Accelerated spread of Fukushima’s waste water by ocean circulation

Gengxin Chen,1,2 Qiang Wang,1,2 and Xiaoqing Chu1,2,*

1State Key Laboratory of Tropical Oceanography, South China Sea Institute of Oceanology, Chinese Academy of Sciences, Guangzhou 510301, China
2Southern Marine Science and Engineering Guangdong Laboratory (Guangzhou), Guangzhou 511458, China
*Correspondence: chuqx@scsio.ac.cn

Received: April 23, 2021; Accepted: April 30, 2021; Published Online: May 4, 2021; https://doi.org/10.1016/j.xinn.2021.100119
© 2021 The Author(s). This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).
Citation: Chen G., Wang Q., and Chu X. (2021). Accelerated spread of Fukushima’s waste water by ocean circulation. The Innovation 2(2), 100119.

Japan announced that the treated waste water contaminated by the wrecked Fukushima Daiichi Nuclear Power Plant will be released to the Pacific Ocean. Since the waste water still contains tritium and trace amounts of other radionuclides, the decision immediately raises many general concerns for people, especially residents of neighboring countries, and has been condemned by environmental groups and fisheries organizations.

Two wind-driven western boundary currents converge near the Fukushima coast. As the strongest current in the North Pacific Ocean, the Kuroshio originates from the bifurcation of the North Equatorial Current (NEC) at about 12°N–15°N to the east of Philippine coast; it flows northward passing the Philippine and Taiwan coasts, enters south of Japan through the Tokara Strait, and eventually separates near the Fukushima coast to the open ocean, accompanied by large-amplitude meanders and energetic pinched-off eddies.

In the open basin, the Kuroshio is renamed the Kuroshio Extension, and its transport can reach as high as 130 Sv (1 Sv = 10⁶ m³/s) in the region of Kuroshio recirculation, 100 times of the entire global river discharge. Another western boundary current, the Oyashio Current, flows southwestward along the coast of Hokkaido, and partly converges with the Kuroshio flowing east–northeastward.

The radionuclides would be redistributed by the active ocean currents and eddies. Massive energetic cyclonic and anticyclonic eddies with diameter of tens to hundreds of kilometers are generated from the Kuroshio meanders and the collision of the warmer Kuroshio and colder Oyashio. These eddies and the southern recirculation, together with turbulent diffusion can transport the radionuclides toward the East China Sea (ECS) (route 1 in Figure 1). Many of these eddies are highly nonlinear and capable of advecting the radionuclides long distances with high concentration and low dissipation. Eddies near the Kuroshio Extension also significantly increase subduction of the radionuclides into the mode water, a thick layer of water with homogeneous properties in the subsurface ocean; through recirculation, the radionuclides can be quickly transported toward the ECS. The numerical simulation shows that the radionuclides reach the ECS about 1 year.1 The Kuroshio branch in the ECS further transports the radionuclides northeastward, and exchanges significantly with the ECS shelf current.2 As a result, the radionuclides appear in the Yellow Sea and Japan Sea further north.

The majority of the radionuclides would be transported eastward by the Kuroshio Extension and the Oyashio Current. Because of the large-scale subtropical gyre, the radionuclides would be carried out by the clockwise circulation and eventually reaches the low-latitude part of the Kuroshio (route 2 in Figure 1). As the Kuroshio flows northward, it passes the Luzon Strait which connects the western Pacific Ocean with the South China Sea. Parts of the Kuroshio water intrudes into the South China Sea through the Luzon Strait, particularly in winter, and forms a loop current. In addition, mesoscale eddies can also contribute to the westward transport through the Luzon Strait. These give rise to the South China Sea throughflow, which transports water masses and radionuclides into the South China Sea, as depicted by the thin yellow dashed arrow.

The eastward transportation in the open Pacific Ocean takes about 5 years to cross the Pacific basin, a rough estimation based on the climatological ocean reanalysis data of Simple Ocean Data Assimilation. When the eastward progression approaches the west coast of North America, it bifurcates into the northward flowing Alaska Current and the southward flowing California Current. The southward branch joins the westward flow in the subtropical gyre, including the flowing NEC, and starts a new cycle (route 3 in Figure 1). In addition, the eddy-induced meridional transport helps to spread the radionuclides to the whole Pacific Ocean.

In addition to the northward flowing Kuroshio, the NEC bifurcates into the southward flowing Mindanao Current. The radionuclides thus could be transported to the equatorial area and the tropical Indonesian seas. Through the Indonesian throughflow (ITF), an oceanic pathway for the Pacific and Indian inter-ocean exchange, the radionuclides would enter the Indian Ocean and spread over the whole basin through its circulation system. They can be carried out by the Agulhas Current, the western boundary current of the South Indian Ocean, to the South Indian Ocean; around the tip of South Africa the Agulhas current meets with the eastward Antarctic Circumpolar Current and the radionuclides are redistributed to the global ocean by this “Great

Figure 1. Schematic showing routes for spread of radionuclides Contours denote the mean sea surface height field with units in m, distributed by the Archiving, Validation, and Interpretation of Satellite Oceanographic (AVISO) from 1993 to 2018. The gray streamlines denote eddy fields on January 1, 2020, based on surface geophysical current anomalies from AVISO.
Conveyor Belt.” In addition, at the tip of South Africa, there is a small portion of the radionuclides that can be carried out by mesoscale eddies into the South Atlantic Ocean and eventually redistributed over the whole Atlantic Ocean.

The ocean is a complex and changeable system, which presents a significant challenge for marine monitoring. It is difficult to fully understand the distribution of the radionuclides and their impacts. Global warming has made extreme climate and weather events more frequent, which further increases the difficulty in forecasting ocean currents and the distribution of the radionuclides. Marine scientists and biologists expressed concerns about the possible impacts of the discharge on marine life and on humans, and suggested a more cautious decision. The price of all of the disorderly discharge of waste generated by our production and lifestyle is ultimately paid by all human beings.

REFERENCES

1. Behrens, E., Schwarzkopf, F.U., Lübbecke, J.F., et al. (2012). Model simulations on the long-term dispersal of $^{137}$Cs released into the Pacific Ocean off Fukushima. Environmental Research Letters 7. https://doi.org/10.1088/1748-9326/7/3/034004.

2. Yang, D.-Z., Huang, R.X., Yin, B.-x., et al. (2018). Topographic beta spiral and onshore intrusion of the Kuroshio Current. Geophysical Research Letters 45, 287–296. https://doi.org/10.1002/2017GL076614.

3. Cai, W., Santos, A., Wang, G., et al. (2014). Increased frequency of extreme Indian Ocean dipole events due to greenhouse warming. Nature 510, 254–258.

4. Jalaludin, B., Johnston, F., Vardoulakis, S., et al. (2020). Reflections on the catastrophic 2019–2020 Australian bushfires. The Innovation 1, 100010. https://doi.org/10.1016/j.xinn.2020.04.010.

5. Wei, K., Gouy, C., Duan, H., et al. (2020). Reflections on the catastrophic 2020 Yangtze River basin flooding in Southern China. The Innovation 1, 100038. https://doi.org/10.1016/j.xinn.2020.100038.

ACKNOWLEDGMENTS

We thank Dr. Rui Xin Huang for his valuable suggestions. This work is supported by NSFC 41822602, 2017YFB0502700, XDB42000000, NSFC 41776026, NSFC 42076021, Youth Innovation Promotion Association CAS (2017397), and GML2019ZD0306.

DECLARATION OF INTERESTS

The authors declare no competing interests.