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SUPERSTRUCTURE ICING IN THE NORTH CHUKCHI, SOUTH CHUKCHI AND HOPE BASIN AREAS

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by

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INTRODUCTION

Icing is mainly a function of the amount of water which remains liquid after striking a ship’s or fixed platform’s surface and the elapsed time before this water freezes. There are two types of ice accumulation, rime ice and glaze ice. Rime is rough, milky, opaque ice with minimal adhesion and is formed when small, super-cooled drops of water freeze on contact with a surface. It does not spread and can form at any temperature in the icing range. Glaze is formed on slow freezing of large super-cooled drops. It can spread over a larger surface and is harder to remove than rime icing (the preceding paragraph has been paraphrased from Berry et al., 1975).

Ice accretion depends on many factors. Meteorology and sea conditions are paramount (see below). However, vessel size, navigational peculiarities, structural design, kinematic and thermodynamic interaction at the surface of a design member and water droplets (stagnation zones on a surface, Ackley and Templeton, 1979) also become critical.

EFFECTS ON SHIPS

Ships such as fishing trawlers, smaller merchant ships, and Coast Guard Cutters are most vulnerable to icing due to less freeboard and the increased amount of travel time through an area experiencing icing conditions. It should be noted that the right combination of events can produce icing on large vessels also. Icing on a vessel increases its weight, changes its trim, elevates its center of gravity, decreases its metacentric height and increases its sail area and heeling moment leading to extreme handling difficulties (Berry et al. 1975).

ICING ON OFFSHORE STATIONARY PLATFORMS

As on ships, a coating of ice on external surfaces can elevate the platform's center of gravity. In addition, the ice will usually form in stagnation zones on the windward side (Ackley and Templeton, 1979) causing an imbalance weight distribution on a platform. Vertical and horizontal members of offshore structures are designed to meet oscillatory stresses due to wave action. The forces on the structure are made up of hydrodynamic drag and inertial (mass) components. Icing changes the physical characteristics of structure members, such as diameter, surface roughness, mass and flexural response (Ippen 1966). Therefore, a fixed structure's ability to withstand a design wave is questionable after and during an extreme ice accumulation.

Depending on freezing rates, the ice forming on structures due to sea spray will generally have a salt content much less than the sea salinity and may even approach O $^{0}/_{00}$ salinity. The maximum pressure produced by water freezing in a confined space is 30,000 lb in^{-2}. This stress on a structure or ship occurring during a freezing sea spray condition can drastically weaken support members.

METEOROLOGY AND SEA CONDITIONS (the following subsections have been paraphrased from Berry et al., 1975)

FREEZING RAIN AND SNOW

Freezing rain itself seldom reaches large enough accumulations to be the sole source of danger to a ship. However, combined with freezing salt spray (see below) it becomes dangerous since, as freshwater, it freezes faster than salt water and can act as a nucleus for faster ice accumulation from salt spray, Snow is not considered a threat due to inherent lack of adhesion.

ARCTIC SEA-SMOKE

Arctic sea-smoke forms when extremely cold air flows over much warmer water, The water vapor that results from the ensuing evaporation condenses immediately in the cold air and super-cooled droplets become visible as rising columns of “steam”. Weight of ice deposited is only a problem if the conditions exists for a long time since it is a low wind phenomenon,

“SEA ICE”

Water taken over the side of the ship will not freeze readily unless trapped by ice chocked rails and ports. This is considered a minimal hazard.

FREEZING SPRAY

This report has been developed mainly for freezing spray conditions. This is the most common and dangerous form of icing, resulting in glaze ice characterized by high density and great adhesion power. This type of icing is a function of several simultaneously occurring variables:

Air Temperature

The critical range for this study is from O“F to 32°F (-18°C to O“C). At temperatures below 0°F the water striking the structure will usually be in the form of non-adhering small dry ice crystals (Berry et al., 1975).

Wind

Sea spray generation depends on the wave height and period of waves. Waves in turn depend on the duration of the wind and fetch. Generally, the higher the wind speed for the above temperature range, the greater the ice accumulation. The range of wind speeds covered in this study are from 25 knots (12,5 ms‘^{1}) to 60 knots (30 in^{s-}l). Data indicate that wind speeds below 25 knots do not produce icing, while wind speeds in excess of 60 knots are rare. Wu (1982) mentions that a wind speed of 12.5 ms^{-1} is considered the incipient velocity for entrainment of water “particles in air (without need of waves).

Effect of the Ice Pack

When the ice pack concentration reaches 50% areal coverage, superstructure icing is thought to be minimal since wave formation is reduced and freezing spray is eliminated.

Sea Temperature

The criticial range of sea surface temperatures are 28” F (-2.2° C) to 48° F (8.9° C). Seawater of normal salinities is generally frozen below 28° F. The upper value of 48° F is not an impediment to freezing since sea spray can be cooled rapidly when air temperatures are below 28° F.

A dangerous layer of ice accumulation occurs at 3.9 in (10 cm, Berry et al., 1975) . Of the five icing categories used in this study, extreme icing would produce this thickness in 4.5 hours, heavy icing would produce this thickness in 8 hours, and light icing would produce this thickness in one day.

CONSTRUCTION OF ICING MAPS

To construct icing contours for the figures discussed below (see end of text), two data sources were used. The monthly positions of the northern, southern and mean 5/8 areal coverage sea ice edge are shown in Brewer et al. (1977) for the Chukchi Sea. Their ice edge positions were derived from 17 years of aerial, ship and satellite observations of the pack ice edge (1954 through 1970). Recently Dr. William Stringer (University of Alaska) completed a sea ice occurrence probability study (as yet unpublished) using satellite data collected from 1973 to 1984. His study was based on sea ice of <u>any concentration</u> appearing in designated map grid areas during weekly time periods from June through November. As a result, Stringer's 50% ice frequency position (over each month) was more "conservative" (appeared farther south) than the mean 5/8 areal coverage position of Brewer et al. (1977) but had the same general shape except for November. The same description fits the monthly comparisons of the northern limits of 5/8 areal coverage position (Brewer et al., 1977) with the 100% sea ice probability ice edge (Stringer) and the southern limit of the 5/8 areal coverage position (Brewer et al., 1977) with the 0% sea ice (open water) probability ice edge (Stringer). Despite differences in data types and length of the studies, the results seemed quite consistent. Therefore, the position of the mean, maximum (southernmost) and minimum (northernmost) sea ice edge used below were taken as the average of the corresponding edges from the above two data sources. Average and extreme contours of sea surface and air temperatures for map construction came from Brewer et al. (1977).

The wind speed and temperature data in Table la (North Chukchi) and Table lb (Hope Basin) came from the nearest marine areas and least orographically modified shore stations (when marine area data was unavailable) shown in Brower et al, (1977). There is no evidence of any area in the Chukchi having monthly mean winds of 25 knots (12.5 ins-l). Therefore mean wind contours were not useful in constructing icing maps. The World Meteorological Organization (W.M.O.) lists 28 knots (14 ins-l) as the onset of dangerous wind speeds (gale level winds) and 50 knots (25 ins-l) as the onset of real storm level winds. Hence, these levels were used as the critical winds for mean and extreme icing. Table 1 shows the % time of occurrence of gale and storm level winds during possible icing months. In addition the % of air temperatures below 0° F (18° C), which generally preclude superstructure icing, are shown. It must be noted that while the percentages are low for the total time of occurrence of these wind speeds, the probability of these speeds existing in each month is 100% and the duration of these speeds are sufficient to produce severe icing provided the other environmental conditions are met. Therefore, fixed structures which remain in place in one location over many months will be more susceptible to icing than vessels which may move in and out of a given area.

A new nomogram for superstructure icing in Alaskan waters has been used which is similar to but replaces that of Wise and Comiskey (1980). The nomogram, also developed by Comiskey, was discussed by L. D. Leslie (Arctic Environmental Information and Data Center) at the “Symposium on Meteorology and Oceanography of the High Northern Latitudes” (October, 1984, Anchorage). It has icing rates double those of the previous nomogram.

Five rates of ice accumulation are used in icing maps (Figs. 1-25) constructed for this study. The codes for these rates are shown on the

Table 1a. Characteristics of Structural Icing Months for the North Chukchi (Region A).

Icing Months	% Winds >28 kn (14 m s^{-1}) W.M.O.* Gale	% Winds >50 kn (25 m s^{-1}) W.M.O.* Storm	% air temperature <-18° C)
June	5	0	0
July	3	0	0
August	4	0	0
September	6	<1	0
October	6	0	4
November	~5**	0**	~50**

Note: Under conditions of mean sea ice extent, the North Chukchi area has some open water for the months of August, September and October only.

Table 1b. Characteristics of Structural Icing Months for the Hope Basin (Region C).

Icing Months	% Winds >28 kn (14 m s^{-1}) W.M.O.* Gale	% Winds >50 kn (25 m s^{-1}) W.M.O.* Storm	% air temperature <-18° C)
May	10	0	0
June	3	0	0
July	5	<1	0
August	5	<1	0
September	7	<1	0
October	14	<1	8
November	~14**	1**	~40**

*W.M.O. ≡ World Meteorological Organization.

**Data average from three coastal sites with least amount of orographic modification

These tables were compiled from Brewer et al. (1977). It is assumed that the south Chukchi (Region B) has statistics that are a mean of the statistics of Region A and C. The Regions A, B, and C are defined on the Figure Cover Page at the end of the text.

Figure Cover Page along with map outlines of the North Chukchi (A), South Chukchi (B), and Hope Basin (C) area locations. The dividing line between the North Chukchi and South Chukchi areas is roughly the 50 m isobath. The most common waves in any ocean are gravity waves which range in periods from 1 to 30 S (Kinsman, 1965). The 50 m isobath represents a transition depth from deep to shallow water for a majority of these very common waves. As waves move from deep to shallow water, they slow down, shorten in length, become higher and less stable making it easier for the wind to blow their tops off. Therefore, a given swell type (wind waves that have traveled out of their generating area) will produce more icing in the shallower South Chukchi area than the North Chukchi for similar wind speeds.

Superstructure icing is precluded above the ice edge line shown on the Figures below (see end of text). It must be remembered that sea ice edge positions, whether mean, minimum, or maximum, will have corresponding sea surface temperatures which have "adjusted" to the edge position with the lowest sea temperatures adjacent to the ice. These sea surface temperatures will have a much greater thermal inertia than th atmosphere above them. Therefore, even on minimum sea ice extent years with higher than average sea surface temperatures, a sudden cold front with high winds can move into the Chukchi Sea and produce severe icing. For the time scales important to superstructure icing, atmospheric conditions will generally change quicker than oceanic conditions and appear to be the most critical variable in the "puzzle".

DESCRIPTIONS OF ICING MONTHS

The Chukchi Sea conditions presented monthly are for mean, maximum and minimum sea ice edges with corresponding sea surface temperature fields. Each of these three edge positions are in turn matched to mean, maximum and minimum recorded air temperature fields. The resulting nine possible environmental combinations are subjected to wind speeds of 28 knots (14 ms^{-1}) and 50 knots (25ms^{-1}). Eighteen environmental combinations have been evaluated for each icing month. Despite this extensive study, real icing conditions will fall somewhere between the conditions shown on the maps below. Table 1 shows that gale force winds average 5% and 8% of each month in the North Chukchi and Hope Basin regions, respectively. This is a time period of at least 36 hours. Even light icing conditions produce a dangerous ice accumulation of 3.9 inches (10 cm) in under 24 hours (see Meteorology and Sea Conditions Section). Table 2 catalogs these combinations from May through November in the North Chukchi (A), South Chukchi (B) and Hope Basin (C) regions. The Figure Cover Page shows the area designations and superstructure icing (S1) codes. The months with the greatest chance for superstructure icing in all three regions are September and October.

MAY

Four out of the 18 chosen environmental combinations for S1 exist (see Table 2). This month shows the A and B regions to be completely covered by sea ice and C, only partially uncovered with the sea ice edge at its minimum

Table 2. Possible Structural Icing Months for Hope Basin, North Chukchi and South Chucki Regions.

