Tidally-driven submesoscale coherent eddies at Naruto Strait in the Seto Inland Sea, Japan

*Yusuke Uchiyama[1], Shota Yanase[1], Xu Zhang[1]

1. Graduate School of Engineering, Kobe University

"Whirlpools" at Naruto Strait in the Seto Inland Sea (SIS), Japan, are widely recognized as an extraordinary dynamic and beautiful natural phenomenon. The strait lies between Awaji Island and Shikoku Island in the SIS, and has a quite narrow opening of 1.4 km. Rapid currents are often generated due to tidal level differences on two sides of the strait, *i.e.*, Harima-nada Sea to the north and the Kii Channel to the south, most prominently during every spring tide. The narrow strait induces intensive tidal currents accompanied by vigorous submesoscale eddies, resulting in one of the most energetic "whirlpools" in the world. However, because little has been investigated scientifically on the Naruto whirlpools from a geophysical standpoint, we conduct a very high-resolution, quadruple-nested downscaling ocean modeling based on the JCOPE-ROMS system to provide a solid scientific view of the Naruto whirlpools. The outermost boundary conditions for the ROMS models are imposed from the assimilative JCOPE2 reanalysis at the perimeter of the L1 model. The lateral grid spacing is then successively refined from 1/12° (~10 km, JCOPE2), 2 km (ROMS-L1), 600 m (L2), 100 m (L3), and finally down to 20 m (L4). Barotropic tides are imposed on the L2 model, which spontaneously propagate into the inner L3 and L4 models through the open boundaries. Approximately a 16 km x 16 km region with the 1.4 km-narrow strait topography is analyzed with the inner-most L4 model, which enables us to realistically reproduce the complex flow field with submesoscale eddies comprising whirlpools around Naruto Strait as precisely as possible. A synoptic computation for three spring-neap tidal cycles for the late summer condition in 2015 is carried out to achieve the statistical significance of temporally varying tidal fluctuations.

It is quantitatively identified that tidal sea-surface elevation in the Harima-nada Sea lags about three hours behind that in the Kii Channel, because of the counter-clockwise propagation of M_2 tidal waves around Awaji Island. This pahse delay results in a pronounced meridional pressure gradient force that drives energetic tidal currents at the strait. Mean residual transport occurred at the strait is determined as southward dominant, from the Harima-nada Sea to the Kii Channel. Depth-dependency is apparent in the residual transport at the cross-section of the strait, which is characterized by the northward transport near the surface and the center of the strait, while by the southward transport along the bed. A kinetic energy budget analysis indicates that the work done by lateral mean velocity shear and horizontal Reynolds stress is enhanced by squashing tidal currents to increase the mean to eddy kinetic energy conversion, which is almost solely attributed to generation of vigorous eddies around the tidal currents. Therefore, lateral shear instability plays a major role in the eddy generation mechanism. On the other hand, as the density fields are rather homogeneous on the two sides of the strait, buoyancy-driven baroclinic instability barely takes place over there.

Keywords: tidal current, narrow strait, submesoscale eddy