Response to reviewers: "*Google Earth Engine Digitisation Tool (GEEDiT) and Margin change Quantification Tool (MaQiT) – simple tools for the rapid mapping and quantification of changing Earth Surface Margins*", by James M. Lea

I wish to thank both reviewers for their highly constructive comments on the manuscript, suggestions for how GEEDiT and MaQiT could be improved, and their applicability broadened. These have been taken on board and nearly all of the recommendations made have now been implemented within the tools themselves. In light of the reviewers comments, a complimentary tool to GEEDiT is now also provided (*GEEDiT Reviewer*) that allows users to visualise datasets that have previously been generated by GEEDiT for (1) quality control, and (2) to filter the temporal coverage of existing data.

The substantial changes to the text are associated with moving instructions regarding how to use the codes to a supplementary readme file. The specifics of the changes made are outlined in the responses below and in a 'minor modifications' section at the end of this document. Throughout reviewers comments are highlighted in blue, and author responses in black.

Reviewer 1 – William Armstrong

General comments

The author presents newly-developed tools implemented in Google Earth Engine and Matlab to facilitate researchers analyzing margin change from the satellite record. The author then undertakes a proof-of-concept study on an Iceland outlet glacier to document differences in terminus change measurements as observed by different satellites and quantified by different approaches. C1 The general motivation for this research (accelerating the pace of discovery in earth science) is strong and the tool will certainly be beneficial to other researchers. As a community, we should encourage and acknowledge work like this that produces a tool to facilitate the entire field's progress. The paper is well-written and organized. My only major comments relate to a significant amount of text about operation of the tools that seems unnecessarily specific and could be moved to supplemental text, a readme, and/or tutorial that accompanies the tools. I offer several suggestions that would make the software more versatile, but do not consider implementing these changes as critical for manuscript publication. I therefore recommend this manuscript to be accepted after minor revisions addressing the issues I present below in "Specific comments"

Specific comments

- How would this routine work for circular margins (e.g., lakes, city boundaries, cropland extents, etc.)?

Following this suggestion, a new option has been implemented within GEEDiT that allows users to delineate circular margins that will be exported as polygons. Both lines and polygons are able to be digitised within the same session, and on the same image. The MaQiT shapefile conversion tool has also been modified to account for this, now creating separate shapefiles of polygon and polyline features from individual/merged GeoJSON outputs. When combined with the option to append notes to individual margins this will allow users to map many different types of features from individual images, with metadata retained for subsequent analysis outside of GEEDiT in traditional GIS platforms. Changes to the text have been made to reflect this in the now supplementary readme file (steps 7 and 9 of GEEDiT section)

- Should the instructions beginning on L96 be a supplement instead of main text? These seem very specific and like a step-by-step walkthrough that doesn't necessarily belong in the main text. This kind of reads more like a user manual than material for a science paper. I recognize this is all important information for using the software, but it seems like it could be included in a readme file or an online tutorial

All information regarding how to use the GEEDiT and MaQiT tools have now been placed into a supplementary document. Access to tool links/downloads will be available via a website to allow updates in the codes to be reported, legacy versions to be accessed, and FAQs from users to be addressed.

L110 – Why do you recommend geoJSON as output format? Portability across platforms and programs? You later address this (L209-212), but the reader may wonder here

It has been clarified at the first mention of GeoJSON files why this is the preferred output format (L90). As WA highlights, in the original version of the manuscript it mentions that the reason GeoJSON is preferred is that Google Earth Engine (hereafter GEE) currently does not support export of shapefiles. Users have the option (but are discouraged) to output data as kml or kmz files for visualisation in Google Earth. Exporting data in these formats may present problems related to preservation of metadata if they attempt to subsequently convert to shapefiles using 'out of the box' kml conversion tools in ArcGIS and QGIS.

L120-121 – The limitation to one platform when using "custom" composite images seems like a big limitation. For example, I like to visualize Landsat 8 imagery in a R,G,B = [b7,b5,b3] = [SWIR, NIR, green] composite. Would it be possible to specify a wavelength or band name (e.g., SWIR) and have GEEDiT look up the appropriate C2 band number for that satellite? Could this allow uniform use of composites across platforms? I am aware that the exact wavelengths will vary across platforms, but it is definitely better than comparing a R,G,B = [b7,b5,b3] = [SWIR, NIR, red] for Landsat 5 with the same band numbers for Landsat 8 (where b3 = green)

I agree that this is not ideal, though given that different satellites included in GEEDiT have differing band numbers that relate to different wavelengths there is currently no practical way for this to be consistently implemented. It is not necessarily a large limitation given the rapidity with which the tool allows imagery to be visualised, and users do have the option to specifically select satellites that they wish to analyse the data for. Similarly, the names of the individual bands (e.g. SWIR, NIR, red, green etc.) are not included directly in image metadata making outlining of these options in anything other than an ad hoc approach (which is desirable to avoid) problematic.

