Appendix 4

Appendix 4

LAGRANGIAN DRIFTER OBSERVATIONS IN SAN DIEGO BAY: DATA REPORT

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INTRODUCTION

The goal of this project was to collect data which would aid in identification of processes which are responsible for the dispersion of natural and anthropogenic substances in a tidally influenced coastal bay. Previous studies have suggested several mechanisms that enhance tidal dispersion, and a number of field and numerical experiments have confirmed that dispersion in these systems is much greater than would be expected from turbulent eddy diffusion alone.

The purpose of this field observation series was to observe possible mechanisms which might contribute to enhanced dispersion. Two mechanisms which were expected to be important are shear dispersion and tidal trapping. We also wanted to measure tidal excursion to quantify a major spatial scale that might influence dispersion.

This report is a collation and summary of Lagrangian drifter data collected under NRaD Contract #N66001-94-M-1213 and California Regional Water Quality Board (San Diego Region) Interagency Agreement 1-188-190-0 in San Diego Bay, California from May through September of 1994. We made measurements on four days in three areas of the bay. Five to fourteen drifters were deployed in each field deployment and tracked by differential and relative Global Positioning System (GPS) methods. These methods are generally accurate to within a few meters, and to roughly ten meters, respectively. Deployment durations ranged from a few hours to a full tidal cycle. Figure 1 shows the areas encompassed by each of the four deployment series this report covers.

DESCRIPTION OF INSTRUMENT

Positioning System

The drifter system consists of a base station, a fleet of drifters (18 at present), and a monitoring station located on the drifter tracking vessel. Figure 2 shows a general schematic of the system.

The base station consists of a 6-channel differential GPS receiver, a UHF packet radio, a modem, a microprocessor to control the system, and UHF and GPS antennae. The GPS receiver in the base station receives precise timing and satellite position information from the constellation of GPS satellites and calculates its distance (pseudorange) from each satellite. The differences between the known and calculated distances (pseudorange corrections) for each satellite are broadcast over the UHF packet radio.

Each drifter has an electronics package similar to the base station. The drifter GPS engine is configured to receive the satellite messages, generate the local pseudoranges, receive the UHF-broadcast pseudorange corrections from the base station, and calculate

its corrected position. The corrected positions are then recorded in onboard memory. Sample period was normally 5 s.

The relatively small size of the drifters precludes storing enough batteries on board to continuously telemeter data back to a land station. However, to aid in the recovery of the drifter fleet, each drifter broadcasts its position at a programmable interval. A monitor station onboard the tracking vessel receives and displays the position of the drifters as they sequentially report their positions.

Drifter Body

The drifter body is a modification of an existing design used by Davis [Davis, et al, 1982; Davis, 1985] (Figure 3). This proven design is inexpensive, self-contained, reliable, rugged, and easily transportable. The drifter may be adjusted for droguing at depths from -0.5 to -15 m. In this series of observations, the drogue centroid is at -0.8 m.

The projected area of the drogue is approximately 1 m^2 and the electronics package is carried in a central PVC pressure case. In the presence of moderate wind and wave conditions, the water-following performance of the drifter has a drift-to-wind-velocity ratio of 0.002 (George and Largier, 1995).

FIELD DEPLOYMENTS

Deployment Series 1, May 18, 1994

The May 18 deployment was a preliminary attempt to describe the outflow jet at the mouth of San Diego Bay. Twelve drifters were deployed on the ebbing tide in three deployment groups. In each deployment group, four drifters were arranged in a line across the channel at buoys 7 and 8. One drifter was deployed on each side of the channel and the other two were deployed in shallower water near Point Loma and Zuniga Jetty. Figure 4 shows the tidal heights during the deployment.

The first four drifters were deployed at 4:45 AM. Times and approximate positions of each deployment are shown in Table 1.

Table 1. Deployment Group 1 May 18, 1994

Drifter #	Location	Deployment Time	Comments
1-5*	West Channel	4:45-13:15	Noisy Data
1-7*	West Shallows	4:45-13:15	Noisy Data
1-11*	East Shallows	4:45-13:25	Noisy Data
1-15*	East Channel	4:45-11:50	Instrument failed at 11:50

* indicates data plotted

The recorded drifter tracks (Figure 5) indicate an initial strong jet to the south. The drifters appear to have been drawn into a recirculation eddy east of the channel as the tide turns.

Velocities were around 0.2 m/s in the jet, slowing to 0.1 m/s as the drifters were drawn eastward. The data exhibit intermittent interference with the GPS signal, a phenomenon observed in all of the San Diego Bay deployments. We have not seen this problem in areas away from San Diego Bay and, although unexplained, we expect that it is related to some local source of electromagnetic radiation.

The next group of drifters were released at the same location as Group 1 beginning at 5:25. Three of the four drifters returned data. Deployment times and locations are shown in Table 2.

Table 2. Deployment Group 2 May 18, 1994

Drifter #	Location	Deployment Time	Comments
1-2*	East Channel	5:25-12:27	Noisy Data
1-9*	East Shallows	5:30-7:00	Instrument failed at 7:00
1-16*	West Channel	5:32-12:07	Noisy Data
1-17	West Shallows	5:33	Instrument failed

* indicates data plotted

The recorded drifter tracks (Figure 6) again indicate an initial strong jet with an apparent recirculation eddy to the east of the channel. Velocities were about 0.15 m/s.

The third group of drifters were released at the same locations, beginning at 8:07. Only two of these returned useful data. Deployment times and locations are shown in Table 3.

Table 3. Deployment Group 3 May 18, 1994

Drifter #	Location	Deployment Time	Comments
1-10	West Shallows	8:07	Drifter not recovered
1-12*	East Channel	8:10-10:40	One data offset section
1-13*	West Channel	8:16-11:47	One data offset section
1-18	East Shallows	8:17	Instrument failed

* indicates data plotted

The recorded drifter tracks (Figure 7) again indicate an initial strong jet, extending about 4 km from the mouth, with the beginning of an apparent recirculation eddy to the east.

Each of the releases indicates that there was a convergence zone near latitude 32.64, likely due to the attachment of the outflow jet to the sloping bottom. If this was the cause of the

convergence, the divergence south of latitude 32.63 was likely to have been caused by the lifting off of the jet from the bottom.

Each release also indicates the beginning of recirculation to the east as the drifters reach the latitude 32.63.

Deployment Series 2, June 27, 1994

The purpose of the June 27 deployment was to investigate mean and dispersive flows near Shelter and Harbor Islands at the north end of San Diego Bay. Fourteen drifters were deployed first on the ebbing tide and then on the flood in five deployment groups. Figure 8 shows the tidal heights during the deployment. Within each deployment group, the drifters were arranged across the channel in two, three or four clusters. Each cluster contained three or four drifters.

The first group was launched at 1:43 AM, about 1.5 hours after high tide. Two clusters of three drifters were deployed at the north and south sides of the bay. Two clusters of four were deployed at the sides of the channel itself. Times and approximate positions of each deployment are shown in Table 4.

Table 4. Deployment Group 1 June 27, 1994

Cluster and Drifter #	Cluster Location	Deployment Time	Comments
1-1	South Side	1:43	Large data offsets
1-10		1:43	Large data offsets
1-18*		1:43-3:26	
2-6	Channel (South)	1:50	Large data offsets
2-7*		1:50-3:31	
2-9		1:50	Large data offsets
2-14		1:50	Large data offsets
3-3	Channel (North)	1:54	Large data offsets
3-5		1:54	Large data offsets
3-8		1:54	Large data offsets
3-16		1:54	Large data offsets
4-11	North Side	1:59	Large data offsets
4-12		1:59	Large data offsets
4-17		1:59	Large data offsets

* indicates data plotted

Due to the unexplained intermittent interference with the GPS signal in the San Diego Bay area, only two drifters recorded plausible data. The indicated positions of the other drifters varied wildly.

The two realistic drifter tracks are shown in Figure 9. Both drifters indicate a weak cross-channel flow until they reach shallow water on the west side of the channel where they then turn southward. Figure 10 shows velocities for the two drifters of 0.2 m/s increasing to 0.4 m/s.

The second deployment yielded no useable data due to the signal interference mentioned above.

The third deployment was launched at 4:55 AM, during the middle of the ebb. Drifters were deployed on the south edge in the shallows, and at the north side of the channel. Times and approximate positions of each deployment are shown in Table 5.

Table 5. Deployment Group 3 June 27, 1994

Cluster and Drifter #	Cluster Location	Deployment Time	Comments
1-3	Channel	4:55	Large data offsets
1-5*		4:55-6:52	
1-11		4:55	Large data offsets
1-12		4:55	Large data offsets
2-1	South side	5:22	Large data offsets
2-7*		5:22-7:03	
2-9*		5:22-7:04	
2-10		5:22	Large data offsets

* indicates data plotted

Three drifters from this deployment yielded useable data; two at the south edge and one in the channel (Figure 11). The drifters deployed at the south edge drifted into very shallow water at less than 0.2 m/s (Figure 12) while the channel drifters crossed the channel and continued south at about 0.35 m/s.

Group 4 was deployed early in the flood tide. Three clusters of drifters were deployed at the south side of the bay, in the channel and on the north side. Eight of the eleven drifters yielded useable data. Times and approximate positions of each deployment are shown in Table 6.

Table 6. Deployment Group 4 June 27, 1994

Cluster and Drifter #	Cluster Location	Deployment Time	Comments
1-1*	South Side	9:19-10:51	Slightly noisy data
1-9*		9:18-10:51	Slightly noisy data
1-10		9:19	Large data offsets
1-18		9:19	Large data offsets
2-3*	Channel	9:05-10:55	
2-7*		9:05-10:55	
2-11		9:05	Large data offsets
2-12*		9:05-10:51	
3-5*	North Side	9:08-10:17	
3-14*		9:06-10:17	
3-16*		9:07-10:17	

* indicates data plotted

The drifters were deployed in a narrow part of the bay and diverged rapidly as they moved into a wider section (Figure 13). The southern cluster moved into shallow water as they did on the ebb. Velocities of this cluster were as high as 0.35 m/s until they moved into very shallow water and velocities dropped below 0.10 m/s (Figure 14). The middle cluster moved in a fairly straight line up the channel at speeds of 0.2 to 0.3 m/s (Figure 15). The northern cluster moved in a straight line at increasing velocities of 0.2 to 0.35 m/s until they reached the vicinity of Harbor Island where they turned sharply to the east and slowed to 0.2 m/s (Figure 16). The northern cluster showed more dispersion than the other two.

Deployment 5 began at 11:05 during the strong flood tide. Three clusters of drifters were deployed at the south side of the by, in the channel and on the north side. Nine of the eleven drifters yielded useable data. Times and approximate positions of each deployment are shown in Table 7.

Table 7. Deployment Group 5 June 27, 1994

Cluster and Drifter #	Cluster Location	Deployment Time	Comments
1-3*	Channel	11:05-12:07	
1-7*		11:05-12:07	
1-11*		11:05-12:07	
1-12*		11:05-12:07	
2-1*	South Side	11:10-12:08	
2-9*		11:09-12:07	
2-10		11:09	Large data offsets
2-18		11:09	Large data offsets
3-5*	North Side	11:27-12:40	
3-14*		11:27-12:40	
3-16*		11:27-12:40	

* indicates data plotted

All three clusters of drifters moved in straight, non-diverging lines up the channel toward Harbor Island (Figure 17). Velocities ranged from 0.35 to 0.5 m/s with the northern cluster moving most rapidly and the southern cluster most slowly (Figures 18-20).

We are uncertain why the GPS interference was more severe during the ebb and prior to sunrise. While there is anecdotal evidence of GPS problems among boat operators on San Diego Bay, other Differential GPS systems have worked well in the Bay.

The high velocities and strong cohesion of the drifters during this deployment series showed that there is very little dispersion, at either the group or cluster scale, in the "bend" part of the bay.

Deployment Series 3, August 23, 1994

The goals of the August 23 deployment were threefold: to determine the tidal excursion at the channel constriction near the Coronado bridge, to look for tidal trapping in Glorietta Bay, and to see what dispersive effects occur in the vicinity of the topographic widening of the bay beyond the constriction.

Five drifters were deployed just after low tide in a line across the narrowest part of the bay northwest of the Coronado bridge. The drifters were tracked through the full tidal cycle (Figure 21). This deployment was conducted with "bump-and-run" differential GPS positioning. A commercial differential GPS station was mounted on the boat, which was sequentially positioned alongside the drifters after they were deployed. As the boat's GPS

antenna neared each drifter, the GPS-indicated position of the boat was noted. The GPS antenna was usually positioned within 1-2 m of the drifter.

The boat was run at full speed between the five drifters for the duration of the deployment. At the beginning of the deployment drifters were sampled roughly every 15 or 20 minutes. The sample period increased to 20-30 minutes as the drifters spread. A spline curve was fit to the position time series of each drifter and then resampled at one-minute intervals.

Figure 22 shows all of the drifter tracks, while Figures 23-27 show individual tracks, for clarity. Figures 28-33 show equal time segments (two hours duration) of all of the drifter tracks to aid in visualizing the flow for different drifters at the same time. The symbol marks are approximately 10 minutes apart. The jog in the path of drifter D7 (Figure 25) occurred when it was moved out of the way of a ship.

Figure 28 shows the drifters progressing southward into the bay. For reasons which are not clear, drifter D14 accelerated ahead of drifter D05 and crossed westward into the mouth of Glorietta Bay where it slowed markedly. The other drifters continued along the main channel, although drifters D05 and D07 crossed the path of drifter D12. For the next two hours (Figure 29), the four drifters in the channel began to diverge, while drifter D14 turned slowly with the tide change. In the next time interval (Figure 30), the four drifters in the channel turned with the tide and began moving seaward. The most seaward drifters turned first. Drifter D14 turned to the left, while the other drifters turned to the right (toward the deepest part of the ship channel). These are the last positions available for drifter D05, which was found under a navy pier at the next sample time.

In the 12:20 - 14:20 time period (Figure 31), the easternmost drifter (D17) moved very rapidly down the ship channel, while drifters D07 and D12 continued moving across the shallows toward the channel. Drifter D14 accelerated as it emerged from Glorietta Bay and entered the main channel. During the next two-hour period (Figure 32), drifter D14 (coming from Glorietta Bay) joined drifter D17 in the ship channel. Drifters D12 and D07 moved slowly down the ship channel. In the final period (Figure 33), the two seaward drifters turned with tide and began moving back into the bay. The other two drifters continued moving seaward, but it is expected that they would have turned soon if left in the water.

This deployment indicates a maximum tidal excursion of about 4.5 km with the predicted tidal range of 1.65 m as shown in Figure 21. Trapping of water in Glorietta Bay was indicated by the motion of drifter D14. Based on large observed separation of drifters after a full tidal cycle (up to 4 km), strong longitudinal dispersion may be expected in this part of the Bay.

Deployment Series 5, September, 9 1994

The goals of the September 9 deployment were to further investigate both tidal trapping in Glorietta Bay and mixing effects in the sudden widening of the bay beyond the constriction.

Nine drifters were deployed in three groups of three, beginning just after low tide at buoy 24 seaward of the Coronado bridge. The drifters were tracked through the full tidal cycle

(Figure 34). This deployment was conducted using relative GPS, with the reference station on the pier at the NRaD dock. All nine drifters returned usable data.

Figure 35 shows the first deployment group, released at 05:53. Symbols on the plots are at 20 minute intervals. The westernmost drifter, D12 moved back and forth in a line until the tide turned at which time it was rapidly drawn into mid-channel and transported seaward rapidly. The center drifter, D17, moved slowly into the entrance to Glorietta Bay and remained there until the tide turned, similar to D14 in the previous experiment. However, instead of moving north and out like D14, D17 moved northeastward toward the main channel. Drifter D01 was deployed in the main channel and moved quickly up the channel. As the tide turned, D01 turned to the east and eventually began moving outward again, similar to D7 and D12 in the previous deployment.

Figure 36 shows the second deployment group, released at 07:54. The westernmost drifter, D04 moved in three distinct clockwise circles during the flood tide, indicative of energetic shear eddies at the side of the channel. As the tide turned this drifter was rapidly drawn outward and into mid-channel, as was D12. The center drifter, D11, moved rapidly up the channel. Drifter D08 was deployed in the main channel and moved quickly up the channel, crossing to the west behind drifter D11. As the tide turned, D08 turned to the east and began moving outward again, similar to D01 in the previous launch.

Figure 37 shows the third deployment group, released at 09:53. The westernmost drifter, D18, moved up the bay in the shallows until the tide changed and then, after a clockwise turn (like D14 in the previous launch), crossed the channel and moved outward on the east bank to Seaport Village. The center drifter, D05, moved rapidly up the channel, drifted into the shallows, then slowed until the tide changed, when it was drawn into the main channel and outward, like D01 and D08 previously. Drifter D16 was deployed in the main channel and moved quickly up the channel. As the tide turned, D16 stalled, like D11 before it.

The most striking result of this deployment is that in each group, drifters which were deployed roughly 100 m apart across the channel finished the tidal cycle with along-channel separations of 5-7 km. As in previous deployments, a least one drifter was caught in Glorietta Bay. Note also the marked difference in inflow and outflow paths across the shallows. Inflows are relatively straight lines independent of the water depth, while on the outflow, drifters drain across-channel to deeper water.

REFERENCES

Davis, R. E., J. E. Dufour, G. J. Parks, and M. R. Perkins, 1982: Two inexpensive current following drifters. Ref. No. 82-28, Scripps Institution of Oceanography, 54 pp., La Jolla, CA.

George, R, and J. L. Largier: Description and performance of fine-scale drifters for coastal and estuarine studies. Submitted to *J. Atmos. and Oceanic Tech.*

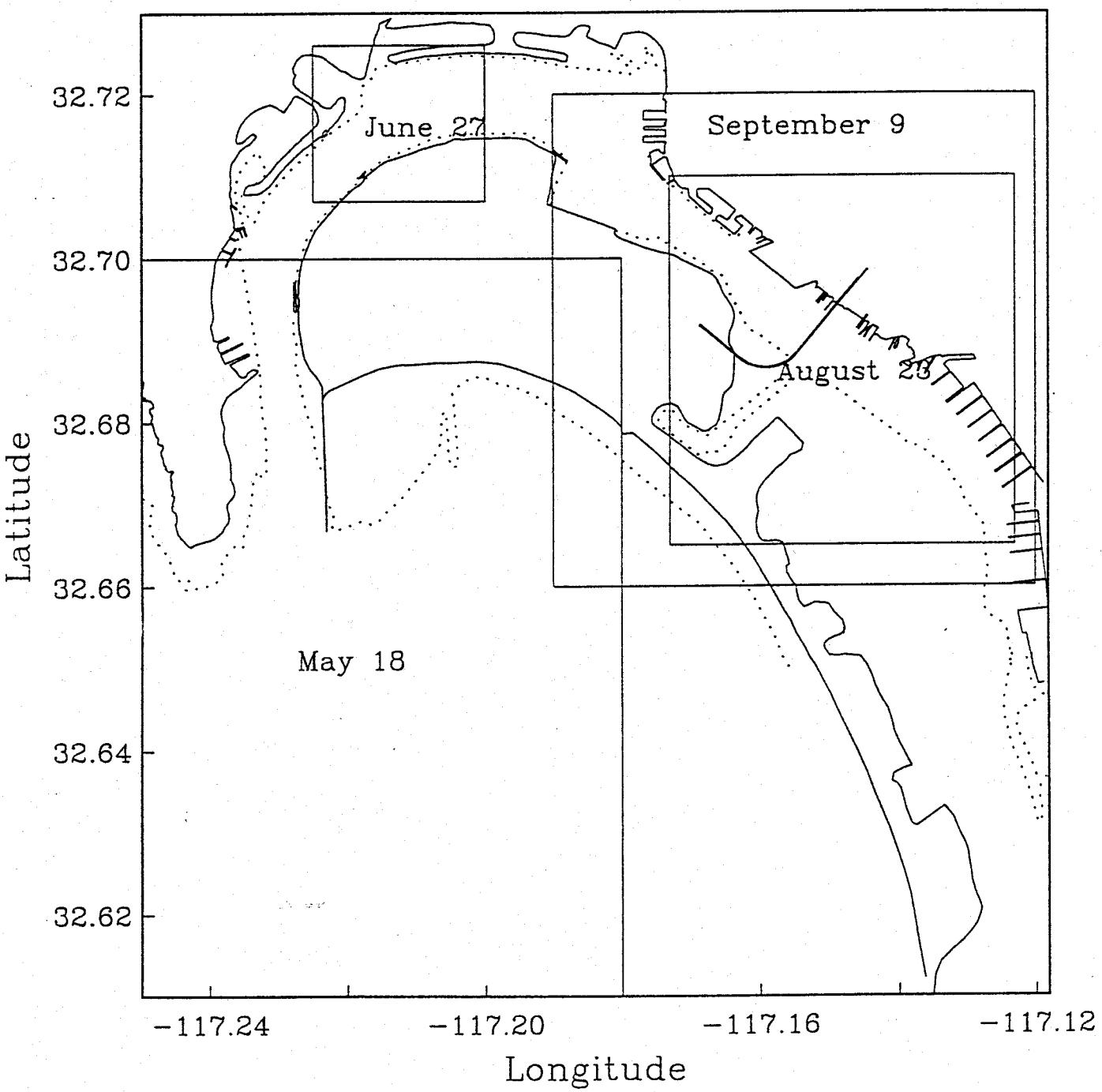

Figure 1. Areas of San Diego Bay covered by study.

