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U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
Environmental Research Laboratories

Water Movement Within the Apex of the New York Bight During Summer and Fall of 1973

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MARINE ECOSYSTEMS ANALYSIS PROGRAM OFFICE

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WATER MOVEMENT WITHIN THE APEX OF THE NEW YORK BIGHT DURING SUMMER AND FALL OF 1973

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WATER MOVEMENT WITHIN THE APEX OF THE NEW YORK BIGHT DURING SUMMER AND FALL OF 1973

R. L. Charnell
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An investigation of the water movement within the New York Bight Apex was made during the summer and fall of 1973. Observations from this study produced a fairly consistent picture of a general clockwise circulation for the mean and low frequency (periods greater than 40 hr) current motions. Additionally, the effects of stratification on the vertical structure of the flow showed the difference between the summer and late fall flow regimes. There also appeared to be, for low frequencies, excellent spatial coherence between stations in the apex area and a fairly strong relation between meteorological forcing and current motions; currents tended to lag wind by up to 18 hr.

1. INTRODUCTION

The Marine Ecosystems Analysis (MESA) New York Bight Project is currently in the field phase of a program designed to evaluate changes in the water quality of the region. The physical oceanographic part of the effort is oriented to supplying information that will lead to understanding the mechanisms of water movement and material dispersion and eventually will result in a hierarchy of predictive models for use by coastal zone planners and managers.

Overall net movement of water on the continental shelf off southern New England and the Middle Atlantic States is to the west, southwest, and south, parallel to the continental margin (Bumpus, 1973). However, the complete picture is quite thoroughly masked by high spatial and temporal variability.

It is of considerable interest to understand the flow patterns within what is commonly called the apex of the New York Bight--the area within 50 km of the harbor mouth. The major dump sites of metropolitan New York-New Jersey are located in this zone. However, few field data exist with which to construct an adequate description of water movement in this coastal area. Most of what is presently known about the physical oceanography of the apex is based in part on historic data collected on behalf of the U.S. Army Corps of Engineers in 1969-70. Data include temperature and salinity values, recovery information of surface and seabed drifters, and current meter observations. Analysis of these data by

Charnell and Hansen (1974) suggests that the major features of the spatial structure of circulation that relate to disposal of waste materials in shelf waters of the New York Bight are as follows:

(a). In the immediate vicinity of the entrance to the Hudson and Raritan Rivers estuary, the oceanographic regime is dominated by discharges from these rivers. As in all such estuaries, there is a seaward flow of brackish water in near-surface layers. At sea, this discharge turns to flow southward, paralleling the New Jersey shoreline. Lower in the water column, there is return flow of external water into the estuaries. In spite of its importance in the oceanographic and ecological systems of the estuaries and bight, this superposed flow system is to be recognized in measurements only as a slight imbalance of the much stronger ebb and flood tidal currents in the respective layers.

(b). There is strong evidence that outside the region of strongest influence of river effluent, there is persistent clockwise circulation. In its most inshore portion, off New Jersey and Long Island, this flow runs counter to the general flow over the continental shelf adjacent to this part of the coast. Although its existence in some areas of critical interest relative to ocean dumping is strongly supported by historic data, its horizontal extent and vertical structure are imperfectly known at present.

This picture, which represents present understanding of apex water circulation, is inadequate. Consequently, first efforts of the MESA New York Bight Project were designed to supply data from fixed-level current meters to improve understanding of this aspect of the physical oceanography. Structure of spatial variability of the kinematics within the New York-New Jersey area has been the prime focus of the current observation; temporal variability seriously complicates this investigation. This report summarizes results obtained from the first two phases of the current meter measurements which were conducted from August through December 1973.

2. DIRECT CURRENT MEASUREMENTS IN NEW YORK BIGHT APEX

During the first field year of the MESA New York Bight Project, a major effort was made to collect background data on water movement in the apex. Measurements were made to provide data on mean currents as well as temporal and spatial variations in circulation in the region surrounding the dumpsites. One objective of the current meter array was to provide data to test the hypothesis of clockwise circulation in the apex. To meet these objectives, the main placement of recording current meters occurred in transects perpendicular to the New York and New Jersey shores. Current meter stations were also placed (a) in the Sandy Hook-Rockaway transect; (b) adjacent to Long Island, east of the main set of stations; and (c) about 55 km southeast of the harbor mouth. A summary of station locations and designations is given in figure 1.

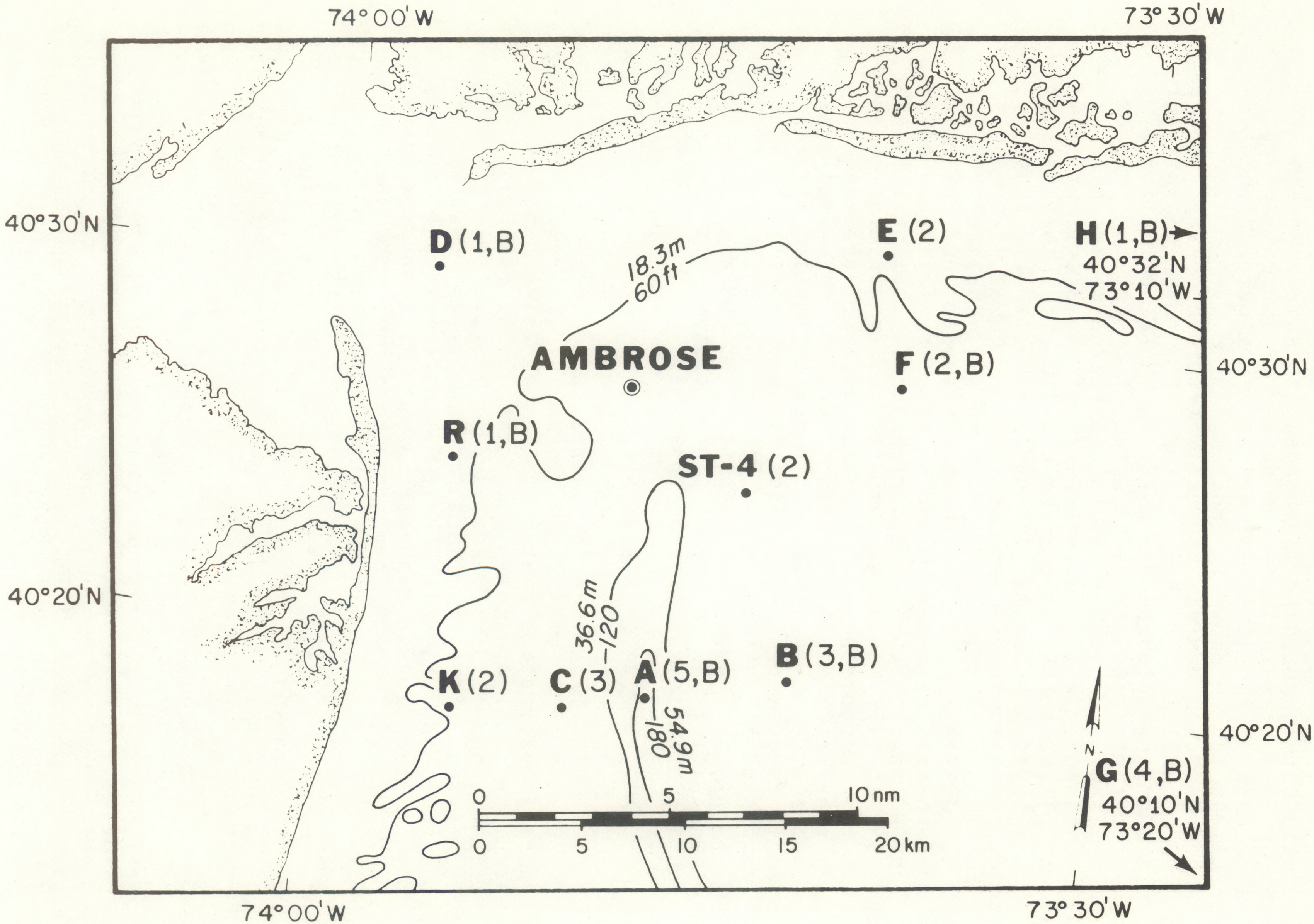

Figure 1. Station locations for the MESA current meter measurement program conducted in August-December 1973.

The numbers within parenthesis adjacent to some of the station designations indicate the number of current meters placed at each station; B indicates a bottom meter placed approximately 100 cm above the bottom.

Aanderaa model RCM-4, internally recording current meters, were used exclusively in this program. For these measurements, a 10-min sampling interval was used. With the exception of stations having a single current meter, the stations were of the taut-wire, subsurface-float design. A sketch of a typical mooring is in figure 2. On several stations, a current meter was placed so that the rotor was 1 m above the bottom. For this purpose a modified version of the standard Aanderaa, called an inverted meter, was used.

The array of stations was occupied twice during the last half of 1973: Phase I. August-September; and Phase II. October-December. Maximum period of sampling for each phase was about 45 days. Near the end of Phase I, station ST-4 was placed near the sewage sludge dumpsite and obtained a 2-week record concurrent with the main array. Table I summarizes mooring information and record lengths for acceptable observations made during these two phases. Station R was deployed in support of a Radio Isotope Sand Tracer (RIST) study conducted in November. The RIST study, conducted by the Marine Geology and Geophysics Laboratory of AOML, is described elsewhere (Swift et al., 1975), but the current meter record has been included in the present analysis.

3. CURRENT METER DATA

3.1 Phase I Environmental Conditions

Phase I observations were made during late summer, a period during which apex water historically is strongly stratified (Charnell and Hansen, 1974). As part of this program, two cruises for collecting water column data at 25 stations were made while the Phase I stations were occupied. The salinity-temperature-depth (STD) data from these cruises (Hazelworth et al., 1974) show that a strong pycnocline, due primarily to thermal stratification, existed about midway in the water column; there was a progression from multilayer structure at the beginning of Phase I to two well-defined layers. The majority of current meter data collected as part of Phase I was obtained from the lower portion of the water column.

3.2 Phase II Environmental Conditions

Phase II current measurements were begun in late October and completed early in December. For these observations, several stations were added to the Phase I array to increase measurement density in those transects perpendicular to Long Island and to the New Jersey coast.

