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S A Cunningham, M J Griffiths, J Hemmings & S G Alderson et al

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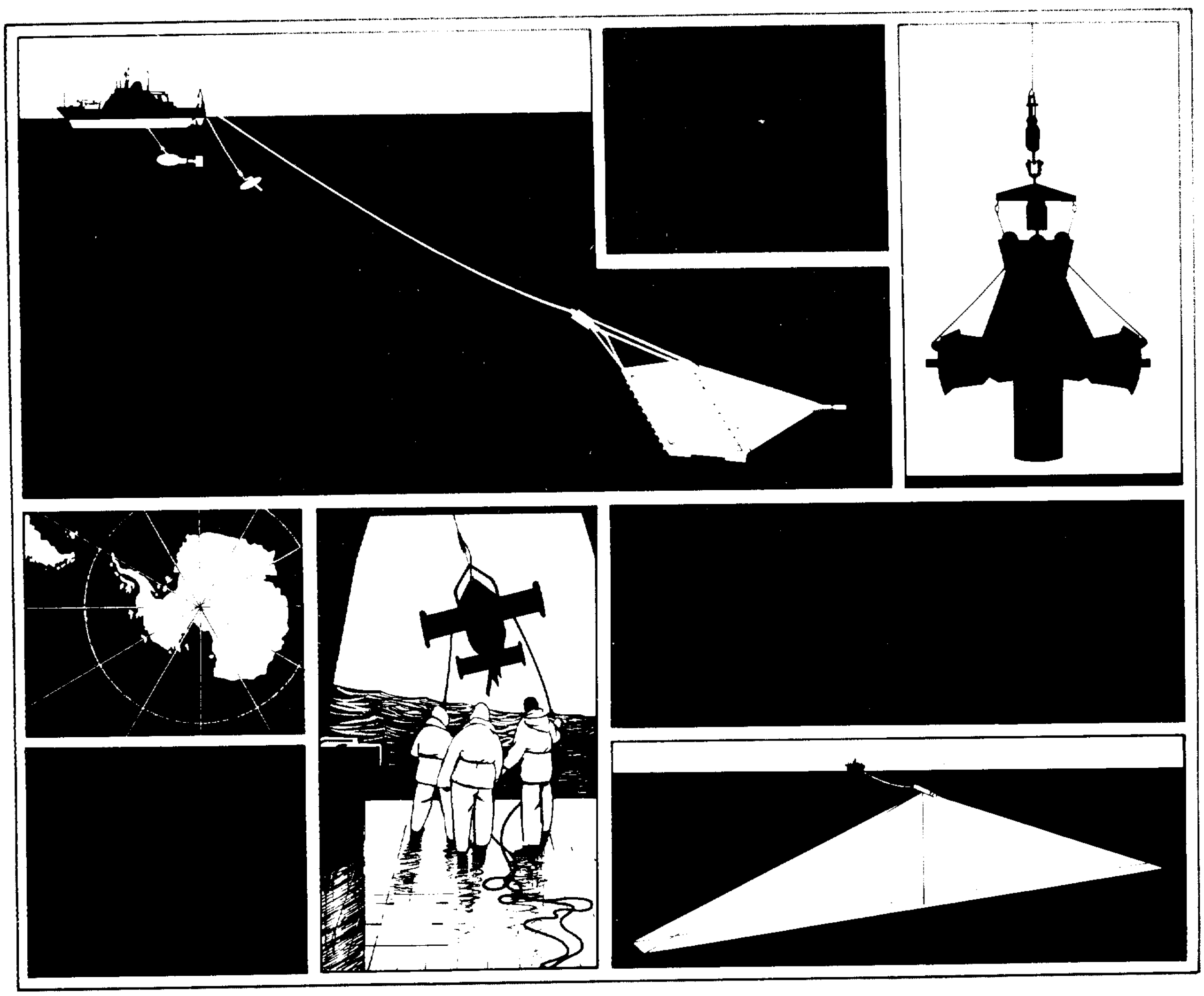

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ABSTRACT

This data report presents SeaSoar data from *RRS Charles Darwin* Cruise 58 and 59 (24 April - 9 June 1991). Data were collected in the Northeast Atlantic between 39° to 54° N, 11° to 34° W. With the aid of a new winch, SeaSoar undulated between the surface and 500m every 2.5 km, measuring CTD data with a double conductivity cell CTD unit. Chlorophyll 'a' and scalar irradiance were also measured. Six meridional legs, four degrees apart were surveyed. The western four legs were 1500 km long and the others 900 km and 600 km. The legs were surveyed in three degree sections between full depth CTD casts. The meridional legs were joined by seven zonal sections. Processing and calibration of the data are described in this report and the data are presented as contoured sections.

Variables contoured against pressure are potential temperature, salinity, sigma0, sound velocity, scalar irradiance and chlorophyll. Temperature and salinity are also contoured against sigma0.

The aims of Vivaldi are to;

- calculate seasonal upper ocean heat and fresh water budgets
- map isopycnic potential vorticity variations from the sub-tropical gyre to the sub-polar gyre
- map interannual changes in the properties of water masses formed by deep convection
- calculate statistics of upper ocean parameters and air sea fluxes
- investigate the role of eddies.

KEYWORDS

ATLNEAZO
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"CHARLES DARWIN"/RRS - cruise(1991)(58)
"CHARLES DARWIN"/RRS - cruise(1991)(59)
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SCALAR IRRADIANCE
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TEMPERATURE

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1. INTRODUCTION

RRS Charles Darwin Cruise 58 sailed from Barry on Wednesday 24 April 1991, and arrived in the Azores on Thursday 16 May 1991. The second leg, Cruise 59, departed the Azores on Saturday 18 May 1991 and finished in Barry on Sunday 9 June 1991. A region bounded by 39° to 54° N and 11° to 34° W in the Northeast Atlantic was systematically surveyed using a combination of SeaSoar for measurements in the upper 500 metres, and full depth CTD stations, Figure 1. The survey consisted of six meridional legs four degrees apart, made up from twenty seven SeaSoar sections each three degrees in extent. The meridional legs were joined by seven zonal legs of which two were repeated sections. Each SeaSoar section was bounded by full depth CTD stations giving thirty eight CTD stations (including three repeats). CTD data from Cruise 58 and 59 are reported by (GRIFFITHS et al, 1992).

Details of individual projects and other measurements made on the Cruise are given in the Cruise Report (POLLARD, LEACH and GRIFFITHS, 1991).

2. DATA COLLECTION

Data were collected from three instruments fitted to the SeaSoar. A Neil Brown Mk III CTD, a Chelsea Instruments fluorometer and a Photosynthetically Available Radiation meter (PAR) to measure scalar irradiance. The CTD had been modified by adding an extra conductivity cell, hence enabling two independent conductivity measurements to be made. A new horizontal drum winch system holding 700m of faired cable substantially improved the depth penetration of SeaSoar. Towing at 8 knots (4 ms^{-1}) SeaSoar undulated between the surface and 500m in approximately 11 minutes, a distance of 2.5 km.

The full depth CTD data were used to fix the absolute calibration of each SeaSoar section. In addition, an improved SeaBird thermosalinograph and hourly underway sampling of the surface salinity allowed much tighter control of SeaSoar salinities than was possible on previous SeaSoar cruises. Tables 1 and 2 give details of individual SeaSoar sections.

3. DATA PROCESSING AND CALIBRATION

3.1. Data acquisition

The shipboard computer system and data acquisition path has been described by (POLLARD, 1986 a), (POLLARD et al, 1986 b), (VOSS et al, 1986) and (CUNNINGHAM, 1992) in preparation.

3.2. Initial calibration

Having read the data into PSTAR format the following calibrations were applied to the raw data:

Pressure P_{cal}(dbar) = $1.000287*(0.01*P_{raw})-2.2282$

Temperature T_{cal}(°C) = $0.99908320*(0.0005*T_{raw})-0.1020392$

Conductivity $C1_{cal}$(mmho/cm) = $0.99572*(0.001*C_{raw})$

Conductivity $C2_{cal}$(mmho/cm) = $0.99830*(0.001*C_{raw})$

Chlorophyll 'a' Chla(mg/m^3) = $\exp(0+1.3773)*(0.001*Fluor_{raw}))-1.2278$

NB:- After section 9 on Cruise 59, conductivity cell C1 failed and was replaced by a new cell. This was nominally calibrated with the same calibration as was applied to C2, as no calibration was available for the new cell. The two channels were then swapped so that what had previously been C2 became C1 and vice versa. Hence the nominally calibrated cell was now C2; ie

$C1_{cal}$(mmho/cm) =$0.99830*(0.001*C_{raw})$

$C2_{cal}$(mmho/cm) =$0.99830*(0.001*C_{raw})$

Pressure, temperature and conductivity calibrations were from the most recent laboratory calibrations on the 5th, 8th and 12th of April 1991. The irradiance calibration was also from a laboratory calibration. Chlorophyll 'a' was initially given a nominal calibration.

Temperature from the platinum thermometer was corrected for temperature lag using a time constant of 0.22 seconds. Salinity was then calculated from the 1983 equation of state.

Temperatures were calibrated to the ITS-90 scale and then derived oceanographic variables were computed by the usual algorithms.

3.3. Editing

Methodologies for editing and despiking SeaSoar data, relating to CTD units carrying only a single conductivity cell, have been given by (COLLINS et al, 1983) and (POLLARD et al, 1987). On Cruise 58 and 59 a new method had to be established to deal with the double conductivity cells. This arrangement gave two conductivity channels and hence two salinity channels. The philosophy that was developed used one channel as the primary channel and the other the secondary; the object was then to produce one channel of high quality salinity data by using the secondary channel to correct foulings and spikes in the primary channel.

Spikes and jumps in the salinity data are caused by detritus, usually biological material, entering the conductivity cell and interfering with the conductivity measurements. Offsets or jumps to low salinities are of the order 0.01 to 0.05 though in some circumstances they can be much higher.

Every four hours SeaSoar data were read into PSTAR format, calibrated and profile plots of all parameters and potential temperature against salinity (θ/S) curves were produced. These plots were then inspected for spikes and fouling events.

As the secondary salinity channel was to be used to correct the primary channel by swapping data from one to the other, it was essential that both channels gave the same salinity. In general there was always an offset between the two channels and the secondary salinity was fitted to the primary by adding the difference of the two channels to the secondary salinity. This maintained the relative calibration of the two channels. The two salinities then overlay each other except where one or other cell fouled.

Hence the relative calibration of the primary salinity is maintained for the four hour section of data being edited. All of the above procedures are discussed in detail in (CUNNINGHAM, 1992). The absolute salinity calibration will be discussed in section 3.6.

3.4. Gridding

Four hour files were appended to create a file of one second data which corresponded to a section between two CTD stations.

The data were then gridded against pressure and distance run, with a bin resolution of 4 km by 8 dbars. Potential density was then recalculated from the gridded file to correspond to the averaged temperatures and salinities in the gridded file. The data were also gridded onto potential density with bin resolution 4 km by 0.02 kg/m^3. Finally both gridded files were further averaged to reduce noise by creating 6 km averages every 4 km.

GPS navigation was used to add positional information to the SeaSoar data. (POLLARD, LEACH and GRIFFITHS, 1991) estimated that in port the rms position fixing error was 6m, while at sea an upper bound was calculated to be 25m.

3.5. Final thermosalinograph calibration

Seabird TSG data were read into PSTAR in sections corresponding to a SeaSoar section between CTD stations, and calibrated. The following calibrations were applied to the data:

$$H_{temp}\ (^{\circ}C) = -63.6289 + 7.441474E\text{-}3 * FH - 2.067987E\text{-}7 * FH^2 + 2.880193E\text{-}12 * FH^3$$

where H_{temp} is the housing temperature

FH is typically around 16000

Level A value = FH - 12000

$$Rtemp\ (^{\circ}C) = -12.43502 + 3.137205E\text{-}3 * FR - 8.350152E\text{-}8 * FR^2 + 1.532481E\text{-}12 * FR^3$$

where R_{temp} is the sample temperature

FR is typically around 11000

Level A value = (FR - 2000) / 2

$$Hcond\ (mmho/cm) = 8.80739112E\text{-}7 * FC^{5.1} + 4.30906377E\text{-}1 * FC^2 - 4.38268295 - 2.25947132E\text{-}4 * H_{temp}$$

where H_{cond} is the sample conductivity

FC is (SeaBird count) / 2000

Level A value = (Seabird count / 2) -3000

The sample temperature resolution is 0.0018 °C but is degraded to 0.0036 °C by the Level A conversion. Conductivity is resolved to 0.005 mmho/cm, but again the Level A conversion reduced that to 0.01 mmho/cm.

The TSG data were then merged on time with the hourly underway bottle data. The salinity differences between bottle and TSG data were determined and the mean and deviation for that section calculated. The mean offset between the two salinities was then applied to the TSG salinity as a calibration factor. Table 3 lists the mean TSG and bottle salinity differences for each section and the results are plotted in Figure 2b.

3.6. Final salinity calibration

During Cruise 58 and 59 SeaSoar was recovered at approximately 300 km intervals between full depth CTD stations. With hourly sampling for surface salinities and continuous monitoring of the surface salinity and temperature with the thermosalinograph (TSG) there was an unprecedented opportunity to have daily calibrations of the SeaSoar via the CTD stations and continuous underway calibration data from the TSG. The procedures have been discussed in detail by (CUNNINGHAM, 1992) but will be outlined below.

The calibration of the full depth CTD's is given by (GRIFFITHS et al, 1991). To determine the absolute calibration of the SeaSoar, θ/S curves at the start and end of each section were compared to the θ/S curves from the CTD stations. A relative shift to be applied to that SeaSoar section was then determined. Fitting of the θ/S curves was to 0.005 in salinity. The internal consistency of each section was also checked by drawing an envelope of the θ/S curves for that section.

Hourly underway samples of surface salinity were drawn from the non-toxic supply. These samples were analysed using a Guildline Salinometer and used to calibrate the TSG (see below).

Previous methods using underway sampling to calibrate the SeaSoar data are given by (POLLARD et al, 1987). These involved taking the difference in salinity of the near surface bin of gridded data and the underway sample. This gave piecewise salinity differences which were then used to calibrate gridded SeaSoar data. (KING et al, 1991) used an improved method where a 5m vertical average of each SeaSoar surfacing event was calculated, and these events were compared to the surface bottle values which had been drawn to correspond in space to the SeaSoar surfacing. This method led to a "significant reduction" in the mean deviations of the estimated residuals between the SeaSoar data and underway samples. One disadvantage of both methods is that they produce rather few data points for the estimate of the residual salinities and hence have a rather course resolution in the horizontal. By using the surface samples to calibrate the TSG and then merging the TSG data with the one second SeaSoar data we get more comparison points at every SeaSoar surfacing.

Table 3 lists the mean and deviation of the salinity residuals for Cruises 58 and 59. Figure 2a shows the results graphically. Figures 3 and 4 show a time series of TSG sea surface salinities, and the residual difference between the TSG and SeaSoar salinities. Individual differences between the TSG and SeaSoar salinities were noisy, having a mean standard deviation of about 0.009. This was due to the operating mode of the TSG and could be improved on in the future. The final residuals were calculated by applying a low pass filter to the salinity differences. This was done by applying a top hat filter of width 24 hours every hour. This is shown in figures 3 and 4 as trace 2. The statistics of the residuals may be succinctly summarised thus; for the sixteen sections in Cruise 58, 100% of the mean residuals for each section are less than 0.005 and for the seventeen sections of Cruise 59, 94% of the mean residuals are less than 0.005 and 100% less than 0.01; the mean standard deviation of the residuals for Cruise 58 and 59 being 0.0088 and 0.009 respectively, Table 3.

The mean residuals between the TSG and the SeaSoar were expected to be low because each SeaSoar section had been absolutely calibrated against the CTD data to a precision of 0.005. What was found was that the calibration against the TSG identified sections where the fit had been less than satisfactory , for instance, caused by a poor match between the CTD and SeaSoar θ/S curves due to eddies or strong frontal features. Because of the higher spatial resolution achieved with the TSG compared with earlier methods of calibrating against underway bottle data, the TSG is able to show where fouling events have affected the surface data and were missed at an earlier stage of processing, perhaps because the θ/S were highly variable due to a strong frontal feature.

3.7. Final chlorophyll calibration

The initial nominal calibration applied to the raw fluorometer output voltage (flvolts) was found to be of limited use because of the extent of the variation in fluorescence yield (measured fluorescence per unit chlorophyll concentration) during the course of the survey. Data resulting using this original calibration were therefore discarded.

The final calibration outlined below gives the derived chlorophyll-*a* estimate (chlfl) using measured chlorophyll-*a* fluorescence and scalar irradiance (uwirr) in conjunction with extracted chlorophyll from water samples.

These data were first de-spiked and edited as follows. Flvolts was despiked using a running median filter, allowing a maximum deviation of 100 mV from the median of 5 data cycles. Uwirr was despiked using a running median filter on ln(uwirr), allowing a maximum deviation of 1 from the median of 5 data cycles. The data were then plotted for visual inspection and removal of any remaining data which were clearly due to instrumental or logging problems.

Linear response chlorophyll-*a* fluorescence (fluor) was calculated from:

$$\text{fluor} = \text{antilog}_{10}\ (\text{flvolts}/1000).$$

This corresponds to the input voltage to the logarithmic unit of the Chelsea Instruments "Sub-Aquatracka" fluorometer, which has a full scale range of 1 to 10000 mV. The logarithmic unit gives 2V output per decade change of input. The output is in the range 0 to 8V full scale which is then multiplied by a factor 0.5 by the logging software to give flvolts (mV).

During each SeaSoar run, surface samples were drawn for pigment analysis from the nontoxic supply at approximately 1 hour intervals, timed to coincide with surfacing of the SeaSoar. Extracted chlorophyll from these samples was measured using a Turner Designs fluorometer. These samples were used to calibrate the *in vivo* fluorescence measured on the SeaSoar.

Averages for fluor and uwirr were extracted from the SeaSoar files over a 2 dbar pressure band, centred on 4 dbar, to match the sampling times with a ±3 minute cut-off. (These criteria were relaxed for fluor where there were data gaps of more than 3 hours. In these cases top 10m averages were taken, with a ±5 minute cut-off, to replace absent data values. This applies to less than 10% of data points).

A fluorometer offset of 1.4 mV was estimated from examination of fluorescence data corresponding to extracted chlorophyll. This offset is defined as the linear response fluorescence reading in the absence of extractable chlorophyll-*a* and is attributable to instrument noise and to other fluorescent substances in the water with emission spectra interfering with that of chlorophyll-*a*. Fluorescence yield was calculated using fluor corrected by this offset.

The observed fluorescence yield data and scalar irradiance data were used to derive components of a model which gives estimated values for yield at any point in the SeaSoar data set. This yield estimate comprises an estimate of the night-time or unquenched yield (i.e. the fluorescence per unit chlorophyll in the absence of any quenching effect due to light) and an estimate of the quenching factor, based on measured irradiance. The model assumes no variation of unquenched yield with depth; the calibration is based on surface samples and can therefore be expected to be less accurate in the thermocline where the species composition of the phytoplankton may be different.

The quenching factor Q is given by

$$Q(b,uwirr) = 1 + b\,(Q_o(uwirr) - 1),$$

where Q_o is a quenching function of the form

$$Q_o(uwirr) = 1 + K_1\,(1 - \exp(K_2 * uwirr))$$

and b is a correction factor allowing for daily variation in the amplitude of the quenching response (i.e. the quenching for a given light level). Both Q and Q_o are defined to refer to the ratio of unquenched yield to actual yield.

