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Acoustic Doppler Current Profiler
Observations During the Coastal Jet
Separation Project
on R/V Wecoma,
August 23 to September 2, 1994

by

S. D. Pierce, J. A. Barth and R. L. Smith

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Date Report 161
Reference 95-3
November 1996

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**Acoustic Doppler Current Profiler Observations
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We present velocity observations from a shipborne acoustic Doppler current profiler (ADCP) on R/V *Wecoma* during cruise W9408A, August 23 to September 2, 1994. The ADCP processing procedures are described in detail. This cruise was part of the Coastal Jet Separation project, funded by the National Science Foundation, to study how and why a strong alongshore coastal current turns offshore, crosses steep bottom topography, and becomes an oceanic jet. The focus of the cruise was a series of high-resolution SeaSoar (CTD) and ADCP surveys across the continental margin upstream and downstream of Cape Blanco, Oregon (43°N). The ADCP was an RD Instruments hull-mounted 153.6 kHz unit. Data were collected nearly continuously for the 10 day period, in a region extending about 200 km along the coast and 100 km offshore. Vertical bin length was 8 m and the typical depth range in open water was 20–400 m. To reference the ADCP velocities, we used conventional global positioning system (GPS) navigation, supplemented by bottom-tracking where possible.

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INTRODUCTION

This report presents observations of velocity from a shipborne acoustic Doppler current profiler (ADCP) on the R/V *Wecoma* during cruise W9408A, August 23 to September 2, 1994. This cruise was part of the Coastal Jet Separation project, to study how and why a strong alongshore coastal current turns offshore, crosses steep bottom topography, and becomes an oceanic jet. The cruise was organized around the collection of SeaSoar (CTD) data. The SeaSoar towed undulating vehicle was deployed during six periods, for a total of 7.6 days of the cruise (Figure 1). The SeaSoar data and a cruise narrative are described in a separate data report, Barth et al. [1996]. The reader unfamiliar with basic ADCP principles and terminology is referred to the helpful *Practical Primer*, RD Instruments [1989].

The ADCP was an RD Instruments hull-mounted 153.6 kHz narrow-band model, with 4 beams oriented 30° from vertical. The ADCP transducer was at a depth of 5 m. We set up the instrument with a pulse length of 12 m, a bin width of 8 m, and an ensemble averaging time of 2.5 min. Bottom-tracking was turned on for 12 different periods of the cruise when the bottom was visible to the ADCP. The number of pings per ensemble varied from 51–140 when bottom-tracking was enabled and from 126–148 when bottom-tracking was off. The error velocity threshold for raw pings during data collection was 1 m/s, the blank-beyond-transmit length was 4 m, and only 4-beam solutions were used. No corrections for pitch and roll were made; errors associated with these are likely to be small (Kosro, 1985). Table 2 on the last page of this report is a copy of the file used to configure the RDI

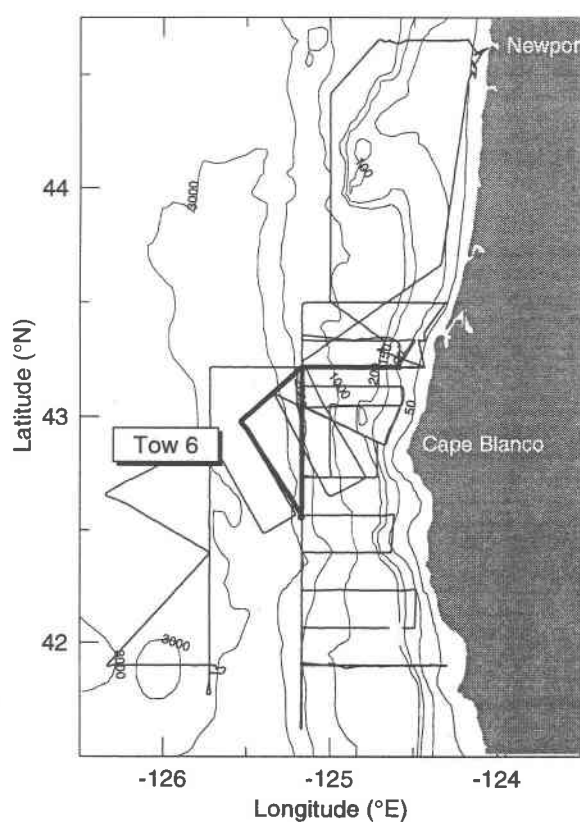
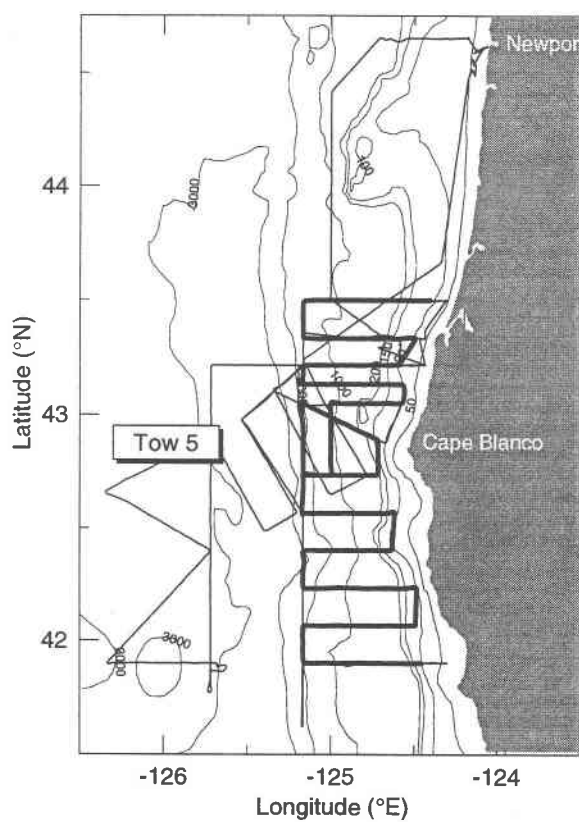
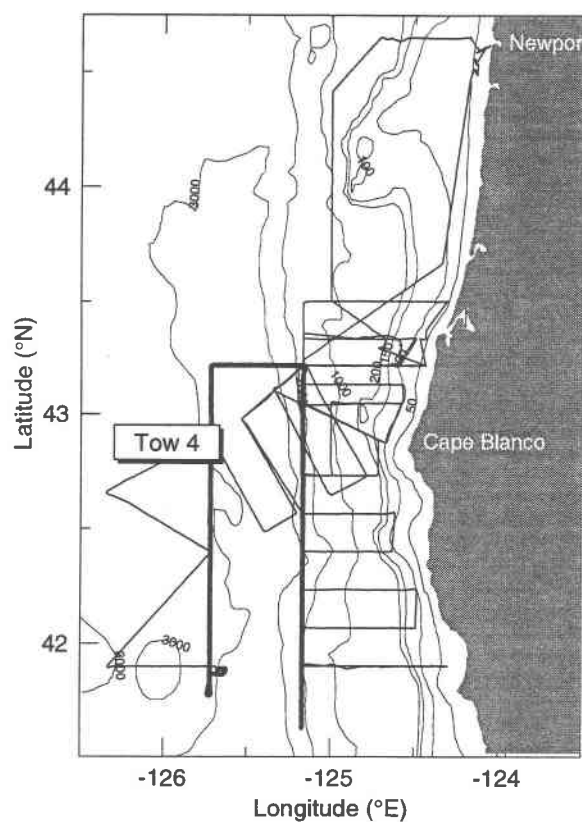
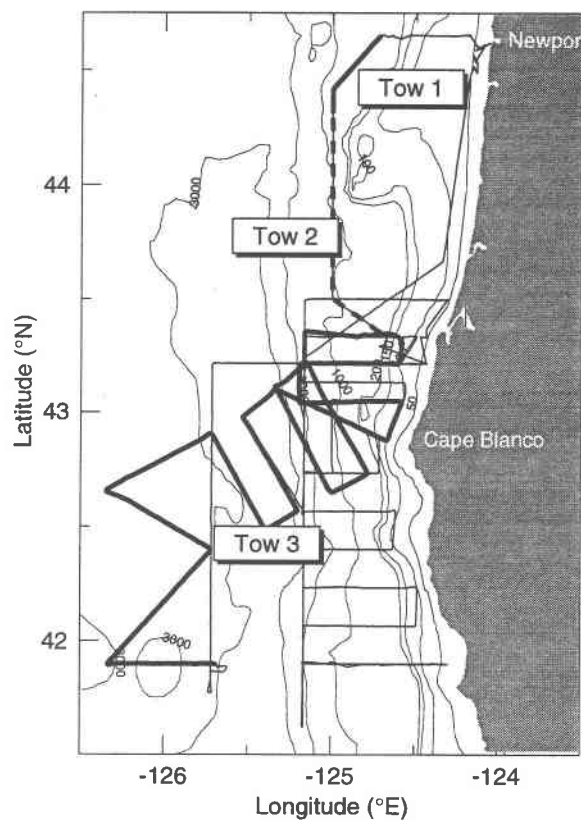


Fig. 1. W9408A shiptrack (thin line, repeated on each panel) and SeaSoar tows (heavier lines).

data acquisition system.

The ADCP operated continuously during the cruise except for short interruptions required to change system parameters, insert new diskettes, or repair minor problems. The 5 largest gaps were 14, 9, 7, 6, and 2 min in length; the others were each less than 1 min. Only 16 min worth of gaps occurred during SeaSoar towing, where the ADCP data are especially valuable. The percentage-good-pings per ensemble and amplitude (AGC) statistics appear reasonable over the entire cruise (Figure 2), with mean percentage-good-pings greater than 50% down to a depth of 425 m. More discussion of these diagnostics is in the EDITING section below.

The ADCP data were initially processed and displayed in real-time by the RDI data acquisition system running on a personal computer. Additional shipboard and shore processing were accomplished using some components of the Common Oceanographic Data Access System (CODAS) software package made available by the University of Hawaii (Firing et al., 1995), running on a Sun Sparc 10. Parts of the CODAS software required the Matlab language, and the plots for this report were made using the Gri package (Kelley, 1995). Conventional global positioning system (GPS) navigation from a Trimble 4000AX was integrated into the ADCP data stream using a "user exit" program. GPS fixes were obtained within a few seconds of the end of each ADCP ensemble. Ship's heading was by gyro compass. The quality of the GPS data was good except for an 80 min period close to the end of SeaSoar tow 3, beginning August 27, 1712 UT, when the constellation was lost. We filled in this gap with LORAN-C navigation recorded by the shipboard MIDAS system. The LORAN-C appears consistent with the GPS in this area; rms differences between LORAN-C and GPS for 1 h before and 1 h after this gap were ± 38 m in the zonal and ± 218 m in the meridional directions.

EDITING

As the data quality decreases with depth, we must decide on the deepest usable bin for each 2.5 min ensemble. In addition, the data must be edited for interference with the sea floor in shallow water and for occasional interference from the CTD hydrographic wire and other objects. To flag and remove suspect data points, several methods were used in combination during post-processing, as recommended by Firing et al. [1995] and others:

- The percentage-good-pings per ensemble cutoff was set to 50%; below this point data were not used. The %-good-pings is a record of the proportion of raw pings within the 2.5 min ensemble which are

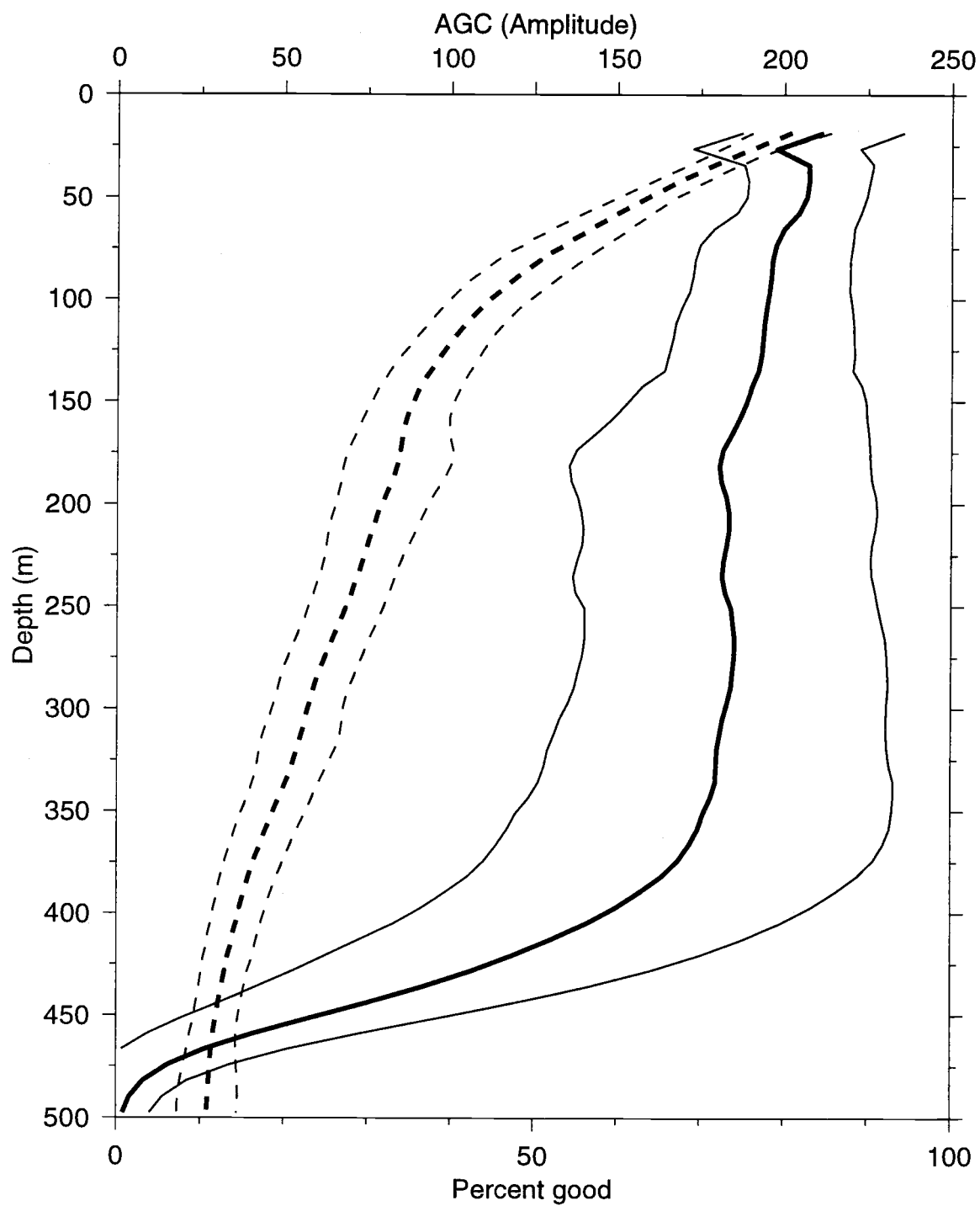


Fig. 2. Percentage-good-pings (solid) and AGC amplitude (dashed) means and standard deviations for the entire cruise, as a function of bin depth.

judged good internally by the RDI firmware and subsequently included in the ensemble average.

- The automatic gain control (AGC) gives an indication of the echo return signal strength, scaled such that 1 AGC count corresponds to about a 0.45 dB change in signal power. The AGC decreases with bin depth in general. A small increase with depth may simply indicate the presence of a strong scattering layer due to a large zooplankton population, while a larger increase is probably a reflection off of the sea floor. Individual ensembles were scanned for increases of AGC with depth >25 counts, and the deepest subsequent bin where a local maximum is reached was taken as an indication of sea floor location.
- In the deep water case, where no sea floor echo is detected, the AGC will eventually stop decreasing with depth and become constant. This constant level is the noise floor; the signal of interest is no longer present. We use a noise margin of 10, retaining bins which have AGC greater than 10 above the noise floor.
- The second differences with respect to z of u , v , and w were calculated for each profile (denoted $d2u$, $d2v$, and $d2w$ respectively). If the $d2w$ value exceeded a cruise-long 2 standard deviation threshold and either $d2u$ or $d2v$ also exceeded a 2 s.d. threshold, the bin was flagged as suspect. The $d2w$ threshold was 31.8 mm/s and the $d2u$ and $d2v$ thresholds were 111.0 mm/s. This method is recommended by Firing et al. [1995] as a good way of detecting interference with one of the four ADCP beams, possibly caused by a CTD wire.
- Since the ADCP initially measures velocity along the axes of four beams, which are then transformed to the 3-dimensional components u , v , and w , there is redundancy in the scheme. This redundancy is used within the RDI firmware to make two distinct estimates of the vertical velocity w . The difference between these two estimates is called the error velocity and is a useful data quality indicator. A large error velocity indicates an inconsistency among the oceanic velocities sampled by each of the 4 beams. Thus it is another way of detecting interference with one of the beams caused by an object. We reject individual bins which have an error velocity above 6 cm/s, a relatively conservative choice (Zedel and Church [1987], for example, recommend using 17 cm/s); the results are not very sensitive to the choice.
- As additional precaution against sea floor interference, the profile was cut off at 85% of the estimated depth from the above methods or at 85% of the bottom-track depth (if available), whichever was

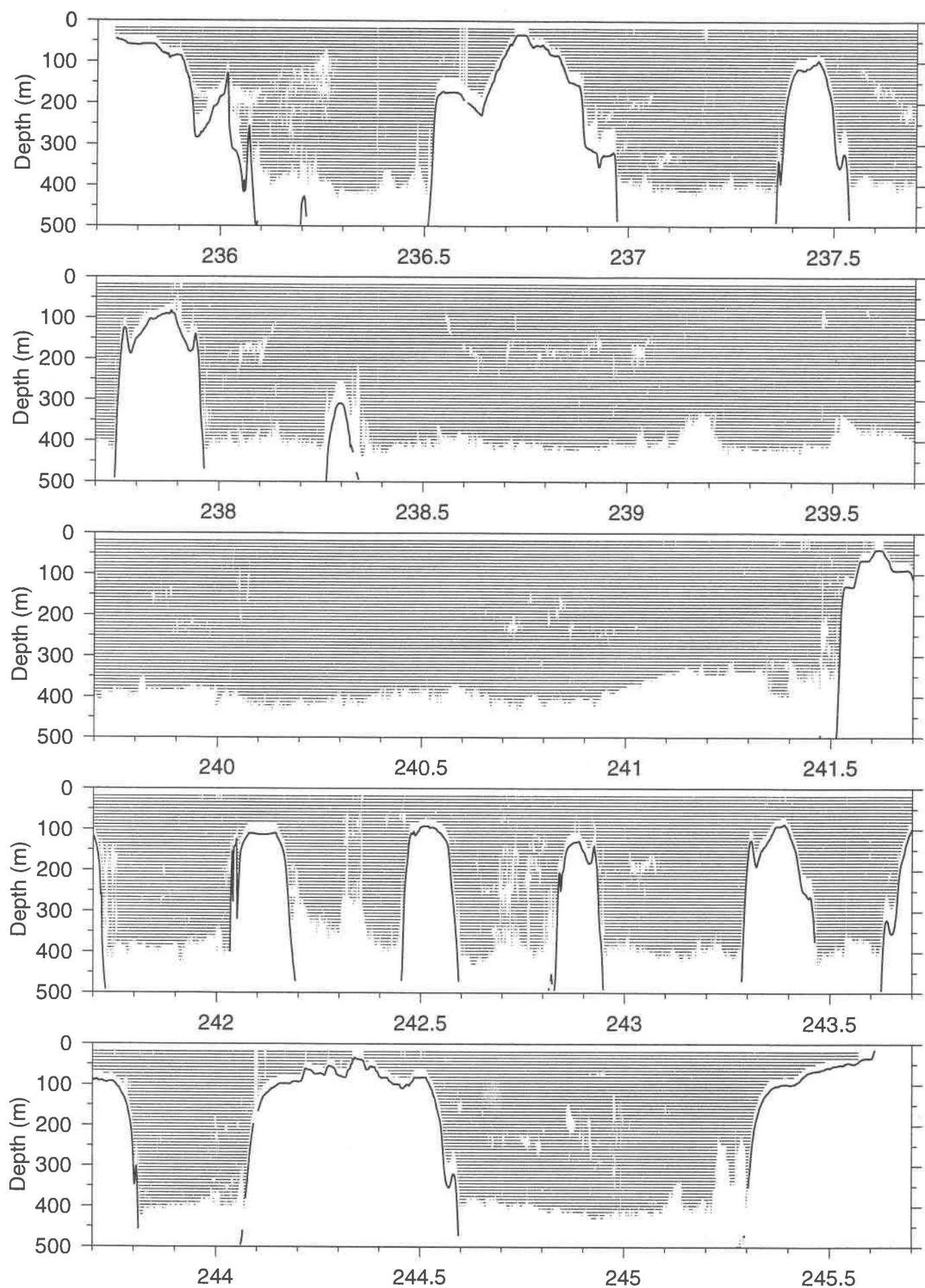


Fig. 3. Data points remaining after editing.

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smaller. It is particularly important to guard against sea floor interference when crossing regions with steep bottom topography, as in the present case.

The result of the editing is shown in Figure 3, where good data points are plotted and missing points appear as white space. The line beneath is the ADCP bottom-track depth. Many of the minor blank regions correspond to SeaSoar deployments, recoveries, or CTD stations, where the object in the water interfered briefly with one or more of the 4 ADCP beams.

CALIBRATION

Sound speed

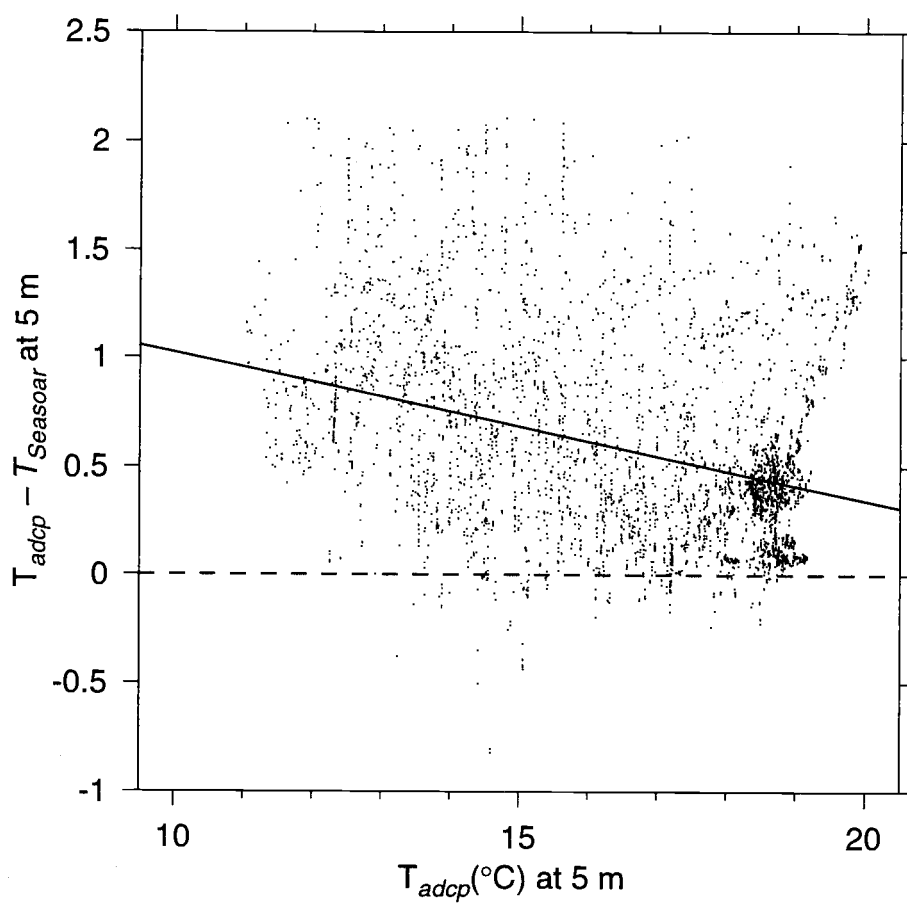
Sound speed was calculated from temperature measured at the ADCP transducer and an assumed constant salinity, using the Chen & Millero sound speed formula. The salinity of 32.25 PSU was the post-cruise mean of all SeaSoar measurements between 4.5–5.5 m; this brackets the transducer depth of 5 m. The ADCP thermistor was also post-calibrated using the SeaSoar temperature data between 4.5–5.5 m (Figure 4). A least-squares regression to temperature was significant, and the ADCP temperature was corrected as follows: $T_{corr.} = -1.70 \pm 0.04 + T \times 1.068 \pm 0.003$. The uncertainty associated with the temperature calibration leads to a maximum error in velocity of ± 0.1 cm/s. Using an assumed constant instead of a measured salinity leads to an estimated velocity error of ± 0.2 cm/s. Both of these are negligible compared to other sources of error.

Mean, minimum, and maximum sound speeds were calculated at each nominal 8 m bin using the total range of SeaSoar temperature and salinity found at that depth. Correct bin depths were found by integrating the mean sound speed profile. The uncertainty at each depth was figured by using the minimum and maximum sound speed profiles. The uncertainty is ± 0.1 m at a depth of 20 m and ± 1 m at 300 m.

Sensitivity and Alignment

We use the bottom-track method to determine and correct for the sensitivity error β (where the ADCP data are scaled up by $\beta + 1$) and the ADCP/gyro misalignment angle α , following Joyce [1988]. We assume that the bottom track velocity averaged over some segment of the cruise track should be equal and opposite to the ship velocity from navigation. The degree to which this is not true provides values for α and β .

Fig. 4. ADCP thermistor calibration



Using 59 hourly averages, we find $\beta = -0.003 \pm 0.004$. For α , we figure both an offset and a slope with time (Figure 5). Physically, the offset can be associated with a fixed transducer misalignment while the slope is due to gyro compass drift over time. The offset of $1.51 \pm 0.11^\circ$ and drift of $0.14 \pm 0.03^\circ$ per day are reasonable values (Pollard and Read, 1989). At worst (at highest ship speed of 7.2 m/s), the α and β uncertainties imply unknown biases of 1.4 and 2.9 cm/s respectively.

NAVIGATION

To reference the ADCP velocities to absolute (earth) coordinates, ship speed was determined by bottom-tracking where possible (about 1/4 of the cruise, Figure 3); elsewhere navigation was applied using the reference layer method (with a 30–62 m reference layer). Following Kosro [1985] or Wilson and Leetmaa [1988], we first calculate the absolute velocity of the reference layer, smooth it to reduce navigational noise, and then subtract the shear profile for each ensemble to determine absolute velocities at all depths. For the 50 hours when both bottom-tracking was available and the depth was greater than 62 m, the reference layer method was also applied, in order to test the accuracy of the latter. Differences between bottom-tracked and navigation-derived velocities are assumed to be mostly due to errors associated with the navigation.

Both the navigation data set at the raw sampling interval (2.5 min) and the reference layer absolute velocities derived from it are noisy. To be useful they must be smoothed or filtered. This is a difficult filtering problem since it is not a simple case of removing noise from a time series; this is both a time and a spatial series. We did this in a two-step process:

- The raw position data were smoothed with a smoothing spline in x and y . This spline minimizes the overall curvature of the result, while not exceeding a given rms-error-allowed deviation ep from the raw data. The spline algorithm is by Reinsch [1967] and available as IMSL library routine *dcssmh*. We found that ep values of either 40 or 55 m gave the best overall performance (Figure 6b, bold line). We settle on the ep of 40 m, since we want to guard against oversmoothing the ship's track. The 40 m value for ep is within the range of published estimates of GPS uncertainty (Hofmann-Wellenhof et al., 1994), thus consistent with the premise that the spline is removing noise from the data.
- We used the position data to calculate absolute reference layer velocities. These noisy velocities were then low-pass filtered in a robust manner (excluding velocities > 2 s.d. from the mean) in the time domain with a Blackman window: $w(t) = 0.42 - 0.5\cos(2\pi t/T) + 0.08\cos(4\pi t/T)$. The choice of

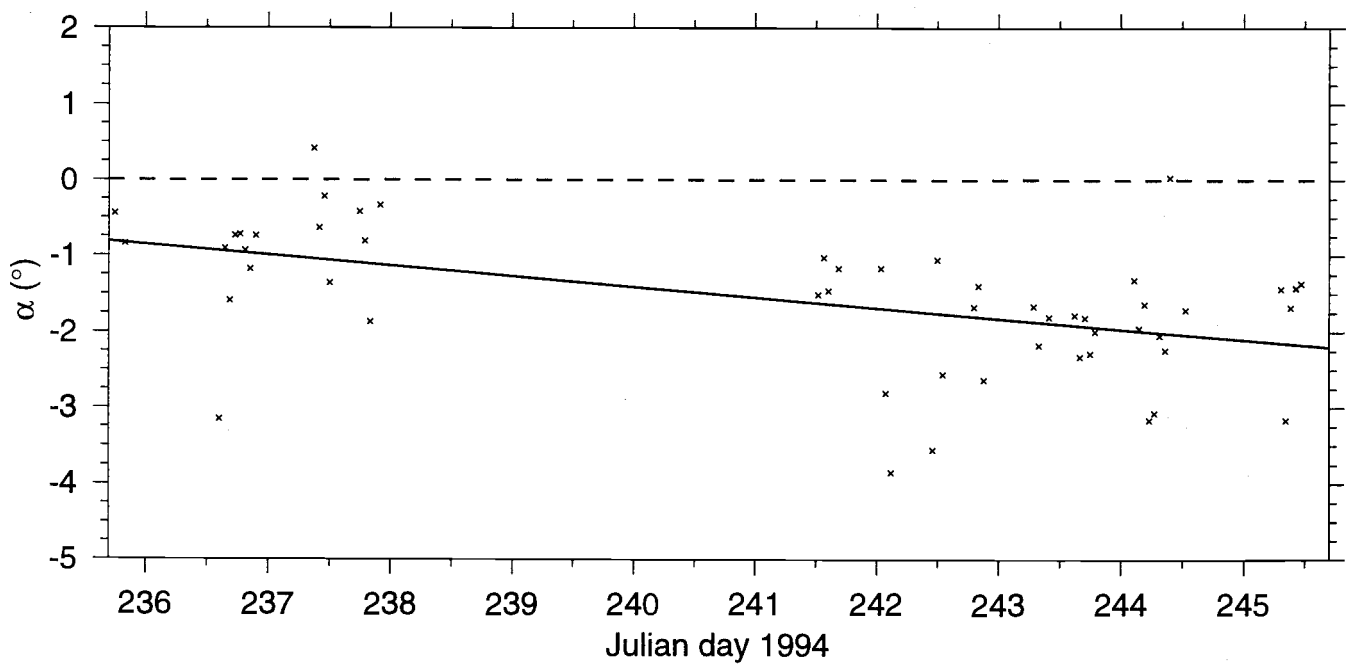


Fig. 5. Hourly average values of misalignment angle α , figured by navigation and bottom-tracking using the method of Joyce [1988]. The linear regression yields a slope of $0.14 \pm 0.03^\circ$ per day and an offset of $1.51 \pm 0.11^\circ$.

the filter half-width T is discussed below. The resulting smoothed velocities are also integrated back to obtain a new consistent and smooth set of ship positions. This step uses the *smoothr* routine in the CODAS package.

The first of the above steps is a relatively minor yet beneficial one; the second is more important. The second step is the only smoothing method recommended by Firing et al. [1995], yet they also admit that it is ad hoc and not necessarily optimum. It is not surprising, therefore, that with the addition of the first step (our spline smoothing of the raw positions), we are able to do slightly better.

To evaluate the results, we computed rms differences between the final reference layer velocities obtained using navigation and the same velocities obtained from bottom-tracking. In Figure 6a, the 30 min choice for the filter half-width, T , was suggested by the break in the curves. A longer filter would mean further possible distortion of oceanic features (in the absolute velocity) of interest, while a shorter one results in more noise from navigation. The result of the smoothing spline step is a modest decrease in the rms error (Figure 6a). For the 30 min filter, U_{rms} went from 7.0 to 6.7 cm/s and V_{rms} went from 7.8 to 6.9 cm/s. The difference between the U and V result is associated with the ocean circulation in this area; the natural variability in V is larger than U . The spline leads to greater improvement because more noise was present initially. The spline provides a modest improvement for a range of filter choices from 25–70 min.

SYNOPSIS OF UNCERTAINTIES

The inherent short-term random uncertainty in an ADCP velocity for a 2.5 min ensemble and 8 m bin ranges between ± 1.1 and ± 2.6 cm/s (RDI, 1989). The range is due to variability in the number of pings per ensemble. This form of error will be reduced with further averaging. For the typical case of 10 min averaged data, the short-term random uncertainty is at most ± 1.3 cm/s.

If bottom-tracking is used, the absolute ADCP velocity may have an unknown bias of 1 cm/s (due to inherent limitations of the bottom-track method, RDI [1989]). If bottom-tracking is not used, the absolute ADCP velocity may have an unknown bias of 2.3 cm/s (combination of sensitivity and alignment errors). In addition, the absolute velocity has a random error due to navigational uncertainty of ± 6.8 cm/s and is low-pass filtered to suppress motions with time scales of less than 30 min (for features which are depth-independent throughout the 30–62 m reference layer). For the typical case of 10 min data, the effective filtering of the reference layer is 40 min (the original 30 min filter convolved

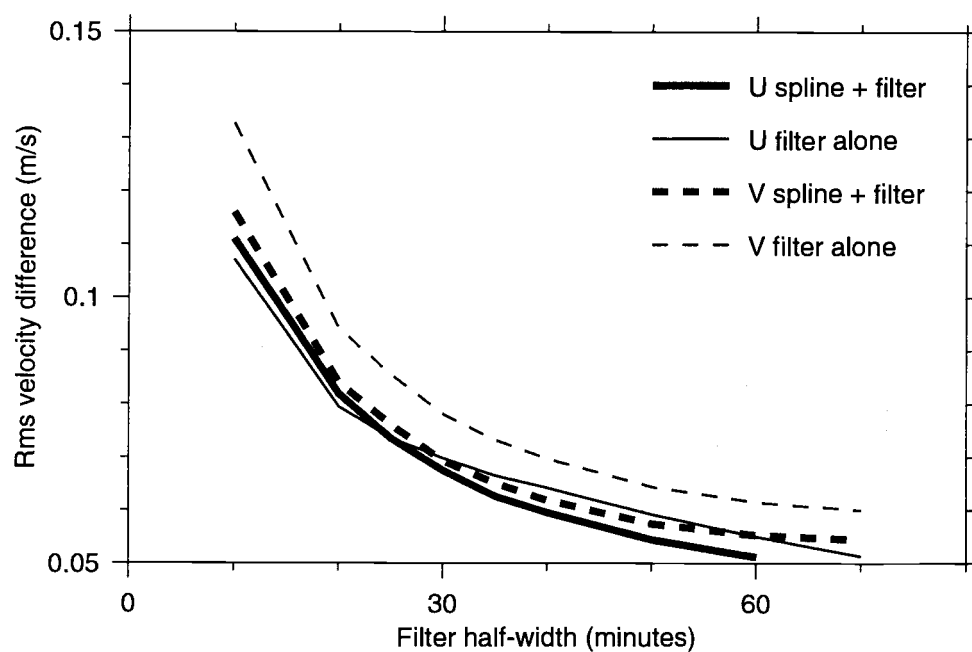


Fig. 6a. Rms difference between absolute velocities of the reference layer from navigation and bottom-tracking, vs. low-pass filter width. The spline smoothing parameter ep is kept fixed at 40 m.

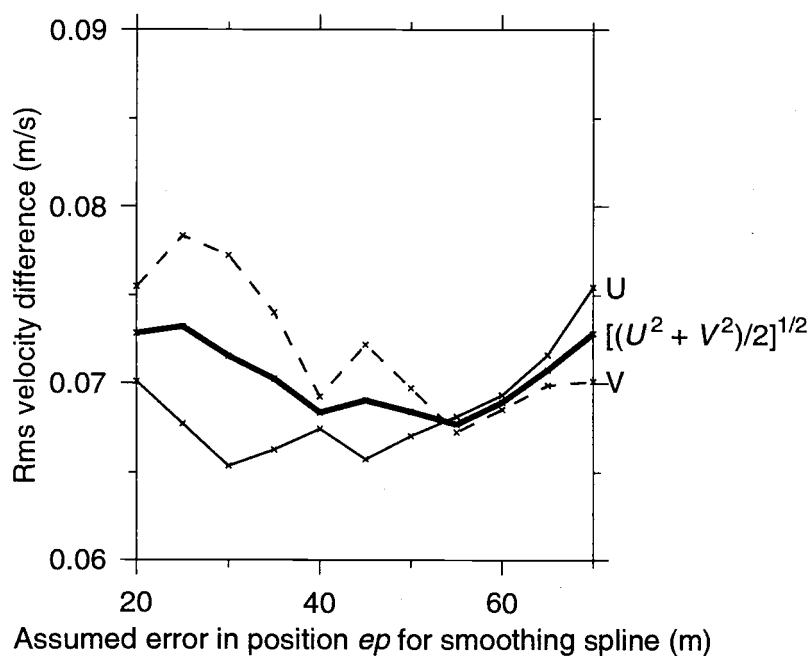


Fig. 6b. Rms difference between absolute velocities of the reference layer from navigation and bottom-tracking, vs. spline-smoothing parameter. The low-pass filter width is kept fixed at 30 minutes while the assumed rms position error ep is varied.

with the 10 min block average), so this error is reduced to ± 6.1 cm/s.

DATA PRESENTATION

First, on pp. 17-21, we show the time series of 10-min averaged ADCP vectors at the surface (a 10 m layer centered at 25 m depth), with ship location plotted below.

Next, on pp. 22-43, maps of ADCP vectors at 25, 50, 75, 100, 150, 200, 250, 300, and 350 m depths are displayed for two time periods (before and after year day 241.07822, 29-Aug-94 01:52:37 UTC), each representing roughly half of the cruise period. Each vector is a 5 km spatial average in the horizontal and 10 m in the vertical.

The vertical sections of ADCP velocity are contoured using a Barnes objective analysis scheme with 3 iterations, as described in §3.6 of Daley [1991]. The horizontal (vertical) grid spacings are 1.2 km (8 m), and the successive smoothing lengthscales are 9.6 km (48 m), 4.8 km (24 m), and 2.4 km (12 m). Velocity contour units are cm/s, and negative regions are shaded. The location of each section is indicated on a small map to the right of each plot. Table 1 on p. 15 lists the times and positions of the line endpoints.

Vertical sections are made of east (U) and north (V) velocity for all SeaSoar/ADCP lines (pp. 44-155), *cross-track* velocity for diagonal SeaSoar/ADCP lines (pp. 156-168), deeper U and V velocity for all ADCP lines (pp. 170-291), and deeper *cross-track* velocity for diagonal ADCP lines (pp. 292-305).

The data described in this report will be publicly available from the National Oceanographic Data Center Joint Archive for Shipboard ADCP (JASADCP). The JASADCP is accessible through the web at <http://www.soest.hawaii.edu/caldwell/>.

ACKNOWLEDGMENTS

We thank the *Wecoma's* Marine Technicians, Marc Willis and Mike Hill, for their assistance in collecting high-quality ADCP and SeaSoar data. We are grateful for the superb service provided by the *Wecoma's* officers and crew. Mike Kosro provided valuable advice on the collection and processing of the ADCP data. This work was supported by the National Science Foundation through Grant OCE-9314370.

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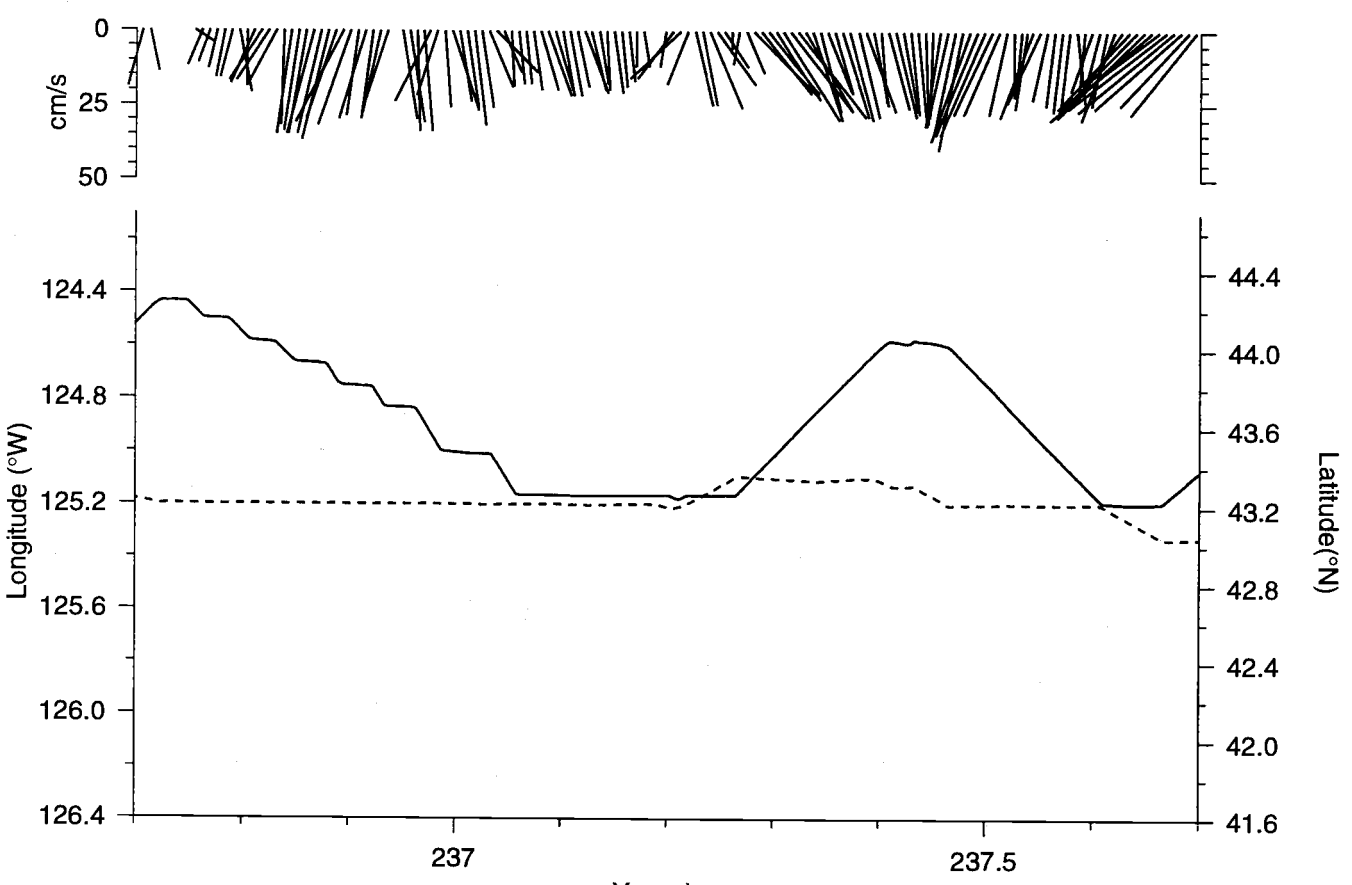
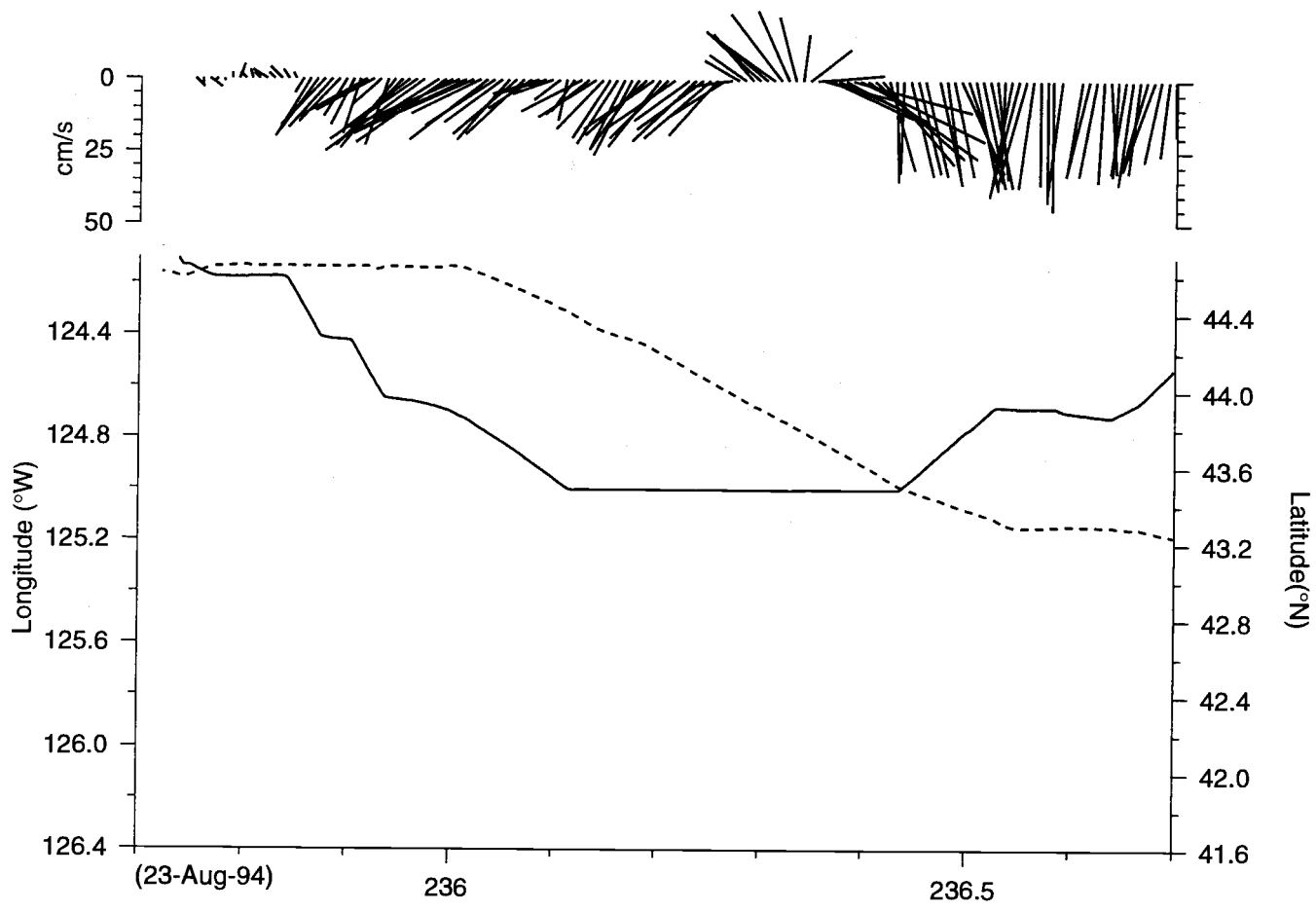
Table 1. W9408A line definitions and waypoints

Line name	Seasoar tow	Waypoints	Latitude (°N)	Longitude (°W)	Time (year day UTC)
a0	—	NH-buoy	44 36.5	124 08.2	235.75060
a	1	NH-25	44 39.1	124 38.8	235.99236
b0	1	A1	44 25.0	125 00.0	236.11236
b	2	recovery	44 19.1	125 00.0	236.14858
c	2	deployment	44 17.1	125 00.1	236.16667
FM CTD	—	A2	43 30.0	125 00.0	236.44323
0-1	3	A3	43 20.0	124 40.0	236.53343
1	3	FM-9	43 13.0	125 10.0	237.19653
1-2	3	B1	43 20.0	125 10.0	237.26668
2	3	B2	43 20.0	124 35.0	237.40106
2-3	3	B3	43 13.0	124 36.0	237.46374
3	3	B4	43 13.0	125 10.0	237.60896
3-4	3	B5	43 03.0	125 10.0	237.66469
4	3	B6	43 03.0	124 35.0	237.83339
4-5	3	B7	42 52.5	124 40.0	237.89301
5	3	C6	43 06.0	125 20.0	238.08160
5-6	3	C3	43 13.0	125 10.0	238.14910
6	3	C4	42 44.0	124 47.0	238.33302
6-7	3	C5	42 38.4	125 00.0	238.39498
7	3	C6	43 06.0	125 20.0	238.56529
7-8	3	C7	42 58.9	125 31.8	238.63083
8	3	C8	42 34.0	125 12.0	238.79883
9	3	C9	42 29.0	125 23.7	238.84777
10	3	C10	42 54.3	125 43.1	239.00609
11	3	D1	42 40.0	126 20.0	239.18299
12	3	D2	42 24.0	125 43.1	239.36606
		D3	41 54.0	126 20.0	239.59054
		D4	41 54.0	125 43.1	239.76041
13	4	D4	41 54.0	125 43.1	239.91808
14	4	E1	43 13.0	125 43.1	240.42291
15	4	E2	43 13.0	125 10.0	240.55296
CR CTD	—	E3	41 37.9	125 10.0	241.07822
		CR-1	41 54.0	124 18.0	241.61388

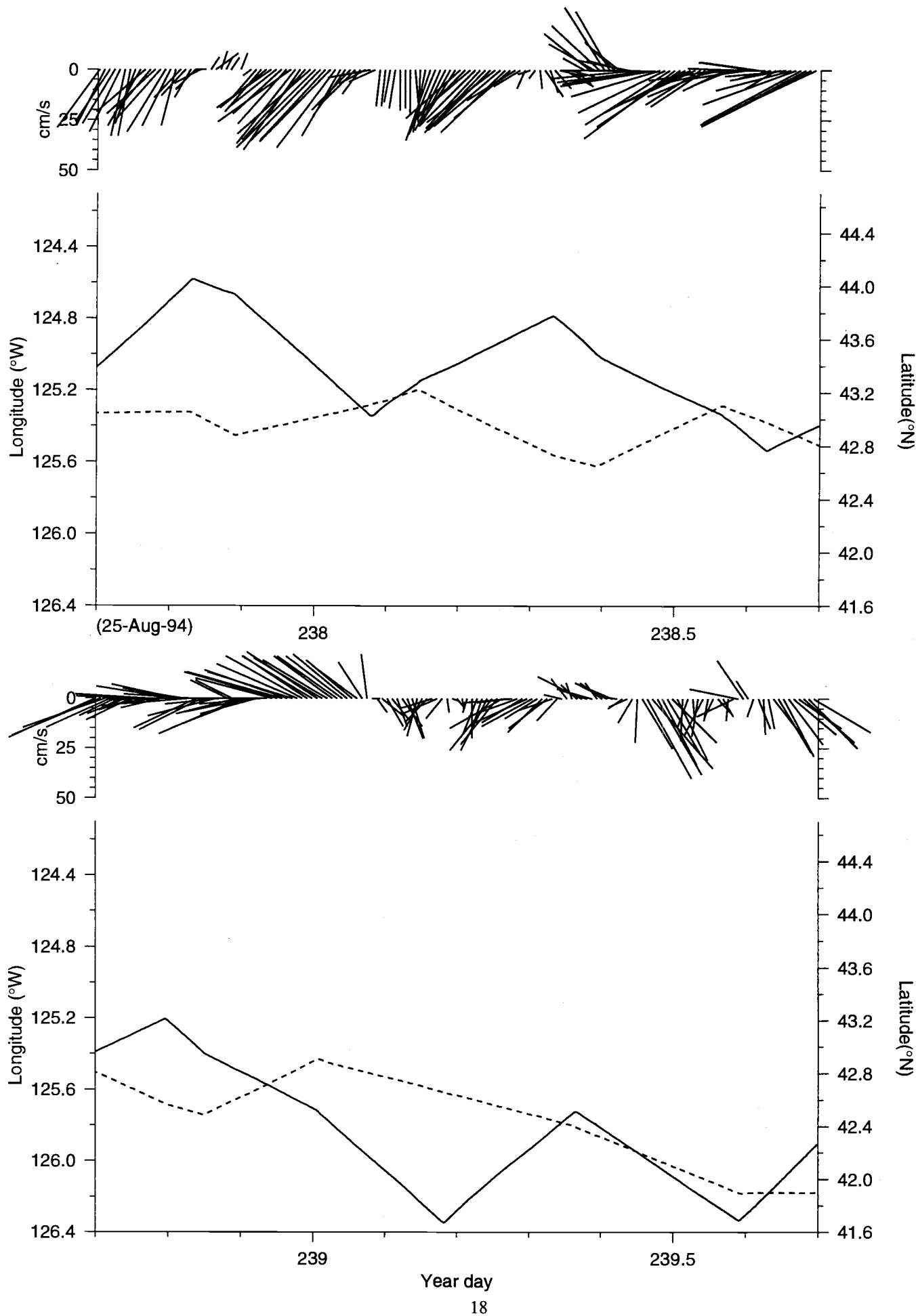
(Table 1 continued)

Line name	Season	Waypoints	Latitude (°N)	Longitude (°W)	Time (year day UTC)
16	5	F1	41 54.0	124 28.0	241.69306
16-17	5	CR-8	41 54.0	125 10.0	241.87027
17	5	F3	42 04.0	125 10.0	241.91979
17-18	5	F2	42 04.0	124 28.0	242.08259
18	5	F5	42 14.0	124 29.0	242.14956
18-19	5	F4	42 14.0	125 10.0	242.30961
19	5	F7	42 24.0	125 10.0	242.35918
19-20	5	F6	42 24.0	124 37.0	242.49523
20	5	F9	42 34.0	124 39.0	242.55606
20-21	5	F8	42 34.0	125 10.0	242.68956
21	5	F11	42 44.0	125 10.0	242.74337
21-22	5	F10	42 44.0	124 43.0	242.84197
22	5	F12	42 53.5	124 43.0	242.89497
23	5	B5	43 03.0	125 10.0	243.01163
23-24	5	F11	42 44.0	125 10.0	243.11317
24	5	F13	42 44.0	125 00.0	243.15485
25	5	F14	43 03.0	125 00.0	243.26567
25-26	5	B6	43 03.0	124 34.0	243.36902
26	5	G1	43 08.0	124 34.0	243.39477
26-27	5	G2	43 08.0	125 10.0	243.54061
27	5	B4	43 13.0	125 10.0	243.56602
27-28	5	B3	43 13.0	124 36.5	243.70751
28	5	B2	43 20.0	124 29.5	243.75531
28-29	5	B1	43 20.0	125 10.0	243.91462
29	5	G3	43 30.0	125 10.0	243.96764
		G4	43 30.0	124 21.0	244.15161
30	6	H1(FM-4)	43 13.0	124 35.0	244.51806
31	6	H2(FM-9)	43 13.0	125 10.0	244.65897
32	6	H3	42 58.9	125 31.8	244.77424
33	6	H4	42 34.0	125 10.0	244.94764
34	—	H2(FM-9)	43 13.0	125 10.0	245.18744
35	—	turn	43 40.4	124 19.7	245.36911
		NH-near	44 30.2	124 09.7	245.54390

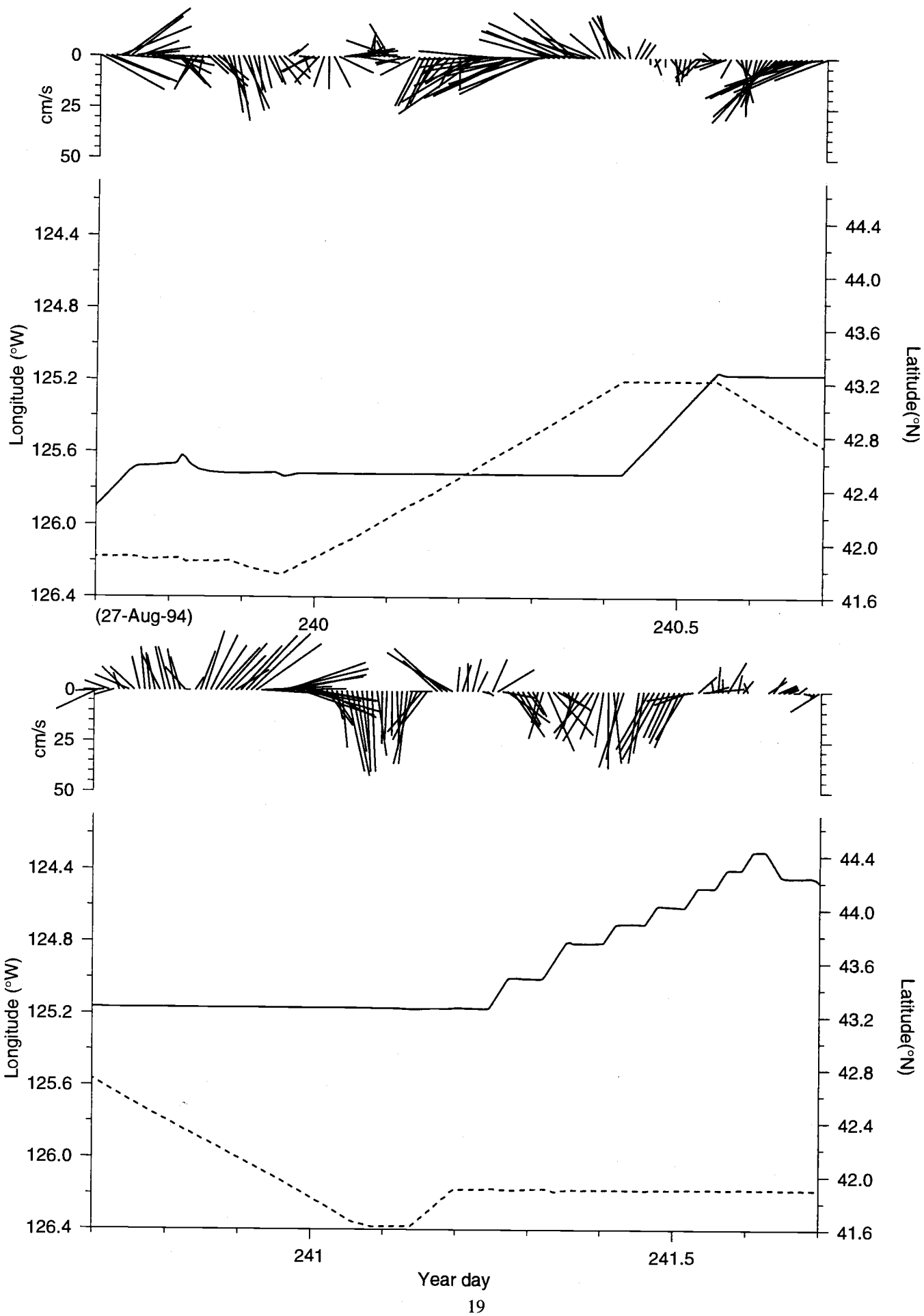
ADCP at 25 m depth, with longitude (solid) and latitude (dashed):



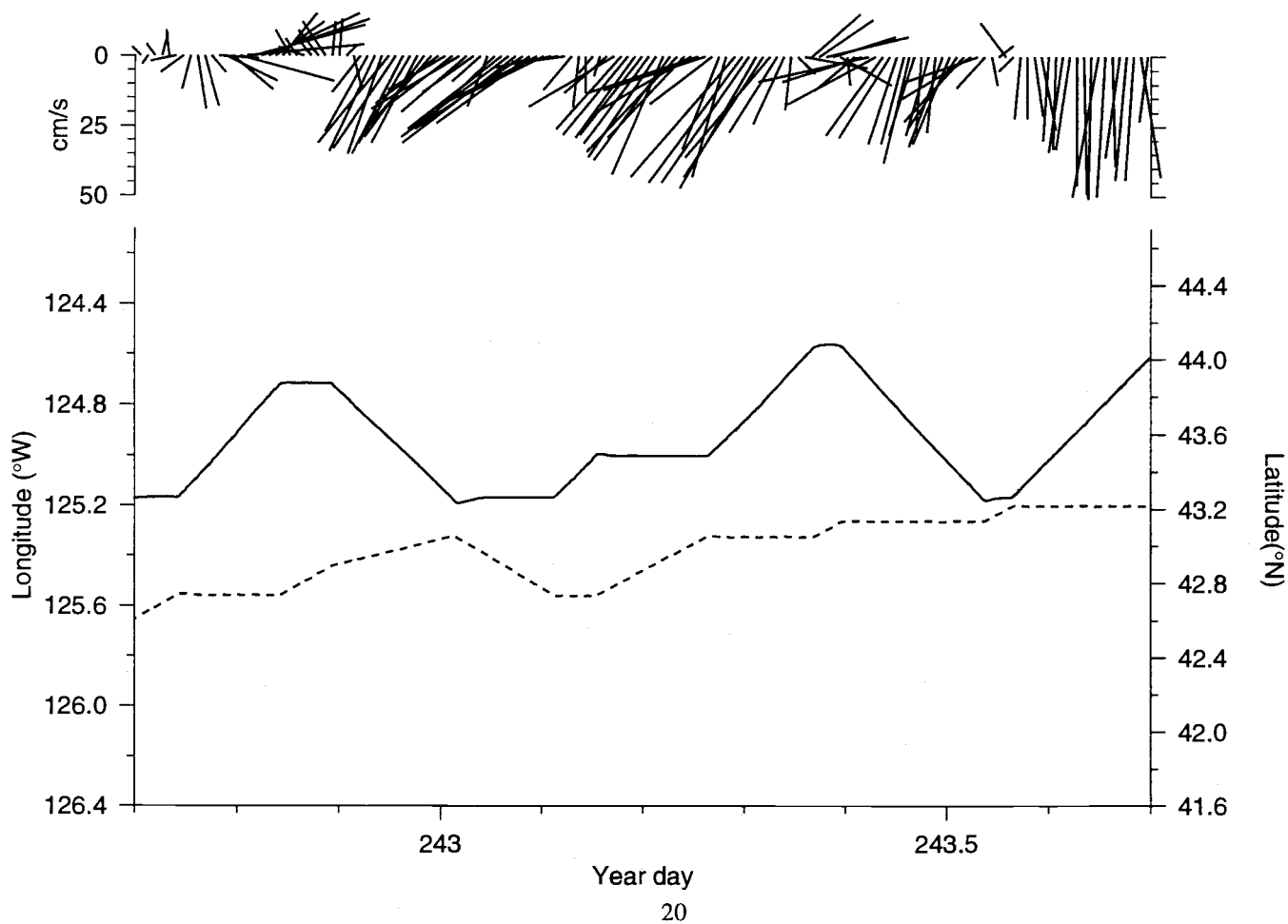
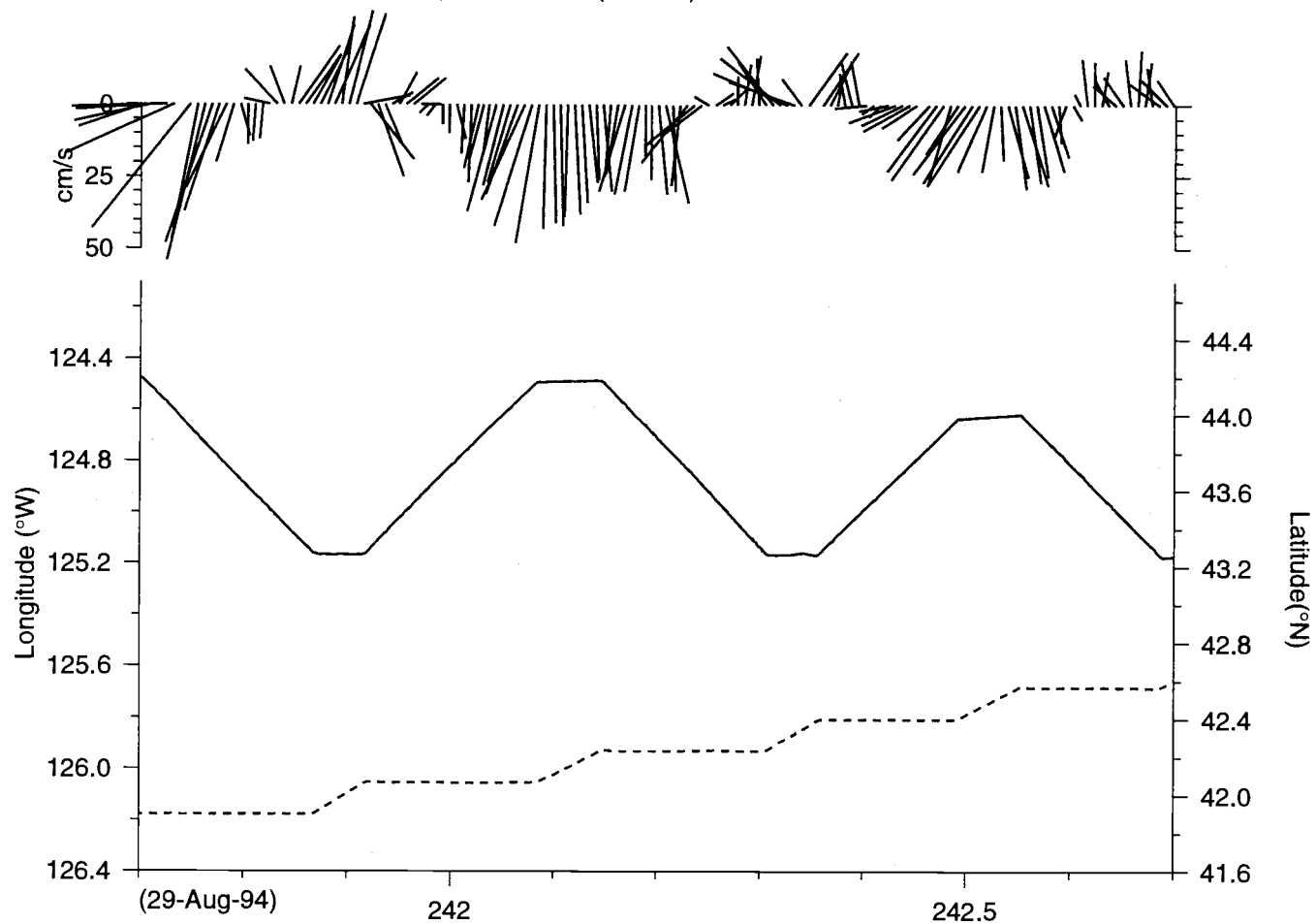
ADCP at 25 m depth, with longitude (solid) and latitude (dashed):



