Institute of Oceanographic Sciences
Deacon Laboratory

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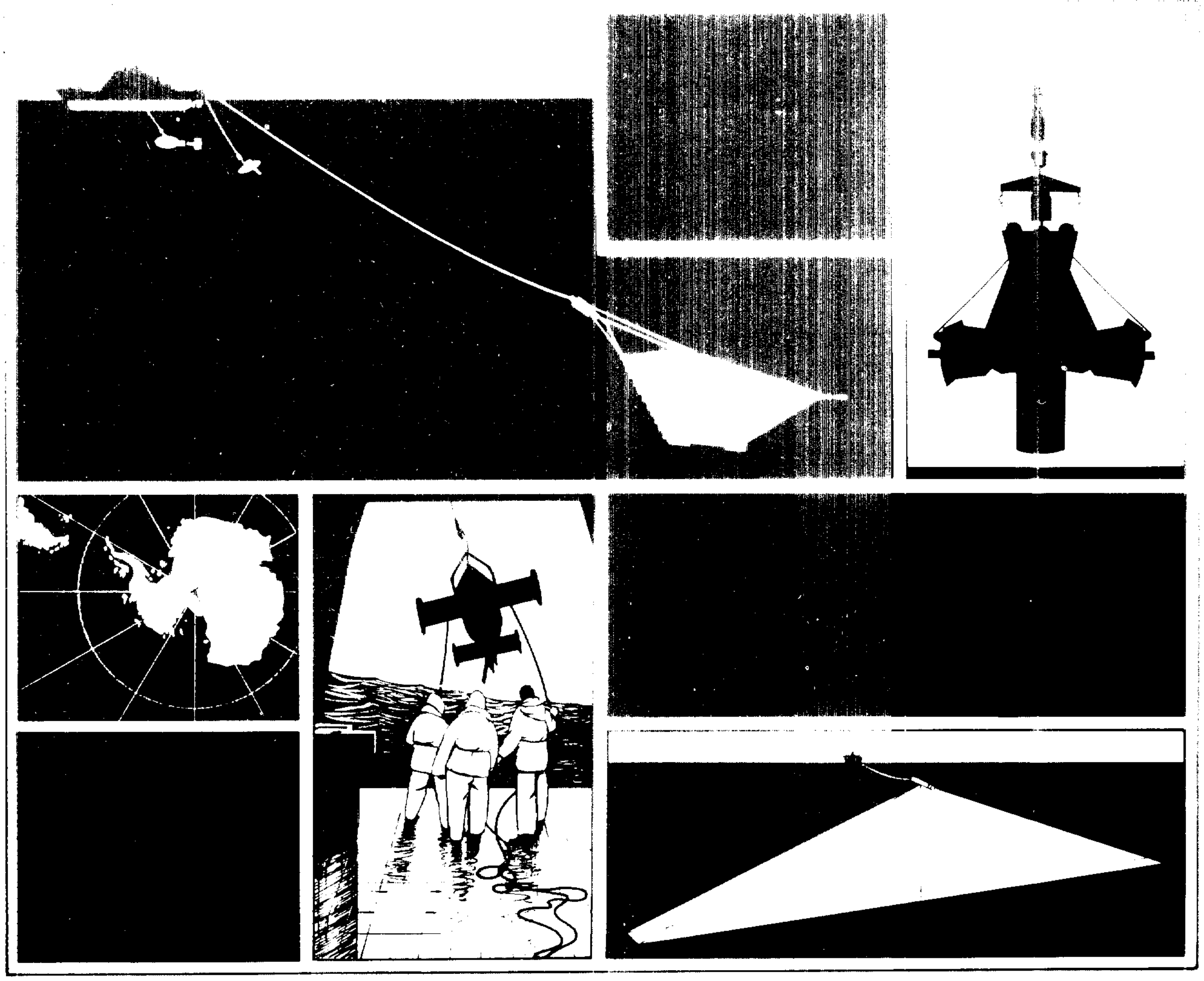
Report No 289 1991



Natural Environment Research Council

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ABSTRACT

During Cruise 189 of RRS Discovery (9 March - 8 April 1990) SeaSoar CTD data, including fluorometer data, were collected in the north east Atlantic Ocean. Four major sections were worked inside a box, 43-52°N, 17-8°W, to study variations in the θ/S relationship of newly ventilated mode water. The sections follow closely the track of RRS Discovery Cruise 181, covered 12 months earlier. Calibration and processing of the data are described in this report, and the data are presented in the form of contour plots of potential temperature, salinity, potential density and fluorescence.

KEYWORDS
ATLANTIC OCEAN
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FLUORESCENCE
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POTENTIAL TEMPERATURE
SALINITY
SEASOAR

ISSUING ORGANISATION

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INTRODUCTION

RRS Discovery Cruise 189 sailed from Cardiff on Friday 9 March, 1990, and arrived in Barry on Sunday 8 April. Further details, as well as individual project reports, are given in the Cruise Report (King et al. 1991a). The cruise consisted of two periods during which CTD stations were worked, punctuated by approximately eight days of SeaSoaring. Data from 59 CTD stations are reported by King et al. (1991b), with SeaSoar data being the subject of the present report. Cruise 189 was the second of a pair of cruises to the same region, and the ship track followed closely that of Cruise 181 (Pollard et al., 1989) in April 1989. The first three sections, defined below, were exact repeats of Cruise 181 sections; the fourth was modified slightly because of time constraints. SeaSoar data from Cruise 181 are reported by Read et al. (1991).

Figure 1 shows a ship track for the Cruise. The portion of the track shown with a thicker line is the part for which SeaSoar data were collected, and for which data are shown in this report. A number of SeaSoar trials were carried out earlier in the cruise, but the data are not reported here. These trials are listed as runs 1-5 in Table 1.

Unfortunately, the shipboard Acoustic Doppler Current Profiler (ADCP) failed early in the cruise, so no ADCP data are available.

DATA COLLECTION

Data were collected from a Neil Brown Mk III CTD, deployed in the IOSDL SeaSoar vehicle. The vehicle cycled between the surface and approximately 350m, the depth reached depending mainly on towing speed and sea state. The different SeaSoar deployments are listed in Table 1, with the sections occupied shown in Table 2. The sections are designated 17W, 15W, 12W and 9W, according to the approximate longitude at the midpoint of the section. The 9W section was occupied in two parts; shortage of time towards the end of the cruise meant that after a SeaSoar vehicle failure, we could not afford the luxury of waiting around for repairs. Two full depth CTD stations were worked on 8°25'W before the SeaSoar section was completed.

DATA PROCESSING AND CALIBRATION

Sampling

CTD data were passed from the CTD deck unit to a 'Level A' interface, and then to a SUN workstation for processing using the PSTAR suite of data processing programs. The CTD data were sampled at 8Hz, and reduced to one-second averages by the Level A; additionally, the data were backed up at the deck unit by logging the raw 8Hz data directly onto 9-track tape. However, the Level A data capture worked perfectly and back-up data were not used.

Past experience has shown that CTD oxygen data collected on the SeaSoar are not satisfactory. Accordingly, no oxygen sensor was deployed.

The SeaSoar was fitted with a fluorometer, interfaced with the CTD.

Initial calibration

Programme CTDCAL was used to provide initial calibration of pressure, temperature, conductivity and fluorescence, and to compute salinity. The following were used:

$$P_{cal} \text{ (dbar)} = 0.999898 * (0.01 * P_{raw}) - 0.5$$

$$T_{cal} \text{ (°C)} = 0.9990762 * (0.0005 * T_{raw}) - 0.009374$$

$$C_{cal} \text{ (mmho/cm)} = 1.00527 * (0.001 * C_{raw})$$

$$\text{Chla (mg/m}^3) = \exp (4.14 * (0.001 * \text{Fluor}_{raw}) - 3.17)$$

The pressure offset was chosen as the observed deck offset, and the temperature calibration was from the most recent laboratory calibration (9 February 1990). Prior to the start of SeaSoar work, the CTD was lowered from the midships winch to 600m, and samples collected in Niskin Bottles for salinity calibration. This provided the initial cell conductivity ratio. The initial fluorometer calibration was taken from a previous cruise.

Salinity was calculated from the 1983 equations of state, after speeding up the response of the platinum thermometer with a time constant of 0.23 seconds. The time constant was chosen from early SeaSoar data by overplotting down and up θ-S curves and adjusting the time constant to minimise hysteresis between them.

Temperatures are calibrated to the ITS-90 scale (Saunders, 1990). For the purpose of computing derived oceanographic variables, temperatures were first converted to the 1968 scale, using

$$T_{68} = 1.00024\ T_{90}$$

as suggested by Saunders, and the usual algorithms were then used.

Editing

SeaSoar data were assembled into files of four hours duration for calibration, initial plotting and editing. Hardcopy profile plots of all parameters, also θ-S curves, were routinely produced, and examined for data errors.

The simplest kind of errors to eliminate were data spikes, which could be identified from the plots and removed from the 4-hour data files.

More subtle errors arise when the conductivity cell is fouled, giving rise to offset (low) salinity values; typical offsets are of order 0.01 to 0.05. Most of these can be identified by careful examination of θ-S curves, and one of two remedies taken. Often, there is a clear indication of both fouling and recovery, in which case a constant offset may be added to bring the θ-S curves in line with surrounding profiles. Otherwise, for example if recovery has been gradual, or at a poorly defined time in a region of strong vertical gradients of properties, suspect sections of data have to be discarded. Further details are given by Pollard et al. (1987). This procedure maintains **relative** salinity calibration over periods of several hours. **Absolute** calibration is described below.

Gridding

For each 12 hours, the edited four-hourly files are appended, merged with navigation, gridded and contoured. Details of this procedure are given by Pollard et al. (1987). The gridding consists of assigning data to bins 8db deep and 4km along track, followed by averaging of all data in a bin. Usually, bins contain 15 or more one-second averages. Potential density (gamma0) and dynamic height are computed for the gridded files; these files are then regridded with potential density as the vertical coordinate. Navigation is by GPS (at least 16 hours per day) and transit satellite.

Final salinity calibration

On recent IOSDL SeaSoar cruises, and initially for this cruise, final salinity calibration was achieved following the technique of Pollard et al. (1987); this procedure was completed before reaching Barry. Samples were drawn from the ship's non-toxic seawater supply once per hour (155 samples were used for the final calibration) and analysed using a Guildline Autosal. The salinity value from the corresponding near-surface bin of gridded SeaSoar data was extracted and a comparison undertaken. The resulting file of differences was fitted by eye with a piecewise constant function of time, which was then merged with gridded SeaSoar data to produce corrected salinities. The correction varied from -0.03 at the start of the cruise to -0.06 at the end. The residuals of bottle-SeaSoar salinities, after this correction procedure, had the following statistics: 75% of residuals had magnitude no greater than 0.005, and 92% no greater than 0.01; the standard deviation of the residuals was 0.006.

One disadvantage of the above procedure arises from comparing bottle salinities with *gridded* SeaSoar data. Because of the gridding procedure, it is possible that a comparison is made between a bottle sample and a SeaSoar measurement that had been made up to 4 km away, or between a bottle sample and a SeaSoar value that arises from averaging more than one surfacing event. Although horizontal gradients of surface salinity are often small, so this effect will not be significant, a new analysis of SeaSoar surface salinities was performed. In the new procedure, near-surface SeaSoar data were extracted from the (despiked) four-hourly files. For each surfacing event, data from 1 to 5 db depth were averaged to produce a SeaSoar value for near-surface salinity. These values were now compared with bottle salinities, which had been drawn at times designed to correspond with surfacing events, to produce a time-series of bottle minus SeaSoar residuals. Although these residuals lead to corrections to the SeaSoar data that are very similar to those derived following the Pollard et al. procedure, many of the individual differences are reduced; in particular, nearly all of the differences larger than 0.01 have been removed. This leads to a significant reduction in the standard deviation of the residuals, and hence an estimate of the errors of the SeaSoar data that is smaller than would have been the case using the old scheme. Figure 2 shows a time series of surface salinity (taken from the finally corrected SeaSoar data), the bottle minus SeaSoar residuals using the new comparison procedure, a low-pass version of the residuals, which was used to correct the SeaSoar data, and the residuals between the bottle samples and the final SeaSoar data. The latter has been offset so that -0.07 represents zero difference. The statistics of these residuals represent an improvement over those quoted above, and are as follows: 91% of residuals have magnitude no greater than 0.005, and 98% no greater than 0.01; the standard deviation of the residuals is 0.003. It is our belief that this is the best available guide to the absolute accuracy of the salinity calibration.

Note in passing that the low-pass filter was achieved by taking a 21-point running mean of the data. Since the bottle samples were drawn hourly, this resulting correction should represent drifts in the conductivity cell on time-scales of one day or longer.

Final chlorophyll calibration

The procedure for final chlorophyll calibration was similar to that for final salinity calibration. Samples were drawn from the non-toxic supply once every four hours and analysed on a bench fluorometer. Details of the analytical procedure are in the Cruise Report. As with the Pollard et al. (1987) method for salinity correction, corresponding near-surface SeaSoar values were taken from the gridded files for comparison. Whereas the salinity data could reasonably be corrected by applying an offset that varied slowly with time, this is not appropriate for fluorescence data. The main correction that is required is for the effect whereby fluorescence yield per unit chlorophyll (measured by the fluorometer on SeaSoar) is reduced in the presence of daylight. Thus values of chlorophyll in the upper 30 metres or so computed from daytime fluorescence data will be low. This is illustrated by the time series of the ratio of surface sample chlorophyll to surface SeaSoar chlorophyll shown in Figure 3.

The final calibration was done in two stages, and applied post-cruise. First, the set of all SeaSoar/bottle comparisons was compiled. To this was added a small number of comparisons made when the Fluorometer was mounted on the CTD frame. A total of 118 Chlorophyll analyses was available, of which the majority were duplicates. After reducing duplicate values to single estimates of sample chlorophyll, a total of 45 SeaSoar/bottle comparisons were available, of which 22 were considered to be 'night-time'. These 22 samples were used to produce a new exponential calibration, namely

$$\text{Chla (mg/l)} = \exp\left(3.67 * (0.001 * \text{Fluor}_{raw}) - 3.16 \right) .$$

This calibration was then applied to the entire cruise dataset. The residuals between SeaSoar values and these 22 night-time bottle values after applying the new calibration are summarised in Table 3.

