in providing mail carriers, FAGERLUND 1925). In the Åland Sea, between Signilskär and Grisslehamn, a system of signals even was organized from 1789 onwards. Originally cannon shots, later visual signals were used to indicate the possibilities of traffic across the ice. However, no systematic notes have been preserved on the actual signals.

Navigation, it must be borne in mind, in the era of sailing ships came to a standstill during the winter. Quite thin ice early in the winter was enough to impede these vessels, and the drifting floes of the end of winter could also damage them. Thus navigation generally ended before the first ice appeared in harbours and off the coasts, and it was not resumed in the spring until the ice had disappeared; hence, there were no ships' reports from the sea. But for rivers, where efforts were made to maintain traffic as long as possible, notes on freezing and breaking up of the ice have been made for a long time (EASTON 1928, JOHANSSON 1932).

4. The decisive culmination point in ice observations in the Baltic was the introduction of steam as the motive power for ships in the 19th century, and especially the replacing of paddle-wheels by propellers and the building of the ships' hulls of steel. Once increasingly strong screws were fitted ships were able to sail in ice which had been impossible to penetrate earlier. Thus gradually regular winter traffic was introduced by steamship. Plans for regular winter traffic had actually been proposed as early as about 1839, when the then Chief of the Swedish Postal Administration had suggested that Finland acquire a small steamship for conveying the mails

in the Åland Sea (Ramsay 1947). But it was too early for the plan to be put in practice. The first mail steamer to ply on year-round traffic in the area of the northern Central Baltic, the »Polhem», was put into service in 1858 between Visby and Västervik.

It was for navigational reasons that increasing attention began to be devoted to the occurrence of ice in the sea. Orders were given in Russia in 1838 that the extinguishing and lighting of lights in lighthouses was to depend on whether or not the entire field of view of the station was ice-covered. This led to the introduction of notes on ice conditions in connection with entries on extinguishing the light, e.g. by several lighthouses in the Gulf of Finland. In Denmark in 1843 Skagen Lighthouse introduced a special system of signal flags to give warning to navigators of ice in the Danish Straits (Speerschneider 1925). This purely practical arrangement may be considered the beginning of ice informations in Denmark, and it resulted in the recording of the sea ice observations.

Ice observations were initiated for scientific reasons also, however, as a rule in connection with »suitable» climatological and phenological observations. These observations were systematized in Finland when, in 1846, the ice observations were included in the programme of Suomen Tiedeseura (Scientific Society of Finland). The records consist mainly of notes about the time of freezing and disappearance of ice in rivers and inland lakes, but observations were also made at certain points along the sea coast (*Öfversigt af Finska Vet.-Soc. Förhandl.* 1853). In the other Baltic countries such as Estonia, Latvia and Lithuania, systematic observations e.g. by lighthouses were organized in the 1850's and 1860's (Leyst 1887).

5. The severe winter of 1871 in the Baltic and North Sea regions led to the construction of icebreakers, which was of decisive significance for winter navigation. Because of the difficulties caused by ice in Hamburg, an icebreaker, the »Eisbrecher I», was designed and built. As several hard winters occurred in the 1870's and 1880's still more icebreakers were built (Palmén, K. E. 1894). The efficient icebreakers »Sampo» (Finnish) and »Jermak» (Russian) were completed in the late 1890's. Side by side with the icebreakers it became necessary to build merchant vessels reinforced for going in the ice not only to enable them to follow the icebreakers but also to keep the traffic going on their own in fairly heavy ice, as e.g. in the Archipelago Sea. By way of summary of the development of winter navigation it can be said that in the late 1890's navigation was able to continue in moderately severe winters in the northern Central Baltic throughout the winter.

6. With winter navigation developing, increasing attention was paid to the making of ice observations, although originally it was concerned with organizing observations made by the permanent coastal observation stations. In Sweden, for instance, systematic observations by lighthouses

and pilot stations were organized in 1871 (ÖSTMAN 1937). In Russia, ice observations at lighthouses were reorganized in 1888 (ŠPINDLER 1893).

In Finland, Sea Captain D. J. SJÖSTRAND had put forward a proposal in 1887 for the making of ice observations at lighthouses. This proposal for the first time included the three main points of ice research in the Baltic: fast ice, drift ice and pressured ice (JURVA 1937). Later on observations were planned by the Finnish Meteorological Commission. A special form was printed, with columns for the thickness of ice (separately for the total thickness of ice, thickness of the clear part of ice, »blue ice» and the dull part on it — formed of thawed snow — (German »Schnee Eis») and thickness of snow cover), location of the edge of the fast ice, occurrence of drift ice and pressured ice, occurrence of lanes and of open water. Drawing of an ice map was then included. Such observations were started in 1893 at Hanko Lighthouse. In the winter of 1898 detailed observations were introduced at the lighthouses of Söderskär, Harmaja, Porkkala and Jussarö, and in the winter of 1900 at those of Russarö, Utö and (Baltic) Bogskär. The observations of the last-mentioned, in particular, were concerned with the open sea of the Baltic. At these stations the data were entered twice a week, on Tuesday and Friday. Ice situation maps were also drawn on the same days (KARSTEN 1911). — Other Finnish lighthouses recorded less detailed observations.

Ice observations in general found a wider working basis after they were connected with other hydrographic research at the 1898 Congress of Natural Scientists in Stockholm. As a result, ice observations were entrusted to separate bodies, representing the scientific aspect and the practical aspect. In Finland the organization was subordinated to the Scientific Society of Finland, but worked in close co-operation with the then Luotsihallitus (Pilot and Lighthouse Service).

Information on the ice conditions of the open sea was reported also from vessels engaged in winter navigation. To start with this observation work was not organized; the data was contained in log entries and issued to the press. Beginning from the winter of 1899 this part of the ice observation work in Finland was undertaken by passenger ships (KARSTEN 1911). On each trip made during the winter season, they gave a report in the form of maps illustrating the ice conditions prevailing along the route (Figure 2). On the same maps were entered the observation points at which, according to an agreed programme, surface water temperature and a salinity sample were taken. In the first winters, when the ice was slightly above average in abundance fairly extensive data were recorded, primarily from the area of the northern Central Baltic; in 1902, for instance, no less than 57 maps containing ice information were submitted. The subsequent winters were mostly mild, and little ice was present in the northern Central Baltic. Maps submitted by ships contained primarily hydrographic observations,

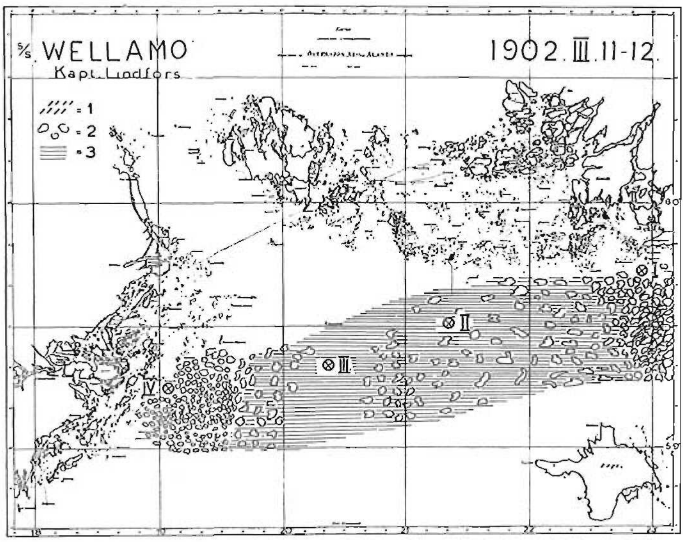


Figure 2. Ice situation March 11—12, 1902, drawn on the map by the master of the »Wellamo», Captain ARTHUR LINDFORS, for the open sea route Hanko—Stockholm.
Explanations: 1 = pressured ridges, 2 = drift ice, 3 = open water, I, II, III and IV points along the route where hydrographic observations were made.

and the occasional data on ice were primarily from the vicinity of Hanko. In 1912 this co-operation began to suffer from the fact that the Finnish Pilot and Lighthouse Service was placed directly under the Russian Board of Admiralty. The outbreak of the First World War with the cessation of regular navigation in the open sea of the Central Baltic put a complete stop to ice observations made by passenger boats.

7. However, the outbreak of the First World War did not interrupt ice research and information, for commercial requirements gave way to military. In Finland efforts were made to maintain and even intensify the ice observations by permanent coastal stations mentioned above. In 1915 the former monthly reports from these observation stations were replaced by weekly ones, and the ice situation map was to be drawn every Friday. In addition, all lighthouses and pilot stages received orders to make these special observations. This reorganization was possible in war conditions as the employees of the Finnish Pilot and Lighthouse Service were simply ordered to carry out this work (WITTING: *Havsf. 1919*).

As regards the open sea of the northern Central Baltic, however, the availability of ice information was reduced; e.g. the personnel of Bogskär Lighthouse in 1914, for security reasons, were withdrawn, and the enemy destroyed the lighthouse the same year. On reconstruction after the war it was replaced by an automatic Aga-lighthouse (Picture 2).

Picture 2. Bogskär Lighthouse in summer. (Direction ESE. Finnish Board of Navigation photo.)

Information on conditions in the open sea, it is true, was received during the war e.g. from naval craft (HELSINGIUS 1918), but ice research was rendered difficult by the fact that all data collected and issued were classified as secret.

Immediately after the war the veil of secrecy was lifted from all ice information but the little traffic there was at that time found the mine fields in the Central Baltic an even worse obstruction than ice. Hence ice observations in the open sea remained very limited. But soon after the war it began to develop and was quite considerable in scope by the 1920's.

B. OBSERVATIONS BY LIGHTHOUSES ON ICE CONDITIONS DURING AND AFTER THE 1920's.

8. The material available from lighthouses and other permanent coastal stations covers ice observations and ice reports. The ice observations included the records and the telegrams in clear kept by lighthouses and pilot stages. The ice reports included telegrams in code.

In Finland the data were recorded on the special form drawn up in 1915 mentioned above. Of great importance for the study of ice conditions in the northern Central Baltic were the observations of the Russarö, Bengtskär, Utö and Lågskär lighthouses. The observations were continued regularly until the early 1940's when, due to the conditions of war, they were at least partly discontinued in the winters of 1941 and 1942 at the Russarö and Bengtskär lighthouses and the Hanko pilot stage and, since the winter of 1945, at the Porkkala lighthouses.

There was a special weekly form for recording ice data (Figure 3). The top of the form has columns for the daily entry of information on the location of the edge of the fast ice, occurrence of drift ice and its direction of movement, and the areas of open water. In addition there were columns in which to enter the ice thicknesses separately for the fast ice and drift ice and for drift ice frozen solid. The lower part of the form was completed once a week, on Fridays, with more detailed data on the different types of ice: new ice, drift ice, ice frozen solid and fast ice. In addition, entries were made regadring the occurrence of open water, data on navigation etc. Both the mimeographed and printed instructions on making ice observations (*Istjänsten i Finland* 1937) enphasized the importance of reports on the occurrence of different types of ice. — In addition to the ice observation form, the ice conditions were entered on Fridays, and sometimes on several other days of the week, on a special map, scale 1: 100 000 or 1: 200 000 (Figure 4).

DATE	DAY OF THE WEEK	VISIB (KM)	FAST ICE EXTENT, LIMITS	QUANT 1-10	DRIFT ICE PRESSURED ICE EXTENT, LIMITS	MOVING FROM	QUANT 1-10	OPEN WATER EXTENT, LIMITS	QUANT 1-10	THICKNESS FAST ICE	THICKNESS DRIFT ICE	THICKNESS PRESS ICE	SNOW COVER	POINT OF MEASURING
24	SATURD.		Fast ice about 10 sea miles outside Utö		Drift ice outside fast ice over northern Central Baltic	E	10	Out of view	0	18	12		1	By the fairway W of Utö
25	SUNDAY		Ditto		Ditto	ENE	10	Ditto	0	20	14		1	
26	MONDAY		No observation owing to bad visibility		No observation owing to bad visibility	ESE	?	No observation	?	22	?		3	
27	TUESDAY		Ditto		Ditto	E.	?	Ditto	?	23	?		5	
28	WEDN.D.		Ditto		Ditto	E	?	Ditto	?	24	?		7	
29	THURSD.		Fast ice about 2 sea miles outside Utö		Drift ice outside fast ice	E	9	Lane outside Utö 3 sea miles wide	9	25	?		8	
30	FRIDAY		Ditto. Lane covered with new ice		Ditto	ENE	9	Out of view	0	26	?		9	

DETAILED REPORTS OF ICE ON FRIDAY, ON 30 Jan 1942.

ICE RIND, SLUDGE: New ice one night old in the 3 sea miles wide lane beginning 2 sea miles outside Utö
LEVEL FAST ICE: Level fast ice for 2 sea miles outside Utö, thickness 26 cm.
ICE FROZEN SOLID: No
DRIFT ICE: On the northern Central Baltic beginning 5 sea miles outside Utö.
PRESSURED ICE: No
RIDGES OF PRESSURED ICE: No
SNOW COVER (CM): 9 cm
LANES: Out of view
OPEN WATER: Out of view
NAVIGABILITY: With assistance of ice breaker
TRAFFIC ON ICE: Walked from Jan. 17 to Bokulla and Jurmo
FIT FOR WALKING: Fit for walking from Jan. 17
FIT FOR DRIVING: Fit for driving from Jan. 19
FISHING, SEAL HUNTING: No fishing

Fjalar Forssell.

Figure 3. A Finnish weekly form recording ice data. The form has been filled in by Lighthouse Master FJALAR FORSSELL, Utö. (The whole text translated into English.)

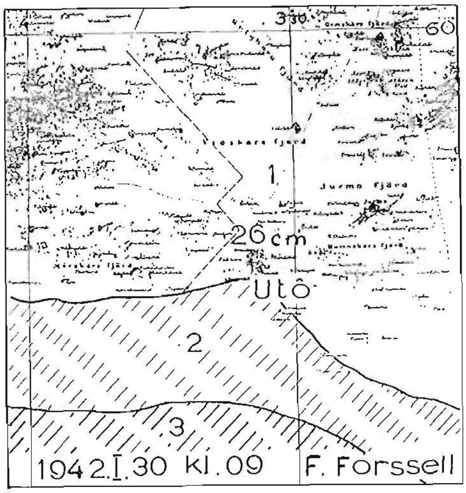


Figure 4. Ice situation of Utö surroundings Jan. 30, 1942, 0900. Map drawn by Lighthouse Master Fjalar Forsell.
Explanations: 1 = fast ice, 2 = lane, approx. 3 sea miles wide, 3 = heavy drift ice.

In Sweden the records of ice observations at lighthouses were very concise and consisted of data entered during the winter on a form which was finally approved in 1895. It listed seven questions regarding ice conditions, viz., the freezing of the coast and of open waters, strength of ice and disappearance of ice of this area, maximum ice thickness in winter, and also the freezing of the open sea and the occurrence of the drift ice on it. Apart from ice conditions the form contained questions on navigability (ÖSTMAN 1937). The records of ice observations in Sweden have recently been reorganized.

In Sweden the ice observations by lighthouses must be considered to include also the brief reports in clear, added if necessary to the ice code telegrams described below (*Bestämmelser* 1946). For instance, on Jan. 30, 1943, the following report was submitted:

Hanö: »At sea, NW and NE 24, SE and SW 34. Two steamers icebound 1 dist. min. E and NNE, respectively, from the Lighthouse.»

The point where the steamers were reported icebound was the fast ice edge.

9. Apart from the ice observations, material is also contained in the ice reports based on the ice code which was introduced in Germany after the First World War and adopted by all the Baltic countries in the early 1920's. To begin with the different countries employed different codes, but gradually separate uniform codes were adopted by the southern and the northern Baltic countries. Finally, at the 5th Hydrological Conference of the Baltic states held in Helsinki in 1936, the so-called Baltic Ice Code was approved for use in both the southern and northern Baltic (STAKLE 1936). According to it, every report district sent a two-figure message »In». In this pair of figures the first figure refers to ice conditions, the second to navigability, as follows (some changes have been made in the terminology after the new definitions of ice terms):

I = Ice conditions

0 No ice
1 Loose sludge or new ice
2 Fast ice
3 Drift ice
4 Heavy sludge or close belts of drift ice
5 Lane in the ice parallel to the coast
6 Thick fast ice
7 Heavy drift ice
8 Pressured ice
9 Pressure of ice
X No report

n = Effect of the ice on navigation

0 Navigation unobstructed
1 Navigation possible for steamers, difficult for sailing vessels
2 Navigation difficult for low-powered steamers, closed to sailing vessels
3 Navigation possible for powerful steamers
4 Navigation possible only for vessels constructed to withstand ice
5 Navigation kept open by icebreaker
6 Channel opened through the ice
7 Navigation temporarily closed
8 Navigation closed
9 Not known owing to bad visibility
X No report

For instance, we have the following telegram from Sweden, Jan. 30, 1942:

Utklippan: «Today X9, yesterday at sea NW 50, NE 84, SE 84, SW 74.»

C. SHIPS' REPORTS FROM THE 1920'S ONWARDS.

10. With the increase in traffic after the First World War more ice observations on the open sea of the Baltic were received in the form of ships' reports.

Ice observations were entered, as in the earlier winters, in ships' logs, but as a rule only in cases where ice had affected navigation. Hence, the logbook contains entries such as the removal of the log because of ice risk, encountering of thicker ice, etc. The following examples are taken from a Finnish logbook of winter 1942:

»Gottfrid» (en route from Gdynia to Turku):

Jan. 19, 1942, at 1336 Bogskär Lighthouse 334°, distance 3 sea miles. Log hauled in because of ice.

1530 Bearing 240° from Utö Beacon, distance 24 sea miles. Ice encountered.

1620 Encountered icebreaker »Jääkarhu» upon which icebreaker assistance was received towards Utö.

As a rule, fuller entries were made in the logbooks of icebreakers. In the winter of 1942, for instance, the extension of the ice off Utö towards the northern Central Baltic could be followed from the log entries of the Finnish icebreakers »Jääkarhu» and »Tarmo», as follows:

»*Jääkarhu*» (logbook):

Jan. 19, 1942 at	1515	Assistance to ships discontinued at the edge of *open water*. Utö lying N 10°E, *distance 17 sea miles*.
Jan. 22,	2000	Utö radio 50°, *distance from Utö approx. 35 sea miles*. Assistance to ships discountinued, changed course eastward to assist ships SE of Bogskär, 11 sea miles.
	2130	Began to assist ships. Steered several courses in efforts to avoid pressured ice.
Jan. 23,	1300	Bogskär NNW = 8.6 sea miles (on the way out).
	1430	Assistance discontinued, return trip commenced.
Jan. 27,	0120	Stopped approx. 5 sea miles SE of Bogskär as it proved impossible, due to *rough sea*, and darkness, to approach the ship (»Helgoland») stranded off Bogskär.
	1345	»Alkaid» arrived in the vicinity.
	1800	»Alkaid» put out to sea. Salvage was interrupted due to *heavy ice*. Remained close to »Helgoland», south of the reef.
Jan. 28,	2200	Turned into Utö fairway.
Feb. 1,	1040	Left Utö southward.
	1145	Came up with the »Tarmo» and »Alkaid» 5 sea miles south of Utö. Began to assist »Alkaid» towards harbour. The »Tarmo» on her own.
	1240—1300	Stopped because of pump failure. Made rushes at *thick pressured ice*.
	1350	Reached Utö.

»*Tarmo*» (logbook):

Jan. 27, 1942 at	2000	Arrived at Bogskär where icebreaker »Jääkarhu» was in in the vicinity of the stranded »Helgoland». Because *ice was driving* the engine was kept running in order to keep us in the vicinity of »Helgoland».
Jan. 28,	1820	Bow was again made fast to the »Helgoland» amidships.
	2130	Parted from »Helgoland» as *ice began to force the stern* on to the rocks.
Jan. 31,	0920	Began to assist »Alkaid» to Utö. (Position 12 sea miles SW of Bogskär.)
Feb. 1,	0130	*Stuck in pressured ice*.
	0245	Assistance discontinued because of *heavy ice*.
	0245	Direction Utö 10°.
	0810	Assistance to »Alkaid» resumed.
	0950	Direction Utö 9° and Lillharu 51° (= position 5 sea miles south of Utö).
	1000	Stopped to wait for the »Jääkarhu» for assistance because of *severe ice situation*.
	1145	»Jääkarhu» arrived, beginning to assist »Alkaid» towards Hanko.

The Swedish icebreakers have kept a special ice diary in which more complete descriptions of ice conditions are entered. For instance, the ice diary of the Swedish icebreaker »Atle» has the following entry, illustrating the development of a severe ice situation off Häradskär in the winter of 1942.

»Atle» (ice diary):

Jan. 24, 1942 — Sailed southward from Stockholm to assist the ships frozen in between Hävringe and Häradskär. Strong NNE breeze increasing to storm, temperature —20°C. Dense snow. Ice was driving SW at a speed of 2 to 3 knots. Ice was pressing strongly, forming heavy ridges. Isolated lanes were opening, but rapidly closing. Assistance confined mainly to taking ships offshore. The ships were freed and assisted into a lane running in NE direction, instructed to follow the lane and await further assistance. (Assistance given: two ships position 17.5 sea miles off Ländsänkan Lighthouse, 9 ships position 12.5 sea miles NE the Storkläppen Lighthouse).

11. Availability of ice data directly from the open sea was very much affected by the great developments in wireless telegraphy, partly during the First World War, enabling the direct relaying of information from the open sea. In 1919, for instance, regular information in the form of radiograms had been received from the Finnish icebreaker »Wäinämöinen», admittedly via the coastal stations, by the Merentutkimuslaitos — Havsforskningsinstitutet (Institute of Marine Research). The installation of radio equipment in merchant vessels was started in the 1920's, which made it possible for them also to transmit ice reports direct from the open sea, from more distant points than those reached by the icebreakers. The transmission of ice reports in the form of radiograms was finally organized in Finland when the Institute of Marine Research obtained its own wireless station in 1930 (WITTING: *Havsf. 1930)*.

Wireless ice bulletins sent out by ships, above all by the icebreakers, have constituted a very important part of the ice information received from the open sea. Finnish icebreakers sent in these reports twice a day or more frequently. They contained, in clear, data on ice conditions, assistance given, prevailing weather and other important factors, roughly similar to the extract from the »Atle's» ice diary mentioned above. In the winter of 1940, because of the war, the exchange of wireless messages with the radio station of the Institute of Marine Research ceased entirely. In the winters of 1941—1944, also due to the war, the reports were issued in the ice code and contained only brief information on ice conditions, whereas for the severe winter of 1947 the wireless ice bulletins are issued in clear and fairly rich in detail. To illustrate this it may be mentioned that the number of radiograms received by the Institute of Marine Research in the winter of 1942 was 447 in all and 182 of them originated from the open sea area of the Central Baltic. In the winter of 1947 the number of radiograms was 1 022 in all, 182 of them from the open sea of the Central Baltic.

12. Another means of obtaining as complete information as possible on conditions in the open sea, required primarily for research work, was a special ice log designed by the Institute of Marine Research in collaboration with Merenkulkuhallitus (Finnish Board of Navigation). In 1927 this log was made compulsory for all Finnish merchant ships engaged in winter traffic (*Suomen Asetuskokoelma* 1927). The ice log contained a form for each day of the voyage, and on it were entered ice conditions in the fairway by hours. The form had a special column for the quality of the ice, entered in accordance with the ice code described above. Further there were columns for the direction and speed of drift of the ice. In addition other detailed data, e.g. the ice edge, could be entered. On completion of each voyage the forms were sent to the Institute of Marine Research. During the first winters, with fairly abundant ice, ice logs were kept on several vessels, e.g. in the severe winter of 1929 on 23 vessels (WITTING: *Havsf. 1929*). But in the subsequent mild winters of the 1930's it was comparatively rare for vessels to encounter ice in the open sea and the number of ice logs received has therefore been low.

13. A major effort to shed more light on ice conditions throughout the Baltic came with the organization of the so-called Baltic Ice Week, 12—18 February, 1938. At the instigation of the »Ständiges Bureau der Baltischen Hydrologischen Konferenzen» (Baltic Hydrological Commission) the Institute of Marine Research sent out the ice logs described above to all vessels then in traffic. In addition, the permanent observation stations of all the Baltic countries, such as lighthouses and port authorities also received ice observation forms modelled on the Finnish weekly forms. Similarly, air reconnaissance flights and other special methods of observation were organized in order to obtain as complete and uniform observation material as possible from the entire area. This particular winter, however, happened to be mild, and part from the Bothnian Bay ice appeared only in the coastal waters, if at all (GRANQVIST 1938 a, b).

The collection of information from all ships at sea at the time was arranged again the following winter, 28 January to 3 Fabruary, 1939. But this winter too proved a mild one, and not all countries co-operated fully.

To give some idea of the extensive organization of the ice observations aimed at during these international ice weeks, in the open sea alone the number of vessels participating and the ice logs completed by them are listed below:

	Feb. 12—18, 1938 Ice logs	Vessels	Jan. 28—Feb. 3, 1939 Ice logs	Vessels
Finland	191	42	246	55
Sweden	31	8	3	1
Denmark	8	5	2	1
Germany	162	45	41	17
Latvia	20	6	—	—
Estonia	4	1	—	—
Total	416	107	292	74

Finally the ice logs in Finland were discontinued in the winter of 1940 after the outbreak of war, just when there happened to be several extremely severe winters. The ice logs were not reintroduced until January 26, 1949.

D. REPORTS FROM AIR RECONNAISSANCE FLIGHTS.

14. With the remarkable technical progress made in aviation during the First World War it became possible to extend air reconnaissance flights to cover the frozen sea. Initially, however, the main object of the flights was to locate icebound ships, e.g. in Finland the flight on February 28, 1916, to search for the Finnish steamers »Ariel» and »Lapponia» which had frozen fast a month earlier (Hellström 1922, Granqvist 1926). In this instance the aircraft failed to locate the vessels, and typical of the conditions in those days is the fact that information on their fate was not received until April 30, some three months after their departure. This shows that at that time, as a rule, no information was received from the open sea.

But fairly early on, at least in 1920, certain flights were made for the sole purpose of obtaining information on ice conditions for sea traffic (Jurva 1925). Although the advantages of aerial reconnaissance for ice research were fully realised the flights of the 1920's at least were only occasional in character, though the need for them in the fairly severe winters became increasingly apparent year by year. The main object of the flights remained the search for icebound steamers, and, in the Gulf of Finland, even their supply with provisions, as for instance in the winter of 1926 (*Hufvudstadsbladet*, Jan. 13, 1926). One flight was made far out into the northern Central Baltic, to a point south of Utö, where the icebound »Mira» (Finnish) was located by it. Ice data were included in the report submitted.

Ice reconnaissance flights became more regular in the severe winter of 1929, when it became necessary e.g. for Germany to resort to aerial reconnaissance to search for vessels icebound in the southern Central Baltic. The need for air reconnaissance arose in the first place from the fact that far from every vessel was equipped, even at that time, with a wireless for transmitting distress signals. In addition to the special German reconnaissance the normal Copenhagen—Hamburg passenger line gave fairly regular reports on ice conditions (RICHTER 1933). Taking all these into account, about 20 flights are mentioned from the southern Central Baltic in the winter of 1929; it is interesting to compare figures with later developments. Aerial photos were taken on these flights, a practice which had been advocated earlier (LUENSEE 1928). In addition, Germany was making serious efforts at that time to organize regular reconnaissance flights. Regular reconnaissance flights were also planned by other countries (SLAUCITAJS 1929 a, *Den Danske Istjeneste* 1936).

Regular flights for the sole purpose of reconnoitring ice conditions were being carried on in Finland by the 1930's, mainly over the Gulf of Finland. During these flights ice data were drawn in on maps, mostly 1: 400 000, with written supplementary explanations. Other Baltic countries too were ready for regular ice reconnaissance flights, although there was no great need for them in the mild winters of the 1930's (KOCH 1936, SPEERSCHNEIDER 1936). In Germany the work was entrusted to the »Deutsche Luftsport-Verband» (German Aero Club) from the winter of 1935 (STAKLE 1936).

15. During the severe winters of 1940—42 information on ice conditions was considered secret again, because of the war, and ice reports were given no general release. When information was required on ice in the open sea each Baltic country concerned was forced to resort to air reconnaissance.

Hence, in winter 1940, Swedish passenger planes began to carry out ice observations along their routes from Stockholm to Visby and Riga (ÖSTMAN 1940). The following winter the air routes in operation were from Stockholm to Visby, Helsinki, Berlin and Warsaw (ÖSTMAN 1941, LILJEQUIST: *Isvintern 1941—42)*. Military planes also participated in air reconnaissance. All these flights issued reports in clear as e.g. the following:

Report from flight across the northern Central Baltic, Jan. 17, 1942:

»From Huvudskär outward fast newly-frozen ice with unrestricted swell. Within this area isolated strips of pancake ice, length 2—3 sea miles, width 200—300 m. Up to 30 sea miles from the coast thin ice rind as far as the area where eastern wind prevailed. After that ice-free.»

The data were also drawn in on maps, scale 1: 10 000 000 (Figure 5), or on sketch maps (Figure 6).

In Denmark air reconnaissance flights from Copenhagen covered the Danish Straits and the coast of Jylland, and the southern Central Baltic as far east as Bornholm *(Is- og besejlingsforholdene 1941—1942)*. From these flights reports in clear were issued e.g. the following:

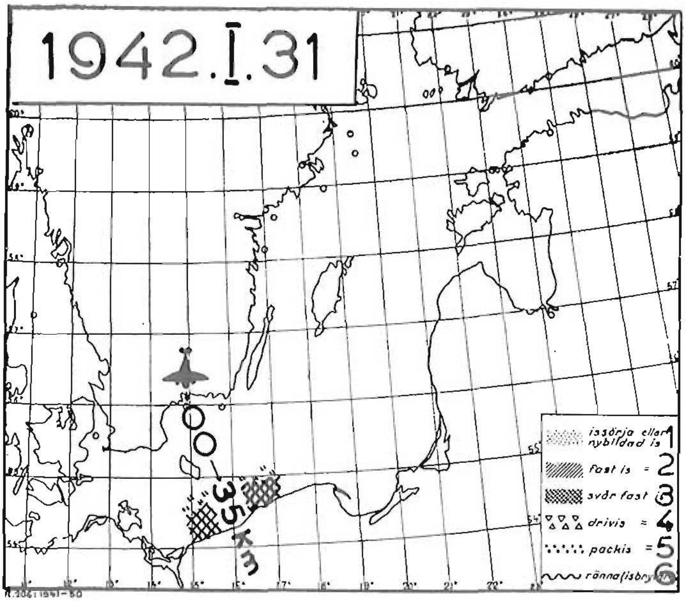


Figure 5. Map drawn during the Swedish air reconnaissance flight across the southern Central Baltic, Jan. 31, 1942.
Explanations: Fast ice and new ice 35 km off the German coast, then open water.

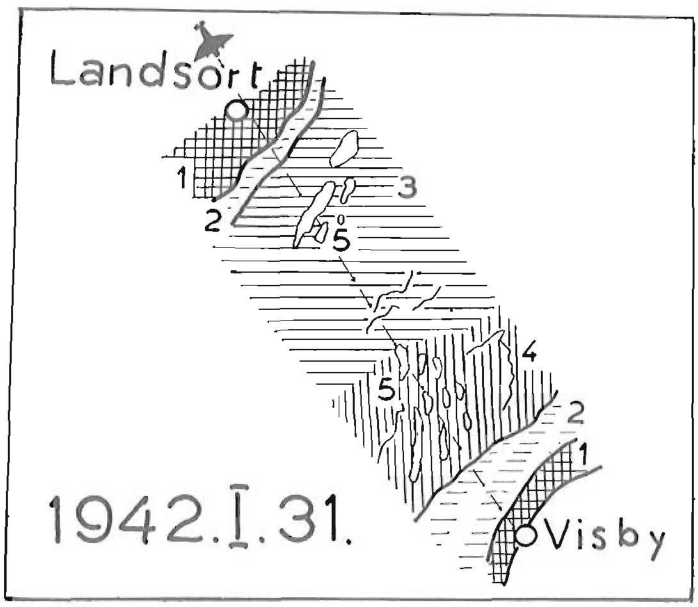


Figure 6. Map drawn during the Swedish air reconnaissance flight from Stockholm via Landsort to Visby, Jan. 31, 1942.
Explanations: 1 = fast ice, snow-covered, 2 = lane, covered with new ice, 3 = unbroken ice, snow-covered, 4 = thinner ice, snow-covered, 5 = cracks and narrow lanes.

R e p o r t f r o m f l i g h t Bornholm-Copenhagen, Jan. 30, 1942:

»The first 1/3 of the distance Rönne — Falsterbo partly ice-free, 1/4 of the remainder small floes, the balance large floes. Falsterbo — Copenhagen fast ice with isolated lanes.»

R e p o r t f r o m f l i g h t Copenhagen—Bornholm, Feb. 4, 1942:

»Heavy fast ice on the coast between Trelleborg and Sandhammaren. From there on large ice floes with new ice in between up to the northern side of Bornholm.»

(»Small» and »large» after the former terminology!)

In Germany air reconnaissance in the winter of 1940 continued to be the responsibility of the »Deutsche Luftsport-Verband» but by the winter of 1941 special »Luftwaffe» (German Air Force) units had been entrusted with the task. Transport planes also participated in the work. The briefing for these reconnaissance flights devoted great attention to the recognition of the different types of ice. In addition, orders were given to communicate the results in clear or code *(Merkblatt für die Eiserkundung* 1940). During the winters of 1940—42 a total of 202 ice reconnaissance flights are reported (BÜDEL 1943), but unfortunately the original material was destroyed in an air raid on Hamburg in 1944. However, a number of these reports are published in the daily ice bulletins *(Eisbericht* 1941/1942).

During the »Winter War» in 1940, ice information on the open sea of the northern Central Baltic was not required in Finland for navigation. Flights were carried out primarily for general surveillance purposes. In the winter of 1941 also the number of ice reconnaissance flights was fairly small. But in the winter of 1942 numerous flights were carried out far out over the Central Baltic, primarily to ascertain ice conditions for navigation, and large numbers of photographs were taken. Reconnaissance results were reported in clear e.g. as follows:

R e p o r t f r o m f l i g h t over the western Gulf of Finland, Jan, 1, 1942, at 1150—1330:

»East of the line Jussarö — Paldiski ice resembling pressured ice and snow-covered ice. West of this line, snow-free, thin smooth ice, with small openings, diameter 10—50 m. Edge of open water along the line Morgonlandet 5 sea miles S — Osmussaar 10 sea miles E».

The observations were also reported on maps (Figures 15—28). In drawing these maps attempts were made to depict ice conditions as seen from the air. No established symbols like triangles for drift ice were used, as it was impossible to describe all the details with their aid. The special instructions worked out in the winter of 1942 for aerial ice reconnaissance emphasized recognition of the various ice types from aerial photographs. Great attention was also paid to drawing the maps (PALOSUO 1952). In the winter of 1942 ice reconnaissance for military operations was carried out in the eastern part of the Gulf of Finland.

16. In the later winters of the 1940's ice reconnaissance flights varied in number with the conditions. In the winter of 1947, reconnaissance by Swedish passenger planes over the Central Baltic was common (LILJEQUIST: *Isvintern 1946—47*). From the winter of 1948 on, in Finland, ice reconnaissance flights have been fairly regular although, over the sea of the Central Baltic, they have been less frequent as the winters have been comparatively mild.

