Combination of GRACE monthly gravity field solutions from different processing centers

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Introduction

Since the GRACE satellites were launched in 2002, different gravity solutions using the GRACE K–band data and GPS data have been produced by several institutions. Due to their different data processing methods and data rejection criteria, the noise level and availability of each solution are different. Combining the individual solutions can be a way to generate more consistent and reliable solutions. To realize this advantage of the combined solutions, the *European Gravity Service for Improved Emergency Management (EGSIEM)* project is to produce meaningful combined gravity solutions using data from the GRACE mission for various purposes in both science community and public. As a first step to produce combined solutions, we investigated available GRACE monthly gravity solutions and compared them without and with filtering in spatial domain. Then, we selected suitable individual monthly solutions for the combined solutions and assessed the quality of the combined solutions.

GRACE monthly gravity solutions

The available GRACE monthly gravity solutions provided officially through the ICGEM website (`http://icgem.gfz-potsdam.de/ICGEM/`) are listed in Table 1 with the labels used in this study.

Table 1: List of GRACE monthly solutions

Label	Solution Name	Institution	Max.deg.	Note
AUB02_G060* **AUB02_G090****	AIUB Release 2	AIUB	60 90	Celestial Mechanics Approach
CSR05_G060* **CSR05_G096****	UTCSR Release 5	CSR	60 96	Direct approach
DMT01_G120	DMT–1	TU Delft	120	Acceleration approach (pre-filtered)
GFZ5a_G090**	GFZ Release 5	GFZ	90	Direct approach
GRG03_G080	GRGS Release 3	GRGS	80	Direct approach (regularized)
GRZ00_G060* **GRZ00_G090**** **GRZ00_G120**	ITSG 2014	ITSG, TU Graz	60 90 120	Short arc approach (stochastic covariances)
JPL05_G060 **JPL05_G090****	JPL Release 5	JPL	60 90	Direct approach
TNJ01_G060*	Tongji Release 1	Tongji Univ.	60	Modified short arc approach

*: included in the combined solution of maximum degree 60
**: included in the combined solution of maximum degree 90

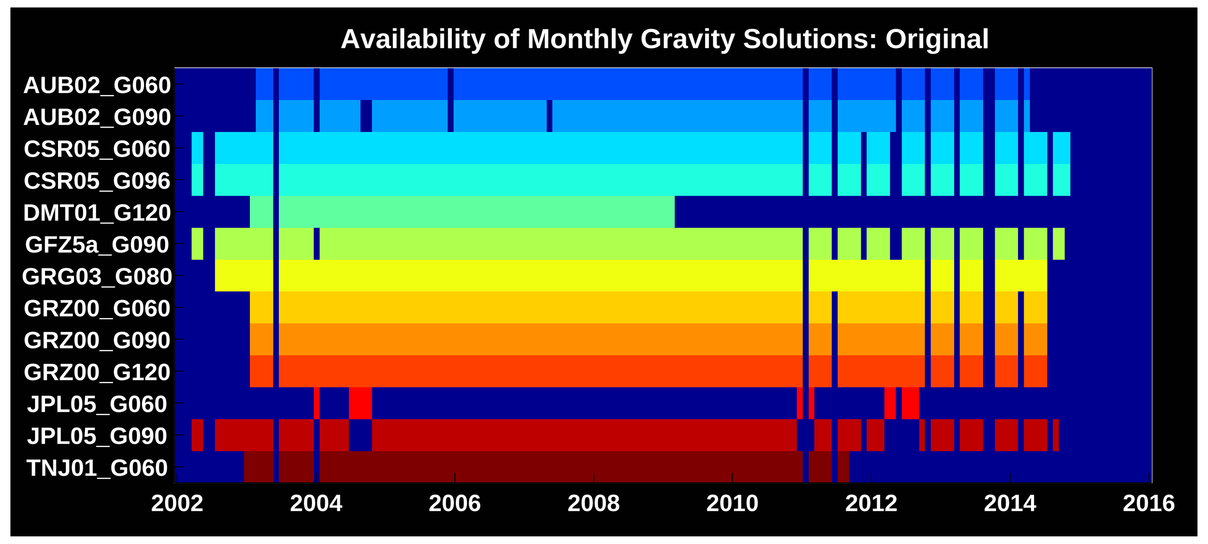

Figure 1: Availability of the GRACE monthly gravity solutions available at the ICGEM website. (The deep blue color indicates that there is no solution.)

