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NAVARIN BASIN MESOMETEOROLOGY

THOMAS L. KOZO

Research Scientist

VANTUNA Research Group

Occidental College

1600 Campus Road

Los Angeles, CA 90041

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NAVARIN BASIN MESOMETEOROLOGY

I. SUMMARY OF OBJECTIVES AND CONCLUSIONS.

The objectives of the Navarin Basin program were:

1. Comparison of recent meteorological data from the Bering Sea with historical data and determination of its impact on Navarin Basin transport.

2. Coordination of data analysis with Jan Leendertse and David Liu (Rand Corp.) to provide input to their pollutant transport model.

3. To provide data summaries and presentations at three meetings: (a) Beaufort-Navarin Transport Coordination Meeting, "(Seattle; June 10, 1982; (b) Navarin Basin Oceanography and Pollutant Transport Meeting (Santa Monica; September 21, 1982); (c) Navarin Synthesis Meeting (Anchorage; October 25, 1982).

4. To determine the relationship of data from meteorological stations (with long historical records) near the Navarin Basin to Navarin Basin stations for the purpose of extrapolation and characterization.

5. To attempt to discern a relationship between data from stations in the Navarin Basin and data from Nome (used in the Rand Model).

6. To develop a synthetic time series of winds in designated months for the Navarin Basin to apply to oil spill models.

Results of this study have shown that the surface winds fields at St. Matthew Island and the Navarin Basin (cross correlation ..75) are correlated.

This mesocale correlation implies that expensive and vulnerable buoy systems on the sea surface may not be necessary for meteorological data collection. Instead, a land-based system on St. Matthew Island can give adequate coverage. However, there is a poor correlation (cross correlation ..25) between Navarin Basin winds and Nome winds. This was expected since there is a separation distance of over 700 km between the basin center and Nome.

The above mentioned Santa Monica meeting with the Rand representatives changed the thrust of this particular project. Synthetic time series (Markov models) of winds were already developed at Rand for particular locations in the Bering Sea and key coastal areas. In addition, the Bering Sea area was subjected to 3.5 "model" cyclones per month as discerned from their historical data banks. The local synthetic winds and the "model" cyclones were used as input to the Rand oil spill model and simulated weather conditions based on historical data evolved. This study has nevertheless provided an algorithm (Markov type) for the Navarin Basin winds as previously developed for the Beaufort (Kozo, 1981) .

The recent data from Navarin Basin and other Bering Sea sites (see Kozo, 1982) compares with historical data (Brewer et al., 1977 and Overland, 1981). This fact was presented at both the Santa Monica and the Anchorage meetings (see above) during Navarin Basin discussions. In addition, Overland (personal communication) felt that geostrophic winds calculated from historical pressure data could be used to reconstruct wind characteristics in the Navarin Basin.

II. INTRODUCTION

A. General Nature of the Study

In July, 1981, Exxon deployed a number of automated satellite communication weather stations in the Bering Sea as part of a floating buoy and island based network. Weather data from these stations were considered nonproprietary and made available to the public through the NOAA Data Buoy Office in Bay St. Louis, Mississippi. The data consisted of atmospheric pressure, air temperature, and surface wind velocity.

The surface pressures were used to calculate geostrophic winds for comparison to actual measured surface winds. The surface wind data at various sites was subjected to cross correlation analysis to determine if historical data from long existing sites (land stations) could be used to evaluate and extrapolate conditions in the Navarin Basin. Monthly data summaries were made combining historical data (from World War II) and recent data. Also a general method for generating artifical time series of winds is presented.

B. Relevance to Problems of Petroleum Development

Winds are important driving mechanisms for summer surface currents in the Bering Sea, therefore> any attempt to predict resultant current trajectories must include an estimation of the surface wind field. Oil spills from whatever cause will be strongly influenced by the wind regime. Cleanup and containment operations in areas of whale migration and rich fishing grounds can be aided by real time predictions or "nowcasting" of surface wind conditions via satellite.

III. CURRENT STATE OF KNOWLEDGE

The Bering Sea (excluding the Alaska Coastline) has had two year-round weather reporting sites (NWS), one on St. Lawrence Island and one on St. Paul Island (Pribilof Islands). These are separated by 660 km, and surface wind conditions are not expected to be similar (Kozo, 1981). The July, 1981 establishment of an EXXON sponsored weather net (pressure, temperature and wind velocity) that covered the Navarin Basin, St. Matthew-Hall area, the Aleutian Basin, St. George Basin and Norton Basin provided a method of determining reliable geostrophic winds and ground truthing them with surface wind data. Kozo (1979) illustrated the increased detail in the pressure field (Beaufort Sea Coast) when data from offshore buoys and/or additional temporary land pressure measuring sites were added to the NWS data set. It must be mentioned, however, that estimation of surface winds measured at land stations through use of calculated geostrophic winds is complicated by the existence of local summer sea breeze circulations (Kozo, 1982b) and local orographic effects.

IV. STUDY AREA

Exxon sponsored satellite transmitting meteorological stations were deployed in July, 1981 at six locations, (A, B, C, D, E, and F in Fig. 1):

(A) Navarin Marex (buoy)--60.3°N 177.0°W.

(B) St. Matthew Island--60.3°N 172.3°W.

(C) St. Lawrence Marex (buoy) 62.0°N 168.0°W.

(D) St. Paul Island 57.2°N 170.3°W.

(E) St. Lawrence Island 63.3°N 170.3°W.

(F) Bristol Basin Marex (buoy) 57.7°N 160.0°W.

This network of stations allows for combinations of pressure triangles such as AED and ECD, which can be used to compute geostrophic winds. These computed winds theoretically exist for locations inside the triangle boundaries, but give the best approximation near the geometric center. Triangle AED (Fig. 1) has a solution center near St. Matthew Island which has an automated station that provides simultaneous surface wind data 4.5 meters above the ground. A and C are surface pressure and wind measuring at-sea buoys, but exist at the corners of their respective pressure triangles.

V. SOURCES, METHODS AND RATIONALE OF DATA COLLECTIONS

The purpose was to look at characteristics of wind data in the Navarin Basin using information from the new Exxon array. The basic data collection period was from 1 August 1981 through 31 March 1982. The Bristol Basin buoy failed on 12 October 1981. The Navarin Basin buoy failed on 14 October 1981. The St. Lawrence Basin buoy was retrieved on 26 October 1981 to prevent ice damage. The land station on St. Matthew Island began to degrade in February 1982. To complete a year cycle (August to August) data (St. Matthew Island) from the early 1940’s was used for April through July.

Because of these problems with the new data, a comparison of Navarin Basin buoy data (while the buoy was operational) and St. Matthew Island data was made. St. Matthew Island is the closest land point to the Navarin Basin proper, has a historical data base {limited), and simultaneous wind data compares well with that of the Navarin Basin (Kozo, 1982). The data was collected by satellite transmitting automated ❑eteorological stations. The wind speed, wind direction, and temperature data were transmitted through the GOES (United States) system, white the ARGOS (France) was used for pressure and position information. These stations were installed in the locations " (Fig. 1) by Brown and Caldwell (Costa Mesa, CA). The data has been made available to the public since 1 October 1981 through the National Data Buoy Office in Bay St. Louis, Mississippi. (phone: [601] 688-2834) with a three-month time lag between data arrival and data release.

VI. DISCUSSION OF RESULTS

A. Relationship of New Data to Historical Data

Fig. 2 is a map of the eastern Bering Sea with the Navarin Basin (dashed line) and the Navarin Marex buoy (dot) shown (Overland, 1981) . The Bering has been divided into five marine areas, A-E (Brewer et al., 1977), and most of the Navarin Basin is outside both area A and B. However, the seasonal migration of the ice pack (Overland, 1981) brings most of the basin under a cold arctic and continental influence from January through May. This influence makes the Navarin Basin similar to area A for these month. Fig. 3 (Overland, 1981) shows wind roses for area A in the months of February (winter example) and August (summer example) adapted from Brewer et al. (1977). A high percentage of north and northeast winds are seen for February with speeds greater than 17 kn (dividing by two is a rough conversion of knots to meters per second). The wind speeds in August (summer) for area A are lower than in winter, and winds show little evidence for preferred direction.

Table 1 (H.O. Pub. #9, 1966) shows wind speed categories and sea state codes as defined by the World Meteorological Organization. These are helpful in relating the terms storm, gale, and breeze to actual recorded wind speeds and wave heights. Table 2 shows the National Climatic Center breakdown of 16 wind directions which is used in the bivariate distribution data below. Fig. 4 is a map of St. Matthew Island which is the closest data collection site to the Navarin Basin. Brewer et al. (1977) did not include the island in his historical data presentation which is puzzling, since it was occupied during World War II from 1942 to 1945 by the U.S. military. Meteorology data was collected at site 0, which though subject to orographic (mountain elevations in feet) and thermal effects (sea breeze), has winter and summer characteristics similar to marine area A (see above, Overland, 1981). The Exxon weather station site implanted in July 1981 is shewn as N in Fig. 4. This site was chosen to minimize orographic effects, but it could not avoid sea breeze effects.

As mentioned above, transmitted data quality began to degrade by February 1982. The station was refurbished by summer 1982, but the newer data from the summer of 1982 is not included in this study due to a three-month lag in processing at the National Data Buoy Office. Again, the new Exxon data was similar in character to the marine area A data and also similar to the World War II data. Therefore, the bivariate distribution data presented below has the data from sites O and N (Fig. 4) combined except for the months of April through July where Exxon data was not obtained in 1982.

B. Bivariate Distribution Data

Figs. 5-16 show the eastern Bering Sea in the twelve calendar months respectively. They show the outline of the Navarin Basin region (thin black line), the ice edge (thick black line) and the most dominant wind directions (the thinner the arrow head the less the directional variation) at St. Matthew Island (B). The ice edge positions represent the most southern latitudes reached for 15 day means (Potocsky, 1975). Tables 3-14 are bivariate distributions of all available St. Matthew Island wind speed and wind direction data for the twelve calendar months with the total observations included (three hourly data). These tables alternate with the Fig. 5-16 for comparison purposes. Again it must be mentioned that limited data collection in the Navarin Basin proper has shown a correlation to St. Matthew Island data which is of necessity the main data source for characterizing the Navarin Basin area. Figs. 5-9 show that the ice edge can cover at least 50% of the Navarin from January through May. The wind data in this period as summarized in Tables 3-7 is very similar to the wind rose data mentioned above for February (Overland, 1981). Figs. 10-14 show from June through October, the ice edge is no longer a major influence in the Navarin Basin. The wind data for these months (Tables 8-12) show a drop in overall wind speed and lack of dominant (high percentage) preferred wind directions. The months of November and December (Figs. 15 and 16 and Tables 13 and 14 have characteristics similar to the winter months reflecting a continental influence [Overland, 1981]).

c. Monthly Data Summaries

The characteristics of the monthly wind data (for all available years) acquired from St. Matthews Island have been summarized in Fig. 17. $\bar{V}s$ ≡ the average wind speed, Vm ≡ maximum wind speed and STEADY ≡ the wind steadiness. The steadiness of the wind (Halpern, 1979) is the ratio of the magnitude of the mean wind vector $(\bar{u}^2 + \bar{v}^2)^{\frac{1}{2}}$ to the mean magnitude, $\overline{(u^2 + v^2)^{\frac{1}{2}}}$ expressed in percent. Trade winds for example (tropics), among the ❑ost constant of winds, can have a steadiness greater than 90%. As expected from the above discussion, the months of ice growth and ice cover dominance show the greater wind speeds with most steadiness. The monthly temperature data (for all available years) from St. Matthew Island is summarized in Fig. 18. $\bar{T}$ ≡ average temperature and T_{-} ≡ lowest temperature. The data again show expected patterns.

D. Correlation versus Distance of Station Separation

Fig. 19 shows a plot of zero-lag cross correlation coefficients for wind data from collection sites in the Bering Sea as a function of separation distance from the Navarin Basin center. The points are correlation averages of the u and v components of the wind for the months of August and September, 1981 for data locations listed in order of increasing distance from the Navarin Basin. These are St. Matthew Island, St. Lawrence Island and Nome, with their distances shown along the absicissa in Fig. 19 respectively.

E. Applicability of Data to the Navarian

The at-sea data buoy in the central Navarin did not last beyond mid-October (see above). The necessity for switching to St. Matthew data is now apparent. Also the applicability of surface wind data from Nome to the Navarin Basin appears nonexistent. In the September, 1982 Santa Monica meeting Overland stressed the applicability of historic geostrophic wind data from weather maps to the Navarin Basin. Kozo (1982a) has also shown that calculated geostrophic winds from pressure triangles such as AED (Fig. 1) can be very well correlated to surface wind data from stations contained within the triangle boundaries. The absence of coastline induced thermal contrasts and orographic effects in the central Bering Sea make geostrophic approximations a possibility for deriving an historical data base and an attractive alternative to a large data gathering effort.

