Upper Ocean Measurements of Water Masses and Circulation in the Japan Sea

Stephen C. Riser
School of Oceanography, University of Washington, Seattle, Washington 98195 USA
Phone: (206) 543-1187 Fax: (206) 329-0858 Email: riser@ocean.washington.edu

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http://flux.ocean.washington.edu

LONG-TERM GOALS

It is my long-term goal to develop a better understanding of the ventilation sites and processes involved in the production of the intermediate and deep waters of the world ocean. The Japan Sea is an excellent example of a site where deep and/or intermediate level convection occurs in winter, with several water masses being formed as a result of this air-sea interaction. The work done as part of this grant was carried out in order to be able to estimate the upper ocean circulation in the Japan Sea over the course of several winters and to directly observe winter convection events in greater detail than was previously possible.

OBJECTIVES

The objective of this work was to collect a large number of high quality temperature and salinity profiles from the Japan Sea during all seasons, over the course of several years, in order to be able to estimate the total geostrophic circulation in the upper ocean (ie, above 800 m) and to examine in detail the sites where winter convection occurs in the northwestern Japan Sea. Additionally, it was highly desirous to be able to examine the pathways that seawater parcels might take to exit from the Japan Sea into the Okhotsk Sea and the North Pacific.

APPROACH

In order to carry out this work, 35 profiling floats were deployed in the Japan Sea in August of 1999. The floats were parked at a depth of 800 m and programmed to collect CTD profiles and transmit their data every 7 days. The floats were deployed in close collaboration with Prof. Kuh Kim of Seoul National University (Korea), Prof. J-H Yoon of Kyushu University (Japan), and Dr. Yuri Volkov of the Far Eastern Regional Hydrometeorological Research Institute (Russia). These collaborators helped in gaining clearances for deployments inside their respective EEZs. In addition, Dr. Volkov provided a quality research vessel (the *Professor Khromov*) with a highly capable crew that deployed most of the floats.

WORK COMPLETED

The floats were designed to last for 3 years, and 90% of them did indeed last this long. Some lasted longer than 4 years and are still being tracked, and it is likely that a few will continue to operate in excess of 5 years. A map of the region showing the tracks of all of the floats is shown in Figure 1. As can be seen, some of the floats have left the Japan Sea via Tsugaru Strait into the N. Pacific and through Soya Strait into the Okhotsk Sea. On float entered the Okhotsk Sea through Soya Strait and subsequently entered the N. Pacific through Bussol Strait in the Kurils. As of this writing, over 4000 profiles of temperature and salinity have been collected by the floats, as shown in Figure 2.

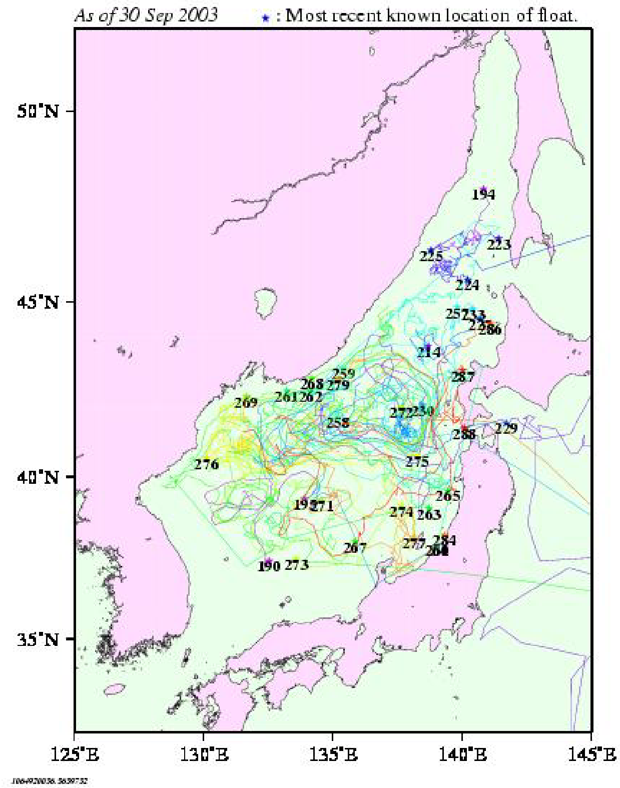

Figure 1. Trajectories of all floats deployed in the Japan Sea, 1999-2003.

