SOME CONSIDERATIONS ON ICE NAVIGATION IN THE POLAR BASIN.

by

N. N. ZUBOV, *Oceanographic Institute, Moscow.*

The study of the ice of the Polar basin, of its origin, distribution and physico-chemical nature, as well as the possibility of forcing vessels through it, is one of the fundamental problems of the Second International Polar Year. It is for this reason that all the expeditions sent out by the U.S.S.R., which were to carry out work in the Polar basin in 1932, were strongly recommended to give particular attention to the study of the ice.

An opportunity arose to study the ice, particularly as to the possibility of passing through it, during our expedition in the Oceanographic Institute's vessel *Knipovitch.*

When circumnavigating Franz-Josef Land, in August-September 1932, we ran into the ice on 2nd September near Whiteland, in about Lat. 81°50' N., Long. 63° E, and emerged therefrom on 6th September in Lat. 79°10' N., Long. 54°30' E.

During this time, having covered about 300 sea-miles, we met with ice of various origins and conditions which we were able to observe under varying states of weather and in areas of the sea the dynamic conditions of which are extremely different.

The observations of the ice, as well as the results of these observations and of my previous experience, will be set out in my report of the voyage around Franz-Josef Land and will be followed by proofs, examples and by a bibliographic list dealing therewith. For the present they are given in the form of certain short theses which may be divided into three groups. In the first (para. I-V) is given an idea of polar ice, of its general circulation and distribution; in the second (para. VI-IX), an idea as to the formation and the melting of the ice, and, in the third (para. X-XVII) some recommendations in connection with navigation in ice.

I. — Ice may be classified under three principal categories according to the area which it occupies and according to its characteristic features, viz: "pack", floating ice and "pripaï" (fast-ice).

(1) By the name "pack" is meant ice of considerable age, of low temperature and of considerable and even thickness, 3 to 5 metres (10 to 16 1/2 ft.). This ice is very solid, is pressed into a compact mass by periodical compressions and, consequently, is nearly monolithic; its salinity is very low and it is nearly free of air bubbles. The "pack" forms fields of great extent and is quite impassable by vessels of whatever size and power they may be. The "pack" fills the central part of the Polar basin as far as (approximately) the 600 metre (328 fm.) depth-line. Ice of "pack"-like character may be found near the shores of the polar islands which are not influenced by warm ocean currents and by coastal waters, but which at the same time are subjected to the influence of prevailing winds which provide the compression which is indispensable for the formation of "pack". Thus, for example, near the east coast of Graham Bell Island, which the warm Atlantic water, passing through the straits of Franz-Josef Land, scarcely reaches and which, on the other hand, is exposed on the northeast to the northeasterly storms which prevail there in winter, we found some "pripaï" the monolithic nature and the thickness of which gave it the characteristics of "pack".

(2) Floating ice consists of isolated pieces of ice and not very extensive fields (the vertical, as well as horizontal, dimensions of which increase in winter) that are either formed independently in the open sea or as the result of the breaking up of fields of "pack" and of their transport away from the place of their formation, of fast ice (pripaï) as well as of the ice from glaciers. It is for this reason that among floating ice, ice of entirely different ages and origins may be found, though the principal mass may consist of one-year ice which reaches, in flat fields, a thickness of 2 metres (6 ft.). The whole extent of the Polar basin between the "pack" area (300 fm. line) and the 25 metre (13 3/4 fms) line (see XVII) is crowded with floating ice.

(3) "Pripaï" or fast ice is fixed ice which forms in winter near the coasts, in narrow channels and in bays, as well as between the coast and "stamukhi" (stranded floe bergs which act as islands. In summer "pripaï" is usually broken up, as the result of the melting process and by winds and by currents, and, when carried out into the open sea, enters into the category of floating ice; or, if it remains in place, it becomes part of the new formation of "pripaï" during the next winter. From all the above it is evident that the principal mass of "pripaï" is of annual origin.