F. Synthetic Time Series

Synthetic time series based on Markov models for data locations chosen to provide input to the Rand oil spill trajectory model have been developed at Rand using the most recent data available, therefore, an extensive discussion in this report is not necessary. However, Kozo (1982) discussed a technique based on the following equation (Chow, 1964):

$$X_t = r\,X_{t-1} + (1-r)\,\bar{x} + S_x\,(1-r^2)^{\frac{1}{2}}e_t$$

where X_t is the present value, X_{t-1}, is the immediately preceding value, r is the lag-one autocorrelation coefficient, $\bar{x}$ and S_x are the mean and standard deviation respectively of the historical data and et is a normally distributed random component with a zero mean and a standard deviation of one. This equation will generate X_t's for speed and direction that are normally distributed and preserve the mean, variance and first order correlation coefficient of the historical data (Fiering and Jackson, 1971). For example, the Navarin Basin buoy data (from A, Fig. 1) in the month of August (1981) has a mean wind direction of 145.71°, a standard deviation of 114.9°, and a lag-one autocorrelation coefficient of .45. These can be inserted into the above equation to generate synthetic wind directions. Similarly, synthetic wind speeds for August can be generated through use of an average wind speed of 5.7 ms^{-1}, and Sx =2.4 ms^{-1} and a lag-one autocorrelation coefficient of ,55.

VII. CONCLUSIONS

Navarin Basin meteorological data has been shown to be correlated to St. Matthew Island data when simultaneous data existed. St. Matthew Island is the closest point to the Navarin Basin where historical and recent data can be combined to provide a representative data base. The weather data compiled in Brewer et al. (1977) for marine area A is very representative of the St. Matthew Island data.

VIII. NEEDS FOR FURTHER STUDY

The sea breeze effects on St. Matthew Island and the winter orographic effects should be studied and isolated to determine their probable effects on the existing data base.

The historical weather map data for the Bering Sea should be examined to determine monthly wind speed and direction characteristics for the Navarian Basin and to increase the data base time span.

IV. REFERENCES

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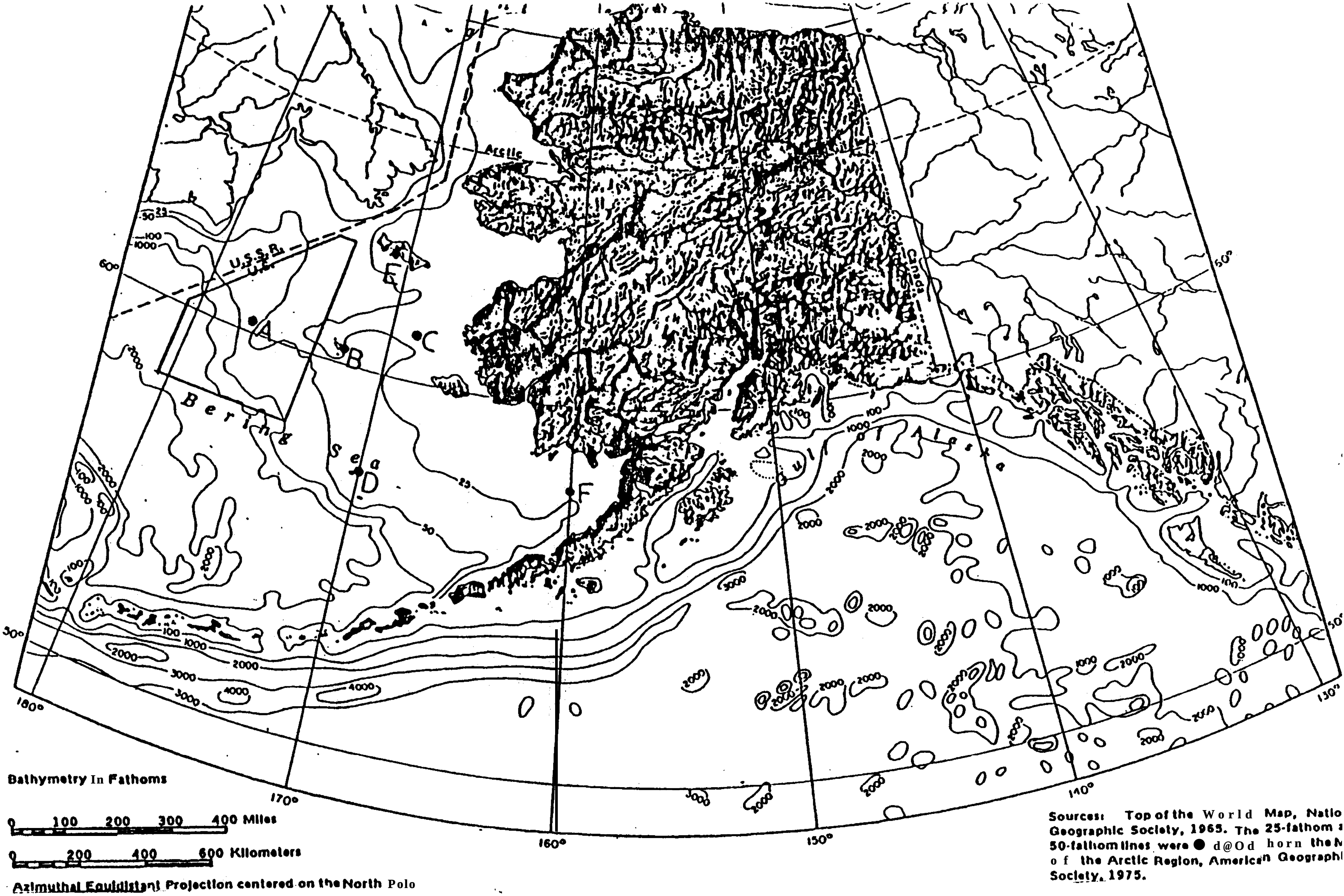


Figure 1. Exxon sponsored satellite transmitting meteorological stations (A-F). The **Navarin** Basin study area is outlined (solid black line) with the at-sea buoy location at position A.

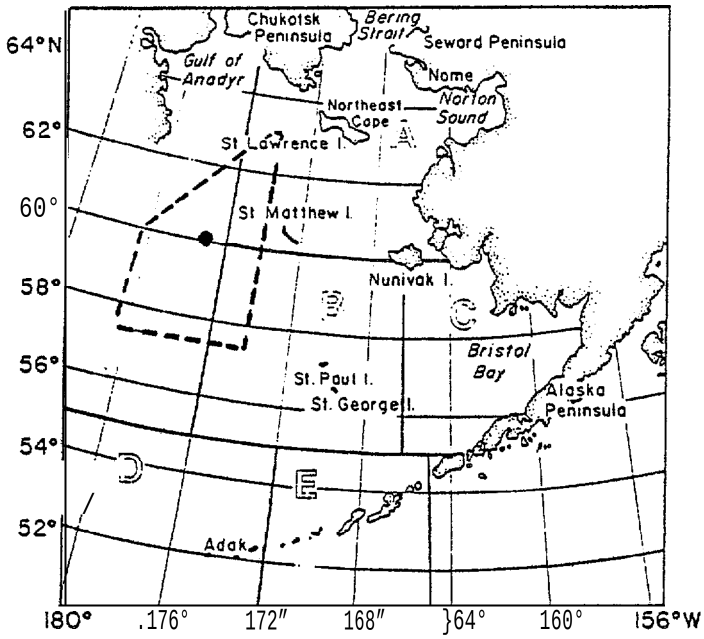


Figure 2. Navarin study area (dashed line) and its relationship to historical data areas (A-E) as represented in Brewer et al. (1977).

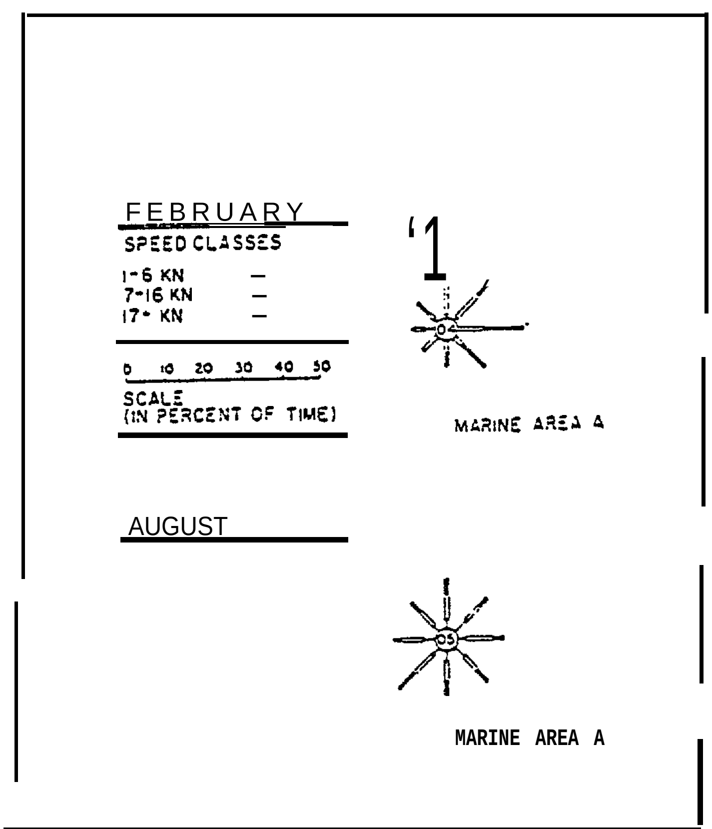


Figure 3. Wind roses for area A (Fig. 2) for February and August.

Wind speed				Seaman's term	World Meteorological Organization (1964)	World Meteorological Organization	
knots	mph	meters per second	km per hour			Term and height of waves, in feet	Code
under 1	under 1	0.0-0.2	under 1	Calm	Calm	Calm, glassy,	0
1-3	1-3	0.3-1.5	1-5	Light air	Light air		
4-6	4-7	1.6-3.3	6-11	Light breeze	Light breeze	Calm, rippled, 0-1/3	1
7-10	8-12	3.4-5.4	12-19	Gentle breeze	Gentle breeze	Smooth, wavelets, 1/3-1 2/3	2
11-16	13-18	5.5-7.9	20-28	Moderate breeze	Moderate breeze	Slight, 2-4	3
17-21	19-24	8.0-10.7	29-38	Fresh breeze	Fresh breeze	Moderate, 4-8	4
22-27	25-31	10.8-13.8	39-49	Strong breeze	Strong breeze	Rough, 8-13	7 -
28-33	32-38	13.9-17.1	50-61	Moderate gale	Near gale	Very rough, 13-20	6
34-40	39-46	17.2-20.7	62-74	Fresh gale	Gale		
41-47	47-54	20.8-24.4	75-88	Strong gale	Strong gale		
48-55	55-63	24.5-28.4	89-102	Whole gale	Storm	High, 20-30	7
56-63	64-72	28.5-32.6	103-117	Storm	Violent storm	Very high, 30-45	8
64-71 72-80 81-89 90-99 100-108 109-118	73-82 83-92 93-103 104-114 115-125 126-136	32.7-36.9 37.0-41.4 41.5-46.1 46.2-50.9 51.0-56.0 56.1-61.2	118-133 134-149 150-166 167-183 184-201 202-220	Hurricane	Hurricane	Phenomenal, over 45	9

Table 1. Wind speed and sea state categories as defined by the World Meteorological Organization.

Direction from which the wind is blowing in special 16 point WBAN code.

11 - North		349"411"
12 - North-Northeast		012°-033°
22 - Northeast		034°-056°
32 - East-Northeast		057°-0 78°
33 - East		079"-101"
34 - East-Southeast		102"-223"
44 - Southeast		224"-146"
54 - South-Southeast		147"-16S"
55 - South		169"-192"
56 . South-Southwest		192°-213°
66 - Southwest		214*-Z.%*
76 - West-Southwest		237"-SS"
7 7 - west		259°-281°
78 - West-Northwest		2S2"-303"
SS - Northwest		304"-326"
18 - North-Northwest		" .327"-348"

Table 2. National Climatic Center breakdown of 16 wind directions which is used in the bivariate distribution data for Tables 3-14.

