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The Cryosphere
Discussions

Interactive comment on "Constraining GRACE-derived cryosphere-attributed signal to irregularly shaped ice-covered areas" *by* W. Colgan et al.

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We thank Anonymous Referee #1 for their interest in our work, and appreciate the mathematical rigor which they impart. We would like to address the three major comments (numbered 1 through 3) while the discussion forum is still "open", in case Anonymous Referee #1 can provide further insight. My co-authors and I intend to address the remaining minor comments in final discussion.

Re: #1 Dependence of ensemble mean on initial conditions – We have now executed an ensemble in which the "high resolution" mass change values (m-dot) are initialized as an array of random numbers uniformly distributed between -100 and +100 kg/m2/a,

rather than a constant 0 kg/m2/a throughout the domain. This range of initial values is the same order of magnitude as the absolute mean value of the anticipated inversion field (~ 120 kg/m2/a). For illustrative purposes, I have uploaded an animation supplementary to this discussion comment that visualizes the iterative inversion of a single simulation under these revised initial conditions (Animation 1). This animation is comparable to the animation supplementary to the discussion paper. After approximately 10 iterations the magnitude and variability of the inferred m-dot fields appear similar in both animations.

Under these revised initial conditions, an ensemble of 1000 simulations converges on a total Greenland cryosphere-attributed mass loss of 250 ± 26 Gt/a (Figure 1). This is not significantly different from the 251 ± 25 Gt/a under the original initial conditions used in the discussion paper (c.f. discussion paper figure four). The spatial pattern of this inferred mass loss is also virtually identical to the original initial conditions (Figure 2; c.f. with discussion paper figure nine). We therefore suggest that the ensemble mean is relatively insensitive to the choice of initial conditions over the range 0 to 100 kg/m2/a. We agree that the limited extent of the inversion domain, in tandem with prescribed peripheral boundary conditions, contributes to this insensitivity. Additionally, as the difference field (discussion paper equation one) essentially takes on the value/magnitude of the ultimate GRACE solution field in the first iteration, initial condition hysteresis is inherently minimized.

Re: #2 Dependence of ensemble uncertainty on initial conditions and observed value – We recognize the dependence of ensemble uncertainty on the input GRACE-derived spherical harmonic representation of mass change. We accommodate this dependency by perturbing the spherical harmonic representation within its associated uncertainty in each simulation. The uncertainty field derived from initializing simulations with an array of random numbers uniformly distributed between -100 and +100 kg/m2/a (as per #1) confirms that ensemble node uncertainty is indeed dependent on initial conditions (Figure 3). In comparison to the node uncertainty associated with the original initial conditions used in the discussion paper, node uncertainty increases by up to 60 kg/m2/a in the ice sheet interior, as well as around peripheral nodes where ice coverage is < 1.

We acknowledge that this revised node uncertainty is a more realistic representation of the uncertainty associated with an inferred mass change value in the ice sheet interior. At peripheral nodes, however, where fractional ice coverage (F) is < 1, we contend that this results in a substantial overestimate of uncertainty. As the iterative update of m-dot is dependent on F, if a node with relatively small ice coverage is initialized with a relatively large m-dot value, the iterative update can never overcome the hysteresis of initial conditions. This not an issue in the ice sheet interior, where F = 1. We contend that it is not realistic to initialize the inversion by assigning cryosphere-attributed mass change of (for example) 100 kg/m2/a over the 26ˆ2 km2 area of a grid cell that might have (for example) only 1 % ice coverage.

We therefore propose initializing m-dot with an array of random numbers uniformly distributed between -100 and +100 kg/m2/a that has been multiplied by ice fraction (Figure 4). This satisfies the more realistic representation of uncertainty in the ice sheet interior proposed by Anonymous Referee #1, while also honouring the inherent requirement of uncertainty to go to zero where ice coverage goes to zero. Simply put, where no ice cover exists, there is negligible uncertainty in the cryosphere-attributed contribution of mass change (i.e. m-dot = less than a negligible threshold value).