The second part of the procedure concerned the correction for daytime suppression of the fluorescence. Dr. M. Fasham and others are currently working on algorithms to correct this effect that involve making in-situ measurements of solar radiation on SeaSoar. No such data were collected on Cruise 189, so a correction factor for gridded data has been estimated as follows:

The 45 ratios of surface sample chlorophyll to SeaSoar chlorophyll have been plotted as a time series (Figure 3), which clearly reveals the diurnal variation. This time series is interpolated in time to produce a multiplicative correction factor for the surface bin (centred at six metres). This is a function of time denoted by $F_6(t)$.

The decay of the correction factor towards unity is assumed to be exponential. Thus corrections for the bins centred on depth d metres are given by

$$F_d(t) = 1 + (F_6(t) - 1)\, e^{-0.15\,(d - 6)} \quad .$$

with no correction for bins below 30m. The decay length scale of 0.15 represents less rapid attenuation than is observed with a transmissometer (approximately 0.3 per metre). However, we would expect the wavelength used in the transmissometer (660nm) to be attenuated more rapidly than the light associated with the daytime suppression effect. The table below gives two examples of how the correction factor approaches unity, for cases where the 6-metre bin has factors of 2.50 and 1.50.

Depth, d	Factor, F_d	
6	2.50	1.50
14	1.45	1.15
22	1.14	1.04
30	1.04	1.01
>30	1.00	1.00

DATA PLOTS

The data from each of the four sections are presented as contoured plots. For each section there are plots of potential temperature, salinity, potential density (gamma0) and chlorophyll with pressure as the vertical coordinate, and also of salinity with potential density as the vertical coordinate. Note that chlorophyll is annotated in the data plots with the variable name 'newfluor'.

The data have been gridded using distance run as the along-track coordinate, and are plotted using an evenly-spaced latitude as the horizontal variable. The 17W section has been split into a northern and southern part; the remaining sections are plotted with the entire section in a single panel. As indicated elsewhere, the data for the 9W section were collected in two parts, the first runs northwards from 43.5°N and the second runs south from 47.5°N; the join is at 46°20'N, where the time difference is 23 hours 20 minutes.

In order to produce tidier contour plots, small gaps in the gridded CTD data have been eliminated by linear interpolation over one or two bins in the horizontal. The SeaSoar failures did not give rise to gaps in sections, because the repaired vehicle was redeployed in such a position as to provide a small amount of overlap.

The plots are arranged so that each double page spread shows the same variable for four sections - 9W, 12W, 15W, 17W (southern part). The plots for the northern part of 17W are included at the end.

Contour intervals

Contour levels may be deduced from the shaded bars, shown on pages 20-21. For each variable, the same shading is used in all plots. Major contours are indicated by changes in shading intensity, and have the following values

potemp	11, 12, 13	°C
salinity	35.5, 35.6, 35.7	
gamma0	27.0, 27.1, 27.2	kg/m^3
chlorophyll	1.1, 3.1, 5.1	mg/m^3

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J. Smithers provided calibration data for the CTD; M. Stirling provided assistance and advice in advance of the cruise, concerning chlorophyll analysis. M. Fasham provided valuable advice on the suppression of fluorescence in the presence of solar radiation.

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Table 1. Start and stop times of SeaSoar runs. The first five runs were trial deployments; data are not included in the report.

run number	start time	latitude degrees(N)	minutes	longitude degrees(W)	minutes	stop time	latitude degrees(N)	minutes	longitude degrees(W)	minutes	comments
1	73/1250	41	49.56	15	01.41	73/1640	41	47.80	15	36.67	after CTD11971
2	74/1300	41	38.59	17	35.93	74/1600	41	40.15	18	00.80	after CTD11974
3	75/1330	41	45.05	20	07.18	75/1720	41	59.19	20	15.07	after CTD11977
4	77/0840	45	25.89	19	56.83	77/1330	45	56.23	19	55.74	after CTD11983
5	78/1320	47	53.86	19	34.37	78/1800	48	21.42	19	36.25	after CTD11987
6	84/2000	51	51.31	16	27.67	90/1035	44	04.53	10	24.95	134h 35min loss of CTD signal
7	90/1540	43	58.20	10	33.52	91/1420	46	23.01	08	10.87	22h 40min hydraulic failure
8	92/0520	47	27.34	08	25.30	92/1340	46	19.86	08	25.30	8h 20min end of survey

Table 2. Definition of Section numbers of data displayed in contour plots.

Section	Start lat. °N	Start lon. °W	Stop lat. °N	Stop lon. °W
17W	51.9	16.5	44.0	17.0
15W	44.0	17.0	47.5	14.5
12W	47.5	14.5	43.5	11.0
9W	43.5	11.0	47.5	8.4

Table 3 Distribution of differences between SeaSoar and sample chlorophylls.

Chlorophyll difference mg/m^3	0.0-0.10	0.10-0.25	>0.25	Total number	mean mg/m^3	std.dev. mg/m^3
Number in range	12	7	3	22	-0.01	0.17

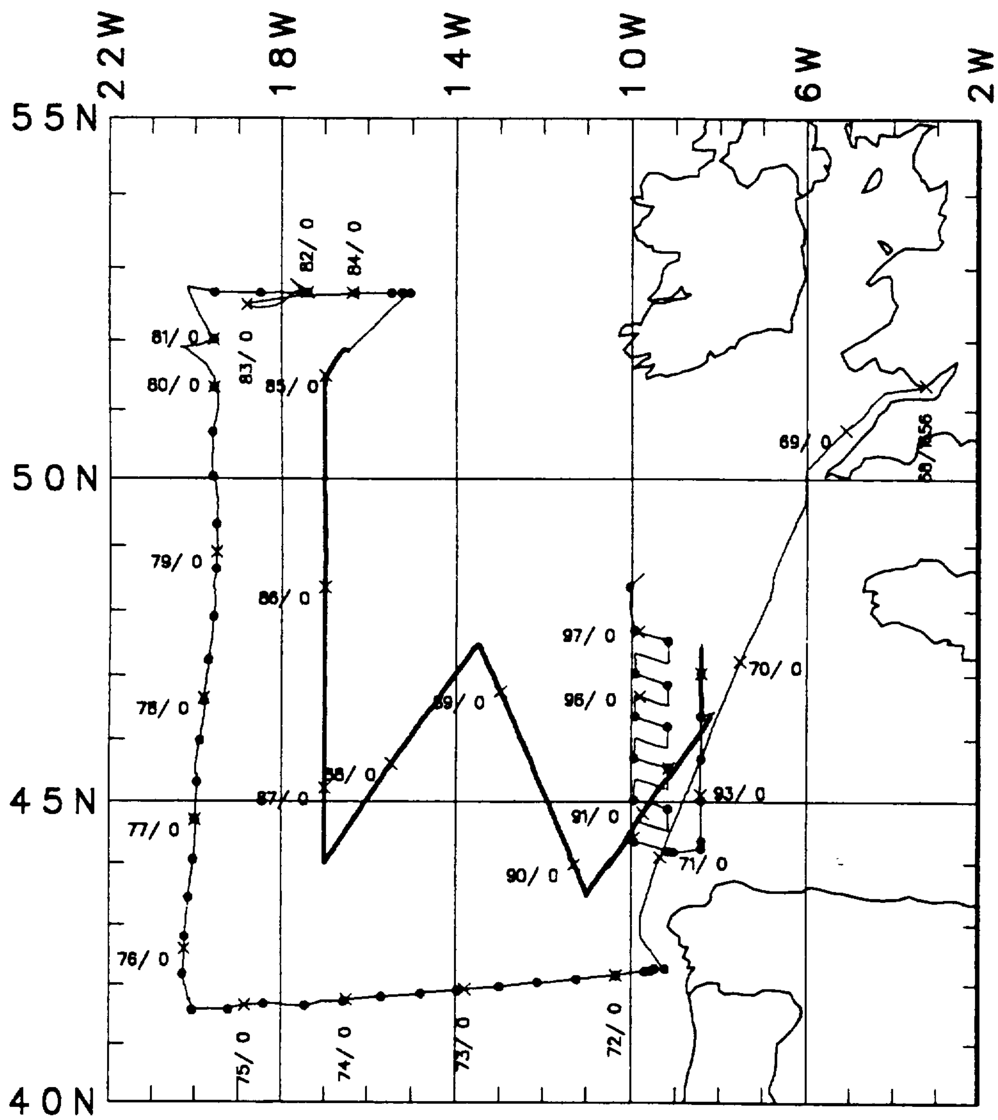


Figure 1. Cruise Track for RRS Discovery Cruise 189, 9 March - 8 April 1990. The crosses show the ship's position at 0000Z on the days indicated. Day 68 = 9 March. The thicker portions of the track denote sections of SeaSoar data.

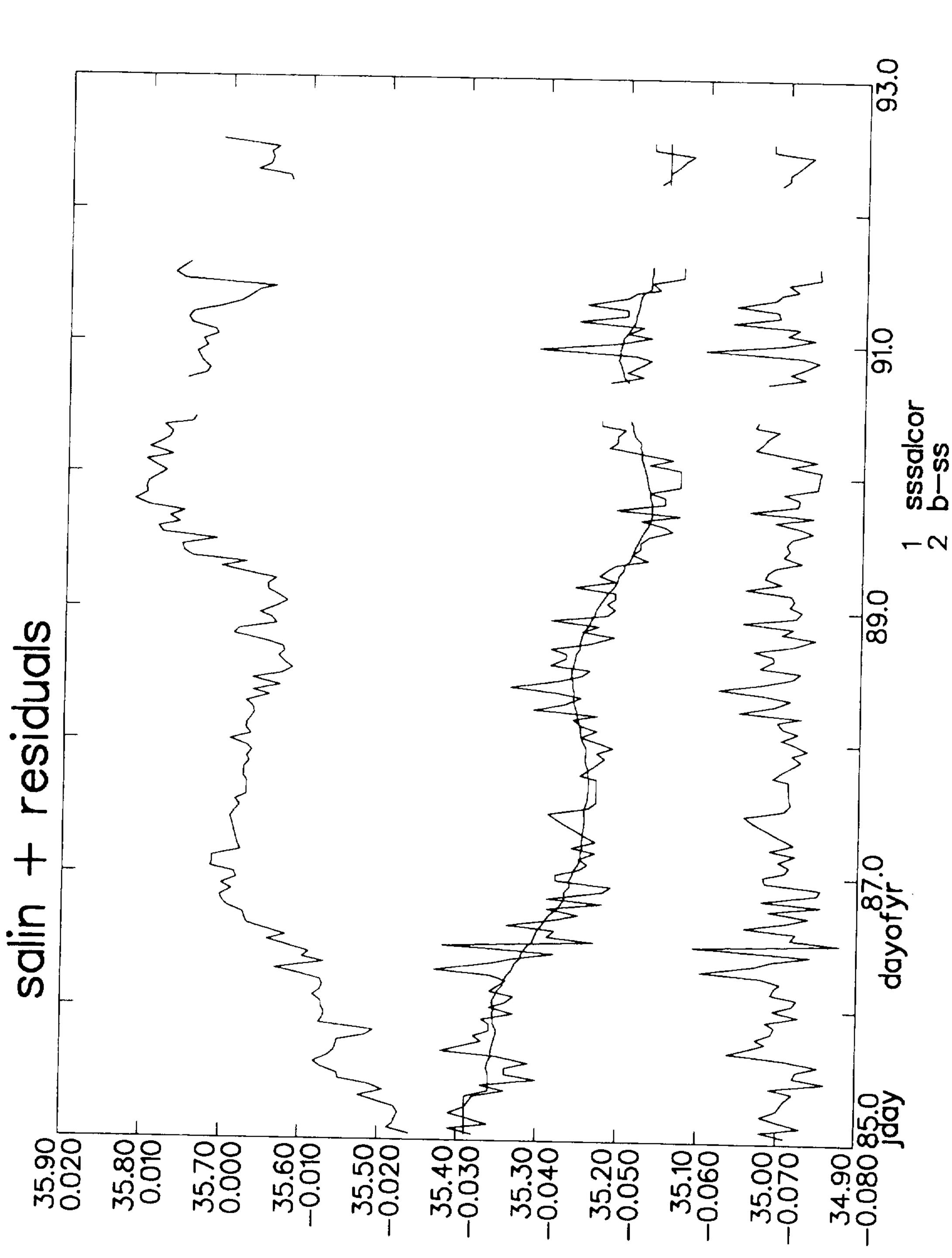


Figure 2. Time series of sea surface salinity (upper curve, corrected SeaSoar values corresponding to bottle samples), unsmoothed and smoothed residuals between bottle samples and near-surface SeaSoar samples (middle curves), and residuals after final salinity correction has been applied (lower curve, offset by -0.07).

