THE DIURNAL TIDES
ON THE NORTHEAST CONTINENTAL SHELF
OFF NORTH AMERICA

by

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B.A., Swarthmore College
(1978)

SUBMITTED TO THE DEPARTMENT OF
EARTH AND PLANETARY SCIENCES
IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE
DEGREE OF

MASTER OF SCIENCE IN
PHYSICAL OCEANOGRAPHY

at the

MASSACHUSSETTS INSTITUTE OF TECHNOLOGY

September 1981

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August 1, 1981

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ABSTRACT

The diurnal tides are presented on the Northeast continental shelf off North America, from Nova Scotia to Cape Hatteras. Available current meter data were analysed using the response method, which calculates the tide as an empirical modification to a reference time series, here the equilibrium tide. The results are tabulated for the K_1 and O_1 diurnal tides, and the M_2, S_2 and N_2 semi-diurnal tides, along with an estimate of the 95% confidence limits. Maps of the K_1 tidal ellipses, as well as maps of the K_1 currents are presented for different phases of the tide. In order to complete the picture of the tide, I obtained analysed coastal sea level and bottom pressure data, and also present a cotidal-corange map of the K_1 tide.

I have attempted to model the observed K_1 pressure field by calculating the allowed free and forced waves for a series of cross-shelf sections, using the linearized inviscid shallow water equations and the assumption of a two-dimensionnal straight shelf. The theoretical solutions are then fitted to the data using a least squares method. The model results confirm that the diurnal tide is composed of both a Kelvin wave and a shelf wave, with the Kelvin wave dominating the pressure field, and the shelf wave dominating the currents. The free waves account for roughly 99% of the variance of the difference of the observed pressures and the calculated forced wave, but unfortunately some of the observed features are not accurately reproduced . Possible improvements would include the addition of bottom friction and a better description of long-shore topography, especially as concerns the transition from the Gulf of Maine to the New England shelf.

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Title: Senior Scientist
Woods Hole Oceanographic Institution

Acknowledgements

Much of this work was done in cooperation with B. Butman and J. Moody of the United States Geological Survey (USGS), and with W. Brown of the University of New Hampshire (UNH). Butman and Moody are developing a description of the semi-diurnal tide in the same area and Brown is examining sea surface tides as determined by bottom pressure sensors and coastal tide stations.

I would like to thank my advisor, Bob Beardsley, for his support through this year. Ken Brink gave some valuable suggestions on the manuscript. Carl Wunsch supported me for a semester through an ONR contract, Sea Grant and the Education office at the Woods Hole Oceanographic supported me for the remainder. Many thanks to the USGS for their support in computer time, without which the theoretical analysis and much of the data analysis could not have been done; and to the people in Graphics at the Woods Hole Oceanographic Institution who produced many of my figures. Finally, thanks to Anne-Marie Michael for the final typing touches.

Table of Contents

I) Introduction

Coastal tides are an important phenomenon, accounting for a significant ammount of the ocean's energy on the shelf. Their signal dominates the sea level and current spectrum for frequencies of order one cycle per day or greater, making the determination of other physical processes at those frequencies difficult. Conversely, their high energy implies that shelf currents can be strongly influenced by the tides, both through tidal rectification and tidal friction. Tidal currents also play an important role in mixing, material dispersion and sediment transport.

I present here a study of the diurnal tide from Nova Scotia to Cape Hatteras. The southern point essentially marks the boundary between two different tidal regimes, a strongly semi-diurnal regime to the north and a more diurnal regime to the south. The northern limit marks the end of the Gulf of Maine-Scotian shelf region. The recent proliferation of current meter and pressure gauge recordings on the shelf permits a thorough study of shelf tides in this area. Figure 1 shows the location of our current meter and pressure stations, with a perhaps (?) coincidental concentration around Woods Hole.

Part II outlines the methods of analysis, including the estimation of 95 percent confidence limits, while Part III displays the result of that analysis for the K_1 tide, with a cotidal-corange map for the surface tide, and a series of maps of the velocity components for different phases of the tide. Part IV presents a simple model to fit to the K_1 pressure data along different cross-shore transects. I show that, to a first approximation, the data can be explained by a combination of a Kelvin wave and a shelf wave, and a third wave forced by the equilibrium tide. Part V offers some possible mechanisms by which the fit between the data and the calculated waves could be improved.

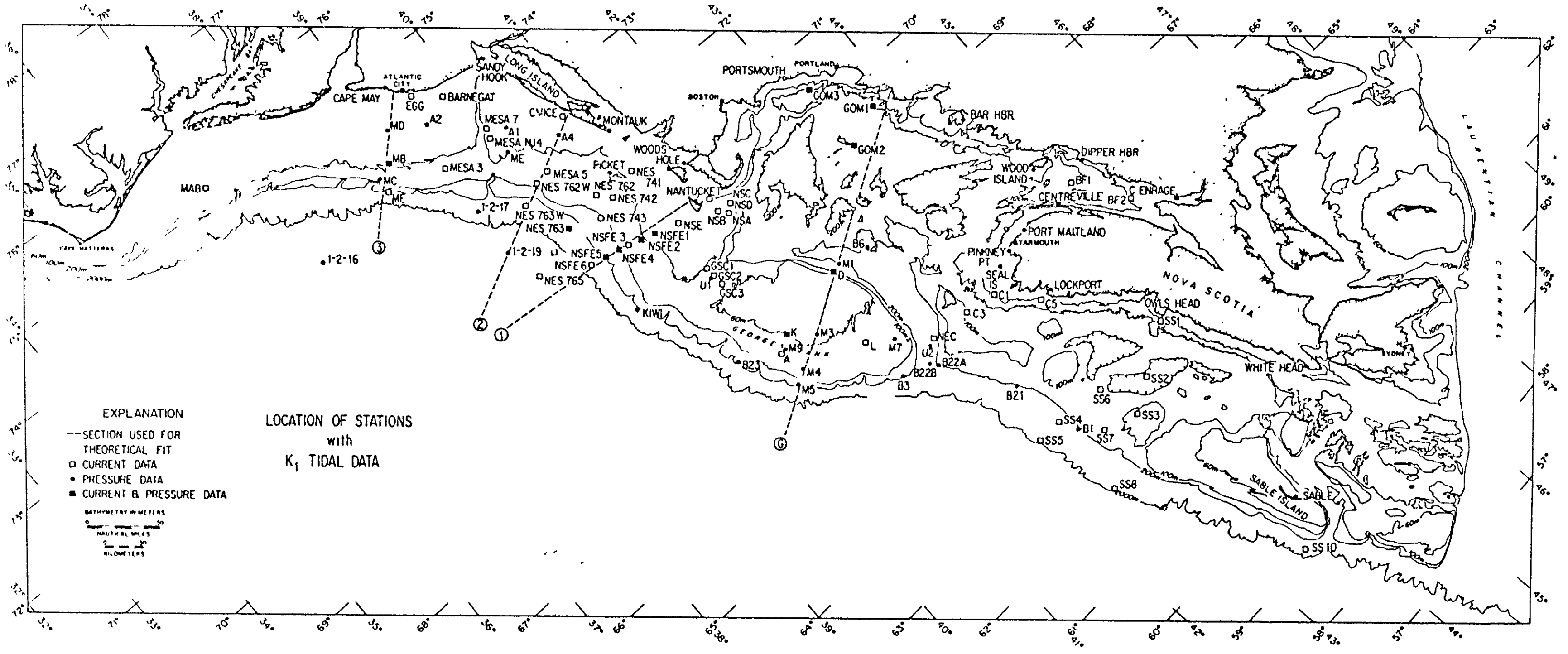

LOCATION OF STATIONS
with
K_1 TIDAL DATA
EXPLANATION
--SECTION USED FOR THEORETICAL FIT
□ CURRENT DATA
• PRESSURE DATA
■ CURRENT & PRESSURE DATA
BATHYMETRY IN METERS
NAUTICAL MILES
KILOMETERS
CAPE HATTERAS
CHESAPEAKE BAY
MABO
CAPE MAY
ATLANTIC CITY
EGG
BARNEGAT
SANDY HOOK
LONG ISLAND
MONTAUK
MESA 7
A1
A2
A4
CVICE
MESA NJ4
ME
MD
MB
MC
MF
MESA 3
MESA 5
NES 762W
NES 762
NES 742
NES 741
NES 743
NES 763W
NES 763
NES 765
1-2-17
1-2-19
1-2-16
FICKET
WOODS HOLE
NANTUCKET
NSC
NSD
NSB
NSA
NSE
NSFE 1
NSFE 2
NSFE 3
NSFE 4
NSFE 5
NSFE 6
KIWI
BOSTON
PORTSMOUTH
PORTLAND
GOM 3
GOM 1
GOM 2
BAR HBR
DIPPER HBR
WOOD ISLAND
BF1
BF2
CENTREVILLE
C ENRAGE
PORT MAITLAND
YARMOUTH
PINKNEY PT
SEAL IS
C1
C3
C5
LOCKPORT
OWLS HEAD
SS1
SS2
SS3
SS4
SS5
SS6
SS7
SS8
SS10
B1
B21
B22A
B22B
B23
B3
B6
NEC
U1
U2
GSC 1
GSC 2
GSC 3
M1
D
M3
M4
M5
M7
M9
K
L
A
GEORGES BANK
NOVA SCOTIA
WHITE HEAD
SABLE ISLAND
SABLE
SYDNEY
LAURENTIAN CHANNEL
①
②
③
⑥

FIGURE 1

II) Data Analysis Methodology

A) Analysis Methods

The analysis of tidal data differs from standard time series analysis, since the high energy content of the important tidal lines precludes a naive use of Fourier Transforms, due to severe leakage to adjacent bands. The deterministic nature of the astronomical forcing means that the tidal frequencies are well known, however, so that the appropriate use of this knowledge can greatly simplify the time series analysis.

There are two methods principally in use to analyse tidal data. The harmonic method performs a Fourier analysis at selected tidal frequencies. Various corrections are then applied to correct for the fact that the main tidal frequencies are not the harmonics of a fundamental, as called for by simple Fourier theory. The *vade mecum* of harmonic analysis is the 1941 manual of Paul Schureman. A modern variant is the use of FFT routines on today's high speed computers. Since the frequencies are no longer exactly aligned with the tidal frequencies, leakage is particularly severe, so that this variant is best used on long time series (i.e. a year or more).

The second principal method was developed by Munk and Cartwright (1966). Known as the response method, it calculates the tide as an empirical modification to a known input potential. More specifically, the predicted tide η_p can be written

$$\eta_p(t) = \sum_s w_s \, V(t-\tau_s)$$

where V is the input potential, and the weights w_s are chosen such that η_p is a least-squares fit to the actual data. Following convolution theory, w_s can then be thought of as the impulse response of the sea surface (or currents) at that point. The choice of a suitable input potential is a matter of convenience. If there is a nearby location where the tide is accurately known, then the predicted tide for that location can be used as the input potential. On the other hand, the equilibrium tide is easier to produce, but may provide a less accurate solution. The equilibrium tide is the theoretical tide one would calculate for a non-inertial homogeneous ocean on a smooth sphere, and can be calculated directly from the known astronomical constants. The various frequencies of the harmonic method are selected based on an expansion of this potential.

The response theory is intellectually more appealing than the harmonic method. The latter uses a knowledge of the more important lines, while the former takes into account the entire equilibrium potential. Also, the use of Fourier analysis for the harmonic method implies that certain record lengths are better than others for resolving a given line. As a corollary to this, a minimum of fifteen days of data is necessary to resolve the major lines (M_2, S_2, N_2, K_1, O_1). The response method has no such drawbacks; in particular, the calculation of a predicted tide should be more accurate, since there are no assumptions made as to which frequencies are important. In addition, the response method has the added attraction of incorporating some physics into the otherwise purely numerical analysis: namely, that the response of a given location is directly related to that of a nearby site, or to the equilibrium tide. In practice, it turns out that both methods yield fairly similar results, given an adequate record length. In particular, we lose some of the advantages of the response method by requiring it to calculate given harmonic constituents, rather than a full predicted tide. Because of its convenience, we chose to use the response method.

B) Noise Determination

Following Munk and Cartwright (1966), I plan to use the noise to signal ratio σ as a basic parameter of the quality of the calculation, such that

$$\sigma^2 = \text{variance of noise} / (2L \times \text{recorded variance}),$$

where

L = length of series in lunar months,

and the variances are averaged over the appropriate tidal band. This definition was used by Munk *et al.* (1970), and is a slight variation on the original formula proposed by Munk and Cartwright (1966), where L was replaced by p, the number of independant segments over which the variances were averaged. In such a way, band averaging can be substituted for piece averaging: following standard spectral analysis, a month of data gives a maximum resolution of one cycle per month, or, using the language of tidal analysis, resolution of tidal groups. The major tidal lines fall within separate, distinct groups, with the exception of the S_2 and K_2 lines, which are separated by one cycle per year. Thus L can be thought of as the degrees of freedom associated with separating the various tidal groups. The final error estimate will be valid for a given band, diurnal or semidiurnal, rather than for a specific line. This assumes that most of the residual variance is due to baroclinic tides, rather than white noise, as explained in Munk et al. (1970). Hence the error estimates will be conservative estimates for the major lines.

In order to calculate the noise variance, I calculate a predicted tide, creating a tidal time series to match the inputted data. If I subtract this predicted series from the observed one, I then get a residual time series, which can easily be analysed spectrally, as it has a nearly normal distribution. To obtain the noise variance, I then average over each tidal band, defined as m cycles/lunar day ± 4.5 cycles/lunar month, where m is the species number. Note that this process does not entail Fourier analysis of the raw data, so that I avoid having to deal with the strong leakage associated with the very energetic tidal signals.

The leakage problem also makes it undesirable to calculate the recorded variance directly. Instead, I will assume that the recorded variance is the sum of the prediction variance, and of the residual variance. I have just outlined how to calculate the latter; the program calculates the former, which is basically the covariance with 0 lag of the predicted diurnal or semi-diurnal tide with the observations.

Given σ, Munk and Cartwright (1966) calculate probability distributions for the amplitude and phase of the admittance, respectively:

$$p(\rho)=(\rho/\sigma^2)\exp(-(\rho-1)^2/2\sigma^2)(\exp(-\rho/\sigma^2)I_0(\rho/\sigma^2)),$$

$$p(\theta)=(2\pi)^{-1}\exp(-1/2\sigma^2)(1+F(\cos\theta/\sigma)),$$

where

$$F(x)=x\ \exp(x^2/2)\int_{-x}^{\infty}\exp(-t^2/2)\ dt,$$

with

$$\rho=\tilde{R}/R,$$

$$\theta=\tilde{\theta}-\text{true phase}.$$

~ denotes estimated quantities, R=true admittance. These equations are integrated with respect to ρ and θ, with limits of integration determined by the condition that 2.5 percent of the distribution lie on either side of the integrated span. Plotting these limits as a function of σ gives figures 2 and 3, which reproduce Munk and Cartwright's (1966) figure 16.

The pressure data were analysed at the UNH using the harmonic method. Note that the error analysis performed at the UNH assumes that the tidal residual is mainly white noise. This means that errors in neighbouring constituents are assumed independent of each other, so that error bars for the major tidal lines of each band tend to be lower than they would be using my procedure. In terms of consistency, all current data has been processed using one assumption, all pressure data the other. Thus, while the result is not as satisfactory as if one single method had been used, comparison among current stations or among pressure stations is still meaningful.

FIGURE 2

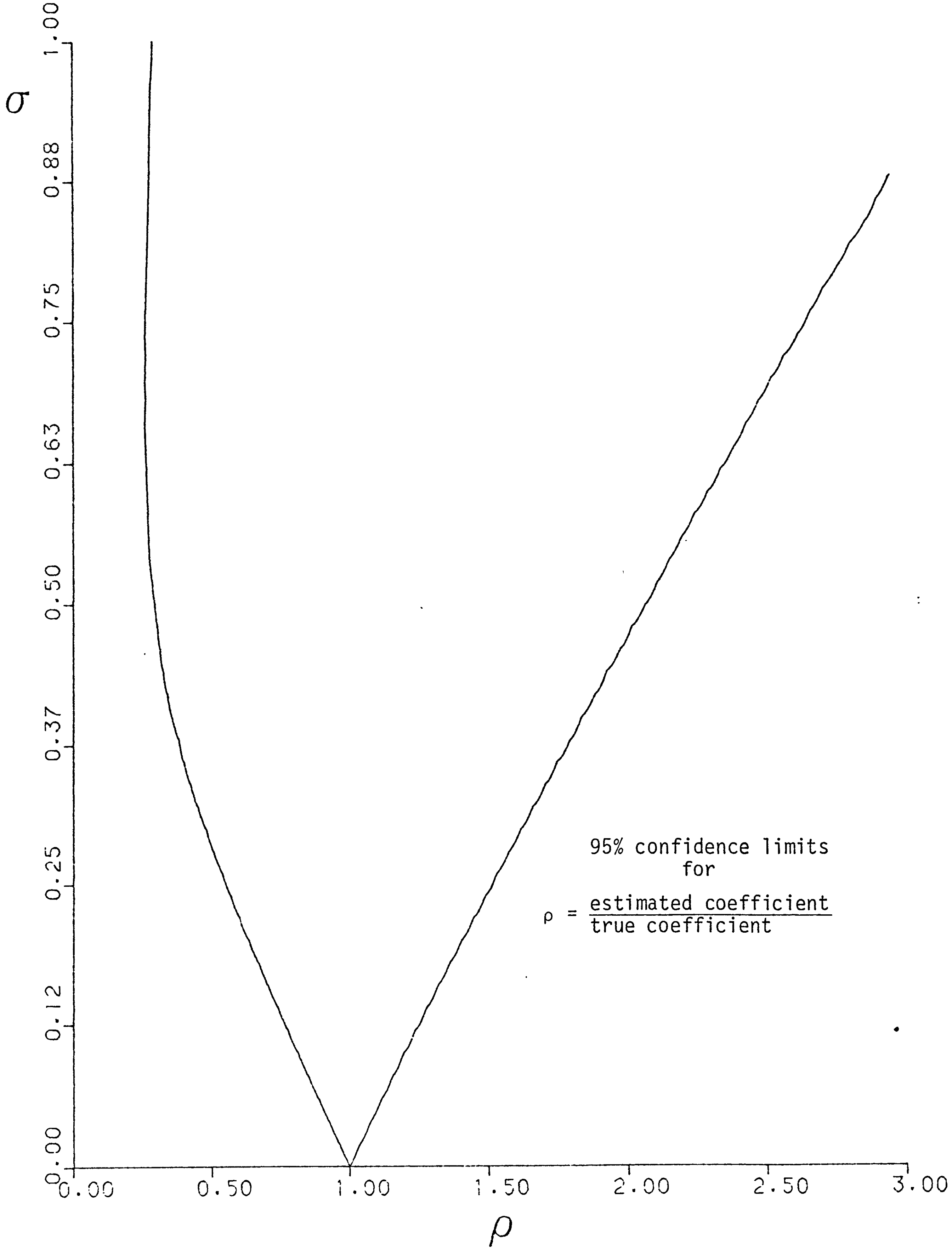
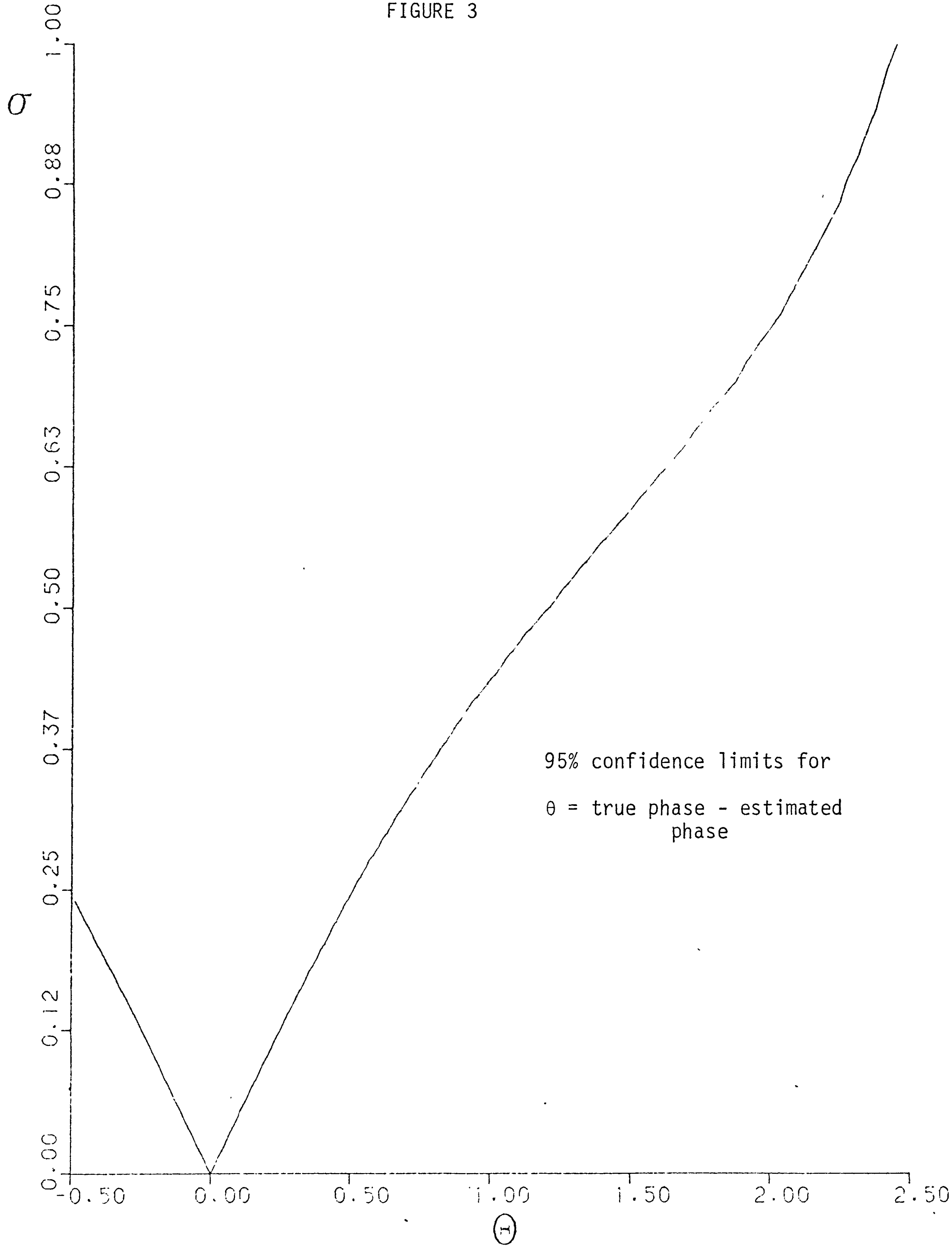

σ
1.00
0.88
0.75
0.63
0.50
0.37
0.25
0.12
0.00
0.00
0.50
1.00
1.50
2.00
2.50
3.00
ρ
95% confidence limits
for
ρ = estimated coefficient / true coefficient

FIGURE 3


σ
1.00
0.88
0.75
0.63
0.50
0.37
0.25
0.12
0.00
-0.50
0.00
0.50
1.00
1.50
2.00
2.50
Θ
95% confidence limits for
θ = true phase - estimated phase

III) The Observed K1 Tide and Tidal Currents

The results of the analysis are tabulated in tables A1 and A2, and maps are shown in figures 4 to 11.

a) cotidal map

Figure 4 shows the data used to contour figure 5. The object was to draw as smooth a representation as possible, given the 95 percent confidence limits which accompanied most of the UNH data. As such, it is only one of several possible mappings, the one which seemed most logical and plausible. Offshore, there is a sweep of the tides from North to South, generally conforming to the picture of the global K_1 tide as we know it. (See figure 6, reproduced from Defant (1961)). I also took into consideration the presence of an amphidrome near Sable Island, as observed in most global models. Note the appearance of a virtual amphidrome located South of Cape Cod, and a severe twisting of the cotidal lines over the Northeast Channel. The highest amplitudes are around fifteen centimeters and are found in the Gulf of Maine, the lowest are around seven centimeters, in the vicinity of Cape Cod.

b) velocity maps

Outside of the bottom boundary layer, the velocities show only a small phase and amplitude shift with depth, confirming the barotropic nature of the tides. Thus, in figures 7 to 11, we show the maximum currents within a given mooring, since these should have the smallest errors, and still should be characteristic of the location. Figure 7 shows representative current ellipses, while figures 8 to 11 show the K_1 currents at various phases of the tide.