We note that while uncertainty at a given node is sensitive to choice of initial condition, uncertainty at the ice sheet scale is not similarly dependent on initial condition. Ice sheet uncertainty would only be sensitive to individual node uncertainties if it were computed as a function of individual node uncertainties (e.g. root mean squared of individual node uncertainties times area). This type of uncertainty calculation, however, is only applicable to uncorrelated variations, and would substantially overestimate the true uncertainty associated with the mass change of the ice sheet as a whole. This is apparent from the implemented stopping criterion, which ensures that the ice sheet

wide uncertainty associated with a given inversion is « 1 Gt/a. Therefore, while the revised initial condition increases individual node uncertainties, it does not change ice sheet wide uncertainty.

Re: #3 Dependence of ensemble mean on fractional ice coverage – It is correct that the inversion as implemented attributes cryospheric mass loss to be proportional with fractional ice coverage. For example, ten times more mass change is attributed to a node with F = 1.0 than a neighbouring node with F = 0.1. While in reality specific mass loss (i.e. mass loss per unit ice area) typically increases to a maximum at peripheral nodes, the inversion would need a secondary piece of independent information in order to distinguish contrasts in mass change between adjacent ice-containing nodes. As we explicitly state in the discussion paper, since fractional ice coverage is the only new information applied to the GRACE solution, the inversion only constrains cryosphere-attributed mass changes to ice-covered areas and is not capable of distinguishing spatial heterogeneity in mass loss between individual ice containing nodes.

In a revised version of our paper we will clarify that m-dot (cryosphere-attributed mass change per unit area) is not equivalent to specific m-dot (cryosphere-attributed mass change per unit ice-covered area) and include a figure of specific m-dot, which may be calculated as m-dot divided by F (Figure 5). We note that GRACE mascons are conventionally expressed in units of water equivalent thickness per time, and not corrected for underlying ice-covered area, typically due to the implicit assumption of F = 1 at all ice sheet nodes (e.g. Barletta et al., 2012). As we are similarly interested in the ultimate mass change at each node due to cryospheric processes (i.e. the mass change "felt" by GRACE at each node throughout the entire domain after accounting for differences in ice fraction), we do not presently couch our mass changes as specific rates per ice-covered area.

References

Barletta, V. R., Sørensen, L. S., and Forsberg, R.: Variability of mass changes at basin scale for Greenland and Antarctica, The Cryosphere Discuss., 6, 3397-3446, doi:10.5194/tcd-6-3397-2012, 2012

Figure Captions

Figure 1 - Sensitivity analysis of the ensemble mean when the inversion is initialized with an array of random numbers uniformly distributed between -100 and +100 kg/m2/a. Comparable to discussion paper figure four (in which the inversion is initialized with an array of 0 kg/m2/a).

Figure 2 - Sensitivity analysis of the spatial distribution of inferred mass changes when the inversion is initialized with an array of random numbers uniformly distributed between -100 and +100 kg/m2/a. Comparable to discussion paper figure nine.

Figure 3 - A primary sensitivity analysis of the spatial distribution of uncertainty in inferred mass changes. A: Uncertainty at a given node when the inversion is initialized with a constant array of 0 kg/m2/a (from discussion paper figure eight). B: Uncertainty at a given node when the inversion is initialized with an array of random numbers uniformly distributed between -100 and +100 kg/m2/a. C: Difference.

Figure 4 - A secondary sensitivity analysis of the spatial distribution of uncertainty in inferred mass changes. A: Uncertainty at a given node when the inversion is initialized with a constant array of 0 kg/m2/a (from discussion paper figure eight). B: Uncertainty at a given node when the inversion is initialized with an array of random numbers uniformly distributed between -100 and +100 kg/m2/a times fractional ice coverage. C: Difference.

Figure 5 - Specific rate of mass change per unit ice-covered area, calculated by dividing inferred rate of mass change by fractional ice coverage.

Animation 1 - A sample Monte Carlo inversion to convergence over 85 iterations when the inversion is initialized with an array of random numbers uniformly distributed between -100 and +100 kg/m2/a. Comparable to discussion paper animation one.

