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 BreiǍˇramerkurjökull 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 BreiǍˇramerkurjökull 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.

1   Google Earth Engine Digitisation Tool (GEEDiT), and Margin change Quantification Tool (MaQiT) –

2   simple tools for the rapid mapping and quantification of changing Earth surface margins

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11   **Abstract**

12   The visualisation and exploration of satellite imagery archives coupled with the quantification of

13   margin/boundary changes are frequently used within earth surface sciences as key indicators of the

14   environmental processes and drivers acting within a system. However, the large scale rapid

15   visualisation and analysis of this imagery is often impractical due to factors such as computer

16   processing power, software availability, internet connection speed, and user expertise in remote

17   sensing. Here are described two separate tools that together can be used to process and visualise

18   the full Landsat 4-8 and Sentinel 1-2 satellite records in seconds, enabling efficient mapping (through

19   manual digitisation) and automated quantification of margin changes. These tools are highly

20   accessible for users from a range of remote sensing expertise, with minimal computational, licensing

21   and knowledge-based barriers to access. The Google Earth Engine Digitisation Tool (GEEDiT) allows

22   users to define a point anywhere on the planet and access all Landsat 4-8/Sentinel 1-2 imagery at

23   that location, filtered for user defined time frames, maximum acceptable cloud cover extent, and

24   options of predefined or custom image band combinations via a simple Graphical User Interface

25   (GUI). GEEDiT also allows georeferenced vectors to be easily and rapidly mapped from each image

26   with image metadata and user notes automatically appended to each vector. This data can then be

27   exported to a user's Google Drive for subsequent analysis. The Margin change Quantification Tool

28   (MaQiT) is complimentary to GEEDiT, allowing the rapid quantification of these margin changes

29   utilising two well-established methods that have previously been used to measure glacier margin

30   change and two new methods via a similarly simple GUI. MaQiT is also suitable for the (re-)analysis

31   of existing datasets not generated by GEEDiT. Although MaQiT has been developed with the aim of

32   quantifying tidewater glacier terminus change, the tool can be applied to other margin changes

33   within earth surface science where margin/boundary change through time is of interest (e.g. coastal

34   and vegetation extent change). It is hoped that these tools will allow a wide range of researchers and

37

1. Introduction

39 Satellite data provide an invaluable record of spatial and temporal change on the Earth's surface.

40 However, the volume and scale of data available for analysis (coupled with computational, software

41 licensing, data storage, internet connectivity, and knowledge based barriers to entry) mean that

42 users may require a significant amount of time to go from downloading an image to finalising its

43 analysis. This can be exemplified in the study of tidewater glacier calving margins where a large

44 volume of remote sensing imagery exists, though spatially large scale studies are often required to

45 focus on a number of census timeframes (e.g. Cook et al., 2005; Moon and Joughin, 2008; Carr et al.,

46 2017; Bunce et al., 2018), while detailed studies often focus on a relatively small number of sites

47 (e.g. Bevan et al., 2012; Motyka et al., 2017).

48 The availability of satellite imagery via application programming interfaces (APIs) and

49 increasingly via platforms such as Google Earth Engine (Gorelick et al., 2017), Sentinel Hub's Earth

50 Observation Explorer (Sinergise, 2018), and Planet (Planet Labs Inc., 2018) mean that these data are

51 becoming increasingly accessible. However, the ability of users to access these data at such a large

52 scale is currently limited by the need for either knowledge of ~~scripting~~ coding and/or downloading,

53 storage and processing of substantial volumes of data. Even where users are comfortable with such

54 requirements, images may still prove time consuming to effectively visualise and finally ~~, and finally~~

55 analyse, thus taking further time. This can severely limit the scale of analysis that it is practical for

56 researchers to undertake.

57 The identification of temporally evolving margins digitised from this imagery is frequently

58 used across earth surface sciences to provide key temporal and/or spatial insight into the system of

59 interest (e.g. Kuenzer et al., 2014; Roelfsema et al., 2013; Fitzpatrick et al., 2014; Lynch et al., 2016).

60 Although different geoscientific problems will have different temporal and spatial data coverage

61 requirements, a user's ability to map ~~these boundarie~~margins accurately will depend on the

62 effective visualisation of imagery, while generating temporally detailed datasets is dependent on

63 achieving this efficiently and consistently for a large number of images. However, even if a

64 substantial volume of ~~observational~~ margin change data can be generated, a subsequent issue is the

65 ~~ability to~~ rapid~~ly~~ and accurate~~ly~~ quantif~~y~~ication of these changes ~~in the spatial data that are~~

66 ~~produced~~.

67 This study presents ~~two~~ three simple-to-use tools that when used together ~~aims to~~

68 significantly improve~~s~~ the efficiency of visualising and exploring satellite imagery, while also allowing

69 the rapid mapping and quantification margin changes directly from them. The first is the Google

70 Earth Engine Digitisation Tool (GEEDiT), which allows the rapid visualisation, mapping and export of

71 digitised margins without the need to download imagery to the user's computer. It is also possible to

72 use GEEDiT to map multiple features directly from an individual image, and append notes to

73 individual margins and images. The second is the GEEDiT Reviewer tool that allows data previously

74 generated by GEEDiT to be quality controlled and filtered. The second third is the Margin change

75 Quantification Tool (MaQiT) that allows the rapid quantification of these digitised margin changes,

76 utilising two existing methods and two new methods that have commonly been used in the

77 quantification of tidewater glacier margin change (Lea et al., 2014). Although initially developed for

78 glaciological applications, each of these quantification methods are likely to have applications in the

79 quantification of margin change in other areas of earth surface sciences such as coastal change, lake

80 level evolution, and vegetation and urban extent change, amongst others.