In flat fields pripaï sometimes reaches a thickness of 2 metres (6 ft.) and as a rule spreads from the coast to the 25 metre (13 3/4 fm.) line. Naturally, in narrow channels, "pripaï" may be met with in much deeper water.

II. — The general circulation of the ice of the Polar basin, which is determined by the direction of the ocean currents, depends on two phenomena; firstly on the circulation of the atmosphere above the Polar basin and the surrounding adjacent seas, and secondly, on the influx into the Polar basin of water not only of oceanic origin but also of coastal origin and on the compensatory efflux of the water from the Polar basin.

(1) The "cap" of cold air above the central part of the Polar basin has an anticyclonic movement (clockwise) and this creates a movement, in the same direction, of the separate fields of "pack" which cover this part of the basin. On account of the deflecting influence of the Earth's rotation all movements in the northern hemisphere tend to incline to the right. This induces a supplementary pressure in the "pack" towards the centre of rotation and reduces the compression on the "pack" at its periphery.

(2) The air of the temperate latitudes, which surrounds the cap of cold air, has a cyclonic (counter clockwise) movement and, thus, communicates a general movement in the same direction to the floating ice.

(3) The easterly movement of the floating ice is increased still further by the enormous masses of water carried along by the North Cape and Spitsbergen Currents from the Atlantic Ocean as well as by the rivers of the European and Asiatic coasts.

These water masses, flowing towards the centre of the basin, incline to the right also.

(4) In conformity with the general easterly movement of the floating ice, and in consequence of the deflecting effect of the Earth's rotation, enormous masses of ice and water, as they approach the N.E. extremity of Greenland, turn to the southward and together with fields torn away from the main body of the pack are carried away by the East Greenland current through the strait between Spitsbergen and Greenland.

(5) The Bering Strait is too narrow and shallow to have any important effect on the general circulation of the water of the Polar basin. Theory indicates that it is along its west coasts that a current should tend to the southward and along east coasts that it should tend in the opposite direction. Nevertheless, local influences, *i.e.* wind and the distribution of pressure, in particular cases, completely change these rules.

(6) Each neighbouring sea has its own specific system of currents (usually of cyclonic character in the northern hemisphere) which is determined by the influx of waters of different origins, and by the deflecting force of the Earth's rotation. In fairly wide straits two inversely flowing currents are formed; they tend towards the coast to their right (relative to the current). Thus, for example, in the western part of the strait between Spitsbergen and Franz-Josef Land, the waters move in a southerly direction and, in the eastern part, in a northerly direction. In channels, currents usually flow in one direction only, conforming to the general circulation of the water in the Polar basin. As examples, at Matotchkin Char, in Karsky Vorota Strait, in Schokalsky Strait, etc., the waters move in an easterly direction.

(7) The water brought to the Polar basin by rivers, by inclining to the right, gives rise to a cyclonic movement in the water of the sea which is to their left. For example, the current from the Ob-Yenissei contributes to the formation of a cyclonic movement in the southern part of the Kara Sea. The water from the Lena causes a similar movement in the Brothers Lapteff Sea.

(8) It is evident that the direction of sea currents depends very largely on the shape of the coast. However, the relief of the bottom has an influence on the speed as well as on the direction of the currents. A current passing over isolated banks always has its velocity reduced on account of friction.

Yet again, in the northern hemisphere, currents tend to the right as they round islands and isolated banks, and to the left as they pass over cavities or depressions which may lie in their courses.

III. — As said above, the "pack" moves in a clockwise direction and the floating ice in the opposite direction.

As a result, at the line of contact of the two contiguous currents running in opposite directions, the ice is broken up and thus is formed the Great Northern Polynya (Lead). The formation of the Polynya is assisted by the deep water which in the Polar basin is warmer, rising here to the surface of the sea and contributing to the melting of the ice.

