Supporting Information

Charrassin *et al.* 10.1073/pnas.0800790105

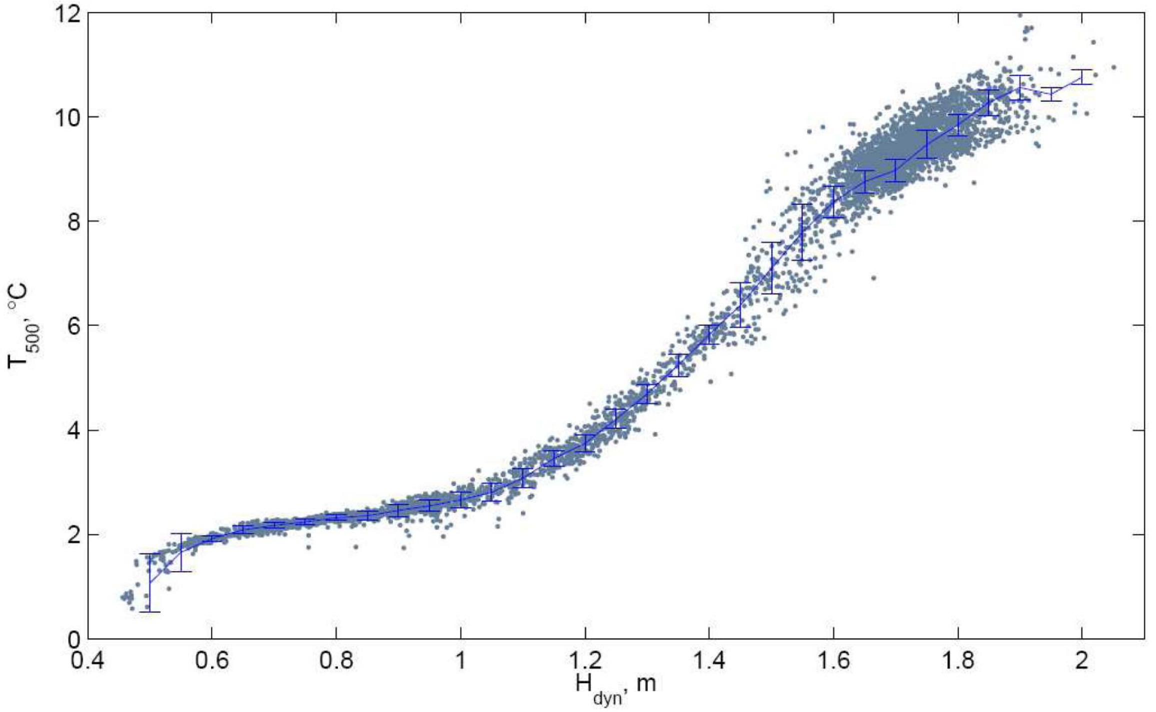

Fig. S1. Temperature at 500 m versus dynamic height at sea surface relative to 1,500 m, using data from Argo floats between 90°E and 150°E. The error bars indicate the temperature error related to the mapping of Argo profiles on SSH field. The circumpolar-mean temperature errors translate to a typical uncertainty of 0.043 m in dynamic height. This error can be translated into an error in locating the fronts by multiplying by (the inverse) dynamic height gradient. The resulting mean spatial error in mapping the fronts using the temperature-dynamic height relationship is 31 $\pm$ 18 km. This estimate using the mean SSH gradients is an upper bound of the mapping error resulting from use of synoptic SSH fields, because the instantaneous SSH gradients are larger and would result in smaller mapping errors.