81

82 **2.1 Google Earth Engine Digitisation Tool (GEEDiT), and GEEDiT Reviewer GEEDiT**

83 GEEDiT is and GEEDiT Reviewer are written in JavaScript within Google Earth Engine's (GEE) API

84 (Gorelick et al., 2017). The toolGEEDiT is designed to allow satellite imagery from Landsat 4-8 and

85 Sentinel 1-2 to be visualised rapidly within a standard web-browser, also allowing the digitisation

86 and export of polyline and/or polygon vector data in GeoJSON (Georeferenced JavaScript Object

87 Notation format), or KML/KMZ (Keyhole Markup Language/Keyhole Markup Zipped format

88 compatible with Google Earth) formats. GEE does not currently support the export of data in

89 shapefile format, though a tool is included within MaQiT to both merge and convert GeoJSON files to

90 a single shapefile (see section 3). This means that data digitised during multiple GEEDiT sessions can

91 be merged and/or converted for use either in MaQiT or a traditional Geographic Information System

92 (GIS) platform.

93 The GEEDiT Reviewer Tool is separate to GEEDiT, allowing users to review existing datasets

94 generated by GEEDiT. It can be used to both quality control their own and others data against the

95 original imagery used for margin digitisation, and filter datasets based on the temporal requirements

96 for their research question. To use GEEDiT Reviewer the data generated needs to be uploaded to

97 GEE as an 'asset' (see Supplementary readme file). Users also have the option to make assets

98 publically accessible via the privacy options associated with each file within GEE.

99 The tools has have been developed and tested usingin Google Chrome, though should also

100 other widely used browsers such as Internet Explorer, Mozilla Firefox and Safari.

101 Access to GEE for research, education and non-profit use is free of charge, though potential

102 users are required to register for access (https://signup.earthengine.google.com/). The only other

103 requirement is access to Google Drive (included as part of signing up to a Gmail email address),

104 which is also free. The tool can be run and used by following the steps ~~below~~ outlined in the

105 supplementary readme file appended to this article (~~Figure~~Supplementary 1).~~.~~ Video guides that

106 explore the functionality of GEEDiT and GEEDiT Reviewer have also been produced

107 **(https://www.youtube.com/channel/UCboaSHUmNaY7eAeScS0B2_Q)**.

108 ~~1. Click on a link that provides access to the shared code, or copy and paste the shared code~~

109 ~~into the central code editor panel. This should be saved to the scripts folder in the left panel~~

110 ~~using the 'Save' button above the code editor panel. This step only needs to be done the~~

111 ~~first time GEEDiT is used.~~

2.2 Image visualisation

113 GEEDiT can visualise imagery from optical imaging platforms as either natural (true colour), false

114 colour or custom band combinations. Sentinel-1 synthetic aperture radar (SAR) data can also be

115 visualised as grayscale images (Table 1). SAR data exist in either single or dual band polarisation

116 bands, though not every band is collected for every scene. To maximise the temporal and spatial

117 coverage for the tool, GEEDiT will visualise whichever single polarisation band is available (either

118 horizontal transmit/horizontal receive [HH], or vertical transmit/vertical receive [VV]) for both

119 ascending and descending orbits for a particular time and location. The polarisation and type of orbit

120 (ascending/descending) of each SAR image is displayed in the top right panel alongside the satellite

121 name, date and image number/total number of images available.

122 Note that ~~a feature's location for~~the location accuracy of a feature identified in Sentinel 1

123 imagery can be significantly degraded in areas that have undergone several meters of ~~significant~~

124 topographic change ~~(~~relative to the digital elevation model used for terrain correction (SRTM 30 for

125 areas <60° latitude, otherwise ASTER DEM). The scale of geolocation error will also variable

126 depending on~~) can be significantly impacted by~~ whether the image was acquired during an ascending

127 or descending orbit (see Section 4). Care should therefore be taken in using Sentinel 1 data in such

128 scenarios (e.g. where significant surface thinning of a glacier/ice sheet has occurred). Qualitative

129 checks for this can be achieved by comparison of Sentinel 1 data with optical satellite data acquired

130 at a similar time.

131 A summary of the default parameters used to visualise both the optical and SAR imagery is given

132 in Table ~~2~~1. Further information regarding each satellite image collection can be obtained by

133 searching for it in the ~~GEE~~ search bar at the top of the GEE ~~screen~~interface.

134

2.3 Output of margin/boundary data

136 Vector data are output by GEEDiT in decimal degrees format so as to be easily read by GIS software
137 and/or subsequently converted to different spatial projections. Key metadata that link each margin
138 to information about the image it has been digitised from are appended to each digitised line (Table
139 3see Supplementary readme). This includes each image's unique path identifier, meaning that
140 results generated by GEEDiT are directly traceable back to its original image. This can be achieved
141 using GEEDiT Reviewer, where existing datasets can be quality controlled and filtered. If it is
142 anticipated that the data digitised in GEEDiT will be analysed subsequently in a different GIS
143 environment, it is recommended that data are output as GeoJSON files (this is the default option),
144 since these can be merged/converted to shapefile format using MaQiT. Note that kml/kmz files do
145 not always allow metadata to be retained when they are imported into standard GIS software
146 packages such as ArcGIS and QGIS using 'out of the box' tools. Exporting data from GEEDiT/GEEDiT
147 Reviewer in kml/kmz formats therefore may make subsequent analysis problematic.
148
149 **3. Margin change Quantification Tool – MaQiT**
150 MaQiT has been produced to rapidly quantify marginal change for use in subsequent analysis
151 (outputs provided as Excel/OpenOffice compatible csv spreadsheets and as initial plots generated by
152 the tool), and also convert and merge single/multiple GeoJSON/shapefile files into a single shapefile.
153 Although MaQiT uses methods that have been developed for the quantification of tidewater glacier
154 margin change (e.g. Lea et al., 2014), they will be transferable to tracking margin changes in other
155 environments. Each quantification method has its own benefits and pitfalls, meaning that
156 appropriate method selection should be based primarily on the research question being asked.
157
158 **3.1 Installing/running MaQiT**
159 Although MaQiT has been written in Matlab®, its code has been compiled into a standalone
160 application (installers available for Windows and Mac) meaning that it can be installed and run by
161 users without a Matlab® license and free of any charges. The only pre-requisite for this is to
162 download the free software, Matlab® Runtime, though this should be prompted for automatically
163 once the first time the installer is opened. Users do not require a general Matlab® license to run
164 MaQiT.
165 For users with aIf users do have a general Matlab® license, MaQiT can also be run by copying
166 all the scripts to a single directory and running the MaQiT.m script. This will open MaQiT's graphical
167 user interface (GUI), allowing it to be used in a similar manner to the standalone application (Figure
168 2see Supplementary 1). The methods used by MaQiT can also be run programmatically as Matlab®
169 functions. Where multiple datasets from large numbers of sites exist, this provides the potential for

