Technical Note 04

Usage Guidelines for GFZ RL03 and JPL RL02 GRACE Gravity Fields & Atmosphere/Ocean Background Models

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Purpose:

The purpose of this note is to recommend usage guidelines for the currently available monthly Level-2 GSM product series. Following these guidelines is essential if long-term trends/slopes in the current time-series are to be interpreted because these Level-2 GSM product series are conditional upon errors in slopes of the non-tidal atmosphere and ocean model used as background model in GRACE processing.

The following series (and only these) are relevant for this note:

- CSR Level-2 Products: Release 01 (CSR-RL01, April 2002 to present)
- GFZ Level-2 Products: Release 03 (GFZ-RL03, February 2003 to present)
- JPL Level-2 Validation Products: Release 02 (JPL-RL02, February 2003 to present)

Recommendation:

(i) ***Over land areas***, if the secular or inter-annual variability within the GFZ-RL03 and JPL-RL02 product series are of interest, then the summed product (**GSM+GAB**) must be used. This summed series is free of the false trend/slope shown by the GSM-only time-series.

(ii) Users of GRACE Level-2 products ***over oceans*** should normally analyze the summed product (**GSM+GAC**). This combination represents the total long-period oceanic variability sensed by GRACE and is also free of the false trend/slope in the relevant GSM-only time series.

(iii) Do not use the degree 0 and degree 1 terms of the GAB and GAC products.

Note: While recommendation (ii) and (iii) are generally valid for all product releases from any of the SDS centers (CSR, GFZ, JPL), recommendation (i) is an interim solution specific for GFZ-RL03 and JPL-RL02 product series only. The series CSR-RL01 and the past releases from GFZ (i.e. RL01, RL02) and JPL (RL01) are not affected and do not need to consider recommendation (i). Same shall hold for future releases from GFZ and JPL.

Background:

The GRACE Level-2 products, labeled GSM-2_*, represent mean updates to the gravity field of the Earth over the applicable GRACE data span and are relative to a selection of background gravity field models. Details can be found in the *GRACE Level-2 Gravity Field User Handbook (GRACE 327-734, Rev. 2.1, May 2, 2006).* Thus a sequence of GSM-2 products represents

(i) geophysical phenomena left un-modeled in the background – most notable of which at present is continental hydrology;
(ii) errors in the long-period variations within the background models – e.g. atmosphere or ocean; and
(iii) errors of gravity field data processing.

This note discusses the impact of a specific case of (ii) on interpretation of long-term evolution of Earth gravity field estimates from GRACE.

As part of the background models, a combined model for atmospheric pressure variability and non-tidal ocean variability is used for de-aliasing. This model output is denoted as the Level-1B product AOD1B in GRACE processing. The AOD1B product is a daily file of 6-hour time series of geopotential harmonics. The Level-2 GAC-2_* product is its average over the GRACE solution span. The GAA-2_* and GAB-2_* products are atmosphere and ocean-only sub-components of the GAC-2_* product.

There have been two versions of AOD1B products used in creating GRACE Level-2 products available presently to the users. The AOD1B_RL01 has used ECMWF 6-hr atmosphere models with the PPHA barotropic ocean model. The AOD1B_RL03 has used the same ECMWF 6-hr atmosphere models with the OMCT baroclinic ocean model. These product versions are described in detail in the *AOD1B Product Description Document (GRACE 327-750, Rev. 2.2, April 26, 2006).*

In both of these AOD1B products, spatial distribution of mass loads from model outputs are converted to spherical harmonics of the Earth gravity field. The degree-0 and 1 terms from this output are set to zero and the remainder is used as background model in GRACE data processing.

The AOD1B_RL01 background model has a small (but finite) long-term drift. In contrast, the AOD1B_RL03 background model has a large slope in the total mass of the ocean due to (i) freshwater run-off between 2001 and 2004 and (ii) the change to mass conservation on January 1, 2005 using an ocean mass value which causes a jump in the resulting C00 value (see *AOD1B Product Description Document*). When degree 0 & 1 terms are dropped in GRACE data processing, the resulting geopotential field contribution has a small slope over the ocean, but in compensation, there is now a very large slope over the land.