In general, the current ellipses are aligned with the local topography, with the maximum currents occuring near the shelf break. There is only a slight cross-shelf phase shift. The smallest currents observed were within the Gulf of Maine, the largest south of Nantucket Shoals.

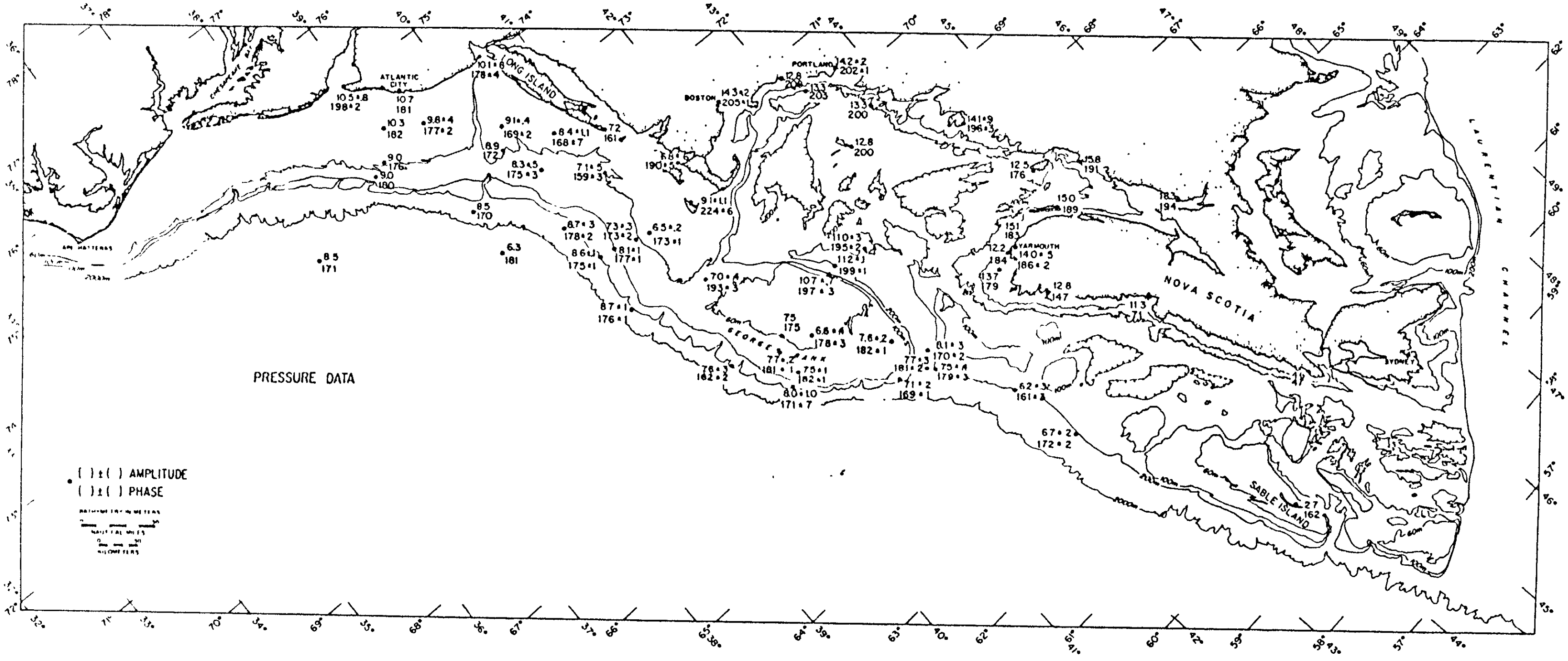

PRESSURE DATA
( ) ± ( ) AMPLITUDE
( ) ± ( ) PHASE
ATLANTIC CITY
LONG ISLAND
BOSTON
PORTLAND
YARMOUTH
NOVA SCOTIA
GEORGES BANK
SABLE ISLAND
SYDNEY
LAURENTIAN CHANNEL

FIGURE 4

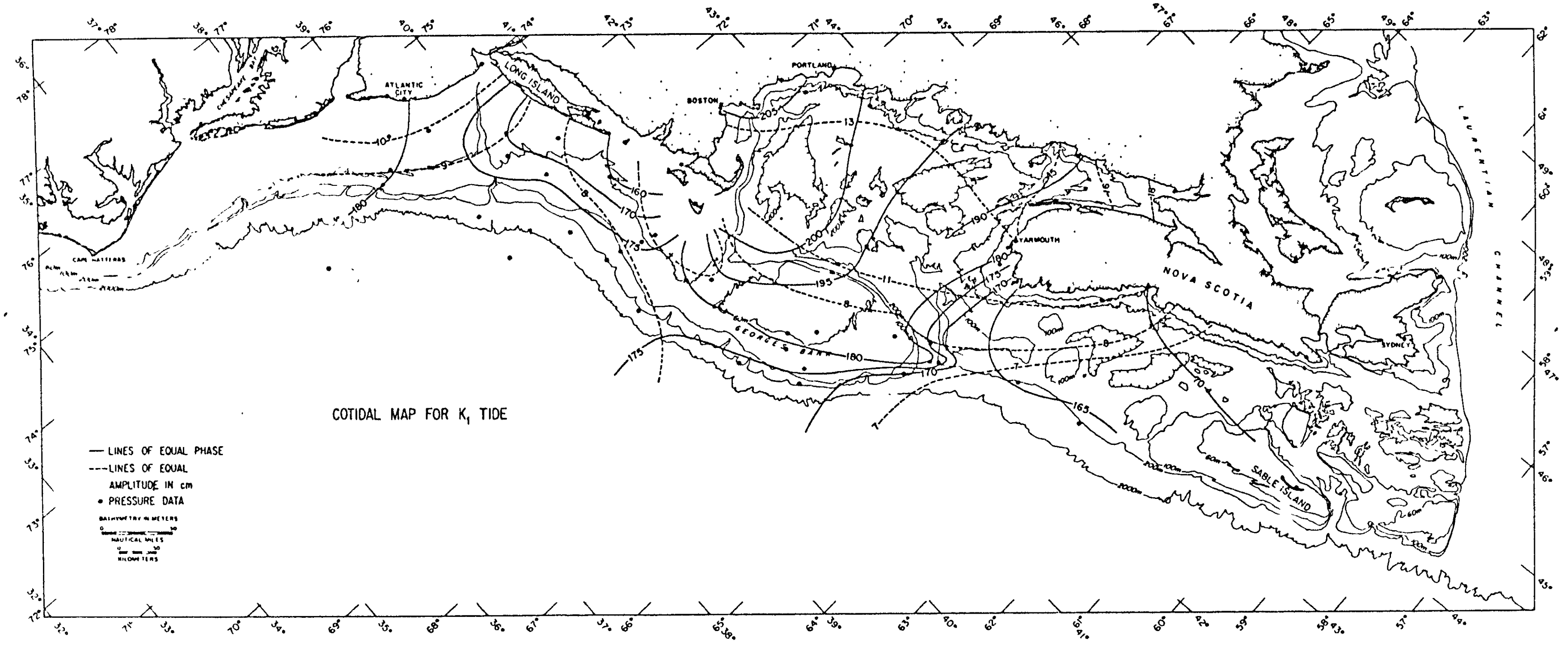
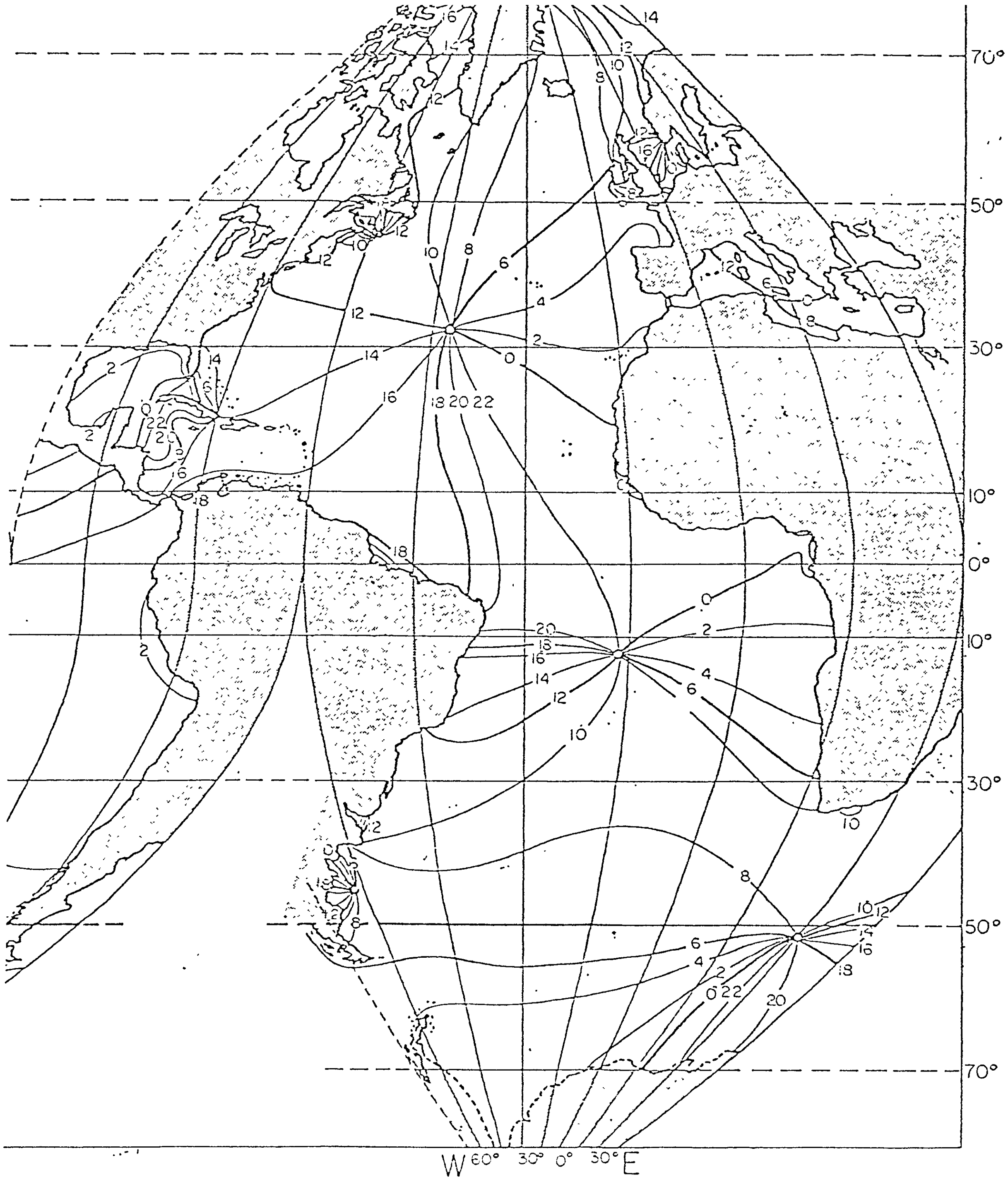

COTIDAL MAP FOR K1 TIDE
— LINES OF EQUAL PHASE
---LINES OF EQUAL AMPLITUDE IN cm
• PRESSURE DATA
BATHYMETRY IN METERS
NAUTICAL MILES
KILOMETERS
ATLANTIC CITY
LONG ISLAND
BOSTON
PORTLAND
YARMOUTH
NOVA SCOTIA
SYDNEY
SABLE ISLAND
GEORGES BANK
CAPE HATTERAS
LAURENTIAN CHANNEL
160
170
173
175
180
190
195
200
205
165
13
11
10
9
8
7

FIGURE 5



K_1 Tide, Greenwich Hours

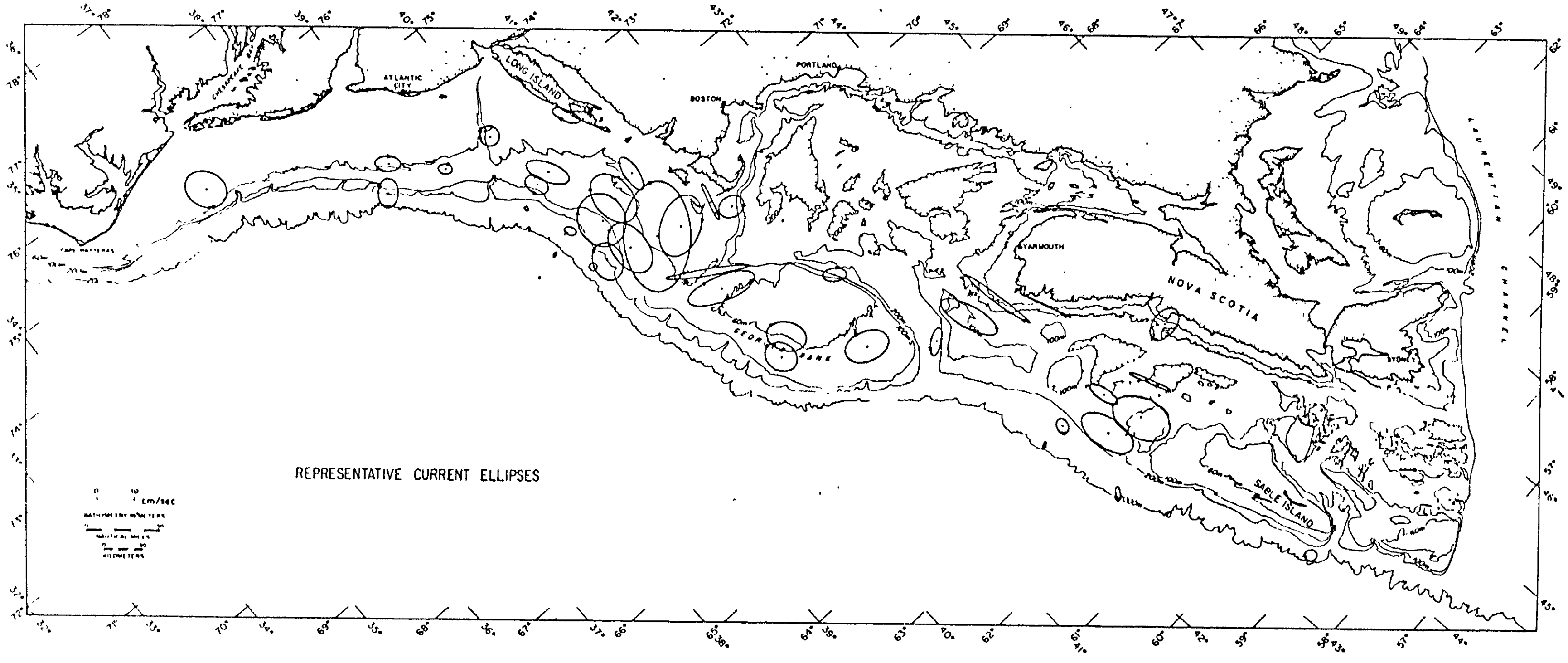
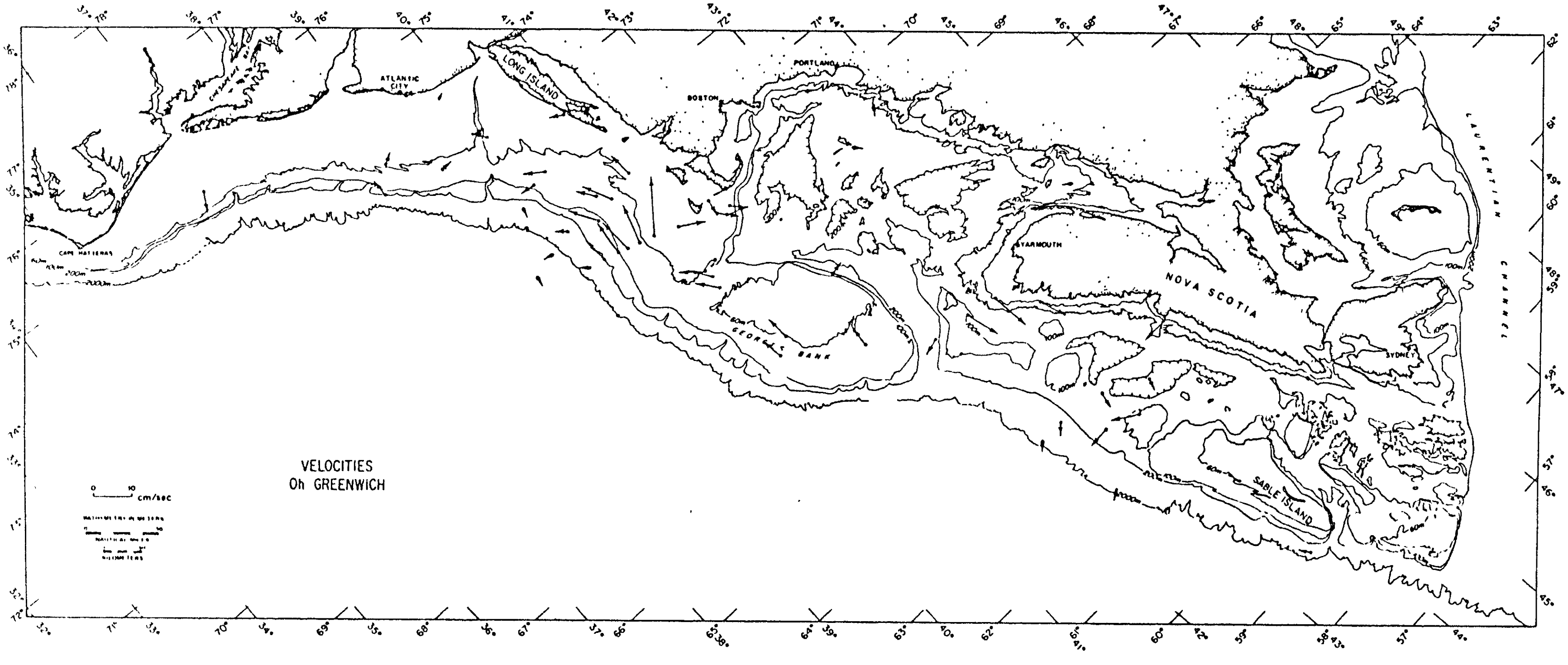

REPRESENTATIVE CURRENT ELLIPSES
cm/sec
CAPE HATTERAS
CHESAPEAKE BAY
ATLANTIC CITY
LONG ISLAND
BOSTON
PORTLAND
YARMOUTH
NOVA SCOTIA
GEORGES BANK
SABLE ISLAND
SYDNEY
LAURENTIAN CHANNEL

FIGURE 7



LONG ISLAND
ATLANTIC CITY
BOSTON
PORTLAND
CAPE HATTERAS
GEORGES BANK
YARMOUTH
NOVA SCOTIA
SABLE ISLAND
SYDNEY
LAURENTIAN CHANNEL
VELOCITIES
Oh GREENWICH
0 10 cm/sec

