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Woods Hole Oceanographic Institution

Woods Hole, MA 02543

KAPEX RAFOS Float Data Report 1997-1999 Part B: Float Trajectories at 750 m in the Benguela Current

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Approved for Distribution:

Nelson G. Hogg, Chair

Department of Physical Oceanography

Abstract

Thirty-two RAFOS floats were launched at the depth of intermediate water, near 750 m, in the Benguela Current along 30S and its extension along 7W. The floats were tracked acoustically for two years during 1997–1999. Seven floats looped in three Agulhas Current rings, which drifted west northwestward at a mean velocity of around 5 cm/sec. Floats not in Agulhas rings tended to drift westward at around 2 cm/sec in the latitude band 22S–35S. North of 22S three floats drifted eastward. This report describes the float trajectories and summarizes the main results. These are the first subsurface long-term Lagrangian data in the Benguela Current.

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Introduction

The overall objective of the Benguela Current Experiment is to measure the northward flow of intermediate water in the eastern South Atlantic. This water comprises a large part of the upper layer of the thermohaline conveyor belt or meridional overturning circulation in the Atlantic. Upper layer water flows northward across the equator into the northern North Atlantic where the water is cooled and transformed into deep water, which returns southward as a deep western boundary current. The goal of this experiment is to obtain the first long-term Lagrangian measurements in the Benguela Current, which is the origin of the northward-flowing intermediate water in the South Atlantic and in the Benguela Current extension, which is the main conduit of intermediate water westward across the South Atlantic (Figure 1).

The Benguela Current Experiment is one component of the larger Cape of Good Hope Experiments, KAPEX (Boebel *et al*., 1998). The overall objective is to study the interocean exchange of subsurface waters between the Atlantic and Indian Oceans south of Africa. Other components of KAPEX launched floats in the Agulhas Current and in the South Atlantic Current south of our floats. The new float trajectories in these two regions have recently been described by Boebel *et al*. (2000). Some of the Benguela Current floats drifted over the mid-Atlantic Ridge into the western South Atlantic and into the region of the WOCE Deep Basin Experiment (DBE) where other acoustic floats have been tracked (Boebel *et al*., 1999) and are being tracked (Ollitrault, 1999) in the intermediate water. The overall goal of these experiments is to develop a circulation scheme for intermediate water in the South Atlantic that is based on direct measurements of the velocity field. Results from KAPEX have been published in a special issue of *Deep-Sea Research II* which includes results from the Benguela Current Experiment (Richardson and Garzoli, 2003).

Deployment Cruise

Thirty RAFOS floats, two ALFOS floats, and two moored sound sources were launched from the R/V *Seward Johnson* during a cruise from Cape Town to Recife, September 4–30, 1997 (Figure 2). In addition to the float work, 44 CTDO-LADCP stations to 2000 m were obtained, XBT surveys mapped three Agulhas rings, and seven surface drifters were deployed in the rings

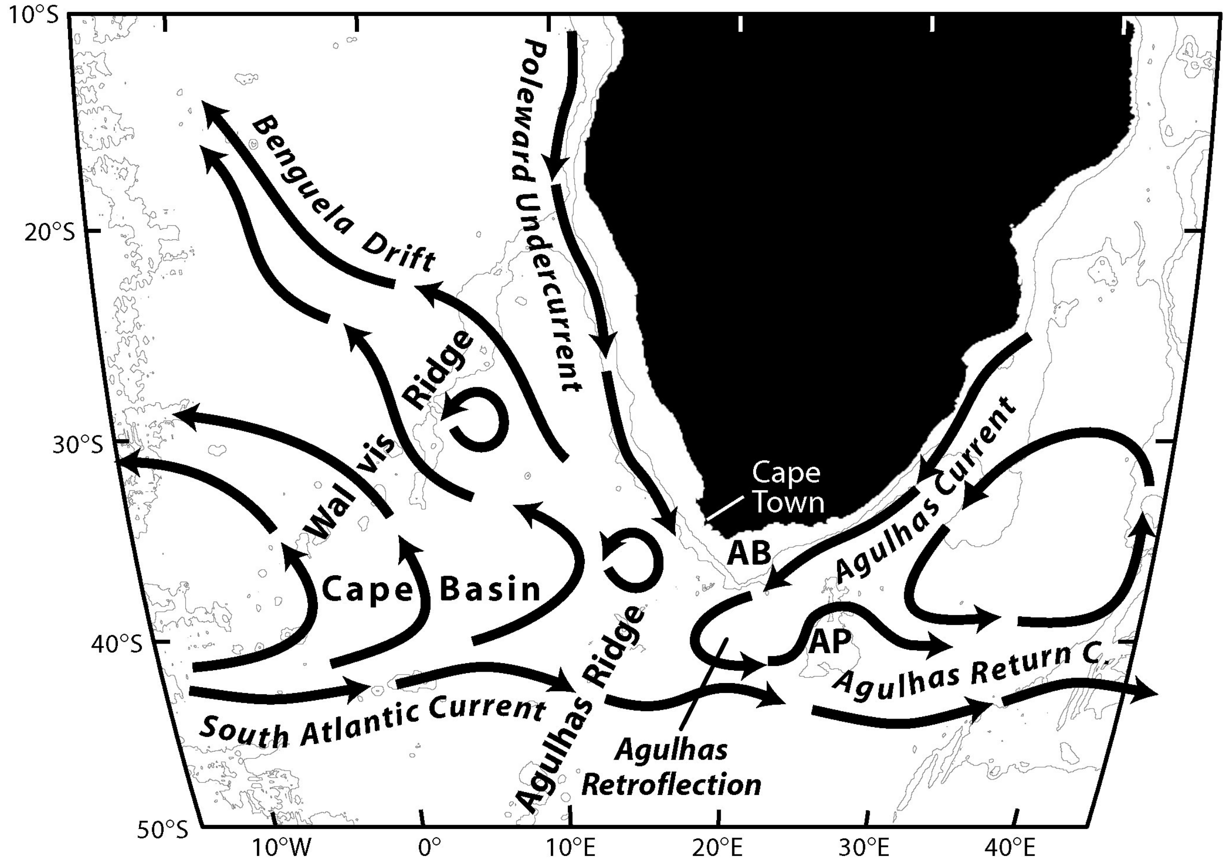

Figure 1: Schematic circulation diagram of currents at the intermediate water level (~750 m) in the vicinity of South Africa showing the general location of the Benguela Current (after Boebel *et al*., 1998). The new float data described in this report reveal that intermediate water in the Benguela Current flows westward across the mid-Atlantic Ridge between 22S–35S versus flowing northwestward as indicated in this figure. Two anticyclonic Agulhas Current rings, which form near 40S 18E and drift northwestward are also indicated. Depth contours are 1000 m and 3000 m.

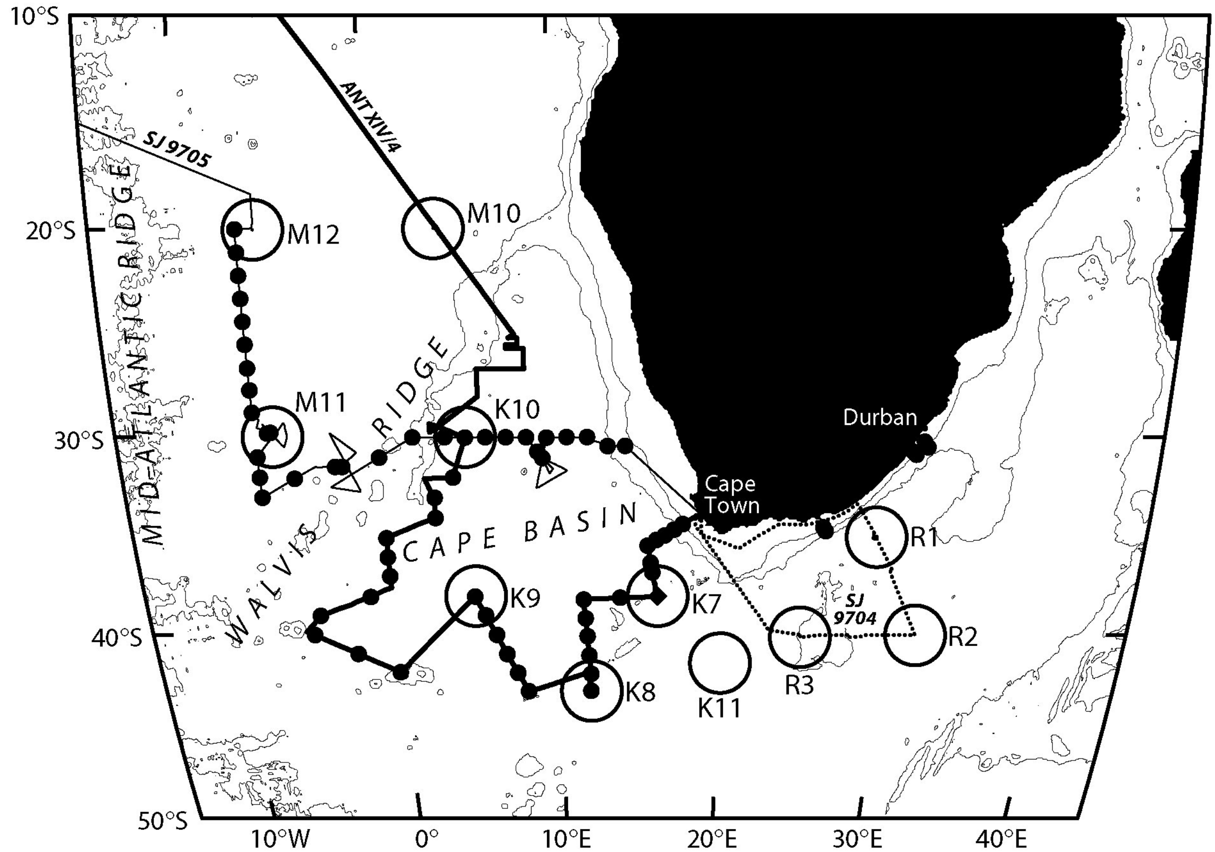

Figure 2: Location of KAPEX cruise tracklines, RAFOS float deployments (dots) and sound sources (large circles, where R is for Rhode Island, K for Kiel, and M for WHOI) (see Boebel *et al*., 1998 and Boebel *et al*., 2000). The Benguela Current experiment launched floats along 30S (nominal) and 7W on R/V *Seward Johnson* cruise SJ9705 in September 1997 from Cape Town to Recife.

(Roubicek *et al*., 1998; Garzoli *et al*., 1999). The rings were previously identified by satellite altimetry and tracked by altimetry (Garzoli *et al.*, 1999) back to their formation near the Agulhas Current retroflection located near 40S 18E.

The floats were launched along two lines, one roughly along 30S that cuts across the Benguela Current and the other along 7W that cuts across the Benguela Current extension. Seven floats were launched in the three Agulhas rings that were located near the cruise track (see Garzoli *et al*., 1999).

Floats

The RAFOS floats (see Rossby *et al*., 1986) were purchased from Seascan Corporation in Falmouth, Mass., and assembled, calibrated (temperature, pressure) and ballasted at WHOI (Tables 1, 2). The floats recorded temperature, pressure, and times of arrival (TOAs) from moored sound sources. At the end of their missions the floats dropped weights, rose to the surface and transmitted data to WHOI via the Service Argos satellite system.

The floats are quasi-isobaric and were ballasted for a depth of 750 m which lies near the center of the intermediate water layer in the Benguela Current region. The initial float depths ranged from 660 db to 800 db and the mean initial depth was 737 db (Table 1). Ten floats were programmed to record TOAs twice per day during 18-month missions; 20 floats recorded TOAs once per day during 24-month missions. Two additional ALFOS floats (ALACE–RAFOS) obtained from Webb Research Corporation were used to monitor the sound sources. These floats returned to the ocean surface for two days at monthly intervals by means of active ballasting similar to an ALACE float (Davis *et al*., 1992). At the surface they transmitted acoustic data like the RAFOS floats.

Twenty-eight (93%) of the 30 RAFOS floats successfully surfaced and transmitted data. Two floats (375, 408) were never heard and we do not know why they failed. Float 407 went too deep, dropped its weight and surfaced after two days. Floats 385 and 392 surfaced before the end of their missions because of low battery voltage. The amount of data obtained compared to the amount attempted is around 88%. Overall we obtained 46 float-years of data from the RAFOS floats. One ALFOS float ceased after 130 days, but the other continued to work successfully to February 2001, 3 1/2 years from launch.

Float Clock Corrections

In principal float clock drift can be estimated by comparing the float clock to time recorded by the Argos data system when the float surfaces. In practice we found residual errors (of unknown source) of around 20 seconds for the 18-month floats (Table 2). We calculated a further correction to the float clocks by assuming the sound source clocks were correct and by using the distances between the floats and sound sources to estimate when the last TOAs should have been recorded. The small drift of the source clocks made this possible.

Sound Sources

Three sound sources were purchased from Webb Research Corporation and were moored at depths near 800 m (Table 3). Two sources were launched from the R/V *Seward Johnson* and the third from the R/V *Polarstern*. This help from our German colleagues allowed us time to survey the three Agulhas rings. One of the three sources (M10) ceased transmitting on January 7, 1999; the other two continued to the end of the experiment and are presently aiding French float tracking in the western basin (M. Ollitrault, personal communication).

Our three sources were part of an extended KAPEX source array to track floats over a large area around South Africa (Figure 2, Table 3). Some of the Benguela Current floats drifted across the mid-Atlantic Ridge into the western South Atlantic where tracking was supplemented by the DBE acoustic array (Hogg and Owens, 1999).

Most sound sources were not retrieved so that their clock drifts could not be accurately measured. Fortunately the drift rate of the source clocks is small (< 0.01 sec/day) so that source drift is usually not a significant problem. Source clock corrections (Table 3) were estimated from the surface positions of some floats and their last recorded TOAs (see Boebel *et al*., 2000). In addition a time series of source clock corrections was generated using TOAs from the monthly surfacings of the ALFOS float. Due to a 10 sec ALFOS clock jump (for unknown reasons) and other possible errors only the relative source clock drift rates (one source relative to the others) could be estimated using the ALFOS data. The various estimates confirm small source clock drift rates.

Float Tracking

Floats were tracked using Matlab-based tracking software developed by Martin Menzel in Germany and Olaf Boebel at URI (based on URI programs) and modified by Heather Hunt Furey at WHOI. An average speed of sound of 1484 m/s was estimated from the float launch locations and first TOAs. This was then used to calculate distances between floats and sound sources using TOAs. Float positions were calculated by least square triangulation using distance time series from three sources. Gaps less than 10 days long were linearly interpolated. In general the time series data and trajectories were good quality and few problems were encountered. Position errors are estimated to be around 4 km based on this and earlier float experiments (see for example, Richardson and Wooding, 1999). Position time series were smoothed by means of a Gaussian-shaped filter ($\sigma = 1$ day) of weights 0.054, 0.244, 0.404, 0.244, and 0.054 for positions spaced at one-day intervals. An equivalent filter was applied to positions spaced at one half day (.028, .066, .124, .180, .204, .180, .124, .066, .028). This reduced random position errors, tidal and inertial fluctuations and gave nicer looking trajectories. The smoothed time series were subsampled once per day for the 18-month floats. Finally a cubic spline function was passed through the position series to calculate velocity along the trajectories.

Preliminary Results

The long-term float drifts can be seen in the displacement vectors, which connect launch locations and surface positions (Figures 3–6). All floats in the band 22S–35S went westward. Most of the floats launched east of the Walvis Ridge along 30S drifted westward across the Walvis Ridge and those launched along 7W drifted westward across the mid-Atlantic Ridge except for three floats north of 22S, which went eastward. The longest displacement vectors were from the floats launched in the three rings.

Float trajectories are more complicated than the displacement vectors but several distinctive patterns are apparent (Figures 7–10). To help see the patterns the trajectories were subdivided into two groups based on looping characteristics. In the first are looping portions of trajectories which are interpreted to be floats trapped in the swirl velocity of discrete eddies like the three Agulhas rings (R1–3, Figure 11). In the second are nonlooping portions of trajectories which are located outside of discrete eddies (Figure 12). The seven trajectories in Agulhas rings

R1–R3 showed that they translated quite steadily west northwestward at around 5 cm/sec (Figure 13). The mean velocity (and standard error) of the three rings calculated by combining the three individual mean ring velocities using the longest looping float in each ring is $\overline{u} = -5.2 \pm 0.3$ cm/sec, $\overline{v} = 1.4 \pm 0.2$ cm/sec or 5.4 cm/sec toward 286°. Ring 1 zonal velocity was $\overline{u} = -4.6$ cm/sec, smaller than the other two. This ring appeared to slow as it passed over the Walvis Ridge which reduced its mean velocity. West of the Walvis Ridge, Ring 1 translated at a mean zonal velocity of $\overline{u} = -4.9$ cm/sec, closer to the velocity of the other two rings.

In the band 22S-35S the seven 7W line floats translated westward over the mid-Atlantic Ridge (Figure 9). The average velocity over two years of these floats (391, 401, 403, 404, 410, 411 and 412) was $\overline{u} = 2.3 \pm 0.2$ cm/sec, $\overline{v} = 0.1 \pm 0.1$ cm/sec, where the standard error was calculated from the seven mean velocity values of the individual floats. Relative to this mean velocity of the background flow at 750 m the Agulhas rings translated westward at around 2.9 cm/sec and northward at around 1.3 cm/sec. The rings' northward velocity component advected ring water northward across the generally westward flowing Benguela Current extension.

North of 22S, floats 393, 405, and 409 drifted eastward in a current that clearly marked the northern boundary of the Benguela Current extension. All three floats ended up in regions of very low mean velocity, two (393 and 409) near 21S 5W. In this region the floats oscillated in a northeastward–southwestward direction with ~200 km characteristic displacements and a ~120 day period. These oscillations could be caused by Rossby waves formed in the Angola–Benguela frontal zone located equatorward of the floats.

Trajectories in the region between the Walvis Ridge and Africa are more complex than the trajectories farther west (Figures 14, 15). Note that the subsurface displacements of ALFOS float 101 were included in Figure 14. A surprising result is that all six of the easternmost floats launched along 30S (excluding floats in Ring 1 which drifted northwestward) drifted various distances southward, counter to the mean direction of the near surface Benguela Current, before crossing over the Walvis Ridge (Figure 16, 17). Three floats (392, 395, 398) drifted southward then turned and drifted northwestward in the Benguela Current. During four months of its southward drift float 395 looped in cyclone C3 and during six months of its northwestward drift, float 395 looped in anticyclone R7, possibly an Agulhas ring. Since the anticyclones are most likely Agulhas rings we label them R4–R7. Float 392 looped in cyclone C1 on the way south and float 398 looped for four months in anticyclone R5 which was translating northwestward. Two floats (101, 402) drifted quite far south, 880 km to 38.0°S for float 402 and 750 km to 36.8°S for float 101, but they both turned northward, passed close to their launch locations after 12 months (402) and 17 months (101) and subsequently turned westward. Float 402 looped for nine months in cyclone C2 that went, generally, westward. These two floats (101, 402) imply large-amplitude low-frequency fluctuations of meridional velocity east of the Walvis Ridge. The sixth float (397) initially drifted westward around the northern side of ring R1, then dipped southward 3.2° near the Walvis Ridge and was entrained into anticyclone R5, and then turned northwestward. Taken together these six floats imply that a large amount of southward flow occurred in the region east of the Walvis Ridge at least during the first several months of the float experiment and possibly longer. All six floats eventually turned more westward in the Benguela Current and its extension clearly showing that the southward flow feeds into the Benguela Current.

The floats in the Cape Basin east of Walvis Ridge revealed the general translation of eddies there, northwestward for three anticyclones and one cyclone, southwestward for two cyclones (Figure 15). Floats in three eddies (R4, R5, C2) that encountered the Walvis Ridge stopped looping, implying a disruption of the normal eddy swirl velocity by the Ridge. Because of the intense eddy motions and the low-frequency fluctuations in this complicated eastern region, the six floats do not give a very accurate picture of the mean circulation there. They do show that mesoscale eddies are energetic and strongly advect the floats.

Summary

In general the floats and sound sources worked well, and high quality data were obtained. The floats were successfully tracked throughout a wide region of the South Atlantic using a large array of sources. The floats were carefully ballasted as seen in their consistent initial depths. Only one float was either ballasted too deep or leaked which caused it to sink below its safe depth, to drop its weight and to return to the surface. Two other floats were never heard for unknown reasons. Overall the success rate was around 90% based on obtaining trajectories from 27 of the 30 RAFOS floats. A total of 46 float-years of trajectories was obtained. Interesting preliminary results concern the translation of Agulhas rings and other eddies, the complicated inflow to the Benguela Current, the rather steady westward flow in the Benguela Current extension over the mid-Atlantic Ridge, and an eastward current located at the northern edge of the Benguela extension.

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Table I
Benguela Current Floats

Float	Posi-tions per day	Launch Date	Launch Lat (°S)	Launch Lon (°E)	Surface Date	Surface Lat (°S)	Surface Lon (°E)	Initial Press (db)	Initial Temp (°C)	CTD Station	Comments
RAFOS:											
375	2	970914	31.449	-2.270	990305	--	--	--	--	19	Not heard
376	2	970914	31.449	-2.588	990305	26.837	-21.147	800	8.1	20	Ring 2
383	2	970909	30.830	9.212	990301	30.892	0.056	770	7.3	8	Ring 1
384	2	970911	30.003	1.998	990305	28.075	-2.115	710	5.2	17	
385	2	970909	30.704	9.113	980731	27.850	4.270	790	6.4	9	Ring 1, low battery
386	2	970915	32.048	-4.995	990308	31.659	-14.745	740	5.7	24	
387	2	970917	29.781	-6.087	990309	24.406	-25.539	770	7.4	28	Ring 3
388	2	970910	30.000	3.832	990304	30.938	-5.059	720	5.3	16	
390	2	970909	30.976	9.337	990301	24.780	-12.059	770	7.4	7	Ring 1
391	1	970919	24.399	-6.999	990909	22.691	-20.354	690	5.2	37	
392	1	970905	30.420	14.161	990321	32.513	-2.855	660	4.7	2	Low battery
393	1	970920	22.200	-7.001	990910	21.427	-6.396	730	4.8	39	
394	2	970911	30.999	-0.002	990304	28.334	-18.913	750	5.3	18	Entrained into Ring2
395	1	970909	30.000	7.333	990830	32.447	-4.121	750	5.2	13	
396	1	970910	30.002	4.996	990830	26.504	-11.480	730	5.2	15	
397	1	970907	30.012	9.660	990827	27.047	-7.203	750	4.7	6	
398	1	970906	29.985	10.812	990827	26.532	-4.530	750	4.7	5	
399	1	970917	29.813	-6.275	990907	24.733	-29.788	780	6.8	29	Ring 3
401	1	970918	28.800	-7.001	990907	27.881	-17.961	730	5.5	33	
402	1	970906	29.986	11.986	990827	29.169	-2.582	740	4.9	4	
403	1	970918	27.701	-6.999	990908	28.408	-26.035	730	5.2	34	
404	1	970919	25.499	-6.998	990908	23.225	-21.583	770	5.3	36	
405	1	970920	19.999	-7.000	990910	20.128	-2.089	740	4.9	41	
406	1	970911	30.000	6.161	990830	34.555	-15.605	790	4.6	14	
407	1	970906	30.427	13.148	970907	30.277	12.976	--	--	3	Too deep
408	1	970915	32.995	-7.010	990904	--	--	--	--	25	Not heard
409	1	970920	21.097	-7.000	990910	22.569	-3.329	660	5.2	40	
410	1	970920	23.299	-6.999	990909	23.817	-22.54	680	5.3	38	
411	1	970915	31.997	-6.998	990905	29.611	-20.44	700	5.9	26	
412	1	970916	30.992	-7.000	990905	34.377	-21.31	710	5.7	27	
ALFOS:											
101	--	970909	29.999	8.499	010106	23.471	-15.46	710	4.7	12	
102	--	970919	26.637	-6.995	980123	27.058	-5.803	710	4.9	35	

The mean initial depth and temperature of the RAFOS floats is 737 ± 7 db and 5.6 ± 0.2°C. The ring floats were the deepest and warmest 780 ± 5db and 7.2 ± 0.2°C because of the depression of the thermocline in the center region of the rings. The mean initial depth and temperature of floats launched outside rings was 725 ± 7 db and 5.1 ± 0.1°C.

Table 2: Float Clock Drifts and Calibration Coefficients

Float No.	Clock Drift (sec)	Add'l Drift (sec)	Net Drift (sec)	Temperature Logarithmic Coefficients a	b	c	Pressure Linear Coefficients a	b
376	-39.7	-15.7	-55.4	3.144	0.2669	0.0070	-5.7	278.1
383	-14.0	-21.3	-35.3	3.142	0.2680	0.0069	-12.5	274.7
384	15.0	-21.4	-6.4	3.142	0.2682	0.0067	-7.4	278.3
385	-7.6	-- [a]	-7.6	3.144	0.2658	0.0070	1.8	276.0
386	72.6	-18.7	53.9	3.144	0.2666	0.0072	-23.8	276.5
387	-13.3	-22.4	-35.7	3.145	0.2661	0.0069	-9.9	273.8
388	-13.6	-22.0	-35.6	3.145	0.2671	0.0068	11.9	277.5
390	-5.6	-20.9	-26.5	3.145	0.2670	0.0066	2.1	272.1
391	-43.3	-1.9	-45.2	3.142	0.2675	0.0069	0.8	277.9
392	-61.4	-- [a]	-61.4	3.143	0.2673	0.0070	7.6	274.4
393	-37.5	0.5	-37.0	3.145	0.2666	0.0068	18.8	277.3
394	-28.5	-22.2	-50.7	3.144	0.2682	0.0066	-8.5	272.5
395	-54.6	-4.8	-59.4	3.142	0.2692	0.0067	2.5	277.5
396	-24.1	-- [a]	-24.1	3.142	0.2688	0.0067	9.6	278.5
397	-51.7	-15.6	-67.3	3.142	0.2684	0.0069	8.8	280.0
398	-23.3	-15.5	-38.8	3.142	0.2694	0.0067	-9.1	277.3
399	-18.2	-1.9	-20.1	3.142	0.2663	0.0070	4.5	277.2
401	-60.3	-1.5	-61.8	3.147	0.2655	0.0070	-16.8	277.4
402	-49.9	0.2	-49.7	3.145	0.2665	0.0068	-8.1	277.7
403	-53.3	-2.0	-55.3	3.144	0.2676	0.0069	-27.2	278.0
404	-50.5	1.6	-48.9	3.146	0.2663	0.0069	17.5	276.5
405	-54.6	-1.5	-56.1	3.144	0.2665	0.0069	-1.0	278.7
406	-45.7	4.0	-41.7	3.142	0.2672	0.0069	-0.8	277.1
409	-46.3	5.4	-40.9	3.144	0.2673	0.0070	-28.3	277.7
410	-45.4	-1.7	-47.1	3.127	0.2852	0.0047	0.2	275.7
411	-44.1	-0.6	-44.7	3.147	0.2645	0.0072	-15.8	273.5
412	-50.8	0.8	-50.0	3.144	0.2683	0.0068	10.3	276.3

a) No TOA recorded immediately before float surfaced.

"Clock drift" is the total drift of the clock over the duration of the mission calculated by comparing the float clock to the Argos satellite clock when the float surfaced and by adjusting for the initial offset at launch. The "additional drift" was calculated using the last recorded TOA before surfacing, the distance between the source and the surface position of the float, and the estimated speed of sound. These two drift rates were added to obtain the "net drift." The 18 month floats required a rather large ~20 sec additional drift correction for unknown reasons. Temperature was measured with Yellow Springs Instrument Company thermistors model 44032 which were calibrated in a water bath. The overall accuracy is approximately ±0.01°C based on the residuals to the curve through calibration points. The temperature coefficients determined by calibration are listed and corrected temperature T is calculated by using $T = [1000/(a + bt + ct^3)] - 273.16$, where $t = \log((tcounts + 1000)/1000)$. Pressure was measured with Data Instruments EAF pressure transducers which were calibrated in a pressure tank. Corrected pressure (db) is given by $P = a + bp$ where p is float pressure in counts divided by 1000. The residuals about the linear fit to the calibrated pressures suggests the accuracy of pressure is around ±1 db. See Hunt *et al.* (1998) for a more complete description of the calculation of temperature and pressure.

Table 3
Sound Sources

Source ID [a]	Source Site [b]	Transmit Time (GMT) [c] hr:min:sec	Clock drift [d] (sec)	Transmit Interval (hours)	Source Depth (m)	Latitude (°S)	Longitude (°E)	Start Date	End Date	Comments
194	M5	01:00:00	0.0054	24	2100	14.094	-30.061	950223	--	
195	M6	00:30:00	0.0056	24	2070	22.108	-33.634	950309	--	
196	M9	01:00:00	0.0067	24	2130	27.131	-30.605	950310	--	
197	M8	00:30:00	0.0035	24	2040	27.097	-20.197	950314	--	
198	M7	01:29:25	0.0058	24	2160	19.737	-22.713	950316	--	
007	K7	01:30:00	0.0000	12	990	37.988	16.095	970324	980922	Bad clock
008	K8	01:00:07	0.0000	12	1000	42.960	11.972	970326	--	
009	K9	00:30:05	0.0000	12	960	37.983	5.085	970329	--	
010	K10	01:00:04	0.0000	12	1130	30.002	5.007	970404	990514	Retrieved
011	M11	01:30:00	0.0000	12	800	29.986	-5.978	970916	--	
012	M12	01:00:00	0.0000	12	800	20.010	-6.024	970920	--	
020	M10	00:30:04	0.0000	12	740	19.935	3.942	970408	990107	Died
005	B5	00:30:00	0.0000	24	1150	27.000	-40.000	971129	--	

a) Sources 194-198 were deployed as part of the Brazil Deep Basin Experiment (DBE) (Hogg and Owens, 1999). B5 was deployed in support of SAMBA (Ollitrault, 1999). All other sources were deployed as part of KAPEX.

b) M = WHOI, K = German (IFM-Kiel), and B = French (IFREMER).

c) The sound sources transmitted an 80-second swept acoustic signal which linearly increased from 259.4Hz to 260.9Hz. Clock offsets were applied to the transmit times to adjust for estimated clock corrections for sources 8, 9, 10 and 20.

d) Clock drift is in seconds per transmission interval. The clock drifts of the DBE sources were estimated from previous instrument recoveries.

Appendix A: Summary Figures Showing Preliminary Results

Figures 3–17 show float displacement vectors and trajectories, subdivided by float deployments in different geographical areas (30S, 7W, and Cape Basin) and into floats looping in eddies and floats outside of eddies. Observed eddies include counterclockwise rotating Agulhas Current rings and clockwise rotating cyclones.

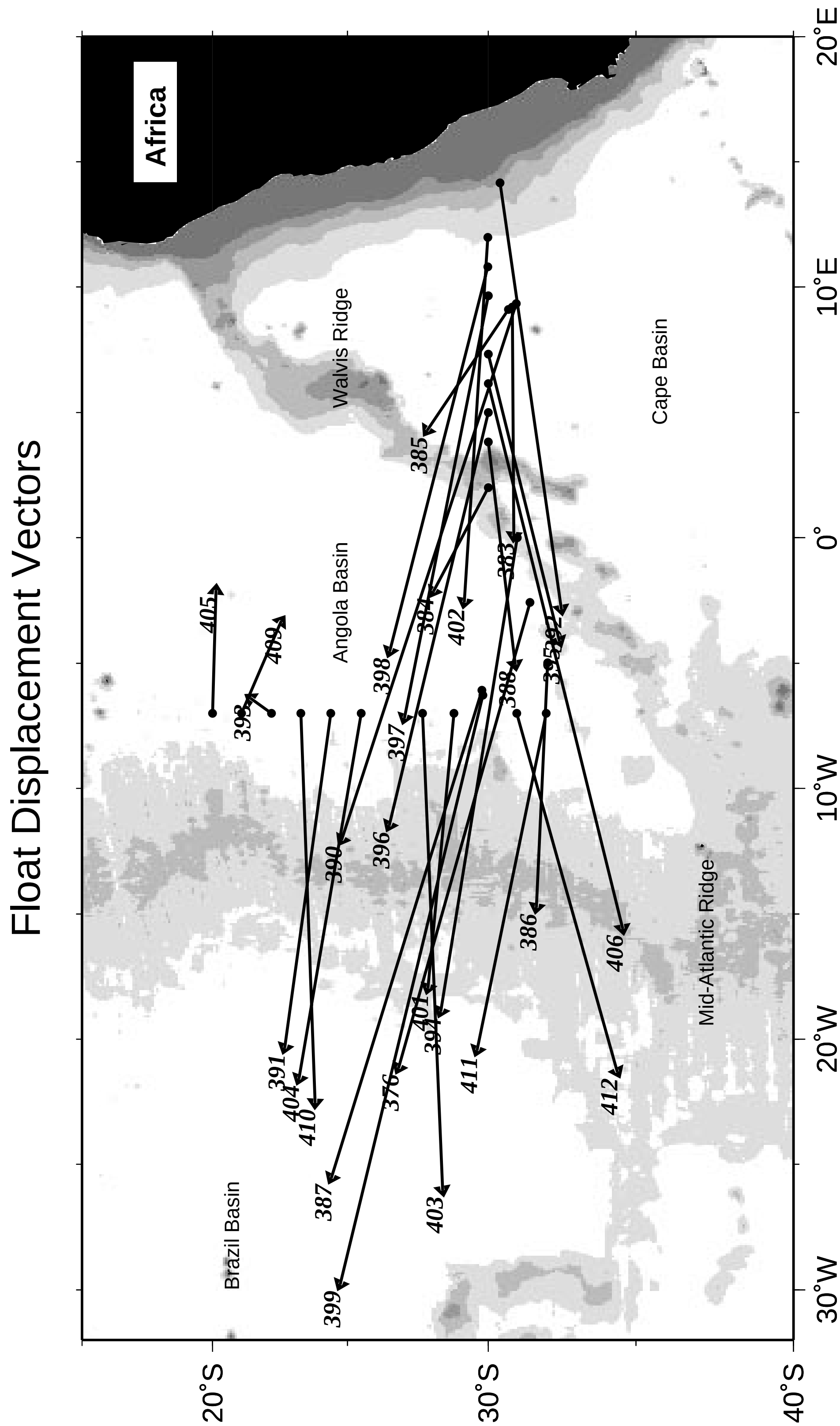

Float Displacement Vectors
Africa
Walvis Ridge
Angola Basin
Cape Basin
Brazil Basin
Mid-Atlantic Ridge
20°E
10°E
0°
10°W
20°W
30°W
20°S
30°S
40°S
405
409
385
398
384
402
383
388
397
396
390
386
406
401
391
404
410
376
411
412
387
403
399

Figure 3

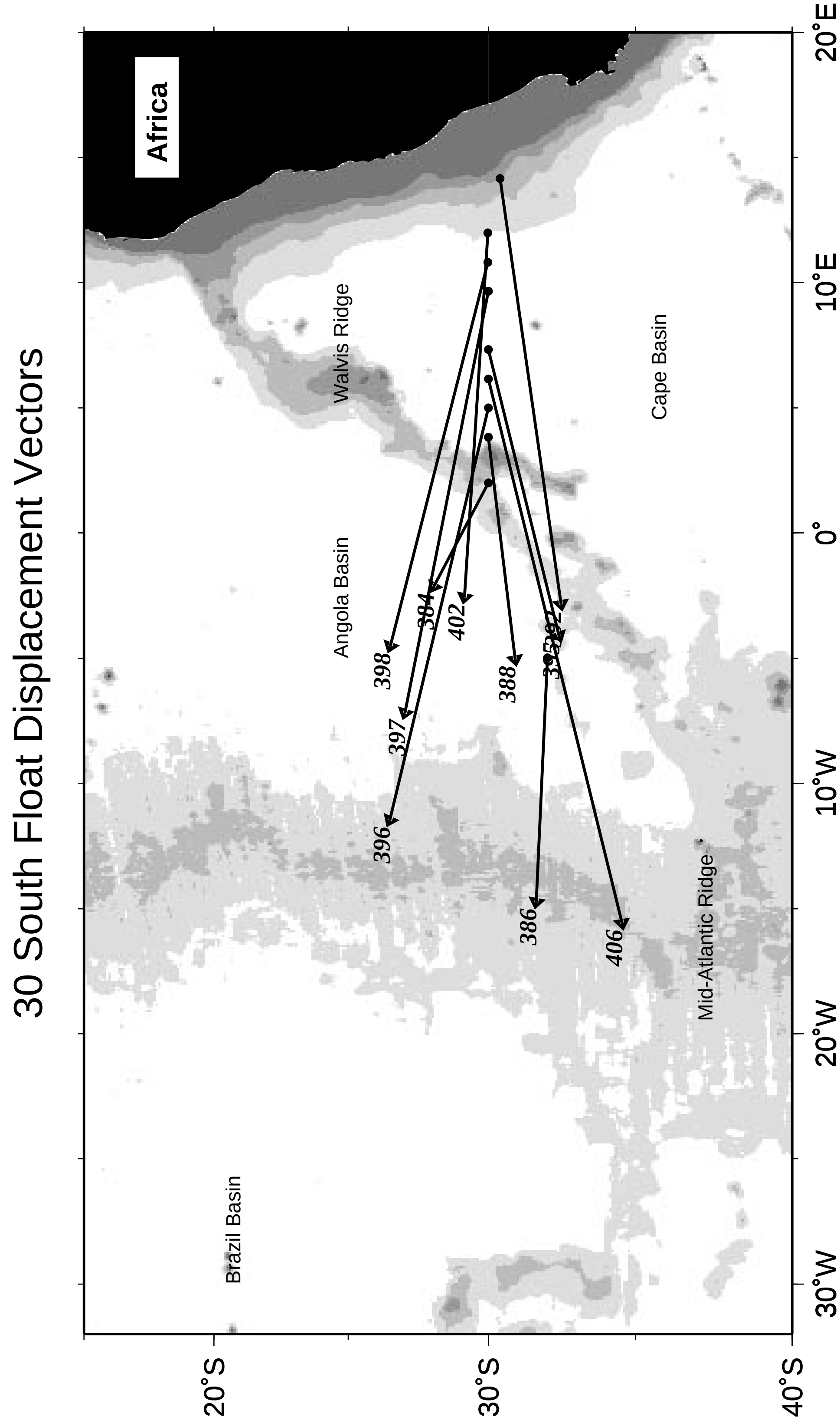

30 South Float Displacement Vectors
Africa
Walvis Ridge
Cape Basin
Angola Basin
Mid-Atlantic Ridge
Brazil Basin
384
402
398
397
396
388
386
406
20°E
10°E
0°
10°W
20°W
30°W
20°S
30°S
40°S

