RESEARCH REPORT
REPORT 739
18 OCTOBER 1956

CURRENT, TEMPERATURE, TIDE, AND ICE GROWTH MEASUREMENTS, EASTERN BERING STRAIT-CAPE PRINCE OF WALES 1953-55

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THE PROBLEM

Conduct survey and field studies in the Arctic Ocean which will furnish basic geophysical data significant to arctic naval warfare. This report covers an evaluation of data obtained during the period 1953 through 1955 at the Cape Prince of Wales Field Station. The operation of the station continues as part of an over-all program to obtain physical-oceanographic data pertinent to predicting ice coverage for the Bering-Chukchi-Beaufort Sea area.

RESULTS

1. A northerly volume transport varying from 0.8 to 3.1 $\times 10^6$ cubic meters per second appears characteristic of the period August through November.
2. An area of maximum current velocities is indicated in the 8-to-12 mile section of the eastern Bering Strait.
3. Omitting initial freeze-up discontinuities, the logarithm of accumulated degree days below 29°F exhibits essentially a linear relationship with fast ice accretion at Wales, Alaska.
4. Average total ice growth at Wales is 46 to 48 inches, with first slush ice formed late October to early November and fast ice break-up normally completed by mid-June.

RECOMMENDATIONS

1. Extend and make simultaneous oceanographic and meteorological measurements essential to a detailed analysis of the sea ice-heat budget regime.
2. Continue measurements of average water transport through the Bering Strait.
3. Conduct daily sea water temperature measurements from strategic points along the northwestern Alaskan coast.
4. Conduct sonar studies in respect to the effect of ice coverage and movement on ambient noise and passive detection ranges.

ADMINISTRATIVE INFORMATION

This work was initiated under SW 01402, NE 121217-1 (NEL L6-1), and was carried out by members of the Special Research Division. The report was approved for publication 18 October 1956.

The over-all program at Wales has included observations on related special projects, as follows, for other NEL codes and Naval activities, as time and manpower permitted; these projects are to be reported by the cognizant activity.

1. Microwave propagation to determine the variation in radar signals over fixed paths and to study effect of ice coverage as well as meteorological conditions along the transmission path.
2. Ultra-low-frequency propagation and variation in signal strength.
3. Atmospheric radioactivity background measurements.

New facilities to be installed at Wales during the summer of 1956 include complete new electrode systems using Type-216 submarine harbor defense cable together with sea units for the study of (a) bottom temperatures (at 1-, 2-, and 5-mile offshore points), (b) wave amplitude and period, (c) low frequency ambient noise spectrum, (d) water velocity at a fixed position, (e) variation in water depth and ice movement, and (f) sound velocity.

Major changes in the Wales Field Station were the erection during the summer of 1955 of two standard 20-foot-by-48 foot BuYards and Docks arctic-type quonsets to provide essential storage, laboratory, and garage space and the installation of a 15,000-gallon bulk diesel fuel storage and distribution system.

The author wishes to acknowledge the contribution of E. E. Howick and R. N. Rowray to the direct field measurement program and to the tedious task of reducing the numerous field data, and the assistance of A. C. Walker in the design and construction of thermal units and electrode elements. Many unnamed people participated in the field work and encountered much discomfort, particularly during the current survey program; to these hardy individuals the author offers his thanks.

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INTRODUCTION

One of the primary projects at the Cape Prince of Wales Field Station, Wales, Alaska, is the continuing and long range study of the volume transport of water through the eastern Bering Strait, the water temperature oscillations throughout the year, the effect of meteorological phenomena and tides on the net water transport, and the over-all relation to ice distribution.

The intent is not the evolution of an extensive ice forecast program, but rather the evaluation of physical-oceanographic data in a particular system, the possible extrapolation of these data and procedures to similar systems in the arctic area, and the incorporation of pertinent information into existing ice prediction programs.

Field Station facilities, general measurement program and instrumentation have been reported.[1] (See list of references at end of report.) This report covers the measurement period 1953 through 1955 and summarizes 1954 current measurements conducted simultaneously from seven anchor positions located along a 20-nautical-mile line extending due west from Wales, Alaska.

These data have been used to calibrate an electromagnetic system which records potentials generated by tidal-water transport. Average monthly transport through a 25-mile section of the eastern Bering Strait has been computed and is presented herein together with monthly bottom sea water temperatures and tidal data.

A projected, additional report will study the transport on the basis of temperature-density distribution and will compare the results with the direct observations reported herein.

CURRENT MEASUREMENTS

direct observations

METHOD AND INSTRUMENTATION

On 1 August 1954, in conjunction with the 1954 Joint Canadian-U. S. Beaufort Sea Expedition, a series of simultaneous current observations were taken for approximately 14 hours. Seven stations were located along a 20-nautical-mile line extending due west from the Cape Prince of Wales Field Station across the eastern Bering Strait (fig. 1). The 8- and 12-mile positions were occupied by the icebreakers,

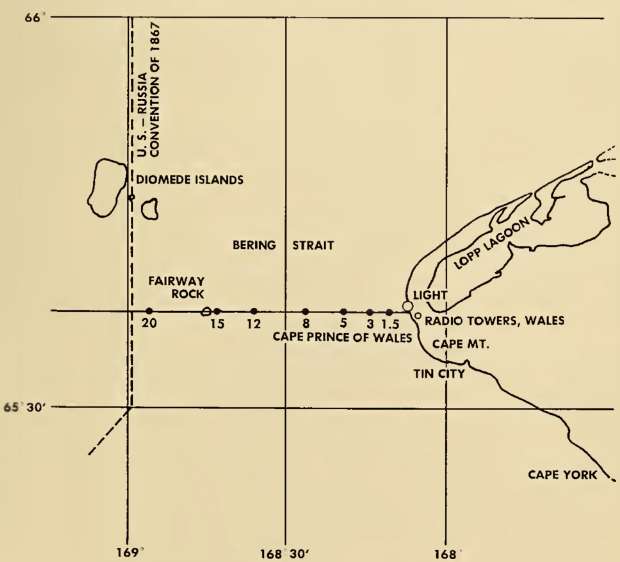


Figure 1. Location of current stations, 1 August 1954, in the Eastern Bering Strait.

USCGC NORTHWIND and USS BURTON ISLAND (AGB 1). Measurement platforms at the 1.5-, 3.0-, 5.0-, 12.0-, and 15.0-mile positions were two LVT-3(C)'s, two LCVP's, and one Greenland Cruiser.

Current profiles were taken at all stations using the biplane (drag) method of Pritchard and Burt.[2] Metal biplanes with the following characteristics were used in lieu of weighted wooden drags:

Drag material	Aluminum (Alclad 24ST)	Iron
Cross plane dimensions (inches)		
Thickness	5/32	1/4
Width	18	18
Height	12	12
Ave. wt. in air (lb)	7.34	30.88
Ave. wt. in sea water (lb)	4.86	27.04
Velocity range (3° to 45° wire angle, knots)	0.23 to 0.98	0.53 to 2.33

Wire angles were determined with inclinometers using standard oceanographic observing techniques.

Surface currents were determined from drifting aluminum biplanes submerged 3 feet beneath the sea surface. To minimize wind effects biplane support floats were constructed to provide only a slight positive buoyancy. Velocity was calculated from the time required for a 200-foot drift of the submerged biplane. An initial drift of 50 feet was allowed before commencing measurement to obviate inertial effects.

Surface currents and velocity profiles from 5 to 45 meters were taken at approximately half-hour intervals. Measurements at the 1.5- and 3.0-mile positions were curtailed early, since increasing seas necessitated returning to shore the amphibious vehicles located at these positions.

In addition to surface current observations and velocity profiles using the biplane method, for comparative data a series of velocity measurements were taken at the 20-mile station using an Ekman current meter. Roll at the 20-mile position probably did not exceed 2 feet in amplitude during the measurement period. However, even this slight roll will give erroneous direction and velocity with the Ekman current meter and must be kept in mind when interpreting these data.

Prior to 0800 the LCVP at the 5-mile position dragged anchor badly and, throughout the measurement period, the boat was subjected to a very severe cross chop and roll. This effect probably accounts for the low values prior to 0800. These data have, consequently, been omitted in later transport calculations.

DISCUSSION OF DATA

Complete surface current observations and velocity profile data from the seven stations are presented in the Appendix, tables 1 and 2, respectively.

Average current velocities of 0.3 to 0.5 knot (zero at the two most seaward stations) were recorded from 0200 to 0500. Velocities increased rapidly after 0500 at all stations reaching maximum average values of 1.7, 1.8, 1.8, 2.0, 1.5, and 1.2 knots, respectively, at the 3-to-20 mile positions. The data indicate that an area of maximum velocity gradient probably exists in the 5-to-12 mile sector.

All currents were predominantly north-setting, except for low velocity values recorded prior to 0500 at the 15- and 20-mile stations. The variation in direction was most pronounced at the 15-mile station, particularly in the surface current observations. From 0200 to 0600 the water appeared to be moving slowly in a clockwise eddy from south to north. Decrease in velocity with depth determined by submerged biplanes and checked at the 20-mile station by an Ekman current meter was slight throughout the observation period.