FIGURE 8

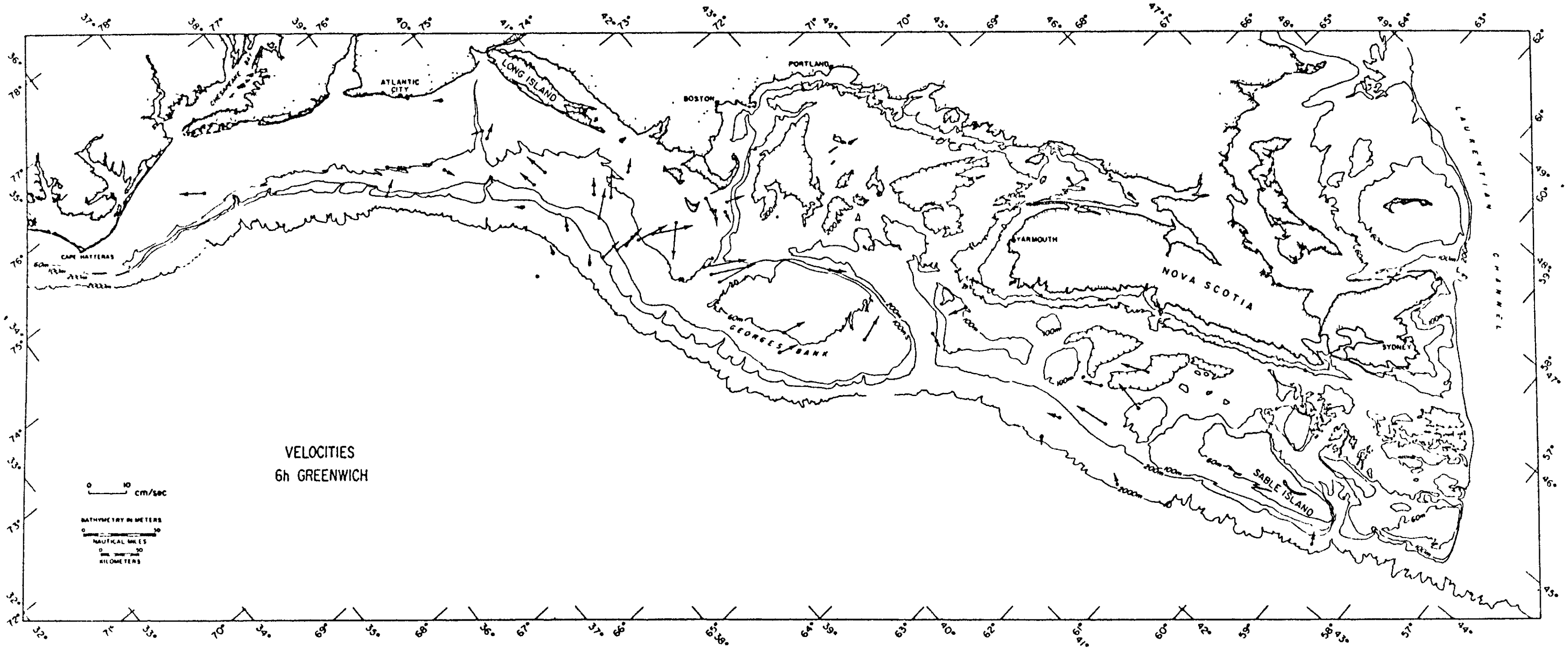

VELOCITIES
6h GREENWICH
0 10 cm/sec
BATHYMETRY IN METERS
NAUTICAL MILES
KILOMETERS
CAPE HATTERAS
CHESAPEAKE BAY
ATLANTIC CITY
LONG ISLAND
BOSTON
PORTLAND
GEORGES BANK
YARMOUTH
NOVA SCOTIA
SYDNEY
SABLE ISLAND
LAURENTIAN CHANNEL

FIGURE 9

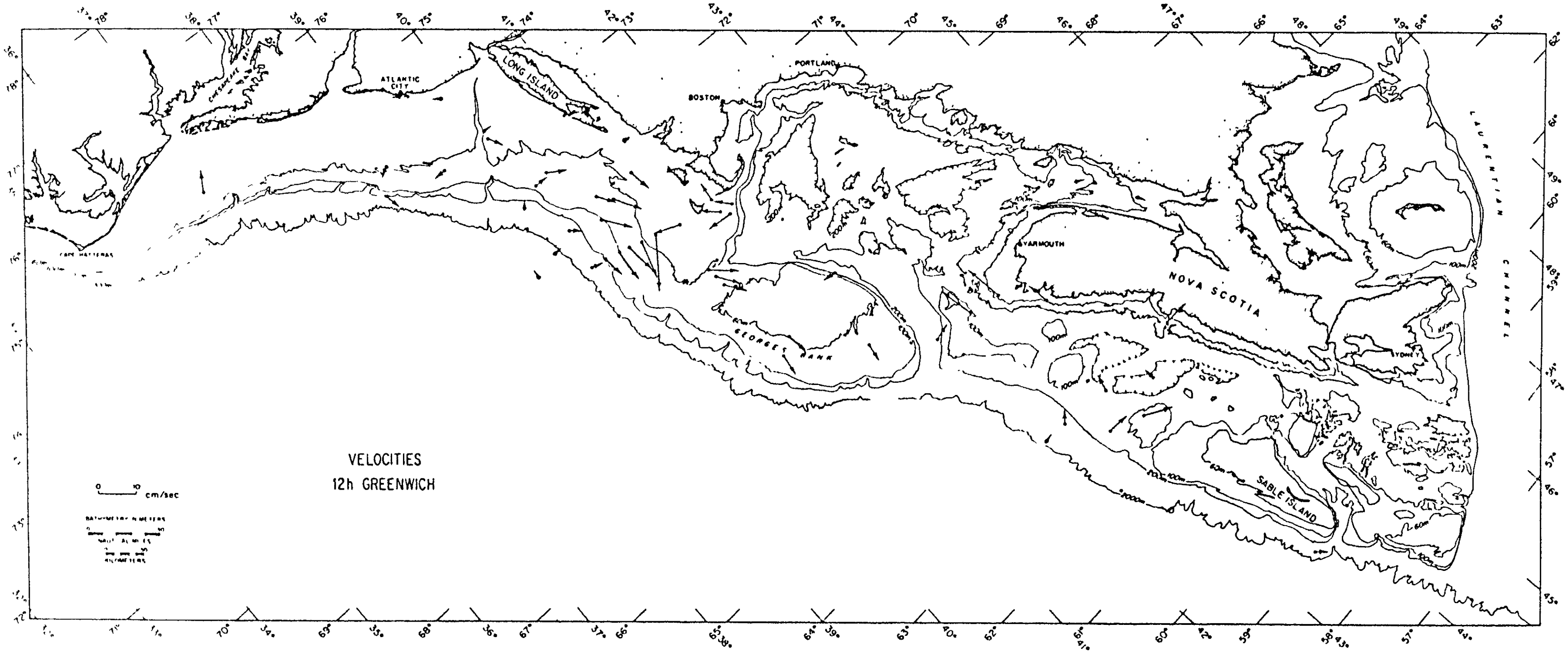

VELOCITIES
12h GREENWICH
cm/sec
ATLANTIC CITY
LONG ISLAND
BOSTON
PORTLAND
YARMOUTH
NOVA SCOTIA
GEORGES BANK
SABLE ISLAND
SYDNEY
LAURENTIAN CHANNEL
CAPE HATTERAS
100m
60m
200m
2000m

FIGURE 10

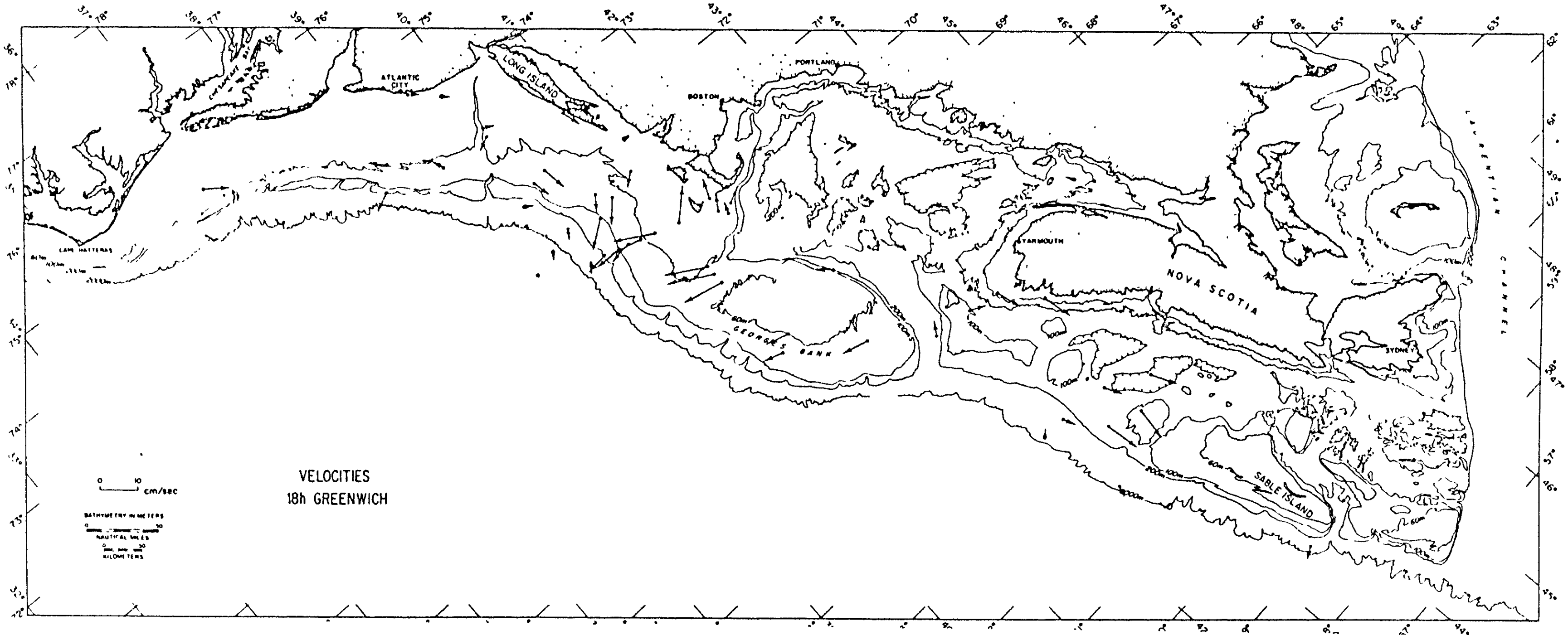

VELOCITIES
18h GREENWICH
0 10 cm/sec
BATHYMETRY IN METERS
NAUTICAL MILES
KILOMETERS
CAPE HATTERAS
ATLANTIC CITY
LONG ISLAND
BOSTON
PORTLAND
GEORGE'S BANK
YARMOUTH
NOVA SCOTIA
SABLE ISLAND
SYDNEY
LAURENTIAN CHANNEL

FIGURE 11

IV) A Theoretical Model for the K1 Tide

A) Procedure

I attempt here to develop a theoretical model which will reproduce in part some of the observed features of the K_1 surface tide and currents. I first find the free and forced solutions to the shallow water equations for realistic cross-shelf profiles. I have chosen four such profiles, where I had at least three pressure stations more or less aligned in the cross-shelf direction. These sections are identified by the dashed lines in figure 1. The first one uses the Nantucket Shoals Flux array as a basis, and stretches South of Cape Cod. The second one starts from Long Island, the third from Atlantic City. The fourth stretches across the Gulf of Maine and Georges Bank. I then fit the solutions to the pressure data along those sections using a least-squares procedure. I chose to fit to the pressure data only, since it is inherently cleaner than current meter data. Much of what follows is based on Munk et al. (1970), and Cartwright et al. (1980).

B) Derivation of Governing Equations

Start from the linear shallow water equations,

$$\begin{aligned} &u^*_{t^*}-fv^*=-g(\eta^*-\eta_E{}^*)_{x^*}, \\ &v^*_{t^*}+fu^*=-g(\eta^*-\eta_E{}^*)_{y^*}, \qquad\qquad (4\text{-}1) \\ &\eta^*_{t^*}+(h^*u^*)_{x^*}+(h^*v^*)_{y^*}=0, \end{aligned}$$

with $\eta_E{}^*$ a forcing term, here the equilibrium tide. In a right-handed coordinate system, take the y axis to be aligned with the coast, and x* equal to 0 at the coast, positive offshore. Assume that the depth is a function of offshore distance only,

$$h^*=h^*(x^*) \qquad (4\text{-}2)$$

I next scale the terms by the following representative quantities

$u^\circ, v^\circ \sim U,$

$\partial_t \sim f,$

$\partial_x, \partial_y \sim L^{-1},$

$h \sim H,$

$\eta^\circ \sim fUL/g,$

where L is some estimate of the shelf width and H is some estimate of the offshore depth. I chose L=200km, H=2400m for sections 1,2,3, and L=500km for section G. Then system (1) becomes

$$u^\circ{}_t - v^\circ = -(\eta^\circ - \eta_E{}^\circ)_x, \qquad (4\text{-}3a)$$

$$v^\circ{}_t + u^\circ = -(\eta^\circ - \eta_E{}^\circ)_y, \qquad (4\text{-}3b)$$

$$D^2 \eta^\circ{}_t + (hu^\circ)_x + (hv^\circ)_y = 0, \qquad (4\text{-}3c)$$

where

$D^2 = f^2L^2/gH = (L/\text{Rossby radius of deformation})^2.$

Now assume propagating solutions proportionnal to exp $i(ky-\omega t)$. (4-3a) and (4-3b) can then be solved for u and v to get:

$$u=(i\omega(\eta-\eta_E)_x-ik(\eta-\eta_E))/(1-\omega^2),$$
$$v=(-\omega k(\eta-\eta_E)+(\eta-\eta_E)_x)/(1-\omega^2).$$

Introducing these into (4-3c) yields a single governing equation for the free surface elevation

$$(h\eta_x)_x-(k^2h+kh_x/\omega+(1-\omega^2)D^2)\eta=$$
$$(h\eta_{Ex})_x-(k^2h+kh_x/\omega)\eta_E \qquad (4\text{-}4)$$

Free solutions are obtained by solving (4-4) with η_E set to 0.

C) The Free Wave Solutions

I wish to solve

$$(h\eta_x)_x-(k^2h+kh_x/\omega+(1-\omega^2)D^2)\eta=0 \qquad (4\text{-}5a)$$

with the appropriate boundary conditions

$$hu=0 \text{ at } x=0,$$

or

$$\omega h\eta_x-kh\eta=0 \quad \text{at } x=0, \qquad (4\text{-}5b)$$

and

$$\eta\to 0 \quad \text{as} \quad x\to+\infty. \qquad (4\text{-}5c)$$

(4-5a) can be reduced to a system of two coupled first order equations by setting

$$Y_1=\eta,$$
$$Y_2=h\eta_x,$$

so that (4-5a) becomes

$$Y_1'=Y_2/h, \qquad (4\text{-}6a)$$
$$Y_2'=(k^2h+kh_x/\omega+(1-\omega^2)D^2)Y_1. \qquad (4\text{-}6b)$$

(4-5b) becomes

$$Y_2 - khY_1/\omega = 0 \qquad \text{at } x=0. \qquad (4\text{-}6c)$$

The appropriate deep sea solution to (4-5a) when h=1 for $x \geq 1$ is

$$\eta = \exp-(k^2+(1-\omega^2)D^2)^{1/2}x,$$

so that the appropriate boundary condition at x=1 is

$$Y_1' + (k^2+(1-\omega^2)D^2)^{1/2}Y_1 = 0 \qquad x=1. \qquad (4\text{-}6d)$$

Equations (4-6) can easily be solved numerically for realistic profiles. Huthnance (1975) showed that for the case of a monotonic depth profile, the free solutions for sub-inertial frequencies consist of a Kelvin wave, and a series of shelf waves, all of which propagate phase with shallow water on the right, and decay exponentially offshore. The first shelf wave mode has one zero crossing, the second two, and so on. For a given wave number k, higher modes have lower frequencies, and generally, for a given frequency and mode number there are two solutions to the dispersion relation, with phase propagation in the same direction but with the energy propagation of the shorter wave in the opposite direction. Here, the frequency peak of the second mode lies below the K_1 frequency, so that only the Kelvin wave and the first shelf mode exist as free waves.

D) Forced Wave Solutions

Now solve equation (4-4)

$$(h\eta_x)_x - (k^2h + kh_x/\omega + (1-\omega^2)D^2)\eta =$$
$$(h\eta_{Ex})_x - (k^2h + kh_x/\omega)\eta_E$$

where the forcing is taken to be the equilibrium tide, modified to take into account the self attraction of the tidal bulge and the deformation of the yielding sea bottom. $\eta_E{}^*$ is then

$$\eta_E{}^*=.69V/g$$

where V is the equilibrium tidal potential. Now V sweeps across the earth from east to west every 24 hours for the diurnal tide, or with a non-dimensionnal wave number

$$\alpha=L/(r\cos\theta)$$

with r radius of the earth and θ latitude. Relative to a coastline at an angle ϕ from true North, I can write

$$\eta_E=\exp i(\alpha_E x+\beta_E y-(\omega t-G_E)),$$

where $\alpha_E=-\alpha\cos\phi,$

$\beta_E=-\alpha\sin\phi,$

$G_E=$ West longitude of $x=0$.

Here,

$\alpha=4.08\times10^{-2}$ for sections 1,2,3,

$\alpha=0.12$ for section G,

$\phi=45^\circ$ for all sections,

Dimensionnaly,

$$\eta_E{}^*(0)=H_E,$$

where

$H_E=9.68$cm for profiles 1 and 2,

$=9.55$cm for profile 3,

$=9.74$cm for profile G.

The solution to (4-4) can be written as

$$\eta_F=\eta_E+R(x)\exp i(\beta_E y-\omega t). \tag{4-7a}$$

Substituting (4-7b) into (4-4) gives

$$(hR_x)_x-(\beta_E{}^2h+\beta_E h_x/\omega+(1-\omega^2)D^2)R=(1-\omega^2)D^2\eta_E \qquad (4\text{-}7b)$$

I need, once again, u=0 at x=0, or

$$\omega R_x-\beta_E R=0, \qquad x=0, \qquad (4\text{-}7c)$$

and for $x\to\infty$, we need $\eta_F\to\eta_E$, or $R\to0$ as $x\to\infty$, or in equivalence to (4-6c)

$$R_x+(\beta_E^2+(1-\omega^2)D^2)^{1/2}R=0 \qquad x=1 \qquad (4\text{-}7d)$$

This system of equations is easily solved numerically, involving only a slight modification to equations (4-6), namely the inclusion of a near constant term on the right hand side of (4-7b).

E) Results

Figures 12 to 19 show the solutions to the free and forced problems. Only the longer of the two first mode shelf waves are displayed, as the velocities associated with the shorter waves were unreasonably high in the subsequent least squares fit. The velocity profiles are obviously more sensitive to small variations in cross-shelf topography than the elevation profiles. Since there is a good deal of approximation involved in the determination of the topography, this is clearly another reason why the model wave fitting to data should be based on pressures only.

Table I below summarizes the long-shore dimensionnal characteristics of the waves for each profile.

Table I

	Kelvin	Shelf	Forced
Profile 1	$k=-5.2\times10^{-4}$/km	$k=-1.4\times10^{-2}$/km	$k=\beta_E=-5.2\times10^{-4}$/km
	$\lambda=11979$km	$\lambda=462$km	$\lambda=43558$km
	$c=501$km/hr	$c=19$km/hr	$c=1820$km/hr
Profile 2	$k=-5.2\times10^{-4}$/km	$k=-1.3\times10^{-2}$/km	
	$\lambda=12106$km	$\lambda=501$km	SAME AS
	$c=506$km/hr	$c=21$km/hr	PROFILE 1
Profile 3	$k=-4.7\times10^{-4}$/km	$k=-1.3\times10^{-2}$/km	
	$\lambda=13312$km	$\lambda=493$km	SAME AS
	$c=556$km/hr	$c=21$km/hr	PROFILE 1
Profile G	$k=-4.8\times10^{-4}$/km	$k=-2.6\times10^{-3}$/km	
	$\lambda=13022$km	$\lambda=2407$km	SAME AS
	$c=544$km/hr	$c=101$km/hr	PROFILE 1

Note that characteristics of the three waves are fairly similar for profiles 1 to 3. In the Gulf of Maine, however, while wavenumbers for the Kelvin and forced waves are similar, the shelf wave is radically different, with a wavenumber about four times smaller than that for the other profiles. Clearly, then, the transition of the shelf wave from the Gulf of Maine to beyond is non-trivial. For the Kelvin wave, Miles (1972) shows that a sustained displacement of the coastline induces a change of phase of order $(kx_1)^2$, where x_1 is the magnitude of the displacement. For the Gulf of Maine, x_1 is roughly 300km, so that $k^2x_1^2$ is roughly .02. I thus expect the Kelvin wave to propagate from the Gulf of Maine onto the New England Shelf without noticeable change.