May	June	July	August	September	October	November	Sea Ice Extent*	Environmental Conditions
								28 Knot (14 ms-1) Gale Class Winds
I	TH	TH	TH	TH	TH	TN		Max. Air Temp. (1%)
I	M(C)†	L(B) ,L(C)†	L(A) ,L(B),L(C)†	H(A), M(B), L(C)†	H(B),H(C)†	TL	Mean**	Min. Air Temp. (1%)
I	TN	TH	TN	L(A) ,L(B)†	H(A) ,H(B) ,M(C)†	M(C)†		Mean Air Temp.
I	I	TH	TH	TH	TH	I		Max. Air Temp. (1%)
I	I	L(C)†	L(B),L(C)†	M(B),M(C)†	VH(C)†	I	Max.**	Min. Air Temp. (1%)
I	I	TH	TN	TR	M(C)†	I		Mean Air Temp -
TH	TH	TH	TH	TH	L(A)†	M(A), L(B), L(C)†		Max. Air Temp. (1%)
VH†	M(C),M(B)†	L(A),L (B) †	L(A),L(B)†	M(A), L(B),L(C)†	M(B) ,M(C)†	TL	Min. **	Min. Air Temp. (1%)
M(C)†	TH	TR	TN	L(A) ,L(B)†	H(A) ,M(B) ,L(C)†	VH(A),VH(C)†		Mean Air Temp.
								50 Knot (25 ms-1) Storm Class Winds
I	TH	TH	TH	TH	TH	TN		Max. Air Temp. (1%)
I	VH(C)†	M(B),L(C)†	H(A) ,M(B) ,L(C)†	VH(A) ,VH(B) ,H(C)†	E(A) ,E(B) ,E(C)†	TL	Mean**	Min. Air Temp. (1%)
I	TH	TH	TN	M(A) ,L(B)†	VH(A) ,VH(B) ,H(C)†	E(C)†		Mean Air Temp.
I	I	TH	TH	TH	TH	I		Max. Air Temp. (1%)
I	I	M(C)†	H(B),H(C)†	VH(B),VH(C)†	E(C)†	I	Max.**	Min. Air Temp. (1%)
I	I	TH	TH	TH	VH(C)†	I		Mean Air Temp.
TH	TH	TH	TH	TH	H(A) †	VII(A) ,H(B) ,M(C)†		Max. Air Temp. (1%)
E(C)†	VII(B) ,VH(C)†	H(A),L(B)†	H(A),M(B)†	VH(A),H(B) ,M(C)†	E(A),E(B) ,VH(C)†	TL	Min.**	Min. Air Temp. (1%)
VH(C)†	TH	TN	TN	M(A) ,L(B)†	E(A), VH(B),H(C)†	E(A),E(B) ,E(C)†		Mean Air Temp.

Factors Precluding Icing
- I ≡ Sea ice covering area
- TL ≡ Air temperature too low
- TH ≡ Air temperature too high
- SS ≡ Sea surface temperature too high

† ≡ Icing Possible

Worst Icing Possible
- E ≡ Extreme
- VH ≡ Very heavy
- H ≡ Heavy
- M ≡ Moderate
- L ≡ Light

Regions
- C ≡ Hope Basin
- A ≡ North Chukchi
- B ≡ South Chukchi

*Mean, max. and min. sea ice extent also corresponds to mean, max. and min. sea surface temperatures recorded extent (Figs. 1 and 2). Figure 1 shows S1 under mean air temperatures with (a) for 28 knot winds and (b) for 50 knot winds. The 50 knot case can result in very heavy icing in Region C, Figure 2 shows S1 under minimum recorded air temperatures for conditions of 28 and 50 knot winds. In Figure 2b for 50 knot winds, extreme icing conditions will occur. It should be noted that the combined probability of finding any open water in Region C along with extreme minimum air temperatures and 50 knot winds in May is almost negligible (less than .01%).

JUNE

Four out of the 18 chosen environmental combinations for S1 exist (see Table 2). With the sea ice edge at its mean extent, only Region C is uncovered (Fig. 3). A mean or maximum recorded air temperature field is too warm for icing. Under minimum air temperatures, moderate (Fig. 3a) and very heavy (Fig. 3b) icing levels are reached for 28 knot and 50 knot winds, respectively. The minimum extent of sea ice recorded shows Regions B and C open (Fig. 4). Only minimum air temperatures produce S1 at levels up to moderate and very heavy for wind speeds of 28 knots (Fig. 4a) and 50 knots (Fig. 4b) , respectively. S1 chances in June are greater than in May, but Region B has a less than .01% probability and Region A has O probability.

JULY

Only six out of 18 chosen environmental combinations for S1 exist (see Table 2). Mean or maximum air temperature fields are too warm for icing. For a mean sea ice edge and minimum recorded air temperatures, light S1 (Fig. 5A) and up to moderate S1 (Fig. 5b) can be seen for 28 knots and 50 knots, respectively in Region B. Region A is completely covered by sea ice and most of Region C has air temperatures above freezing, precluding icing (Fig. 5). Maximum sea ice extent with minimum air temperatures show light S1 (Fig. 6a) and up to moderate S1 (Fig. 6b) in Region C only, since sea ice covers Regions A and B. Minimum recorded sea ice extent uncovers Regions A, B and C (Fig. 7). The sea surface temperatures associated with minimum sea ice extent preclude S1 in Region C, however. Region B would suffer light S1 under 28 to 50 knot winds, but Region A would reach heavy icing conditions under 50 knot winds (see Fig. 7a and b). S1 chances in July are greater than in June, but Region C conditions will never get beyond light icing and chances in Region A are less than .01%. Typical July temperatures would preclude any icing. This is a month of high ship traffic in the study area.

AUGUST

S1 can exist for six out of 18 chosen environmental combinations (see Table 2). As in July, mean or maximum air temperature fields are too warm for icing. A mean sea ice edge coupled with a minimum air temperature field produces light S1 in Regions A, B, and C for 28 knot winds (Fig. 8a). Fifty knot winds will produce heaving icing in Region A, moderate icing in Region B, and light icing in Region C (Fig. 8b). It should be noted that most of Region A is covered while most of Region C is too warm for icing (Fig. 8).

Maximum sea ice extent with a minimum air temperature field precludes S1 in Region A due to sea ice extent and eliminates S1 in most of Region C due to temperatures above freezing (Fig. 9), S1 can change from light to heavy in both Regions B and C under wind conditions of 28 knots (Fig. 9a) and 50 knots (Fig. 9b), respectively.

Minimum sea ice extent and a minimum air temperature field precludes S1 in Region C and most of B because the sea surface temperatures associated with this edge position would be too warm (Fig. 10). All region A would be susceptible to S1 with conditions of light changing to heavy if wind speeds changed from 28 knots (Fig. 10a) to 50 knots (Fig. 10b).

S1 chances in August are greater than in July because there is more open water under average ice edge conditions. However, chances of heavy icing in Region B or C are less than .01%. Typical August temperatures would preclude icing. Ship traffic in August is typically high.

SEPTEMBER

S1 can exist for 10 of 18 selected environmental combinations (see Table 2). Maximum air temperature fields were too warm for S1 (Table 2). A mean sea ice edge coupled with a minimum air temperature field (1% probability) can produce S1 in all Regions, A-C (Fig. 11). A change in wind speed from 28 knots (Fig. ha) to 50 knots (Fig. 11b) can produce very heavy icing conditions in Region A which is closest to the mean ice edge.

A mean sea ice edge subjected to a mean air temperature field is the most probable situation that would be encountered (Fig. 12). S1 is not encountered in Region C and most of Region B due to air temperatures above freezing (Fig. 12). Region A can reach moderate S1 at wind speeds of 50 knots (Fig. 12b) which have a less than 1% chance of occurring in September (Table la).

A maximum sea ice extent condition precludes S1 in Region A (Fig. 13) and is far enough south that a mean or maximum air temperature field would produce air temperatures above freezing for open water areas in Regions B and C. Condition of a minimum air temperature field with winds of 28 knots (Fig.

13a) and 50 knots (Fig. 13b) will produce moderate and very heavy SI, respectively, in Regions B and C. However, the chance for this set of events occurring is less than ,01%.

A combination of minimum sea ice extent and a minimum air temperature field (less than .01% probability) will produce S1 in Regions A-C (Fig. 14). However, the sea surface temperature field associated with this sea ice edge will have ocean temperatures too high (SS) for icing in most of Region C, Under 28 knot winds only moderate icing levels are reached in Region A (Fig, 14a), while 50 knot winds produce very heavy icing in a portion of Region A (Fig. 14b) .

Minimum sea ice extent coupled with mean air temperatures will result in no S1 in most of Regions B and C due to air temperatures above freezing (TH) (Fig. 15) . A change from 28 knot winds (Fig. 15a) to 50 knot winds (Fig. 15b) will increase the S1 from light to moderate in part of Region A.

SI chances in September are greater than August because the average temperatures are lower and there is more open water under average ice edge conditions. Ship traffic would be high during this month. Typical September conditions would preclude icing in Region B or C with moderate icing at 50 knot wind speeds (not common, see Table la) in Region A.

OCTOBER

S1 can exist for 14 of 18 selected environmental combinations (see Table 2). This month is the one with the greatest probability of icing. It is fortunate that ship traffic is not as high as July, August or September in Regions A-C at this time of year.

A mean sea ice edge and minimum air temperature field (Fig. 16) will produce extreme SI under 50 knot winds in Regions A-C (Fig. 16b). It must be noted that at wind speeds of 28 knots (Fig. 16a) sea spray would freeze before striking a structure and not adhere. This condition is designated TL and covers most of Region B and the open water portion of Region A.

The most typical conditions are those of a mean sea ice edge and mean air temperature field (Fig. 17). They can produce heavy icing in the same regions under 50 knot winds (Fig. 17b) . Gale force winds have a 10% probability (mean of statistics for Regions A and C in Tables la and b) of occurrence in Region B.

A maximum sea ice edge extent will cover Regions A and B precluding S1 there. In combination with minimum air temperatures over Region C, S1 will range from very heavy (Fig. 18a) to extreme (Fig. 18b) under winds of 28 knots and 50 knots, respectively. In combination with mean air temperatures over Region C, S1 will range from moderate (Fig. 19a) to very heavy (Fig. 19b) under wind speeds of 28 knots and 50 knots, respectively.

A minimum sea ice edge extent combined with maximum recorded air temperatures (less than .01% probability) will result in S1 in Region A only (Fig. 20) . These conditions will result in light S1 and heavy S1 Region A under winds of 28 knots (Fig. 20a) and 50 knots (Fig. 20b), respectively.

A minimum sea ice edge and minimum air temperatures (less than .01% probability) will produce moderate S1 in Region C under 28 knot winds (Fig. 21a). However, the low temperatures (TL) would cause spray to freeze before striking the ship, resulting in no S1 in Region A and most of Region B. At 50 knots, Region A and most of Region B would be subjected to extreme S1 (Fig. 21b), while most of Region C would reach very heavy icing.

A minimum sea ice edge with mean air temperatures results in some kind of S1 over all three regions (Fig. 22). The most dominant S1 changes from light to moderate in Region C, moderate to heavy in Region B, and moderate to very heavy in Region A as wind speeds change from 28 knots (Fig. 22a) to 50 knots (Fig. 22b), respectively.

Typical October conditions would have Region A mostly ice covered precluding S1 there. However, gale force winds in Region B (10% chance, Table la and b combined) and Region C (14% chance, Table lb) could produce moderate S1 and light S1, respectively.

NOVEMBER

S1 can exist for six out of 18 selected environmental combinations (see Table 2). A maximum recorded sea ice edge precludes open water in Regions A-C so S1 would be non-existent.

A mean sea ice edge will have open water in a portion of Region C only (Fig. 23) . Maximum air temperatures are too warm and minimum air temperatures are too cold for icing in Region C. Mean air temperatures will produce heavy icing and extreme icing under 28 knot winds (Fig. 23a) and 50 knot winds (Fig. 23b), respectively. Gale force winds under these typical conditions can be expected 14% of the time (Table lb).

Conditions of a minimum sea ice edge and maximum air temperatures (less than .01% chance) can produce S1 levels up to very heavy in Regions A and B under 50 knot winds (Fig. 24b). Most of Region C would have air temperatures above freezing (Fig. 24) under these conditions , eliminating a chance for S1.

A minimum sea ice edge and mean air temperatures (combined 1% chance) would produce very heavy and extreme S1 under 28 knots (Fig. 25a) and 50 knots (Fig. 25b) winds respectively. It should be noted that a minimum air temperature field produces temperatures too low for S1.

If open water exists in Region A, B, or C in November, there is a better than 10% chance of heavy icing under gale force winds (see Table lb).

SUMMARY

Remember that real icing conditions will fall somewhere between the environmental combinations chose for Figures 1-25 and Table 2. Ocean thermal inertia will make atmospheric changes, which operate on a shorter time scale, the most dangerous for evolving S1 conditions. For example, sudden cold fronts with high winds can move into the Chukchi Sea under average sea ice edge extent and produce heavy icing in the "warm" months of July and August. September and October are the months with the greatest chance for S1. Table 2 shows that they have the most possible combinations for S1 (10 September, 14 October). All conditions other than mean conditions have a 1% chance of occurrence. Therefore, any two independent combinations of these 1% probability conditions have a .01% chance of occurrence. However, sea ice extent and sea surface temperatures are not independent.

A polynya exists along the Alaskan Chukchi coast between Pt. Barrow and Pt. Hope in the months of February to April when the study area is usually ice covered (Stringer, 1982). Stringer's study (eight years of data) has shown that this polynya is closed 77% of the time in February and averages 12 km wide. In April, it is closed 62% of the time and averages 1 km wide. This would not be a corridor for major ship traffic and would have limited fetch for wave production.

FURTHER STUDY

A data gathering program should be initiated for the North Chukchi, South Chukchi, and Hope Basins. Among the parameters measured during icing events should be salinity of adhering ice, materials with or without coatings adhered to, percentage due to sea spray, ship size, ship speed, types of waves, wave directionality and thickness of ice, Also, some type of meteorological early warning system should be studied.

