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DRIFT BUOY INTERCOMPARISON TEST RESULTS

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1. INTRODUCTION

Intercomparison tests of drift buoys to be used in the Tropical Ocean-Global Atmosphere (TOGA) Pan Pacific Surface Current Study were conducted from the NOAA Ship OCEANOGRAPHER during its cruise from American Samoa to Hawaii in support of the Equatorial Pacific Ocean Climate Studies (EPOCS) program. The ship departed American Samoa on May 10, 1988 and arrived in Honolulu, Hawaii on June 4, 1988. While underway the primary tasks included CTD sampling with chemical and nutrient analysis, deploying and recycling ATLAS, current meter and upward-looking acoustic Doppler mooring arrays, population surveys of aquatic and bird species, and the buoy intercomparison tests.

Detailed tests were carried out on the Low-Cost Tropical Drifter (Bitterman and Hansen, 1986), designed and built at the NOAA Atlantic Oceanographic and Meteorological Laboratory, Miami, Florida, and the Ministar drifter (Niiler et al., 1987), designed and built by Technocean, Inc. and by the Scripps Institution of Oceanography (SIO), La Jolla, California. Additional testing was done using a tether and float of the thermistor chain buoy designed and used by IFREMER, Brest, France, and the Low Cost Drifter (Dahlen, 1986), designed by the MIT Draper Laboratory, Cambridge, Massachusetts. The purpose of these tests was to quantitatively determine the effectiveness of each design as a Lagrangian tracer under a variety of ocean surface, subsurface, and wind conditions. A series of six tests (Figure 1) were performed lasting approximately 36 hours, and this report presents a detailed summary of the results.

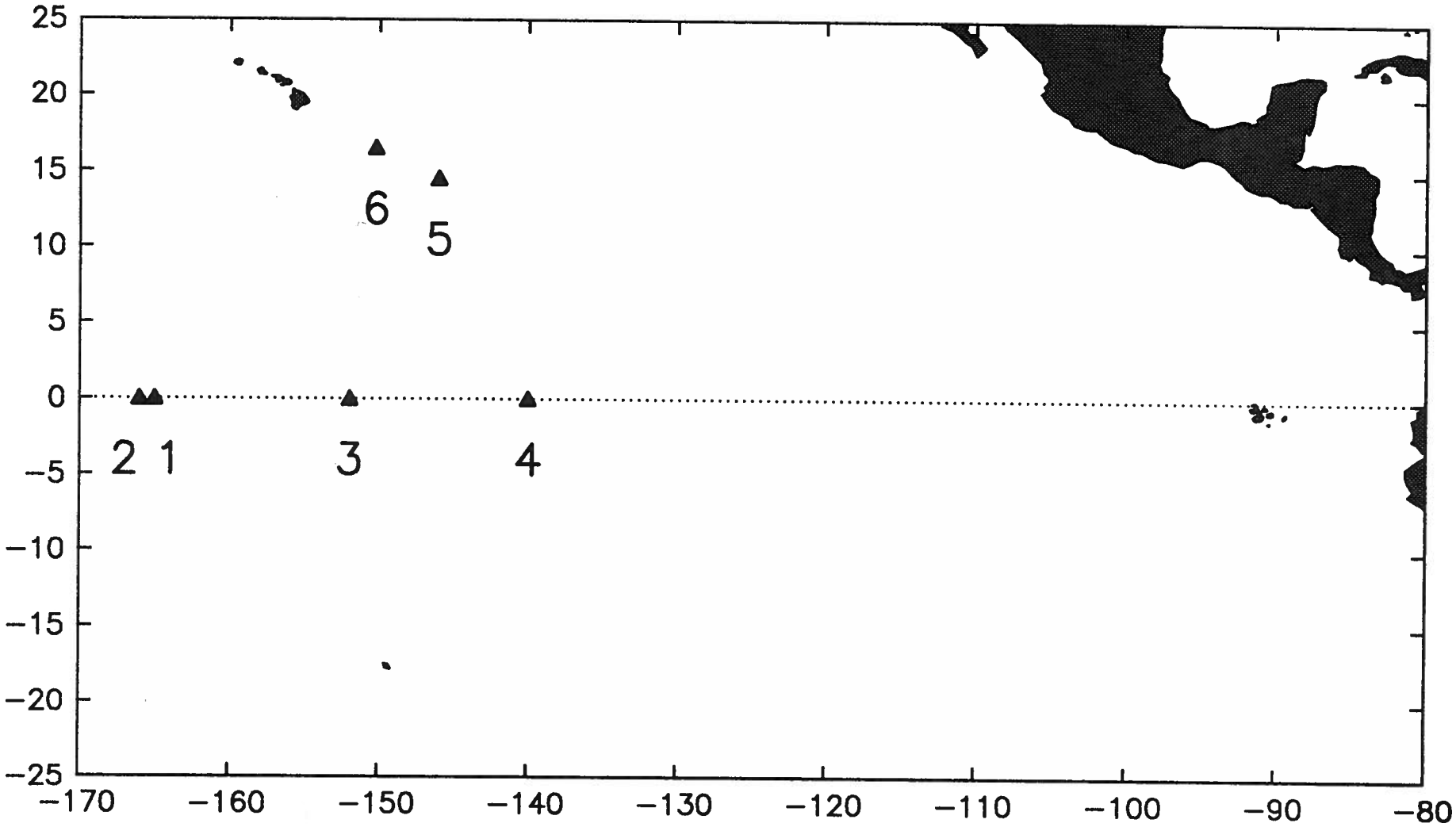
2. STATEMENT OF THE PROBLEM

Drift buoys used to infer ocean currents from the buoy displacement over time typically consist of a surface float containing a radio transmitter, batteries, and associated electronics, and a subsurface float designed to couple the buoy to the water layer of interest. Imperfect coupling of the buoy to the water surrounding it will cause the buoy to "slip" relative to the water and introduce errors into the derived currents. Wind forces, surface wave action, and current shear acting on the surface float and the tether line connecting it to the drogue are major contributors to slip. To minimize this slippage, the cross-sectional areas of the hull and tether line are typically made small relative to the cross-sectional area of the drogue. However, few measurements of this slippage exist and the performance of a given buoy design in actually following the currents is poorly understood.

Model studies are helpful but it is usually impossible to duplicate open ocean conditions within the relatively small confines of a test tank. Likewise, mathematical analysis is helpful but the three-dimensional motion of the buoy and drogue in a complicated wave field quickly results in a very difficult problem.

Comparison of buoy motion with moored current meters or other measurements of the current field is difficult because the two measurements systems quickly separate and the small signals of interest are difficult to distinguish from small-scale spatial variability of the currents. Therefore, the approach used in these tests is to directly measure the slip of the buoy with current meters attached to the drogue itself. The overall objective is to obtain enough measurements over a wide variety of wind and shear conditions so that an empirical estimate of the slip can be made as a function of these parameters.

FIGURE 1: BUOY INTERCOMPARISON TEST SITES



Drift buoys used in the TOGA Pan Pacific surface current study are designed to track the water layer between 10 and 20 m depth with a design goal (1985) of 2 cm/sec of slippage in wind and sea conditions to Beaufort 4 (5.5 to 8.0 m/sec).

3. DESCRIPTION OF THE BUOYS

For the purpose of this test, a mockup of the hull and an instrumented drogue were constructed for the AOML spar and the SIO Ministar. The hulls did not contain batteries or electronics which are normally used to transmit the data and location signals to the ARGOS satellites, but were made to duplicate the outside dimensions and weights of the actual designs.

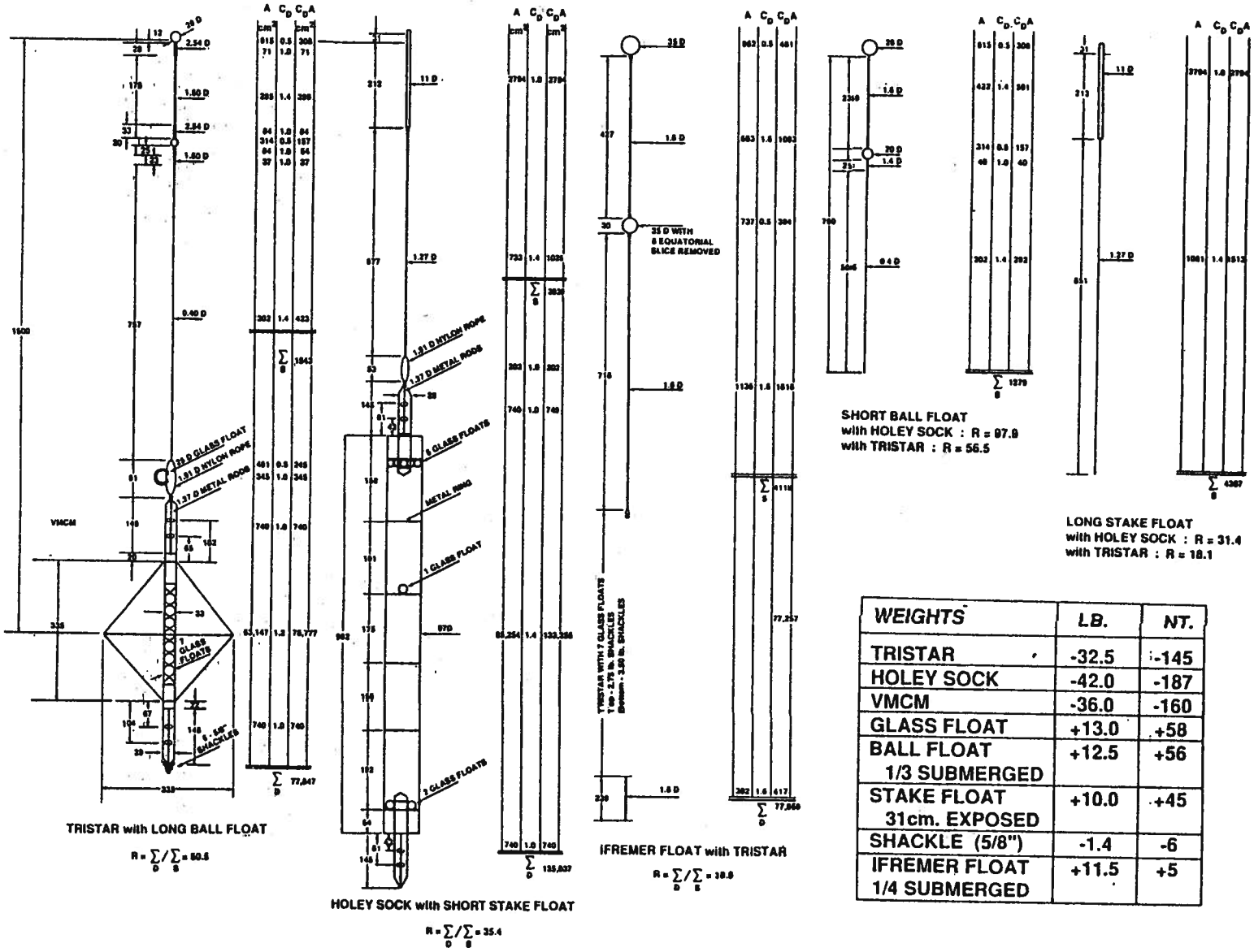
Similarly, the two drogues were designed to duplicate as closely as possible the dimensions of drogues normally used except that each one included a vector measuring current meter (VMCM) mounted at the top and bottom with the propellers exposed to the flow of water immediately above and below the drogue. To compensate for the additional weight of the current meters, 10-inch diameter glass ball floats were mounted internally in the drogue to reproduce the normal submerged weight. Each VMCM also included pressure and temperature sensors, primarily to monitor vertical motion of the drogue and determine exactly its depth. The added mass of the current meters is not expected to have any significant effect on the performance of the drogues since they are well coupled to any vertical motion of the water surrounding them. Similarly, the flow around the drogue will only suffer a minimal disturbance due to the exposed propellers and will not measurably affect slip of the drogue.

Figure 2 presents a detailed summary of the dimensions, weight, cross-sectional area (A), drag coefficient (Cd), and drogue (D) to hull (S) area ratio (R) for all components of each of the buoy/drogue combinations used in the tests.

The holey sock drogue (Figure 3) is a nylon fabric tube one meter in diameter and ten meters long with six rings spaced evenly along its length to keep it fully open when submerged. It is normally attached to the tether line with six 5 cm wide nylon straps and has a 6.4 kg lead rod sewn into the bottom ring for ballast. Ten 30 cm diameter holes are spaced evenly along its length to aid in fabrication and reduce vortex shedding when deployed.

The holey sock test drogue was identical in dimensions but the top and bottom rings were modified to include brackets for mounting a VMCM. The electronics case of each current meter was positioned inside the holey sock leaving only the propellers protruding from each end. Eight glass ball floats were needed for correct ballasting and these were attached to wires within the drogue. When submerged, the tether line tension was about 4.5 kg.

The Tristar drogue (Figure 4) is constructed as three 240 cm x 240 cm square dacron panels mounted orthogonally in three planes with the tether line attachment at one vertex. The arms supporting the panels are hinged at the center so that the drogue can be folded for shipment and then fall open to their fully open position after deployment. The center support member telescopes for further compression during storage. The test drogue included a central spine made of aluminum tubing with brackets for holding a VMCM at each end. Again the electronics cases of the current meters were enclosed within this central spine leaving only the propellers exposed at each end. Eight



WEIGHTS	LB.	NT.
TRISTAR	-32.5	-145
HOLEY SOCK	-42.0	-187
VMCM	-36.0	-160
GLASS FLOAT	+13.0	+58
BALL FLOAT 1/3 SUBMERGED	+12.5	+56
STAKE FLOAT 31cm. EXPOSED	+10.0	+45
SHACKLE (5/8")	-1.4	-6
IFREMER FLOAT 1/4 SUBMERGED	+11.5	+5

Figure 2. Buoy test configurations.

glass ball floats were required to support the additional weight of the current meters and extra aluminum, with seven enclosed within the spine and the eighth attached outside the drogue above the top current meter. Six shackles at the bottom were needed to complete the ballasting, resulting in a net weight of 3.8 kg in the water.

The SIO Ministar hull (Figure 4) includes a 28 cm diameter plastic surface float which contains the batteries, transmitter, antenna and sea surface temperature sensor, and a 20 cm diameter subsurface float attached to the tether line approximately 250 cm below the surface float. This subsurface float provides added flotation and effectively decouples the drogue from the motion of the surface float. By doing this the surface float is able to ride the surface waves while the motion and stresses on the drogue are greatly reduced, thus enhancing its survivability. Tether line material is polyethylene impregnated wire rope reinforced with epoxy filled neoprene tubing at the attachment points on the spheres.

The AOML spar buoy is constructed from ordinary 11.4 cm outside diameter, schedule 40 polyvinylchloride (PVC) tubing, 240 cm long, with a cap on the top end and a threaded fitting on the lower end for attaching the drogue. The transmitter and antenna are mounted inside the capped end of the tube with the battery in the opposite end, and when deployed it floats vertically with the top 40 cm above the water. Lead weights were used to match the weight of the battery and electronics for the tests. The holey sock drogue is attached with a 1.27 cm diameter nylon rope such that the top of the drogue is at 10 m depth.

The IFREMER spherical hull and tether is similar to the SIO configuration although larger in diameter and is designed to support a thermistor chain within the tether line. For these tests, this float was deployed only with the Tristar drogue which was attached to the tether line so as to be centered at approximately 15 m depth.

The Draper Lab LCD includes a pill-shaped surface float 36.5 cm in diameter by 21 cm thick with 30 cm diameter by 12.8 m long holey sock drogue. The drogue is attached to the hull with a 1.27 cm diameter 10 m long polypropylene tether line.

Because the 10 m length of the holey sock exceeded the 3.4 m length of the Tristar drogue, two additional hull and tether combinations for the SIO sphere and the AOML spar were built. This allowed interchanging hulls and drogues while maintaining the drogues and a constant depth. The short ball float refers to the spherical hull/tether combination used with the holey sock whereas the long stake float refers to the AOML spar/tether combination used with the Tristar drogue. By attaching various tethers to various drogues, drag area ratios between 18 and 98 could be set up. The effect of different drag area ratios on drifter slip was one of the important effects to be evaluated in this study.

4. TEST PROCEDURE

Tests were conducted during the course of the cruise at the six sites shown in Figure 1. These sites were selected to obtain data under a variety of surface wave, subsurface shear, and wind conditions. The two buoy configurations to be tested were deployed typically 50 to 100 m apart and allowed to drift freely for periods of one to two hours. During this period the ship

remained down wind from the buoys to monitor their progress. Following the free drifting period, the buoys were either retrieved, or personnel standing by in a small boat pulled in the drogue, changed the hull configuration and redeployed the buoys for an additional one to two hours.

Positions of the buoys were tracked from the ship during the free drifting period by making simultaneous observations of the ship's position, the visual angle of declination of the buoy below the horizon as measured with a sextant, and the true bearing of the buoys from the ship obtained from the ship's alidade. Section 6 describes the technique used to convert these readings to displacements.

Other data collected in support of the drift tests included wind speed and direction as monitored by the meteorological sensors on the ship, sea swell height and direction as estimated visually by ship's personnel, and subsurface current data collected by the Doppler acoustic current profiler which was run continuously throughout the cruise.

During some of the tests, divers were deployed to visually photograph and observe the motion and condition of each configuration. Handheld dispensers of liquid rhodamine solution were used to generate small clouds of dye which were then visually tracked by the divers in order to get an idea of the small scale flows around the drogues.

Tables 1.1 through 1.6 are chronological records of each test including ship position, true bearing, declinations to the buoys being tested, and environmental data. In later sections where the tests are divided into two parts, for instance tests 1A and 1B, the A part refers to the configurations as initially deployed and the B part is after the drogue and hull have been switched.

5. BUOY DRIFT VELOCITIES DERIVED FROM SHIPBOARD OBSERVATIONS

Observations of the range and true bearing to each of the buoy configurations were made from the ship's bridge during most of the tests. These observations were converted to horizontal displacements as shown in Figure 5. The angle of the horizon relative to the local vertical, Φ, can be computed as shown in equation 1 and, for the bridge height of 12.2 m, is equal to 89.89 degrees. The angle of declination, Δ, measured with a sextant is then subtracted to give the angle of the buoy relative to the local vertical. The range, approximately x in Figure 5, is computed from equation 2.

Tables 2.1 through 2.5 and Figures 6 through 10 summarize the results of the observations from tests 2 through 6. The average drift velocities for each of the tests were then computed from the displacements and deployment times and are summarized in Table 2.6.

6. VECTOR MEASURING CURRENT METER RESULTS

The two vector measuring current meters included on each of the instrumented drogues were set up, tested, and sealed prior to shipment to the ship. Each was programmed to continuously sample both current components at every rotation of the propeller and compute a 7.5 minute vector average which was then written to magnetic tape within the instrument along with the pressure and water temperature.

TABLE 1.1: TOGA PAN PACIFIC SURFACE CURRENT STUDY DRIFTER CALIBRATION EXPERIMENT.

TEST #1 DATE: 16 MAY 1988 LOCATION: 0°N, 165°W SUBSURFACE CONDITIONS: MIXED LAYER 26 M

Time (Zulu)	Local	Chronology	Notes
19:49	9:49	Spin #05 VMCM; Tristar top	Bridge above sea level: 34'8"
19:50	9:50	Spin #11 VMCM: Tristar bottom	Observers's eye: 39'8" above sea level
20:23	10:23	Tristar free; long ball float	------
20:29	10:29	Spin #12 VMCM; sock top	------
20:30	10:30	Spin #6 VMCM; sock bottom	------
21:07	11:07	Sock free; short stake float	Short stake floats 6" out of water (too deep - not used again)
21:56	11:56	Attach to sock for float exchange	------
22:09	12:09	Sock free; short ball float	------
22:21	12:21	Attach to Tristar for float exchange	------
22:31	12:31	Tristar free; long stake float	Long stake floats 28" out of water
23:10	13:10	Recovery attach to sock	(make adjustment for Test #2 by addition of 2 shackles)
23:40	13:40	Recovery attach to Tristar	------
00:10	14:10	All on board	------

ENVIRONMENTAL DATA

Time (Zulu)	Local	Ship		Sock		Tristar		Wind (knt./°T)		Sea (Ft./°T)	
		Latitude °N	Longitude °W	Incl.	Bear.	Incl.	Bear.	Spd.	Dir.	Ht.	Dir.
21:21	11:21	00°00.430	164°50.100	-----	-----	-----	-----	14	090	3-5	090
21:39	11:39	00°00.463	164°49.664	-----	-----	-----	-----	14	095	3-5	090
21:43	11:43	00°00.455	164°49.616	-----	-----	2°46.5'	205°	14	095	3-5	090
21:50	11:50	00°00.505	164°49.398	-----	-----	3°29.8'	108°	16	095	3-5	090

TABLE 1.2: TOGA PAN PACIFIC SURFACE CURRENT STUDY DRIFTER CALIBRATION EXPERIMENT.