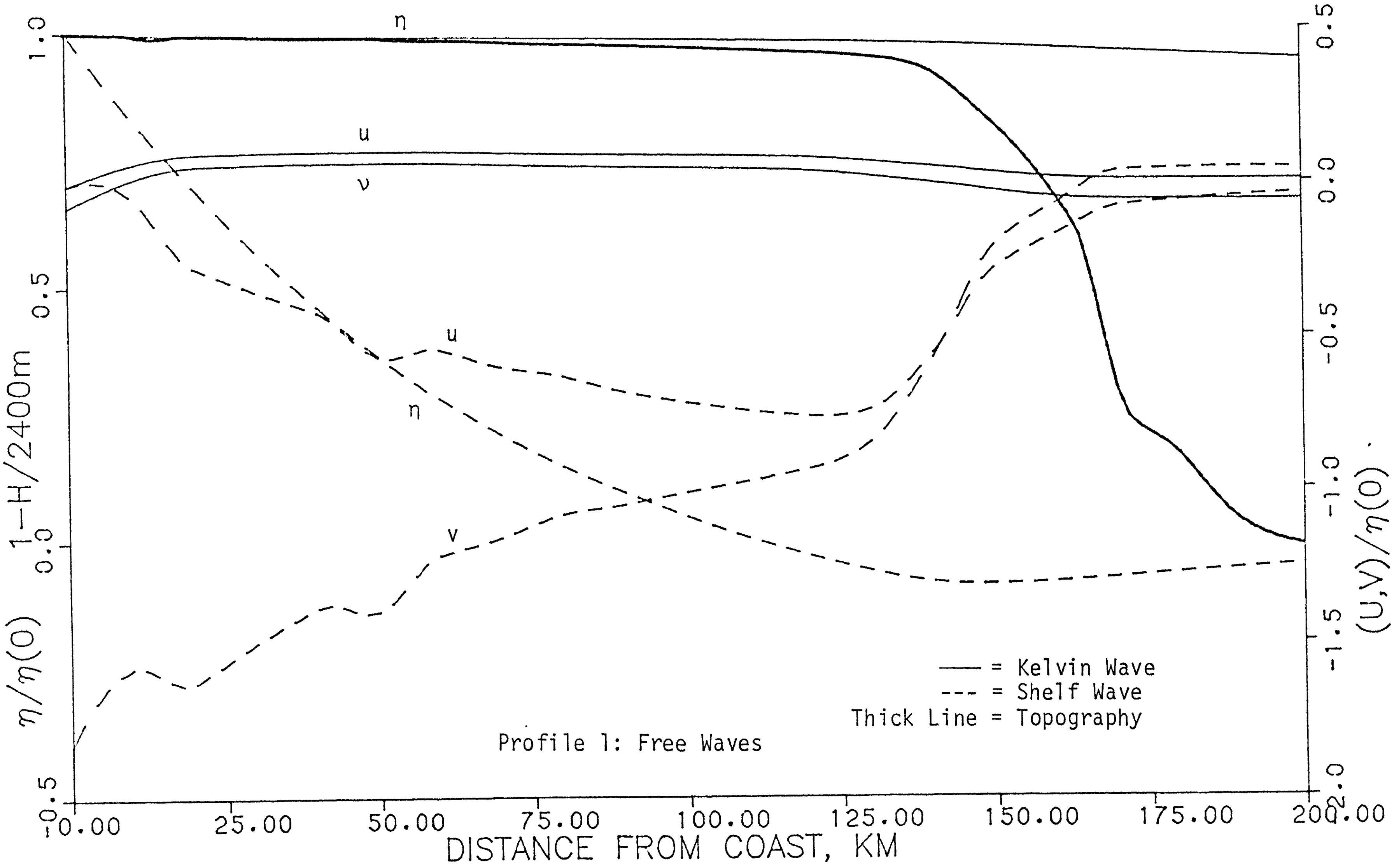

η
u
ν
u
η
v
η/η(0)   1−H/2400m
(U,V)/η(0)
DISTANCE FROM COAST, KM
-0.5
0.0
0.5
1.0
-2.0
-1.5
-1.0
-0.5
0.0
0.5
-0.00
25.00
50.00
75.00
100.00
125.00
150.00
175.00
200.00
—— = Kelvin Wave
--- = Shelf Wave
Thick Line = Topography
Profile 1: Free Waves

FIGURE 12

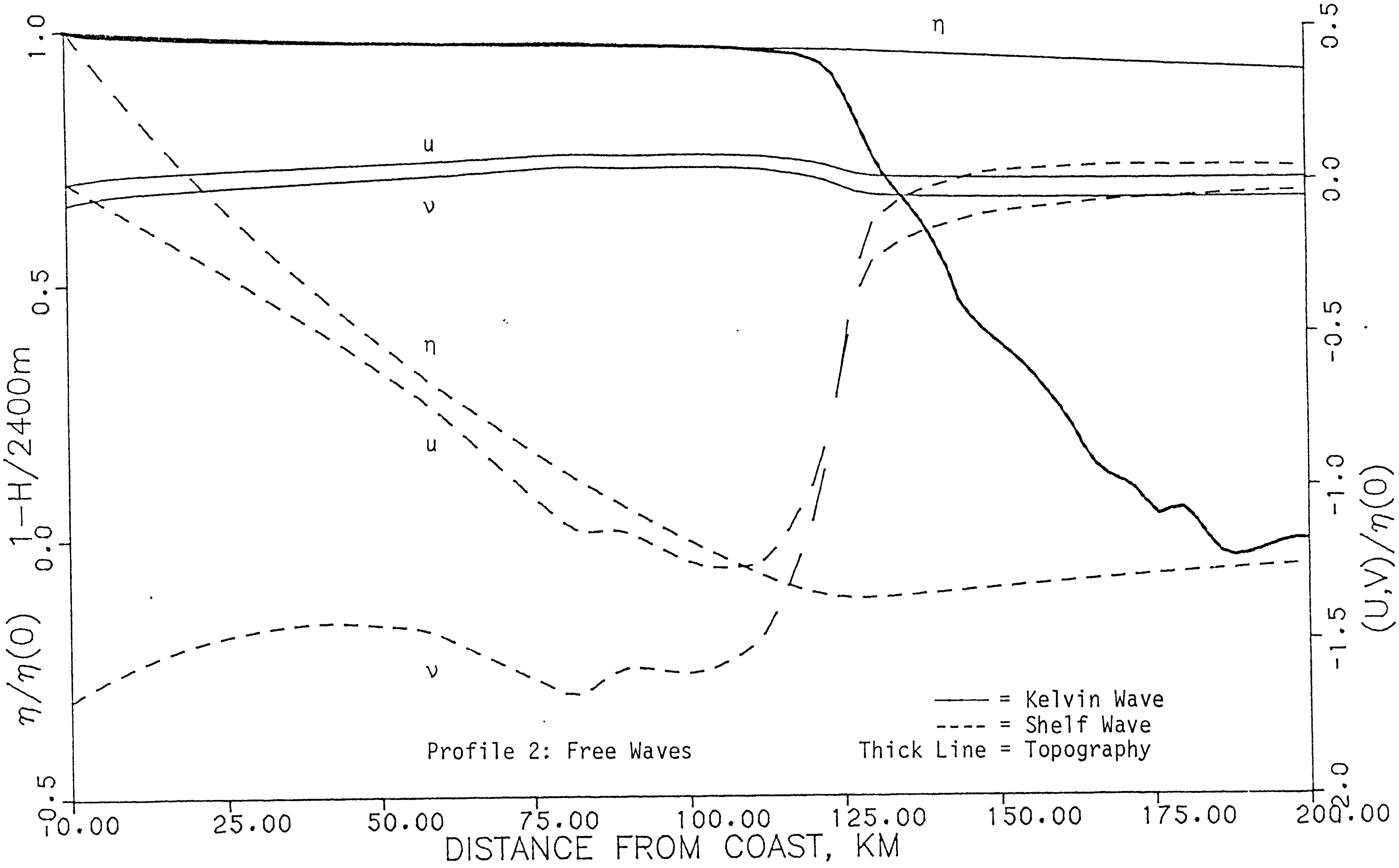

η
u
ν
η
u
ν
Profile 2: Free Waves
——— = Kelvin Wave
---- = Shelf Wave
Thick Line = Topography
1.0
0.5
0.0
-0.5
η/η(O)   1−H/2400m
0.5
0.0
-0.5
-1.0
-1.5
-2.0
(U,V)/η(O)
0.00
25.00
50.00
75.00
100.00
125.00
150.00
175.00
200.00
DISTANCE FROM COAST, KM

FIGURE 13

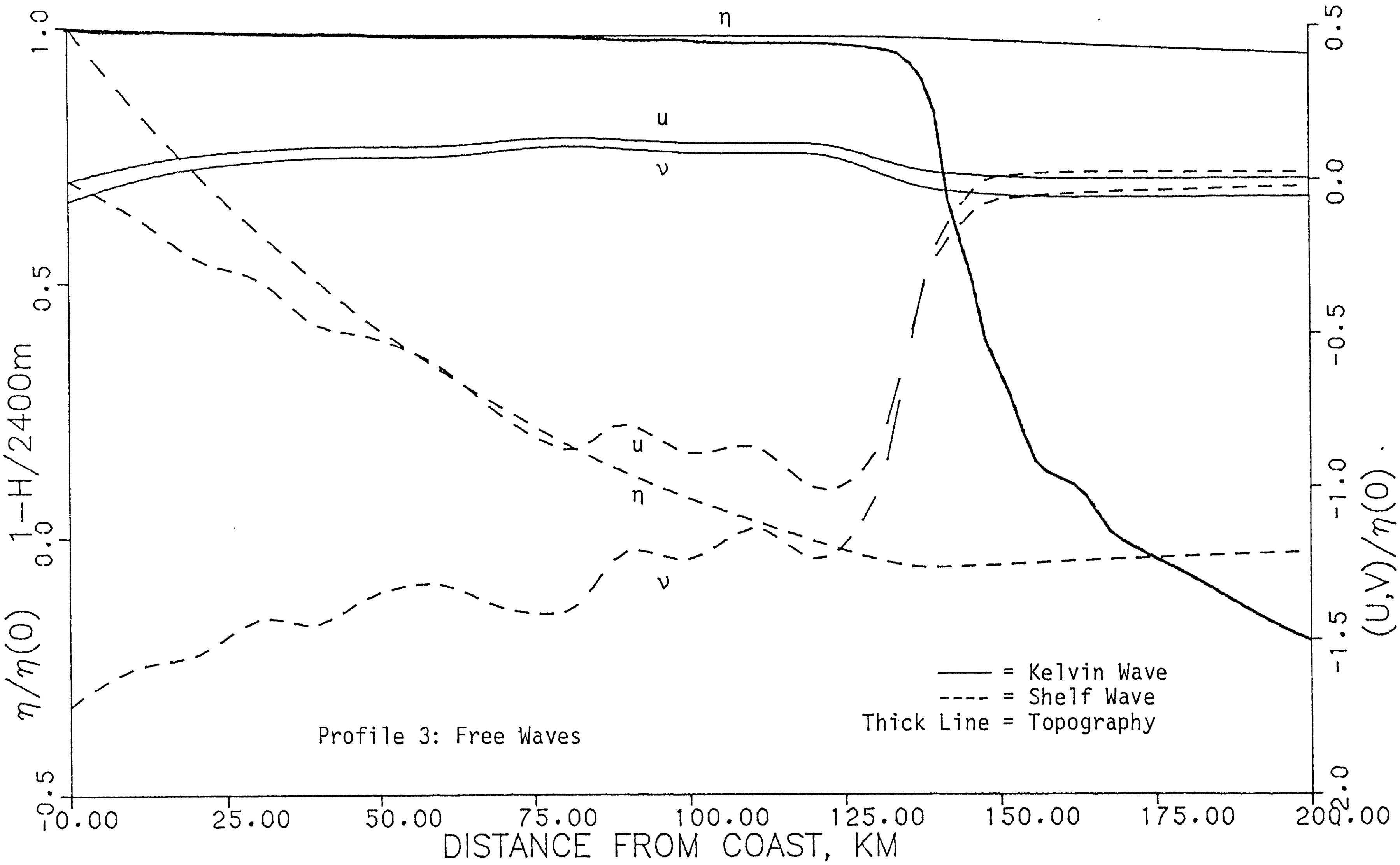

η
u
ν
u
η
ν
1.0
0.5
0.0
-0.5
η/η(0)   1−H/2400m
0.5
0.0
-0.5
-1.0
-1.5
-2.0
(U,V)/η(0)
0.00
25.00
50.00
75.00
100.00
125.00
150.00
175.00
200.00
DISTANCE FROM COAST, KM
—— = Kelvin Wave
---- = Shelf Wave
Thick Line = Topography
Profile 3: Free Waves

FIGURE 14

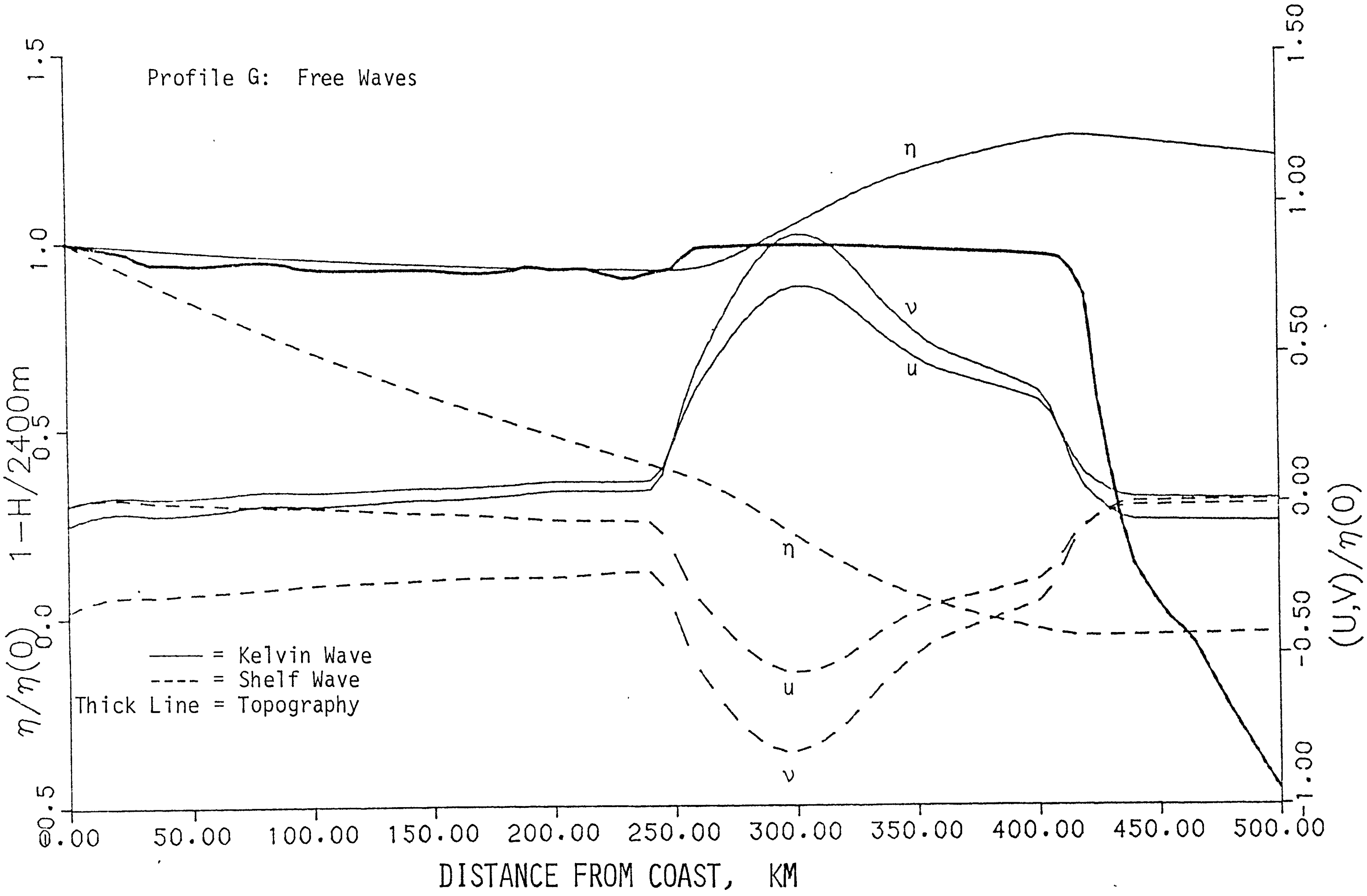

Profile G: Free Waves
η
ν
u
η
u
ν
—— = Kelvin Wave
---- = Shelf Wave
Thick Line = Topography
η/η(O)
1−H/2400m
(U,V)/η(O)
1.5
1.0
0.5
0.0
−0.5
1.50
1.00
0.50
0.00
−0.50
−1.00
0.00
50.00
100.00
150.00
200.00
250.00
300.00
350.00
400.00
450.00
500.00
DISTANCE FROM COAST, KM

FIGURE 15

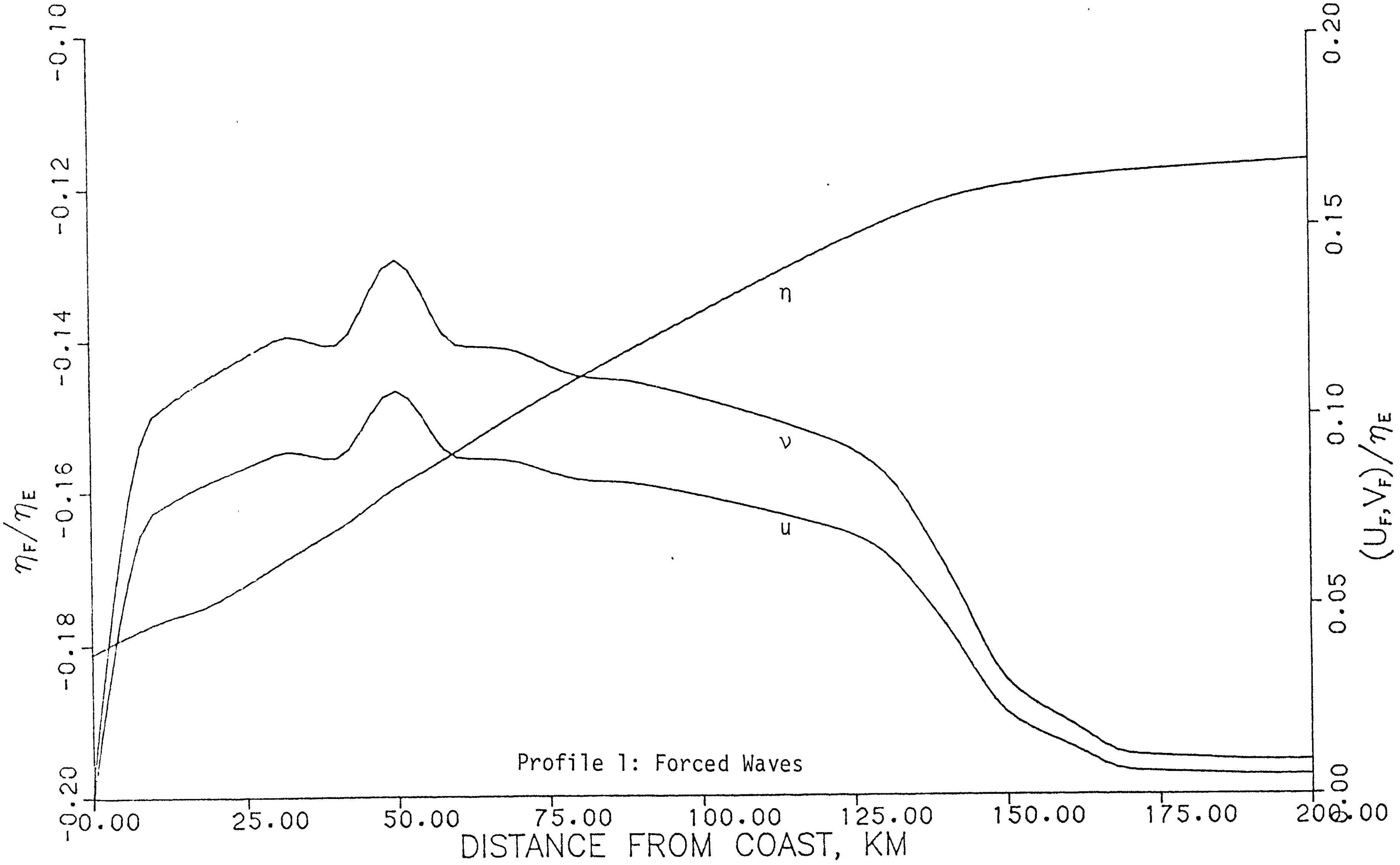

η_F/η_E
-0.10
-0.12
-0.14
-0.16
-0.18
-0.20
$(U_F,V_F)/\eta_E$
0.20
0.15
0.10
0.05
0.00
η
ν
u
Profile 1: Forced Waves
0.00
25.00
50.00
75.00
100.00
125.00
150.00
175.00
200.00
DISTANCE FROM COAST, KM

FIGURE 16

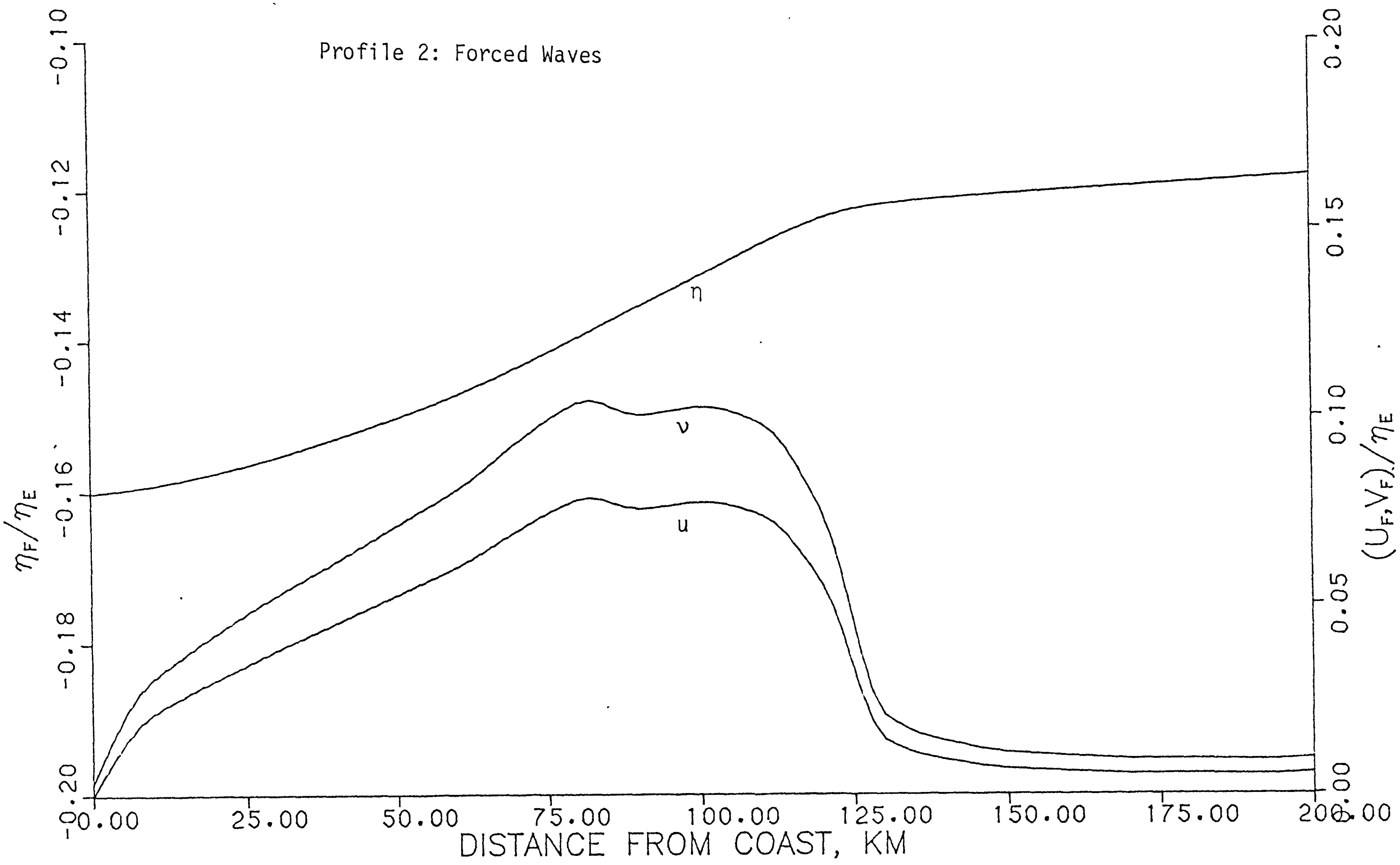

Profile 2: Forced Waves
η
ν
u
η_F/η_E
-0.10
-0.12
-0.14
-0.16
-0.18
-0.20
$(U_F,V_F)/\eta_E$
0.20
0.15
0.10
0.05
0.00
0.00
25.00
50.00
75.00
100.00
125.00
150.00
175.00
200.00
DISTANCE FROM COAST, KM