The contrast between the two cases is shown in Figures 1.a-b, which show global slope from a simple slope/intercept and annual/semi-annual fit to the GAC time series (the monthly averages of the 6-hr AOD1B products).

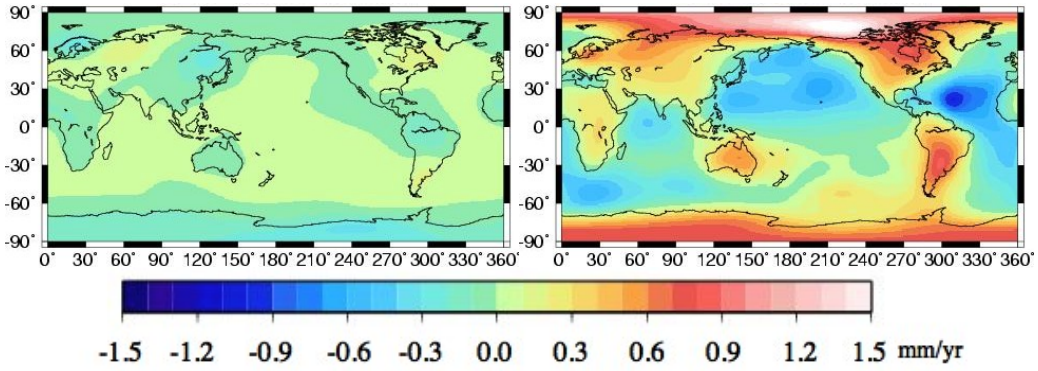

Figure 1 Estimates of geoid height slope from AOD1B-RL01 (1.a - left) and AOD1B-RL03 (1.b - right), using monthly average fields from November 2002 through October 2005. Degree 0 and 1 terms from the harmonic expansions have been dropped from the calculations.

The GRACE Level-2 processing methodology is such that any long-term drifts or errors introduced in the background models will be compensated by an equal and opposite drift in the monthly gravity estimates. Therefore, in response to the apparent false trend in the ocean component of the AOD_RL03 background model (Figure 1.b), the GRACE geopotential estimates (i.e. the GSM products) show a corresponding corrective slope.

Of the available Level-2 products, the GFZ-RL03 GSM products and JPL-RL02 GSM products are susceptible to this effect, since these product series are based on the AOD_RL03 background model. The impact of the corrective action is described in the next section.

Correcting Impact on Products:

In the following the impact of neglecting or re-adding the GAB product to the GFZ RL03 (or JPL RL02) GSM time series is shown for the time period January 2004 until December 2005.

For each month a mean oceanic AOD1B field is computed including all available days within the particular month (the GAB product). Three different AOD1B products have been investigated: AOD_RL01 (using the mass conserving barotropic PPHA model), AOD_RL03 (using the non mass conserving baroclinic OMCT ocean model) and AOD_RL04 (a test version of OMCT assuming mass conservation). Then, for each month the synthesis of the GAB spherical harmonics up to degree and order 100 is computed on a 1x1 degree grid. Degree 0 and 1 term are ignored, no smoothing is applied. From the time series of the 24 monthly grids the RMS and a trend in each pixel is determined. Prior to the determination of the trend a mean value is removed in each pixel. Figure 2 shows the resulting RMS variability and the secular trend in terms of geoid height.

It can be seen that in the common 2-year period all products show comparable spatial distribution and magnitude for the oceanic signal. However, there are also significant differences:

- The PPHA model has no variability in the northern oceans because it does not provide output above 65 degrees latitude. In contrast, OMCT provides signals in the Artic (left panel).
- AOD_RL03 shows a larger variability in the Baltic Sea because the AOD_RL03 bathymetry has no connection between the Baltic Sea and the North Atlantic. This is obviously corrected in AOD_RL04. The spatial distribution and amplitude of the variability is comparable between AOD_RL03 and AOD_RL04 (middle and bottom left).
- The AOD_RL03 oceanic product displays additional trends compared to AOD_RL01 in the Northern oceans, the Hudson Bay and in the Baltic Sea (top and middle right).
- There are significant spurious trends on land visible (e.g. South America, Antarctica, Australia) which do not exist in AOD_RL01 and AOD_RL04 (right panel).
- Except for the secular signal in the northern oceans these trends have vanished in the AOD_RL04 product which indicates that these trends are a spurious feature of the freshwater flux in AOD_RL03 (middle and bottom right).
- Consequently, the mass conserving AOD_RL01 and AOD_RL04 products give comparable variability and trends, except for the northern oceans, which are not modeled in AOD_RL01.