Figure 4

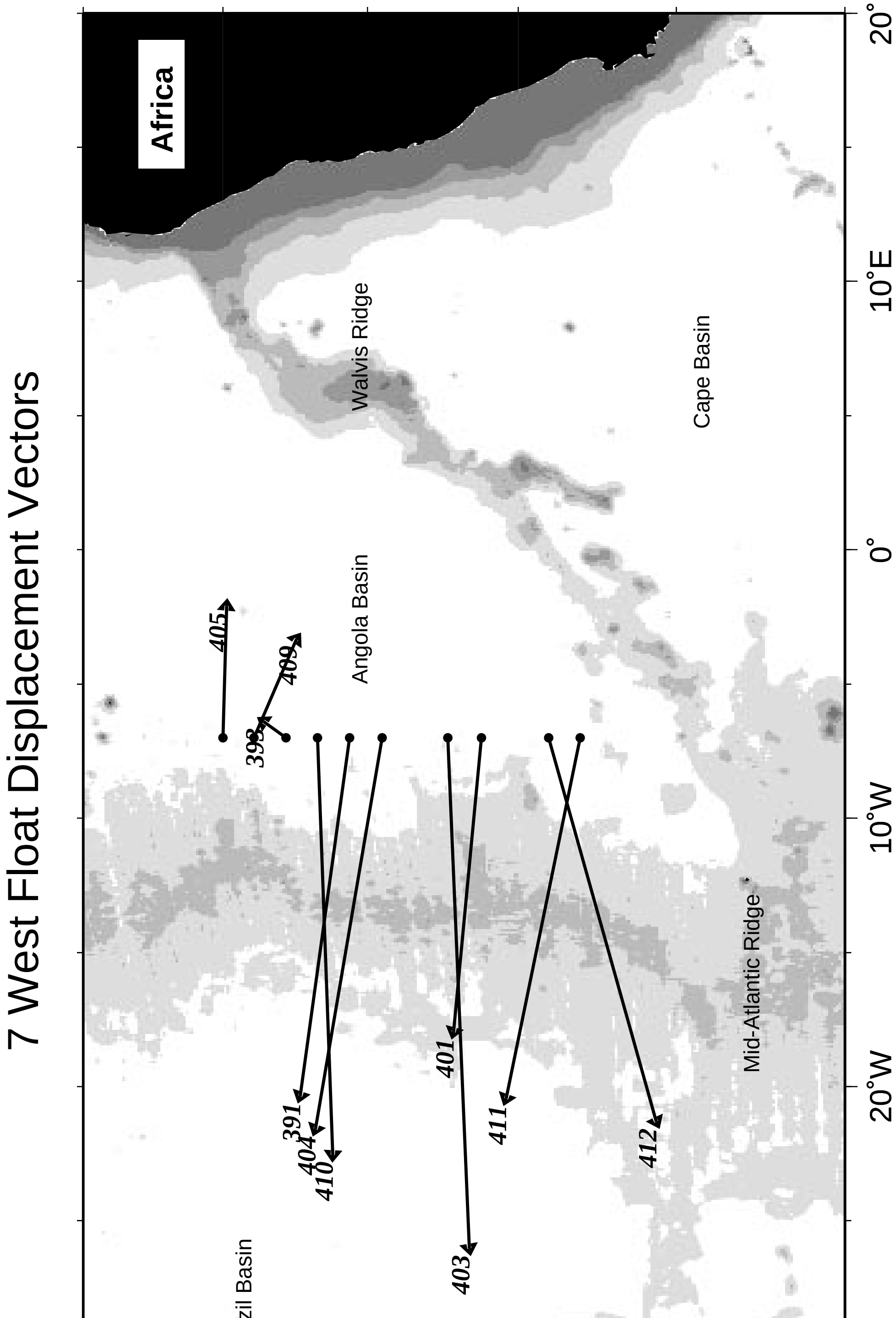
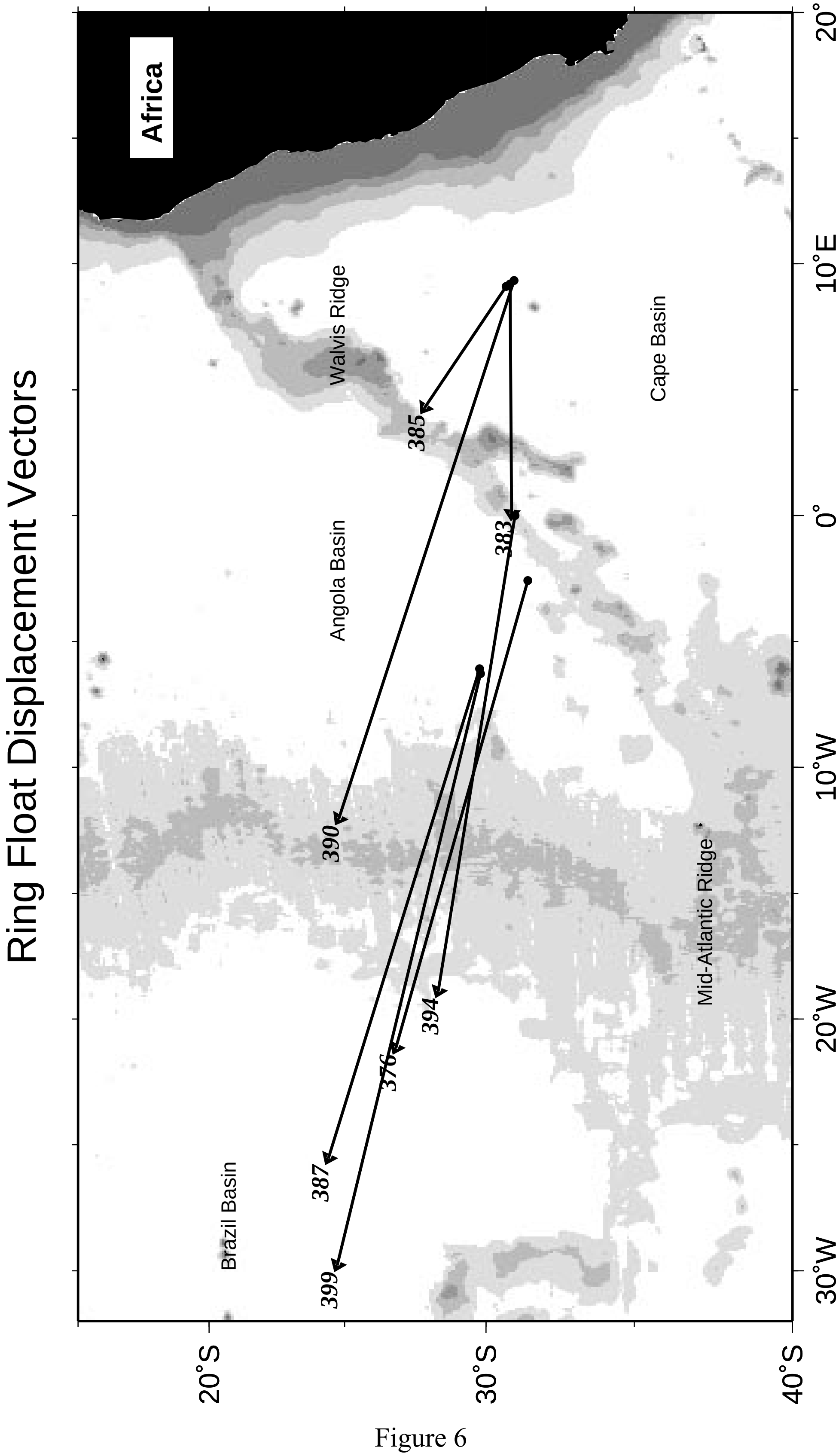
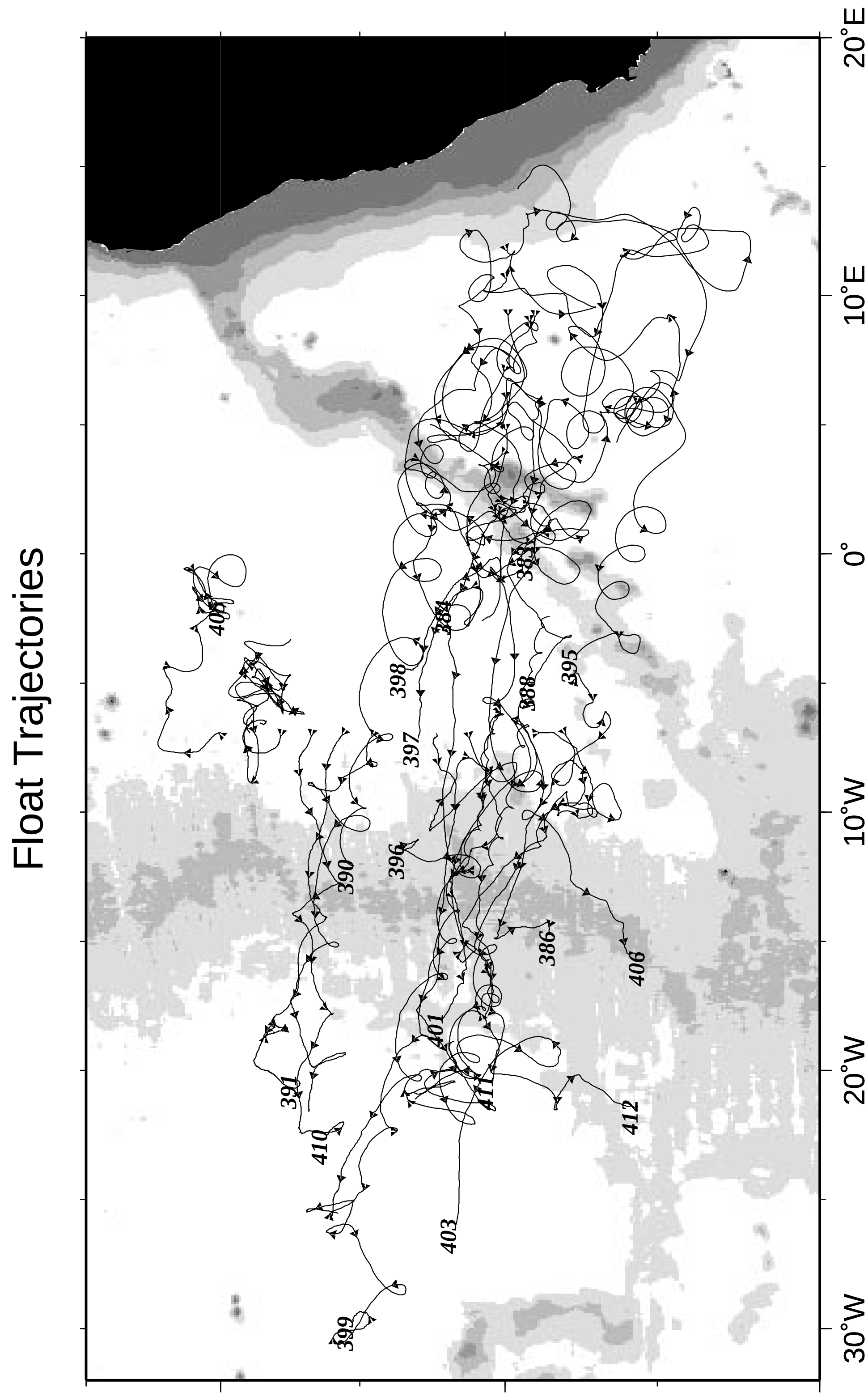

7 West Float Displacement Vectors
Africa
Walvis Ridge
Cape Basin
Angola Basin
Mid-Atlantic Ridge
Brazil Basin
405
409
398
391
404
410
401
403
411
412
20°S
30°S
40°S
30°W
20°W
10°W
0°
10°E
20°E

Figure 5



Ring Float Displacement Vectors
Africa
Walvis Ridge
Cape Basin
Angola Basin
Mid-Atlantic Ridge
Brazil Basin
385
383
390
394
376
387
399
20°E
10°E
0°
10°W
20°W
30°W
20°S
30°S
40°S

Figure 6



Float Trajectories
20°S
30°S
40°S
30°W
20°W
10°W
0°
10°E
20°E
399
403
410
391
411
412
401
386
406
390
396
397
398
388
395
384
385
405

Figure 7

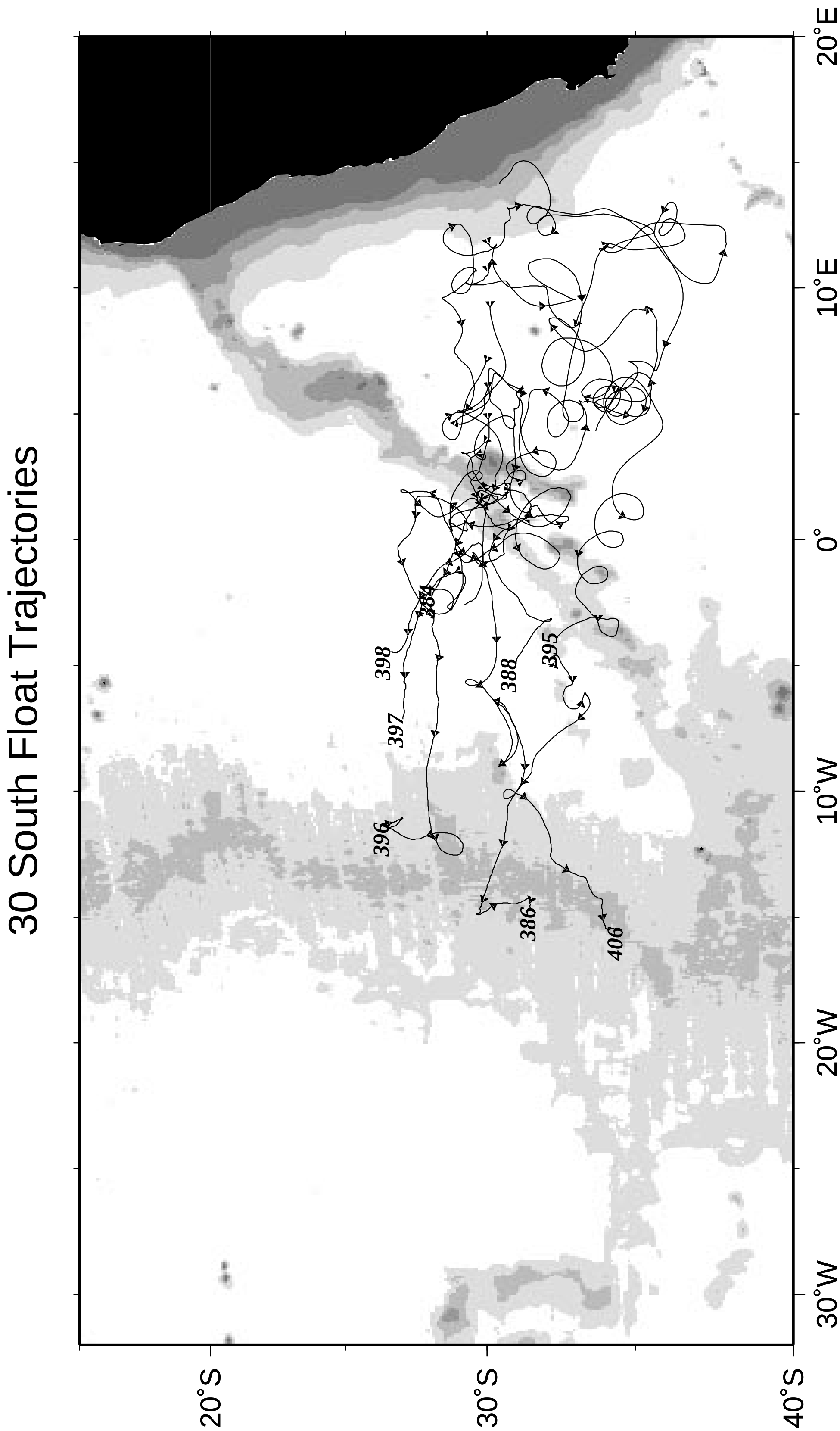

30 South Float Trajectories
20°E
10°E
0°
10°W
20°W
30°W
20°S
30°S
40°S
398
397
396
388
395
386
406
384

Figure 8

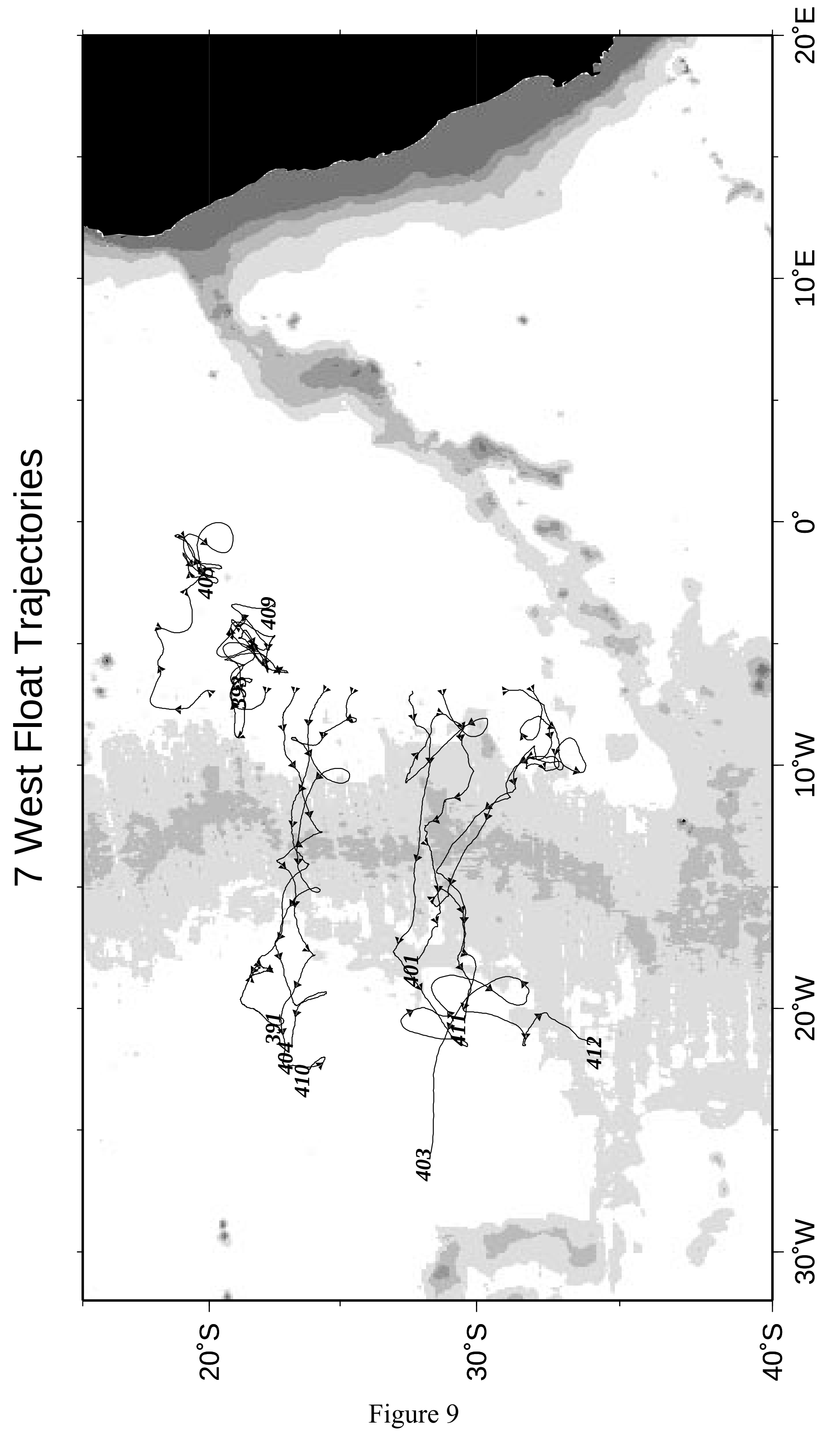
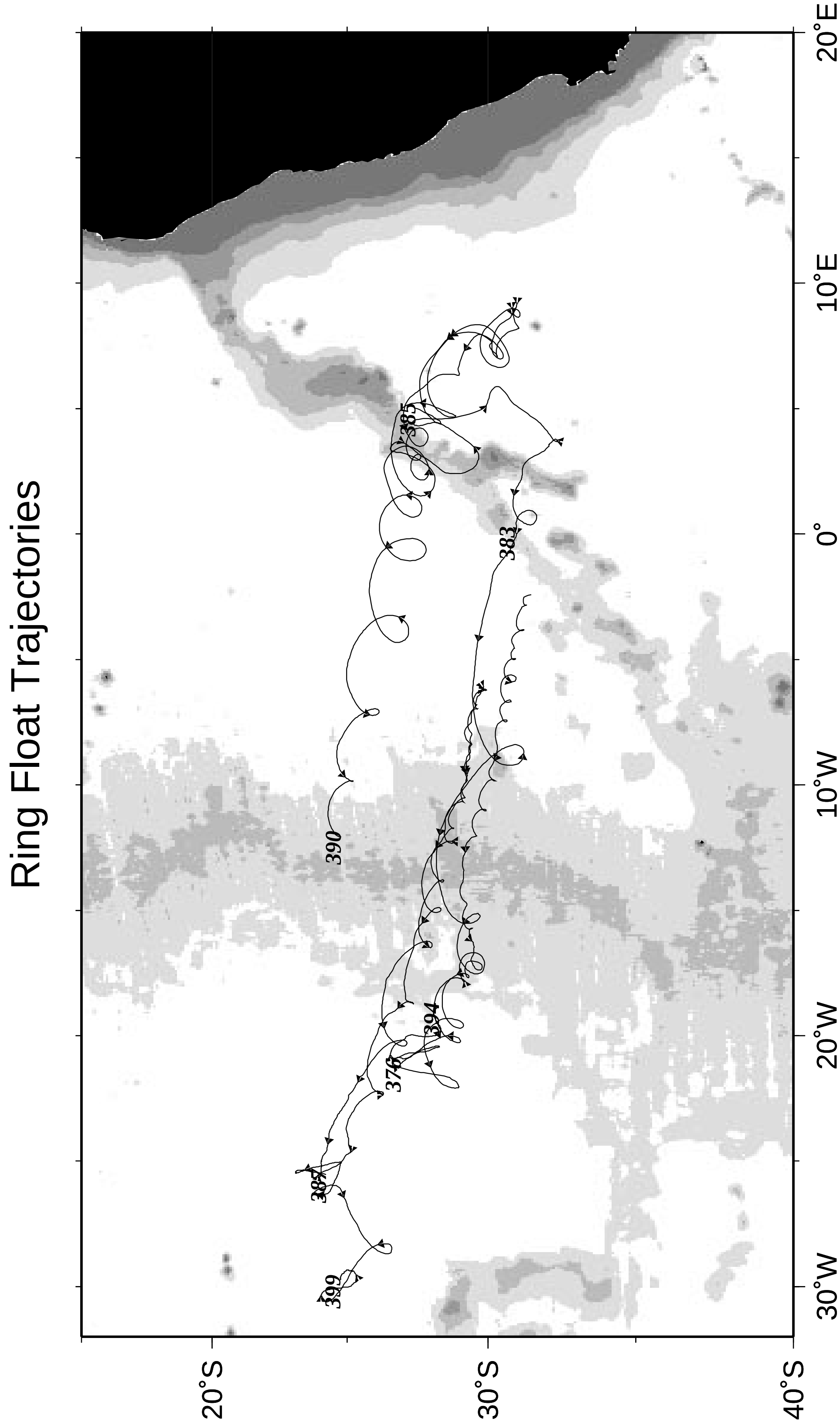

7 West Float Trajectories
20°E
10°E
0°
10°W
20°W
30°W
20°S
30°S
40°S
409
401
391
404
410
411
412
403

Figure 9



Ring Float Trajectories
20°E
10°E
0°
10°W
20°W
30°W
20°S
30°S
40°S
385
383
390
394
376
387
399

Figure 10

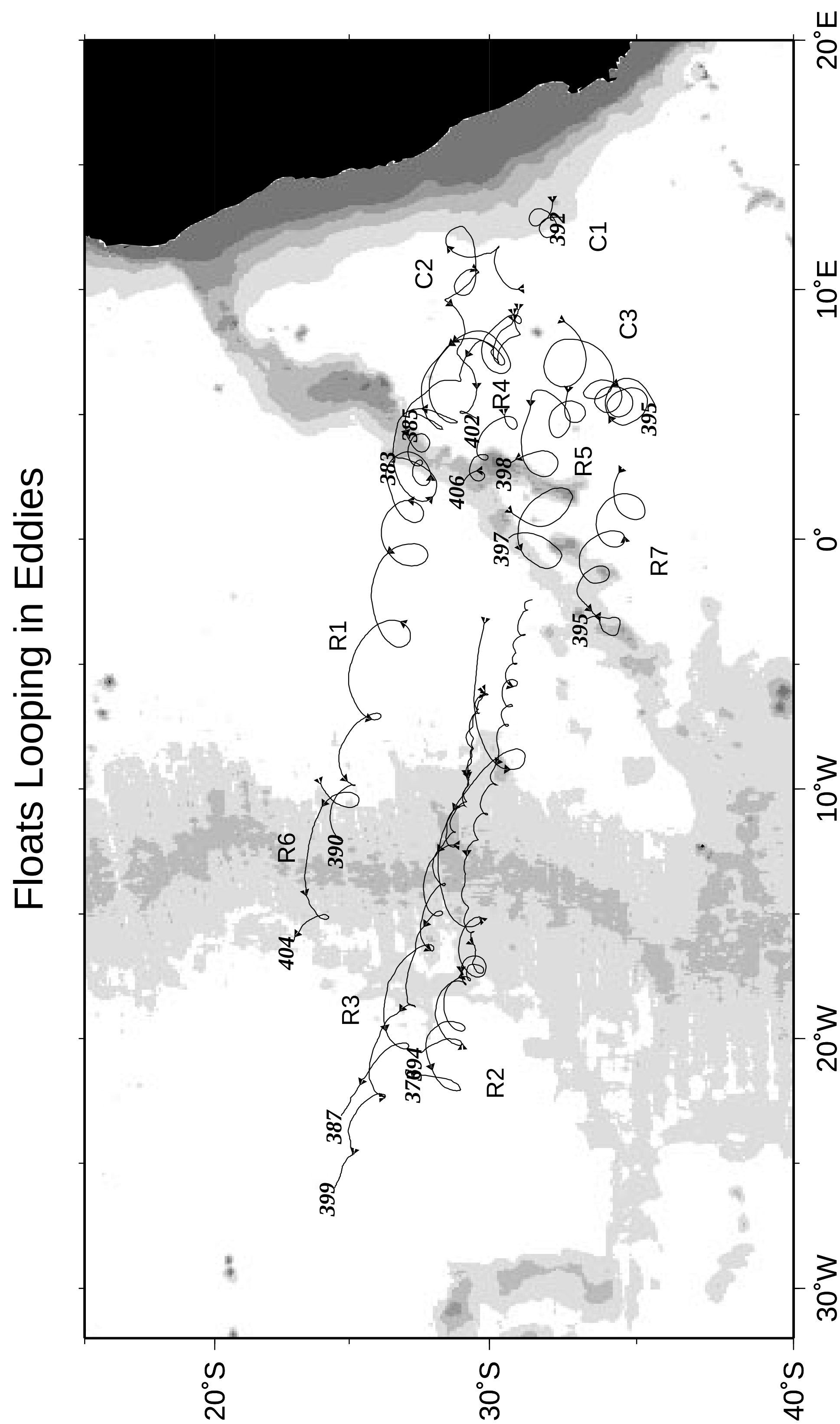

Floats Looping in Eddies
20°E
10°E
0°
10°W
20°W
30°W
20°S
30°S
40°S
C1
C2
C3
R1
R2
R3
R4
R5
R6
R7
383
385
387
390
392
395
397
398
399
402
404
406

Figure 11

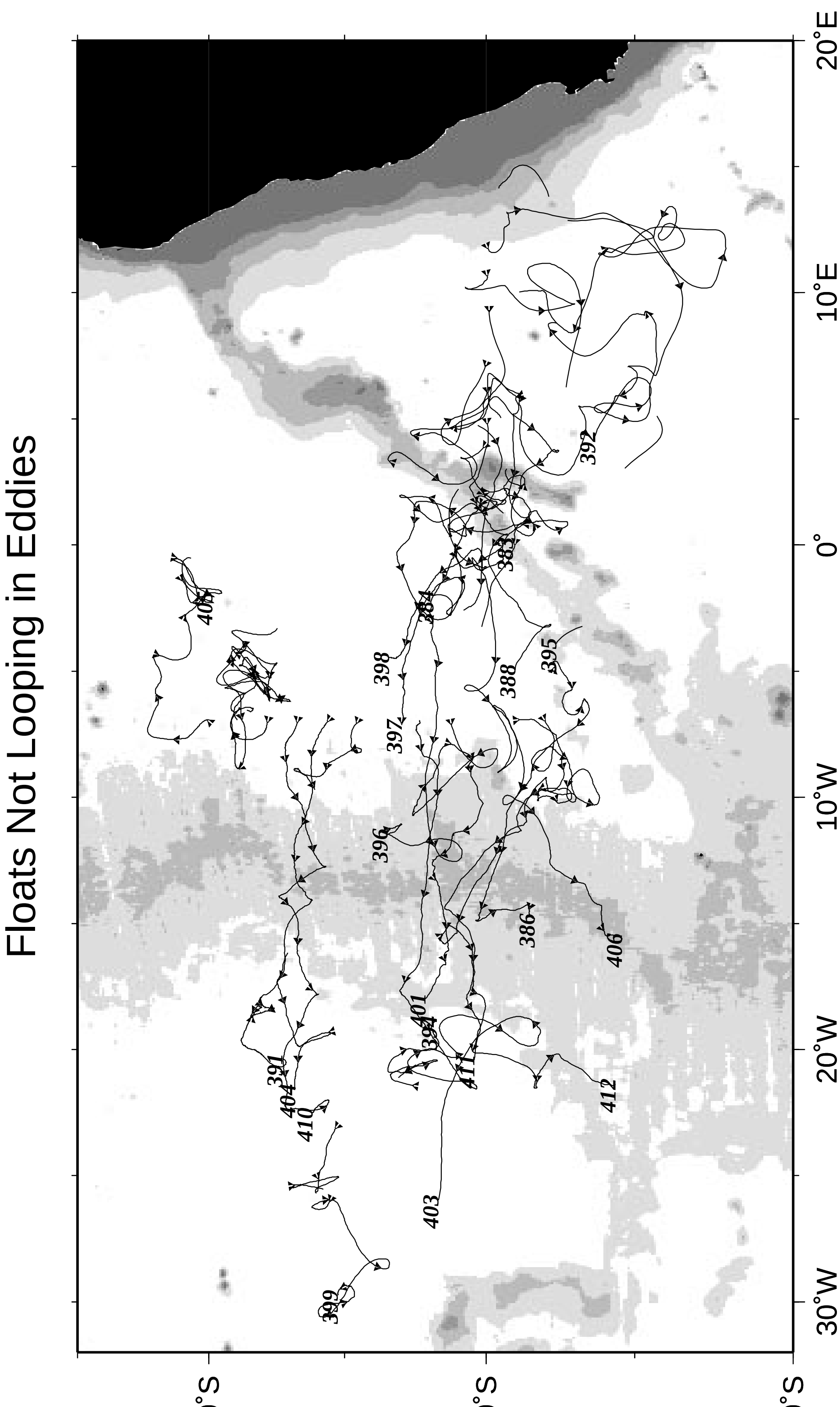

Floats Not Looping in Eddies
20°S
30°S
40°S
30°W
20°W
10°W
0°
10°E
20°E
392
383
384
395
388
398
397
396
386
406
401
394
411
412
391
404
410
403
399
405

Figure 12

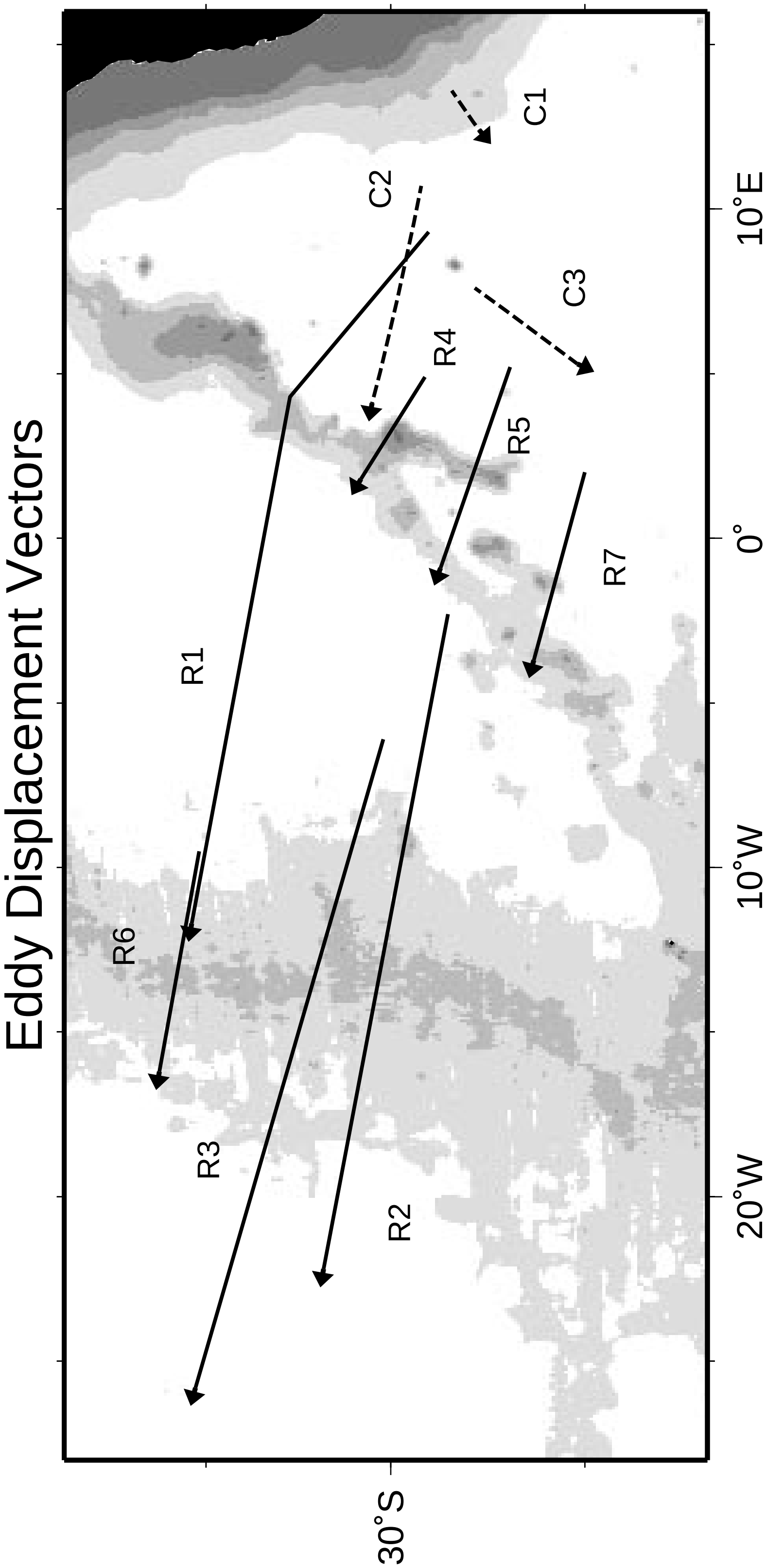

Eddy Displacement Vectors
C1
C2
C3
R1
R2
R3
R4
R5
R6
R7
10°E
0°
10°W
20°W
30°S

Figure 13

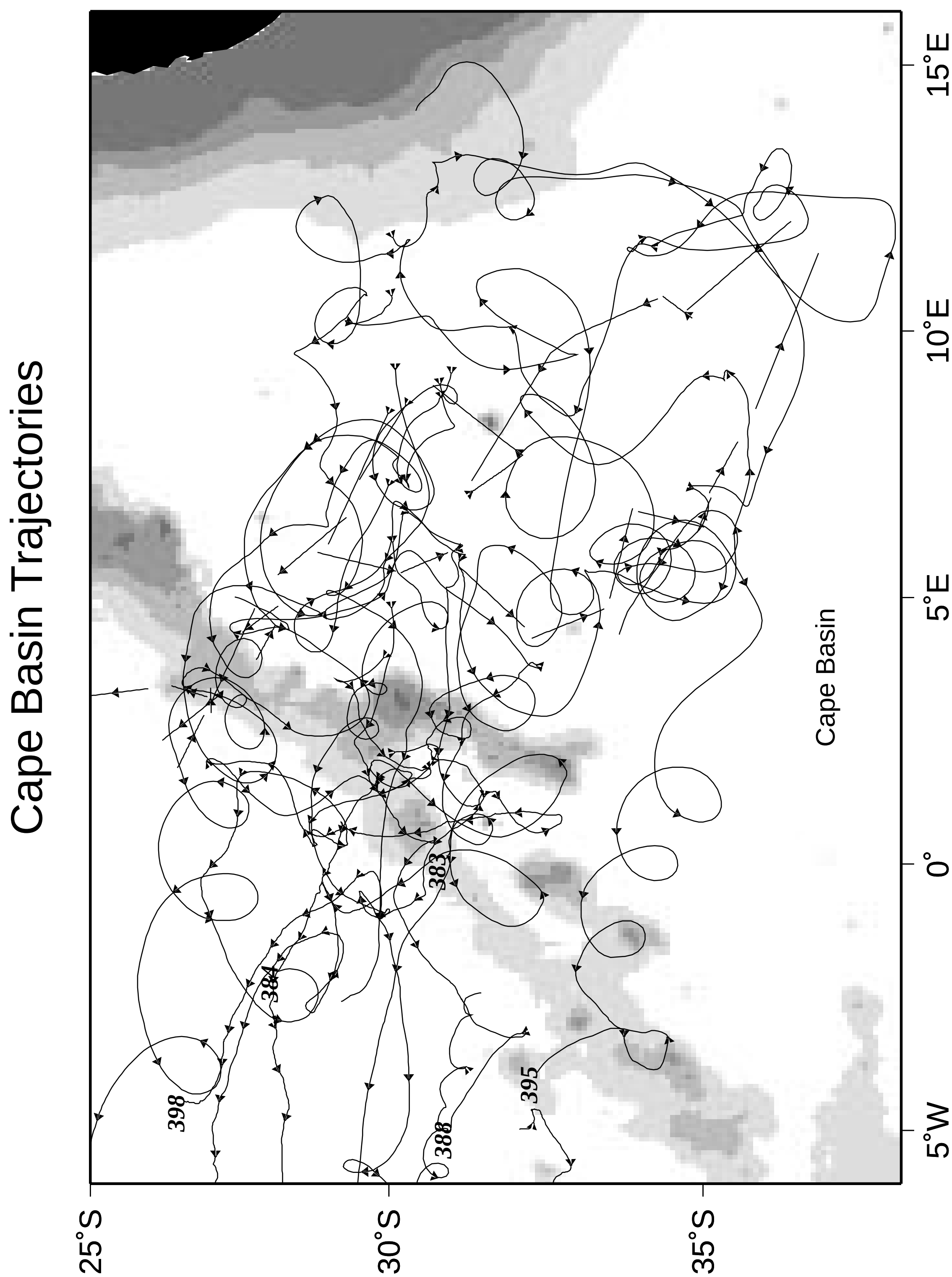

Cape Basin Trajectories
Cape Basin
25°S
30°S
35°S
5°W
0°
5°E
10°E
15°E
398
384
383
395

