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Technical Report No. 184

**CURRENT MEASUREMENTS
IN THE CANADIAN BASIN OF THE ARCTIC OCEAN,
SUMMER, 1965**

by

J. A. Galt

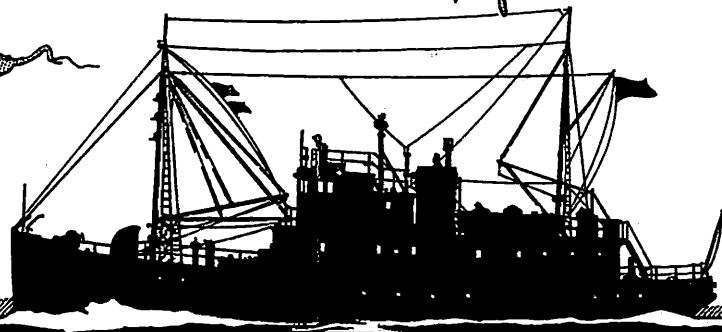
**Scientific Program
Under the general direction of
Lawrence K. Coachman**

**Arctic Institute of North America
Subcontract ONR-368**

and

**Office of Naval Research
Contract Nonr-477(37)
Project NR 083 012**

**Reference M67-15
March 1967**



SEATTLE, WASHINGTON 98105

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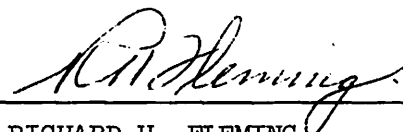
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ABSTRACT

Current measurements were made from Ice Island T-3 during the summer of 1965. Two current regimes were identified. One was in the pycnocline where a strong current core developed occasionally. The second was in the nearly isopycnal water below 400 meters, where the currents were slow and no significant shear was found. Inertial oscillation was detected in the island's drift.

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INTRODUCTION

Direct current measurements in the Arctic Ocean are relatively scarce. The following sets of measurements have been reported in the literature:

A suite of direct current measurements made from the ice station North Pole-2 in 1950-51 was reported by Somov (1954-55). Observations were carried out at 10, 75, 150, and 1,000 m for eleven and a half months with the frequency of observations depending on the other kinds of observations being made. Typically, the current readings were repeated every few hours. The currents were reported as movement relative to the 1,000-m level. Celestial navigation was used to determine the ice drift. Somov did not discuss the results.

Some drogue current measurements were made from Drift Station Alpha during the International Geophysical Year in the depth range immediately below the ice and were reported by Hunkins (1966a). Celestial navigation was used to determine the ice drift. During periods of steady drift, a boundary layer was observed just below the ice, and an Ekman spiral layer extended down to about 18 m below that.

Hunkins also made some measurements of current speed at depths of 100, 200, and 500 m below Fletcher's Ice Island (T-3) during the summer of 1963. These were used along with the trace from a precision depth recorder to show that a considerable amount of inertial motion was present in the draft of the island (Hunkins, 1966b).

Twenty-nine current measurements from numerous of the Soviet North Pole stations were reported by Nikitin and Dem'yanov (1965). Total currents at 750 or 1,000 m were obtained by leaving continuous recording current meters in place for periods that ranged from 58 to 291 hours. The ice motion was determined by celestial navigation and then subtracted from the integrated current records. The velocities reported ranged from 0 to 5 cm/sec and showed considerable variation in both direction and velocity.

In addition to the direct current measurements that have been made, there have been some attempts to determine the general circulation of the Arctic Ocean by an analysis of the observed mass and temperature fields.

After reviewing all the temperature and salinity data available, Coachman and Barnes (1961) were able to trace a portion of the water coming through the Bering Strait. It spreads across the Chukchi Sea and appears in the Canadian Basin as a temperature maximum at approximately 75 m. The layer seems to travel clockwise around a gyre covering most of the Canadian Basin.

In a second paper by the same authors (Coachman and Barnes, 1963), some 300 deep hydrographic stations from the Arctic were analyzed to determine the flow of the Atlantic water that enters the Arctic Ocean north of Spitsbergen. Other theories for the circulation of the Atlantic water were also reviewed in the paper. Figure 1 shows their conclusions.

The measurements reported in the present paper were made from the drifting station T-3 during the summer of 1965.

MEASUREMENTS AND METHODS

Fletcher's Ice Island (T-3) is an ice block 12 km by 7 km and between 30 and 50 m thick. It drifts with the surrounding pack ice. During the summer of 1965, it was located near 76°N ., 140°W . (Figure 2 shows the drift track of the island during the summer.)

The position of the island was determined by celestial navigation using a theodolite. Three lines of position were used as a fix. The triangle of error thus obtained varied in size but its radius averaged 0.37 km. The azimuth angle of a base line on the island was checked during each fix and in no case did the island rotate rapidly enough to bias any of the current measurements.

Wind data on T-3 were obtained from a continuously recording anemometer located 2 m above the ice level. The record was visually averaged with respect to speed and direction for hourly intervals.

Hydrographic casts were made several times during the summer. Neither the local time-dependent changes nor the small amount of island motion were enough to cause a significant difference between stations with the exception of the top few meters. The water column was characterized by a relatively pronounced pycnocline extending from just below the ice to a depth of 300 m. Below this the water remained nearly isopycnal all the way to the bottom (approximately 3,600 m).

The current measurements that were made fall into three groups that correspond to three distinct depth ranges in the water column. The uppermost group of measurements were started below the Ekman layer and extended down to 400 m and therefore covered the region of the pycnocline. The intermediate depth-range current measurements were made between 500 and 1,500 m, where there was almost no density variation. And, finally, bottom current measurements were made 2 or 3 m above the sea bed. The data have been reported by Tripp (1966).

The measurements made in the pycnocline and intermediate depth ranges were obtained with Tsurumi-Seikikosaku-Sho (TSK) meters of an Ekman type and are reported as motion relative to the island. The threshold sensitivity of these meters varied from 1.2 to 1.8 cm/sec. Currents greater than this were considered to be accurately measured to within 10% for speed and $\pm 10^{\circ}$ in direction.

The bottom current measurements were obtained with Carruthers' Pisa Tubes (Carruthers, 1958) which measured the current relative to the bottom. Threshold sensitivity for these instruments is approximately 0.5 cm/sec and currents with magnitudes greater than this were measured to an accuracy of 15 to 20% for speed and $\pm 15^{\circ}$ in direction.