In a next step from 23 monthly GFZ RL03 GSM gravity fields, all based on the non mass conserving RL03 AOD1B background products and covering the period February 2003 until December 2004, the RMS variability and the linear trends are determined as described for the GAB products. The top row of Figure 3 shows the result for the GSM products, the bottom row for the sum of the GSM and GAB product to take into account the spurious AOD1B RL03 linear trends on land. Thus, the sum of GSM+GAB gives the non-modeled gravity signal over land (e.g hydrology) and oceans plus the averaged monthly short-term mass variations over the oceans.

The RMS variability clearly shows the additional signals over the oceans introduced by the GAB products (as expected). Over the continents no change in the variability is visible.

The derived linear trends differ qualitatively and quantitatively. Over the northern oceans the re-adding of the GAB introduces the quite large positive trend already seen in Figure 2 (middle row, right). The same is observed in Hudson Bay and for Antarctica (the white color indicates trends larger the maximum of the color scale of 3 mm/year) amplifying the trends observable already in the GSM-only case. Over the continents on the southern hemisphere large negative trends of up to 6-7 mm/year are visible which are obviously identical in both cases (GSM-only and GSM+GAB). In the southern ocean the spatial pattern of the secular trend signals is changed when introducing the GAB product consistent with the sign of the trends from the GAB products only visible in Figure 2 (middle row, right).

