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Notes on the time-space variations in the features and dynamics of the East Greenland pack ice

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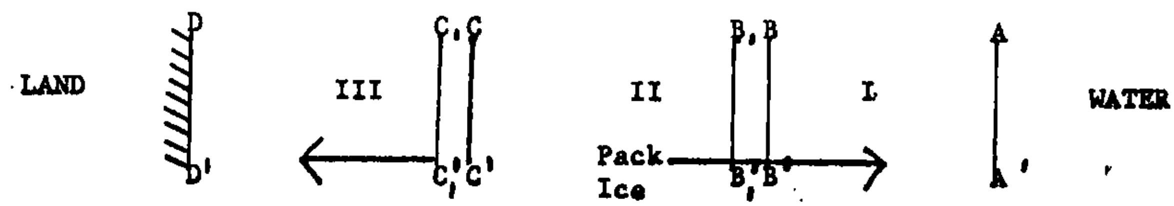
The East Greenland pack ice, for many reasons, is considered unique and singularly important among those ice regimes that comprise the sea ice of the Arctic Basin and its marginal zones. This area, at the season of maximum coverage, stretches from the Greenland Sea between northeastern Greenland and West Spitzbergen, along the entire eastern coast of Greenland, reaches the very southern most tip at Kap Farvel and continues beyond for as much as several hundred miles upward along the southwestern coast. Here documented speeds in the flow of ice are up to four, and more, times greater on the mean than is the case in the Central Arctic Basin waters. From a global heat balance point of view, this drift stream of ice and Arctic Surface Water represents the major efflux zone of water, ice and heat outward from the central polar pack ice regions. Beneath this surface layer of ice and water a reverse floe exists at the same time. This subsurface influx feeds the entire Arctic Basin with the second major water mass, the subsurface Atlantic Water which is of tropical origin. In order to describe more fully the unique aspects of this ice regime, a schematic diagram is presented immediately below.

FIGURE 1: SCHEMATIC DIAGRAM OF EAST GREENLAND PACK ICE



In Figure 1, three major zones are described. Zone I represents the most dynamic of the three, especially from the point of view of its being subject to nearly instantaneous response to the wide variations in wind speed and direction. Its width varies in direct proportion to these changes in the intensity of the offshore and onshore components of the prevailing northeasterly winds. The width of Zone I is between 0 - 120 nautical miles; usually, however, it ranges between 20 to 30 (see below). Zone I may be thought of as an "Ice Factory". With the frequently occurring - and changing - offshore winds huge quantities of new, first-year and sometimes, multi-year ice are advected into the warm waters where they are very quickly destroyed. This destruction is believed to be brought about primarily by the cold and warm water masses that usually lie in direct juxtaposition along the ice edge, line AA'. The normal storm track trajectory for the North Atlantic is characterized by cyclones moving northeastward in a generally parallel movement with respect to the ice edge northward in the mid-Atlantic Ocean. Frequently sharp reversals are interspersed with one-three day period of relatively stagnant or motionless conditions from the point of view of air stress. In such quiesent periods, ice forms very quickly in the very shallow but F 3
cold and low salinity surface water layer caused by the previously

described meltings. Thus in the mid-winter months (December - March, inclusive) thousands of square miles of new ice are frequently formed. Following the quiesent period, sharp increases in the onshore components of ice drift result in the crushing and deformation of this new ice. Consequently the ice edge is moved toward or into the position BB'.

Numerous sporadic occurrences of this phenomenon in any month where air temperatures are below the freezing point of sea water (Approximately 28.5°F) result in a secondary belt or zone represented in Figure 1 by the parallel lines BB' and B,B,. This region of intensively ridged and hummocked ice has only recently been recognized as an important occurrence which may have profound effects on acoustical propagation and ambient noise as well as upon surface ship sea ice penetration operations and by the ice production mechanism contributing toward the mass balance of arctic pack ice as a global basis. This BB' - B,B,' zone varies widely in time and space throughout the East Greenland regions from a few to ten or miles across; a modal width however is probably between one and three miles. Thus, after intensive, sustained onshore ice drift, Zone I might be completely obliterated and vessels approaching the ice would encounter a sharp boundary comprised of heavy, densly concentrated ice.