Average current velocities were calculated by computing the arithmetic mean for each set of profiles taken at the anchor stations. These values are presented graphically in figure 2.

Average hourly wind speeds and tidal data, both measured at the Cape Prince of Wales Station, Wales, Alaska, during the current survey period, are shown in figure 3. Comparison of figures 2 and 3 suggests a correlation between current speed, tide, and wind. Since current observations did not cover a complete tidal cycle, positive conclusions cannot be drawn. Data from the electrode system (presented later in this report) show a corresponding early morning increase in water transport during flood tide, but show very little decrease in transport from 1245 to 1700 (during ebb tide). The tide range off Wales is small, generally of the order of 8 inches. The change from low tide at 0445 to high tide at 1245, on 1 August 1954, measured 11.7 inches

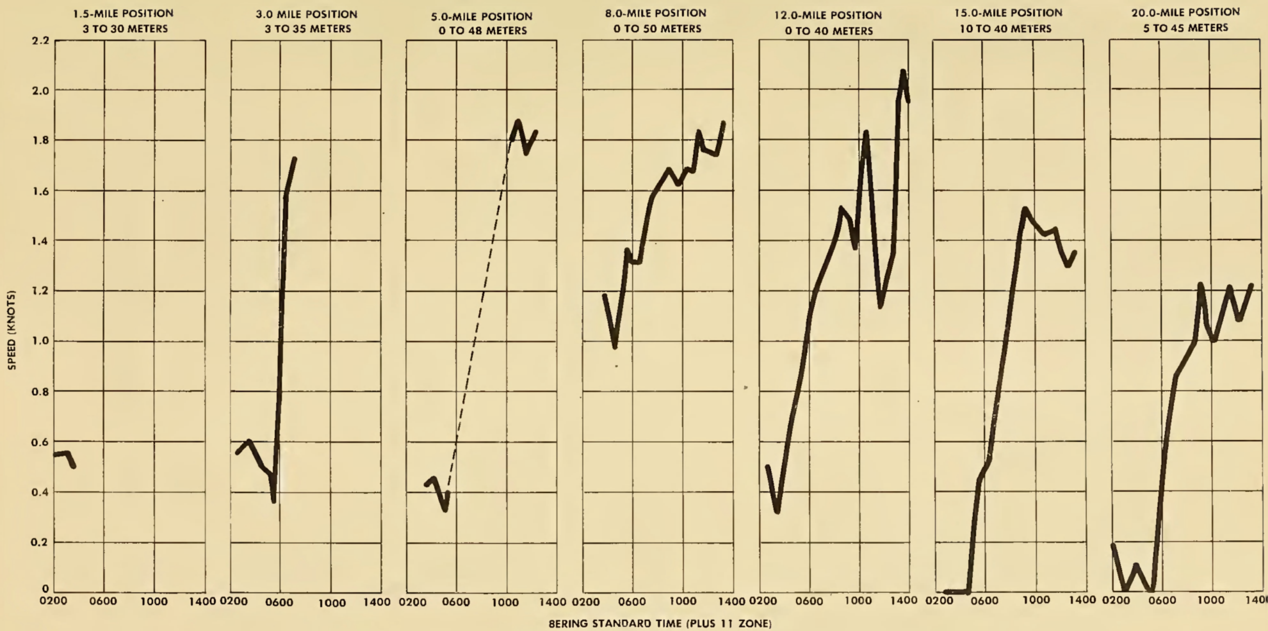


Figure 2. Average hourly current velocities from profile measurements, 1 August 1954.

compared to a 2.4-inch change from 1245 to 1700. It is possible that the wind effect (average wind speed, 21 mph) is sufficient to mask the extremely low tidal range during this period.

Dall[3] concluded that the northly current through the Strait is probably chiefly dependent on the tide for its force and direction, while studies in 1949 by Lesser and Pickard[4] indicate that the current through the Bering Strait is not primarily tidal in character, nor does it have a major tidal component. It is apparent that the relation of tides to the water transport through the Bering Strait remains a contradictory subject, and the problem can be resolved only by a well coordinated tide and current measurement program which covers sufficient tidal cycles to permit a valid analysis.

Assuming velocity measurements at the 20-mile position are valid to 25 nautical miles, the average volume transport through a 25-mile vertical section of the Strait extending due west from the Field Station (along the measurement line of fig. 1) has been calculated for the 1 August 1954 observation period.

For transport calculation purposes the 25-mile section was divided into bands of average current velocity as indicated in figure 4 (crosses denote anchor station positions and depths).

The average northerly water transport through a 25-mile section of the eastern Bering Strait is $10^6 \times$ cubic meters per second for the period from 0200 to 1400 is shown in figure 5. The average maximum transport value of 1.84×10^6 cubic meters per second is significantly higher than previous average values for the entire strait of 0.88 computed by Sverdrup[5] and 1.28 determined as a summer value based on oceanographic observations taken in 1949.[4]

The current data clearly indicate the erroneous interpretation which can be drawn from a series of current measurements taken at varying time intervals and positions in the Bering Strait, and are indicative of short term fluctuations in current and transport which may be encountered.

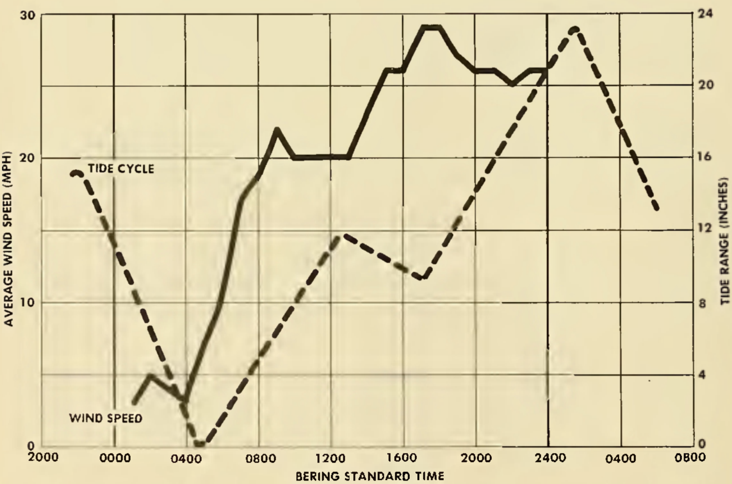


Figure 3. Average hourly wind speed and tide range, 1 August 1954, Wales, Alaska.

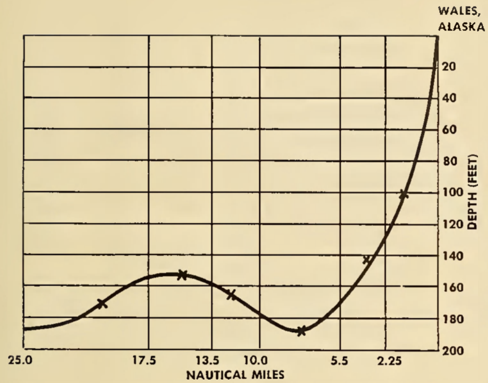


Figure 4. Cross-section along east-west measurement line from Wales, Alaska.

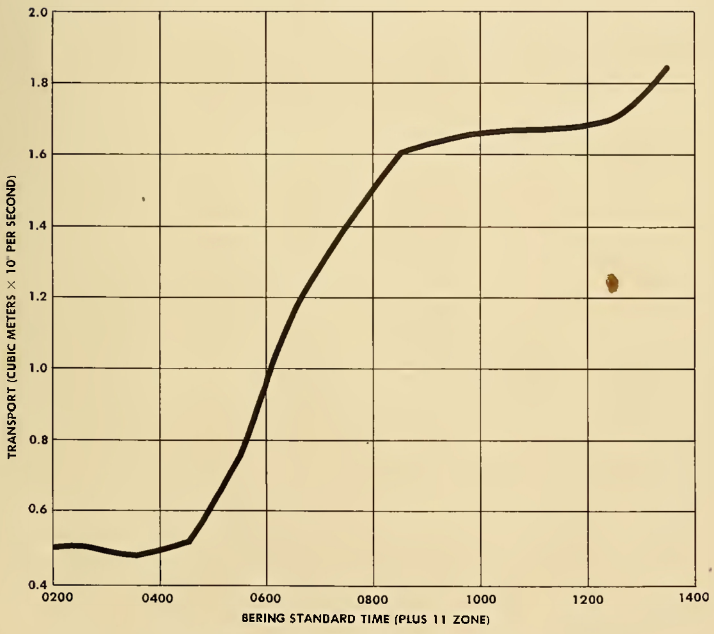


Figure 5. Average northerly water transport through a 25-mile section of the Eastern Bering Strait, 1 August 1954.

electric potential measurements

The possibility of measuring tidally generated potentials in bays and through ocean channels has been considered and discussed by numerous investigators.[6-9] The method has been employed in the study of mass water transport between Key West and Havana, and the average mass transport of the Florida Current for the period of August 1952 to August 1954 has been reported by Wertheim.[10]

Electric potentials were initially measured in the Bering Strait in 1949.[11] Continuation of these studies in 1951-1952 yielded only sketchy results, primarily because of installation problems associated with maintaining electrode-cable systems in an area subject to ocean freezing and ice movement.