In order to give an idea of the number of ice reconnaissance flights carried out and above all of the immense developments in this field, their number in the severe winters of 1940—1942 and 1947 is given below:

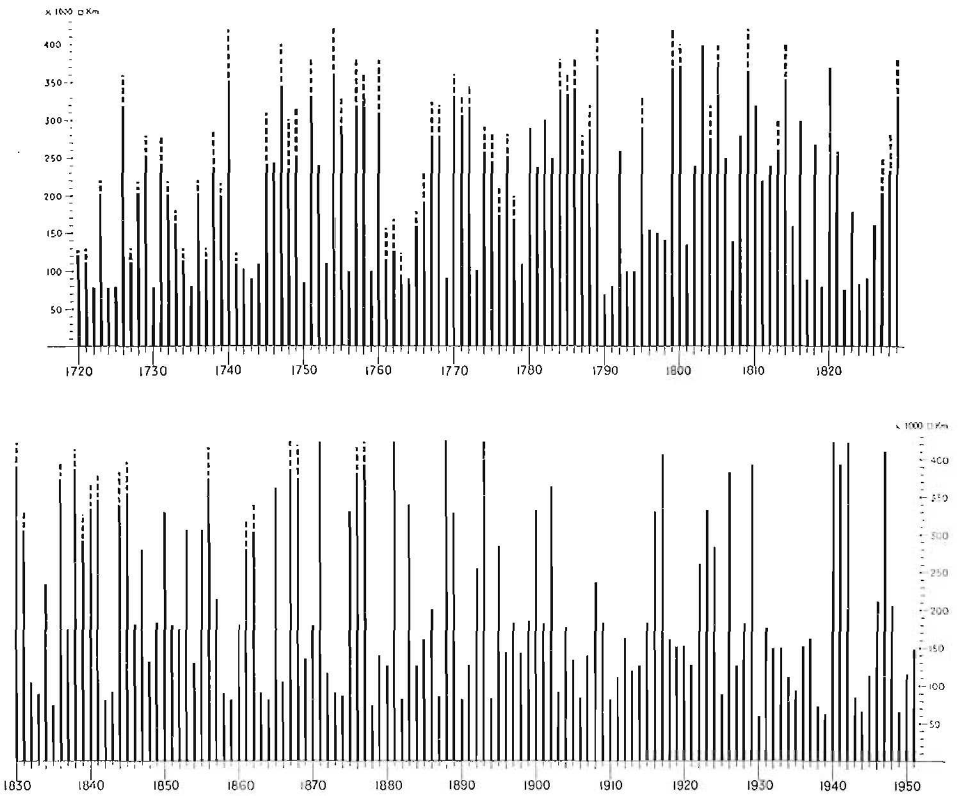
Winter	Finland	Sweden	Denmark	Germany
1940	8	(13)		(20)
1941	4	(8)		
1942	87	163		(67)
1947	8	47		

(The figures in brackets indicate that there may possible have been more ice reconnaissance flights not recorded)

E. THE OCCURRENCE OF SEVERE ICE WINTERS.

17. The occurrence of severe winters may be studied by means of the following diagrams (Figures 7—8) by JURVA (1942, 1952 a and 1953). They give the maximum extent of ice in the area of the Baltic for each of the 231 winters of 1720—1950. With the Baltic completely frozen over the length of the corresponding column stands for 420 000 sq km. For the winters with the least ice the maximum extent of ice equals nearly 60 000 sq km (i.e. approx. like ice conditions on December 19, 1942, Figure 29).

The diagrams show that severe ice winters were relatively infrequent in the early 18th century, and that winters with abundant ice were more numerous at the end of the 18th and during the 19th century. Particularly in the 1870's and the 1880's the Baltic was often completely frozen over, e.g. in the winters of 1871, 1877, 1881 and 1888. The last in this series of severe winters was the winter of 1893, in which year the Baltic was frozen over completely again. Since then winters have generally been less severe; particularly in 1904—1914 and 1930—1939 there was little ice, the result of the exceptionally high winter temperatures of those periods. The cycle of mild ice winters terminated at the end of the 1930's; in the early 1940's there were three consecutive rigorous winters, and the Baltic was



Figures 7—8. Variations in the maximum extents of the ice cover of the Baltic in ice winters 1720—1829 (according to JURVA 1953) and 1830—1951 (according to JURVA 1944, 1952 a). The gradings indicate the maximum extent of the ice cover, with 1 000 sq. km as the unit.

completely frozen over in the winters of 1940 and 1942. The winter of 1942, in particular, was exceptionally severe. There was one other hard winter in the 1940's viz. the winter of 1947, when the open sea of the Baltic was covered by ice.

The distribution of these 231 winters (1720—1950) by the maximum extent of ice has been calculated by the author from the diagrams by JURVA, referred to above. The result is as follows:

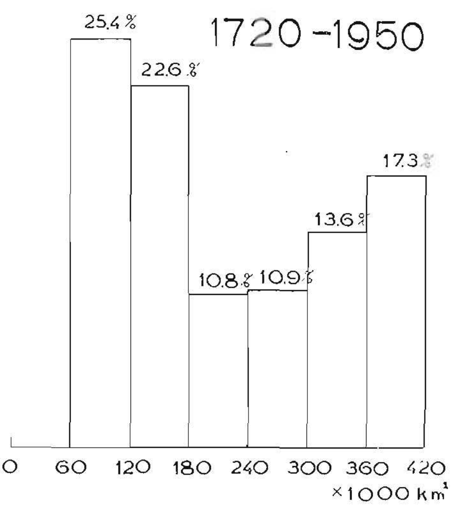


Figure 9. Frequency distribution of the maximum extents of the ice cover of the Baltic in winters 1720—1950 (231 winters), calculated from Figures 7—8. (Numerial values in text.)

Extent of ice in 1 000 sq km	Number of ice winters Absolute	Relative (per cent)
— 60	—	—
61— 90	40	17.2
91—120	19	8.2
121—150	29	12.6
151—180	23	10.0
181—210	9	3.9
211—240	16	6.9
241—270	8	3.5
271—300	17	7.4
301—330	20	8.7
331—360	10	4.3
361—390	12	5.2
391—420	28	12.1

This distribution has also been represented graphically (Figure 9).

These two representations show that mild ice winters predominate numerically when the ice is less than 180 000 sq km in extent (i. e. approx. like ice conditions on January 16, 1942) accounting for nearly half of all the winters. Severe ice winters are also remarkably frequent; an extent of ice of 300 000 sq km (i. e. approx. like ice conditions on January 23, 1942. Figure 31) is reached approx. every third winter. Medium-severe winters are least in number. This distribution seems natural as the Central Baltic must be considered an almost closed basin. Its shallow coastal areas freeze fairly rapidly, even during cold spells of short duration, whereas the water masses of the open sea require a much longer time to cool and permit ice formation. Only in rigorous winters, characterized by prolonged very cold spells, is ice formed in the open sea of the southern Central Baltic. The upper limit, 420 000 sq km, i. e. ice cover throughout the Baltic, is often reached considerably before the culmination point of the ice winter, the date from which the ice cover begins to diminish. The severer the winter the thicker the ice cover of the open sea can become. However, the present diagram will not concern itself with the development taking place after the Baltic is completely frozen over. Hence in the present diagram the distribution of the extent of the ice cover is similar e.g. to the description of cloudiness, with upper and lower limits (CONRAD and POLLAK 1950).

18. In order to be able to study in greater detail the dependence of the freezing of the Baltic on general climatological conditions the author has compared the maximum extents of the ice cover in the different winters, as given above, with average temperatures of the corresponding winter months, i. e. December—March. As is shown by LILJEQUIST (1943), this average temperature of the winter months gives a climatologically serviceable quantity, at least as far as Stockholm is concerned. The interdependence of these quantities can be seen from Figure 10 covering the 195 winters of 1756—1950, the period during which temperature have been recorded in Stockholm. The abscissa shows the maximum extents of ice in

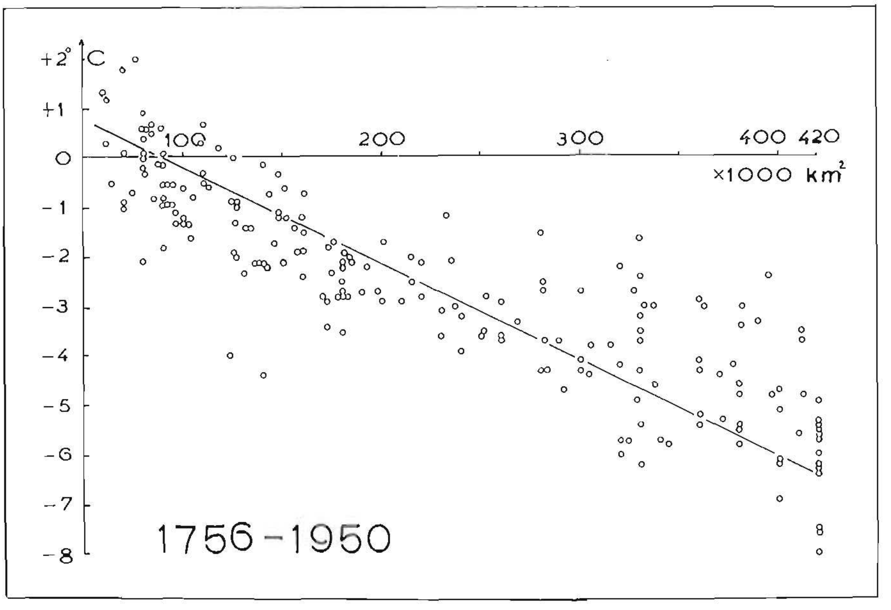


Figure 10. The relation between the maximum extent of the ice cover in the Baltic (the abscissa) and the average temperature of the corresponding winter months, i.e. December—March, in Stockholm (the ordinate).

1 000's of sq km and the ordinate the average temperatures of the winter months in Stockholm. If their interdependence is assumed to be linear, the straight line drawn into the figure by the method of least squares, shows this dependence.

According to the figure it seems that winters have been of abundant ice, over 300 000 sq km, when the average temperature of the winter months in Stockholm has been —4°C or less. Complete freezing-over of the Central Baltic has occurred when the corresponding Stockholm average temperature has been approx. —5.5°C or less. Admittedly, in the winter of 1947 the value was —4.7°C, but as will be seen further below the open sea of the Baltic, in that year, received its ice cover in exceptional circumstances. The lowest value, —8.0°C, was recorded in the »Winter of the French Revolution» of 1789. It must be mentioned that the average temperature in Stockholm in December 1788 was —10.4°C and in January 1789 —8.2°C. During these cold spells e.g. the Danish Straits were frozen so hard that sledge traffic could be maintained across them (Speerschneider 1915). February was milder, with an average temperature of —4.5°C in Stockholm. During February the ice was broken in the Kattegat and partly also in the Danish Straits. March saw another cold period; the average temperature in Stockholm was —8.8°C. The Danish Straits and the Kattegat froze over again. The ice did not disappear from Danish waters until the end of March. The third lowest average winter temperature in Stockholm was reached in the winter of 1942, —7.7°C.

Although the average temperature of certain winters was low, such as e.g. winter 1814 —6.9°C, they are not counted among the severest ice winters. The average temperature for December 1813 in Stockholm was —1.8°C, whereas the January 1814 mean fell to the remarkable low of —14.3°C. The Danish Straits began to freeze over soon after the New Year. January 27 saw drift ice in the Central Baltic in the vicinity of the Christiansö Lighthouse, but due to mild weather navigation was unobstructed until mid-February. The cold spells of that time — the average February temperature in Stockholm was —8.6°C — resulted in the formation of ice over very large areas. The vicinity of Christiansö was covered by ice from 15—23 February. Due to the short duration of the cold spell the open sea of the Central Baltic was barely ice-covered throughout. At the end of February the ice began to diminish. March was fairly mild, with an average temperature of —2.7°C. It seems, as has been emphasized by several researchers, that complete freezing-over of the Baltic can only take place, as a rule, early in February. The coldest point, a singularity, in the mean temperature of Helsinki appears on February 8 (Simojoki 1953).

Certain points in the figure appear to differ considerably from the general distribution; this is due to the fact, pointed out by Jurva, that difficulties of various kinds are encountered in determining the maximum extent of the ice. The material available is rather incomplete for the pre-1880 period and hence the results for the years prior to this time are not as reliable as the rest. Because of lack of detailed notes on ice conditions it has been necessary to estimate the maximum extent of ice with the aid of climatological etc. factors. Temperatures recorded from localities other than Stockholm e.g. Uppsala, Helsinki, Leningrad, Riga and Copenhagen have been resorted to. Such estimated analyses have been indicated in the diagram by Jurva by a broken line, but in calculating the distribution the present author has only included the highest values.

19. The present investigation deals with the class of severe ice winters, with special attention paid to the greatly varying ice conditions of the open sea of the Central Baltic. As was seen from the introduction, ice conditions in the Central Baltic have received increasing attention since winter navigation began. But it is just in the severe ice winters earlier that ice observations from the open sea have been very few, almost non-existent. Observation material serviceable as the basis of a scientific study of ice conditions was only brought in by the ice reconnaissance flights of the severe winters of the 1940's.

The winter of 1942 has been selected for detailed treatment and description. As can be seen (N. 16), it was in this year that the greatest number of ice reconnaissance flights was carried out. The present author was then serving in the Finnish Air Force as a flight lieutenant, working with the unit entrusted with the task of performing the ice reconnaissance flights, and thus he had an opportunity of following from the air the development of ice conditions.

In this treatise the author will firstly give a continuous account of the development of the ice on the open sea. This is based to a very important extent on pictures taken during the flights. Only some of these are published in the present study. Secondly an account of the phases of the severe ice winters will be given. This is based on maps drawn during the flights. These observations, which form the basis of the present study, are completed with material from the Institute of Marine Research and corresponding institutes abroad engaged on ice research. In addition to this, valuable material, secret because of the war, has been obtained from the ships' logs of vessels in winter navigation at that time, and of icebreakers. It has been possible to supplement some of these log entries with personal accounts given by the ships' officers. And by using all possible material the author has drawn ice situation maps showing certain phases of development in the ice conditions of the Central Baltic in severe winter of 1942.

This exceptionally severe ice winter of 1942 is then compared with the severe ice winters of 1940 and 1947, for which the material available is considerable more limited than that for the winter of 1942. Hence the winter of 1942 definitely remains the only severe ice winter to date on which observation material from the Central Baltic region is available in sufficient quantities to permit a description of the general course of such a winter.

Furthermore, using the material available on the other severe winters known to have occured earlier, the description has been extended into a general description of the course of severe ice winters in the Central Baltic. The so-called normal stages of a severe ice winter have been defined by means of JURVA's (1937) cartographic method. Hence JURVA's graphical representations have been extended to cover the severe ice conditions in the Central Baltic.

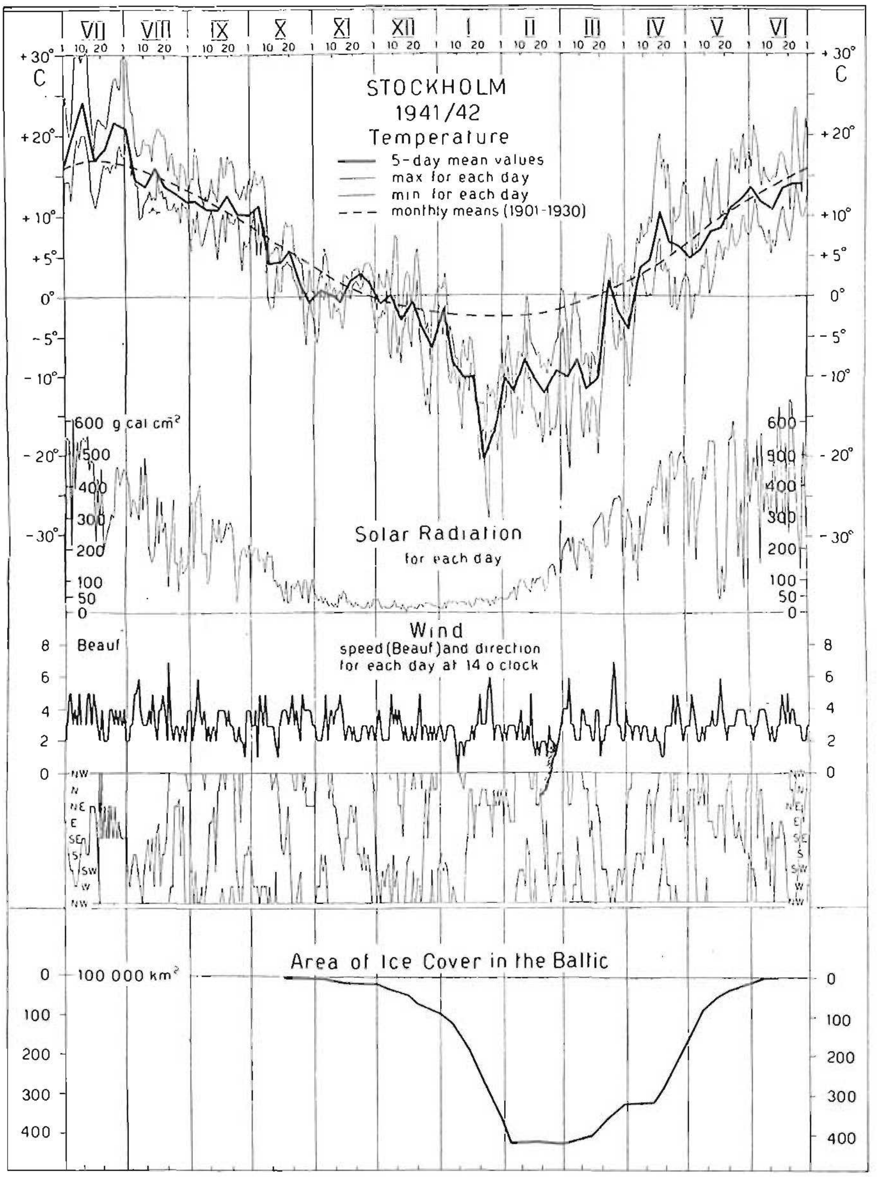


Figure 11. The meteorological factors (temperature, solar radiation and wind) in Stockholm and the area of ice cover in Baltic in the winter of 1942.

II. THE SEVERE ICE WINTER OF 1942.

A. THE SPREADING OF THE ICE OVER THE NORTHERN CENTRAL BALTIC, 1941. XII. 23—1942. I. 18.

20. Freezing began earlier than usual in the northern part of the Bothnian Bay in the autumn of 1941. The shallow bays froze in the middle of October as a result of the first frosts which came then (Figure 11). But the freezing over was quite exceptionally early in the south, in the region of the Gulf of Finland; during the following frost period, at the end of October, ice formed in the coastal bays. During the third frost period, which came in the middle of November, ice covered the inner archipelago of the Gulf of Finland.

It was exceptional to have three periods of frost as early as this.

A new and comparatively hard period of frosts began in the early part of December. In the middle of December the open sea of the Gulf of Finland was iced over throughout the field of view of the fixed observation stations along the coast as far west as Pellinki (Figure 29). December 20—22 the weather was milder, with a variable, mostly W-wind. The first flight to reconnoitre ice conditions went up over the eastern Gulf of Finland on December 23. It was found from an aerial photograph (Picture 6) taken

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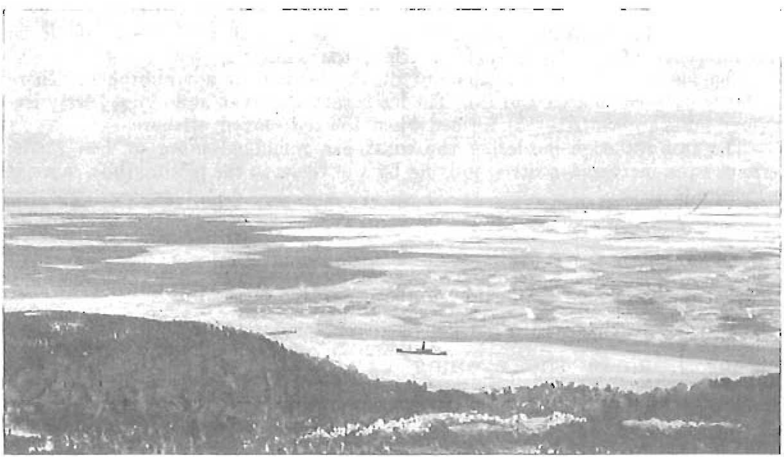


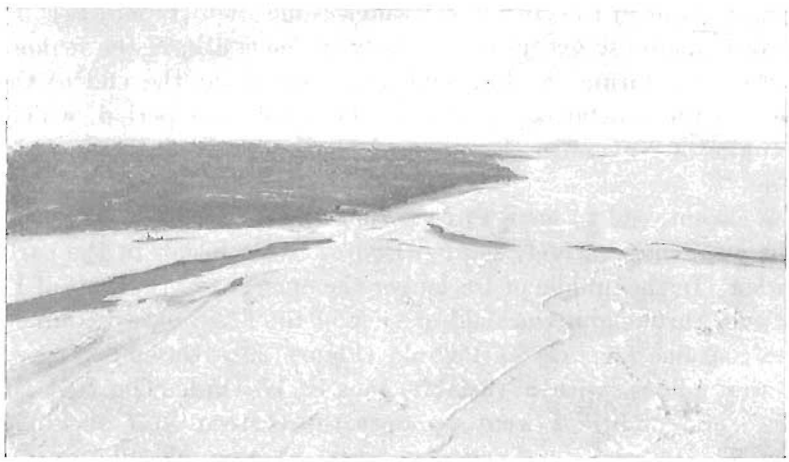
a b

Picture 6. B r o k e n i c e d r i f t i n g o n t h e o p e n s e a. (Gulf of Finland south of Kotka, 1941. XII. 23. Finnish Air Force photo.)

A typical ice situation at sea at the beginning of winter. The wind, too moderate to drive the ice away, has broken the ice covering the sea surface (a2—b2). The shore, a point of support for the ice, is bordered by the coastal fast ice edge which extends a little further out than the vessel seen in the picture (b1). The wind has not been strong enough to set this coastal fast ice in motion.

on this flight that the ice cover of the open sea south from Kotka was definitely broken. The photo shows clearly that the increased wind on the preceding day, with its possible by-phenomena, could break the ice cover, though the ice was certainly fairly thin at this time.

21. December 23 the frost increased and a new period of hard frost set in. With the wind weak, new ice formed rapidly on the sea. Four days later, i. e. December 27, very hard frost in the central part of the Gulf of Finland left the fields of view of Harmaja, Porkkala and Jussarö observation



Picture 7. Almost unbroken ice cover on the sea. (Gulf of Finland south of Kotka, 1942. I. 7. Air Force photo.)

The ice now covers the whole of the outer sea, but not unbroken. There are lanes (a2—c3, d3, e3 and f3). The ice is rather uneven and older, partly ice-covered lanes appear (d1—e3), formed when the ice moved offshore.

The fast ice edge bordering the coast has remained more or less static, perhaps even increased a little, judging by the vessel in the picture (b3), same as in Picture 6.

stations, among others, totally ice-covered. On the following day the weather became a little milder and it began to snow, and after a couple of days' mild weather i. e. in the evening of December 31, the wind shifted to S and increased to 3—4 Beauf. An air reconnaissance flight was sent up to ascertain the development of ice conditions. In the report made after the flight (N. 15) it was mentioned that the snow-covered ice reached from east to the line Jussarö—Paldiski, and new snow-free ice to the line Morgonlandet (west of Hanko)—Osmussaar. Both of these ice edges appeared during several winters; their origin was due to hydrographic conditions. The above-mentioned ice was formed on December 27 and snow had fallen on it during the following days. On December 31 this ice started to move and was pressured against the coast of Finland; pressured ice about 4 metres thick was formed off Porkkala, among other places. The snow-free ice was formed after the snowfall, i. e. on December 30 and 31, and thus was only a night or two old. In this new ice, it was mentioned, there were small openings 10—15 metres in diametre; these probably originated through the moving of the ice. Openings can also appear in

2

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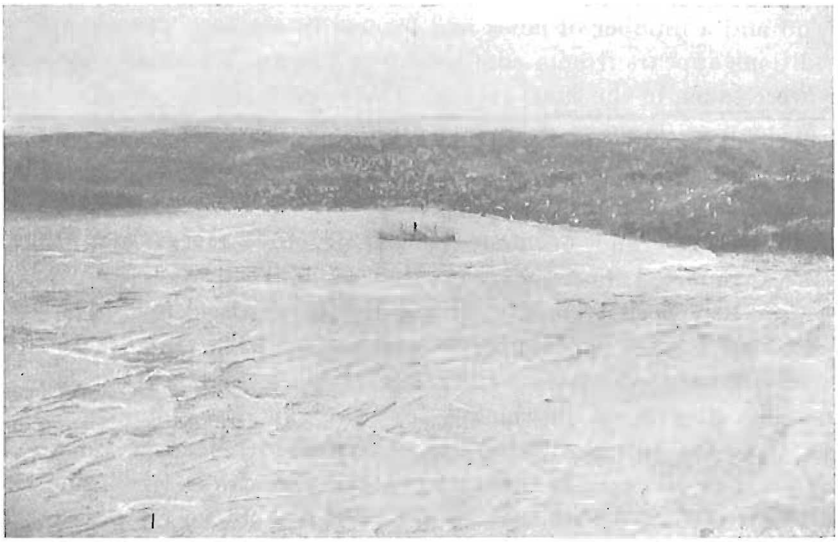


a b

Picture 8. Heavy uneven ice outside the skerries. (Gulf of Finland south of Kotka, 1942. II. 4. Air Force photo.)

As in earlier pictures there is a level fast ice edge close to the coast, near the vessel seen in the picture (b2). Offshore the ice is very uneven, full of ridges (a1) formed by the pressing of the ice. Abundant snow and snow drifts can be seen on the ice. No lanes are visible, but narrow cracks opened up occasionally though the ice was already quite thick. Cracks generally begin at the fast ice edge of the coast or at some supporting point such as a rock, shoal etc.

sea ice formed during calm weather in the region of the archipelago; they are popularly referred to as »breathing openings of the sea», or »openings for feeding» (ice report from the Ruotsalainen pilot-stage 1915. XII. 18, among others). However, in the region of the archipelago at least the formation of the openings appears to be influenced by the basin bottom and currents it forms, and this can hardly be used to explain the origin of the openings in sea ice.

22. On January 6 a strong outbreak of arctic air mass began to push outwards from the north southward over Finland, resulting in the formation of a ridge of stationary high air pressure over Scandinavia. By January 15 the outbreak of cold air had reached Germany, where the independent cold

air pool (»Kaltlufttropfen»), mentioned below, was formed. Thus a period of severe frost had begun.

At the beginning of the outbreak of cold air over the eastern part of the Gulf of Finland the wind was initially from N, and then varied, but was rather strong throughout. January 7 an air reconnaissance flight took off over the eastern Gulf of Finland. It found that the entire sea area was covered with fairly thick ice, but as a result of the wind the ice had been in motion and a number of lanes had formed in the ice. The change in the ice conditions appears from a comparison of Picture 7 with Picture 6. Both photos were taken in the same region. The view of the ice situation appears from the map of January 9 (Figure 30).

23. Ice had appeared in the northern part of the Åland Sea by January 9. The wind blew from N, slackening later, mostly E—SE. Icing continued on the Åland Sea and on January 16—17 the Märket and Understen lighthouses reported fast ice over the whole field of view. A »bridge of fast ice» had been formed over the northern Åland Sea. The ice was measured near Märket on January 16 and proved to be 5 cm thick. A week later, on January 23, it was 14—18 cm thick and a week later still, January 30, 26—35 cm in thickness. That this ice remained unbroken through the hard storms of the end of January (mentioned later) shows that »the ice bridge» over the Åland Sea can in cases like this be regarded as a part of the fast ice fringe surrounding the coast when the border has extended to its maximum.

24. Meanwhile the ice mentioned in the air reconnaissance flight report of January 1 moved from the western part of the Gulf of Finland to the northern Central Baltic. On January 16 ice covered the whole field of view of Utö Lighthouse, and on the sketch map of ice conditions drawn at the Institute of Marine Research on the same day the ice edge was shown along a line Tahkuna Point—Kökarsören (south of Kökar). The following day, January 17, ice had formed on the Swedish coast as well, mentioned e. g. in a Swedish flight report (N '15) as far out as 30 sea miles from the coast.

25. Peculiar to the period studied is the fact that the formation of ice occurred during frosty weather with a weak wind. The temperature was not even, however, and the frost increased from time to time to very hard. It was during these temperature minima that quick formation of the ice was observable. When the frost lessened and the weather generally grew more windy the ice on the open sea broke up and started to move. The extent of breaking-up of the ice depends usually mainly on its thickness, but additional factors were the wind force, its duration and direction, and the direction of the coast line of the sea basin. No major storm occurred, however, as is apparent from the above, until during the next weather period at the end of January.

B. DRIFTING OF THE ICE, 1942. I. 19—31.

26. The above-mentioned outbreak of cold air over Finland and on to Germany resulted in the development of a cold air pool (»Kaltlufttropfen») over the latter country. SCHERHAG (1948) reports on it:

»An arctic air mass, in the form of a closed upper low, had already advanced over Europe earlier; it had reached Finland on January 8 and on the 15th divided over Germany where one fork was driven to the North Sea on the south-west flank of a Scandinavian high pressure while another fork was caught by a central-Russian low pressure and remained there. On January 18 a smaller, independent cold air pool was formed over north-west Germany while the Russian dome, considerably reinforced on the arrival of another cold trough penetrating from the north-west, again reached out over Germany from across the Baltic. In a few days, however, it was pushed back eastward with the main mass. There it united with a low pushing westward from the interior of Siberia. This low reached the district of Moscow on the 23rd and on the day after the atmospheric space around Smolensk; on the date shown here (Figure 12) it was still perceptible above the Baltic Sea.

This surface low was accompanied, in the free atmosphere, by unusually low temperatures and a corresponding upper cyclone. When, the night before, it passed Riga the lowest temperatures measured to date above the European atmospheric space were recorded in several layers. . . It may be mentioned, further, that the average temperature of the 1000—500 mb layer was lower than that corresponding to the January average at the cold pole, which best illustrates the unusual intensity of this cold air pool.»

The map of relative topography 1000—850 mb has been drawn (Figure 13) to illustrate the unusual intensity of this cold air pool.

27. The development of the weather described above affected the development of ice conditions so that on the evening of January 19 the wind increased, in the Gulf of Finland and in the northern Central Baltic to strength 5—6 Beauf., N—NE. An air reconnaissance flight established that the ice was broken in the eastern Gulf of Finland, an area where the ice was already fairly thick on the open sea. But the breaking now, compared with that at the beginning of the winter, was restricted to narrow lanes and cracks only. The air reconnaissance flight mentioned that these narrow lanes and cracks had formed along the western coast of Suursaari and from the south end of Suursaari westward to Ruuskeri.

28. In the western Gulf of Finland and northern Central Baltic, where the ice was fairly new and therefore still thin, it began, on the contrary, to move, drifting away from the Finnish coast. It was considered unnecessary to carry out air reconnaissance flights in this region as regular reports on ice and navigation conditions were being received from the icebreaker »Jääkarhu» which was assisting there. It appears from entries in the ship's log (N. 10) that the edge of the open water, on January 19, was 17 sea miles from Utö, direction 190 degrees. The Finnish ship »Gottfrid», which arrived from the south on the same day, recorded that the ship's log had been removed by Bogskär Lighthouse because of the ice (N. 10), which was probably

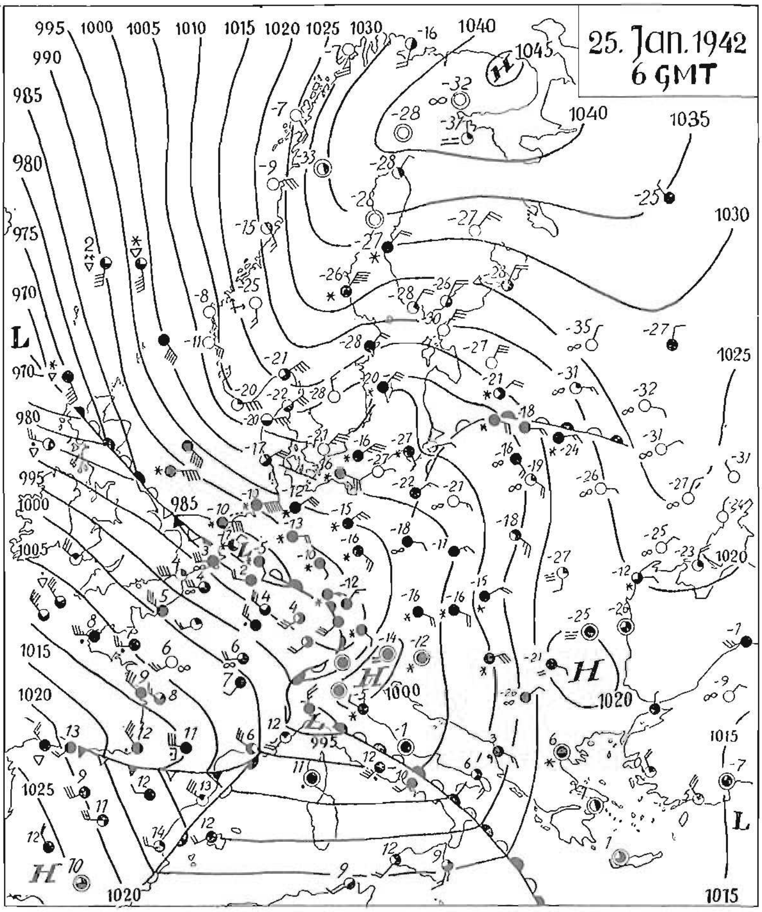


Figure 12. The arrival of cold air poo (»Kalttluftropfen») in Germany, Jan. 30 at 0800 (= 0600 GMT). (Synoptic weather map, sea level according to (SCHERHAG 1948).

sludge drifting outwards. The vessel did not meet heavy ice until 24 sea miles from Utö, direction 240 degrees. It is apparent that the outer edge of a drifting ice field is not even. Depending on the various structures of the different parts of the field they are generally set in reciprocal motion and the edge of the field assumes an uneven shape.

On the following day, January 20, although the wind calmed down its influence on ice conditions in the open sea of both the western Gulf of Finland and the northern Central Baltic was very considerable. The ice in this area had been set in motion, a fact of definite significance for the development that followed.