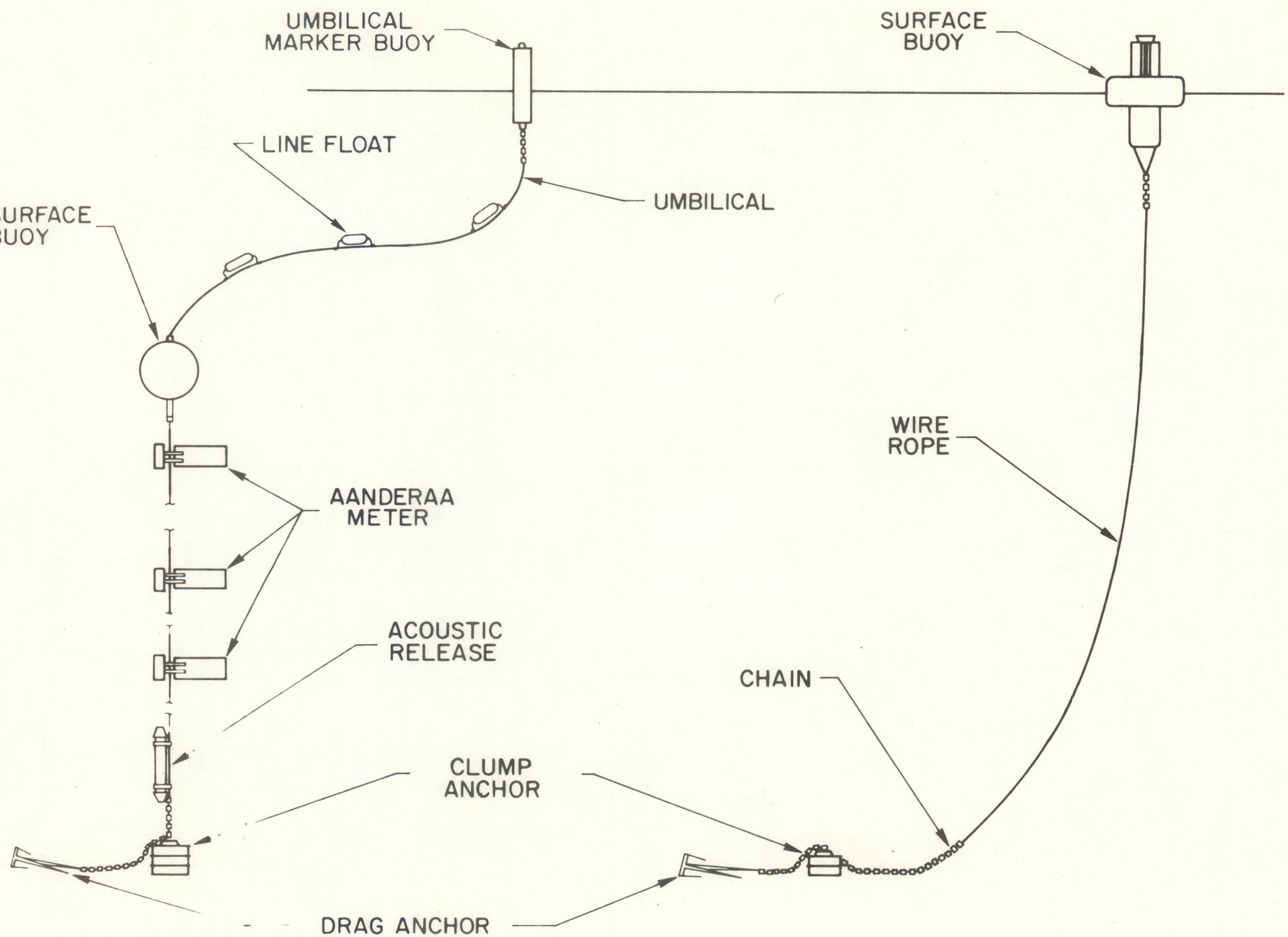

Figure 2. Standard mooring system.

Table I.

Mooring Information and Record Lengths of Acceptable Observations Made During Phases I and II.

	Station	Meter #	Station depth (m)	Distances from bottom (m)	40-hr lp start time (GMT)	Coordinates (Julian Days)
Phase I	A	A1	44.9	8.9	239 (0000)	40°19.4'N 73°47.8'W
		A2		14.9		
		A3		25.0		
	B	B1	25.9	8.9	239 (0000)	40°20.0'N 73°43.5'W
	C	C1	23.8	2.7	240 (0000)	40°18.4'N 73°51.5'W
		C2		8.6		
	D	D1	10.0	0.9	246 (0000)	40°29.7'N 73°56.7'W
	E	E1	16.5	7.6	247 (0000)	40°32.0'N 73°40.9'W
	F	F1	23.5	0.9	247 (0000)	40°28.2'N 73°40.0'W
		F2		8.9		
	G	G1	37.6	3.1	265 (0000)	40°10.2'N 73°24.8'W
		G2		15.2	251 (0000)	
	H	H1	24.7	8.9	252 (0000)	40°33.4'N 73°10.6'W
	ST-4	41	28.4	2.7	271 (0000)	40°25.0'N 73°45.1'W
		42		11.0		
Phase II	A	A1	46.1	0.9	300 (0000)	40°19.0'N 73°48.0'W
		A2		8.9		
		A3		14.9		
	C	C1	22.9	8.6	300 (0000)	40°18.4'N 73°50.9'W
	D	D1	10.3	0.9	301 (0000)	40°29.7'N 73°56.7'W
	E	E1	16.5	2.7	301 (0000)	40°32.0'N 73°41.0'W
	F	F1	22.9	8.9	301 (0000)	40°28.4'N 73°40.0'W
	K	K1	20.1	0.9	300 (0000)	40°18.0'N 73°55.0'W
		K2		8.9		
	R	R1	13.7	0.9	319 (0000)	40°25.0'N 73°56.0'W

Ambrose Tower (wind data) 40°27.6'N 73°49.8'W

Observations made during Phase II occurred after the apex water had reached a nearly homogeneous condition, indicative of winter character. Historical data suggest this breakdown of stratification occurs early in October and homogeneous conditions exist until January with a gradual cooling. Data from STD casts made during Phase II (Hazelworth et al., 1974) show apex water to be conforming to these general conditions.

3.3 Initial Data Processing-Filtering

Data from both phases were filtered to remove noise and partition the series into three frequency bands. Three basic filters were used: 3-hr low-pass, 40-hr low-pass, and 40-hr high-pass. Figures 3a and 3b show the response for both 3-hr and 40-hr low-pass filters. It should be mentioned here that all useable data were included. Those stations excluded such as I and J (not discussed) were either too short (2 days or less), had a poor signal-to-noise ratio, and/or large gaps in the speed or direction data. The 3-hr low-pass filter was used to smooth the raw data and to resample the time series into a more convenient number of points; the filtered series were resampled every hour. In addition, the data were partitioned into low and high frequency time series, so that low and high frequency processes could be examined separately. A period of 40 hr can be used to distinguish conceptually between low and high frequency processes by excluding frequencies with periods less than 2 days. The 40-hr high-pass data include tidal and inertial frequencies by admitting frequencies with periods less than 2 days but longer than 3 hr. A summary of results from these filter operations is presented in table II.

3.4 Character of Low Frequency Variations in Flow

Figure 4 shows the mean current vectors for Phase I. The vectors represent net movement in the lower portion of the water column over the entire observational period. Record lengths and statistics associated with each station are given in table II. Figure 5 relates selected data from the inner stations to the offshore station G during Phase I. Figure 6 shows the mean current vectors for apex stations occupied during Phase II. These data support the hypothesis of anticyclonic circulation in the low frequency component for flow in the apex. Data for station D in both phases show a net bottom outflow, contrary to what might be expected from estuarine circulation principles. This result is probably due to the stations not being located in Ambrose channel but atop the shallower area to the southwest.

Mean speeds for Phase I are a reasonably consistent 4 to 10 cm/s. This speed is substantially below the instantaneous speeds characteristic of this period. The data records exhibit a high degree of variability due primarily to tides, but with winds dominating flow for significant portions of the

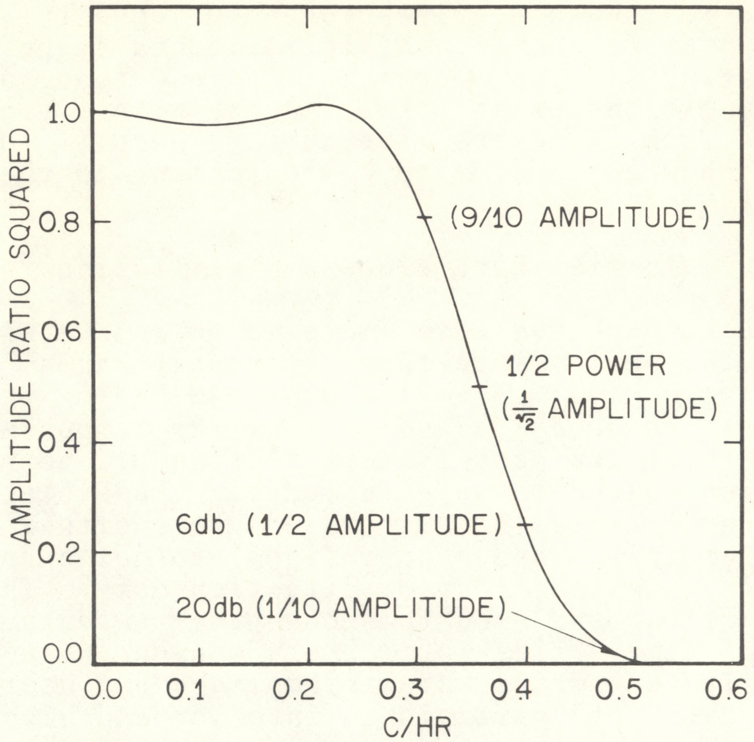

Figure 3a. Response of 3-hr low-pass filter.

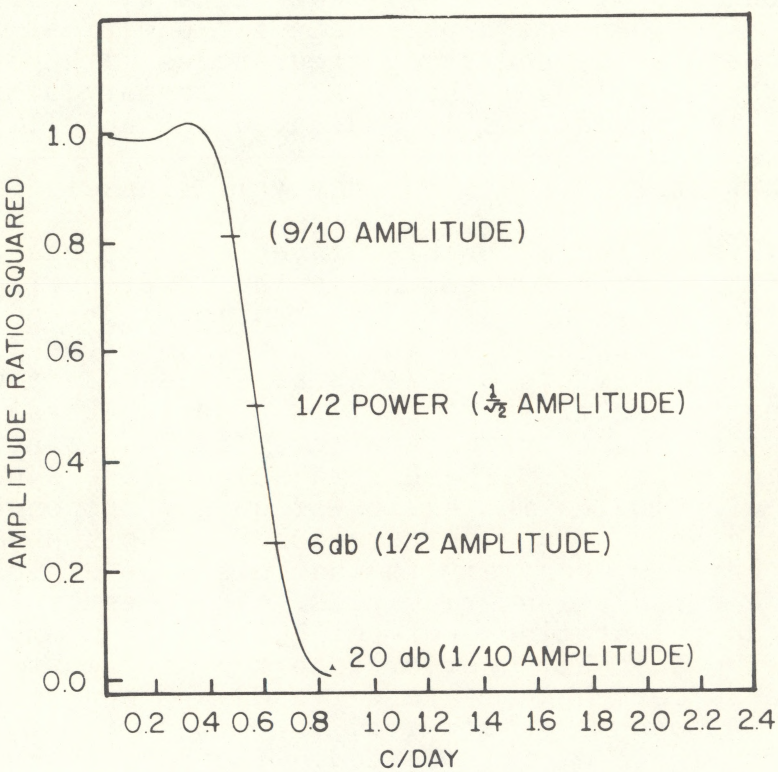

Figure 3b. Response of 40-hr low-pass filter.

Table II.

Record Lengths and Statistical Information for Each Station in Phases I and II.