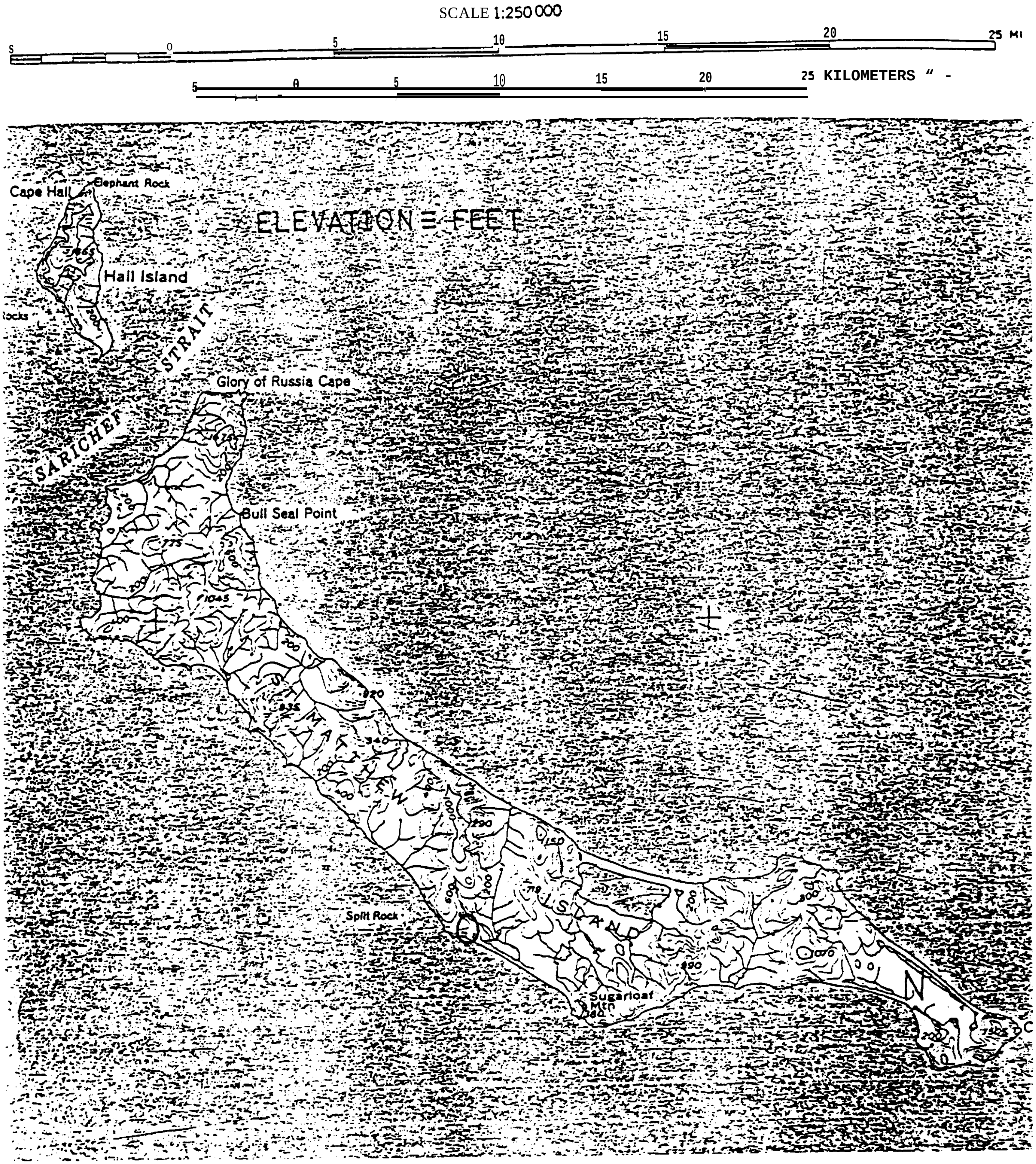


Figure 4. The locations of the Exxon weather station site (N) and the World War II weather site (0) on St. Matthew Island.

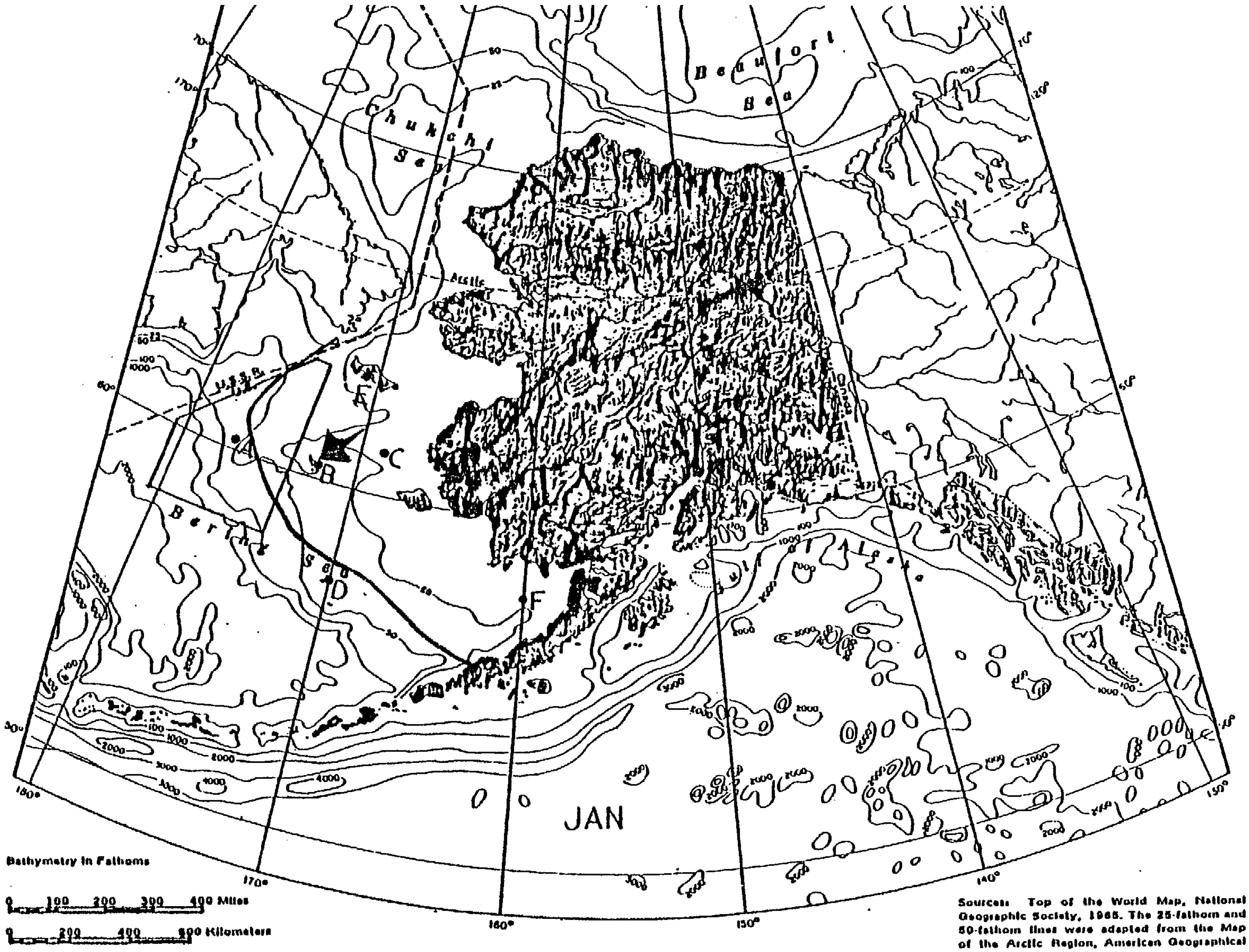


Figure 5. The most dominant wind direction (arrow, St. Matthew Island B) and ice edge position (thick black line) in relation to the Navarin Basin region for January.

SPEED (M/S)

Jan (Total ohs. 723)

DIRECTION	0-2	2-4	4-6	i-8	8-10	10-1 2	12-14	4-16	16-M	18-20	20-22	22-24	24-26	26-28	28-30	OTAL	%
326-348.5	2	6	6	2	4	1	1									22	3.0
303.5 -326.0	1	8	3													12	1.6
281.0 -303.5	1		1													2	.2
258.5-281		3	1	1	2	1	5									13	1.8
236.0 -258.5	1			1		1										3	.4
213.5 -236,0	2	5		1	2	1										11	1.5
191.0-213.5	2	2	1	3	1											9	1.2
168.5-191.0	5	7	5	2	2	2	1		1							25	3.5
146.0 -168.5	3	3	5	2	9		1	3	1	2						29	4.0
123.5 -146. 0	9	9	3	2	3	4	1	3		1						35	4.8
101.0-123.5	3	6	10	15	11	5	2									52	7.2
78.5 -101.0	2	5	3	9	10	7	8	1	1	1						47	6.5
56.0-78.5	3	2	12	14	17	11	11	11	8	4	1					94	13.0
33.5 -56.0		9	17	20	24	19	19	11	5	3	4					132	18.[illegible]
11.0-33.5	7	10	19	15	27	22	23	15	17	11	7	4	1	1		184	25.4
348.5-11.0	8	5	4	9	9	5	5	5		1	1	1				53	7.[illegible]
																723	

≥ GALE CLASS = 17.2%

Table 3. Bivariate distributions of all available St. Matthew Island wind speed and direction data (three hourly) for the month of January.

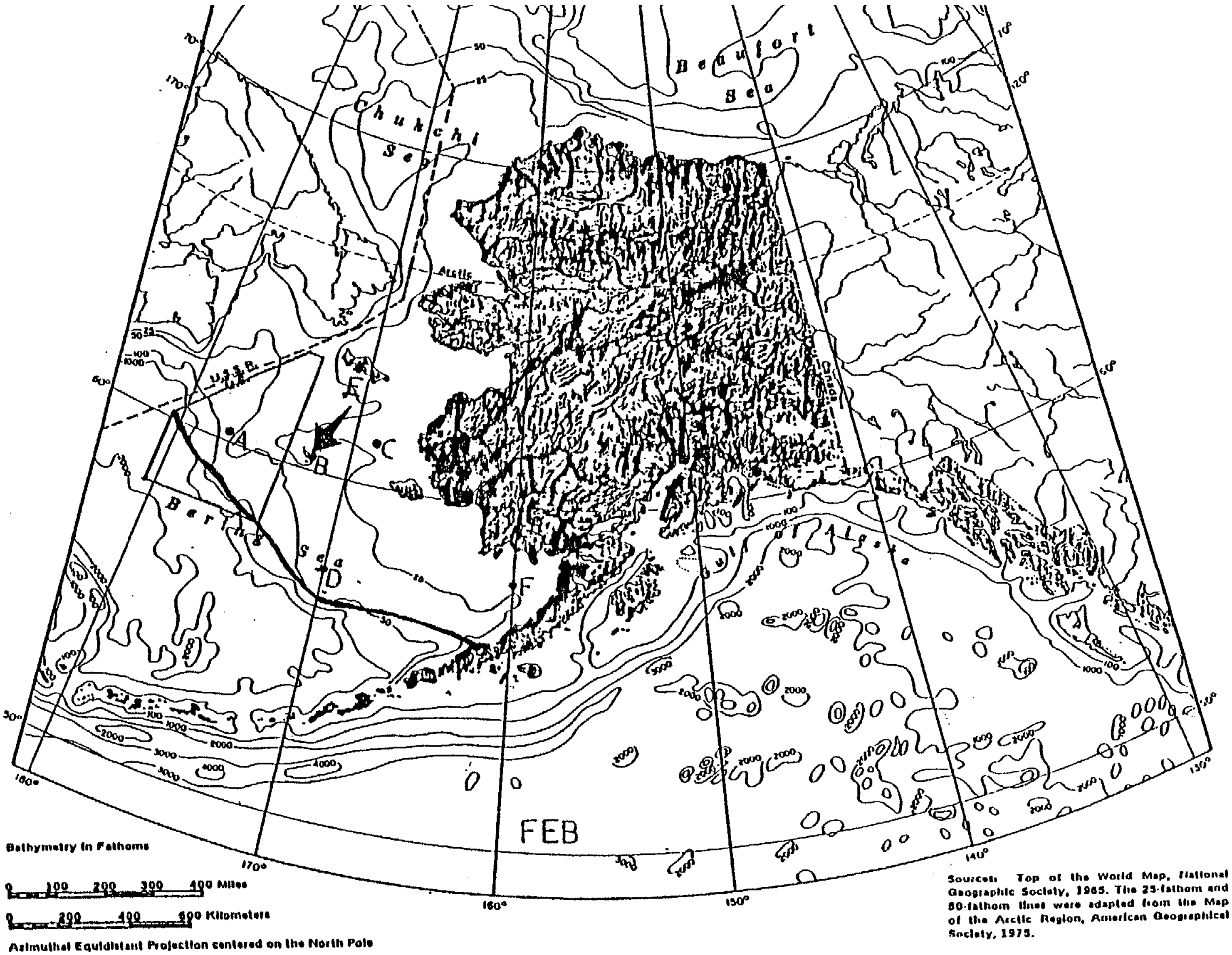


Figure 6. The most dominant' wind direction (arrow, St. Matthew Island B) and ice edge position (thick black line) in relation to the Navarin Basin region for February.