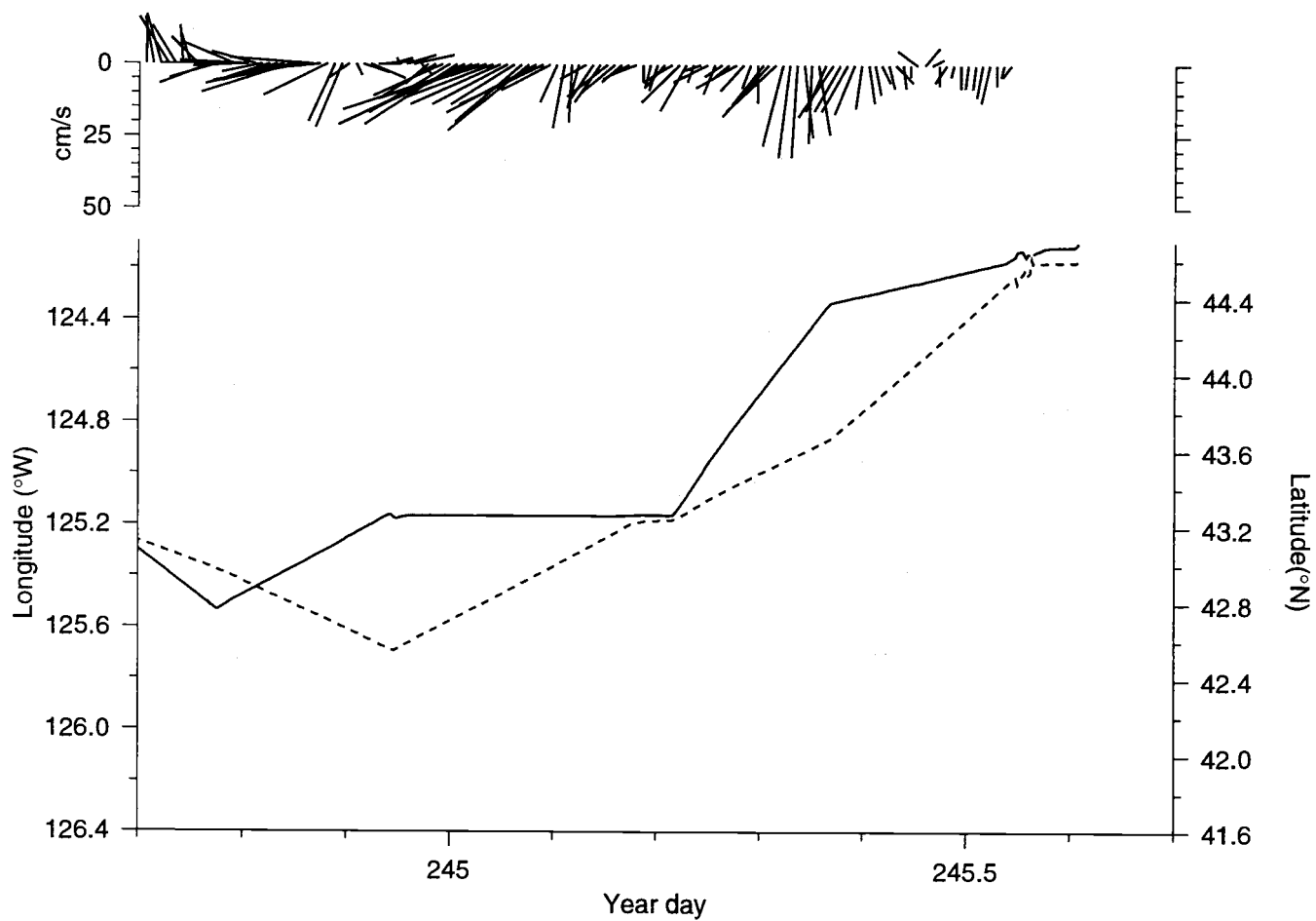
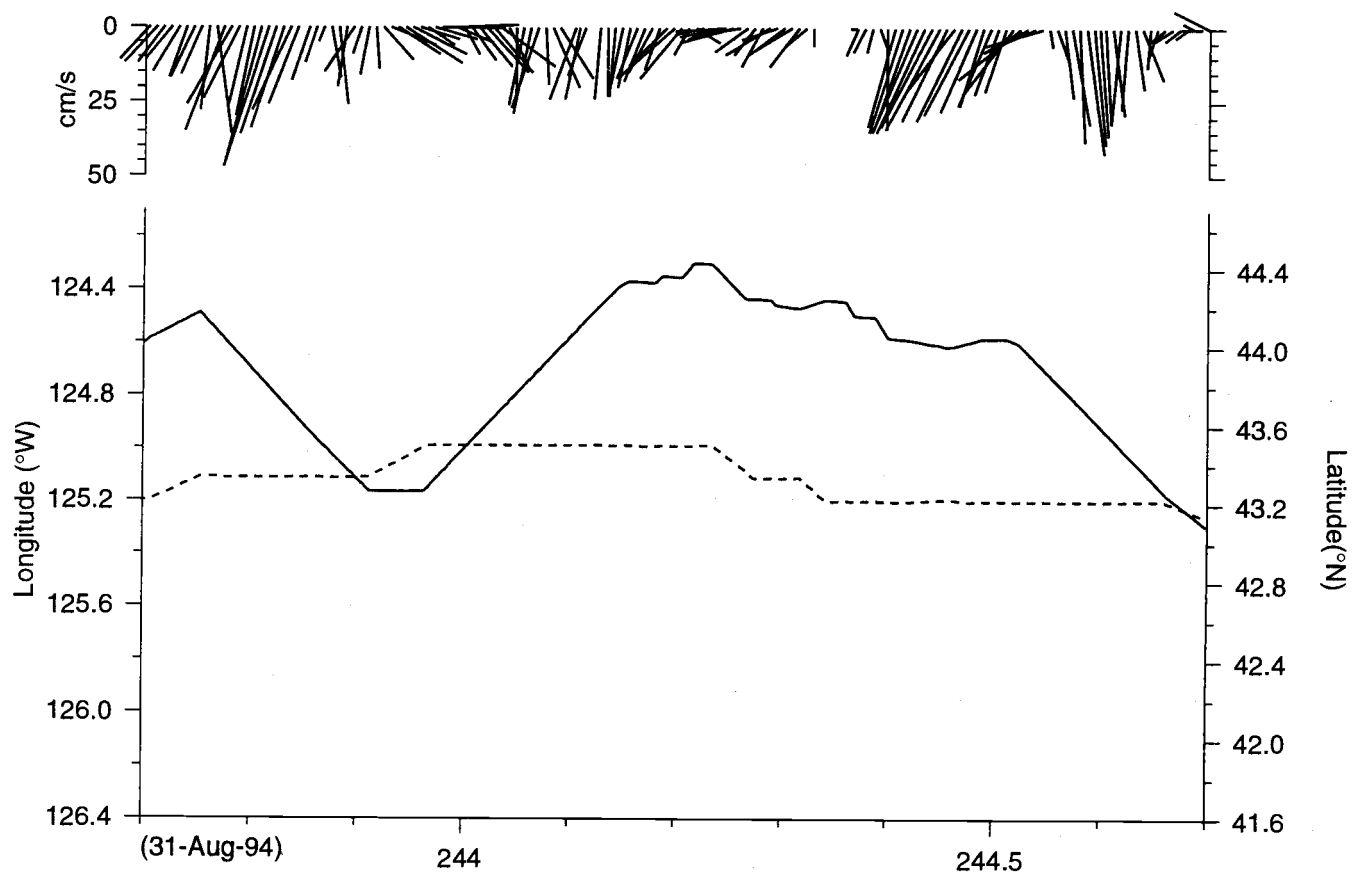
ADCP at 25 m depth, with longitude (solid) and latitude (dashed):

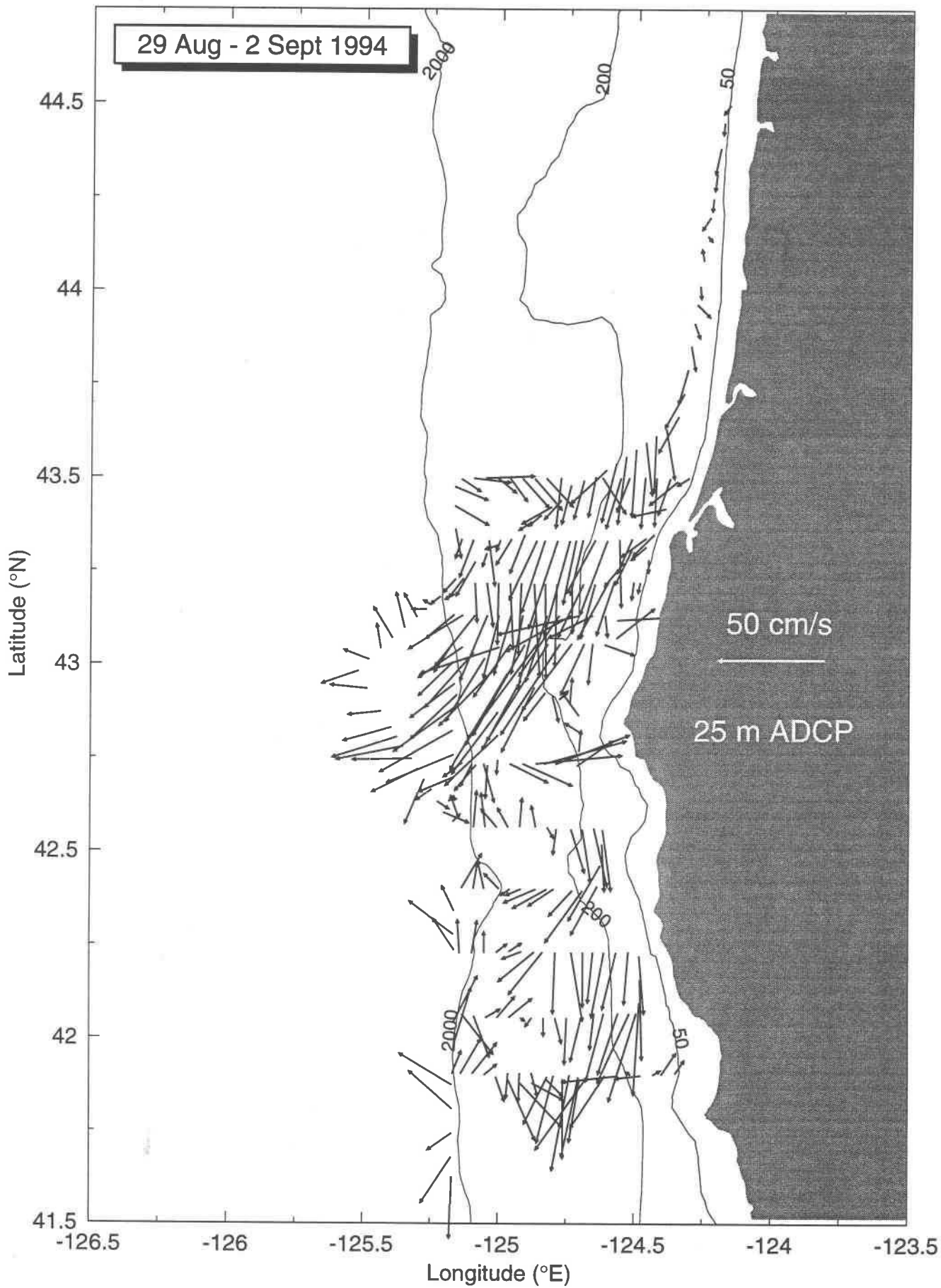


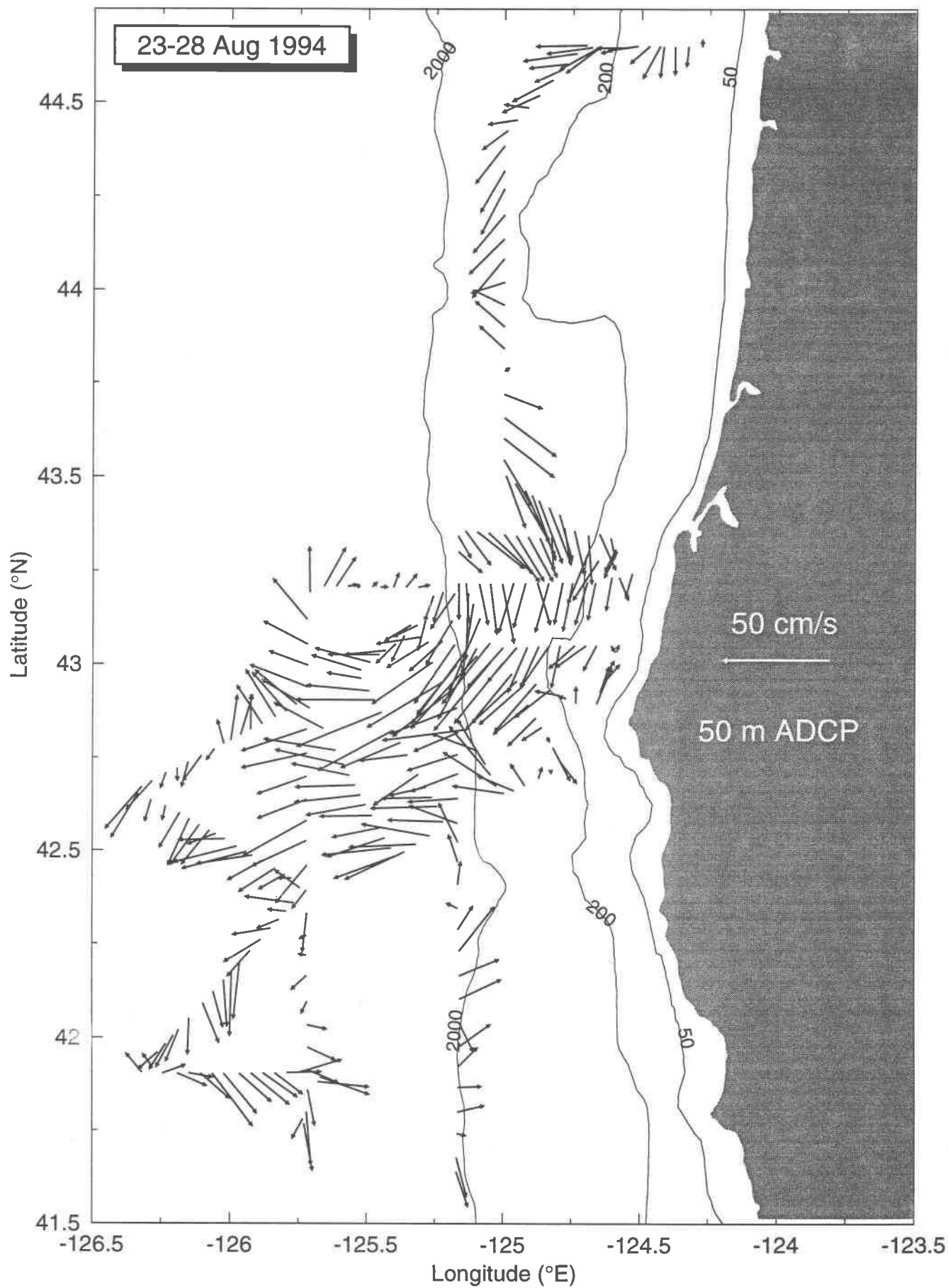
ADCP at 25 m depth, with longitude (solid) and latitude (dashed):

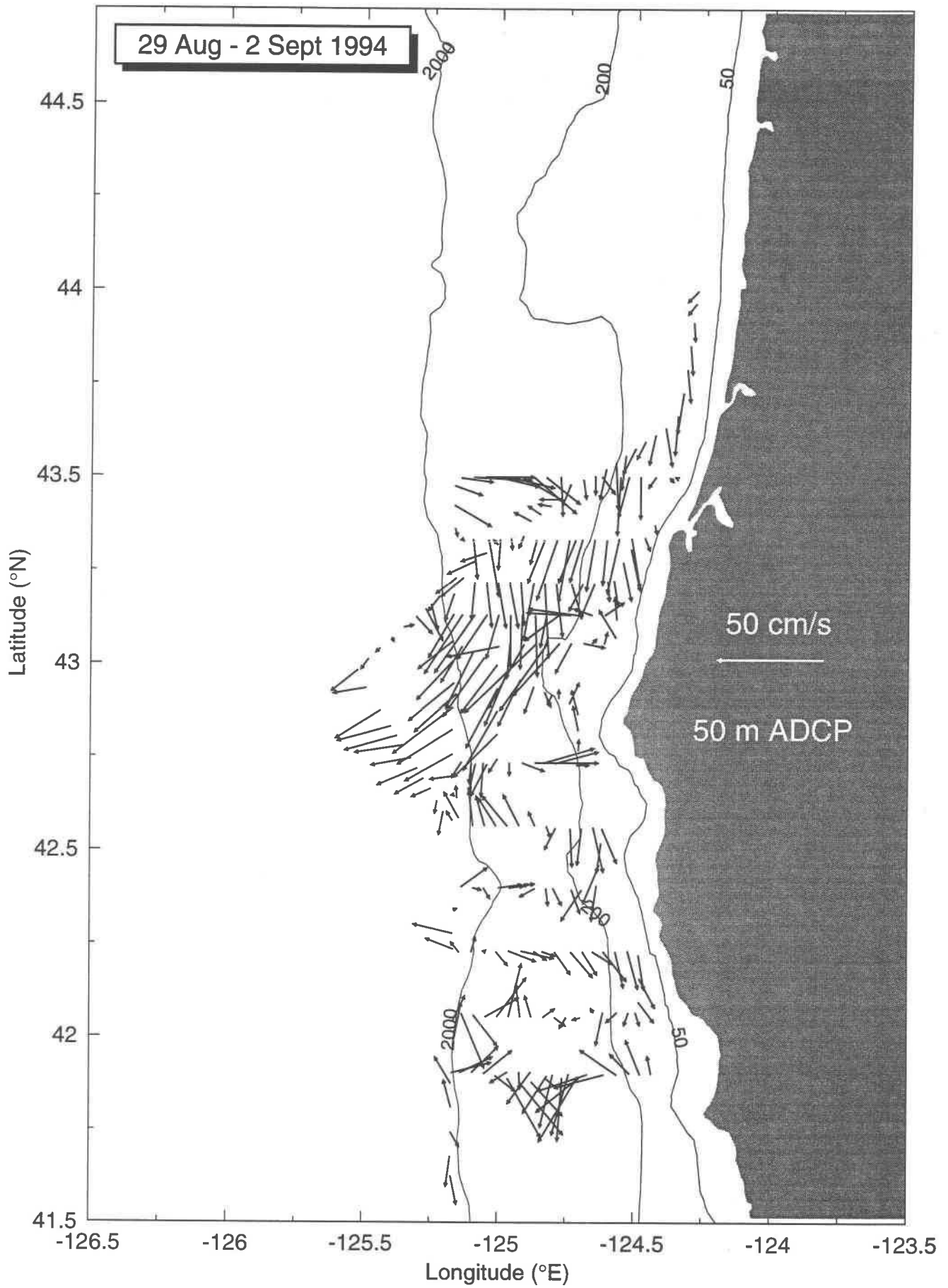


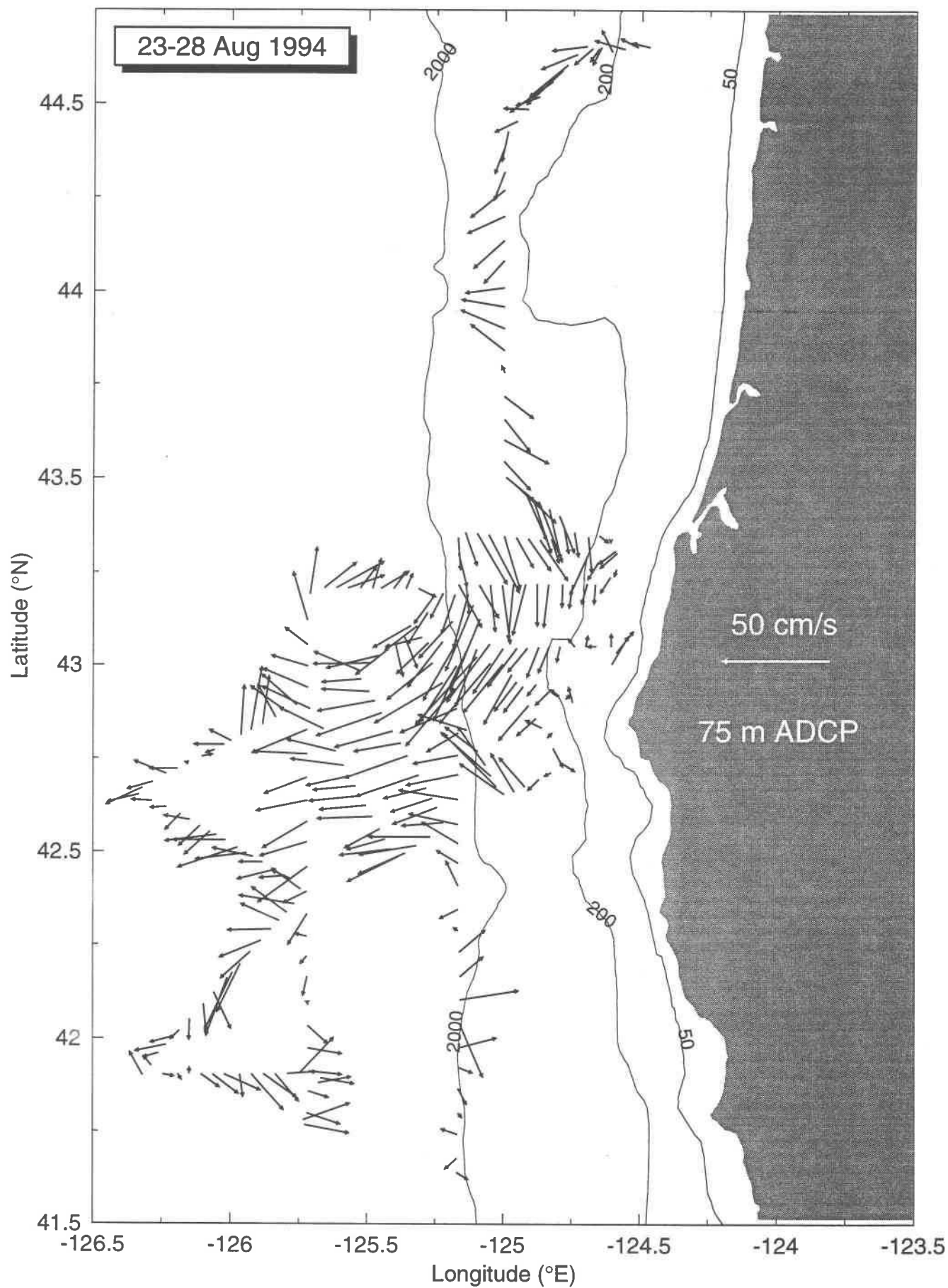
ADCP at 25 m depth, with longitude (solid) and latitude (dashed):

