

Reply to RC2

We thank the reviewer for their thorough reading and constructive comments, which will help to improve the manuscript. In the following, we cite the reviewers' text and add our own answers and planned text modifications in green.

General comments

The authors present a method to estimate pan-Arctic drag coefficients using observations of sea ice surface feature parameters from ICESat-2. The results show that the drag coefficient is both spatially and temporally variable, and that pan-Arctic drag coefficients can be estimated with the use of satellite observations. It is the first analysis of monthly pan-Arctic drag coefficient estimates of its kind. I assume this will be welcomed in the model community.

Below I will address some specific scientific questions and technical corrections. Based on these, I would like to suggest minor corrections to be made before publication.

My biggest concern is the use of the OIB/ICESat-2 correction and the lack of discussion on the uncertainties and errors this will introduce. The regression is only trained on 4 days of observations in April for a specific location of the Arctic, and is then assumed to still hold over different types of sea ice and other months of the year. I understand there is no more data to use and thus I won't suggest changes to the methods, but I do think a discussion on the downsides of this method is necessary.

A discussion exploring these downsides will be added in the final paper; we thank the author for pointing out the lack thereof.

See below for additional comments.

Specific comments

- One of the big uncertainties introduced by the methods used in this paper is the OIB model correction to the observed form drag coefficient. This model is trained on the comparison between OIB airborne lidar measurements and ICESat-2 satellite observations for the near-coinciding 4 days in April 2019 in the Lincoln Sea and the Arctic Ocean north of Greenland. This region is for the majority covered in MYI, also in the month these observations were made (see <https://nsidc.org/data/nsidc-0611/versions/4>).

This model is then applied to the observations for the full pan-Arctic area discussed in this study, and to each season and for the years 2019, 2020 and 2021. I doubt this relation between the ICESat-2 form drag coefficient and the OIB ATM form drag coefficient will be the same in areas that are predominantly covered in FYI or in other seasons of the year. I understand there are not more near-coincident observations in other regions and months available, so this is the best that can be done now, but I think it is important to include a discussion on the effects these assumptions have on the presented modelled drag coefficient, especially because the model regression coefficient is large and impacts the results a lot.

As mentioned, the discussion exploring these uncertainties will be added in the final paper.

- One the same argument, it would be useful to present some statistics on the presented regression model (Eq. 6). How good is the fit? It would also be interesting to see this fit for the observations of the 4 days separately. Are they similar or does it change for the different days and different flight paths?

With regards to the fit, it has been modified to include no y-intercept as the negative y-intercept caused some small form drag coefficients to be negative: which is unrealistic. In terms of additional statistics, uncertainties will be explored and the mean square error reported.

- Explain why the value of 0.2 m is used as threshold (line 153). You've mentioned you have also tested using 0.8 m, but no other values were tried?

Some cutoff must be introduced to effectively partition centimeter-scale roughness that is associated to skin drag and form drag associated to obstacles (in this case anything above the 20 cm cutoff), and we chose one which has been used before (e.g., Castellani et al., 2014, Petty et al., 2017) for better a comparison with previous evaluations of Arctic sea ice topography.

- Figure 4A: if you already know this is not a good direct comparison because of the ice drift in between days, maybe it's better to leave this figure out? I think it will only raise doubts and confusion because the fit does not look good, even though you don't really expect it to be good? I think Figure 4B is better because here the drift doesn't influence the comparison.

The figure mentioned has been removed.

- One of the most exciting things of this preprint is the pan-Arctic sea ice roughness dataset it accompanies. I would suggest making this dataset easily accessible: add a link to the data availability statement and include the dataset as an asset on the The Cryosphere page

A link has been added to the data availability section.

Technical corrections

L4. Add 'Ice' to the full name of ICESat-2

Corrected

L5. Replace 'as well airborne surveys' with 'as well as airborne surveys'.

Corrected

L12. I would clarify that it is the drag coefficient of MYI that is above $2.0 \cdot 10^{-3}$

Clarified

L13. I don't understand this last sentence. Do you mean the drag coefficient of this region of MYI is at least $1.5 \cdot 10^{-3}$ everywhere every year?

Added clarification

L22. 'which needs to be better understood': why? There is more discussion of the importance and relevance later in the text, but it would be good to have at least one sentence here to convince the reader this topic is important before going into the more technical details.

Added following explanation:

"By also mapping 3-month aggregates for the years 2019, 2020 and 2021 for better regional analysis, we found the thick multiyear ice area directly north of the Canadian Archipelago and Greenland to be consistently above $2.0 * 10^{-3}$ with the most of the multiyear ice portion of the Arctic typically registering $\sim 1.5 * 10^{-3}$ in Spring."

L32. 'Smoother in comparison' with what?

Added “rough” in the sentence to make sure it is clearer that "smoother in comparison to multiyear" ice is implied.

L110. Change ‘campaign’ to plural: ‘campaigns’

Corrected

L147. The Rayleigh Criterion introduced here is never explained.

An appropriate introduction has been added

L185. Replace ; with ‘and’.

Corrected

L204. The function to compute the coefficient of resistance might need a reference?

Reference added

L271. Change 03 to 0.3

Corrected

L347. Change ‘a annual’ to ‘an annual’

Corrected

L408. Add figure number

Corrected

L436. Change ‘first-ice’ to ‘first-year ice’ or ‘FYI’

Corrected

References

Castellani, G. , Lüpkes, C. , Hendricks, S. and Gerdes, R. (2014): Variability of Arctic sea-ice topography and its impact on the atmospheric surface drag , *Journal of Geophysical Research: Oceans*, 119 (10), pp. 6743-6762 . doi: 10.1002/2013JC009712

Petty, A. A., M. C. Tsamados, and N. T. Kurtz (2017), Atmospheric form drag coefficients over Arctic sea ice using remotely sensed ice topography data, spring 2009–2015, *J. Geophys. Res. Earth Surf.*, 122, doi:10.1002/2017JF004209