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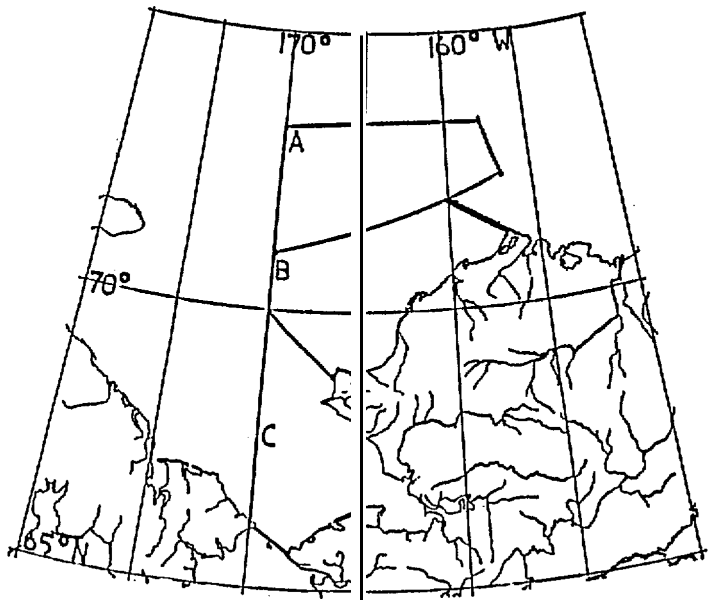
FIGURE COVER PAGE



STUDY REGIONS

A ≡ North Chukchi

B ≡ South Chukchi

C ≡ Hope Basin

(Sea Ice Edge)

(Icing Categories) (Inches per 3 hours)

	Extreme	2.50 +
	Very Heavy	1.50 to 2.49
	Heavy	1.00 to 1.49
	Moderate	.50 to .99
	Light	0 to .49

(Factors Precluding Superstructure Icing)

I ≡ Sea ice covering area

TL ≡ Air temperature too low

TH ≡ Air temperature too high

SS ≡ Sea surface temperature too high

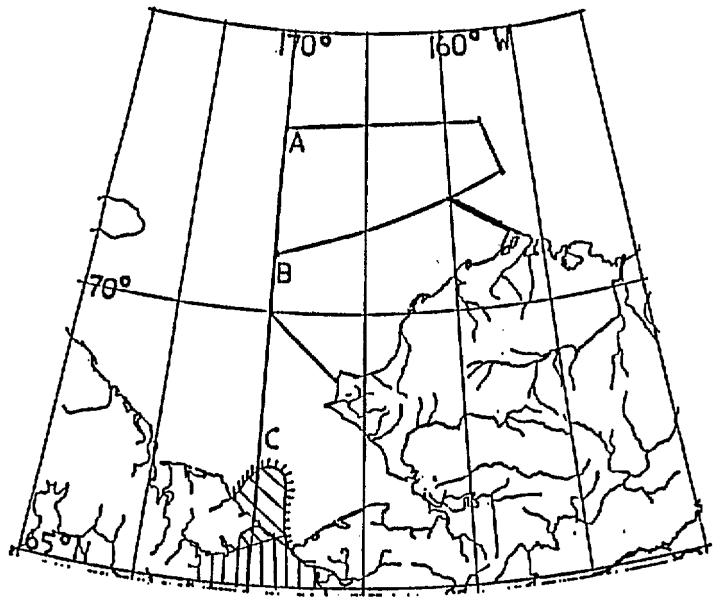


Figure la. May superstructure icing (S1) for conditions of minimum sea ice extent, maximum sea surface temperatures, mean air temperatures> and 28 knot winds.

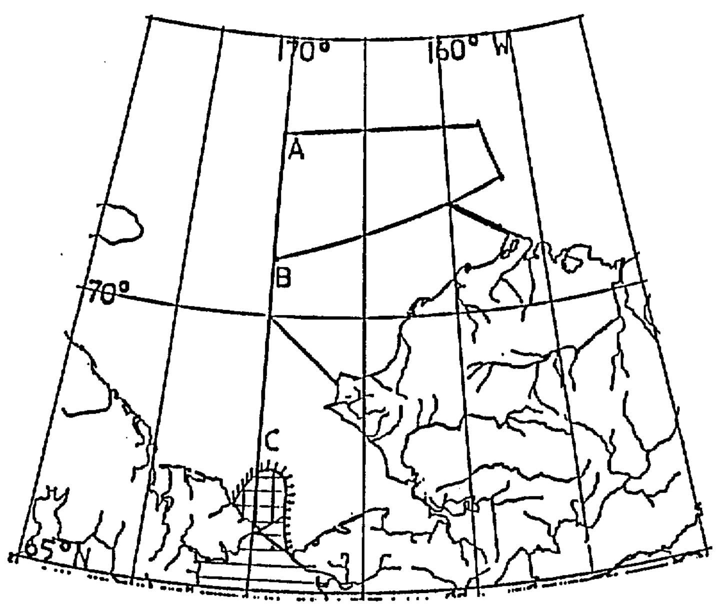


Figure lb. May S1 for the above conditions except with 50 knot winds.

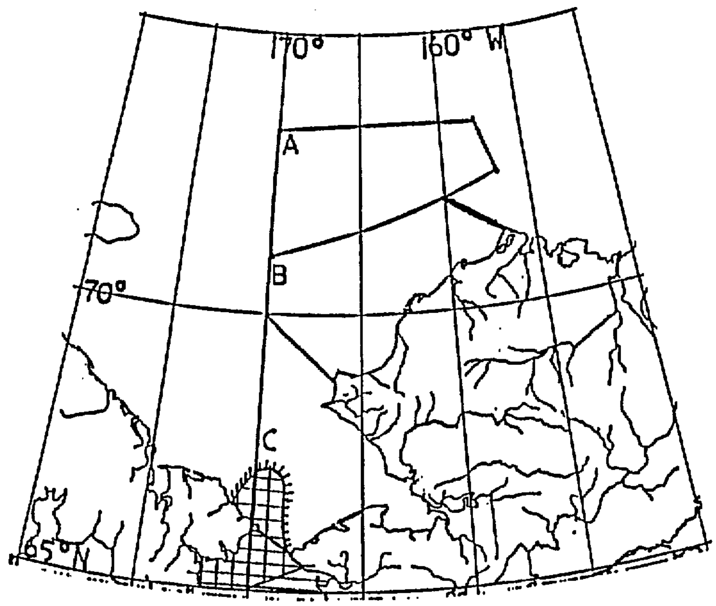


Figure 2a. May S1 for conditions of minimum sea ice extent, maximum sea surface temperatures, minimum air temperatures, and 28 knot winds.

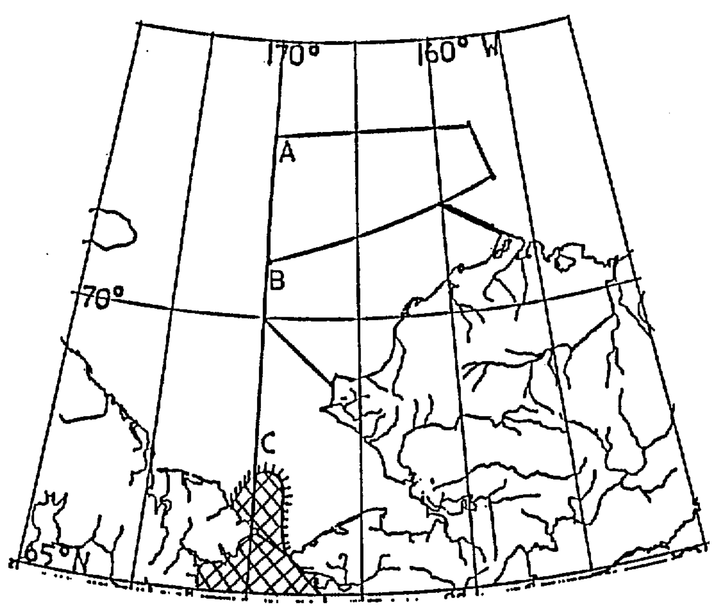


Figure 2b. May S1 for the above conditions except with 50 knot winds.

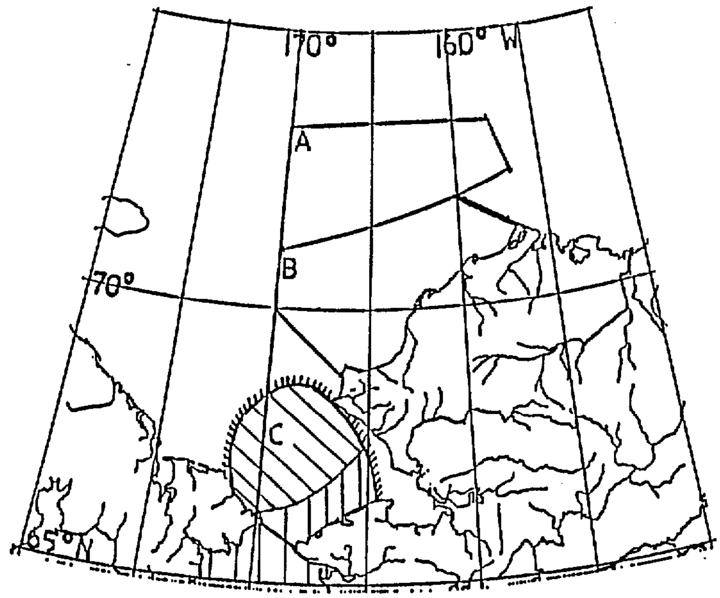


Figure 3a. June S1 for conditions of mean sea ice extent, mean sea surface temperatures, minimum air temperatures, and 28 knot winds.

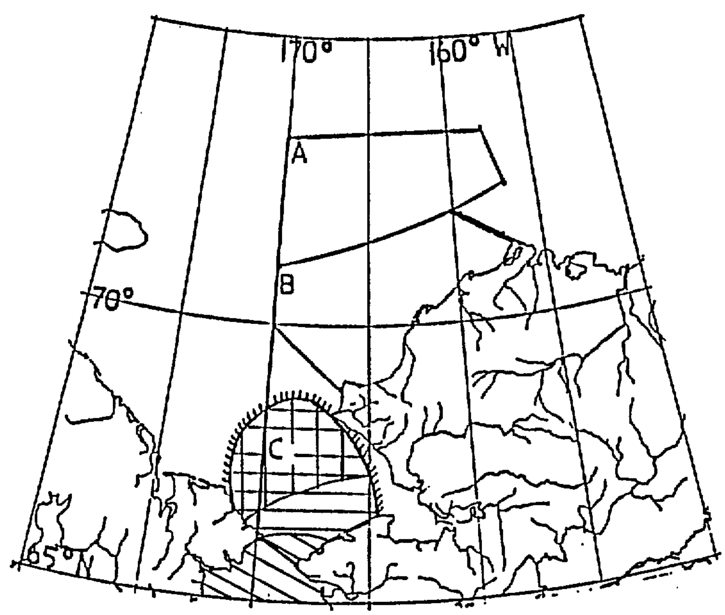


Figure 3b. June S1 for the above conditions except with 50 knot winds.

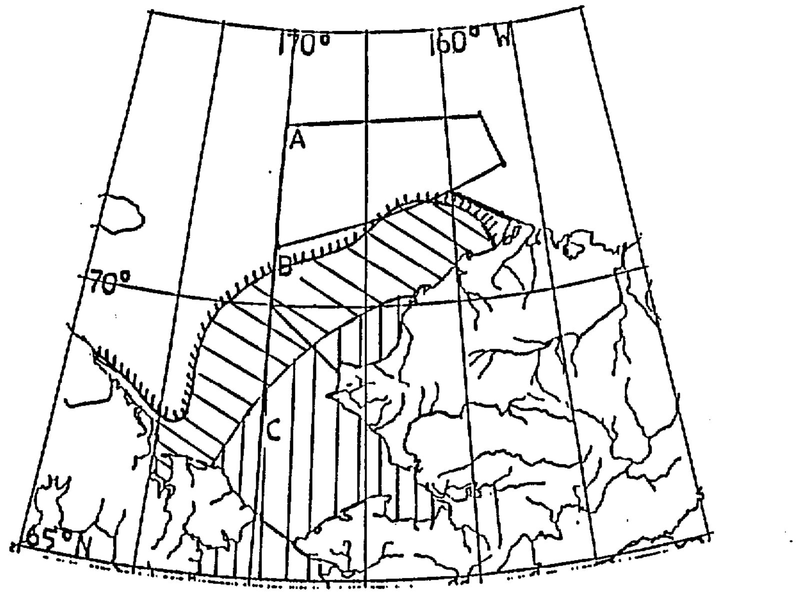


Figure 4a. June S1 for conditions of minimum sea ice extent, maximum sea surface temperatures, minimum air temperatures, and 28 knot winds.