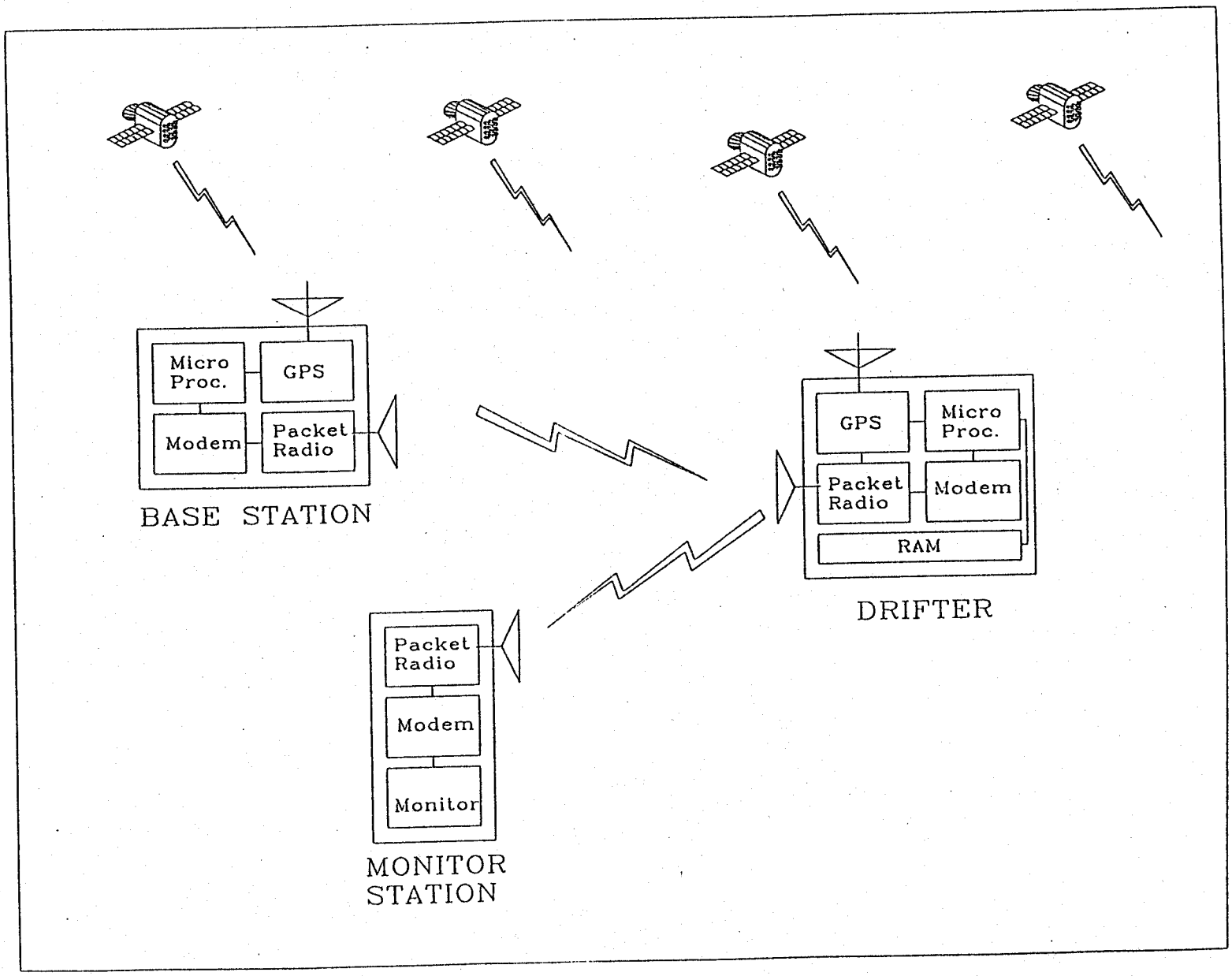

Figure 2. Cartoon of drifter system.

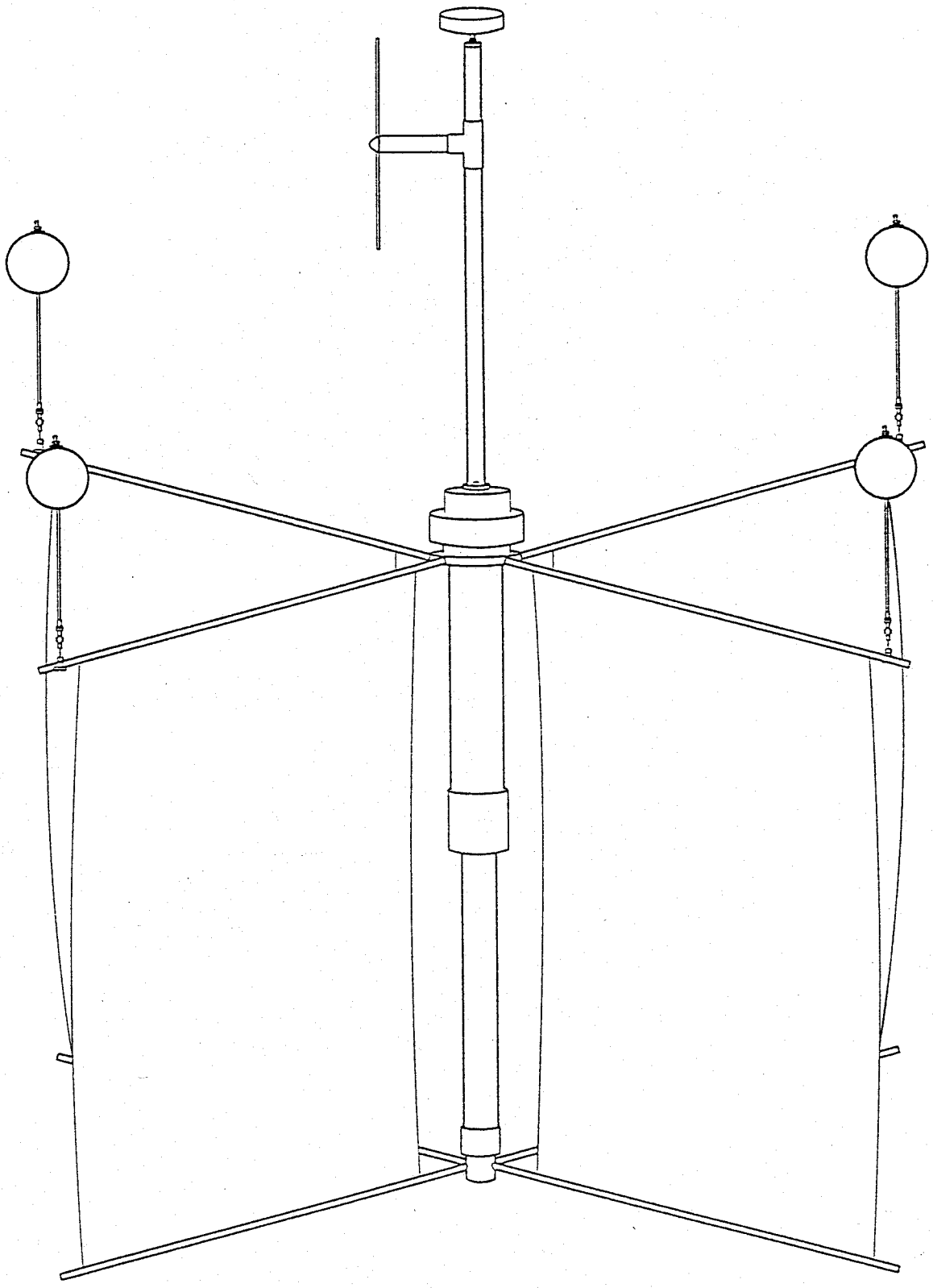

Figure 3. Drifter body, showing central PVC pressure case, coated cloth vanes, styrofoam floats, and antenna structure.

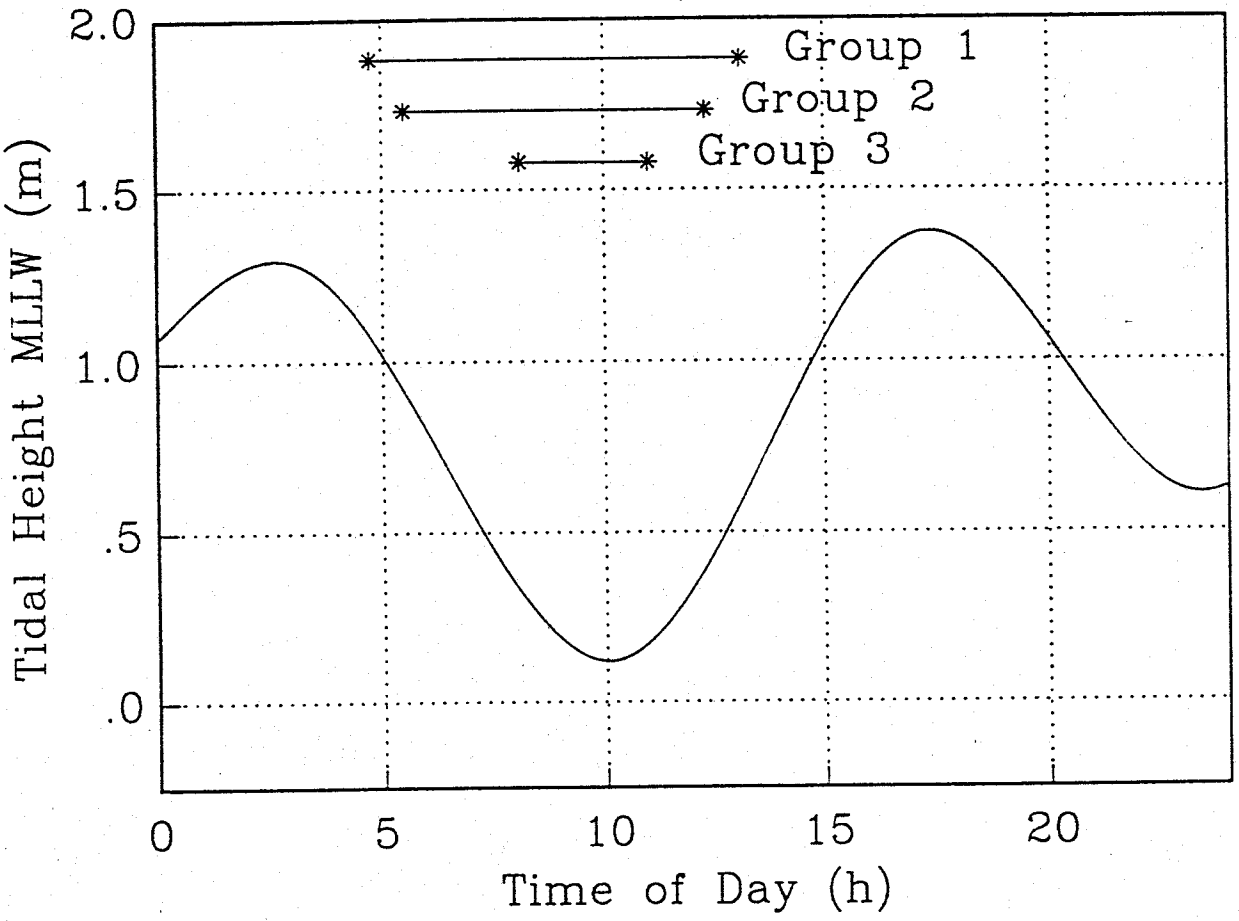

Figure 4. Tidal heights and deployment times for May 18, 1994.

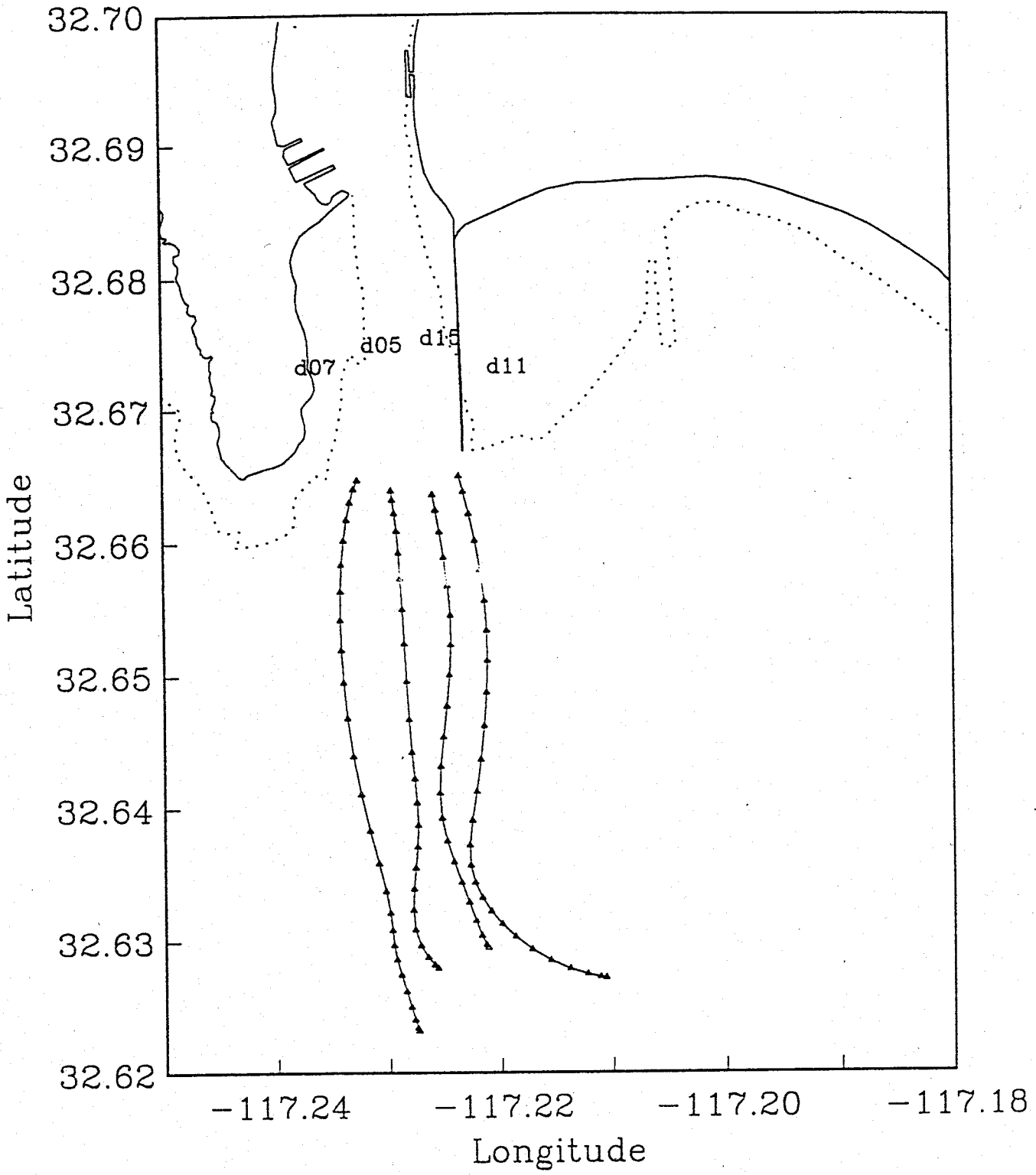

Figure 5. Group 1 drifter tracks for May 18, 1994. Note convergence of drifters near Latitude 32.64 degrees.

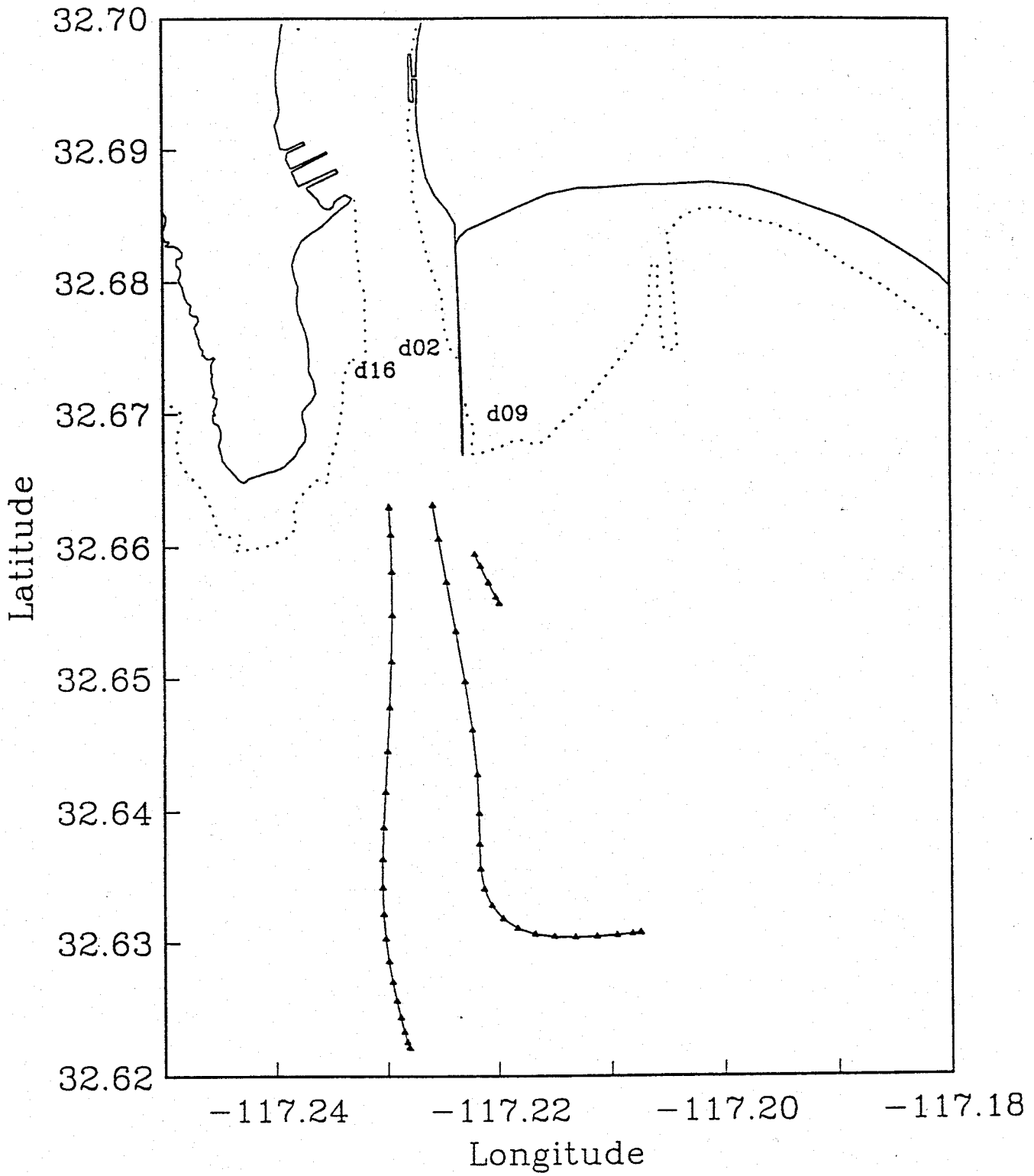

Figure 6. Group 2 drifter tracks for May 18, 1994.

