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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 #2 for their interest in our work. We appreciate the keen eye with which they have reviewed our methodology. We would like to address their six major comments (numbered 1 through 6) while the discussion forum is still "open", in case Anonymous Referee #2 can provide further insight. My co-authors and I intend to address the remaining minor comments in final discussion.

Re: #1 Clarification of precise inversion data – We apologize for being unclear in our discussion paper: We are indeed inverting the gridded ultimate rate of mass change field, not individual spherical harmonic coefficients. The inversion is therefore executed

in the Cartesian (or "node") domain, rather than the spherical harmonic domain. We will explicitly state this clarification in a revised copy of the manuscript. We will similarly clarify that we regard the "characteristic scaling length" of a Gaussian filter as being equivalent to its "standard deviation". We note that spherical harmonics have only been available up to degree 60 since the inception of GRACE. Thus, it is not possible to truncate spherical harmonic solutions at higher orders (Tapley et al., 2004). We also note that rather than being prescribed a priori, the Gaussian filter length scale subsequently used by the inversion algorithm (200 km) was established through a sensitivity analysis to establish the optimal length scale at which the inversion minimized the root-mean-squared error when compared with the input GRACE data (discussion paper Figure 7). Thus, we contend that the combination of degree 60 spherical harmonic solution and Gaussian filter length scale of 200 km does indeed preserve maximum information of the magnitude and spatial distribution of mass changes throughout the inversion process, while honouring the fundamental spatial resolution of the GRACE satellites.

Re: #2 Generating spherical harmonics from ground-level data – We completely agree that there is a pressing need for coarser resolution spherical harmonic solutions to be derived from higher resolution inverted ground-level mass change fields (i.e. discussion paper Figure 10; Barletta et al., 2012) to facilitate further inversion validation. This would certainly close the circle: generating higher resolution ground-level fields through inversion, and then forward modeling the corresponding coarser resolution spherical harmonic fields, and so on. We have given significant thought to forward modelling the spherical harmonic solution space that corresponds to the inverted field we present. As we are inverting/inferring a trend over a given period, rather than absolute mass anomalies at each monthly GRACE time point, we would have to carefully stitch this cryospheric trend into a forward model of global mass anomalies over the time period. This forward model would also have to incorporate the usual suite of processes that can substantially influence gravimetry observations (i.e. corrections for atmospheric, oceanic, isostatic rebound, etc.). We view this as a non-trivial task. We are currently working towards a framework to develop and implement such a complimentary forward model.

Re: #3 GRACE L2 product – The GRACE Level 2 (L2) product includes time-variable (monthly) gravity fields. These fields are often normalized (i.e. divided by a period mean), and described as mass anomalies, typically in units of cmWE. Applying a temporal trend through a suite of monthly mass anomaly fields can yield a spatial distribution of rate of mass change (in cmWE/a). The method we present can indeed invert such an L2-derivative. In a revised manuscript, we will clearly state this when the inversion data is introduced. Our preference for a mascon-derived spherical harmonic stems from the notion that mascons (arguably) provide a better format for isolating specific gravimetry signals than spherical harmonics (compare, for example, Velicogna and Wahr, 2006 and Jacob et al., 2012). As stated in the paper, however, the statistical inversion benefits from relatively smooth spatial gradients in mass change associated with spherical harmonics, rather than relatively sharp contrasts in mass change at cell boundaries associated with mascons. Thus, we have selected a mascon-derived spherical harmonic solution.

Re: #4 Mascon to spherical conversion – We note that mascons and spherical harmonics have been previously demonstrated to be inter- convertible/changeable, essentially by representing mascons as a set of differential potential coefficients ("delta" coefficients) added to the mean GRACE L2 field (see equations 1 and 2 in Luthcke et al., 2013 or Chao et al., 1987). Thus, we do contend mascon and spherical harmonic solutions are directly comparable. In our revised manuscript, we will clarify that conversions between spherical harmonics and mascons are established practice. Regarding non-zero ocean values, we acknowledge that there is some signal leakage from terrestrial (cryospheric) mascons into ocean mascons. Luthcke et al. (2013) do constrain oceanic mass changes via forward modelling during their reduction of KBBR data in a series of iterated monthly mascons. Oceanic leakage is most pronounced in northern Baffin Bay, where terrestrial mascons surround ocean mascons on three sides, and the forward model used to constrain oceanic mass changes may fail to reproduce

true oceanic signal. This signal leakage, however, is formally incorporated in the error estimate associated with the trend in cryospheric mass change used in the inversion.