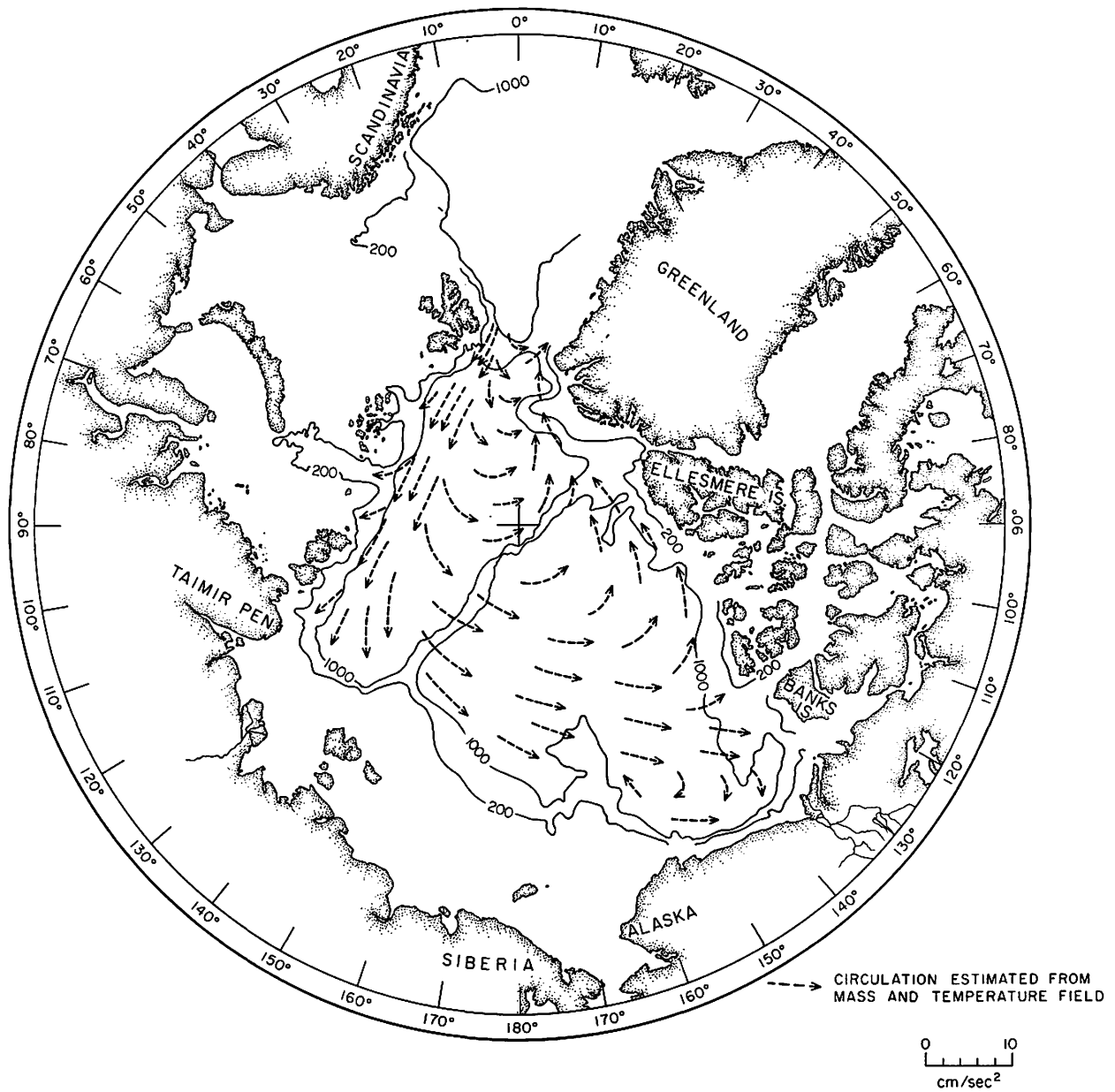


Fig. 1. Circulation of the Atlantic water in the Arctic Ocean.
(After Coachman and Barnes, 1963)