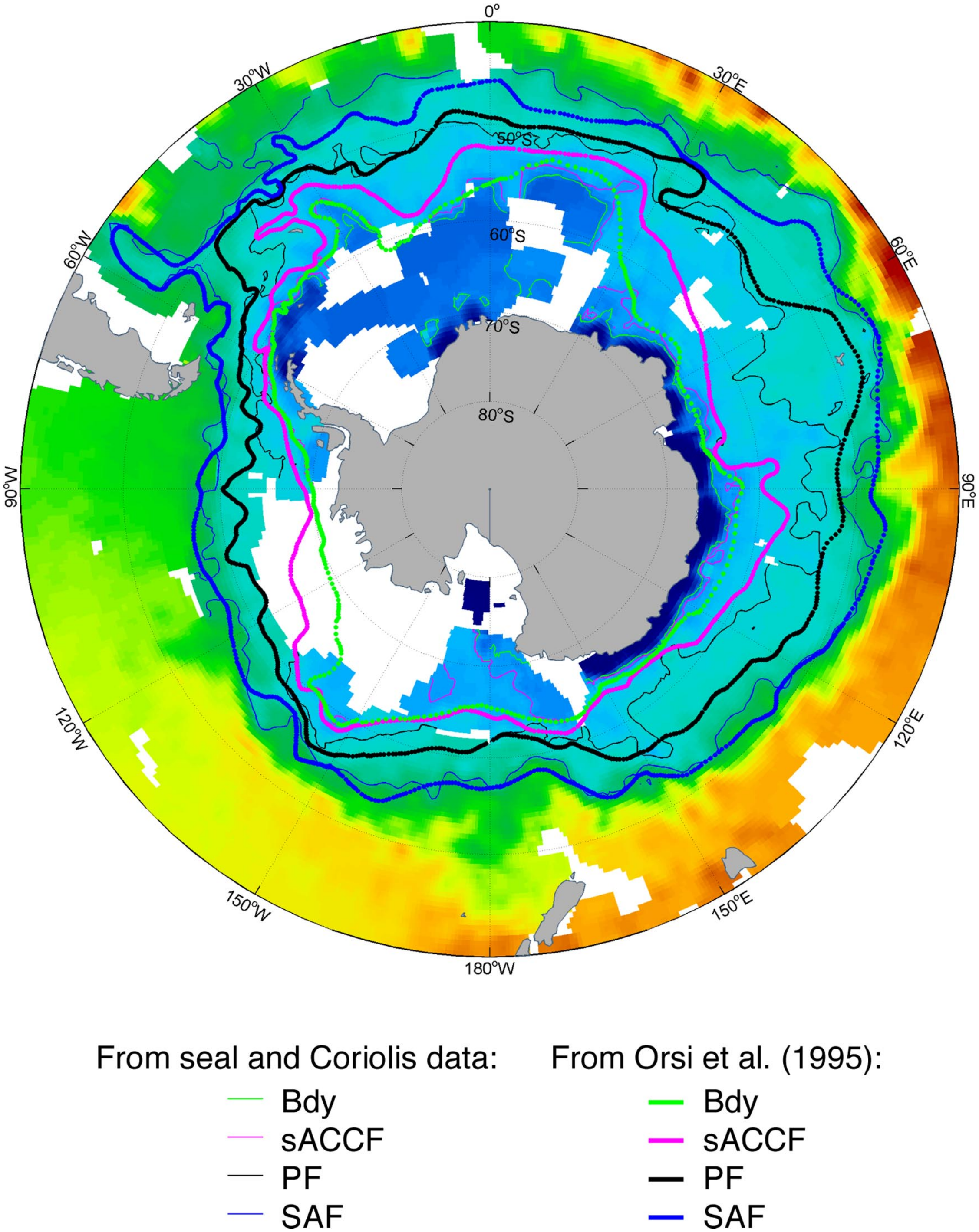

Fig. S2. Temperature field at 500 m during 2004–2005 from the merged Coriolis and elephant seal databases. Mean front positions during 2004–2005 derived from Coriolis and seal data (thin lines), and from climatology [Orsi AH, Whitworth T, Nowlin WD (1995) *Deep-Sea Res I* 42:641–673] (thick lines). For Coriolis and seal data, plotted fronts are Bdy, southern branch of sACCF, and central branches of PF and SAF.

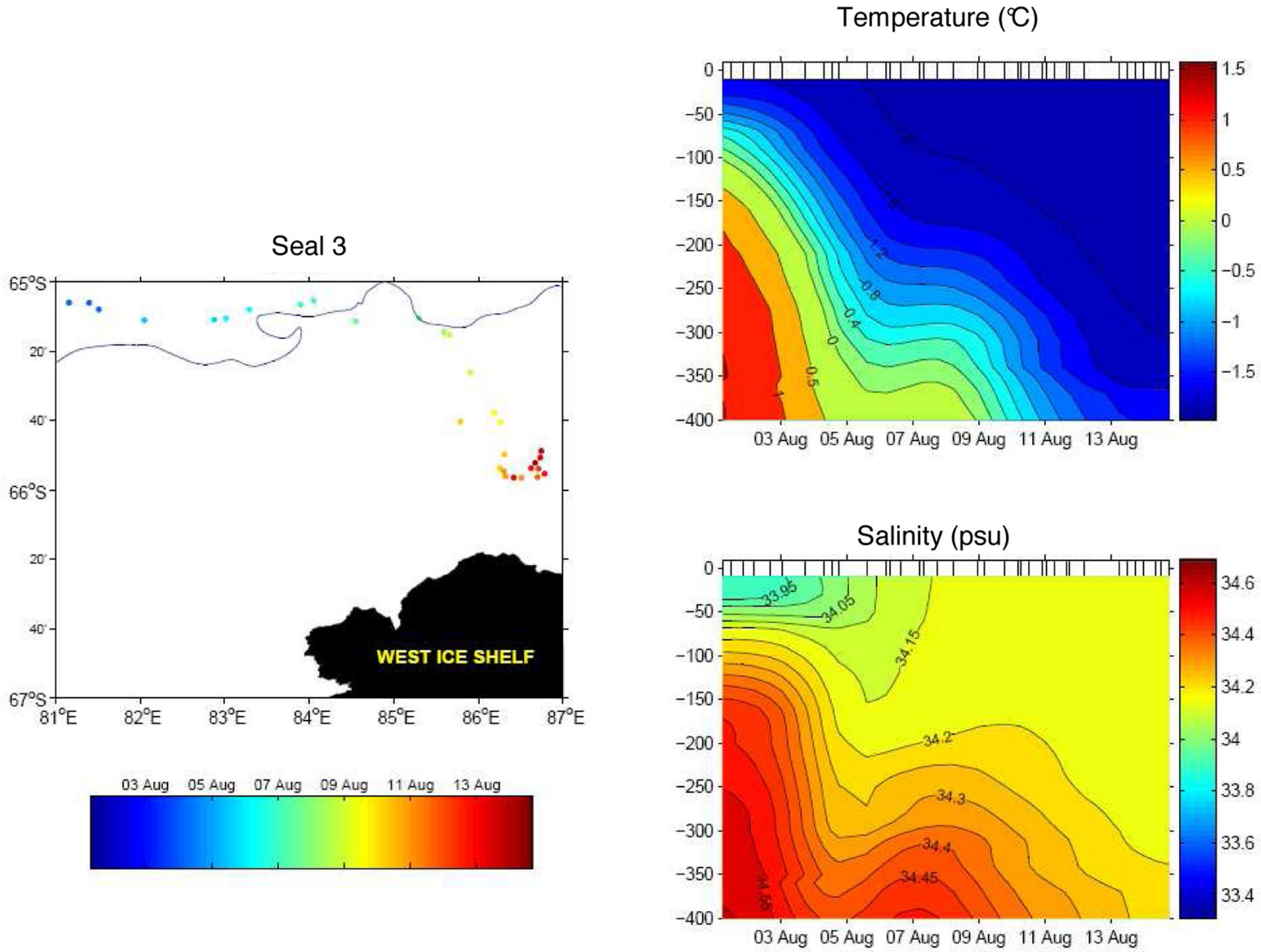

Fig. S3. Temperature and salinity measured by seal 3 in August 2004 near 84°E (indicated by a yellow star in Fig. 1*B* and by black dots in Fig. 3*A*); tick marks on top of sections indicate the timing of individual profiles.