Re: #5 R and Rij – As mentioned above (Re: #1), we are not inverting individual spherical harmonic coefficients. Therefore, we are not applying a constant R across all coefficients. Rather, the purpose of R in Eq. (1) is to apportion a random amount of the ultimate error in the GRACE-derived rate of cryospheric mass change to the input field of a given simulation. As R varies randomly between simulations over a normal distribution (centered on 0 with a standard deviation of 1), it serves to randomly apply the 1-sigma spatial error term over the ensemble of simulations (discussion paper Figure 2B). Over a large number of simulations, the rate of mass change at any given node is therefore subject to a wide range of error perturbations. We appreciate there may be some confusion between R and Rij; both variables denote random numbers, with the only difference being that the latter is indexed in Cartesian coordinates while the former is not. Unlike R, Rij varies each iteration within a simulation, and represents a field of random numbers to perturb the iterative update term ("delta" in Eq. 2). Admittedly our notation could use improvement throughout the manuscript. For example, applying a superscript "k" to Rij would more clearly denote that its value is iteration dependent. We intend to address such notation inconsistencies and add an appendix of variable notation in a revised version of this manuscript.

Re: #6 Description of method – In a revised version of this manuscript we will endeavour to improve the algorithm description by ensuring: (i) every parameter is defined upon first appearance, (ii) every parameter is also listed in an appendix of variable notation, (iii) an overview of the method is provided prior to going through the method, (iv) the method description is divided into sub-sections (e.g. 2.1, 2.2, etc.), each introduced and concluded with summary sentences, to break-up the current 2300 word single method section, and finally (v) inclusion of the attached figure, which provides a conceptual overview of the iterative inversion in flowchart format.

Figures

Figure 1 - Flowchart overview of inverting a given coarser spatial resolution GRACE-derived spherical harmonic rate of mass change field (MˆG_ij) into an ensemble of higher spatial resolution inferred rate of mass change fields (m_ij). An ensemble of simulations are performed, each of which is comprised of an iterative inversion to convergence as defined by Eq. 4.

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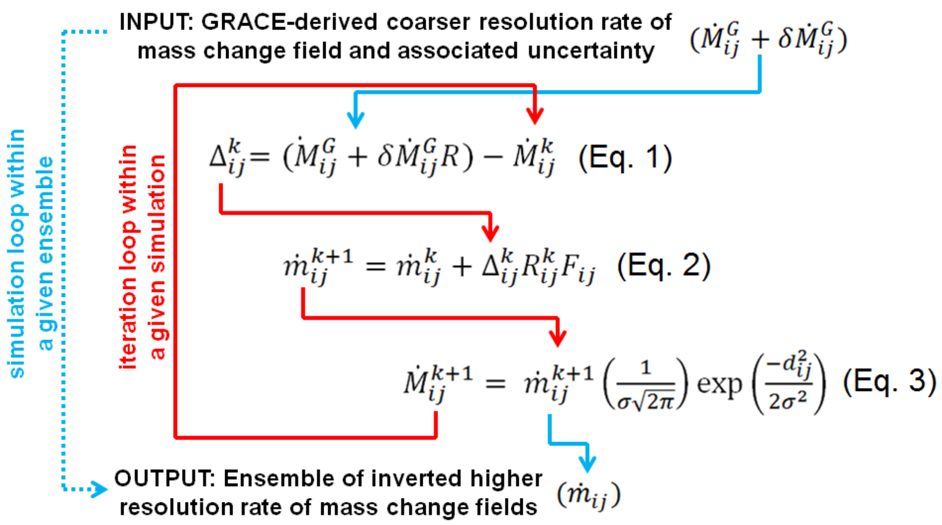

Fig. 1.