FIGURE 17

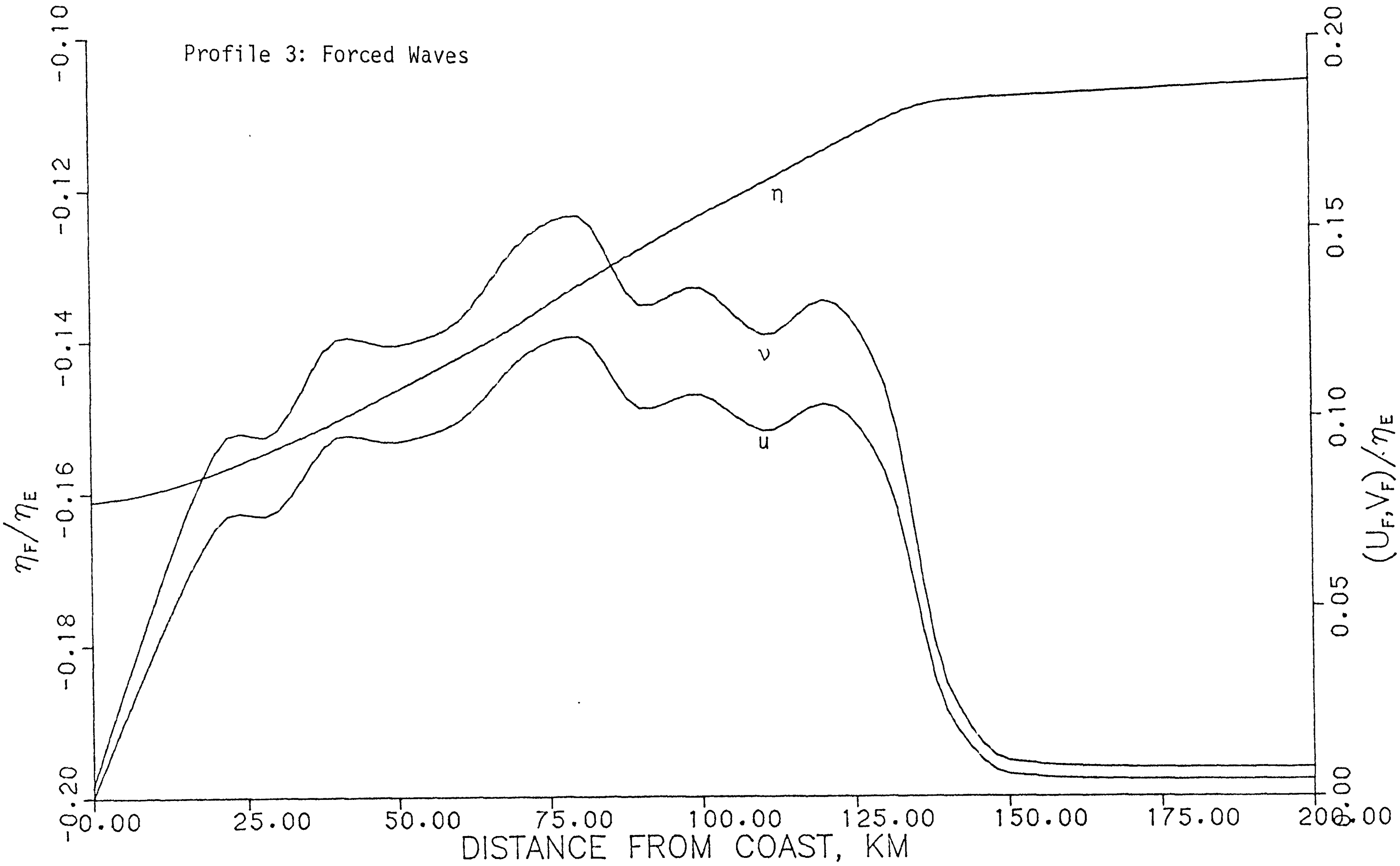

Profile 3: Forced Waves
η
ν
u
η_F/η_E
-0.10
-0.12
-0.14
-0.16
-0.18
-0.20
$(U_F,V_F)/\eta_E$
0.20
0.15
0.10
0.05
0.00
0.00
25.00
50.00
75.00
100.00
125.00
150.00
175.00
200.00
DISTANCE FROM COAST, KM

FIGURE 18

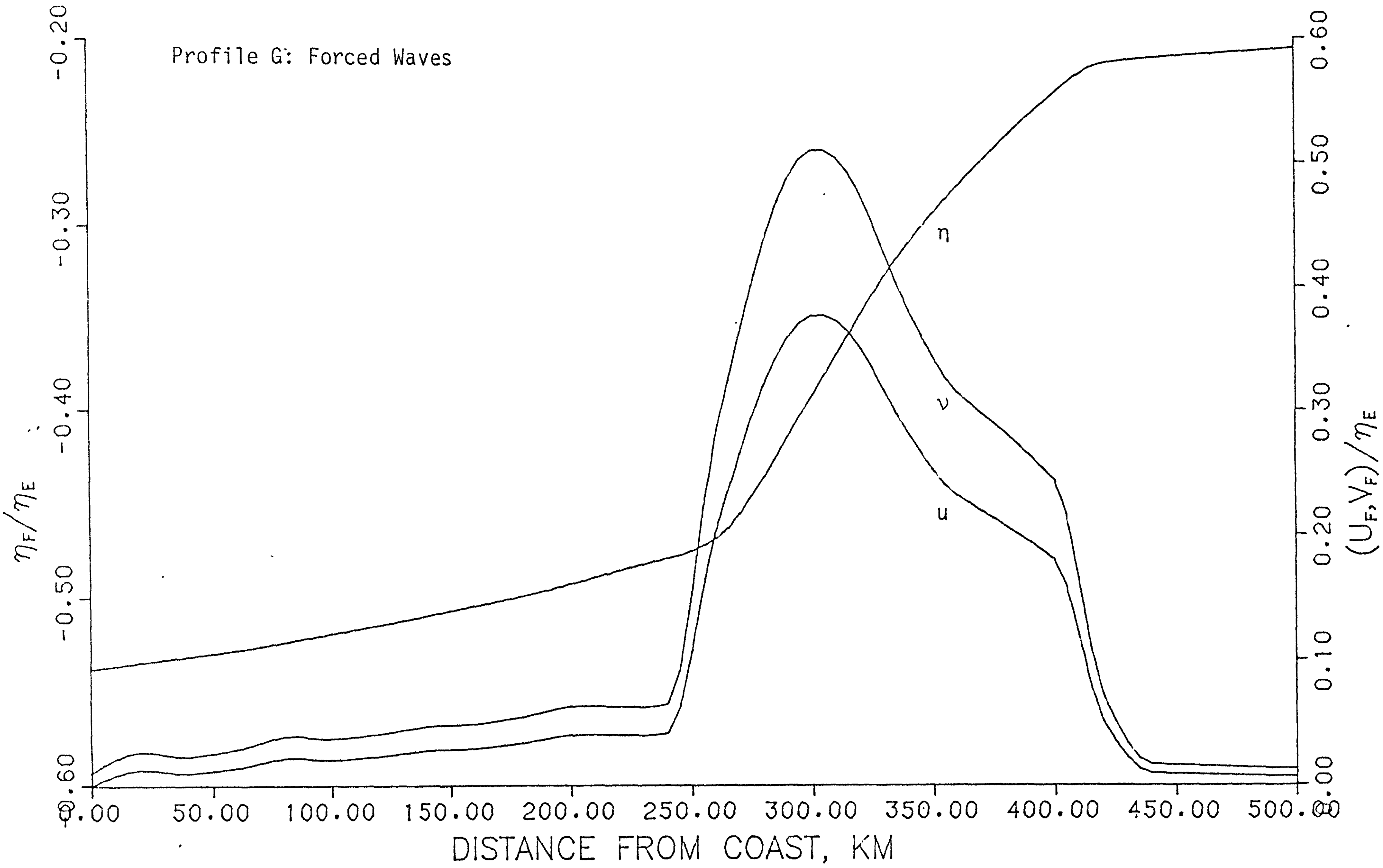

Profile G: Forced Waves
η_F/η_E
-0.20
-0.30
-0.40
-0.50
-0.60
$(U_F,V_F)/\eta_E$
0.60
0.50
0.40
0.30
0.20
0.10
0.00
η
ν
u
0.00
50.00
100.00
150.00
200.00
250.00
300.00
350.00
400.00
450.00
500.00
DISTANCE FROM COAST, KM

FIGURE 19

F) Model to Data Fit

Since the transition of the shelf wave from the Gulf of Maine to the New England Shelf is so problematic, I chose to limit attention to sections 1 through 3 for the main least squares fit. The Kelvin and shelf waves are being fit to the data, the forced problem being totally determined. I regard the amplitudes and phases of the Kelvin and shelf waves to be fixed, so that the only difference from profile to profile is a propagation term, exp(iky). The residual, E, can be written as

$$E=\Sigma\ (D_i-F_i-K_i-S_i)(D_i-F_i-K_i-S_i)^*$$

where i=1,11 numbers stations along profiles 1,2 or 3.

D_i are the various data points, taken from table A1,

$D_i=H_i \exp iG_i$,

$F_i=A_F \exp i(\text{longitude})$=forced term,

$A_F=H_E(1+R_i)$ (see Sec. IV-D),

$K_i=A_K H_{Ki} \exp i(k_K y+\theta_K)$=Kelvin wave,

$S_i=A_S H_{Si} \exp i(k_S y+\theta_S)$=Shelf wave.

H_K, H_S are the normalized sea surface heights calculated previously. A_K, A_S, θ_K, θ_S are the unknowns; y is the distance between sections and is 0 for profile 1; k is the average of the wavenumbers for the profile through the station and the profile upshelf before it. I then take partials of E with respect to $A_K \cos \theta_K$, $A_K \sin \theta_K$, $A_S \cos \theta_S$, $A_S \sin \theta_S$ and set them to 0. This gives me a system of four linear equations in four unknowns, easily solved.

G) Results of Fit

Results of the pressure data fit are displayed in table II. The eleven stations used for the fit are: NSFE1, NSFE2, NSFE4, NSFE5 for profile 1; A4, MESA5 and 1-2-19 for profile 2; Atlantic City, MD, MB and MC for profile 3. Variances are calculated for all eleven stations. "Data variance" is actually the variance of the observed tide minus the forced response, and is thus the variance that has to be reduced by the least-squares fit.

Table II

	Profile 1	Profile 2	Profile 3
	y=0	y=-160km	y=-380km
Kelvin	amp=13.2cm	amp=13.2cm	amp=13.2cm
	ph.=208°	ph.=213°	ph.=219°
Shelf	amp=2.6cm	amp=2.6cm	amp=2.6cm
	ph.=-82°	ph.=38°	ph.=197°
Forced	amp=7.9cm	amp=8.1cm	amp=8.0cm
	ph.=70°	ph.=72°	ph.=74°

Data	Obs.	Calc.	Obs.	Calc.	Obs.	Calc.
	NSFE1		A4		Atl. Cit.	
H,G (cm,deg)	6.5,173	8.6,177	8.4,168	7.4,168	10.7,181	10.6,188
	NSFE2		MESA5		MD	
	7.3,173	8.8,174	8.3,175	7.9,172	10.3,182	8.9,185
	NSFE4		1-2-19		MB	
	8.1,177	8.7,169	6.3,181	7.6,170	9.0,176	8.0,182
	NSFE5				MC	
	8.6,175	8.8,167			9.0,180	7.6,181

Data variance=1933.2cm^2 Residual variance=22.1cm^2

Kelvin variance=1841.2cm^2 Shelf Variance=11.3cm^2

Using the calculated amplitudes and phases for η, the associated cross-shelf u and along-shelf v velocities can be calculated for the current meter stations which lie along the various profiles. These composite velocities are listed in Table III.

Table III

Profile 1

Station	u		v	
	Amp.	Phase	Amp.	Phase
NSE	1.5	-133	4.7	100
NSFE1	2.1	-148	4.6	99
NSFE2	2.1	-145	3.7	101
NSFE3	2.3	-150	3.2	103
NSFE4	2.3	-152	3.1	101
NSFE5	2.3	-155	3.0	100

Variance Kelvin=13.8cm^2/sec^2

Variance Shelf=72.8cm^2/sec^2

Variance Forced=11.4cm^2/sec^2

Profile 2

Station	u		v	
	Amp.	Phase	Amp.	Phase
CMICE	.6	-63	3.4	-143
MESA5	3.4	-61	4.3	-150
NES762W	3.8	-60	4.2	-150
NES763W	.4	-59	.8	41

Variance Kelvin=5.3cm^2/sec^2

Variance Shelf=73.0cm^2/sec^2

Variance Forced=3.2cm^2/sec^2

Profile 3

station	u		v	
	Amp.	Phase	Amp.	Phase
EGG	.2	-77	4.9	22
MB	.8	112	2.5	29
MF	1.7	117	2.7	31

Variance Kelvin=8.2cm^2/sec^2

Variance Shelf=45.2cm^2/sec^2

Variance Forced=4.6cm^2/sec^2

From the above, clearly the Kelvin wave dominates the pressure signal, while the shelf wave dominates the velocity field. The dominance of the shelf wave velocities is apparent in the data: despite the combination of three different waves with very different characteristics, the cross-shelf structure of the velocities is remarkably coherent. Figure 20 shows the predicted cotidal-corange map, for comparison with figure 5. Note the progression of the Kelvin wave offshore, while nearshore the interaction with the shelf wave "traps" the phase lines to the coast. There is a virtual amphidrome 120km from Profile 1, and the hint of another beyond Profile 3. While similar patterns can be seen in figure 5, the detail is not reproduced. In particular, the virtual amphidrome of figure 5 is shifted westward in figure 20. Figures 21 to 23 compare the suitably rotated velocities for each profile, with the observed velocities on the right, and the corresponding predicted velocities on the left. In all these figures, the ellipses are oriented so that the vertical is true North. Apart from Profile 1, the calculated velocities are not embarassingly different from the observed ones, and in most cases lie within the 95 percent confidence limits.

I used a similar scheme for the Gulf of Maine. Propagation from the Gulf to the New England Shelf was assumed to have little effect on the Kelvin wave phase speed, allowing the Kelvin wave phase to be set as $(k_K y + \theta_K)$. The shelf wave amplitude and phase were allowed to vary. The unknowns in this case are thus the amplitude of the Kelvin wave, and the amplitude and phase of the shelf wave. The seven stations used were GOM1, GOM2, M1, D, M3, M4 and M5. The results are displayed below.

Table IV

Gulf of Maine

y=+280km

Kelvin Ampl.=9.7cm	Shelf Ampl.=10.4cm	Forced Ampl.=4.5cm
Phase=200°	Phase=230°	Phase=70°

Stations	Observed		Calculated	
GOM1	ampl.=13.3	Phase=200	ampl.=14.8	Phase=205
GOM2	12.8	200	12.9	201
M1	11.2	199	9.4	189
D	10.7	197	9.1	186
M3	6.6	178	9.0	166
M4	7.5	182	9.3	160
M5	8.0	171	9.3	159

Data variance=1393.5cm^2　　Residual Variance=42.7cm^2

Kelvin variance=766.7cm^2　　Shelf Variance=181.7cm^2

Table IV (cont.)

Velocities

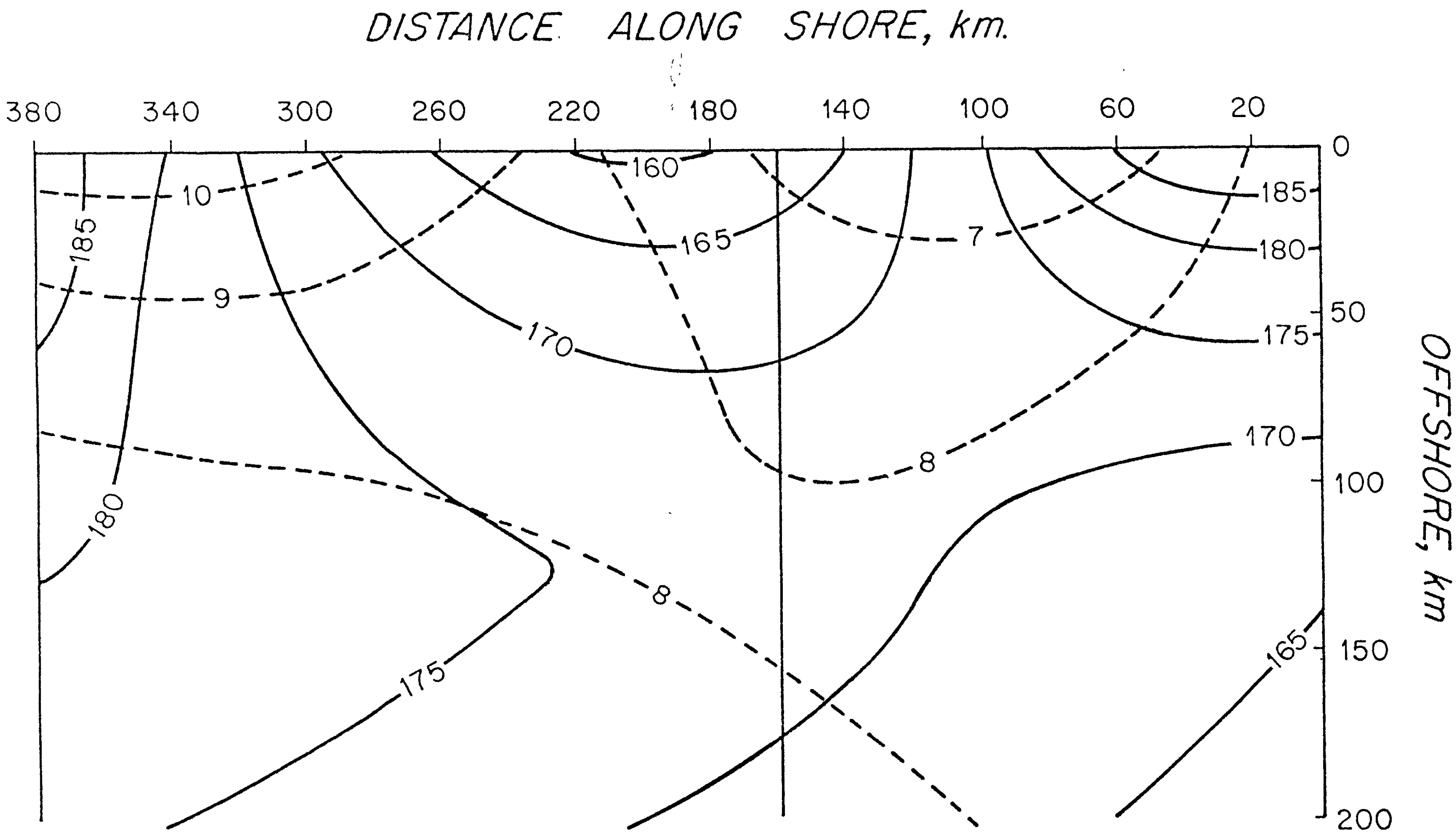
station	u		v	
	Amp.	Phase	Amp.	Phase
GOM1	.3	-74	3.8	49
GOM2	.4	-92	3.2	52
D	2.8	-172	4.9	83
K	3.6	-162	5.0	97

Variance Kelvin=69.8cm^2/sec^2

Variance Shelf=90.2cm^2/sec^2

Variance Forced=24.1cm^2/sec^2

As can be seen, the residuals are proportionately much greater than for the other profiles. Figure 24 compares the observed to the calculated velocities. Despite the poorness of the pressure fit, the velocities compare quite well.



Predicted Co-tidal Map for Profiles 1 to 3.