Another mechanism, not present in the Central Arctic Basin, must be described. In Zone I long period swells are generated on frequent occasions, by the cyclones described above, following a fetch directly into the pack. They are believed to contribute significantly to the ridge ice zone area represented by BB' - B,B,'. These swells not only play a very important part in breaking the new Zone I ice into pancake and other small ice forms but, at the same time, to contribute significantly to the severe noises which so frequently have been reported by submarines traversing this region. The exact physical understanding of this mechanism is only now being studied, mainly through the ARPA sponsored marginal ice zone work under the direction of Dr. W.K. Lyon of NURDC (SD). In any evaluation work of weapons systems, the fetches and durations of swells affecting Zone I and the other components of the East Greenland Drift Stream can be documented and studied much more readily then is the case in the central Arctic Basin and other marginal seas. This is so because of the excellent network of surface air pressure reporting systems located at the 150 mile intervals along the entire East Greenland coast and by the relatively good coverage provided by stations on Spitzbergen, Jan Mayen, Iceland and the ocean weather station, ALFA.

Zone II, in Figure 1, represents the generally widest and most easily described features of this regime. In this area the predominantly multi-year ice floes move steadily southward. Mean monthly velocities are approximately 8nm/day in the northern most portions of the Greenland Sea and increase gradually to a mean monthly velocity of 11nm/day in the vicinity of the Denmark Straits. Daily speeds of ice drift in Zone II have been known to reach 1-1/2 knots (30nm/day). The zone frequently displays widths of 150-200, or more, nautical miles.

Zone II has ice characteristics that are very similar to those prevailing in the Central Arctic Basin with a few exceptions. Because of the natural divergence caused by increased velocities as one proceeds southward, frequent large openings, generally polynas, exist with a much greater frequency than found in the central Arctic Basin. The size of these features frequently display diameters on the order of magnitude of miles - and even ten's of miles.

Documented proof of the character of Zone II has been provided by the Russian station SP-1 and the USN station ARLIS II as well as by the earlier observations of buoys, ship wreckage, etc. Southward of Scoresby Sound, latitude 70^0, the summer East Greenland ice character in Zone II is exceptional in that it is quite different from that found in most of the central arctic regions. In the July - September months, the unsually severe ridging created in the BB' - B,B,' zone in Figure 1 and other regions to be described below (CC' - C,C,') result in extremely ridged, fragmented remnants of this pressure ice together with fragments of multi-year ice. The first year ice and level portions of such multi-year ice have completely disintegrated at this time leaving only the thickly compacted pressure ice. In the southern Greenlandic coastal waters this ice has been uniquely termed "Storis".

Zone III is characterized by, in the winter months from December through April, inclusive, relatively flat fast ice extending from the coast seaward to the ten fathom line. Interspersed within this ice are significant numbers of icebergs, bergy bits and growlers. Data on which to base any quantitative description of the occurrence of these glacial fragments which originate from the Greenland ice cap are much too sparse. It can only be said that the northeasterly winds and prevailing currents keep those bergs and glacial fragments confined generally to Zone III. A sprinkling of these glacial ice phenomena does occur not only in Zones I and II but, on occasions, for distances of many hundreds of miles to the seaward of the ice edge, line AA'.

In the June period the fast ice zone, because of the bathymetry, varying between 5-40 miles, generally disintegrates quickly as a result of the warming influences caused by the "Spring Freshet" along the edge of the steep ice cap dominated Greenlandic coastal regions. By mid-July Zone III is usually obliterated by such intense melting.

The same - but with lesser intensity and frequency - factors of alternate offshore onshore stress discussed above result in another severe ridge zone characterized by CC' - C_1C_1' in Figure 1 when the onshore component occur in all but the summer seasons. With offshore stresses this same region is marked by a "flaw lead". This lead varies from series of tiny cracks to completely open or newly refrozen regions having a width of up to ten or more miles on occasion throughout the period when the fast ice is present. The frequency of iceberg calving and their presence in Zone III increases markedly at the time following the spring frezhet. After September a gradual lessening in the density of the icebergs within Zone III does occur.