29. As in the weather development described above the air pressure gradient in Finland became high, which caused cold Siberian air to flow into

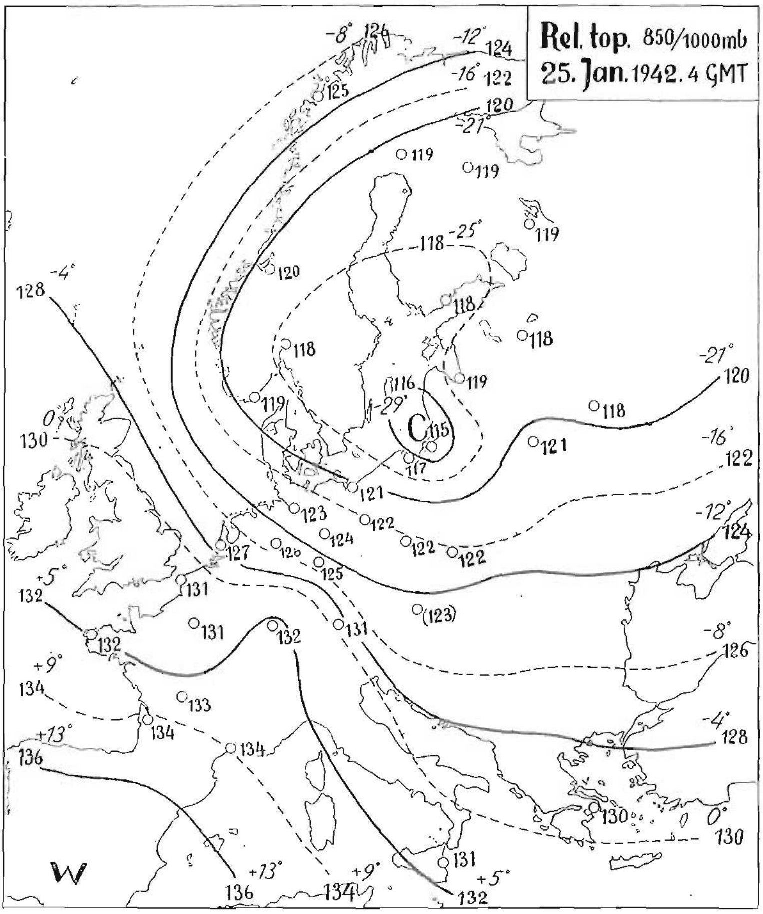


Figure 13. The place of cold air pool, Jan. 30 at 06 (= 04 GMT). (Map of relative topography, 1 000—850 millibar. The map shows, in addition to the relative heights of the air mass in 10 gpm, their average temperatures).

the Baltic area. January 22 the wind increased again, at first N—NW, strength 3—6 Beauf. The wind shifted in time to NE, January 24 increasing to a storm. The next day, January 25, the wind grew still stronger, reaching its maximum on January 26 when it was 9 Beauf. at times (report from the Swedish ice-breaker »Atle», among others). The strength of the storm is apparent from the fact that in the Bothnian Sea, off Öregrundsgrepen, the big Swedish icebreaker »Ymer» found it impossible to assist a convoy of four merchantmen southwards. She had to circle around them for nearly two days to prevent them from being nipped by big pressured ridges.

On the northern Central Baltic coast off Utö the increasing wind carried the drifting ice further west — Lågskär Lighthouse among other stations reported by January 24 already the presence of drift ice over the whole south field of view. Probably, however, the ice drifted close to Finnish territorial waters judging by the fact that the Bogskär area, further south, was reported open two days later when, on January 26, the »Helgoland» en route to Finland ran aground at Bogskär because of bad visibility.

On January 27, at 0120, the fact that the sea was very rough around Bogskär showed also that there was still open water when the »Jääkarhu» (N. 10) arrived to save the »Helgoland». It is further apparent that the Finnish »Ostrobotnia» which arrived from the south at 0840 met ice 20 sea miles from Utö; the vessel stopped to await assistance.

The accident to the »Helgoland» led to an air reconnaissance flight, and on January 27 it was established that a narrow lane, about 50 m wide, had begun in the western Gulf of Finland near Jussarö and continued westward along the fast ice edge past Bengtskär Lighthouse. This proved that the ice started to move in the western part of the Gulf of Finland. Additional proof of this came in a report from Estonia that a lane had opened in the south of the Gulf of Finland, west of Naissaar. No further details of the movement of the ice were obtainable as the reconnaissance flight had to be abandoned because of bad visibility near Utö. It is remarkable, though, that no wide lane was observed. It proves that the drift ice field of the open sea does not move as a whole but in small sections. Narrow lanes open through the ice field and »feed» the open sea with ice floes.

The same day, January 27, when the wind had shifted to N, the ice began to shift further southward from the vicinity of the Finnish coast. Salvage work at Bogskär had to be interrupted for some time when the ice reached that area. The icebreaker »Tarmo» also arrived on the same day to lend assistance (N. 10). In spite of the obstruction of ice the salvage operations were successful in that both crew and cargo of the »Helgoland» were saved. The vessel itself remained wrecked on the ridge of rock.

When the ice began to shift southwards the »Ostrobotnia» waiting in the ice edge off Utö moved more to the south and finally decided to go to Visby. But in the vicinity of the northern point of Gotland it observed that the sea between the Swedish mainland and Gotland was filled by heavy ice floes. The »Ostrobotnia» turned back to the north and reached a point 25 sea miles SW of Bogskär. Then a German ship, probably the »Alkaid», was observed NW and the »Ostrobotnia» took a course on it. But it had to go through a big ice flow and in the middle of this flow it became icebound and finally, on January 30, stopped there. The »Alkaid» reached Bogskär January 27 (N. 10).

The »Jääkarhu» left Bogskär on January 28. There was no mention made of obstacles encountered on the return journey to Turku, even off Utö. The »Tarmo» on the other hand was very much slowed up by ice when on January 31 it moved off to assist the »Alkaid». The obstruction increased the nearer the »Tarmo» got to Utö. Finally, on February 1, it stopped in heavy ice about 5 sea miles south of Utö to await the arrival of the big »Jääkarhu». The latter icebreaker arrived the same day, but in the work of assisting the »Alkaid» to Utö, before they reached the fast ice area, the »Jääkarhu» had to plough through heavy pressured ice and was forced to stop because of a faulty pump. This had occurred when bits of ice from heavy pressured ice were sucked into the bottom scuttle — more than 6 m under the sea surface — with the cooling water. This gives some idea of the thickness and amount of drift ice that had been pressed against the skerries in spite of a slight increase of the wind — in the morning of January 29 it blew from SE 5 Beauf. Navigation via Utö thus came to an end.

30. There was quite thick ice off the Swedish coast on January 22, e.g. level with Hävringe and 12—17 sea miles offshore (Figure 31). The same day, when the wind got up, this ice started to move. On January 24, according to the ship's log entries made by the Swedish icebreaker »Atle» (N. 10), the ice off the Hävringe and Häradskär lighthouses was drifting in a SW direction at a speed of 2—3 knots, which is a considerable speed to attain in the open sea (Pälsi 1924, d'Allinge 1932, Richter 1933). Such speeds have only rarely been observed, e.g. in scattered ice by Bogskär 1909. IV. 2, 3 knots, the wind being 7 Beauf. N.

On the day of the log entry mentioned above, January 24, vessels in the ice in the vicinity of Hävringe and Häradskär ran the risk of drifting onto shoals, and the Swedish icebreakers »Atle» and »Isbrytare II» had to come to their assistance and lead them out from the vicinity of the skerries. But conditions changed quickly. On January 25 already heavy floes appeared between the Swedish mainland and Gotland. Some of these floes were encountered by the »Suomen Poika» the same day at 0940, 25 sea miles north of Stenkyrkehuk (in northern Gotland), and the ship returned to Visby harbour. Other ships too put into Visby and Oxelösund, but some 25 vessels remained icebound in the drifting ice and had to wait for assistance from icebreakers. One of the last vessels to reach Visby harbour was the Finnish ship »Karin Thorden». She had come up from the south and met en route, at about the southern point of Öland, sludge and even ice floes. Off Visby she was nipped in heavy ice and only succeeded in reaching the shelter of harbour with the assistance of the pilot ship.

January 27, when the wind had shifted to N, the ice drifted away from the coastal sector between Svenska Högarne and Landsort and ice conditions in these areas became easier for navigation. It was reported that a weak German ship from near Kopparstenarne succeeded in getting to a point off Landsort without assistance. But further south, around Hävringe and Häradskär, the ice drifted coastwards and pressured ice was formed. On the next day, when the wind dropped, the velocity of the ice drift diminished and pressure in the ice field weakened. But it is noteworthy that it did not cease. The »Atle's» ice log records that the ice pressure continued at Hävringe and Häradskär even after the wind had calmed down on January 30. The captain of the »Ostrobotnia» which was still icebound 25 sea miles SW of Bogskär said that »there was very severe pressure when it was calm. The vessel, however, was held very well in the middle of a large ice floe. Ice pressure continued even when the wind had shifted to SE on January 31». It is interesting to find that a radiotelephone report on January 31 mentioned that the ice continued to move in the same direction as formerly because of the sea current.

31. An extension of the ice seawards from the coast was observable in the southern Central Baltic during this period. While vessels were still anchored in the open water off Swinemünde on January 18 the Finnish ship »Vega» reported having encountered thin ice on her way south about 6 sea miles north of Arkona on January 20 at 2200, and heavy drift ice closer to Swinemünde. Four days later, on January 24, the »Ostrobotnia», mentioned before, observed outside Swinemünde ice over its whole field of view. On January 25 the wind was ESE 5—6 Beauf. and the ice started to move, drifting away from the German coast. The »Ostrobotnia» travelled in open water eastward along the German coast and took a course northwards to the open sea off Jershöft.

The extraordinarily hard frost during the next days resulted in the freezing process continuing fast. A remarkable occurrence was observed in Danish waters on January 25— the forming of an »ice bridge» across Öresund at Ven. On January 31, at the end of the period now under review, freezing in the southern Central Baltic had progressed so far that, according to a Swedish air reconnaissance flight report (Figure 5), heavy unbroken ice was observable on the German coast and, some 35 km or 20 sea miles further out, thin ice. The central part of the Baltic remained open.

32. Characteristic of the period studied is the breaking-up of the ice on the open sea by the stiff wind and its drifting westwards from the Gulf of Finland. This moving, particularly the heavy floes, is depicted on a map (Figure 14) drawn from reports available to the author. It appears from the map that the heavier floes that had moved between the Swedish mainland and Gotland came from further north, off the archipelago of Stockholm. Perhaps these ice floes had come from as far away as the sea area off Utö and from even further east.

The number of drifting floes was not large enough, of course, in the initial stages to fill the entire sea area west of Gotland (»Gotland Sea»). But drift ice is of great importance. It passes over the sea water not totally cooled by this time; it leaves behind small pieces, point congelation. So that in the hard frost — an average of —20°C — new ice, thickening quickly, was formed continuously in the broken lanes, even on the wider areas of open water This helps to explain the presence of the immense ice masses in the western sea reaches of Gotland, ice which filled the area with surprising speed and led to the dramatic navigational developments described above.

It is not in fact rare for ice to be driven westwards in the Gulf of Finland, and even in the northern Central Baltic area (*cf.* Figure 2). But that it should happen so early and be so clearly traceable is uncommon. The same reason — ice being driven westward — causes the emptying of the Gulf of Finland of ice in a very short time in the spring. This would appear to prove that the Gulf of Finland is an offshoot of the Central Baltic not only in the stratification of its water mass and its current conditions (WITTING

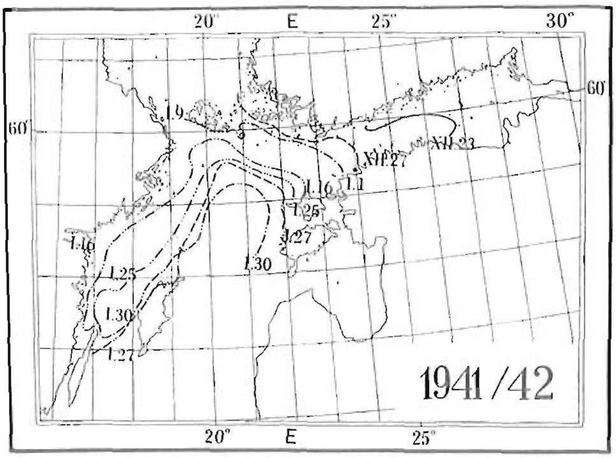


Figure 14. Ice edges in the northern Central Baltic at consecutive dates in the ice winter of 1942.

1911) but also in the development of ice conditions. On the other hand both freezing and melting occur in the hydrographically nearly independent Bothnian Sea and Bothnian Bay themselves, apart from small exchanges with other sea regions.

C. THE TIME OF FINAL FREEZING OF THE CENTRAL BALTIC, 1942. II. 1—7.

33. In the development of the weather, as reported by SCHERHAG (1948), the high air pressure formed in Scandinavia towards the end of January remained very nearly unchanged early in February. The frost continued hard, whereas the wind was not very strong. Formation of new ice was very abundant. On January 31, in the eastern area of the Gulf of Finland, as mentioned earlier, the ice was unbroken. An air reconnaissance flight on February 4 confirmed this. The ice had by then grown heavy. The situation can be seen from a comparison of the air photo taken that day (Picture 8) with the air photos taken earlier in the same region (Pictures 7 and 6).

But even ice fields as heavy as this can break up. The air reconnaissance flight flown on the following day, February 5, noted a 0.5 m wide crack in the ice by the west coast of Suursaari, and a couple of days later another flight observed a narrow crack to the south of Someri and somewhat further out from the Finnish coast running in a NE—SE direction. The cracks described above had probably been opened up in the evening of February 4 when the wind was E—SE, 4 Beauf., but the main reason for their appearance may have been the rapid sinking of the sea level (HELA 1948).

34. In the Åland Sea, in the northern part of which a small »bridge of fast ice» had been formed at Märket and Understen in the middle of January, fast ice had formed in the southern area as well — the entire area of the field of view of the observation station on Lågskär was reported covered in fast ice January 30. »The ice bridge of the Åland Sea» thus extended southward. Later, when the central Baltic ice started to move, it was established

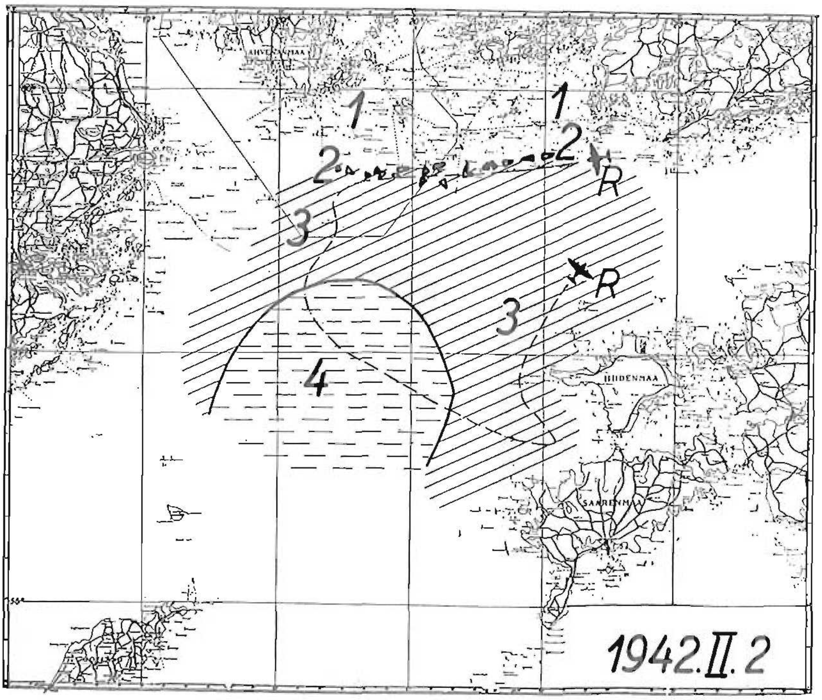


Figure 15. Ice reconnaissance flight, 1942, Feb. 2, 1000—1325, over the northern Central Baltic.
Explanations: 1 = fast ice, 2 = small refrozen lanes and openings, 3 = continual ice cover, with small refrozen lanes and openings here and there, 4 = ice area with lanes and fairly large openings. No uninterrupted open water was observed in the whole district reconnoitred. R = flight route.

that the fast ice extended about 12 sea miles south of Lågskär, with its edge along the line Kökarsören — position of the lightship »Svenska Björn» (Figure 17). At the same time the fast ice bridge in the northern area of the Åland Sea spread. According to air reconnaissance flights performed later it extended from the Tartarus shoal (= about 6 sea miles north of Sälskär Lighthouse) to the Finngrundet shoal. The expansion of the fast ice bridge to cover the southern area of the Åland Sea also seems to have occurred previously in such extremely rigorous winters, and trips were made over the ice from Lemland, the south point of Åland, right across to Stockholm (FAGERLUND 1925).

35. An air reconnaissance flight from Finland was flown over the northern Central Baltic on February 2. Open water was no longer visible, even though the flight extended quite far south (Figure 15). Three days later, February 5, another air reconnaissance flight could not find any change in the edge of the ice areas in the northern Central Baltic (Figure 16). In the central parts of the sea, where thinner ice had been reported by both flights,

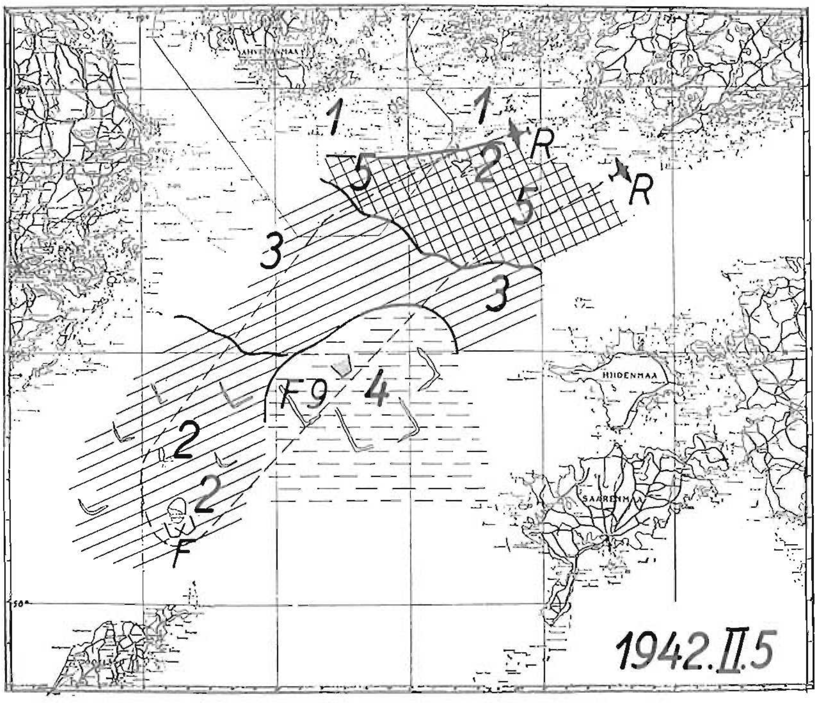


Figure 16. Ice reconnaissance flight, 1942, Feb. 5, 0940—1345. Explanations: 1 = fast ice, covered by snow, 2 = openings. North of Gotska Sandön an area of open water, originated with ice moving under SE wind, 3 = fairly even ice, covered by snow, 4 = weaker even ice, F = the objects photographed, F9 = Picture 9 (in the text), R = flight route.

there were big fissures. As can be seen in the photo taken on the last flight heavier floes occurred, originating in the Gulf of Finland (Picture 9). Most of the area, however, was covered in rather thin ice, proving that this part of the Central Baltic had been the last to freeze over on January 29—30.

36. In the southern Central Baltic a Swedish air reconnaissance flight had established on January 31, as mentioned above (Figure 5), that the ice on

Picture 9. A *fairly recently-formed ice cover.* (Northern Central Baltic, 1942. II. 5. Air Force photo.)

In the lower part of the picture (1—3) can be seen fairly recently-formed ice snow-blotted. The thickness of ice, about 10 cm, had been established from the edge of the black opening visible in the middle of the photo (b2). This confirms the earlier ice reconnaissance flight report that this part of the northern Central Baltic froze later than the other parts, viz. about January 30.

To the right of the hole is a white ridge of pressured ice with a typically meandering course (c2—d1—d2). Both opening and ridge establish that the ice is in motion.

In the top of photo (a4—d3) is a dark lane. Close to this, on the left of the photo (a3), are white, heavy floes which probably drifted there earlier from the Gulf of Finland.

the German coast at Kolberg extended about 20 sea miles offshore. On February 2 an air reconnaissance flight over the same fairway established that the sea was frozen from the German coast to at least level with Bornholm. Observation northward of this point to the Swedish coast proved impossible because of cloud, but according to reports from observation stations on the south coast of Sweden and from Bornholm this area too was covered with ice on February 2—3. This is confirmed by the Danish air reconnaissance flight also (N. 15).

Thus the southern Central Baltic had an ice shield extending from the west at least as far up as level with Bornholm in the east, and open water could only exist further east in the Central Baltic around the basin of Danzig and northwards from there. It was reported from Germany (BÜDEL 1943) that by February 5 the entire Central Baltic was ice-covered; this assertion was probably based on the German air reconnaissance flight performed at that time.

The following day, February 6, hard frost and calm weather prevailed throughout the Baltic, continuing to some extent on the subsequent days. This resulted in the ice in the Baltic becoming considerably heavier.

37. Characteristic of the period studied was formation of ice in climatic conditions distinguished by fairly calm weather and temperatures an average of — 20°C. The entire Central Baltic was ice-covered and the ice that had formed last had time to grow fairly heavy before storms of any severity occurred. A consequence of this was that the shift of ice to the southern Central Baltic, especially west of Bornholm, was limited, and ice conditions did not become nearly as difficult as during the winter of 1947.

D. MOVEMENT OF THE ICE, 1942. II. 8—17.

38. At the end of the first week in February a centre of low air pressure had moved from the West to Norway, a consequence of which was that the wind which had been weak increased to 3—6 Beauf. S—SW, on February 8. This change in the wind was followed by a fairly sudden rise in the sea level, about 15 cm, experienced throughout the Gulf of Finland from Hamina to Degerby in Åland during the day in question (HELA 1948). This resulted in an increase in the water in the Gulf of Finland and clearly had some influence on the ice field. An air reconnaissance flight the next day, February 9, established that the cracks by Suursaari, reported earlier, had been pressed together and that water had risen on to the ice above them.

39. A Swedish air reconnaissance flight on February 8 reported from the northern Central Baltic that a lane had opened off Södermanland parallel to the coast about 25 km or 14 sea miles offshore from Häradskär Lighthouse (LILJEQUIST: *Isvintern 1941—42*). One day later, on February 9, the wind shifted more to the W—NW and the lane widened. On February 10 an air reconnaissance flight from Finland established that the lane had actually begun off Utö and started in a SW direction, about 5 sea miles wide, to outside the Swedish archipelago (Figure 17). In an oblique air photo taken at about 2 000 m a lane of this width even looks like a rather narrow, dark ribbon — see upper part of the photo (Picture 10). The picture also shows smaller lanes. These were formed during the movement of the ice field and have divided it into sections, even into floes. Movement of

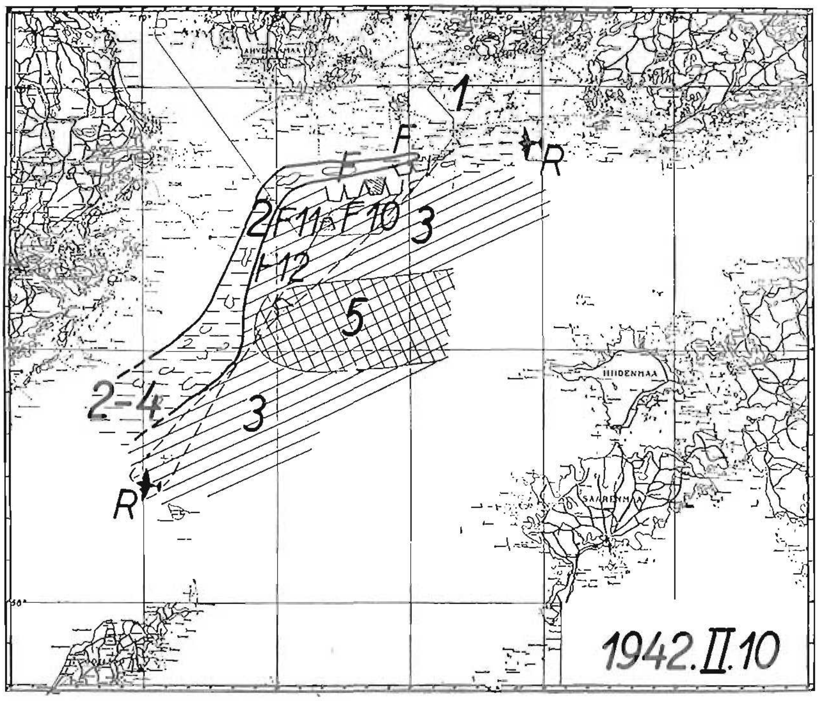


Figure 17. Ice reconnaissance flight, 1942, Feb. 10, 1045—1420. Explanations: 1 = fast ice, 2 = broad lane, beginning from Utö and running along the »extended» fast ice edge in a SWerly direction. The lane is not completely open but has new ice and large open water areas, 3 = thick unbroken ice cover, 4 = new ice in the lane, 5 = pressured ice, F = objects photographed, F 10, 11, 12 = Pictures 10, 11, 12 (in the text), R = flight route.

an ice field does not generally lead to the formation of major open areas. These smaller lanes can thus be called the »feeding lanes» of the ice field. The lanes are already partly covered with thin new ice.

40. In addition to the formation of lanes pressure occurs when the ice field moves. The biggest pressured ice masses form against a coast or some obstruction lying to windward of the field. Thus hummocks of ice had formed on the shores of Gotska Sandön, stated in a report from Sweden to be extremely high. Bogskär shoals constitute a similar obstruction to the moving ice field. They were photographed from the air on the February 10 (Pictures 11 a, b).

Ice conditions around Bogskär must have been almost similar to those in the photo, from the descriptions given, in the winter of 1889. In that year ice was seen on the sea for the first time on February 8, and during the frost of —10° —13°C it rapidly grew heavier. On February 13 the ridges were 25 feet or 7—8 m high around Vestra Bogskär, where the lighthouse was located, but even then they were 4—5 fathoms or 7—9 m from the rock itself.

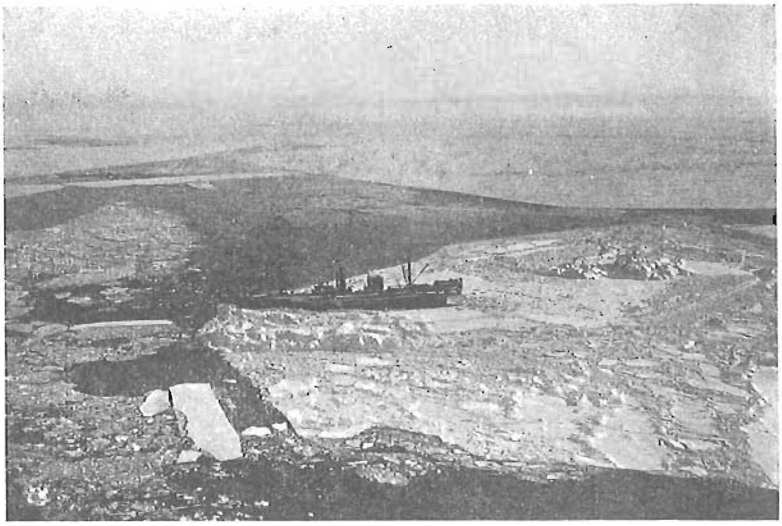
Picture 10. A lane parallel to the coast. (Northern Central Baltic south of Kökar, 1942. II. 10, 1205 hours. Height 1 200 m, direction N. Air Force photo.)

This photo was taken north of Bogskär Lighthouse, looking N towards the Finnish coast. Kökar is just visible as a dark spot in the upper right of the picture (c5). The lane, which is 5 sea miles wide and opens off the fast ice edge is visible as a dark, horizontal stripe in the middle of the photo (a4—c4).

The light figures in the foreground are pressured ice formations (a1—b1—c1.) The dark zigzag lines (a3—c2) are typical lanes appearing in the ice when it moves. During a frost these lanes rapidly cover with new ice and the total area of the ice field increases. Thus these can be called the »feeding lanes» of the moving ice field.

There was a dramatic change in the development of these conditions on February 13 in 1889. The wind shifted to SW and continued to increase in force. On the following day it was raging at 10 Beauf. The hummocks around Vestra Bogskär were washed by waves which reached as high as the top storey of the lighthouse. The iron plates of the outer walls of the ground floor and the first floor of the lighthouse were damaged by the storm and water poured in through the gaps. According to the lighthouse crew of the time the heavy swell caused the damage (Andersin), but it seems probable that the ice played some part in the accident.

The lighthouse crew, forced to remain in the upper part of the tower, were afraid that the lighthouse would collapse if the storm continued. On the next day, however, February 15, the storm began to calm down and from then until April the sea was covered with drift ice, which stilled the swell and was regarded as their salvation by the lighthouse crew. Typical of the conditions of that time is the fate of the crew. As always in winter they had to remain isolated in their quarters and news of the damage to the lighthouse was not received until April 19, when the »Express», a small



Picture 11a. Pressured ice ridges and hummocks. (»Helgoland» aground near Bogskär Lighthouse in the northern Central Baltic, 1942. II. 10, 1200 hours. Height 50 m, direction ESE. Air Force photo.)

Western Bogskär proper, which formerly had a habitable lighthouse and is now an automatic Aga-lighthouse, is visible right (e4). The rock, which is snow- and ice-covered, is about 4 m high. This ice is even, probably formed by the spray from the waves.

In the immediate vicinity of the lighthouse there are some hummocks but general the ice is level, as it is said to have been in the winter of 1889. Further out the rock is surrounded by a belt of hummocks. This can be seen more clearly from the enlargement (Picture 11b) and by comparing it with Picture 2 taken in summer.

On the shore (b1) where the »Helgoland» ran aground is a big pile of ice. It was evidently formed during the moving of the ice field (N. 39) when a wide lane was opened off e. g. Utö and Lågskär lighthouses.

Open water has appeared to the north of the ridges. Small, drifting ice cakes (a4) and very thin ice rind are visible there (b4).

but successful Finnish winter steamer made the first trip through the open water from Hangö to Stockholm.

41. A photograph (Picture 12) was taken during the air reconnaissance flight of February 10, showing the »Ostrobotnia» — icebound as has already been mentioned — towards the end of January about 25 sea miles SW of the Bogskär Lighthouse. The photo shows pressured ice in the ice field itself with no real shoal or other obstruction visible. It may be mentioned that these pressured ridges by the vessel had formed before the »Ostrobotnia» had got icebound. Then the ice by the vessel remained unbroken, but about 2 km behind it very heavy pressured ridges were formed.

42. The wind was stiff between February 10 and 15, generally SE—SW. Ice from the open sea started to drift northwards, and a Swedish air recon-

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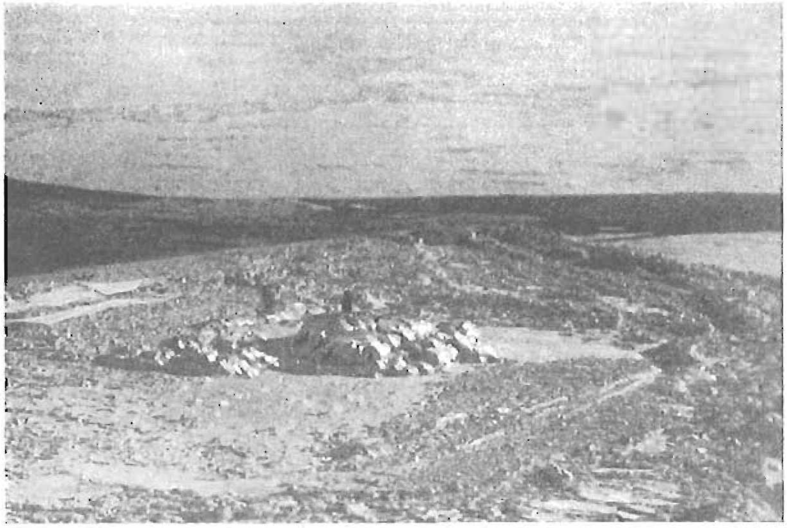

c d e f g

Picture 11b. B o g s k ä r L i g h t h o u s e in rigorous winter, 1942. II. 10. (An enlargment of Picture 11a.)

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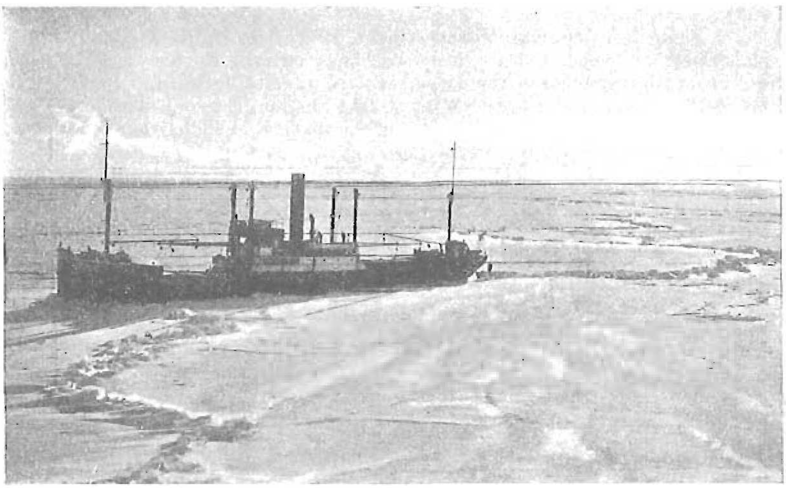


a b c d

Picture 12. P r e s s u r e d i c e w i t h r i d g e s f o r m e d d u r i n g t h e m o v e m e n t o f the i c e f i e l d. (»Ostrobotnia» icebound in the northern Central Baltic about 25 sea miles SW of Bogskär Lighthouse 1942. II. 10, 1305 hours. Height about 30 m, direction SE. Air Force photo.)

The ridges of pressured ice visible in the photo (a1—a2 and b2—d2—c3) are very typical of such formations when ice is in motion in the open sea. An idea of the size of the formation can be obtained by comparison with the men standing close to the ship's stern and on top of a ridge. The ridge appears to be a good metre above water level, which is abnormally high. The general course and shape of the ridges is more clearly seen in Pictures 13—14.