Coefficients K_1 and K_2 were determined for each Cruise by fitting the model using the ratio of a first approximation of unquenched yield to the observed yield, using day-time data only. The first approximation of unquenched yield was generated from the average observed yield reciprocal (chlorophyll per unit fluorescence) for each night, linearly interpolated to give day-time values. Values of b were derived by linear regression of the yield ratio against Q_o for each day. (Figures 5 & 6.)

The final estimate for unquenched yield was generated by using the quenching factor to correct the observed data for reciprocal yield for the effects of light and then applying a 12 hour moving average to the corrected data. (Figures 7 & 8.)

The estimated unquenched yield reciprocal at each sample time and the value of the correction factor b for each day were linearly interpolated onto the SeaSoar data and chlfl calculated from:

$chlfl = (fluor - f_0) * Q(b,uwirr) * X_{n2}$

where f_0 is the fluorometer offset and X_{n2} is the unquenched yield reciprocal.

The quenching function coefficients were:

CD58 $K_1 = 3.96 \pm 1.20$

$K_2 = -0.00717 \pm 0.00331$

CD59 $K_1 = 2.34 \pm 0.32$

$K_2 = -0.0171 \pm 0.0048$

Comparing chlfl with the extracted chlorophyll values (chl) gives error statistics as summarised below. The relative deviation is defined as (chlfl - chl) / chl.

	Mean modulus relative deviation	R^2
CD58	21.0%	87%
CD59	19.1%	83%

Figures 9 and 10 show the distribution of the relative deviation against time.

3.8. Final scalar irradiance calibration

The calibration applied to scalar irradiance was as follows;

$Uwirr(W/m2)=-4.975*(0.001*uwirr_{raw})+2.3443$

This variable is defined as the scalar irradiance of the Photosynthetically Available Radiation (PAR). The definition implies integration over all directions. The light meter used has a hemispherical upward orientated collecting surface but the irradiance readings may be considered to represent scalar irradiance since, in most areas of the ocean, most of the light is in the refraction zone. Where there is significant backward scattering, such as in a coccolithophore bloom, this will be a source of error.

A problem was encountered in the data from the PAR meter. The level A program did not inspect the sign bit for this variable, so that the raw voltage was, in essence, fully rectified. It had the effect of introducing a sub-surface maximum in the calibrated irradiance. This was rather laboriously corrected and the data recalibrated. On Cruise 59 a more efficient way of correcting the data was devised. The raw data were derectified using a graphics package and then merged with the appropriate SeaSoar file and calibrated.

4. DATA PLOTS

The data are presented as contoured meridional sections, corresponding to 7.5° of latitude, from 39°N to 46.5°N and from 46.5°N to 54°N. Note that Leg W was completed as one section, while legs X-A have breaks at 48°N, where the southern and northern points were completed in CD58 and CD59 respectively. Potential temperature, salinity, sigma0, sound velocity, scalar irradiance and chlorophyll 'a' are contoured against pressure. Potential temperature and salinity are also contoured against sigma0.

Contour intervals are as follows:

Potential Temperature	0.5°C
Salinity	0.05 psu
Sigma0	0.05 kgm^{-3}
Sound Velocity	2.0 ms^{-1}
Scalar Irradiance	Log scale W m^{-2}
Chlorophyll 'a'	0.05 mg m^{-3}

5. ACKNOWLEDGEMENTS

The first Vivaldi cruise was a great success. Over 10,000 km of high quality SeaSoar data were gathered and processed on ship. Particular thanks go to the ship's masters, Paddy MacDermott and Mike Harding, the officers and crew of *RRS Charles Darwin*.

Attention to detail and hard work from the scientists and technical staff ensured the high quality of all the SeaSoar data.

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TABLE 1

SeaSoar runs Darwin Cruise 58

Vivaldi reference	Run	Deployment or recovery date	time	Section	Comments
	1	26/4/91	1836 2118	none	Trial run. Data not processed
B48 - B45	2	27/4/91 28/4/91	0812 0335	SS11001	IOS block used, resulted in slow recovery and fairing loss. Wing edge bent
B45 - B42	3	 29/4/91	0829 0615	SS11002	RVS block used
B42 -	4		1146 1406	none	Transmissometer blanking plug leakage Data not processed
A42 - A45	5 6	30/4/91 01/5/91	0750 1337 1448 0646	SS11003 SS11003 (cont)	Noisy data, traced to faulty fluorometer lead Steamed on during repair then redeployed Hard to control block rotation
A45 - A48	7 8	 02/5/91	1114 1300 1517 0814	SS11004	Would not fly, leaky hydraulics suspected Much fairing loss during recovery. Block now has bar for rotational control Brooms nearly eliminated fairing loss Bottom tail plane missing and impellor bent
A48 - Z48	9	 03/5/91	1340 0901	SS11005	
Z48 - Z45	10	 04/5/91	1319 1239	SS11006	
Z45 - Z42	11	 05/5/91	1710 1530	SS11007	Nose squashed on stern, weight bolts sheared
Z42 - Z39	12	 06/5/91	1915 1822	SS11008	
Z39 - Y39	13	 07/5/91	2234 1856	SS11009	Heavy pitching, difficult launch 1324-1513 trials on passage
Y39 - Y42	14	 08/5/91	2231 2030	SS11010	Ploughshare now lays fairing on drum
Y42 - Y45	15	09/5/91 10/5/91	0020 0031	SS11011	
Y45 - Y48	16	 11/5/91	0332 0203	SS11012	
Y48 - X48 X48 - X45	17	 12/5/91 13/5/91	1105 1122 1130 1021	SS11013 SS11014	CTD not possible so SeaSoar not recovered, alter course from 270 to 171 and continue Wing edge plate bent again
X45 - X42	18	 14/5/91	1349 1256	SS11015	
X42 - X39	19	 15/5/91	1600 1327	SS11016	

TABLE 2

SeaSoar runs Darwin Cruise 59.

VIVALDI reference	Run	Deployment or recovery date	time	Section	Comments
W39 -		19/5/91	1115	SS12001	Control poor.
W42	20	20/5/91	0720		
W42 -			1030	SS12002	Loss of control.
	21		2024		
		20/5/91	2145	SS12002	Control poor.
W45	22	21/5/91	1118	(cont)	
W45 -			1539	SS12003	Control good.
W48	23	22/5/91	1307		
W48 -			1809	SS12004	Loss of control.
	24		1930		
		23/5/91	1947	SS12004	Loss of control.
W51	25		1615	(cont)	
W51 -			2108	SS12005	Control good.
W54	26	24/5/91	2215		
W54 -		25/5/91	0145	SS12006	New Par lead.
X54	27		2116		
X54 -		26/5/91	0209	SS12007	,,
X51	28	27/5/91	0049		
X51 -			0445	SS12008	W/O counter u/s.
X48	29	28/5/91	0530		
X48 -			0900	SS12009	Cond1 failing.
Y48	30	29/5/91	0643		
Y48-			1138	SS12010	New cell & term'n
Y51	31	30/5/91	1027		
Y51 -			1908	SS12011	Control good.
Y54	32	31/5/91	1648		
Y54 -			2130	SS12012	,,
Z54	33	01/6/91	1438		
Z54 -			1823	SS12013	,,
Z51	34	02/6/91	1644		
Z51 -		03/6/31	0209	SS12014	Loss of control.
	35		0454		
		03/6/91	0630	SS12014	New valve leads.
Z48	36	04/6/91	0122	(cont)	
Z48 -			1036	SS12015	Control good.
A48	37	05/6/91	0708		
A48 -			1500	SS12016	New term'n.
A51	38	06/6/91	1445		
A51 -		07/6/91	0500	SS12017	Control good.
A54	39	08/6/91	0229		

TABLE 3

Section	CD58 SeaSoar v's TSG				TSG v's Bottles			
	Mean	Std. Dev	N	SE_3 of mean	Mean	Std. Dev	N	SE_3 of mean
sal1001	0.004	0.007	273	0.0013	-0.020	0.004	13	0.0033
sal1002	0.000	0.005	242	0.0010	-0.018	0.005	12	0.0043
sal1003	-0.001	0.006	344	0.0010	-0.015	0.004	22	0.0026
sal1004	0.003	0.006	291	0.0011	-0.015	0.006	19	0.0041
sal1005	0.000	0.010	157	0.0024	-0.019	0.006	15	0.0046
sal1006	0.000	0.007	333	0.0012	-0.017	0.005	22	0.0032
sal1007	0.003	0.007	95	0.0022	-0.014	0.005	22	0.0032
sal1008	-0.002	0.008	145	0.0020	-0.018	0.004	24	0.0024
sal1009	0.001	0.012	209	0.0025	-0.014	0.004	20	0.0027
sal1010	0.005	0.007	204	0.0015	-0.018	0.006	20	0.0040
sal1011	0.000	0.013	268	0.0024	-0.020	0.005	21	0.0033
sal1012	0.002	0.012	253	0.0023	-0.019	0.004	20	0.0027
sal1013	-0.002	0.009	211	0.0019	-0.018	0.004	25	0.0024
sal1014	-0.002	0.009	192	0.0019	-0.016	0.004	20	0.0027
sal1015	0.000	0.009	247	0.0017	-0.013	0.006	17	0.0044
sal1016	0.001	0.013	296	0.0023	-0.008	0.006	18	0.0042
Mean =	0.0008	0.0088		Mean =	-0.0164	0.0049		
Std. Dev =	0.0021	0.0026		Std. Dev =	0.0031	0.0009		

Section	CD59 SeaSoar v's TSG				TSG v's Bottles			
	Mean	Std. Dev	N	SE_3 of mean	Mean	Std. Dev	N	SE_3 of mean
sal2001	0.002	0.009	174	0.0020	0.003	0.011	20	0.0074
sal2002	0.000	0.008	73	0.0028	-0.003	0.008	22	0.0051
sal2003	0.004	0.011	179	0.0025	-0.011	0.006	21	0.0039
sal2004	0.003	0.010	156	0.0024	-0.017	0.005	21	0.0033
sal2005	0.003	0.008	106	0.0023	0.016	0.006	24	0.0037
sal2006	-0.001	0.007	132	0.0018	-0.021	0.003	19	0.0021
sal2007	0.005	0.008	194	0.0017	-0.012	0.010	23	0.0063
sal2008	-0.001	0.008	153	0.0019	-0.009	0.005	25	0.0030
sal2009	0.002	0.009	123	0.0024	-0.008	0.004	22	0.0026
sal2010	0.002	0.011	158	0.0026	-0.005	0.004	22	0.0026
sal2011	0.000	0.006	182	0.0013	-0.003	0.007	21	0.0046
sal2012	0.003	0.009	195	0.0019	-0.003	0.005	17	0.0036
sal2013	-0.009	0.018	128	0.0048	-0.002	0.010	21	0.0065
sal2014	0.000	0.011	76	0.0038	0.002	0.011	21	0.0072
sal2015	-0.001	0.005	70	0.0018	0.010	0.004	20	0.0027
sal2016	0.000	0.006	175	0.0014	0.011	0.006	22	0.0038
sal2017	0.001	0.009	118	0.0025	0.013	0.007	22	0.0045
Mean =	0.0008	0.0090		Mean =	-0.0042	0.0066		
Std. Dev =	0.0031	0.0029		Std. Dev =	0.0099	0.0026		

N = Number of Observations

$$SE_3 = 3 \times \frac{\text{mean}}{\sqrt{N}}$$

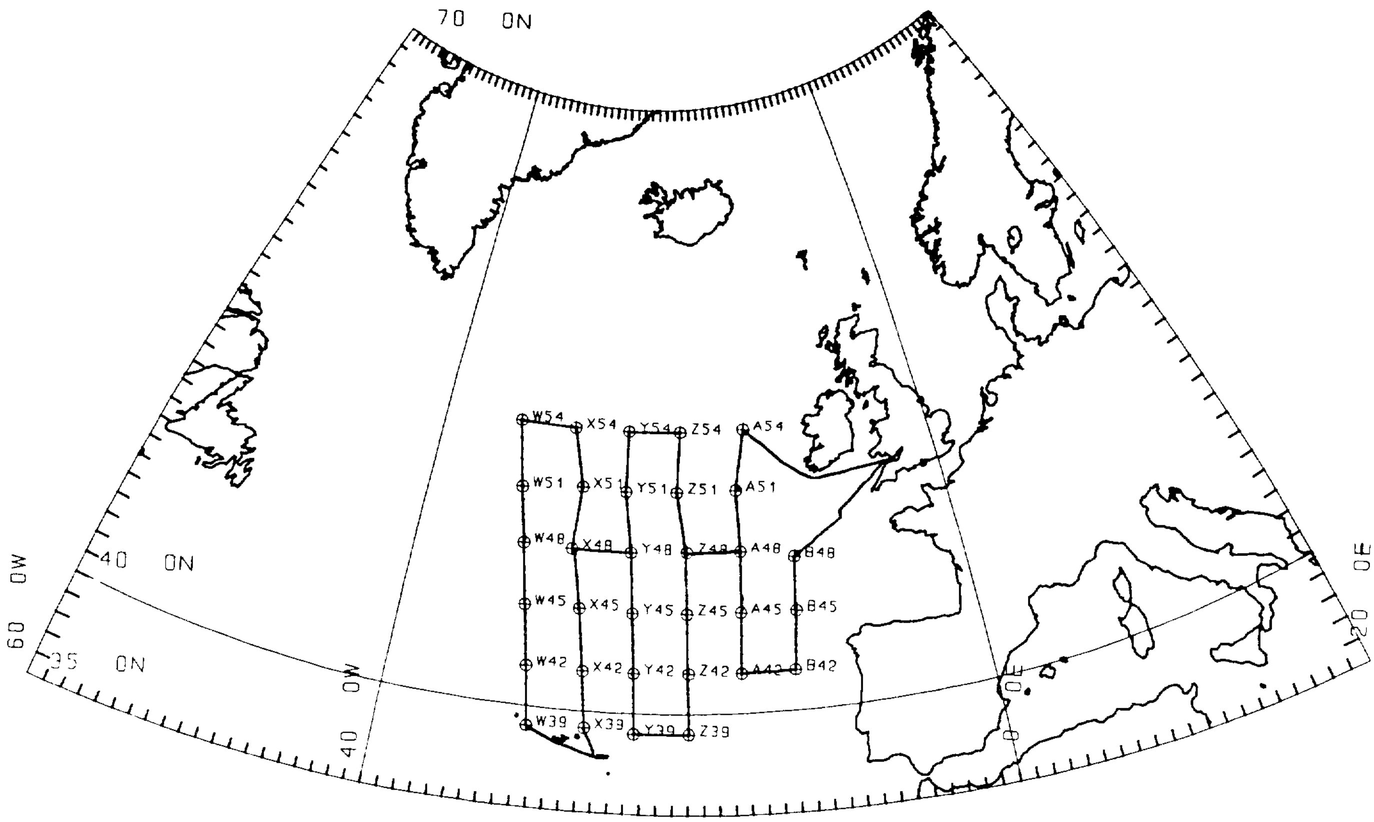


Figure 1: RRS Charles Darwin Cruises 58 and 59, 25 April to 16 May; 18 May, 10 June 1991.
Track Chart and CTD locations, Vivaldi '91.

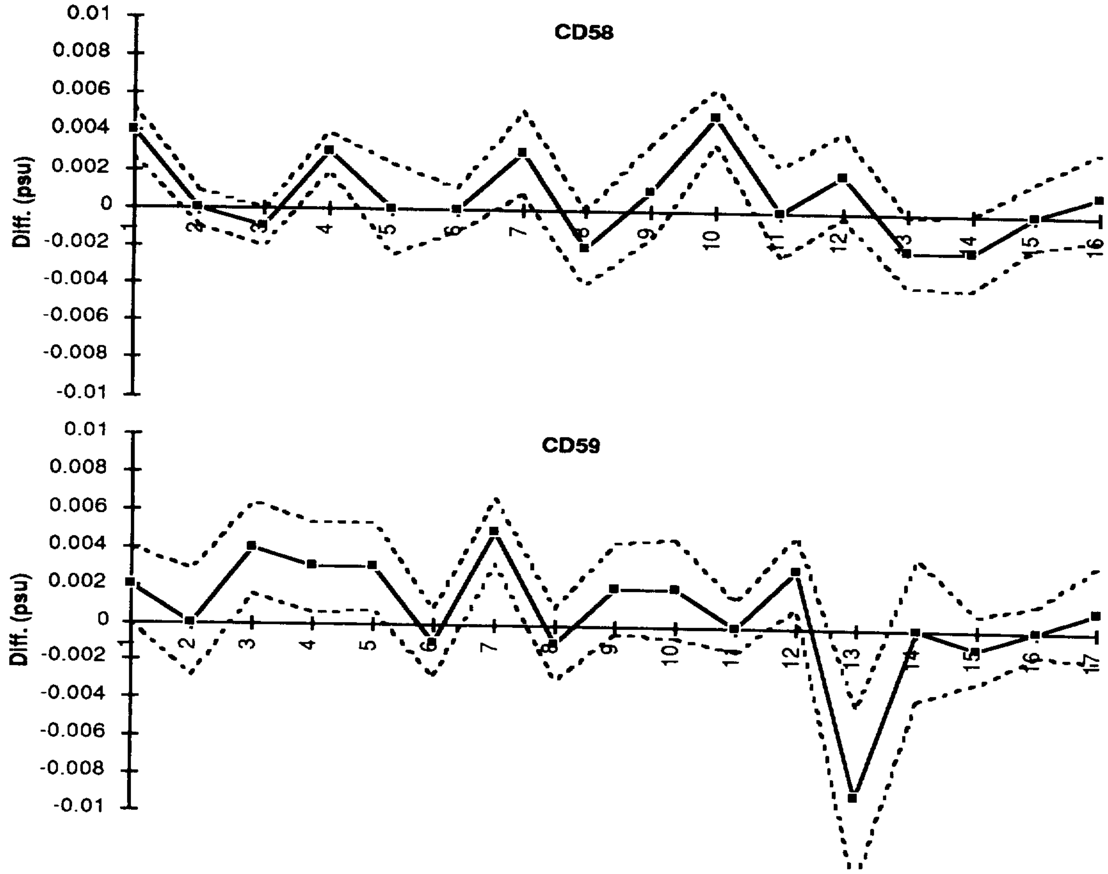


Figure 2a: Residual salinities between the SeaSoar and the TSG.