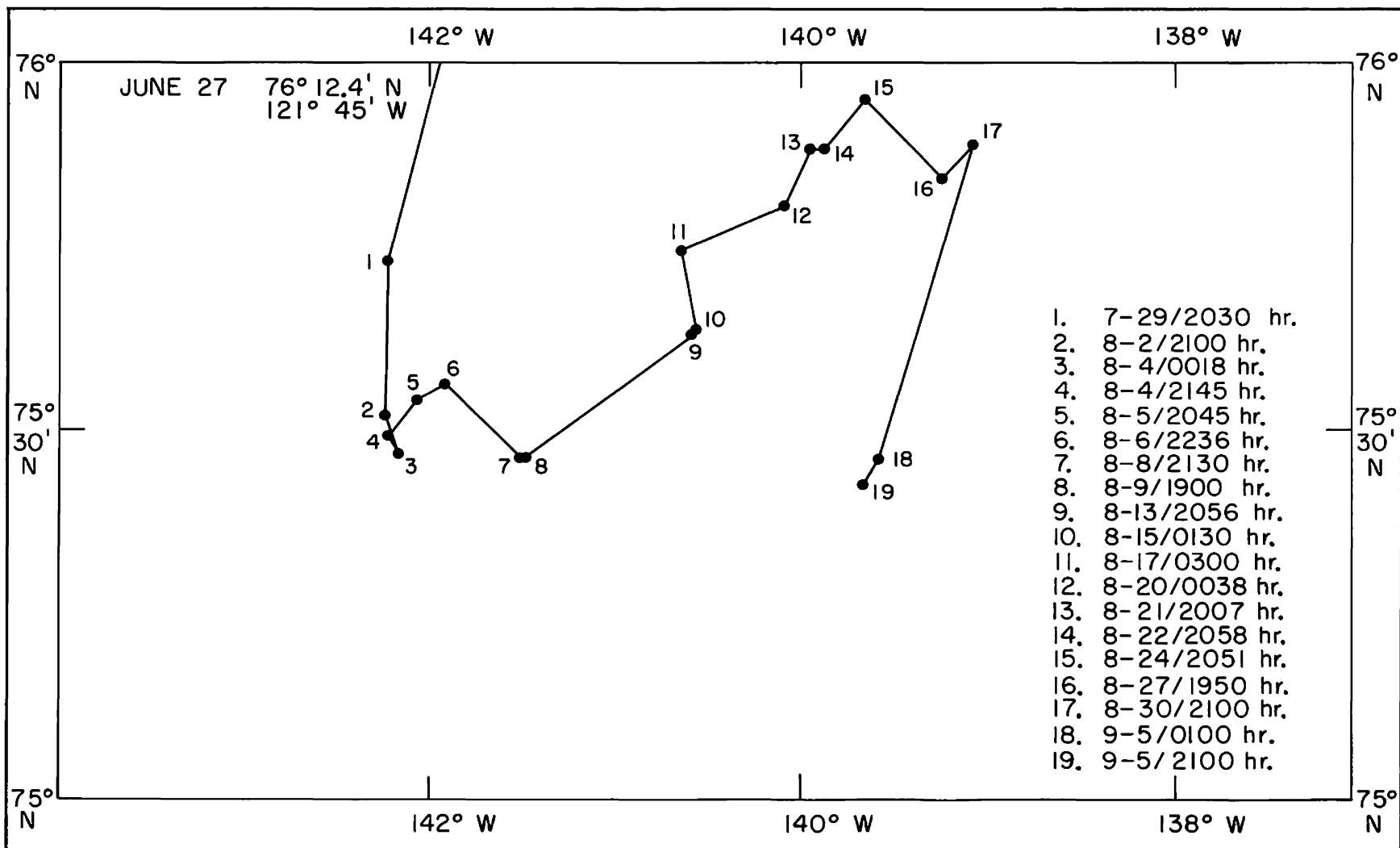


Fig. 2. Drift track of T-3 during the summer of 1965.

RESULTS AND DISCUSSION

Pycnocline Current Measurements

The pycnocline current measurements were begun on August 1st and showed a surprisingly strong current core centered at 150 m. Figure 3 gives the depth dependence of the current, measured relative to the island, for the next seven days. Marked fluctuations in the magnitude are present with less pronounced changes in the profile. The trace of the sigma-t values as a function of depth (Fig. 3) indicates the extent of the density stratification in this depth range. The lower third of Fig. 4 shows a trace of the current speed at 150 m measured relative to the island as a function of time. The maximum velocity observed was 57 cm/sec.

As the island motion contributes to these relative measurements, two checks were made to determine its effect. First, celestial fixes were obtained on 2, 4, 5, and 6 August, and in no case did the island move more than 7.4 km in a day. This would correspond to a maximum island speed of 8.6 cm/sec, a small value compared to the measured speeds. Secondly, the velocity relative to the island at the 2,000-m level was measured on 1, 2, and 4 August. The currents at this level were small (the same order as the island motion) and did not reflect any of the much stronger fluctuations seen at the 150-m level.

From these checks it was concluded that the apparent high velocities of this core were in fact due to the water motion, and the motion was confined to the relatively narrow level between 50 and 300 m; and thus the island motion would appear only as small fluctuations in Figs. 3 and 4.

By 8 August, the velocity of the core was reduced to below 10 cm/sec and was thus in the range of the fluctuations introduced by the island's drift. The velocity at 150 m remained at this low level through the end of September.

The single finding of this high-velocity core during the summer of 1965 suggests that this is not a particularly common phenomenon. The only other source of direct current measurements covering this region are those taken from NP-2 and reported by Somov (op. cit.). During the eleven and a half months that those measurements were continued, two of these current cores seemed to develop with appreciable magnitudes. One occurred 1-3 August 1950 at 78°43' N., 169°57' W. (Fig. 4). For this current core the maximum velocity obtained was about 45 cm/sec, and its duration from start to finish was only 3 days. A second current core appeared 10-17 January 1951 at 80°27' N., 163°22' W. (Fig. 4). The maximum velocity associated with it was about 28 cm/sec and its duration was 7 days.

In all of these current cores, the direction of the current changed. For the T-3 data, the direction rotated about 180° counter-clockwise in a period of approximately 5 days; and then as the speed was decreasing the direction changed clockwise about 50°. The core of 1-3 August observed from NP-2, although of shorter duration, showed similar behavior. The second core observed from NP-2 in January rotated some 250° clockwise in a week.

