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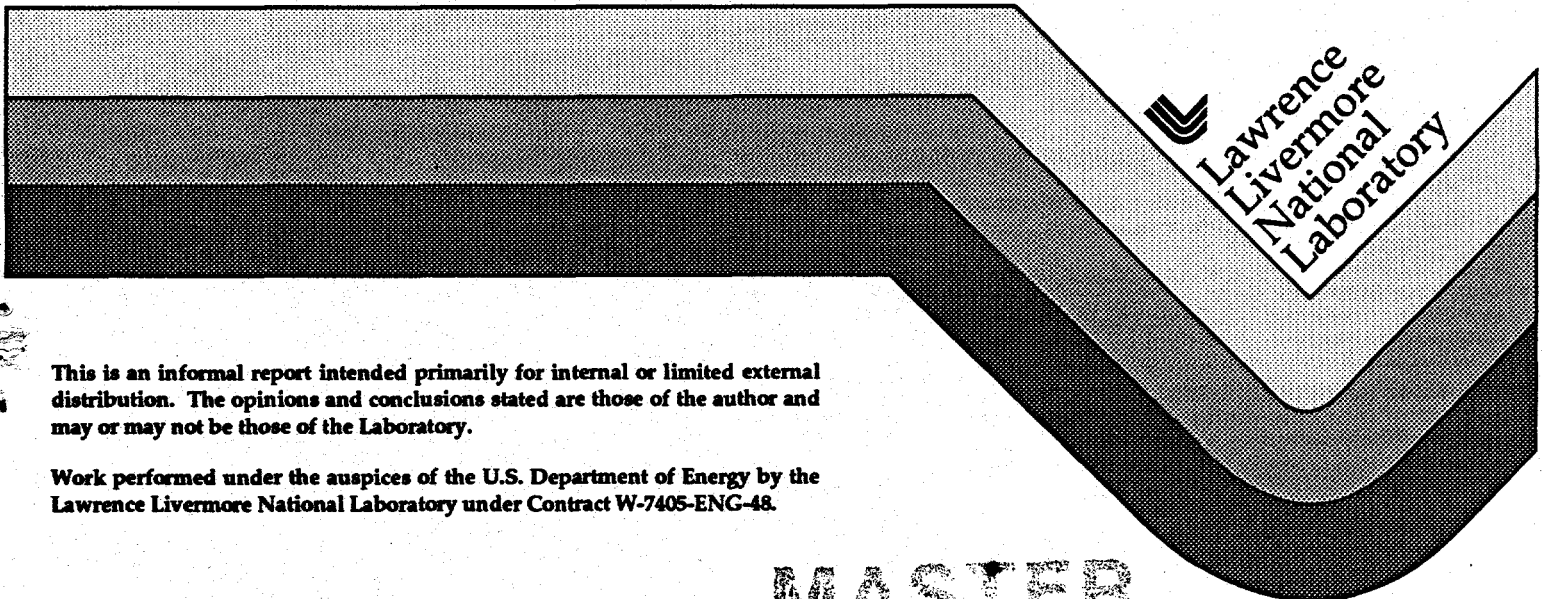
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Loch Linnhe Experiment 1994 Background Stratification and Shear Measurements

Part 1: Profile Summary and Dispersion Relations

H. F. Robey
D. L. Ravizza

October 10, 1994



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Loch Linnhe Experiment 1994

Background Stratification and Shear measurements

Part 1 : Profile Summary and Dispersion Relations

Introduction

This report documents water column measurements made during the 1994 Loch Linnhe experiment, a joint US/UK radar ocean imaging experiment. Part 1 summarizes the profiles of temperature, salinity, density, Brunt-Vaisala frequency, and horizontal currents resolved into along and cross track directions. Internal wave dispersion relations, phase and group velocities, and eigenfunctions for modes 1 and 2 are computed for each profile. The effect of depth on these derived internal wave parameters is examined as well by computing eigenvalues and eigenfunctions for two different depths.

The trials were conducted in Loch Linnhe, Scotland during the period from September 4, 1994 to September 17, 1994. The measurements reported herein were made from on board the R. V. *Calanus*, a research vessel operated by the Dunstaffnage Marine Laboratory (DML). The *Calanus* was moored approximately 125 meters from the track of the wake generating ship, either the R. V. *Colonel Templer* or a "Dog" class tug, the *Collie*. The depth at the mooring location was approximately 45 meters, while the depth at the closest point along the ship track was approximately 80 meters. For further details of the experiment, one is referred to the Loch Linnhe Experiment 1994: Trial Plan, Draft Version 3.0.

Experimental Setup

Profile measurements were made of both the ambient density profile as well as the ambient shear profile using an InterOcean S4 current meter with fast response conductivity, temperature, and depth (CTD) sensors. The table on the following page lists the sensor type, range, resolution, accuracy, and response time of each sensor.

The sampling rate for all sensors was 2 Hz (S4 burst mode), and the analog channels (C,T, and D, tilt, and compass) were sampled using a 14 bit A/D converter. The S4 was profiled using a variable speed (0-2 m/s) winch coupled to the gantry at the stern of the *Calanus*. A 20 Kg weight was attached approximately 2 m below the S4. The winch was typically operated at a profiling rate of 0.25 m/s giving a depth uncertainty due to vertical motion of +/- 1.6 cm (less than the sensor resolution). The gantry was positioned at its most extended position to minimize the interference on the velocity measurements from ship generated motions near the surface. Since the prevailing tidal currents in Loch Linnhe had their largest magnitudes up and down the Loch (essentially parallel to the orientation of the *Calanus*), it was decided on 9/13 to move the profiling location to the starboard side of the *Calanus*, approximately 2 meters from the location of the DML profiling instrumentation. This change did seem to clean up the near surface current measurements somewhat. Throughout the experiments the current data was automatically corrected for the local variation between true and magnetic North. A compass correction of -9° was used to obtain true North.

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S4 Sensor Specifications

Variable	Sensor type	Range	Resolution	Accuracy	Response Time
Velocity	Electro-magnetic	0-350 cm/s	0.5 cm/s (burst mode)	2% of reading +/- 1 cm/s	Continuous
Direction	Flux-Gate Compass	0-360°	0.5°	2°	Continuous
Tilt		+/-45°	0.06°	+/-0.25°	Continuous
Conductivity	Inductive	5-65 mS	0.01 mS	+/-0.02 mS	60 msec
Temperature	Platinum	-5 to 45°C	0.003°C	+/-0.02°C	60 msec
Depth	Semiconductor Strain Gage	1000 dBar	0.06 dBar	+/-1.5 dBar	60 msec

Validation of current measurements

Several tests were conducted to assess the reliability of the S4 velocity measurements during profiling. In theory, the S4 electromagnetic velocity sensors which measure two orthogonal horizontal velocity components should be insensitive to vertical motion. Several factors, however, could contaminate these measurements. The first factor considered is the sensor tilt. If the S4 deviated significantly from a horizontal position, then the vertical profiling velocity V would induce an apparent horizontal velocity with a magnitude of $V \sin(\theta_{\text{tilt}})$. The tilt was therefore continuously monitored, and as shown in figure 1 of the Appendix is less than 2.5° for this particular profile. This corresponds to a tilt induced horizontal velocity error of 1.05 cm/s at a profiling velocity of 0.25 m/s, and therefore reduces the sensor resolution by a factor of two. This value is still within the absolute accuracy, however. There is obviously a strong correlation between the horizontal current magnitude and the induced tilt. It is for this reason that this particular profile was used as an example, since it has a rather large current of 34 cm/s.

The effect of the magnitude and direction (up vs. down) of the profiling velocity on the measured horizontal currents was examined as well. In this report, all profiles are reported for the up cast only. No discernible difference between up cast and down cast was seen on the conductivity or temperature profiles. Figure 2 shows the two profiles for the along-track current profile. As can be seen, the large scale features of the profile are the same for both directions. Small variations of typically less than 5 cm/s are seen between the two profiles, but variations of this magnitude are seen even on two repeated profiles in the same direction and are therefore believed to be due to real variations in the fluid currents with time.

The effect of profiling velocity on the measured currents is shown in Figure 3, which shows two profiles taken approximately 5 minutes apart. Both profiles are shown for the up cast, one at a velocity of 0.26 m/s and one at 0.52 m/s. Again, the large scale features

of the profile are very repeatable with small differences in the currents of order ± 5 cm/s. These variations are again believed to be real. Comparison of any two profiles taken approximately one hour apart throughout the duration of the trials (Summary Profiles Section) shows that there is considerable change in the current profiles over this time interval. This is again believed to be real variation in the ambient currents, as the large-scale features are in reasonable agreement with the known tidal variation in the Loch.

Profile Summary and Dispersion Relations

In the following section, the daily profiles are summarized. Profiles were performed roughly on the hour, beginning an hour before the start of the first run and continuing until after the completion of the last run of the wake generating ship. For each profile, plots are shown of the temperature, salinity, density, Brunt-Vaisala frequency, and the two velocity components along the direction of the ship track (038°) and perpendicular to it (308°). The profiling procedure was as follows. The S4 was lowered into the water and allowed to thermally equilibrate for 1 minute before beginning the profile. For all the profiles shown in this report, the profiling speed was 0.26 m/s, and the depth was approximately 45 meters. At the bottom of the profile, the S4 was held steady for 30 seconds before beginning the upcast.

The density profile is internally calculated from the profiles of temperature, salinity, and pressure (depth) using the UNESCO 80 equation of state for sea water. All three profiles are plotted with no smoothing. The BV profile was smoothed with a moving 7-point average which corresponds to an average over approximately 1 meter in depth. The BV and the two current profiles were then further smoothed with a moving 5-point average.

In this report, dispersion relations are computed from the BV profiles alone, setting all current profiles equal to zero. In part two, the current profiles will be included in the solution of the Taylor-Goldstein equation in order to assess the effect of shear on the dispersion relation. One additional parameter that is considered in this report, however, is the effect of the bottom topography on the computed dispersion relations and corresponding phase and group velocities. As noted earlier, the depth at the location of the *Calanus* mooring was 45 meters, while at the nearest point along the ship track the depth was approximately 80 meters. The depth has a significant effect on the long wave portion of the dispersion relation. The long wave phase speed, for example, can easily differ by 10 cm/s depending on the local depth of the water column. The reason for this is that Loch Linnhe has a small but finite gradient all the way to the bottom, and for waves of order of the local depth, this gradient contributes significantly to the computed eigenfunctions and eigenvalues. In order to gain some idea of the variation of the dispersion relation from the ship track to the instrumented site, dispersion relations were computed for both depths. For 80 meters, the measured profile was extrapolated from 45 to 80 meters assuming a constant gradient. This assumption is well justified, as measurements in deeper locations show this to be the case. An example of such a profile to a depth of 100 meters is shown in the summary section on 9/17/94 at 10:57 GMT.

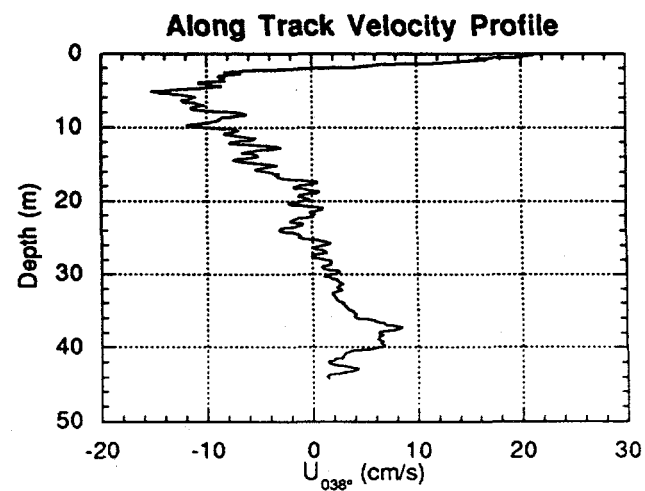
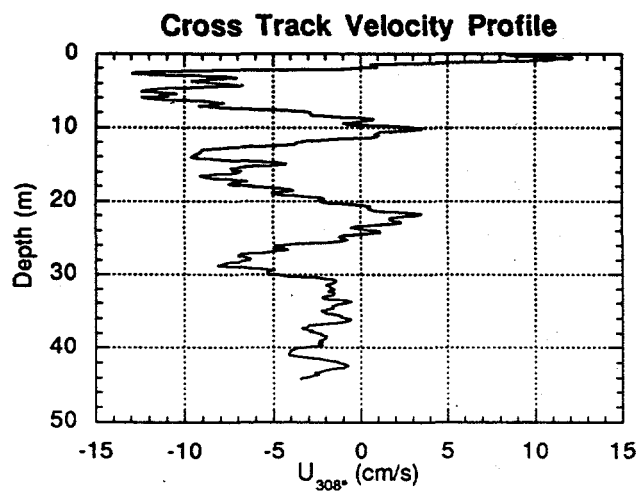
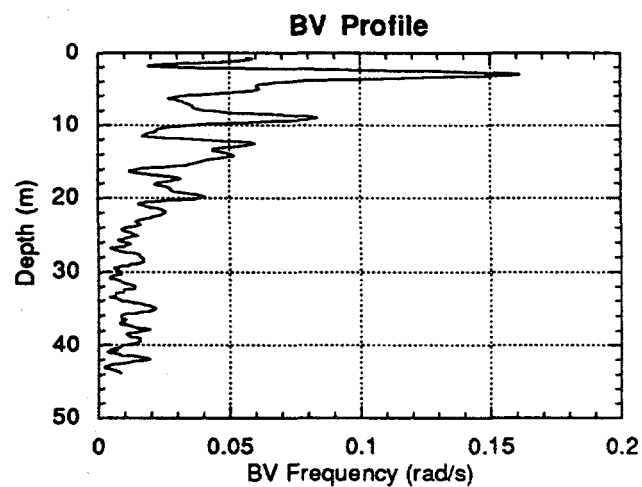
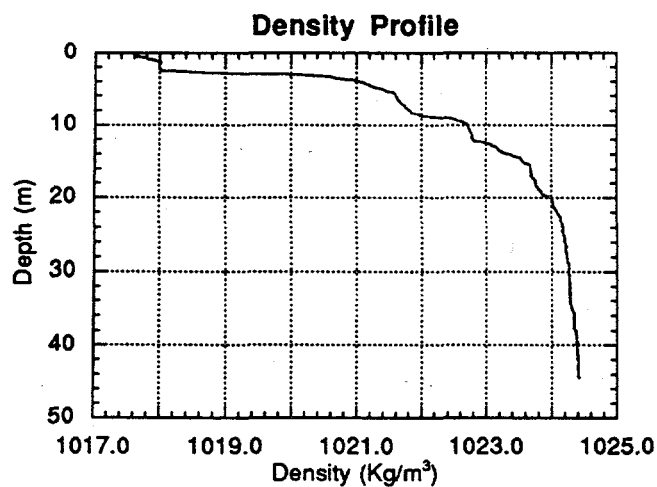
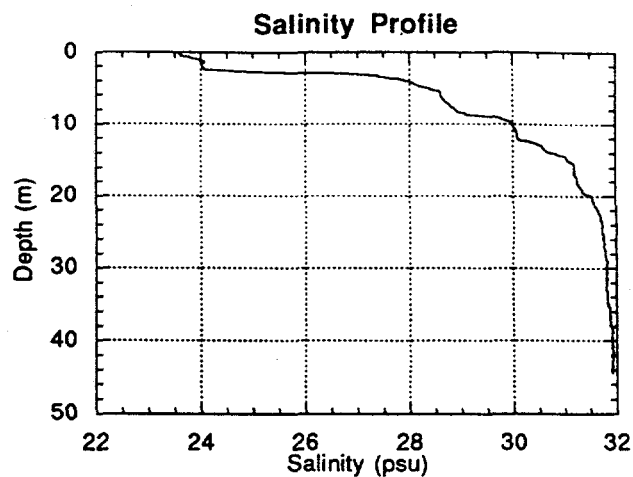
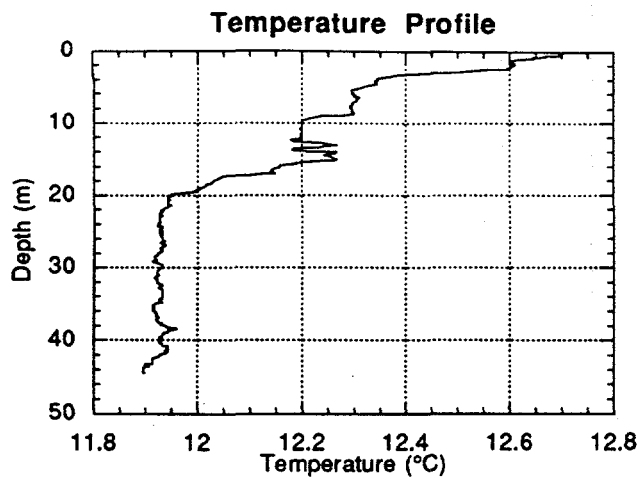
For the computed internal wave parameters, the Taylor-Goldstein equation was solved with wavenumber as a parameter and frequency ω as the eigenvalue (except for $k=0$, in which case the long-wave phase speed $c_p(0)$ is solved for directly). The range of wavenumbers chosen corresponds to wavelengths from 20 meters to infinity. A shooting method is used with a 4th order Runge-Kutta integration step. The boundary conditions at $z=0, D$ were enforced to an accuracy of 10^{-15} . Eigenfunctions are normalized to a maximum of +1 (Note that with this chosen normalization, mode 2 eigenfunctions can take on negative values less than -1).

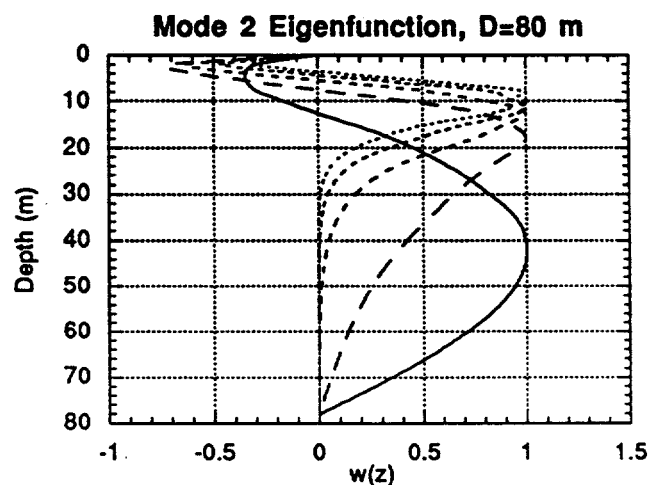
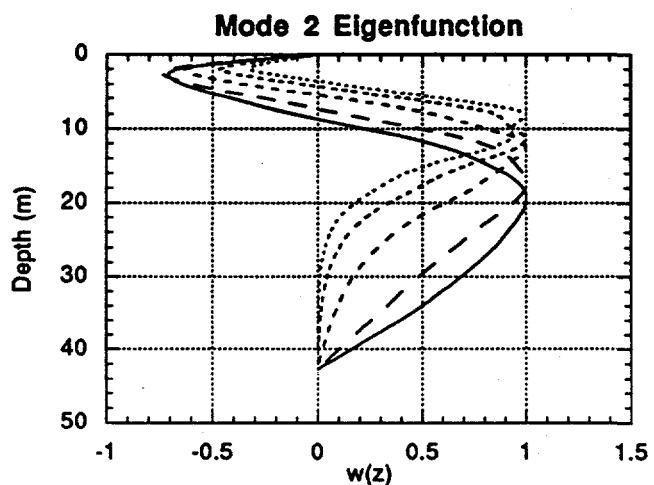
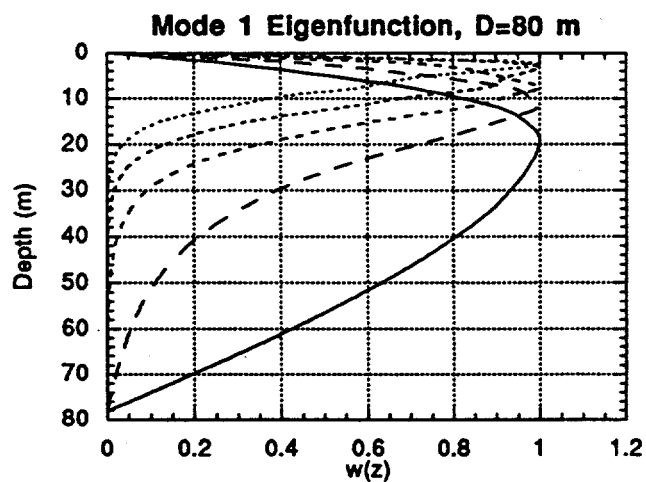
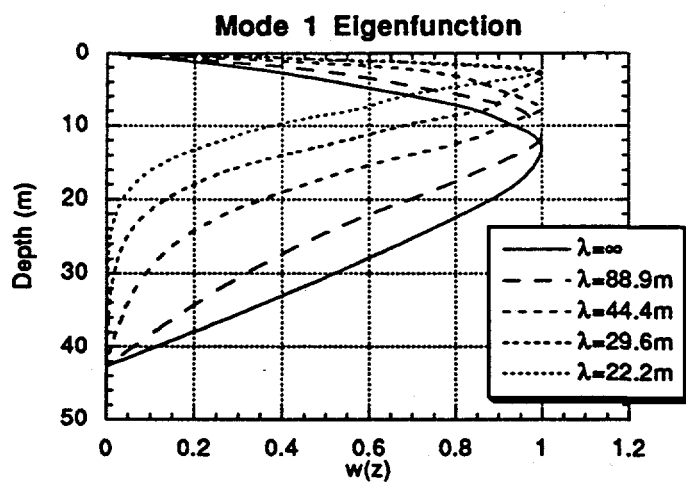
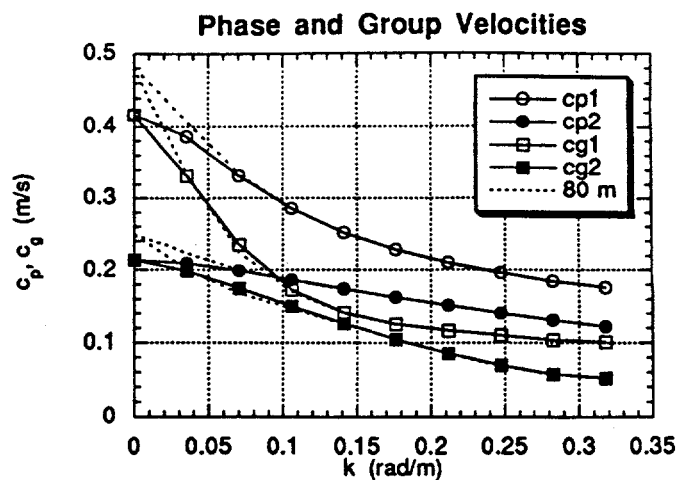
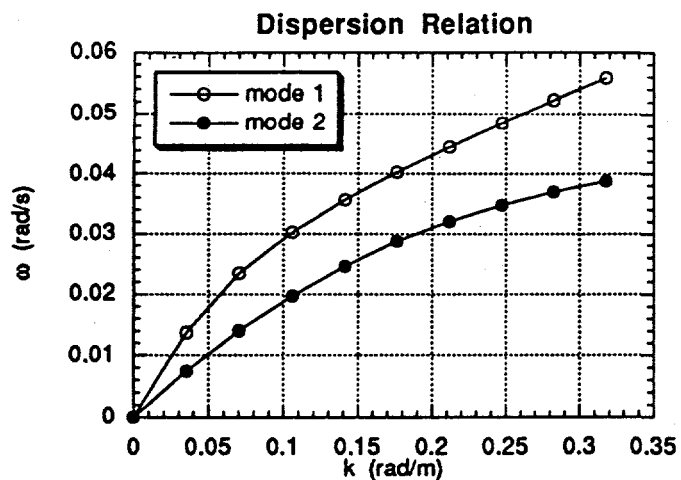
The following table summarizes the date and times of each of the profiles. In each case, the basic profiles and computed internal wave dispersion characteristics are shown on facing pages. Profiles are shown for the entire duration of the ship runs with two exceptions. No profiles were taken on 9/6 as moorings were being moved, and no profiles were recorded on 9/15 as sea conditions prevented the Calanus from tying on to the moorings.

Summary of Profiles

Date	Time (GMT)	Page
9/4/94	14:42	6
	15:45	8
	16:42	10
	17:43	12
9/5/94	13:14	14
	14:21	16
	15:35	18
	16:28	20
	17:17	22
9/7/94	15:59	24
	16:58	26
	17:58	28
9/8/94	09:19	30
	10:17	32
	11:16	34
	12:16	36
	14:16	38
	15:16	40
	16:00	42
9/9/94	09:30	44
	10:30	46
	11:30	48
	12:30	50
	13:30	52
9/10/94	09:59	54
	11:00	56
	11:59	58
	13:00	60
	14:00	62
	15:00	64
9/11/94	16:00	66
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	12:55	72
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	14:55	76
	15:55	78

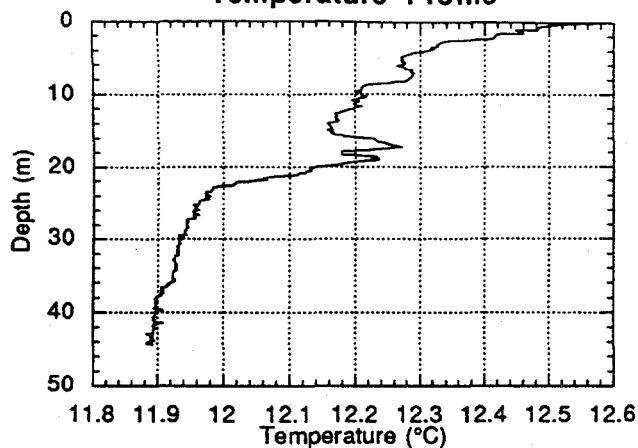
Date	Time	Page
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	11:30	82
	12:30	84
	13:30	86
	14:31	88
	16:30	90
9/13/94	12:30	92
	13:31	94
	14:30	96
	15:30	98
	16:29	100
9/14/94	13:00	102
	14:00	104
	15:00	106
	16:00	108
	17:00	110
9/16/94	10:30	112
	13:30	114
	14:30	116
	15:30	118
	16:30	120
	17:30	122
9/17/94	10:57	124
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	15:30	130
	16:30	132
	17:30	134



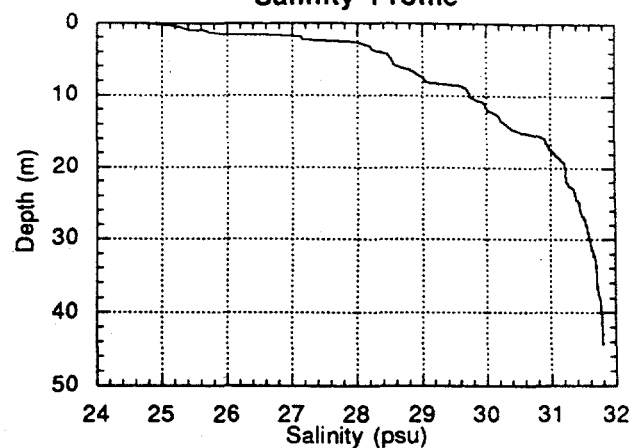


9/4/94, 15:45 GMT

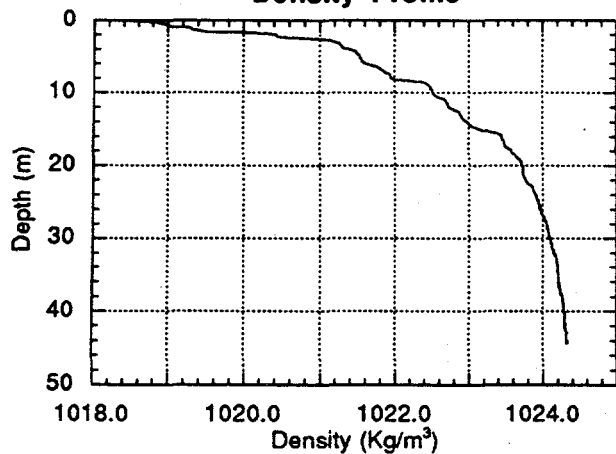
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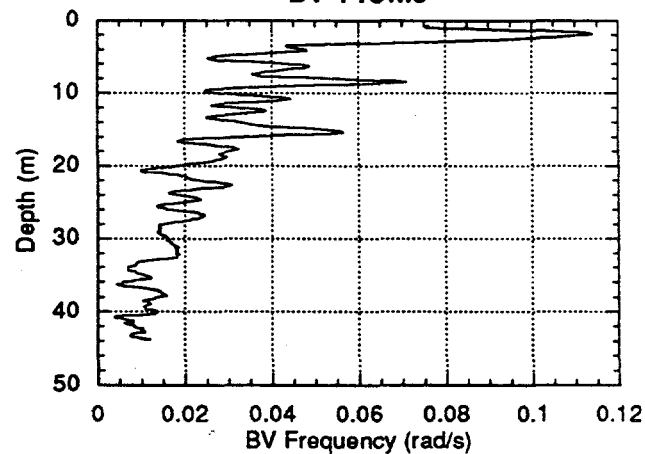
Salinity Profile



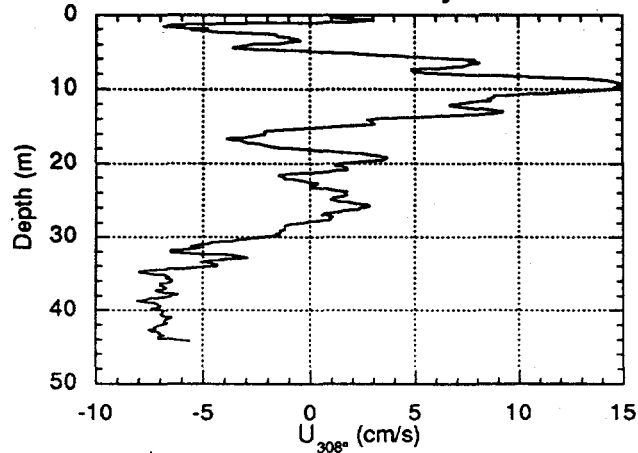
Density Profile



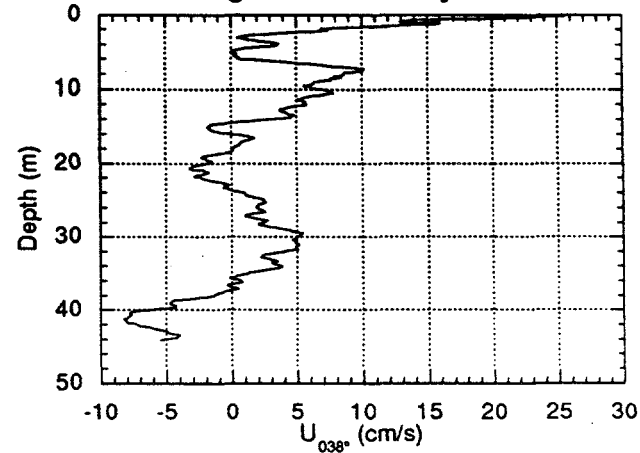
BV Profile

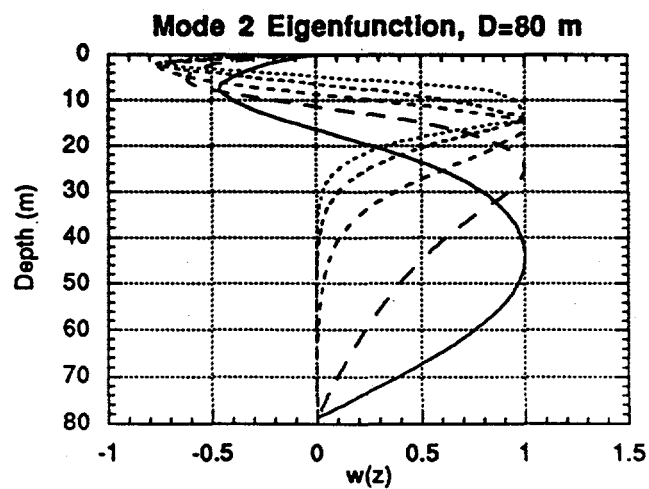
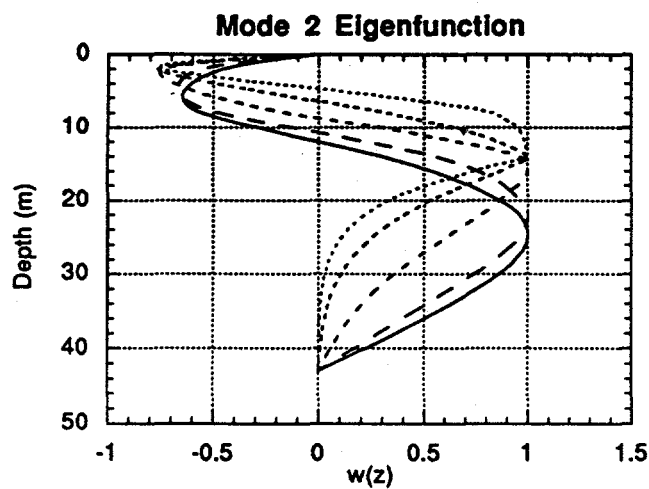
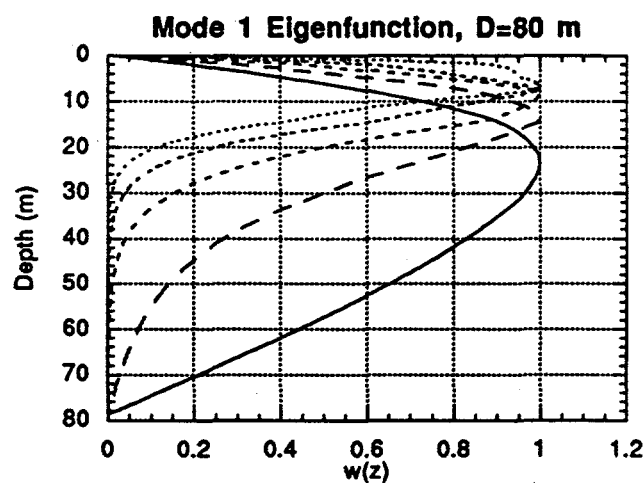
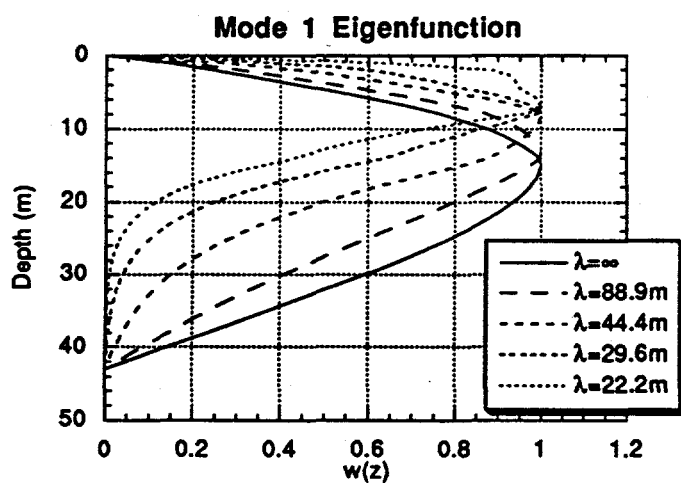
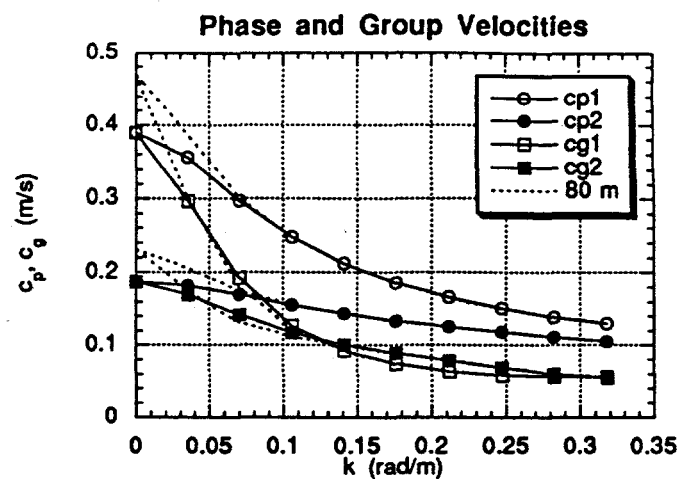
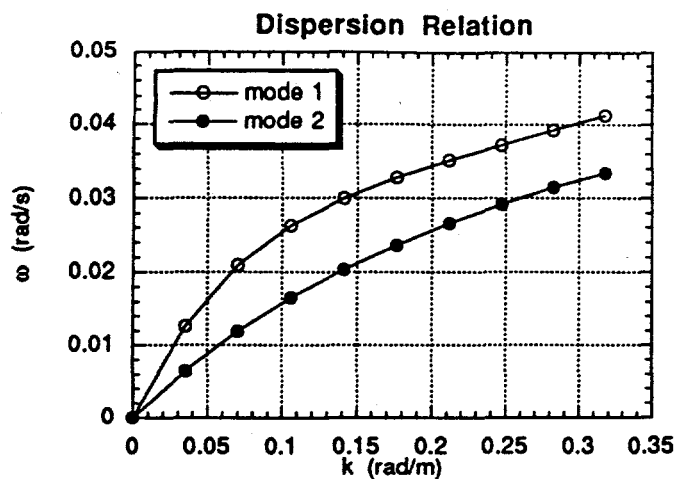


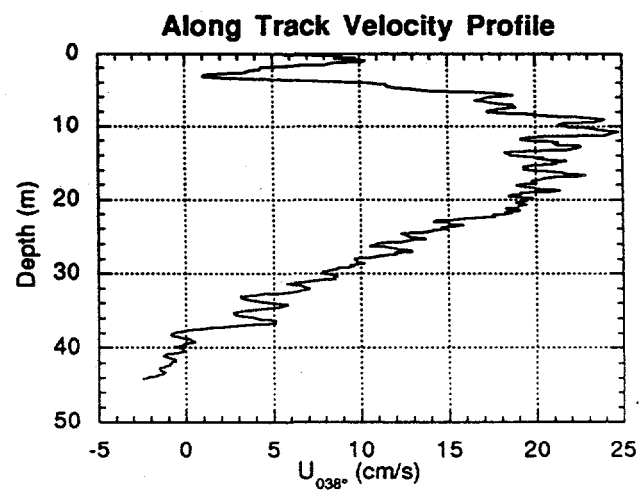
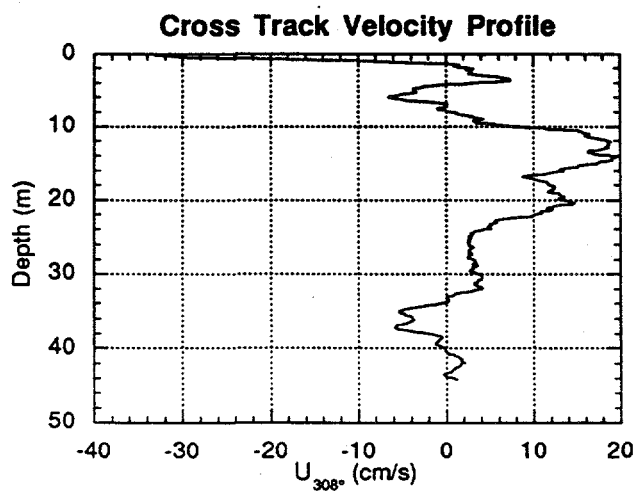
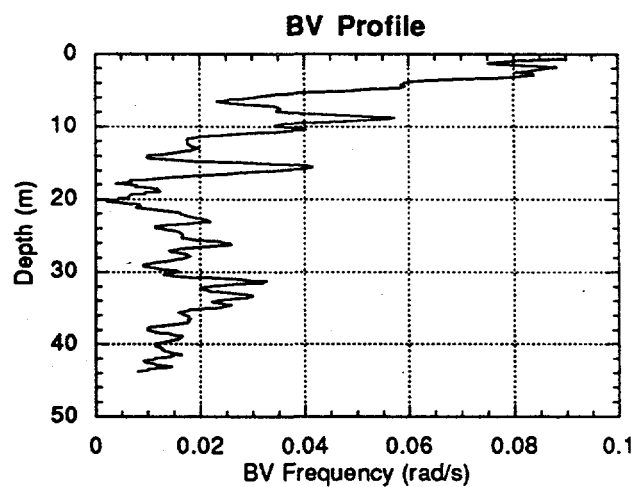
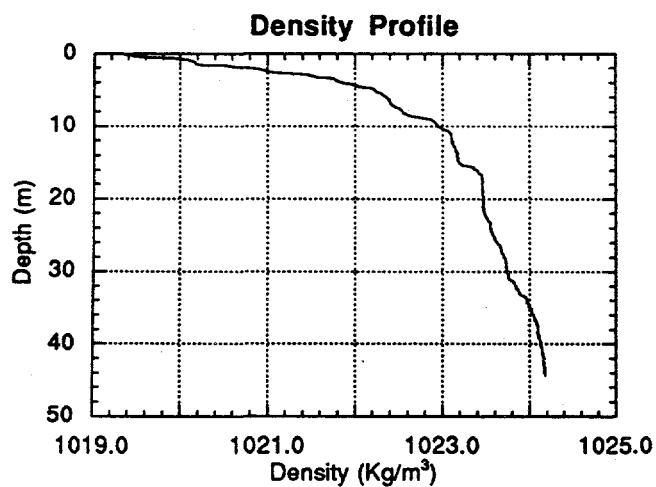
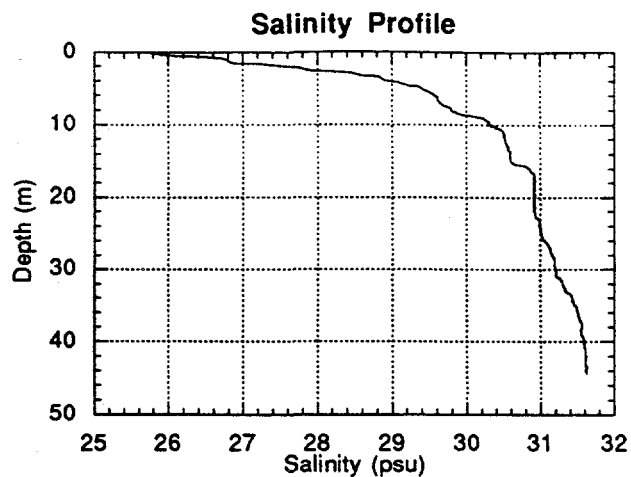
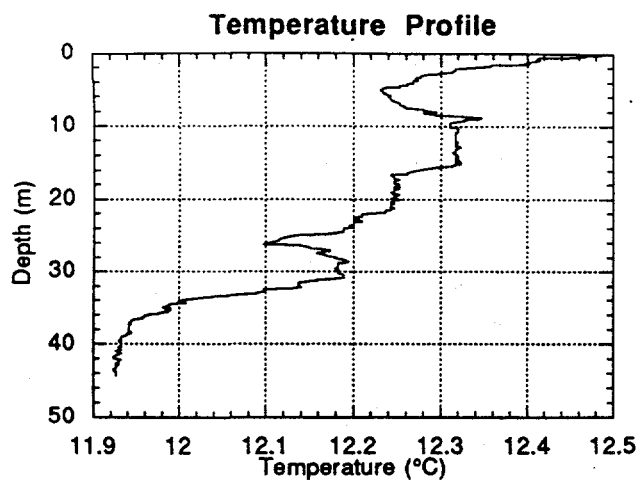
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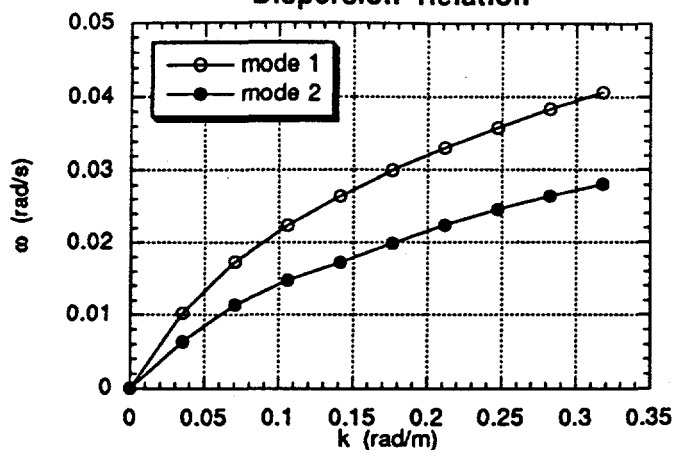
Along Track Velocity Profile



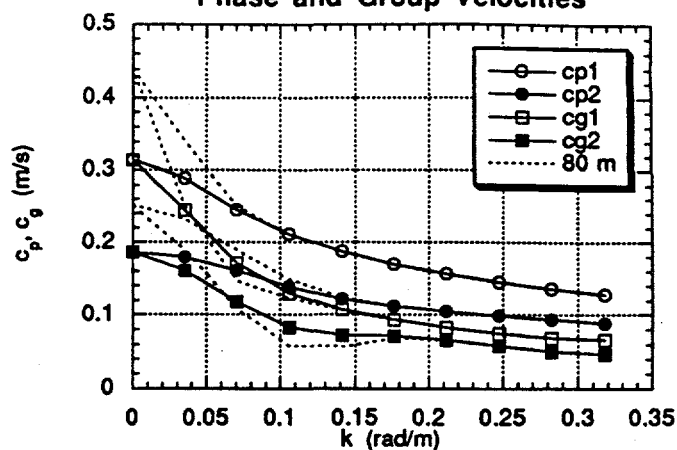




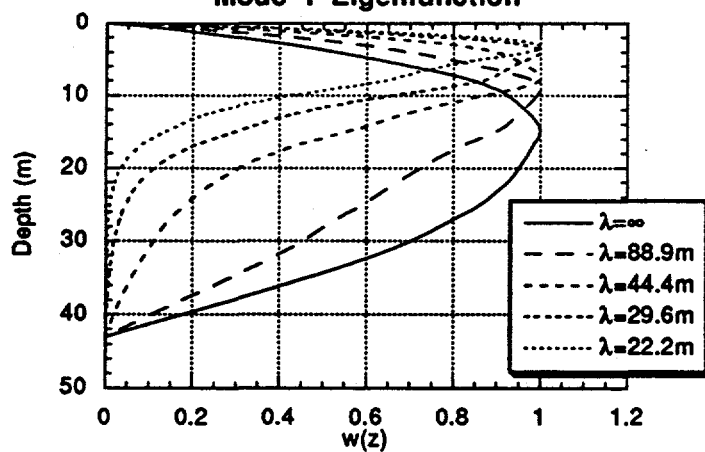
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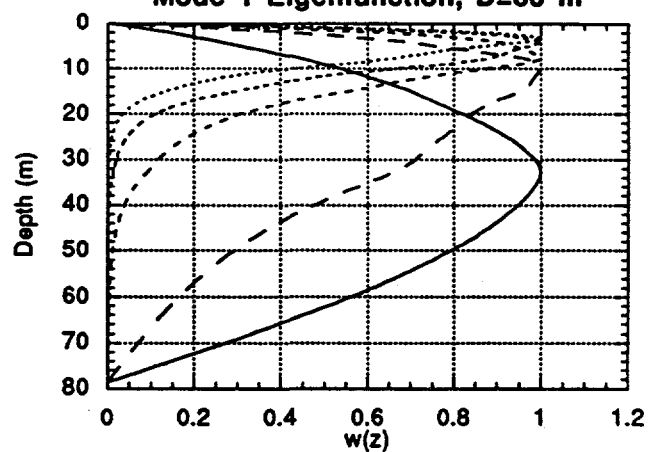
Phase and Group Velocities



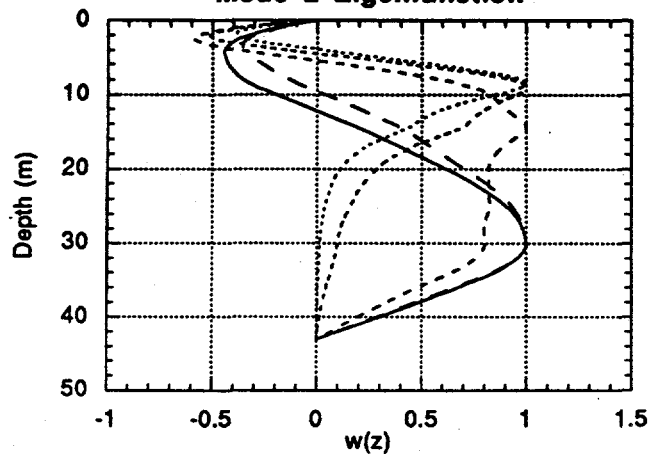
Mode 1 Eigenfunction



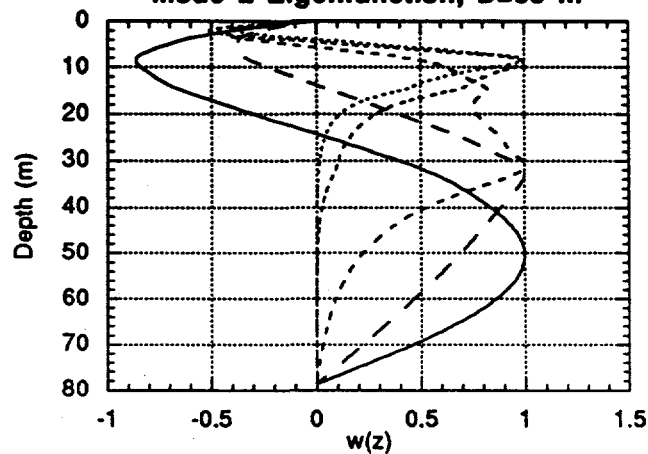
Mode 1 Eigenfunction, D=80 m

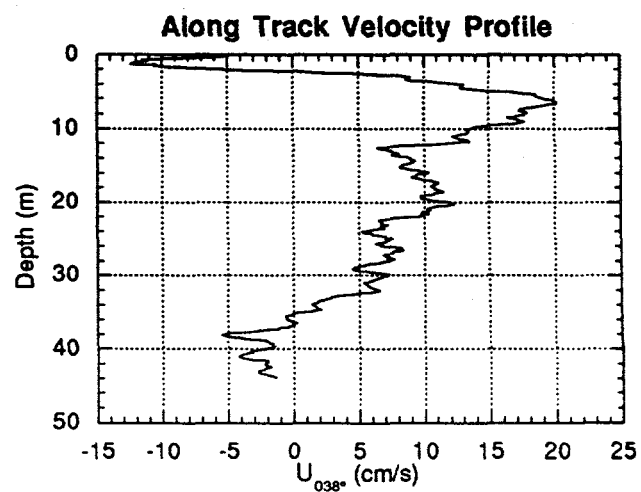
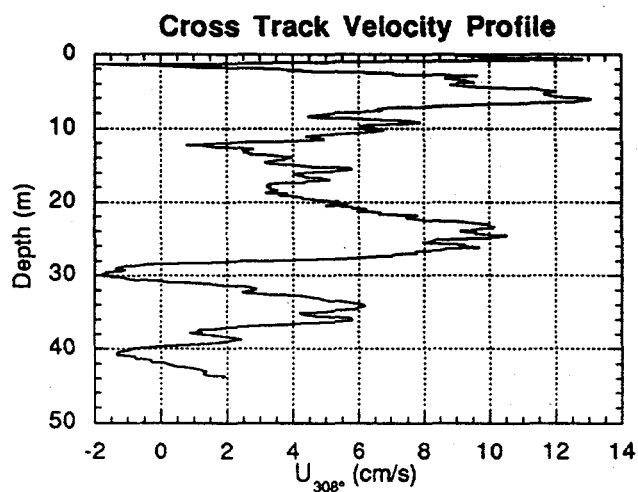
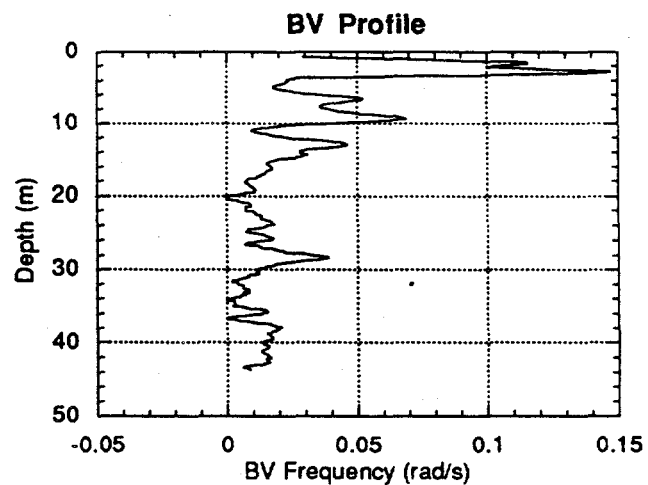
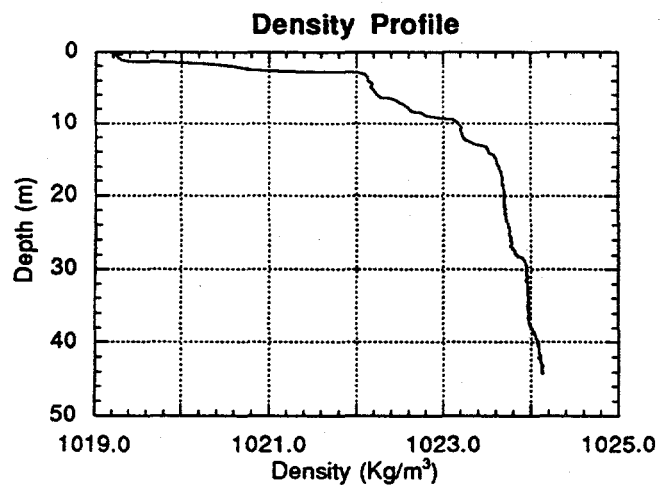
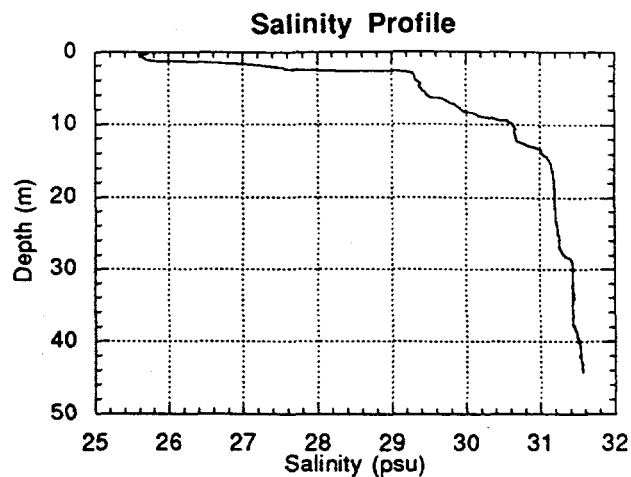
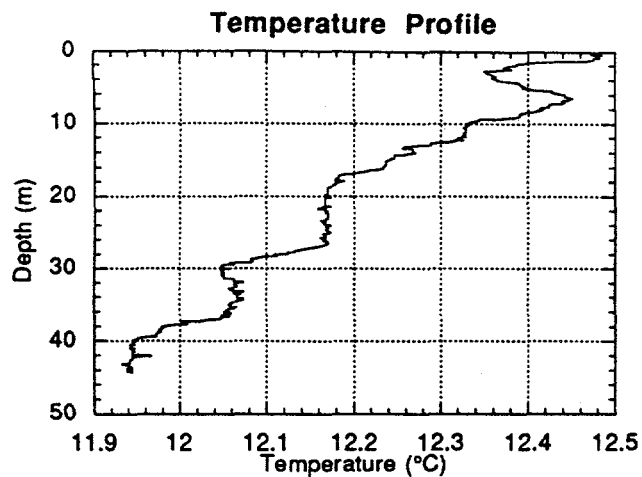


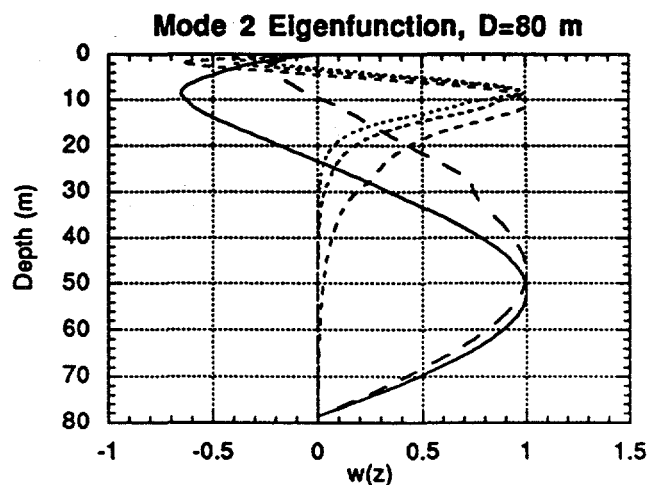
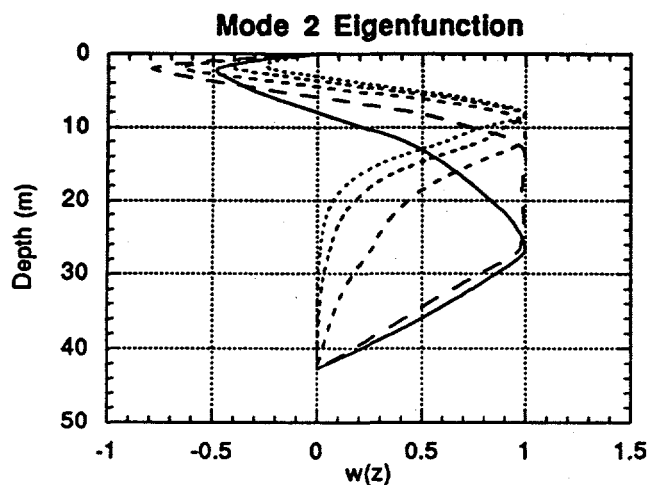
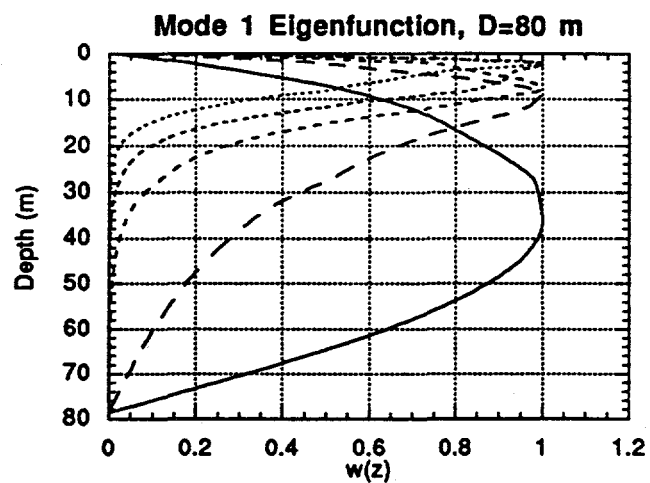
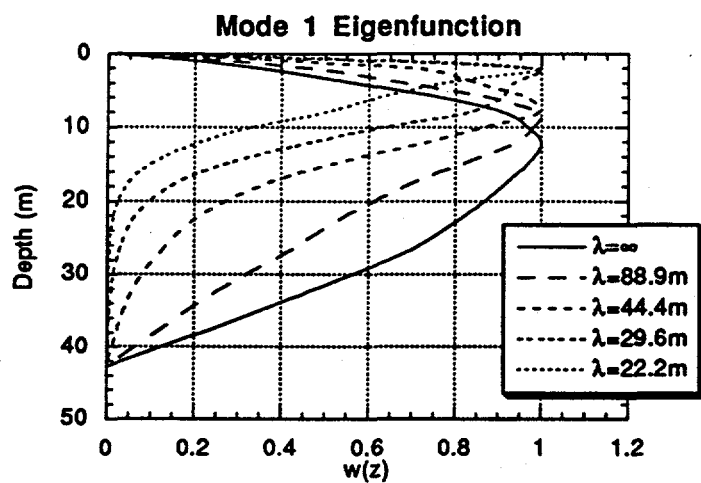
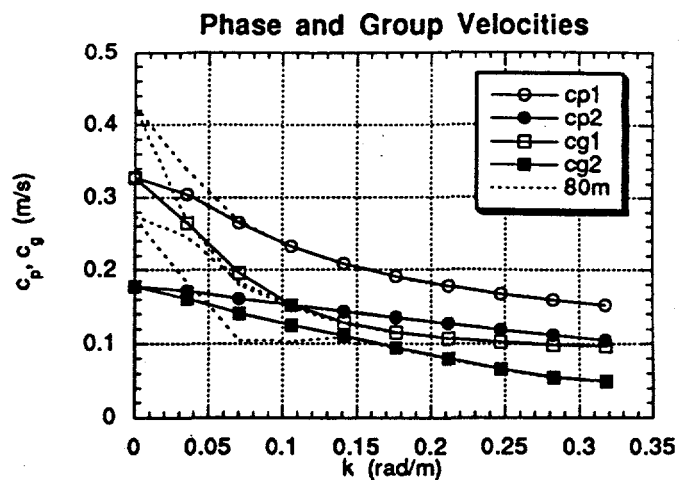
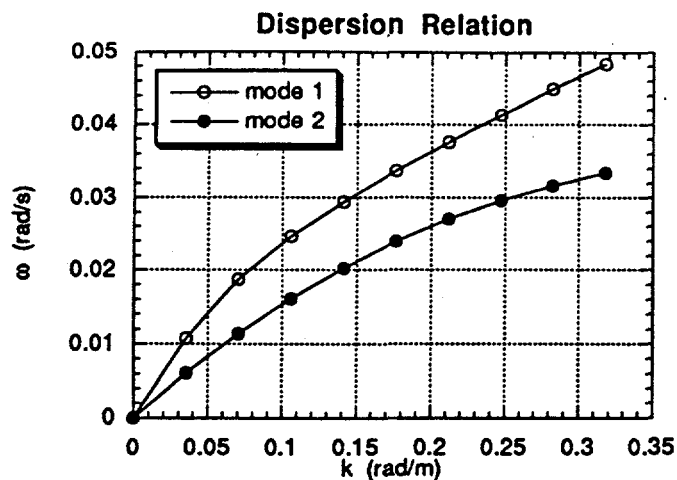
Mode 2 Eigenfunction

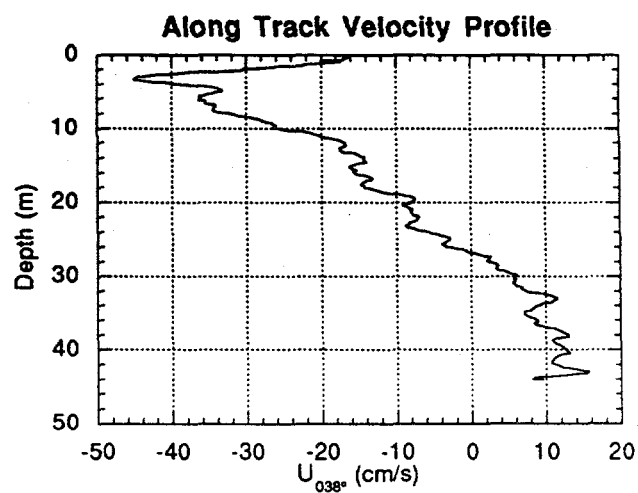
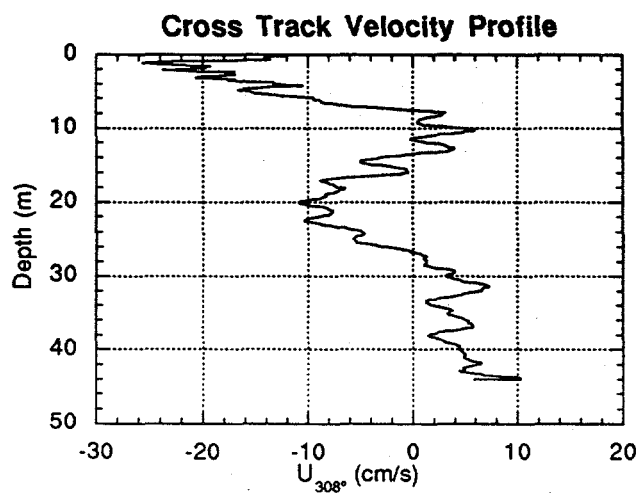
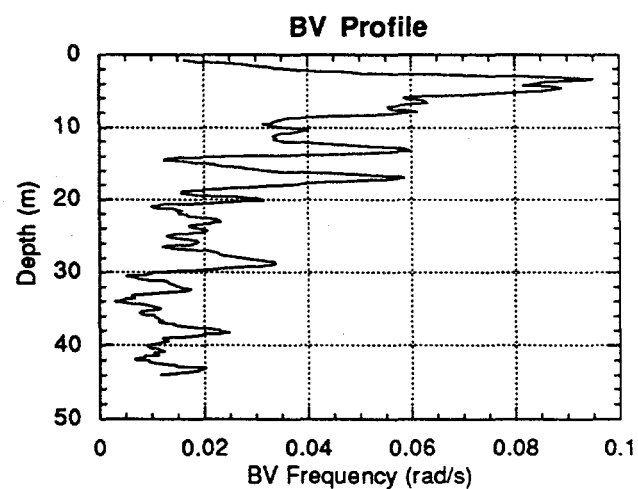
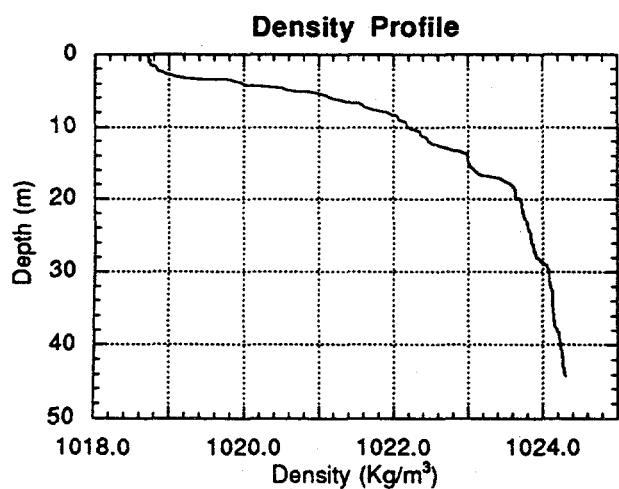
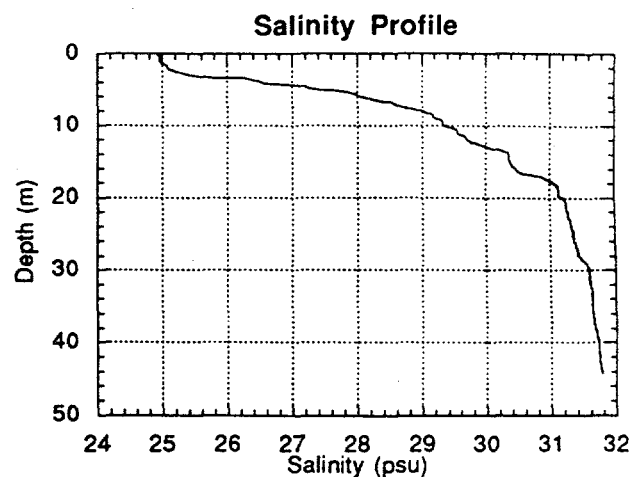
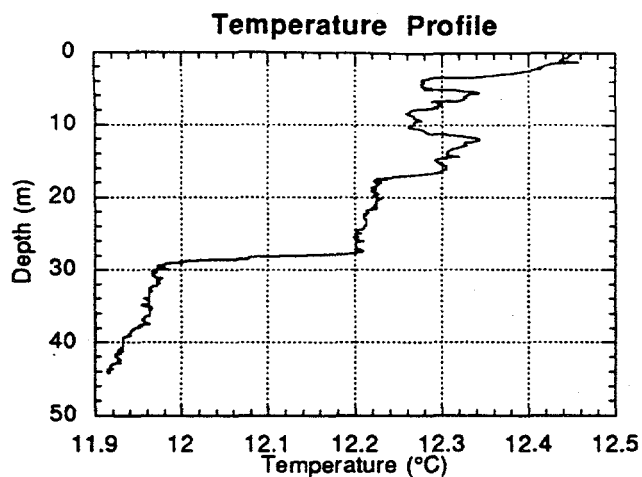


Mode 2 Eigenfunction, D=80 m

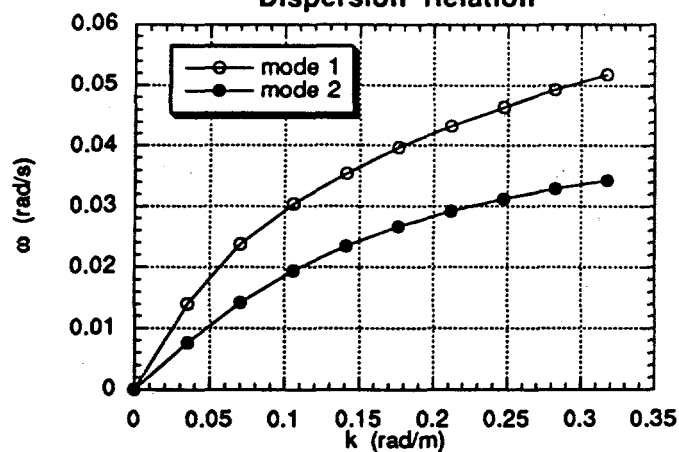




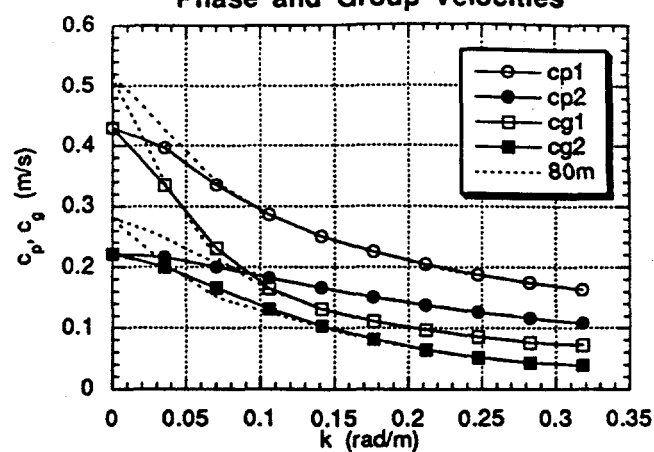




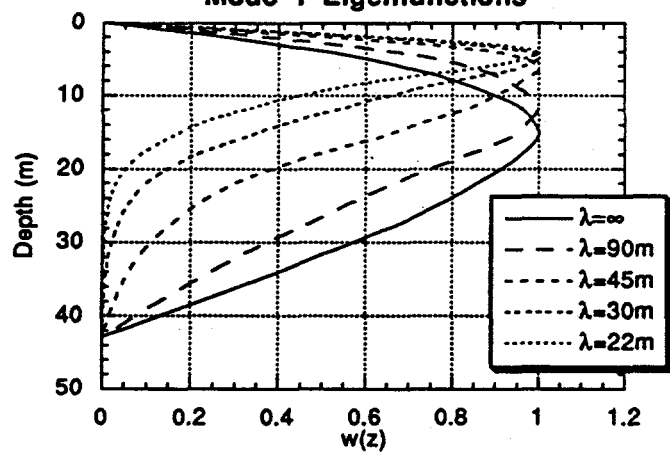
Dispersion Relation



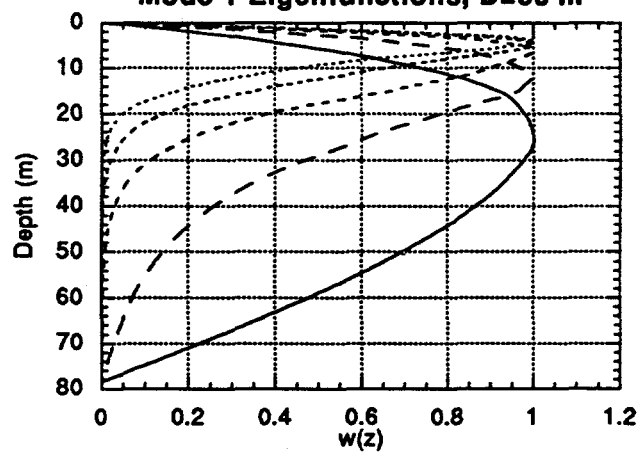
Phase and Group Velocities



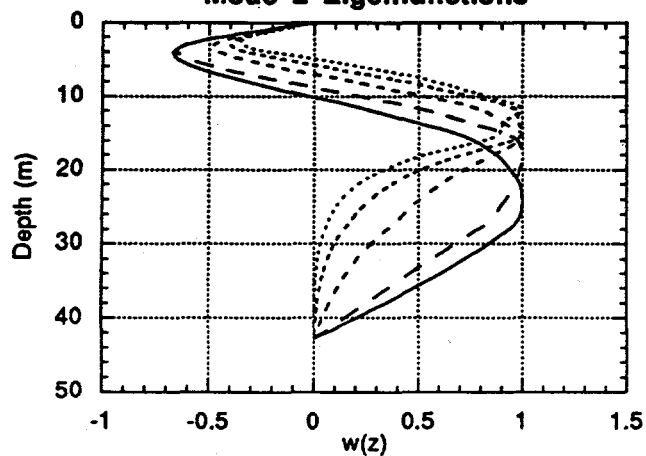
Mode 1 Eigenfunctions



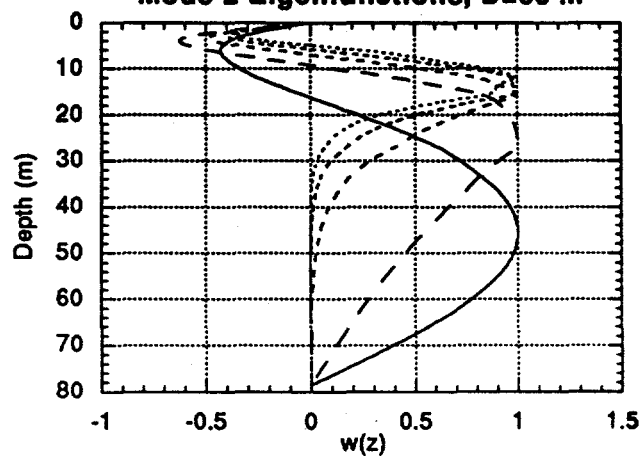
Mode 1 Eigenfunctions, D=80 m

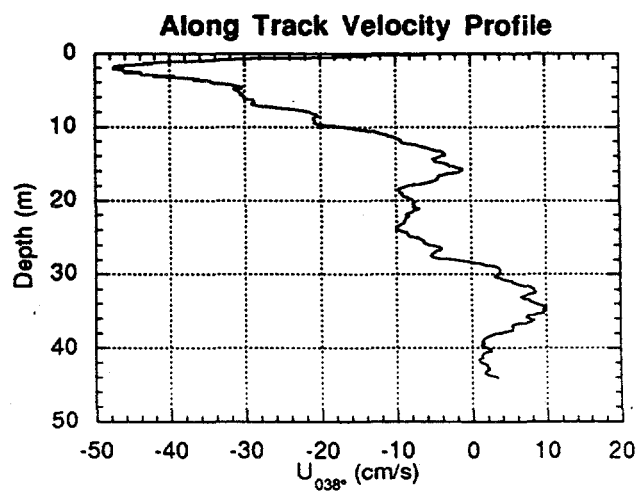
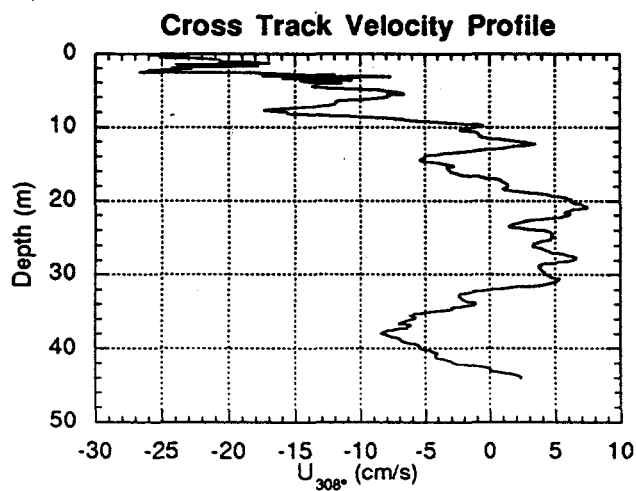
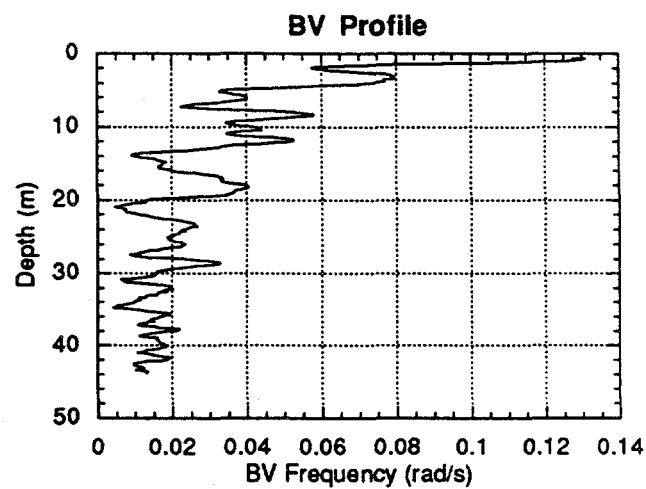
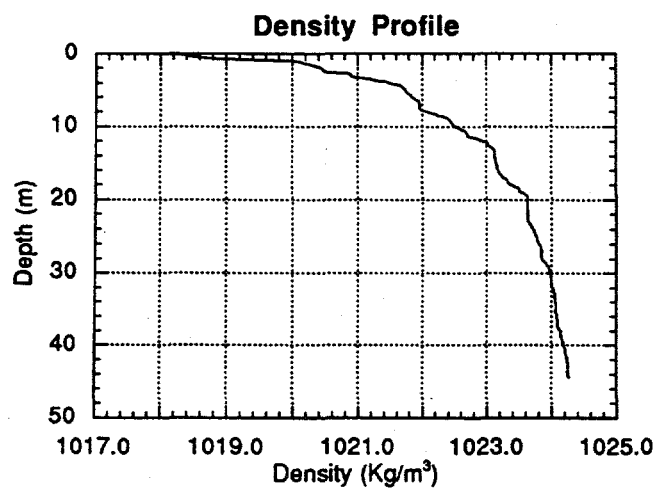
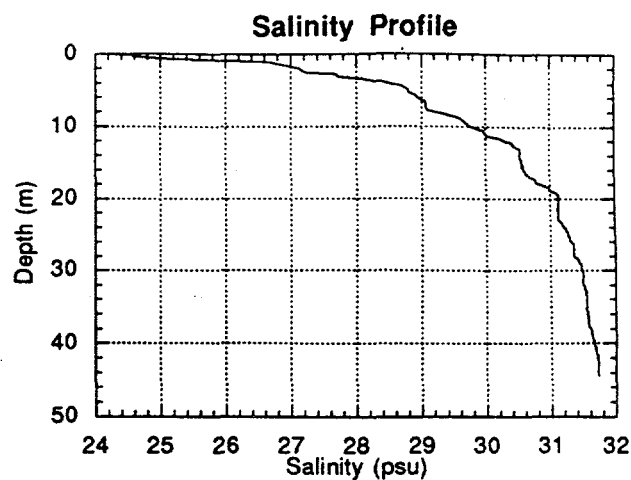
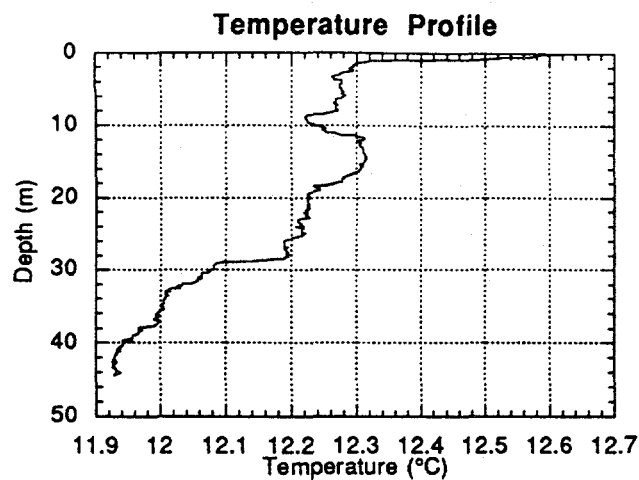


Mode 2 Eigenfunctions

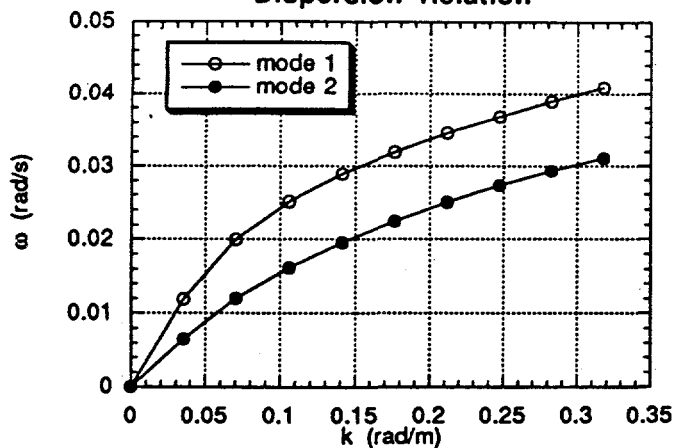


Mode 2 Eigenfunctions, D=80 m

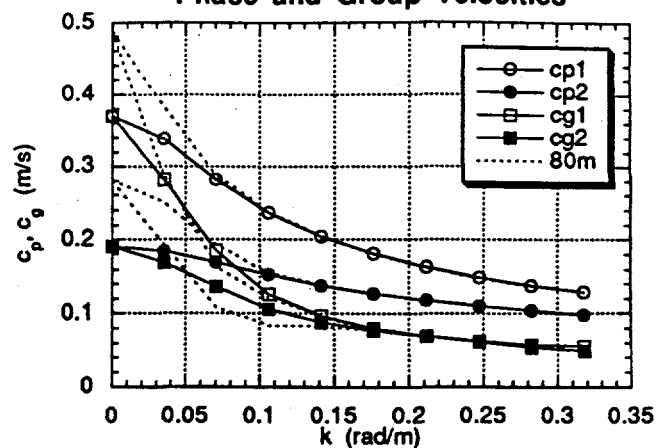




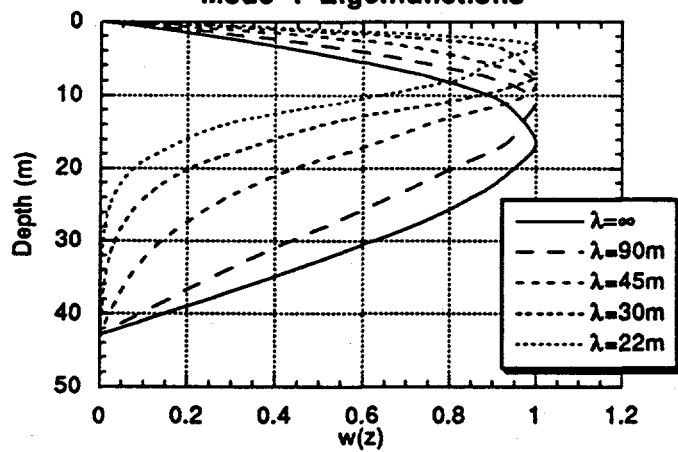
Dispersion Relation



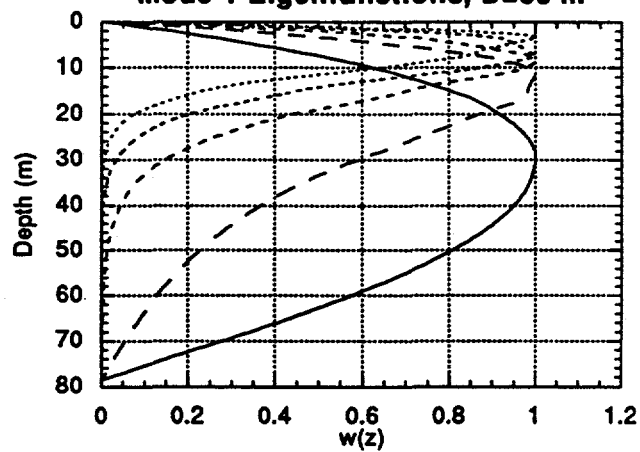
Phase and Group Velocities



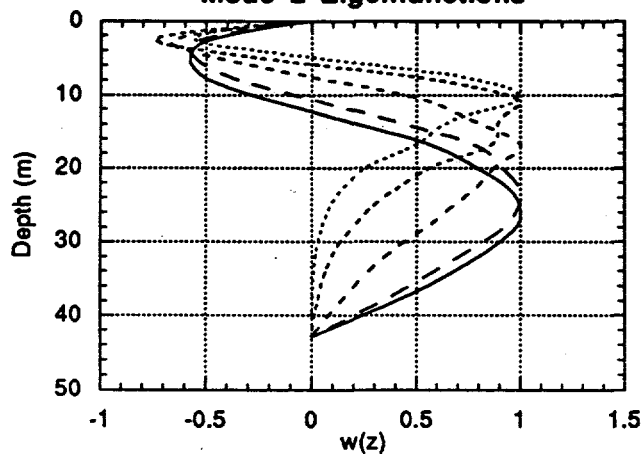
Mode 1 Eigenfunctions



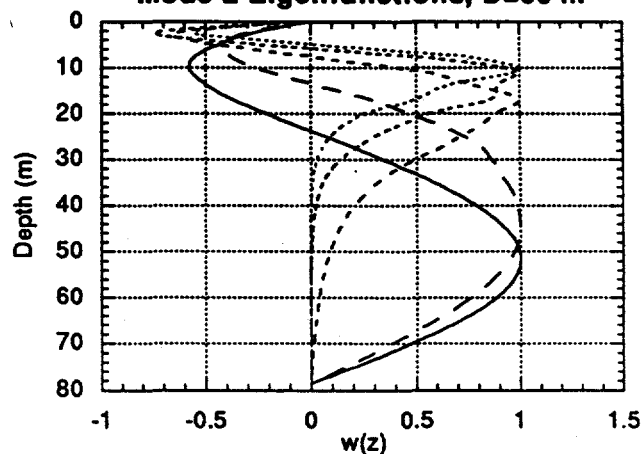
Mode 1 Eigenfunctions, D=80 m



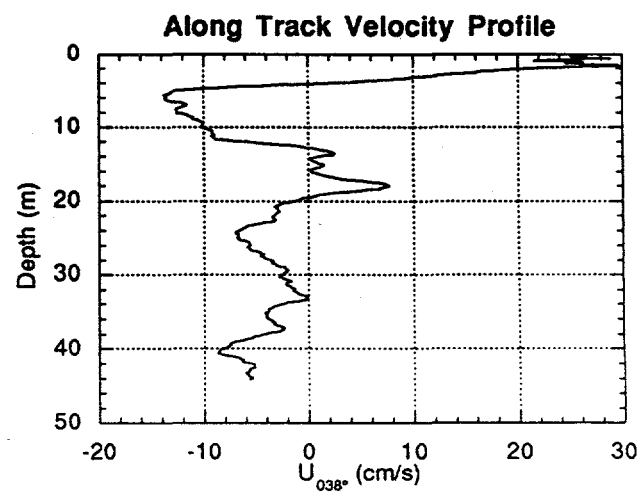
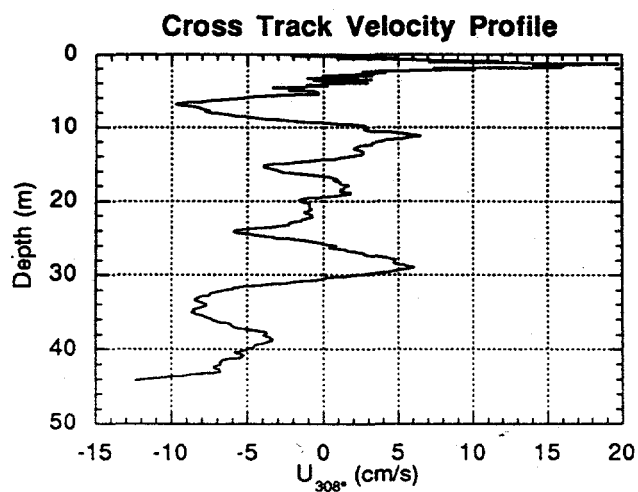
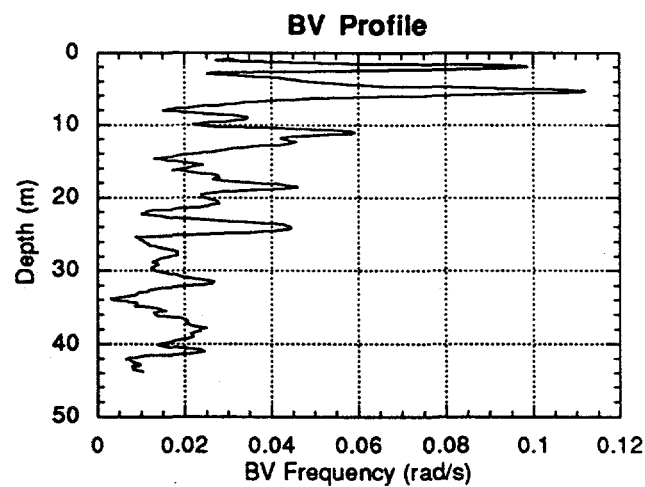
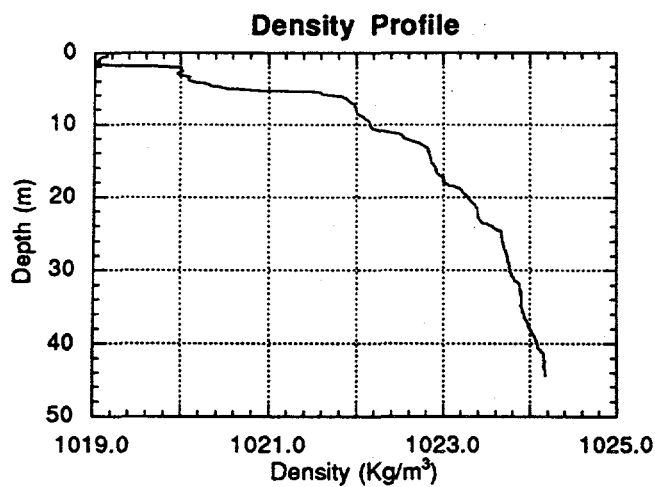
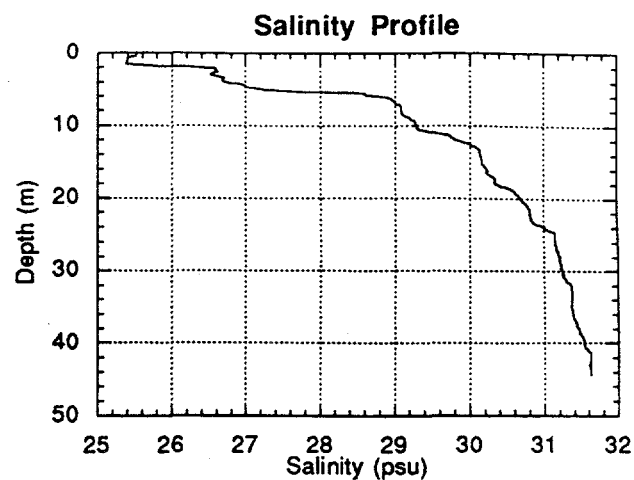
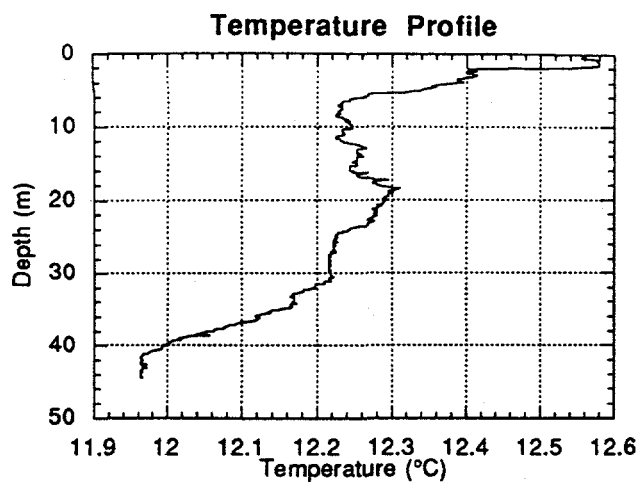
Mode 2 Eigenfunctions

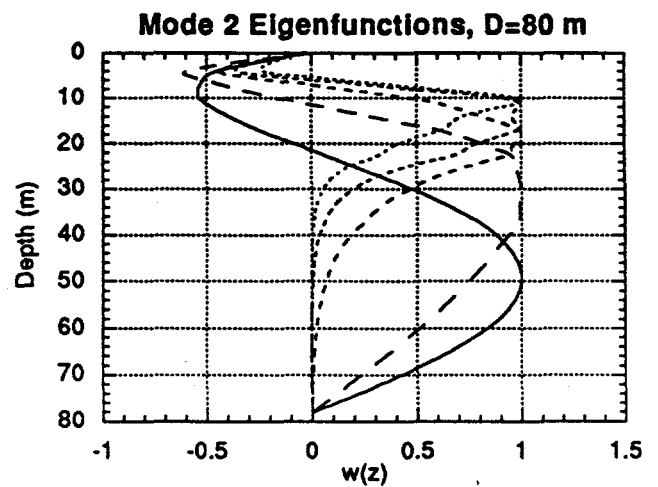
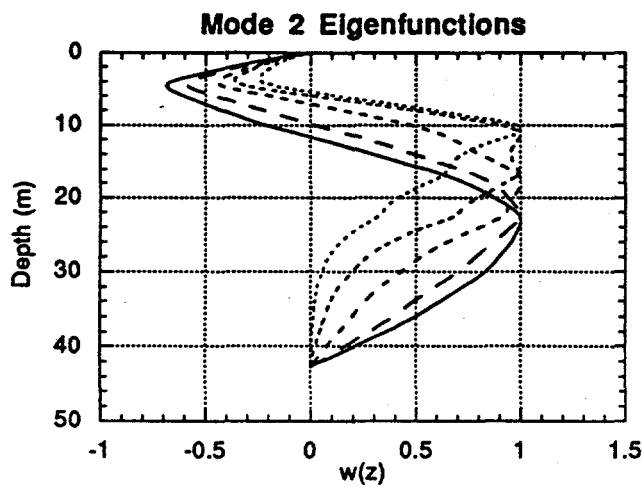
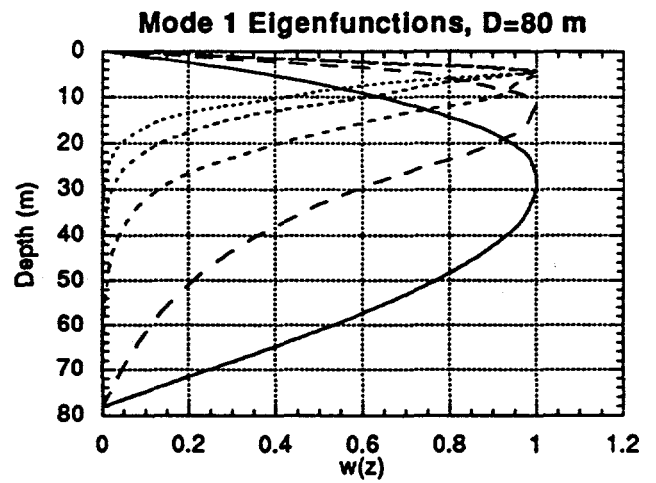
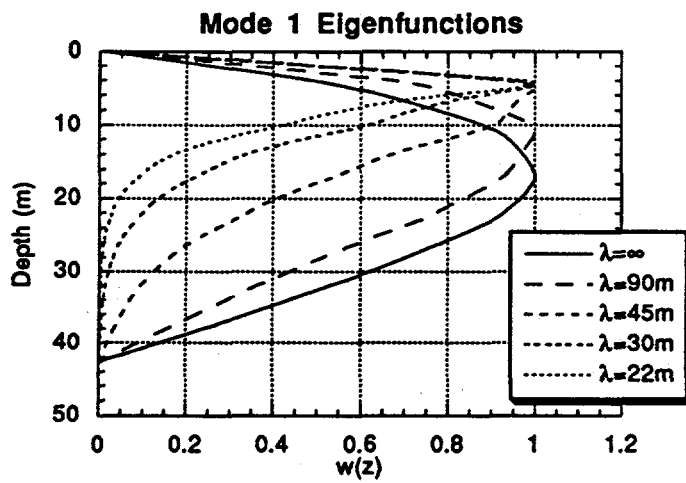
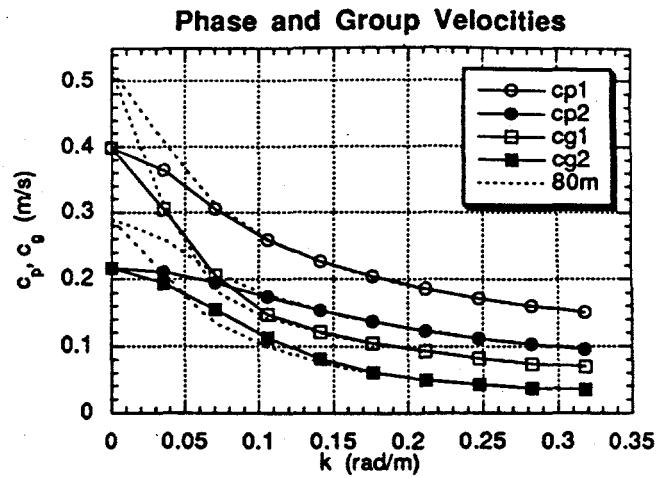
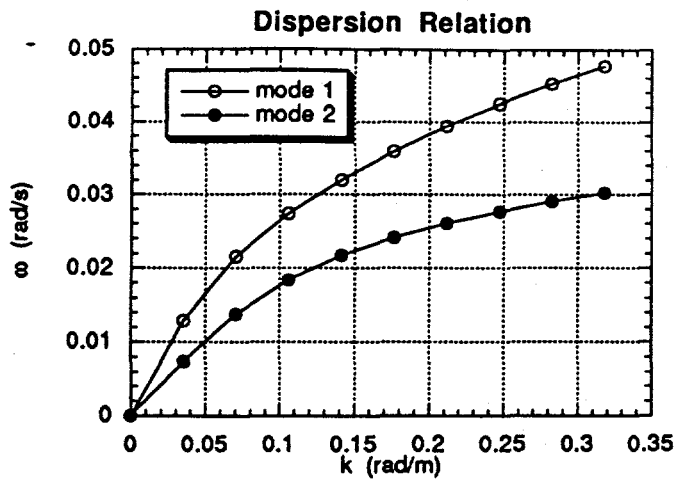


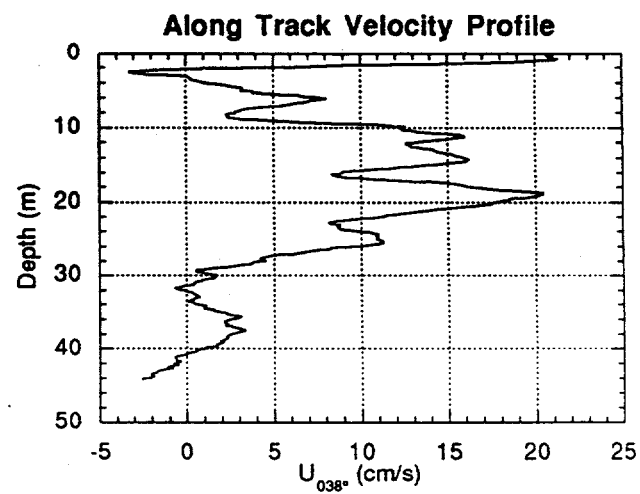
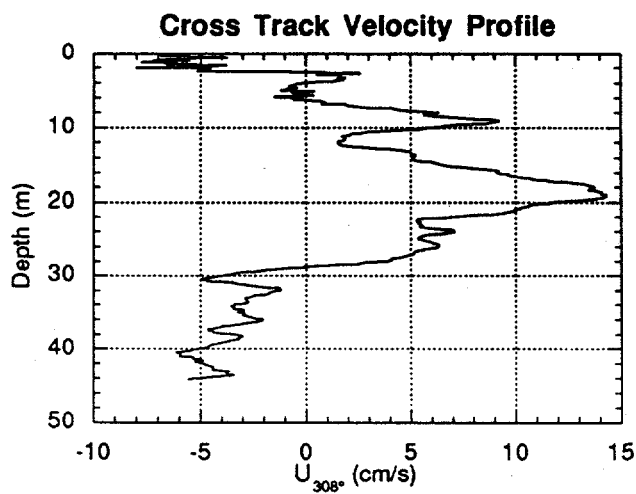
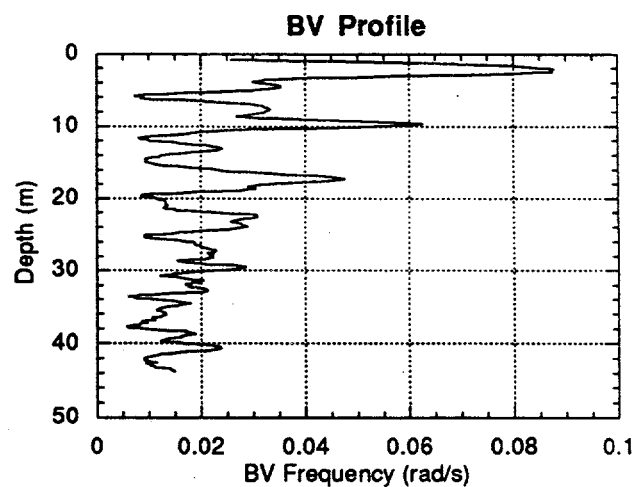
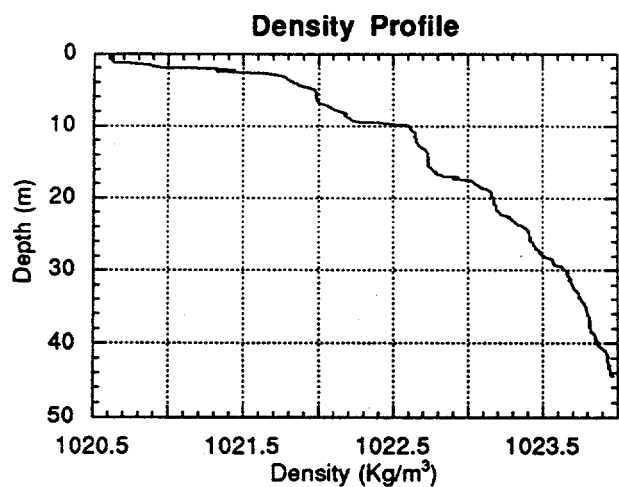
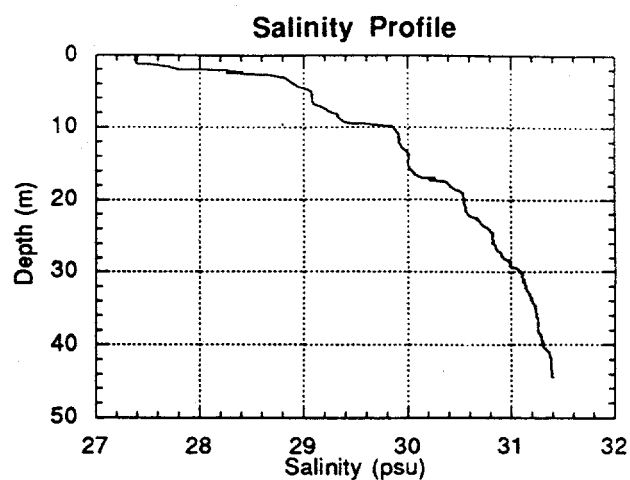
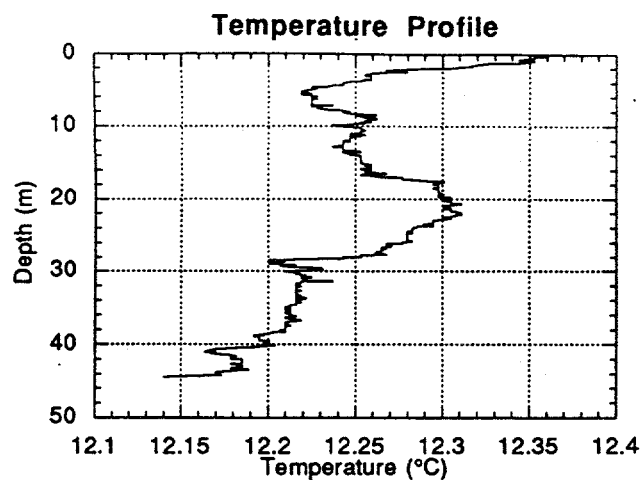
Mode 2 Eigenfunctions, D=80 m