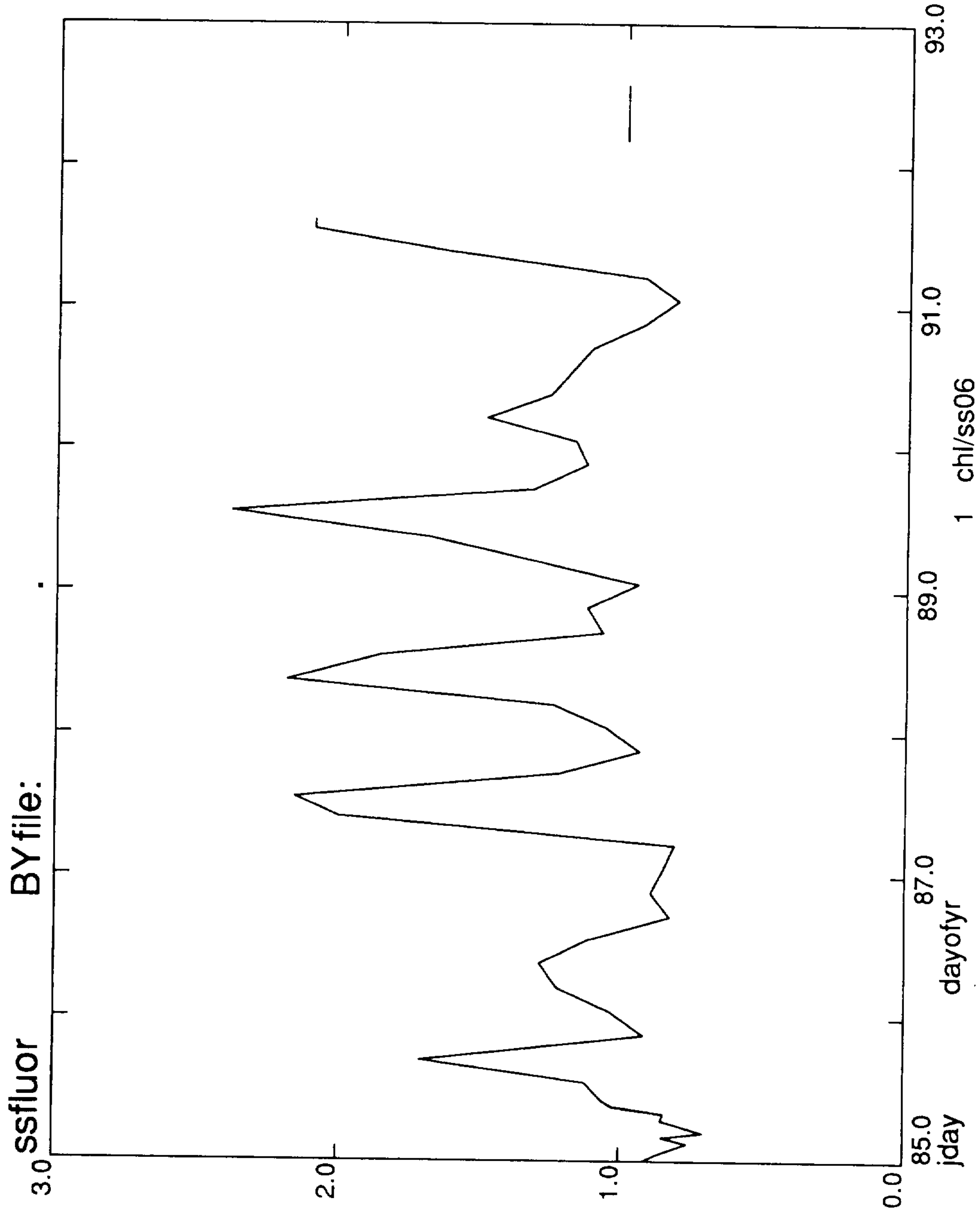
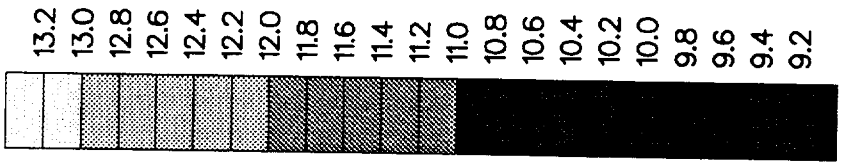
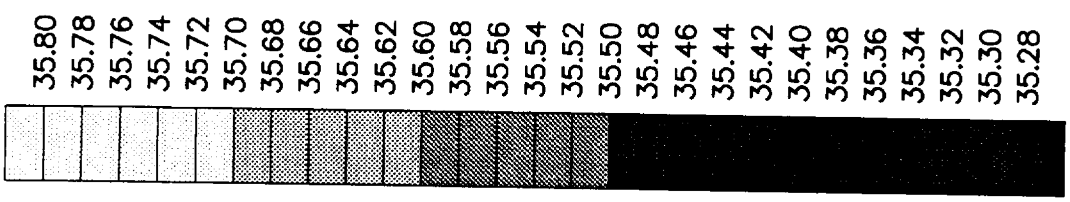


Figure 3. Time series of ratio between surface sample chlorophyll concentration (from pumped non-toxic supply) and near-surface SeaSoar samples.



Potential temperature (°C)



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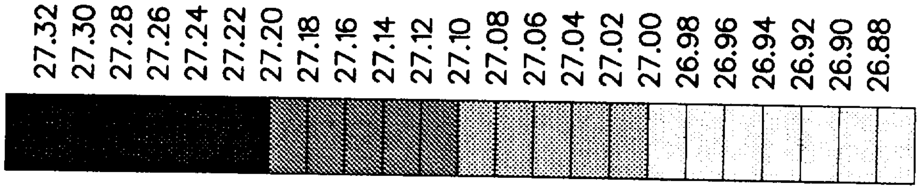

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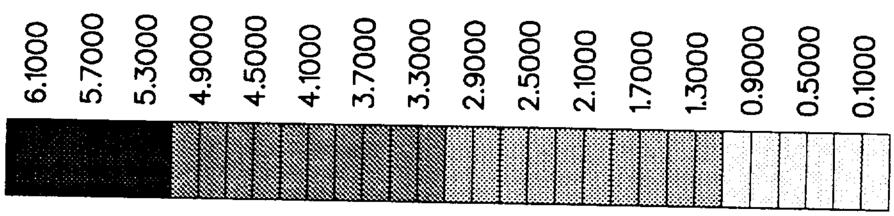
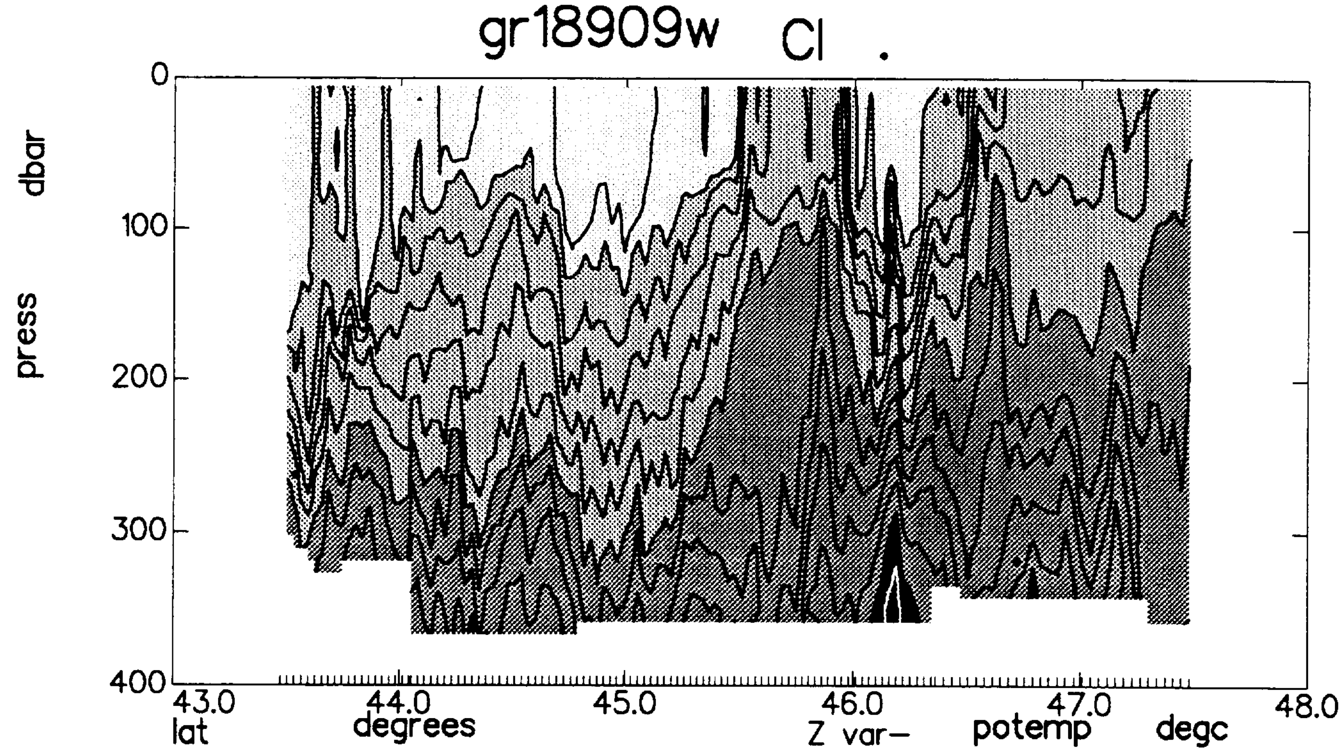