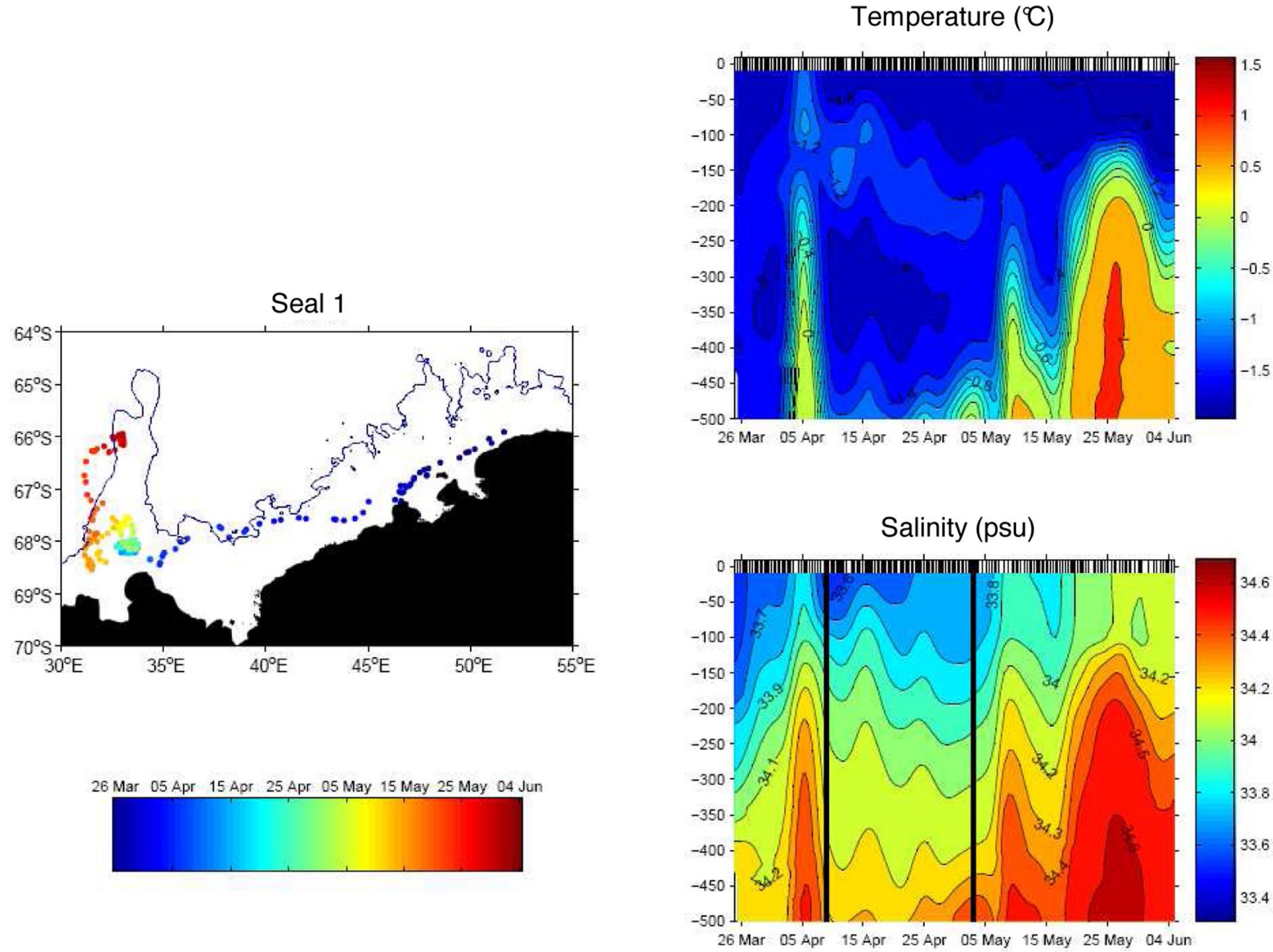

Fig. S4. T and S measured by seal 1 in April–May 2004 near 34°E (indicated by a blue star in Fig. 1*B*). Tick marks on top of sections indicate the timing of individual profiles. Heavy vertical lines on salinity plot indicate the period used to calculate ice formation rates from the salinity budget.

