

Investigation of the distribution of ^{137}Cs in the surface layer of the Southern Ocean (Atlantic sector)

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ABSTRACT An investigation of the latitudinal distribution of concentrations of ^{137}Cs at 19 stations in the surface water of the Southern Ocean on cross-sections to the South from the Cape of Good Hope (section SR2) and in the Drake Passage (30th cruise "Academic Ioffe", 01.12.2009–09.01.2010) was performed. The data obtained reinforced the time-dependent exponential decrease in the ^{137}Cs concentrations in the surface water of the Atlantic sector of the Southern Ocean. Increased ^{137}Cs concentrations were found in the Drake Passage and in the section SR2 in the vicinity of the Polar Front. The average value of ^{137}Cs concentrations for all measurements equals $0.18 \text{ Bq}\cdot\text{m}^{-3}$ $\sigma = 0.11$.

Keywords: Radioactivity / Cs-137 / seawater / Southern Ocean

RÉSUMÉ Enquête sur la distribution de ^{137}Cs dans la couche superficielle de l'océan Austral (secteur de l'Atlantique).

Les distributions latitudinales des concentrations de ^{137}Cs pour 19 stations dans les eaux de surface de l'océan Austral le long des sections effectuées, la première au sud du cap de Bonne-Espérance (SR2 section) et le seconde dans le détroit de Drake (la 30^e croisière de l' « Academic Ioffe » : 01.12.2009–01.09.2010) ont été obtenues. Les données reçues montrent la décroissance exponentielle des concentrations de ^{137}Cs dans les eaux de surface du secteur atlantique de l'océan Austral. Dans notre étude, nous avons également trouvé une augmentation des concentrations de ^{137}Cs dans le détroit de Drake et pour la section SR2 à proximité du front polaire. La valeur moyenne des concentrations de ^{137}Cs pour toutes les mesures est de $0,18 \text{ Bq}\cdot\text{m}^{-3}$ $\sigma = 0,11$.

1. Introduction

Spatial and temporal variations of ^{137}Cs concentrations in the surface waters of the global ocean for the period from 1957 to 2005 were investigated by Inomata *et al.* (2009). It was shown that according to these data in the Atlantic sector of the Southern Ocean, the ^{137}Cs concentrations decreased exponentially after 1961 from the highest concentration ($5.4 \pm 0.4 \text{ Bq}\cdot\text{m}^{-3}$) in 1961 to (0.8 ± 0.3) in the 1990s. Later, in 2002, the ^{137}Cs concentration ($0.7 \pm 0.2 \text{ Bq}\cdot\text{m}^{-3}$) in this region was similar to that measured in the 1990s. It was assumed that at 50–60 S and near the Antarctic

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coast an additional input of ^{137}Cs into these waters took place (Gulin and Stokozov, 2005).

It was also assumed that the increased ^{137}Cs concentrations may be connected to an additional input of ^{137}Cs from melted water from adjacent continental glaciers. In our study we tried to obtain additional data in the Drake Passage and in the other regions of the Southern Atlantic Ocean to confirm or reject the conclusion that ^{137}Cs concentrations have not significantly changed at 50–60° S.

2. Materials and methods

The hydrological structure of the Southern Ocean is determined by the Antarctic Circumpolar Current (ACC). From north to south, the frontal jets of the Antarctic Circumpolar Current border the Southern Atlantic Ocean into zones with specific hydrological, hydrophysical and hydrochemical structures. Such different hydrological conditions with various intensities of vertical and horizontal mixing suggest the different half-lives of ^{137}Cs . It obviously must be the effect on spatial latitudinal distribution of ^{137}Cs concentrations in the surface water of this region. In our study, an investigation of the latitudinal distribution of concentrations of ^{137}Cs at 19 stations in the surface water of the Southern Ocean in sections to the south from the Cape of Good Hope (SR2 – section Southern Repeater in the International Program of Climate Variability) and in the Drake passage (30th cruise "Academic Ioffe", 01.12.2009–09.01.2010) was performed. Sections crossed the main frontal systems in the Southern Ocean which were identified as the Subtropical Front (STF), the Subantarctic Front (SAF), the Polar Front (PF) and the southern boundary of the ACC (Orsi *et al.*, 1995). A schematic representation of the fronts is shown in Figure 1. The real locations of the fronts have seasonal fluctuations. During a cruise the positions of the fronts were identified according the set of hydrophysical criteria (Sievers and Nowlin, 1984). The Subantarctic Front is characterized by the maximum horizontal gradient of temperature. The position of the Polar Front was determined by the location at which the depth of the minimum temperature dips below 200 m (Deacon, 1933; Mackintosh, 1946).