TEST #2 DATE: 17 MAY 1988 LOCATION: 0°N, 166°W SUBSURFACE CONDITIONS: MIXED LAYER 12 M

Time (Zulu)	Local	Chronology	Notes
19:28	9:28	Spin #05 VMCM; Tristar top	———
19:29	9:29	Spin #11 VMCM; Tristar bottom	———
19:41	9:41	Spin #6 VMCM; sock bottom	———
19:42	9:42	Spin #12 VMCM; sock top	———
19:46	9:46	Tristar free; long ball float	———
20:05	10:05	Sock free; long stake float	———
21:16	11:16	Attach to sock	———
21:23	11:23	Sock free; short ball float	White caps/confused
21:30	11:30	Attach to Tristar	Wind waves/seas
21:39	11:39	Tristar free; long stake float	Increase with time
22:35	12:35	Recovery attach to sock	———
22:48	12:48	Recovery attach to Tristar	———
00:00	14:00	All on board	———

ENVIRONMENTAL DATA

Time (Zulu)	Local	Ship		Sock		Tristar		Wind (knt./°T)		Sea (Ft./°T)	
		Latitude °N	Longitude °W	Incl.	Bear.	Incl.	Bear.	Spd.	Dir.	Ht.	Dir.
———	10:21	00°00.707	166°00.352	———	———	———	———	18	——	——	——
20:27	10:27	00°00.835	166°00.482	1°11.5′	136°	3°48.5′	219°	16	092	4–5	092
20:41	10:41	00°01.088	166°00.720	0°54.5′	129°	5°25.5′	187°	17	089	4–5	090
20:55	10:55	00°01.229	166°00.910	0°57.3′	119°	15°54.5′	170°	22	088	4–5	090
21:13	11:13	00°01.516	166°00.952	0°54.9′	131°	4°35.0′	198°	20	091	4–6	090
21:31	11:31	00°01.576	166°00.879	2°26.3′	136°	1°21.9′	291°	20–16	085	4–6	090
21:44	11:44	00°01.741	166°00.921	3°16.5′	161°	0°57.5′	288°	20–16	085	5–6	090
22:23	12:23	00°02.406	166°01.185	1°19.7′	168°	1°29.3′	266°	20	085	5–6	090
———	13:20	———	———	———	———	———	———	22	098	——	090

TABLE 1.3: TOGA PAN PACIFIC SURFACE CURRENT STUDY DRIFTER CALIBRATION EXPERIMENT.

TEST #3 DATE: 19 MAY 1988 LOCATION: 0°N, 152°W SUBSURFACE CONDITIONS: MIXED LAYER 19 M

Time (Zulu)	Local	Chronology	Notes
19:21	9:21	Spin #12 VMCM; sock top	Holey sock torn on deployment
19:22	9:22	Spin #6 VMCM; sock bottom	Retrieve and repair
19:22	9:22	Spin #5 VMCM; Tristar top	------
19:23	9:23	Spin #11 VMCM; Tristar bottom	------
19:39	9:39	Tristar free; short ball float	Short ball float on Tristar for entire Test #3
21:04	11:04	Spin #12 and #6 VMCM again	------
21:15	11:15	Sock free; long stake float	------
21:20	11:20	Divers on sock	White caps decreasing
-----	-----	Divers off sock	"Confused" wind driven sea
-----	-----	Divers on Tristar	------
21:35	11:35	Divers off Tristar	------
22:56	12:56	Recovery attach to sock	------
23:23	13:23	Recovery attach to Tristar	*Ship recovery - wind 15° off starboard bow
23:45	13:45	All on board	------

ENVIRONMENTAL DATA

Time (Zulu)	Local	Ship		Sock		Tristar		Wind (knt./°T)		Sea (Ft./°T)	
		Latitude °N	Longitude °W	Incl.	Bear.	Incl.	Bear.	Spd.	Dir.	Ht.	Dir.
21:27	11:27	00°01.189	151°57.415	-----	-----	-----	-----	16	95	3-5	095
21:38	11:38	00°01.218	151°57.226	3°21.5'	141°	1°44.7'	181°	17	108	3-5	095
21:52	11:52	00°01.248	151°56.977	3°00.0'	174°	1°32.8'	192°	14	106	3-5	095
22:44	12:44	00°01.739	151°56.592	1°00.0'	63°	1°10.4'	63°	14	98	3-4	095
23:04	13:04	00°01.635	151°56.986	Sock: 30 yds. abeam to Starboard*				12-14	---	3-4	095
23:(?)	-----	00°01.918	151°55.862	Tristar: 30 yds. abeam to Starboard*				12-14	---	3-4	095

TABLE 1.4: TOGA PAN PACIFIC SURFACE CURRENT STUDY DRIFTER CALIBRATION EXPERIMENT.

TEST #4 DATE: 24 MAY 1988 LOCATION: 0°N, 140°W SUBSURFACE CONDITIONS: MIXED LAYER 12 M

Time (Zulu)	Local	Chronology	Notes
20:40	10:40	Spin #5 VMCM; Tristar top	Broken rubber band; spin could have started earlier
21:04	11:04	Spin #11 VMCM; Tristar bottom	------
21:08	11:08	Spin #12 VMCM; sock top	Tristar rotors are a "bit stiff," instruct divers to spin in water
21:09	11:09	Spin #6 VMCM; sock bottom	------
21:50	11:50	Sock free; long stake float	------
22:04	12:04	Divers on sock	------
22:07	12:07	Divers off sock	------
22:11	12:11	Tristar free; IFREMER float	------
22:14	12:14	Divers on Tristar	Divers report Tristar spar broken at hinge
22:21	12:21	Divers off Tristar	Temporary repair affected; spin props
22:48	12:48	Zodiak inspects Tristar	------
22:53	12:53	Light on IFREMER buoy	------
23:06	13:06	Divers on sock	------
23:25	13:25	Divers off sock	------
23:41	13:41	Divers on Tristar	Repair of Tristar okay
23:52	13:52	Divers off Tristar	------
00:33	14:33	Recovery attach on sock	------
00:47	14:47	Recovery attach on Tristar	------
01:14	15:14	All on board	Tristar rotors spin "freely" after recovery

ENVIRONMENTAL DATA

Time (Zulu)	Local	Ship		Sock		Tristar		Wind (knt./°T)		Sea (Ft./°T)	
		Latitude °N	Longitude °W	Incl.	Bear.	Incl.	Bear.	Spd.	Dir.	Ht.	Dir.
22:04	12:04	00°59.433	140°00.187	-----	-----	-----	-----	8	110	1-2	130
22:16	12:16	00°59.411	140°00.057	2°48.4′	132°	1°48.9′	178°	8	120	---	---
22:42	12:42	00°59.563	140°00.187	1°18.9′	105°	1°39.2′	117°	8-6	138	1-2	130
23:03	13:03	00°59.596	140°00.152	0°55.9′	105°	0°59.9′	127°	8-6	132	1-2	130
23:28	13:28	00°59.482	139°59.764	2°18.7′	132°	2°00.0′	177°	10	121	2-3	130
23:48	13:48	00°59.403	139°59.678	2°05.5′	135°	1°41.4′	176°	8-10	120	2-3	130
00:21	14:21	00°59.230	139°59.230	1°42.9′	161°	1°18.0′	189°	8-10	110	2-3	130

TABLE 1.5: TOGA PAN PACIFIC SURFACE CURRENT STUDY DRIFTER CALIBRATION EXPERIMENT.

TEST #5 DATE: 1 JUNE 1988 LOCATION: 14°35'N, 146°08'W SUBSURFACE CONDITIONS: MIXED LAYER 63 M

Time (Zulu)	Local	Chronology	Notes
19:53	9:53	Spin VMCM #12 and #06; holey sock	At 7:40 noted rubberband on #6 was missing
20:05	10:05	Sock free; long ball float	------
20:06	10:06	Spin VMCM #11 and #05; Tristar	------
20:21	10:21	Tristar loose; IFREMER float	------
20:22	10:22	Draper LCD loose	LCD deployed 20 ft. cross-wind of holey sock
20:32	10:32	Divers on sock and LCD	------
20:36	10:36	Divers up	------
21:17	11:17	Divers on Tristar	------
21:27	11:27	Divers up	------
21:32	11:32	Zodiak exchanges floats on sock	------
21:44	11:44	Sock loose; long stake float	------
21:55	11:55	Redeploy LCD	LCD deployed 20 ft cross-wind of holey sock
21:56	11:56	Divers on sock and LCD	All three floats within 30 ft. radius
22:08	12:08	Divers up	------
23:26	13:26	Tagline on Tristar	------
23:45	13:45	Tagline on sock	------
00:09	14:09	All on board	------

ENVIRONMENTAL DATA

		Ship		Sock		Tristar		LCD		Wind (knt./°T)		Sea (Ft./°T)	
Time (Zulu)	Local	Latitude °N	Longitude °W	Incl.	Bear.	Incl.	Bear.	Incl.	Bear.	Spd.	Dir.	Ht.	Dir.
20:29	10:29	14°35.459	146°08.095	-----	-----	-----	-----	-----	-----	18	060	4-6	060
20:47*	10:47	14°35.225	146°08.291	7°29.7'	106°	3°43.1'	84°	8°43.6'	107°	16-18	060	4-6	060
20:55	10:55	14°35.201	146°08.378	8°00.0'	143°	5°27.0'	108°	8°34.5'	168°	16	060	3-5	060
21:15	11:15	14°35.071	146°08.668	11°45.8'	108°	4°36.7'	92°	13°36.5'	168°	16	060	3-5	060
21:37	11:37	14°35.005	146°08.988	12°26.5'	168°	12°23.0'	150°	**	**	16	060	3-5	060
22:00	12:00	14°34.923	146°09.221	7°26.3'	148°	8°27.2'	137°	7°30.0'	153°	18	58	3-5	60
23:12	13:12	14°34.720	146°10.336	1°32.1'	70°	2°06.9'	66°	2°15.0'	71°	16	60	3-5	60
23:24	13:24	14°34.814	146°10.344	2°47.9'	91°	4°14.0'	90°	2°42.0'	92°	16	60	3-5	60

*Fixes of dubious quality--ship moving.
**20 ft. cross-wind from stake.

TABLE 1.6: TOGA PAN PACIFIC SURFACE CURRENT STUDY DRIFTER CALIBRATION EXPERIMENT.

TEST #6 DATE: 2 JUNE 1988 LOCATION: 16°25'N, 150°15'W SUBSURFACE CONDITIONS: WEAK MIXED LAYER AT 16 M

Time (Zulu)	Local	Chronology	Notes
20:02	10:02	Spin Tristar VMCM #5 and #11	———
20:04	10:04	Spin sock VMCM #6 and #12	———
20:12	10:12	Sock free; with long stake float	———
20:22	10:22	Tristar free; with long ball float	———
20:27	10:27	LCD 3 yards from sock	———
20:35	10:35	Divers on sock and LCD	———
20:54	10:54	Divers up	———
21:24	11:24	Ship close to LCD; wake kicks LCD upwind	Wind gusty, occasional squall to 24-28 knots
21:38	11:38	Attach to sock; remove spar	———
21:41	11:41	Sock free; short ball float	———
21:44	11:44	LCD 3 yards from sock	———
21:45	11:45	Attach to Tristar; remove ball	———
21:50	11:50	Tristar free; long stake float	———
21:51	11:51	Divers on Tristar	———
21:51	11:51	Ship close to sock; wake kicks sock upwind	———
21:56	11:56	Divers up	———
22:54	12:54	Winds slack to 14 knots/sunshine	Variability of Sat. Nav. is ± .020 nm.
23:20	13:20	Tagline on sock	———
23:41	13:41	Tagline on Tristar	———
23:49	13:49	Tristar on board	———

ENVIRONMENTAL DATA

Time (Zulu)	Local	Ship		Sock		Tristar		LCD		Wind (knt./°T)		Sea (Ft./°T)	
		Latitude °N	Longitude °W	Incl.	Bear.	Incl.	Bear.	Incl.	Bear.	Spd.	Dir.	Ht.	Dir.
20;32	10:32	16°25.132	150°15.732	5°36.0'	134°	2°46.1'	134°	5°40.5'	124°	16	57	4-6	60
20:35	10:35	16°25.146	150°15.769	7°22.9'	143°	3°03.2'	132°	8°28.1'	151°	20	60	4-6	60
20:48	10:48	16°25.275	150°15.811	3°44.9'	158°	2°26.3'	150°	3°33.0'	161°	18	60	4-6	60
21:00	11:00	16°25.338	150°15.824	12°49.8'	180°	3°44.9'	158°	9°37.2'	185°	20	60	4-6	60
21:10	11:10	16°25.431	150°15.890	5°47.8'	160°	2°42.9'	149°	7°30.0'	174°	22-16	65	4-6	60
21:24	11:24	16°25.588	150°15.992	6°34.1'	138°	3°03.9'	138°	9°47.1'	133°	22-16	65	4-6	60
21:35	11:35	16°25.665	150°15.996	3°16.9'	179°	2°23.0'	151°	4°19.5'	190°	18	60	4-6	60
21:56	11:56	16°25.774	150°16.069	11°36.0'	157°	4°01.7'	132°	7°56.3'	150°	18	55	4-6	60
23:07	13:07	16°26.325	150°16.353	4°45.3'	123°	1°56.3'	148°	3°59.0'	143°	18	54	4-6	60
23:12	13:12	16°26.323	150°16.417	4°48.9'	106°	2°29.3'	150°	5°17.9'	158°	16	60	3-5	60

TABLE 2.1: CALCULATION OF RELATIVE DISPLACEMENT OF BUOYS.

EXPERIMENT #2 DATE: 17 MAY 1988

Ship					Sock						
Time	Latitude	Longitude	Ys (0°=0)	Xs (166°=0 m)	Incl.	Bearing	Range (m)	X (m)	Y (m)	X+Xs (166°=0 m)	Y+Ys (0°= 0)
20:27	0°00.835′	166°00.482′	1549	-894	1°11.5′	136°	536	372	-386	-522	+1163
20:41	0°01.088′	166°00.720′	2019	-1336	1°54.5′	129°	684	531	-430	-805	+1589
20:55	0°01.229′	166°00.910′	2280	-1688	1°57.3′	119°	655	573	-318	-1115	+1962
21:13	0°01.516′	166°00.952′	2813	-1766	1°54.9′	131°	680	513	-446	-1253	+2367
21:31	0°01.576′	166°00.879′	2924	-1631	2°26.3′	136°	274	190	-197	-1441	+2727
21:44	0°01.741′	166°00.921′	3230	-1709	3°16.5′	161°	206	67	-194	-1692	+3036
22:23	0°02.406′	166°01.185′	4464	-2199	1°19.7′	168°	485	101	-474	-2098	+3990

Tristar						
Incl.	Bearing	Range (m)	X (m)	Y (m)	X+Xs (166°= 0 m)	Y+Ys (0°=0)
3°48.5′	219°	178	-112	-138	-1006	1411
5°25.5′	187°	126	-15	-125	-1351	1894
15°54.5′	170°	42	+7	-41	-1681	2239
4°35.0′	198°	148	-46	-141	-1812	2672
1°21.9′	291°	473	-441	+170	-2072	3094
0°57.5′	288°	652	-620	+201	-2329	3431
1°29.3′	266°	436	-435	-30	-2634	4434

TABLE 2.2: CALCULATION OF RELATIVE DISPLACEMENT OF BUOYS.

EXPERIMENT #3 DATE: 19 MAY 1988

Ship					Sock						
Time	Latitude	Longitude	Ys (0°=0)	Xs (152°=0 m)	Incl.	Bearing	Range (m)	X (m)	Y (m)	X+Xs (152°=0 m)	Y+Ys (0°= 0)
21:27	0°01.189'S	151°57.415'	----	----	-------	----	---	---	---	----	----
21:38	0°01.248'S	151°57.226'	-2316	5147	3°21.5'	141°	202	127	-157	5274	-2473
21:52	0°01.248'S	151°56.977'	-2316	5609	3°00.0'	174°	224	23	-223	5632	-2539
22:44	0°01.739'S	151°56.592'	-3227	6323	1°00.0'	63°	628	559	285	6882	-2942

Tristar						
Incl.	Bearing	Range (m)	X (m)	Y (m)	X+Xs (166°= 0 m)	Y+Ys (0°=0)
1°44.7'	181°	376	-7	-375	5140	-2692
1°32.8'	192°	421	-88	-412	5521	-2728
1°10.4	63°	543	484	246	6808	-2980

TABLE 2.3: CALCULATION OF RELATIVE DISPLACEMENT OF BUOYS.

EXPERIMENT #4 DATE: 24 MAY 1988

Ship					Sock						
Time	Latitude	Longitude	Ys (1°N=0 m)	Xs (140°=0 m)	Incl.	Bearing	Range (m)	X (m)	Y (m)	X+Xs (140°=0 m)	Y+Ys (1°N=0 m)
22:16	0°59.411′	140°00.057′	-1093	-105	2°48.4′	132°	239	178	-160	73	-1253
22:42	0°59.563′	140°00.187′	-811	-347	1°18.9′	105°	490	473	-127	126	-938
23:08	0°59.596′	140°00.152′	-750	-282	0°55.9′	105°	669	646	-173	364	-923
23:28	0°59.482′	139°59.764′	-961	+438	2°18.7′	132°	288	214	-193	652	-1154
23:48	0°59.403′	139°59.678′	-1108	+597	2°05.5′	135°	317	224	-224	821	-1332
00:21	0°59.230′	139°59.230′	-1429	+1429	1°42.9′	161°	382	124	-361	+1553	-1790

Tristar						
Incl.	Bearing	Range (m)	X (m)	Y (m)	X+Xs (140°= 0 m)	Y+Ys (1°N=0 m)
1°48.9′	178°	362	13	-362	-92	-1455
1°39.2′	117°	396	353	-180	6	-991
0°59.9′	127°	629	502	-379	220	-1129
2°00.0′	177°	331	17	-331	455	-1292
1°41.4′	176°	388	27	-387	624	-1495
1°18.0′	189°	495	-77	-489	1352	-1918

TABLE 2.4: CALCULATION OF RELATIVE DISPLACEMENT OF BUOYS.

EXPERIMENT #5 DATE: 1 JUNE 1988

Ship					Sock						
Time	Latitude	Longitude	Ys (14°35.0′)	Xs (146°8.00′)	Incl.	Bearing	Range (m)	X (m)	Y (m)	X+Xs (146°8.00′)	Y+Ys (14°35.0′)
20:47	14°35.225′	146°08.291′	417	-523	7°29.7′	106°	91	87	-25	-436	392
20:55	14°35.201′	146°08.378′	373	-679	8°00.0′	143°	86	52	-69	-627	304
21:15	14°35.071′	146°08.668′	132	-1199	11°45.8′	108°	58	55	-18	-1144	114
21:37	14°35.005′	146°08.988′	9	-1774	12°26.5′	168°	55	11	-54	-1763	-45
22:00	14°34.923′	146°09.221′	-143	-2192	7°26.3′	148°	92	49	-78	-2143	-221
23:12	14°34.720′	146°10.336′	-520	-4194	1°32.1′	70°	424	398	145	-3796	-375
23:24	14°34.814′	146°10.344′	-345	-4209	2°47.9′	91°	240	240	-4	-3969	-349

Tristar						
Incl.	Bearing	Range (m)	X (m)	Y (m)	X+Xs (146°8.00′)	Y+Ys (14°35.0′)
3°43.1′	84°	182	181	19	-342	436
5°27.0′	108°	125	119	-39	-560	334
4°36.7′	92°	148	148	-5	-1051	127
12°23.0′	150°	55	27	-48	-1747	-39
8°27.2′	137°	81	55	-59	-2137	-202
2°06.9′	66°	314	287	128	-3907	-392
4°14.0′	90°	160	160	0	-4049	-345

LCD						
Incl.	Bearing	Range (m)	X (m)	Y (m)	X+Xs (146°8.00′)	Y+Ys (14°35.0′)
8°43.6′	107°	78	75	-23	-448	394
8°34.5′	168°	80	17	-78	-662	295
13°36.5′	168°	50	10	-49	-1189	83
7°30.0′	153°	91	41	-81	-2151	-224
2°15.0′	71°	296	280	96	-3914	-424
2°42.0′	92°	248	248	-9	-3961	-354

TABLE 2.5: CALCULATION OF RELATIVE DISPLACEMENT OF BUOYS.