Chlorophyll (mg/m^3)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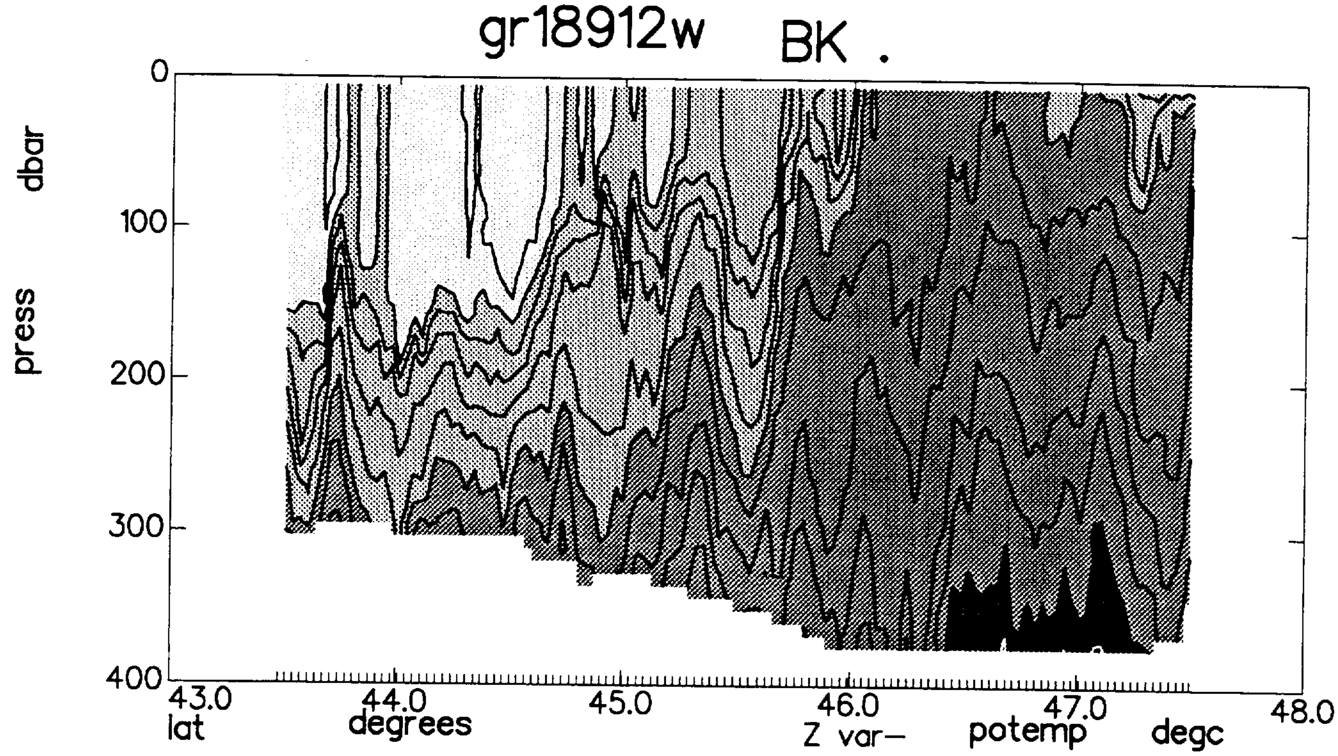
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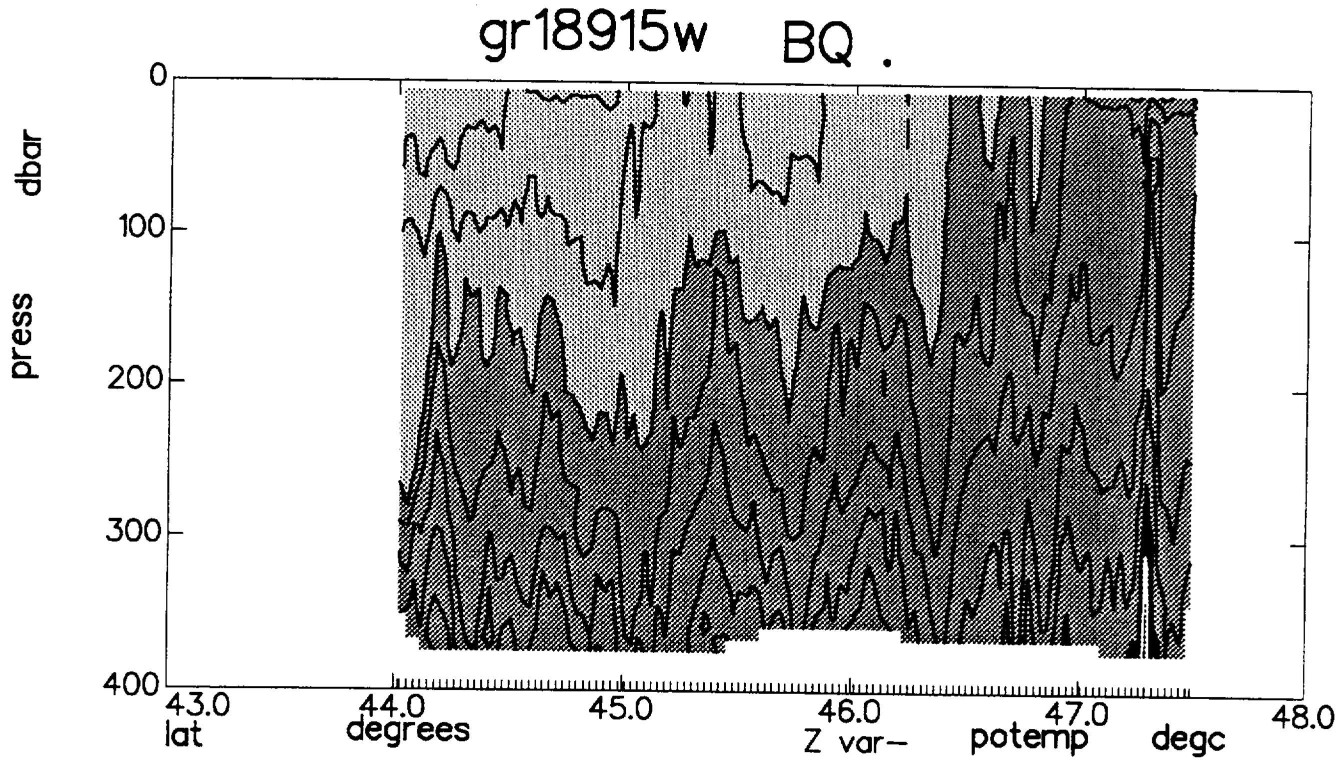
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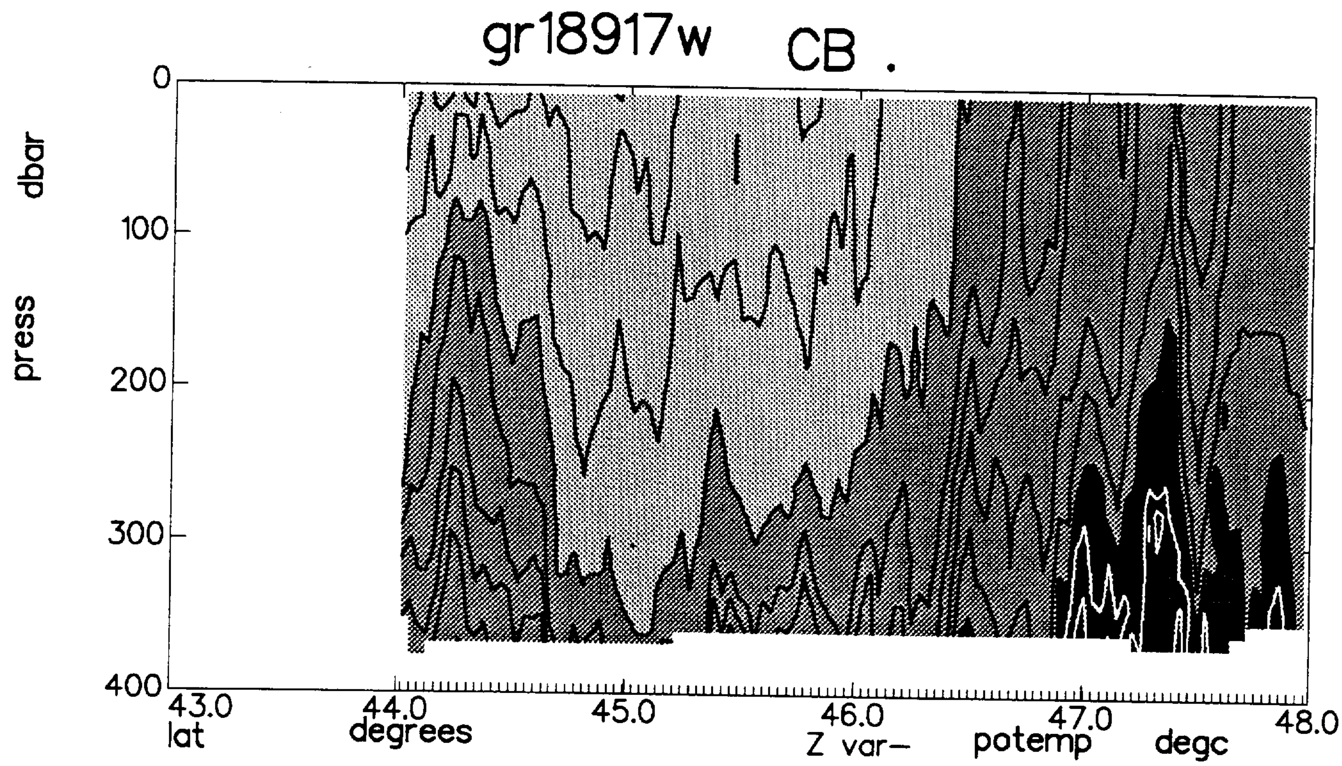
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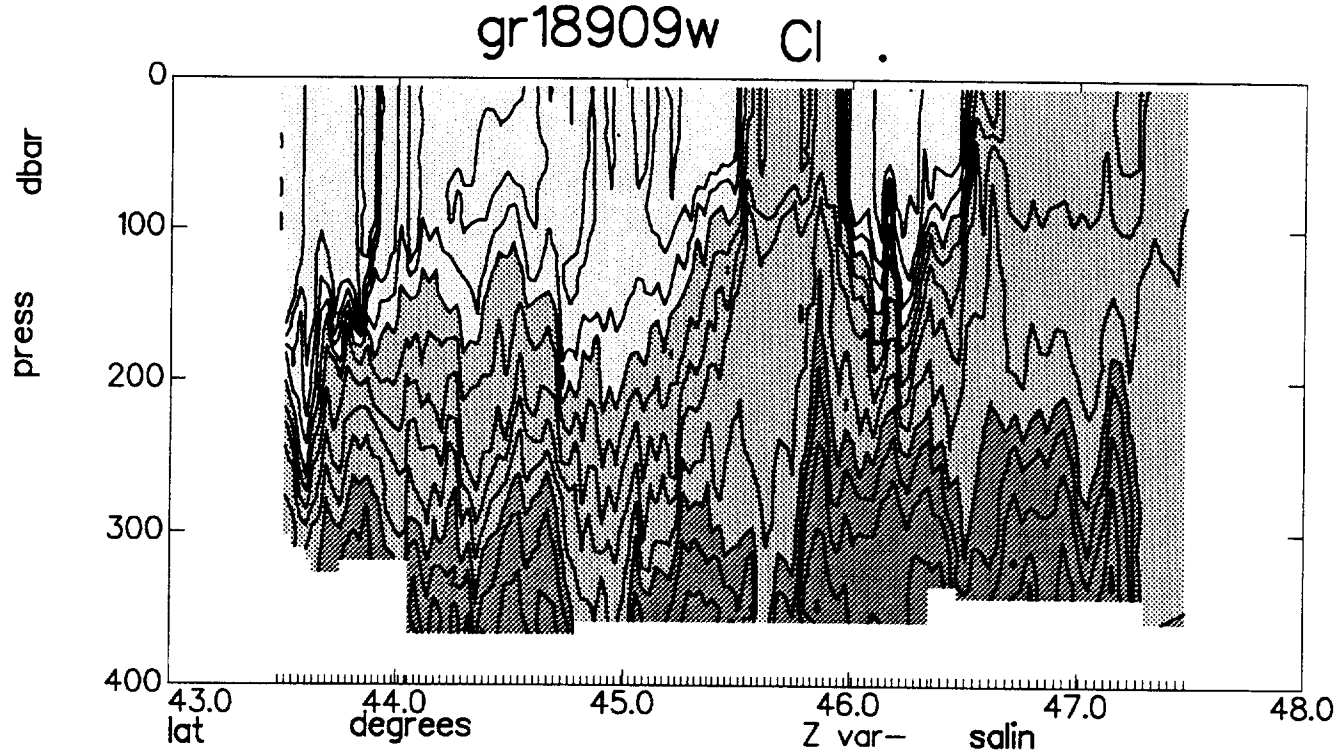
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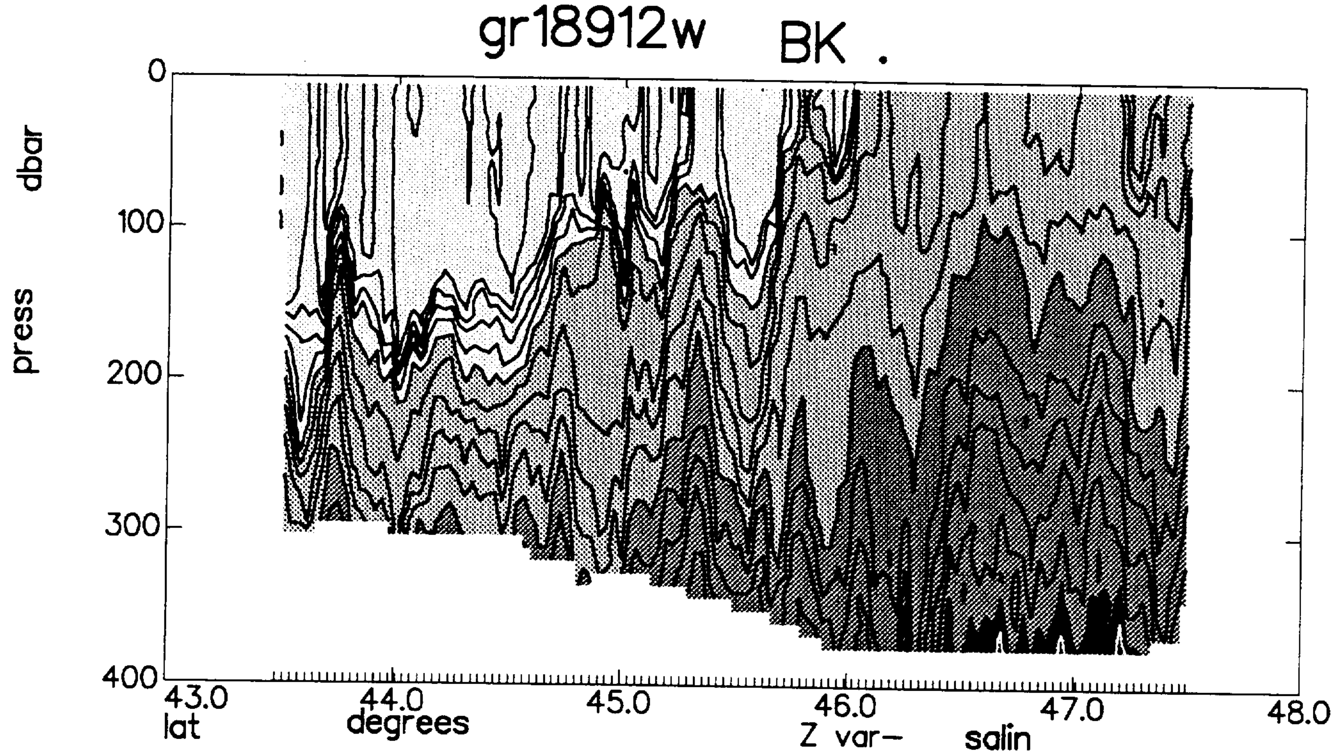
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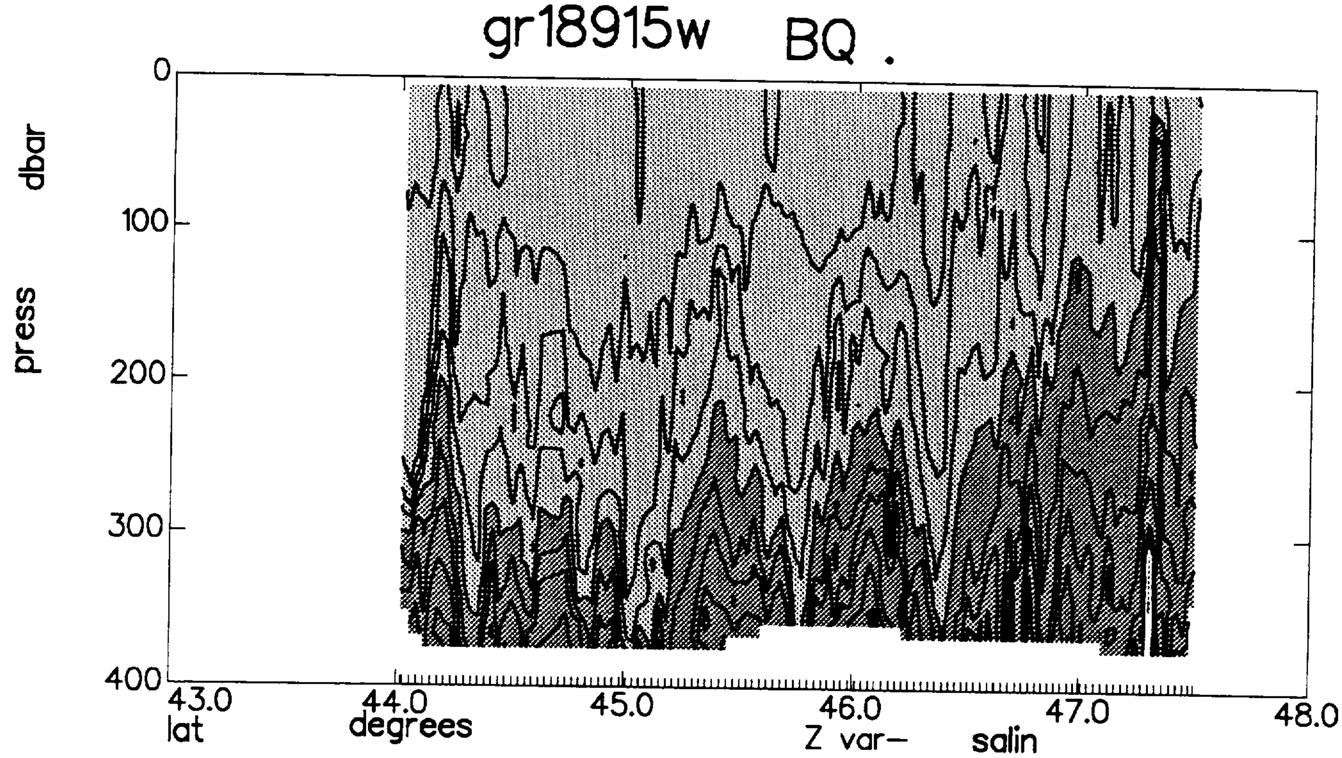
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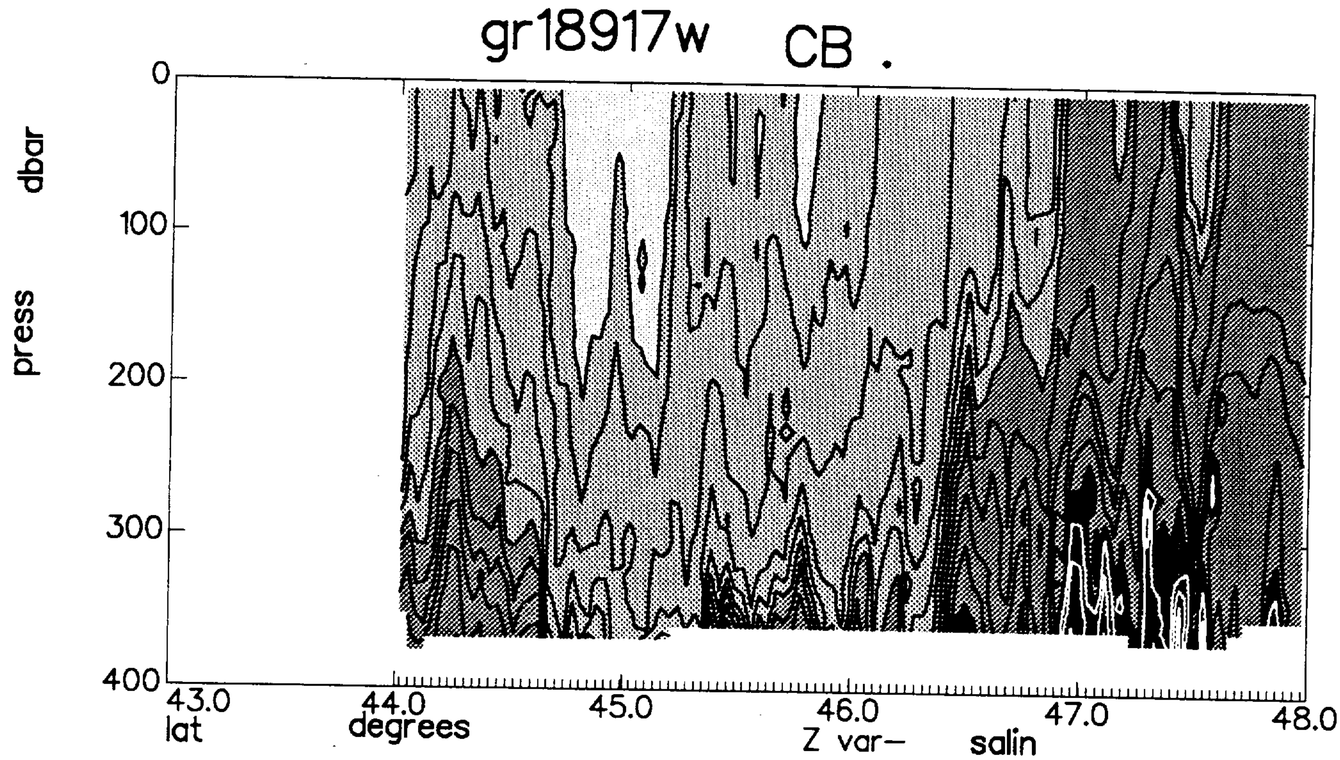
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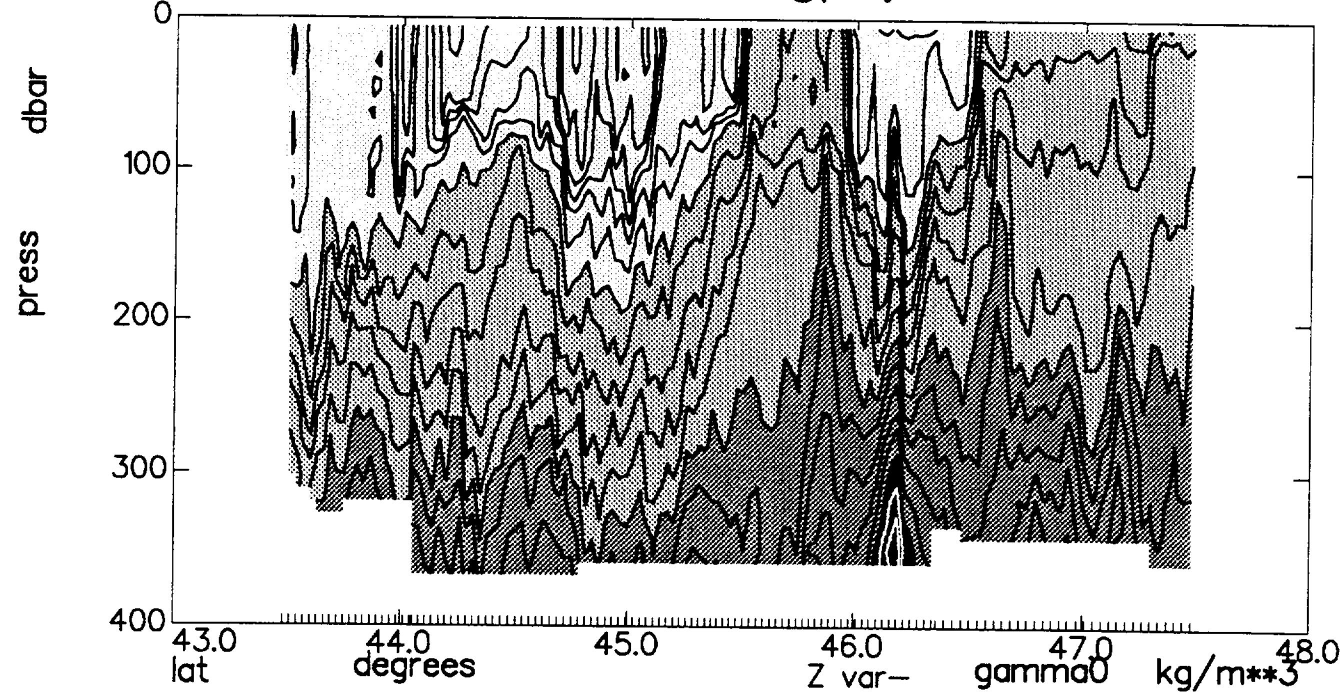