170 large scale rapid analysis. The results generated after the analysis of each location can be accessed

171 via a data structure named *Results* in the Matlab® workspace, or be written to a csv spreadsheet

172 ~~similar to that~~identical to that produced by the ~~GUI~~standalone application. MaQiT also makes use of

173 publically submitted functions obtained from the Mathworks File Exchange (Palacios, 2006; D'Errico,

174 2012a; 2012b; 2013; Dugge, 2015). Copies of these functions are compiled into the standalone

175 version of MaQiT, and are included in the ~~folder that will be appended to this publication~~code files

176 appended to this publication. Instructions regarding the required inputs for MaQiT and how to use

177 the tool are included in the Supplementary readme file.

178 ~~3.2 MaQiT inputs~~

179 **3.~~3~~2 Methods of quantifying margin/boundary changes in MaQiT**

180 Four different methods of quantifying margin changes are included in MaQiT, two of which are

181 established approaches that are used in the tracking of tidewater glacier terminus change (e.g. Cook

182 et al., 2005; Lea et al., 2014), while two are new methods designed for the same purpose, though

183 with potential wider applications.

184

185 **3.~~3~~2.1 Centreline method**

186 This is the simplest approach to tracking margin~~al~~ change, measuring the linear distance along a

187 centreline between two boundaries (e.g. Cook et al., 2005; VanLooy and Forster, 2008; ~~Figure~~

188 ~~3~~Figure 1**a**). This approach provides a one-dimensional measure of change that does not account for

189 the behaviour of the entire margin; only the point of intersection between the centreline and the

190 margin (Lea et al., 2014). While this method is simple, the method is best suited to

191 scenarios/research questions where it can be assumed that the margin is uniformly

192 advancing/retreat, or the area of the margin that is of interest is narrow (i.e. a few pixels across). If

193 either of these assumptions are not valid, or a higher level of detail is required, then an alternative

194 method of tracking change would be more suitable.

195

196 **3.~~3~~2.2 Curvilinear Box Method**

197 This method provides a linear measure of margin advance/retreat by defining a box of fixed width

198 spanning the centreline that intersects with the margin, before dividing the area of this box by its

199 width (Lea et al., 2014; ~~Figure 3~~Figure 1**b**). The user is required to define the box width. The result

200 provides the one dimensional distance from the start of a centreline to the mean location of the part

201 of the margin that intersects with the box. This method provides a more representative width-

202 averaged value of marginal change compared to the centreline method. The method is an extension

203 of the box method used by Moon and Joughin (2008) though has the advantage that the defined box

204 does not need to be rectilinear (i.e. it allows the box to follow potentially non-linear topographic

205 features such as fjords/valleys).

206 If the defined box width is wider than the margin itself/one or more edges of the box do not

207 intersect with the margin, the box will be 'closed' by lines that take the shortest distance from the

208 start/end points of the margin to the box edge. If this scenario is a possibility (i.e. if the box width is

209 greater than that of the margin width), it is important that the centreline used extends upstream

210 and downstream of the margins for a greater distance than the shortest path between the

211 centreline and the start/end points of any of the digitised margins (i.e. the centreline should extend

212 up/downstream for >>half ofmore than thetwice the width of the longest margin). Failure to do this

213 may result in errors in the geometry of the boxes used to obtain measurements. This can be checked

214 visually using the 'Plot output' option in MaQiT, which shows the geometries of each box that is used

215 to quantify margin change. If errors of this nature do occur, it is recommended that the user re-

216 draws the centreline using GEEDiT Reviewer, extending the start/end points of the centreline further

217 up/downstream.

218 Although this method has the potential to account for a higher proportion of the margin

219 than the centreline method, it will not account for the entire margin. It is therefore suitable to apply

220 if the user is interested in obtaining an averaged measure of change for a particular section of the

221 margin.

222

223 **3.32.3 Variable Box Method**

224 This method is similar to the curvilinear box method, though instead of using a fixed box width it

225 uses the full width of the margin (Figure 3Figure 1c). The width of each box is defined as the total

226 distance between the start and end nodes of the margin. This allows a one dimensional distance of

227 change to be determined that includes the full extent of the digitised margin. This has the advantage

228 of accounting for all margin information available, though sSimilar caveats apply to this method as

229 the curvilinear box method.

230 To ensure the accuracy of results given by this method, it is important that the start/end

231 points of each margin are at physically meaningful locations. To ensure the comparability of results

232 this is especially important where it is possible that the margin will have occupied a given location

233 more than once. An example of this would be a tidewater glacier, with physically meaningful

234 start/end points being the two points at which the glacier margin, sea and land meet (i.e. the

235 distance between the start and end points of the margin would give an accurate measurement of

236 glacier width). If only part of the ice front was digitised then the method would give an inaccurate

237 result that may not be comparable to subsequent observations. Where the method is applied using

238 arbitrarily/semi-arbitrarily defined start/end points then the variable box method may over/under

239 predict extent depending on how much of, and what parts of the margin have or have not been

240 digitised.

241

242 **3.~~3~~2.4 Multi-centreline method**

243 This method extends the centreline method to include multiple centrelines that span the width of a

244 margin. This results in many one-dimensional measures of change across the entire margin width,

245 thus allowing the spatial variability of margin advance/retreat to be quantified (~~Figure 3~~Figure 1**d**).