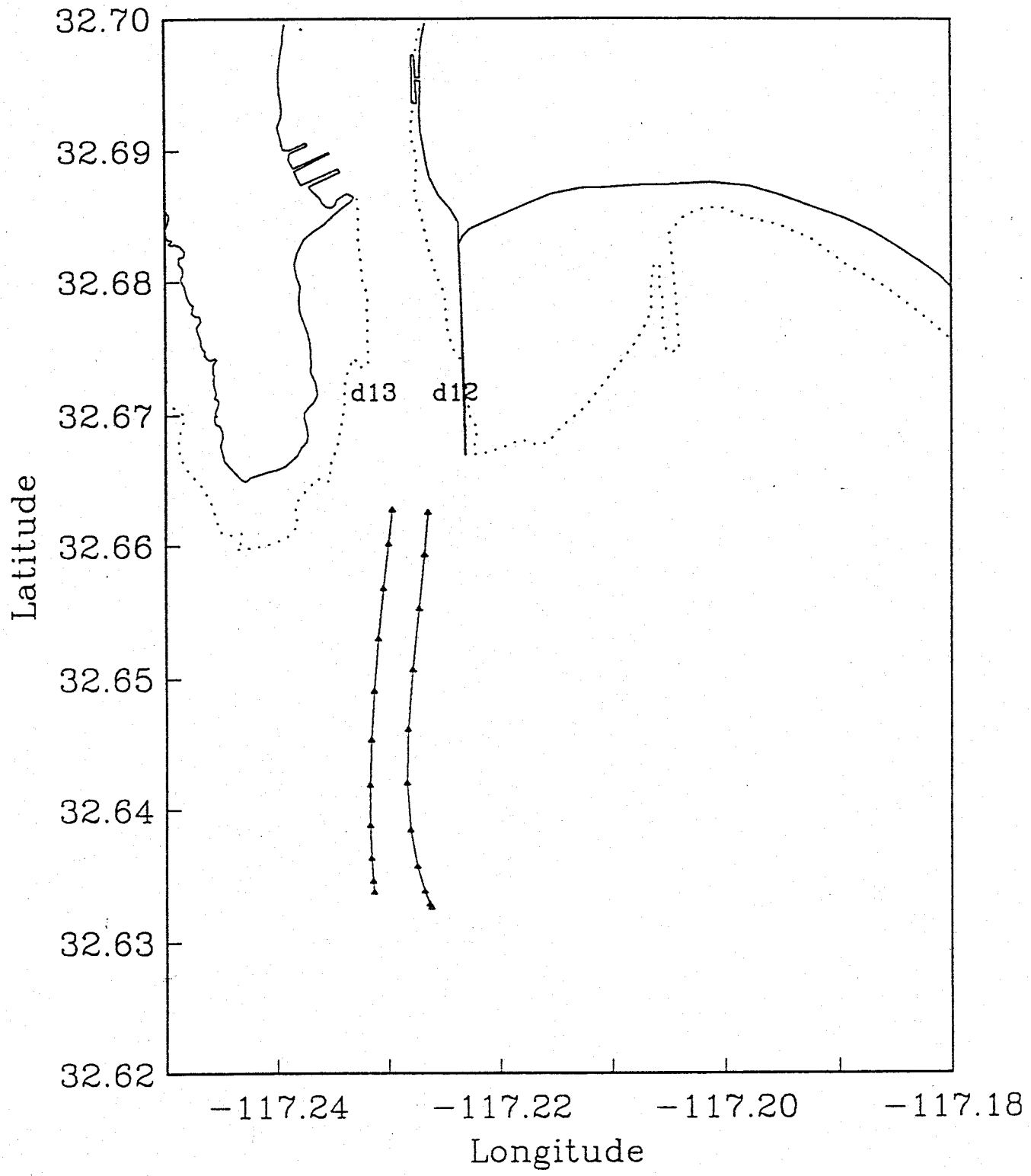

Figure 7. Group 3 drifter tracks for May 18, 1994.

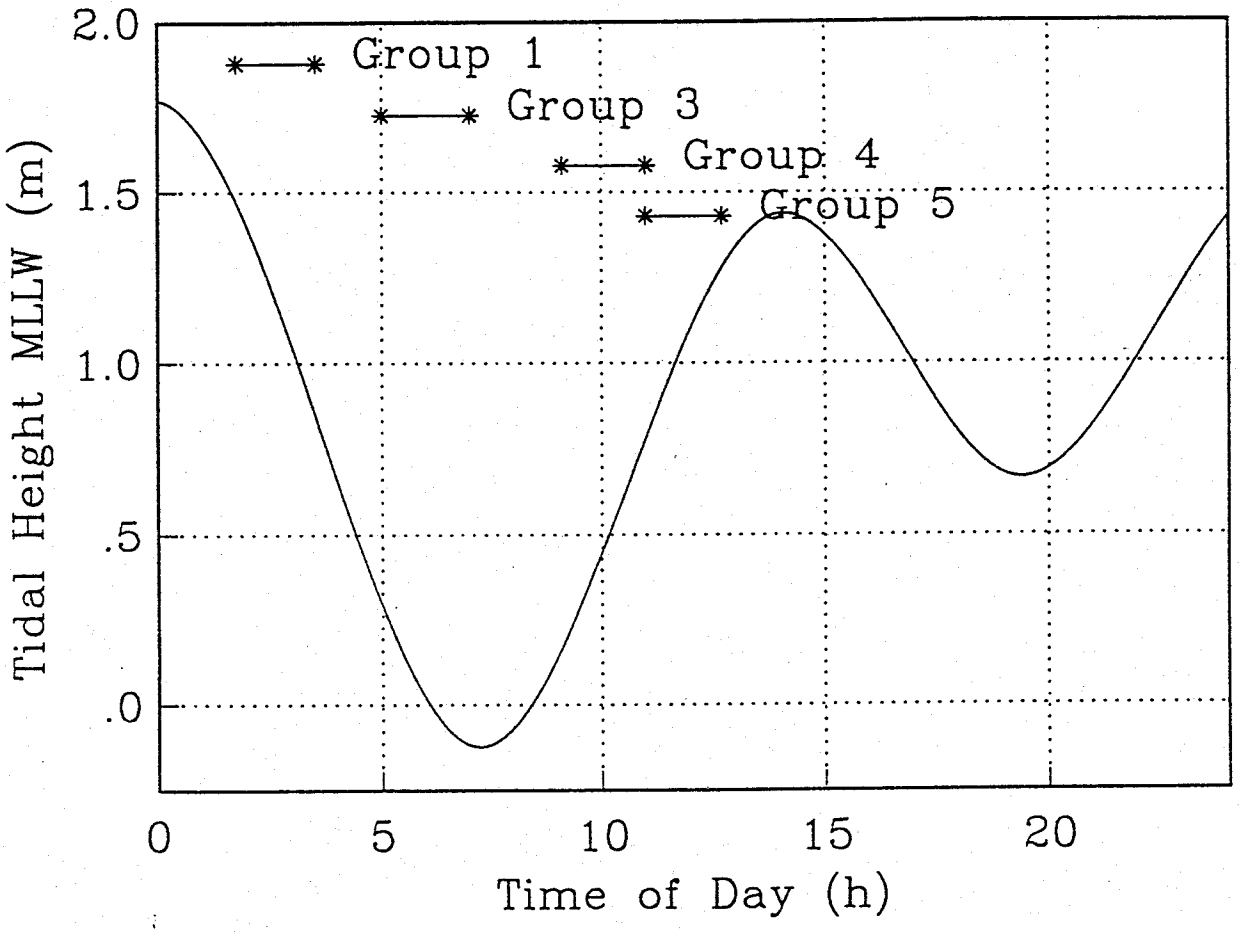

Figure 8. Tidal heights and deployment times for June 27, 1994.

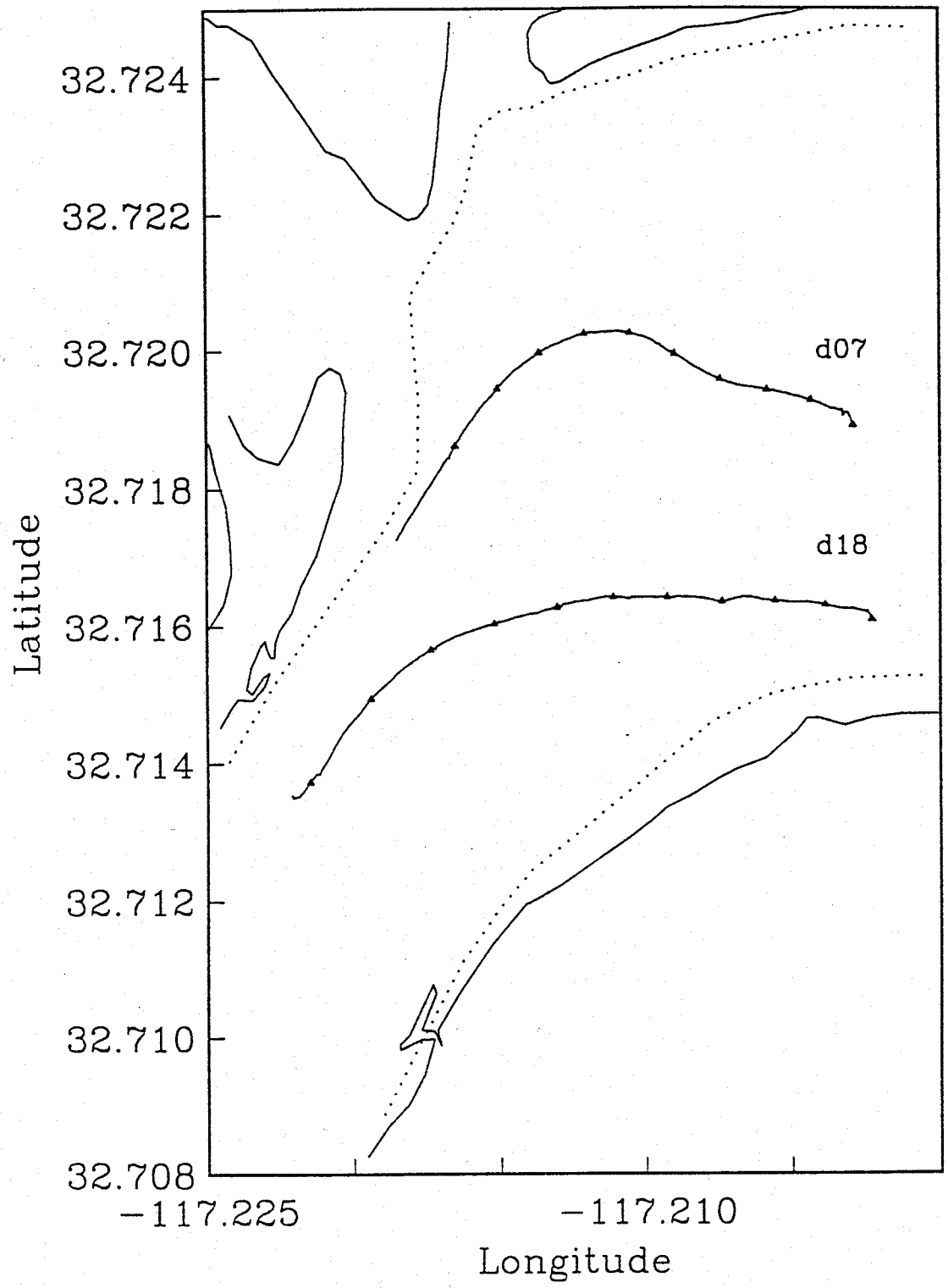

Figure 9. Group 1 drifter tracks for June 27, 1994.

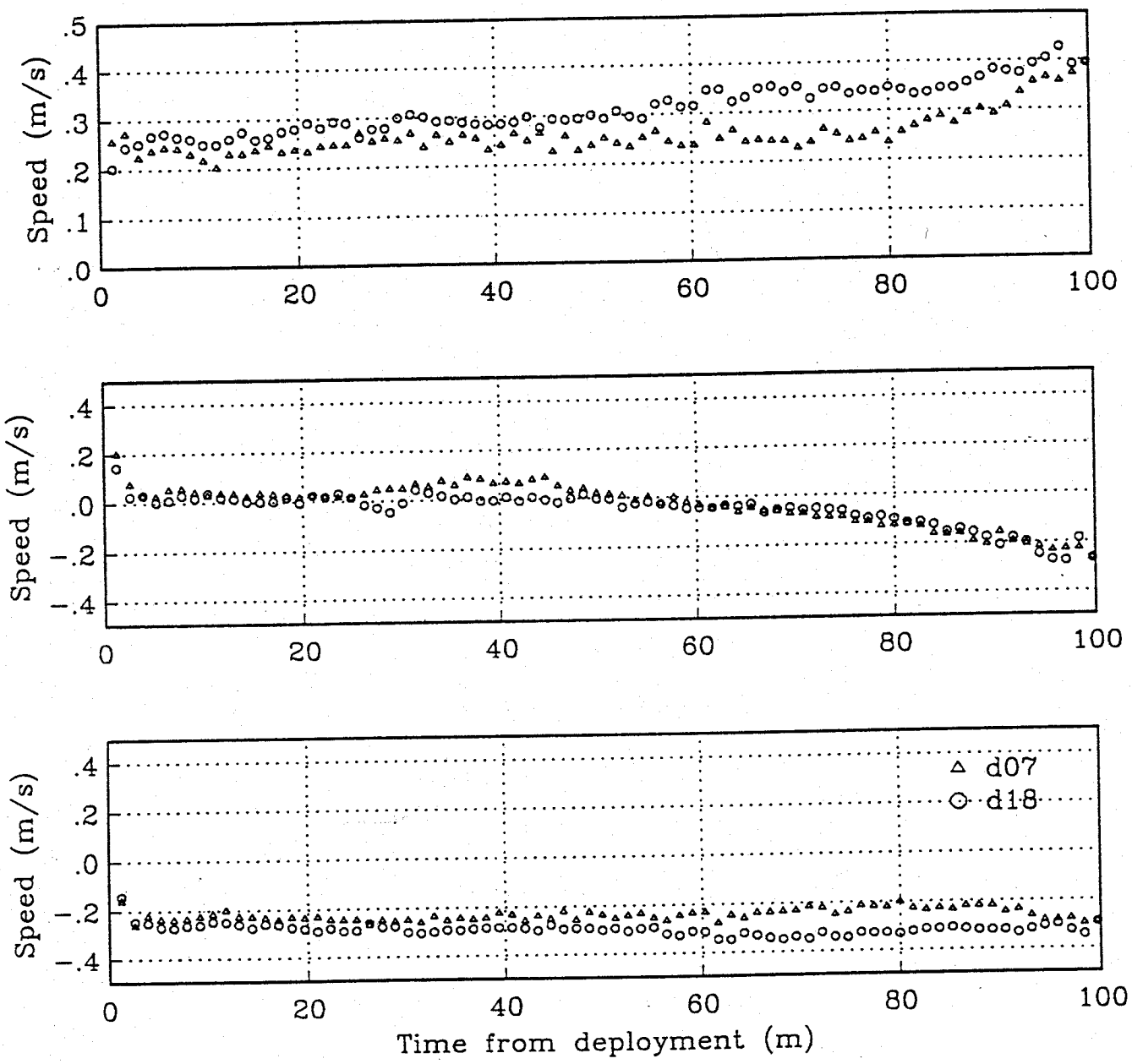

Figure 10. Group 1 drifter velocity components, June 27, 1994.
From top, total speed, north-south component, east-west component.

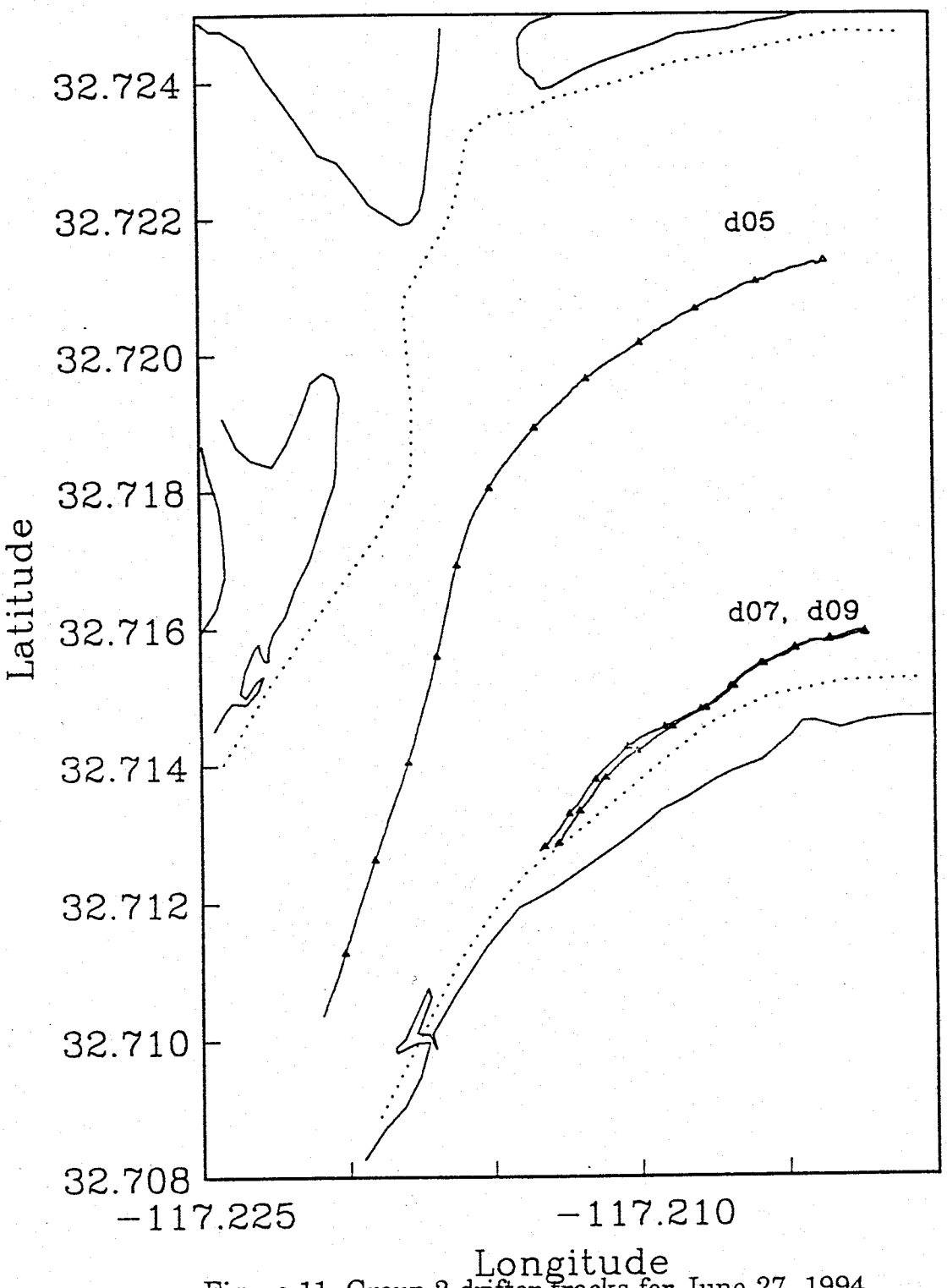

Figure 11. Group 2 drifter tracks for June 27, 1994.