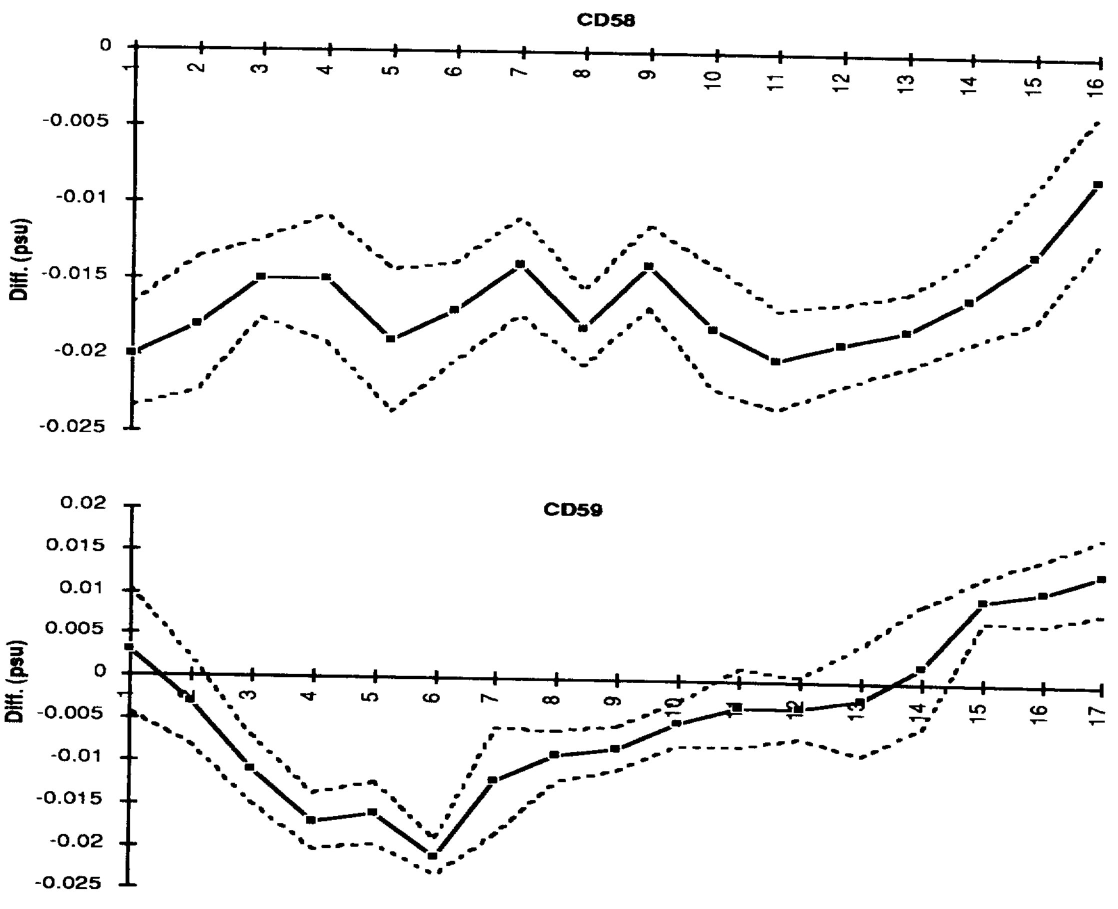


Figure 2b: Residual salinities between bottle samples and the TSG.
x-axis: Section Number
Error Bars: Three Standard Errors of the Mean

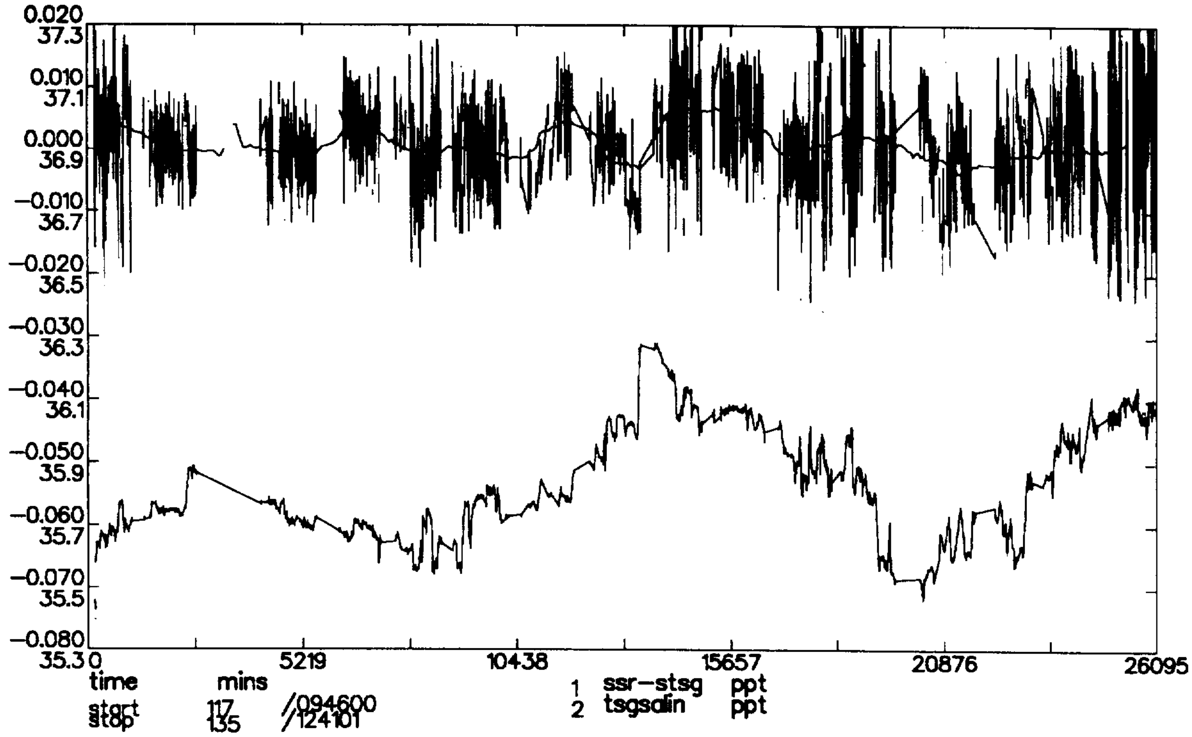


Figure 3: CD58
1. SeaSoar salinity minus TSG salinity.
2. Low pass filtered SeaSoar/TSG salinity differences.
3. TSG surface salinities.

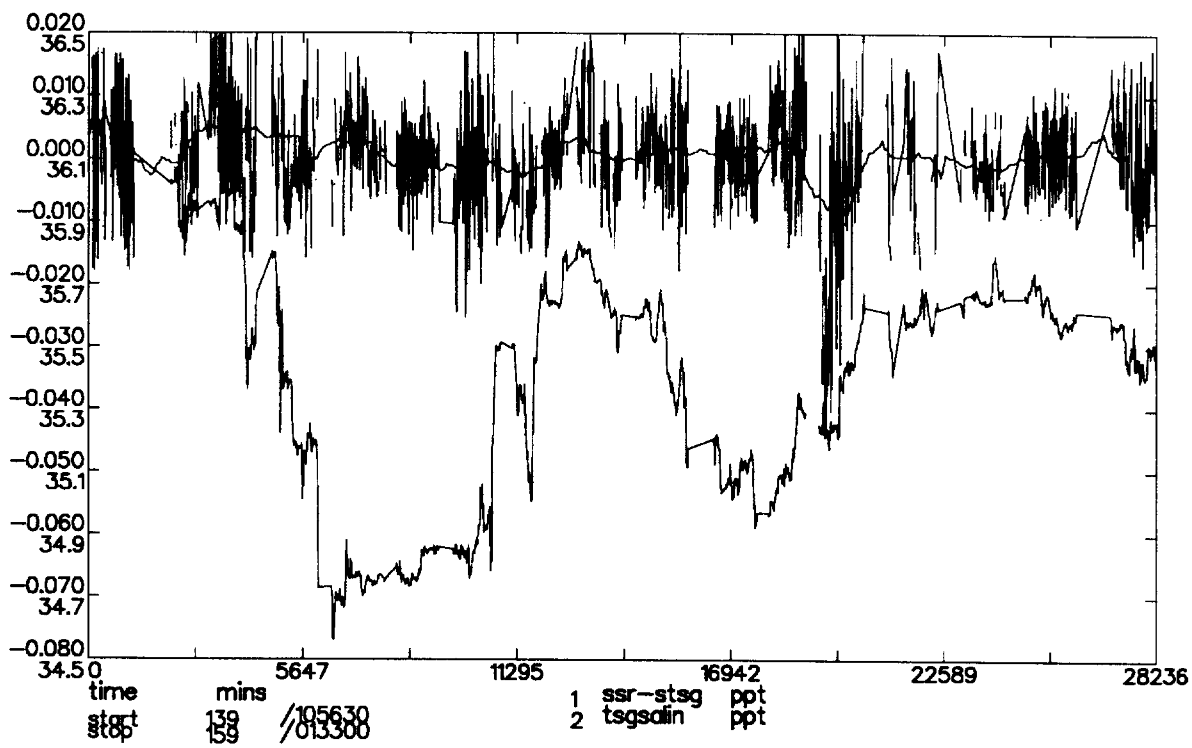


Figure 4: CD59
1. SeaSoar salinity minus TSG salinity.
2. Low pass filtered SeaSoar/TSG salinity differences.
3. TSG surface salinities.

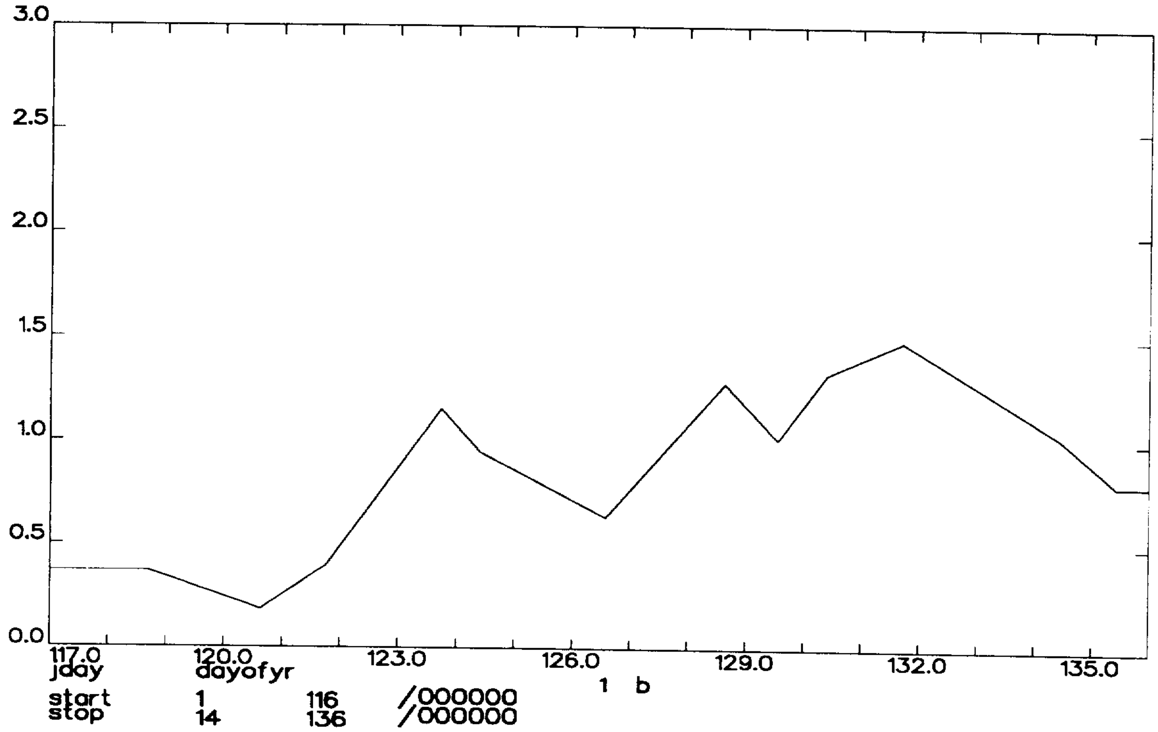


Figure 5: Relative amplitude of fluorescence quenching response (b) for CD58.

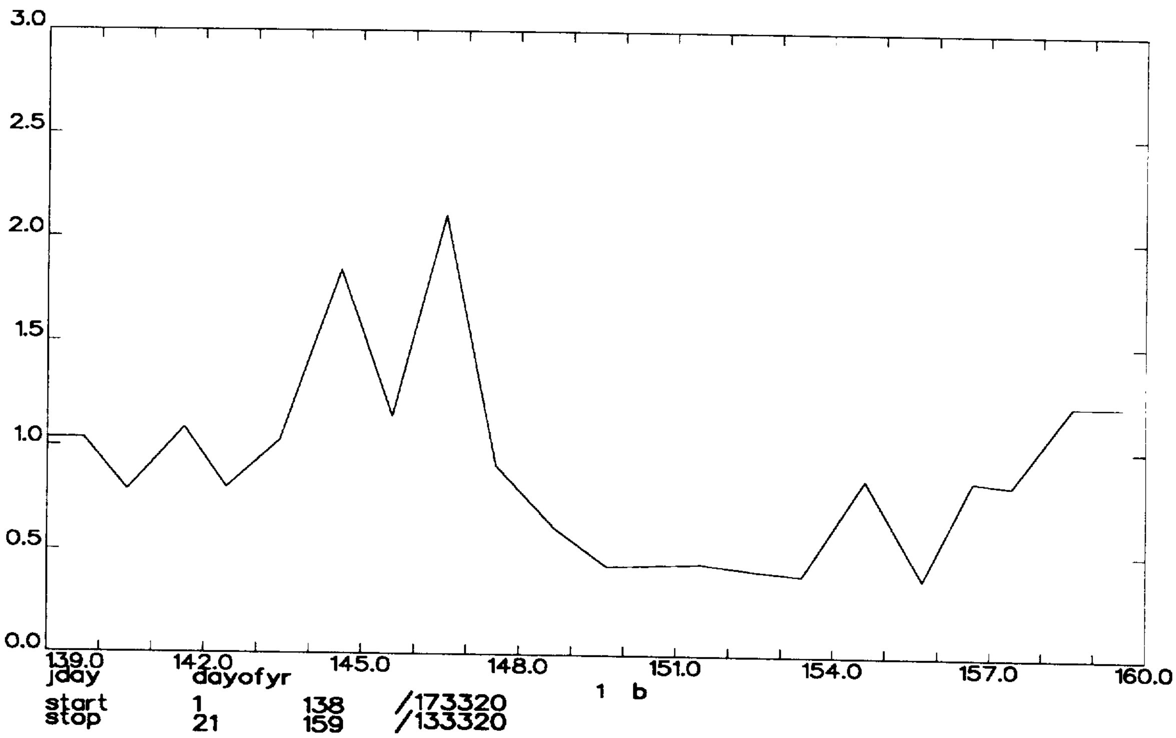


Figure 6: Relative amplitude of fluorescence quenching response (b) for CD59.

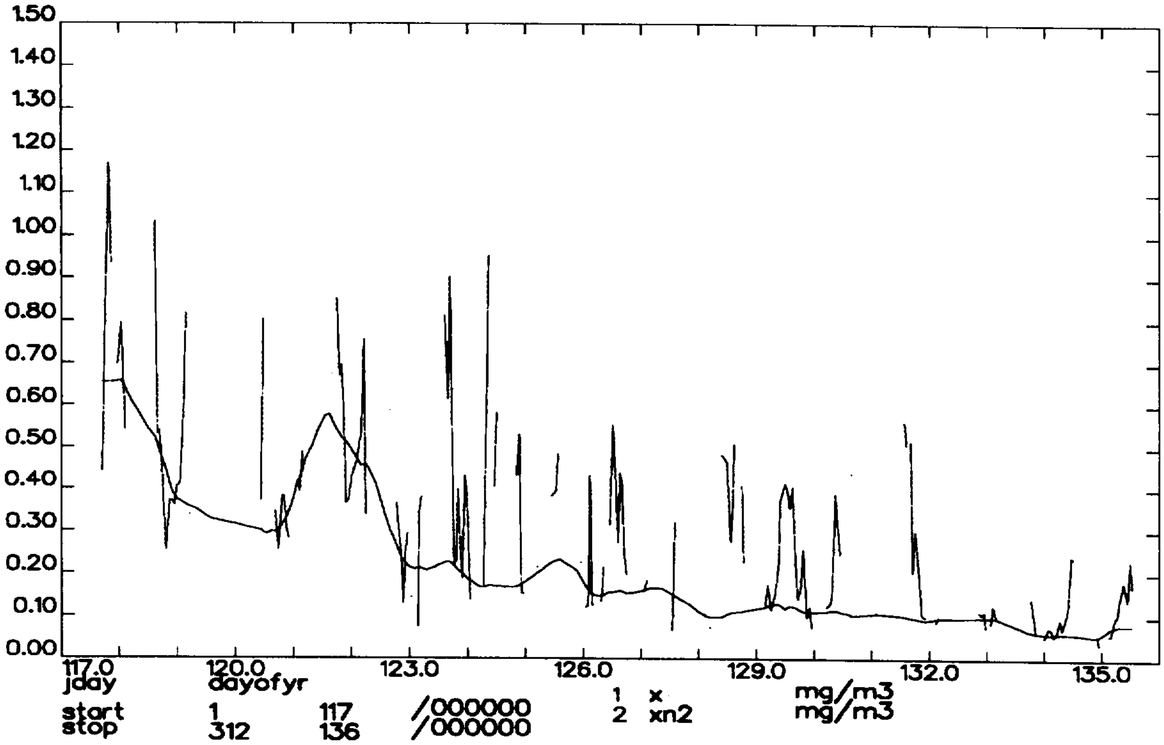


Figure 7: Observed fluorescence yield reciprocal (chlorophyll per unit fluorescence) and final estimate of unquenched yield reciprocal (x_{n2}) for CD58.

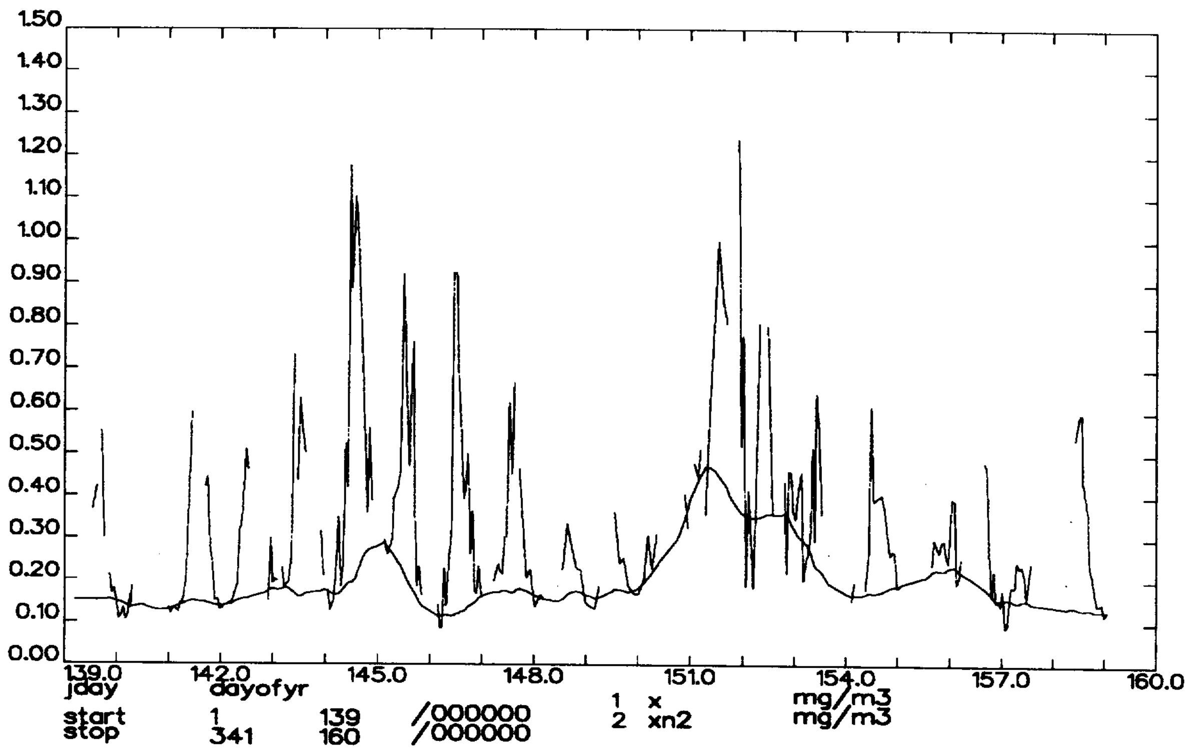


Figure 8: Observed fluorescence yield reciprocal (chlorophyll per unit fluorescence) and final estimate of unquenched yield reciprocal (x_{n2}) for CD59.