Data below apply to 40-hr lp and 40-hr hp series (Δt=1.0 hr)

Sta.	Meter #	Record length # of pts.	cm/s mean N component	cm/s mean E component	HPV high-pass variance	LPV low-pass variance	Squared mean speed	HPV÷ total variance	Total variance divided by the squared mean speed
				Phase I					
A	A1	980	-0.33	-1.11	48.4	104.0	1.3	0.32	117.2
	A2		1.88	0.26	59.3	119.5	3.6	0.33	49.7
	A3		4.22	1.75	104.9	67.4	21.0	0.61	8.2
B	B1	984		Distorted by bad data					
C	C1	956	-0.43	0.12	98.8	67.5	0.2	0.59	
	C2		5.49	1.55	214.9	115.2	32.5	0.65	10.2
D	D1	810	-1.03	3.93	540.8	17.9	16.5	0.97	33.8
E	E1	836	1.01	10.36	401.4	185.4	108.4	0.68	5.4
F	F1	837	0.34	0.86	33.8	13.3	0.9	0.72	55.8
	F2		0.44	6.40	383.2	168.4	41.2	0.69	13.4
G	G1	720	-0.90	-0.94	59.5	27.9	1.7	0.68	51.7
	G2	722	-3.99	-7.19	194.1	64.3	67.6	0.75	3.8
H	H1	694	-2.01	-0.18	381.6	116.6	4.1	0.77	121.5
ST-4	41	262	4.70	3.14	92.1	28.9	32.0	0.76	3.8
	42		6.62	6.94	297.6	106.9	92.0	0.74	4.4
				Phase II					
A	A1	1009	4.83	-0.77	32.5	223.6	23.9	0.13	10.7
	A2		7.06	-2.25	65.9	517.0	54.9	0.11	10.6
	A3		16.76	-3.22	88.8	581.0	291.3	0.13	2.3
C	C1	1011	9.22	-0.45	181.4	311.9	85.2	0.37	5.8
D	D1	911	-3.73	2.71	904.4	45.1	21.3	0.95	44.7
E	E1	980	2.10	7.24	139.6	221.1	56.8	0.39	6.4
F	F1	982	0.79	13.26	241.7	354.5	176.5	0.41	3.4
K	K1	1011	2.70	-1.96	23.1	59.6	11.1	0.28	7.5
	K2		7.74	1.67	189.6	297.8	62.7	0.39	7.8
R	R1	480	7.60	1.94	181.2	23.0	61.5	0.89	3.3

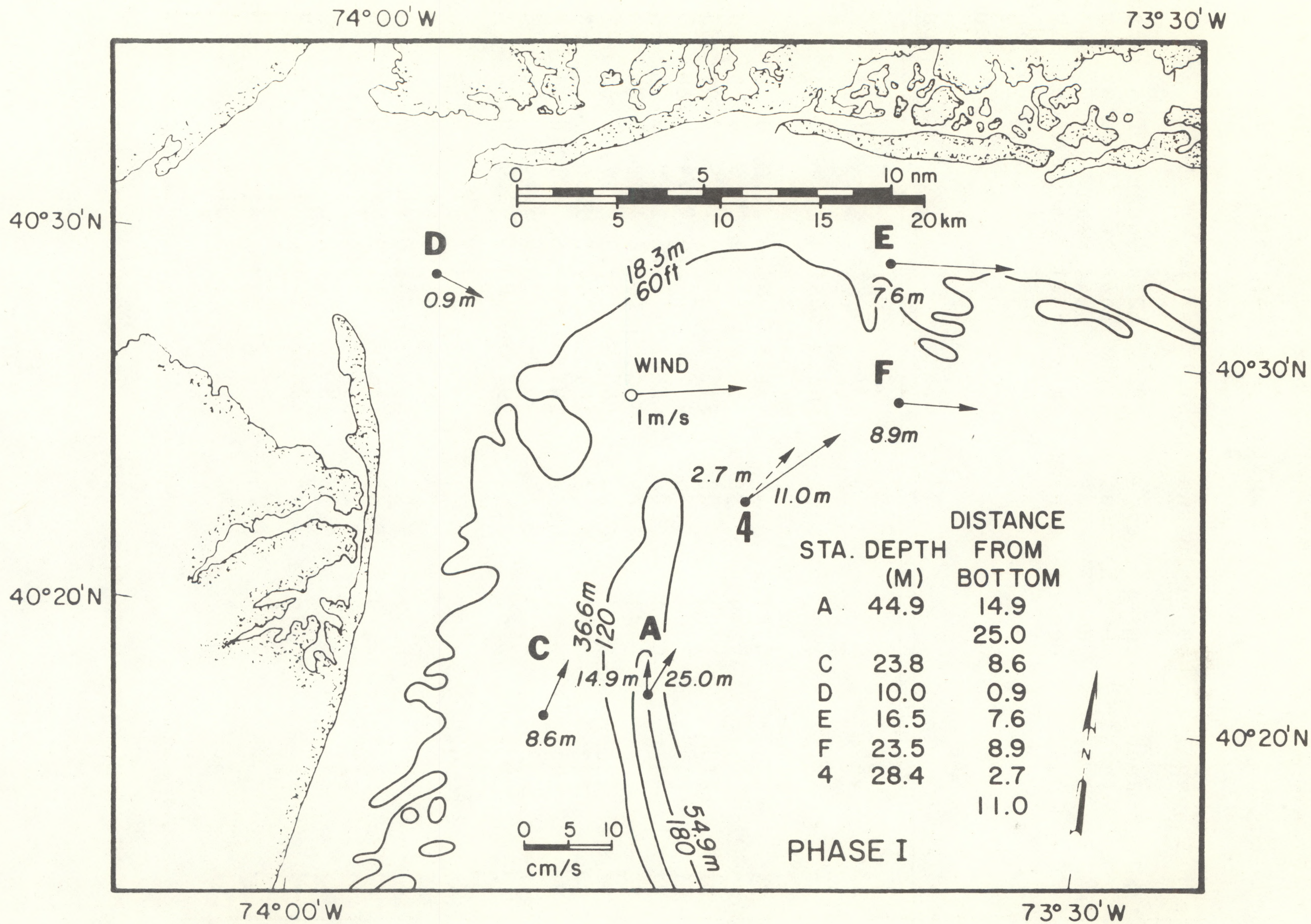

Figure 4. Mean current vectors for measurements during August-September 1973.

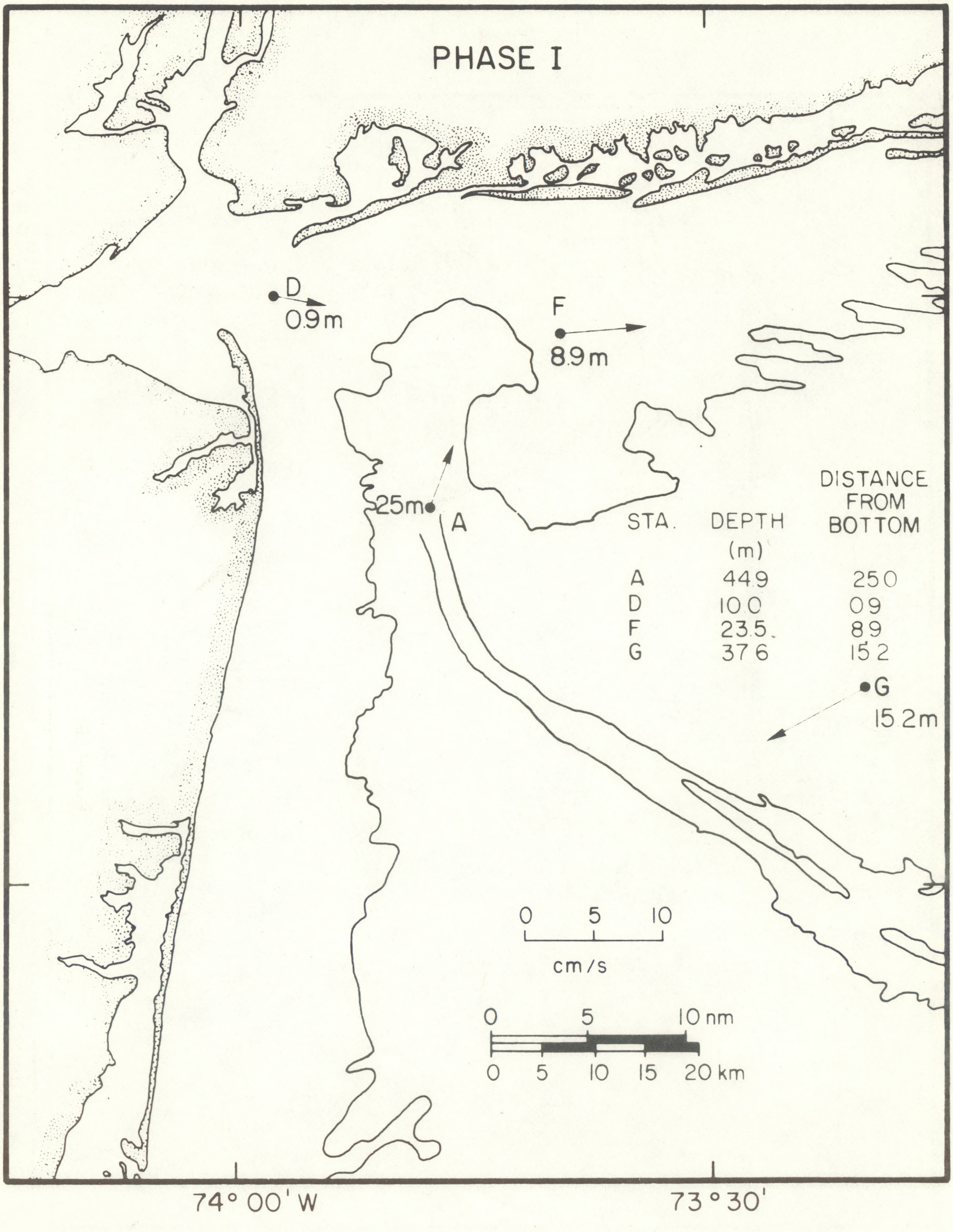

Figure 5. Mean current vectors for measurements during August-September 1973, relating outer station G data to data from selected apex stations (cf. fig. 4).