Section 2.1 – Throughout this section, it seems like references should be made to Figure 1.

This section has now been moved to a supplementary file. Each section is now associated with figure panels.

L134 – Is it possible to jump to a certain image? Or do you have to "continue to next" several times if you want to pick up halfway through the stack?

Changes have been made to the GEEDiT code to allow users to skip between image numbers. Error catching conditions have been also included to prevent the code from crashing in case a user makes a typo (e.g. includes a letter or number beyond the maximum number of images) when selecting the image to skip to. This helps limit potential for user data loss during digitisation.

L139-140 – Can you script a key stroke (e.g., ctrl+z) to undo a mistakenly drawn vertex? This would be nice for minimizing clicks and mouse motion.

To my current knowledge, it is not possible to implement keystroke commands within GEE. If this functionality becomes available (and/or if I find out how to do it!) then this will be built into new versions of GEEDiT.

L141 – What is the structure of the geoJSON file? How are multiple margins stored within this file? Is each margin stored as a top-level dictionary (in Python terms, I'm not sure what this is actually called in JSON – the things with key-value pairs), with each date as a sub-dictionary, which then contains

the lat/lon's of the margin vertices?

The GeoJSON files exported by GEEDiT according the following structure with four fields:
Ogrinfo 1 – shows that the file structure is made up of one layer named ', containing the geometry type (e.g line string, polygon). Where there are multiple layers within the file structure you would see for example:
1: 'filename' (Line String)
2: 'filename' (Polygon)
3: 'filename' (….)
where 'ogrinfo 2/3/4' – show the full detail of each layer as follows:
'*ogrinfo 2*' starts by giving the defining details (e.g. number of individual features, maximum rectangular extent, projection) and then lists the field names created.
'*ogrinfo 3*' is the detail retained for each individual feature (e.g. the unique image identifier in the layer, followed by the notes for each field, and finally the co-ordinates of each node in the line string.
'*ogrinfo 4*' as for '*ogrinfo 3*' but containing margin unclear information

L144-145 – This seems like another significant limitation with this tool. Could you include a field for user-specified margin names that could be used to organize margins and allow multiple margins in one image to be digitized? This seems like it would slow the pace of change analysis if each margin needed its own file.

In order to quantify margin change (for example, for a tidewater glacier) each glacier requires its own centreline (the ability to digitise this is now included within both GEEDiT and GEEDiT Reviewer). Consequently a glacier by glacier approach to quantification makes sense so as to avoid MaQiT accidentally including margins that are unrelated to the glacier in question. Digitisation of one margin per image for this purpose also makes sense in terms of speed and consistency, given that digitising multiple margins would require panning around an image. If a user wishes to digitise multiple margins in a given image, the names relating to individual margins can be appended to the metadata as a note and the resulting margins subsequently filtered within a GIS platform for use within MaQiT.

L170 – This is somewhat intuitive, but are those dates the first and last images used for margin delineation? This should be specified.

This is now specified clearly in the readme supporting information document.

L219-220 – Have these tools been used yet to document changes in non-glacier systems or is this still on the horizon? This is somewhat unclear and you suggest several times that this tool is exportable to other systems, but I wonder if there may be issues specific to other systems that could hinder this tool's versatility?

The tools have not yet been used to quantify margin change in non-glacier systems, though there is significant potential for this. It is highly likely that there will be system-specific issues that will arise, though it is intended that the tool will be updated subsequently to account for these if/when common issues occur. Subsequent versions of the codes will be made available via the website that has been produced and go live upon publication of the manuscript.

Section 2.1 – if you have existing margin outlines, can these be visualized within your current workspace? In Step 9 you discuss merging, but it is not clear to me if you could import existing margin polylines into your current session.

In response to this comment I have built a new tool *GEEDiT Reviewer* (complimentary to GEEDiT) that will allow users to import, visualise, review and filter existing datasets for their particular data

quality and data coverage needs. A full explanation of this is now included in the readme supplementary information.

L249-251 – Cautionary notes on direction to digitize shapefile seems like readme material
L296-306 – Again, caveats about how long centerline should extent up/downstream from terminus seem like more readme material than journal paper material.
This information has been moved to the readme file.