246 MaQiT visualises the distance changes that occur as colour change on an *xy* plot (see Section 4).

247 Where the process of interest may occur over timescales longer than the intervals between

248 observations, it is also possible to define the temporal 'window' over which margin changes will be

249 quantified that will improve data visualisation. For example, if a margin observation exists every 8

250 days, but the research question requires comparison of observations made between every 30 to 40

251 days apart, this can optionally be defined and MaQiT will automatically filter the observations. These

252 results can also be output to csv files as time-distance tables.

253

254 **3.4 Viewing results from MaQiT**

255 The results generated by MaQiT for each method can be visualised as a series of plots that are

256 automatically generated by the tool. Due to the nature of each method, the plots used to visualise

257 the results vary between methods (i.e. the centreline method does not include a plot to check box

258 geometry as it does not require using a box). For the centreline, and curvilinear and variable box

259 methods there are either three or four plots shown (e.g. Supplementary 2; Figures **S1-4**). The first

260 plot shows all the margins to allow the user to check that they have been read in correctly by MaQiT.

261 The second plot is only included for the curvilinear and variable box methods as it allows the user to

262 check that the box geometries have been constructed correctly and whether redrawing of the

263 centreline is necessary. The third plot shows a time series of distance change of the margin. The

264 multi-centreline method provides a different output, showing results as a series of 4 rows of plots

265 that show (1) marginal change including every available observation; (2) marginal change using the

266 defined temporal window (if a temporal window is not defined this plot will be identical to the first

267 plot); (3) absolute distance change between observations from one margin to the next observation;

268 and (4) rate of margin change between observations (e.g. Figure ~~S4~~5**b**). The left column of plots

269 shows changes occurring for the entire margin width, while the right column shows for reference the

270 one dimensional results that would otherwise be generated by the centreline method.

271   It is strongly recommended for all methods that users view results generated by MaQiT as a
272   quality control measure of both the user's data and the successful execution of the analysis.
273   Users with a standalone MaQiT installation are able to output results to a csv file for
274   subsequent analysis. Values output include year, month, date, serial date (i.e. number of days since
275   January 0th 0000 AD), margin position on flowline, margin position relative to most retreated, margin
276   change compared to previous observation, rate of change from previous observation, margin width,
277   and (for box methods only) box widths and box area. Users with a Matlab® license are able to
278   interrogate and subsequently analyse output via the *Results* data structure that is generated and
279   located in the workspace and/or export data to a csv file. ~~Due to the nature of the data generated by~~
280   ~~the multi-centreline method (i.e. xyz data that are problematic to systematically write to a csv file),~~
281   ~~MaQiT standalone installation users are not able to write results from this method~~Note that the
282   multi-centreline method outputs data as three csv files showing margin position, margin change
283   from the previous observation, and rate of margin change from the previous observation.
284

285   **4. Case study – Margin change at Breiðamerkurjökull, Iceland**
286   Breiðamerkurjökull, SE Iceland (64.11° N 16.22° W) is an outlet glacier of the Vatnajökull ice cap that
287   drains into the tidal lagoon, Jökulsárlón (~~Figure 4~~Figure 2). The calving margin of the glacier was
288   digitised at monthly intervals (where possible) for each of Landsat 8, Sentinel 2, and Sentinel 1 (both
289   ascending and descending orbits) for January 2014 to January 2018. This allows a broad
290   intercomparison of any systematic biases that may exist between these platforms in an area that has
291   undergone significant elevation change relative to the DEM used for terrain correction of the
292   imagery (Bjornsson et al., 2001). A total of 587 images were viewed during digitisation, with 133 ice
293   fronts digitised in total. The summary statistics of the digitised margins are given in ~~Table 5~~Table 3.
294   Visualisation and digitisation of the margins were undertaken in four sessions, taking a total time of
295   2 hours, 3 minutes. ~~Note that the level of detail users should aim to digitise margins at will be~~
296   ~~dependent on their research question.~~ An ~~approximate~~ metric for the level of detail obtained for a
297   margin ~~can be obtained~~is given as part of the Results/csv output by dividing the total length of the
298   margin by the number of points digitise it (e.g. ~~Table 5~~Table 3). Shapefiles of the combined Landsat 8
299   and Sentinel 2 records of margin change are included as a supplementary file as example data.
300   Once digitisation of the ice margins was complete, MaQiT was used to convert and merge
301   the GeoJSON files generated by GEEDiT to a single shapefile. The appended supplementary data can
302   also be visualised in GEEDiT Reviewer by copy and pasting the path *users/Jmleaglacio/Breida_L8_S2*
303   *into the tool.*

304   It should be emphasised that the method of margin change quantification that should be
305 used for this type of data is heavily dependent on the research question that the user is seeking to
306 address. The analysis undertaken here is only to provide a demonstration of the methods available
307 in MaQiT.
308

4.1 ~~Results of c~~Case study results

4.1.1 Intercomparison of results from different satellites

311 The curvilinear box method (width = 2000 m) was used to illustrate if any systematic differences
312 exist between margins digitised from different satellites (~~Figure 5~~Figure 3). Results show that while
313 similar patterns and magnitudes of change are given for each satellite, margins digitised from
314 Sentinel 1 imagery show clear under and over-estimation of margin extent (relative to Sentinel 2 and
315 Landsat 8 imagery) for descending and ascending orbits respectively. One to one matches in results
316 are not expected as image acquisitions for the different satellites did not always fall on the same
317 day, while the margin of Breiðamerkurjökull is known to flow rapidly (>5 m d^{-1}; Voytenko et al.,
318 2015), meaning that the margin has the potential to be highly dynamic over short timescales (cf.
319 Benn et al., 2017).
320   Though results from Sentinel 2 and Landsat 8 are broadly comparable, ~~Figure 5~~Figure 3
321 illustrates that for Sentinel 1 imagery there can be significant mismatch in areas where significant
322 elevation change has occurred ~~(~~relative to the DEM used for initial terrain correction~~)~~. In
323 environments where considerable elevation change has not occurred the mismatch should be less,
324 though margins from ascending and descending orbits (automatically appended by GEEDiT to margin
325 metadata) should still be checked for systematic biases. Due to the 'oblique looking' nature of
326 Sentinel 1 image acquisitions (compared to 'vertical looking' for optical satellite imagery), the
327 magnitude of mismatches in areas of elevation change are likely to be variable across an image.
328   The~~se~~ mismatches shown in these results demonstrate that considerable care should be
329 taken in combining observations from Landsat/Sentinel 2 imagery with Sentinel 1 imagery.
330