Please also note the supplement to this comment:
http://www.the-cryosphere-discuss.net/7/C1191/2013/tcd-7-C1191-2013-supplement.zip

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Interactive comment on The Cryosphere Discuss., 7, 3417, 2013.

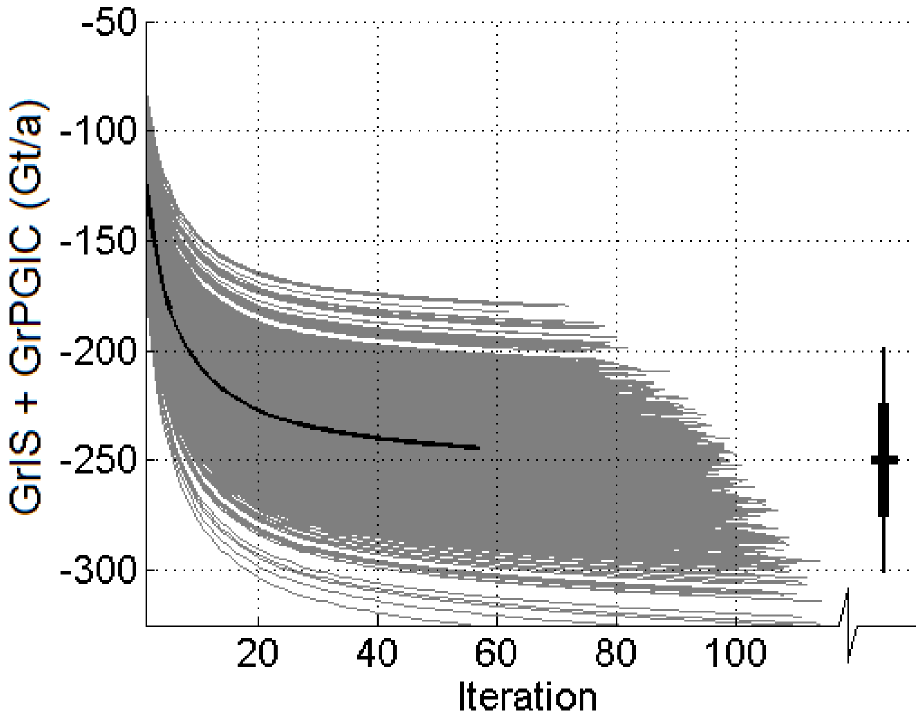
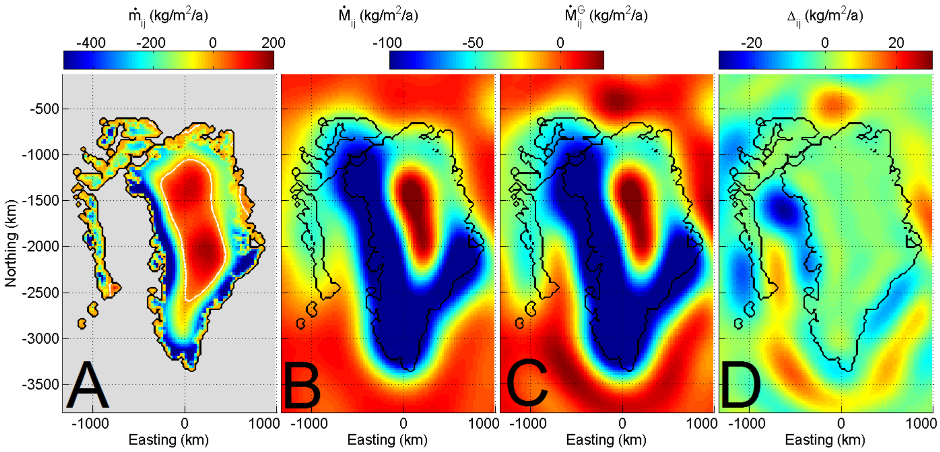