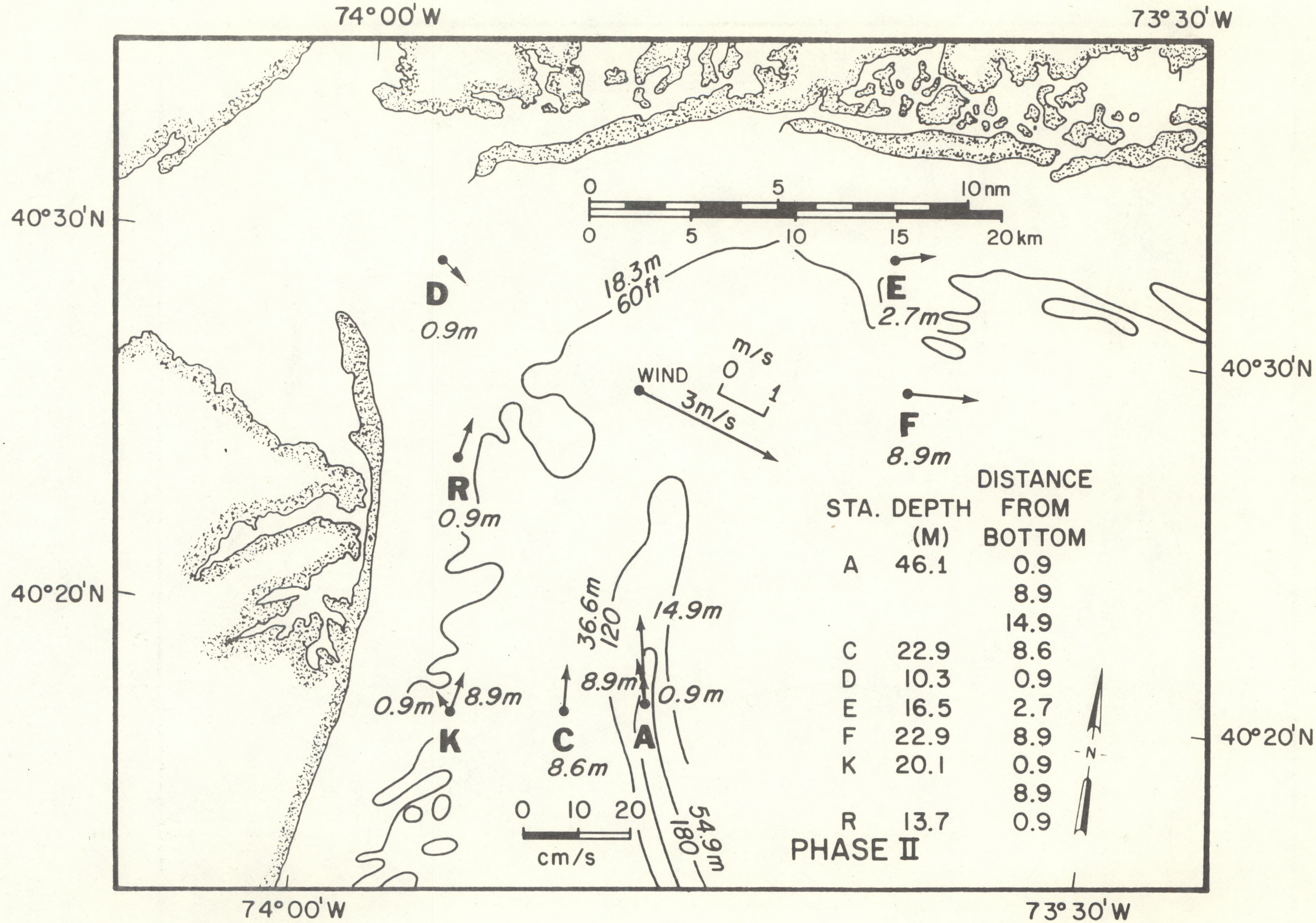

Figure 6. Mean current vectors for measurements during October-December 1973.

records. Characteristically, at station F, maximum speeds are about 50 cm/s, nearly an order of magnitude greater than the long-term mean.

Data from station H adjacent to Long Island show a weak mean speed (3 cm/s) and a direction of flow toward the southwest. This direction is consistent with shelf flow reflected by station G (fig. 5), but represents a reversal of the nearshore flow depicted by station F. During this measurement period, station H appears to occupy a position outside of the apex gyre. Station G data may not indicate the position of the southeast limb of the gyre, but do indicate that general long-term movement on the shelf is toward the southwest.

A preliminary examination of records from several levels at selected stations suggests that the effect of stratification on currents is significant. When a layered density structure exists (Phase I), the flow in various layers generally has different speeds and directions; during the nonstratified conditions, measurements at various levels on a single station generally show flow to be more uniform top to bottom. The mean vectors at station A for each phase show this quite clearly. This situation may be significant relative to competence of flow to erode or suspend particulate material in bight waters.

3.5 Current Roses

While speeds representative of long-term mean flow are generally higher for Phase II than for Phase I, due to the higher level of wind energy input to the water column, direction for this component of the flow is not significantly different for the two periods. Figure 7 shows a summary of direction data for apex stations and is a composite of both phases; the number adjacent to each station indicates the height of the current meter above the bottom. These data include all periods greater than 3 hr. The histograms of figure 7, in polar form, show the frequency distribution of currents partitioned into 10-deg increments; the length of each line represents the percentage of the total record occupying that direction segment. Data taken from the transect denoted by stations A and K show that flow is generally northward, while for the Long Island transect (stations E and F) flow is predominantly eastward.

Comparison of stations E and F indicates that further offshore there is a greater tendency for cross-contour flow than at the inner stations. Strong directionality exhibited by data from station A can probably be attributed to its location in the Hudson Shelf Channel.

Although the station at the sewage sludge dumpsite was not reoccupied during Phase II, its Phase I direction data have been included for comparison. This station exhibits bimodal direction character; favored flow directions at this site are to the northeast, in agreement with clockwise flow,

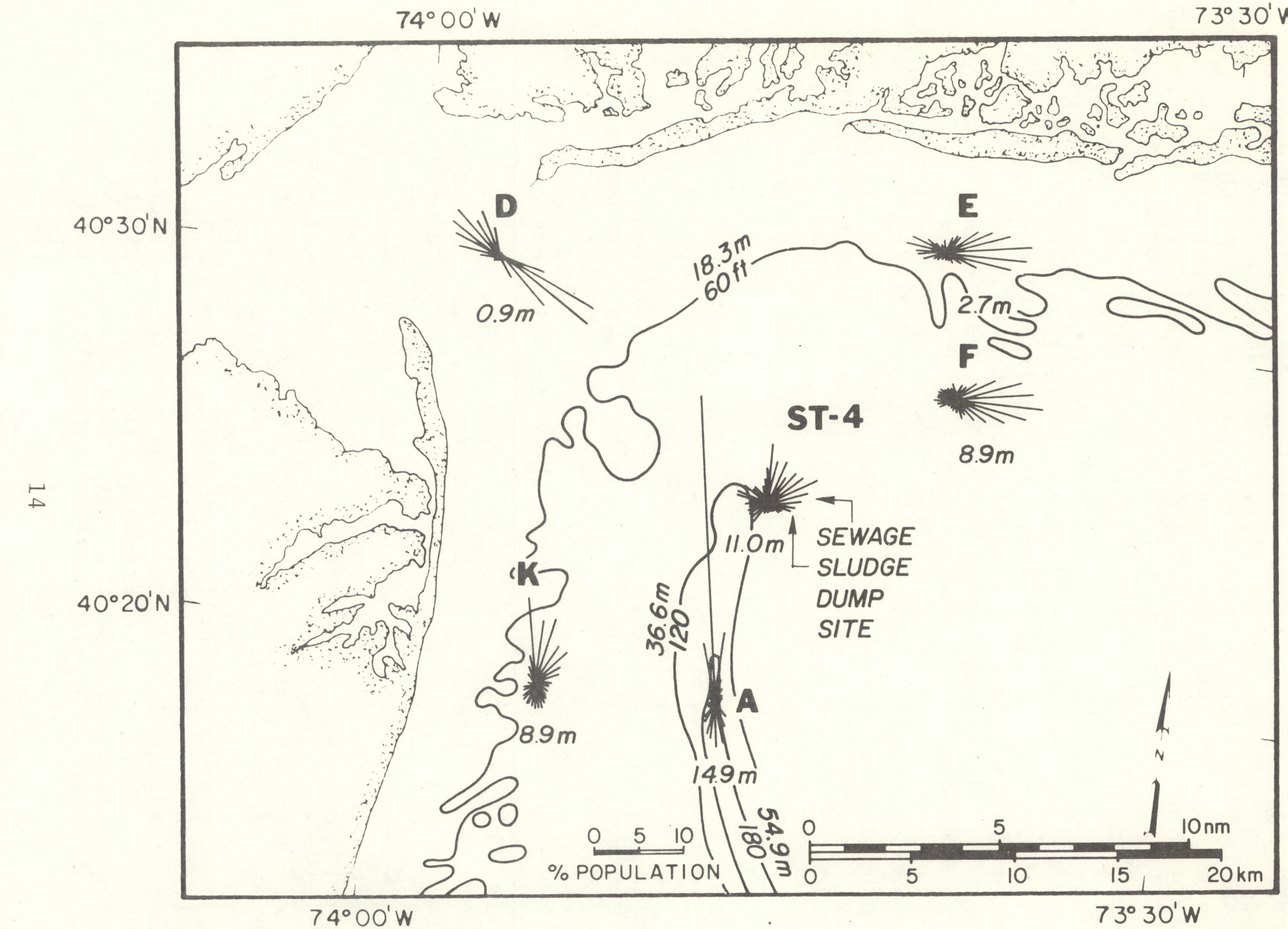

Figure 7. Direction histograms for apex stations during both Phases I and II. Data have been 3-hr low-pass filtered.

and to the northwest, perhaps associated with an estuarine bottom flow into the mouth of the Hudson Estuary.

Data presented in figure 7 have been 3-hr low-pass filtered, but otherwise reflect both low and high frequency processes. The roses tend to show a structure similar to that seen in the mean current vectors of figures 4 and 6. The high frequency component of flow can be examined in a display similar to figure 7, but using the high-pass component of each record. Figures 8, 9, and 10 summarize direction data for the high frequency processes; the figures display histograms for the 40-hr high-pass time series. There are two figures for Phase I; figure 8 shows roses for the current meters nearer the surface, and figure 9 displays the roses for the current meters nearest the bottom. Because low frequency direction data are not included in these current roses, each rose is basically symmetric about a major axis. By comparing figures 8 and 9, it can be seen that the frequency distributions of direction data exhibit a rotation of the major axis with depth. This feature occurred at a time when the water column was strongly stratified.

Frequency distributions shown in figure 10 for the Phase II data are not significantly different from Phase I data. There were a few additional stations during Phase II. By comparing the roses of the 3-hr low-pass data and the 40-hr high-pass data, orientation of the major axis appears to shift; for almost all stations, the high frequency component has a stronger tendency for onshore flow.

It should be noted also that no phase information is contained in these roses. This means that material introduced into the water column at the same place but at different times in the tidal cycle could be transported in completely opposite directions.

3.6 Vector Time Series of 40-Hr Low-Pass Data

The low frequency content of these data can also be displayed as a vector time series or stick diagram. All of the stations off the New Jersey shore (fig. 11, 12, 13, and 14) show mostly northward flow, and the stations perpendicular to Long Island (fig. 15) show mostly eastward flow. The most obvious difference between Phase I and Phase II data is the much higher speeds during Phase II, probably attributable to the much higher windspeeds during the second phase, Progressive vector diagrams of the wind for both phases are shown in figure 16. During Phase II, a major reversal of flow occurred near Day 305. This reversal and associated high speed were observed in conjunction with passage of a major storm front through the area.