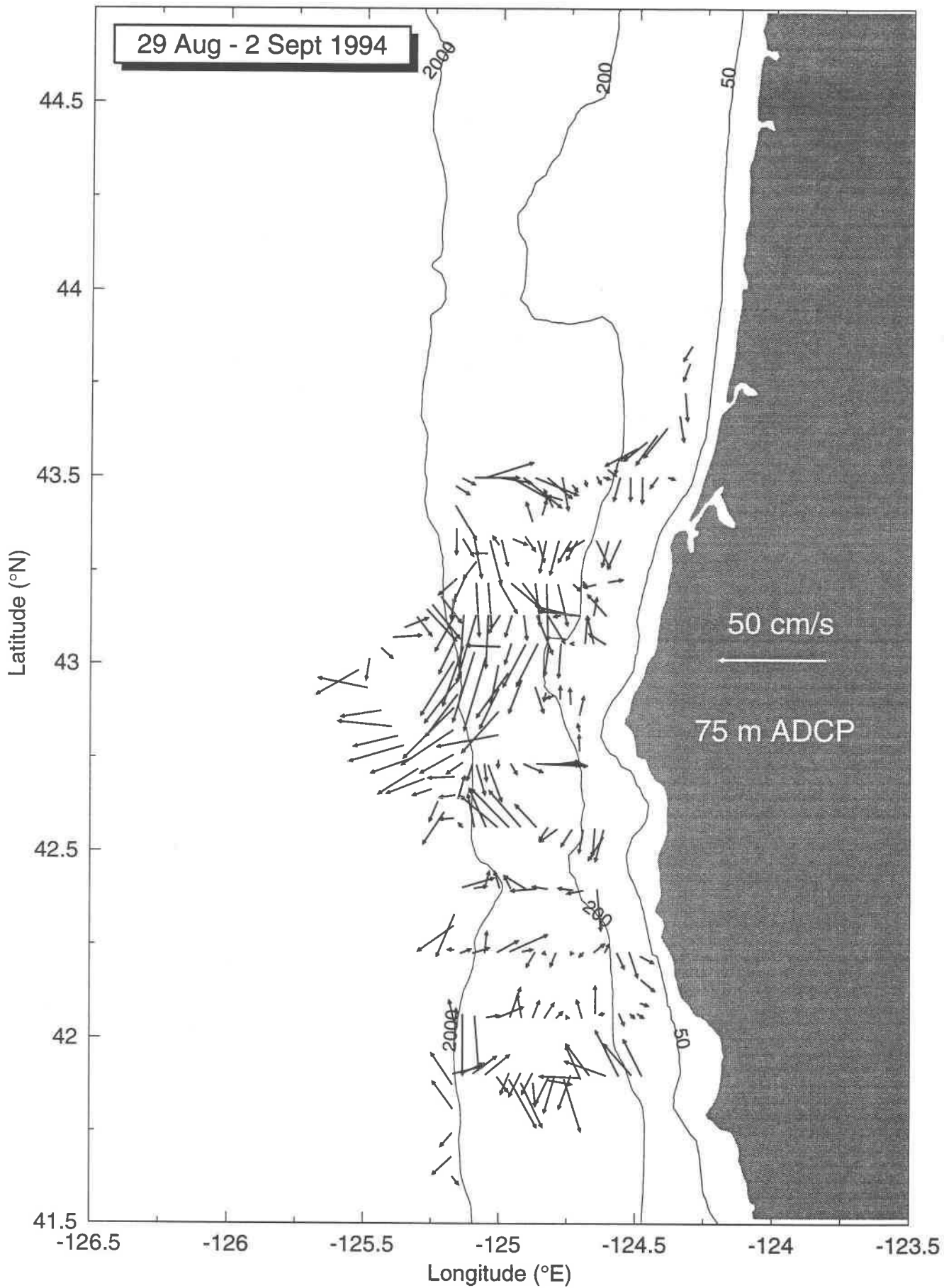


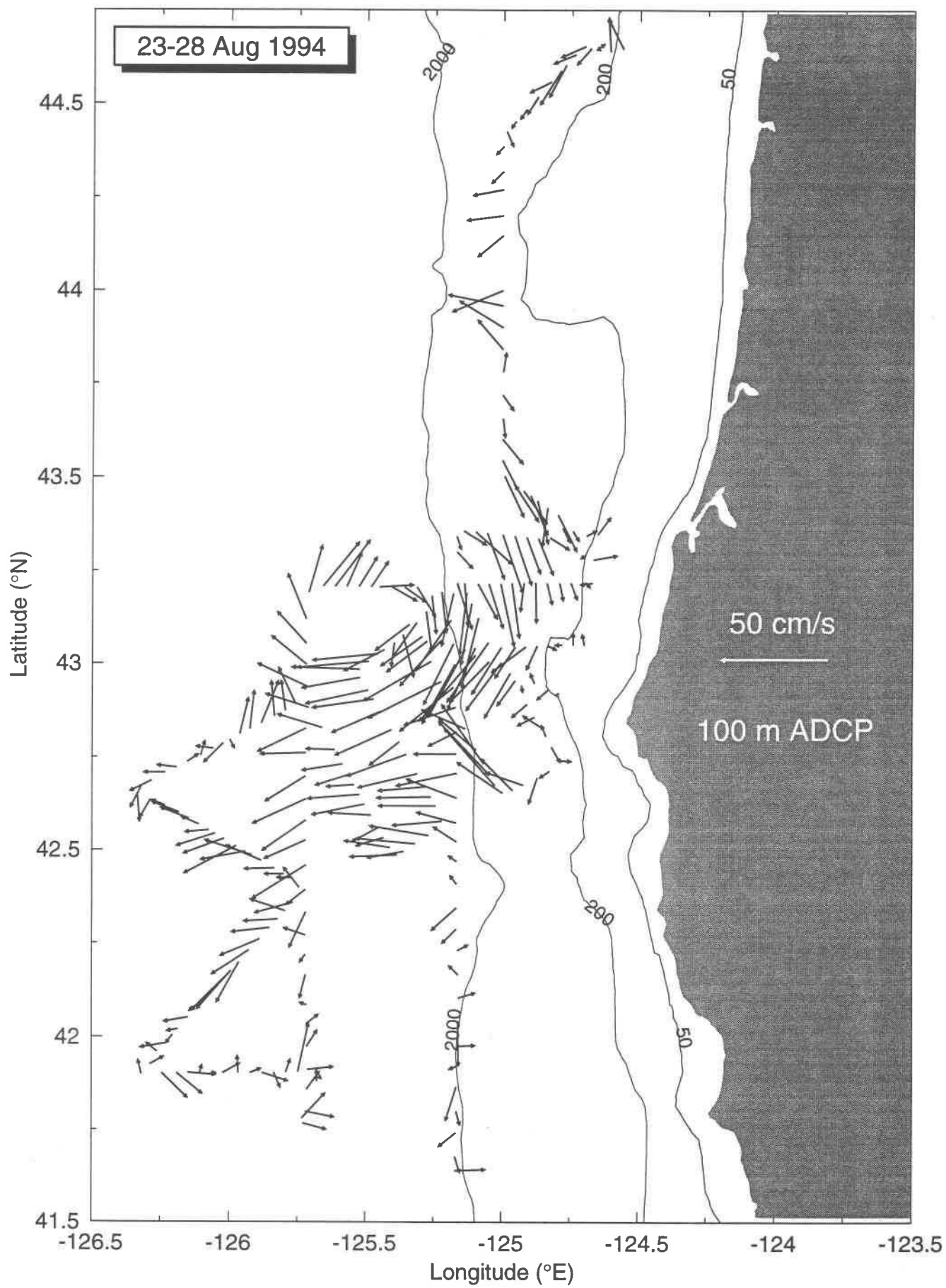


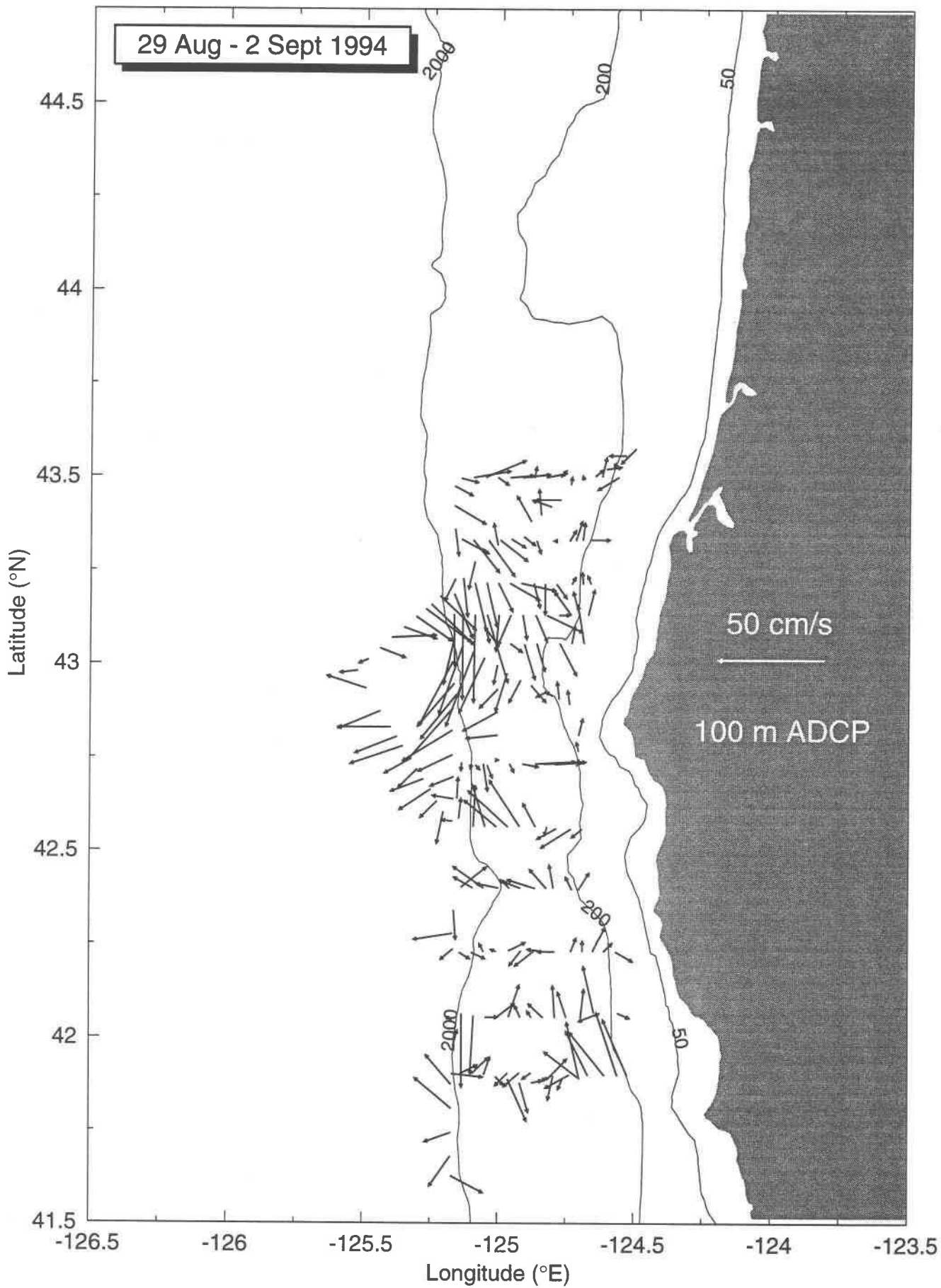


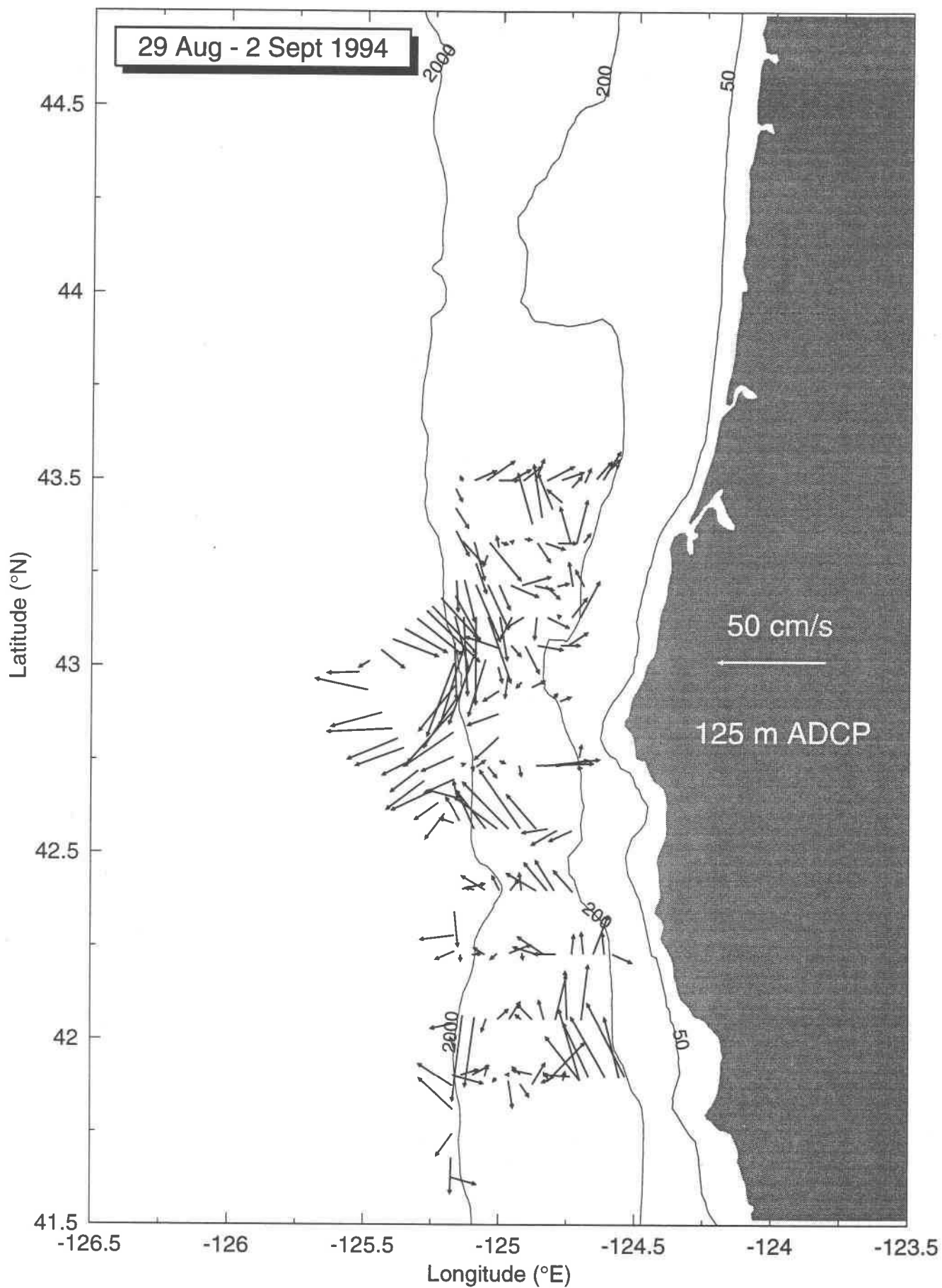


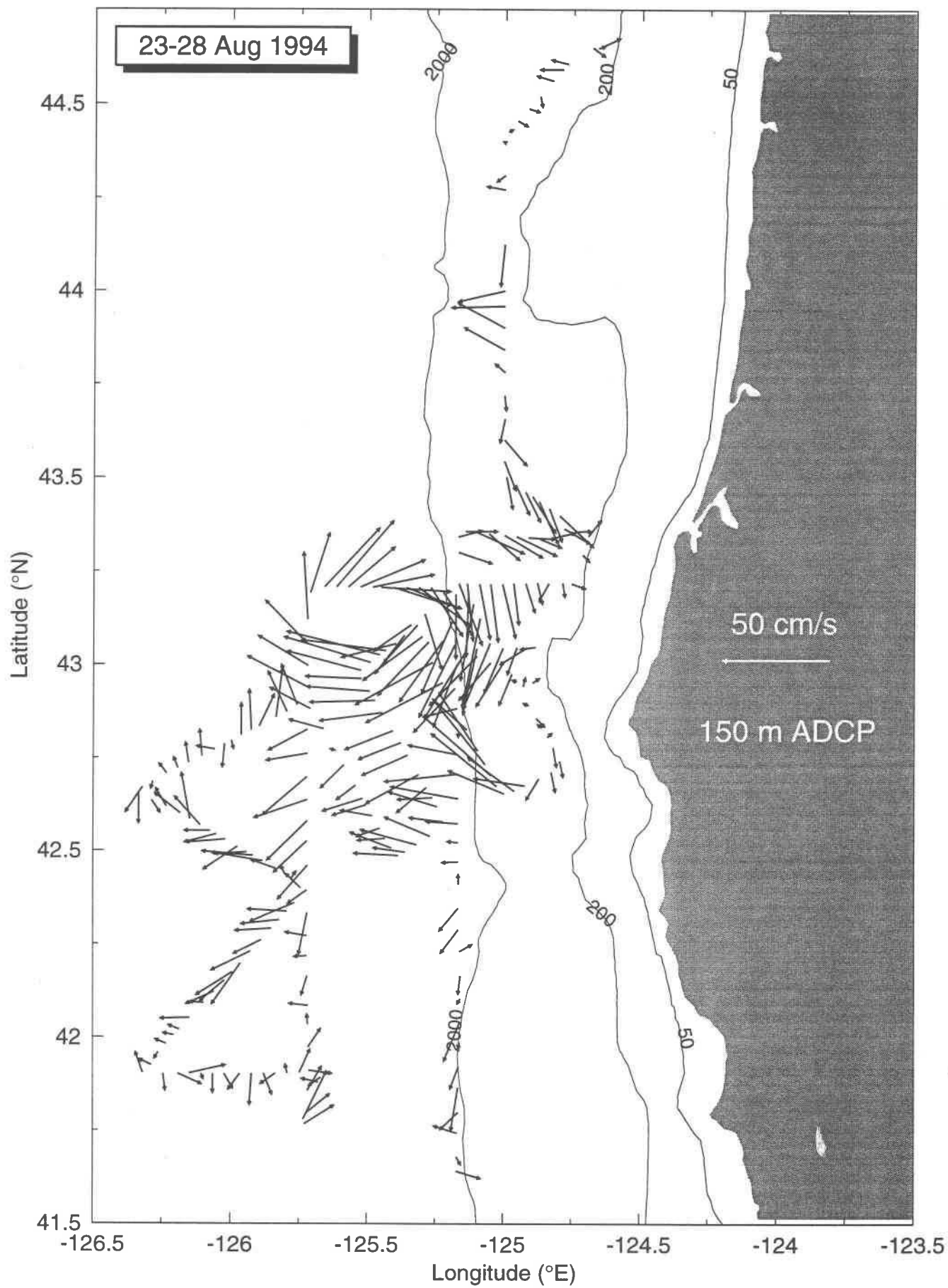


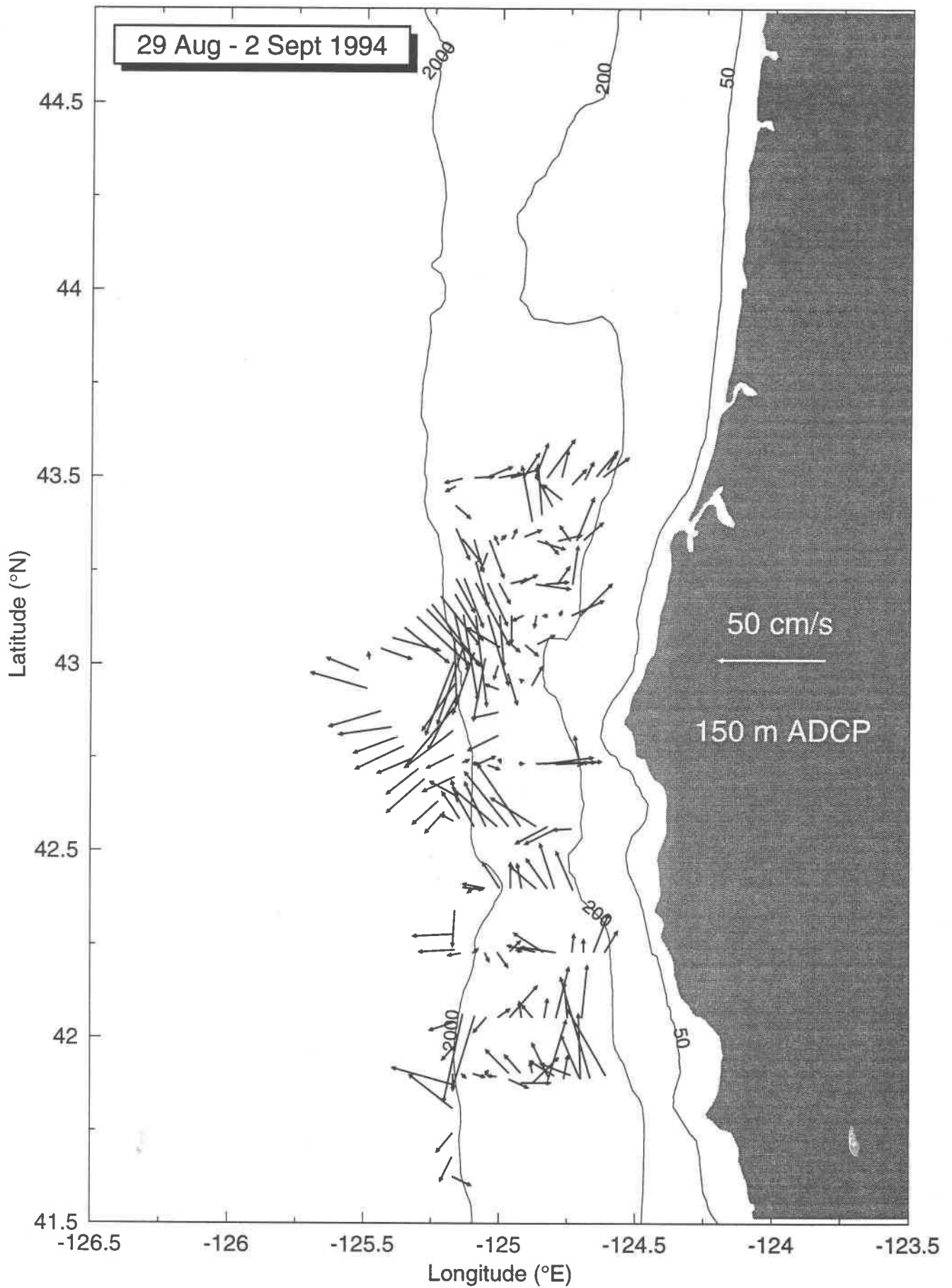


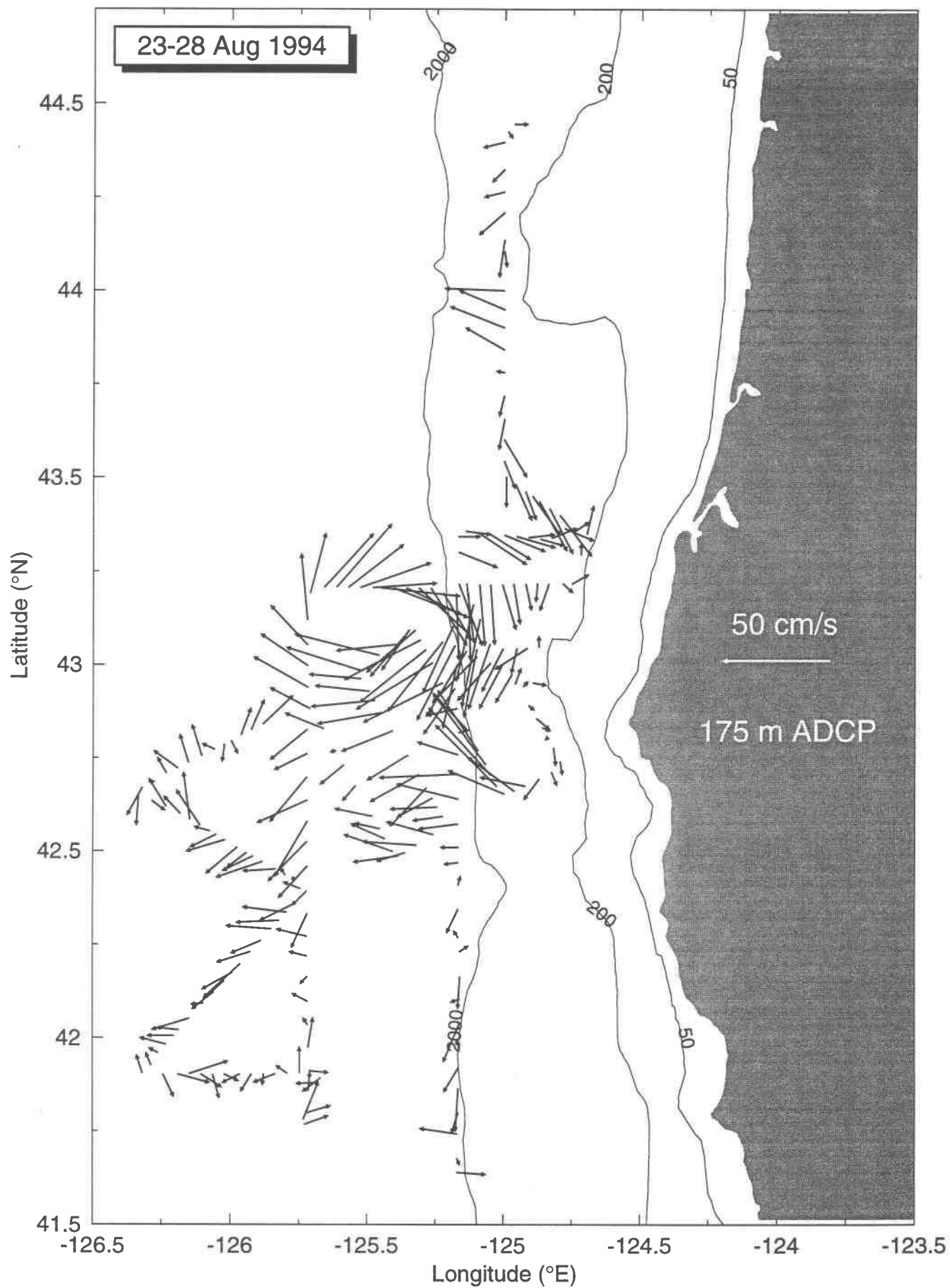


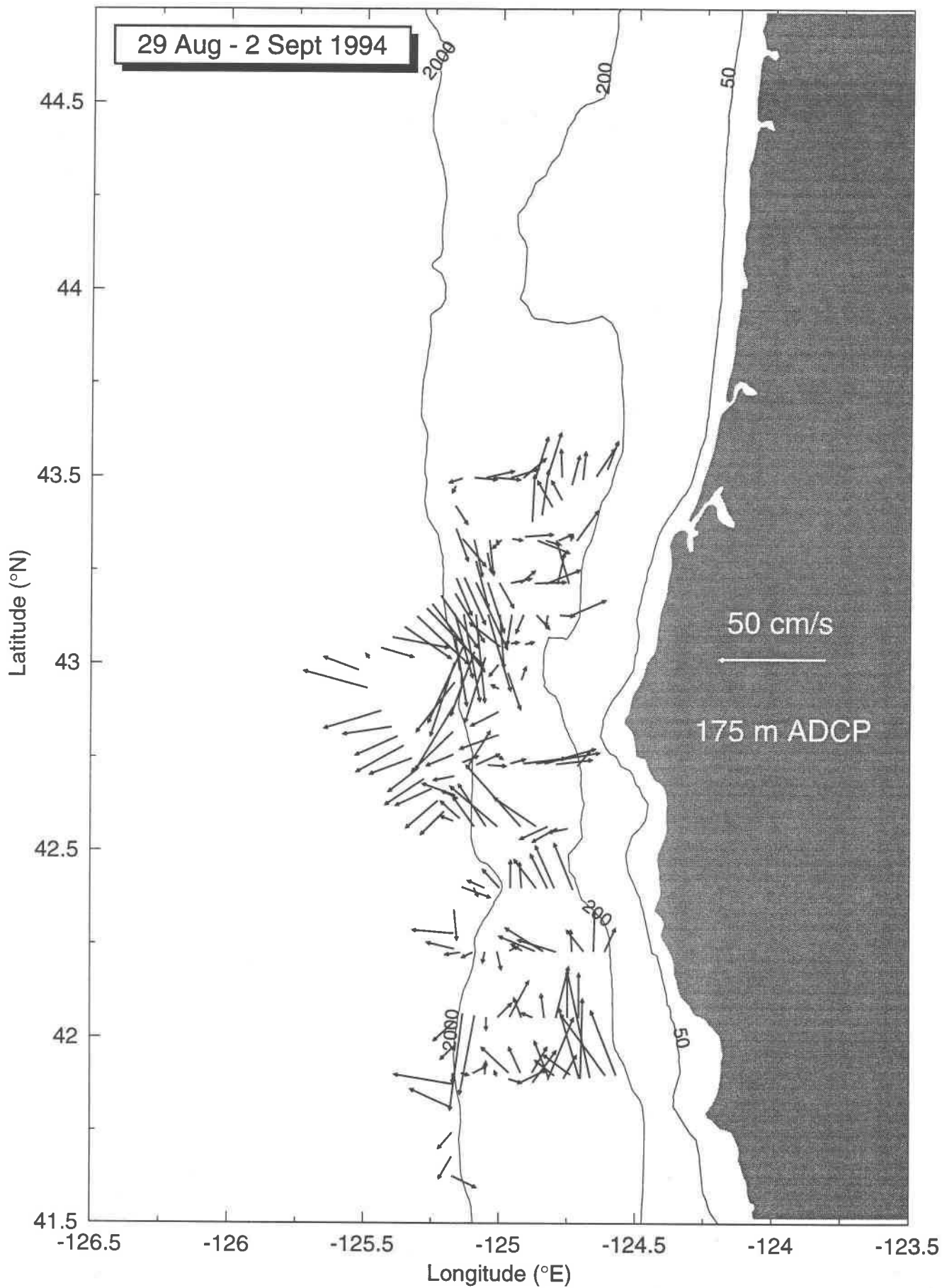


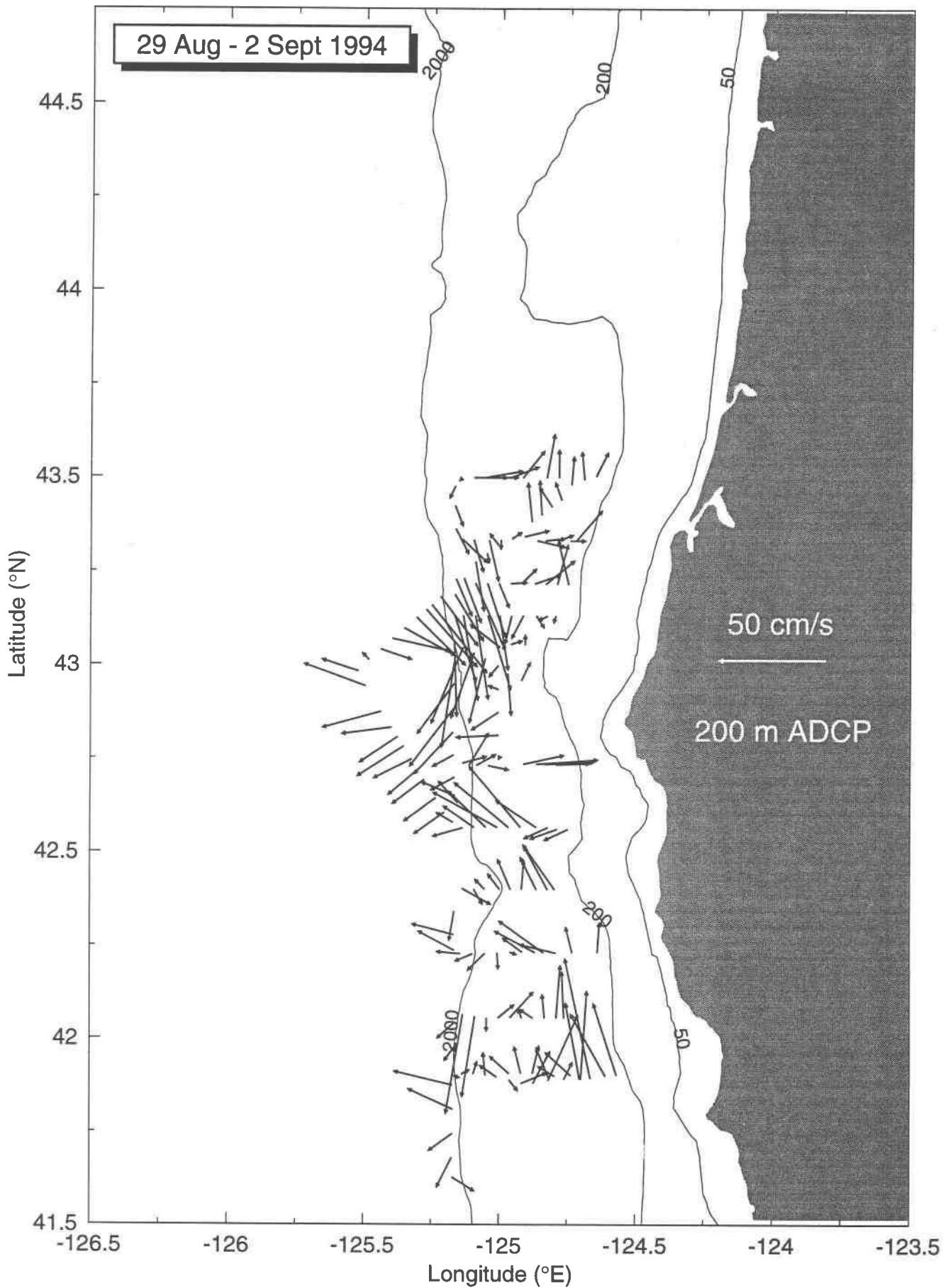


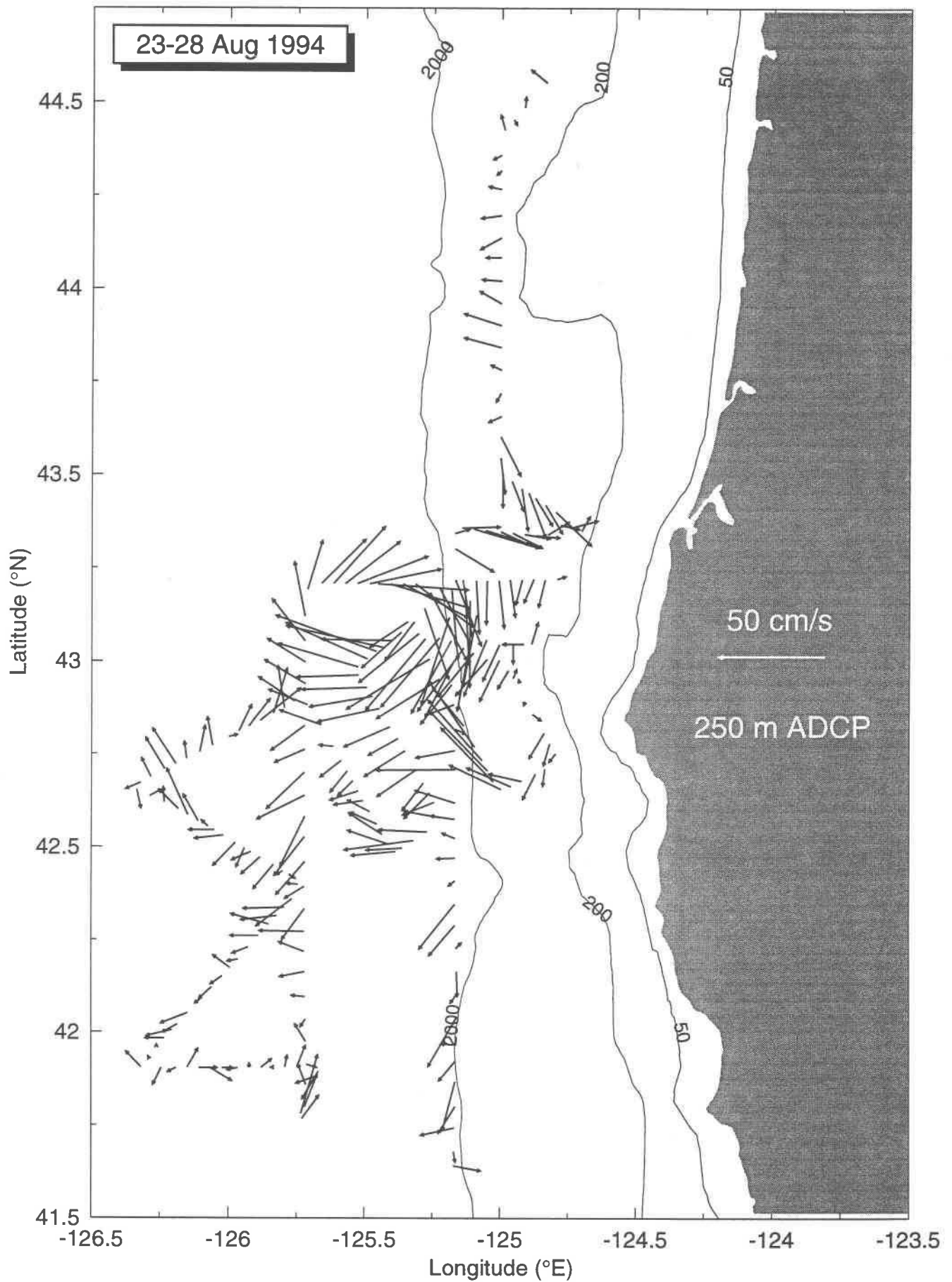


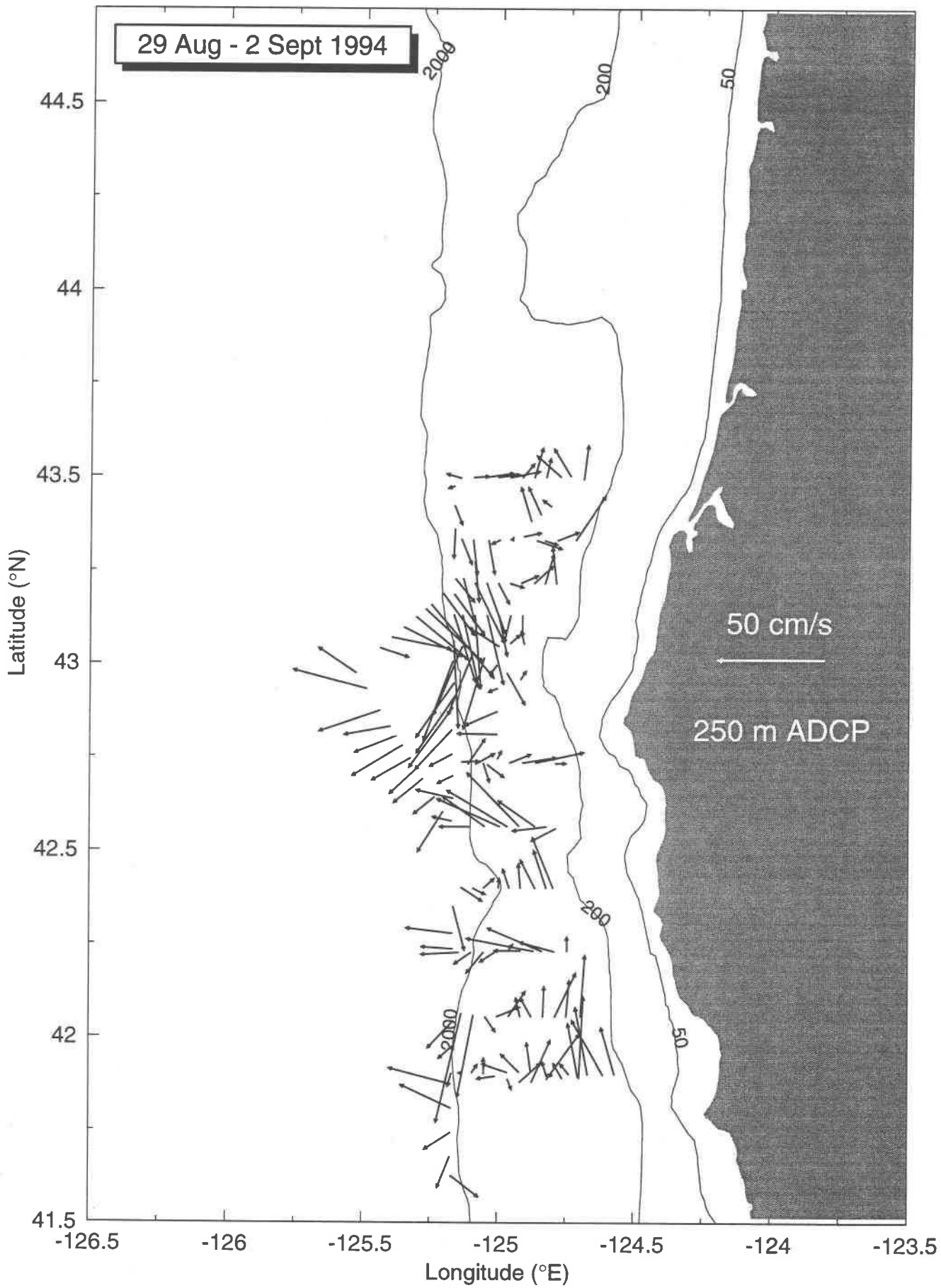


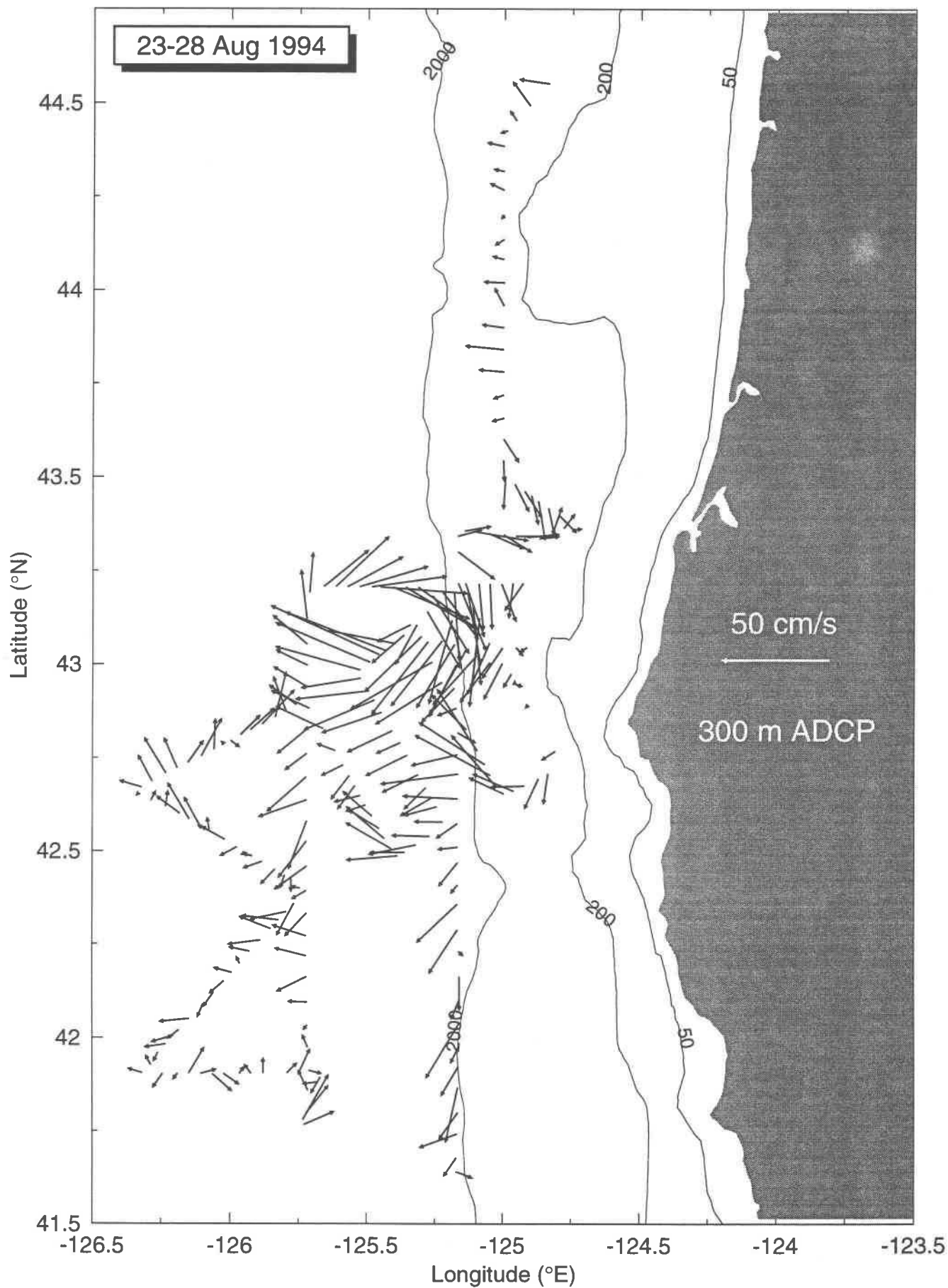


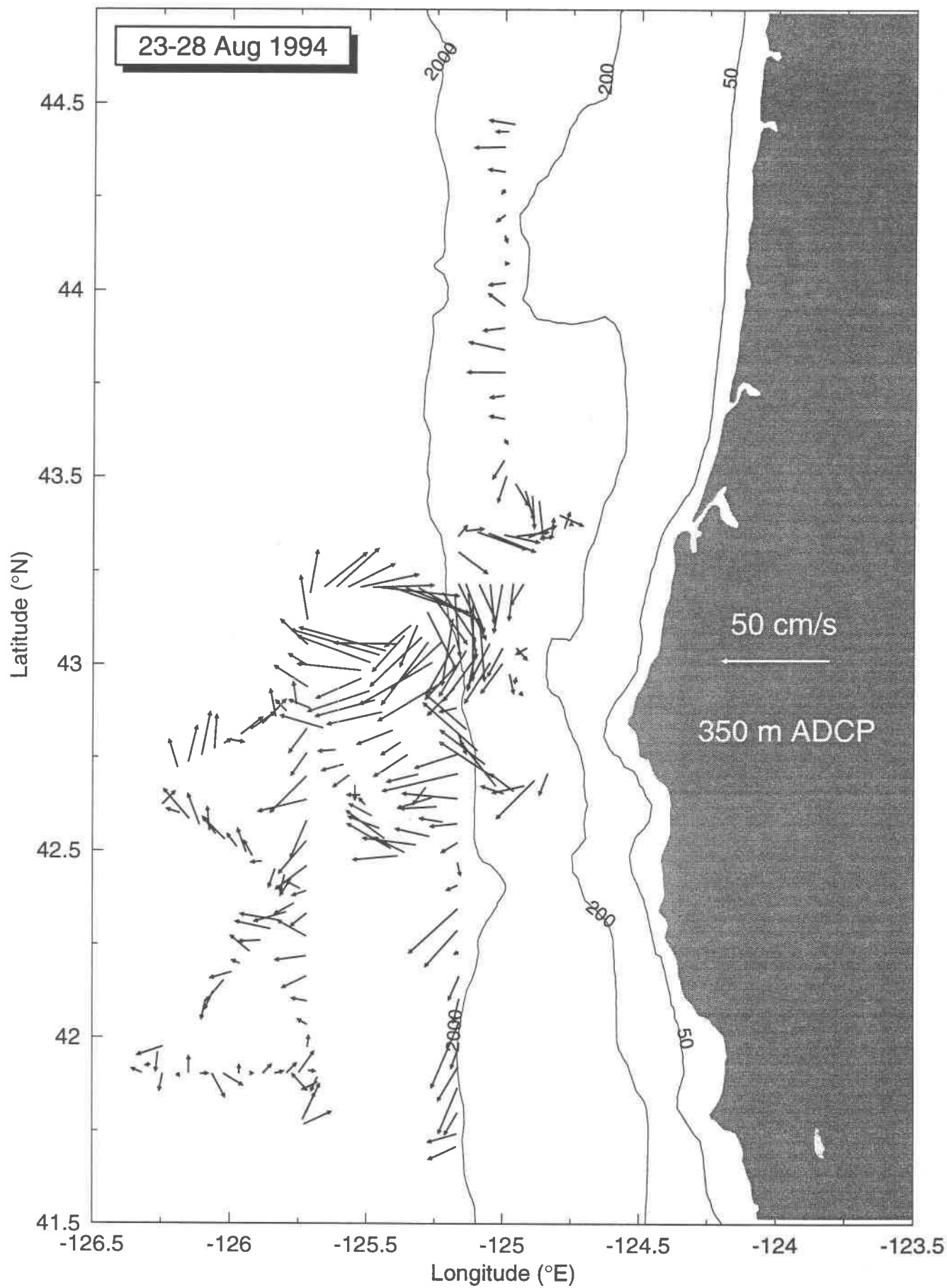




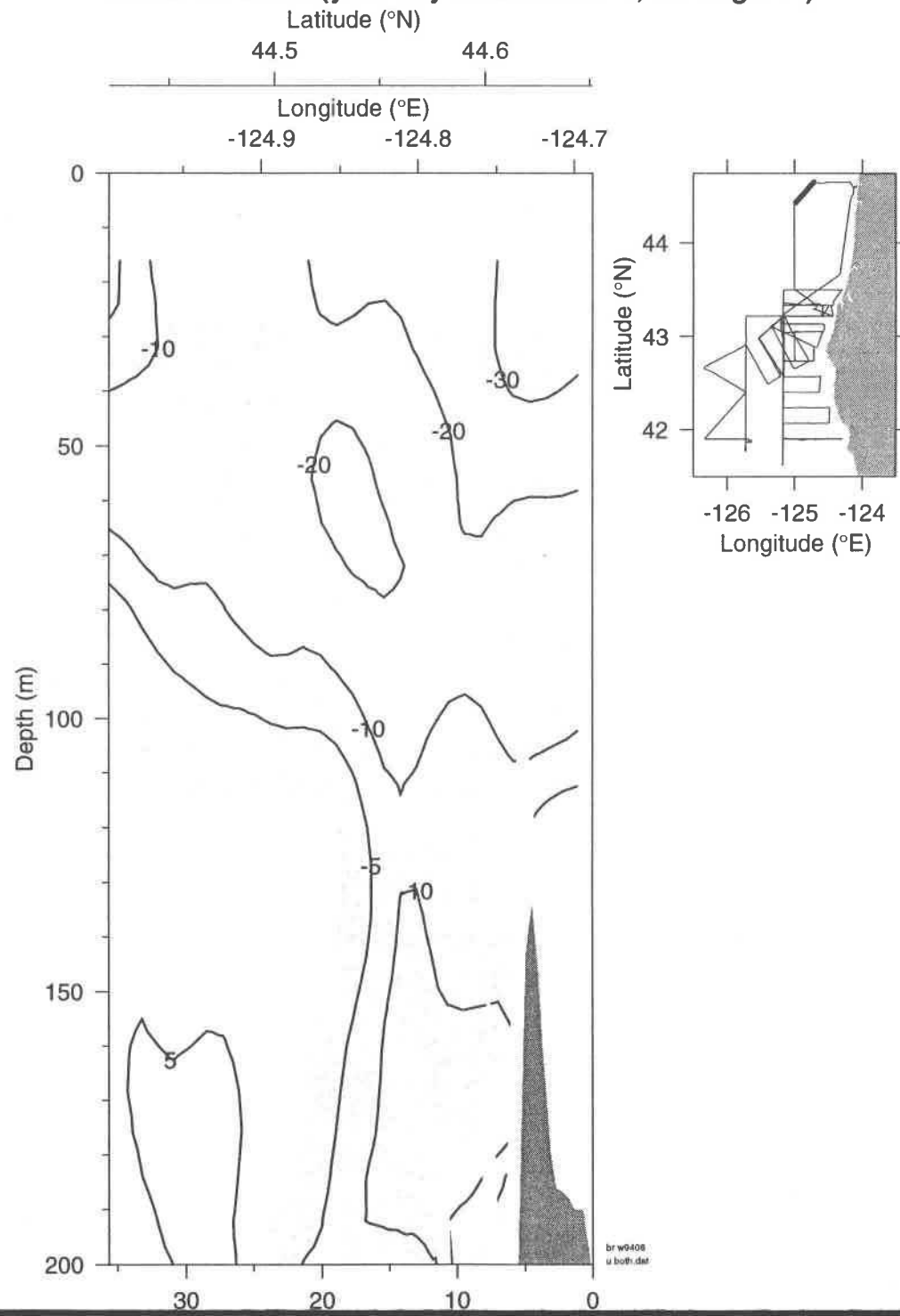








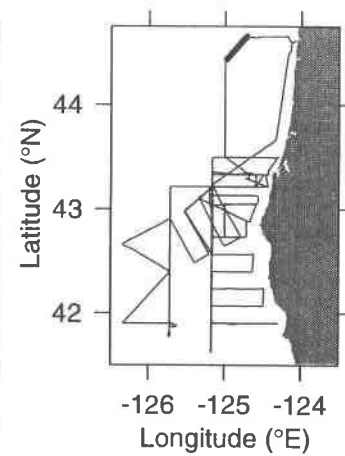
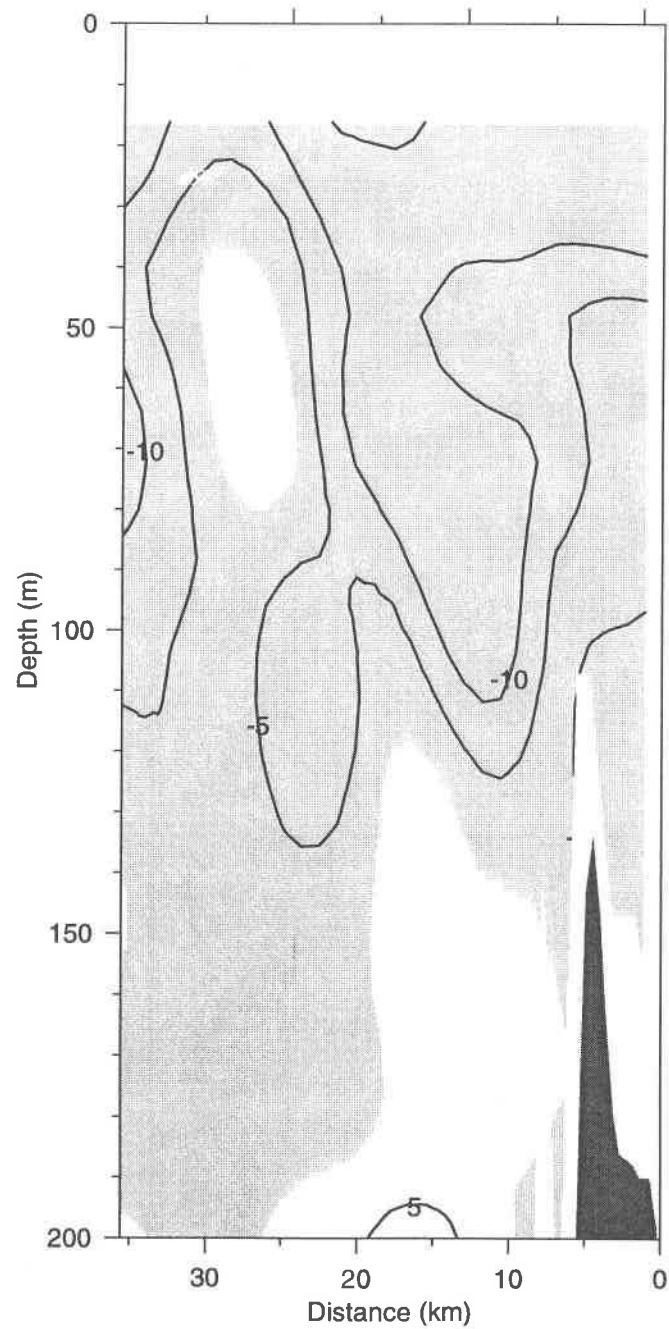
ADCP Line a U (year day 235.99-236.11, 24-Aug-94)



ADCP Line a V (year day 235.99-236.11, 24-Aug-94)

Latitude (°N)
44.5 44.6

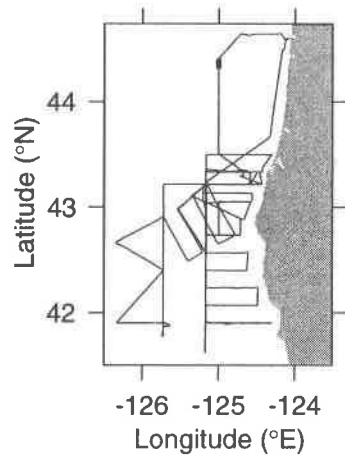
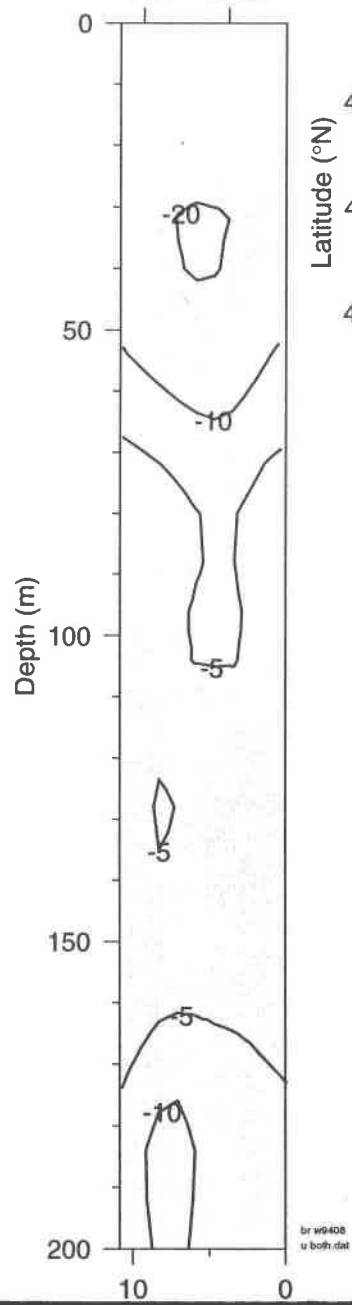
Longitude (°E)
-124.9 -124.8 -124.7



ADCP Line b0 U (year day 236.12-236.15, 24-Aug-94)

Longitude: -125.00 °E

Latitude (°N)
44.4 44.35

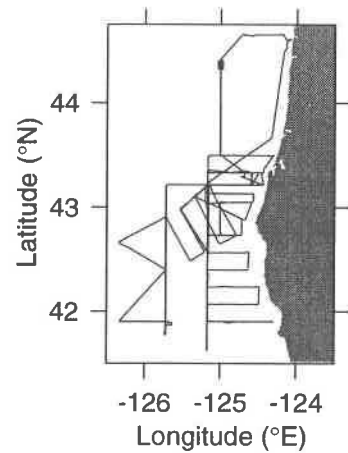
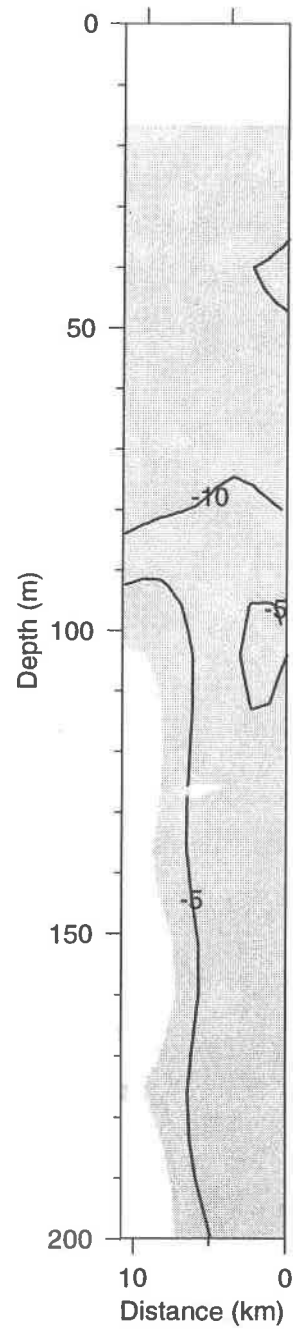


br w9408
u both.dat

Longitude: -125.00 °E

Latitude (°N)

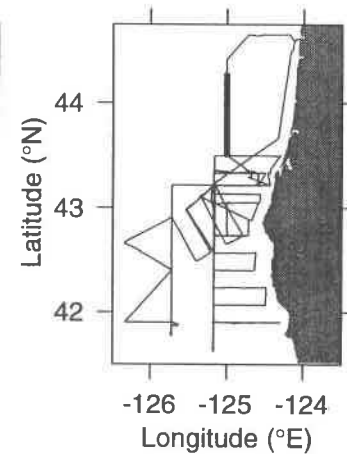
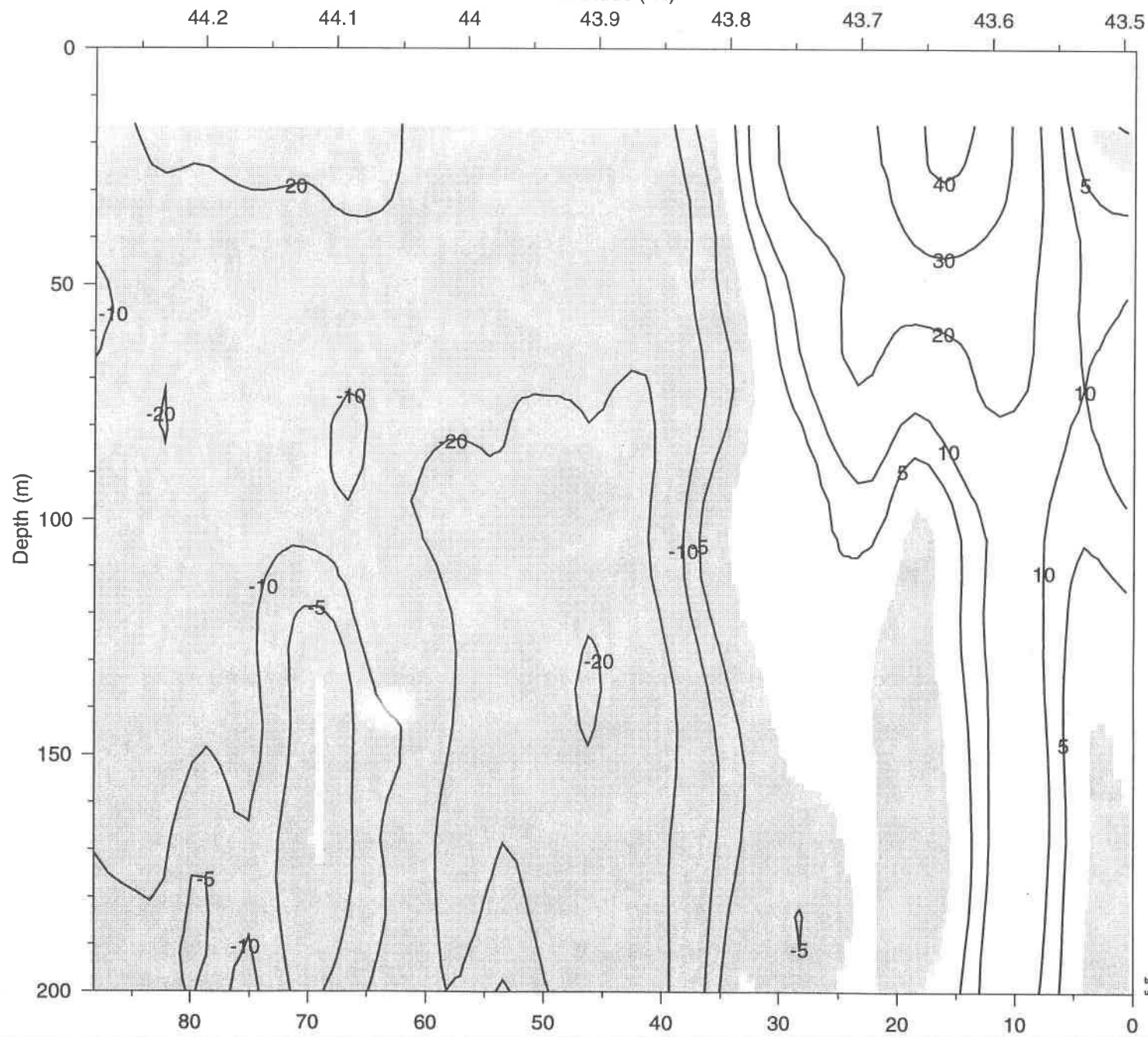
44.4 44.35



ADCP Line b U (year day 236.17-236.44, 24-Aug-94)

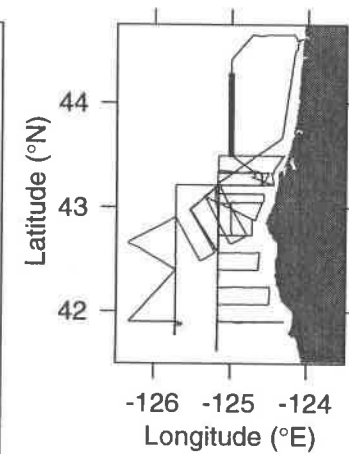
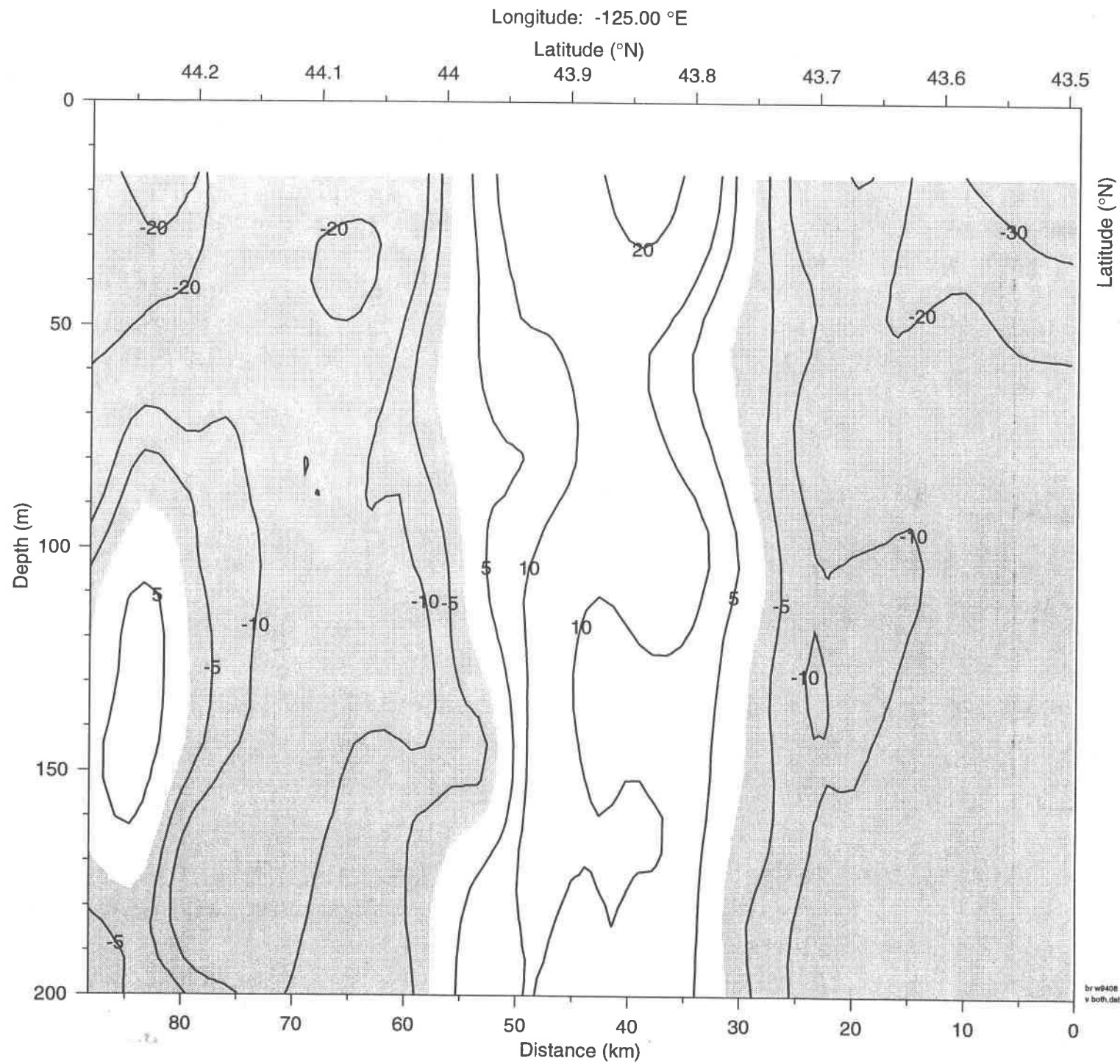
Longitude: -125.00 °E

Latitude (°N)



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u both def.

ADCP Line b V (year day 236.17-236.44, 24-Aug-94)



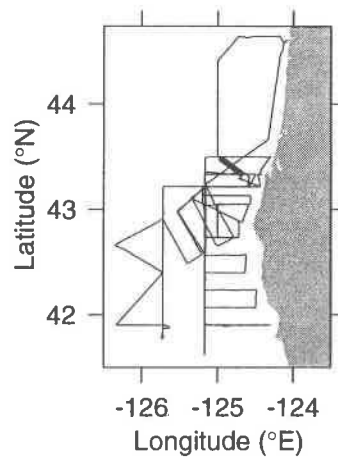
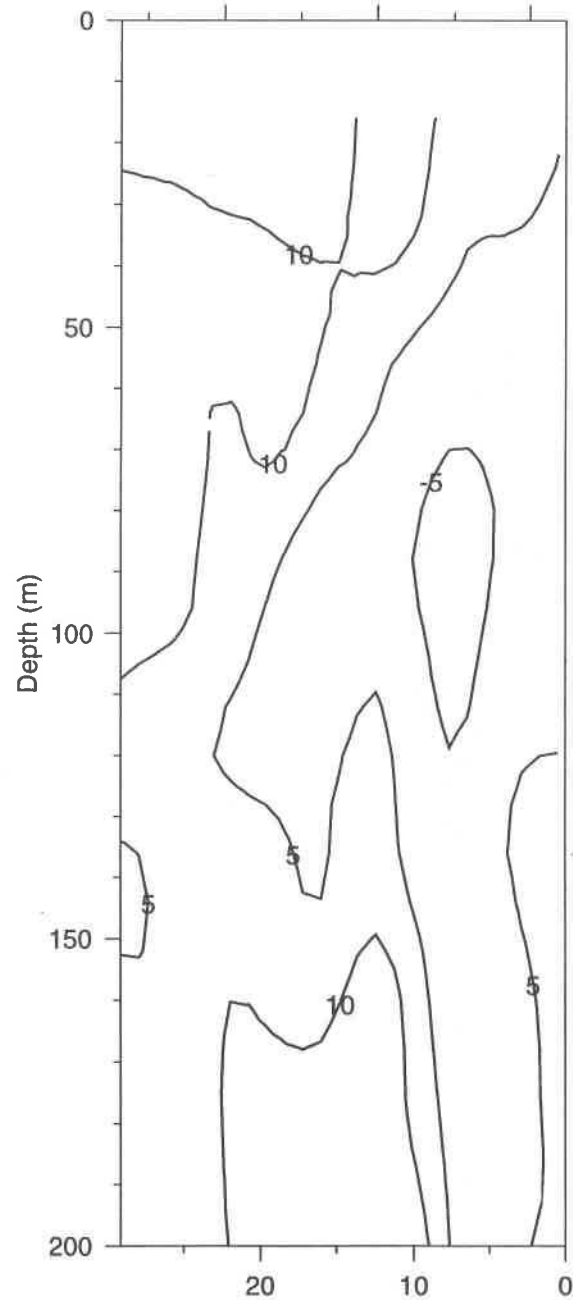
ADCP Line c U (year day 236.44-236.53, 24-Aug-94)

Latitude (°N)

43.45 43.4 43.35

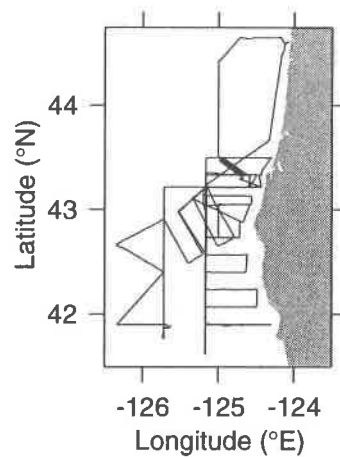
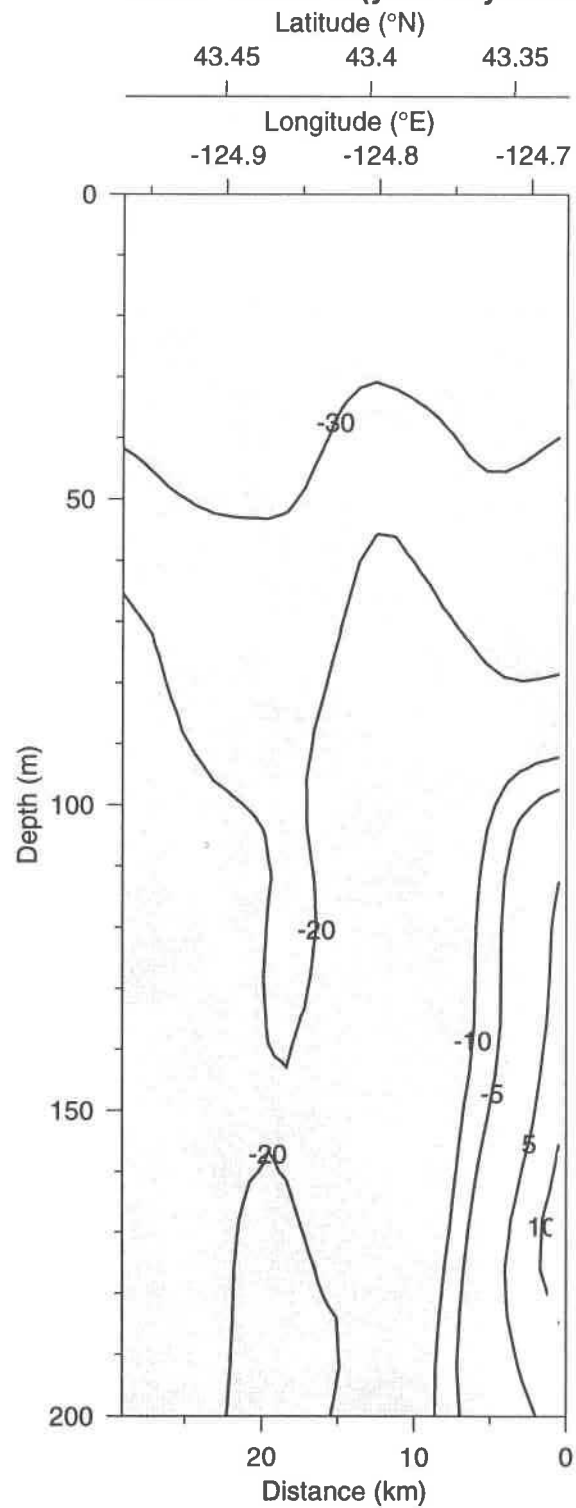
Longitude (°E)

-124.9 -124.8 -124.7



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u both.dat

ADCP Line c V (year day 236.44-236.53, 24-Aug-94)



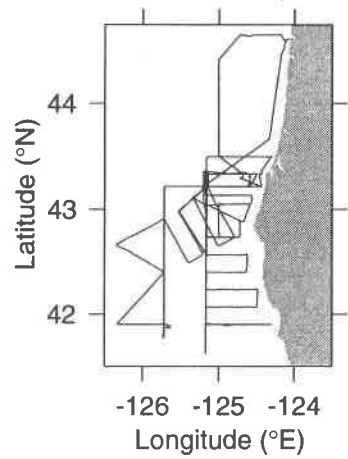
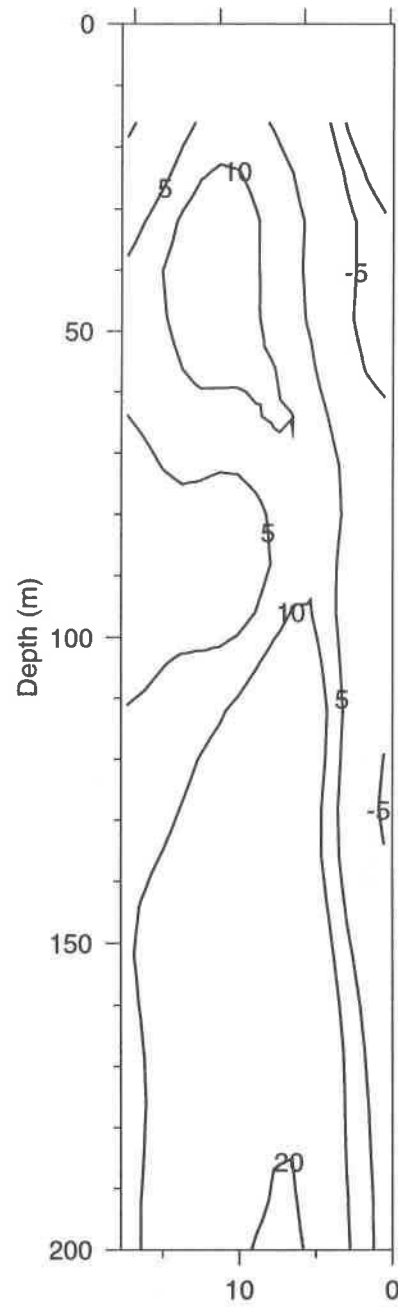
br w0408
v both.dat

ADCP Line 0-1 U (year day 237.20-237.27, 25-Aug-94)

Longitude: -125.17 °E

Latitude (°N)

43.35 43.3 43.25 43.2



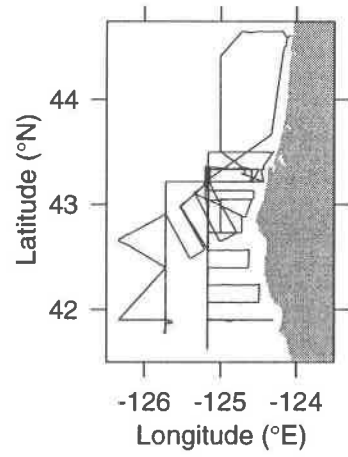
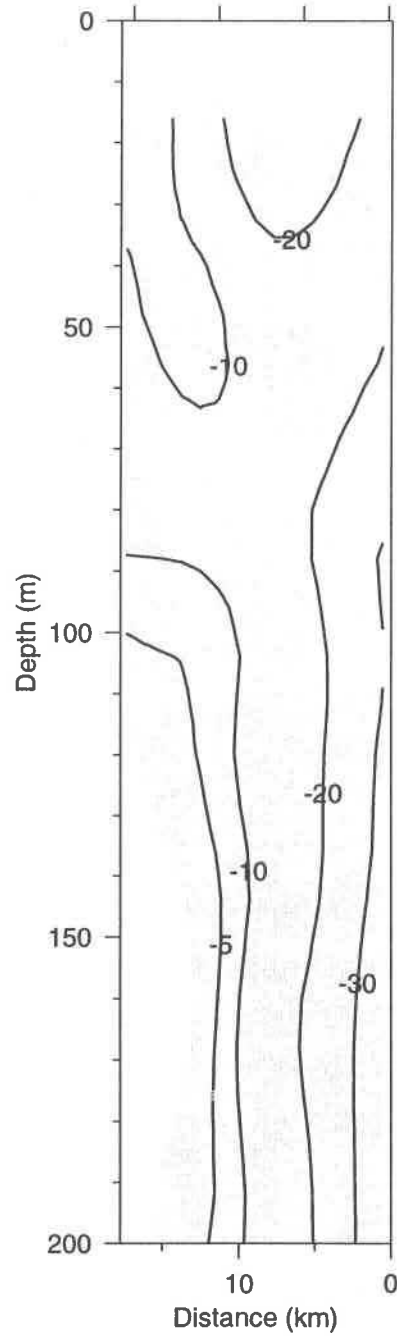
br w9408
u both del

ADCP Line 0-1 V (year day 237.20-237.27, 25-Aug-94)

Longitude: -125.17 °E

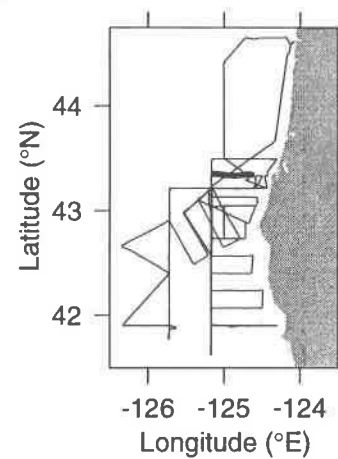
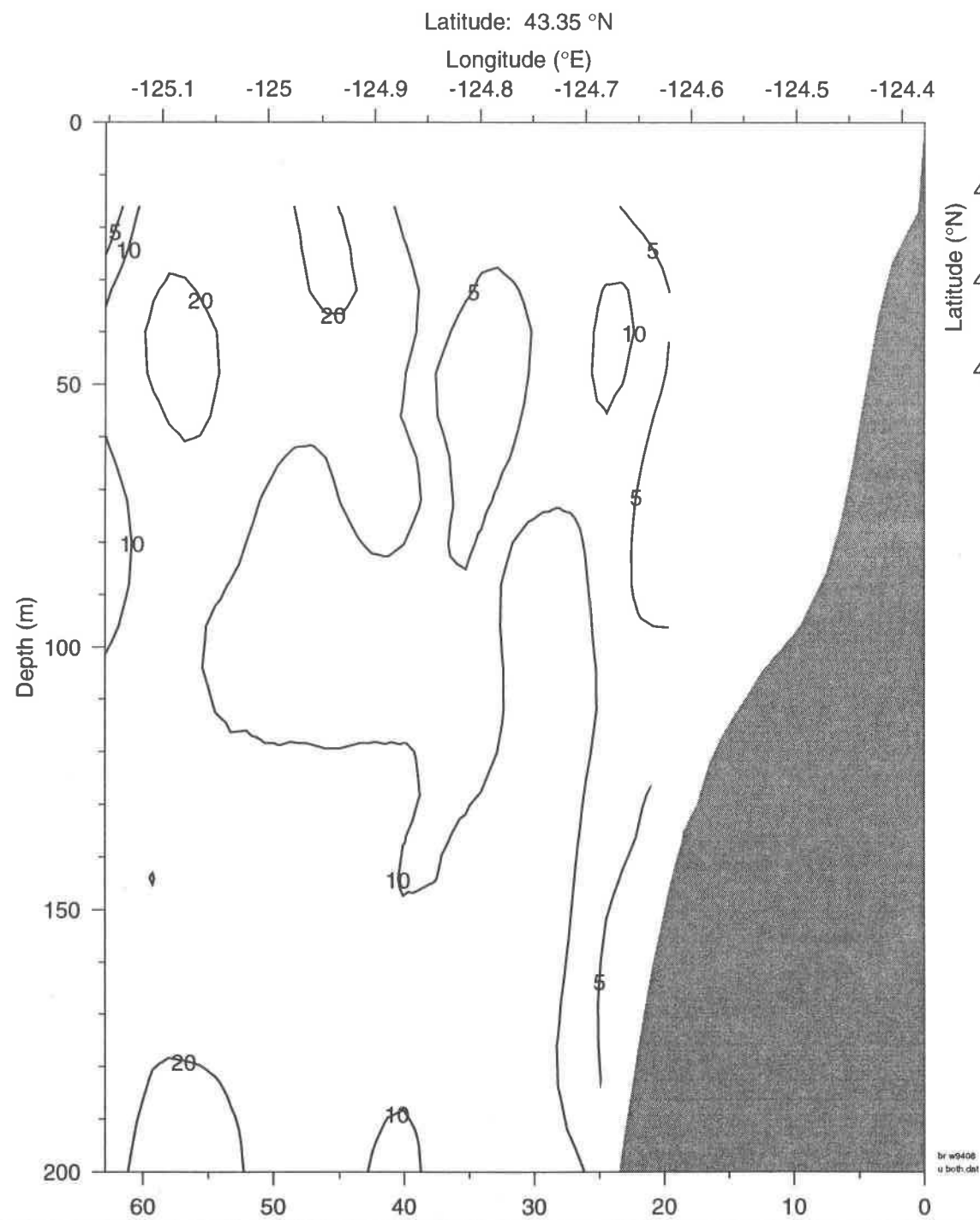
Latitude (°N)

43.35 43.3 43.25 43.2



br w9408
v both.dat

ADCP Line 1 U (year day 237.27-237.40, 25-Aug-94)



br w9408
u both.dat

Latitude: 43.35 °N

Longitude (°E)

-125.1 -125 -124.9 -124.8 -124.7 -124.6 -124.5 -124.4

0

50

Depth (m)

100

150

200

60

50

40

30

20

10

0

Distance (km)

30

-20

-10

-5

5

10

br w9408
v both del

44

43

42

-126

-125

-124

Longitude (°E)

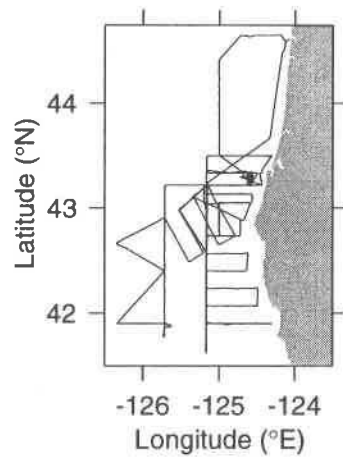
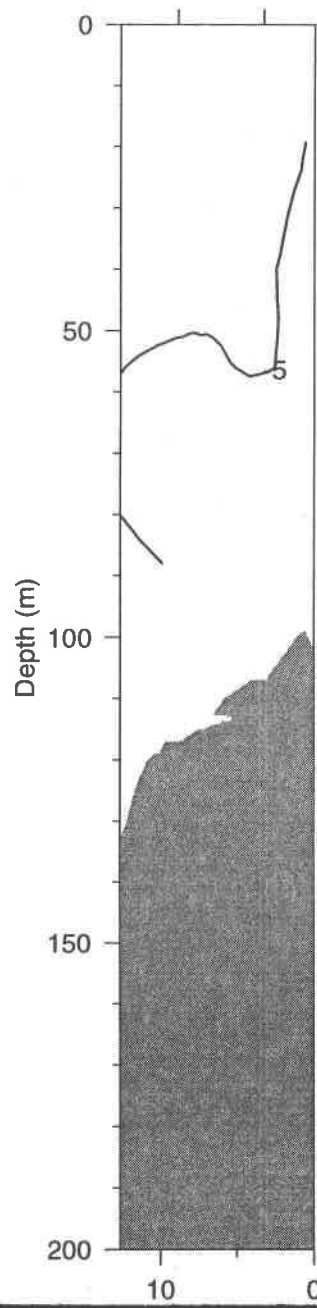
Latitude (°N)

55

ADCP Line 1-2 U (year day 237.40-237.46, 25-Aug-94)

Longitude: -124.59 °E

Latitude (°N)
43.3 43.25

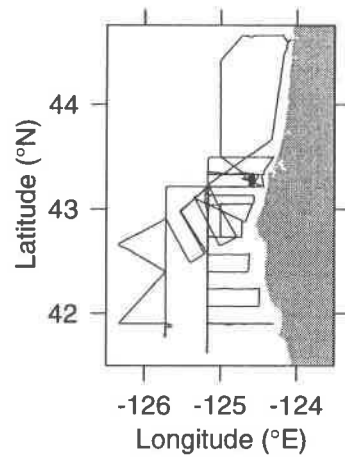
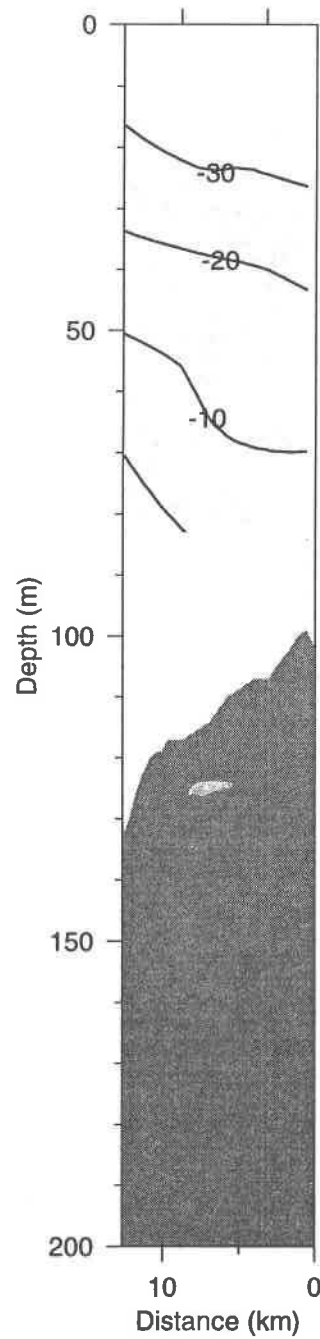


br w5408
u both det

ADCP Line 1-2 V (year day 237.40-237.46, 25-Aug-94)

Longitude: -124.59 °E

Latitude (°N)
43.3 43.25



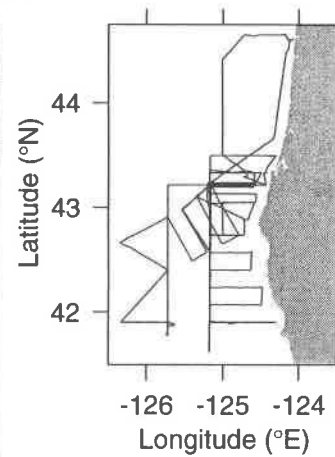
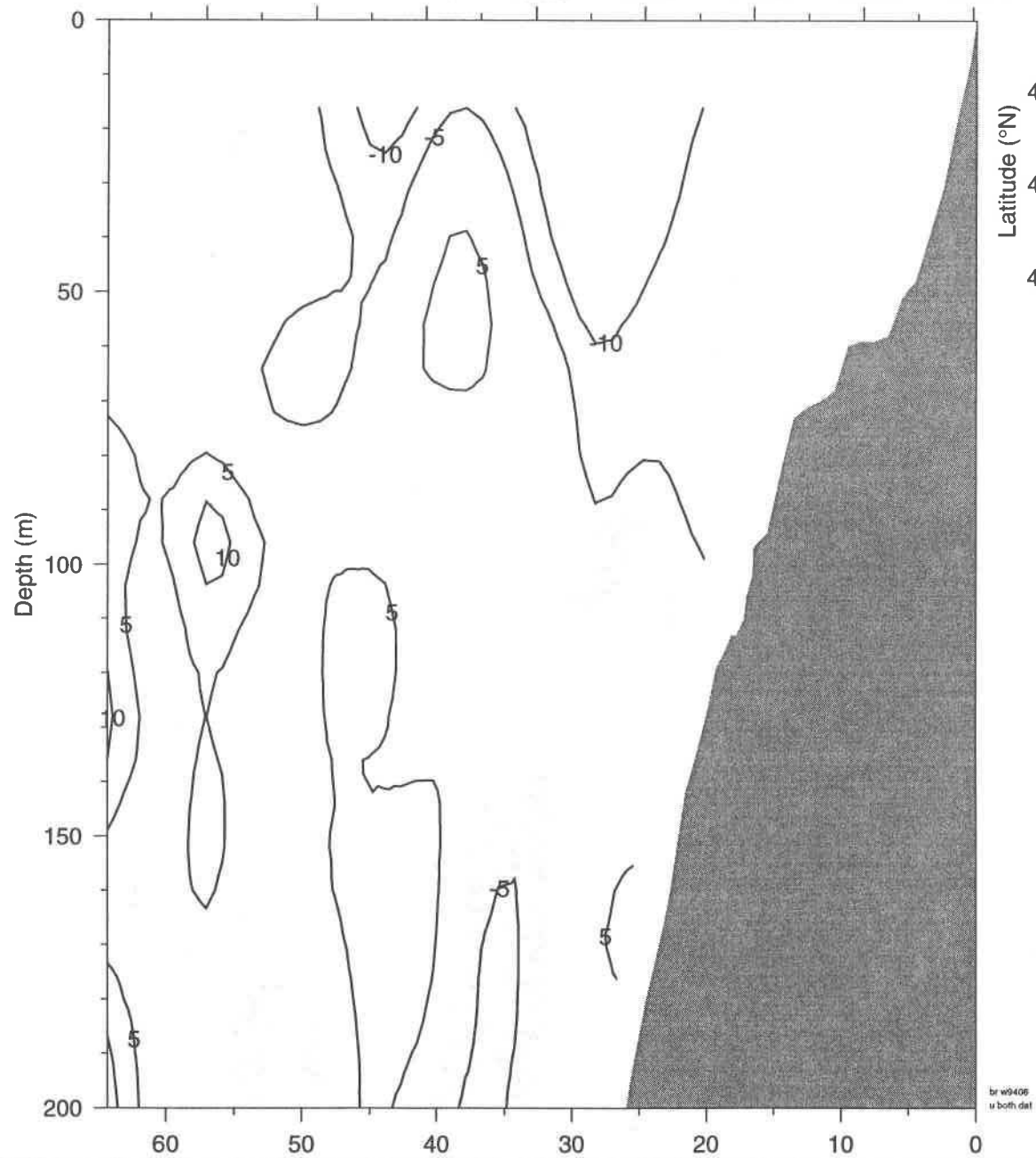
br w0408
v both del

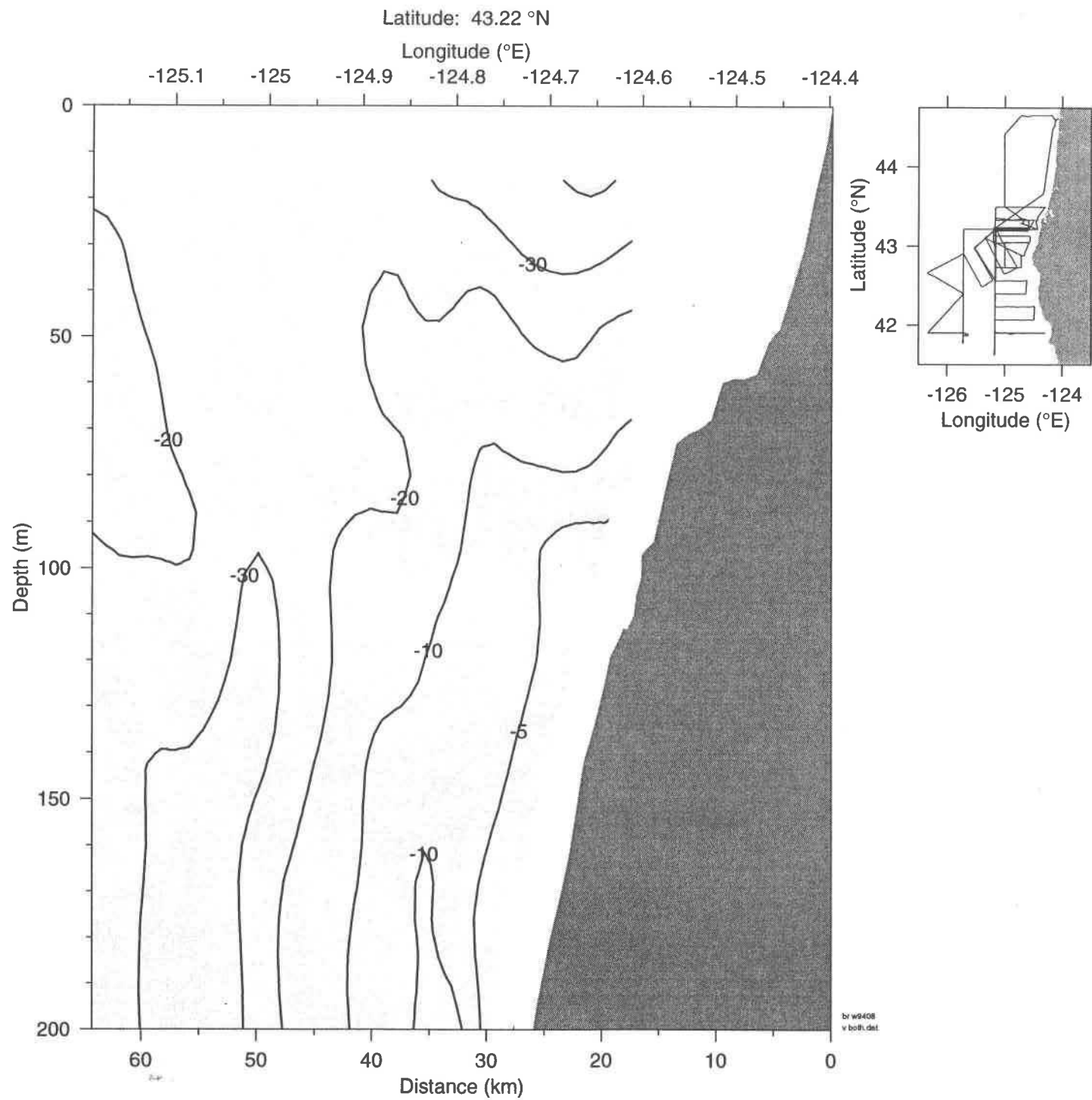
ADCP Line 2 U (year day 237.46-237.61, 25-Aug-94)

Latitude: 43.22 °N

Longitude (°E)

-125.1 -125 -124.9 -124.8 -124.7 -124.6 -124.5 -124.4





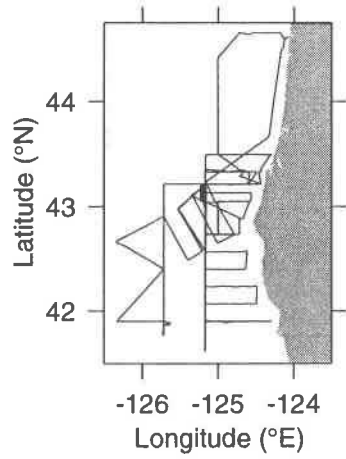
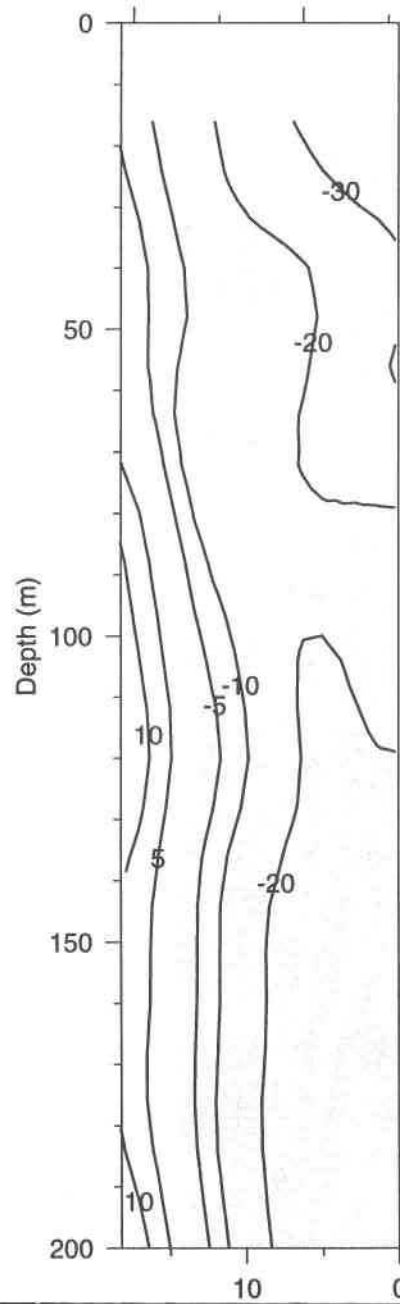
ADCP Line 2-3 U (year day 237.61-237.66, 25-Aug-94)

Longitude: -125.20 °E

Latitude (°N)

43.2

43.1



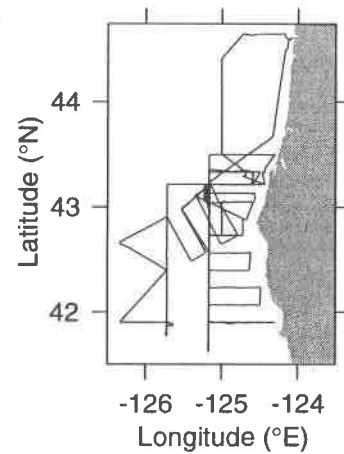
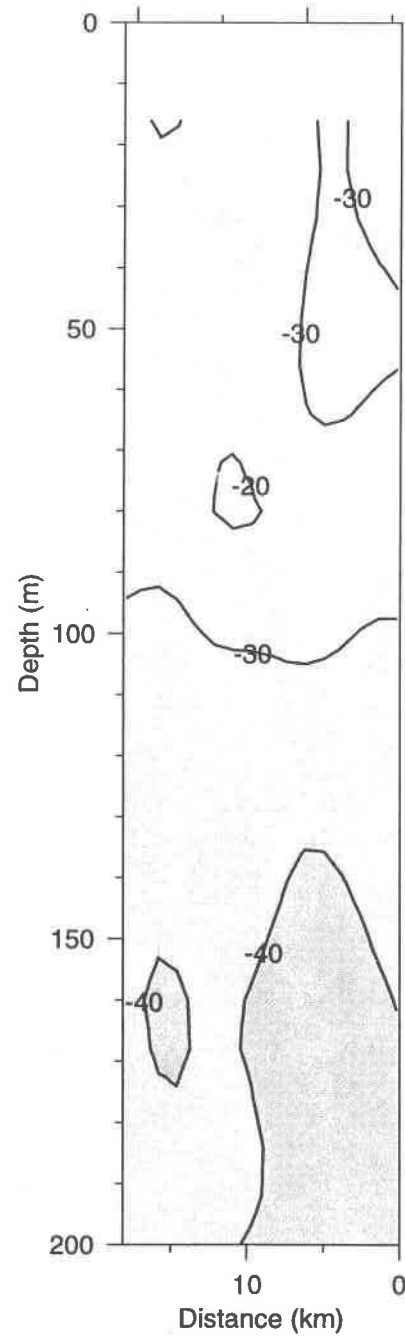
ADCP Line 2-3 V (year day 237.61-237.66, 25-Aug-94)

Longitude: -125.20 °E

Latitude (°N)