Figure 14

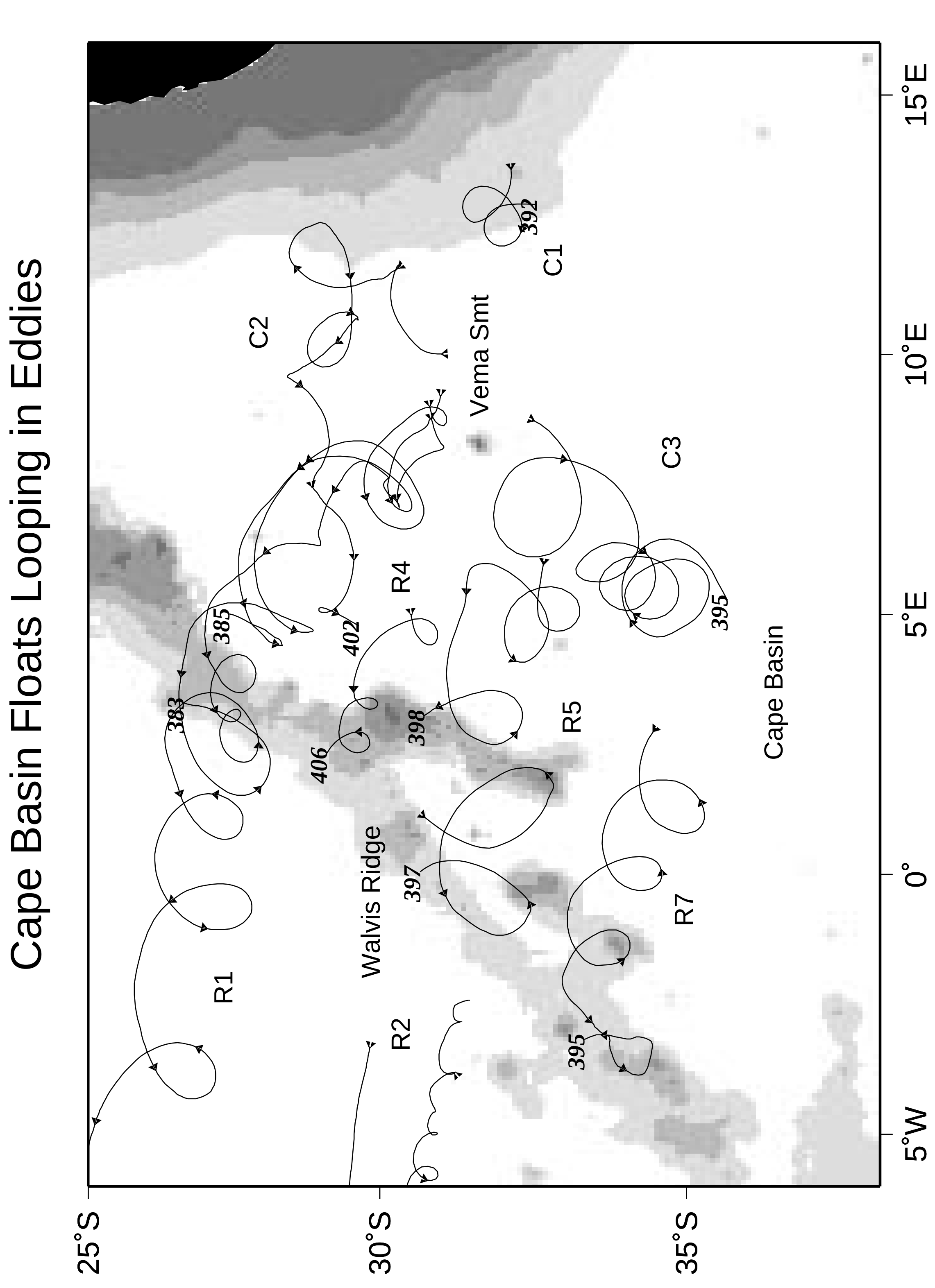

Cape Basin Floats Looping in Eddies
25°S
30°S
35°S
5°W
0°
5°E
10°E
15°E
R1
R2
Walvis Ridge
R4
R5
R7
C1
C2
C3
Vema Smt
Cape Basin
383
385
392
395
397
398
402
406

Figure 15

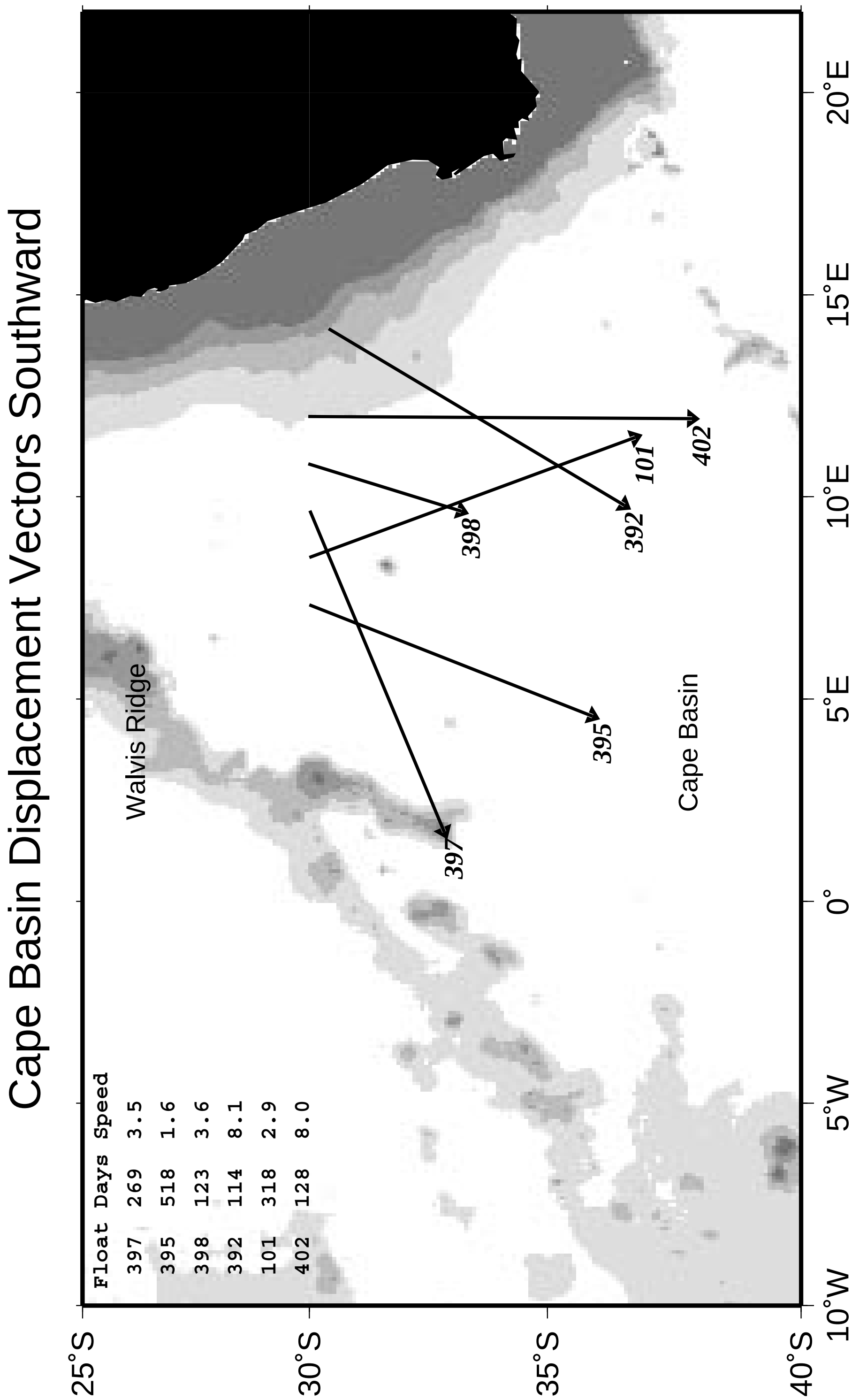


Figure 16: Southward displacements of the easternmost six floats launched along 30S (excluding floats in ring 1 which translated northwestward). Displacement vectors are drawn between the float launch locations and the southernmost points of each trajectory. The southernmost displacement of ALFOS float 101 is included even though its subsurface drift was interrupted when the float surfaced for 2 days every month. The accumulated surface displacement of 101 on its way southward is 77 km northwestward, counter to the overall southward displacement of 800 km.

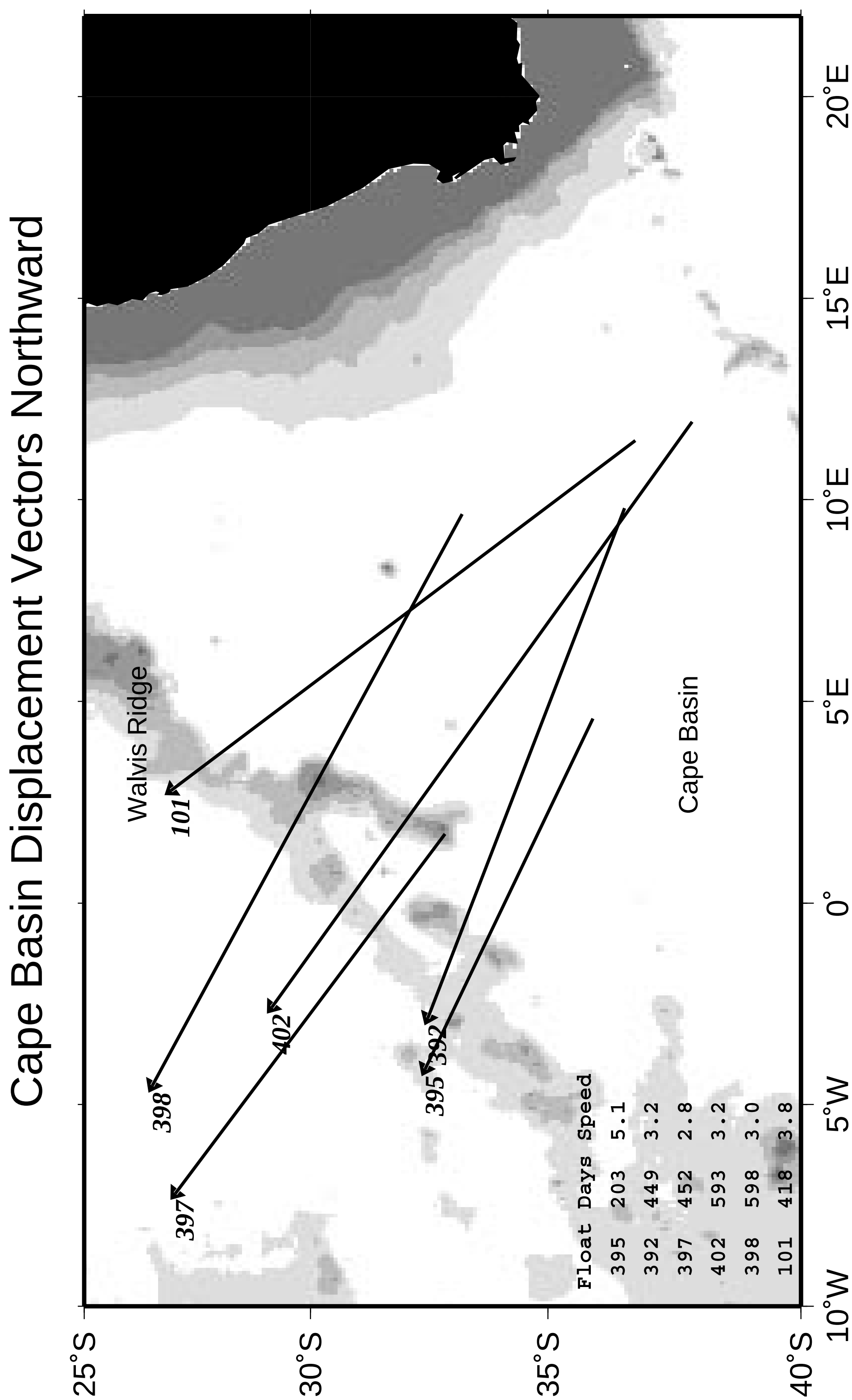
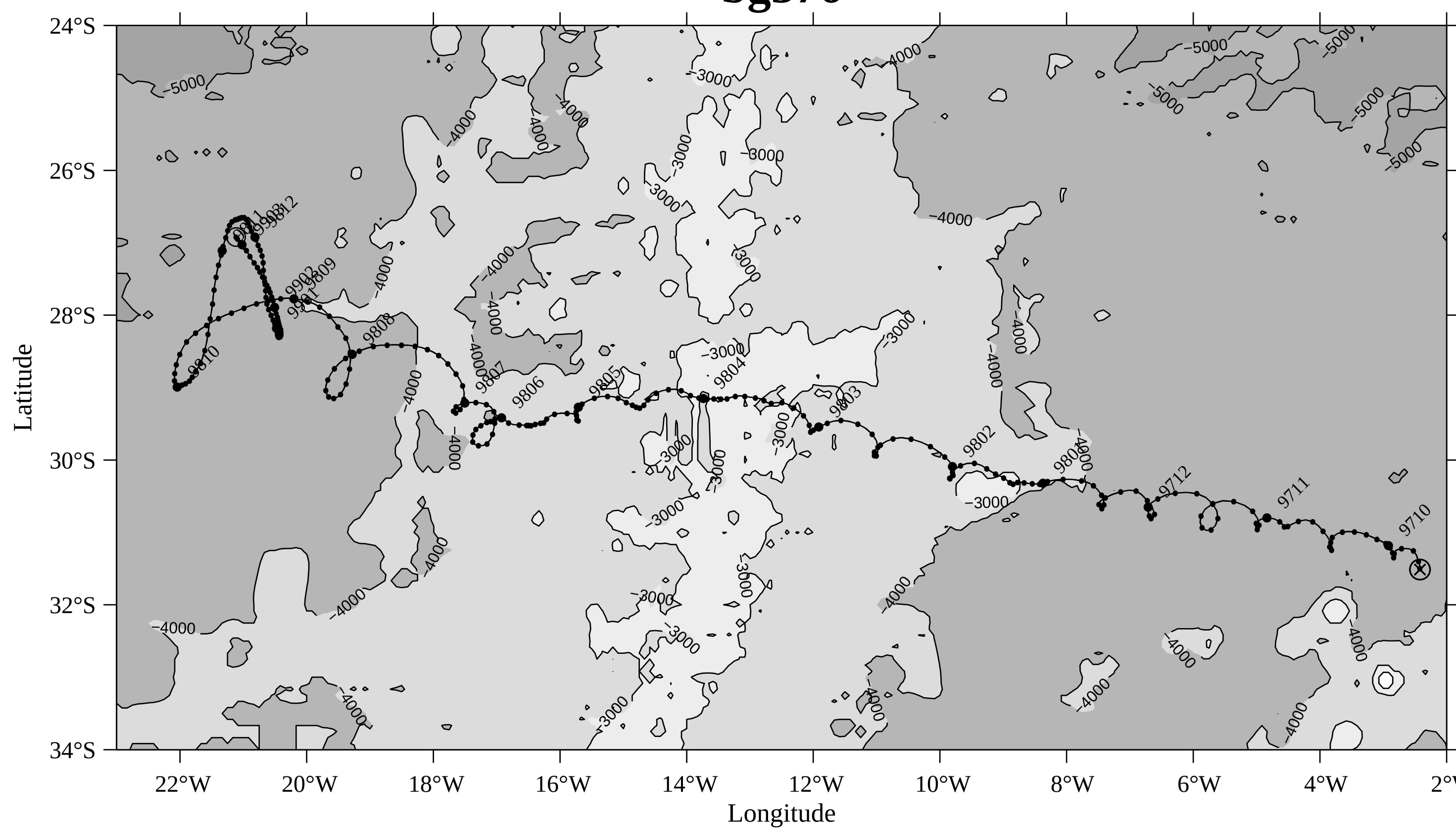


Figure 17: Displacement vectors between the southernmost points shown in Figure 16 and the surface positions at the end of the float mission (after two years). Floats 101 and 402 returned northward and passed close to their launch locations before turning more westward, implying low frequency variations in the meridional flow off the eastern boundary.

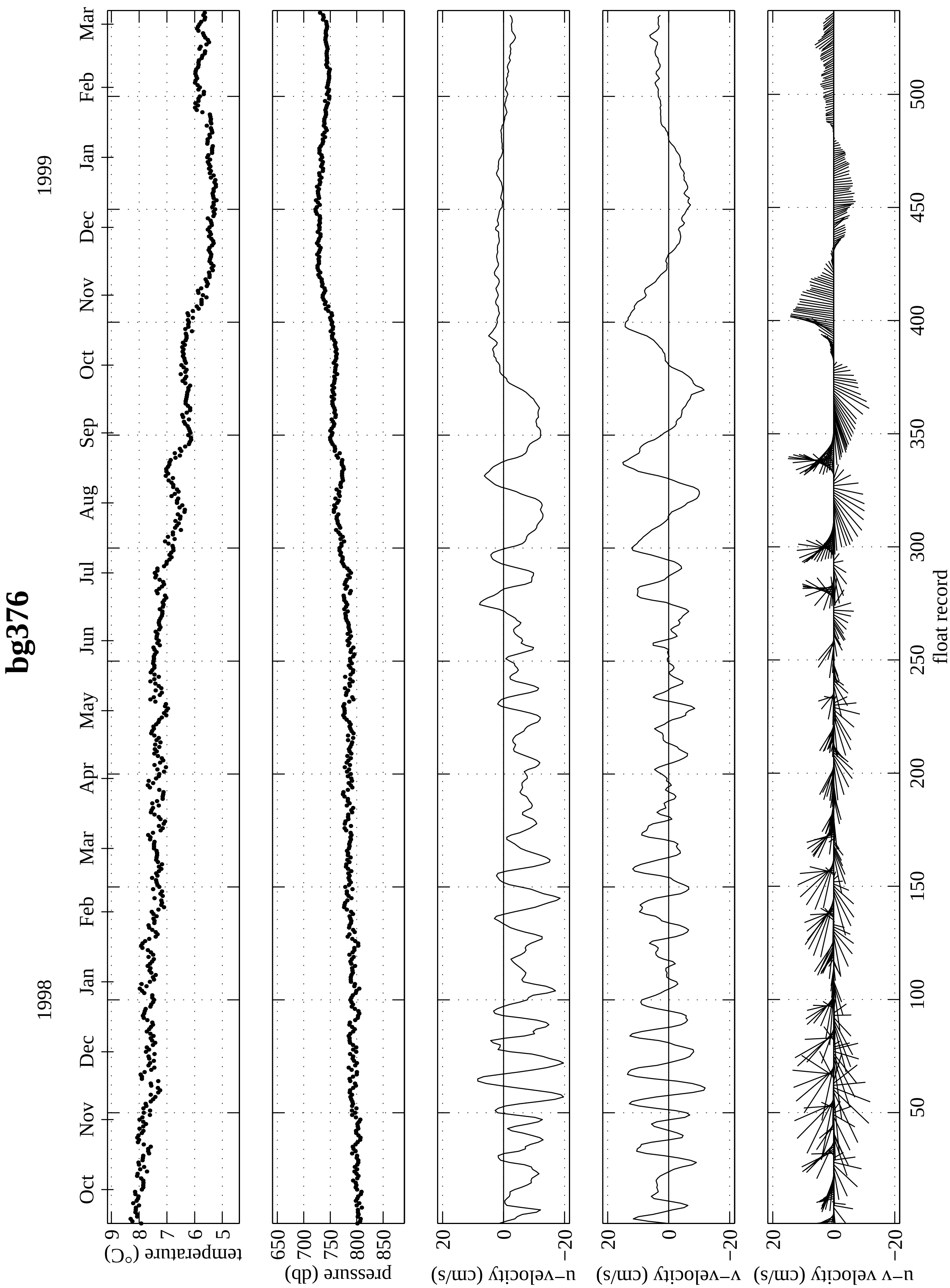
Appendix B: Individual Float Trajectories and Time Series

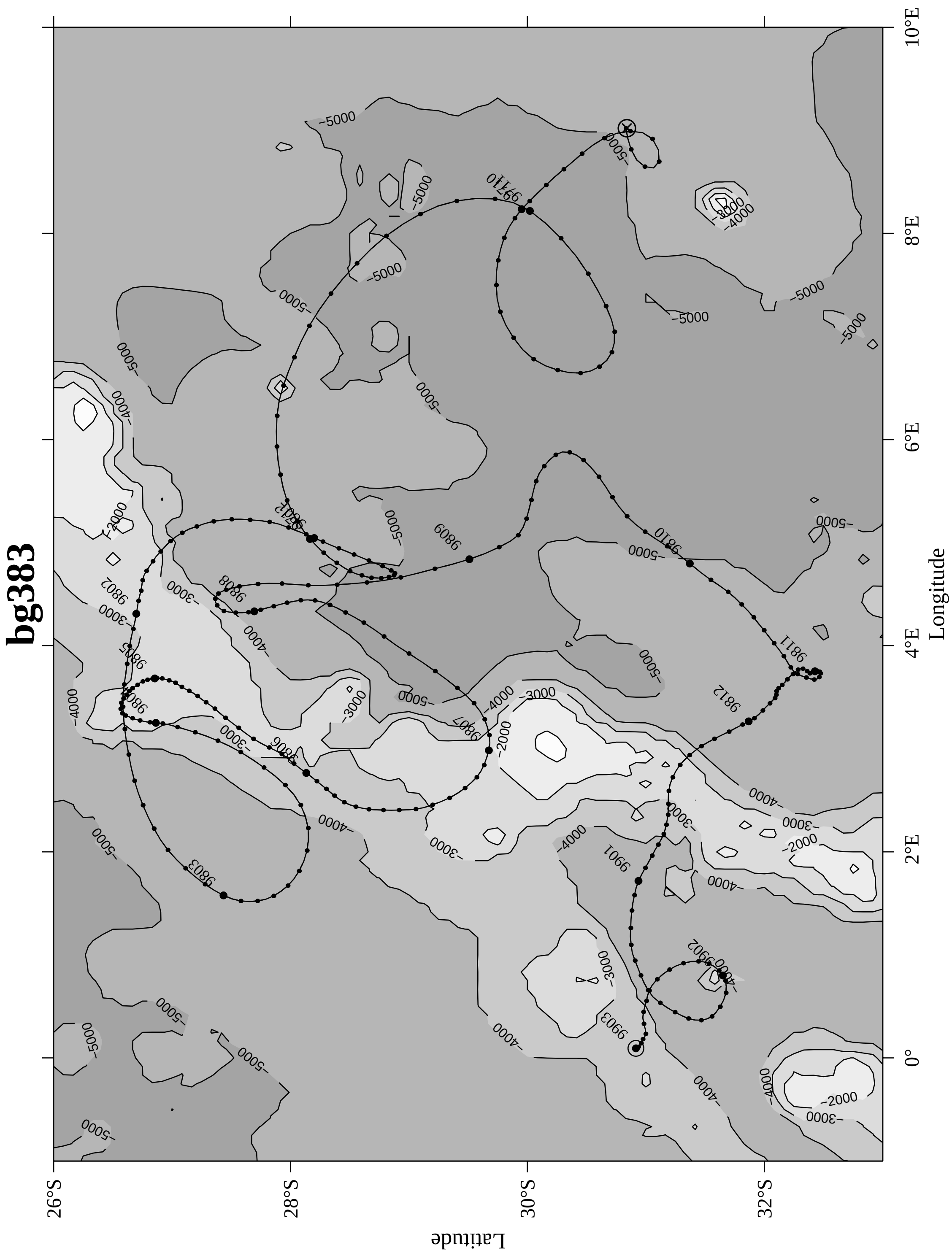
The following figures show detailed RAFOS float trajectories and time series of temperature, pressure and velocity for each float ordered by float number. The start position is shown by a circle with an X in it. Alternate-day positions are shown by small dots and the beginning of each month by larger dots. Sea floor topography is indicated by contours at 1000 m intervals. Monthly submerged tracks of the two ALFOS floats and their temperature and pressure series are included.

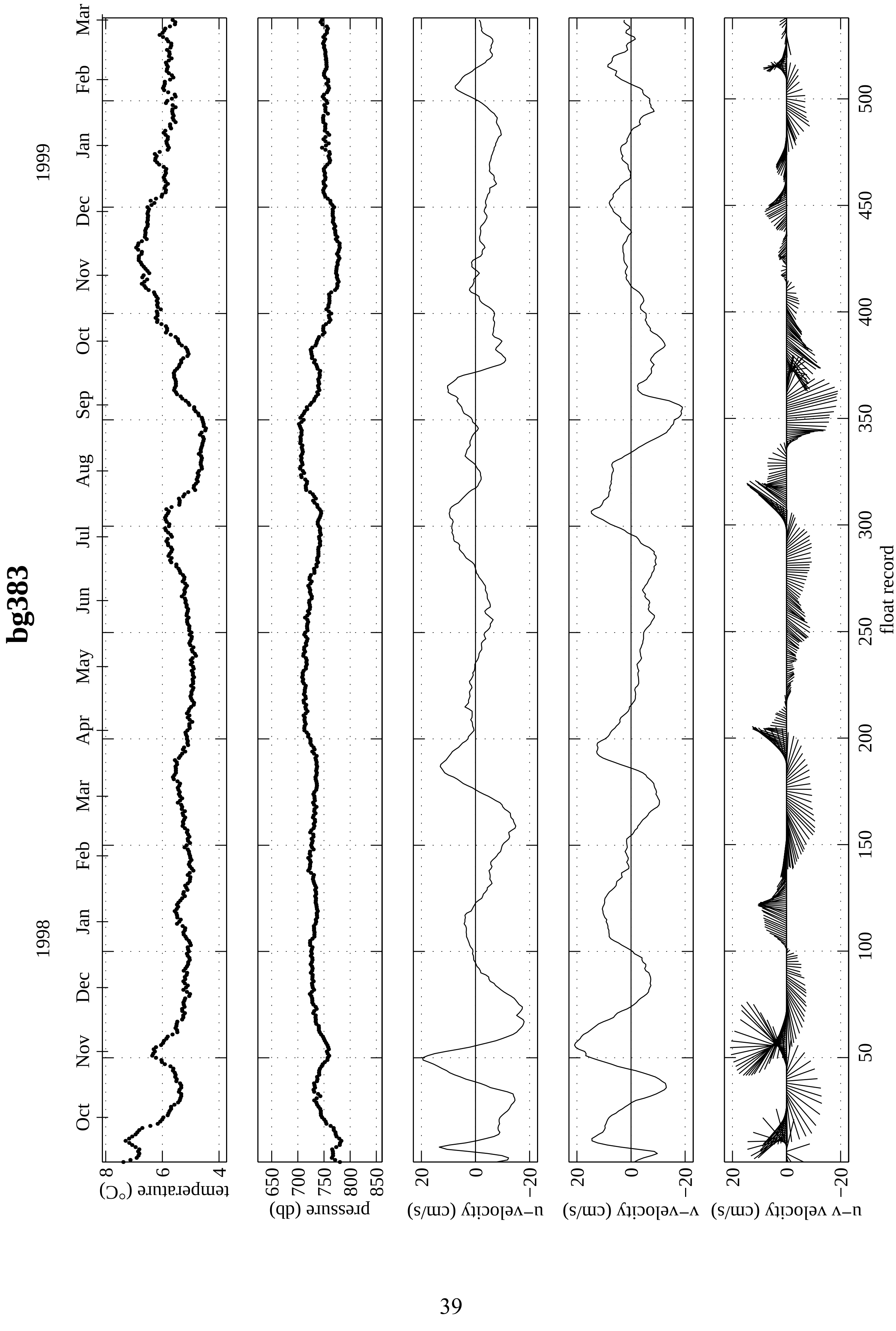
bg376

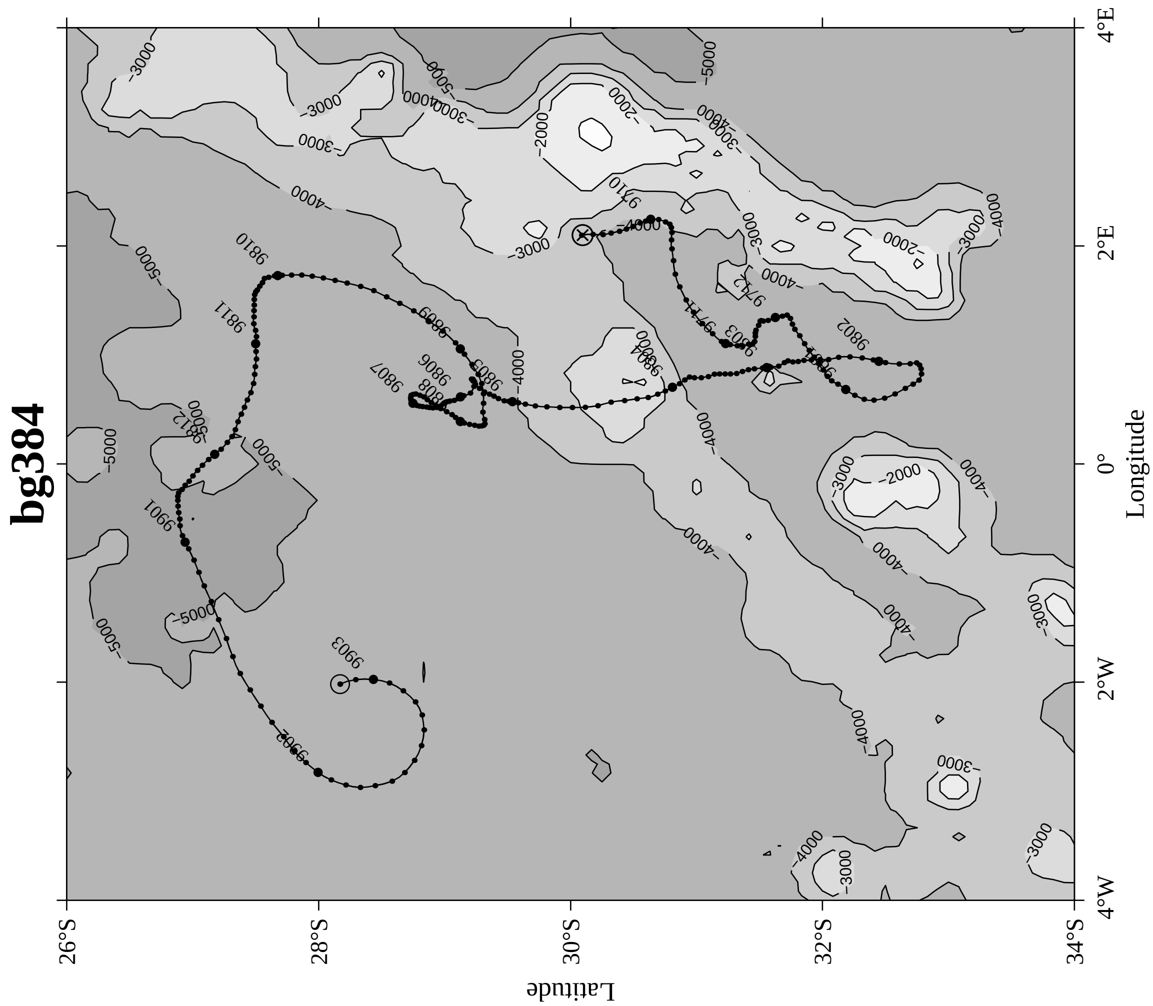


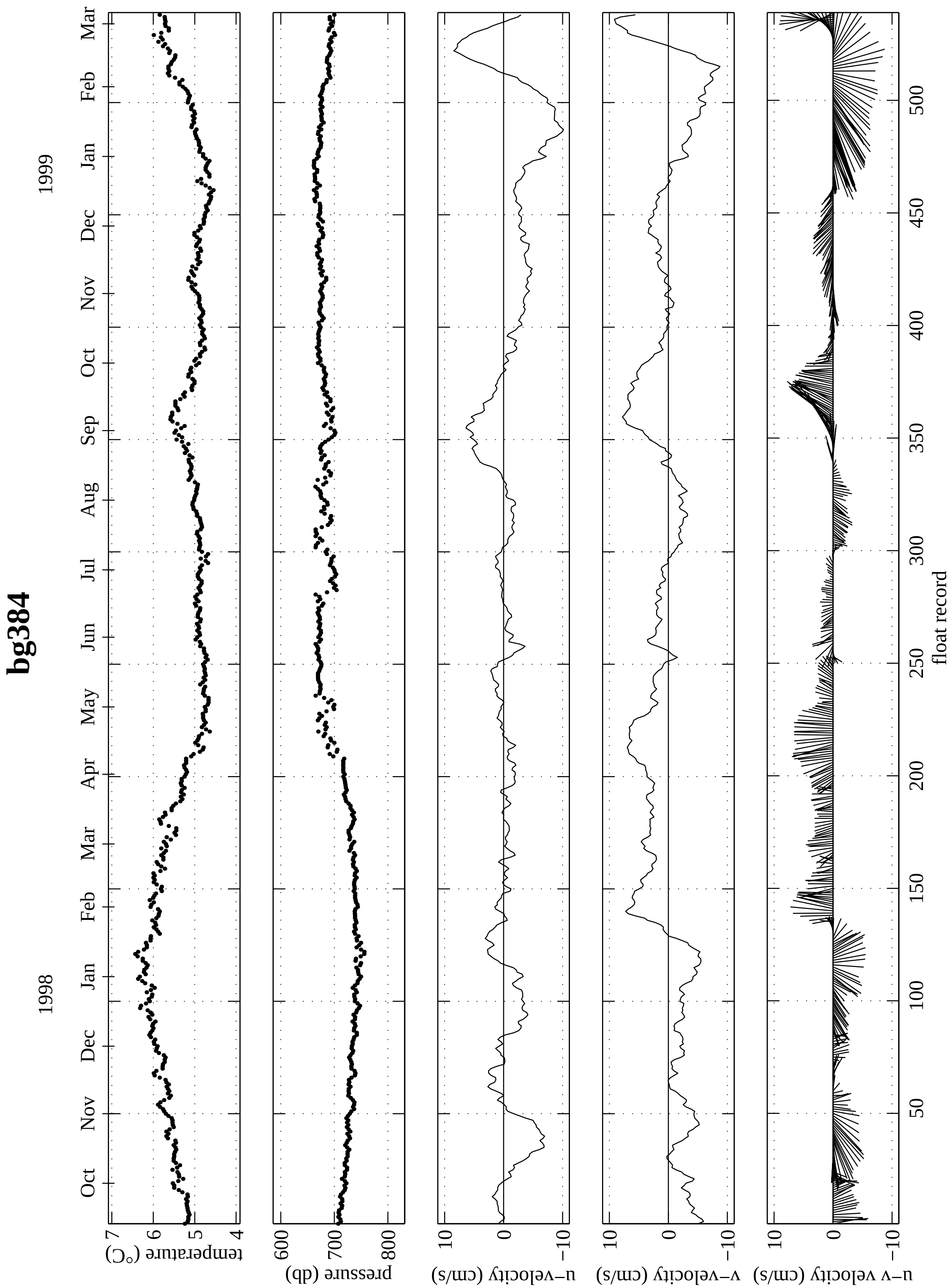
Latitude
24°S
26°S
28°S
30°S
32°S
34°S
Longitude
22°W
20°W
18°W
16°W
14°W
12°W
10°W
8°W
6°W
4°W
2°W
−5000
−4000
−3000
9710
9711
9712
9801
9802
9803
9804
9805
9806
9807
9808
9809
9810
9812
9902


bg376
1998
1999
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
temperature (°C)
pressure (db)
u−velocity (cm/s)
v−velocity (cm/s)
u−v velocity (cm/s)
float record

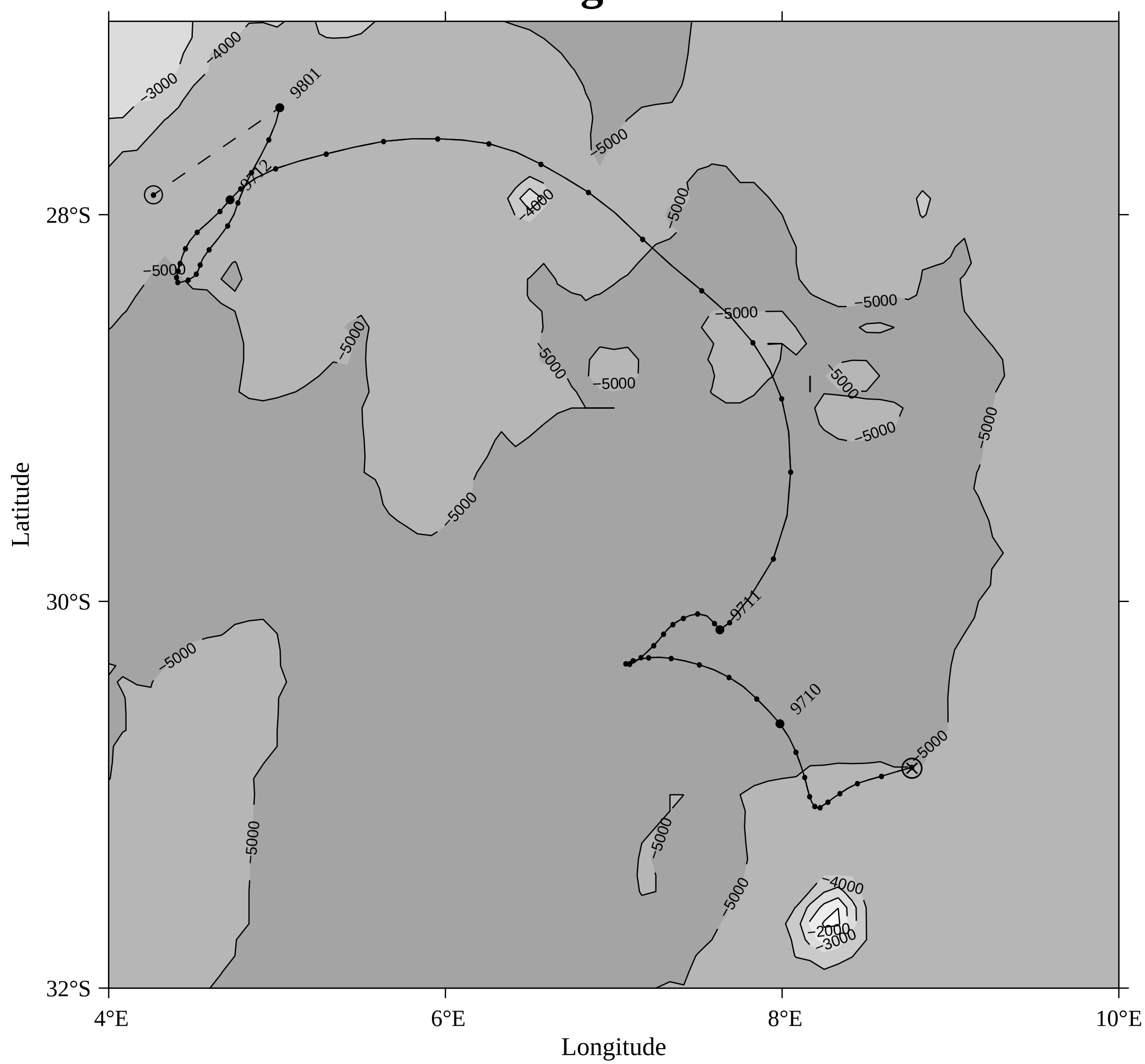

bg383
Longitude
Latitude
26°S
28°S
30°S
32°S
0°
2°E
4°E
6°E
8°E
10°E


bg383
1998
1999
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
temperature (°C)
pressure (db)
u−velocity (cm/s)
v−velocity (cm/s)
u−v velocity (cm/s)
float record

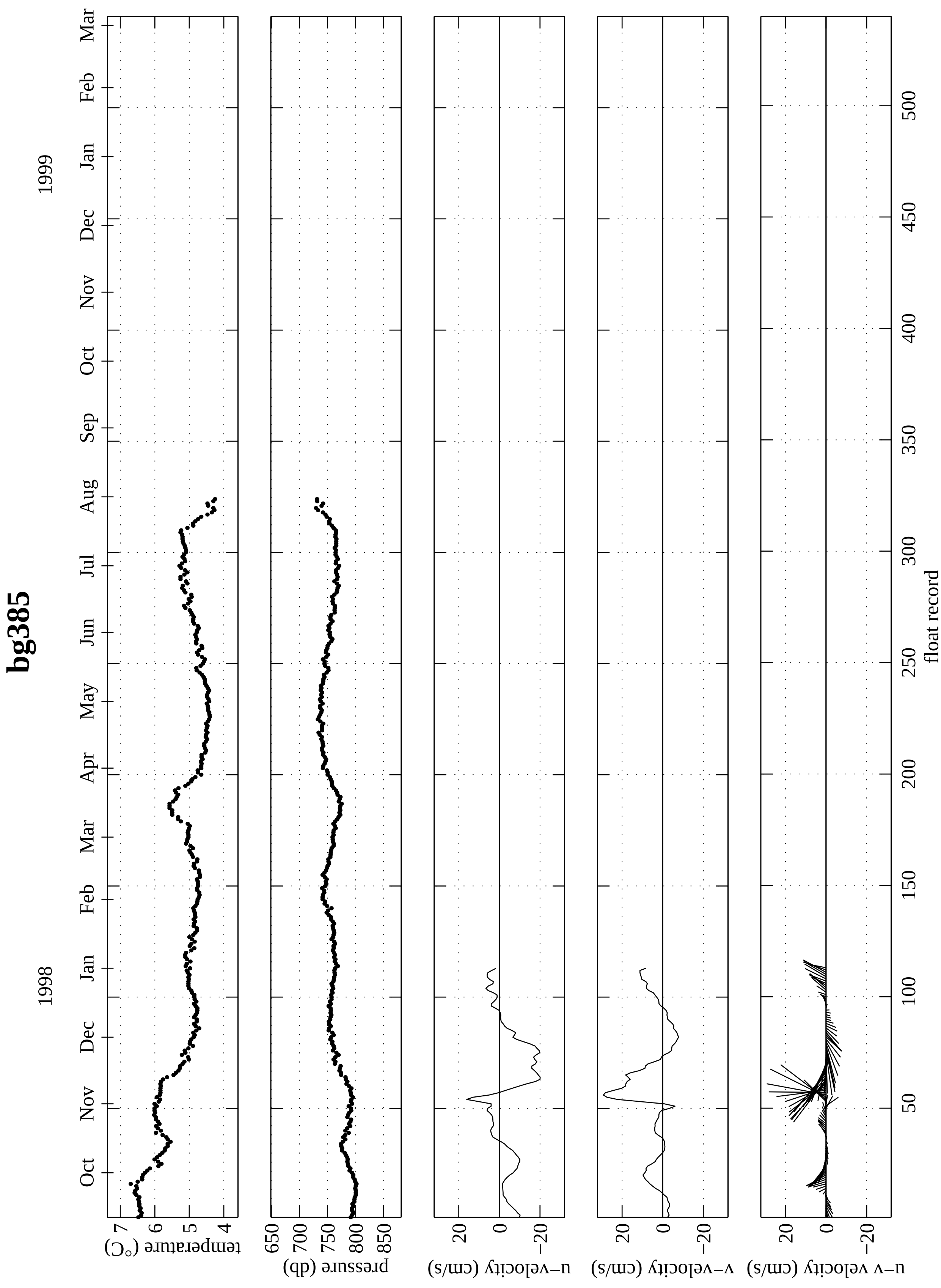

bg384
26°S
28°S
30°S
32°S
34°S
Latitude
4°W
2°W
0°
2°E
4°E
Longitude
-2000
-3000
-4000
-5000


bg384
1998
1999
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
temperature (°C)
pressure (db)
u−velocity (cm/s)
v−velocity (cm/s)
u−v velocity (cm/s)
float record

