G11C-3512: Maximizing recovered spatial resolution for glacial mass loss through hierarchically defined mixed-resolution regression mascons

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Summary

GRACE and GRACE Follow-On have long provided monthly estimates of Earth's time-variable gravity field, yielding surface mass change maps from spherical harmonics and mascons at 300-400km spatial resolution. In this presentation, we share initial findings of a new, mixed-resolution regression mascon solution that facilitates further potential resolution improvements. Building on the regression mascon technique in *Loomis et al. (2021*), we attempt to improve our recovery of the trend and annual signal in Alaska and Greenland.

Mascons Background

Monthly Mascons

Today, GRACE mascon solutions are available off-the-shelf from four Centers, and mascons range in size from 1-arc-deg to 3-arc-deg. Each center uses a slightly different solution estimation strategy, but all solutions include some form of regularization in the inversion and all are realized as monthly estimates of surface mass change. While these are excellent for studying regional mass change at monthly intervals, they are necessarily limited by the design of the mascons and the resolution of GRACE at monthly intervals.

Regression Mascons

The GSFC regression mascons (Loomis et al., 2021) have shown that higher spatial recovery is possible by trading off temporal resolution; in that solution, higher resolution (up to 111 km, or 1-arc-degree) gravity models of the trend and annual signal are computed by stacking the full normal equations of all GRACE(-FO) months. Figure 1 shows the recovered trend from the GSFC regression trend mascons in comparison to those from the GSFC and JPL monthly solutions, as well as the recovered annual signal amplitude from the monthly solutions.

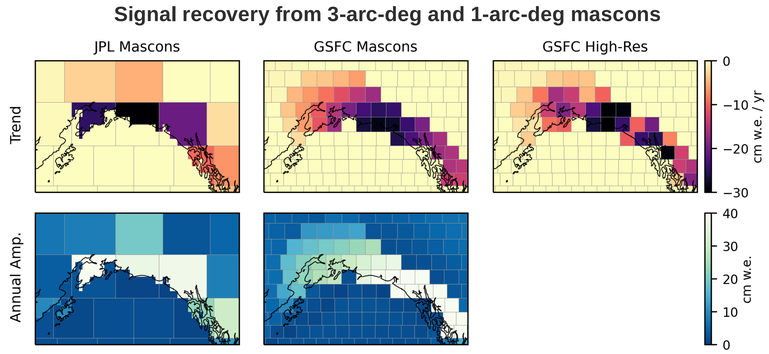


Figure 1: Recovered Trend and Annual Amp. from GRACE/GFO using the JPL 3-arc-deg and GSFC 1-arc-deg mascons. The GSFC "High-Res" trend is a direct inversion for the trend from Level-1B ranging observations, rather than an estimate from a TWS monthly solution.

Fast Mascons (Croteau et al., 2021)

The "fast mascon" approach provides a framework for rapidly iterating solutions to test the effects of different parameterization choices. Provided that full normal equations are available, the fast mascon approach is mathematically equivalent to the methods used in the GSFC and CSR mascon solutions while improving computational efficiency by calculating the solution inverse in the spectral domain and separating mascon estimation from Level-1B processing. We use the ITSG-Grace2018 degree 96 product in this study (Kvas et al., 2019).

This Study

As part of a larger study looking at better characterizing Vertical Land Motion in Kodiak and Katmai, Alaska, we desire a more spatially accurate realization of the long-term trend and annual signal in the Gulf of Alaska. Here, we combine the fast mascon formulation with the regression mascon technique to rapidly iterate a new mixed-resolution mascon solution. These mixed-resolution mascons better conform to coastlines and glacier and ice sheet boundaries. We also examine results for the Greenland.