--- lines of equal amplitude in cm
—— lines of equal phase
vertical lines = location of profiles

FIGURE 20

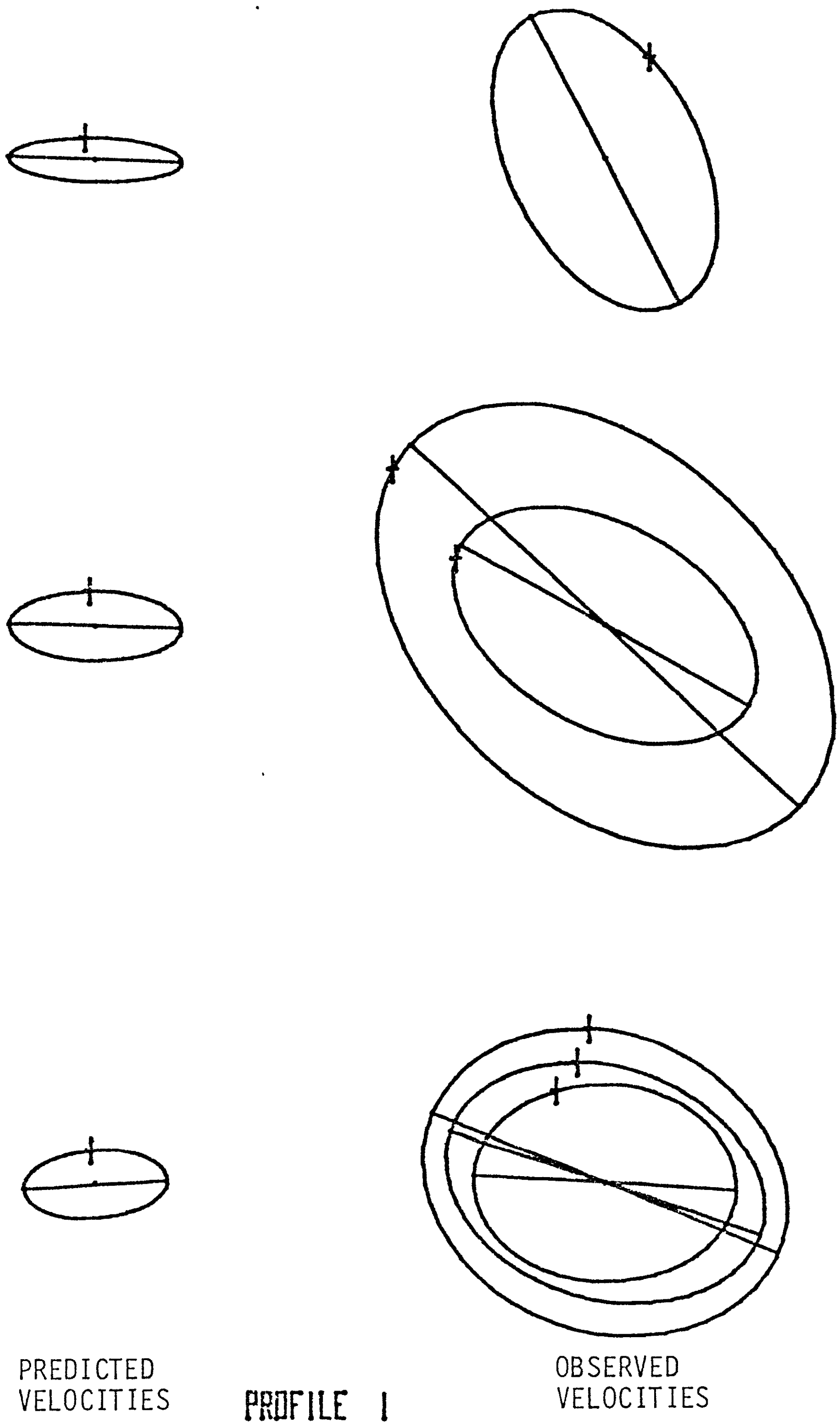
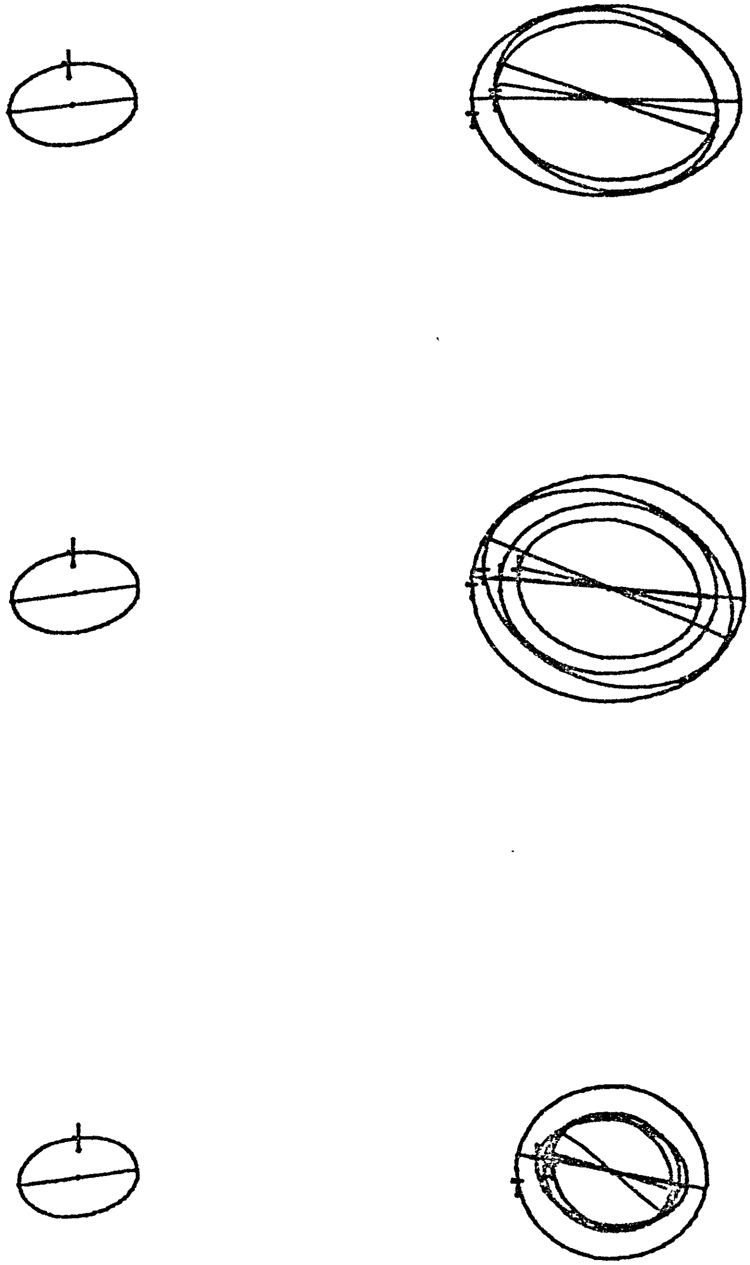


FIGURE 21a

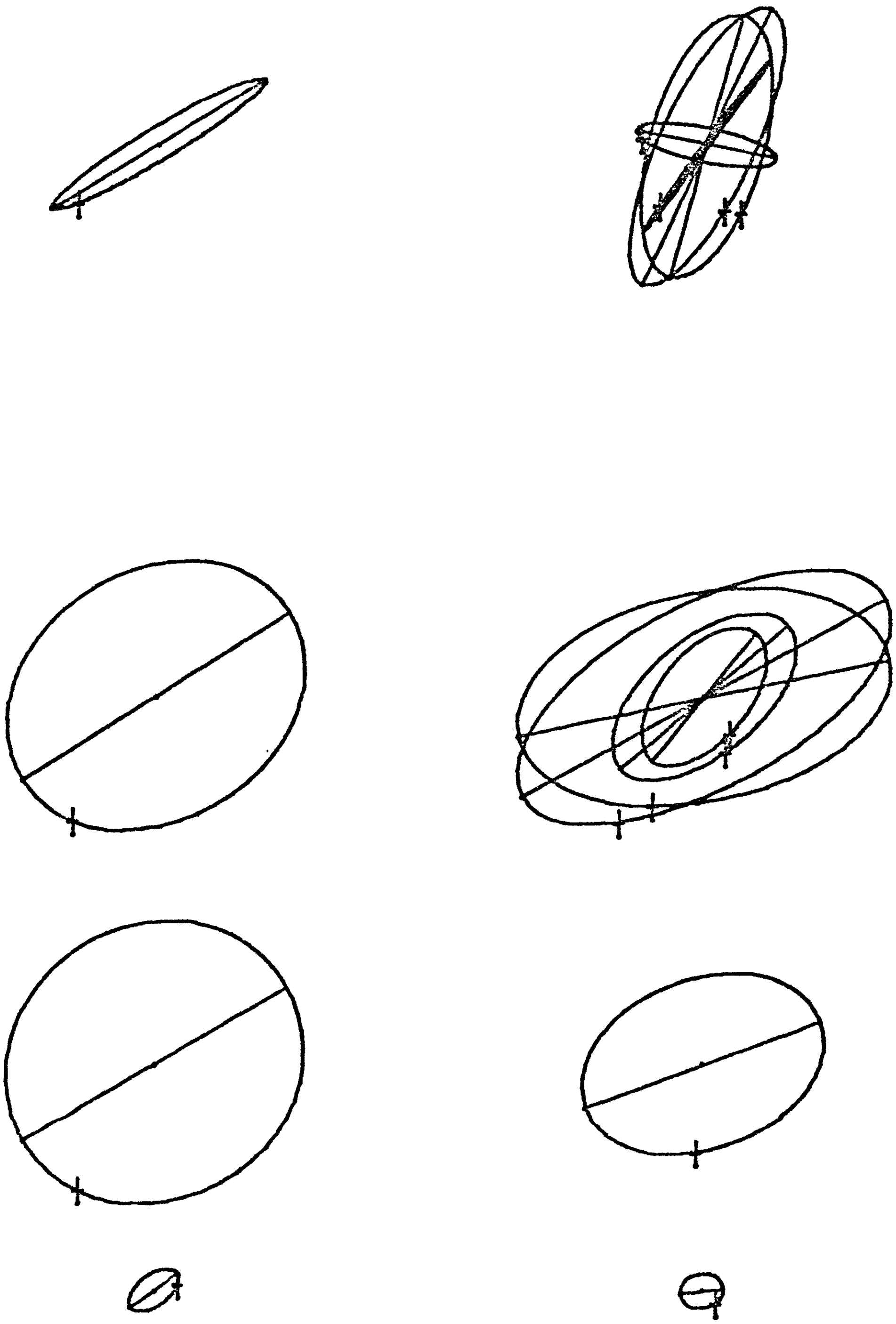


PREDICTED
VELOCITIES

OBSERVED
VELOCITIES

PROFILE 1 (CONT.)

FIGURE 21b



PROFILE 2

PREDICTED
VELOCITIES

OBSERVED
VELOCITIES

FIGURE 22

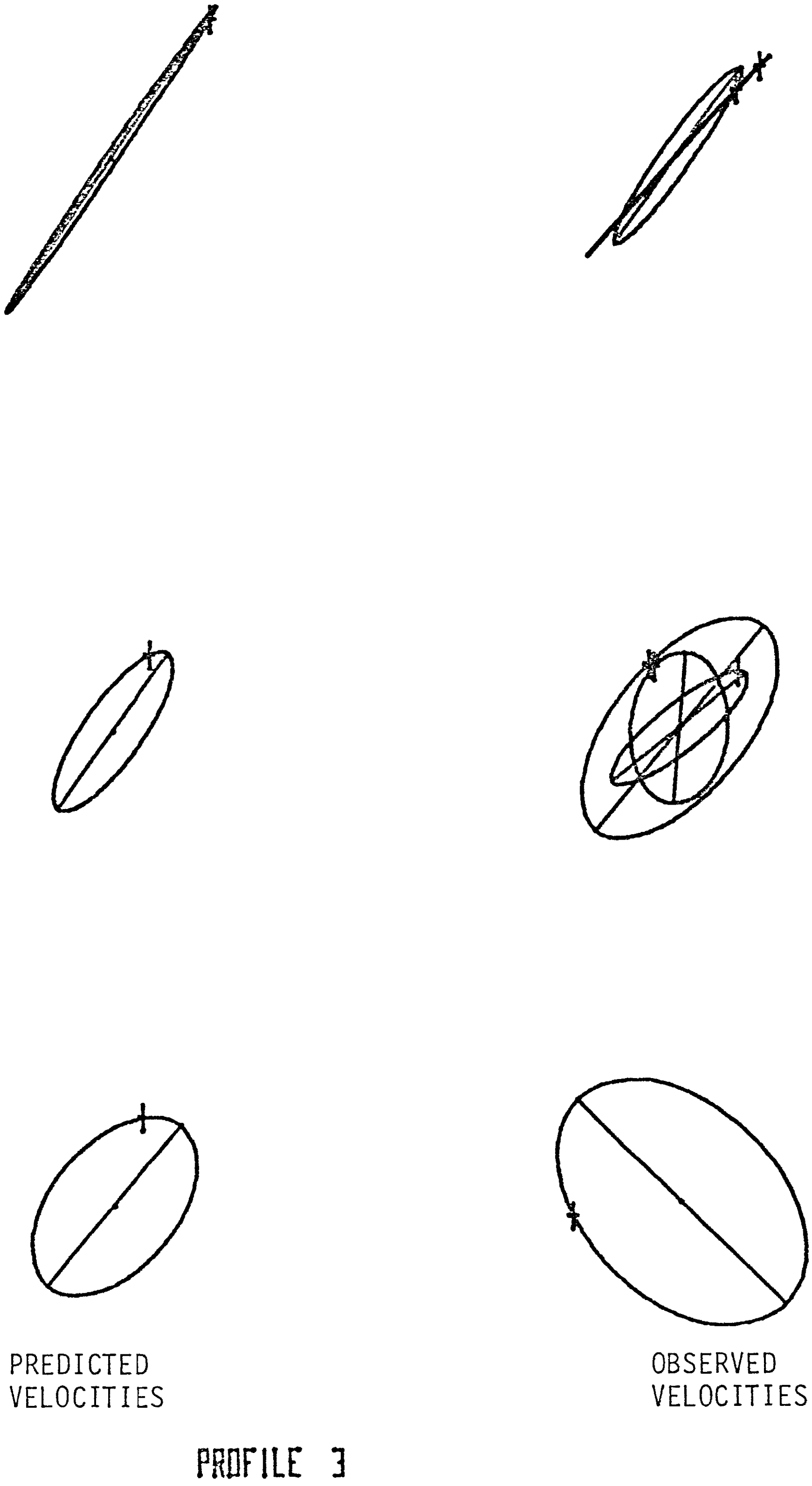


FIGURE 23

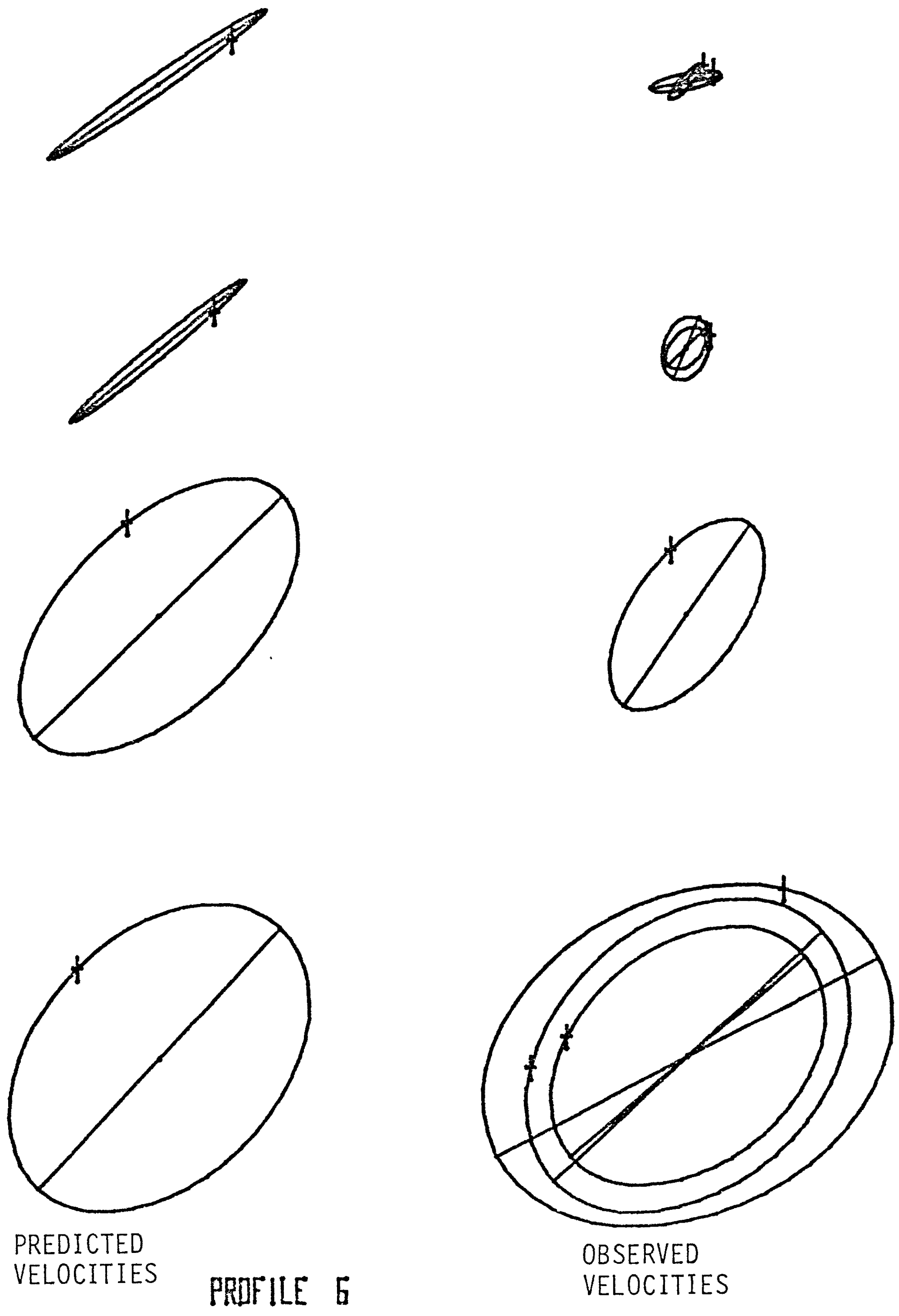


FIGURE 24

V) Discussion

Despite the low residuals, the comparison of figures 5 and 19 shows that the fit is not as good as one could wish. In particular, the virtual amphidrome south of Cape Cod which seems to be caused by the Gulf of Maine is not described at all by the predicted fit. In addition, a quick glance at figures 21 to 24 will show that the worst discrepancies for the velocities also occur for profile 1, where the theory is unable to explain the relatively large observed currents. I tried pushing my simple theory to its limits: I included the short first mode shelf wave, but this did not lower the pressure residuals appreciably, and made the velocities too high. The amplitudes of the Kelvin and Shelf waves were also allowed to vary from profile to profile. In order to get a least-squares fit, the variation in the shelf wave amplitude from profile to profile became unrealistically large, indicating that there should be easier ways of improving the fit. There are two types of changes that could be incorporated into the model. The first consists of improving on the physics, by incorporating new physical processes into the equations of motion. The second consists of dealing with long-shore variations in topography.

There are two physical processes that come to mind: baroclinic effects, and frictional effects. Baroclinicity is of secondary importance. Huthnance (1978) shows that the effects of stratification are greatest at high wavenumbers. The frequencies for a given wavenumber are raised, so that there may be no shorter first mode wave at the K_1 frequency.

Lines of constant velocity tend to tilt away from the vertical with increasing stratification, so that shorter waves may become bottom trapped. In light of this, there should be no great modifications to the model from the inclusion of stratification, especially since the shorter first mode shelf wave has not been included. Frictional effects are likely to be more important. Brink and Allen (1978), in the limit of low frequency shelf waves ($\omega << f$), show that incorporating a linear friction term $-rv/h(x)$ produces a cross-shelf phase shift, such that flow nearshore leads offshore flow. Mofjeld (1980) demonstrates similar behaviour for the Kelvin wave. Table II shows such a trend, with near-shore calculated phases higher than observed, and near-slope calculated phases lower than observed. Thus, if an extension of the Brink and Allen (1978) study were to yield similar phase shifts, we would see an improvement in the fit. In particular, the strong semi-diurnal currents on Georges Bank contribute to enhanced bottom friction in that location.

So far, the shelf has been assumed to be infinitely long, with no alongshore variations in depth. The various solutions then have been assumed to flow smoothly into one another, at least for profiles 1 through 3. Again, following Miles (1972), these assumptions are probably valid for the Kelvin wave and the forced wave, due to their very large scales. Hsueh (1980) shows that alongshore variations in topography tend to scatter the shelf wave into all possible modes at the same frequency. In addition, the scattering of the incoming wave produces a cross-shore phase shift downstream of the irregularity, the sign of which depends on the sign of h_y. Here, where only the first mode is permitted, the scattering is limited to forward scattering of the incoming wave, to backscattering into the shorter first mode wave, and, (e.g. Brink, 1980), to scattering into non-propagating higher modes. The phase shifts are likely to cancel each other out, over a long and varied length of coast line.

Finally, there is the transition problem from the Gulf of Maine to the New England shelf. This is likely to be an important consideration, since the cotidal map shows a significant effect of the Gulf on the New England shelf, in particular helping to define a virtual amphidrome. The problem is not trivial, since it involves the matching of the shelf wave across the Northeast Channel to the north, and the Great South Channel to the south. At a more basic level, the Gulf of Maine is approximately 400 km long, or a fraction of the wave length of the shelf wave, so that the existence of the shelf wave in this context is in doubt. This is clearly an area for further study, possibly by a numerical model for the region.

VI) Conclusion

I have analysed available current meter data on the continental shelf from Nova Scotia to Cape Hatteras. I have tabulated the tides for five major lines, M_2, S_2, N_2, O_1 and K_1 (see appendix). I obtained analysed pressure data for the same area, and examined the K_1 tide in detail. Offshore, there is a general sweep of the tide from north to south. Near the coast, there is a virtual amphidrome south of Cape Cod. This amphidrome coincides with a zone of high velocities (~ 10cm/sec). Current ellipses are generally aligned with the local topography.

Following procedures used by Munk *et al.* (1970), and Cartwright *et al.*

(1980) we have gone one step further by calculating wave forms for four realistic profiles. A least squares fit to three of these shows that, despite its shortcomings, the model can account for a good deal of the variance in the K_1 pressure field. Clearly, in addition to the forced wave, there exists a Kelvin wave and a shelf wave, with the Kelvin wave dominating the sea surface field, and the shelf wave the velocity field. The forced wave is a first order local response to the gravitational forcing, while the free Kelvin and shelf waves are a response to the incoming deep sea tide, and a secondary response to the interaction of the forced wave with the shelf.

I have outlined ways of extending our model, with the most likely improvements taking into account bottom friction and the transition from the Gulf of Maine to the New England shelf.

One would expect similar results to hold wherever $D^2=f^2L^2/gH$ is small enough. Huthnance (1975) shows that ω is a monotonically decreasing function of D for a given k, and Buchwald and Adams (1968) show that for a given offshore depth H there is a maximum allowed frequency ω_{max}. If ω_{max} is less than ω_{K1}, then there will be no diurnal shelf wave, so that diurnal currents will consequently be small.

VII) Appendix

Tables are presented of the analysed tides for pressures and currents. The harmonic constants for five major lines, M_2, S_2, N_2, K_1 and O_1 are listed along with the 95 percent confidence limits where possible. Confidence limits for the pressures apply only to the K_1 harmonic constants. Amplitudes are in centimeters for the pressures, centimeters per second for the velocities, and degrees for all phases. The phases are all referenced to Greenwich.

The data records for the Mid Atlantic Bight stations were made available by W. Boicourt of the Cheasapeake Bay Institute. I personally analysed most of the current data, with the following exceptions: Scotian Shelf stations SS were taken from Petrie (1974); Bay of Fundy stations were obtained from a data report (Inshore Tides and Currents Group, 1966); New Jersey Coast stations are from EG+G (1978); USGS data is courtesy of B. Butman and J. Moody of the USGS. As for pressures, most are courtesy of W. Brown, UNH, with the following exceptions: Canadian stations, with the exception of Yarmouth, are from a report by the Tides and Water Levels Marine Science Branch, Department of Energy (1969). Portsmouth and Atlantic City are from a report by the Coast and Geodetic Survey (1942); stations 1-2-16, 1-2-17 and 1-2-19 are from a report of the IAPSO Advisory Committee (1979); stations MB, ME, K, MC, and MD are, as above, courtesy of the USGS.