4.2 Intercomparison of methods for quantifying margin change

332 Observations of margin change at Breiðamerkurjökull obtained from Landsat 8 are used to
333 demonstrate the different methods of margin change quantification included in MaQiT.
334

4.2.1 One-dimensional measures of margin change

336 The centreline, curvilinear box, and variable box methods provide one-dimensional measures of
337 margin change (i.e. how far advanced/retreated a margin is relative to the distance along a

338 centreline). ~~Figure 6~~Figure 4 shows that each of the methods record similar overall patterns of

339 retreat), though at times diverge from each other depending on method/parameter choice. In

340 particular, the centreline method displays a high degree of variability (e.g. 2015-18) as it reflects

341 margin change in an extremely localised area. This is in contrast to the other methods that provide

342 results that are more representative of the margin as a whole. It should also be noted that while

343 each method generally agrees on the sign of margin change (i.e. advance or retreat) this is not

344 always the case. In general, methods that account for larger proportions of the margin (i.e. the

345 variable box and curvilinear box method [width = 2000 m]) are more likely to disagree with methods

346 that account for less of the margin (i.e. centreline and curvilinear box methods [width = 1000 m]).

347 This highlights the importance of the need to carefully select method/parameter choice with respect

348 to the research question that is being addressed.

349

350 **4.2.2 Multi-centreline method**

351 The multi-centreline method provides a two-dimensional representation of margin change,

352 highlighting regions of the margin that are more susceptible to advance/retreat, in addition to the

353 timing and magnitude of this. It also provides a means of visualising two dimensional change as a

354 time series rather than relying on maps of margin change that may otherwise be difficult to interpret

355 in a meaningful way (e.g. ~~Figure 7~~Figure 5a). For the case study observations were obtained at

356 approximately monthly intervals, though the method has been applied so as to highlight changes

357 over seasonal timescales (60 to 120 days). Results show that the centre of Breiðamerkurjökull's ~~the~~

358 margin is consistently the most retreated (~~Figure 7~~Figure 5**bi, ii**), and that there is little seasonal

359 consistency across the entire margin as to whether it advances/retreats, and at what rate (~~Figure~~

360 ~~7~~Figure 5**biii, iv**).

361

362 **4.3 MaQiT performance**

363 ~~Table 6~~Table 4 shows performance metrics of each method from the standalone version MaQiT. The

364 speed at which users would be able to complete comparable analysis without MaQiT is highly

365 dependent on an individual's existing GIS and/or coding competence. However, for those without

366 coding skills and entry level GIS training it may take a user several minutes to obtain a single value

367 that quantifies the position of one margin. MaQiT therefore provides a potentially major

368 improvement in the efficiency with which users can analyse their data. Results produced by MaQiT

369 are also guaranteed to be methodologically consistent and replicable. This makes MaQiT highly

370 suited to the (re-)analysis of repository datasets of margin change.

371

5. Summary

372

373 Together GEEDiT, GEEDiT Reviewer and MaQiT provide simple tools for rapid satellite image

374 visualisation, exploration and initial assessment (via notes appended to metadata), digitisation of

375 margins from imagery, review and filtering of existing datasets, and quantification of their changes

376 via multiple methods. They have the potential to dramatically improve the efficiency with which

377 these analyses can be undertaken, and the accessibility of these data to a wide range of researchers

378 both with and without knowledge of coding. The lack of the requirement to download, process and

379 store imagery on a user's computer, coupled with simple GUIs and no fee-paying licensing

380 requirements also improves the accessibility to these data through the removal of traditional

381 barriers to entry associated with remote sensing and GIS. The tools are therefore suitable for users

382 ranging from high school students to academics.

383 GEEDiT provides flexibility for the way in which imagery is visualised (i.e. true colour, false

384 colour and custom band combinations), while MaQiT gives users the flexibility to rapidly quantify

385 and output measures of margin change. The case study of the calving glacier Breiðamerkurjökull

386 highlights the potential for mismatch between imagery collected via ascending/descending orbits of

387 Sentinel 1 relative to optical imagery satellites such as Landsat and Sentinel 2. Consequently users

388 should take care in combining margin records from Sentinel 1 those of Landsat/Sentinel 2, especially

389 where significant elevation change may have occurred relative to the DEM that is used for terrain

390 correction of imagery in Google Earth Engine.

391 Intercomparison of the two existing and two new methods of margin change quantification

392 available in MaQiT illustrate the potential for obtaining potentially substantial differences in margin

393 change values when analysing the same data. This highlights the importance of users selecting the

394 most suitable margin quantification method for their particular research problem. The new

395 multicentreline method also provides a means of visualising margin change as a time series

396 potentially in a clearer manner than it is possible to cartographically. While these techniques have

397 predominantly been developed for the quantification of tidewater glacier margin change, they could

398 also be useful for researchers investigating coastal change, dune migration and vegetation extent

399 changes amongst other areas of earth surface science.

400

6. Availability of tools

401

402 Links to GEEDiT and GEEDiT Reviewer, and downloads for MaQiT can be found at the following

403 website: www.liverpoolGEE.wordpress.org

404

405 **7. Acknowledgements**

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409   acknowledged are Jack Boitier, John Cordall, Phoebe Cox, Elaine Crimmins, Ajjay Dhesi and Thomas
410   Hutton who extensively tested an earlier version of MaQiT as part of their undergraduate
411   dissertations.