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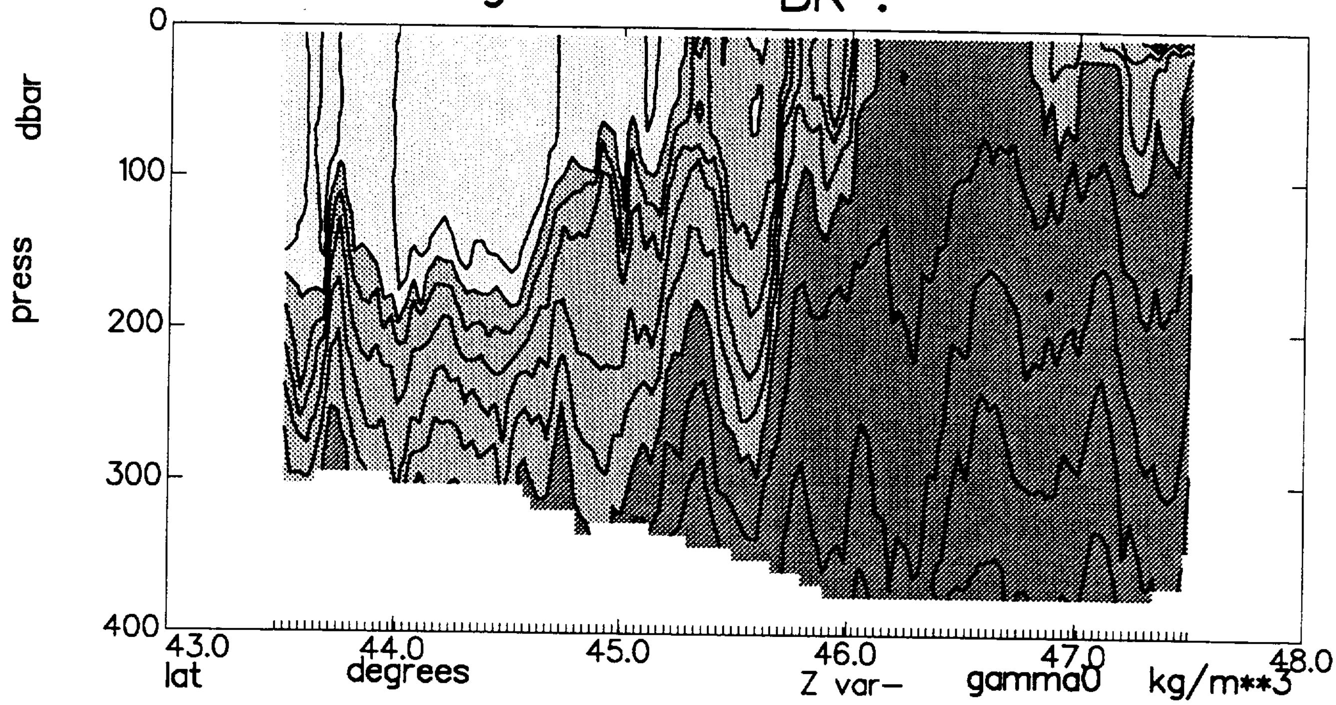