EXPERIMENT #6 DATE: 2 JUNE 1988

Ship					Sock						
Time	Latitude	Longitude	Ys (16°25.0′)	Xs (150°15.0′)	Incl.	Bearing	Range (m)	X (m)	Y (m)	X+Xs (150°15.0′)	Y+Ys (16°25.0′)
20:32	16°25.132′	150°15.732′	245	-1306	5°36.0′	134°	122	88	-85	-1218	160
20:35	16°25.146′	150°15.769′	271	-1372	7°22.9′	143°	93	56	-74	-1320	197
20:48	16°25.275′	150°15.811′	510	-1446	3°44.9′	158°	181	68	-168	-1378	342
21:00	16°25.338′	150°15.824′	627	-1470	12°49.8′	180°	53	0	-53	-1470	574
21:10	16°25.431′	150°15.890′	800	-1587	5°47.8′	160°	118	40	-111	-1547	689
21:24	16°25.588′	150°15.992′	1091	-1769	6°34.1′	138°	104	70	-77	-1699	1014
21:35	16°25.665′	150°15.996′	1234	-1776	3°16.9′	179°	206	4	-206	-1772	1028
21:56	16°25.774′	150°16.069′	1436	-1907	11°36.0′	157°	59	23	-54	-1884	1382
23:07	16°26.325′	150°16.353′	2458	-2413	4°45.3′	123°	143	120	-78	-2293	2380
23:12	16°26.323′	150°16.417′	2455	-2527	4°48.9′	106°	141	136	-39	-2391	2416

Tristar						
Incl.	Bearing	Range (m)	X (m)	Y (m)	X+Xs (150°15.0′)	Y+Ys (16°25.0′)
2°46.1′	134°	242	174	-168	-1132	77
3°03.2′	132°	221	164	-148	-1208	123
2°26.3′	150°	274	137	-237	-1309	273
3°44.9′	158°	181	68	-168	-1402	459
2°42.9′	149°	247	127	-212	-1460	588
3°03.9′	138°	220	147	-163	-1622	928
2°23.0′	151°	280	136	-245	-1640	989
4°01.7′	132°	168	125	-112	-1782	1324
1°56.3′	148°	341	181	-289	-2232	2169
2°29.3′	150°	269	135	-233	-2392	2222

LCD						
Incl.	Bearing	Range (m)	X (m)	Y (m)	X+Xs (150°15.0′)	Y+Ys (16°25.0′)
5°40.5′	124°	120	99	-67	-1207	178
8°28.1′	151°	81	39	-71	-1333	200
3°33.0′	161°	191	62	-181	-1384	329
9°37.2′	185°	71	-6	-71	-1476	556
7°30.0′	174°	91	10	-91	-1577	709
9°47.1′	133°	70	51	-48	-1718	1043
4°19.5′	190°	157	-27	-155	-1803	1079
7°56.3′	150°	86	43	-74	-1864	1362
3°59.0′	143°	170	102	-136	-2311	2322
5°17.9′	158°	129	48	-120	-2479	2335

TABLE 2.6: Average Drift Velocities.

Test	Time	Holey Sock X	Holey Sock Y	Tristar X	Tristar Y	Low-Cost Drifter X	Low-Cost Drifter Y
2A	20:27	-522	1163	-1006	1411	---	---
	21:13	-1253	2367	-1812	2672	---	---
delta	:46	-731	1204	-806	1261	---	---
drift (cm/sec)		-26.5	+43.6	-29.2	+45.7	---	---
2B	21:31	-1441	2727	-2072	3094	---	---
	22:23	-2098	3990	-2634	4434	---	---
delta	:52	-657	1263	-562	1340	---	---
drift (cm/sec)		-21.1	+40.5	-18.0	+42.9	---	---
3	21:38	5274	-2473	5140	-2692	---	---
	22:44	6882	-2942	6808	-2980	---	---
delta	1:06	1608	-469	1668	-298	---	---
drift (cm/sec)		+40.6	-11.8	+42.1	-7.3	---	---
4	22:16	73	-1253	-92	-1455	---	---
	00:21	1553	-1790	1352	-1918	---	---
delta	2:05	1480	-537	1444	-463	---	---
drift (cm/sec)		+19.7	-7.2	+19.3	-6.2	---	---
5A	20:47	-436	392	-342	436	-448	394
	21:37	-1763	-45	-1747	-39	1189*	83*
delta	1:24	-1327	-437	-1405	-475	-741	-311
drift (cm/sec)		-44.2	-14.6	-46.8	-15.8	-44.1	-18.5
5B	22:00	-2143	-221	-2137	-202	-2151	-224
	23:24	-3969	-349	-4049	-345	-3961	-354
delta	1:24	-1826	-128	-1912	-143	-1810	-130
drift (cm/sec)		-36.2	-2.5	-37.9	-2.8	-35.9	-2.6
6A	20:32	-1218	160	-1132	77	-1207	178
	21:35	-1772	1028	-1640	989	-1803	1079
delta	1:03	-554	868	-508	1247	-596	901
drift (cm/sec)		-14.7	+23.0	-13.4	+33.0	-15.8	+23.8
6B	21:56	-1884	1382	-1782	1324	-1864	1362
	23:12	-2391	2416	-2392	2222	-2479	2335
delta	1:16	-507	1034	-610	898	-615	973
drift (cm/sec)		-11.1	+22.7	-13.4	+19.7	-13.5	+21.3

*Duration of LCD drift for this test was 20:47 to 21:15, for a delta time of 00:28.

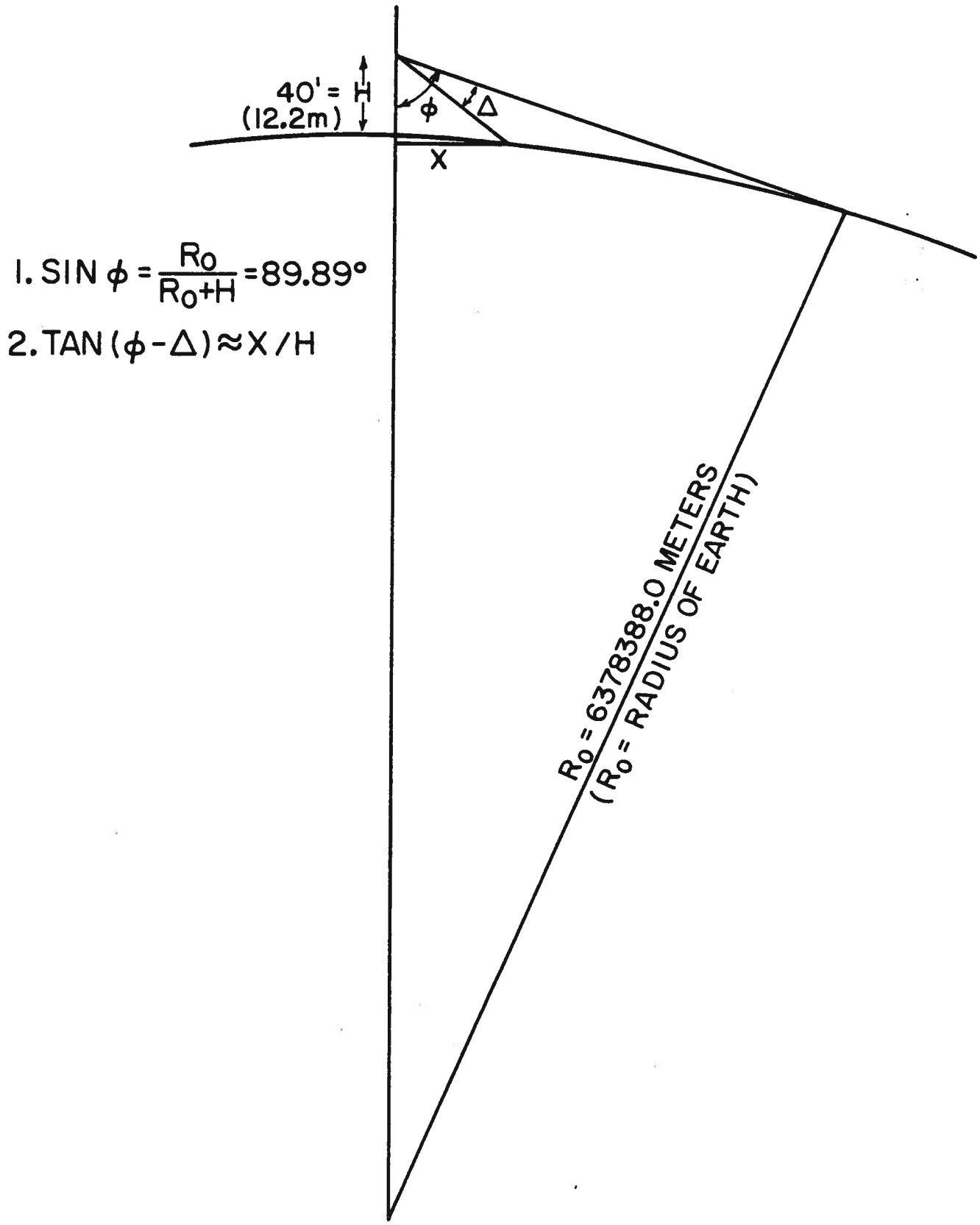


Figure 5. Conversion of shipboard observations to displacements.

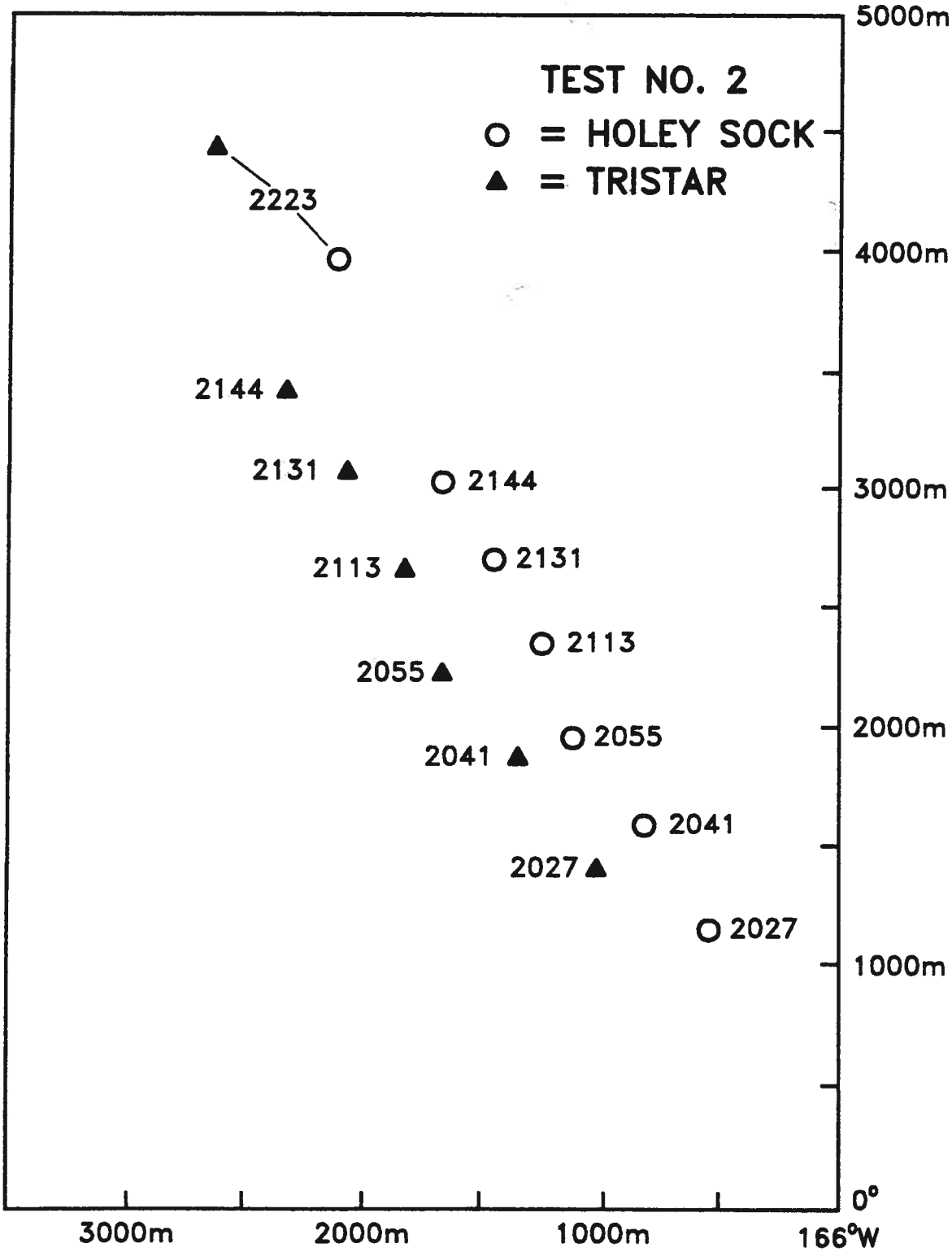


Figure 6. Buoy trajectory (test 2).

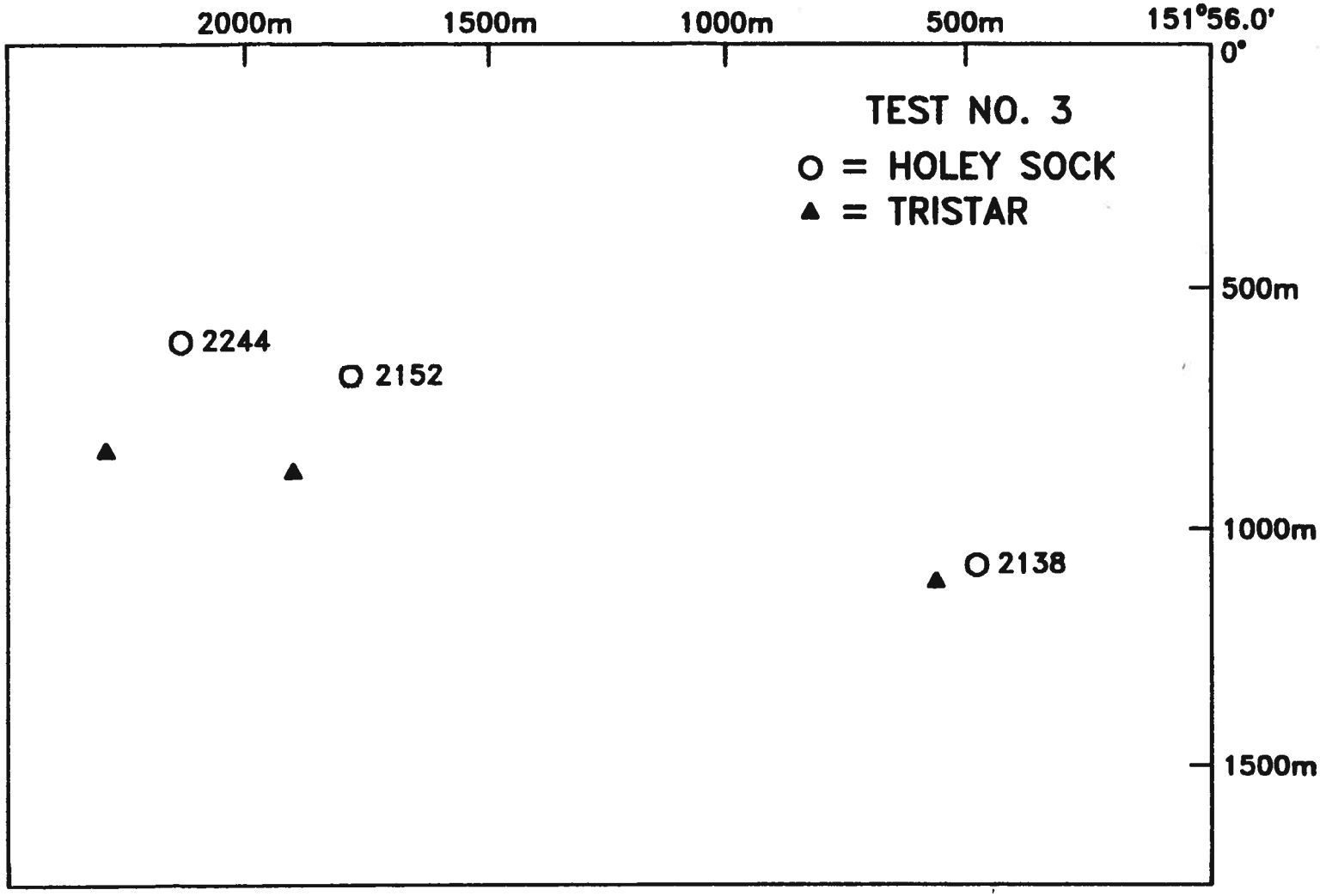


Figure 7. Buoy trajectory (test 3).

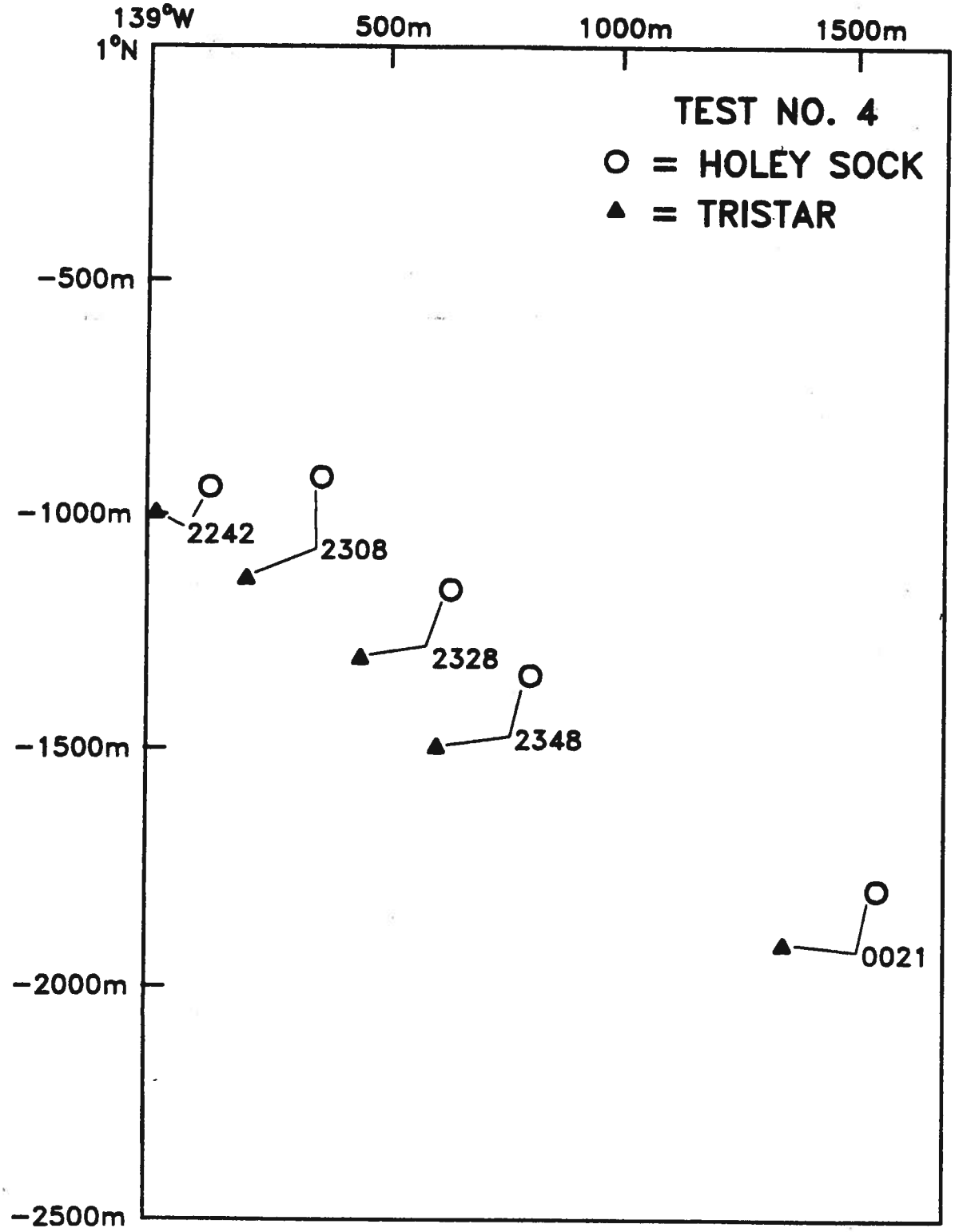


Figure 8. Buoy trajectory (test 4).