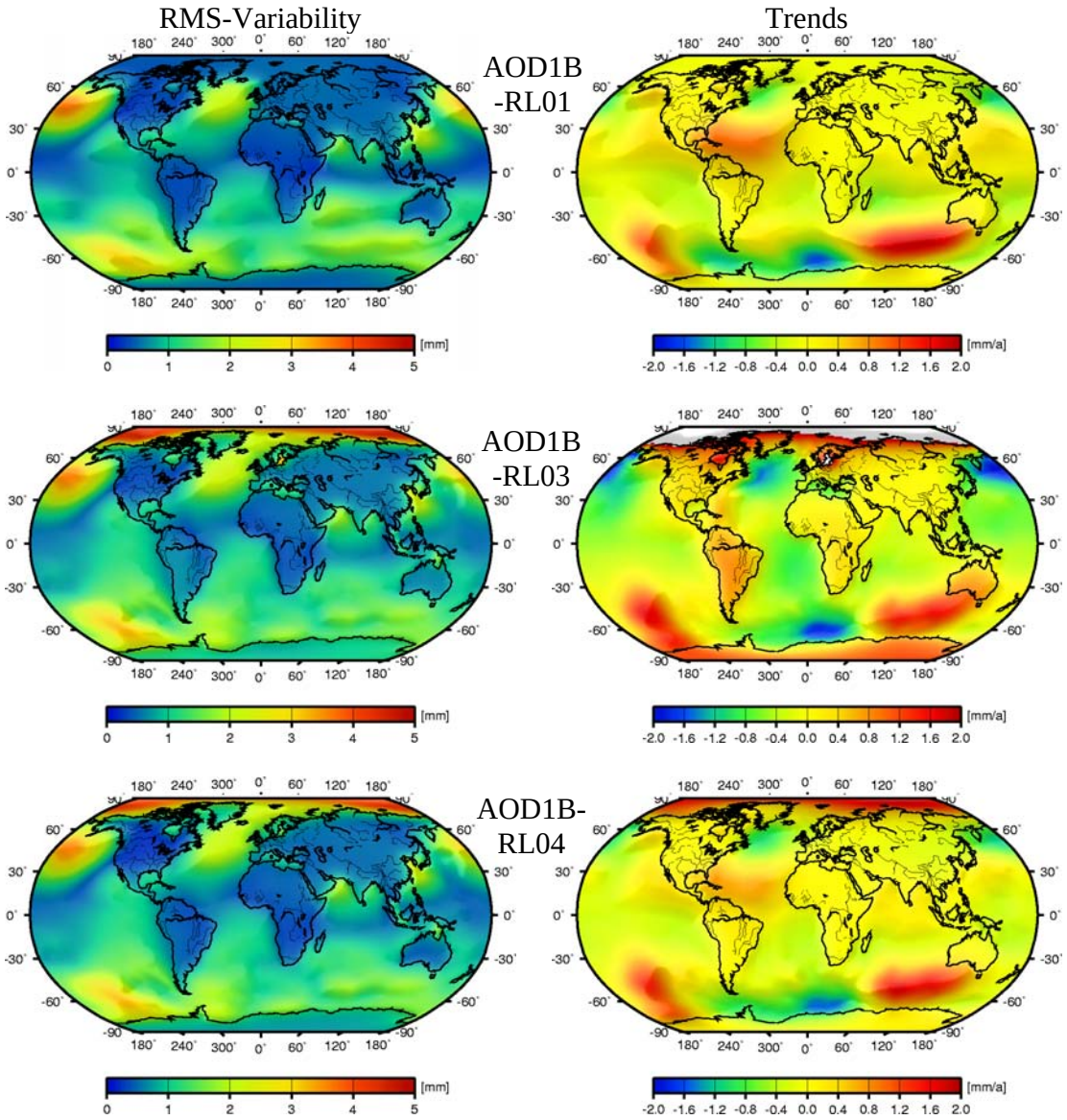

Figure 2 RMS variability and trends in terms of geoid heights of 24 monthly averaged AOD1B products (only oceanic part) between January 2004 and December 2005 derived from RL01 (PPHA model, top row), RL03 (non mass conserving OMCT model,middle row) and RL04 (mass conserving OMCT model, bottom row) on a 1x1 degree grid (pixel wise mean removed, maximum degree 100, C20 variations included, degree 01 and 1 terms ignored, no smoothing).

