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学 位 論 文 要 旨
Dissertation Summary

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論　文　名：トカラ海峡周辺海域における黒潮と地形の相互作用が栄養塩とプランクトン成長に与える影響に関する研究

(Dissertation Title): Influences of the Kuroshio-topography interactions around the Tokara Strait on the nutrient supply and plankton growth

The Kuroshio is one of the western boundary currents that are the strongest ocean current in the world. Referred as the “nutrient stream”, the Kuroshio transports a tremendous amount of water heat, salt, and associated materials (e.g., dissolved inorganic nutrients) along its pathway, and has significant effects on downstream environments. The Kuroshio Paradox is proposed that in spite of the oligotrophy in the upper layer, various types of fishes use the Kuroshio region as their spawning and nursery grounds, and form good fishing grounds. Recently, the questions of where and how the nutrient-rich subsurface water in the Kuroshio region is supplied to the euphotic zone for the use of phytoplankton have attracted much attention. It has been noted that the Kuroshio mainstream inevitably passes through several rough topographies, including seamounts and islands in the Tokara Strait, and causes irregular fluid motions in the wake, such as eddy generation and shedding (Von Karman Vortex Street), turbulent mixing, upwelling, and trapped lee wave. Thus, the Kuroshio-topography interactions and their influences on the nutrient supply and plankton growth are concerns in this study.

When the Kuroshio Current passes by islands, a surface phytoplankton bloom is often observed in the wake of the island. To investigate its causes, a typical case for the Kuroshio region, in which a geostrophic current (1 m/s) passes around a cylindrical island, was simulated. The biogeochemical response is calculated by a combination of POM (Princeton Ocean Model) and eNEMURO, a standard lower-trophic-level marine ecosystem model including 17 biological components. The results show that the concentrations of dissolved inorganic nitrogen, phytoplankton, and zooplankton in the surface layer increased in the wake of the island. The phytoplankton concentrations averaged in the euphotic zone increase mainly in cyclonic eddies, where the nutrients are supplied from the deep layer. The sum of biogeochemical processes related to the phytoplankton increased immediately behind the island and had a maximum growth rate at 50 km downstream, which gradually decreased to a low value further from the island. Among four types of phytoplankton, the pico-phytoplankton dominated the bloom behind the island, which was also observed in the Tokara Strait. A simulation for the passive tracer without the biogeochemical processes indicated that the hydrodynamic processes directly contributed to 50% of the increase in the surface phytoplankton concentration in the wake in summer. However, with the winter condition, the surface phytoplankton concentration decrease in the wake. The difference is caused by the presence of a subsurface chlorophyll-a maximum in summer and the absence of it in winter. With an increase in island size, the size of eddies, the distance between eddies, and surface phytoplankton concentration also increased. For the first 300 km behind the island, no obvious zooplankton growth was observed. However, a long-time simulation by a box type of eNEMURO indicates that the trophic transfer from phytoplankton to zooplankton likely emerged further away from the island, which provides

a possible explanation of the Kuroshio Paradox.

The examination of the Kuroshio-Seamount interactions began from the situation of barotropic current. Two kinds of flow patterns appear around the seamount: flow-over and flow-around regime. The key parameter of transition between them is the Froude number. A small Froude number (< critical Froude number ~0.4) implies the flow-around regime, in which the flow skirts seamounts and leads predominantly to the generation of wake vortices, with potentially some lee wave generation at the top. Based on the linear theory, the lee wave performance is controlled mainly by the ratio of inflow velocity U and stratification N, which is known as the vertical wavelength of the first mode lee wave $\lambda_z = 2\pi U/N$. If the summit of the seamount is deeper than λ_z, the high mode lee waves appear at the summit of the seamount.

Following the above understanding, we know that most of the seamounts in the Tokara Strait belong to the flow-around regime. A vertical average of DIN concentration (passive tracer) in the euphotic zone (<110 m) is used to evaluate the nutrient supplement in the simulation. The seamount whose summit is 400 m below the sea level or deeper cannot supply the nutrient to the euphotic zone. For the taller seamounts whose summit is shallower than 400 m, the amount of nutrients supplied to the euphotic zone is in proportion to the height of the seamounts. The nutrient enhancement around islands is significantly larger than that around seamounts.

As results of the first mode lee wave, a high-low-high pattern of nutrient distribution is presented around the seamount. While the upwelling and flow circling around the tall seamount contributes to the high nutrient value on the left side of the seamount wake. The closer the seamount to the Kuroshio axis, the stronger the nutrient supply is. Nutrient supply to the euphotic zone is larger on the left side of the Kuroshio than on the right side. As the simulations are extended to multiple seamounts, we found when the distance between two seamounts is larger than 20 km, they act approximately as two individual seamounts. The close proximity of the seamounts likely destroys the hydrodynamic field of an individual seamount and has an important influence on the flow field in their vicinity. The lee wave at their summit becomes stronger although their lee vorticities are still independent.

Numerical simulation on the Kuroshio flowing over realistic topography around the Tokara Strait is carried out to confirm the results from idealized topography. A comparison of realistic topography and flatted topography indicates that the Kuroshio-topography interactions highly enhance the concentration of nutrients in the euphotic zone. Therefore, the wake of the Tokara Islands is highly efficient for nutrient supply and plankton growth. The satellite data also observed the increase of Chl-a concentration in the wake of the Tokara islands. The enhanced nutrients are transported by the Kuroshio downstream to the area south of Shikoku Island, Japan. Local and remote responses to the nutrient supply occurring in the Tokara Strait are expected as the influences of Kuroshio-topography interactions.