SPEED (M/S)

Feb. (Total obs. 571)

DIRECTION	0-2	2-4	4-6	6-8	?3-10	10-12	12-14	4-16	6-18	18-20	20-22	22-24	24-26	26-28	28-30	TOTAL	%
326-348.5	5	4	7	4	5	7	2			1·						35	6.1
303.5-326.0	2	6	5	5	2											20	3.5
281.0-303.5	4	1	2	1	1											9	1.5
258.5- 281	2	1	6	2												11	1.9
236.0-258.5	2	3	2	1	2											10	1.8
213.5-236.0	3	2	2	1	2											10	1.8
191.0 -213.5	-	2	6		1	1										12	2.1
168.5-191.0	I	1	3	2	1	1										8	1.A
146.0-168.5	4	4	4	LO	4	'4	2									32	5-6
123.5-146.0	3	3	4	7	4	2	2	5	5	- "						35	6.1
101.0-123.5	n	6	5	1	1											14	2.4
78.5-101.0	3	10	9	7	4	1	1									35	6.1
56.0-78.5	,	5	2	1	1	2			1	3	.4		3			23	4.0
33.5-56.0	3	4	4	3	5	12	" 10	3	·1	5						56	9.8
11.0-33.5	2	7	10	7	27	25	28	20	24	3	6	1				160	2.8
348.5-11.0	2	10	7	13	27	21	16	9	7	5	3	4	0	1		101	17.7

≥ GALE CLASS .20.0,

Table 4. Bivariate distributions of all available St. Matthew Island wind speed and direction data (three hourly) for the month of February.

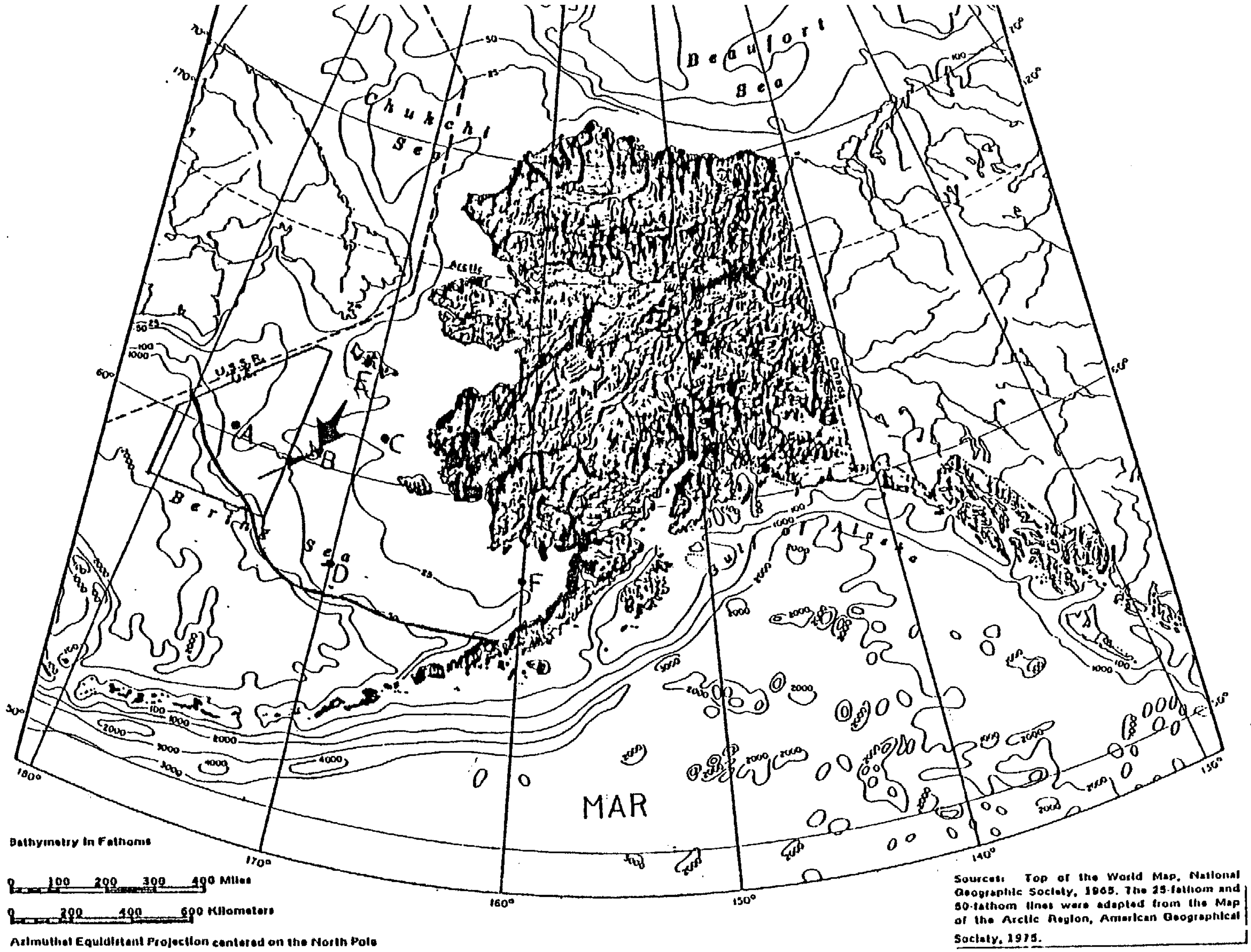


Figure 7. The most dominant wind direction (arrow, St. Matthew Island B) and ice edge position (thick black line) in relation to the Navarin Basin region for March.

SPEED **(M/S)**

March (Total ohs. 640)

DIRECTION	0-2	2-4	4-6	6-8	8-10	10-12	12-14	4-16	16-18	18-20	20-22	22-24	24-26	26-28	28-30	TOTAL	%
326-348.5	2	14	23	27	18	14	13	2								113	17.4
303.5 -326.0	3	4	5	7	4	2	1									26	4.0
281.0 -303.5	1	3	4	2	3		2									15	2.3
258.5- 281	1	1	5	5		1										13	2.0
236.0-258.5	2	10	8	6	2		1	1	1							31	4.8
213.5-236.0	5	10	3	6	7	1	1		1							34	5.2
191.0 -213.5	1		1	4	2	2										10	1.5
168.5 -191.0	1	1	6	1	5	1	2		1							18	2.8
146.0-168.5	7	3	9	4	2	5	2	3								35	5.4
123.5 -146.0		2	3	6	1	3	3	2								20	3.1
101.0 -123.5	1	3	5	2	6											17	2.6
78.5-101.0	1	4	9	4	1	1	3		1	1						25	3.9
56.0-78.5	3	1	3	4	4	6	6	2		1						30	4.6
33.5-56.0	1	7	9	2	8	6	6	3	1							43	6.6
11.0-33.5	3	7	15	21	10	22	19	9	7	3	4	1				123	19.0
348.5-11.0	8	a	22	10	17	11	8	2	1							87	13.4

≥ GALE CLASS = 7.3%

Table 5. Bivariate distributions of all available St. Matthew Island wind speed and direction data (three hourly) for the month of March.

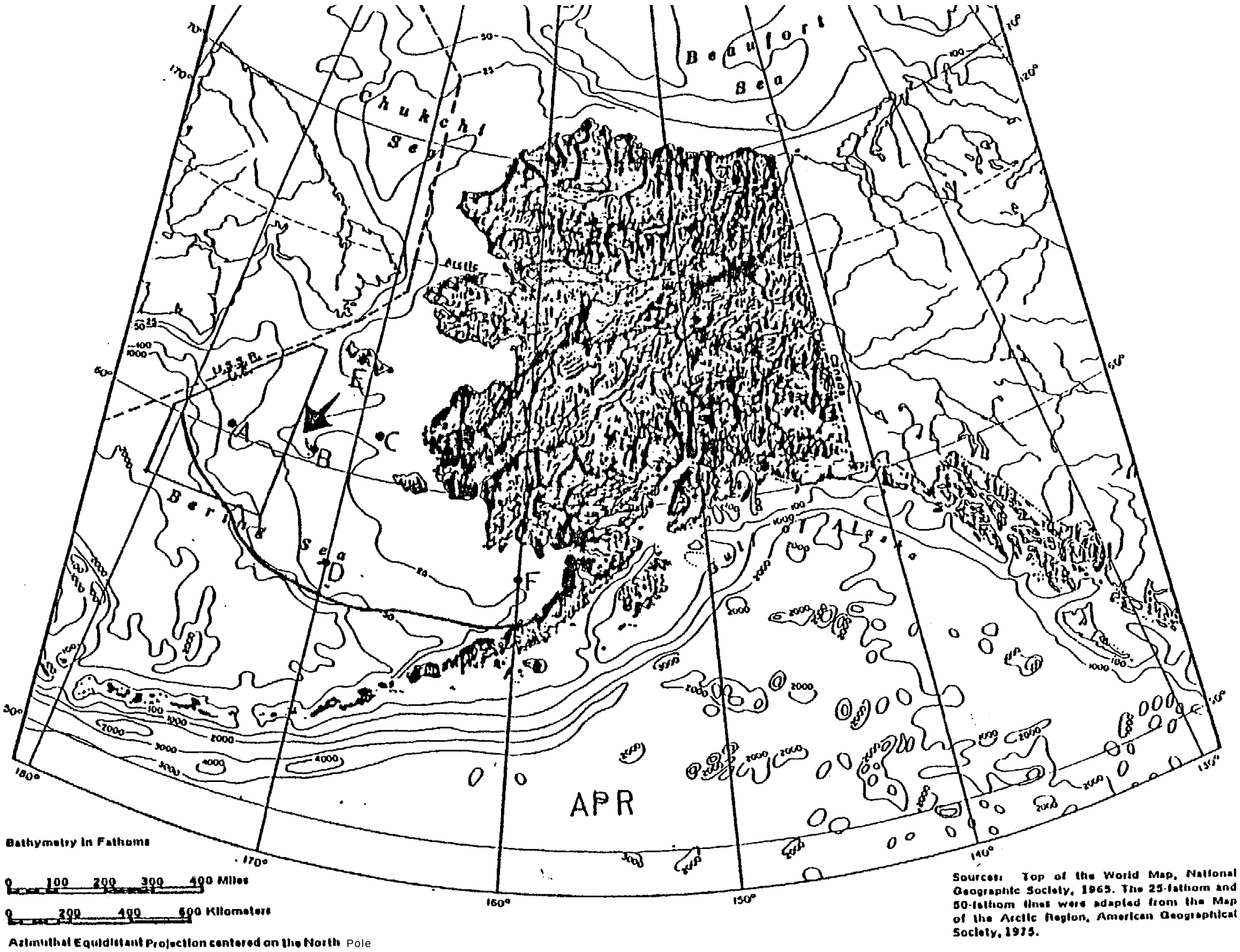


Figure 8. The most dominant wind direction (arrow, St. Matthew Island B) and ice edge position (thick black line) in relation to the Navarin Basin for April.

SPEED (M/S)

April (Total ohs. 465)

DIRECTION

	0-2	2-4	4-6	6-8	8-10	10-12	12-14	14-16	16-18	18-20	20-22	22-24	24-26	26-28	28-30	TOTAL	%
326-348.5	2	10	8	7	10	2	1			.						40	8.6
303.5 -326.0	4	7	4													15	3.2
281.0- 303.5	1	11	11	3	2											28	6.0
258.5- 281	4	11	12	3												30	6.5
236.0-258.5		10	6	5	1											22	4.7
213.5-236.0	3	1	3	1		1										9	1.9
191.0-213.5		3	10	1												14	3.0
168.5 -191.0	4	5	2	2	1											14	3.0
146.0-168.5	4	6	7		1	1										19	4.1
123.5-146.0	3	7	11	9	2	2	2									36	7.7
101.0-123.5		3	4	2	2	1	3									15	3.2
78.5-101.0		2		1	1	3										7	1.5
56.0-78.5		3	3	9	19	9	3									46	9.9
33.5-56.0	2	8	16	10	7	2	3	2	3	1						54	11.6
11.0-33.5	3	4	12	16	27	10	8	3								83	17.8
348.5-11.0	6	6	5	8	5	3										33	7.1

≥ GALE CLASS = 1.9%

Table 6. Bivariate distribution of all available St. Matthew Island wind speed and direction data (three hourly) for the month of April.

