

***Interactive comment on “A fully automated methodology for differentiating rock from snow, clouds and sea in Antarctica from Landsat imagery: A new rock outcrop map and area estimation for the entire Antarctic continent” by A. Burton-Johnson et al.***

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Dear Reviewer #2 (Anonymous),

Many thanks for your helpful and thorough review of our submitted manuscript to The Cryosphere. We have addressed each of your comments below and in the revised manuscript (included along with the additional revised supplementary material in the supplement to this reply).

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Gratefully,

Alex Burton-Johnson

Authors' response to Review 2:

Overall Assessment

Burton-Johnson et al. present a novel methodology, using freely-available remote sensing data, to perform a classification for the surface of Antarctica. The techniques used in the manuscript improve on existing methodologies which have inconsistencies for the presented problem (automated differentiation between rock, ice/snow, and water). I have included further comments / questions below, but ultimately recommend this manuscript for publication with minor revisions addressed.

- Again, many thanks for your positive comments and review.

Impact

I'd like to comment about the availability and quality of existing Antarctic geospatial (vector) datasets; the Antarctic Digital Database (ADD) has been the de facto standard for open, continent-wide, generally non-scientific base data layers (e.g. coastlines, lakes, rock outcrops, contours, etc.). With this manuscript and the resulting vector dataset of rock outcrops, the authors have contributed significantly to the improvement of Antarctic mapping and geospatial data. Moreover, the methodology presented here allows for the continued refinement of the aforementioned dataset using more recently acquired Landsat 8 imagery or imagery from other, higher-resolution multispectral optical sensors. Although some parameters may need to be revisited for other sensors, the authors presentation of the methodology and delivery of the ArcPy script provide a great launch point for further application (even for novice remote sensing scientists).

- As with our reply to Reviewer 1, we hope that providing the new dataset and ArcPy script will help improve increasing availability of open access data for Polar research.

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## Specific Comments/Questions

### Data Selection

The Landsat 8 OLI sensor is an appropriate sensor for this study, given its spatial resolution, revisit frequency, multispectral bands, and cost. Notwithstanding the data incapacity at extreme southern latitudes, can the authors comment on the selection of individual images to be used? Did the authors set any threshold for to certain sun elevations, time of year, or cloud-cover percentage [mentioned P1 L25] Also, given that Antarctic's rock can be covered in snow at any time, were there efforts to exclude those types of images by manual inspection? If either case, for the selection of images in the study, these thresholds should be noted.

- Where possible, images were selected that were taken during the Austral summer between September and March; had solar elevation angles  $>20^\circ$ ; and have  $<30\%$  cloud cover, with only a small number of tiles having to be used that do not meet these requirements in areas where better data did not exist at the time. This is now detailed in "Section 2.1 Input Data". We note that the amount of snow cover on Antarctica's rock outcrops can be variable, and this is resolved to some degree by the use of multiple images being analysed for most areas of the continent (also detailed in "Input Data" and the section: "Procedure C. Applying the masks and merging the datasets").

### Accuracy Assessment

I believe that the authors have provided a thorough assessment of the accuracy of their methodology and succinctly describe its use and limitations. Can the authors comment if any ground-based verification has been completed? For example, spectrometer samples from the various classification types (e.g. shaded rock, shaded ice) would verify the spectral signatures and further refine (or confirm) the threshold values used.

- Ground-based spectral data does exist, and at the coarse resolution of Landsat imagery, spectral library measurements would also be valid. However, this project aimed

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to develop an in-scene technique using thresholds defined on TOA reflectance data.

### Total Outcrop Area

The total outcrop area, I anticipate, is going to be highly cited. Please provide the methodology or source for calculating the "total land area of Antarctica." The final result of 0.18% will vary based on that value. Moreover, it may be beneficial to provide error bars for the final figure.

- The classification accuracy is now included, taking in to account the omission and commission errors. This now allows determination of the error on the total outcrop area figure ( $0.18\% \pm 0.05\%$ ). Modifications are included in the text and in Fig. 10 to account for this, including the equation defining the accuracy calculation and the inclusion of the mean classification accuracy values in Fig. 10a.

### Methodology

The authors are lacking sufficient explanation of the dataset merging procedure, especially for overlapping tiles. The authors state that for overlapping tiles if any of the "pixel stack" was classified as rock it was included as rock. Please provide justification for this technique. Furthermore, I believe that the algorithm could be greatly improved with the inclusion of many overlapping tiles. This would remove outliers (e.g. seasonal snow differences) and offer a measure of statistical significance; for example for 5 overlapping images all 5 images provided the same result, that pixel would be assumed to reduce both omission and commission disagreements.

