Response to Reviewer 1:

We would like to thank Reviewer 1 for dedicating time to carefully read our manuscript and provide feedback. We sincerely think their detailed comments have helped us to improve the manuscript. Here it follows a point-by-point response to the reviewer's report (text in black denotes the comments provided, while text in blue denotes our response), associating with the revised manuscript with the track of the changes.

Comments (in black): The study investigated the transport and long-term fate of radionuclides released from wastewater in the global oceanic environment, using FDNPS release as a case study. The authors applied a more comprehensive transport and biogeochemical model – MITgcm ocean tracer model to run a short- to medium-term predictions for current status and model validation, and then predicted a longer-term fate until 2100 under an intermediate scenario and the low-end and high-end emission scenarios for the uncertainty range. The work is extremely significant, as 1) the health risks posed by the radionuclides released after the earthquake and the ongoing release with intentional wastewater discharge is of concern globally; and 2) although previous studies have modelled some radionuclides regionally after the disaster, we obviously would like to know the risks of all major radionuclides in the long-term future in the global ocean, considering the continuous release. This study used a model capable to consider multiple radionuclides and their essential biogeochemical processes, which is important and interesting.

Response (in blue): We sincerely thank the reviewer for the positive and constructive comments. Below we provide point-by-point responses to the comments and indicate the corresponding revisions made in the manuscript.

The manuscript is well organized and prepared. The model performance is validated reasonably using observational data. The authors clearly showed the temporal and spatial pattern of radionuclides. The detailed questions below should be addressed before acceptance.

1. For the emissions in the method section, is there any reference for the assumption that the discharge will last until 2050? Is the assumption more likely to be for a conservative or aggressive assessment?

We appreciate this comment. The assumption of continuous discharge until 2050 is based on the Japanese government's announcement in 2021 that the estimated release of treated wastewater was expected to last for about 30 years (https://www.cnbc.com/2021/04/13/japan-to-release-water-from-fukushima-nuclear-plant-into-sea-in-2-years.html?msockid=2952ddfd6d92623923f5c9b56cb26327). Compared with the actual discharge scenario described in TEPCO (2023) Environmental Impact Assessment Report, as noted by reviewer #2, our setup can be regarded as a more conservative (upper-bound) estimate intended to capture the potential long-term impact.

This approach ensures that the uncertainty range covers the possible maximum duration of releases. We added the Methods section to explicitly clarify the rationale.

Line 190: "To facilitate a direct comparison with the actual discharge plan, the inventories reported in TEPCO's *Radiological Environmental Impact Assessment Report Regarding the Discharge of ALPS Treated Water into the Sea* (TEPCO, 2023) have also been incorporated into Table 1. The tritium discharge in our low-end scenario is comparable to TEPCO (2023), while the ^{14}C and ^{129}I releases are of similar magnitudes. For particle-reactive radionuclides such as ^{60}Co, ^{90}Sr, ^{137}Cs, ^{106}Ru, ^{134}Cs, and ^{125}Sb, our estimates are approximately one order of magnitude higher than those in TEPCO (2023), reflecting a more conservative assumption for potential release fractions."

2. Why did the authors choose to simulate the short-term concentration till 2016 for validation? Is this relevant to the sampling year of the available observation data?

Yes, the short-term validation period was chosen to match the time frame of available observational datasets. Most monitoring programs reported surface and subsurface radionuclide concentrations from 2011 to 2016 in the North Pacific (e.g., Aoyama et al., 2013; Smith et al., 2014; Kaeriyama et al., 2016). After 2016, observations became sparse, which limited the opportunity for systematic comparison. We clarified this in the text.

Line 250: "The short-term validation period (2011–2016) was chosen to correspond with the time span of most available observational datasets, as extensive monitoring of surface radionuclide concentrations in the North Pacific was conducted during this period."

3. It is not to say that you have to assess the consequent risks quantitatively, but is it possible to add a bit discussion on the last section. For example, what's the potential short-term and long-term exposure risks. Is there enough toxicological data for assess this for the combined contamination of such many radionuclides. Can we be sure about the risks based on the predications and available toxicological data of radionuclides both in the short-term and long-term exposure?

We agree with the reviewer that it is valuable to briefly discuss potential exposure risks. In the revised manuscript, we added a paragraph in the Disucussions section.

Line 476: "While this study does not provide a quantitative risk assessment, our results establish an essential basis for evaluating potential human exposure. The simulated radionuclide distributions represent the environmental concentrations that determine the external and internal exposure pathways identified in previous studies (Fisher et al., 2013; Jones, 2013). Using a concentration factor (CF) approach (IAEA 2004), the radionuclide concentrations in seafood can be estimated from seawater and sediment concentrations. Human health risk is thus directly related to the radiation doses received, which are measured as the energy absorbed by biological tissues from ionizing radiation (in sievert, Sv). To estimate this dose, the biota radioactivity concentration (e.g. in a unit of Bq L-1) is converted to radiation dose using th dose coefficient (DC), which depends on the type of radiation decays (e.g., α or β type) and the half-life of the radionuclides (Eckerman et al., 2012). The total radiation dose is then calculated by summing the contributions of individual radionuclides, weighted by their respective DC values. Although some radionuclides exhibit relatively high CFs and ingestion DCs, the cumulative effects of long-term exposure to multiple radionuclides remains poorly constrained. Therefore, our model outputs presented here serve as a critical input for future assessments of human and ecological health risks by providing spatiotemporally resolved radionuclide concentrations under different emission scenarios."

4. Please check the language again, as there are minor grammar mistakes, for example, lines 94-96

We carefully proofread the manuscript and corrected grammatical and typographical errors, including those pointed out by the reviewer.

Line 97-101: "Model fidelity is influenced by numerous numerical and environmental factors such as model resolution, diffusion parameters, temperature, salinity, wind, tides, and particle size distributions. Recent studies have tested these parameters to refine simulations, demonstrating that they can substantially affect the transport and transformation of radionuclides (Kamidaira et al., 2021; Tsumune et al., 2024; Li et al., 2015)."