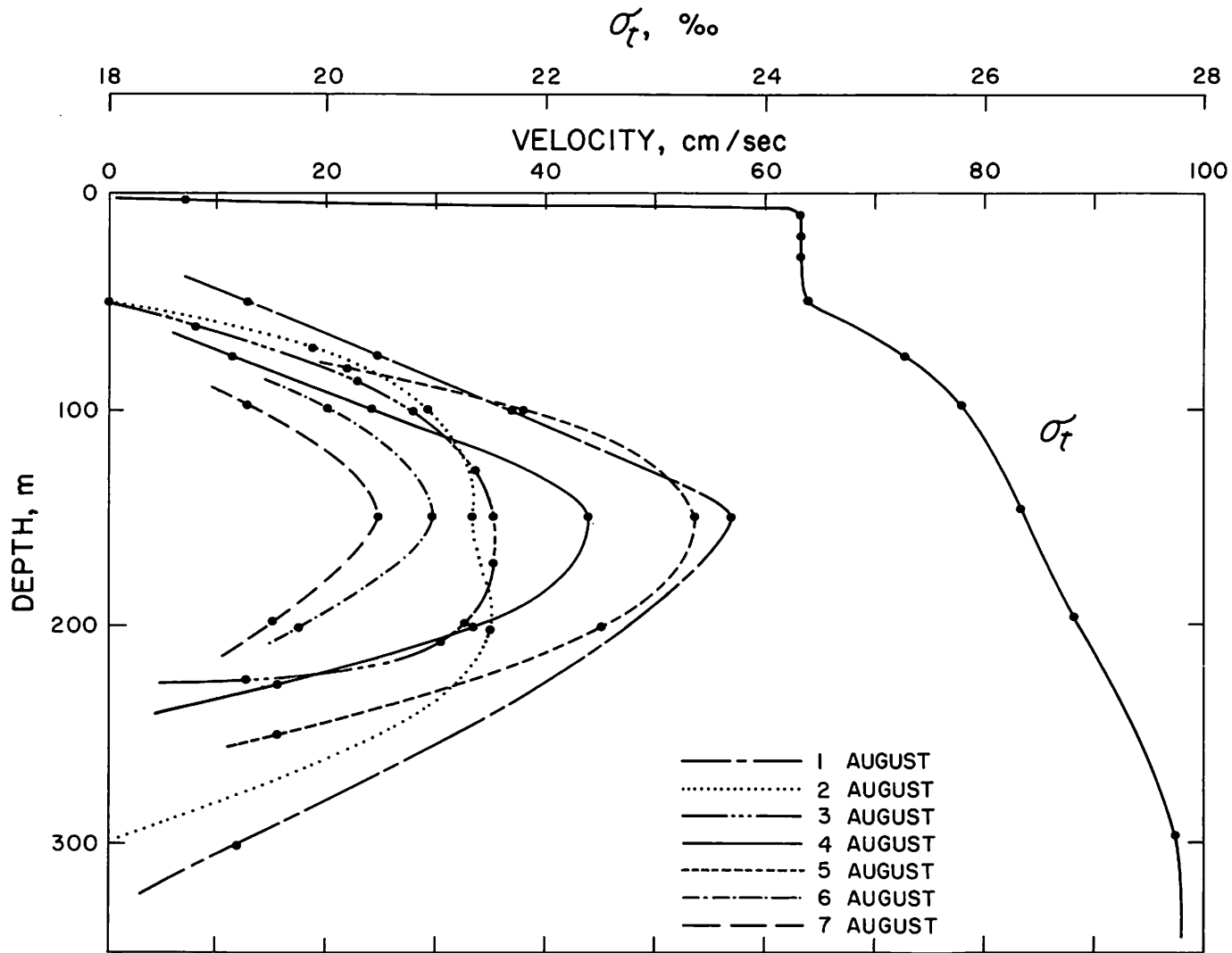
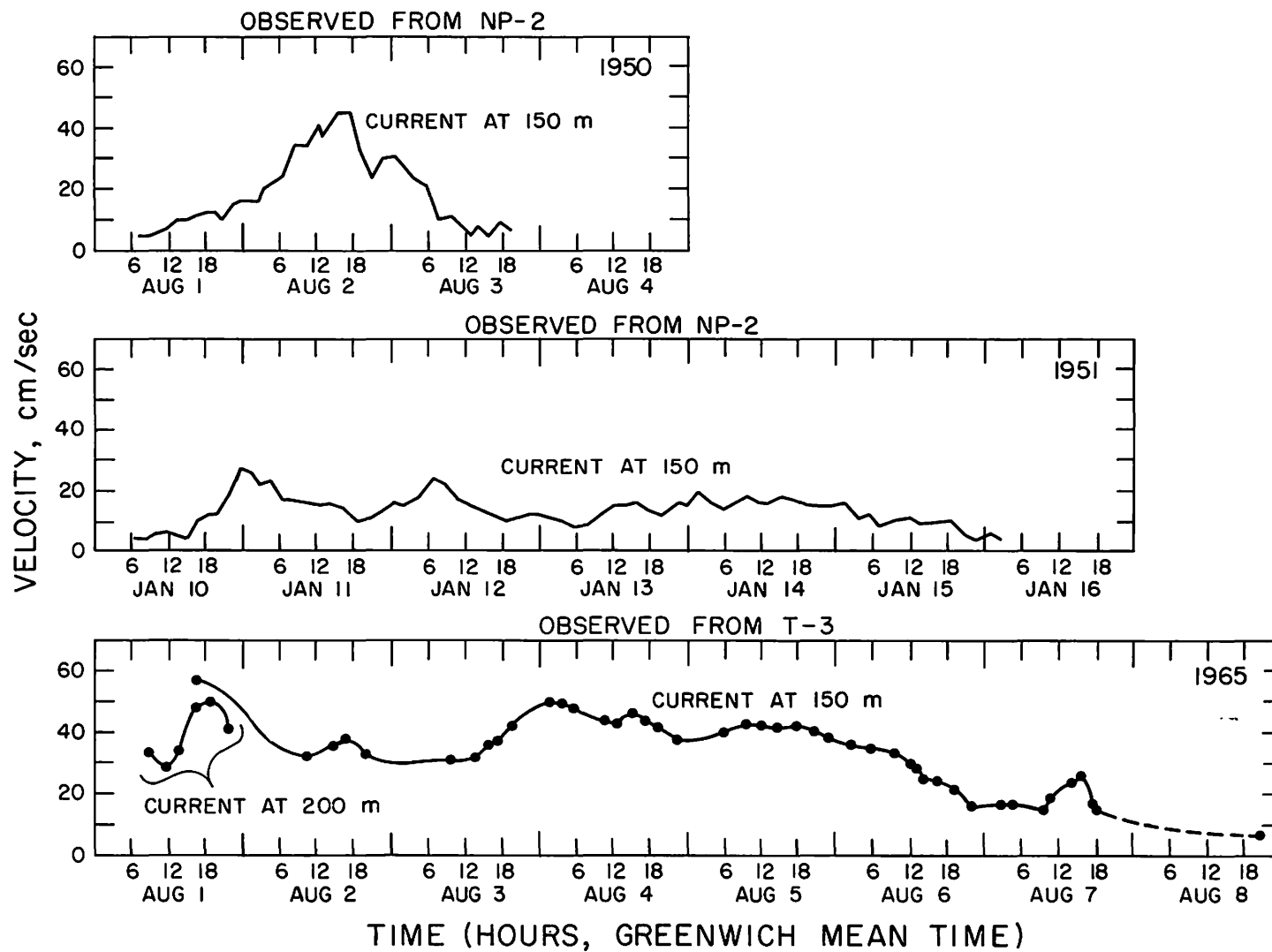


Fig. 3. Current core measured from T-3 during August 1965, and the mean vertical density distribution during the period.



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Fig. 4. Currents at 150 meters from NP-2 and T-3 data.

It is apparent from these observations that this current core is not a persistent or particularly frequent phenomenon. It does not seem likely that only further field study could yield the necessary information for defining the cause of this high speed current, and therefore a mathematical model study is being undertaken.

The vorticity equation suggests that for a current core to develop away from boundaries in water that initially has very little velocity shear, the nonlinear interactions between the mass field and the pressure field (i.e., the solenoid term in the vorticity equation) must be significant. The importance of the nonlinear momentum terms or the frictional terms is not immediately obvious, but with the high shears that develop, they may be significant.