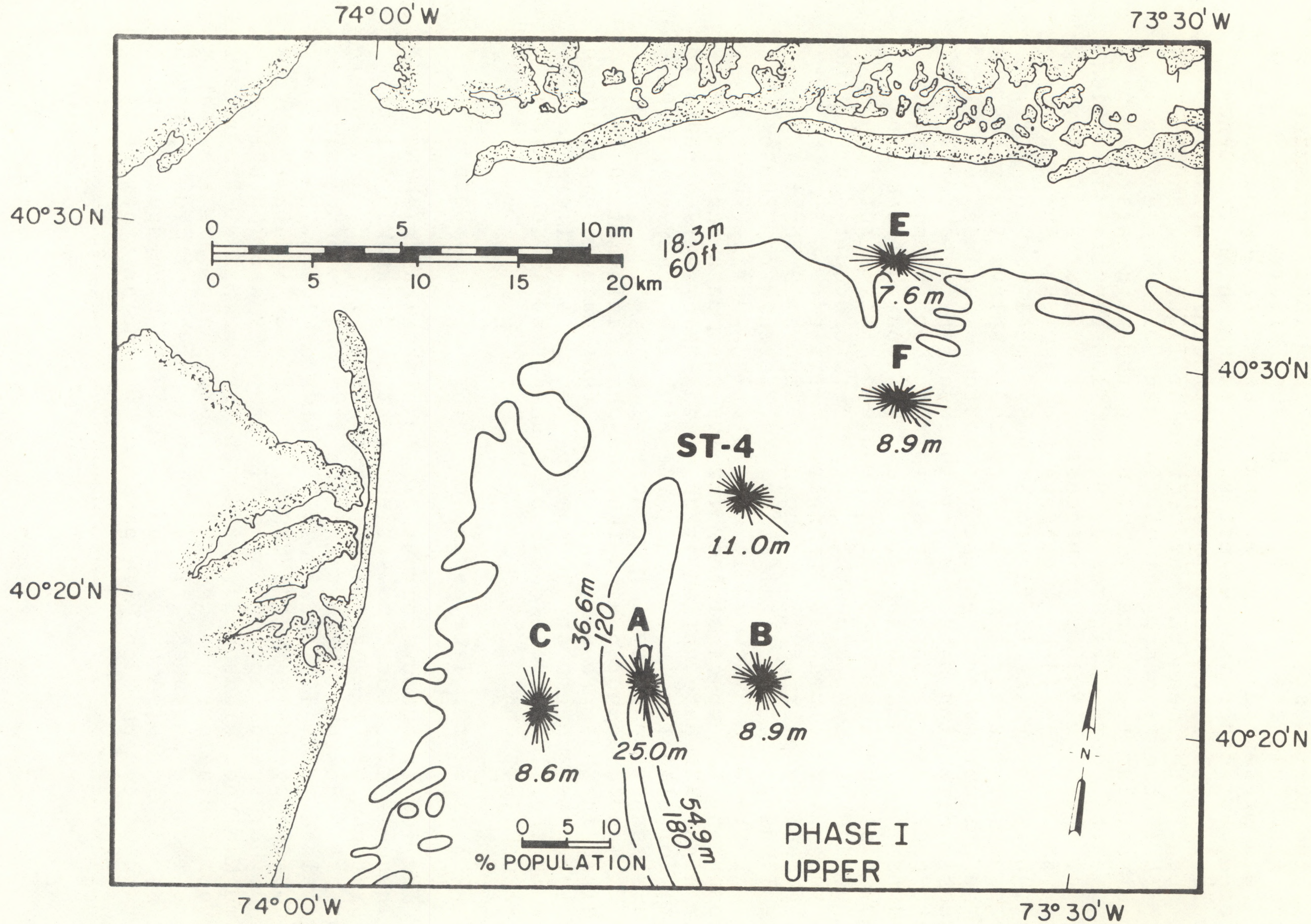

Figure 8. Direction histograms of 40-hr high-pass data for Phase I measurements in the upper portion of the water column.

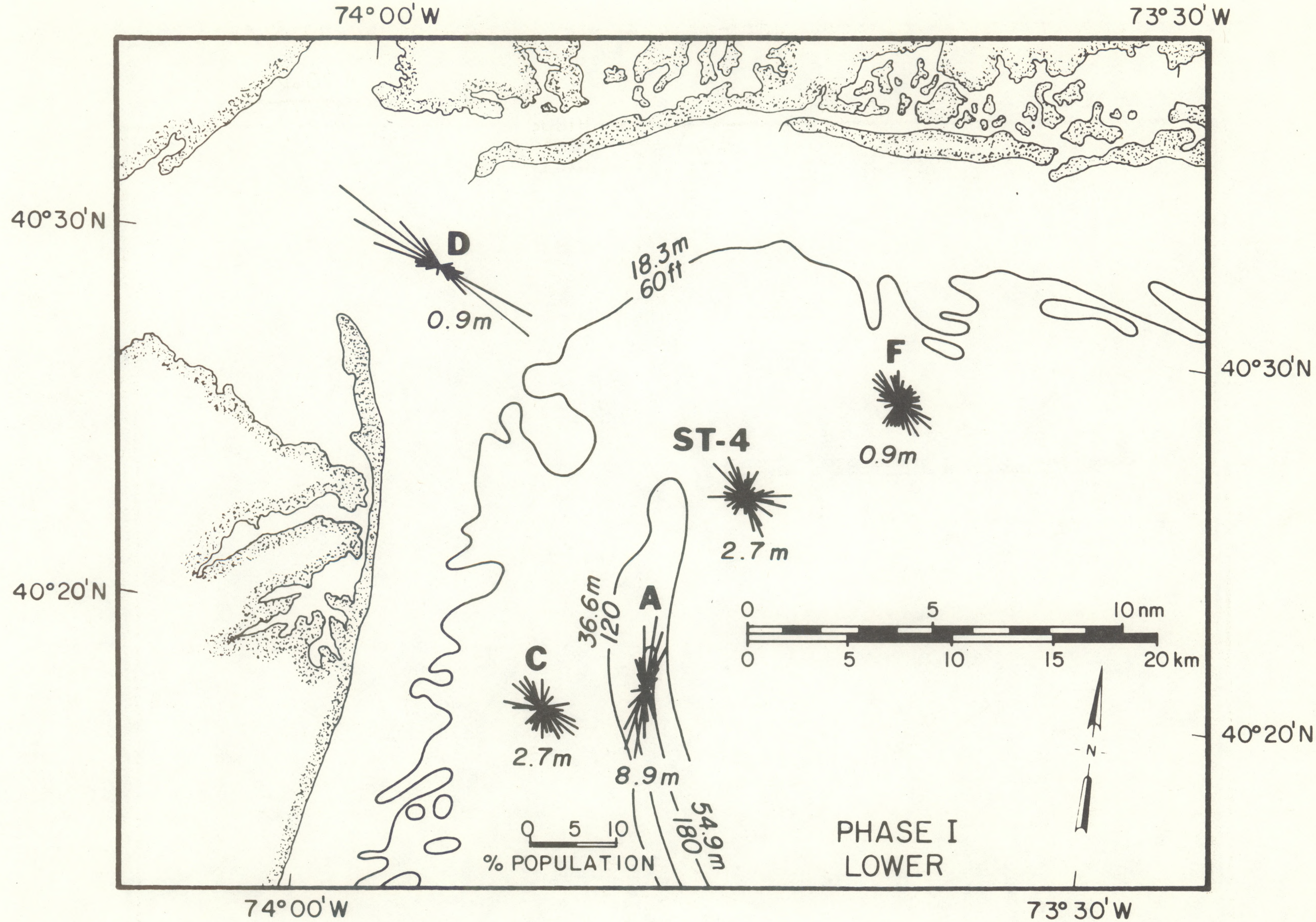

Figure 9. Direction histograms of 40-hr high-pass data for Phase I measurements in the lower portion of the water column.

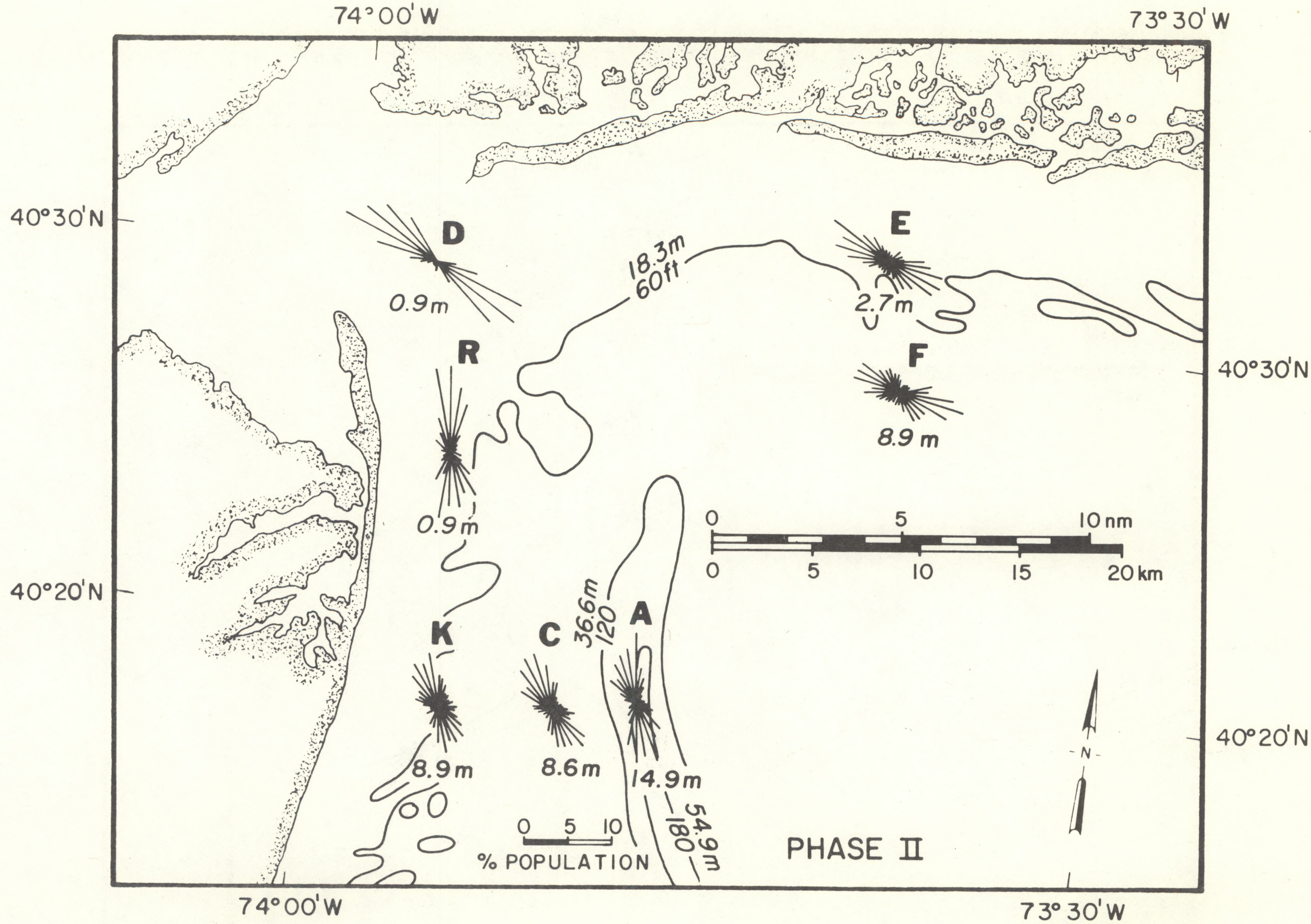

Figure 10. Direction histograms of 40-hr high-pass data for Phase II measurements.