Figure 1 shows the availability of the monthly solutions from the institutions listed in Table 1 from the year 2002 to 2014. Each solution was screened using the variability over the oceans as a quality measure. The criterion of three times of standard deviation was used twice successively in order to remove outliers. In the first screening and the second screening, 1.62% and 2.05% of the numbers of monthly solutions were excluded respectively. As shown in Figure 1, there are more data gaps before the year 2003 and after 2011. A time window from February 2003 to February 2009 was selected for comparison of the individual monthly gravity solutions. There was a previous similar study using four different solutions (Sakumura et al., 2014). In this study, we included all the solutions in Table 1 in the comparison to investigate possibility of combination with more solutions.

Comparison of the individual solutions

To compare each monthly solution listed in Table 1, we first grouped the individual monthly solutions according to their maximum degrees. To investigate signal agreement of the different individual monthly gravity solutions, we computed mean equivalent water height (MEWH) of various river basins using the individual solutions without and with filtering. Figure 2 shows the MEWHs of two different river basins: Danube basin and Amazon basin. The periodic seasonal changes of the equivalent water heights in both basins are clearly visible in Figure 2. Each figure also shows that the groups of the individual solutions are similar enough to be combined. However, the DMT01_G120 showed different behavior which is explained by the pre-filtering in their data processing, as shown in the last graph of Figure 2.