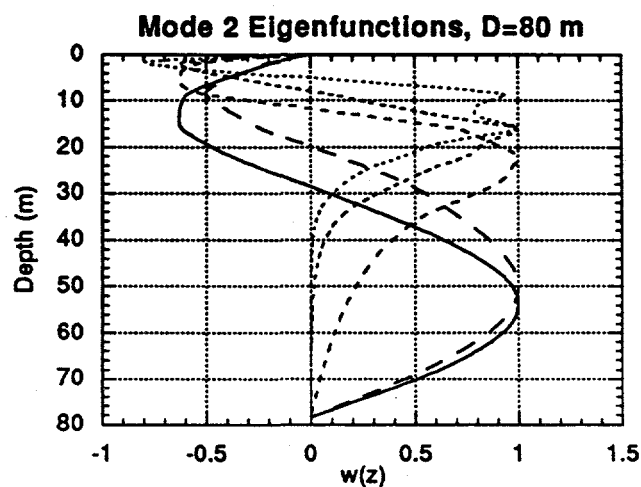
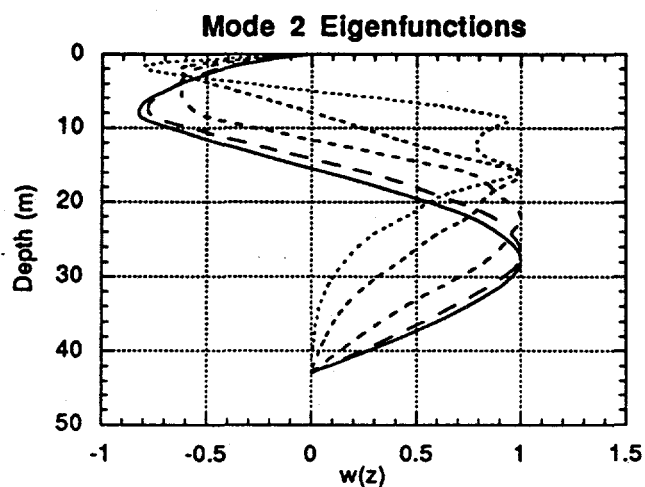
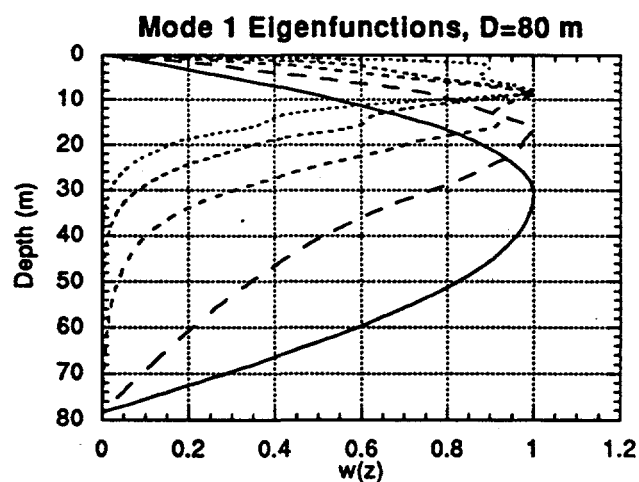
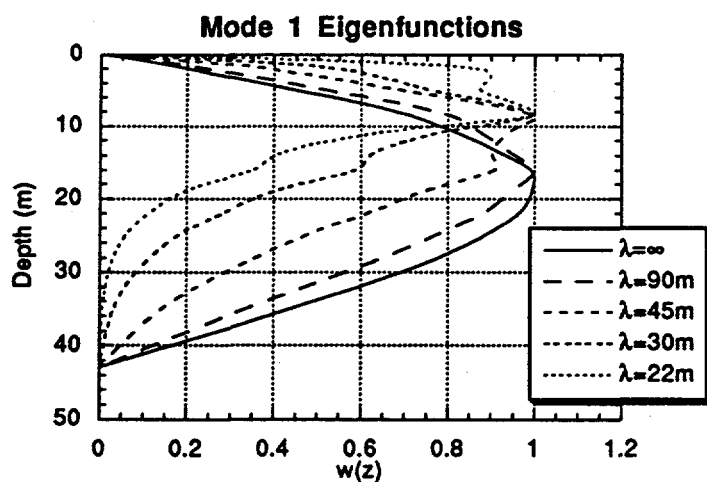
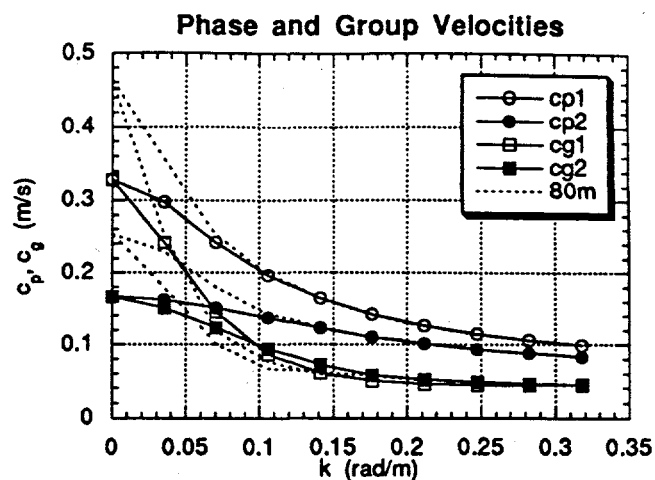
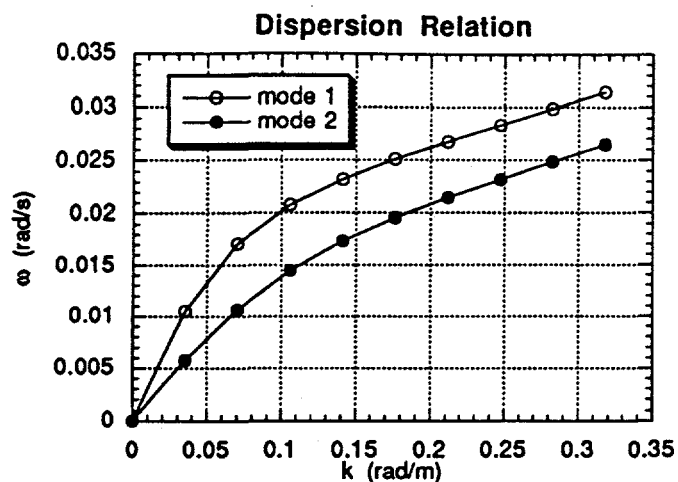


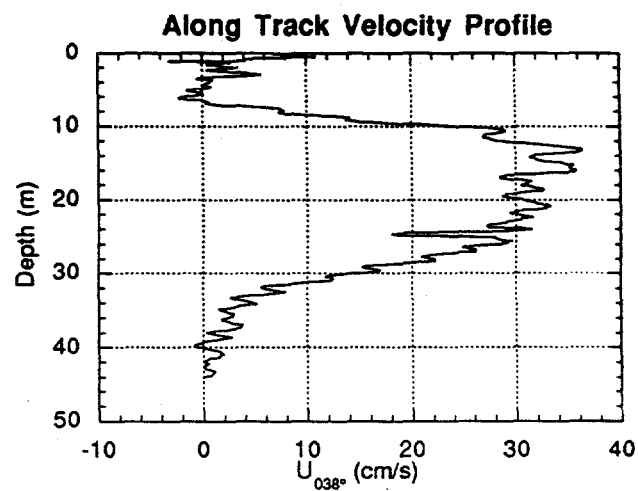
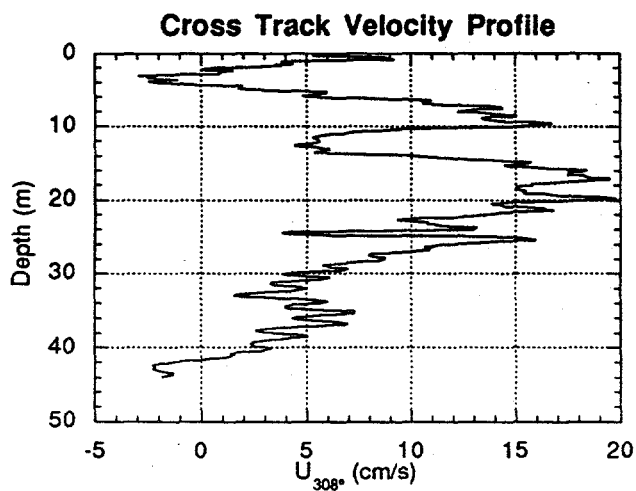
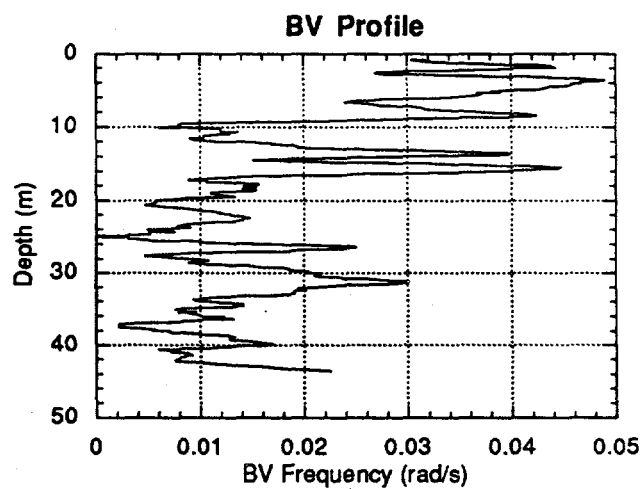
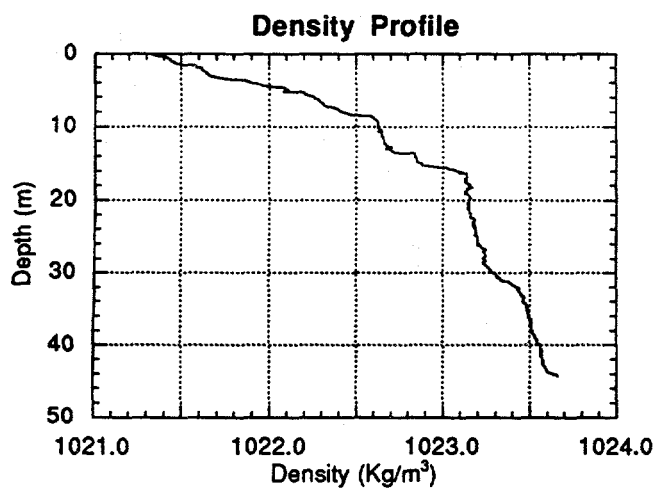
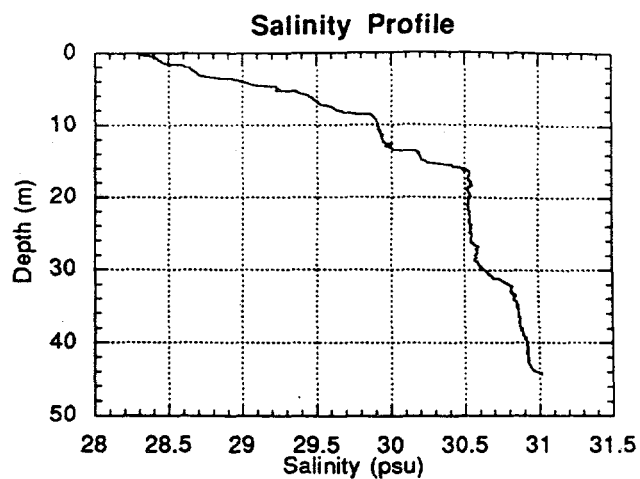
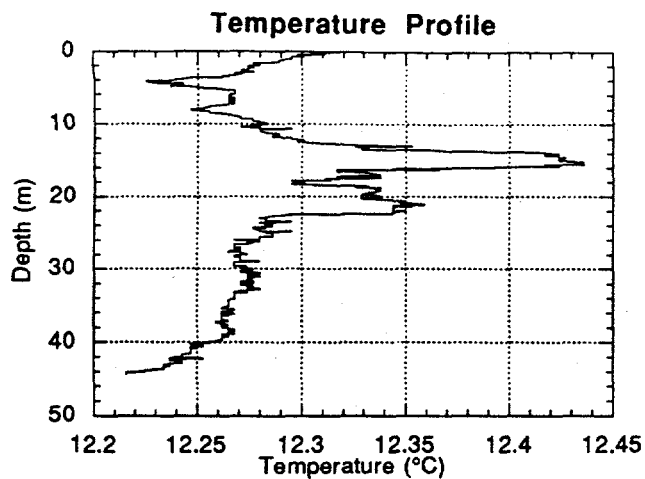
9/5/94, 15:35 GMT



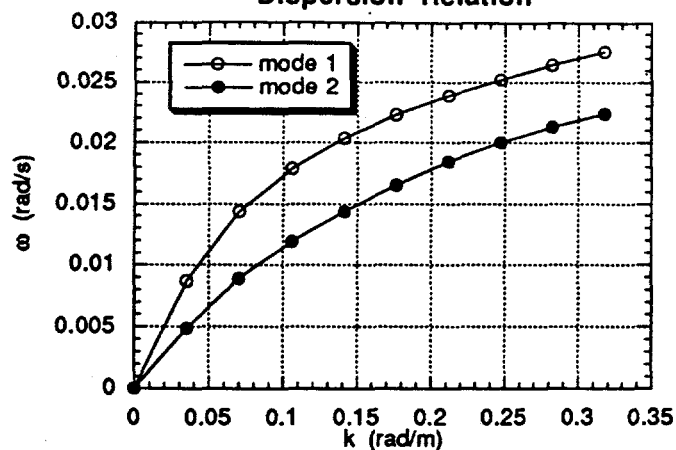




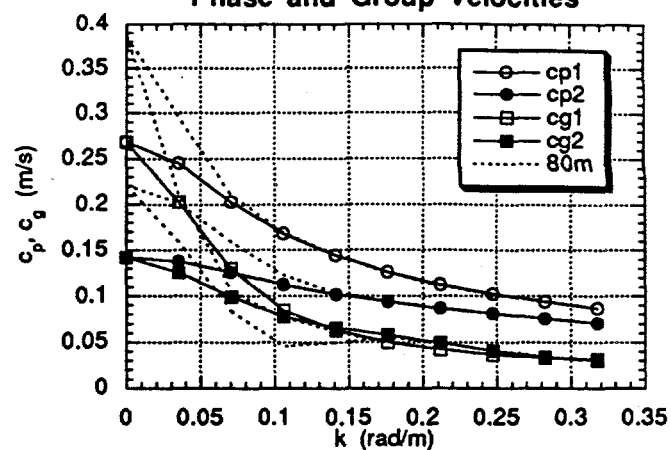




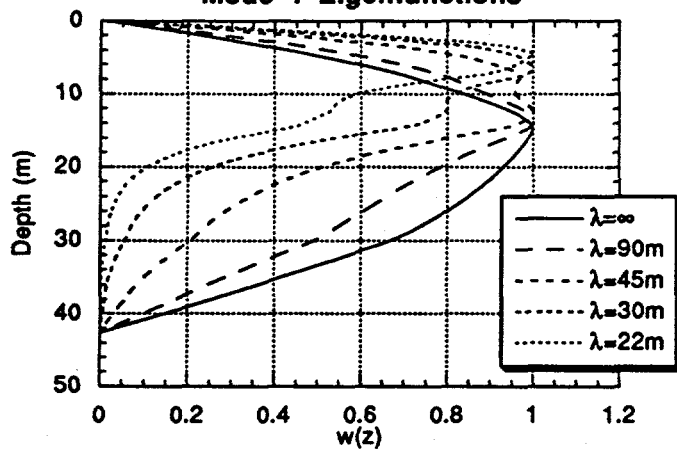
Dispersion Relation



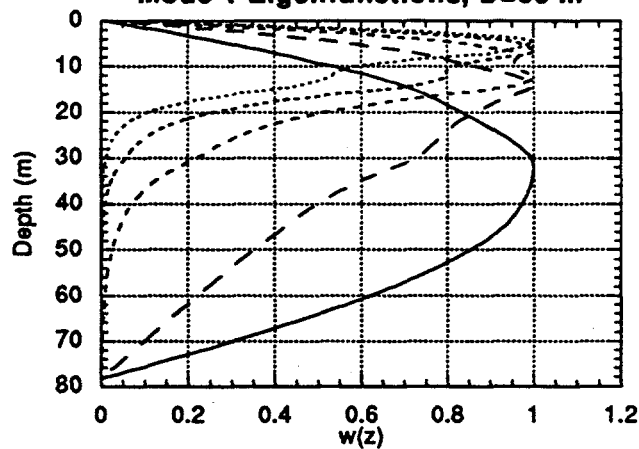
Phase and Group Velocities



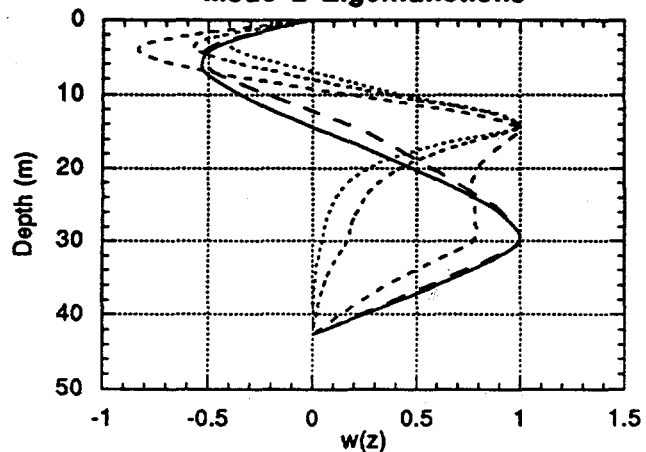
Mode 1 Eigenfunctions



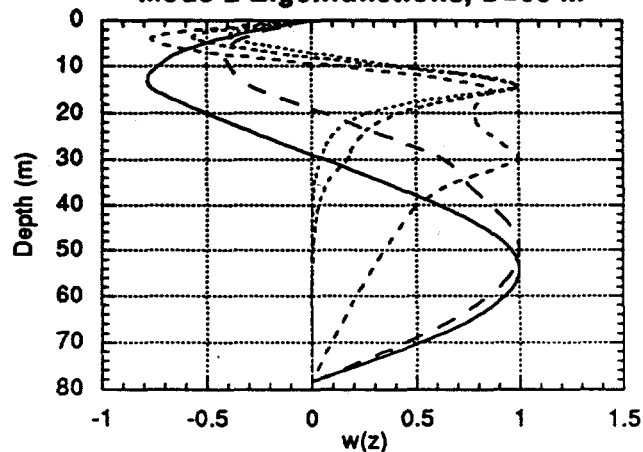
Mode 1 Eigenfunctions, D=80 m

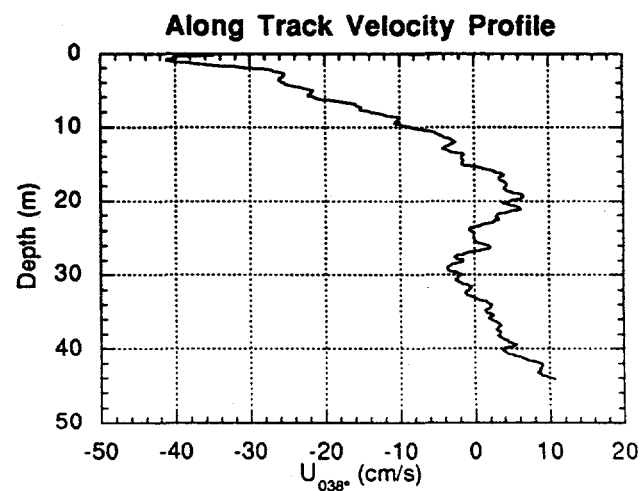
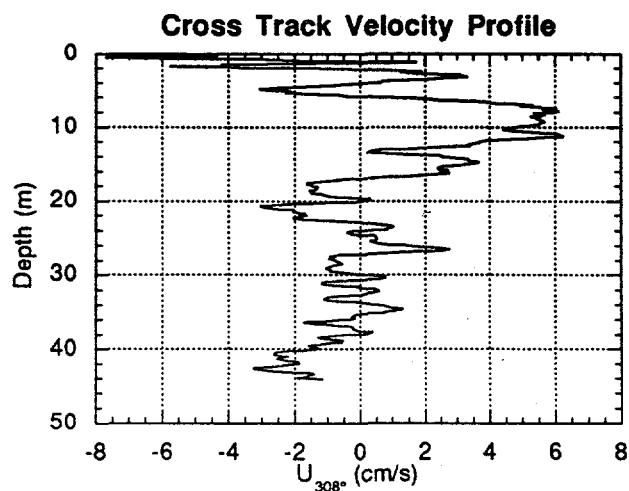
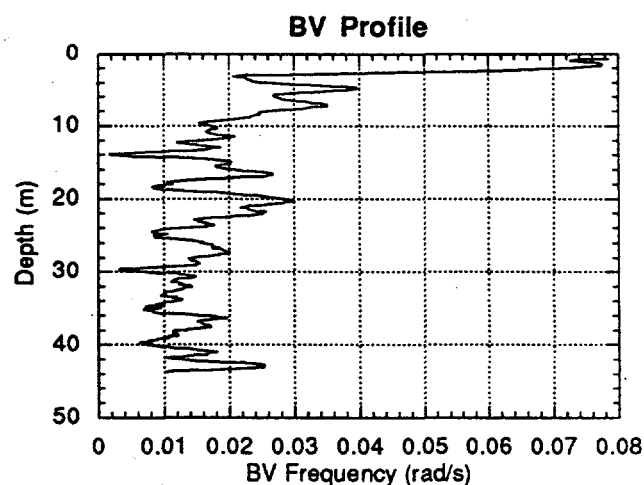
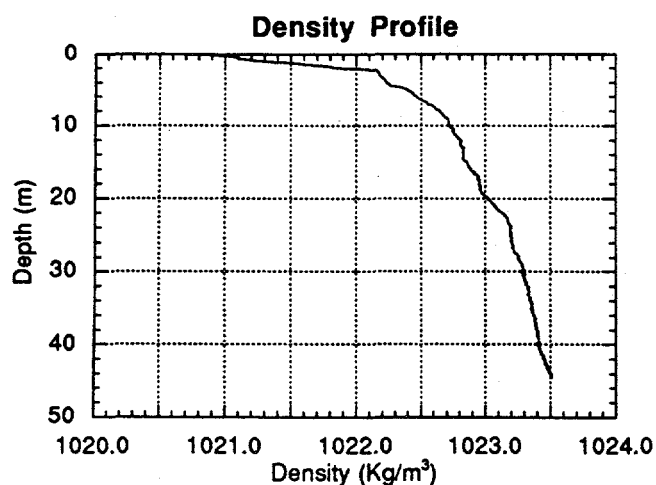
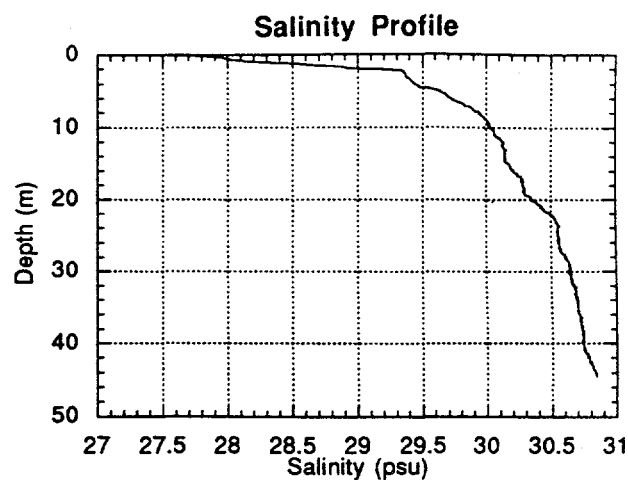
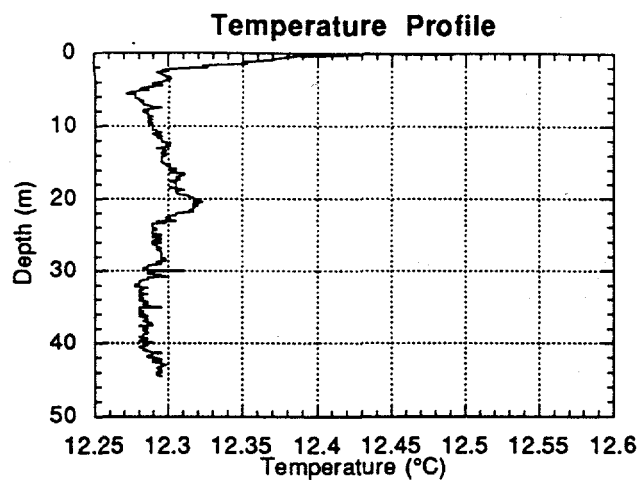


Mode 2 Eigenfunctions

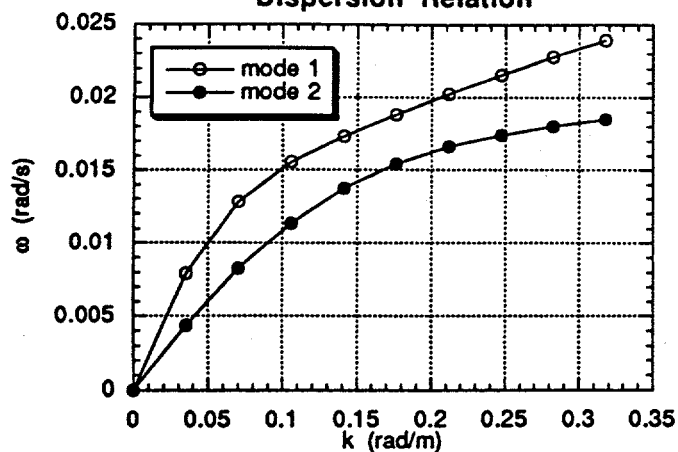


Mode 2 Eigenfunctions, D=80 m

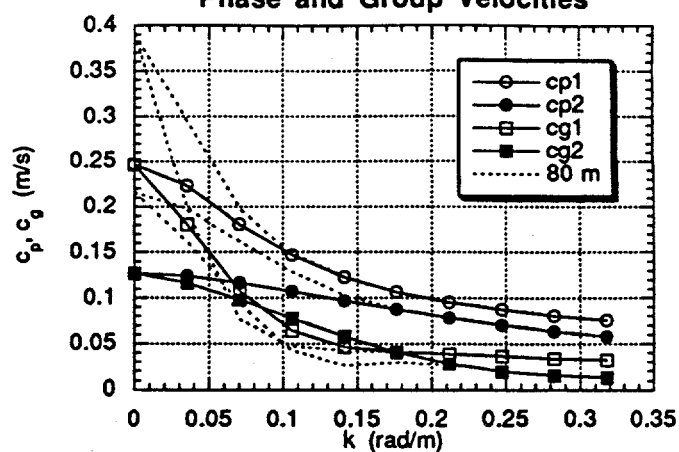




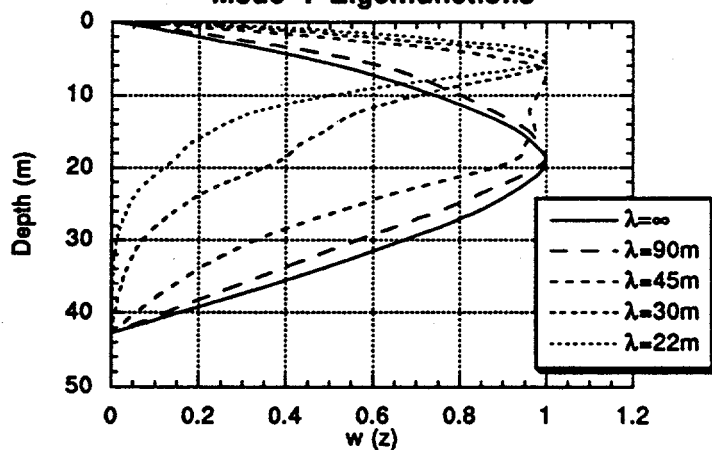
Dispersion Relation



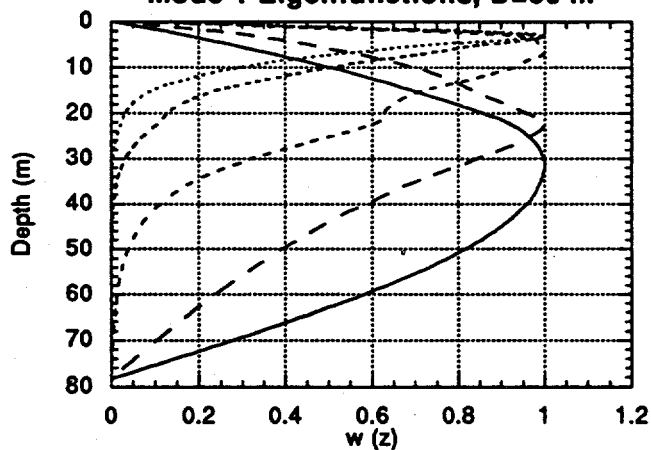
Phase and Group Velocities



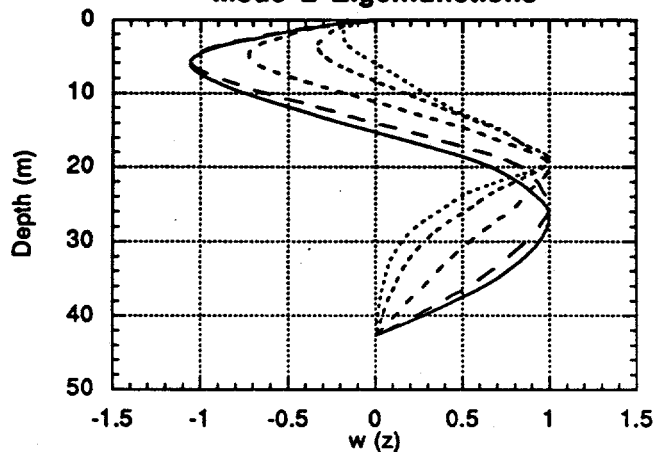
Mode 1 Eigenfunctions



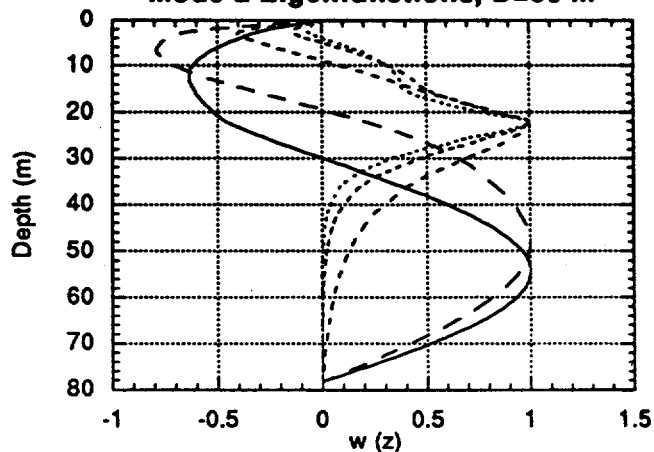
Mode 1 Eigenfunctions, D=80 m

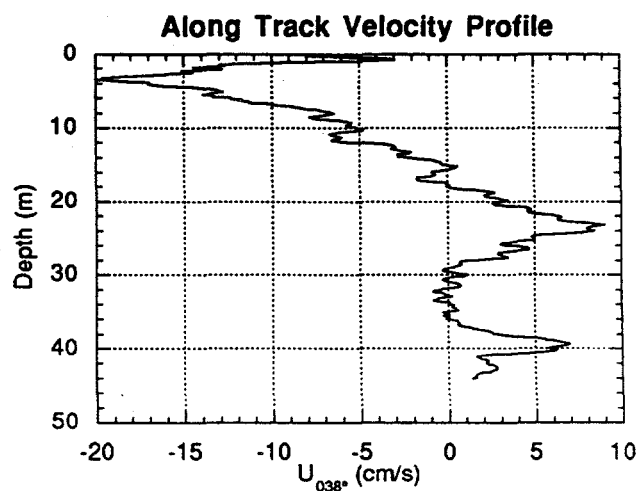
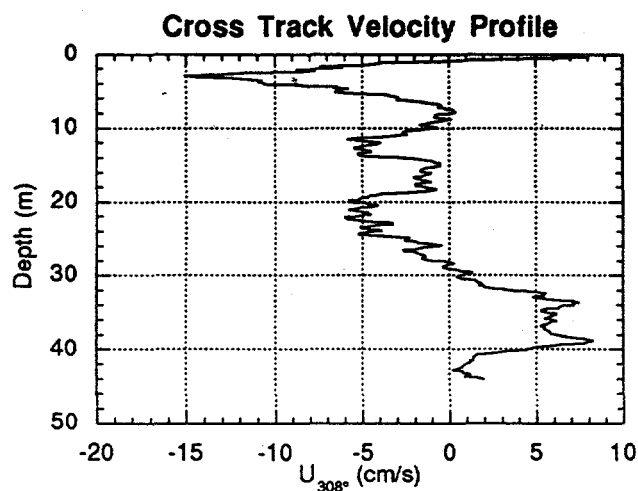
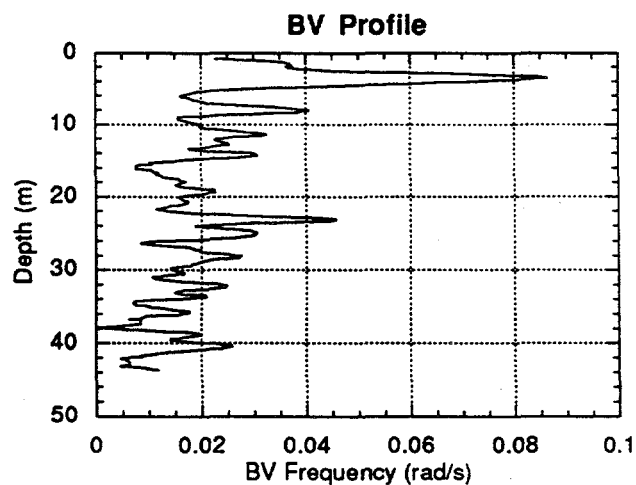
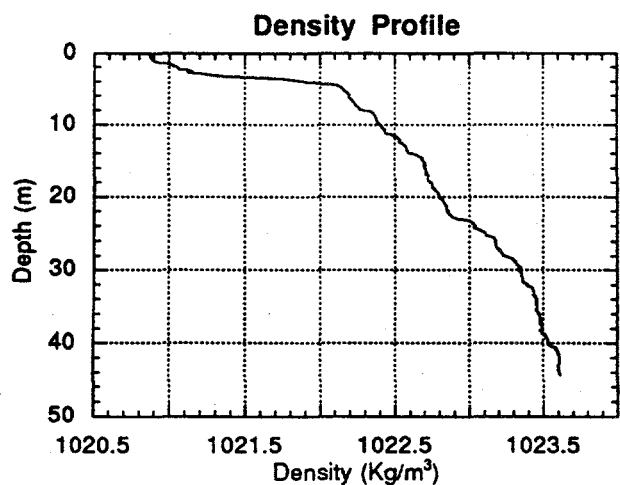
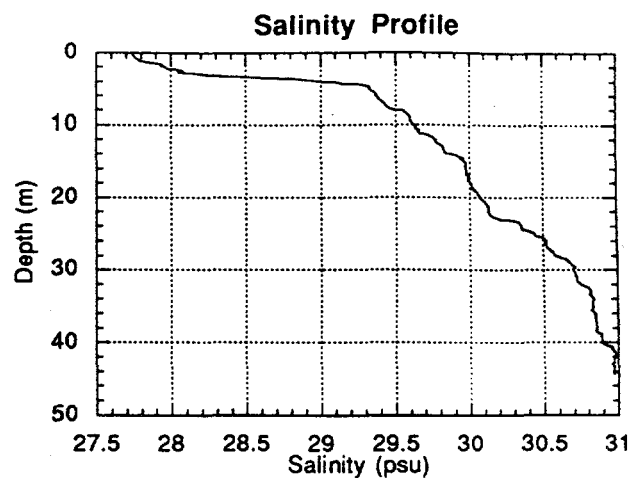
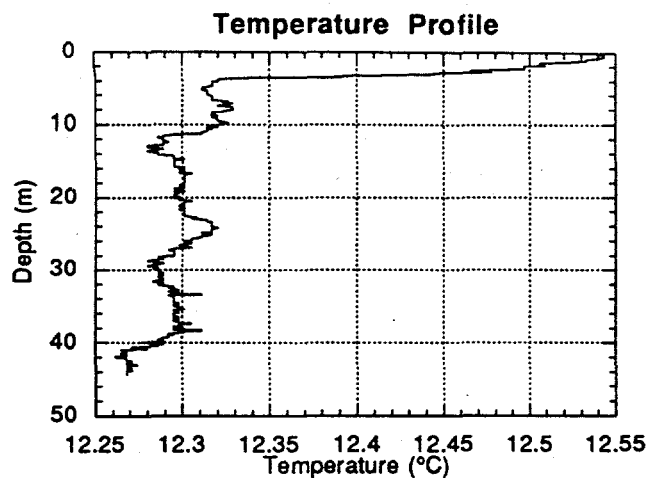


Mode 2 Eigenfunctions

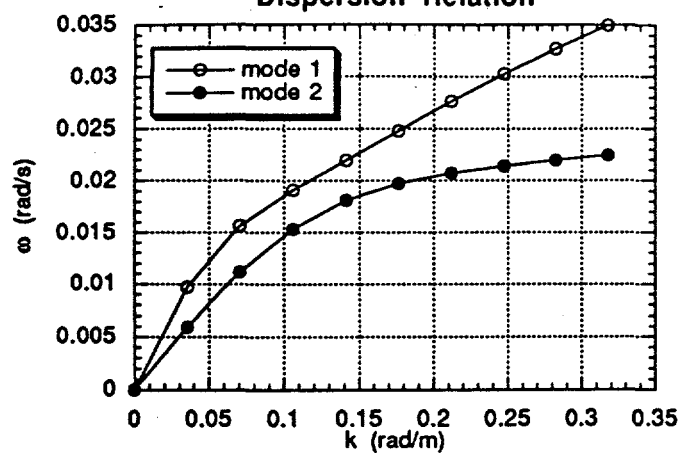


Mode 2 Eigenfunctions, D=80 m

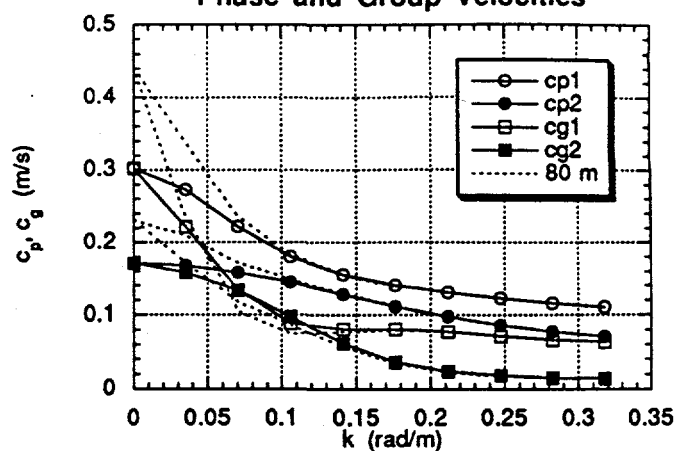




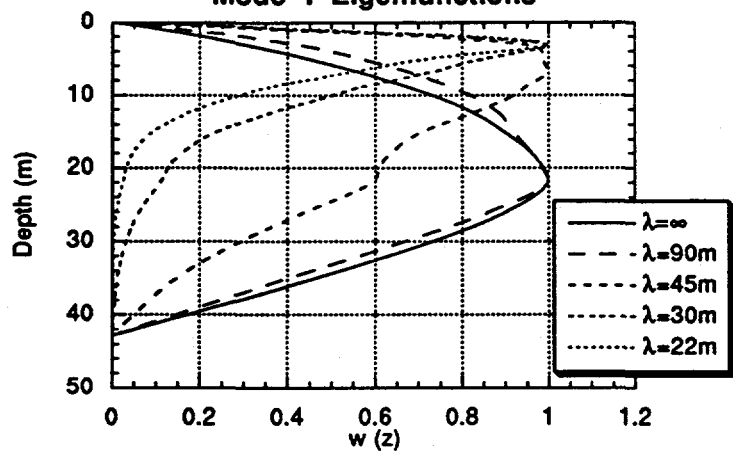
Dispersion Relation



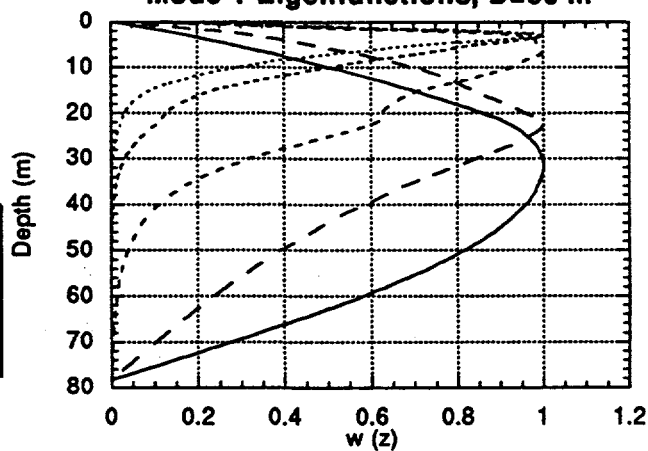
Phase and Group Velocities



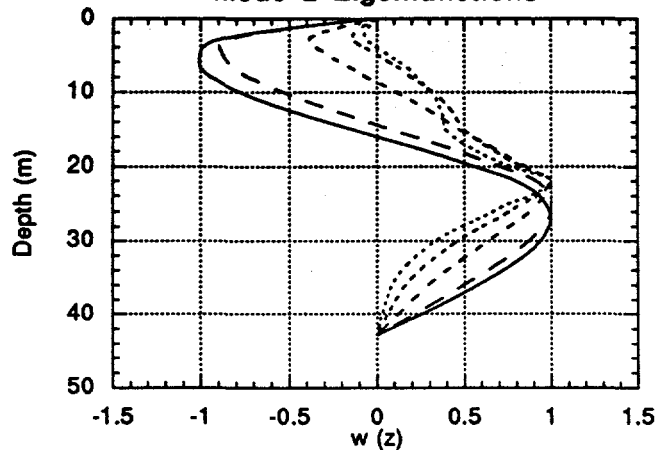
Mode 1 Eigenfunctions



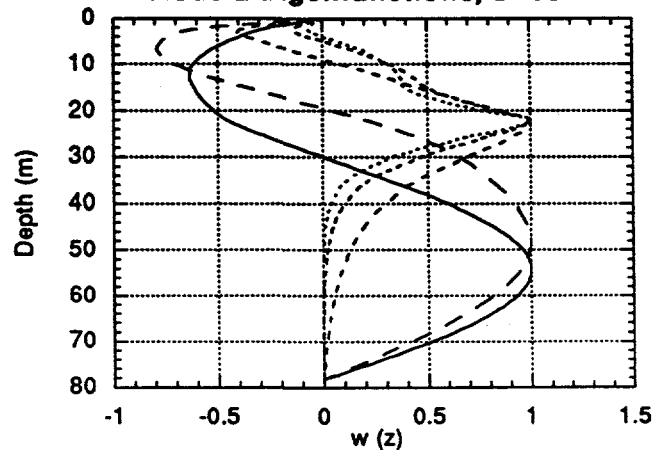
Mode 1 Eigenfunctions, D=80 m



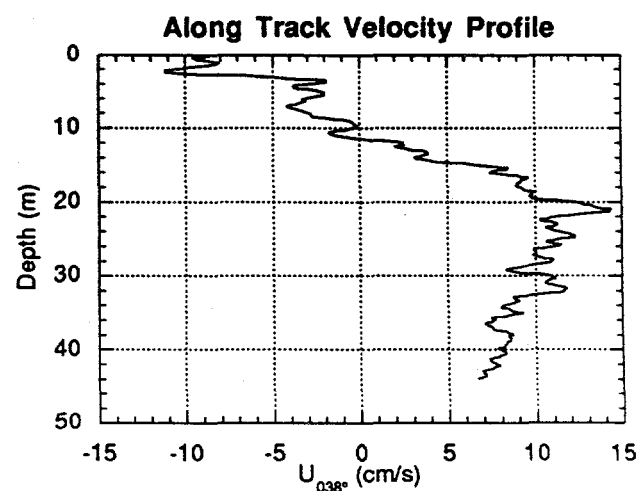
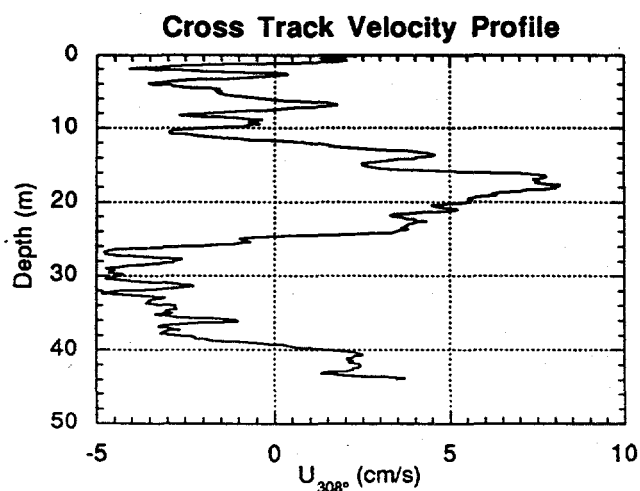
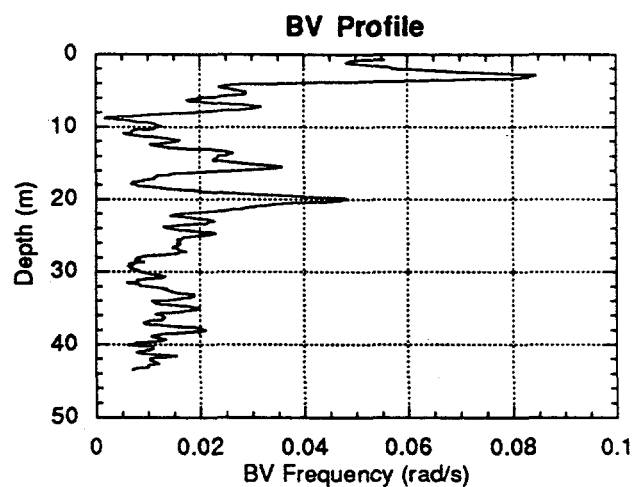
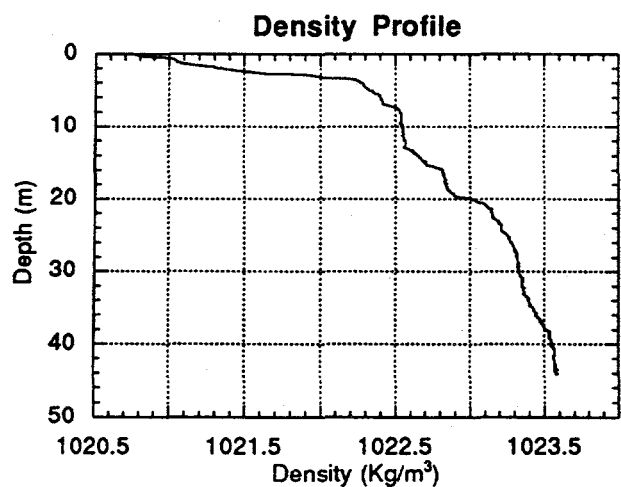
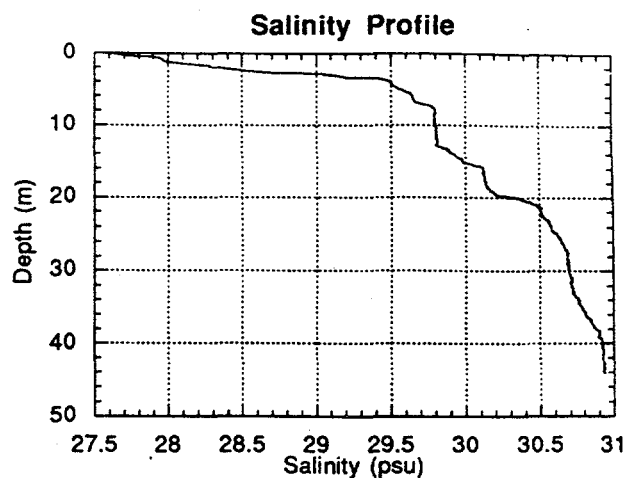
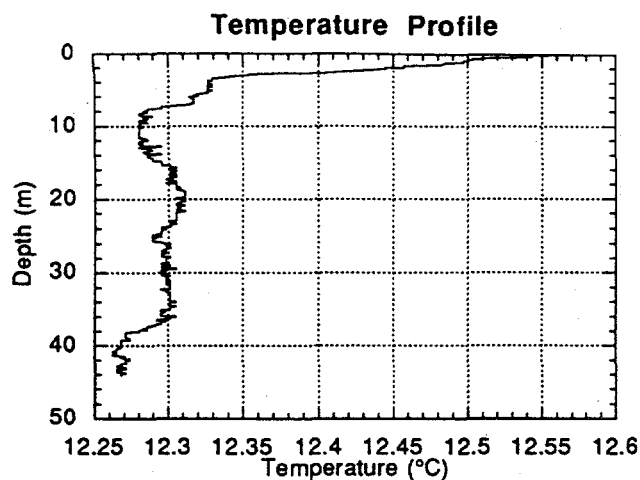
Mode 2 Eigenfunctions



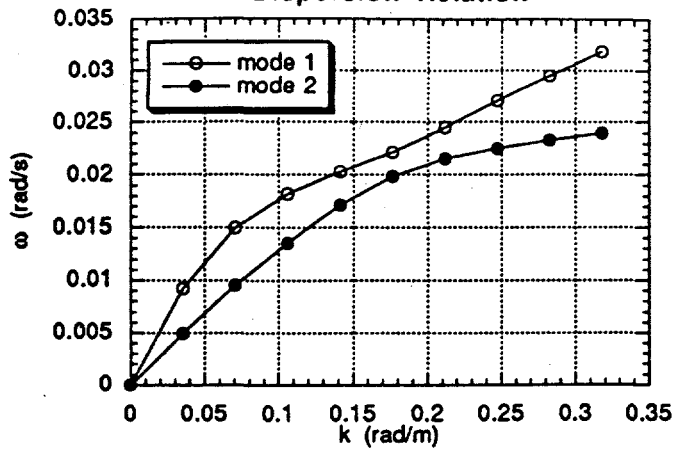
Mode 2 Eigenfunctions, D=80 m



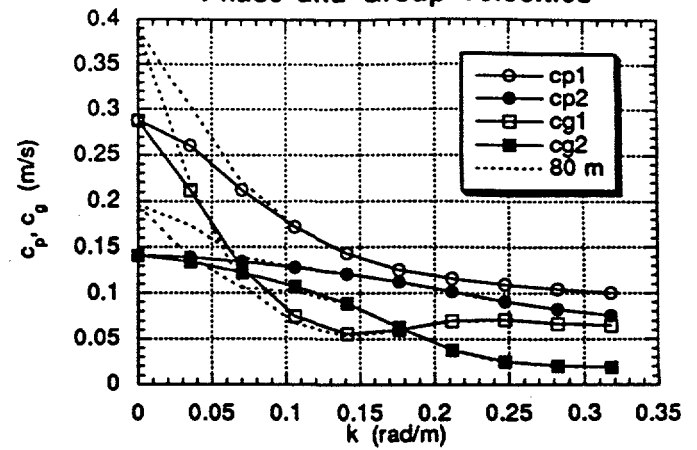
9/7/94, 17:58 GMT



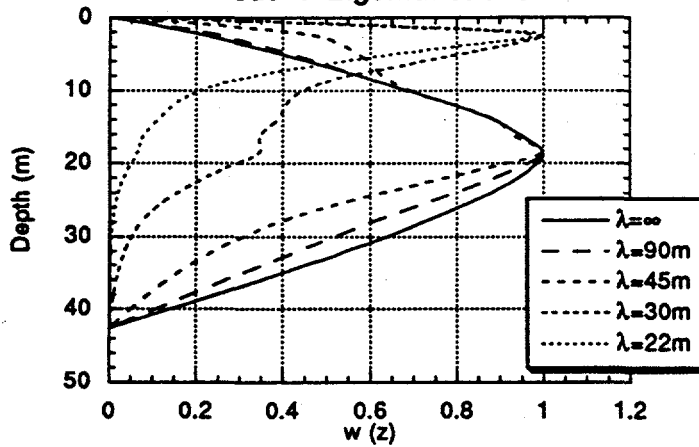
Dispersion Relation



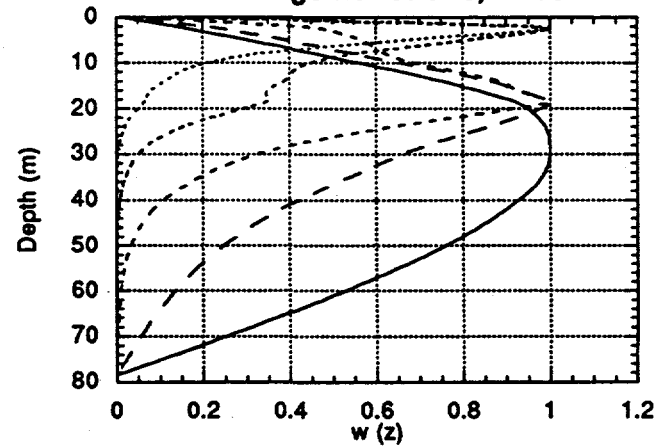
Phase and Group Velocities



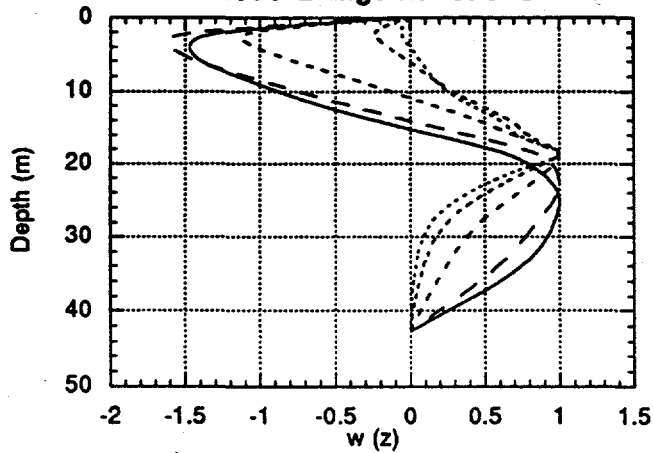
Mode 1 Eigenfunctions



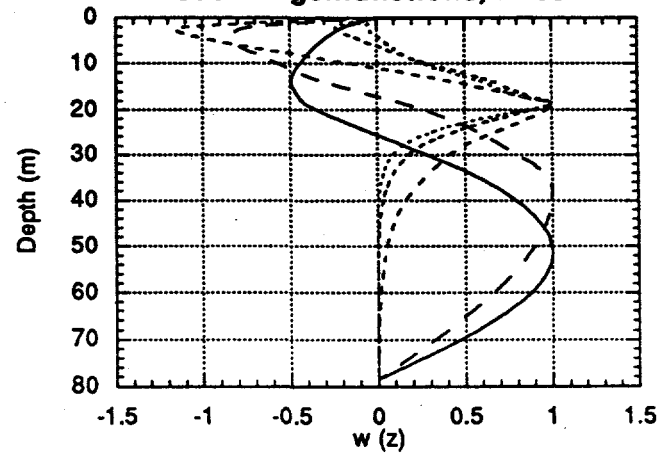
Mode 1 Eigenfunctions, D=80 m



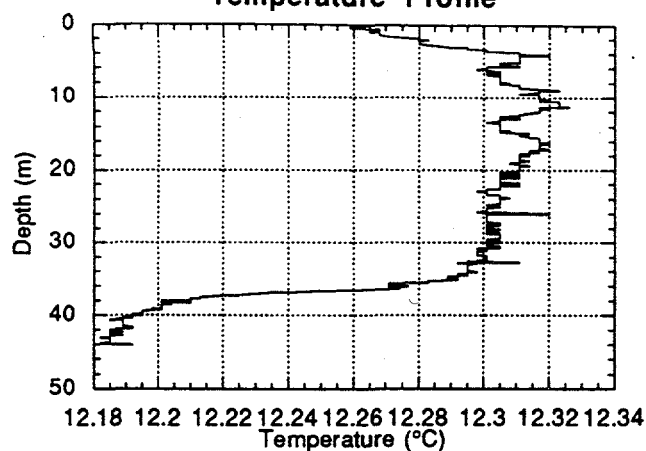
Mode 2 Eigenfunctions



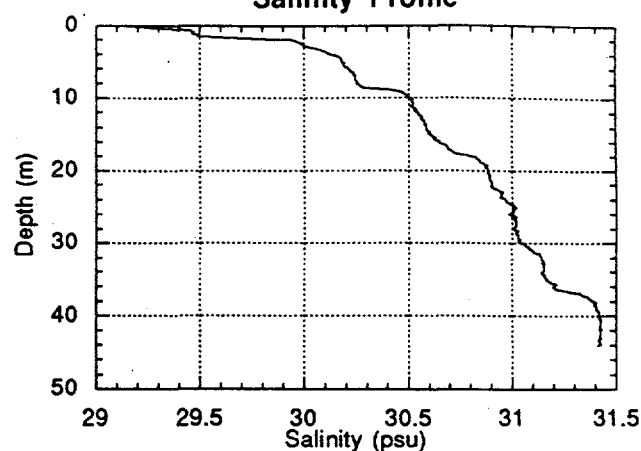
Mode 2 Eigenfunctions, D=80 m



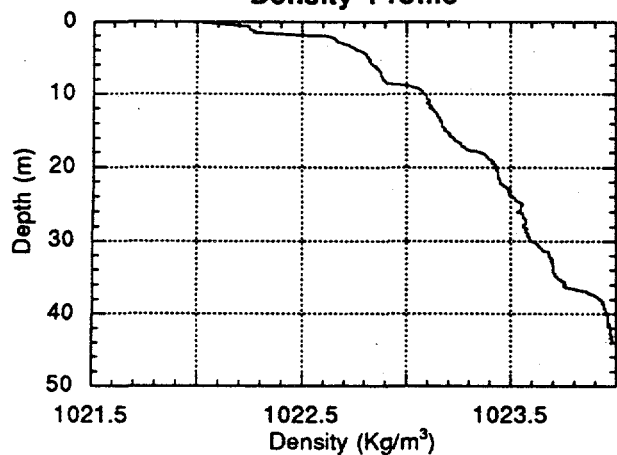
Temperature Profile



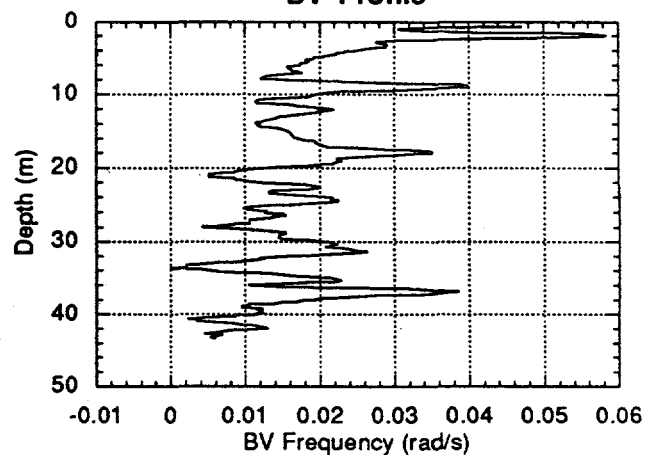
Salinity Profile



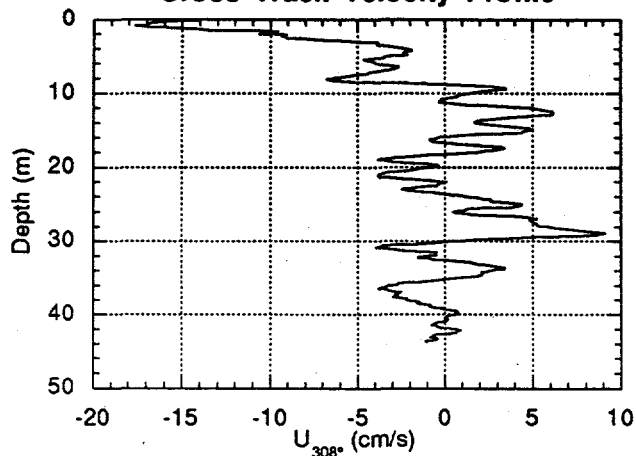
Density Profile



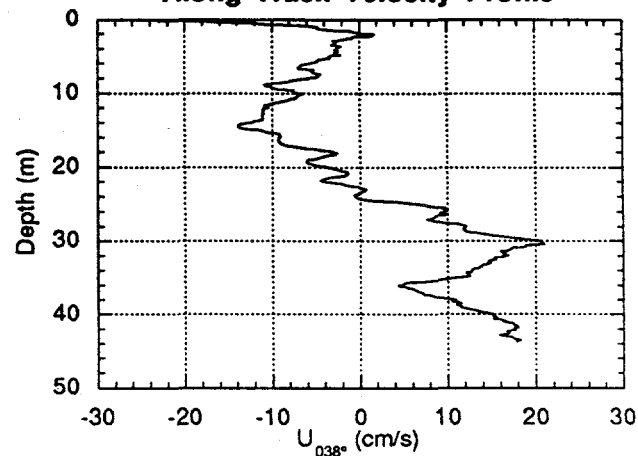
BV Profile

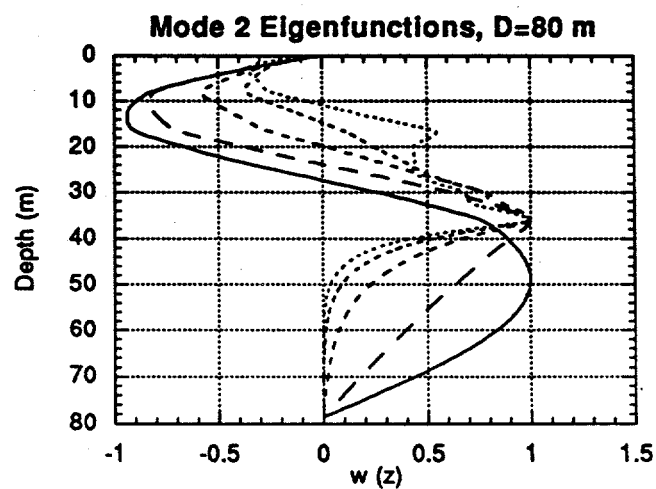
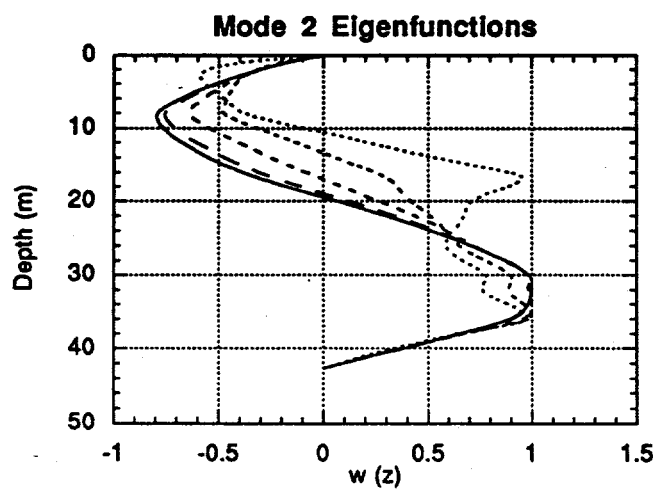
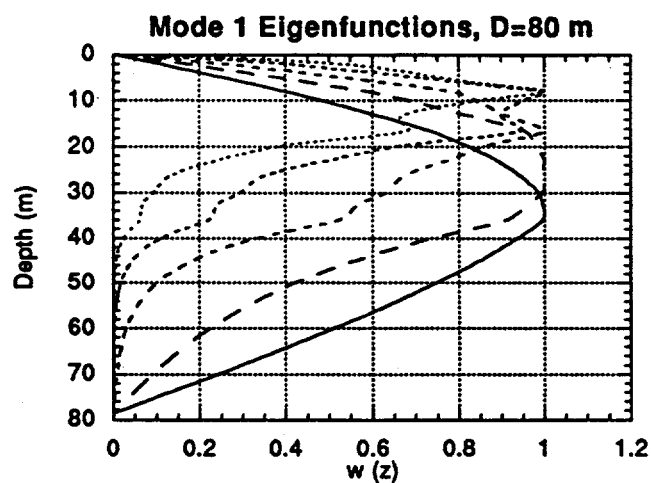
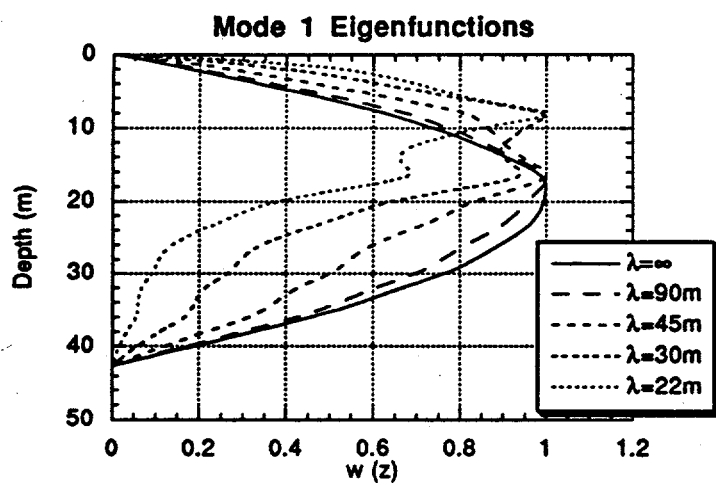
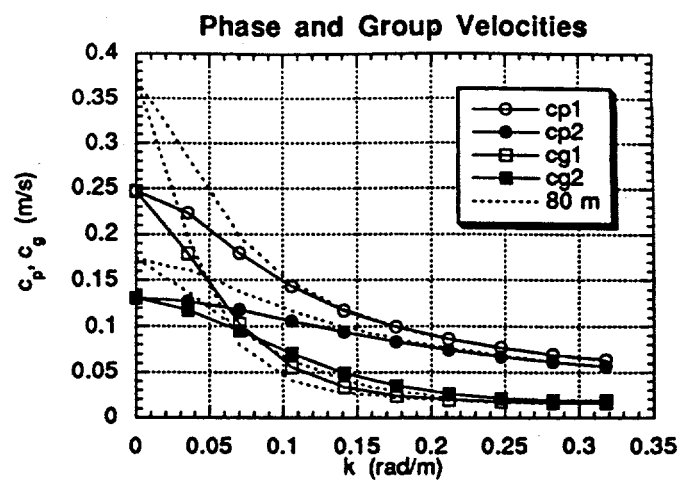
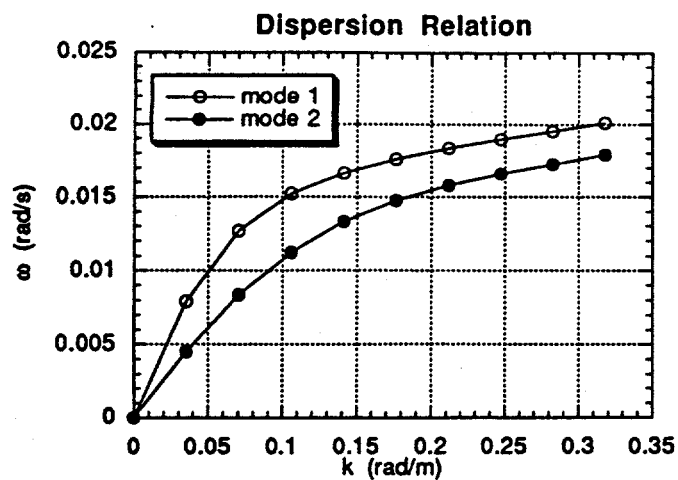


Cross Track Velocity Profile

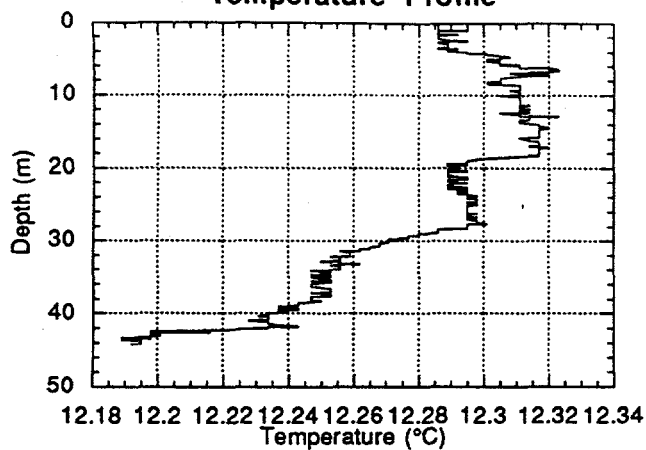


Along Track Velocity Profile

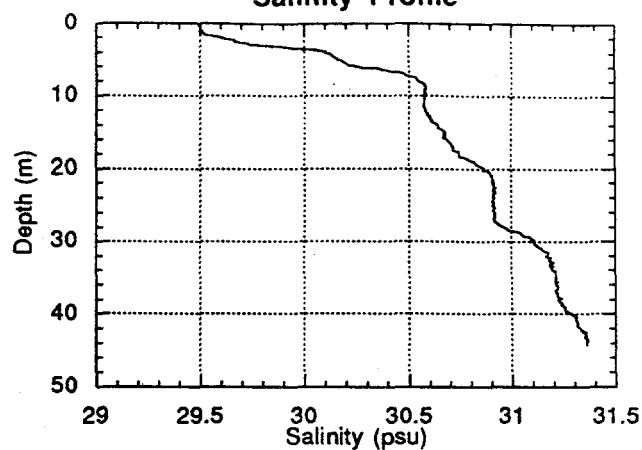




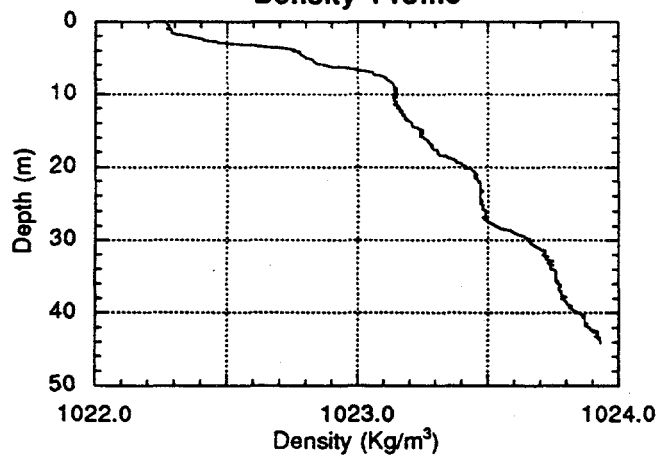
Temperature Profile



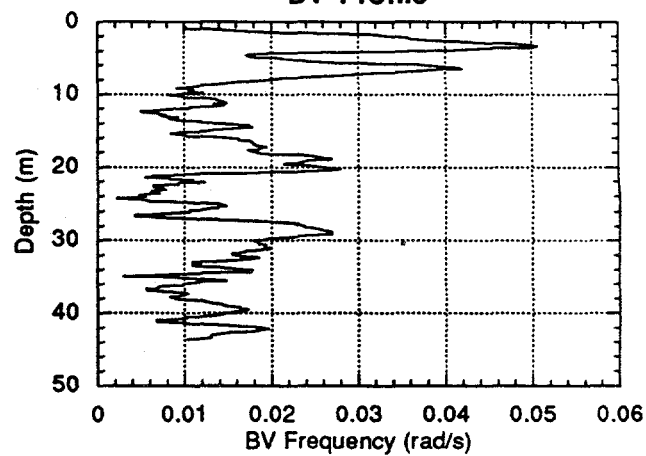
Salinity Profile



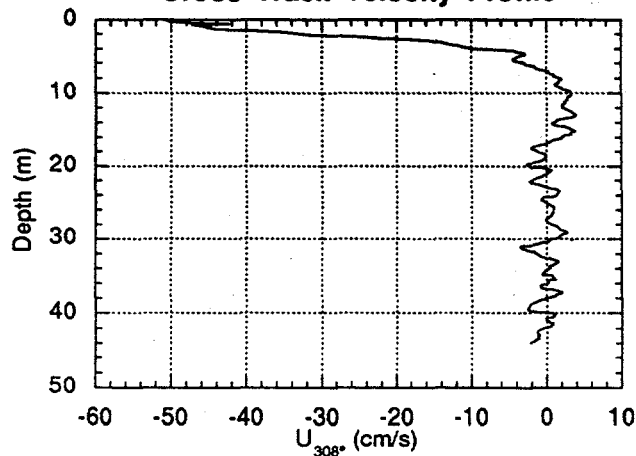
Density Profile



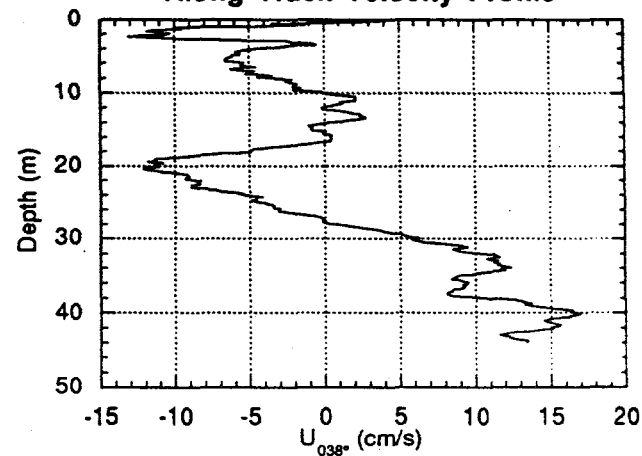
BV Profile

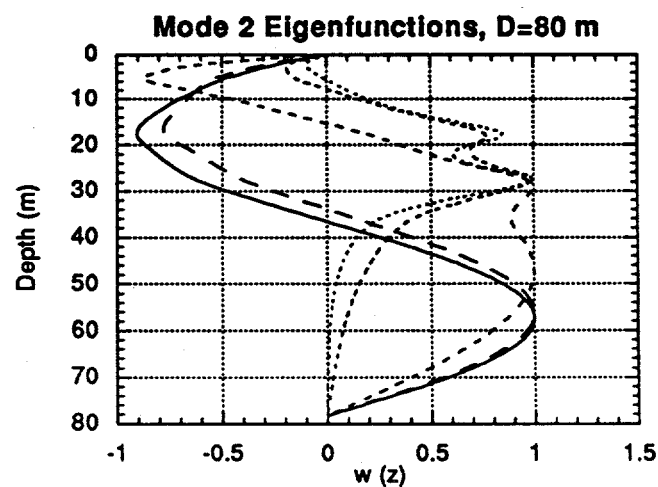
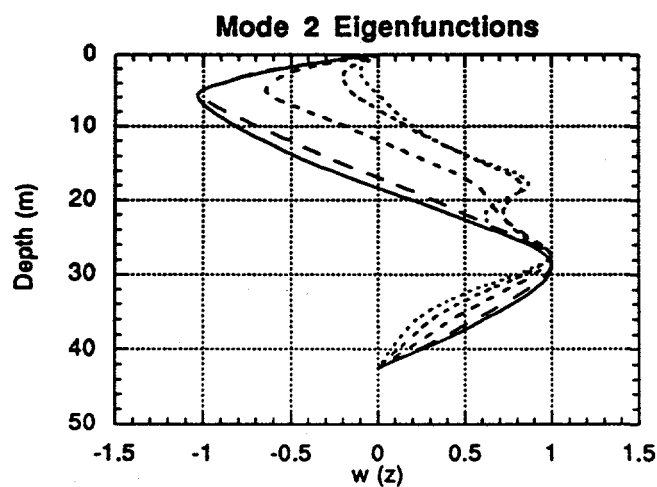
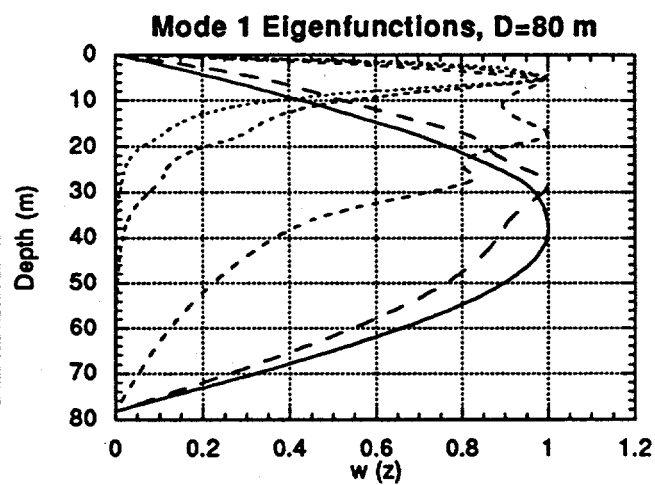
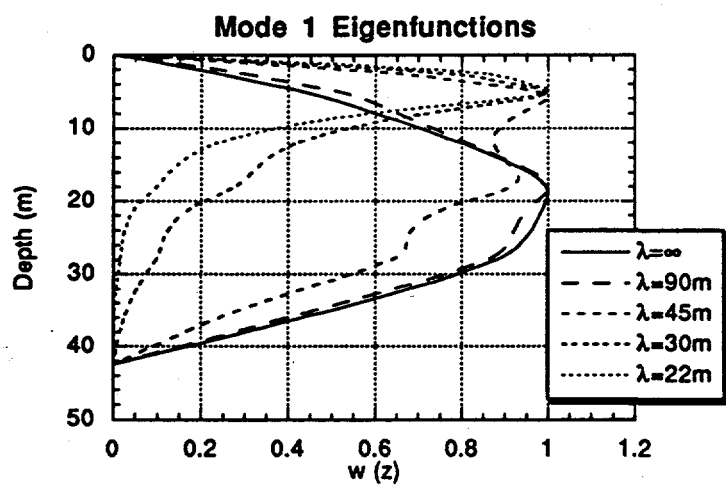
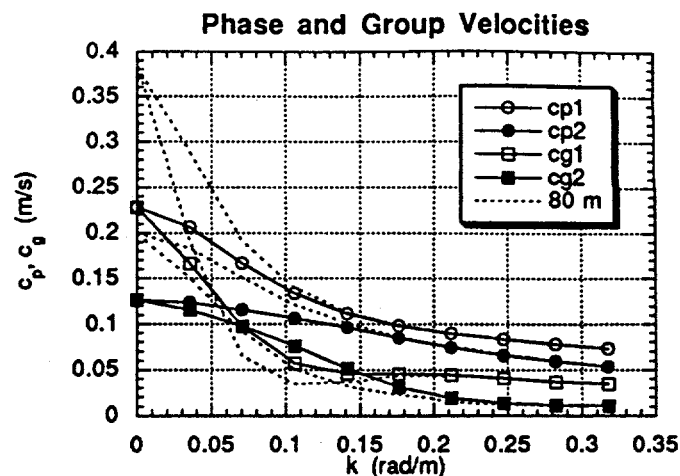
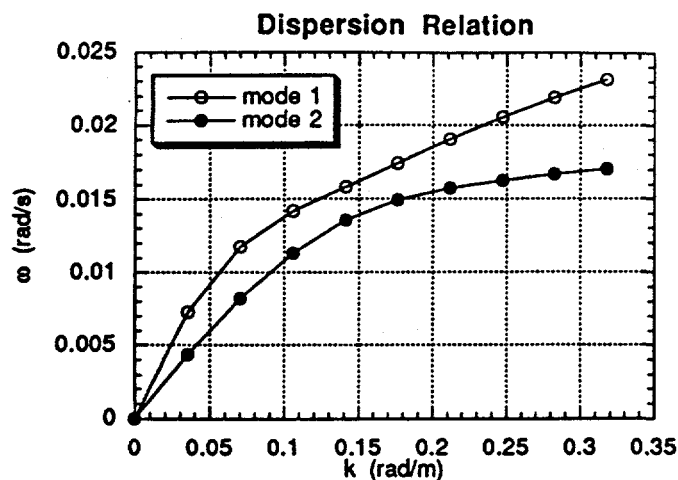


Cross Track Velocity Profile



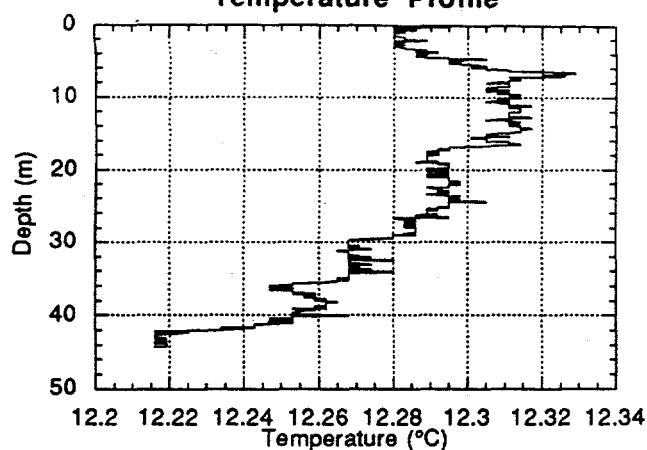
Along Track Velocity Profile



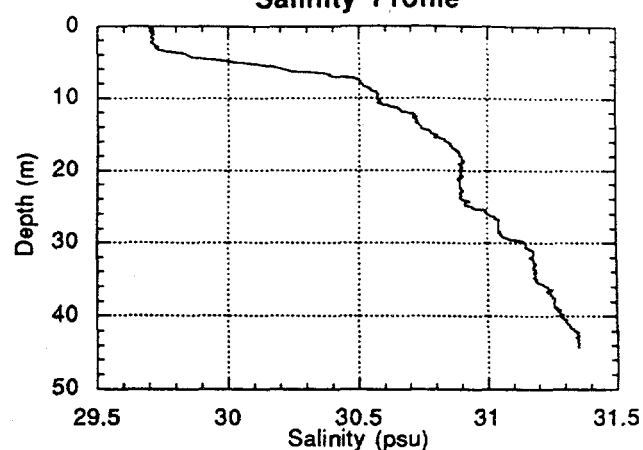


9/8/94, 11:16 GMT

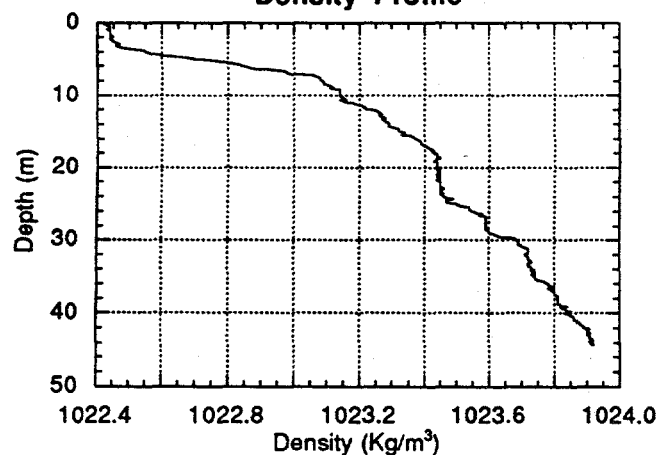
Temperature Profile



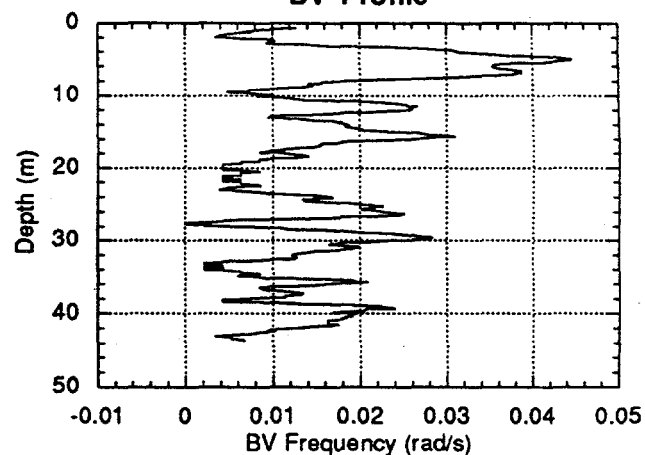
Salinity Profile



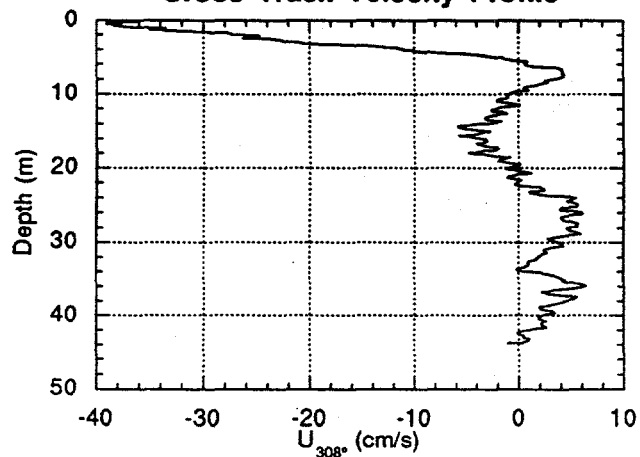
Density Profile



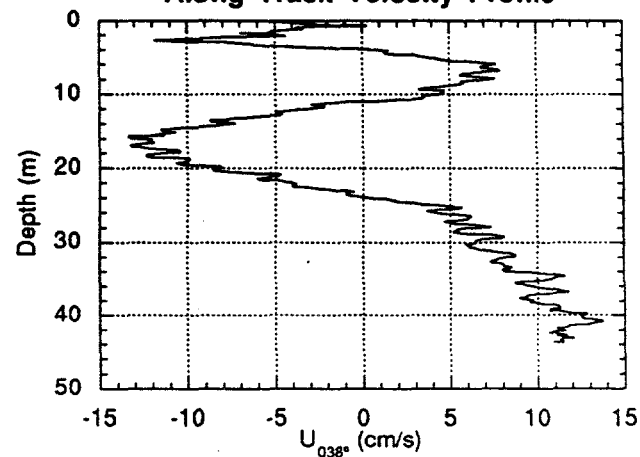
BV Profile

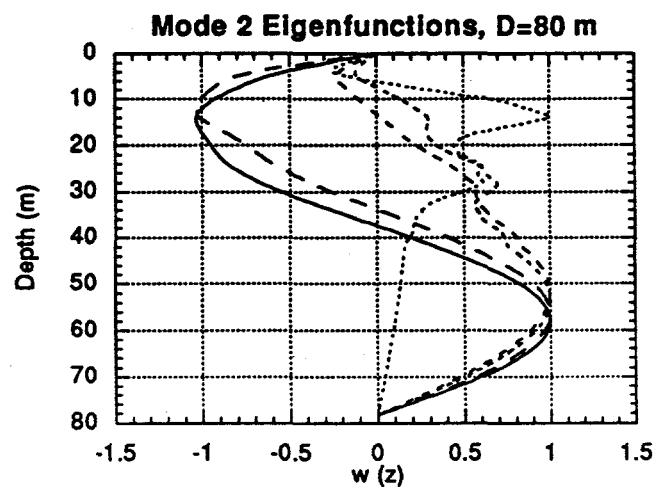
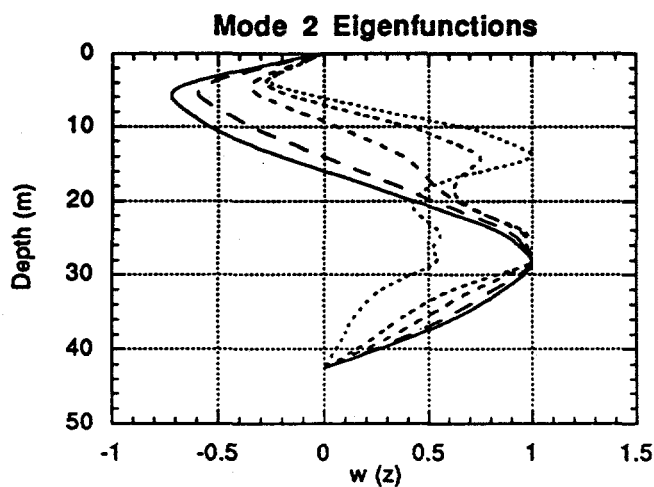
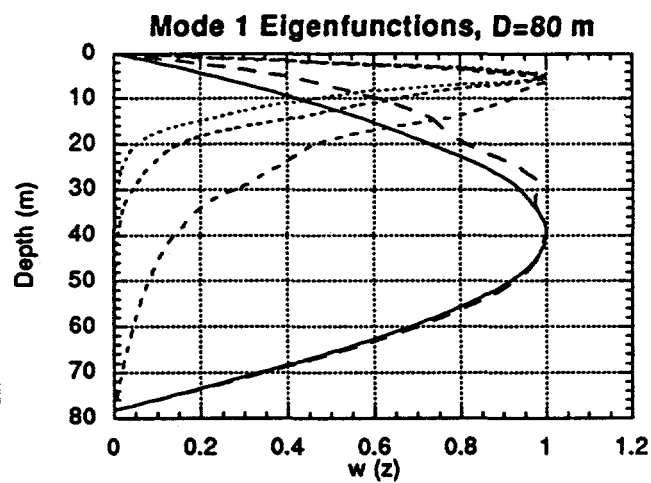
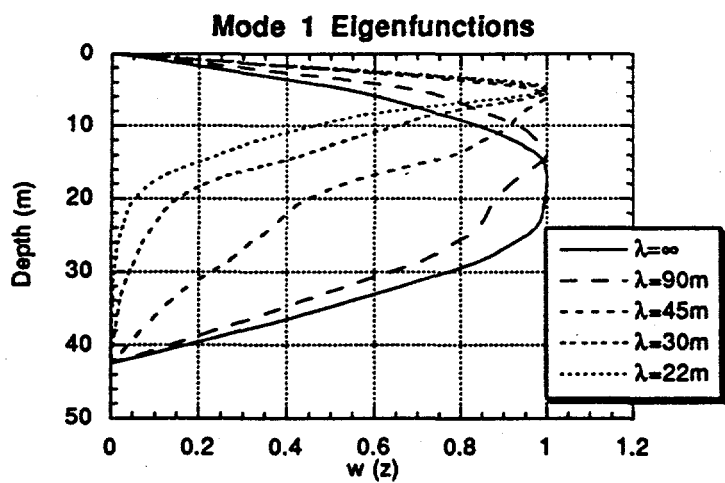
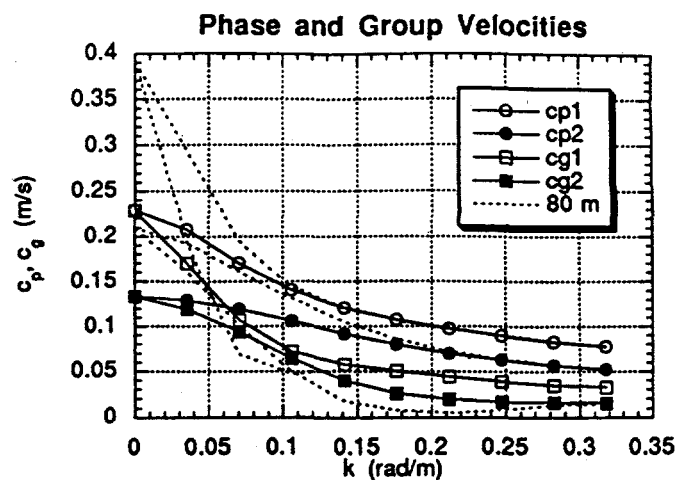
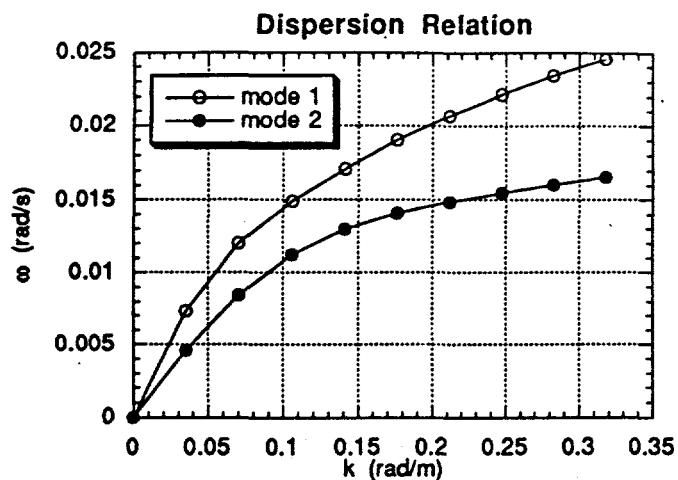


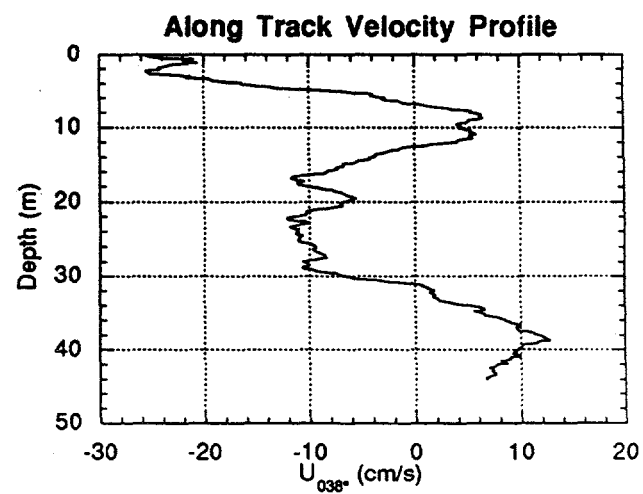
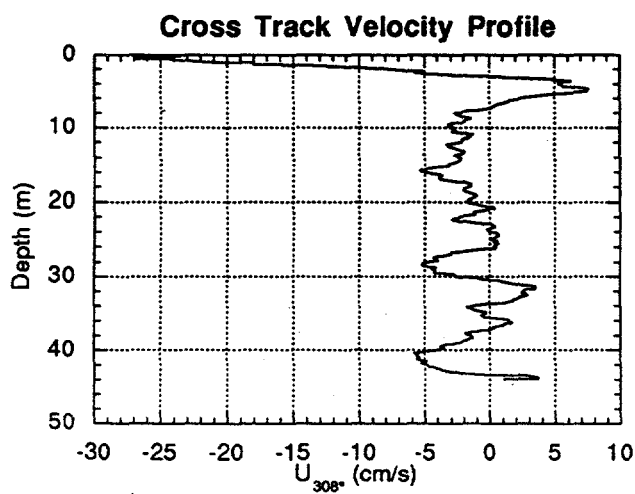
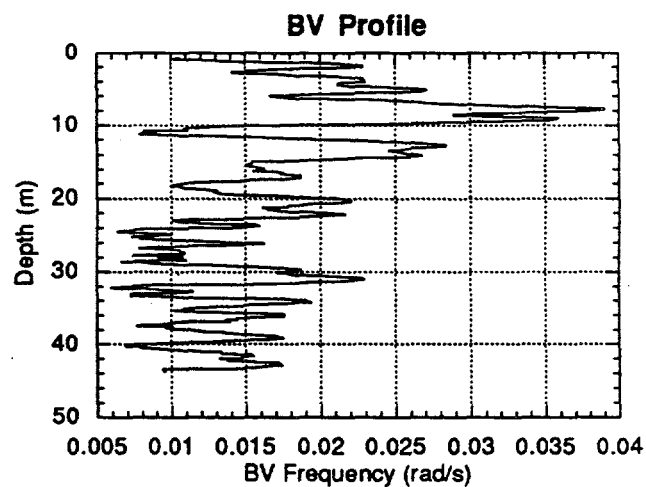
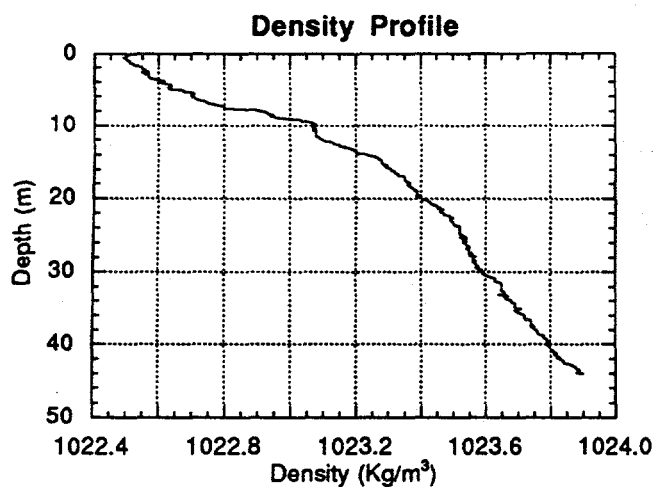
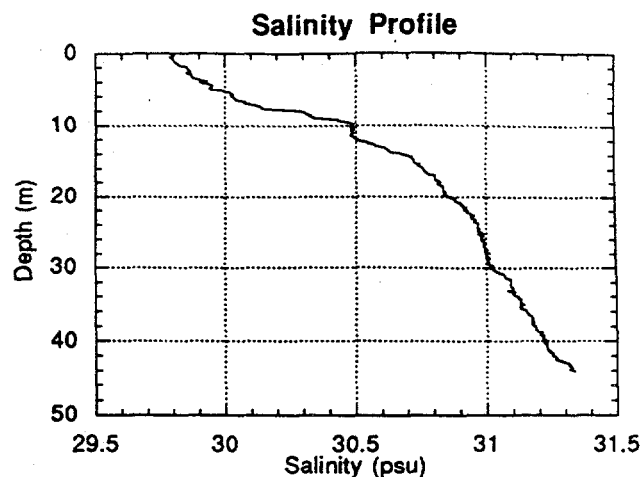
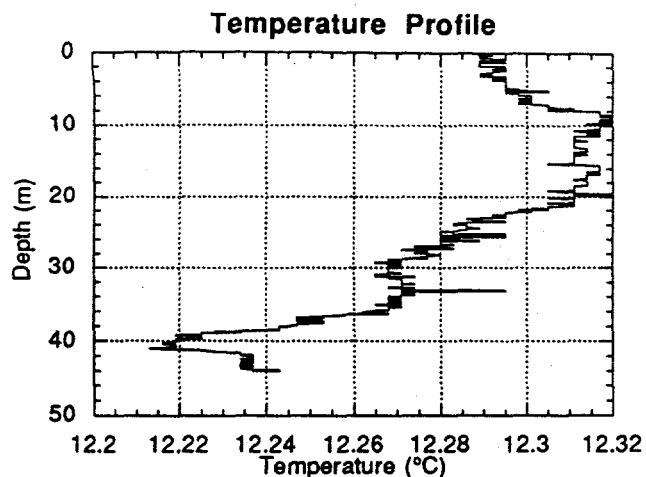
Cross Track Velocity Profile