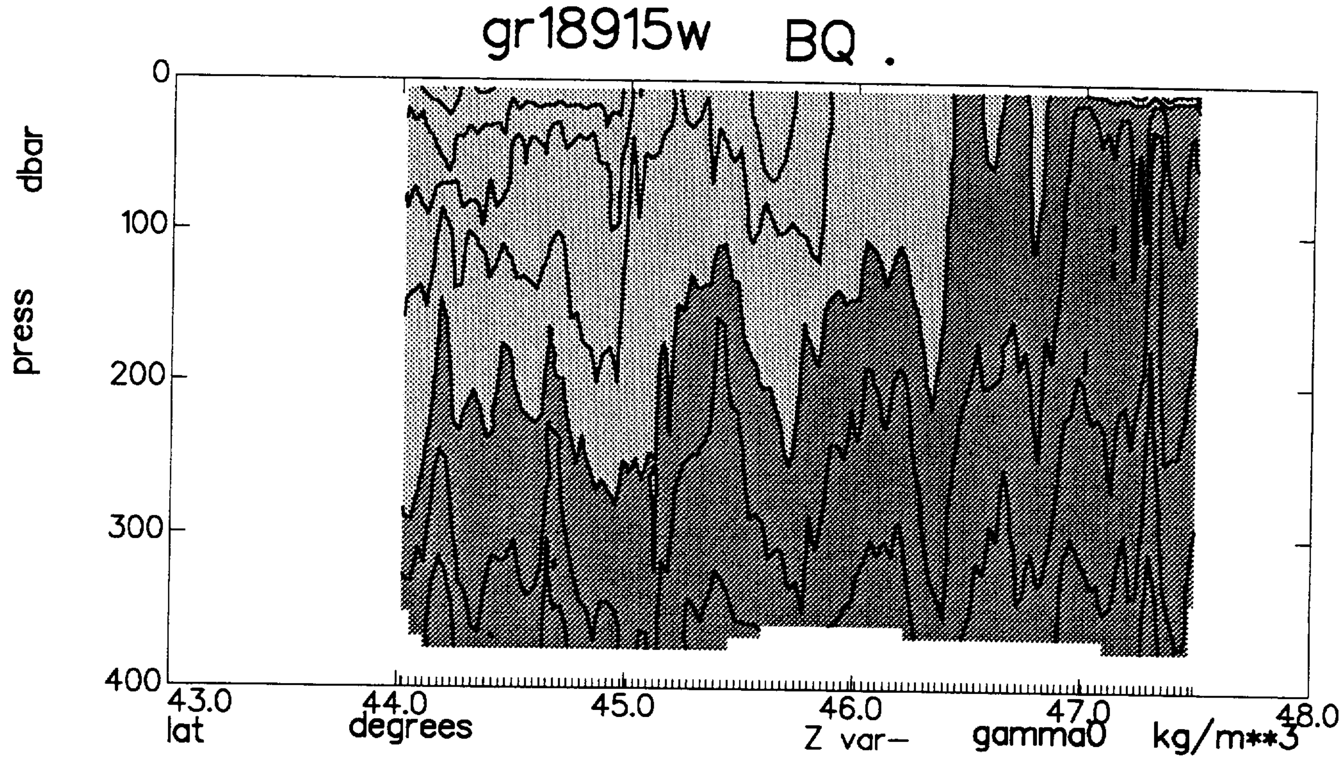
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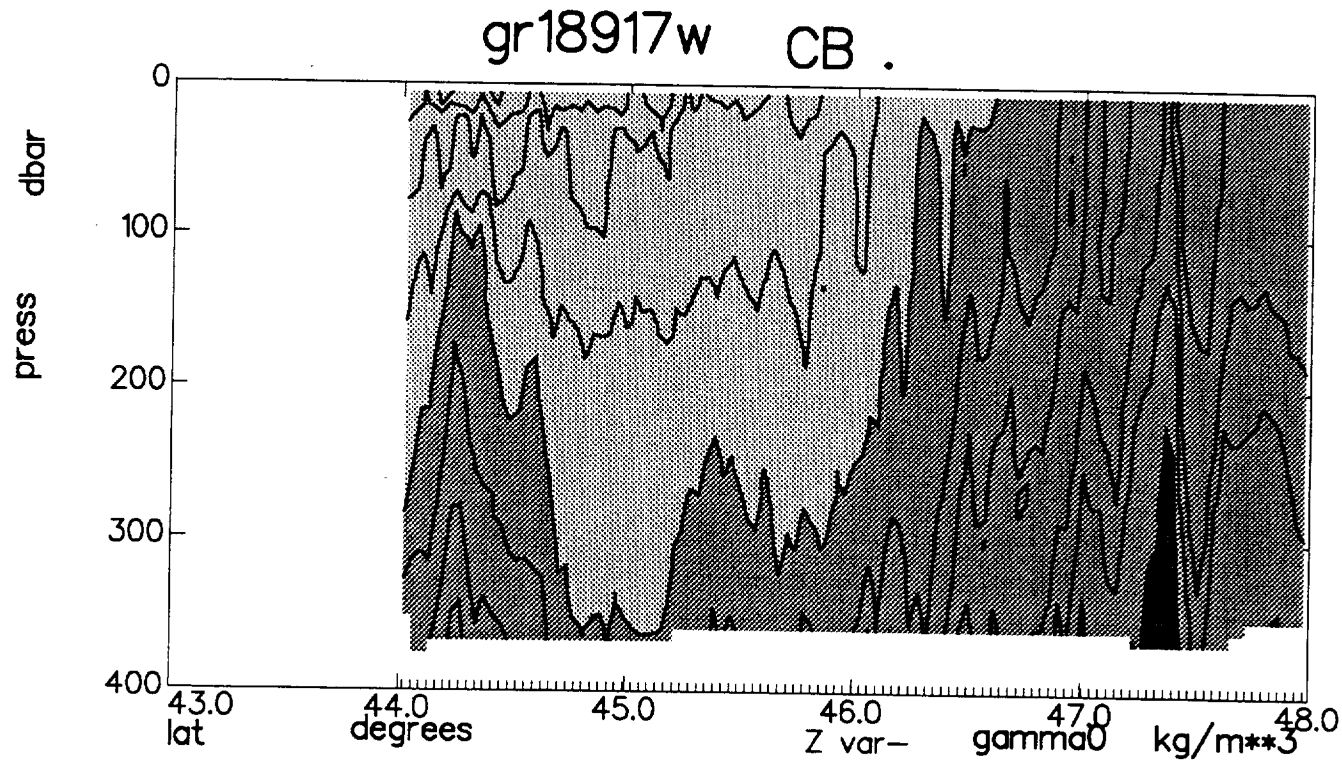
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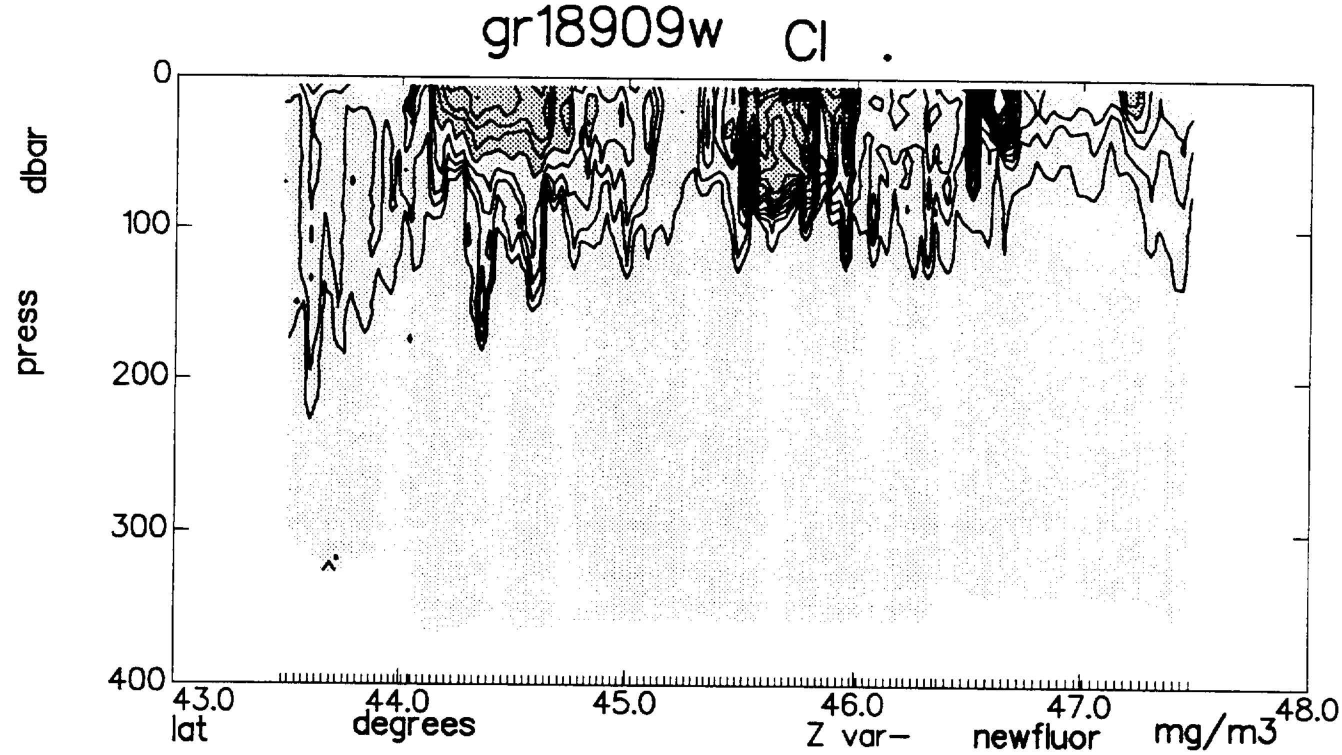
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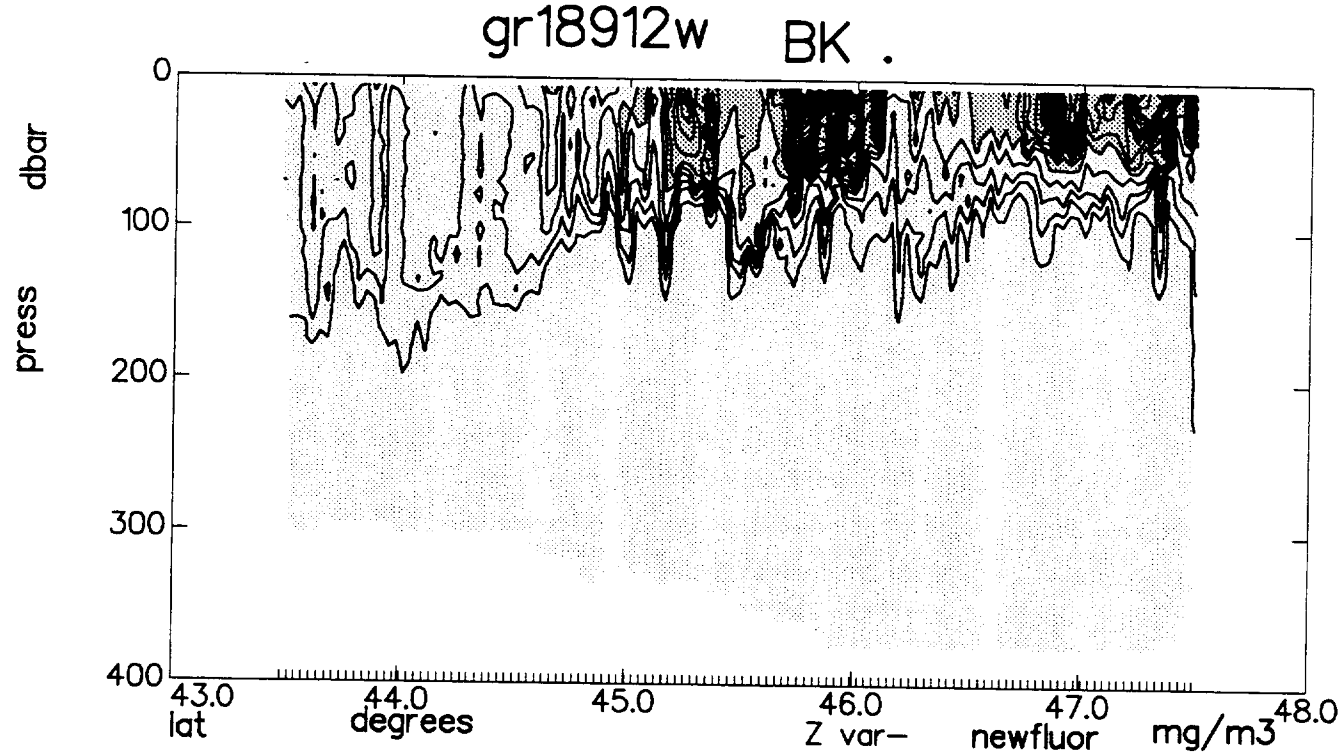
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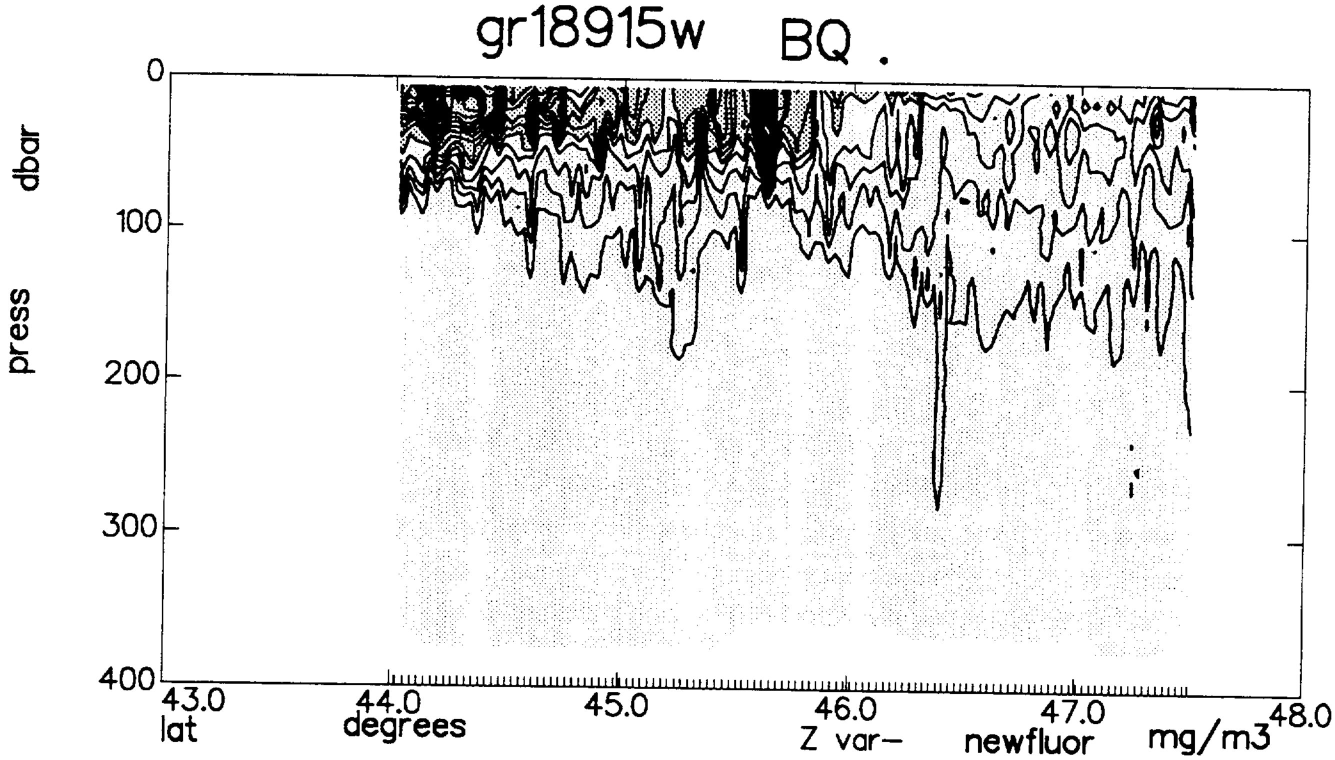
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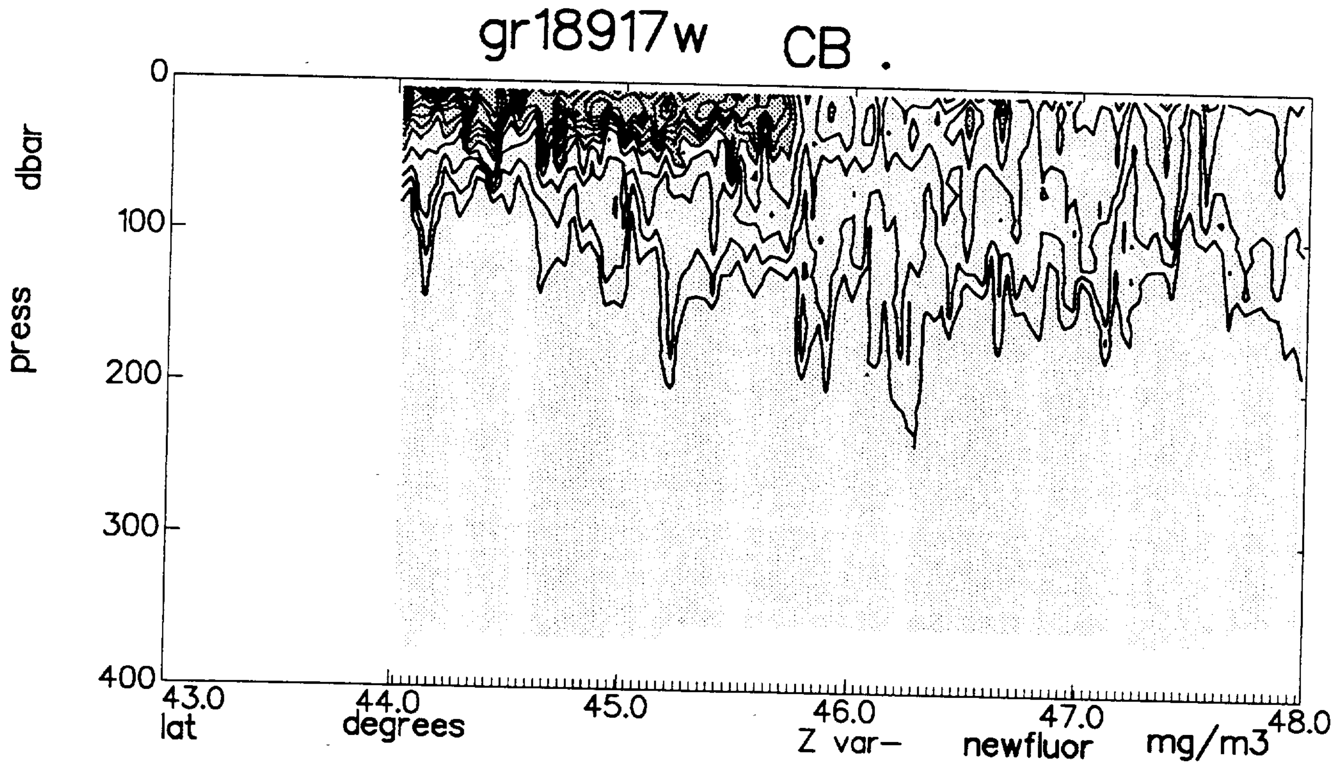