In the Eurasian sector, the Great Polynya passes north of Spitsbergen, Franz-Josef Land, Severnaya Zemlya, the Liakhovski Islands and Wrangel Island. It is most strongly pronounced off the north coasts of these islands, where it may be observed even in winter. From time to time it becomes covered, in the straits between the islands, with ice brought sometimes from one side and sometimes from the other.

IV. — The total quantity of floating ice in the Polar basin during the season of navigation is by no means the same every year. In fact, owing to the influence of various factors, it is subject to considerable variation. In this respect the highest importance must be attributed to the temperature of the Atlantic and Pacific waters which enter the Polar basin. The influence of the Atlantic water is most marked in the Barents and Kara Sea areas and it may be observed all along the northern Asiatic coast of the Polar basin as far as Bering Straits. The influence of the Pacific water is well defined along the N.E. coast of America.

These waters, spreading gradually to the eastward along the continental slope and partly rising to the surface, mix with the water of the top layer which is nearly fresh on account of the presence of river water and melted snow, thus governing the salinity and the temperature of these waters. Naturally the higher the temperature of these oceanic waters which rise to the surface the less the ice met with in the corresponding area.

The most closely studied variations of temperature and of velocity of propagation of water in the Polar basin are those of the warmer Atlantic waters. It has been determined, for example, that the water observed during a certain year northward of Spitsbergen takes a whole year to reach the area lying northward of the line Franz-Josef Land-Severnaya Zemlya etc. This makes it possible to make long period forecasts (some years ahead). In fact, by taking regular observations of the thermal conditions of the Atlantic waters in any area to the westward — as, for example, is being done by the Oceanographic Institute in the Barents Sea along the Kola meridian (33 1/2° E.) — sufficiently accurate predictions may be made of the general quantity of ice in the Barents and Kara Seas and even further eastward.

Of course, the probability of such forecasts based on the thermal regime would be improved if corrections were applied thereto, taking into account the general quantity of ice observed in the sea during the preceding year and also the severity of the previous winter, even though this severity depends on the temperature of the oceanic water and on the general quantity of ice in the Polar basin.

V. — Though the quantity of floating ice that may be assumed to be in a certain area of the Polar basin depends principally on the factors enumerated in the previous paragraph and though this may be calculated and forecasts thereof made, nevertheless the distribution of the given quantity of ice in this area of the sea during a certain period depends principally on the direction, the steadiness and the velocity of the wind.

It is clear that the influence of the wind, which is small when there is but a mediocre amount of ice (as was the case in 1931 and 1932 in the Barents and Kara Seas), is of the greatest importance and is sometimes even decisive during years in which ice is abundant, as was the case, for example, in the Barents Sea in 1912, 1917 and 1929.

It is evident that the distribution of the general quantity of ice in the various areas of a given basin depends on the wind: the wind, as will be seen later, has an influence on the grouping of the ice, making it penetrable or impenetrable. It has, also, a great influence on the process of ice formation and on that of the melting of the ice. Indeed, when the wind is strong, even when the air is at a temperate temperature, there is a much more rapid increase of the whole mass of ice in winter than when there is no wind and there is an intense frost; in the latter case a thin skin of ice forms quickly and protects the underlying layers of the water from cooling. On the contrary, a strong wind during the melting of the ice is a positive factor; owing to the sea raised by the wind, the movement of the water around the ice is more lively and to the destruction of the ice by the action of the accumulated heat of the water is added the purely mechanical destruction due to the waves.

In this last respect winds perpendicular to the edge of the ice are of great importance, whereas winds which blow along the edge have scarcely any effect on the state and position of the ice. Thus, for example, in the Barents Sea, the northerly winds in summer break off from the edge pieces of ice and isolated fields (floes) and drive them into the warmer water of the North Cape Current, where they melt gradually. On the other hand, southerly winds drive the warmer water of the North Cape Current on to the edge of the ice and break the edge up. I had the opportunity in July to observe the edge of the ice in the central part of the Barents Sea and after a southerly storm lasting three days it had receded no less than 60 nautical miles to the northward. The westerly and easterly winds in the Barents Sea have scarcely any effect on the total amount of ice, which is merely drifted to and fro.