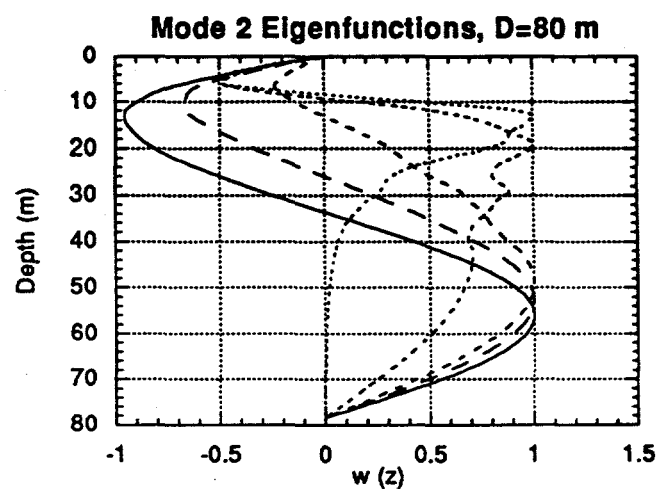
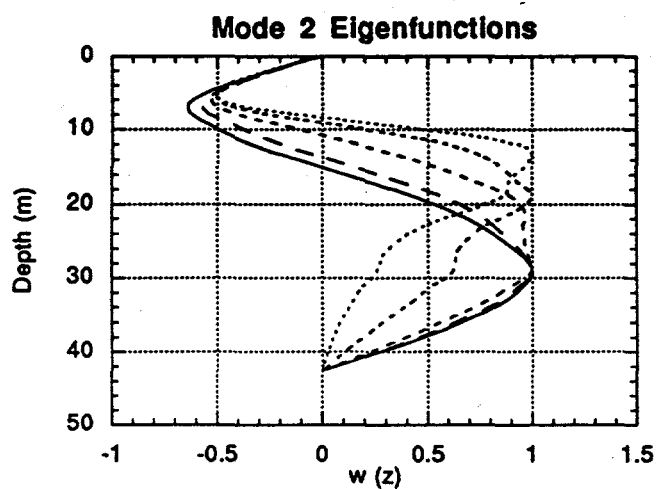
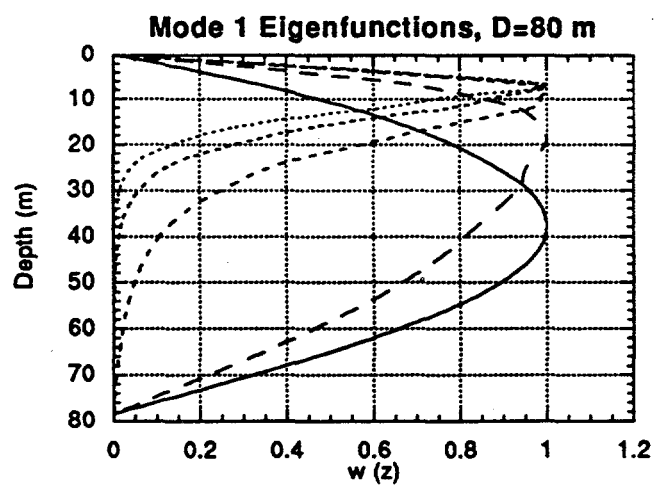
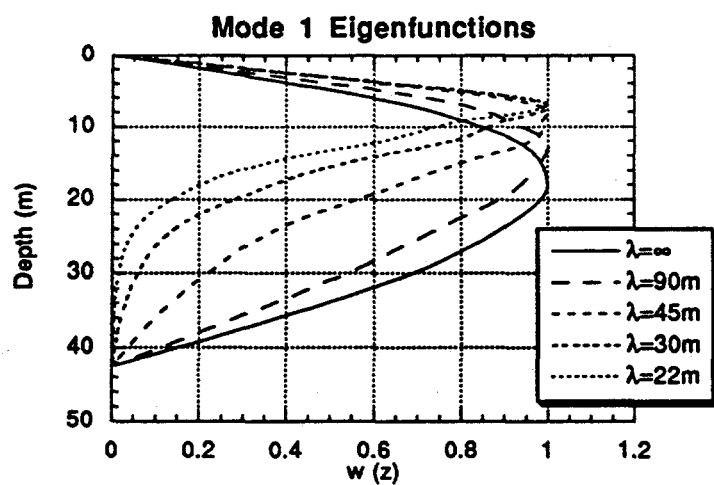
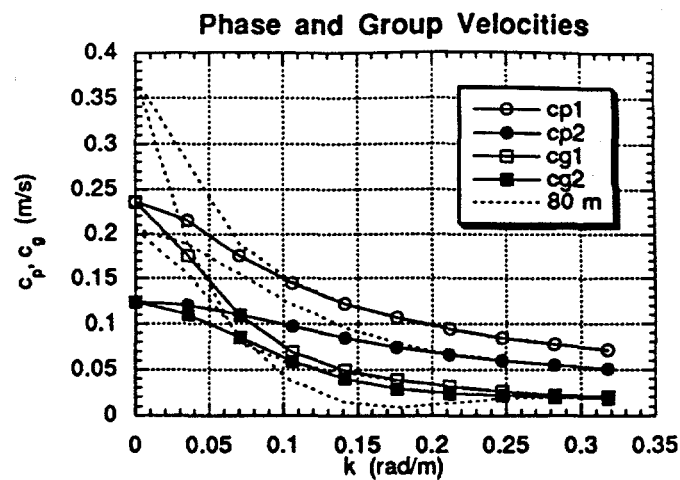
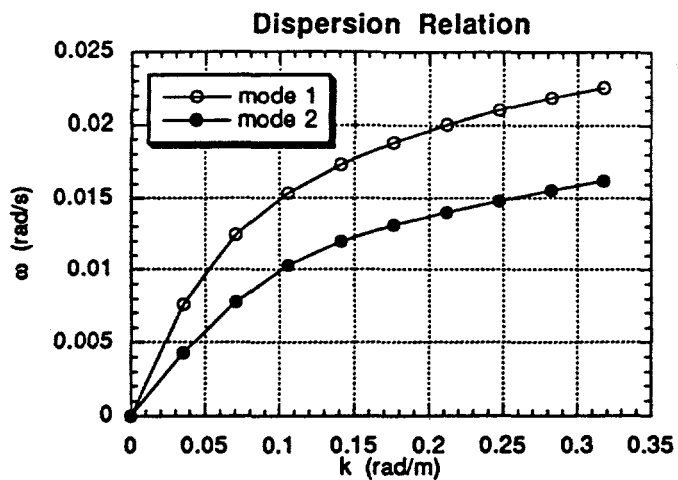


Along Track Velocity Profile



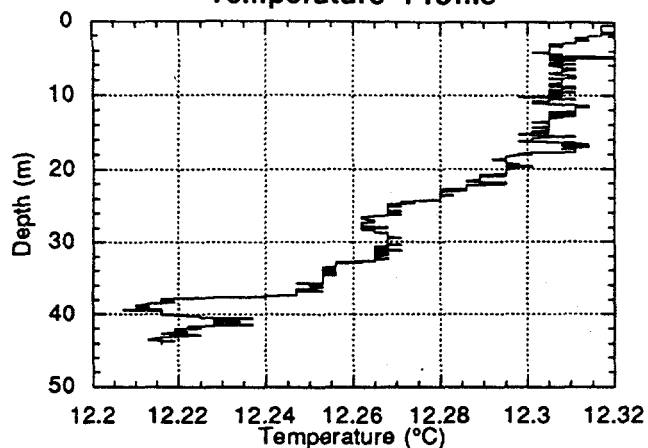




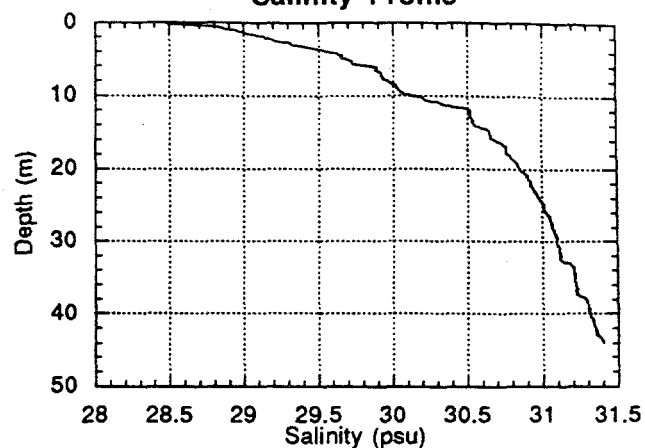


9/8/94, 14:16 GMT

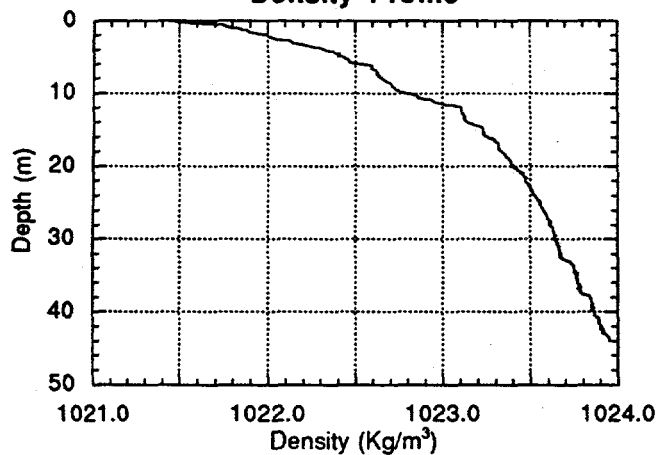
Temperature Profile



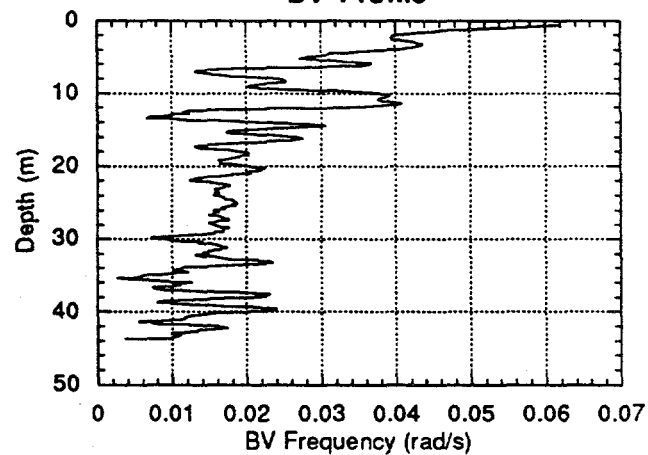
Salinity Profile



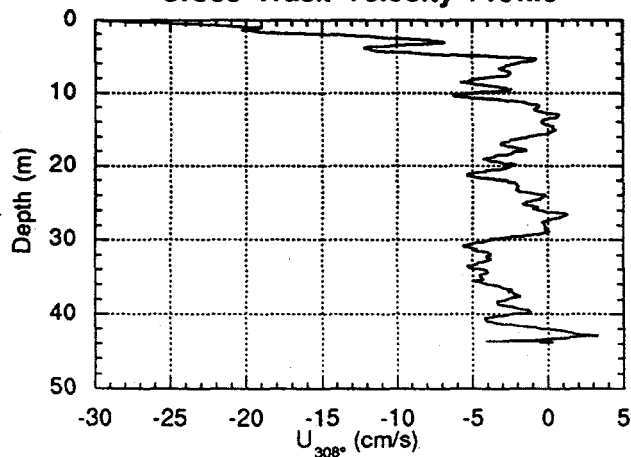
Density Profile



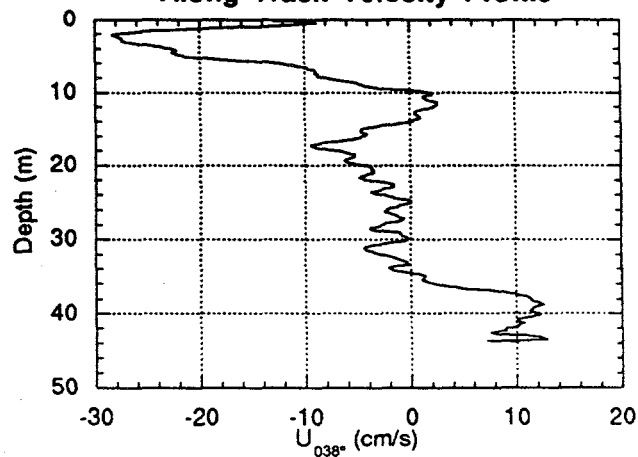
BV Profile

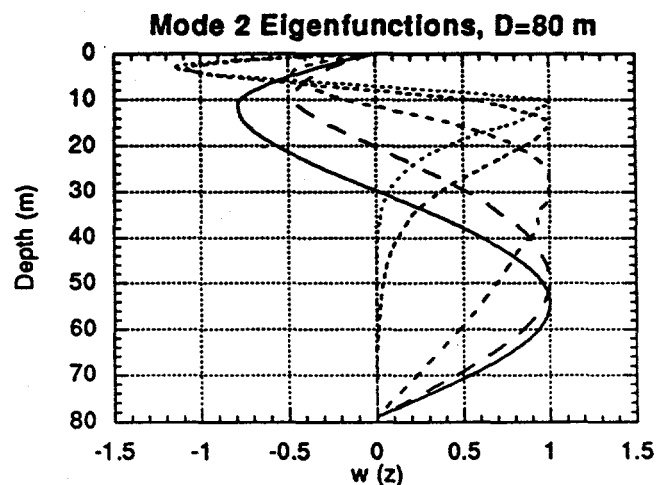
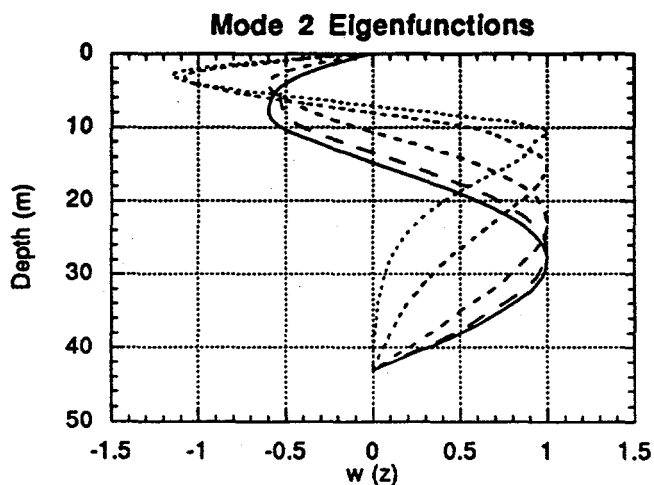
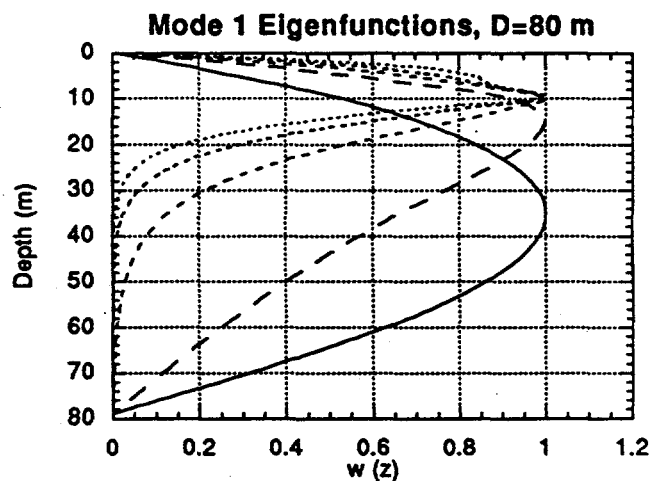
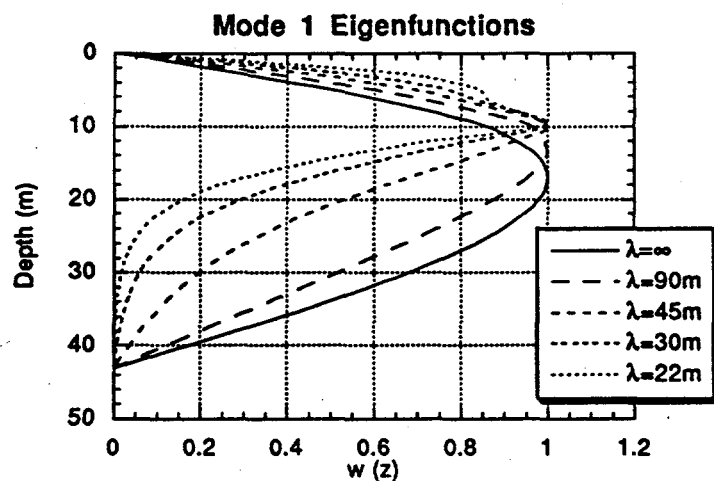
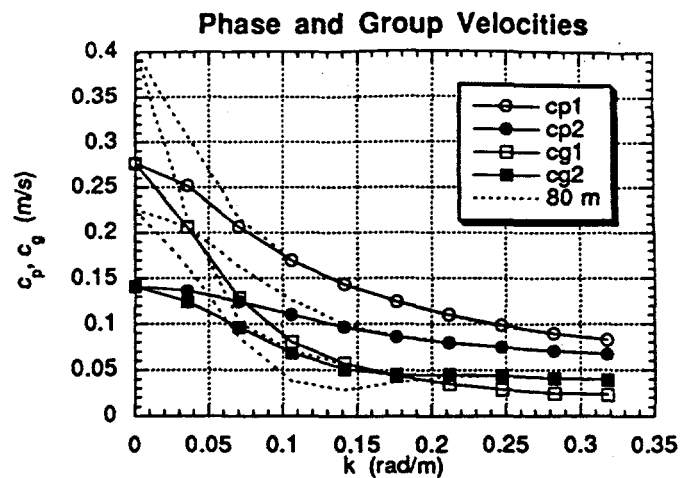
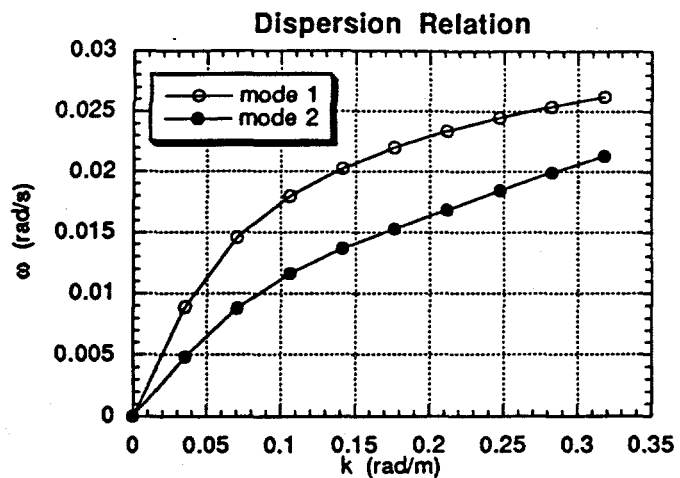


Cross Track Velocity Profile

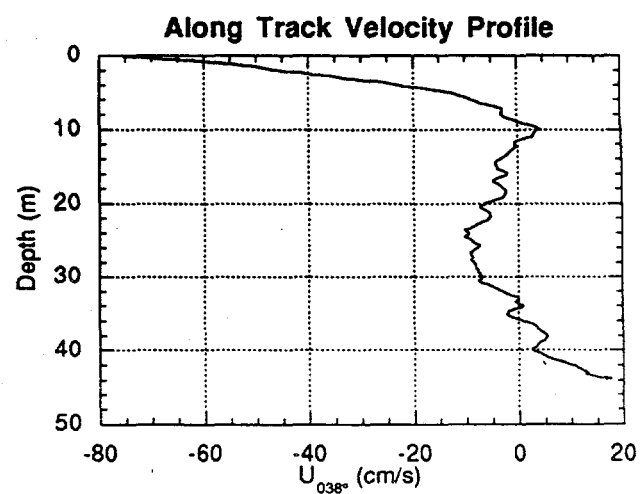
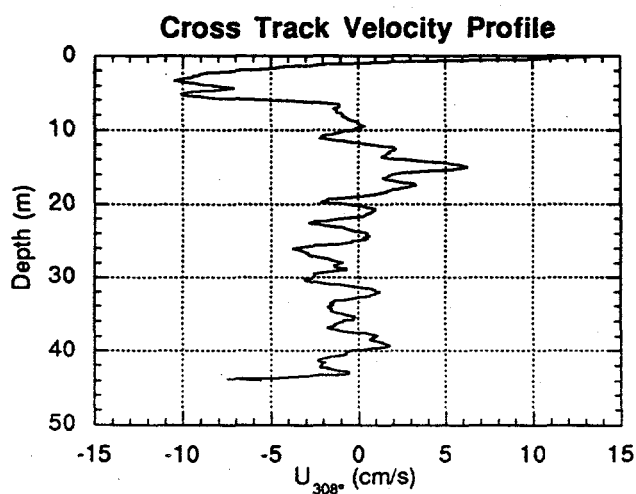
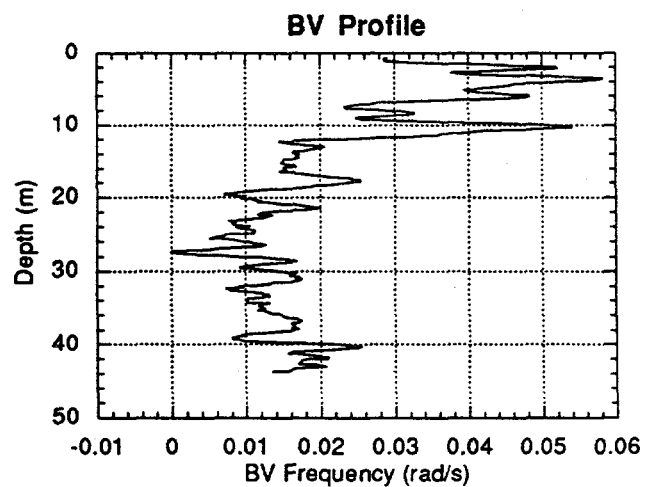
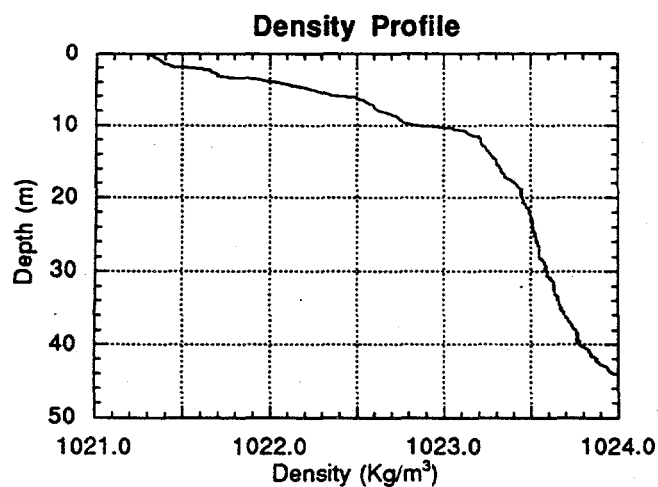
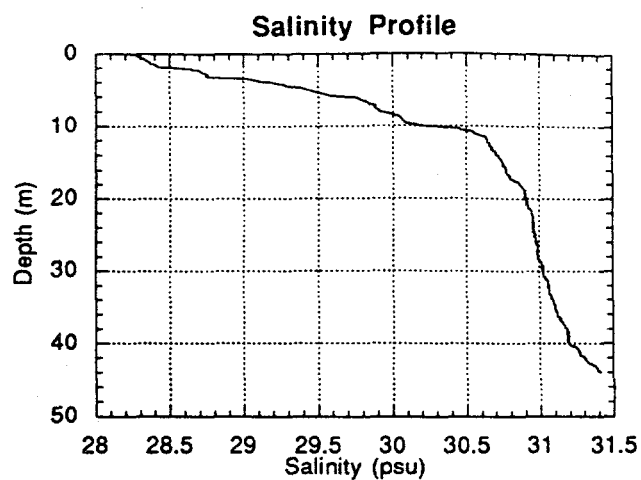
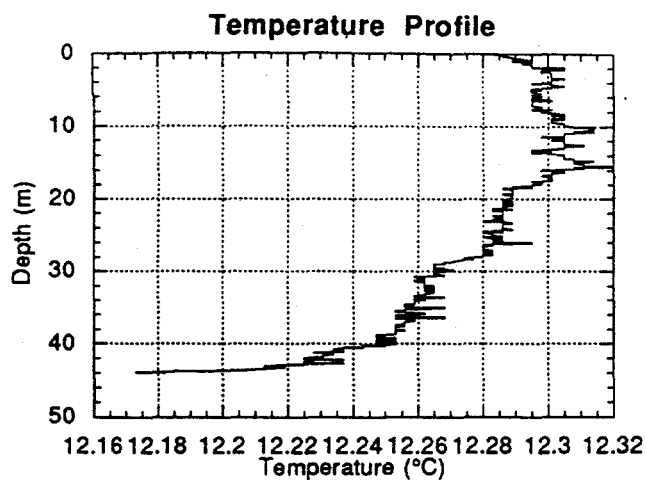


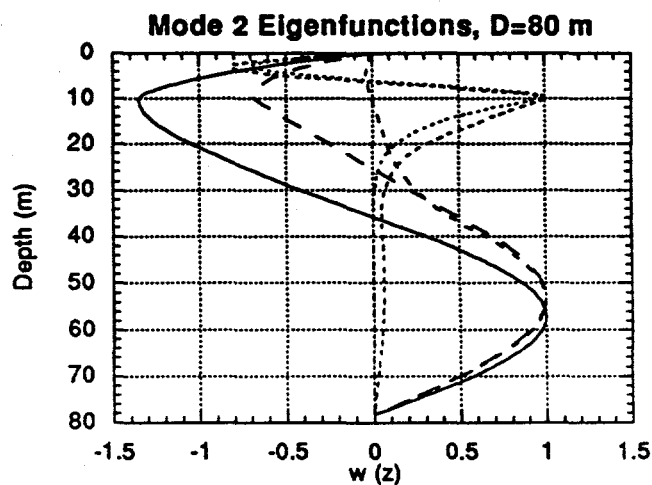
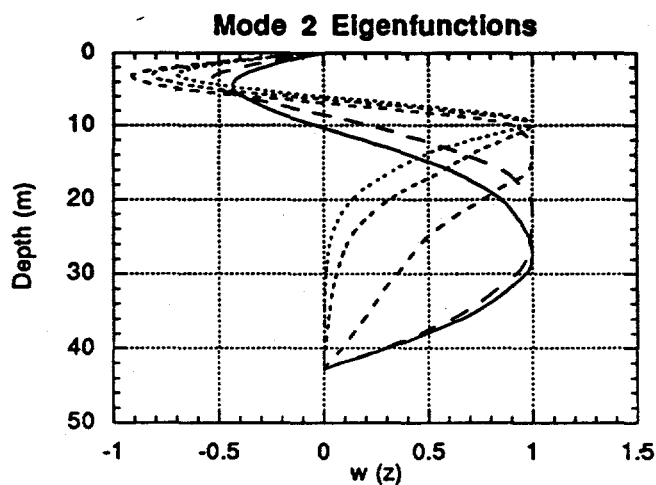
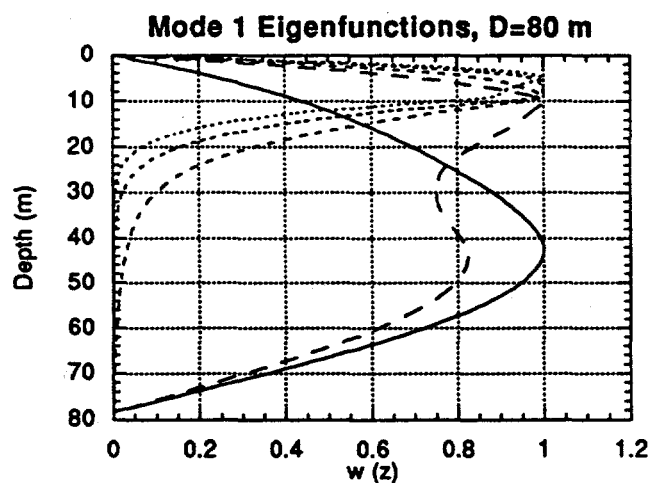
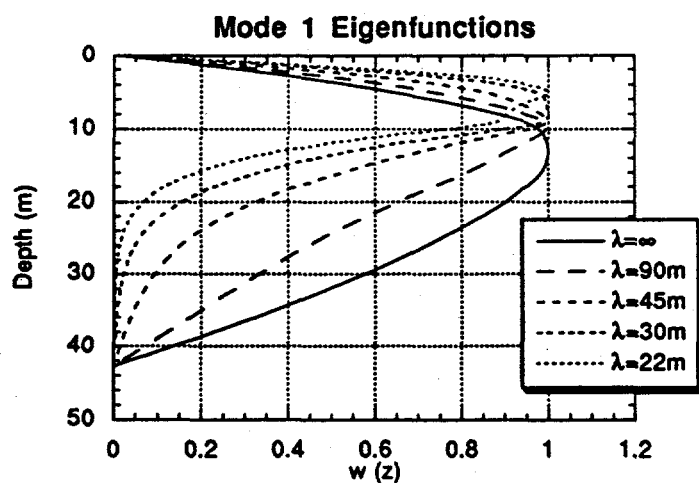
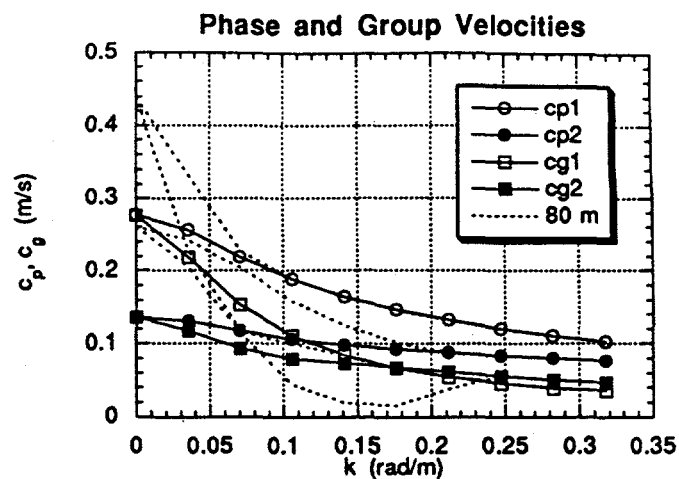
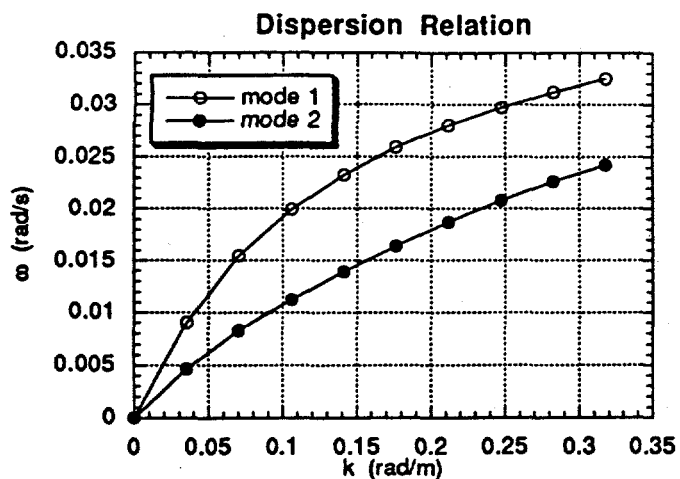
Along Track Velocity Profile



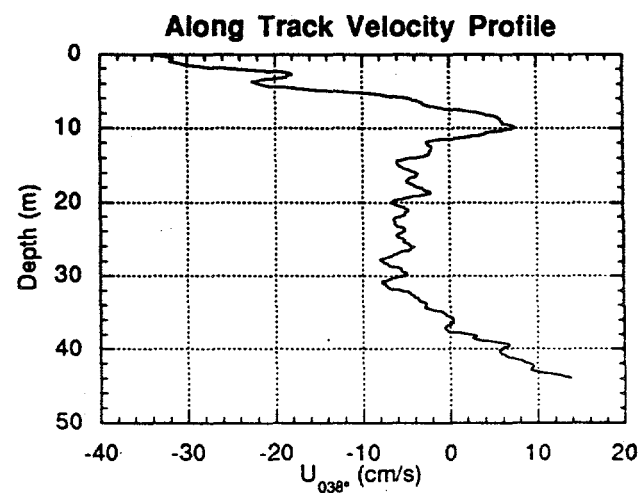
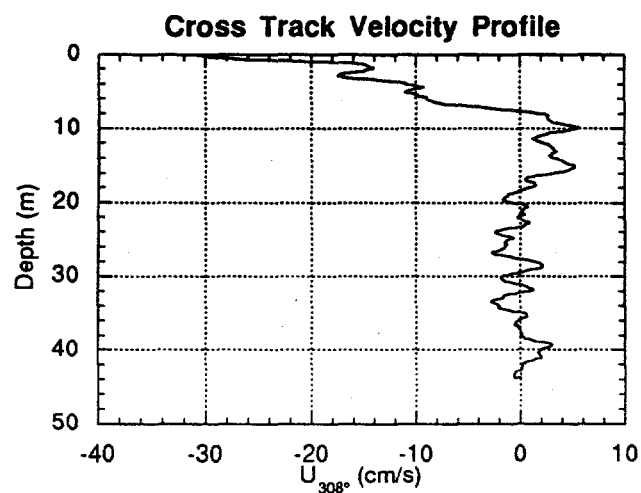
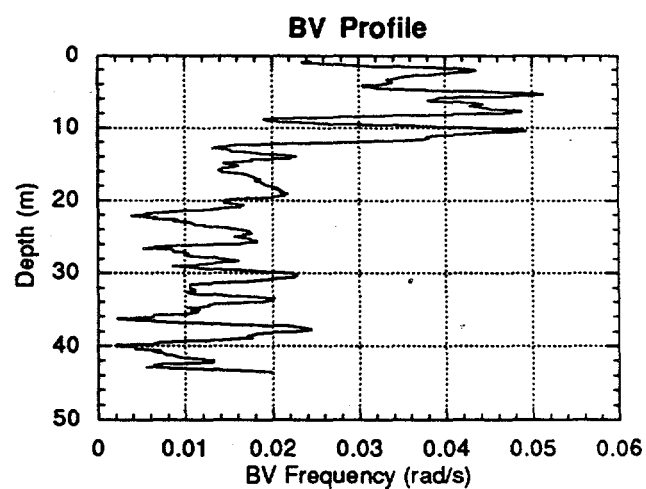
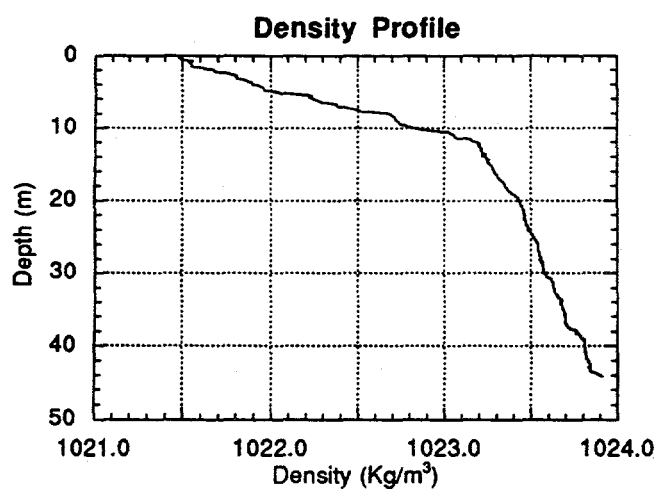
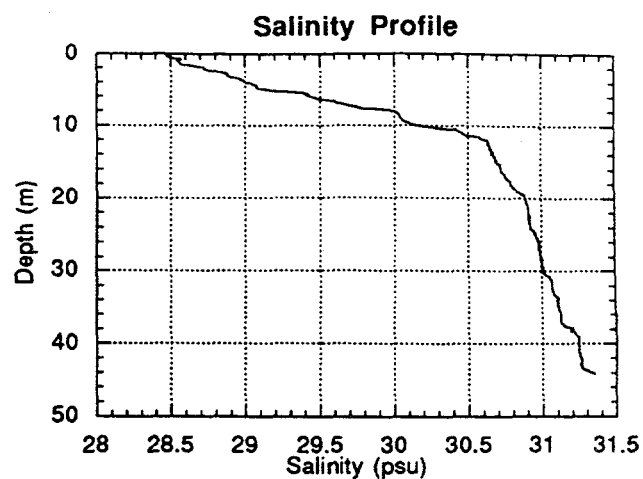
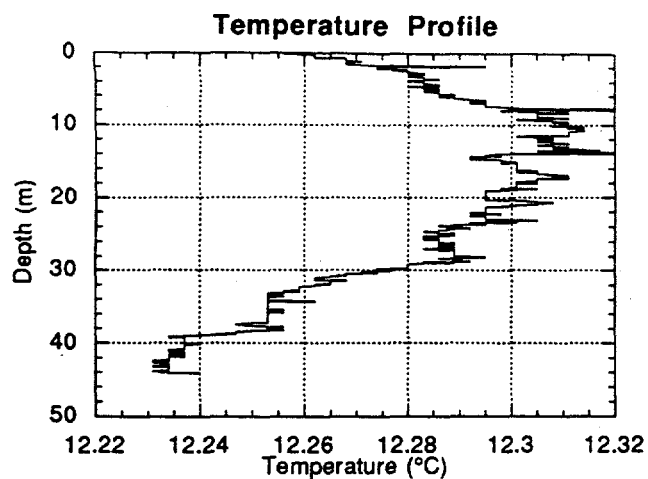


9/8/94, 15:16 GMT

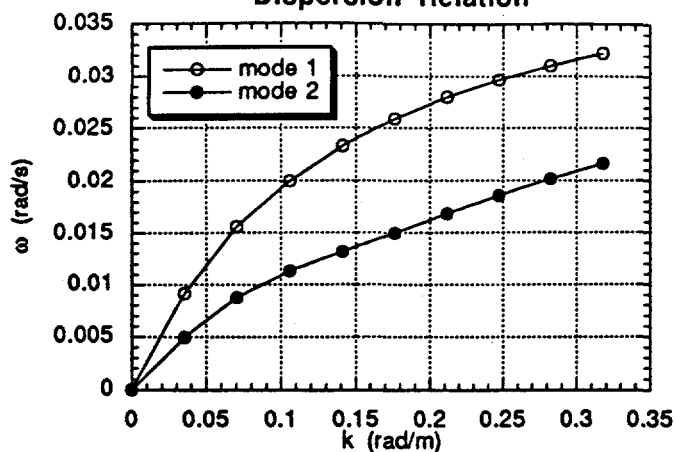




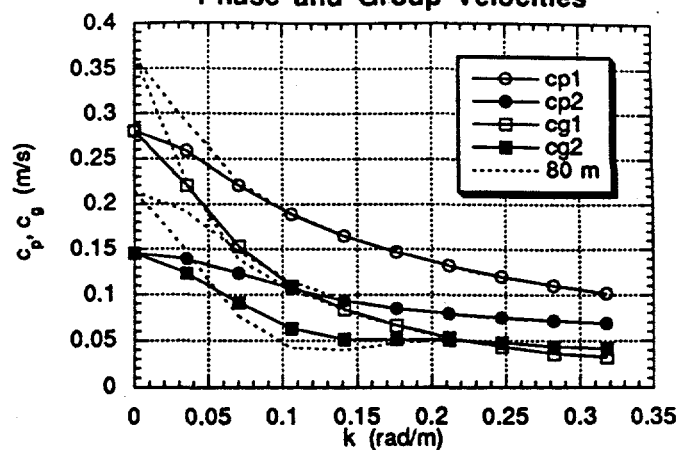
9/8/94, 16:00 GMT



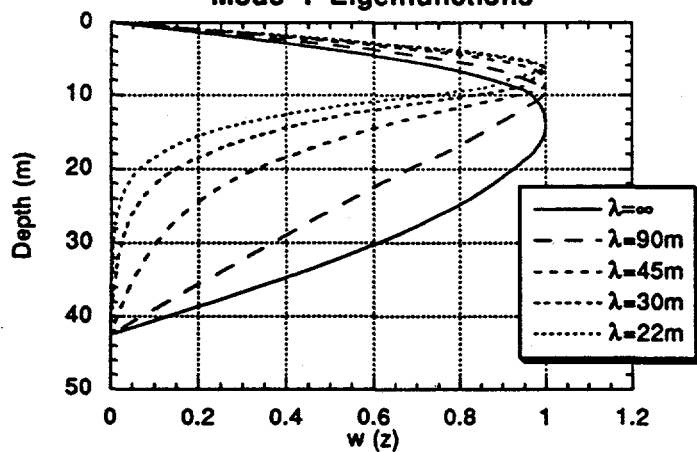
Dispersion Relation



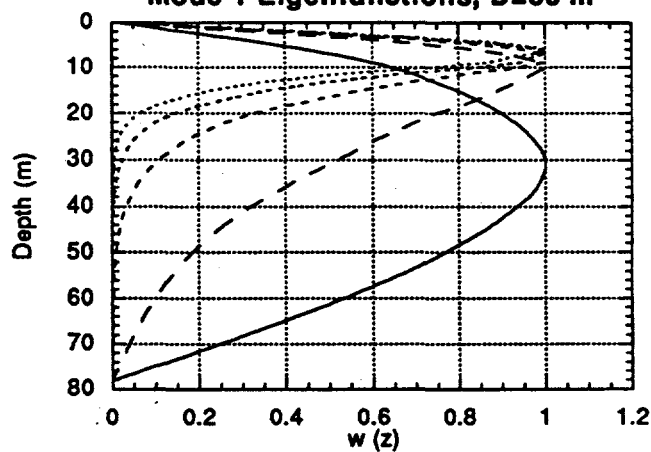
Phase and Group Velocities



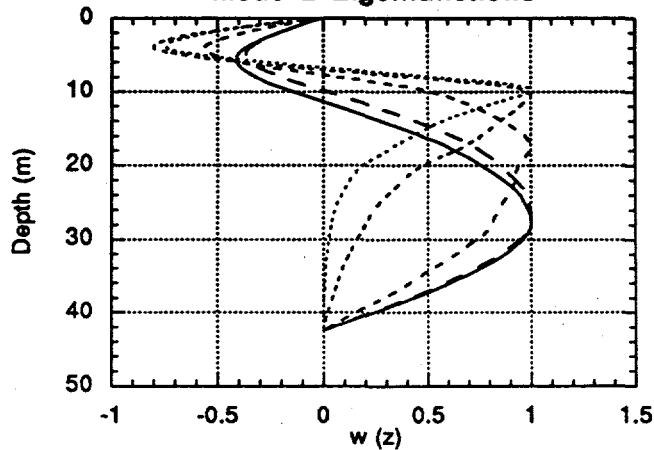
Mode 1 Eigenfunctions



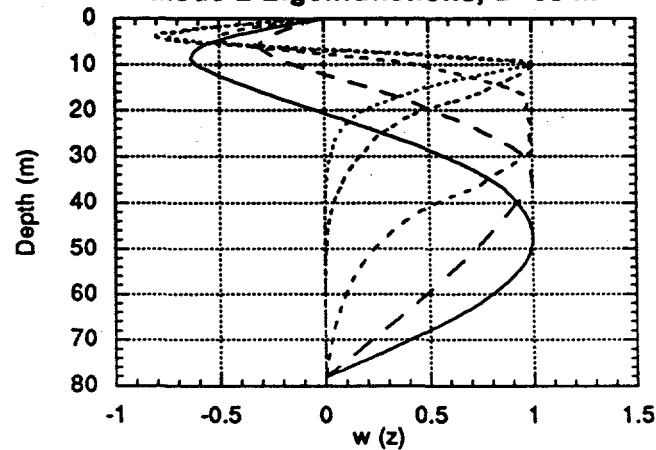
Mode 1 Eigenfunctions, D=80 m

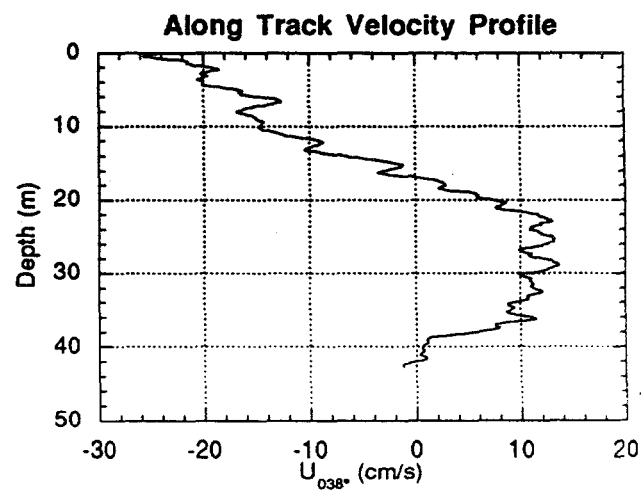
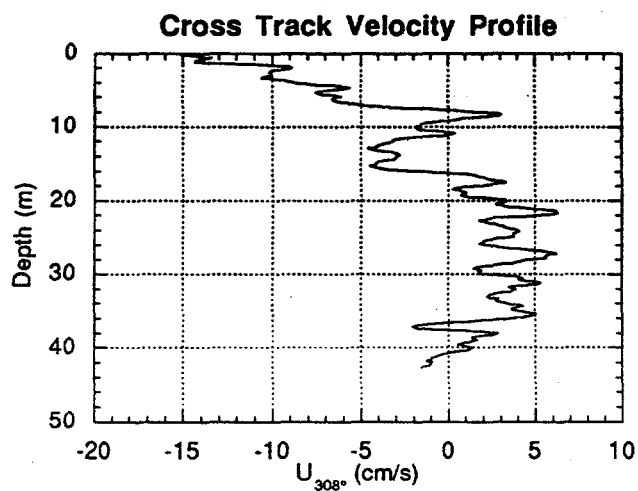
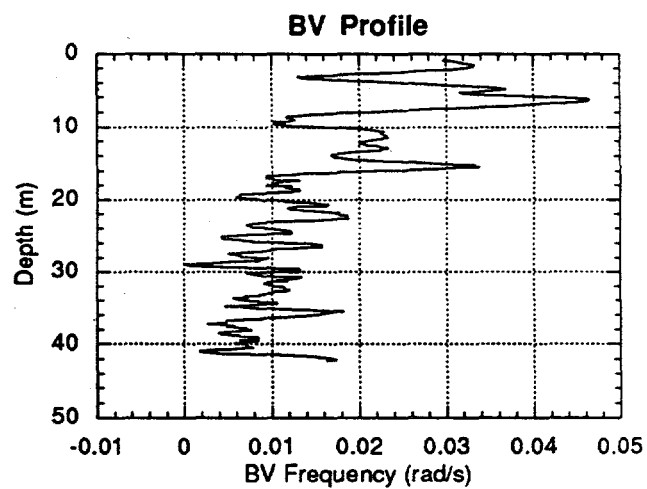
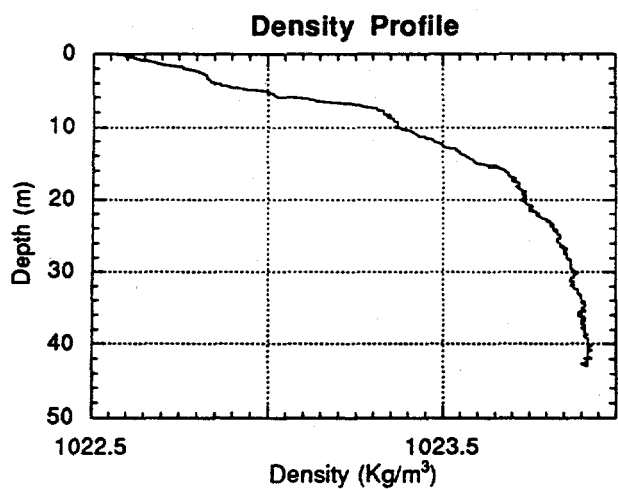
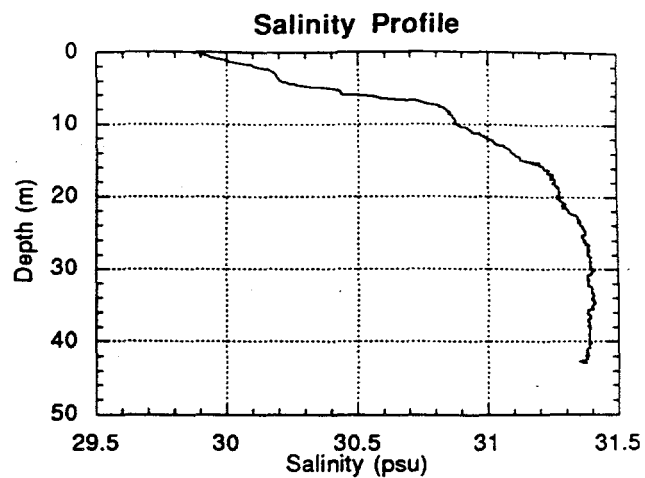
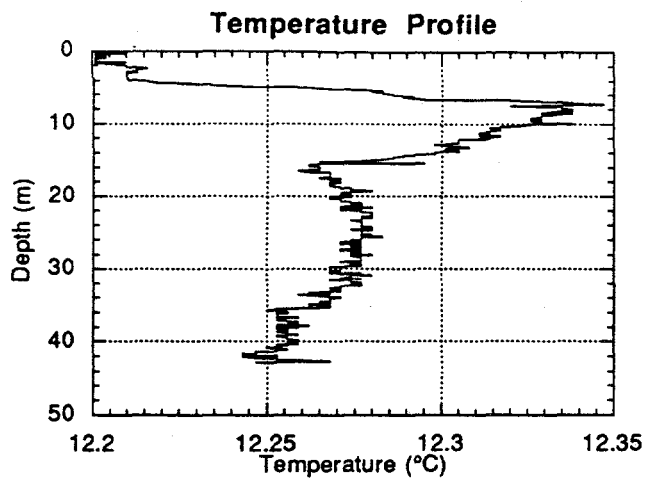


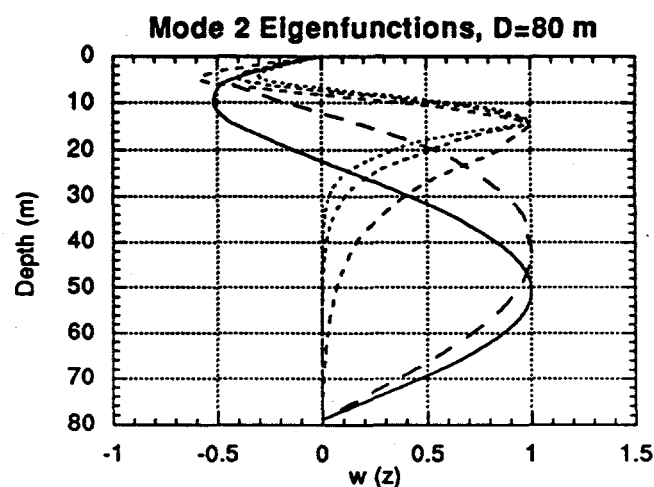
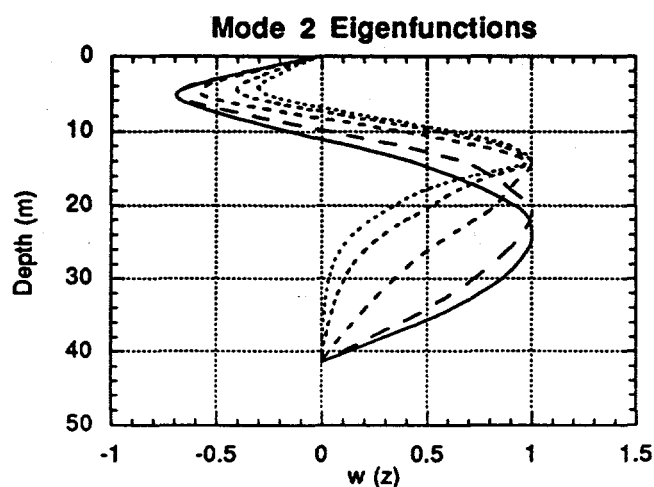
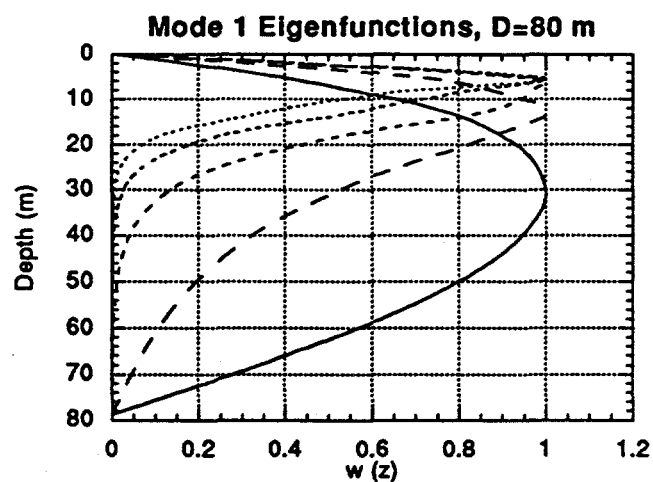
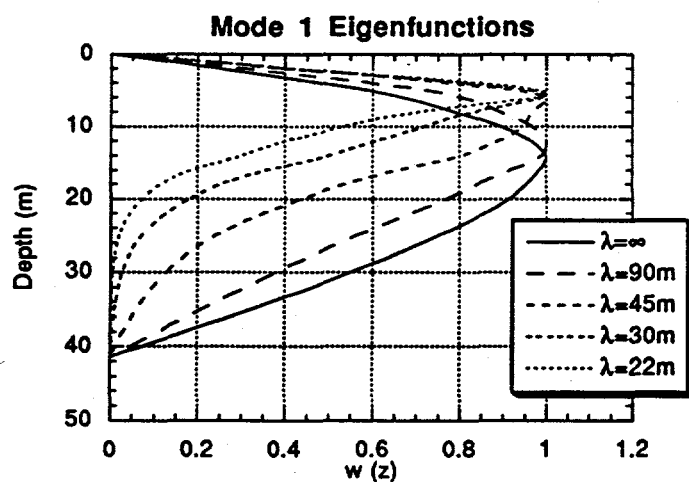
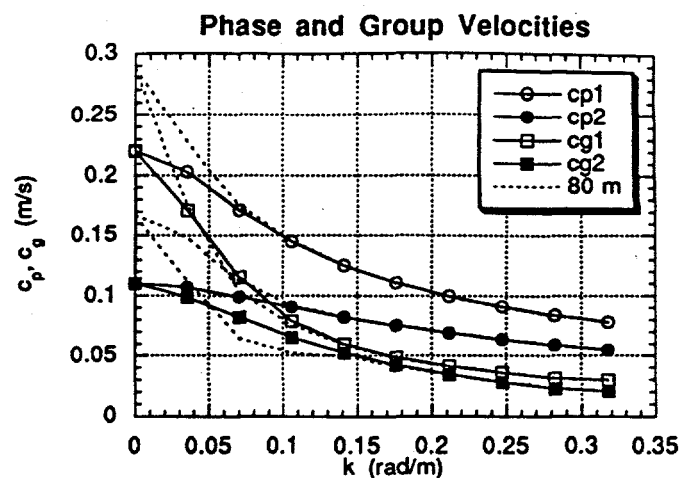
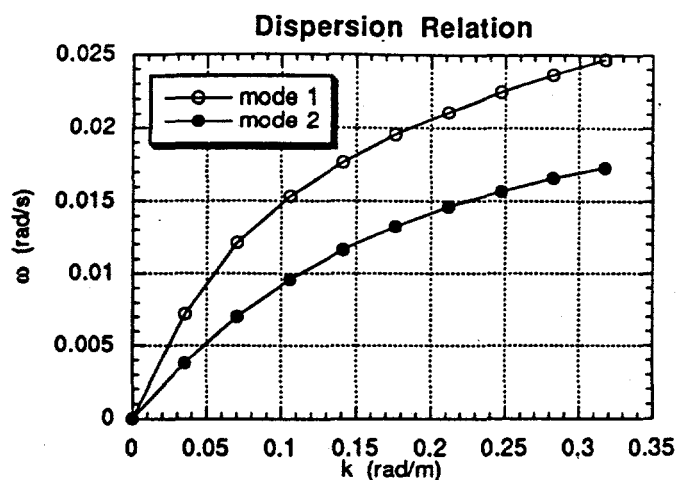
Mode 2 Eigenfunctions

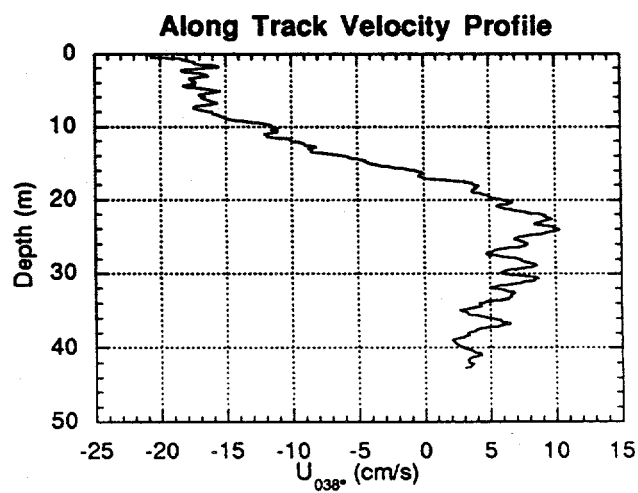
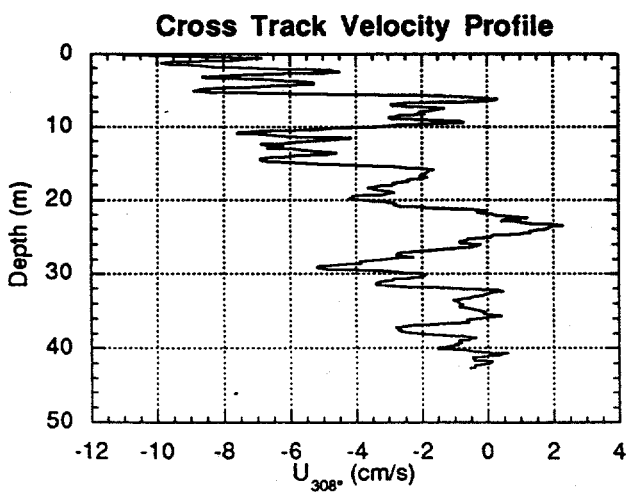
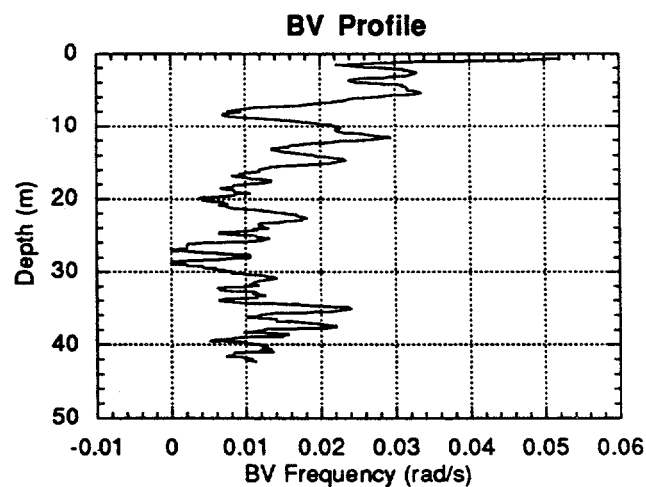
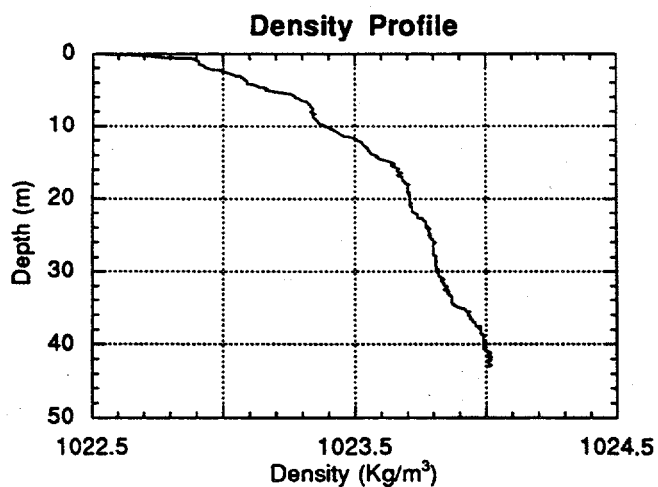
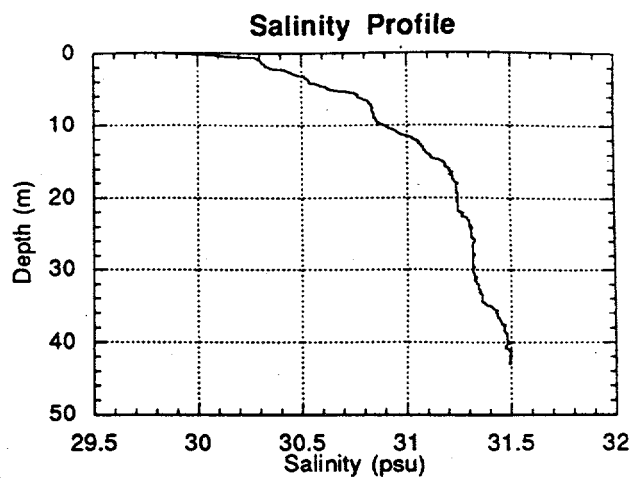
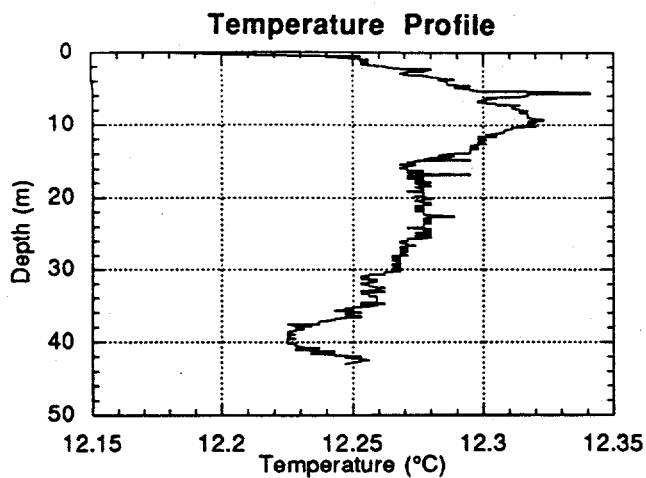


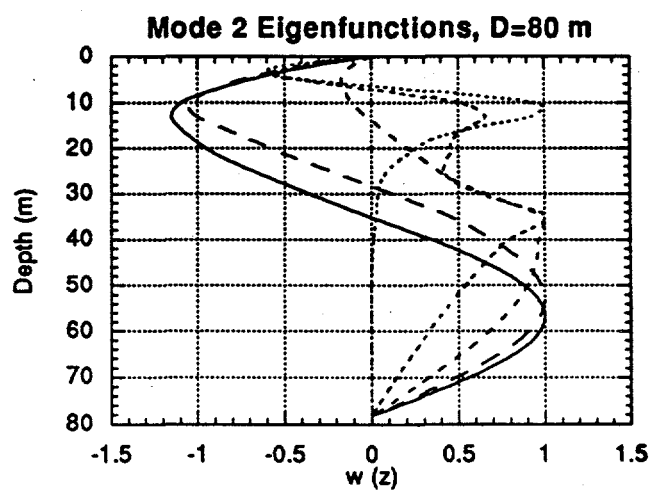
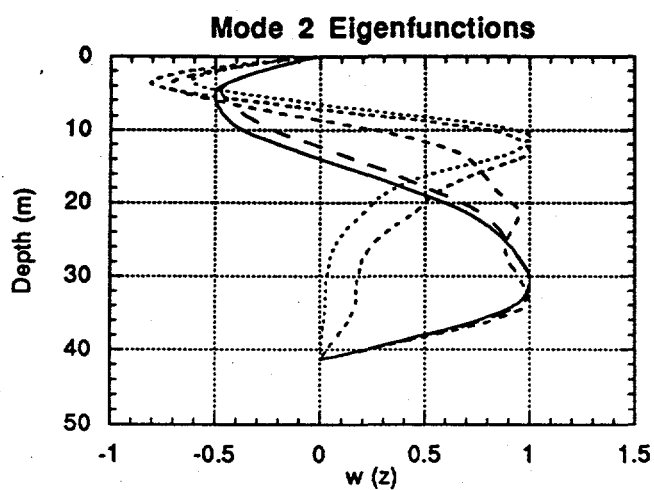
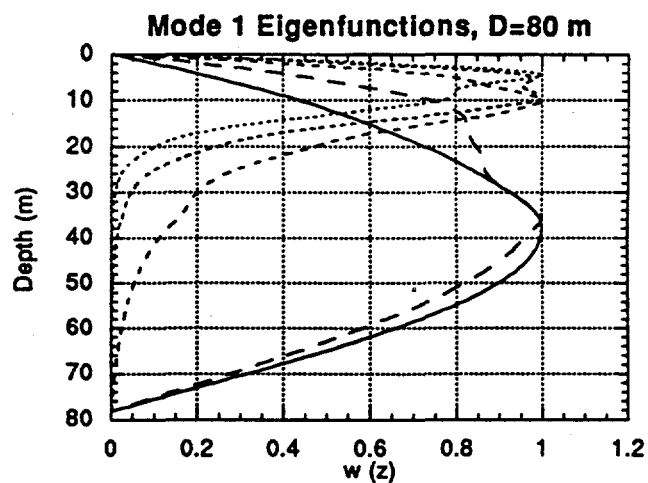
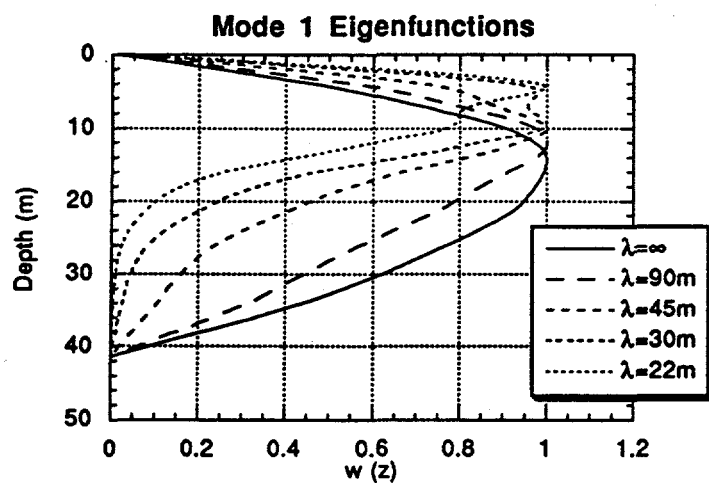
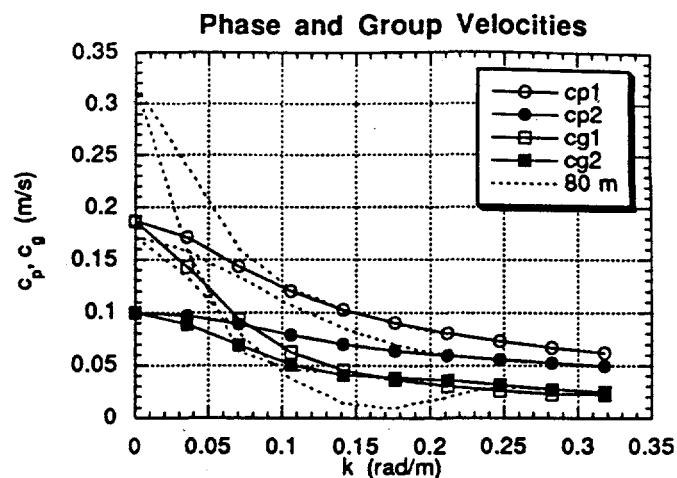
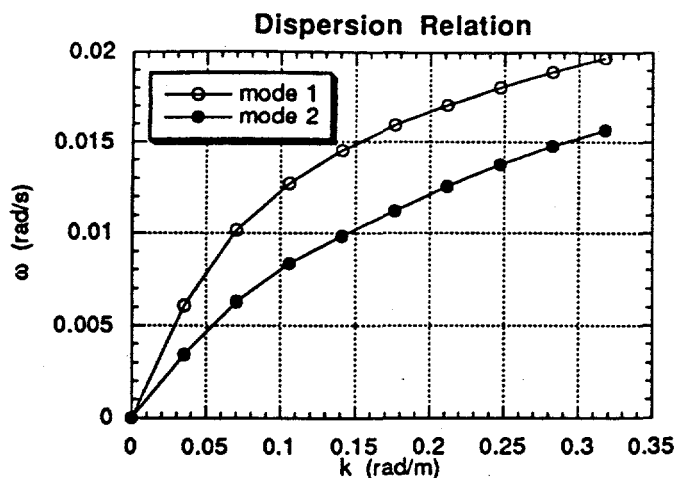
Mode 2 Eigenfunctions, D=80 m

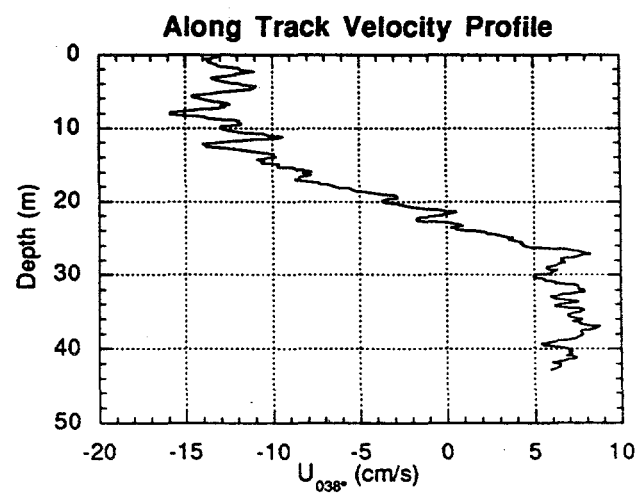
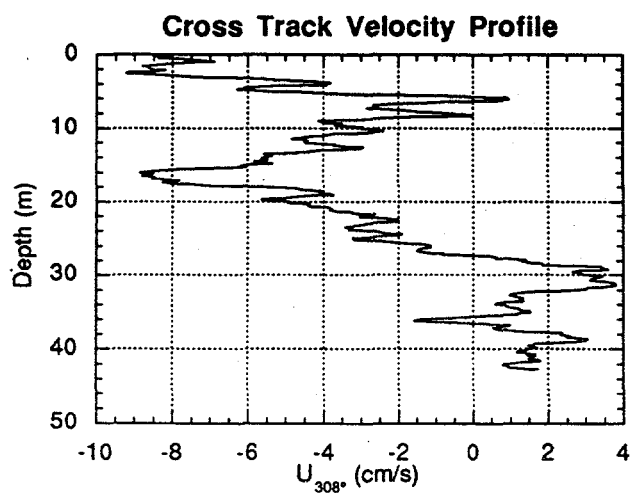
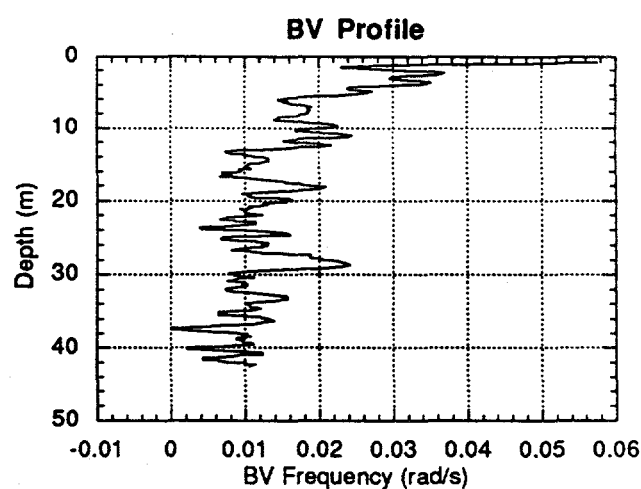
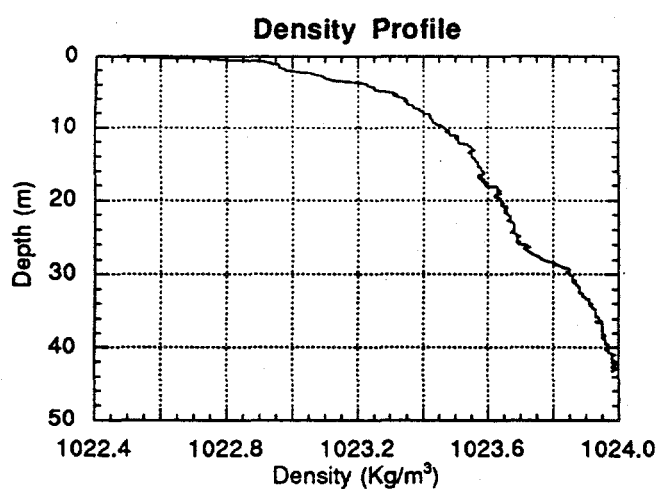
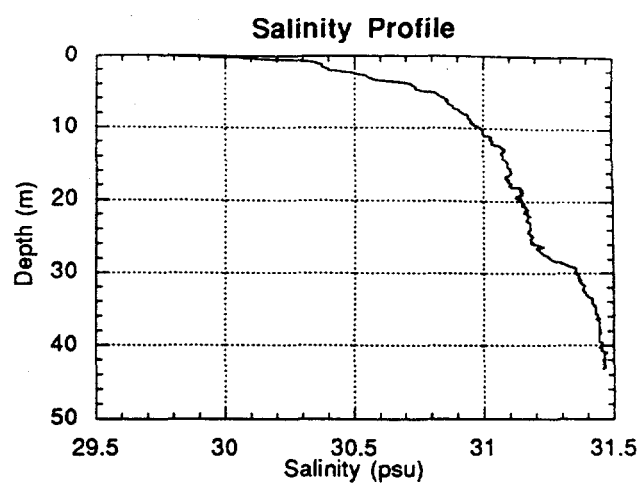
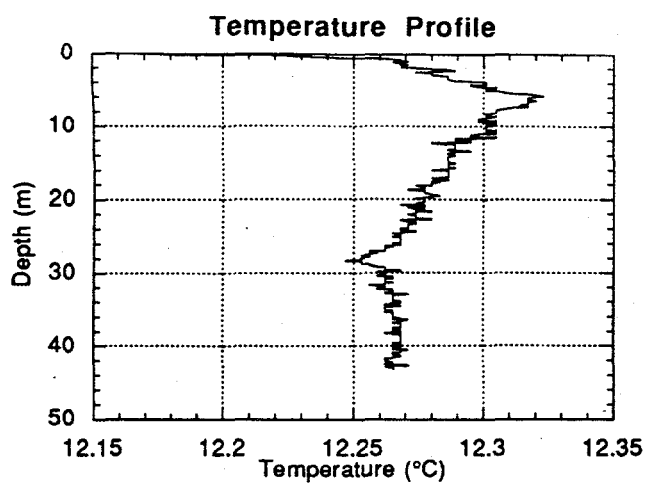




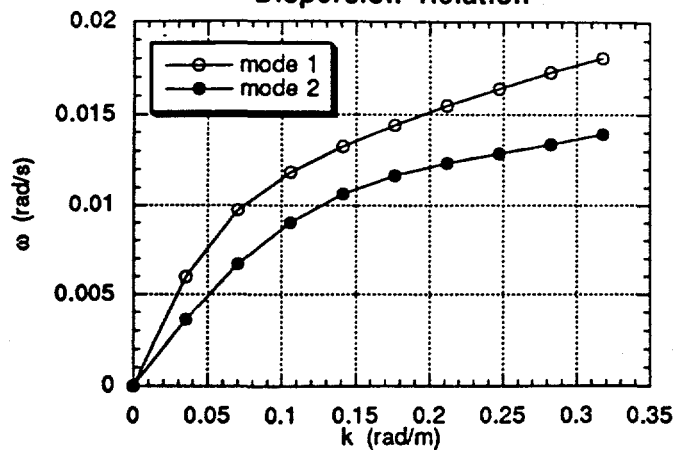




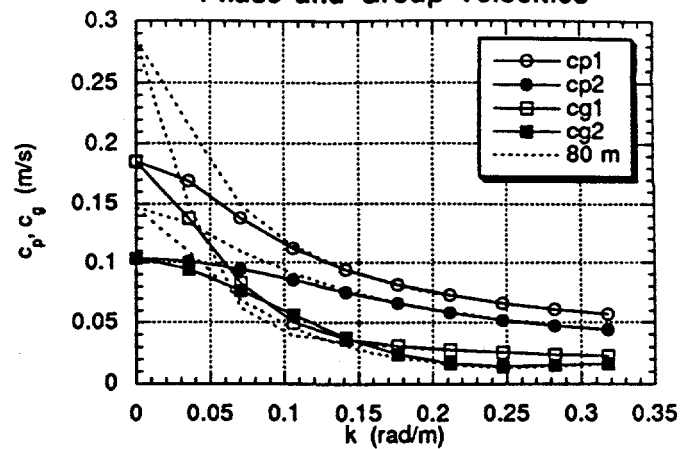




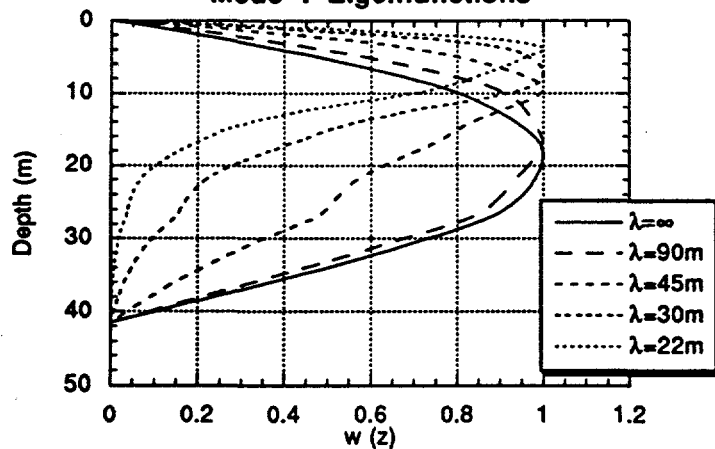
Dispersion Relation



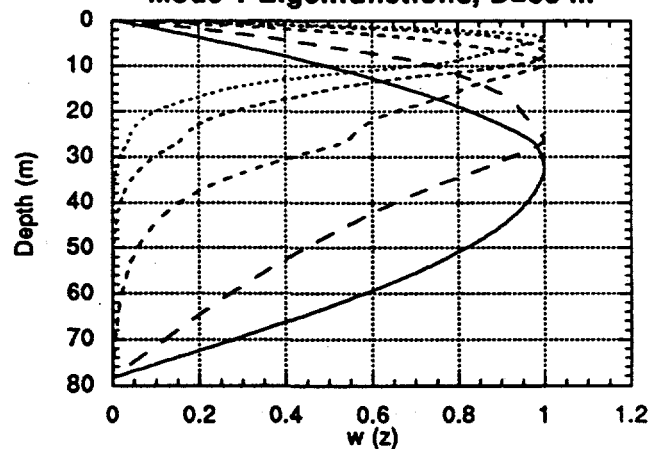
Phase and Group Velocities



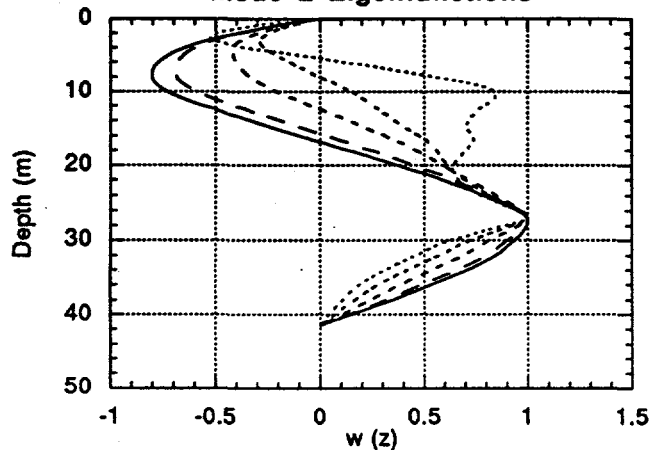
Mode 1 Eigenfunctions



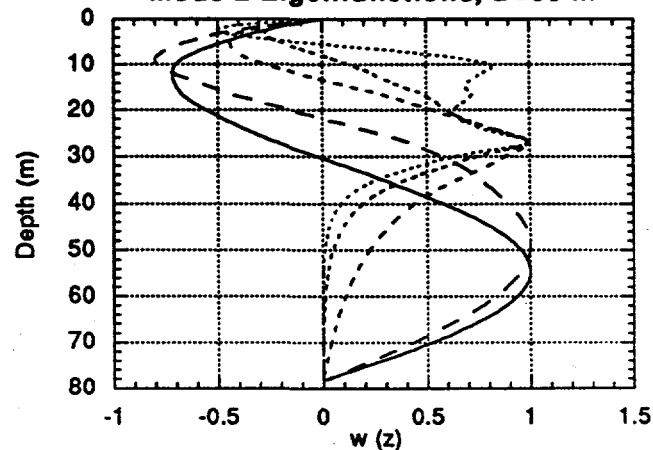
Mode 1 Eigenfunctions, D=80 m

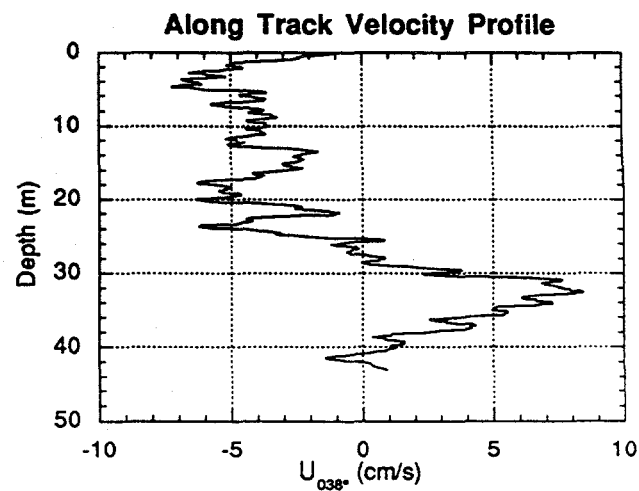
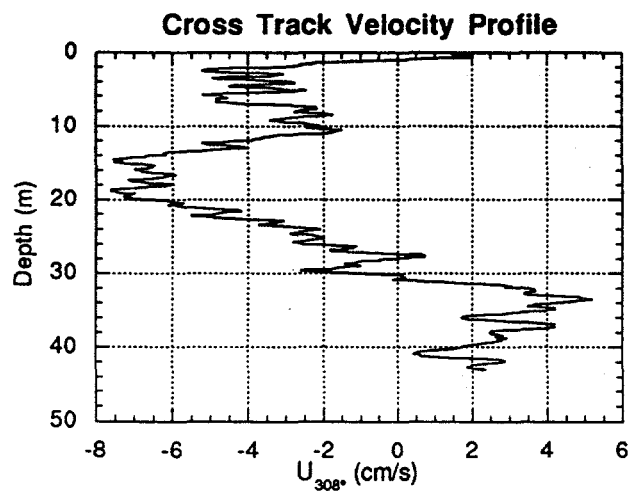
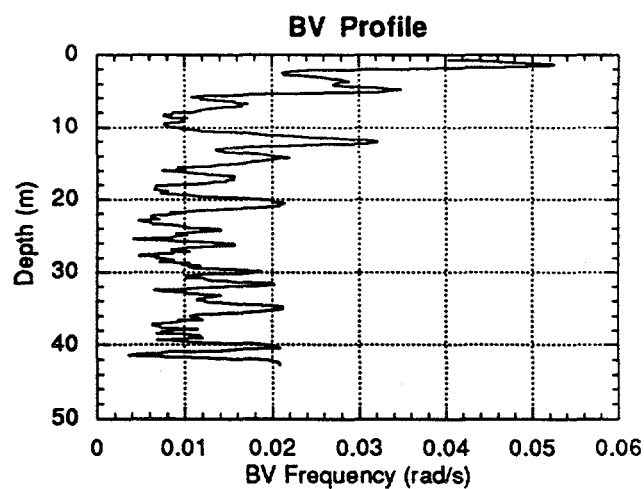
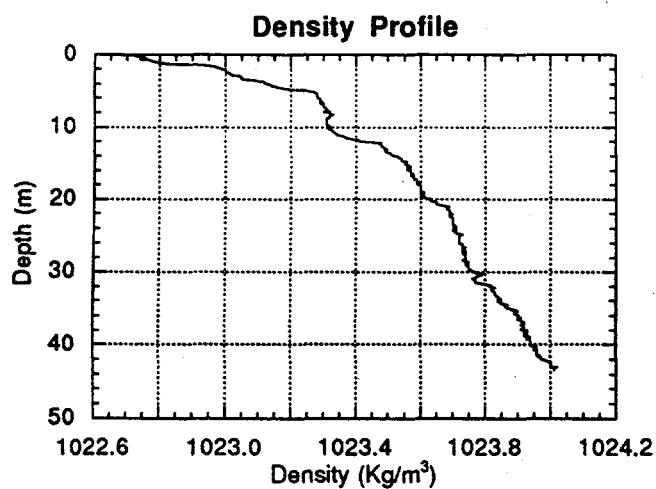
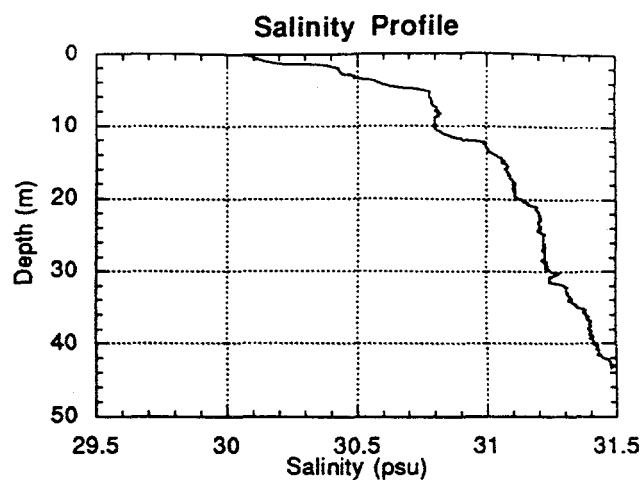
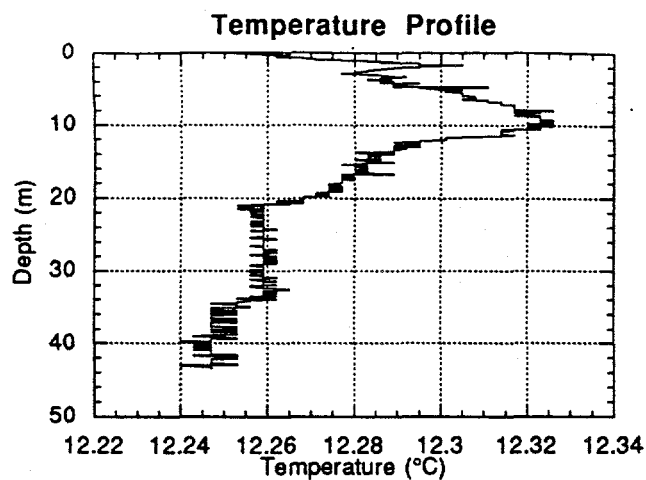


Mode 2 Eigenfunctions

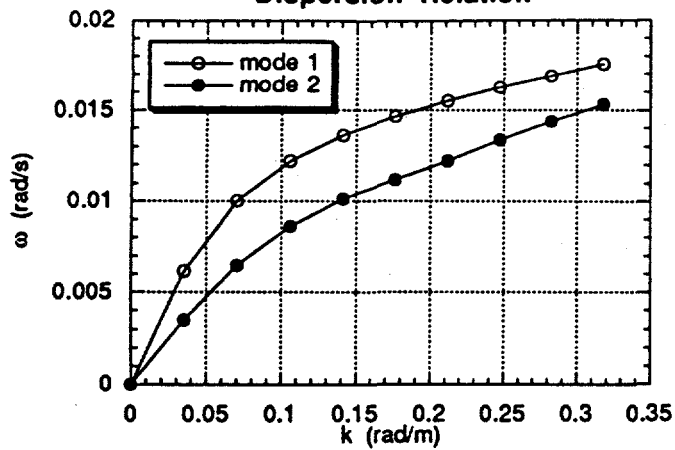


Mode 2 Eigenfunctions, D=80 m

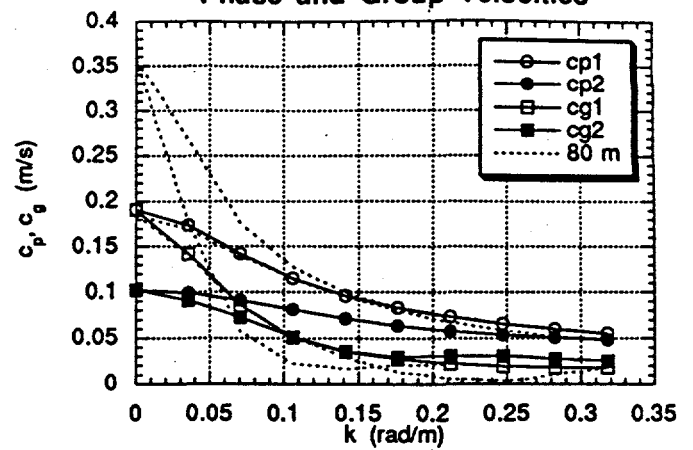




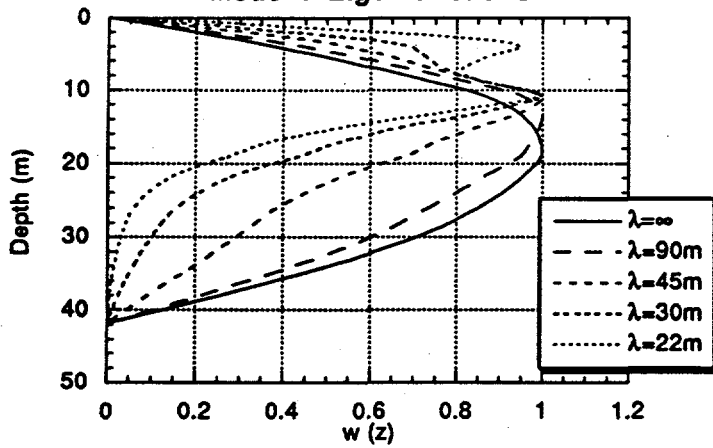
Dispersion Relation



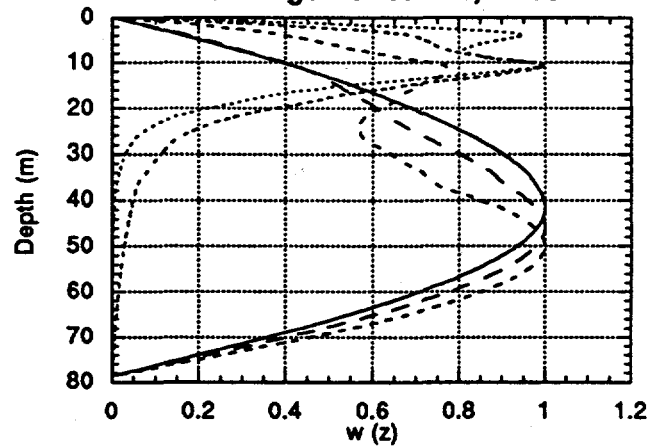
Phase and Group Velocities



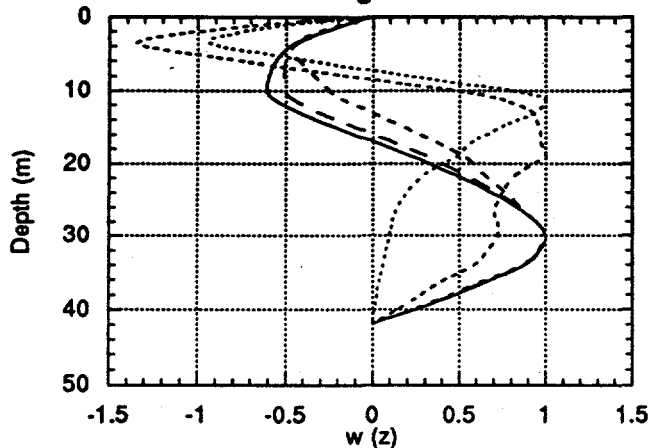
Mode 1 Eigenfunctions



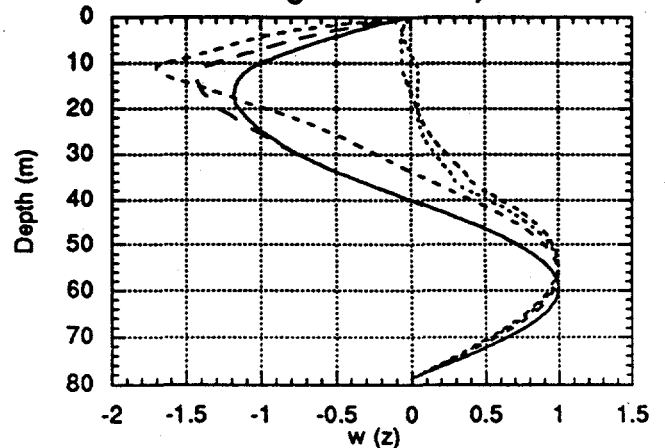
Mode 1 Eigenfunctions, D=80 m

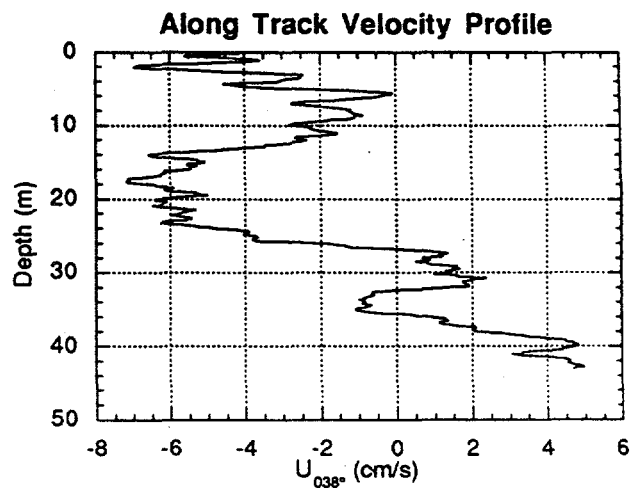
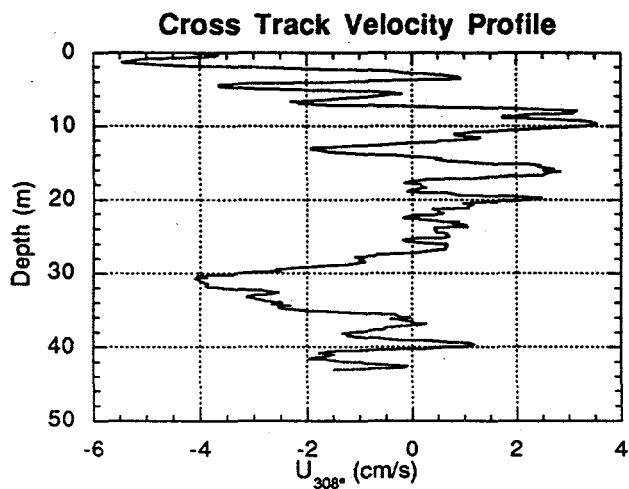
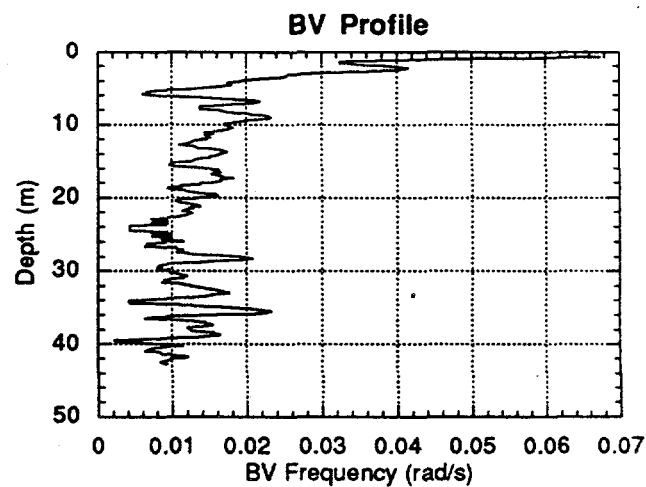
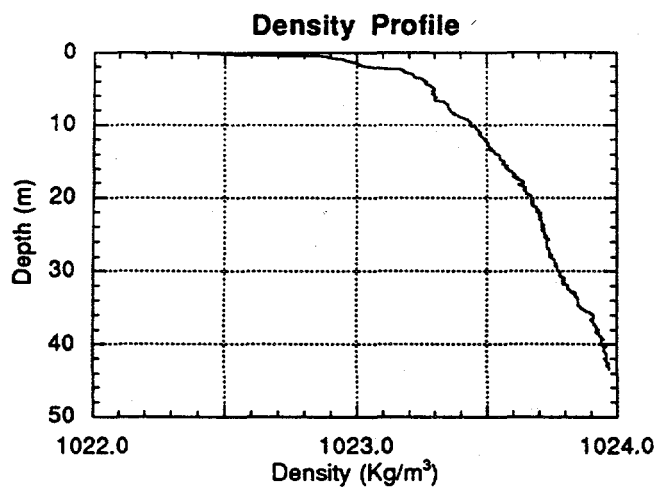
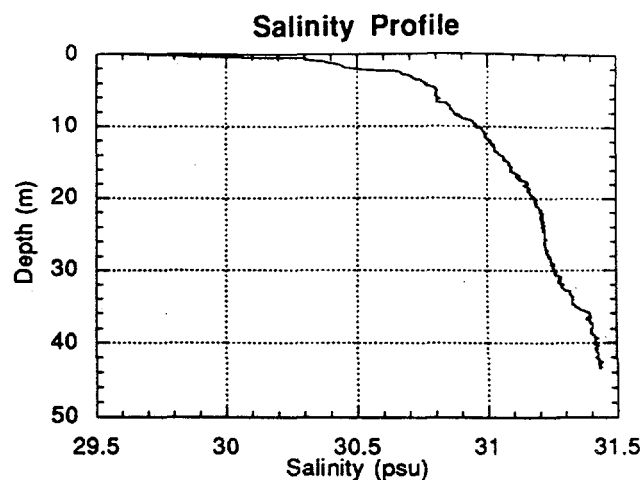
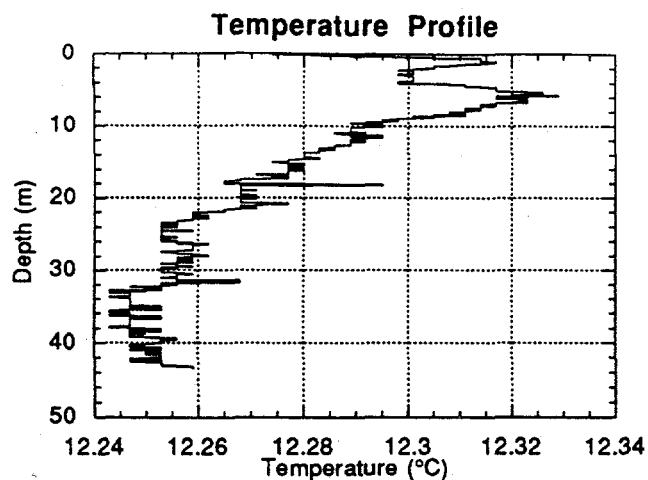