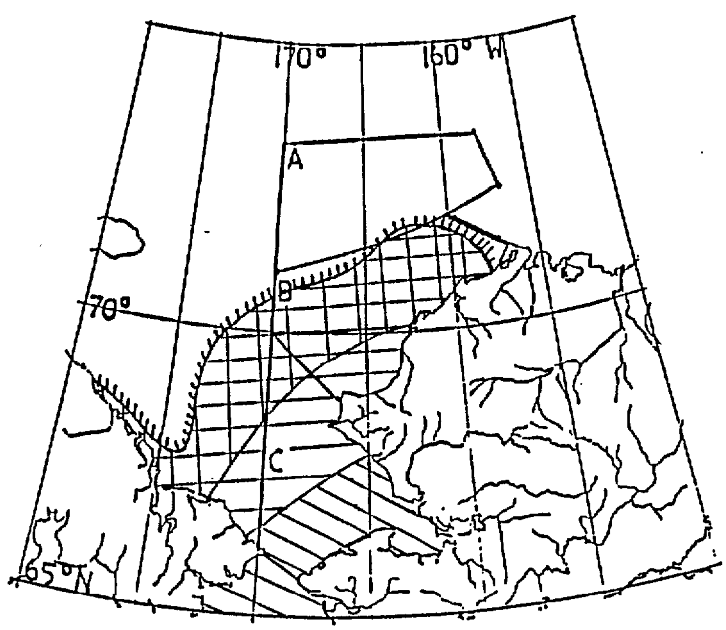


Figure 4b. June S1 for the above conditions except with 50 knot winds.

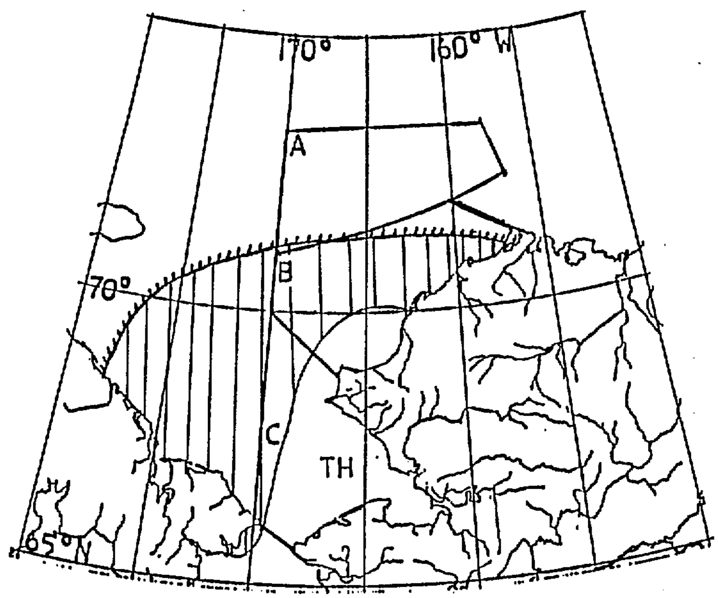


Figure 5a, July S1 for conditions of mean sea ice extent, mean sea surface temperatures, minimum air temperatures, and 28 knot winds.

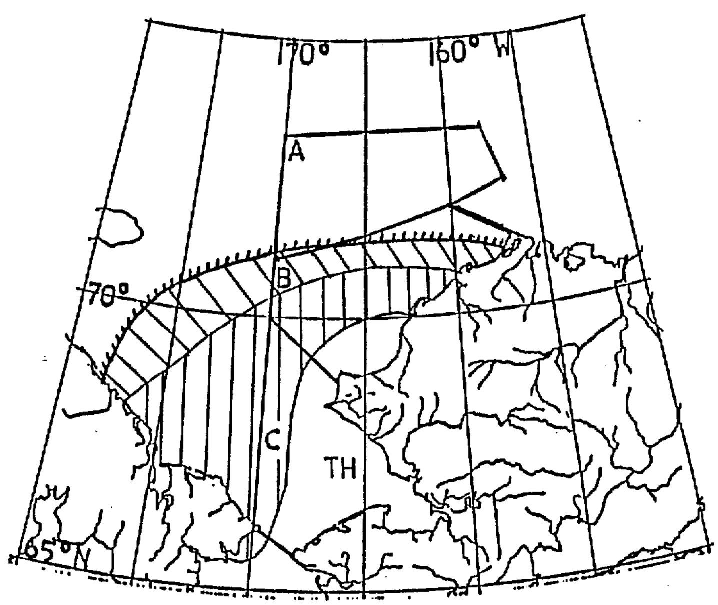


Figure 5b. July S1 for the above conditions except with 50 knot winds.

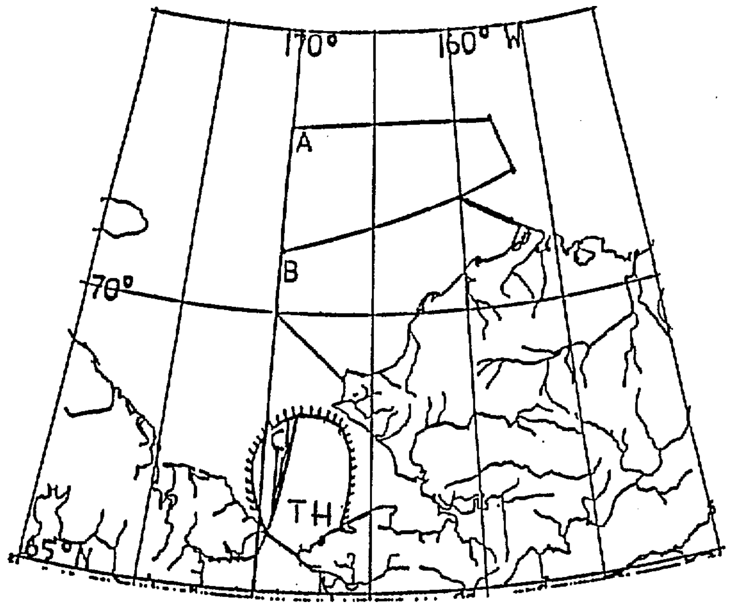


Figure 6a. July S1 for conditions of maximum sea ice extent, minimum sea surface temperatures, minimum air temperatures, and 28 knot winds.

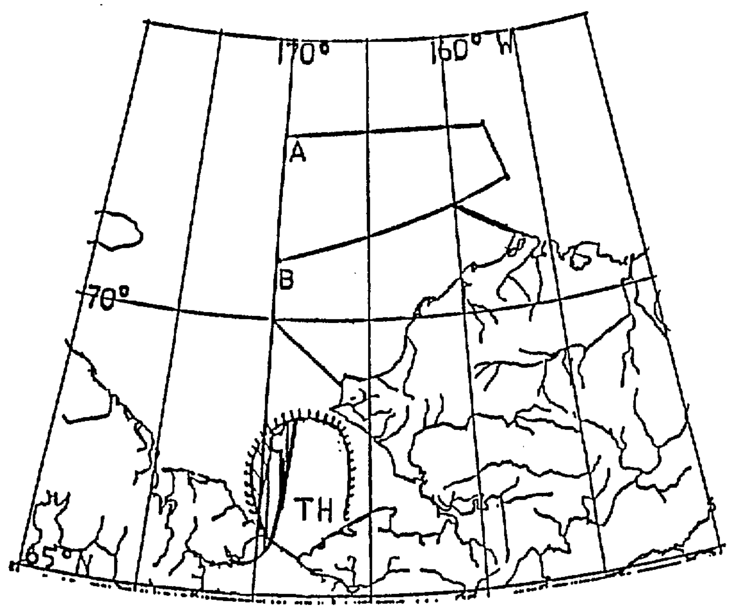


Figure 6b. July S1 for the above conditions except with 50 knot winds.

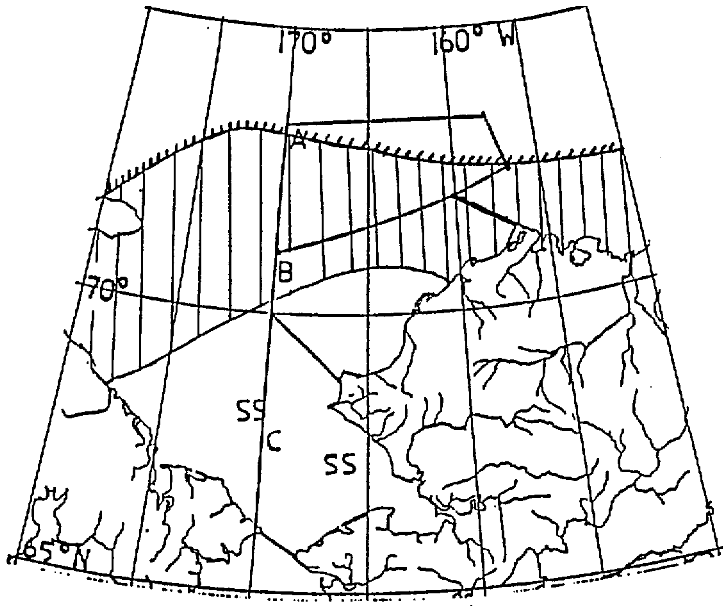


Figure 7a. July SI for conditions of minimum sea ice extent, maximum sea surface temperatures, minimum air temperatures, and 28 knot winds.

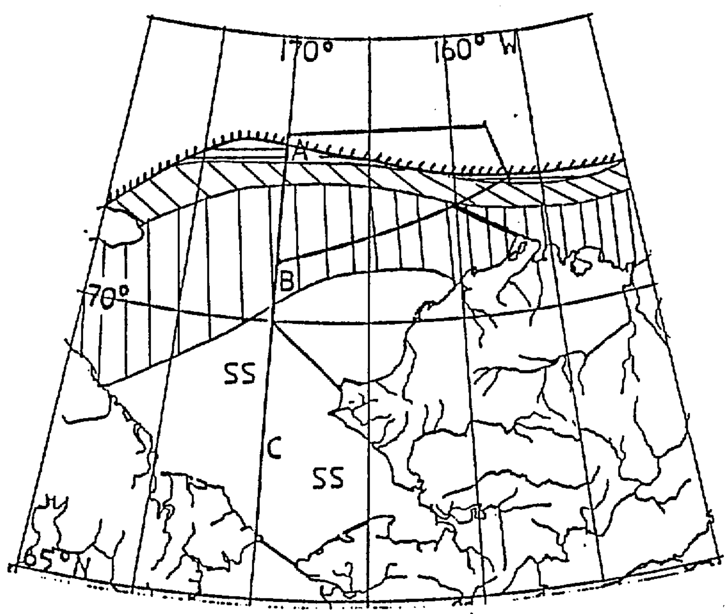


Figure 7b. July S1 for the above conditions except with 50 knot winds.

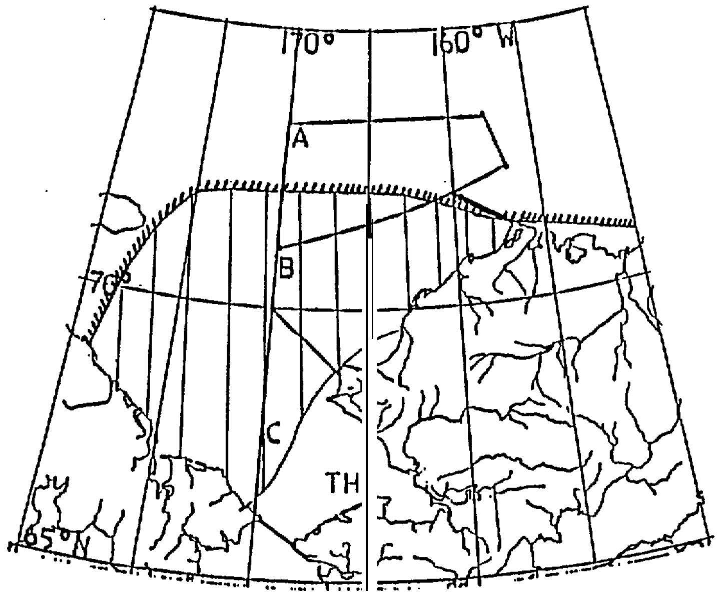


Figure 8a. August S1 for conditions of mean sea ice extent, mean sea surface temperatures, minimum air temperatures, and 28 knot winds.

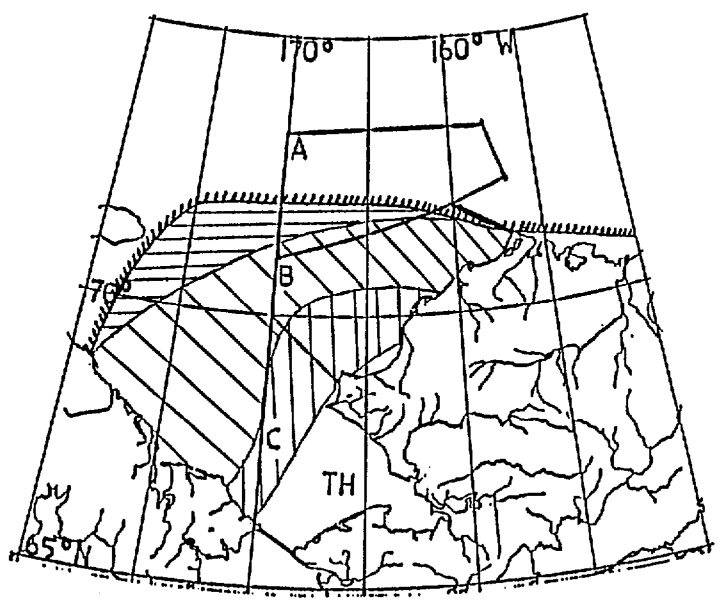


Figure 8b. August S1 for the above conditions except with 50 knot winds.

