Review about the paper

GOCO06s – A satellite-only global gravity field model

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General remarks:

This paper describes the generation and the characteristics of the satellite-only gravity field model GOCO06s. The computation of this model was done in a joint work by the partners of the GOCO consortium. GOCO06s has been already published last year for the user community on the ICGEM data base and on the GOCO webpages. This paper now accompanies the publication of the GOCO06s data set and will help users to understand the background of this model. GOCO06s is one of the best global satellite-only gravity field models currently available and it benefits especially from the matter of fact that data from practically all recent gravity satellite missions were included and combined via a refined combination technique. I appreciate especially that the authors published along with the model very valuable supplementary material comprising the full variance-covariance matrix of the static spherical harmonic coefficients and estimated co-seismic mass changes. The content and the outline of this paper is convincing for me. The paper is written in good English wording. I recommend only minor revision according to my specific remarks below:

Specific remarks:

Page 2, lines 34/35:

- The statement “Starting with the dedicated CHAllenging Minisatellite Payload satellite mission … different LEO satellites were tracked by GPS” is not 100% correct. There were LEO satellite missions before CHAMP with GPS receivers onboard, for instance Topex/Poseidon. CHAMP was the first satellite gravity mission with a GPS receiver onboard. Please modify this statement accordingly.
- Please correct this typo**: Reigbar** et al. 1999 → **Reigber** et al. 1999, please correct this name also in the reference list.

Page 2, line 48:

The reference Battrick 1999 is right. Nevertheless, I suggest to give a more recent reference in addition to Battrick 1999, for instance Floberghagen et al. 2011:
Rune Floberghagen, Michael Fehringer, Daniel Lamarre, Danilo Muzi, Björn Frommknecht, Christoph Steiger, Juan Piñeiro, Andrea da Costa: Mission design, operation and exploitation of the gravity field and steady-state ocean circulation explorer mission, J Geod (2011) 85:749–758, DOI 10.1007/s00190-011-0498-3

Page 3, line 83 – 85:

The statement “Basically, GRACE normal equations processed by GFZ (Dahle et al., 2019) are combined with GOCE normal equations assembled with the so-called direct approach (Bruinsma et al., 85 2014; Pail et al., 2011) and SLR normal equations.” is not fully correct, since some of the GRACE and SLR normal equations used for the DIR-models were generated by CNES/GRGS. I suggest to modify this sentence as follows:

Basically, GRACE normal equations processed by CNES/GRGS (Bruinsma et al. 2010) or GFZ (Dahle et al., 2019) are combined with GOCE normal equations assembled with the so-called direct approach (Bruinsma et al., 2014; Pail et al., 2011) and SLR normal equations.”

The additional reference is:
Bruinsma, S. L., J. M. Lemoine, R. Biancale, and N. Vales (2010), CNES/GRGS 10-day gravity field models (release 2) and their evaluation, Adv. Space Res., 45(4), 587–601, doi:10.1016/j.asr.2009.10.012

Sections 2.2 and 2.3:

I see a contradiction regarding GRACE between the sections 2.2. and 2.3:

In section 2.2 the GRACE contribution is described. Here among others it is said: “The normal equations feature a static part parametrized up to degree/order **200** and **secular and annual variations up to degree/order 120**…”

In contrast, in section 2.3 GRACE is mentioned again, but here as one of the LEO satellites and you write: “For CHAMP, GRACE, TerraSAR-X, TanDEM-X and SWARM we set up the normal equations up to degree and order **120**…” and “For all LEO satellites, **only the static** gravity field was modeled…”
I think, GRACE is mentioned in section 2.3 by mistake. Therefore, you should remove GRACE from section 2.3. Then, in section 2.2 some sentences about the used GRACE kinematic orbit positions should be added, similar to such for the other LEOs in lines 143 – 145.

Section 2.2, 2.3 and 2.4:
You estimated temporal gravity variations for GRACE and SLR only. But its known that other satellites like CHAMP, GOCE (here the long wavelengths only based on the kinematic orbits) and Swarm were also sensitive for temporal gravity field variations. You mentioned this in principle in the introduction. Do you think it makes sense to include both satellites here to improve the estimates of the long wavelengths, for instance in a future upgrade of GOCEO06s? Could you please add some sentences about this question e.g. in section 2.3 or in the introduction?

Page 7, line 174:

I suggest to give the obtained relative weights. This would be of interest to others users which are processing SLR data.

Page 8, formulae (11) and (12):
Could you please also give the relative weights applied for GOCE, GRACE and the LEO satellites?

Page 8, lines 201/202

You said, "… the SLR system of normal equations was artificially down weighted by a factor of 10 in each iteration step." Did you try other factors for down weighting? If you used only one factor you can never be sure that your empirical down weighting factor is optimum. Please comment.

Page 15, line 320 and Figure 7:

"… evaluated close to the epicenter of the 2004 Indian Ocean earthquake…" Please give the location of this point. Is it east or west of the fault line? Please give the precise geographical coordinates ore indicate the position in the map of figure 6a.

Figure 7:

The caption for this figure is inaccurate since the location is not mentioned. I suggest to write: "Comparison of estimated secular variation from GOCO05s, GOCO06s (including estimated co-seismic mass change) and filtered GRACE monthly solutions in terms of equivalent water height (EWH) **for a location close to the epicenter of the 2004 Indian Ocean earthquake (c.f. figure 6a)**

Page 16, lines 331 – 341

Your discussion about figure 8 is partially not clear for me:

You statement "The other large differences between the compared models in degrees below 60 are primarily explained by the respective reference epochs (for example, 2010-01-01 for GOCO06s and 2010-09-01 for GOCE DIR6)" is a little bit misleading: Even the spectra of Goco06s and GOCE DIR6 are closely together below degree 60. Please discuss e.g. the difference between GOCEO06s and GOCE TIM5 which is significantly larger.

Your statement "Concerning the GOCE gradiometer reprocessing we can see improvements from degree 150, where these data start to dominate the solutions…." is unclear for me, since the difference spectra of all five compared models are almost the same. Please explain better what you mean.

Page 17, figures 8 and 9:

- In the captions of both figures it's said that "8 degree polar cap (are) excluded" in the degree variances. This statement is unclear for me. Does it mean, that you start to exclude polar gap components beyond degree 8 up to the maximum degree? What is in detail excluded, some low order coefficients? Please explain. I suggest to explain the exclusion of the polar gaps for the spectra within the text of chapter 4 and not in the captions.

- Beside of the polar gap comment I ask you to modify the captions as follows:

  Figure 8: Difference degree amplitudes of various state-of-the-art satellite-only models to the combined model XGM2016

  Figure 9: Difference degree amplitudes to GOCO06s (solid lines) and the corresponding formal errors (dashed lines) for the individual GOCO06s components…

Page 18, lines 372 – 374:

“In addition, an independent GRACE/GOCE satellite-only combination model namely GOCE-DIR6 is used for comparisons, which to a large extent is based on the same amount of GRACE and GOCE data as GOCO06s (Förste et al., 2019)”

This sentence is inaccurate and the place of the mentioned reference is disadvantageo. I suggest to rewrite as followes:

“In addition, an independent SLR/GRACE/GOCE satellite-only combination model namely GOCE-DIR6 (Förste et al., 2019) is used for comparisons, which to a large extent is based on the same amount of SLR, GRACE and GOCE data as GOCO06s.”

Page 2, Table 2:

Which maximum degree was used for the various Earth’s gravity field models? Please give the number. It should be the same in all cases. If not, please discuss.

The item “annual/secular variations” and the related model is given in brackets there. Why?