Mode 2 Eigenfunctions

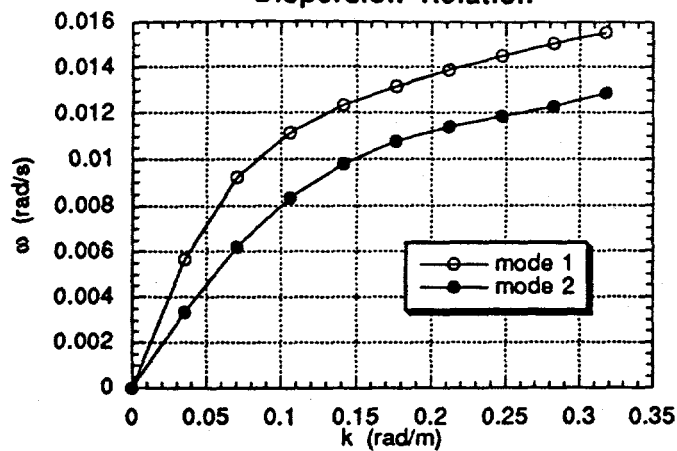


Mode 2 Eigenfunctions, D=80 m

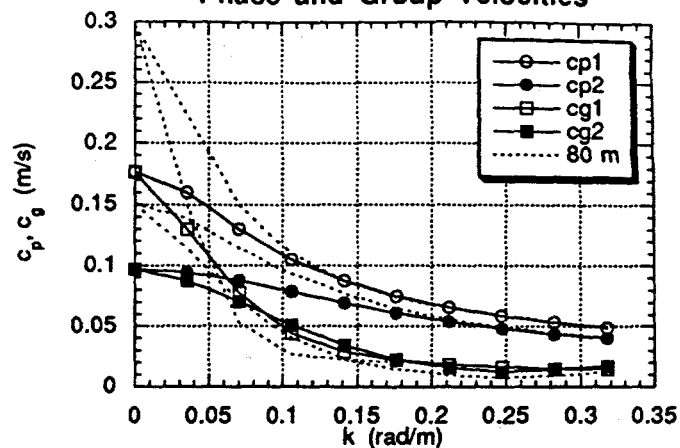




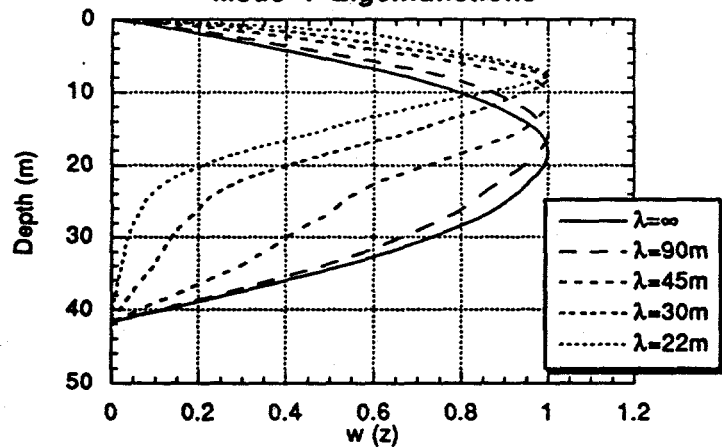
Dispersion Relation



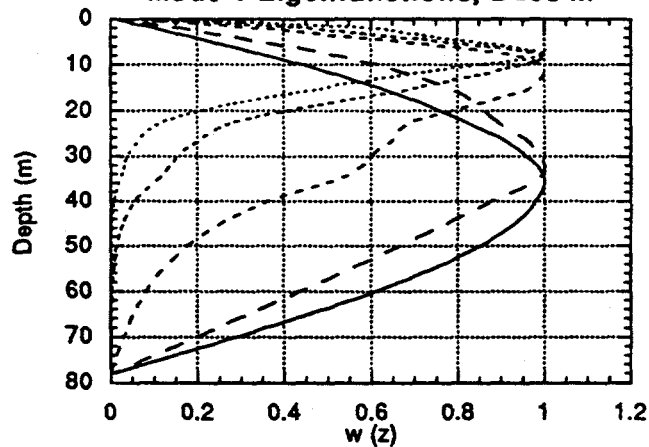
Phase and Group Velocities



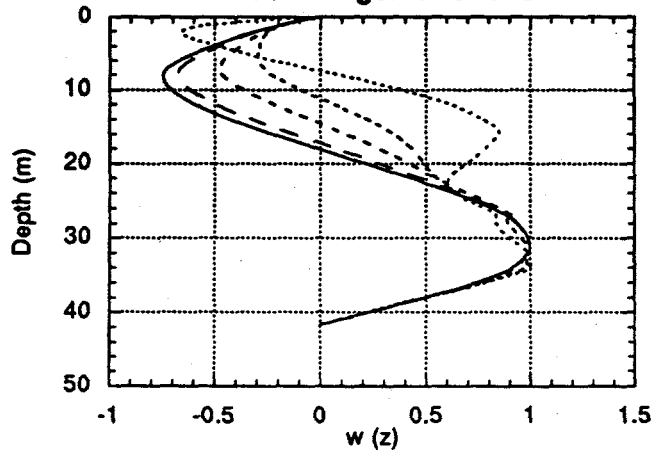
Mode 1 Eigenfunctions



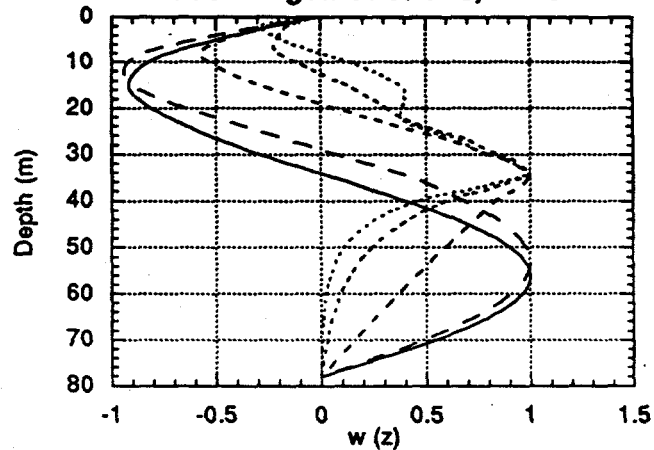
Mode 1 Eigenfunctions, D=80 m



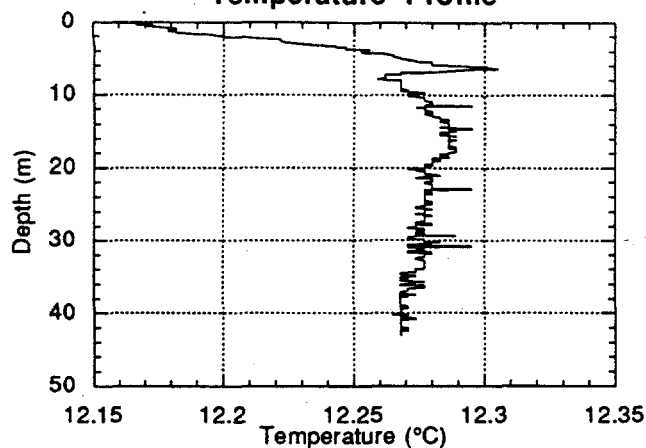
Mode 2 Eigenfunctions



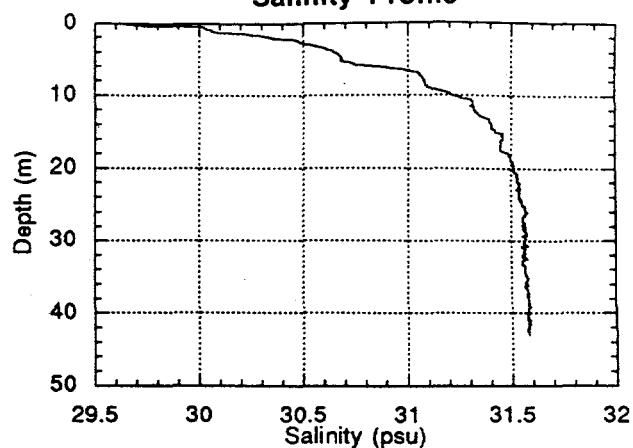
Mode 2 Eigenfunctions, D=80 m



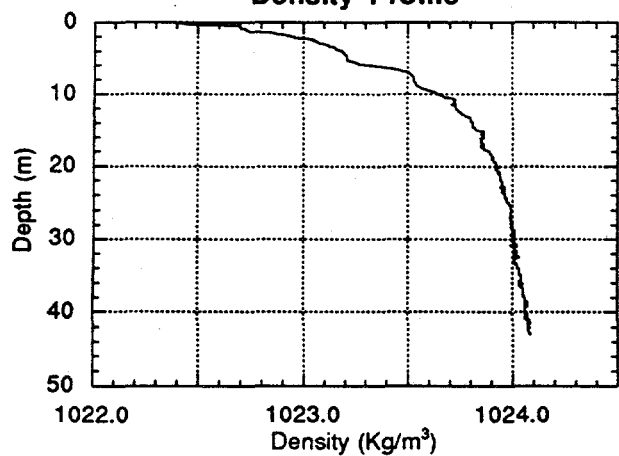
Temperature Profile



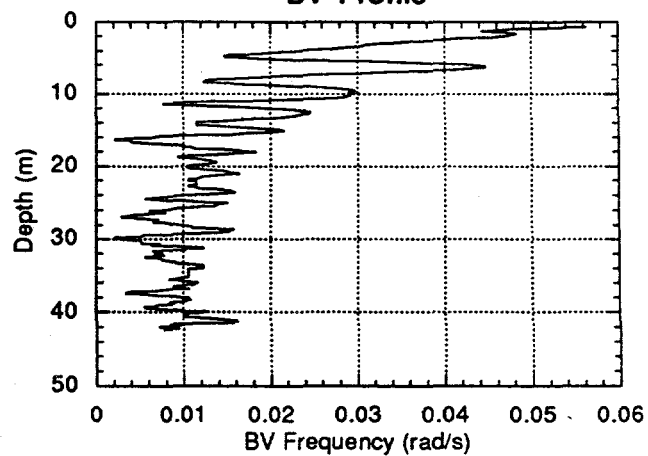
Salinity Profile



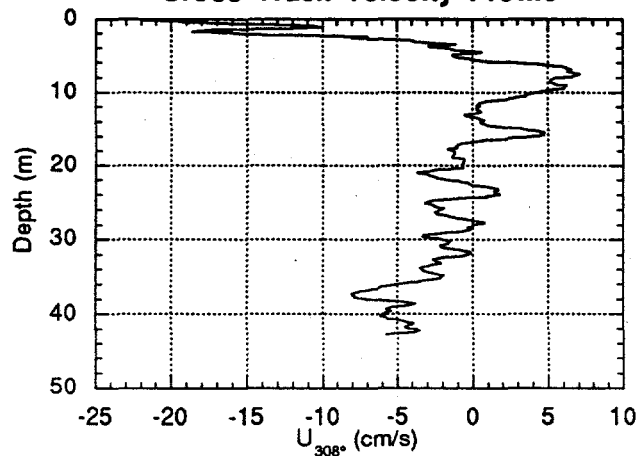
Density Profile



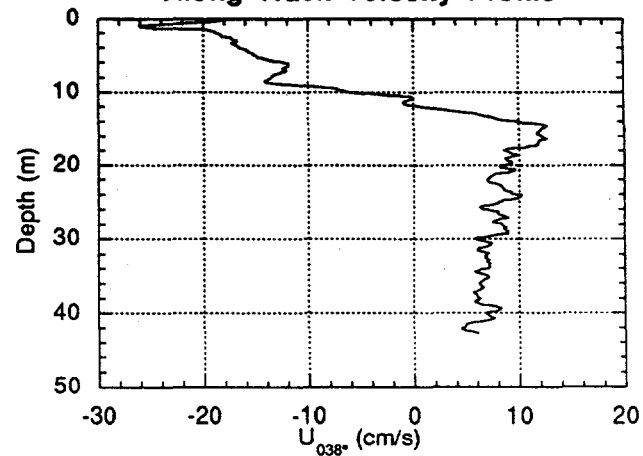
BV Profile



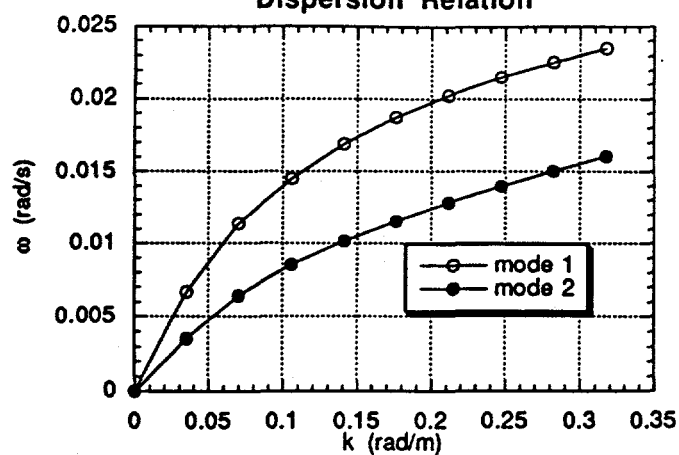
Cross Track Velocity Profile



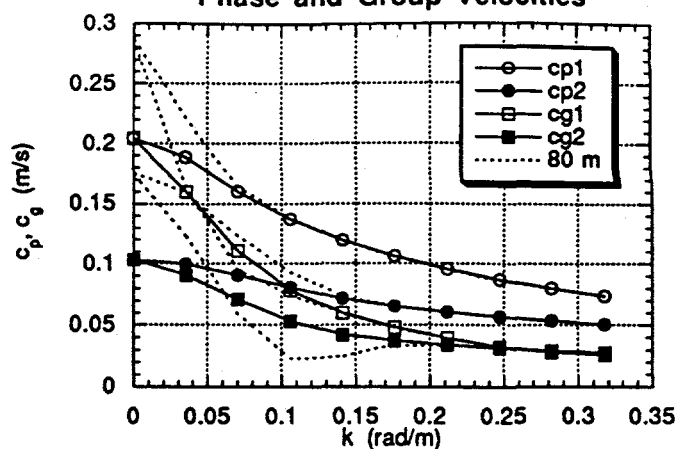
Along Track Velocity Profile



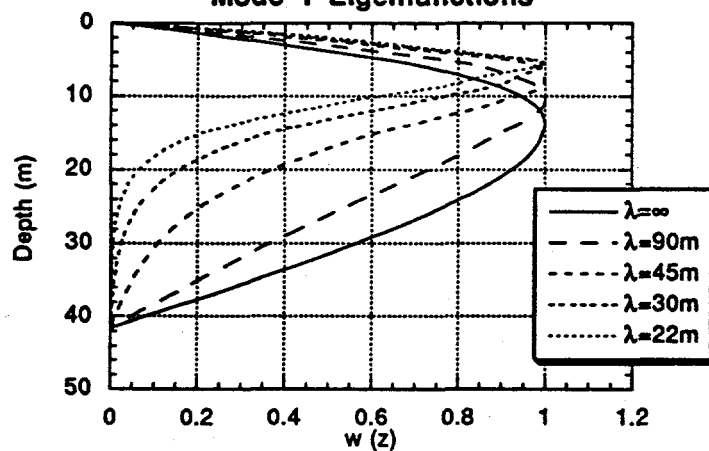
Dispersion Relation



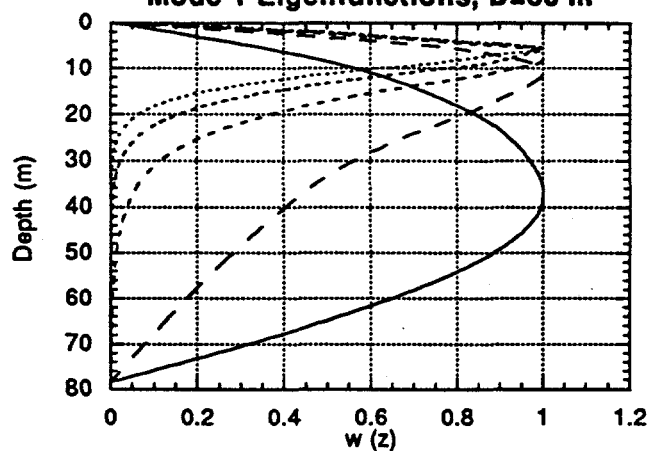
Phase and Group Velocities



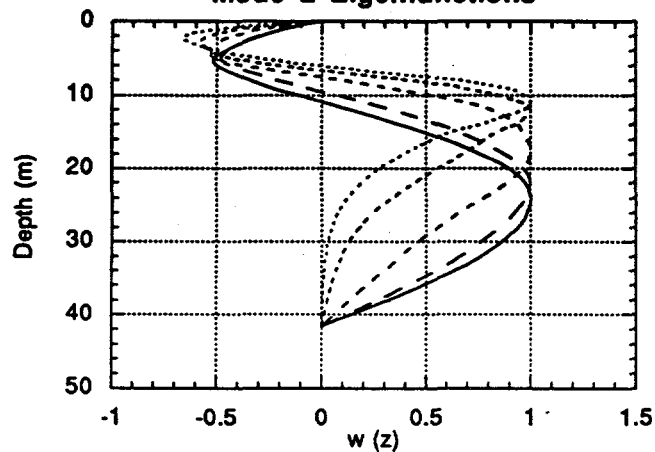
Mode 1 Eigenfunctions



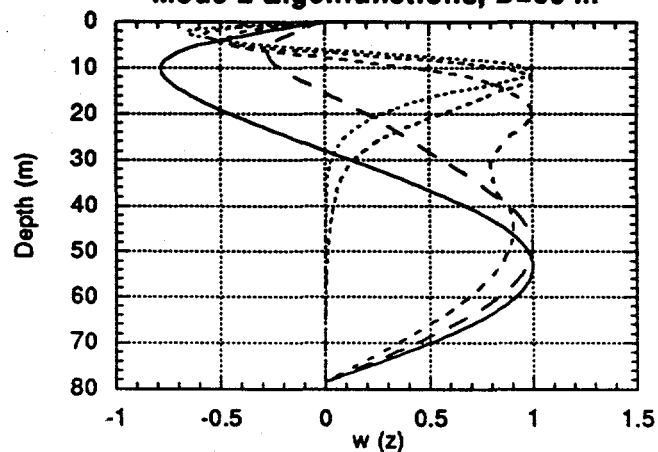
Mode 1 Eigenfunctions, D=80 m

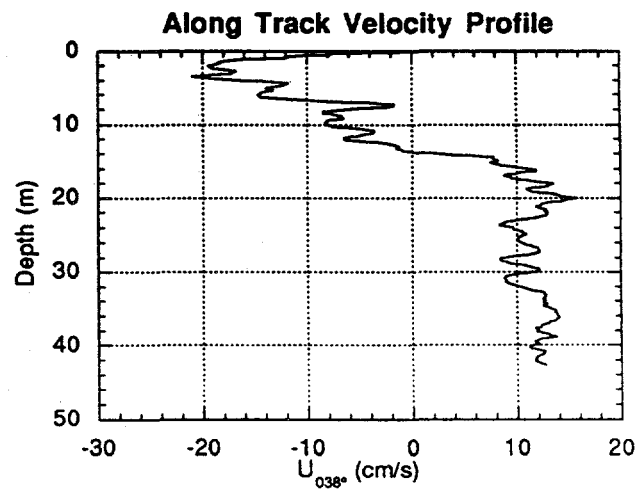
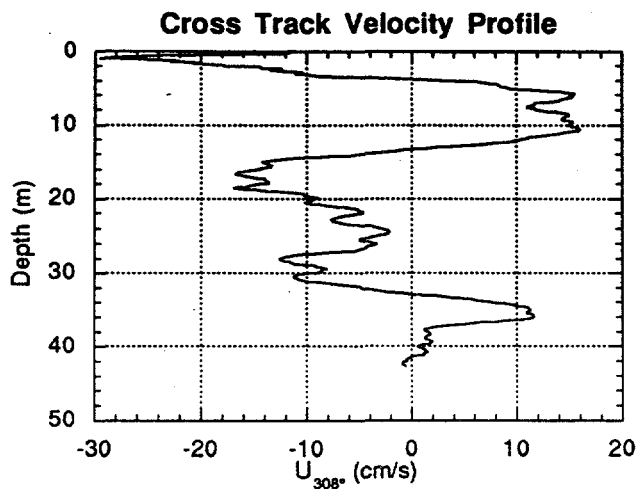
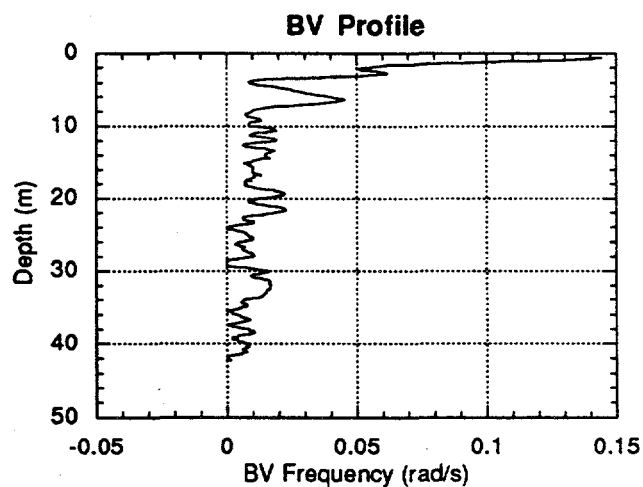
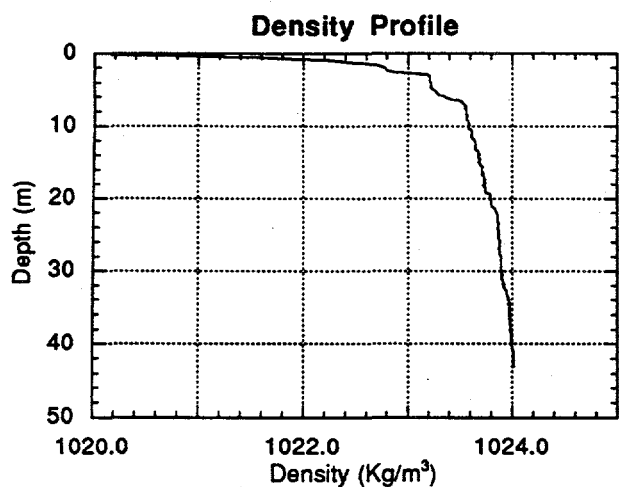
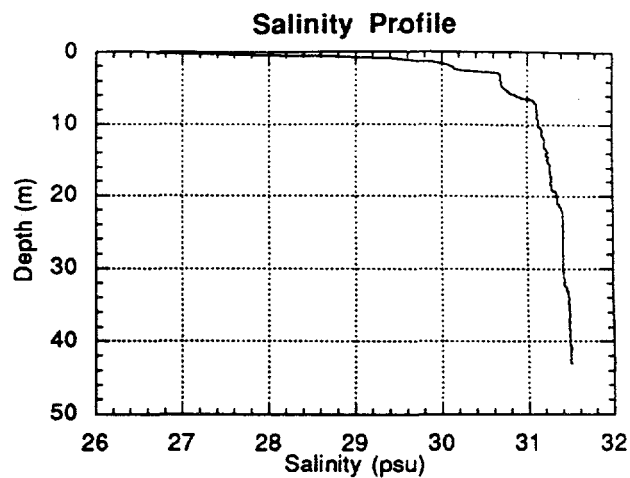
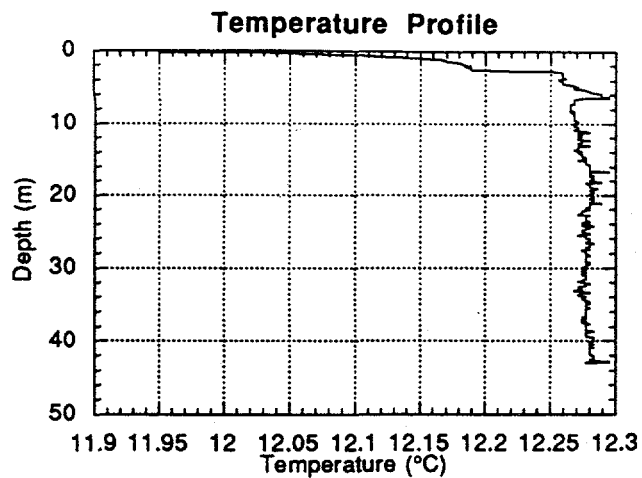


Mode 2 Eigenfunctions

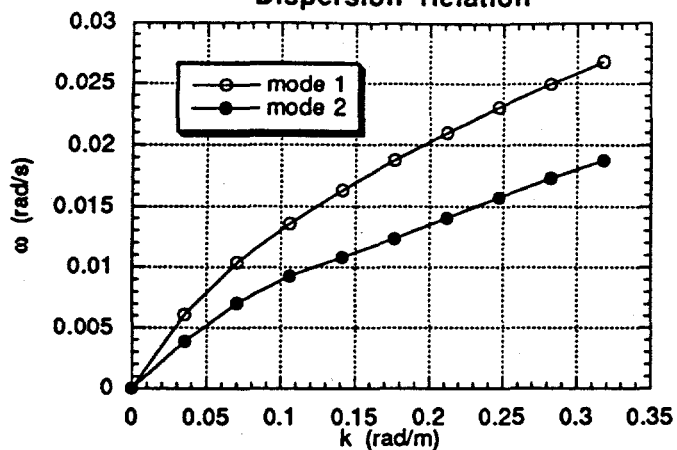


Mode 2 Eigenfunctions, D=80 m

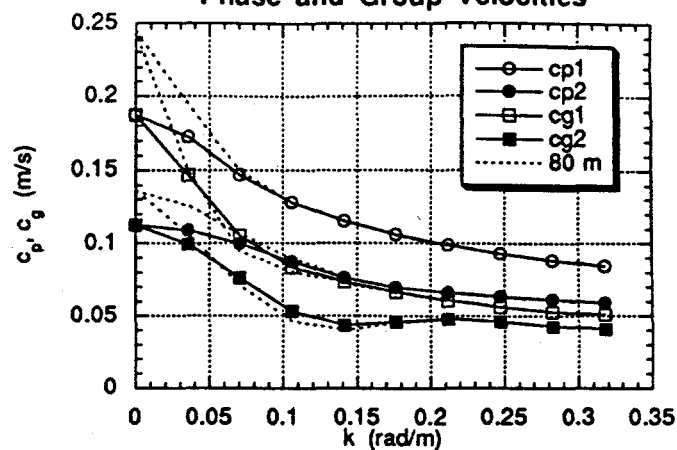




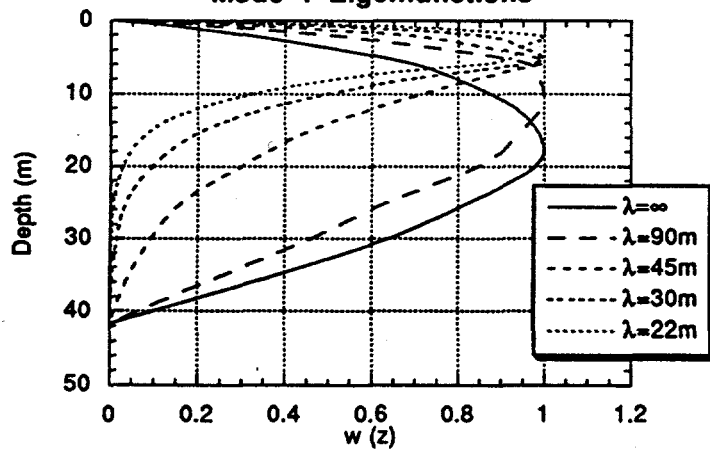
Dispersion Relation



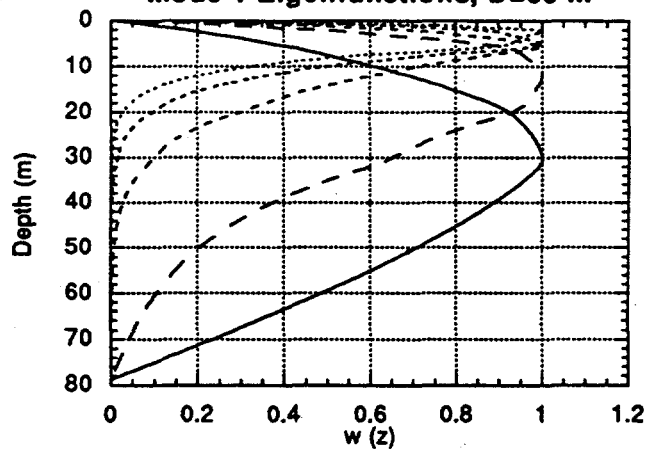
Phase and Group Velocities



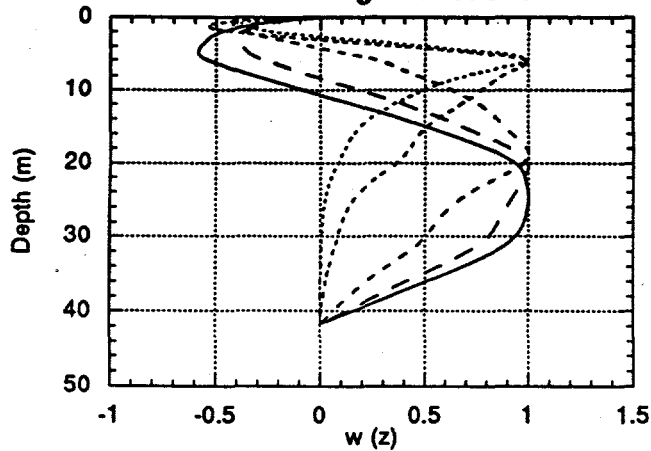
Mode 1 Eigenfunctions



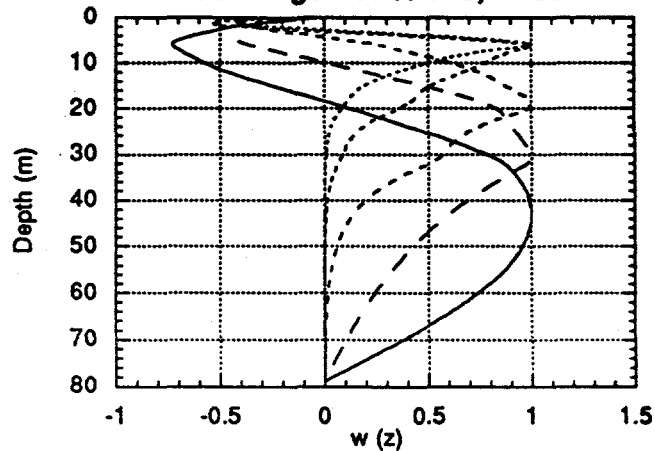
Mode 1 Eigenfunctions, D=80 m

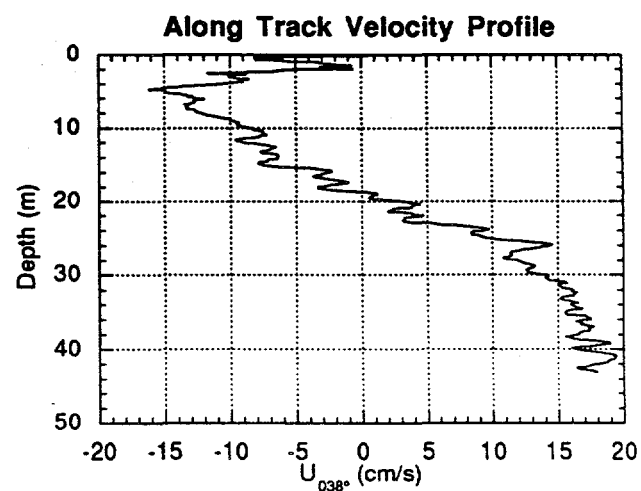
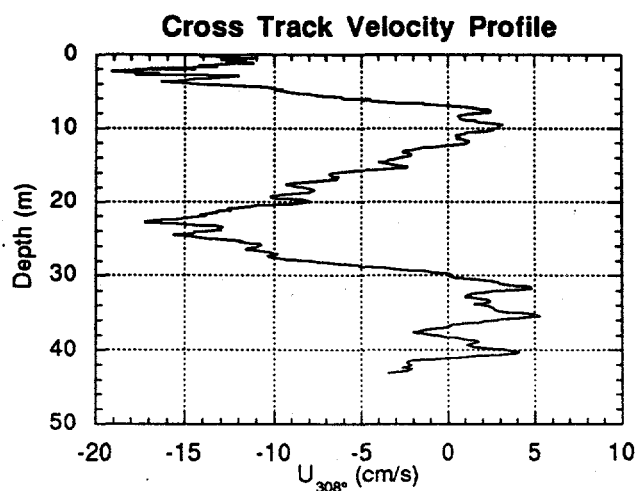
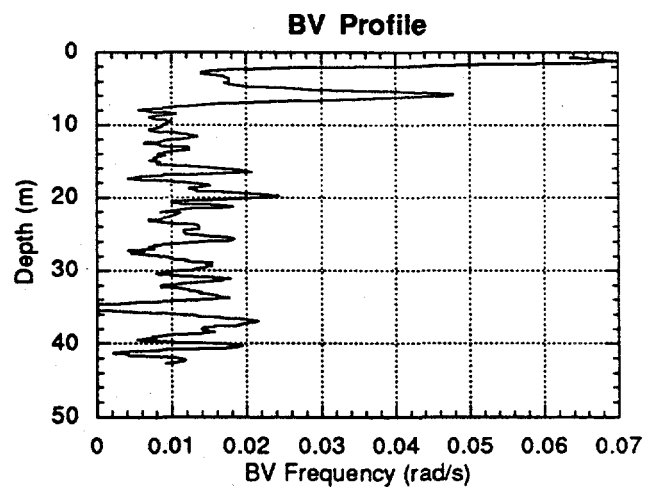
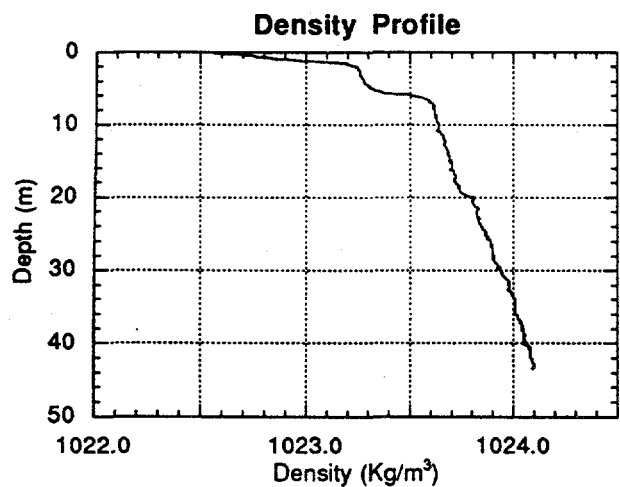
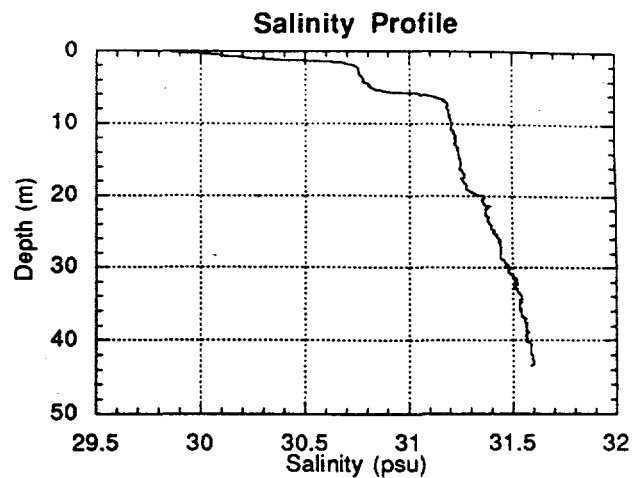
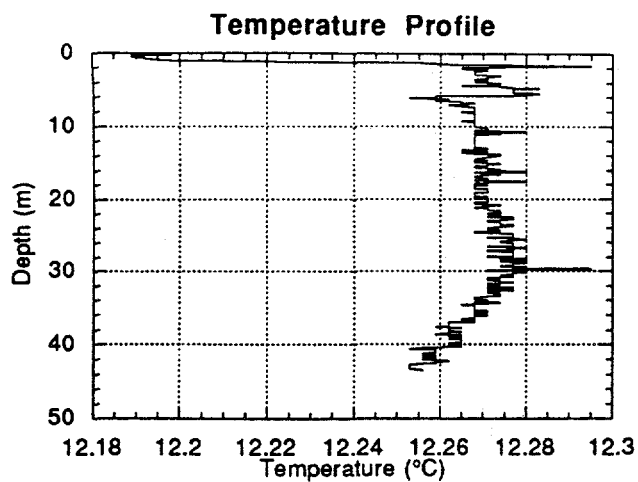


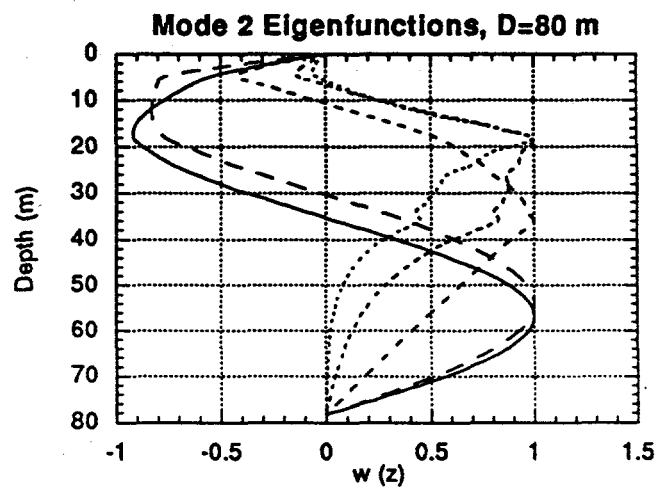
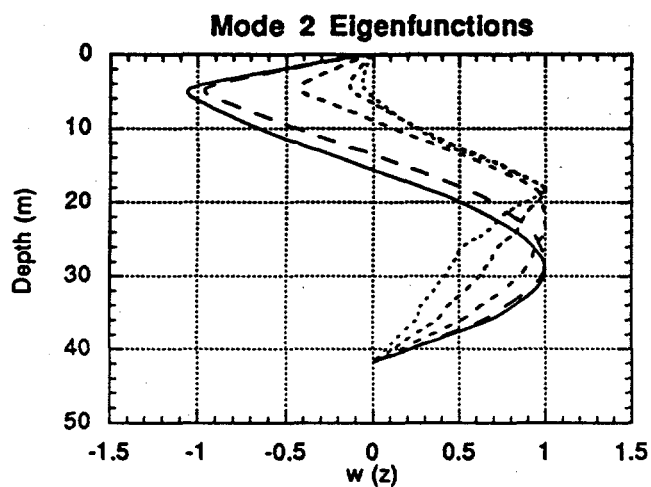
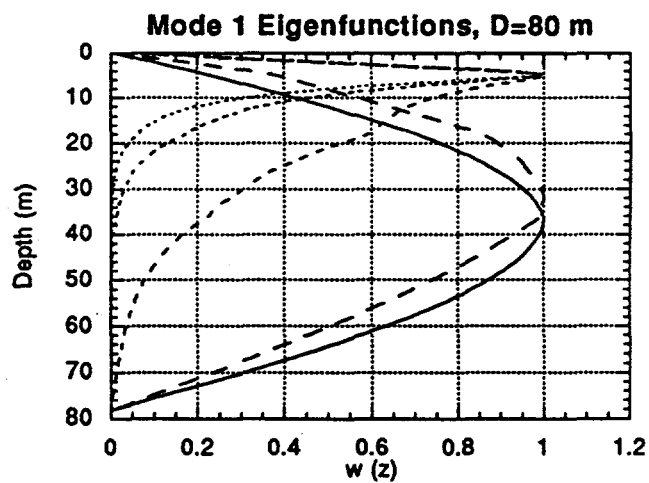
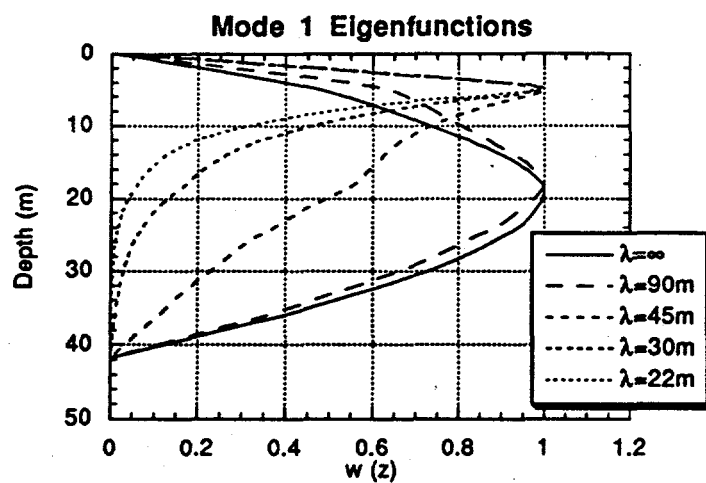
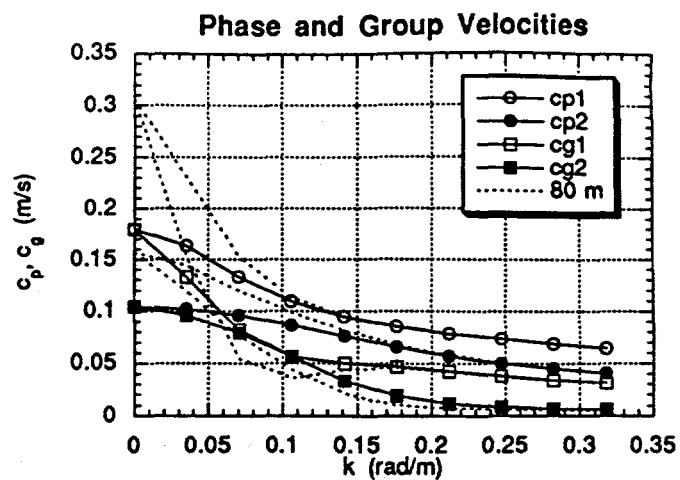
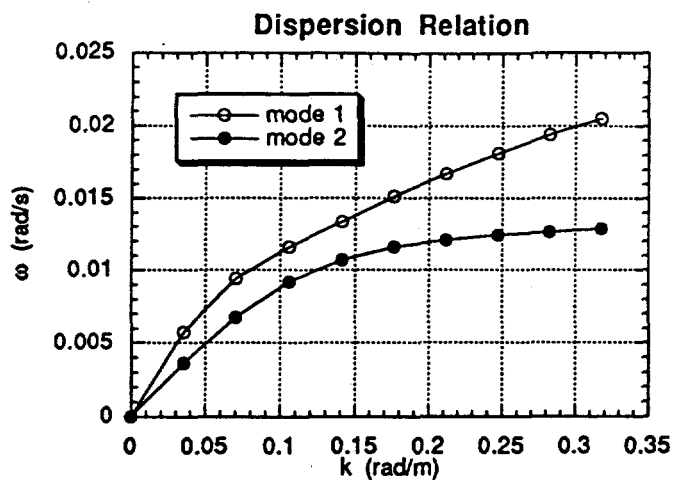
Mode 2 Eigenfunctions

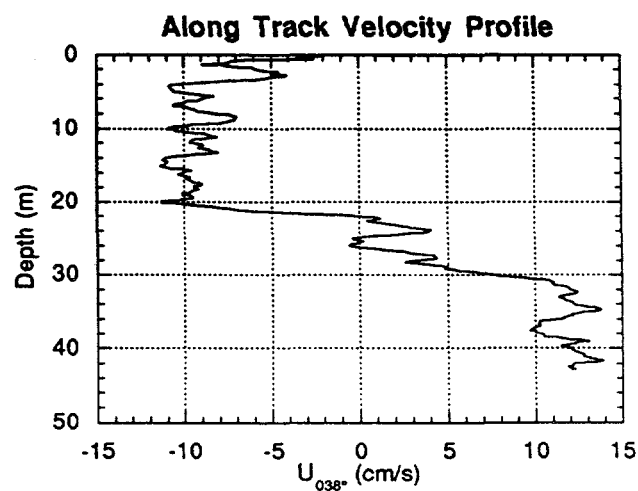
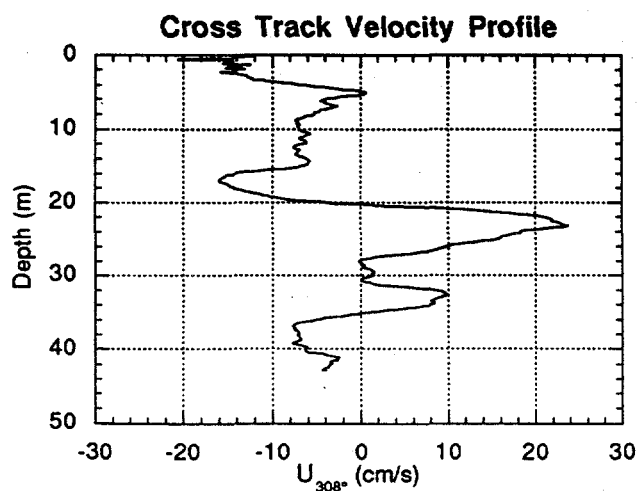
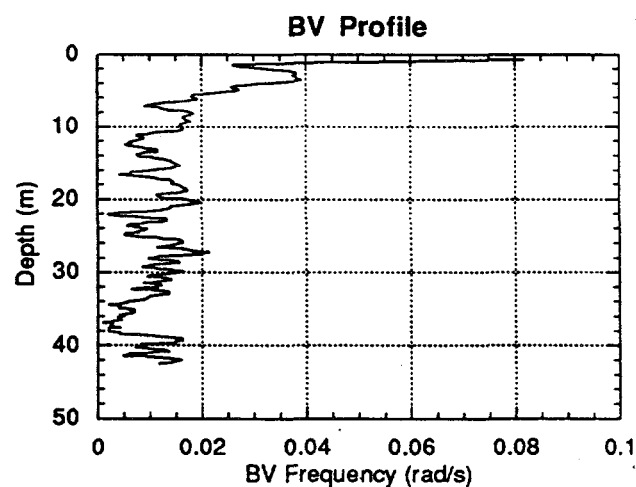
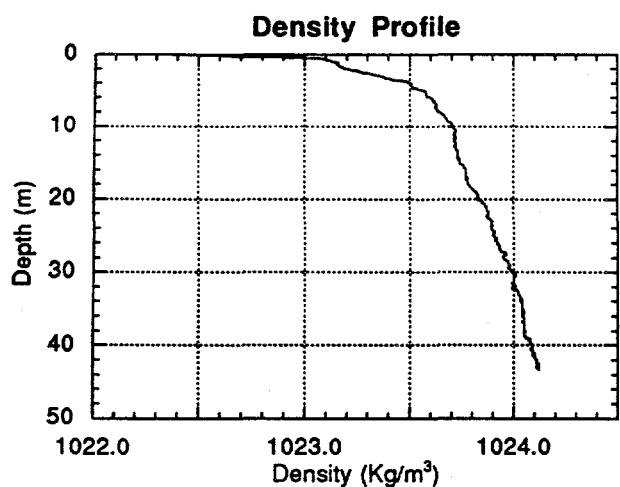
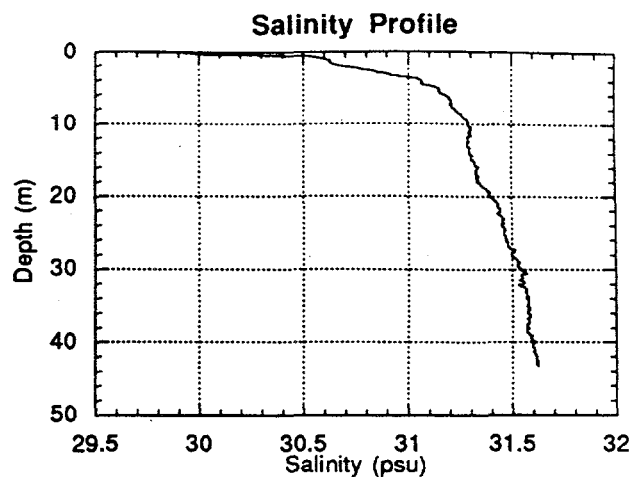
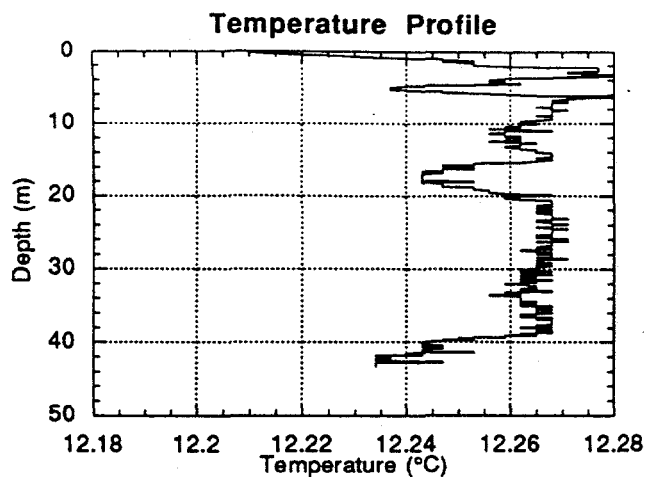


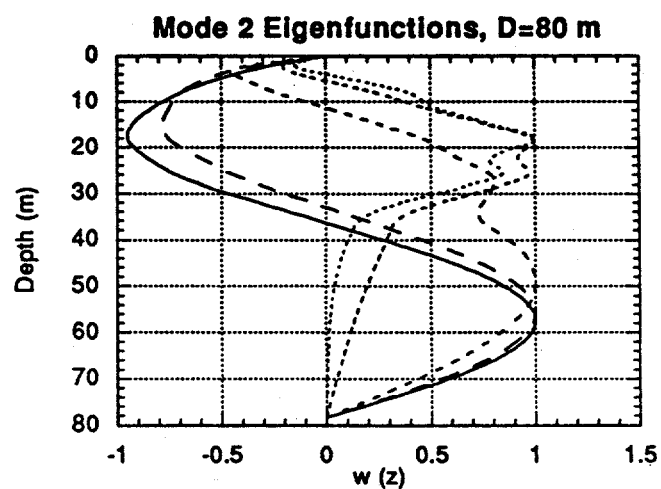
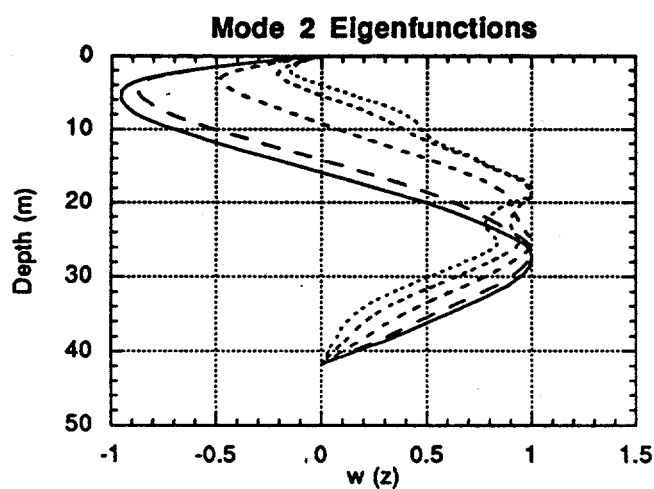
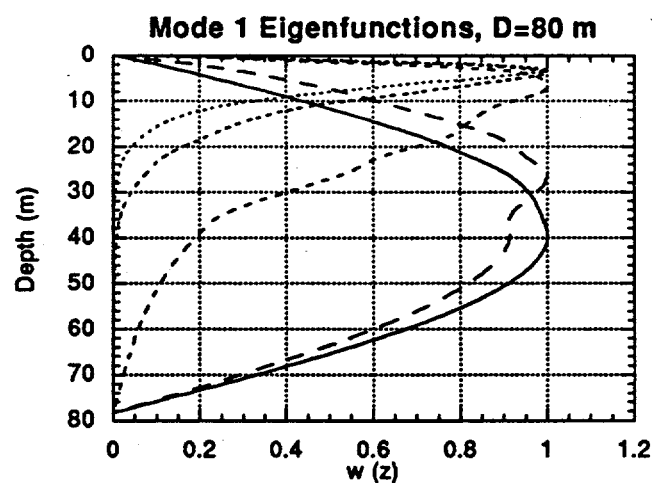
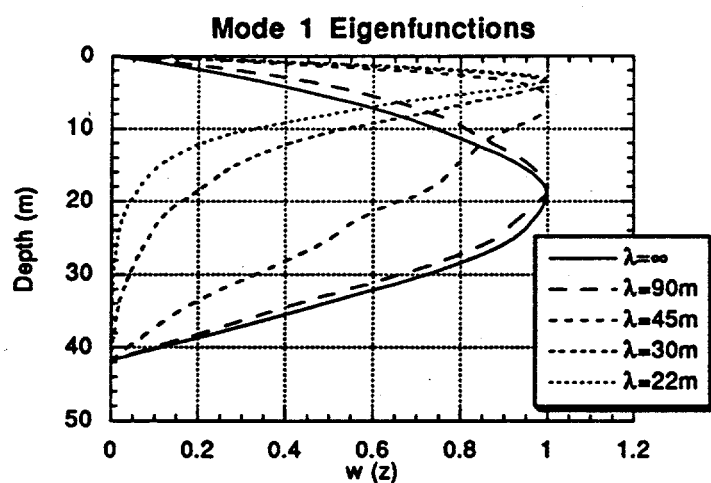
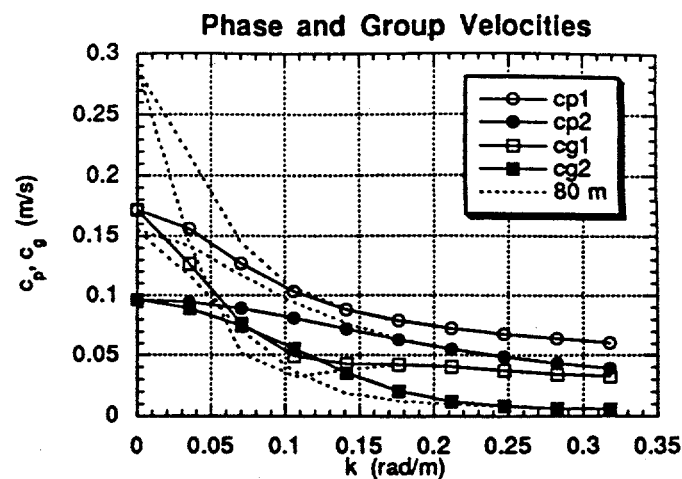
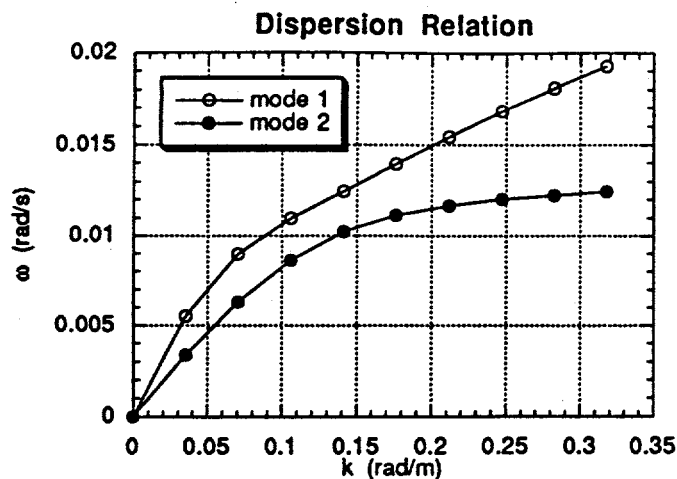
Mode 2 Eigenfunctions, D=80 m

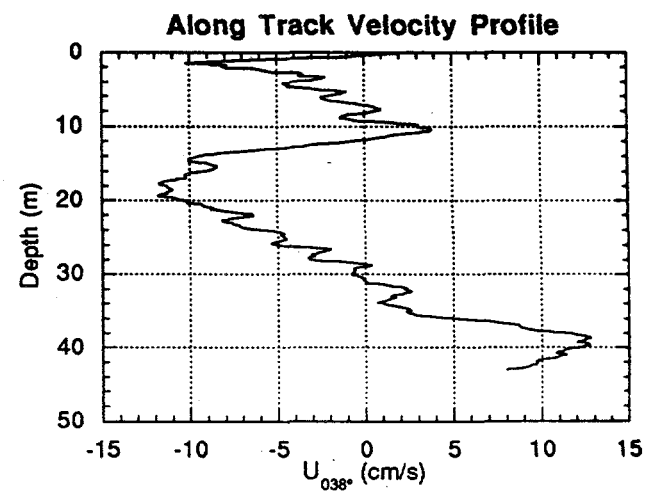
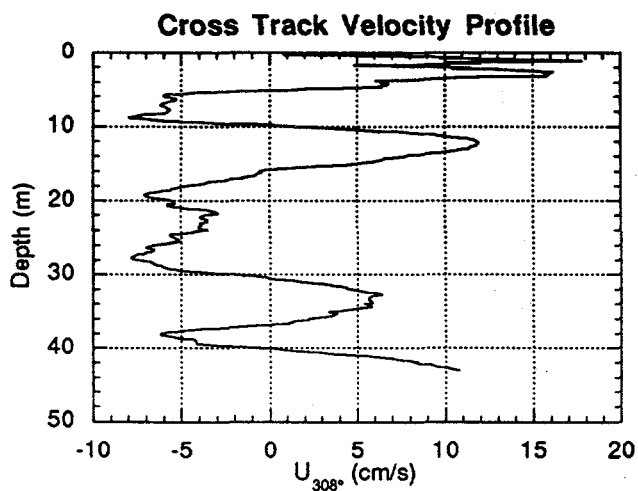
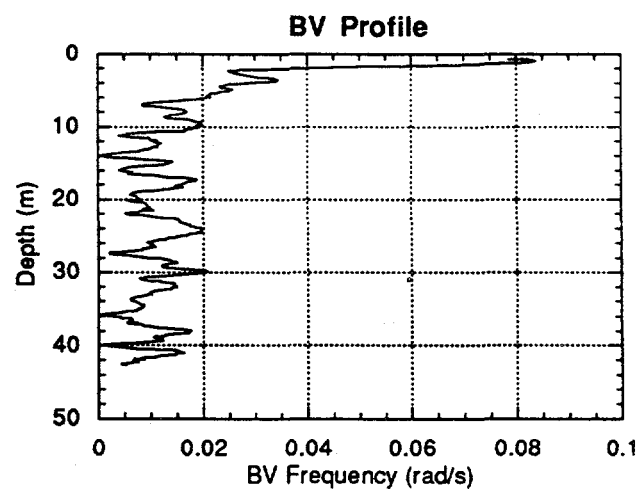
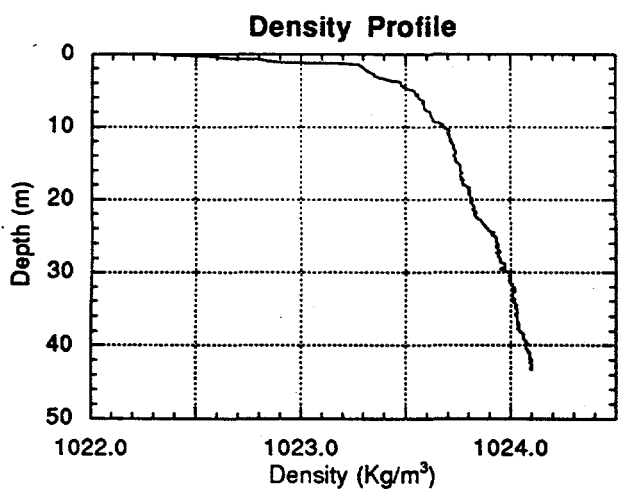
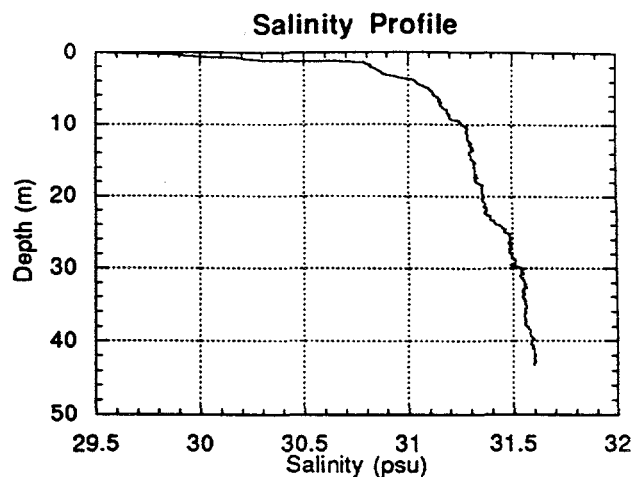
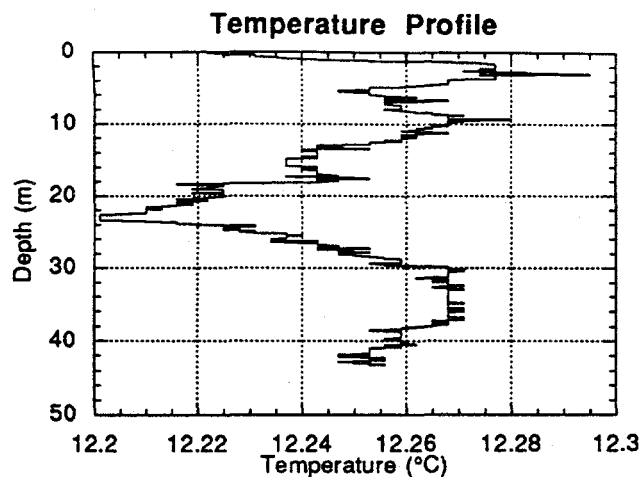




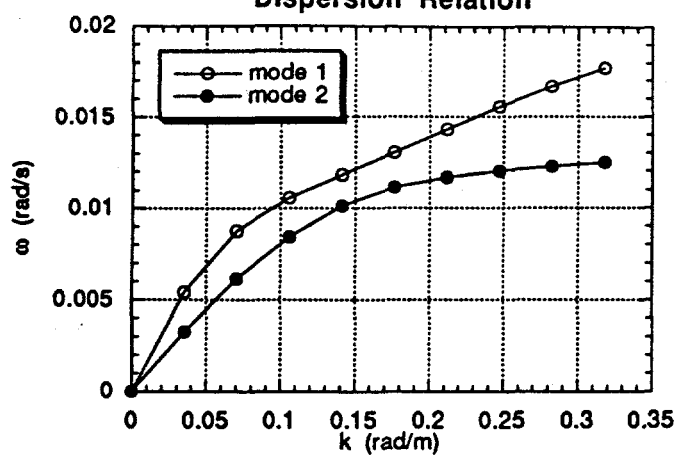




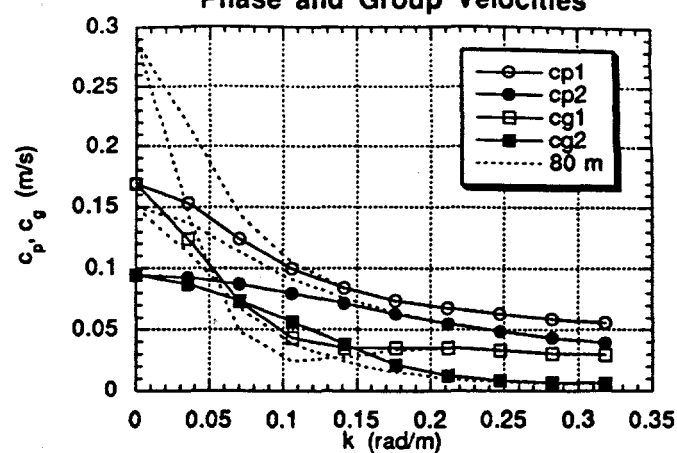




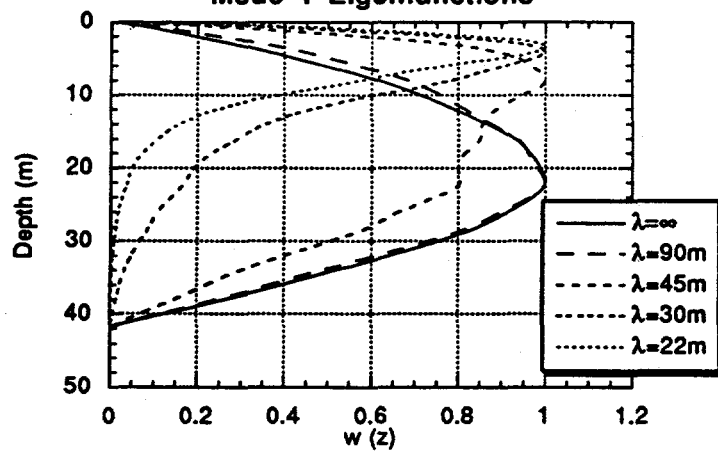
Dispersion Relation



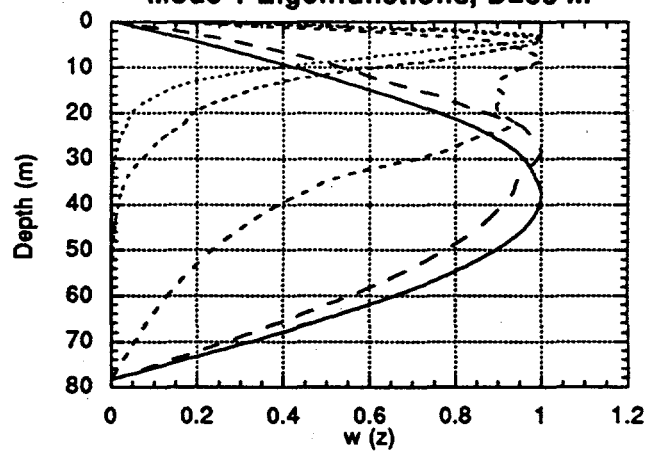
Phase and Group Velocities



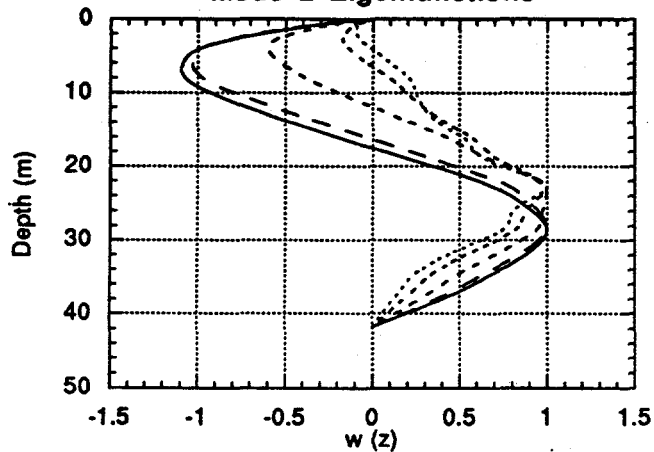
Mode 1 Eigenfunctions



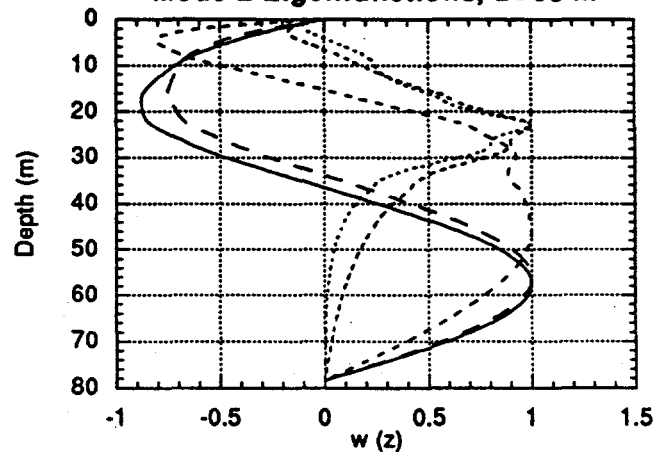
Mode 1 Eigenfunctions, D=80 m

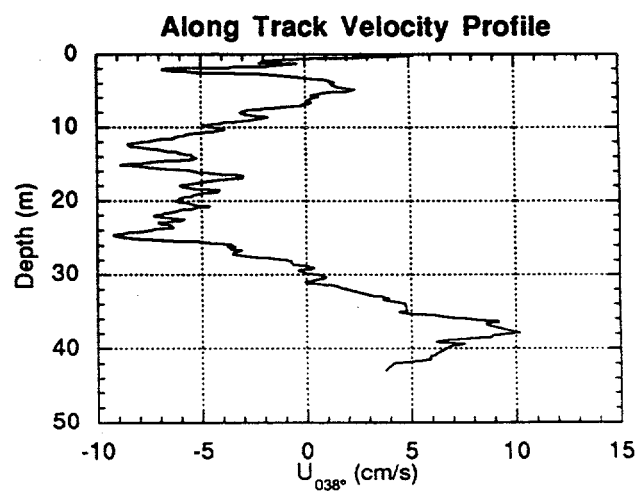
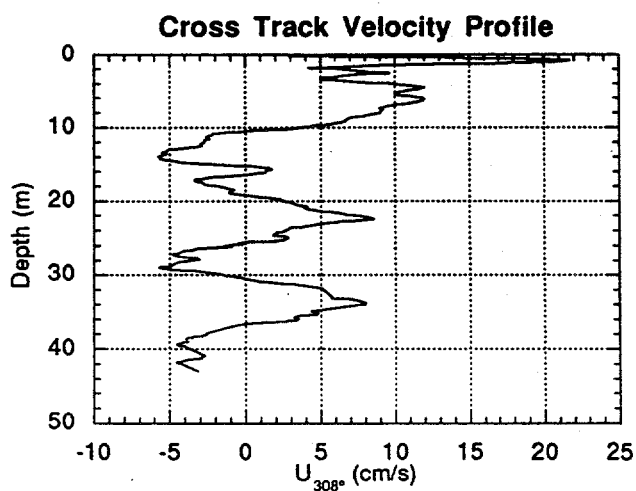
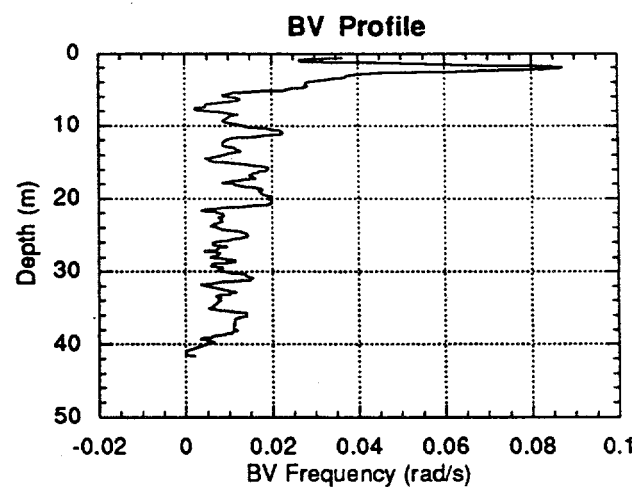
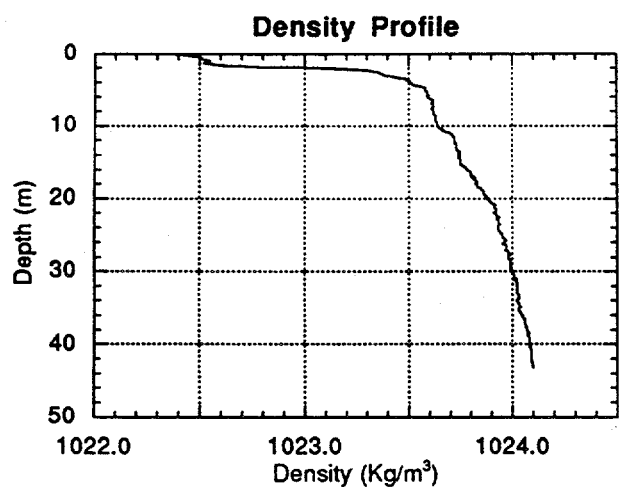
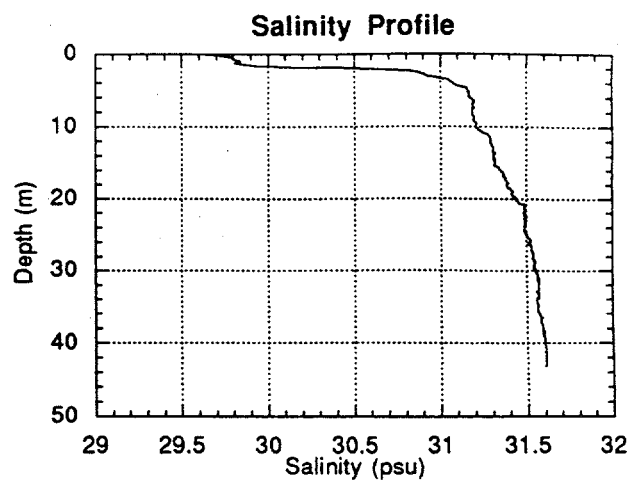
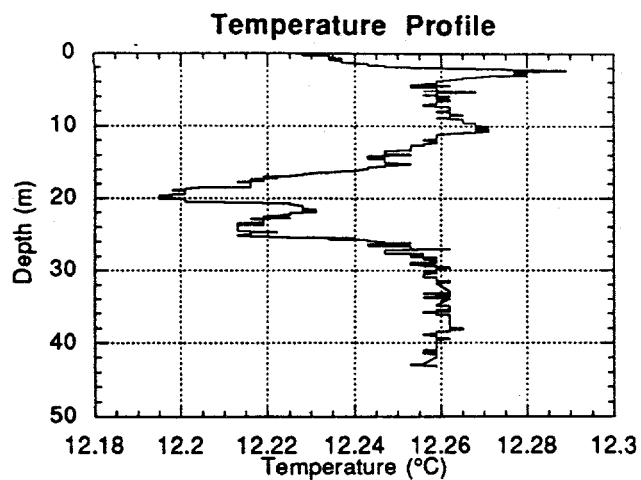


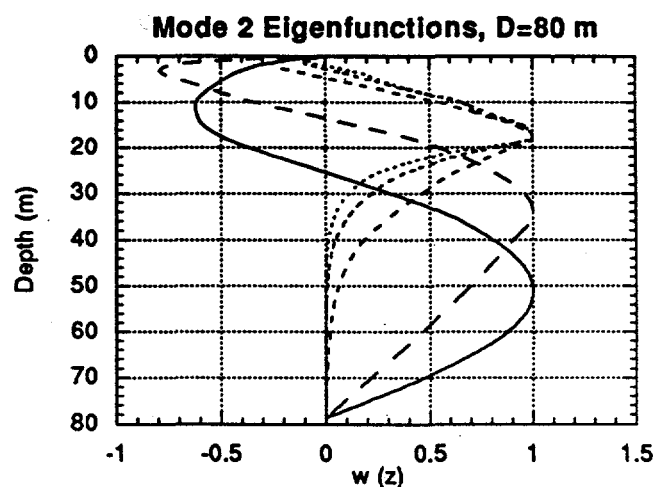
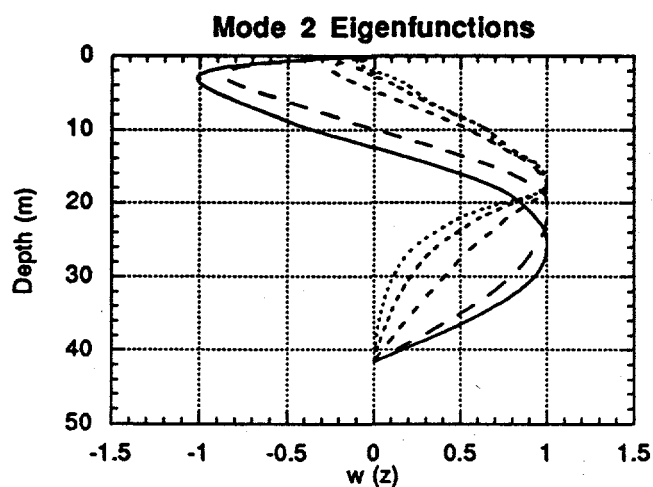
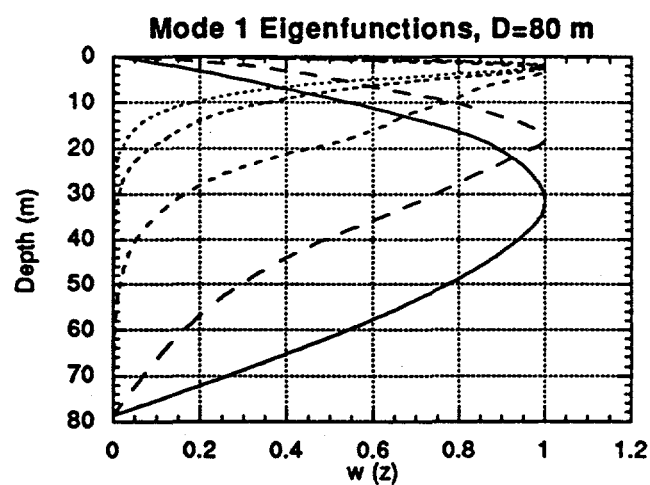
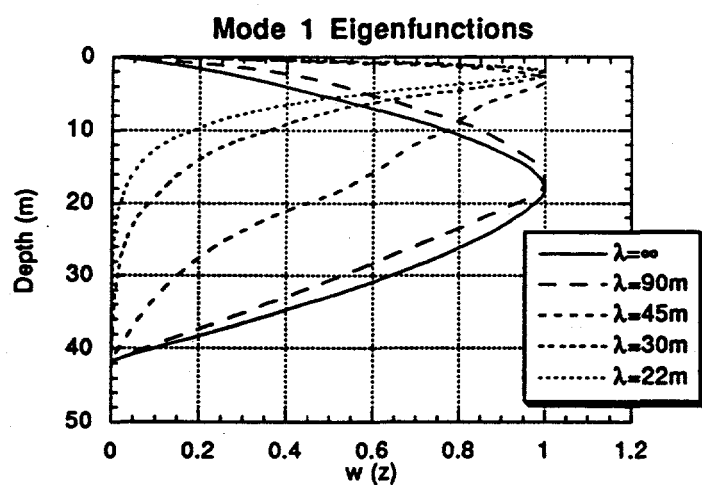
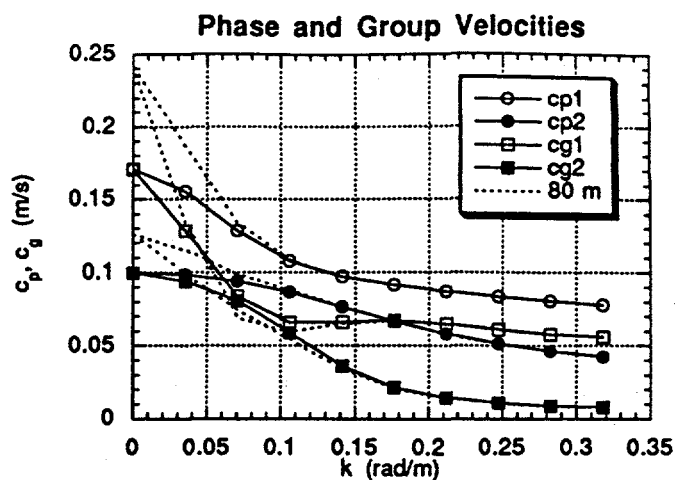
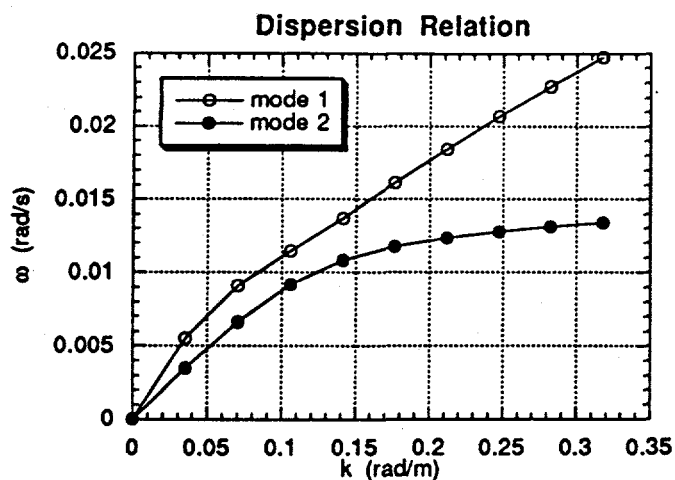
Mode 2 Eigenfunctions

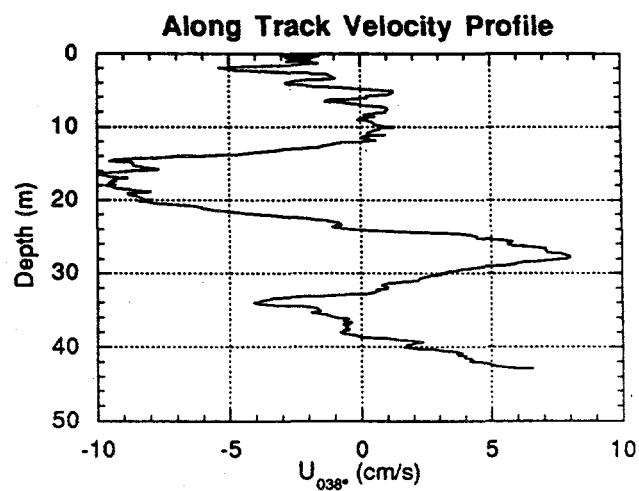
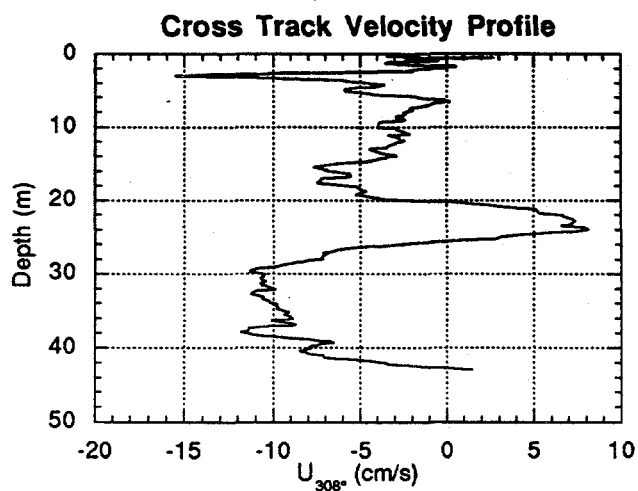
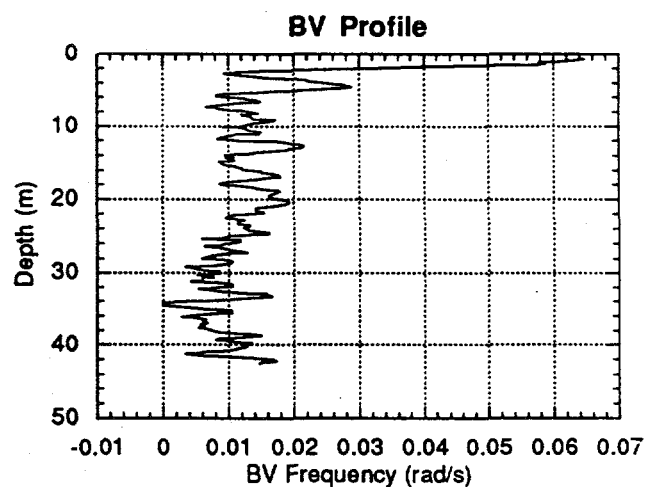
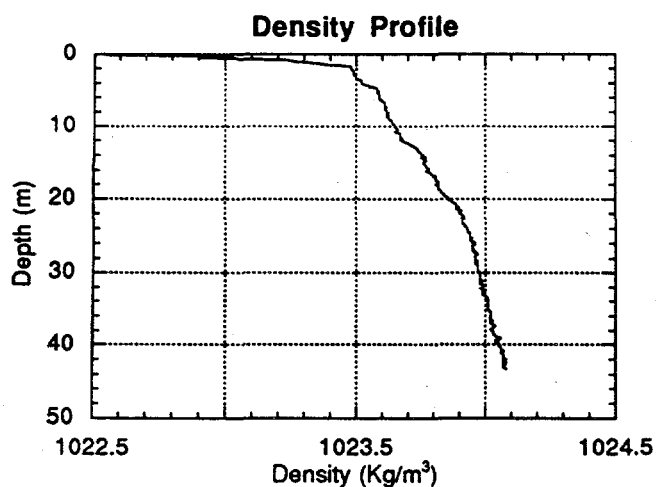
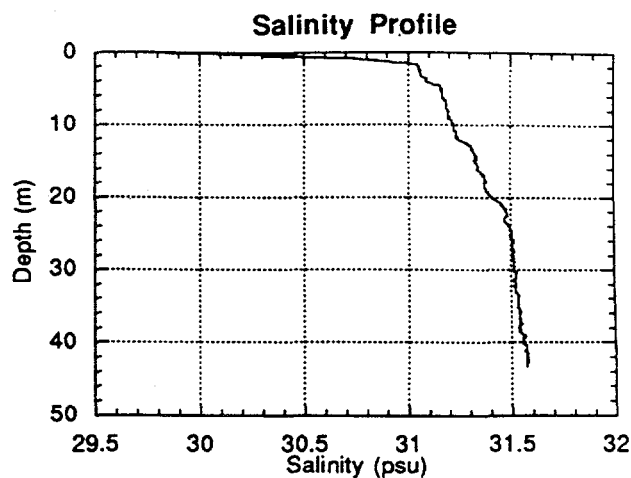
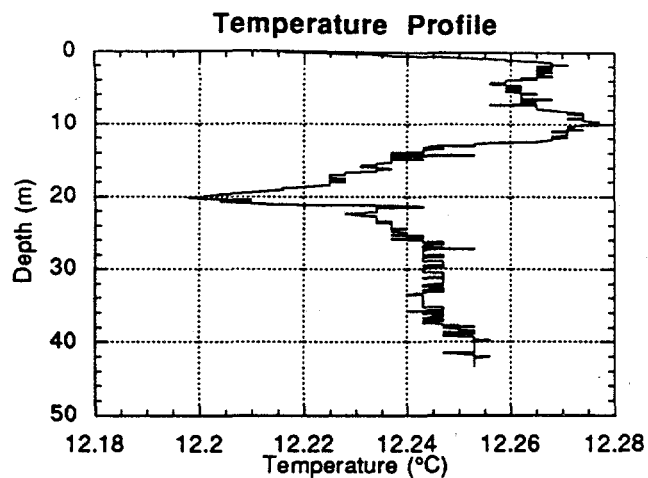


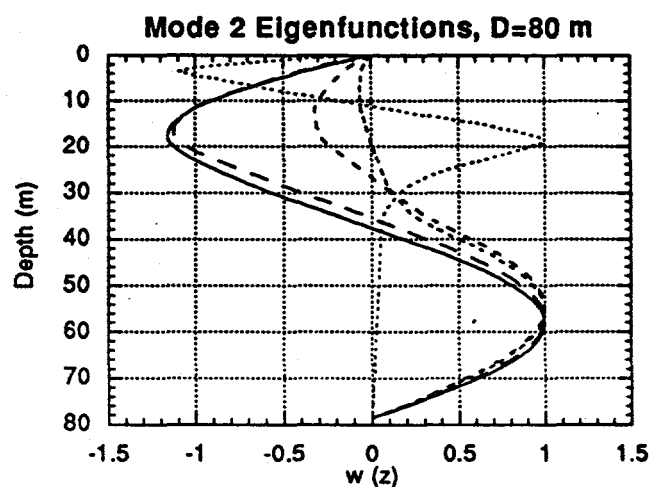
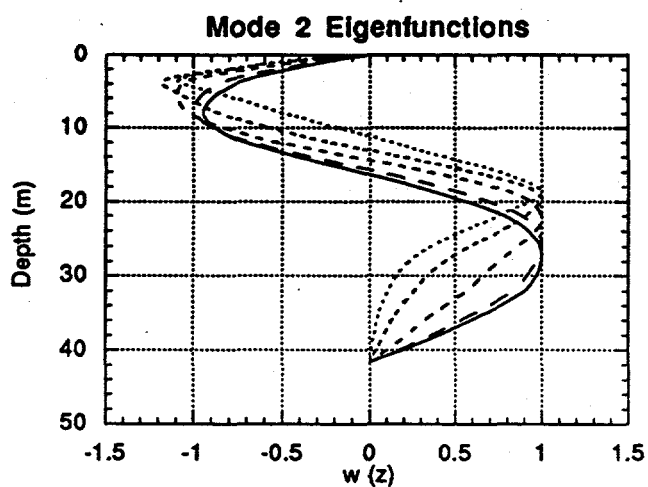
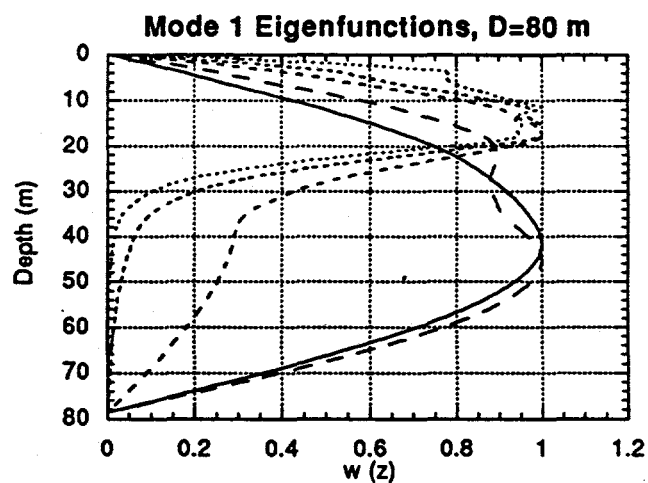
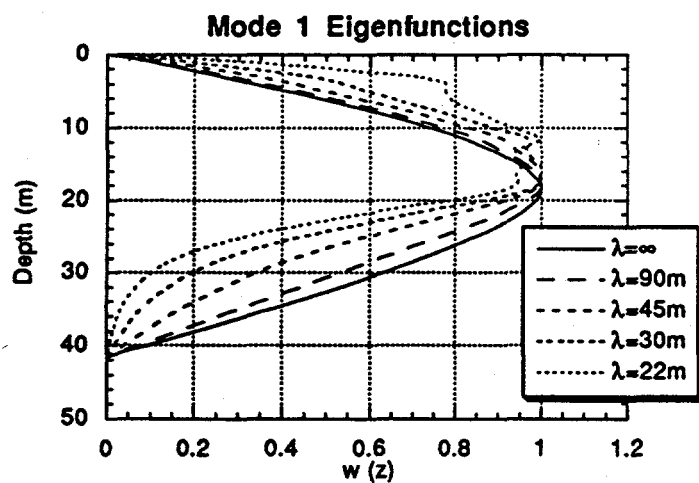
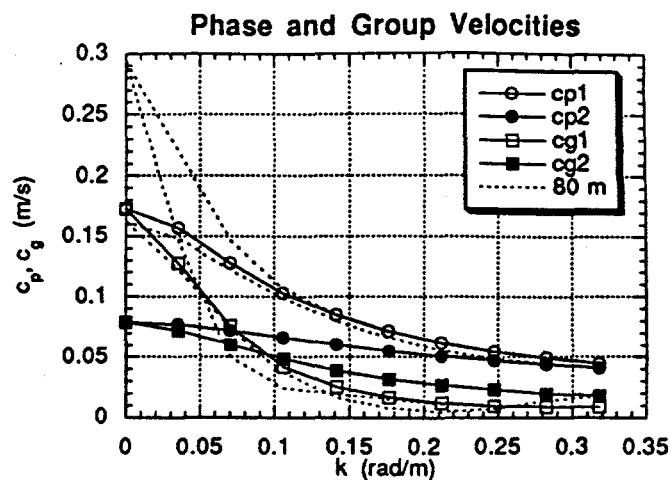
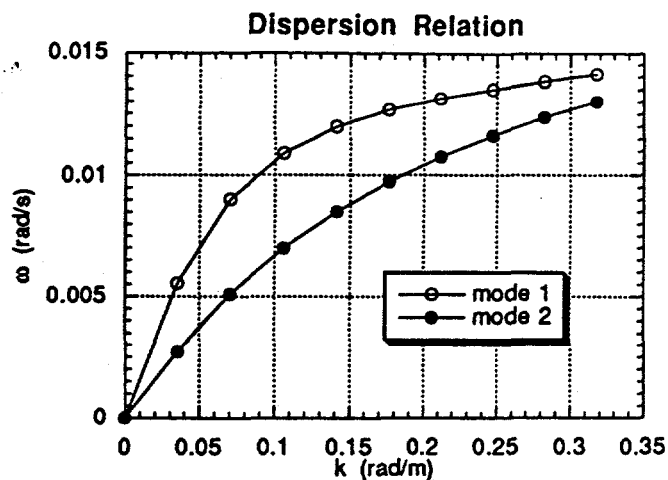
Mode 2 Eigenfunctions, D=80 m

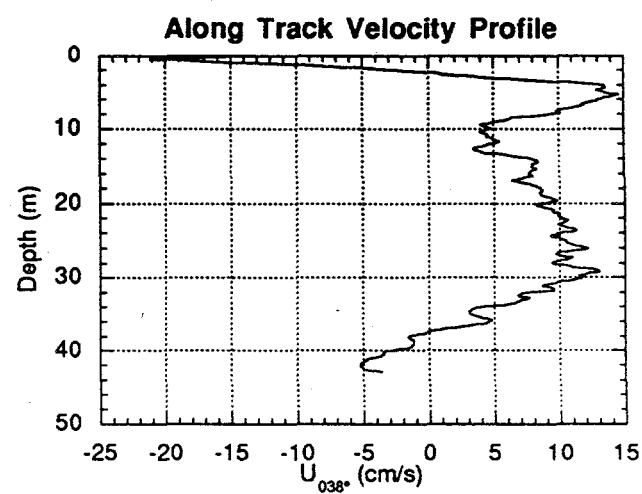
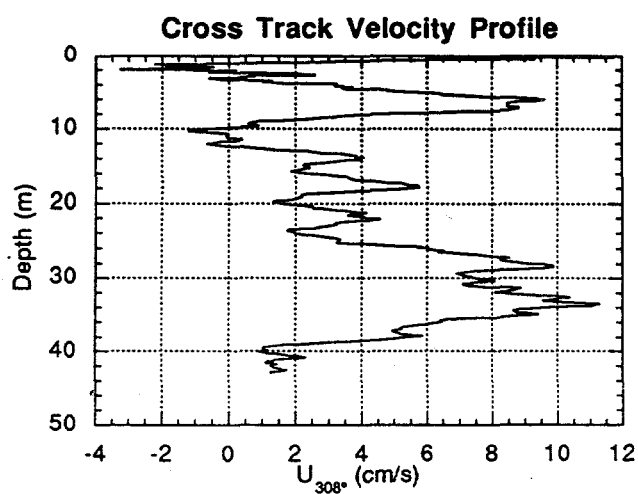
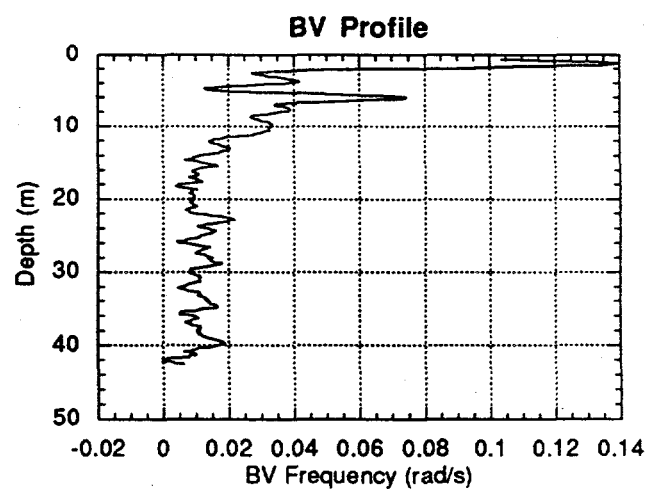
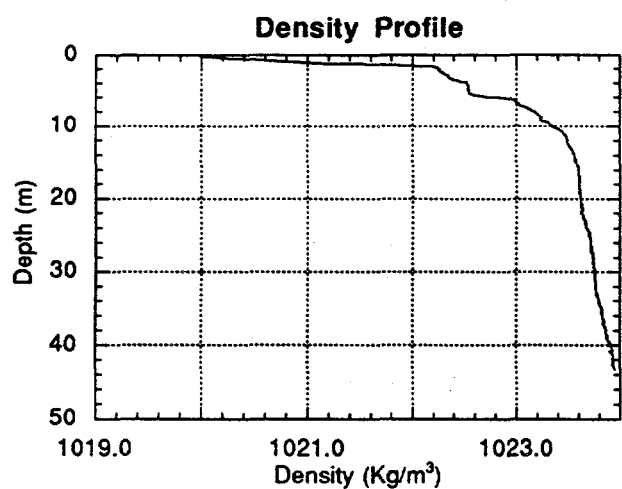
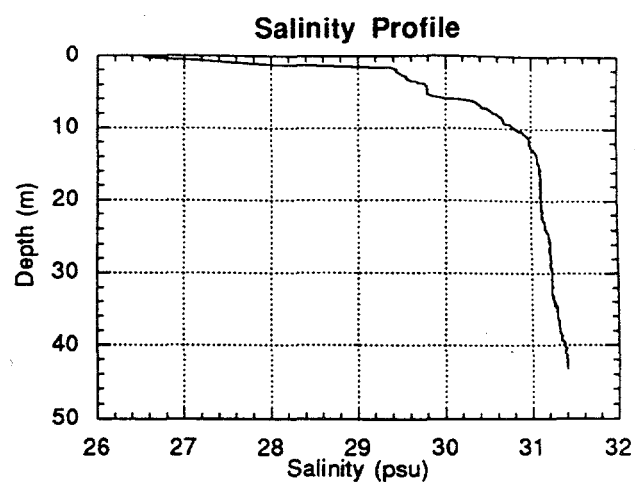
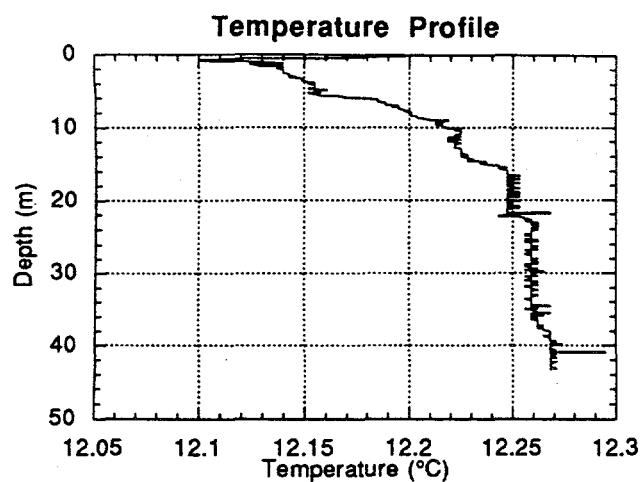


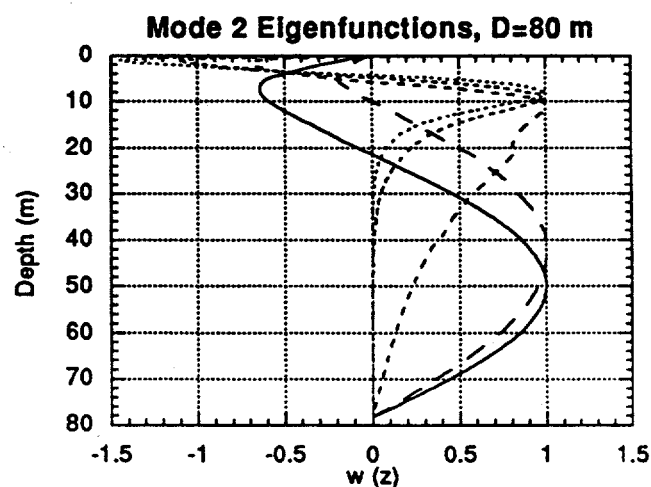
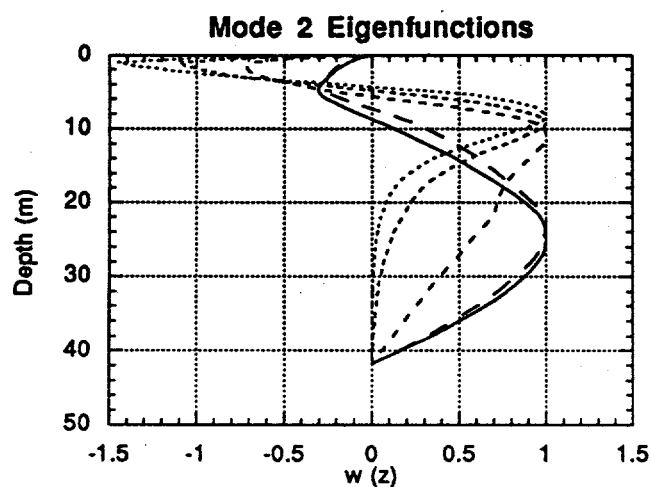
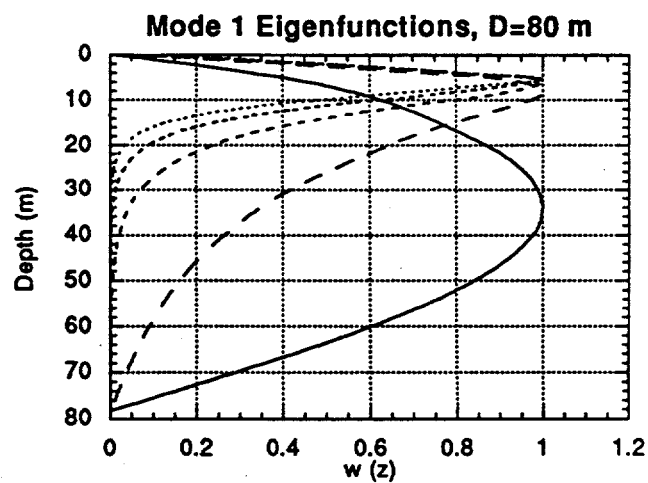
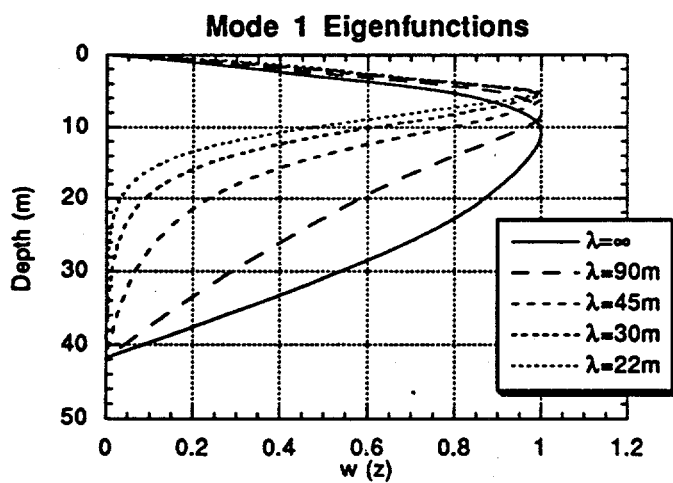
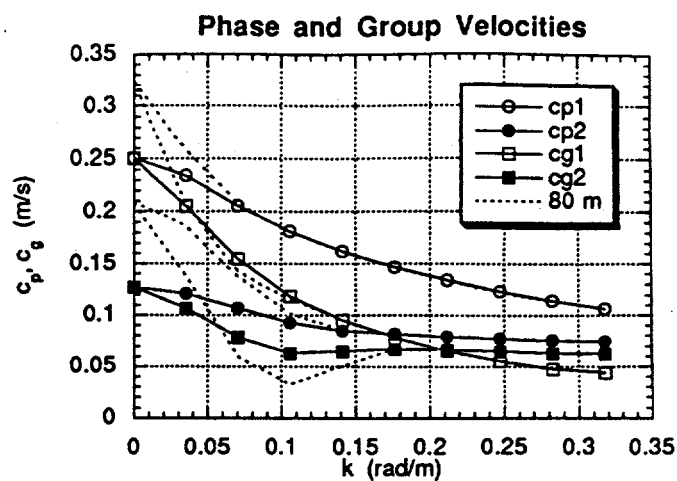
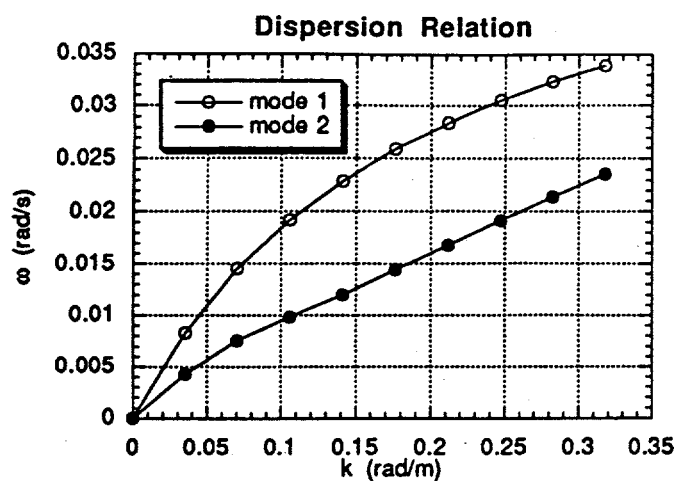