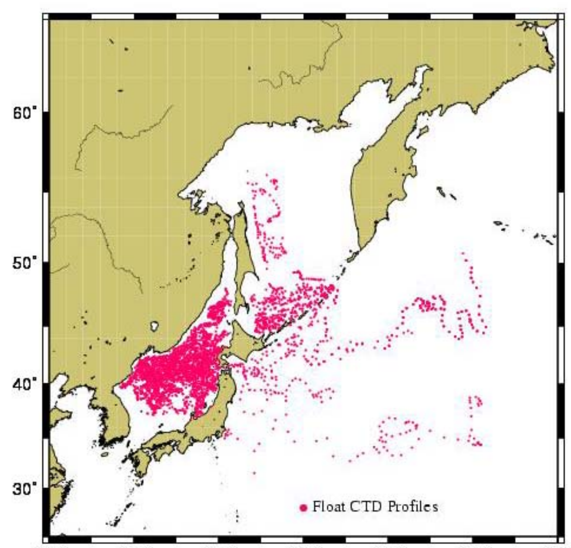

Figure 2. Locations of all CTD profiles collected by UW profiling floats in the NW Pacific, 1999-2003. Some of the floats, especially those in the Okhotsk Sea, were deployed using funds from other grants.

RESULTS

The float trajectories and the velocities associated with them have been used to construct maps of the absolute velocity at a depth of 800 m in the Japan Sea. The data have been binned by season, so that the seasonally-varying portion of the geostrophic circulation can be estimated. Using the CTD profiles in conjunction with these velocity maps, the dynamic height field can be estimated, and the resulting relative geostrophic flow can be estimated at all levels above 800 m. Combining the 800 m absolute velocities and the dynamic heights yields the absolute geostrophic circulation at all levels above 800 m. The only assumption in this estimate is that the flow is geostrophic; there are no assumptions of levels of no motion. The resulting seasonal geostrophic circulation at the sea surface estimated from the floats and profiles is shown in Figure 3.

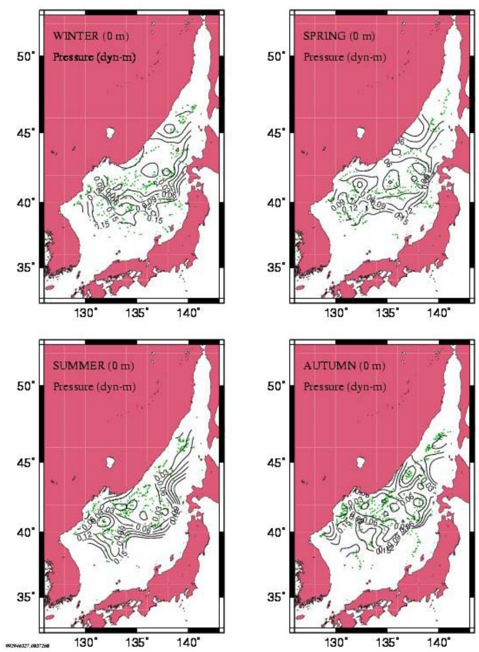

Figure 3. Seasonal maps of the geostrophic circulation at the sea surface estimated from profiling floats in the Japan Sea. The green dots denote the positions of profiles. Contour units are dynamic centimeters.

The maps show that features such as the Liman Current (southward flow along the Russian coast) and the Tsushima Current (northward flow along the Japan coast) are highly seasonally-dependent; the Liman Current is mainly barotropic and is strongest in winter, while the Tsushima Current is mainly baroclinic and strongest in summer. In winter, convection takes place along the Russian coast off Vladivostok. Convection profiles in this region show nearly well-mixed values of temperature and salinity between the sea surface and depths of 800 m. The locations of all observed sites of convection between 1999 and 2003, superimposed upon the wintertime geostrophic streamfunction at the sea surface, is shown in Figure 4. The locations of these sites show that the most likely region for convection appears to be in areas of relatively weak geostrophic flow at the sea surface; this implies that convection can occur as columns of fluid remain in the region off Vladivostok for a relatively long time during the winter and are subject to northwest winds blowing off Siberia. Simple models of the heat flux and mixing in such convection regions are consistent with this idea (see Riser, 2003;