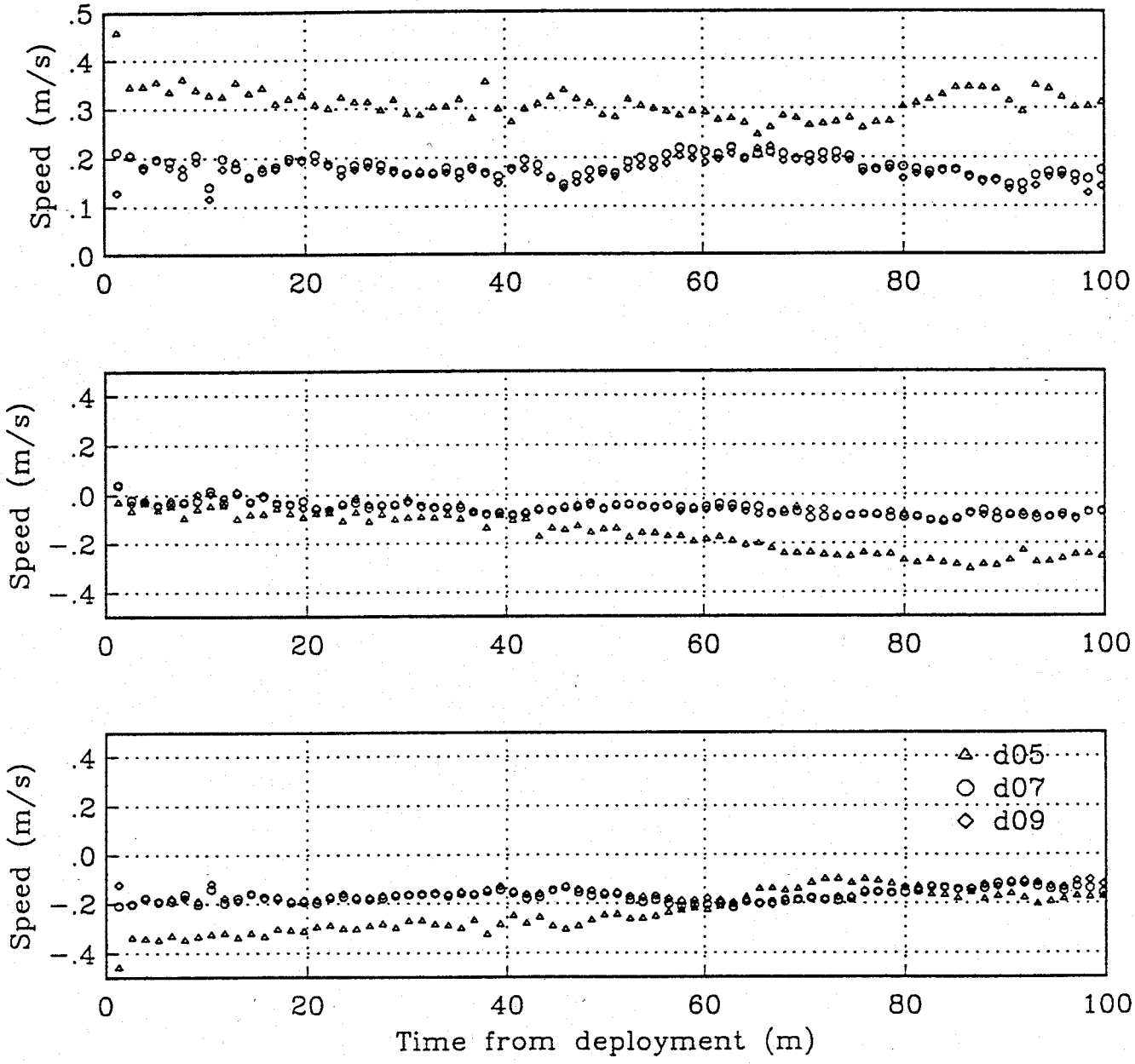

Figure 12. Group 2 drifter velocity components, June 27, 1994.
From top, total speed, north-south component, east-west component.

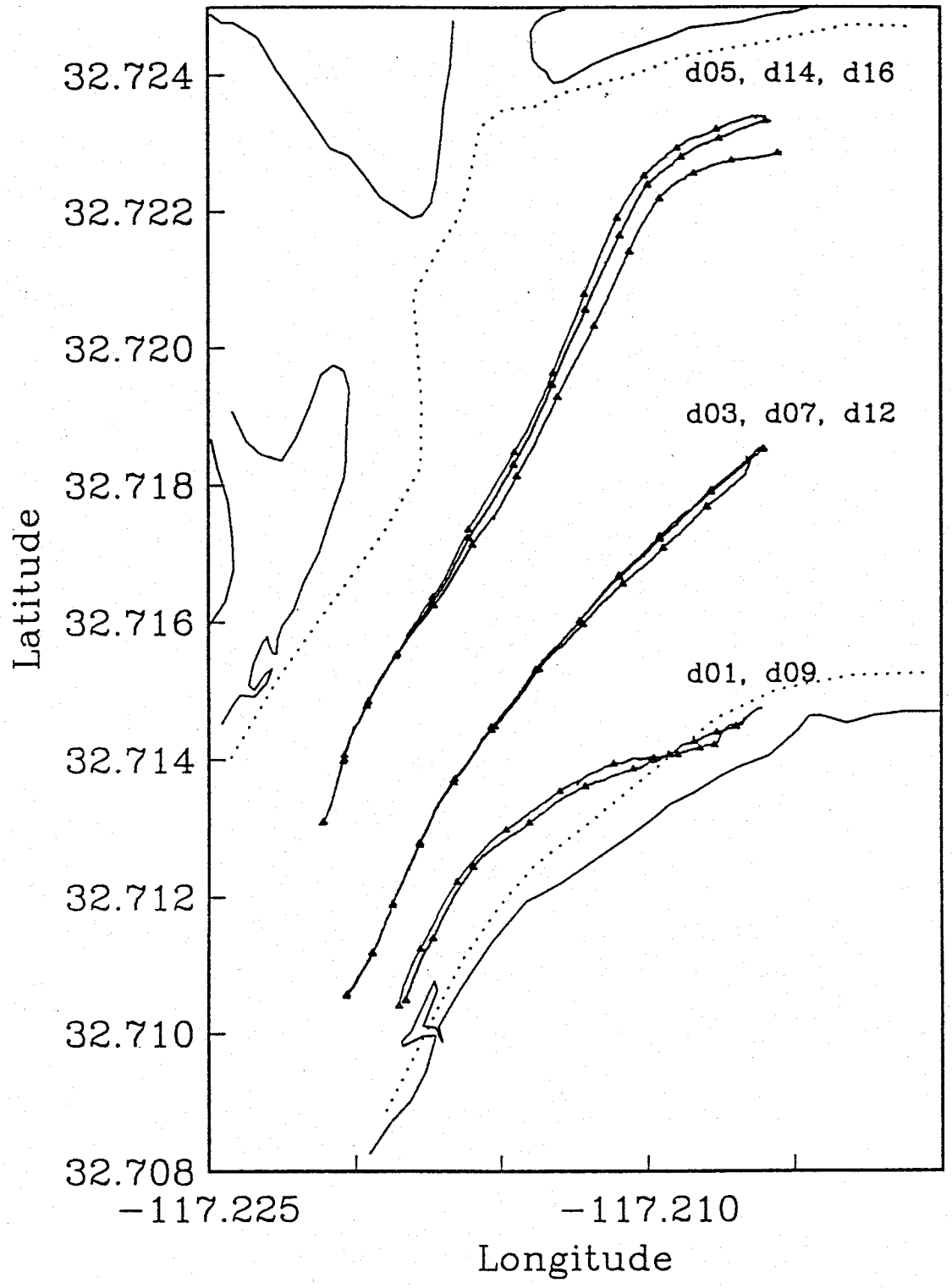

Figure 13. Group 3 drifter tracks for June 27, 1994.

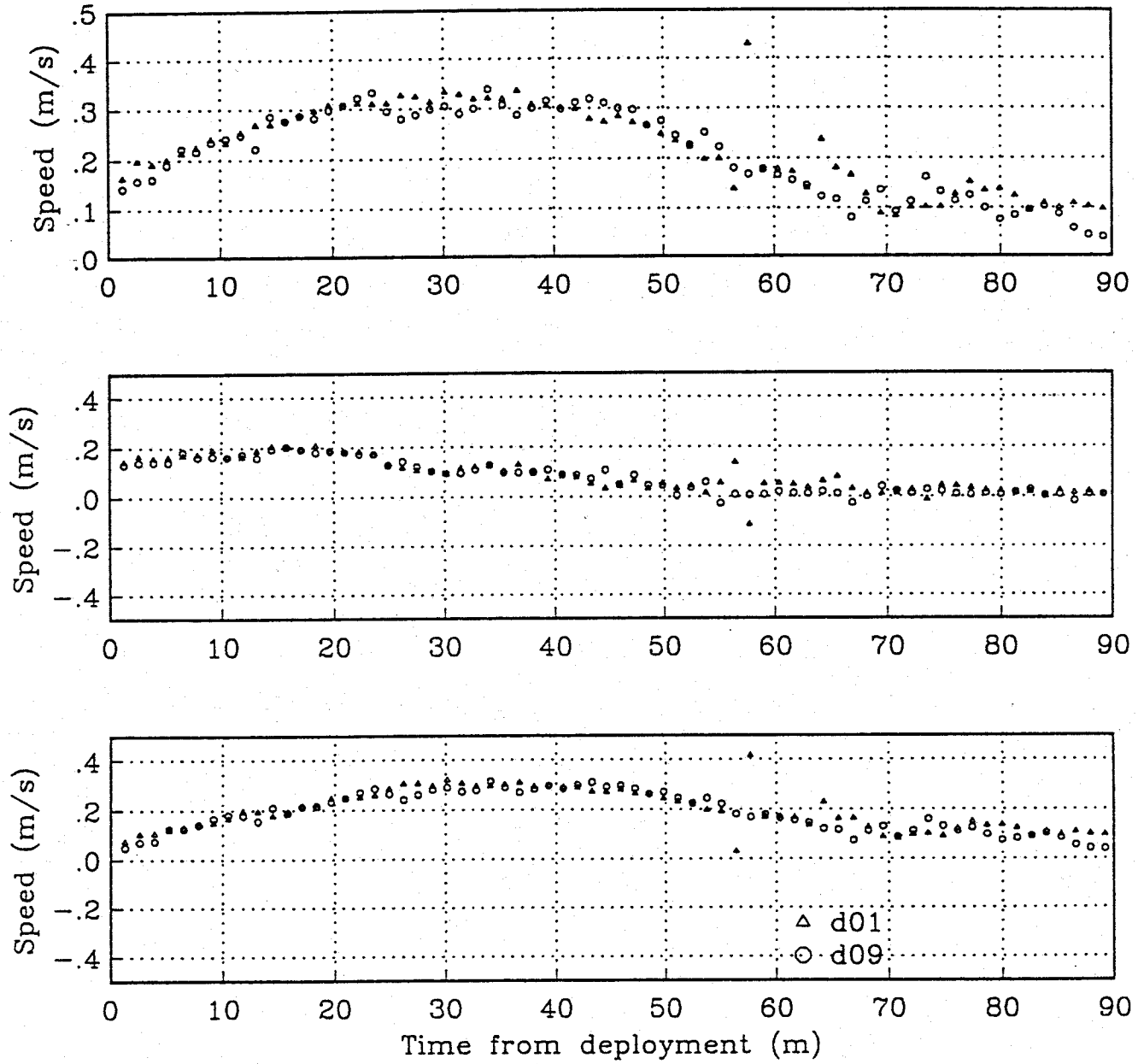

Figure 14. Group 3, southern cluster velocity components, June 27, 1994. From top, total speed, north-south component, east-west component.

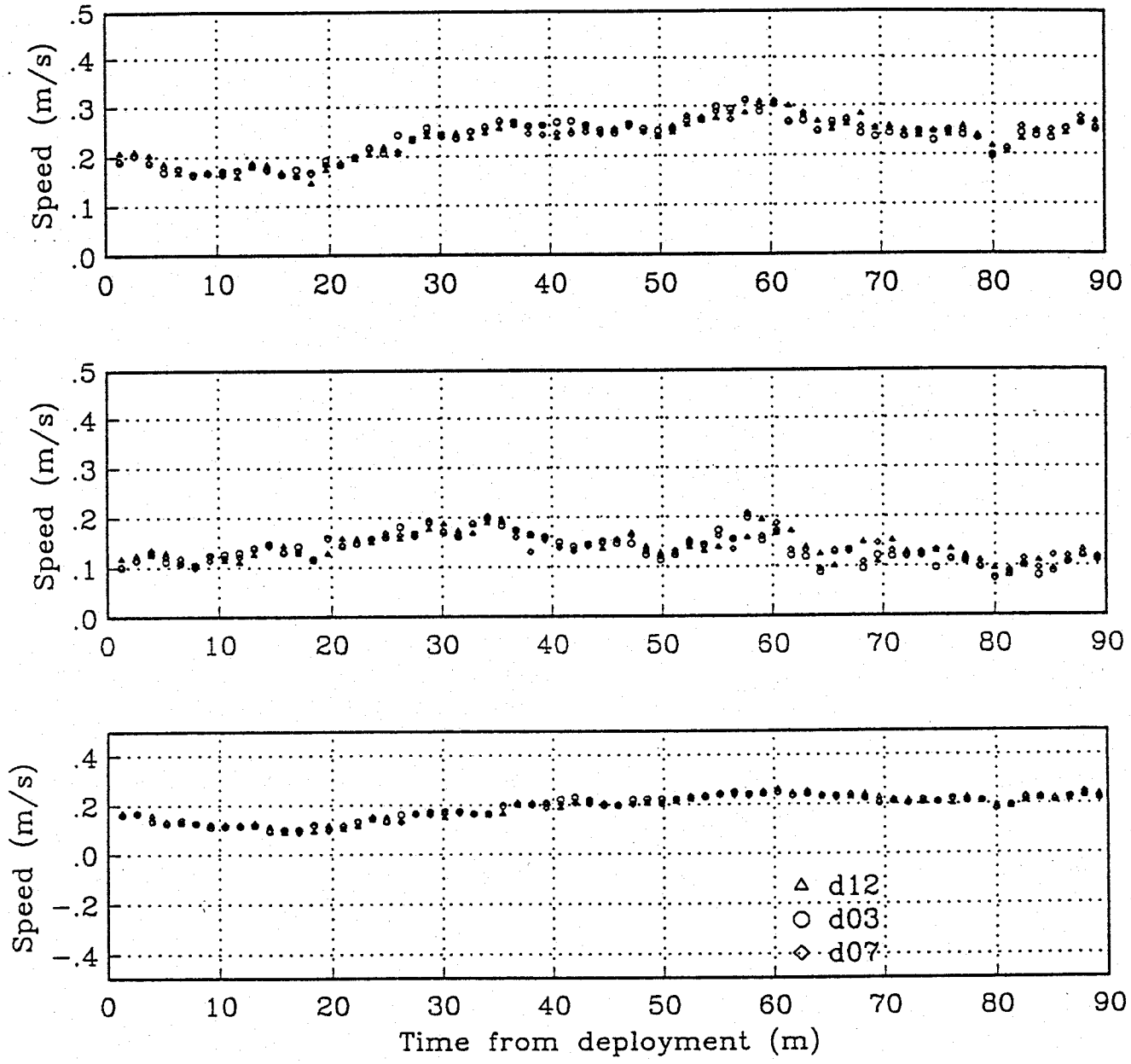

Figure 15. Group 3, middle cluster velocity components, June 27, 1994. From top, total speed, north-south component, east-west component.

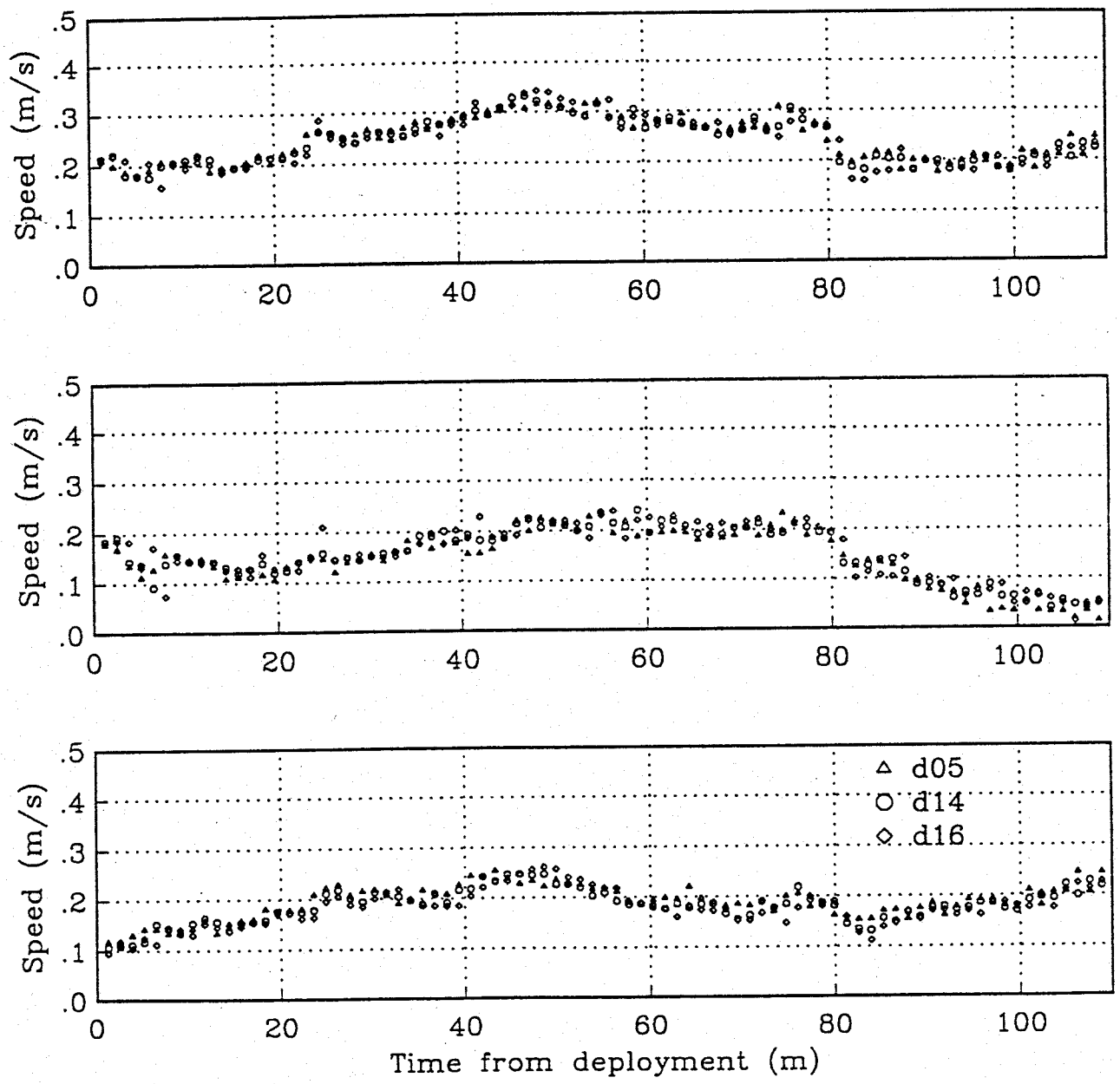

Figure 16. Group 3, northern cluster velocity components, June 27, 1994. From top, total speed, north-south component, east-west component.