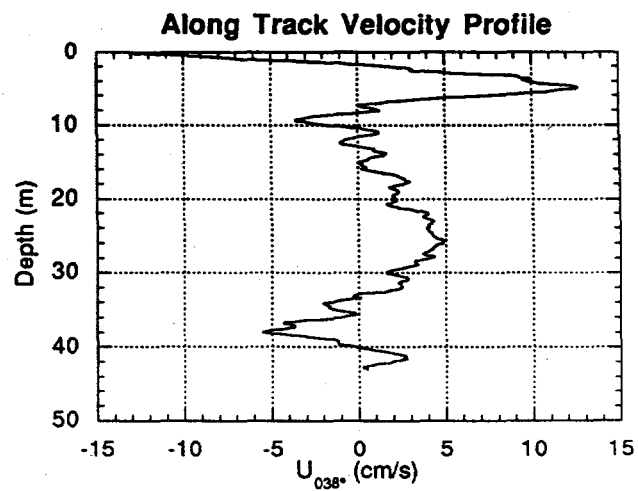
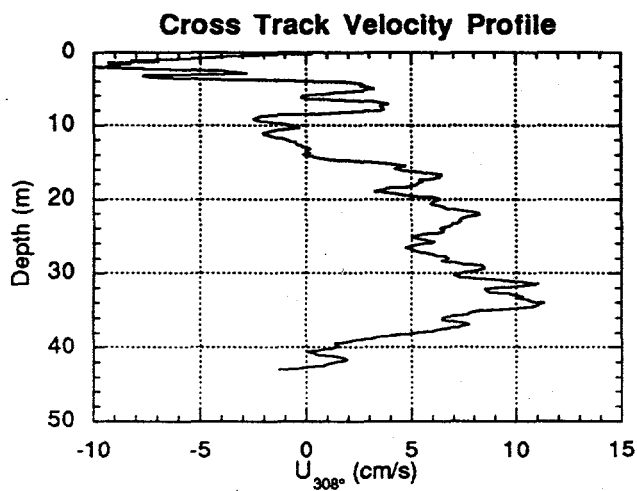
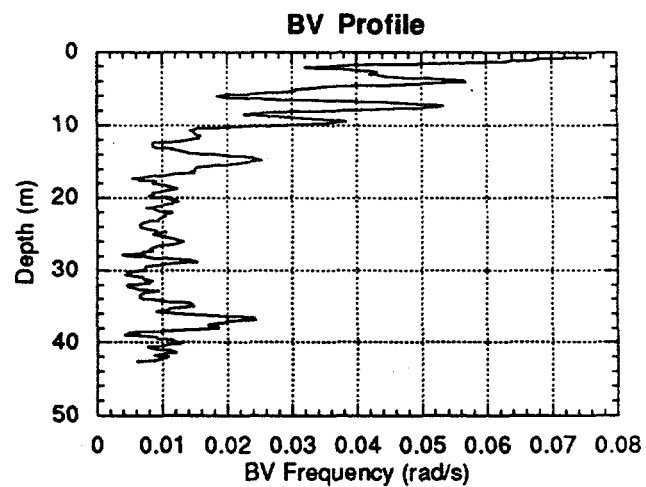
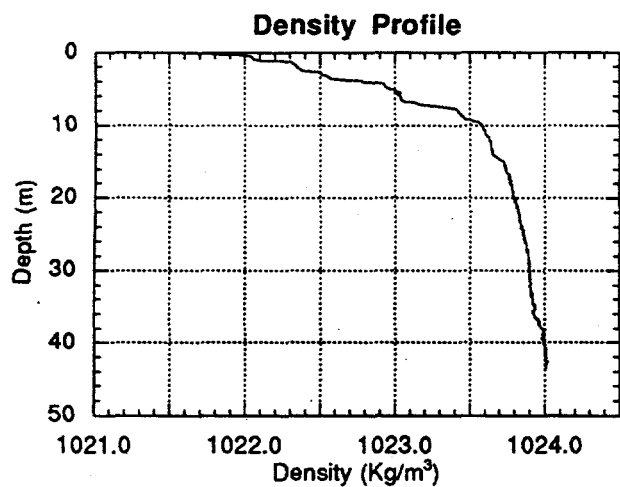
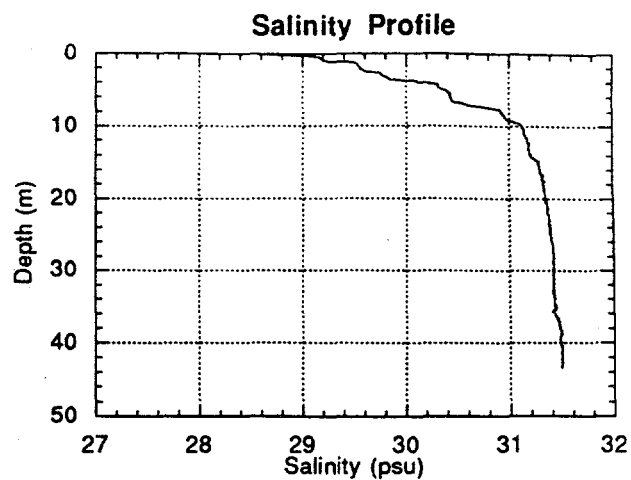
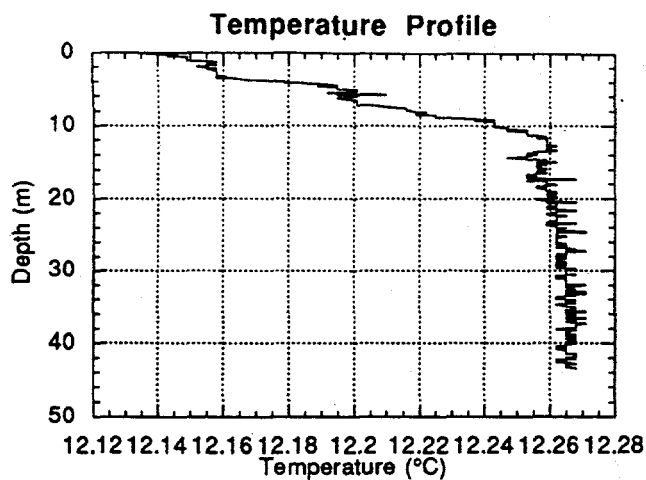




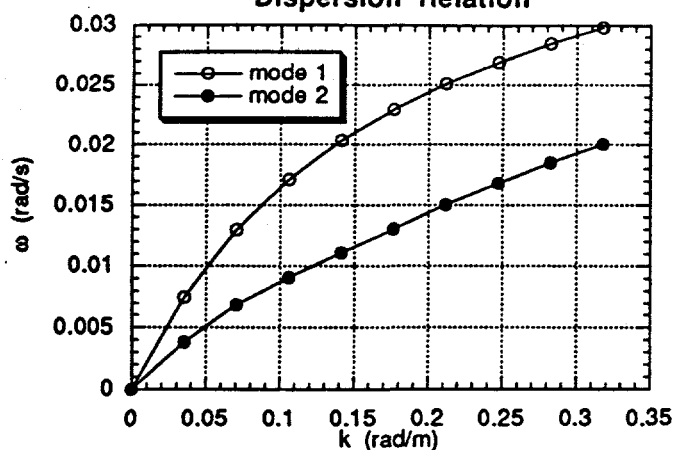




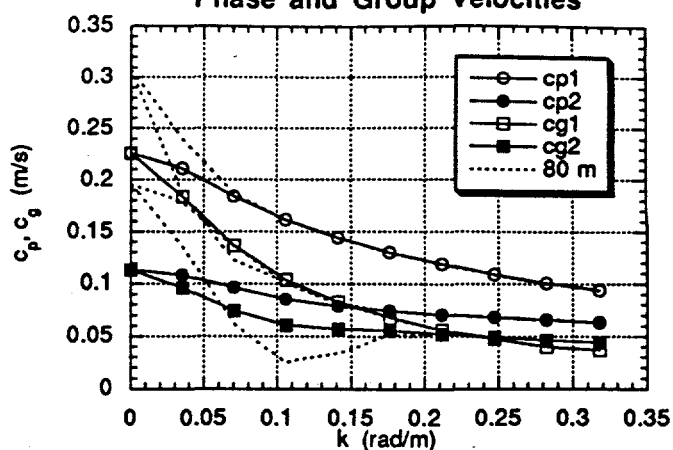




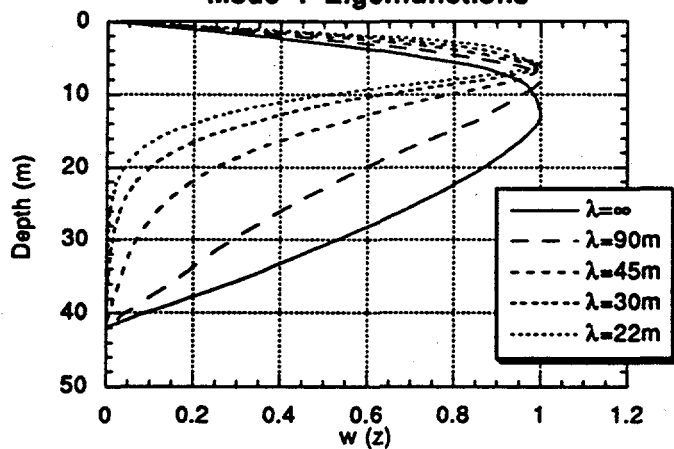
Dispersion Relation



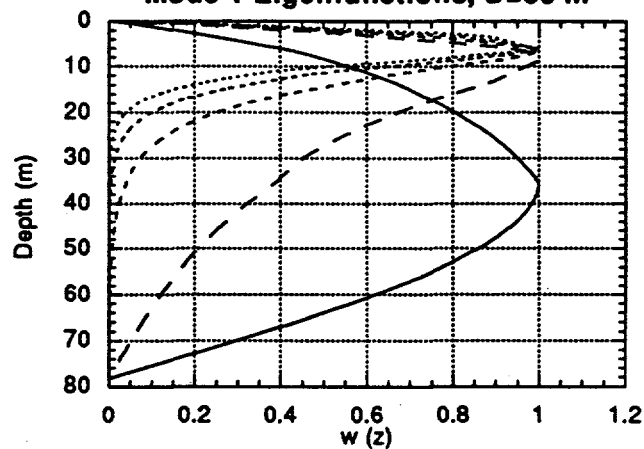
Phase and Group Velocities



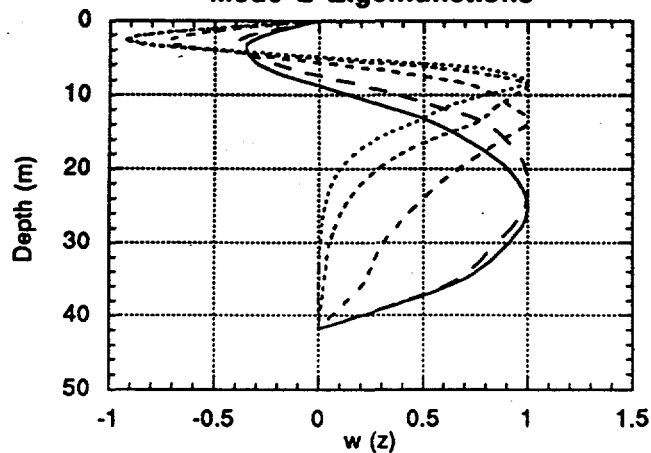
Mode 1 Eigenfunctions



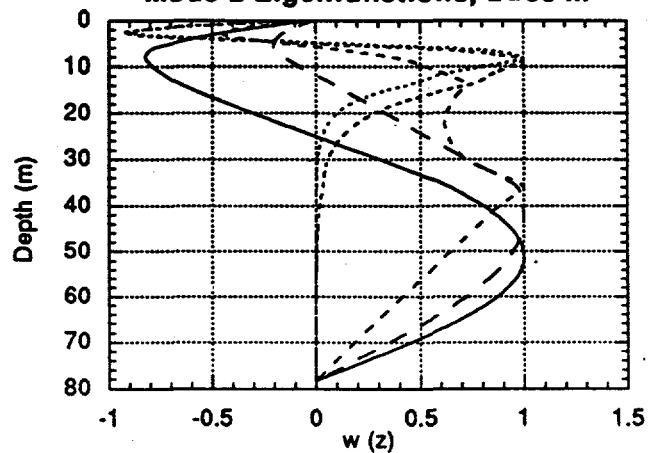
Mode 1 Eigenfunctions, D=80 m

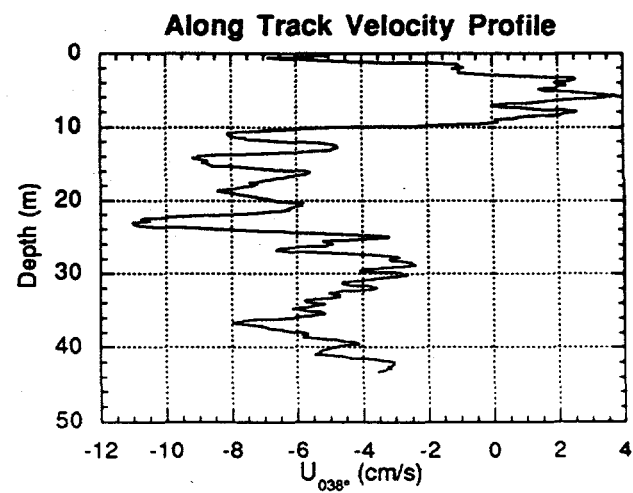
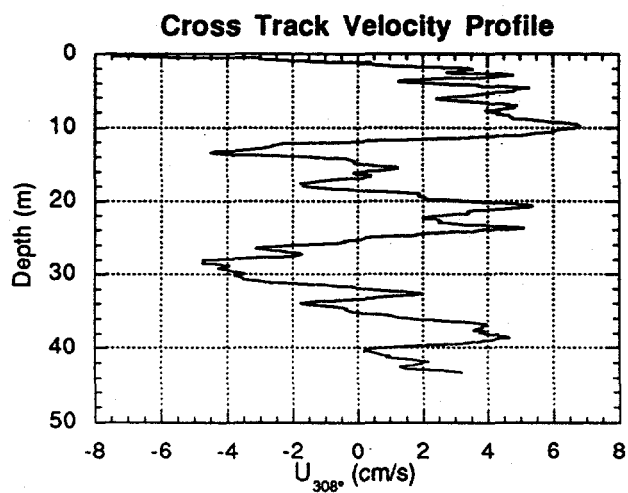
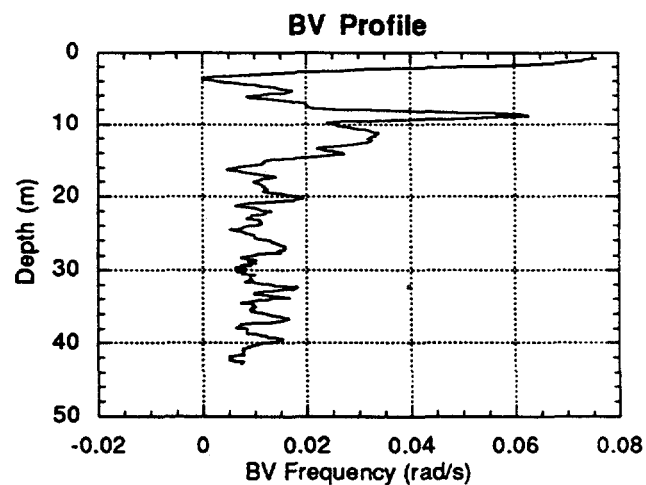
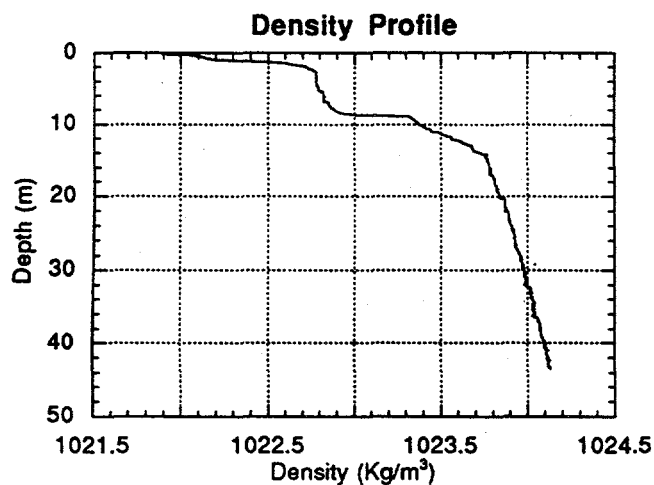
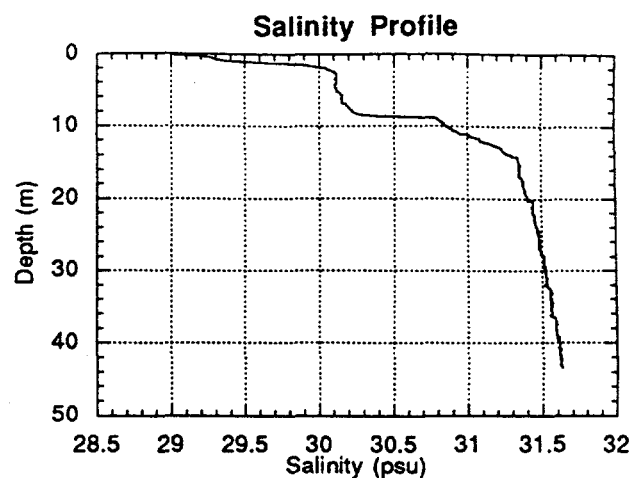
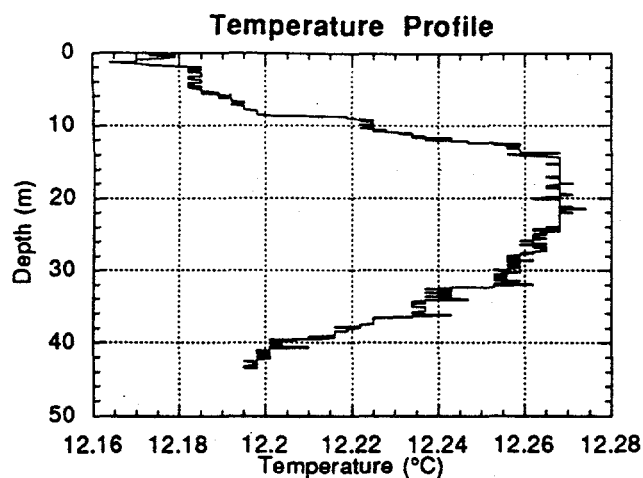


Mode 2 Eigenfunctions

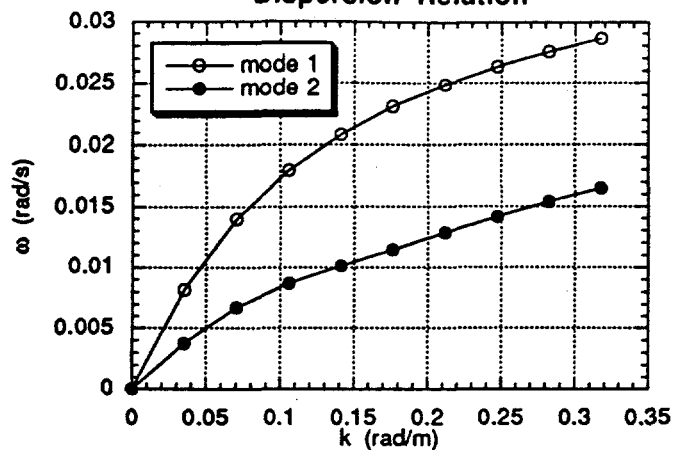


Mode 2 Eigenfunctions, D=80 m

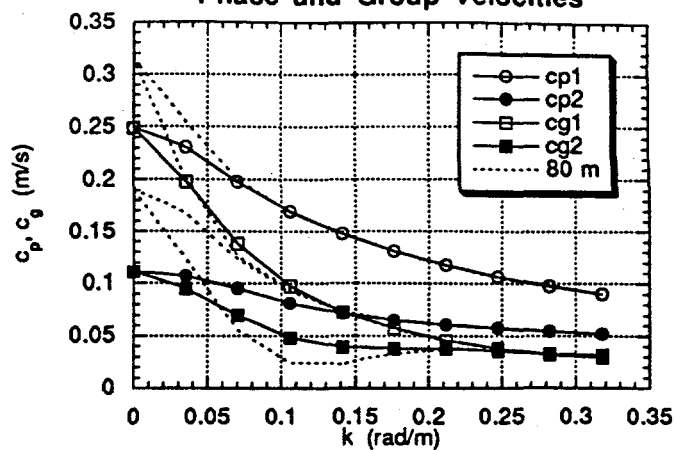




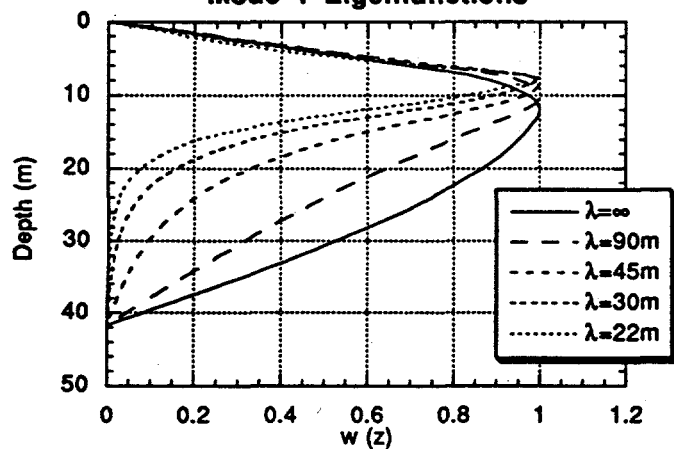
Dispersion Relation



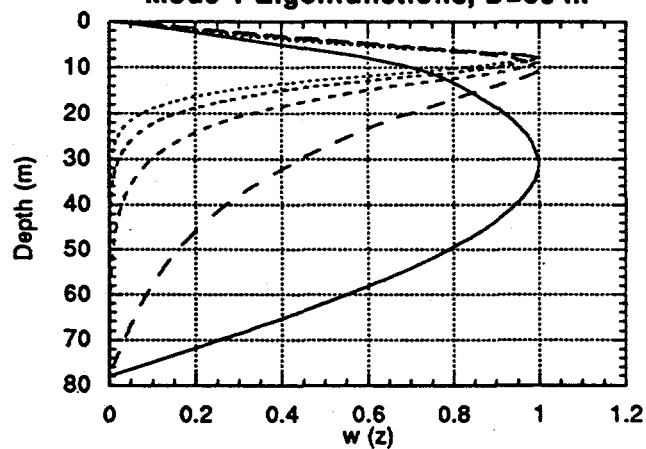
Phase and Group Velocities



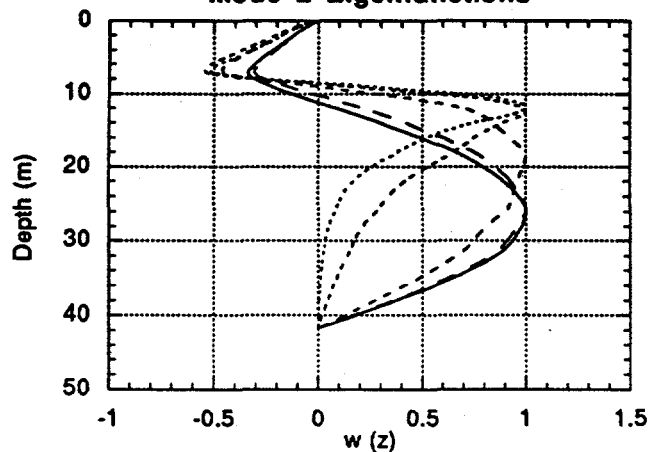
Mode 1 Eigenfunctions



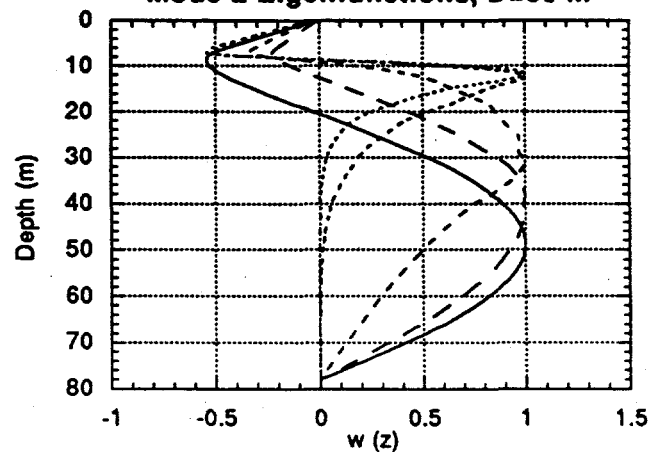
Mode 1 Eigenfunctions, D=80 m

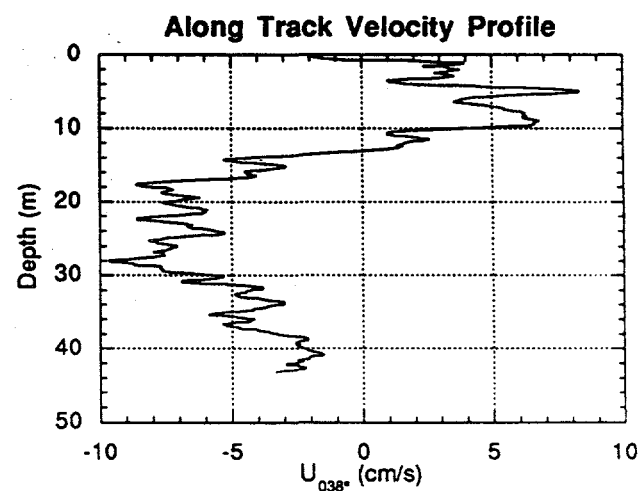
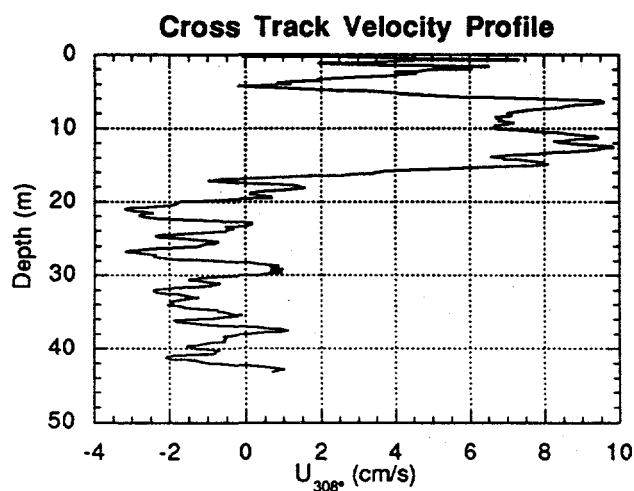
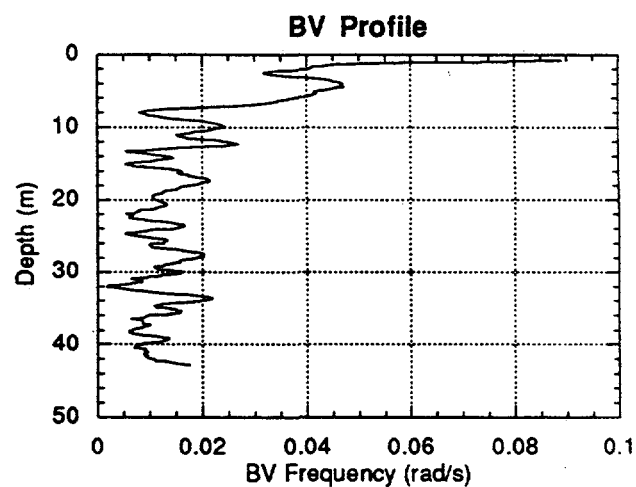
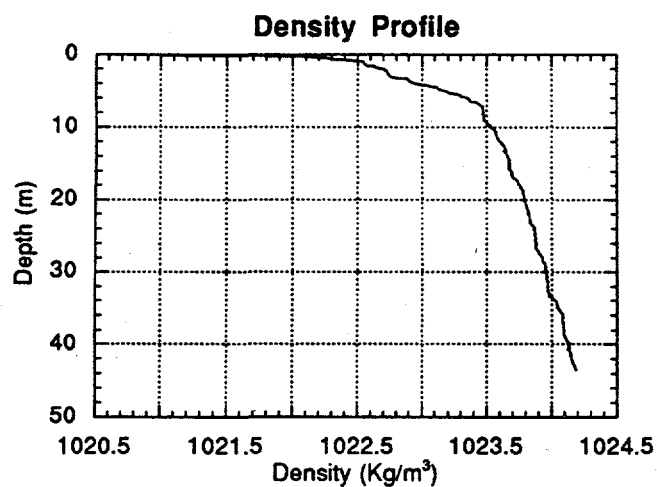
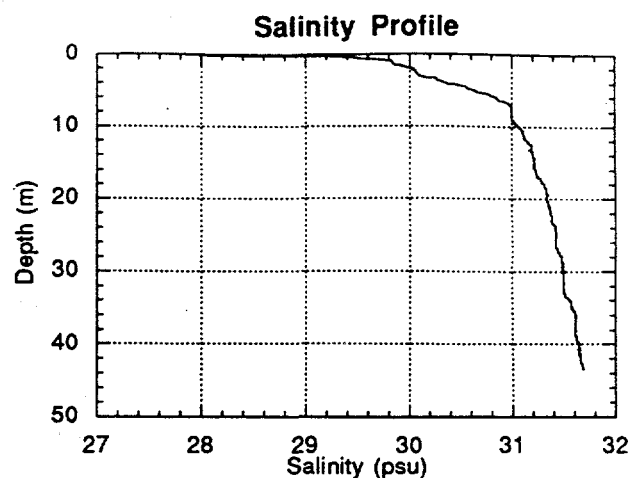
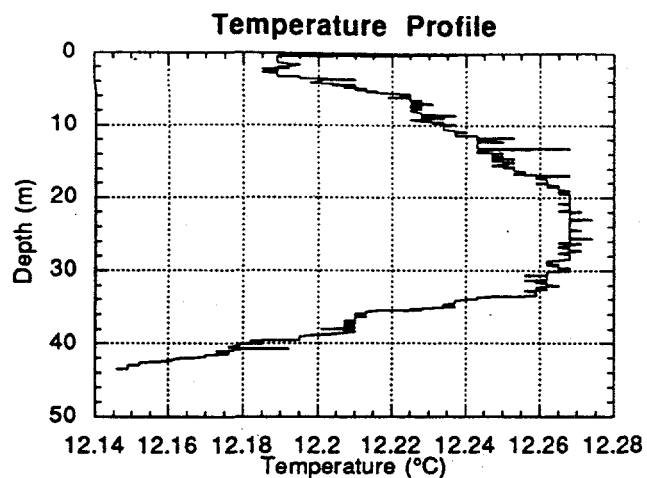


Mode 2 Eigenfunctions

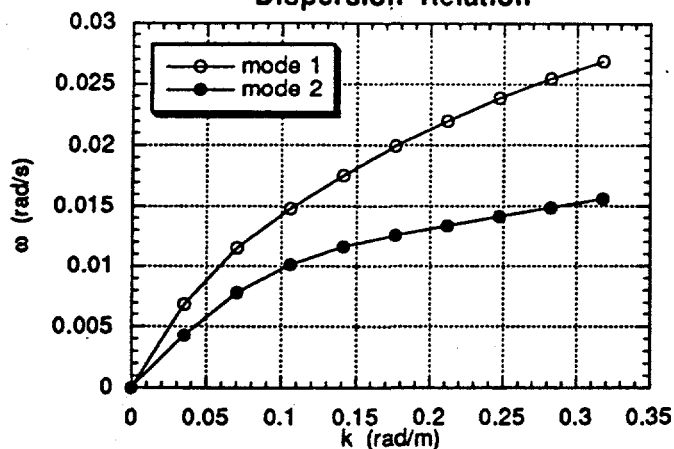


Mode 2 Eigenfunctions, D=80 m

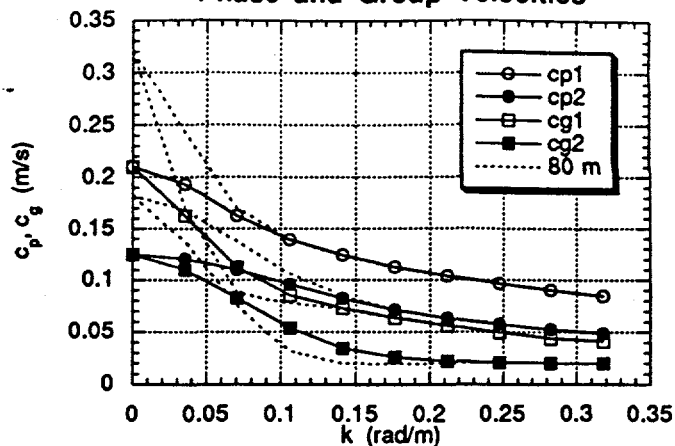




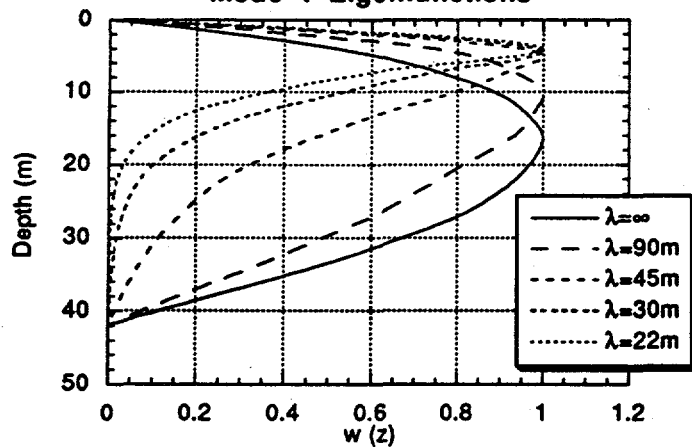
Dispersion Relation



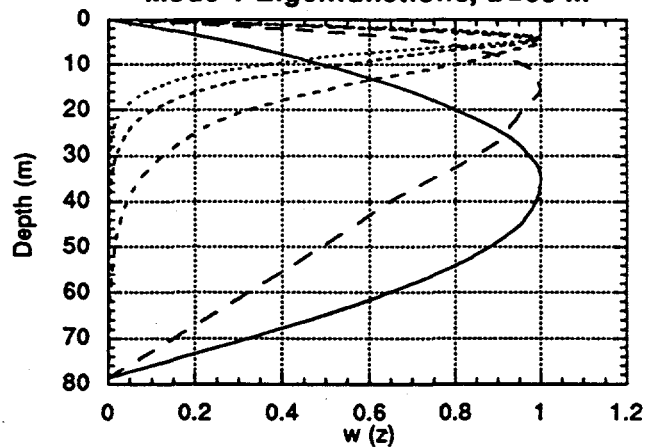
Phase and Group Velocities



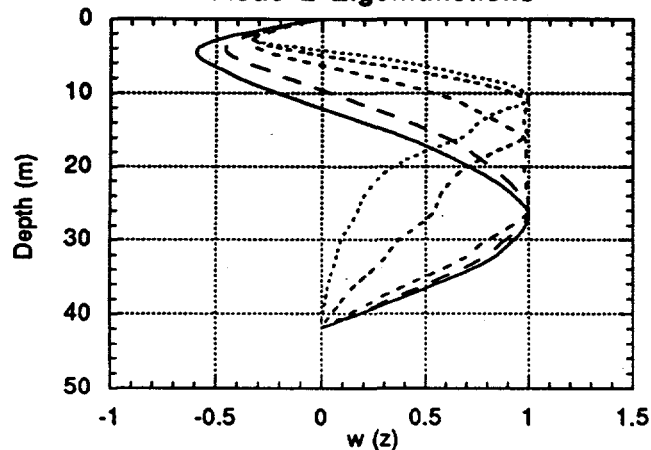
Mode 1 Eigenfunctions



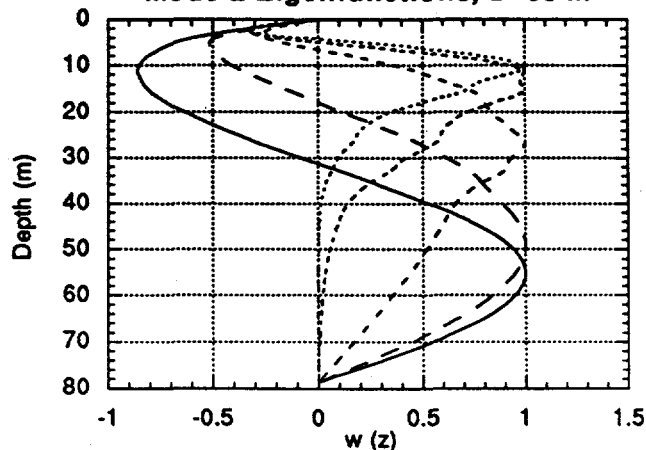
Mode 1 Eigenfunctions, D=80 m

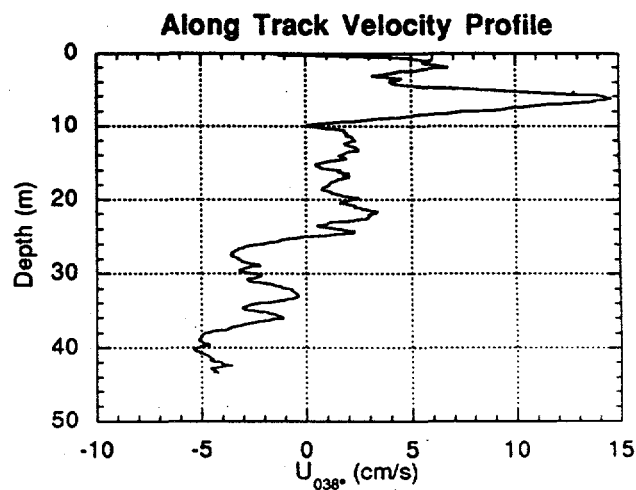
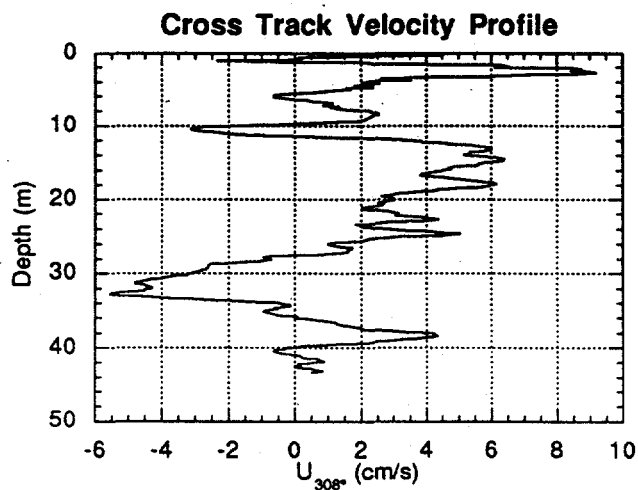
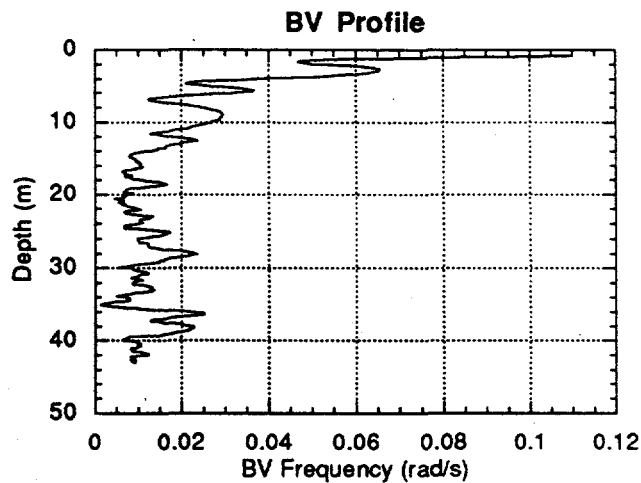
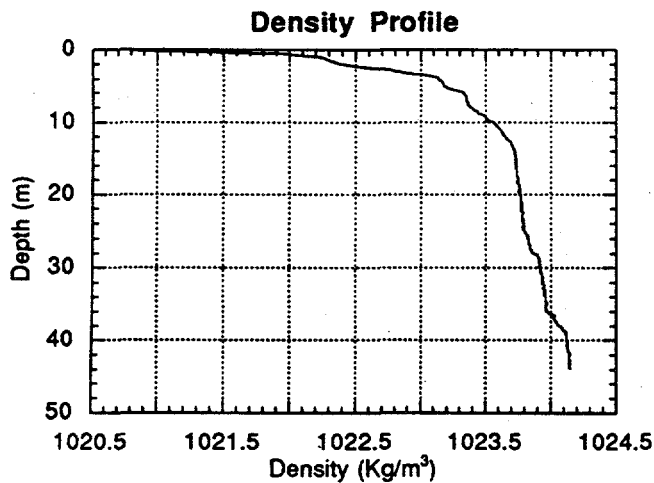
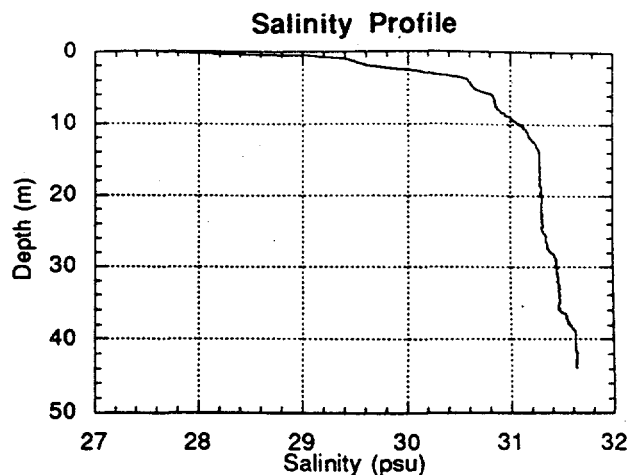
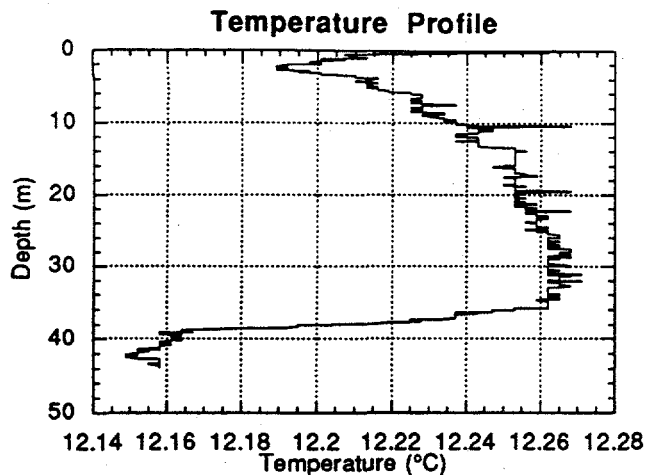


Mode 2 Eigenfunctions

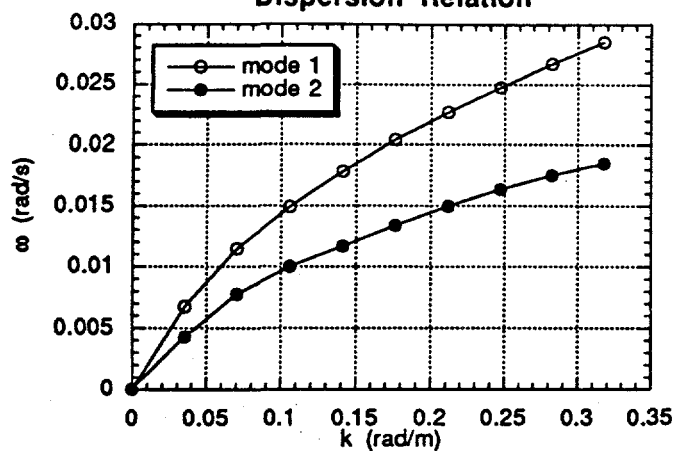


Mode 2 Eigenfunctions, D=80 m

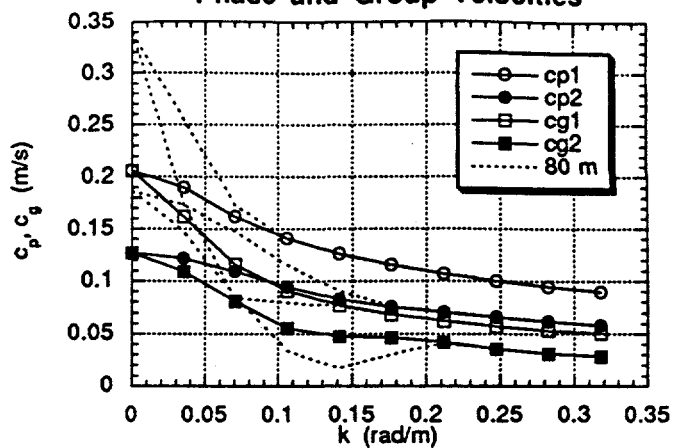




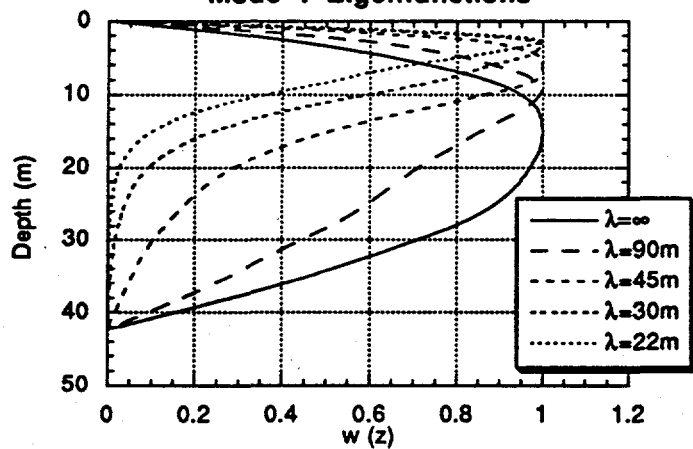
Dispersion Relation



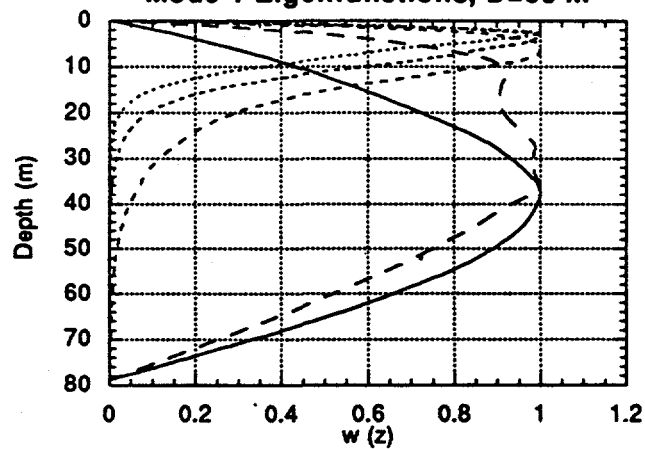
Phase and Group Velocities



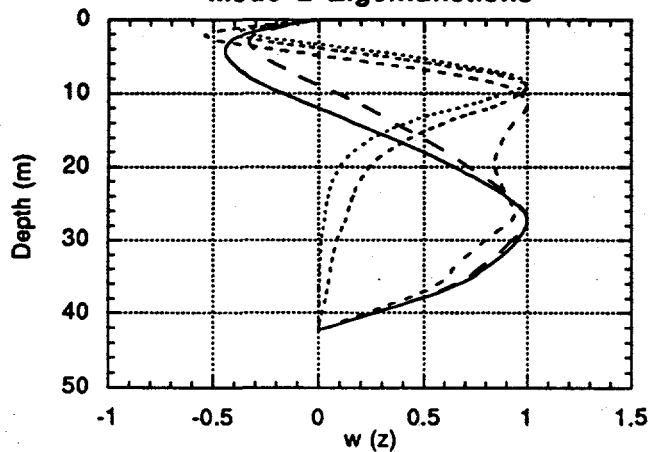
Mode 1 Eigenfunctions



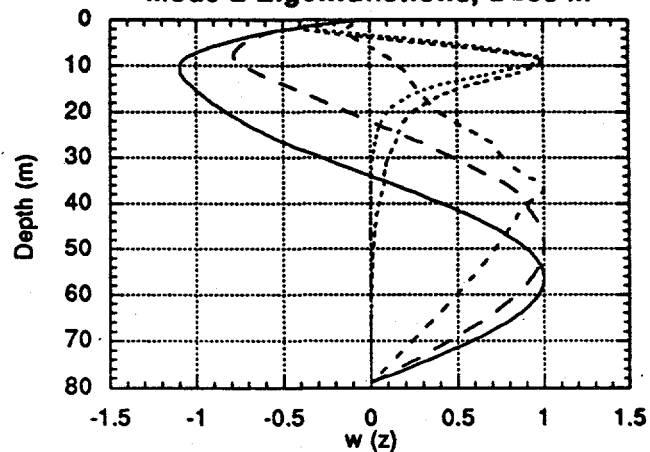
Mode 1 Eigenfunctions, D=80 m

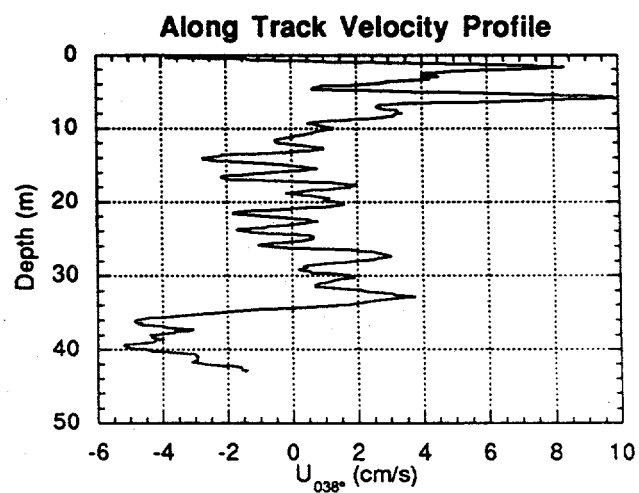
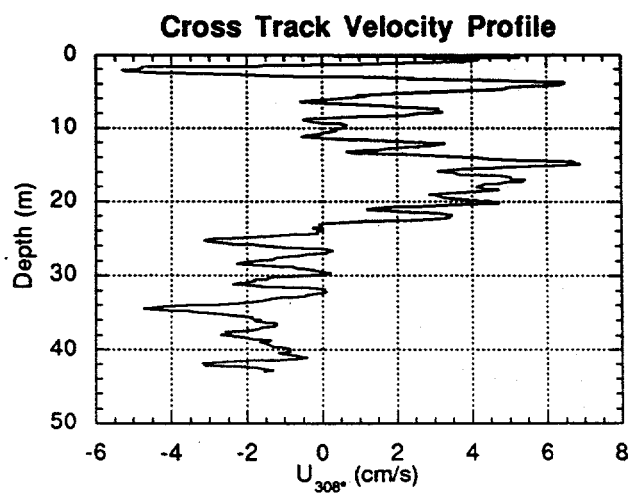
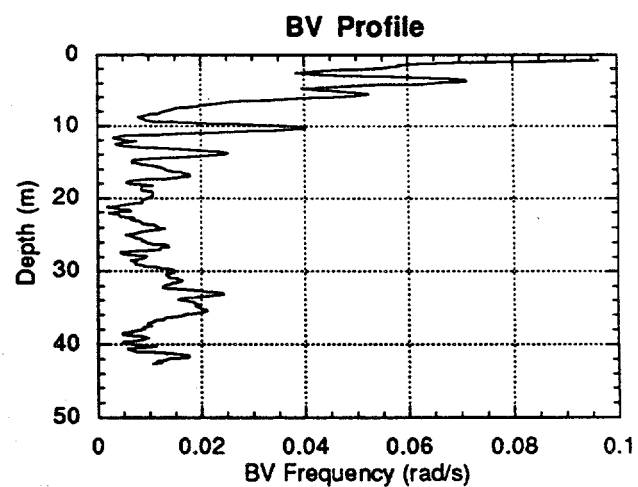
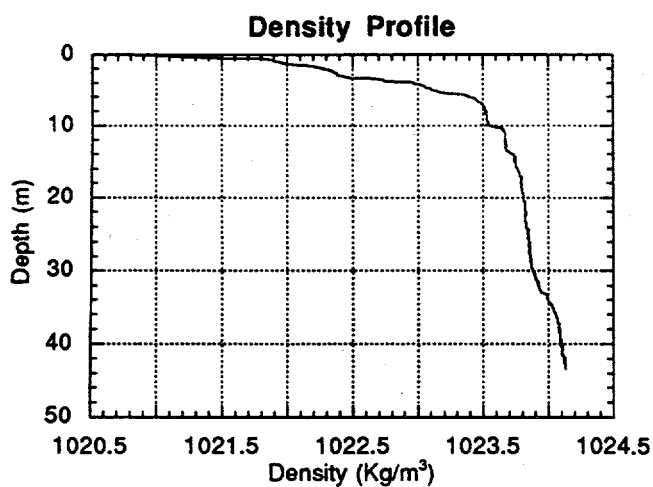
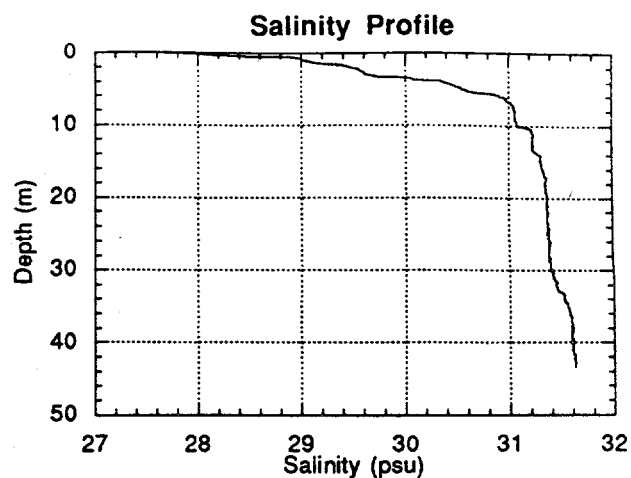
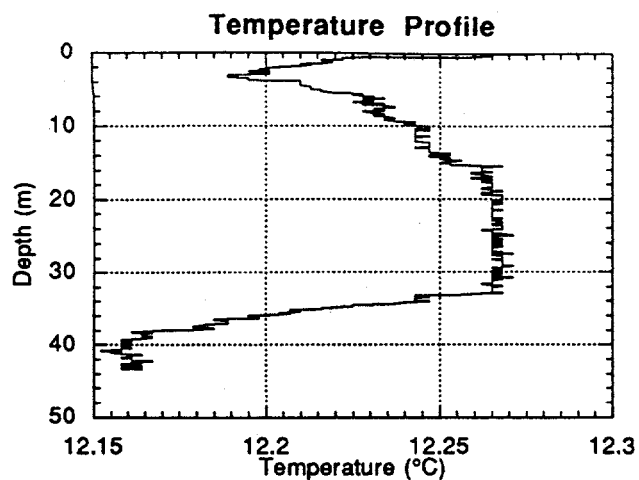


Mode 2 Eigenfunctions

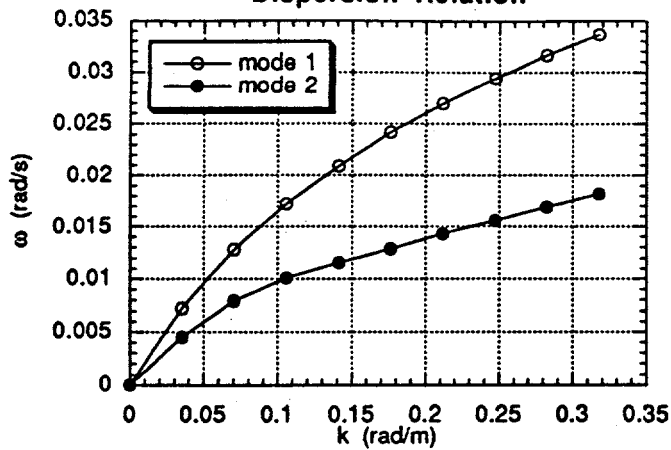


Mode 2 Eigenfunctions, D=80 m

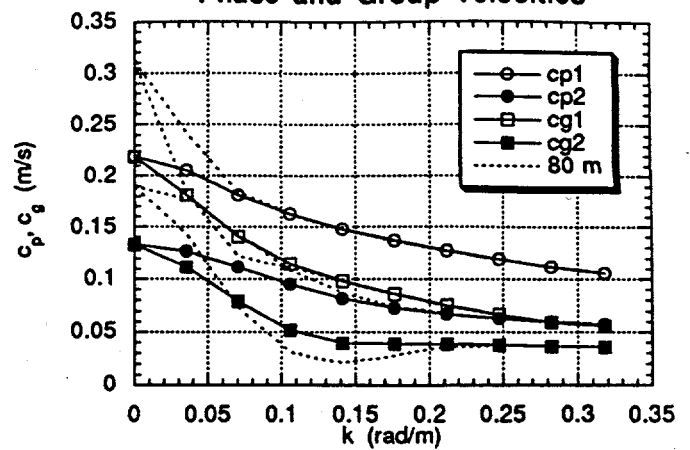




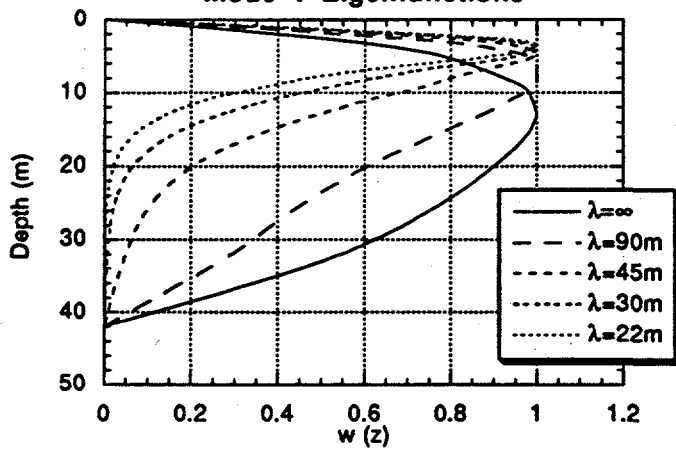
Dispersion Relation



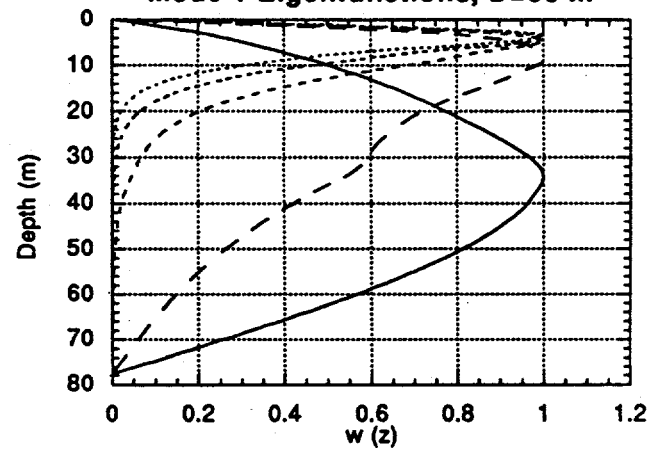
Phase and Group Velocities



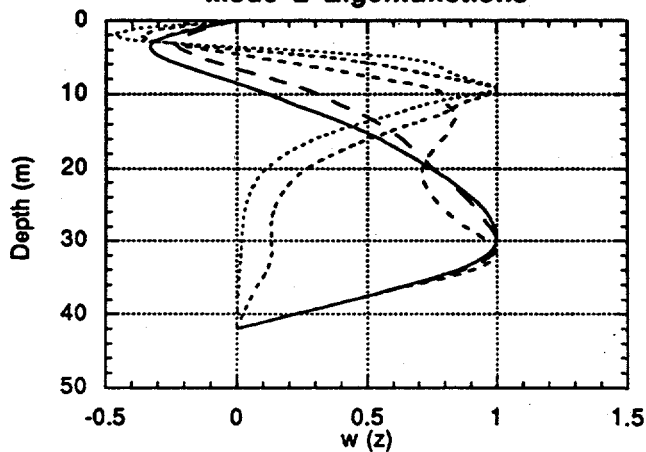
Mode 1 Eigenfunctions



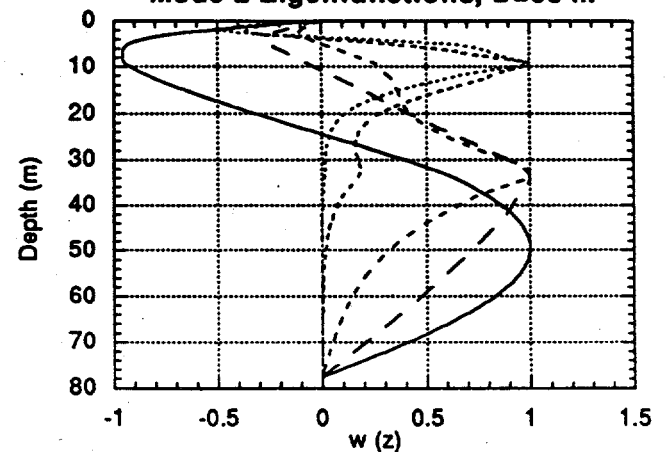
Mode 1 Eigenfunctions, D=80 m

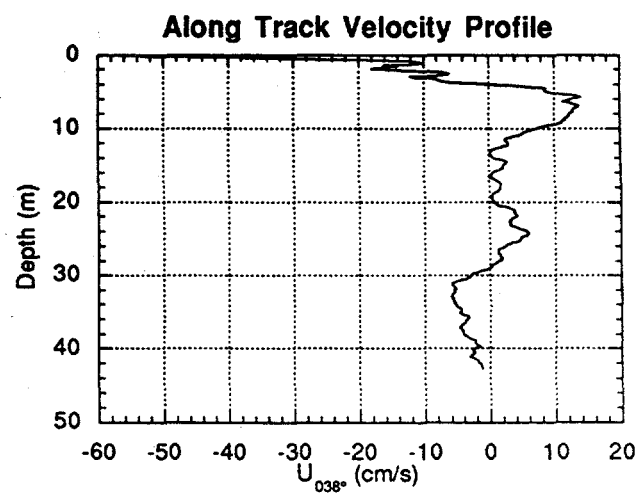
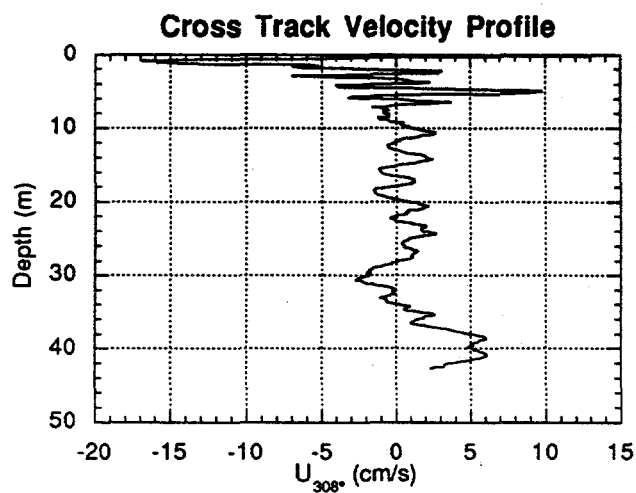
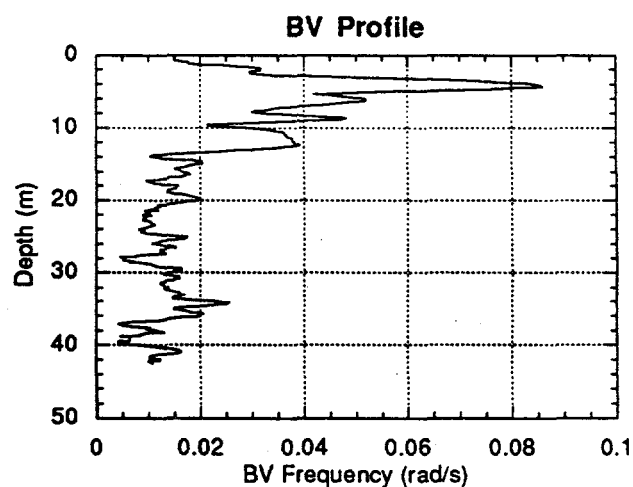
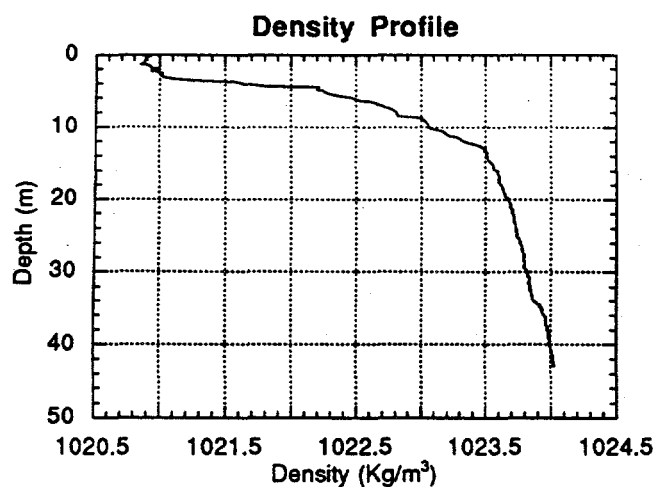
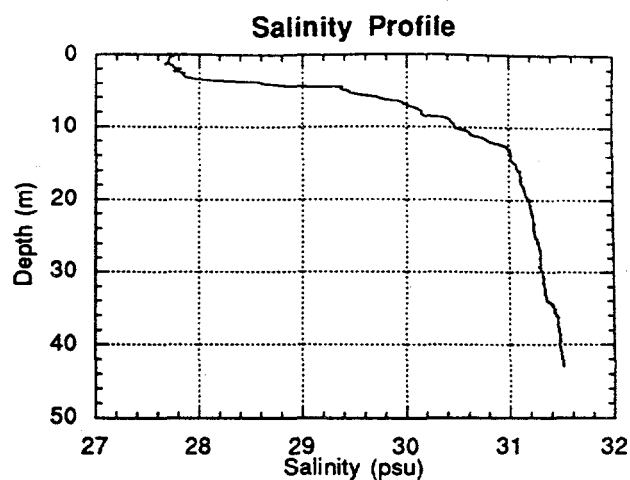
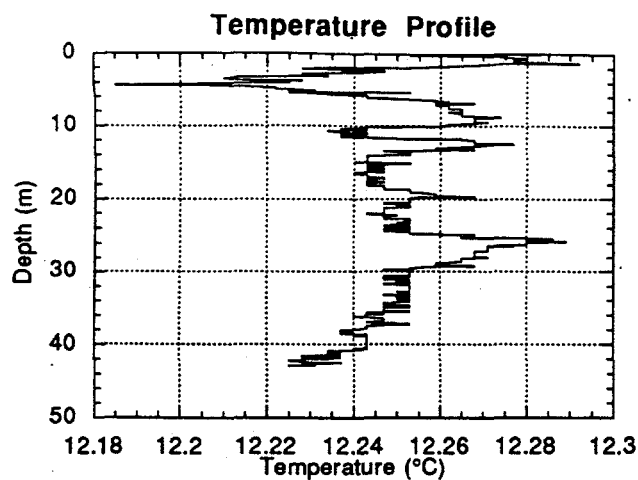


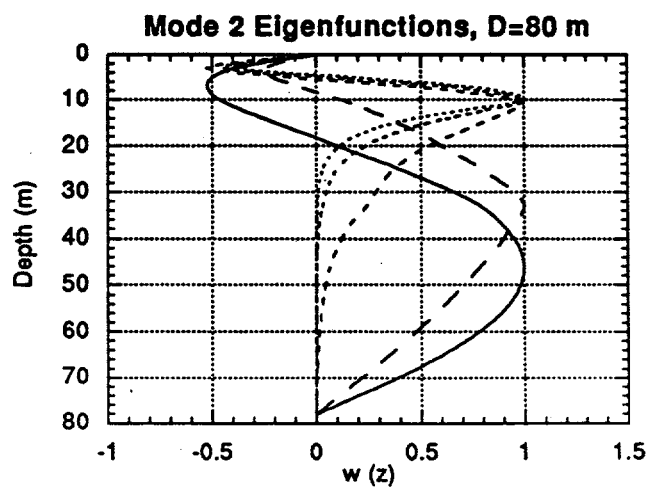
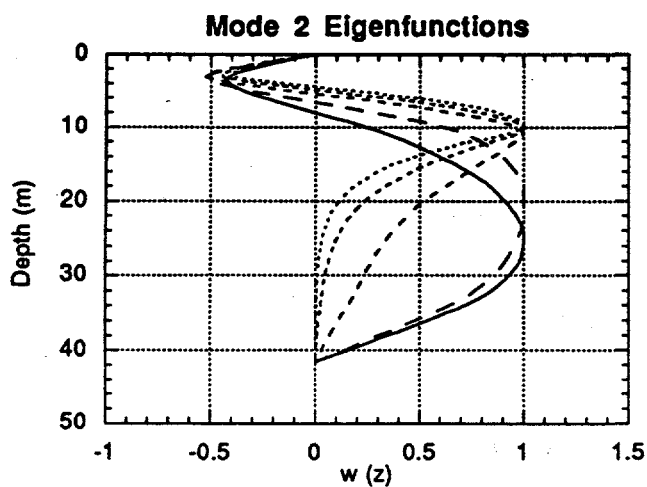
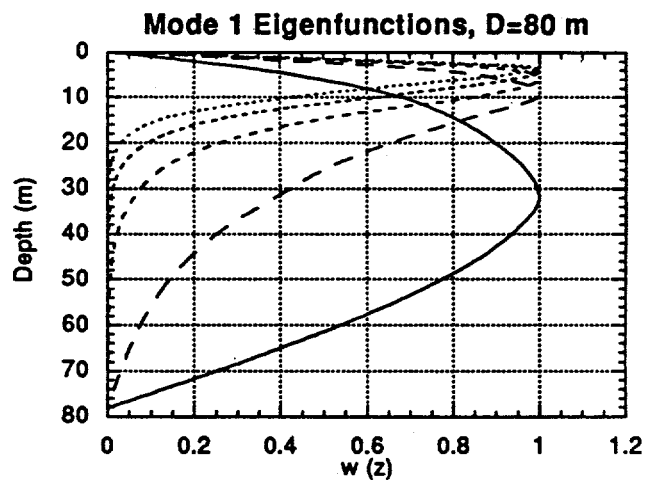
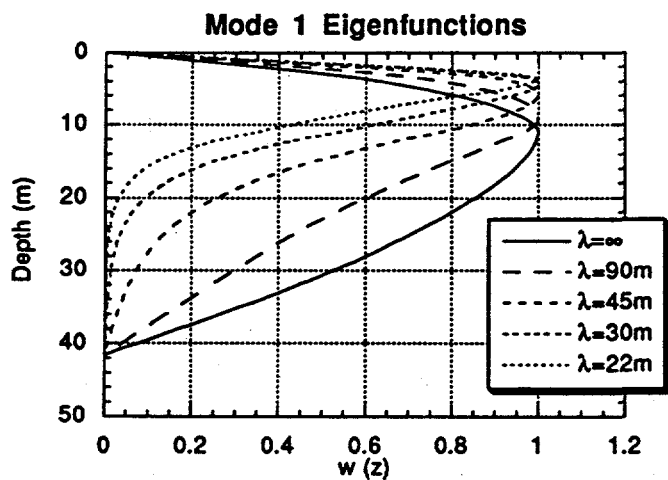
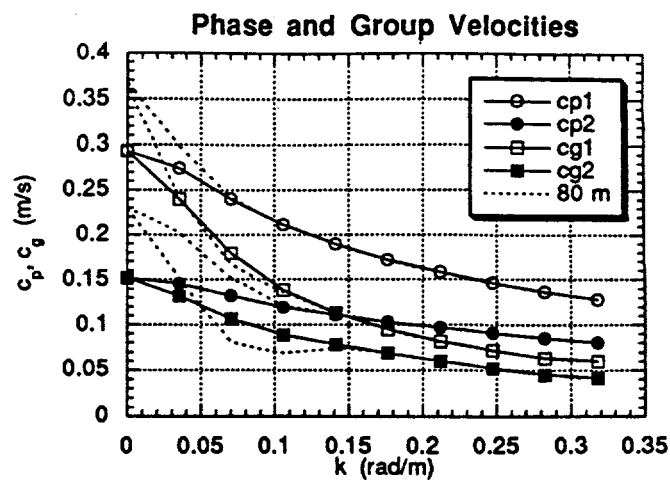
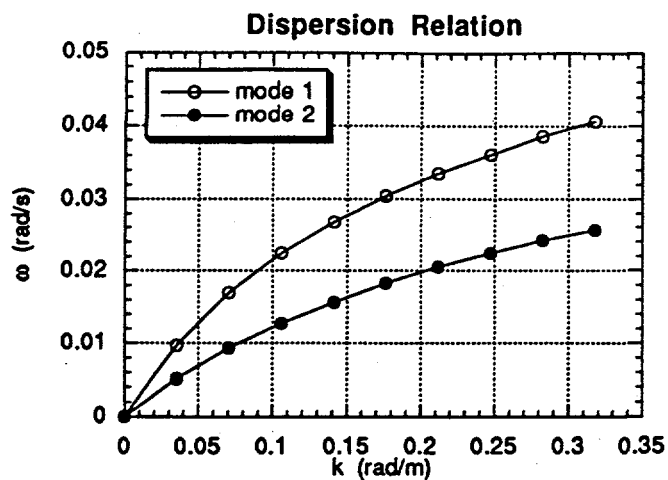
Mode 2 Eigenfunctions

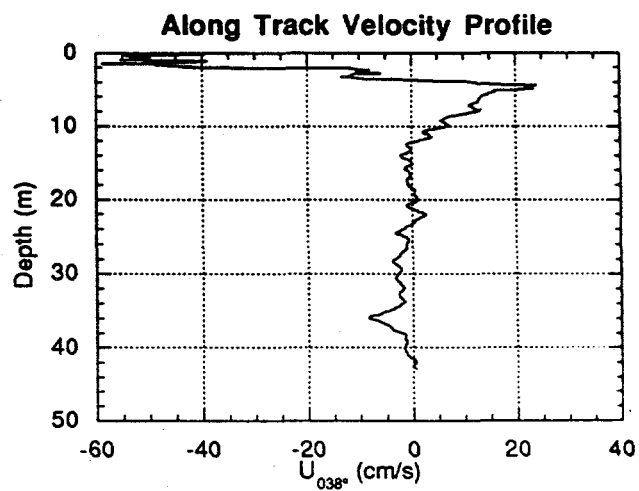
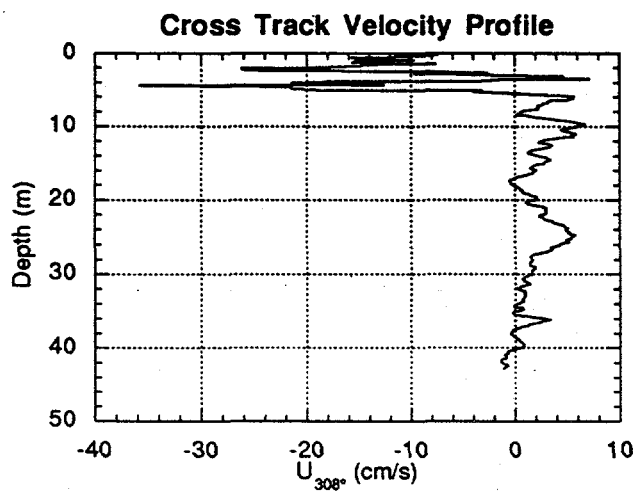
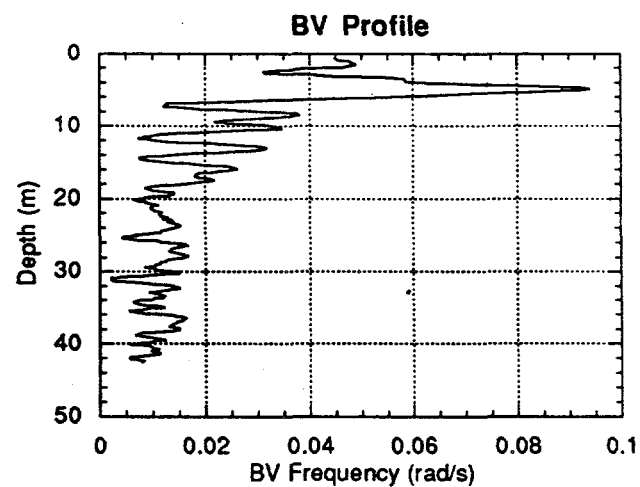
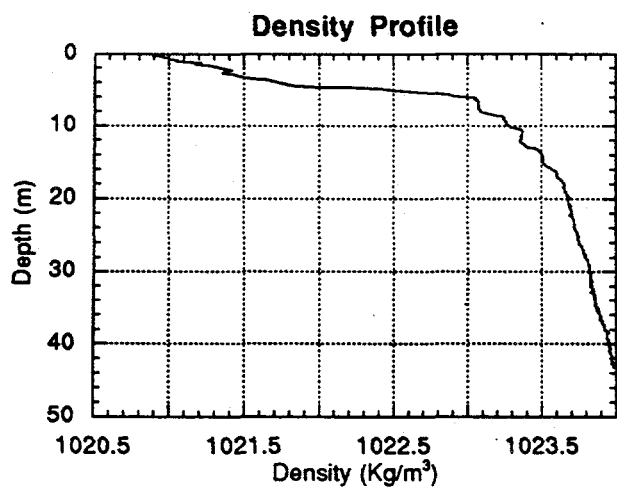
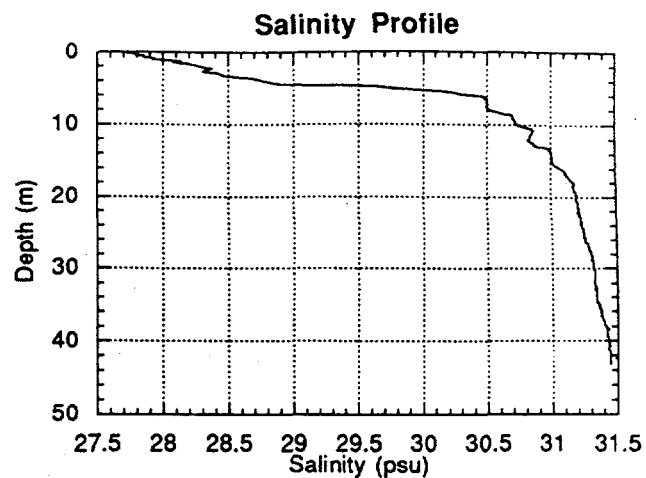
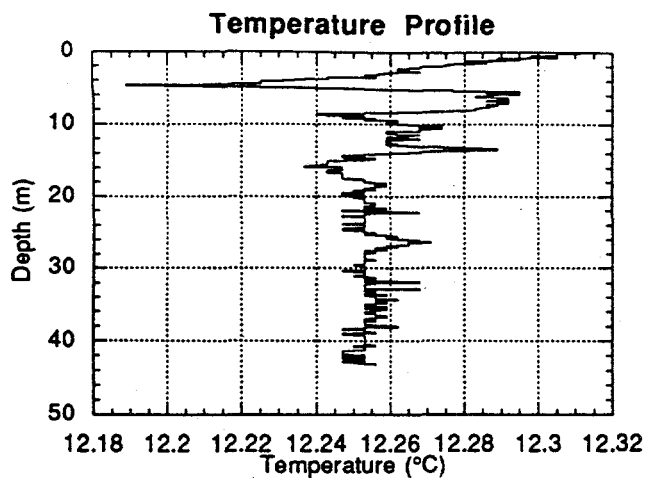


Mode 2 Eigenfunctions, D=80 m

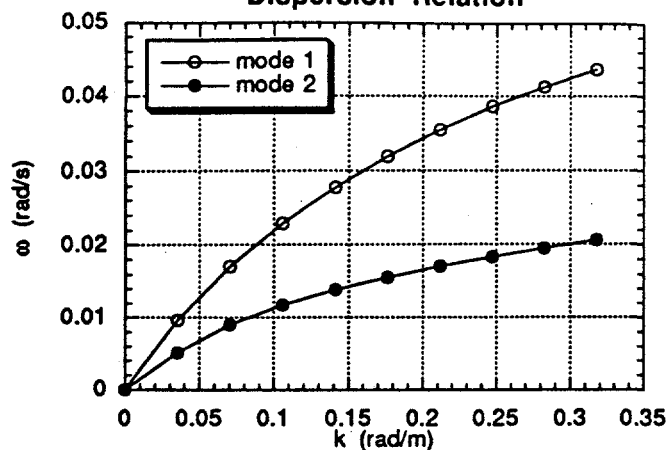




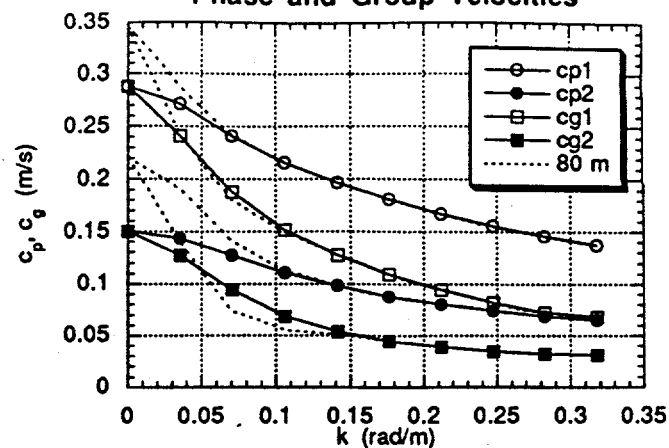




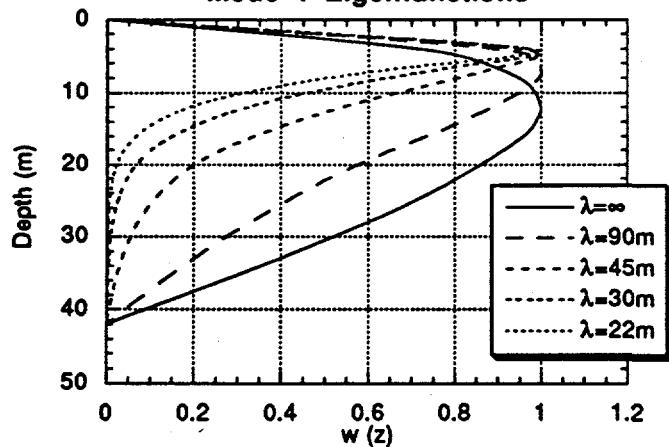
Dispersion Relation



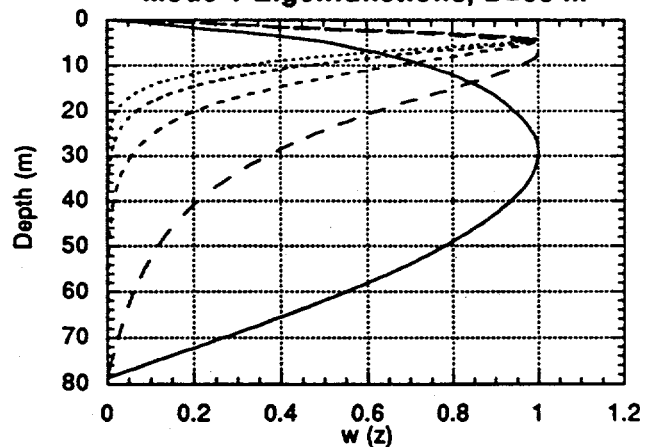
Phase and Group Velocities



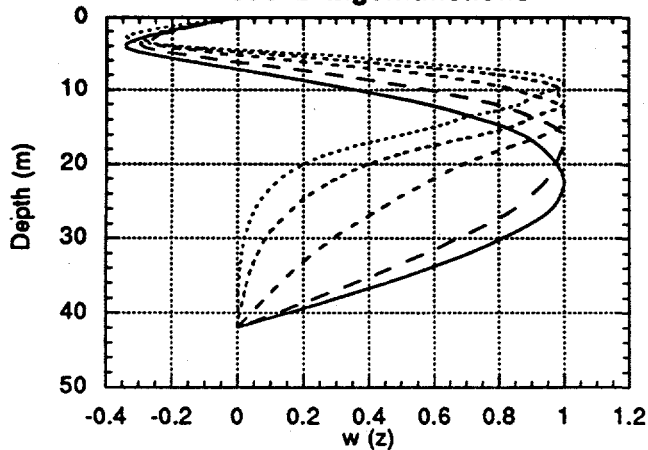
Mode 1 Eigenfunctions



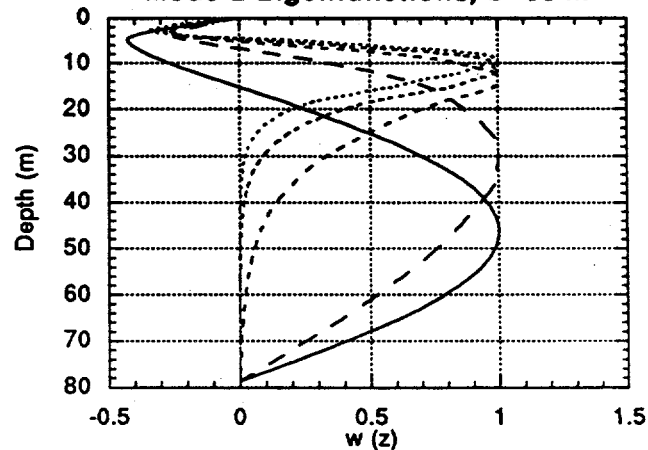
Mode 1 Eigenfunctions, D=80 m

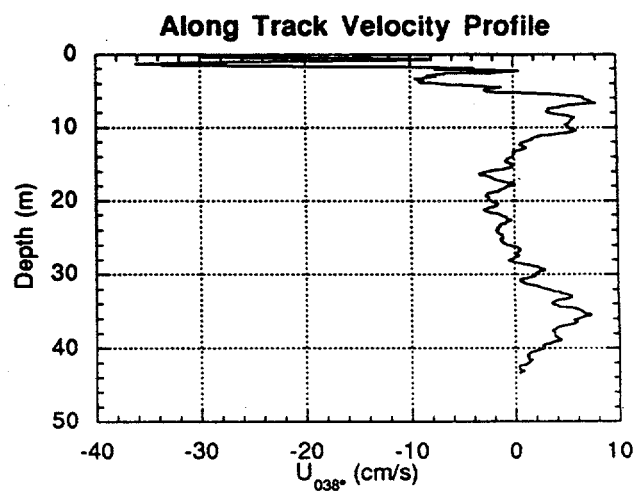
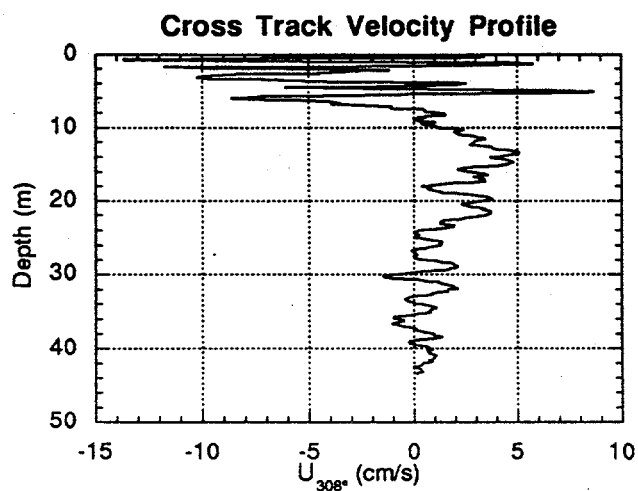
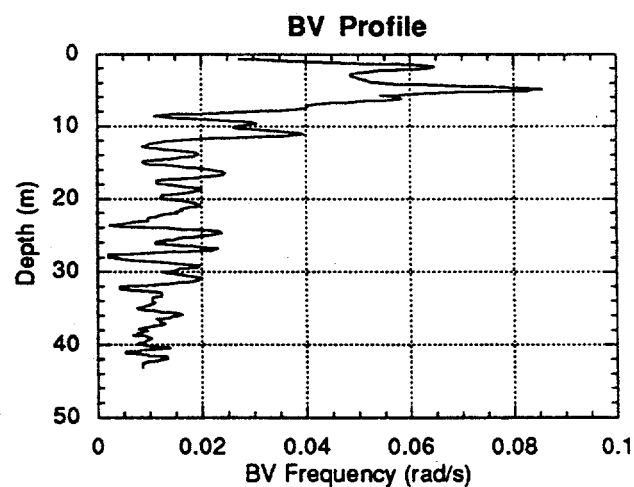
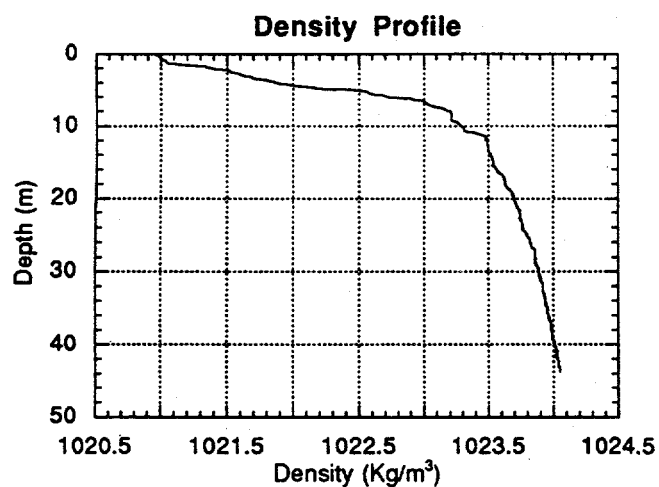
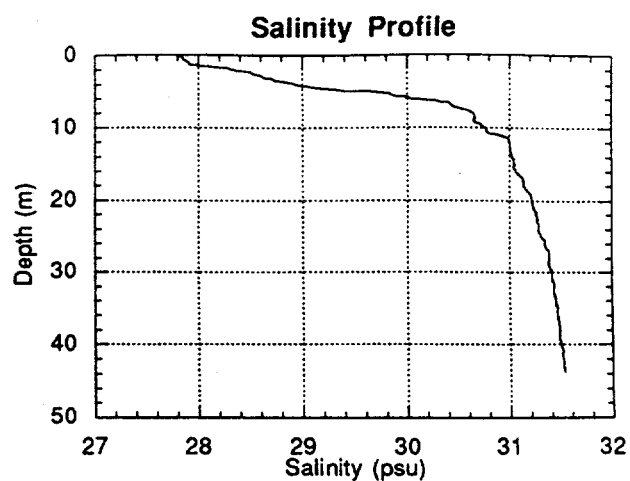
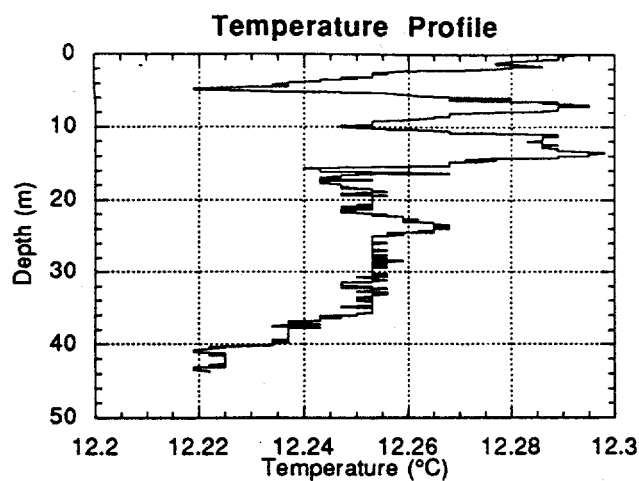


Mode 2 Eigenfunctions

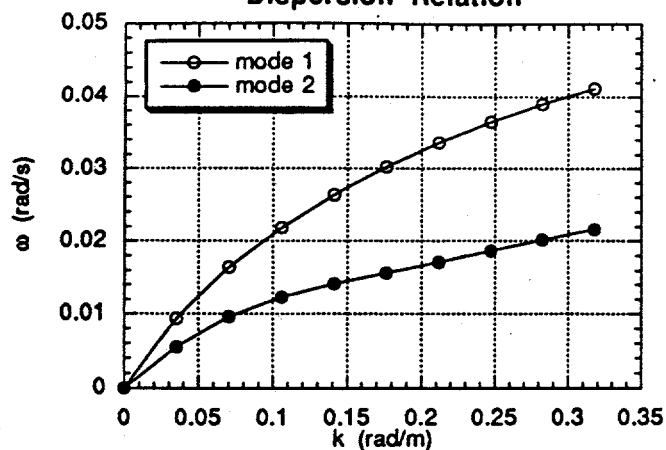


Mode 2 Eigenfunctions, D=80 m

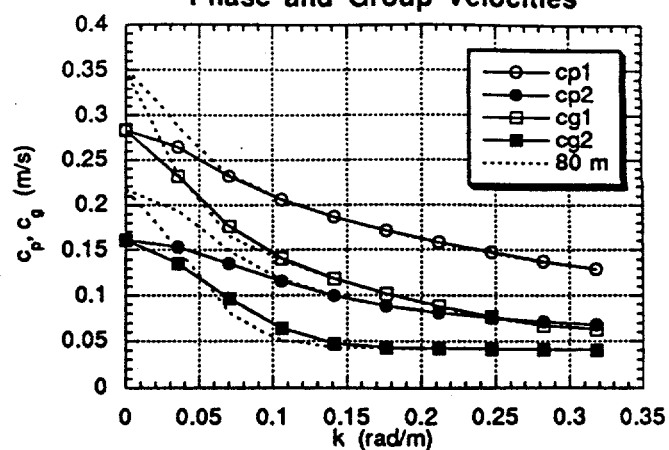




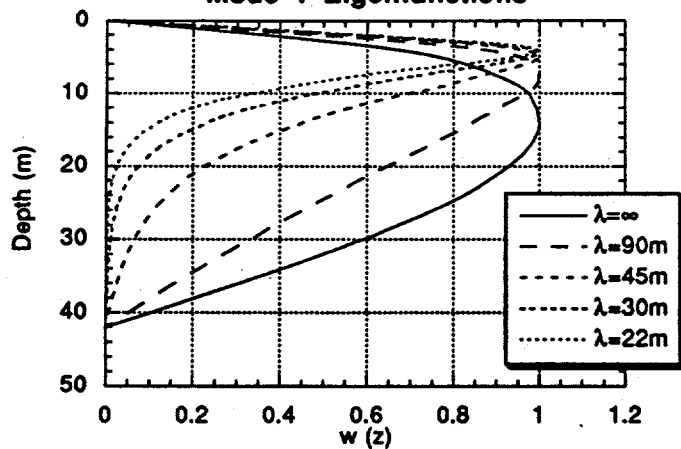
Dispersion Relation



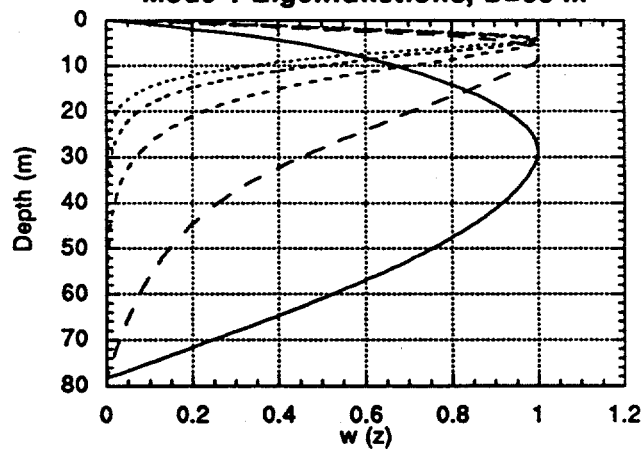
Phase and Group Velocities



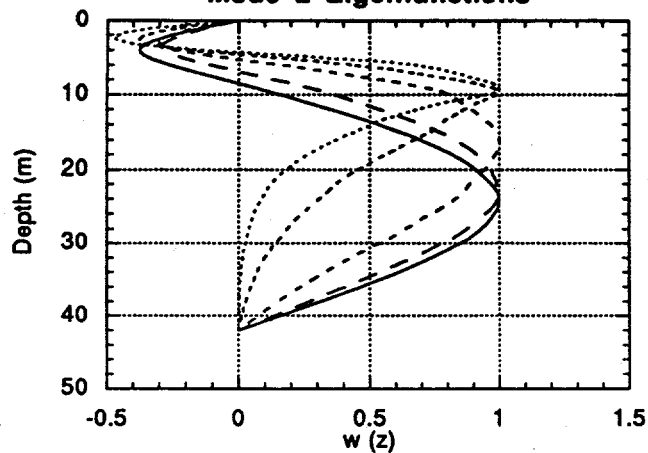
Mode 1 Eigenfunctions



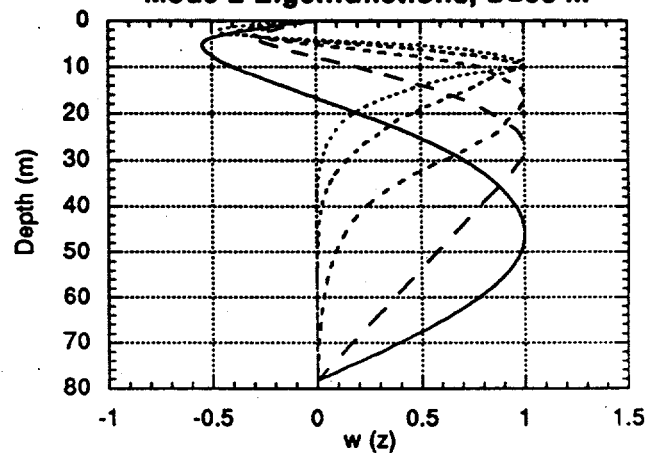
Mode 1 Eigenfunctions, D=80 m

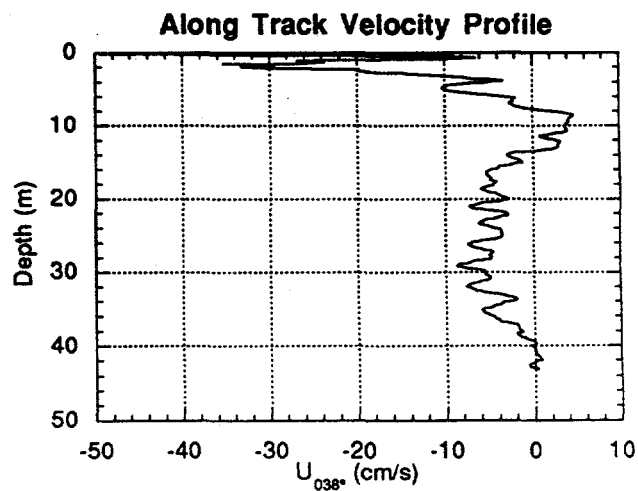
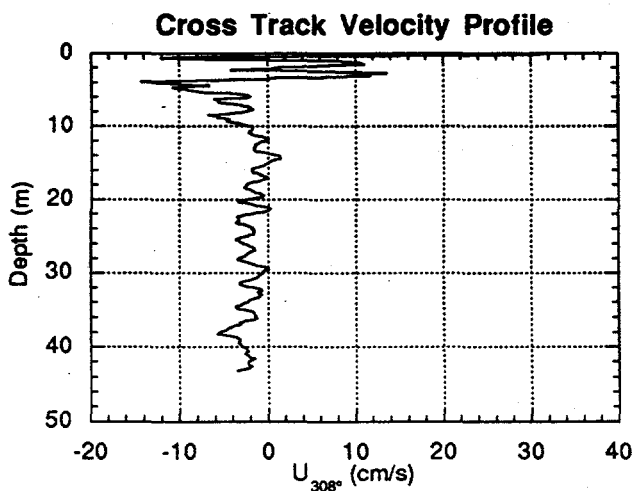
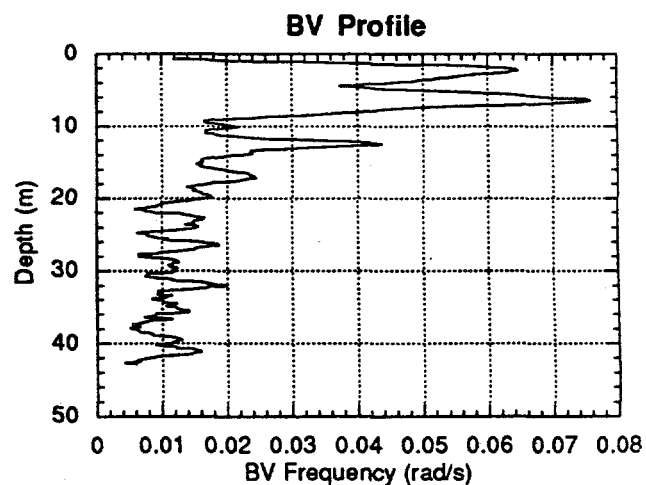
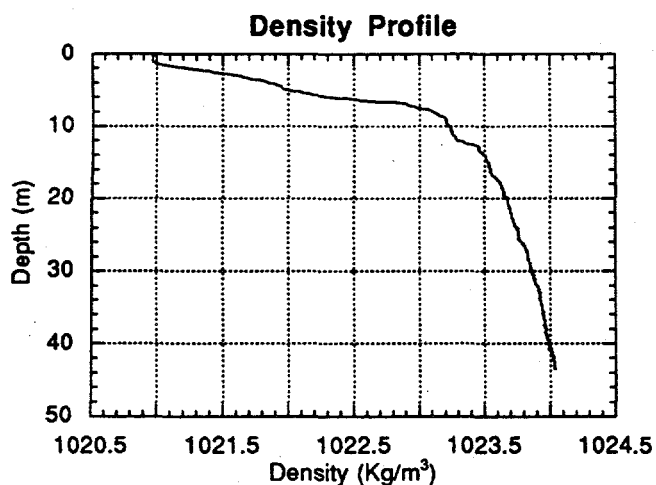
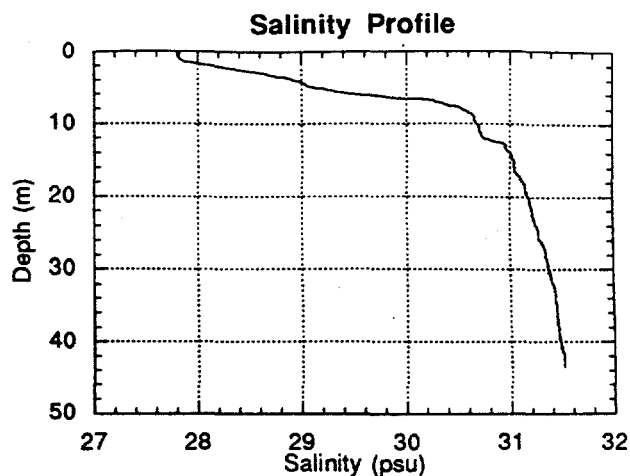
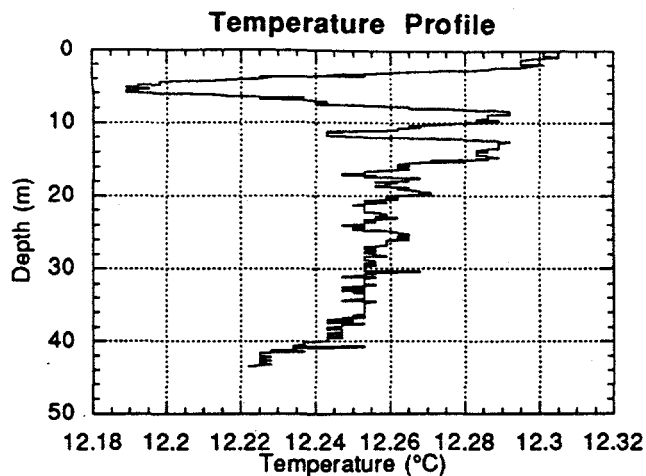