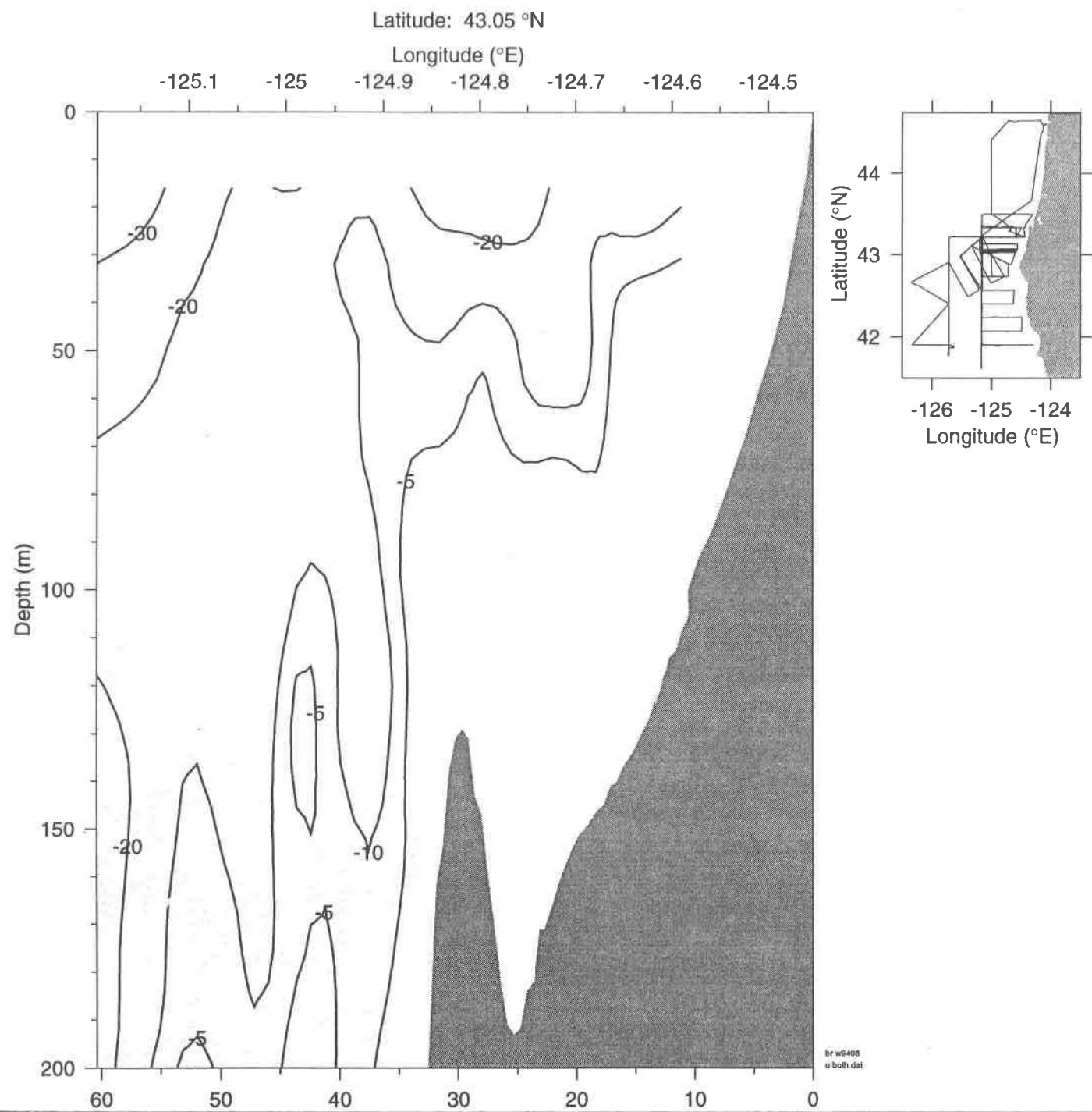
43.2

43.1



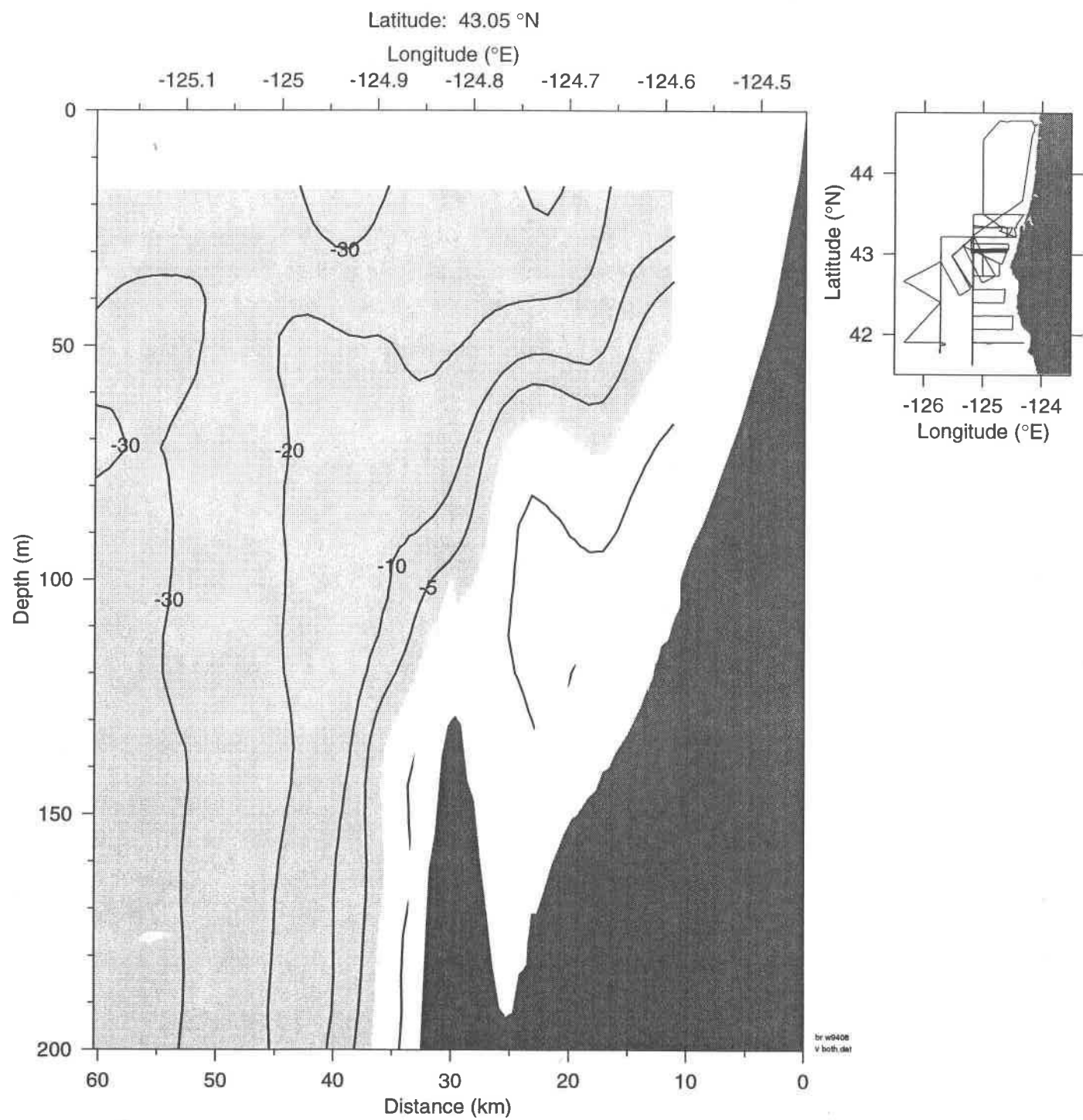
br w0408
v both.dat

ADCP Line 3 U (year day 237.67-237.83, 25-Aug-94)



ADCP Line 3 V (year day 237.67-237.83, 25-Aug-94)

63

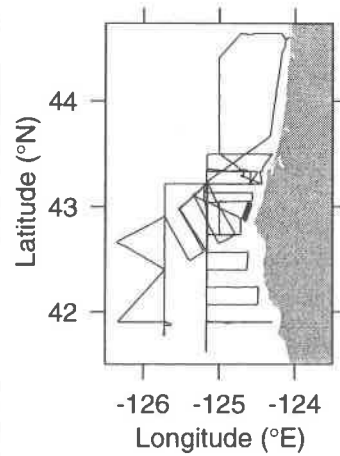
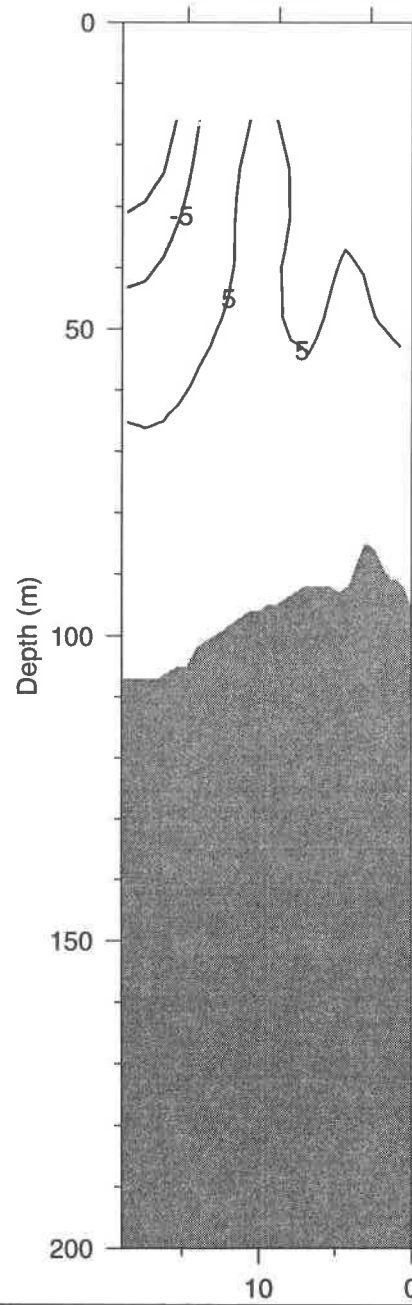


ADCP Line 3-4 U (year day 237.83-237.89, 25-Aug-94)

Longitude: -124.63 °E

Latitude (°N)

43 42.95 42.9



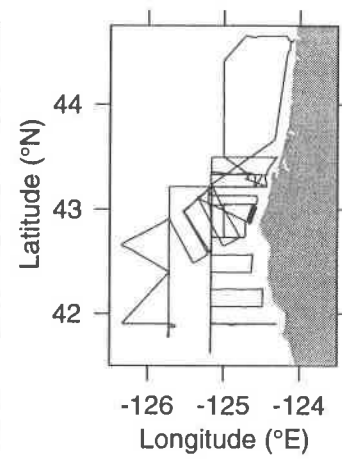
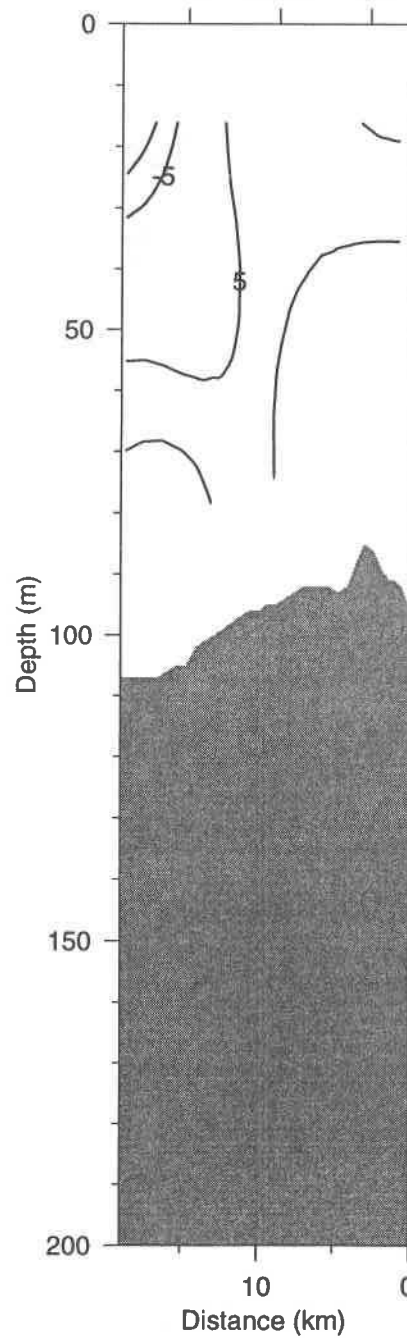
br w9408
u both.dat

ADCP Line 3-4 V (year day 237.83-237.89, 25-Aug-94)

Longitude: -124.63 °E

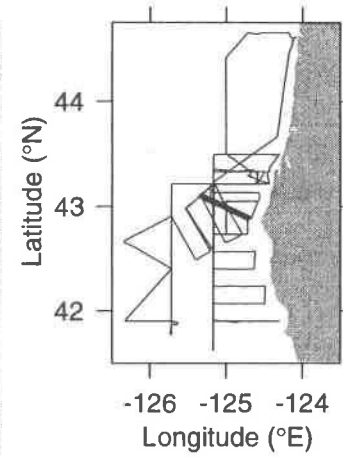
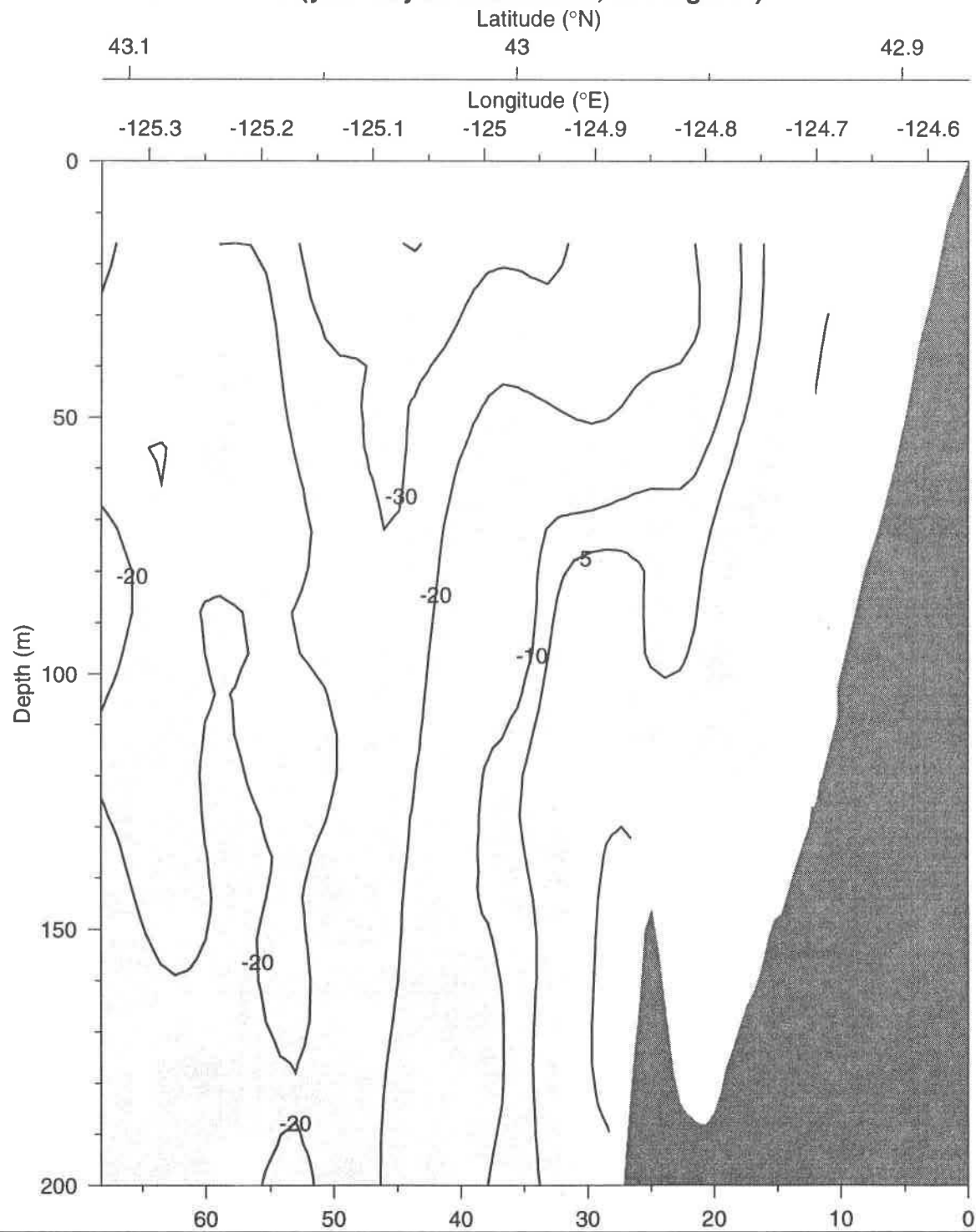
Latitude (°N)

43 42.95 42.9



br w9408
v both dat

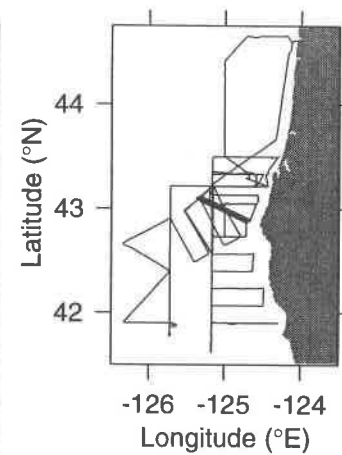
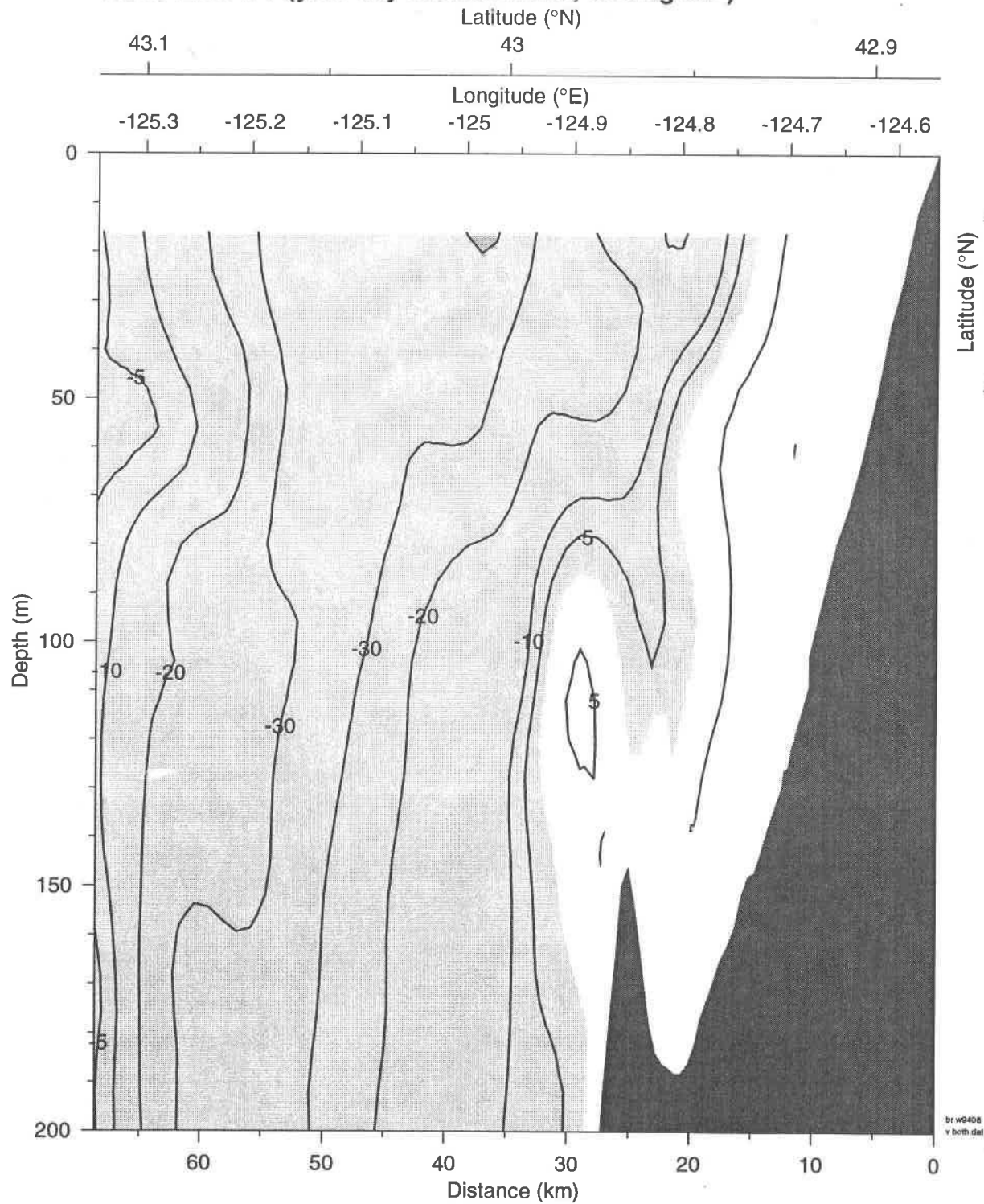
ADCP Line 4 U (year day 237.89-238.08, 25-Aug-94)



br w9408
u both.dat

ADCP Line 4 V (year day 237.89-238.08, 25-Aug-94)

67



br w9408
v both dat

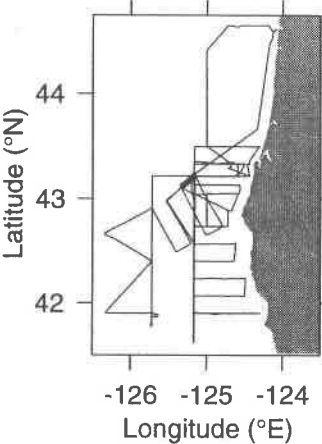
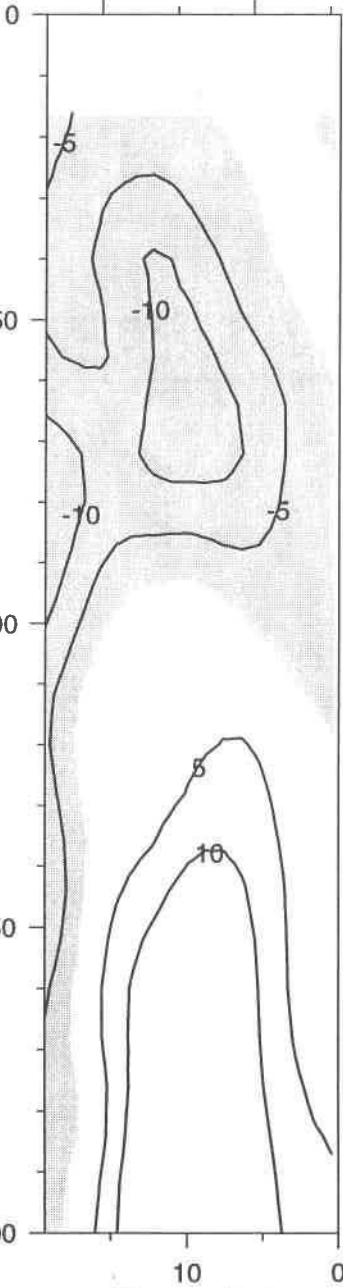
ADCP Line 4-5 U (year day 238.08-238.15, 26-Aug-94)

Latitude (°N)

43.15 43.2

Longitude (°E)

-125.3 -125.2



br w9408
u both.dat

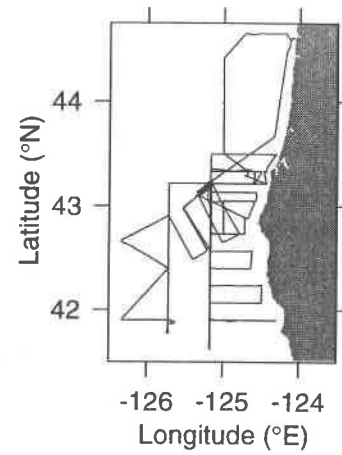
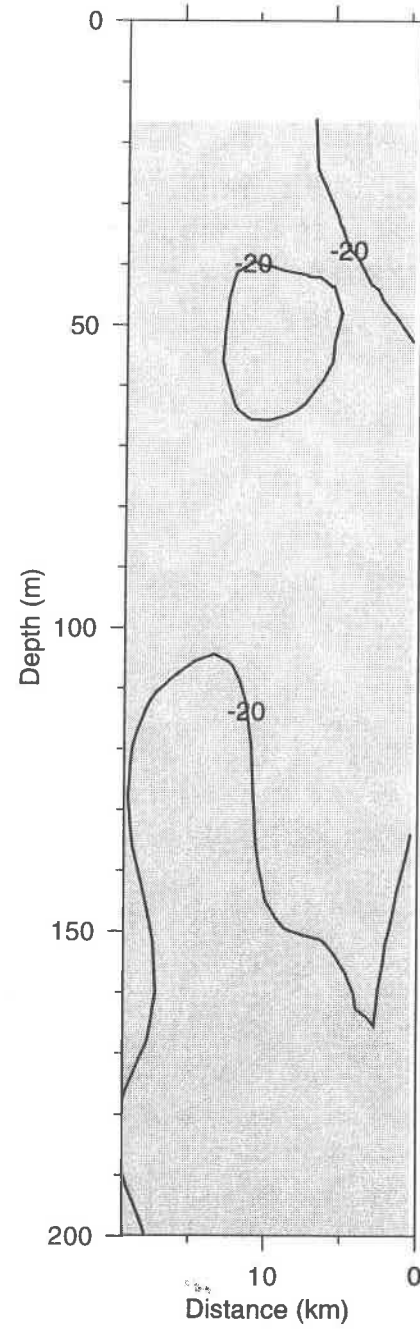
ADCP Line 4-5 V (year day 238.08-238.15, 26-Aug-94)

Latitude (°N)

43.15 43.2

Longitude (°E)

-125.3 -125.2

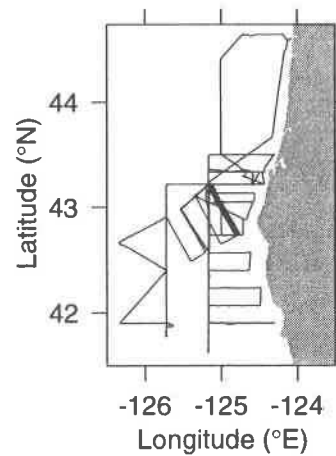
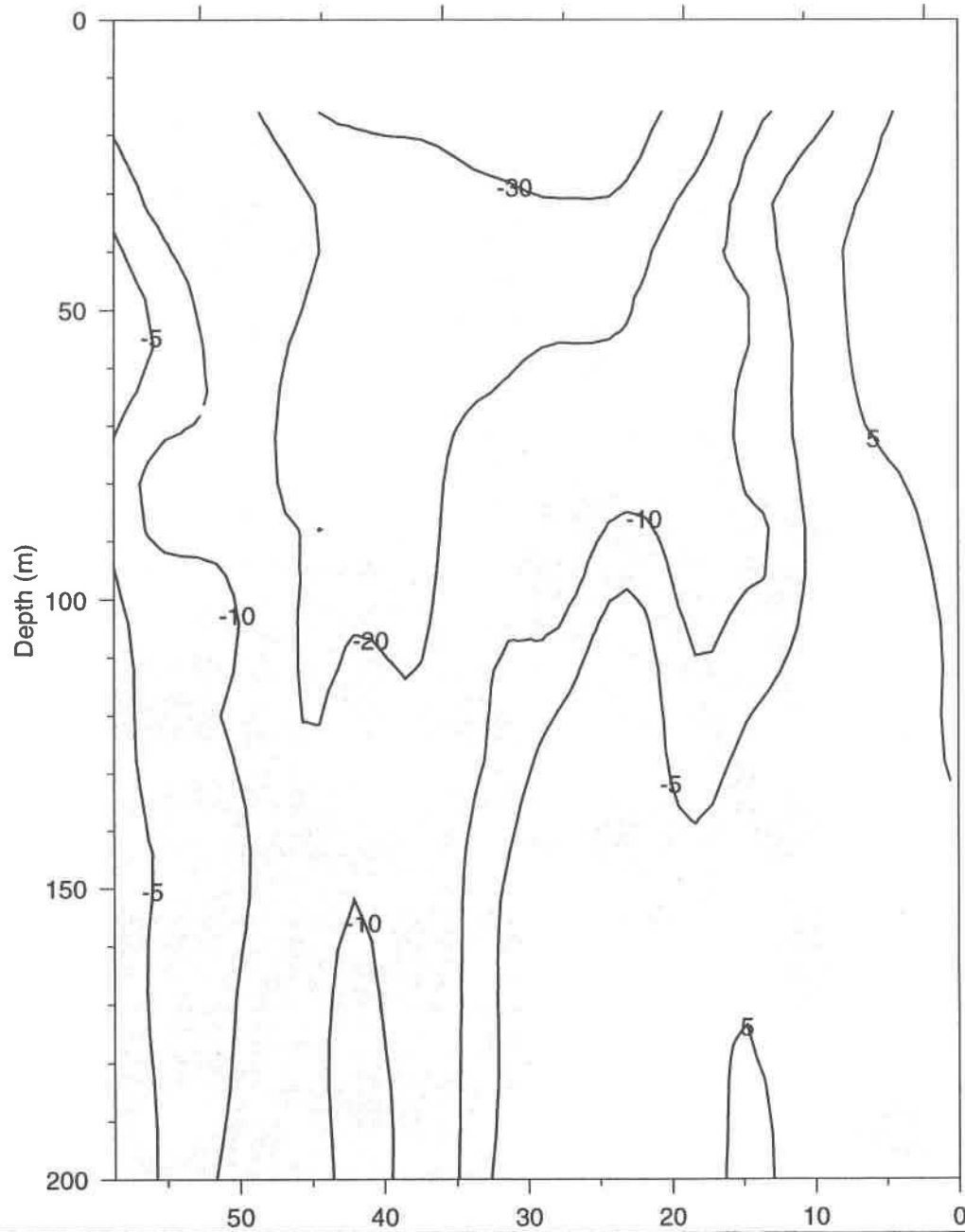


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v both.dal

ADCP Line 5 U (year day 238.15-238.33, 26-Aug-94)

Latitude (°N)
43.2 43.1 43 42.9 42.8

Longitude (°E)
-125.1 -125 -124.9 -124.8



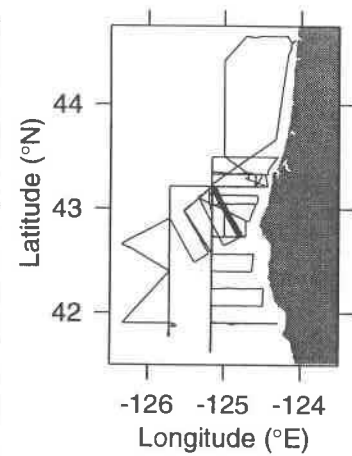
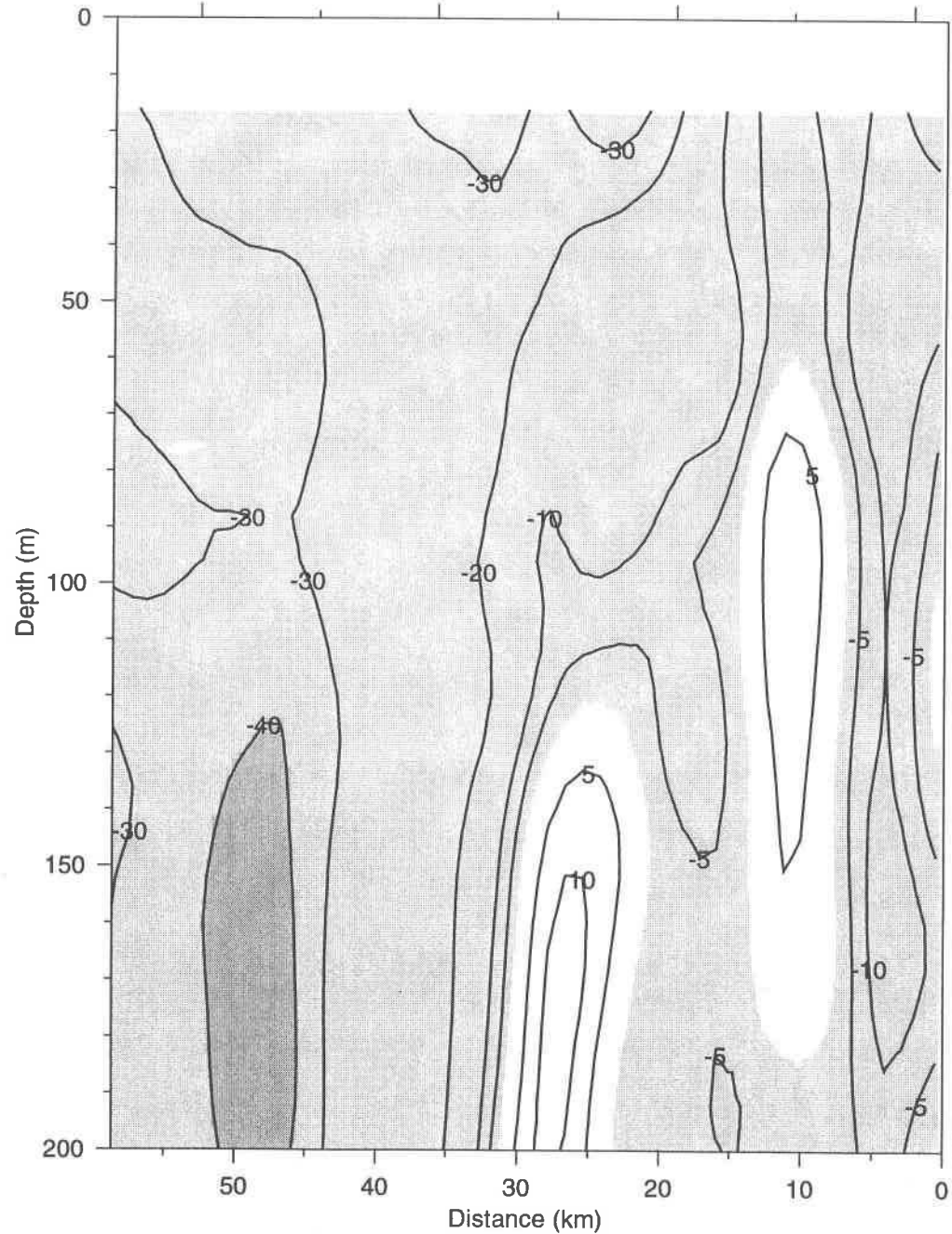
brw9408
u both.dat

ADCP Line 5 V (year day 238.15-238.33, 26-Aug-94)

Latitude (°N)
 43.2 43.1 43 42.9 42.8

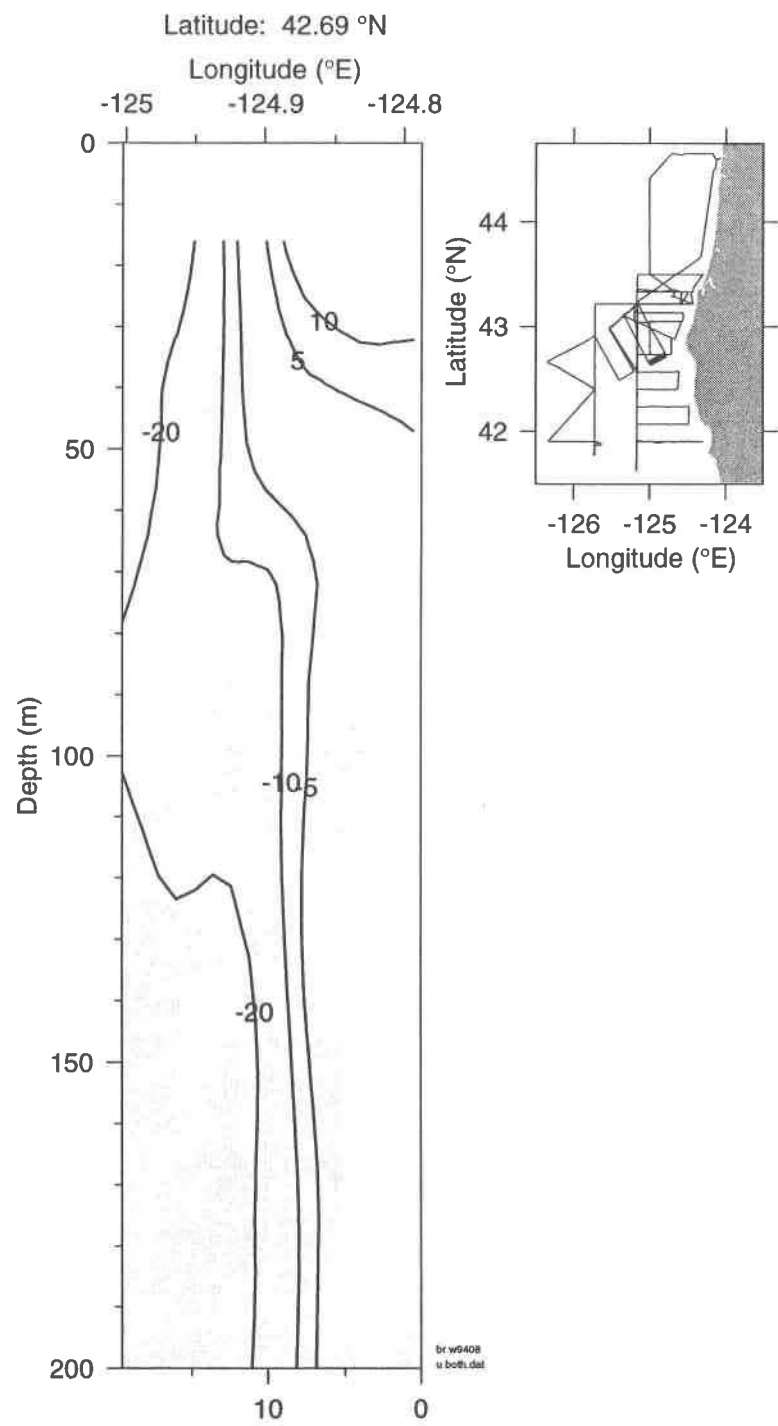
Longitude (°E)
 -125.1 -125 -124.9 -124.8

71



br w9408
 v bo8.dat

ADCP Line 5-6 U (year day 238.33-238.39, 26-Aug-94)

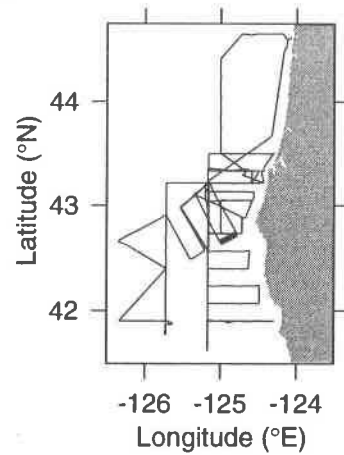
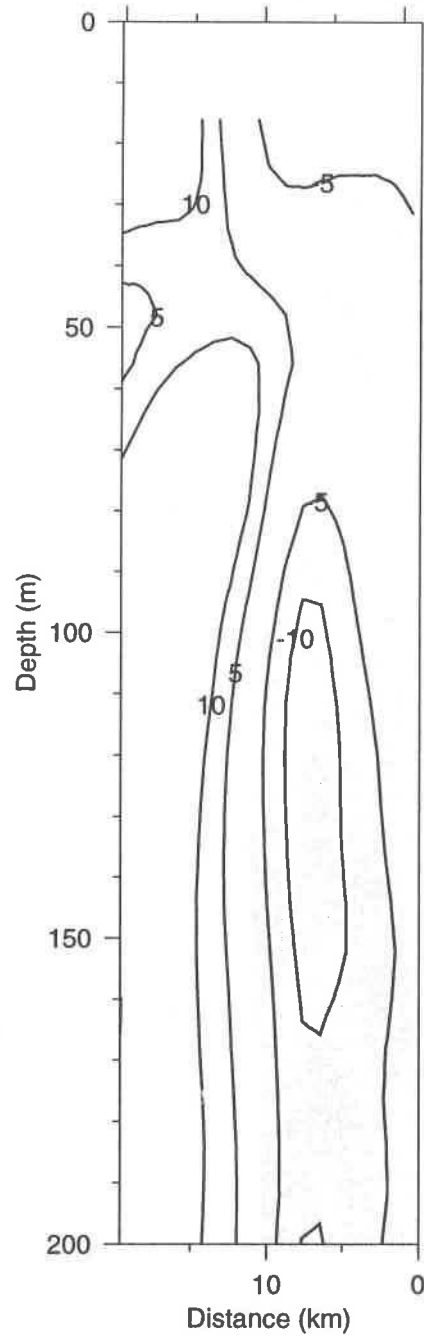


ADCP Line 5-6 V (year day 238.33-238.39, 26-Aug-94)

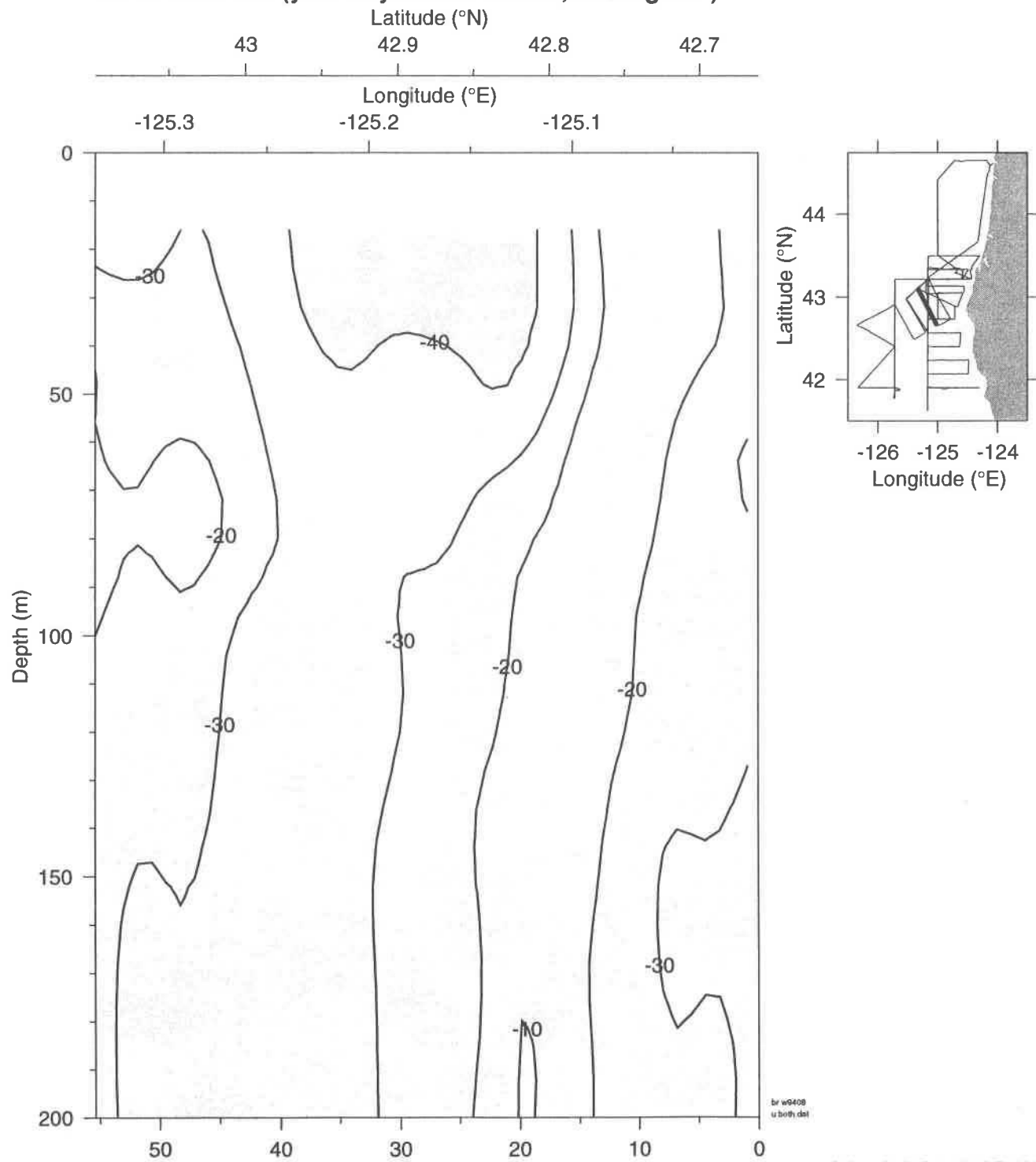
Latitude: 42.69 °N

Longitude (°E)

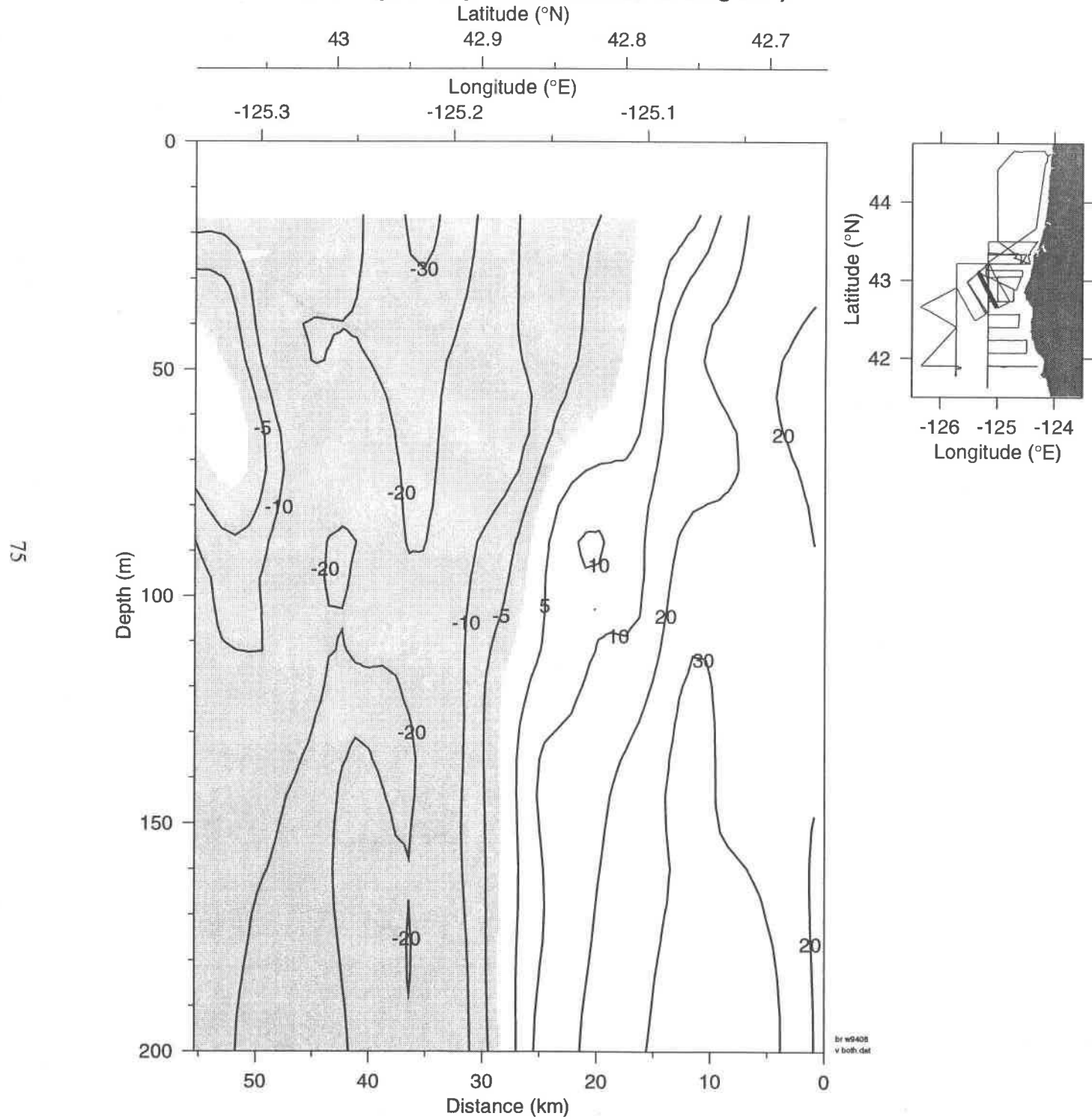
-125 -124.9 -124.8



ADCP Line 6 U (year day 238.40-238.57, 26-Aug-94)



ADCP Line 6 V (year day 238.40-238.57, 26-Aug-94)



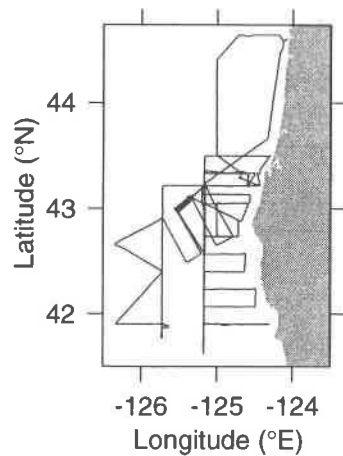
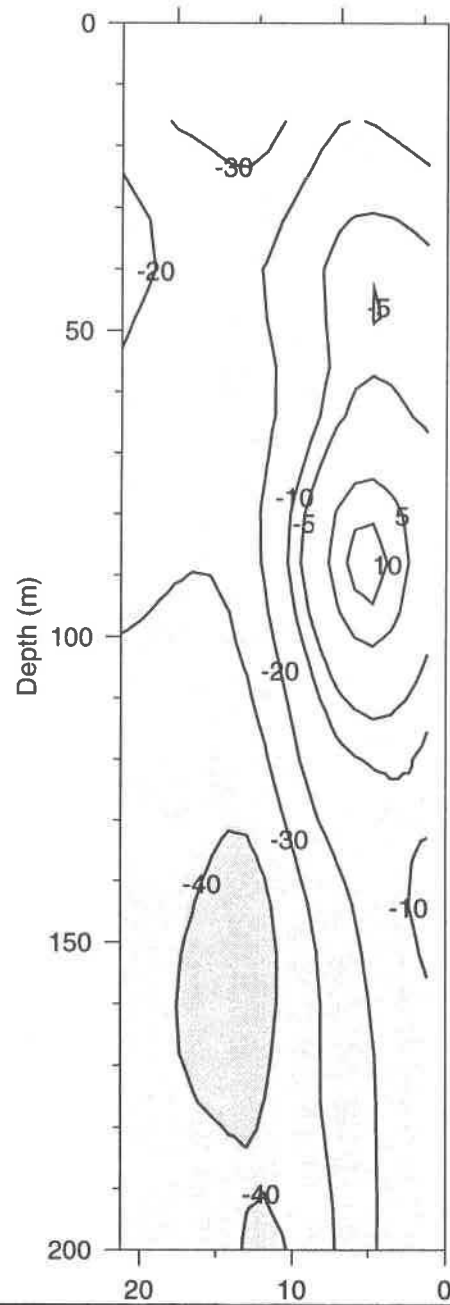
ADCP Line 6-7 U (year day 238.57-238.63, 26-Aug-94)

Latitude (°N)

43 43.05 43.1

Longitude (°E)

-125.5 -125.4



br w9408
u both.dat

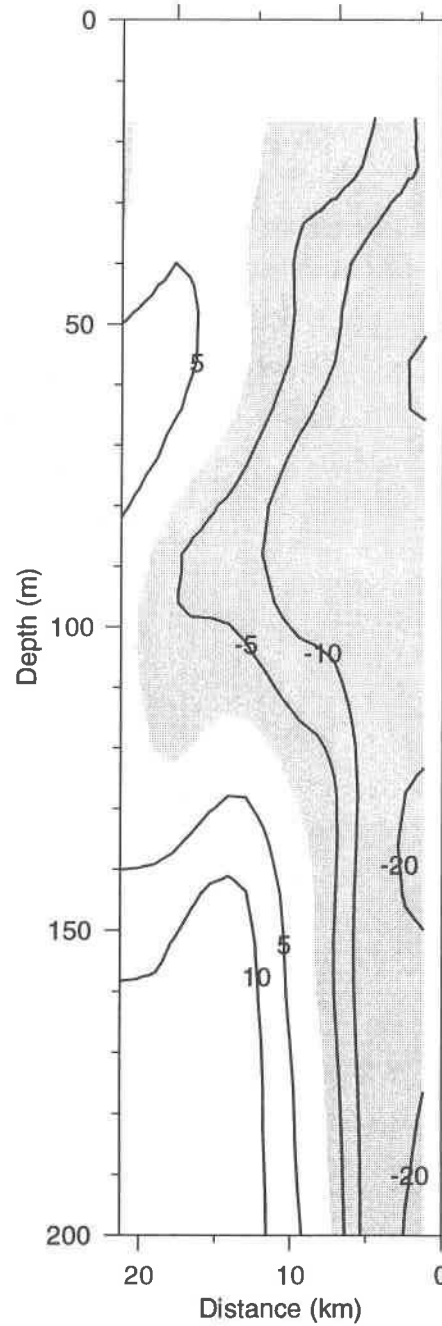
ADCP Line 6-7 V (year day 238.57-238.63, 26-Aug-94)

Latitude (°N)

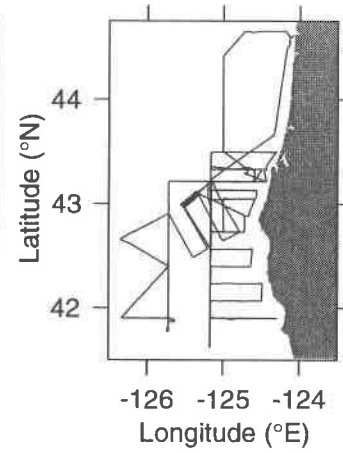
43 43.05 43.1

Longitude (°E)

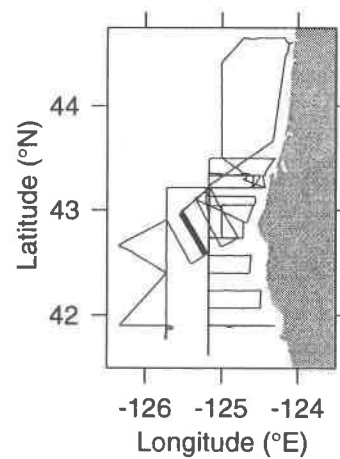
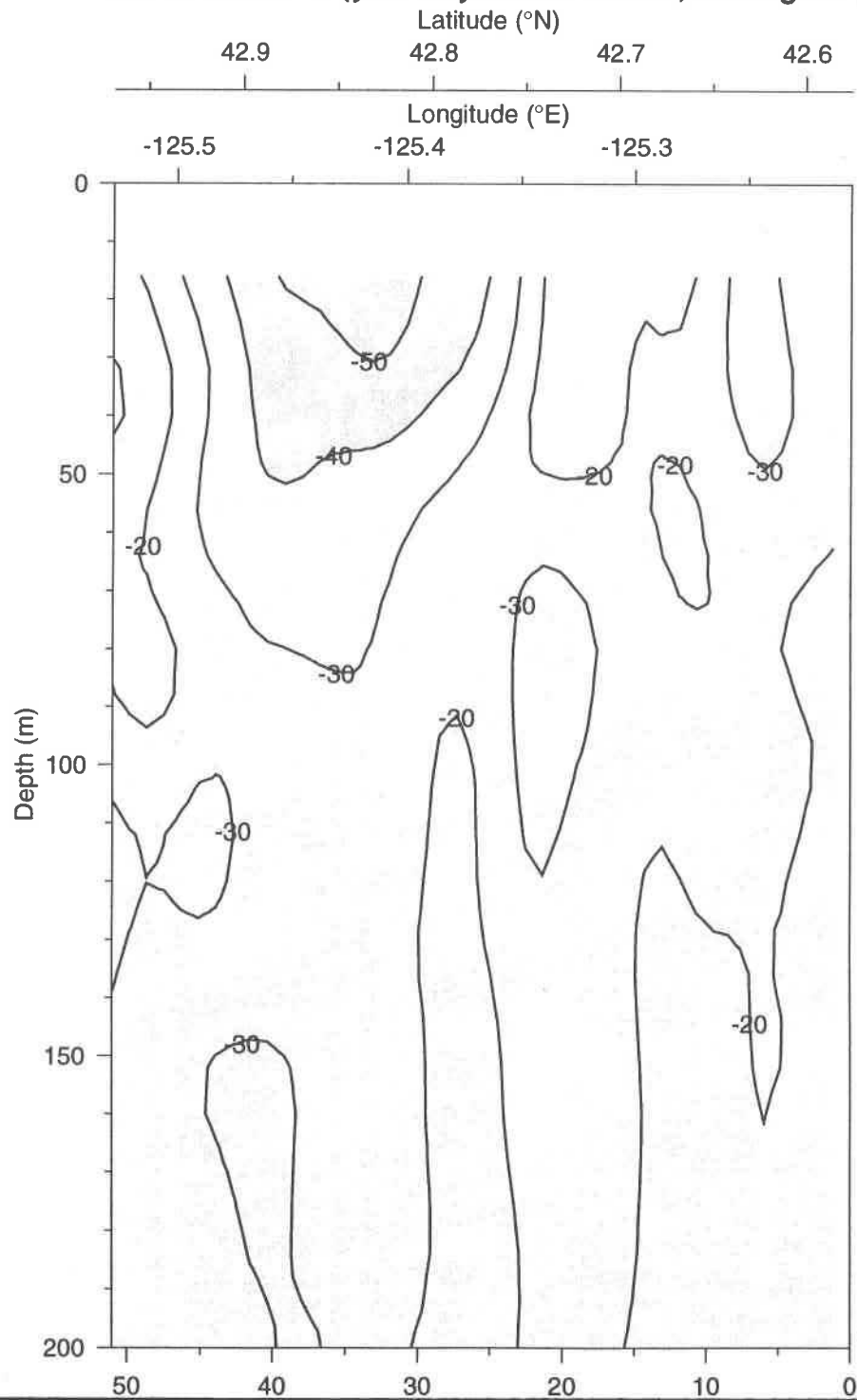
-125.5 -125.4



br v0406
v both.dat

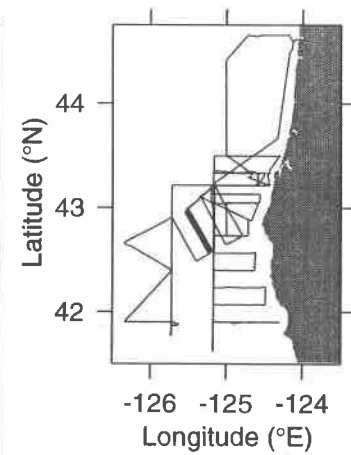
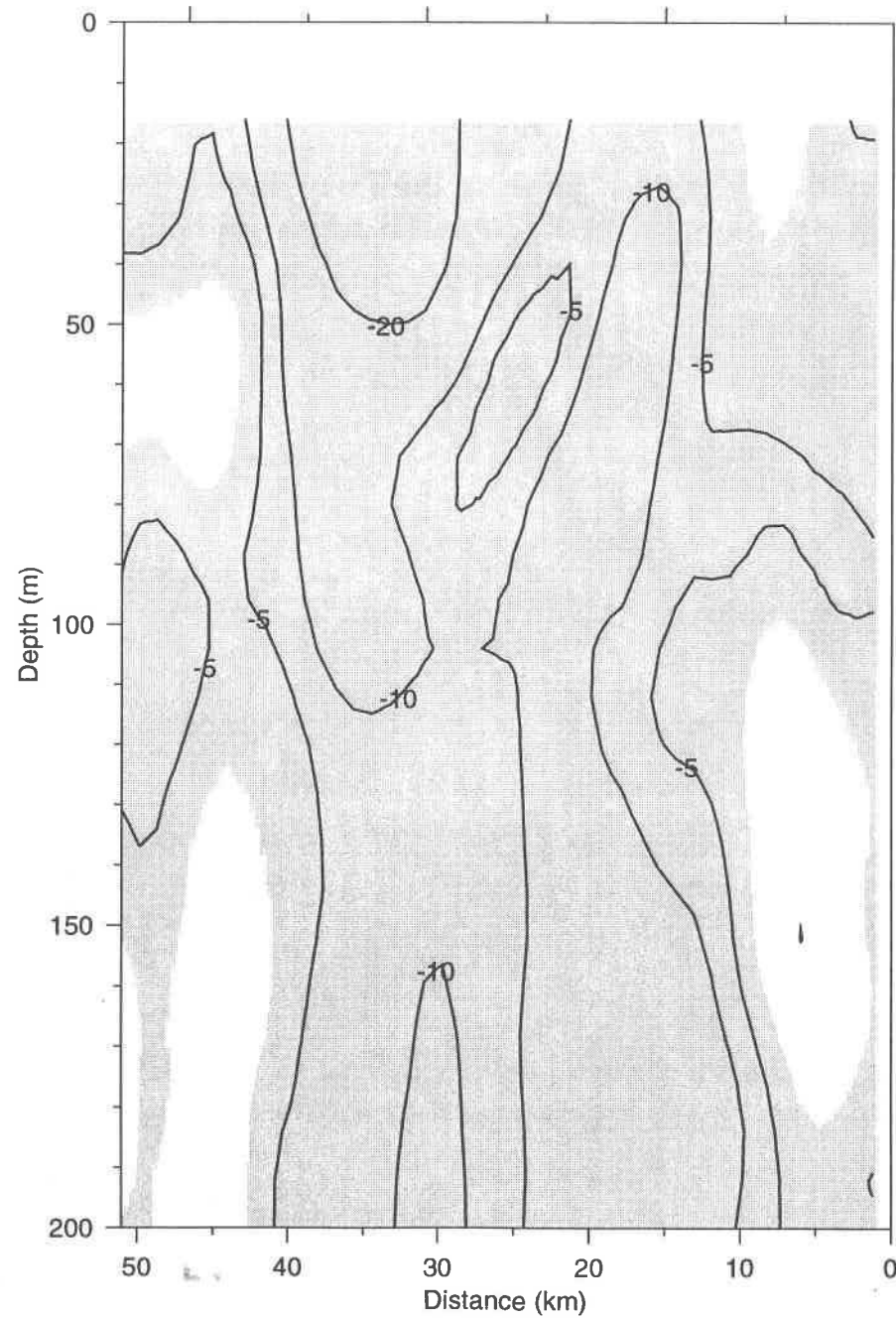
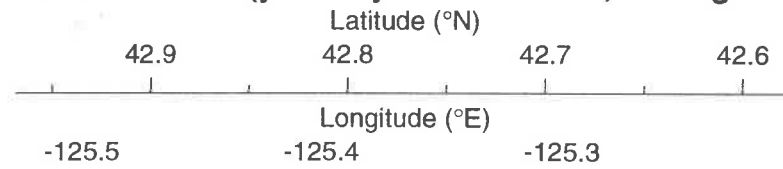


ADCP Line 7 U (year day 238.63-238.80, 26-Aug-94)



br w6408
u both del

ADCP Line 7 V (year day 238.63-238.80, 26-Aug-94)



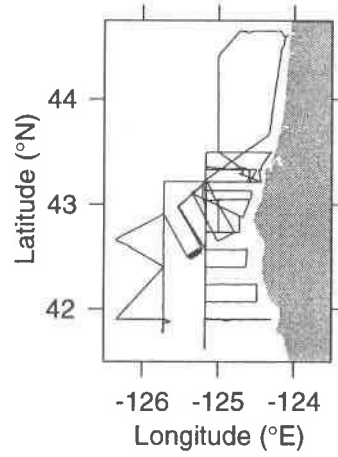
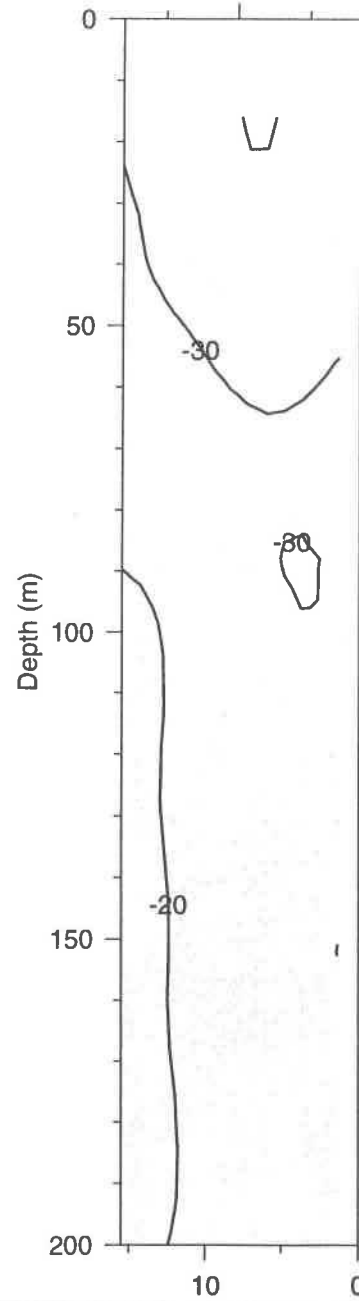
br w9408
v both.dat