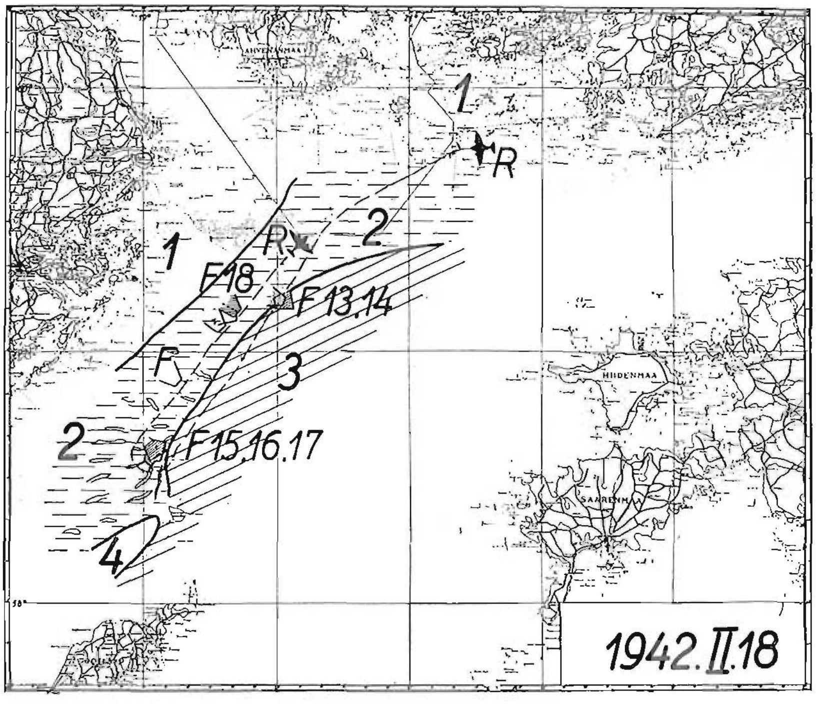
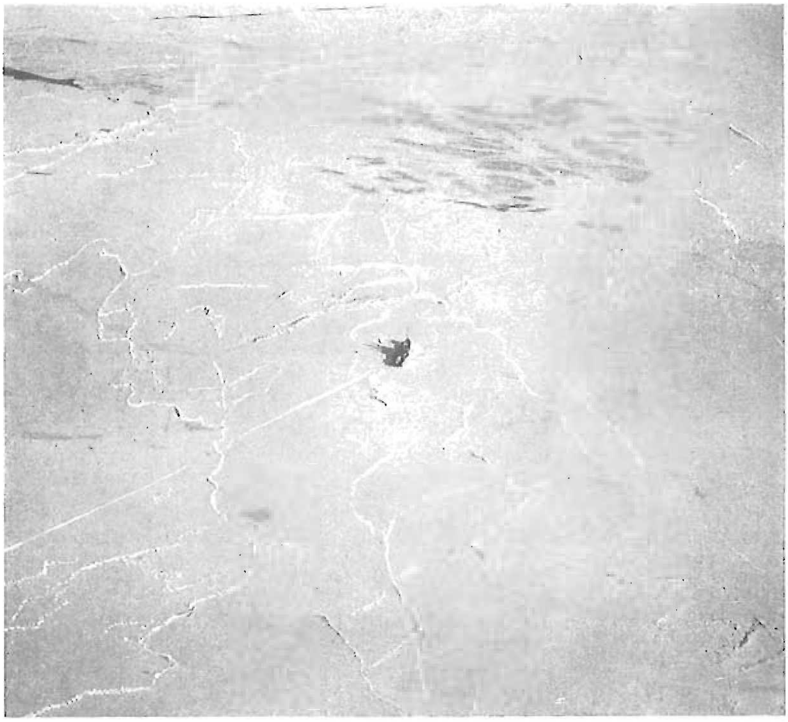


Figure 18. Ice reconnaissance flight, 1942, Feb. 18, 1000—1430.
Explanations: 1 = thick fast ice, 2 = wide lane, covered by new ice, with minor lanes. From Kopparstenarne the lanes seem to radiate outward, 3 = thick continuous ice, 4 = open water area SW of Gotska Sandön, F = objects photographed, F 13—17 = Pictures 13—17 (in the text), R = flight route.

naissance flight report on February 11 mentions broken ice from the German coast to off Landsort. This flight thus covered part of the area of the Central Baltic as well, an area on which no ice reconnaissance flight reports had been made (excluding the possible German reports) since the freezing of the entire Central Baltic.

On February 18 an air reconnaissance flight went up from Finland over to the northern Central Baltic (Figure 18). It established that the ice round the »Ostrobotnia» was several square kilometres in area and unbroken, and that the vessel itself was undamaged (Pictures 13—14). In general, however, the ice field had broken up as can be seen from air photos taken on the same flight (Pictures 15—17).

When the ice field was set in motion northwards, the old heavy drift ice far out to sea was seen to be shifting closer to the zone of skerries on the coast, and the young ice off Utö and Lågskär covering the wide lane parallel with the coast was observed to drift together and build up ice ridge after another. They proved so difficult to penetrate that on



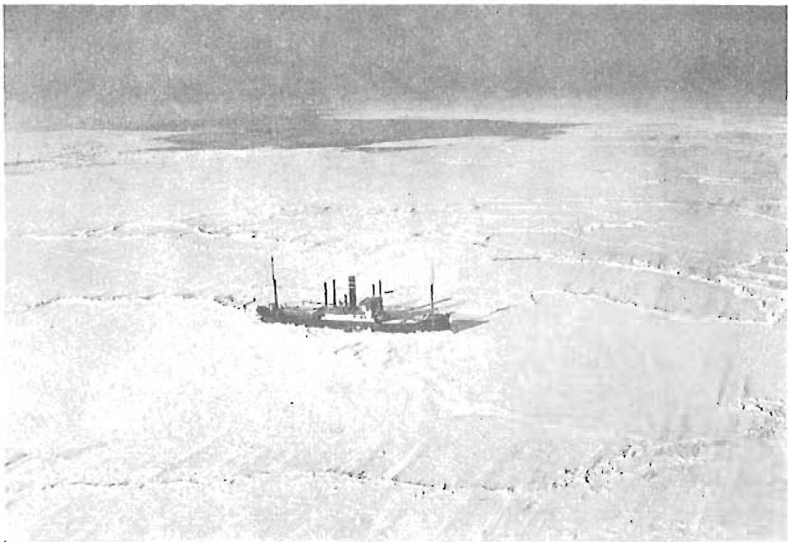
Picture 13. A field of pressured ice. (»Ostrobotnia» icebound in the northern Central Baltic about 25 sea miles of Bogskär Lighthouse, 1942. II. 18, 1200 hours. Height 1 200 m, direction NE. Air Force photo.)

The ridges of pressured ice form a sort of fairly regular network. The two main directions in which they radiate are E—W (a4—c1) and, with some exceptions, at right angles to this direction (a1—b2). Thus the level »plots» (d1) left between the pressure formations are also regular.

In the immediate vicinity of the vessel the ice field remained immobile and unbroken. The closed channel is seen aft of the ship (a2—c3). It may be mentioned that lanes were formed further out in the field on February 10—15. Some of them can be seen in the upper part of the photo (a5).

February 20 when the icebreakers »Jääkarhu» and »Sisu» tried to reach the sea from Utö they only made 12 sea miles in two days.

43. The ice from the Central Baltic had started to move during the period under study as a result of the winds blowing from various directions. The picture revealed by air photos taken during this period is similar to the regular picture of events when ice starts moving, e.g. during an earlier period when the ice drifted from Utö and Bogskär southwards along the Swedish archipelago. The ice fills breaks, lanes appear, and where the field encounters an obstruction — even within itself — the ice drifts together



Picture 14. A field of pressured ice. (The vicinity of the »Ostrobotnia», 1942. II. 18, 1205 hours. Height 100 m, direction NNW. Air Force photo.)

The centre of the photo (a1—c1, a2—c2, a3—c3) shows how regular pressured ice formation can be on the open sea. Similar regularity can be observed in other parts of the picture too. The ridges in the centre of the photo formed before the »Ostrobotnia» became icebound, i. e. on January 27. The ship has stopped by a big ridge.

A wide, dark lane can be seen in the upper part of the picture (b4). This part of the system of lanes formed on February 8 and the following days. The unbroken ice (a1—a3), many square kilometres in total area, remained in this state until the beginning of March and thus preserved the vessel.

and pressure occurs. During the time it moves the ice field therefore is exposed to a series of mechanical occurrences, though these events follow a certain regular course. The sequence of events can be summarized as follows:

— when the ice field drifts offshore cracks and lanes open up which divide the field up into floes. On the other hand pressured ice forms against the coast on the leeside of the field or against other obstructions, and in the ice field itself as well.

— when the wind begins to shift, or as a result of the various speeds at which the different parts of the field are drifting, relative movement within the field of its different parts can occur. As a result of this the ice field becomes further broken-up and, depending on the wind, can be »ground» into small pieces.

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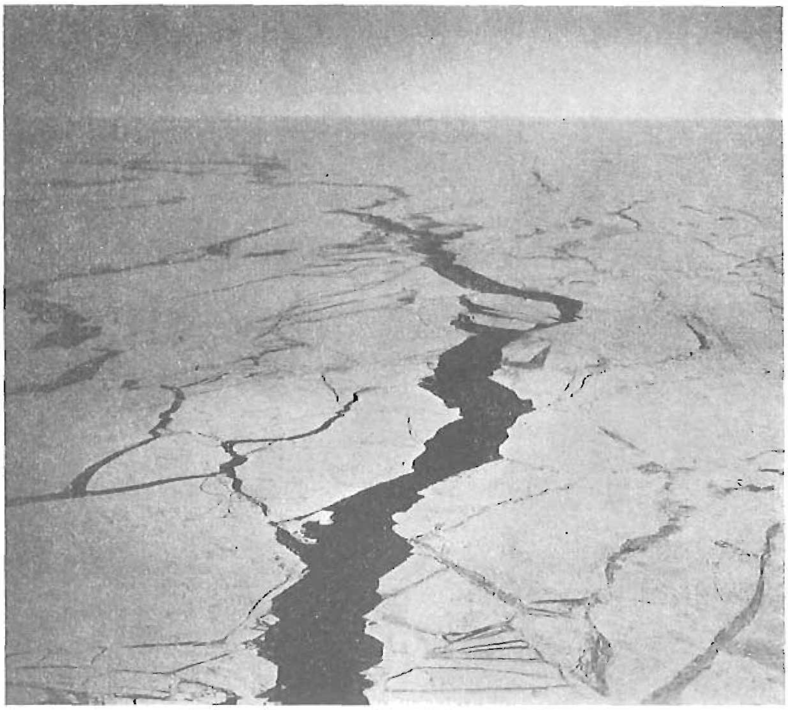
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a b c d

Picture 15. Lanes broken in the ice field. (Northern Central Baltic, in the vicinity of Kopparstenarne, 1942. II. 18, 1230 hours. Height 1 200 m, direction W. Air Force photo.)

The 4—7 Beauf. S wind of February 12 both pressed the ice field against the Archipelago and broke it up, forming cracks in it. Two days later, when the wind had shifted to NE, the cracks extended to the lanes seen in the photo. At the left of the photo (a2) the lanes have grown fairly wide; on the right of the picture (d2) it can be seen that they have only just opened up and are therefore narrow. The typically meandering course of the wide lane (b1—c2) is in part due to the varying structure of the ice field.

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Picture 16. L a n e s b r o k e n i n t h e i c e f i e l d. (Northern Central Baltic in the vicinity of Kopparstenarne, 1942. II. 18, 1233 hours. Height 1200 m, direction N. Air Force photo.)

Ice fields on the open sea of the Baltic are not at all homogenous in structure, e. g. lower down on the right of the picture (c1) is a darker area. This is thinner ice formed in the »feeding lanes». The meandering course of the broken lanes owes its character to this varying structure of the ice field and to the influence of the various winds. The twisting lanes in the left of the picture (b2) appear to indicate that the different parts of the ice field can be twisted in relation to one other during the movement of the ice. The almost straight lane in the middle of the picture (a4—c3) is full of sludge and ice cakes, in addition to which new ice has formed at the open points.

(Pictures 16—17 are of the same region and the corresponding points are: Picture 16: b2 — Picture 17: c3.)

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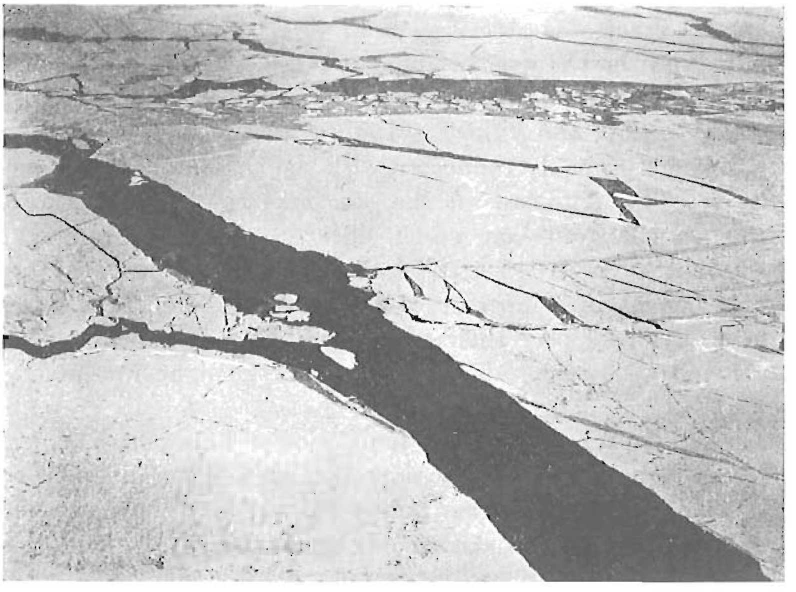


a b c

Picture 17. L a n e s b r o k e n i n t h e i c e f i e l d. (Northern Central Baltic, in the vicinity of Kopparstenarne, 1942. II. 18, 1235 hours. Height 1 200 m, direction NNE. Air Force photo.)

The wide strait in the middle of the picture (c1—a3) has formed as a consequence of the major shifting of the ice field and its division into vast areas. The short lanes seen in the middle of the picture (b2) were formed as a result of stresses within the ice field itself, i. e. when the originally almost parallelogram-shaped ice field was pressed between two more extensive ice areas it broke into floes along the lines of these lanes.

E. THE ICE GROWS THICK, 1942. II. 18—22.

44. February 18—22 the prevailing weather for almost the entire Baltic region was frosty, the wind was quietening down.

The ice in the eastern part of the Gulf of Finland had begun to crack at this time. A crack was observed on an air reconnaissance flight on February 17. It ran from the west of Suursaari to Kaunissaari (west of Kotka). Another crack was observed on February 19 to the south of Someri running in an E—W direction, and a third to the west of Lavansaari running N—S. These cracks were probably connected with the changes, small as they were, in sea level. The tendency of the sea level to sink and the currents caused by such changes — on which, unfortunately, there are no records available — must be regarded as the main causative factors in the apperance of cracks. Changes in temperature and in sea volume arising from the main causes obviously play their part in crack formation. The change in temperature in the day time (about—6°C) and in the night time (about—13°C) was about 7°C.

45. The lanes opened in the preceding period in the northern Central Baltic were covered during this hard frost period with, naturally, new ice. Ice formation was observed at some points by the air reconnaissance flight mentioned above which was carried out on Fenruary 18. The forming of new ice can be seen in a photo taken on that occassion (Picture 18). On February 21 a Swedish air reconnaissance flight also reported an ice field between Gotland and the Swedish mainland broken only by a 100—500 m wide lane on the coast running in a NE direction from Arkö past Landsort (LILJEQUIST). A Finnish air reconnaissance flight on the following day, February 22, established that the lanes in the northern Central Baltic were finally frozen tight. The development of the i c e c o n d i t i o n s had thus reached one of its p e a k p o i n t s (Figure 32).

46. With the considerable thickness attained by the ice of the Baltic some »bridges» of immobile ice were formed, although they only appear from the reports of the period following. Thus from the Swedish coast to Gotland, on February 24, a 1—2 km wide lane was reported on the Swedish coast off Landsort and Arkö. Apparently this lane continued southwards as far as the northern point of Öland in much the same way, as it was reported by a Swedish air reconnaissance flight on March 3. The same flight reported the ice between the northern point of Öland and the south of Gotland to be whole, though a new lane had started from the middle of Öland southwards. Also on March 3 the Finnish icebreaker »Sisu» reported fast ice from a point 30 sea miles SSE of the northern point of Öland. Thus it can be concluded that a »bridge» of immobile ice had formed between the south of Gotland and north of Öland. This had occurred earlier during severe winters only, last in the winter of 1838 when the mail was carried over the ice from Visby to Öland (SPEERSCHNEIDER 1915).

Picture 18. The lanes opened up in moving sea ice are coverd over with new ice. (Northern Central Baltic, 1942. II. 18, 1210 hours. Height 800 m, direction NW. Air Force photo.)

In the middle of February the ice field of the northern Central Baltic sea was broken up by stiff winds, as can be seen from earlier pictures. The hard frost resulted in new ice forming over the lanes. The ice rind formed during the wind seems to have piled up against a heavy floe, evidently forming the striped area in the lower left of the picture (a1—a2). The rest of the lane was probably coverd a little later and seems now to be full of circular-shaped fragments. This kind of new ice structure can be seen quite clearly at the edge of the above-mentioned striped area (b2), where a lane had existed recently.

In spite of the decreasing wind the ice field is in a state of constant motion, judging by the new lanes formed (a3—a4) and the rafting of new ice. The latter phenomenon can be clearly observed in the right of the picture (c3, c4) between heavy snow-covered ice floes.

A similar »fast ice bridge» was to be found further south, extending from the Swedish coast to Bornholm. Such a »bridge of fast ice» appears only in very severe winters. It was possible to cross the ice on foot in winter 1838. But for the channels left by the icebreakers, it would, as SPEERSCHNEIDER (1927) points out, have been possible in the winter of 1893. It is probable that the fast ice bridge in the winter 1942 was formed on February 19. The Hammeren Lighthouse on Bornholm reported fast ice in its field of view from that day (Baltic ice code = 67) and Simrishamn on the Swedish coast reported at the same time that the situation was unchanged, i.e. heavy pressured ice (Baltic ice code = 84). »The Bornholm fast ice bridge» must have been very narrow since later on March 2 Hanö (east of Simrishamn) and Sandhammaren (west of Simrishamn) reported that the ice was broken in their field of view.

47. Ice conditions became difficult off the Pomeranian coast at the end of February. On February 21 a Swedish air reconnaissance flight reported a narrow fast ice edge off Kolberg followed by a 40 km or 22 sea miles wide zone of drift ice and pressured ice, and finally unbroken snow-covered ice as far as the Swedish coast (LILJEQUIST). Further west, off the German coast, a wide area of immobile ice apparently existed since, as late as March 11, when the »Sisu» was assisting the Finnish steamers »Canopus» and »Rigel» from Swinemünde northwards, the convoy spent the first night at the fast ice edge 17 sea miles to the east of Bornholm. It may be mentioned that the sea west of Bornholm had been covered by immobile ice in the winter of 1947 too (PRAHM 1951).

»A fast ice bridge» typical of severe winters was also formed in Fehmarn Belt in the winter of 1942. How long it lasted this winter is not clear from the material available, especially as navigation in this area had come to a standstill because of the ice.

48. Thus during the period now under review, with frosty weather and a weak wind prevailing, the ice of the open sea in the Baltic grew considerably heavier. As is evidently characteristic of such severe winters »fast ice bridges» were formed with clearly defined areas, e.g. the Gotland — Öland, Bornholm — Swedish coast and Fehmarn — Laaland bridges. But the ice on the open sea of the Central Baltic did not remain immobile during the following, windy period, though it moved in a fairly limited manner.

F. THE EVENTS OF MIDWINTER, 1942. II. 23—III. 19.

49. The frosty weather accompanied by calm weather which had started about the middle of February, continued until towards the end of the month without the wind rising until February 23. On the 23rd it increased, from time to time reaching 5 Beauf., SW. This broke up the ice. As the wind shifted to N on the next day a lane was opened up SW-wards from Utö. The weather being practically calm on the following two days, the ice moved only slightly, and on an ice reconnaissance flight on February 27 from Finland the position of the lane was observed (Figure 19). When the wind increased again on March 2 to 6 Beauf., N—NW, the ice began to move offshore. On the same day a Swedish air reconnaissance flight reported the width of the lane south of the skerries of Åland to be 5—7 km or 3—4 sea miles wide (LILJEQUIST). The beginning of this lane, short and narrow, is just visible in Figure 19 about 10 sea miles south of Lågskär. An air reconnaissance flight from Finland on March 3 established that the lane extended, wide throughout, past Bengtskär Lighthouse to the east as far at least as the area of the skerries of Barö, i. e. to near

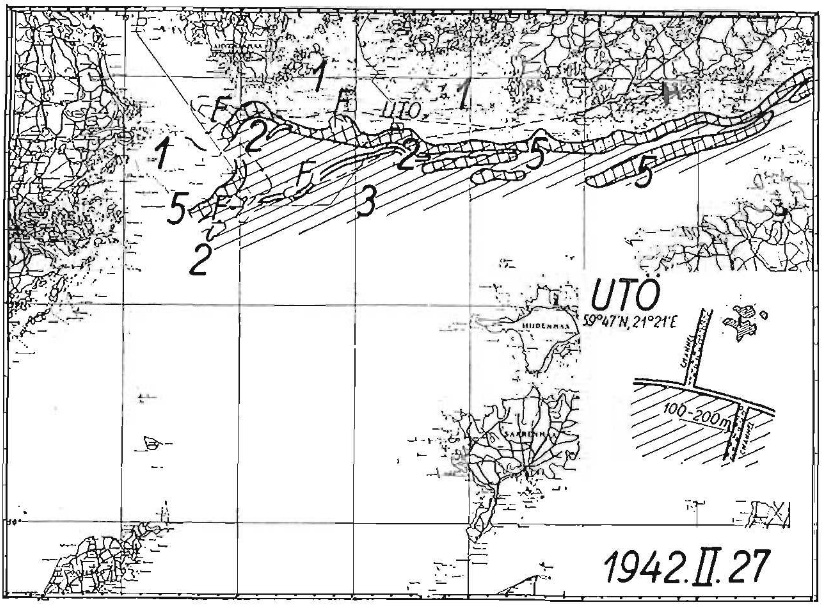
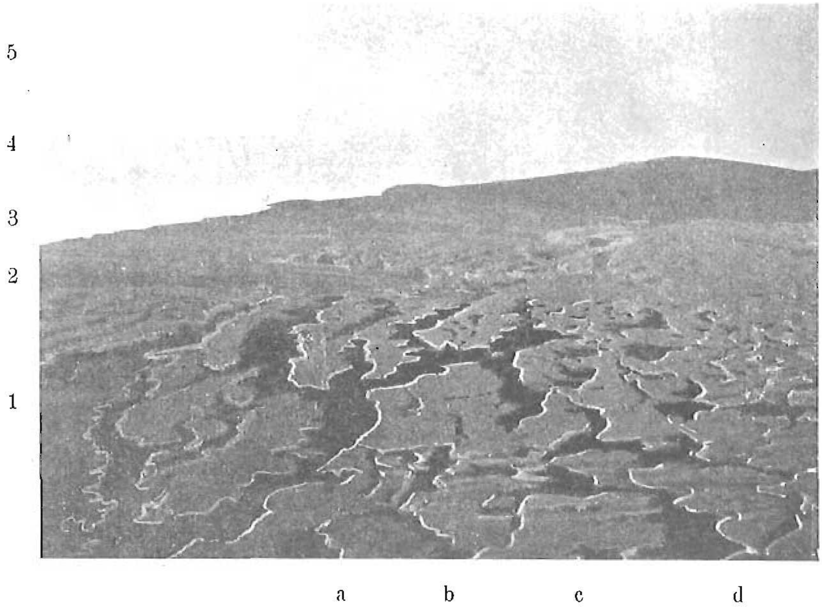


Figure 19. Ice reconnaissance flight, 1942, Feb. 27, 1200—1545. Explanations: 1 = thick fast ice, snow-covered, 2 = lane, width approx. 200—400 m, from Utö to Bogskär. A small open water area south of Lågskär, 3 = continuous thick ice, 5 = pressured ice zones, navigability in the northern Central Baltic very difficult, F = objects photographed, R = flight route.

Inset sketch (in the right-hand margin): the old navigation channel close to Utö showed that the sea ice had moved 100—200 m eastward (generally it moves westward).

Bågaskär Lighthouse. It was rapidly covered with ice during the severe frost (Picture 19).

50. As appears from the description above, the ice in the northern Central Baltic began to drift in the farthest reaches of the sea, about level with Bogskär, and then continued, as it generally does in such cases, close to the outer skerries. Both on the open sea itself and in the area where the »Ostrobotnia» was icebound the ice broke up earlier on this occasion, as appears from the air photo taken on the same day, March 3 (Picture 20). The captain of the »Ostrobotnia» said that the pressure in the ice field was very strong and some large ice floes were left standing on their edge. By the vessel, however, the ice seems to have remained unbroken and continued to protect the vessel until the icebreaker »Jääkarhu» arrived on the same day to assist her to Utö. A similar situation arose in winter 1916; the ice around the »Ariel» and the »Lapponia», icebound in the Bothian Sea (N. 14), broke up and the vessels were in a dangerous position. The »Lapponia» succeeded in getting back into immobile ice, but the »Ariel» was crushed by the pressure and sank.



Picture 19. New ice and ice formation in a newly-opened lane. (Off Utö Lighthouse, 1942. III. 3, 1015 hours. Height 500 m, direction NE. Air Force photo.)

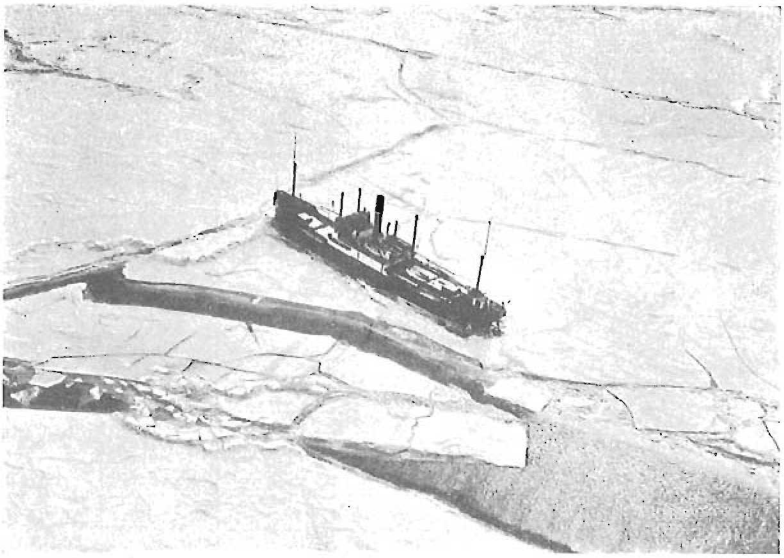
The skerries of Utö are seen in the middle of the picture (b5), in coastal fast ice covered with snow. A wide lane (dark part in the picture) begins about 3 sea miles to the south (c4). This lane is already partly covered in thin, new ice and in parts ice is just forming. Thus it shows ice rind of different ages.

Closest to the fast ice edge is a light striped area (a3—c3) in which »ice film» can be seen in the form of parallel stripes, evidently a result of the wind (*cf.* Picture 1). The »ice film» ends in a lighter area (b2—c3) which has formed right at the fast ice edge and has then been detached by the wind and drifted further seawards.

At the bottom of the picture is an area of broken new ice. The parts in the lower left area (b1) are separated from one another. The rectangular-shaped pieces, regularly repeated, are clear proof of how the wind breaks and scatters the ice.

The light-coloured, curved edges (a1) of the broken pieces of ice on the weather side are apparently the result of drifting »ice film» accumulating against these edges.

The broken pieces to the right of the picture (d3), on the other hand, probably met some obstacle, i. e. thick drift ice and tended to pile up to some extent.



Picture 20. B r e a k i n g u p t h e i c e f i e l d a n d t h e o p e n i n g u p o f l a n e s f a r o u t t o s e a. (Northern Central Baltic in the vicinity of the »Ostrobotnia» some 25 sea miles SW of Bogskär Lighthouse, 1942. III. 3, 1100 hours. Height 200 m, direction SE. Air Force photo.)

The broken lanes and cracks have divided the ice field up into parallelogram-shaped floes (b3, b5, b6). Lanes have opened up in the even ice (b4) as well as along the pressured ridges (b7). To the left of the vessel the lane has opened also along the pressured ridge (a2) which has fallen down into the water. In the lane (b1) can be seen the rippling typical of the surface of open water. Sludge and ice rind have drifted together to the lee of the lane (b2).

The new ice formed in the wide lane off Utö was in constant motion as it lay between two heavier ice masses (Figure 20). With a fairly weak wind this new ice too began to come under pressure. It drifted into a pile but did not yet begin to build up pressured ice (Picture 21).

51. At the end of February the ice began to move in the southern Central Baltic as well in the north. The Germans regard this stage of the ice winter as its peak, and thus the new frost period that started at the beginning of March was regarded as a return of winter *(Eisbericht* N:o 68/1942. II. 28). Night temperatures were still quite low at that time, but day temperatures increased quite considerably becauce of solar radiation (Figure 11). Around this period, with the stormy E winds that came on March 4, the ice bridge from the Swedish coast to Bornholm broke up.

52. Movement of the ice at the end of February and the beginning of March, taking place as described above, must be regarded as a typical midwinter phenomenon for the northern Central Baltic, a decrease in the amount of ice starting later. But in the southern Central Baltic sea ice

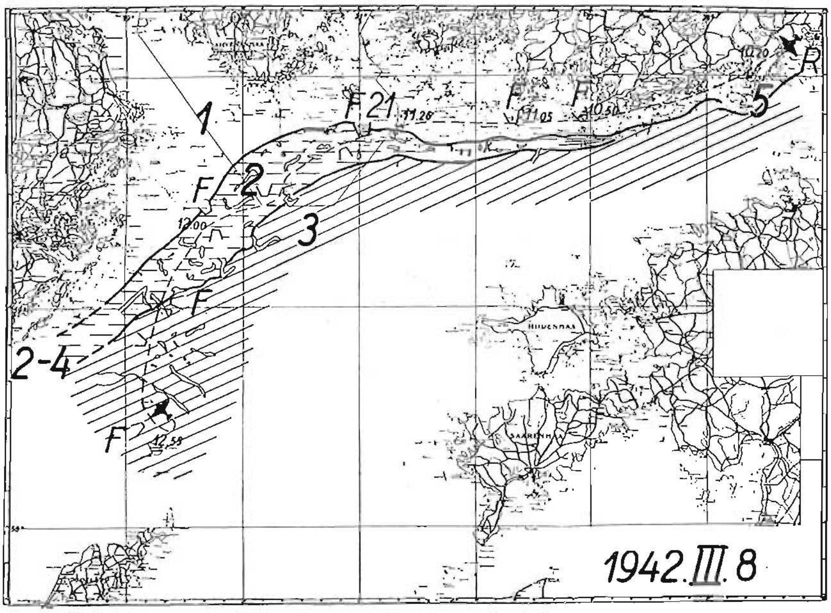


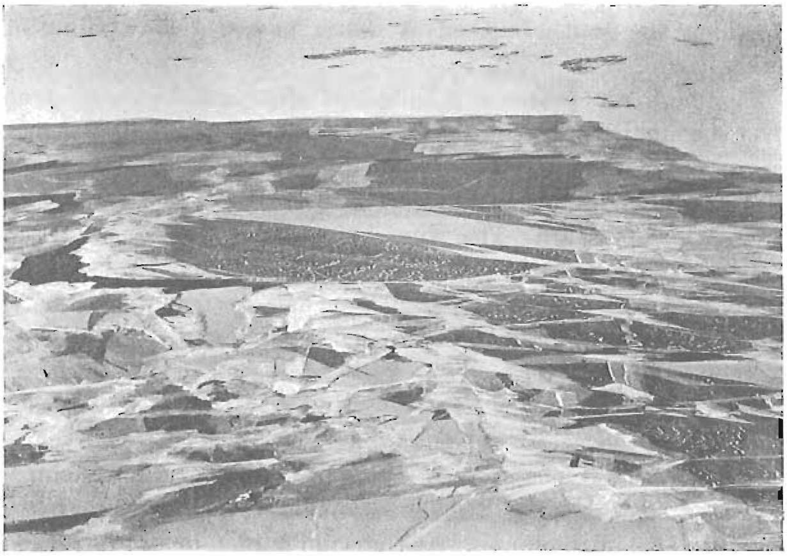
Figure 20. Ice reconnaissance flight 1942, March 8, 1000—1405. Explanations: 1 = coastal fast ice, snow-covered ice, 2 = lane parallel with coast. It begins from Jussarö Lighthouse approx. 400—500 m wide and runs westward. At Utö the lane widens considerably. It is covered with thin ice, with numerous open places. In its western parts, closest to the Swedish coast, this new ice is thinnest, 3 = heavy ice on the open sea, snow-covered. There are lanes here and there in the ice-field. The first transversal lane at Bengtskär Lighthouse, width of lane approx. 1 m. F = objects photographed, F 21 = Picture 21 (in the text). R = flight route. 10.20 = time of plane flying over the spot concerned.

movement at this time of spring is taken as a sign of the arrival of spring and the amount ice generally begins to decrease from then on, though it can sometimes be delayed by a colder weather period arriving later. This phase from midwinter to the early part of the spring is characteristic of the culmination of the ice winter of the open sea of the Baltic, more fullu explained below.

G. THE CULMINATION OF THE ICE WINTER, 1942. III. 20.

53. By the culmination of the ice winter the author means the state prevailing prior to the definitive withdrawal of the ice and its diminution towards final breaking up.

In northern Danish waters, where the freezing had extended across the Kattegat and Skagerak at the beginning of March, this phase was passed on March 14. It was then that the ice of the open sea in these regions was broken up by a stiff SE wind and drifted westwards



Picture 21. A typical example of the rafting of snow-free young ice. (About 8 sea miles west Utö Lighthouse, 1942. III. 8, 1120 hours. Height 800 m, direction NNE. Air Force photo.)

The picture shows the fast ice edge (a4—c4) and on this side of it snow-free ice of different ages formed in a wide lane that opened up on March 2—3. The ice seems to be quite thin closest to the fast ice edge (a3—c3). Further out it is heavier and light, snow-covered floes appear in it (b2). In the course of the opening-up of the lanes the old pressured ice from the sea has moved right outside the photo.

With the shifting of the wind (earlier from the N) on March 6 to W and later to SW the snowfree ice formed in the lane was pressed by old, heavy ice masses which broke it up and cause rafting (b1). The photo gives an idea of the changes that can occur in snow-free young ice in the open sea. The strength of the wind on this occasion was 3—4 Beauf.

along the west coast of Sweden and south coast of Norway until it melted and disappeared. There was no new ice formation and the sea in these regions remained open. March 14, therefore, can be taken as the date of the culmination of the ice winter in northern Danish waters.

54. The same stiff SE wind of March 14 broke up the ice further south as well and drove it offshore from the German coast. But there was no diminution in the quantity of the ice. Some 3—4 days later, however, when the day temperature was a few degrees above zero centigrade, the ice probably began slowly to weaken in spite of the night frosts. A stiff SE wind blew and, on March 19, a zone of open sea or very little ice was formed, 30 sea miles wide, here and there along the East-Pomeranian coast (*Eisbericht* N:o 88/1942. III. 20). The zone thus opened did not close again later, even when the wind blew from a favourable direction. This was probably because the ice began rapidly to melt. Thus March 19 can be considered the day on which the southern Central Baltic passed the culmination of the ice winter.

55. The high air pressure maintained clear weather and strong night frosts over the northern Central Baltic in the middle of March. A centre of high air pressure was located in central Sweden on March 19. On the following day the centre had moved to the east of the Central Baltic and was succeeded by an area of deep low pressure. The wind increased to 4 Beauf. SW, and with it even the ice in the western parts of the Gulf of Finland was set in motion. It was reported from Estonia that a lane had opened up in the southern part of the Gulf of Finland westwards 5—6 sea miles from the northern point of Osmussaar and on past the Point of Ristna in the north. The wind gained in strength during the next few days and shifted to W; the lane on the Estonian coast closed up and the broken ice of the entire northern Central Baltic began to drift to the eastern region of the sea. Simultaneously a lane opened on the east coast of Sweden, growing very wide (LILJEQUIST), and it extended to Utö in the north. As the wind gained in strength the weather became milder overall — the temperature registered no considerable minus reading for the next few days. Hence no new ice was formed and the floes did not bind together. The time when the ice began to break up, i. e. the time when the wind grew stronger — March 20 — can thus be considered as the date of culmination of the ice winter in the northern Central-Baltic.

As is evident from the foregoing the culmination of the ice winter is connected above all with wind conditions, though temperature conditions participate. It must be remembered that the wind had already caused a break-up of the ice of the Central Baltic at the end of February, but the »second winter» that followed on reinforced the ice field and divided the midwinter in two parts. The diminution of the ice which began on March 20 was connected with both wind and temperature, as a result of which the culmination of the ice winter of the northern Central Baltic was very marked.