Section 3.3.4 – It is not clear to me what the advantage of the multi-centerline method is over the variable box method. You show later these are useful for plotting 2D terminus position data, but it is not clear here. Also, it is not clear to me why you are talking about filtering results based upon times between images in this section. Is this feature only available to the data processed in the multi-centreline method?
The multi-centreline method provides an advantage over the variable box method in that it allows users to evaluate margin shape change through time, potentially highlight which parts of the margin are most dynamic and how this variability evolves through time. Filtering of the time series is currently only available within the multi-centreline method since this can significantly impact on the clarity of how the results are visualised relative to the other methods. Results from other methods can also be filtered for visualisation within the spreadsheets of results that MaQiT generates.

L345-354 – Aren't these data also shown in Figure 7? Why not refer to it instead of a supplemental figure?
Reference to this figure is now included in the text.

L400-405 – Is it possible to apply a correction to bring the Sentinel 1 data into agreement with terminus positions observed by the other satellites? Is there a way to predict what this offset will be and correct for it?
Unfortunately it is not possible to predict within GEE what the offset will be, since this would require knowledge of the contemporary topography. It is possible to upload more up to date DEMs into GEE where it may be possible to correct the S1 imagery, though this would likely require a separate bespoke tool and given the currently slow upload times to GEE would be time consuming to process an individual image.

L455 – Are you saying Matlab requires an extension that doesn't cost more to license? Because users would need to have a general Matlab license that costs money, correct? If so, I would clarify this point – the approach is not entirely based upon freeware.
Users do not require a general Matlab license to use MaQiT. Users only require *Matlab Runtime* to run MaQiT, and this is free to download. This has been clarified in the text (L155-160).

Figure 7 – Could you label the sub-panels in b with what the plots show? This would make the figure much clearer to readers.
These panels are now labelled.

Technical corrections
L199 – Do you mean Table 1? Table 2 is just band numbers and associated wavelengths.
This has been changed to refer to Table 1.

L209 – sentence ends abruptly. Meat to read "converted to shapefile format using MaQiT"?
Sentence has now been re-written (L140)

L385 – This is redundant with L379-381. One of these should be cut.
L379-81 has been cut

L488 – 2017a » 2017 (there is no Carr et al. 2017b) Motyka et al. 2017 is not in reference list.
Motyka et al 2017 has been added to the reference list, and mention of Carr et al., 2017b has been removed.

Reviewer 2 – Mauri Pelto

I applaud the author for taking the time to share effective practices for the combined use of the Google Earth Engine Digitization Tool and the Margin change Quantification Tool. A substantial portion of the paper is devoted to both screen shots and description of the approach. This detailed description, along with Figure 1, does not provide a usable sequence of steps a researcher can follow. Though I have some experience with Google Earth Engine, I could not use the sequence of steps here to derive a useful outcome. I would recommend as a supplement that a screen capture video be used to replace Figure 1 (NASA Earthdata example: https://www.youtube.com/watch?v=9ZoqZTmTjmE). I would also suggest that the basic script that is used to generate results for the provided example of BreiÃˇramerkurjökull be shared for one of the techniques. This will ensure the author's approach can be readily followed and adapted to other research studies.

I wish to thank MP for these comments, and I have now produced YouTube videos to help explain the functionality of GEEDiT and GEEDiT Reviewer (**https://www.youtube.com/channel/UCboaSHUmNaY7eAeScS0B2_Q**). Regarding the usability of the code it appears that this comment has arisen from an oversight via Copernicus where MP was not initially sent links to the codes that would allow access (I am however happy to be corrected on this and will readdress comments if that is not the case).

Specific Suggestions

Abstract: make reference to BreiÃˇramerkurjökull as the case study used to demonstrate the techniques.

The abstract has been now re-written and includes mention of the Breiðamerkurjökull case study.

28: . . .of glacier margin/boundary changes. . .

This section has now been re-written

96: In line 96 shared code is referred to, what shared code?

On publication the codes will be shared for general use by the community. Updated codes that follow this review have been sent to the reviewers.

219: "they" must refer to the methods being transferrable. Unclear if there is a set of developed methods, and one would choose from this menu depending on the research question.

This section has been written to ensure that reference to the methods implemented are mentioned at the appropriate point.

231: Figure 2 not of value here, move to supplement or simply into screen capture video.
360-368: Recommend this be in a supplement.

These sections have been moved to a supplementary readme document.

381: What level of detail was used in this case?

The level of digitisation detail are given in the final column of Table **3**.

402: how much elevation change is significant?
This will be dependent on the position of the satellite and the angle between the land surface and the satellite at the time of image acquisition. It is difficult to try and put a precise number to what constitutes "significant" as it will also be dependent on the research question that a user wishes to address, and will also be variable across an individual image. This has now been clarified in the text (**L119 to L126**)

420: The methods are more representative as they also average changes across the front.
This point is now included in the text (**L196-197**)

434: For tidewater glaciers does this tool have potential for even shorter time periods that may help quantify velocity, calving and frontal melt rates, such as in Moyer et al (2017)?.
It does, though this would require uploading imagery to GEE and (potentially substantial) modification of the GEEDiT code to read the imagery metadata. While the tool does not currently possess this functionality it is something that I would like to explore if/when the functionality of GEE is expanded to allow the upload of large datasets of imagery in a practicable way.

