Reply to Review #1:

The authors would like to thank the reviewer for the invaluable comments and suggestions. Below are the replies to each point raised in the review, accompanied by the specific revisions that have been made. The original review comments are presented in *blue italic* font and organized in paragraphs; our replies follow each respective paragraph. Additionally, the revisions are highlighted in blue in the revised manuscript and marked with 'REV1'.

The paper is concerned with the estimation of the depth of MIZ affected by the penetration of incoming ocean waves using the altimeter onboard CS2. The wave-affected sea ice regions were identified from two distinctive features of the CS2 waveform characteristics, namely the Stack standard Deviation (SSD) and the Trailing Edge Shape (TES) parameters. An inversion procedure was thus developed and applied in the MIZs of the Atlantic sector of the Arctic over 12 winters from 2010 to 2022. ICESat2 data and Sentinel-1 SAR images were used for comparison to validate the CS2 retrievals.

The paper is well-written and the inversion methodology is accurately described. Results are also discussed in comprehensive detail.

I have only a few minor remarks as suggestions for the authors:

p. 1 last row: Besides frictional processes, wave attenuation in sea ice occurs also as a result of the energy scattering among floes.

Reply: The authors appreciate the reviewer for pointing out the mechanisms of wave attenuation in the marginal ice zone. We have revised the aforementioned statement as follows:

“Furthermore, in the marginal ice zone, wave energy attenuation is predominantly governed by a diversity of processes, which can mainly focus on two mechanisms: dissipation due to interactions between ice floes and the ocean (Doble et al., 2015; Ardhuin et al., 2020; Voermans et al., 2021) and redistribution of energy through the floe-induced wave scattering (Kohout et al., 2006; Squire, 2020).”

p. 2 rows 35-40: For completeness, it would be useful to mention that spaceborne SAR can image with spatial modes able to distinguish short waves that decay within the first tens of kilometers inside the ice edge of the MIZ. These MIZ regions are typically formed by frazil, grease, and pancake ice, which are becoming the most populated ice types in the Arctic (Wadhams et al. 2018; De Carolis et al. 2021).

Wadhams, P., Aulicino, G., Parmiggiani, F., Persson, P. O. G., & Holt, B. (2018). Pancake ice thickness mapping in the Beaufort Sea from wave dispersion observed

in SAR imagery. Journal of Geophysical Research: Oceans, 123, 2213–2237. https://doi.org/10.1002/

2017JC013003

De Carolis, G., Olla, P. & De Santi, F. SAR image wave spectra to retrieve the thickness of grease-pancake sea ice using viscous wave propagation models. Sci Rep 11, 2733 (2021). https://doi.org/10.1038/s41598-021-82228-x

Reply: The author thanks the reviewer for the suggestion of adding SAR-based MIZ observations in this part of the manuscript. We have incorporated the recommended content into the manuscript as follows:

"To resolve waves in the MIZ, high-resolution satellite payloads are typically required, including various optical sensors, Synthetic Aperture Radar (SAR), and laser altimetry of ICESat-2 (IS2) (Markus et al., 2017; Horvat et al., 2020; Collard et al., 2022). These advanced payloads facilitate detailed analysis of sea ice characteristics in the MIZ, including the floe size distribution as well as the wave propagation and attenuation in ice-covered regions(Wadhams et al., 2018; De Carolis et al., 2021; Stopa et al., 2018)".

p. 7 rows 155-160: How reliable is it to use the sigma0 and its variability information in cases of extreme winds to detect the MIZ boundary?

Reply: The author thanks the reviewer's comment on the feasibility of Sigma_0 for detecting MIZ boundary. We argue that the waveform power of CryoSat-2 (CS2), which characterizes the backscatter at nadir-looking angles (<2-deg), is sufficient to detect the presence of sea ice and distinguish MIZ from open water. Among all the cases we have carried out retrieval, the CS2 waveforms all show drastically higher power on sea ice (MIZ) than the nearby ocean, no matter how strong the waves are on the ocean.

It is worth noting that: the slant-looking backscatter is not suitable for the differentiation between sea ice and open water. Under high ocean conditions, the backscatter on the open ocean is very strong and even higher than that over sea ice. However, over open water at nadir-looking angles, the backscatter mechanism is different from the Bragg-type backscatter at slant-looking angles, which is modulated by wind and the ensuing capillary waves. On the contrary, higher winds (i.e. rougher seas) will slightly reduce the nadir-looking backscatter (instead of increasing it).

Furthermore, the backscatter is very homogeneous over the ocean (along the CS2 track) since the ocean's condition has much larger spatial scales than sea ice. However, a very large variability of backscatter is present over the sea ice-covered regions due to the backscatter being mostly determined by highly variant snow/surface conditions. To summarize, the CS2 backscatter (along with its distribution) can be used to determine the MIZ's outer boundary.

p. 9 row 200: "scanning of in the whole..." may be missing a word after "of".

Reply: The author is grateful to the reviewer for identifying the incorrect language in this sentence. It has been revised as follows:
"Second, we scan the entire range of potential value of ξ (from 0 to π, relative to the east)."

Please revise figure captions: symbols, colored lines, and boxes should be explained in more detail.

Reply: The author appreciates the reviewer's valuable feedback. We will revise the figure captions to include more detailed information of the symbols, colored lines, and boxes for better clarity and understanding. The modifications are highlighted in the revised manuscript.