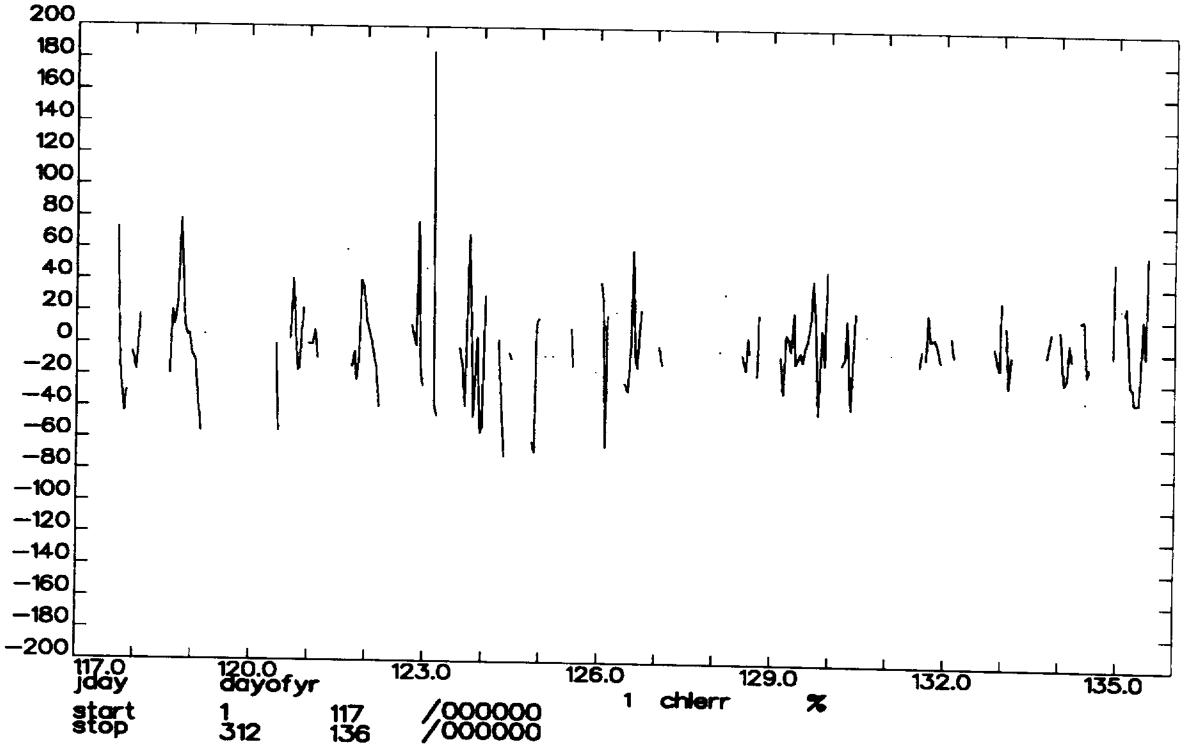


Figure 9: Distribution of % relative deviation of derived chlorophyll, with respect to extracted chlorophyll, for CD58.

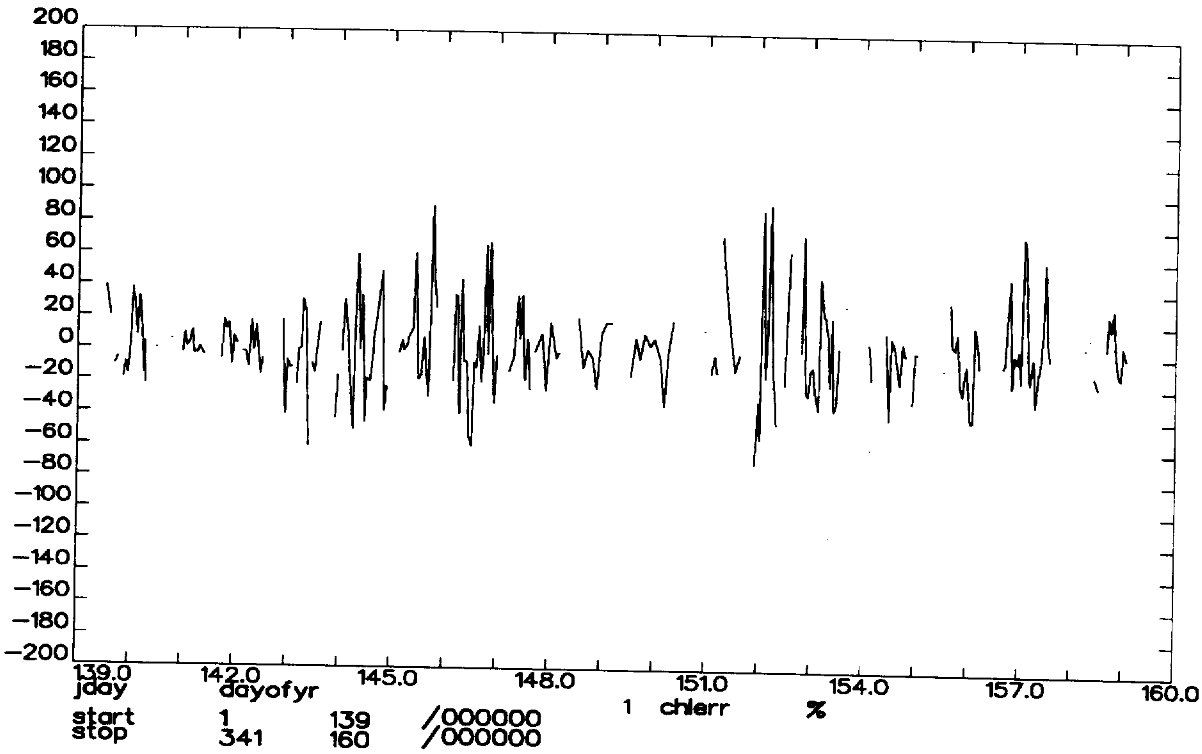
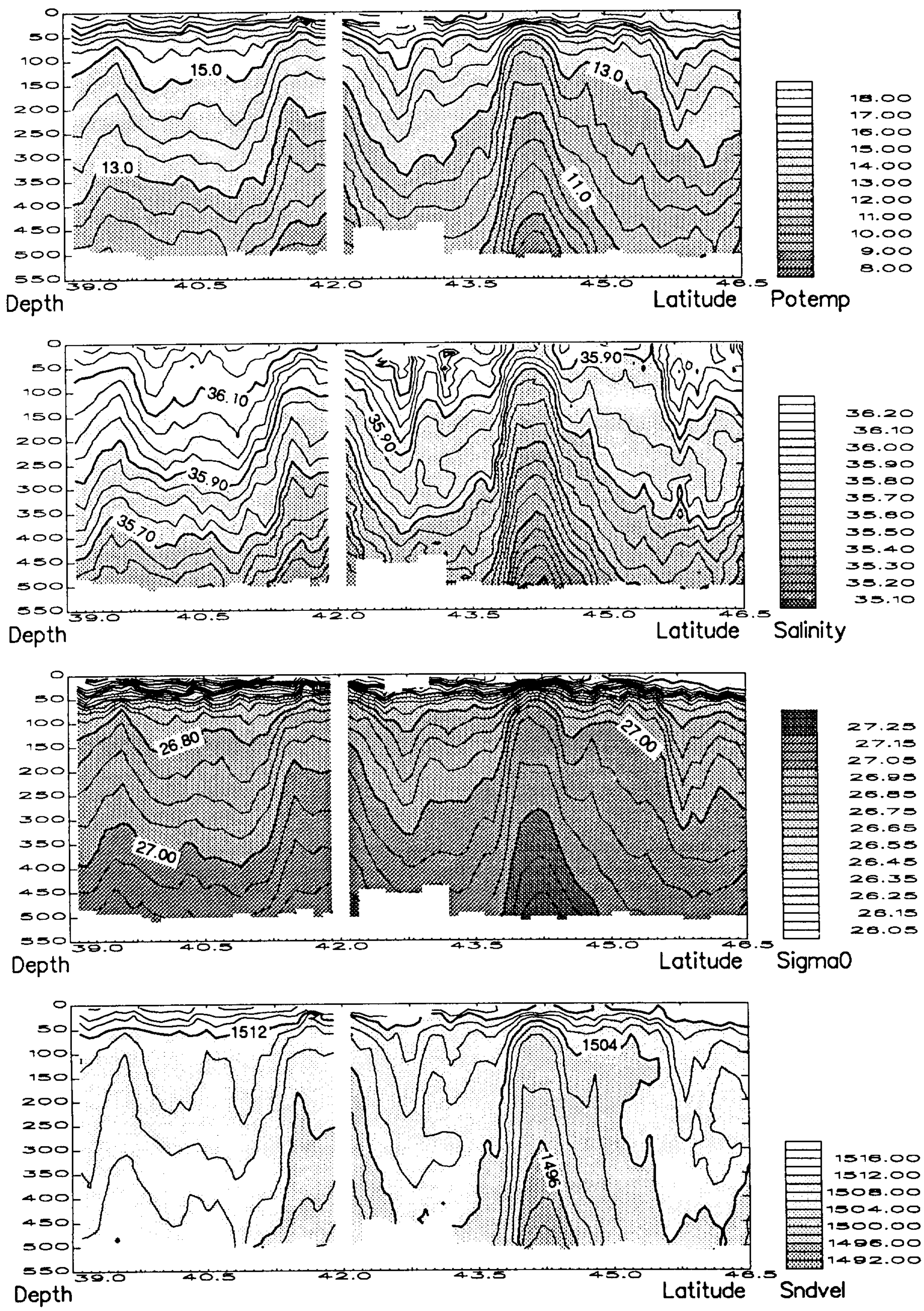
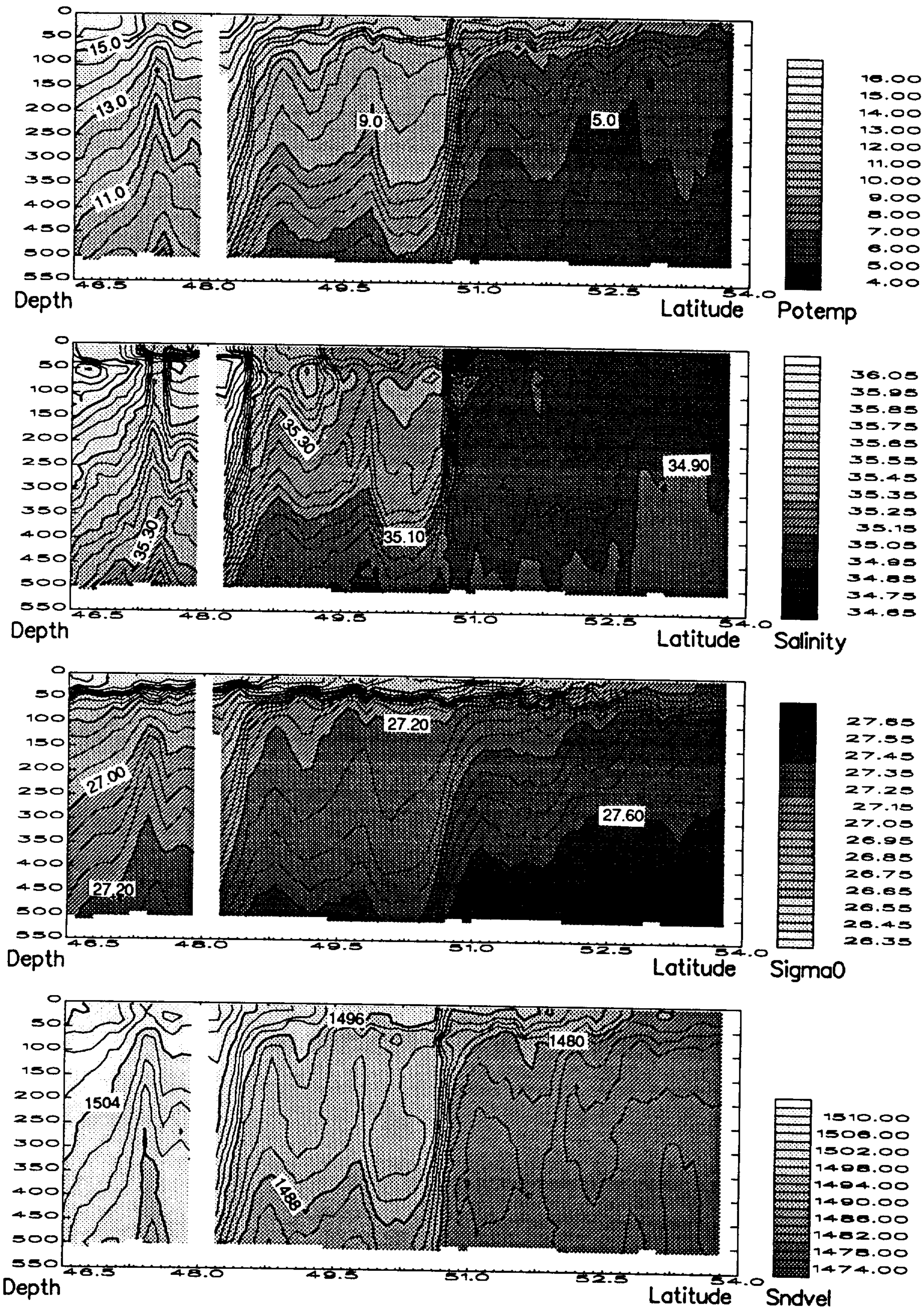


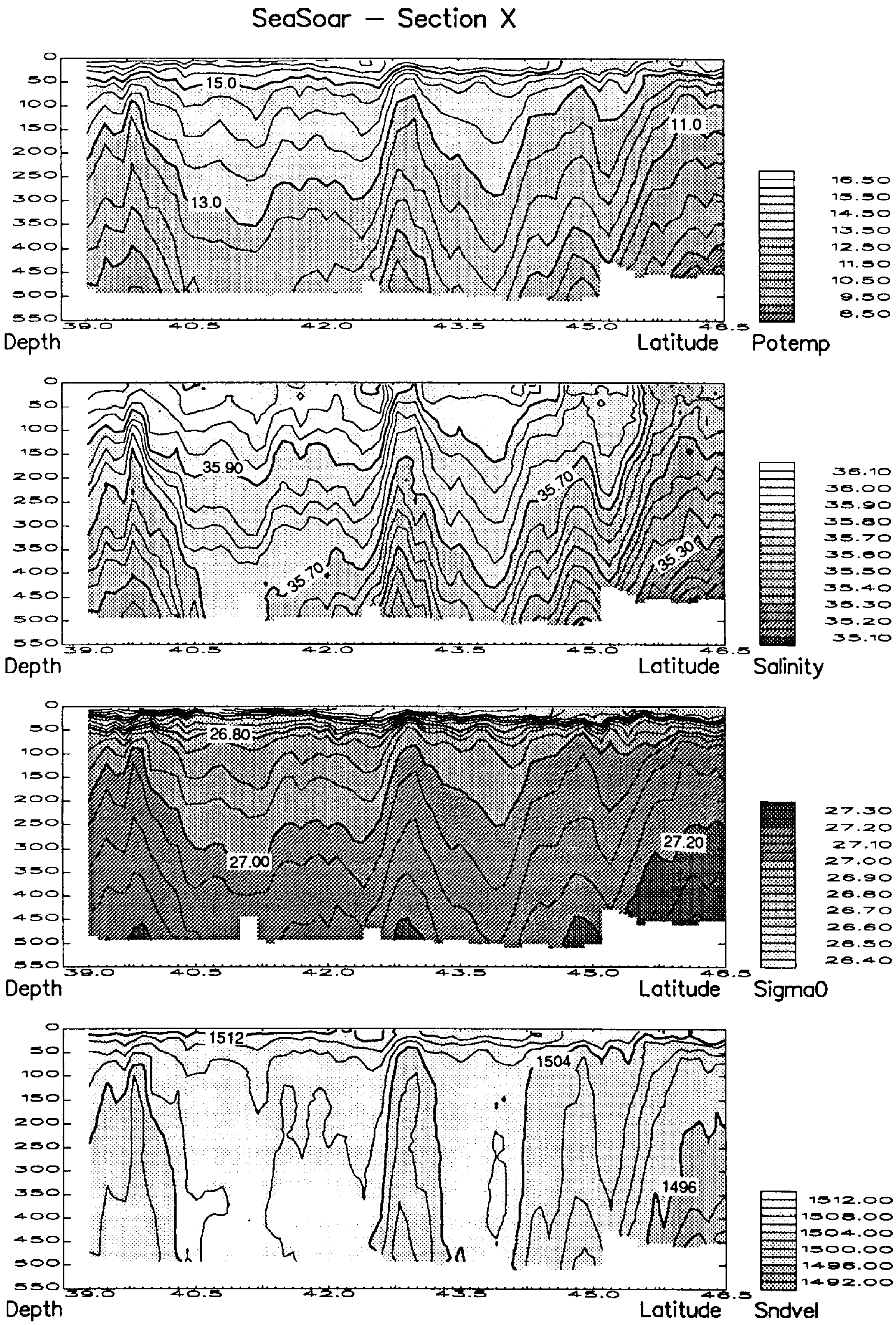
Figure 10: Distribution of % relative deviation of derived chlorophyll, with respect to extracted chlorophyll, for CD59.