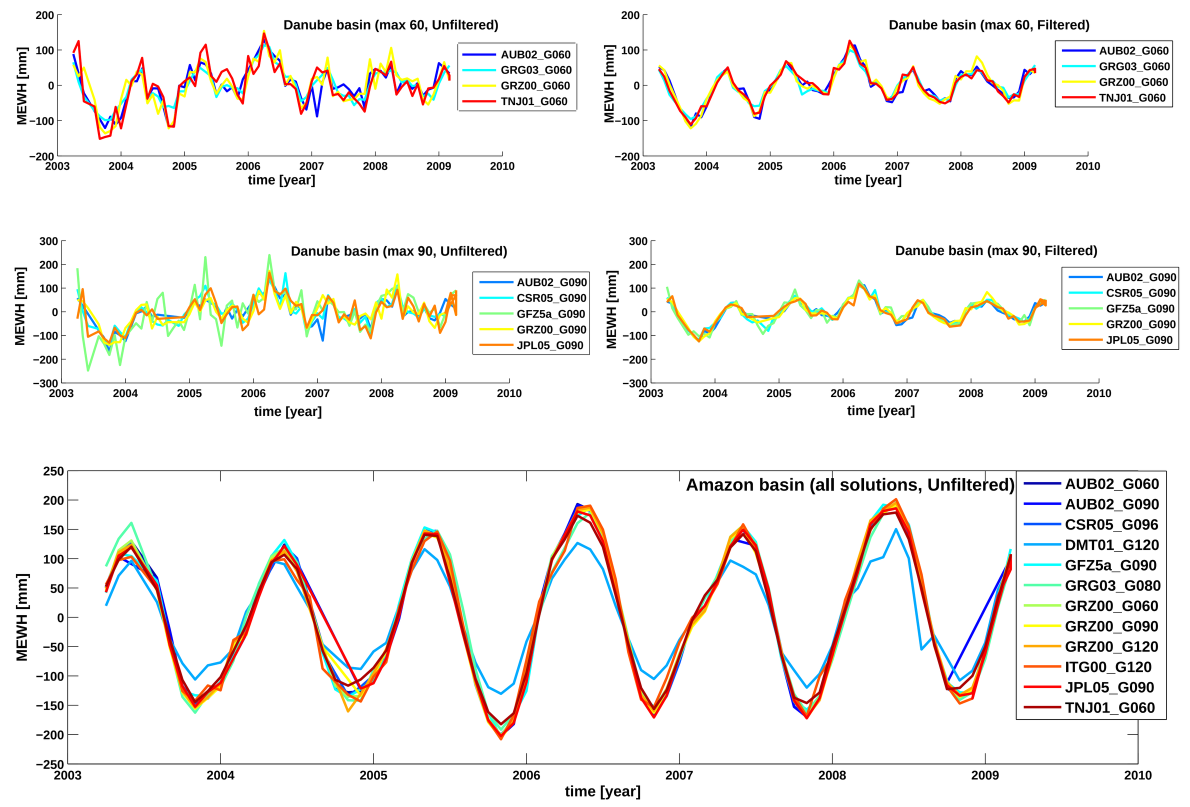

Figure 2: Change of mean equivalent water heights of Danube basin and Amazon basin calculated using the GRACE monthly gravity solutions: (top,left) maximum degree of 60, unfiltered solutions; (top,right) maximum degree of 60, filtered using Gaussian filter of 300km; (middle,left) maximum degree of 90, not filtered; (middle,right) maximum degree of 90, filtered using the same Gaussian filter; (bottom) all solutions (The solutions with higher degree coefficients than 60 were truncated at degree 60 in this graph).

We also computed the weighted standard deviations (wSTD) of the monthly gravity solutions in the ocean regions for both unfiltered and filtered solutions for noise assessment (see Figure 3). The C20 coefficients were not included in the calculation. The degree 90 solutions are more variable than the degree 60 solutions due to the noise in their high degree coefficients. Because the GRG03_G080 solutions showed different behavior distinctly, we did not include those solutions in the combination.