- Details of the mosaicking process and justification for the use of overlapping tiles are now included in the text: "As most areas were covered by multiple overlapping Landsat tiles, any pixels identified as rock exposure by any of the overlying tiles was included as exposed rock in the final dataset. This was achieved by mosaicking the binary raster files produced by the workflow and taking the maximum pixel value. If a pixel was classified as snow it was designated "0" by the script, or "1" if it represents

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rock. Consequently this mosaicking process stores rock outcrop pixels (“1”) in the raster mosaic in preference to snow (“0”). By analysing multiple overlapping tiles the methodology becomes more sensitive to identifying rock outcrops; allows detection of rock outcrops even when they are obscured by clouds in one tile of the input data; and makes the methodology less sensitive to seasonal or short term variation in snow cover.” We also like the suggestion of using the number of overlapping tiles as a way of assigning a degree of statistical significance and will consider it in future versions of the dataset. One issue is that a number of areas are only covered by very few tiles due to cloud cover, especially on the Antarctic Peninsula, so a script using this methodology would need to assign a degree of significance to each individual pixel and details of this stored in its metadata. This should be feasible and is definitely something to consider.

#### Future Considerations

Please note that in Section 4.3, many of these satellites have already launched, not “under development or planned for launch” – please update this for the currency of publication date. I do appreciate the authors’ consideration for higher resolution datasets and that this technique is not sensor specific (although does have certain requirements, e.g. band availability).

- Details of each satellite program’s progress have been included and updated.

#### Technical Comments

[P2 L5] “several” seems unnecessary

- Word deleted

[P2 L15] “more strongly”→ “stronger”

- Reworded as recommended

[P2 L33] Remove extra space after “ablation”

- Space deleted

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[P3 L26] How do you define “strong illumination” and “minimal cloud cover”

- The following text is now included: “To ensure strong illumination we only used images taken during the day in the Austral summer between September and March. An estimate of cloud cover is included in the metadata for Landsat 8 images, and for all but four scenes images could be used with less than 30% cloud cover.”

[P5 L26] “LANDSAT” → “Landsat 8”

- Corrected

[P8 L13] “Digitalglobe’s” → “DigitalGlobe”

- Corrected

[P8 L13] “Worldview-3” → “WorldView-3”

- Corrected

[P8 L26] Period, not comma, before “The new map, . . .”

- Corrected

[P9 L1] Note the acknowledgements section is included twice in the manuscript

- Repeated section removed.

[Fig 4] The box containing “create a new raster for sunlit rock...” should read “four” requirements, not “three”

- Wording corrected

[Fig 7] These figures, in general, are very difficult to understand given the scale of the map and density/overlap of the outlines. Although the authors’ intention is valid, the detail provided by the outlines are indiscernible for several of the figures. Moreover, the underlying satellite imagery is often covered by the outlines. I suggest reducing the number of examples and subsequently enlarging them to provide the reader with more

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detail to better communicate the purpose of the figure.

- Each figure is discussed in section 3.1 so should ideally be shown in the paper. Consequently we have resized the figure to take two pages whilst still keeping the total article length concise. The images are enlarged further (one image per page) in the PDF document now included as supplementary material.

[Fig 8] Should the new rock outcrop dataset only include areas where there is tile coverage? Can the authors be certain that there are no outcrops  $>82^{\circ}40'S$  (the stated domain) that do not have a tile for this analysis? For example, there is a tile gap on the margin (Bryan Coast, Ellsworth Land).

- The new outcrop dataset could have been left with just the areas with tile coverage and not completed for the continent using the existing ADD rock outcrop dataset. However, most users would require a continent-wide dataset and so it was decided that splicing the two datasets would greatly increase the usability of the new work. As off-nadir images start to be collected we hope that an update of this dataset in the future will reduce our reliance on the old data. Although the existing ADD rock outcrop dataset is less accurate than the new, Landsat 8 derived data, it is very good at highlighting any areas of outcrop on the continent, even exaggerating the areas of small outcrop. Consequently we were able to select tiles covering all exposures of rock on the continent and by visually comparing the tile areas with the LIMA mosaic are confident that this is the case.

[Fig 11] It is very reasonable for manual digitization to clean up the dataset. Can the authors provide the areas that were manually edited after the analysis? If that metadata is unknown, the reproducibility for a given tile is in question.

- Some misidentified pixels were present in all coastal scenes containing seawater. This is now specified in the text. However, as no manual editing was done on land the repeatability of this methodology should not be affected (this is now included in the text).

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Please also note the supplement to this comment:

<http://www.the-cryosphere-discuss.net/tc-2016-56/tc-2016-56-AC2-supplement.zip>

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Interactive comment on The Cryosphere Discuss., doi:10.5194/tc-2016-56, 2016.

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