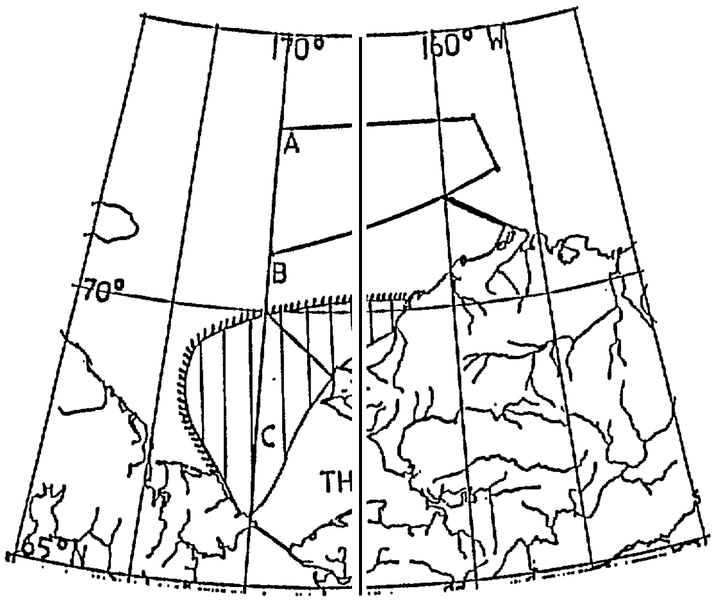


Figure 9a. August S1 for conditions of maximum sea ice extent, minimum sea surface temperatures, minimum air temperatures, and 28 knot winds.

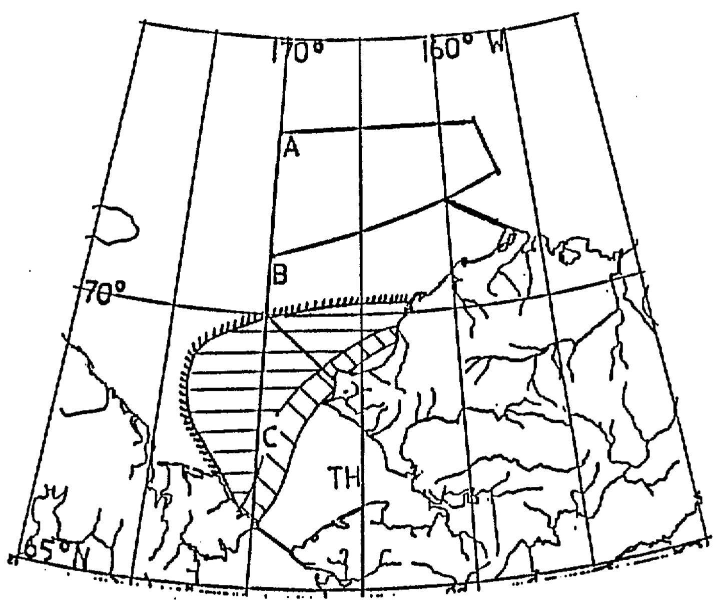


Figure 9b. August S1 for the above conditions except with 50 knot winds.

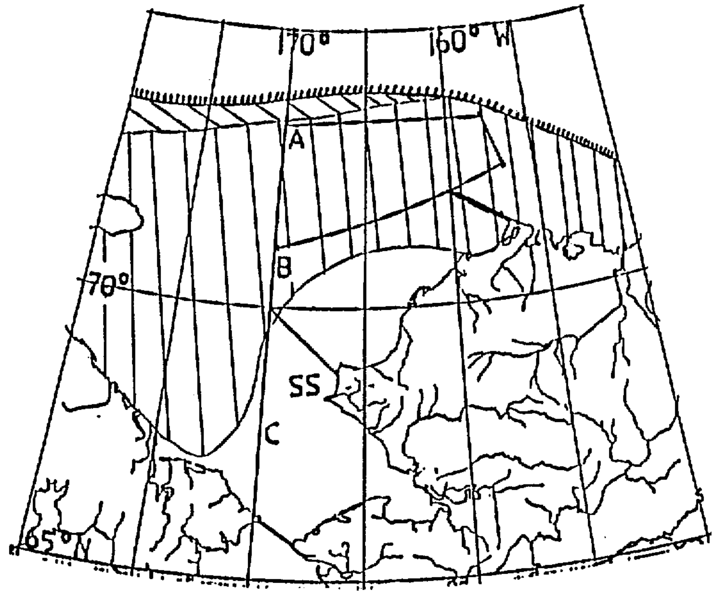


Figure 10a. August S1 for conditions of mininum sea ice extent, maximum sea surface temperatures, minimum air temperatures, and 28 knot winds.

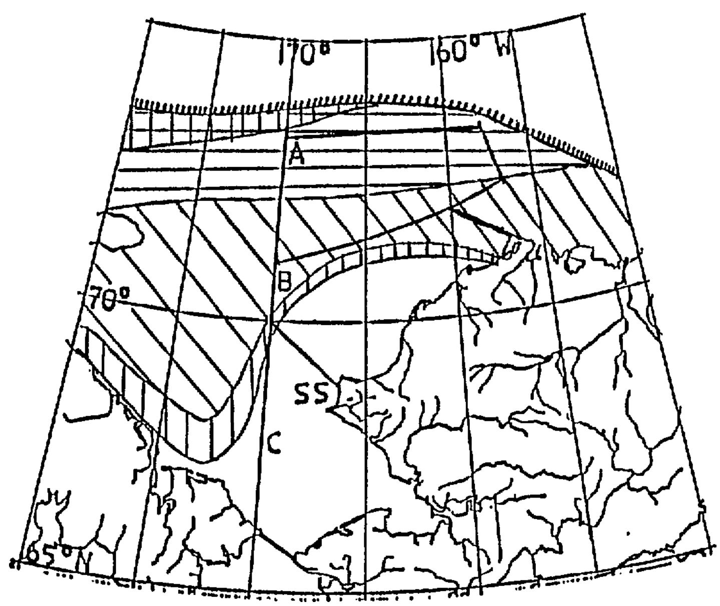


Figure 10b. August S1 for the above conditions except with 50 knot winds.

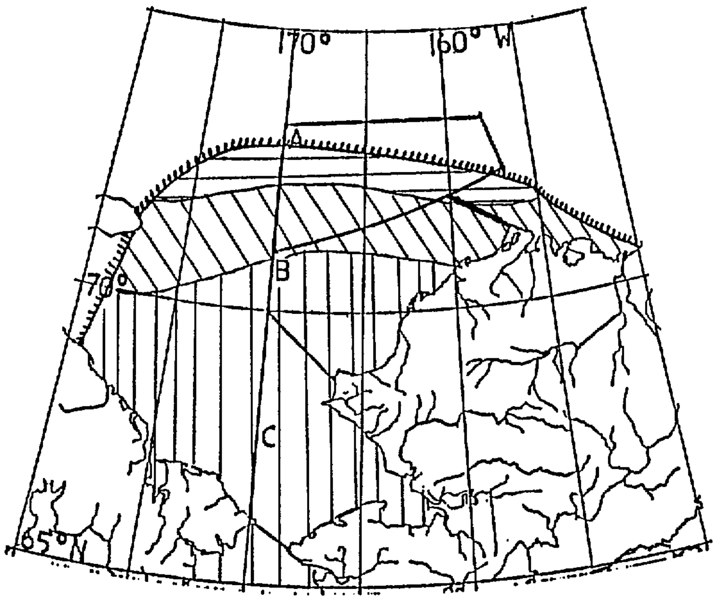


Figure ha. September S1 for conditions of mean sea ice extent, mean sea surface temperatures, minimum air temperatures, and 28 knot winds.

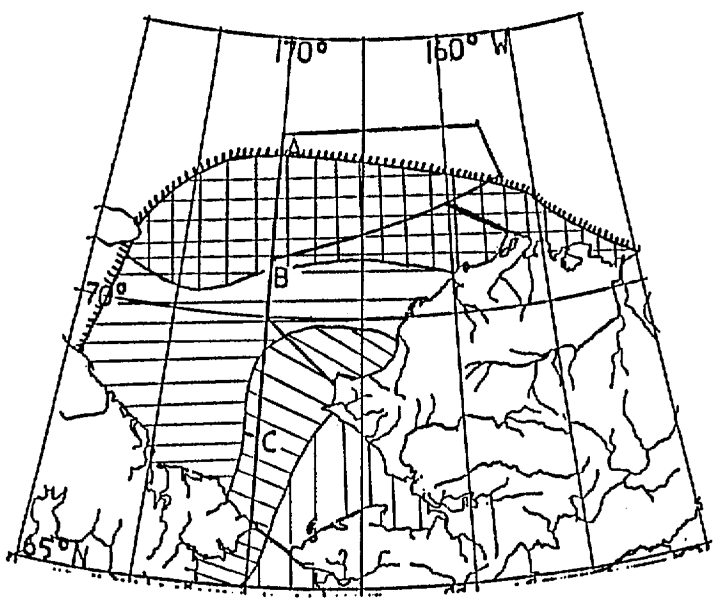


Figure 11b. September S1 for the above conditions except with 50 knot winds.

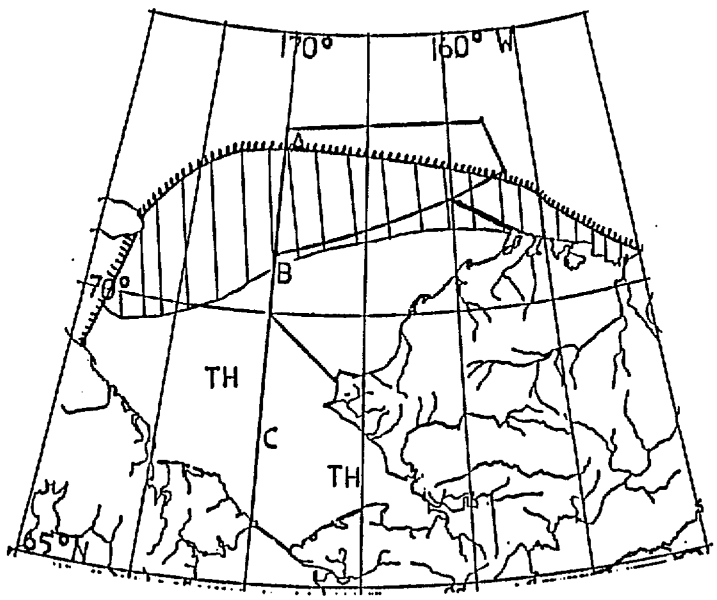


Figure 12a. September S1 for conditions of mean sea ice extent, mean sea surface temperatures, mean air temperatures, and 28 knot winds.

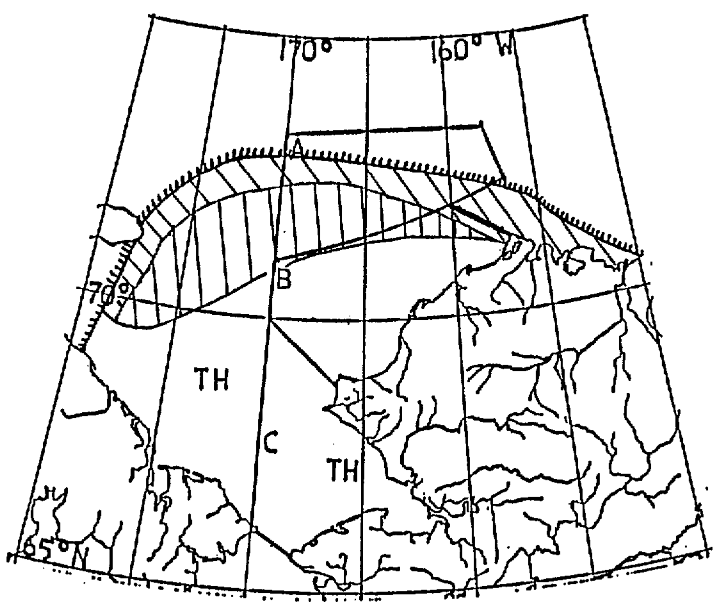


Figure 12b. September S1 for the above conditions except with 50 knot winds.

