

Report on our activity in the framework of the grant ESA PECS C 98056 Final report

Contributors to this report

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This grant project began in September 2007. It consisted of 4 areas of simulations and preparation for the actual GOCE data (which were made available in mid 2010, after a delay), three submitted AO's, accepted and supported by ESA in 2007 in the frame of ESA GOCE; one item (the first in the following list) has occurred as a result of consultations with Dr. Rune Floberghagen (at that time ESA ESTEC, Noordwijk), GOCE Project Manager. The last item, geomorphologic use of EGM 2008 for Himalaya, included into (4), was wholly unexpected geo-application. Meantime GOCE data has appeared available and we utilized them – measurements from the on-board gradiometer in the form of the gravity field model EIGEN 6C and the kinematic orbits of GOCE for the inversion to the gravity field parameters to degree/order roughly 100.

The following items are studied:

1. *Orbit choice and tuning for GOCE measuring phases*

(responsible person: Aleš Bezděk)

2. *Novel geodetic computational methodologies*

(responsible person: Josef Sebera)

3. *Comparison of detailed satellite and terrestrial data*

(responsible person: Pavel Novák).

4. *Detection of hidden impact (meteoritic) structures on the Earth surface*

(responsible person: Jaroslav Klokočník).

Now expanded to geomorphology, too.

The **financial plan for 2011** and its fulfilment is added.

1. Orbit choice and tuning for GOCE measuring phases.

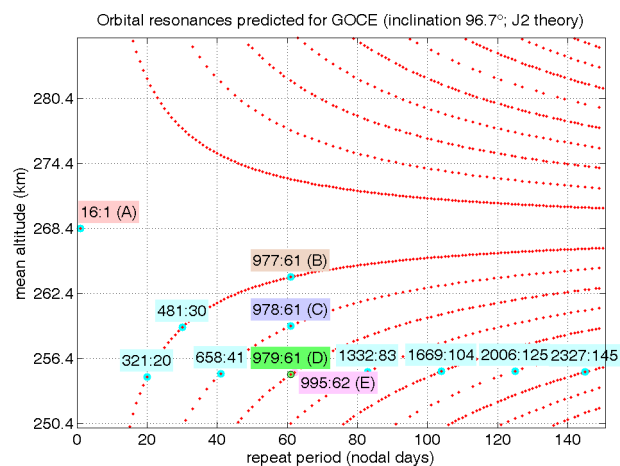
(prepared by A. Bezděk, J. Klokočník, and J. Kostelecký)

Starting in 2008, this item has occurred as a result of consultations with Dr. Rune Floberghagen, GOCE Project Manager, and his colleagues.

Using the full-scale numerical propagator, we investigated the satellite's free fall from the initial injection altitude of 280 km down to the first measurement phase altitude. During this decay phase the satellite passed below the 16/1 resonance (268.4 km). The effect of this resonance, together with the uncertainty in the solar activity prediction, had a distinct impact on the evolution of the orbital elements. Then, to maintain a near-constant and extremely low altitude for the measurement operational phases, the satellite uses an ion thruster to compensate for the atmospheric drag. In order to obtain the ground track grid dense enough for a proper sampling of the gravitational field, ESA set constraints for a minimum ground track repeat period. We studied suitable repeat cycles in vicinity of the 16/1 resonance; we found that they differ greatly in stability towards small perturbations of the satellite's mean altitude and in temporal evolution of the ground track coverage. The results obtained from the usual analytical treatment of orbital resonances were refined by more realistic numerical simulations. Finally, we formulated suggestions that might be useful in GOCE orbit planning. We presented these results at EGU [5].

Following the successful insertion of GOCE in its orbit on 17 March 2009, we closely followed the actual orbital decay of the spacecraft from the initial altitude of 280 km in a nearly "free-fall" regime, where the commissioning of the onboard instruments took place. We analyzed both this early orbit phase as well as the repeatability conditions of the planned GOCE orbits during the measurement operational phases in paper [1].