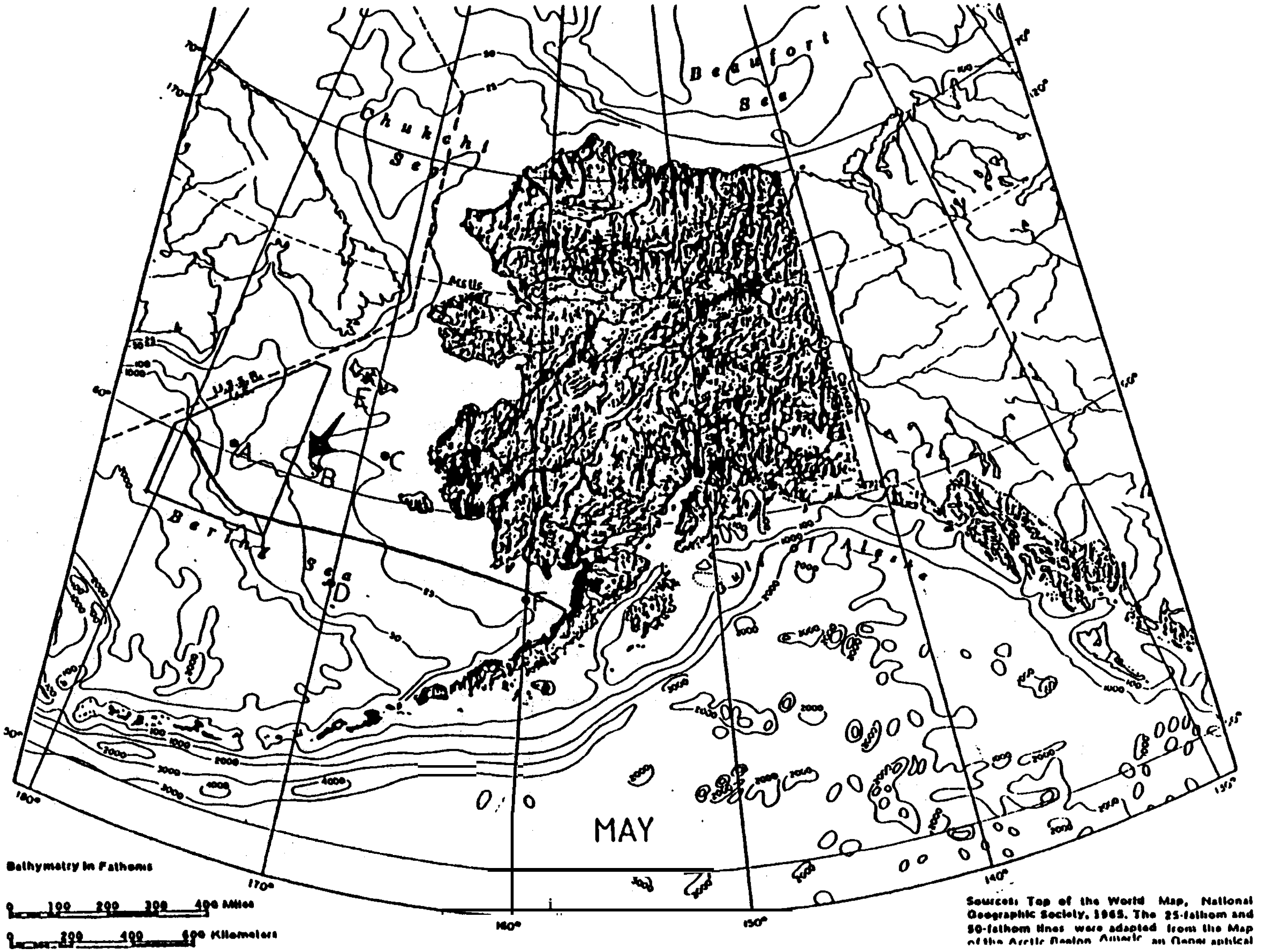


Figure 9. The most dominant wind direction (arrow, St. Matthew Island B) and ice edge position (thick black line) in relation to the Navarin Basin region for May.

SPEED (M/S)

May (Total ohs. 445)

DIRECTION	0-2	2-4	4-6	6-8	8-10	10-12	12-14	14-16	16-18	18-20	20-22	22-24	24-26	26-28	28-30	TOTAL	%
326-348.5	2	11	14	9	2											38	8.5
303.5 -326.0	4	10	5	2												21	4.7
281.0 -303.5	2	3	2	3												10	2.2
258.5- 281	1	4	5	1												11	2.5
236.0-258.5	2	7	6	4												19	4.3
213.5-236.0	3	13	8	2			1									27	6.1
191.0 -213.5	a	11	6	4	3											32	7.2
168.5 -191.0	7	3	5	2	4	1										22	4.9
146.0- 168.5	6	7	2	3	1	.										19	4.3
123.5 -146.0	7	6	6	2		1										22	4.9
101.0 -123.5		1	2	2			1									6	1.3
78.5 -101.0	5	3	5	9	2	1		2								27	6.1
56.0 -18.5	1	4	8	9	e	4	3									37	8.3
33.5-56.0	3	11	18	6	4	1	3	1	1							48	10.9
11.0-33.5	3	13	31	15	26	19	9	2	1							119	26.7
348.5-11.0	3	10	9	5		1										28	6.3

≥ GALE CLASS = 1.5%

Table 7. Bivariate distributions of all available St. Matthew Island wind speed and direction data (three hourly) for the month of May.

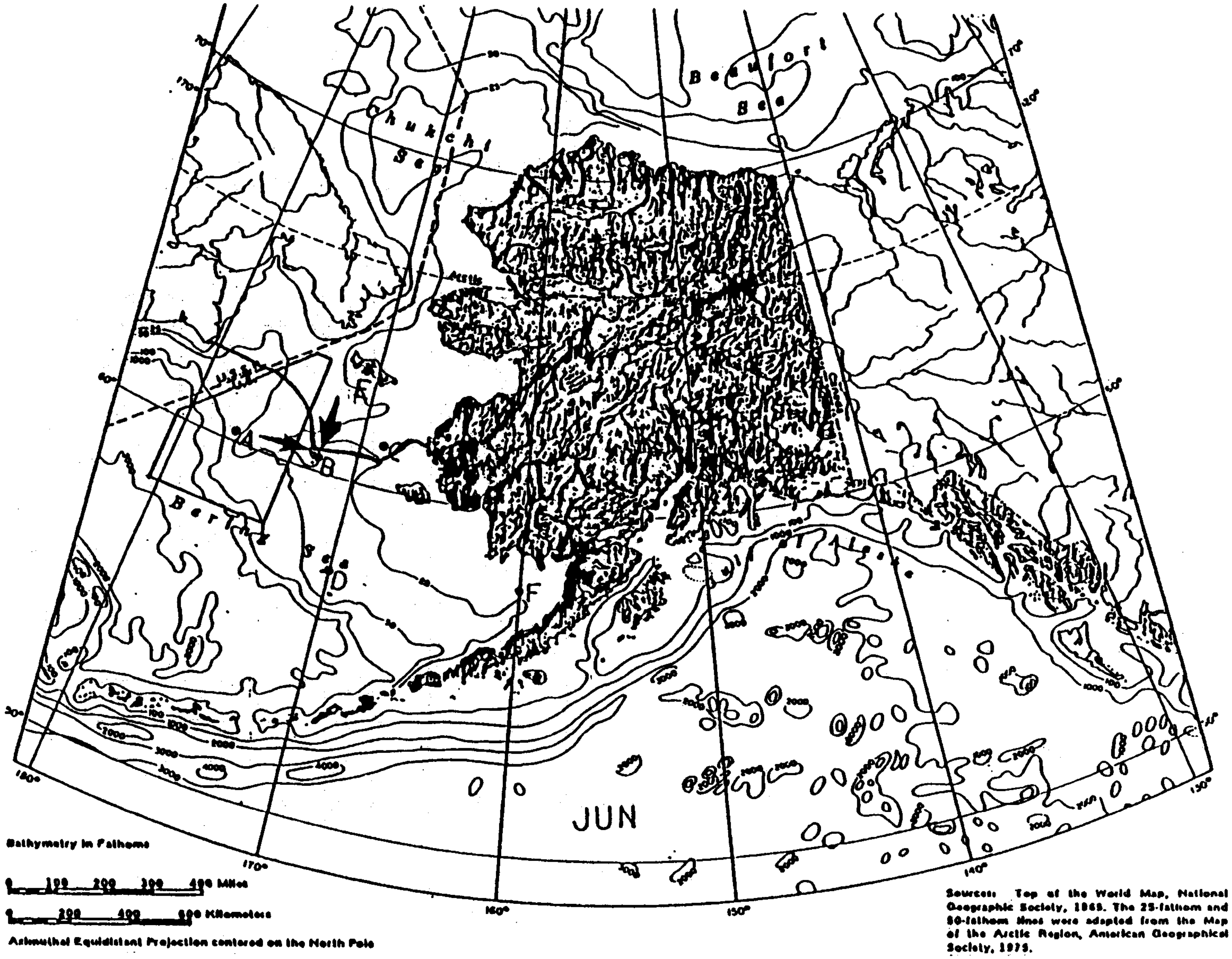


Figure 10. The most dominant wind direction (arrow, St. Matthew Island B) and ice edge position (thick black line) in relation to the Navarin Basin region for June.

SPEED (M/S)

June (Total obs. 445)

DIRECTION	o-2	2-4	4-6	6-8	8-10	10-12	12-14	4-16	16-18	18-20	20-22	22-24	24-26	26-28	28-30	TOTAL	%
326-348.5	6	9		3	1											19	4.3
303.5 -326.0	9	11	3	4	2											29	6.5
281.0-303.5	2	5	10	15	6	4	2	1								53	11.9
258.5- 281	7	5	14	13												39	8.8
236.0-258.5	12	10	11	1												34	7.6
213.5-236.0	9	23	10	2												44	9.9
191.0-213.5	4	11	5													20	4.5
168.5-191.0	5	10	3	1	1											20	4.5
146.0-168.5	4	7	2													13	2.9
123.5-146.0	10	14	3													27	6.1
101.0 -123.5	3															3	.7
78.5-101.0		3														3	.7
56.0-78,5	1	3	3													7	1.5
33.5-56.0	.5	3	6	5	6	6										31	7.0
11.0-33.5	4	11	10	16	16	9	2	1								69	15.5
348.5-11.0	7	7	10	6	4											34	7.6

≥ GALE CLASS = .4%

Table 8. Bivariate distributions of all available St. Matthew Island wind speed and direction data (three hourly) for the month of June.

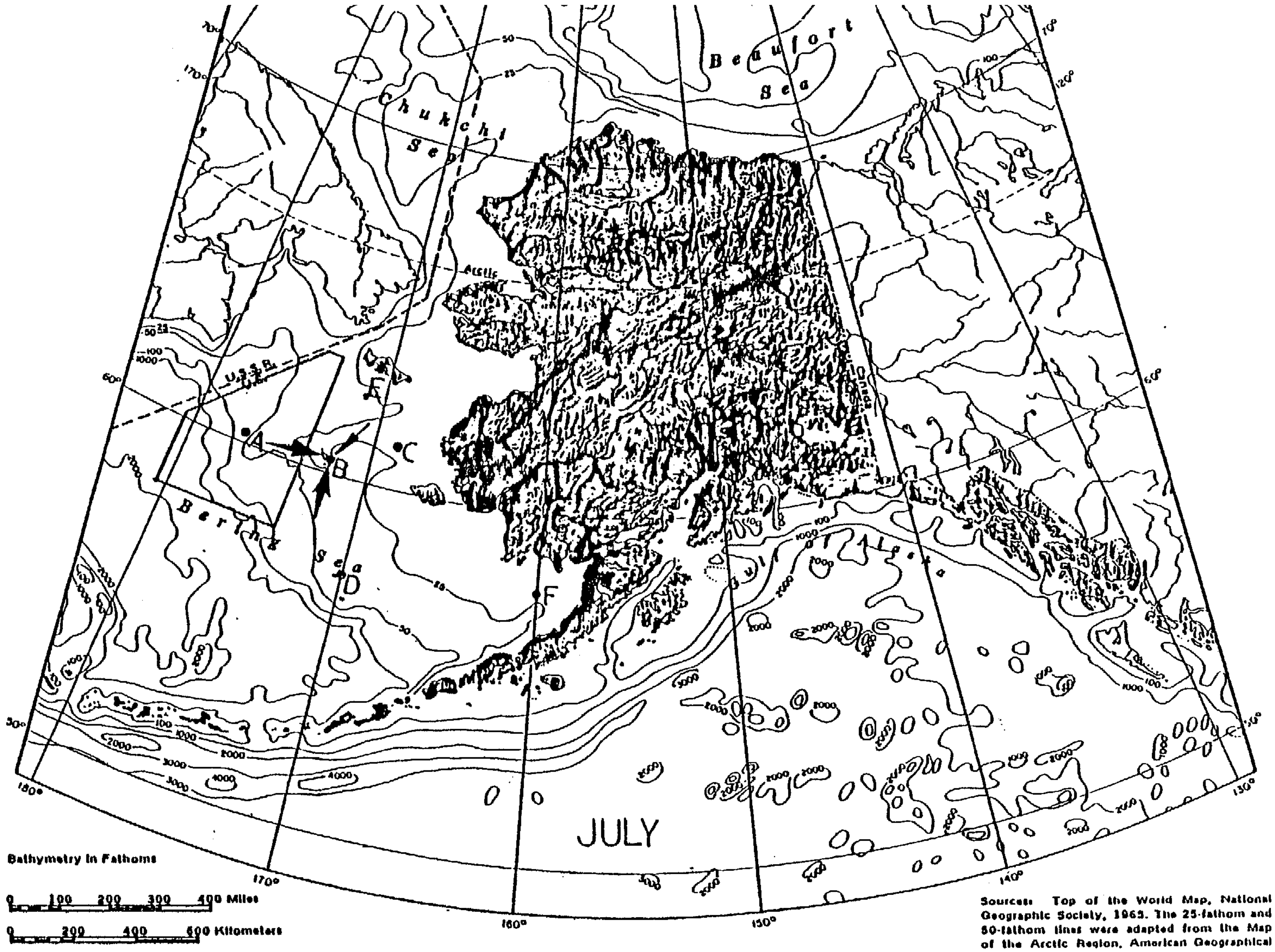


Figure 11. The most dominant wind directions (arrow) near St. Matthew Island which are representative of the Navarin Basin region for July.