VI. — Every year, since 1898, the Danish Meteorological Institute has published charts of the state of the ice in the Polar basin for the five summer months (April-August). In the better known (from this point of view) seas, such as, for example, the Barents Sea, the average monthly limits of the ice are shown on these charts, based on the data obtained during the preceding 25 years. The Hydrographic Department of the U.S.S.R. publishes information on the ice conditions in the seas of the U.S.S.R. These data, as well as other material, show that the ice covering in the southern areas of the Polar basin completes a cycle of evolution, both as to thickness and extent, towards the beginning of the month of May. Thereafter the quantity of ice diminishes gradually each month and this lessening becomes very rapid during July and August.

The least ice occurs towards the end of September and the beginning of October when the renewed process of ice formation is initiated.

Ice formation proceeds slowly during the early months of winter for, before freezing, the water has to be cooled sufficiently to reach the point of congelation. It is for this reason that the formation of ice becomes rapid during February and March, after which it is somewhat hampered by the action of the sun.

From the very beginning of the winter cooling, the upper layers of water gradually become colder and therefore heavier, and consequently, mix with the lower layers. The greater the difference in the salinity of the upper layer and of the lower layer, the deeper the propagation of this process.

The smaller the depth of this process, the more rapid is the process of lowering of the temperature of the water to its freezing point and the quicker the process of ice formation. This is why ice forms first in those places where the water is not deep, *i.e.* near the coast and above shoals and isolated banks, as well as in those areas where the upper layers of the water have had their salinity reduced, compared with the lower layers, on account of the influx of fresh water from rivers and from recent melting of ice. Next, the ice, spreading with these areas as centres, advances in different directions or breaks up, and winds and currents carry it out into the open sea where there are considerable depths; thereafter a further formation of ice is initiated in the less deep places. Separate pieces of ice and ice fields which were not melted during the previous season act similarly as centres for the formation of new ice.

For instance, in the following areas of the Barents Sea the formation begins first: in the Petchora Sea, near the coast and on the coastal banks of Novaya Zemlya, near the southern shores of Spitsbergen and near its islands, on the Perseus and Central Banks, on the southeastern shores of Franz-Josef Land, etc.

In areas where the sea is deeper, particularly if the difference between the salinity of the upper layers and that of the lower layers is not relatively great, the formation of ice begins very late. As an example, the central part of the White Sea is scarcely ever frozen over. Hence the necessity for following the deep water route in order to reach high latitudes during the season of ice formation.

VII. — Nevertheless, the formation of ice does not always begin at the surface of the sea. Provided that there is rapid cooling (air temperature low, clear sky, intense radiation) and a rapid vertical circulation or intermixing of water layers the necessary nuclei of condensation for the initiation of ice formation may arise throughout the mass of water in which the mixing is occurring.

In this case, if the mixing extends right down to the bottom, ice (ground ice) forms around the objects which lie at the bottom of the sea. Such ice will rise to the surface if its buoyancy becomes greater than the weight of the object around which the block of ice was formed.

The same phenomenon may occur, under the same conditions, in the deep areas of the sea also, if the upper layers are so much fresher than the lower layers that, even at the temperature of freezing, the upper are lighter than the lower layers.

More than once, at the beginning of winter, the phenomenon of the formation of under surface ice has been observed in the deep layers near the coasts of Greenland and Spitsbergen, as well as in the rivers which freeze in winter and it has happened sometimes that ships have found themselves surrounded by ice which has risen from the bottom of the sea; this ice brought up with it from the bottom stones, pieces of rock and other objects around which the formation of ice had taken place.

VIII. — The melting of the ice takes place mostly at the expense of the heat of the water which surrounds it, or at the expense of the heat brought from other areas by currents, or else at that of the heat of the sun absorbed by the local water.