Due to the very low solar activity, which affected the atmospheric drag counteracted by the onboard ion thrusters, the GOCE team chose the altitude for the first measurement phase to be 254.9 km, which was 8 km below the altitude announced at the time of the launch. This is a 61-day repeat orbit (the orbit *D* in Fig. on right hand side). This is an important change from the point of view of the repeatability character of the ground tracks - regular and dense enough grid of the ground tracks is essential for the success of the whole mission. Thus, we updated our computations and graphs for this new lower altitude range. In a short report sent to the GOCE team in 2009, we stated our main conclusion that a nearby 62-day repeat orbit (orbit *E* in Figure on the right hand side), which would be about 200 m higher than the actually planned 61-day orbit at 254.9 km, would produce a more regular Earth coverage. GOCE Mission Manager Rune Floberghagen answered us that even if this suggestion had come too late for the actual planning of the altitude for the first measurement phase, this 62-day option would certainly be considered in the following measurement phase 2.



Several resonant orbital configurations, studied as candidates for GOCE measurement operational phases [2].

The first major and very important international meeting related to GOCE in 2010 was ESA Living Planet Symposium in Bergen, Norway, where the first GOCE gravity models were officially released by ESA. We presented there our results on fine orbit tuning [2] of GOCE orbit for the mapping phases of the mission, we paid a particular attention to the proposed possible repeat orbits for the next measurement phase (see Fig. on previous page) In November 2010 ESA approved the extension of the GOCE mission from April 2011 until the end of 2012. The second important international symposium devoted to GOCE was the “GOCE User Workshop”, organized at the Technische Universität München, Germany, 31 March – 1 April, 2011 (see the after next section).

The success in fine orbit tuning for GOCE, which is a follow-on analysis of the GRACE problem with the 61/4 resonance, inspired us to extend our analysis to the planetary orbiters [3]. In the case of Mars orbiters, the situation is similar to that of satellites revolving around the Earth, and our conclusions may actually help Mars orbit designers to choose better orbits from gravity modelling point of view “at almost no cost” just by shifting the mean altitude by a few hundred metres to avoid low order resonances. For the Moon, Mercury and Venus no similar problems in gravity sampling arise, as their rotation rate is too slow for an orbiter to repeat the ground tracks in a reasonably short time.

Results of the fine orbit tuning were also presented at the WEGENER meeting in Istanbul 2010 [8]. The application of the same approach to bistatic altimetry (GNSS-Reflectometry) has been studied at ESA Workshop in Barcelona [5] and resulted in publication [4]. The concept of bistatic altimetry can be extended and enriched by a proper fine orbit tuning to keep a short revisit time but long repeat time.

Published contributions:

- [1] Bezděk A, Klokočník J, Kostelecký J, Floberghagen R, Gruber Ch, 2009. Simulation of free fall and resonances in the forthcoming GOCE mission. *Journal of Geodynamics* 48(1), 47–53.
- [2] Bezděk A, Klokočník J, Kostelecký J, Floberghagen R, Sebera J, 2010. Some aspects of the orbit selection for the measurement phases of GOCE. *Proceedings of the ESA Living Planet Symposium*, Bergen, Norway, 28 June–2 July, ESA SP-686.
- [3] Klokočník J, Bezděk A, Kostelecký J, Sebera J, 2010. Orbit tuning of planetary orbiters for accuracy gain in gravity-field mapping. *Journal of guidance, control, and dynamics* 33(3), 853–861.
- [4] Klokočník J, Bezděk A, Kostelecký J, 2012. GNSS-R concept extended by a fine orbit tuning. *Advances in Space Research* 49, 957–965.

Oral or poster presentations:

- [5] Bezděk, A., Klokočník, J., Kostelecký, J., Floberghagen, R., Gruber, C., 2009. Simulation of free fall and resonances in the forthcoming GOCE mission. *EGU General Assembly*, Vienna, Austria, 19–24 April.
- [6] Bezděk A., 2009. Geodetická mise GOCE - aktuální, výběr dráhy pro měřickou fázi. *Meeting of the Centre of the Earth's Dynamics Research (CEDR)*. Třešť, September 2009.