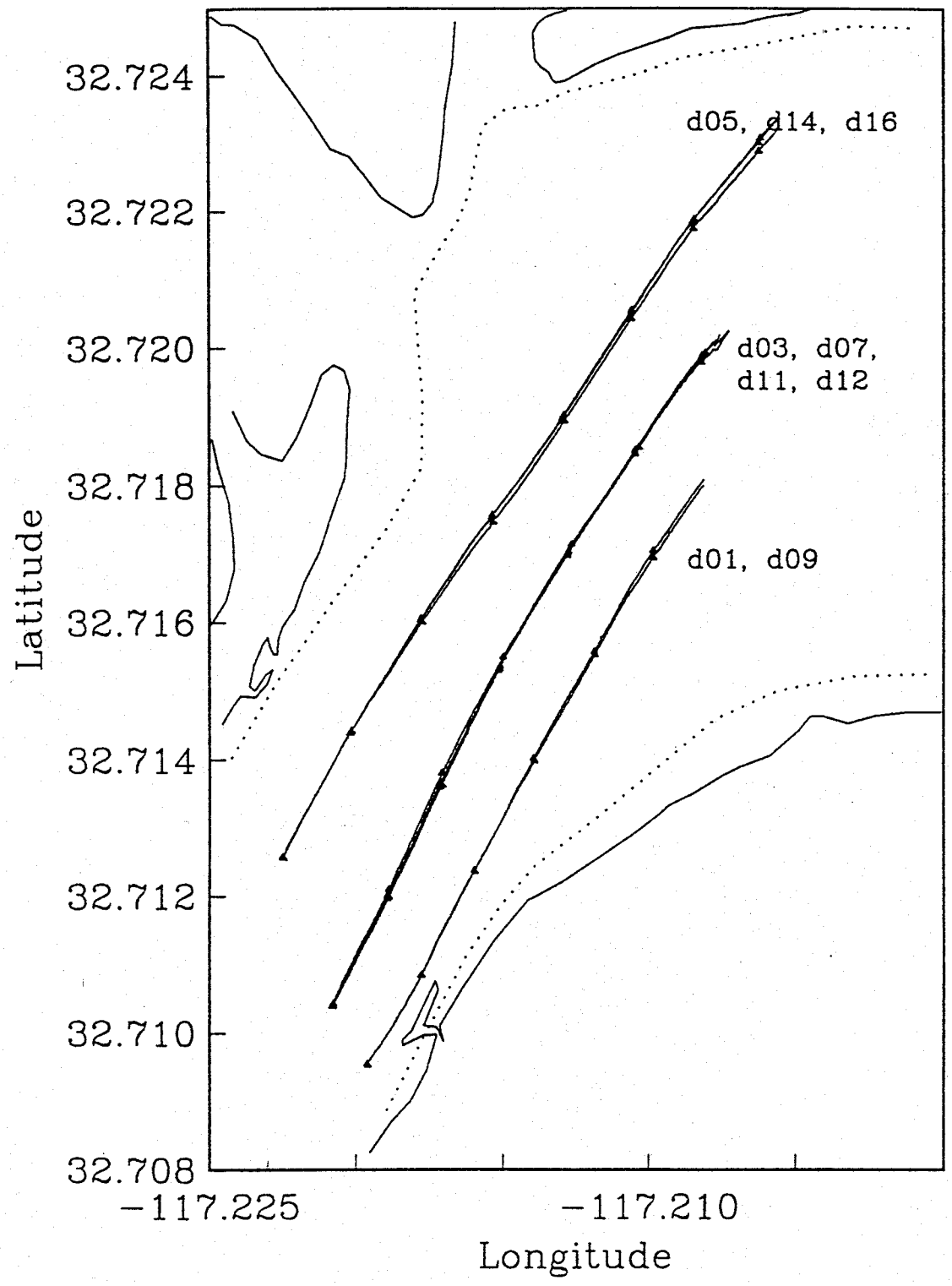

Figure 17. Group 4 drifter tracks for June 27, 1994.

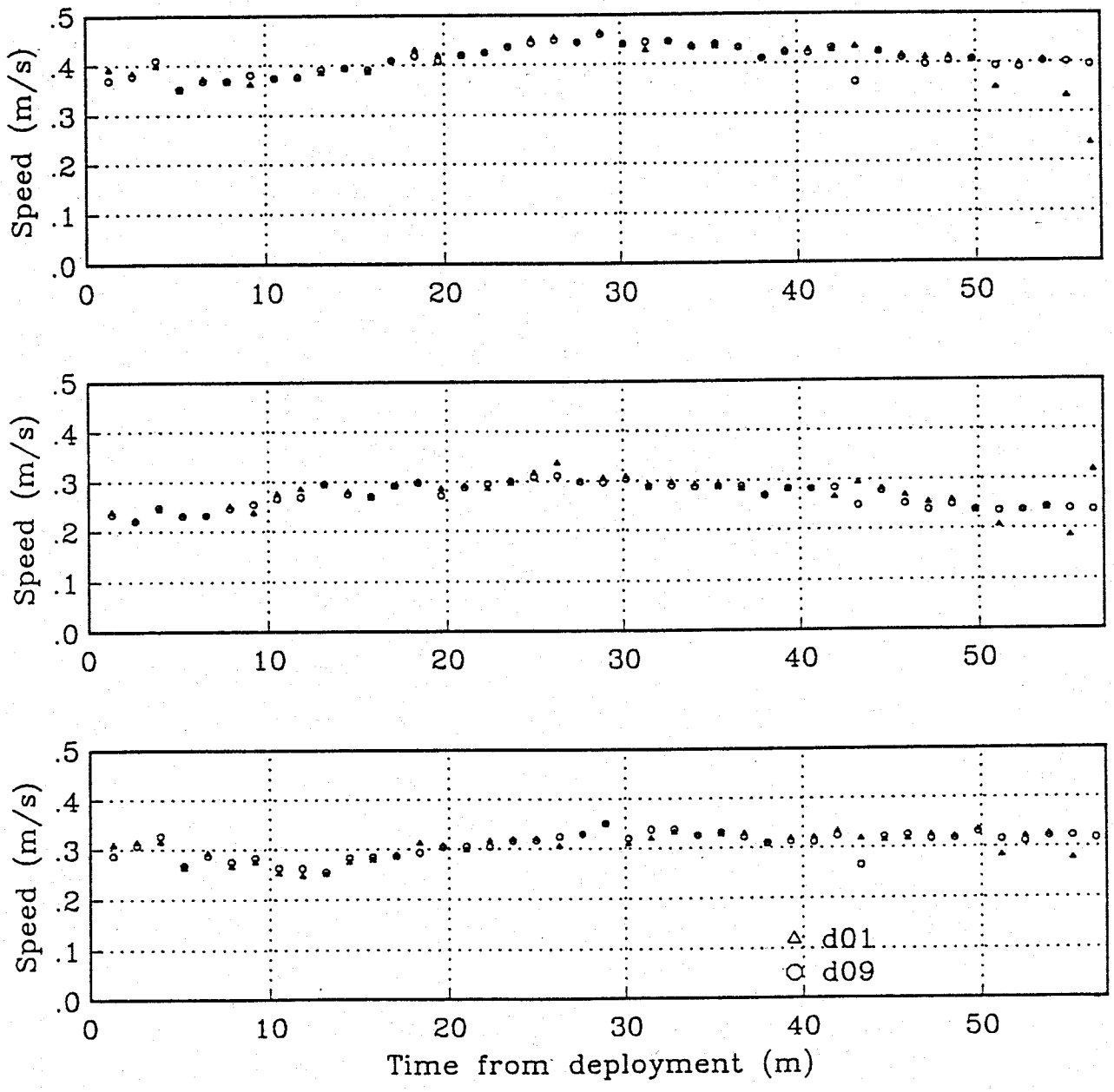

Figure 18. Group 4, southern cluster velocity components, June 27, 1994. From top, total speed, north-south component, east-west component.

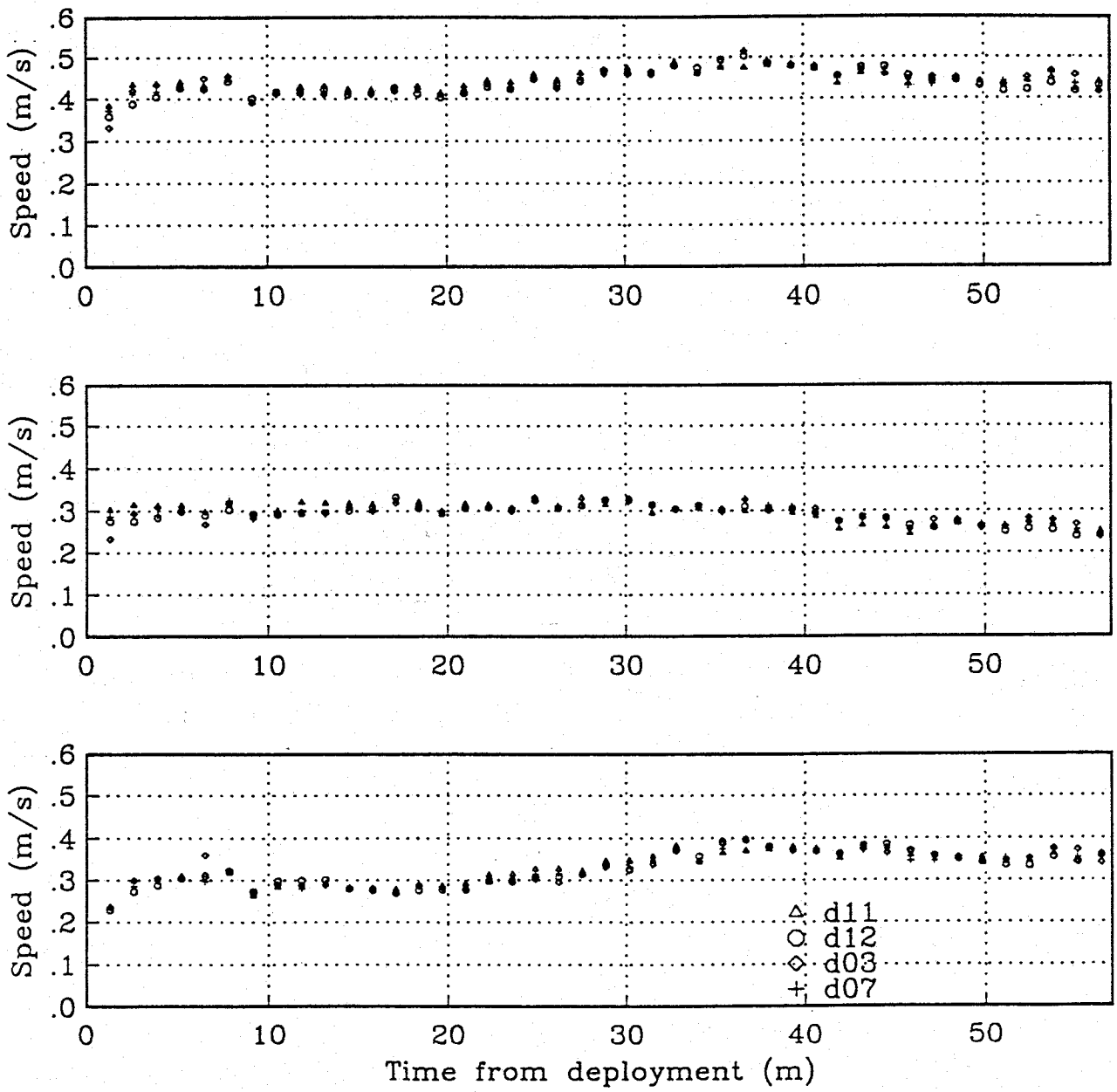

Figure 19. Group 4, middle cluster velocity components, June 27, 1994. From top, total speed, north-south component, east-west component.

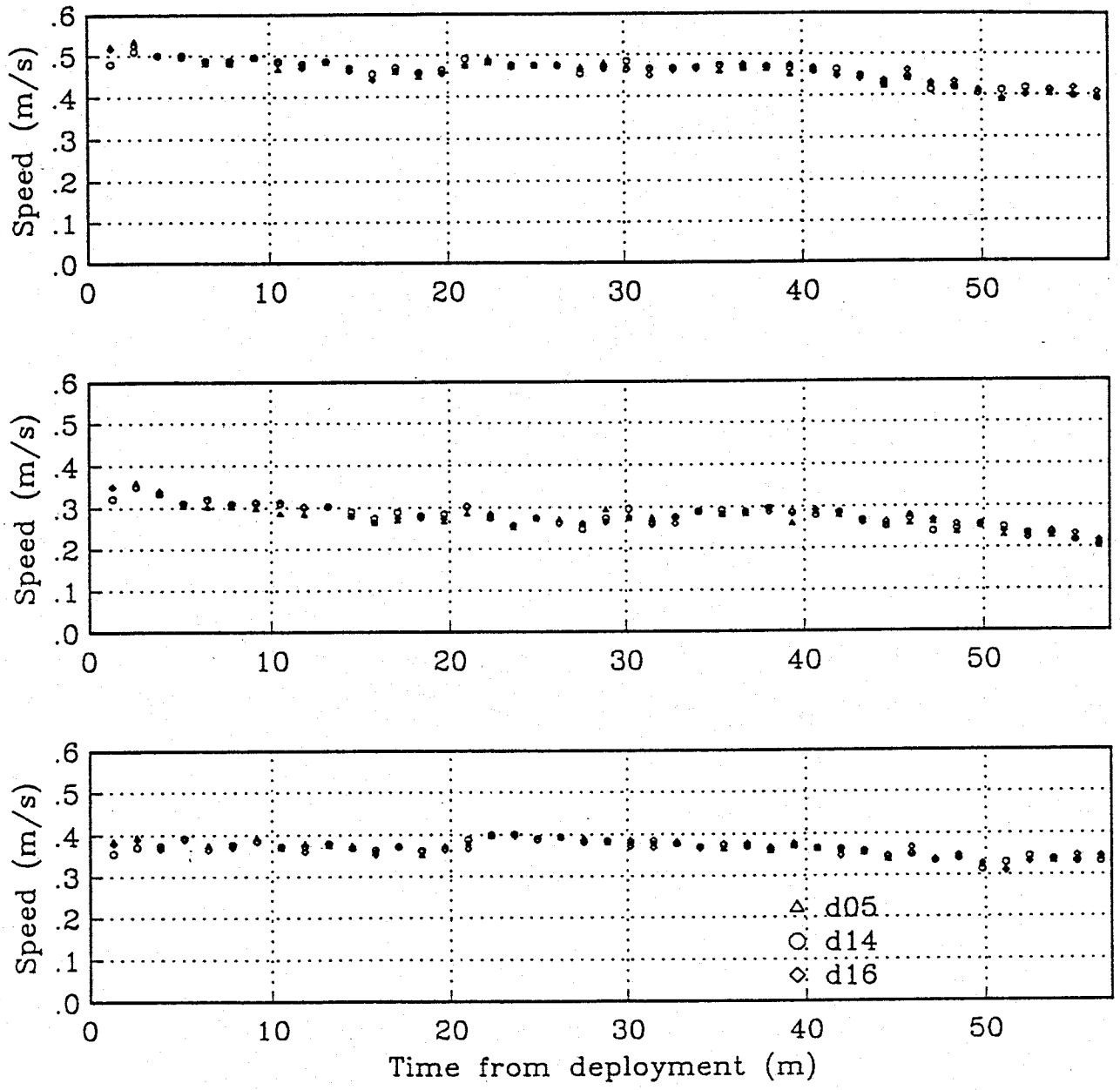

Figure 20. Group 4, northern cluster velocity components, June 27, 1994. From top, total speed, north-south component, east-west component.

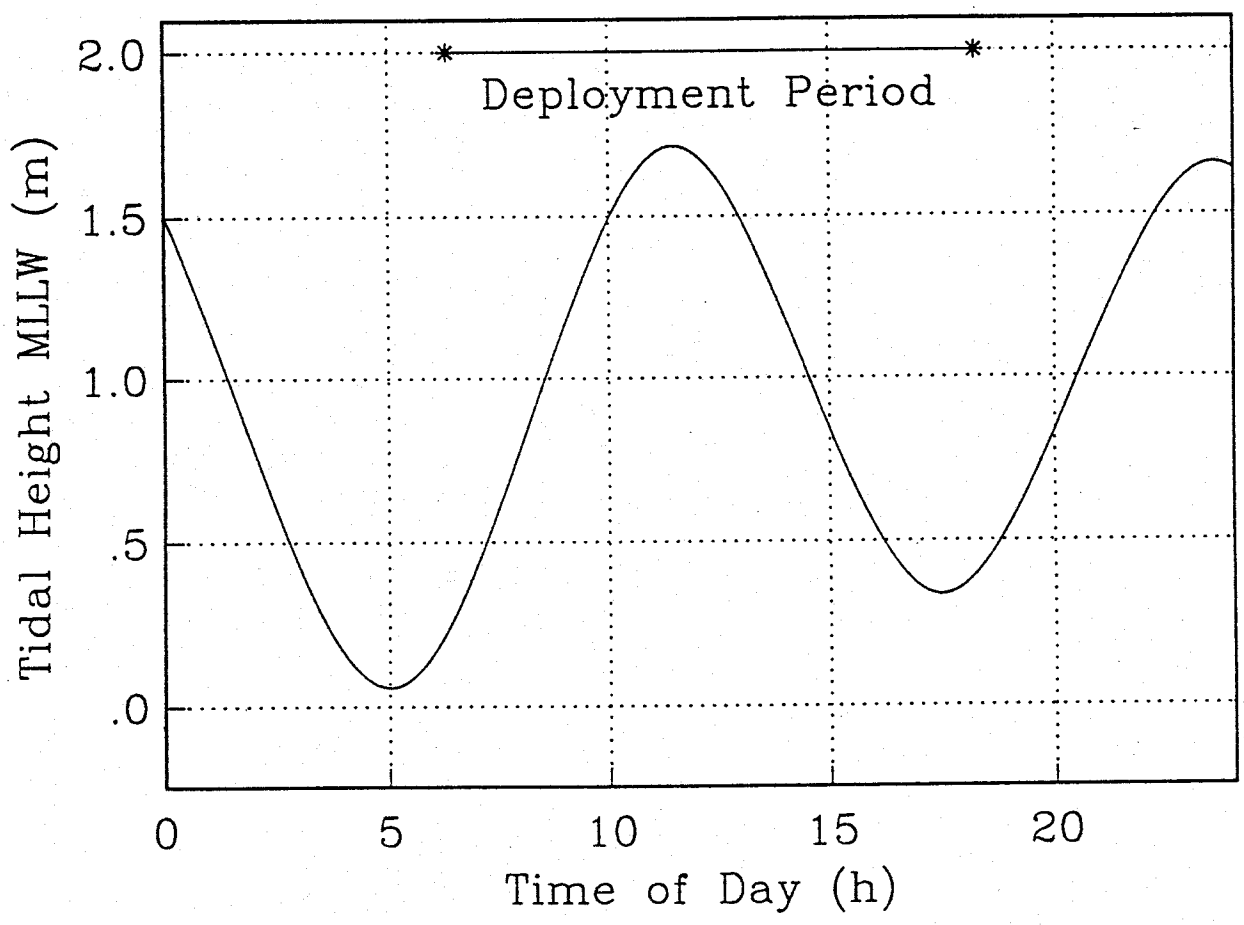

Figure 21. Tidal heights and deployment period for August 23, 1994.