Fig. 1. see caption above



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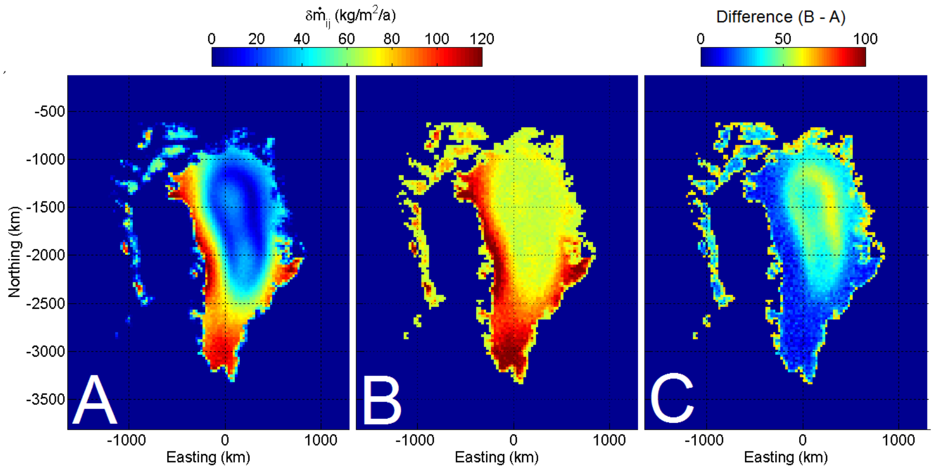

Fig. 3. see caption above

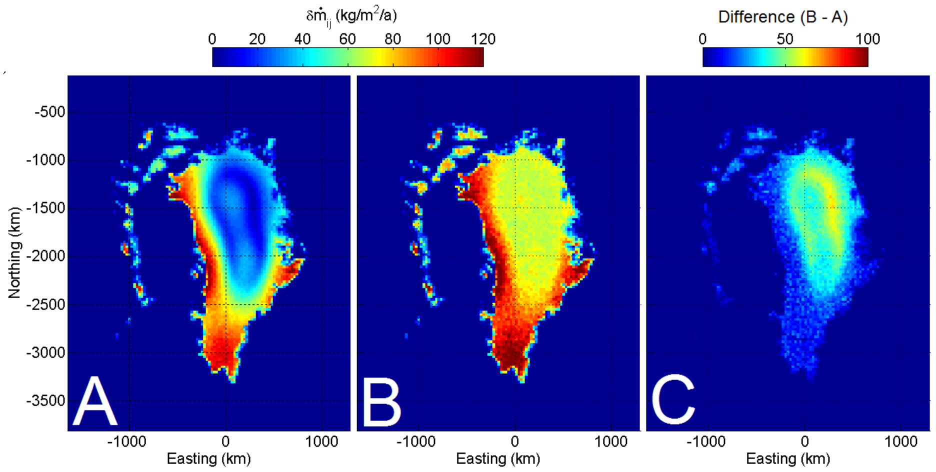

Fig. 4. see caption above

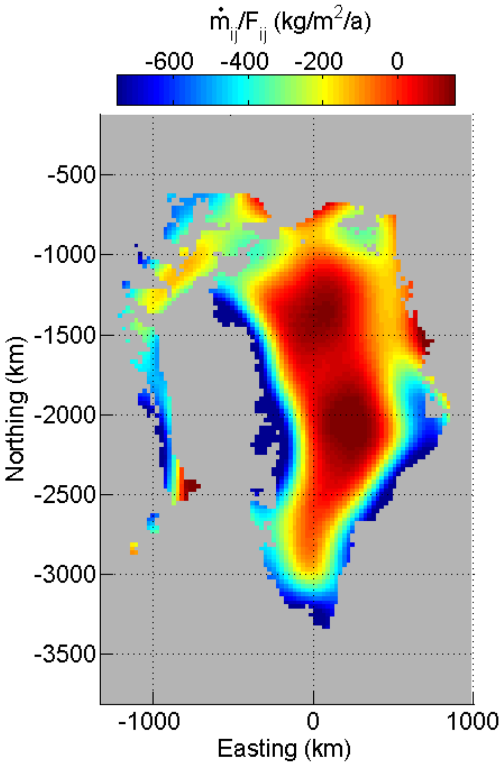

Fig. 5. see caption above