56. Because of two-parted character of the midwinter the passing of the culmination of the ice winter cannot, however, always be determined with such exactness. In the winter of 1941, for instance, the ice cover in the middle of February extended quite far out and open water could only be observed from about level with the southern point of Gotland to the Gulf of Danzig (ÖSTMAN 1941). The ice winter of the southern Central Baltic culminated about this time when the ice became broken up at the end of the month and drifted e.g. from the Pomeranian coast out to the sea and with the increasing air temperature began to melt and disappear *(Atlas,* Deutsche Seewarte 1942). The ice broke up in the northern Central Baltic at the same time, i. e. at the end of February. At the beginning of March ice e. g. from Utö drifted southwards. The »second winter» covered over with thin ice the lanes that opened up in the northern Central

Baltic and the outer edge of the broken ice broke finally much further south than it had in February. The ice reached its furthest extent in the northern Central Baltic, therefore, at the end of March in spite of the fact it had time to diminish from its February level. As, in addition, within the region of the Archipelago Sea the fast ice had softened in places early in March and the sounds with the strongest currents were open, the spring phase had started by then. The decisive factor in determining the culmination is that in the phase of early winter must be included the phases in which the diminution continues to lead to an early winter phase. After the culmination diminution leads again to spring conditions (JURVA 1937).

In cases like the winter of 1941, when it is difficult to determine the exact time of culmination of the ice winter, a longer period must be taken for study, i. e. the period covering all the phases to be included in the period of culmination. This point of view has been followed by JURVA (1937) in this classification of ice conditions into three main groups: 1) the time of growth of extension of the ice, 2) the time of the maximum extension of ice and 3) the time of diminution and disappearance of ice. ARNOLD-ALABIEFF (reported by STAKLE 1936) determines the general progress of the ice winter in the same way. For conditions in the eastern Gulf of Finland he has determined the following times: 1) the time of growth of the ice, from the beginning of the winter for about 80 days or until the middle of February, 2) the time of maximum extension of ice, from the middle of February to the middle of April and 3) the »ice spring», from the middle of April to the end of winter or the middle of May.

H. THE TIME OF WIDE AREAS OF OPEN WATER, 1942. III. 21—IV. 4.

57. The definitive culmination was followed in the northern Central Baltic in general by an occasional stiff W—SW wind and milder weather. The lane from Utö SWwards — mentioned earlier in the section on culmination — remained open during this period. This was established by e.g. air reconnaissance flights from Finland on March 21 and from Sweden on March 23 (LILJEQUIST). On March 26 the wind shifted to NW—N, strength 5—8 Beauf., and the weather became colder. The ice from the northern Central Baltic drifted still further southwards. Thus an air reconnaissance flight from Finland on March 29 established a very wide area of open water in the northern Central Baltic (Figure 21). The open water stretched from off Utö as far south as the eye could see. According to Swedish reports Gotska Sandön was in open water, but further south the area of open water narrowed to a width of 10—20 km or 6—11 sea miles, as a Swedish reconnaissance flight reported on March 30 (LILJEQUIST). The frost had led to the formation of thin new ice, as appears from the photo taken in the vicinity of Bogskär

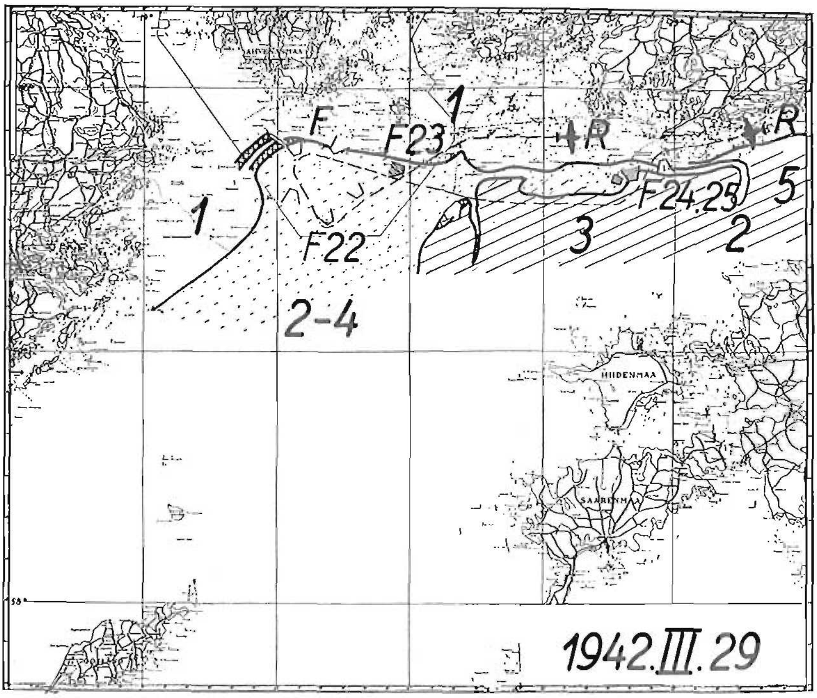


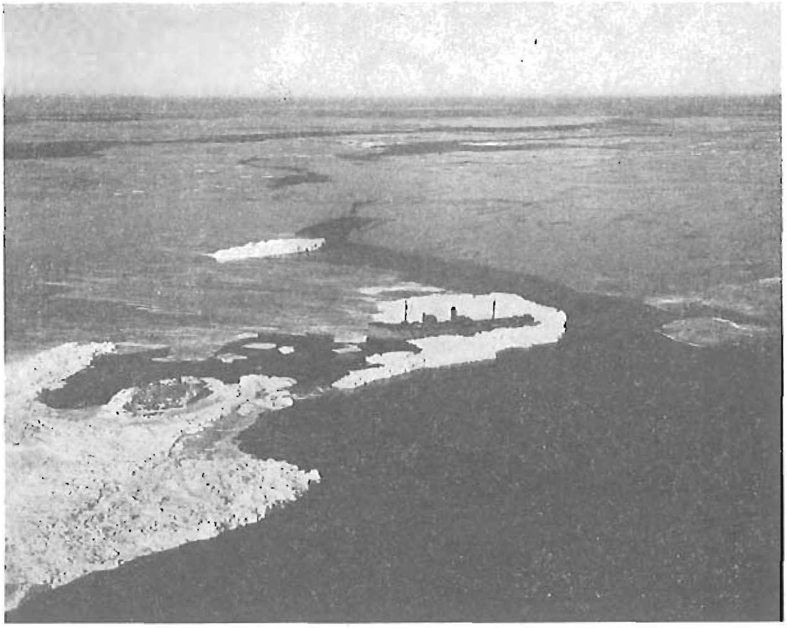
Figure 21. Ice reconnaissance flight, 1942, March, 29, 0810—1100. Explanations: 1 = fast ice, 2 = lane beginning from Jussarö Lighthouse. Close to Utö the open water expands into open sea, its eastern edge southwards from Utö some sea miles and then turning SW towards Gotland, 3 = old thick snow-covered ice, in movement in its entirety, 4 = ice rind or thin new ice. Close to the fast ice edge the new ice has drifted together, 5 = immobile ice with ice ridges. The pressured ice by Lågskär is in two zones, close to the edge of the fast ice. F = objects photographed, F 22—25 = Pictures 22—25 (in the text), R = flight route.

(Picture 22). But a prerequisite for this type of ice is that the surface water remains cold and the wind weak — which in fact was the case on March 29. In spite of the weak wind a thin new ice in the spring like this can be set in motion and drift into piles, as can be seen from the photo taken at the time (Picture 23). It may be mentioned that the sea traffic to Finland, which until then had been routed via Landsort to the archipelago of Stockholm and from there through the Åland Sea to the Archipelago Sea, could now make a course direct from the sea to Utö.

The air reconnaissance flight map of March 29 showed that in addition to the ice of the open sea the ice of the fast ice edge also was broken in its outer parts. The apparent cause of the break-up was the swell, as appears from the photos taken in the vicinity of the Bengtskär Lighthouse (Pictures 24 and 25).

New ice must have been formed on the open sea during the night frosts

5
4
3
2
1



a b c d

Picture 22. The wide area of open water of the northern Central Baltic and the piles of pressured ice around the ridges of Bogskär. (Bogskär Lighthouse, 1942. III. 29, 0940 hours. Height 100 m, direction NNW. Air Force photo.)

The lane that originally formed off Utö on March 21 was widened out to a broad stretch of open water by the stiff NNW wind of March 26 and now extended southwards beyond Bogskär Lighthouse. The lighthouse rock, visible at the left of the photo (a2), is already snowless. But high piles of ice still exist around the rock and the ridge in the middle of picture (c3 = on which the »Helgoland» is stranded) as well as on another rock still further out (b5).

The open sea around Bogskär is partly covered by the thin ice set in motion though not totally »swept» away by a weak wind. A result of the ice movement can be seen to the left of the ridges where there is an area of thin ice that has piled up (b4) and to the east of the lighthouse where there is an area of thin ice that has piled up (b4) and to the east of the lighthouse where there is open water (d1). The piling of thin ice can be seen more clearly in Picture 23.

at the end of March. But this new ice, only one night old, melted away for the most part in daytime. Thus in their major features ice conditions remained more or less unchanged (Figure 33).

58. The time of wide areas of open water described immediately above began with the wind breaking up the ice of the open sea, though there was no real diminution of ice volume in spite of this. Thin, new ice was formed on the open sea at night, but the ice volume was unable to increase. Yet there was no diminution of the ice volume either, and hence the frosts of this period could only delay the coming of spring.

4

3

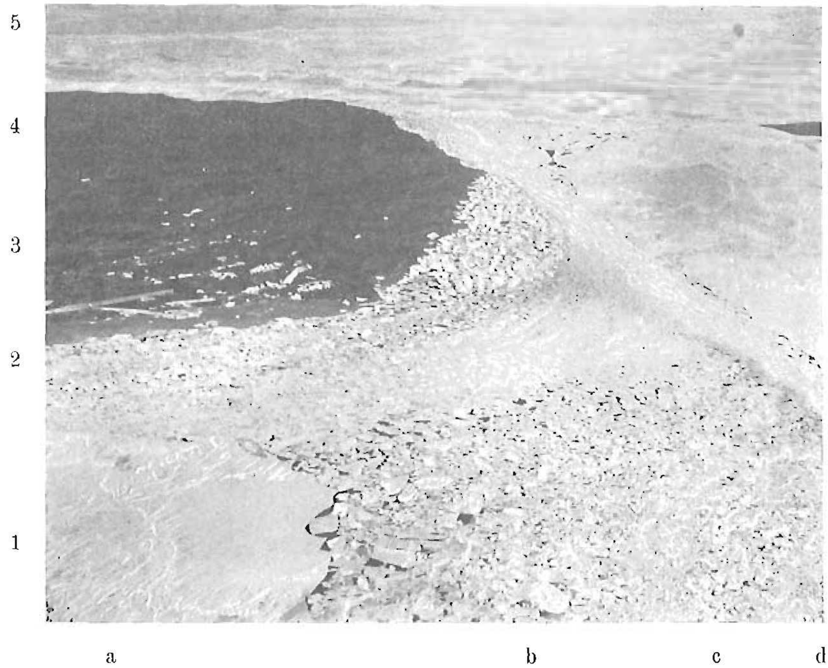
2

1

a b

Picture 23. The piling-up of thin ice formed in an area of extensive open water. (Northern Central Baltic south off Utö, 1942. III. 29, 1000 hours. Height 30 m, direction W. Air Force photo.)

The piling-up has occurred in the form of successive belts of ice (b1, b2, a3, a4). Within each band the pieces have »dovetailed» into one another (b2), which is typical. The entire figuration of the area photographed is very regular and uniform in shape.



Picture 24. I c e b r o k e n b y t h e s w e l l f r o m t h e f a s t i c e e d g e, f l o a t i n g i n a w i d e a r e a o f o p e n w a t e r. (Off Bengtskär Lighthouse, 1942. III. 29, 0900 hours. Height 600 m, direction NNW. Air Force photo.)

The parts detached from the fast ice edge are frozen solid and further in the background of the photo (a5—c5) is more level fast ice. A SW wind (i e. a wind blowing across the picture from lower left) has broken up a part of the fast ice edge. Next the sea swell against the fast ice edge broke it into cakes, some of which were »ground» to thick sludge (b4—d2).

On March 27, when the wind shifted to NW—N, the broken pieces moved along the fast ice edge (to the right) and close drift ice or a pressured zone was formed — as is typical — at the border of the open water (b2). Right on the edge of open water the cakes are more sparse (b3), as can be seen from Picture 25. The open water surface, at the time the photo was taken, was covered in thin, new ice (a4).

3

2

1

a b

Picture 25. Cakes broken off the fast ice edge by swell. (Off Bengtskär Lighthouse, 1942. III. 29, 0903 hours. Height 400 m, direction NNE. Air Force photo.)

The area shown here corresponds to the area of floes closest to the open water border as in Picture 24. The angular shape of the cakes and the fact that some of them still carry uneroded pressured ice formations (a1, b2) are convincing evidence of the fact that the floes originated in the fast ice edge and that the ice was very »steely» at the time.

The picture also reveals that the new ice seen in Picture 24 has started to move and pile up (a3).

I. THE MELTING AND DISAPPEARANCE OF ICE ON THE OPEN SEA OF THE CENTRAL BALTIC. 1942. IV. 5—25.

59. The night frost at the beginning of April was losing its force and a weak SW current of air entered the Baltic. The wind set the ice in the southern Central Baltic in motion and a wide lane opened up in the western areas of Möen and Rügen as the ice drifted towards the southern coast of Sweden. The area of open water further east, on the Pomeranian coast, grew still larger. The warm weather, night temperature now over 0° C, quickly weakened the fast ice of this section of the coast and it broke off and drifted out to sea.

60. On April 5—6 a wind from the same SW direction set the ice of the northern Central Baltic moving. This resulted in the wide area of open water off Utö decreasing overall, and it was even closed in places. The ice ceased to move about April 12 with the arrival of high air pressure conditions and the calming of the wind. An air reconnaissance flight from Finland on the following day observed abundant drift ice in the northern Baltic, but quite extensive stretches of open water were now seen to appear between the floes (Figure 22). Similar conditions were created in the sea region

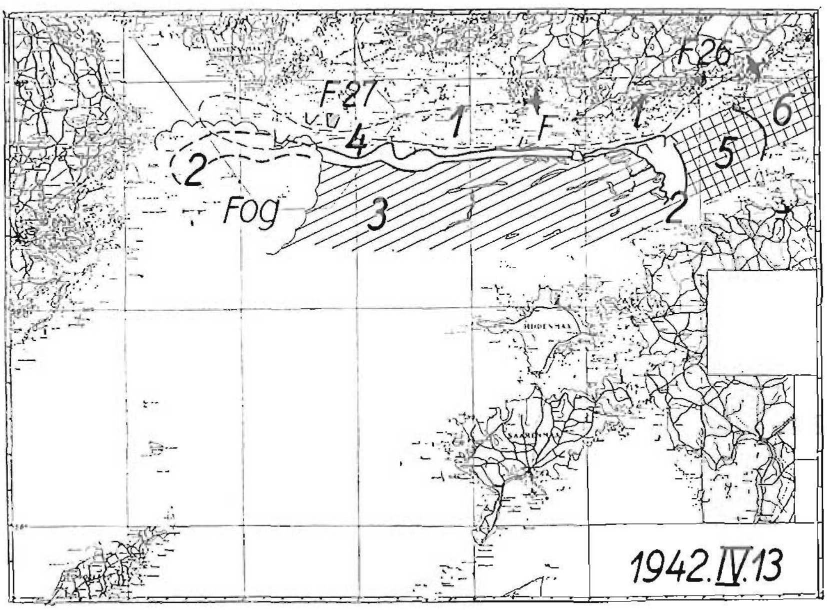


Figure 22. Ice reconnaissance flight, 1942, Apr. 13, 1130—1425.
Explanations: 1 = fast ice, from which snow has begun to melt, 2 = lane beginning from Jussarö Lighthouse nearly in the same way as in Figure 21. Width of lane at Bengtskär approx. 1 sea mile. Off Utö the lane widened, further west fog covered the sea area, 3 = ice-field composed of large ice floes, 4 = open places that had appeared at certain points inside the fast ice edge, 5 = immobile ice on the open sea from which snow had melted, 6 = immobile ice on the open sea, snow covered, F = objects photographed, F 26—27 = Pictures 26—27 (in the text), R = flight route.

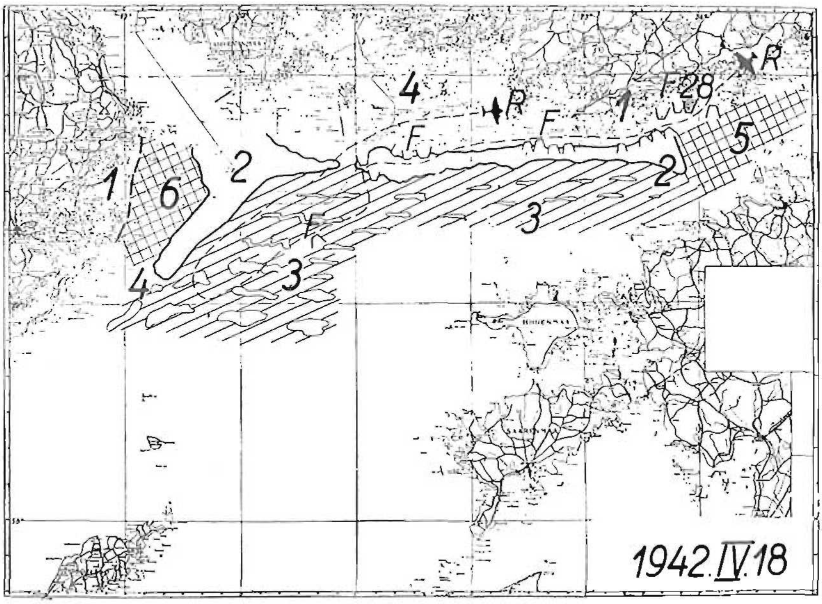


Figure 23. Ice reconnaissance flight, 1942, Apr. 18, 0915—1325. Explanations: 1 = dark fast ice, 2 = lane westward from Jussarö Lighthouse, 3 = open drift ice, large floes, dark, fragile ice, 4 = open places. From south of Bogskär, lanes running E—W, growing in size the further south they are, 5 = immobile ice, 6 = partly broken fast ice, F = objects photographed, F 28 = Picture 28 (in the text), R = flight route.

west of Gotland where, according to a Swedish air reconnaissance flight on the same day, April 13, as much as 40 per cent of the area was reported open (Liljequist).

61. The temperature remained high, in the night as well, and its influence was seen in the »toughening» of the ice. This was established e. g. when the »Sampo» and »Sisu» were at work off Landsort on April 14—15 the icebreakers did not break up the ice in the usual way — the ice bent and was then finally torn up. The icebreakers found themselves icebound from time to time, nipped between ice which was bent as though »under tension», and it proved very difficult to get under way. Thus for a couple of days the work of assistance became more diffcult than usuail, although conditions in general seemed to be fairly easy (Figures 23 and 34).

The spring weather led to melting of the snow on the ice, especially in the region of the archipelago close to the coast where it turned to slush, as can be seen from the photo taken in the region of Barö archipelago (Picture 26). The melted water ate into the ice under-surface and not even the night frosts were able to delay the process to any mentionable extent although they did result in the freezing of the surface layers of the slush into ice some centimetres thick. Coastal observation stations, e. g. Barösund, re-

Picture 26. Level ice at the coastal fast ice edge in spring. (Region of the Barö Archipelago, 1942. IV. 13, 1155 hours. Height 1 000 m, direction N. Air Force photo.)

The snow completely covering the ice has begun to melt, and on both sides of the old channel (a2—c1) made by an icebreaker at the beginning of winter the ice shows bare spots in places (b2). Closer to the skerries (b3) the ice is almost completely bare. The slush formed from the melting snow on the ice gives it a dark appearance in the photo. According to measurements made at Barösund pilot station the slush on the ice was 5—10 cm thick.

During the following cold nights an ice cover about 1 cm thick was formed on top of the sludge, but it melted away during the day. This sort of partial freezing of the slush lying on the ice surface, especially in more northerly regions, is the cause of the varying thickness ascertained by measurements of the total depth of the ice in spring (*cf.* Blüthgen 1937).

dorted on April 21 that the ice had »dried» — this was due to the fact that the melting water had eaten holes right through the ice, letting the water run away. As far as navigation was concerned this weakening of the ice in the archipelago meant that scarcely any assistance was now required in the fast ice zones. But assistance is needed later on at the moment of breaking up of the ice.

The snow lying on the ice of the open sea also began to melt, though more slowly in the region of the archipelago and close to the coast. Because of the unevenness of the snow cover the ice became uncovered in patches, especially close to ridges of pressured ice where snow drifts had formed during the winter (Picture 27).

4
3
2
1

a b

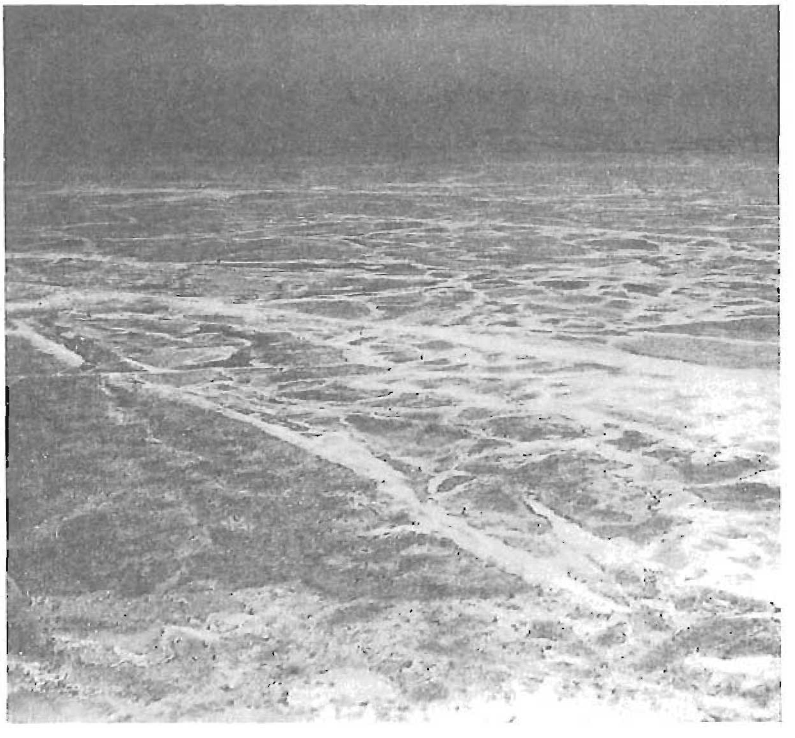
Picture 27. The belt of pressured ice off the fast ice edge in spring. (Kökar, outer sea, 1942. IV. 13, 1320 hours. Height 300 m, direction N. Air Force photo.)

In the foreground can be seen pressured ice formations from the more level areas (b1) of which the snow has more or less melted away. There is still a little snow on the ridges (b2), though in drifts, and they show up lighter in colour against their background. In the middle of the picture (a3—b3) is a light-colored belt of pressured ice formed during the winter by the pressure of the moving ice against the fast ice edge. In the background (a4—b4), partly obscured by mist, begins the level fast ice of the Archipelago Sea.

The photo as a whole shows how much the structure of an ice field actually varies. This variation can be clearly seen when the snow is melting.

Influenced by the temperature the ice weakened still further, as can be seen in the photo taken on April 18 (Picture 28). The pressured ice formations are unchanged in their main features, but a noticeable difference is the fact that the dark ice is studded with dots, apparently holes in the ice. The more level areas of the ice melted rapidly after this and only the pressured ice remained, as appears from photos of the Gulf of Finland and north of Åland taken later (Pictures 29, 30, 32).

62. On April 23 the wind, earlier calm or weak and blowing from SW, shifted to N and increased, from time to time reaching 4 Beauf. On the



Picture 28. *The belt of pressured ice of the outer parts of the fast ice edge, in the first stages of disappearance in spring.* (Barö, outer sea, 1942. IV. 18. Height 400 m, direction NNE. Air Force photo.)

The pressured ice formations are almost identical in form with those in Picture 27. A major difference here, however, is that small openings now appear to be forming in the ice (black spots, especially left in the picture = b1). Once the level spots had completely melted away only the thicker parts of the ice field remained (d2—a3). This situation is illustrated by Picture 32 taken north of Åland later in the spring.

3
2
1

a b c

Picture 29. *Ice field of the open sea breaking up in the spring.* (Gulf of Finland, south of Pellinki, 1942, May 3, 1415 hours. Height 30 m, direction SE. Air Force photo.)

The field of the open sea, that had been frozen solid, has broken up into floes in the spring. The field reveals both old pressured ice (a1) and new pressured ice (c2). The area is very uneven throughout. The ice is still snow-covered throughout. Sealers, whose boat is seen in the centre of the photo (b3), carry out difficult sealing trips through this type of ice.

3
2
1

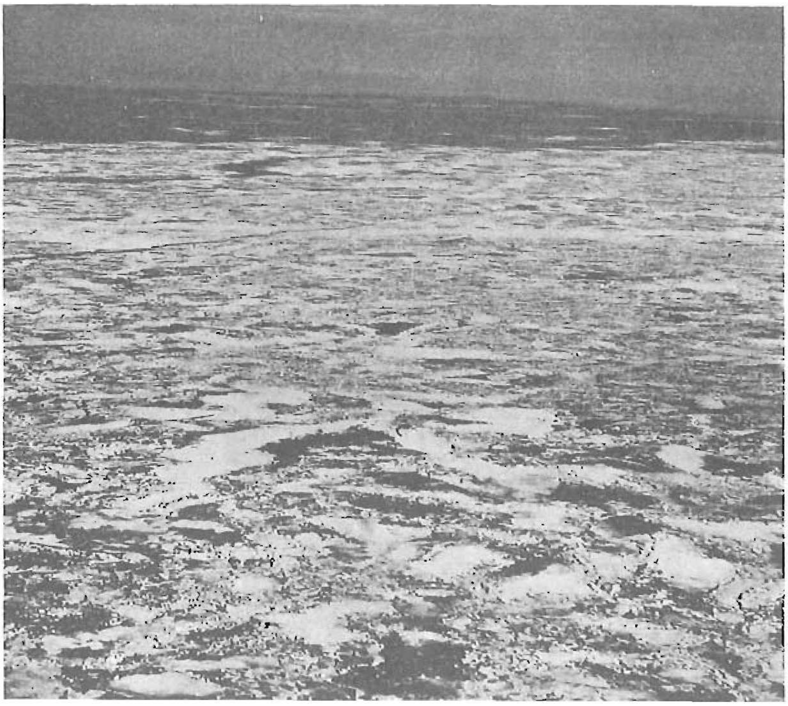
a b c

Picture 30. Pressured ice of the outer parts of the fast ice edge in the spring. (Northern border of the Åland Archipelago, 1942. V. 12, 1120 hours. Height 30 m, direction N. Air Force photo.)

The photo illustrates a type of pressured ice in which the pressure probably occurred fairly late and no snow drifts formed against the ridges (a2—b3). The ice field has a number of stretches of open water (c1) and the entire area seems to be loose. The ice itself is white, perhaps fragile, spring ice.

2

1



a b c

Picture 32. The spring pressured ice, in the second stages of disappearance. (Northern border of Åland, 1942. V. 12, 1128 hours. Height 300 m, direction N. Air Force photo.)

The level spots in the ice field had melted away. Only thicker parts and ridges of the ice field remain (b1) and even those are in process of melting. At this stage of melting the pressured ice is easily set in motion to the open water (a2—c2) and remnants of pressured ice like this are usually the last ice encountered in the Baltic region in spring.

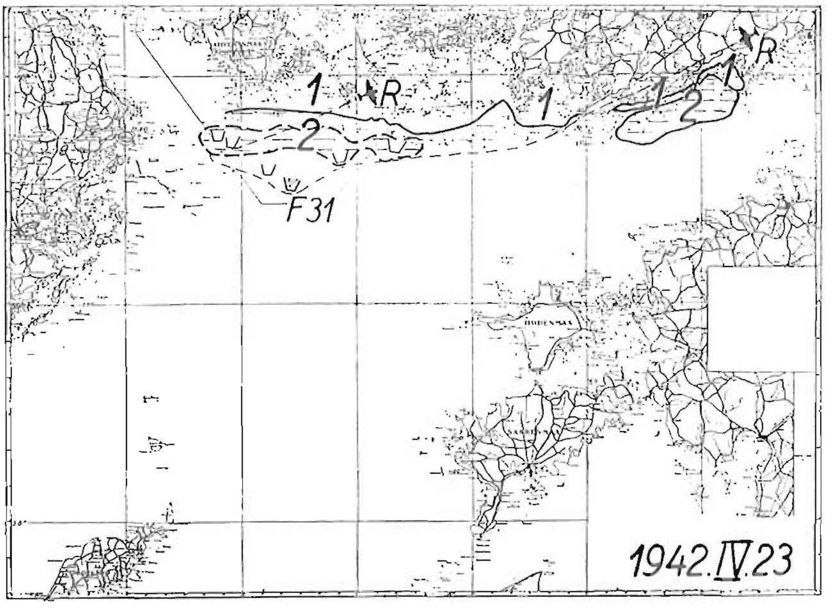


Figure 24. Ice reconnaissance flight, 1942, Apr. 23, 1010—1345.
Explanations: 1 = dark fragile fast ice. In the Barö Archipelago there is only a narrow zone of ice; the inner bays are already open, 2 = scattered ice floes, F = objects photographed, F 31 = Picture 31 (in the text), R = flight route.

following day the wind was further N, varying 5—6 Beauf. Then the ice of the open sea off the fast ice edge of the Finnish and Swedish coast began to drift out to sea, where remnants of ice were to be found (Figure 24). Occasional pressured ice also appeared on the sea, as well as fragments formed from the hummocks detached from the rifts (Picture 31). On May 4 ships reported having met ice for the last time in the open sea of the northern Central Baltic near Gotska Sandön. In the southern Baltic the ice pressed against the south coast of Sweden and skerries of Denmark broke off on May 5 and drifted out to sea. Ice was reported as late as May 15 *(Is- og Besejlings Forholdene 1941—42).*

63. As the temperature during the period studied was comparatively high, especially from the time when the night temperature grew higher than 0°C, the ice melted rapidly. Noticeable is the weakening of the more even places in the ice field and their subsequent melting. This was very important for navigation since once the ice weakened it was no longer able to link the pressured ridges together and keep the ice field whole, and e. g. parts of the pressured ice ridge gave way to the force of an icebreaker and made assistance a comparatively easy matter. Once the level parts of the ice field had melted completely the remaining thicker pressured ice formations became completely detached and were set in motion by wind and sea currents, drifting out to the open sea, even considerable distances.

The development is of the following order: first the areas of open water increase; the ice of the more even parts of the sea ice weakens and melts; the subsequent greater mobility of the remaining fragments of heavy pressured ice is characteristic of the end of the winter not only in the Central Baltic but also in its bays, i. e. the Gulf of Finland (Figures 25—28) and the Bothnian Bay regions. The last ice, i. e. scattered floes, was reported in the Gulf of Finland region by the air reconnaissance flights on May 27 over Haapasaari and Suursaari. The last fragments of the Bothnian Bay were reported to have disappeared off Ajos on June 13.

3

2

1

a b

Picture 31. A pile of ice preserved on a ridge breaking loose in spring. (Bogskär Ridge, 1942. IV. 23, 1125 hours. Height 500 m, direction WSW. Air Force photo.)

Although there was open water around Bogskär big piles of ice continued on the ridges (b2 and b3) for a long time, preserving the »Helgoland» in their midst. The rising sea level on April 23 led to the breaking loose of the ice in the sea, and the swell in particular broke it up into cakes (a1). Occasionally a bigger block of ice could be detached from the ridge and, unchanged in form, drift further out to sea.

a

Picture 33. A fast ice edge in the spring dissolving in the region of the inner skerries. (The centre of the Archipelago Sea, 1942. V. 12, 1405 hours. Height 300 m, direction N. Air Force photo.)

As ice in the inner Archipelago Sea cannot move it melts where it forms. The ice seen in the picture (a1) is very porous and it allows pools to form (a2). The final melting of the ice can take place very rapidly, in one or two days.

In the more extensive areas of the open sea, e. g. Western Hanko, Gullkrona, Skiftet and Delet, the wind sets the ice moving, the ice drifts to the open sea and melts there.

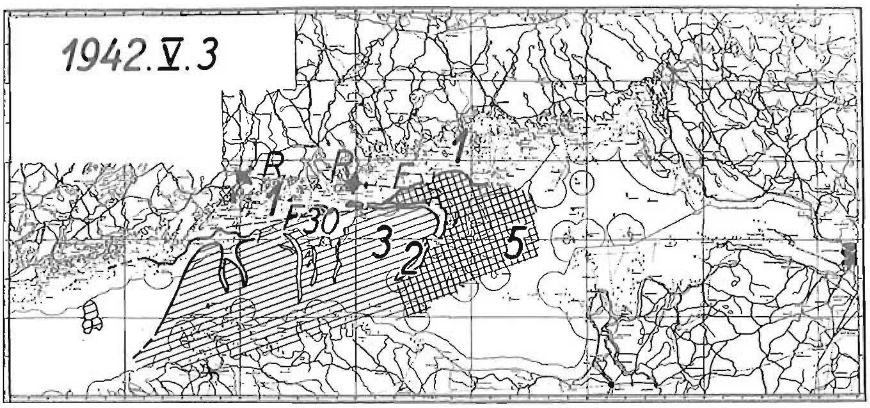


Figure 25. Ice reconnaissance flight, 1942, May 3, 1315—1545.
Explanations: 1 = fast ice, 2 = wide lane begins from Vaindloo and runs via Runskeri and south of Pellinki to off Helsinki. Further in the west the lane widens into open water. 3 = drift ice, with plenty of lanes running N—S, 5 = drift ice frozen over, F = objects photographed, F 30 = Fig. 30 (in the text), R = flight route.

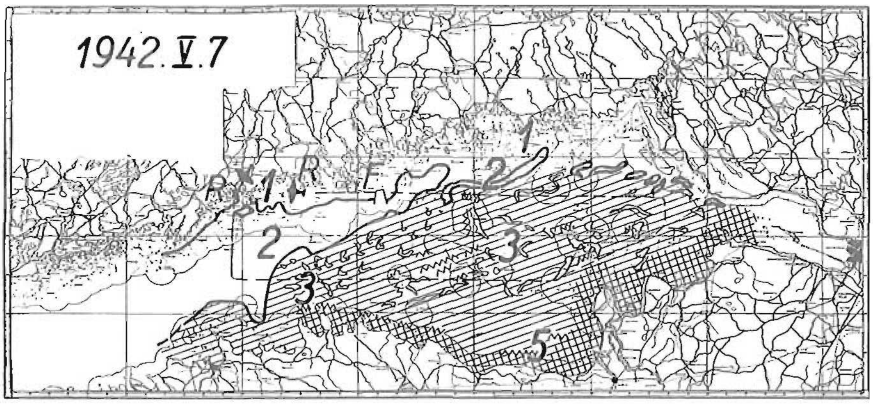


Figure 26. Ice reconnaissance flight, 1942, May 7, 0700—0900.
Explanations: 1 = fragile fast ice. Small cakes broken off from the outer fast ice border area. The bays of the coast were open. 2 = a lane begins from the region of Tammio and widens into open water in the region of Pellinki. 3 = drift ice, fragile from Runskeri westward; plenty of openings and pools in the area. East of Runskeri the ice is more solid, with local pressured ridges. High hummocked ice on the shores of islands. 5 = solid-frozen drift ice.