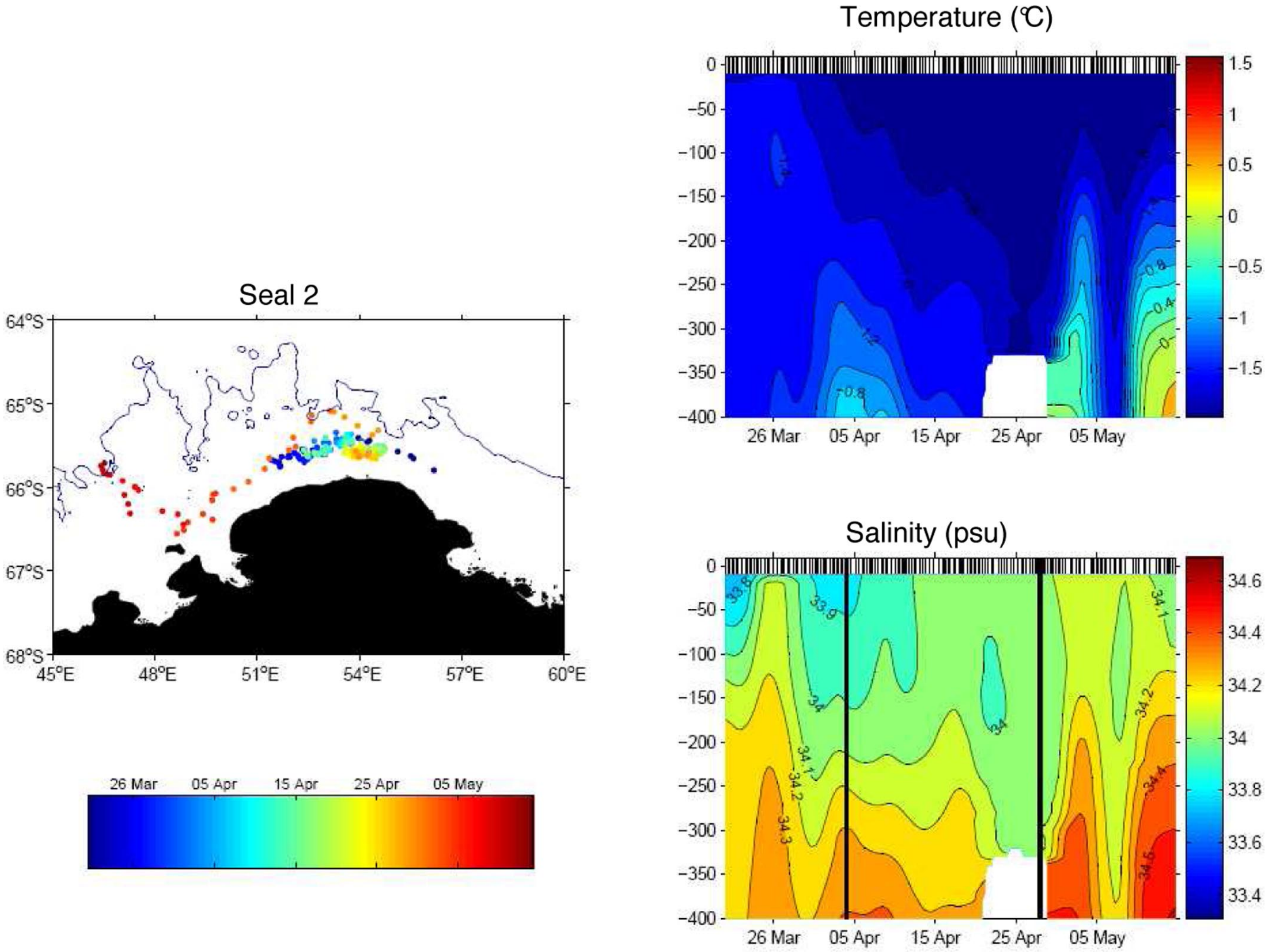

Fig. S5. T and S measured by seal 2 in March–May 2004 near 54°E (indicated by a white star in Fig. 1*B*). Tick marks on top of sections indicate the timing of individual profiles. Heavy vertical lines on salinity plot indicate the period used to calculate ice formation rates from the salinity budget.

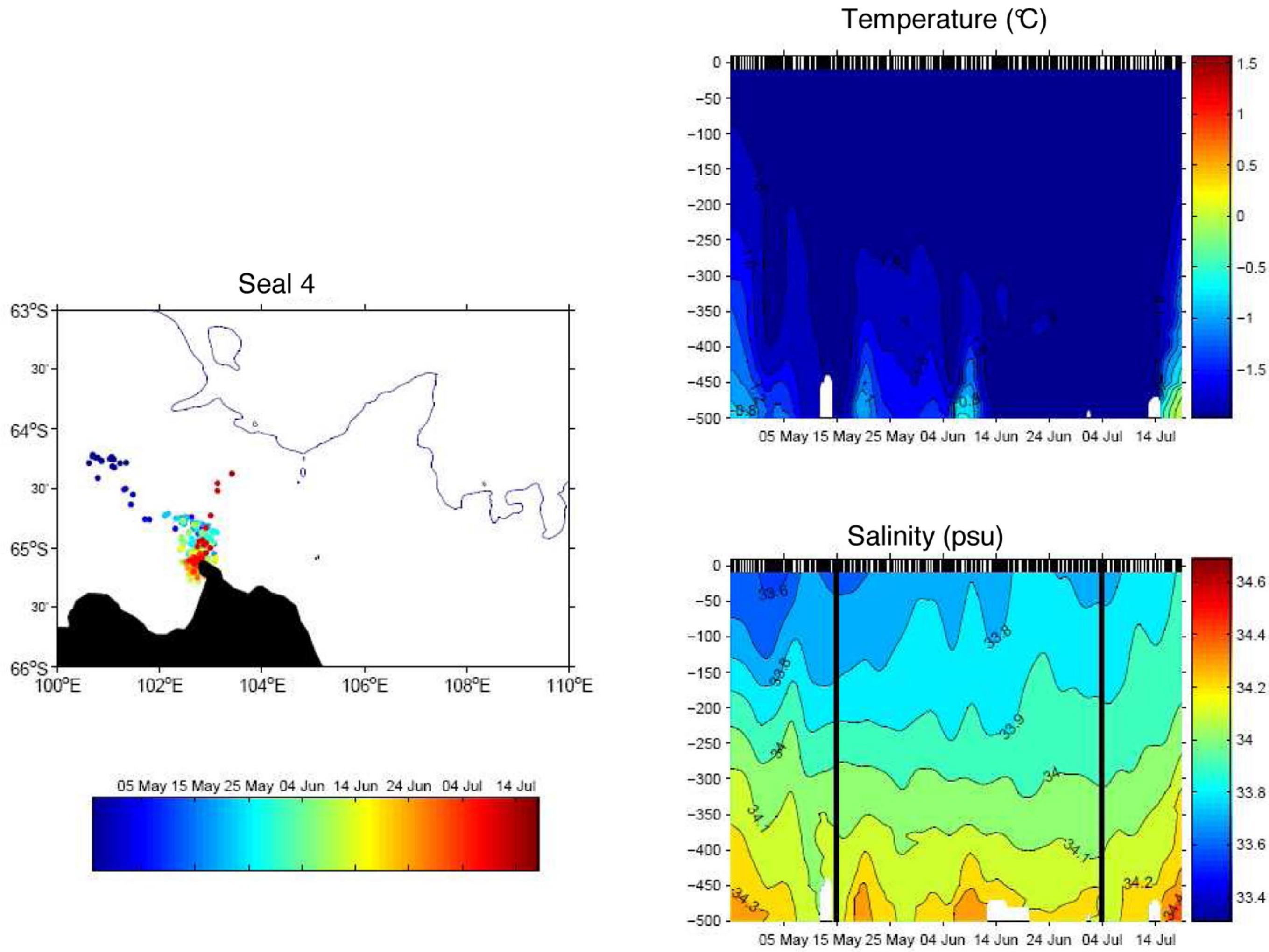

Fig. S6. T and S measured by seal 4 in May 2004 near 103°E (indicated by a green star in Fig. 1*B*). Tick marks on top of sections indicate the timing of individual profiles. Heavy vertical lines on salinity plot indicate the period used to calculate ice formation rates from the salinity budget.