442: MaQIT is highly dependent on coding skill, yet for those without coding skill it takes time to derive a single margin change value. For this group of users, myself included, how usable is MaQIT?
Both GEEDiT and MaQiT require no coding skill at all to use. However, if a user wishes to undertake more complex analysis of large repository datasets (e.g. 10s to 1000s of glaciers) MaQiT *can* be applied programmatically to substantially accelerate analysis. For an earlier version of MaQiT I applied this approach to the analysis of data from the Murray et al. (2015) dataset (Lea, 2017, *AGU poster presentation*), and it was able to complete analysis for each margin of each glacier, using each method in the following times:
Centreline method – 41.6 seconds
Curvilinear box method – 79.7 seconds
Variable box method – 892.8 seconds [note performance for this method has been improved to be comparable to the curvilinear method since this analysis was initially undertaken]

465: Is it possible to incorporate UAV photogrammetry or LIDAR data into MaQIT as a compliment to satellite imagery, that may have more detailed boundary mapping such as the type of data used by Fischer et al (2015) and Ryan et al, (2015). No detail need be provided just a basic explanation of whether it is possible in these two tools.
While it is technically possible to upload such imagery for analysis within GEEDiT, the upload speeds to the GEE servers are currently limited, meaning that getting the data into GEE would likely be very time consuming. However, analysis of margin migration in MaQiT is possible for any vector data as long as the shapefile contains a 'Date' field in addition to the 'X', 'Y' and 'Geometry' fields that are normally associated with vector data. This potentially allows the re-analysis of existing datasets that have not be produced in GEEDiT (e.g. Murray et al., 2015).

References

Lea, JM (2017) Simple tool for the rapid, automated quantification of glacier advance/retreat observations using multiple methods, presented at 2017 Fall Meeting, AGU, New Orleans, LA, 11-15 Dec. https://agu.confex.com/agu/fm17/meetingapp.cgi/Paper/269637

Murray, T., Scharrer, K., Selmes, N., Booth, A.D., James, T.D., Bevan, S.L., Bradley, J., Cook, S., Llana, L.C., Drocourt, Y. and Dyke, L., 2015. Extensive retreat of Greenland tidewater glaciers, 2000–2010. *Arctic, Antarctic, and Alpine research*, *47*(3), pp.427-447.

Minor modifications

L50 – Bunce et al reference added

L56 – ‘scripting’ changed to ‘coding’

L58 – ‘This can severely limit the scale of analysis that it is practical for researchers to undertake.’ Added

L65 – ‘boundaries’ changed to ‘margins’ to ensure consistency of terminology through the text.

L67-70 – minor changes to phrasing to improve clarity

L75-76 – mention of GEEDiT Reviewer now included

L84-86 – renumbering of sections and mention of GEEDit Reviewer included

L94-102 – brief explanation of GEEDiT Reviewer inserted, and rephrasing of sentence on browser compatibility

L105-108 – New sentence to reflect section being moved to a supplementary readme and availability of a YouTube video.

L119-129 – more detailed explanation of potential geolocation issues with sentinel 1, and changing of table numbers

L134-142 – changes reflect section being moved to supplementary readme information and minor sentence clarifications

L159-164– freeware aspect of MaQiT emphasised (reflecting reviewer comments)

L167-168 – changes made to reflect that the multi-centreline method in MaQiT has now been modified to output csv files

L171-4, L180, L182 – reflects info being moved to supplementary and renumbering of sections/figures

L191-194 - reflects info being moved to supplementary and renumbering of sections/figures

L207 – clarification of sentence to remove >> symbol

L211 – reflects availability of GEEDiT Reviewer

L218-223, L237-240 – renumbering of sections/figures

L243-247 – clarification and change of text to reflect improved functionality of MaQiT

L254-255 – renumbering of sections/figures

L257-258 – minor sentence clarification

L263 – renumbering of figure

L274-276 – inserted to reflect improved functionality of MaQiT

L280-281, L286-289 – renumbering of table

L290-219 – inclusion of example shapefile data as supplementary

L293-295 – inserted to reflect availability of GEEDiT Reviewer

L301, L304, L311 – renumbering of section/figure

L316 – sentence clarification

L316-319 – changed in response to reviewer comment

L329, L346, 348-350, 353 – renumbering of figure/table

L363, 365-368, 371 – changes made to strengthen summary

L390-392 – where to access tools now appended.