For this reason, at the beginning of summer, melting commences in the coastal zone where the ice, which becomes dirty owing to the proximity of land, absorbs the heat of the sun more rapidly than does clean sea ice. Thereafter the melting becomes more intensive in areas where, for some reason or another about the beginning of the polar summer, expanses of open water occur which absorb the heat of the sun and then give it up for melting the ice. Besides, melting occurs very rapidly in the areas exposed to the influence of ocean currents.

Hence the areas of the Polar basin which have the least ice are those on coasts open to active warm currents such as, for example, the western and northern coasts of Spitsbergen and of Franz-Josef Land (the Spitsbergen Current), the western coast of Novaya Zemlya (the North Cape Current) etc. In opposition thereto, those areas which are protected from the influence of these currents by islands are those which have most ice. For example the areas of the Barents and Kara Seas which are most covered with ice are: the neighbourhoods of Hope Island, the Charles Islands, Gilles Island, west coast of Spitsbergen, southeastern coast of Franz-Josef Land, the eastern coast of Novaya Zemlya, etc.

As a matter of fact these are the parts which receive the coldest waters of the North Cape and Spitsbergen Currents.

On the other hand the velocity of currents is always much reduced above shoals and not very deep banks. Thus, in the neighbourhood of shoals and banks, the warmer water from the Atlantic or from rivers enters but very slowly at the beginning of the summer. Hence the movement of ice is more impeded above these banks than over the neighbouring deeps and depressions. For example, in the Barents Sea in the beginning and middle of summer, ice may be met with over the Perseus and Central Banks as well as above the Goussinaya Bank whereas the area to the northward, in greater depths, is already clear of ice.

IX. — During the season of melting, the water is in direct contact with the surface of the ice and is greatly chilled at the expense of the specific heat of fusion, and, though this breaks the equilibrium of the separated layers of water and certain vertical as well as horizontal movements are produced therein, the rate of melting is reduced. It is for this reason that any exchange of water caused by wind, sea, and currents, and particularly by tides, contributes to the clearing of ice from the area under consideration. The gorlo of the White Sea may may be taken as a characteristic example of this. Here, on account of tidal phenomena, the water, in certain parts, becomes mixed up from the surface to the very bottom and the clearing of the ice occurs rapidly in spring, though in winter an intensive ice formation takes place here.

In opposition to this, in calm areas, e.g. at the centres of the anticyclonic clockwise movement of the water, the melting of the ice takes place very slowly.

The stagnation in any given area may be estimated by studying charts showing the permanent currents and tidal streams. If such charts are not to be had, practically the same results may be deduced from the character of the bottom. At equal depth in any given area, the smaller the particles which form the bottom (e.g. as in mud), the more stagnant the area as compared with another where the bottom consists of coarser particles (e.g. sand). Brown and black muds are particularly characteristic of stagnant areas.

A permanent uprising to the surface of the sea of the warmer water of the underlying layers takes place at the centres of the cyclonic movements. This uprise contributes to the melting of the ice.

X. — Modern technique permits navigation in ice in the areas of floating ice only, i.e. anywhere to the southward of the Great Northern Polynya. The possibility of such navigation is determined by two conditions: first — the degree of dispersion of the ice and, second — the state of the ice. It is a fact that, however solid the separate fields and isolated floes may be, the ice-covered area may be passed through by vessels of any displacement and type if they are separated by sufficiently wide lanes of clear water. The possibility of forcing a way through the ice, to break through ice dams and fields even, is determined by the possibility for the separate or broken floes to move and to open out to allow the ship to pass through, i.e. by the disunity of the ice.

The possibility of forcing a passage through ice is determined not only by the dimension and form of the ice but still more by its state, i.e. by its formation, age and temperature.

Sea-ice, as is well known, consists of pure sweet-water ice surrounding cells filled with a strong solution of salts dissolved in sea water and air bubbles.