The development of a mathematical model including the nonlinearities will not be attempted here. Possible approaches, however, might be made through numerical techniques using finite differences. The possibility of using perturbation techniques to represent the pressure field might also prove useful. These studies are being pursued.

Mid-depth Current Measurements

The current measurements made between 500- and 1,500-m depths were all less than 10 cm/sec and it was therefore necessary to have an accurate estimate of the drift of the island during the period that the measurements were being made. Thus, to obtain a set of current readings a fix was taken, then current measurements relative to the ice island were started and repeated as often as winch speeds would allow, until the next fix was taken. One set of satisfactory measurements was obtained on 5 September. The fixes used are shown in Fig. 5, and the current measurements relative to the ice island are shown in Fig. 6.

It appears that the relative current at 500, 1,000, and 1,500 m was nearly independent of depth and made up of a mean and a periodic component. The period of the oscillatory part of the current was between 12 and 13 hr.

The measurements made by Hunkins (1966b) indicated that T-3 frequently exhibited inertial motion. If the periodic component of the current record shown in Fig. 6 is due to inertial motion (the inertial period at this latitude is 12.4 hr), we must expect that an impulse of energy had been given to either the ice or the water.

An evaluation of the wind data (Fig. 7) indicates the source of this impulse was most likely wind stress. On 4 September at 0400 hours the wind decreased from 7.2 to 4.6 m/sec in 3 hr. Later the same day between 1100 and 1500 hours the wind nearly doubled. After an additional 10 hr, the wind increased again for a few hours then dropped to nearly calm conditions which continued throughout the period of current measurement.

During observations on the shallower current core, it was apparent that the time required for T-3 to respond noticeably to wind changes was

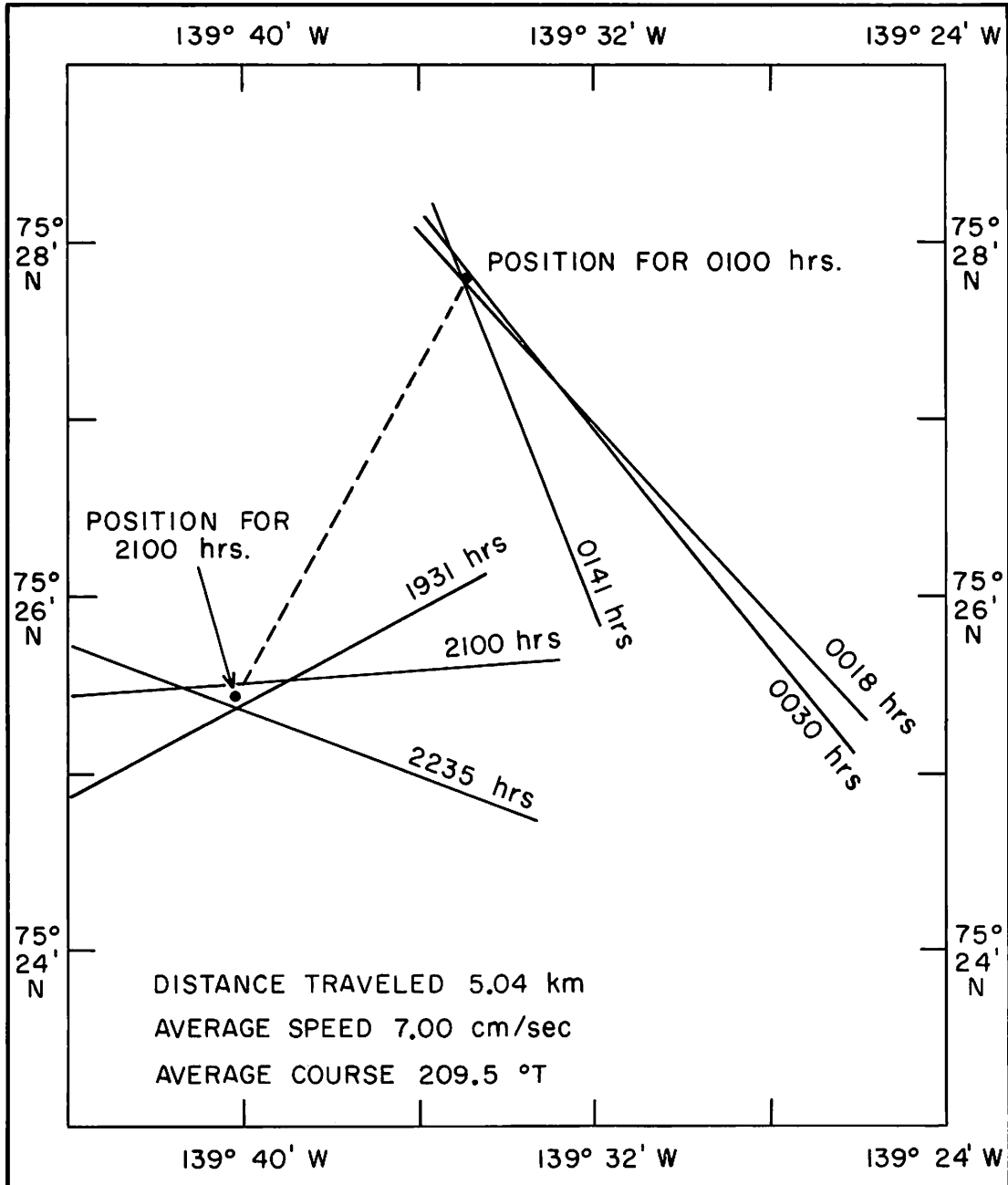


Fig. 5. Celestial fixes taken during mid-depth current measurements on 5 September 1965.