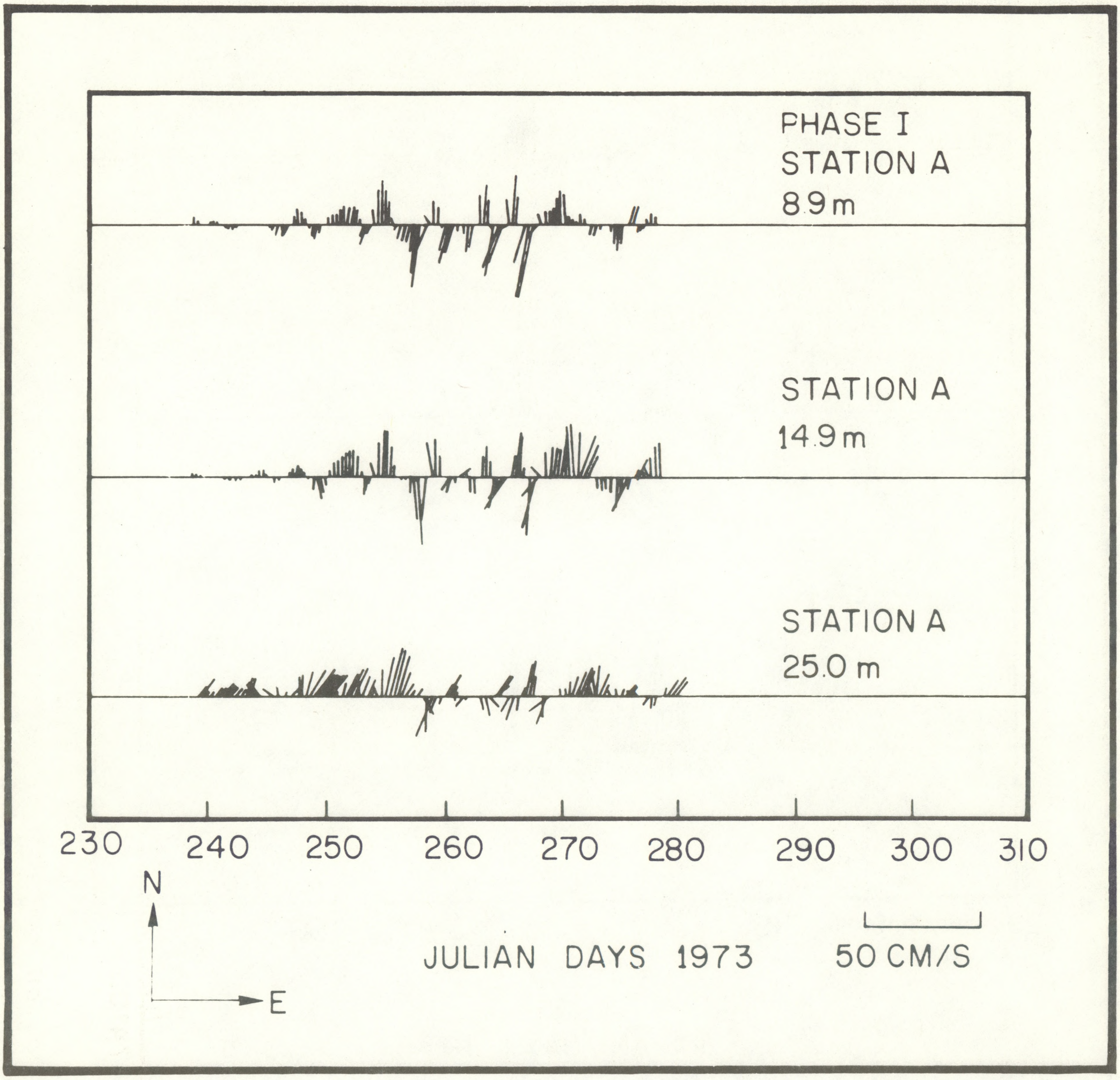

Figure 11. Vector time series of 40-hr low-pass data from station A during August-September 1973.

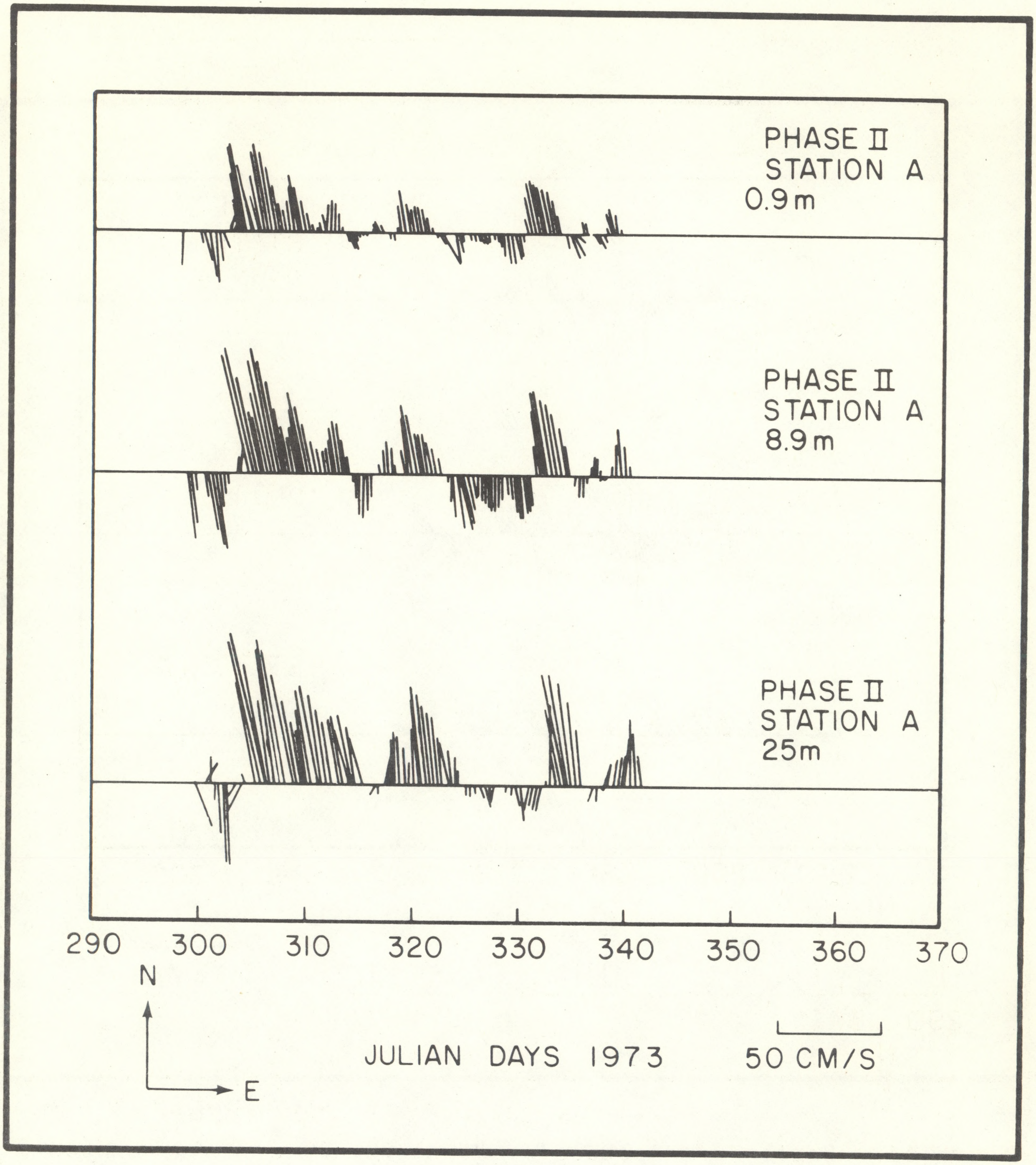

Figure 12. Vector time series of 40-hr low-pass data from station A during October-December 1973.

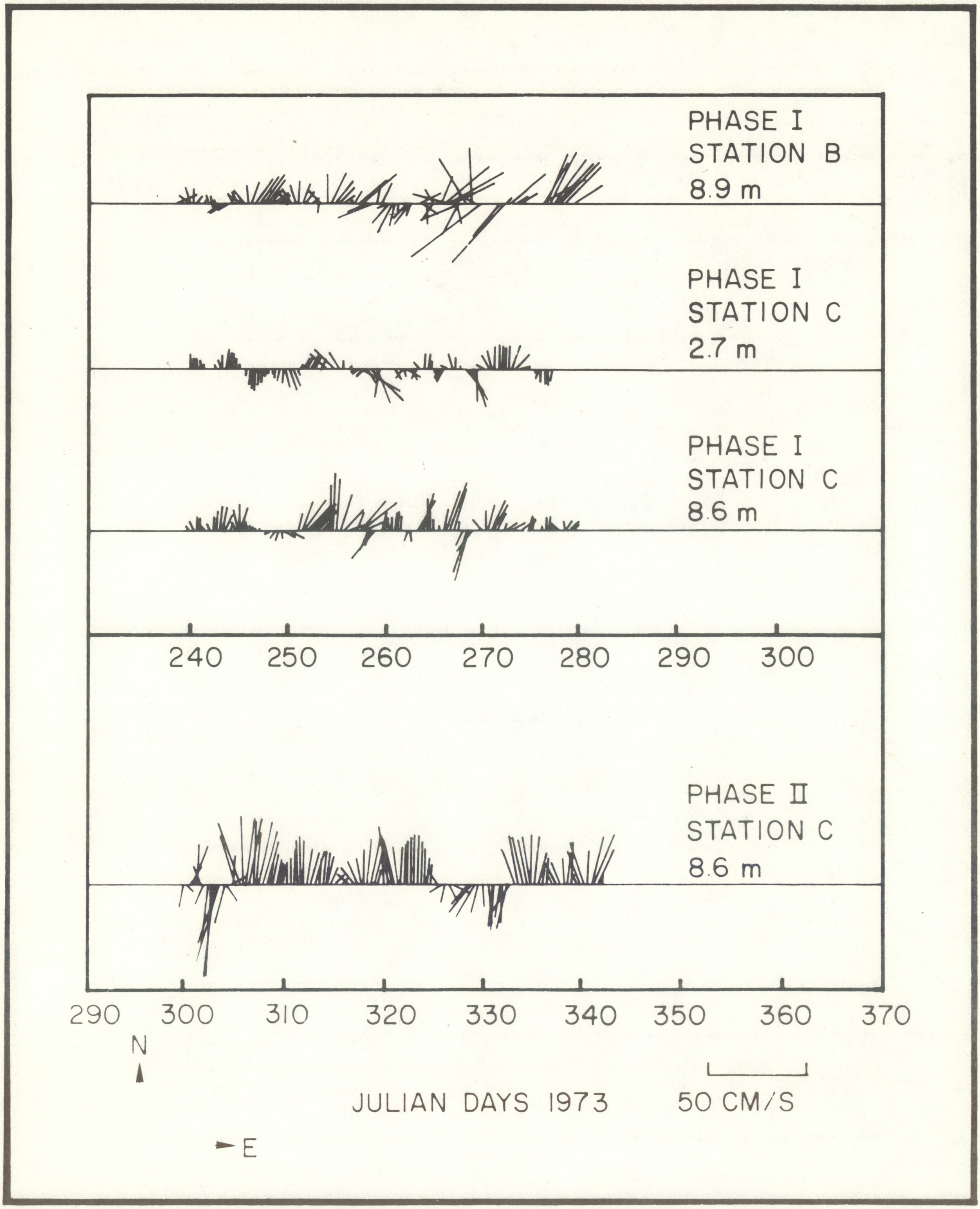

Figure 13. Vector time series of 40-hr low-pass data from stations B and C from August-September 1973 and from station C during October-December 1973.

