High-resolution modeling of ocean energy southwest of Japan

刘, 天然

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氏　　名　: 刘　天然

Name

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（日本南西域における海洋エネルギーの高解像度モデリング）

Title

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論　文　内　容　の　要　旨

Thesis Summary

The development of high-performance computing promotes the realistic simulations with high-resolution ocean models for fishery, navigation safety, ocean oil tracking, and many other applications. One example is the ocean power, which is the object of this thesis. The ocean owns enormous amounts of natural energy. The ocean renewable energy can be classified into five types: tidal energy, wave energy, current energy, thermal energy, and salinity gradient energy. Among them, the ocean current power can achieve high efficiency, and the Kuroshio current, as the strongest western boundary current, flows very close to Japan coast. In 2017, New Energy and Industrial Technology Development Organization (NEDO) and Ishikawajima-HarimaHeavy Industries (IHI) carried out the Kuroshio current power generation experiment in the Tokara Strait. The ocean thermal energy is also receiving more increasing attention because of its sustainability and environment-friendly characteristics. In addition, it is a stable resource that can generate power at all times. In 2013, an experimental plant called Okinawa OTEC Demonstration Facility was constructed in Kumejima Island. Therefore, this thesis attempts to estimate the ocean current power and thermal energy potential southwest of Japan using high-resolution regional ocean models, in order to select the proper site and depth for ocean renewable power plants. The impacts of Kuroshio large meander and tides are considered for better understanding. The thesis even tackles to enhance the accuracy of the model representing the thermal structure and velocity distribution by inverse modeling.

In Chapter 2, the DR_E model was used to represent the ocean state south of Japan. The ocean current power potential of the Kuroshio Current was estimated based on the simulation results. To choose the proper site for ocean current power generation experiment, three candidate areas were assessed by comparing the average current speed, the stability of the current vector, and the ocean current power potential. To study the impact of Kuroshio large meander, two experiments during the periods with and without large meander were carried out. The model was validated by comparing the results with ADCP measurements across the Tokara Strait and south of Cape Shionimisaki.

The results showed that the average current speed around the Tokara Strait is the weakest of the three candidate areas. In addition, the current speed south of Cape Shionomisaki is the greatest during non-large-meander period. However, the average current speed and stability there decrease significantly when the Kuroshio large meander appears. By comparison, the current is stable and strong south of Cape Ashizuri regardless of the Kuroshio large meander. Thus, the area south of Cape Ashizuri is a promising site for ocean current power generation experiment, and the average ocean current power density there can reach 1 kW/m2. However, an extraordinary strong and long-term

Kuroshio large meander occurred since August 2017. The Kuroshio axis occasionally leaves far away from the coast south of Cape Ashizuri, which has not been expected by these results. We also calculated four indices to further determine the promising area south of Cape Ashizuri. We found the maximum number of ocean current power plants constructed in the well-conditioned area exceeds 100 with the total power over 6 MW.

In Chapter 3, the ocean thermal energy potential around the Aguni Basin west of the Okinawa Island was estimated using DR_Ek model. The Aguni Basin lies near the eastern boundary of the Okinawa Trough where the tidal mixing is strong. The DR_Ek model was able to resolve the strong and complex tidal motions near the coast. To study the tidal effect, the simulations with and without tides were conducted. The simulated potential temperature and salinity were compared with the XCTD measurements near the OTEC plant on Kumejima Island.

In the Aguni Basin, the cold deep water intrusion cools the water, which is balanced by vertical eddy diffusion due to tidal mixing. Based on this deep layer thermal equilibrium, we proposed the perturbation method estimating the ocean thermal energy potential. This method and the modified Wick-Schmitt method were compared with the original Wick-Schmitt method and Nihous method. The results showed that the Wick-Schmitt method and Nihous method overestimate the ocean thermal energy potential with the realistic turnover time in the Aguni Basin, implying the methods and parameters used for global estimation may not be applicable to the Aguni Basin. On the other hand, the modified Wick-Schmitt and perturbation methods proposed in this study can improve the estimation. The results also showed that the ocean thermal energy potential in the Aguni Basin is five orders greater than the present mechanical limit. The strong and sustainable power generation is available near the northeastern slope of Kumejima Island within a short distance to the coast. The strong upwelling near the boundary of the Aguni Basin results from the strong tidal mixing. The large OTEC power can be also expected in the East China Sea due to vigorous tidal mixing.

It is noted that we assumed that the surface warm water keep its temperature much easier than the deep cold water, so the heat transport in deep layers of Aguni Basin was considered as the environmental limit of ocean thermal energy potential in this study. Thus, the temperature gradient in deep layers determines the potential instead of the temperature difference between surface and deep layers.

An ocean model reflecting realistic ocean state is critical for the estimation of ocean power potential. Thus, the satellite altimeter data assimilation based on the approximate Kalman filter was studied in Chapter 4. The domain of the DR_Ep model covers part of the shallow East China Sea shelf and deep Okinawa Trough southwest of Japan. Twin experiments were adopted to evaluate the data assimilation. The pseudo observations were generated along the tracks of AVISO multi-satellite altimeter data in the East China Sea.

To compare the data assimilation effects of surface and lateral boundary control, the process noises of the surface and lateral boundary forcings were separately determined by minimizing the root-mean-square difference of temperature. The results showed that traditional surface boundary control performs well in shallow area of the model domain, but the assimilation effects decay rapidly to depths. By comparison, the lateral boundary control improves the surface and subsurface representation of the ocean state. The effect of lateral/surface boundary control can/cannot propagate to deep layers. The cross spectral analysis indicated that the long-term variability with period longer than several weeks can be effectively improved by assimilating satellite altimeter data. Thus, other measurements should be assimilated in the meantime to promote the representation of the Kuroshio variations.