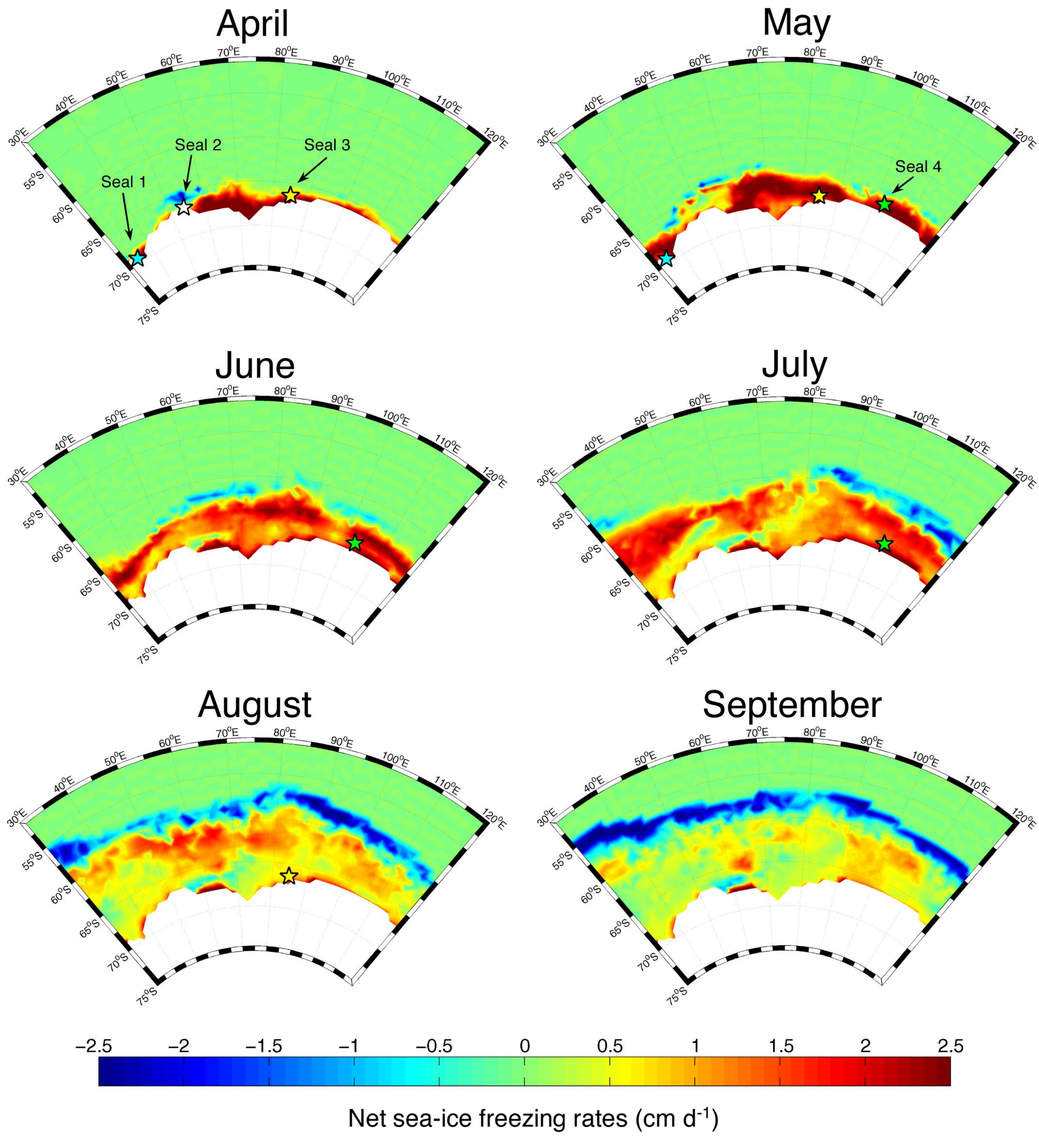

Fig. S7. Monthly net sea-ice growth rates (cm/d) from a finite-element coupled sea-ice ocean model (FESOM) [Timmermann R, Danilov S, Schröter JA (2006) *Geophys Res Abstr* 8:07063]. Stars indicate the positions of seal salinity time series used to calculate sea-ice formation rates (Table 1, Figs. 3 and 4, and Figs. S3–S6).

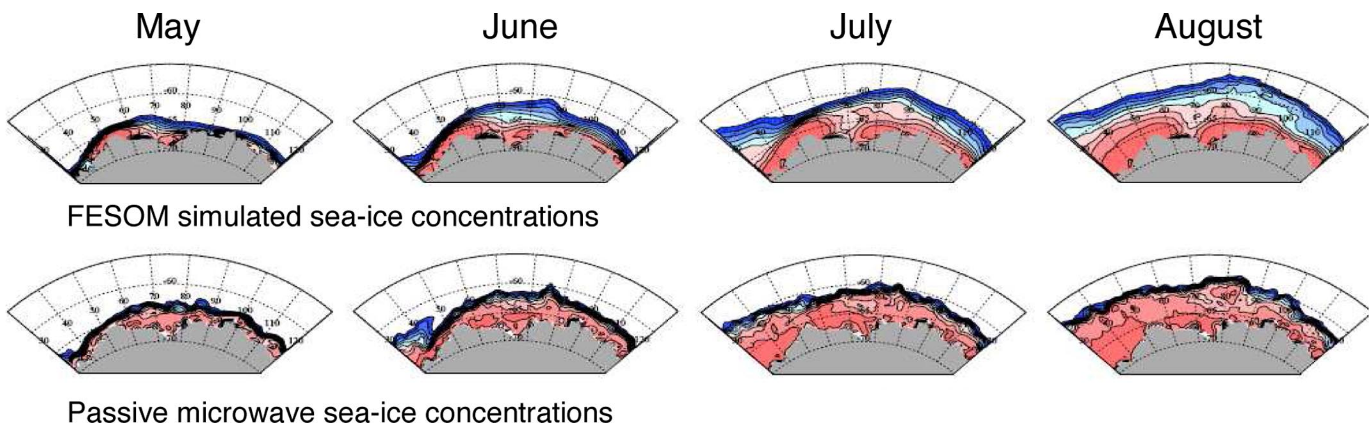

Fig. S8. Monthly mean ice concentrations from the FESOM [Timmermann R, Danilov S, Schröter JA (2006) *Geophys Res Abstr* 8:07063] simulation (*Upper*) and from passive microwave data [Cavalieri DJ *et al.* (1992) NASA Technical Memorandum 104559 (National Aeronautics and Space Administration, Washington, DC)] (*Lower*) for May, June, July, and August 2004. Horizontal resolution is approximately 80 km for model data and 25 km for observations. Accuracy of satellite-derived ice concentration is reported to be within 5% of the actual sea-ice concentration in winter but increases to ≈10% during the summer season and for ice thickness below 20 cm [Cavalieri D, Parkinson C, Gloersen P, Zwally HJ (1996, updated 2006) *Sea Ice Concentrations from Nimbus-7 SMMR and DMSP SSM/I Passive Microwave Data*, *May–August 2004* (National Snow and Ice Data Center, Digital media, Boulder, CO)]. Considering these uncertainties and the differences in resolution, the model simulates the seasonal growth of the sea-ice cover in good agreement with observations.