ADCP Line 7-8 U (year day 238.80-238.85, 26-Aug-94)

Latitude: 42.53 °N

Longitude (°E)

-125.3



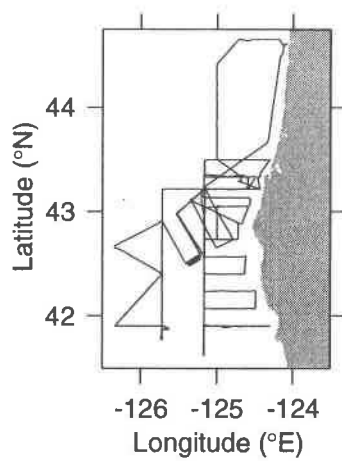
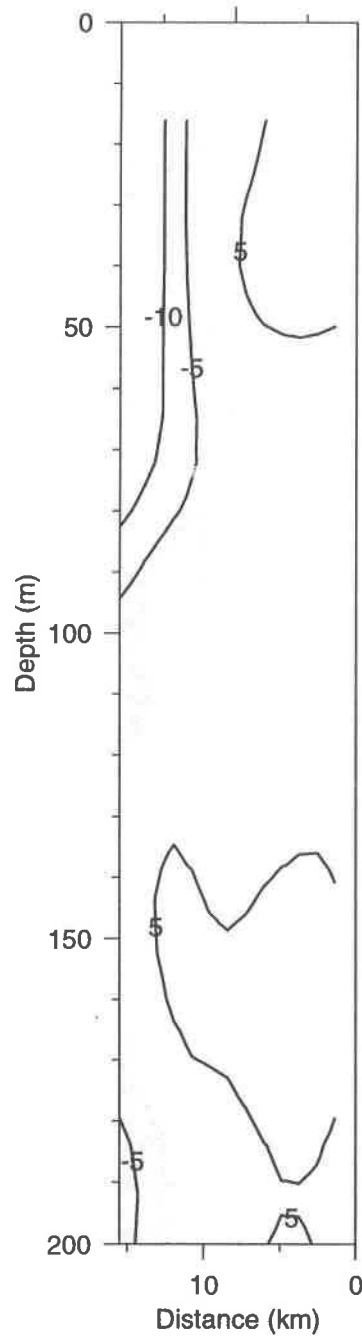
br w9408
u both.del

ADCP Line 7-8 V (year day 238.80-238.85, 26-Aug-94)

Latitude: 42.53 °N

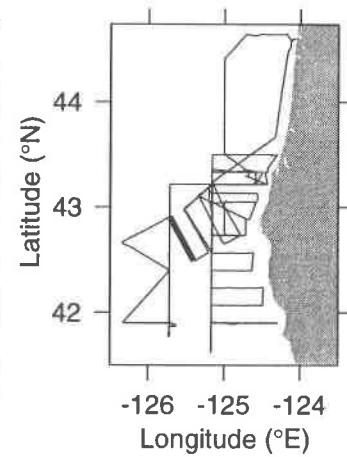
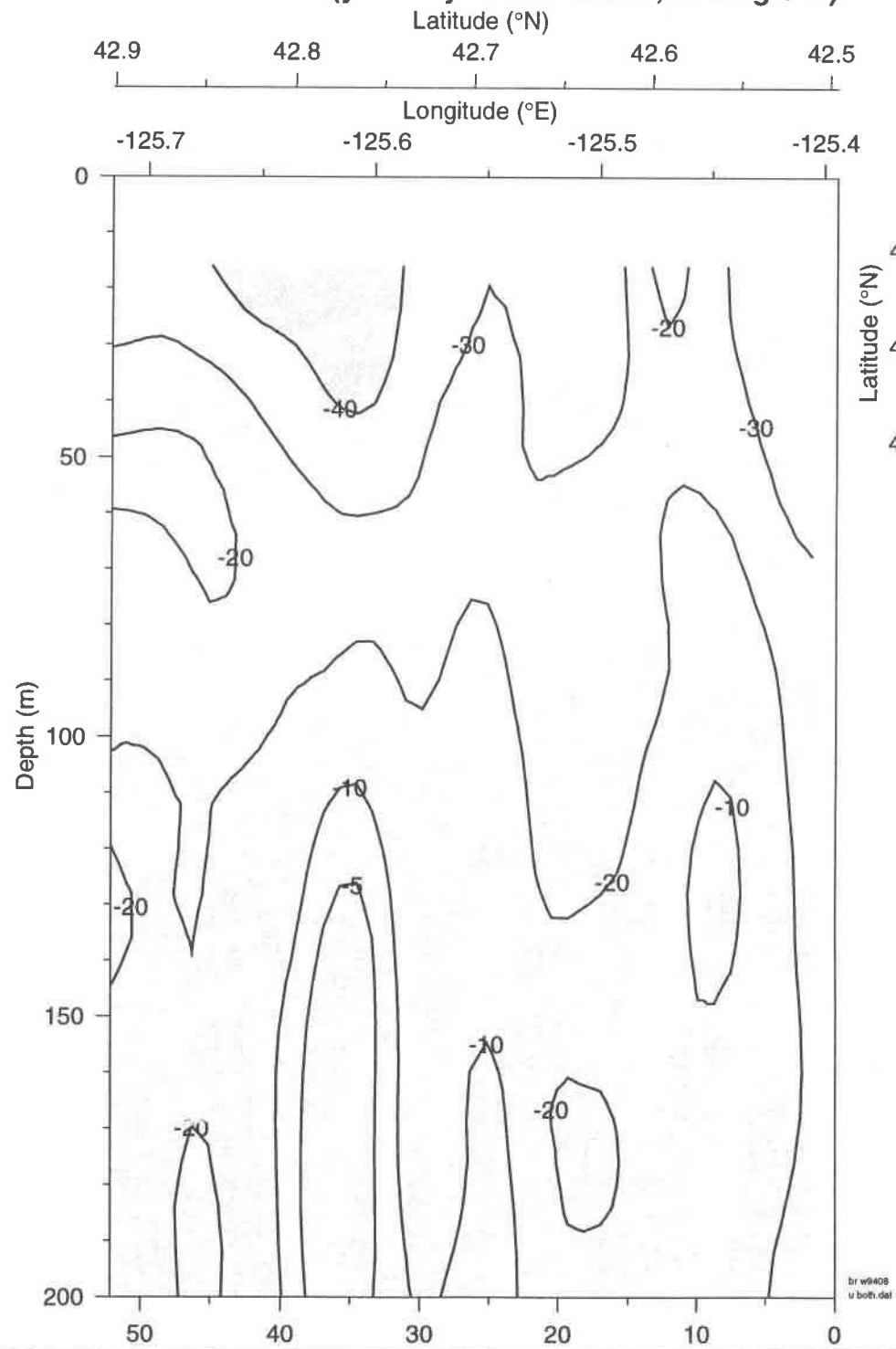
Longitude (°E)

-125.3

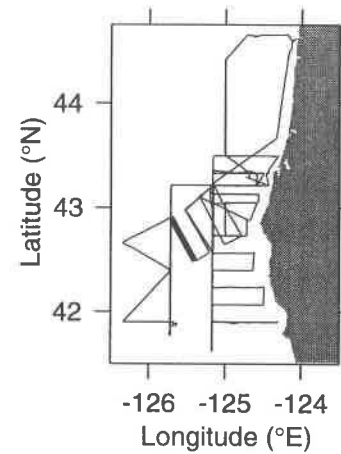
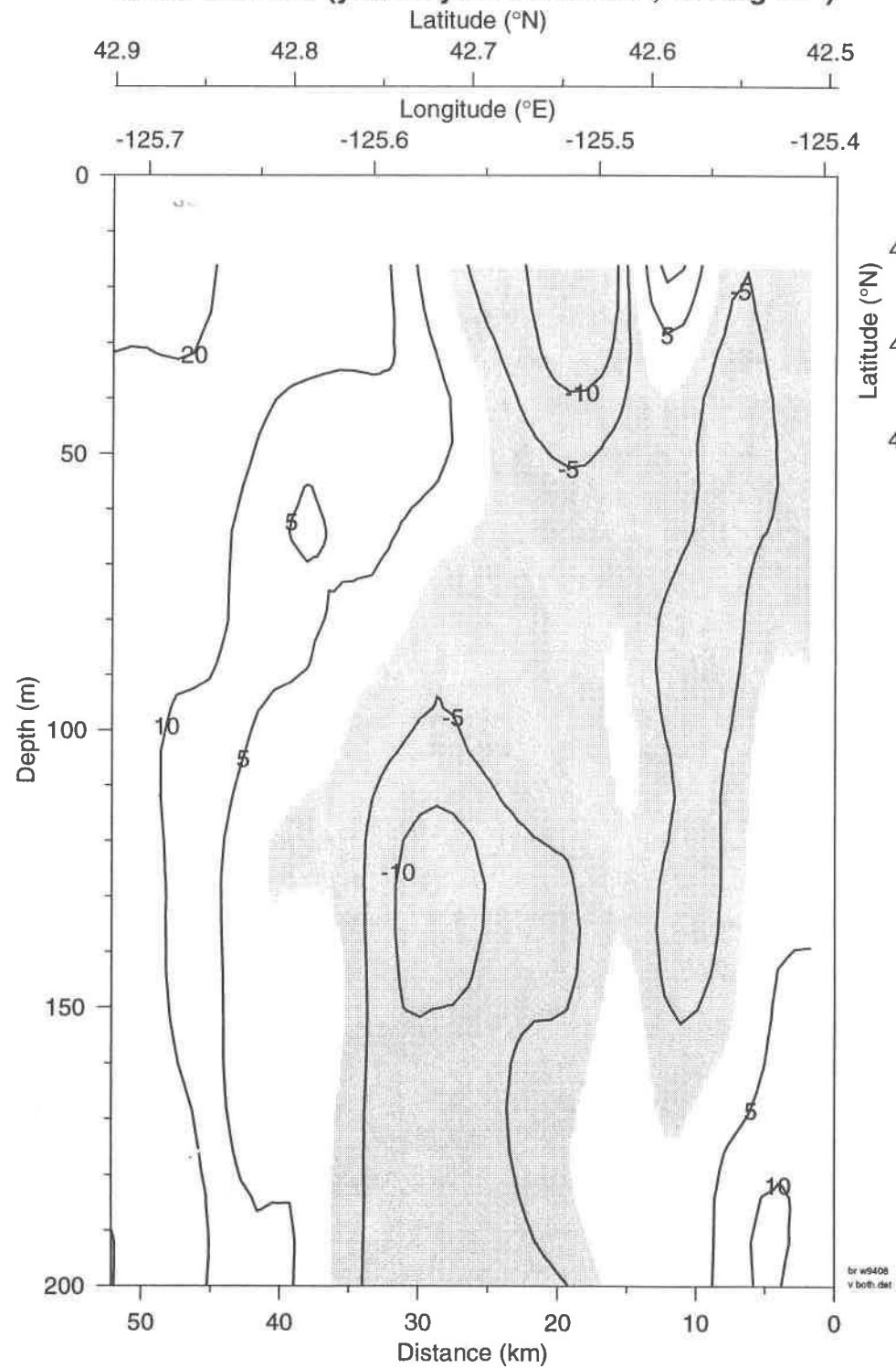


br w9408
v both.daf

ADCP Line 8 U (year day 238.85-239.00, 26-Aug-94)

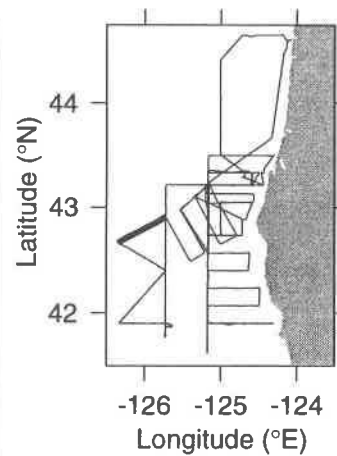
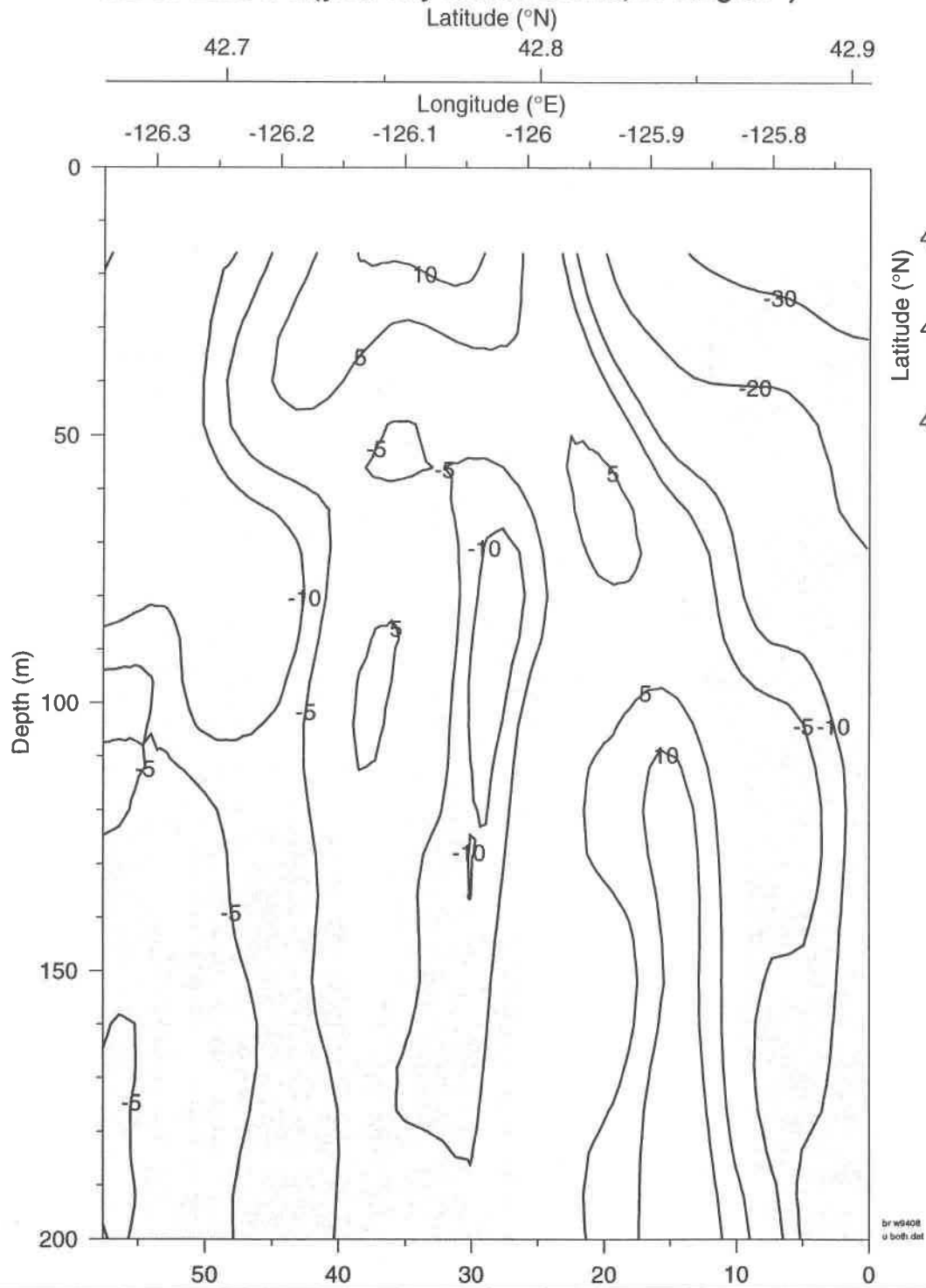


ADCP Line 8 V (year day 238.85-239.00, 26-Aug-94)



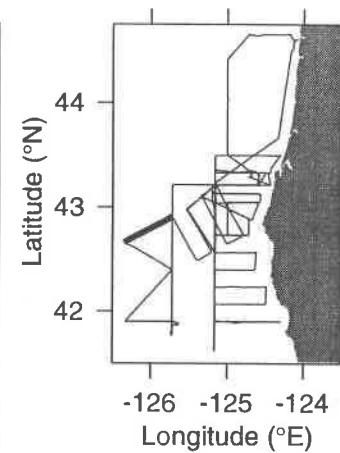
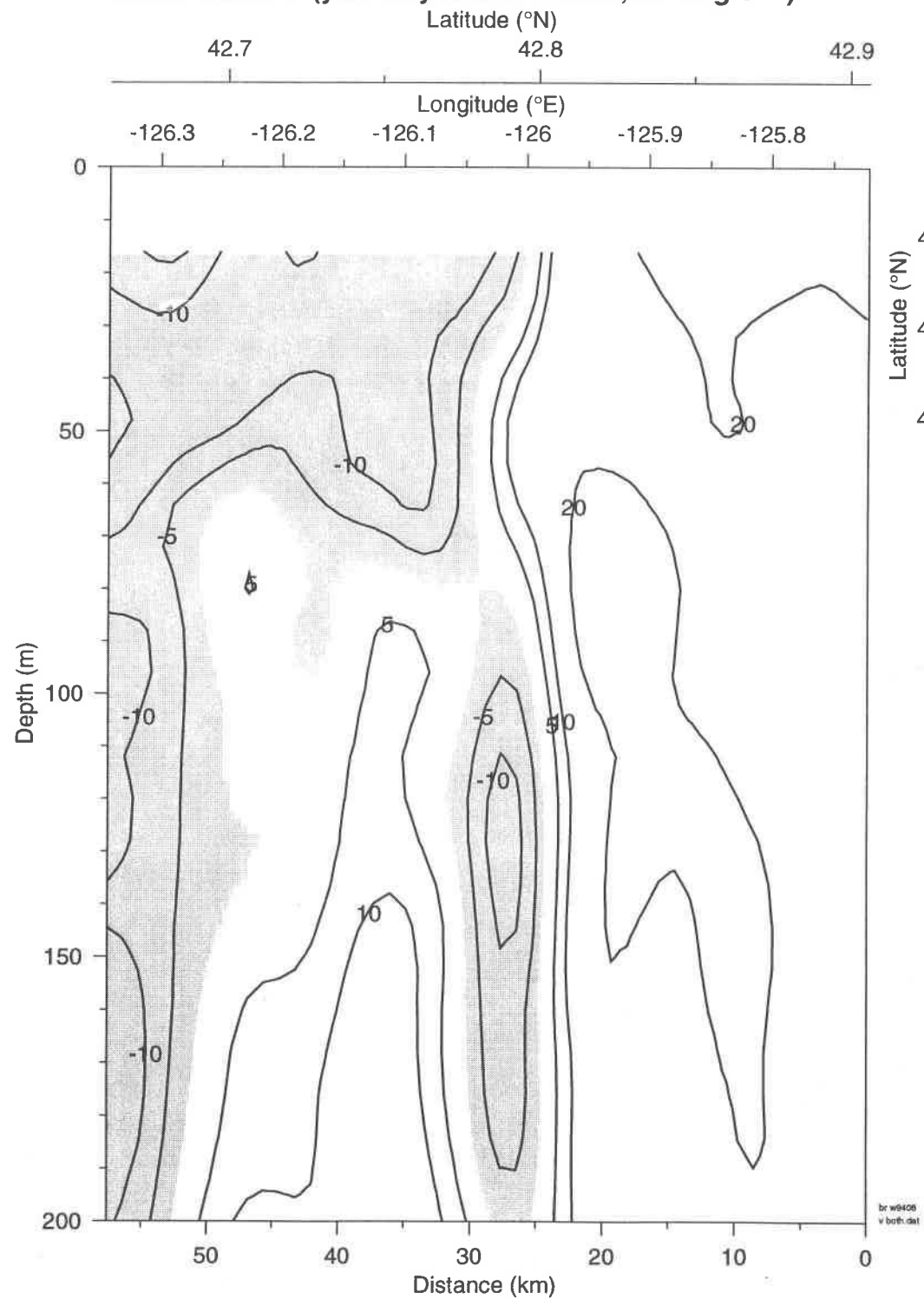
br w5408
v both.dal

ADCP Line 9 U (year day 239.01-239.18, 27-Aug-94)

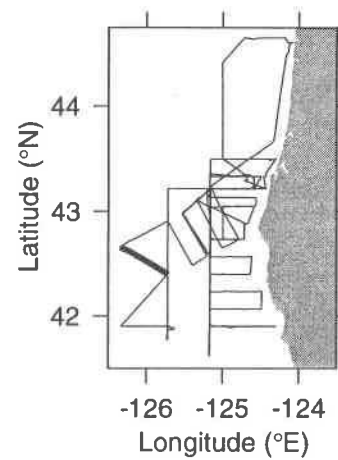
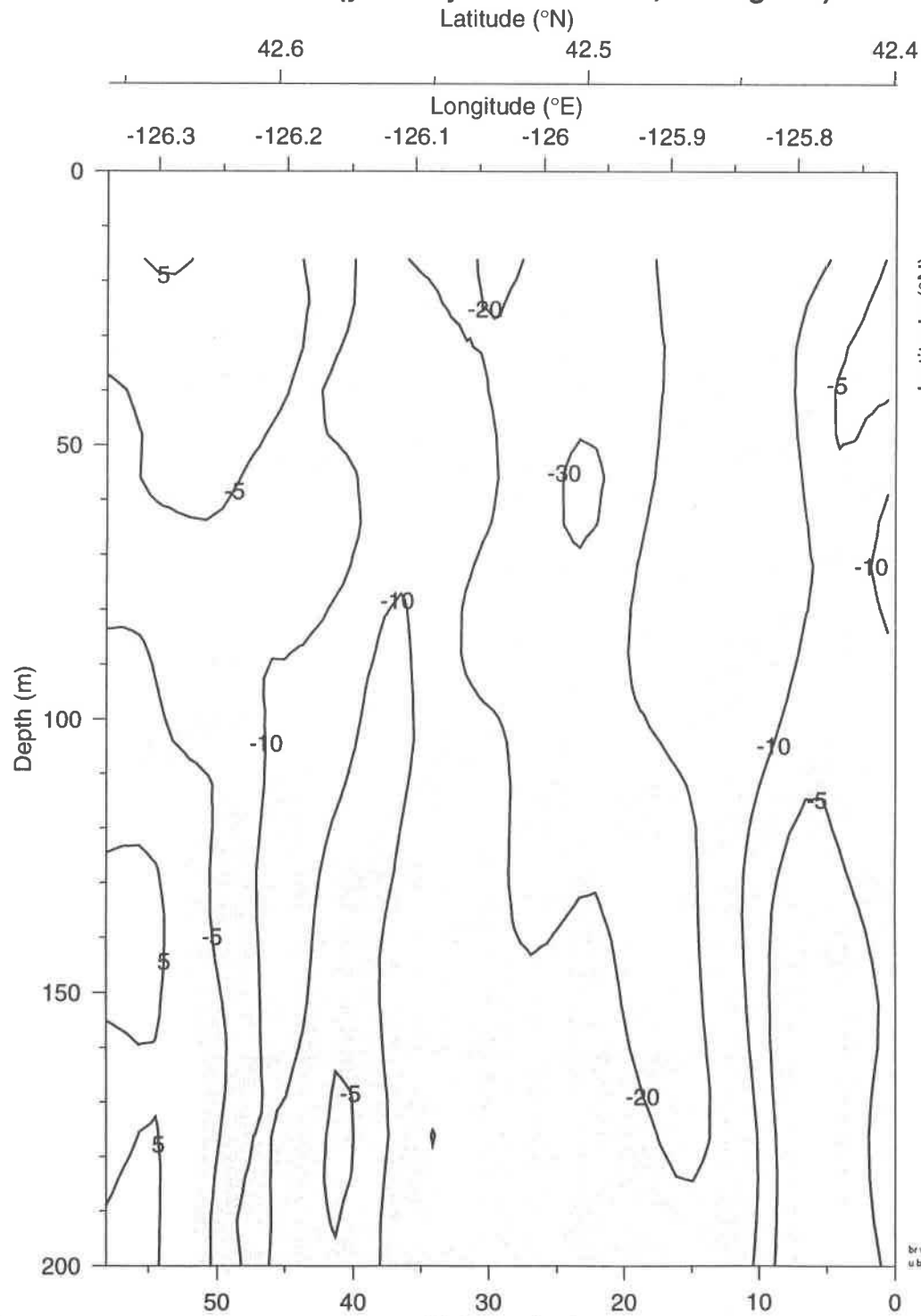


br w9408
u both.dat

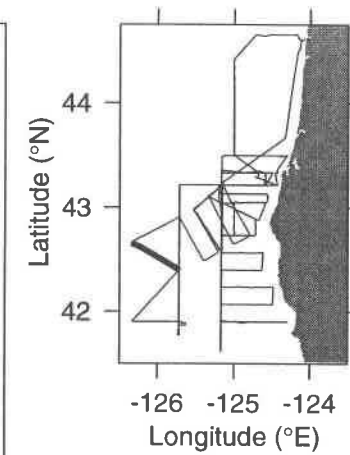
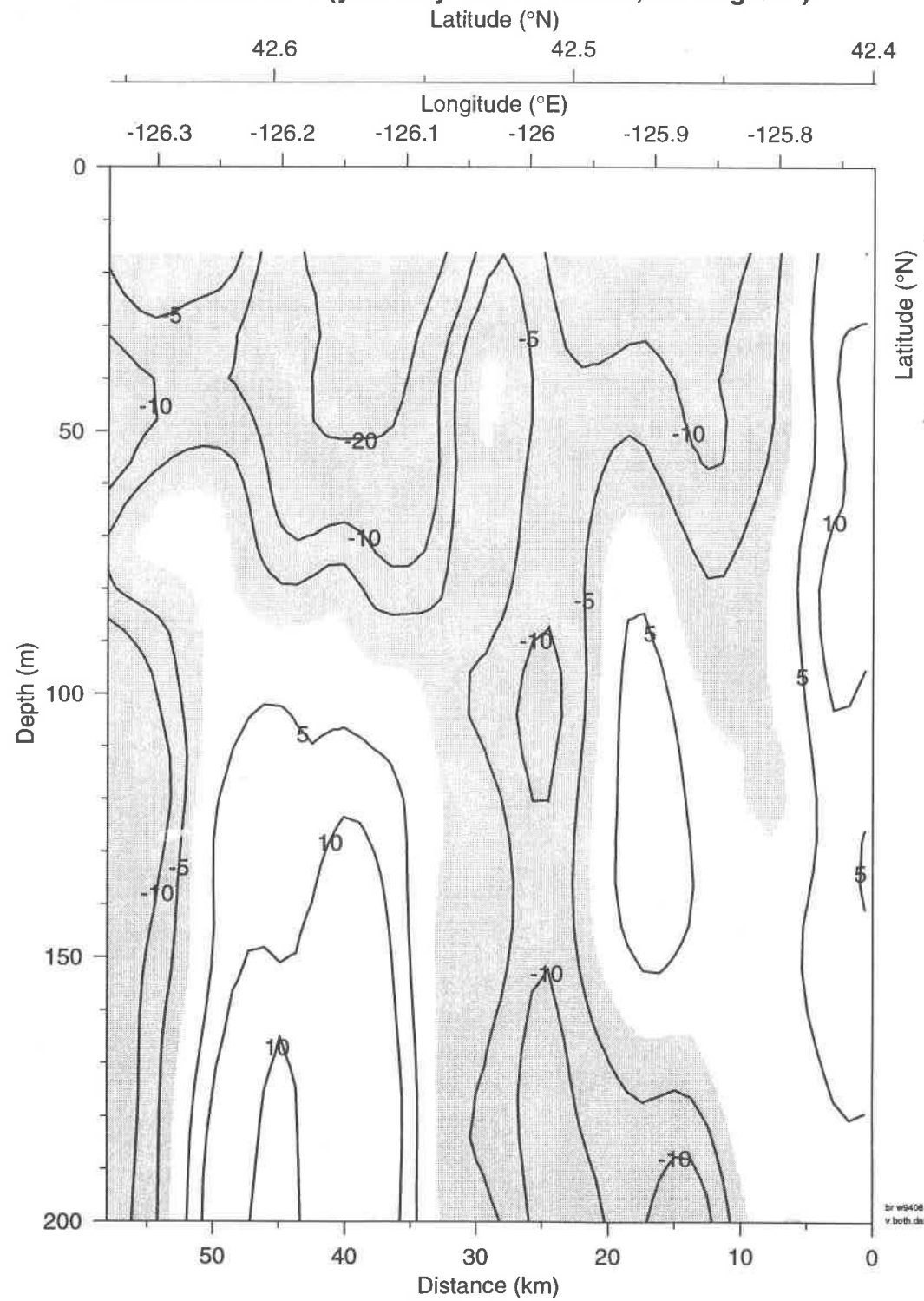
ADCP Line 9 V (year day 239.01-239.18, 27-Aug-94)



ADCP Line 10 U (year day 239.18-239.37, 27-Aug-94)



ADCP Line 10 V (year day 239.18-239.37, 27-Aug-94)



br w9408
v both.dal

ADCP Line 11 U (year day 239.37-239.59, 27-Aug-94)

Latitude (°N)

42

42.1

42.2

42.3

Longitude (°E)

-126.3

-126.2

-126.1

-126

-125.9

-125.8

0

Depth (m)

50

100

150

200

Latitude (°N)

44

43

42

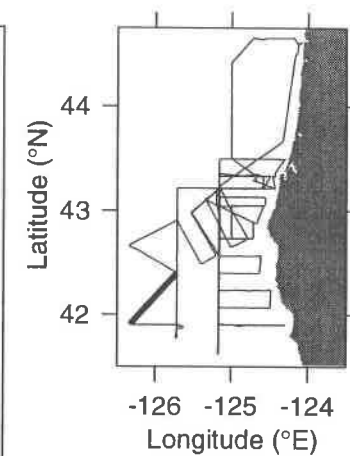
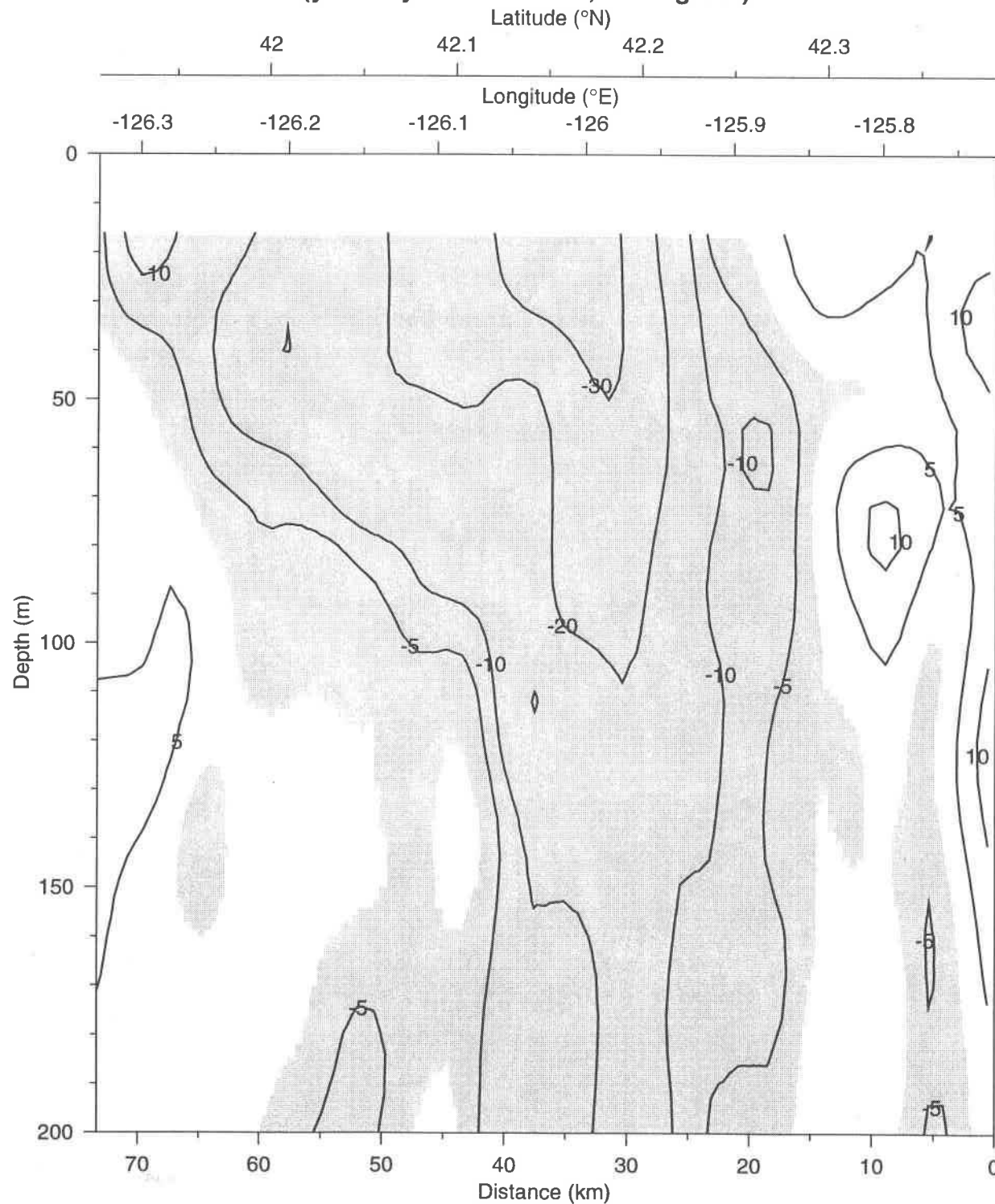
-126 -125 -124

Longitude (°E)

for w9408
is both del

ADCP Line 11 V (year day 239.37-239.59, 27-Aug-94)

68



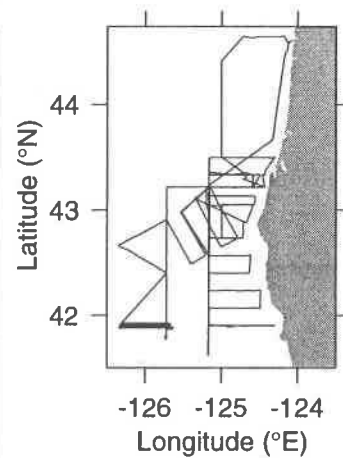
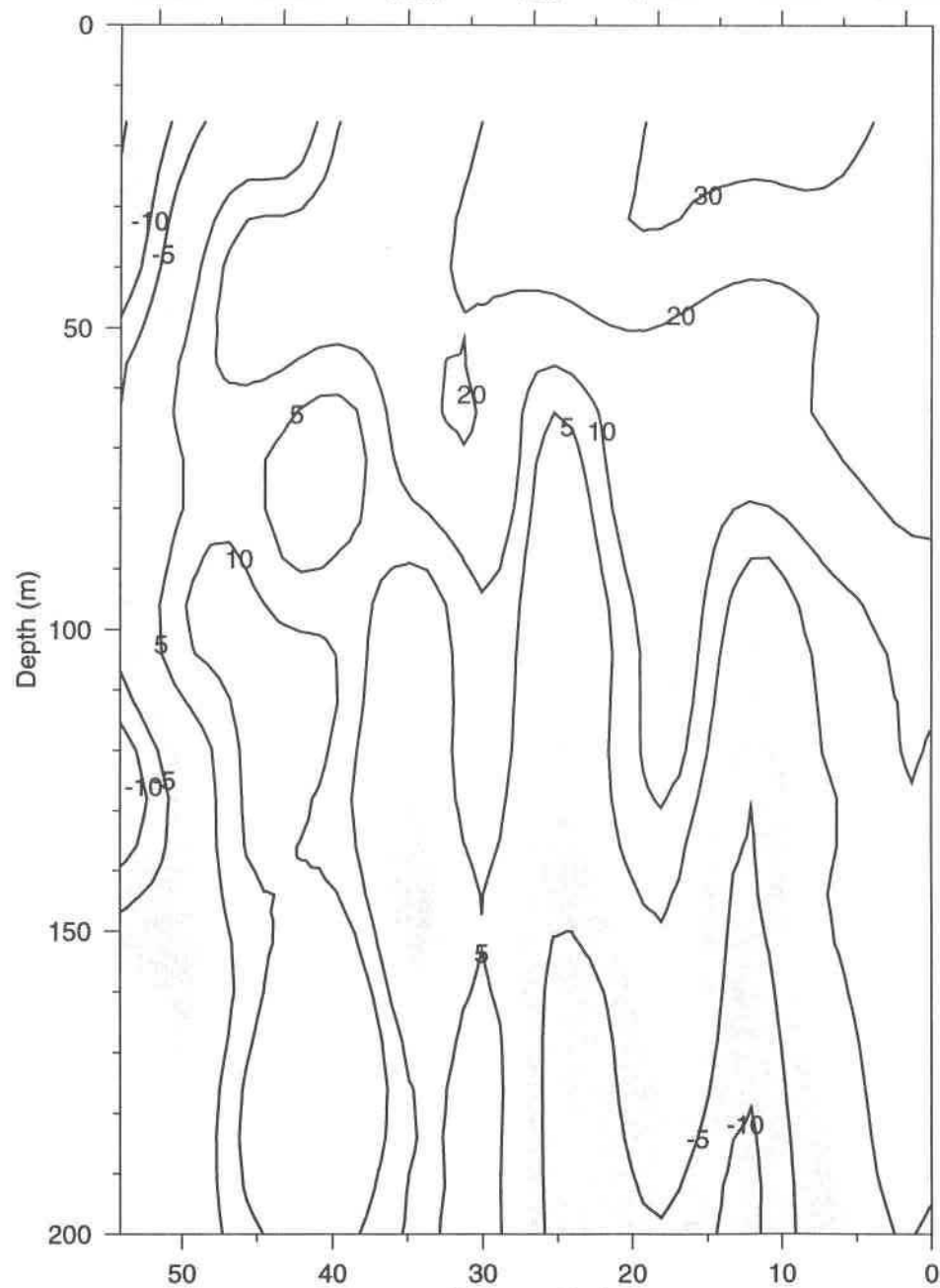
br w9406
v both det

ADCP Line 12 U (year day 239.59-239.76, 27-Aug-94)

Latitude: 41.90 °N

Longitude (°E)

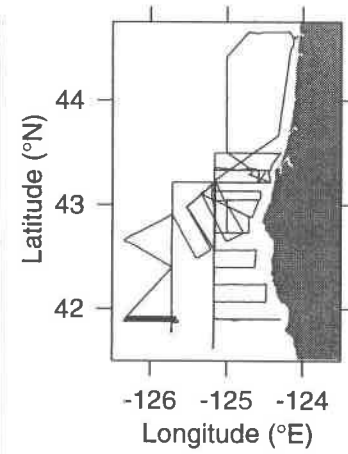
-126.3 -126.2 -126.1 -126 -125.9 -125.8 -125.7



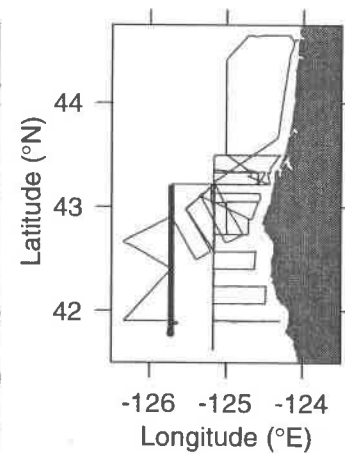
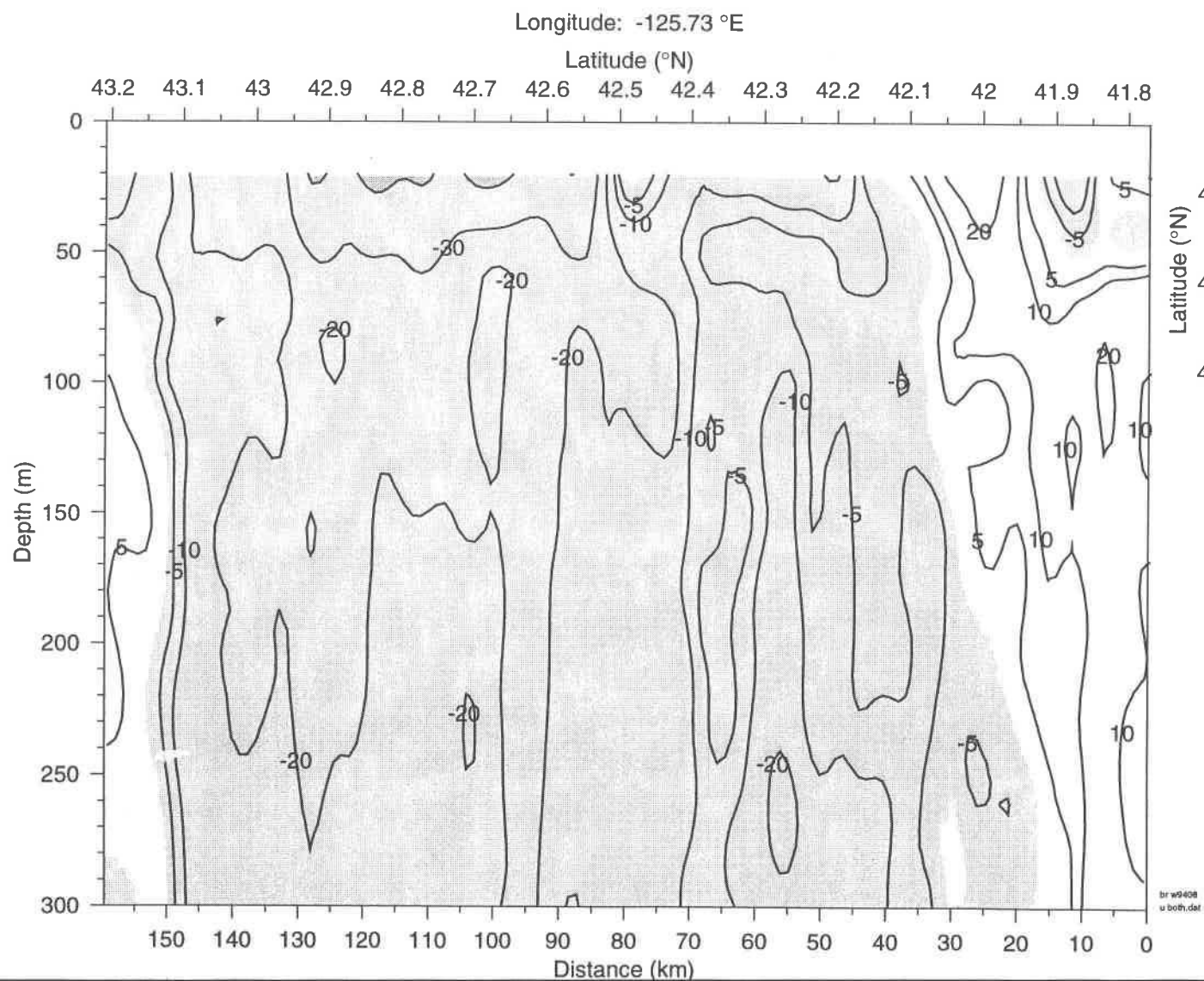
br w9408
u both.dat

91

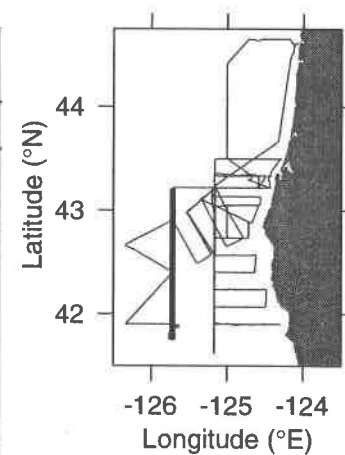
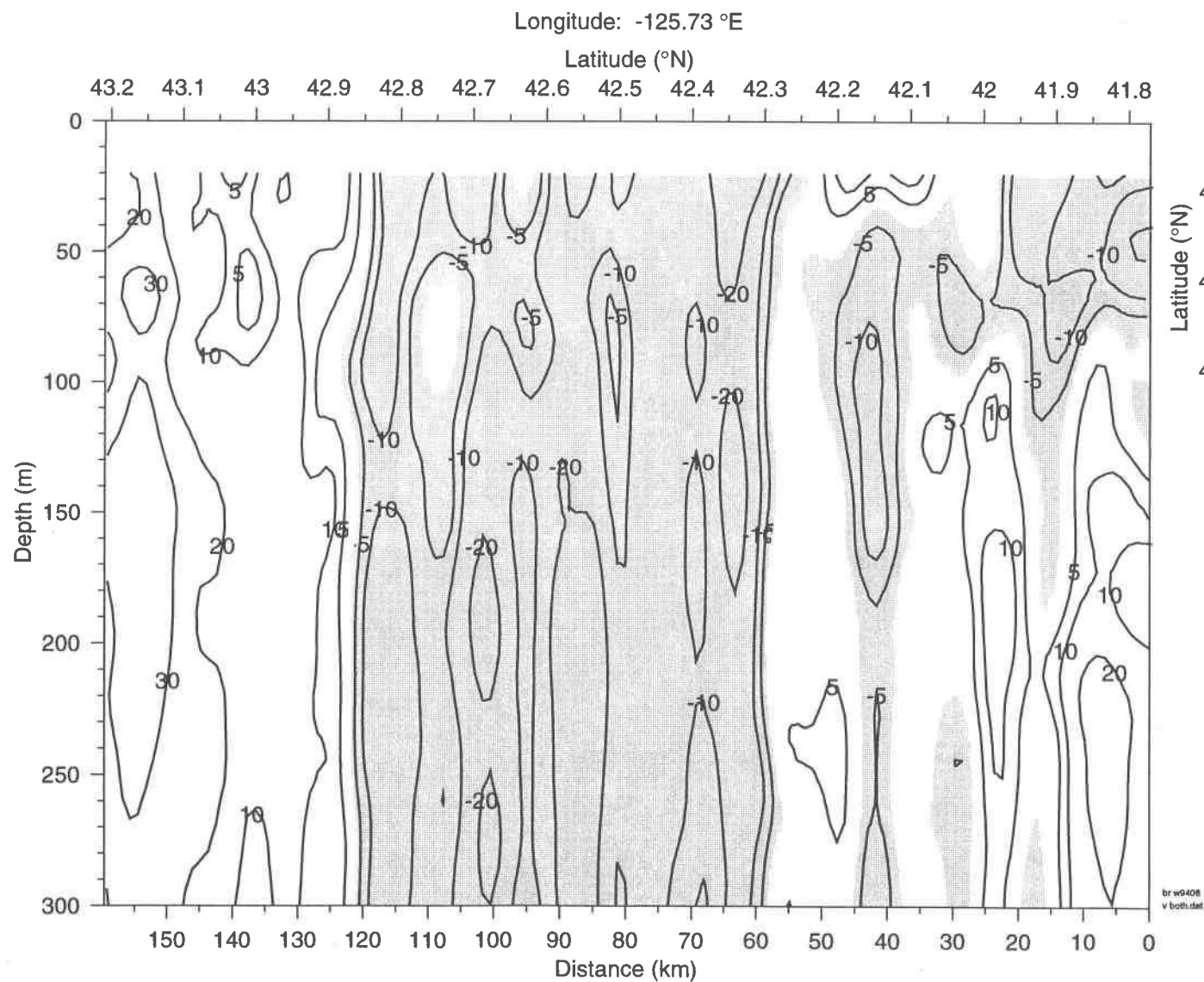
Longitude (°E)



ADCP Line 13 U (year day 239.92-240.42, 28-Aug-94)



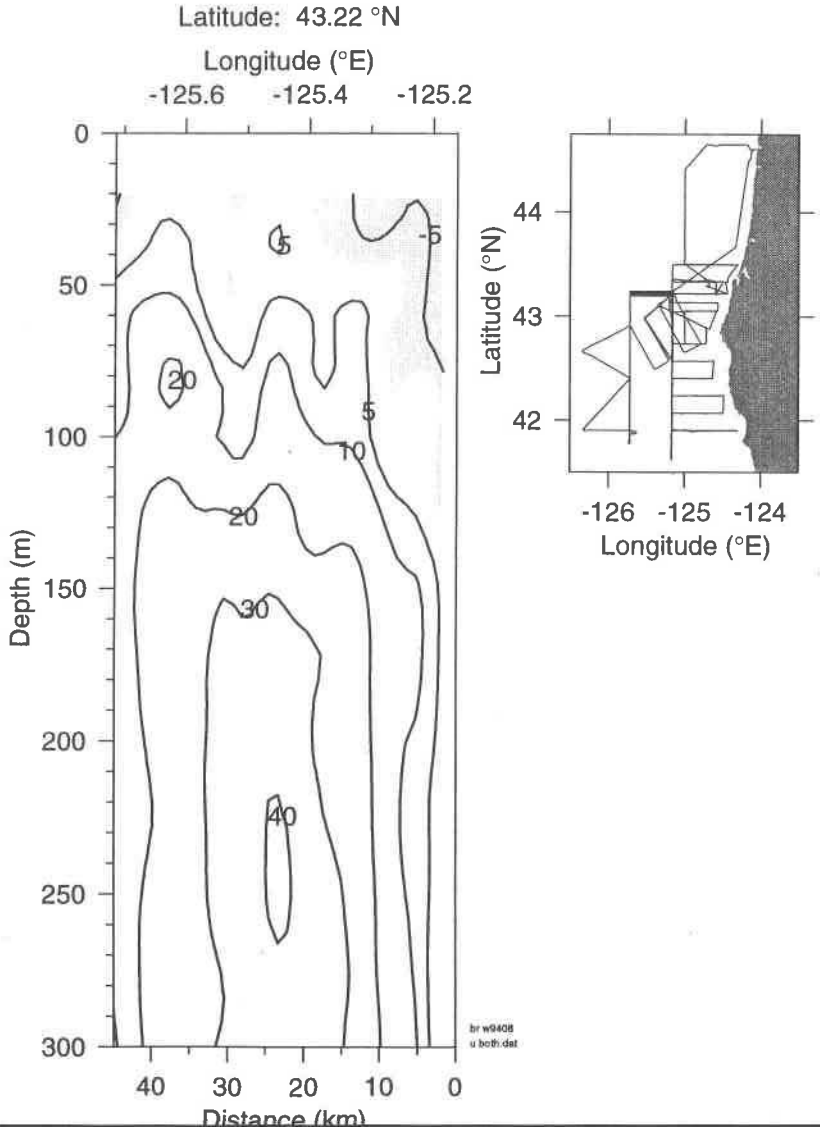
ADCP Line 13 V (year day 239.92-240.42, 28-Aug-94)



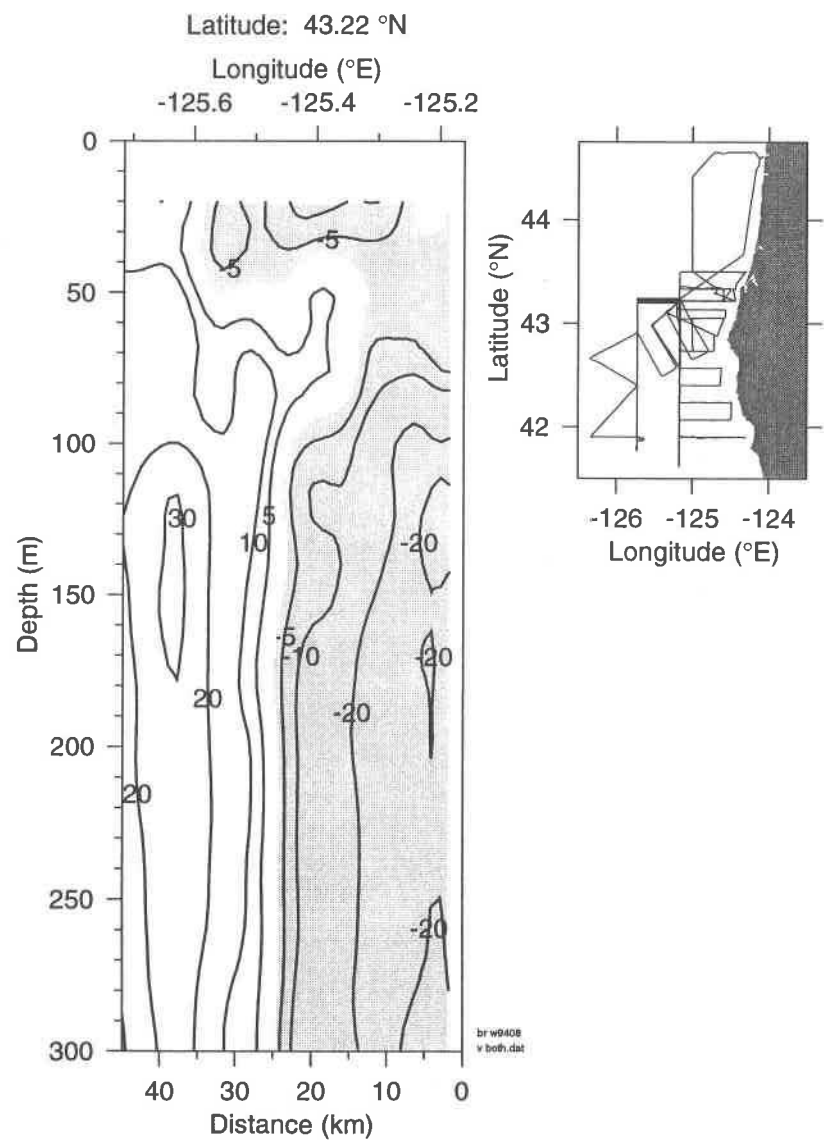
br w9408
v both.dat

ADCP Line 14 U (year day 240.42-240.55, 28-Aug-94)

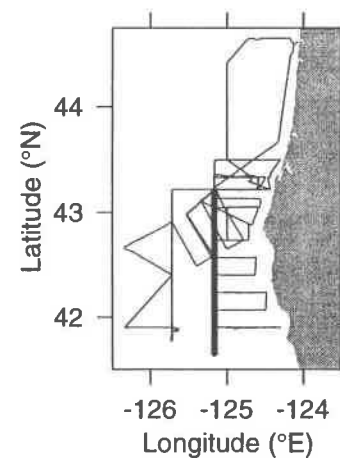
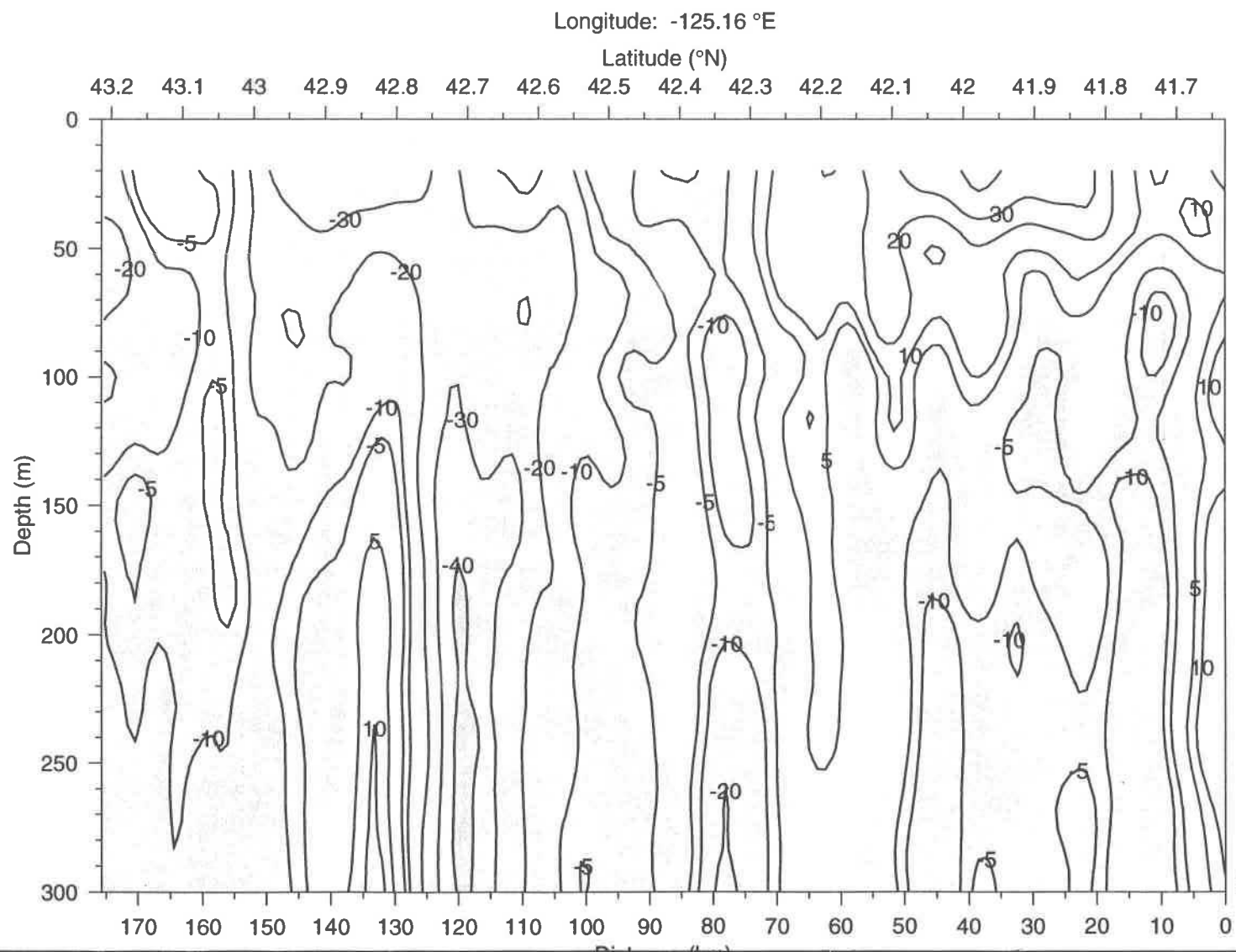
94



ADCP Line 14 V (year day 240.42-240.55, 28-Aug-94)

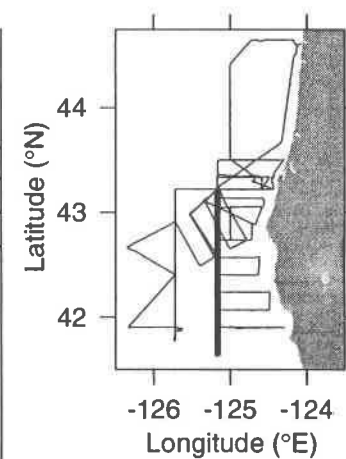
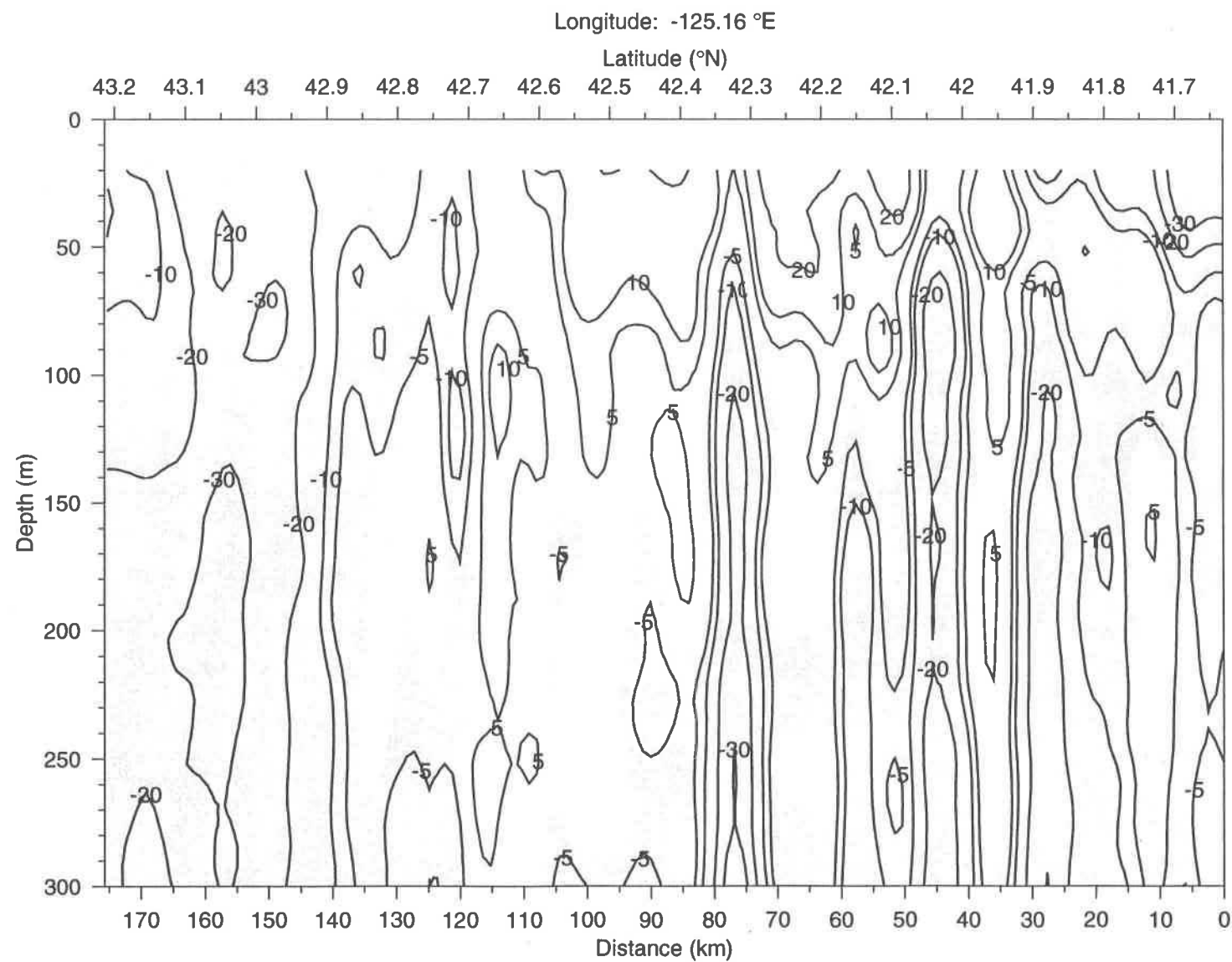


ADCP Line 15 U (year day 240.55-241.08, 28-Aug-94)



br w9408
u both dat

ADCP Line 15 V (year day 240.55-241.08, 28-Aug-94)