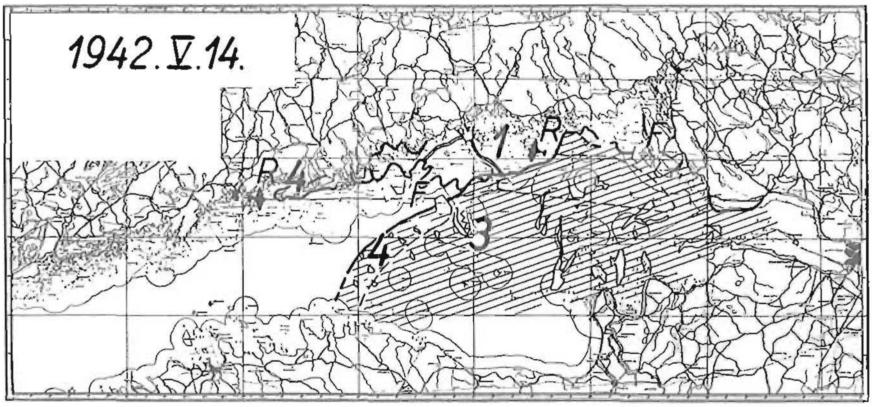


Figure 27. Ice reconnaissance flight, 1942, May 14, 0700—0910. Explanations: 1 = fast ice, fragile. Inner bays open, and pools in the central area. 3 = fragile drift ice, small floes. 4 = fragile ice or sludge. F = objects photographed, R = flight route.

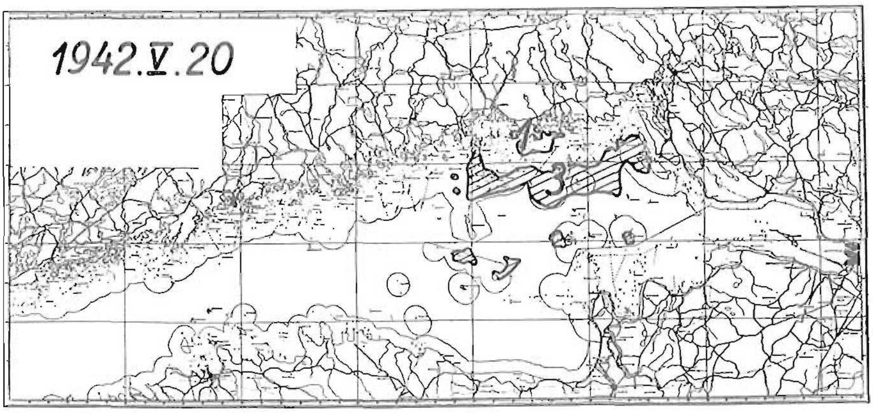


Figure 28. Ice reconnaissance flight, 1942, May 20, 1350—1550. Explanations: 1 = easy fast ice in the region of Tammio. 3 = fragile drift ice east of Haapasaari and in the region of Lavansaari and Tytärsaari.

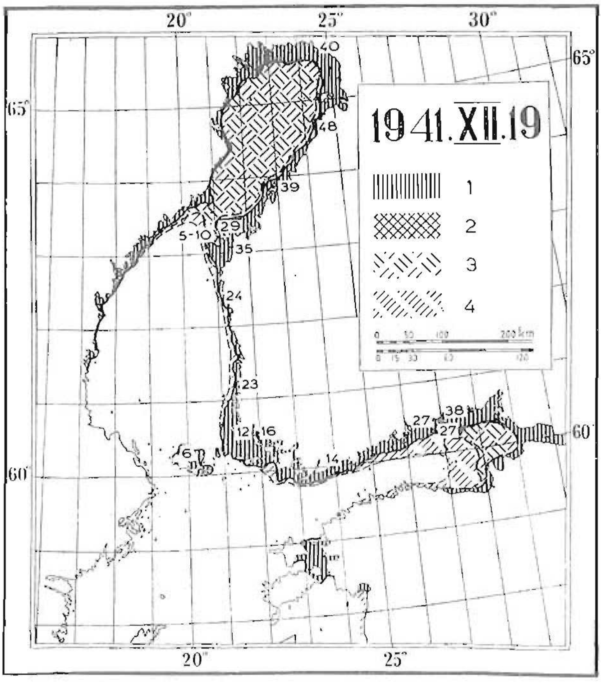


Figure 29. Ice situation Dec. 19, 1941.

Explanations: 1 = fast ice, 2 = drift ice, frozen solid, 3 = drift ice, loose, 4 = new ice, 5 = sludge. 23 = the thickness of ice 23 cm.

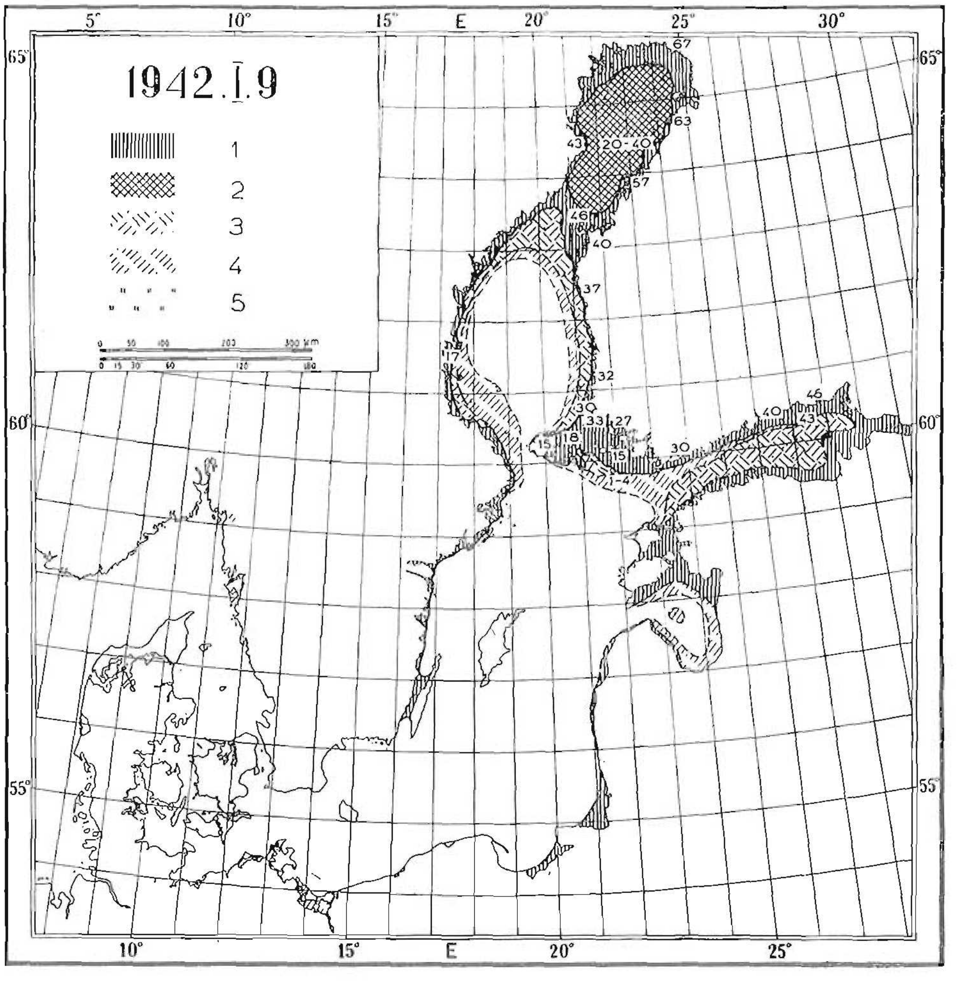


Figure 30. Ice situation, Jan. 9, 1942.

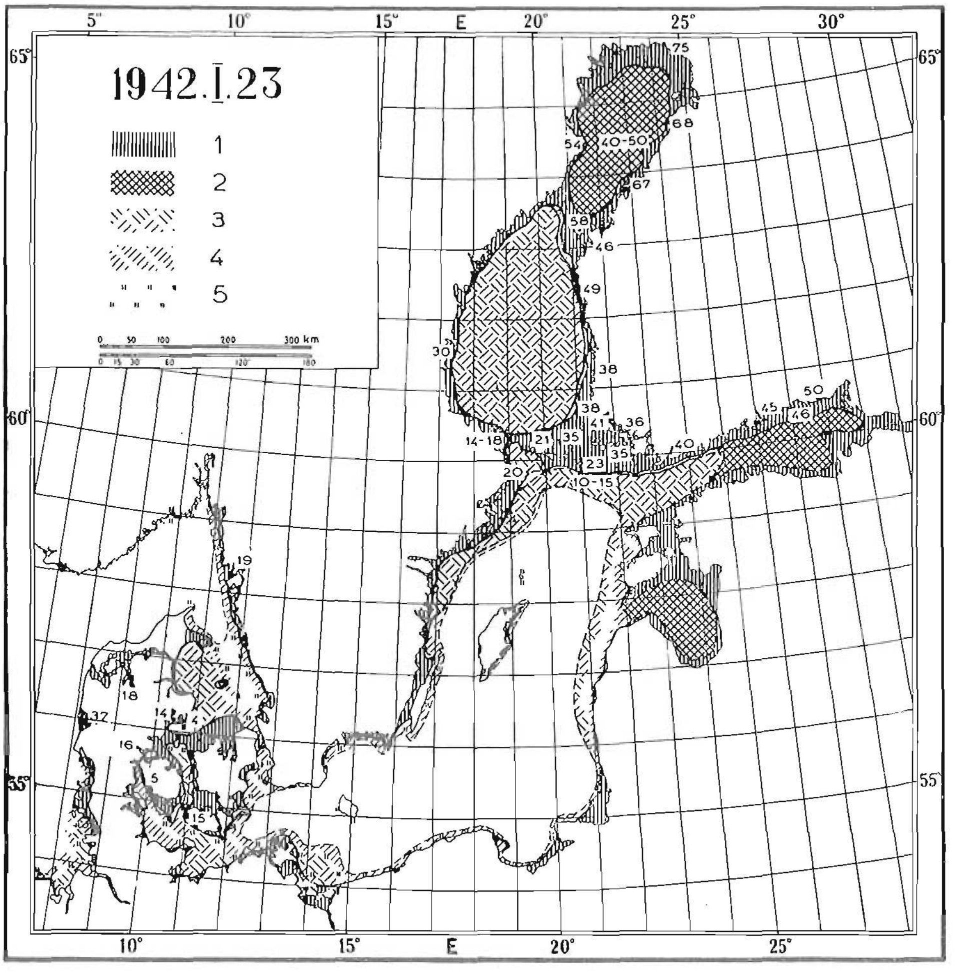


Figure 31. Ice situation Jan. 23, 1942.

Ice situation, Jan 30, 1942 (Figure 38).

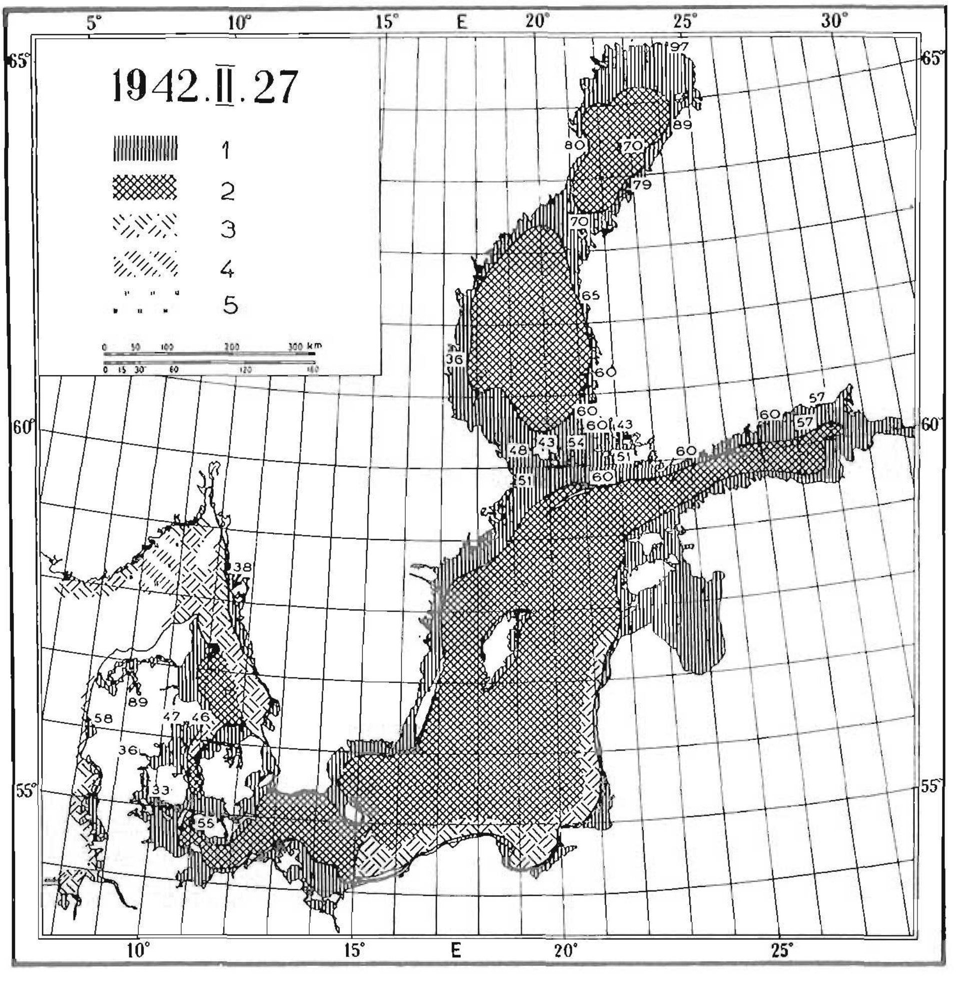


Figure 32. Ice situation Febr. 27, 1942.

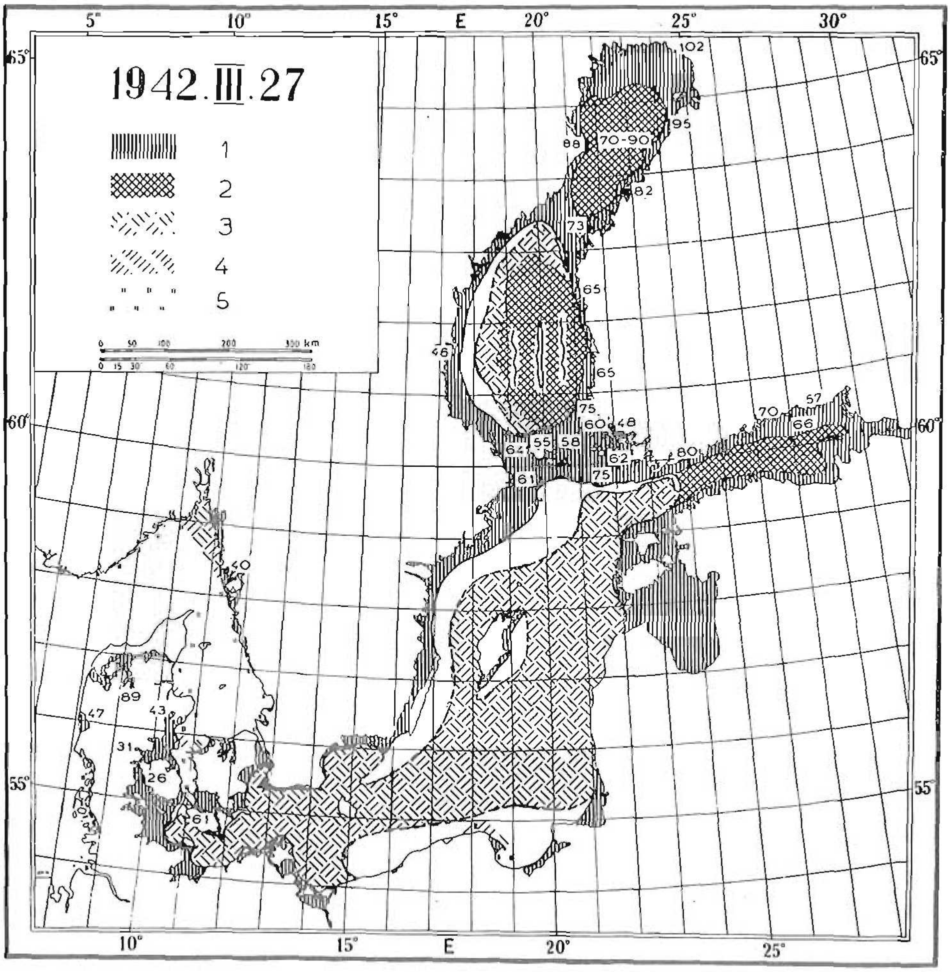


Figure 33. Ice situation, March 27, 1942.

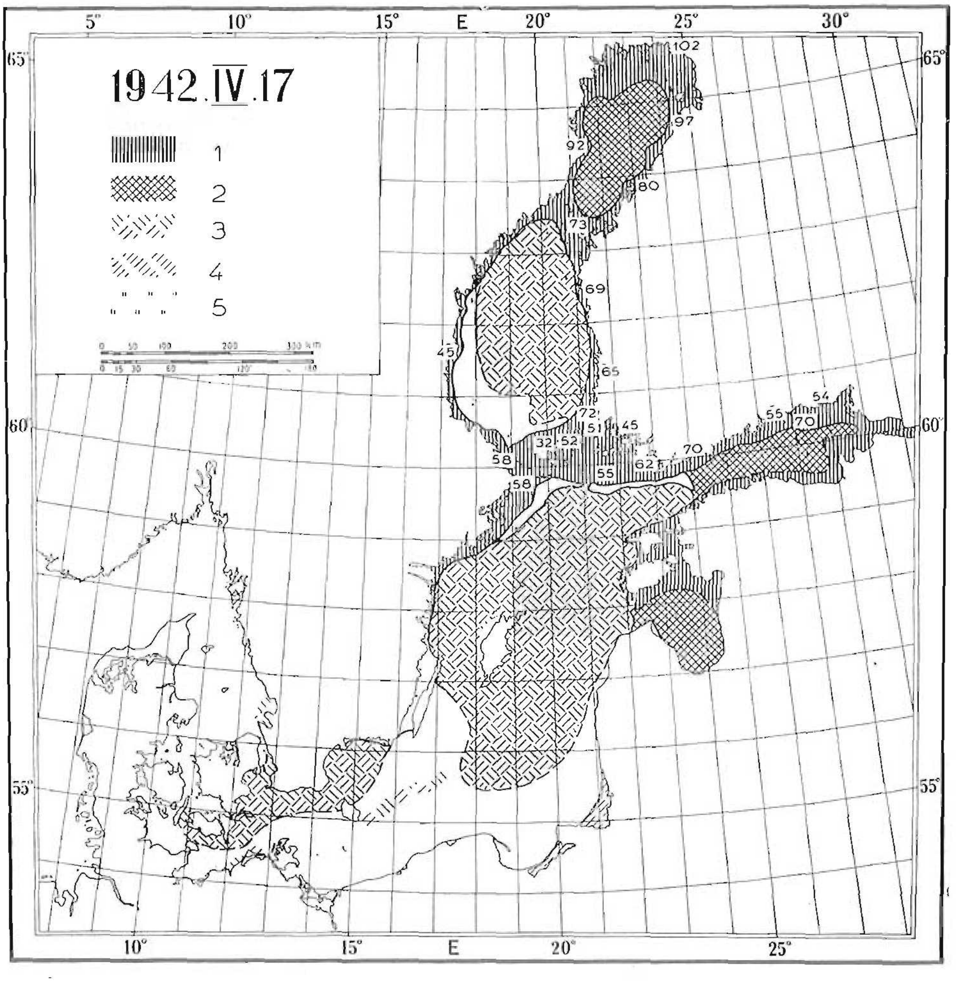


Figure 34. Ice situation, April 17, 1942.

III. OTHER SEVERE ICE WINTERS.

64. In order to study the general character of severe ice winters and to make comparisons with those severe ice winters on which adequate observation material to meet scientific requirements is available, i. e. the winter of 1942, discussed above, and the winters of 1940 and 1947, it is necessary first to give a brief description of the freezing of the open sea during these few severe ice winters.

A. THE FREEZING OVER OF THE CENTRAL BALTIC IN THE WINTER OF 1940.

65. As regards development in the winter of 1940, as SCHERHAG (1948) points out, a remarkable feature is the development typical of many severe winters, viz. that the atmospheric pressure was found to be remarkably high in the polar region on the Greenland side as early as in December. Several frost cycles in fact were observable in the Baltic region in December and early January.

January 15 the atmospheric pressure in Greenland had reached a remarkably high value. As a low pressure simultaneously prevailed in Central Russia very cold air began to flow westward at high speed from the northern side of this low pressure, and a very severe frost period began in the region of the Baltic. The outbreak of cold air resulted in Germany in an independent cold air pool (»Kaltlufttropfen») which persisted in the area for nearly a week.

January 15 the sea of the Gulf of Finland was still open as far east as the meridian of Pellinki. In the Gulf of Bothnia the Bothnian Sea was also open for the most part (JURVA 1941 b). Ice then formed very rapidly on the parts of the sea still open, and on January 27, with a fairly weak, 3—4 Beauf. NE wind blowing, the northern Central Baltic even, off Utö, froze.

The same day the German »Valeria», on her way from Stockholm to Danzig, reported easy drift ice 10 sea miles seaward of Landsort (*Eisbericht* 1939/1940). She reported easy drift ice further south also, e. g. in the vicinity of Hoburg off the southern tip of Gotland. On her arrival in the Gulf of Danzig on January 30 she reported drift ice already as from the vicinity of Brüsterort.

The ice forming in the sea was set in motion by the NE wind and drifted outwards off the eastern coast of the Central Baltic. For instance, the German »Karibisches Meer», bound from Reval to Pillau, reported that the going was through dense drift ice all the time, locally pressured. Further westward, according to ice code reports, drift ice appeared around Gotska Sandön and Fårö, the northern tip of Gotland, on February 6.

66. The above-mentioned cold air pool in the German area began to move on January 24 towards the Baltic region from where, reinforced, it pushed back to German territory on February 7. February 12 its centre was in the region of Hamburg, from where, moving slowly, it arrived in East Germany about February 20.

The frost was at its severest, below —20°C, on February 7—11, and the formation of new ice must have been very intense during this time. Around Högby and Kapelludden lighthouses on the coast of Öland the fields of view were definitely ice-covered by February 8. After this date all the land observation stations in the district of the northern Central Baltic reported ice within the field of view. February 10 the Stockholm—Riga Swedish passenger plane reported the northern Central Baltic totally frozen (ÖSTMAN 1940).

67. In the southern Baltic, according to ice code reports, thin ice had formed on January 8—9 in the sea off the Pomeranian coast. However, the ice on the sea did not remain permanent throughout. On January, 16—17 new ice formation was observed; however, it did not obstruct navigation to any considerable degree. January 31 German aerial reconnaissance reported drift ice all along the Pomeranian coast, and no open water was reported *(Eisbericht* 1939/1940). By contrast, German aerial reconnaissance extending further north on February 4 reported open water still south of Bornholm, in the vicinity of Adlergrund shallow *(Eisbericht* 1939/1940).

February 8, according to ice-code reports, the horizons of even the last land observation stations reporting open water were definitely ice-covered, as. e. g. around Bornholm. As, on February 8, in addition to severe frost the weather was very nearly calm, it is apparent that any areas possibly still open by then, like lanes etc., became ice-covered.

Total freezing of the open sea of the Central Baltic, thus, in this winter, had taken place during severe frost and slightly windy weather. Hence the development was seemingly more regular during weather that remained the same in character (i. e. unchanged), whereas in the winter of 1942 the final freezing was preceded by a period of stormy weather before the freezing could occur in calm weather.

68. The initial development of the winter of 1940 in the Central Baltic continued at first as in the winter of 1942 when on February 13 the wind set in motion the ice of the open sea and breaking-up was observed according to the ice code reports. Further evidence of this is the fact that on February 13 the Swedish icebreaker »Ymer», sailing south from Landsort, met open water about level with Visby and continued in open water until she arrived off Hammeren Lighthouse in Bornholm. There the »Ymer» met thin ice at first, with lanes in it. Close to the German coast, near Arkona, the ice changed to drift and pressured ice and became more difficult to force. The conclusion that can be reached from this is that a wide lane or an area of open water had appeared off the eastern and southern coast of Sweden. At the same time, according to the icecode reports, the ice had broken up in the eastern part of Central Baltic off the Estonian and Latvian coast.

69. In the winter of 1940 the ice of the open sea was not reinforced to any considerable degree after February 20, as in the winter of 1942, for a remarkable change occurred in the weather. The above-mentioned cold air pool above east Germany began to move southward fast on February 20, and by February 22 it had reached the Balkans, continuing southward into the Mediterranean region. As a result weather in the Baltic region grew milder suddenly on February 21. On February 25—26 the frost did increase temporarily, but e. g. on the eastern edge of Öland off Högby and Kapell-udden lighthouses there was open water all the time, according to the ice code reports. A stiff storm was blowing on February 27, breaking up still further the open sea ice. On March 1 the wind shifted to N and the loose ice rapidly drifted southwards. The open water off the southern coast of Sweden extended at that time as far west as Trelleborg, and the Swedish icebreaker »Atle» on route from Trelleborg to Arkona reported it as being 30 sea miles wide.

With the ice drifting south a wide lane or an area of open water also appeared off the Finnish coast in the northern Central Baltic. But the large ice masses thus set in motion closed the area of open water on the eastern coast of Sweden. The entire central and southern Central Baltic also probably filled with heavy drift ice in the same way. The »Ymer», on a course from Landsort to Danzig on March 4 met no further open water apart from a few small lanes throughout her voyage. On her return journey too she encountered no larger areas of open water.

70. The definitive culmination of the ice winter of 1940 occurred on March 8 when a SW wind set in motion the ice in the southern Central Baltic and it started to drift seawards from the German coast. The »Atle» reported the same day that ice conditions from a navigational point of view had become easier off Arkona.

The diminution of the ice and its subsequent melting and disappearance occurred in the spring in largely the same way as during the winter of 1942 (Jurva 1947).

71. There was a similarity between the winters of 1940 and 1942 in that the freezing over of most of the Central Baltic occurred during calm, frosty weather. The ice only began to move after this. But in the winter of 1940 the ice had no time to thicken to the extent that it did in the winter of 1942 and thus its mobility on both sides of the culmination was considerably greater.

B. EXTENSION OF ICE OVER THE CENTRAL BALTIC IN THE WINTER OF 1947.

72. In general freezing in the autumn of 1946 was later than usual, though ice had formed in the archipelago of the Bothnian Bay as early as during the frost period of November 10—22 (SIMOJOKI 1952).

About mid-December a strong outbreak of cold air occurred, resulting in the growth of ice, and for instance the inner skerries of the Gulf of Finland froze over. Early January saw frosty weather and further ice formation and by the middle of the month, when the weather became milder again, fast ice had formed along the entire coast of Finland. There was also ice in the open sea of the eastern Gulf of Finland as far approximately as the meridian of Pellinki and in the open sea of the Bothnian Bay up to about level with Raahe.

73. A new frost period began on January 19 and lasted without a break until past the middle of March. In this connection it may be mentioned that a cold air pool penetrated France on January 26—28 from the Ukraine; SCHERHAG (1948) has reported on the special circumstances involved on this occasion.

Ice formation was rapid during this frost period. On January 24 there was thin ice on the open sea of the Gulf of Finland as far as approximately the line Jusarö—Naissaar. January 25—26 the frost increased to very hard and the northern Central Baltic off Utö froze over on the following day. On February 4, with another increase in the frost to very hard there was rapid formation of ice and on February 7 the ice edge of the northern Baltic stretched from off Lågskär Lighthouse to Ristna Point. On February 15 the Finnish icebreaker »Sisu» reported ice 28 sea miles out from Utö, though the last stretch of this, 7 sea miles wide, was thin, new ice. So much new ice was formed on the following day that the icebreaker »Tarmo» left the vessels she had escorted in the open water 40 sea miles SSW of Utö. One of these same vessels, the »Aldebaran», reported having encountered floes further south. According to a Swedish air reconnaissance flight there was heavy drift ice off Landsort and from there to Visby mostly open water on February 21 (LILJEQUIST: *Isvintern 1946—47).*

74. Freezing in the southern Central Baltic had been remarkably rapid during the same period. Öresund froze over January 25—27 and on February 2 the ice edge stretched from Trelleborg to Stevens Lighthouse (LILJEQUIST). The easterly wind pressed the ice against the coast and by

February 8 navigation to Trelleborg was quite difficult. On February 11 a Swedish air reconnaissance flight reported heavy ice from the Danish sounds to longitude 13° E in the Baltic, (i. e. as far approximately as the meridian of Trelleborg) and from there sludge to longitude 14°E (i. e. slightly west of Bornholm); further east in the vicinity of Bornholm there was open water. Navigation via Öresund ceased after the »Atle» left for Poland on February 16 to escort the Swedish coal ships. On this voyage she encountered ice off the German coast 17 sea miles north of Hela Point. February 19 a Swedish air reconnaissance flight over the western Baltic reported an unbroken ice cover as far as a line Arkona—Adlergrund—Sandhammaren, i. e. close to Bornholm. The same flight observed that new ice had formed in Hanöbukten as well, but that east of Bornholm the southern Central Baltic was still open.

75. In the latter half of February the air pressure in Greenland had reached a remarkably high value. Cold air outbreaks to Scandinavia with a considerable change in the development of ice conditions on the Baltic. On February 22 the wind shifted to the N and increased to stiff, registering force 6 Beauf. for two of the following days. The wind set the ice in motion and a wide lane or an area of open water formed from about Russarö to about Söderarm Lighthouse. This open water, however, rapidly covered over with new ice. The area of open water with new ice grew so wide that the icebreaker »Tarmo», en route from Utö to SW encountered nothing but thin new ice, even in the vicinity of Bogskär Lighthouse in the northern Central Baltic. The »Tarmo» had a limited quantity of coal on board and did not continue to provide assistance further south. The convoy steered towards the Archipelago of Stockholm and met the edge of fast ice off Sandhammaren. At the same time a wide area of open water was reported in the east off the Estonian and Latvian coast.

At the beginning of this windy period there was mostly open water in the open sea of the Central Baltic, as the above reports indicate. As late as February 23 a Swedish air reconnaissance flight reported that the middle of the open sea between Rixhöft Lighthouse on the German coast and Öland was open or partly sludge-covered. But on the following day large floes appeared along a line Gdynia—Hoburg, or a little east of it, and these covered 8/10 of the area. The southward drift of the ice had thus begun.

The remaining open water in the open sea and the lanes were covered by ice during the hard frost of February 27, and from this date the Central Baltic was practically frozen over. As the frost continued hard until the middle of March the ice became quite thick, but stiff E winds on March 6—7 kept the ice of the open sea in motion and pressed it against the east coast of Sweden. In the southern Central Baltic the storms pressed the ice e. g. against the entrance to Öresund; off Falsterbo it was frozen to the bottom as far down even as 18 m (GRUE 1948).

76. The culmination of the ice winter in the northern waters of Denmark can be considered to have occurred by March 6—7 when the E wind mentioned above broke up the ice in the Skagerak and it drifted seawards. But in the Central Baltic the culmination was delayed until about March 14 when a stiff E wind broke up the ice and lanes were opened up here and there. The actual melting of the ice and its disappearing began about March 22 when a milder SW air current entered the Baltic area. One result of this was that on March 28 the »Ymer» was able to break a way through the heavy pressured ice around Öresund and it was possible to recommence navigation by that route after an interruption that had lasted some six weeks.

About April 5 the weather became still warmer and the ice began to diminish and disappear. On April 9 the ice started to drift seawards in the northern Central Baltic off the Archipelago Sea and on April 15 a Swedish air reconnaissance flight reported that most of the northern Central Baltic was open (LILJEQUIST).

77. The winter of 1947 proved to have quite a different character from those of 1942 and 1940. Development in the southern Central Baltic in the early winter already was abnormal in that freezing in that area proceeded very much more rapidly. Stiff easterly winds prevailing at that time drove the ice against the Danish coast and made navigation difficult. Proof of how difficult conditions were is the closing of navigation via Öresund for a period of six weeks although it continued in the northern Baltic throughout the winter, admittedly within certain limits. The main difference, however, lies in the fact that while the open sea of the Central Baltic was frozen over in 1942 and 1940 by an increase of ice, in 1947 the Central Baltic was covered with large ice masses which drifted both north-south and east-west. The lanes or the areas of open water between these ice masses then became ice-covered. The development of the spring phases, on the other hand, was almost along identical lines.

IV. A GENERAL DESCRIPTION OF SEVERE ICE WINTERS.

A. THE CARTOGRAPHICAL METHOD OF JURVA FOR STUDIES OF ICE CONDITIONS.

78. As demonstrated, especially in the last part of the previous chapter, the course of the ice winter can vary greatly in different winters. To make the ice winters comparable in spite of the great variations that occur in time and in the extent of the ice cover calls for some sort of »normal winter» or more accurate »comparison winter» as a standard. To construct such a winter JURVA (1937) has used a cartographical method of illustrating the ice conditions off the Finnish coast and the seas bordering on it. On this method JURVA (1941 a) states:

»To build up the comparison winters (from the winters of 1915—1925) ice situations as s i m i l a r as possible were used, independent of when these situations arose during the different winters — however with the limitations that on each occasion only the situation at the growing period of the ice or only that at the diminution period of the ice were regarded as similar. In other words, by d e t a c h i n g the event, i. e. the course of the ice winter from t i m e, situations were selected from different winters that were mutually corresponding and represented the same point in the general course of the winter. From these conditions, then, an »ideal ice situation» was deduced; and this in its turn formed the basis for the »normal stage», which corresponded to the actual situation used to determine this point in the general course of the different winters.»

JURVA chose as the element on which he principally based the comparisons t h e f a s t i c e f r i n g e on the Finnish coasts. Almost every winter ice gradually grows in the early winter, passing through almost identical situations. Equally it diminished by the end of the winter, passing through »spring situations». The ice outside the coastal fast ice i. e. the ice on the open sea differs much more in growth than has been observed by defining norms based on its relative occurrence, i. e. as frequencies.

79. In defining the normal winter JURVA finally arrived at the stages (Figure 35) corresponding to ice situations with a probability of 4—5/10 of the occurrence every winter because few ice situations only were available corresponding to the more severe phases and these were connected with the stage of culmination of the »normal ice winter». In this connection JURVA (1937) mentions the following:

»We can take it that the normal phases of the culmination of midwinter are divided into several new stages. The new stages of the autumnal period correspond to ice situations during which freezing in the Central Baltic is still on the increase. On the other hand the new stages appearing in the spring period of the culmination of midwinter correspond to ice situations during which the ice is diminishing from its former level. In other words, if we had enough material on ice situations the normal stages already deduced could in course of the time be completed and developed until they covered the most severe time of freezing of the Baltic and the corresponding time of the melting and thus we could define a new group of normal stages for the midwinter period.