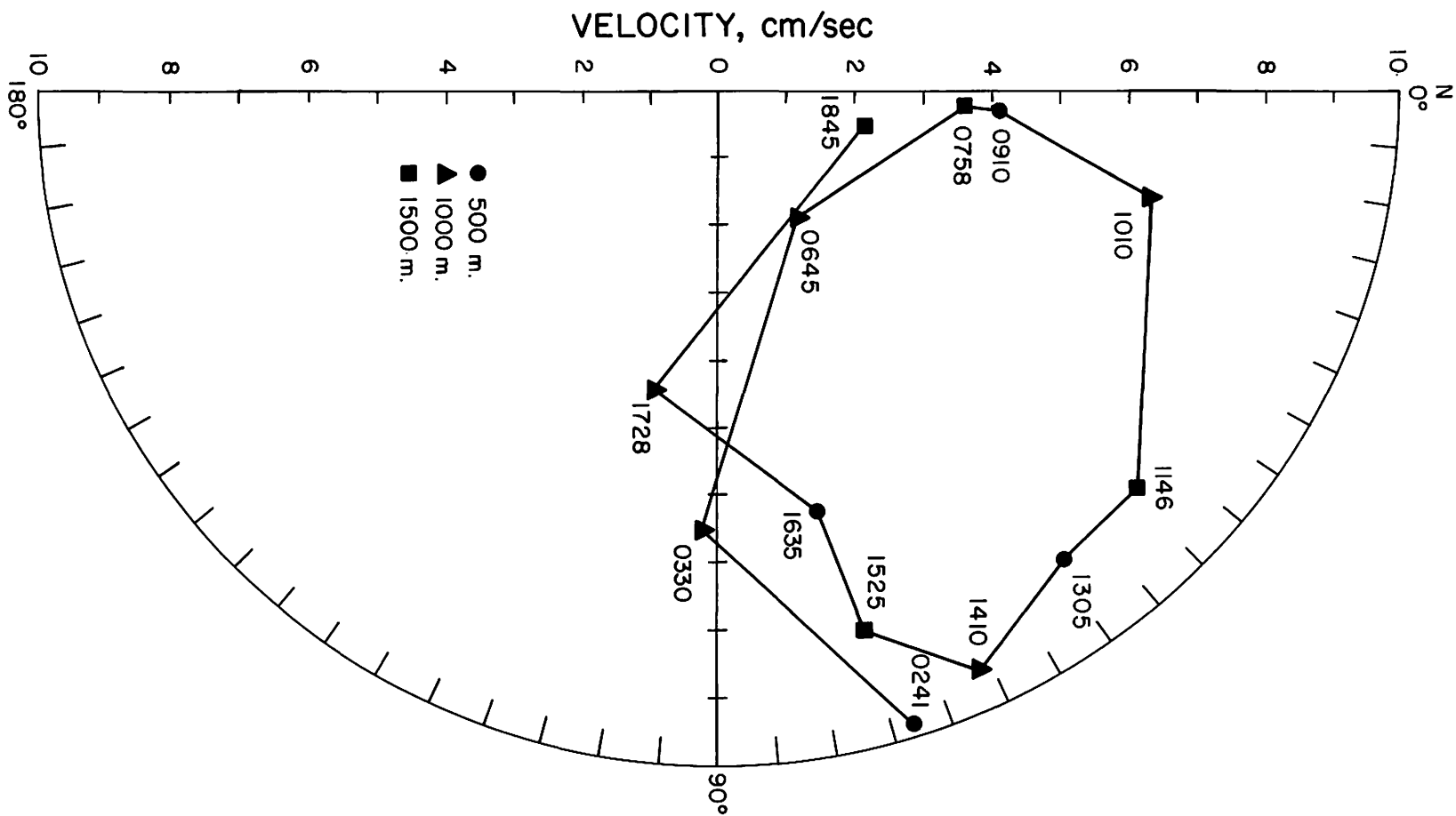


Fig. 6. Polar diagram of currents measured at 500, 1,000 and 1,500 meters from T-3 during September 1965.

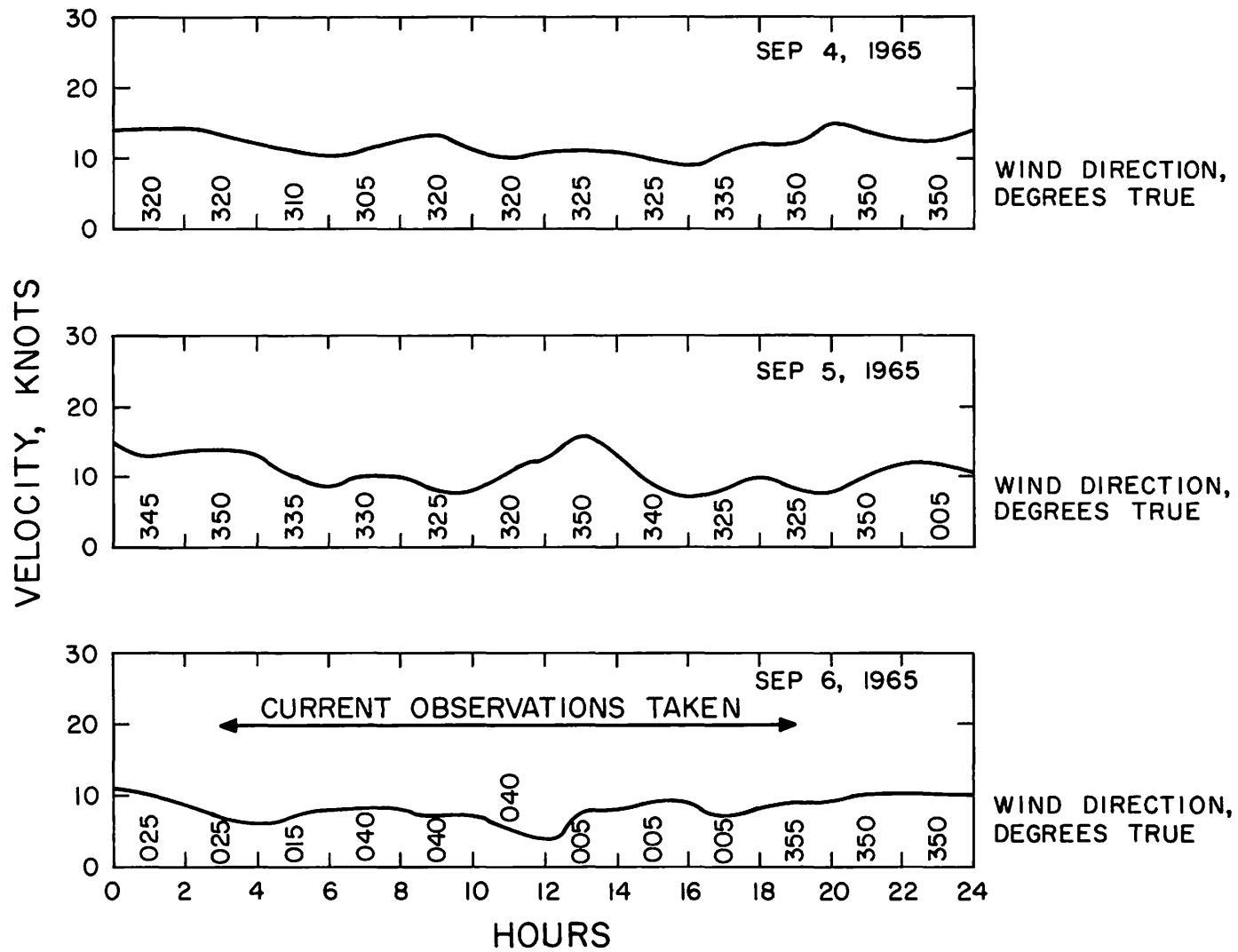


Fig. 7. Ground wind velocities measured on T-3 during September 1965.