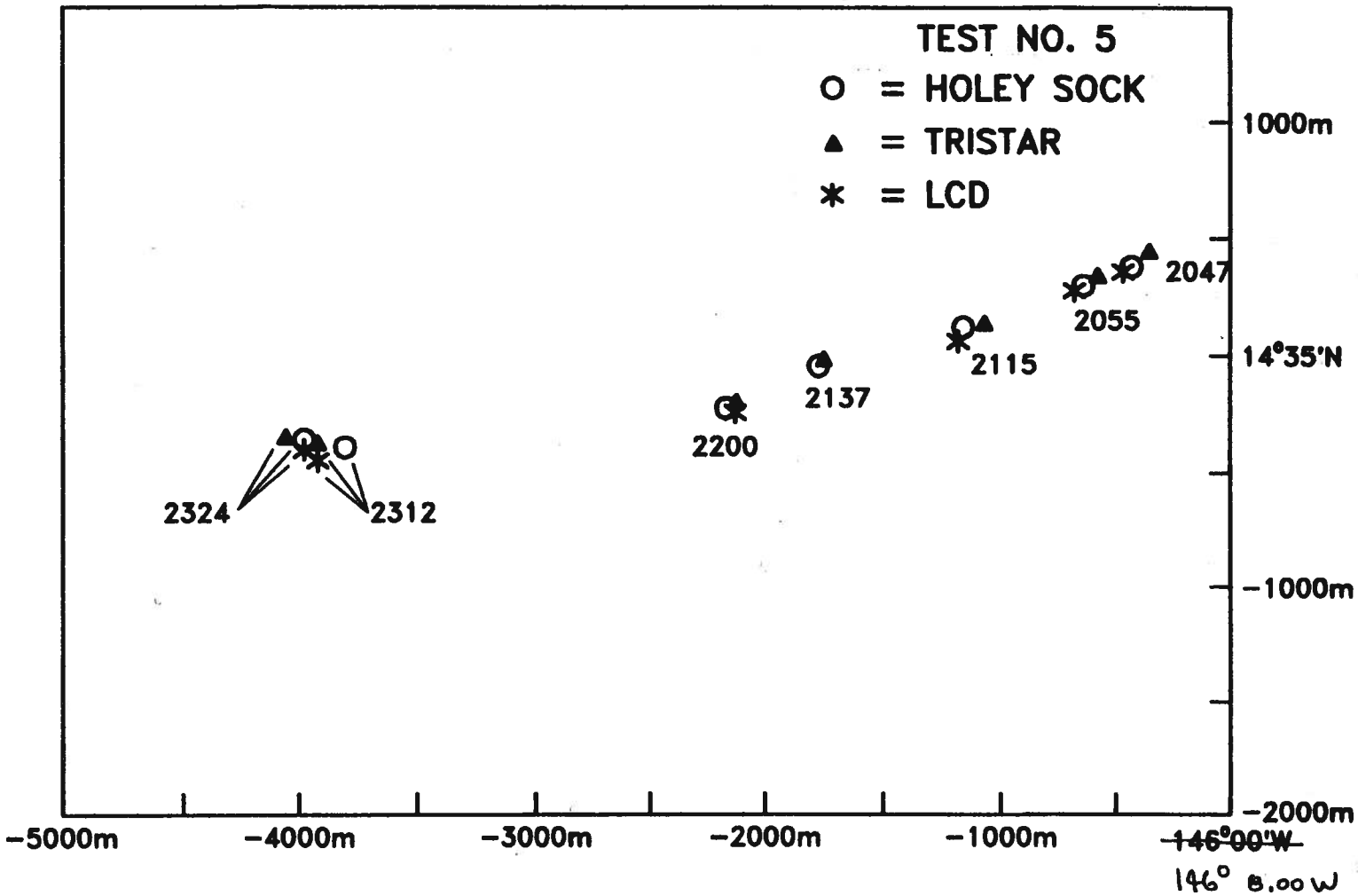


Figure 9. Buoy trajectory (test 5).

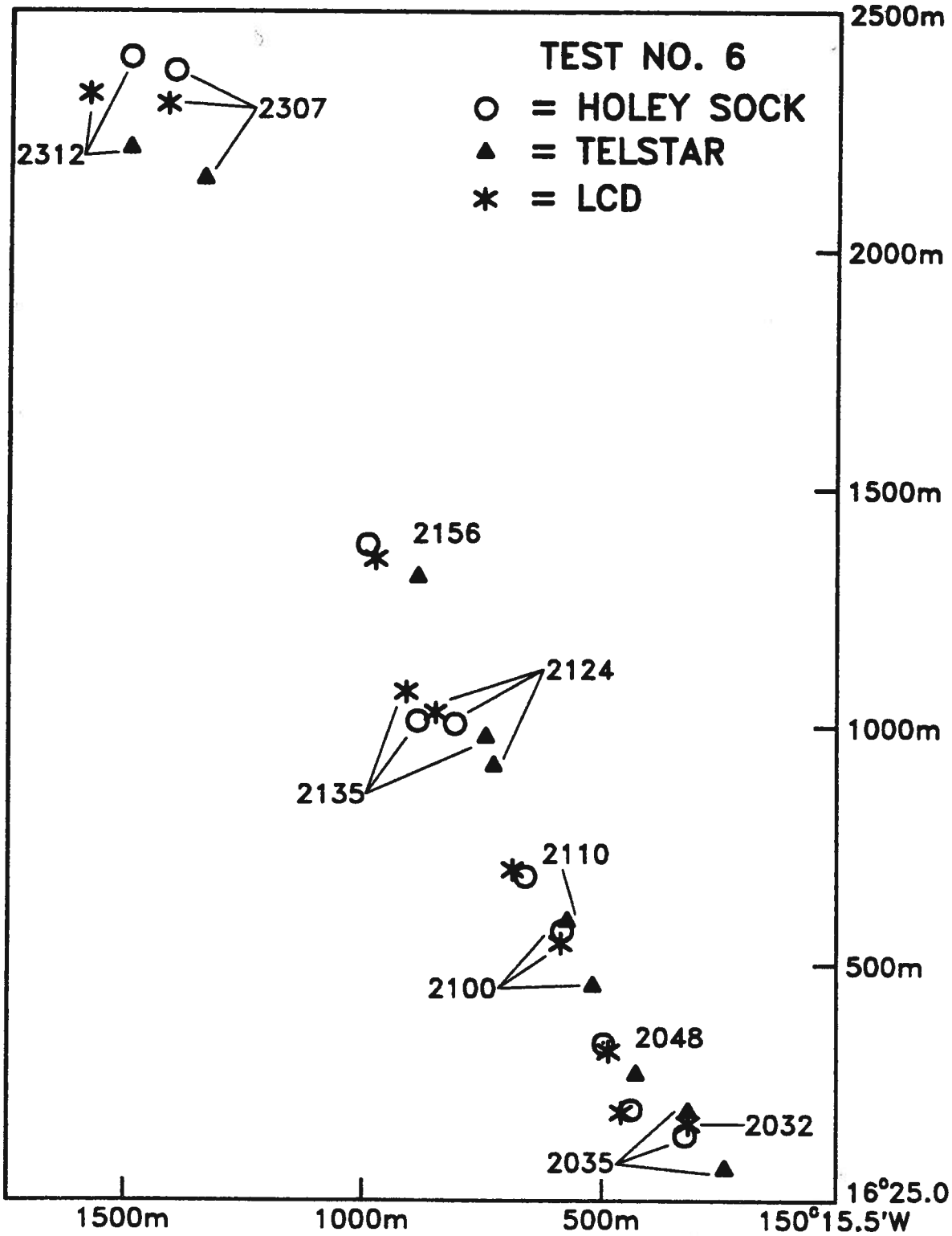


Figure 10. Buoy trajectory (test 6).

Tables 3.1 through 3.19 list all the current meter data from all of the tests; data was omitted from the time divers were under water or when the small boat was attaching lines to the drifters. The data from the two current meters can be decomposed into two components: the average motion of the drogue relative to the surrounding water, or slip, plus the current difference over the length of the drogue, or shear. The slip is given by the average of the current measured by both VMCMs, and the shear is equal to the difference of the two. For each of the tests, the slip and shear and the associated standard deviation of each were computed and averaged over the duration of the deployment.

7. ACOUSTIC DOPPLER CURRENT PROFILER RESULTS

An RD Instruments Model VM 0150 Acoustic Doppler Current Profiling (ADCP) system mounted aboard the OCEANOGRAPHER was operated continuously throughout the cruise. 150 kHz acoustic pulses from a 4 beam transducer mounted on the hull of the ship are transmitted down through the water column beneath the ship. The Doppler frequency shift of the backscattered signal is measured as a function of depth to obtain current profiles relative to the ship. Conversion to the earth-referenced coordinate system is accomplished by subtracting out the ship's motion as derived from the navigation data.

During all the buoy validation tests, the range bin size of the ADCP was set to 4 m, i.e., currents were measured every 4 m in depth beneath the ship. Since the depth of the ship's hull is approximately 5 m and there is a blanking period equivalent to a distance of 2 m before the system begins making the Doppler measurements, the first range bin is centered at 9 m depth. A complete profile consisting of the ship heading and the forward and athwartship current velocity from each of the 64 (or 128) range bins is computed every 1.5 seconds. These are converted to east and north components, vector averaged for one minute and then stored by the data logging system along with Global Positioning System (GPS) navigation data.

In processing the data, the one-minute averages were vector averaged for the duration of each test and then referenced to the top range bin at 9 m depth. The standard deviation was also computed for each of the range bins. Current profiles referenced to the top range bin for each of the tests are shown in Figures 11 through 20 and summarized in Table 4.

Comparisons between the earth referenced Doppler profiler current and the buoy velocities as derived from the visual sightings generally showed poor agreement and so are not included here. The reasons for this are unclear although the following may contribute substantial errors into the profiler data.

(1) Ship maneuvers during the course of the tests requiring frequent changes in ship engine speed and propeller pitch may disturb the local current field beneath the ship or direct bubblers into the path of the acoustic beams giving erroneous velocity data. The performance of the ADCP installation on the OCEANOGRAPHER while maneuvering on station is not known.

(2) Frequent course changes will introduce sizable short-term errors into the ship's gyro compass.

TABLE 3.1: Current Meter Data (Test #1: Holey Sock with Short Stake Float).

Time (Zulu)	Top VMCM				Bottom VMCM				Average			Difference (top-bottom)			
	u	v	T	P	u	v	T	P	u_{av}	v_{av}	P_{av}	Δu	Δv	ΔT	ΔP
21:17	0.40	0.40	26.63	13.45	2.20	1.80	26.63	23.88	1.30	1.10	18.66	-1.80	-1.40	0.00	-10.43
21:25	-0.90	-0.10	26.65	13.66	2.20	2.70	26.61	23.45	0.65	1.30	18.56	-3.10	-2.80	0.04	-9.79
21:32	0.00	0.00	26.61	13.78	1.60	2.50	26.61	23.53	0.80	1.25	18.66	-1.60	-2.50	0.00	-9.75
21:40	-0.30	0.10	26.63	13.55	2.50	1.60	26.61	23.53	1.10	0.85	18.54	-2.80	-1.50	0.02	-9.98
21:47	0.40	0.80	26.63	13.55	2.20	2.70	26.61	23.51	1.30	1.75	18.53	-1.80	-1.90	0.02	-9.96
21:55	0.50	0.00	26.61	13.94	1.60	2.20	26.61	23.69	1.05	1.10	18.82	-1.10	-2.20	0.00	-9.75
Mean	0.02	0.02	26.63	13.65	2.05	2.25	26.61	23.60	1.03	1.23	18.63	-2.03	-2.05	0.01	-9.94
Std. deviation	0.49	0.31	0.01	0.16	0.34	0.43	0.01	0.15	0.24	0.28	0.10	0.69	0.51	0.01	0.24

TABLE 3.2: Current Meter Data (Test #1: Holey Sock with Short Ball Float).

Time (Zulu)	Top VMCM				Bottom VMCM				Average			Difference (top-bottom)			
	u	v	T	P	u	v	T	P	u_{av}	v_{av}	P_{av}	Δu	Δv	ΔT	ΔP
22:17	0.30	-0.10	26.63	10.77	0.60	0.90	26.63	20.59	0.45	0.40	15.68	-0.30	-1.00	0.00	-9.82
22:25	0.40	0.20	26.63	10.70	1.20	0.90	26.63	20.57	0.80	0.55	15.64	-0.80	-0.70	0.00	-9.87
22:32	-0.10	0.00	26.65	11.05	1.20	0.80	26.63	20.59	0.55	0.40	15.82	-1.30	-0.80	0.02	-9.54
22:40	-0.20	-0.20	26.67	11.08	2.70	1.40	26.63	20.41	1.25	0.60	15.74	-2.90	-1.60	0.04	-9.33
22:47	0.00	0.00	26.69	10.82	1.60	0.60	26.63	20.51	0.80	0.30	15.66	-1.60	-0.60	0.06	-9.69
22:55	-1.70	0.00	26.71	10.82	2.20	1.30	26.65	20.67	0.25	0.65	15.74	-3.90	-1.30	0.06	-9.85
Mean	-0.22	-0.02	26.66	10.87	1.58	0.98	26.63	20.56	0.68	0.48	15.72	-1.80	-1.00	0.03	-9.68
Std. deviation	0.70	0.12	0.03	0.14	0.69	0.28	0.01	0.08	0.32	0.12	0.06	1.24	0.35	0.02	0.19

TABLE 3.3: Current Meter Data (Test #2: Holey Sock with Long Stake Float).

	Top VMCM				Bottom VMCM				Average			Difference (top-bottom)			
Time (Zulu)	u	v	T	P	u	v	T	P	u_{av}	v_{av}	P_{av}	Δu	Δv	ΔT	ΔP
20:17	-7.20	0.50	26.32	13.69	11.10	5.40	26.22	23.20	1.95	2.95	18.44	-18.30	-4.90	0.10	-9.51
20:25	-0.80	1.50	26.32	13.80	8.80	6.80	26.24	23.41	4.00	4.15	18.60	-9.60	-5.30	0.08	-9.61
20:32	-3.40	1.50	26.34	13.87	9.20	5.70	26.26	23.39	2.90	3.60	18.63	-12.60	-4.20	0.08	-9.52
20:40	-0.40	-0.20	26.34	13.54	10.20	7.20	26.26	23.47	4.90	3.50	18.50	-10.60	-7.40	0.08	-9.93
20:47	-0.30	0.00	26.32	13.54	11.20	7.40	26.24	23.25	5.45	3.70	18.40	-11.50	-7.40	0.08	-9.71
20:55	-2.80	-1.00	26.34	13.69	9.50	5.90	26.26	23.25	3.35	2.45	18.47	-12.30	-6.90	0.08	-9.56
21:02	-4.60	0.70	26.36	13.85	10.70	6.30	26.28	23.36	3.05	3.50	18.61	-15.30	-5.60	0.08	-9.51
21:10	-5.80	1.30	26.34	13.49	10.90	6.70	26.24	23.25	2.55	4.00	18.37	-16.70	-5.40	0.10	-9.76
Mean	-3.16	0.54	26.34	13.68	10.20	6.43	26.25	23.32	3.52	3.48	18.50	-13.36	-5.89	0.09	-9.64
Std. deviation	2.42	0.84	0.01	0.14	0.87	0.67	0.02	0.09	1.11	0.51	0.09	2.88	1.12	0.01	0.14

TABLE 3.4: Current Meter Data (Test #2: Holey Sock with Short Ball Float).

	Top VMCM				Bottom VMCM				Average			Difference (top-bottom)			
Time (Zulu)	u	v	T	P	u	v	T	P	u_{av}	v_{av}	P_{av}	Δu	Δv	ΔT	ΔP
21:32	-6.90	1.20	26.38	10.68	7.80	4.60	26.28	20.39	0.45	2.90	15.53	-14.70	-3.40	0.10	-9.71
21:40	-4.90	1.20	26.40	10.93	9.60	5.30	26.30	20.55	2.35	3.25	15.74	-14.50	-4.10	0.10	-9.62
21:47	-6.00	2.00	26.38	10.83	9.00	4.80	26.32	20.50	1.50	3.40	15.66	-15.00	-2.80	0.06	-9.67
21:55	-6.40	3.60	26.38	10.68	10.20	3.90	26.30	20.63	1.90	3.75	15.65	-16.60	-0.30	0.08	-9.95
22:02	-3.80	2.80	26.42	10.73	7.60	2.10	26.34	20.60	1.90	2.45	15.66	-11.40	0.70	0.08	-9.87
22:10	-3.80	2.60	26.40	10.65	8.10	2.70	26.36	20.60	2.15	2.65	15.63	-11.90	-0.10	0.04	-9.95
22:17	-3.10	1.20	26.42	10.83	9.10	2.60	26.34	20.63	3.00	1.90	15.73	-12.20	-1.40	0.08	-9.80
22:25	-2.70	1.90	26.38	10.76	9.70	3.20	26.32	20.42	3.50	2.55	15.59	-12.40	-1.30	0.06	-9.66
22:32	-5.60	3.20	26.44	10.81	9.50	2.30	26.32	20.60	1.95	2.75	15.71	-15.10	0.90	0.12	-9.79
Mean	-4.80	2.19	26.40	10.77	8.96	3.50	26.32	20.55	2.08	2.84	15.66	-13.76	-1.31	0.08	-9.78
Std. deviation	1.43	0.86	0.02	0.09	0.87	1.12	0.02	0.09	0.82	0.52	0.06	1.70	1.69	0.02	0.12

TABLE 3.5: Current Meter Data (Test #3: Holey Sock with Long Stake Float).

Time (Zulu)	Top VMCM				Bottom VMCM				Average			Difference (top-bottom)			
	u	v	T	P	u	v	T	P	u_{av}	v_{av}	P_{av}	Δu	Δv	ΔT	ΔP
21:17	-3.30	0.00	25.82	13.71	7.80	4.30	25.67	23.30	2.25	2.15	18.50	-11.10	-4.30	0.15	-9.59
21:40	-1.40	-1.30	25.74	13.69	4.80	3.60	25.63	23.22	1.70	1.15	18.45	-6.20	-4.90	0.11	-9.53
21:47	-4.20	-2.00	25.74	13.92	6.00	2.90	25.65	23.17	0.90	0.45	18.55	-10.20	-4.90	0.09	-9.25
21:55	-2.00	-0.50	25.71	13.72	8.00	2.90	25.63	23.22	3.00	1.20	18.47	-10.00	-3.40	0.08	-9.50
22:02	-2.10	-1.00	25.72	13.69	6.50	3.30	25.65	23.43	2.20	1.15	18.56	-8.60	-4.30	0.07	-9.74
22:10	-3.50	-1.30	25.72	13.61	9.00	5.30	25.59	23.20	2.75	2.00	18.41	-12.50	-6.60	0.13	-9.59
22:17	-1.90	-1.20	25.74	13.79	9.90	4.90	25.61	23.43	4.00	1.85	18.61	-11.80	-6.10	0.13	-9.64
22:25	-1.00	-0.40	25.76	13.77	8.30	4.50	25.63	23.27	3.65	2.05	18.52	-9.30	-4.90	0.13	-9.50
22:32	-1.10	-1.10	25.76	13.92	7.70	3.50	25.65	23.27	3.30	1.20	18.60	-8.80	-4.60	0.11	-9.35
22:40	-3.40	-0.50	25.78	13.71	10.10	4.40	25.63	23.22	3.35	1.95	18.47	-13.50	-4.90	0.15	-9.51
22:47	-2.70	-1.10	25.74	13.72	10.80	4.20	25.61	23.33	4.05	1.55	18.52	-13.50	-5.30	0.13	-9.61
Mean	-2.42	-0.95	25.75	13.75	8.08	3.98	25.63	23.28	2.83	1.52	18.51	-10.50	-4.93	0.12	-9.53
Std. deviation	1.02	0.53	0.03	0.09	1.75	0.76	0.02	0.08	0.94	0.51	0.06	2.15	0.83	0.03	0.13

TABLE 3.6: Current Meter Data (Test #4: Holey Sock with Long Stake Float).