Table A1

COASTAL AND OFFSHORE
PRESSURES
FROM NOVA SCOTIA
TO CAPE HATTERAS

Coastal Pressures

				K1		95% limits		O1		M2		S2		N2	
				H cm	G deg	H cm	G deg	H cm	G deg	H cm	G deg	H cm	G deg	H cm	G deg
Whitehead	45.23N	61.18W		4.6	47										
Owl's Head	44.53N	64.00W		11.3	71										
Lockeport	43.70N	65.12W		12.8	147										
Pinkney Pt	43.72N	66.07W		12.2	184										
Port Maitland	43.98N	66.15W		15.1	183										
Yarmouth	43.80N	66.13W	326 days	14.0	186	±.5	±2	11.1	164	165.8	62	23.3	90	32.1	33
Centreville	44.55N	66.03W		15.0	189										
Wood Isl.	44.60N	66.80W		12.5	176										
Dipper Hbr	45.10N	66.43W		15.8	191										
C. Enrage	45.60N	64.78W		18.3	194										
Portland	43.65N	70.25W	239 days	14.2	202	±.2	±1	11.2	185	137.2	102	22.0	135	30.0	72
Portsmouth	43.08N	70.73W		12.8	208										
Boston	42.35N	71.04W	242 days	14.3	205	±.2	±1	11.3	187	137.4	108	21.3	143	30.8	78
Woods Hole	43.51N	43.67W	211 days	6.8	190	±.6	±5	6.4	203	22.8	36	6.2	39	7.7	22
Nantucket	41.28N	70.10W	211 days	9.1	224	±1.1	±6	8.4	218	42.9	135	3.9	156	11.3	108

Coastal Pressures(cont.)

				K1		95% limits		O1		:	M2		S2		N2	
				H	G	H	G	H	G	:	H	G	H	G	H	G
				cm	deg	cm	deg	cm	deg	:	cm	deg	cm	deg	cm	deg
Montauk Pt	41.08N	71.81W	113 days	7.2	161			4.1	194	:	33.4	10	7.9	29	8.4	0
Sandy Hook	40.47N	74.01W	237 days	10.1	178	±.8	±4	5.8	172	:	67.1	10	14.9	40	15.2	356
Atlantic City	39.35N	74.42W		10.7	181					:						
C. May	38.95N	74.83W	208 days	10.5	198	±.8	±2	8.4	187	:	71.1	28	13.3	54	16.0	11

Offshore Pressures

				K1		95% limits		O1		:	M2		S2		N2	
				H cm	G deg	H cm	G deg	H cm	G deg	: :	H cm	G deg	H cm	G deg	H cm	G deg
Sable Isl.	43.97N	59.80W		2.7	162					:						
B1	42.80N	63.21W	62 days	6.7	172	±.2	±2	5.4	177	:	48.3	350	11.0	24	12.5	323
B21	42.62N	64.38W	57 days	6.2	161	±.3	±3	5.4	178	:	48.7	356	10.4	24	13.2	341
Seal Isl.	43.48N	66.00W		13.7	179					:						
M7	41.96N	66.33W	183 days	7.6	182	±.2	±1	6.5	178	:	41.0	38	8.6	59	9.7	12
U2	42.23N	65.85W	160 days	8.1	170	±.3	±2	6.3	177	:	45.4	24	9.1	46	11.9	358
B22A	42.12N	65.57W	57 days	7.5	179	±.4	±3	5.7	182	:	45.6	4	9.6	30	12.2	347
B22B	42.05N	65.63W	57 days	7.7	181	±.3	±2	5.6	182	:	44.0	9	9.0	33	12.0	351
GOM1	40.67N	69.38W	56 days	13.3	200			10.9	183	:	131.0	100	22.0	128	29.3	63
GOM2	43.18N	69.08W	57 days	12.8	200			10.5	184	:	120.5	98	20.3	126	27.0	62
GOM3	43.22N	70.28W	73days	13.3	203			10.6	185	:	126.6	104	21.8	132	29.0	68
B3	41.72N	65.80W	84 days	7.1	169	±.2	±1	5.7	177	:	39.6	1	8.7	29	10.0	336
D	41.99N	67.79W	94 days	10.7	197	±.7	±3	8.8	186	:	77.2	92	19.0	162	18.3	65
M1	42.07N	67.83W	556 days	11.2	199	±.1	±1	8.5	185	:	78.2	92	12.2	121	18.0	63
B6	42.47N	67.72W	62 days	11.0	195	±.3	±2	9.0	180	:	88.3	87	13.3	119	20.9	57

Offshore Pressures(cont.)

				K1		95% limits		O1		:	M2		S2		N2	
				H cm	G deg	H cm	G deg	H cm	G deg	:	H cm	G deg	H cm	G deg	H cm	G deg
M3	41.33N	67.25W	122 days	6.6	178	±.4	±3	6.6	179	:	39.6	22	9.8	15	10.0	354
M4	40.92N	66.97W	266 days	7.5	182	±.1	±1	5.4	190	:	38.3	15	12.2	68	9.2	356
M5	40.73N	66.81W	404 days	8.0	171	±1.0	±7	6.1	178	:	40.5	356	9.2	24	9.3	337
K	41.05N	67.57W	4x29 days	7.5	175					:						
B23	40.37N	67.75W	57 days	7.6	162	±.3	±2	6.1	183	:	40.4	356	8.7	22	8.8	341
M9	40.89N	67.39W	316 days	7.7	181	±.2	±1	5.8	189	:	38.7	21	11.8	37	9.7	358
U1	40.82N	69.00W	136 days	7.0	193	±.4	±3	7.4	192	:	25.9	47	4.8	58	7.1	21
KIWI	39.90N	69.42W	78 days	8.7	176	±.1	±1	6.7	180	:	41.4	349	8.1	15	11.0	334
NSFE1	40.69N	70.14W	365 days	6.5	173	±.2	±1	5.6	190	:	38.7	356	8.9	18	9.4	340
NSFE2	40.49N	70.21W	58 days	7.3	173	±.3	±2	5.9	188	:	40.4	354	8.7	17	9.6	338
NSFE4	40.22N	70.31W	374 days	8.1	177	±.1	±1	6.5	185	:	41.8	353	9.2	18	9.7	336
NSFE5	40.04N	70.38W	365 days	8.6	175	±.1	±1	6.5	183	:	41.9	351	9.1	17	10.3	335
PICKET	40.72N	71.32W	79 days	7.1	159	±.5	±3	5.3	182	:	42.4	334	9.5	0	12.0	317
NES763	39.93N	71.05W	136 days	8.7	178	±.3	±2	6.9	181	:	43.3	349	8.9	17	10.4	332
A4	40.57N	72.30W	61 days	8.4	168	±1.1	±7	5.1	178	:	48.1	346	11.4	12	12.1	329

Offshore Pressures(cont.)

				K1		95% limits		O1		:	M2		S2		N2	
				H	G	H	G	H	G	:	H	G	H	G	H	G
				cm	deg	cm	deg	cm	deg	:	cm	deg	cm	deg	cm	deg
MESA5	40.19N	72.00W	183 days	8.3	175	±.5	±3	5.9	185	:	46.8	349	10.4	15	11.3	331
1-2-19	39.17N	71.37W	43 days	6.3	181			9.6	166	:	44.7	350	9.1	26	11.2	341
1-2-17	39.22N	72.17W	29 days	8.5	170			8.1	185	:	43.8	345	9.5	8	9.1	332
A1	40.12N	72.91W	184 days	9.1	169	±.4	±2	5.8	175	:	53.4	378	11.7	15	12.9	330
ME	39.95N	72.60W	3x29 days	8.9	172					:						
A2	39.40N	73.73W	180 days	9.8	177	±.4	±2	6.7	174	:	54.4	352	11.8	19	13.1	333
MD	38.98N	74.05W	4x29 days	10.3	182					:						
MB	38.73N	73.63W	3x29 days	9.0	176					:						
MC	38.53N	73.52W	3x29 days	9.0	180					:						
1-2-16	37.37N	73.08W	29 days	8.5	171			7.4	178	:	43.4	340	8.8	6	9.8	323

Table A2

VELOCITIES
FROM NOVA SCOTIA
TO CAPE HATTERAS

Scotian Shelf

		K1		O1		95% limits		M2		S2		N2		95% limits	
		H cm/s	G deg	H cm/s	G deg	H %	G deg	H cm/s	G deg	H cm/s	G deg	H cm/s	G deg	H %	G deg
SS1,14 44.4N 63.5W 14m	E	2.9	272												
	N	5.3	175												
SS1,95 44.4N 63.5W 95m	E	1.8	77												
	N	2.3	221												
SS2,20 43.8N 63.0W 20m	E	4.2	253												
	N	1.7	232												
SS2,50 43.8N 63.0W 50m	E	5.5	282												
	N	2.3	267												
SS2,95 43.8N 63.0W 95m	E	3.9	279												
	N	2.7	285												
SS2,250 43.8N 63.0W 250m	E	3.0	295												
	N	3.6	315												

Scotian Shelf(cont.)

		K1		O1		95% limits		M2		S2		N2		95% limits	
		H cm/s	G deg	H cm/s	G deg	H %	G deg	H cm/s	G deg	H cm/s	G deg	H cm/s	G deg	H %	G deg
SS3,20 43.4N 62.7W 20m	E	7.4	269												
	N	4.9	187												
SS3,50 43.4N 62.7W 50m	E	7.8	245												
	N	5.5	169												
SS3,95 43.4N 62.7W 95m	E	4.2	280												
	N	3.9	226												
SS6,50 43.3N 63.4W 50m	E	4.4	312												
	N	2.0	241												
SS6,130 43.3N 63.4W 130m	E	2.6	309												
	N	2.9	286												
SS7,50 43.0N 62.9W 50m	E	7.4	270												
	N	4.4	198												

Scotian Shelf(cont.)

		K1		O1		95% limits		:	M2		S2		N2		95% limits	
		H cm/s	G deg	H cm/s	G deg	H %	G deg	:	H cm/s	G deg	H cm/s	G deg	H cm/s	G deg	H %	G deg
SS7,118	E	4.4	308					:								
43.0N 62.9W								:								
118m	N	4.3	243					:								
SS4,20	E	2.0	304					:								
42.7N 63.5W								:								
20m	N	1.7	206					:								
SS4,150	E	1.5	314					:								
42.7N 63.5W								:								
150m	N	1.5	217					:								
SS4,500	E	.2	123					:								
42.7N 63.5W								:								
500m	N	.2	194					:								
SS4,980	E	.9	53					:								
42.7N 63.5W								:								
980m	N	.6	177					:								
SS5,150	E	.1	163					:								
42.4N 63.5W								:								
150m	N	.4	240					:								

Scotian Shelf(cont.)

		K1		O1		95% limits		M2		S2		N2		95% limits	
		H cm/s	G deg	H cm/s	G deg	H %	G deg	H cm/s	G deg	H cm/s	G deg	H cm/s	G deg	H %	G deg
SS5,1000	E	.4	79												
42.4N 63.5W															
1000m	N	.8	234												
SS8,200	E	1.5	289												
42.6N 62.1W															
200m	N	1.3	150												
SS8,1500	E	.3	19												
42.6N 62.1W															
1500m	N	.3	14												
SS10,200	E	.2	189												
43.6N 59.1W															
200m	N	.2	210												
SS10,500	E	.4	253												
43.6N 59.1W															
500m	N	.8	272												
SS10,1500	E	1.6	208												
43.6N 59.1W															
1500m	N	1.8	127												

Scotian Shelf(cont.)

		K1		O1		95% limits		M2		S2		N2		95% limits	
		H cm/s	G deg	H cm/s	G deg	H %	G deg	H cm/s	G deg	H cm/s	G deg	H cm/s	G deg	H %	G deg
C1,16M 43.19N 65.72W 16m 3886hrs dir=14T	E	8.5	-29	5.8	-81	-28,+63	±22	86.9	160	12.5	258	16.9	125	-6,+6	±3
	N	3.8	316	2.5	243	-38,+108	±36	11.8	85	3.3	181	1.4	40	-25,+48	±19
C1,30M 43.19N 65.72W 30m 3885hrs dir=14T	E	7.8	-33	6.2	-84	-26,+52	±20	78.3	142	9.8	231	15.1	112	-5,+5	±3
	N	3.5	318	2.0	155	-34,+82	±36	5.8	14	.4	124	.3	4	-25,+48	±19
C1,50M 43.19N 65.72W 50m 4174hrs dir=14T	E	5.9	-29	4.3	-70	-22,+38	±16	44.1	148	6.0	243	9.7	124	-34,+82	±29
	N	2.9	321	1.8	288	-28,+63	±22	7.8	278	1.0	330	.6	343	-28,+63	±22
C3,16M 42.83N 65.83W 16m 3866hrs dir=14T	E	5.6	2	4.6	-44	-27,+57	±21	51.0	177	7.5	264	10.7	161	-7,+8	±4
	N	3.3	348	2.6	274	-45,+170	±49	18.8	28	1.8	74	2.8	4	-18,+29	±13
C3,48M 42.83N 65.83W 48m 2464hrs dir=14T	E	6.8	-2	6.4	-43	-17,+25	±11	59.5	166	8.9	248	11.9	145	-4,+4	±3
	N	3.9	316	3.5	150	-25,+48	±19	23.7	27	2.4	112	4.8	-3	-9,+11	±6
C3,100M 42.83N 65.83W 100m 3865hrs dir=14T	E	3.3	13	3.2	-52	-27,+57	±21	41.0	165	6.0	257	9.9	144	-9,+11	±6
	N	3.5	1	2.0	305	-33,+79	±29	18.8	7	2.0	136	3.3	343	-15,+20	±10

Scotian Shelf(cont.)

		K1		O1		95% limits		M2		S2		N2		95% limits	
		H cm/s	G deg	H cm/s	G deg	H %	G deg	H cm/s	G deg	H cm/s	G deg	H cm/s	G deg	H %	G deg
C5,16M 43.57N 65.10W	E	3.9	239	2.8	229	-52,+257	±71	6.1	96	.6	-17	1.8	134	-61,+285	±109
16m 4077hrs dir=14T	N	.9	66	.8	133	-56,+270	±88	6.0	297	2.6	212	2.0	-9	-54,+270	±80
C5,31M 43.57N 65.10W	E	7.9	212	6.3	175	N/A	N/A	14.4	-28	1.5	99	2.8	-43	N/A	N/A
31m 4177hrs dir=14T	N	3.6	88	2.0	57	N/A	N/A	1.7	122	2.1	157	.2	100	N/A	N/A
C5,51M 43.57N 65.10W	E	6.4	-50	4.2	-11	N/A	N/A	10.1	189	1.2	123	2.0	204	N/A	N/A
51m 4161hrs dir=14T	N	2.6	307	1.7	6	N/A	N/A	6.4	271	.8	284	1.4	280	N/A	N/A

North East Channel

		K1		O1		95% limits		M2		S2		N2		95% limits	
		H cm/s	G deg	H cm/s	G deg	H %	G deg	H cm/s	G deg	H cm/s	G deg	H cm/s	G deg	H %	G deg
NEC11 42.33N 65.91W 100m 4901hrs dir=48T	E	3.2	43	2.2	-63	-36,+92	±32	13.7	100	4.2	157	2.4	74	-15,+22	±10
	N	1.5	148	.7	106	-33,+79	±28	49.7	0	9.1	73	9.7	-21	-6,+7	±4
NEC12 42.33N 65.91W 150m 4901hrs dir=48T	E	1.9	43	1.7	-74	-40,+127	±40	19.4	84	3.2	204	5.1	62	-13,+18	±9
	N	2.6	139	1.3	67	-26,+56	±21	53.7	-5	7.8	99	12.2	-31	-6,+7	±4
NEC13 42.33N 65.91W 210m 4901hrs dir=48T	E	1.8	11	1.3	-74	-35,+89	±32	15.0	39	.5	178	2.4	27	-17,+25	±11
	N	2.6	136	1.0	37	-30,+64	±24	47.2	-21	5.8	86	9.8	-43	-6,+7	±4

Bay of Fundy

		K1		O1		95% limits		M2		S2		N2		95% limits	
		H cm/s	G deg	H cm/s	G deg	H %	G deg	H cm/s	G deg	H cm/s	G deg	H cm/s	G deg	H %	G deg
BF11	E	.9	105												
44.8N 66.2W															
13m	N	.2	169												
dir=-18T															
BF12	E	1.1	117												
44.8N 66.2W															
50m	N	.2	175												
dir=-23T															
BF21	E	1.5	127												
45.2N 65.3W															
10m	N	.2	192												
dir=-31T															
BF22	E	1.4	126												
45.2N 65.3W															
25m	N	.0	217												
dir=-31T															

Gulf of Maine

		K1		O1		95% limits		M2		S2		N2		95% limits	
		H cm/s	G deg	H cm/s	G deg	H %	G deg	H cm/s	G deg	H cm/s	G deg	H cm/s	G deg	H %	G deg
GOM11 43.67N 69.38W 33m 1370hrs	E	.5	2	.7	-21	N/A	N/A	4.2	287	.4	253	1.0	254	N/A	N/A
	N	.5	28	.2	-99	N/A	N/A	7.5	-4	.9	126	1.5	313	N/A	N/A
GOM12 43.67N 69.38W 68m 1365hrs	E	.9	40	.3	4	-28,+64	±22	3.4	-22	.6	86	.7	279	-44,163	±47
	N	.3	-17	.2	154	-50,+233	±63	4.0	32	1.3	180	1.2	-12	-46,186	±53
GOM21 43.18N 69.08W 33m 1390hrs	E	.7	-8	1.4	-26	N/A	N/A	8.2	233	2.9	32	3.0	212	N/A	N/A
	N	.9	67	.3	106	N/A	N/A	11.9	10	2.2	102	2.0	-35	N/A	N/A
GOM22 43.18N 69.08W 68m 1386hrs	E	.5	10	.5	-18	-44,+163	±47	5.7	240	.6	71	1.7	209	-18,+29	±13
	N	.3	71	.3	22	-67,+285	±132	7.1	16	.4	214	1.3	-5	-25,+49	±19
GOM23 43.18N 69.08W 180m 1389hrs	E	.6	-14	.7	-50	-49,+223	±60	5.8	218	.8	291	1.4	184	-18,+28	±13
	N	.6	48	.2	73	-44,+163	±47	8.6	-14	2.0	103	1.7	-41	-13,+18	±9
GOM31 43.21N 70.28W 33m 1776hrs	E	.6	-21	.3	231	-46,+186	±53	2.7	228	.2	91	.9	204	-28,+63	±22
	N	.7	32	.6	18	-50,+233	±63	5.7	-26	.8	120	1.3	302	-20,+33	±14

Gulf of Maine(cont.)

		K1		O1		95% limits		M2		S2		N2		95% limits	
		H cm/s	G deg	H cm/s	G deg	H %	G deg	H cm/s	G deg	H cm/s	G deg	H cm/s	G deg	H %	G deg
GOM32 43.21N 70.28W	E	.1	131	.4	-11	-57,+285	±92	1.1	240	.3	317	.1	50	-40,+117	±38
68m 1777hrs	N	.3	55	.3	-34	-56,+270	±86	3.0	-23	1.0	73	.4	309	-23,+43	±17

Nantucket Shoals

		K1		O1		95% limits		M2		S2		N2		95% limits	
		H	G	H	G	H	G	H	G	H	G	H	G	H	G
		cm/s	deg	cm/s	deg	%	deg	cm/s	deg	cm/s	deg	cm/s	deg	%	deg
NSA05	E	.7	60	1.9	63	-51,+245	±61	7.7	40	2.7	169	2.3	23	-26,+47	±19
41.51N 69.60W															
5m 1440hrs	N	4.4	-3	6.4	3	-45,+170	±34	58.8	-16	16.3	102	16.3	304	-19,+30	±14
NSA25	E	1.4	63	1.2	35	-42,+144	±42	6.4	16	.3	172	1.5	-14	-22,+35	±16
41.51N 69.60W															
25m 1523hrs	N	4.5	-3	1.8	-21	-36,+92	±32	59.3	319	9.4	44	11.9	288	-7,+9	±5
NSB10	E	3.4	40	2.4	24	-24,+41	±18	37.0	20	1.8	130	6.8	355	-10,+12	±6
41.43N 69.73W															
10m 1002hrs	N	2.9	-31	1.1	-27	-22,+35	±16	62.9	345	4.7	66	11.0	319	-7,+8	±4
NSC08	E	4.5	44	3.9	9	-30,+61	±23	45.9	32	1.9	117	8.4	9	-10,+12	±6
41.61N 69.99W															
8m 1002hrs	N	1.3	251	.9	218	-42,+150	±44	14.9	247	1.0	280	1.5	245	-17,+27	±12
NSD16	E	2.3	25	.6	274	-53,+257	±75	21.5	327	4.1	144	5.4	292	-22,+41	±17
41.61N 69.73W															
16m 1002hrs	N	3.2	306	.5	187	-46,+186	±53	41.5	345	2.6	82	9.3	320	-13,+16	±8
NSE10	E	5.4	67	2.7	64	-45,+178	±51	39.5	10	5.8	216	14.9	333	-37,+104	±34
40.98N 70.07W															
10m 993hrs	N	7.2	-47	4.6	-54	-52,+257	±72	35.0	267	5.6	164	13.2	245	-32,+69	±26

Great South Channel

		K1		O1		95% limits		M2		S2		N2		95% limits	
		H	G	H	G	H	G	H	G	H	G	H	G	H	G
		cm/s	deg	cm/s	deg	%	deg	cm/s	deg	cm/s	deg	cm/s	deg	%	deg
GSC12	E	5.7	127	3.9	81	-20,+33	±14	28.6	89	2.3	165	6.2	59	-6,+6	±3
40.87N 69.18W															
27m 3580hrs	N	8.6	118	5.6	80	-17,+26	±12	59.6	40	8.0	117	13.2	16	-3,+4	±2
GSC13	E	5.6	125	3.9	80	-19,+32	±14	27.3	77	2.7	138	6.2	54	-7,+8	±4
40.87N 69.18W															
49m 3580hrs	N	6.6	117	4.0	79	-19,+30	±13	48.6	33	7.0	113	10.7	13	-4,+4	±2
GSC21	E	6.2	131	3.5	102	-32,+72	±28	29.1	108	4.1	173	6.7	69	-14,+19	±9
40.85N 69.02W															
10m 2626hrs	N	8.6	109	6.6	77	-24,+45	±18	70.5	40	9.7	98	14.8	11	-5,+6	±3
GSC22	E	5.0	135	3.2	96	-25,+48	±19	27.9	107	2.2	210	6.5	69	-9,+11	±6
40.85N 69.02W															
42m 3649hrs	N	8.8	112	6.4	80	-17,+26	±12	69.3	37	8.9	113	15.1	6	-4,+4	±3
GSC23	E	2.0	-56	3.1	-87	-25,+50	±19	11.8	163	2.7	258	1.0	173	-24,+45	±18
40.85N 69.02W															
76m 3649hrs	N	3.9	-38	7.1	-65	-24,+45	±18	19.0	11	4.8	162	2.9	299	-21,+36	±15
GSC31	E	3.8	154	2.0	118	-27,+57	±21	28.1	117	2.3	199	5.3	88	-9,+12	±6
40.85N 68.81W															
10m 4114hrs	N	8.2	107	5.6	72	-16,+25	±11	71.4	34	8.2	118	15.5	4	-5,+6	±3

Great South Channel(cont.)