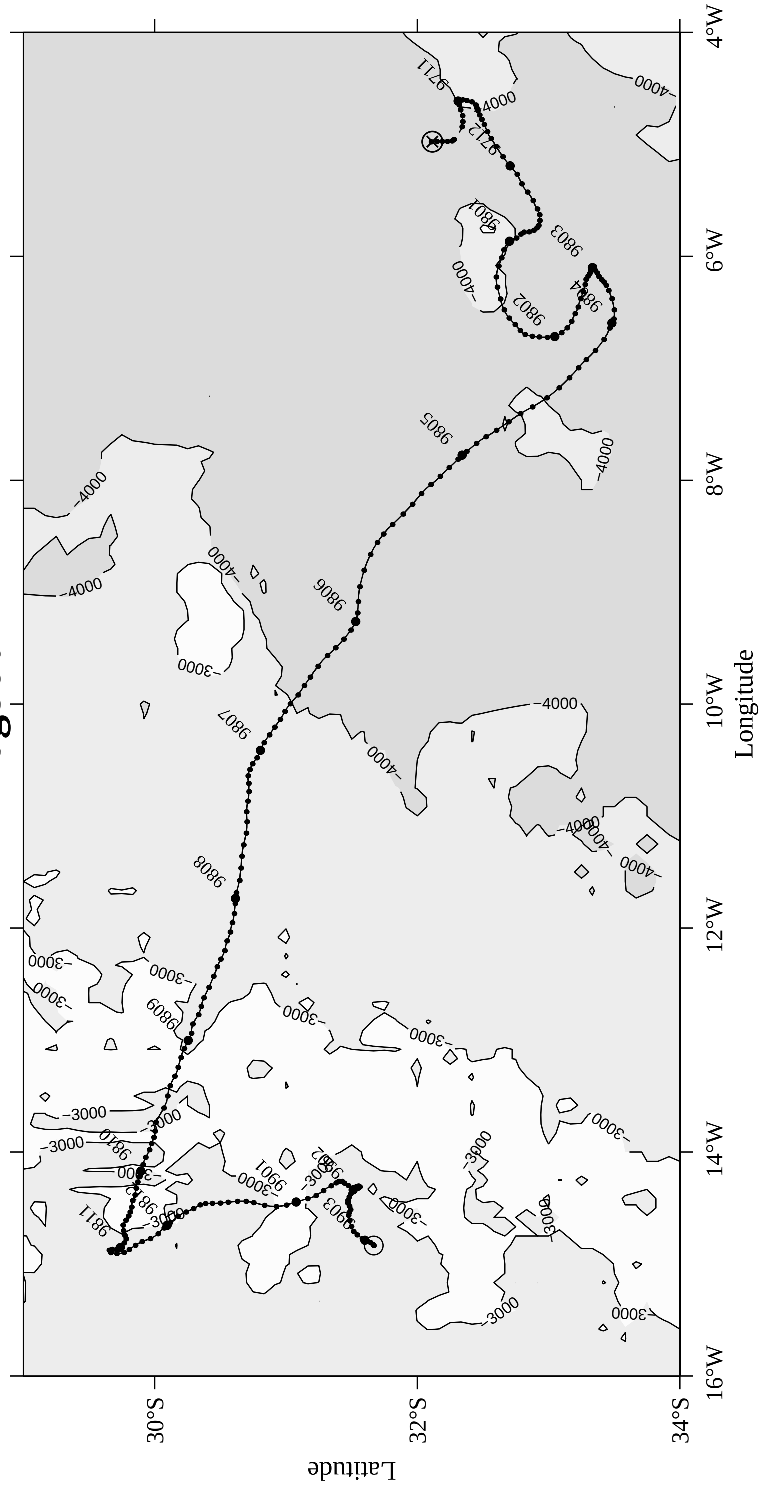
bg385



9801
9712
9711
9710
−3000
−4000
−5000
−2000
28°S
30°S
32°S
4°E
6°E
8°E
10°E
Latitude
Longitude


bg385
1998
1999
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
temperature (°C)
pressure (db)
u−velocity (cm/s)
v−velocity (cm/s)
u−v velocity (cm/s)
float record

bg386


Longitude
Latitude
4°W
6°W
8°W
10°W
12°W
14°W
16°W
30°S
32°S
34°S
-4000
-3000
9711
9712
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9803
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9805
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9809
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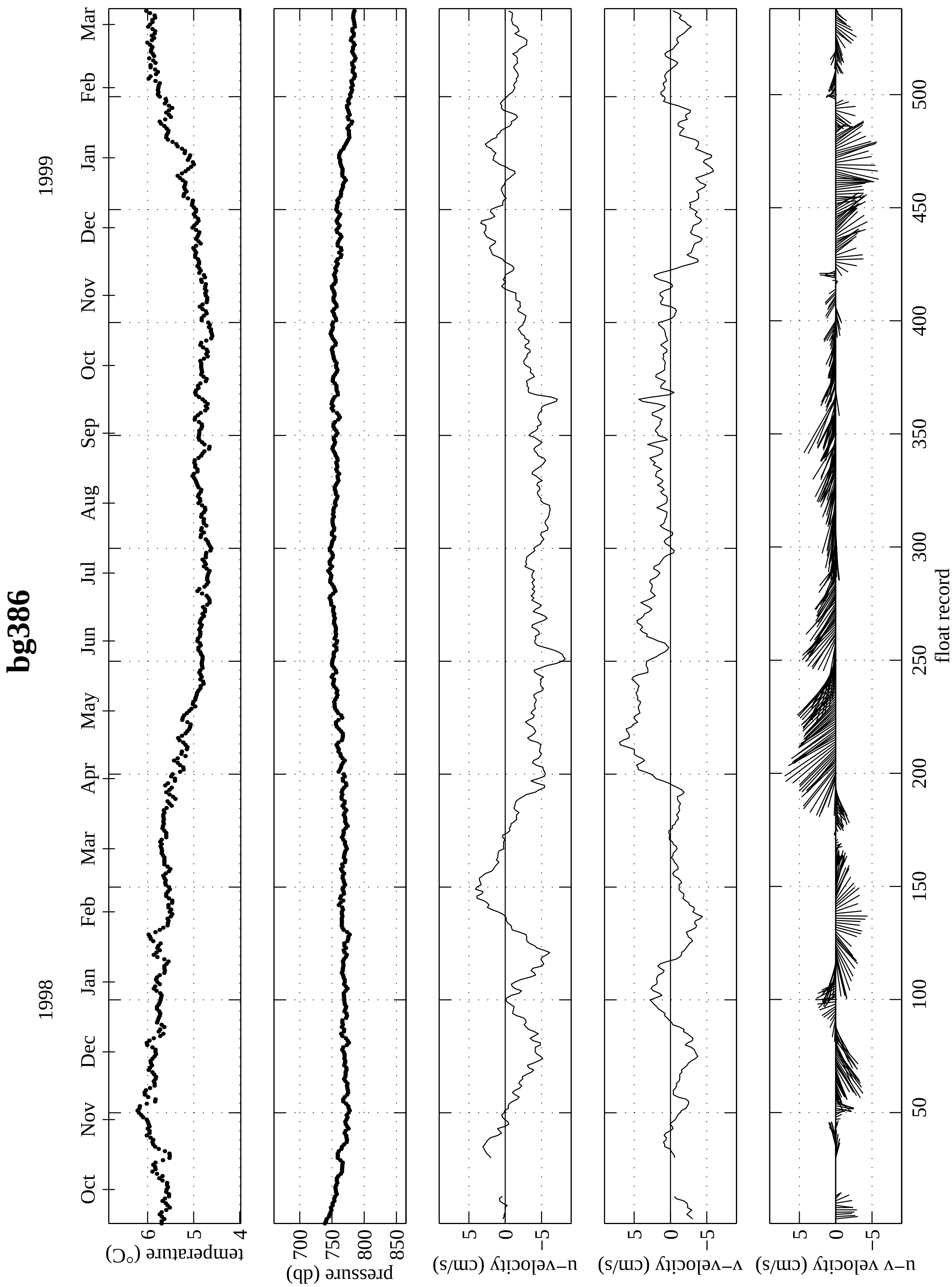
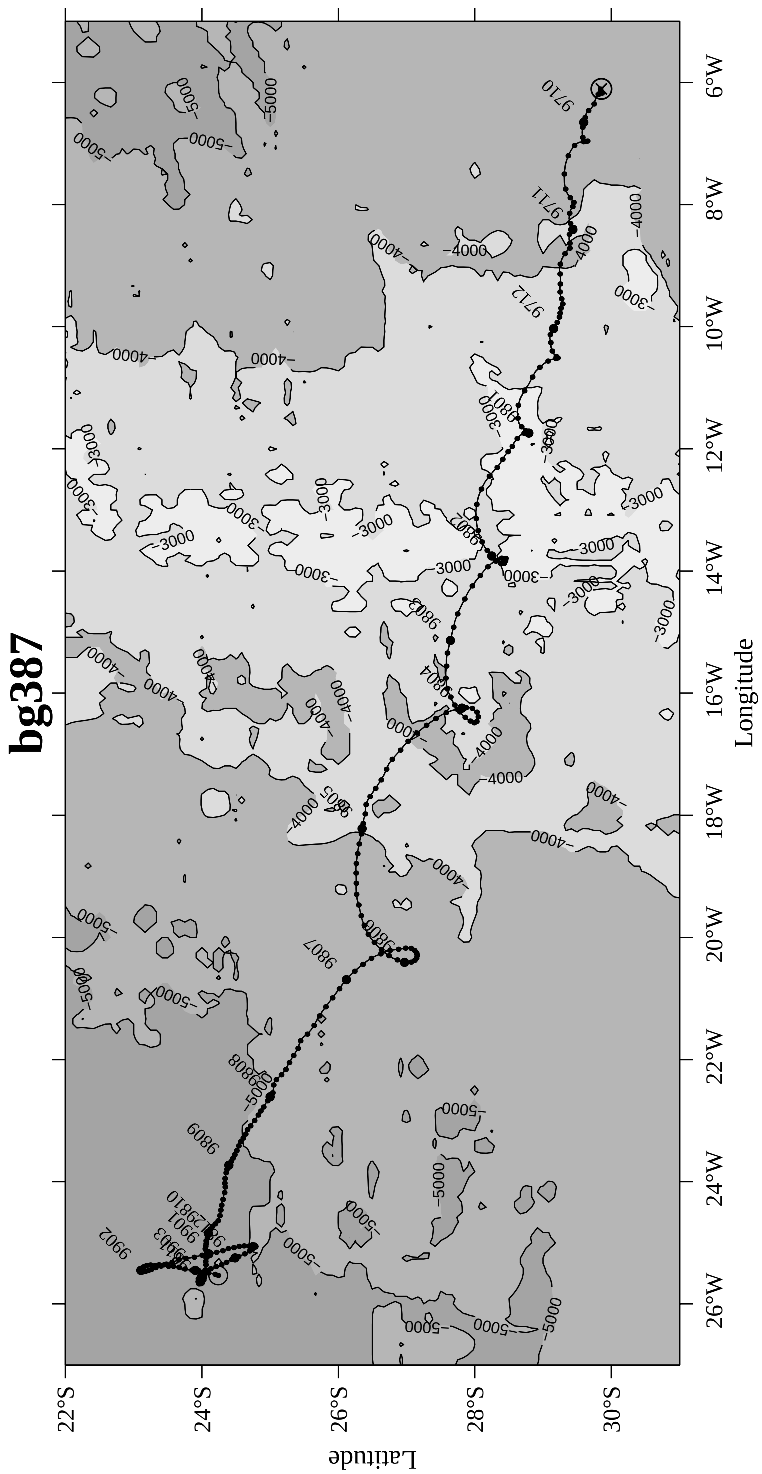
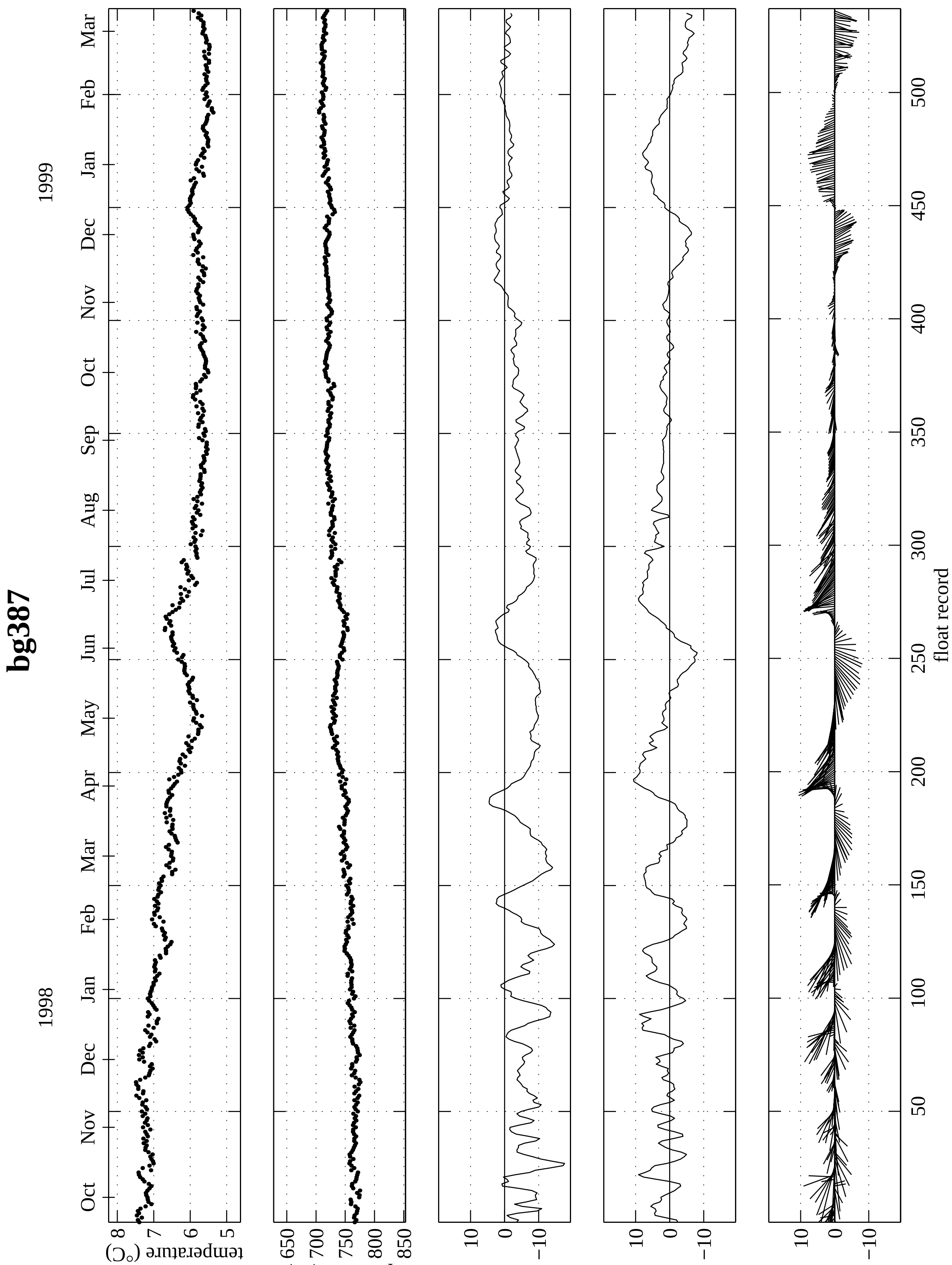
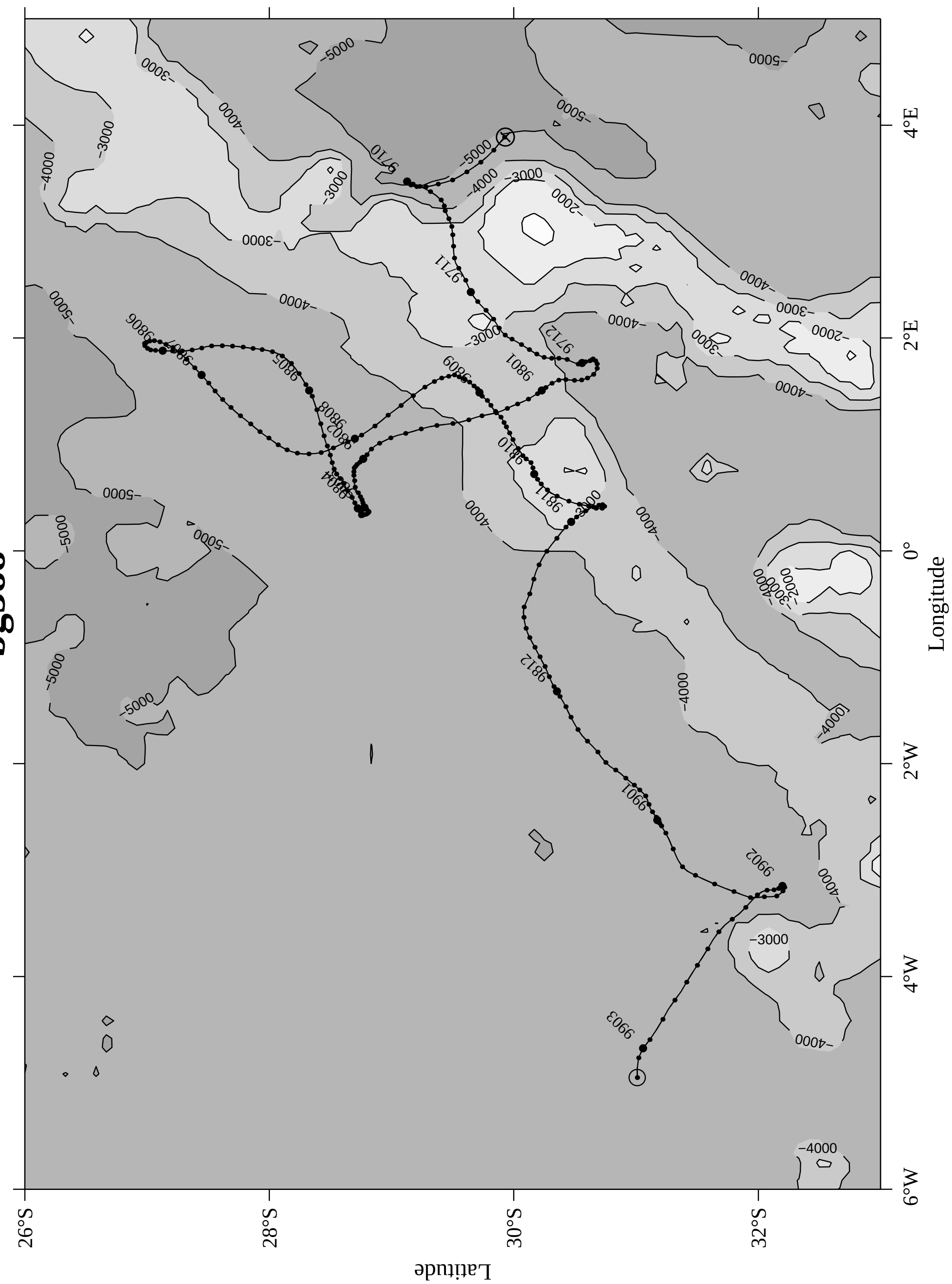
9811
9901
9902
9903

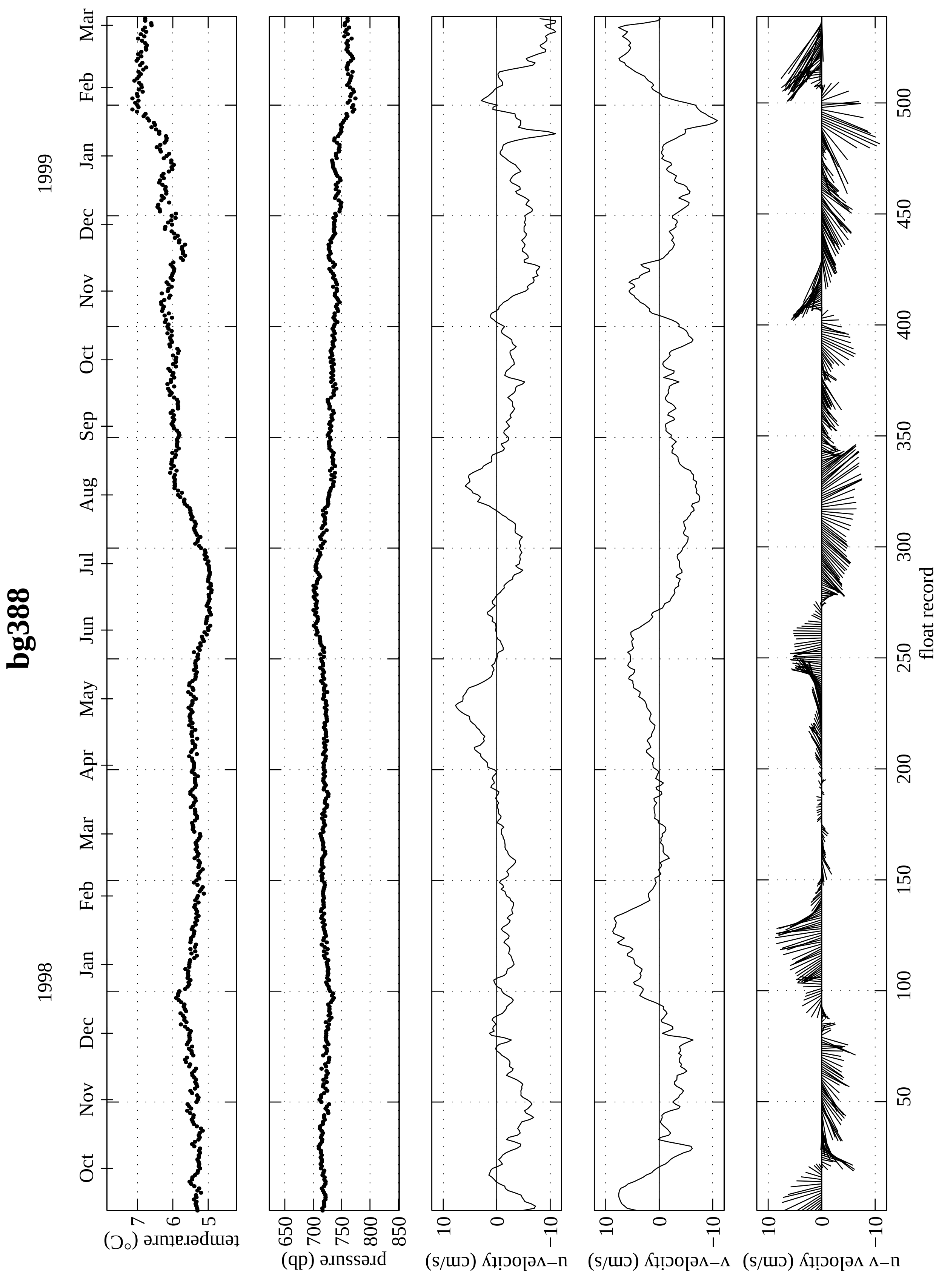

bg386
1998
1999
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
temperature (°C)
pressure (db)
u−velocity (cm/s)
v−velocity (cm/s)
u−v velocity (cm/s)
float record


bg387
Longitude
Latitude
6°W
8°W
10°W
12°W
14°W
16°W
18°W
20°W
22°W
24°W
26°W
22°S
24°S
26°S
28°S
30°S

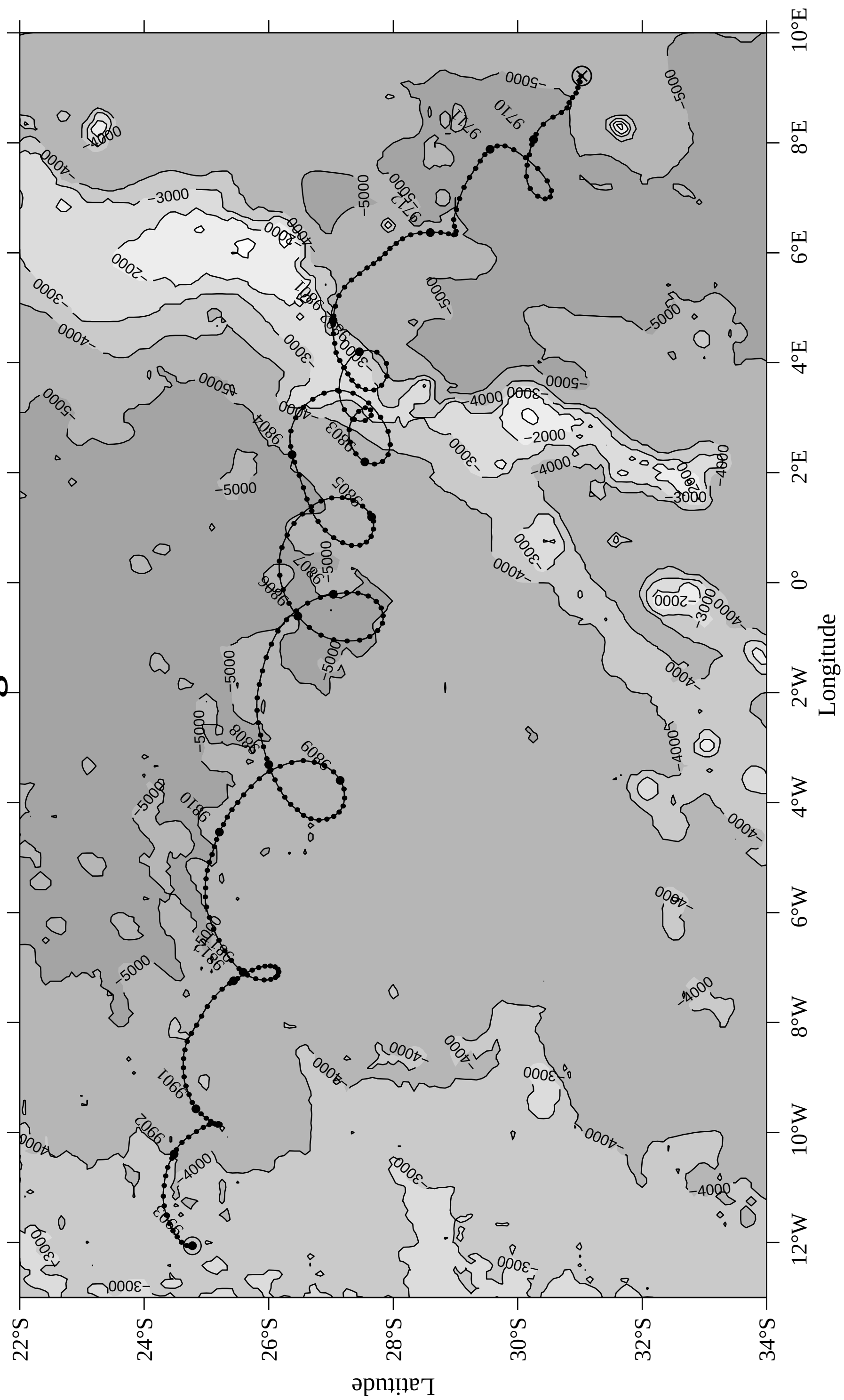

bg387
1998
1999
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
temperature (°C)
pressure (db)
u−velocity (cm/s)
v−velocity (cm/s)
u−v velocity (cm/s)
float record

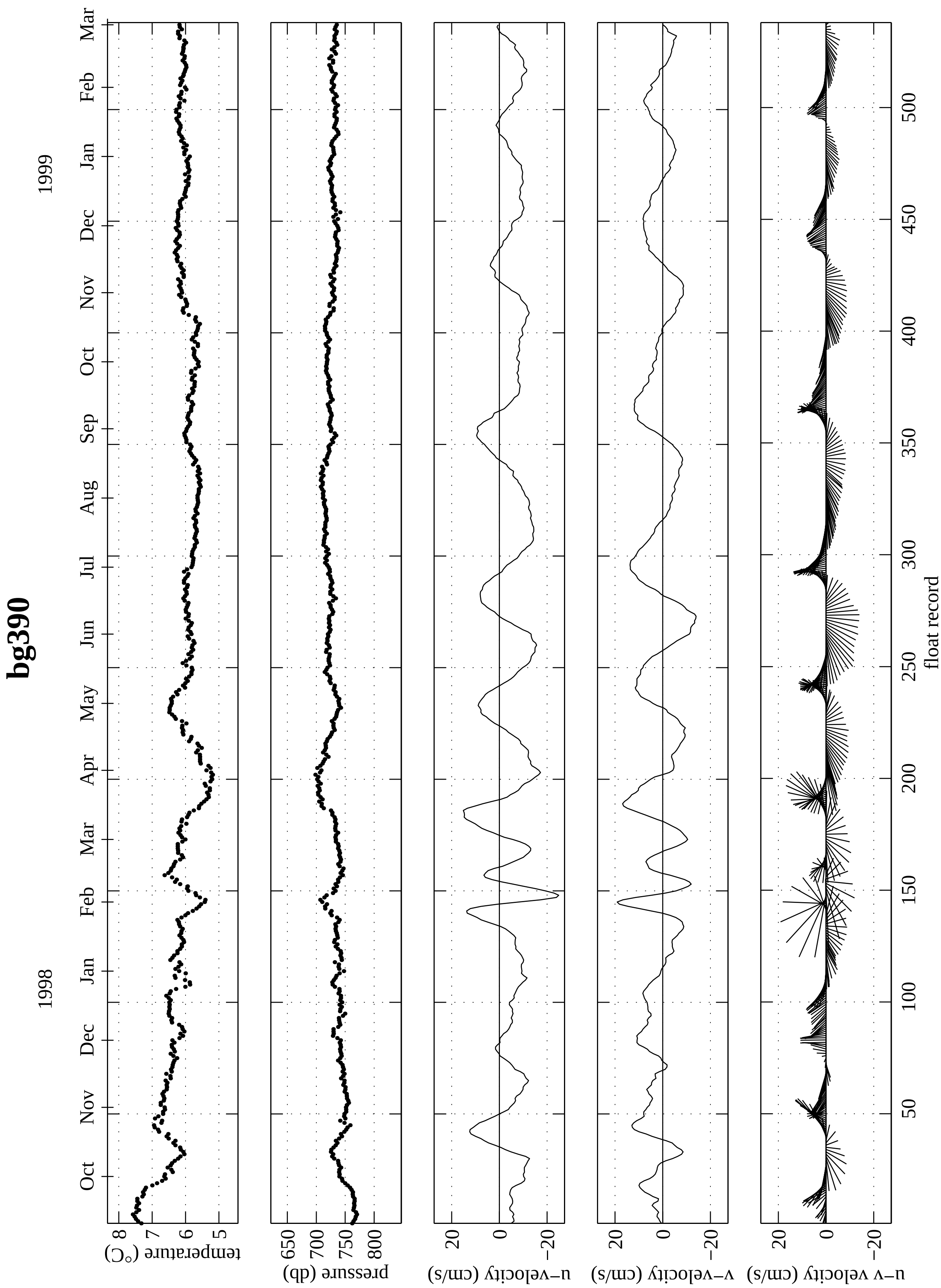
bg388

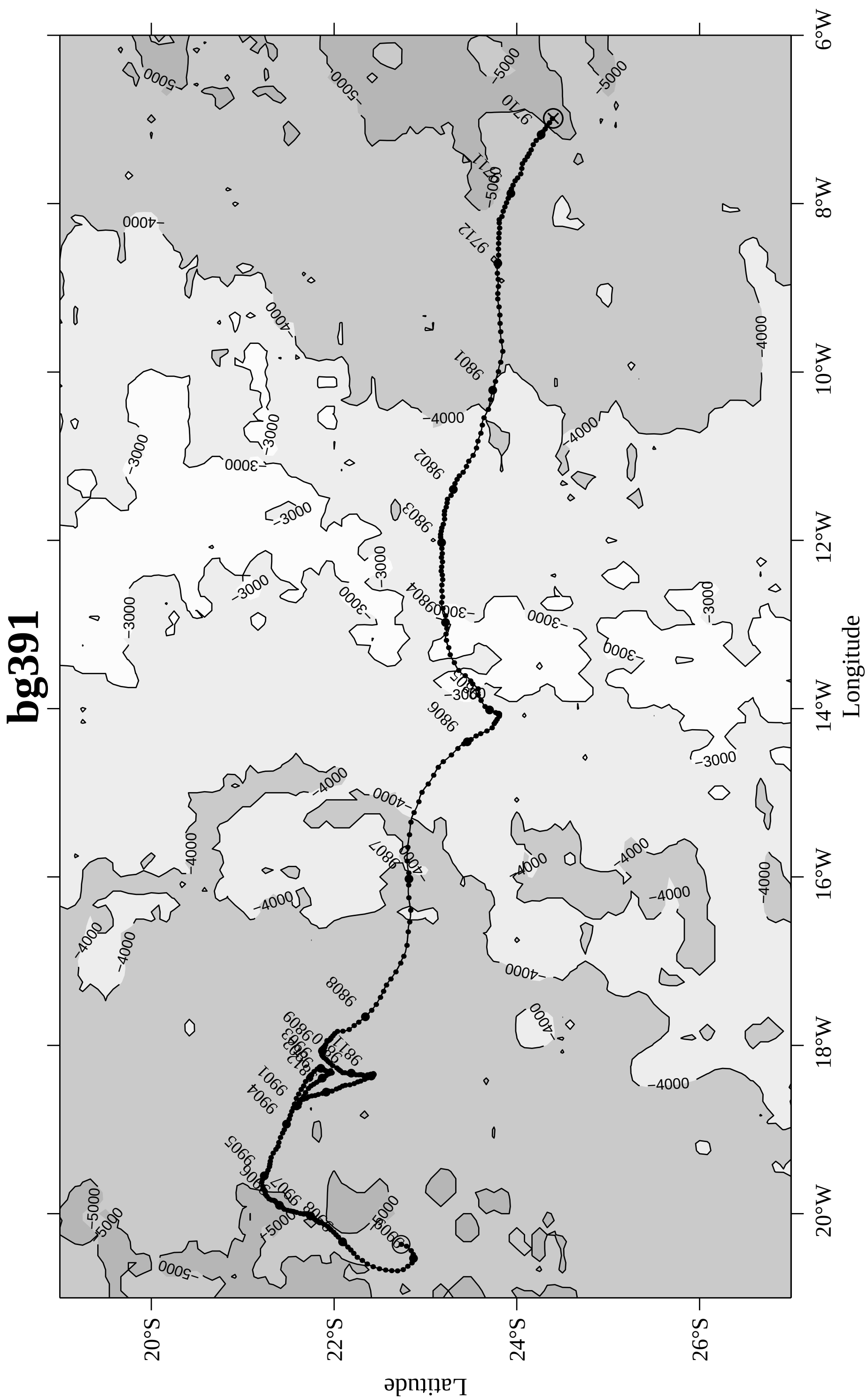


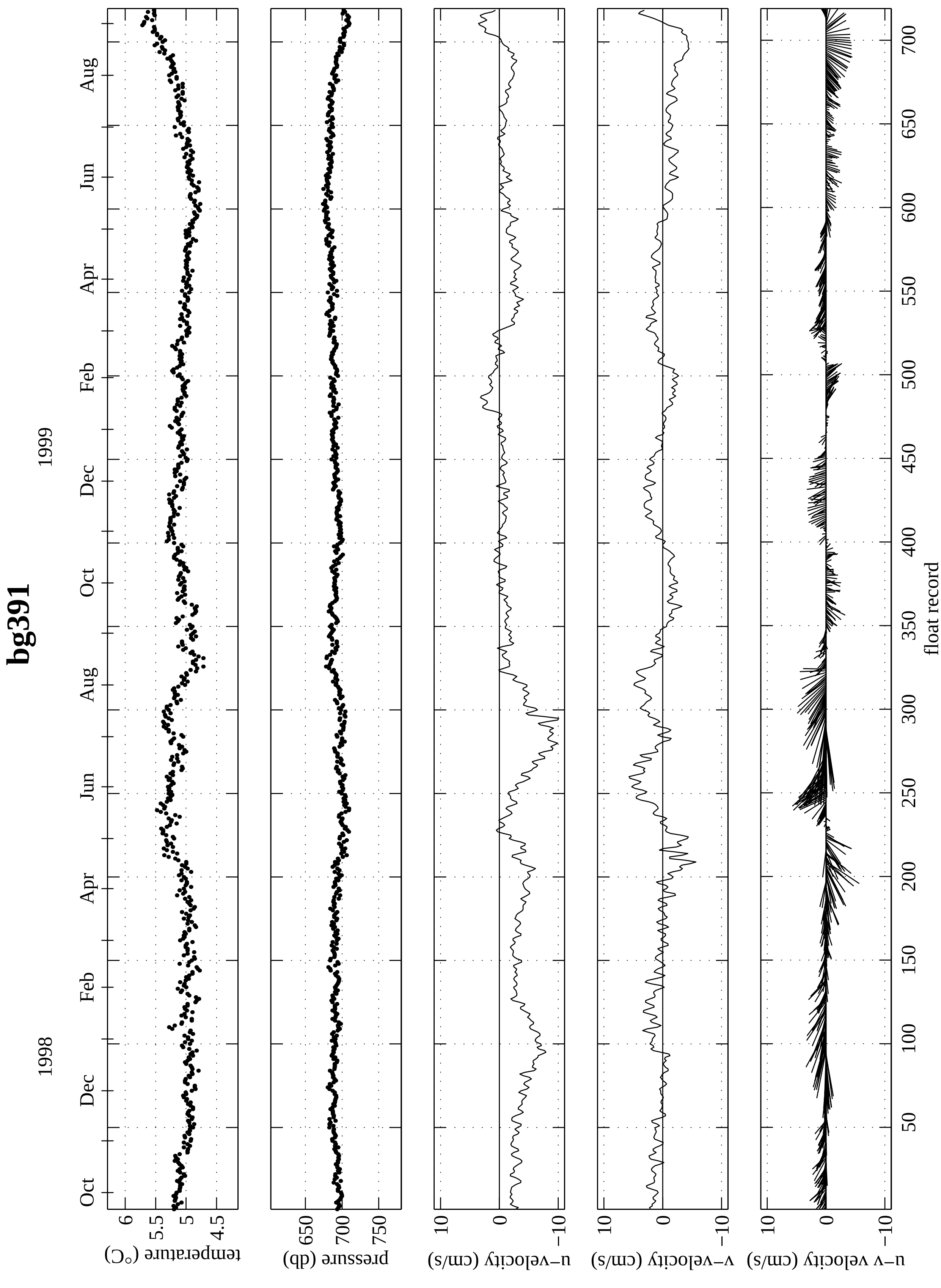

bg388
1998
1999
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
temperature (°C)
7
6
5
pressure (db)
650
700
750
800
850
u−velocity (cm/s)
10
0
−10
v−velocity (cm/s)
10
0
−10
u−v velocity (cm/s)
10
0
−10
50
100
150
200
250
300
350
400
450
500
float record

bg390

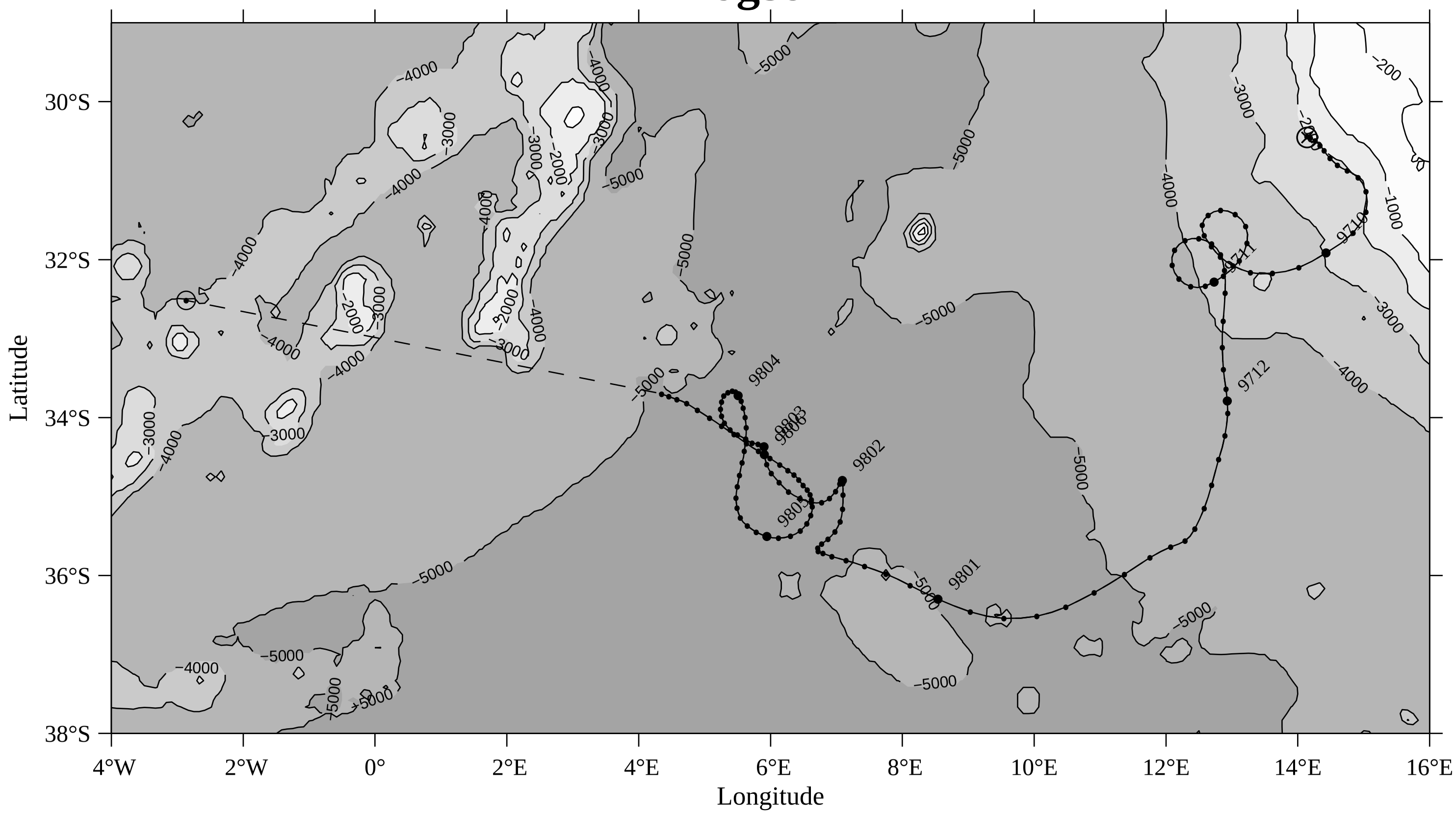

Longitude
Latitude
22°S
24°S
26°S
28°S
30°S
32°S
34°S
12°W
10°W
8°W
6°W
4°W
2°W
0°
2°E
4°E
6°E
8°E
10°E


bg390
1998
1999
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
temperature (°C)
pressure (db)
u−velocity (cm/s)
v−velocity (cm/s)
u−v velocity (cm/s)
float record