Time (Zulu)	Top VMCM				Bottom VMCM				Average			Difference (top-bottom)			
	u	v	T	P	u	v	T	P	u_{av}	v_{av}	P_{av}	Δu	Δv	ΔT	ΔP
22:02	0.10	0.50	25.29	13.84	5.10	-1.90	25.26	23.29	2.60	-0.70	18.57	-5.00	2.40	0.03	-9.45
22:10	-1.20	0.70	25.31	13.78	4.50	-2.70	25.24	23.26	1.65	-1.00	18.52	-5.70	3.40	0.07	-9.48
22:17	-0.30	-0.30	25.29	13.63	5.00	-2.10	25.26	23.34	2.35	-1.20	18.49	-5.30	1.80	0.03	-9.71
22:25	0.00	-1.00	25.29	13.63	3.90	-2.00	25.26	23.34	1.95	-1.50	18.49	-3.90	1.00	0.03	-9.71
22:32	0.20	-0.60	25.27	13.61	4.80	-2.00	25.26	23.23	2.50	-1.30	18.42	-4.60	1.40	0.01	-9.62
22:40	0.00	-1.20	25.27	13.73	5.40	-2.00	25.26	23.29	2.70	-1.60	18.51	-5.40	0.80	0.01	-9.56
22:47	-0.10	-1.10	25.27	13.71	5.80	-2.30	25.26	23.29	2.85	-1.70	18.50	-5.90	1.20	0.01	-9.58
22:55	0.00	-0.10	25.27	13.68	5.80	-2.70	25.24	23.34	2.90	-1.40	18.51	-5.80	2.60	0.03	-9.66
23:02	0.00	0.00	25.26	13.56	6.10	-3.30	25.22	23.18	3.05	-1.65	18.37	-6.10	3.30	0.04	-9.62
23:25	-0.10	0.80	25.26	13.58	6.30	-3.20	25.22	23.21	3.10	-1.20	18.40	-6.40	4.00	0.04	-9.63
23:32	0.00	0.10	25.26	13.63	6.80	-3.70	25.20	23.16	3.40	-1.80	18.40	-6.80	3.80	0.06	-9.53
23:40	0.00	-0.10	25.26	13.68	6.00	-3.60	25.22	23.21	3.00	-1.85	18.44	-6.00	3.50	0.04	-9.53
23:47	0.10	-0.40	25.26	13.89	5.50	-3.50	25.22	23.32	2.80	-1.95	18.60	-5.40	3.10	0.04	-9.43
23:55	0.00	0.00	25.26	13.74	5.30	-3.10	25.24	23.16	2.65	-1.55	18.45	-5.30	3.10	0.02	-9.42
00:02	0.30	-0.20	25.26	13.74	6.10	-3.00	25.22	23.24	3.20	-1.60	18.49	-5.80	2.80	0.04	-9.50
00:10	0.00	0.00	25.26	13.63	6.20	-3.00	25.24	23.23	3.10	-1.50	18.43	-6.20	3.00	0.02	-9.60
00:17	0.10	-0.20	25.26	13.61	6.00	-3.50	25.24	23.37	3.05	-1.85	18.49	-5.90	3.30	0.02	-9.76
00:25	0.20	0.00	25.26	13.74	6.30	-3.30	25.24	23.29	3.25	-1.65	18.52	-6.10	3.30	0.02	-9.55
Mean	-0.04	-0.17	25.27	13.69	5.61	-2.83	25.24	23.26	2.78	-1.50	18.48	-5.64	2.66	0.03	-9.57
Std. deviation	0.31	0.54	0.01	0.09	0.71	0.61	0.02	0.06	0.44	0.31	0.06	0.66	0.97	0.02	0.10

TABLE 3.7: Current Meter Data (Test #5: Holey Sock with Long Ball Float).

Time (Zulu)	Top VMCM				Bottom VMCM				Average			Difference (top-bottom)			
	u	v	T	P	u	v	T	P	u_{av}	v_{av}	P_{av}	Δu	Δv	ΔT	ΔP
20:17	1.00	-0.70	24.92	13.70	0.90	1.00	24.92	23.19	0.95	0.15	18.44	0.10	-1.70	0.00	-9.49
20:25	0.50	-0.70	24.92	13.49	1.00	1.60	24.89	22.66	0.75	0.45	18.08	-0.50	-2.30	0.03	-9.17
20:32	0.30	0.50	24.91	13.29	1.50	2.20	24.89	22.98	0.90	1.35	18.14	-1.20	-1.70	0.02	-9.69
20:40	0.50	0.80	24.91	13.24	2.20	2.40	24.89	22.88	1.35	1.60	18.06	-1.70	-1.60	0.02	-9.64
20:47	0.60	0.40	24.89	13.62	1.60	0.60	24.89	23.14	1.10	0.50	18.38	-1.00	-0.20	0.00	-9.52
20:55	0.20	0.50	24.91	13.44	1.30	0.40	24.89	23.14	0.75	0.45	18.29	-1.10	0.10	0.02	-9.70
21:02	0.30	0.60	24.91	13.65	0.80	0.00	24.89	23.19	0.55	0.30	18.42	-0.50	0.60	0.02	-9.54
Mean	0.49	0.20	24.91	13.49	1.33	1.17	24.89	23.03	0.91	0.69	18.26	-0.84	-0.97	0.02	-9.54
Std. deviation	0.25	0.58	0.01	0.17	0.45	0.85	0.01	0.18	0.24	0.52	0.15	0.54	1.03	0.01	0.17

TABLE 3.8: Current Meter Data (Test #5: Holey Sock with Long Stake Float).

Time (Zulu)	Top VMCM				Bottom VMCM				Average			Difference (top-bottom)			
	u	v	T	P	u	v	T	P	u_{av}	v_{av}	P_{av}	Δu	Δv	ΔT	ΔP
21:47	-0.10	0.00	24.91	13.85	2.10	2.70	24.89	23.41	1.00	1.35	18.63	-2.20	-2.70	0.02	-9.56
22:10	-0.40	0.10	24.96	13.72	2.60	2.20	24.89	23.56	1.10	1.15	18.64	-3.00	-2.10	0.07	-9.84
22:17	0.00	0.00	24.96	13.85	2.00	2.10	24.89	23.46	1.00	1.05	18.66	-2.00	-2.10	0.07	-9.61
22:25	-0.20	0.40	24.96	14.03	3.20	2.80	24.89	23.25	1.50	1.60	18.64	-3.40	-2.40	0.07	-9.22
22:32	-1.20	0.90	24.98	13.90	4.50	1.30	24.89	23.62	1.65	1.10	18.76	-5.70	-0.40	0.09	-9.72
22:40	-0.70	0.60	24.96	13.85	5.30	1.90	24.89	23.38	2.30	1.25	18.61	-6.00	-1.30	0.07	-9.53
22:47	-0.40	0.50	24.96	13.95	4.10	2.20	24.89	23.41	1.85	1.35	18.68	-4.50	-1.70	0.07	-9.46
22:55	0.30	0.00	24.94	13.72	3.70	2.60	24.89	23.41	2.00	1.30	18.57	-3.40	-2.60	0.05	-9.69
23:02	0.60	0.80	24.94	13.75	4.20	0.70	24.89	23.56	2.40	0.75	18.66	-3.60	0.10	0.05	-9.81
23:10	0.00	0.40	24.96	13.75	3.00	1.00	24.89	23.35	1.50	0.70	18.55	-3.00	-0.60	0.07	-9.60
23:17	-0.30	0.20	24.98	13.72	2.40	0.90	24.89	23.46	1.05	0.55	18.59	-2.70	-0.70	0.09	-9.74
23:25	0.10	1.10	24.98	13.64	3.00	1.50	24.91	23.46	1.55	1.30	18.55	-2.90	-0.40	0.07	-9.82
23:32	0.30	1.10	24.96	14.00	2.90	1.20	24.91	23.59	1.60	1.15	18.80	-2.60	-0.10	0.05	-9.59
Mean	-0.15	0.47	24.96	13.83	3.31	1.78	24.89	23.46	1.58	1.12	18.64	-3.46	-1.31	0.06	-9.63
Std. deviation	0.45	0.39	0.02	0.12	0.95	0.69	0.01	0.10	0.45	0.29	0.07	1.19	0.97	0.02	0.16

TABLE 3.9: Current Meter Data (Test #6: Holey Sock with Long Stake Float).

Time (Zulu)	Top VMCM				Bottom VMCM				Average			Difference (top-bottom)			
	u	v	T	P	u	v	T	P	u_{av}	v_{av}	P_{av}	Δu	Δv	ΔT	ΔP
20:25	0.00	0.10	25.03	14.08	2.20	2.20	25.05	23.45	1.10	1.15	18.77	-2.20	-2.10	-0.02	-9.37
20:32	-0.10	0.20	25.05	13.82	2.20	1.00	25.05	23.45	1.05	0.60	18.64	-2.30	-0.80	0.00	-9.63
21:02	0.30	-0.50	25.05	13.79	1.60	2.30	25.05	23.35	0.95	0.90	18.57	-1.30	-2.80	0.00	-9.56
21:10	0.00	0.10	25.05	13.69	1.30	2.40	25.03	23.37	0.65	1.25	18.53	-1.30	-2.30	0.02	-9.68
21:17	-0.40	0.00	25.07	13.84	0.20	1.20	25.05	23.53	-0.10	0.60	18.69	-0.60	-1.20	0.02	-9.69
Mean	-0.04	-0.02	25.05	13.84	1.50	1.82	25.05	23.43	0.73	0.90	18.64	-1.54	-1.84	0.00	-9.59
Std. deviation	0.22	0.25	0.01	0.13	0.74	0.59	0.01	0.06	0.44	0.27	0.09	0.63	0.73	0.01	0.12

TABLE 3.10: Current Meter Data (Test #6: Holey Sock with Short Ball Float).

Time (Zulu)	Top VMCM				Bottom VMCM				Average			Difference (top-bottom)			
	u	v	T	P	u	v	T	P	u_{av}	v_{av}	P_{av}	Δu	Δv	ΔT	ΔP
21:47	0.00	0.50	25.05	10.60	1.70	3.10	25.03	20.22	0.85	1.80	15.41	-1.70	-2.60	0.02	-9.62
21:55	-0.90	0.80	25.03	10.83	0.30	1.90	25.03	20.38	-0.30	1.35	15.60	-1.20	-1.10	0.00	-9.55
22:02	0.10	0.10	25.03	10.68	1.10	1.40	25.03	20.59	0.60	0.75	15.64	-1.00	-1.30	0.00	-9.91
22:10	0.10	0.50	25.03	10.94	1.40	1.70	25.03	20.46	0.75	1.10	15.70	-1.30	-1.20	0.00	-9.52
22:17	0.30	0.90	25.03	10.81	2.40	0.70	25.03	20.49	1.35	0.80	15.65	-2.10	0.20	0.00	-9.68
22:25	0.70	1.00	25.03	10.76	1.30	1.00	25.03	20.54	1.00	1.00	15.65	-0.60	0.00	0.00	-9.78
22:32	0.40	0.80	25.03	10.89	0.60	0.90	25.03	20.41	0.50	0.85	15.65	-0.20	-0.10	0.00	-9.52
22:40	0.10	0.90	25.03	10.66	1.00	1.20	25.05	20.43	0.55	1.05	15.55	-0.90	-0.30	-0.02	-9.77
22:47	-0.40	0.70	25.03	10.89	0.90	1.00	25.05	20.43	0.25	0.85	15.66	-1.30	-0.30	-0.02	-9.54
22:55	0.20	0.30	25.05	10.91	1.30	1.20	25.05	20.38	0.75	0.75	15.64	-1.10	-0.90	0.00	-9.47
23:02	0.40	0.40	25.07	11.04	2.30	1.90	25.05	20.59	1.35	1.15	15.82	-1.90	-1.50	0.02	-9.55
Mean	0.09	0.63	25.04	10.82	1.30	1.45	25.04	20.45	0.70	1.04	15.63	-1.21	-0.83	0.00	-9.63
Std. deviation	0.41	0.27	0.01	0.13	0.61	0.65	0.01	0.10	0.45	0.30	0.09	0.53	0.79	0.01	0.13

TABLE 3.11: Current Meter Data (Test #1: Tristar with Long Ball Float).

Time (Zulu)	Top VMCM				Bottom VMCM				Average			Difference (top-bottom)			
	u	v	T	P	u	v	T	P	u_{av}	v_{av}	P_{av}	Δu	Δv	ΔT	ΔP
21:25	0.50	0.60	26.53	13.51	0.90	0.90	26.49	17.19	0.70	0.75	15.35	-0.40	-0.30	0.04	-3.68
21:32	0.30	0.30	26.53	13.54	0.60	0.50	26.49	17.05	0.45	0.40	15.30	-0.30	-0.20	0.04	-3.51
21:40	0.20	0.10	26.55	13.44	1.10	0.70	26.49	17.08	0.65	0.40	15.26	-0.90	-0.60	0.06	-3.64
21:47	0.60	0.00	26.53	13.64	2.00	0.80	26.49	17.13	1.30	0.40	15.39	-1.40	-0.80	0.04	-3.49
21:55	0.80	0.30	26.53	13.58	1.10	0.60	26.49	17.13	0.95	0.45	15.35	-0.30	-0.30	0.04	-3.55
22:02	0.50	0.40	26.53	13.64	1.90	1.20	26.49	17.08	1.20	0.80	15.36	-1.40	-0.80	0.04	-3.44
Mean	0.48	0.28	26.53	13.56	1.27	0.78	26.49	17.11	0.88	0.53	15.33	-0.78	-0.50	0.04	-3.55
Std. deviation	0.20	0.20	0.01	0.07	0.51	0.23	0.00	0.05	0.30	0.17	0.04	0.48	0.24	0.01	0.08

TABLE 3.12: Current Meter Data (Test #1: Tristar with Long Stake Float).

Time (Zulu)	Top VMCM				Bottom VMCM				Average			Difference (top-bottom)			
	u	v	T	P	u	v	T	P	u_{av}	v_{av}	P_{av}	Δu	Δv	ΔT	ΔP
22:40	1.10	0.60	26.55	13.64	2.40	2.00	26.51	17.13	1.75	1.30	15.39	-1.30	-1.40	0.04	-3.49
22:47	1.40	0.90	26.53	13.61	2.40	2.10	26.51	17.16	1.90	1.50	15.39	-1.00	-1.20	0.02	-3.55
22:55	1.20	0.30	26.55	13.71	2.40	2.00	26.51	17.19	1.80	1.15	15.45	-1.20	-1.70	0.04	-3.48
23:02	1.30	0.30	26.55	13.58	3.10	1.50	26.51	17.16	2.20	0.90	15.37	-1.80	-1.20	0.04	-3.58
23:10	1.00	0.70	26.55	13.68	2.70	2.30	26.51	17.24	1.85	1.50	15.46	-1.70	-1.60	0.04	-3.56
23:17	0.80	0.30	26.55	13.58	3.10	1.90	26.51	17.16	1.95	1.10	15.37	-2.30	-1.60	0.04	-3.58
23:25	1.30	0.10	26.55	13.58	3.70	1.90	26.51	17.13	2.50	1.00	15.35	-2.40	-1.80	0.04	-3.55
Mean	1.16	0.46	26.55	13.63	2.83	1.96	26.51	17.17	1.99	1.21	15.40	-1.67	-1.50	0.04	-3.54
Std. deviation	0.19	0.26	0.01	0.05	0.46	0.23	0.00	0.04	0.25	0.22	0.04	0.50	0.22	0.01	0.04

TABLE 3.13: Current Meter Data (Test #2: Tristar with Long Ball Float).

Time (Zulu)	Top VMCM				Bottom VMCM				Average			Difference (top-bottom)			
	u	v	T	P	u	v	T	P	u_{av}	v_{av}	P_{av}	Δu	Δv	ΔT	ΔP
19:55	-1.60	0.60	26.24	13.71	3.90	2.30	26.20	17.25	1.15	1.45	15.48	-5.50	-1.70	0.04	-3.54
20:02	0.20	-0.30	26.24	13.71	2.20	3.20	26.24	17.17	1.20	1.45	15.44	-2.00	-3.50	0.00	-3.46
20:10	-1.40	-0.10	26.24	13.55	7.50	4.00	26.12	17.08	3.05	1.95	15.32	-8.90	-4.10	0.12	-3.53
20:17	-3.00	0.80	26.24	13.65	5.80	1.80	26.11	17.22	1.40	1.30	15.43	-8.80	-1.00	0.13	-3.57
20:25	-4.50	-0.90	26.20	13.68	4.50	3.20	26.14	17.22	0.00	1.15	15.45	-9.00	-4.10	0.06	-3.54
20:32	-0.50	1.20	26.22	13.71	5.40	2.10	26.14	17.30	2.45	1.65	15.51	-5.90	-0.90	0.08	-3.59
20:40	-0.80	0.00	26.22	13.68	5.30	3.70	26.14	17.19	2.25	1.85	15.44	-6.10	-3.70	0.08	-3.51
20:47	-2.00	0.10	26.24	13.65	6.00	3.30	26.14	17.14	2.00	1.70	15.39	-8.00	-3.20	0.10	-3.49
20:55	-2.60	-0.80	26.22	13.55	5.80	2.90	26.16	17.17	1.60	1.05	15.36	-8.40	-3.70	0.06	-3.62
21:17	-0.60	1.20	26.12	13.72	4.60	0.30	26.05	17.25	2.00	0.75	15.49	-5.20	0.90	0.07	-3.53
Mean	-1.68	0.18	26.22	13.66	5.10	2.68	26.14	17.20	1.71	1.43	15.43	-6.78	-2.50	0.07	-3.54
Std. deviation	1.33	0.72	0.04	0.06	1.35	1.03	0.05	0.06	0.80	0.36	0.06	2.14	1.63	0.04	0.04

TABLE 3.14: Current Meter Data (Test #2: Tristar with Long Stake Float).

Time (Zulu)	Top VMCM				Bottom VMCM				Average			Difference (top-bottom)			
	u	v	T	P	u	v	T	P	u_{av}	v_{av}	P_{av}	Δu	Δv	ΔT	ΔP
21:40	1.70	-1.20	26.14	13.82	3.60	2.20	26.09	17.47	2.65	0.50	15.64	-1.90	-3.40	0.05	-3.65
21:47	1.90	-0.70	26.14	13.98	5.50	2.40	26.11	17.39	3.70	0.85	15.68	-3.60	-3.10	0.03	-3.41
21:55	2.00	0.40	26.16	13.98	4.60	1.20	26.09	17.50	3.30	0.80	15.74	-2.60	-0.80	0.07	-3.52
22:02	0.80	-0.20	26.16	13.95	4.30	2.00	26.11	17.52	2.55	0.90	15.74	-3.50	-2.20	0.05	-3.57
22:10	0.50	-0.10	26.16	13.95	4.30	1.70	26.11	17.52	2.40	0.80	15.74	-3.80	-1.80	0.05	-3.57
22:17	1.60	-0.20	26.12	13.85	5.60	1.40	26.09	17.47	3.60	0.60	15.66	-4.00	-1.60	0.03	-3.62
22:25	1.80	-0.30	26.16	13.88	5.70	2.20	26.09	17.41	3.75	0.95	15.65	-3.90	-2.50	0.07	-3.53
22:32	0.80	0.20	26.14	13.98	5.10	1.30	26.11	17.41	2.95	0.75	15.69	-4.30	-1.10	0.03	-3.43
Mean	1.39	-0.26	26.15	13.92	4.84	1.80	26.10	17.46	3.11	0.77	15.69	-3.45	-2.06	0.05	-3.54
Std. deviation	0.55	0.47	0.01	0.06	0.71	0.43	0.01	0.05	0.51	0.14	0.04	0.75	0.86	0.02	0.08

TABLE 3.15: Current Meter Data (Test #3: Tristar with Short Ball Float).

