Interactive Comment on
"The first complete glacier inventory for the whole of Greenland",
by P. Rastner et al., *The Cryosphere Discussions*, 6, 2399-2436 (2012):
J. Graham Cogley, August 2012

General Comments
The title of this paper is self-explanatory and accurate. The authors have applied semi-automated methods for the identification of glacier ice to a large number of satellite images covering the periphery of Greenland. The image-processing and other analytical methods, including manual correction of the preliminary automated results and checks on accuracy, are described in detail. Most of the images date from 1999–2002, so that the composite view of the ice is nearly a "snapshot". The resulting glacier-complex outlines are matched to a digital elevation model, with which the complexes are subdivided into glaciers along drainage divides and the resulting glaciers are assigned topographic attributes.

To tackle the practical problem of distinguishing between the ice sheet and the peripheral glaciers, the authors define three "connectivity levels" for the latter, ranging from "physically separate" to "difficult to distinguish". They recommend treating the difficult-to-distinguish glaciers as part of the ice sheet, a working compromise that will probably satisfy most needs. No matter how the peripheral glaciers are classified, they turn out to be considerably more extensive than as estimated in earlier studies based on incomplete information.

The number of minor stylistic corrections needed is rather large, and there is a moderate amount of repetition that needs to be addressed. Nevertheless the text is clear for the most part. The work has evidently been done competently, and the importance of the contribution is obvious: for the first time we have a complete accounting of the ice cover of Greenland at the level of single glaciers. The ice sheet has yet to be subdivided, but the peripheral glaciers can now be studied in much more detail than has been possible hitherto. There is a wealth of important information in the results of this study, ranging from an accurate and only mildly diachronous estimate of total ice-covered area to a map of median glacier elevations that can serve as a very good representation of the equilibrium-line altitude. Projections of the glaciers' evolution under 21st-century climatic forcing can also be expected to become far more reliable. In summary, it is important that this work be published.

Substantive Comments
P2400
L2 I would change "important" to "essential".

Done

L6 "local glaciers and icecaps (GIC)": The authors' terminology is frequently confusing. First, an acronym could be avoided if the paper followed IPCC usage and defined "glaciers" to mean "glaciers and ice caps". Second, "GIC", "glacier" and "glacier entity" are used inconsistently; for example it does not make sense to speak of "subdividing GICs into glaciers". A consistent terminology is offered by the *Glossary of Glacier Mass Balance and Related Terms*: a "glacier complex" is a collection of contiguous glaciers. The authors are engaged in mapping *glacier complexes* from imagery and subdividing them into their constituent *glaciers*, and I suggest using these terms throughout. "glacier entity" is especially undesirable, because it is used as if it meant

sometimes one and sometimes the other of the two terms I am suggesting.

We agree that the use of terminology should be consistent throughout the paper and carefully checked it.
We could work with the new terminology used in IPCC AR5 as suggested but prefer to use the old one here as AR5 is not yet published (i.e. accessible). In addition, we often cite previous studies that refer to local (or peripheral) glaciers and icecaps (GIC). So using it here guarantees consistency in the terminology with earlier work and the GCOS terminology for the essential climate variable that is still GIC.

Our use of the term 'entity' refers to GIS terminology and defines a polygon with an ID. This is not the same as a glacier, as one glacier can be composed of more than one polygon, e.g. when the profile is interrupted (and the lower part being a regenerated glacier). We agree to use glacier complexes for contiguous ice masses before they are separated and changed the term throughout.

P2402
L11-12 Dyurgerov and Meier (2005) give 76,200 km^2, citing Dowdeswell and Hambrey 2002, *Islands of the Arctic* (which I have not seen).

Thanks for the note, we have changed it.

P2404
L9 There is no supplement as such. Call it an Appendix.

Done

P2406
L13 The centre coordinates would be more useful information than just "Greenland".

Centre coordinates can be provided but they are in our opinion better suited for interpretation by software rather than humans. For our purpose path - row - date and UTM zone are much more 'handy' for clear identification of the scenes used. We have now changed the text to "all scenes spanning UTM zones 18-28 N"

L26 This is not very clear. Is the "15 m buffer" really only 15 m wide, or should the text say "±15 m"? If the former, saying "adding a buffer of width 15 m to the exteriors of all …". The point should also be made that the ±3% error applies only to glacier complexes. Within complexes, single-glacier errors will differ by an amount dependent on the length of ice margin, the length of the glacier's divides, and a "divide error", presumably unknown, that will be perfectly anti-correlated with the corresponding errors of the glacier's neighbours. (One glacier's loss is the other glacier's gain.)