SPEED (M/S)

July (Total obs. 716)

DIRECTION	0-2	2-4	4-6	6-8	8-10	10-12	12-14	14-16	16-18	18-20	20-22	22-24	24-26	26-28	28-30	TOTAL	%
326-348.5	1	3	2	2	1	1	1									14	2.0
303.5-326.0	6	12	5	4	3											30	4.2
281.0-303.5	3	23	30	10	8	2										77	10.8
258.5- 281	5	25	19	6	1											56	7.8
236.0-258.5	14	24	15													53	7.4
213.5-236.0	27	31	11	5	2											76	10.6
191.0-213.5	14	27	4	1												46	6.4
168.5-191.0	26	31	6	4	1											68	9.5
146.0-168.5	18	26	7													51	7.1
123.5-146.0	17	26	9	4	2	4										62	8.7
101.0-123.5	2	5	7	3												17	2.4
78.5-101.0	2	10	15													27	3.8
56.0-78.5	2	2	9	6	4											23	3.2
33.5-56.0	6	4	4	4	1											19	2.7
11.0-33.5	3	10	12	13	15	4	13	4								74	10.3
348.5-11.0	4	5	8	4	1	1										23	3.2

≥ GALE CLASS = .5%

Table 9. Bivariate distributions of all available St. Matthew Island wind speed and direction data (three hourly) for the month of July.

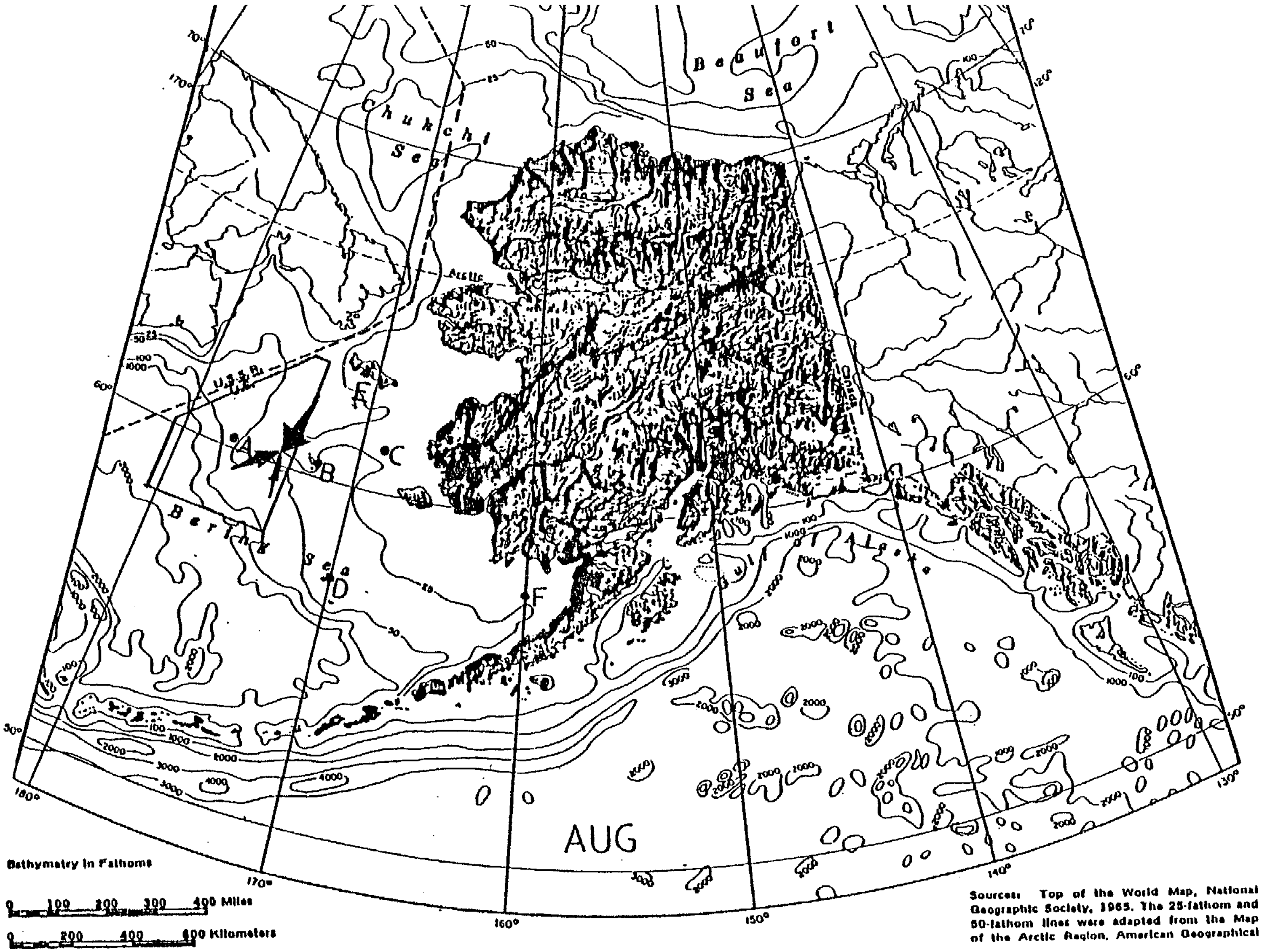


Figure 12. The most dominant wind directions (arrow) near St. Matthew Island which are representative of the Navarin Basin region for August.

SPEED (H/S)

August (Total obs. 1201)

DIRECTION	0-2	2-4	4-6	6-8	8-10	10-12	12-14	14-16	16-18	18-20	20-22	22-24	24-26	26-28	28-30	TOTAL	%
326-348.5	4	10	20	17	1											52	4.3
303.5-326.0	11	24	16	4	3	1	1									60	5.0
281.0-303.5	3	20	13	11	4											51	4.2
258.5-281	11	19	24	15	12											71	5.9
236.0-258.5	9	17	25	10	11	2	1									75	6.2
213.5-236.0	14	30	21	9	7											81	6.7
191.0-213.5	8	12	10	9	2	2	2									45	3.7
168.5-191.0	19	30	14	7	1	1	2									74	6.2
146.0-168.5	12	26	17	11	7	3	1									77	6.4
123.5-146.0	22	32	13	a	10	8	3									96	8.0
101.0-123.5	4	6	17	a	10	2		3								50	4.2
78.5-101.0	6	17	20	14	12	7	1									77	6.1
56.0-78.5	3	10	16	17	13	7										66	5.5
33.5-56.0	8	33	17	8	9	3	1									79	6.6
11.0-33.5	6	39	30	24	20	8	6	2								135	11.2
348.5-11.0	7	21	38	23	3	13	2									112	9.3

≥ GALE CLASS = .4%

Table 10. Bivariate distributions of all available St. Matthew Island wind speed and direction data (three hourly) for the month of August.

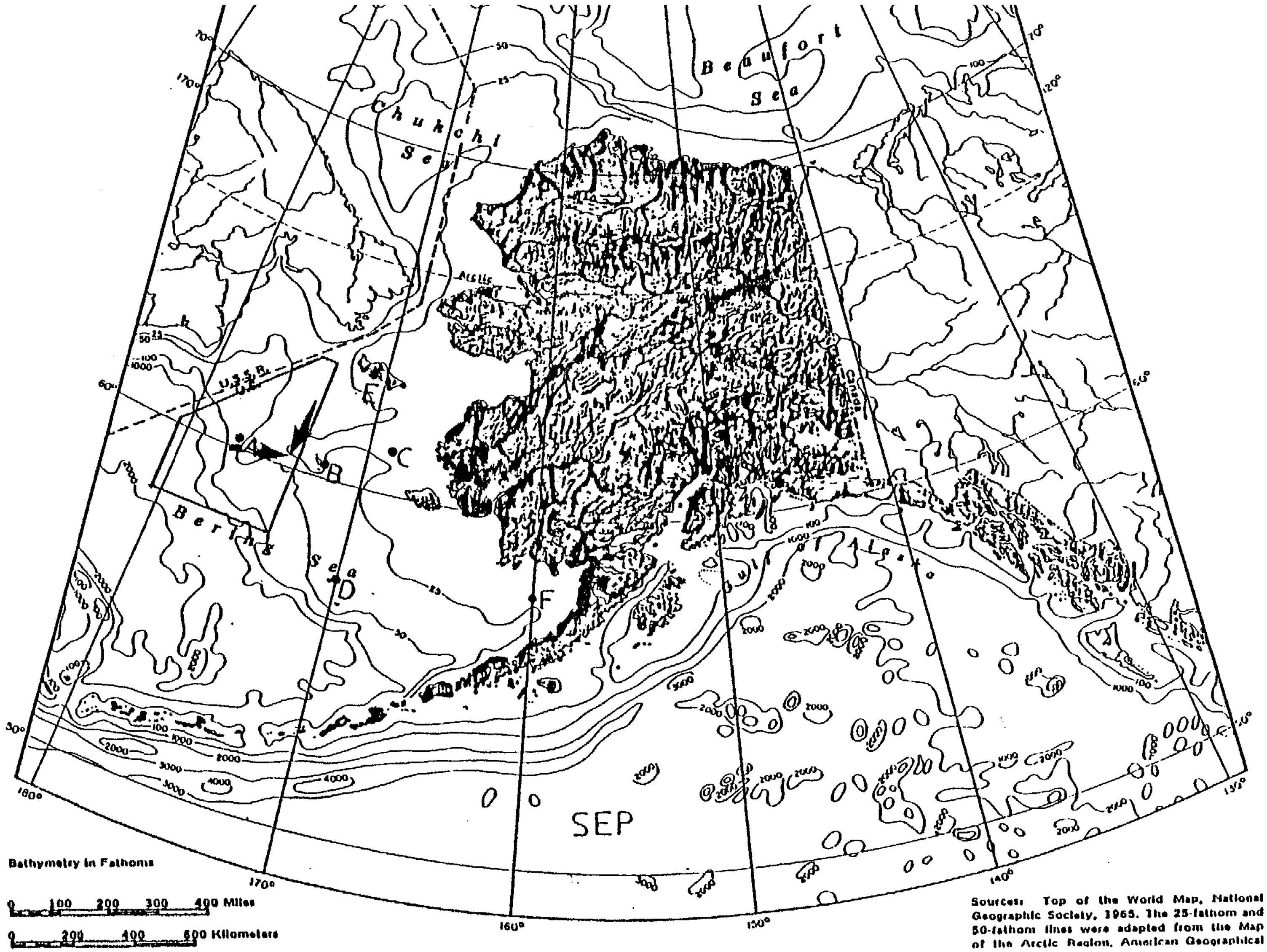


Figure 13. The most dominant wind directions (arrow) near St. Matthew Island which are representative of the Navarin Basin region for September.

SPEED (M/S)

September (Total obs. 951)

DIRECTION	0-2	2-4	4-6	6-8	8-10	10-12	12-14	14-16	16-18	18-20	20-22	22-24	24-26	26-28	28-30	TOTAL	%
326-348.5	4	23	17	20	21	2										87	9.1
303.5-326.0	6	25	16	14	1	6										68	7.2
281.0-303.5	10	24	27	14	11											86	9.0
258.5-281	8	16	14	10	3											51	5.4
236.0-258.5	12	23	25	15	4	3	3									85	8.9
213.5-236.0	9	11	13	10	11	2										56	5.9
191.0-213.5	9	1.9	8	13	2		1									52	5.5
168.5- 191.0	4	6	8	4	6	1										29	3.0
146.0 -168.5	5	10	11	7	4	· 4	1									42	4.4
123.5 -146.0	9	12	7	6	2	1										37	3.9
101.0-123.5	2	5	9	3	2				1							22	2.3
78.5-101.0	2	15	17	4	2″		2									42	4.4
56.0-78.5	, 7	9	10	4	3	3	3	5	1							45	4.7
33.5-56.0	. 1	11	13	8	6	1		1								41	4.3
11.0-33.5	6	12	35	20	16	5	1	1								96	10.1
348.5-11.0	7	22	23	26	21	7	5	1								112	11.0

= GALE CLASS = 1%

Table 11. Bivariate distributions of all available St. Matthew Island wind speed and direction data (three hourly) for the month of September.