Mode 2 Eigenfunctions

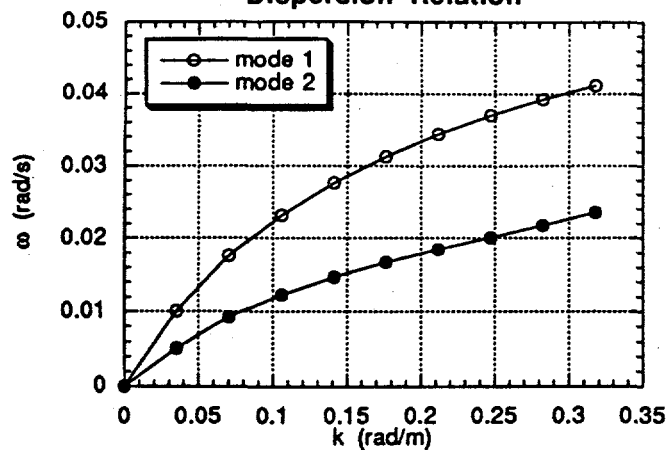


Mode 2 Eigenfunctions, D=80 m

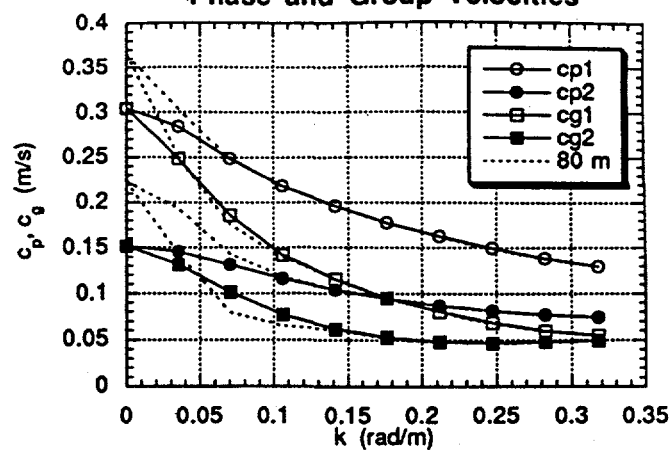




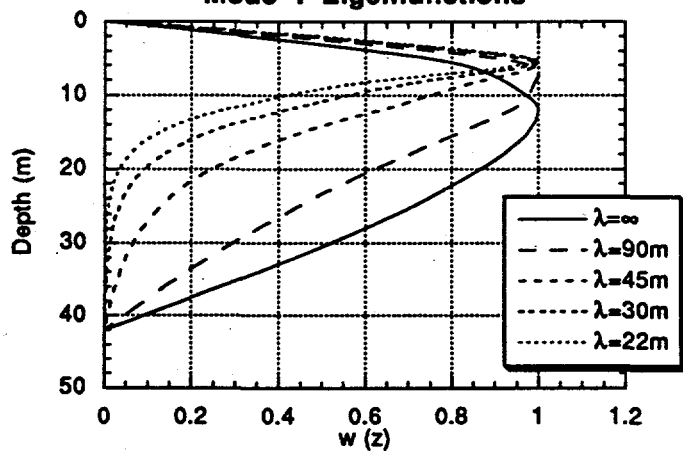
Dispersion Relation



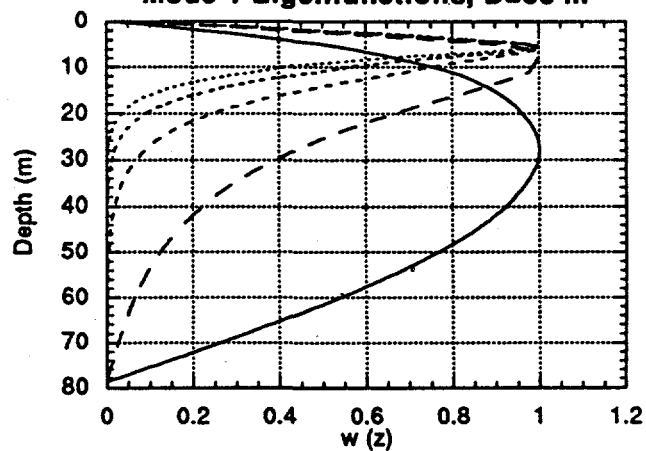
Phase and Group Velocities



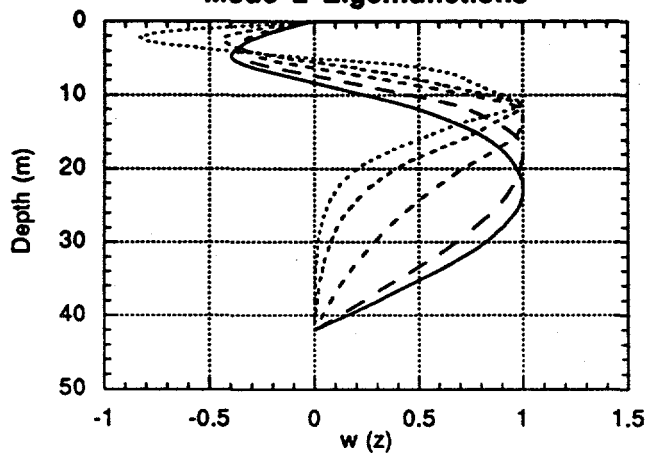
Mode 1 Eigenfunctions



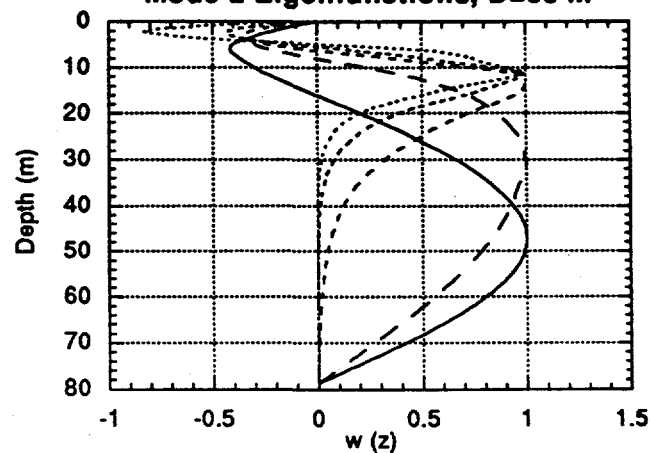
Mode 1 Eigenfunctions, D=80 m

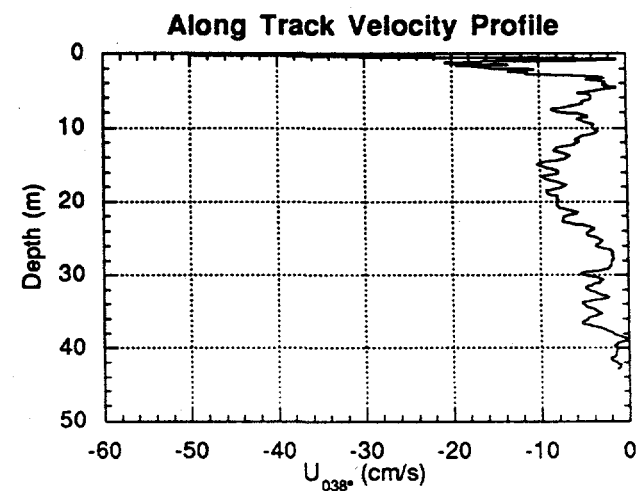
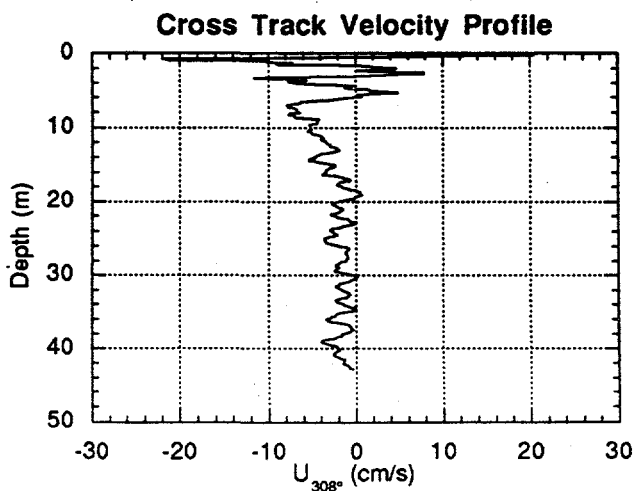
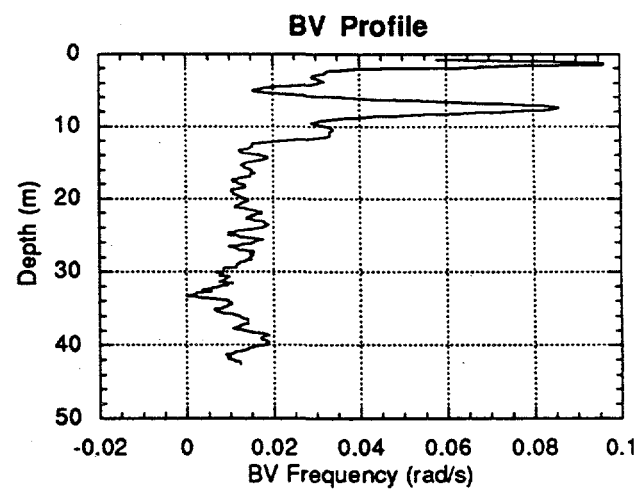
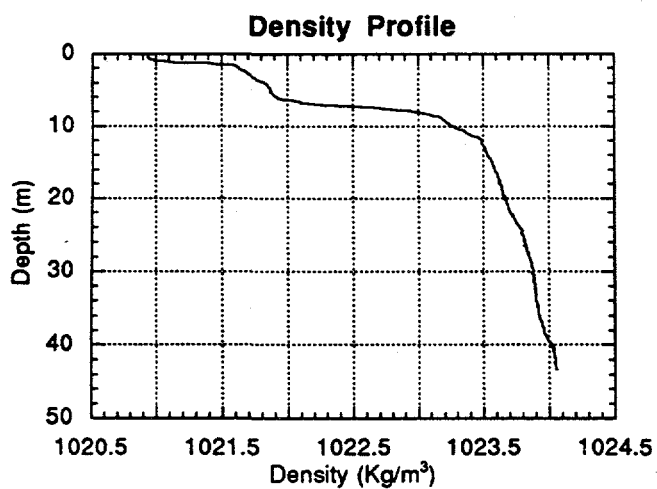
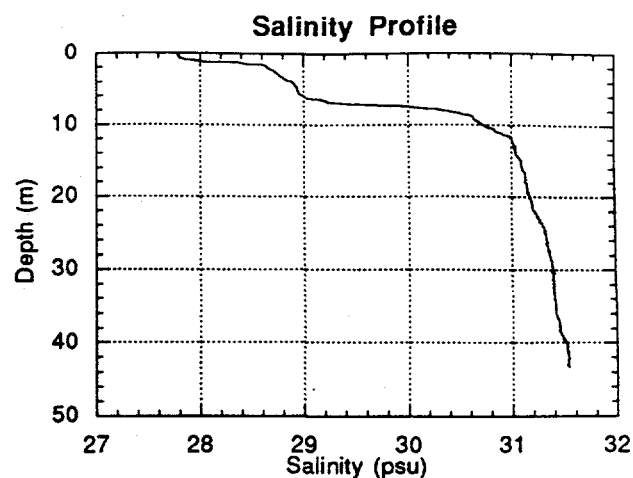
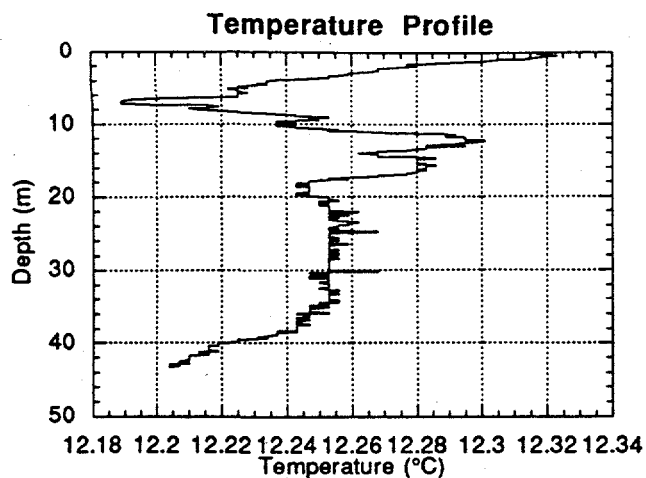


Mode 2 Eigenfunctions

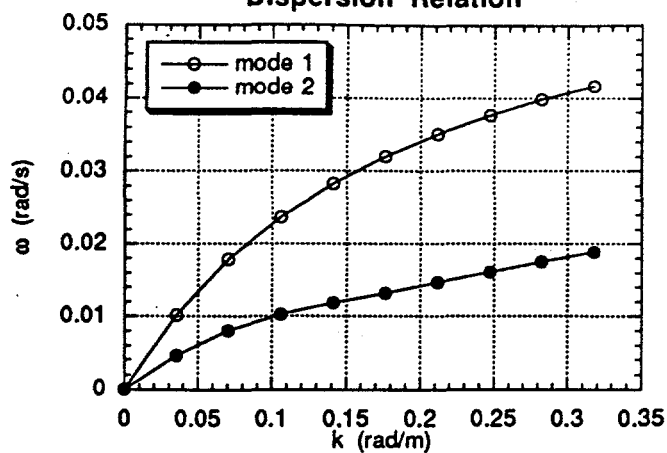


Mode 2 Eigenfunctions, D=80 m

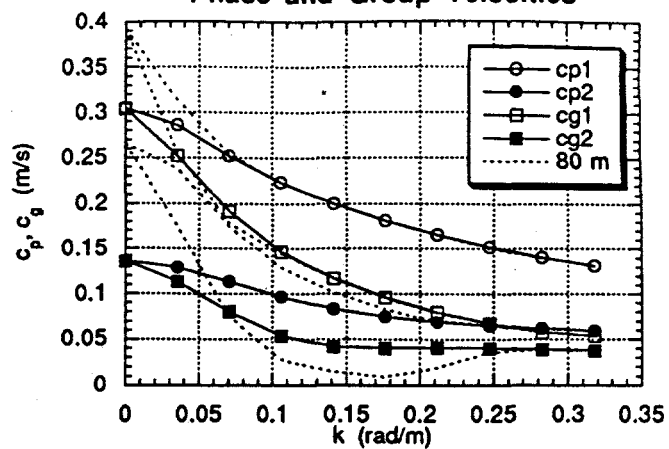




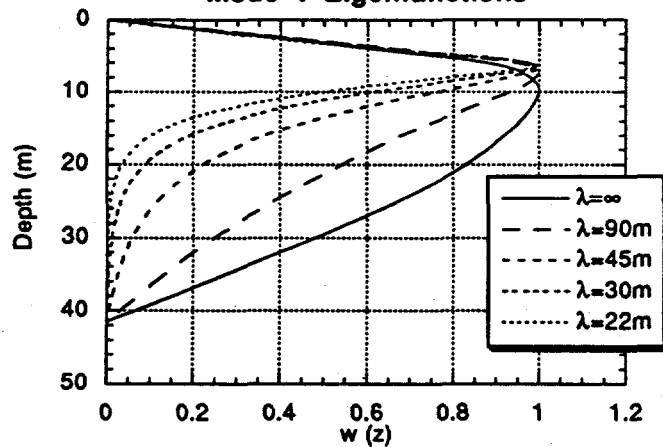
Dispersion Relation



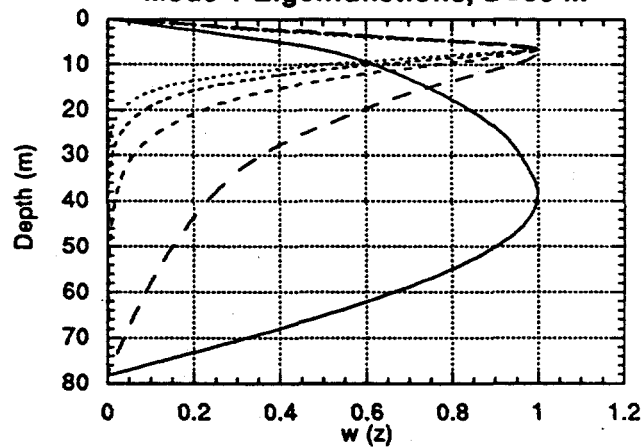
Phase and Group Velocities



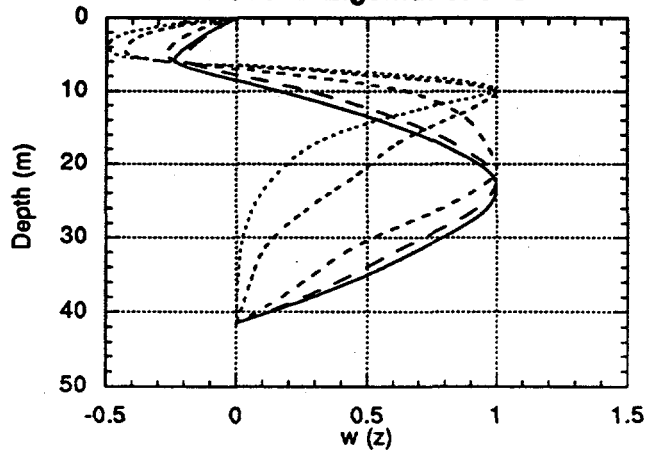
Mode 1 Eigenfunctions



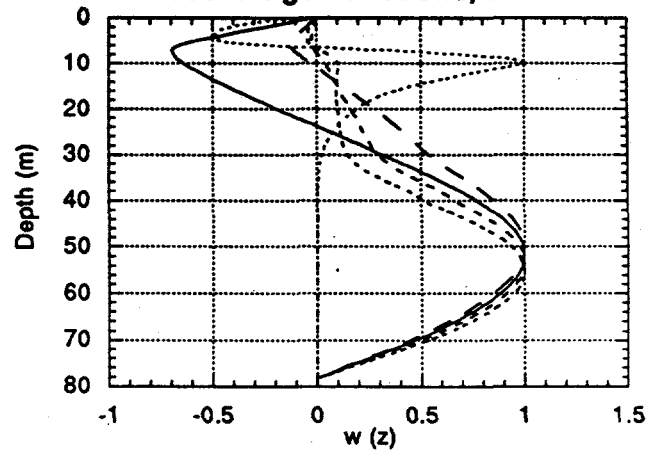
Mode 1 Eigenfunctions, D=80 m

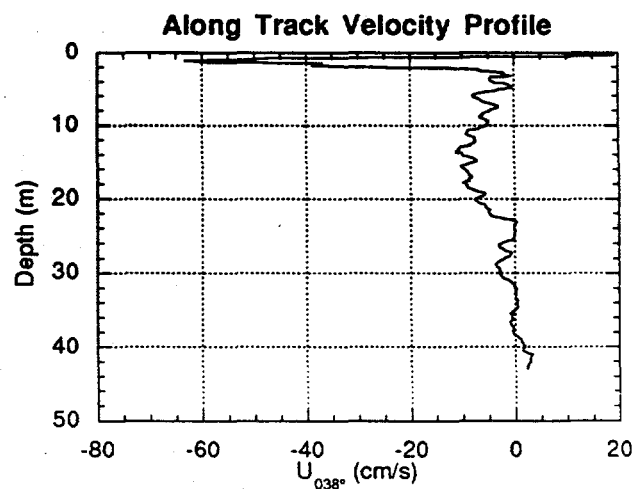
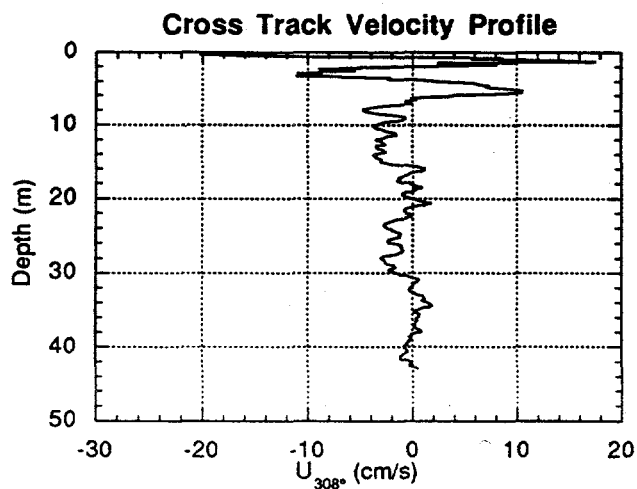
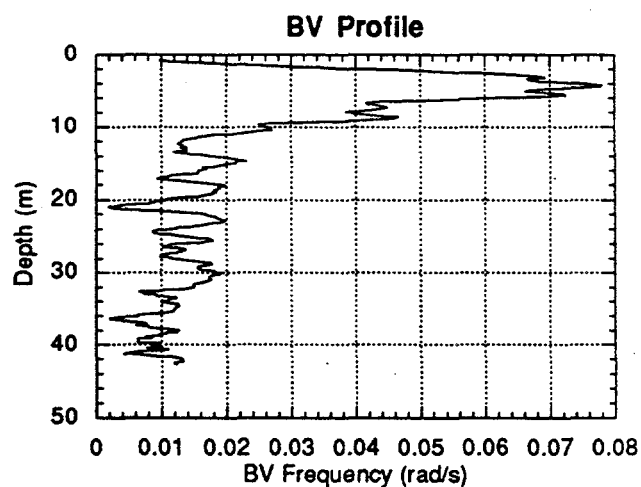
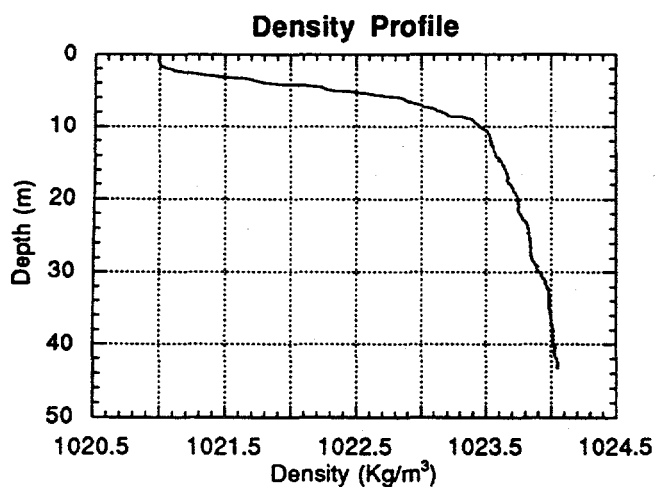
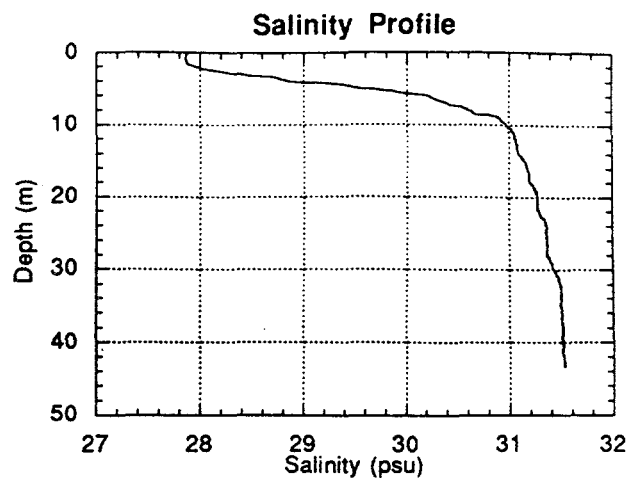
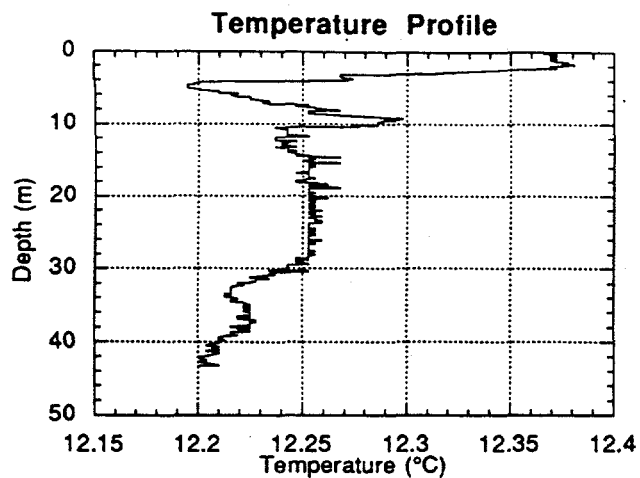


Mode 2 Eigenfunctions

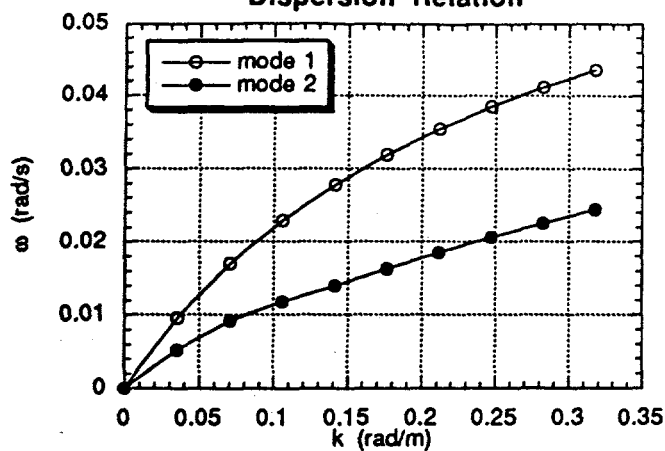


Mode 2 Eigenfunctions, D=80 m

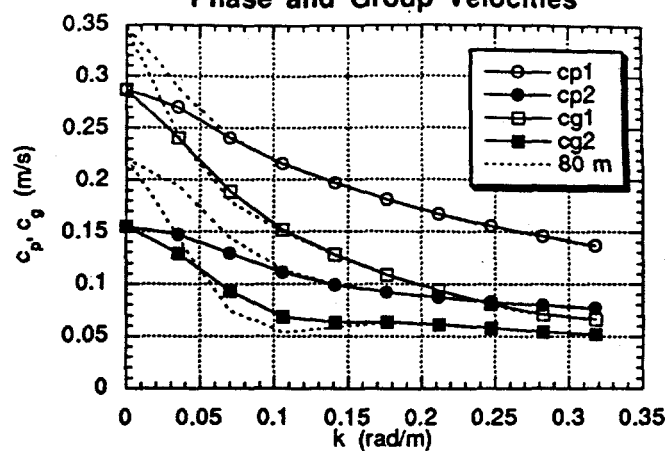




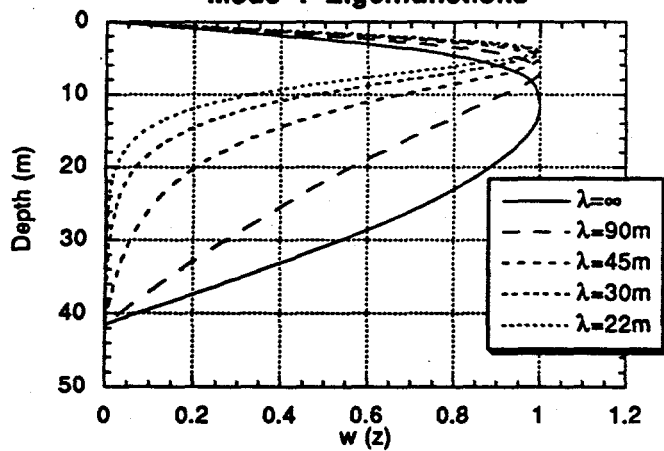
Dispersion Relation



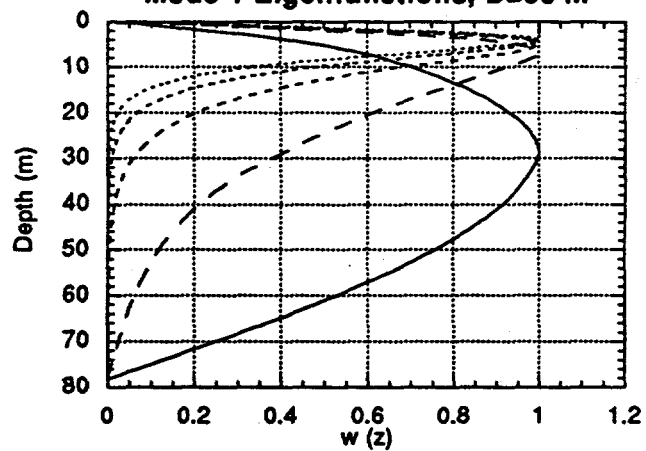
Phase and Group Velocities



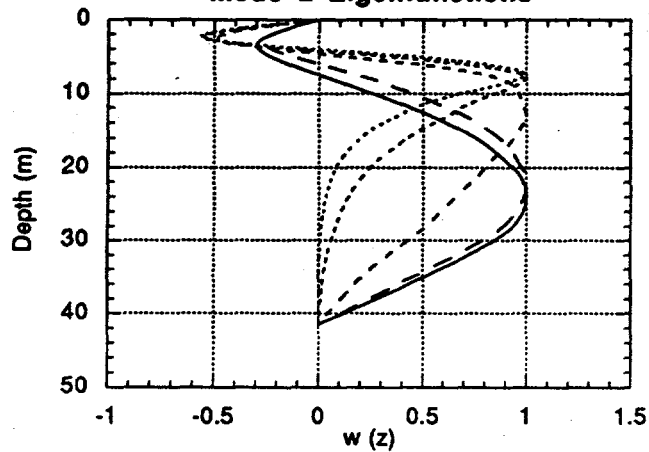
Mode 1 Eigenfunctions



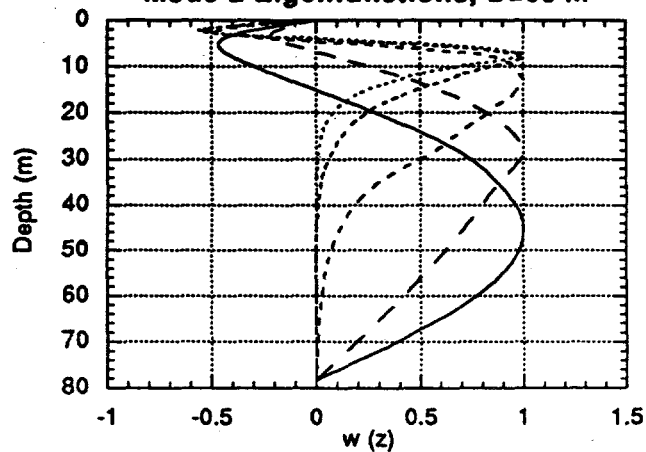
Mode 1 Eigenfunctions, D=80 m

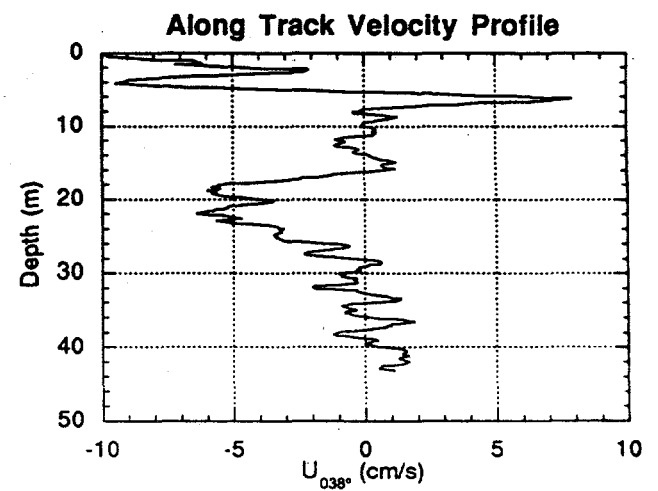
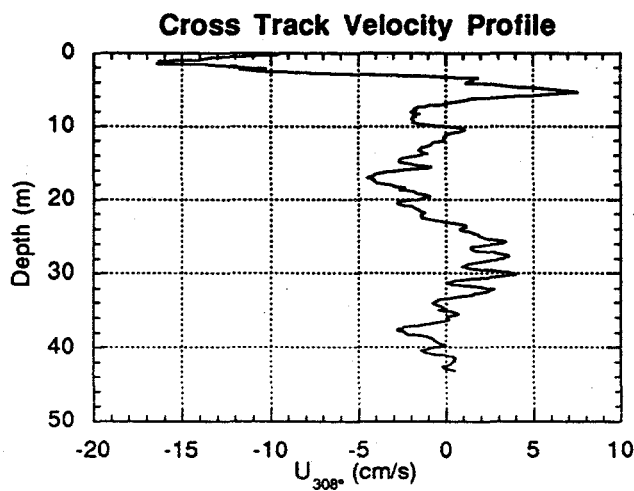
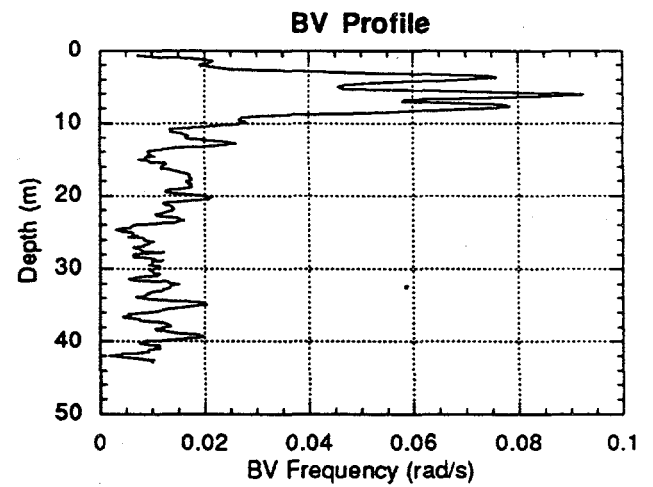
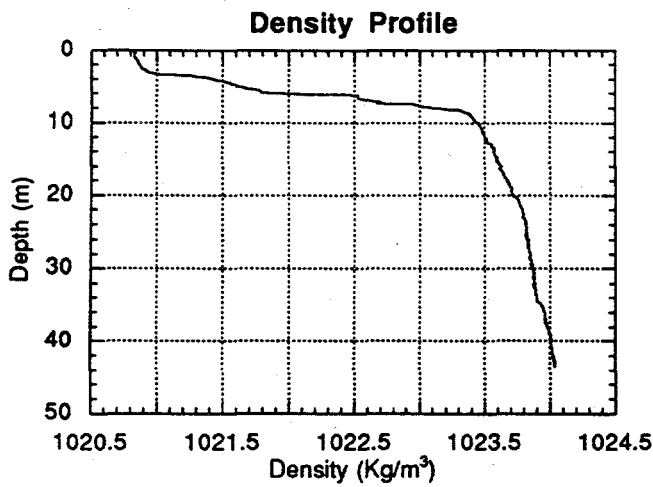
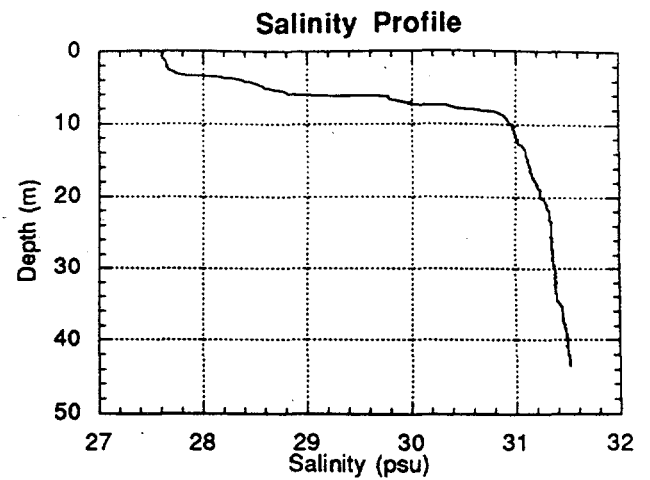
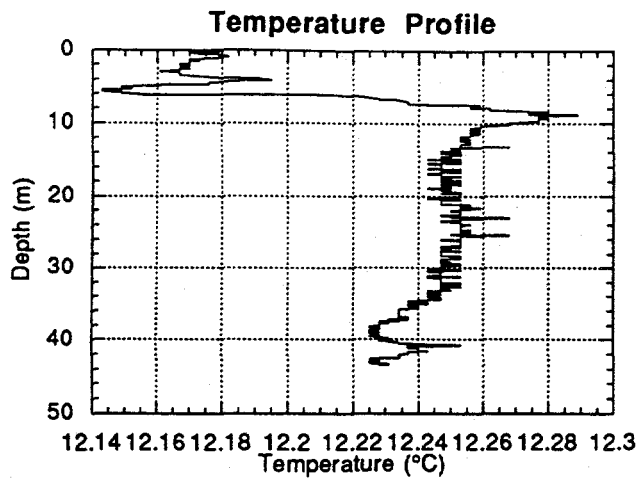


Mode 2 Eigenfunctions

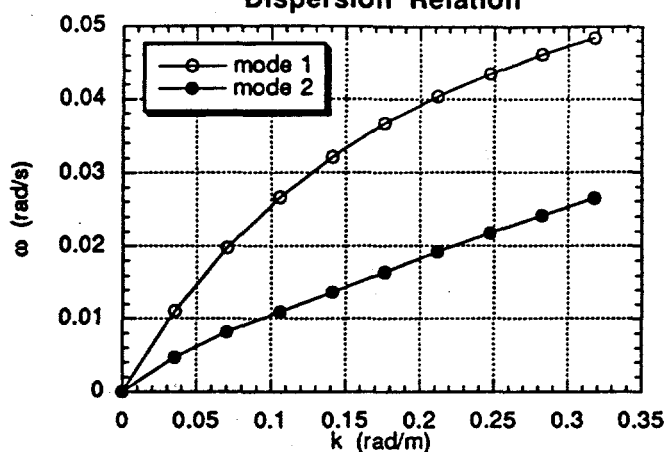


Mode 2 Eigenfunctions, D=80 m

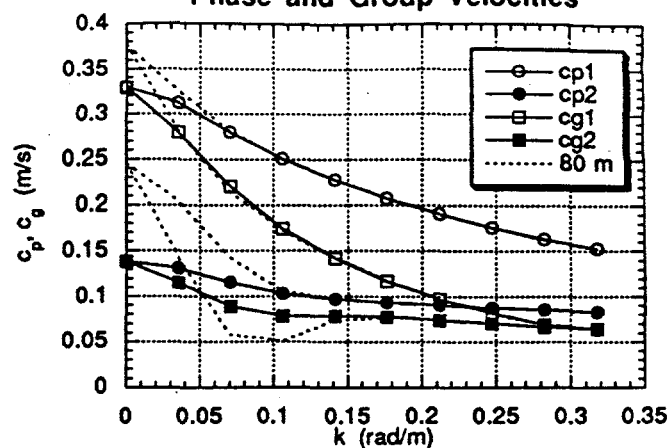




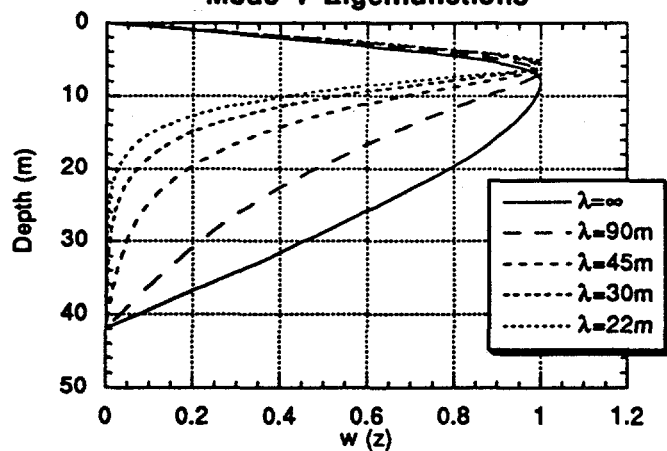
Dispersion Relation



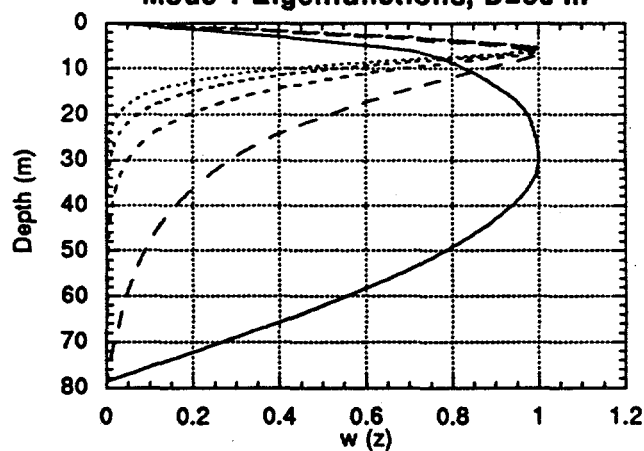
Phase and Group Velocities



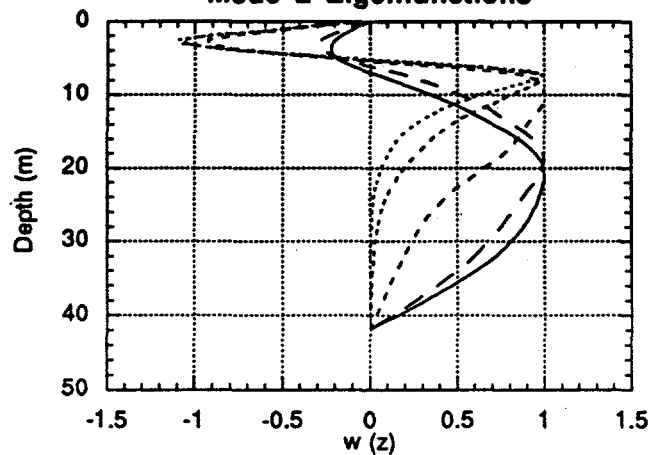
Mode 1 Eigenfunctions



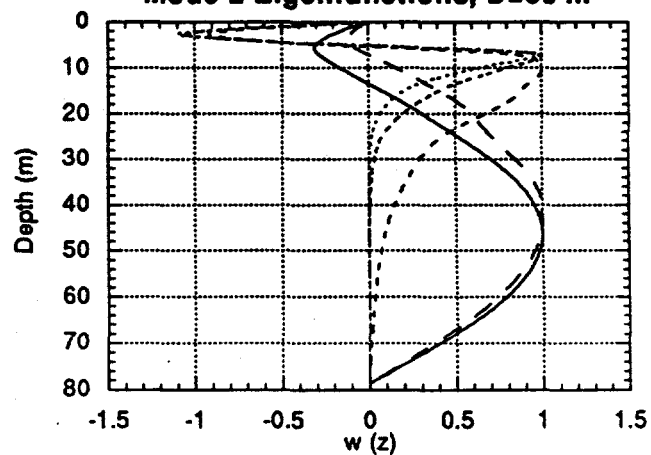
Mode 1 Eigenfunctions, D=80 m



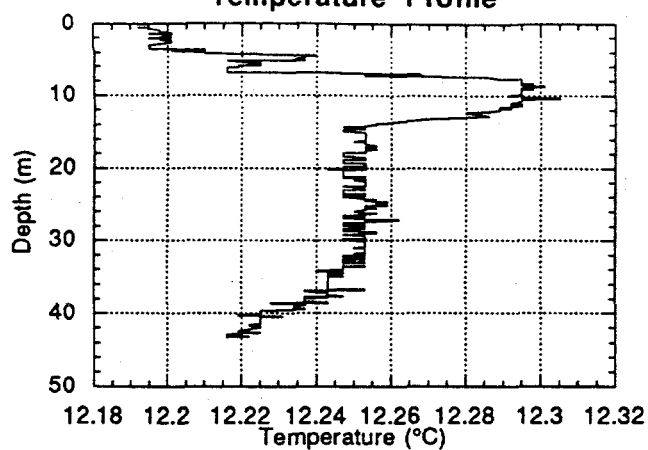
Mode 2 Eigenfunctions



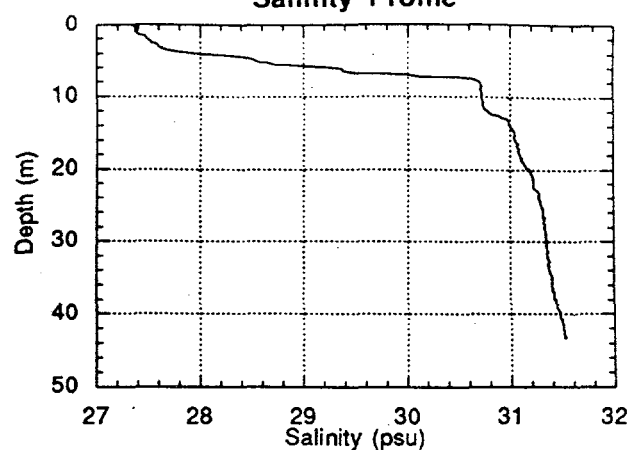
Mode 2 Eigenfunctions, D=80 m



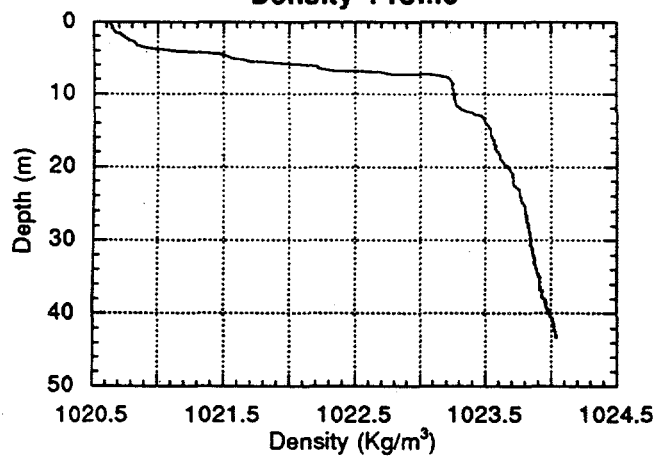
Temperature Profile



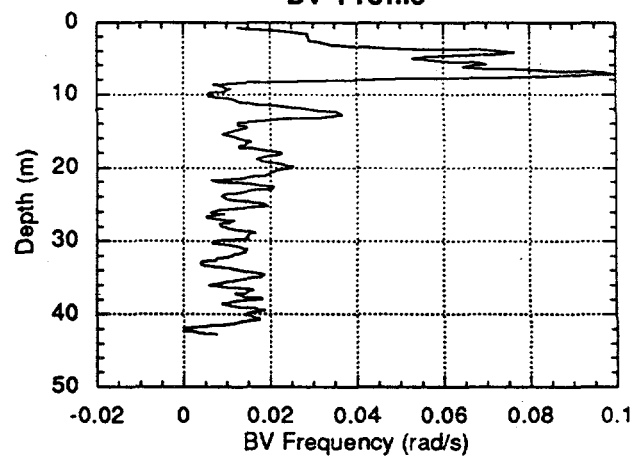
Salinity Profile



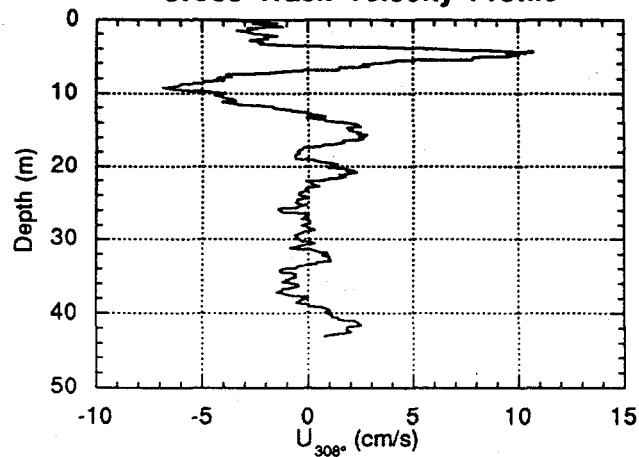
Density Profile



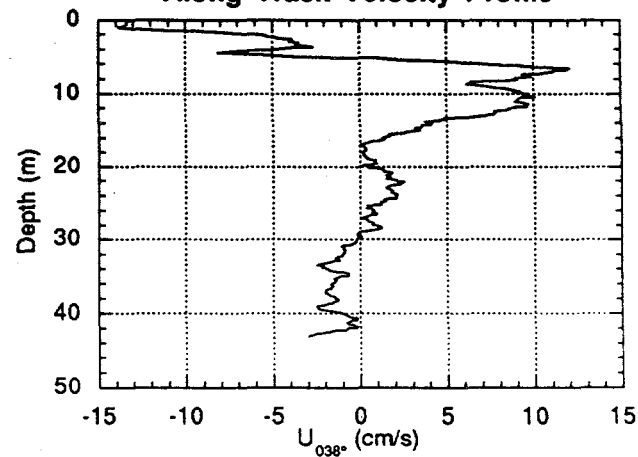
BV Profile

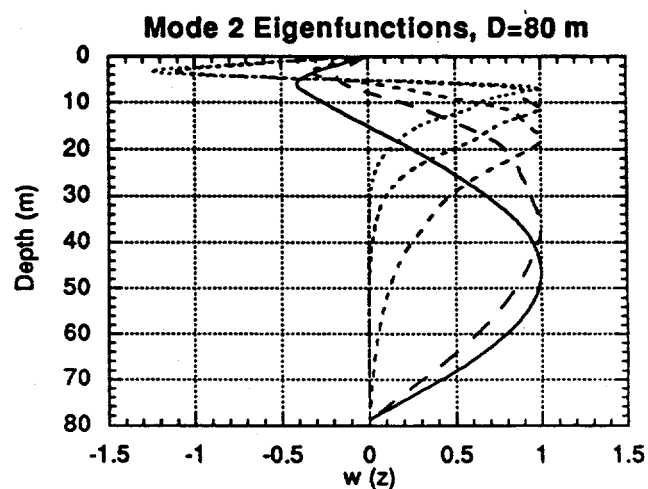
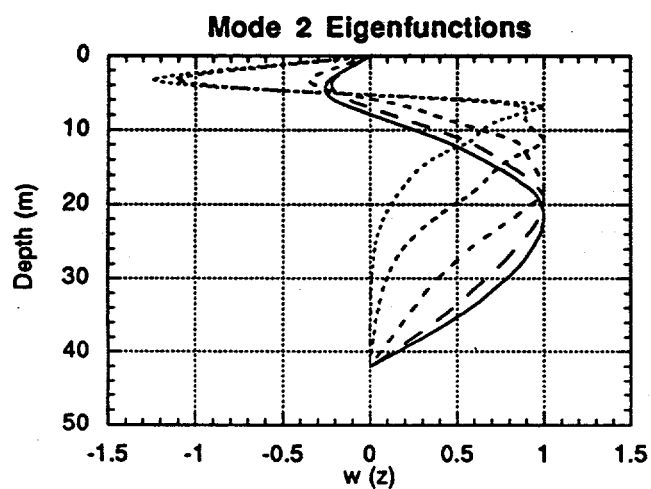
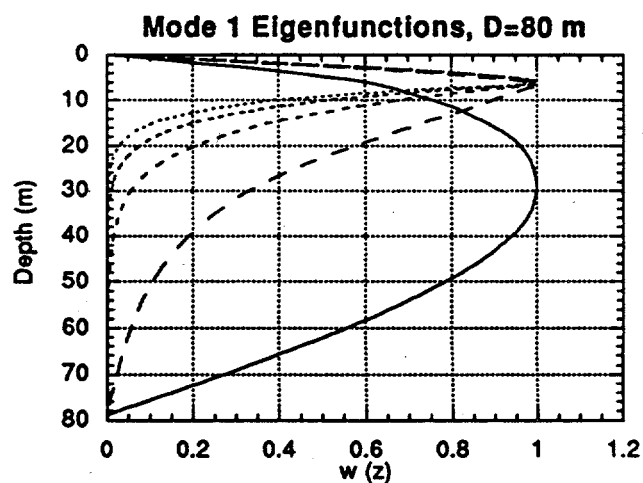
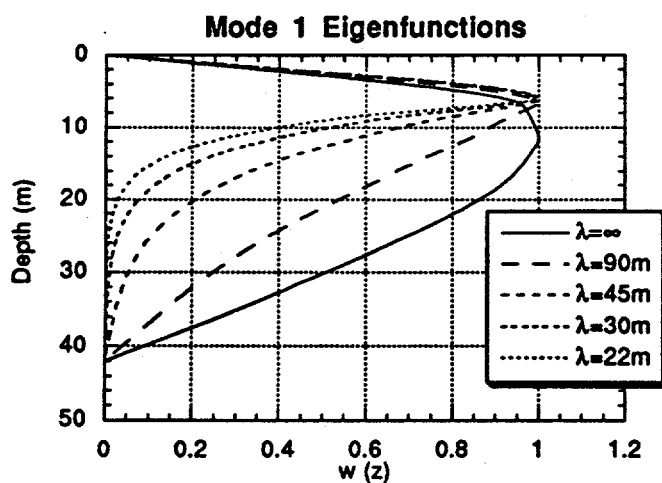
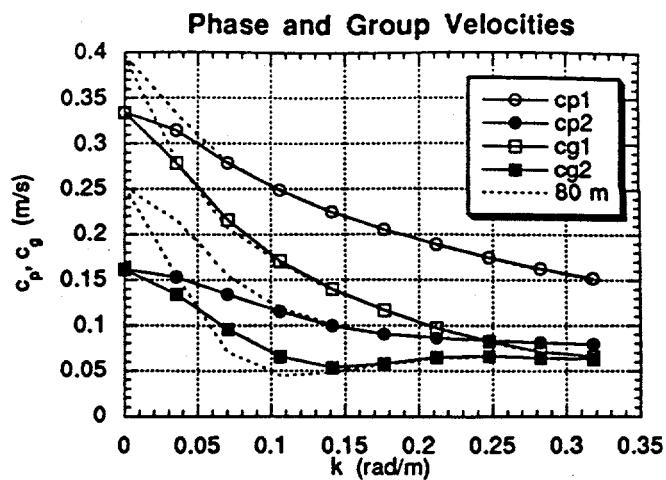
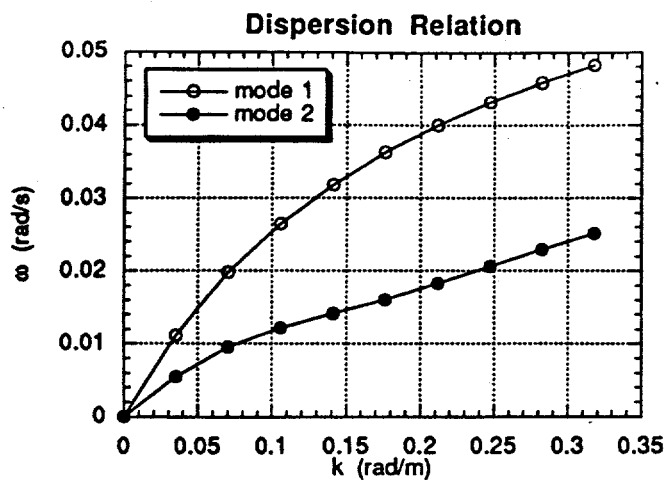


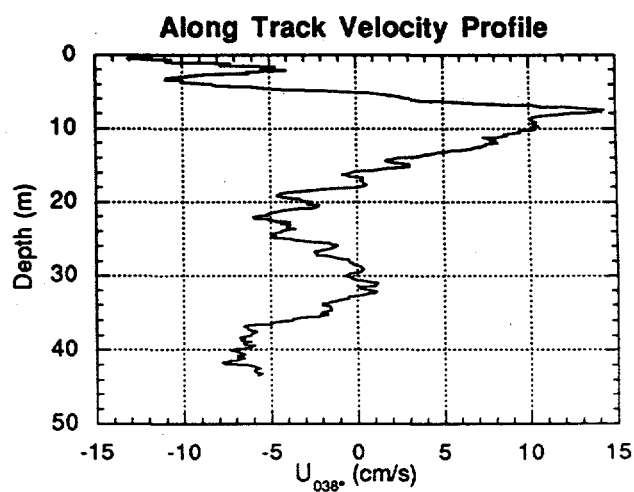
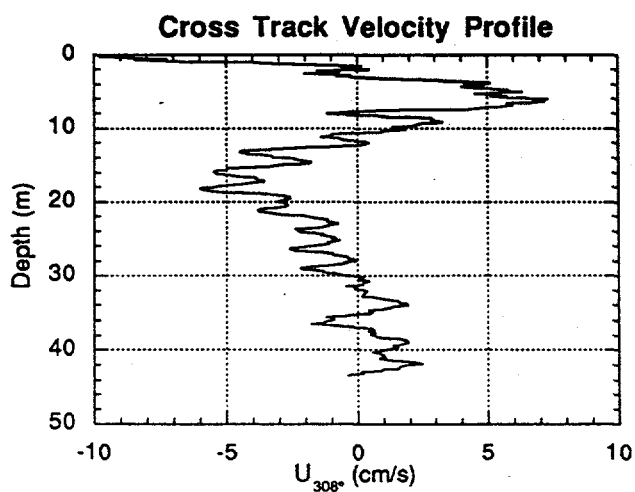
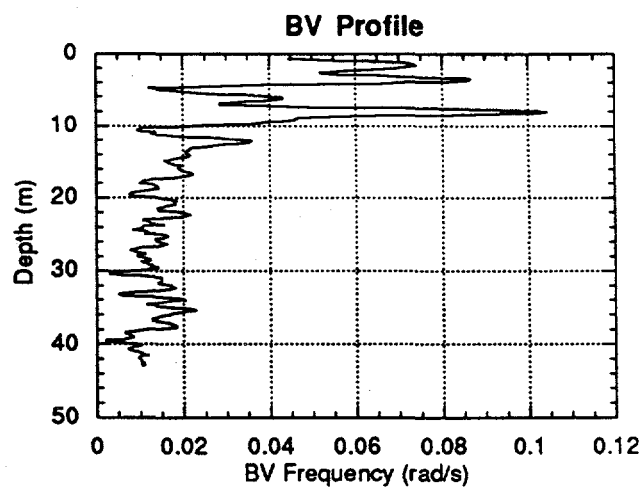
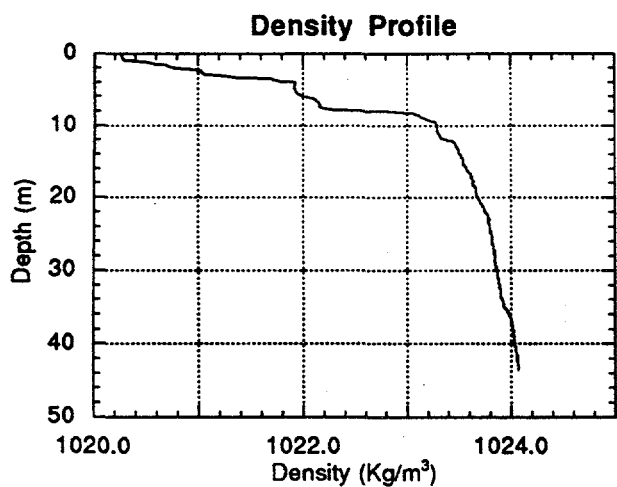
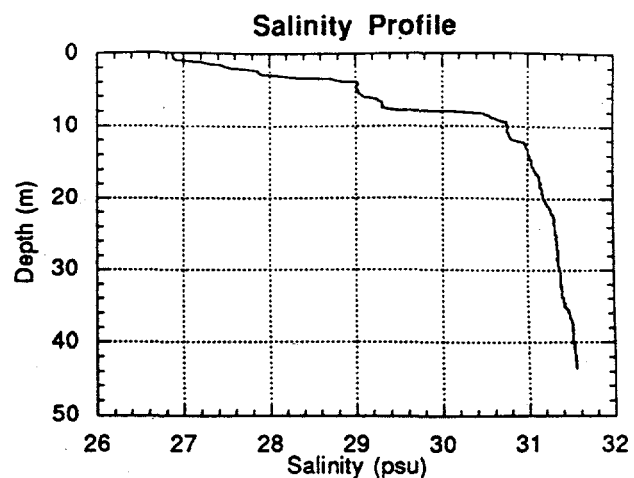
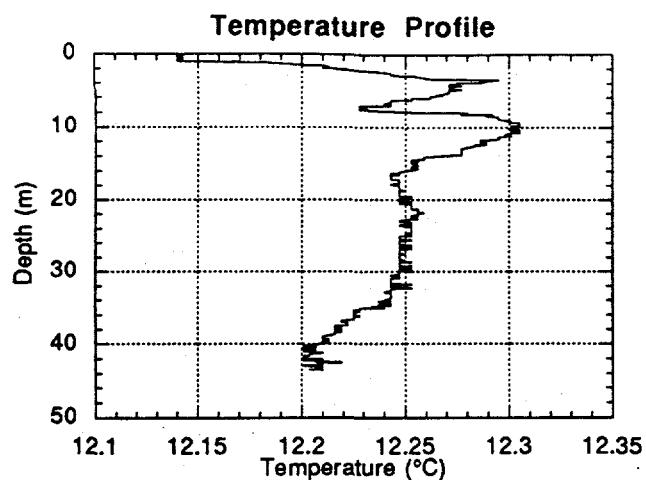
Cross Track Velocity Profile



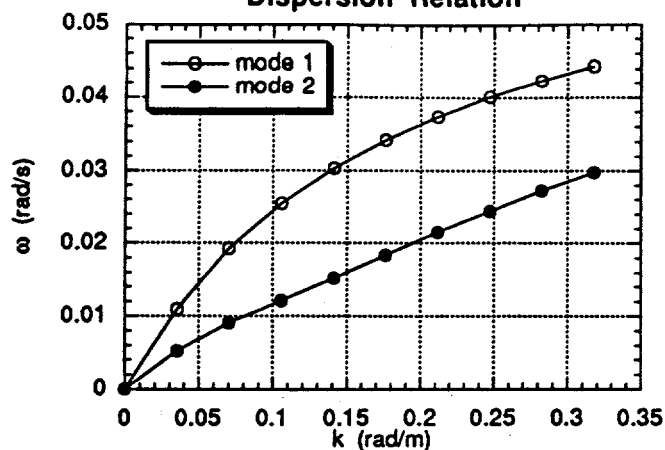
Along Track Velocity Profile



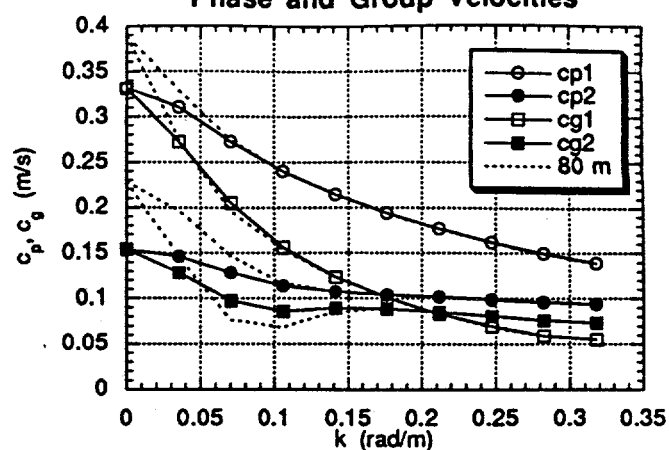




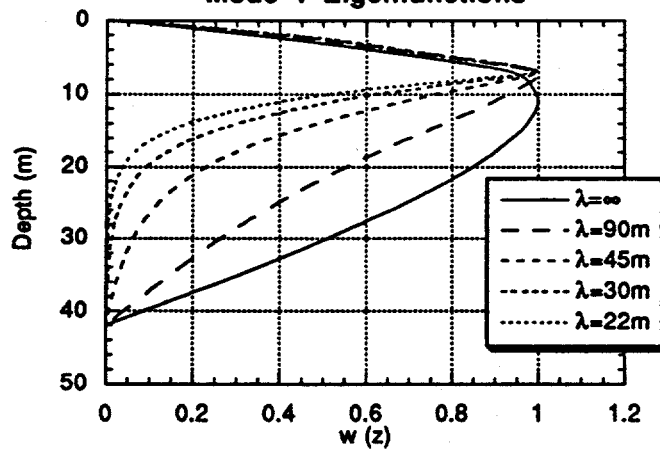
Dispersion Relation



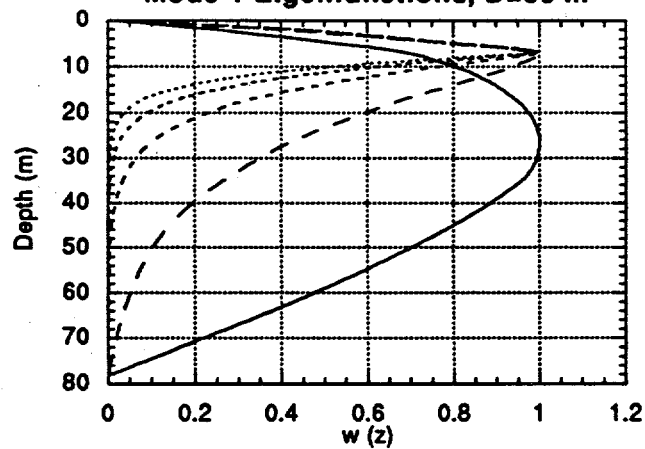
Phase and Group Velocities



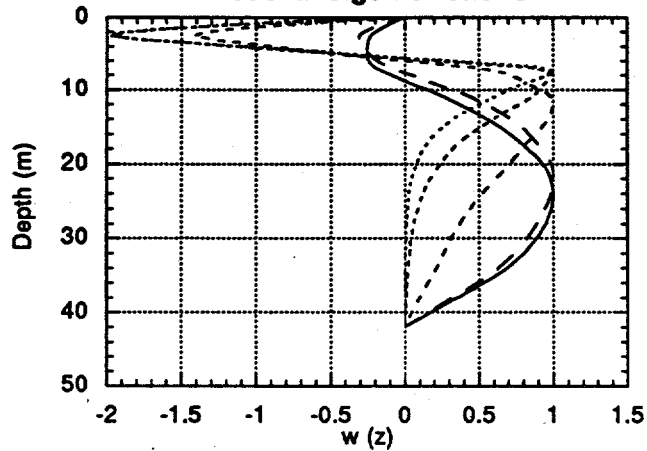
Mode 1 Eigenfunctions



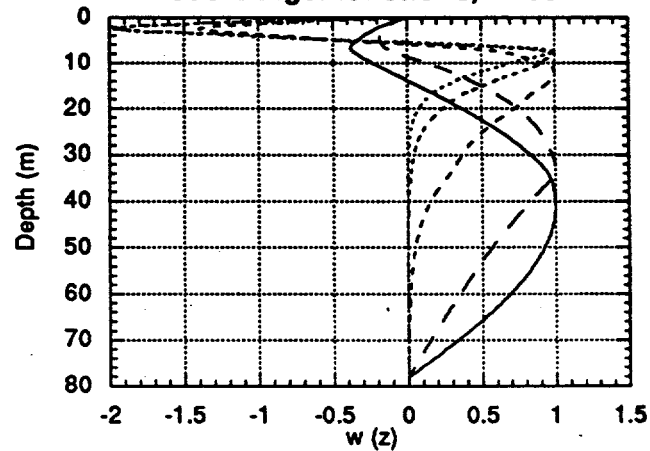
Mode 1 Eigenfunctions, D=80 m



Mode 2 Eigenfunctions

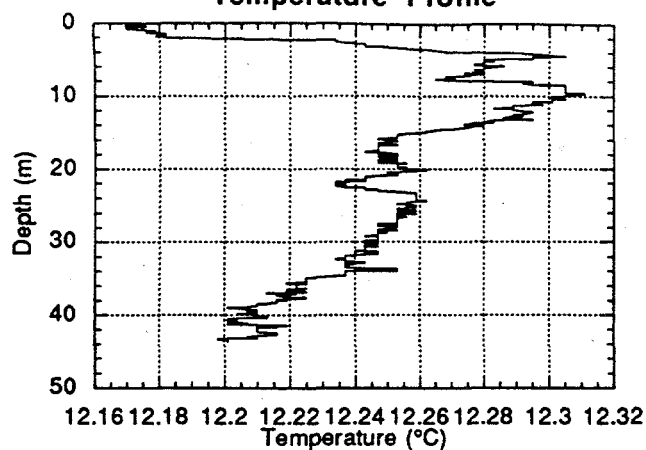


Mode 2 Eigenfunctions, D=80 m

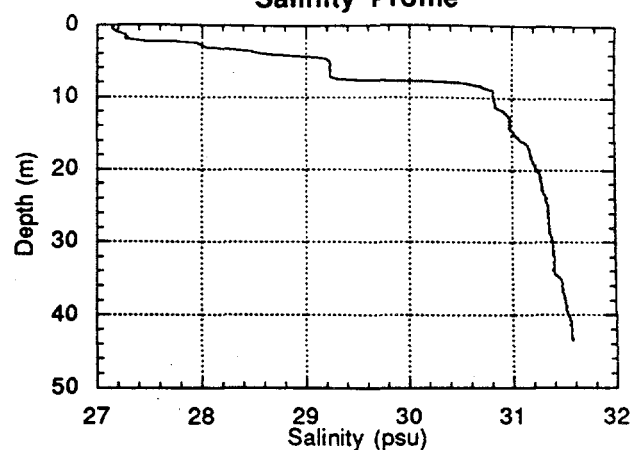


9/13/94, 15:30 GMT

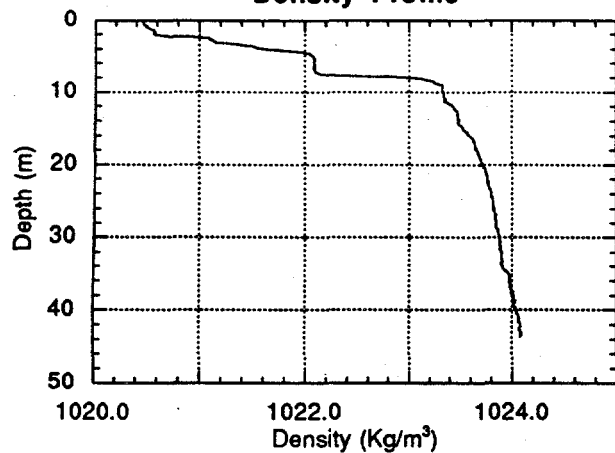
Temperature Profile



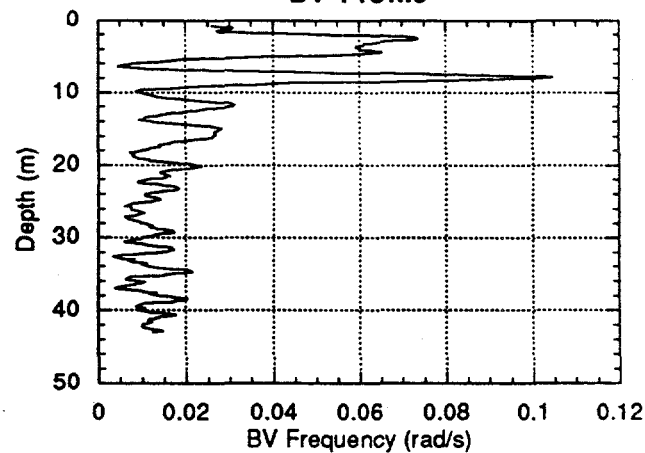
Salinity Profile



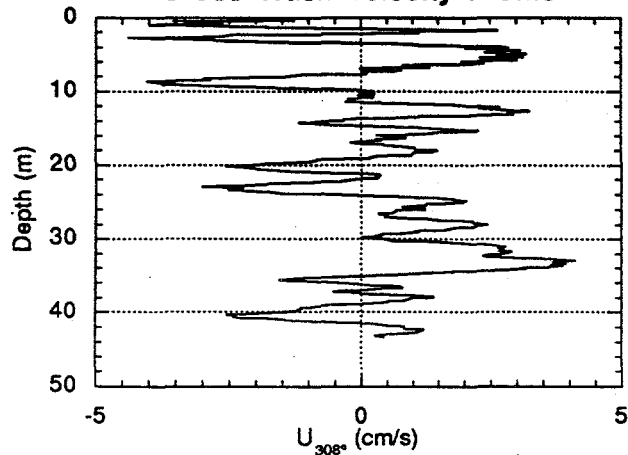
Density Profile



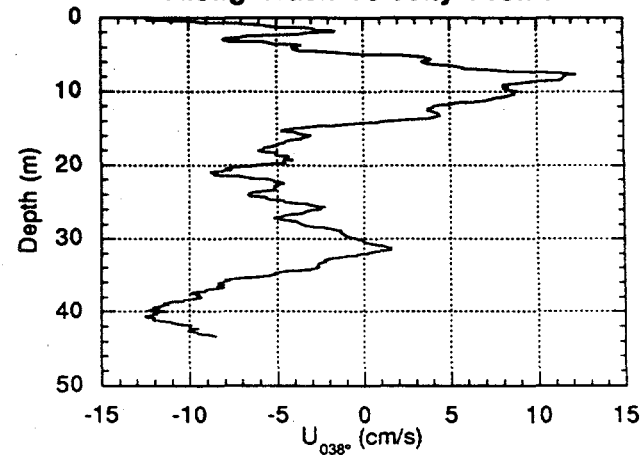
BV Profile



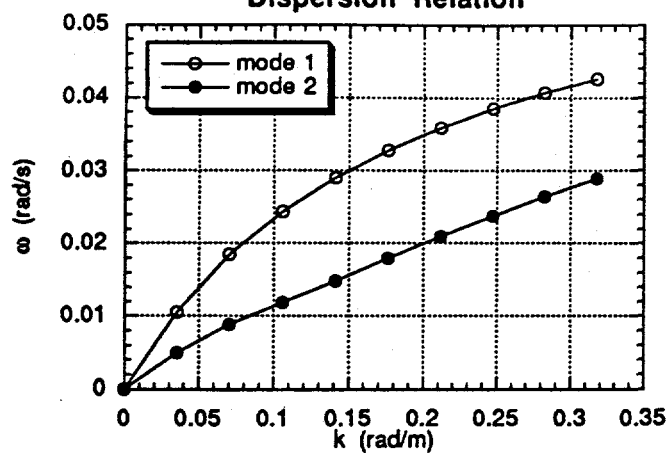
Cross Track Velocity Profile



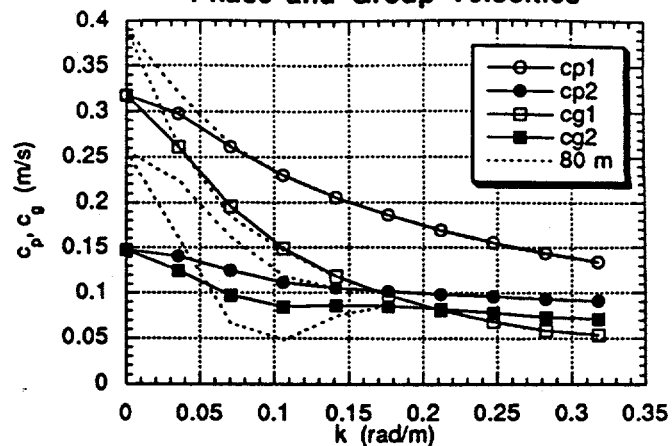
Along Track Velocity Profile



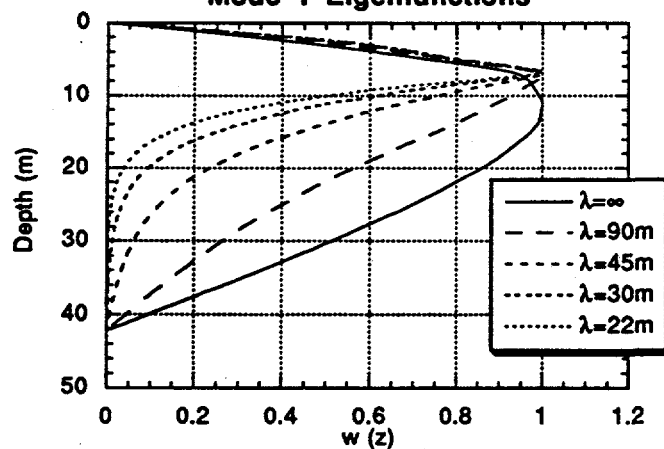
Dispersion Relation



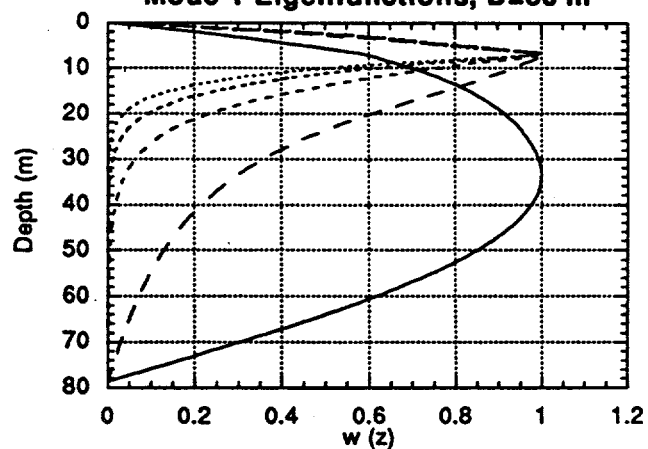
Phase and Group Velocities



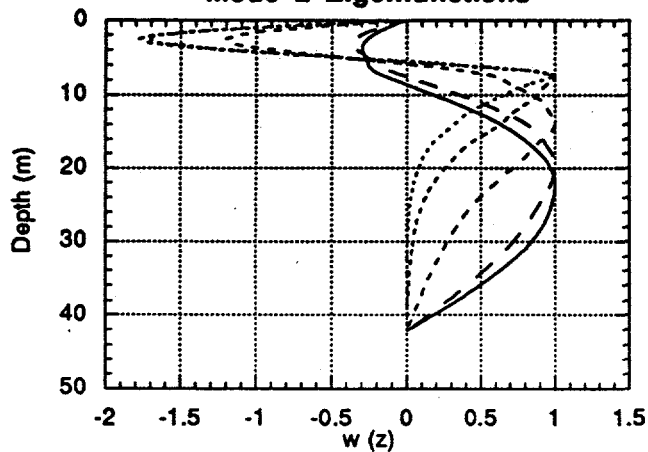
Mode 1 Eigenfunctions



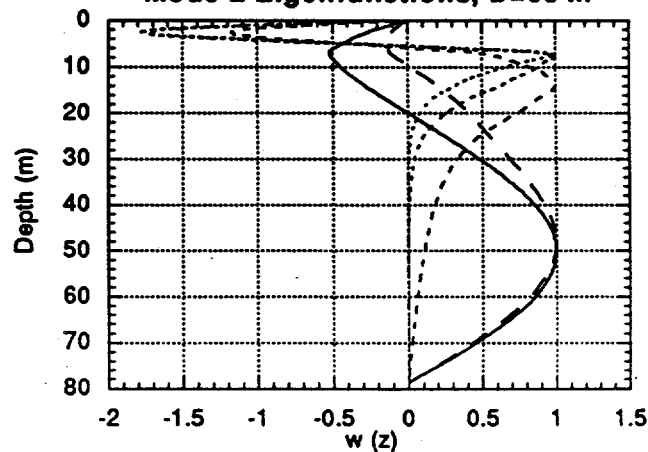
Mode 1 Eigenfunctions, D=80 m

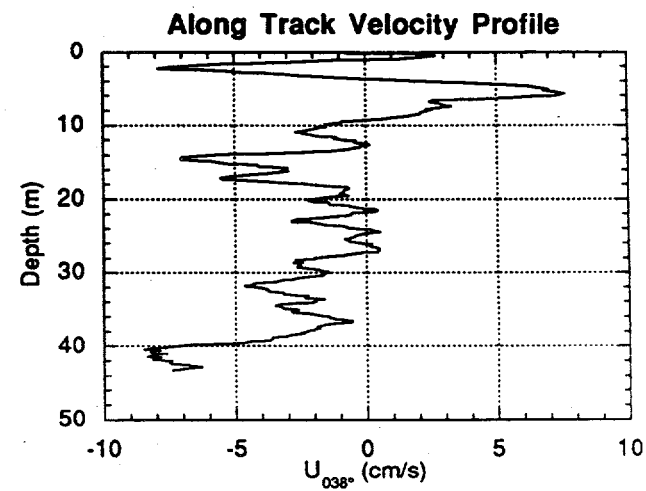
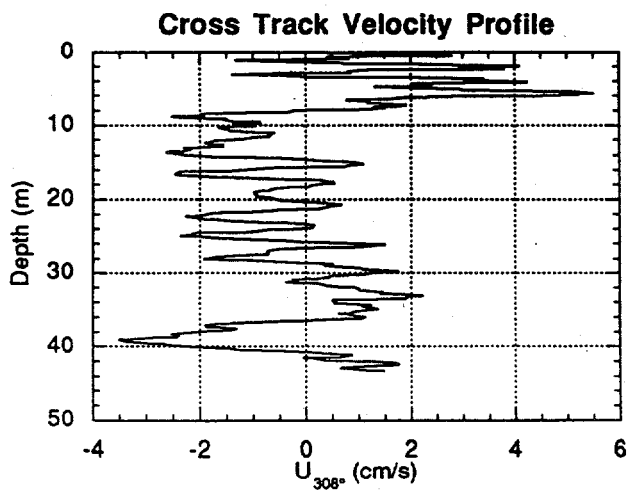
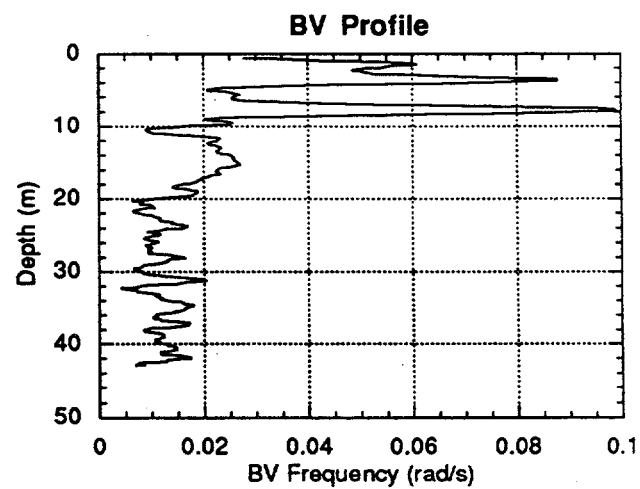
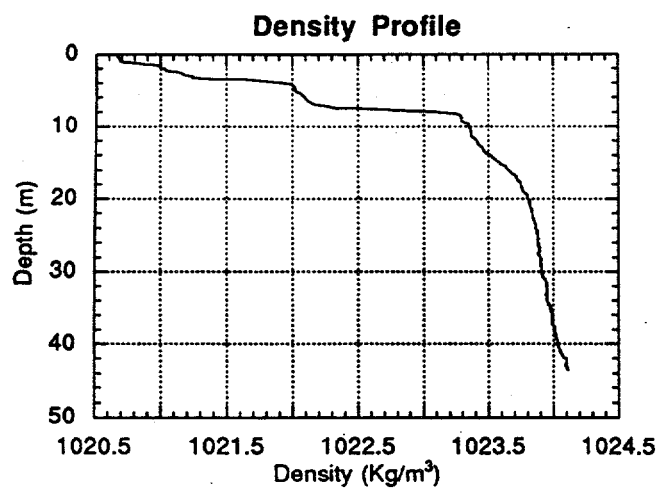
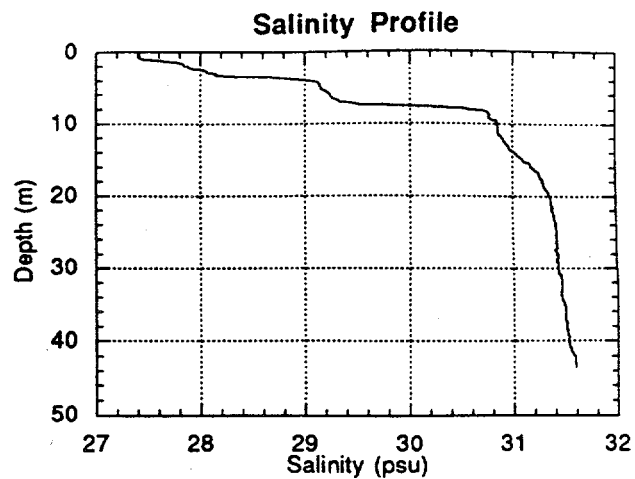
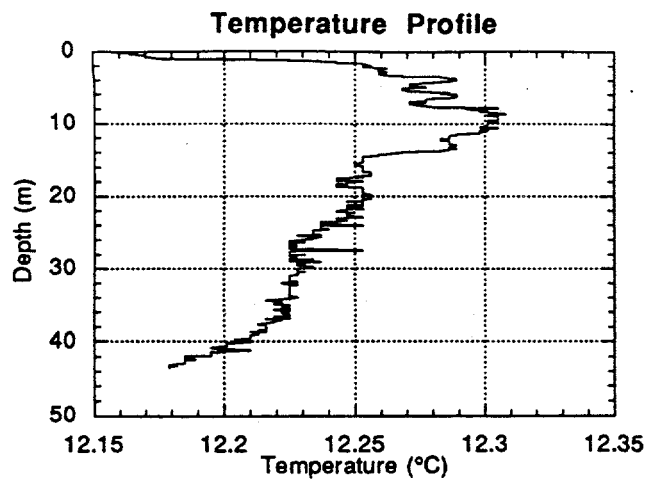


Mode 2 Eigenfunctions

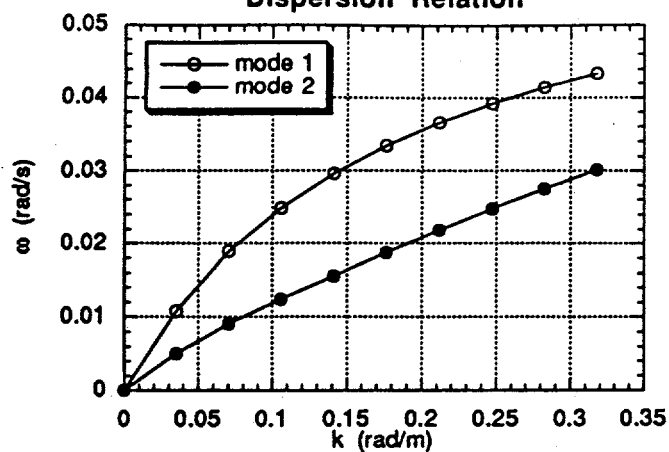


Mode 2 Eigenfunctions, D=80 m

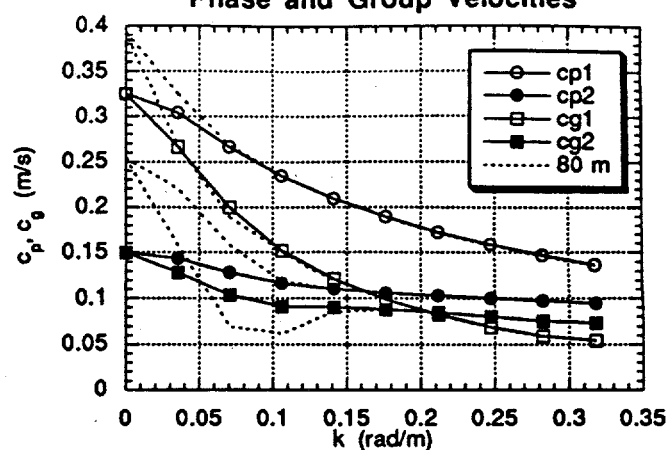




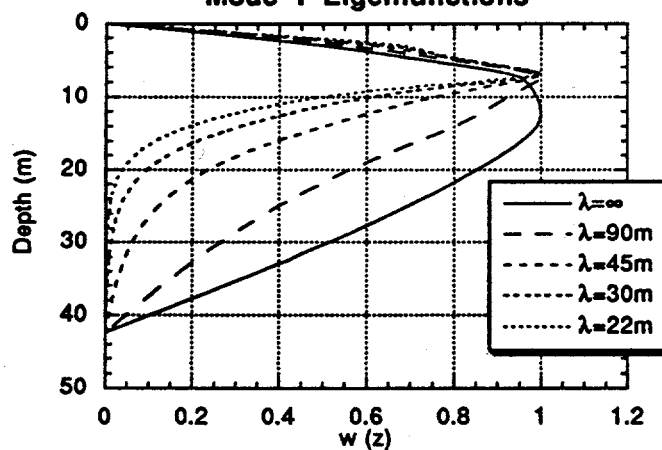
Dispersion Relation



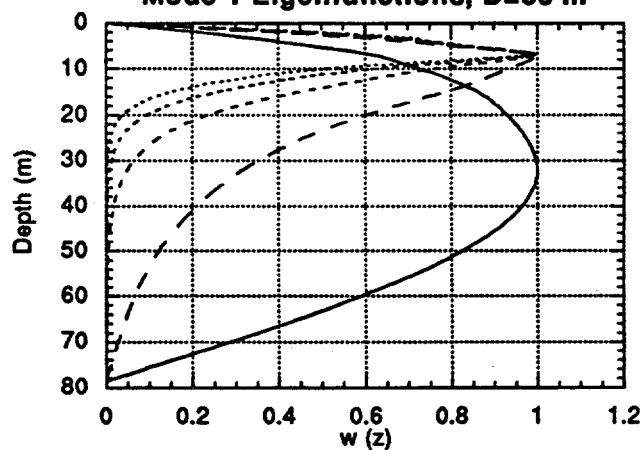
Phase and Group Velocities



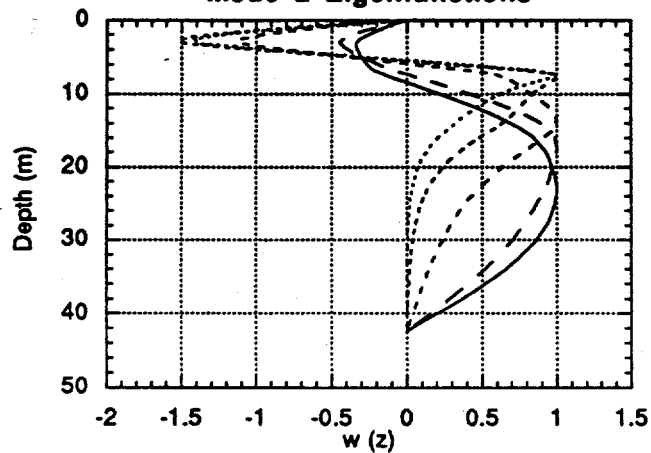
Mode 1 Eigenfunctions



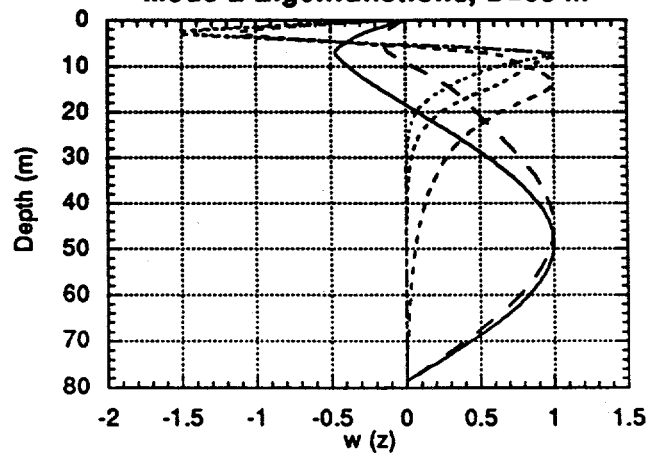
Mode 1 Eigenfunctions, D=80 m

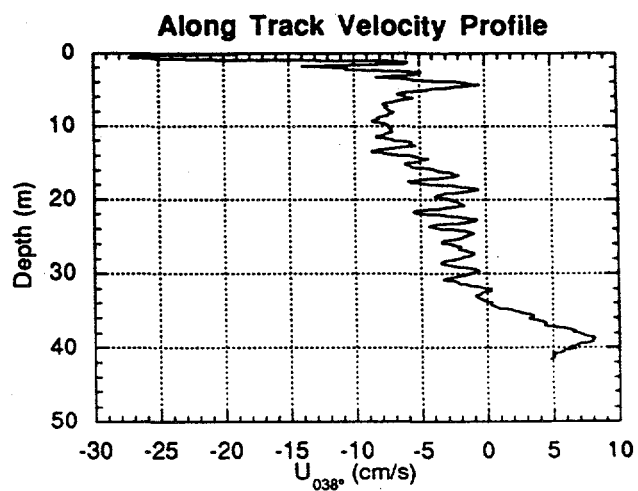
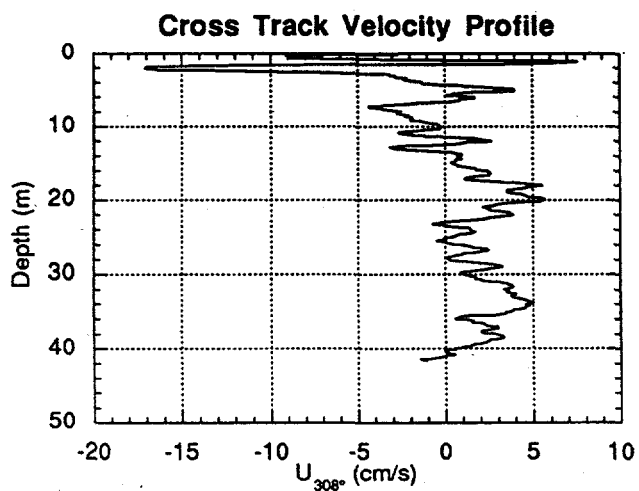
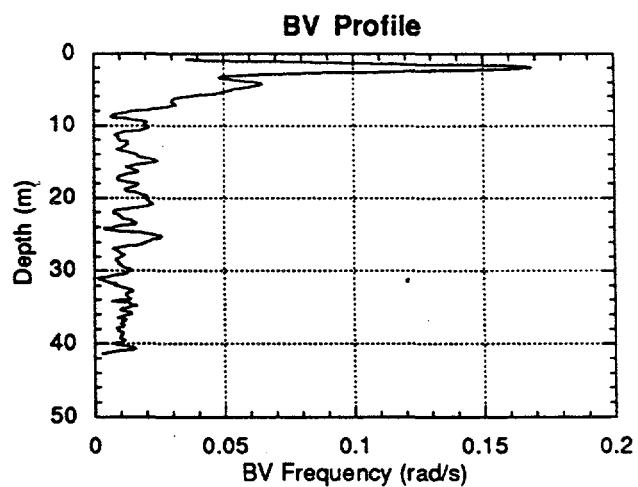
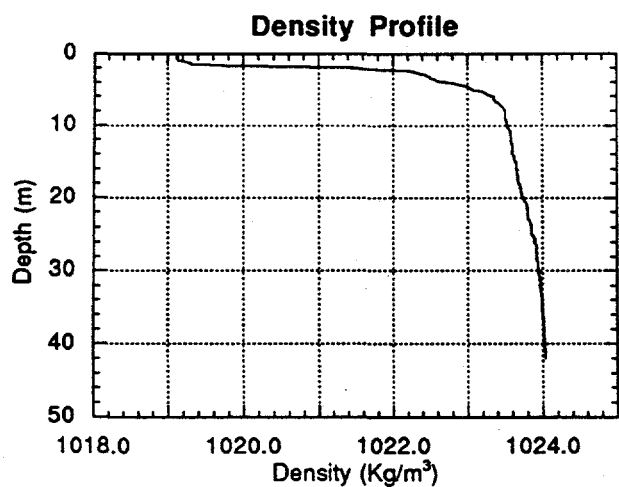
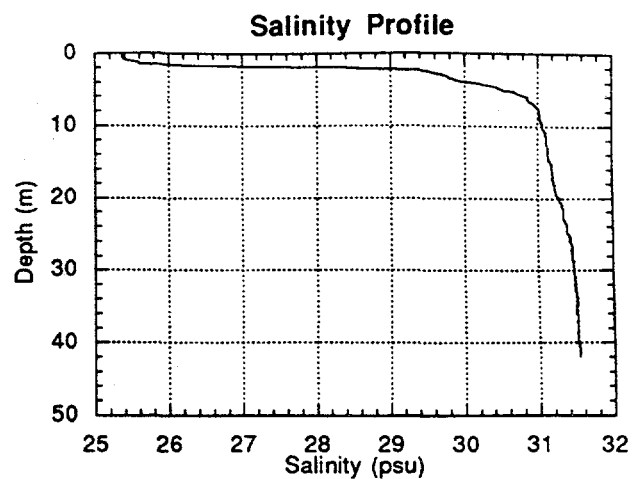
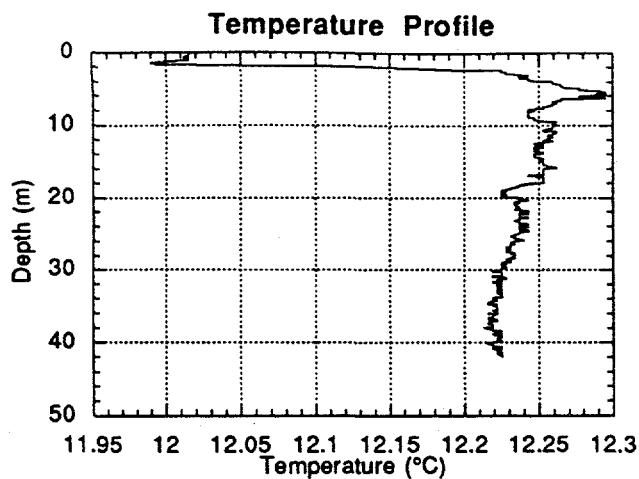