References

Croteau, M. J., et al. (2021). GRACE fast mascons from spherical harmonics and a regularization design trade study. *Journal of Geophysical Research: Solid Earth*, 126, e2021JB022113. doi:10.1029/2021JB022113

Kvas, A., et al. (2019). ITSG-Grace2018: Overview and evaluation of a new GRACE-only gravity field time series. *Journal of Geophysical Research: Solid Earth*, 124, 9332–9344. doi:10.1029/2019JB017415

Loomis, B. D., et al. (2021). High-spatial-resolution mass rates from GRACE and GRACE-FO: Global and ice sheet analyses. *Journal of Geophysical Research: Solid Earth*, 126, e2021JB023024. doi:10.1029/2021JB023024

Hierarchical Mascons

The new set of mascons are initialized from the JPL 3-arc-deg mascon definitions. Each mascon is divided into nine 1-arc-deg mascons, and then these are further sub-divided into ½-arc-deg and ¼-arc-deg mascons as shown in Figure 2.

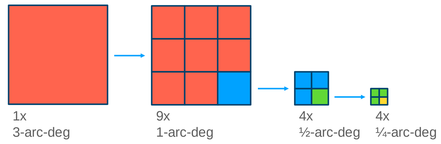


Figure 2: Hierarchical mascon layers defined in this experiment, from 3-arc-deg to 0.25-arc-deg.

We use a weighted least squares approach to estimate the mascon state , Δ**m**, from GRACE(-FO) ranging observations, **d,** as follows (simplified for understandability):

$$\Delta\mathbf{m} = (\mathbf{A}^T\mathbf{W}\mathbf{A})^{-1}\,\mathbf{A}^T\mathbf{W}\mathbf{d}$$

where **A** is the partial derivative matrix of the observations with respect to the global set of mascons. As with the regular GSFC and CSR mascons, we define **A** ≡ **HL**, where **H** is the partial derivative matrix of the ranging observations with respect to spherical harmonics and **L** is the partial derivative matrix of spherical harmonics with respect to the mascons. The hierarchical design of our new mascon set is useful because the partial terms in **L** for any larger mascon equals the sum of those same terms for the set of smaller mascons within that mascon.

We can selectively sub-divide mascons only where needed for a particular study. For example, an investigation into glaciers can keep far away ocean and land mascons relatively coarse. One could also selectively use smaller mascons to better match coastlines or other geographic boundaries, as shown in Figure 3 for a single 3-arc-deg mascon that is bisected by a coastline.

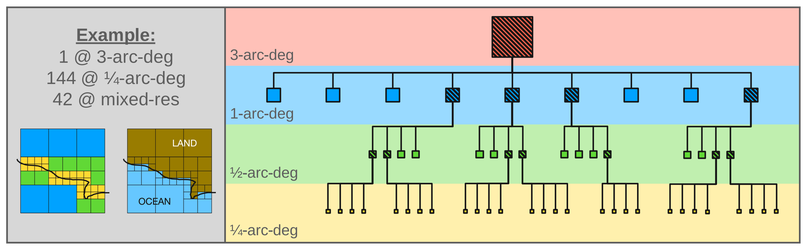


Figure 3: Example showing the reduction in terms for a mixed-resolution realization vs. a fully high-resolution realization for a generic mascon near a coastline.

Test Case: Gulf of Alaska and Greenland

In this study, we devise a mixed-resolution set of mascons aimed at better describing glaciated areas in Alaska and Greenland. Mascons are 3-arc-deg over the ocean, 1-arc-deg over land, ½-arc-deg over ice sheets, and ¼-arc-deg along coastlines. This minimizes the parameters to be estimated while maximizing potential resolution gains along coastlines and over glaciers.

To illustrate the benefits of this design, Figure 4 shows maps of % ice coverage for Greenland and the Gulf of Alaska. The first map for each region is from a ½-deg gridded field, which is then binned into 3-arc-deg, 1-arc-deg, and the full mixed resolution mascons. As seen in the figure, mixing lower and higher resolution mascons allows for better recovery of exact coastlines and ice sheet definitions without adding additional mascons in other locations (e.g., over the ocean).

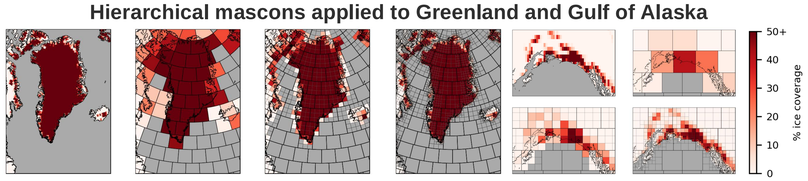


Figure 4: % ice coverage in Greenland and Gulf of Alaska, represented by increasingly smaller layers of hierarchical mascons. For each region, sub-figures show ice coverage for the following resolutions: ½-deg grids, 3-arc-deg mascons, 1-arc-deg mascons, ¼-to-1-arc-deg mascons.