SeaSoar — Section W

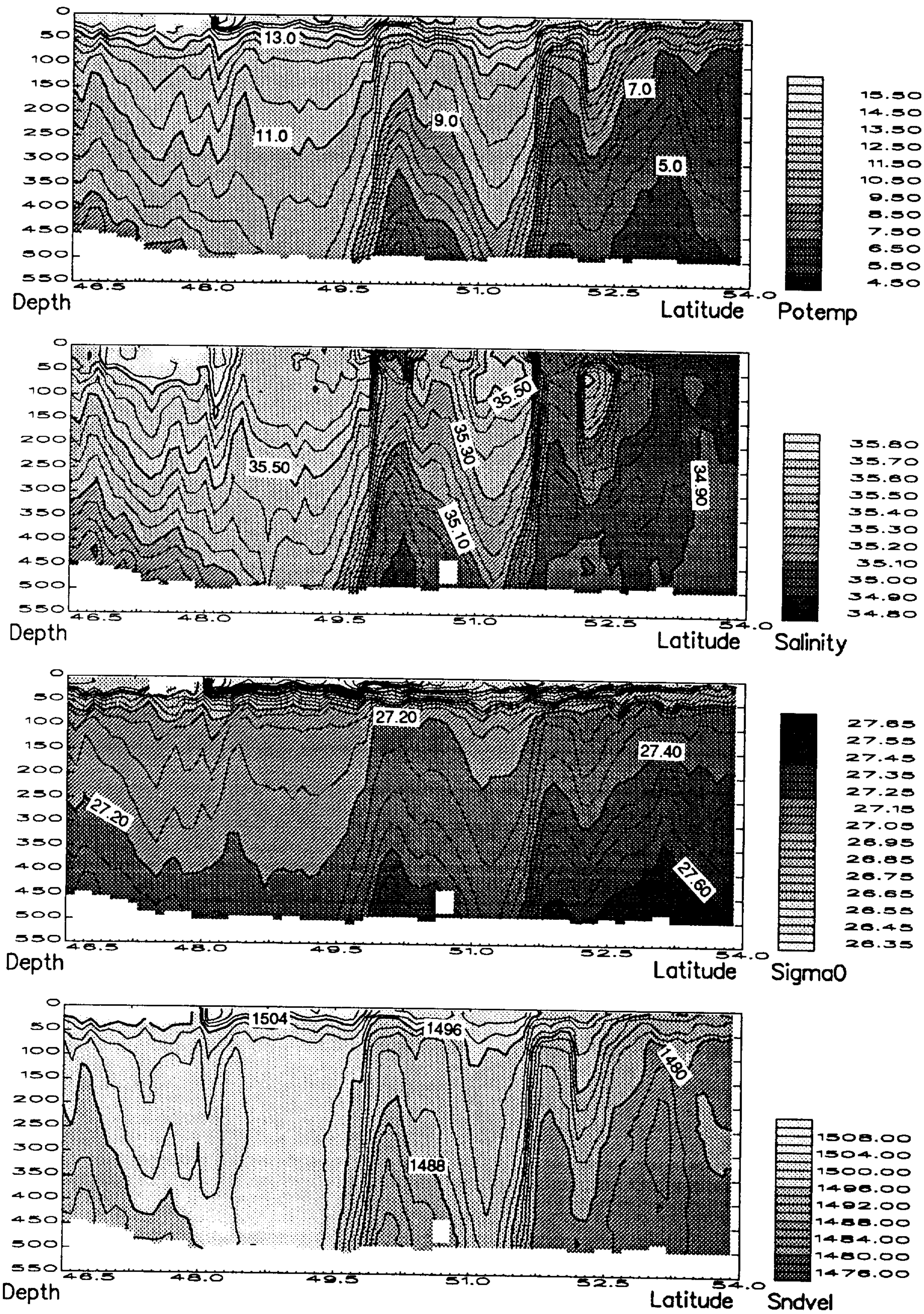


SeaSoar — Section W

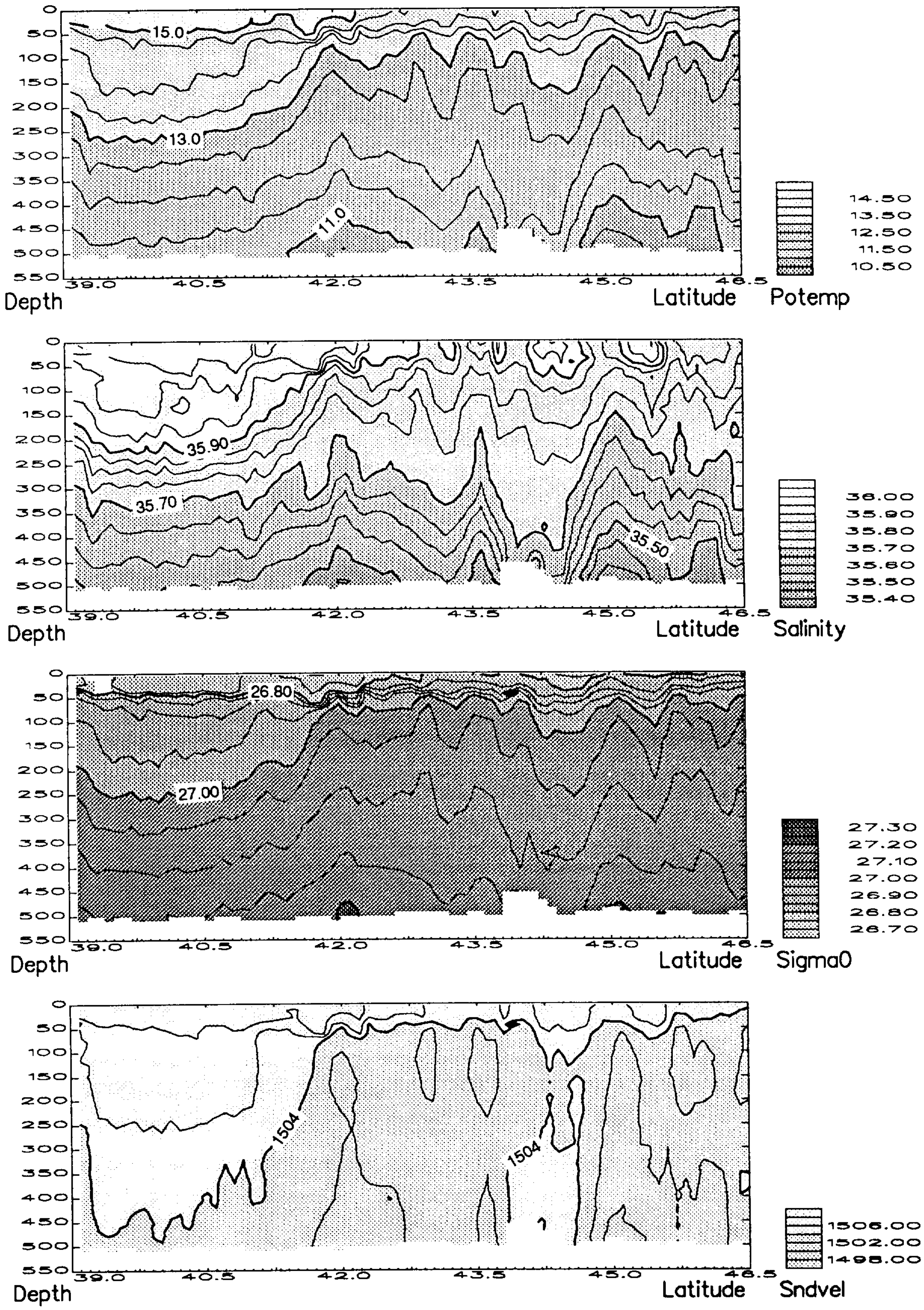


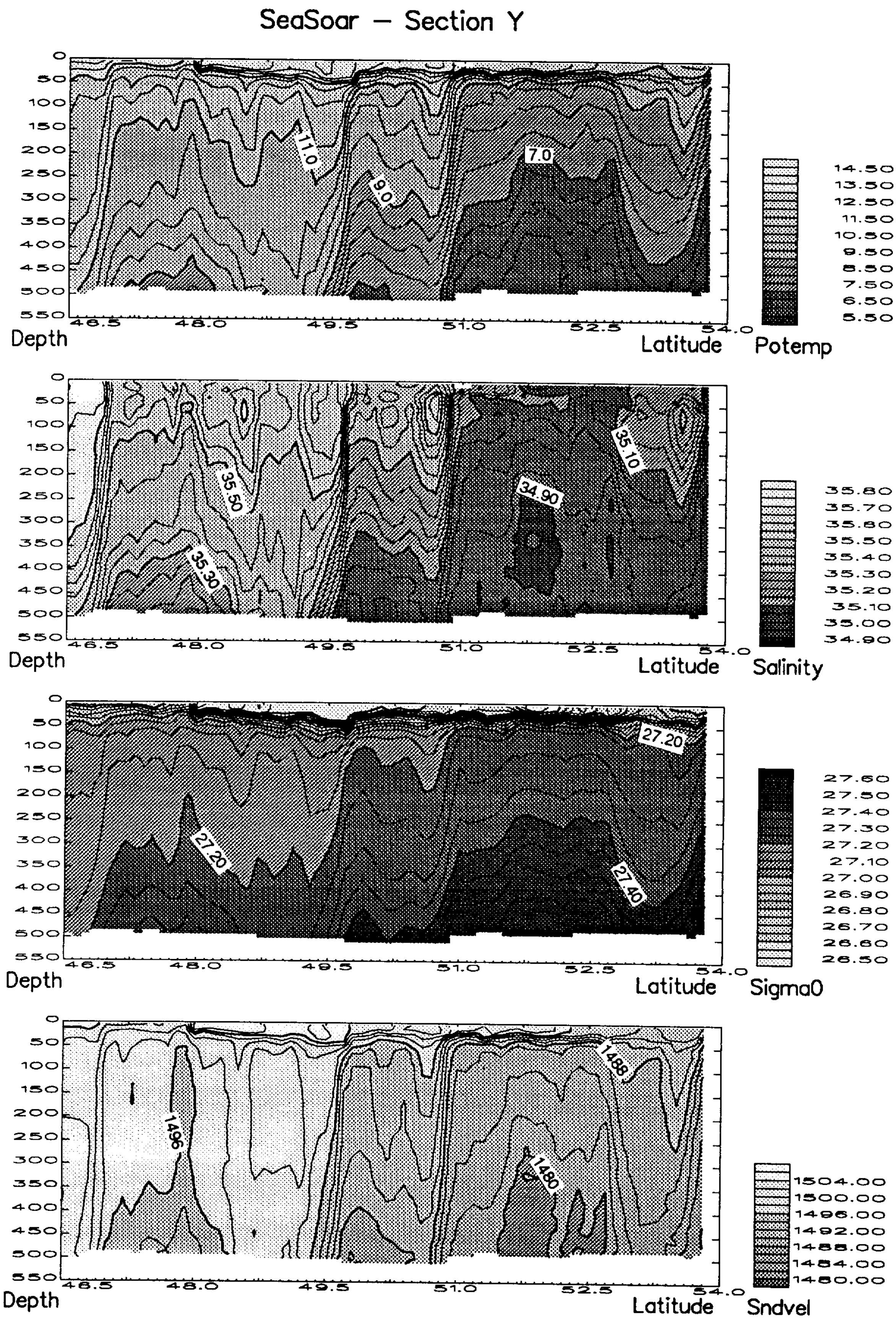

SeaSoar — Section X
15.0
11.0
13.0
Depth
Latitude
Potemp
16.50
15.50
14.50
13.50
12.50
11.50
10.50
9.50
8.50
35.90
35.70
35.30
35.70
Salinity
36.10
36.00
35.90
35.80
35.70
35.60
35.50
35.40
35.30
35.20
35.10
26.80
27.00
27.20
Sigma0
27.30
27.20
27.10
27.00
26.90
26.80
26.70
26.60
26.50
26.40
1512
1504
1496
Sndvel
1512.00
1508.00
1504.00
1500.00
1496.00
1492.00
0
50
100
150
200
250
300
350
400
450
500
550
39.0
40.5
42.0
43.5
45.0
46.5