Mode 2 Eigenfunctions

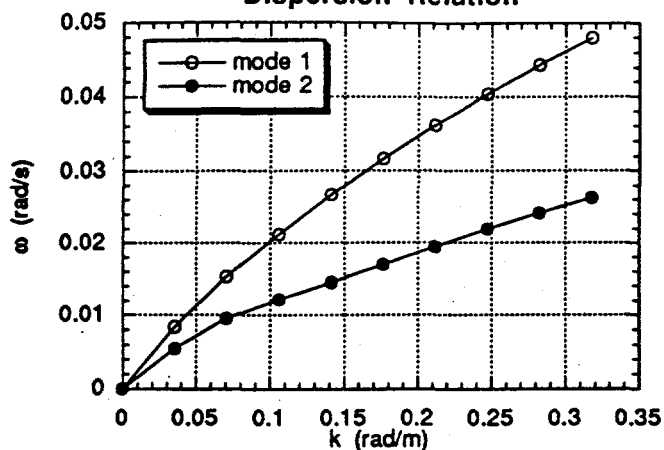


Mode 2 Eigenfunctions, D=80 m

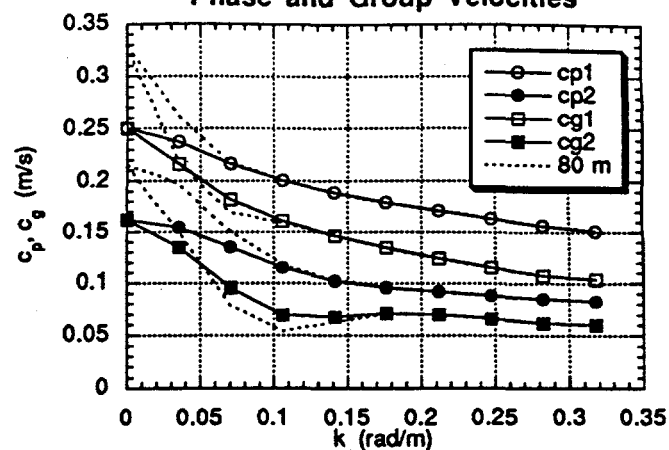




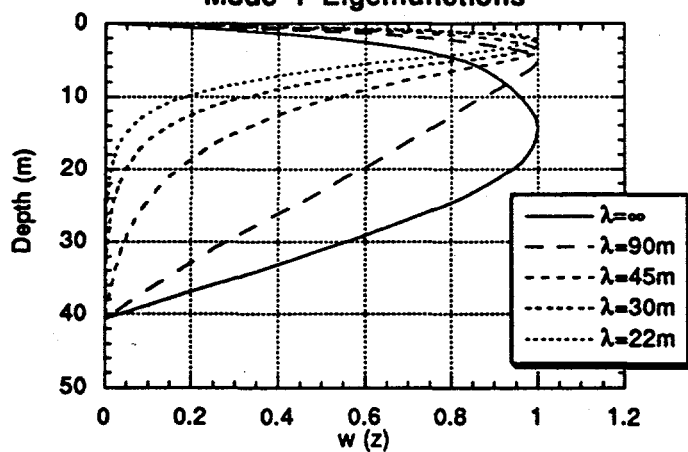
Dispersion Relation



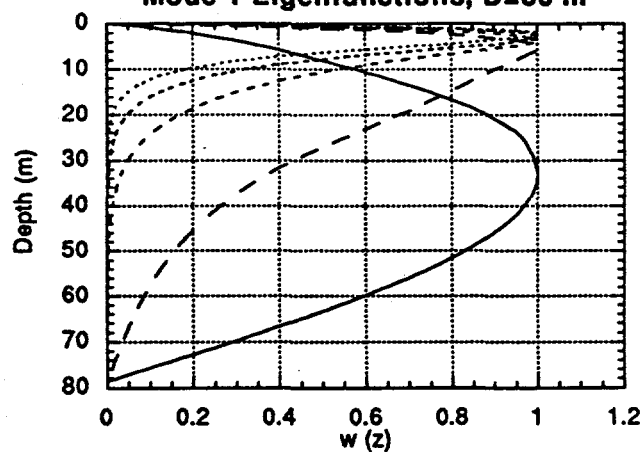
Phase and Group Velocities



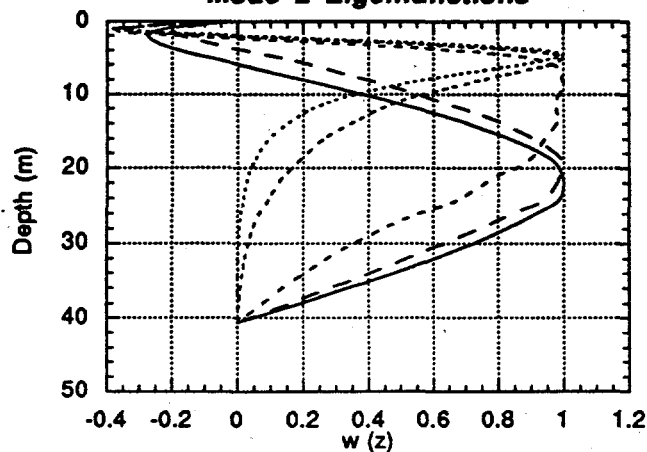
Mode 1 Eigenfunctions



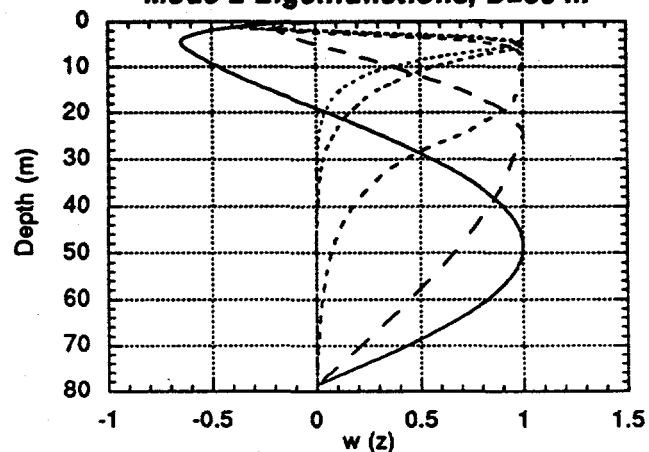
Mode 1 Eigenfunctions, D=80 m

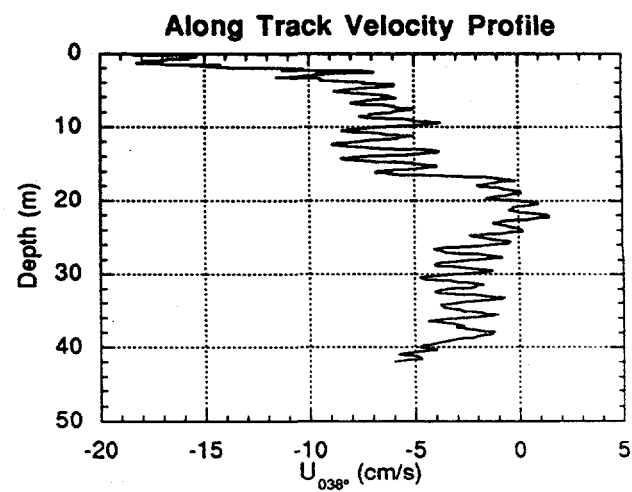
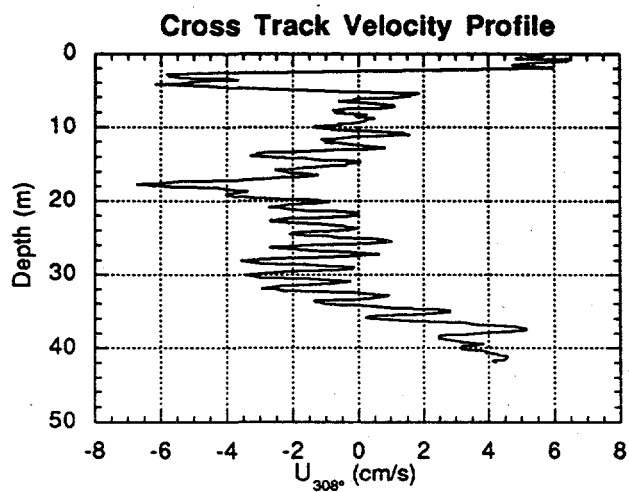
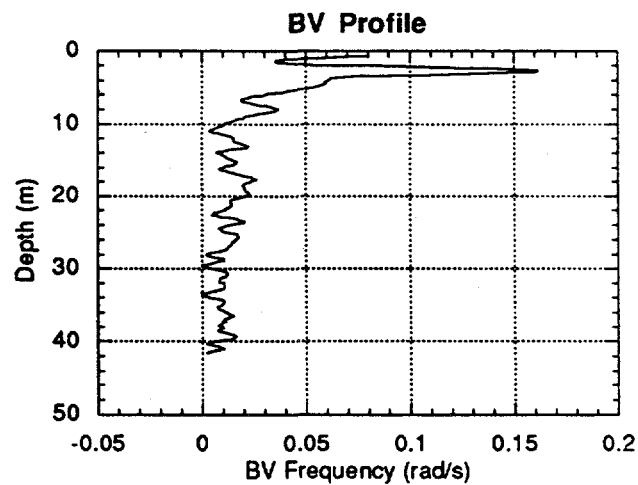
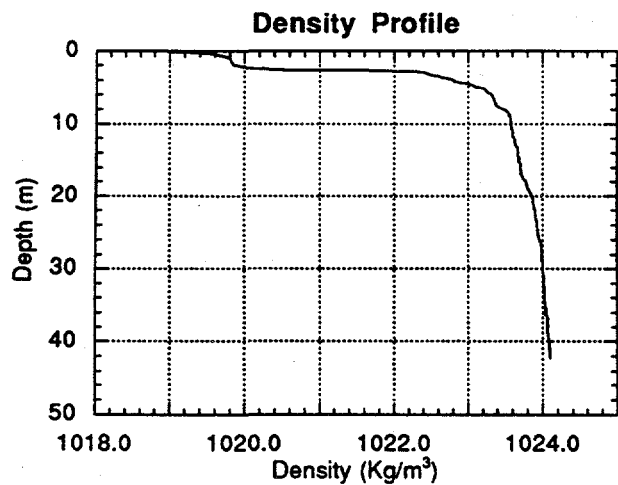
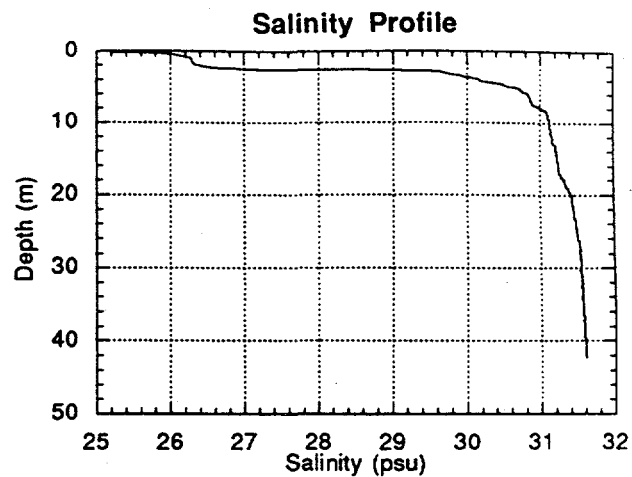
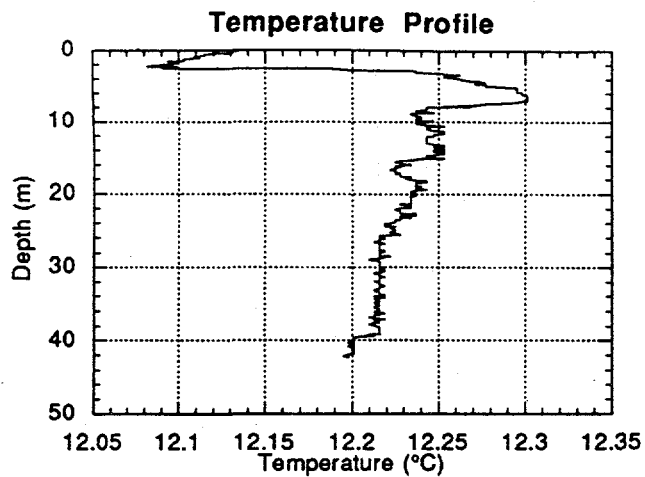


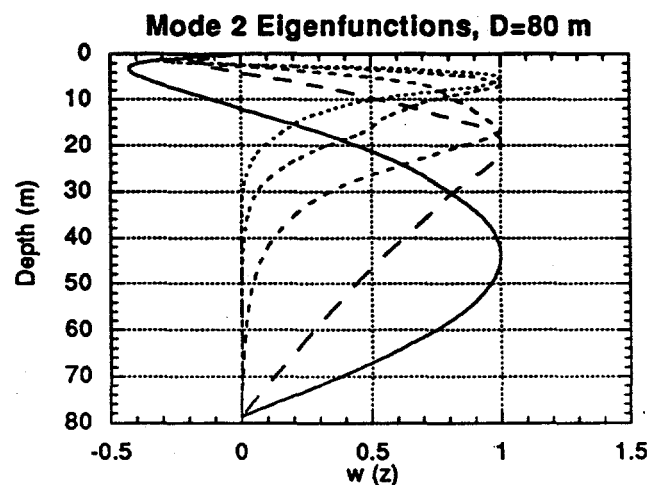
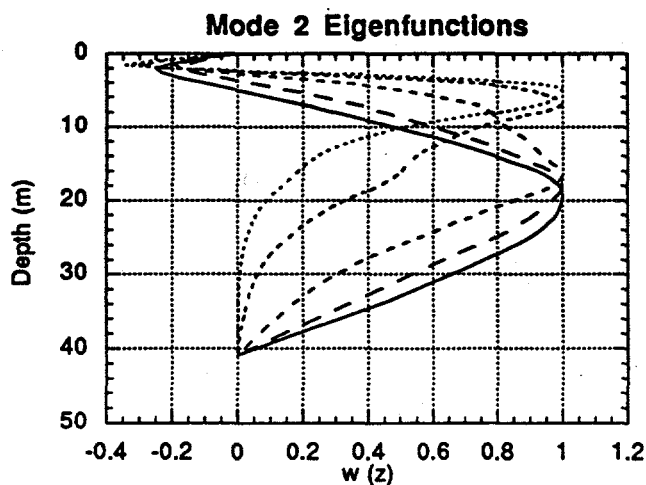
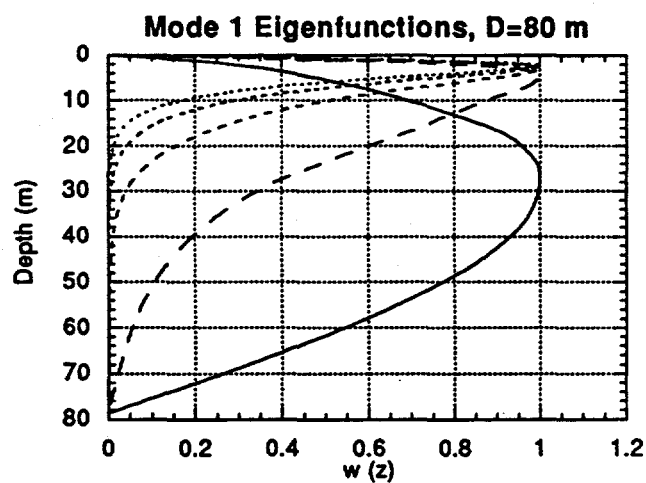
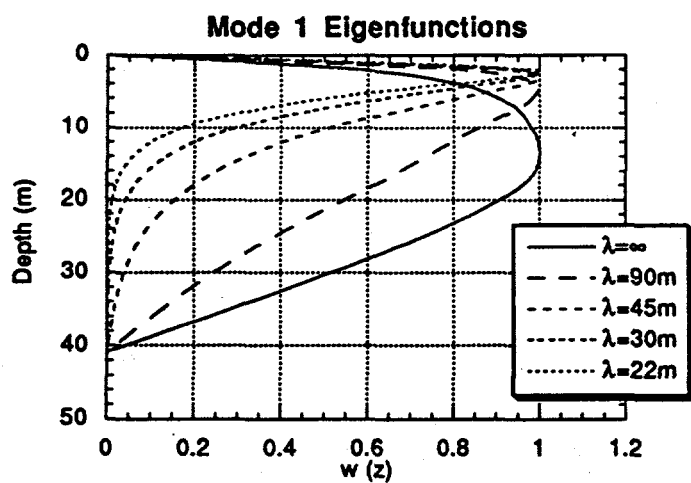
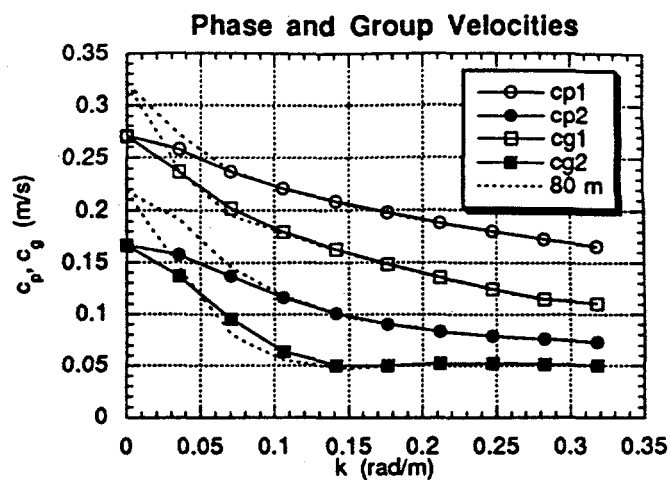
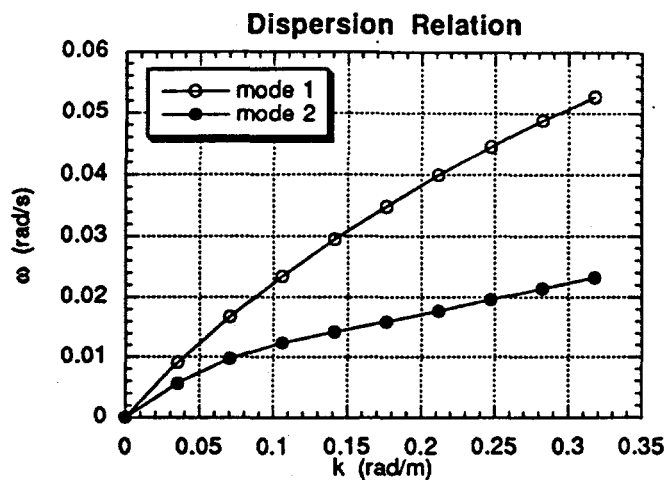
Mode 2 Eigenfunctions

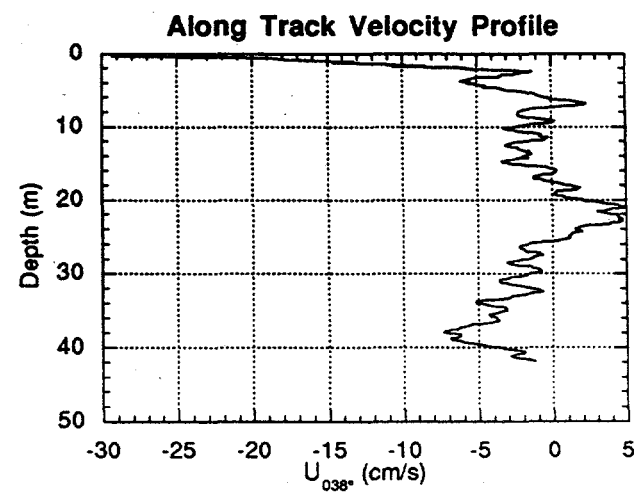
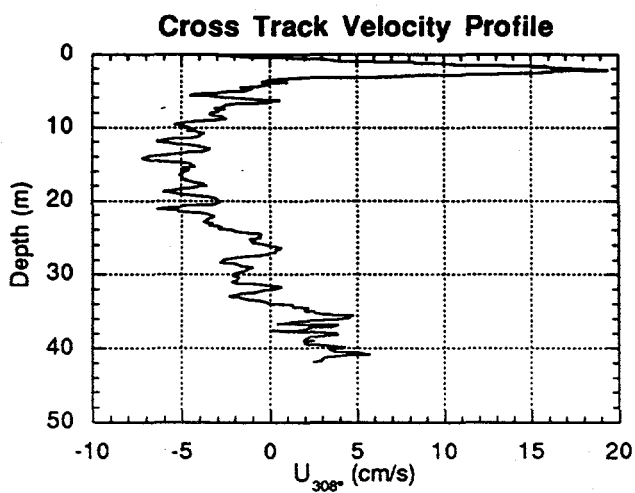
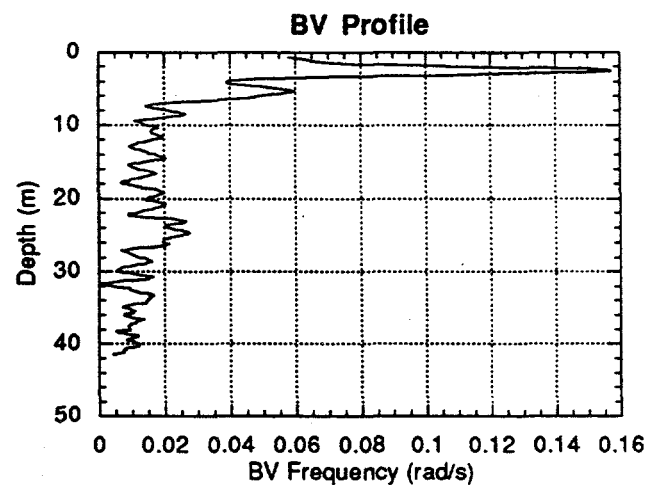
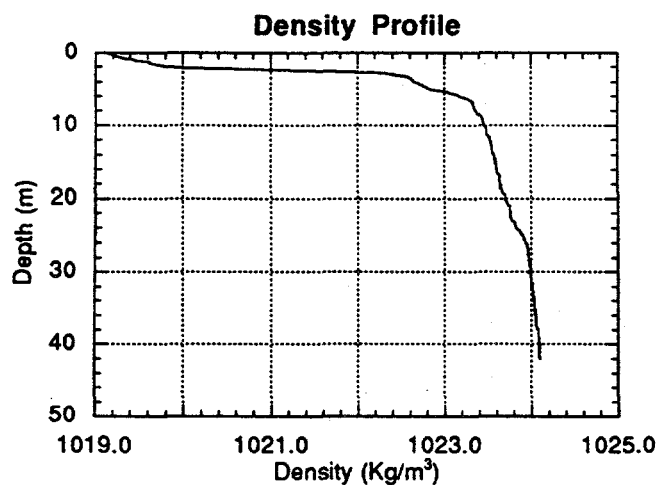
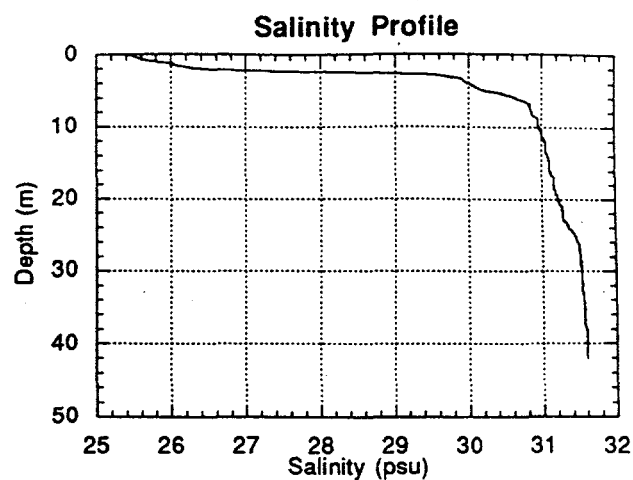
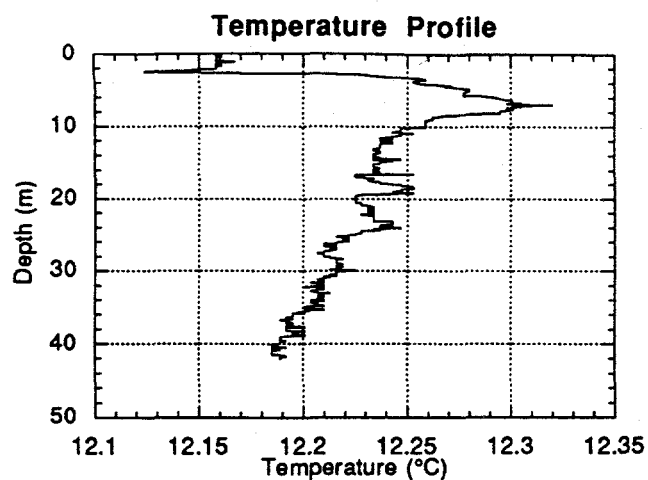


Mode 2 Eigenfunctions, D=80 m

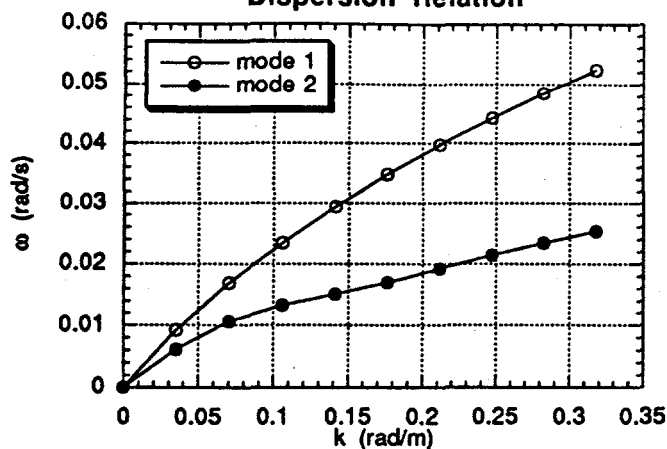




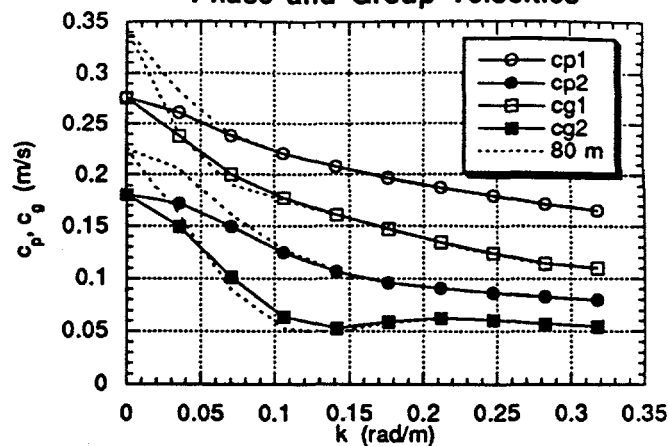




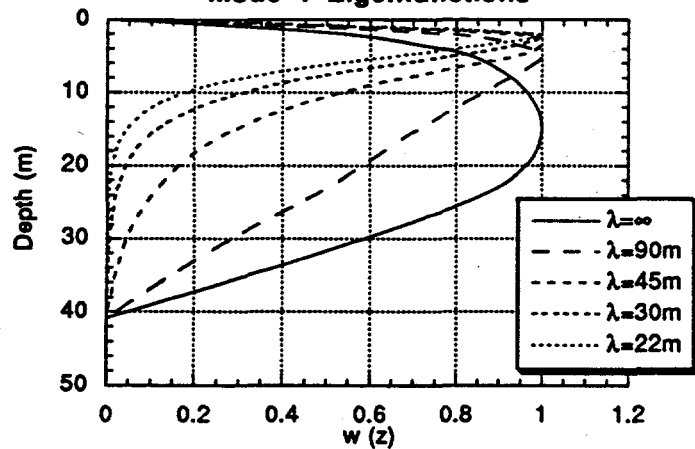
Dispersion Relation



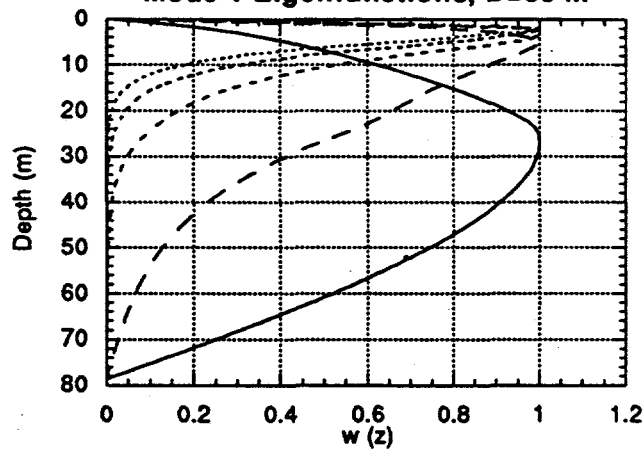
Phase and Group Velocities



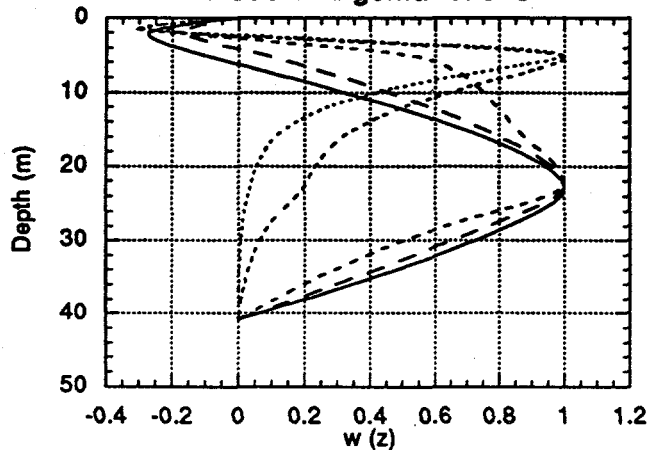
Mode 1 Eigenfunctions



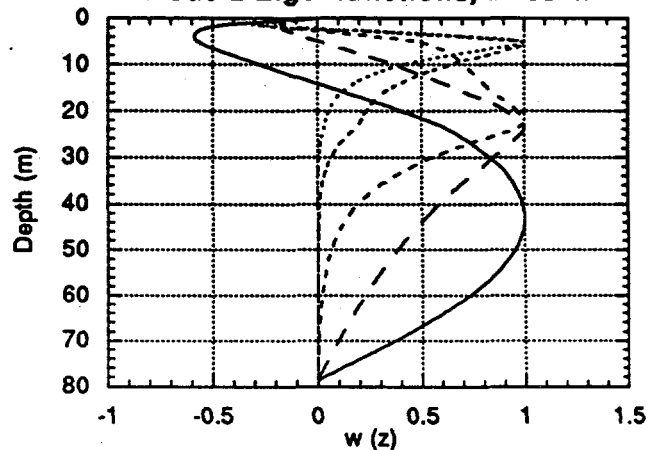
Mode 1 Eigenfunctions, D=80 m

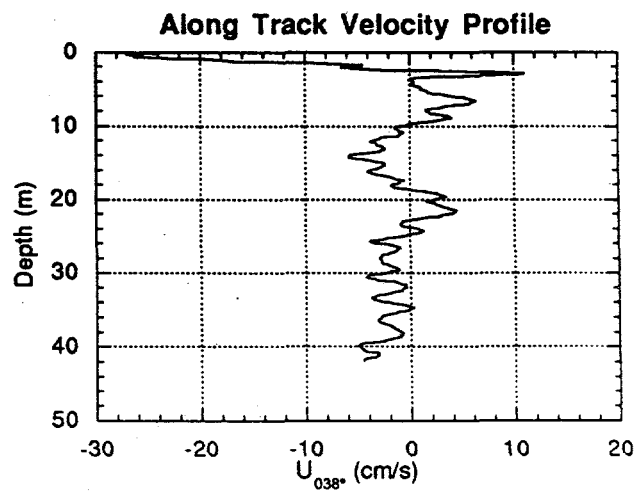
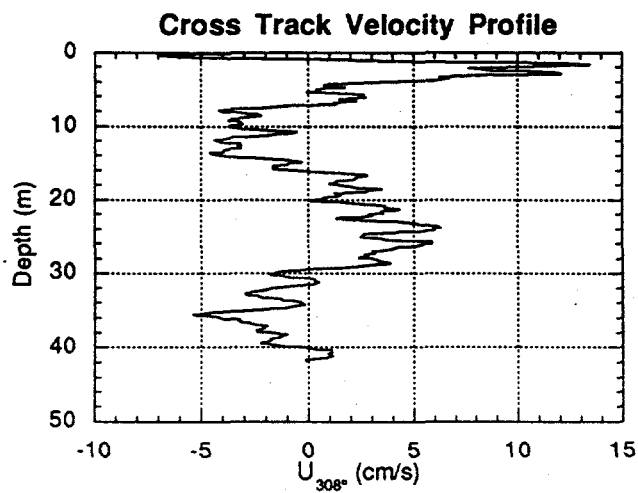
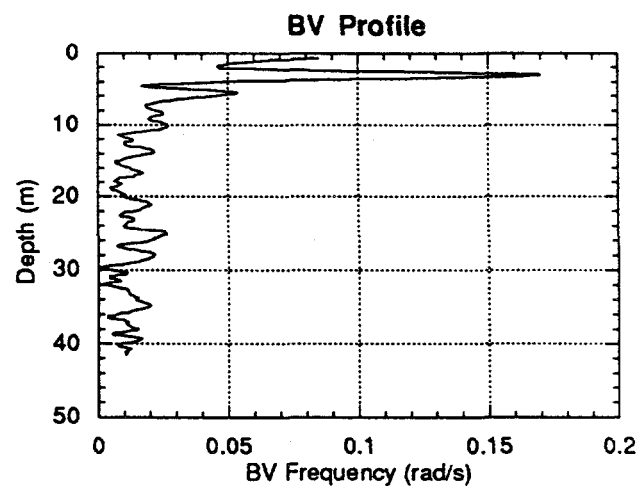
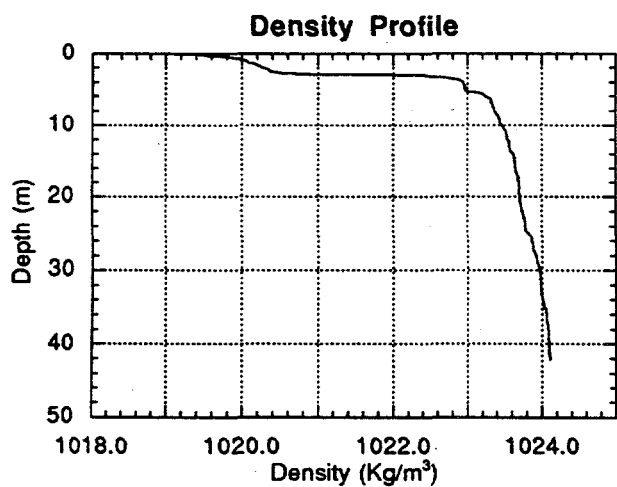
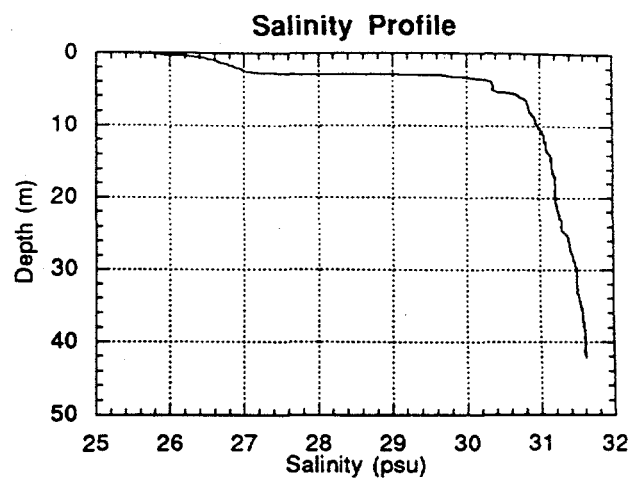
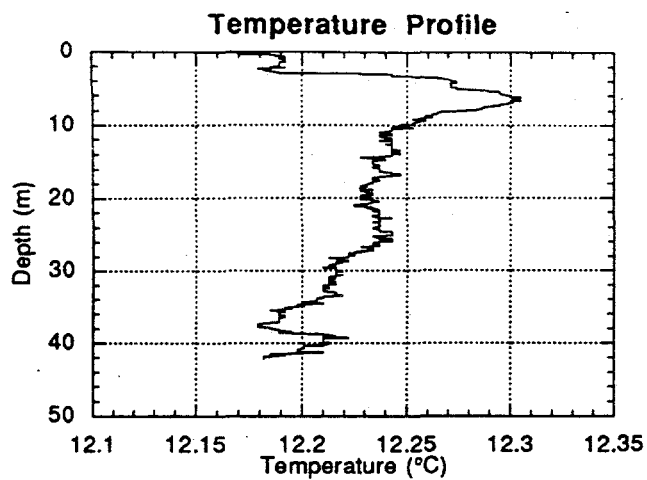


Mode 2 Eigenfunctions

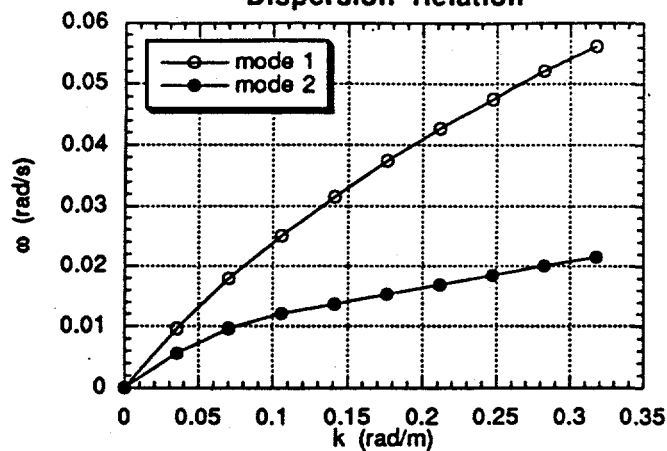


Mode 2 Eigenfunctions, D=80 m

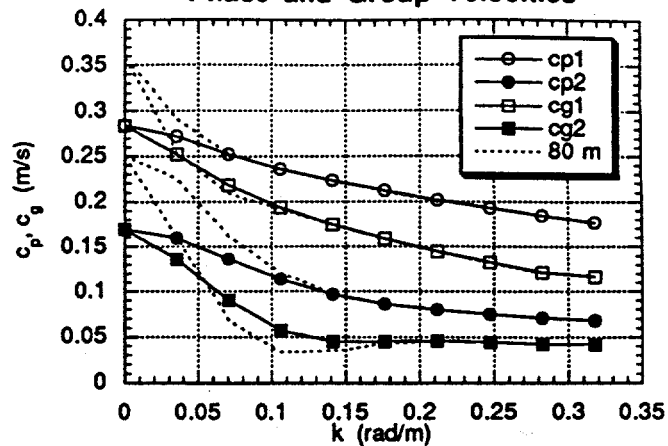




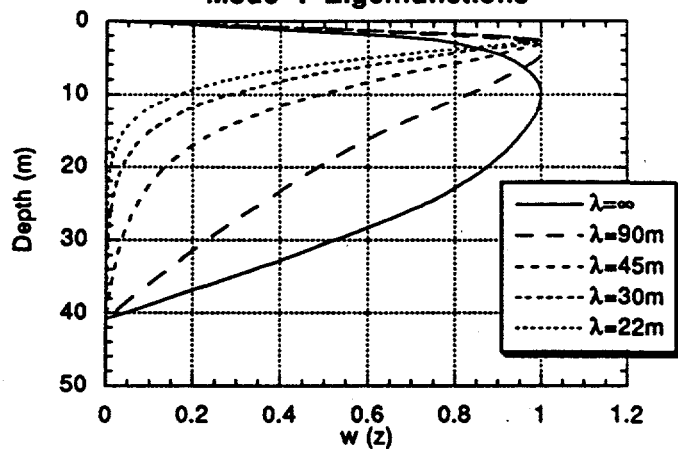
Dispersion Relation



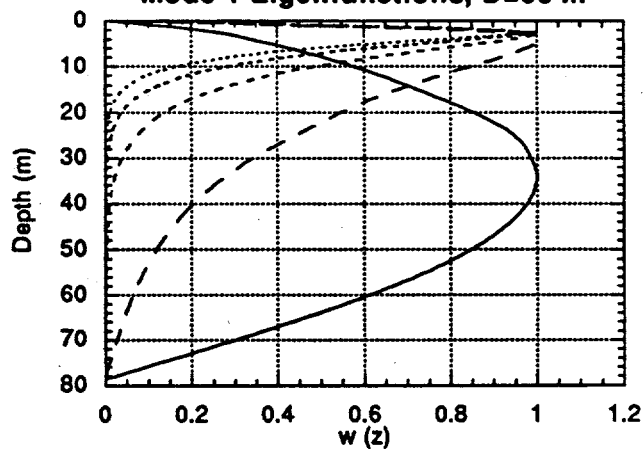
Phase and Group Velocities



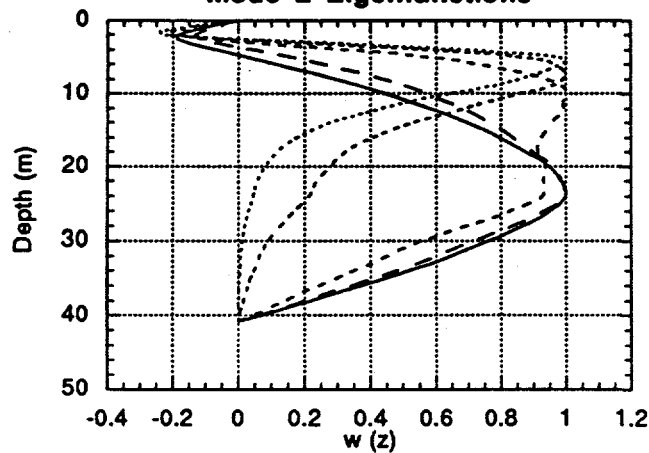
Mode 1 Eigenfunctions



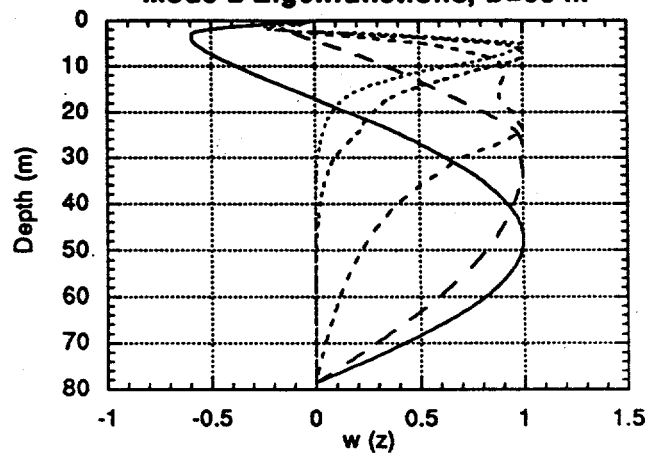
Mode 1 Eigenfunctions, D=80 m

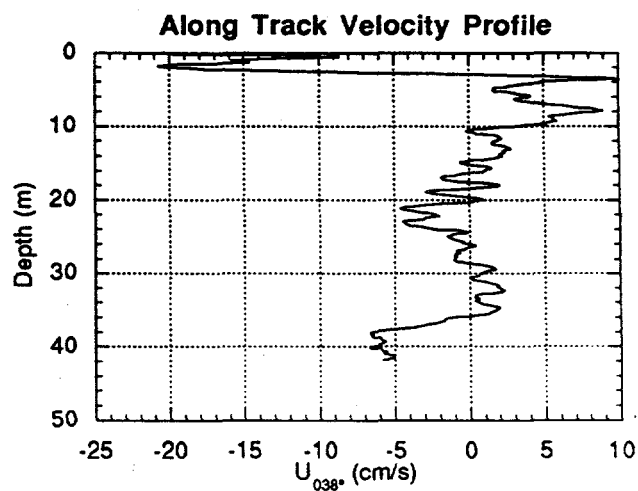
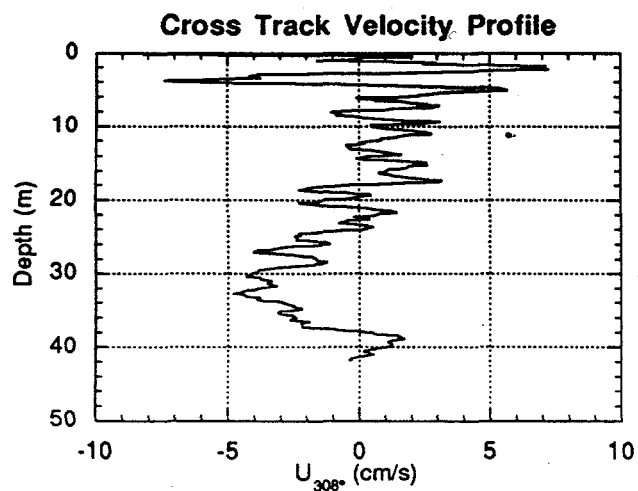
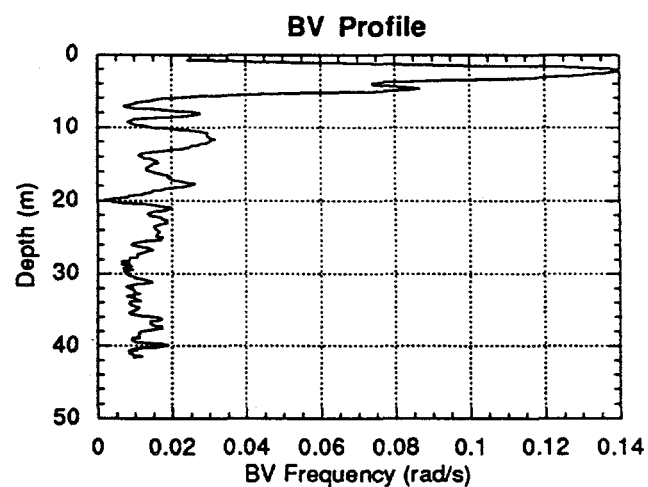
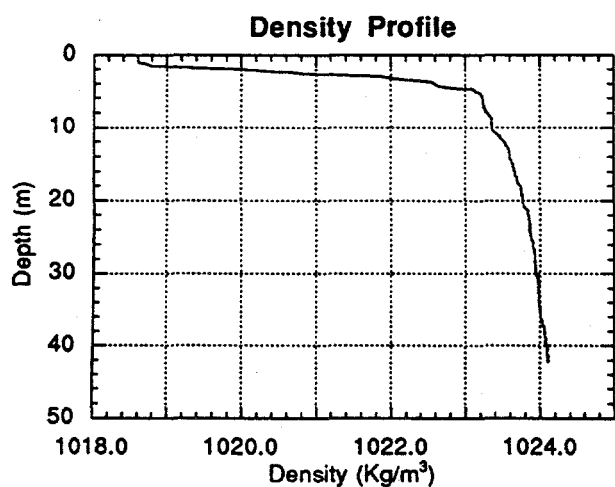
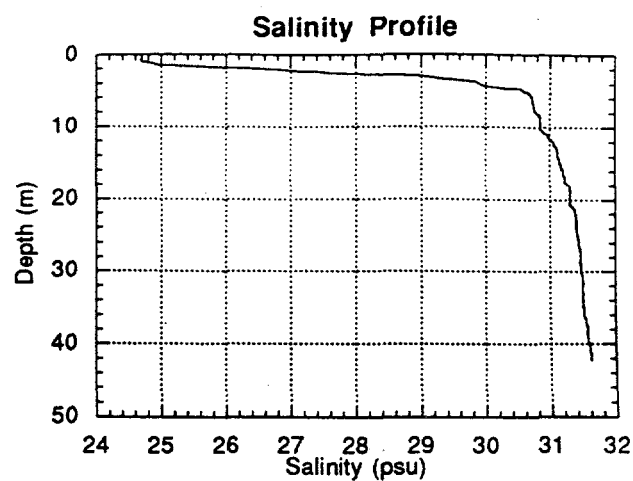
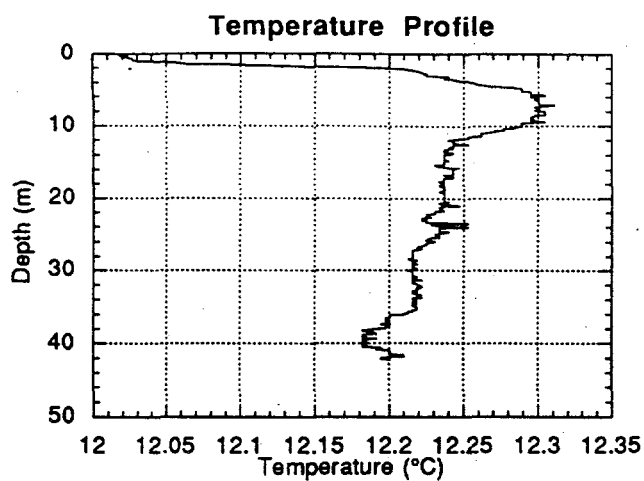


Mode 2 Eigenfunctions

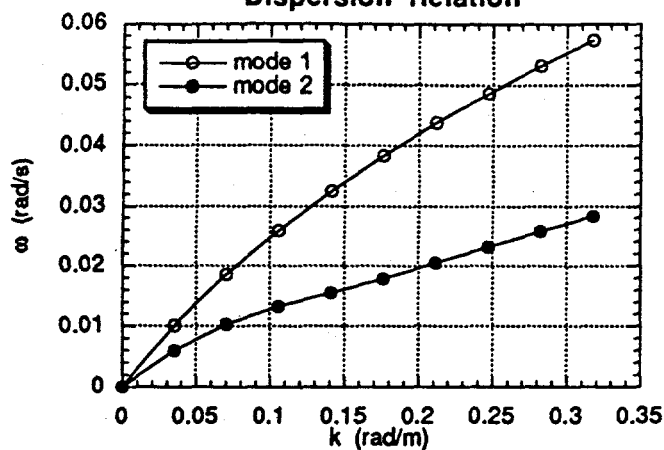


Mode 2 Eigenfunctions, D=80 m

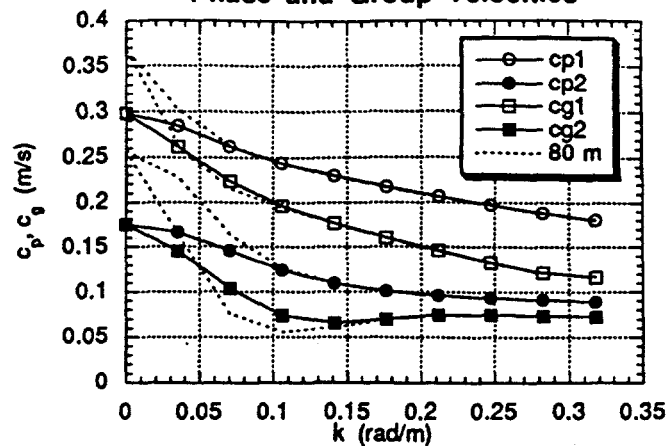




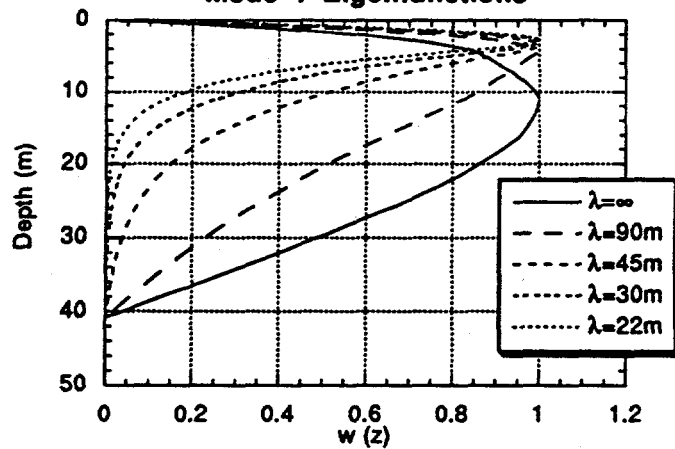
Dispersion Relation



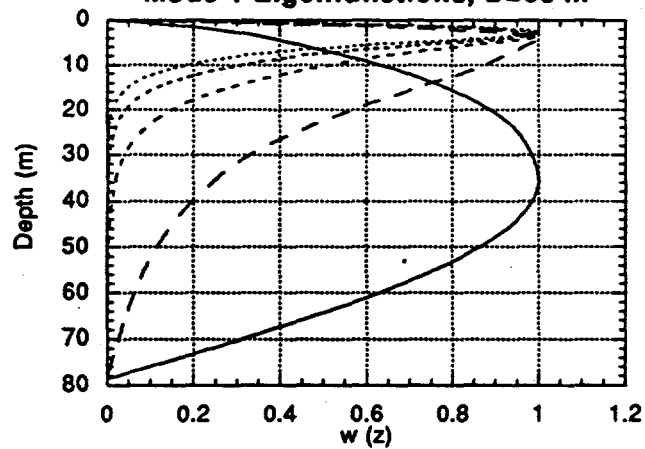
Phase and Group Velocities



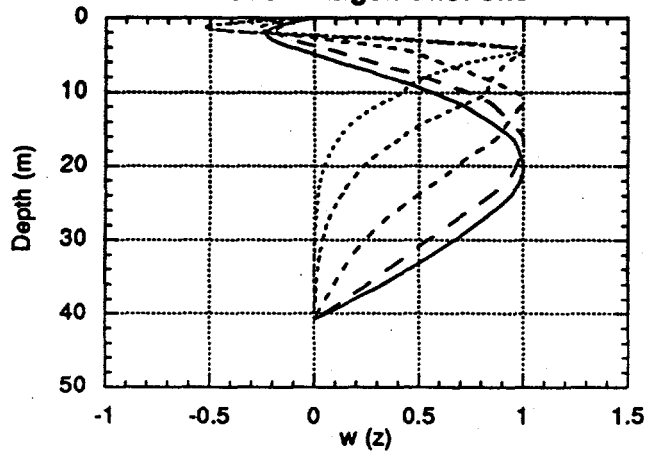
Mode 1 Eigenfunctions



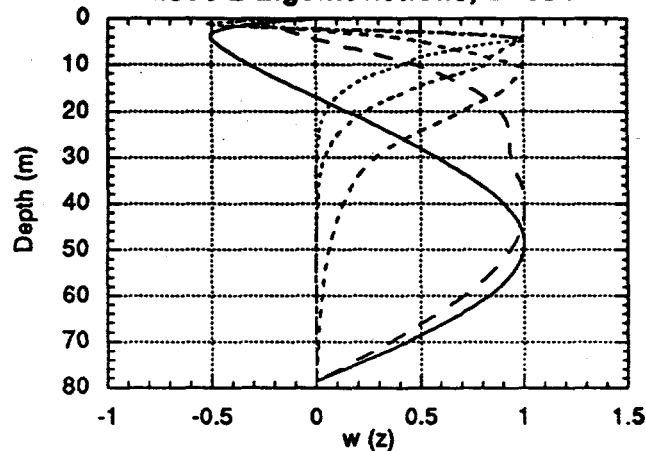
Mode 1 Eigenfunctions, D=80 m

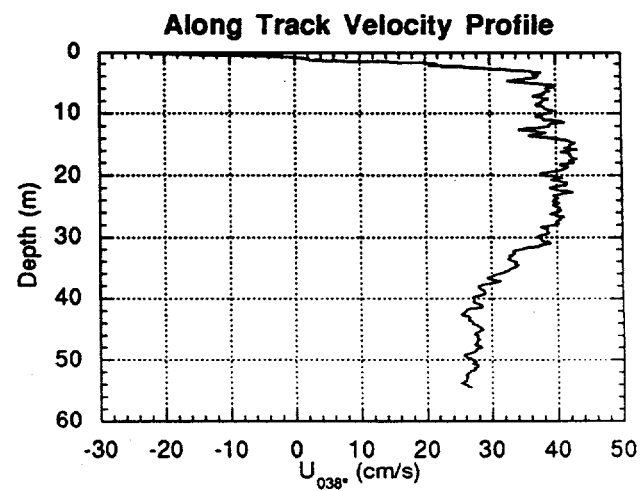
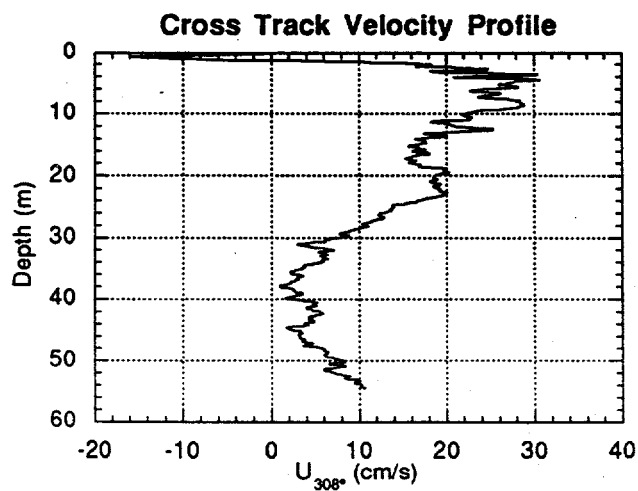
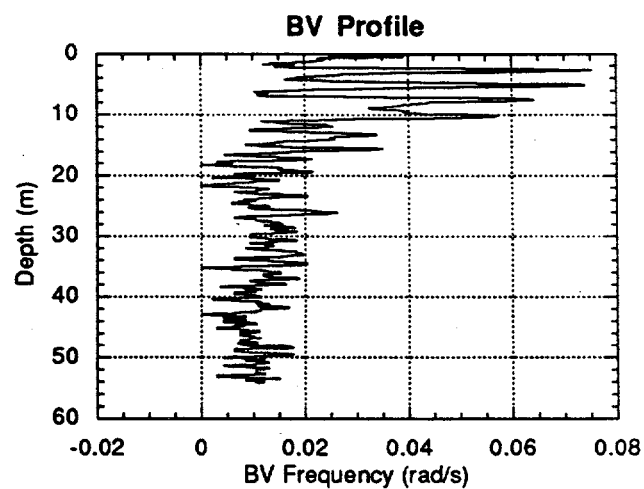
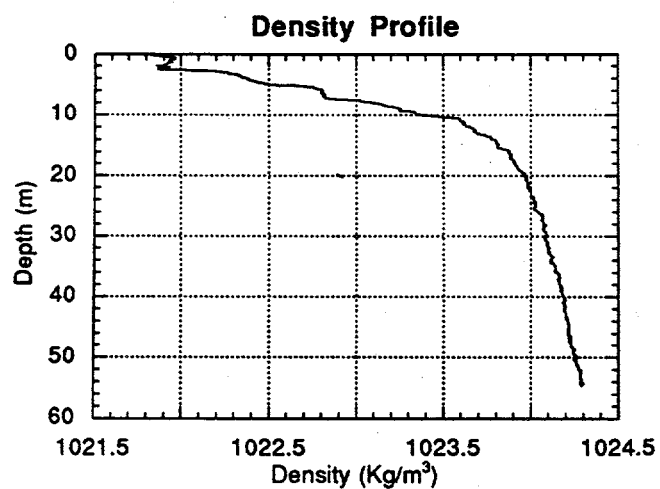
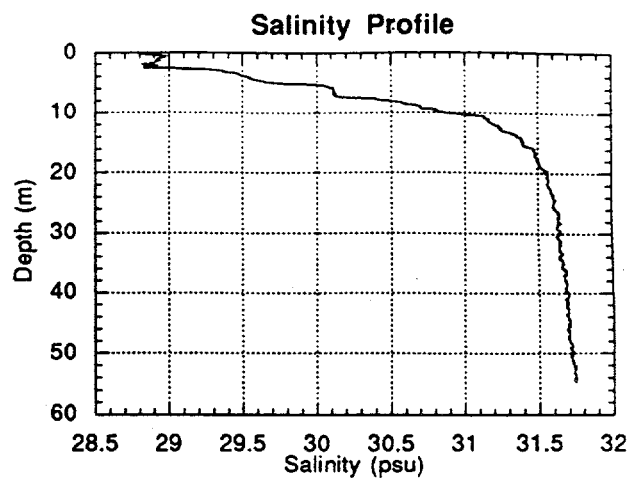
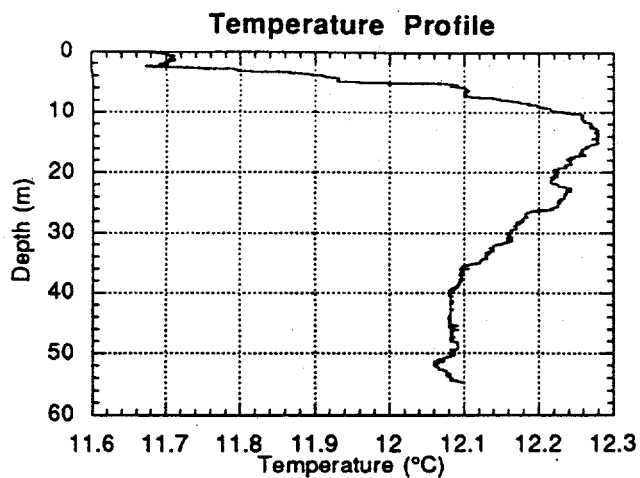


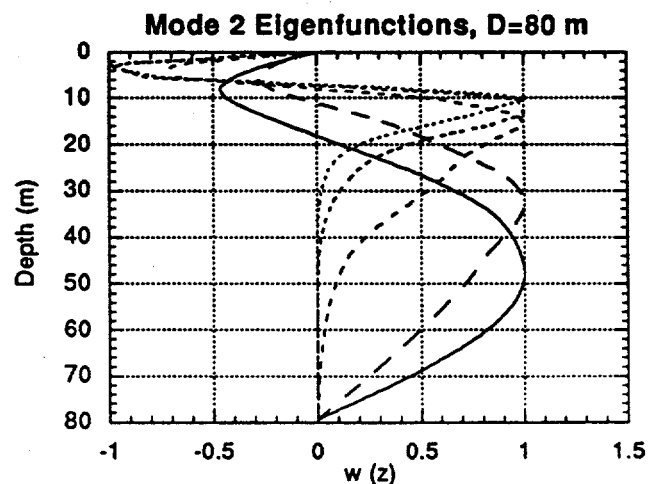
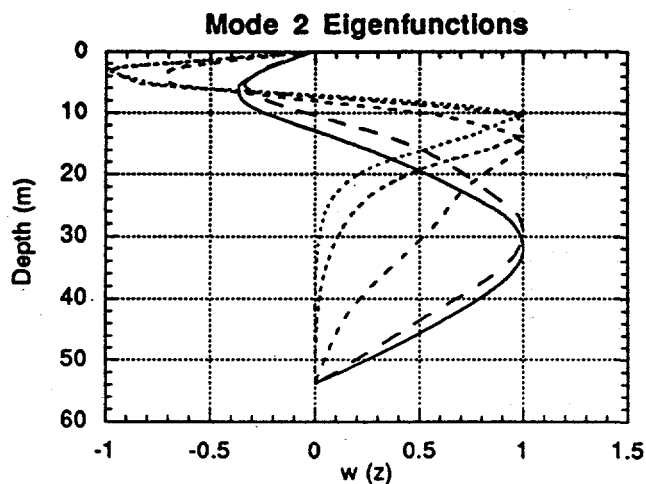
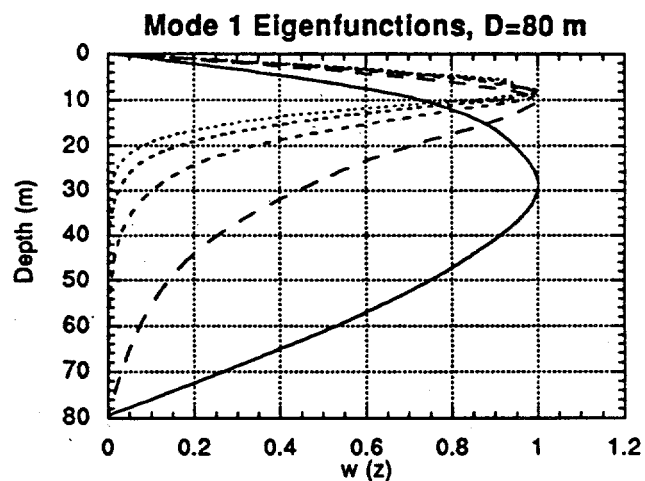
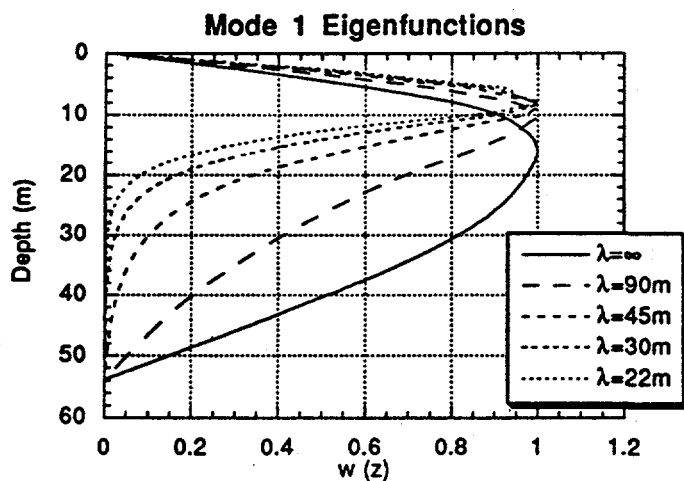
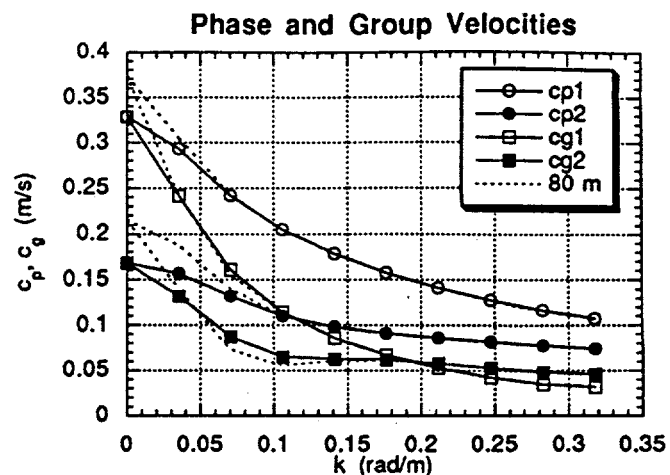
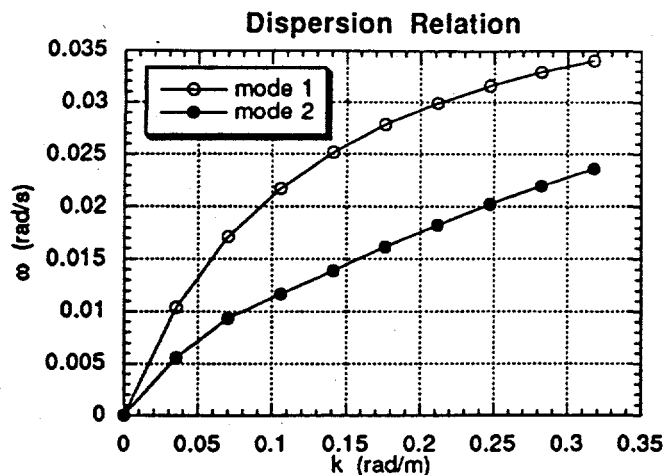
Mode 2 Eigenfunctions

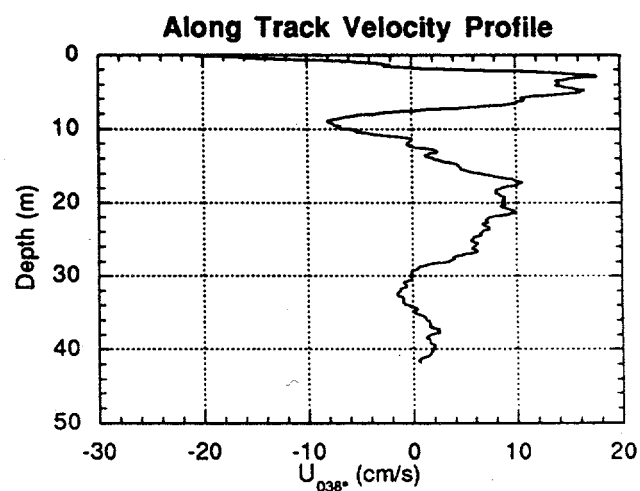
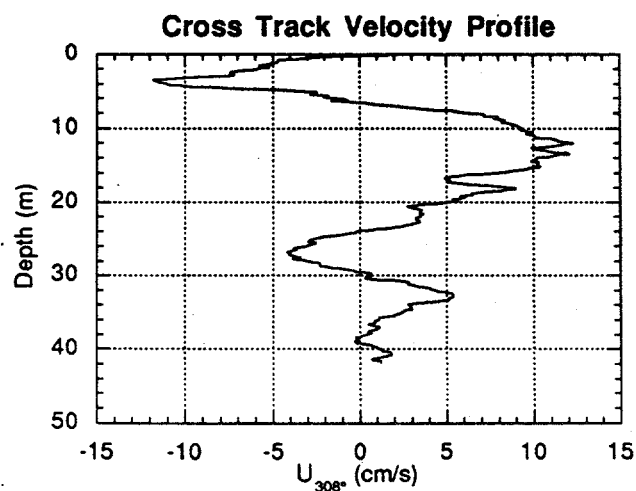
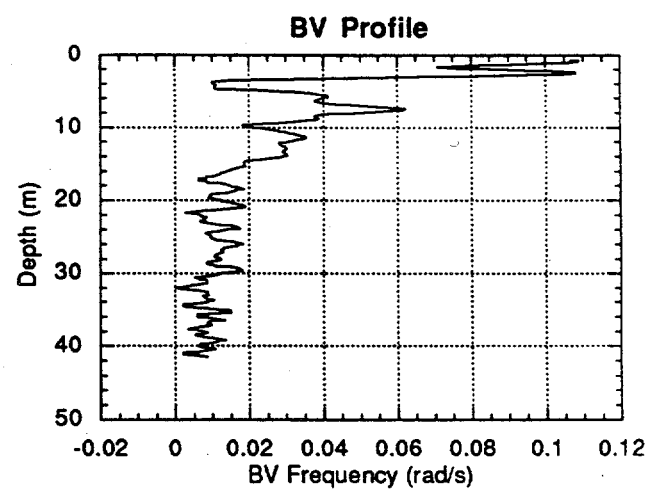
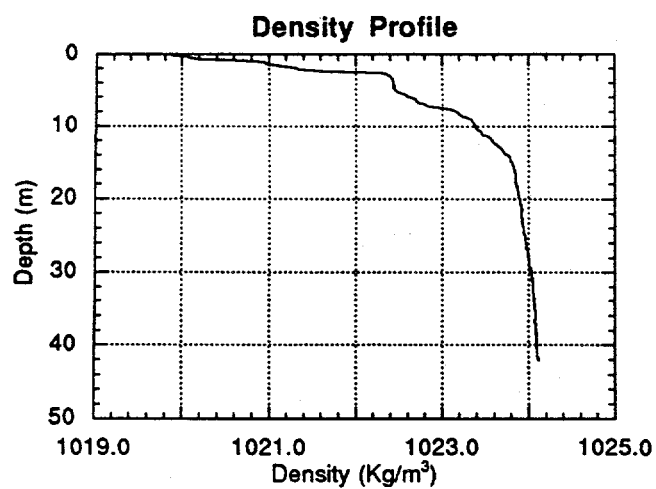
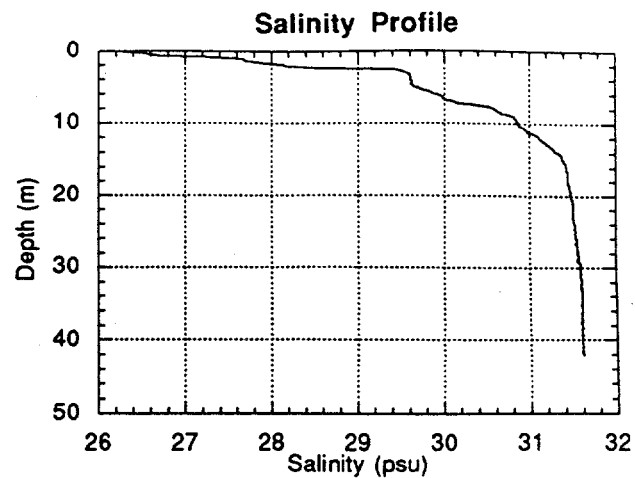
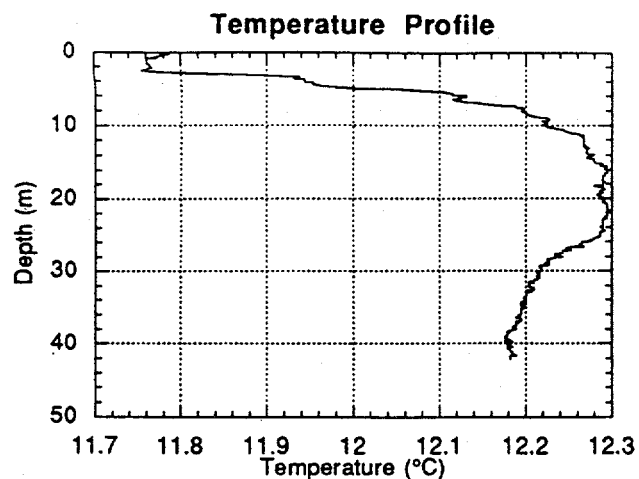


Mode 2 Eigenfunctions, D=80 m

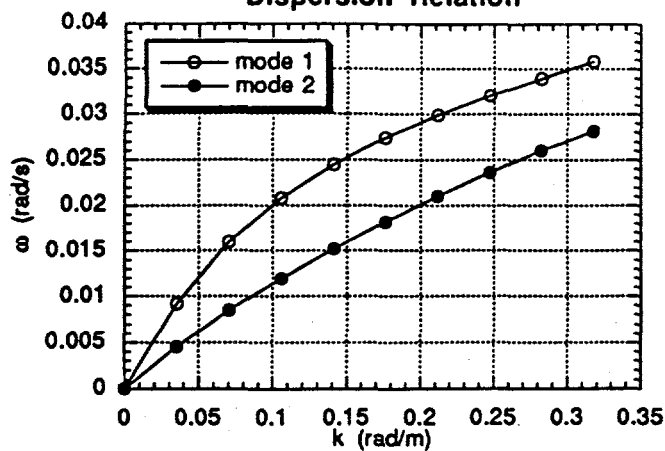




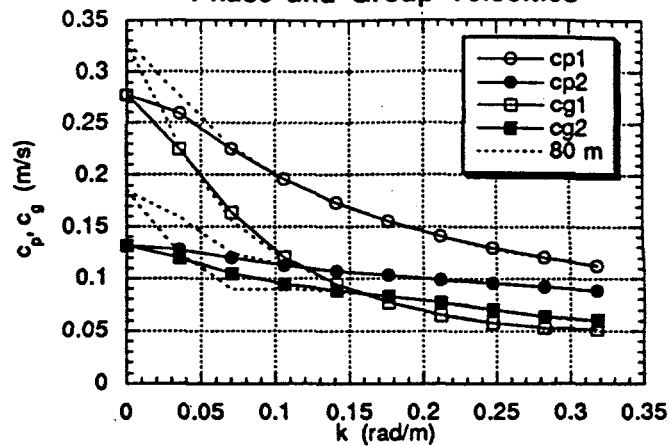




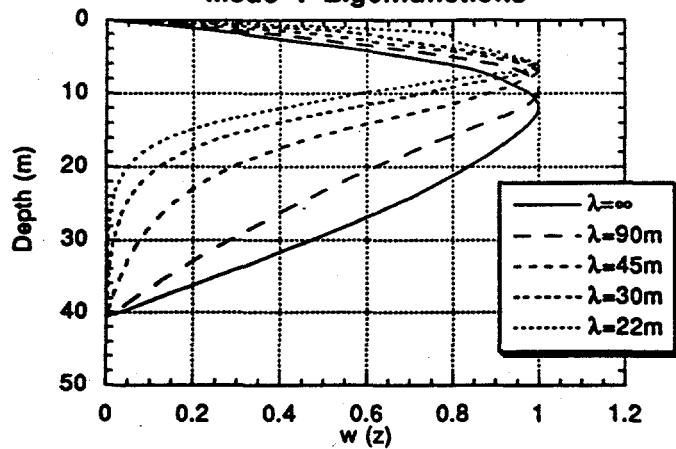
Dispersion Relation



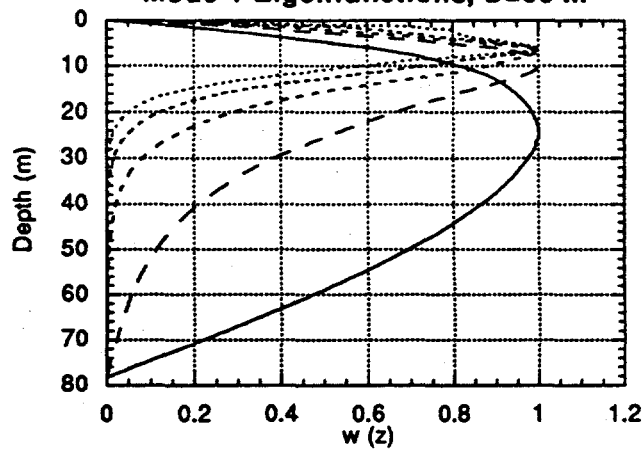
Phase and Group Velocities



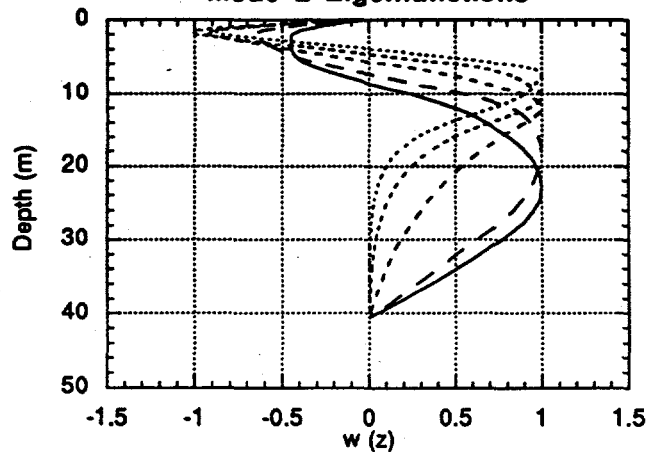
Mode 1 Eigenfunctions



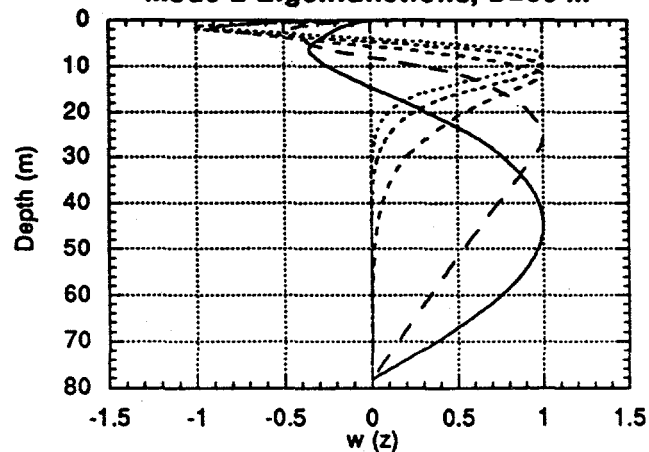
Mode 1 Eigenfunctions, D=80 m



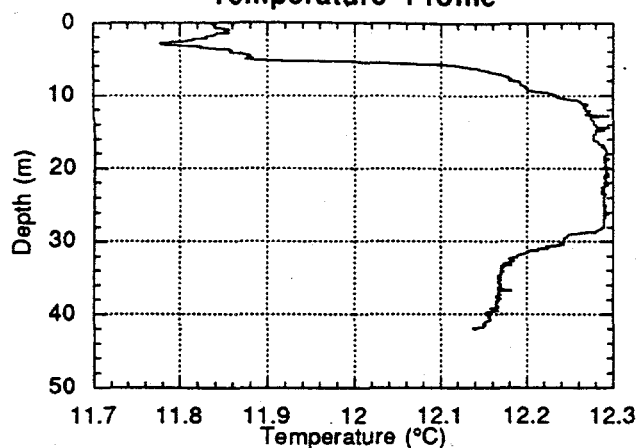
Mode 2 Eigenfunctions



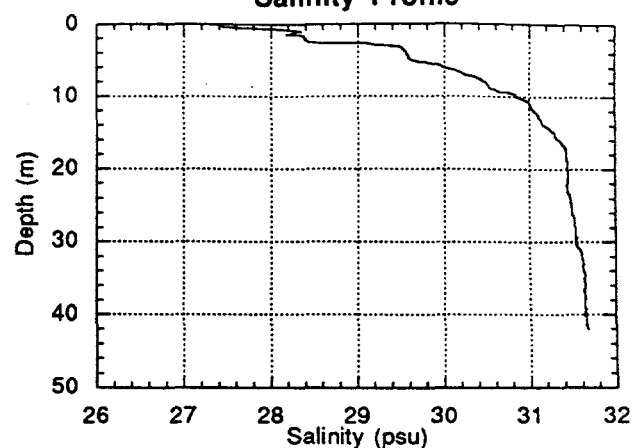
Mode 2 Eigenfunctions, D=80 m



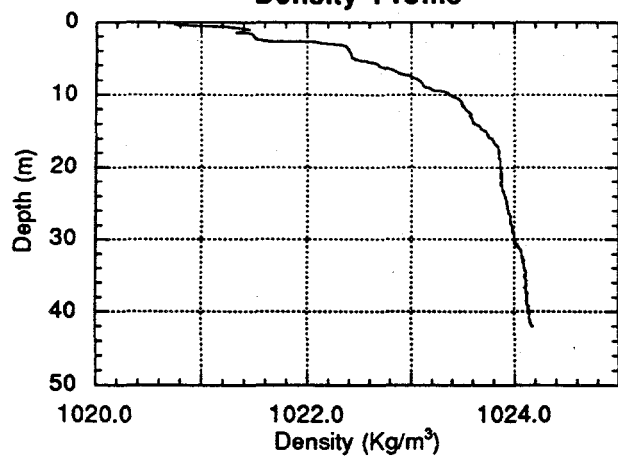
Temperature Profile



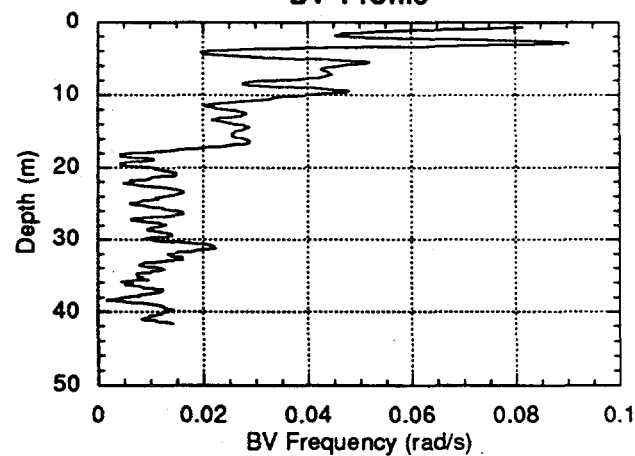
Salinity Profile



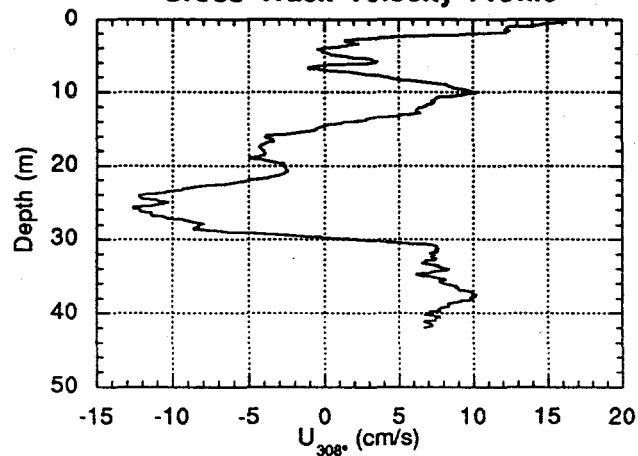
Density Profile



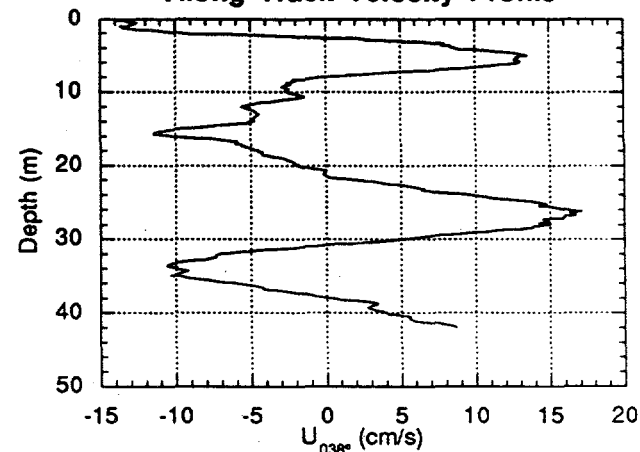
BV Profile



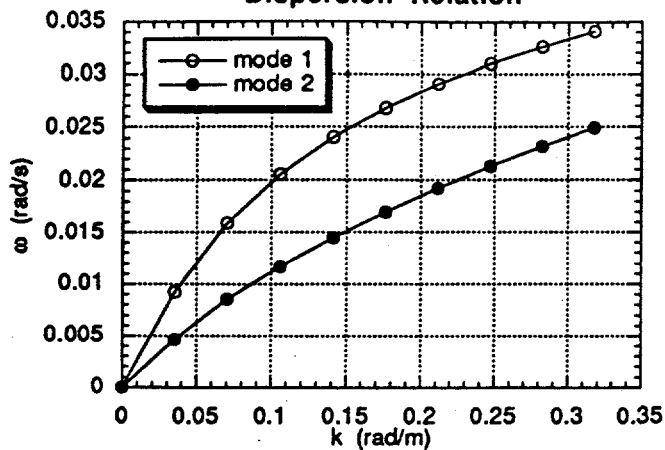
Cross Track Velocity Profile



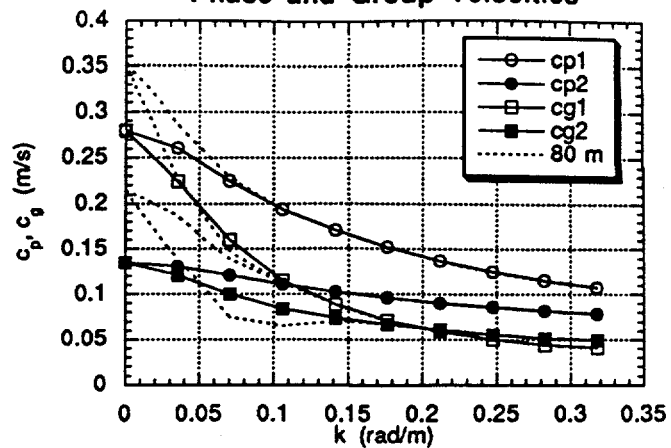
Along Track Velocity Profile



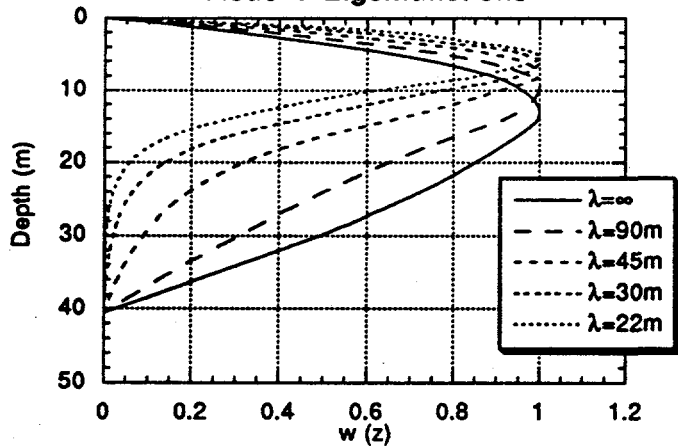
Dispersion Relation



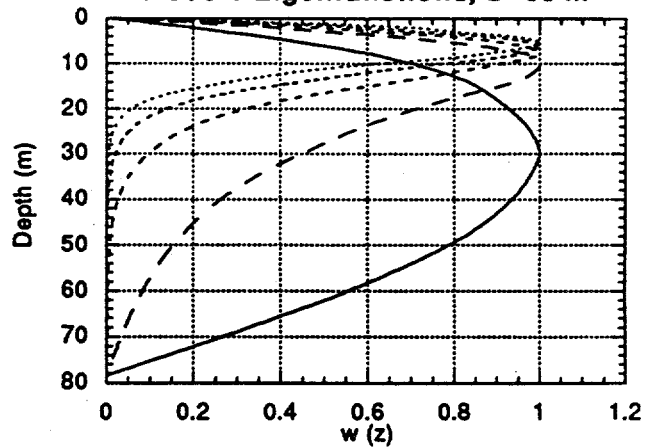
Phase and Group Velocities



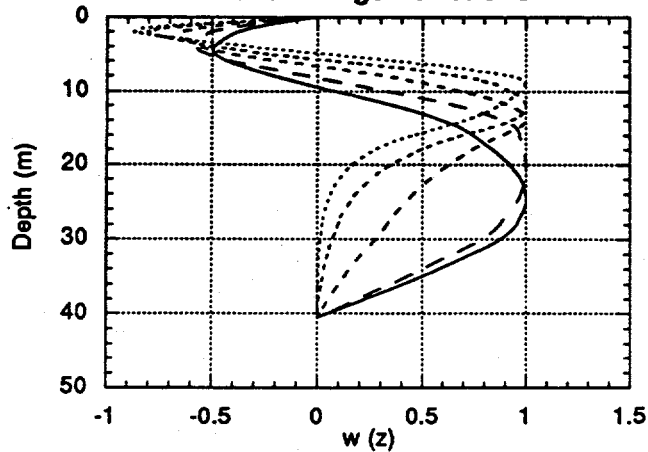
Mode 1 Eigenfunctions



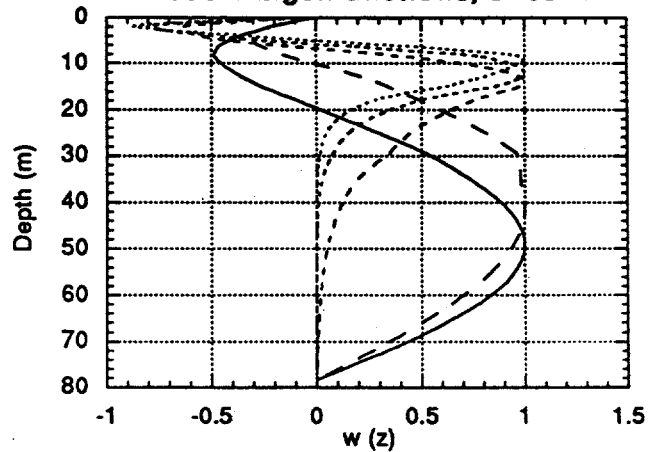
Mode 1 Eigenfunctions, D=80 m



Mode 2 Eigenfunctions

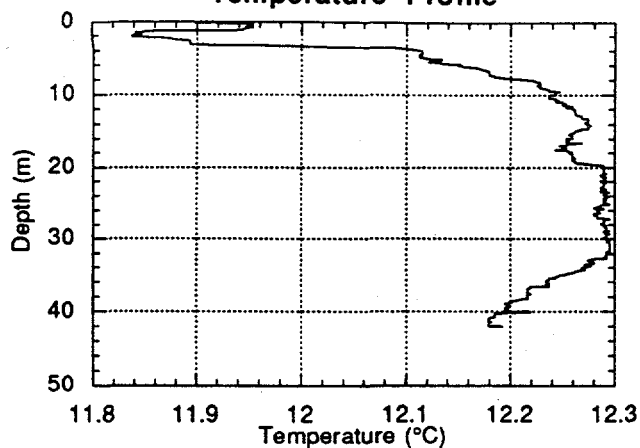


Mode 2 Eigenfunctions, D=80 m

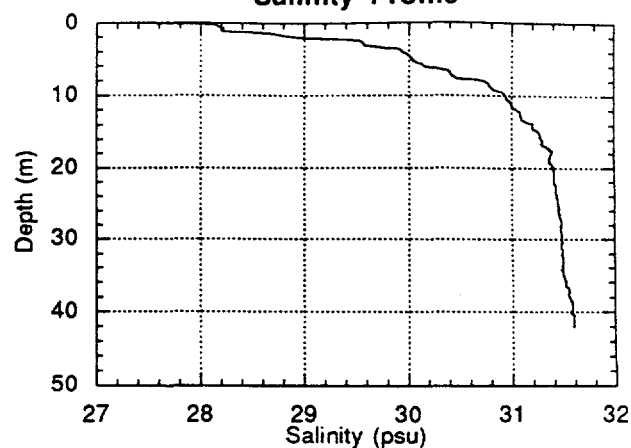


9/16/94, 15:30 GMT

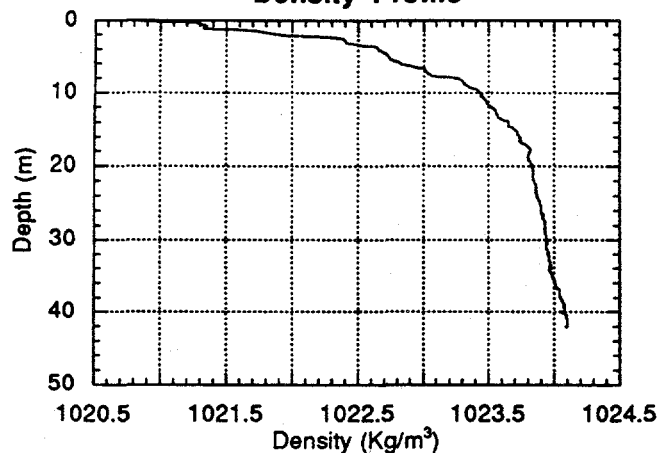
Temperature Profile



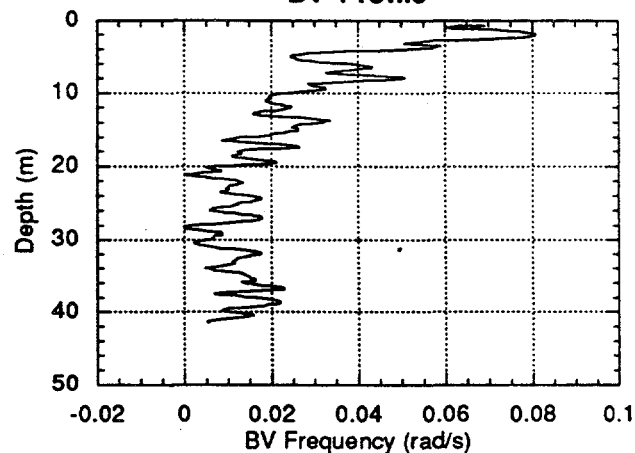
Salinity Profile



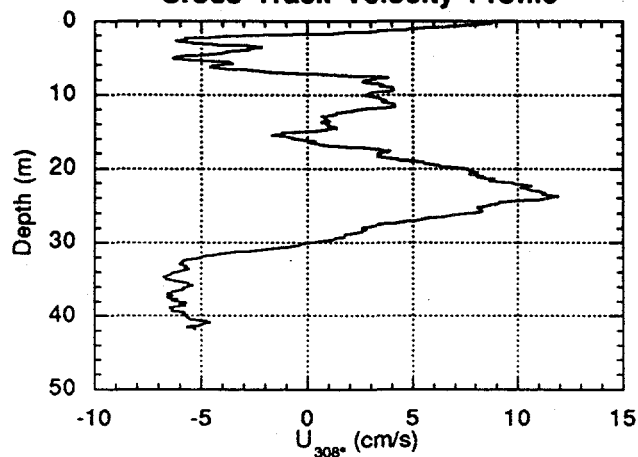
Density Profile



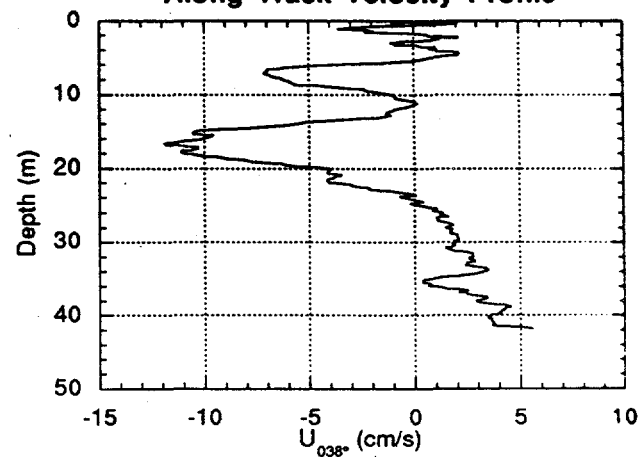
BV Profile



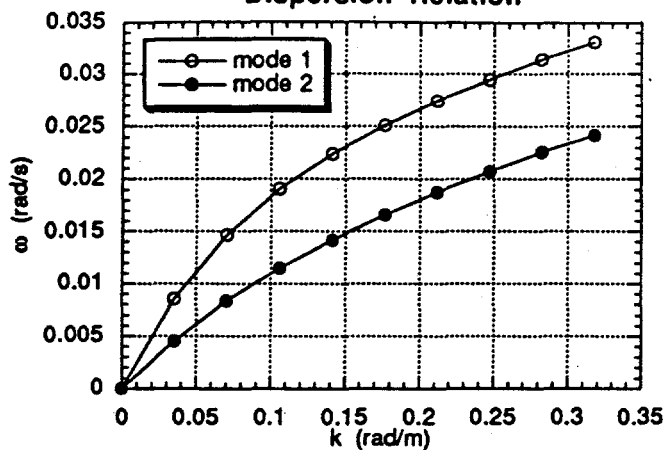
Cross Track Velocity Profile



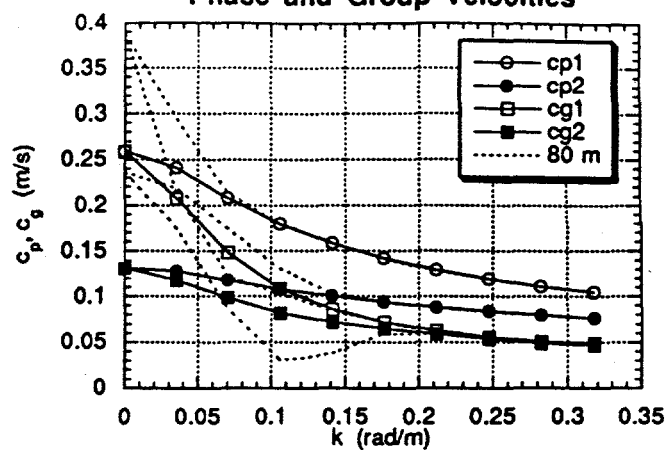
Along Track Velocity Profile



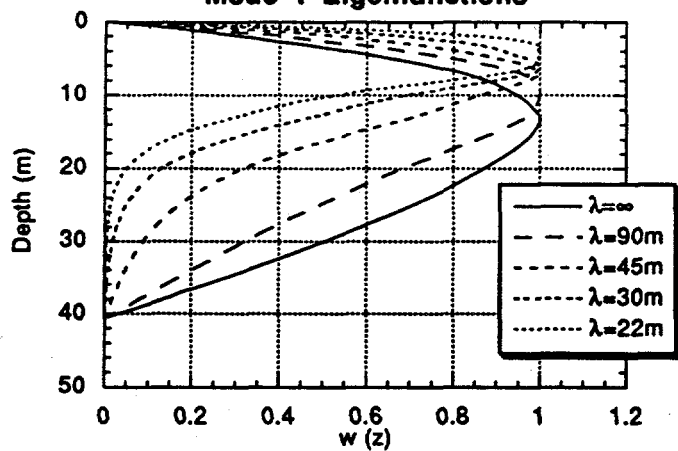
Dispersion Relation



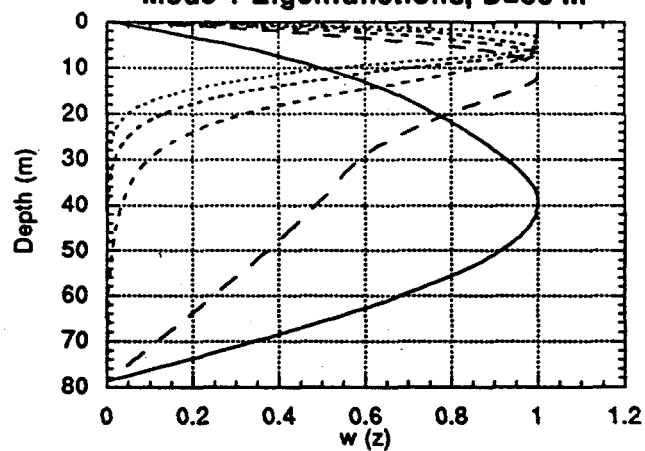
Phase and Group Velocities



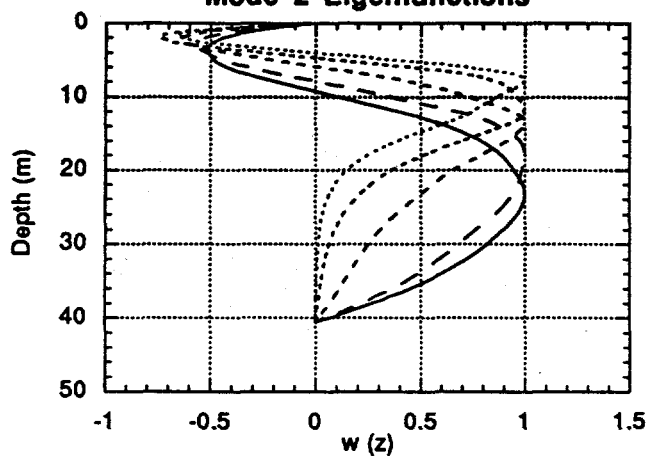
Mode 1 Eigenfunctions



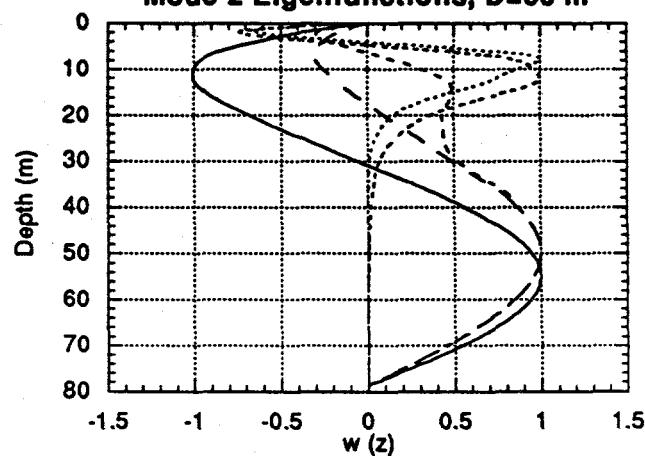
Mode 1 Eigenfunctions, D=80 m

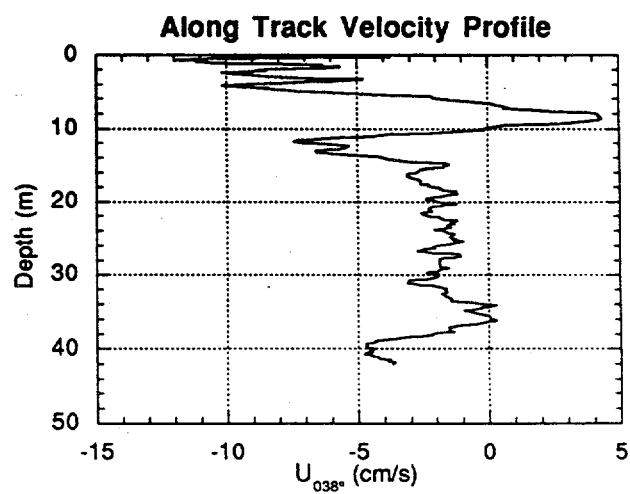
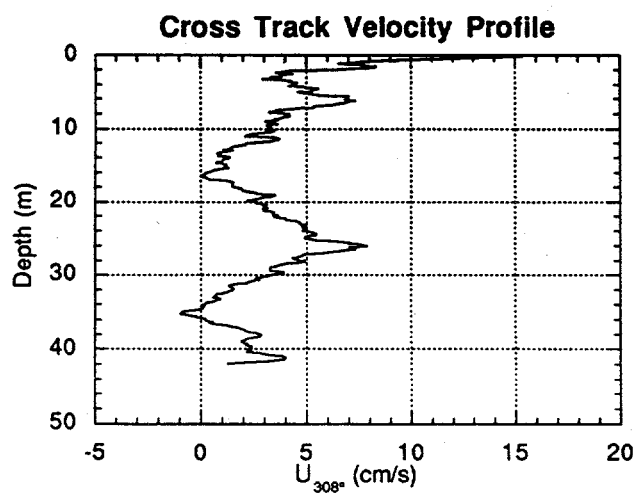
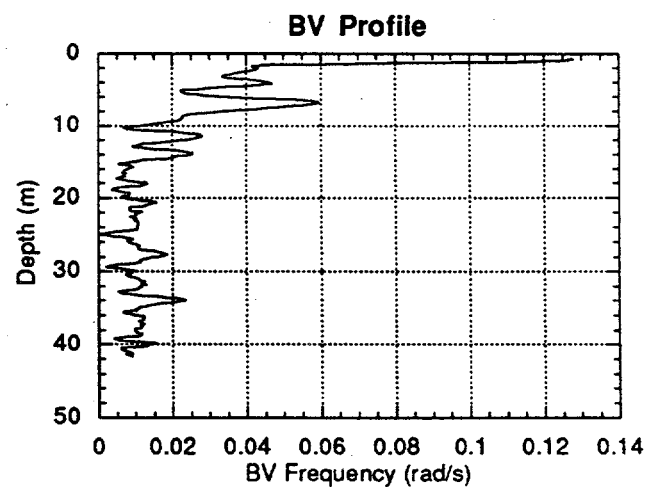
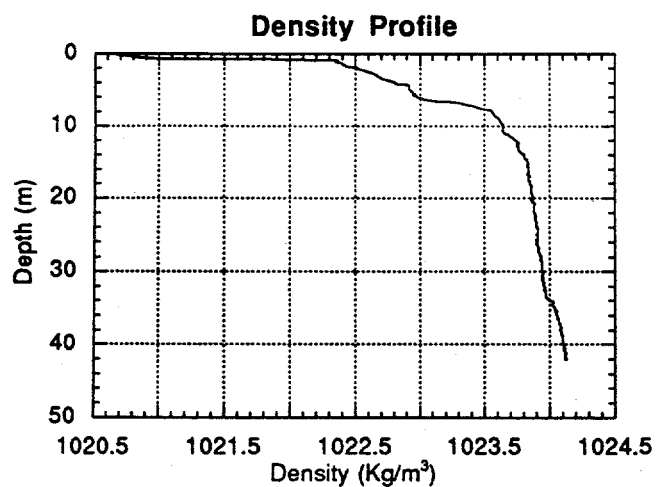
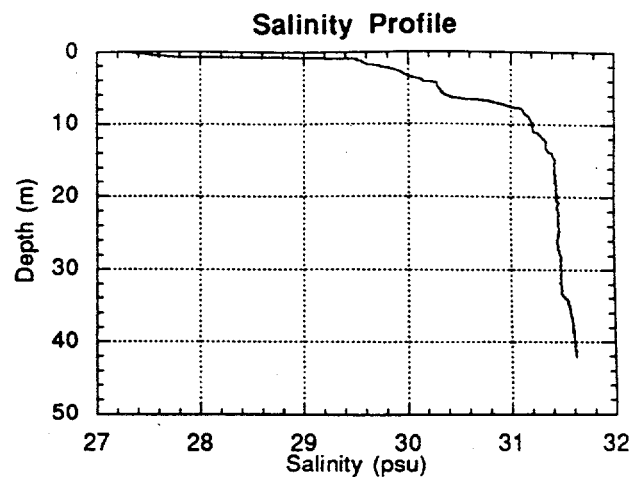
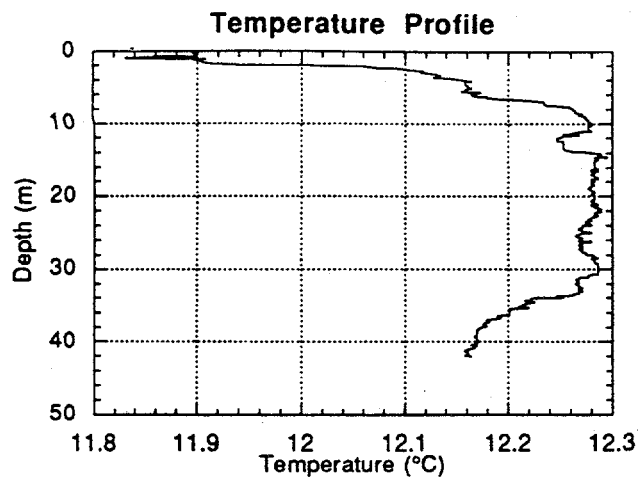