Figure 2: SCHEMATIC WIND STRESS PATTERN ON EAST GREENLAND PACK ICE

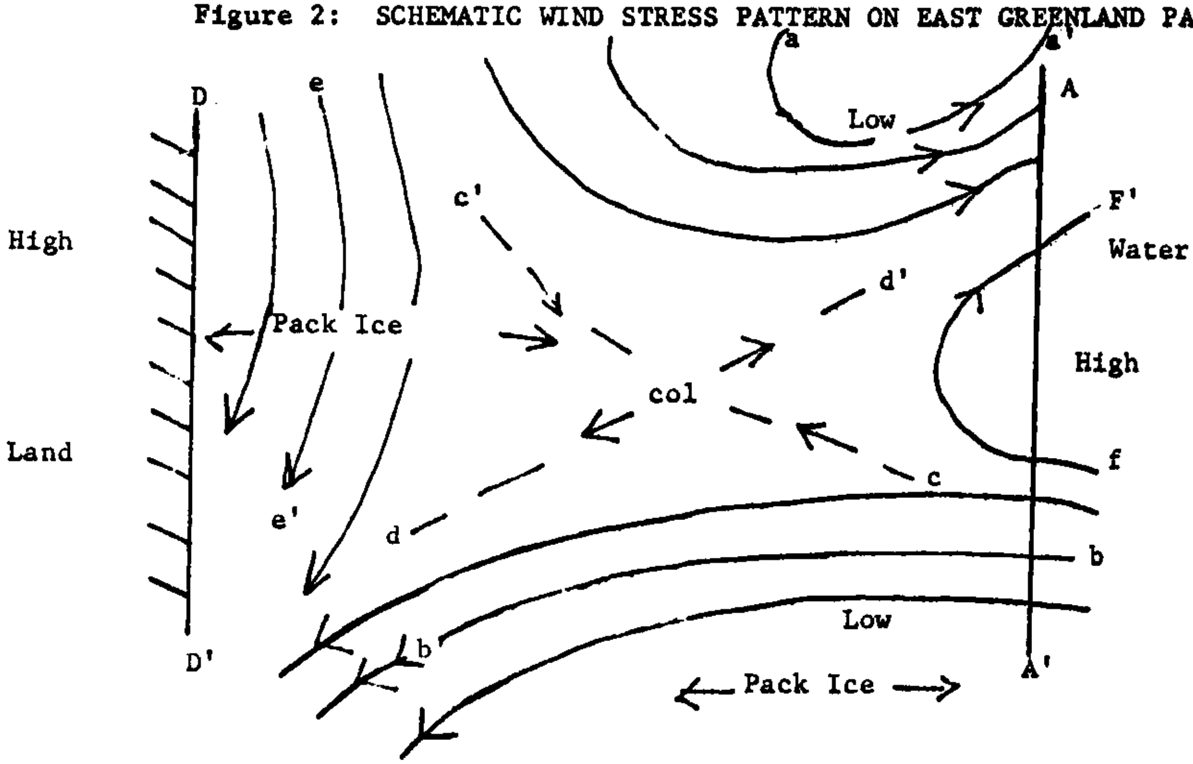


Figure 2 describes a typical situation which characterizes the wind stress field of the East Greenland Drift Stream. It also serves to illustrate various types of situation that sequentially occur in the East Greenland

Drift Stream. In this figure AA' again represents the outer ice pack edge and DD' represents the coastal boundary. The offshore winds that cause large scale melt and disintegration are represented by the stream line aa'; the onshore stream lines at the outer pack edge and in the coastal shore are represented by bb'. The col situation, as illustrated in the center of Figure 2, does occur frequently. In a case such as this, near zero motions occur in areas ten's of miles wide between regions displaying the offshore and onshore drift. Effectively, a complete separation of the normal southernly flow of pack ice may thus result. In Figure 2, cc' and dd' represent conditions in this col area where convergence is occurring along one axis and divergence along the other; at the same time strong southward drift, ee' is occurring in Zones II and III at the same time as weak variable motions are occurring along the outer ice pack edge, ff'. Examination of sequential weather maps occurring from day to day will reveal a variety of the components of the situation shown in Figure 2, occurring alternately. Not shown but frequently occurring in the East Greenland Drift Stream is the situation created by intensive storms. These storms result in hurricane force winds, on occasions, with motions and deformations of an intensity rarely experienced in the central Arctic Basin and many of the other marginal seas. Since small floes get into equilibrium motion with the wind much more quickly than larger floes, speeds of 2 knots, (48nm/day) and more may result from the hurricane winds; no measurements of such Zone I type movements have ever been reported in East Greenland waters. Soviet investigators have measured such individual floe movements in low ice concentrations by coastal radar, but only in the marginal seas of the Eurasion Arctic.

In conclusion, the ice in the East Greenland Drift Stream is probably the most dynamic of all North American Arctic ice regimes. Experiments in its dynamic behavior must take this variability, together with most adverse weather, into account.