論文の内容の要旨

論文題目　Multi-scale structures formed by the Tsushima Warm Current in the Sea of Japan

（対馬暖流が形成する日本海のマルチスケールな構造）

氏名　矢部（重村）　いつか

The Sea of Japan, a familiar ocean adjacent to the Japanese archipelago, is controlled by various multi-scale phenomena: the Tsushima Warm Current (TWC), the Subpolar Front (SPF), the subarctic gyre, the abyssal circulation, mesoscale eddies, submesoscale structures, tides, internal waves, and turbulence. Comprehensive study is required to understand each phenomenon and their interactions precisely. However, such study has not conducted yet due to the lack of accumulation of observational data. The purpose of this thesis is to contribute to the overall understanding of the multi-scale phenomena in the Sea of Japan. We carried out research from two perspectives.

Firstly, the seasonal variation of the large-scale phenomena including the TWC, the SPF and mesoscale eddies were examined. These are the phenomena in the upper part of the Sea of Japan. Their pathways were determined based on the satellite-based sea surface height, which covers the entire area over 25 years. We specifically classified four branches based on their upstream positions around the Tsushima Strait and examined their downstream pathways which have not been clarified yet in the central and the eastern Sea of Japan. In regions west of 133°E, they mutually flow independently, whereas they become scrambled at eastern longitudes. Our analyses revealed that the three branches, excluding that along the SPF, showed a confluence in the regions around the Oki Islands and off the Noto Peninsula. The seasonal variation of those branches is addressed by this study. In the Yamato Basin, the TWC branches, particularly the offshore south branch, were affected strongly by the seasonal development of mesoscale eddies and their location. Basin-wide anti-cyclonic and cyclonic eddies develop during winter and summer, respectively. In the eastern area, the TWC branches, mostly exiting towards the Pacific Ocean through the Tsugaru Strait, notably meander in winter, but they were straightforward in summer.

Secondly, small-scale phenomena such as inertial oscillation, internal gravity waves (IGWs) and turbulence were investigated based on the current velocities by the mooring system. Kinetic energy from atmospheric disturbances is one of the main sources in the Sea of Japan. IGWs transport it horizontally and vertically from the surface mixed layer to ocean interior. The near-inertial internal waves (NIWs) with the local inertial frequency are the most energetic among the IGWs in the Sea of Japan. Wind-induced NIWs were examined using a year-round mooring observation off Sado Island in the eastern part of the Sea of Japan. The mooring system was constructed by two sets of acoustic Doppler current profilers and seven of single-layer current meters, covering the upper 1200 m in the full depth of 1770 m. From the data, the local inertial frequency and its vicinity showed the dominant peak especially in the upper 1200 m in depth, which persisted throughout the year. Any constituent from oceanic tide was negligibly small. Downward propagation of wind-induced NIWs was clearly observed several times during the mooring period of 2019-2020. Noticeable events of NIW were initiated typically by cyclones passing in summer and relatively persistent outbreaks of northwesterly wind from the Eurasian continent in winter. In this region, meanderings of the TWC and mesoscale eddies add complexity to the behaviors of NIWs. Vertical shears of current velocities were strong at 200–300 m inside the anti-cyclonic eddy. The amplification of NIW signature occurred at depths near the bottom end of the eddy's core. On the other hand, vertical shears were strongest at the surface and decreasing with depth inside the cyclonic eddy. The gradient Richardson number suggested the turbulent mixing through the breaking of the NIWs by Kelvin-Helmholtz instability in all event terms. Around the depth of strong vertical shears (250–300 m), reflection of NIWs was identified from the slope of iso-phase lines. The reflection layer is the pycnocline between the TWC water and the Japan Sea Proper Water. Near-inertial oscillation was determined over the large portion of water column underneath the reflection layer. A large vertical wavelength from the refraction can account for the nearly barotropic nature in the lower layer.

Using actual oceanic data we have investigated multi-scale phenomena of the TWC, the SPF, mesoscale eddies, near-inertial oscillation, NIWs, and turbulence. The importance of each phenomenon and their interactions were shown in the comprehensive understanding of the current system.