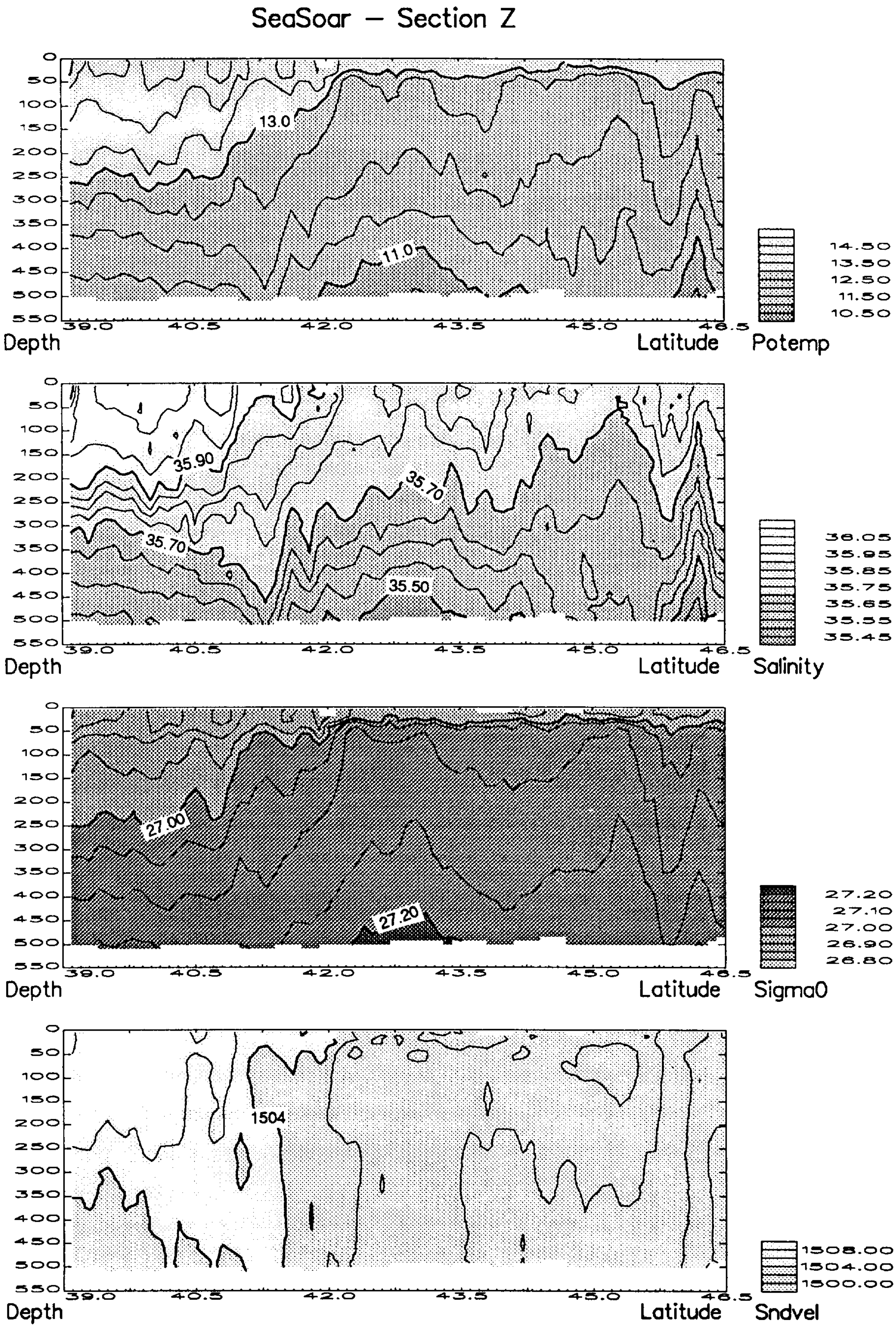
SeaSoar — Section X

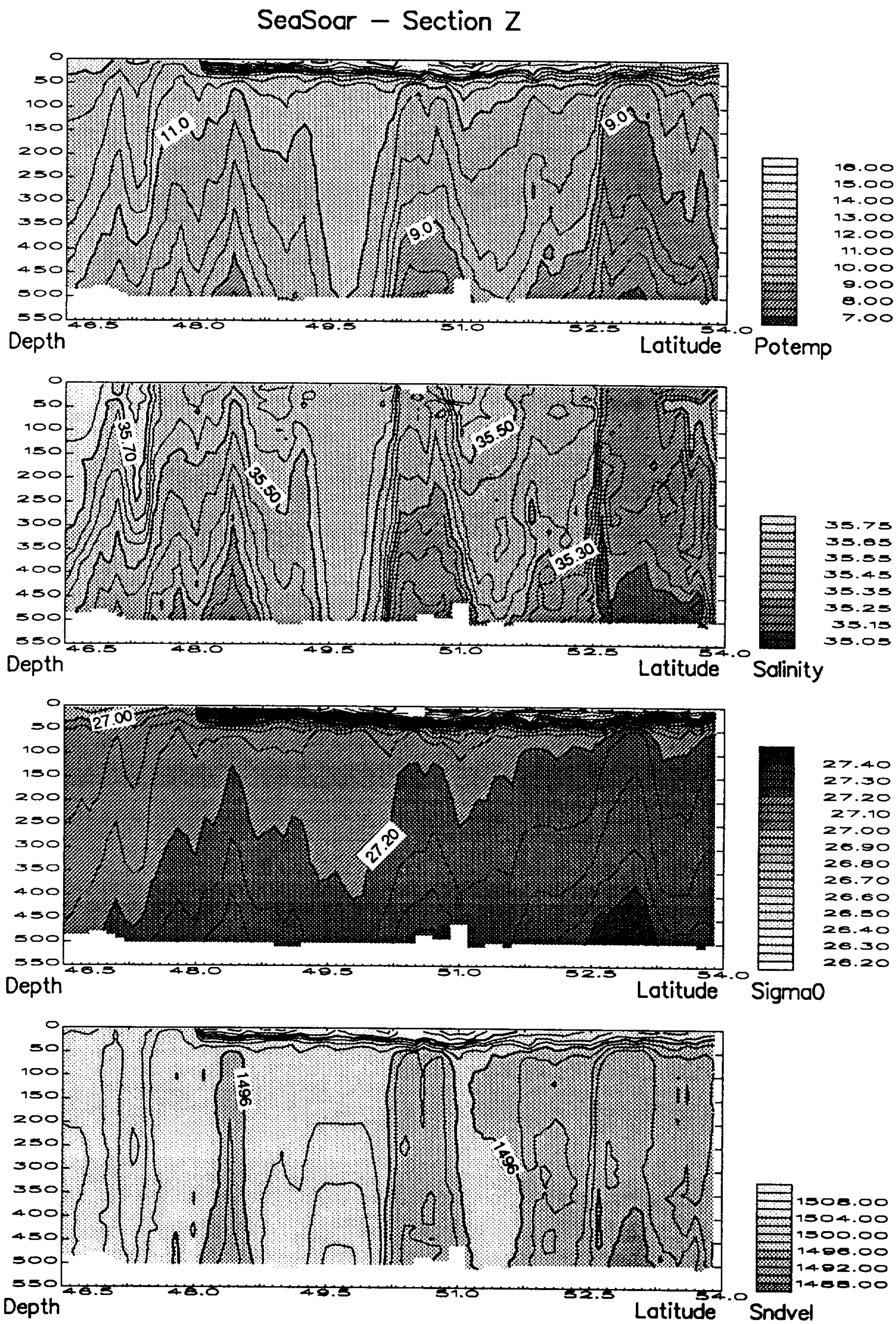


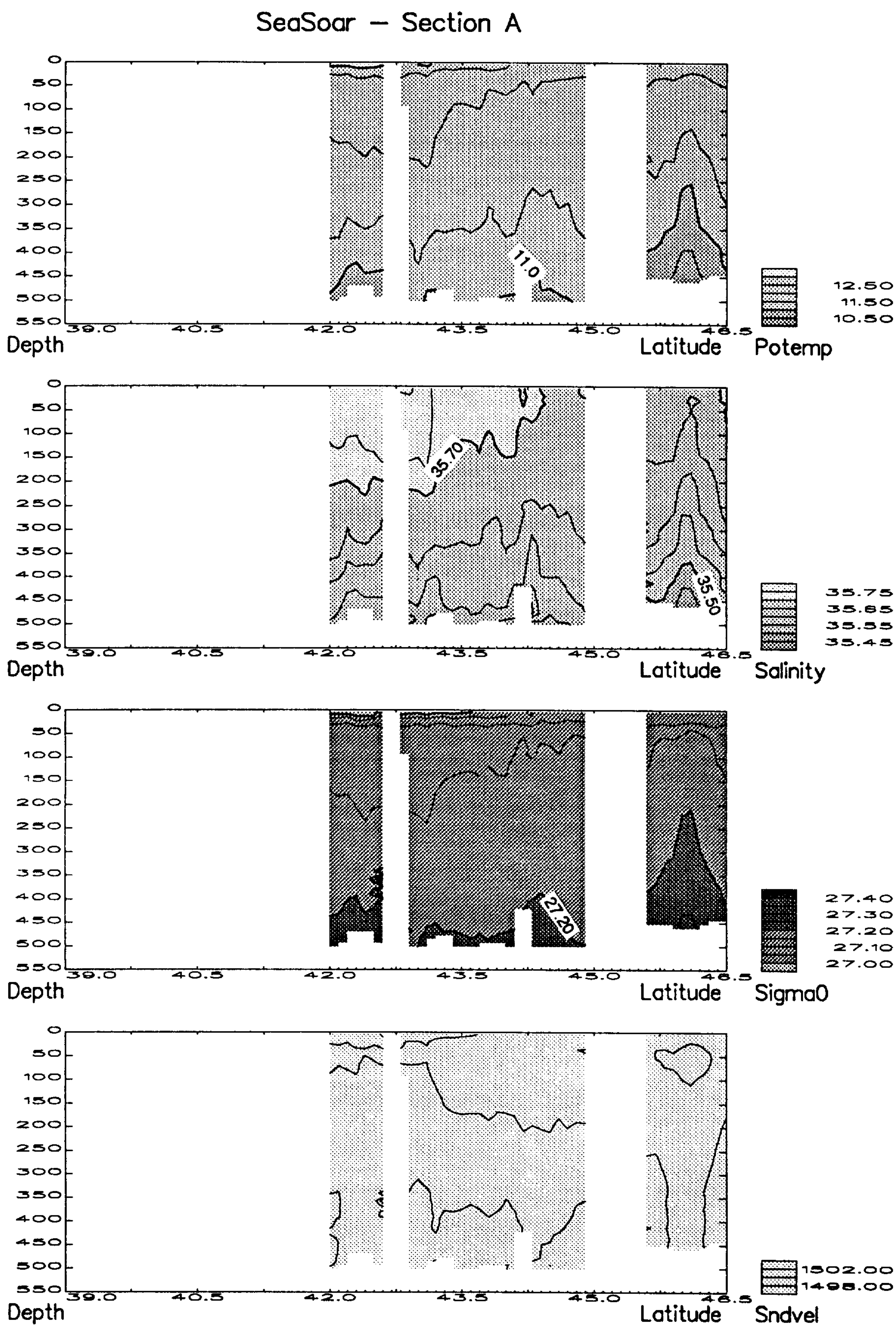
SeaSoar — Section Y



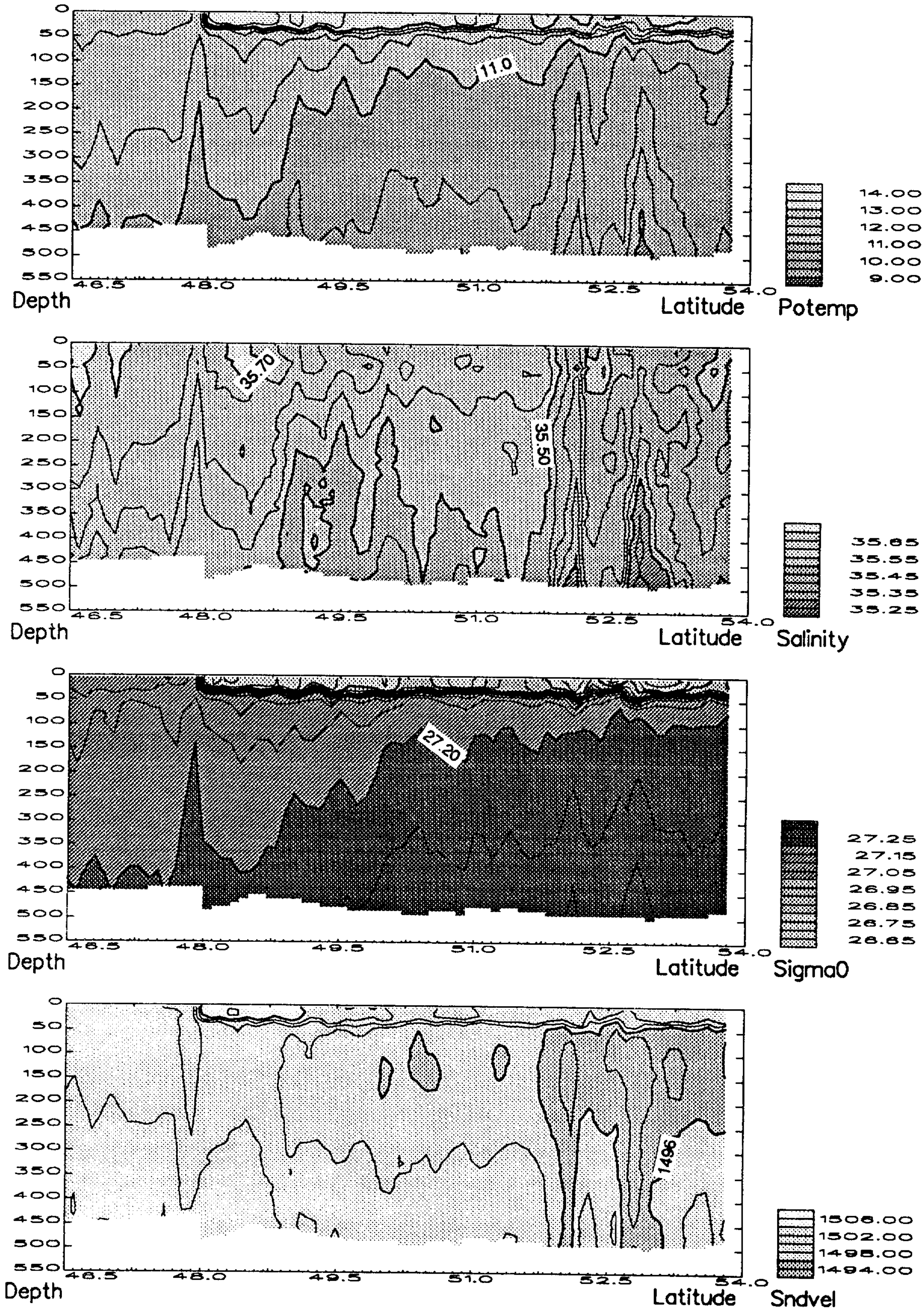

SeaSoar — Section Y
0
50
100
150
200
250
300
350
400
450
500
550
46.5
48.0
49.5
51.0
52.5
54.0
Depth
Latitude
11.0
9.0
7.0
14.50
13.50
12.50
11.50
10.50
9.50
8.50
7.50
6.50
5.50
Potemp
35.50
35.30
35.10
34.90
35.80
35.70
35.60
35.50
35.40
35.30
35.20
35.10
35.00
34.90
Salinity
27.20
27.20
27.40
27.60
27.50
27.40
27.30
27.20
27.10
27.00
26.90
26.80
26.70
26.60
26.50
Sigma0
1488
1496
1480
1504.00
1500.00
1496.00
1492.00
1488.00
1484.00
1480.00
Sndvel

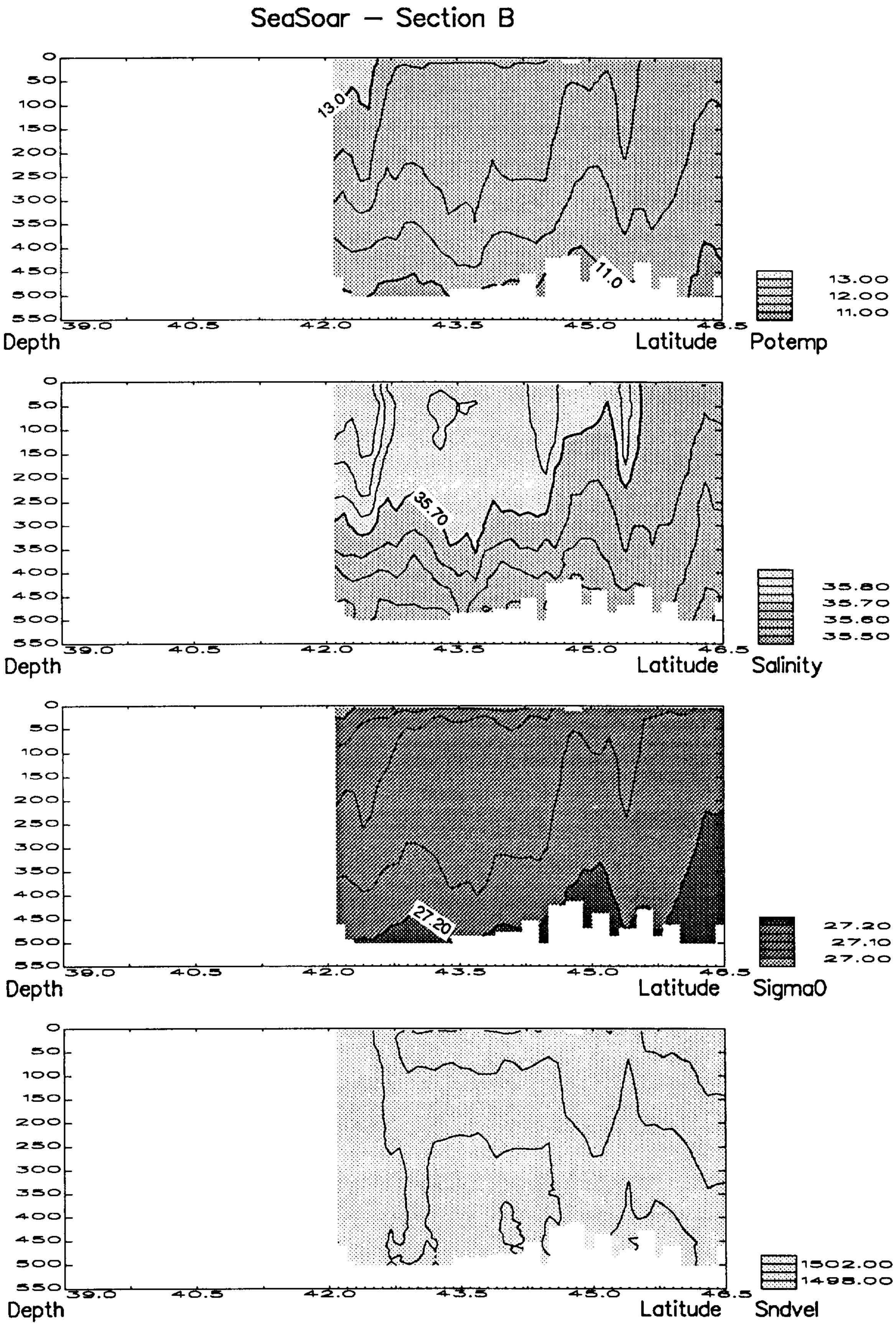

SeaSoar — Section Z
Depth
Latitude
Potemp
13.0
11.0
14.50
13.50
12.50
11.50
10.50
Salinity
35.90
35.70
35.50
36.05
35.95
35.85
35.75
35.65
35.55
35.45
Sigma0
27.00
27.20
27.20
27.10
27.00
26.90
26.80
Sndvel
1504
1508.00
1504.00
1500.00
0
50
100
150
200
250
300
350
400
450
500
550
39.0
40.5
42.0
43.5
45.0
46.5


SeaSoar — Section Z
Depth
Latitude
Potemp
Salinity
Sigma0
Sndvel
46.5
48.0
49.5
51.0
52.5
54.0
11.0
9.0
35.70
35.50
35.30
27.00
27.20
1496
16.00
15.00
14.00
13.00
12.00
11.00
10.00
9.00
8.00
7.00
35.75
35.65
35.55
35.45
35.35
35.25
35.15
35.05
27.40
27.30
27.20
27.10
27.00
26.90
26.80
26.70
26.60
26.50
26.40
26.30
26.20
1508.00
1504.00
1500.00
1496.00
1492.00
1488.00

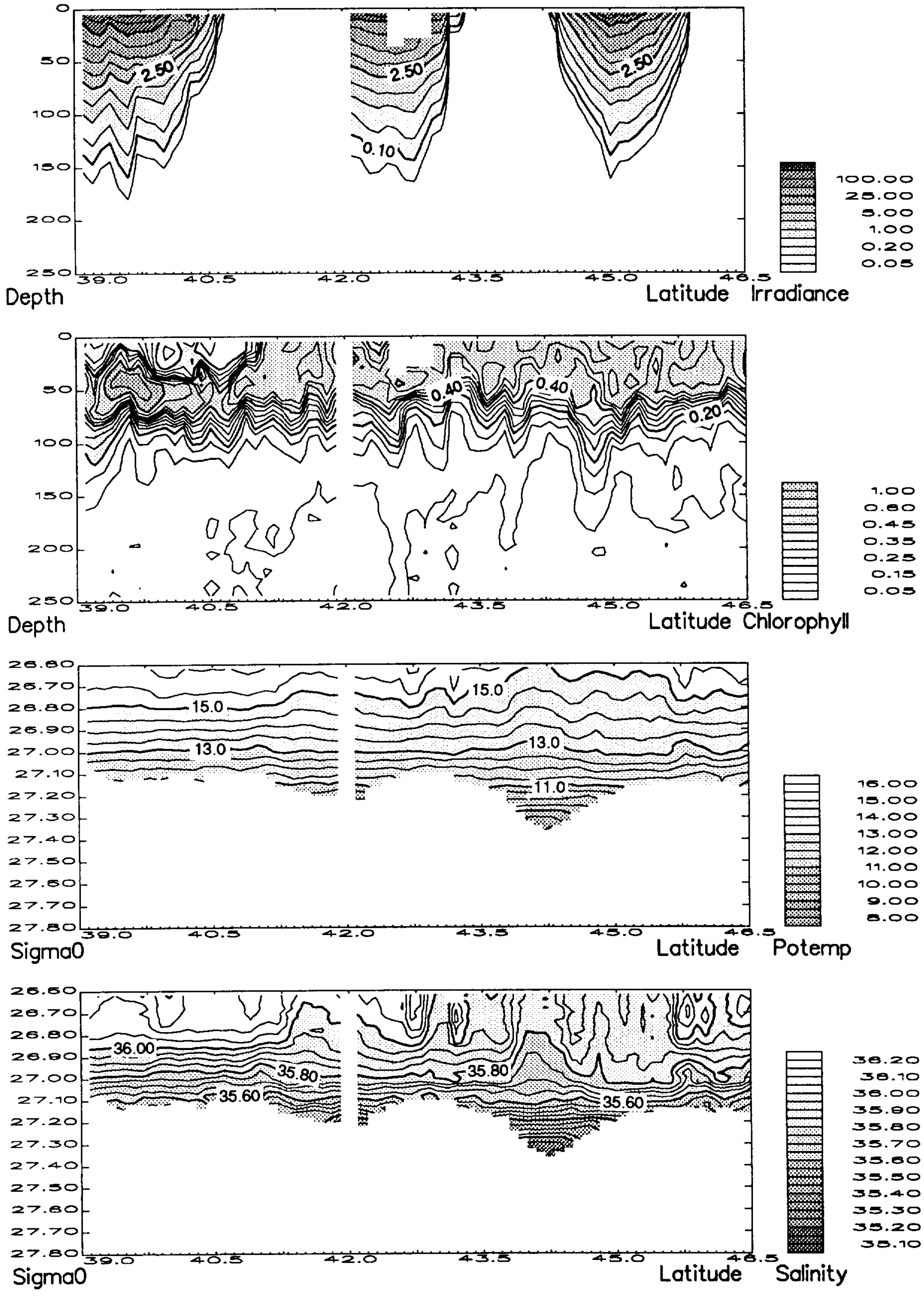

SeaSoar — Section A
Depth
Latitude
Potemp
12.50
11.50
10.50
11.0
Salinity
35.75
35.65
35.55
35.45
35.70
35.50
Sigma0
27.40
27.30
27.20
27.10
27.00
27.20
Sndvel
1502.00
1498.00
0
50
100
150
200
250
300
350
400
450
500
550
39.0
40.5
42.0
43.5
45.0
46.5