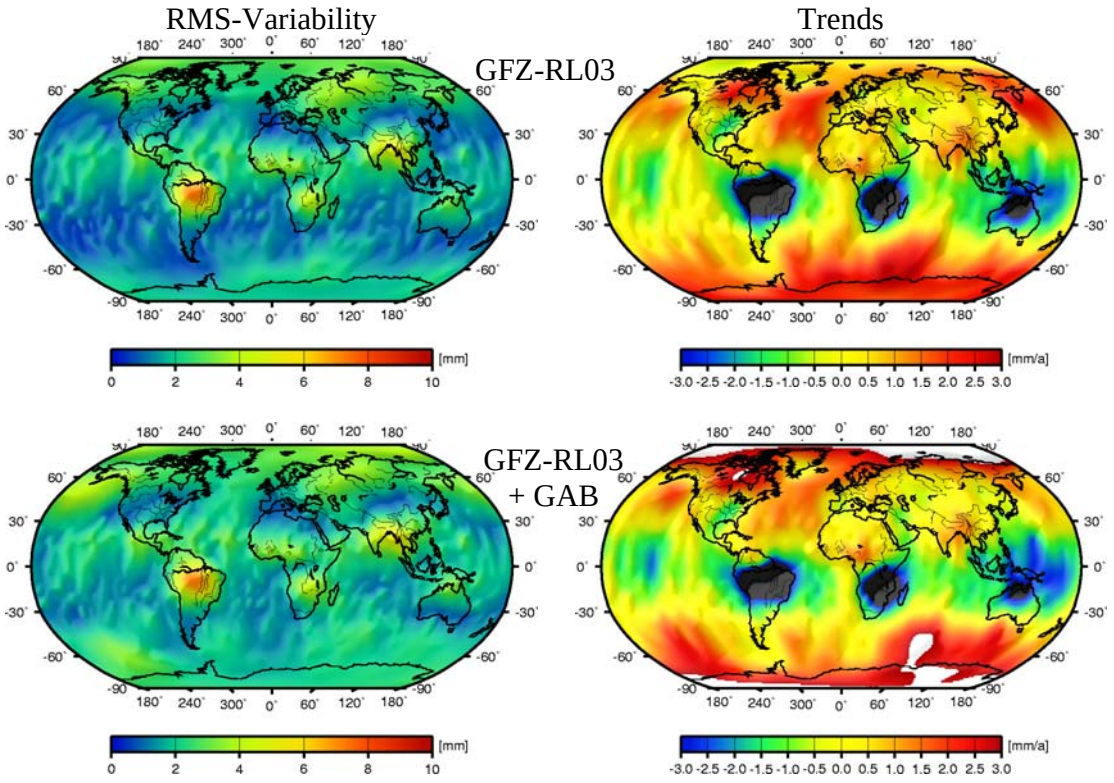

Figure 3 RMS variability and trends in terms of geoid heights of 23 monthly GFZ-RL03 products between February 2004 and December 2005 versus their mean (top row). Same results for in the bottom row for the GAB-corrected GFZ-RL03 product (sum of GSM and GAB files). Gaussian averages with 500 km filter radius, C20 included.

Finally, 19 GFZ RL03 GSM and GSM+GAB products have been compared with 19 CSR RL02 GSM products (the latest non-public reprocessed CSR solution still based on RL01 AOD1B products), both commonly available in the period February 2003 until April 2005. Missing months are June 2003 (accelerometer data gap), January 2004 (not yet processed at GFZ) and June until October 2004 (4d repeat orbit). Figure 4 shows the RMS variability and the linear trends for the GFZ GSM RL03 products (top), the GFZ+GAB corrected RL03 products (middle) and CSR RL01 solutions (bottom). Comparing the GSM-only solutions (top and bottom rows) indicates that the GFZ RL03 solutions has some larger secular geoid changes in the northern ocean and over Antarctica which are not present in the CSR solutions. These are introduced by the oceanic part of the AOD1B RL03 product. Restoring the GAB product reduces the drift to the order of magnitude seen in the CSR RL02 time series. In general, the trends over land from the GFZ GSM+GAB are much closer to the CSR solutions than when ignoring the GAB spurious signals (correlation increases from 0.81 for the GFZ-RL03 vs. CSR-RL02 case to 0.87 for the GFZ-RL03+GAB vs. CSR-RL02 case).