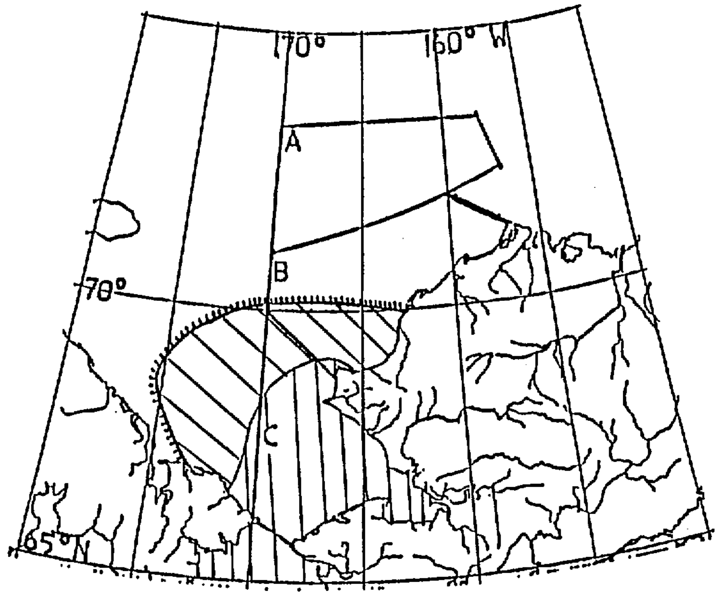


Figure 13a. September S1 for conditions of maximum sea ice extent, minimum sea surface temperatures, minimum air temperatures, and 28 knot winds.

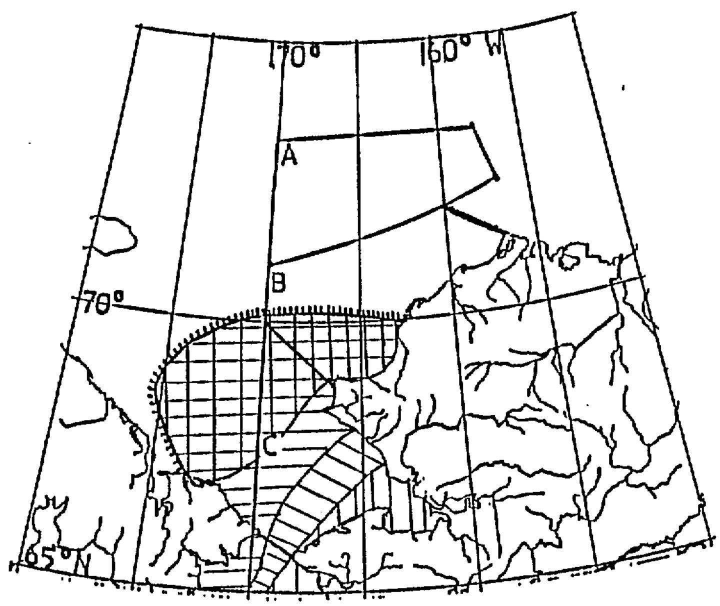


Figure 13b. September S1 for the above conditions except with 50 knot winds.

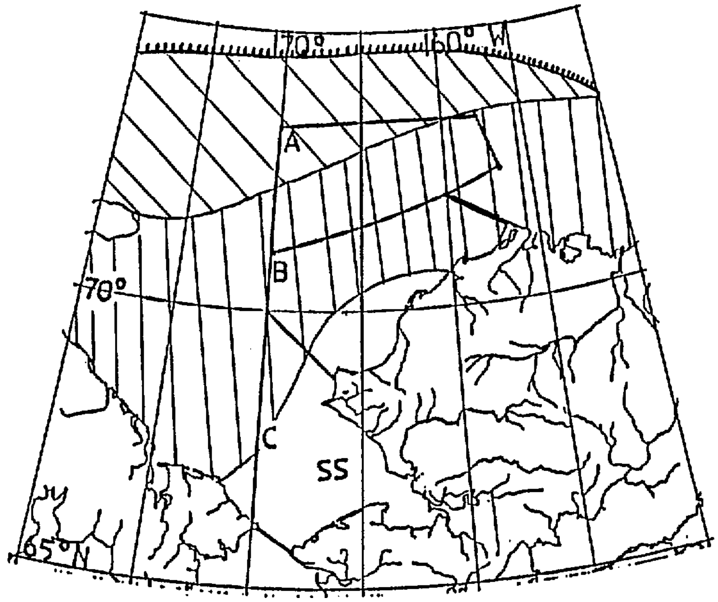


Figure 14a. September S1 for conditions of minimum sea ice extent, maximum sea surface temperatures, minimum air temperatures, and 28 knot winds.

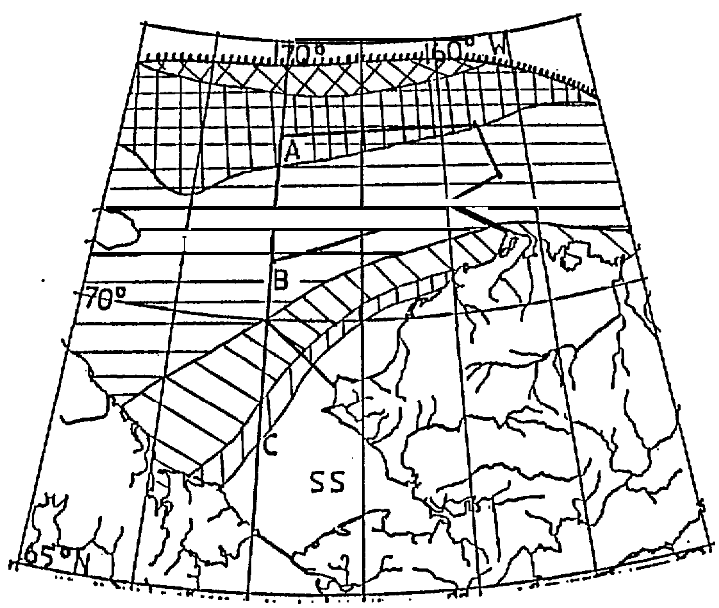


Figure 14b. September S1 for the above conditions except with 50 knot winds.

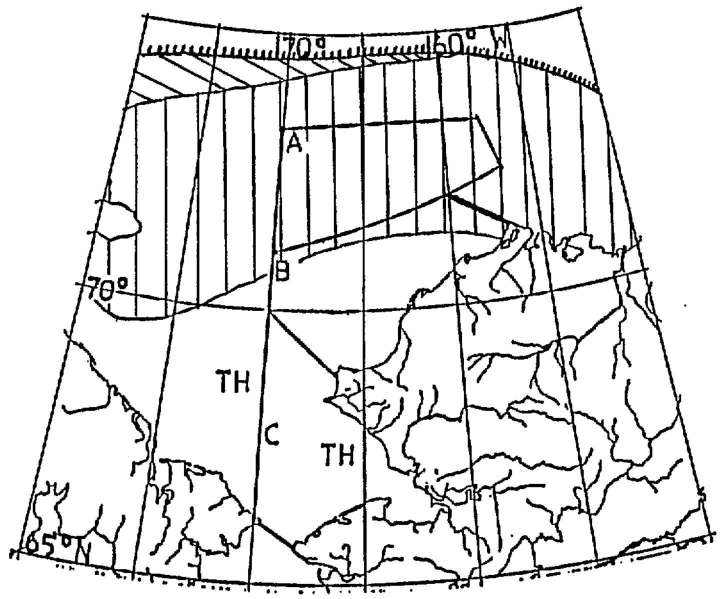


Figure 15a. September S1 for conditions of minimum sea ice extent, maximum sea surface temperatures, mean air temperatures, and 28 knot winds.

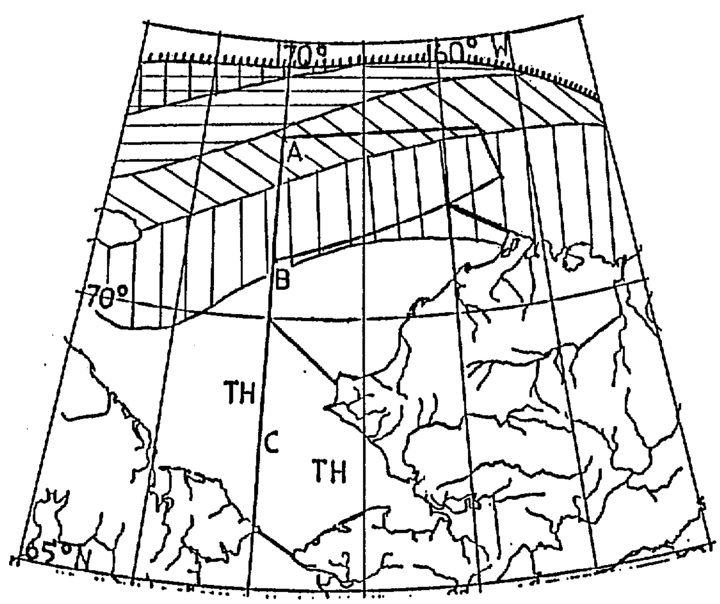


Figure 15b. September S1 for the above conditions except with 50 knot winds.

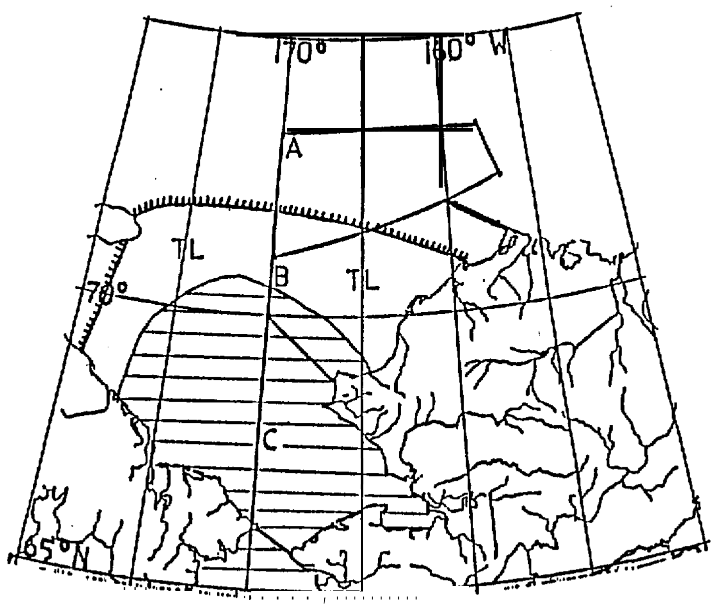


Figure 16a. October S1 for conditions of mean sea ice extent, mean sea surface temperatures, minimum air temperatures, and 28 knot winds.

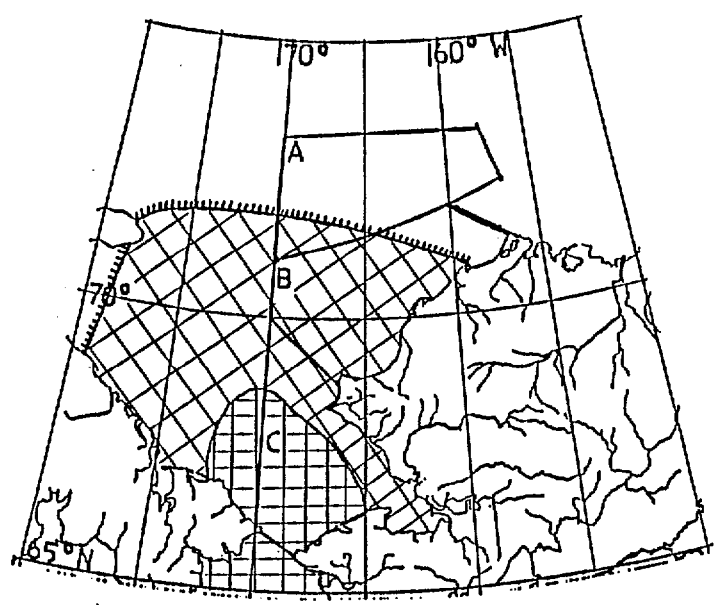


Figure 16b. October S1 for the above conditions except with 50 knot winds.

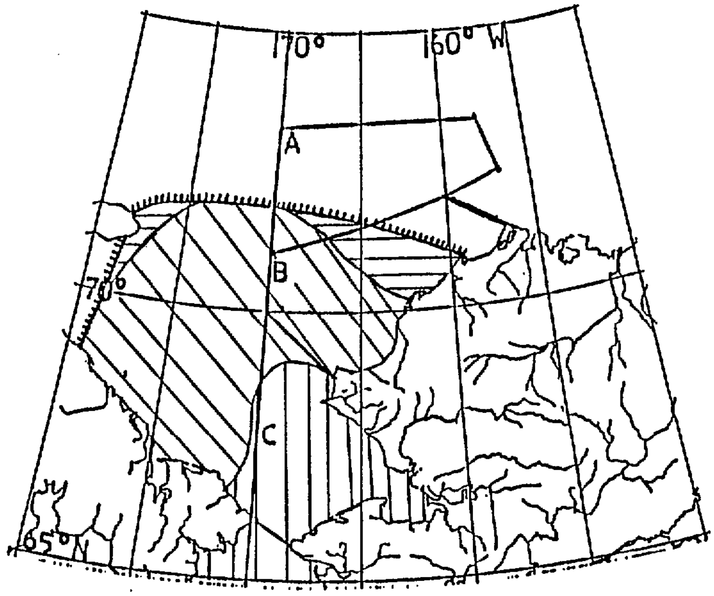


Figure 17a. October S1 for conditions of mean sea ice extent, mean sea surface temperatures, mean air temperatures, and 28 knot winds.