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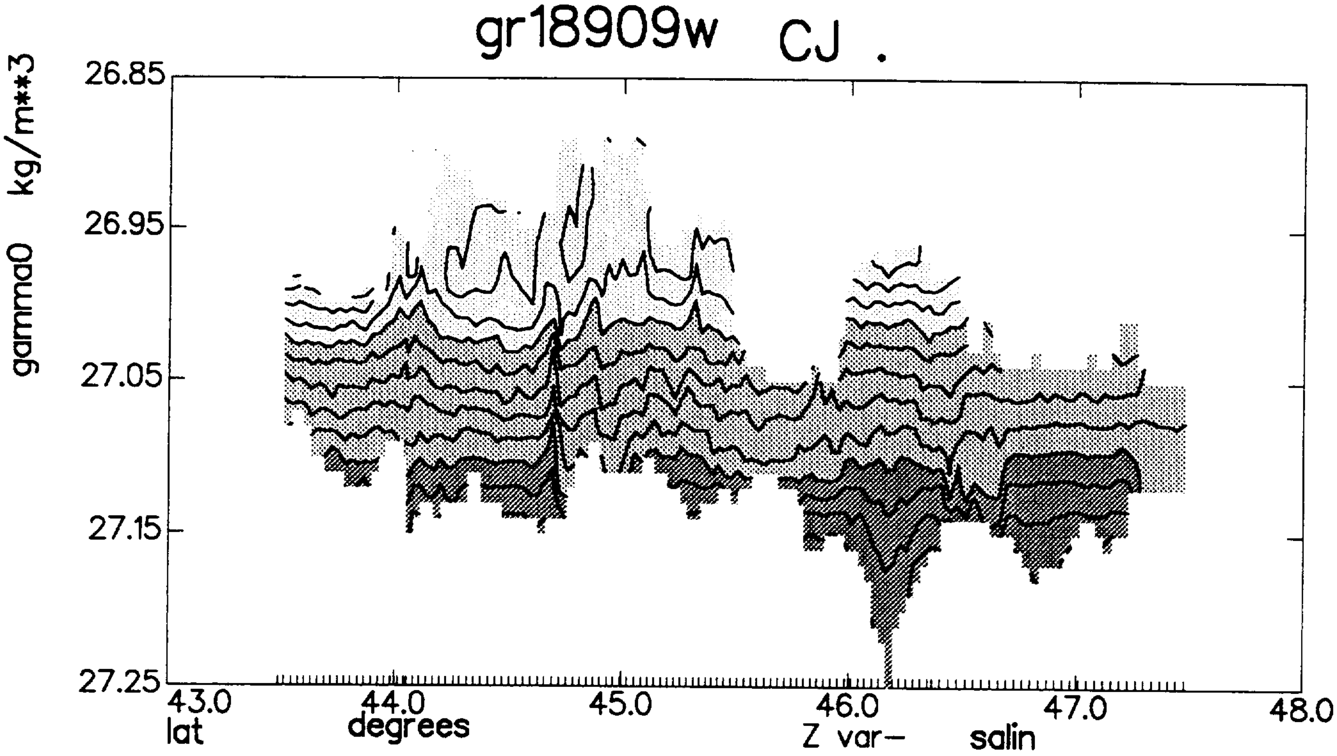
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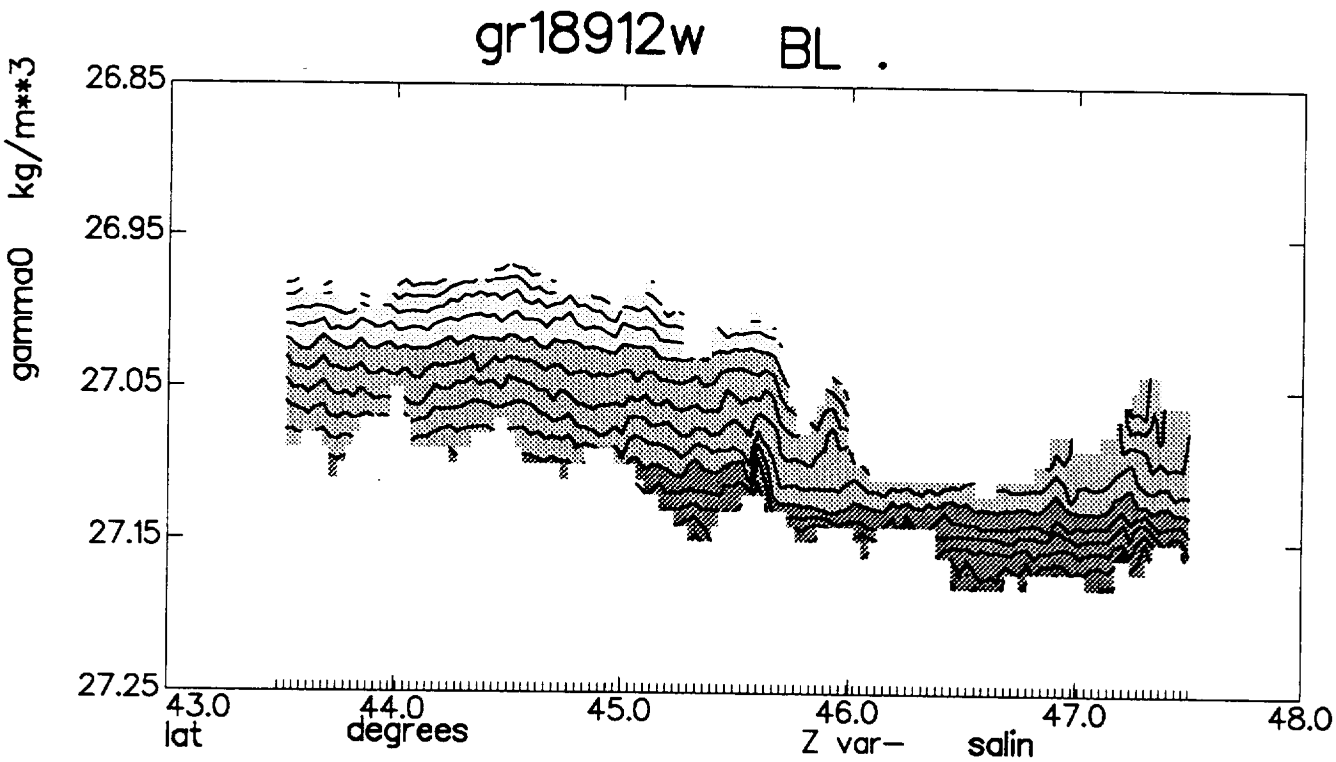
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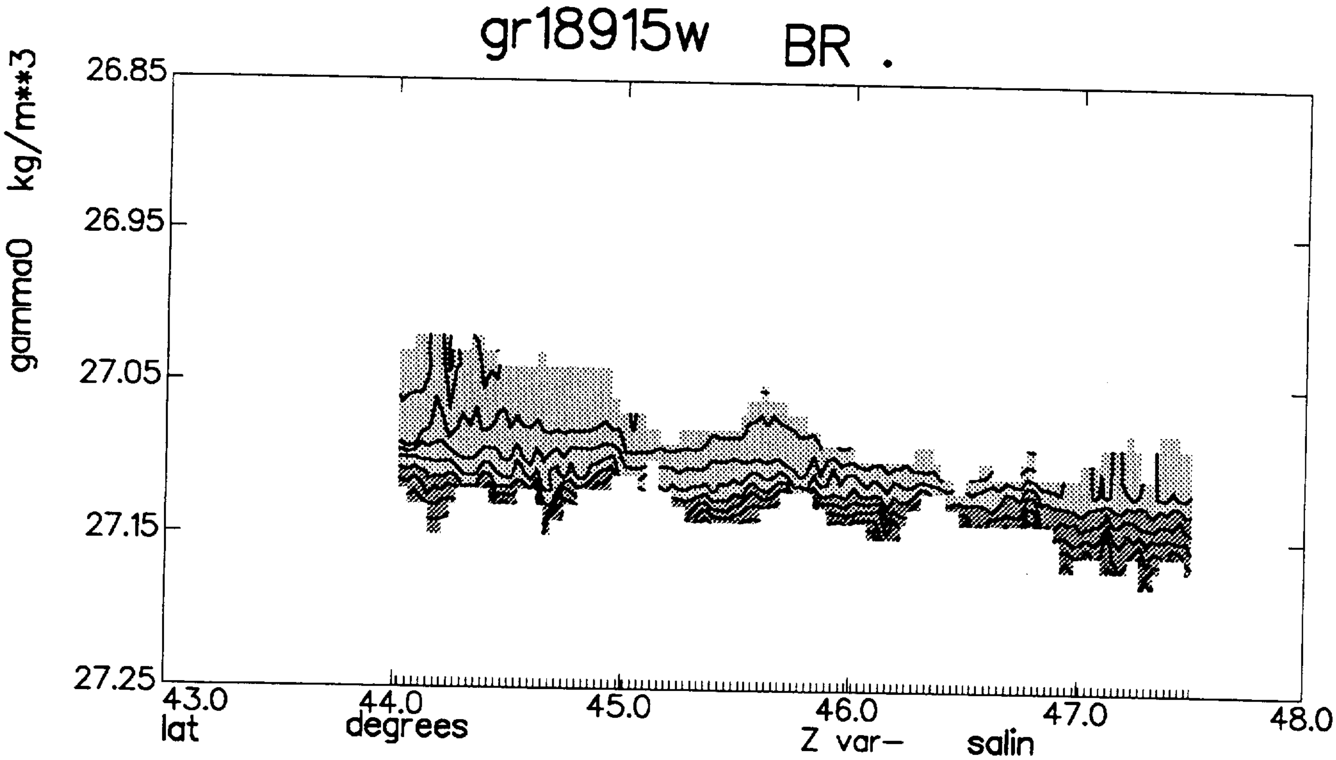
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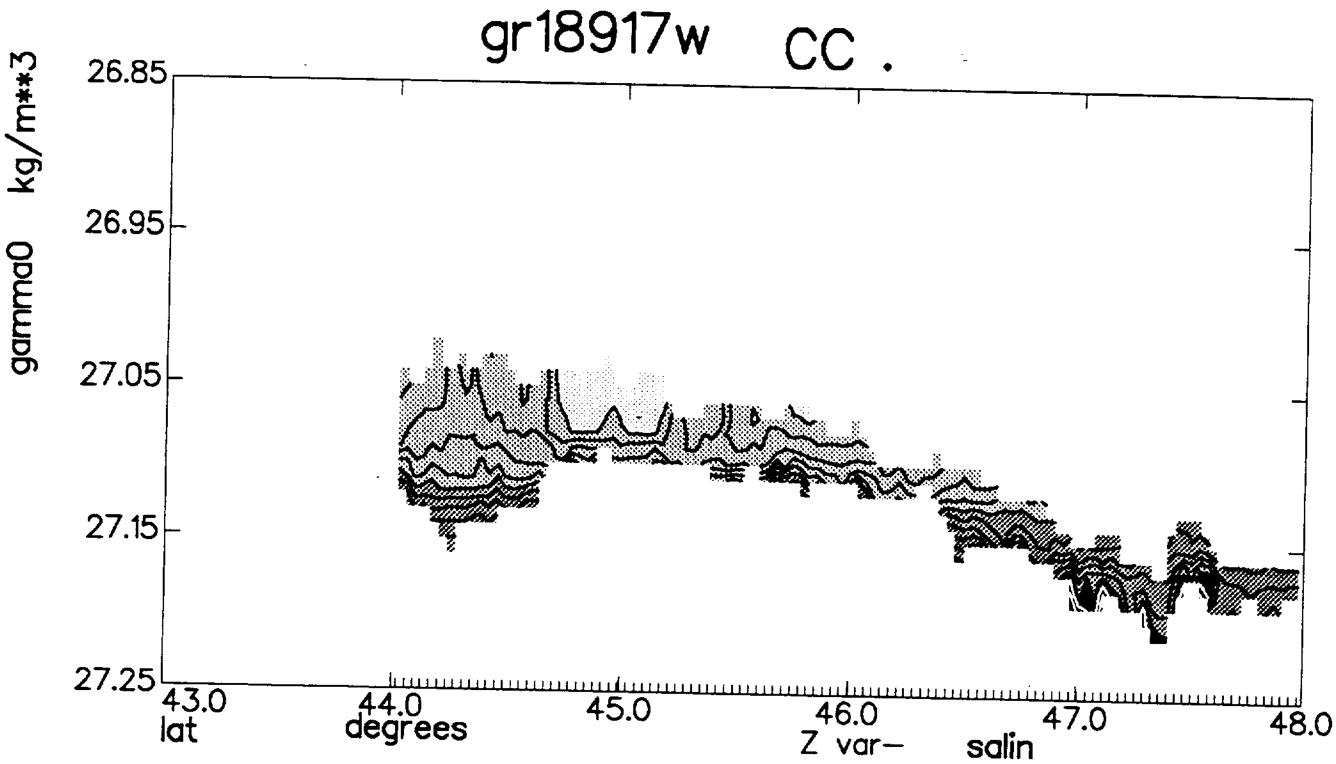
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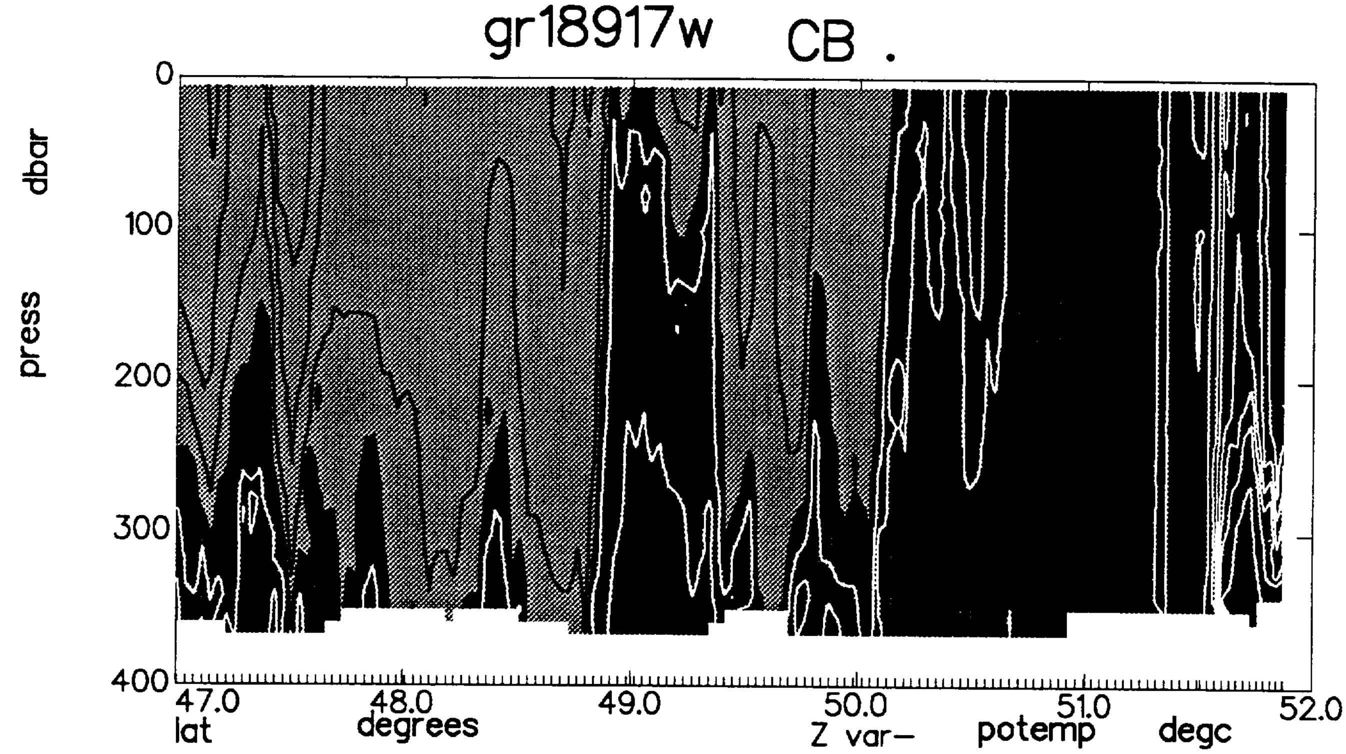