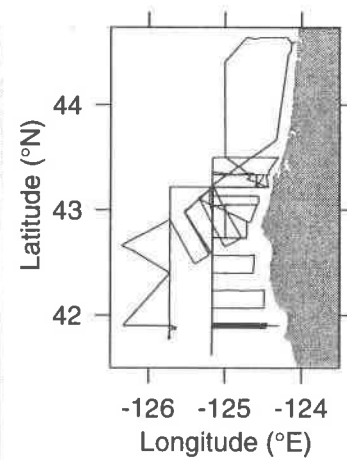
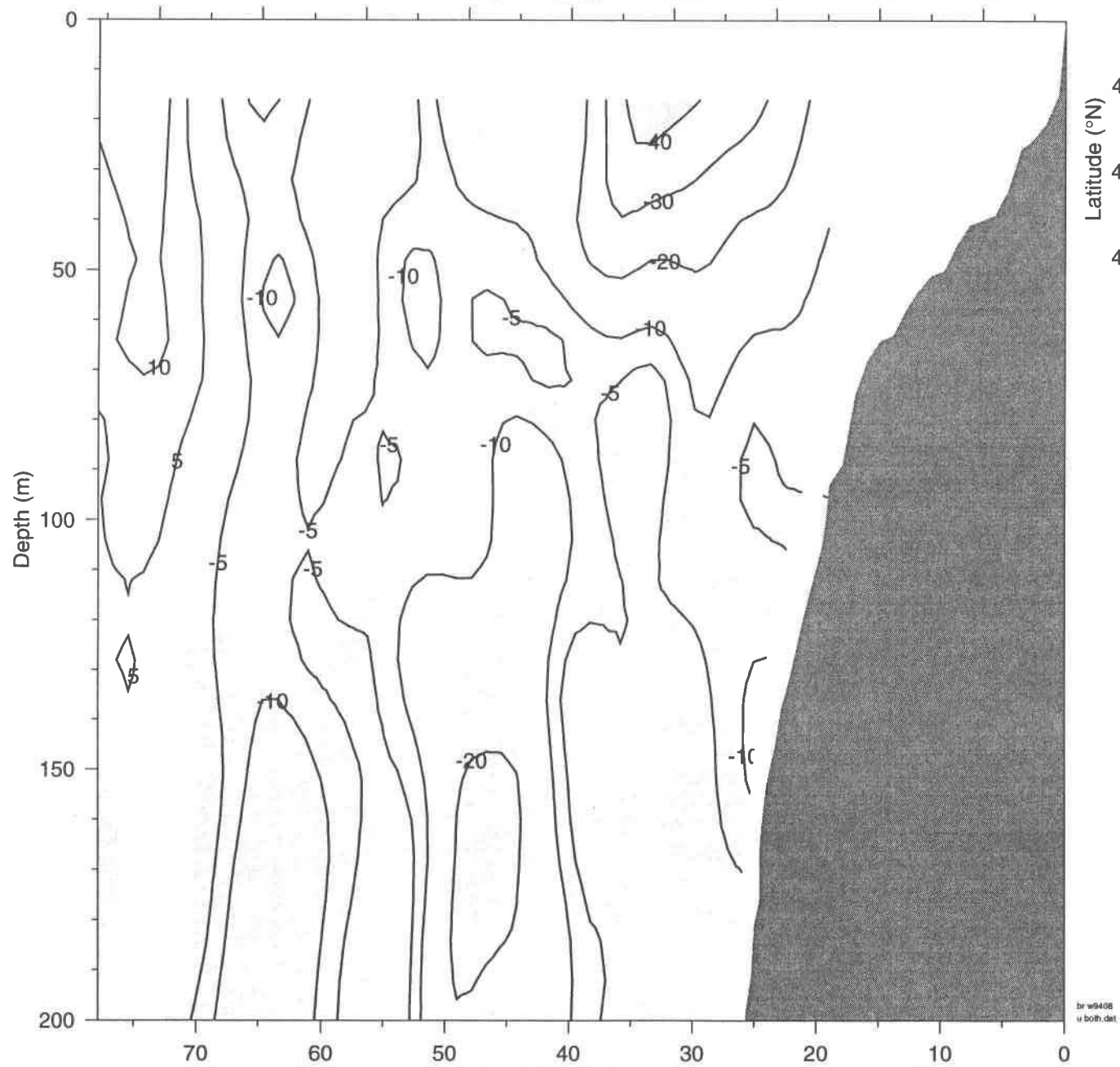
br w9408
v both.dat

ADCP Line 16 U (year day 241.69-241.87, 29-Aug-94)

Latitude: 41.90 °N

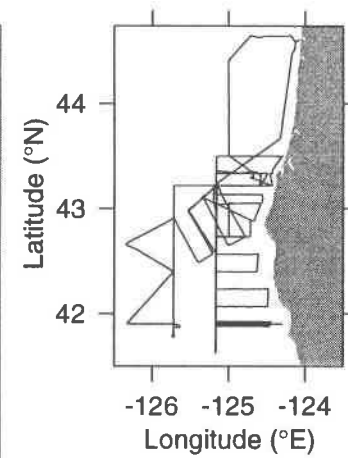
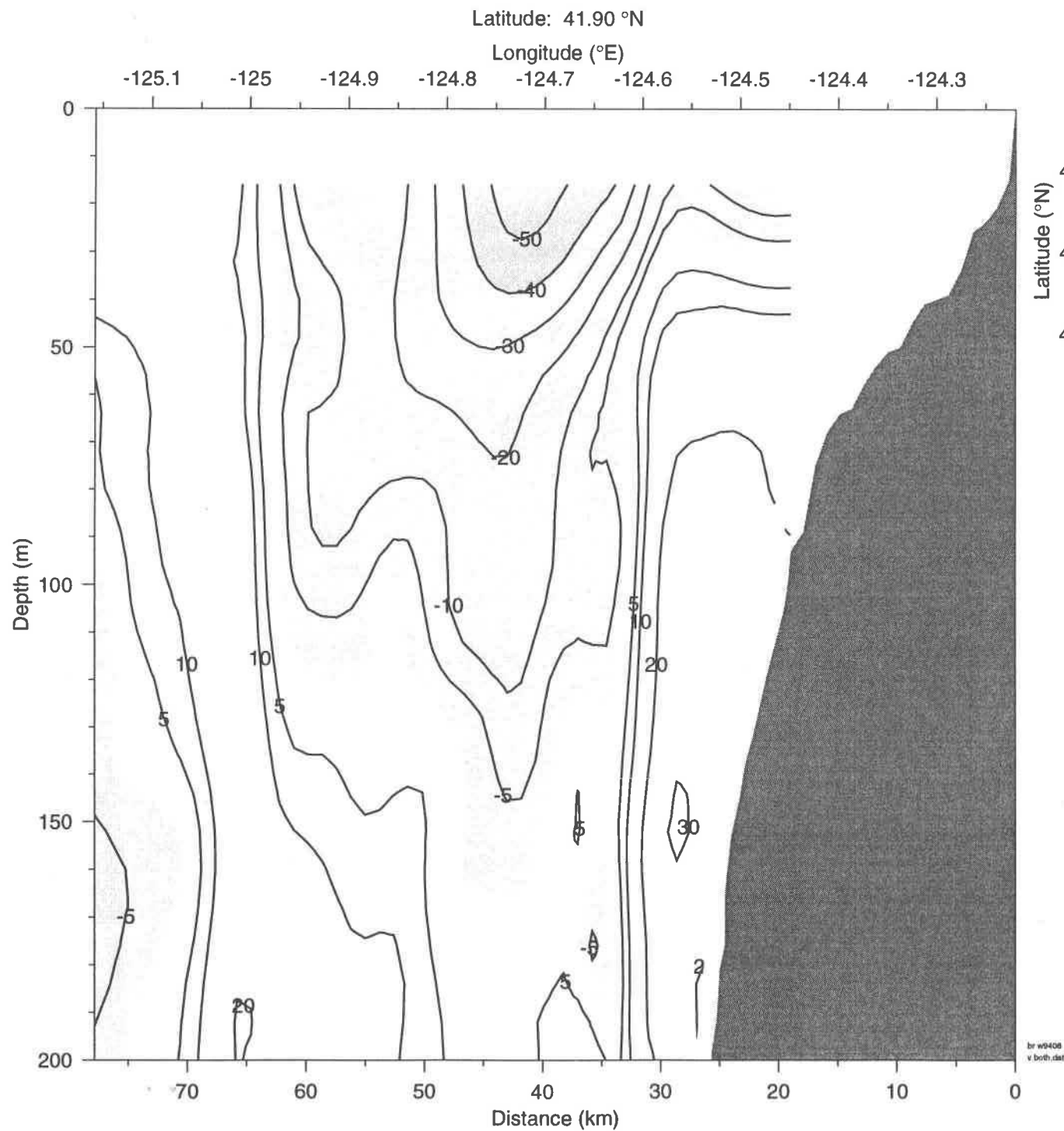
Longitude (°E)

-125.1 -125 -124.9 -124.8 -124.7 -124.6 -124.5 -124.4 -124.3



br w9408
v both.dat

ADCP Line 16 V (year day 241.69-241.87, 29-Aug-94)



100

100

100

100



100

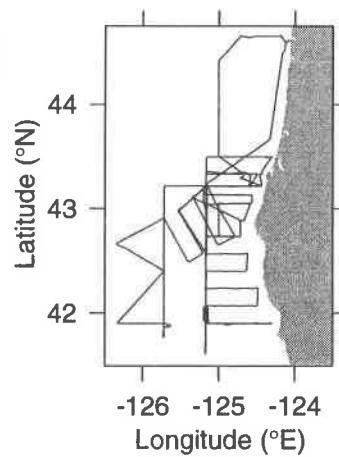
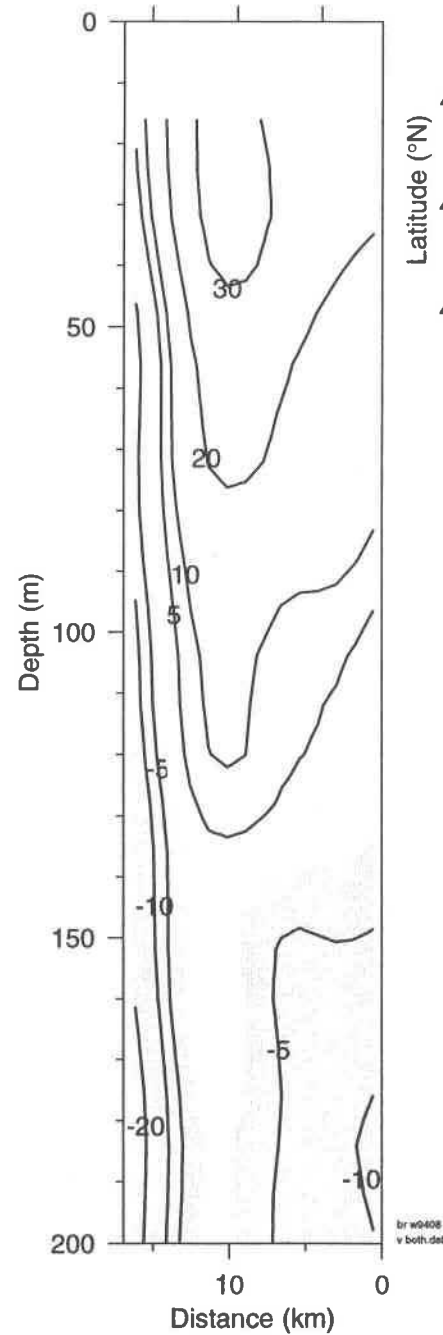
100

ADCP Line 16-17 V (year day 241.87-241.92, 29-Aug-94)

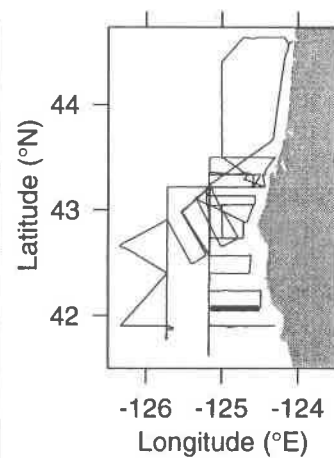
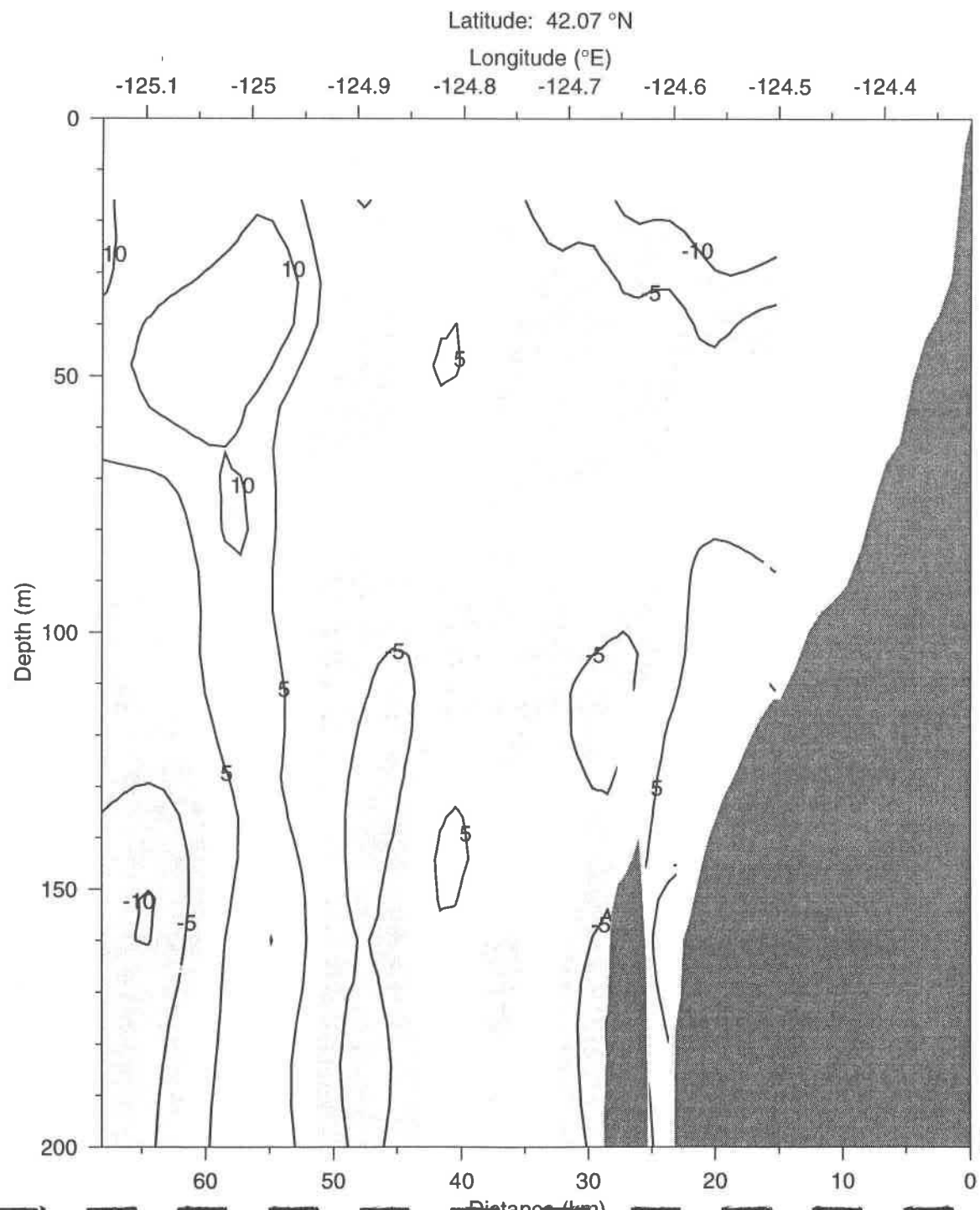
Longitude: -125.17 °E

Latitude (°N)

42.05 42 41.95



ADCP Line 17 U (year day 241.92-242.08, 30-Aug-94)



br w6408
u both.dat

ADCP Line 17 V (year day 241.92-242.08, 30-Aug-94)

Latitude: 42.07 °N

Longitude (°E)

-125.1 -125 -124.9 -124.8 -124.7 -124.6 -124.5 -124.4

0

50

100

150

50

200

Depth (m)

60

50

40

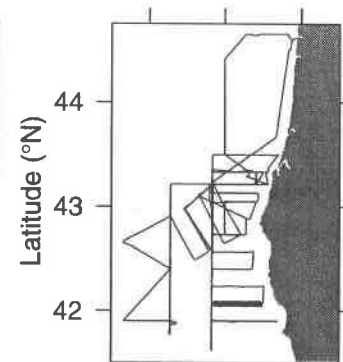
30

20

10

0

Distance (km)



Latitude (°N)

-126 -125 -124

Longitude (°E)

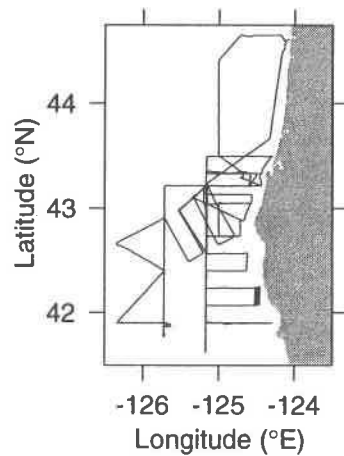
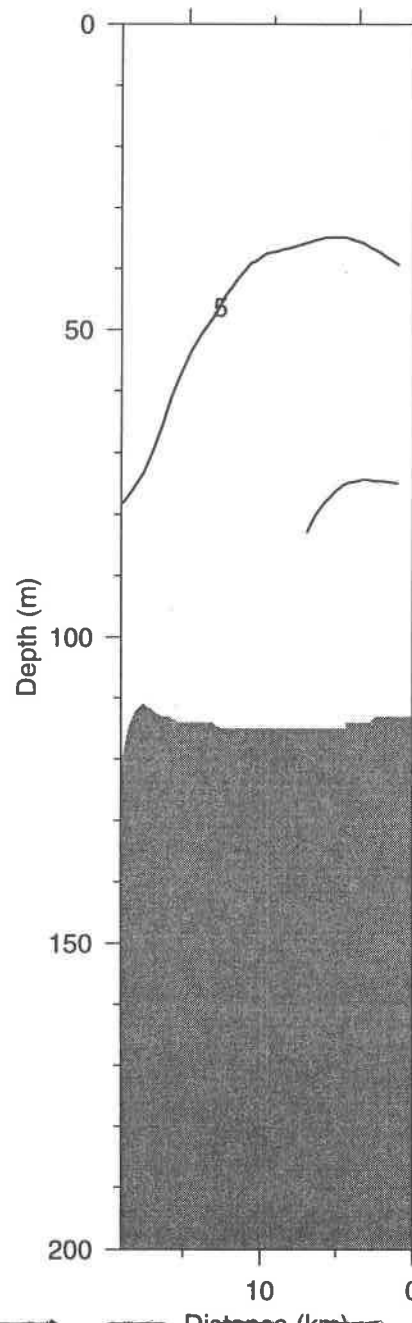
br w9408
v bo94.dat

ADCP Line 17-18 U (year day 242.08-242.15, 30-Aug-94)

Longitude: -124.49 °E

Latitude (°N)

42.2 42.1



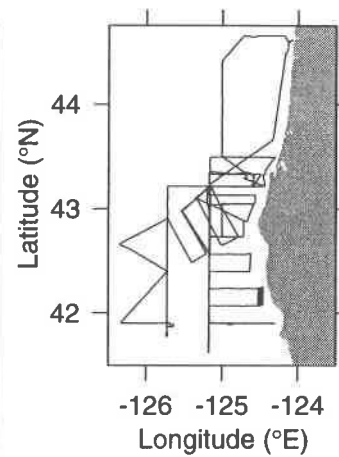
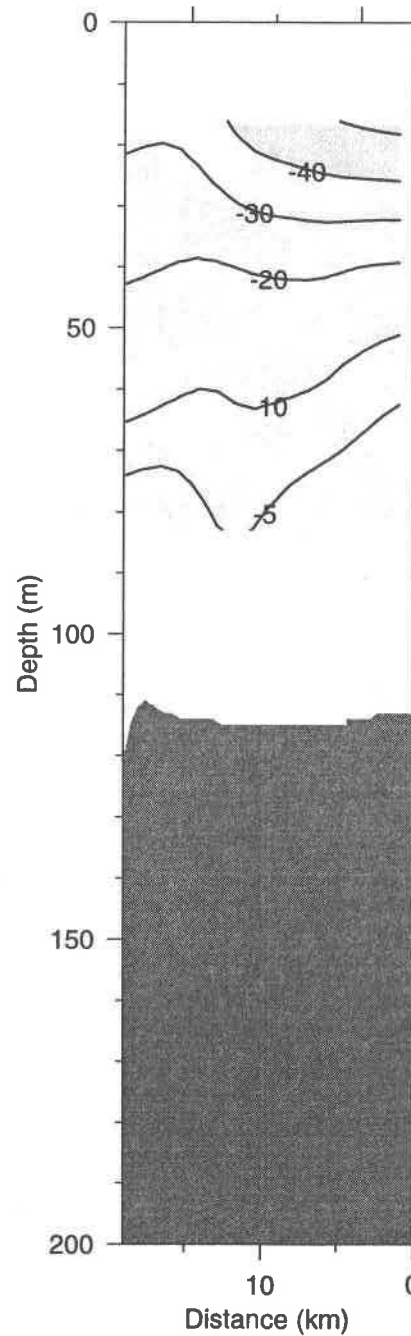
br w9408
u both.dat

ADCP Line 17-18 V (year day 242.08-242.15, 30-Aug-94)

Longitude: -124.49 °E

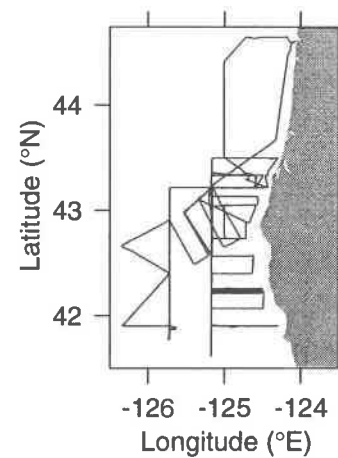
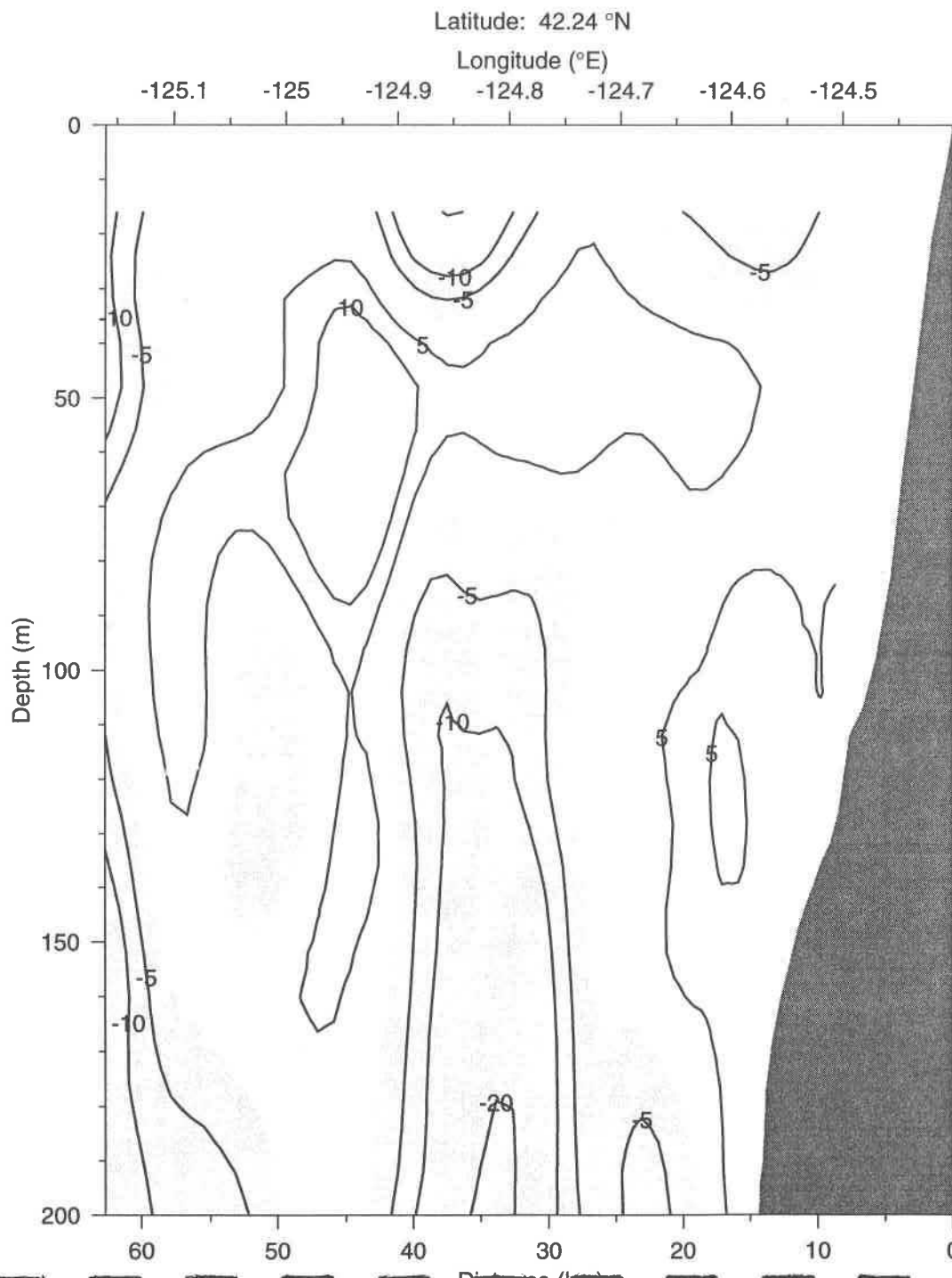
Latitude (°N)

42.2 42.1



br w9408
v both.dat

ADCP Line 18 U (year day 242.15-242.31, 30-Aug-94)



ADCP Line 18 V (year day 242.15-242.31, 30-Aug-94)

Latitude: 42.24 °N

Longitude (°E)

-125.1 -125 -124.9 -124.8 -124.7 -124.6 -124.5

0

50

100

150

200

Depth (m)

60

50

40

30

20

10

0

Distance (km)

10

5

5

5

5

5

5

5

5

5

5

5

5

5

5

5

5

5

5

5

5

5

30

20

10

5

5

5

5

5

5

5

5

5

5

5

5

5

5

30

20

10

5

5

5

5

5

5

5

5

5

5

5

5

5

5

br w0405
v both.dat

Latitude (°N)

44

43

42

-126

-125

-124

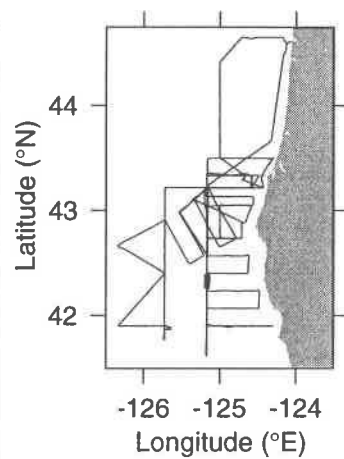
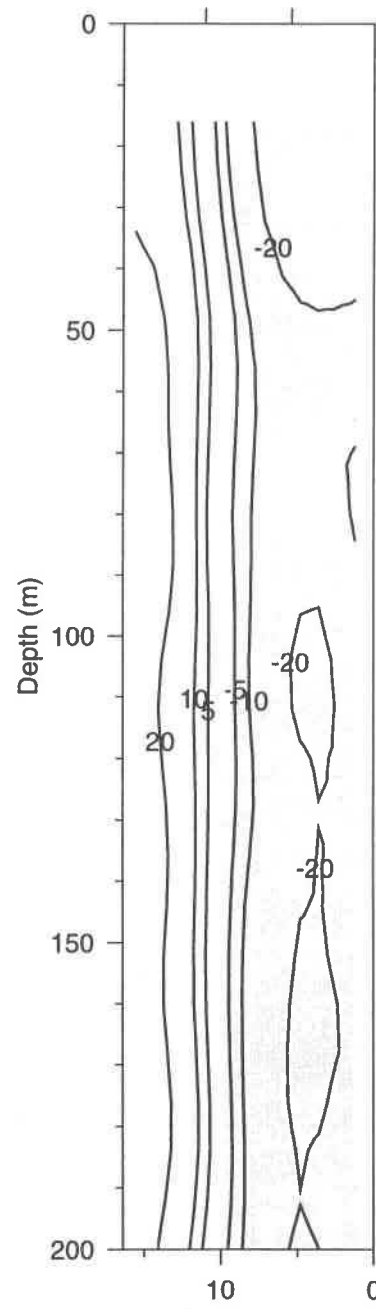
Longitude (°E)

ADCP Line 18-19 U (year day 242.31-242.36, 30-Aug-94)

Longitude: -125.16 °E

Latitude (°N)

42.35 42.3



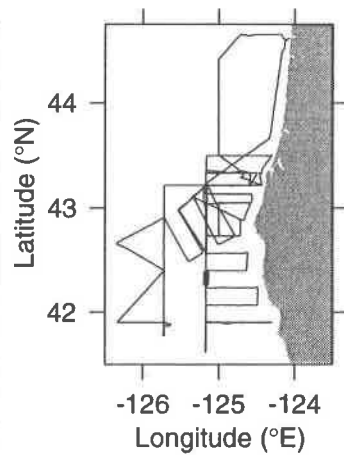
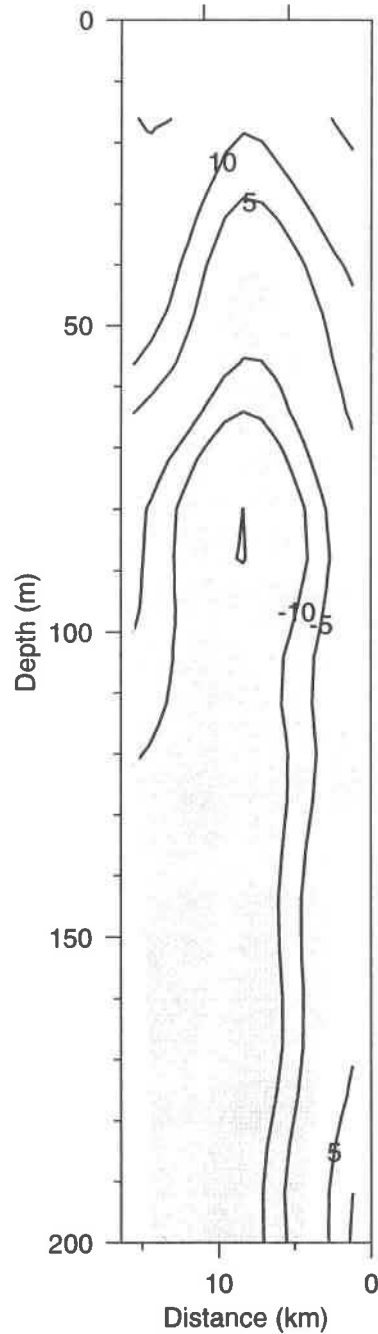
br w9408
u both.dkt

ADCP Line 18-19 V (year day 242.31-242.36, 30-Aug-94)

Longitude: -125.16 °E

Latitude (°N)

42.35 42.3



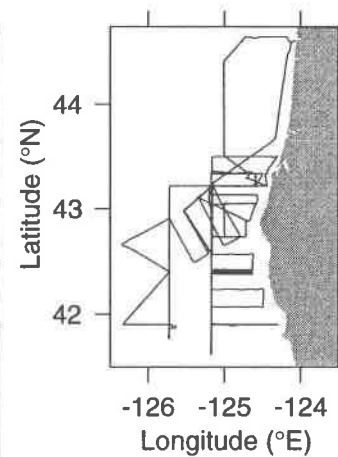
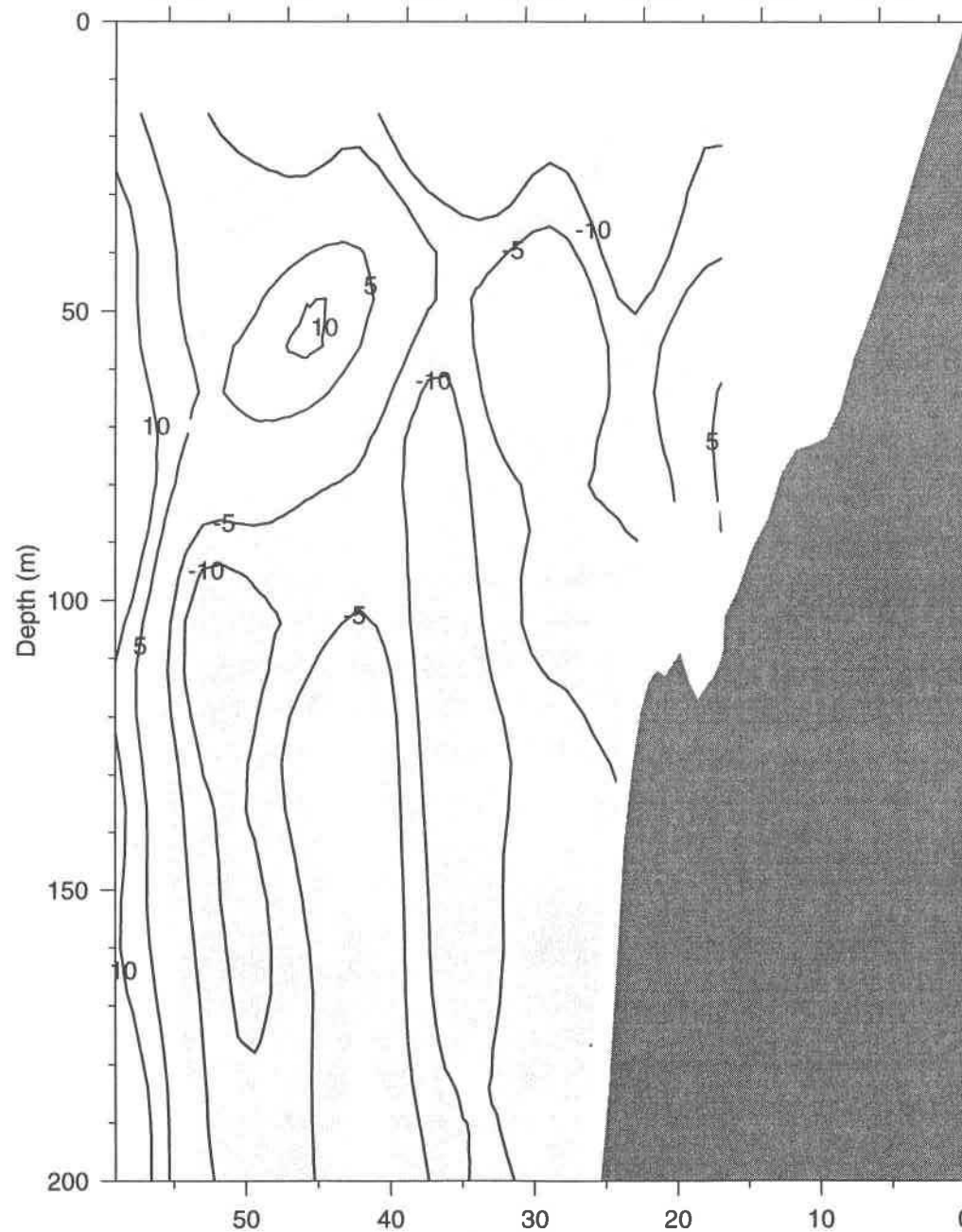
br w9408
v both.daf

ADCP Line 19 U (year day 242.36-242.49, 30-Aug-94)

Latitude: 42.40 °N

Longitude (°E)

-125.1 -125 -124.9 -124.8 -124.7 -124.6 -124.5



br w9408
u both dal

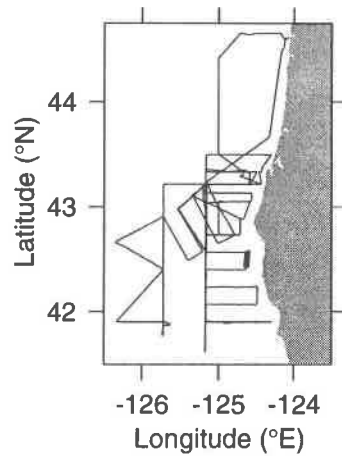
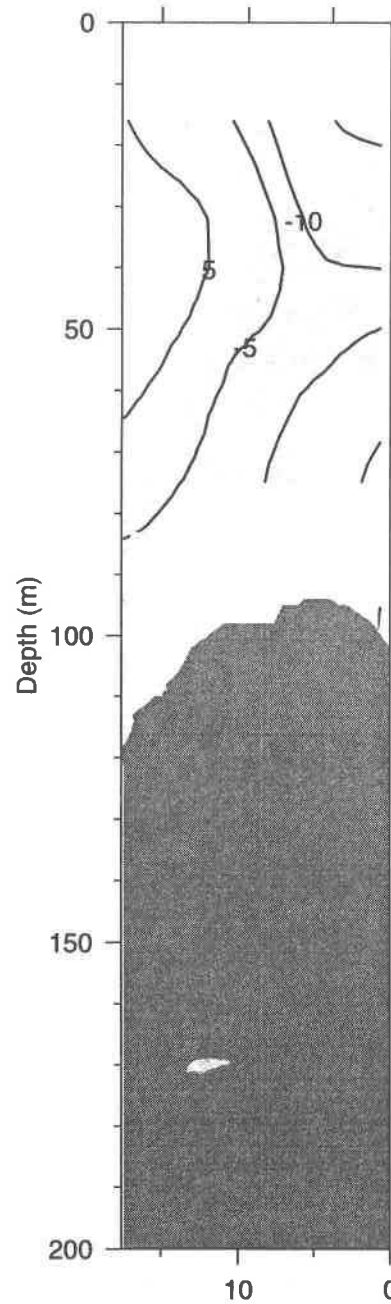


ADCP Line 19-20 U (year day 242.50-242.56, 30-Aug-94)

Longitude: -124.62 °E

Latitude (°N)

42.55 42.5 42.45



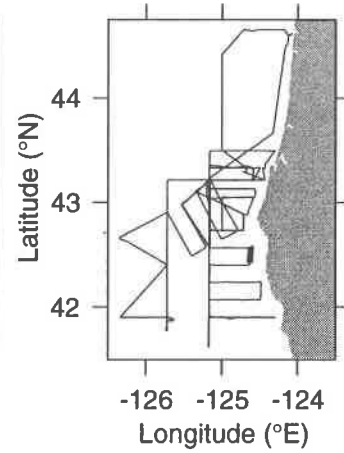
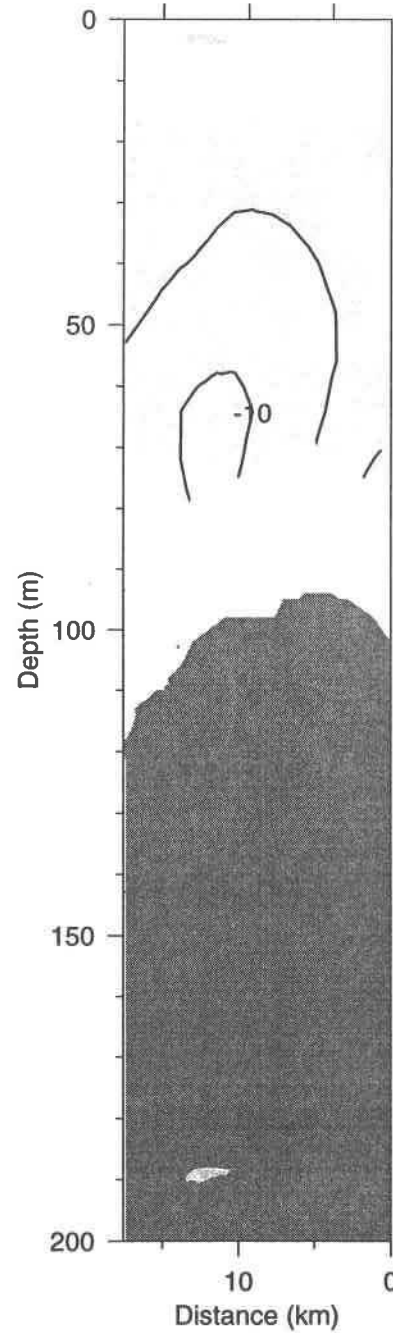
br w9408
u both dat

ADCP Line 19-20 V (year day 242.50-242.56, 30-Aug-94)

Longitude: -124.62 °E

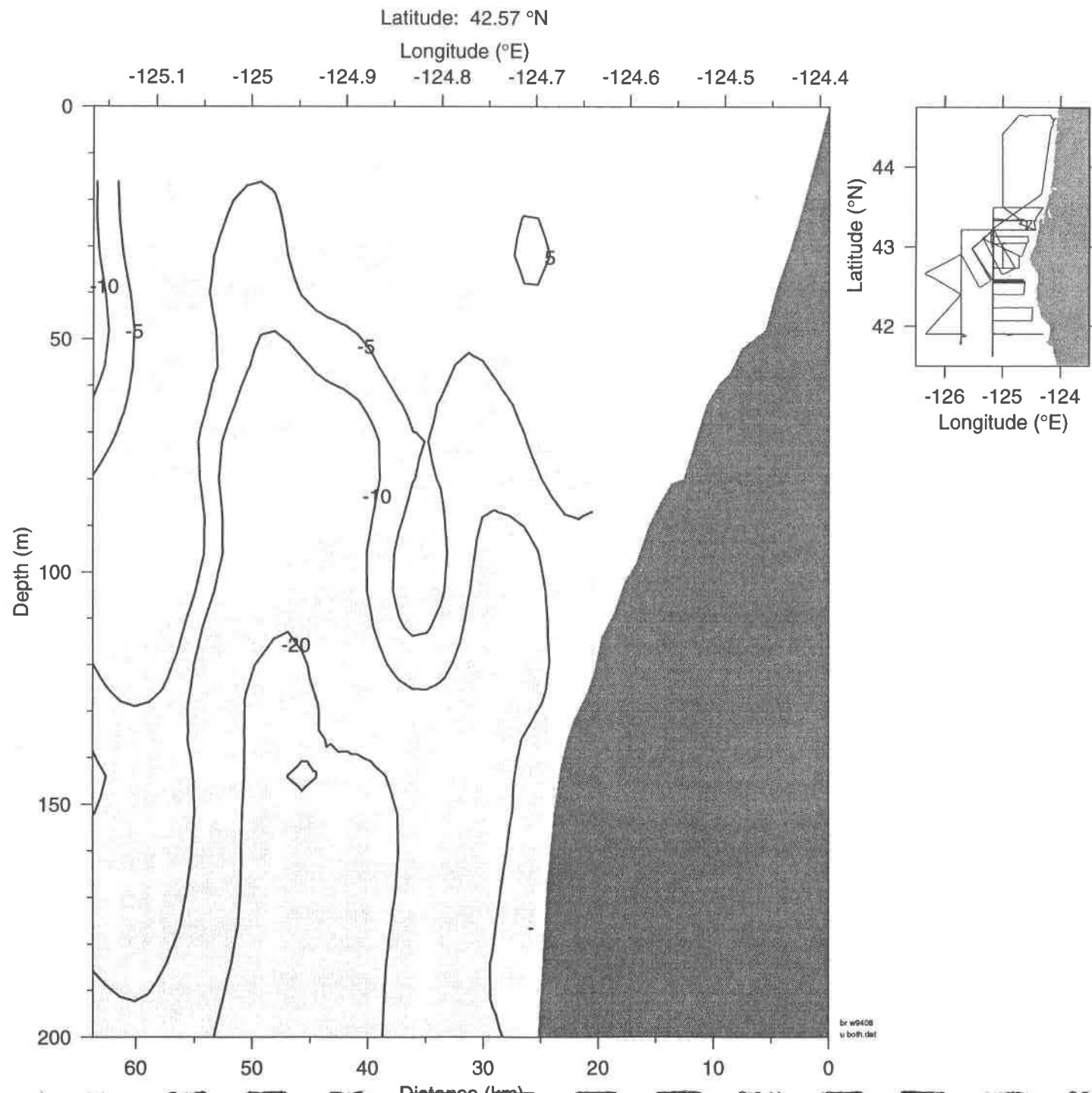
Latitude (°N)

42.55 42.5 42.45



br w9408
v both.dat

ADCP Line 20 U (year day 242.56-242.69, 30-Aug-94)

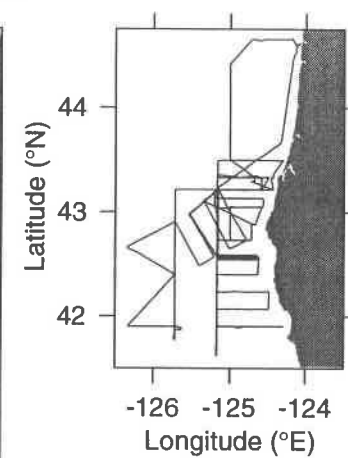
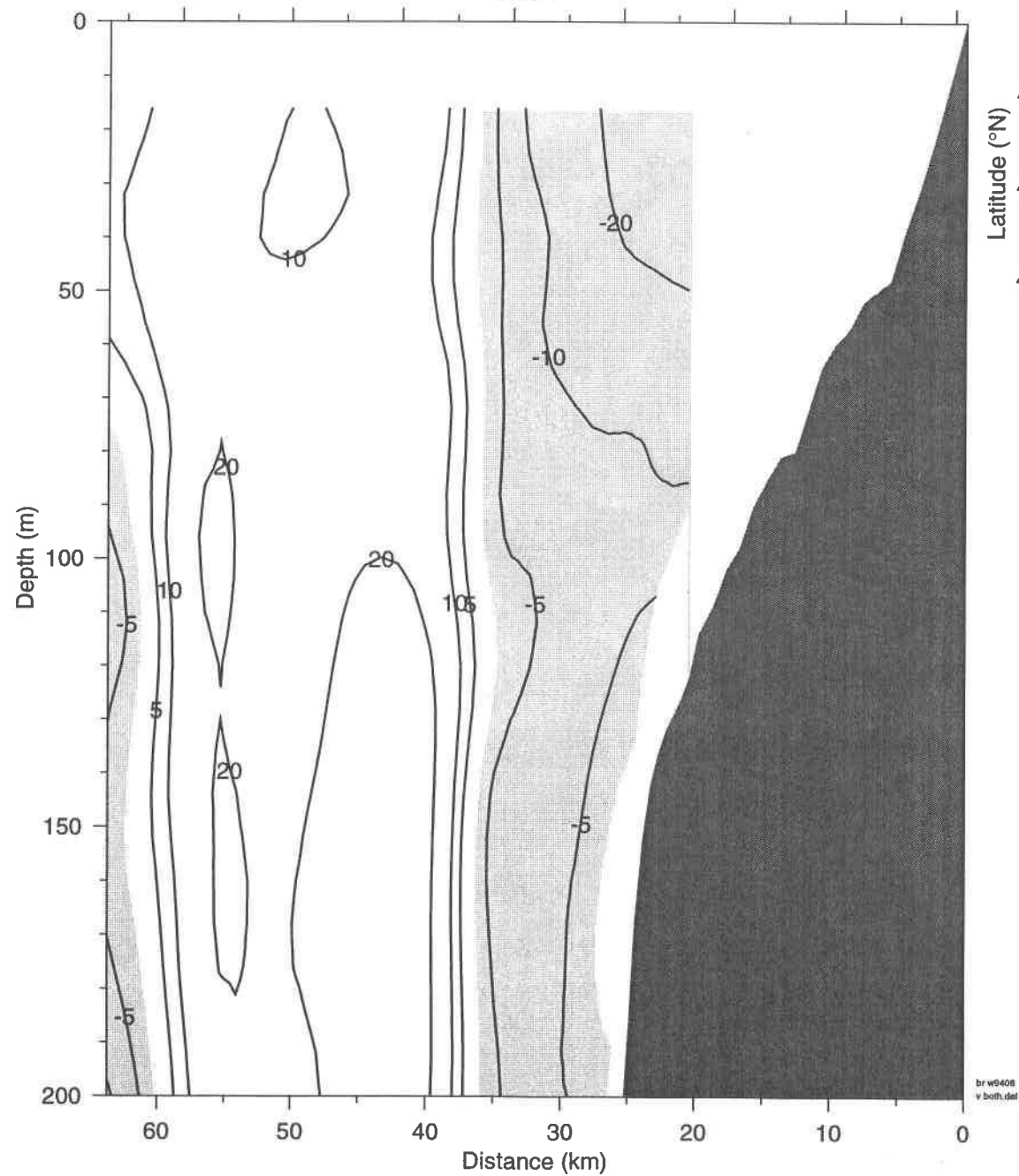


ADCP Line 20 V (year day 242.56-242.69, 30-Aug-94)

Latitude: 42.57 °N

Longitude (°E)

-125.1 -125 -124.9 -124.8 -124.7 -124.6 -124.5 -124.4



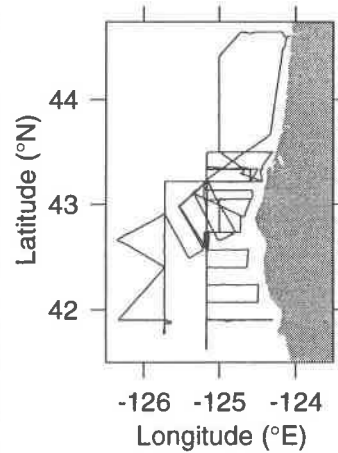
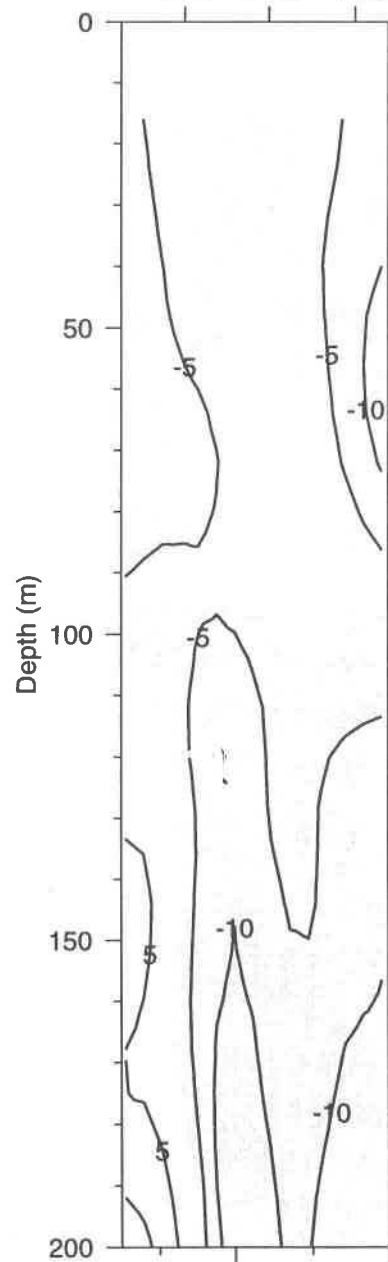
br w0408
v both.daf

ADCP Line 20-21 U (year day 242.69-242.74, 30-Aug-94)

Longitude: -125.17 °E

Latitude (°N)

42.7 42.65 42.6



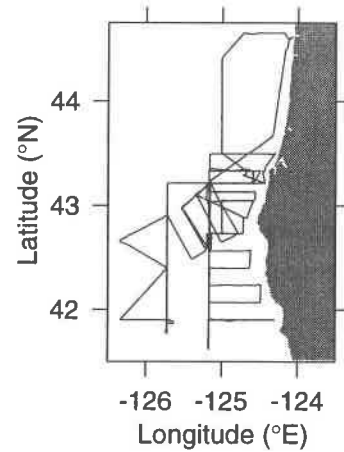
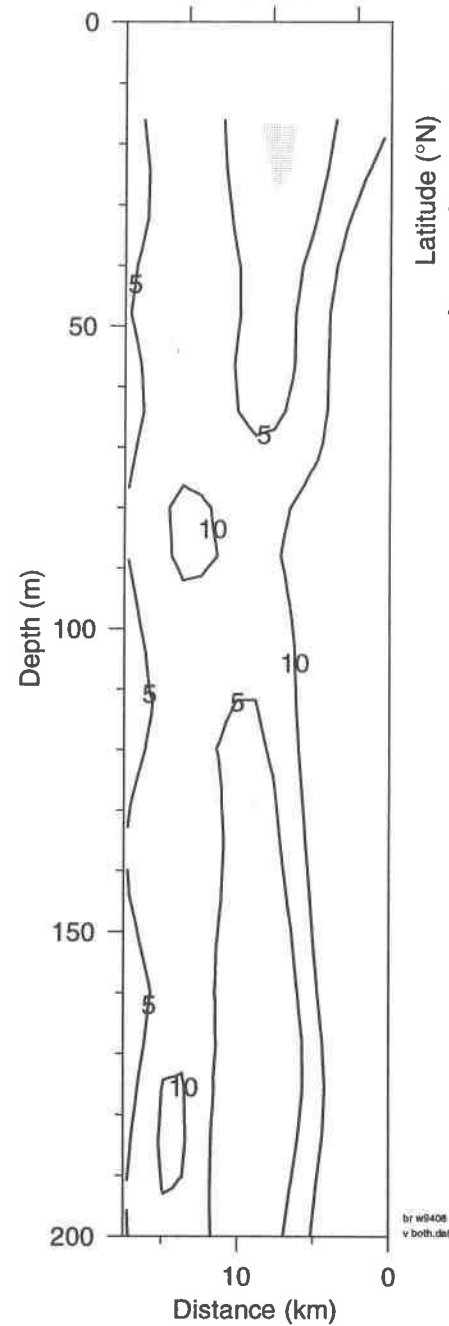
br w9408
u both.dat

ADCP Line 20-21 V (year day 242.69-242.74, 30-Aug-94)

Longitude: -125.17 °E

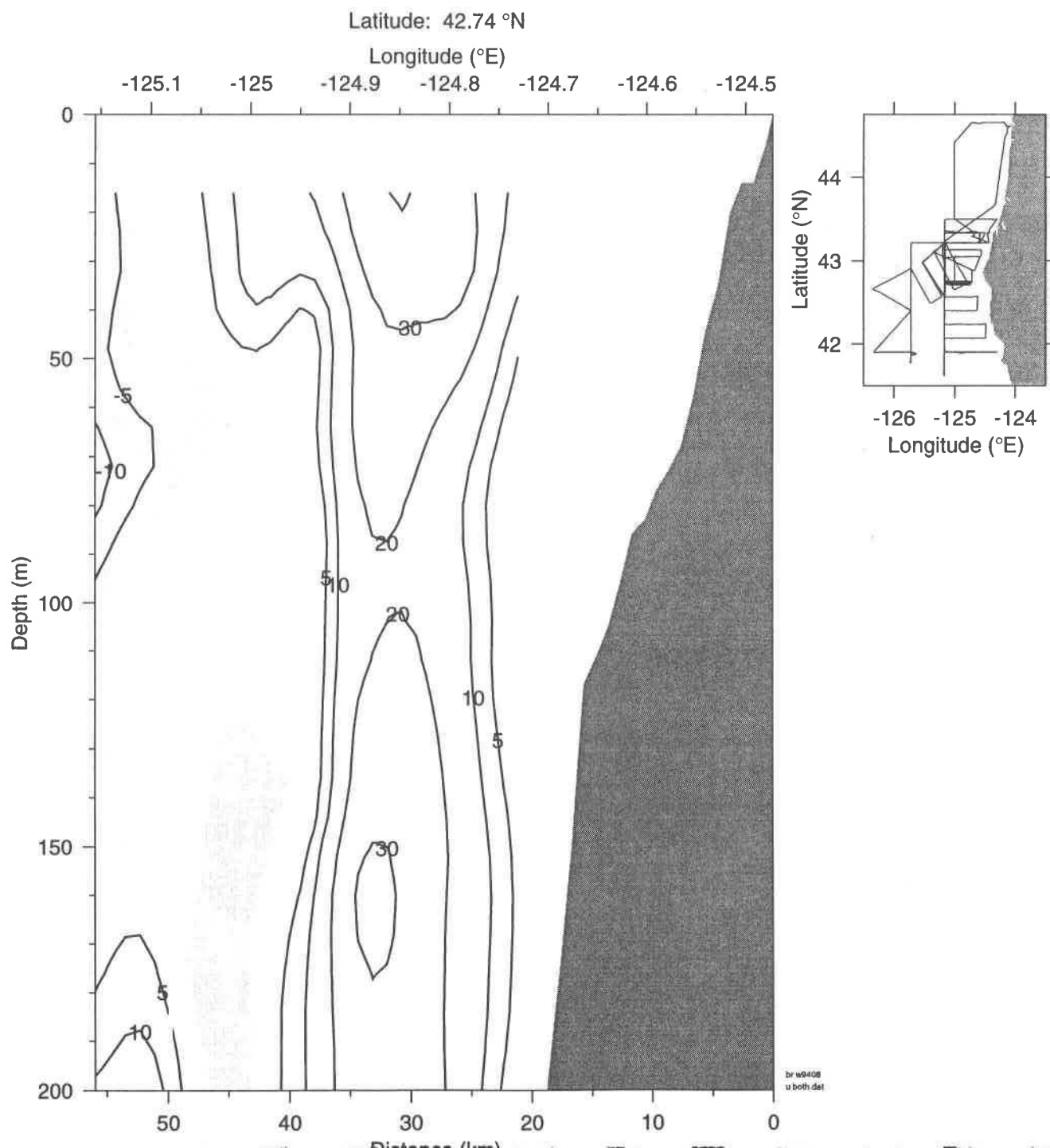
Latitude (°N)

42.7 42.65 42.6



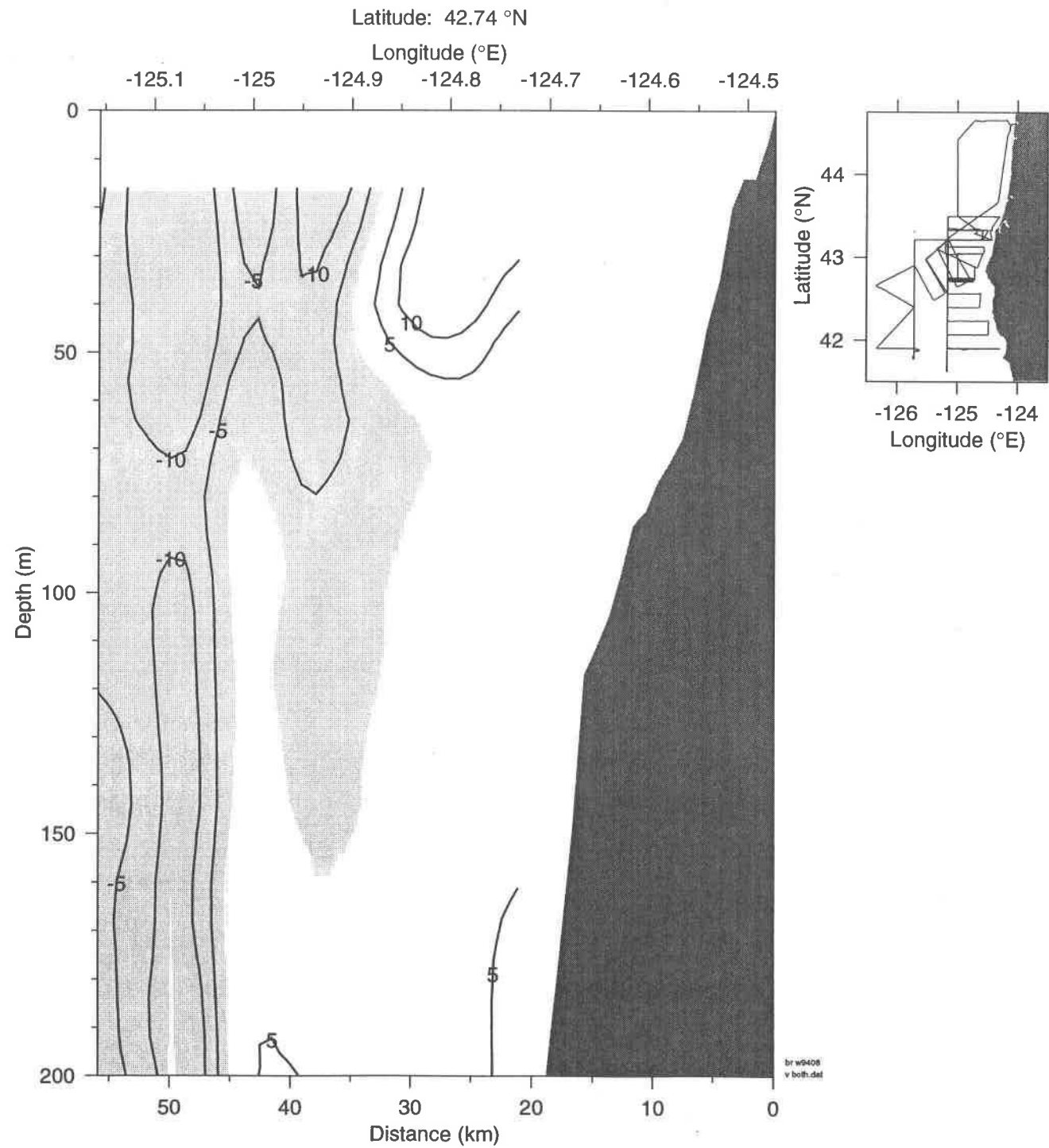
br w9408
v both.dat

ADCP Line 21 U (year day 242.74-242.84, 30-Aug-94)



ADCP Line 21 V (year day 242.74-242.84, 30-Aug-94)

119

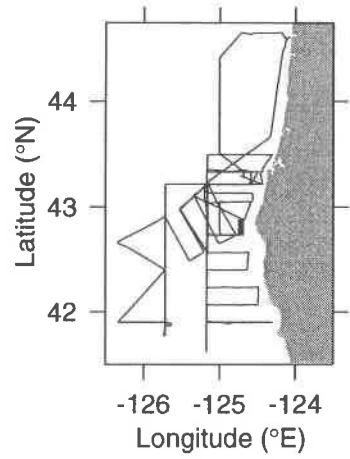
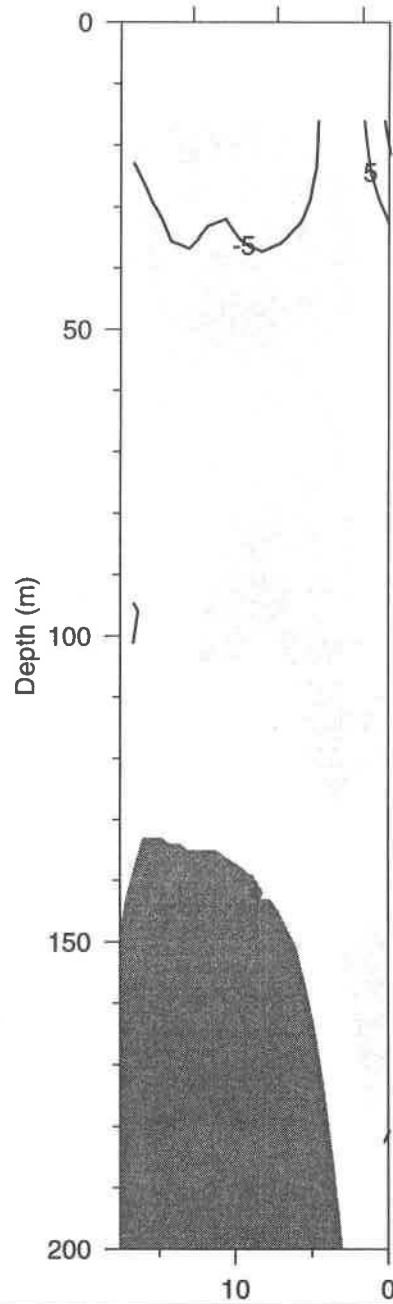


ADCP Line 21-22 U (year day 242.84-242.89, 30-Aug-94)

Longitude: -124.72 °E

Latitude (°N)

42.85 42.8 42.75



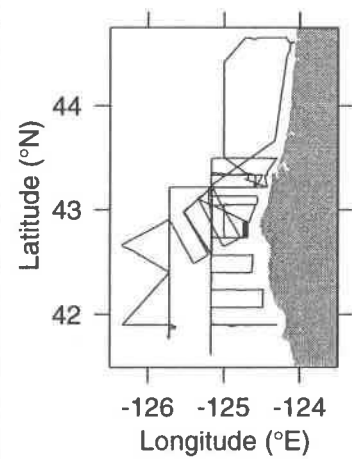
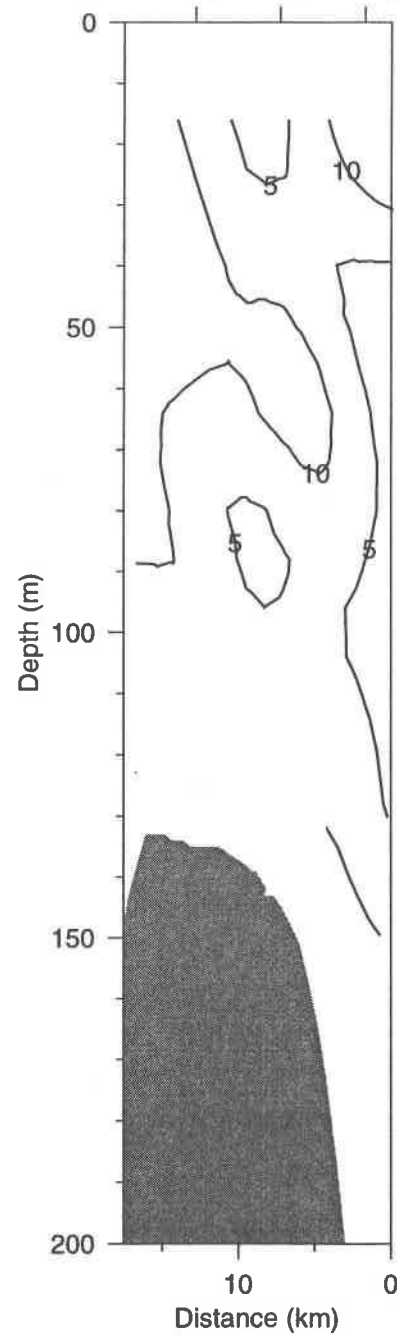
br w9408
u both.dat