The samples of water (100 L) from the surface layer of the sea were taken with a bucket. To discover the radiochemical ^{137}Cs concentrations in the samples of sea water, a consecutive filtration of the water (100 L) through 2 capsules filled with a selective sorbent for ^{137}Cs (cobalt ferrocyanide) was used (the technique developed by H. Livingston: Livingston *et al.*, 1988).

The activity of ^{137}Cs on the absorbers was measured at the Laboratory of Dosimetry and Environmental Radioactivity, Chemical Faculty, Lomonosov

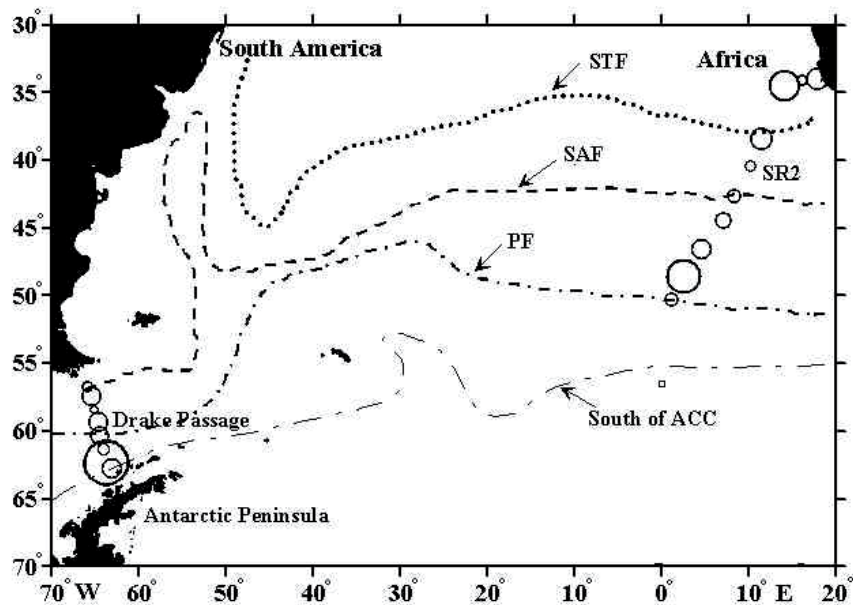


Figure 1 – Position of the sampling sites and schematic representation of fronts in the South Atlantic Ocean. Source: mainly Peterson and Stramma (1991), with minor additions from several other compilations (Berger and Wefer, 1996).

Moscow State University, using a γ -ray spectrometer with a GC-3020 detector manufactured from ultrapure Ge. The relative efficiency for the ^{60}Co line (1.332 MeV) was 30%, and the resolution was 1.8 keV. We used GENIE-2000 PC software. Counting errors were expressed as $\pm 2\sigma$. The efficiency of sorption of the dissolved ^{137}Cs was calculated by comparison of activities on the first and second serial ferrocyanide absorbers. The mean efficiency of sorption was 0.71 ± 0.16 .

3. Results and discussion

The surface concentrations of ^{137}Cs measured in the water along the sections are presented in Tables I and II.

The latitudinal distribution of ^{137}Cs concentrations in section SR2 and in the Drake Passage is presented in figures 2 and 3.