Time (Zulu)	Top VMCM				Bottom VMCM				Average			Difference (top-bottom)			
	u	v	T	P	u	v	T	P	u_{av}	v_{av}	P_{av}	Δu	Δv	ΔT	ΔP
19:47	0.20	1.60	25.71	11.10	2.00	1.40	25.65	14.46	1.10	1.50	12.78	-1.80	0.20	0.06	-3.36
20:02	0.00	1.20	25.63	10.90	0.50	1.10	25.61	14.57	0.25	1.15	12.73	-0.50	0.10	0.02	-3.67
20:10	0.50	0.00	25.63	11.00	2.60	0.30	25.59	14.46	1.55	0.15	12.73	-2.10	-0.30	0.04	-3.46
20:17	0.10	-0.20	25.63	11.03	1.60	0.90	25.59	14.63	0.85	0.35	12.83	-1.50	-1.10	0.04	-3.60
20:25	0.40	-0.30	25.63	11.03	2.60	1.60	25.59	14.52	1.50	0.65	12.78	-2.20	-1.90	0.04	-3.49
20:32	0.40	-0.10	25.63	10.97	2.70	1.00	25.57	14.41	1.55	0.45	12.69	-2.30	-1.10	0.06	-3.44
20:40	0.10	-0.10	25.63	10.97	1.80	1.60	25.59	14.46	0.95	0.75	12.72	-1.70	-1.70	0.04	-3.49
20:47	0.40	-0.10	25.65	11.00	1.70	1.10	25.59	14.57	1.05	0.50	12.78	-1.30	-1.20	0.06	-3.57
20:55	0.10	-0.20	25.63	10.97	2.60	1.90	25.59	14.60	1.35	0.85	12.79	-2.50	-2.10	0.04	-3.63
21:02	0.30	-0.30	25.63	10.97	1.70	1.20	25.59	14.57	1.00	0.45	12.77	-1.40	-1.50	0.04	-3.60
21:10	0.30	-0.10	25.63	10.90	3.10	2.20	25.57	14.41	1.70	1.05	12.65	-2.80	-2.30	0.06	-3.51
21:47	0.00	0.00	25.63	11.00	5.80	2.00	25.55	14.35	2.90	1.00	12.68	-5.80	-2.00	0.08	-3.35
21:55	-1.40	-0.10	25.63	11.03	4.30	1.00	25.55	14.52	1.45	0.45	12.78	-5.70	-1.10	0.08	-3.49
22:02	-1.50	0.00	25.63	11.03	3.40	0.40	25.57	14.46	0.95	0.20	12.74	-4.90	-0.40	0.06	-3.43
22:10	0.30	0.00	25.63	11.00	3.80	1.40	25.55	14.52	2.05	0.70	12.76	-3.50	-1.40	0.08	-3.52
22:17	-0.10	0.10	25.63	11.00	3.90	0.80	25.57	14.54	1.90	0.45	12.77	-4.00	-0.70	0.06	-3.54
22:25	-0.60	0.20	25.65	10.90	4.50	0.00	25.57	14.52	1.95	0.10	12.71	-5.10	0.20	0.08	-3.62
22:47	-0.10	0.30	25.65	10.90	4.50	1.50	25.57	14.52	2.20	0.90	12.71	-4.60	-1.20	0.08	-3.62
22:55	-0.30	0.20	25.67	11.03	5.40	1.60	25.55	14.46	2.55	0.90	12.74	-5.70	-1.40	0.12	-3.43
23:02	0.00	-0.10	25.65	11.03	4.10	1.40	25.59	14.63	2.05	0.65	12.83	-4.10	-1.50	0.06	-3.60
23:10	0.20	0.00	25.65	10.90	4.50	1.40	25.57	14.41	2.35	0.70	12.65	-4.30	-1.40	0.08	-3.51
Mean	-0.03	0.10	25.64	10.98	3.20	1.23	25.58	14.50	1.58	0.66	12.74	-3.23	-1.13	0.06	-3.52
Std. deviation	0.52	0.45	0.02	0.05	1.36	0.54	0.02	0.07	0.63	0.34	0.05	1.62	0.72	0.02	0.09

TABLE 3.16: Current Meter Data (Test #4: Tristar with IFREMER Float).

Time (Zulu)	Top VMCM				Bottom VMCM				Average			Difference (top-bottom)			
	u	v	T	P	u	v	T	P	u_{av}	v_{av}	P_{av}	Δu	Δv	ΔT	ΔP
22:32	0.20	-0.60	25.22	13.56	4.60	-0.80	25.18	17.10	2.40	-0.70	15.33	-4.40	0.20	0.04	-3.54
22:40	0.60	-0.20	25.22	13.59	4.00	-0.30	25.14	17.07	2.30	-0.25	15.33	-3.40	0.10	0.08	-3.48
23:02	1.20	-0.40	25.18	13.43	3.70	-0.70	25.13	17.07	2.45	-0.55	15.25	-2.50	0.30	0.05	-3.64
23:10	1.50	-1.10	25.18	13.46	3.70	-0.60	25.13	17.21	2.60	-0.85	15.34	-2.20	-0.50	0.05	-3.75
23:17	1.90	-1.00	25.18	13.39	4.00	-0.90	25.13	16.99	2.95	-0.95	15.19	-2.10	-0.10	0.05	-3.60
23:25	1.40	-1.10	25.18	13.46	3.70	-0.60	25.13	17.07	2.55	-0.85	15.27	-2.30	-0.50	0.05	-3.61
23:32	1.30	-1.20	25.16	13.39	3.80	-1.10	25.13	16.77	2.55	-1.15	15.08	-2.50	-0.10	0.03	-3.38
23:40	1.10	-0.80	25.18	13.29	3.30	-1.10	25.13	17.21	2.20	-0.95	15.25	-2.20	0.30	0.05	-3.92
23:47	1.40	-0.60	25.16	13.59	3.80	-0.40	25.13	16.93	2.60	-0.50	15.26	-2.40	-0.20	0.03	-3.34
23:55	1.70	-1.10	25.16	13.26	4.20	-1.40	25.11	16.99	2.95	-1.25	15.13	-2.50	0.30	0.05	-3.73
00:02	1.80	-1.10	25.16	13.36	3.50	-1.20	25.13	16.85	2.65	-1.15	15.11	-1.70	0.10	0.03	-3.49
00:10	1.90	-1.00	25.16	13.43	4.60	-1.10	25.11	16.93	3.25	-1.05	15.18	-2.70	0.10	0.05	-3.50
00:17	2.10	-0.90	25.16	13.46	4.50	-0.90	25.11	17.04	3.30	-0.90	15.25	-2.40	0.00	0.05	-3.58
00:25	2.00	-1.20	25.16	13.32	4.10	-1.10	25.13	17.04	3.05	-1.15	15.18	-2.10	-0.10	0.03	-3.72
00:32	2.30	-1.00	25.16	13.53	4.20	-0.30	25.13	16.88	3.25	-0.65	15.20	-1.90	-0.70	0.03	-3.35
00:40	2.40	-1.10	25.18	13.46	4.20	-0.50	25.13	16.99	3.30	-0.80	15.23	-1.80	-0.60	0.05	-3.53
Mean	1.55	-0.90	25.18	13.44	3.99	-0.81	25.13	17.01	2.77	-0.86	15.22	-2.44	-0.09	0.05	-3.57
Std. deviation	0.57	0.29	0.02	0.10	0.37	0.33	0.02	0.11	0.36	0.27	0.07	0.64	0.32	0.01	0.15

TABLE 3.17: Current Meter Data (Test #5: Tristar with IFREMER Float).

Time (Zulu)	Top VMCM				Bottom VMCM				Average			Difference (top-bottom)			
	u	v	T	P	u	v	T	P	u_{av}	v_{av}	P_{av}	Δu	Δv	ΔT	ΔP
21:47	0.00	0.40	24.81	13.53	1.90	1.90	24.76	16.99	0.95	1.15	15.26	-1.90	-1.50	0.05	-3.46
21:55	-0.10	0.80	24.85	13.46	1.60	1.60	24.76	16.86	0.75	1.20	15.16	-1.70	-0.80	0.09	-3.40
22:02	0.50	1.10	24.85	13.30	1.80	1.80	24.78	16.99	1.15	1.45	15.15	-1.30	-0.70	0.07	-3.69
22:10	0.00	0.20	24.85	13.36	1.40	2.30	24.80	16.99	0.70	1.25	15.18	-1.40	-2.10	0.05	-3.63
22:32	0.50	0.40	24.81	13.56	2.60	2.90	24.76	16.99	1.55	1.65	15.28	-2.10	-2.50	0.05	-3.43
22:40	0.60	1.10	24.87	13.43	2.20	3.00	24.80	17.10	1.40	2.05	15.27	-1.60	-1.90	0.07	-3.67
22:47	1.00	0.80	24.89	13.26	3.30	3.70	24.80	17.10	2.15	2.25	15.18	-2.30	-2.90	0.09	-3.84
22:55	1.10	0.50	24.85	13.53	3.60	2.10	24.78	16.83	2.35	1.30	15.18	-2.50	-1.60	0.07	-3.30
23:02	1.30	0.70	24.85	13.26	3.30	1.40	24.80	17.02	2.30	1.05	15.14	-2.00	-0.70	0.05	-3.76
23:10	1.10	1.20	24.87	13.33	2.80	1.90	24.81	16.83	1.95	1.55	15.08	-1.70	-0.70	0.06	-3.50
23:17	1.20	0.50	24.85	13.60	4.00	1.80	24.78	16.66	2.60	1.15	15.13	-2.80	-1.30	0.07	-3.06
Mean	0.65	0.70	24.85	13.42	2.59	2.22	24.78	16.94	1.62	1.46	15.18	-1.94	-1.52	0.07	-3.52
Std. deviation	0.50	0.32	0.02	0.12	0.84	0.67	0.02	0.13	0.65	0.37	0.06	0.44	0.73	0.01	0.22

TABLE 3.18: Current Meter Data (Test #6: Tristar with Long Ball Float).

Time (Zulu)	Top VMCM				Bottom VMCM				Average			Difference (top-bottom)			
	u	v	T	P	u	v	T	P	u_{av}	v_{av}	P_{av}	Δu	Δv	ΔT	ΔP
20:32	0.00	-0.60	24.98	14.00	1.50	0.70	24.92	17.54	0.75	0.05	15.77	-1.50	-1.30	0.06	-3.54
20:40	0.80	0.70	24.96	13.80	0.10	-0.60	24.92	17.32	0.45	0.05	15.56	0.70	1.30	0.04	-3.52
20:47	0.40	1.20	24.96	13.83	0.90	0.00	24.92	17.29	0.65	0.60	15.56	-0.50	1.20	0.04	-3.46
20:55	0.70	0.00	24.96	13.97	2.00	0.90	24.92	17.46	1.35	0.45	15.72	-1.30	-0.90	0.04	-3.49
21:02	0.70	-0.20	24.94	13.80	1.60	0.70	24.89	17.48	1.15	0.25	15.64	-0.90	-0.90	0.05	-3.68
21:10	0.80	0.00	24.94	13.80	0.90	0.90	24.89	17.40	0.85	0.45	15.60	-0.10	-0.90	0.05	-3.60
21:17	0.60	0.00	24.94	13.73	1.00	1.20	24.91	17.40	0.80	0.60	15.56	-0.40	-1.20	0.03	-3.67
21:25	0.50	0.40	24.94	13.80	1.00	0.70	24.91	17.48	0.75	0.55	15.64	-0.50	-0.30	0.03	-3.68
21:32	0.20	0.20	24.96	14.00	0.80	0.60	24.91	17.43	0.50	0.40	15.72	-0.60	-0.40	0.05	-3.43
Mean	0.52	0.19	24.95	13.86	1.90	0.57	24.91	17.42	0.81	0.38	15.64	-0.57	-0.38	0.04	-3.56
Std. deviation	0.26	0.50	0.01	0.10	0.52	0.51	0.01	0.08	0.27	0.20	0.07	0.61	0.92	0.01	0.09

TABLE 3.19: Current Meter Data (Test #6: Tristar with Long Stake Float).

Time (Zulu)	Top VMCM				Bottom VMCM				Average			Difference (top-bottom)			
	u	v	T	P	u	v	T	P	u_{av}	v_{av}	P_{av}	Δu	Δv	ΔT	ΔP
22:17	0.00	1.80	24.98	14.13	0.50	0.70	24.94	17.73	0.25	1.25	15.93	-0.50	1.10	0.04	-3.60
22:25	0.80	1.10	25.00	14.20	0.70	0.70	24.94	17.70	0.75	0.90	15.95	0.10	0.40	0.06	-3.50
22:32	0.70	0.50	24.98	14.20	1.30	1.50	24.92	17.70	1.00	1.00	15.95	-0.60	-1.00	0.06	-3.50
22:40	0.30	0.40	24.96	14.27	1.40	1.90	24.92	17.70	0.85	1.15	15.99	-1.10	-1.50	0.04	-3.43
22:47	0.80	0.30	24.98	14.20	1.40	3.40	24.94	17.81	1.10	1.85	16.00	-0.60	-3.10	0.04	-3.61
22:55	0.90	0.00	25.00	14.20	2.80	3.50	24.92	17.70	1.85	1.75	15.95	-1.90	-3.50	0.08	-3.50
23:02	1.40	0.40	25.00	14.20	2.30	2.10	24.94	17.62	1.85	1.25	15.91	-0.90	-1.70	0.06	-3.42
23:10	1.50	0.10	24.98	14.27	2.40	1.30	24.92	17.81	1.95	0.70	16.04	-0.90	-1.20	0.06	-3.54
23:17	2.00	0.30	24.96	14.23	2.60	2.70	24.92	17.68	2.30	1.50	15.95	-0.60	-2.40	0.04	-3.45
23:25	1.60	0.60	24.98	14.13	2.30	2.80	24.94	17.76	1.95	1.70	15.95	-0.70	-2.20	0.04	-3.63
Mean	1.00	0.55	24.98	14.20	1.77	2.06	24.93	17.72	1.38	1.31	15.96	-0.77	-1.51	0.05	-3.52
Std. deviation	0.59	0.50	0.01	0.05	0.77	0.97	0.01	0.06	0.64	0.37	0.04	0.48	1.36	0.01	0.057

TABLE 4: Doppler Profiler Averages and Standard Deviations.

Test	Bin	Depth	$\overline{U}$	$\overline{V}$	σU	σV
1A	1	9.0	0.0	0.0	9.6	11.2
	2	13.0	1.0	-0.9	9.6	7.4
	3	17.0	-1.6	-1.0	8.7	8.2
	4	21.0	2.2	0.2	8.8	7.8
	5	25.0	3.8	0.6	8.1	6.9
	6	29.0	7.3	-1.2	7.6	8.8
	7	33.0	8.1	-2.5	7.8	7.9
	8	37.0	11.5	-0.3	8.0	8.0
	9	41.0	16.8	-1.8	8.0	7.3
	10	45.0	22.7	-2.6	8.3	8.4
1B	1	9.0	0.0	0.0	8.5	6.0
	2	13.0	0.5	1.6	7.4	7.9
	3	17.0	0.7	-1.7	8.4	6.7
	4	21.0	1.4	-1.1	9.2	6.9
	5	25.0	1.9	0.0	7.9	6.5
	6	29.0	5.7	-1.5	7.7	6.7
	7	33.0	9.7	-3.3	8.0	7.2
	8	37.0	13.7	-0.9	7.6	7.1
	9	41.0	18.0	-1.4	7.6	7.6
	10	45.0	21.6	-3.8	8.9	6.4
2A	1	9.0	0.0	0.0	11.7	9.4
	2	13.0	-7.0	-1.3	8.2	7.6
	3	17.0	-6.4	-0.9	8.2	8.4
	4	21.0	-2.3	-0.5	8.6	7.2
	5	25.0	2.5	-0.2	7.4	7.8
	6	29.0	6.2	-3.1	7.7	6.9
	7	33.0	9.9	-3.8	8.2	7.6
	8	37.0	14.4	-2.9	7.1	7.8
	9	41.0	18.1	-6.0	7.8	7.6
	10	45.0	24.3	-3.3	7.2	8.4
2B	1	9.0	0.0	0.0	12.0	11.9
	2	13.0	-3.3	-2.3	11.7	9.8
	3	17.0	-4.3	-1.5	10.3	9.8
	4	21.0	0.7	-0.4	9.3	7.9
	5	25.0	5.7	0.1	8.2	8.1
	6	29.0	11.8	-3.4	8.1	8.4
	7	33.0	13.0	-4.0	8.6	8.9
	8	37.0	19.8	-5.4	9.2	8.4
	9	41.0	25.1	-4.0	8.6	8.4
	10	45.0	28.7	-4.5	8.6	8.1

TABLE 4: Doppler Profiler Averages and Standard Deviations (cont.)

Test	Bin	Depth	$\overline{U}$	$\overline{V}$	σU	σV
3	1	9.0	0.0	0.0	10.6	9.6
	2	13.0	-2.3	-0.4	8.5	8.0
	3	17.0	-0.8	-1.2	8.9	6.9
	4	21.0	5.9	0.8	7.8	8.7
	5	25.0	11.6	0.5	7.8	6.8
	6	29.0	18.6	2.1	7.8	7.4
	7	33.0	21.7	0.9	8.2	8.8
	8	37.0	27.1	1.0	8.4	7.1
	9	41.0	29.6	2.6	8.6	6.9
	10	45.0	37.8	1.1	8.6	6.9
4	1	9.0	0.0	0.0	9.2	9.4
	2	13.0	-0.2	-3.8	8.6	9.4
	3	17.0	1.7	-5.5	9.2	8.5
	4	21.0	4.0	-6.4	8.2	8.0
	5	25.0	6.0	-12.1	8.6	8.7
	6	29.0	10.0	-17.4	8.2	9.4
	7	33.0	13.3	-26.0	8.6	9.3
	8	37.0	19.3	-36.1	7.7	9.7
	9	41.0	26.5	-40.2	7.5	8.1
	10	45.0	25.7	-35.2	8.9	8.2
5A	1	9.0	0.0	0.0	9.7	8.7
	2	13.0	-1.3	-3.3	8.9	7.0
	3	17.0	0.5	-4.7	9.7	8.0
	4	21.0	2.4	-1.7	8.0	8.9
	5	25.0	5.1	-3.0	8.4	8.1
	6	29.0	3.9	-4.3	7.9	8.2
	7	33.0	3.2	-7.3	7.9	7.6
	8	37.0	0.8	-9.6	8.2	8.8
	9	41.0	2.9	-8.1	8.6	8.2
	10	45.0	3.5	-6.6	7.2	7.8
5B	1	9.0	0.0	0.0	8.1	8.2
	2	13.0	1.1	0.2	6.9	7.9
	3	17.0	2.7	0.6	8.1	7.7
	4	21.0	4.6	-3.9	9.6	7.1
	5	25.0	4.8	-2.8	7.9	8.0
	6	29.0	4.7	-2.4	7.4	7.2
	7	33.0	3.9	-4.7	7.3	7.8
	8	37.0	2.7	-6.9	7.4	7.4
	9	41.0	1.5	-6.4	8.2	8.0
	19	45.0	5.0	-5.7	7.1	7.7

TABLE 4: Doppler Profiler Averages and Standard Deviations (cont.)