In our case we performed a buffer of +15m and assumed that a -15 m buffer creates the same relative area change but with an opposite sign (which is not exactly true). The accuracy is thus given as +/-3%. We changed this accordingly in the text. Your comment on the "divide error" is true. The buffer is around all glacier complexes and differs according to the length of the glacier divide. We have changed the text accordingly: As the location of the manually digitized outlines varied by about 1 TM pixel or 30 m (for clean ice), we determined the precision of the here-derived outlines by applying a + 15 m buffer around all glacier complexes.

P2407
L7 The two sets of connectivity rules are described fairly clearly, and they serve the intended purpose. The subjectivity of the procedure is also acknowledged appropriately. But one very obvious feature is not given any attention: the procedure assumes the existence of an object called the "Greenland Ice Sheet", *of known outline*. The rules cannot be applied until the ice-sheet outline is drawn. You have to identify every ice- sheet divide and assign it to either CL1 or CL2, following which you can apply the topographic heritage rule and then finish by assigning all the CL0s. It should be noted that different results will be obtained depending on whether the heritage rule is applied first to the CL1 or the CL2 glaciers.

You are fully correct in assuming that we also had a complete outline of the ice sheet itself. However, it must not be complete or assigned as such, as the drainage divides are derived from the DEM without knowing where the ice sheet boundary is. Only when these divides are intersected with the outlines of all glacier complexes (incl. the ice sheet) the outline is becoming important for separation from CL1.

The broader significance of these points should be emphasized. For example the inventory is indeed complete for the whole of Greenland, *including* the ice sheet, which differs from the other glacier complexes only in that it is the only one that has not been considered for subdivision. Although it would be large (>10^6 points?) and diachronous (constructed from many scenes differing in date), the ice-sheet polygon could be included in the inventory just like all the other polygons.

This is basically correct and we have assigned the new class ice sheet to the Greenland Ice Sheet polygon (but this will not be included it in the inventory). There are actually a large number of polygons that are not considered for subdivision (e.g. circular shaped ice caps). The difference with the ice sheet is, that it did not have polygon topology prior to (or after) intersection with drainage divides so it just fells off. The reason is that the intersections were performed prior to mosaicing everything, i.e. we come from the outside going inwards rather than from the inside going outwards. This was maybe not so clear before and has now been rewritten.

P2409
L3 Why "zonal"? It confuses the reader by suggesting elevation zones, which do not seem to be relevant. A "zone" seems to be what most people refer to as a "mask". In fact, the sentence could profitably be ended at "aspect)".

This is GIS (ESRI) terminology (the command is called zonalstats) for calculating statistics from a value grid (e.g. a DEM) over specific zones (e.g. glacier entities). The zones can be seen as a mask with IDs (that are required for identification), i.e. in the raster domain grid cells with the same value (glacier ID) refer to a zone. We have now changed zonal with zone and added a comment on how the zonalstats command is working.

P2410
L4-5 In view of the embarrassing mistake documented by Kargel et al. (2012), it would be worthwhile to be more precise about the areas of the ice sheet and of all ice in Greenland. For example, can an uncertainty be attached to either number by multiplying 15 m by the length of all glacier-complex perimeters (plus the margins of the ice sheet)?

We fully agree that an uncertainty for the ice sheet size should be added as well. We have

calculated it in the same way as for the glacier complexes, and added that this is only the technical value related to the uncertainty in the position of the outline. Different interpretations of the connectivity levels or where the drainage divides should be located are not considered.

L11 Change "included" to "excluded from the ice sheet". State briefly why King Christian IV Glacier has been assigned to the ice sheet rather than CL2. Perhaps the ice-sheet divide is too indistinct, or simply does not exist. The extent of ice in question (11,000 km^2 for King Christian IV and almost as much again for its neighbours that would inherit CL2 connectivity) is large.

