Circulation and Mixing of Water Masses of Tatar Strait and the Northwestern Boundary Region of the Japan Sea

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(Received 4 October 1998; in revised form 10 February 1999; accepted 15 February 1999)

The deep waters of the northern portions of the Japan Sea are examined. It is found that the flow regime south of the southern Tatar Strait region is generally cyclonic in the upper ocean, with only weak flows present below depths of a few hundred meters. The Japan Sea appears to be remarkably well-mixed below depths of a few hundred meters, both horizontally and vertically. Based on chlorofluorocarbon measurements, it is concluded that the deep waters of the Japan Sea have been only weakly ventilated in recent decades. Results from a simple box model suggest two possible scenarios for the ventilation of the Japan Sea since the 1930s. In the first scenario, deep ventilation of the Japan Sea was relatively weak, but constant, from the 1930s to the present, with a deep-water residence time of approximately 500 years. In the second scenario, ventilation was relatively vigorous through the mid-1960s, with a deep-water residence time of approximately 100 years; after the mid-1960s, the ventilation of the deep waters stopped. The model results are consistent with the idea that presently the ventilation of the deep water of the Japan Sea is weak or nonexistent.

1. Introduction

The northernmost regions of the Japan Sea are generally ice-covered in winter, and for this reason it has been speculated that some of the densest water of the Japan Sea might originate in this area. Makarov (1905) was perhaps the first to suggest publicly that active convection might take place in the northern Japan Sea in winter, and later Sudo (1986) and Martin et al. (1992), among other investigators, suggested that at least some of the deep water of the Japan Sea might result from winter conditions and the formation of sea ice in these areas. In order to examine this possibility, two hydrographic sections were occupied in the northern part of the Japan Sea during a cooperative US-Russian expedition to study the Okhotsk and Japan Seas that took place in April and May of 1995. Standard hydrographic variables, nutrients, and dissolved oxygen were measured at all stations, and chlorofluorocarbon (CFC) observations were also collected at many sites. A report on these observations, and a discussion of the inferences that can be made concerning deep water formation, circulation, and mixing in the northern Japan Sea, is the topic of this paper.

2. Data

The data used in this work are a subset of a larger dataset obtained during a joint US-Russian expedition in the Okhotsk and Japan Seas that took place in April and May of 1995 aboard the research vessel Akademik Lavrentyev of the Pacific Oceanological Institute, Russian Academy of Sciences, in Vladivostok, Russia. Scientists from the University of Washington and Scripps Institution of Oceanography in the US and the Pacific Oceanological Institute in Russia participated in the cruise. The data were collected using CTD and chemical analysis equipment provided by the Ocean Data Facility at Scripps Institution of Oceanography. While the work was not formally a part of the World Ocean Circulation Experiment (WOCE), it was a major goal of the expedition to collect data of a quality that met WOCE standards of accuracy and precision (see WOCE Data Handbook, 1994); in general, this goal was achieved. CTD data were collected using a Neil Brown Mark 3 system equipped with a General Oceanics rosette sampler, with 24 10-liter Niskin Bottles. For casts where the depth was greater than 1000 m, all 24 bottles were used to collect chemical samples. For shallower casts, fewer than 24 bottles were used. All casts were taken to within 15 meters of the bottom of the ocean. Water samples were collected from each Niskin bottle, and a conductivity/salinity determination was made at sea for each sample using a Guildline AutoSal salinometer and UNESCO standard seawater. The results of this analysis were used to adjust the values of conductivity measured by the CTD package. Using this method, it is estimated that the
values of salinity measured from CTD are accurate to approximately 0.002 practical salinity units (PSU). The CTD was calibrated in a laboratory prior to and immediately following the cruise, and it was determined that the temperature accuracy was better than 0.001°C. Dissolved oxygen samples were collected from each Niskin bottle and analyzed using an automated system based on the modified Winkler method (Carritt and Carpenter, 1966); from comparisons with known standards at the time of analysis, it is estimated that the dissolved oxygen samples are generally good to 0.05 ml/l. Nutrients (dissolved nitrate, nitrite, phosphate, and silicate) were collected from each Niskin bottle and were analyzed using a Technicon autoanalyzer. By comparing duplicate and triplicate samples on several casts with known standards, it was determined that these data are generally good to about 1% of the measured values. In addition to these standard hydrographic parameters, the chlorofluorocarbons CFC-11 and CFC-12 were measured at many stations, using the method outlined in Bullister and Weiss (1988). To avoid contamination from ship-based sources of CFC, a portable analysis van was installed on the ship prior to the cruise, and all CFC analyses were conducted inside of this laboratory. The resulting CFC data were of good quality, with measurement accuracy and precision judged to be 1.2% or 0.006 pmol/kg, whichever is greater, for both CFC-11 and CFC-12. The concentrations are reported on the SIO-1993 calibration scale (Cuninol et al., 1994), and a sample handling blank of 0.006 pmol/kg was subtracted from all CFC-11 samples (there was no detectable blank for CFC-12).

3. Sections

As shown in Fig. 1, the two sections discussed in this paper extend across the southern portion of Tatar Strait at approximately 46°N, from Sakhalin Island on the east to Maximova Point on the Siberian coast (Stations 164–176), and from the center of the Japan Sea perpendicular to the Russian coastline between 44°N and 45°N (Stations 177–