When the process of ice formation occurs in a calm and slowly these incorporations are fewer but if, on the contrary, the formation takes place rapidly, such as, for example, when the mixing process of the water is intense on account of sea or swell, of tidal streams or, in winter, of vertical circulation, their number increases. The less the number of such incorporations the sweeter and the more solid the ice.

For example, a crystalline ice, which is formed when the sea is calm, is much more solid than bottom or under surface ice which comes to the surface in the form of a spongy mass.

In time, on account, first, of thermal variations in the ice which sometimes expand and sometimes contract the salt cells in it and, second, of pressure to which the ice is subjected constantly during winter by the action of storms and currents, the cells are emptied of the solution and are filled with air which is then expelled by pressure. In this way, as the ice ages, it becomes freer of salt, more monolithic and, consequently, more solid.

As to the influence of temperature on the solidity of the ice, it may be said that the solidity of sweet ice, if its temperature is 9° C. below zero (+ 16° F.), is equal to that of a good brick and it remains unchanged by further chilling to 40° C. below zero (— 40° F.), but on the other hand becomes suddenly much weaker when the temperature rises, and at 0°C. (+ 32° F.) the ice resemble a mass of gruel.

The result of this is that it is much easier to pass through the ice during the melting season than during that of ice formation, when the temperature of the ice is lower. The same may be said for periods of thaw and of hard frost.

XI. — In the open and relatively deep parts of the sea, the surface is never entirely covered by ice. The winter storms and tidal currents always break it up and drift it from place to place thus opening up areas of open water which, in turn, become very rapidly covered with new ice during calmer weather and hard frost. Besides, in the open sea, the ice is very rarely homogeneous as to age and formation. Naturally the more recent the ice and the higher its temperature, the more it is subject to destruction either by natural means or by the passage of a vessel; it will be readily understood that, to force a passage through a field of ice, it is very necessary to ascertain the positions and the directions of the older bands of ice.

However, when an ice field, for some reason or other, breaks away and is drifted on to a coast or a stationary "pripaï" or on to a larger field which is moving more slowly, then at the edges of contact, broken small floes piled on to each other (hummocks) form ranges and these are nearly impassable.

The directions of the bands of more recent ice and of the lines of hummocks are relatively regular in most cases, as will be seen later.

XII. — When navigating in more or less open ice consisting of fields which, comparatively speaking, are not very big it may be observed that the spaces open between the floes seem to be aligned in a definite direction in which the vessel can proceed very easily. These directions of the open water ("rasvodye") and even their existence in any given area of the sea, depend on the following :—

(1) The direction of the wind immediately before and at the given moment, as well as on the relative position of the neighbouring coast or fixed ice;

(2) The direction of propagation of the tide wave and the phase of the tide at the given moment, and

(3) The directions and characters of the permanent currents in the given area.

XIII. — A wind which blows on to a coast or fixed ice reduces the size of the open water and, if it be strong enough, it will give rise to hummocks. Naturally the hummock beds form approximately perpendicularly to the direction of the wind which prevails when the pressure is acting. It will be readily understood that it is practically useless to push the vessel on while such winds blow; it is best, under these circumstances, to get away up wind or else to wait.

Obviously, when an offshore wind blows, the quantity and dimensions of the open water increase and, at the same time, it tends to lie in a direction perpendicular to that of the drift due to the wind. This latter direction, as laid down by the ECKMAN theory and as proved by observation, lies 45° to the right of the direction of the wind.

XIV. — If the ice be more or less scattered over a considerable area of the sea, any wind will tend to regroup it. At first, as the wind rises, the separate floes, drifting before the wind, form chains which extend in the direction at right angles to the wind drift, and the stronger the wind and the smaller the floes, the more clearly marked is this phenomenon. Whenever there is a change in the wind the chains which were formed after the previous wind break up; the isolated floes form new groups and, after some considerable time, the open water between the chains of floes realign themselves in a direction at right angles to the surface drift caused by the existing wind.