Obviously, the most desirable procedure for measuring potentials and for studying their relation to water transport involves installation of electrodes on opposite banks of a channel. Since this technique cannot be followed in the Bering Strait, electrodes were bottom-laid, perpendicular to flow, near the eastern side of the Strait and connected to shore recording equipment by appropriate signal links (fig. 6). (A complete description of electrode systems and electrode construction has been given in reference 1.) Edge effects of potential gradients extending inland have been recorded using land electrode systems laid perpendicular and parallel to flow.

Young, Gerrard, and Jevons[7] considered the effect of potential gradients on a set of moored electrodes near one shore of a broad channel and demonstrated that the potential gradient e_1 where v_1 is the observed velocity in the experimental area exhibits the following relation (sea bottom-conducting):

$$e_1 = -Vv_1 s + Cs\rho \text{ (electromagnetic units)}$$

where

V = earth's vertical field (gauss)
v_1 = water velocity (cm/sec)
s = length of water filament (cm)
C = current density (abamperes/cm^2)
ρ = specific resistance of the water (ohms/cm)

Theoretically, C may have a value as great as Vv_0/ρ where v_0 equals the mean velocity across the entire channel and the conductivity of the earth bed is negligible compared to the water. In such an idealized case

$$e_1 = -Vv_1 s + Vv_0 s$$

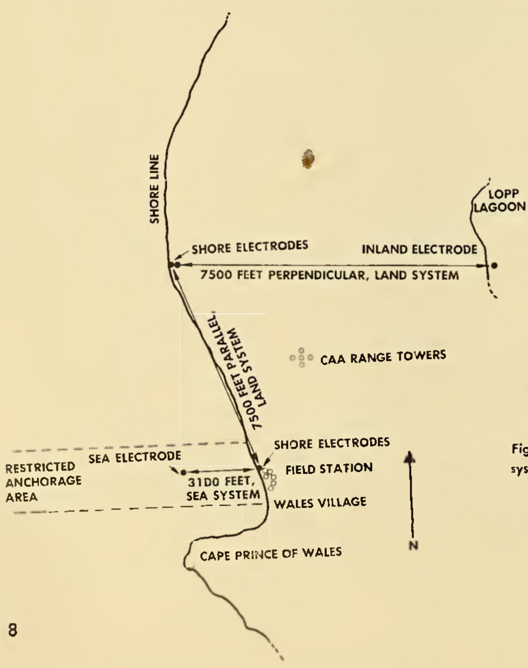


Figure 6. Schematic of land and sea electrode systems.

The effect would be to reverse the sign of e_1 (measured potential) and give the impression that experimental observations disagree even quantitatively with theory.

Potentials measured by the electrodes moored near shore in the eastern Bering Strait generally indicate polarities opposite to that expected from the known direction of water flowing through the system and would lend experimental support to the conclusion that water motion seaward of a moored electrode system can have an overriding effect on the potentials recorded.

Because of the many indeterminate effects contributing to the potentials measured at the Field Station, the electrode system was calibrated from current survey data and an emperical relationship used to convert observed potentials to volume transport values.

The relation between hourly potentials from the sea electrode system and volume transport for a 25-mile section of the eastern Bering Strait (calculated from the 1 August 1954 current measurements) is indicated in figure 7. The displacement from zero may be attributed to several possibilities: (1) electrode polarization, (2) concentration effects, (3) earth currents, and (4) water motion in the western Bering Strait. Further current studies and comparison with simultaneous potential measurements are required to determine the constancy of the displacement and to provide an accurate estimate of cause.

Using the relation in figure 7, average monthly transports through a 25-mile sector of the eastern Bering Strait were computed from potentials recorded on the sea electrode system. The potentials were computed by determining a mean value from the

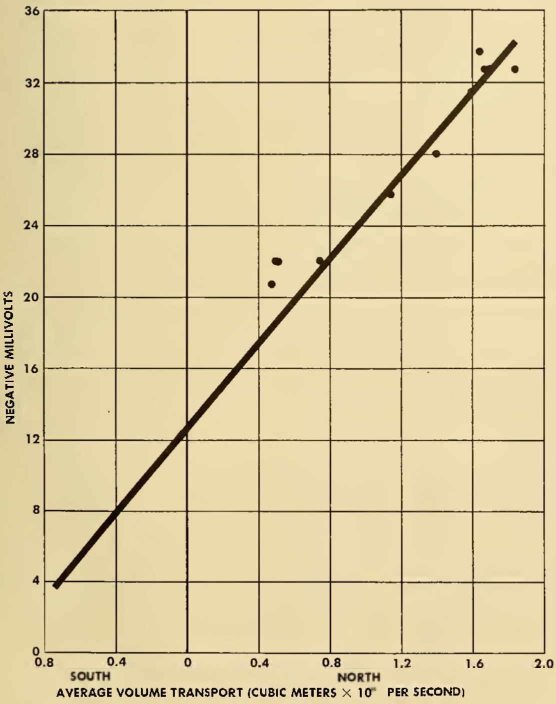


Figure 7. Relation between water transport and potential values from sea electrode system.

daily (0000-2400) voltage records (figs. 8A, 8B) and by calculating an arithmetic monthly average from the daily values.

A similar evaluation of potentials measured on land electrode systems indicates that such systems are generally unworkable, at least for this location, since tidally generated or "transport" potentials are obscured by earth currents and large random fluctuations in signals during the summer months and by variable losses in "pick-up" sensitivity due to the ground freezing during the winter months. The decrease in electrical conductivity between land electrodes is illustrated indirectly by the changes in voltages developed between land silver/silver chloride electrodes and earth grounds as the atmospheric heat input fluctuates (figs. 9A, 9B, and 9C). The irregular signal fluctuations are common to both sea and land electrode systems, although more pronounced in the land system. The electric potential measurements reported by Wertheim[10] exhibit comparable fluctuations and have been related to variations in the magnitude and direction of the horizontal component of the geomagnetic field.

Inspection of the average monthly mass water transport for June 1953 through November 1955 (fig. 10) indicates considerable fluctuation throughout the year both in volume and in direction. A northerly transport for August through November ranging from a minimum of 0.8 to a maximum of 3.1×10^6 cubic meters per second is characteristic of all three years.

The large southerly outflow of water from the Arctic Ocean system in May and June of 1954 (3.8×10^6 cubic meters per second) is somewhat surprising and perhaps contrary to many former opinions, although continuous measurements which provide evidence on the volume and direction of transport through the Strait are extremely meager. It is unfortunate that comparative data for the same period in 1953 and 1955 are unavailable.

The reader is cautioned as to the accuracy of the mass transport data. Until further potential measurements and current calibrations have been conducted, the data presented in figure 10 must be considered tentative. It is obvious that a shift in the empirical calibration curve (fig. 7) could cause appreciable changes in transport values calculated from the average monthly potentials.

SEA WATER TEMPERATURES

Bottom sea water temperatures in the eastern Bering Strait have been measured, 1200 feet offshore in 10 feet of water, from October 1953 to November 1955. Average monthly and daily temperatures for this period are presented graphically in figures 11 and 12.

More significant data in relation to water transport are obtained when the thermal units are laid in deeper water at a distance 4 to 6 miles offshore, where a zone of boundary or transitional flow appears to exist. Data were obtained in this area in 1951[1] and indicated considerable correlation with water movement and wind shifts. The reported measurements, taken near shore in shallow and relatively protected waters, obviously reflect atmospheric radiation and meteorological parameters to a far greater degree than average oceanographic changes and must be considered in the interpretation.

Ice reconnaissance data summarized in terms of the polar pack ice boundary and reported by the U. S. Navy Hydrographic Office[12] illustrate the relative navigability or severity of ice conditions in the Chukchi/Beaufort Seas for the years 1953, 1954, and 1955 and are reproduced in figure 13. From figure 11 it is noted that the average monthly temperatures for August and September 1954 were 2.7°F and 4.0°F higher than for the same months in 1955. This leads to speculation on the contribution of water transport, if any, to the large recession of ice off the northwestern Alaskan coast and the extreme open conditions in the Chukchi Sea during 1954.

A contradictory feature arises, if average monthly volume transport values are considered together with the average monthly temperatures. Since the August-September 1955 transport values are indicated to be approximately twice the volume for the same months in 1954, the total theoretical amount of available "oceanic" heat above 29°F for these two months is only about 50 per cent and 70 per cent as great as for August and September 1955. Thus, it might be reasoned that the water contribution to ice disintegration is slight or negligible.