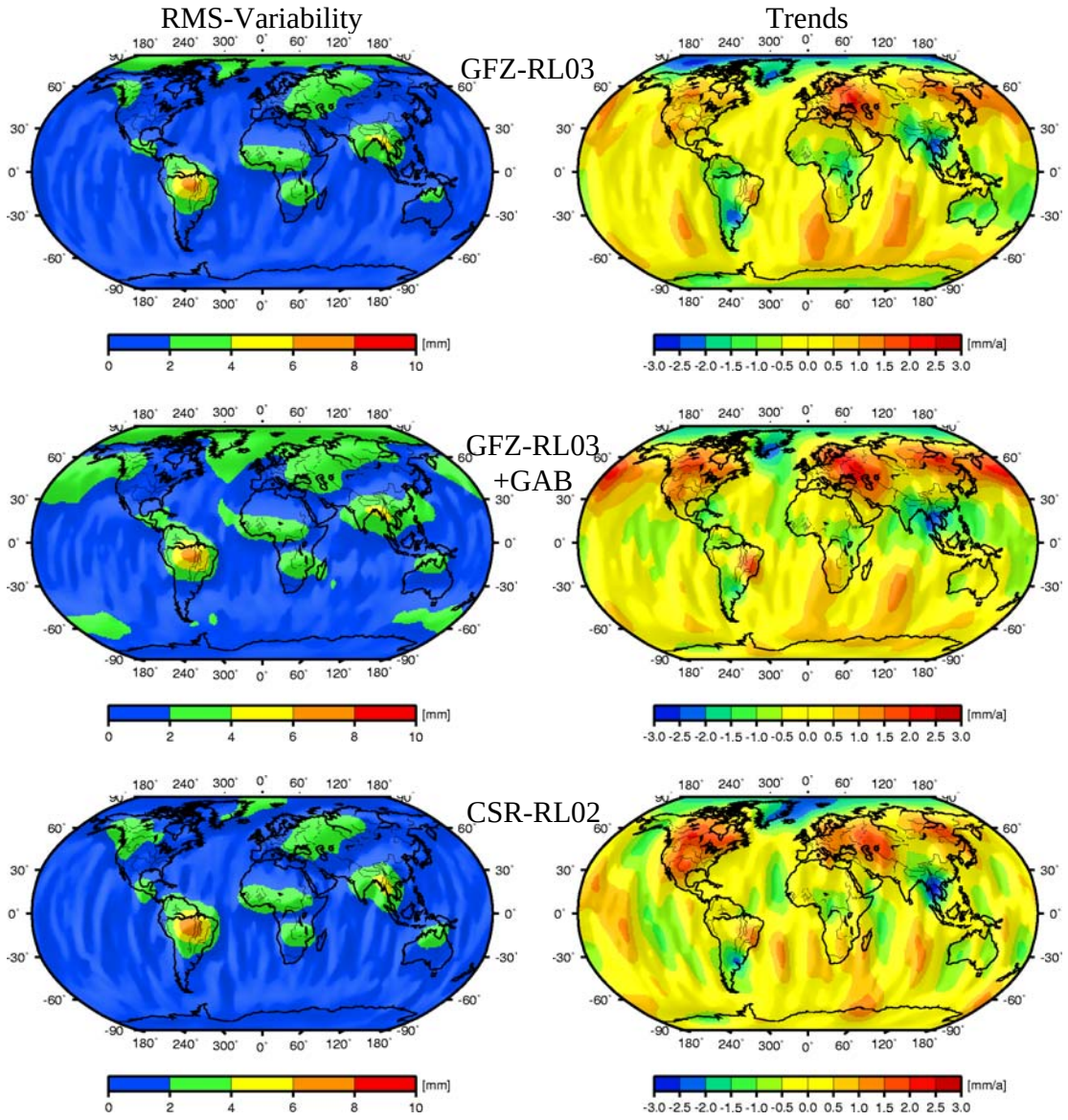

Figure 4 RMS variability and trends in terms of geoid heights of 19 monthly GSM products between February 2003 and April 2005 versus their mean. Top row (GFZ RL03 GSM-only models), middle row GFZ RL03 GSM+GAB corrected models and bottom row CSR RL02 GSM products. Gaussian averages with 500 km filter radius, C20 included.

Conclusion:

The AOD1B RL03 product shows significant trends for the North and South Pole region, the Hudson Bay and the Baltic Sea. While the trend in the northern oceans seems to be a realistic signal, the other variations are obviously artificially introduced by the non mass conserving approach and the change to mass conservation on January 1, 2005. In contrast, the mass conserving AOD1B RL04 test version is much more consistent with AOD1B RL01 except for the Arctic Ocean, where the latter provides no signal.

Restoring the GAB products to the GSM RL03 GFZ (and RL02 JPL) gravity fields helps to reduce the linear trends over the northern ocean and all land areas. For an example based on GFZ-RL03 models the spatial correlation over land with the corresponding CSR-RL02 models increases from 0.81 to 0.87.

Therefore it is strongly recommended to use the GSM+GAB products when analyzing continental geophysical features such as hydrological signals or ice mass variations from GFZ-RL03 and JPL-RL02 GSM product files.

GLOSSARY:

All details of product definitions are provided in the following relevant documents:

(i) AOD1B Product Definition Document (JPL 327-750)
(ii) Level-2 Product User Handbook (JPL 327 734)
(iii) Product Specification Document (JPL 327-720)

Certain key-words are described below:

GSM: Refers to the monthly gravity field estimate product from GRACE

AOD: Is the 6-hr time series representing non-tidal atmospheric and oceanic variability

GAC: Is the monthly mean of the AOD time-series, as used in the GRACE data processing for that month.

GAA: Is the monthly average of the atmospheric pressure time series sub-component of the AOD time series.

GAB: Is the monthly average of the oceanic variability time series sub-component of the AOD time-series.