TABLE I
List of stations and description of water samples collected in section SR2.

N	Data	Station	Coordinates		Depth (m)	Temperature °C	Salinity ‰	Concentration ¹³⁷ Cs Bq.m ⁻³
			Latitude	Longitude				
1	01.12.2009	2158	33°56.22	17°49.68	246	14.50	35.04	0.21 ± 0.05
2	02.12.2009	2201	34°01.68	16°12.06	3586	18.60	35.6	0.09 ± 0.03
3	04.12.2009	2207	34°25.98	14°08.16	4588	19.22	35.617	0.32 ± 0.08
4	07.12.2009	2220	38°21.42	11°27	5115	16.49	35.417	0.21 ± 0.06
5	09.12.2009	2227	40°23.4	10°10.74	4538	16.17	35.299	0.10 ± 0.04
6	11.12.2009	2236	42°34.8	8°17.64	3920	11.06	34.372	0.12 ± 0.04
7	12.12.2009	2241	44°25.38	7°02.28	4566	8.42	33.918	0.15 ± 0.05
8	14.12.2009	2249	46°33.96	4°34.8	4179	7.22	33.814	0.20 ± 0.06
9	16.12.2009	2256	48°31.2	2°35.46	4006	5.75	33.759	0.36 ± 0.06
10	18.12.2009	2262	50°2.98	1°08.4	3035	5.27	33.794	0.12 ± 0.07
11	22.12.2009	2282	56°32.34	0°	3729	0.07	34.159	0.06 ± 0.03

TABLE II
List of stations and description of water samples collected in the section in the Drake Passage.

N	Data	Station	Coordinates		Depth (m)	Temperature °C	Salinity ‰	Concentration ¹³⁷ Cs Bq.m ⁻³
			Latitude	Longitude				
1	02.01.2010	2287	62°42.67	63°05.52	1988	0.58	33.787	0.03 ± 0.01
2	03.01.2010	2293	62°19.48	63°47.67	4195	0.53	33.714	0.50 ± 0.13
3	04.01.2010	2299	61°19.36	64°09.04	3516	0.94	33.748	0.10 ± 0.04
4	05.01.2010	2301	60°20.08	64°30.03	3225	1.79	33.770	0.18 ± 0.05
5	06.01.2010	2311	59°20.75	64°43.03	3559	2.42	33.652	0.19 ± 0.11
6	07.01.2010	2317	58°22.59	65°10.91	3630	3.38	33.776	0.06 ± 0.02
7	08.01.2010	2323	57°23.49	65°31.25	4247	3.73	33.845	0.19 ± 0.04
8	09.01.2010	2328	56°39.76	66°01.87	3945	6.56	33.991	0.09 ± 0.03

Near the coast of South Africa in the upwelling zone surface waters are mixed with low-activity deep waters. The concentrations of ¹³⁷Cs in deep water formations around Antarctica equal 0.025 ± 0.011 Bq.m⁻³ (Aoyama *et al.* 2009). In this place the sharp changes in hydrological conditions and concentrations of ¹³⁷Cs took place.