We agree that this is a region where the uncertainty in interpretation mentioned above comes into play. In this case a drainage divide could be derived from the DEM. However, the divide is very long and is situated in most cases on very shallow ice ridges. Hence, we cannot justify separating the glacier and assigning it to CL2. This would imply that also other, even larger glaciers were separated and assigned to CL2 (and based on feedback we have from other colleagues, we prefer to avoid this).

P2411
L14 Clarify "very reduced influence of the MAAT". I do not know what is being referred to.

It referred to the glacier complexes in the south sector. They are found at lower elevations here so that they experience a higher MAAT then the glacier complexes in the north. We have changed the sentence now to: The lower elevation of glacier complexes in the southern sector hints to a generally higher MAAT (or much higher precipitation) than in the north.

P2412
L6-12 This is an accurate statement of the truth but it is too informal to appear in print and needs to be dressed up. I would say "… with the ice sheet. The divides as derived from flowshed analysis are obtained objectively, but need human … . The interpretation offered here is a working compromise that will help to reduce the risk of double-counting by different groups (Paul, 2011). When …".

Thank you, for this suggestion. We agree and have changed the statements accordingly:
The GIC CL2 was introduced to retain strongly connected local GIC with the ice sheet. The divides as derived from flowshed analysis are obtained objectively, but need human based interpretation to serve various communities. The interpretation offered here is a working compromise that will help to reduce the risk of double-counting by different groups (Paul, 2011).

L14 "all datasets are digitally available": vector "polylines", as opposed to polygons, are needed for the purpose discussed here, and it is very unusual to make them available.

Thank you, we changed it now accordingly:
When better suggestions for a consistent separation came up, it should be possible to refine the divides as all vector polygons are digitally available through the GLIMS database.

P2413

L6 Cogley (2012) is not in the References.

Done

L18 I do not understand “the total area covered by upscaling the size class distribution”, in which “covered” and “class” seem to be redundant and “upscaling” is obscure. But I see no need for a discussion here of volume-area scaling, if that is what is aimed at.

We do not refer here to the volume-area scaling but earlier attempts to estimate the size class distribution from the method proposed by Bahr (1997). This has been clarified in the revised manuscript.

L23-25I do not understand this. Standard inventory practice is to assign a special aspect code for “radial flow” to ice caps. The “certain preference …” clause does not make sense.

The point here is that the standard inventory practise (using hydrologic divisions also for ice caps) does not serve the need for several glaciological applications where an ice cap must be one entity (of a much larger size). In the instance an ice cap is subdivided into glacier (entities) the ice cap is no longer an ice cap but appears as a number of individual glaciers. We clarified the sentence.

P2414
L13-15Why, if it too is accurate, will a different DEM result in different divides and attributes?

In flat terrain, the location of the drainage divide is very sensitive on very small differences in elevation and of course artefacts. Hence, changing the DEM will also change the location of the divides. Though these changes might be small in general, some local differences can have an overall impact. Please see also Fig. 3 in Le Bris et al. (2011) which is illustrating this variability.

P2415
L1 Explain why relative uncertainty is inversely proportional to area (“increases, because the ratio of area to length of perimeter becomes large.”).

A ‘length of the perimeter’ dependent change in area will result in a relatively much larger change in the area of small glaciers than for large glaciers

P2421
Table 1 This table should be rearranged to resemble Table A2, with columns for area and number and rows for CL0, CL1, CL2, ice sheet (“CL3”), ice sheet plus CL2, and the whole island. The numbers in the ice-sheet row are confusing. For example it is not helpful to subtract CL0 area from total area and call it “ice sheet”.

Done

Cited references

Bahr, D.B. (1997) Global distributions of glacier properties: A stochastic scaling paradigm. Water Resources Research, 33 (7), 1669–1679.
Le Bris, R., Paul, F., Frey, H. and Bolch, T. (2011): A new satellite-derived glacier inventory for western Alaska. Annals of Glaciology, 52 (59), 135-143.

Paul (2011)

Stylistic Comments

All stylistic comments were changed accordingly in our text.

P2434
Figure 8 Mention the lowest and highest observed median elevations in the caption.

Ok, we can do that.

If possible, increase the size of the coloured dots of Flade Isblink and the very large glaciers on the on the Geikie Plateau.

Ok, we can see if this is possible.