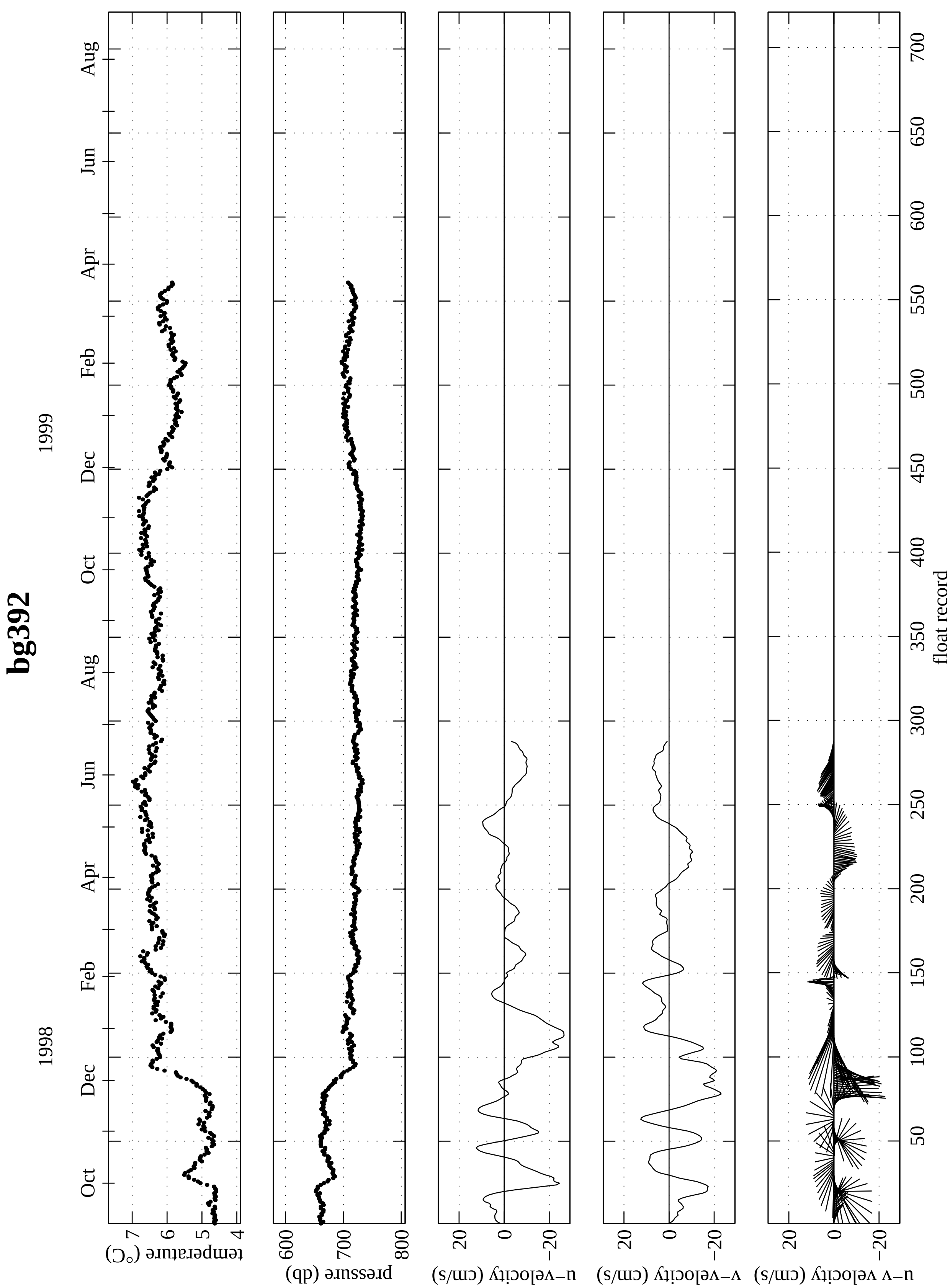

bg391
Longitude
Latitude
20°S
22°S
24°S
26°S
20°W
18°W
16°W
14°W
12°W
10°W
8°W
6°W


bg391
1998
1999
Oct
Dec
Feb
Apr
Jun
Aug
Oct
Dec
Feb
Apr
Jun
Aug
temperature (°C)
6
5.5
5
4.5
pressure (db)
650
700
750
u−velocity (cm/s)
10
0
−10
v−velocity (cm/s)
10
0
−10
u−v velocity (cm/s)
10
0
−10
50
100
150
200
250
300
350
400
450
500
550
600
650
700
float record

bg392



Latitude
Longitude
30°S
32°S
34°S
36°S
38°S
4°W
2°W
0°
2°E
4°E
6°E
8°E
10°E
12°E
14°E
16°E
9710
9711
9712
9801
9802
9803
9804
9806


bg392
1998
1999
Oct
Dec
Feb
Apr
Jun
Aug
Oct
Dec
Feb
Apr
Jun
Aug
temperature (°C)
pressure (db)
u−velocity (cm/s)
v−velocity (cm/s)
u−v velocity (cm/s)
float record
50
100
150
200
250
300
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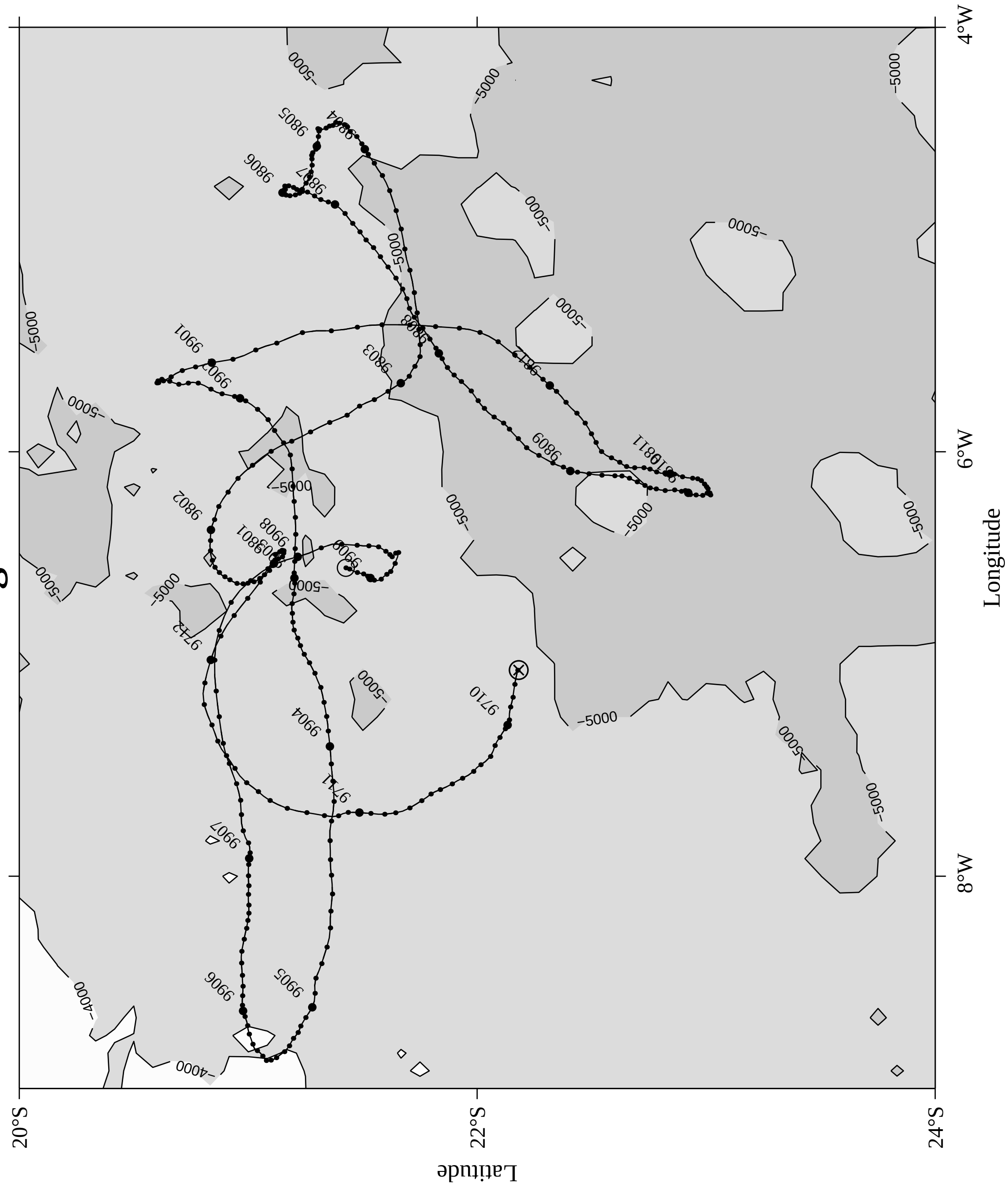
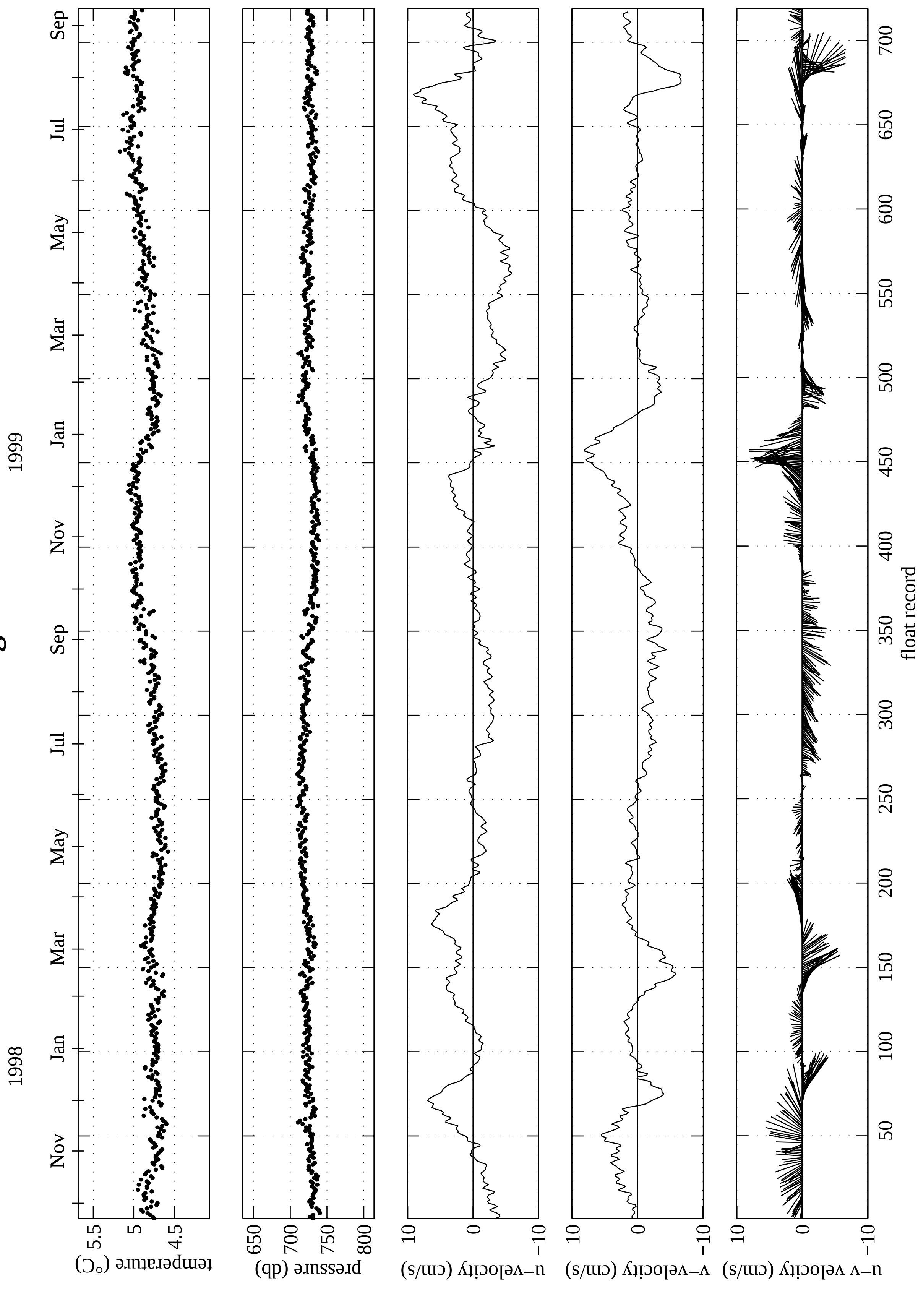
400
450
500
550
600
650
700

bg393

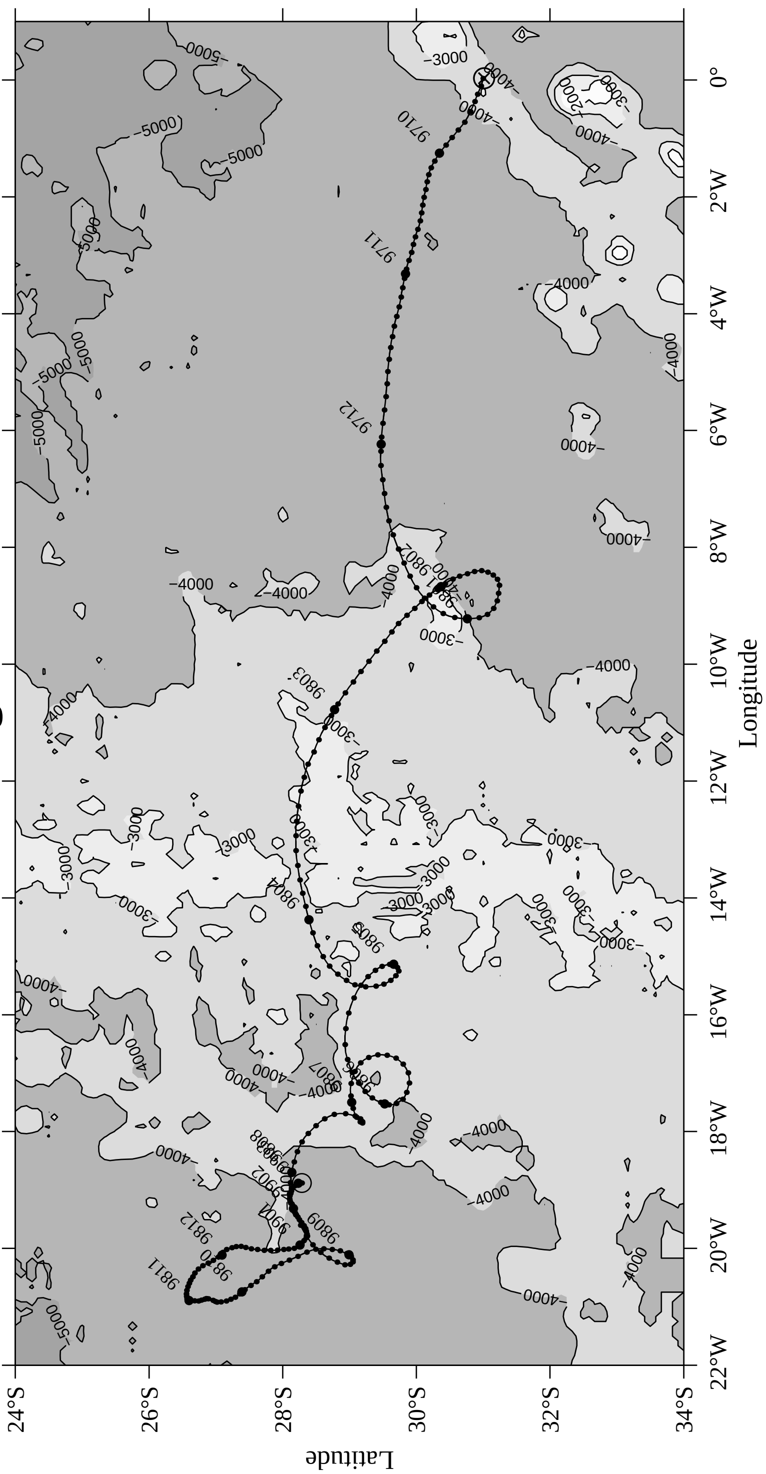


bg393



1998
1999
Nov
Jan
Mar
May
Jul
Sep
temperature (°C)
pressure (db)
u−velocity (cm/s)
v−velocity (cm/s)
u−v velocity (cm/s)
float record

bg394


Longitude
Latitude
0°
2°W
4°W
6°W
8°W
10°W
12°W
14°W
16°W
18°W
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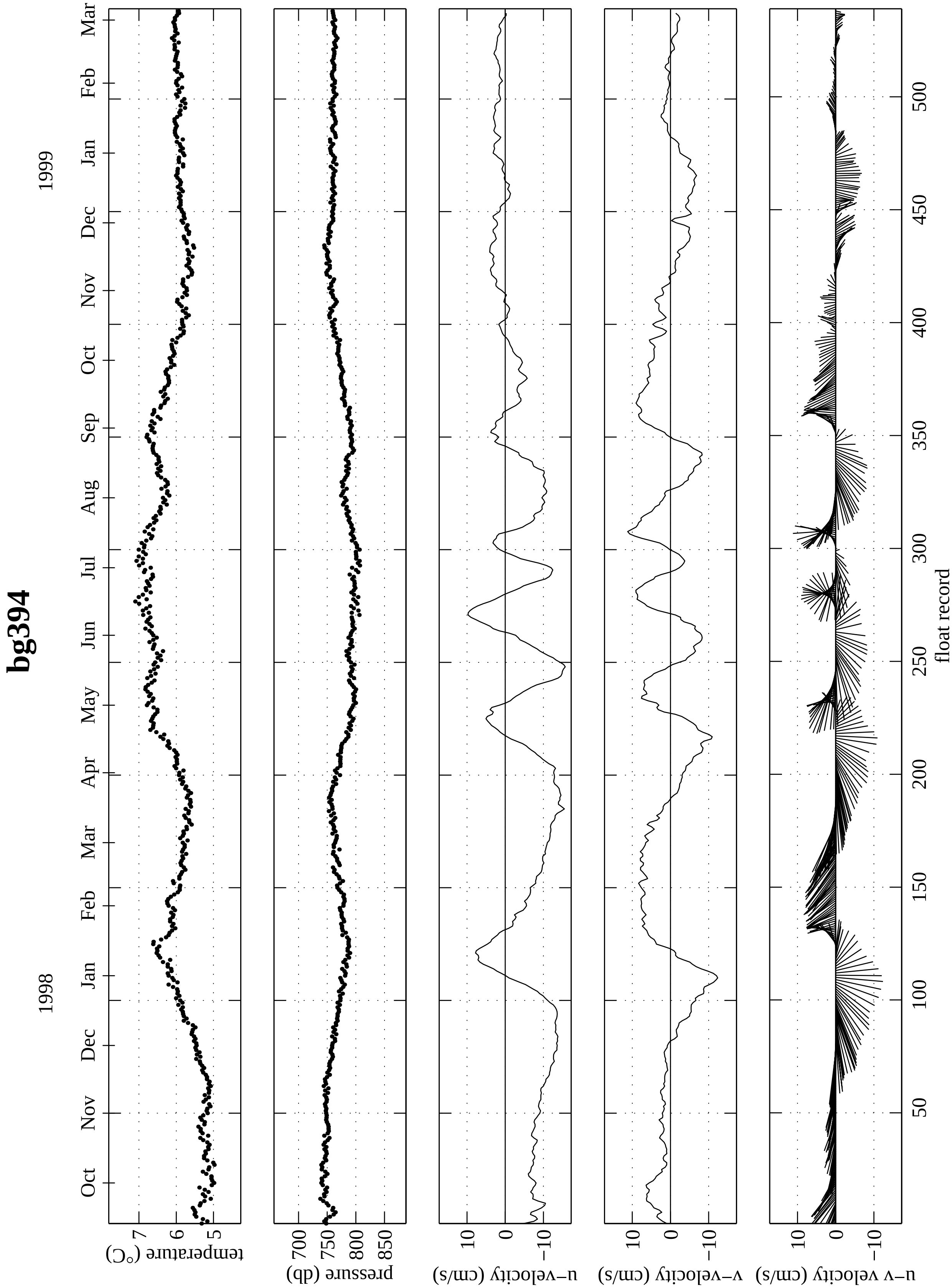
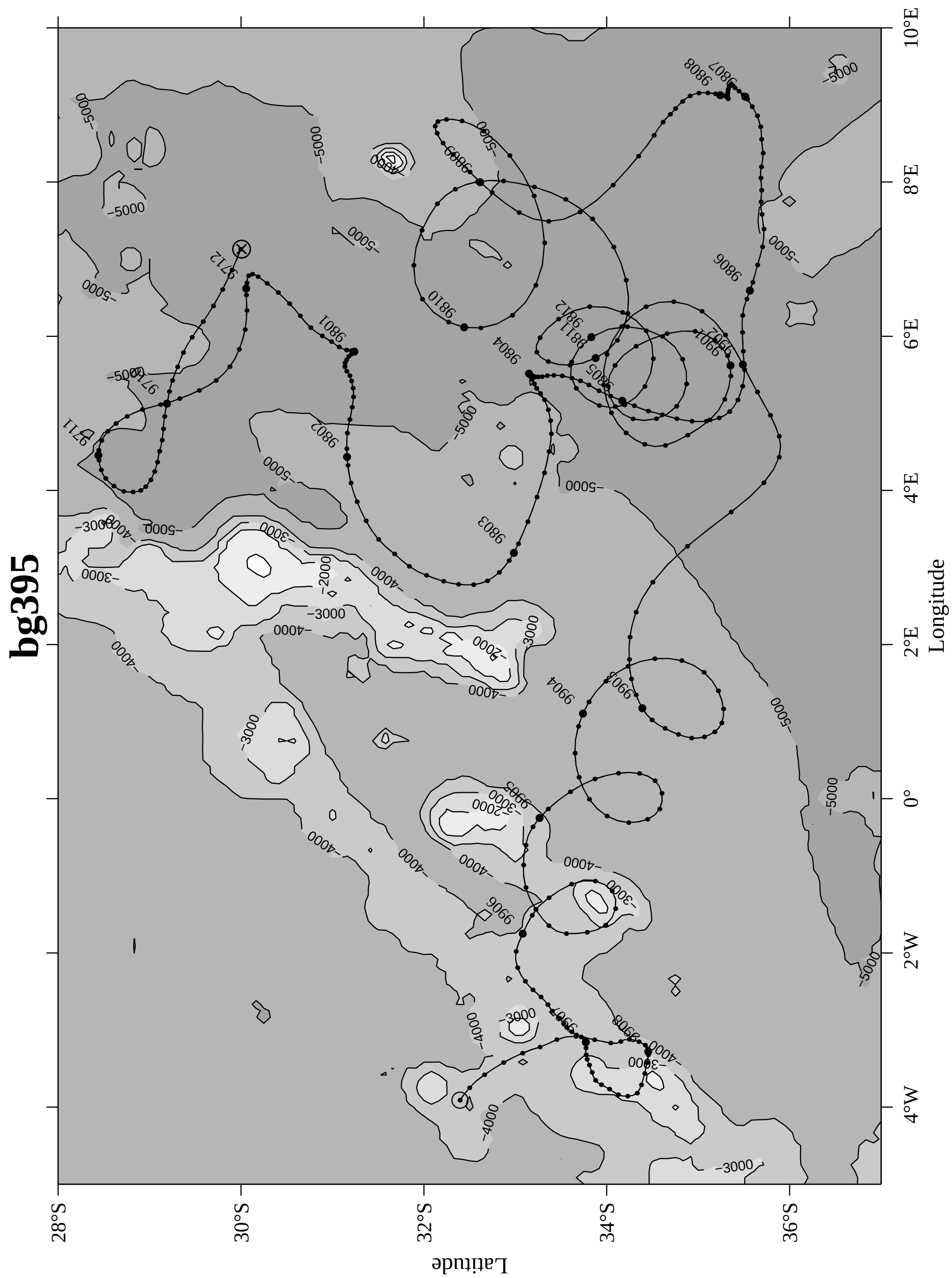
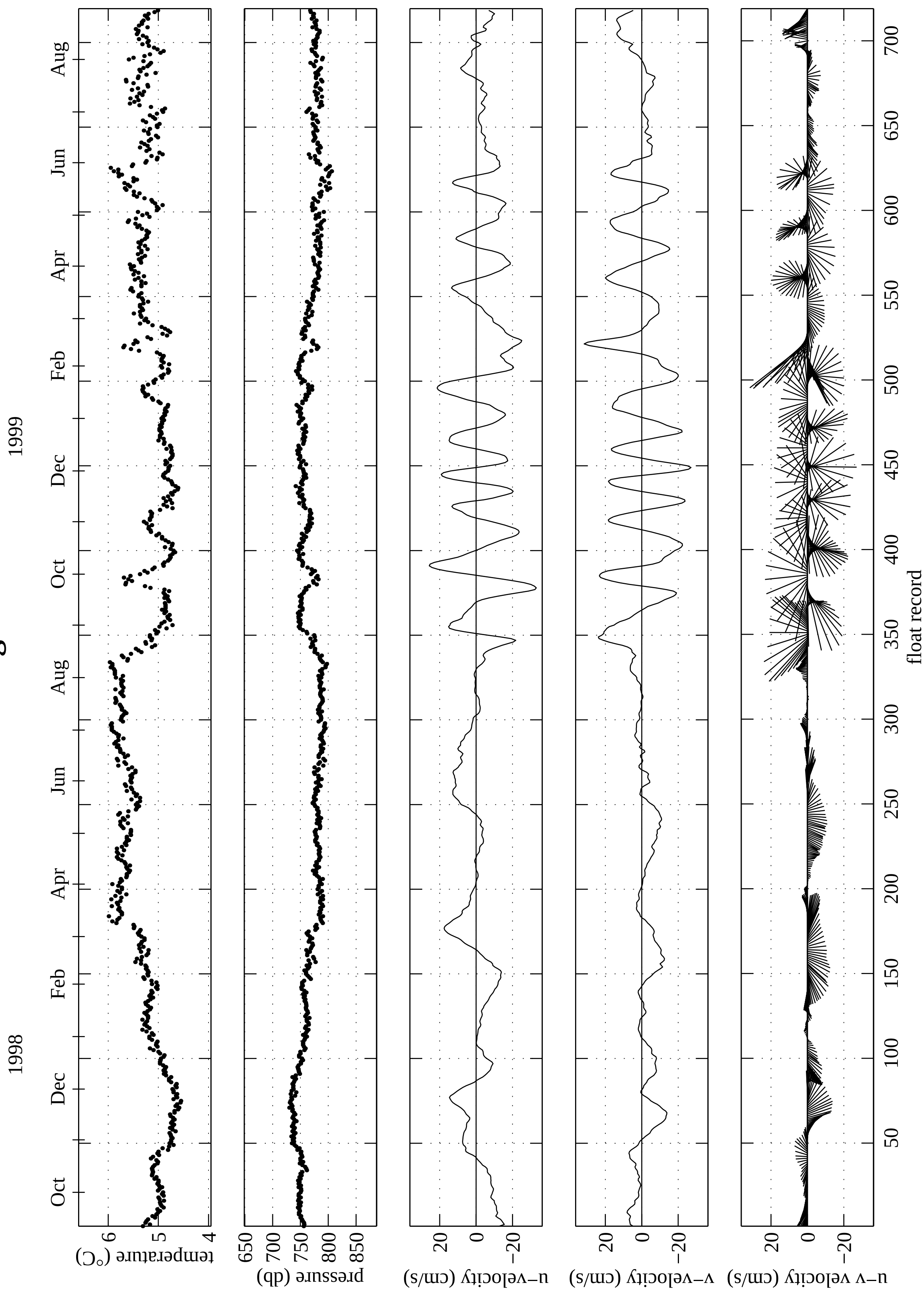
9710
9711
9712
9803



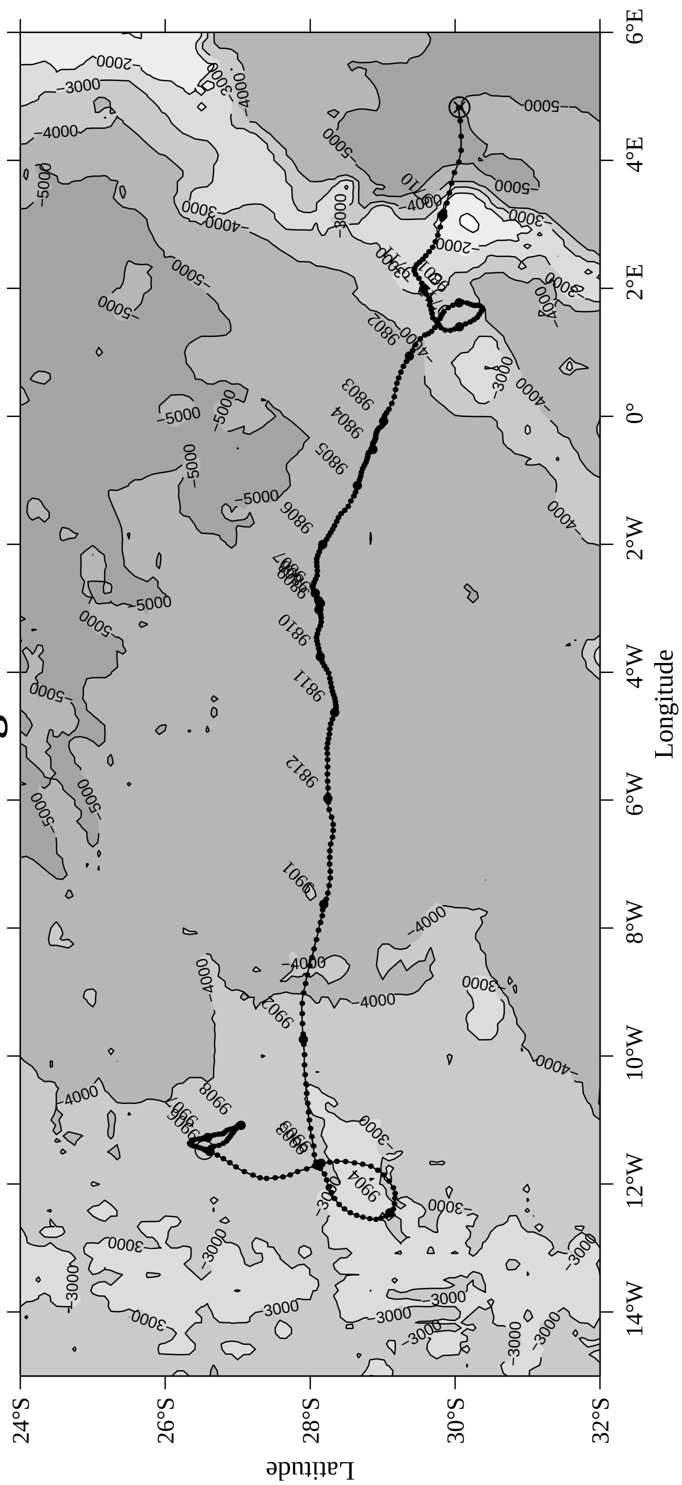
bg394
1998
1999
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
temperature (°C)
pressure (db)
u−velocity (cm/s)
v−velocity (cm/s)
u−v velocity (cm/s)
float record


bg395
Longitude
Latitude
4°W
2°W
0°
2°E
4°E
6°E
8°E
10°E
28°S
30°S
32°S
34°S
36°S

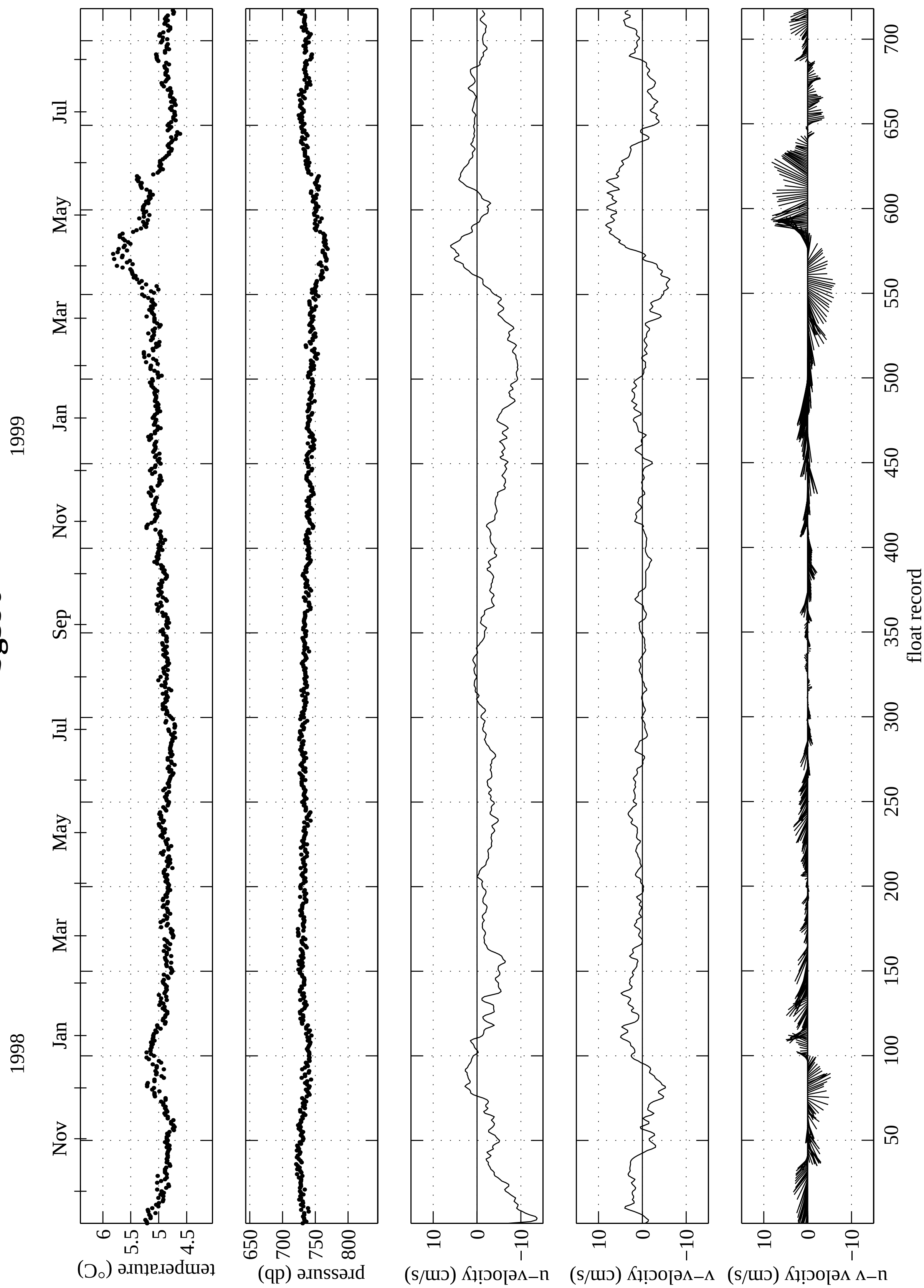
bg395


1998
1999
Oct
Dec
Feb
Apr
Jun
Aug
Oct
Dec
Feb
Apr
Jun
Aug
temperature (°C)
6
5
4
pressure (db)
650
700
750
800
850
u−velocity (cm/s)
20
0
−20
v−velocity (cm/s)
20
0
−20
u−v velocity (cm/s)
20
0
−20
50
100
150
200
250
300
350
400
450
500
550
600
650
700
float record