A

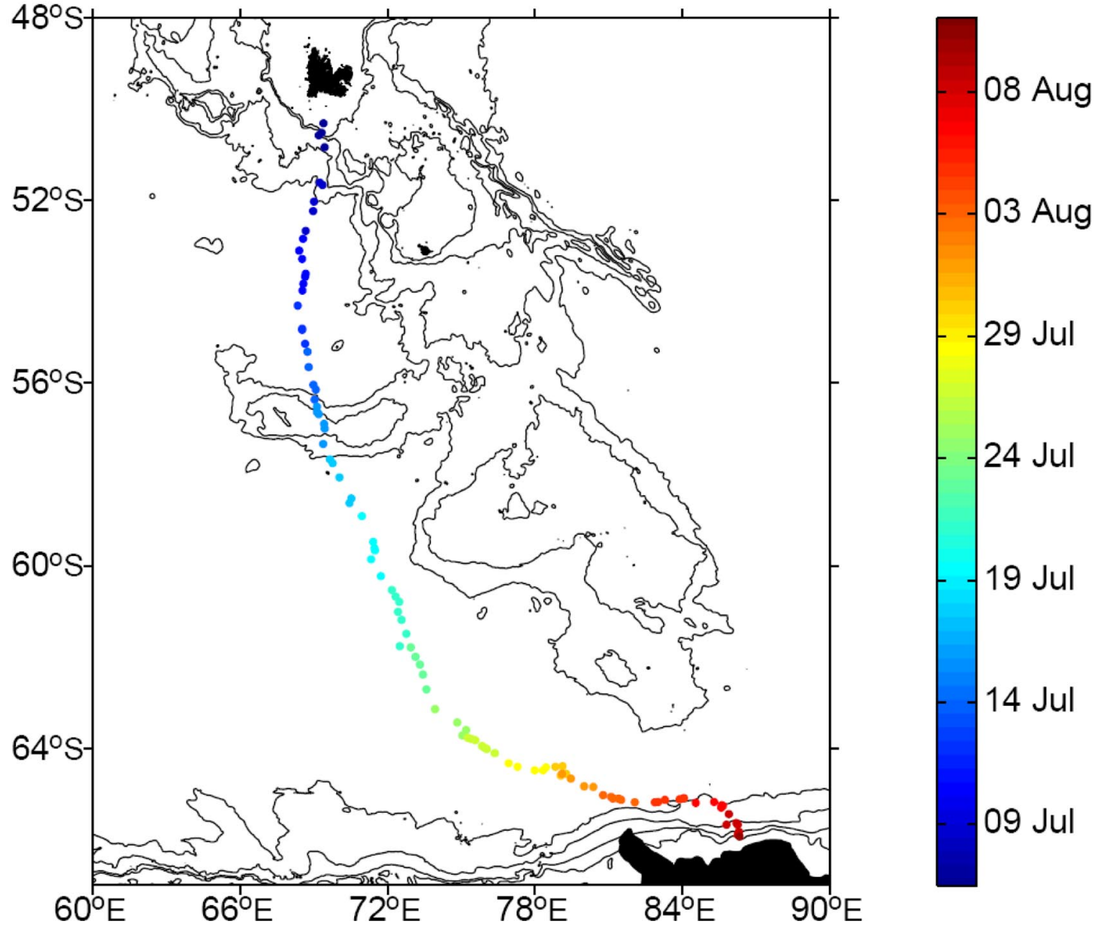

Fig. S9. Comparison of front positions along a seal section inferred using three methods. (*A*) positions of CTD profiles collected by seal 3 in July 2004.