412

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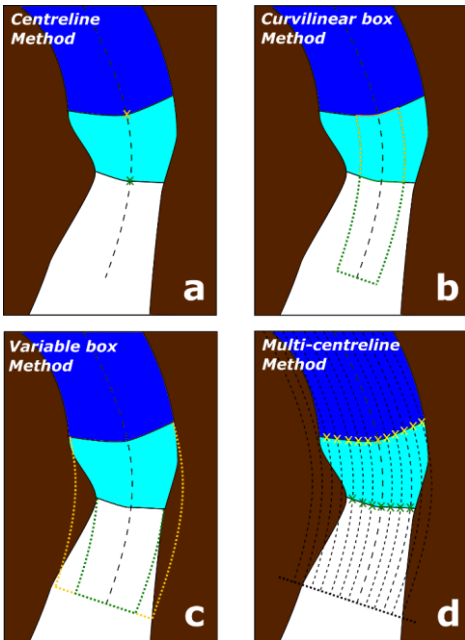
497 **Figures**

499 ~~Figure 1 – Steps for running GEEDiT.~~

500

501 **Figure ~~3~~1**. Methods of margin change quantification that can be applied in MaQiT. Example shows
502 retreat of a tidewater glacier with ice (white), the former glacier extent (light blue) and open water
503 (dark blue). (a) Centreline method takes the linear distance from the start of the centreline to the
504 first point of intersection between the centreline and the margin; (b) Curvilinear box method
505 generates a box of a user defined fixed width that is closed at its downstream edge by the digitised
506 margin, with a one-dimensional measure of the distance from the start of the centreline obtained by
507 dividing the box area by the box width (note that yellow box margin also extends to the start of the
508 centreline); (c) Variable box method operates on the same principle as the curvilinear box method,
509 though box width is automatically defined by MaQiT as the total distance from the end nodes to the
510 centreline; (d) Multi-centreline method operates on the same principle as the Centreline method,
511 though multiple, regularly spaced lines are used to build a two dimensional representation of margin
512 change, with the output using a colour scale to visualise distance.

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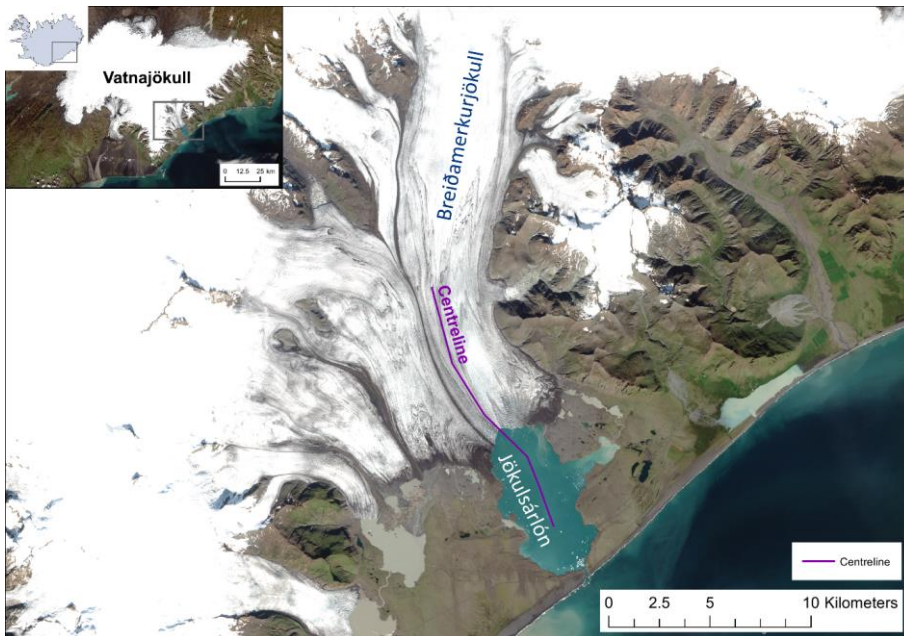
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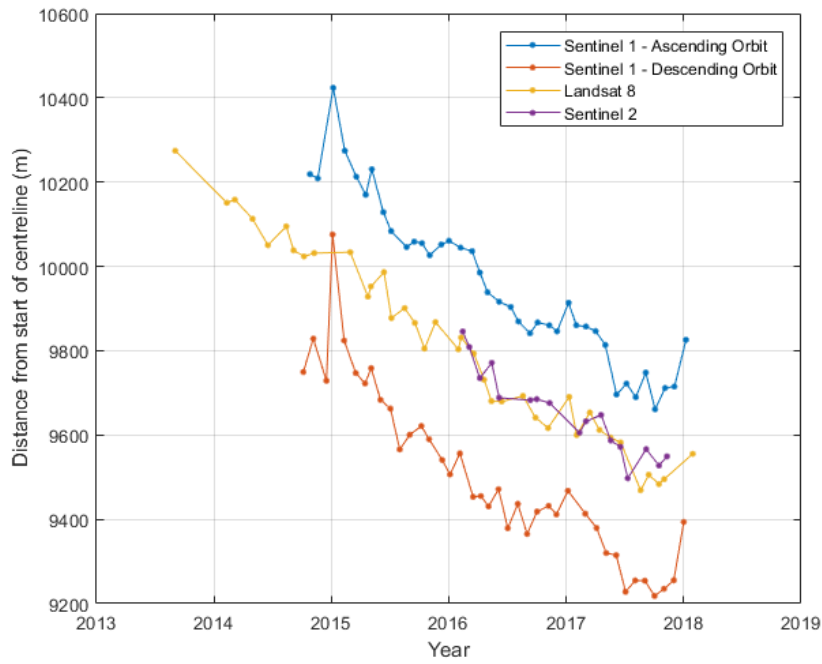
520   ~~Figure 4~~Figure 2 – Location map and centreline of Breiðamerkurjökull, SE Iceland. Imagery shows a

521   colour composite of four Sentinel 2A scenes acquired on 20/8/2017.

