Answer to Referee comment 1 on "Circulation timescales of Atlantic Waters in the Arctic Ocean determined from anthropogenic radionuclides" (from 17 Sep 2020)

Dear Reviewer 1,

Thank you for your review of the paper and your suggestions on how to improve it. We will gladly incorporate all of them into the revised version of the manuscript.

Please find preliminary answers regarding your comments below. We will provide final answers and the revised version of the manuscript after the open discussion is closed (20th October 2020).

On behalf of all co-authors,
Anne-Marie Wefing

This manuscript uses measurements of two long-lived artificial radionuclides (129I and 236U) together with idealized transport models to analyze the tracer transport in the surface and in the mid-depth Atlantic water in the Arctic Ocean. It is shown that analysis of the pair of radionuclides enables the time scales and pathways of the transport, and role of lateral mixing, to be constrained. The paper is well written, contains interesting new results, and I think is suitable for publication in Ocean Science after only a few relatively-minor revisions (see below).

Specific Comments

1. Why are different models used for surface and mid-depth waters? The manuscript just states that different models are used, but there needs to be a discussion of why the same model can't be used for both and/or why one model works for one layer and not the other.

Reply: Thanks for pointing out that this was not stated clearly enough. We have added some sentences to clarify why the different models were used for the different layers in section 1.3. Concretely, the reason behind using different models for the different layers is the following:

Generally, the binary mixing model is only applicable in cases when the advective flow can be assumed to be dominant and lateral mixing within the flow is limited. This assumption is valid only for the surface layer, as has been shown in Smith et al. (2011). In the Atlantic layer, lateral mixing is much more important, invalidating the use of the binary mixing model. In contrast, this process is explicitly accounted for in the TTD model. However, the TTD model does not capture the mixing of different endmembers, e.g., Atlantic and Pacific waters, and therefore cannot be applied to the surface layer.

2. A related issue is the relationship between the different "ages" reported. Can the tracer ages from the binary model be compared with the mean age (or modal age) from the TTDs? These ages are both shown in summary figure 7, but it needs to be clearer if the difference between the ages reflects real differences in transport times or if some of the differences could be due to the age definition.

Reply: One should be careful when comparing circulation times between the surface and the Atlantic layers due to the different underlying models and assumptions. In the surface layer, tracer ages from the binary mixing model only reflect actual ages when the AW flow can be

considered purely advective. In contrast, the TTD model accounts for mixing and the mean and mode ages are different estimates of circulation times. Only in the case of purely advective flow, mean ages, mode ages, and tracer ages are comparable.

However, we found that the mode ages are overall in the same range as the tracer ages and appear to be a suitable measure for the lateral propagation of tracer signals while taking mixing into account.

To clarify this in the paper, the last paragraph of section 4.2.2 was changed to:

> *"In this case, the different age measures deduced from the TTD are also similar and can be compared to tracer ages. If significant mixing is involved, only the TTD model provides meaningful age estimates. We found that overall, mode ages derived from the TTD model for the Atlantic layer are in the same range as tracer ages from the surface layer."*

In the conclusions, the following sentence was added:

> *"For a comparison between tracer ages, mean, and mode ages, the different underlying models for the surface and the Atlantic layers need to be considered. In the case of lateral mixing, tracer ages are not meaningful and mean ages will always exceed mode ages. Here, the choice of the age estimate generally depends on the context."*

3. In the discussion of uncertainties (e.g. appendix A) there should be some mention of the uncertainty in the TTD method due to the choice of G(t). All the analysis assumes the G(t) is an inverse Gaussian, but different mean, and especially mode, ages would be obtained if G had a different functional form. I acknowledge that this uncertainty can't be quantified as easily as some of the other factors, but it should at least be mentioned.

Reply: The choice of G(t) indeed has significant impact on the derived ages. The following comment has been included at the end of section 4.1.3:

> *"The functional form of the Green's function G(t), describing the propagation of the tracer signal, introduces an uncertainty on the reported mean and mode ages. Examples of different functional forms have for instance been discussed in Haine and Hall (2002). The inverse Gaussian form of G(t), which solves the 1D advection-diffusion equation, has been shown to perform well for many oceanographic applications, and is therefore the most widely used functional form."*

4. The Introduction is very long, with multiple subsections, and it is not until page 5 that what is examined in this paper is discussed. As a reader I greatly prefer papers with more concise Introductions that quickly gets to the outstanding questions and what is examined in the paper. Would it be possible to have a more concise Introduction, with some of the subsection in a second section that provides the background on the radionuclides in the Arctic.

Reply: We have slightly rearranged the introduction. The following paragraph has been included at the end of section 1.1:

> *"In this study, the two long-lived anthropogenic radionuclides I-129 and U-236 will be combined to investigate circulation pathways, mixing regimes as well as tracer ages*

of AW in the surface and Atlantic layers of the Arctic Ocean. Obtained ages will be put into the context of available literature data and different approaches on how to estimate circulation timescales will be compared. Strengths and weaknesses especially of applying the transit time distribution model introduced in section 1.3 to anthropogenic radionuclides will be discussed and implications for the Arctic Ocean will be highlighted."

The last paragraph of the introduction (page 5) has consequently been shortened and now reads:

"Based on the two models presented above, we revise circulation features and investigate circulation times of AW in the Arctic Ocean using the combination of I-129 and U-236. The tracers ages and mixing regimes in the surface and Atlantic layers of the Arctic Ocean will be discussed based on both a binary mixing model and an adaptation of the TTD approach to I-129 and U-236".