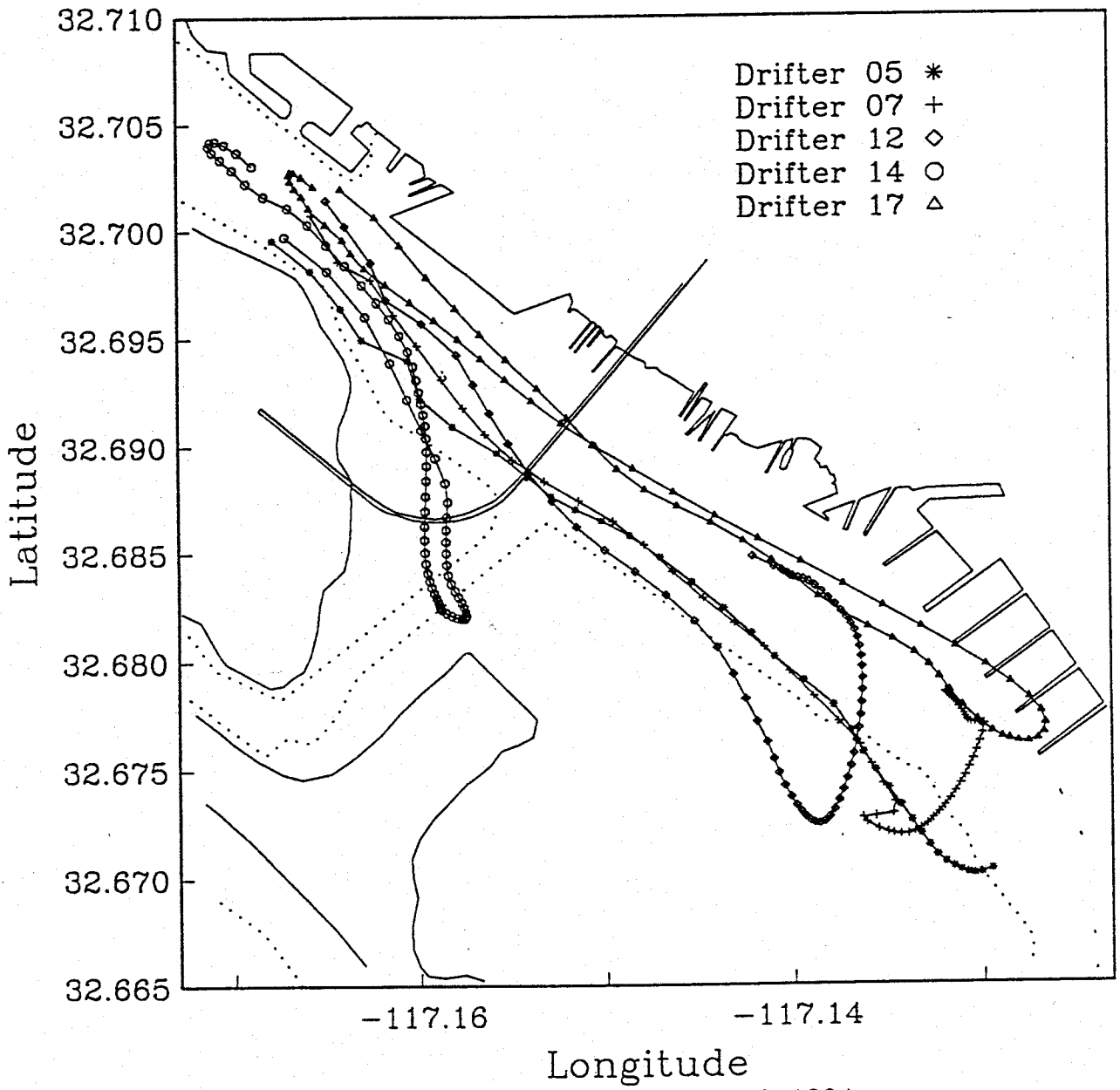

Figure 22. All drifter tracks for August 23, 1994.

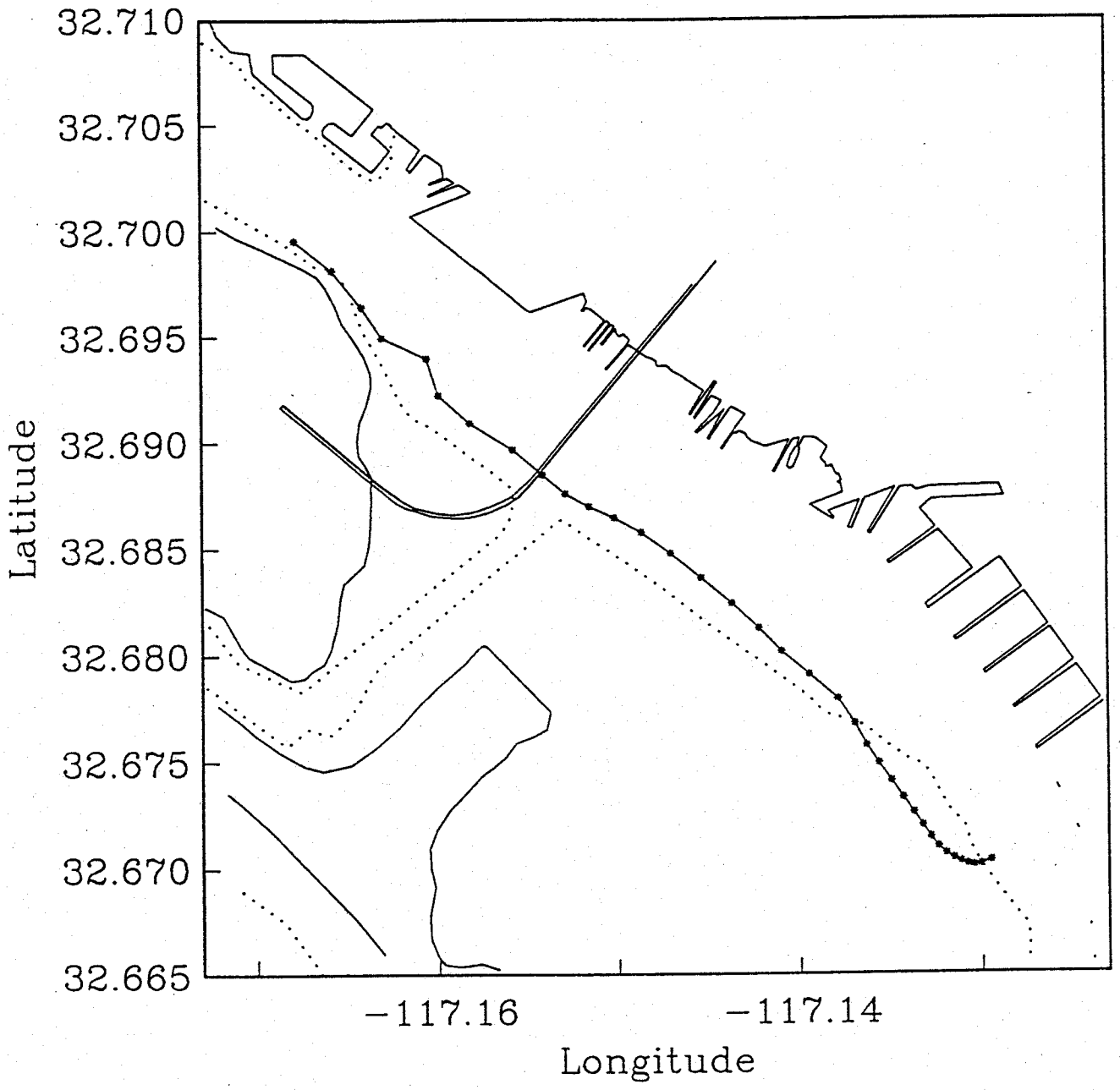

Figure 23. Drifter 5 track, August 23, 1994.

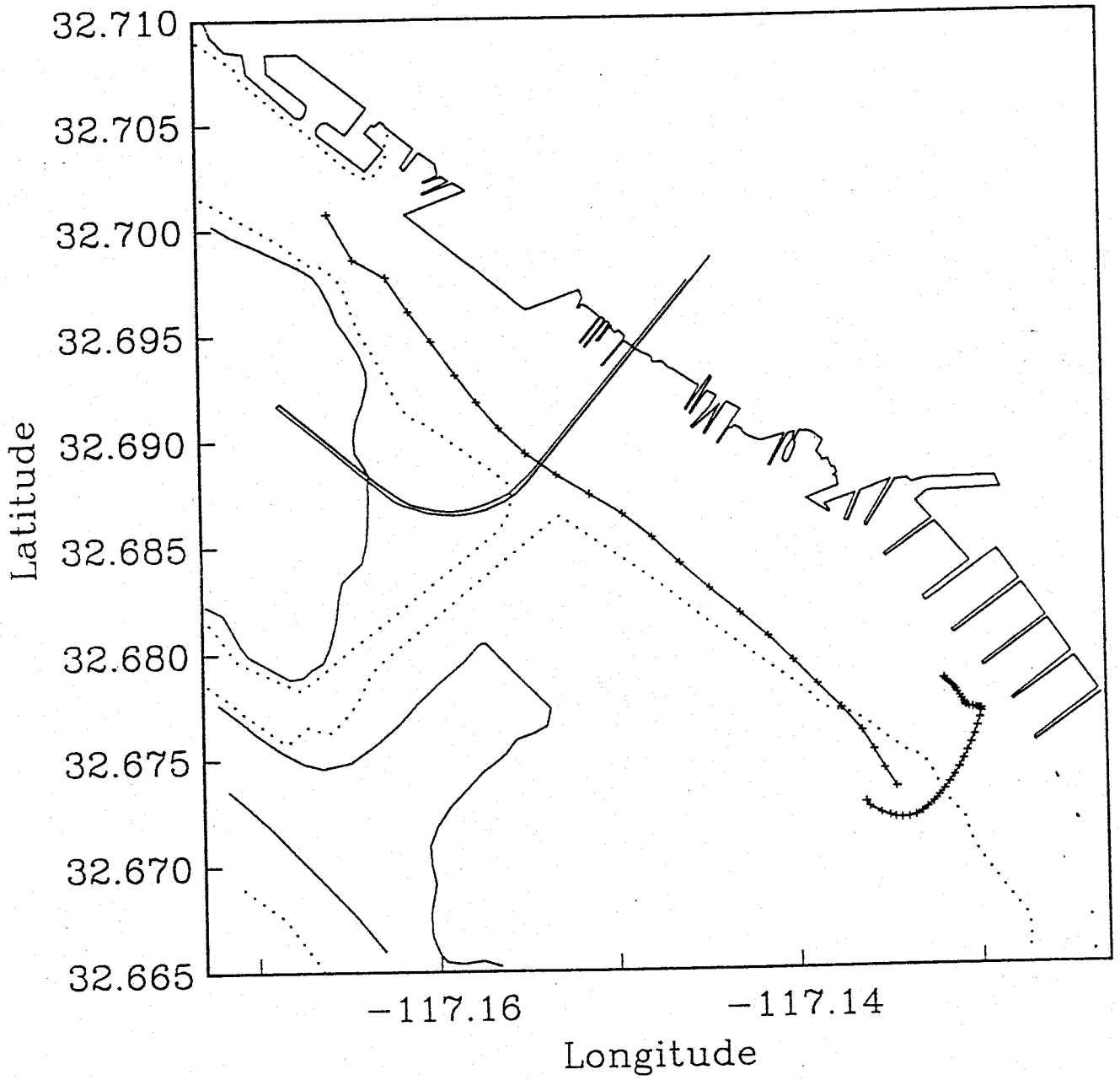

Figure 24. Drifter 7 track, August 23, 1994.

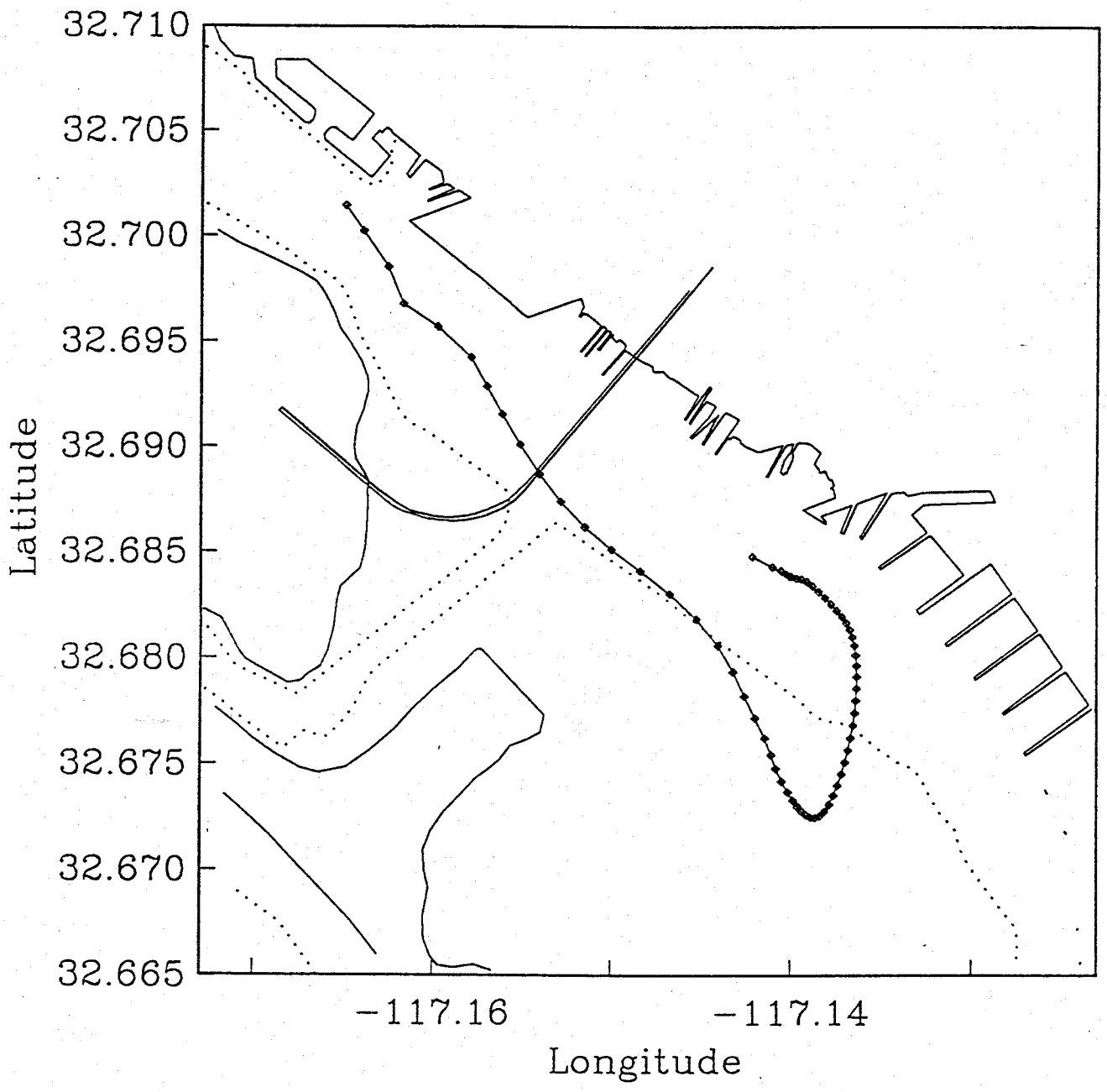

Figure 25. Drifter 12 track, August 23, 1994.

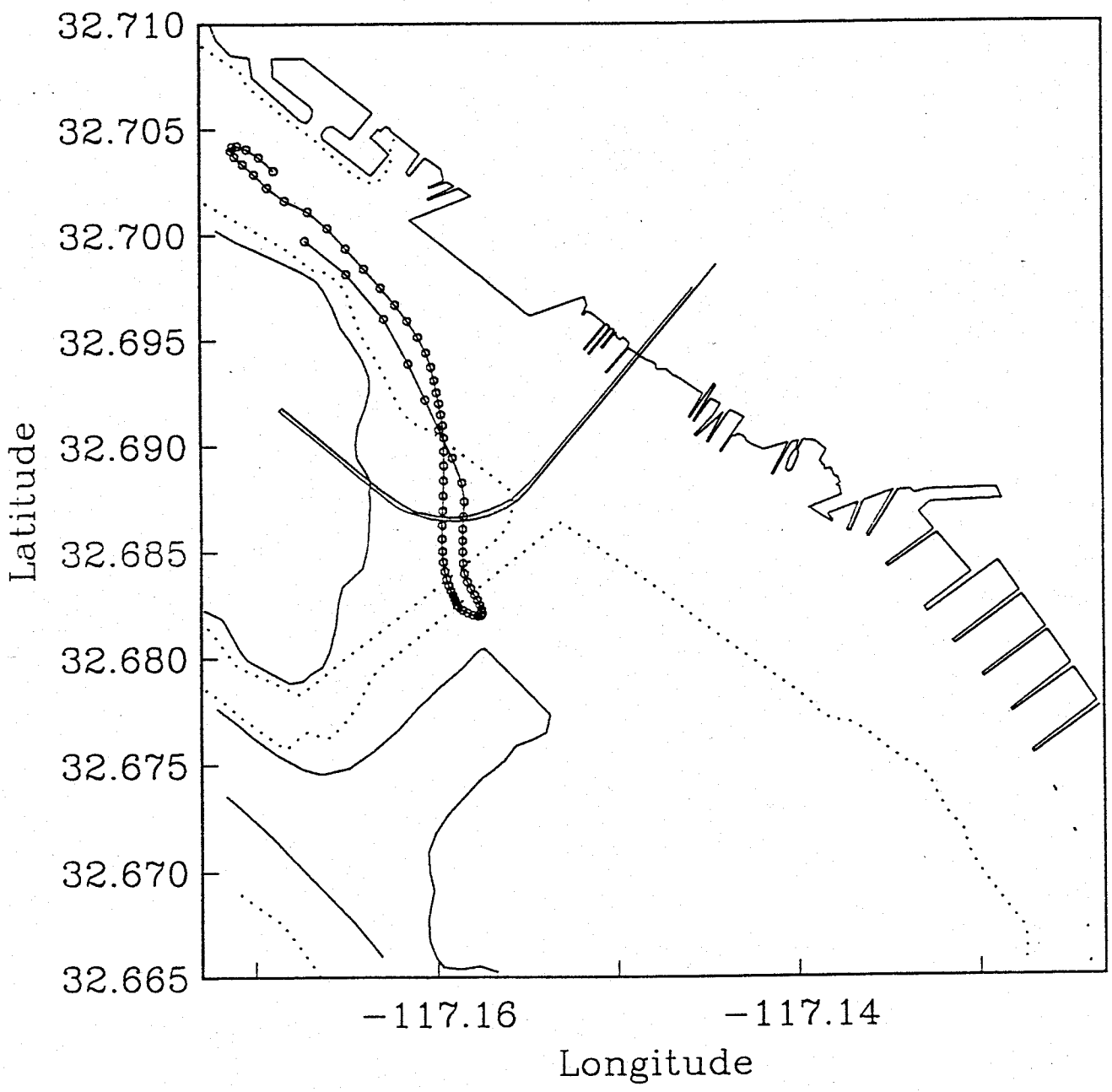

Figure 26. Drifter 14 track, August 23, 1994.

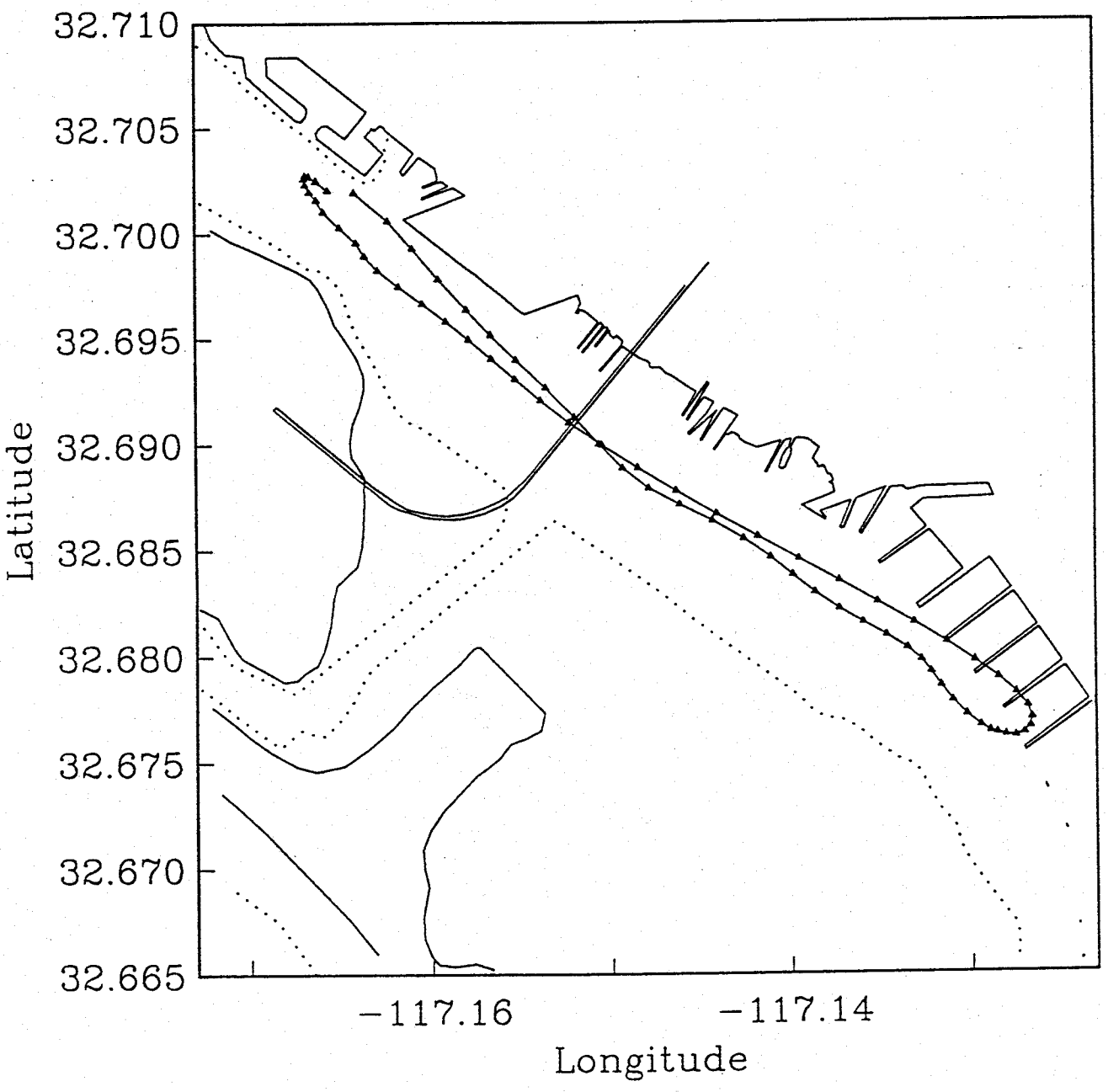

Figure 27. Drifter 17 track, August 23, 1994.