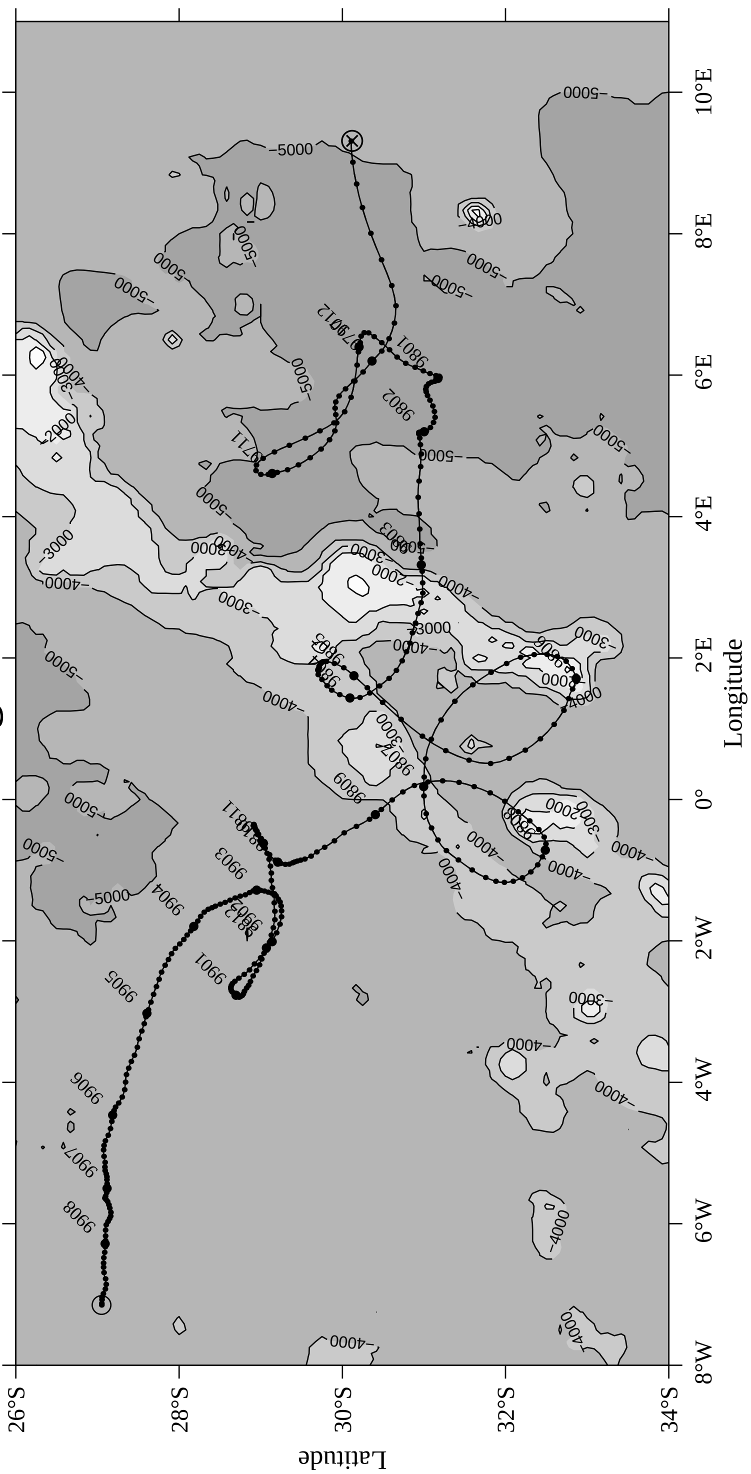
bg396


Longitude
Latitude
14°W
12°W
10°W
8°W
6°W
4°W
2°W
0°
2°E
4°E
6°E
24°S
26°S
28°S
30°S
32°S

bg396


1998
1999
Nov
Jan
Mar
May
Jul
Sep
temperature (°C)
pressure (db)
u−velocity (cm/s)
v−velocity (cm/s)
u−v velocity (cm/s)
float record

bg397



Longitude
Latitude
8°W
6°W
4°W
2°W
0°
2°E
4°E
6°E
8°E
10°E
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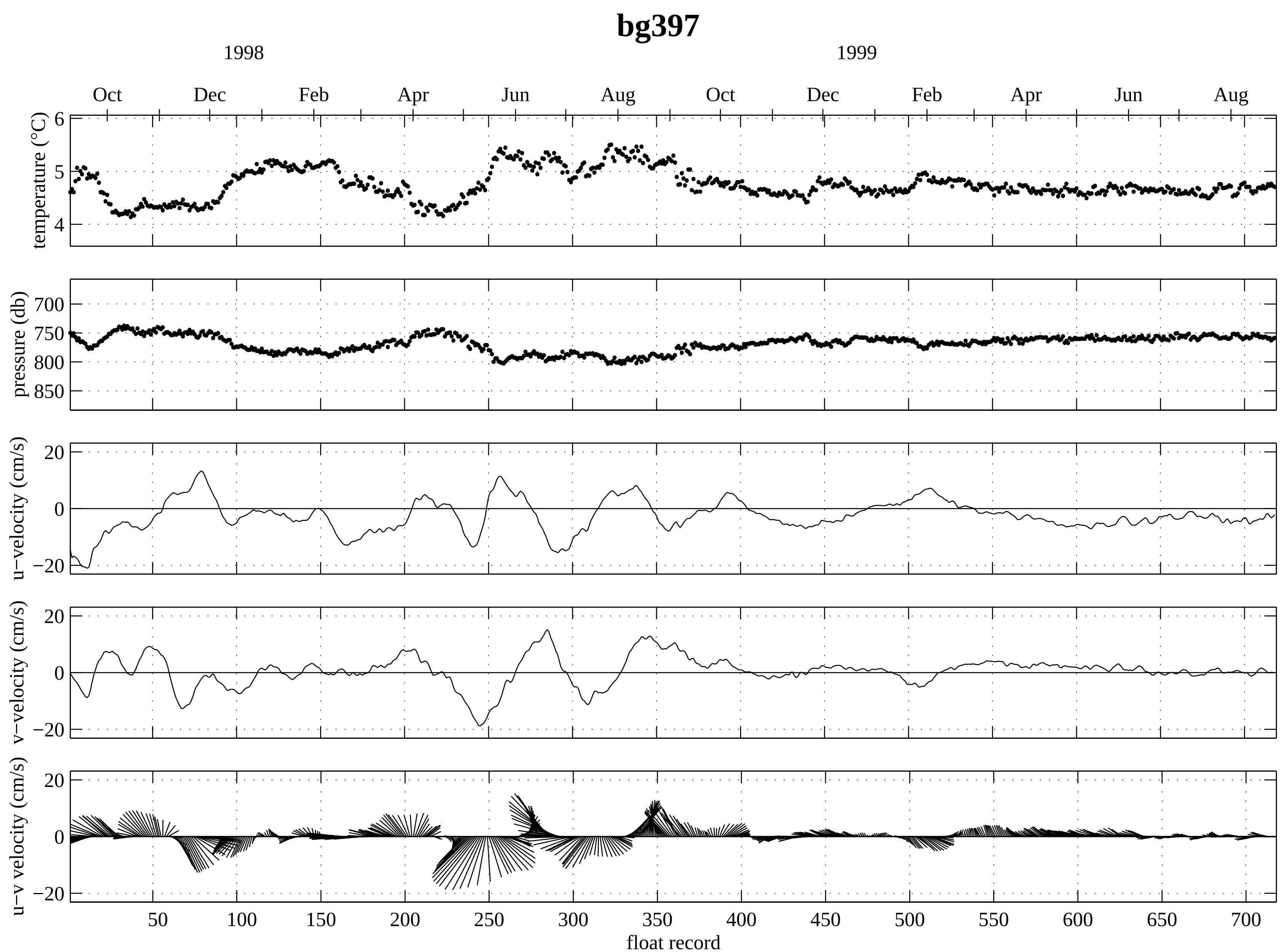
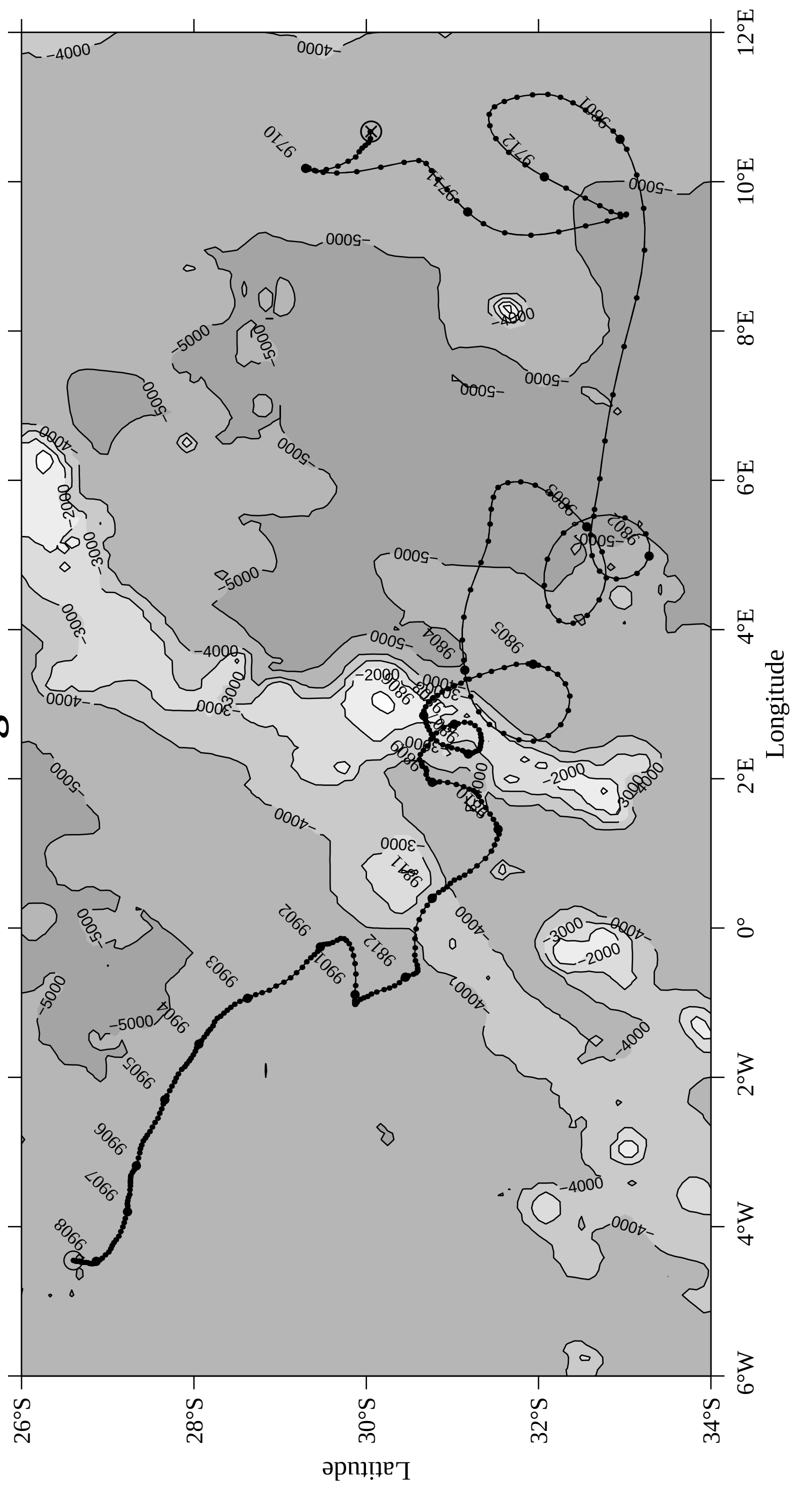
28°S
30°S
32°S
34°S


bg397
1998
1999
Oct
Dec
Feb
Apr
Jun
Aug
temperature (°C)
pressure (db)
u−velocity (cm/s)
v−velocity (cm/s)
u−v velocity (cm/s)
float record

bg398



Latitude
Longitude
26°S
28°S
30°S
32°S
34°S
6°W
4°W
2°W
0°
2°E
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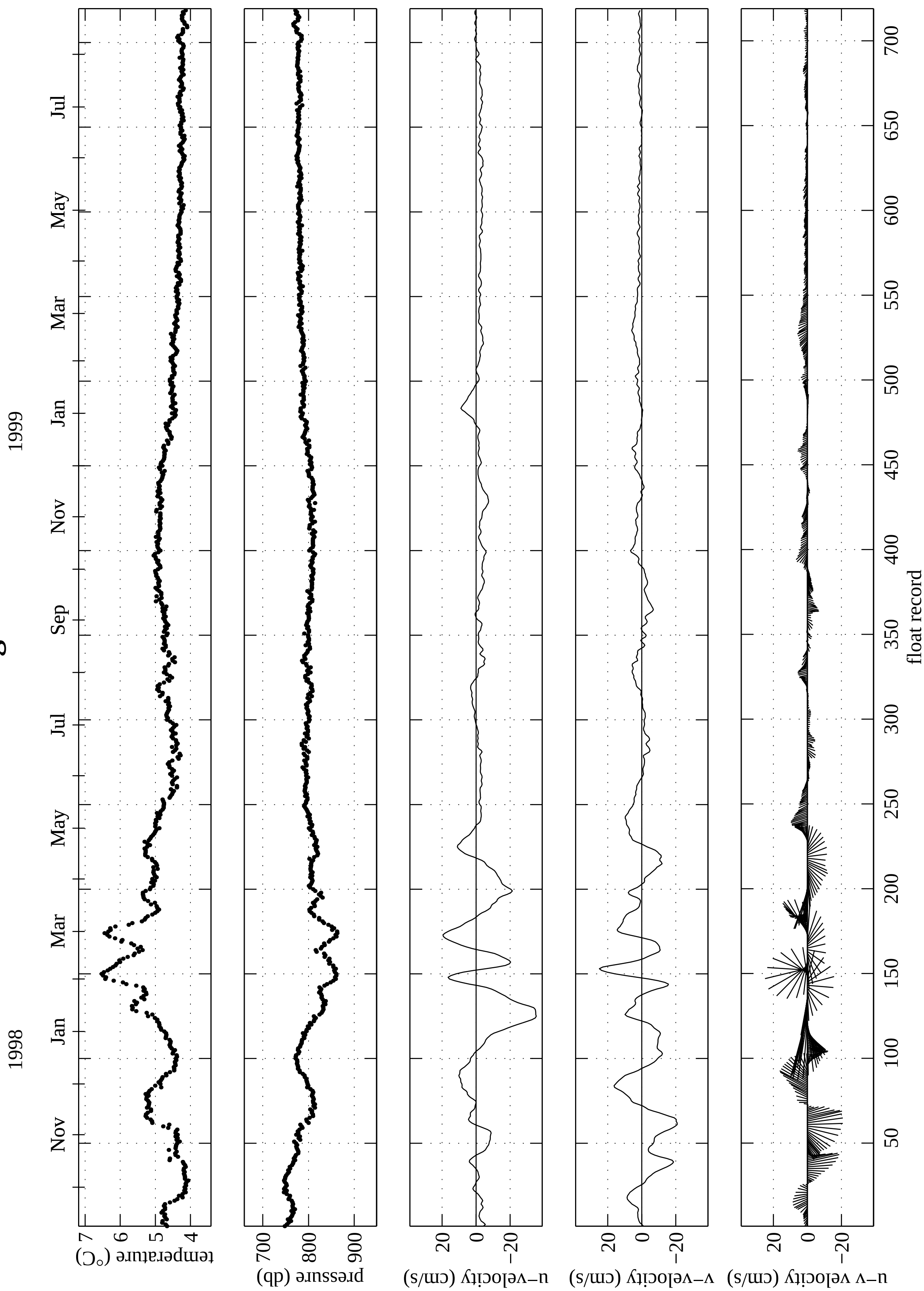
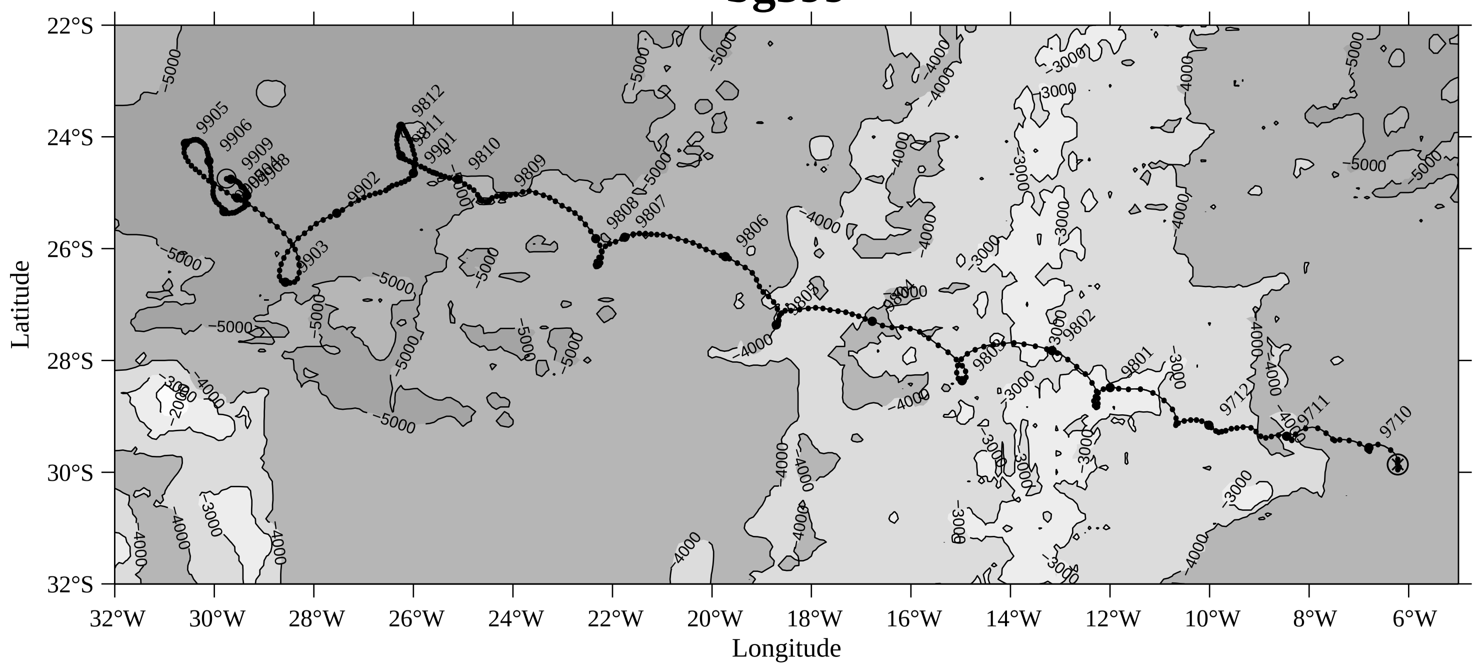
6°E
8°E
10°E
12°E

bg398



1998
1999
Nov
Jan
Mar
May
Jul
Sep
temperature (°C)
pressure (db)
u−velocity (cm/s)
v−velocity (cm/s)
u−v velocity (cm/s)
float record

bg399


22°S
24°S
26°S
28°S
30°S
32°S
Latitude
32°W
30°W
28°W
26°W
24°W
22°W
20°W
18°W
16°W
14°W
12°W
10°W
8°W
6°W
Longitude
9710
9711
9712
9801
9802
9806
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9808
9809
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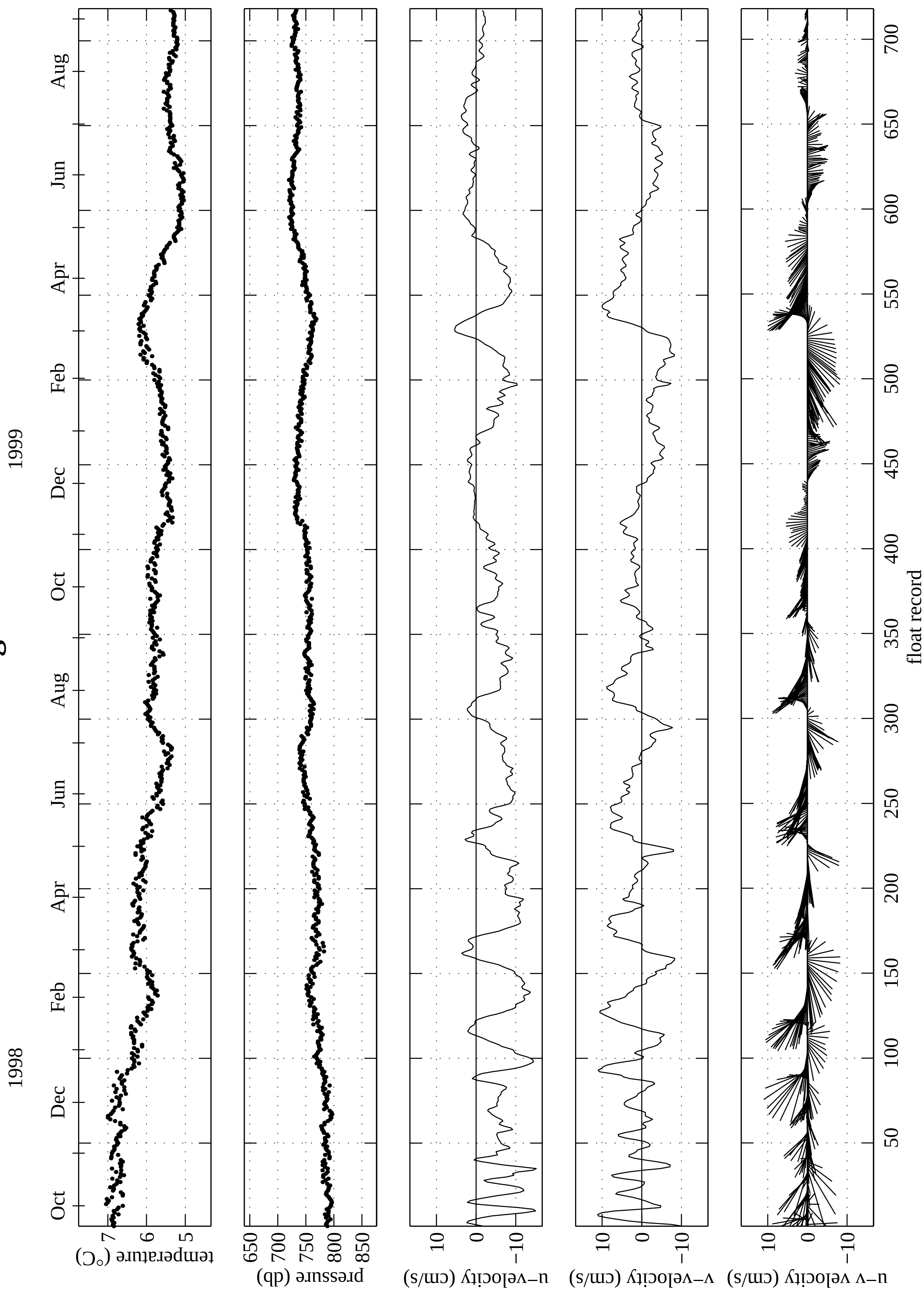
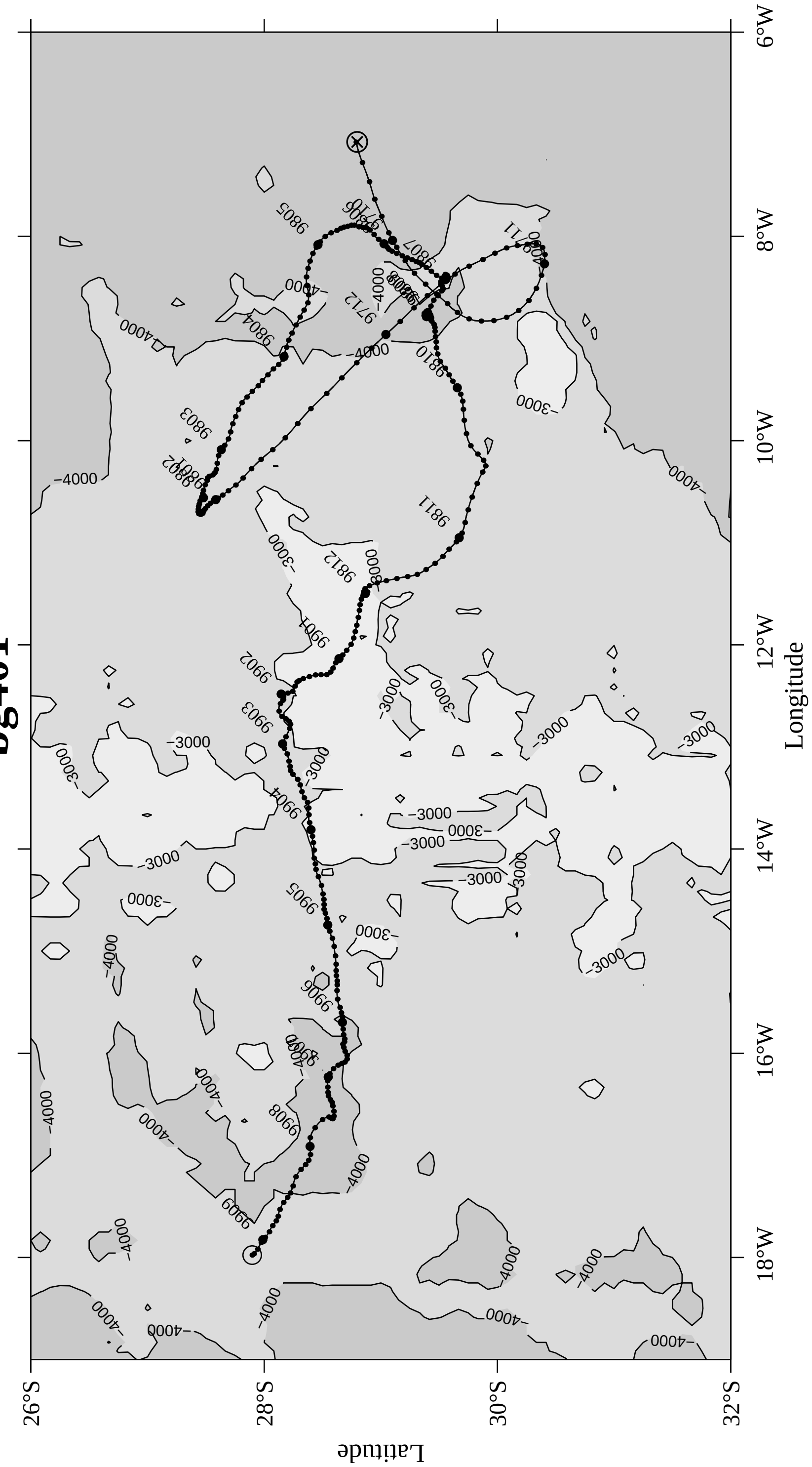
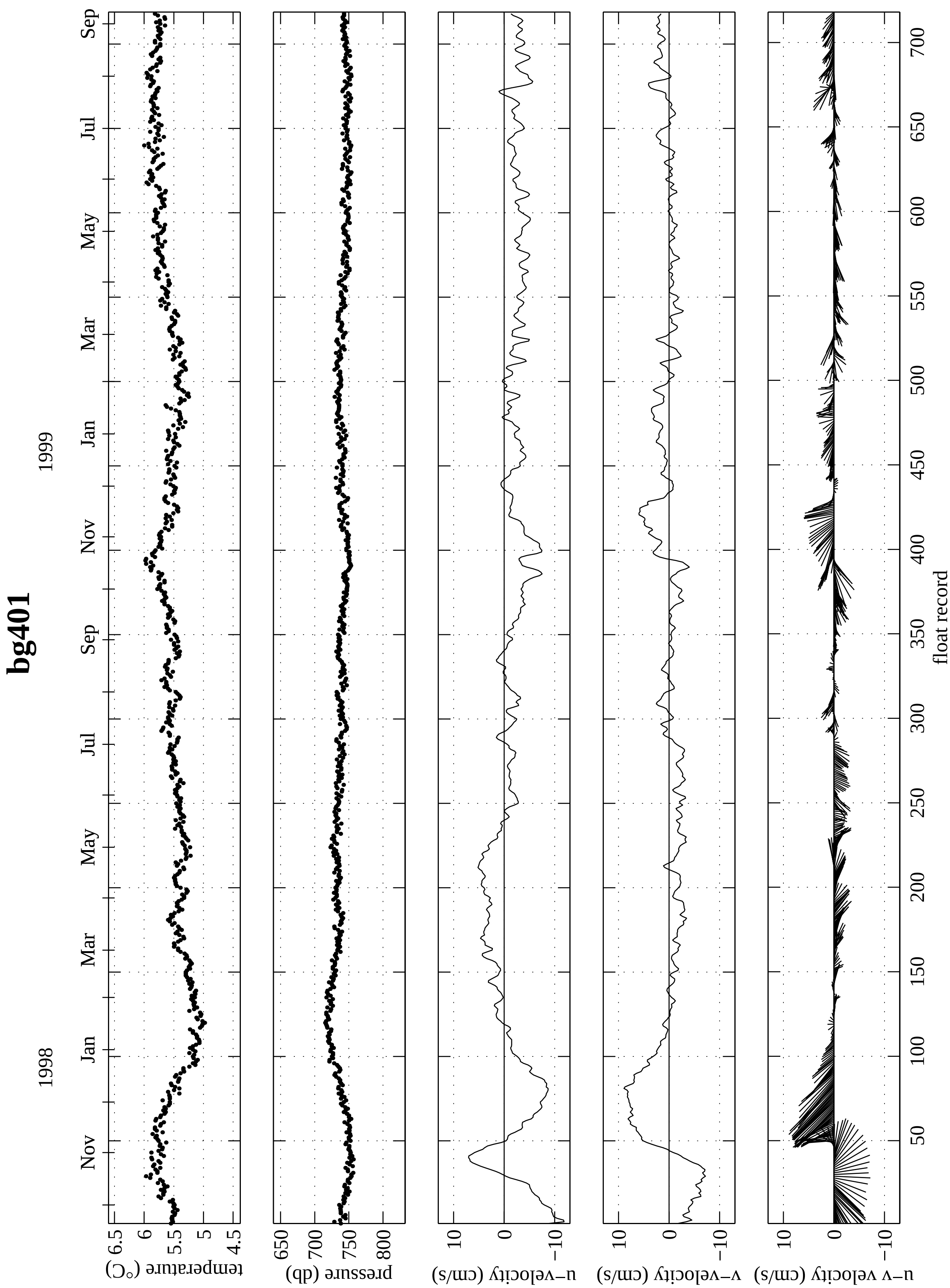
9811
9812
9901
9902
9903
9905
9906
9909

bg399

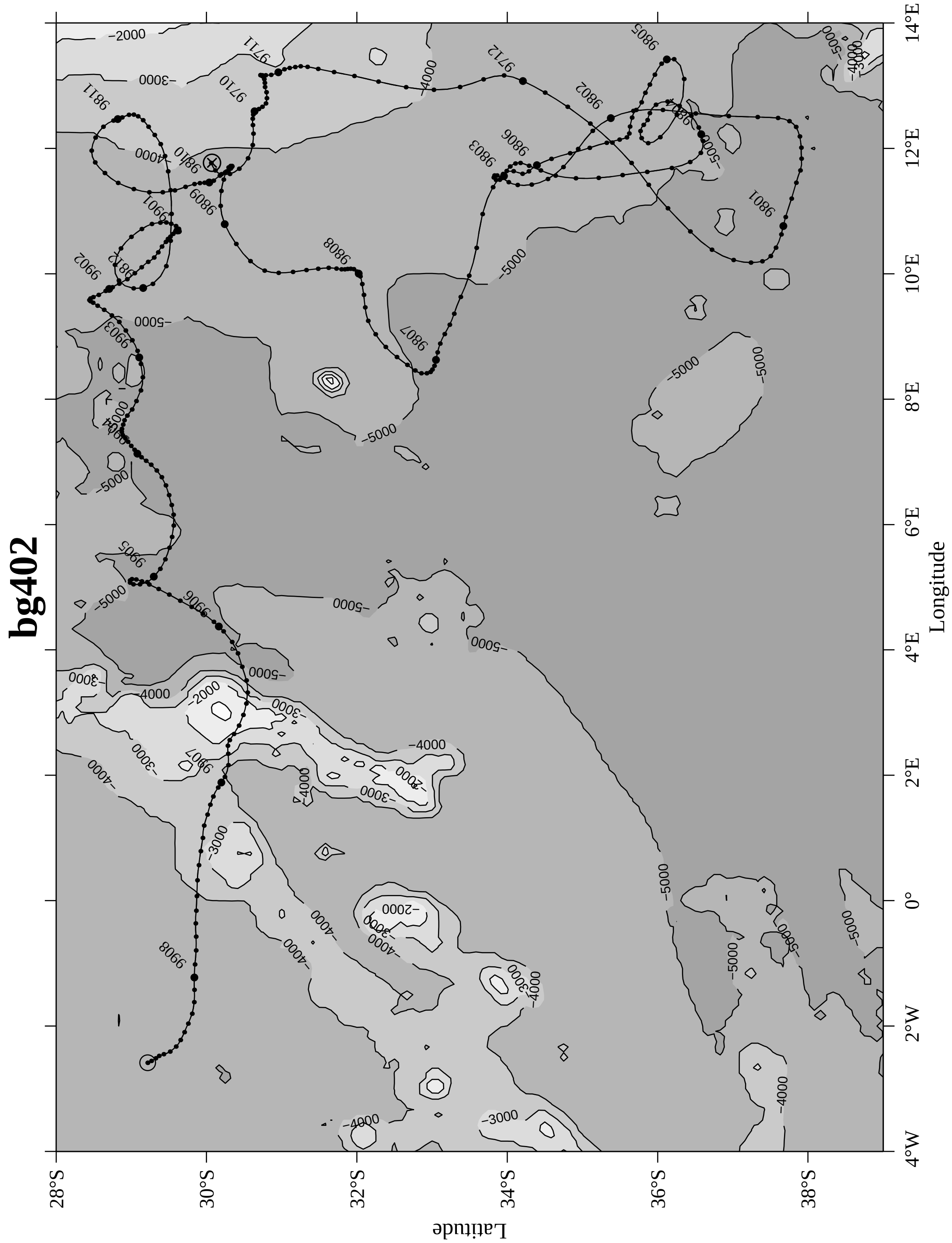

1998
1999
Oct
Dec
Feb
Apr
Jun
Aug
Oct
Dec
Feb
Apr
Jun
Aug
temperature (°C)
pressure (db)
u−velocity (cm/s)
v−velocity (cm/s)
u−v velocity (cm/s)
float record

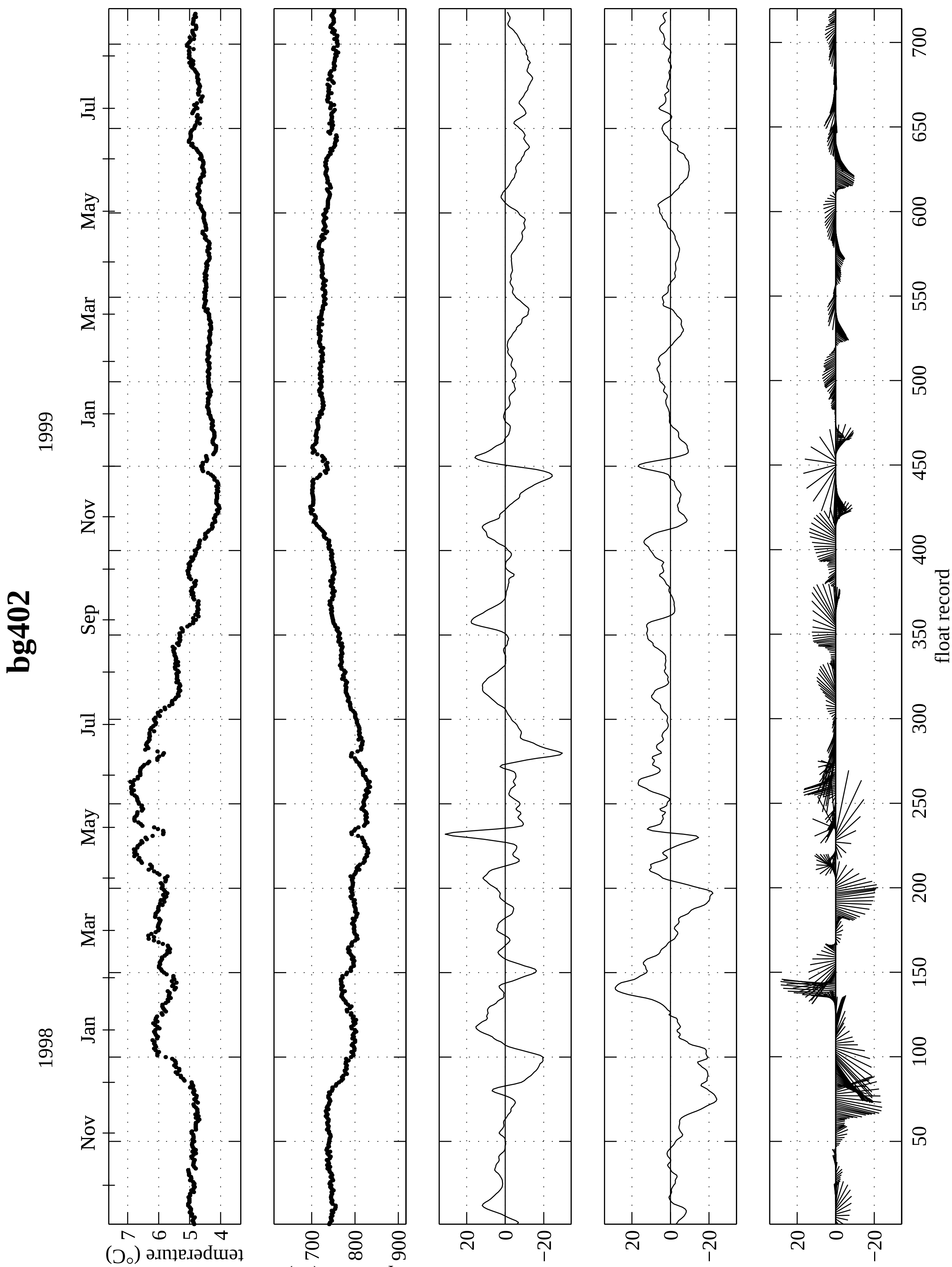
bg401


Longitude
Latitude
6°W
8°W
10°W
12°W
14°W
16°W
18°W
26°S
28°S
30°S
32°S
−4000
−3000