From the preceding data it is apparent that a complete heat budget study which considers all pertinent oceanographic and meteorological parameters in relation to ice growth, dissipation, and movement

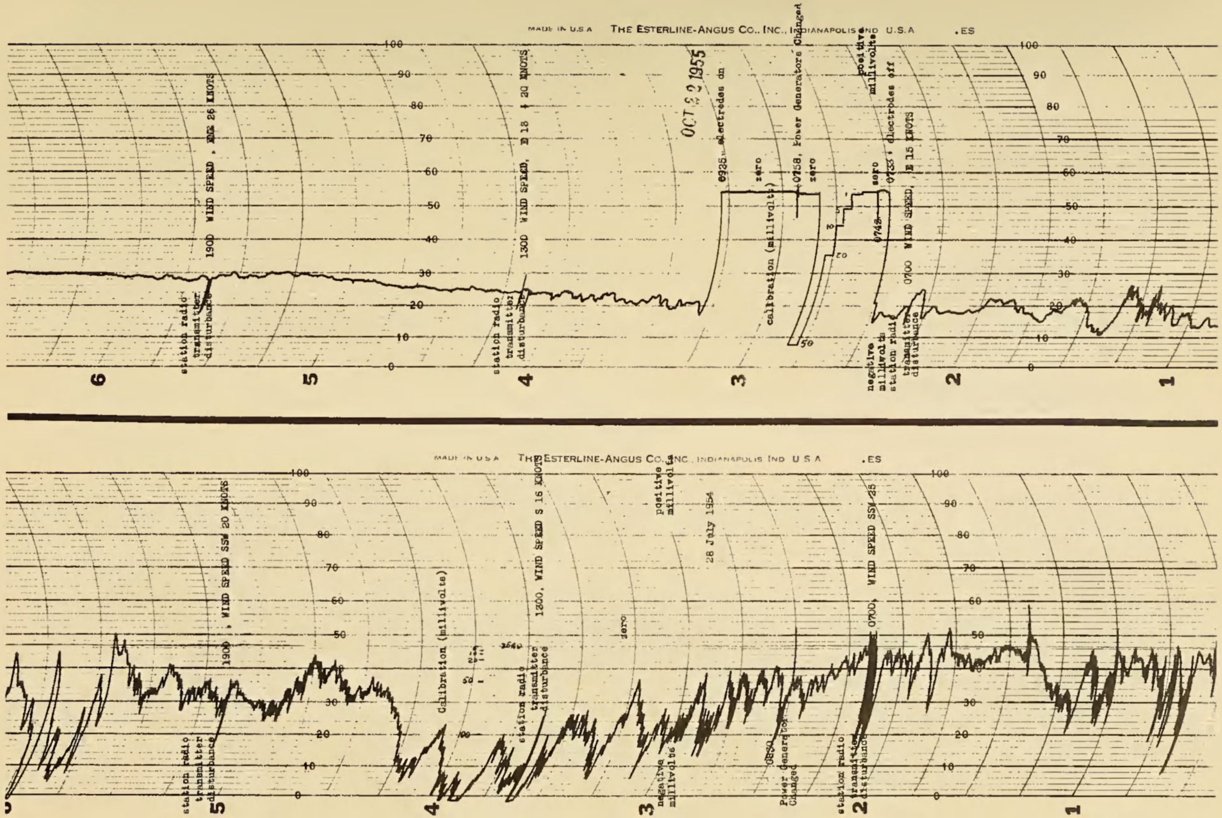


Figure 8. Sample record showing signal voltage versus time.

A. Typical voltages, sea electrodes.

B. Typical voltages, land electrodes, relatively undisturbed period.

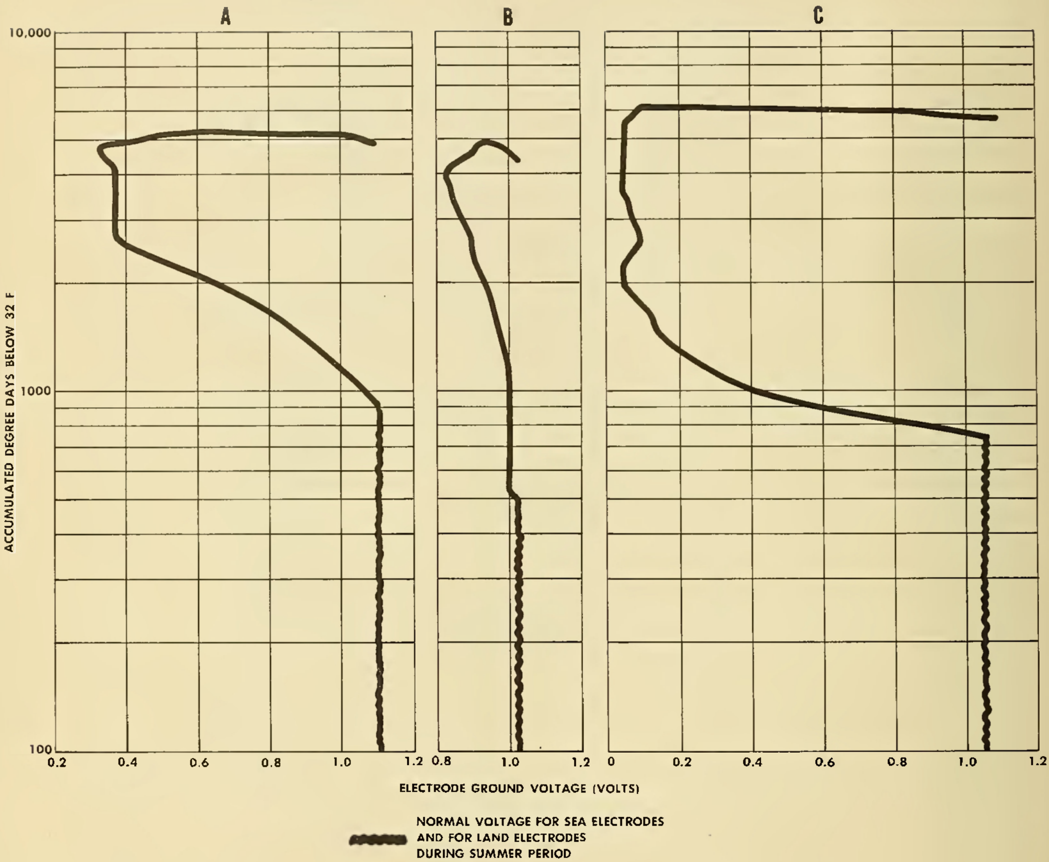


Figure 9. Relation between accumulated degree days below 32°F and potential measured between a land silver/silver chloride electrode and earth ground.

A. Period 17 October 1952 to 1 August 1953.

B. Period 22 October 1953 to 1 August 1954.

C. Period 7 October 1954 to 1 August 1955.

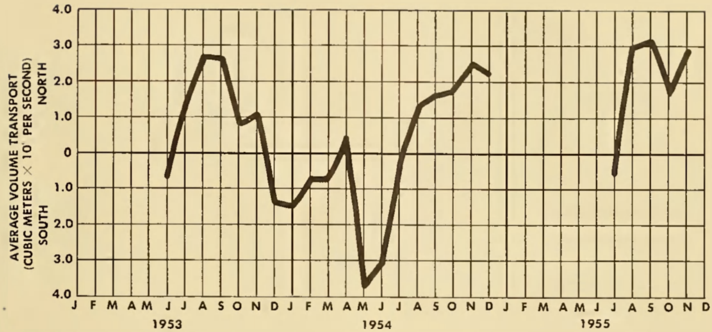


Figure 10. Average monthly volume transport through a 25-mile sector of the Eastern Bering Strait, June 1953 to November 1955.

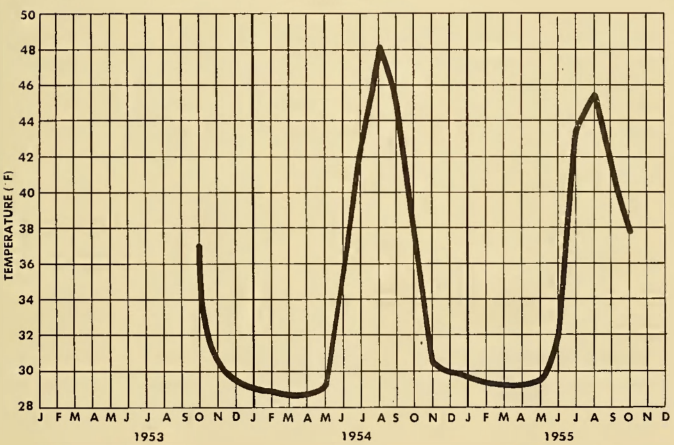


Figure 11. Average monthly sea water temperature, Bering Strait, Wales, Alaska, October 1953 to November 1955.