XV. — At any point in the sea a closing up of the ice may be observed twice daily, as also may an opening up of the ice; such movements are caused by the phenomena of ebb and flow of the tidal stream; at the same time, the moment when pressure occurs coincides with the slack between ebb and flow, whereas the time when the ice opens up corresponds with that of the change from flow to ebb. It is evident that the line joining the points of simultaneous slack water of the homonymous streams is parallel to the frontal line of the flood stream wave, i.e. the cotidal line. For this reason, according to theory, the open water caused by the ebb and flow should lie in the direction of the cotidal lines.

It is obvious, also, that these phenomena of closing and opening are particularly pronounced at the meeting point of floating ice and the coast or a fixed "pripaï".

If a flood stream wave discharges into a strait the depth of which diminishes towards the coast (which is the general rule), the phenomenon itself and the distribution of the open water become more complicated. Then the velocity of propagation of the flood stream wave at any point is directly proportional to the square root of the depth at that point. Hence the crest of the flood stream wave in such strait becomes somewhat curved with the convex side of the curve in the direction of the propagation of the flood. Therefore the surface of the water, on a line across the strait, shows a downward slope from the centre towards the coast during flood and, during the ebb, in the opposite direction. This causes horizontal movements of the particles of water along the slope and the result is that the particles of water describe horizontal orbits of flow near the right hand (of the direction of propagation of the flood stream wave) coast in a clockwise direction; near the coast lying to the left the phenomenon is reversed. This is the reason for the opening up of the ice at the centre of the strait and its crowding near the coasts at the time of reversal of the stream (from flood to ebb).

XVI. — In the northern hemisphere all movements tend to the right under the influence of the Earth's rotation. For this reason, during the drift of the ice, its movement due to permanent currents tends to the right also. Hence, a current which washes a coast on its right drives the ice towards the coast and makes it relatively crowded; conversely a current running along a coast on its left drives the ice away from the coast and leaves open water there. In open parts of the sea, under the influence of this same deflecting force of the Earth's rotation, currents which flow clockwise (i.e. anticyclonic currents) cause the ice to close up towards the centre of movement, whereas counter-clockwise (i.e. cyclonic) currents induce opening up of the ice in the centre and crowding towards the periphery.

The general circulation of water in the upper layer, e.g. in the Barents Sea, is of cyclonic character and thus tends to clear the centre of the sea of ice, but this circulation drives the ice towards the coasts of Novaya Zemlya, Franz-Josef Land and Spitsbergen. The ice does not reach the Murman coast for the warmer waters of the North Cape Current bar its passage.

Naturally such grouping of the ice determined by the directions of the permanent currents, as well as the crowding and opening due to tidal streams, is more clearly pronounced during periods of light winds or calms.

XVII. — The ice accumulations and the hummocks of the Polar basin, as determined by numerous observations, have an average draught of approximately 25 metres (82 feet). During the season of melting, the hummocks broken from the ice fields of the open sea and drifted from place to place by winds and currents eventually approach and ground on shoals and thus become "stamukhi".

In winter during the formation of the ice, these "stamukhi" play the part of islands and shoals, as was said above, and, in the spaces between the "stamukhi" and the coasts "pripaï" is formed.

The whole area off the European and Asiatic coast of the Polar basin from Kanin Noss to Bering Straits is remarkable for its shallow depths and the 25 metres (14 fm.) line lies at a great distance from the coast in certain places. Enormous masses of warm water are discharged by the great rivers of Siberia into this area of the sea and this water induces therein, in summer, rapid melting of the ice, in the first place along the coast itself.

The leads of open water which thus form along the coast are encroached upon by the ice from the open sea under the action of winds which blow perpendicularly to the coast and, in this connection, the chain of "stamukhi", which on an average lie along the 25 metre (14 fm.) line, has a positive action for it is near these "stamukhi" and the offlying islands that the ice fields, driven shoreward by the wind, are stopped.

Consequently, during years of bad ice conditions, navigation in certain sectors of the Polar basin sometimes is possible along the coast only.