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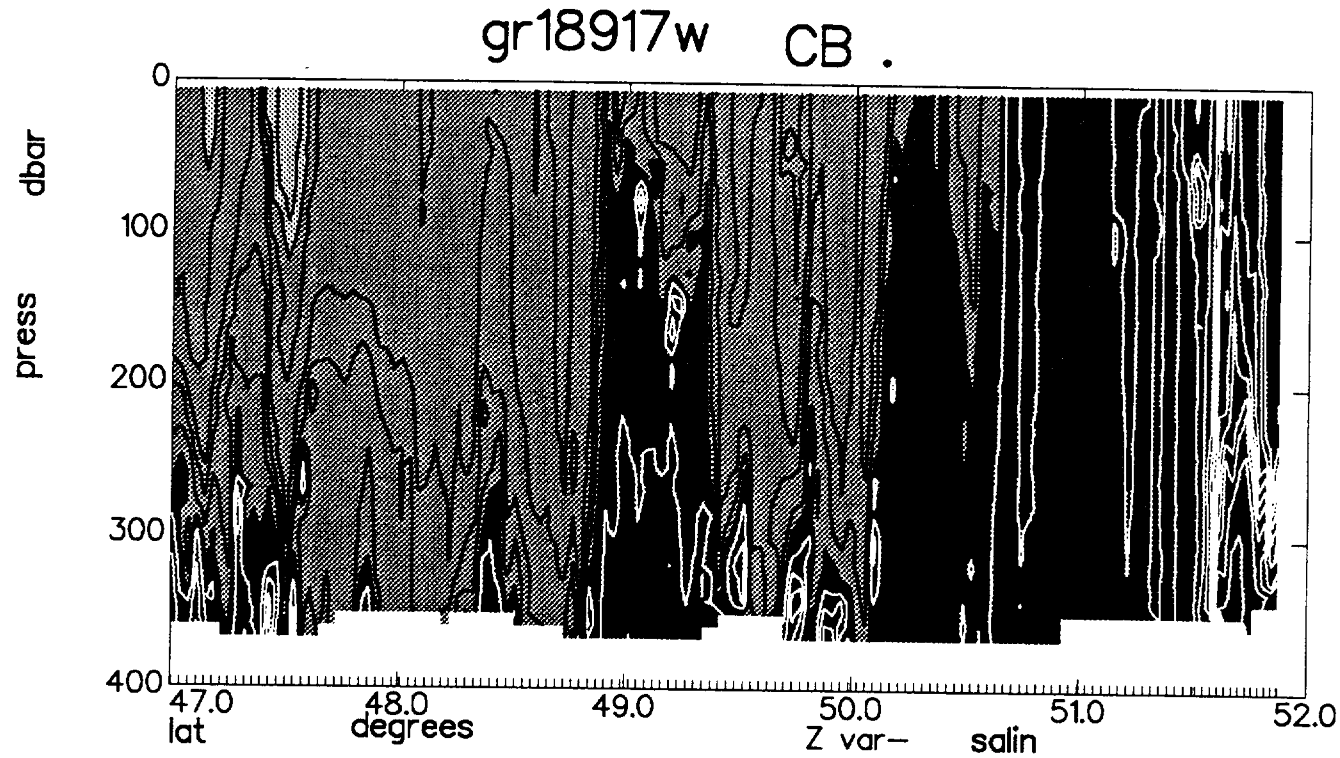
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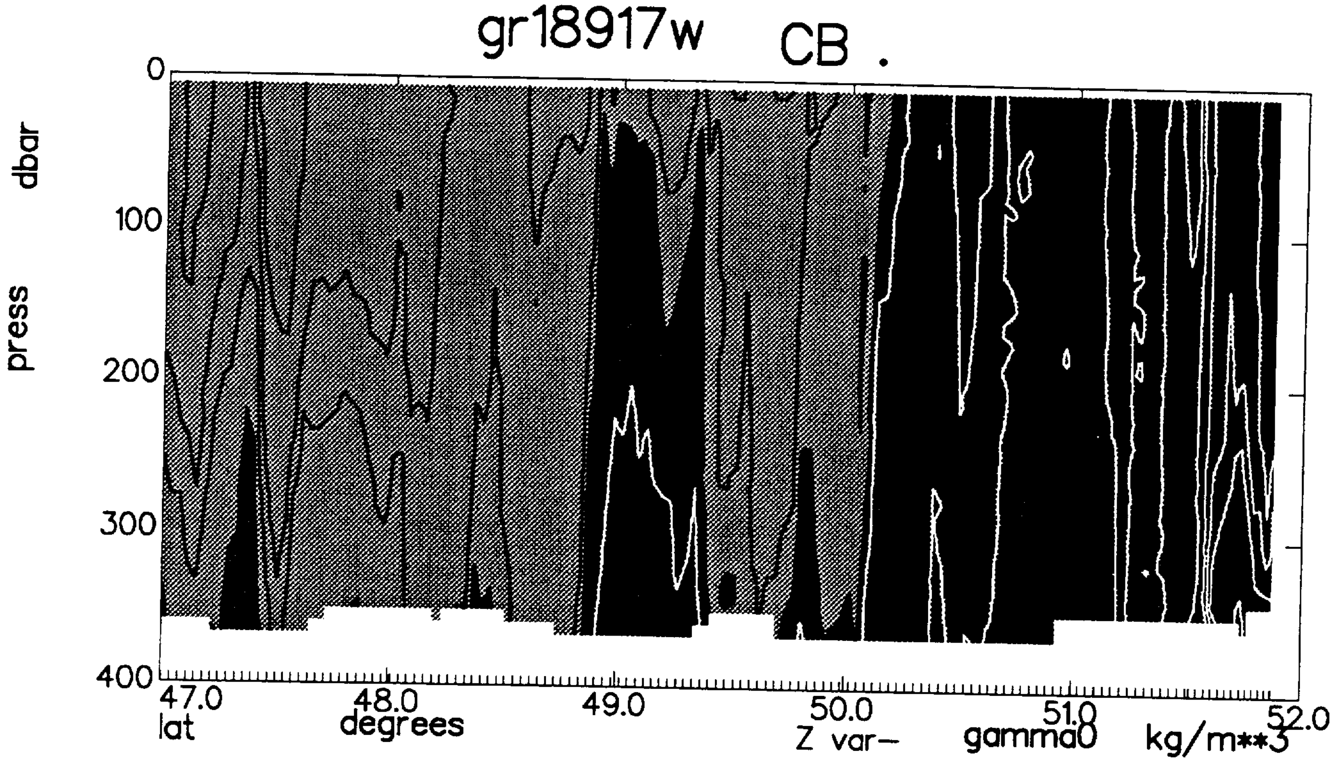
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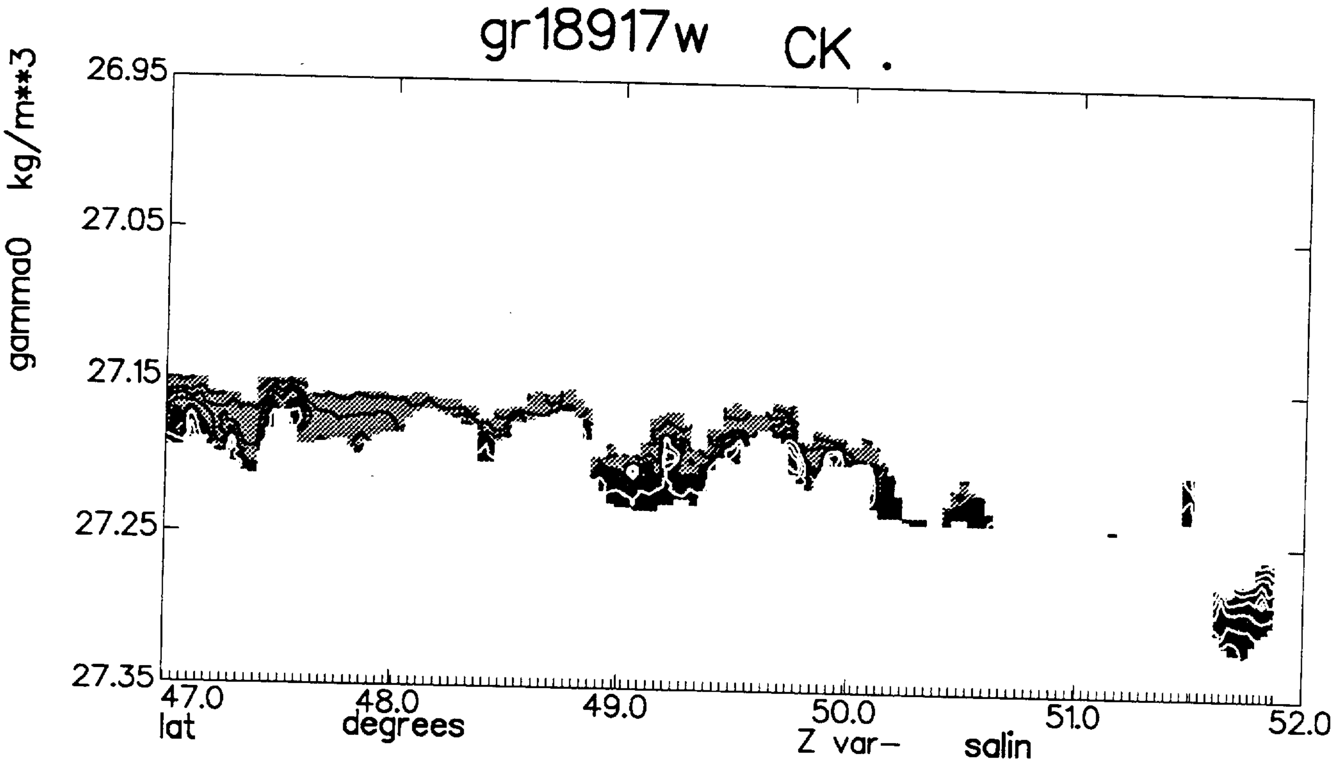
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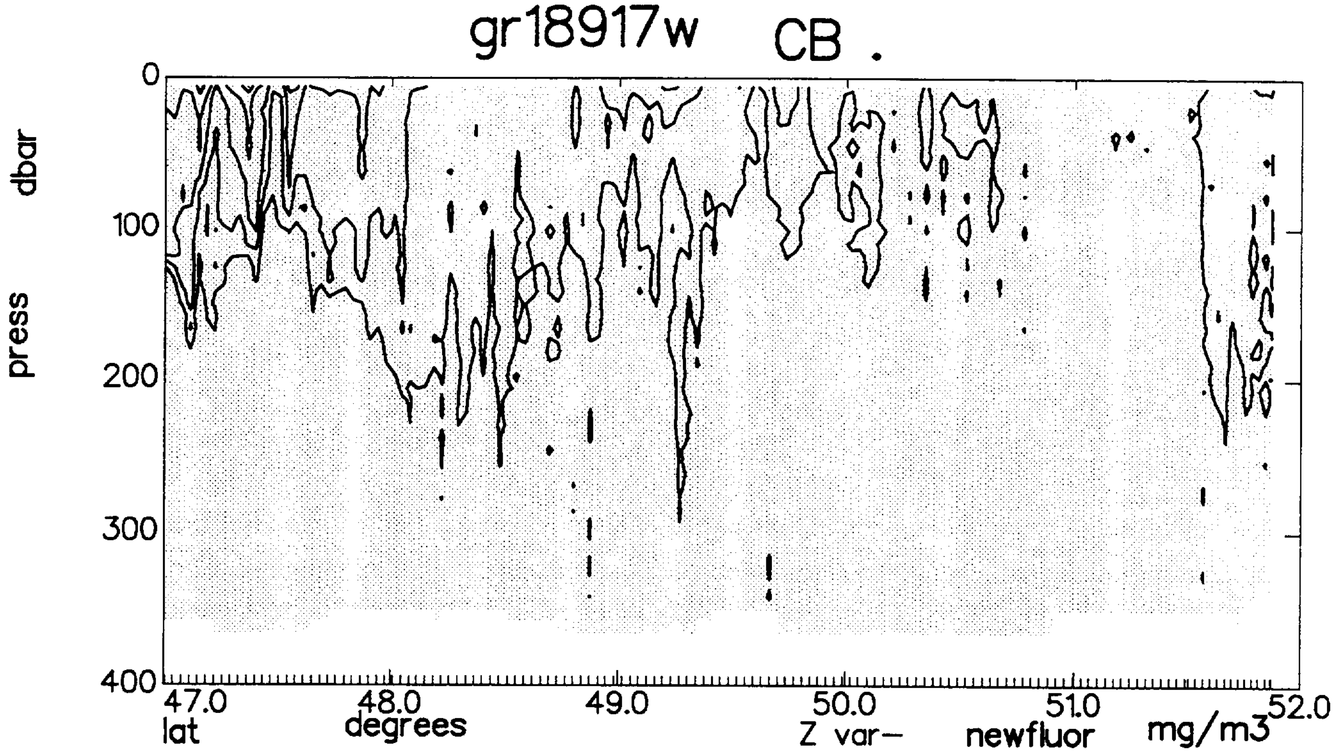
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