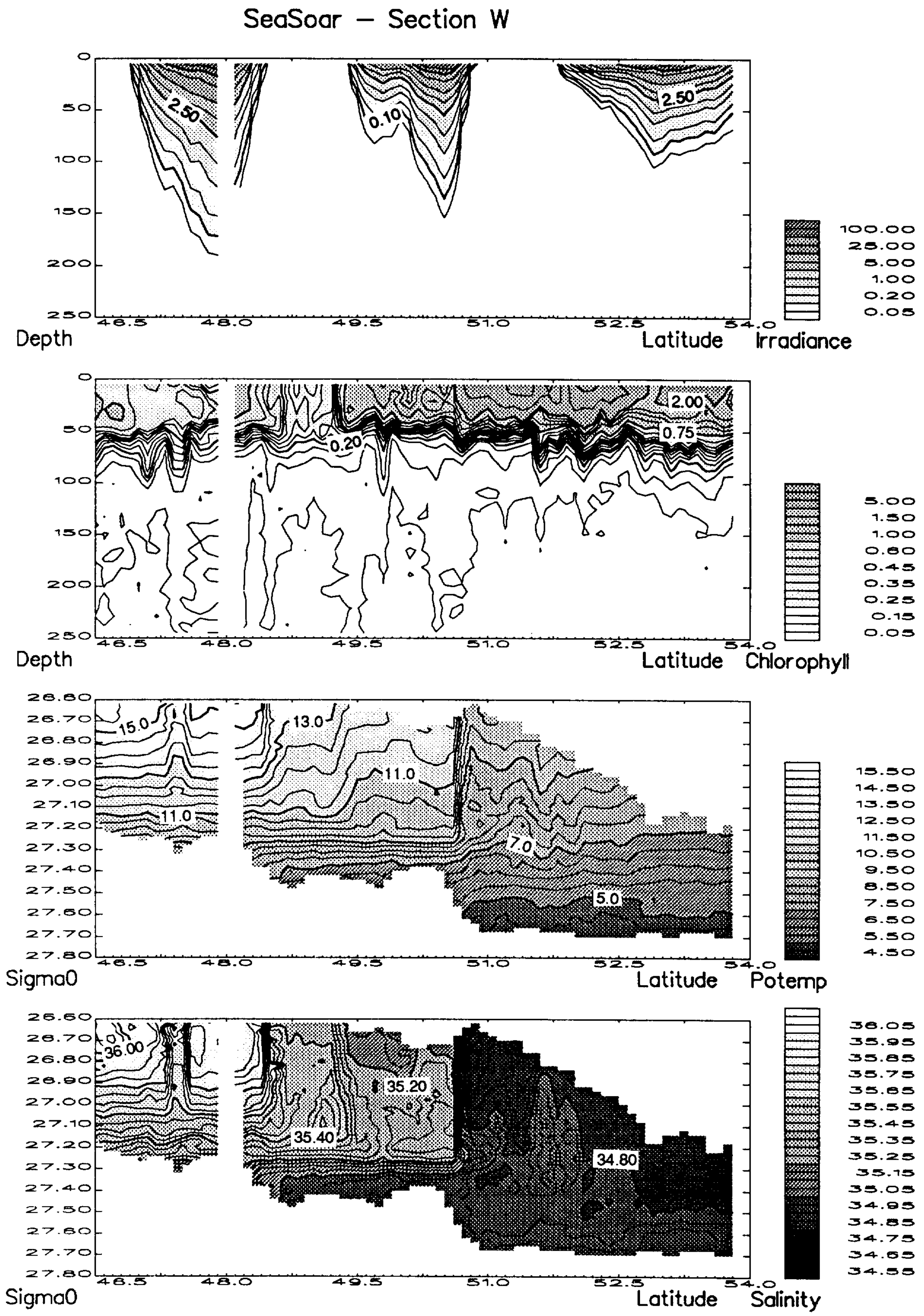
SeaSoar — Section A



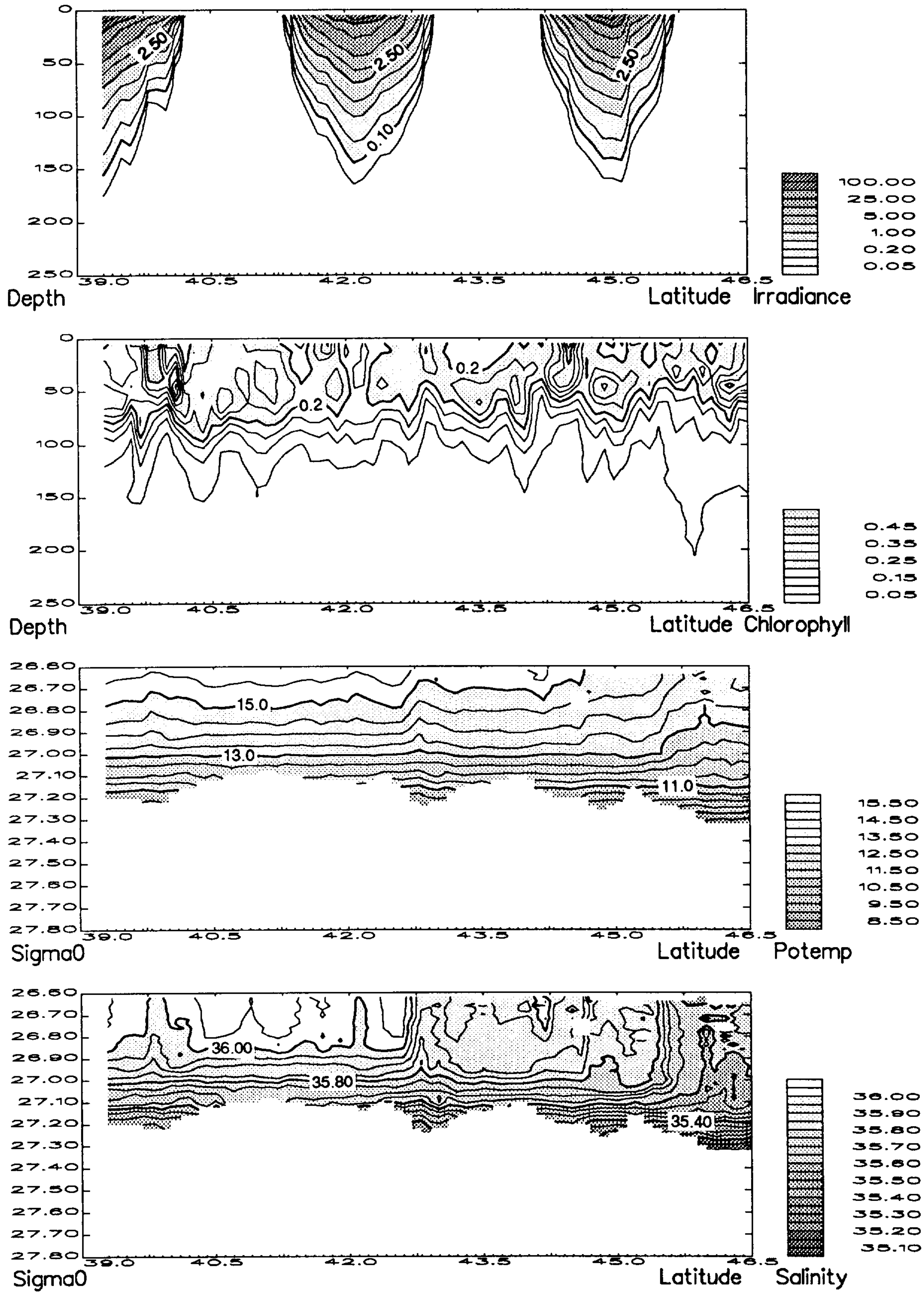

SeaSoar — Section B
Depth
Latitude
Potemp
13.00
12.00
11.00
13.0
11.0
Salinity
35.80
35.70
35.60
35.50
35.70
Sigma0
27.20
27.10
27.00
27.20
Sndvel
1502.00
1498.00

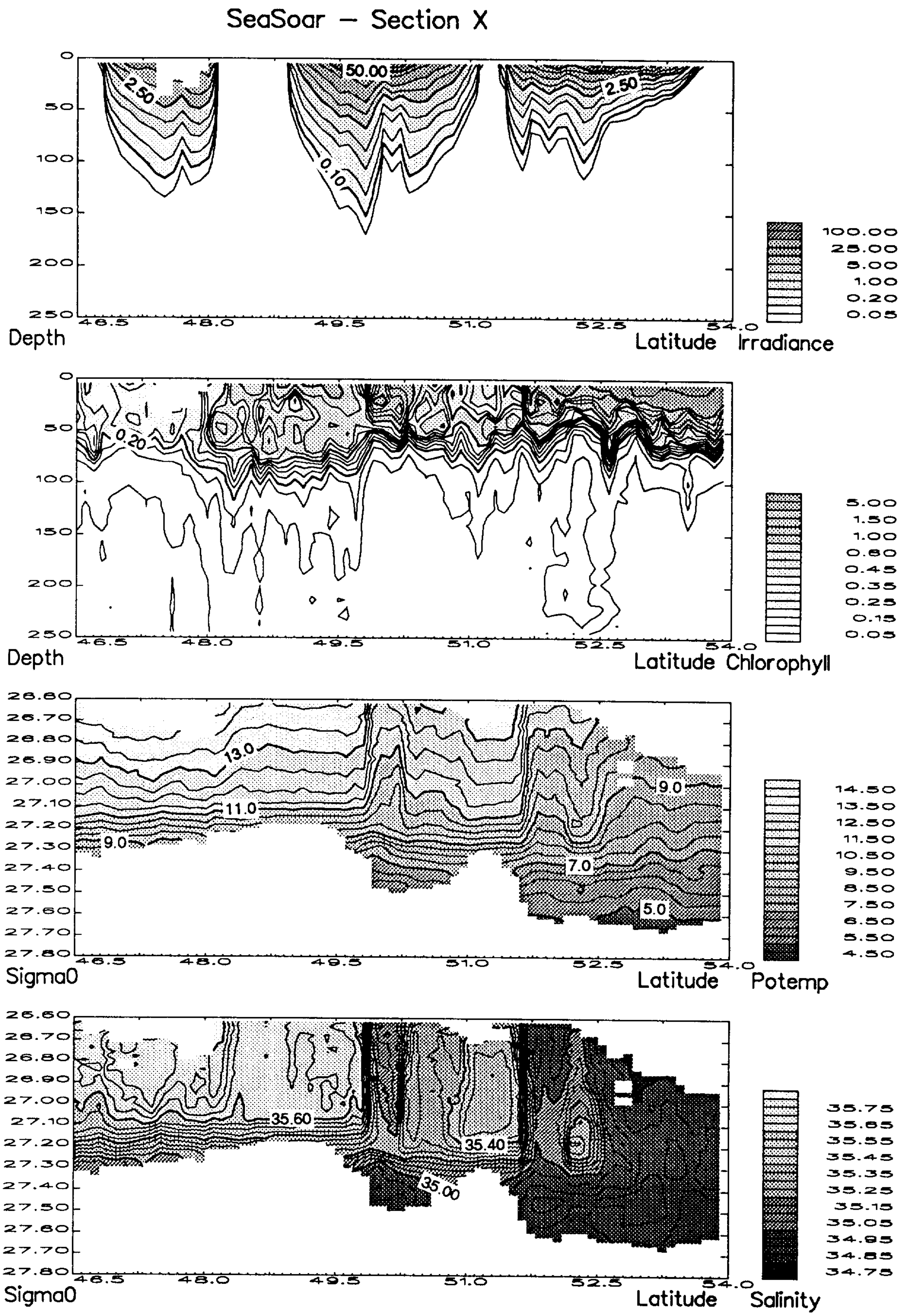
SeaSoar – Section W

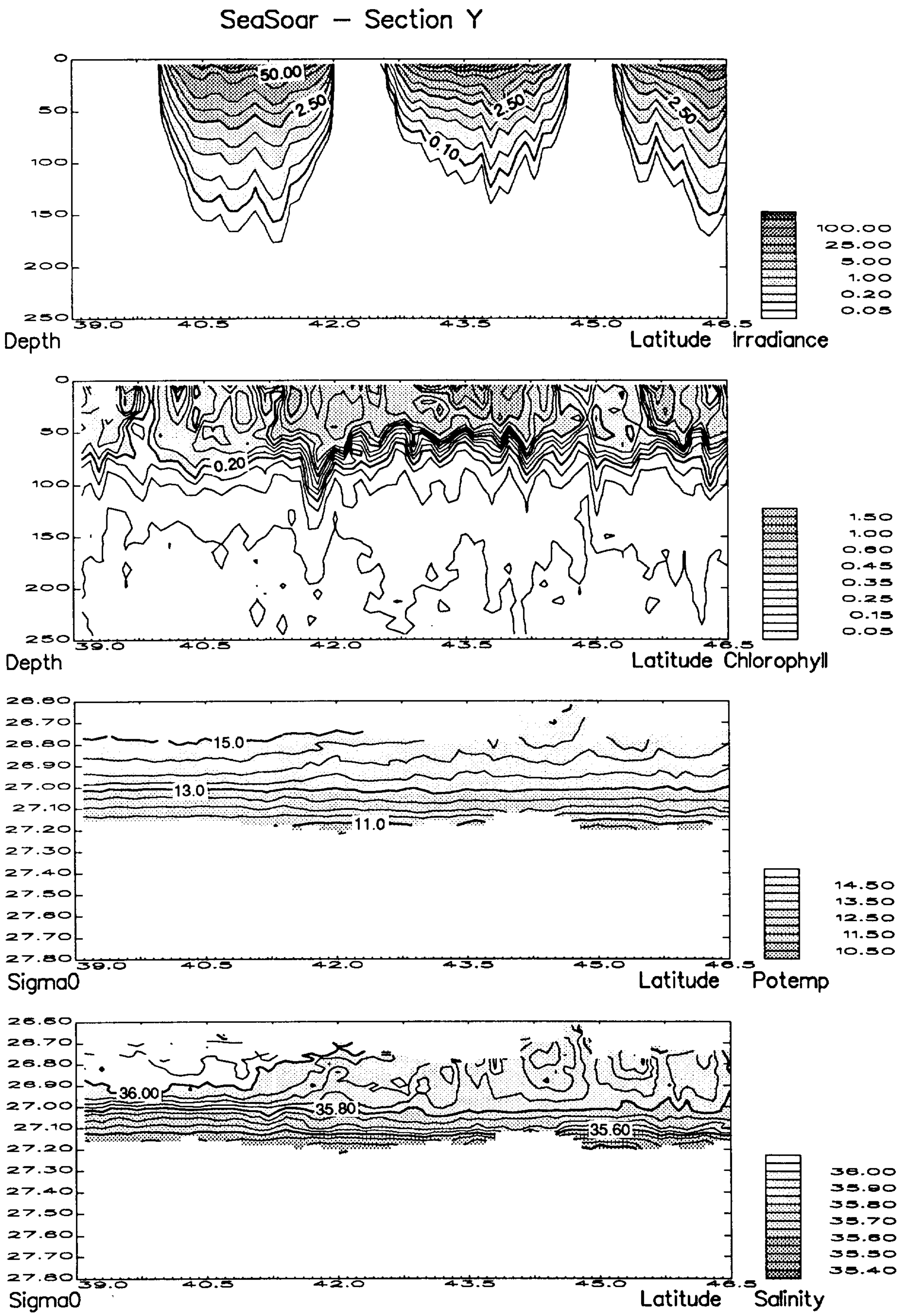



SeaSoar — Section W
Depth
Latitude
Irradiance
100.00
25.00
5.00
1.00
0.20
0.05
Chlorophyll
5.00
1.50
1.00
0.60
0.45
0.35
0.25
0.15
0.05
Sigma0
Potemp
15.50
14.50
13.50
12.50
11.50
10.50
9.50
8.50
7.50
6.50
5.50
4.50
Salinity
36.05
35.95
35.85
35.75
35.65
35.55
35.45
35.35
35.25
35.15
35.05
34.95
34.85
34.75
34.65
34.55

SeaSoar — Section X




SeaSoar — Section X
Depth
Latitude
Irradiance
100.00
25.00
5.00
1.00
0.20
0.05
50.00
2.50
0.10
Chlorophyll
5.00
1.50
1.00
0.60
0.45
0.35
0.25
0.15
0.05
0.20
Sigma0
Potemp
14.50
13.50
12.50
11.50
10.50
9.50
8.50
7.50
6.50
5.50
4.50
13.0
11.0
9.0
7.0
5.0
Salinity
35.75
35.65
35.55
35.45
35.35
35.25
35.15
35.05
34.95
34.85
34.75
35.60
35.40
35.00
46.5
48.0
49.5
51.0
52.5
54.0


SeaSoar — Section Y
Depth
Latitude
Irradiance
100.00
25.00
5.00
1.00
0.20
0.05
50.00
2.50
0.10
Chlorophyll
1.50
1.00
0.60
0.45
0.35
0.25
0.15
0.05
0.20
Sigma0
Potemp
14.50
13.50
12.50
11.50
10.50
15.0
13.0
11.0
Salinity
36.00
35.90
35.80
35.70
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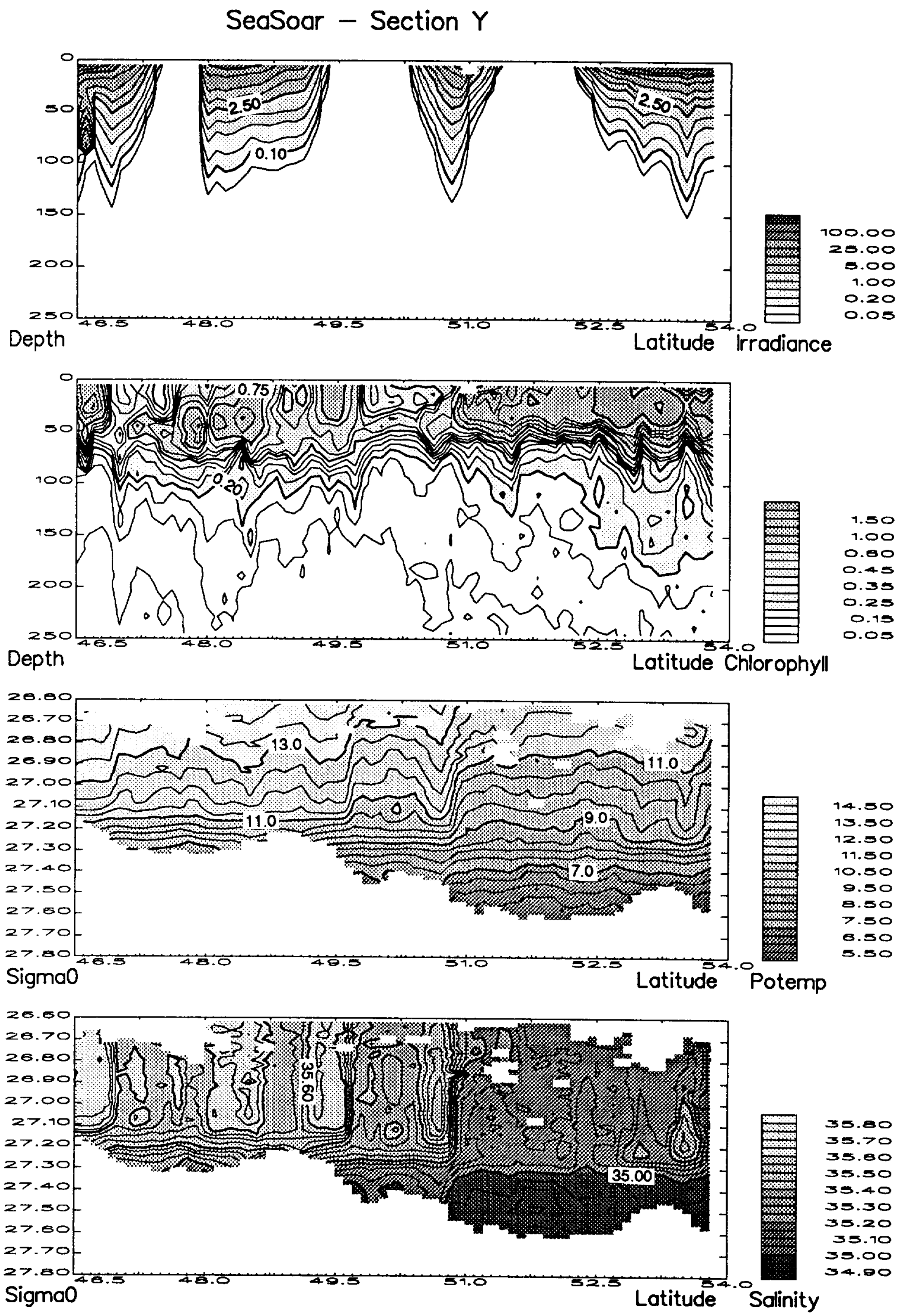
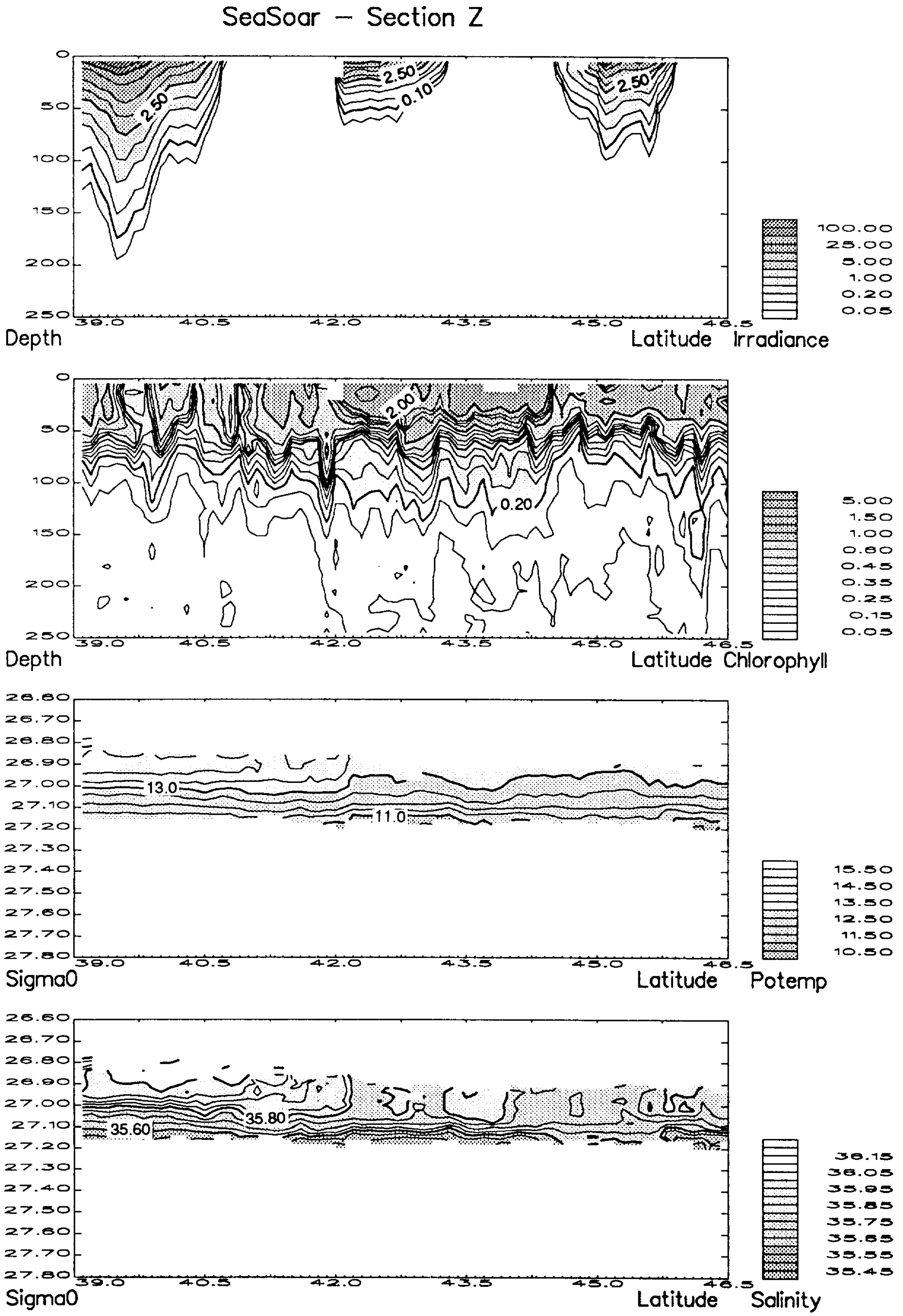
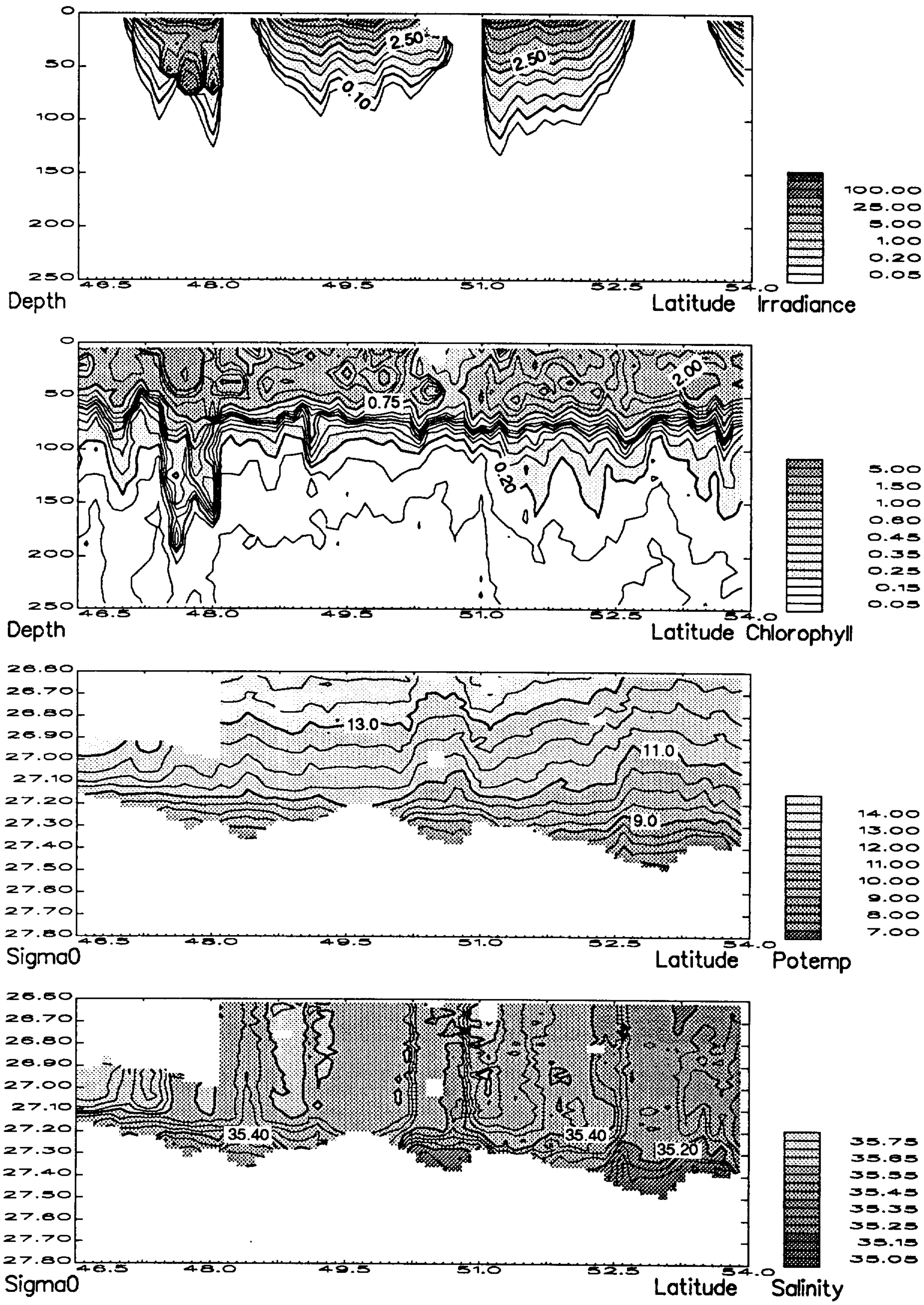
43.5
45.0
46.5