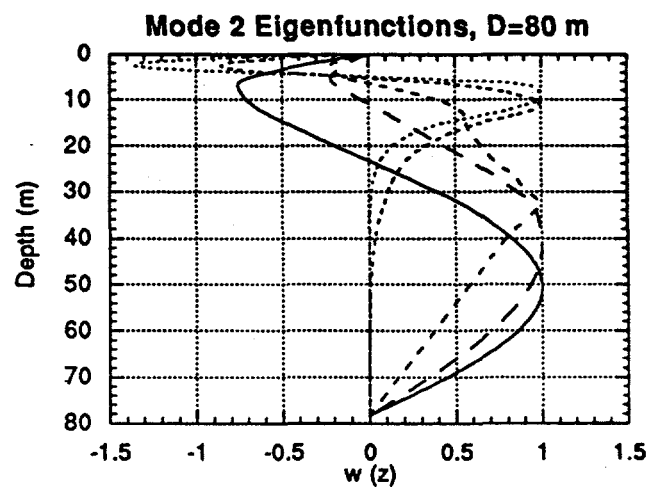
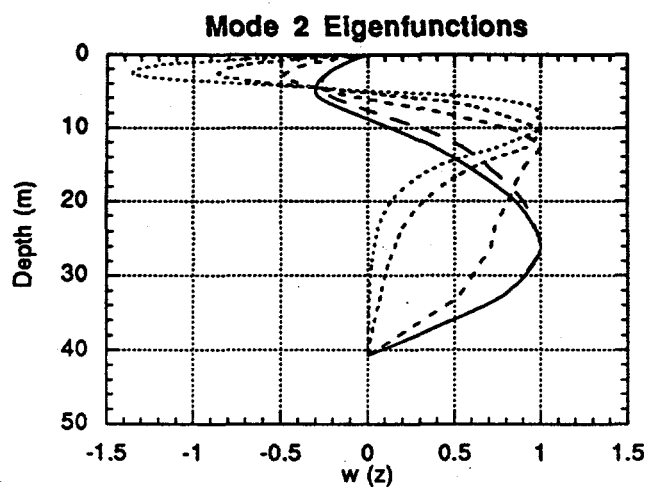
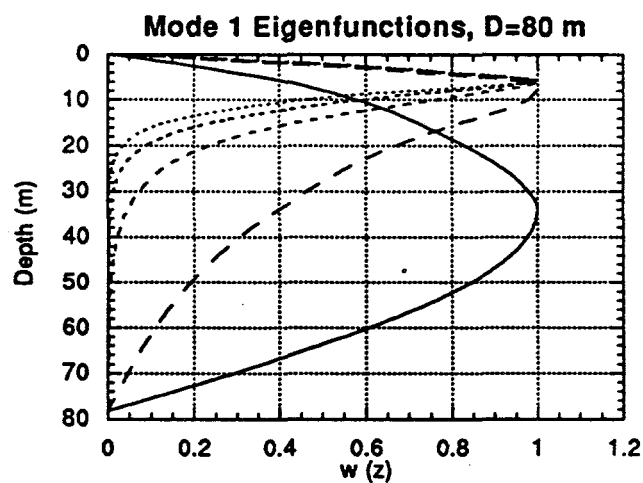
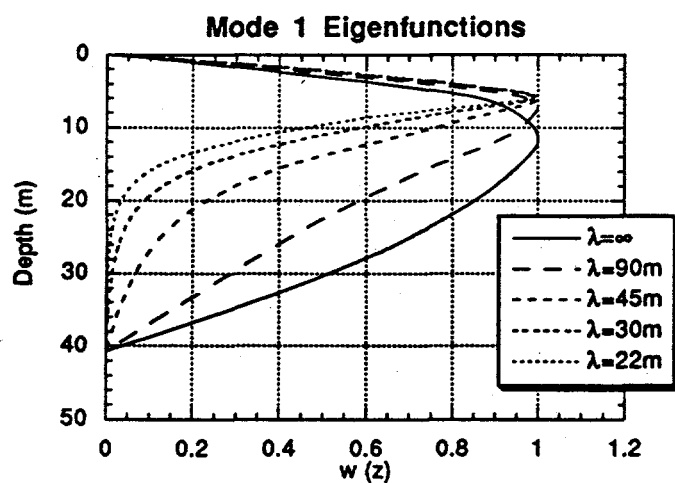
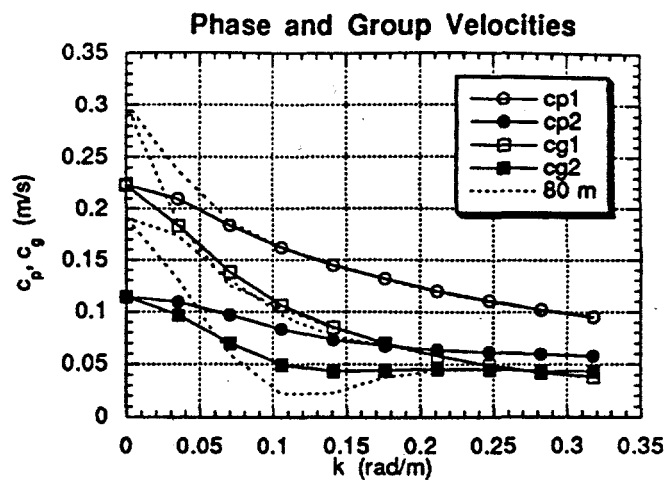
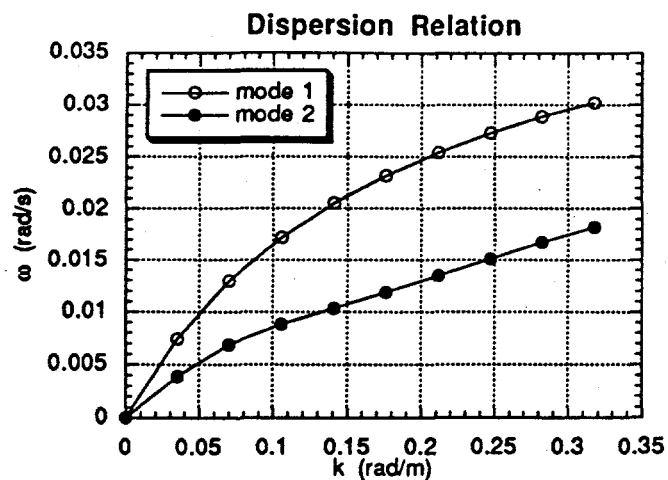
Mode 2 Eigenfunctions

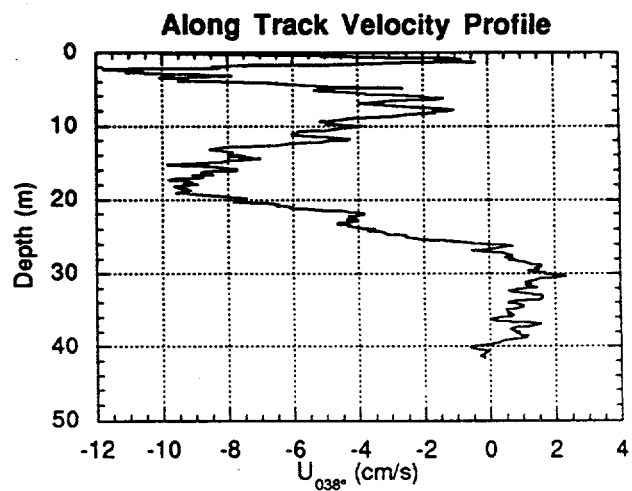
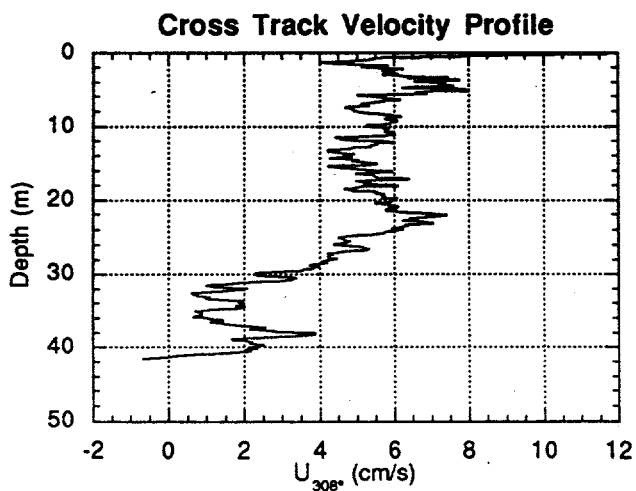
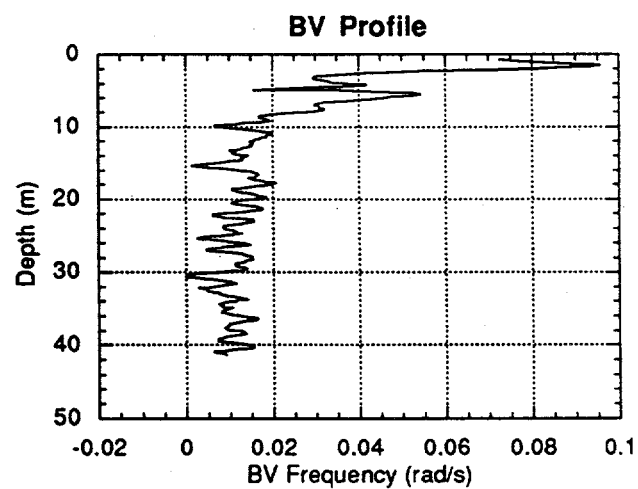
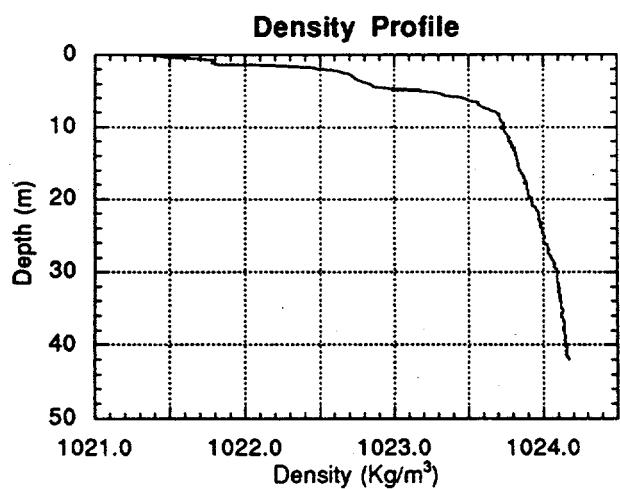
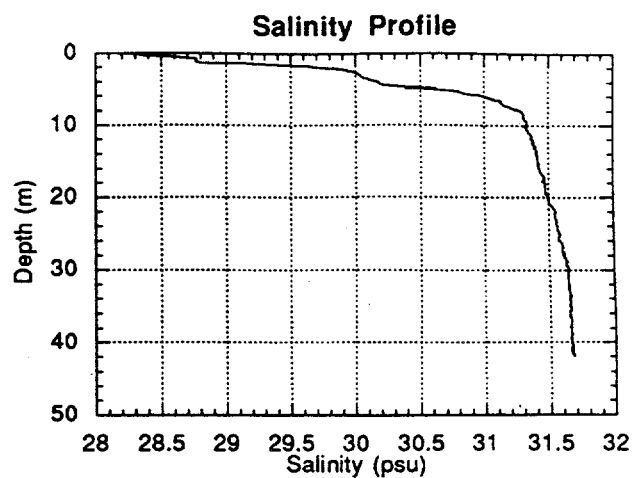
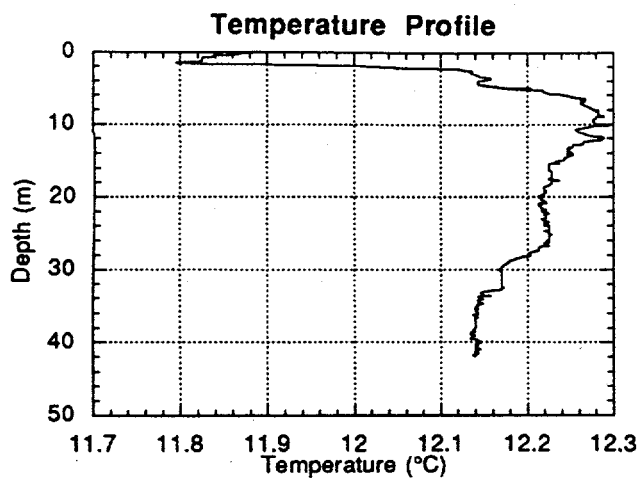


Mode 2 Eigenfunctions, D=80 m

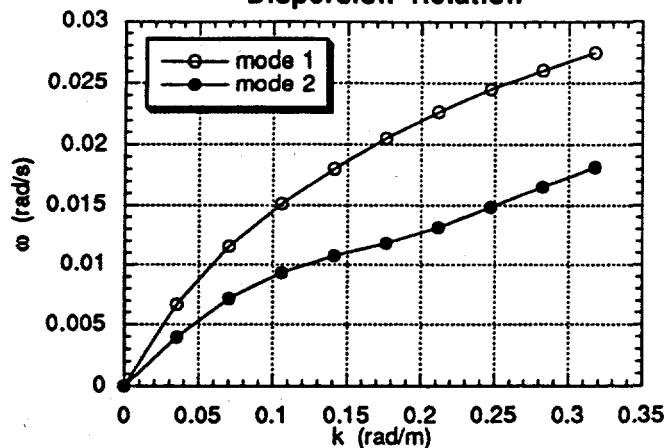




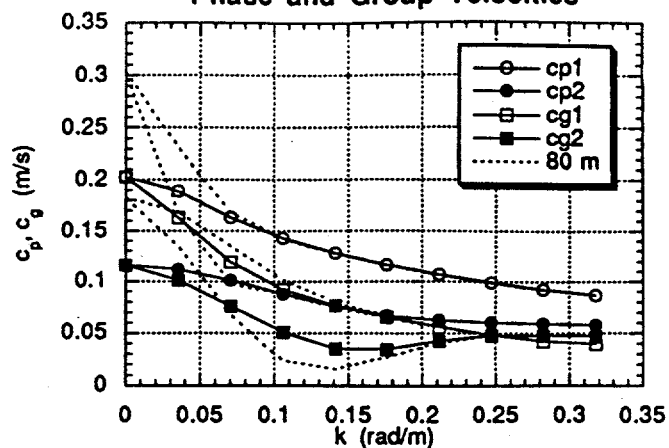




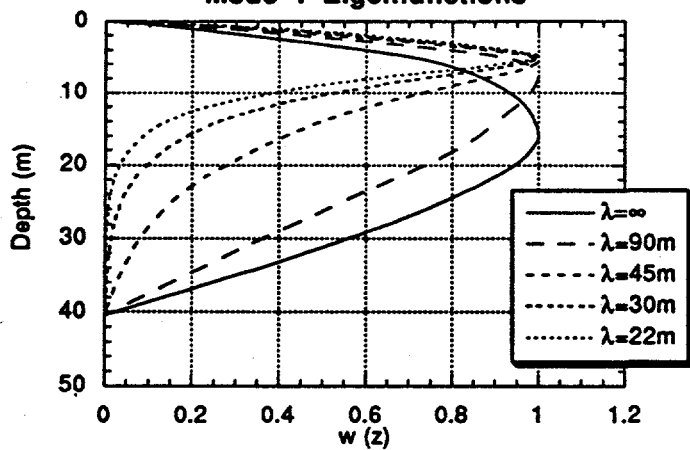
Dispersion Relation



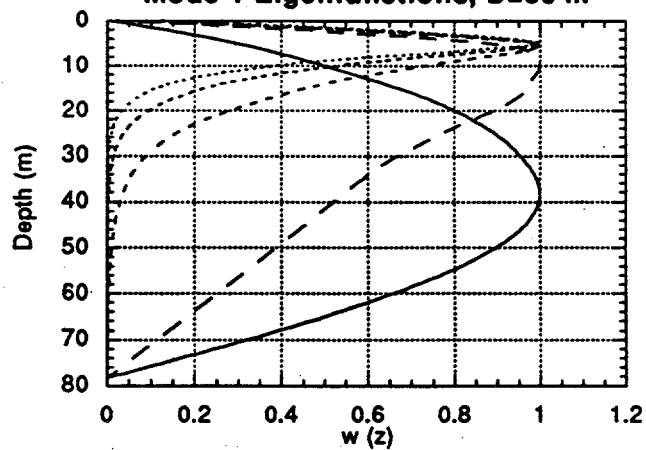
Phase and Group Velocities



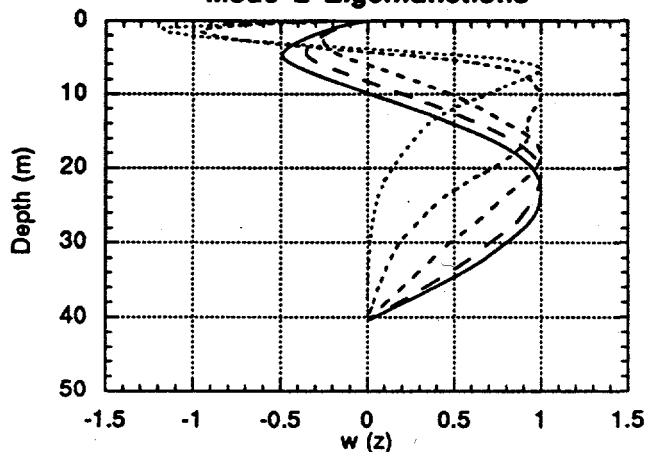
Mode 1 Eigenfunctions



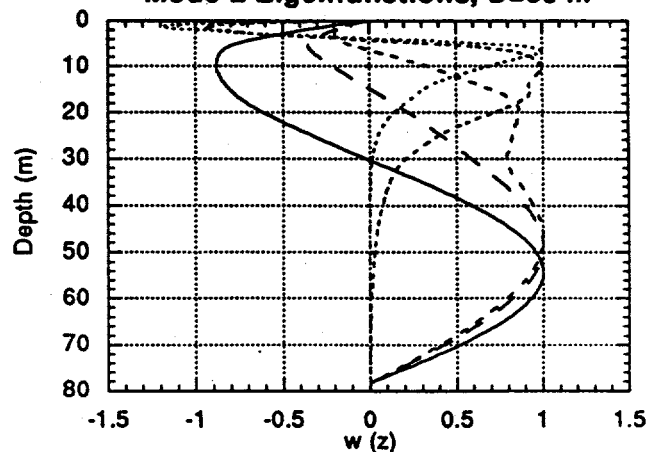
Mode 1 Eigenfunctions, D=80 m

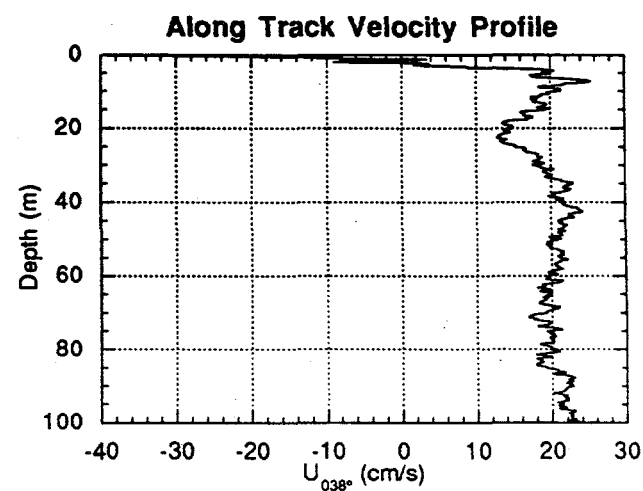
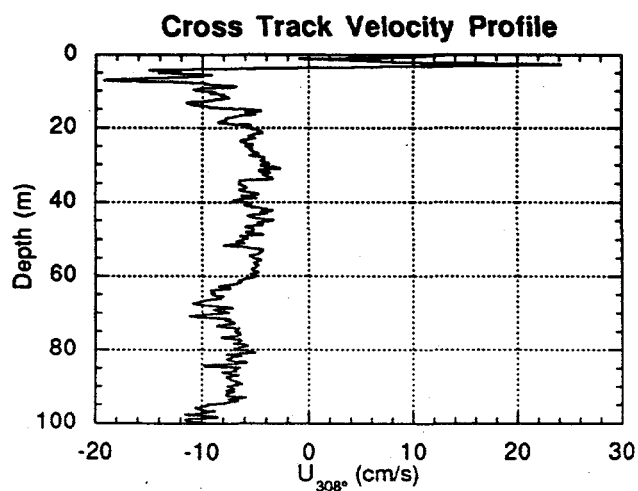
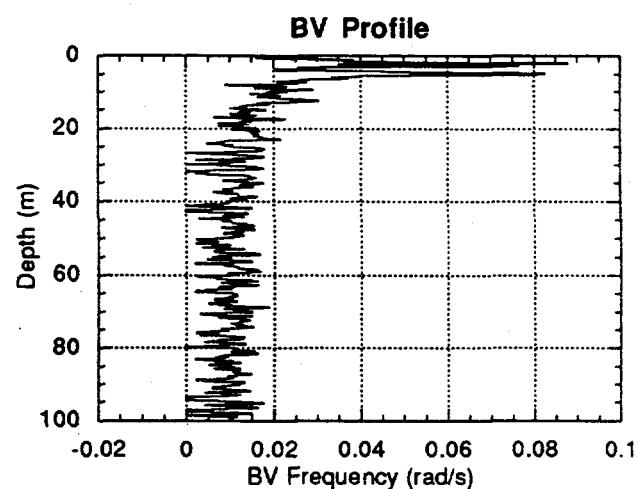
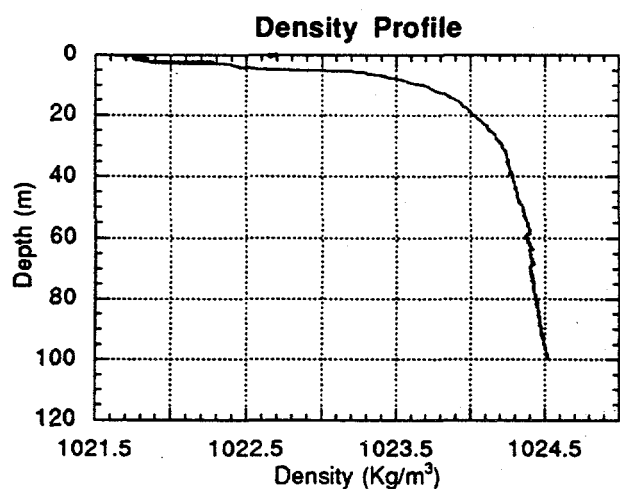
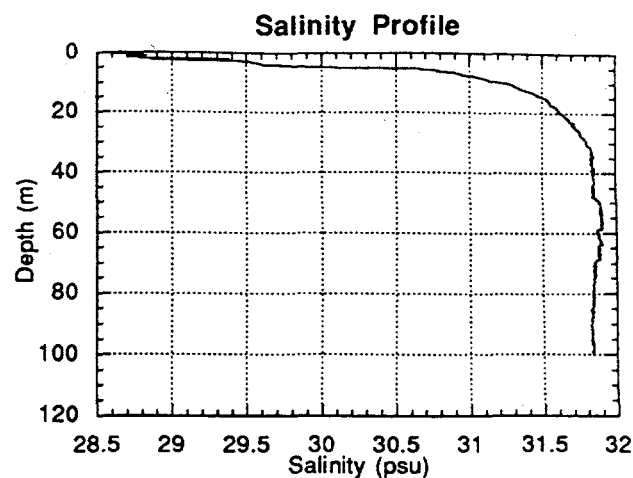
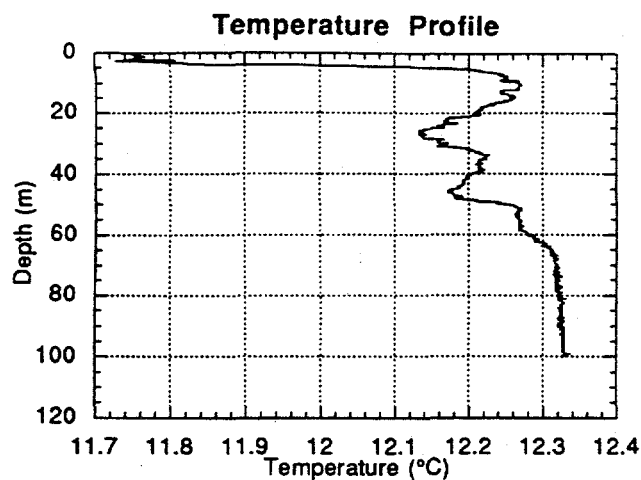


Mode 2 Eigenfunctions

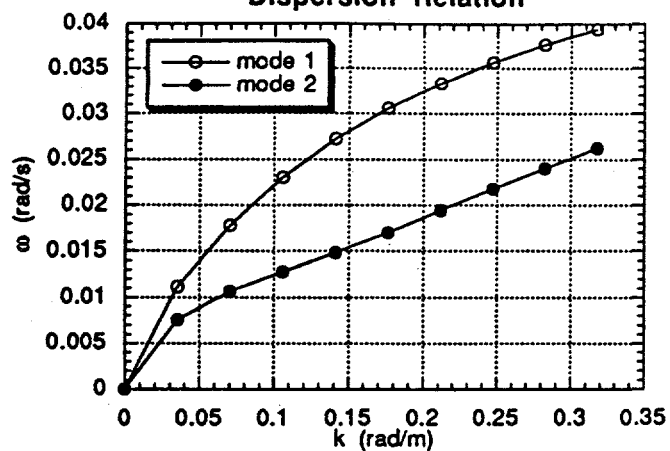


Mode 2 Eigenfunctions, D=80 m

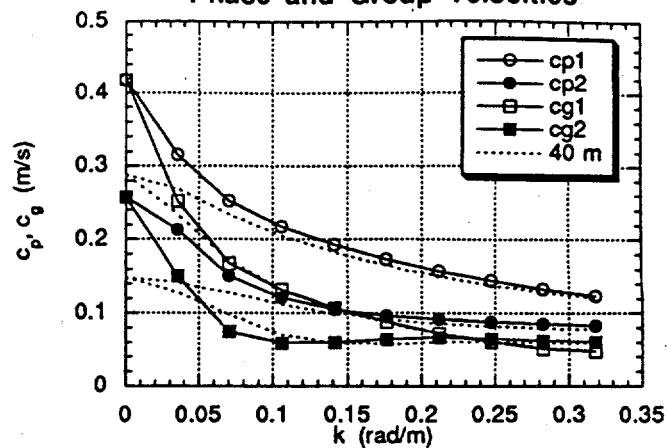




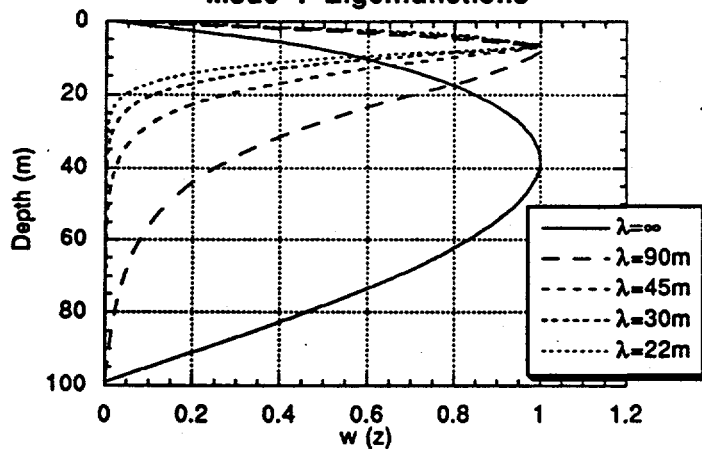
Dispersion Relation



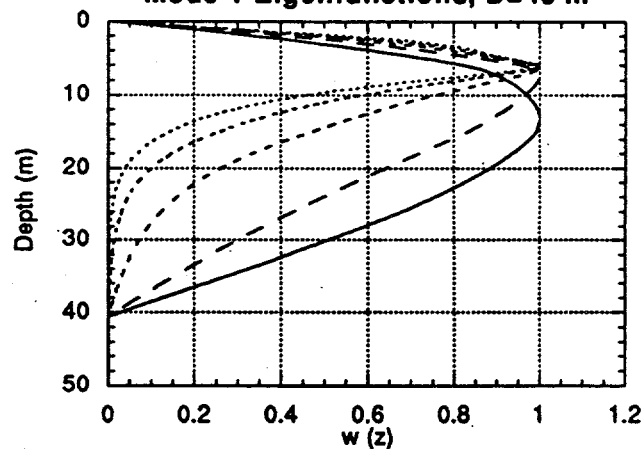
Phase and Group Velocities



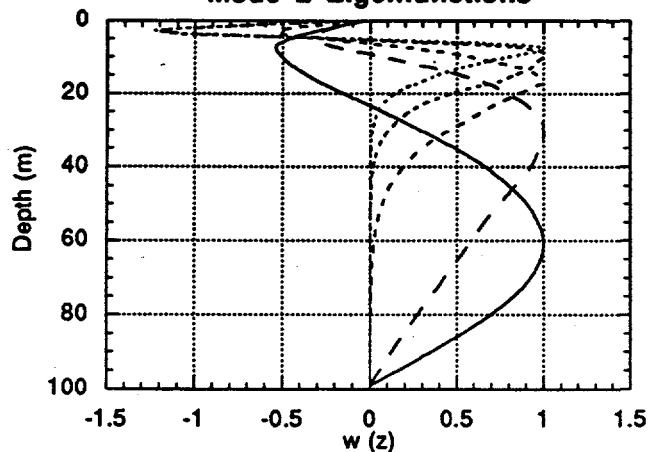
Mode 1 Eigenfunctions



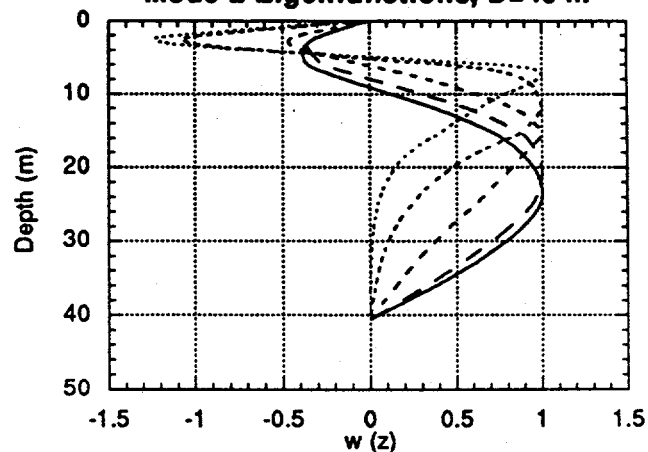
Mode 1 Eigenfunctions, D=40 m

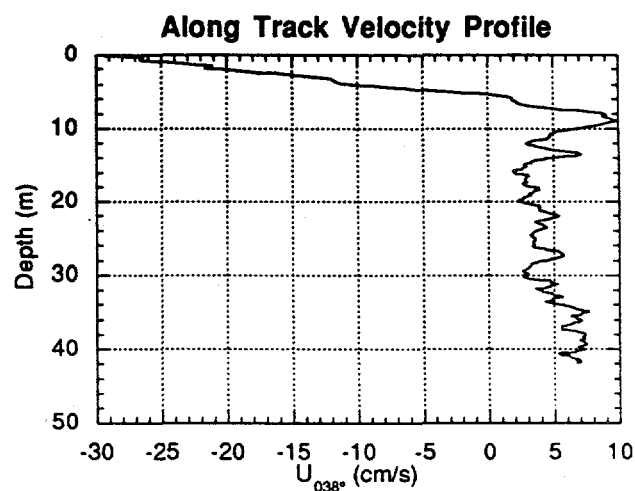
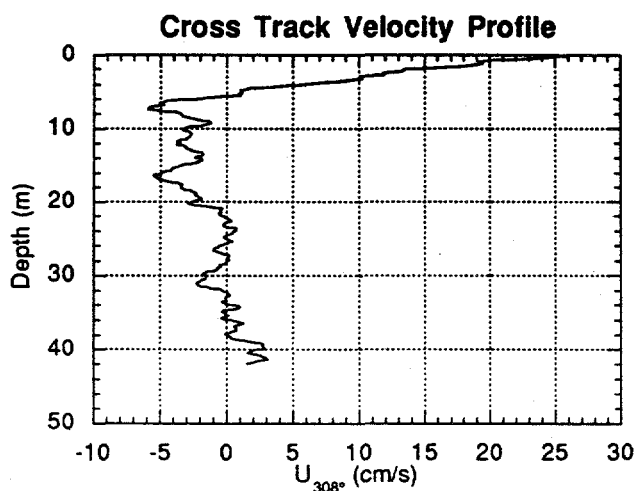
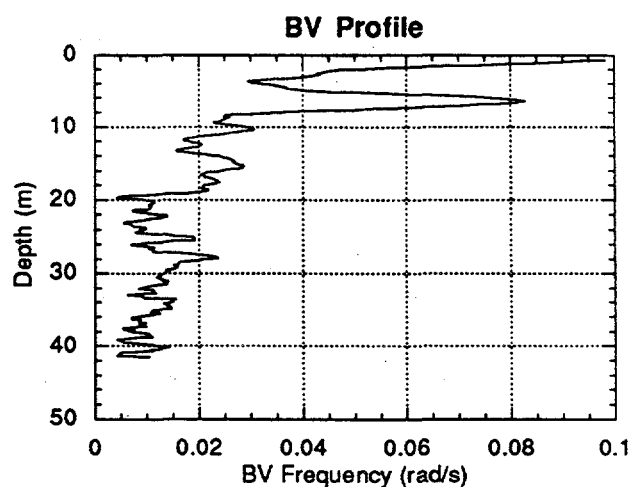
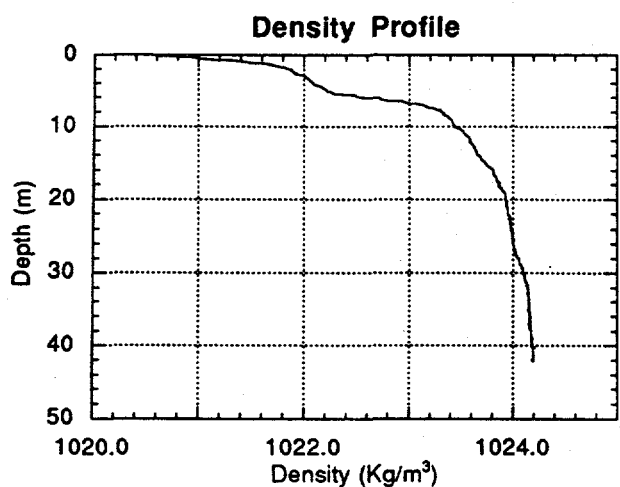
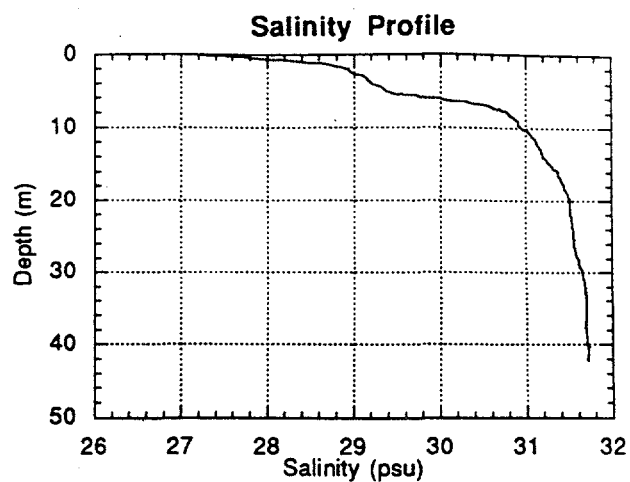
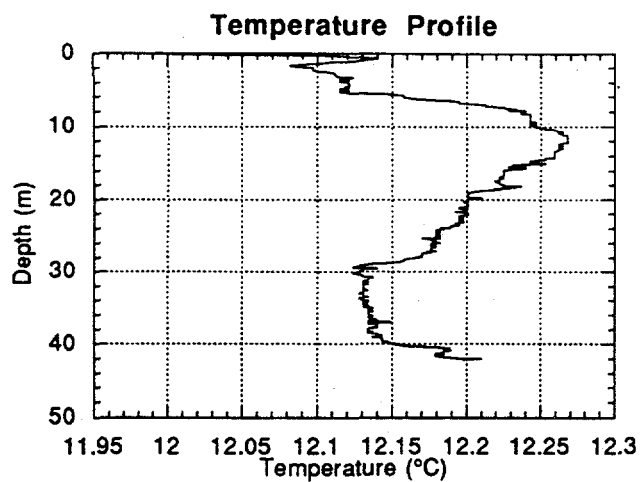


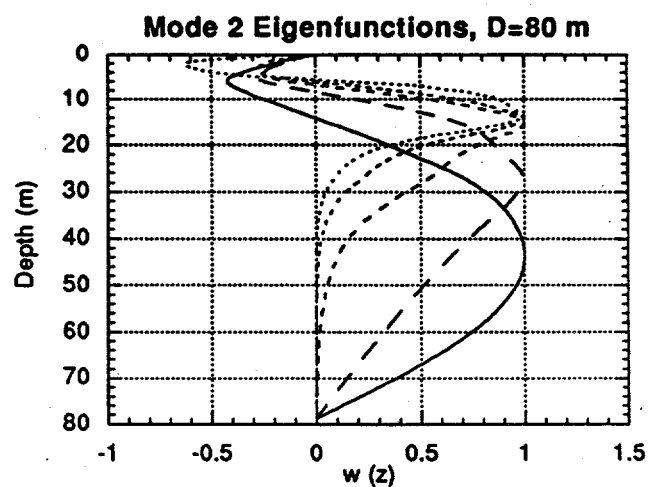
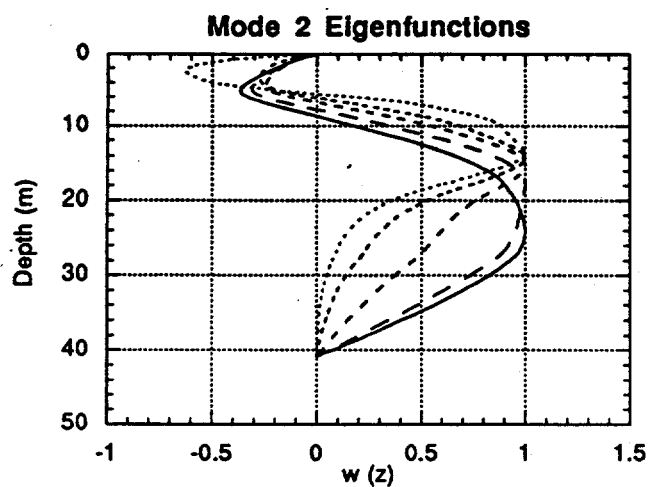
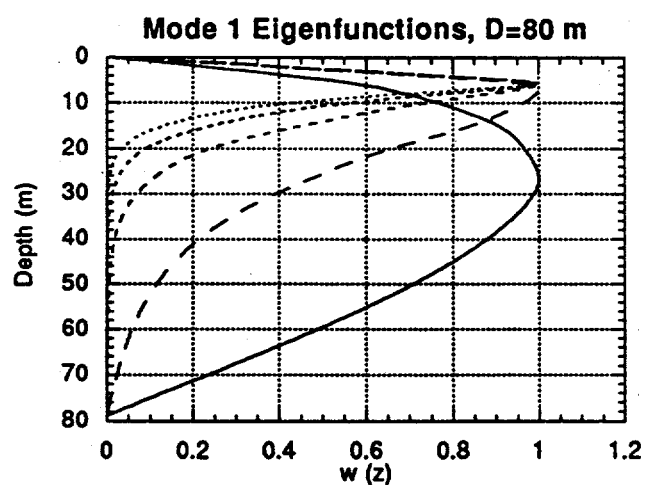
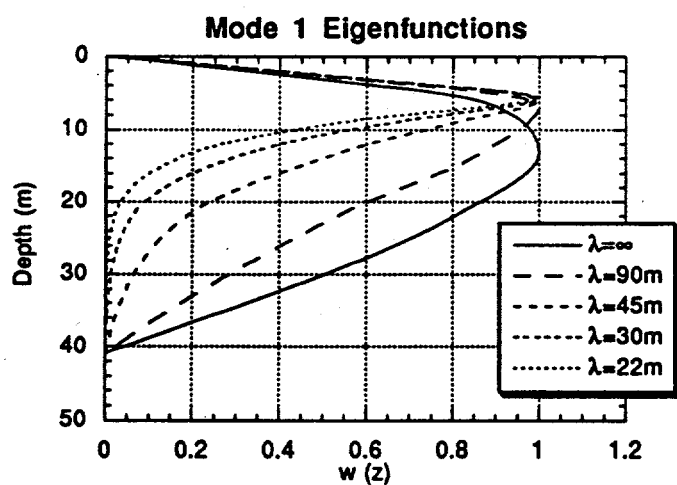
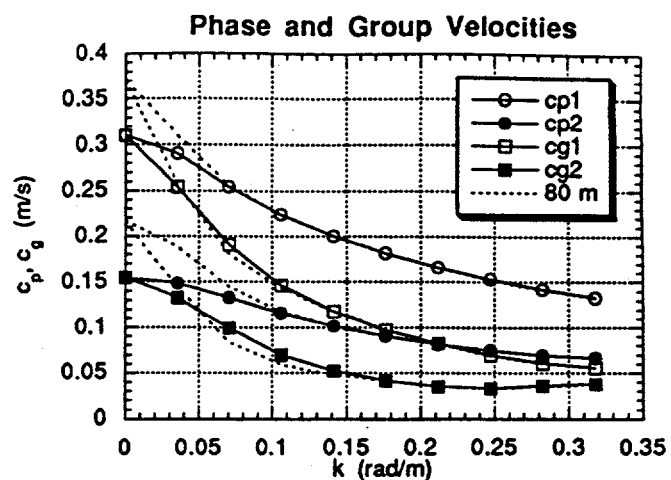
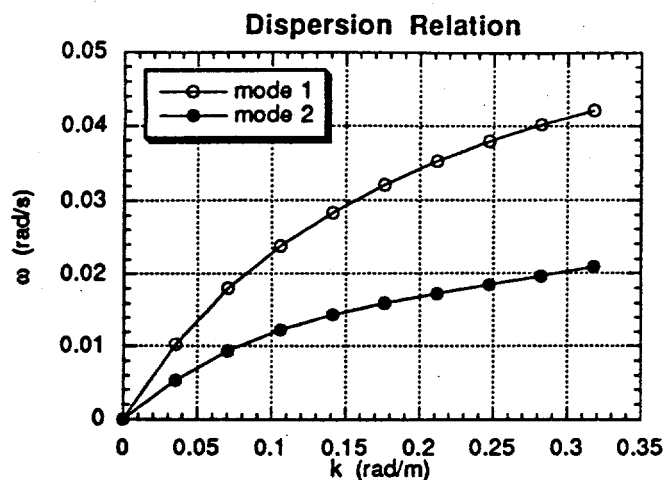
Mode 2 Eigenfunctions



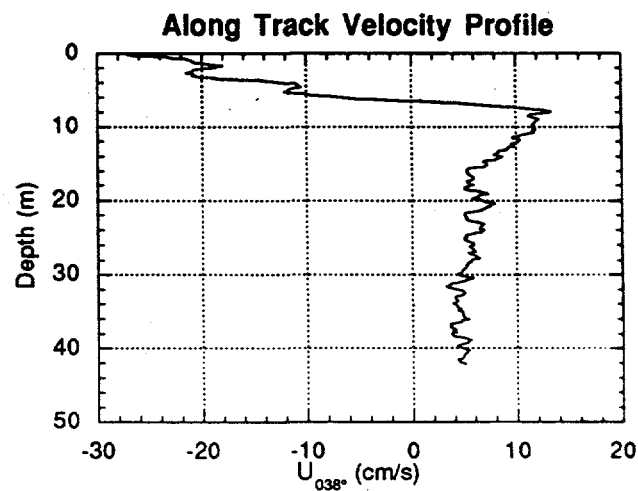
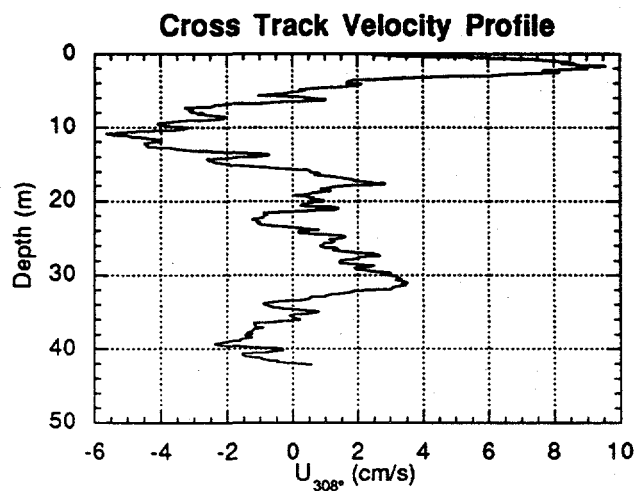
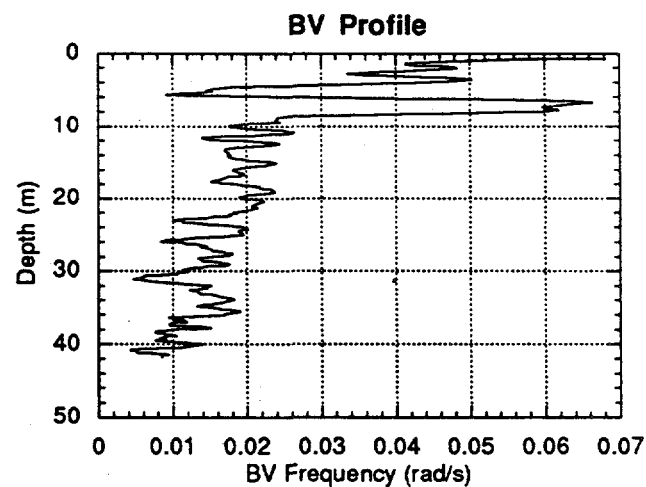
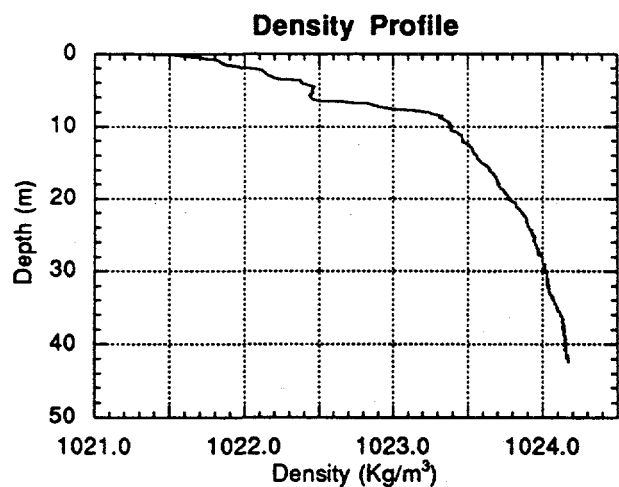
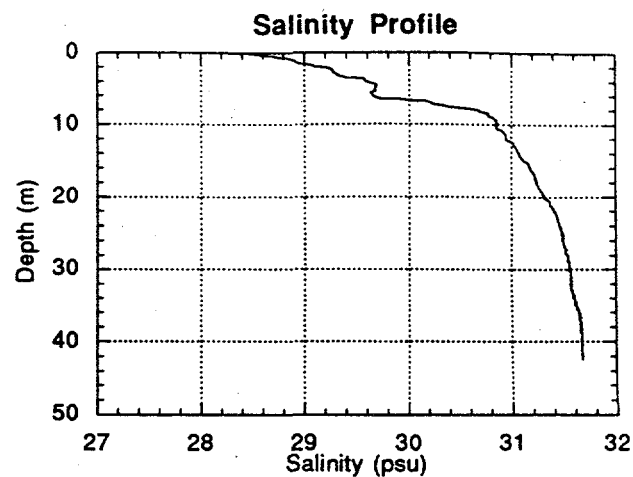
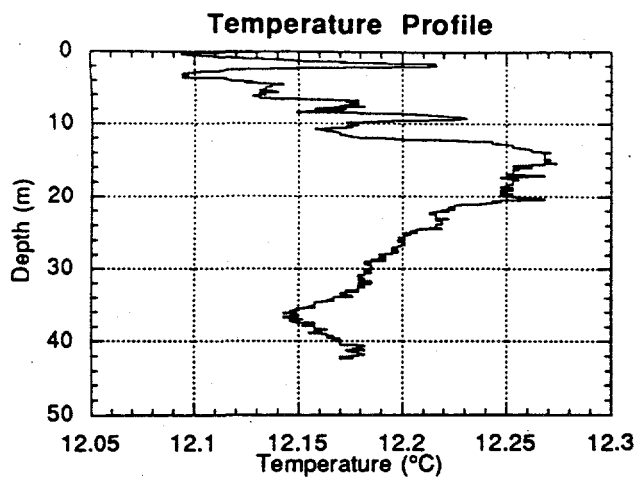
Mode 2 Eigenfunctions, D=40 m

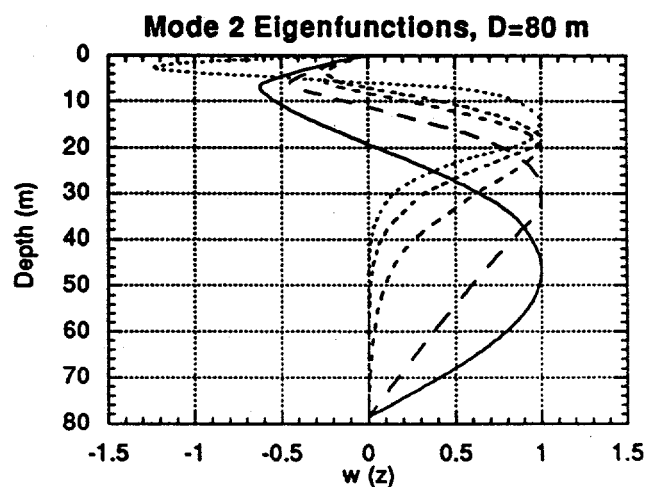
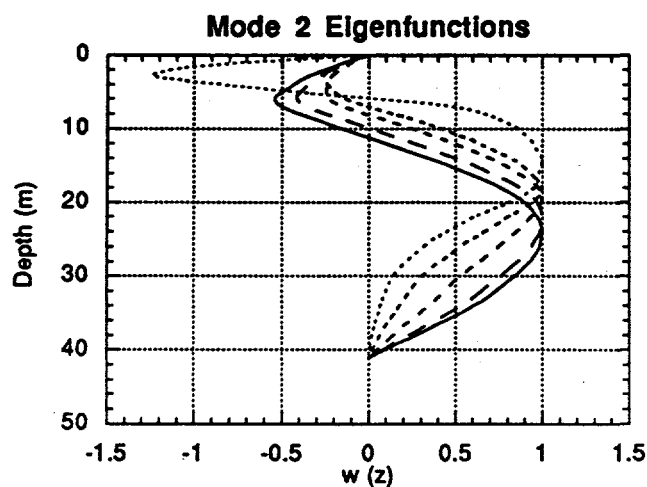
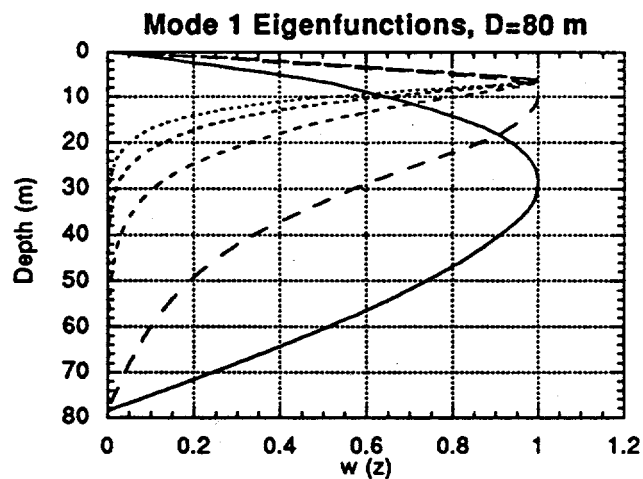
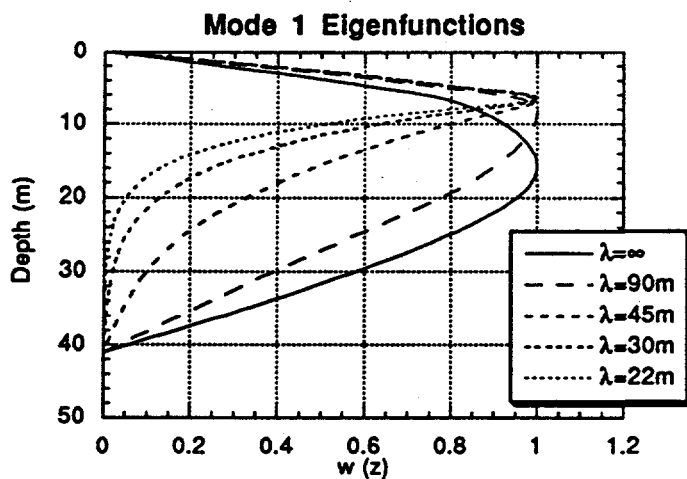
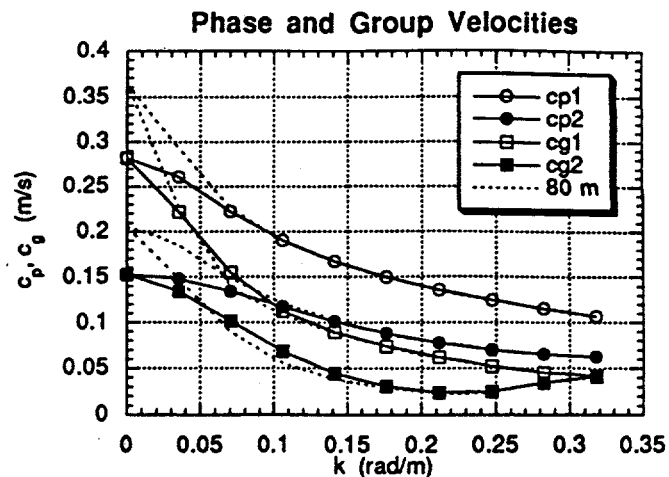
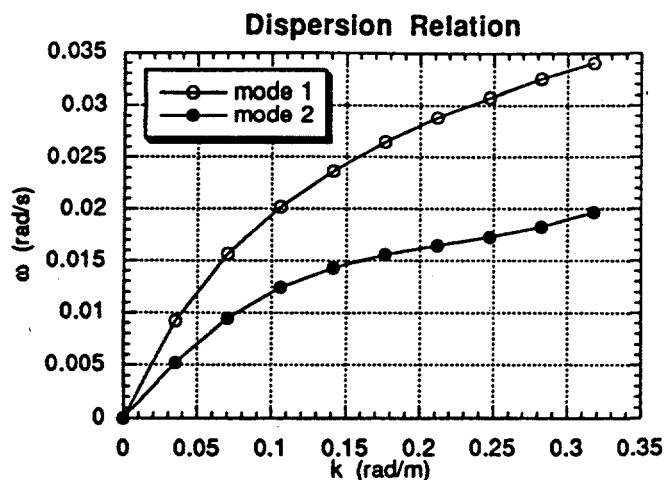


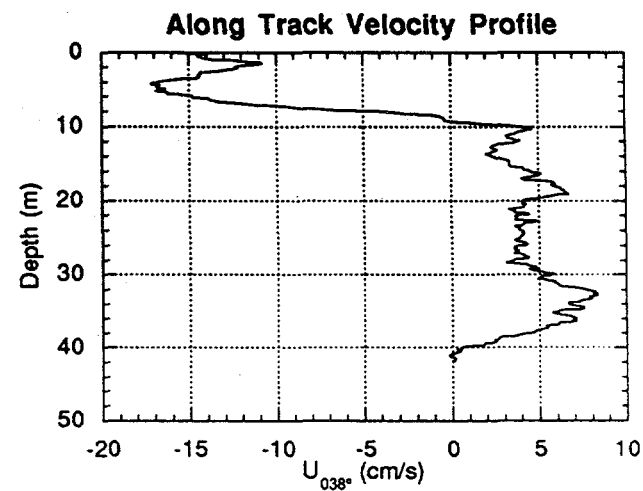
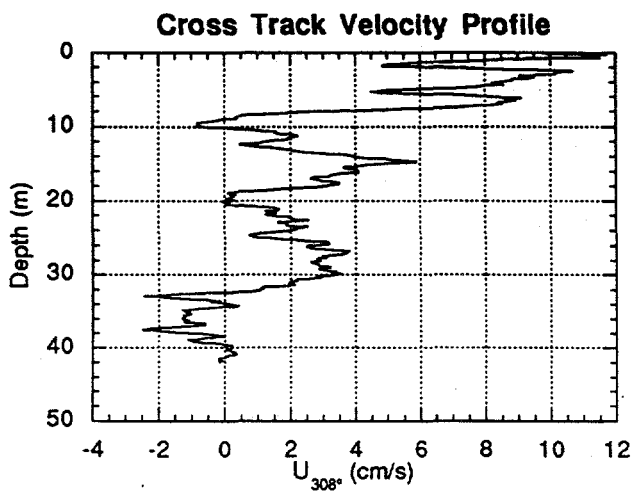
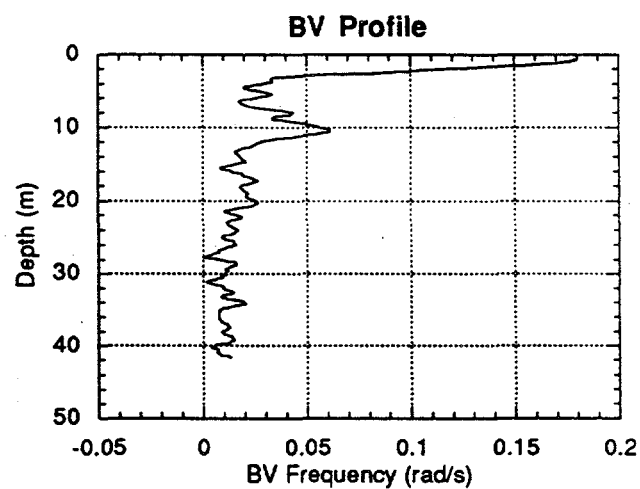
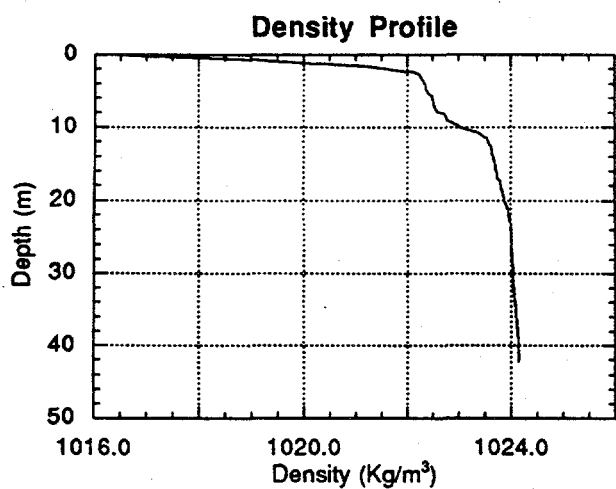
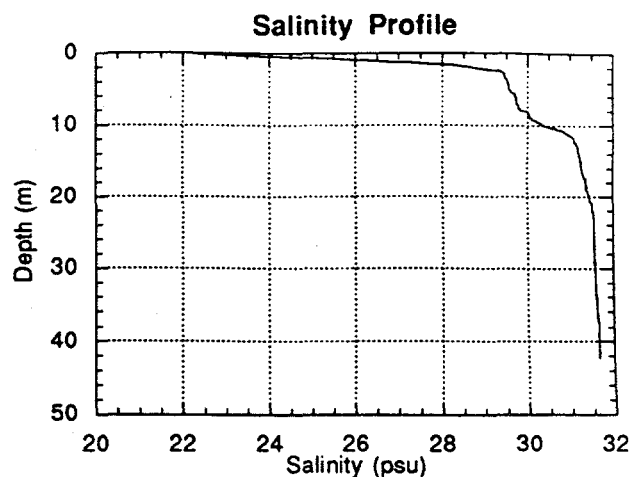
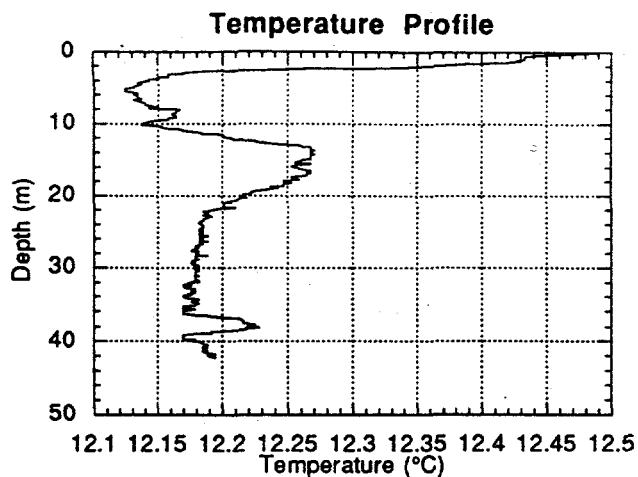




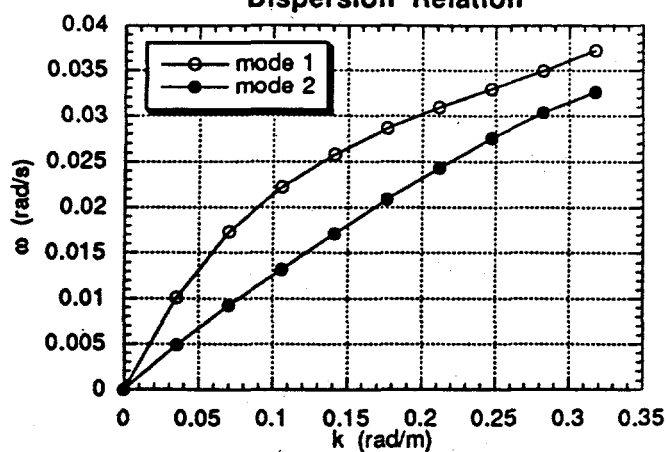
9/17/94, 14:30 GMT



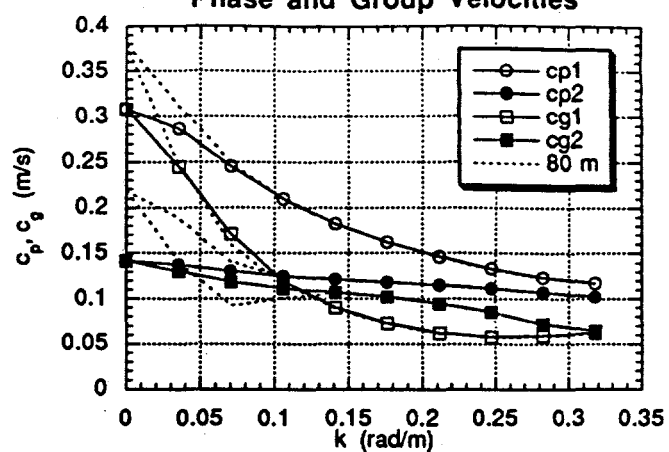




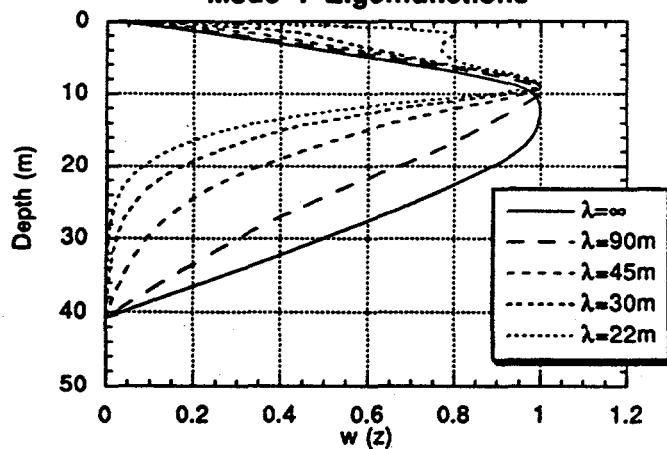
Dispersion Relation



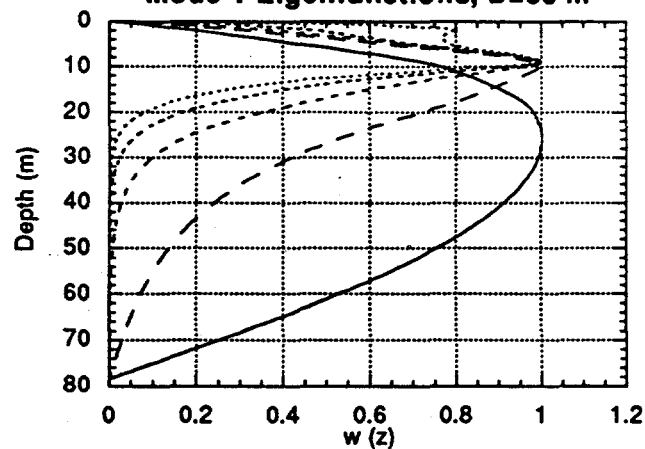
Phase and Group Velocities



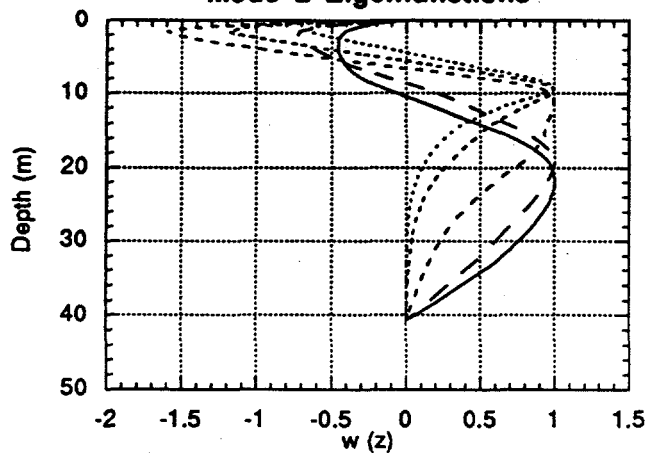
Mode 1 Eigenfunctions



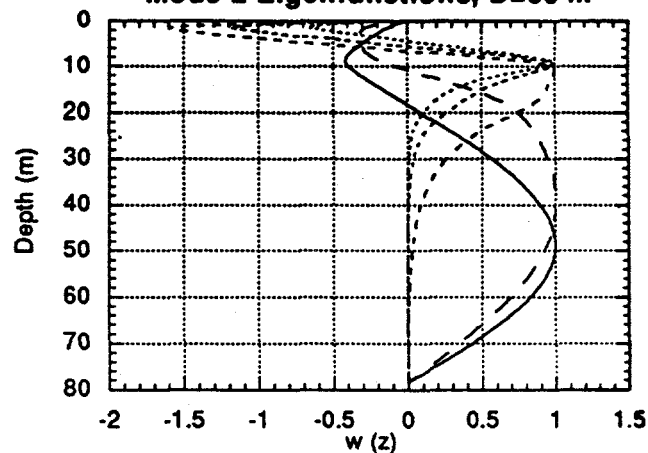
Mode 1 Eigenfunctions, D=80 m

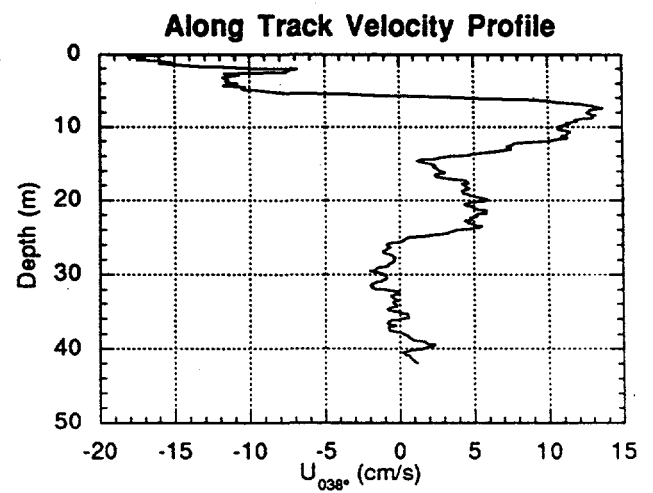
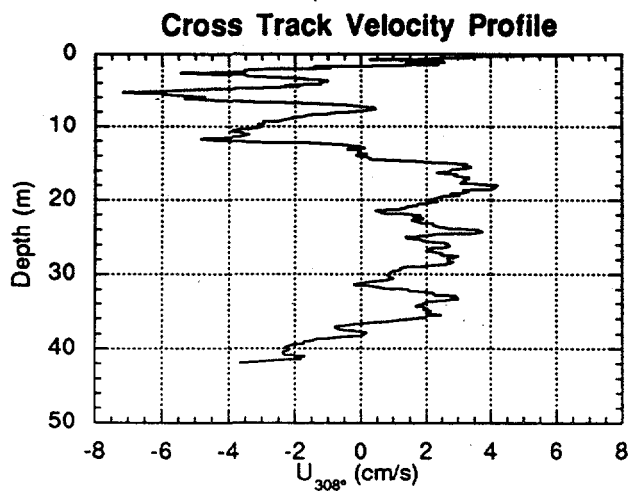
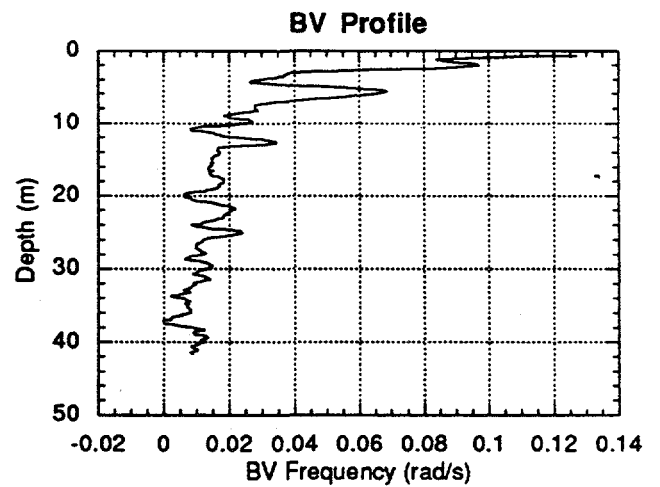
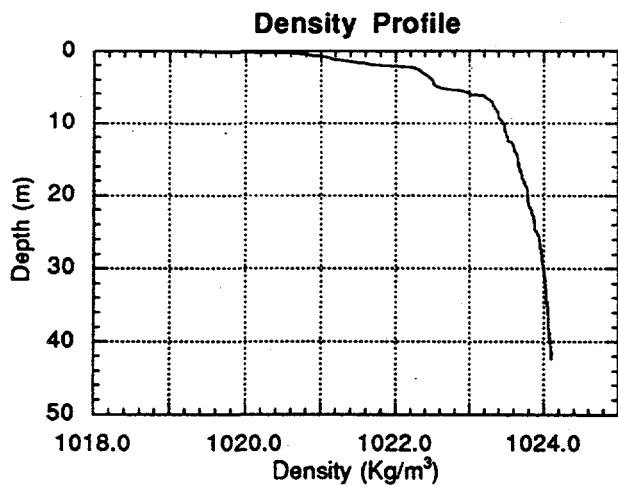
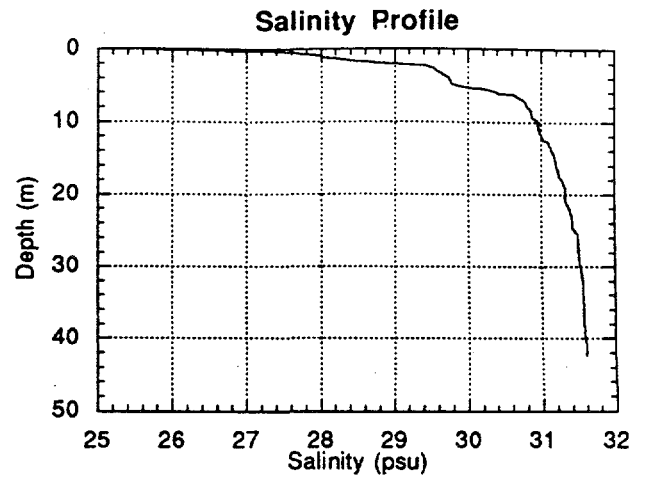
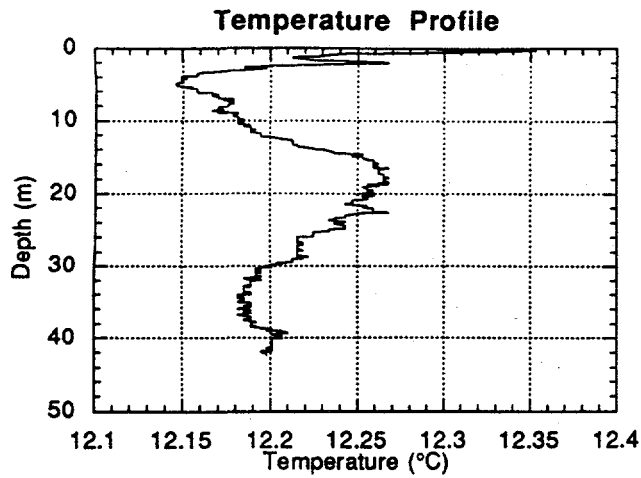


Mode 2 Eigenfunctions

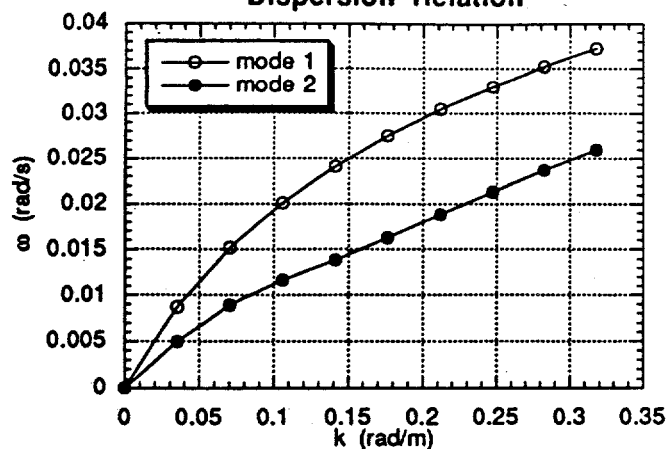


Mode 2 Eigenfunctions, D=80 m

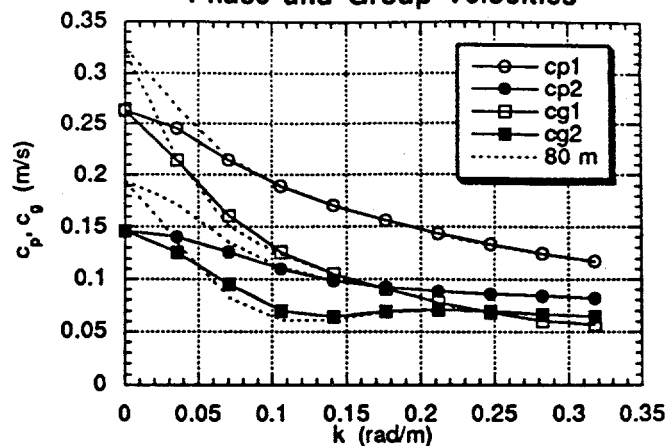




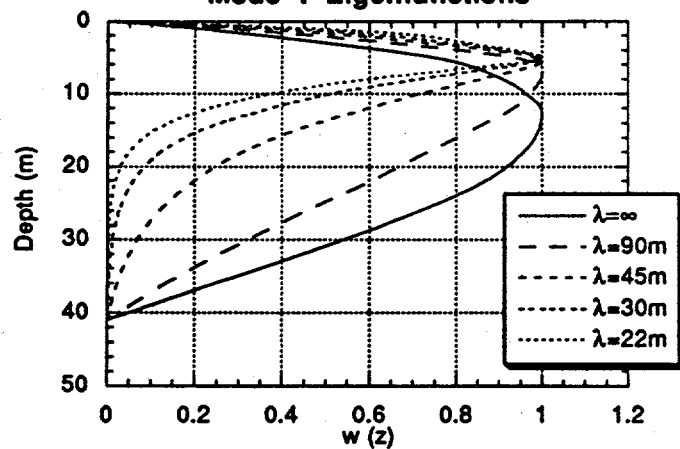
Dispersion Relation



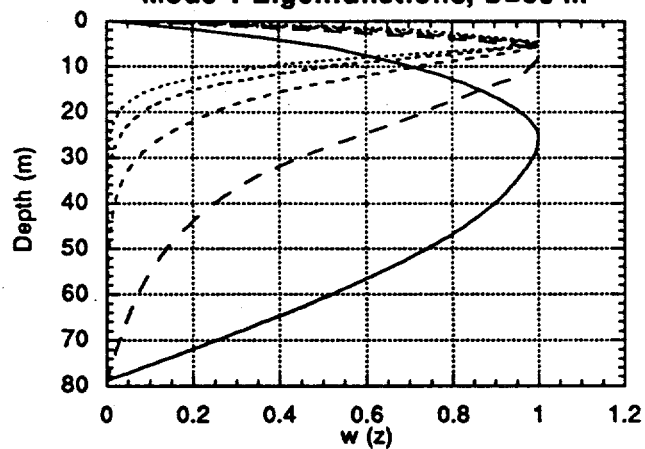
Phase and Group Velocities



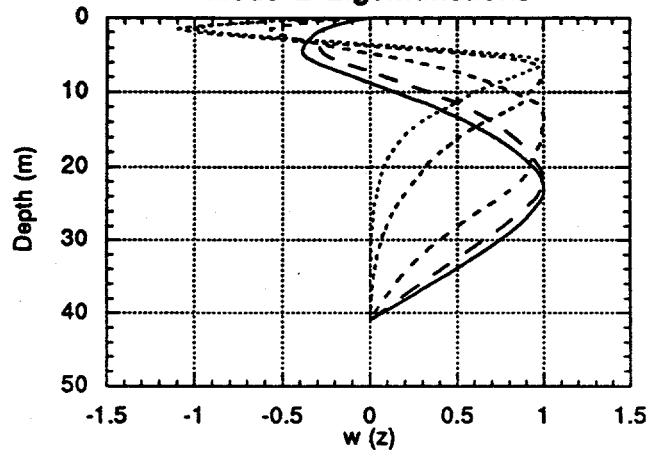
Mode 1 Eigenfunctions



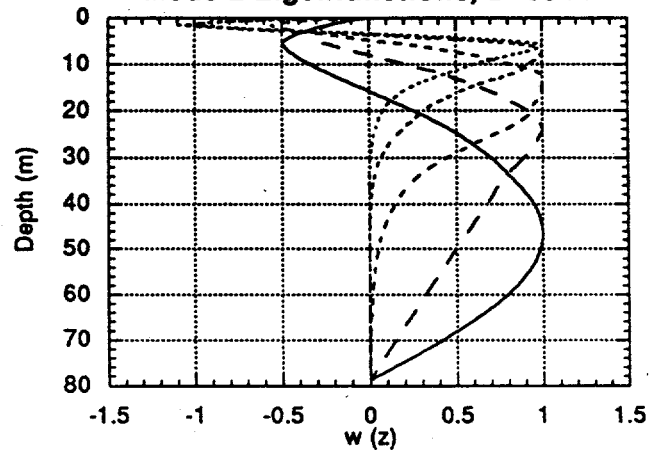
Mode 1 Eigenfunctions, D=80 m

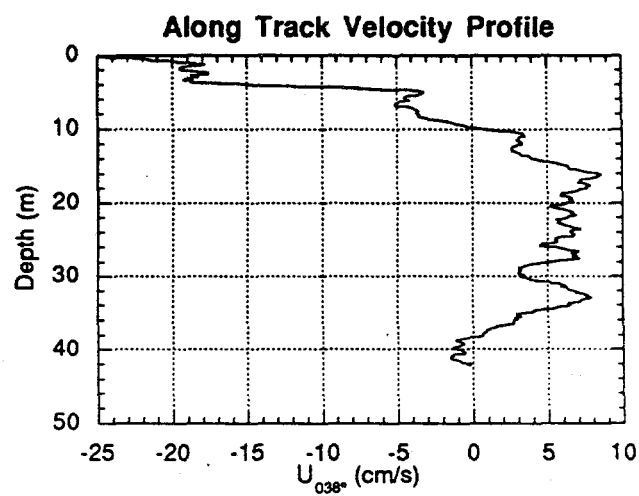
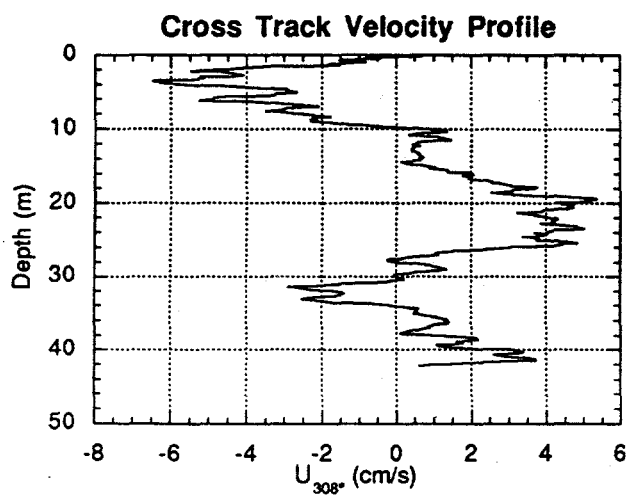
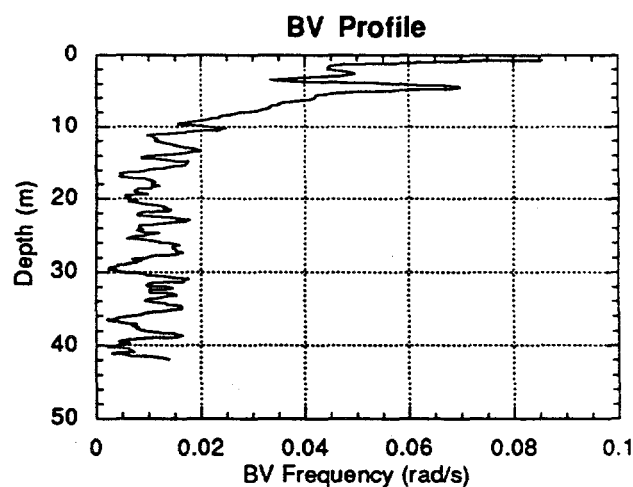
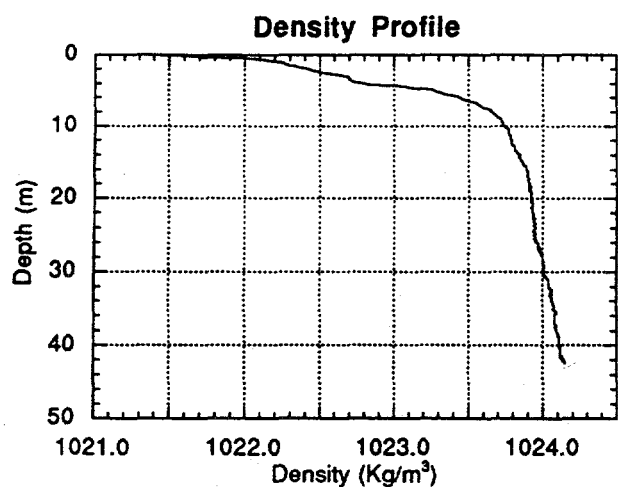
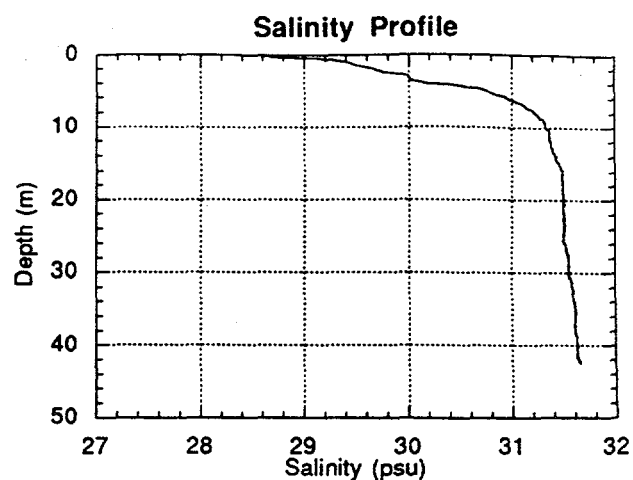
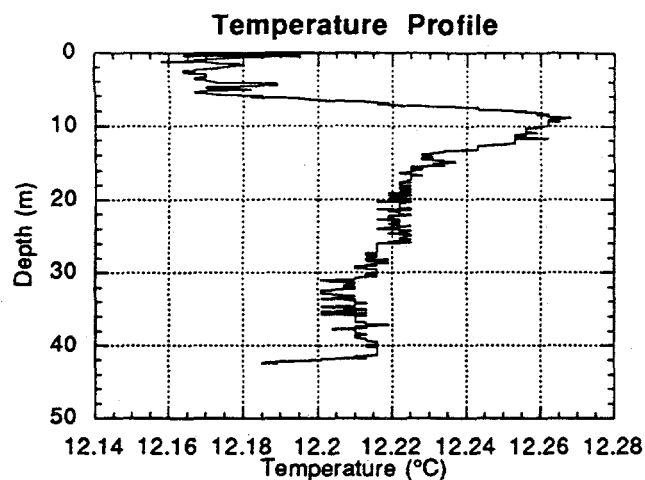


Mode 2 Eigenfunctions

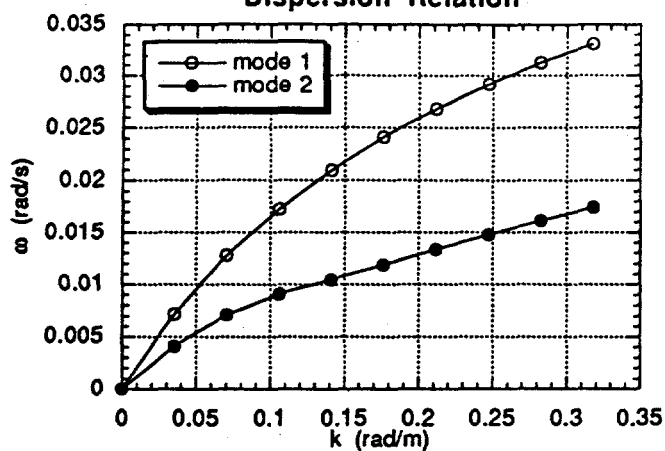


Mode 2 Eigenfunctions, D=80 m

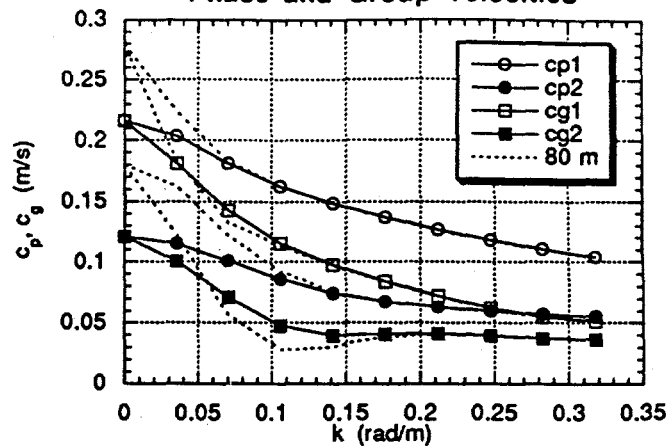




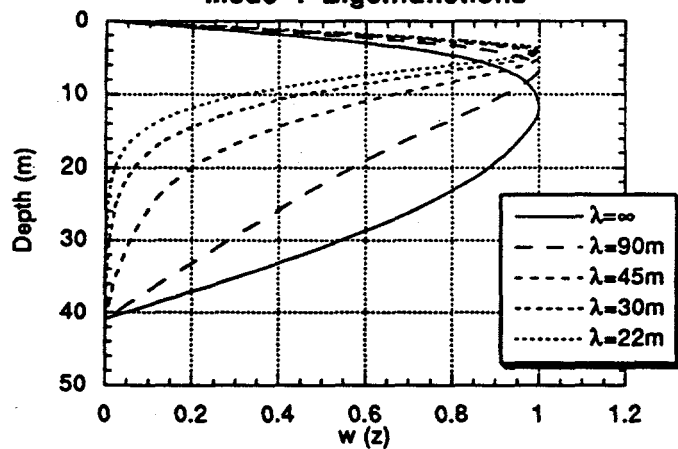
Dispersion Relation



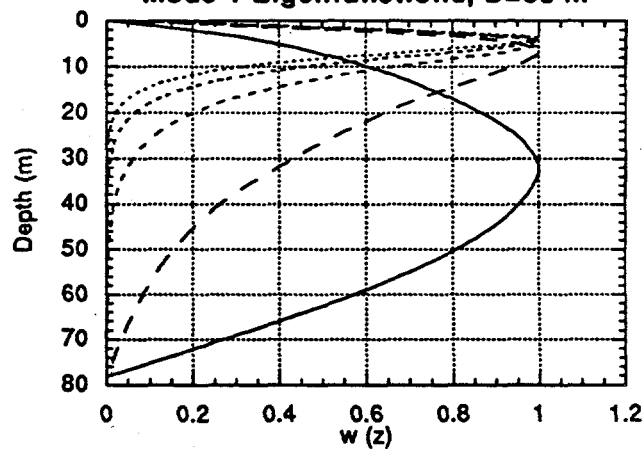
Phase and Group Velocities



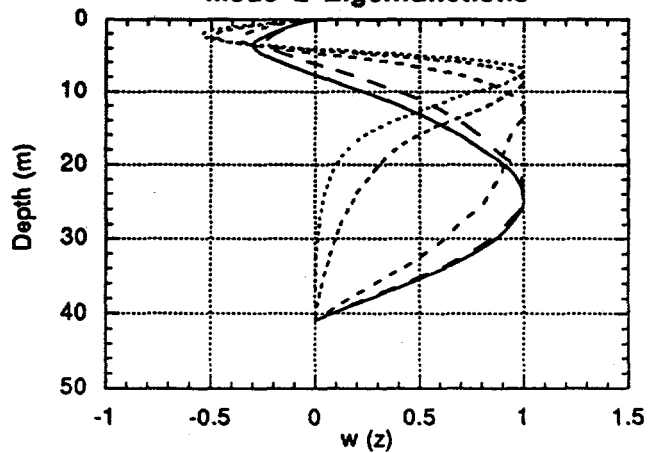
Mode 1 Eigenfunctions



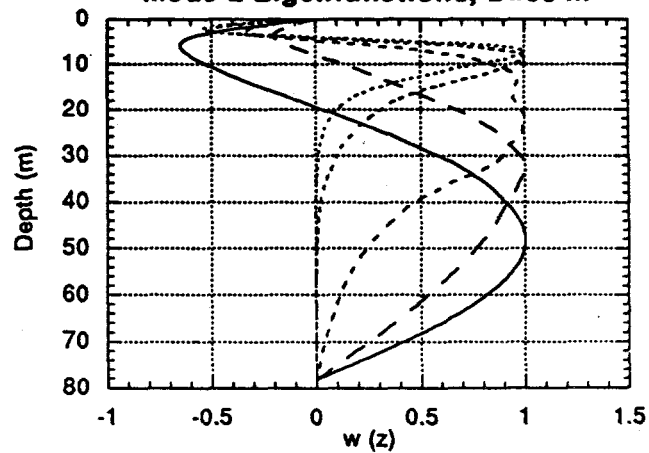
Mode 1 Eigenfunctions, D=80 m



Mode 2 Eigenfunctions

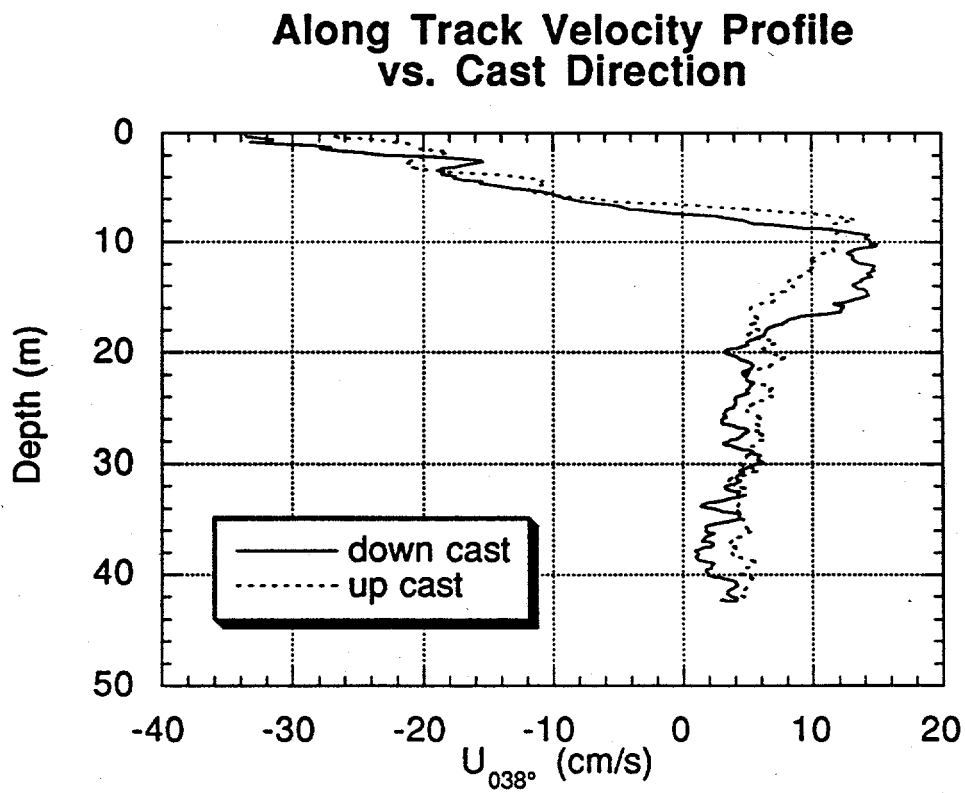
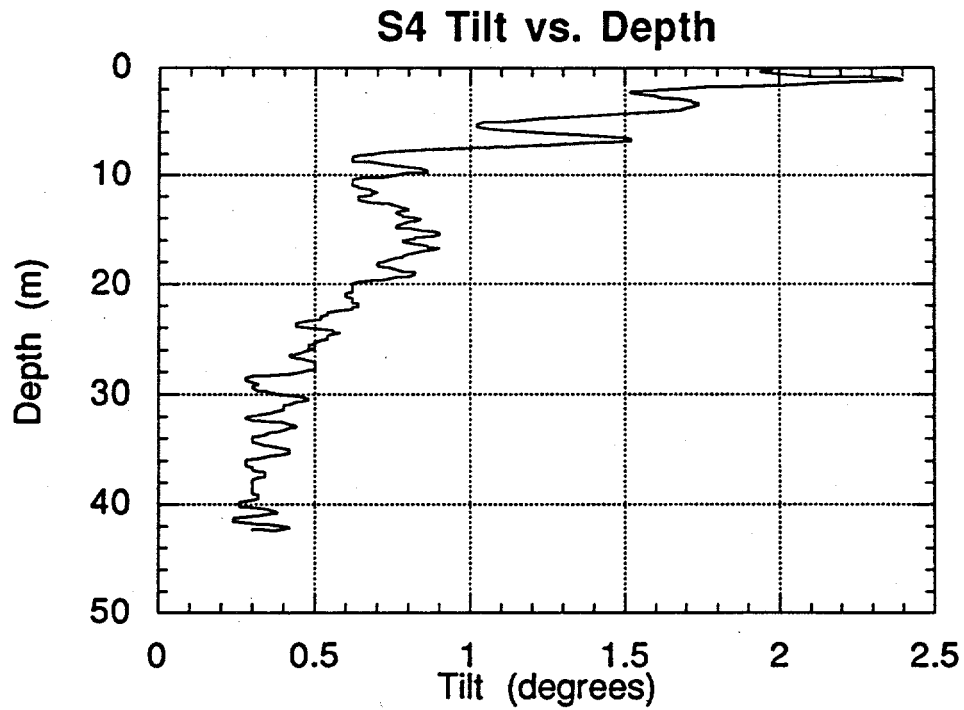


Mode 2 Eigenfunctions, D=80 m



Appendix

9/17/94, 14:30 GMT



Along Track Velocity Profile vs. Casting Speed