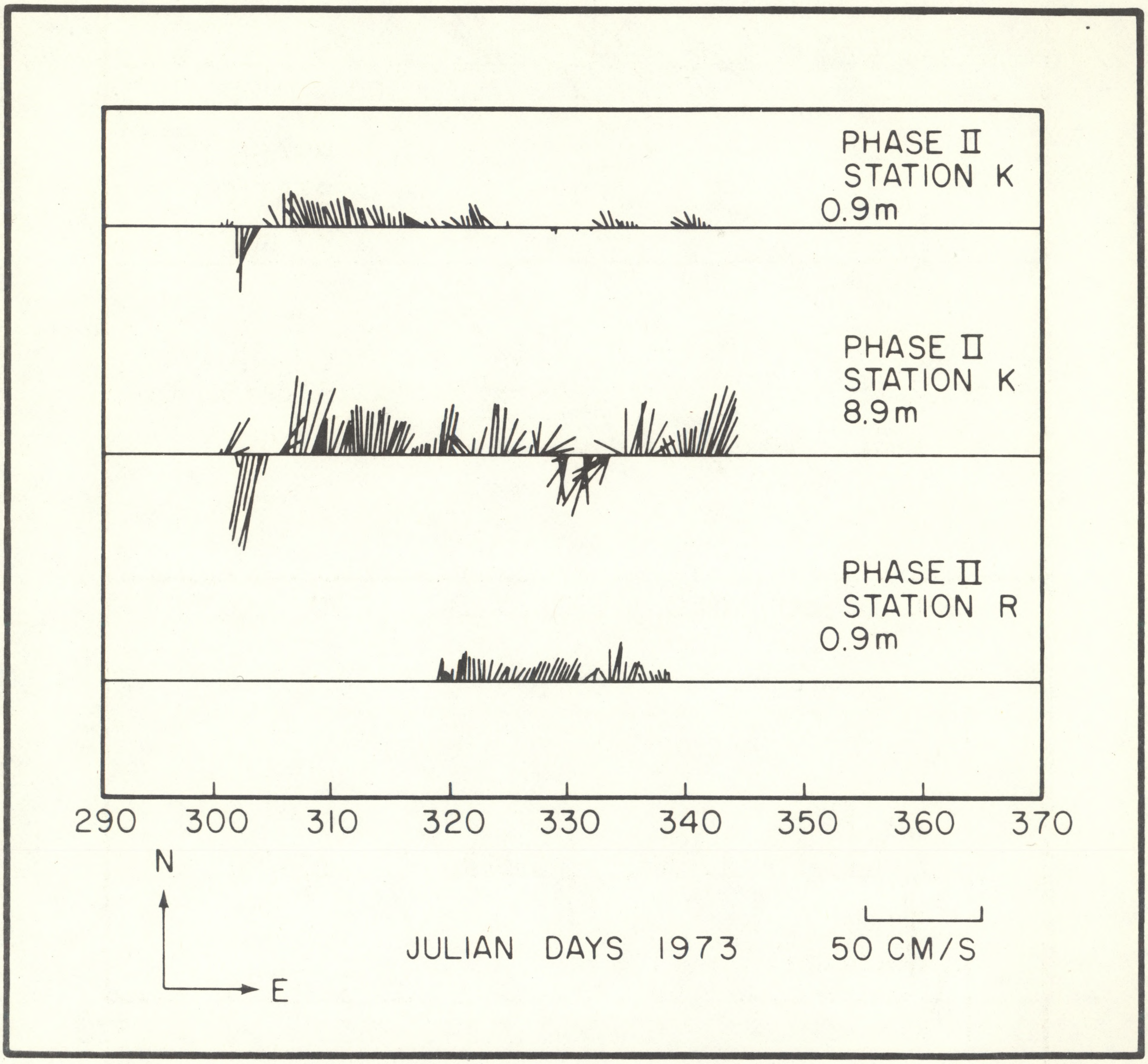

Figure 14. Vector time series of 40-hr low-pass data from stations K and R during October-December 1973.

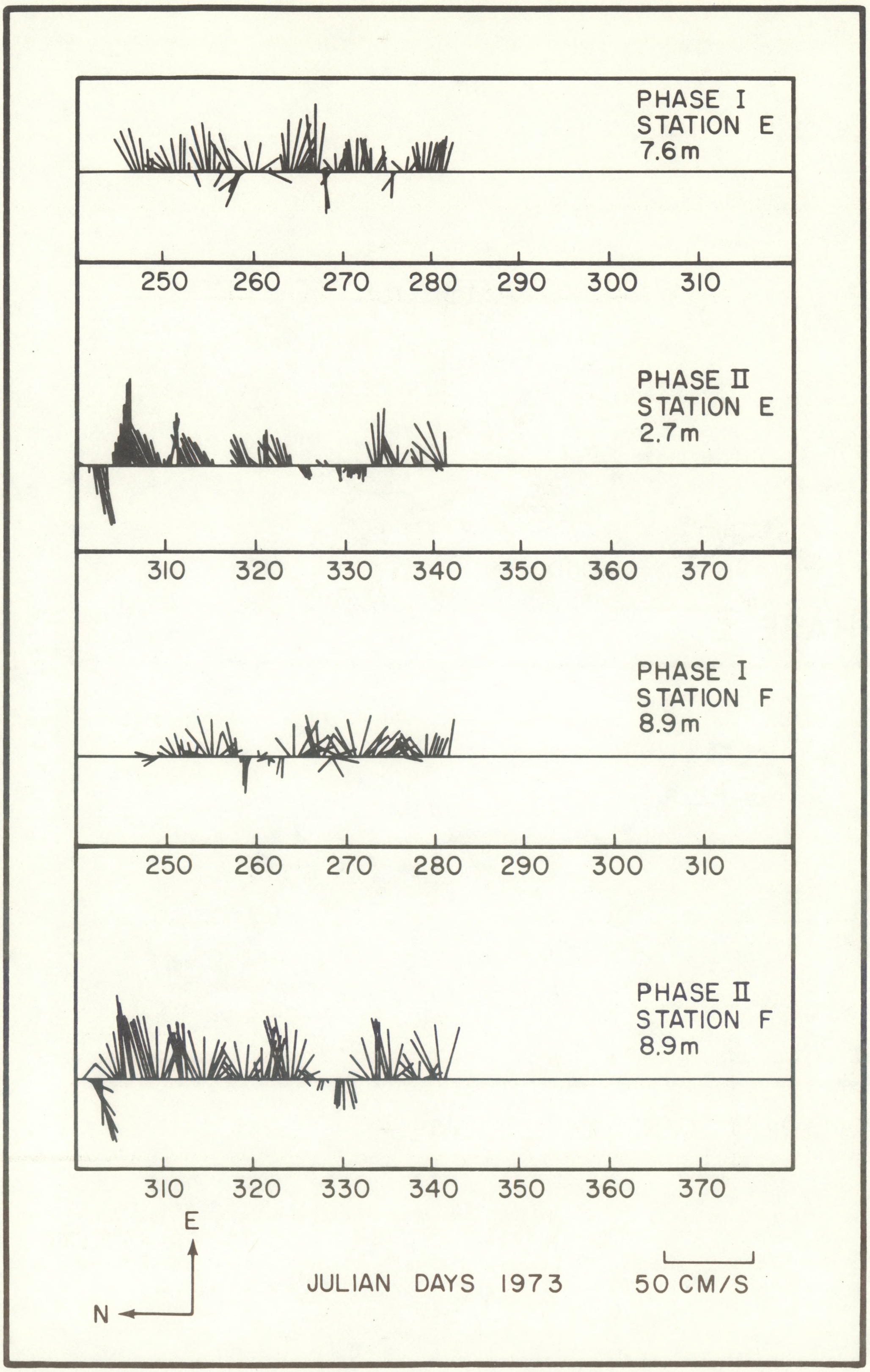

Figure 15. Vector time series of 40-hr low-pass data from stations E and F for both Phases I and II.

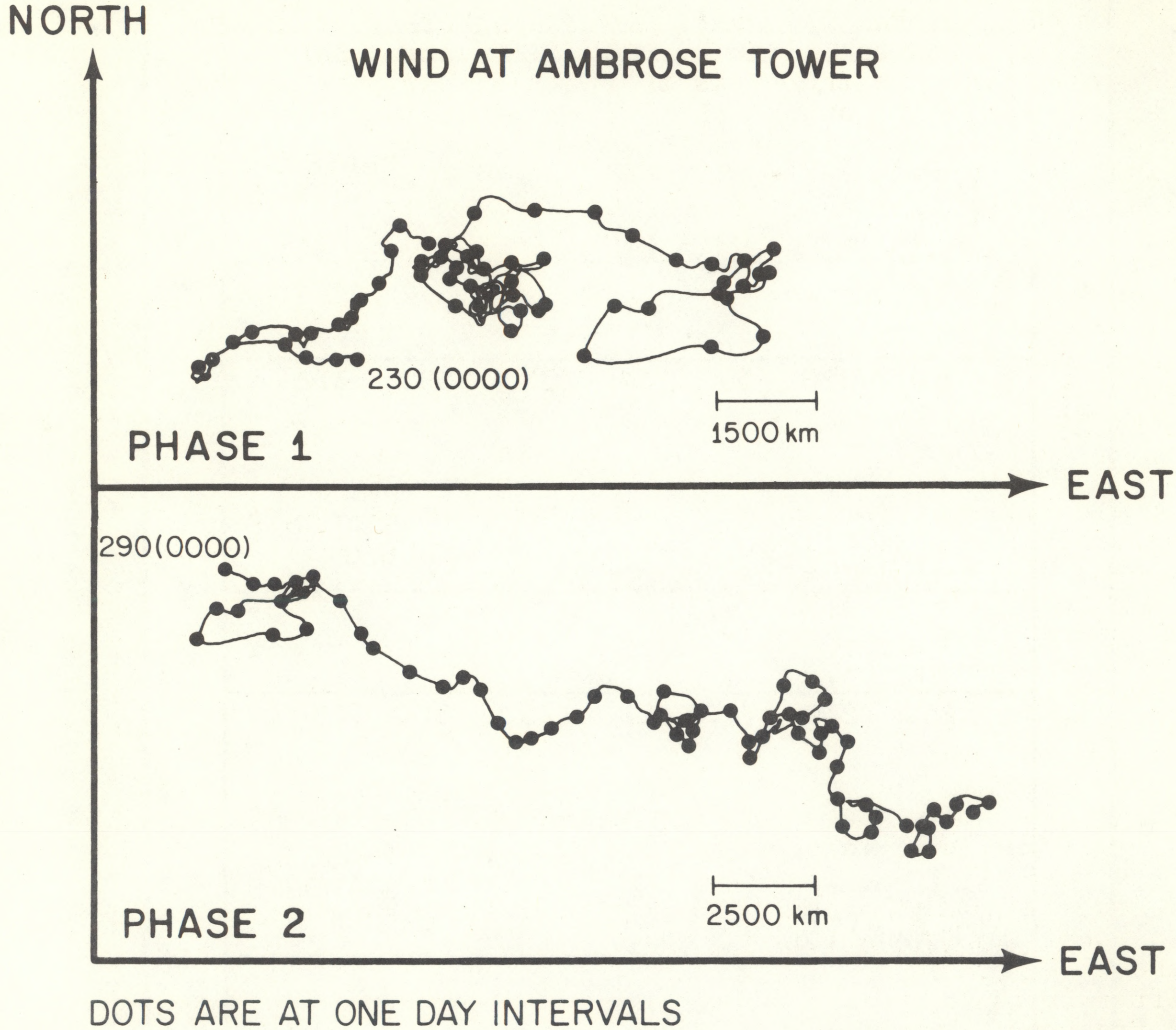

Figure 16. Progressive vector diagrams of wind data taken at Ambrose Light Station during Phases I and II. Indicated start times are in Julian Days and Eastern Standard Time.

3.7 Temporal Variability of Flow

One of the more difficult oceanographic concepts to convey is the distribution of temporal variability in ocean currents. A useful technique for displaying amount and type of flow variability is the energy spectrum. An example of the energy spectrum for station F is shown in figure 17. The curves denoting energy in the east component of flow at station F for Phases I and II are typical of nearshore current measurements in the bight. The major features of these functions are the peaks that occur near periods of 12 hr, 19 to 25 hr, and at the left-hand limit. Respectively, these peaks are associated with semidaily tides, a mixture of inertial currents and daily tides, and longer period variations normally associated with meteorological events amounting to several days. Each of these time scales plays a particular role in the movement of waterborne materials. In general terms, the effect of energetic currents of high frequency is to create turbulence and maintain materials in suspension, but not necessarily to transport or disperse them over long distances. Advective transport is affected by low frequency processes.