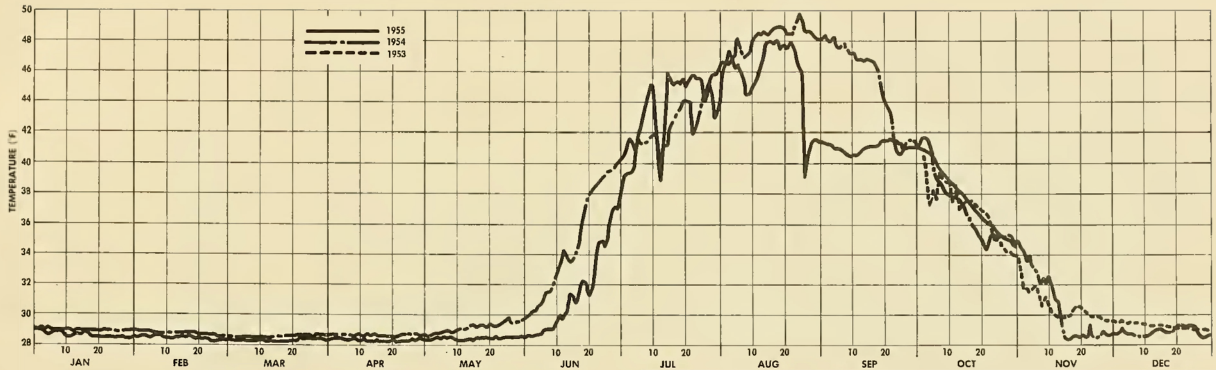


Figure 12. Daily bottom sea water temperatures, October 1953 through October 1955, Bering Strait, Wales, Alaska.

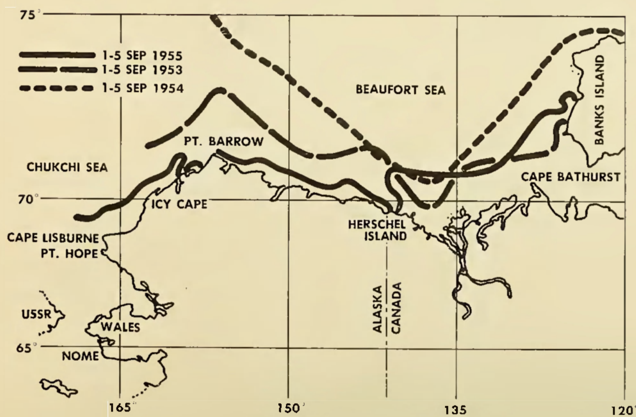


Figure 13. Comparison of polar pack boundary, early September 1953, 1954, 1955.

must be made before consistent "behavior" or prediction formulas can be developed. In order to unravel and to assign quantitative values to each factor or even realistically to group effects contributing to the ice regime, it may well be necessary to extend measurement stations to several strategic points within the system. A minimum requirement for evaluation of the Bering Strait/Chukchi Sea system appears to be coordinated oceanographic measurements from Wales and from a northern station located at Point Hope or Cape Lisburne.

SEA ICE GROWTH

The first slush ice formation off Wales, Alaska, appears from mid-October to mid-November with variable states of slush-pancake-young ice and open water combinations existing until the first or second week of December when ice accretion becomes more uniform, with growth of the solid state continuing until the later part of April to early May. The heat budget then reverses with the break-up progressing rapidly throughout late May and the first two weeks of June. By July the area is free of fast and drift ice except for a few scattered growlers.

The land-fast ice sheet is variable in width from 1 to ½ mile, with the sea ice beyond the fast ice in continual motion throughout the winter season. Typical ice conditions during January in the eastern Bering Strait are illustrated in figure 14.

The rate of growth of sea ice was measured in the fast ice at a point ½ mile offshore during the 1952-1953 and the 1953-1954 ice seasons. Thickness was determined by drilling 1½-inch holes with an auger-type corer and measuring the sheet with a calibrated rod constructed with a spring-loaded arm designed to project against the underside of the ice upon release from the boundaries of the drill hole.

Figure 14. Area between Wales and Diomede Islands illustrating January ice conditions. Fast ice is the dark portion in the lower part of the photograph. All light ice moving north.

The increase in ice thickness with time is shown in figure 15.

Discontinuities exist at the beginning of each season, caused in 1952 by the destruction of the fast ice sheet and in 1953 by the influx of drift ice which remained and developed as the permanent fast ice sheet. Prior to the destruction of the ice on 5 January 1953 by high winds and above freezing temperatures, an estimated thickness of 14 to 18 inches had been attained.

The break-up of the fast ice on 29 May may be indicative of the mild ice conditions experienced off the northern and northwestern Alaskan coast during the summer of 1954 and is approximately two weeks earlier than the average observed time for the 5-year period from 1951 to 1955.

A comparison of ice thickness and accumulated degree days below 29°F is given in figure 16. For each season, degree days are calculated starting with the date the first slush ice was observed. The average daily temperature is computed as the mean of the maximum and minimum air temperature recorded at Wales. Based on the Field Station weather observations, the meteorological factors of cloud cover, wind speed, and humidity and the insulating effect of snow cover on rate of ice growth are generally comparable for the two ice seasons considered here. The snow cover on the ice did not exceed 4 inches throughout the measurement periods. Minor irregularities in the comparison of degree days and ice thickness are expected, due to the limited temperature data and to the method of calculating average daily temperatures.

The discontinuities during the initial formation of the fast ice should be kept in mind, since these have a definite bearing on the slope of the ice formation curve and no doubt account for much of the divergence during early stages of growth. Comparable rates of growth are indicative for both seasons after an ice thickness of 31.5 inches was reached.

The complexity of the variables affecting the ice growth rate is recognized and field studies are now in progress to obtain more complete meteorological, oceanographic, and temperature profile (air-ice-water) data. These observations will be analyzed in greater detail than the preceding data and the observed ice growth compared with theoretical values computed by various methods discussed and summarized by Calaway.[13]

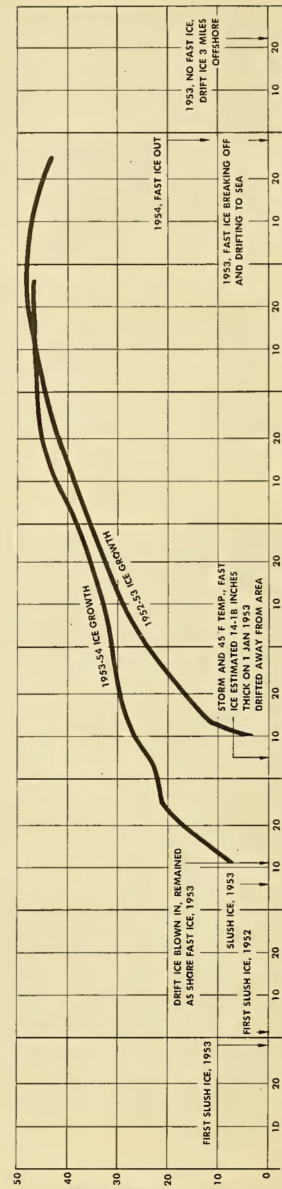


Figure 15. Observed sea ice growth at Wales, Alaska, for 1952-1953 and 1953-1954.

The number of degree days below 29°F in each month, October through May, for the approximate 1952-53 and 1953-54 ice seasons is summarized in table 3.

TABLE 3. Summary of monthly degree days below 29°F at Wales, Alaska, for 1952-1953 and 1953-1954 ice seasons.

Month	Year	Degree Days Below 29°F	Year	Degree Days Below 29°F
October	1952	—77*	1953	4
November	1952	198	1953	276
December	1952	649	1953	964
January	1953	996	1954	918
February	1953	1079	1954	1134
March	1953	1104	1954	710
April	1953	488	1954	322
May	1953	52	1954	—148*
Total		4489		4180

* Minus value indicates degree days above 29°F.

Total degree days for the 1953-54 period are approximately 7 per cent less than for the previous year. The relatively rapid atmospheric warming and the mild air temperatures in the spring of 1954 are reflected in the lower degree day totals for March and April and in the number of degree days above 29°F for May. The significance of these data and the predictable effect, if any, in relation to break-up require further study.

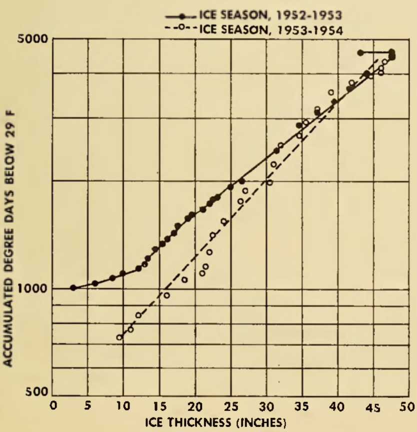


Figure 16. Comparison of ice thickness and accumulated degree days below 29°F for Wales, Alaska.

TIDAL MEASUREMENTS

A secondary type tide station was erected in the surf area off Wales, Alaska, during the summer of 1954 and a series of tide observations taken for a period of 9 weeks from 19 July to 18 September. Observations were conducted primarily to assist in the evaluation of a hydraulic system for measuring fluid transfer from off-shore points and to provide simultaneous tide data in conjunction with electromagnetic transport measurements.