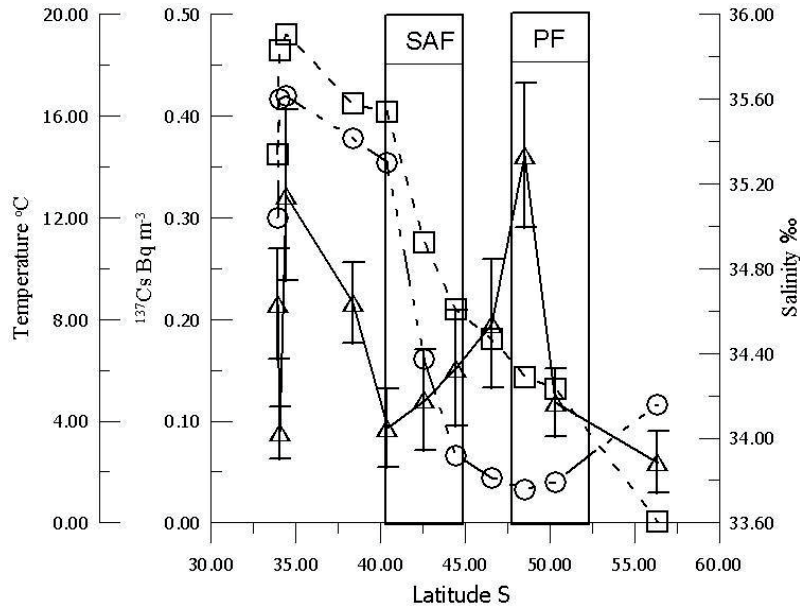


Figure 2. The latitudinal distribution of ^{137}Cs concentrations in section SR2. Δ – ^{137}Cs concentrations, \square – temperature, \circ – salinity.

The concentrations of ^{137}Cs changed from 0.09 ± 0.03 to $0.32 \pm 0.08 \text{ Bq}\cdot\text{m}^{-3}$. The growth in ^{137}Cs concentration was caused by inflow into this area of surface subtropical waters from the Indian Ocean with the Agulhas current (Sievers and Nowlin, 1984). These waters have a higher temperature, salinity and ^{137}Cs concentration ($1.2 \pm 0.6 \text{ Bq}\cdot\text{m}^{-3}$; Inomata *et al.*, 2009).

The ^{137}Cs concentrations decrease with the increase in latitude in the direction of the Subantarctic Front. After crossing the Subantarctic Front, the ^{137}Cs concentrations increased up to the maximal value ($0.36 \pm 0.06 \text{ Bq}\cdot\text{m}^{-3}$) at the Northern boundary of the Polar Front (St. 9). At the same station a local fall in salinity of -33.759‰ (in comparison with the neighborhood stations) was noted. To the South of the Polar Front the concentrations of ^{137}Cs decreased to $0.06 \pm 0.03 \text{ Bq}\cdot\text{m}^{-3}$.

The average value of ^{137}Cs concentrations for the cross-section SR2 was equal to $0.18 \text{ Bq}\cdot\text{m}^{-3}$ $\sigma = 0.10$.

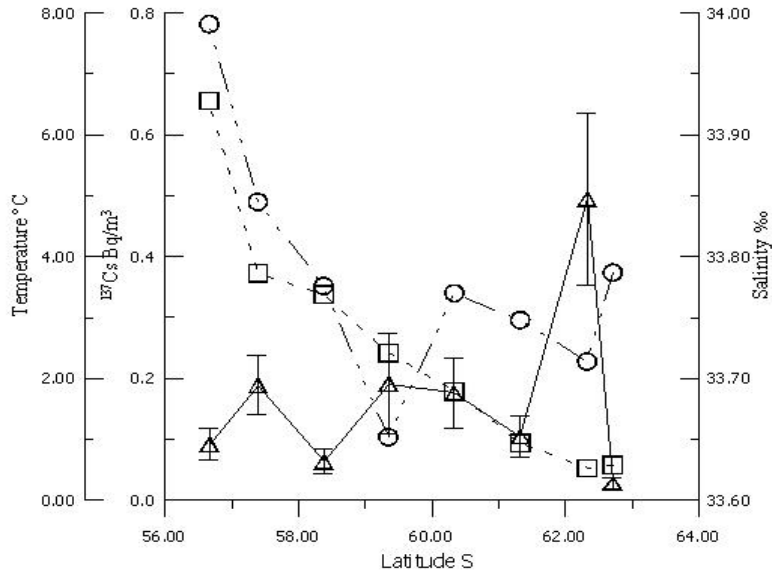


Figure 3. The latitudinal distribution of ^{137}Cs concentrations in the section in the Drake Passage. Δ – ^{137}Cs concentrations, \square – temperature, \circ – salinity.