Variability of the water motions in the apex is reflected by the statistics of the current meter records, tabulated in table II. The variances computed are the sum of the squares of the standard deviations of the velocity components for each of the 40-hr low-pass and 40-hr high-pass time series. In addition, the ratio of high-passed variance (HPV) to total variance and the ratio of total variance to the squared mean speed are also given. The latter ratio is of particular interest in analyzing the dispersion of materials. For station F spectra shown in figure 17, about 70 percent of the current variance occurred at periods less than 40 hr during Phase I. However, during Phase II, these higher frequencies accounted for only 40 percent of the current variance. During Phase II, a similar frequency distribution of current energy was found at the nearshore station K. However, at station A, further offshore, the high frequency portion of current energy is only 30 percent for Phase I, then drops to about 10 percent for Phase II. Generally, for all of these data, there is a shift from high frequency dominance for nearshore stations to low frequency dominance for offshore stations.

3.8 Coherence and Phase Estimates

The apparent steady-state anticyclonic gyre poses interesting questions: What is the spatial coherence and phase of the low frequency motions in the gyre?; and what, if any, relation does the wind have to the dynamics of the apex circulation? To obtain a quantitative description of the low frequency kinematics in the apex, cross spectra, coherence, and phase were computed for the east component of wind and the selected stations A, K, and F. Wind data were

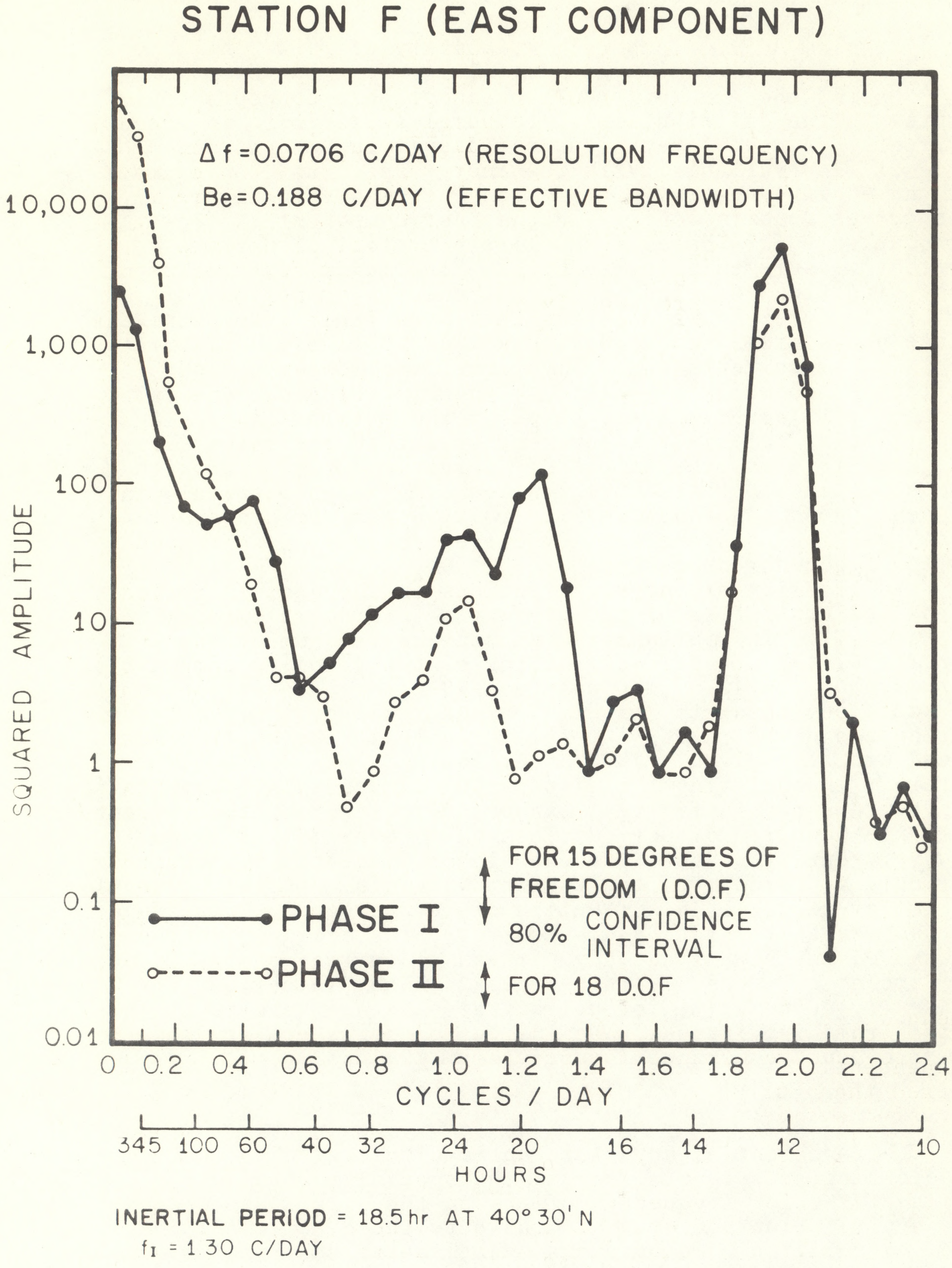

Figure 17. Energy spectra for east component of current measurements at station F for both Phases I and II.

obtained from the standard observations made at Ambrose Tower every 6 hr. Figure 18, summarizing these computations, shows that there are two important frequencies associated with wind forcing. The left-hand column in figure 18 shows the cross spectrum, cross phase, and coherence squared for the east component of wind and the north component of currents at station A during Phase I. The east component of wind is used for coherence and phase analysis because, for the Ambrose data, most wind energy is in the east component. There are two peaks in the cross spectrum; periods corresponding to these peaks are approximately 4 and 7 days. Motions at station A lag the wind by approximately 12 hr for the 7-day period and about 18 hr for the 4-day period. The most significant coherence is approximately 0.7 for the 4-day period. Coherence in the Phase I data suggests that water in the vicinity of station A responds to eastward winds with northward flow; in general, the gyral circulation within the apex seems to be a wind-induced phenomenon.

The center and right-hand columns of figure 18 show for Phase II the cross spectra, cross phase, and coherence squared between the north components of stations A and K and between the north component of K and east component of F, respectively. These data show coherence squared greater than 0.75 for periods greater than 5 days. Additionally, phase differences are negligible. These data indicate that, for the space scale of the apex array, Phase II motions are coherent for frequencies less than those near 0.2 cycles/day.

4. RECAPITULATION

During the last half of 1973, direct current observations were made in the New York Bight Apex. These efforts produced 24 current meter records from <u>in situ</u> recording Aanderaa current meters. These records were partitioned into low and high frequency bands where each band was analyzed for temporal and spatial variability. These analysis produced the following observations:

(a) For the period August-December 1973, the mean flow within the apex consists of clockwise circulation with a mean speed of approximately 4 to 10 cm/s.

(b) Low frequency component of flow is less depth dependent in the late fall when the water column is well mixed than during the summer when a well-developed two-layered system exists.

(c) Low frequency response of apex water to meteorological forcing is coherent over the apex with a phase lag of up to 18 hr. Coherence diminished markedly above 0.2 cycles/day.

(d) Spatial coherence over the study area (35 km) is high with negligible phase lag for frequencies less than 0.2 cycles/day.

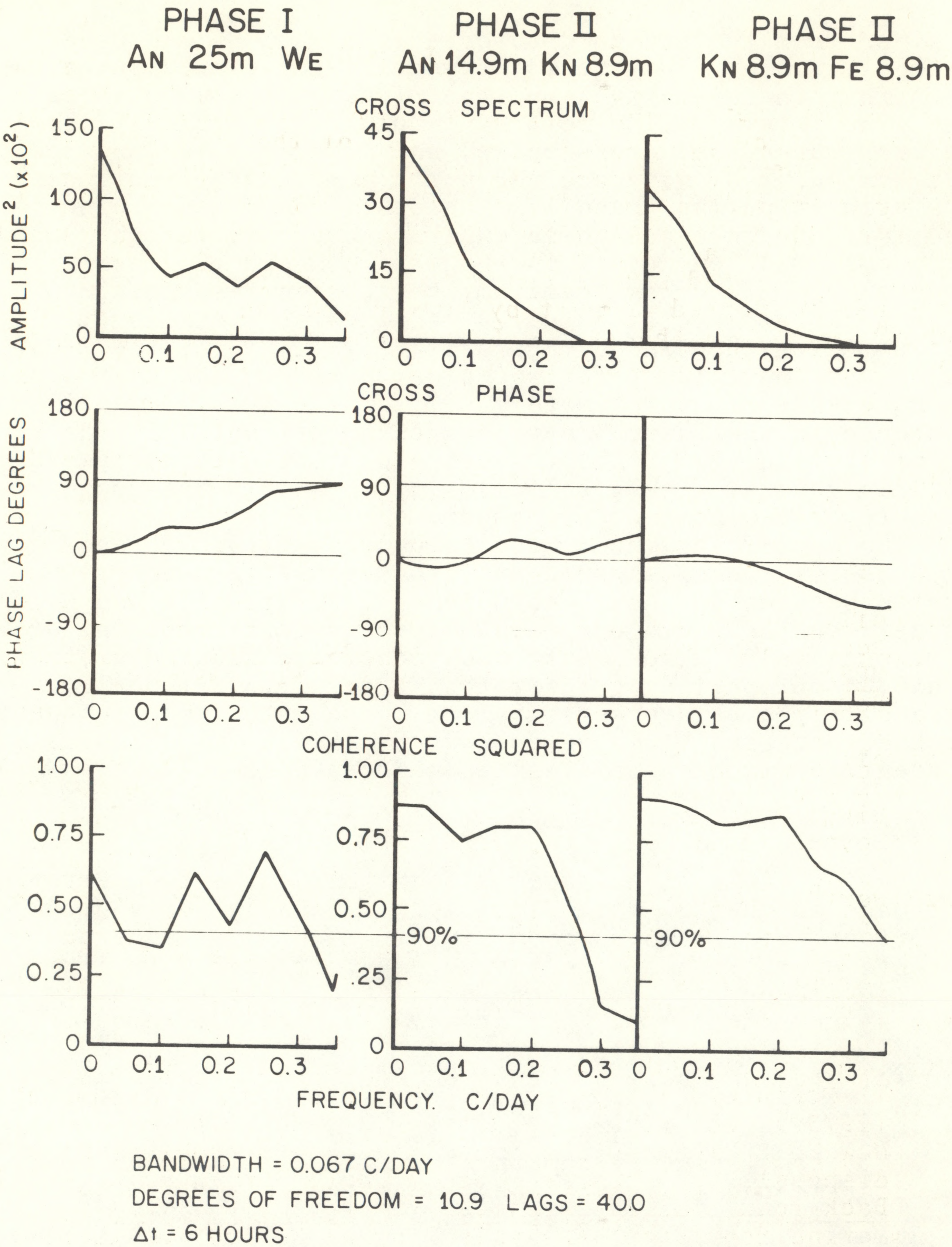

Figure 18. Cross spectra, phase, and coherence estimates for various combinations of wind and current data: (a) Left column: east component of wind and north component of current at station A during Phase I. (b) Center column: north components of currents at stations A and K during Phase II. (c) Right column: north component of current at station K and east component of current at station F during Phase II.

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