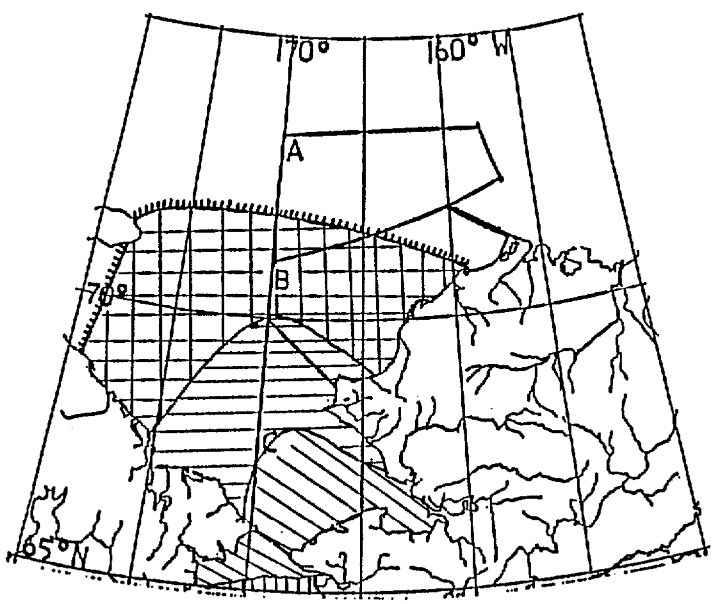


Figure 17b. October S1 for the above conditions except with 50 knot winds.

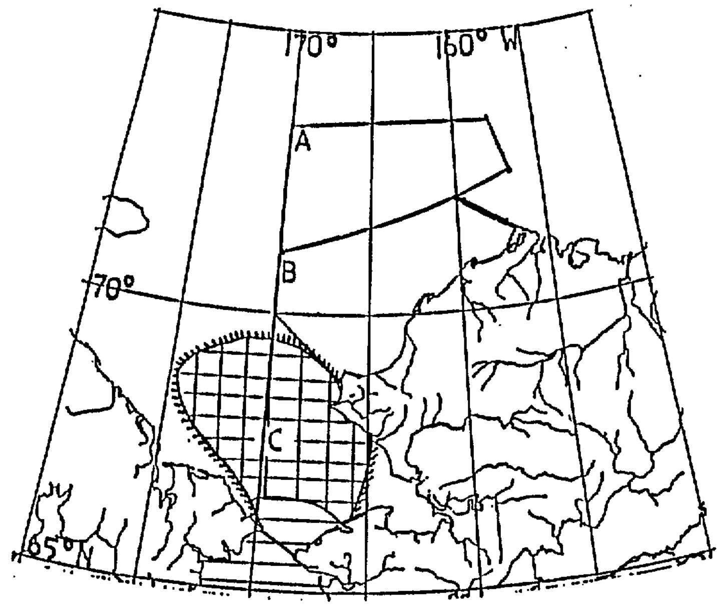


Figure 18a. October S1 for conditions of maximum sea ice extent, minimum sea surface temperatures, minimum air temperatures, and 28 knot winds.

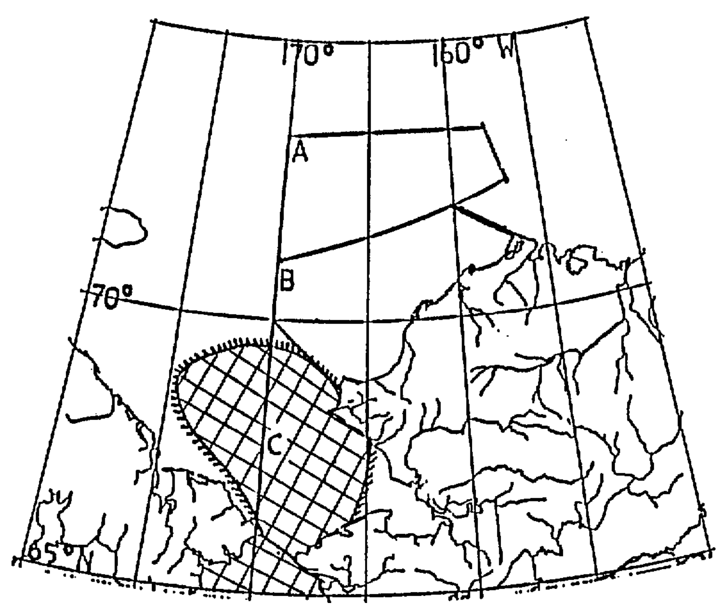


Figure 18b. October S1 for the above conditions except with 50 knot winds.

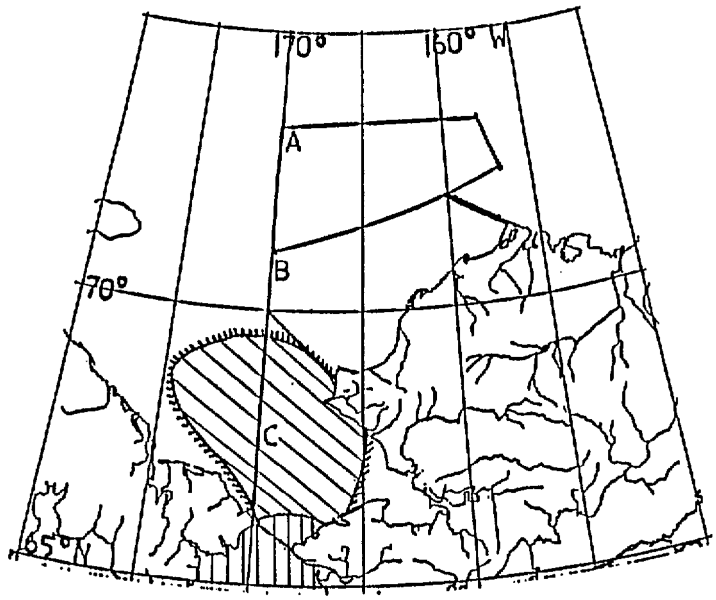


Figure 19a. October S1 for conditions of maximum sea ice extent, minimum sea surface temperatures, mean air temperatures, and 28 knot winds.

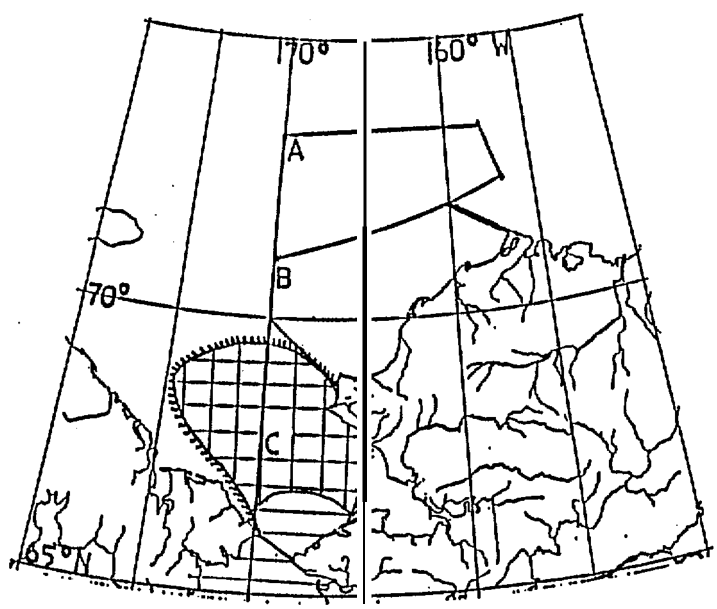


Figure 19b. October S1 for the above conditions except-with 50 knot winds.

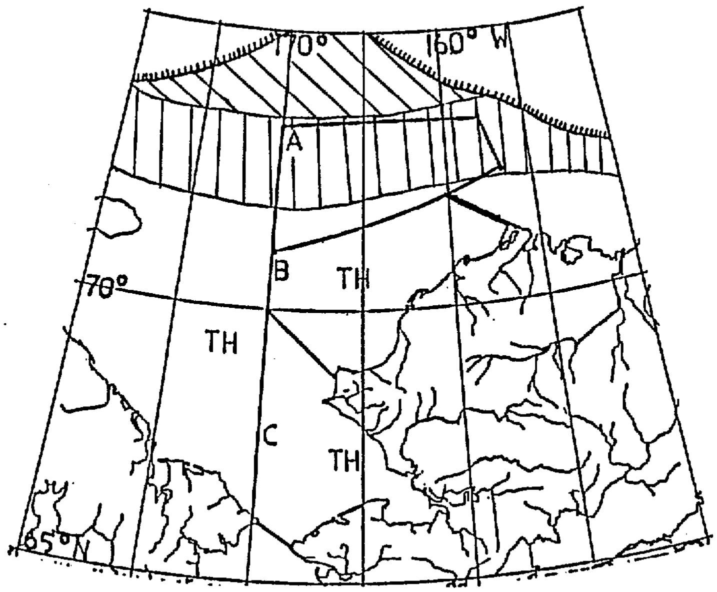


Figure 20a. October S1 for conditions of minimum sea ice extent, maximum sea surface temperatures, maximum air temperatures, and 28 knot winds.

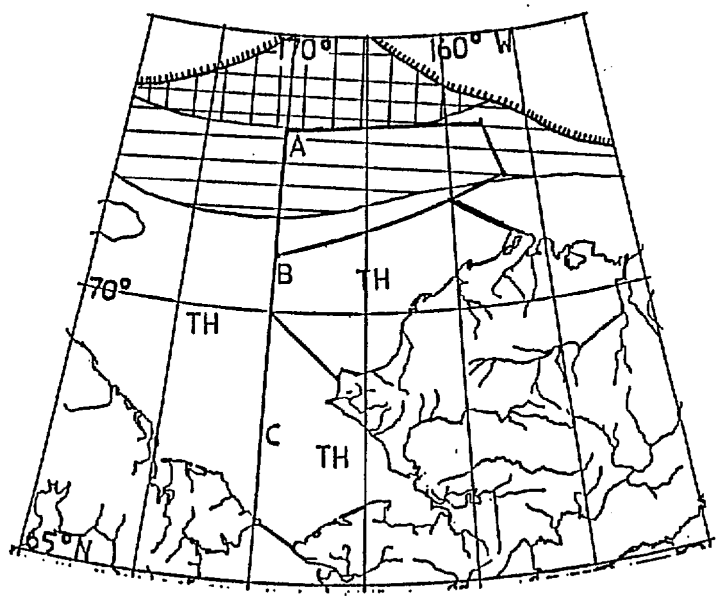


Figure 20b. October S1 for the above conditions except with 50 knot winds.

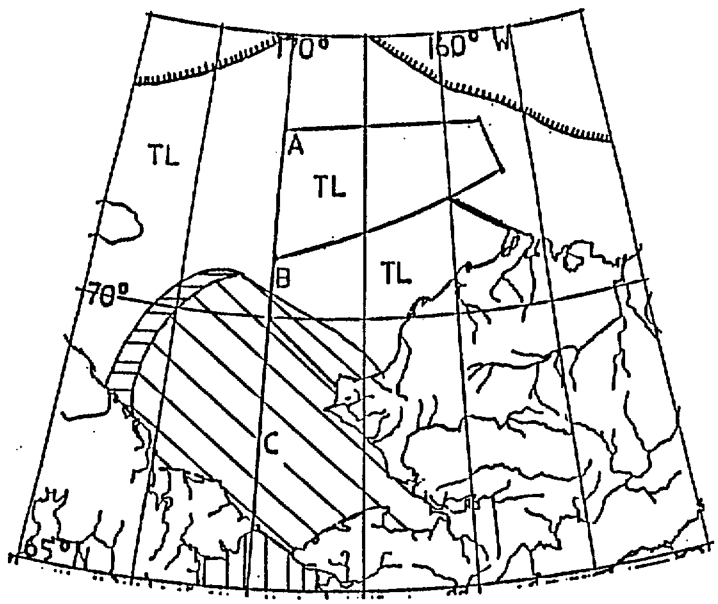


Figure 21a. October S1 for conditions of minimum sea ice extent, maximum sea surface temperatures, minimum air temperatures, and 28 knot winds.

