Japan Geoscience Union Meeting 2013
(May 19-24 2013 at Makuhari, Chiba, Japan)
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ACG36-05 Room:102A Time:May 22 12:00-12:15

Role of river runoffs on ocean environment and fishery production around Funka Bay, Japan

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The land-sea interaction can be comprehensively analyzed by using high-resolution datasets produced by a land-sea-coupled simulation that are well validated based on observational datasets. Recently, a land-sea-coupled model was developed toward an operational ocean prediction system in semi-enclosed Funka Bay (located in northern Japan) to inform fishermen of the real-time ocean state.

Subarctic Oyashio (OW) and subtropical Tsugaru waters (TW) originating from the Kuroshio alternately flow into Funka Bay from the North Pacific and mix at various timescales, leading to unique oceanographic features. The rivers flowing into Funka Bay have small watersheds facing the bay (up to approximately 500 km^2) and supply buoyancy through the snowmelt runoff. These unique features are key for fishery resources managements (e.g., skipjack, salmon, and kelp) and ocean biodiversity.

In this paper, we investigate the role of the river runoff on the formation of water masses and velocity field in the bay based on the high-resolution simulation outputs. We discuss about the influence of the interannual changes of land-ocean environment on the fishery production of kelp. The main factor for poor production of kelp in 2009 is examined by analyzing the remarkable contrast of the land-ocean condition and kelp production between 2008 and 2009.

A coupled land-ocean model was composed of the Kyoto Ocean General Circulation Model (OGCM) using the four-dimensional variational data-assimilation and Hydrometeorological and multi-Runoff Utility Model (HaRUM). The high-resolution simulation was conducted by the three-step nesting method to reproduce the eddy-resolving circulation in/around the bay. HaRUM employed a distributed tank model based on the water mass and heat budgets to estimate the runoff on a daily basis.

The coupled model reproduced a surface salinity field that was in good agreement with observational results and simulated outputs in the bay from 2008 to 2009. The clockwise circulation was generated by wind and river runoff in spring and its vorticity was intensified from March to May. The freshwater discharge takes a seasonal maximum associated with snow-melting events from March to June, indicating that the buoyancy provided by snowmelt runoff intensified the vorticity of the clockwise circulation.

The clear contrast was found in both physical features observed in 2008 and 2009 in the bay. The clockwise circulation in 2009 was stronger than that in 2009. This was induced by higher snowmelt runoff in 2009 than that in 2008. The amount of the summer-time surface water in Funka Bay (FS) was greater in 2009 than in 2008, which is attributable to a larger amount of snowmelt runoff. The intrusion of TW and OW in 2008 was found, but both were hardly found in 2009, leading to the interannual difference in the stratification inherent in the bay. This ocean condition in 2009 affected the annual production and growth rate of kelp.

The impacts of river runoff on the water mass distribution in the bay were evaluated by conducting the sensitivity experiment. Two numerical experiments were conducted; one case used the coupled land-ocean model, and the other used the OGCM without HaRUM in typical year, 2008. The experiment indicated that the FS in the case without HaRUM was much less than the case by the coupled model. The amount of the mixed water MW, a blending of mainly FS and TW through winter surface cooling, was formed in the case of the coupled model, which was much greater than that without HaRUM.

As a result, the river runoffs that supply fresh water, buoyancy, and nutrient into the bay are essential for formation of water masses, circulation, primary production in the bay, respectively. Our results underline the fact that implementation of hydrological processes into ocean simulations is a key factor for a better understanding of the water circulations driven by runoffs into semi-enclosed bays over interannual timescales.

Keywords: land-sea interaction, a land-sea-coupled model, snowmelt runoff, water mass formation, high-resolution simulation, Funka Bay