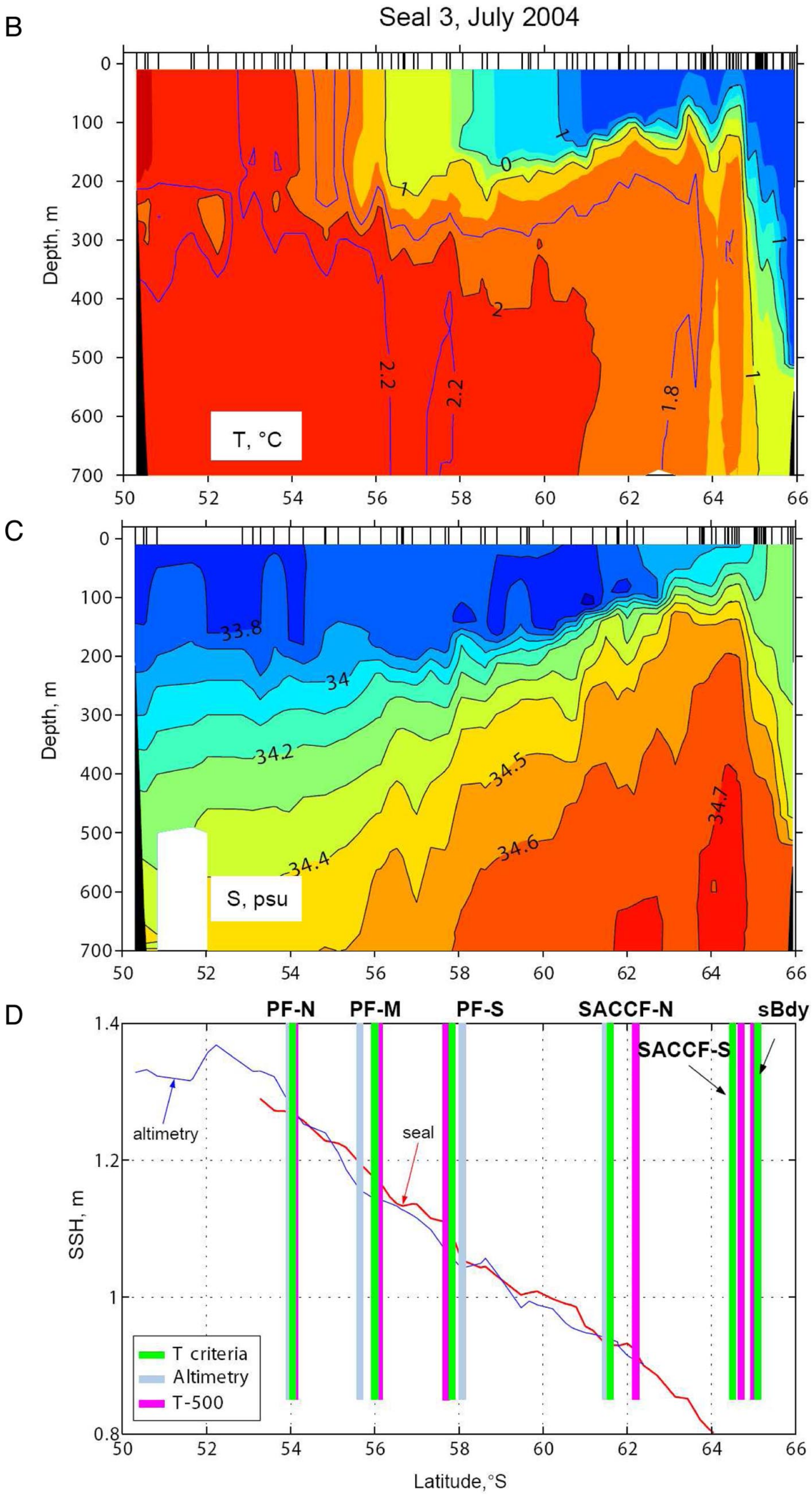

Fig. S9 (continued). Comparison of front positions along a seal section inferred using three methods. (*B* and *C*) Temperature (*B*) and salinity (*C*) sections from the seal data along the seal track shown in *A*. The positions of the measurements are indicated by black dots. (*D*) Altimetry-derived SSH (blue), obtained by adding SSH anomalies as measured by satellite altimetry to the mean surface dynamic height relative to 2,500 m using the WOCE climatology [Gouretski VV, Koltermann KP (2004) *WOCE Global Hydrographic Climatology* (Berichte des Bundesamt für Seeschifffahrt und Hydrographie, Germany), Technical Report 35] interpolated in space and time to the location of the seal transect, and seal-derived SSH (red), obtained by adding the seal SSH relative to 700 m to the 700–2,500 m climatological dynamic height (Gouretski and Koltermann). The positions of the fronts identified by using different criteria are shown as a function of latitude along the section: the temperature-based criteria accounting for multiple fronts (green bars; see criteria below); the altimetry-derived SSH criteria from Sokolov and Rintoul [Sokolov S, Rintoul SR (2007) *J Phys Oceanogr* 37:1394–1412] (gray bars); and the relationship between ocean temperature at 500 m and SSH (magenta bars). The three methods place the frontal branches in similar locations. The temperature criteria used are as follows: PF-N: T = 2.0°C in T_{min} layer; PF-M: T = 1°C in T_{min} layer; PF-S: T = 2.2°C in T_{max} layer; SACCF-N: T = 2.0°C in T_{max} layer; SACCF-S: T = 1.8°C in T_{max} layer; SB: maximum horizontal temperature gradient in the T_{max} layer in the temperature range [1–1.75]°C {Orsi *et al.* [Orsi AH, Whitworth T, Nowlin WD (1995) *Deep-Sea Res I* 42:641–673] as modified in Sokolov S, Rintoul SR (2007) *J Phys Oceanogr* 37:1394–1412 and Sokolov S, Rintoul SR (2002) *J Mar Syst* 37:151–184}.

Table S1. Information on trip duration, diving behavior, and collection of temperature (T) and salinity (S) profiles for each elephant seal included in the study