- [7] Bezděk A, Klokočník J, Kostelecký J, Floberghagen R, Sebera J, 2010. Fine orbit tuning to increase the accuracy of the gravity-field modelling. Presented at *2010 AGU Fall Meeting*, 13–17 December, Moscone Convention Center, San Francisco, California, USA.
- [8] Klokočník J., Bezděk A., Kostelecký J., Orbit tuning for GOCE measuring phases and for planetary orbiters to maximize accuracy gain in the gravity field mapping, pres. at session 4 „Earth Obs. Systems...“, WEGENER 2010, *15th Gen. Assembly Wegener*, Sept. 14-17, Istanbul, Turkey.
- [9] Klokočník J, Bezděk A, Kostelecký J. GNSS-R concept extended by a fine orbit tuning, *ESA Workshop on GNSS-R 2010*, Barcelona.

2. Novel geodetic computational methodologies.

(prepared by J. Sebera, part (d) by A. Bezděk)

a) Satellite altimetry and satellite gradiometry.

We have continued validation-combination efforts of the satellite altimetry and satellite gradiometry that resulted in an internal Deutsches Geodätisches Forschungsinstitut report (DGFI) which will be placed on the DGFI website soon (<http://www.dgfi.badw.de/>). The final conclusions we made are: before both techniques are compared (case of validation) or joined into one data set for the gravity field modelling (case of combination), the data themselves must relate to the same equipotential surface, that is, to the geoid. Secondly it was found that satellite altimetry data must be corrected for the effect of Dynamic Ocean Topography (DOT, see our ESA PECS report 2009) before use in GOCE combination/validation to incorporate the difference between “reality” (ocean surface) and the equipotential surface of geoid. The problem is that DOT models can be based on different approaches causing a difference at the same level of magnitude as the gravity correction itself. However, this problem only affects areas of the main ocean currents (e.g. Gulf stream, Kuroshio current) and thus we recommend the use of satellite altimetry data for GOCE validation-combination over the oceans except over these currents as the uncertainty in DOT modelling is too significant there. See [1].

b) Straightforward parametrization of the Eötvös tensor (Direct approach).

The second intention of this year was to develop the mathematical model for the GOCE data processing. This involves describing the relationship between the observables (GOCE measurements = Eötvös tensor = gravity gradients) and the unknowns represented by the spherical harmonic parameters (parameters of the Earth's gravitational field). In cooperation with Carl A. Wagner from USA we developed an approach based on Hotine's formulation of gravitational potential and its derivatives, a concept that has not been used often in last 15 years although it is very convenient for setting the general observation equation. The problem is that the GOCE gradiometer measures gravity gradients in an arbitrary rotated reference frame dependent upon the satellite orientation which must be determined in order to utilize the data. If the orientation parameters are known, there are two ways to proceed. The first is the rotation of the tensor into a conventional reference frame in which the observation equation can easily be set. However, such a rotation can introduce an unpleasant error from the rotation because the new rotated tensor element is a function of all the original tensor

components that significantly differ in accuracy (V_{xx} , V_{yy} , V_{zz} , V_{xz} are very precise, V_{xy} , V_{yz} are less precise). Thus the rotation of measurements can contaminate the most precise components through incorporation of less accurate ones. On the other hand we can avoid this using the rotated observation equations, where data rotation is substituted by the rotation of the base functions. This prevents error contamination from the less accurate components. To do this we used an elegant Hotine's formulation that offers a favourable algebraic and numeric properties. The structure of the rotated equation is almost the same as the un-rotated equation. This formulation does not need the derivatives of the associated Legendre functions of the first kind and thus, when computing, it is faster than other formulations and in principle less affected by rounding errors. See [2].

c) Ellipsoidal harmonics.