Tidal cycles were measured with a Type 5-FW-1, Instrument Corporation, "portable automatic water level recorder." The instrument utilizes a conventional type 4-inch-diameter float and counterpoise weight attached to a steel tape riding over a 12-inch circumference pen drive wheel. The 5-inch-by-14.5 inch curvilinear chart is cylindrically mounted with rate of advance controlled by an 8-day spring-wound clock.

The recording insturment was mounted atop a 5-inch-diameter-by-12-foot iron float well with the counterpoise weight riding in an adjacent 2-inch-diameter tube. The wells were supported inside a 10-foot tripod, constructed from ⅜-by-3-by-3-inch angle iron, with a 50-inch base leg spread. The tripod was located approximately 300 feet off shore and secured in position with four 100-foot-5/32-inch guy lines running from the upper corners of the tripod to 100-pound danforth type anchors (fig. 17). In spite of moderately heavy surf action, considerable success was achieved in maintaining the equipment in continuous operation. Following one south storm it was necessary to relevel the float well and tripod; however, the procedure is generally applicable to making short term tide studies in remote and unprotected acreas where a more permanent installation is impractical or unwarranted.

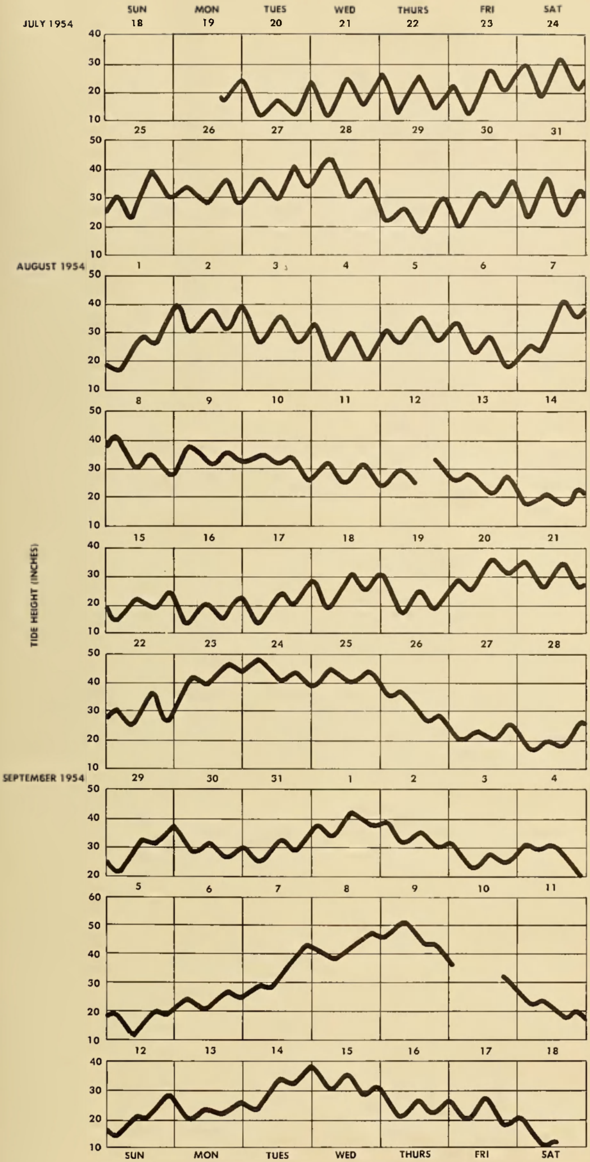
Tidal measurements are summarized in figure 18. The height of water given in inches is based on actual staff readings with zero representing the ocean floor at the tide stand. A permanent inshore bench mark has been established which will permit correlating future observations. All times listed are Bering Standard. The graphic presentation indicates the character of the tidal cycles measured.

A stage height ratio of 5 inches of chart equal to 60 inches of water and a time scale of approximately 1 millimeter equal to 30 minutes were the instrument recording chart coordinates. The estimated reading errors for the time of high and low tides is of the order of 10 minutes and for tide heights is plus or minus 0.2 inch.

A complete analysis correcting for winds, barometric conditions, and other factors effecting tide changes has not been made; however, the following predominate features are noted from inspection of the tidal data. The tides off Wales exhibit considerable diurnal inequality while the average period indicates that the partial tide force is "principal lunar" with the occurrence of high and low waters normally characterized by a semidiurnal variation.

Range between successive maxima and minima are small, averaging 8 inches during the 9-week observation period and ranging from a minimum value of 0.2 inch to a maximum of 18 inches. Strong local winds and storms over the Bering Sea/Bering Strait tend to deform the tidal curve, depressing or enlarging the oscillations and the daily tidal periods. A maximum variation in sea level from low low water to high high water of 51 inches was observed during the July-September recording period.

Figure 17. Offshore tide recording station, Wales, Alaska.



DATE	HIGH TIME	HIGH HT (IN)	LOW TIME	LOW HT (IN)
JULY 1954				
19			1715	17.5
MON	2315	24.7	—	—
20	—	—	0600	11.5
TUES	1200	17.5	1700	11.9
21	0030	23.9	0545	11.9
WEO	1300	25.1	1830	15.5
22	0045	26.9	0630	12.5
THUR	1345	25.7	1915	14.3
23	0130	22.3	0715	12.1
FRI	1445	28.0	2010	20.8
24	0240	29.8	0830	18.7
SAT	1515	32.1	2140	21.3

DATE	HIGH TIME	HIGH HT (IN)	LOW TIME	LOW HT (IN)
JULY 1954				
25	0345	30.7	0900	22.6
SUN	1630	39.4	2300	29.4
26	0500	33.3	1130	27.9
MON	1815	36.3	2300	27.9
27	0600	36.3	1145	29.1
TUES	1830	41.1	2300	33.9
28	0615	43.5	1330	30.1
WED	1930	36.1	—	—
29	0845	25.9	0215	21.7
THUR	2200	30.1	1430	18.1
30	1045	31.9	0330	19.9
FRI	2210	36.2	1630	26.9
31	1015	37.4	0330	23.0
SAT	2200	32.6	1630	24.2

DATE	HIGH TIME	HIGH HT (IN)	LOW TIME	LOW HT (IN)
AUGUST 1954				
1	1245	29.0	0445	17.3
SUN	—	—	1700	26.6
2	0130	40.4	0600	30.5
MON	1315	38.0	1840	31.1
	2345	39.2	—	—
3	1310	35.9	0630	26.9
TUES	—	—	2000	27.1
4	0050	33.1	0710	20.5
WEO	1410	30.1	1950	20.8
5	0200	30.7	0720	26.2
THUR	1430	35.5	2020	27.1
6	0240	33.7	0850	22.9
FRI	1410	28.6	2110	18.1
7	0400	25.8	0710	23.4
SAT	1630	41.4	2130	35.6
8	0350	41.4	1050	30.0
SUN	1615	35.1	2310	27.6
9	0600	37.5	1300	31.2
MON	1900	35.1	—	—
10	—	—	0030	31.8
TUES	0700	34.8	1230	31.8
	1645	34.2	2315	25.8
11	0545	31.8	1145	24.9
WED	1815	31.2	—	—
12	0700	29.4	0015	23.7
THUR	OUT	OUT	OUT	OUT
13	0715	27.9	0230	25.8
FRI	2015	27.0	1500	21.0
14	1000	21.0	0245	17.1
SAT	2145	22.5	1645	17.1

DATE	HIGH TIME	HIGH HT (IN)	LOW TIME	LOW HT (IN)
AUGUST 1954				
15	1115	22.5	0330	15.0
SUN	2230	24.9	1715	19.2
16	1130	21.0	0445	13.8
MON	2330	23.4	1700	15.6
17	1330	24.6	0530	13.8
TUES	—	—	1745	20.4
18	0015	28.8	0620	19.2
WED	1415	31.2	1845	25.2
19	0030	31.5	0800	17.2
THUR	1430	25.0	1930	19.0
20	0300	29.2	0800	25.6
FRI	1530	36.8	2100	30.8
21	0245	35.6	0930	26.6
SAT	1600	35.3	2215	26.7
22	0400	30.3	0900	25.5
SUN	1615	36.3	2130	26.7
23	0630	42.3	1100	39.3
MON	1846	46.8	2315	43.2
24	0530	48.3	1315	40.2
TUES	1830	43.5	—	—
25	0730	44.4	0000	38.4
WED	2000	44.1	1400	39.6
26	0730	36.9	0300	34.8
THUR	2045	28.2	1630	26.4
27	1030	22.2	0400	19.2
FRI	2130	25.3	1600	19.6
28	1100	19.9	0430	16.6
SAT	2300	25.4	1545	17.6
29	1300	32.6	0430	20.9
SUN	2350	37.1	1700	31.1
30	1230	31.4	0720	28.4
MON	—	—	1859	26.3
31	0015	29.9	0615	24.5
TUES	1330	32.6	1815	29.1