XVIII. — The above paragraphs may be summed up by stating that navigation in the ice of the Polar basin is much easier if close attention be given to long period forecasts, to synoptic charts and to the following : — the bathymetric chart, the chart of permanent currents, tide charts, charts of cotidal lines, charts of the character of the bottom and charts of the state of the ice. These last charts, it must be admitted, deal with the past, yet a great deal of useful information may be extracted therefrom as to future conditions, for the quantity of ice at any given time depends always on that existing during the preceding period.

Before entering the ice it is absolutely necessary to investigate its state and position and it should not be forgotten that the longest way by water may be much shorter than a more direct course which passes through ice.

During the voyage itself, advantage should be taken immediately and to the greatest possible extent of any conditions which arise. Conditions in the Polar basin may change very suddenly and a few hours of delay may entail complete failure of the whole programme. But on the other hand, when circumstances are unfavourable, it will be no waste of time to await a favourable change. Even in the winter months a very strong but at the same time favourable wind, warmer weather and changes due to the tide may make it possible to pass through areas of the sea which earlier had seemed entirely impenetrable.

There are always some signs that indicate the presence of ice in the vicinity. To these belong in summer : the fog that almost always hangs over the ice, the lowering of the temperatures of the sea surface, the change of the colour of the sea, the reflection of the ice on the clouds (ice-blink), the appearance of those animals and birds which live on the ice etc.

(1) The lowering of the temperatures of the sea surface near the ice is not a reliable sign. Very often one enters the ice before having noticed any change of temperature. For instance, in 1929 we entered the ice for five or six miles and the temperature of the water remained at 1° C. On the other hand, in 1932, between Franz-Josef Land and Wiese Island, the surface temperatures were about — 1.6° C. and yet we saw no ice. Usually in summer in the warm currents the temperature of the water is comparatively high in spite of the presence of ice.

During summer the open spaces of water in the Polar Basin absorb enormous quantities of heat. For instance, in 1932 the *Dalnevostochnik* observed 10° C. north of Bering Straits. So we may say that fairly high temperatures of the water in spite of the presence of ice indicate that there has been no ice for a long time (or the existence of warm currents), and low temperatures, in spite of the absence of ice, show that there has been ice here lately.

(2) It seems that the colour of the water becomes whitish in the presence of melting ice. It is probably due to glacier ice which is always incorporated in sea ice. This glacier ice, when melting, yields so called "ice milk".

(3) "Ice blink" is the whitish glare in the sky near the horizon produced by the reflection from areas of ice in the vicinity. The opposite to ice blink is "water sky", i.e. the reflection in the clouds of large open spaces of water. These signs also are both not very reliable. Sometimes "ice blinks" are seen where there is no ice at all and "water sky" indicates sometimes the dirty brown ice often met with along the Eurasian coast. It is true however that in fog one always sees a strange whitish glare before discovering an ice field or an iceberg.

(4) The waves of the sea, on account of the friction and the deformation of the wave form by separate ice fields and floes, do not penetrate far into the ice even if it is so scattered that navigation by any ship is possible. So when the swell of the open sea begins to be felt one may be sure that open water is very near in the direction whence this swell comes.

(5) The most reliable sign of the presence of ice is the abundance of organic life that is always connected with the melting process. Some ascribe this fact to the nutritive materials collected in and on the ice. Others ascribe it to the favourable influence of the large ice molecules (polyhydrol molecules) of which the ice consists. Anyhow, the sea near melting ice always swarms with zoo- and phyto-plankton and fish, birds, seals, whales and bears come to the edge of melting ice in search of food. So the appearance of seals and birds which dwell on ice is always a clear sign of the vicinity of ice (or of land). Conversely there is no life on the ice nor in the water nearby if the ice is not melting. For instance the plankton net may be towed for hours in the water among ice fields that are not melting and yet practically nothing will be obtained. For three days when doubling Franz-Josef Land we saw neither bird nor bear on the ice in which we navigated and during several hours almost at the very edge of ice we saw six white bears.