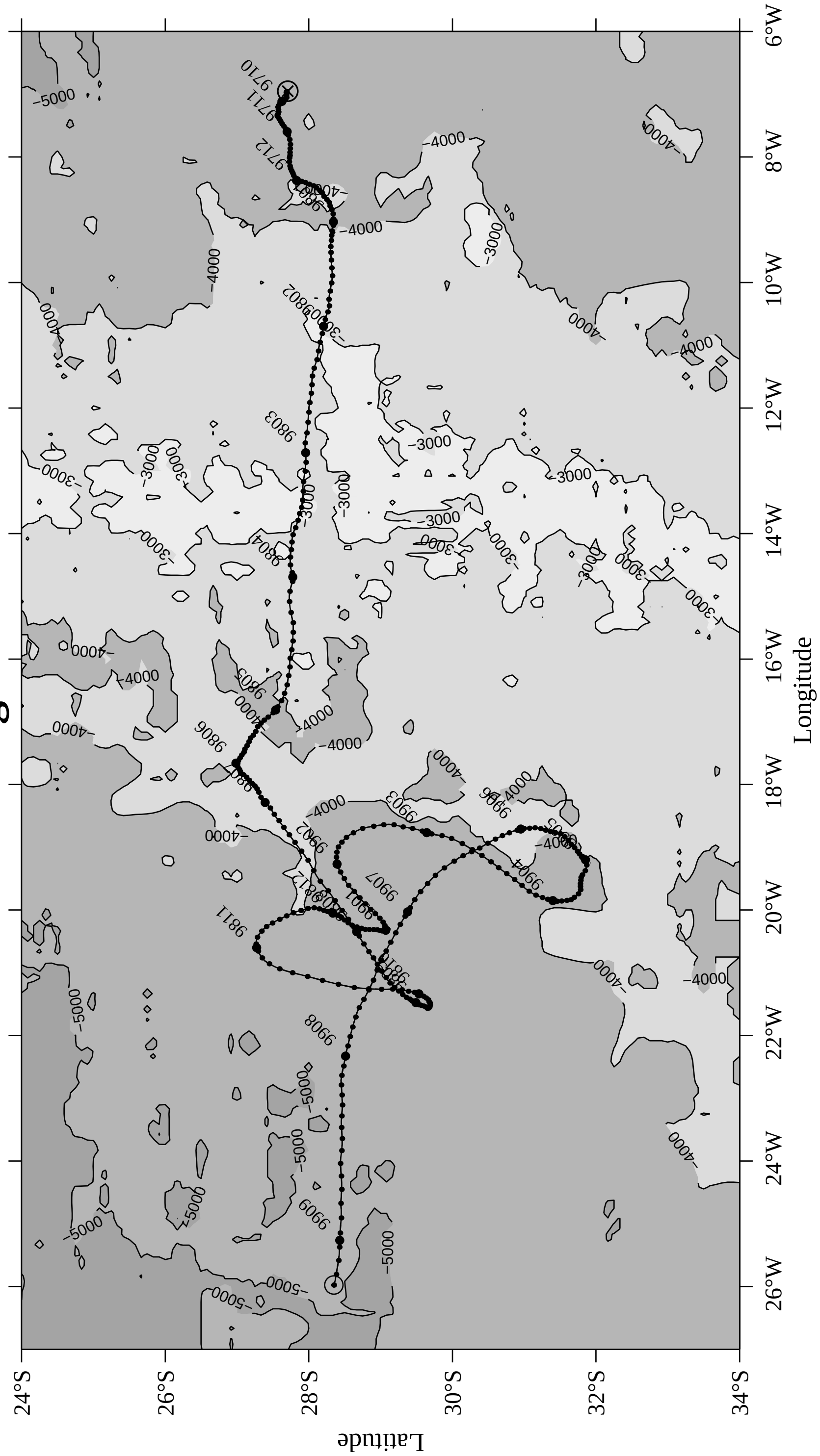


bg401
1998
1999
Nov
Jan
Mar
May
Jul
Sep
temperature (°C)
pressure (db)
u−velocity (cm/s)
v−velocity (cm/s)
u−v velocity (cm/s)
float record

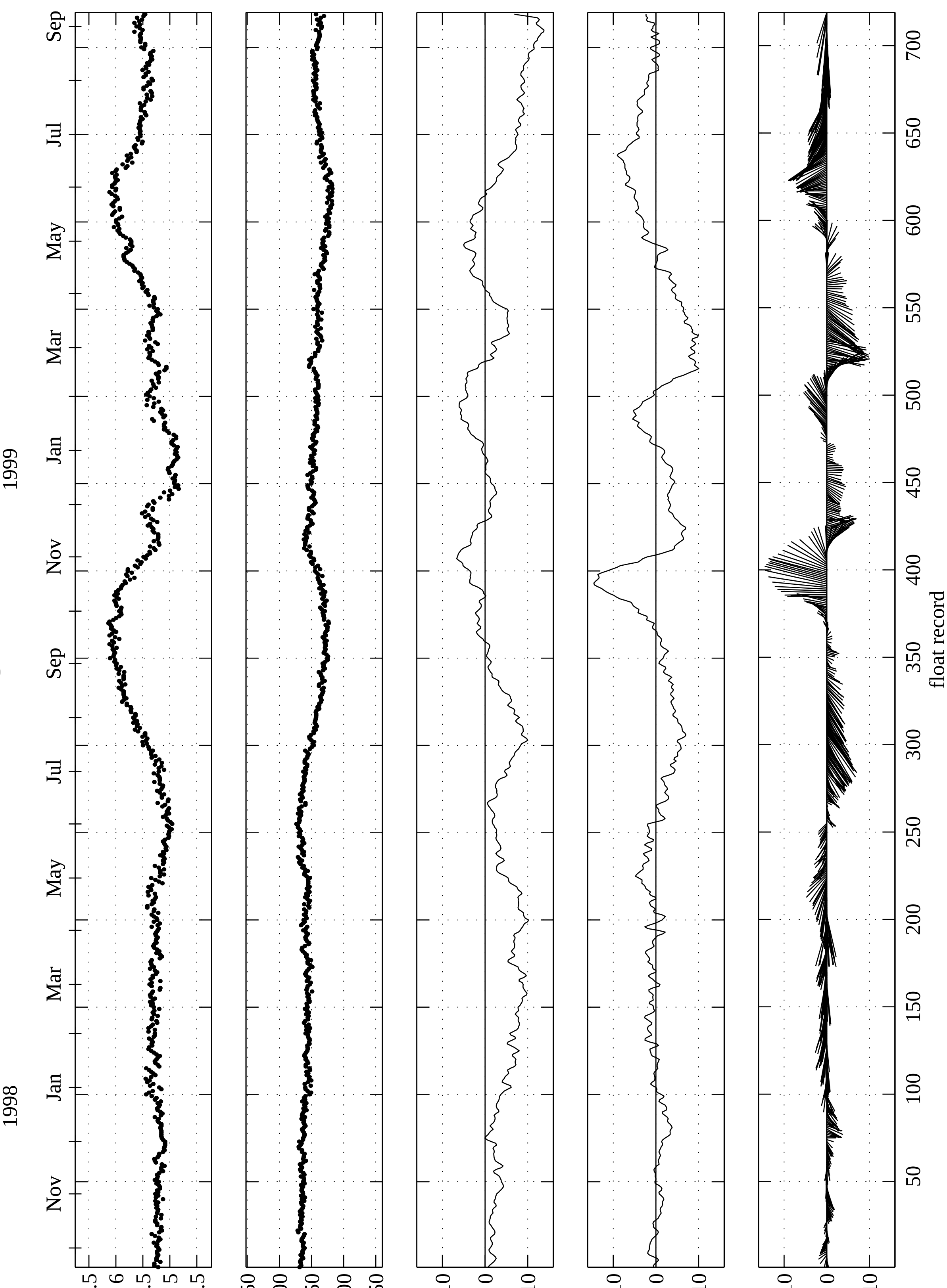

bg402
Longitude
Latitude
28°S
30°S
32°S
34°S
36°S
38°S
4°W
2°W
0°
2°E
4°E
6°E
8°E
10°E
12°E
14°E


bg402
1998
1999
Nov
Jan
Mar
May
Jul
Sep
temperature (°C)
pressure (db)
u−velocity (cm/s)
v−velocity (cm/s)
u−v velocity (cm/s)
float record

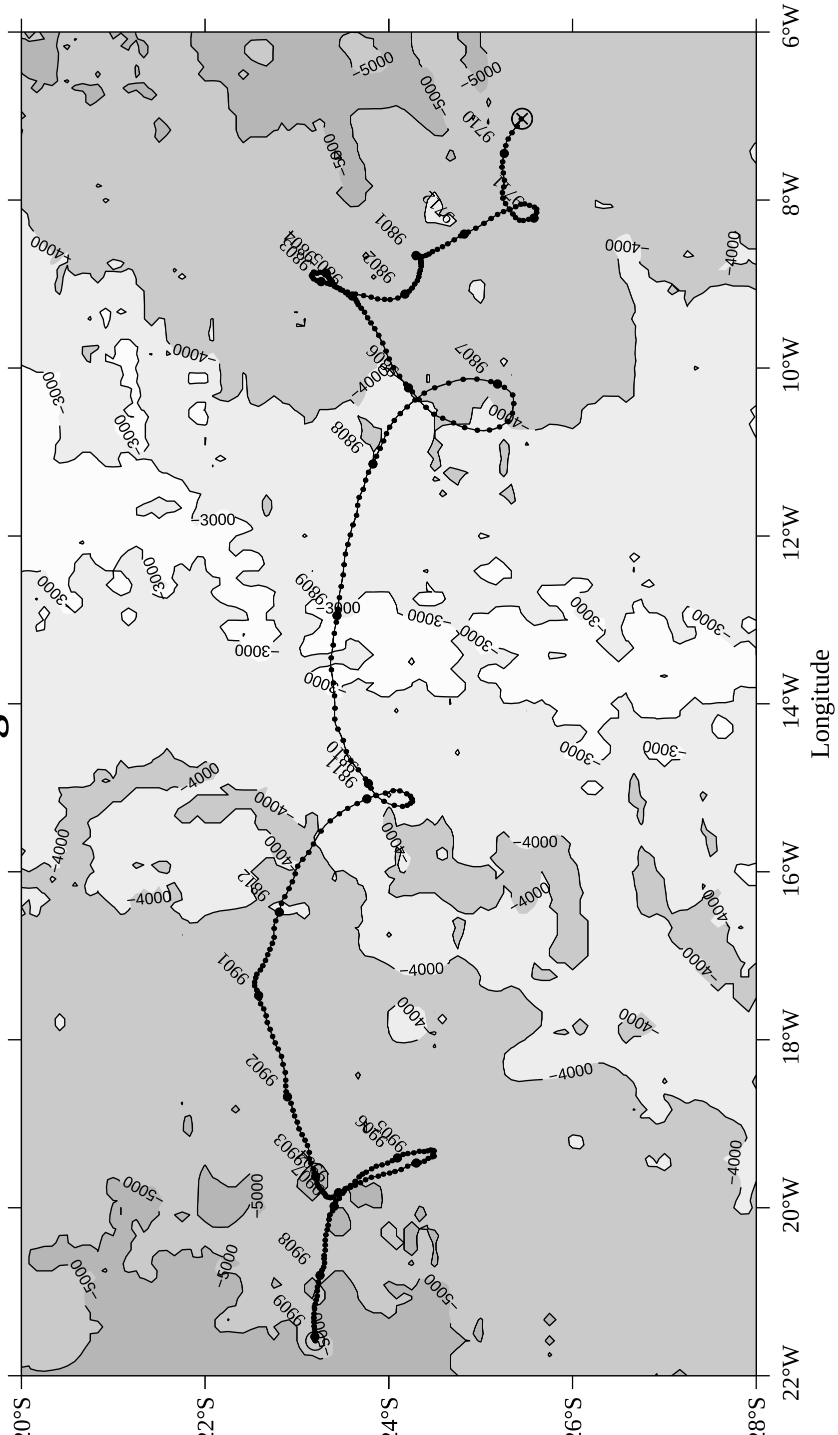
bg403


Longitude
Latitude
6°W
8°W
10°W
12°W
14°W
16°W
18°W
20°W
22°W
24°W
26°W
24°S
26°S
28°S
30°S
32°S
34°S

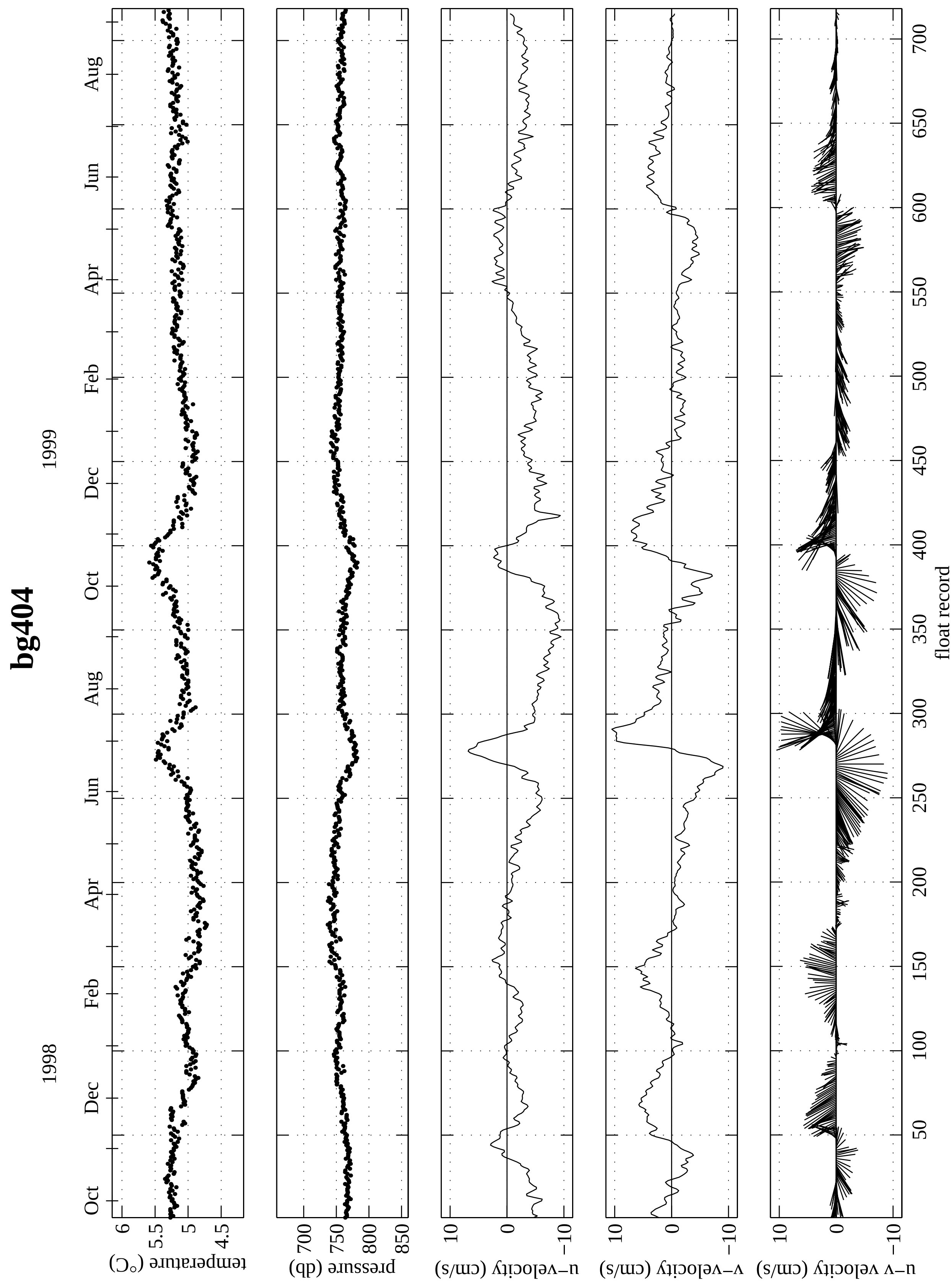
bg403

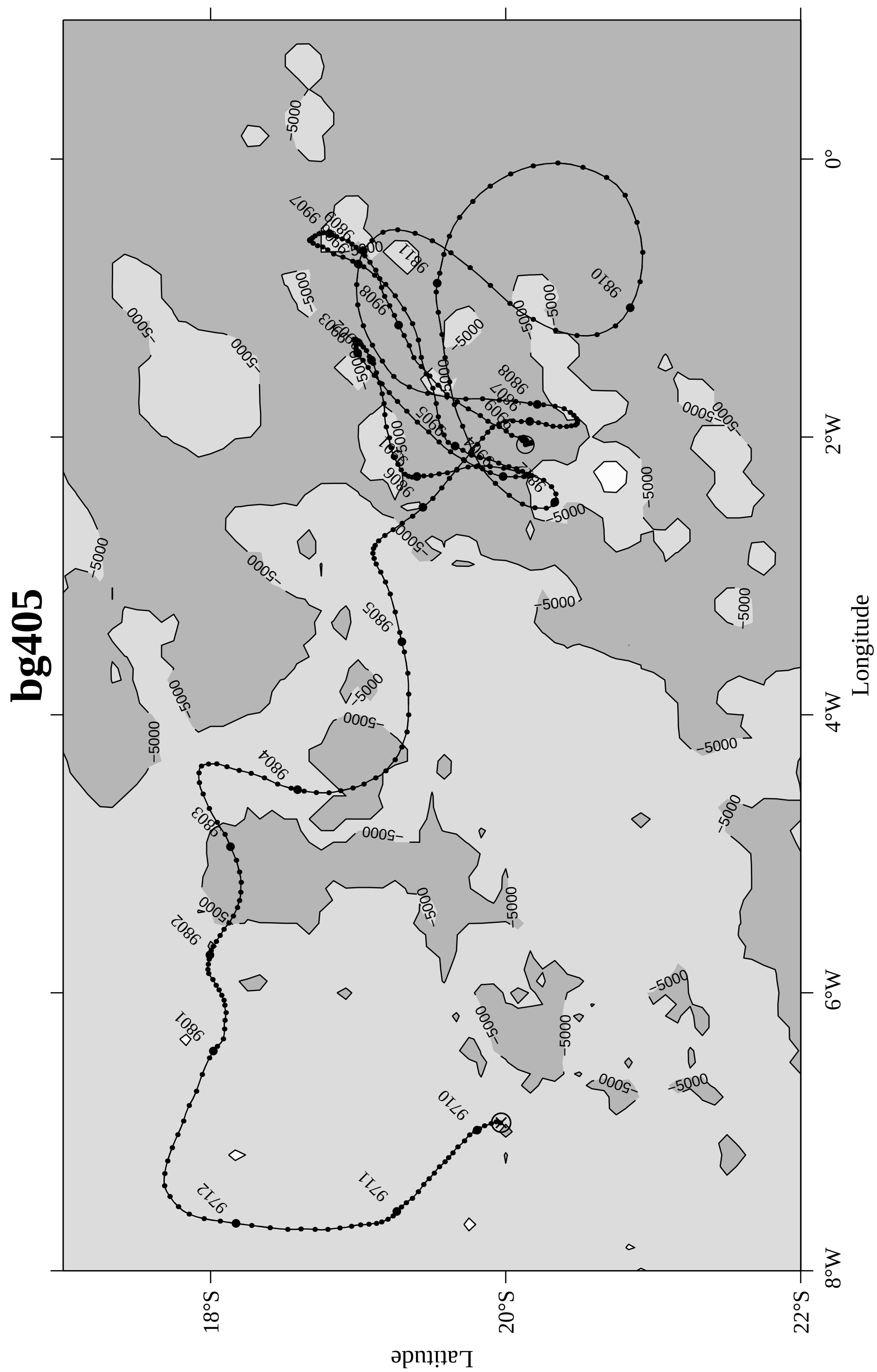

1998
1999
Nov
Jan
Mar
May
Jul
Sep
Nov
Jan
Mar
May
Jul
Sep
temperature (°C)
6.5
6
5.5
5
4.5
pressure (db)
650
700
750
800
850
u−velocity (cm/s)
10
0
−10
v−velocity (cm/s)
10
0
−10
u−v velocity (cm/s)
10
0
−10
50
100
150
200
250
300
350
400
450
500
550
600
650
700
float record

bg404

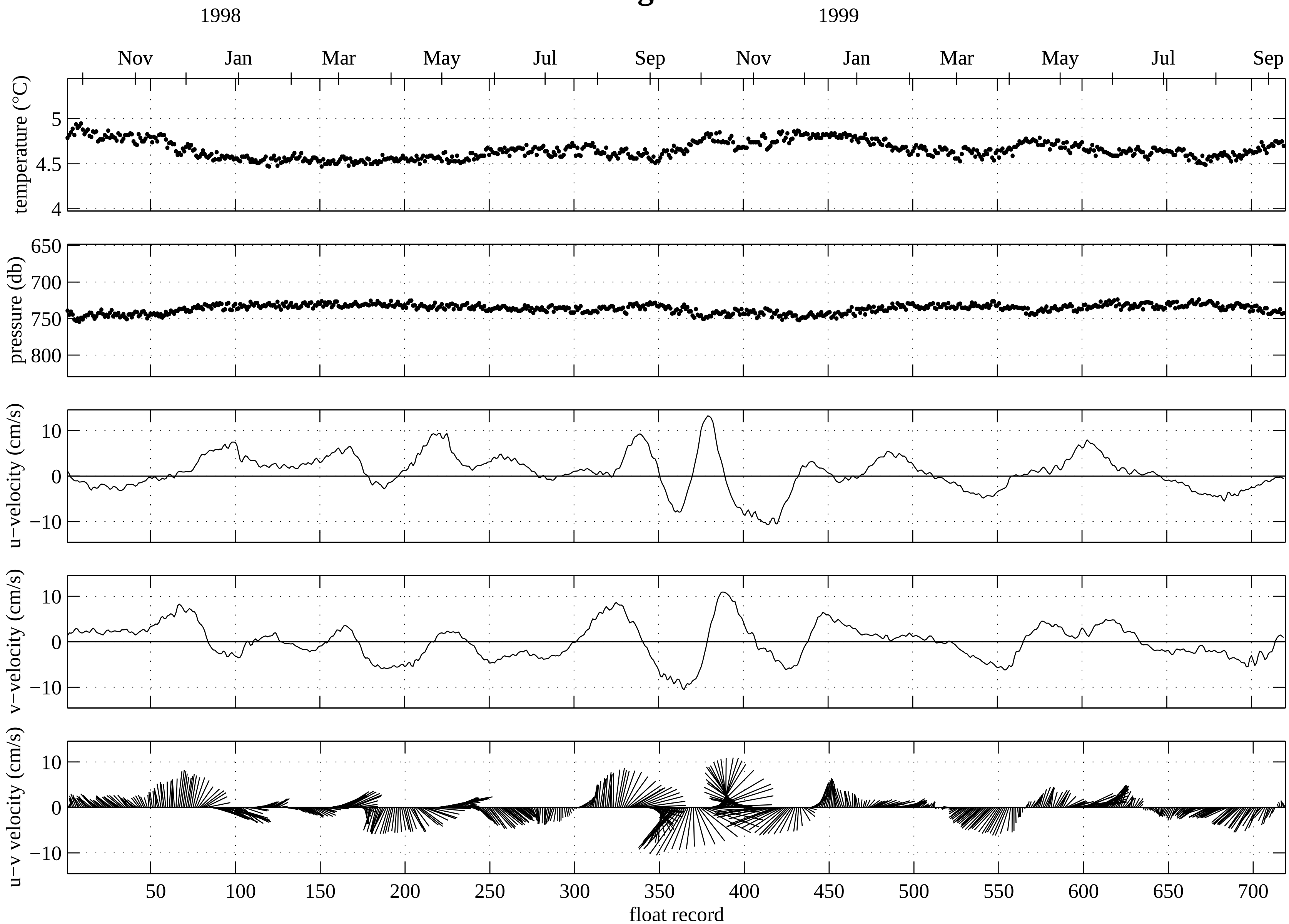


Longitude
Latitude
6°W
8°W
10°W
12°W
14°W
16°W
18°W
20°W
22°W
20°S
22°S
24°S
26°S
28°S

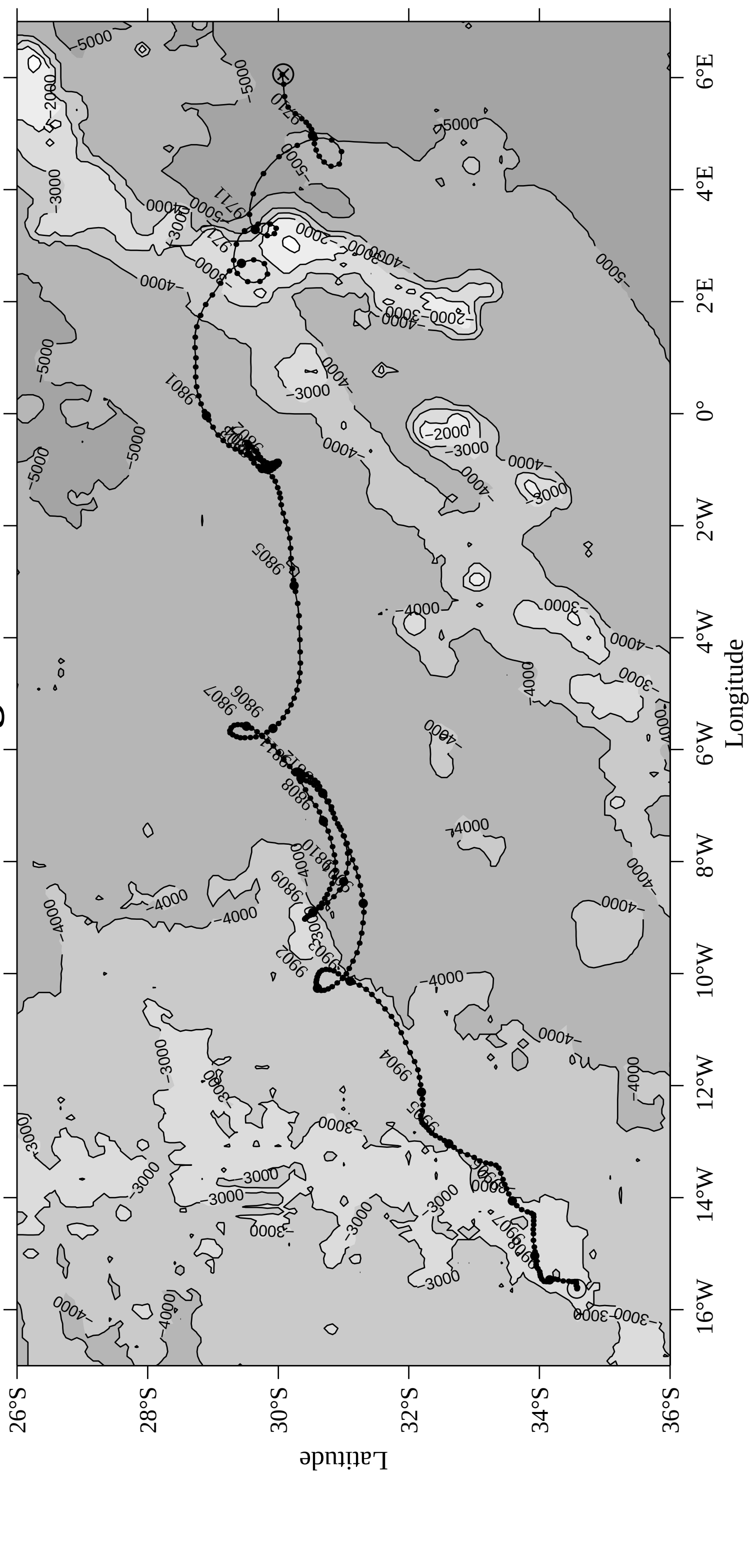

bg404
1998
1999
Oct
Dec
Feb
Apr
Jun
Aug
temperature (°C)
pressure (db)
u−velocity (cm/s)
v−velocity (cm/s)
u−v velocity (cm/s)
float record

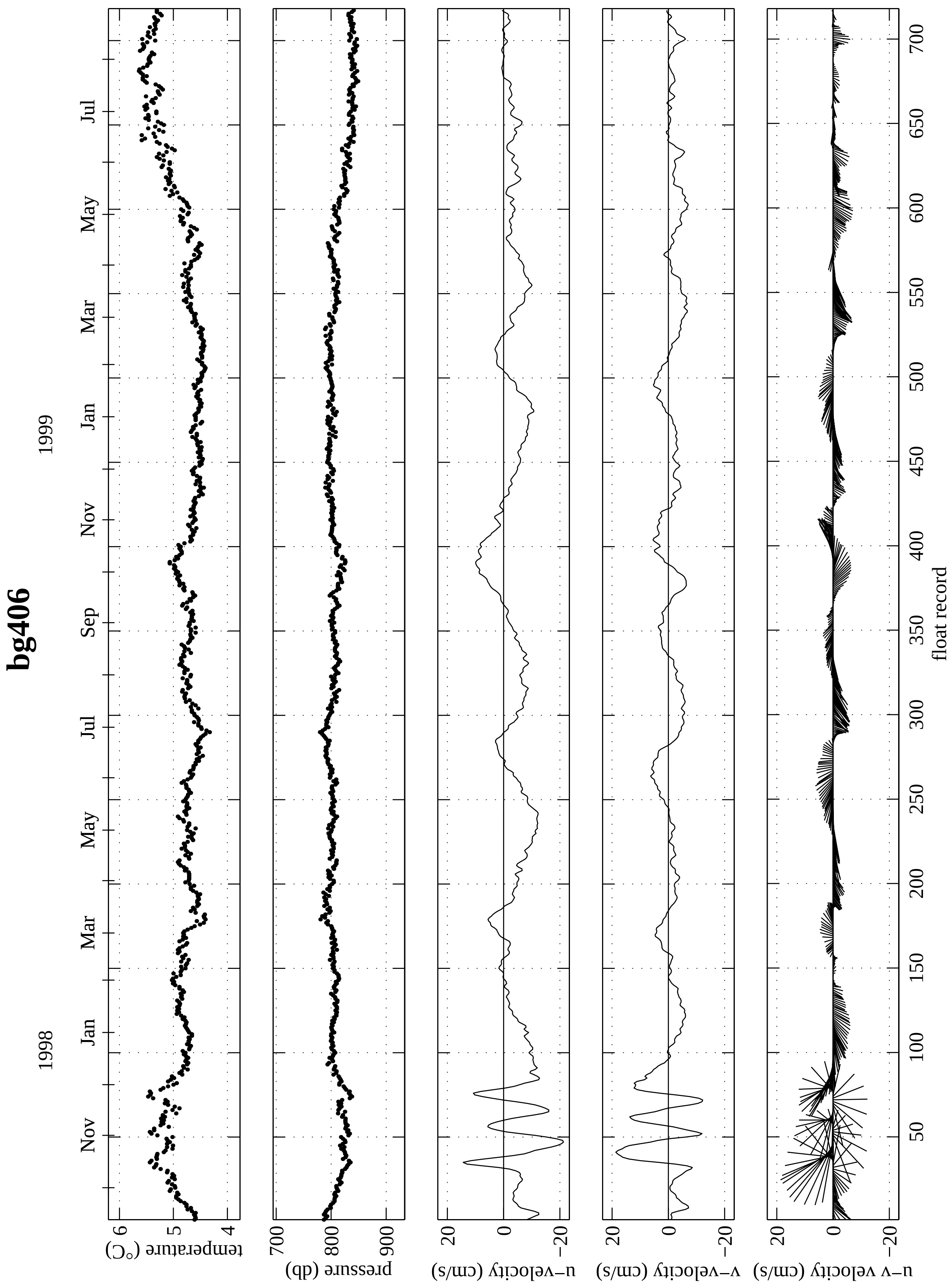

bg405
Longitude
Latitude
18°S
20°S
22°S
8°W
6°W
4°W
2°W
0°
−5000

bg405

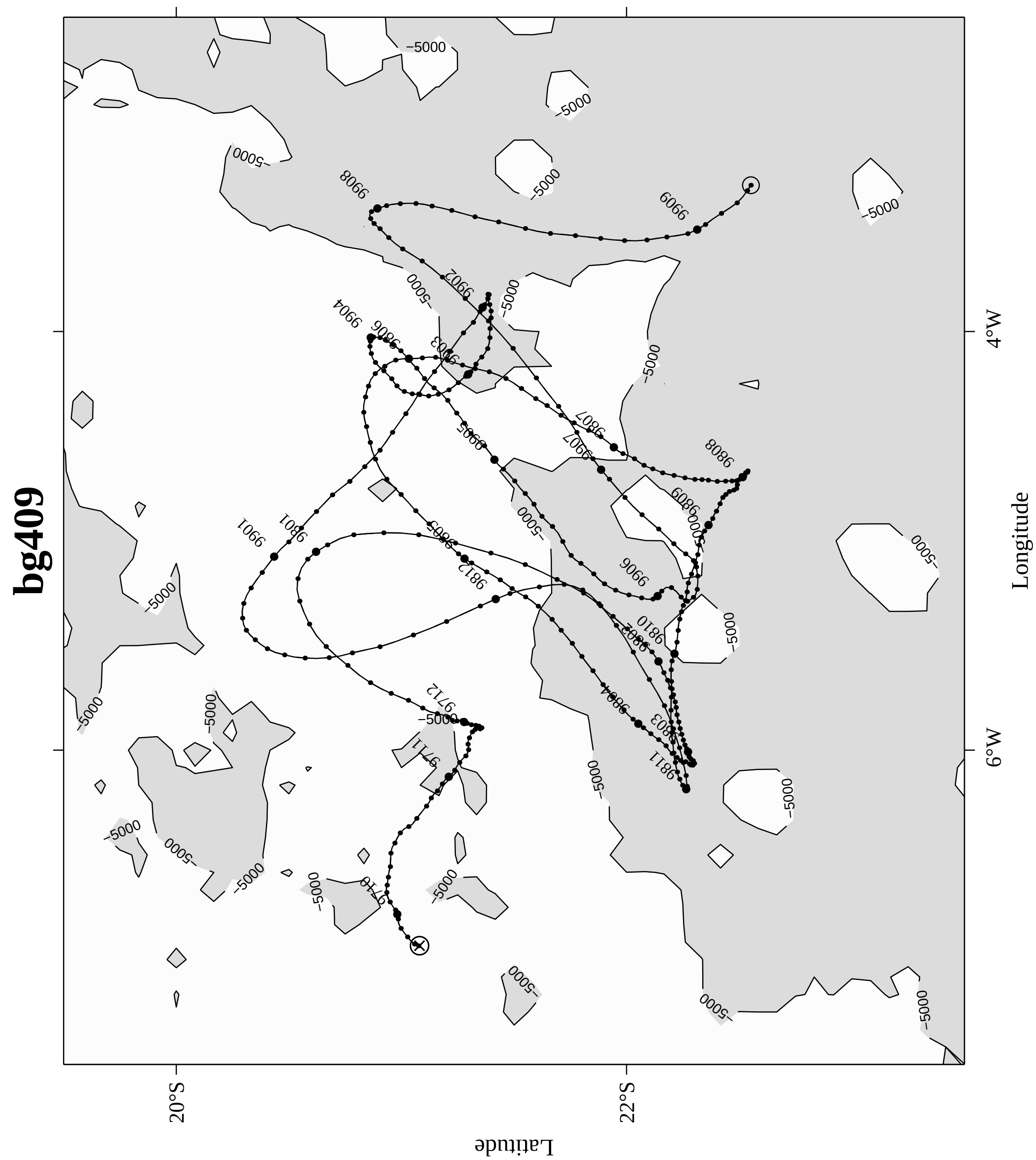

1998
1999
Nov
Jan
Mar
May
Jul
Sep
Nov
Jan
Mar
May
Jul
Sep
temperature (°C)
pressure (db)
u−velocity (cm/s)
v−velocity (cm/s)
u−v velocity (cm/s)
float record

bg406


Longitude
Latitude
16°W
14°W
12°W
10°W
8°W
6°W
4°W
2°W
0°
2°E
4°E
6°E
26°S
28°S
30°S
32°S
34°S
36°S