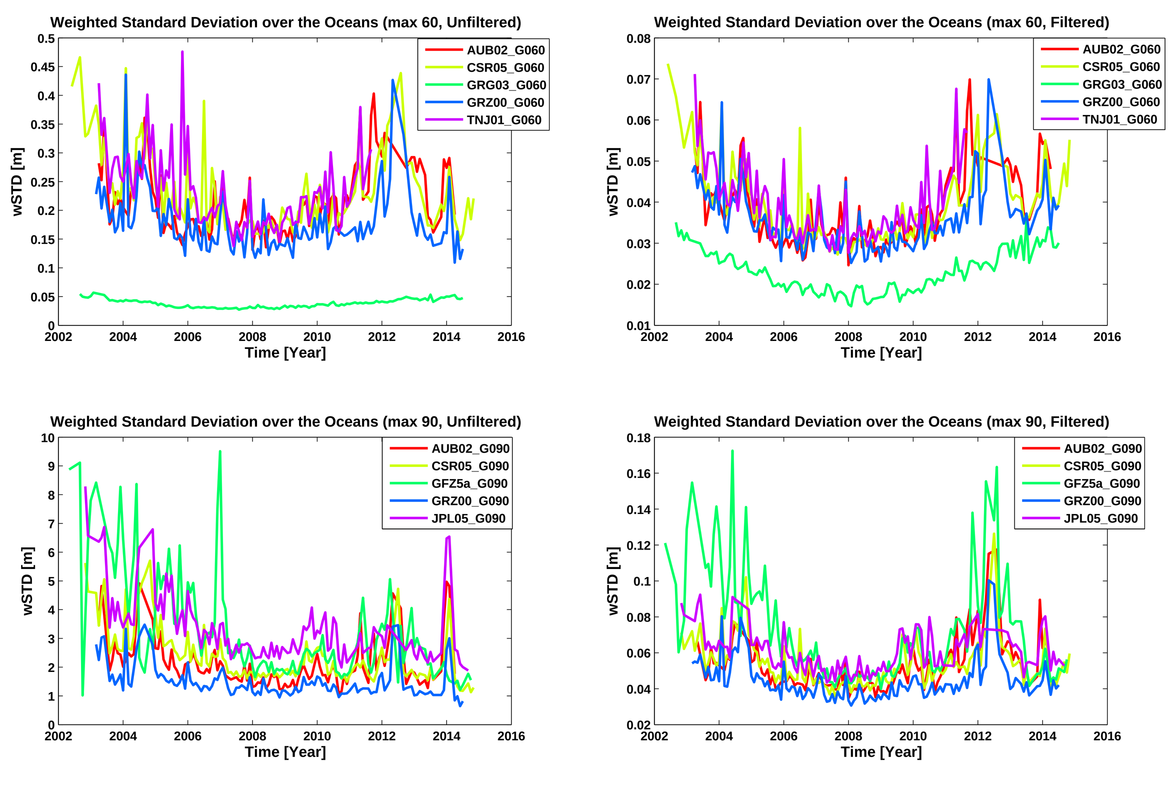

Figure 3: Weighted standard deviations over the oceans from the individual monthly gravity solutions. (top,left) maximum degree of 60, not filtered; (top,right) maximum degree of 60, filtered using Gaussian filter of 300km; (bottom,left) maximum degree of 90, not filtered; (bottom,right) maximum degree of 90, filtered using Gaussian filter of 300km.

Combined solutions

Through the comparison of each monthly solution, we selected [AUB02_G060, CSR05_G060, GRZ00_G060, TNJ01_G060] for degree 60 combined solution and [AUB02_G090, CSR05_G096, GFZ5a_G090, GRZ00_G090, JPL05_G090] for degree 90 combined solution. The CSR05_G096 was truncated to degree 90. The combined solutions were generated by calculating the arithmetic mean of the involved individual solutions without weights. Figure 4 shows that the combined solutions in both 60 degree and 90 degree cases, labeled COMBINED60 and COMBINED90 respectively, improve the solutions in terms of variability over the oceans.

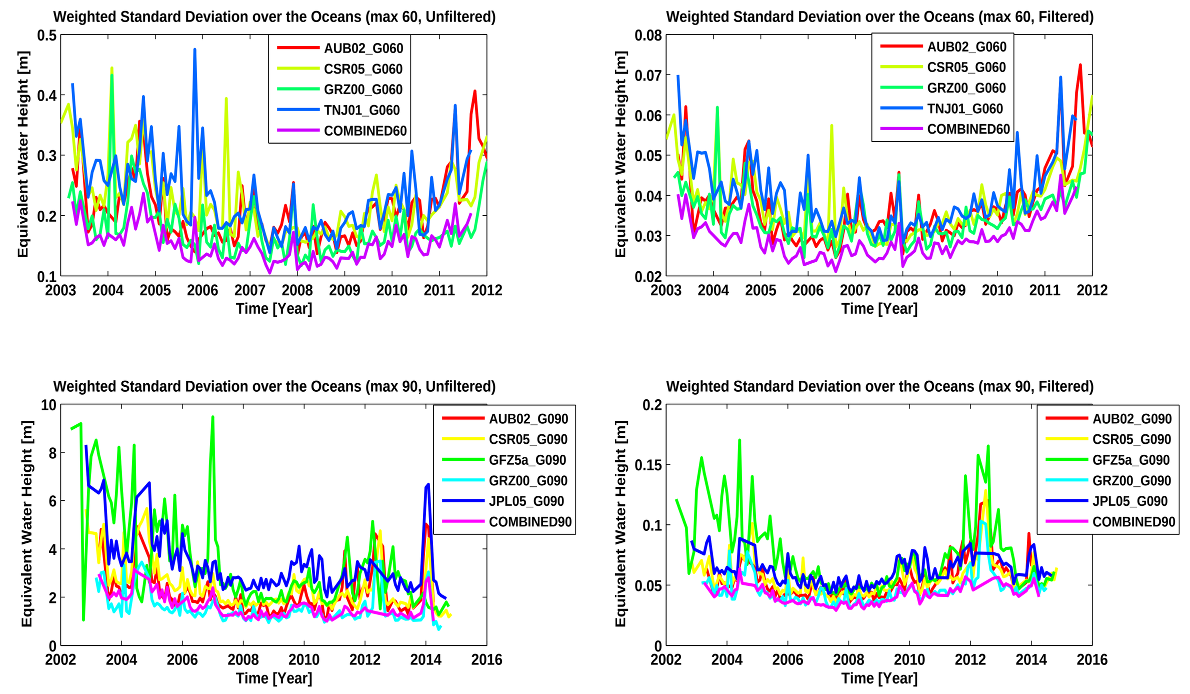

Figure 4: Equivalent water heights of each individual solution involved in the combined solutions and the combined solutions of the individual solutions. (Top, left) maximum degree of 60 and unfiltered; (Top, right) maximum degree of 60 and filtered by Gaussian filter of 300km; (Bottom, left) maximum degree of 90 and unfiltered; (Bottom, right) maximum degree of 90 and filtered by Gaussian filter of 300km.