Initial Results

We estimated monthly mascons from April 2002 to July 2023, as well as a regression solution (bias + trend + annual sine and cosine) using the full normal equation information for all months. Figure 5 shows that trends and annual signals from both the monthly solution and the regression solution better adhere to coastlines, as expected. We also see that the regression solution better localizes the signal. Figure 6 shows ice sheet mass change for Greenland and Antarctica with the monthly mixed resolution mascons. *Note: These results are preliminary and the regularization weights have not been fully tuned.*

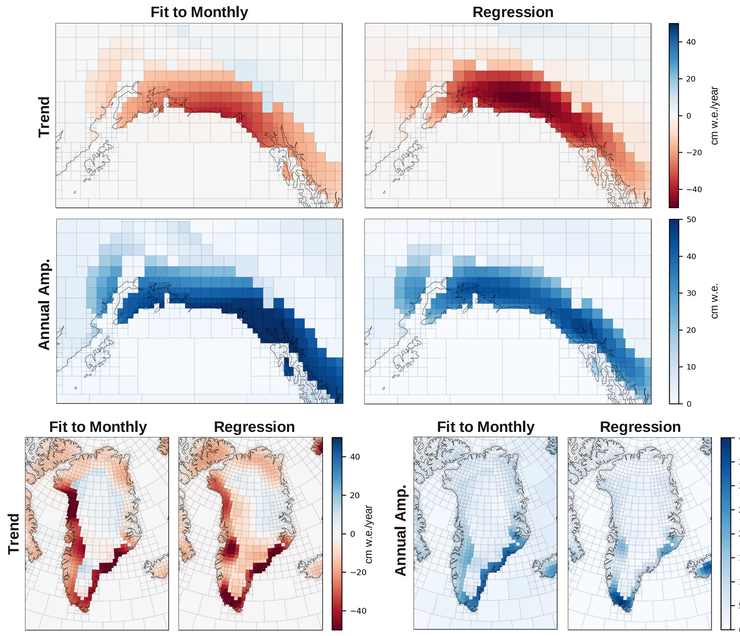


Figure 5: Recovered trends by estimating a monthly solution and then computing the trend from that solution and by directly computing trends as part of a regression model.

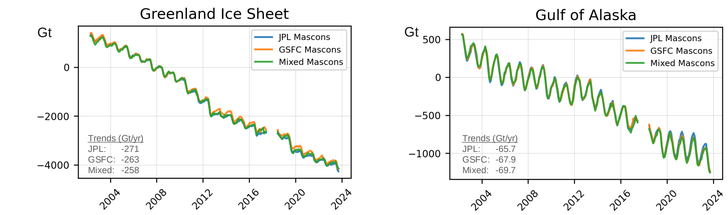


Figure 6: Preliminary ice sheet mass change for Greenland and Gulf of Alaska glaciers from the mixed resolution monthly mascons, compared with the standard JPL and GSFC mascons.

Key Take-Aways & Next Steps

- Higher resolution mascons can better resolve geographic boundaries, such as coastlines, but can become costly to estimate.
- Hierarchical mascons are flexible, allowing higher resolutions only where desired.
- We captured ¼-arc-deg mascons in Arctic and Alaskan glaciated regions while still estimating fewer parameters than a typical 1-arc-degree solution.
- We plan to investigate modelling land deformation from Little Ice Age retreat in Alaska
- We are developing a flexible toolbox for extending hierarchical mascons to any basin(s) of interest (including adaptive mascon grids and regularization strategies).

Acknowledgements

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Related Poster | **T13B-3355**, Monday afternoon: Sauber et al., "Constraining Sources of the Vertical Land Motion Component of Relative Sea Level (RSL) at the Kodiak-Katmai Portion of the Eastern Alaska-Aleutian Subduction Zone"

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