522

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524   **Figure ~~5~~ 3** – Intercomparison of monthly margin positions at Breiðamerkurjökull given by the

525   curvilinear box method (width = 2000 m) digitised from different satellites.

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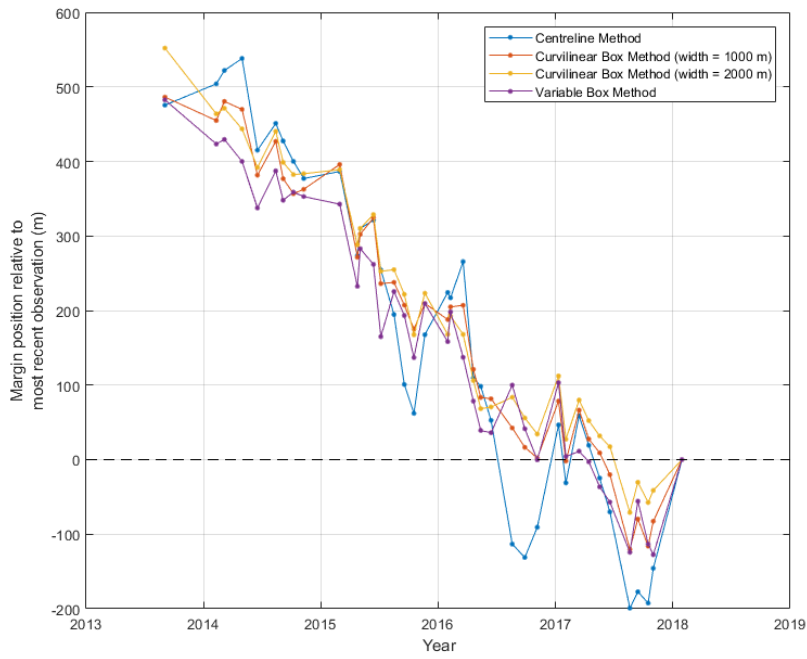
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541 ~~Figure 6~~Figure 4 – Intercomparison of results from different margin quantification methods applied

542 to the Landsat 8 monthly record of margin positions at Breiðamerkurjökull.

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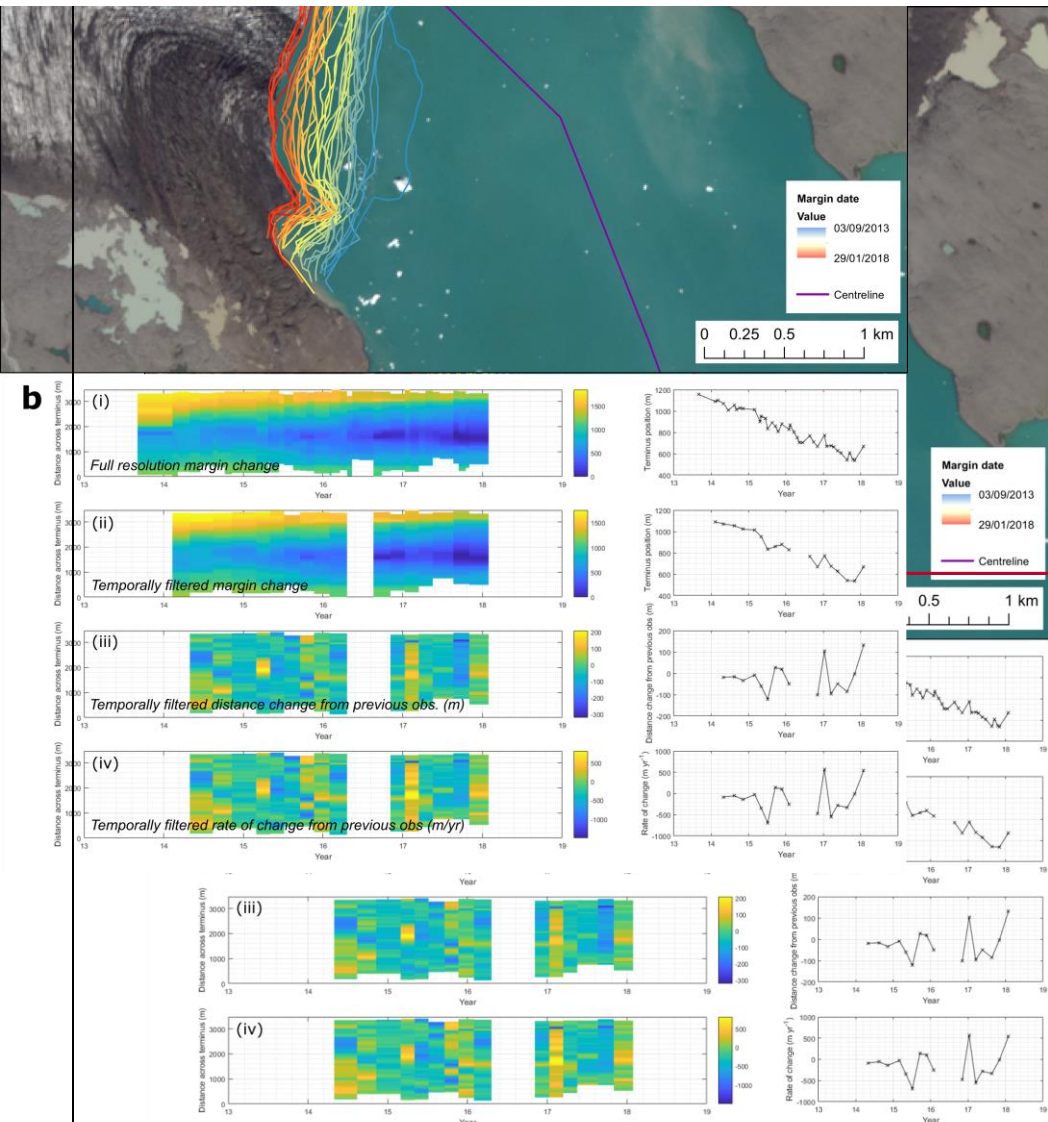
557 .