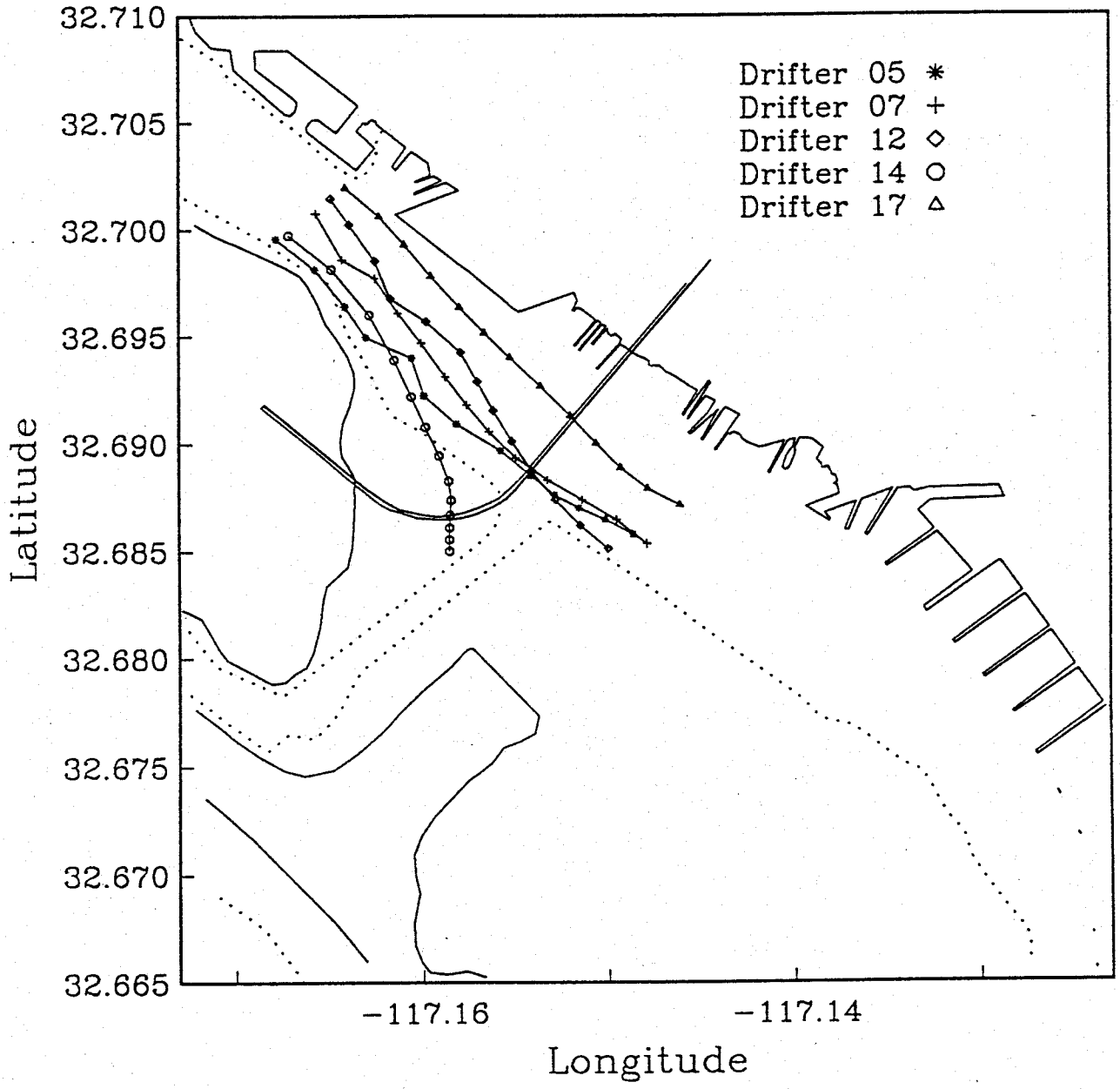

Figure 28. Drifter tracks, 6:20-8:20, August 23, 1994.

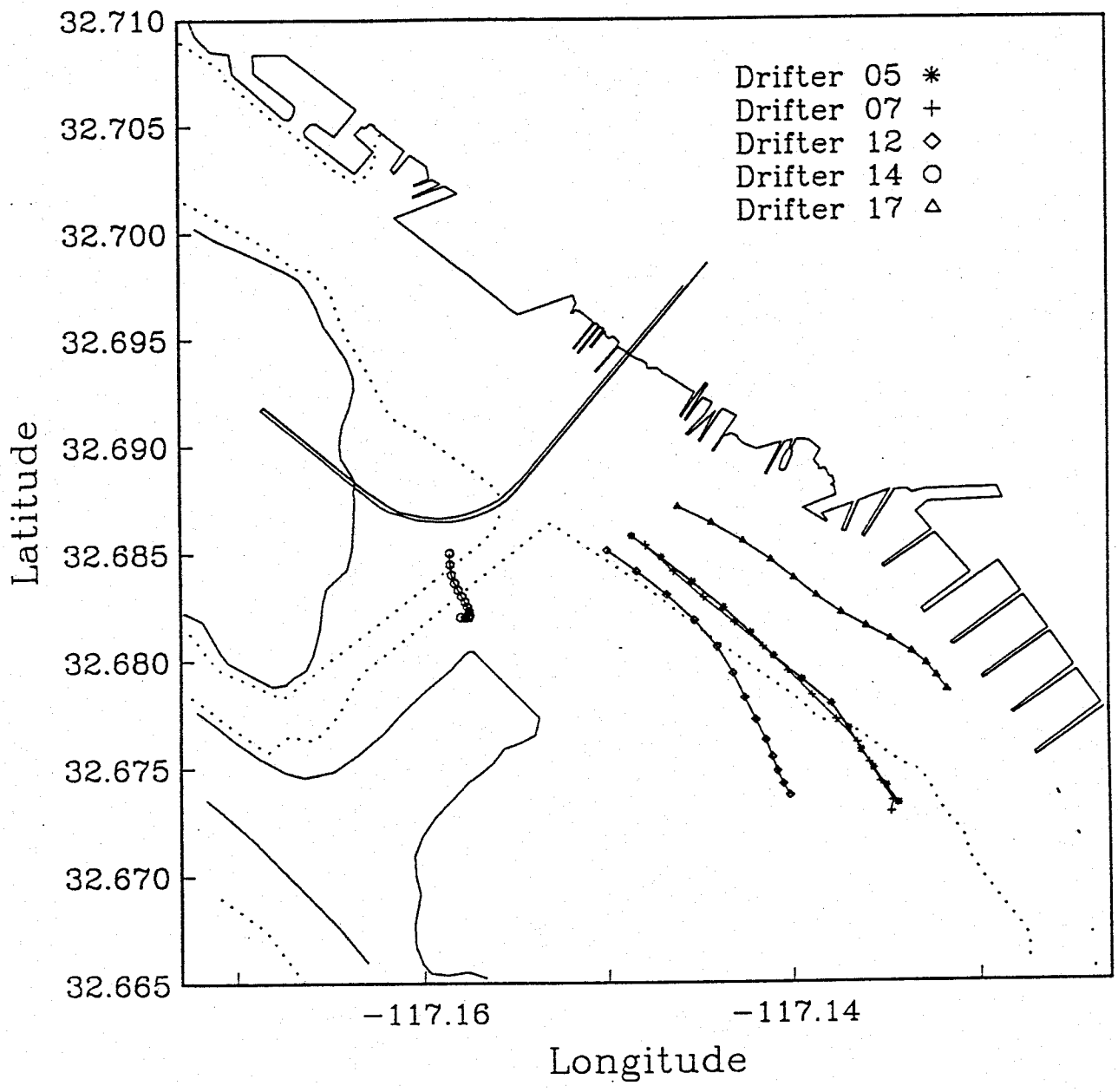

Figure 29. Drifter tracks, 8:20-10:20, August 23, 1994.

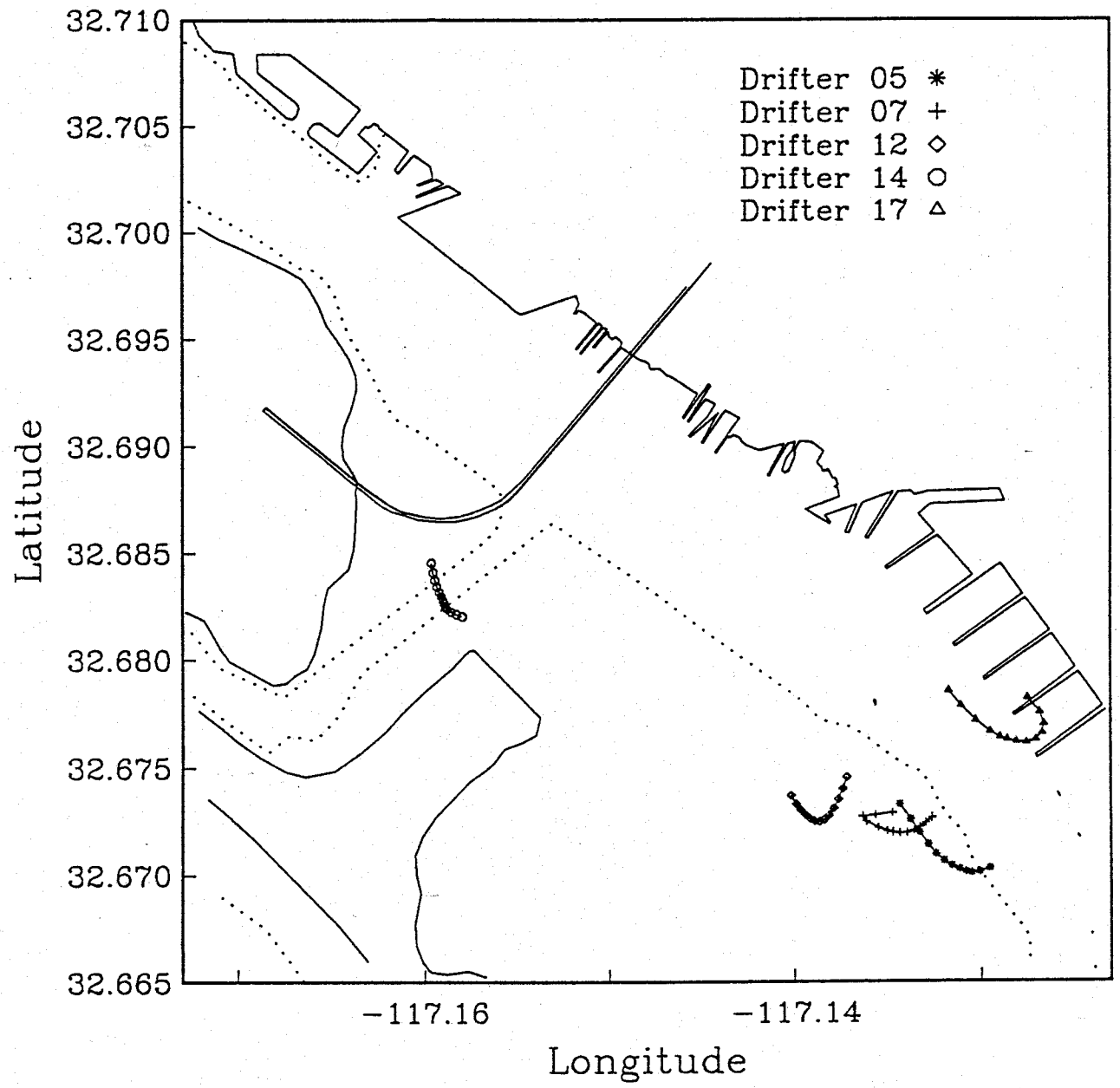

Figure 30. Drifter tracks, 10:20-12:20, August 23, 1994.

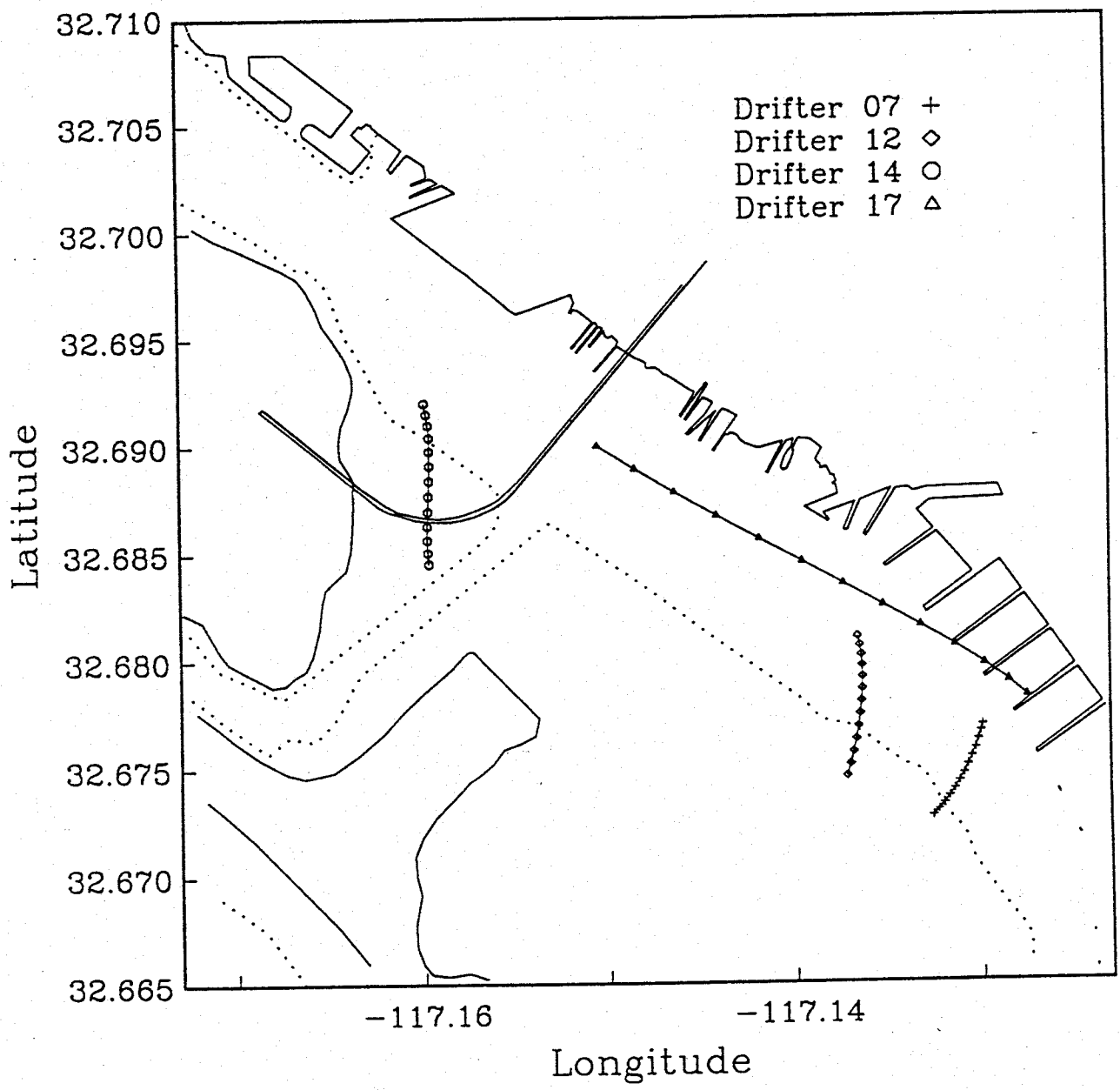

Figure 31. Drifter tracks, 12:20-14:20, August 23, 1994.

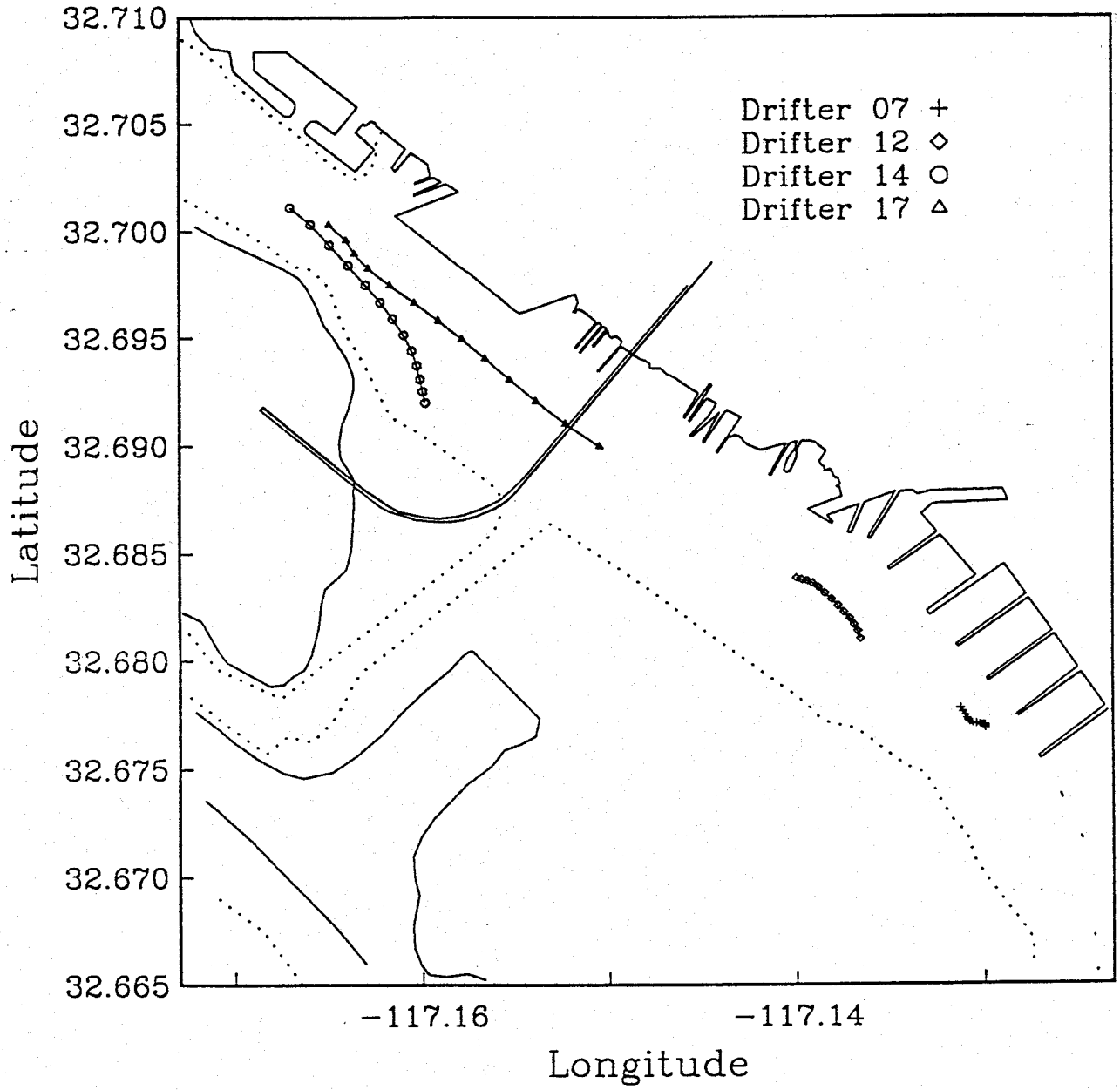

Figure 32. Drifter tracks, 14:20-16:20, August 23, 1994.