In Figure 5, the MEWHs of Greenland from the individual solutions and the combined solutions and their decreasing trends from linear regression are shown. The standard deviations of combined solutions, written in the legend of each graph, are mostly smaller than those of the individual solutions. However, it is also clear that the noise of the individual solutions strongly affects the combined solutions. Even some of the individual solutions during the periods with noisy GRACE measurements can be better than the combined solution. Weights on the individual solutions can make the solutions less affected by the noise of the individual solutions in certain periods.

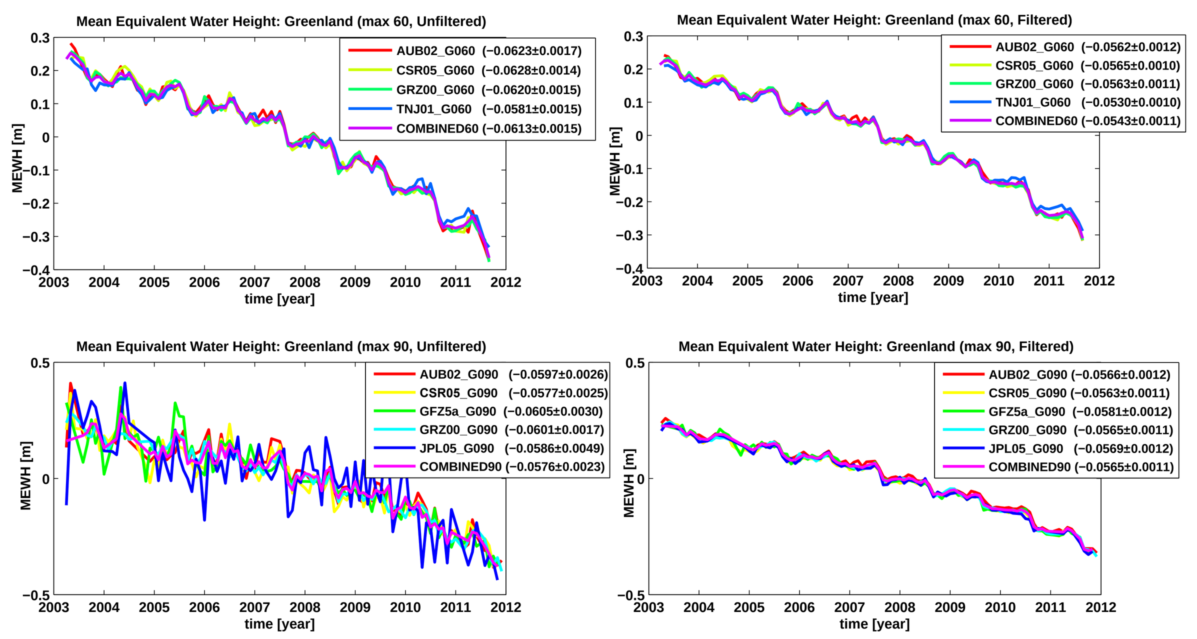

Figure 5: Change of mean equivalent water heights in Greenland from each individual solution and the combined solutions: (Top, left) maximum degree of 60 and unfiltered; (Top, right) maximum degree of 60 and filtered by Gaussian filter of 300km; (Bottom, left) maximum degree of 90 and unfiltered; (Bottom, right) maximum degree of 90 and filtered by Gaussian filter of 300km. (The slopes of decreasing trends from linear regression for each solution are written after the labels of the solutions in the legends.)