558 ~~Figure 7~~Figure 5 – Margin migration for monthly Landsat 8 observations of Breiðamerkurjökull

559 shown as a time series (a) cartographically, and (b) as results from the multi-centreline method.

560 Panel (b) has four rows of plots showing: (i) margin position for all available observations relative to

561 the most retreated position across the margin; (ii) margin position observations separated by at least

562 60 days, and a maximum of 120 days (these values are user defined); (iii) total distance change

563 between observations; and (iv) rate of change of margin in m yr^{-1}. Right hand column of plots display

564 results of the centreline method for comparison.

565

566 **Tables**

567

Satellite	Imagery type	Lifespan	True Colour Bands (R-G-B)	False Colour Bands (R-G-B)	Image resolution (m)	Notes
Landsat 4	Optical	Jul 1982 - Dec 1993	3-2-1	5-4-3	30	Gamma = 2
Landsat 5	Optical	Mar 1984 - Jan 2013	3-2-1	5-4-3	30	Gamma = 2
Landsat 7	Optical	Apr 1999 -	3-2-1	5-4-3	15	Pansharpened from 30 m to 15 m using band 8; Scan line corrector failure after 31/05/2003; Gamma = 2
Landsat 8	Optical	Feb 2013 -	4-3-2	6-5-4	15	Pansharpened from 30 m to 15 m using band 8; Gamma = 2
Sentinel 1A and 1B	SAR	1A - Apr 2014 - 1B - Apr 2016 -	-	-	10	Horiz. transmit/horiz. receive (HH), or vert. transmit/vert. receive (VV); Min. = -20, Max. = 1
Sentinel 2A and 2B	Optical	2A - Jun 2015 - 2B - Mar 2017 -	4-3-2	8-4-3	10	Gamma = 2; Gain = 0.025

Band combinations, gamma options, max./min. ranges and opacity can be varied manually via the 'Layers' tab in the top right of the screen Imagery is always stored in 'Layer 1'

568 **Table 1** – Description of satellites and optional band combinations that are built into GEEDiT. Note

569 that certain user defined custom band combinations may have lower resolution.

570

Band number	Landsat 4 and 5		Landsat 7		Landsat 8		Sentinel 2	
	Band Description	Resolution (m)	Band Description	Resolution (m)	Band Description	Resolution (m)	Band Description	Resolution (m)
1	Blue	30	Blue	30	Ultra blue	30	Coastal aerosol	60
2	Green	30	Green	30	Blue	30	Blue	10
3	Red	30	Red	30	Green	30	Green	10
4	Near-IR	30	Near-IR	30	Red	30	Red	10
5	Shortwave-IR 1	30	Shortwave-IR 1	30	Near-IR	30	Vegetation Red Edge	20
6	Thermal	120* (30)	Thermal	60* (30)	Shortwave-IR 1	30	Vegetation Red Edge	20
7	Shortwave-IR 2	30	Shortwave-IR 2	30	Shortwave-IR 2	30	Vegetation Red Edge	20
8	-	-	Panchromatic	15	Panchromatic	15	Near-IR	10
8A	-	-	-	-	-	-	Narrow near-IR	20
9	-	-	-	-	Cirrus	30	Water vapour	60
10	-	-	-	-	Thermal-IR 1	100* (30)	Shortwave-IR - Cirrus	60

11	-	-	-	-	Thermal-IR 2	100* (30)	Shortwave-IR	20
12	-	-	-	-	-	-	Shortwave-IR	20

571

572 **Table 2** – Description of bands for optical imagery satellites. Asterisks indicate where data have been

573 resampled to the resolution given in brackets.

574

Metadata associated with each margin/boundary	Variable name
Date of image acquisition	date
Name of satellite	satellite
Name of Project	Name
Image identification path	image_path
Is the margin unclear?	unclear
Ascending/Descending Sentinel 1 orbit	Asc_Desc
User notes on an image/margin	notes

575 Table 3 – Fields included in shapefiles produced by GEEDiT/MaQiT

576

Margins/Boundaries compulsory field names

Variable Name	Notes
X	Can be latitude/longitude or UTM. Note that this field is not normally shown in a GIS attribute table
Y	Can be latitude/longitude or UTM. Note that this field is not normally shown in a GIS attribute table
Date	Must be in the format YYYY_MM_DD (the YMD seperators do not have to be _'s though /'s are discouraged
Geometry	Line'/'Polyline'/similar

Centreline/transect compulsory shapefile field names

Variable Name	Notes
X	Can be latitude/longitude or UTM. Note that this field is not normally shown in a GIS attribute table
Y	Can be latitude/longitude or UTM. Note that this field is not normally shown in a GIS attribute table
Geometry	Line'/'Polyline'/similar

577

578 Table 4 – Compulsory field names for shapefile inputs into MaQiT

579

Satellite	Margins Digitised	Mean Path Length (m)	Mean width (m)	Mean number of vertices	Mean distance between points (m)
Sentinel 1 (asc.)	39	5643	3357	70.9	82.7
Sentinel 1 (desc.)	39	6204	3316	67.3	95.6

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Landsat 8	38	4797	3052	61.6	79.7
Sentinel 2	17	4644	2924	64.1	77.2
Total	133	5869	3203	66.6	91.1

580

581 ~~Table 5~~**Table 3** – Summary statistics for the margins digitised from different satellites

582

Method	Satellite	Number of observations	Total calculation time (sec)	Calculation time per observation (sec)
Centreline Method	Landsat 8	38	0.49	0.013
Curvilinear Box Method	Landsat 8	38	3.43	0.090
Variable Box Method	Landsat 8	38	2.81	0.074
Multi-centreline Method	Landsat 8	38	4.56	0.12

583

584 ~~Table 6~~**Table 4** – MaQiT performance metrics