The section in the Drake Passage crosses the zone of the Polar Front and the Subantarctic Front. The average value of the concentration of ^{137}Cs in the surface water in the Drake Passage equals $0.19 \text{ Bq}\cdot\text{m}^{-3}$ $\sigma = 0.13$.

The maximal concentration of ^{137}Cs ($0.50 \pm 0.13 \text{ Bq}\cdot\text{m}^{-3}$) was noted in the southern part of the section, at the southern boundary of the Polar Front. It is the zone of mixing Subantarctic and Antarctic waters. This maximum of ^{137}Cs concentration was also found in the point of the Polar Front with a local minimum of salinity (33.714‰). The maximal concentration of ^{137}Cs obtained is comparable with the results of measurements in the Drake Passage in 2002 ($0.57 \pm 0.15 \text{ Bq}\cdot\text{m}^{-3}$) and in Antarctic coastal water ($0.34 \pm 0.12 \text{ Bq}\cdot\text{m}^{-3}$: Gulin and Stokozov, 2005).

The average value of ^{137}Cs concentrations for all measurements equals $0.18 \text{ Bq}\cdot\text{m}^{-3}$ $\sigma = 0.11$. This value of concentration is significantly lower than the values of $0.8 \pm 0.3 \text{ Bq}\cdot\text{m}^{-3}$ in the 1990s, and in 2002 – $0.7 \pm 0.2 \text{ Bq}\cdot\text{m}^{-3}$ for the Southern part of the Atlantic Ocean (Inomata *et al.*, 2009). Comparison with the

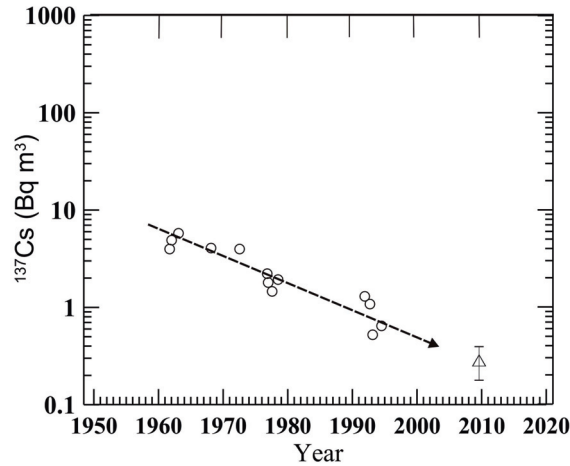


Figure 4. The half-year averaged values for ^{137}Cs concentration in surface seawater of the South Antarctic Ocean – \circ (Inomata *et al.*, 2009) and average value of concentration of ^{137}Cs in the surface water, obtained in the present study – Δ . The line is drawn through the data for the South Antarctic Ocean (Inomata *et al.*, 2009).

data summarized by Inomata *et al.* (2009) for the Antarctic Ocean shows that the graphical interpolation to 2010 points to values $\sim 0.2 \text{ Bq}\cdot\text{m}^{-3}$, which agrees with our average value (Fig. 4). So the data obtained reinforced the time-dependent exponential decrease in the ^{137}Cs concentrations in the surface water of the Atlantic sector of the Southern Ocean.

Thus, the comparison of the measured concentrations of ^{137}Cs in the surface water of the Southern Ocean south of the Cape of Good Hope (section SR2) and in the Drake Passage with the data of Gulin and Stokozov (2005) does not reveal stationary ^{137}Cs concentration levels in the Southern Ocean during the period from the 1990s to 2002. There are not enough measurements to justify such a phenomenon.

4. Conclusion

The data presented in this paper reinforced the time-dependent exponential decrease in the ^{137}Cs concentrations in the surface water of the Atlantic sector of the Southern Ocean.

The average value of ^{137}Cs concentrations for all measurements equals $0.18 \text{ Bq}\cdot\text{m}^{-3}$ $\sigma = 0.11$.

Maximum ^{137}Cs concentrations were found in the Drake Passage and in section SR2 in the vicinity of the Polar Front.

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