Test	Bin	Depth	$\overline{U}$	$\overline{V}$	σU	σV
6A	1	9.0	0.0	0.0	11.6	11.0
	2	13.0	-4.0	-0.2	10.0	8.2
	3	17.0	-2.7	-0.2	7.6	9.9
	4	21.0	-0.9	0.2	7.4	7.3
	5	25.0	-2.6	1.5	7.4	7.4
	6	29.0	-1.4	1.3	7.1	8.2
	7	33.0	-0.1	0.5	7.9	9.0
	8	37.0	0.5	2.4	7.2	7.5
	9	41.0	0.5	2.3	8.2	7.1
	10	45.0	1.7	2.0	7.4	7.3
6B	1	9.0	0.0	0.0	11.3	8.9
	2	13.0	-3.2	-3.2	7.7	8.2
	3	17.0	0.3	-1.9	8.6	6.6
	4	21.0	-0.5	-2.8	8.0	7.4
	5	25.0	2.2	-2.5	7.4	6.9
	6	29.0	1.5	-1.9	8.2	6.6
	7	33.0	3.4	-0.7	8.8	6.7
	8	37.0	3.6	-1.6	8.7	7.1
	9	41.0	5.8	-3.3	7.8	6.7
	10	45.0	3.9	-3.7	8.4	6.9

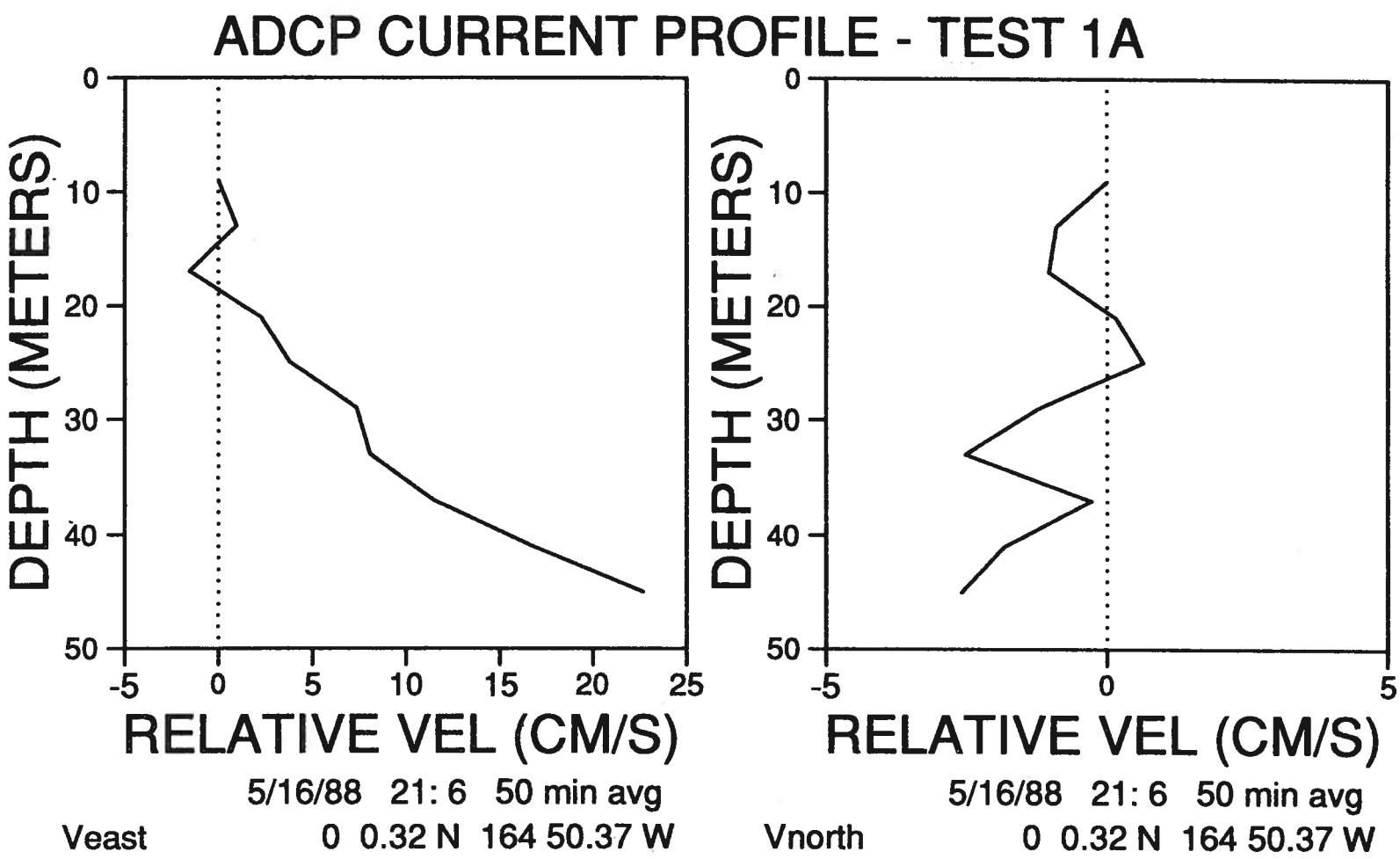


Figure 11. Acoustic Doppler current profile (test 1A).

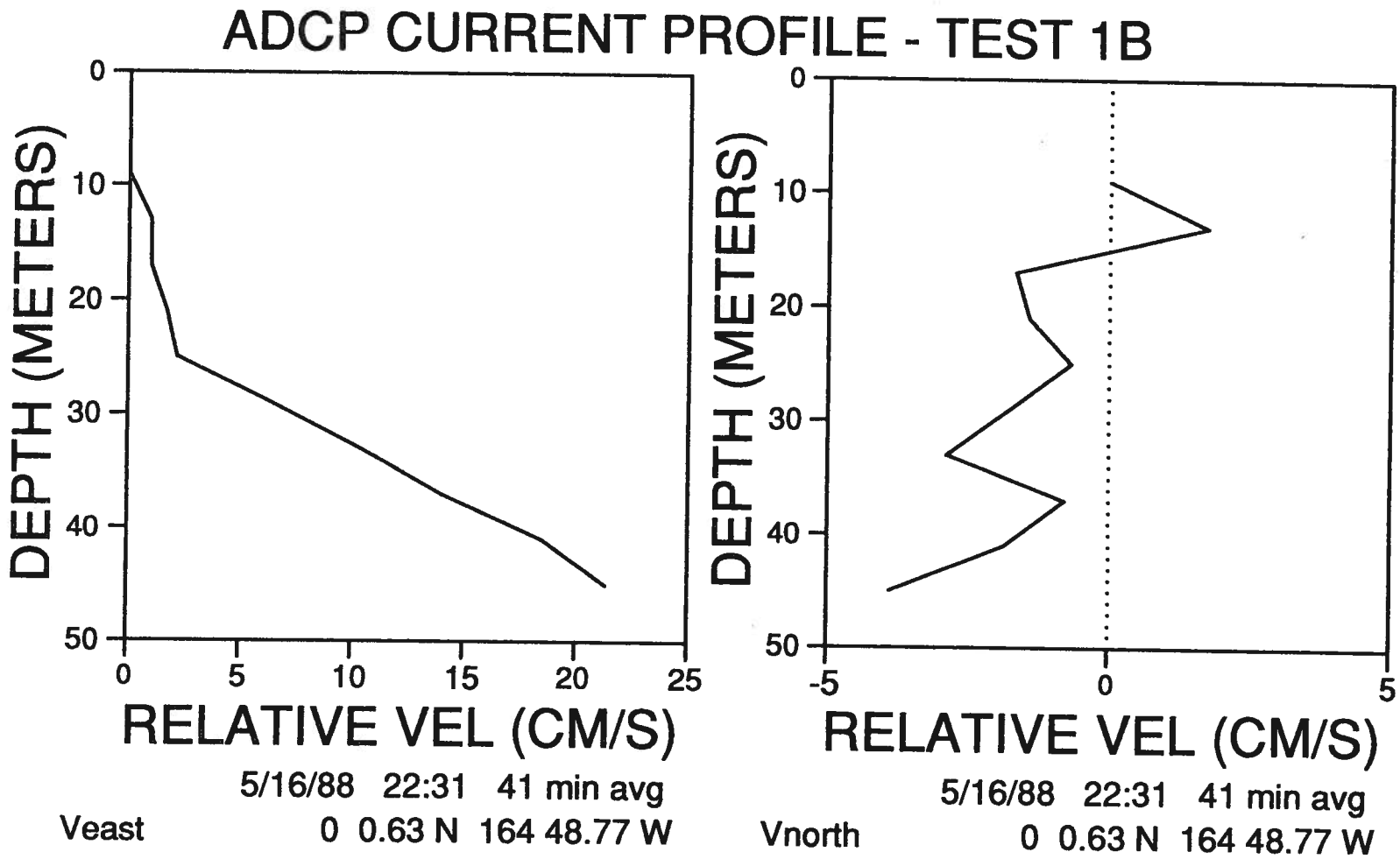


Figure 12. Acoustic Doppler current profile (test 1B).

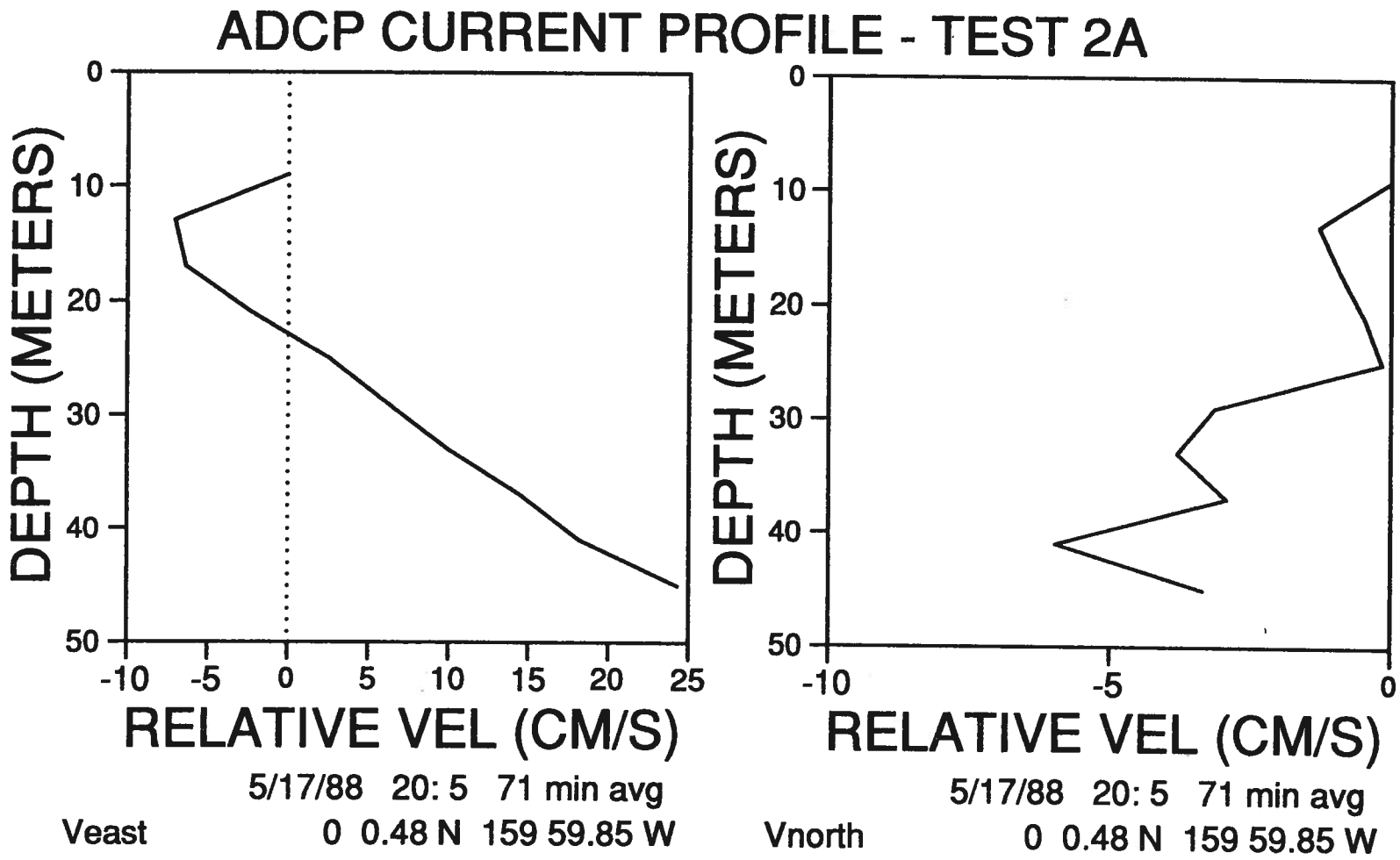


Figure 13. Acoustic Doppler current profile (test 2A).

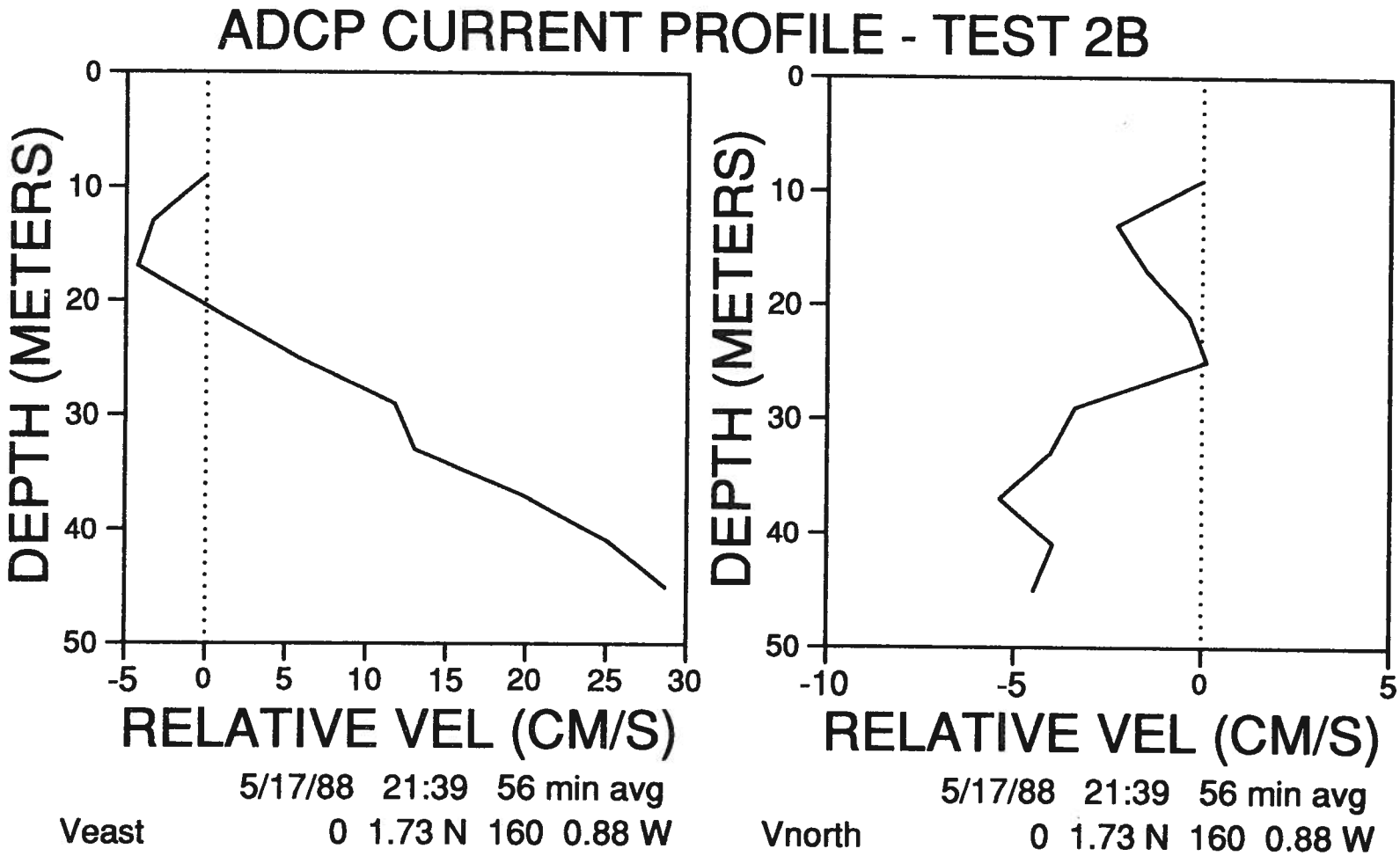


Figure 14. Acoustic Doppler current profile (test 2B).

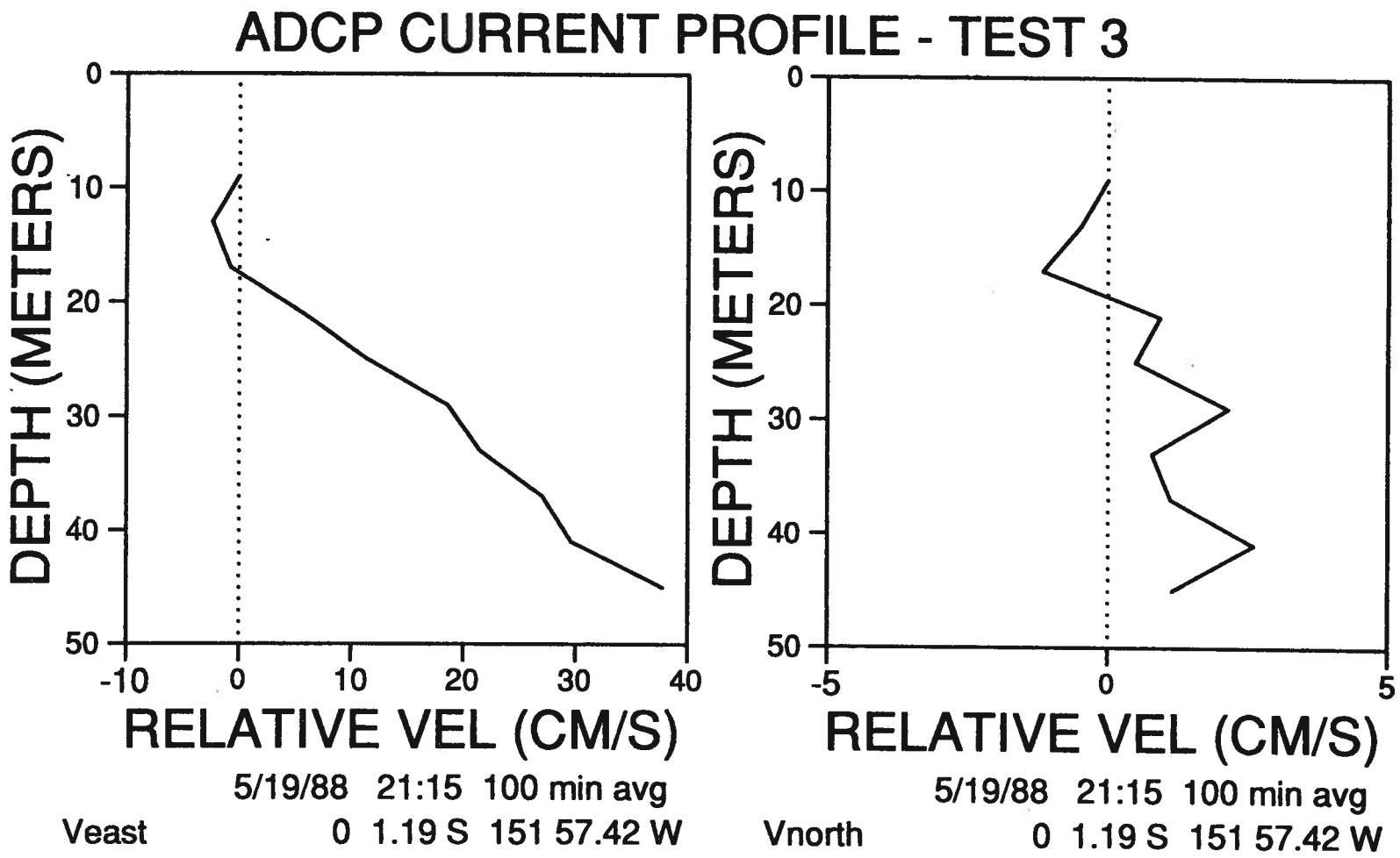


Figure 15. Acoustic Doppler current profile (test 3).