Working with terrestrial data (like in section a) brought us logically to the ellipsoidal modelling of the Earth's gravitational field as the Earth is closer to an ellipsoid than a sphere. The gravity signal on the Earth is better approximated by ellipsoidal functions than by spherical functions. Our first step was to develop the algorithms used for the computation of the associated Legendre functions of the second kind up to the highest degrees/orders which correspond with the most current Earth's gravitational field model, the EGM2008 to $d/o=2190$. These functions are crucial base functions for the development of the Earth's outer gravitational field into a harmonic series. We successfully derived the formulas up to the second derivative required to compute all the potential functionals and optimized them with respect to rounding errors that can be gauged by the Legendre differential equation as it is a generating equation as well as the required condition. For more details see [3, 4].

Published or submitted contributions:

[1] Sebera J., Bouman J., Bosch W., Dynamic ocean topography and vertical gravity gradient computation, *DGFI Report 87*, November 2010.

[2] Sebera J., Wagner C.A., Bouman J., Bezděk A., Klokočník J., Kostecký J., Novák P., Gravitational tensor in the GOCE reference frame by direct harmonic synthesis. Pres. at EGU GA Vienna 2010, *Geophys. Res. Abstracts* 12, EGU2010-7103-3, 2010.

[3] Sebera J., Bosch W., Bouman J., Kostecký J., Klokočník J., Bezděk A. Upward continuation of satellite altimeter data for GOCE validation. Pres. at the *ESA Living Planet Symposium*, Bergen, Norway, 28 June – 2 July 2010.

[4] Sebera J., Bouman J., Bosch W., On computing ellipsoidal harmonics using Jekeli's renormalization, *Journal of Geodesy* (submitted).

d) Gravity field modelling using kinematic orbits of GOCE

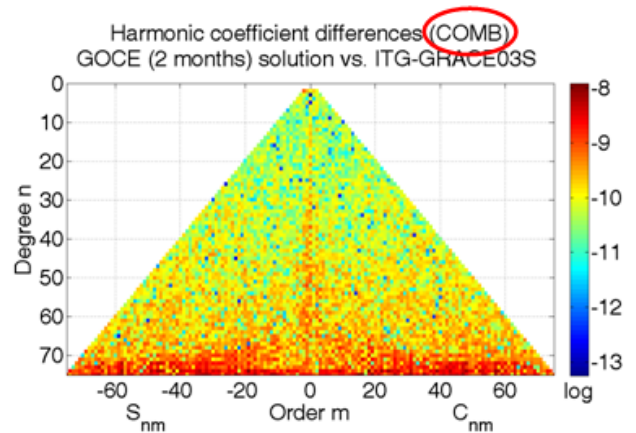
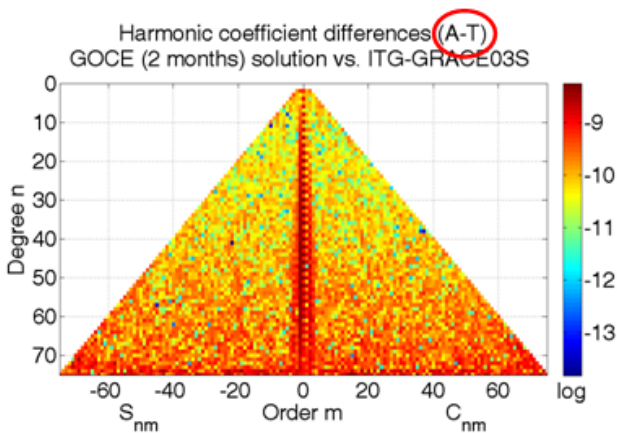
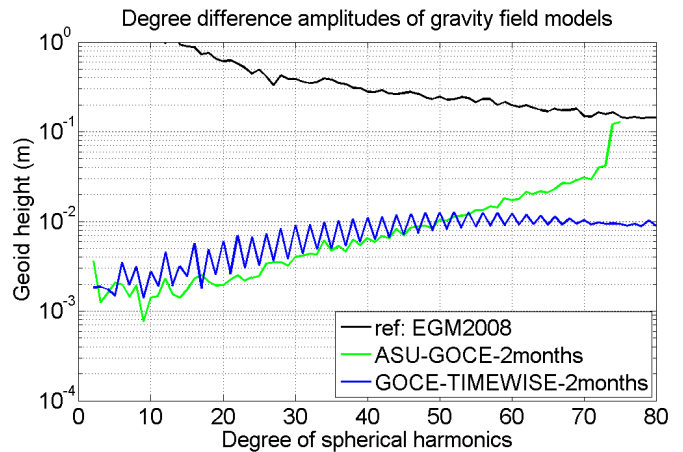
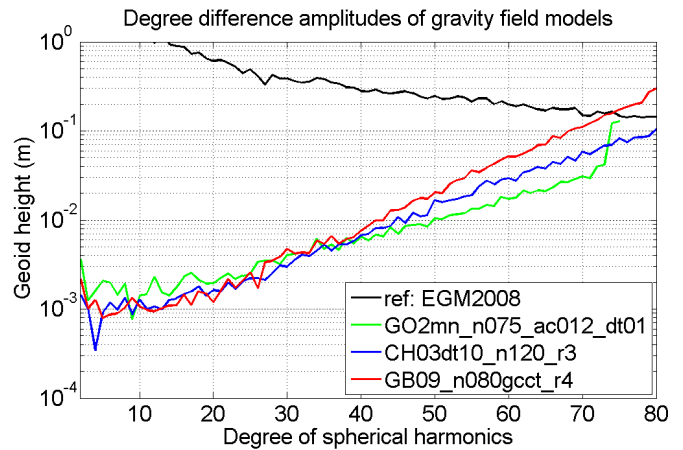
[experimented and reported by A. Bezděk]