ADCP Line 21-22 V (year day 242.84-242.89, 30-Aug-94)

Longitude: -124.72 °E

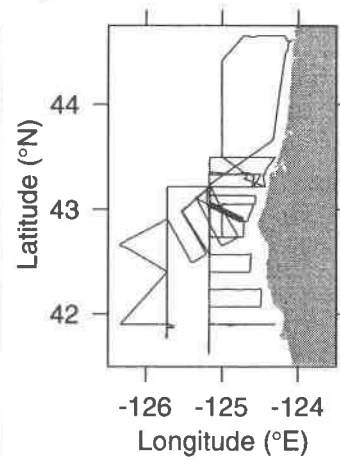
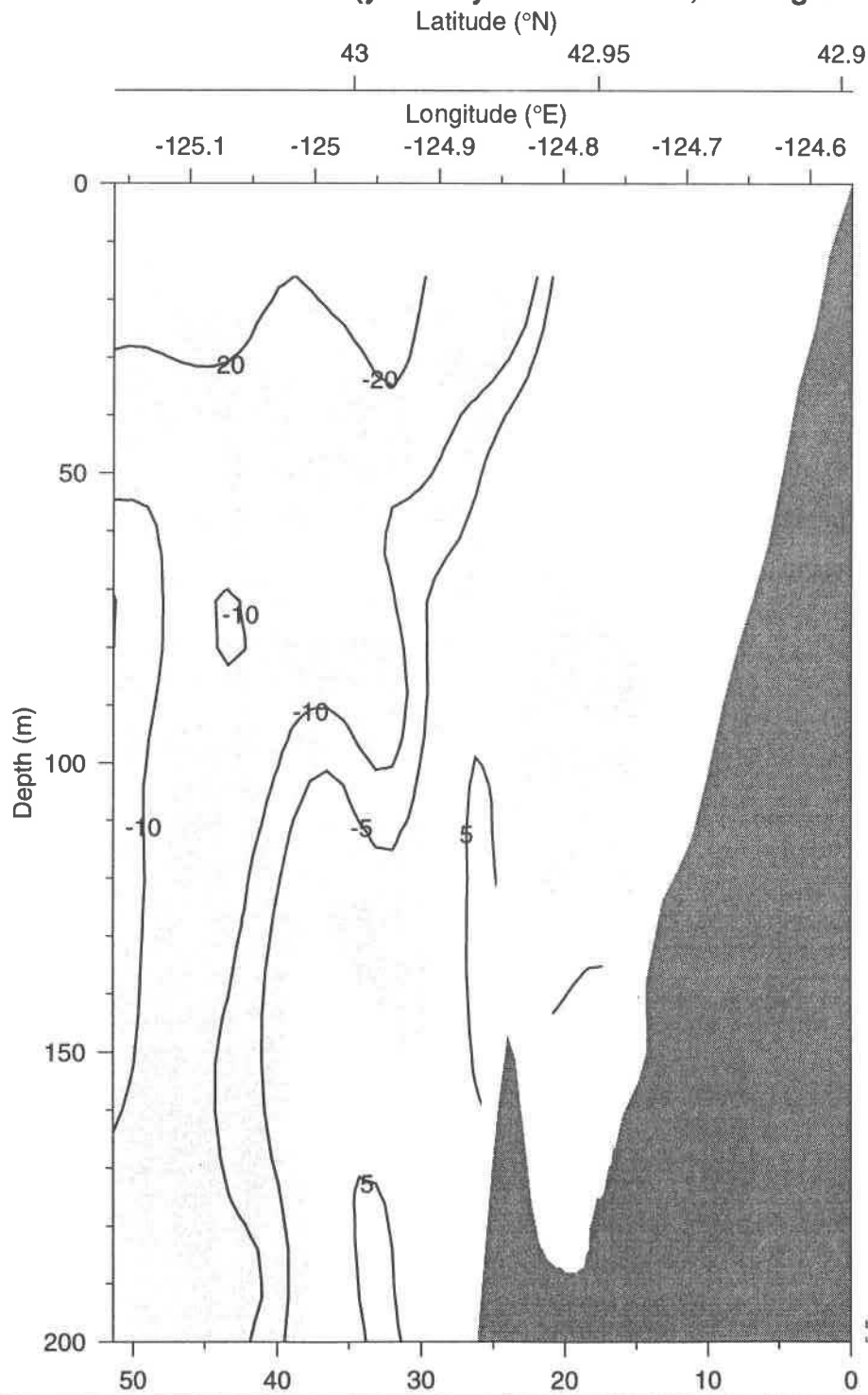
Latitude (°N)

42.85 42.8 42.75

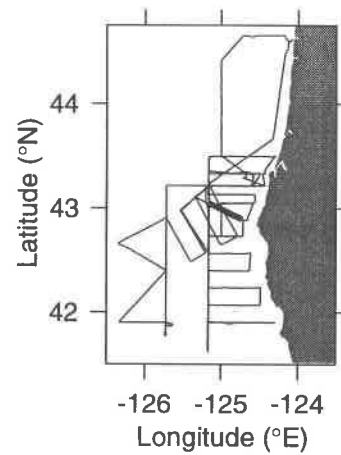
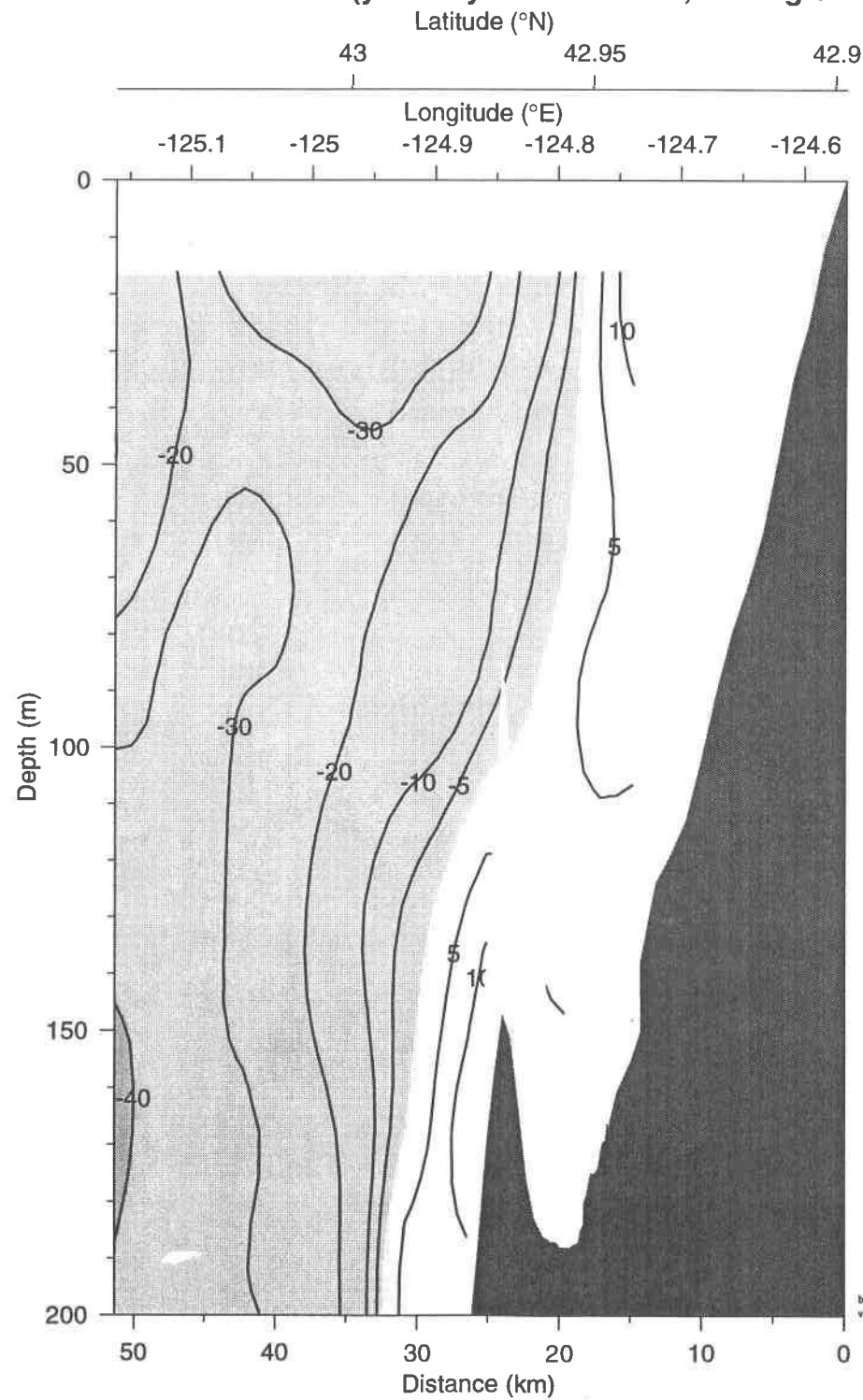


lr w9408
v bofs.dat

ADCP Line 22 U (year day 242.90-243.01, 30-Aug-94)



ADCP Line 22 V (year day 242.90-243.01, 30-Aug-94)



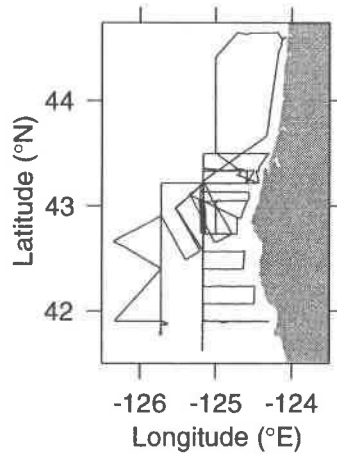
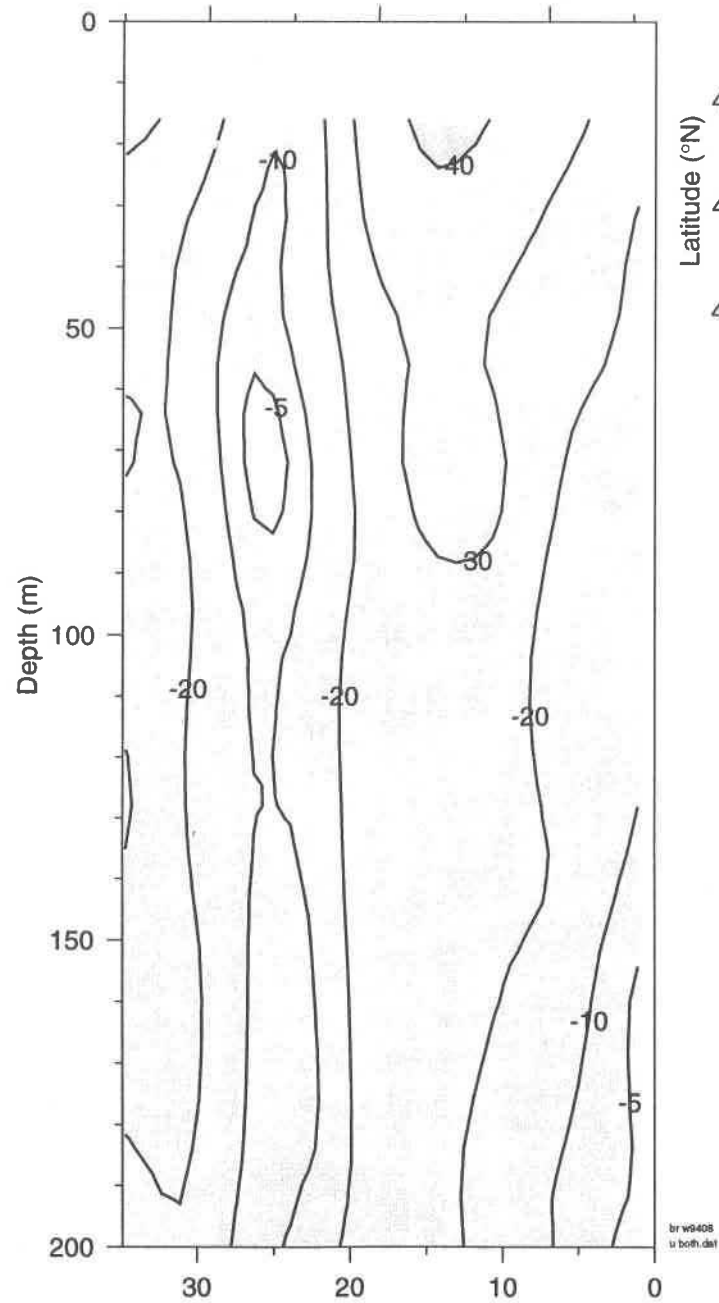
br w6408
v both.dat

ADCP Line 23 U (year day 243.01-243.11, 31-Aug-94)

Longitude: -125.18 °E

Latitude (°N)

43 42.9 42.8



br w9408
u both.dat

ADCP Line 23 V (year day 243.01-243.11, 31-Aug-94)

Longitude: -125.18 °E

Latitude (°N)

43

42.9

42.8

0

50

Depth (m)

100

150

200

Distance (km)

30

20

10

0

-30

-10

-20

-30

-40

-20

-10

-5

5

10

br w9408
v both det

Latitude (°N)

44

43

42

-126

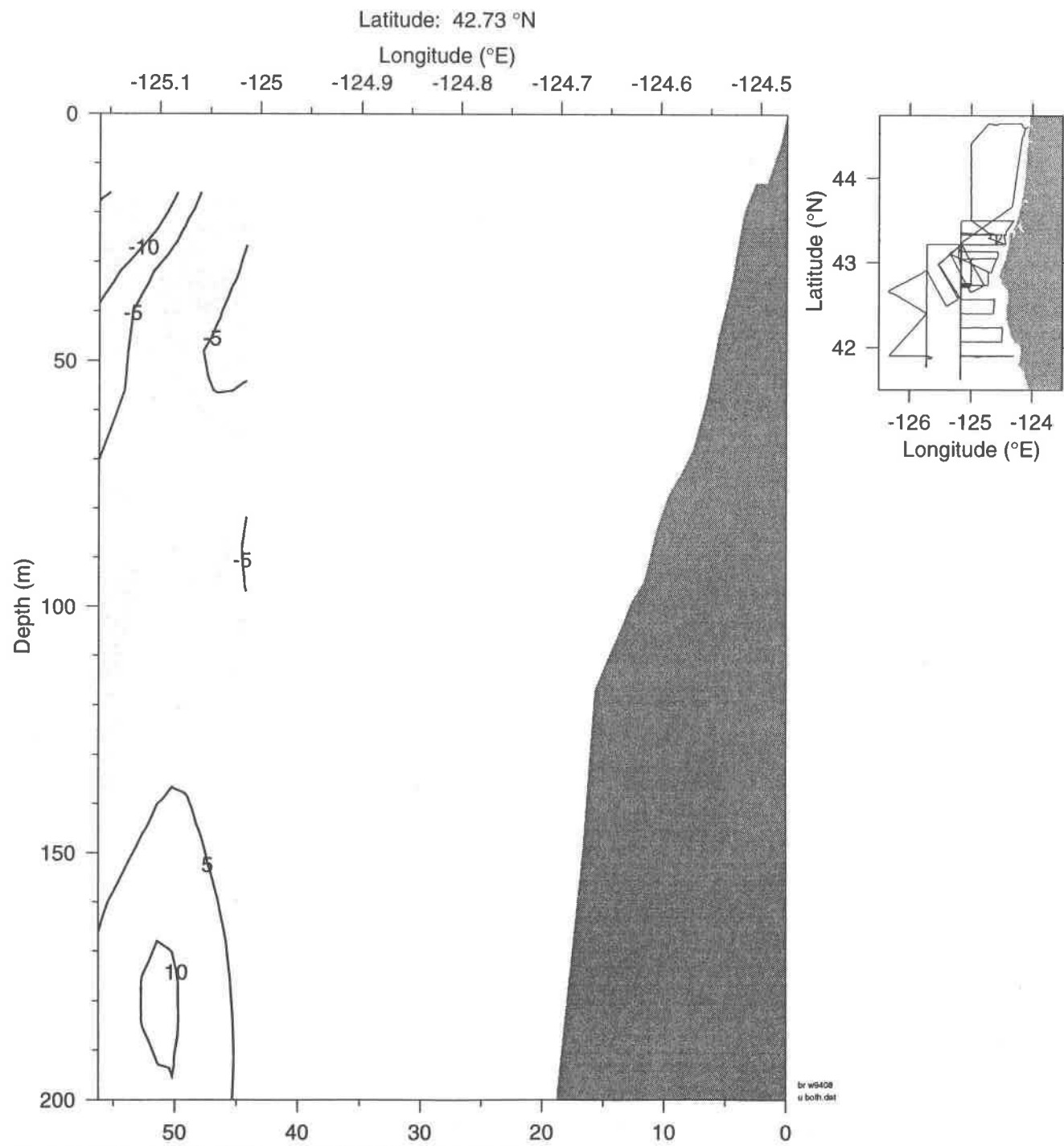
-125

-124

Longitude (°E)

125

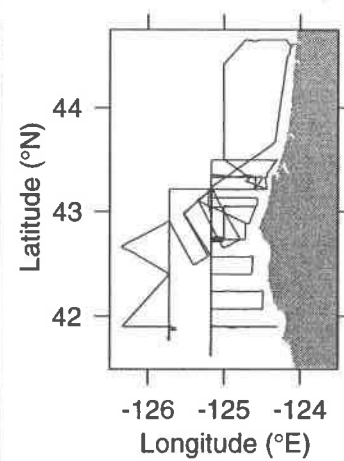
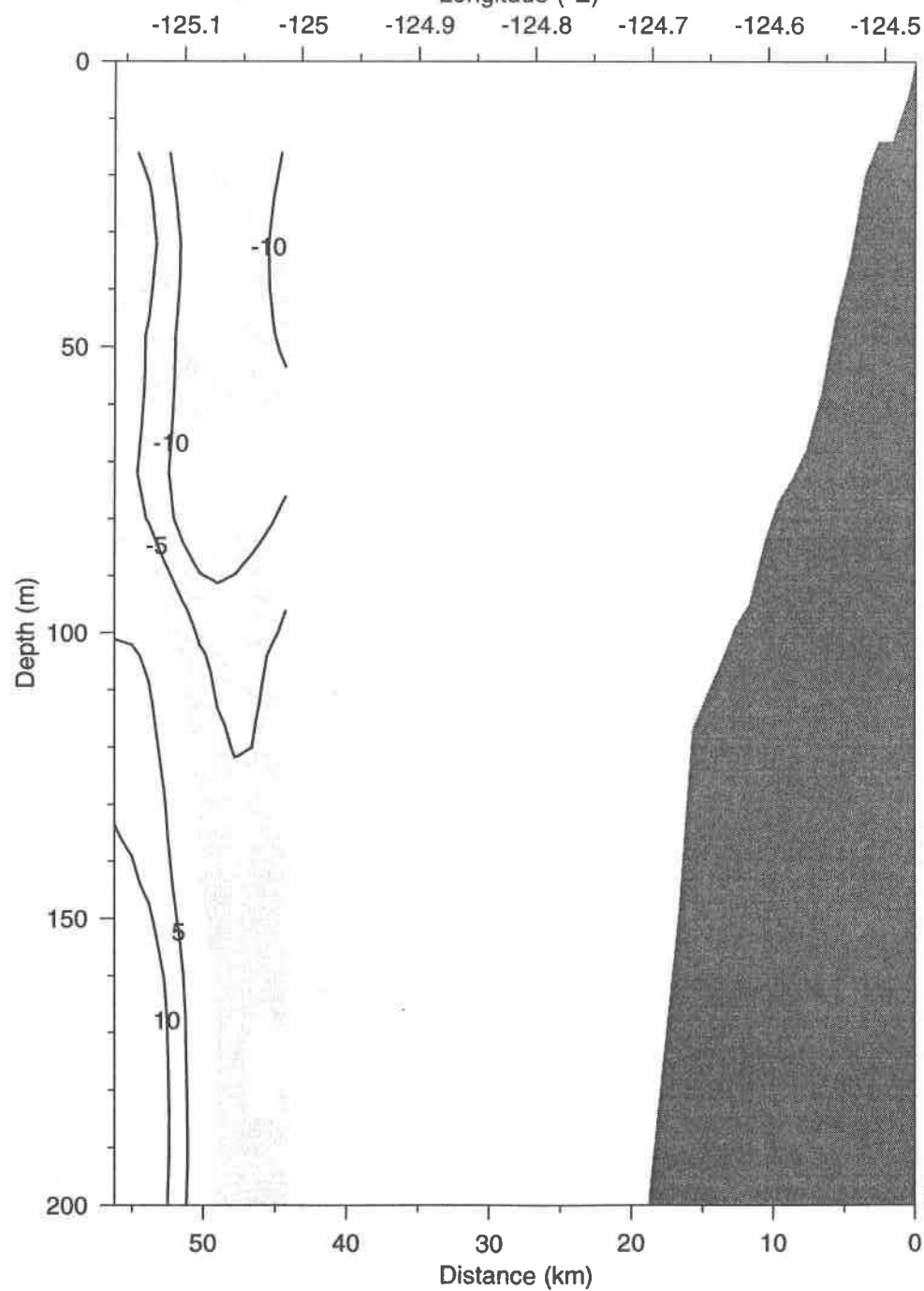
ADCP Line 23-24 U (year day 243.11-243.15, 31-Aug-94)



ADCP Line 23-24 V (year day 243.11-243.15, 31-Aug-94)

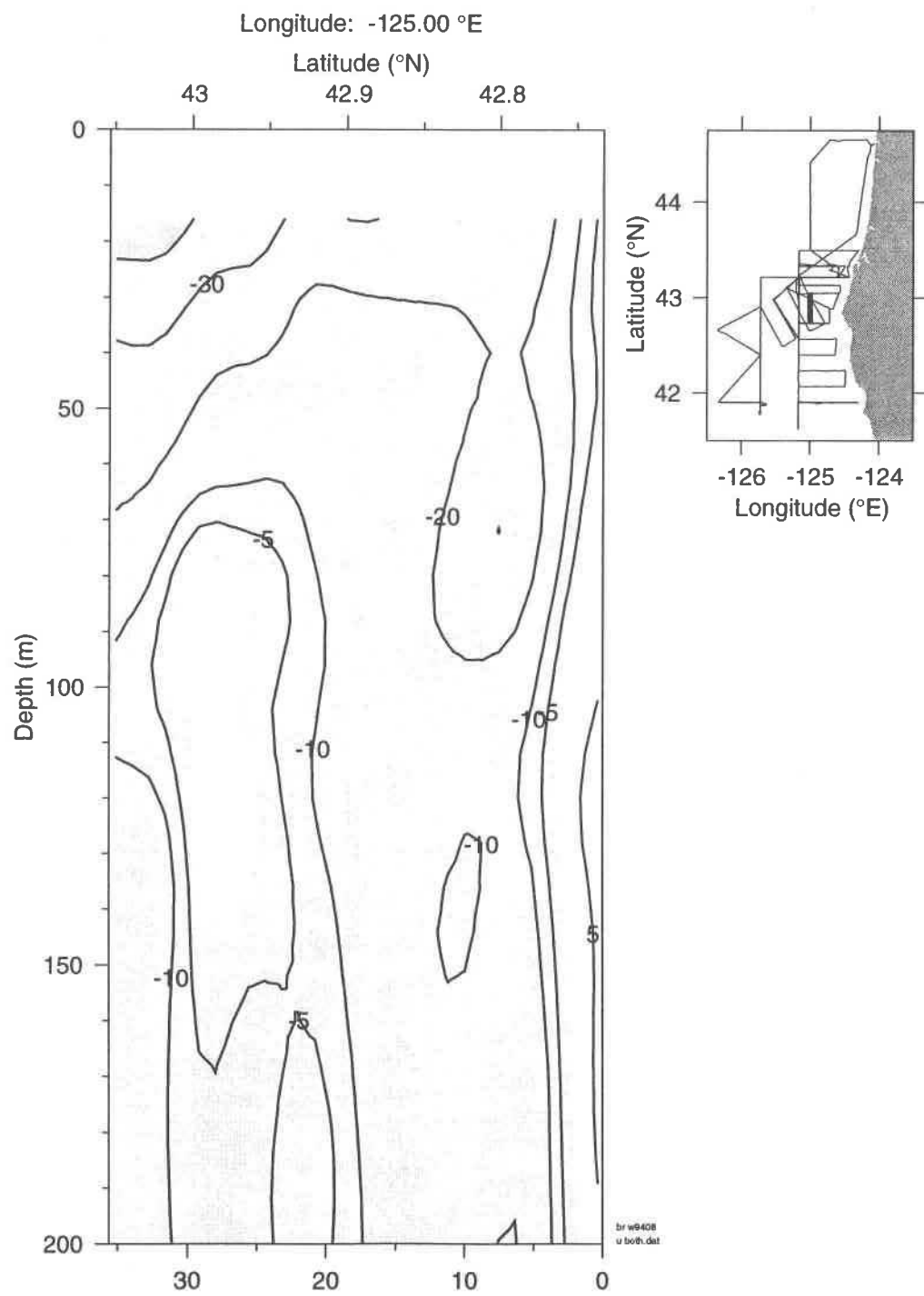
Latitude: 42.73 °N

Longitude (°E)



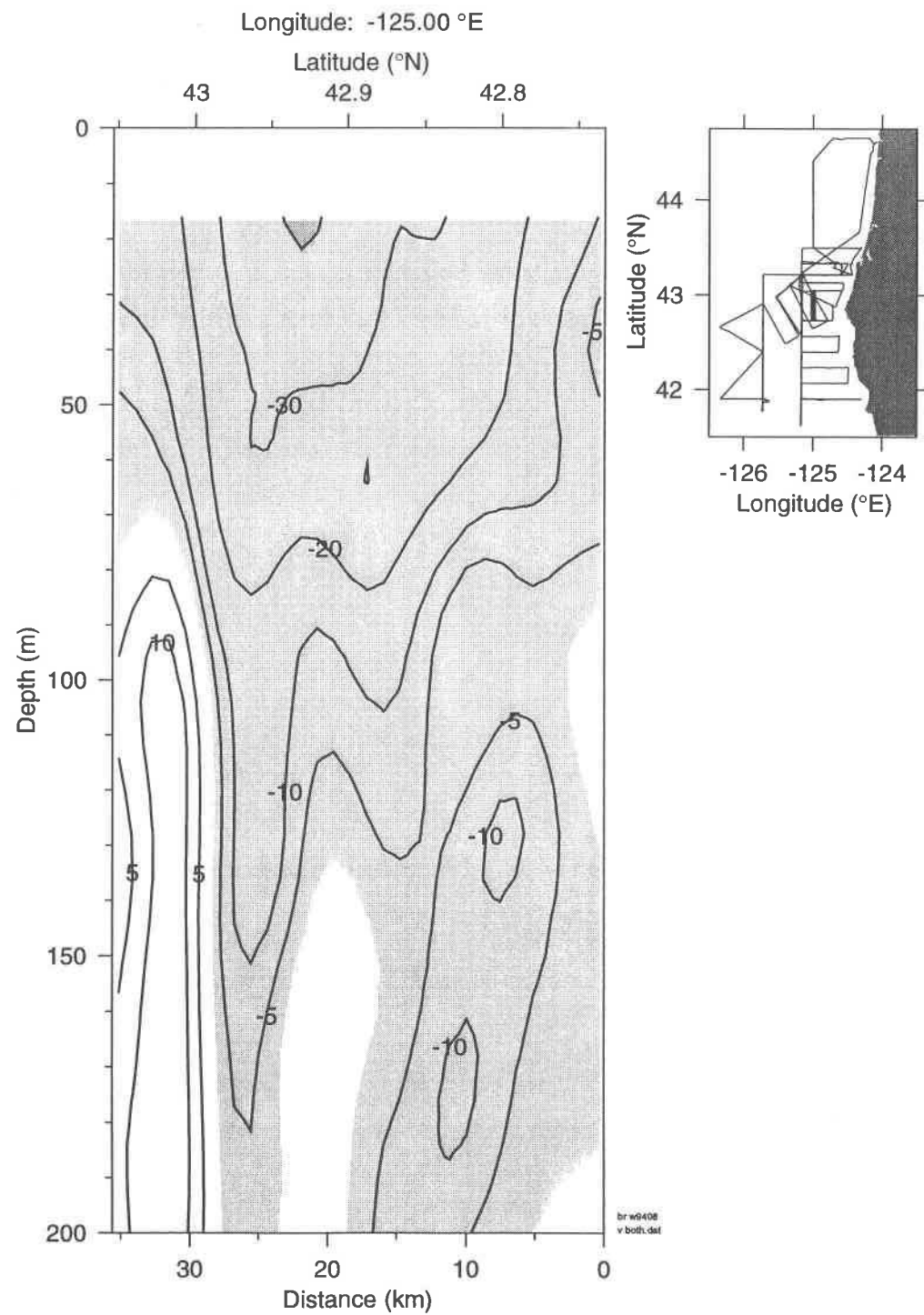
br w9408
v bolfs.dat

ADCP Line 24 U (year day 243.16-243.26, 31-Aug-94)



ADCP Line 24 V (year day 243.16-243.26, 31-Aug-94)

129

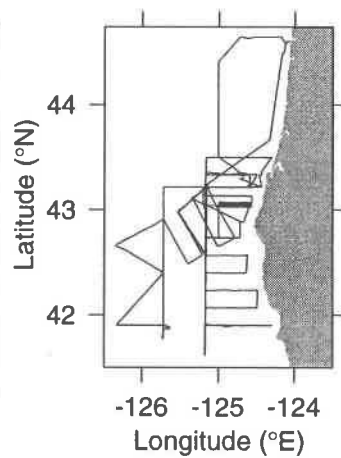
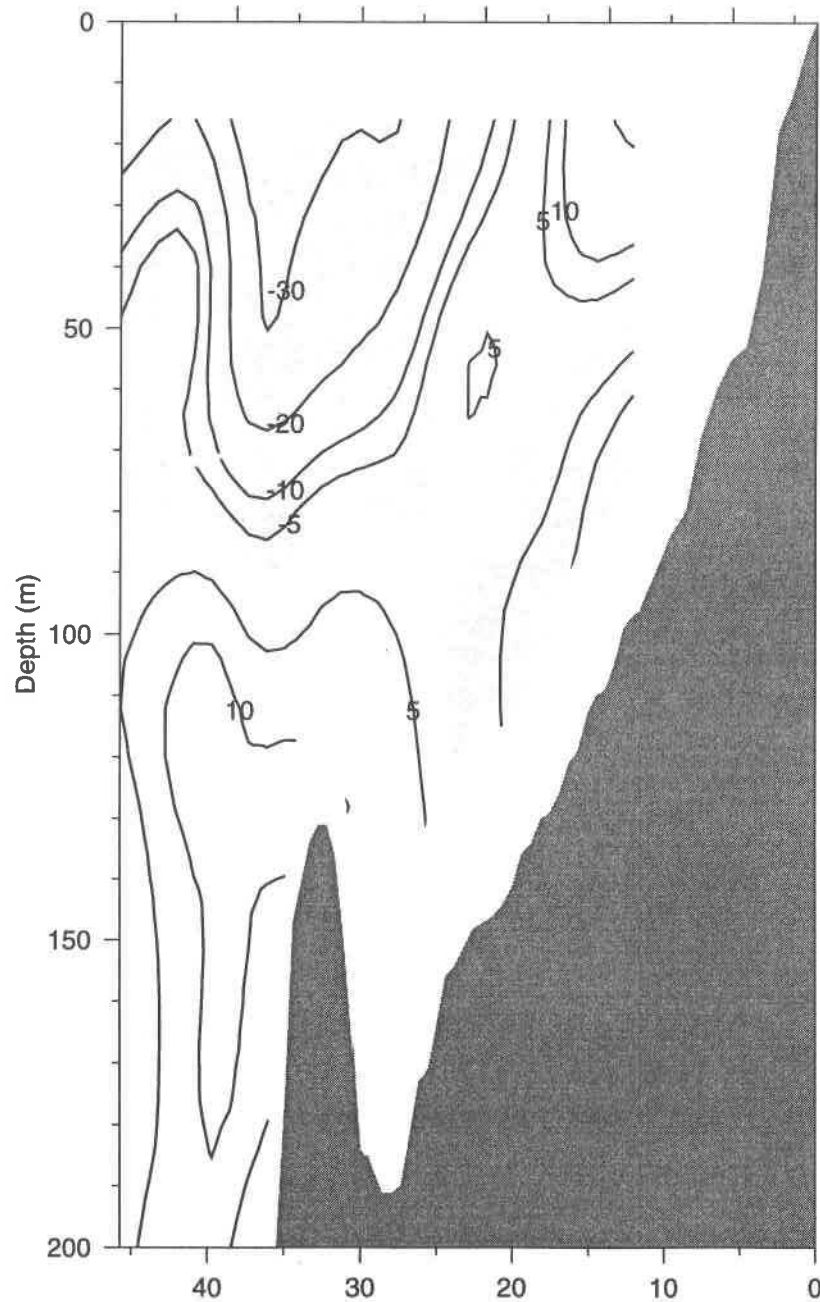


ADCP Line 25 U (year day 243.27-243.37, 31-Aug-94)

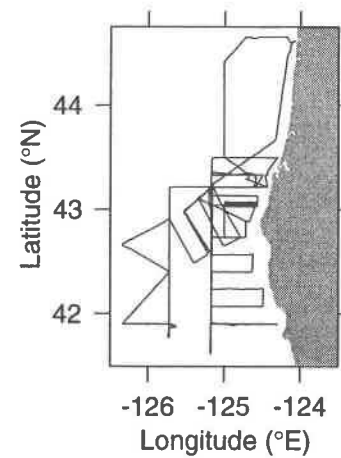
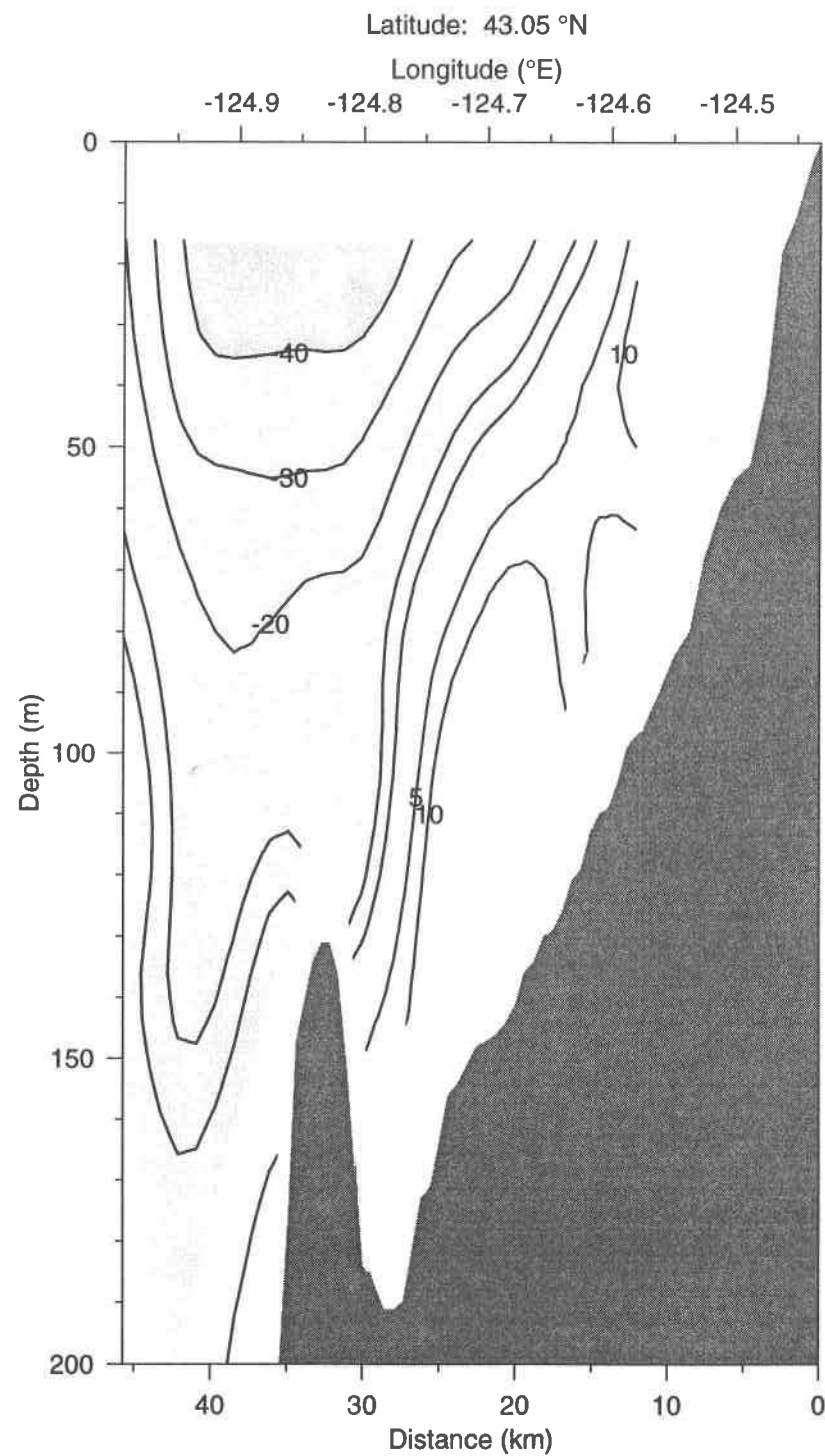
Latitude: 43.05 °N

Longitude (°E)

-124.9 -124.8 -124.7 -124.6 -124.5



br w9408
u both.dat



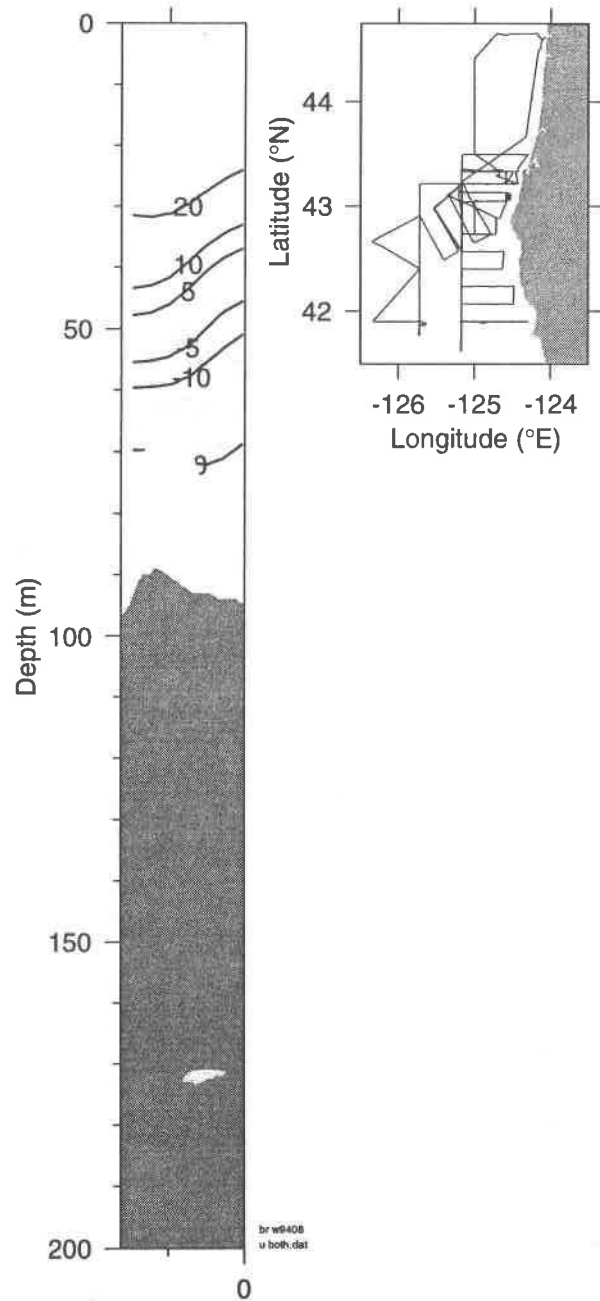
br w9408
v bo61.dat

ADCP Line 25-26 U (year day 243.37-243.39, 31-Aug-94)

Longitude: -124.56 °E

Latitude (°N)

43.1

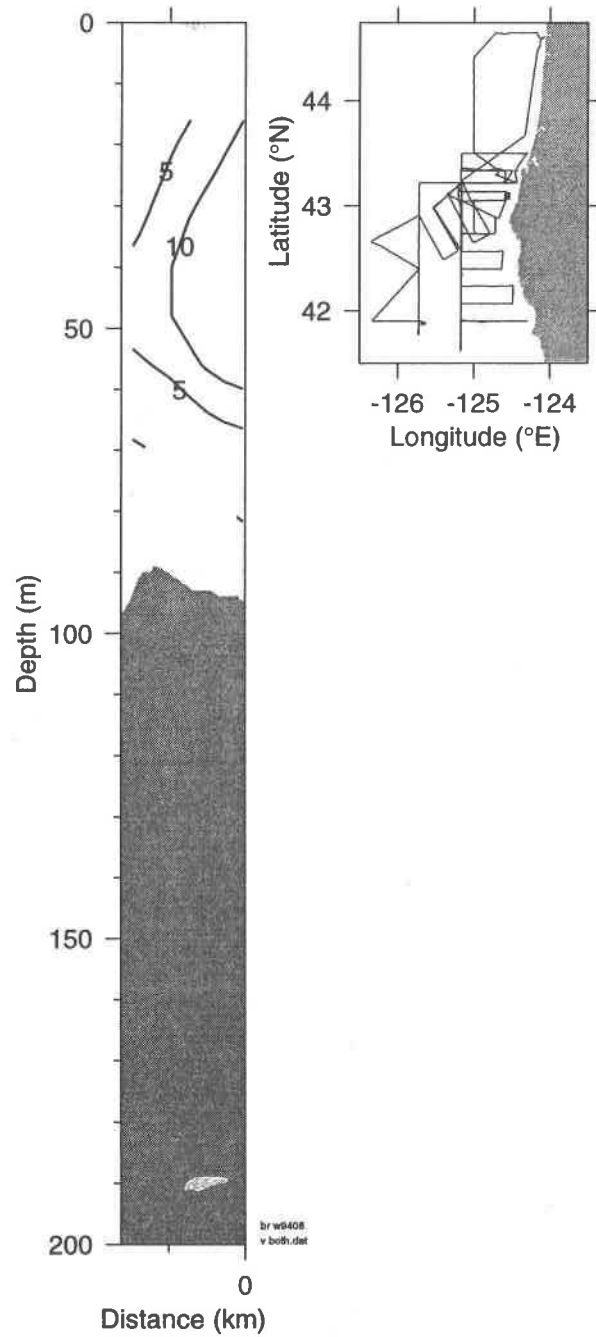


ADCP Line 25-26 V (year day 243.37-243.39, 31-Aug-94)

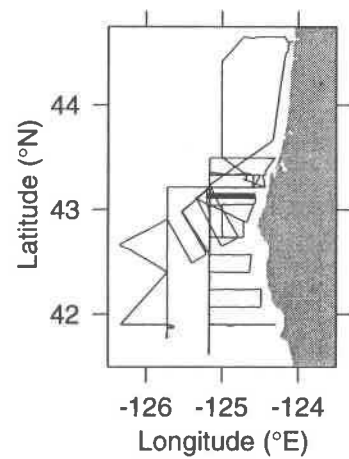
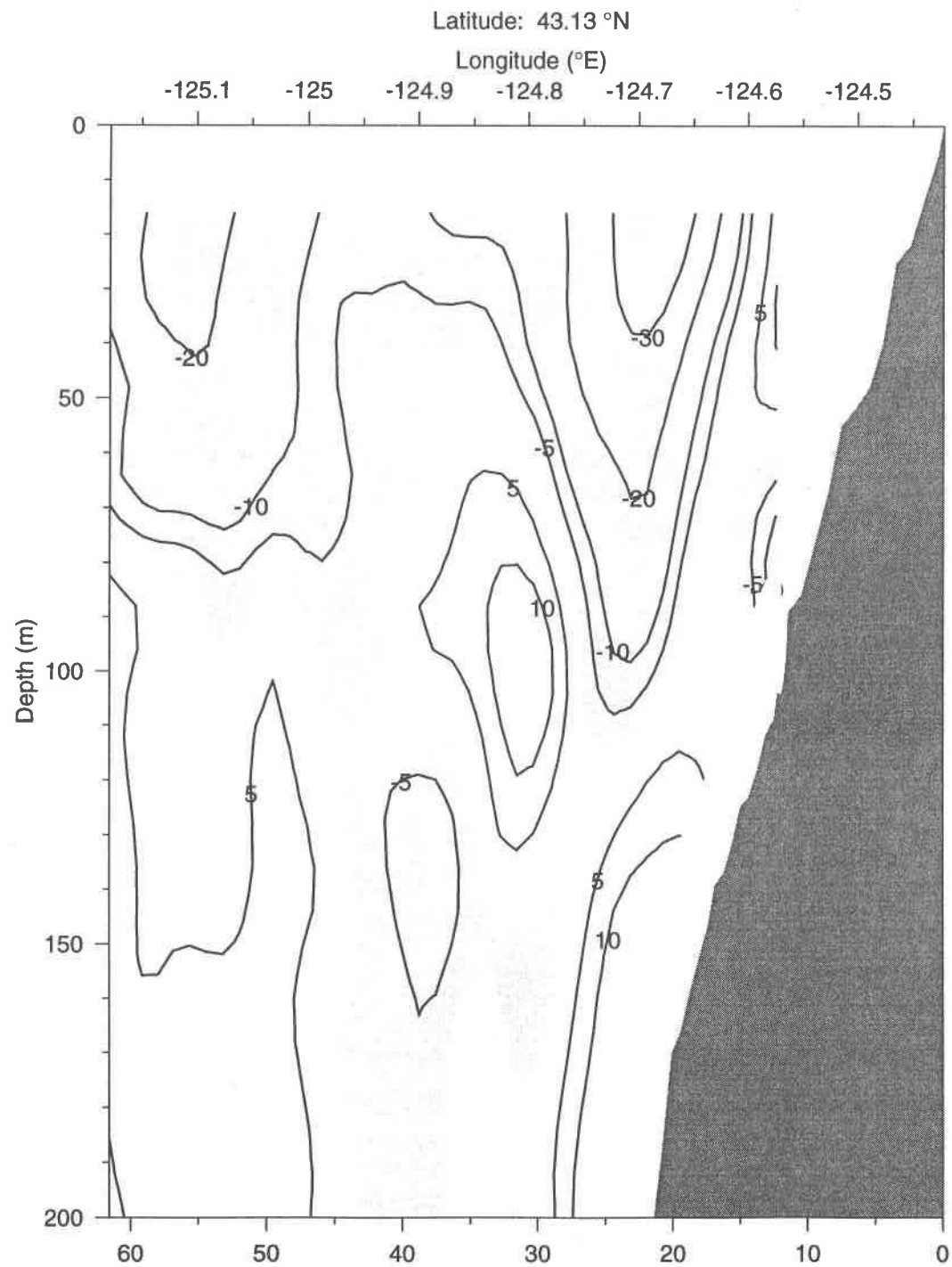
Longitude: -124.56 °E

Latitude (°N)

43.1



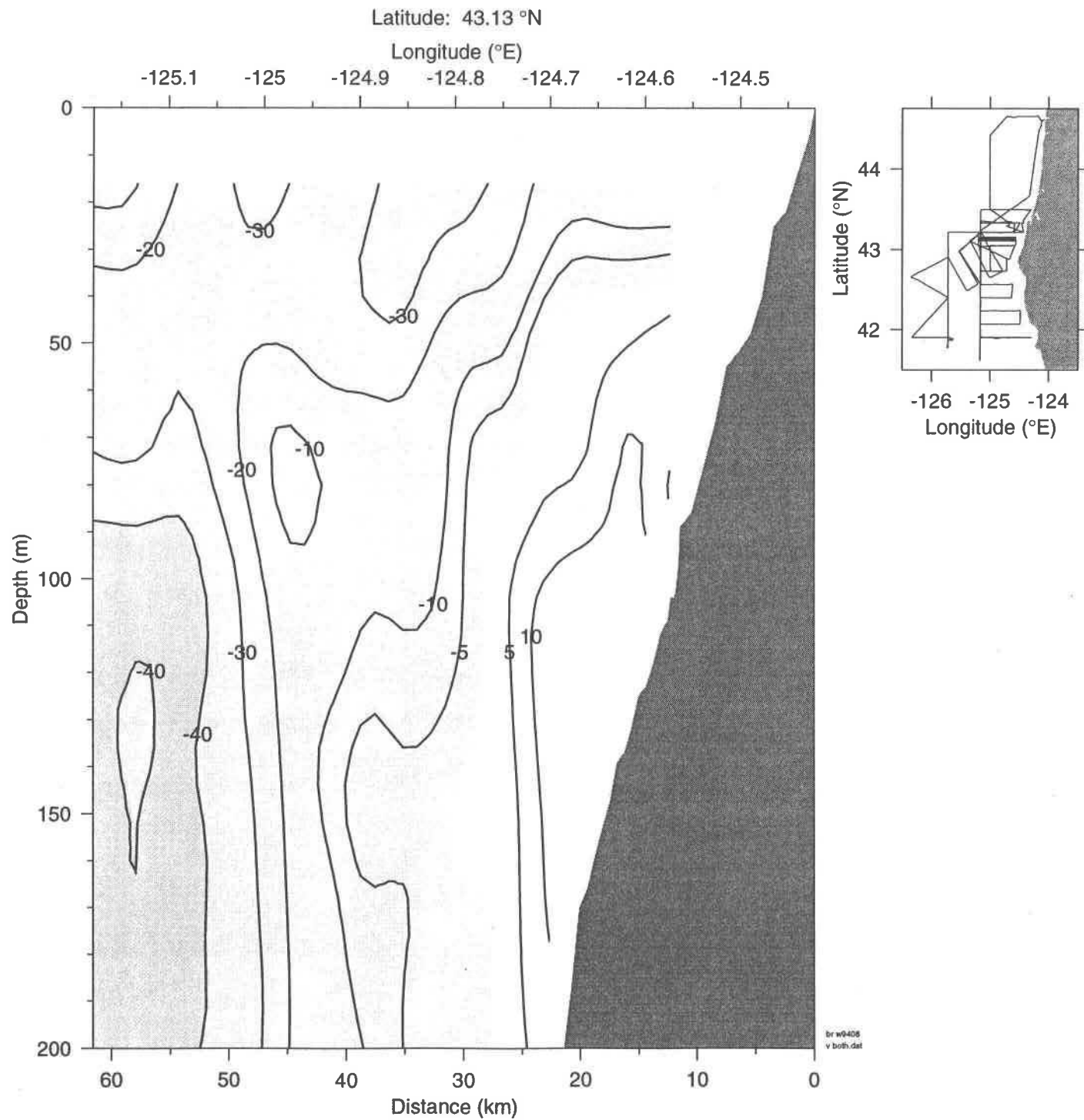
ADCP Line 26 U (year day 243.39-243.54, 31-Aug-94)



br w9408
u both.dat

ADCP Line 26 V (year day 243.39-243.54, 31-Aug-94)

135

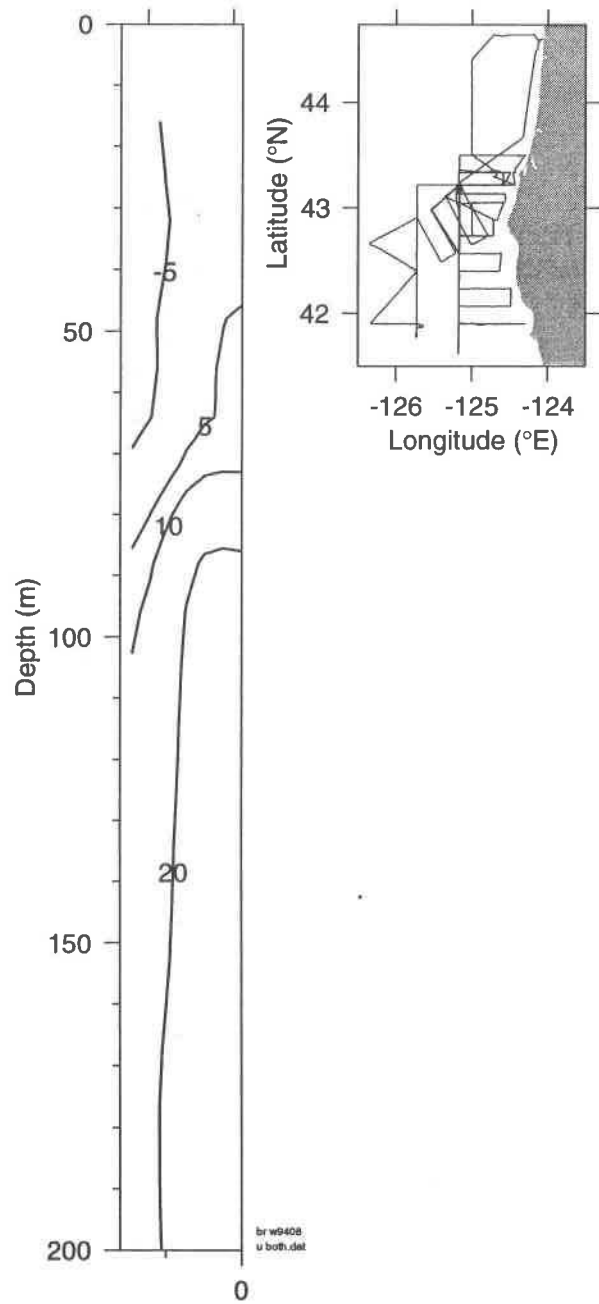


ADCP Line 26-27 U (year day 243.54-243.57, 31-Aug-94)

Longitude: -125.17 °E

Latitude (°N)

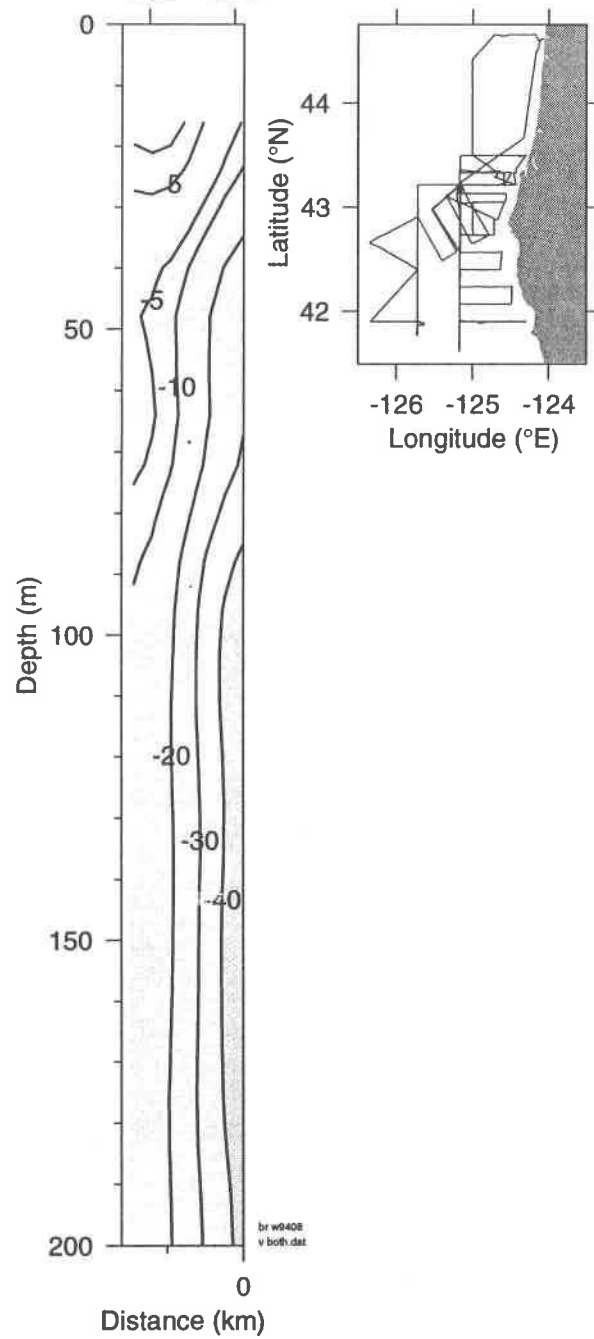
43.2 43.15



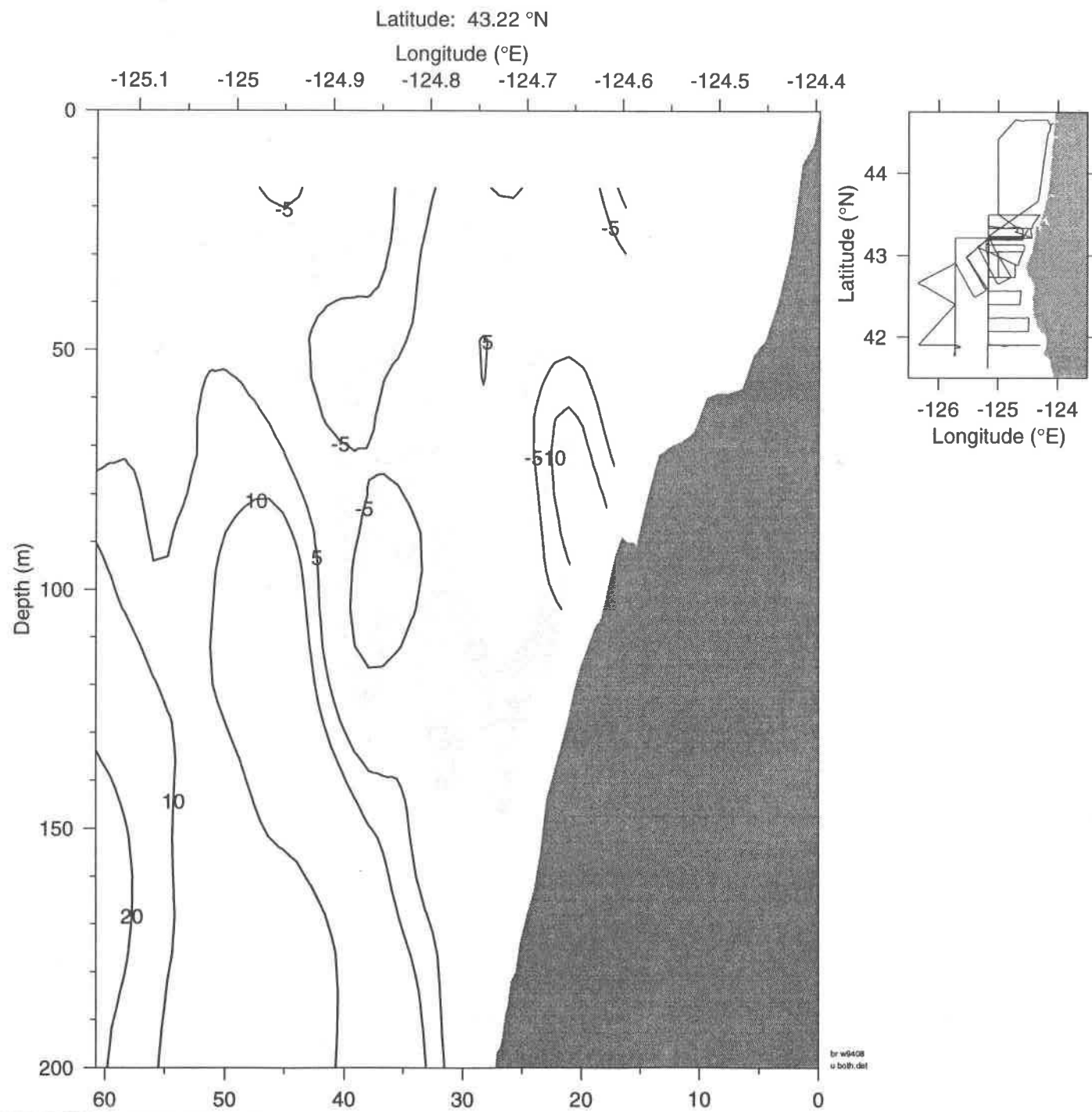
Longitude: -125.17 °E

Latitude (°N)

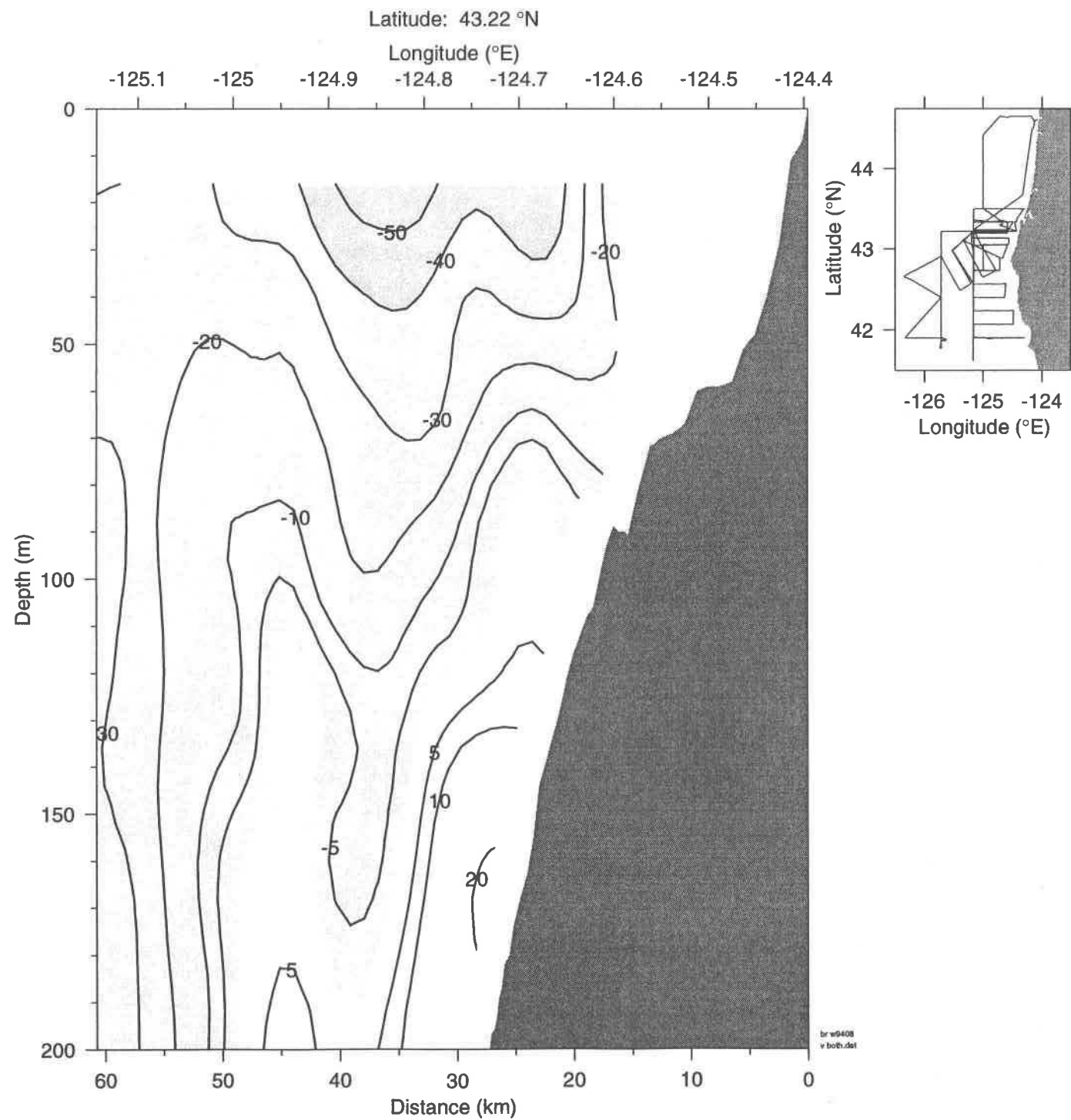
43.2 43.15



ADCP Line 27 U (year day 243.57-243.71, 31-Aug-94)