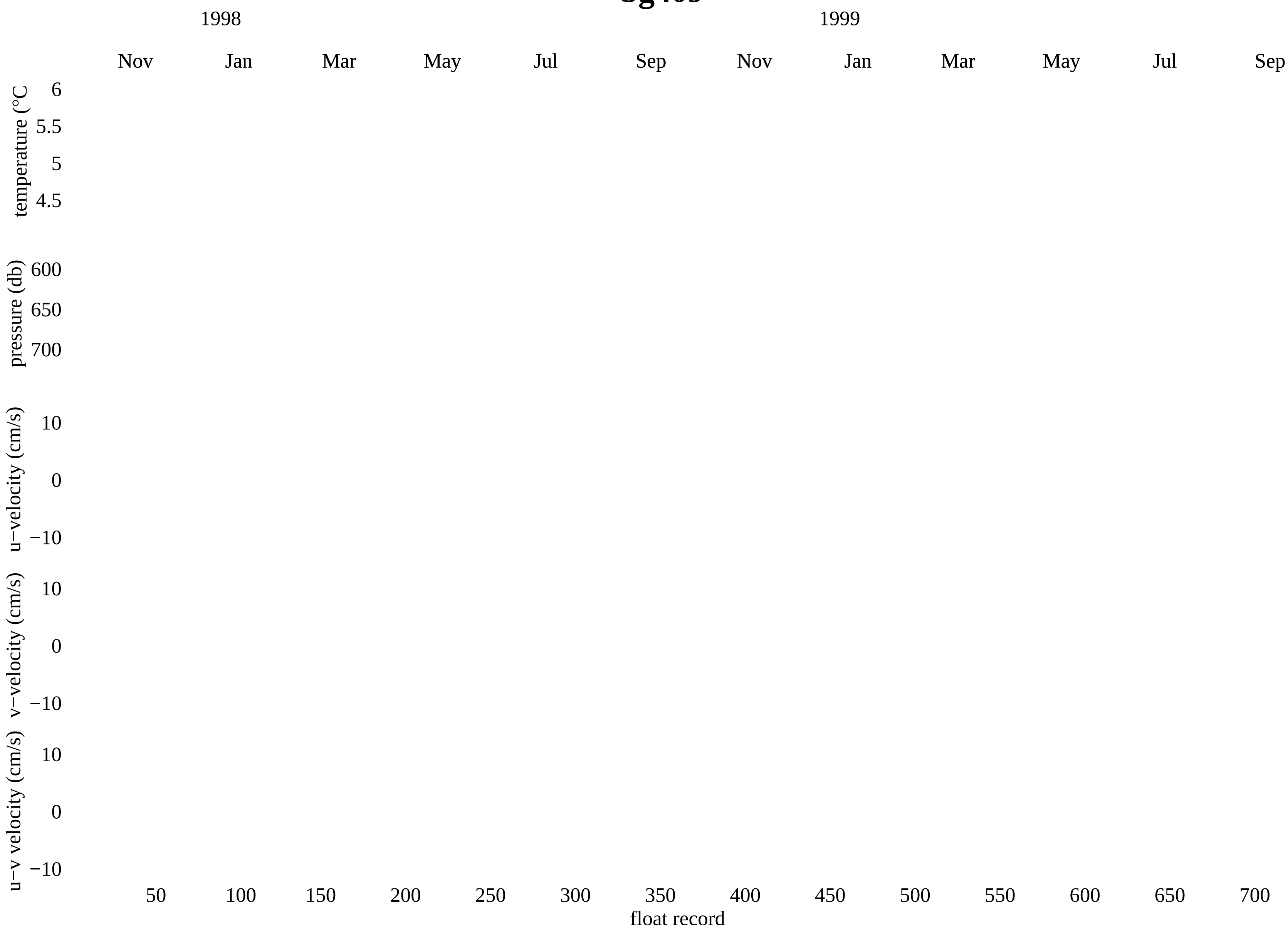

bg406
1998
1999
Nov
Jan
Mar
May
Jul
Sep
Nov
Jan
Mar
May
Jul
temperature (°C)
pressure (db)
u−velocity (cm/s)
v−velocity (cm/s)
u−v velocity (cm/s)
float record

bg409



−5000
20°S
22°S
4°W
6°W
Latitude
Longitude
9710
9711
9712
9801
9803
9804
9805
9806
9807
9808
9809
9810
9811
9812
9901
9902
9903
9904
9905
9906
9907
9908
9909

bg409


1998
1999
Nov
Jan
Mar
May
Jul
Sep
Nov
Jan
Mar
May
Jul
Sep
temperature (°C
6
5.5
5
4.5
pressure (db)
600
650
700
u−velocity (cm/s)
10
0
−10
v−velocity (cm/s)
10
0
−10
u−v velocity (cm/s)
10
0
−10
50
100
150
200
250
300
350
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450
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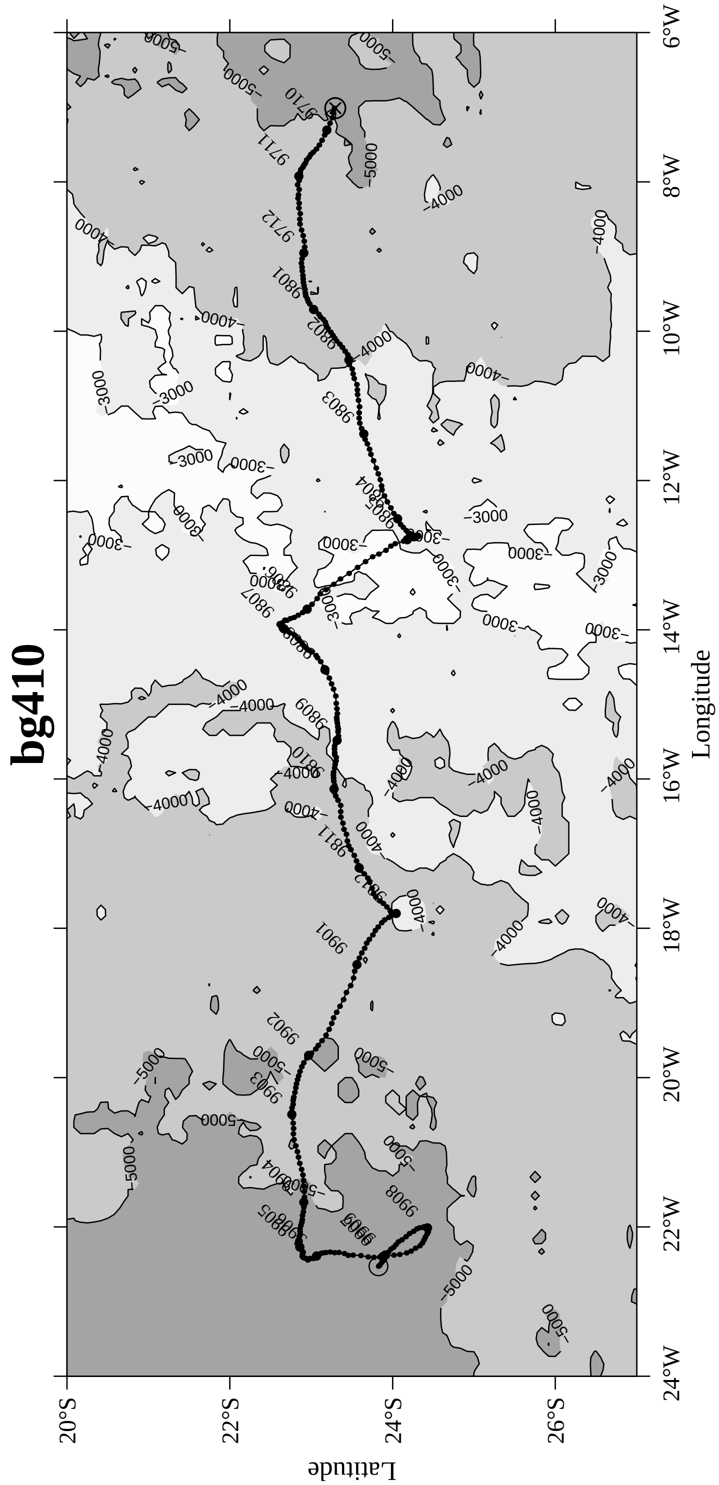
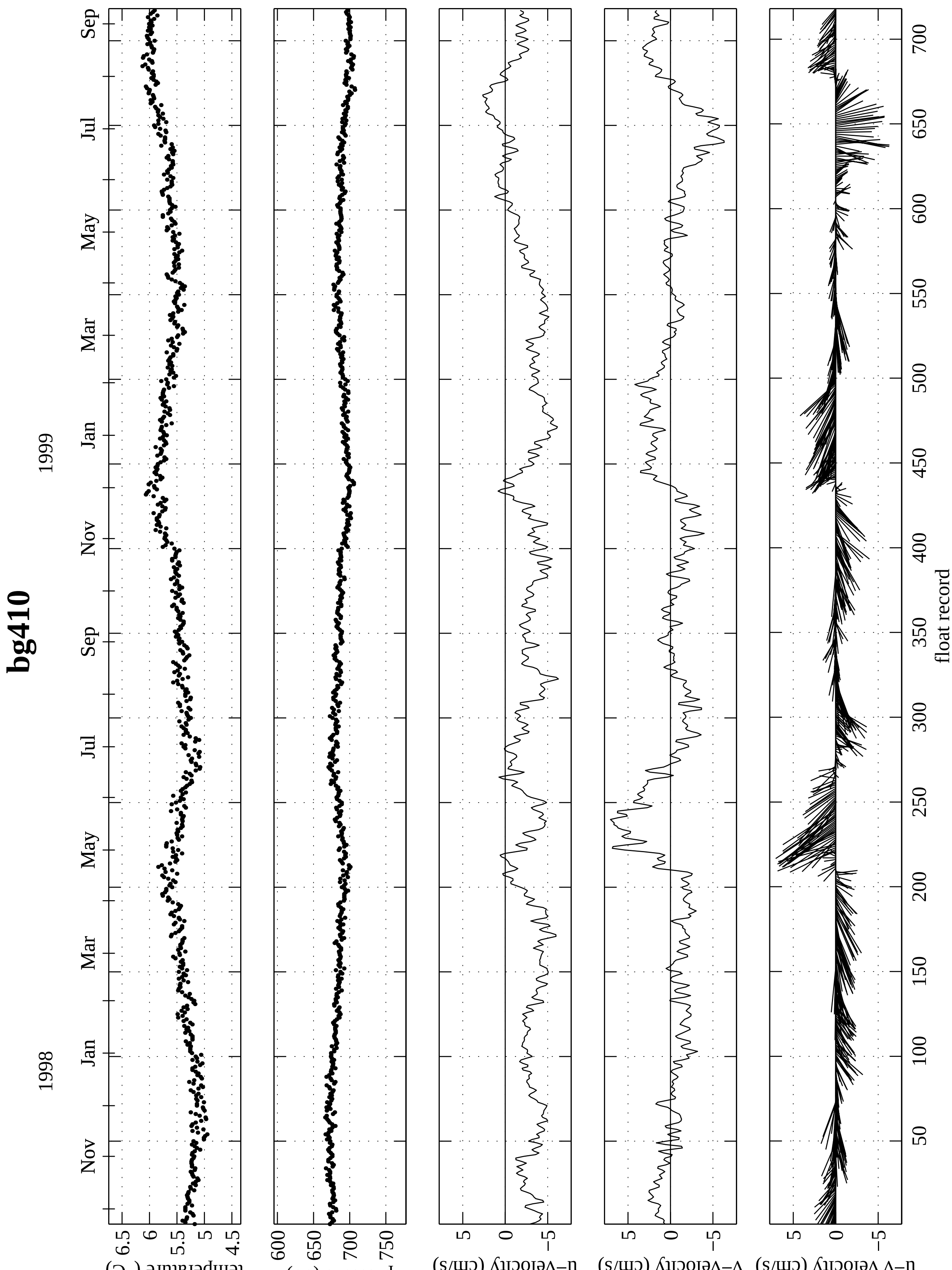
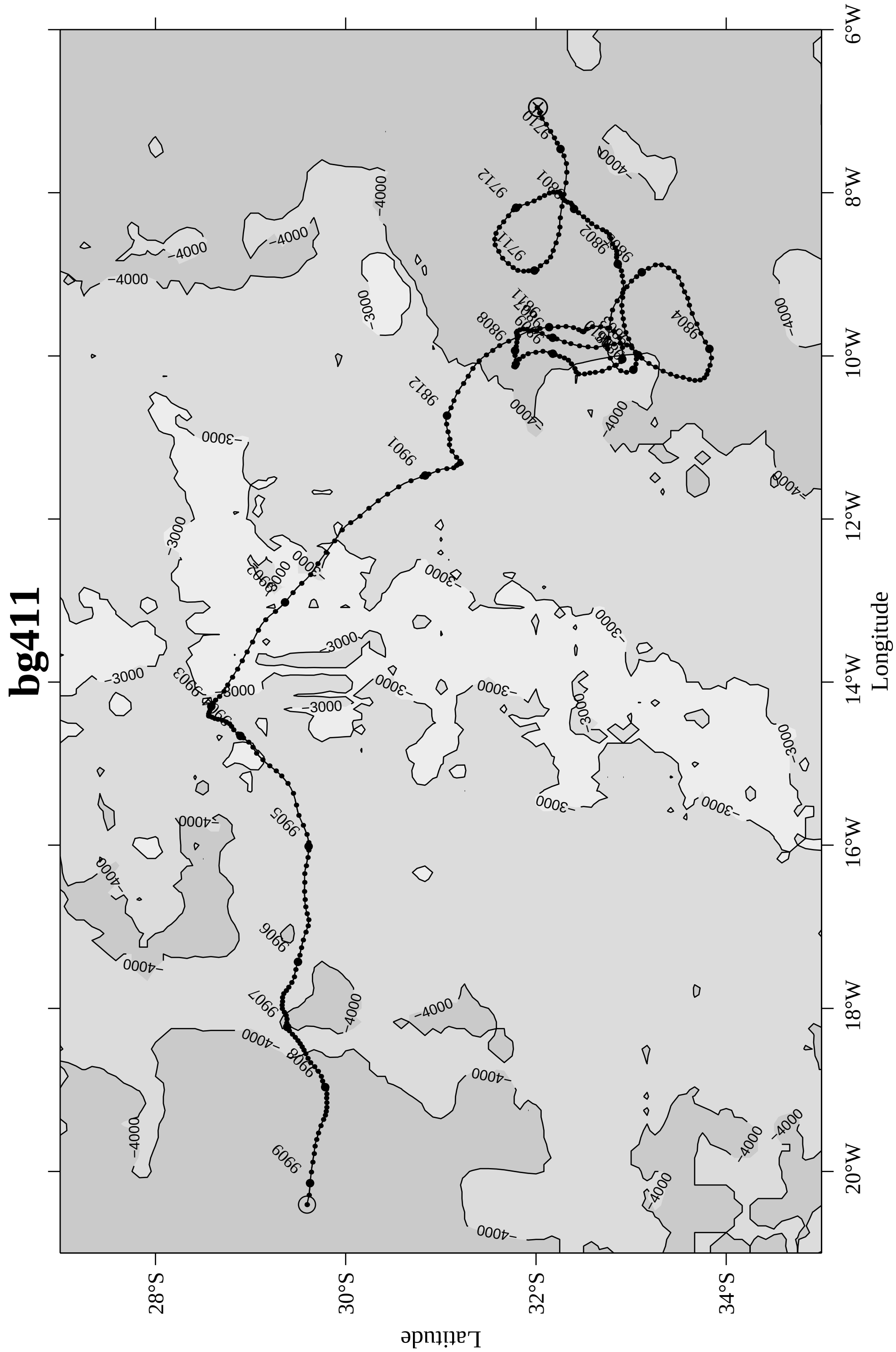
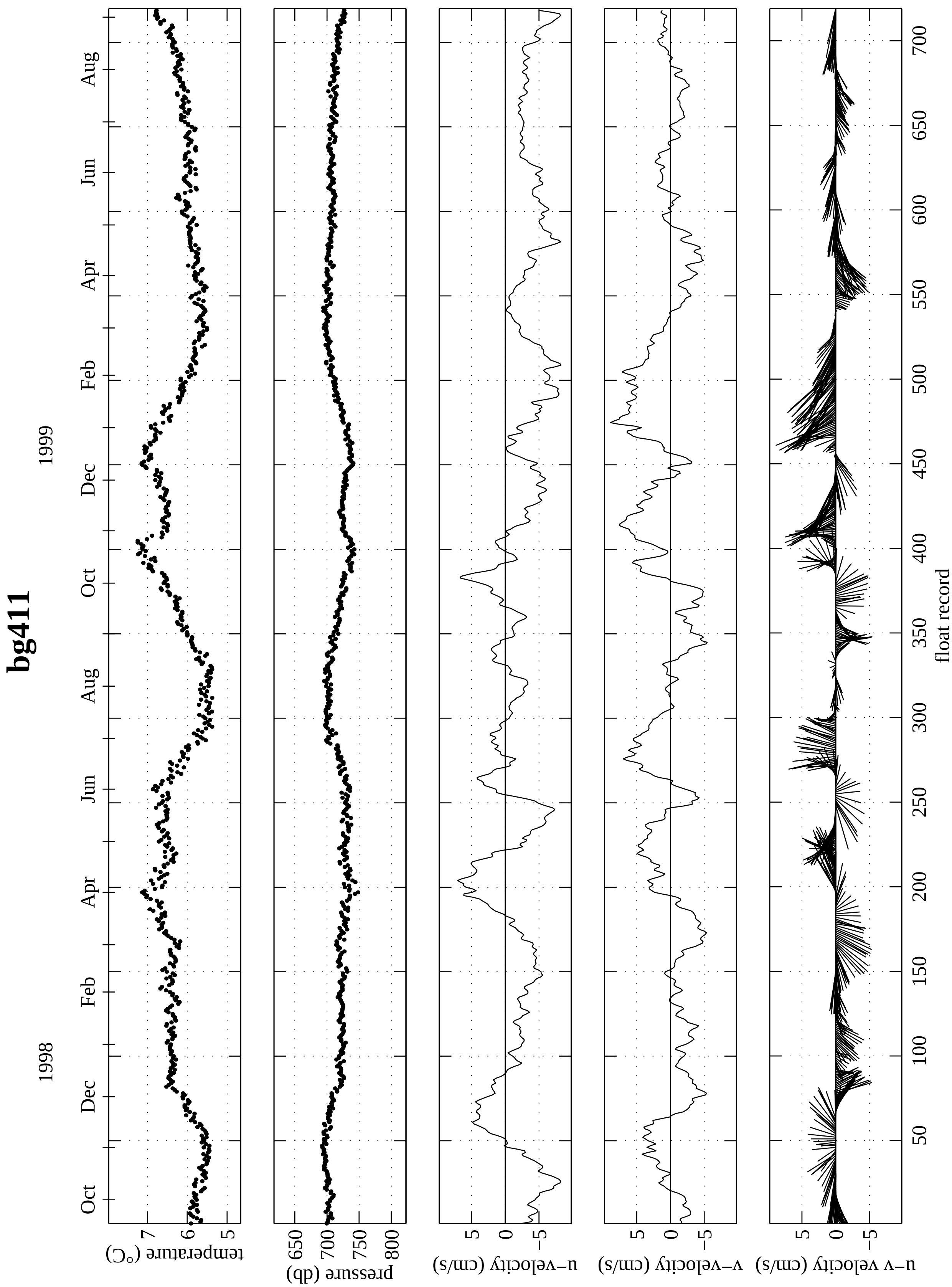
550
600
650
700
float record

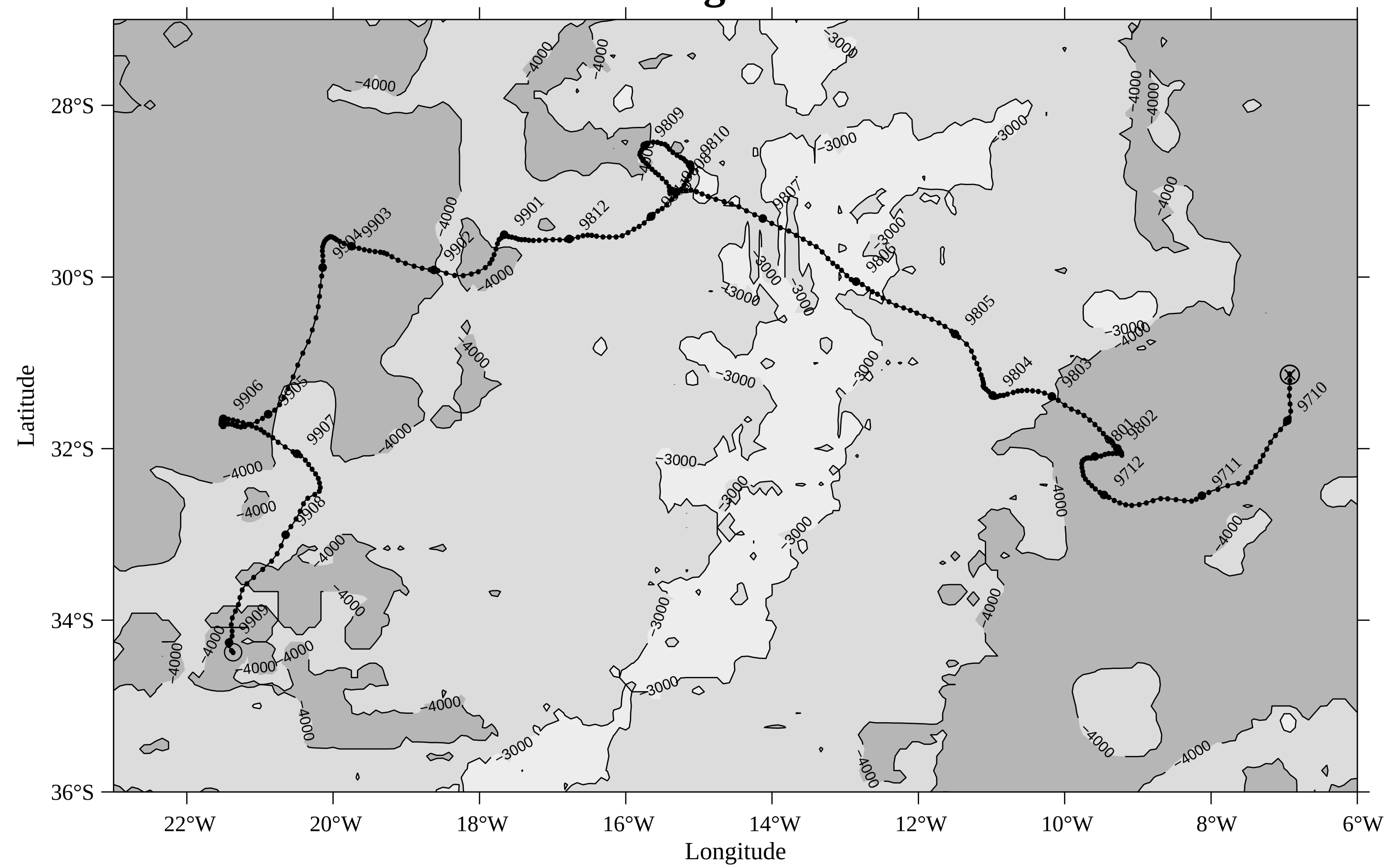

bg410
Longitude
Latitude
24°W
22°W
20°W
18°W
16°W
14°W
12°W
10°W
8°W
6°W
20°S
22°S
24°S
26°S


bg410
1998
1999
Nov
Jan
Mar
May
Jul
Sep
temperature (°C)
pressure (db)
u−velocity (cm/s)
v−velocity (cm/s)
u−v velocity (cm/s)
float record


bg411
Longitude
Latitude
20°W
18°W
16°W
14°W
12°W
10°W
8°W
6°W
28°S
30°S
32°S
34°S
-3000
-4000


bg411
1998
1999
Oct
Dec
Feb
Apr
Jun
Aug
temperature (°C)
pressure (db)
u−velocity (cm/s)
v−velocity (cm/s)
u−v velocity (cm/s)
float record

bg412


Latitude
Longitude
28°S
30°S
32°S
34°S
36°S
22°W
20°W
18°W
16°W
14°W
12°W
10°W
8°W
6°W
9710
9711
9712
9801
9802
9803
9804
9805
9806
9807
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9901
9902
9903
9904
9905
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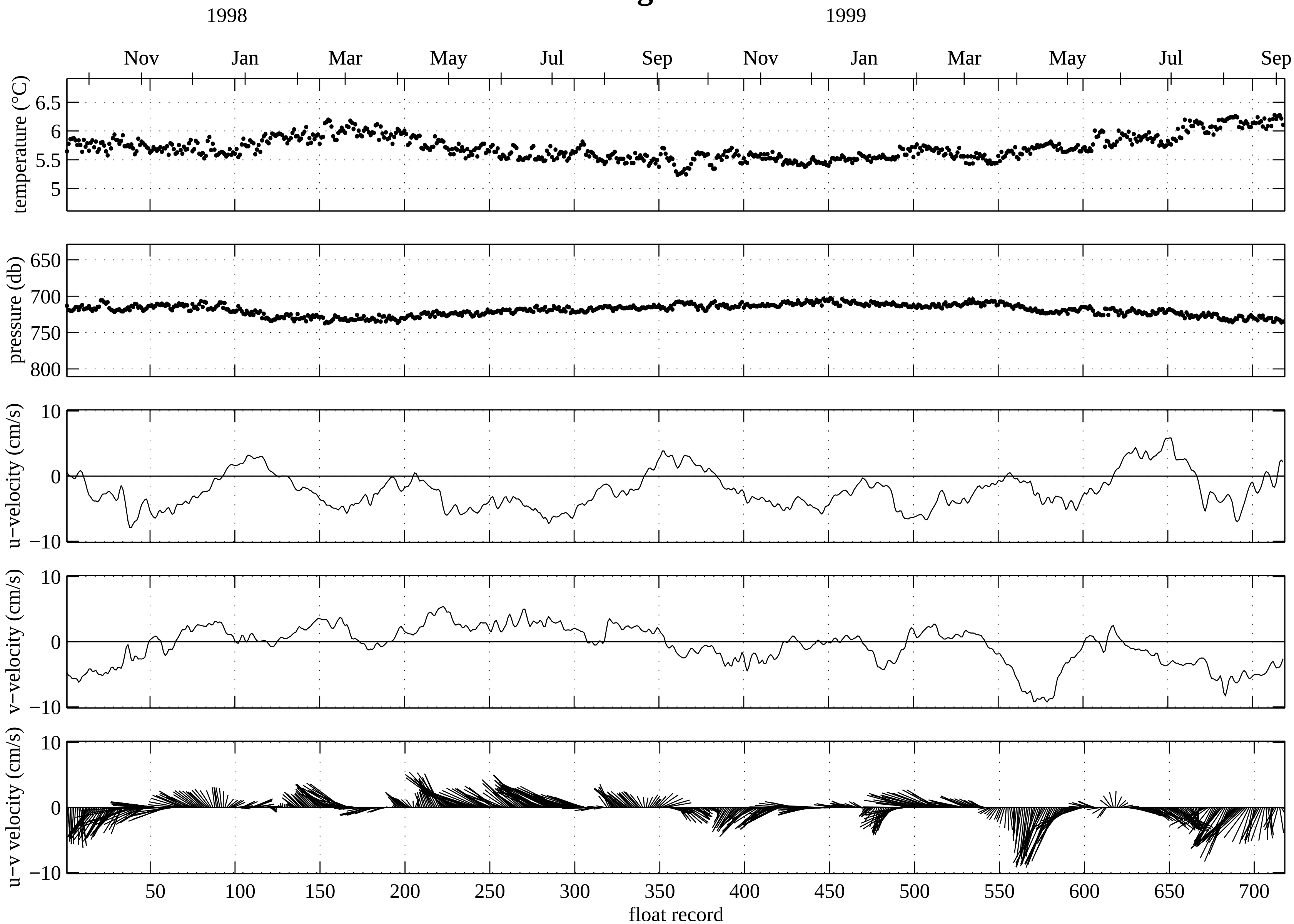
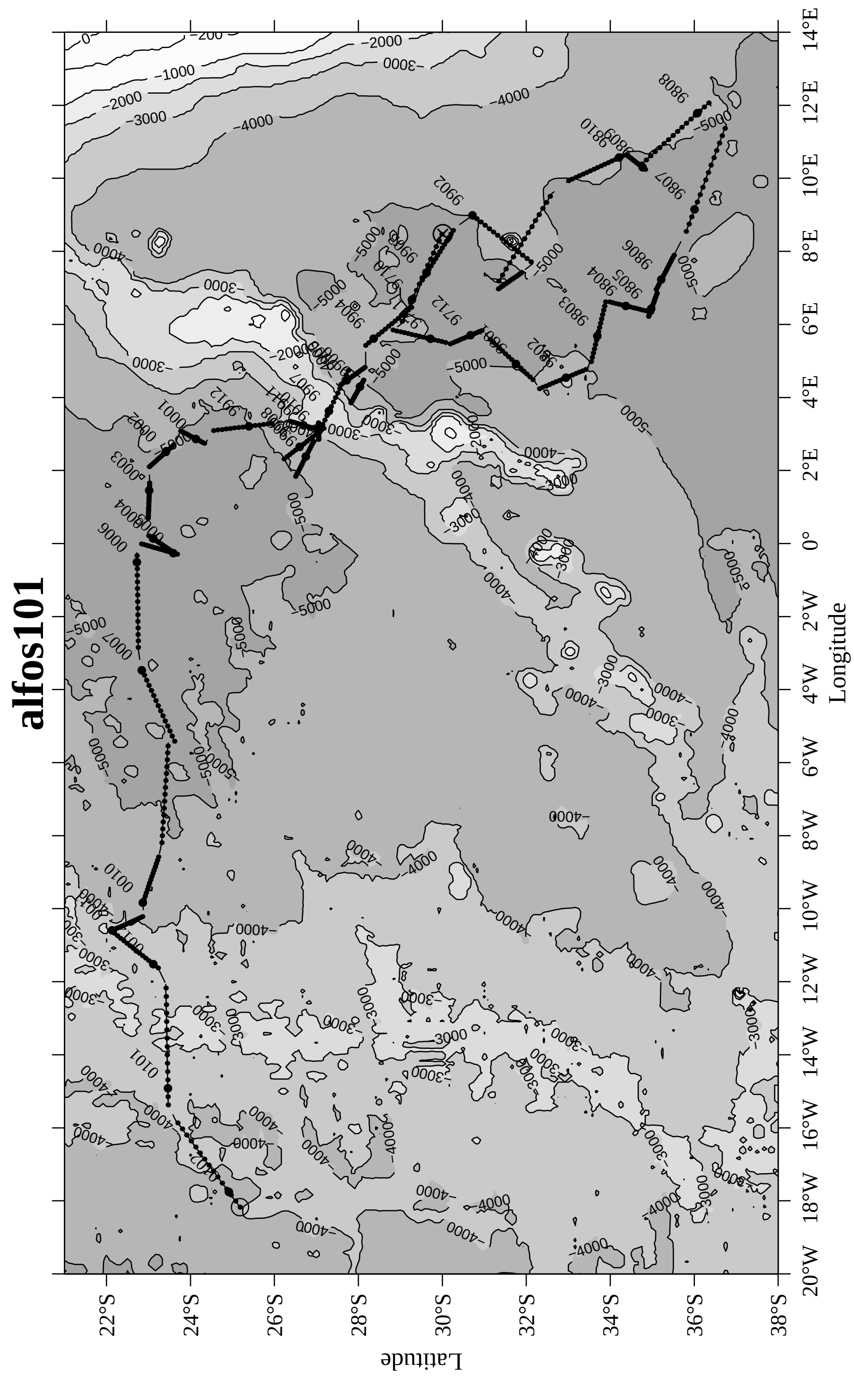
9907
9908
9909
-3000
-4000

bg412



1998
1999
Nov
Jan
Mar
May
Jul
Sep
Nov
Jan
Mar
May
Jul
Sep
temperature (°C)
6.5
6
5.5
5
pressure (db)
650
700
750
800
u−velocity (cm/s)
v−velocity (cm/s)
u−v velocity (cm/s)
10
0
−10
50
100
150
200
250
300
350
400
450
500
550
600
650
700
float record


alfos101
Longitude
Latitude
20°W
18°W
16°W
14°W
12°W
10°W
8°W
6°W
4°W
2°W
0°
2°E
4°E
6°E
8°E
10°E
12°E
14°E
22°S
24°S
26°S
28°S
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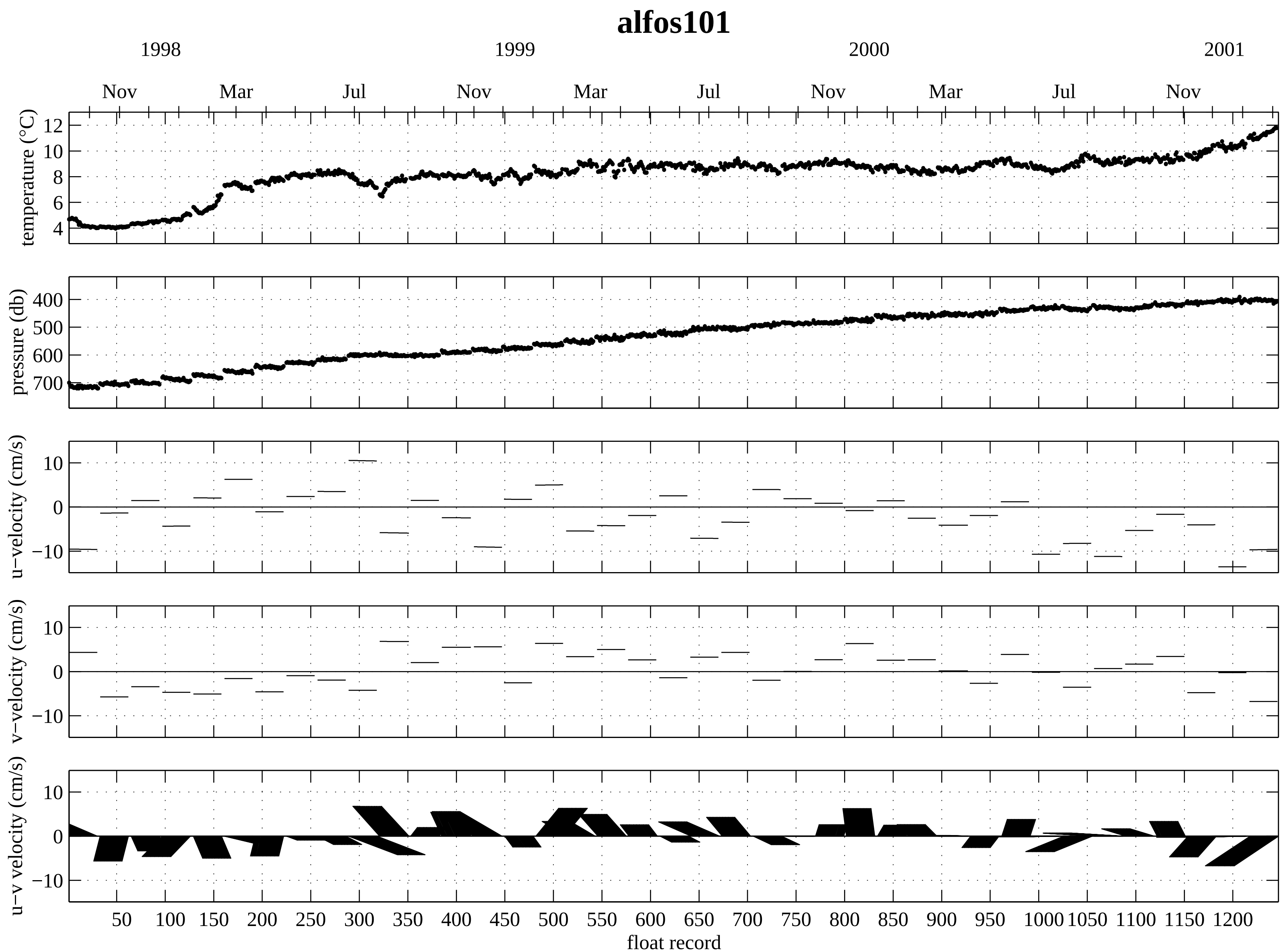
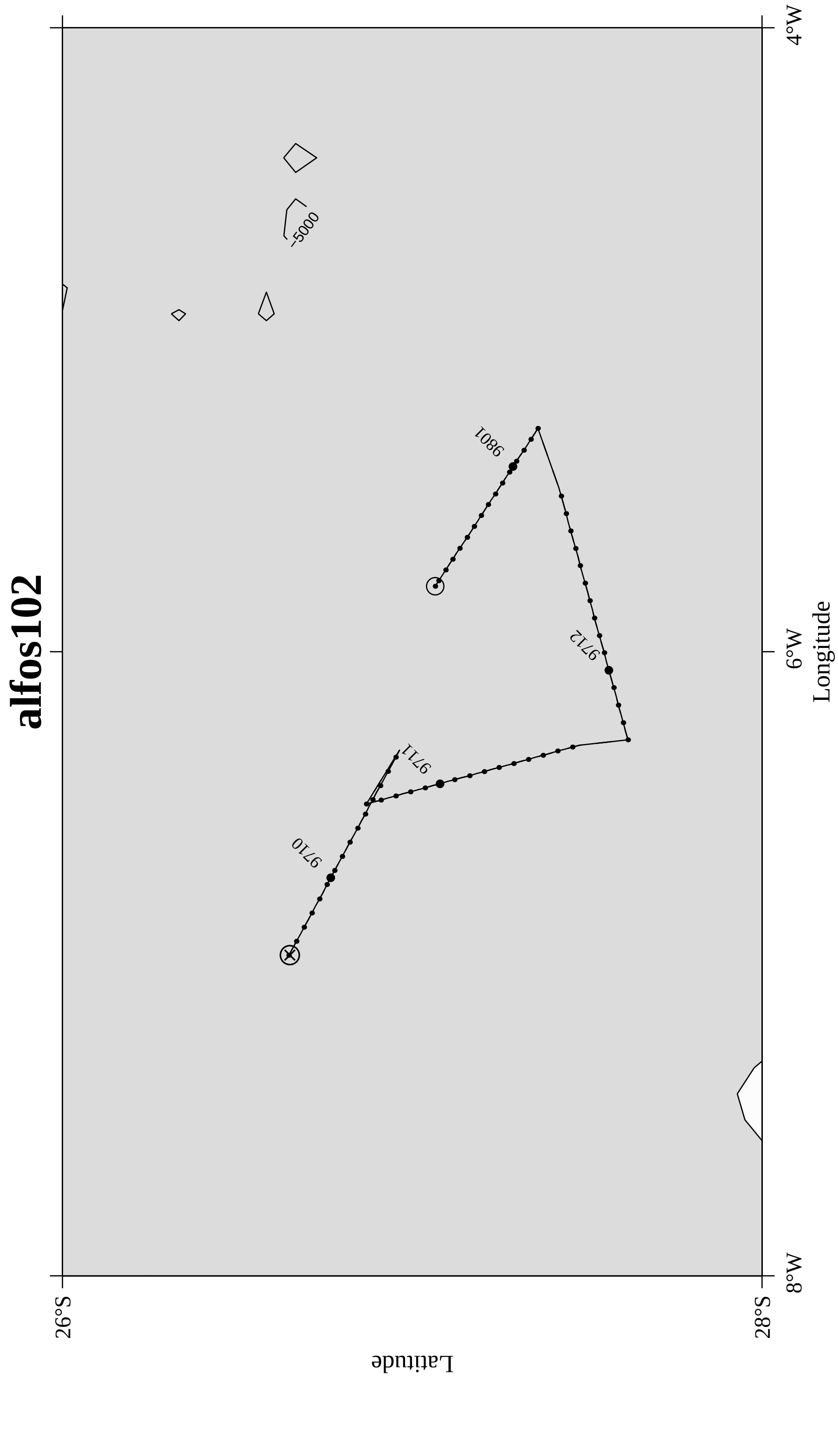
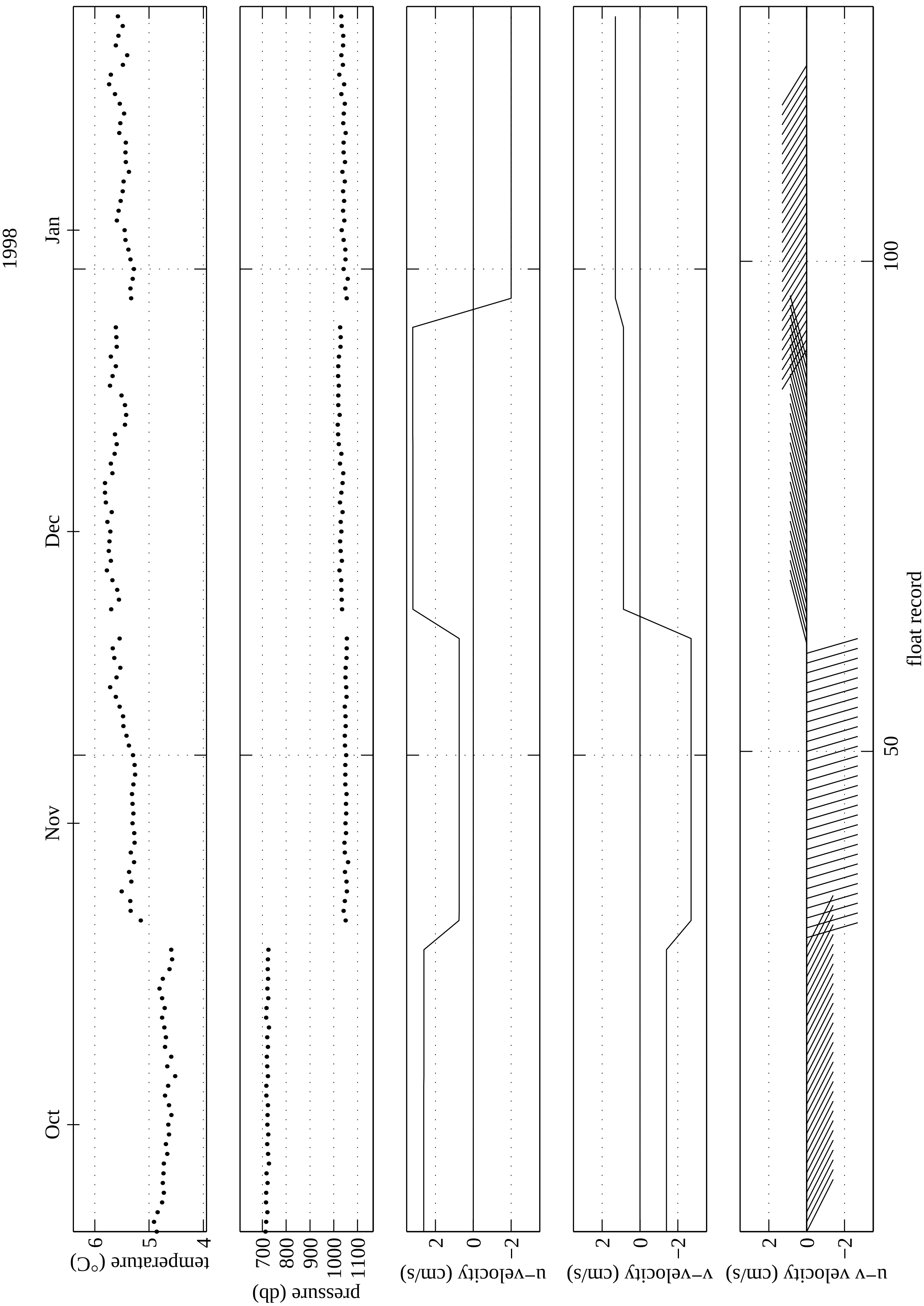
32°S
34°S
36°S
38°S


alfos101
1998
1999
2000
2001
Nov
Mar
Jul
Nov
Mar
Jul
Nov
Mar
Jul
Nov
temperature (°C)
12
10
8
6
4
pressure (db)
400
500
600
700
u−velocity (cm/s)
10
0
−10
v−velocity (cm/s)
10
0
−10
u−v velocity (cm/s)
10
0
−10
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
850
900
950
1000
1050
1100
1150
1200
float record


alfos102
Latitude
26°S
28°S
Longitude
8°W
6°W
4°W
−5000
9710
9711
9712
9801

alfos102


1998
Oct
Nov
Dec
Jan
temperature (°C)
pressure (db)
u−velocity (cm/s)
v−velocity (cm/s)
u−v velocity (cm/s)
float record
50
100

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16. Abstract (Limit: 200 words)

Thirty-two RAFOS floats were launched at the depth of intermediate water, near 750 m, in the Benguela Current along 30S and its extension along 7W. The floats were tracked acoustically for two years during 1997-1999. Seven floats looped in three Agulhas Current rings, which drifted west northwestward at a mean velocity of around 5 cm/sec. Floats not in Agulhas rings tended to drift westward at around 2 cm/sec in the latitude band 22S-35S. North of 22S three floats drifted eastward. This report describes the float trajectories and summarizes the main results. These are the first subsurface long-term Lagrangian data in the Benguela Current.

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