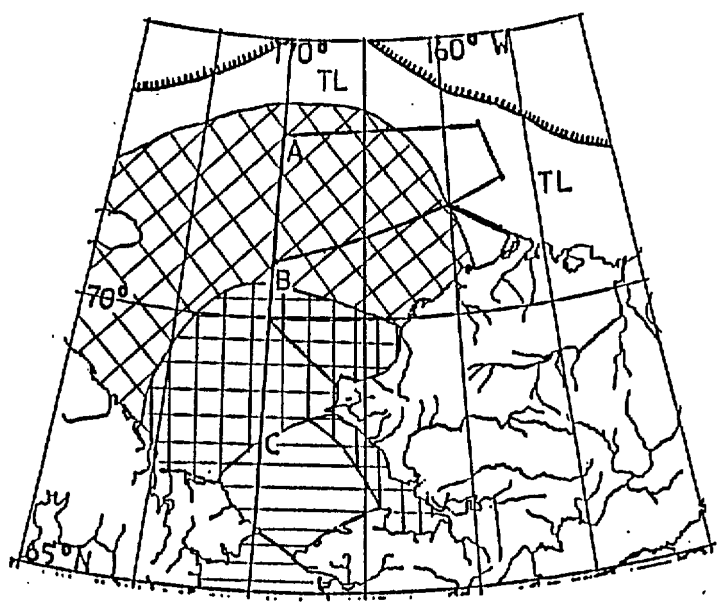


Figure 21b. October S1 for the above conditions except with 50 knot winds.

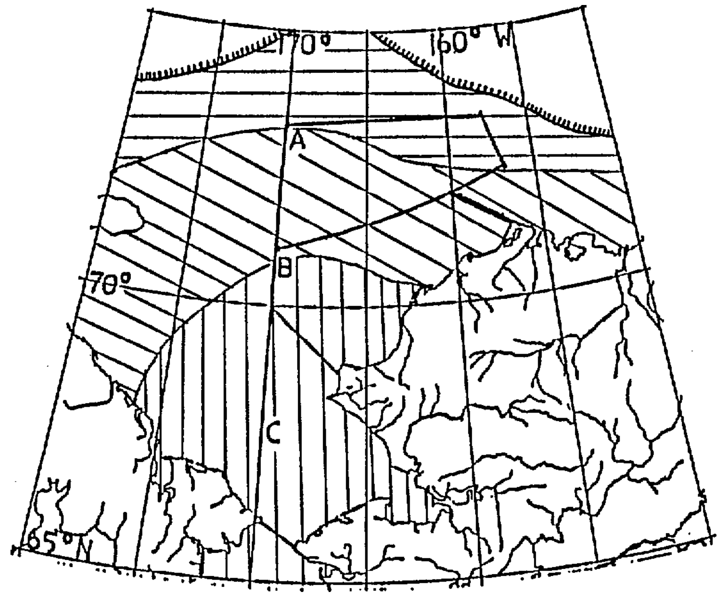


Figure 22a. October S1 for conditions of minimum sea ice extent, maximum sea surface temperatures, mean air temperatures, and 28 knot winds.

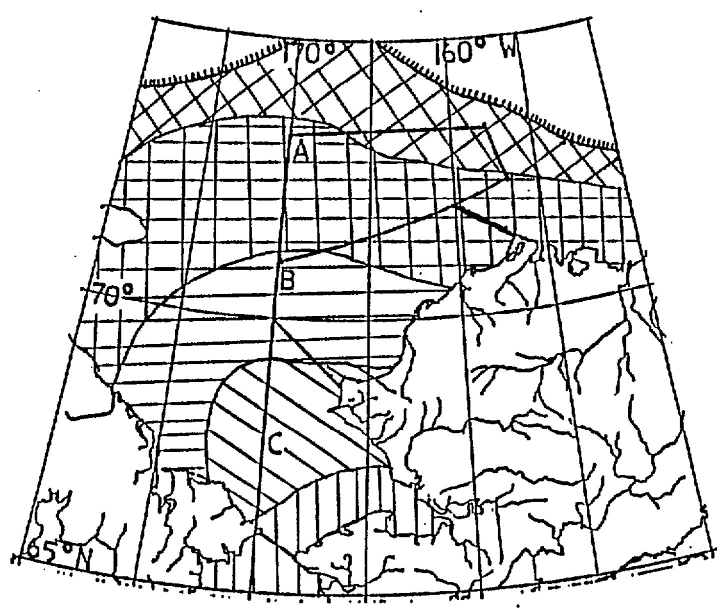


Figure 22b. October SI for the above conditions except with 50 knot winds.

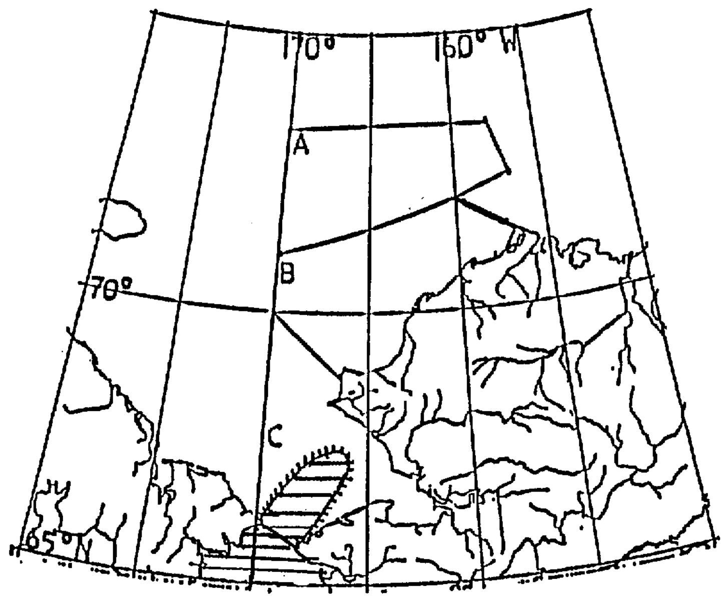


Figure 23a. November S1 for conditions of mean sea ice extent, mean sea surface temperatures, mean air temperatures, and 28 knot winds.

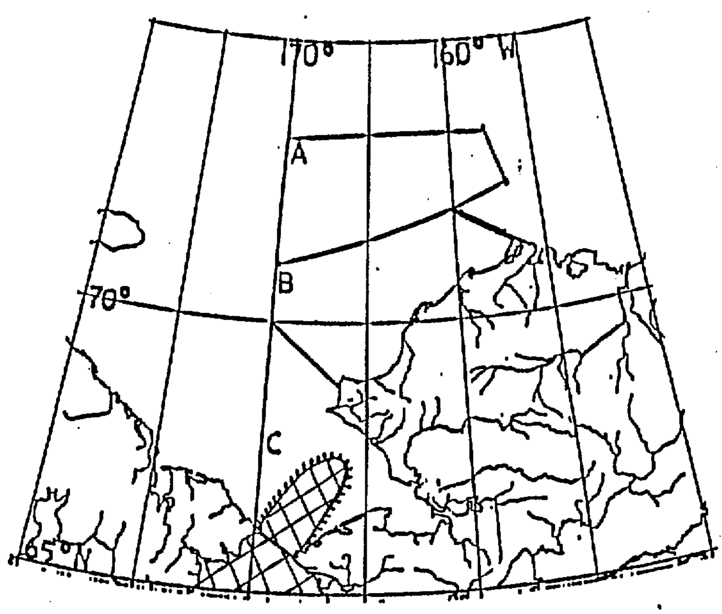


Figure 23b. November S1 for the above conditions except with 50 knot winds.

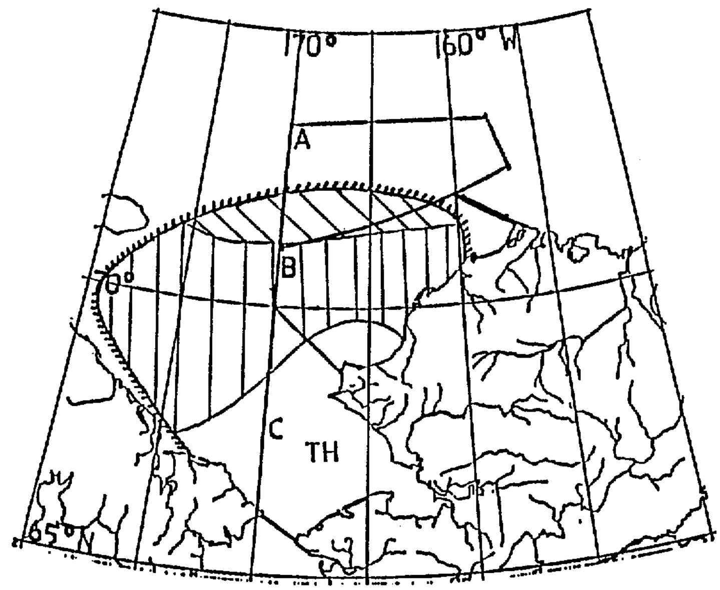


Figure 24a. November S1 for conditions of minimum sea ice extent, maximum sea surface temperatures, maximum air temperatures, and 28 knot winds.

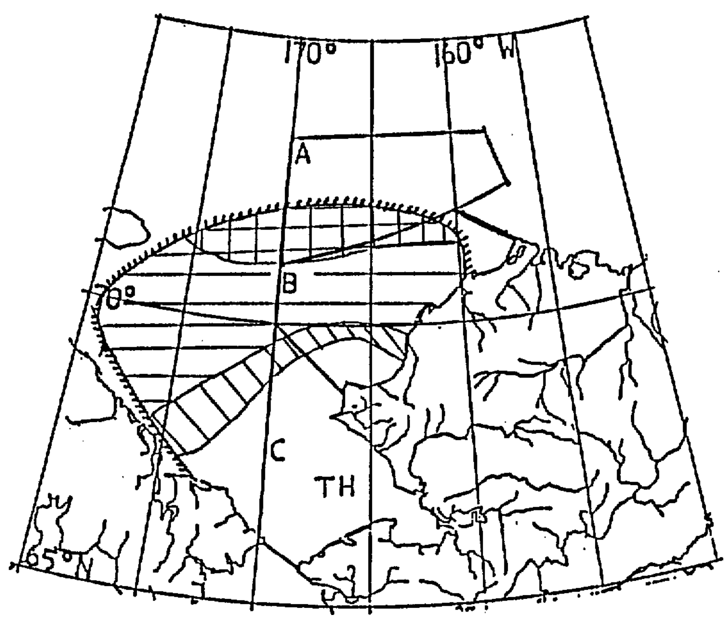


Figure 24b. November S1 for the above conditions except with 50 knot winds,

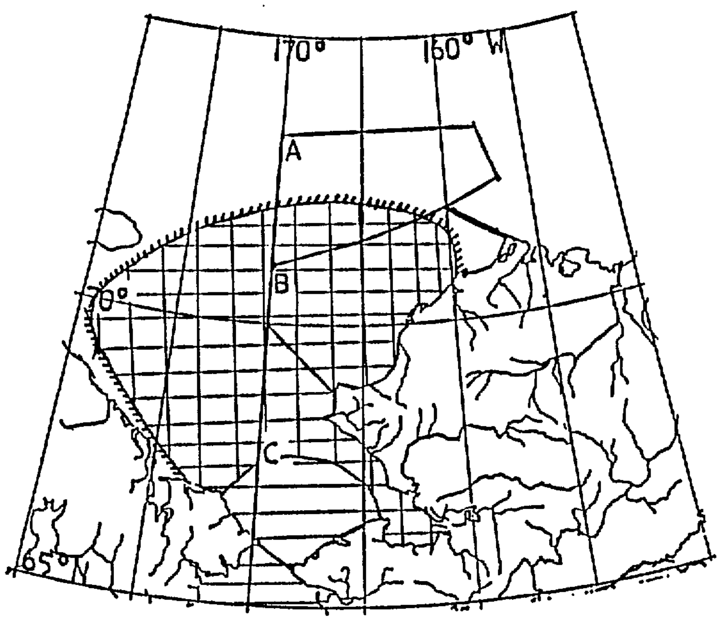


Figure 25a. November S1 for conditions of minimum sea ice extent, maximum sea surface temperatures, mean air temperatures, and 28 knot winds.

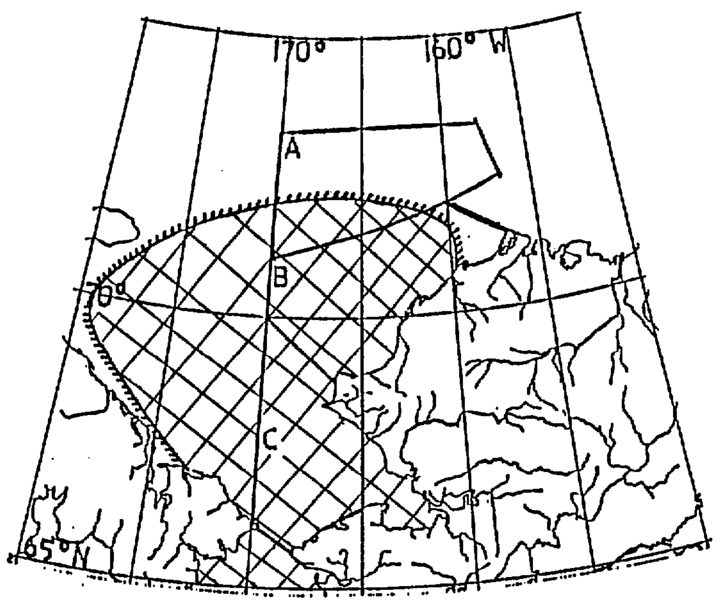


Figure 25b.. November S1 for the above conditions except with 50 knot winds.