between 2 and 4 hr. Therefore, the fluctuations of wind on 4 September not only could give momentum impulses to T-3, but could actually "pump" the drift at the approximate frequency of inertial oscillation.

From the above considerations it was assumed that the periodic component of the current (Fig. 7) was associated with inertial motion of the ice. By combining this assumption with the information obtained from the celestial fixes, it was possible to calculate the current due to the ice island motion. This was subtracted vectorially from the observed currents relative to the ice island to obtain the mean absolute motion of the water at the 500-, 1,000-, and 1,500-m levels. The results are shown in Fig. 8 with the average taken over an inertial cycle. The resulting mean velocities, between 3 and 4 cm/sec, were essentially independent of depth and set to the SSE.

These measurements correspond both in their depth and the manner in which they were obtained to those reported by Nikitin and Dem'yanov (1965). They also correspond to the depths occupied by the Atlantic water as described by Coachman and Barnes (1963).

The results obtained from T-3 and those reported by Nikitin and Dem'yanov have been superimposed on a chart (Fig. 9) showing the flow of the Atlantic water as interpreted by Coachman and Barnes (1963). The general agreement of the observed data with the circulation deduced from the mass and temperature fields seems to be good. A noticeable exception occurred in the current readings centered around 83°N., 150°E. A possible explanation for this discrepancy is suggested by a consideration of the bathymetry. These readings were obtained in the immediate vicinity of the Lomonosov Ridge. It may be that in this region the tendency of the currents to follow contours of bathymetry, which was not considered by Coachman and Barnes, was locally dominant in determining the direction of the current. The other discrepancies appear to be isolated readings which are themselves subject to a large variance. In view of the smoothing that was required in Coachman and Barnes's interpretation, it is impossible to evaluate accurately the significance of these lesser discrepancies.

Bottom Current Measurements

Two reliable readings of the bottom current were obtained. The first was on 16 August, in a depth of 3,795 m. The magnitude of the current was 2.6 cm/sec and it was directed towards 239°T. The second was obtained on 20 August, in a depth of 3,790 m, where the current was 1.5 cm/sec towards 179°T.

In both cases, the speeds were substantially the same as those reported at mid-depth. Likewise, the direction of the bottom current was similar.

The similarity of the bottom current measurements to those found at mid-depth suggests an almost total lack of shear throughout the deeper portion of the water column, and it appears that the nearly isopycnal water below 500 m moves as a unit with significant velocities being present all the way to the bottom.

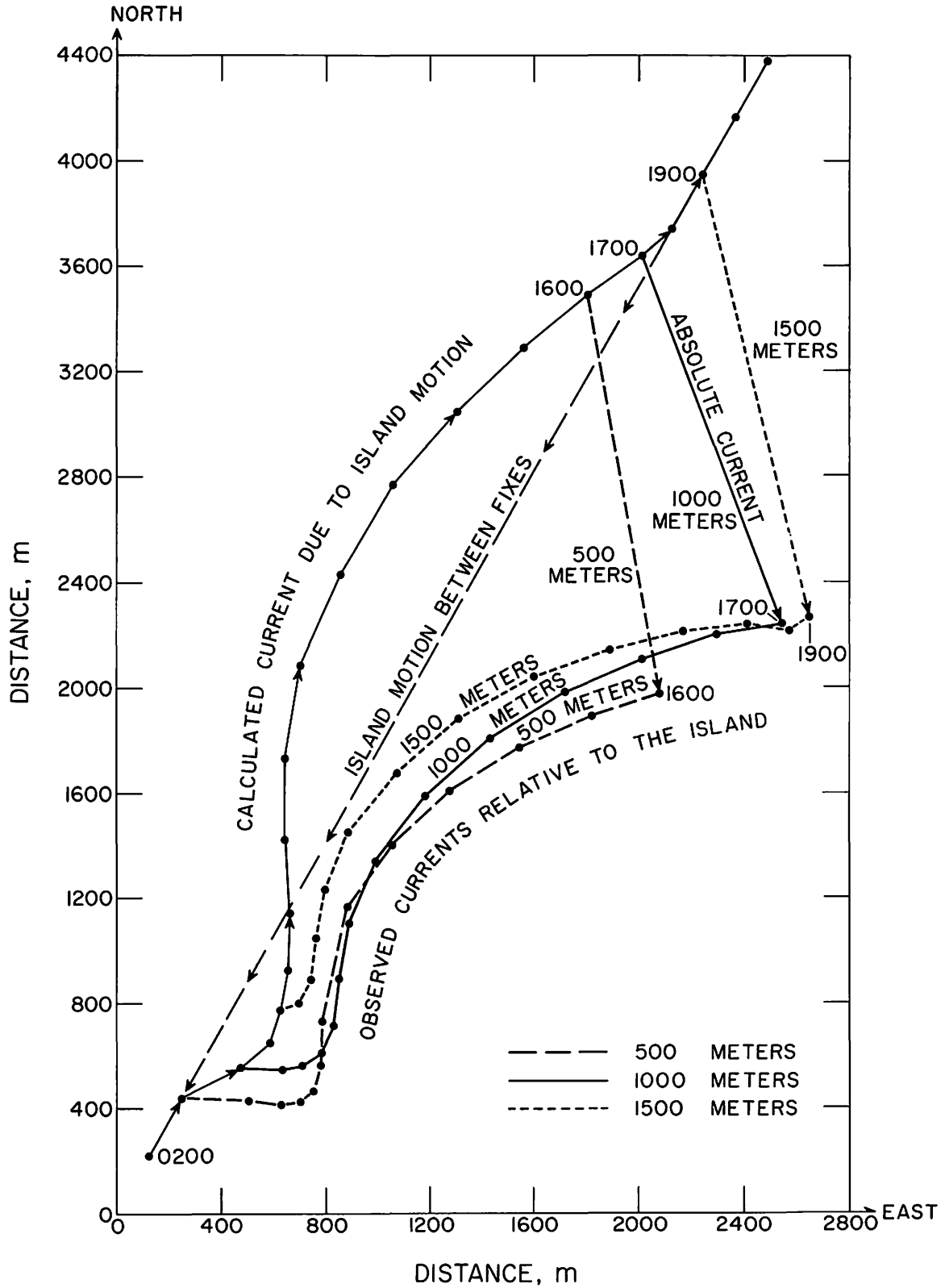


Fig. 8. Hodograph of the current measurements of Figure 6, the position of T-3 at beginning and end of series, and the calculated island motion.