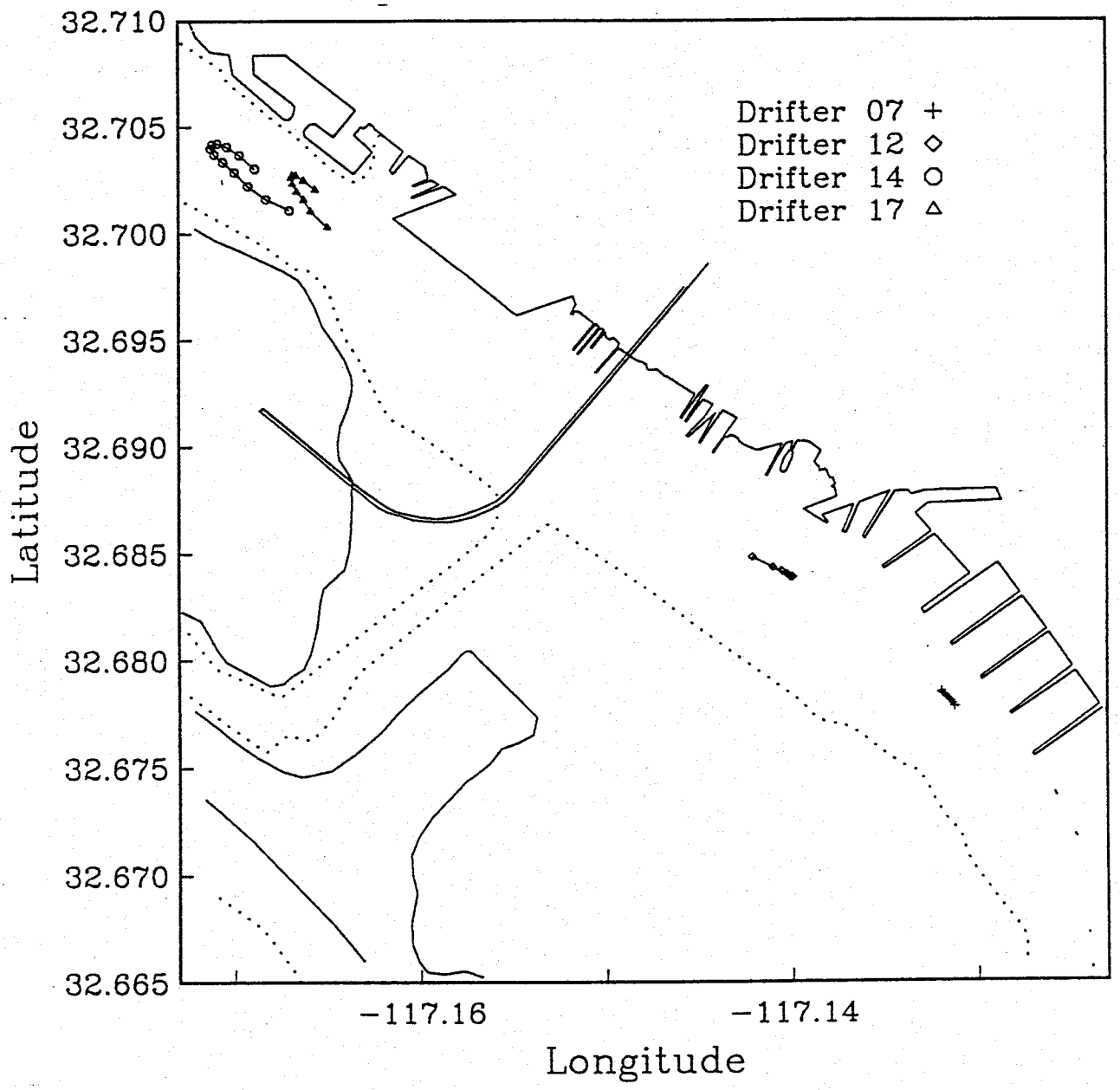

Figure 33. Drifter tracks, 16:20-18:15, August 23, 1994.

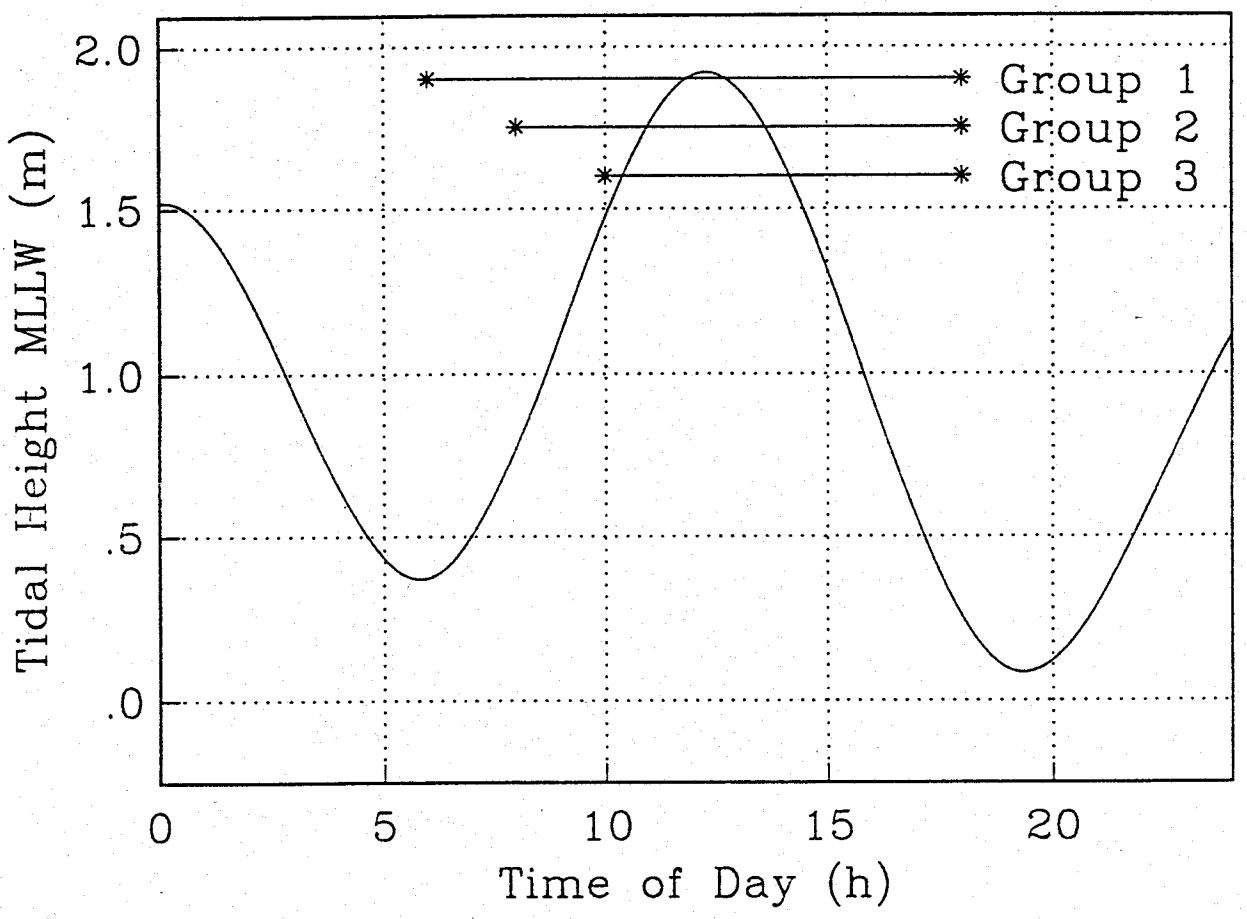

Figure 34. Tidal heights and deployment period for September 9, 1994.

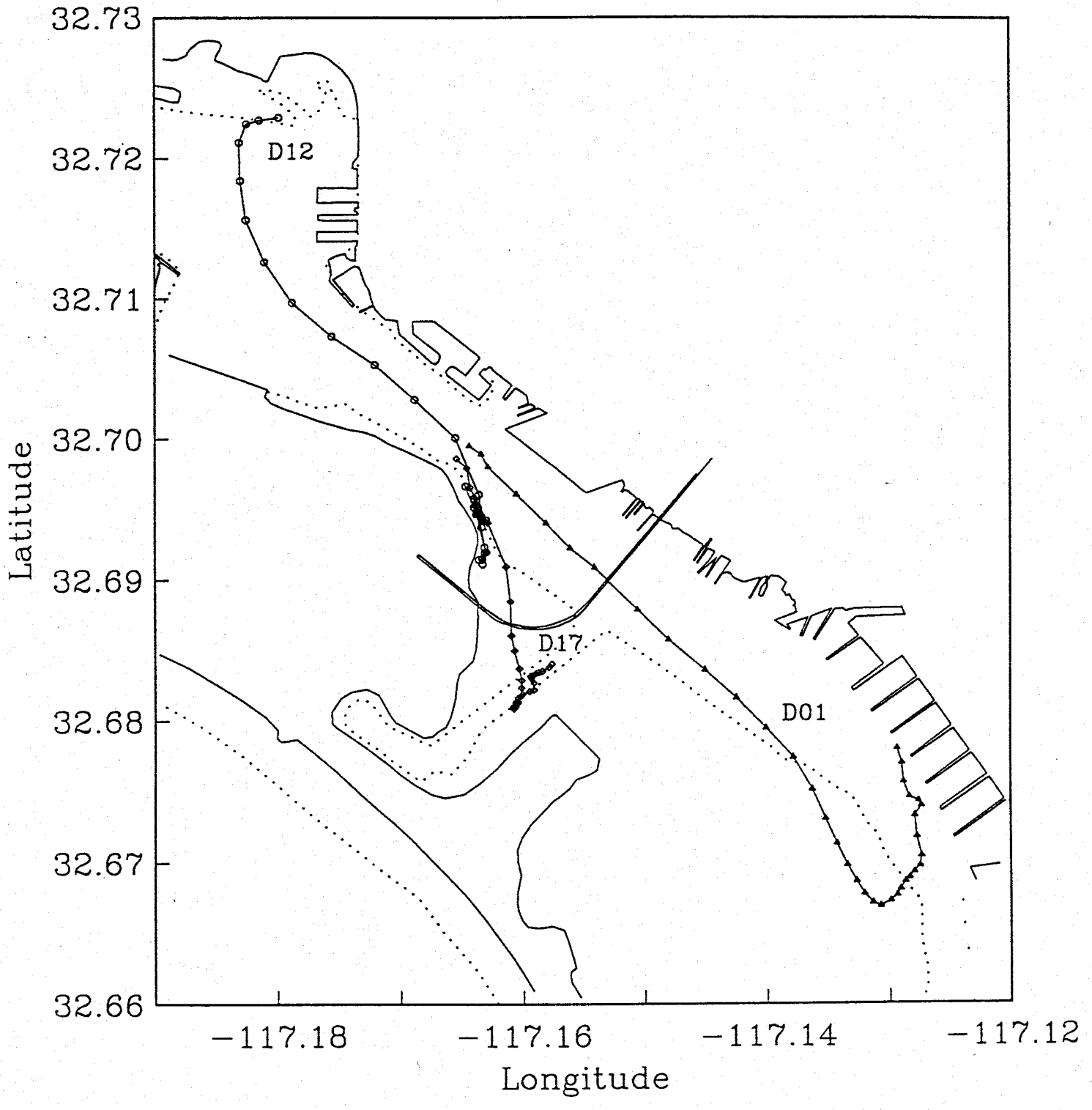

Figure 35. Launch 1 drifter tracks, 5:53 September 9, 1994.

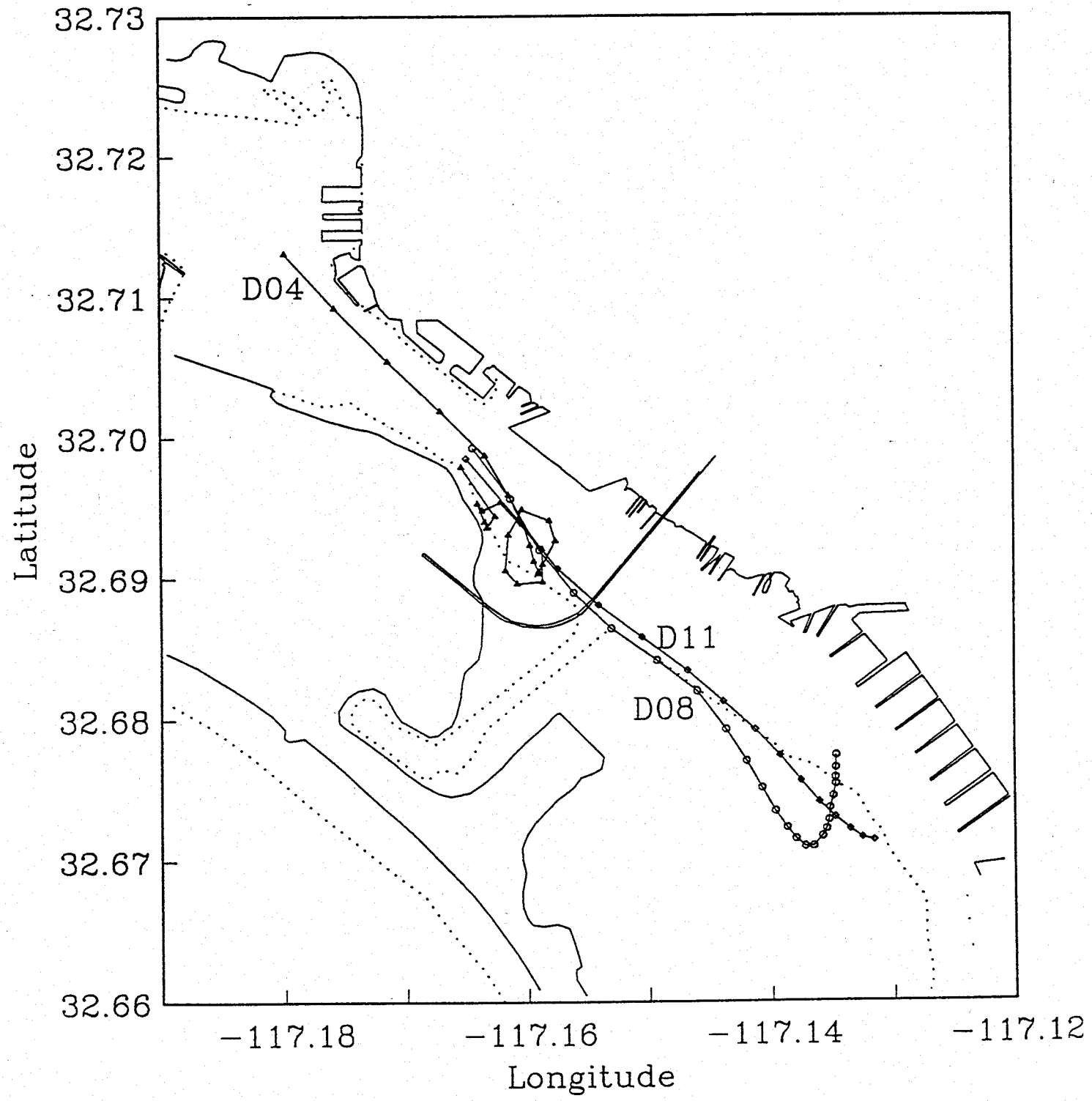

Figure 36. Launch 2 drifter tracks, 7:54 September 9, 1994.

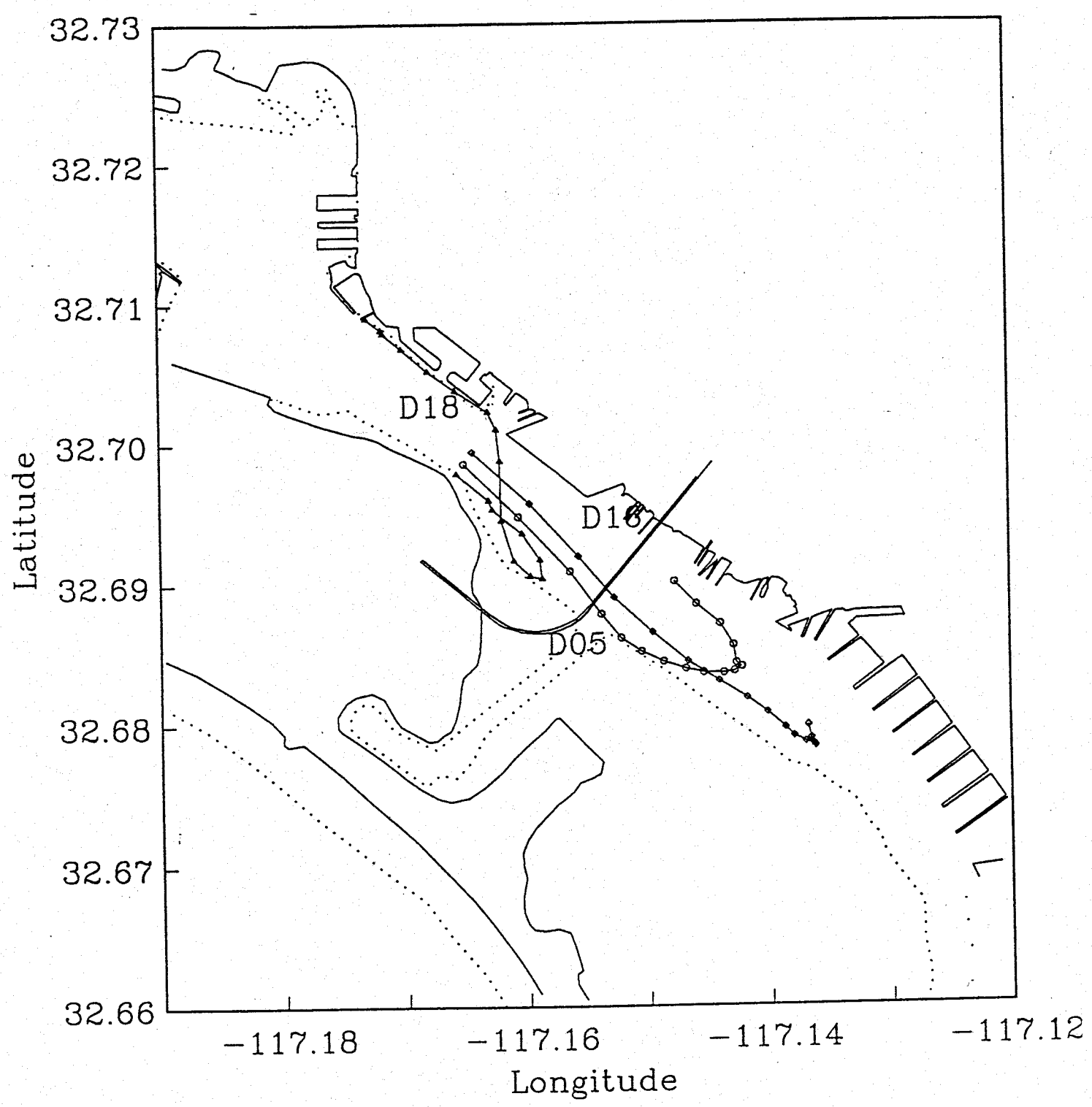

Figure 37. Launch 3 drifter tracks, 9:53 September 9, 1994.