Anthropogenic radionuclides as tracers of climate change in the Pacific Ocean and its northwestern marginal seas

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Climate is the statistical description of the mean and variability of its variables (temperature, precipitation, wind, sea surface temperature, ocean circulation, seawater chemical composition, etc.) over 30 years. Climate change is the deviation from the current climate. The increase in anthropogenic greenhouse gas emissions into the atmosphere since the Industrial Revolution has accelerated global warming with significant impacts on Earth's ecosystems. Oceans, consequently, have been experiencing frequent marine heat waves and a slowdown of the Global Meridional Overturning Circulation (GMOC), disrupting ocean circulations with accompanying changes in biogeochemical processes, including surface ocean acidification and poleward migration of trophic organisms. Anthropogenic radionuclides (ARs), released to the marine environment from nuclear activities since the 1940s, have recorded some climate change impacts on the world ocean in the water, bottom sediment, and biota (e.g., Scleractinian corals). Recent developments in radiometric and mass spectrometry technologies have increased sensitivity by more than 10, enabling us to obtain high-resolution data down to the abyssal ocean using standard Rosette water bottle systems with one/two casts only. The Pacific Ocean is the most extensively sampled for ARs over the several decades among the oceans. Several examples of the temporal and spatial changes in ARs (e.g., 3H, 14C, 90Sr, 129I, 134Cs, 137Cs, and Pu isotopes) in the Pacific Ocean and its northwestern marginal seas are shown here to demonstrate the utility ARs as tracers of climate change occurring in the oceans.

The key contributions of ARs to GMOC studies are the confirmation of the role of Indonesian Throughflow (ITF) from the western tropical North Pacific to the Indian Ocean, the accumulation of ARs in the Indian Ocean Subtropical Gyre, the south Indian Ocean as a final reservoir of contaminants transported from the northern Indian and Pacific Oceans on a time scale of several decades, and the discovery of the cross-equatorial subsurface isopycnal mixing of the North Pacific water to the South Pacific Ocean evidenced by the global fallout 137Cs. Vertical distribution of plutonium isotopes records the ongoing climate change impact in the Sea of Japan, as increasing SST reduces winter convection and eddy activities. ARs were found to be varied due to changes in the offshore vertical mixing induced by the changes in the Asian monsoons and ENSO events in Chinese marginal seas. ARs data has provided reference frames to calibrate and validate global ocean circulation models and the Earth System Models in future scenarios of ocean changes and their impacts. High-resolution time and space distribution of the Fukushima-derived 137Cs obtained in the North Pacific Ocean are essential for future studies of climate change impacts. New international large-scale sampling campaigns covering the world ocean using recently developed high-resolution/sensitive radiometric technologies are needed to generate a robust database to complement the earlier several decade-long observations. The Southern Ocean should receive special attention due to its role in global climate and relatively limited anthropogenic radionuclide data.