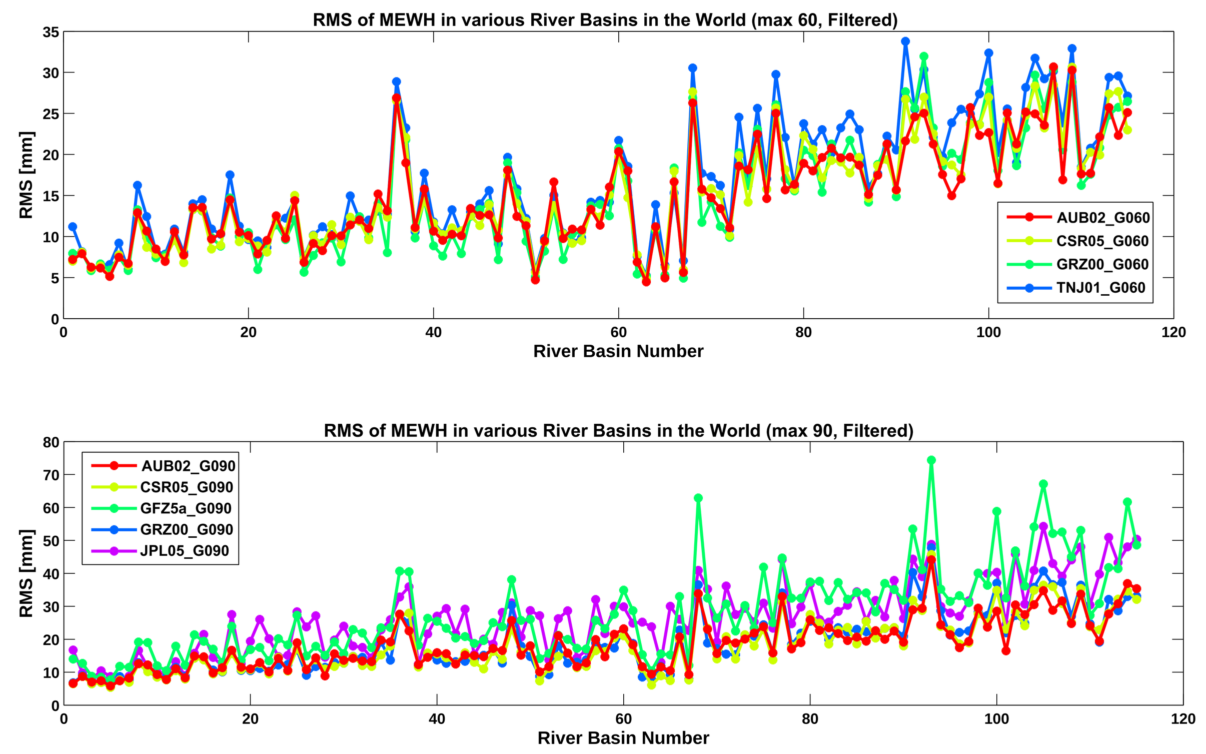

Figure 6: RMS of MEWH of the various river basins in the world for (Top) degree 60 solutions (Bottom) degree 90 solutions. (The river basin number in the x-axes is the numbers assigned to the river basins in the world. These river basin numbers were sorted by the size of river basin in descending order.)

Figure 6 shows the RMS of each individual solution with respect to the combined solution using the MEWH of the river basins in the world. It indicates how much the individual solutions are deviating from the combined solution, which is their arithmetic mean. The overall relative levels of deviations among the different individual solutions in Figure 6 are similar to those in the variability of the wSTD over the oceans for each individual solution, shown in Figure 3. Figure 6 also shows the tendency of increasing RMS when the size of river basin gets smaller. It is due to the much smaller signals in the smaller river basins. An example of that tendency was already shown in Figure 2. The huge Amazon river basin had smooth curves even without filtering whereas the Danube river basin, which is smaller than the Amazon basin, was significantly smoothed after filtering.

Conclusions

To generate combined solutions of each individual GRACE monthly gravity solution by different institutions, we investigated the agreement of the signals using MEWH from each individual solution and the noise levels of the individual solutions using wSTD over oceans. The individual solutions showed similar behavior except for the pre-filtered solutions. The combined solutions were generated by calculating the simple arithmetic mean without weights. It was shown that the combined solution can improve the solutions, especially in terms of noise reduction. Empirical weights can probably improve the combined solutions further.

References

Sakumura, C., S. Bettadpur, and S. Bruinsma. Ensemble prediction and intercomparison analysis of GRACE time-variable gravity field models. *Geophys. Res. Lett.*, 41:1389–1397, 2014. DOI: 10.1002/2013GL058632

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