Seal no.	Origin	Start	End	Record duration, days	Mean depth ± SD	Max. depth, m	Total no. of T profiles	Daily T rate, per day	Total no. of S profiles	Daily S rate, per day	Total distance, km	Daily distance, km/d	Distance between two profiles, km
1	Kerguelen Is	02 Mar. 2004	15 Jul. 2004	135	550 ± 143	947	391	2.9	309	2.3	6,499	48	17
2	Kerguelen Is	24 Feb. 2004	17 Jul. 2004	144	667 ± 143	1,223	403	2.8	307	2.1	5,965	41	15
3	Kerguelen Is	01 Mar. 2004	31 Jul. 2004	152	510 ± 166	1,143	389	2.5	351	2.3	6,645	44	17
4	Kerguelen Is	07 Mar. 2004	24 Apr. 2004	49	693 ± 240	1,318	153	3.1	129	2.6	3,075	63	20
5	Kerguelen Is	08 Mar. 2004	03 Aug. 2004	148	576 ± 177	1,192	425	2.9	338	2.3	8,247	56	19
6	Kerguelen Is	01 Mar. 2004	18 Sep 2004	202	546 ± 181	1,185	509	2.5	435	2.1	8,833	44	17
7	Kerguelen Is	26 Feb. 2004	26 Mar. 2004	29	810 ± 237	1,186	79	2.6	56	1.8	1,089	37	14
8	Kerguelen Is	03 Mar. 2004	26 Jul. 2004	145	563 ± 218	1,418	486	3.3	434	3.0	5,785	40	12
9	Kerguelen Is	28 Feb. 2004	10 Jul. 2004	133	614 ± 255	1494	438	3.3	375	2.8	6,999	53	16
10	Kerguelen Is	04 Mar. 2004	29 Mar 2004	25	549 ± 150	830	120	4.6			2,519	101	21
11	Kerguelen Is	18 Feb. 2005	23 Sep. 2005	217	607 ± 199	1,201	562	2.6	562	2.6	9,273	43	17
12	Kerguelen Is	15 Feb. 2005	03 Jul. 2005	139	546 ± 204	1,276	307	2.2	307	2.2	5,803	42	19
13	Kerguelen Is	05 Feb. 2005	02 May 2005	86	466 ± 168	996	185	2.1	185	2.1	4,855	56	26
14*	Kerguelen Is	26 Jan. 2005	01 Apr. 2005	65	424 ± 134	599	9*	0.1	9*	0.1*	2,083	32	231*
15	Kerguelen Is	05 Feb. 2005	11 Mar. 2005	34	519 ± 170	968	37	1.1	37	1.1	1,417	42	38
16	Kerguelen Is	28 Jan. 2005	01 Apr. 2005	63	617 ± 232	1,210	138	2.2	138	2.2	3,313	53	24
17	Kerguelen Is	24 Feb. 2005	24 Sep. 2005	212	608 ± 173	1,506	445	2.1	445	2.1	9,797	46	22
18	Kerguelen Is	05 Mar. 2005	14 Mar. 2005	9	503 ± 134	776	26	2.5	26	2.5	706	76	27
19	Kerguelen Is	26. Sep. 2005	08 Nov. 2005	44	623 ± 158	1,146	114	2.6	114	2.6	2,660	61	23
20	Kerguelen Is	19 Sep. 2005	28 Sep. 2005	9	777 ± 151	1,044	18	1.8	18	1.8	652	72	36
21	Kerguelen Is	28 Sep. 2005	02 Nov. 2005	36	568 ± 169	1,080	95	2.6	95	2.6	2,082	59	22
22	Kerguelen Is	25 Sep. 2005	22 Nov. 2005	59	655 ± 197	1,248	169	2.8	169	2.8	2,528	43	15
23	South Shetland Is	23 Feb. 2005	10 Oct. 2005	229	564 ± 257	1,694	466	2.0	466	2.0	7,798	34	17
24	South Shetland Is	05 Mar. 2005	07 Oct. 2005	216	490 ± 149	1,104	392	1.8	392	1.8	13,667	63	35
25	South Shetland Is	27 May 2005	08 Oct. 2005	134	467 ± 119	1,014	351	2.6	351	2.6	4,389	33	13
26	South Shetland Is	21 Feb. 2005	22 Nov. 2005	275	607 ± 307	1,386	358	1.3	358	1.3	7,025	26	20
27	South Shetland Is	23 Feb. 2005	30 Oct. 2005	250	516 ± 181	1,134	443	1.8	443	1.8	8,655	35	20
28	South Shetland Is	27 May 2005	19 Nov. 2005	176	589 ± 209	1,320	307	1.7	307	1.7	7,234	41	24
29	South Georgia	03 Feb. 2004	03 May 2004	90	565 ± 187	1,028	162	1.8	162	1.8	5,053	56	31
30	South Georgia	03 Feb. 2004	23 May 2004	110	576 ± 202	1,028	156	1.4	156	1.4	4,990	45	32
31	South Georgia	07 Feb. 2004	15 Feb. 2004	8	572 ± 202	909	29	3.1	29	3.1	543	66	19
32	South Georgia	14 Feb. 2004	19 Aug. 2004	188	618 ± 198	1,028	305	1.6	305	1.6	7,131	38	23
33	South Georgia	15 Feb. 2004	06 Jul. 2004	142	592 ± 238	1,117	207	1.5	207	1.5	6,351	45	31
34	South Georgia	18 Feb. 2004	25 Aug. 2004	189	513 ± 175	969	222	1.2	222	1.2	6,589	35	30
35	South Georgia	12 Feb. 2005	28 Apr. 2005	105	475 ± 165	946	95	0.9	95	0.9	6,718	64	71
36	South Georgia	26 Feb. 2005	19 Oct. 2005	235	522 ± 165	1,428	573	2.4	573	2.4	11,373	48	20
37	South Georgia	14 Feb. 2005	23 Nov. 2005	282	447 ± 168	986	235	0.8	235	0.8	9,776	35	42
38	South Georgia	10 Feb. 2005	14 Sep. 2005	217	546 ± 248	1,404	531	2.4	531	2.4	12,547	58	24
39	South Georgia	30 Jan. 2005	19 Sep. 2005	232	843 ± 438	1,998	411	1.8	411	1.8	12,817	55	31
40	South Georgia	26 Jan. 2005	03 Jul. 2005	168	498 ± 186	1,010	145	0.9	145	0.9	10,273	61	71
41	South Georgia	08 Feb. 2005	13 Nov. 2005	278	481 ± 173	1,032	343	1.2	343	1.2	12,104	43	35
42	South Georgia	07 Feb. 2005	06 Jun. 2005	119	557 ± 190	950	235	2.0	235	2.0	4,356	37	19
43	South Georgia	25 Jan. 2005	09 Apr. 2005	104	407 ± 109	894	295	2.8	295	2.8	6,055	58	21
44	South Georgia	27 Jan. 2005	07 Oct. 2005	253	802 ± 378	1,758	393	1.5	393	1.5	16,288	64	41
45	South Georgia	11 Feb. 2005	13 Sep. 2005	214	566 ± 227	1,550	399	1.9	399	1.9	10,206	48	26
46	Macquarie Is	18 Feb. 2004	20 Jul. 2004	153	561 ± 159	1,085	358	2.3	358	2.3	5,124	33	14
47	Macquarie Is	06 Feb. 2004	08 Jul. 2004	153	542 ± 119	861	408	2.6	408	2.6	5,892	38	14
48	Macquarie Is	27 Jan.2004	20 Jun. 2004	145	526 ± 130	999	324	2.2	324	2.2	6,423	44	20
49	Macquarie Is	31 Jan. 2004	25 Jul. 2004	176	472 ± 195	1,028	350	2.0	350	2.0	6,913	39	20
50	Macquarie Is	12 Feb. 2005	28 Apr. 2005	76	495 ± 161	906	179	2.3	179	2.3	3,521	47	20
51	Macquarie Is	09 Feb. 2005	10 Apr. 2005	60	491 ± 189	1,002	122	2.0	122	2.0	2,561	42	21
52	Macquarie Is	01 Feb. 2005	02 Sep. 2005	213	476 ± 183	1,678	380	1.8	380	1.8	9,960	47	26
53	Macquarie Is	04 Feb. 2005	21 Sep. 2005	229	639 ± 252	1,404	451	2.0	451	2.0	9,675	42	21
54	Macquarie Is	19 Feb. 2005	13 Mar. 2005	23	507 ± 134	966	69	2.9	69	2.9	2,293	101	33
55	Macquarie Is	01 Feb. 2005	28 Aug. 2005	208	560 ± 192	1,146	412	2.0	412	2.0	7,227	35	18
56	Macquarie Is	14 Feb. 2005	03 Jul. 2005	167	627 ± 183	1,606	328	2.0	328	2.0	8,212	49	25
57	Macquarie Is	14 Feb. 2005	05 Oct. 2005	233	540 ± 188	1,314	250	1.1	250	1.1	5,800	25	23
58	Macquarie Is	12 Feb. 2005	17 Sep. 2005	218	598 ± 193	1,236	325	1.5	325	1.5	8,821	41	27
Mean ± SD				145 ± 78	566 ± 89	1,171 ± 264	289 ± 151	2.1 ± 0.8	283 ± 145	2.0 ± 0.6	6,469 ± 3533	49 ± 15	25 ± 11

*Technical failure after a few days at sea so values not included in the mean.