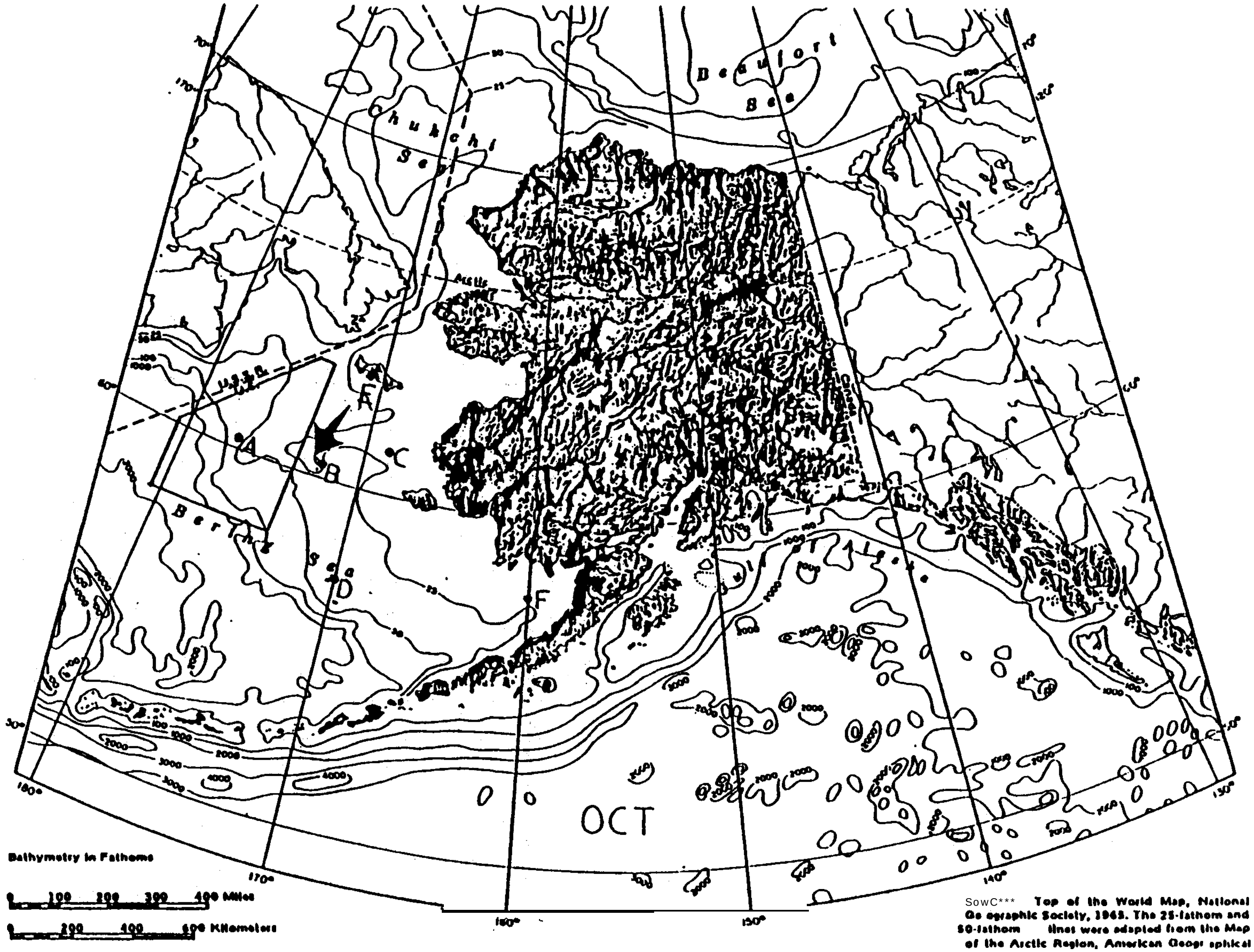


Figure 14. The most dominant wind directions (arrow) near St. Matthew Island which are representative of the **Navarin** Basin region for October.

SPEED (M/S)

October (Total ohs. 462)

DIRECTION \ SPEED (M/S)	0-2	2-4	4-6	6-8	8-10	10-'12	12-14	14-16	16-18	18-20	20-22	22-24	24-26	26-28	28-30	TOTAL	%
326-348.5	1	15	21	19	10	2	1	2	0	1.						72	15.5
303.5-326.0	1	5	7	9	2	1	1		1	1						26	5.6
281.0 -303.5	4	4	7	4	2	1	1	2	1	1						27	5.8
258.5-281				5	6	5										16	3.5
236.0-258.5	1	4	2	10	8	5	2	2	1							35	7.6
213.5-236.0	1	1	1	1	3	1										8	1.7
191.0-213.5	1	4	1	1	2	2	1	1								13	2.8
168.5-191.0																	
146.0- 168.5	1	2	2	1	3	'3		1								13	2.8
123.5- 146.0	3	1	5	4	2	1										16	3.5
101.0-123.5	2	4	9	5	7	4	4									35	7.6
78.5-101.0	3	2	2	3	4	5			4	2						25.	5.4
56.0-78.5	5	5	10	2	3	1	1			1						28	6.1
133.5-56.0	2	5	3	6	4	1	1									22	4.8
11.0-33.5	5	12	15	14	11	6	4	1	1							69	14.9
348.5-11.0	4	12	5	11	12	7	5	6	2	6						70	15.2

≥ GALE CLASS = 7.6%

Table 12. Bivariate distributions of all available St. Matthew Island wind speed and direction data (three hourly) for the month of October.

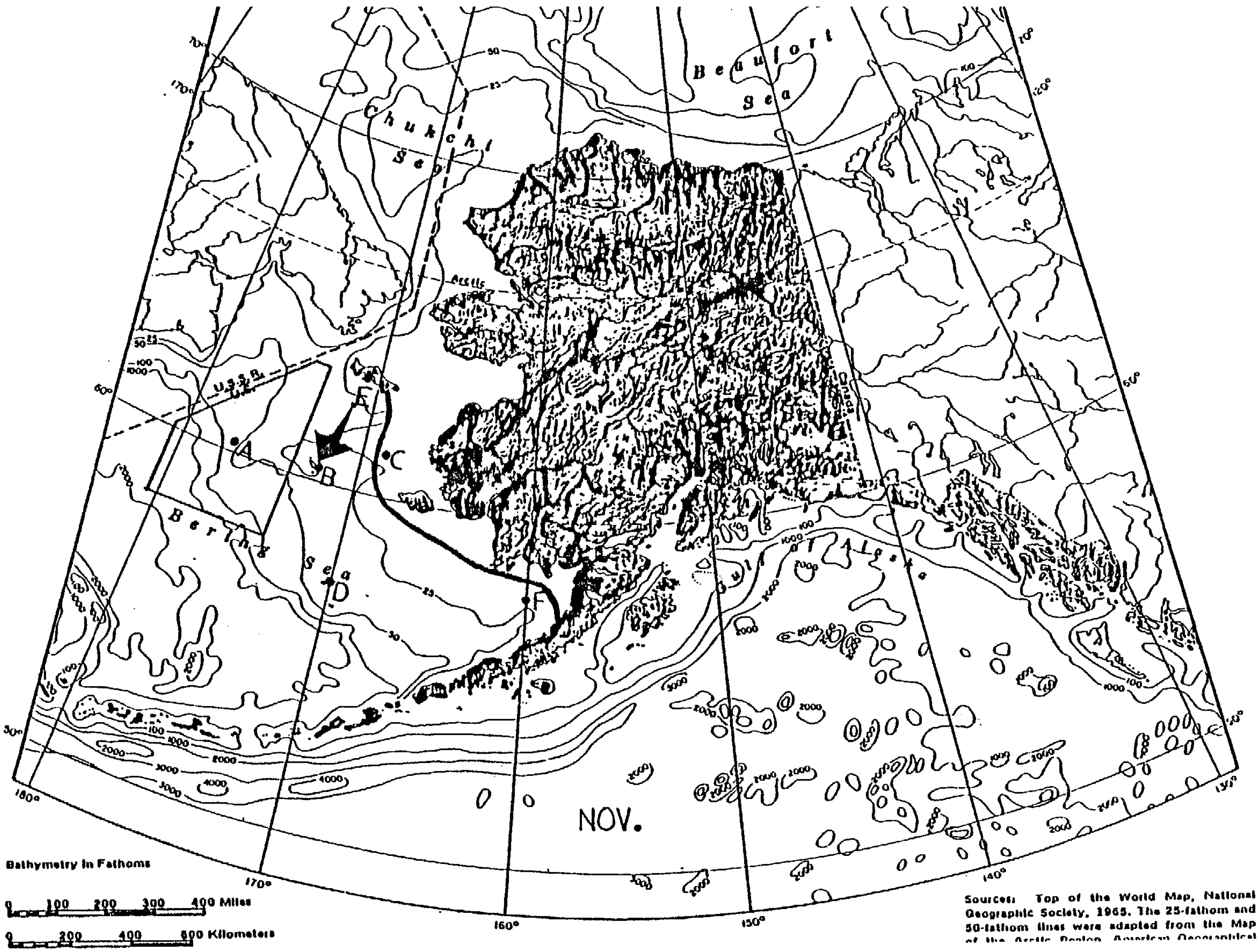


Figure 15. The most dominant wind direction (arrow, St. Matthew Island B) and ice edge position (thick black line) in relation to the Navarin Basin region for November.

SPEED (M/S)

November (Total ohs. 712)

DIRECTION	o-2	2-4	4-6.	6-8	8-10	10-'12	12-14	14-16	16-18	18-20	20-22	22-24	24-26	26-28	28-30	TOTAL	%
32'6-348.5	10	7	8	10	10	3										48	6.7
303.5- 326.0	16	23	10	2	3											54	7.6
281.0 -303.5	2	7	8	2												19	2.7
258.5- 281		2	6	4	1											13	1.8
236.0-258.5		6	5	2	2											15	2.1
213.5-236.0	1	3		3												7	1.0
191.0-213.5		3	1	1												5	.7
168.5-191.0		2	3	4	6											20	2.8
146.0 -168.5		3	4	8	5	3	1									24	3.4
123.5 -146.0		1	3	2	4	2	1	1								1 A	2.Q
101.0-123.5	2		3	3	7	7	6	4	2	1						38	4.9
78.5-101.0		3	6	2	13	7	4	6	4							45	6.3
56.0-78.5		2	6	9	8	12	18	12	6	6	4	1	1			85	11.9
33.5 -56.0		2	8	12	12	4	4	17	11	4	1	1				76	10.7
11.0-33.5	2	6	23	19	24	12	5	4	1							96	13.5
348.5-11.0	9	11	34	26	42	25	7	2								156	21.9

≥ GALE CLASS = 12.2%

Table 13. Bivariate distributions of all available St. Matthew Island wind speed and direction data (three hourly) for the month of November.