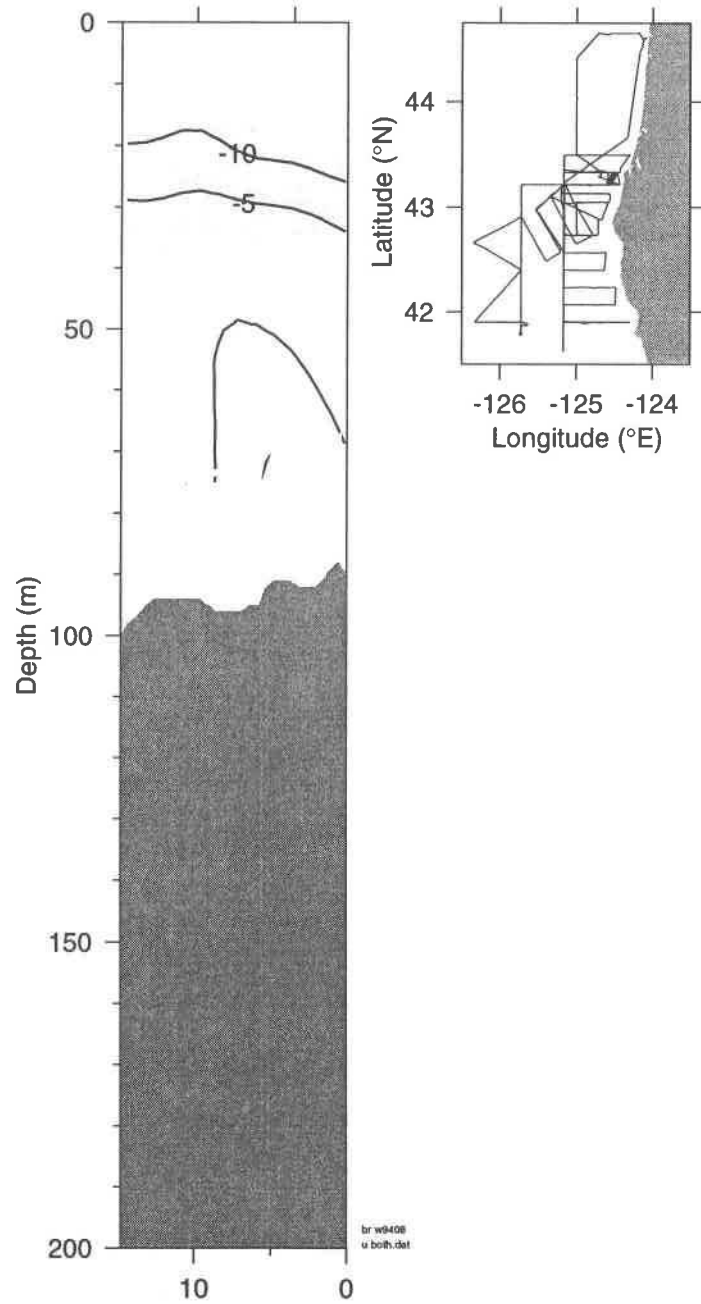
ADCP Line 27 V (year day 243.57-243.71, 31-Aug-94)



ADCP Line 27-28 U (year day 243.71-243.75, 31-Aug-94)

Longitude: -124.54 °E

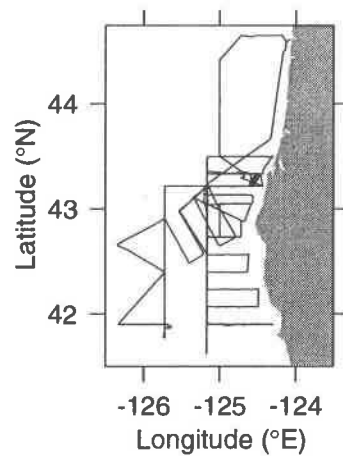
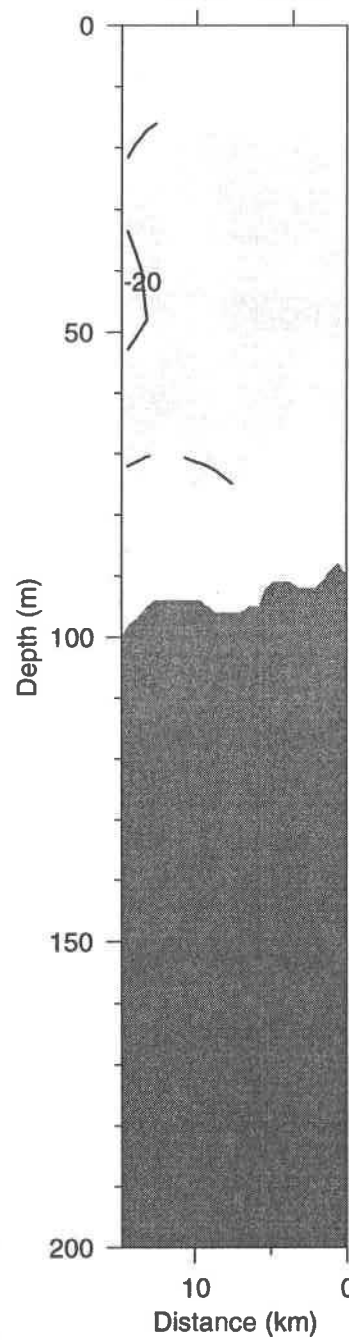
Latitude (°N)
43.3 43.25



ADCP Line 27-28 V (year day 243.71-243.75, 31-Aug-94)

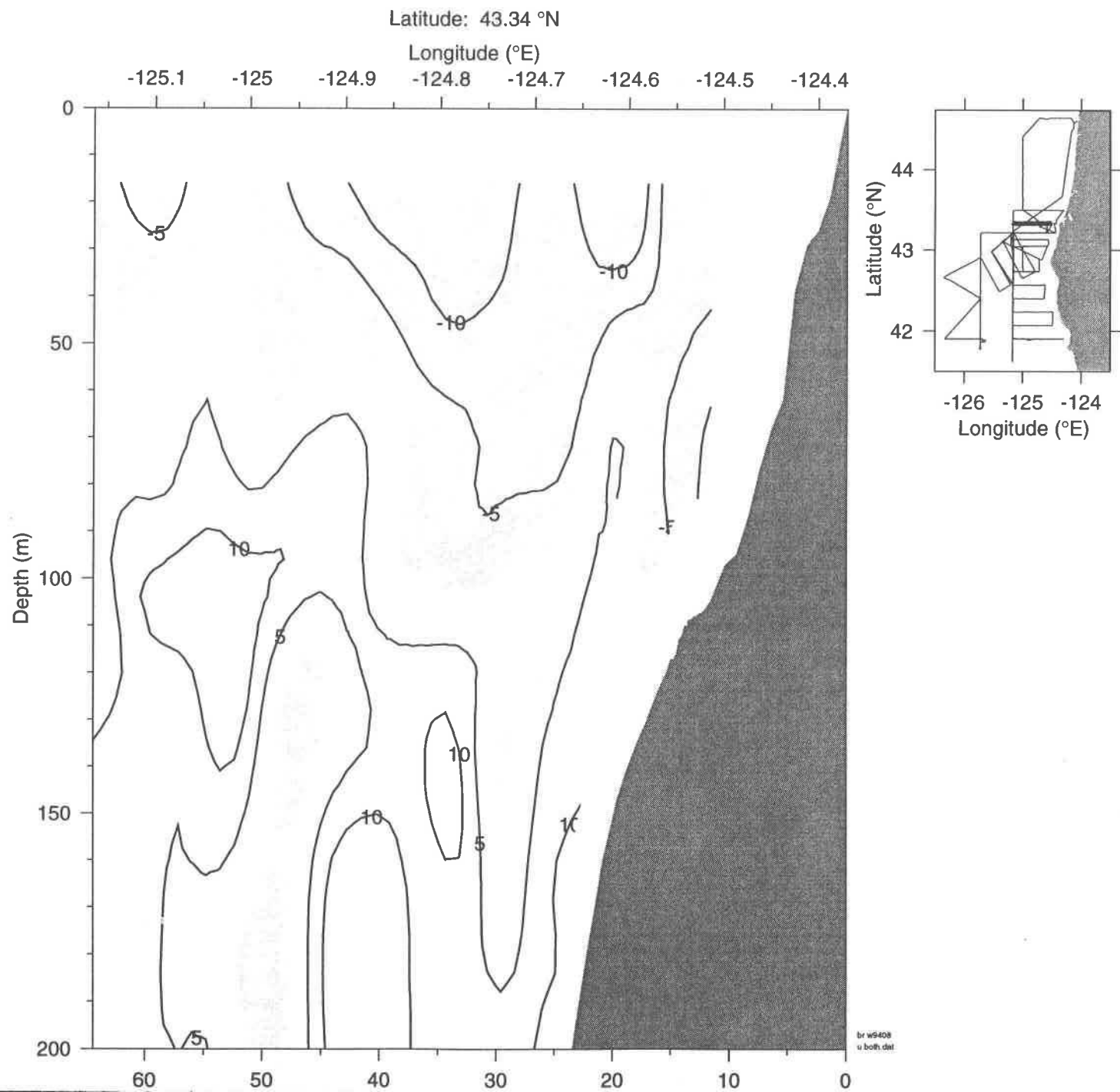
Longitude: -124.54 °E

Latitude (°N)
43.3 43.25



br w9408
v both dot

ADCP Line 28 U (year day 243.76-243.91, 31-Aug-94)



Latitude: 43.34 °N

Longitude (°E)

-125.1 -125 -124.9 -124.8 -124.7 -124.6 -124.5 -124.4

0

50

100

150

200

Depth (m)

60

50

40

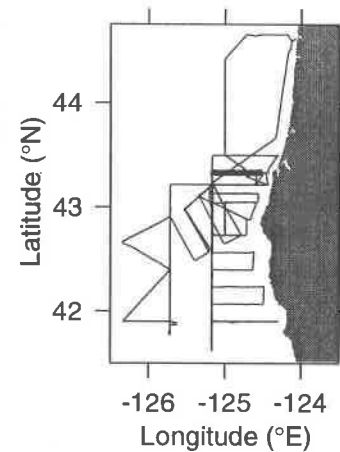
30

20

10

0

Distance (km)



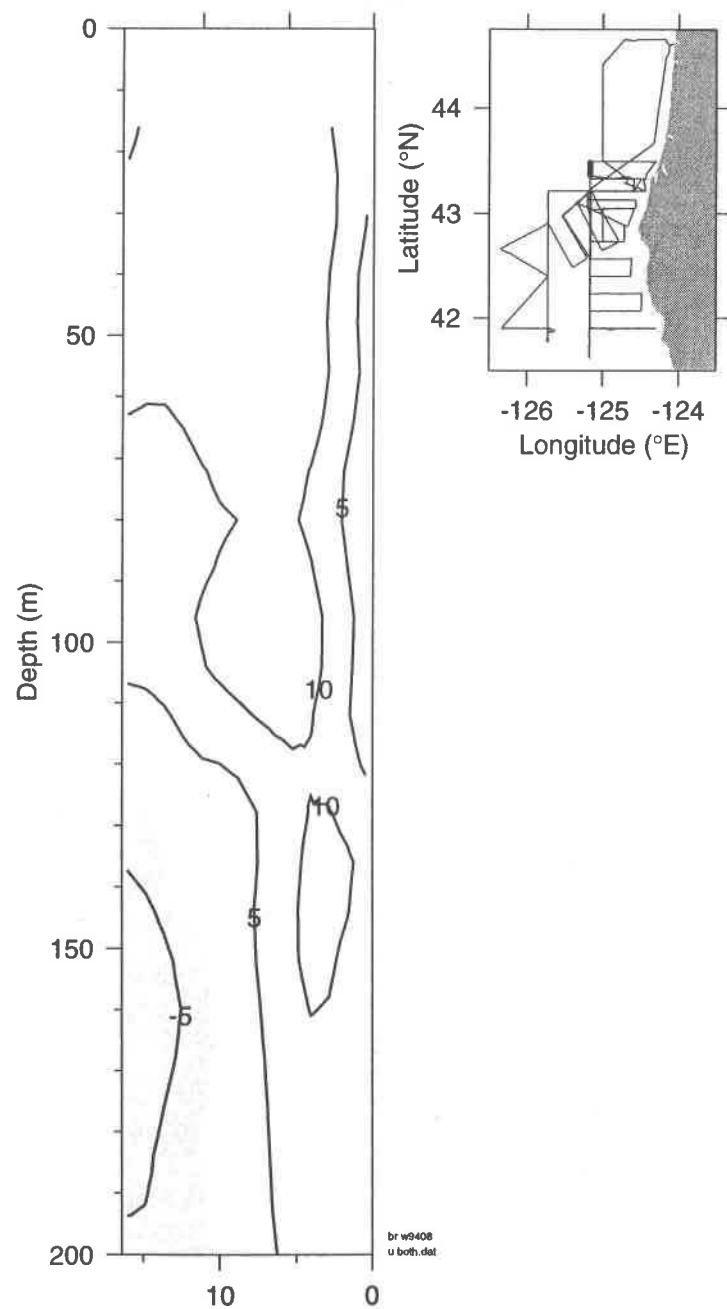
br w9408
v both.del

ADCP Line 28-29 U (year day 243.92-243.97, 31-Aug-94)

Longitude: -125.16 °E

Latitude (°N)

43.45 43.4 43.35

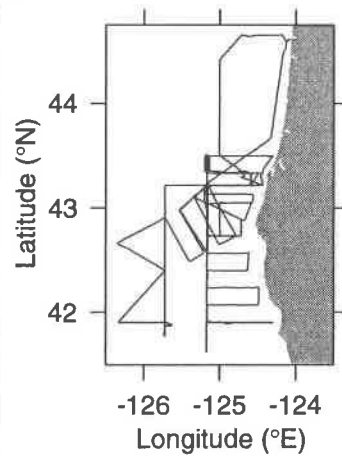
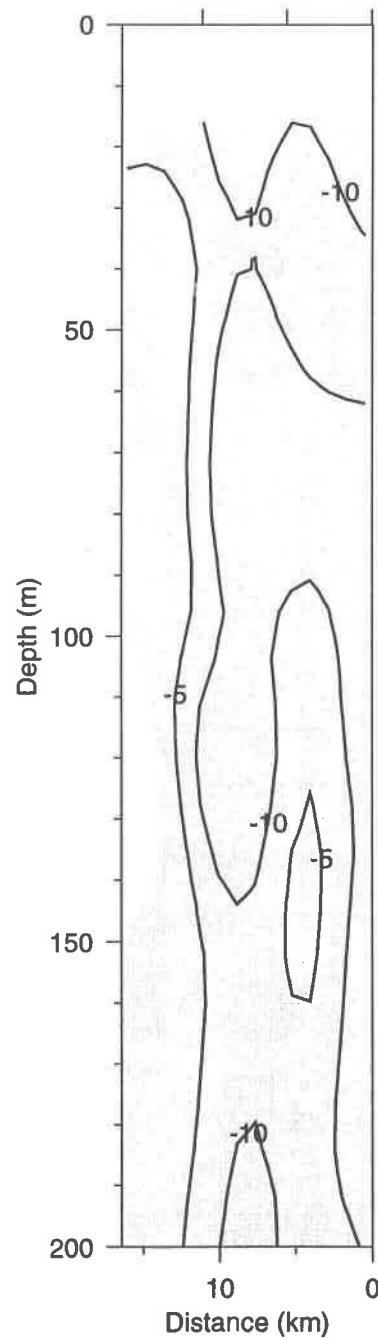


ADCP Line 28-29 V (year day 243.92-243.97, 31-Aug-94)

Longitude: -125.16 °E

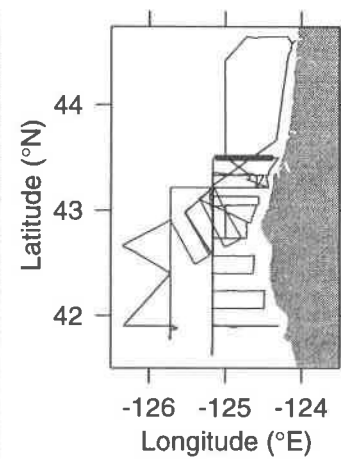
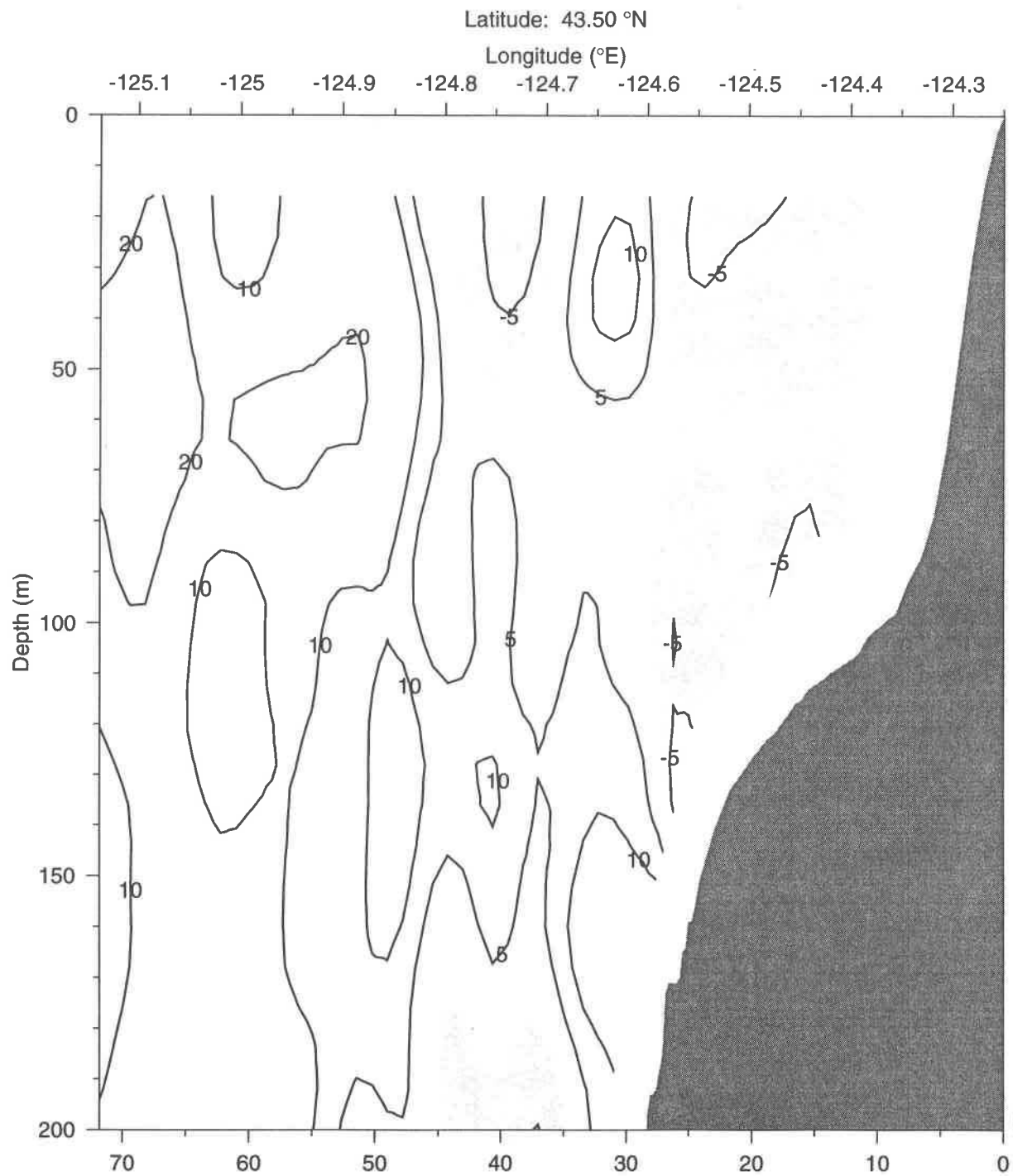
Latitude (°N)

43.45 43.4 43.35



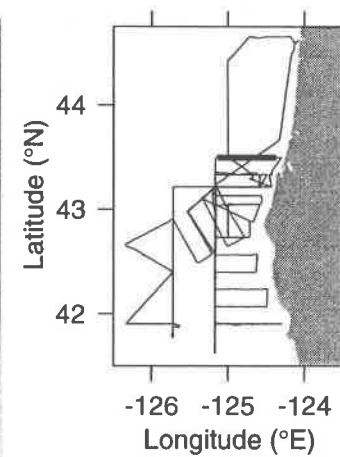
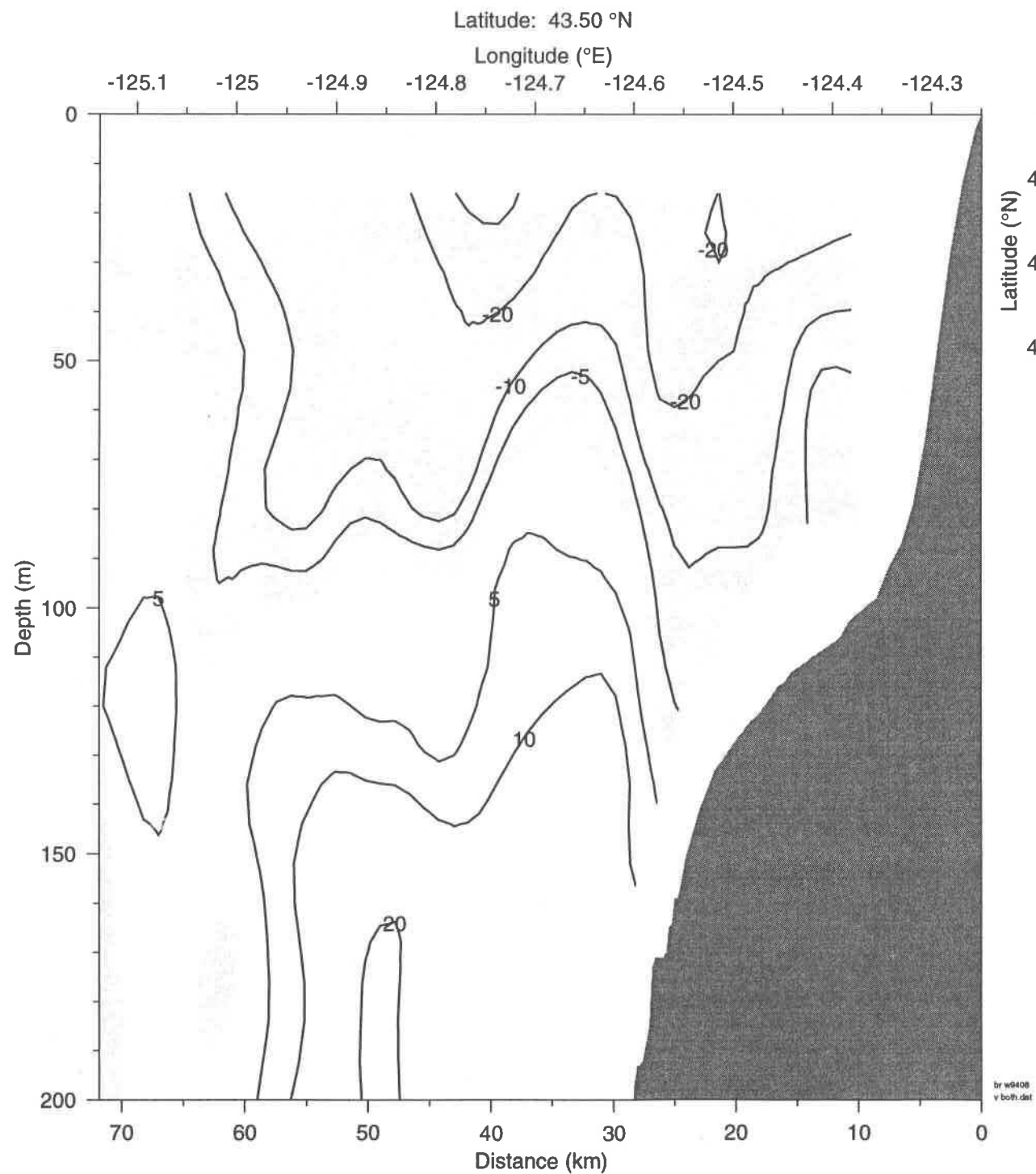
br w9408
v both det

ADCP Line 29 U (year day 243.97-244.15, 01-Sep-94)



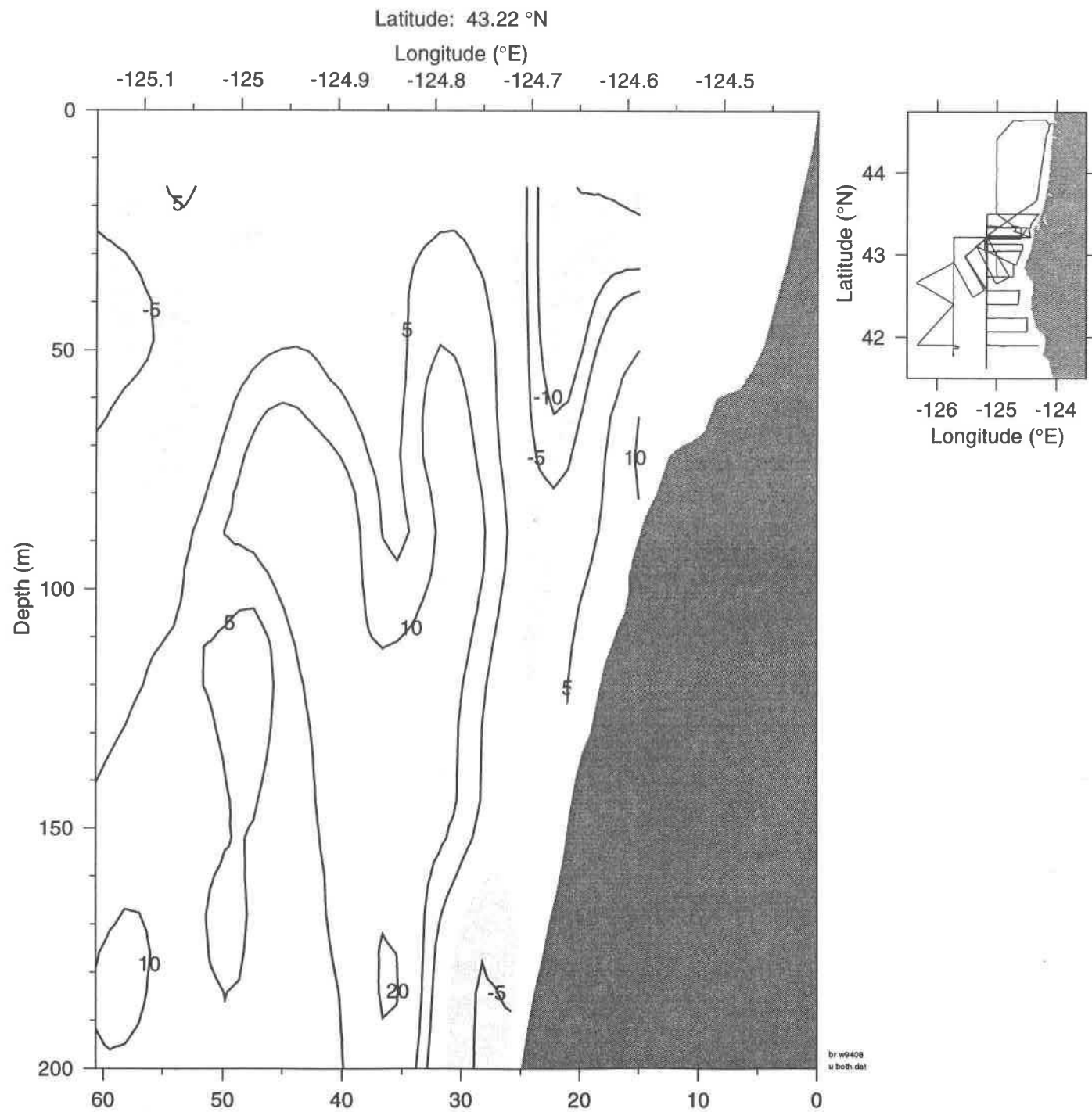
for w9408
u both dat

ADCP Line 29 V (year day 243.97-244.15, 01-Sep-94)



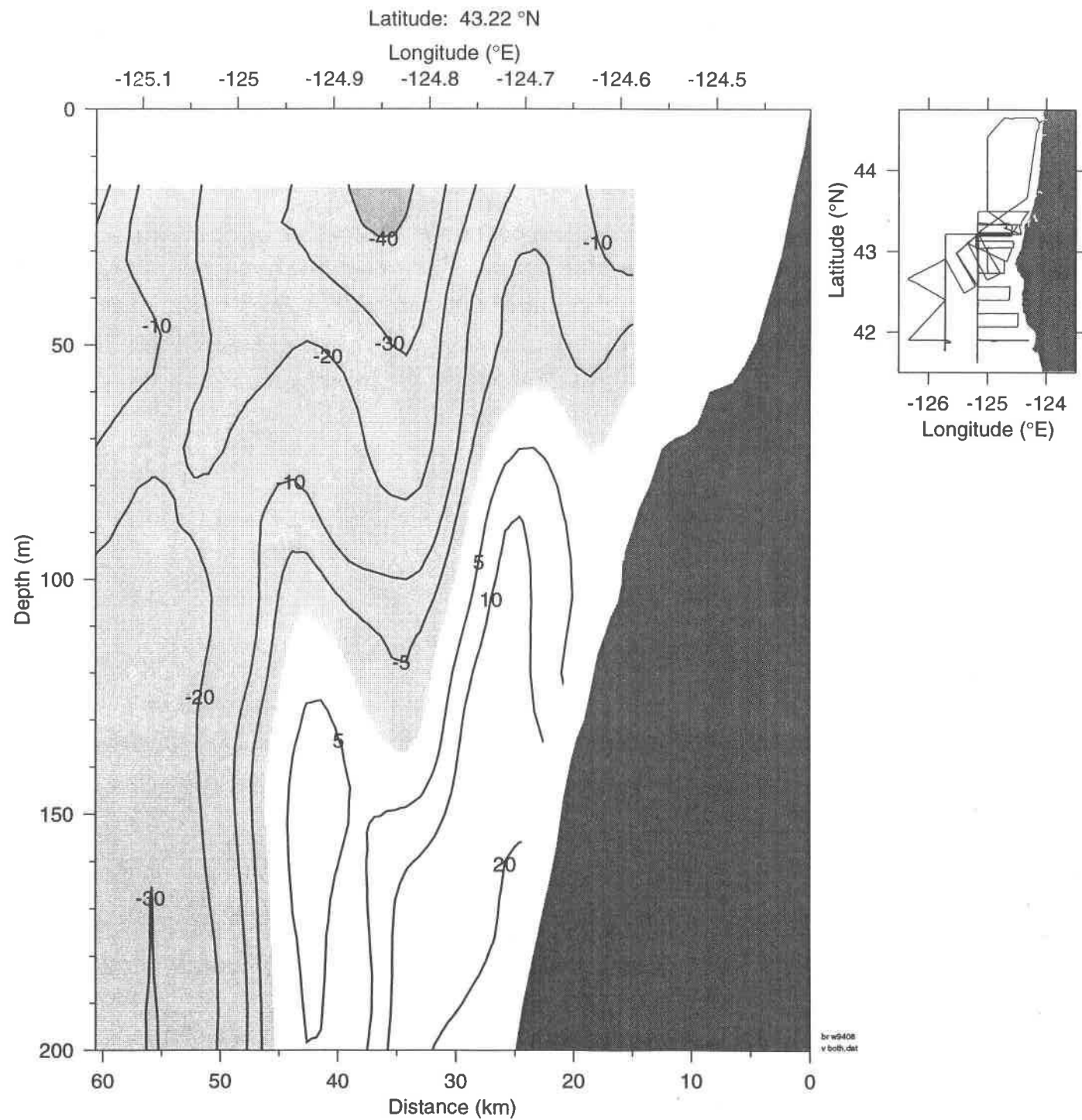
br w9408
v both det

ADCP Line 30 U (year day 244.52-244.66, 01-Sep-94)

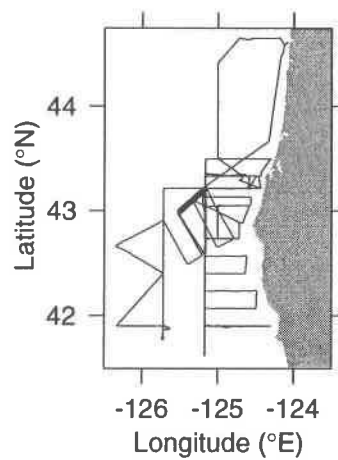
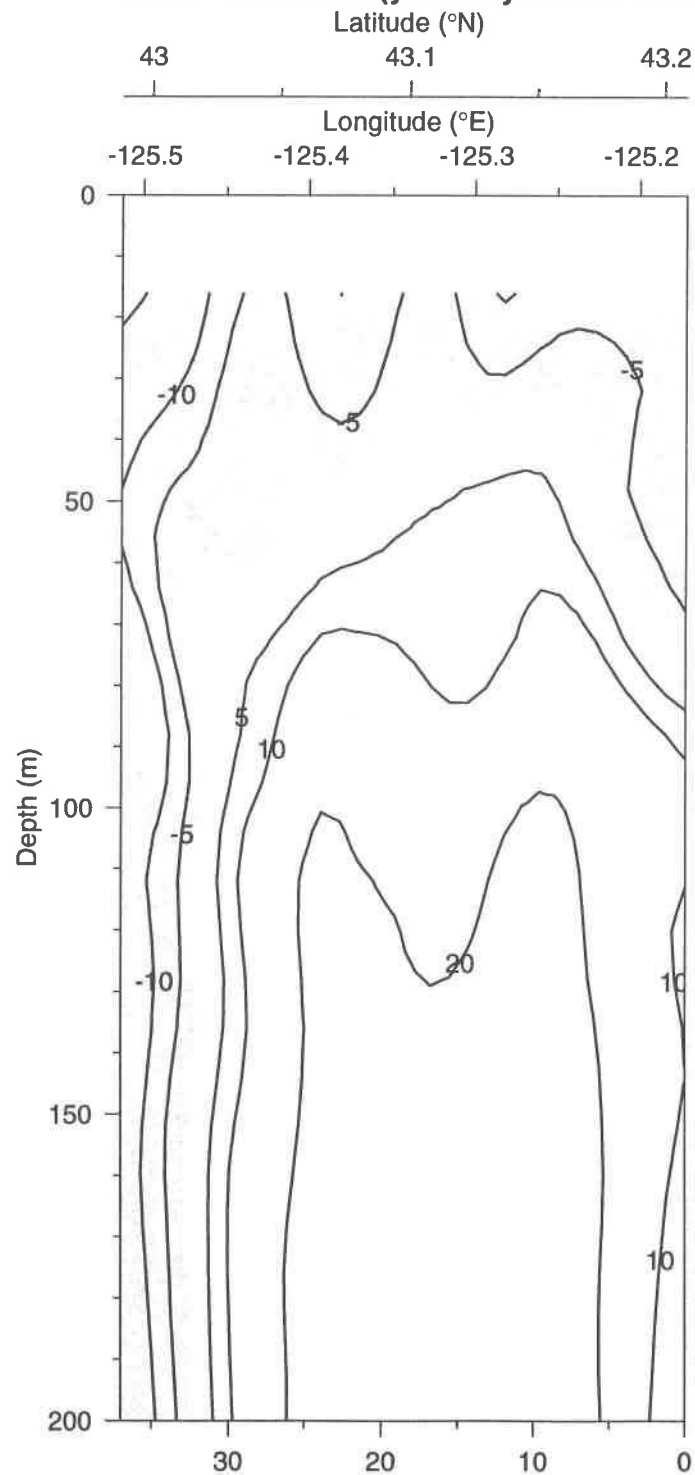


ADCP Line 30 V (year day 244.52-244.66, 01-Sep-94)

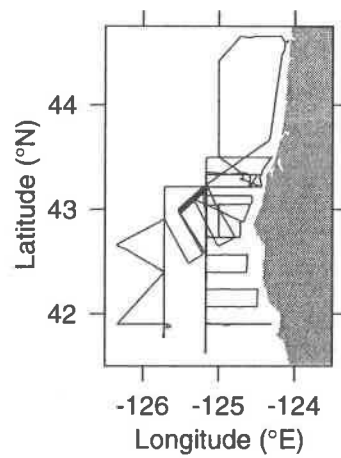
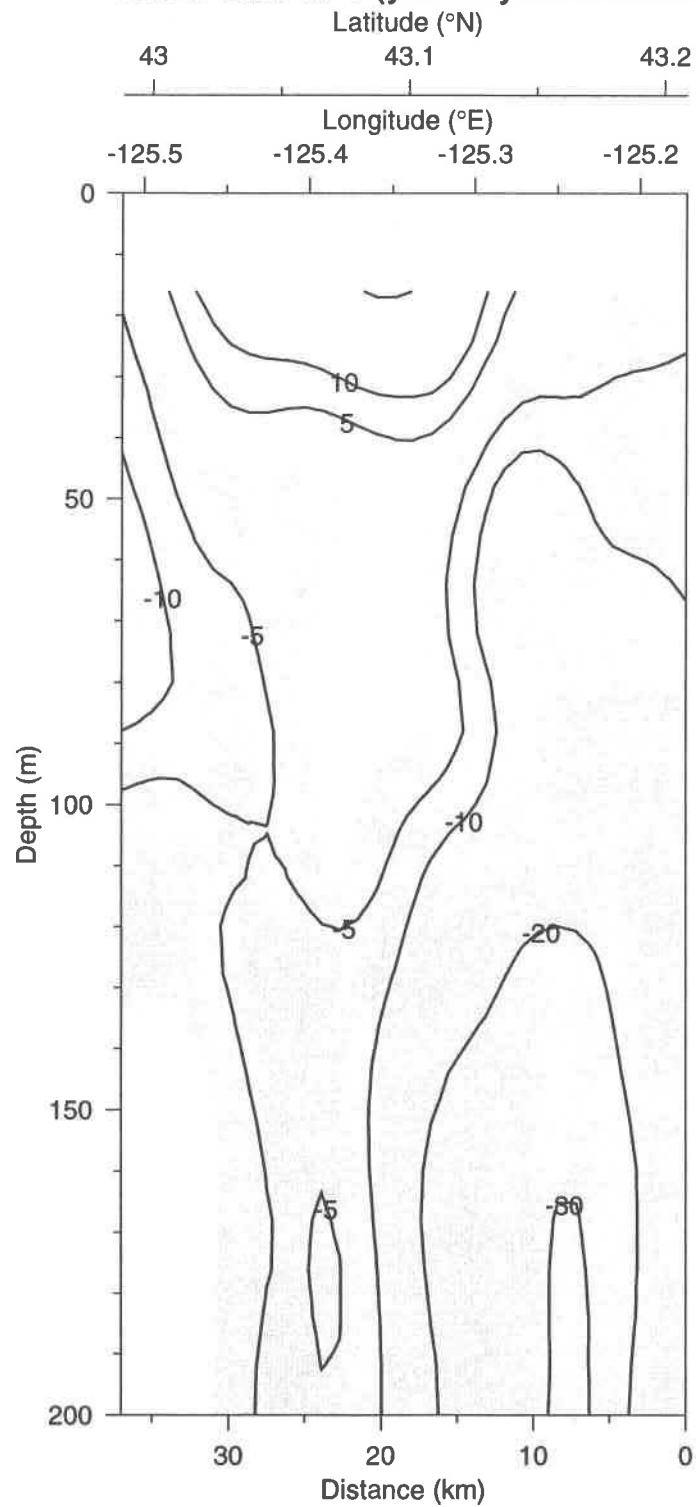
149



ADCP Line 31 U (year day 244.66-244.77, 01-Sep-94)

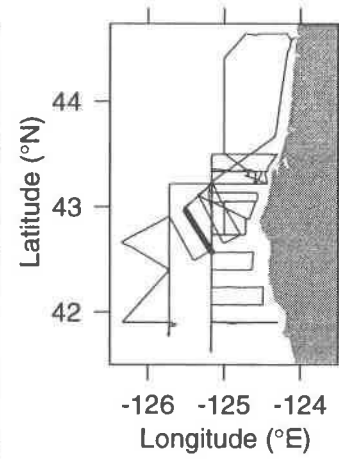
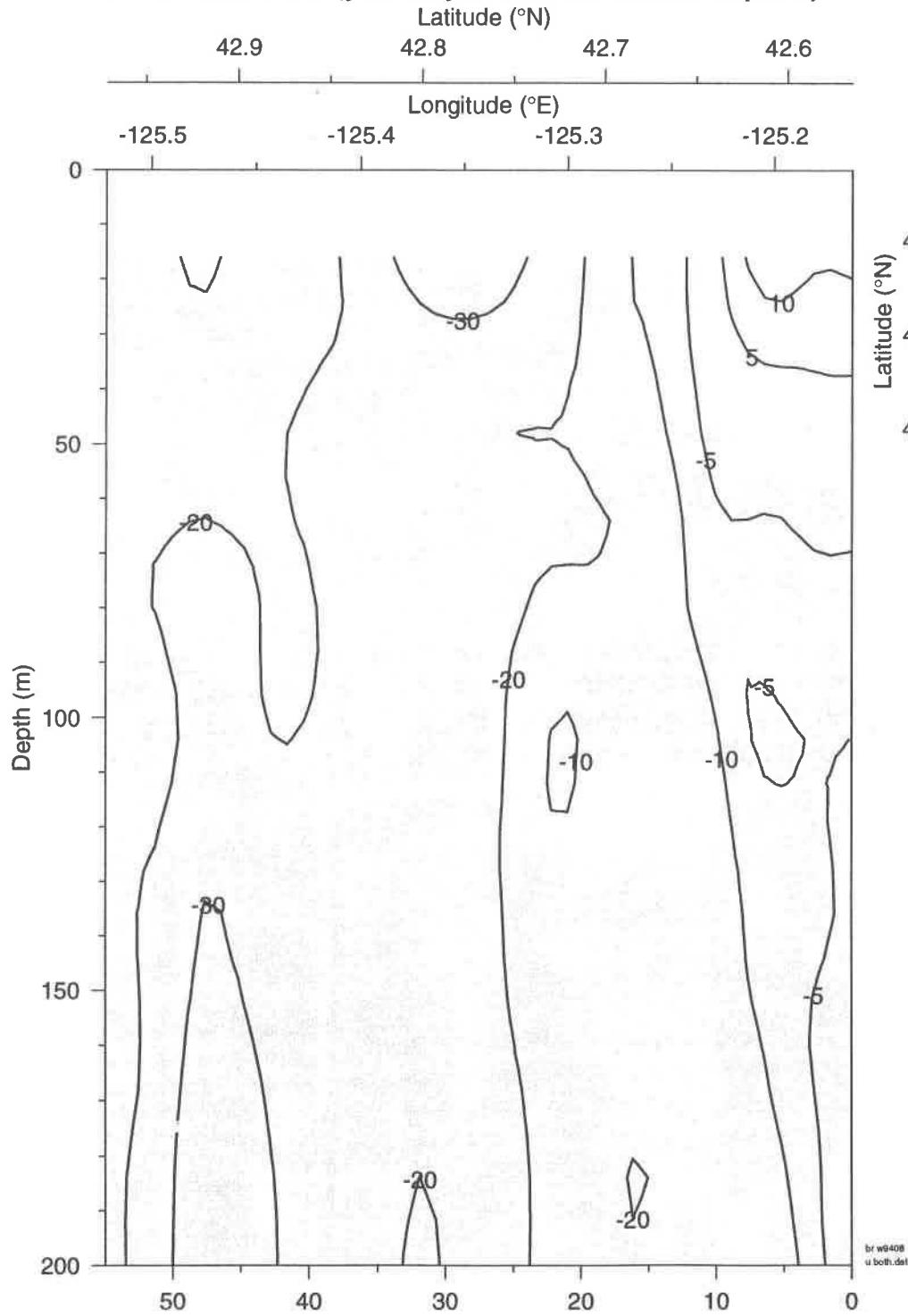


ADCP Line 31 V (year day 244.66-244.77, 01-Sep-94)



br w9408
v both.dat

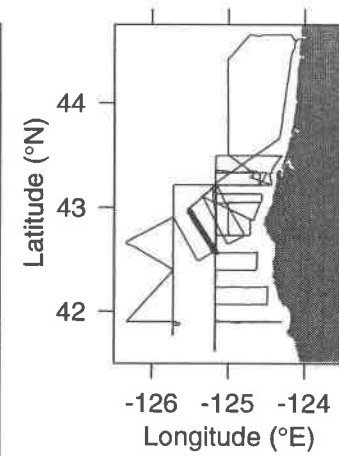
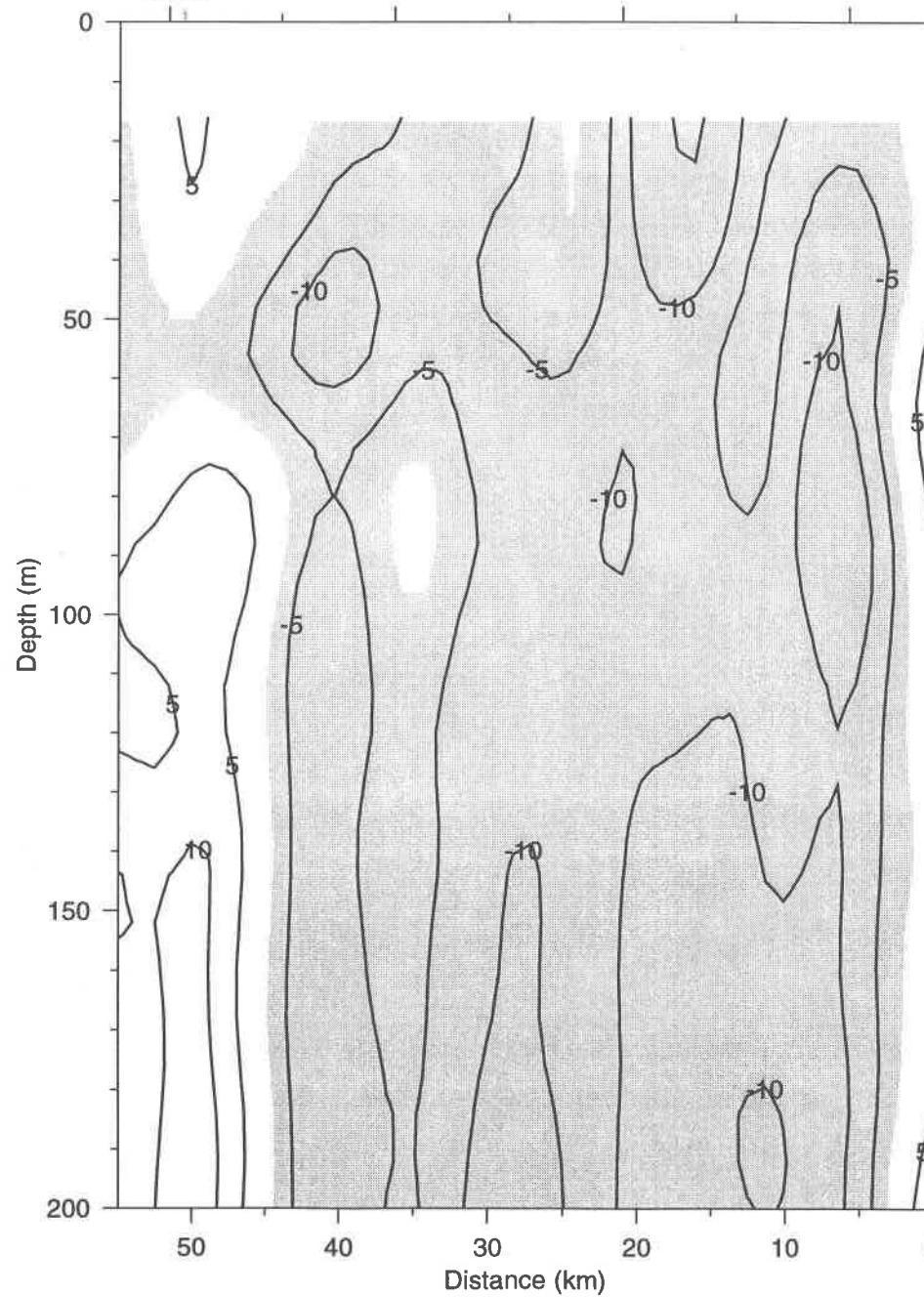
ADCP Line 32 U (year day 244.78-244.95, 01-Sep-94)



ADCP Line 32 V (year day 244.78-244.95, 01-Sep-94)

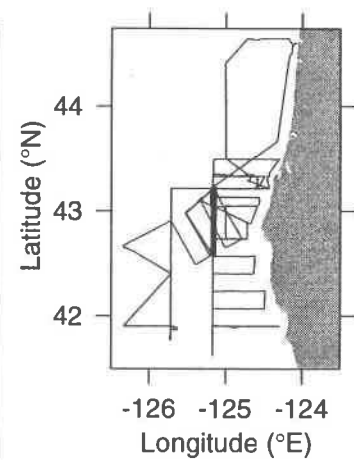
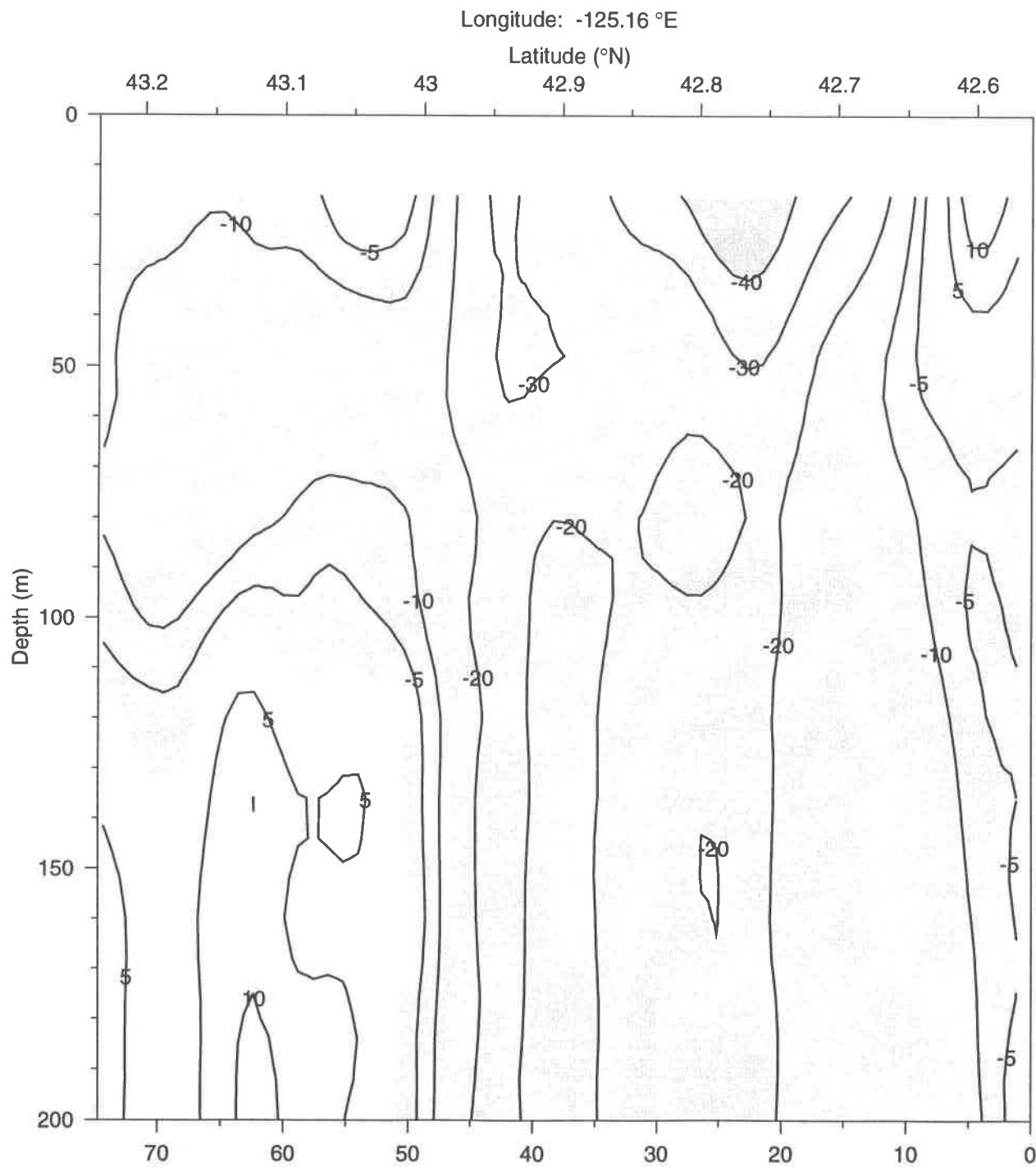
Latitude (°N)
 42.9 42.8 42.7 42.6

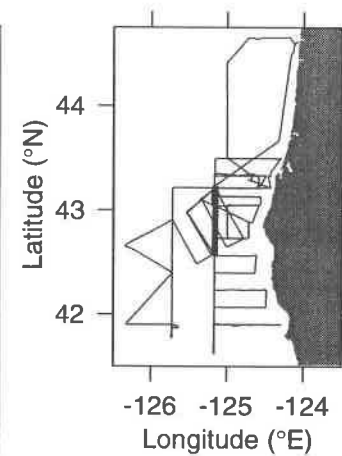
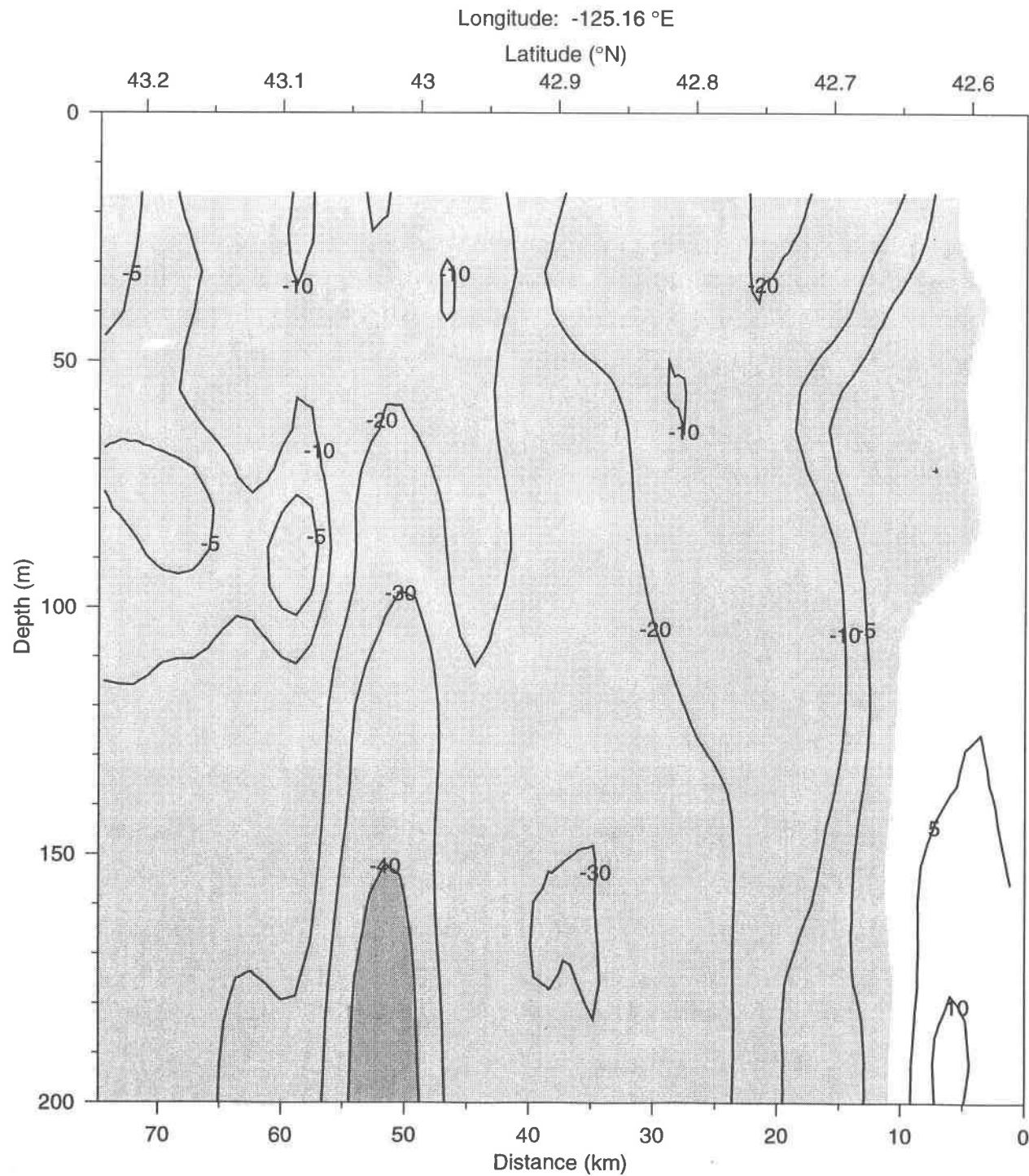
Longitude (°E)
 -125.5 -125.4 -125.3 -125.2



br w8408
 v both.del

ADCP Line 33 U (year day 244.95-245.19, 02-Sep-94)

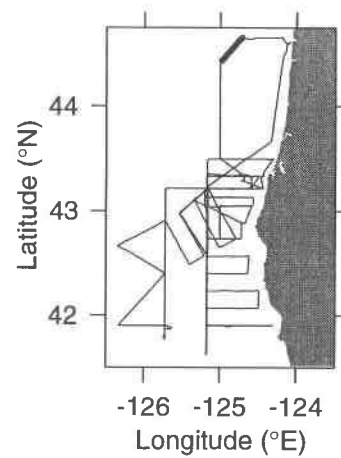
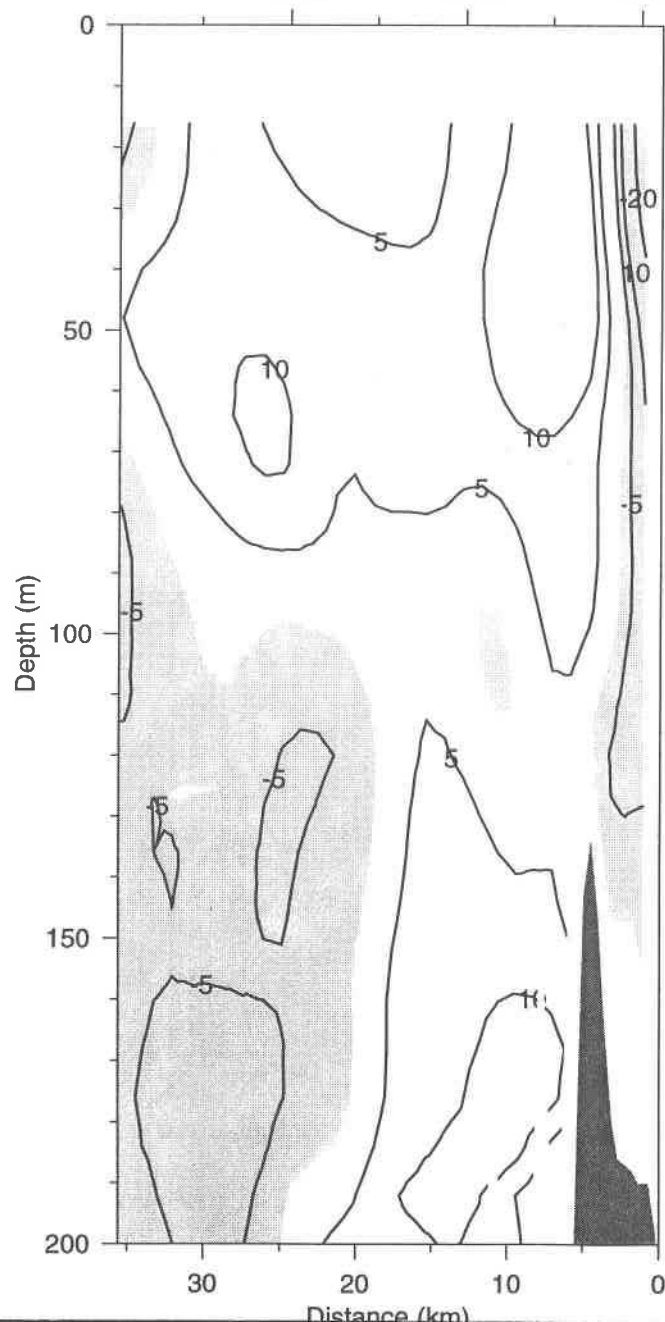




ADCP Line a cross-track (+ towards 314°, year day 235.99-236.11, 24-Aug-94)

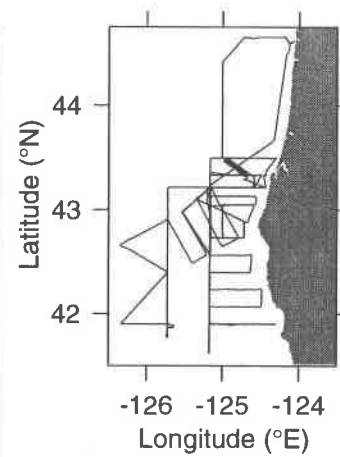
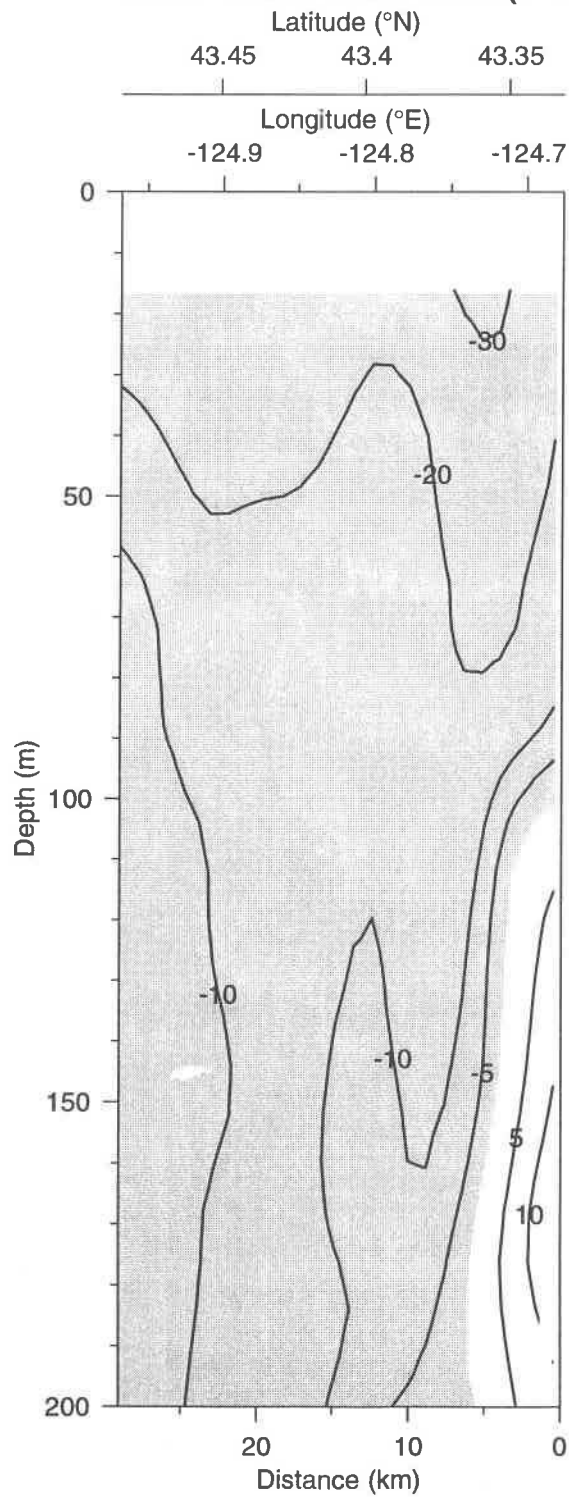
Latitude (°N)
44.5 44.6

Longitude (°E)
-124.9 -124.8 -124.7



br w9408
starboard botship.dat

ADCP Line c cross-track (+ towards 36°, year day 236.44-236.53, 24-Aug-94)



br w9408
port botship.dat