		K1		O1		95% limits		M2		S2		N2		95% limits	
		H cm/s	G deg	H cm/s	G deg	H %	G deg	H cm/s	G deg	H cm/s	G deg	H cm/s	G deg	H %	G deg
GSC32	E	2.8	157	2.1	116	-25,+49	±19	22.1	124	2.6	239	4.7	94	-6,+7	±4
40.85N 68.81W															
51m 2977hrs	N	7.2	107	4.8	64	-18,+29	±13	59.8	29	6.2	108	13.0	3	-4,+4	±2

Nantucket Shoals Flux Experiment

		K1		O1		95% limits		M2		S2		N2		95% limits	
		H cm/s	G deg	H cm/s	G deg	H %	G deg	H cm/s	G deg	H cm/s	G deg	H cm/s	G deg	H %	G deg
NSFE11 40.69N 70.14W	E	11.9	170	6.3	129	-15,+20	±10	27.7	93	3.1	149	6.2	69	-7,+8	±4
10m 4121hrs dir=14T	N	9.6	60	4.5	26	-16,+23	±11	25.1	8	1.9	79	5.2	-22	-7,+9	±4
NSFE12 40.69N 70.14W	E	7.4	169	3.7	131	-18,+27	±13	25.6	66	2.3	147	5.5	35	-6,+6	±3
30m 5334hrs	N	5.7	55	2.6	11	-18,+27	±13	22.7	-19	1.5	87	4.7	304	-7,+8	±4
NSFE21 40.50N 70.21W	E	9.0	108	3.9	72	-19,+28	±13	17.4	314	1.6	21	3.6	279	-7,+10	±5
10m 4663hrs dir=16T	N	7.2	15	3.3	-20	-22,+37	±16	18.1	237	1.9	-37	3.4	192	-9,+11	±6
NSFE22 40.50N 70.21W	E	7.8	112	4.4	71	-15,+20	±10	15.2	315	.9	-28	3.9	289	-7,+8	±4
37m 3658hrs dir=16T	N	5.6	20	2.7	-21	-19,+28	±13	15.7	239	.5	-12	3.8	211	-7,+9	±5
NSFE23 40.50N 70.21W	E	6.2	124	3.5	86	-19,+28	±13	14.9	311	.9	295	3.9	275	-7,+8	±4
52m 6813hrs dir=16T	N	4.9	41	2.9	10	-21,+33	±15	16.2	235	.6	71	3.9	197	-7,+9	±5
NSFE31 40.34N 70.27W	E	6.2	188	3.4	143	-59,+285	±101	10.5	98	2.2	155	2.3	90	-25,+47	±19
10m 1114hrs	N	4.4	97	2.9	54	-60,+285	±106	10.3	23	1.0	61	2.4	17	-31,+67	±25

Nantucket Shoals Flux Exp.(cont.)

		K1		O1		95% limits		M2		S2		N2		95% limits	
		H cm/s	G deg	H cm/s	G deg	H %	G deg	H cm/s	G deg	H cm/s	G deg	H cm/s	G deg	H %	G deg
NSFE32	E	5.2	178	2.7	145	-21,+33	±15	10.9	85	1.0	135	2.2	60	-9,+11	±6
40.34N 70.27W															
30m 5027hrs	N	3.7	82	1.8	58	-28,+54	±22	10.3	9	.3	23	2.1	-24	-12,+14	±7
NSFE33	E	5.2	186	2.4	138	-25,+49	±19	11.7	77	.5	197	3.1	34	-11,+15	±7
40.34N 70.27W															
70m 5027hrs	N	4.2	87	1.8	52	-29,+71	±24	10.5	0	.7	180	2.9	315	-14,+20	±10
NSFE41	E	6.2	190	2.9	151	-26,+53	±20	9.7	112	2.5	236	2.8	27	-23,+41	±17
40.21N 70.30W															
10m 4071hrs	N	5.2	104	2.8	78	-26,+55	±20	11.2	27	2.8	139	3.1	292	-23,+41	±17
dir=14T															
NSFE42	E	4.2	181	2.5	145	-23,+41	±17	8.1	94	.2	289	2.1	57	-15,+21	±10
40.21N 70.30W															
30m 5364hrs	N	3.1	92	1.6	62	-36,+96	±33	8.1	13	.8	245	2.7	-28	-16,+24	±11
NSFE43	E	5.9	192	3.1	137	-20,+34	±15	7.4	100	.7	125	1.7	87	-15,+21	±10
40.21N 70.30W															
60m 4076hrs	N	4.3	96	2.2	64	-23,+44	±17	7.4	21	.5	248	2.0	5	-13,+18	±9
dir=14T															
NSFE44	E	5.0	186	2.5	141	-26,+53	±20	8.0	78	.6	196	1.3	56	-17,+26	±12
40.21N 70.30W															
90m 5364hrs	N	4.0	100	2.0	53	-26,+55	±20	8.0	3	.9	164	1.1	-23	-20,+33	±14

Nantucket Shoals Flux Exp.(cont.)

		K1		O1		95% limits		M2		S2		N2		95% limits	
		H cm/s	G deg	H cm/s	G deg	H %	G deg	H cm/s	G deg	H cm/s	G deg	H cm/s	G deg	H %	G deg
NSFE51 40.04N 70.37W	E	4.4	200	1.7	156	-36,+96	±33	3.1	142	1.3	143	1.2	145	-49,+223	±59
10m 4094hrs dir=14T	N	4.0	110	1.6	75	-44,+163	±47	3.0	65	.7	-25	1.7	61	-49,+245	±61
NSFE52 40.04 70.37W	E	3.5	182	1.9	142	N/A	N/A	2.6	121	.9	133	1.3	150	N/A	N/A
30m 4093hrs dir=14T	N	2.4	93	1.9	48	N/A	N/A	2.4	44	.6	320	1.7	47	N/A	N/A
NSFE54 40.04N 70.37W	E	3.1	200	1.6	151	-26,+54	±20	3.2	86	.4	153	.5	21	-40,+133	±39
90m 4093hrs dir=14T	N	2.7	109	1.3	62	-27,+60	±21	2.8	12	.8	106	.6	271	-46,+186	±53
NSFE55 40.04N 70.37W	E	2.9	196	1.5	138	-28,+62	±22	4.3	83	.6	227	1.0	29	-30,+74	±24
120m 4093hrs dir=14T	N	2.6	96	1.5	61	-27,+58	±21	4.0	2	1.1	138	1.1	276	-35,+89	±31
NSFE56 40.04N 70.37W	E	3.3	203	1.4	142	-25,+51	±19	3.9	116	.5	-34	1.9	71	-36,+96	±33
185m 4093hrs dir=14T	N	2.9	106	1.5	65	-26,+56	±20	4.3	37	1.4	230	2.3	-25	-37,+104	±35
NSFE61 39.85N 70.42W	E	.9	243	1.0	207	-48,+213	±59	1.6	236	1.1	118	.6	151	-55,+270	±84
10m 5398hrs	N	1.1	149	1.7	68	-57,+285	±89	2.4	148	.8	-9	.7	80	-48,+213	±59

New England Shelf 1976

		K1		O1		95% limits		M2		S2		N2		95% limits	
		H cm/s	G deg	H cm/s	G deg	H %	G deg	H cm/s	G deg	H cm/s	G deg	H cm/s	G deg	H %	G deg
NES7621	E	3.7	216	3.1	166	-22,+39	±16	5.9	61	1.1	74	1.4	33	-12,+17	±8
40.46N 71.20W															
38m 3342hrs	N	2.6	131	1.7	88	-31,+64	±25	5.6	-34	1.6	304	1.7	305	-13,+18	±9
NES7622	E	3.7	227	2.6	168	-29,+71	±24	5.7	46	.8	69	.8	16	-22,+40	±16
40.46N 71.20W															
73m 2228hrs	N	2.7	149	1.6	106	-47,+104	±34	6.2	307	1.0	282	.9	288	-25,+51	±19
NES762W	E	3.1	-93	3.1	212	-25,+49	±19	7.4	48	1.4	61	1.9	34	-12,+17	±8
39.92N 71.96W															
38m 4117hrs	N	2.3	191	2.7	143	-30,+63	±25	6.8	290	1.9	304	1.8	281	-14,+19	±9
NES7631	E	1.4	222	1.1	167	-31,+67	±26	.7	117	.1	301	.3	140	-62,+285	±113
39.93N 71.05W															
145m 4337hrs	N	1.2	150	1.0	82	-31,+67	±26	.7	76	.8	266	.4	43	-66,+285	±131
NES763W	E	.5	-51	.3	198	-46,+178	±51	1.7	66	.6	302	.8	43	-40,+127	±40
39.71N 71.78W															
302m 4381hrs	N	.5	222	.5	134	-44,+163	±48	1.2	285	.8	216	.7	299	-47,+194	±53
NES7641	E	.2	255	.2	102	-75,+285	±149	1.6	59	.6	186	.2	53	-42,+150	±43
39.61N 70.94W															
305m 4321hrs	N	.5	118	.5	34	-54,+270	±78	.4	308	.5	93	.2	85	-69,+285	±140

New England Shelf 1976(cont.)

		K1		O1		95% limits		:	M2		S2		N2		95% limits	
		H cm/s	G deg	H cm/s	G deg	H %	G deg	:	H cm/s	G deg	H cm/s	G deg	H cm/s	G deg	H %	G deg
NES7642	E	.4	20	.2	-19	-24,+45	±18	:	.7	74	.3	-17	.3	47	-40,+127	±40
39.61N 70.94W								:								
2005m 4321hrs	N	.2	101	.2	39	-58,+285	±97	:	.1	41	.5	248	.1	317	-65,+285	±128
NES7651	E	.2	8	.2	-32	-29,+61	±23	:	.6	49	.5	109	.1	283	-40,+127	±40
39.28N 70.83W								:								
1995m 4309hrs	N	.1	110	.1	91	-37,+100	±34	:	.4	240	.4	1	.1	150	-47,+194	±53

Current Meter InterComparison Experiment

		K1		O1		95% limits		M2		S2		N2		95% limits	
		H cm/s	G deg	H cm/s	G deg	H %	G deg	H cm/s	G deg	H cm/s	G deg	H cm/s	G deg	H %	G deg
CMICE11 40.78N 72.48W	E	3.4	248	3.5	176	-40,+117	±38	10.2	62	1.2	76	2.2	46	-22,+38	±16
3.7m 593hrs dir=-68T	N	1.5	172	.3	-83	-69,+285	±141	1.6	314	.7	312	.2	-24	-54,+270	±77
CMICE12 40.78N 72.48W	E	3.8	249	3.3	175	-34,+82	±29	10.4	60	1.3	94	2.4	37	-17,+26	±12
7.8m 593hrs dir=-68T	N	1.2	151	.3	-42	-70,+285	±142	2.5	288	.6	319	.4	259	-52,+257	±70
CMICE13 40.78N 72.48W	E	2.6	223	3.3	167	-46,+186	±53	9.2	57	1.1	85	2.2	41	-14,+19	±9
16m 593hrs dir=-68T	N	.7	37	1.1	12	-65,+285	±125	3.1	270	.7	315	.6	260	-34,+79	±29
CMICE14 40.78N 72.48W	E	.5	208	2.1	168	-54,+270	±79	6.6	39	.4	100	1.5	14	-16,+23	±11
25.4m 593hrs dir=-68T	N	1.7	-28	1.0	-98	-50,+245	±65	2.6	219	.3	44	.9	204	-50,+233	±63

New England Shelf 1974

		K1		O1		95% limits		M2		S2		N2		95% limits	
		H cm/s	G deg	H cm/s	G deg	H %	G deg	H cm/s	G deg	H cm/s	G deg	H cm/s	G deg	H %	G deg
NES7411 40.93N 71.21W	E	4.7	202	3.2	169	-33,+79	±28	9.2	77	1.2	123	1.9	51	-9,+12	±6
28m 841hrs	N	2.2	101	1.8	84	-39,+113	±37	9.2	-11	.8	53	2.4	315	-12,+15	±7
NES7421 40.58N 70.99W	E	4.8	196	3.8	171	-33,+79	±28	8.6	67	.9	96	2.4	42	-11,+14	±7
20m 839hrs	N	2.7	95	2.8	79	-48,+223	±59	8.3	-20	.4	275	2.5	316	-15,+22	±10
NES7423 40.90N 70.99W	E	6.9	217	2.5	194	-41,+138	±41	7.9	59	1.2	91	2.0	24	-16,+24	±11
60m 841hrs	N	5.1	128	1.0	123	-52,+257	±70	7.6	-29	.5	-27	2.3	288	-17,+25	±11
NES7431 40.30N 70.86W	E	2.9	197	3.3	174	-30,+74	±24	5.4	71	1.0	72	1.3	60	-22,+38	±16
20m 840hrs	N	2.0	92	2.5	89	-56,+270	±88	5.6	-19	1.4	-16	1.3	-36	-25,+49	±19
NES7433 40.30N 70.86W	E	7.1	216	2.5	170	-47,+69	±56	4.9	72	.1	64	1.3	38	-19,+31	±13
60m 835hrs	N	6.6	126	1.5	97	-48,+213	±57	5.1	-17	.4	-18	1.4	299	-24,+47	±18

New York Bight

		K1		O1		95% limits		M2		S2		N2		95% limits	
		H	G	H	G	H	G	H	G	H	G	H	G	H	G
		cm/s	deg	cm/s	deg	%	deg	cm/s	deg	cm/s	deg	cm/s	deg	%	deg
MESA5A	E	4.6	243	3.0	205	-40,+122	±39	12.3	50	2.8	74	1.7	42	-16,+24	±11
40.19N 72.00W															
21m 1676hrs	N	3.2	190	3.0	141	-44,+163	±48	9.4	300	1.9	4	2.1	284	-21,+37	±16
MESA5B	E	4.7	254	3.5	192	-30,+61	±24	10.8	56	1.4	122	2.2	27	-17,+26	±12
40.19N 72.00W															
41.2m 1676hrs	N	2.7	178	3.1	132	-40,+122	±39	8.4	309	1.0	53	1.6	284	-21,+37	±15
MESA5C	E	2.3	-76	1.7	234	-26,+54	±20	6.2	41	.3	68	1.2	15	-13,+18	±9
40.19N 72.00W															
61.3m 1675hrs	N	2.1	228	1.9	182	-24,+47	±18	5.0	284	1.1	228	1.1	256	-21,+36	±15
MESA5D	E	1.6	-65	1.2	248	-27,+58	±21	4.6	43	.6	59	.9	22	-16,+24	±11
40.19N 72.00W															
66.2m 1675hrs	N	1.7	237	1.6	192	-24,+45	±18	3.0	286	.7	254	.6	264	-25,+52	±20
MESANJ4S	E	2.2	208	3.6	-35	-58,+285	±97	8.4	55	2.2	71	2.8	26	-34,+82	±29
39.92N 72.97W															
1.8m 1720hrs	N	2.5	118	3.0	255	-49,+223	±61	6.2	308	3.0	315	2.2	270	-37,+100	±34
MESANJ4A	E	.9	7	1.4	-71	-44,+156	±46	11.9	66	1.3	166	3.3	56	-20,+33	±14
39.92N 72.97W															
43.3m 1721hrs	N	.7	-29	1.0	243	-39,+117	±38	9.9	302	2.9	22	2.8	287	-27,+58	±21

New York Bight(cont.)

		K1		O1		95% limits		M2		S2		N2		95% limits	
		H cm/s	G deg	H cm/s	G deg	H %	G deg	H cm/s	G deg	H cm/s	G deg	H cm/s	G deg	H %	G deg
MESANJ4D	E	.2	67	.1	-14	-27,+58	±21	1.0	34	.8	30	.3	114	-47,+200	±56
39.92N 72.97W 90.9m 1721hrs	N	.4	50	.1	132	-25,+50	±19	.7	97	.3	259	.3	33	-55,+270	±83
MESA7A	E	.8	244	2.0	243	-63,+285	±120	17.5	74	2.7	135	3.7	49	-18,+28	±12
39.92N 73.10W 18m 2561hrs	N	1.0	8	2.8	177	-39,+117	±38	10.1	300	2.2	310	2.6	324	-21,+35	±15
MESA7B	E	.8	-83	1.3	233	-53,+257	±74	15.1	67	1.6	111	3.6	55	-16,+23	±11
39.92N 73.10W 38.1m 2463hrs	N	1.7	246	1.0	206	-49,+223	±60	9.9	295	2.1	-12	1.7	293	-21,+35	±15
MESA7E	E	.4	253	.5	226	-53,+257	±73	4.2	84	.2	157	.7	87	-29,+59	±23
39.92N 73.10W 65.9m 1511hrs	N	.4	-8	.4	-59	-25,+52	±20	5.0	285	.9	275	1.1	276	-22,+39	±16
MESA3A	E	1.5	90	1.2	-78	-53,+257	±74	13.9	69	1.8	123	3.5	51	-14,+20	±9
39.26N 73.03W 9.2m 2500hrs	N	1.5	24	1.5	217	-39,+117	±38	10.2	307	1.4	-29	3.2	286	-16,+23	±11
MESA3B	E	1.3	77	2.2	-81	-54,+257	±86	16.1	66	1.7	124	3.6	51	-16,+23	±11
39.26N 73.03W 18.8m 2500hrs	N	2.2	7	1.4	206	-39,+113	±37	12.7	305	1.6	-23	3.3	292	-16,+24	±11

New York Bight(cont.)

		K1		O1		95% limits		M2		S2		N2		95% limits	
		H cm/s	G deg	H cm/s	G deg	H %	G deg	H cm/s	G deg	H cm/s	G deg	H cm/s	G deg	H %	G deg
MESA3D	E	.7	60	1.4	4	-45,+170	±50	10.7	80	4.2	69	2.5	79	-16,+24	±11
39.92N 73.10W															
58.3m 1677hrs	N	1.2	-6	1.8	-86	-25,+53	±20	8.9	319	3.5	310	2.3	305	-19,+30	±13

New Jersey Coast

		K1		O1		95% limits		M2		S2		N2		95% limits	
		H cm/s	G deg	H cm/s	G deg	H %	G deg	H cm/s	G deg	H cm/s	G deg	H cm/s	G deg	H %	G deg
Barnegat 39.76N 73.93W	E	.3	46 226												
dir=38T	N	.8	316												
EGG1U 39.47N 74.26W	E	0.0													
4.5m dir=43T	N	3.5	334												
EGG1L 39.47N 74.26W	E	.4	54 234												
10m dir=36T	N	2.8	324												

Mid Atlantic Bight

		K1		O1		95% limits		M2		S2		N2		95% limits	
		H cm/s	G deg	H cm/s	G deg	H %	G deg	H cm/s	G deg	H cm/s	G deg	H cm/s	G deg	H %	G deg
MAB11	E	1.8	-73	1.6	-90	-52,+245	±70	11.4	131	2.4	126	2.8	108	-16,+23	±11
36.83N 75.03W															
8.8m 1273hrs	N	3.6	197	3.7	134	-51,+245	±67	9.4	68	1.2	-20	2.9	44	-28,+64	±22
MAB12	E	4.7	-38	4.0	218	-59,+285	±99	18.1	123	1.7	179	5.2	95	-14,+20	±10
36.83N 75.03W															
20.7m 1246hrs	N	4.6	240	3.6	135	-56,+270	±86	10.9	10	1.9	71	2.9	-5	-18,+27	±12
MAB13	E	.9	-32	.6	47	-53,+257	±76	9.4	110	3.4	158	2.0	72	-19,+30	±13
36.83N 75.03W															
32.3m 1273hrs	N	1.7	193	.3	171	-32,+69	±26	7.5	-23	3.8	-6	1.3	324	-28,+64	±22

USGS

		K1		O1		95% limits		:	M2		S2		N2		95% limits	
		H	G	H	G	H	G	:	H	G	H	G	H	G	H	G
		cm/s	deg	cm/s	deg	%	deg	:	cm/s	deg	cm/s	deg	cm/s	deg	%	deg
L51	E	3.9	155					:								
41.70N 66.60W								:								
51m 5x29days	N	5.7	84					:								
D15	E	2.2	102					:								
41.98N 67.79W								:								
15m 4x29days	N	2.7	47					:								
K15	E	5.8	62					:								
41.05N 67.57W								:								
15m 5x29days	N	4.9	346					:								
K50	E	4.6	166					:								
41.05N 67.57W								:								
50m 3x29days	N	4.5	94					:								
K56	E	3.9	152					:								
41.05N 67.57W								:								
56m 3x29days	N	3.7	81					:								
A15	E	4.7	167					:								
40.85N 67.40W								:								
15m 9x29days	N	3.7	77					:								

USGS(cont.)

		K1		O1		95% limits		M2		S2		N2		95% limits	
		H	G	H	G	H	G	H	G	H	G	H	G	H	G
		cm/s	deg	cm/s	deg	%	deg	cm/s	deg	cm/s	deg	cm/s	deg	%	deg
A45	E	4.3	168												
40.85N 67.40W															
45m 33x29days	N	3.7	89												
A75	E	2.7	186												
40.85N 67.40W															
75m 32x29days	N	2.5	117												
A84	E	2.1	173												
40.85N 67.40W															
84m 10x29days	N	2.0	96												
MB15	E	1.8	30												
38.73N 73.63W															
15m 5x29days	N	1.5	358												
MB45	E	2.6	108												
38.73N 73.63W															
45m 5x29days	N	2.9	54												
MB50	E	1.3	121												
38.73N 73.63W															
50m 5x29days	N	2.0	35												

USGS(cont.)

		K1		O1		95% limits		:	M2		S2		N2		95% limits	
		H cm/s	G deg	H cm/s	G deg	H %	G deg	:	H cm/s	G deg	H cm/s	G deg	H cm/s	G deg	H %	G deg
MF15	E	3.3	209					:								
38.51N 73.27W								:								
15m 4x29days	N	3.3	96					:								

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