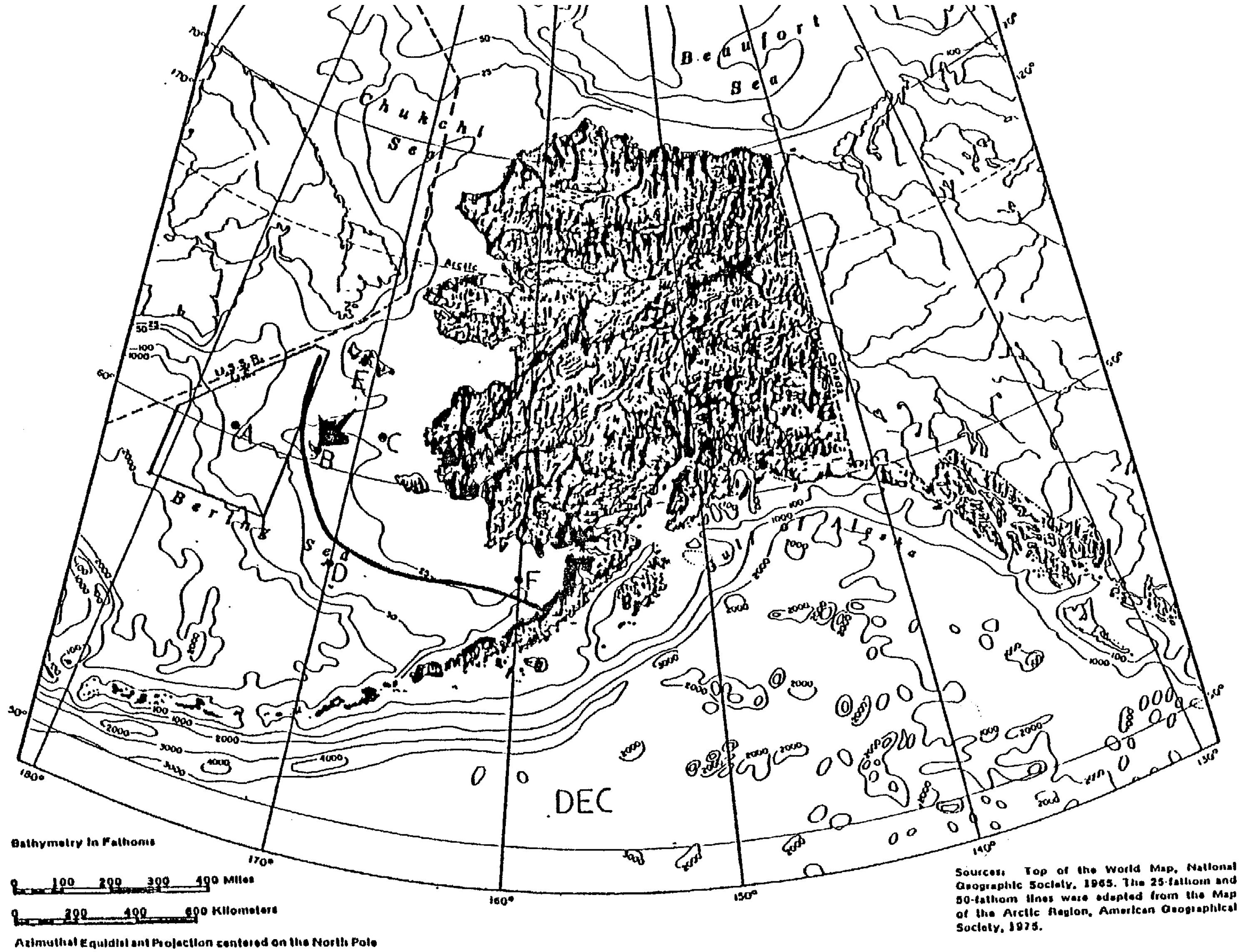


Figure 16. The most dominant wind direction (arrow, St. Matthew Island B) and ice edge position (thick black line) in relation to the Navarin Basin region for December.

SPEED (M/S)

December (Total 724)

DIRECTION	0-2	2-4	4-6	6-8	8-10	10-12	12-14	14-16	16-18	18-20	20-22	22-24	24-26	26-28	28-30	TOTAL	%
26-348.5	7	6	6	6	1											23	3.2
103.5 -326.0	5	6	4													15	2.1
281.0-303.5	3	2	7	3	2	2										19	2.6
258.5- 281	1	4	4	5	6	2	6	2								30	4.1
236.0-258.5	3	2	2	3	2	4										16	2.2
213.5-236.0	1	7	2	2	2	1	1	1								17	2.3
191.0-213.5		3	6	5	7	9	8	2								40	5.5
168.5 -191.0	2	1	2	3		4	7	2	0	1						22	3.0
146.0- 168.5		2	6	10	6	.3										27	3.7
123.5 -146.0	1	2	1	1	6	1	6	2	2							22	3.0
101.0-123.5	1		3	6	3	2	5	5	7	5						37.	5.1
78.5-101.0	1	3	13	7	4	5	6	5	4	3	3	3				57	7.9
56.0-78.5	6	6	21	2	6	2	3	4	8	2	4					64	8.8
33.5-56.0	3	13	18	24	24	12	9	5	9							117	16.2
11.0-33.5	3	12	28	28	15	27	7	11	3,	1		1				136	18.8
348.5-11.0	8	5	19	27	14	9										82	11.3

≥ GALE CLASS. 13.4%

Table 14. Bivariate distributions of all available St. Matthew Island wind speed and direction data (three hourly) for the month of December.

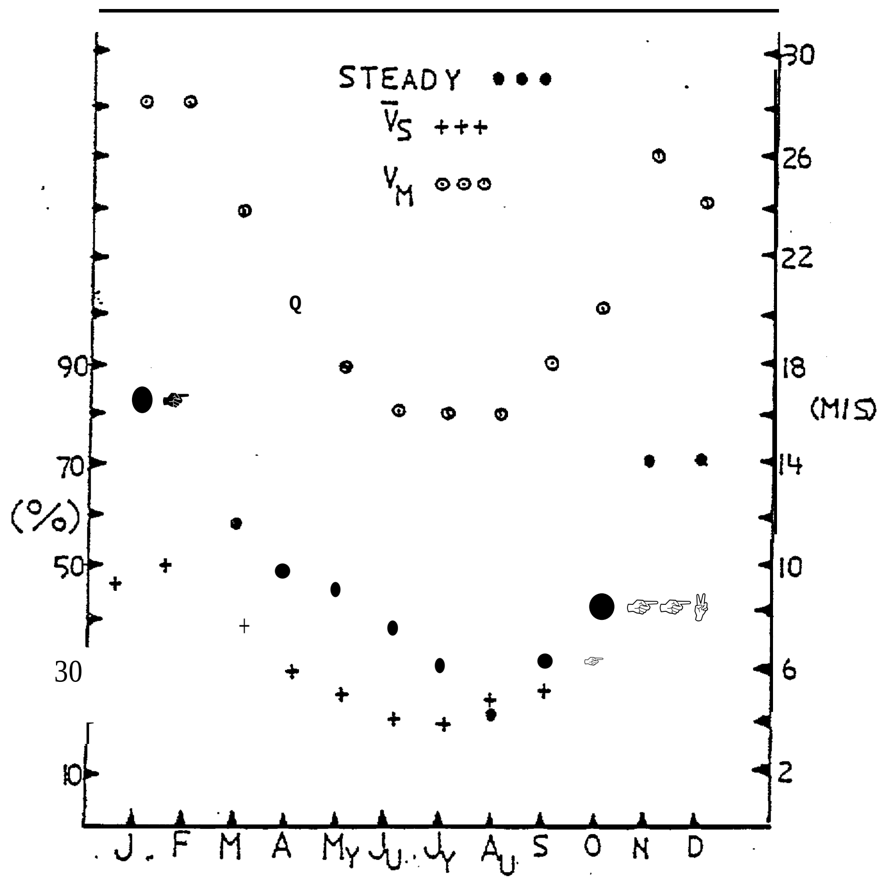
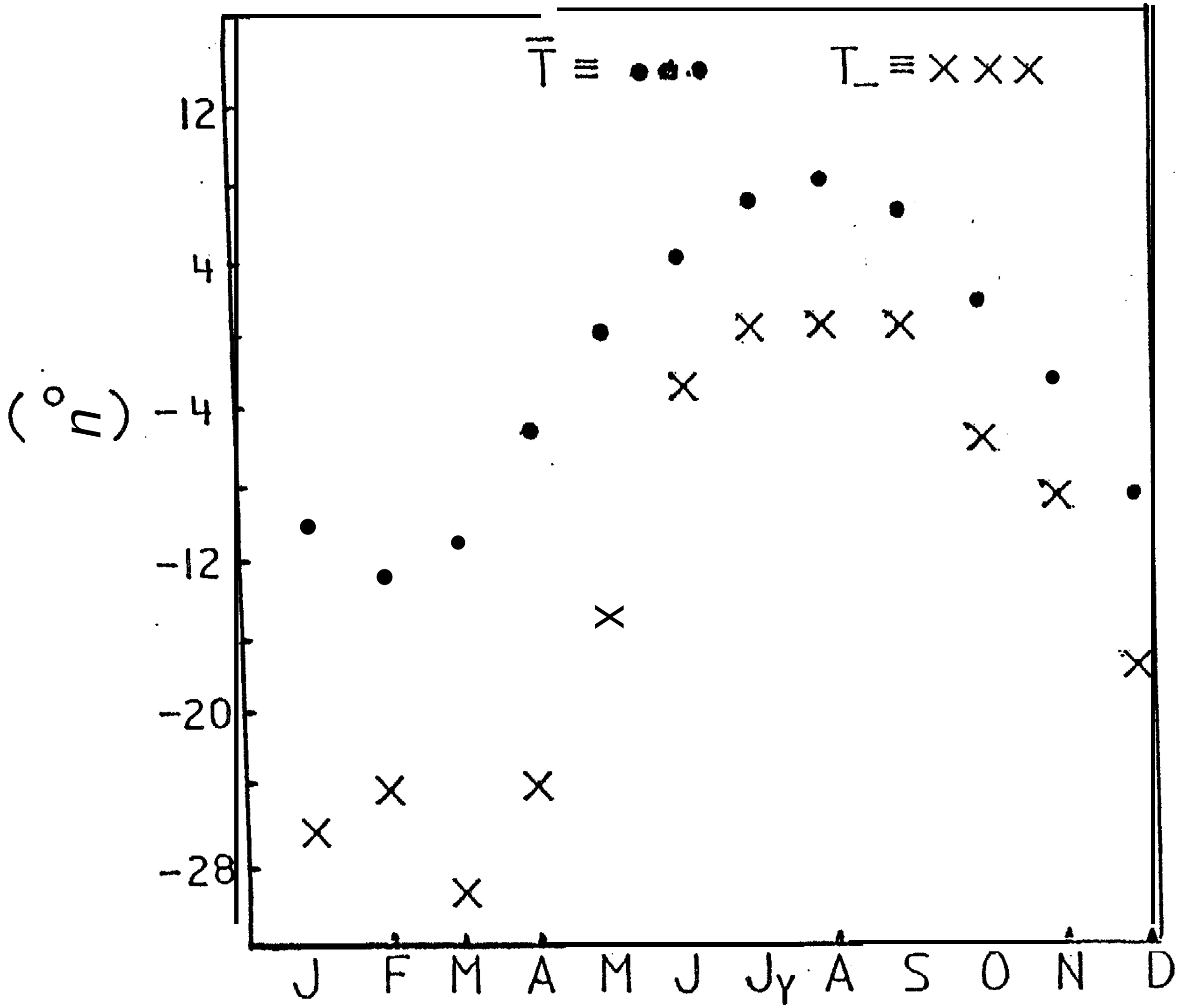


Figure 17. Monthly wind data from St. Matthew Island. $\overline{V}$ ≡ average wind speed, V_M ≡ maximum wind speed (ms^{-1}) and STEADY ≡ wind steadiness (%).



Fi 18. Monthly temperature data from St. Matthew Island $\bar{T}$ ≡ average temperature. T_ ≡ lowest temperature.

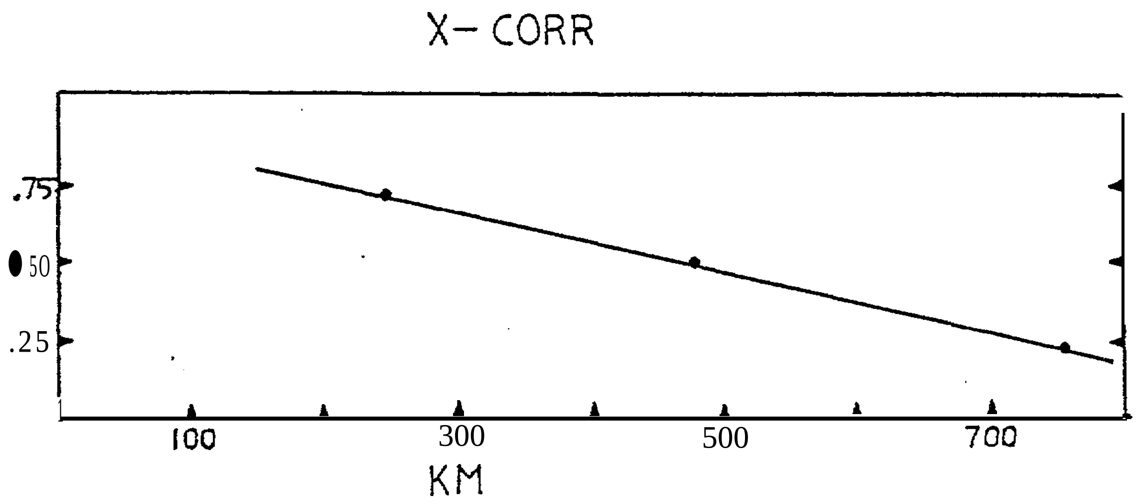


Figure 19. Zero-lag cross correlation coefficients for wind data from collection sites in the Bering Sea as a function of separation distance from the Navarin Basin center.