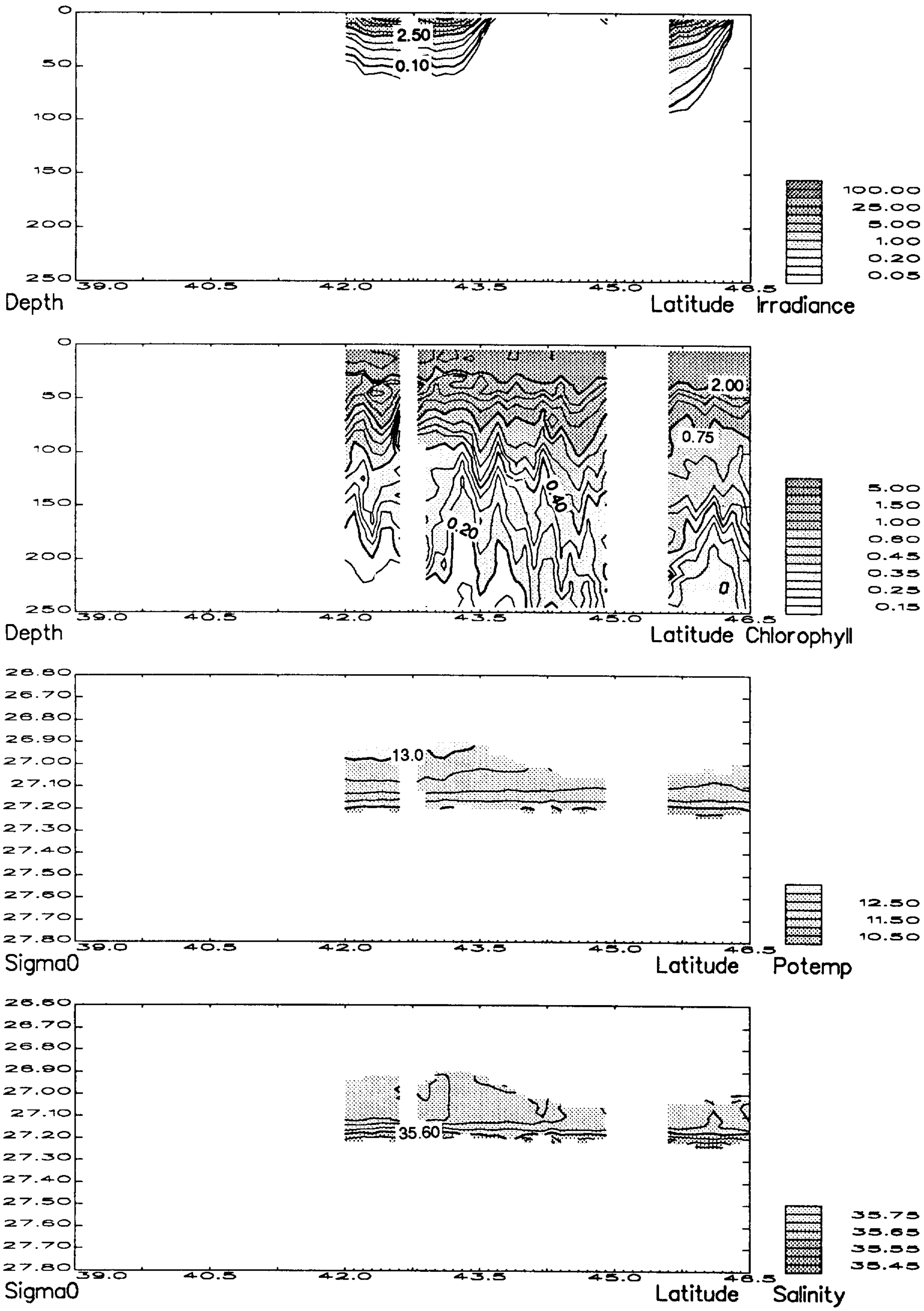

SeaSoar – Section Y
Depth
Latitude
Irradiance
100.00
25.00
5.00
1.00
0.20
0.05
2.50
0.10
Depth
Latitude
Chlorophyll
1.50
1.00
0.60
0.45
0.35
0.25
0.15
0.05
0.75
0.20
Sigma0
Latitude
Potemp
14.50
13.50
12.50
11.50
10.50
9.50
8.50
7.50
6.50
5.50
13.0
11.0
9.0
7.0
Sigma0
Latitude
Salinity
35.80
35.70
35.60
35.50
35.40
35.30
35.20
35.10
35.00
34.90
35.60
35.00

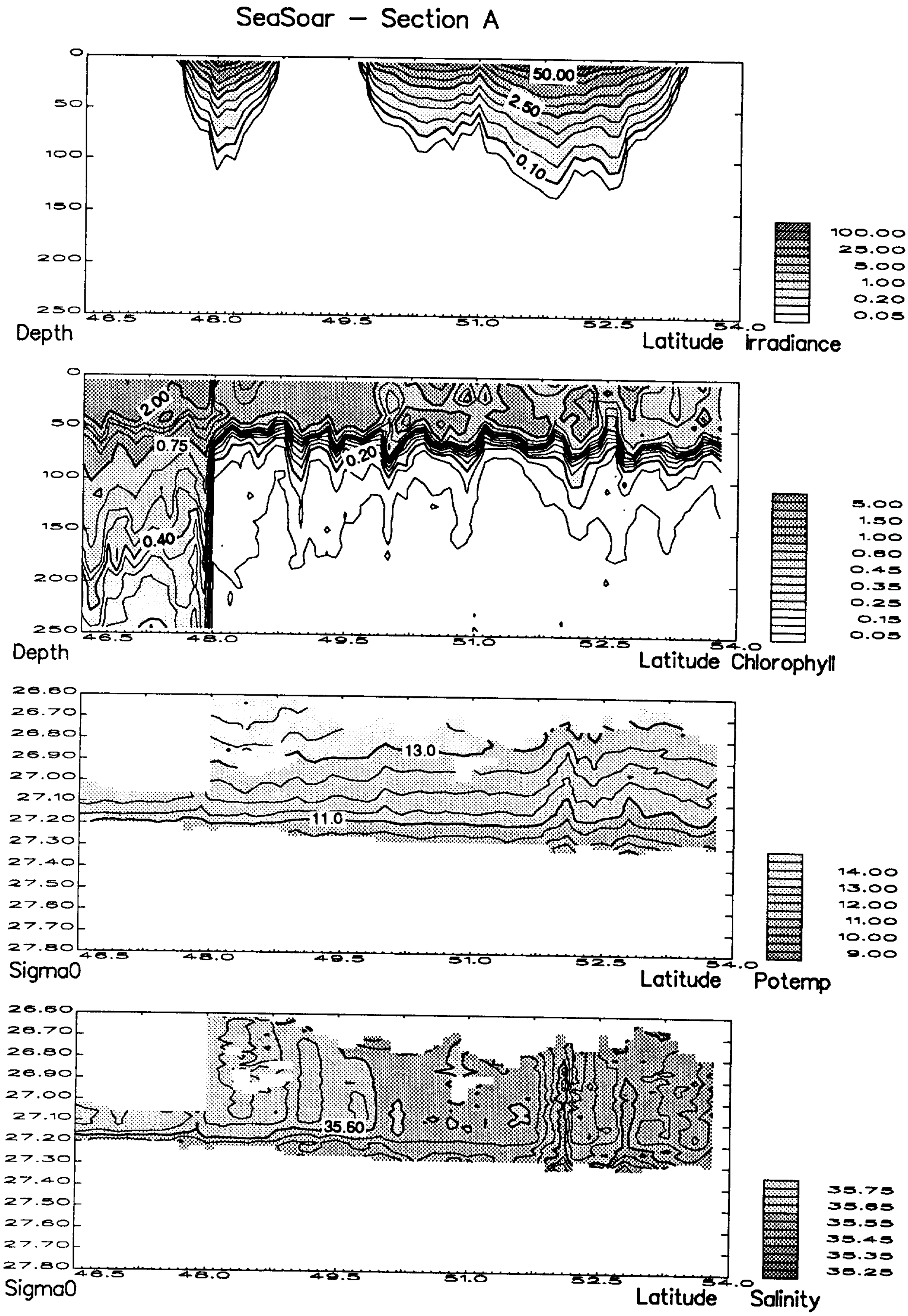

SeaSoar – Section Z
Depth
Latitude
Irradiance
100.00
25.00
5.00
1.00
0.20
0.05
2.50
0.10
Chlorophyll
5.00
1.50
1.00
0.60
0.45
0.35
0.25
0.15
0.05
2.00
0.20
Sigma0
Potemp
15.50
14.50
13.50
12.50
11.50
10.50
13.0
11.0
Salinity
36.15
36.05
35.95
35.85
35.75
35.65
35.55
35.45
35.60
35.80
39.0
40.5
42.0
43.5
45.0
46.5

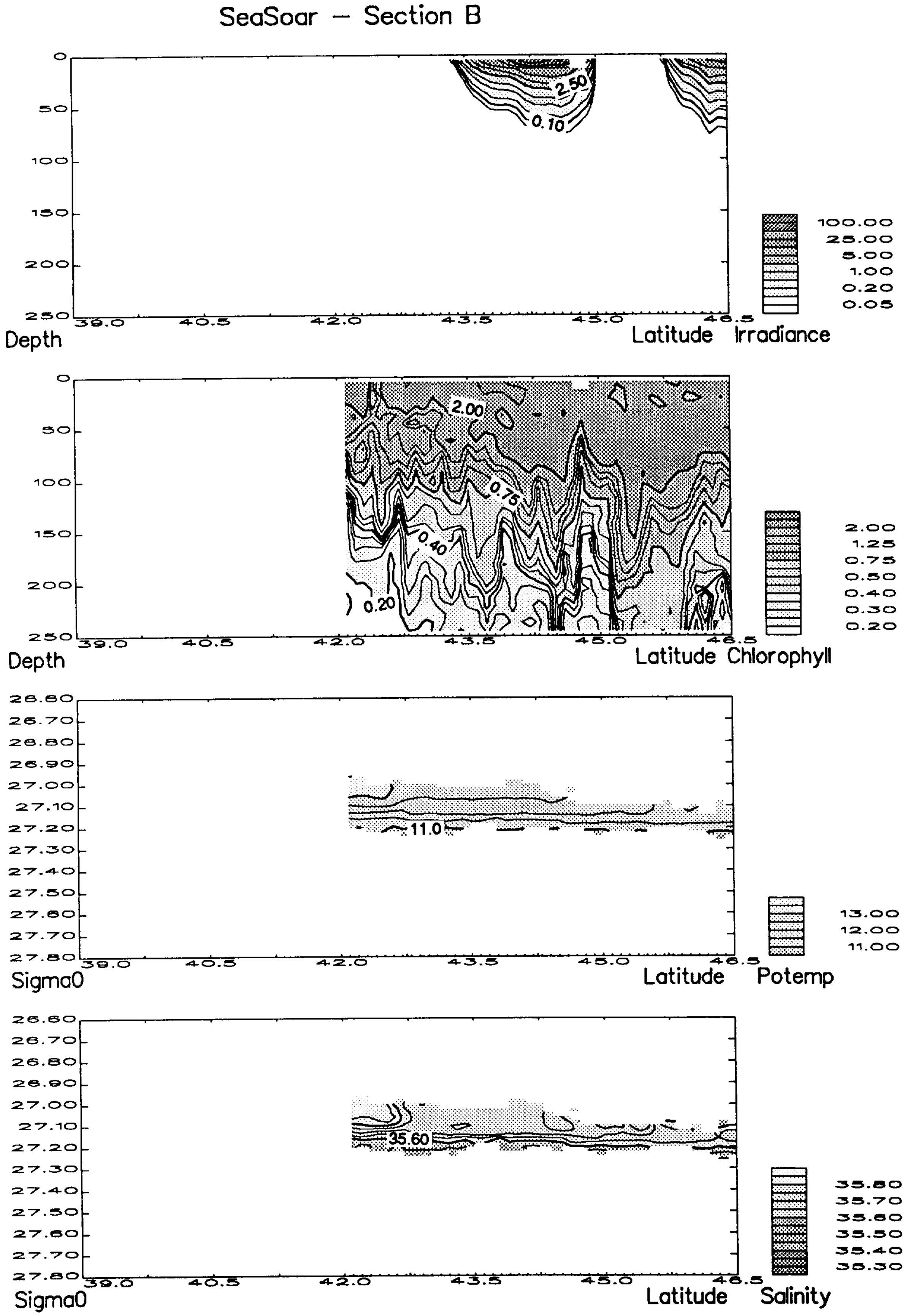
SeaSoar — Section Z



SeaSoar – Section A




SeaSoar — Section A
Depth
Latitude
Irradiance
50.00
2.50
0.10
100.00
25.00
5.00
1.00
0.20
0.05
Chlorophyll
2.00
0.75
0.20
0.40
5.00
1.50
1.00
0.60
0.45
0.35
0.25
0.15
0.05
Sigma0
Potemp
13.0
11.0
14.00
13.00
12.00
11.00
10.00
9.00
Salinity
35.60
35.75
35.65
35.55
35.45
35.35
35.25


SeaSoar — Section B
2.50
0.10
100.00
25.00
5.00
1.00
0.20
0.05
Depth
Latitude
Irradiance
2.00
0.75
0.40
0.20
2.00
1.25
0.75
0.50
0.40
0.30
0.20
Depth
Latitude
Chlorophyll
11.0
13.00
12.00
11.00
Sigma0
Latitude
Potemp
35.60
35.80
35.70
35.60
35.50
35.40
35.30
Sigma0
Latitude
Salinity