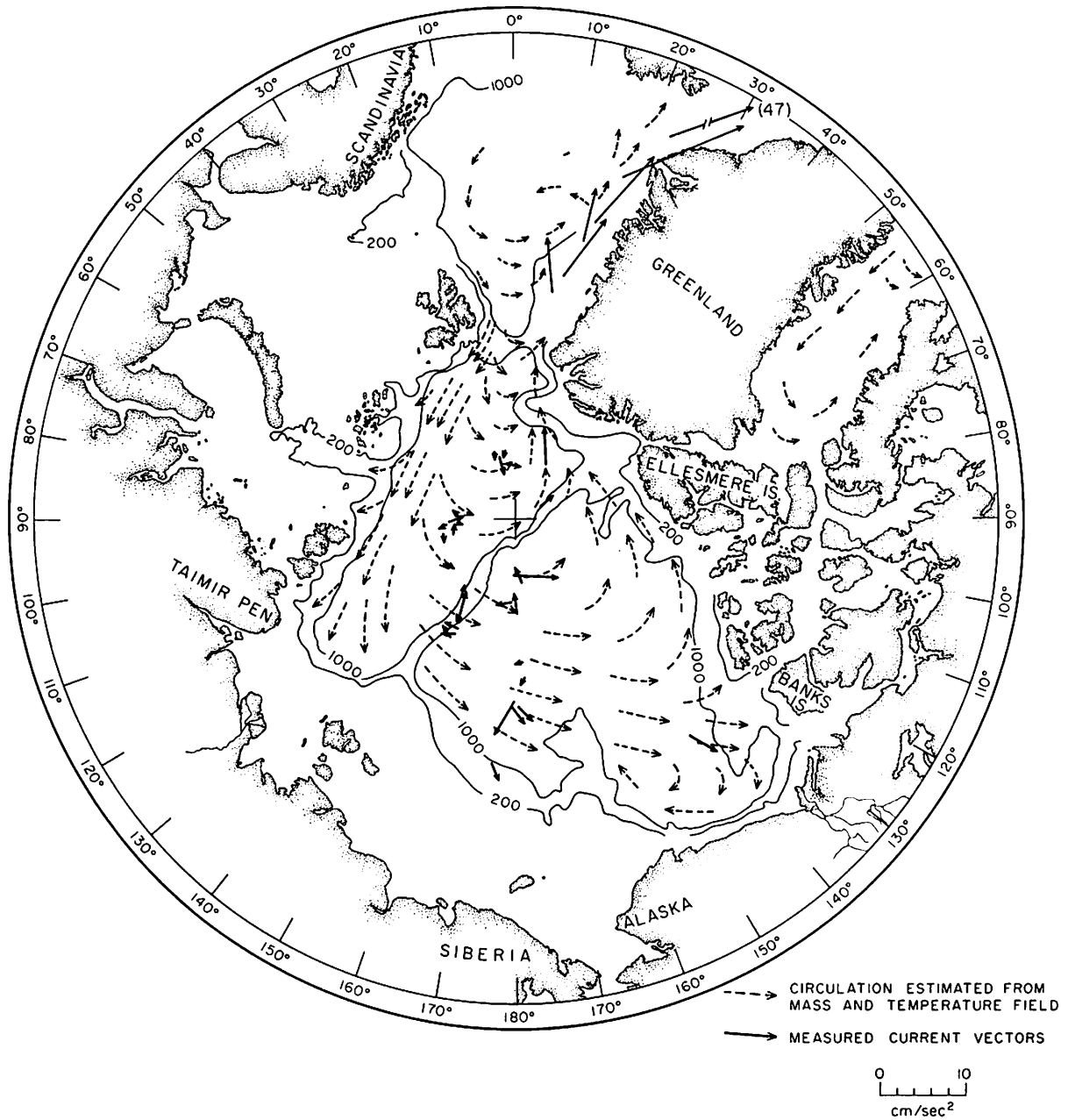


Fig. 9. Mid-depth current measurements from T-3 and those reported by Nikitin and Dem'yanov superimposed on the Atlantic water circulation shown in Figure 1.

SUMMARY AND CONCLUSIONS

The results of the current measurements in the Arctic Ocean made from T-3 during the summer of 1965, combined with the current measurements reported in the literature, can be summarized in terms of three general depth ranges:

An Ekman layer extends from the surface down to a few tens of meters, as documented by Hunkins (1966a), but this layer was not studied during summer 1965.

Below the Ekman layer, a high velocity current core was observed. This current core seems to be an occasional, transient response confined to a relatively narrow depth range associated with the pycnocline. The velocities and the horizontal component of the vorticity that develop are large for this region of the Arctic Ocean. The rotational speed and direction of these current cores may vary, but their period does not appear to be inertial or tidal.

The occasional occurrence of these cores suggests that they are driven by a resonant forcing mechanism, perhaps a moving atmospheric pressure front. A theoretical investigation of this possibility might yield the necessary criteria for setting up an observational program to obtain more detailed information on the nature of these high speed motions.

In the water column below the pycnocline, the current was nearly independent of depth, with significant velocities all the way to the bottom. The magnitudes of the currents were small and of the same order as the deep current measurements that have been reported previously for other portions of the Arctic Ocean. The direction of the flow tended to confirm the circulation of the Atlantic water deduced from the measurements of the mass and temperature fields.

The ice island exhibited inertial oscillations after fluctuations in the wind "pumped" the island at nearly the inertial frequency.

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