DATE	HIGH TIME	HIGH HT (IN)	LOW TIME	LOW HT (IN)
SEPTEMBER 1954				
1	0145	37.5	0630	33.9
WED	1345	42.6	2215	37.5
2	0230	39.0	0845	31.2
THUR	1430	35.4	2020	30.0
3	0110	31.5	0845	22.5
FRI	1500	27.8	2030	24.8
4	0330	30.8	0830	29.2
SAT	1400	30.7	—	—
5	—	—	000	19.3
SUN	0300	19.7	1000	12.2
	1730	20.3	2130	19.3
6	0430	24.7	1045	21.1
MON	1825	27.1	2230	25.6
7	0600	29.5	1000	28.6
TUES	2145	43.0	—	—
8	—	—	0800	38.8
WEO	2030	47.2	—	—
9	0800	51.4	0100	46.0
THUR	1900	43.2	1600	43.0
10	OUT			
FRI	OUT			
11	0841	23.6	0500	22.2
SAT	2030	19.7	1630	17.9

DATE	HIGH TIME	HIGH HT (IN)	LOW TIME	LOW HT (IN)
SEPTEMBER 1954				
12	1115	21.5	0330	14.6
SUN	2200	28.7	1400	20.6
13	1130	24.0	0530	20.1
MON	2300	26.6	1600	22.7
14	1300	34.7	0430	23.5
TUES	—	—	1730	32.9
15	0000	39.0	0700	30.5
WED	1230	35.8	1820	28.6
	2330	31.6	—	—
16	1320	27.9	0700	20.6
THUR	—	—	1845	22.2
17	0015	26.7	0640	19.9
FRI	1245	27.5	1945	17.8
18	0100	20.4	1000	10.7
SAT	1400	11.8	—	—

Figure 18. Tide graph and tables for Wales, Alaska, 18 July 1954 through 18 September 1954.

CONCLUSIONS

1. Average mass water transport through the eastern Bering Strait exhibits considerable fluctuation throughout the year both in volume and direction.

2. A northerly volume transport varying from 0.8 to 3.1×10^6 cubic meters per second appears characteristic of the period August through November.

3. An area of maximum current velocities is indicated in the 8-to-12-mile section of the eastern Bering Strait.

4. Potentials measured with short sea electrode systems can be correlated with mass water transport, while land electrode systems appear generally unworkable for the Cape Prince of Wales area.

5. Bottom sea water temperatures in the eastern Bering Strait attain maximum average values of 45°F to 49°F by late August and reflect north-south shifts in wind direction and water transport.

6. Omitting initial freeze-up discontinuities, the logarithm of accumulated degree days below 29°F exhibits essentially a linear relationship with fast ice accretion at Wales, Alaska.

7. Average total ice growth at Wales is 46 to 48 inches, with first slush ice formed late October to early November and fast ice break-up normally completed by mid June.

8. Tides off Wales are semi-diurnal in variation, with ranges between high and low water during the summer months averaging less than 12 inches.

RECOMMENDATIONS

1. Extend and make simultaneous oceanographic and meteorological measurements essential to a detailed analysis of the sea-ice-heat-budget regime.

2. Continue measurement of average water transport through the Bering Strait by the electromagnetic method and conduct independent water velocity measurements for correlation with transport data.

3. Conduct daily sea-water temperature measurements from strategic points along the northwestern Alaskan coast as an aid to the study of temperature/transport discrepancies.

4. Conduct sonar studies in respect to the effect of ice coverage and movement on ambient noise and passive detection ranges.

5. Study and relate tide and wind contribution to water transport through the Bering Strait.

6. Obtain data on the variation of the horizontal component of the earth's magnetic field and the contribution to the fluctuations present in the water-transport-generated signal potentials.

7. Conduct laboratory experiments to simulate the effect of varying current speeds and direction on electrical potentials generated by simultaneous irregular flow conditions across the Bering Strait.

APPENDIX: SURFACE CURRENT AND VELOCITY PROFILE DATA

TABLE 1. Surface current observations, eastern Bering Strait, 1 August 1954.

Position (n. m. due west line)	Time (BST*)	Current Dir. (to)	Current Speed (kt)
LVT-3(C) No. 1			
1.5	0230	W	0.49
	0310	WNW	0.20
	0345	NW	0.17
LVT-3(C) No. 2			
3.0	0250	NW	0.53
	0300	NW	0.52
	0337	NNW	0.47
	0445	NNW	0.48
	0535	NW	0.56
	0610	N	1.13
	0620	N	1.40
	0705	N	1.69
USCGC NORTHWIND LCVP			
5.0	0300	320°	0.20
	0330	320	0.22
	0400	320	0.24
	0430	350	0.31
	0500	340	0.21
	0530	340	0.19
	0600**	340	0.17
	0630**	Var.	—
	0700**	150	0.11
LCVP recalled, new crew sent out. Boat reanchored 3 miles north of first position.			
	0950	000	2.37
	1110	000	2.42
USCGC NORTHWIND			
8.0	—	341°	0.88
	0658	337	0.94
	0922	015	1.04
	0942	015	0.93
	0945	005	1.20
	1009	359	1.15
	1030	012	1.22
	1042	001	1.18
	1102	015	1.40
	1118	005	1.27
	1133	010	1.45
	1148	010	1.36
	1202	008	1.48
	1219	007	1.35
	1234	012	1.41
	1247	009	1.46
	1300	003	1.43
USS BURTON ISLAND LCVP			
12.0	0200	N	0.25
	0230	N	0.34
	0300	N	0.32
	0330	N	0.49
	0400	N	0.34
	0430	N	0.59
	0500	N	0.88
	0530	N	1.22
	0600	N	1.33
	0634	N	1.29
	0705	N	1.39
	0730	N	1.43
	0801	N	1.48
	0830	N	1.40
	0901	N	1.32
	0930	N	1.32
	1002	N	1.48
	1030	N	1.53
	1100	N	1.60
	1130	N	1.11
	1200	N	1.07
	1230	N	1.25
	1307	N	1.62
	1330	N	1.83
	1400	N	1.56
USS BURTON ISLAND GREENLAND CRUISER			
15.0	0205	180°	0.15
	0240	180	0.11
	0305	195	0.11
	0325	195	0.14
	0405	200	0.14
	0435	250	0.14
	0500	260	0.16
	0540	305	0.36
	0605	335	0.55
	0630	335	0.83
	0700	355	1.13
	0730	355	1.13
	0800	000	1.52
	0830	000	1.50
	0900	000	1.52
	0930	000	1.48
	1005	350	1.25
	1040	350	1.13
	1115	350	0.87
	1145	350	0.99
	1200	350	0.69
	1235	350	0.78
	1300	350	1.03
USS BURTON ISLAND			
20.0	0200	—	0.0
	0230	—	0.0
	0300	—	0.0
	0330	110°	0.32
	0400	115	0.26
	0430	116	0.29
	0500	074	0.19
	0530	010	0.31
	0600	010	0.40
	0630	010	0.44
	0700	009	0.43
	0730	009	0.76
	0800	015	0.80
	0830	013	0.85
	0900	010	1.01
	0930	012	1.06
	1000	023	0.94
	1030	021	0.98
	1100	026	0.95
	1130	024	1.01
	1200	032	0.95
	1230	035	0.95

* Bering Standard Time (plus 11 zone).

** LCVP dragging anchor; values highly questionable.

TABLE 2. Summary of current velocity profile measurements, eastern Bering Sea, 1 August 1955.