We can add this direct to the normal stages already deduced as it is a question of calculating the amount of drift ice that has frozen solid (symbol quadrangle) and the loose and mobile drift ice (symbol triangle) and drawing the corresponding frequency curves for the open sea. In this connection especially at the culmination stages already determined, the real values of the frequency curves will of course have to be redetermined and the curves 0.09, 0.08....0.01 and so on redrawn. In addition a new

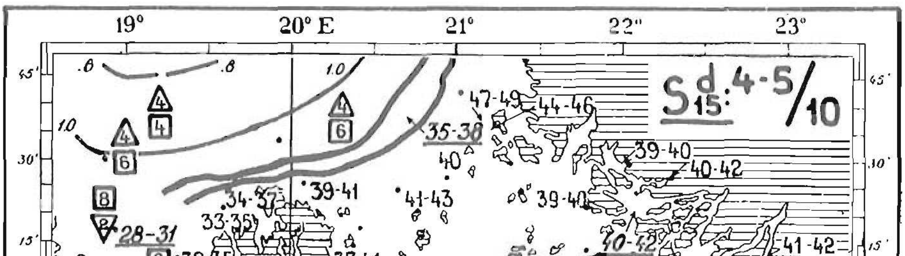


Figure 35. The culmination stage »d 15» of normal winter, defined by JURVA (1937).

determination of the times of appearance of these stages would also be necessary, i. e. to make them correspond to the dates of ice situations in the severe and extremely severe ice winters as well as to the thickness of the ice, if adequate observation material existed for the purpose.»

80. JURVA considers that the deduction of the normal stages to cover the open sea of the Central Baltic would mean above all a redetermination of the rates of frequencies and redrawing of the curves already drawn. This determination of frequencies is made considerably more difficult by the greater mobility of ice in the Central Baltic than it perhaps has in the Gulf of Finland.

It must be mentioned that in severe ice conditions the coastal fast ice edge remained nearly unchanged, disregarding the so-called extended coastal fast ice. Therefore in adapting the cartographical method of JURVA the comparison of ice conditions must be made from the ice outside the fast ice or by the ice thickness. I. e. the comparison is based on i c e v o l u m e, as JURVA (1944, 1952 b) has remarked in another connection. But since for that purpose the thickness of the ice in the open sea must also be known, and since few thickness data are available — because ships travel by the archipelago routes during such severe ice conditions — the present author had to accept the a r e a of the ice cover as a basis for the comparison. How the normal stages or better comparison stages of severe winters have been worked out will be clarified later on.

B. GENERAL REMARKS ON THE MATERIAL DURING THE WINTERS 1926—1950 AND THE REGION STUDIED.

81. The ice winters from which the general stages illustrating the wide freezing of the Central Baltic were to be defined were selected from the period 1926—1950. This decision was influenced by the fact that ice observations on the open sea were not organized internationally until after the First World War and there was a lack of scientifically adequate material, (explained more particulary in Chapter I, Material). These winters form a continuation of the winters 1915—1925, treated by JURVA.

The material of the period chosen has for Finland been partly published as general reviews of each winter in the series of the Institute of Marine Research (GRANQVIST: *Översikt*, JURVA: *Översikt*, SIMOJOKI 1952), and partly it is contained in the archives of the Institute, awaiting publication. It is illustrated in the weekly general maps or maps showing the ice situation each Friday, called »Friday-situation» maps. In other countries such as Denmark regular year books have been published *(Isforholdene, Is- og Besejlingsforholdene)*. This is the case for Germany (PETERSEN: *Die Eisverhältnisse*, OELLRICH: *Die Eisverhältnisse*, BÜDEL 1946, BLÜTHGEN 1948, NUSSER: *Die Eisverhältnisse)*, as well as for Estonia though only until the winter of 1939 (Frisch, Kirde: *Merejää vaatlused)*. In Sweden in addition to the annual reports from icebreakers *(Sveriges statliga isbrytarverksamhet)* the publications principally treat of severe winters only (Östman 1929, 1940 and 1941, Liljequist: *Isvintern 1941—42, 1946—47)*, and this is also the case in Latvia (Slaucitajs 1929 b). More concise summaries of the ice winters mentioned have been published in Russia (Arnold-Alabieff 1926, among others) and Poland. Available in addition are the daily ice reports published in the Baltic countries, some including maps on ice conditions (Finland: *Israpport*, Sweden: *Isberättelse*, Denmark: *Isberetning*, Germany: *Eisberichte)*. Investigations with means have also been taken to consideration (Frish 1933, Petersen und Oellrich 1930, Prüfer 1942, Rudovic 1917, among others).

82. As the starting-point of the study the author has chosen the »Friday-situation» maps, scale 1: 1 250 000 at the Institute of Marine Research, showing as much or more ice as in the ice situations corresponding to Jurva's (1937) important turning-point »d 15» (Figure 35). When ice conditions have changed rapidly use has been made in addition to the »Tuesday-situation» maps and, depending on requirements, sometimes maps of other weekdays as well. The basic material of the present study comprises a total of 60 maps, which, as is mentioned below, have been completed with the information gained later on, especially from the open sea.

As the maps of the Institute of Marine Research cover the sea region from the northernmost part of the Gulf of Bothnia and the easternmost point of the Gulf of Finland to about level with the northern point of Gotland the maps have been completed for the purposes of the present study to include the entire Baltic by employing a new blank map, scale 1: 2 000 000.

83. The preliminary study of the ice situation maps drawn in this way showed that in the southern Central Baltic the meridian of Bornholm seemed to constitute some sort of boundary line for the regional increase of ice from which westwards the ice conditions of the sea and the waters of Denmark form a whole. Eastwards from it the development of conditions seems to accord with development in the rest of the Baltic. Commander R. Rosted from »Statens Istjeneste» (Denmark) and the author have carried out a special study of the Danish waters which will be published in an other connection. In the present study the principal interest has been with the sea region east of Bornholm, but to give a broader view of the whole, ice picture conditions from the Central Baltic the region from the Danish sounds eastwards have also been presented. In the same way the study has been extended in the north to the meridian of Porkkala. Thus instead of the »d»-region employed by Jurva, which principally included the Archipelago Sea and the northern Central Baltic, we have a vaster region »D» stretching from the meridian of Porkkala to the Danish sounds.

C. THE REPORTS OF ICE ON JANUARY 30, 1942 AND THE DRAWING OF THE ICE SITUATION MAP.

84. As an example of how the author finally drew the ice situation maps with the aid of the whole material, e. g. supplementing the ice situation maps available, let us examine the preparation of the »Friday-situation» map on Jan. 30, 1942. This »Friday-situation» has been slected as representing the ice situation just before the definitive freezing of the central Baltic.

The »Friday-situation» map drawn at the Institute of Marine Research of the day mentioned comprises the ice conditions on the Finnish coast and off it. Ice information was restricted during the war winter of 1942, especially as regards reports from ships. The daily radiograms from the Finnish icebreakers were not transmitted in clear but were encoded. In such cases the contents of the reports were brief and there was a possibility of interpretation. The additional information was obtained by going through the entries in the ships' logs of the icebreakers and of the merchantmen in traffic at that time. The author has presented fragments of them in chapter I, section C (N. 10).

The foreign material comprises firstly the particular ice observations from stationary observation stations along the coast. From Sweden the stations included brief reports in clear, added when necessary after the daily ice code reports, e. g. the report from Hanö mentioned before (N. 8). Secondly the material comprises observations made on ships. The radiograms sent by the icebreakers and their log entries were obtained from Sweden and Denmark, e. g. the ice diary of the »Atle» mentioned in Chapter I, section C (N. 10). In addition reports from merchantmen were also obtained. Lastly reports from air reconnaissance flights from different countries have been mentioned earlier, Chapter I, section D (N. 15). For Jan. 30, 1942 there was only one Finnish and one Swedish flight report, and the observations of the former were limited to a narrow stretch from Porkkala to Utö.

85. As the particular ice observations for Jan. 30, 1942 did not cover the whole region of the Central Baltic, use was made of the map by completing it with observations made on the nearest days to the date in question. Reports from air reconnaissance flights were available from the different regions of the open sea, as appears from the following (N.B. the German flights are not included):

	Gulf of Finland	Åland Sea	Northern Central Baltic	By Gotland	Southern Central Baltic
Jan. 17	1	—	—	—	—
Jan. 27	1	—	—	—	—
Jan. 28	—	1	—	—	—
Jan. 29	—	—	1	—	—
Jan. 30	1	—	—	—	1
Jan. 31	1	—	—	1	1
Febr. 1	—	—	—	—	—
Febr. 2	—	1	1	1	1
Febr. 3	—	1	—	1	—
Febr. 4	1	1	—	1	1
Febr. 5	2	2	1	1	1
Febr. 6	1	2	—	1	—

If the weather has caused rapid changes in the conditions the observations of the days nearest to those in question naturally cannot be used as they are. The data corresponding to the situation map were derived from these observations by taking into account the weather conditions, by inter- or extrapolation. The flight over the northern Central Baltic on February 2 established that south of latitude 59°20′N there was a region of more broken ice (Figure 15). The formation of this ice region has already been discussed in connection with the description of the winter of 1942 and the conclusion was reached that the region mentioned was frozen by January 30 although the ice was very thin, one night old at the most. The ice situation map, therefore, depicts conditions as they are.

It is worth mentioning that the same region of more broken ice was established by a reconnaissance flight on the subsequent day, February 5 but its edge then lay approximately along latitude 59°10′N (Figure 16) or 10 sea miles further south than according to the flight map of February 2. From the prevailing weather conditions it would seem that the shift was in reality less great; the difference of 10 sea miles was due to the difficulty of determining the planes' exact position in flight over the open sea without a decca-instrument. In view of the flying routes and the weather conditions the former report is likely to be more correct. An error of 10 sea miles in pinpointing a position over the open sea of the northern Central Baltic seems well within the bounds of possibility, as shown in another connection (Palosuo 1952). In flying over the Gulf of Finland on the other hand the maximum error was 5 sea miles. Over the southern Central Baltic a possible error of 10 sea miles has already been encountered earlier (Richter 1933).

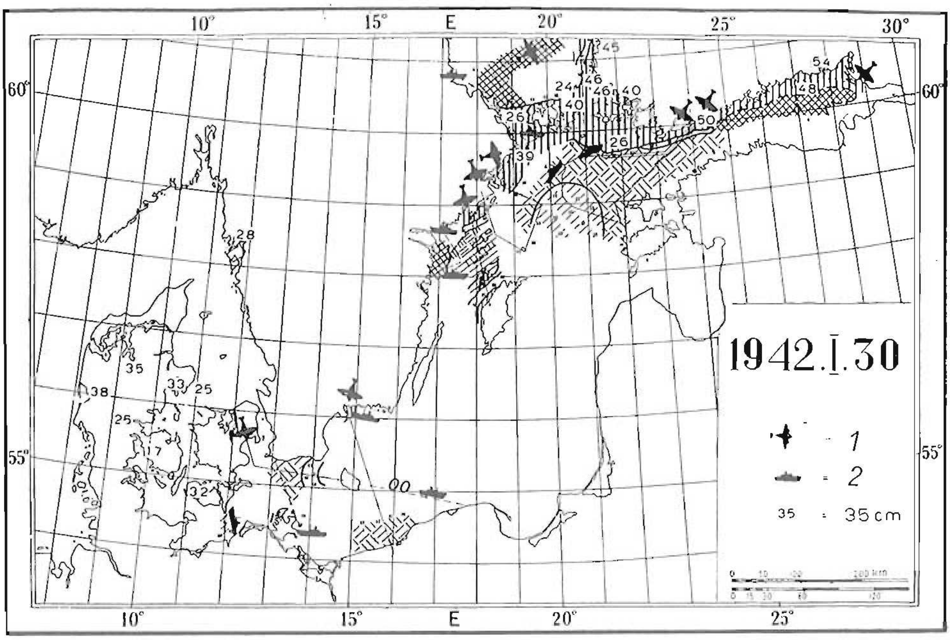


Figure 36. The special ice observations, Jan. 30, 1942, completed with observations made on the nearest days.
Explanations: 1 = reports from air reconnaissance flights, 2 = ships' reports, 35 = the thickness of ice 35 cm.

The special ice observations of January 30 and several days preceding and following are presented in Figure 36.

86. In addition to the special ice observations the actual and more accurate material had also to be compiled in order to complete the map of ice reports given according to the Baltic ice code, reports which could only qualitatively describe real ice conditions.

The code reports for January 30 have been marked on the map for each report region (Figure 37). It appears from the map that there were report regions all over the Baltic coast, the Danish waters having more stations, as marked on the map. Where an ice report was occasionally missing, i. e. a case like the report from Utklippan: X9, instead of the first figure the symbol X has been used which, as the ice code states, means that ice conditions are unknown because of bad visibility or some other obstruction (N.9) — in such cases the value has been deduced by means of interpolation from the values of the nearest day, i. e. January 29 to NW 50, NE 84, SE 84, SW 74 and January 31 to all directions 74. The deduced value for January 30 is 74 all directions and it has been given in parenthesis. When the ice reports are missing from a longer period, as for example for part of the Latvian and Estonian coasts, it has not been possible to complete the report.

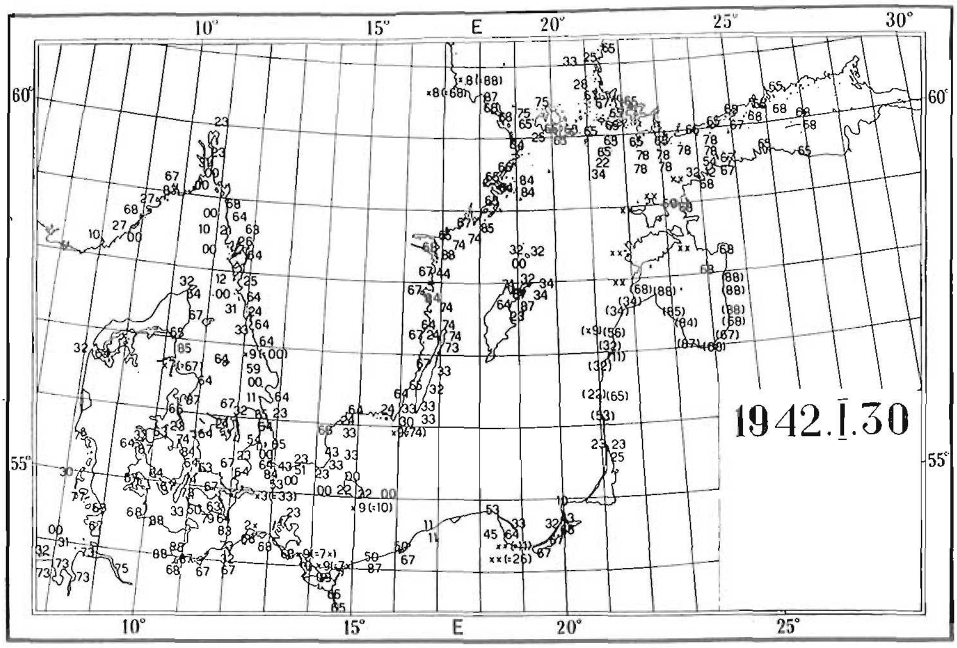


Figure 37. Ice code reports, Jan. 30, 1942. The figures (explained in more detail in N. 9) have been marked for each report region. Where an ice report was occasionally missing, i. e. because of bad visibility or some obstruction, the values have been deduced by means of interpolation from the values of the nearest day and given in parenthesis.

In addition to the advantage that there were ice code reports from all over the Baltic coast, ice reports of this sort are important because they always evaluate the ice situation according to the same principles, incomplete though they are. There must have been some different interpretations of the code, both among private observers and in the different countries. For example in the southern Baltic 15 cm thick ice has been reported as heavy fast ice or I = 6 (Stakle 1936), whereas in the region of the northern Baltic, where the ice grows quite thick nearly every winter, this measurement is rated at a slightly higher value.

In such closed regions as harbours, bays and offshore waters in the archipelago, where the freezing and melting of ice occur nearly simultaneously and equally over the whole region, the codes provide a picture of the ice conditions subject to only very slightly different interpretations. But the code reports from the open sea are not always accurately determined as far as the extension of ice is concerned. Thus on January 30 the report was In = 00, or open water, SW of Gotska Sandön; this has been taken to mean a wide lane opened in consequence of the moving of the ice on the leeside of the island. Before January 30 Gotska Sandön had been surrounded by drift ice in every direction.

87. Ice observations (Figure 36) and ice reports (Figure 37) transferred

to the master map did not cover the whole of the central Baltic. Regarding the former development it can be concluded that the central part of the Central Baltic was still open, although it has not been possible to determine the exact position of the ice edge. In determining the position of the ice edge on the Pomeranian coast the starting point adopted has been the Swedish reconnaissance flight which reported on January 31 that the ice edge was situated 35 km from Kolberg (Figure 5). Bearing in mind the code reports from the German coast stations a zone was drawn from Kolberg eastwards parallel to the coast (this principle cannot be used during the drifting of ice, especially in spring time). From Kolberg westward the ice edge was drawn to near Bornholm. On the last day of the month, according to the train ferry, there was only new ice from Sassnitz to latitude 54°40′N, and drift ice from there to Trelleborg *(Eisbericht* N:o 41/1942. II. 1). The new ice mentioned had probably covered a wide lane that formed in consequence of the S wind at the end of January.

As there was no other ice information from the open sea north of the Pomeranian coast the extension of the ice has been estimated to be the same as during other rigorous winters and the ice edge has been drawn in to correspond with them. Such was the situation e. g. in winter of 1929 *(Iso Tietosanakirja* 1933) and of 1941 *(Atlas,* Deutsche Seewarte, 1942). That this procedure resulted in an approximation to the true situation was clear by the further progress of the ice winter.

The final ice situation map on Jan. 30, 1942 has been presented in Figure 38.

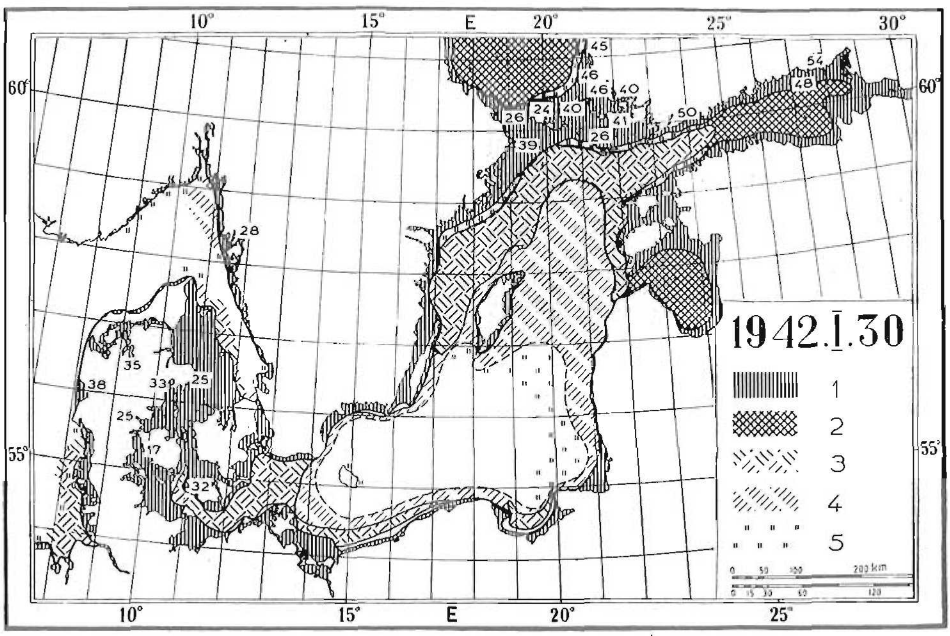


Figure 38. The final ice situation map on Jan. 30, 1942.
Explanations: 1 = fast ice, 2 = drift ice, frozen solid, 3 = drift ice, loose, 4 = new ice, 5 = sludge.

D. THE DIVISION OF THE ICE SITUATION MAPS INTO MAIN AND SUB-GROUPS.

88. As the ice situation maps were completed they were then grouped according to principles similar to those adopted by JURVA (1937) by defining the normal stages.

First the ice situation maps were classified by grouping them in three main groups according to whether the situation belonged to the period of growth, culmination or diminution of ice. This division proved to be easy to perform; in the midwinter phases only was there any doubt about grouping, depending on how the culmination was determined. As pointed out earlier, the length of culmination differed very much. In some cases it was reduced to a culmination moment, in others it was a fairly long culmination period.

89. This division into main groups was followed by sub-groups. For this purpose the approximate limits of the sub-groups were taken as the outer edges of ice corresponding to the most extensive freezing of each winter. In »favourable» cases, i. e. when the freezing occurred during the same weather conditions, e. g. during a calm frost, these edges seemed to lie in certain zones (Figure 39) and thus to provide means

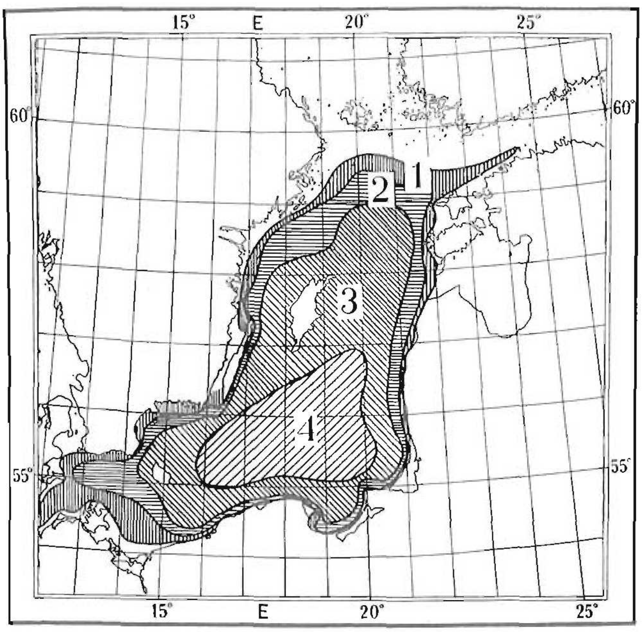


Figure 39. Certain zones in which the ice edges of sub-groups $D_{15}1$—$D_{15}4$ seemed to lie.

for a sub-grouping similar to that used by JURVA, in defining the normal stages. With the aid of the »limits» of the most extensive freezing it was possible to construct 4 phases corresponding to the stages of the growth period of ice. The peak stage has been determined as the stage corresponding to the phase preceded by the definitive freezing of the Central Baltic and during which the ice thickness on the open sea of the Central Baltic has reached a very high value, as in the winter of 1942 at the turn of February—March. In the last main group were placed the phases of diminution and disappearance of ice, giving 4 groups in all, each corresponding to a different stage of diminution. So the actual position of ice edges appearing in nature were obtained for each sub-group — separately for the stages of the growth period of ice and for those of the diminution of ice — to show the various stages in the general course of ice winter. The final general or »D-stages» were then defined from these sub-groups.

With sub-groups approximately defined by their limits, the final grouping of the ice maps was made according to the area of the ice cover. For instance in one sub-group, in addition to the »favourable» cases mentioned earlier (where the ice edges were almost the same) were included situations in which the ice edges differed from the former in shape but where the area of ice cover was almost the same. The ice situation maps to be grouped were, as has been mentioned earlier, predominantly ice situation maps on Friday. But if two consecutive »Friday situation» maps registered such a rapid change that some definite stage was omitted in between an additional ice situation map was drawn for Tuesday or sometimes for other weekdays as well. So for each sub-group in each winter there was at least one map for every phase up to that corresponding to the most extensive freezing.

The final grouping of the ice situation maps is presented diagrammatically in Figure 40. The D-stages have been marked on the figure corresponding to the freezing- over of the Central Baltic examined in the dark-coloured region. The figure has been completed with the analysis of the d-regions (corresponding to the freezing of the Archipelago Sea and the northern Central Baltic, JURVA 1937, 1944 and 1947, SIMOJOKI 1952). JURVA numbered the stages of the d-region so that »d 1—d 14» corresponded to the stages of the growth of ice, »d 15» to the culmination or change-point of the normal ice winter and »d 16—d 25» to the diminution and disappearance stage of ice. The present author has correspondingly marked the stages of the more extensive D-region studied (from the meridian of Porkkala to off the Danish sounds) so that »$D_{15}1$—$D_{15}4$» correspond to the stages of the extension and growth of ice, »$D_{15}5$» the most extensive freezing and »$D_{15}6$—$D_{15}9$» the stages of diminution of ice. The D-stages thus constructed form a natural continuation of JURVA's stages in that they determine more precisely what the peak stage »d 15» of the ice

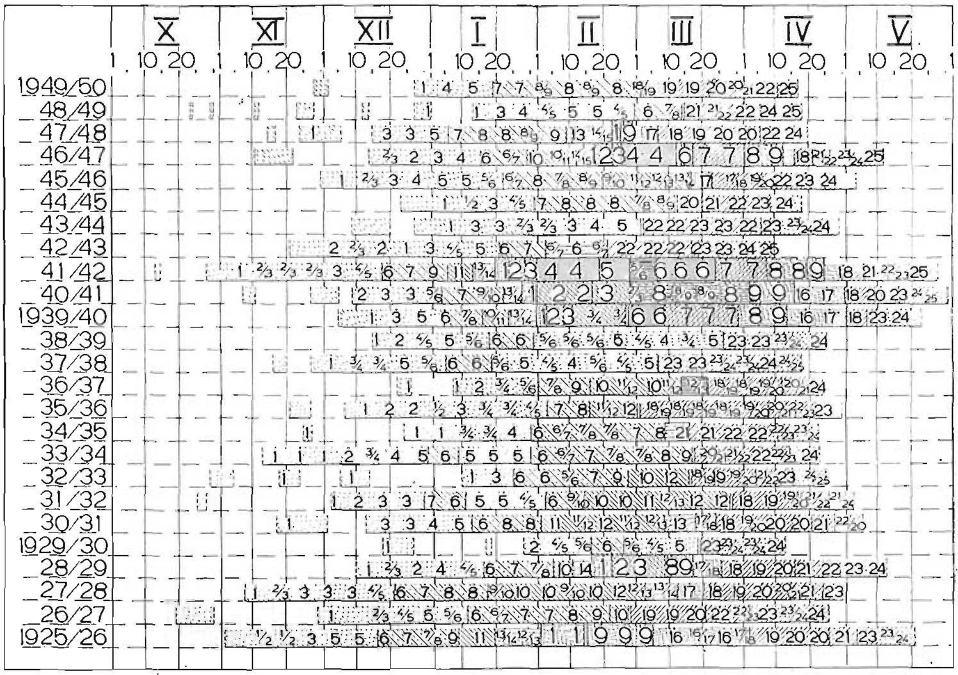


Figure 40. Analyses of ice winters 1926—1950, or the dates of the ice situation reaching the corresponding normal stages in the development of winter. The analyses from the Central Baltic region, $D_{15}1$—$D_{15}9$, are given in the darkest part of the figure. Those from the Archipelago Sea and the northern Central Baltic, d 1—d14 and d 16—d25, are entered in the lighter-coloured parts of the figure (JURVA 1937, 1944, 1947, SIMOJOKI 1952).

winters worked out by JURVA actually is and, in a way, they fulfil JURVA's previously quoted demand for the definition of new stages.

It must be mentioned that during the fairly long culmination period (marked in Figure 40 with horizontal lines) the ice situations can be counted to both the period of growth and the period of diminution of ice. The author has marked in the figure only one of these possibilities.

E. DETERMINATION OF THE FREQUENCY RATES AND CURVES OF THE ICE EDGES IN THE SUB-GROUPS.

90. After the final grouping of ice situation maps the determination of the fequency-rates of the ice edges in each sub-group was carried out according to the method of JURVA (1937).

For this purpose the ice edges of each sub-group were transferred to special so-called »collection maps». For example sub-group $D_{15}3$ had a total

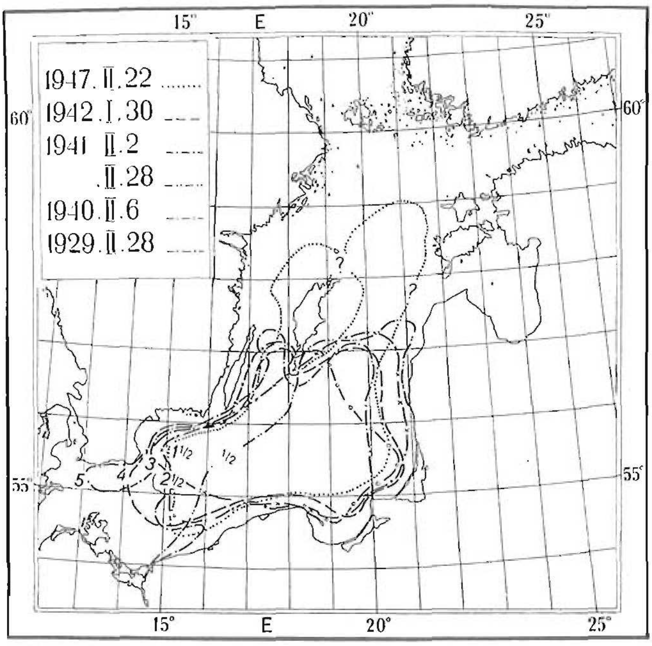


Figure 41. Ice edges in sub-group $D_{15}3$ and their relative frequency rates corresponding to the weights of ice edges beginning from the outermost edge.

of six ice situation maps and different edges on the collection maps (Figure 41). As can be seen from this map, most of the ice edges lay within a comparably narrow zone (width 40—60 km); a few only, e. g. 1947 and 1941. II. 28 show any great difference from this zone of the edges. This difference in position arises from the prevailing meteorological circumstances only. It is noteworthy that the ice of the open sea at this phase is still very mobile and the edges are shaped above all by the prevailing winds. But the area of the ice cover is nearly the same in each ice situation.

91. With the ice edges transferred to the collection maps, the frequency rates corresponding to these curves were calculated. Each edge curve no the collection map was given its own weight. In cases like the winter of 1942, sub-group $D_{15}3$, when there were two ice situations on Jan. 30 from the whole winter, it was given the weight 1. In winter 1941, in the same sub-group, there were a total of two ice situations on Febr. 21 and 28 and both of them was given the weight 1/2. Thus the total weight of each winter in question was 1. In this way, when the material available was very small, no particular winter with a great number of ice situations was able to dominate and possible peculiar traits of this winter were prevented from playing too decisive a role.

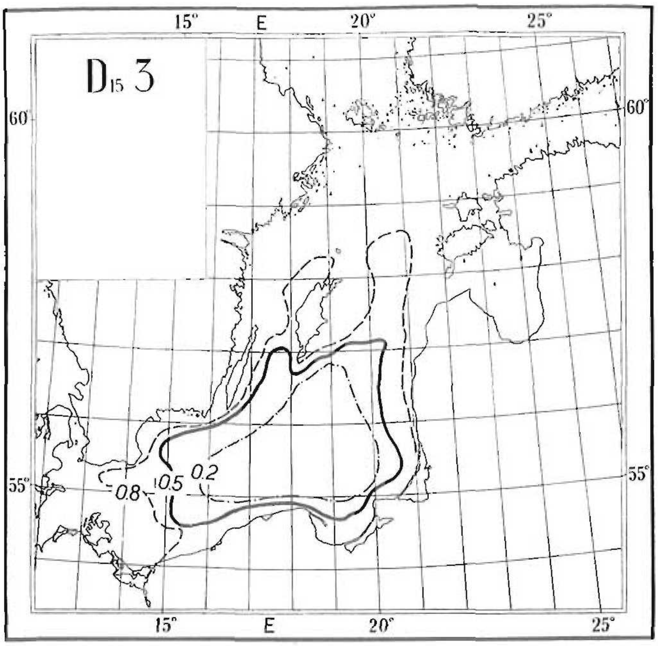


Figure 42. The relative frequency curves of ice edges, 0.2, 0.5 and 0.8, in sub-group $D_{15}3$, determined by values of Fig. 41.

The frequency rates were obtained simply by counting the weights, beginning with the outermost edge. In this way the innermost ice edge always had a frequency rate as high as the number of winters from which the ice situations of the sub-group had been taken. In sub-group $D_{15}3$ this was 5. Dividing these frequency rates by the number of winters mentioned gave the relative frequency rates. The absolute frequency rates of these could be obtained by multiplying the latter rates by the every-winter-probability of this stage.

92. Having found the relative frequency rates corresponding to the ice edges on the collection map, new relative frequency curves were drawn by using special, transparent, so-called combination maps. These, working from the coast seawards, gave the following frequency rates: 0.8, 0.5, 0.2 and 0.0—0.1 (Figure 42).

92. As the number of severe ice winters available for the cartographical study was small some of the sub-groups had few situations only. Since, in addition, the ice situations available could have been formed during »favourable» or »unfavourable» circumstances vis-à-vis the normal stage under definition, some sort of final graphical smoothing had to be made in comparisons with the successive normal stages. The smoothing cor-

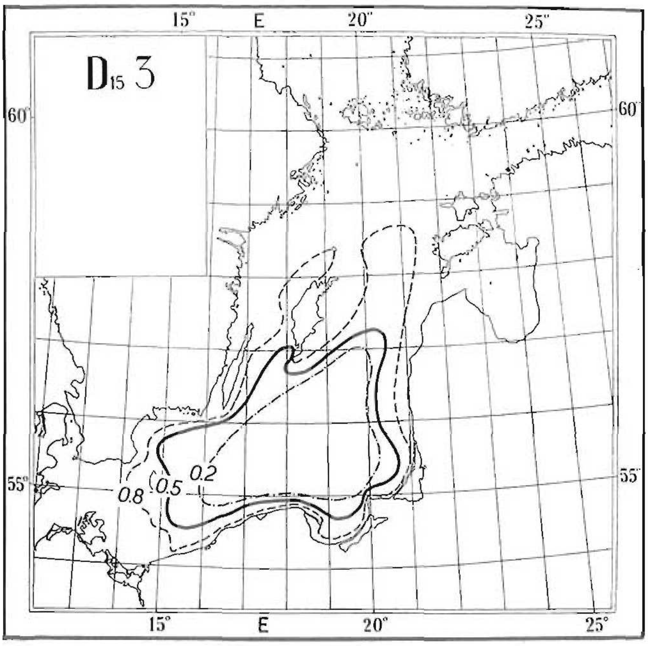


Figure 43. Final, smoothed, ice edge frequency curves 0.2, 0.5 and 0.8 in sub-group $D_{15}3$.

responds to that used by JURVA. This completed the final shape of the normal stage $D_{15}3$ (Figure 43), although the symbols referring to the various kinds of ice and the every-winter-probability and the occurrence times of the stage were still lacking.

The other normal stages D corresponding to other severe ice winters were built up similarly, and the most extensive freezing of the Central Baltic was thus depicted by nine D-stages, $D_{15}1$—$D_{15}9$ (Chapter I). Because of defiences in the material some rectification of the limits may be necessary.

F. THE COMPLETION OF THE NORMAL STAGES BY USING SYMBOLS DEPICTING THE MOBILITY OF ICE.

94. Mobility is a characteristic of ice in the open sea and it has a decisive effect on the development of ice conditions. As has been seen earlier, the mobility of ice is very great while the ice is still thin. The mobility remains considerable, though more limited, when the ice grows in thickness.

The direct observations on ice movements have been obtained from ships' reports or, for Finland, from the notes made at the coastal observation stations. The observations of ice movements, however, are generally incomplete. They have therefore been supplemented, due consideration being paid to weather conditions, above all wind conditions, and the corresponding changes in the position of the ice edge. From these conditions conclusions have been drawn as what the movements of the ice may have been. This mobility of ice has been depicted by symbols, as was done by JURVA. These indicate for each normal stage whether the ice is loose and mobile (symbol triangle) or frozen solid and immobile (symbol quadrangle).

95. To determine the mobility of the ice firstly the duration or periods of the ice situations corresponding to different stages were worked out by analysing the course of the ice winter. For example in winter 1942 on January 29 the development of freezing had advanced so that the ice edge reached inside the edge zone corresponding to the stage $D_{15}3$, and it lasted until January 31 when freezing had spread to the edge zone of the subsequent stage. The period of stage $D_{15}3$, hence, was in this winter only 3 days. The periods of appearance of the different stages are marked in the diagram of sub-groups of ice situations (Figure 40). During the winters of 1926—50 the periods of the stage $D_{15}3$ made a total of 24 days in all.