Danchenkov and Riser, 2003). The convection stations show that convection extends to a depth of 800 m, the parking depth of the floats. In actuality, concomitant shipboard measurements indicate that the convection does not extend below about 1100 m. Thus, this is not deep convection, leading to deep water formation; instead, the convection observed here appears to lead to the formation of intermediate water masses. There is evidence based on chemical tracers (CFC) that deep convection has ceased in the past several decades, resulting in a marked decrease in dissolved oxygen in the deep waters of the Japan Sea (see Riser et al., 1999).

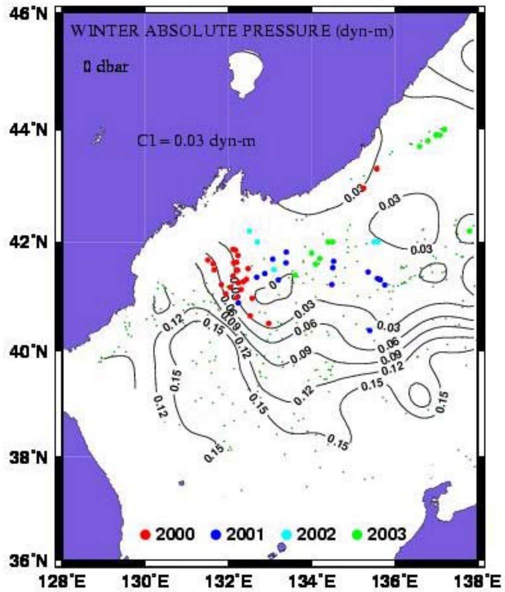

Figure 4. The locations of wintertime convection stations observed from Japan Sea profiling floats during the winters of 2000-2003. Contours show the geostrophic pressure at the sea surface (dynamic cm.) estimated from the float velocities and profiles. Small green dots show the positions of the data used in making the velocity map.

IMPACT/APPLICATIONS

This work is the first to show *in situ* convection in the winter in the Japan Sea region. Several of the countries in the region are attempting to purchase new floats in order to continue this work over several more winters. The data are being used to compare with the flow and water masses produced in the NRL high resolution model of this region and are being assimilated into an operational model of the region at the Naval Oceanographic Office (NAVO). In addition, several of the floats deployed as part of this work were later recovered and recalibrated; their recalibrations, along with others deployed on other grants, have allowed us to make a good estimate of the accuracy and precision of the SeaBird CTD units used in this work and other work. These results appear in Riser and Swift (2003).

TRANSITIONS

The data acquired in this project were all made available for viewing in real-time on a public web page (*http://flux.washington.edu*), and all of the data were put on the GTS by UW within 12 hours of collection. As a result of the success of the float instrumentation and data processing system, NAVO has begun deploying floats in the southern Japan Sea from aircraft, using a technique that was partially developed at UW. In addition, our group at UW is maintaining a web page for NAVO that contains the

NAVO data. The procedure involved is that each day all NAVO float data are automatically sent to UW via the internet and are put on the UW web page *http://flux.ocean.washington.edu/navo*, where the data can be publicly viewed. It is planned that UW will enhance the NAVO web page in the near future.

RELATED PROJECTS

This work was part of a group of ONR-sponsored projects that were part of a DRI on the Japan Sea. The PI (Riser) was one of the leaders of this group. The results of the DRI are being published in a special issue of *Deep-Sea Research*, of which the PI is the editor. 20 papers concerning various aspects of the Japan Sea circulation will appear in this volume, which should be published in spring of 2004.

REFERENCES

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Riser, S. (2003) Circulation and convection in the northern Japan Sea. Submitted to *Deep-Sea Research*.

Riser, S. and D. Swift (2003) Long-term measurements of salinity from profiling floats. Submitted to *Journal of Atmospheric and Oceanic Technology*.

PUBLICATIONS

Danchenkov, M. and S. Riser (2003) Connections between the Japan Sea and Okhotsk Sea through Soya Strait. Submitted to *Journal of Geophysical Research*.

Riser, S. (2003) Circulation and convection in the northern Japan Sea. Submitted to *Deep-Sea Research*.

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