Depth (meters)	Current Dir. (to)	Current Speed (kt)	Current Dir. (to)	Current Speed (kt)	Current Dir. (to)	Current Speed (kt)	Current Dir. (to)	Current Speed (kt)	Current Dir. (to)	Current Speed (kt)	Current Dir. (to)	Current Speed (kt)	Current Dir. (to)	Current Speed (kt)	Current Dir. (to)	Current Speed (kt)	Current Dir. (to)	Current Speed (kt)
Position: 1.5 Nautical Miles																		
Time (BST)→	0200		0300		0330													
3	NW	0.41																
6	NW	0.47	WNW	0.67														
9	NW	0.59																
10					NW	0.59												
12	NW	0.59																
15	NW	0.59																
18	NW	0.59	WNW	0.51														
20					NW	0.51												
21	NW	0.59																
30	NW	0.51	WNW	0.51	NW	0.41												
Calculated avg.	NW	0.55	WNW	0.56	NW	0.50												
Position: 3.0 Nautical Miles																		
Time (BST)→	0237		0327		0.425		0504		0525		0604		0625		0655			
3	NW	0.90	NW	0.75	NW	0.82	NW	0.75	NW	0.82	NNW	0.82	N	1.77	N	1.95		
6	NW	0.59	NW	0.70	NW	0.29	NW	0.29	NW	0.26	NNW	0.67	N	1.48	N	1.77		
10	NW	0.51	NW	0.51	NW	0.41	NW	0.45	WNW	0.26	NNW	0.90	N	1.59	N	1.66		
15	NW	0.51	NW	0.51	NW	0.51	NW	0.56	W	0.26	NNW	1.29	N	1.48	N	1.59		
20	NW	0.57	NW	0.59	NW	0.51	NW	0.47	WSW	0.26	NNW	1.19	N	1.59	N	1.66		
30	NW	0.59	NW	0.54	NW	0.45	NW	0.29	NW	0.37	NNW	1.19	N	1.59	N	1.77		
35	NW	0.23																
Calculated avg.	NW	0.56	NW	0.60	NW	0.50	NW	0.47	NW	0.37	NNW	1.01	N	1.58	N	1.73		
Position: 5.0 Nautical Miles																		
Time (BST)→	0330		0400		0500		0600		0700		1020		1100		1135		1205	
0	320°	0.31	320°	0.41	320°	0.20	320°*	0.0*	140°*	0.29*	000°	2.13	000°	2.13	000°	1.77	000°	1.70
4									140	0.41								
8	320	0.43	320	0.29	320	0.34	320	0.23										
10											000	1.84	000	1.95	000	1.70	000	1.88
14			320	0.51														
15									140	0.67								
20	320	0.55	320	0.51	320	0.41	140	0.23			000	1.77	000	1.95	000	1.77	000	1.91
30											000	1.77	000	1.77	000	1.66	000	1.95
40			320	0.53	320	0.32	140	0.26	140	0.67	000	1.70	000	1.77	000	1.77	000	1.88
45											000	1.59	000	1.70				
46	320	0.43																
47																	000	1.66
48															000	1.77		
Calculated avg.	320	0.43	320	0.45	320	0.32	—	—	—	—	000	1.80	000	1.88	000	1.74	000	1.83

* Dragging anchor, values unreliable 0600-0700.

TABLE 2. *(continued).*

Depth (meters)	Current Dir. (to)	Current Speed (kt)	Current Dir. (to)	Current Speed (kt)	Current Dir. (to)	Current Speed (kt)	Current Dir. (to)	Current Speed (kt)	Current Dir. (to)	Current Speed (kt)	Current Dir. (to)	Current Speed (kt)	Current Dir. (to)	Current Speed (kt)	Current Dir. (to)	Current Speed (kt)	Current Dir. (to)	Current Speed (kt)
Position: 8.0 Nautical Miles																		
Time (BST)→	0345		0430		0515		0530		0600		0630		0730		0850		0935	
0	000°	1.29	345°	0.76	343°	1.25	346°	1.29	335°	141	335°	1.55	335°	1.41	010°	1.59	013°	1.55
5	000	1.12																
10	000	1.29	345	1.12	343	1.21					335	1.16	335	1.44	010	1.70	013	1.44
15	000	0.98							335	1.37								
20	000	1.21	345	0.98	343	1.21	346	1.33			334	1.25	335	1.48	010	1.77	013	1.44
30	000	1.07	345	0.98					335	1.37	335	1.29	335	1.70	010	1.66	013	1.59
40	000	1.41	345	1.03	338	1.29	346	1.44	335	1.29	335	1.29	335	1.73	010	1.63	013	1.84
45							346	1.44			335	1.29	333	1.70	015	1.70	013	1.84
48									335	1.12								
50	000	1.07					342	1.29										
Calculated avg.	000	1.18	345	0.97	343	1.24	346	1.36	335	1.31	335	1.31	335	1.57	010	1.68	013	1.62
Position: 8.0 Nautical Miles																		
Time (BST)→	1012		1045		1115		1145		1235		1305							
0	002°	1.63	001°	1.77	005°	1.88	012°	1.88	012°	1.81	006°	1.91						
5																		
10	002	1.66	001	1.41	005	1.84	012	1.63	012	1.73	006	1.77						
15																		
20	002	1.91	001	1.66	005	1.70	012	1.59	012	1.66	006	1.70						
30	002	1.59	001	1.95	005	2.06	012	1.81	012	1.77	006	1.88						
40	002	1.63	001	1.81	005	1.73	012	1.91	012	1.77	006	2.06						
45	005	1.63	001	1.44	005	1.77	012	1.66	012	1.70	006	1.91						
48																		
50																		
Calculated avg.	002	1.68	001	1.67	005	1.83	012	1.75	012	1.74	006	1.87						
Position: 12.0 Nautical Miles																		
Time (BST)→	0245		0330		0450		0527		0555		0630		0728		0810		0830	
0			N	0.44	N	1.07	N	1.48	N	1.59	N	1.48	N	1.59	N	1.77	N	1.70
5							N	1.07	N	1.33	N	1.33	N	1.33	N	1.59	N	1.70
10	N	0.53					N	0.69	N	0.87	N	1.12	N	1.21	N	1.29	N	1.41
20			N	0.53	N	0.62	N	0.76	N	0.87	N	1.07	N	1.21	N	1.29	N	1.41
25	N	0.53																
40	W	0.44		Nil	N	0.53	N	0.44	N	0.69	N	0.98	N	1.21	N	1.21	N	1.41
Calculated avg.	N	0.50	N	0.32	N	0.74	N	0.89	N	1.07	N	1.20	N	1.31	N	1.43	N	1.53

TABLE 2. *(continued)*.

Depth (meters)	Current Dir. (to)	Current Speed (kt)	Current Dir. (to)	Current Speed (kt)	Current Dir. (to)	Current Speed (kt)	Current Dir. (to)	Current Speed (kt)	Current Dir. (to)	Current Speed (kt)	Current Dir. (to)	Current Speed (kt)	Current Dir. (to)	Current Speed (kt)	Current Dir. (to)	Current Speed (kt)	Current Dir. (to)	Current Speed (kt)
Position: 12.0 Nautical Miles																		
Time (BST)→	0905		0930		1005		1030		1130		1230		1300		1330		1400	
0	N	1.77	N	1.77	N	1.77	N	2.13	N	1.21	N	1.59	N	2.13	N	2.13	N	1.95
5	N	1.59	N	1.41	N	1.77												
10	N	1.48	N	1.21	N	1.70	N	1.77	N	0.87	N	1.59						
20	N	1.59	N	1.21	N	1.41	N	1.59	N	1.21	N	1.21	N	2.13	N	2.13	N	1.95
25																		
40	N	0.98	N	1.21	N	1.70	N	1.84	N	1.21	N	0.98	N	1.59	N	1.95	N	1.95
Calculated avg.	N	1.48	N	1.36	N	1.67	N	1.83	N	1.13	N	1.34	N	1.95	N	2.07	N	1.95
Position: 15.0 Nautical Miles																		
Time (BST)→	0245		0325		0430		0530		0615		0730		0830		0900		0930	
10		0		0		0	300°	0.44	300°	0.53	345°	0.98	000°	1.41	000°	1.52	000°	1.63
20		0		0		0	300	0.44	300	0.53	345	0.98	000	1.48	000	1.59	000	1.55
30		0					300	0.44	300	0.53	345	0.98	000	1.33	000	1.55	000	1.33
40		0		0		0	300	0.44			345	0.98	000	1.33	000	1.41	000	1.33
Calculated avg.	—	0	—	0	—	0	300	0.44	300	0.53	345	0.98	000	1.39	000	1.52	000	1.48
Position: 15.0 Nautical Miles																		
Time (BST)→	1030		1130		1200		1230		1300									
10	355°	1.37	355°	1.41	350°	1.33	350°	1.21	000°	1.33								
20	355	1.41	355	1.52	350	1.33	350	1.33	000	1.29								
30	355	1.48	355	1.48	350	1.41	350	1.29	000	1.41								
40	355	1.41	355	1.33	350	1.33	350	1.33	000	1.37								
Calculated avg.	355	1.42	355	1.44	350	1.35	350	1.29	000	1.35								
Position: 20.0 Nautical Miles																		
Time (BST)→	0200		0300		0400		0500		0615		0700		0830		0900		0930	
0	090°*	0.44		0														
5		0		0		0		0	358°	0.82	009°	0.93	013°	0.98	010°	1.07	012°	1.29
15		0		0	005°*	0.44		0	358	0.69	009	0.98	013	0.98	010	1.25	012	0.93
35		0		0		0		0	358	0.44	009	0.76	013	1.07	010	1.33	012	0.98
45									358	0.44	009	0.76	013	0.98	010	1.21	012	0.98
50	132*	0.44		0		0		0										
Calculated avg.	—	0.18*	—	0	—	0.11*	—	0	358	0.60	009	0.86	013	1.00	010	1.22	012	1.05
Position: 20.0 Nautical Miles																		
Time (BST)→	1000		1125		1200		1300											
0								1.21										
5	023°	1.29	026°	1.25	032°	1.07	035°	1.07										
15	023	0.82	026	1.16	032	1.07	035	1.21										
35	023	0.93	026	1.29	032	1.07	035	1.41										
45	023	0.93	026	1.12	032	1.07	035	1.21										
50																		
Calculated avg.	023	0.99	026	1.21	032	1.07	035	1.22										

* Values appear unlikely.

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3. Ocean currents — Arctic regions

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