96. When the periods of different stages had been determined a study was made of how many days the ice has been on the one hand loose, on the other hand frozen solid. Off Utö, for example, on 19 days of the 24 days of appearance of stage $D_{15}3$ there was loose ice and on 5 days frozen-solid ice. Expressed in decimals 0.8 was the primary value for loose ice (8 in symbol triangle) and 2 for frozen-solid ice (2 in symbol quadrangle) in relation to the total duration of the stage.

The loose ice was, moreover, directly joined to the fast ice edge for 7 days, whereas on 12 days a lane parallel to the coast ran between the fast ice edge and the loose ice. For these latter cases a new symbol is employed for the lane, = =, thus completing the general symbol of loose ice. By also expressing this value in decimals as a proportion of the total duration of the stage $D_{15}3$ we obtain in the case in question 5 for the symbol = = the lane parallel to the coast (5 between two equation signs).

The value of 2 of frozen solid ice, the second value 3 of loose ice (i.e. the primary value 8 of loose ice subtracted by the value 5 of the lane) and the value 5 of the lane are marked on the map providing a picture of the sea ice off Utö during stage $D_{15}3$.

Because of the differences in the observation material the exact determination of the symbols depicting the mobility of ice has not been possible elsewhere than off the Finnish coast. Hence these symbols in the maps present the normal stages (above all) off the Finnish coast only.

G. ICE THICKNESS MEASUREMENTS.

97. The linking of ice thicknesses with the normal stages, which above all are constructed on the basis of the extension of ice, is a difficult task. This difficulty becomes quite clear in the post-culmination stages when the thickness of ice in general continues to grow even after the culmination. At all events it was found necessary to include the ice thicknesses in this study and to present them in the same form as JURVA does the means of ice thickness.

Ice thickness measurements were performed at the stationary observation stations on the Finnish coast and for the most part in the area of fast ice. In the open sea, however, the measurements of ice thickness were generally occasional and performed mainly by icebreakers. In severe winters when navigation e. g. via Utö had ceased, no ice thickness measurements were obtained from the northern Central Baltic.

The study has been restricted to a determination of the mean thickness of ice at certain points of the fast ice region in the Archipelago Sea and the Gulf of Finland. These points are Lypyrtti sound, sea outside Lypyrtti, Enklinge, Märket, Utö, Naantali, Gullkrona and Barösund.

Of the ice thickness measurements made at the stations chosen the ones pertaining to the ice situations of which the normal stages had been worked out were selected. If in some case the ice thickness rate had not been given for the day in question it was interpolated from the measurements of the nearest days. The ice thickness values corresponding to each normal stage was calculated from these values. Thus for instance for the normal stage $D_{15}3$ we had the following ice thicknesses, the means of which were worked out:

	Lypyrtti sound	Lypyrtti sea outside	Enklinge	Märket	Utö	Naantali	Gullkrona	Barösund
1947. II. 21	39	46	45	26	28	53	50	48
1942. I. 30	46	46	40	26	26	40	41	50
1941. II. 19	39	47	50	43	26	29	50	42
1940. II. 8	43	38	50	26	34	40	—	40
1929. II. 28	53	53	47	—	—	29	46	45
Mean	44	46	46	30	29	38	47	45

Finally it is necessary to allow a certain smoothing so that the ice thickness values at the normal stages following each other form an evenly changing series. The final ice thickness values have been marked by figures on the maps of the normal stages at each observation point.

H. THE OCCURRENCE TIMES OF THE NORMAL STAGES AND THEIR PROBABILITIES.

91. For the real course of the severe ice winter to be presented with the help of these normal stages the time at which they occur must be determined, i. e. how quickly they follow each other.

For this purpose, on the basis of the general course of the ice winter, a determination was always made as to which ice situation at each time best corresponded to the normal stage in question. For example: the ice situation of January 30 in the winter of 1942 corresponded to the normal stage $D_{15}3$ and had also been used in its defining. But in the winter of 1941 it was considered that the situation of February 19 best corresponded to this normal stage, although the ice situation maps of February 21 and 28 have been used in its defining. In such a case, when the ice edge remained in the zone of the ice edges of the normal stage for a longer period of time in the same winter, the time taken as the occurrence time of the stage, as before, was the period when the ice edge seemed to be in its average position. Thus the following times were obtained for the normal stages $D_{15}3$ and $D_{15}4$:

	$D_{15}3$	$D_{15}14$
	1947. II. 24	1947. III. 1
	1942. I. 30	1942. II. 2
	1941. II. 19	—
	1940. II. 10	1940. II. 10
	1929. II. 28	—
Mean (1926—1950)	II. 16	II. 10

To compare this value with the values of former winters up to the winter of 1880 it was estimated that the normal stages $D_{15}3$ and $D_{15}4$ had occurred approximately at the following times:

	$D_{15}3$	$D_{15}4$
	1917. III. 15	—
	1893. II. 2	1893. II. 4
	1888. III. 6	1888. III. 10
	1881. II. 6	1881. II. 14
Mean (1915—1950)	II. 20	II. 14
Mean (1880—1950)	II. 15	II. 16

It has been possible to define the so-called comparison winter on the basis of the average occurrence times of the stages obtained in this way. In Figures 44—45 these average occurrence times of each normal stage (calculated in the first place from the period 1915—1950) have been indicated with crosses.

92. Since freezing has its certain maximum speed, as shown by JURVA (1947), the occurrence of the ice situations corresponding to the various stages of freezing must be earlier the more extensive the ice-covered area during the winter. For instance, the total freezing of the open sea of the Central Baltic, corresponding to stage $D_{15}4$, occurs, in the above cases only if the preceding stage $D_{15}3$ is reached relatively early. As stage $D_{15}3$ was reached as late as on March 15 in the winter of 1917, the open sea of the Central Baltic could no longer freeze over and the ice began to diminish rapidly in the southern parts of the Baltic.

If the occurrence times corresponding to the normal stages are placed in chronological order, as has been done by KANAVINS (1947), the above-mentioned example involving the $D_{15}3$ and $D_{15}4$ stages will assume the following form:

$D_{15}3$		$D_{15}4$	
(1942)	I. 30	(1942)	II. 2
(1893)	II. 2	(1893)	II. 4
(1881)	II. 6	(1940)	II. 10
(1940)	II. 8	(1881)	II. 14
(1941)	II. 19	(1947)	III. 1
(1947)	II. 24	(1888)	III. 10
(1888)	III. 6	—	
(1917)	III. 15	—	

As the winters of 1880—1950 — 71 winters in all — are included in this review, the earliest date of occurrence for stage $D_{15}3$, i. e. January 30, has a probability of 1/71, the second date of occurrence, February 2, a probability of 2/71 etc. From this, the following dates of occurrence can be computed corresponding the probabilities 0.01—0.03, 0.05 and 0.10:

Probability (1880—1950)	$D_{15}3$	$D_{15}4$
0.01—0.03	I. 30	II. 2
0.05	II. 7	II. 12
0.10	III. 6	—

By computing the corresponding values for the period 1915—1950 — 36 winters — we get the following dates of occurrence:

Probability (1915—1950)	$D_{15}3$	$D_{15}4$
0.01—0.03	I. 30	II. 2
0.05	II. 7	II. 9
0.10	II. 20	—

The values 0.01—0.03 represent the extremely early occurrences generally occurring in severe winters as in the winter of 1942. The final values, computed in the first place for the period 1915—1950, are entered in the top left corner of the maps showing the normal stages (Chapter I).

93. A perspicuous picture of the probability of occurrence of the normal stages and of the corresponding dates can be obtained by illustrating graphically. The dates are entered on the abscissa of the coordinates, the normal stages being placed consecutively along the ordinate (using the area of the ice cover as a unit). If the winters of 1880—1950, 71 winters in all, are used to start with, the probability value 1/71 = 0.01 is entered in stage $D_{15}3$ against January 30, the value 2/71 = 0.03 against February 2, etc. These entries can be seen in Figure 44, though there the probability values have been computed for the winters of 1915—1950. If the values corresponding to one and the same probability are connected up into curves a some sort of time diagram is obtained from which the course of a severe winter can be demonstrated. However, it must be noted that the occurrence times corresponding to one and the same probability need not necessarily belong to one and the same winter.

Figure 45 (bottom part, area D) shows probability values, computed from the above values, for certain dates of a month, i. e. the 1st, 6th, 11th,

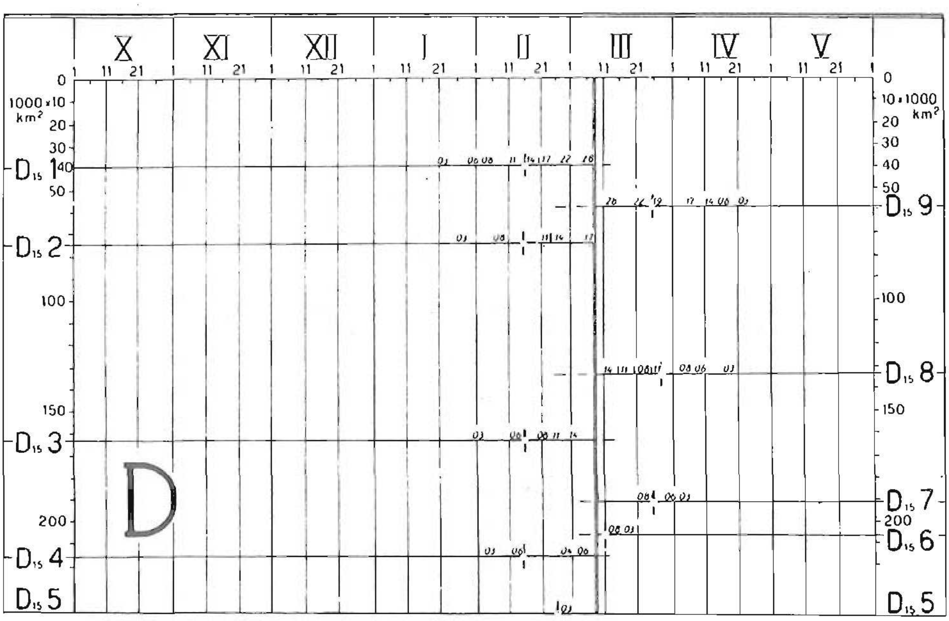


Figure 44. The probabilities of the occurence of the normal stages $D_{15}1$—$D_{15}9$ marked on a diagram with the abscissa the time and the ordinate the area of ice cover. The probabilities are counted from the ice winters 1915—1950.

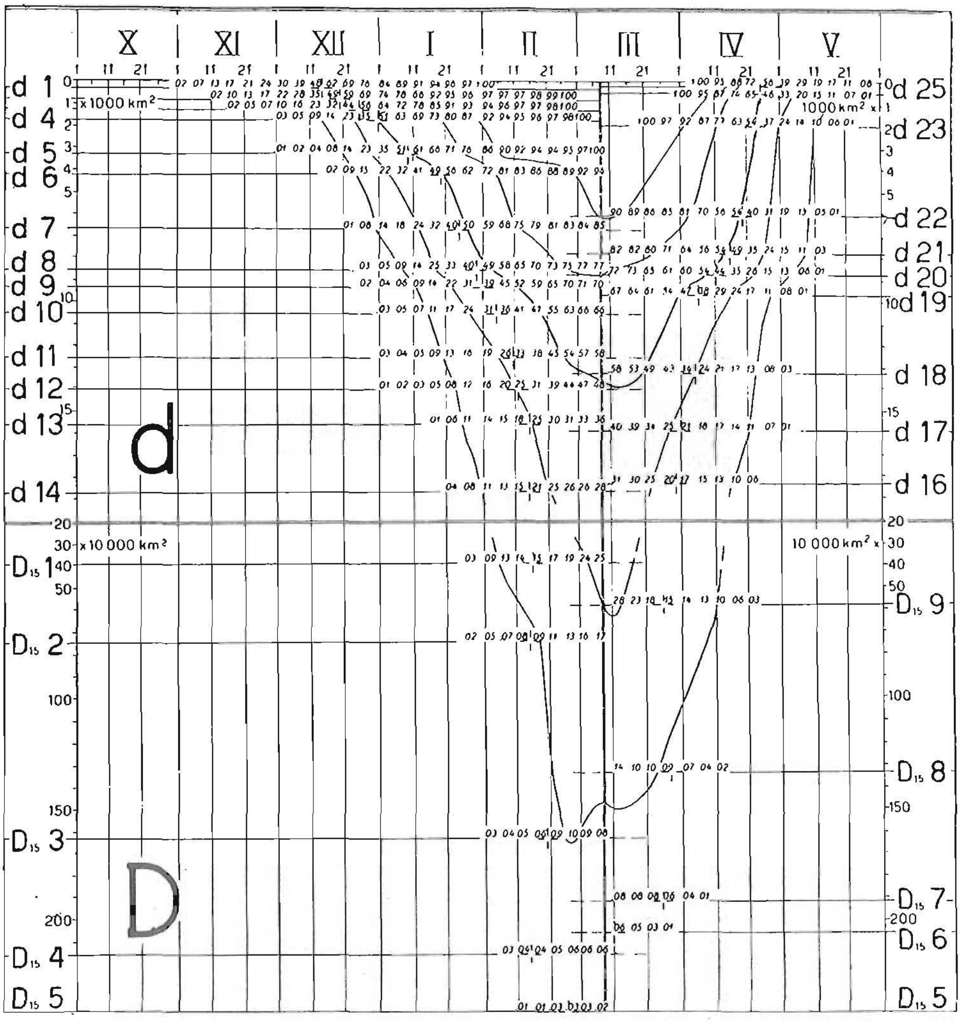


Figure 45. The probabilities of the occurence of the normal stages d 1—d 14, d 16—d 25 (top part of the diagram) and $D_{15}1$—$D_{15}9$ (bottom part of the diagram). The probabilities are counted to the 1st, 6th, 11th, 16th, 21th and 26th of the month from the ice winters 1915—1950. In the top part of the diagram (d) the unit of area of ice cover is 1 000 sq. km and in the bottom part of the diagram (D) the unit is 10 000 sq. km.

16th, 21st and 26th of each month. In addition, Figure 45 (top part, area d gives the corresponding probabilities for the winters of 1915—1950 computed for JURVA's (1937) normal stages d 1—d 14 and d 16—d 24. The curves drawn correspond to the probabilities of occurrence of 0.10, 0.25, 0.50 (thick line), 0.75 and 0.90.

94. As mentioned in the introduction, the author has compared the ice situations with the aid of the area of the ice cover. To this end the surface area of each normal stage was determined by planimeter along frequency curve 0.5. This method gave the following surface areas for the D-stages defined (total surface of area D: 215 500 sq. km. = Central Baltic 202 000 sq. km. + Archipelago Sea 8 300 sq. km. + Åland Sea 5 200 sq. km.):

The stages of growth of ice		The stages of diminution of ice	
↓ $D_{15}1$	39 720 sq. km.	↑ $D_{15}9$	74 710 sq. km.
$D_{15}2$	58 520	$D_{15}8$	134 275
$D_{15}3$	151 330	$D_{15}7$	191 700
$D_{15}4$	215 500	$D_{15}6$	205 260
($D_{15}5$)		($D_{15}5$)	

Taking the surface areas of ice as the ordinate of the socalled time diagram described above, with 10 000 sq. km. as the unit, gives the picture shown in Figure 44 for area D. For greater clarity the corresponding values of JURVA's d-stages are entered in Figure 45, top part. However, because of the small extent of the ice, the unit employed in the latter case is 10 times smaller, i. e. 1 000 sq. km.

This method of presentation offers the advantage of making the ice situations in the immediate vicinity of the culmination comparable, a necessity from the point of view of continuous presentation. As the average date of culmination in the winters of 1915—1950 in the district of the Archipelago Sea and the northern Central Baltic was March 8, the figure has been divided into two parts at this point. The stages illustrating the freezing may naturally occur also on the right-hand side of the dividing line and, conversely, the stages illustrating the diminution of the ice on the left-hand side. It is to be noted that in ice situations like $D_{15}3$—$D_{15}8$, illustrating severe ice conditions in which the culmination is determined from the occurrences of the southern Baltic, the date of the culmination is generally earlier than March 8, being governed in the first place by the occurrences of the northern Baltic.

95. Due to the great variations in the date of culmination the real maximum value of occurrence of the ice stage need not show in the probabilities of the occurrence of the stages computed for individual dates, i. e. the probability of occurrence every winter of the stage; this value must be determined separately. As e. g. stage $D_{15}4$, the total freezing-over of the Central Baltic, in the 36 winters of 1915—1950, occurred three times (in the winters of 1947, 1942 and 1940), the value of probability of occurrence every winter obtained for stage $D_{15}4$ will be 3/36 = 0.08. The corresponding value obtained for the winters of 1880—1950 (winters 1893, 1888 and 1881 too) is 6/71 = 0.09. If, for the sake of comparison, the study is extended to the 120 winters of 1831—1950, it is found that in addition to the winters indicated above the total freezing-over of the open sea of the

Central Baltic occurred in 1877, 1871, 1855 and 1838, making a total of 10 times (SPEERSCHNEIDER 1915, 1927). This gives the value of 10/120 = 0.09 for the probability of occurrence of stage $D_{15}4$ every winter. It may be mentioned that SPEERSCHNEIDER (1915) reports that the Central Baltic was frozen over 3 times in the 18th century, 3 times in the 17th century, 1 time in the 16th century and 3 times in the 15th century. JURVA (1929) obtains the value > 0.05 for the probability of occurrence every winter of the total freezing-over of the Central Baltic.

The final probabilities of occurrence every winter of the various stages are entered in the top left corner (undermost in the text) of the maps showing the normal stages.

96. In order to obtain some idea of the course of the various types of winters the author has grouped the ice winters of 1915—1950 by the normal stage reached by the ice situation in the winter concerned by February 1. The classification of the ice winters was as follows:

Normal stage	Winter
d 1—d 4	1949, 1944, 1930, 1925
d 5—d 7	1945, 1943, 1939, 1938, 1937, 1936, 1935, 1934, 1933, 1932, 1927, 1923, 1919
d 8—d 10	1948, 1947, 1946, 1931, 1929, 1928, 1918, 1915,
d 11—d 13	1924, 1922, 1921, 1920, 1917, 1916
>d 14	1942, 1941, 1940, 1926

In each group the average course of the ice winter was determined from its beginning to its end and entered in Figure 46. (In each group the average course, or the curve corresponding to a probability of 0.50 was drawn as a thick line; in addition, the area limited by the probabilities 0.25 and 0.75 was shaded.)

The figure shows that the group of severe winters generally distinguishes itself from the others by the end of January. An exception is e. g. the winter of 1947, when the ice situation had only reached the normal stage of d 10 in its development by February 1, whereas March 1 the whole open sea of the Central Baltic was frozen over. The course of the ice winters in the different winters in fact is very varying; there are hardly two similar winters to be found.

The present investigations into the severe ice conditions of the open sea of the Central Baltic is based on relatively limited material. Later investigations may produce details which, due to the incomplete material, have had to be left undiscussed here or confirm results which must remain unchecked in the present work. However, as severe winters

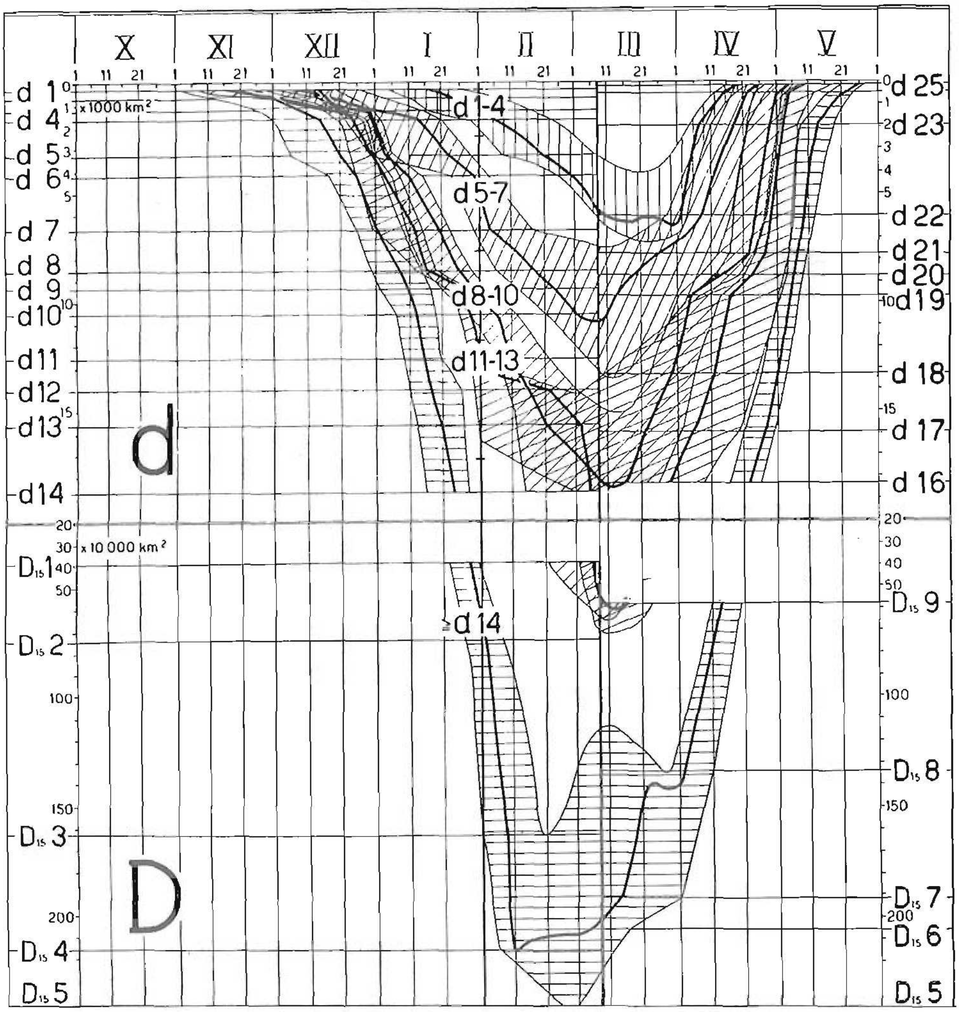
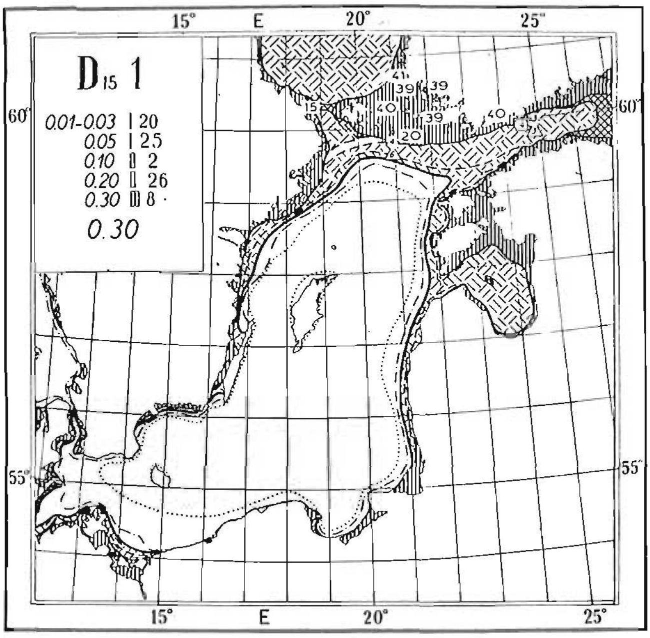


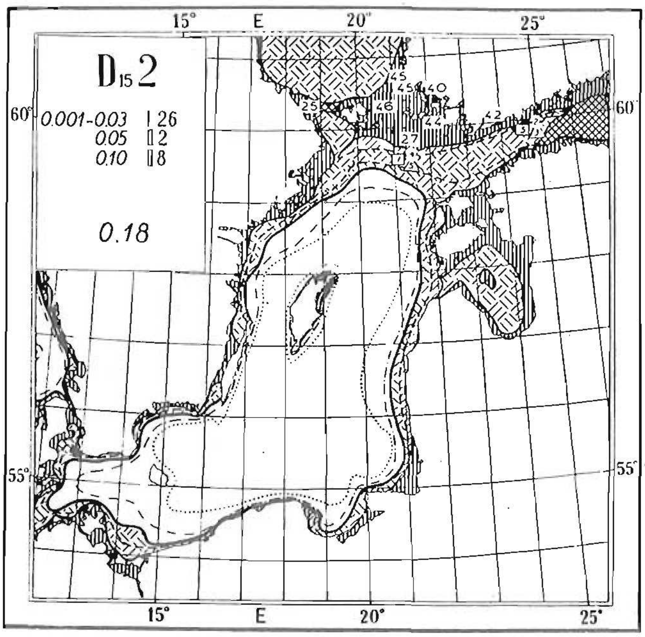
Figure 46. The general course of different winters. The winters 1915—1950 are classified according to the ice situation on February 1 and in every class the probabilities 0.25, 0.50 (thick line) and 0.75 are counted.

in the Central Baltic are rare it may be long before such investigations can be undertaken again. For this reason the author has tried, with the material available, to give an idea of the course of a severe ice winter and to investigate the possibility of making a mutual comparison of several ice conditions.

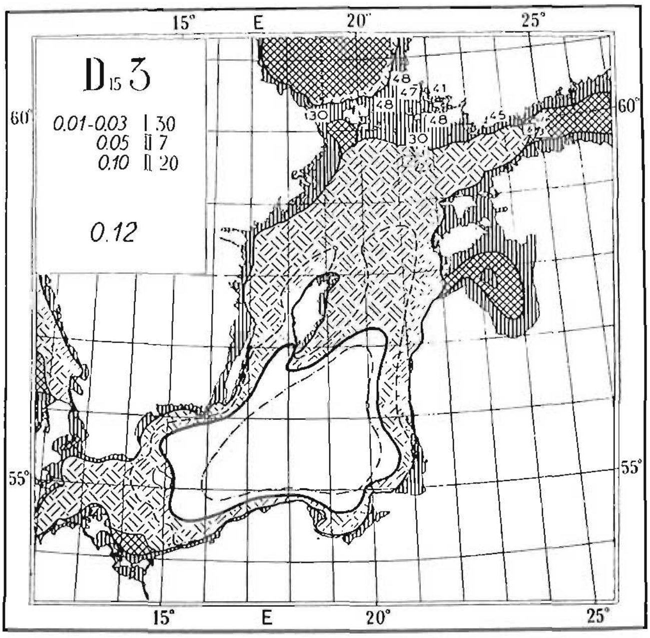
I. THE NORMAL STAGES CORRESPONDING SEVERE ICE CONDITIONS IN THE CENTRAL BALTIC.



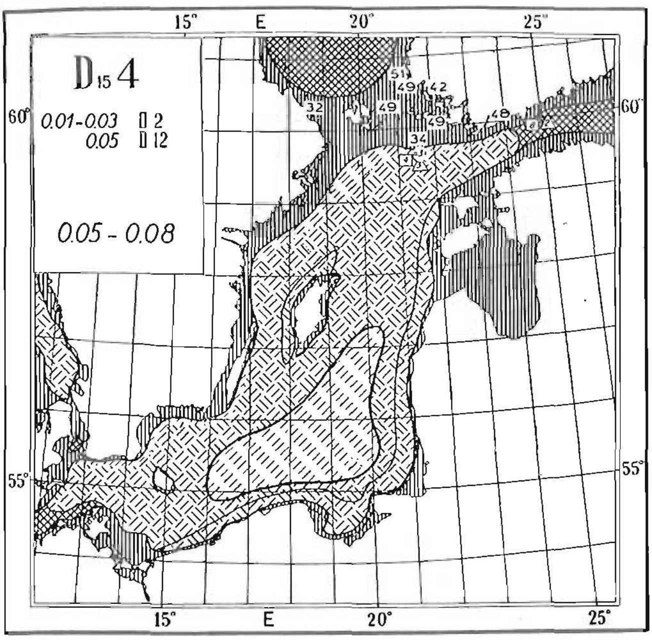
The normal stage $D_{15}1$.
(Explanations afterwards.)



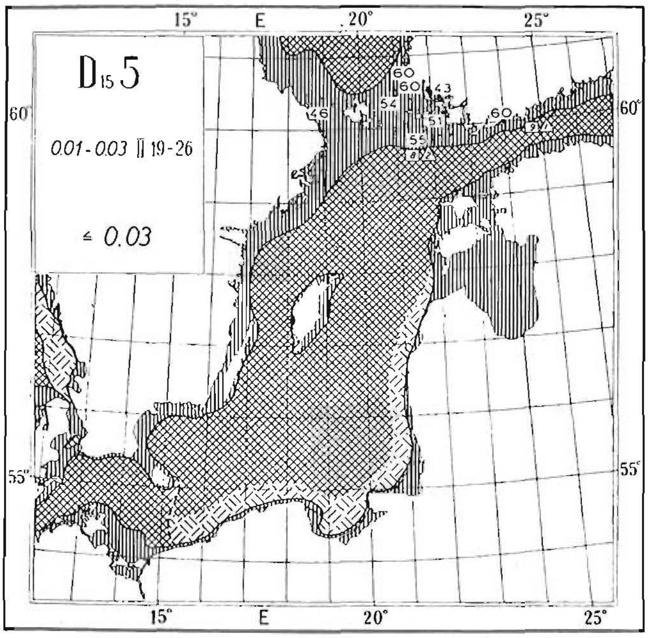
The normal stage $D_{15}2$.



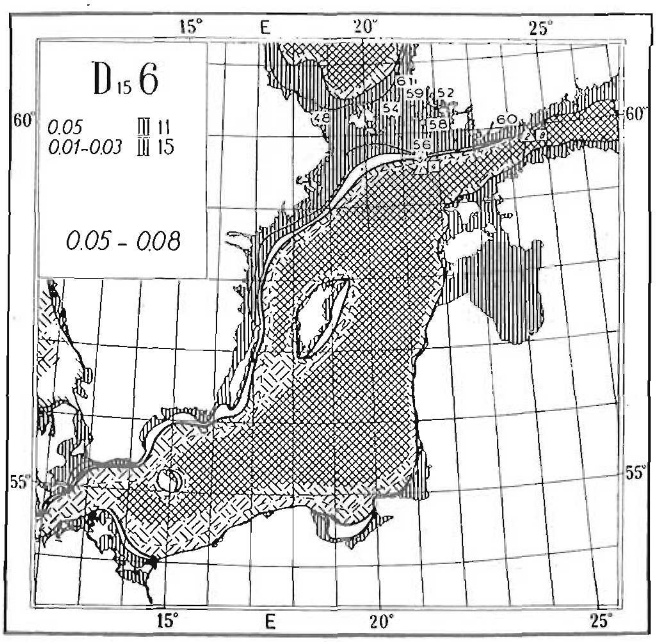
The normal stage $D_{15}3$.



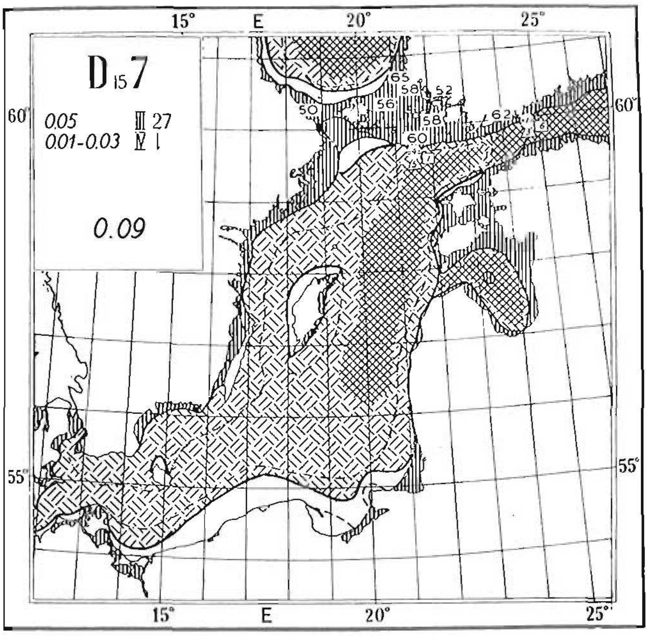
The normal stage $D_{15}4$.



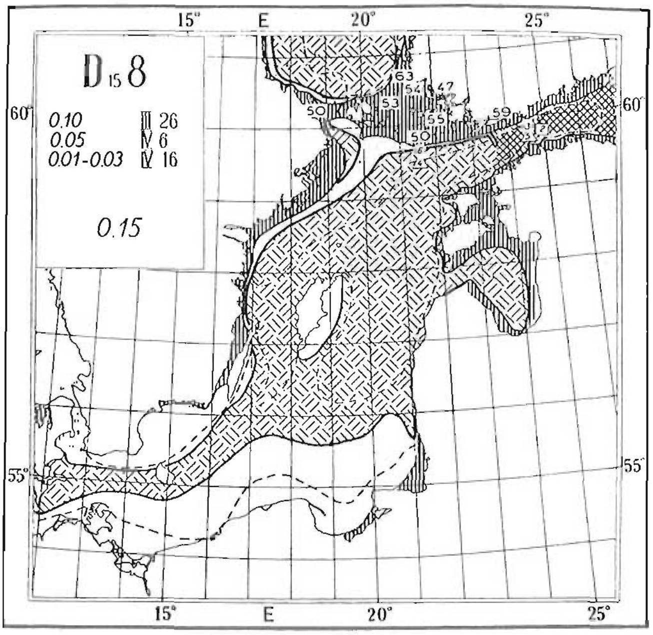
The normal stage $D_{15}5$.



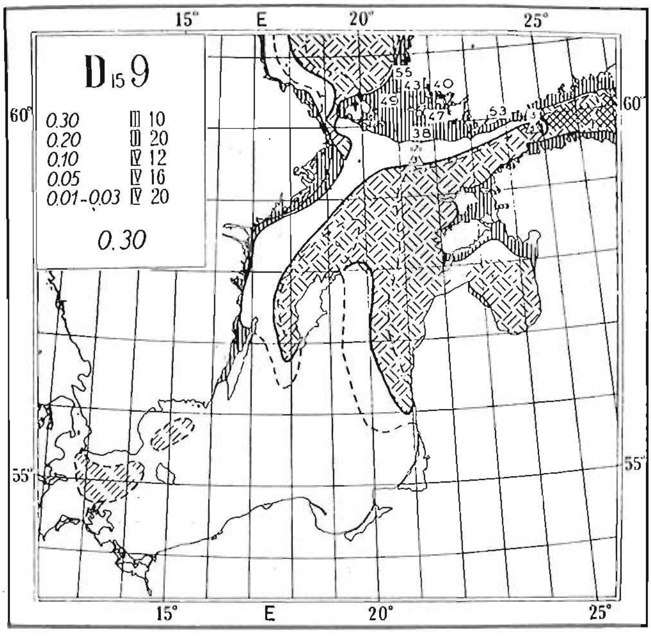
The normal stage $D_{15}6$.



The normal stage $D_{15}7$.



The normal stage $D_{15}8$.



The normal stage $D_{15}9$.

Explanations.

fast ice	frequency 0.8 of the ice edge		
ice, frozen solid	—»— 0.5		
drift ice	—»— 0.2		
new ice	—»— 0.0–0.1		
sludge	frequency of ice, frozen solid		
23 the thickness of ice 23 cm	—»— drift ice		
	—»— a lane		

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