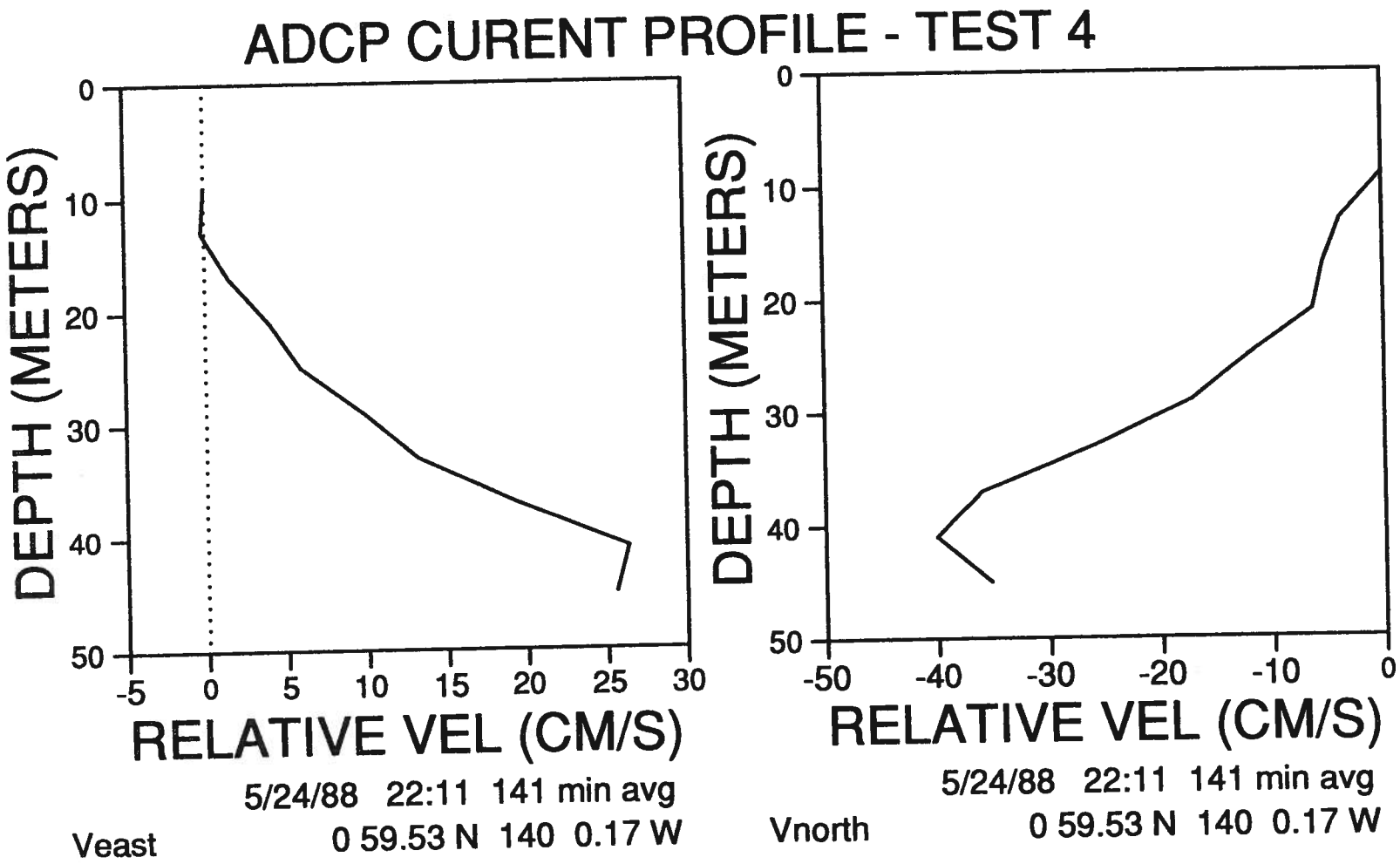


Figure 16. Acoustic Doppler current profile (test 4).

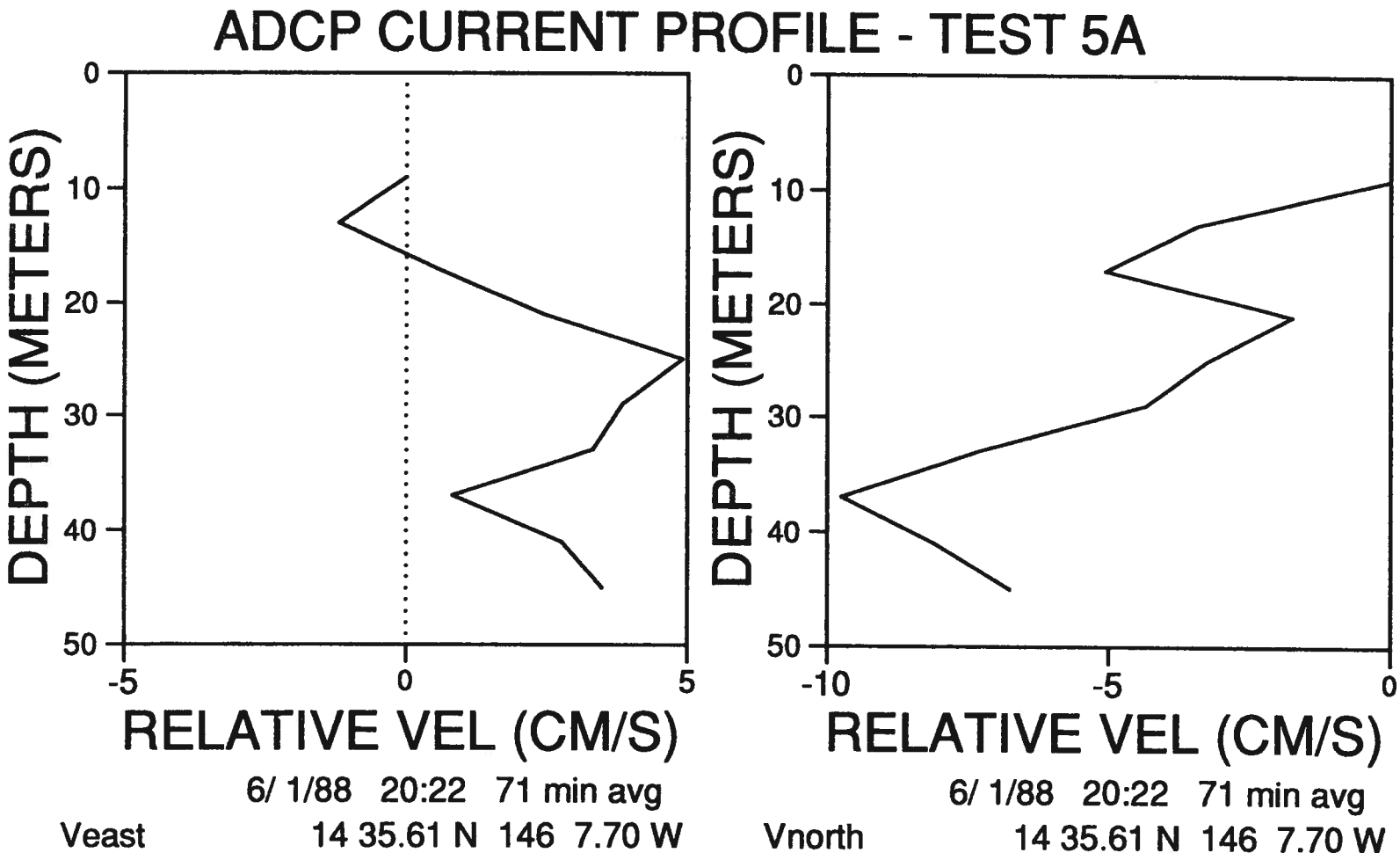


Figure 17. Acoustic Doppler current profile (test 5A).

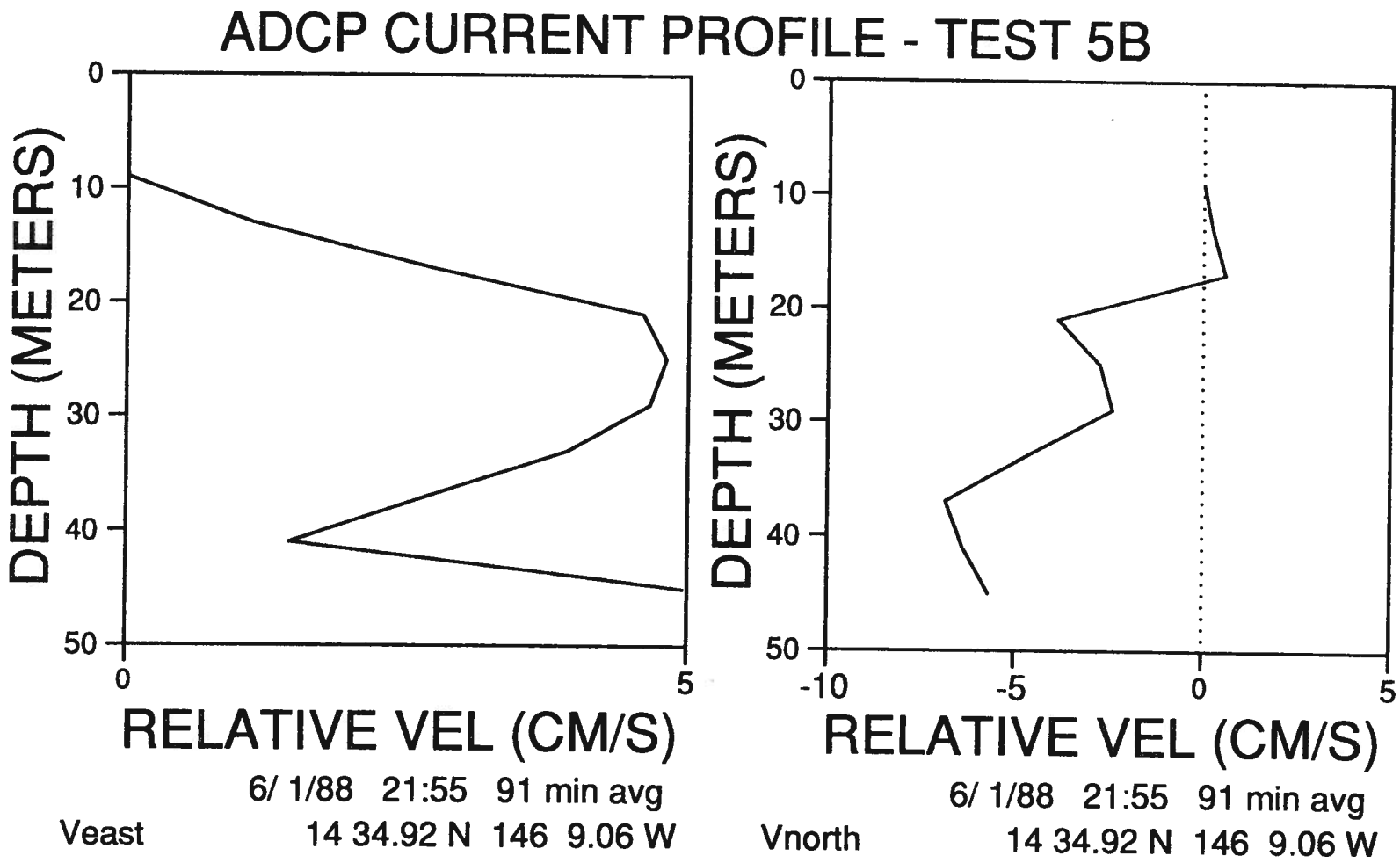


Figure 18. Acoustic Doppler current profile (test 5B).

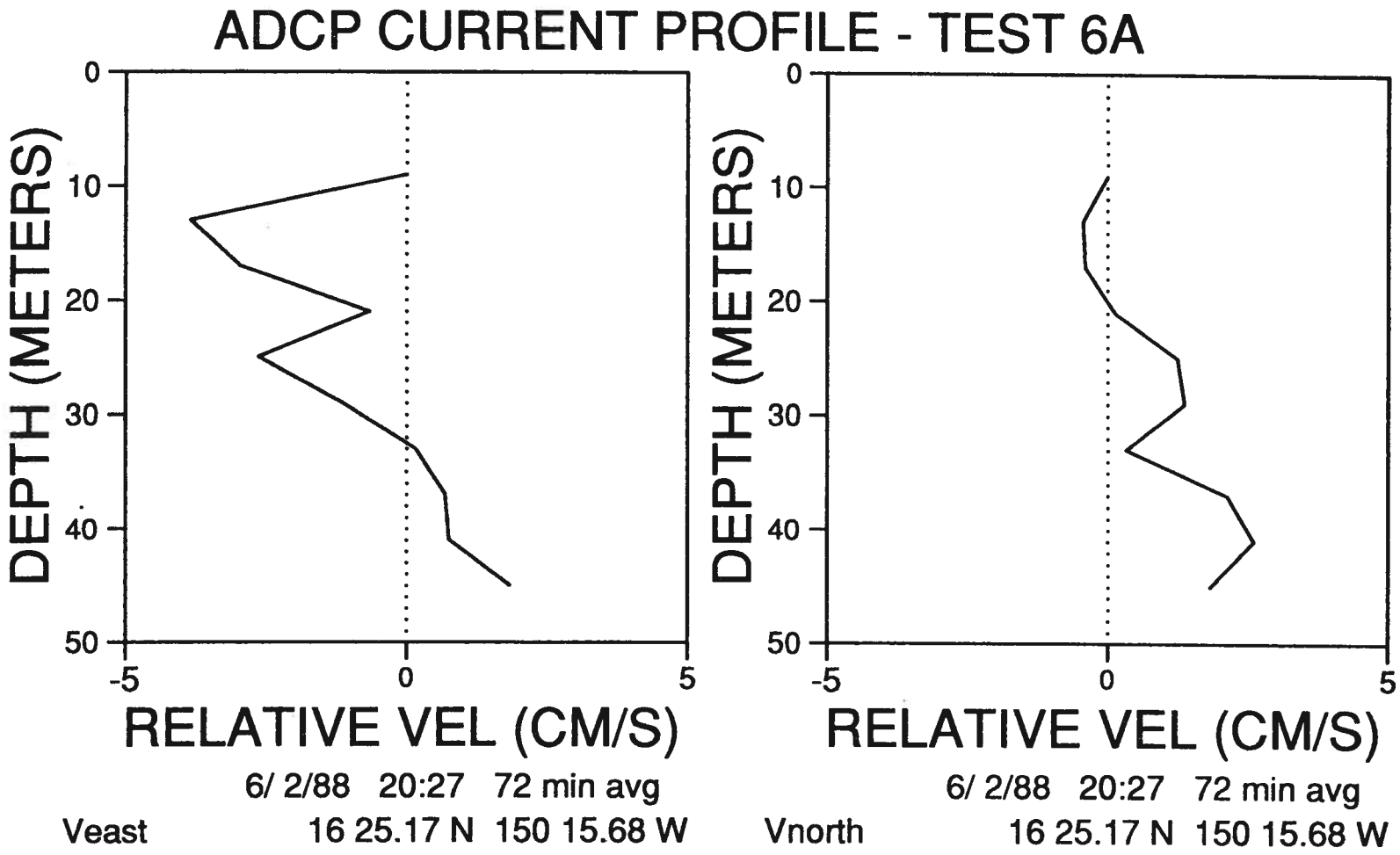


Figure 19. Acoustic Doppler current profile (test 6A).

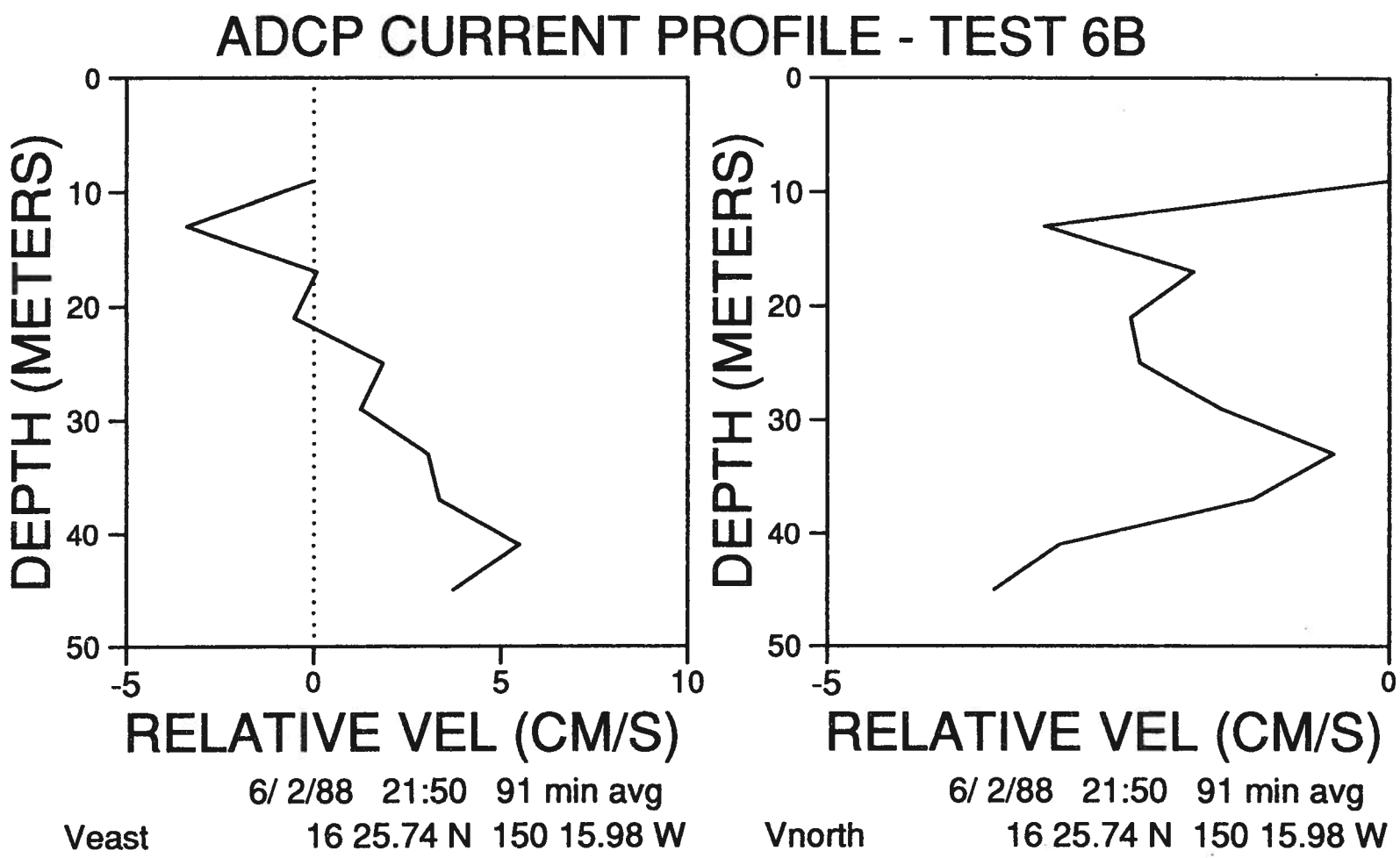


Figure 20. Acoustic Doppler current profile (test 6B).

TABLE 5: 1988 Buoy Test Summary.

			TRISTAR DROGUE								HOLEY SOCK DROGUE											
					VMCM				Drift				VMCM				Drift		Wind Spd		Sea State	
Test	Date	Time	Hull	R	U	V	DU	DV	U	V	Hull	R	U	V	DU	DV	U	V	m/s	Dir	Ht (m)	Dir
1A	5/16/88	21:07 21:56	Ball	50.5	+0.88	+0.53	-0.78	-0.50	-----	-----	Spar	31.4	+1.03	+1.23	-2.03	-2.05	-----	-----	7.2	095	1.2	090
1B	5/16/88	22:31 23:10	Spar	18.1	+1.99	+1.21	-1.67	-1.50	-----	-----	Ball	97.9	+0.68	+0.48	-1.80	-1.00	-----	-----	8.2	095	1.2	090
2A	5/17/88	20:05 21:16	Ball	50.5	+1.71	+1.43	-6.78	-2.50	-29.2	+45.7	Spar	31.4	+3.52	+3.48	-13.36	-5.89	-26.5	+43.6	9.6	095	1.4	090
2B	5/17/88	21:39 22:35	Spar	18.1	+3.11	+0.77	-3.45	-2.06	-18.0	+42.9	Ball	97.9	+2.08	+2.84	-13.76	-1.31	-21.1	+40.5	9.6	090	1.6	090
3	5/19/88	21:15 22:56	Ball	50.5	+1.58	+0.66	-3.23	-1.13	+42.1	-7.3	Spar	31.4	+2.88	+1.52	-10.50	-4.93	+40.6	-11.8	7.5	102	1.2	095
4	5/24/88	22:11 00:33	IFREMER	18.9	+2.77	-0.86	-2.44	-0.09	+19.2	-6.2	Spar	31.4	+2.78	-1.50	-5.64	+2.66	+19.2	-7.2	4.3	122	0.6	130
5A	6/01/88	20:22 21:32	IFREMER	18.9	+1.62	+1.46	-1.94	-1.52	-46.8	-15.8	Ball	97.9	+0.91	+0.69	-0.84	-0.97	-44.2	-14.6	8.6	060	1.3	060
5B	6/01/88	21:55 23:26	IFREMER	18.9	+0.81	+0.38	-0.57	-0.38	-37.9	-2.8	Spar	31.4	+1.58	+1.12	-3.46	-1.31	-36.2	-2.5	8.6	060	1.2	060
6A	6/02/88	20:27 21:38	Ball	50.5	+0.81	+0.38	-0.57	-0.38	-13.4	+33.0	Spar	31.4	+0.73	+0.90	-1.54	-1.84	-14.7	+23.0	9.6	060	1.5	060
6B	6/02/88	21:50 23:20	Spar	18.1	+1.38	+1.31	+0.77	-1.51	-13.4	+19.7	Ball	97.9	+0.70	+1.04	-1.21	-0.83	-11.1	+22.7	8.9	055	1.4	060

(3) The separation of the ship and buoys at times may have reached one nautical mile or more, putting them into different current regimes.

8. ACKNOWLEDGMENTS

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