In 2010 we started to work up the method of gravity field inversion based solely on precise orbital data. Such methods started to be broadly used by space geodesists with the CHAMP onboard GPS receiver data, which provided sufficiently dense and continual sampling of its orbit. Due to the performance limitation of the GOCE gradiometer, the lower part of the GOCE gravity field models has to be based on the orbital data. For producing the full gravity

field model one needs not only to process the gradiometer measurements, but also the orbital data. Actually, the GOCE gravity field solution up to degree/order 20–25 is fully determined by the GPS orbital information.

The first figure shows the positive effect of the extremely low altitude of GOCE (about 255 km). The gravity field model based on only two months of its orbital data is of similar accuracy as the yearly solution of GRACE B (altitude 460 km) and CHAMP (altitude 400 km). For comparing the gravity field models based on orbits we use the models which were derived from the GRACE mission and whose accuracy is estimated to be at least ten times better (here we use the EGM 2008 model).

ESA officially releases three different gravity field models derived from GOCE gradiometer data, each using different processing strategies (Bergen, 2010). From these only the so-called timewise solution is based entirely on the GOCE orbits without applying regularization or other external information. We can compare our orbit-based solution with this timewise solution, which is a combination of orbit-based and gradiometer-based contributions. Our solution seems to be of comparable or better quality at degrees below ~ 30 , then the gradiometer contribution starts to dominate it.



Contrary to many teams, which use only the along-track part of the orbital information, our method makes use of the vector equation, which allows to combine solution from all three directions. Indeed, the graphs show that the combined solution is more accurate in the central part than the along-track solution alone.

We presented the first results using the real-world orbital data of CHAMP, GRACE and GOCE satellites at several workshops [1–3] and currently we prepare a journal publication. One of the plans of our team is to produce the full gravity field model from GOCE data; we need, therefore, these lower degree models for the combination with the high-frequency part of the gravity spectrum obtained from the GOCE gradiometer (studied in Item 3 of this PECS project, see below).

Oral or poster presentations:

- [1] Bezděk A, Klokočník J, Kostecký J, Sebera J, 2011. Gravity field modelling from kinematic positions using the generalized least squares. Presented at *4th International GOCE User Workshop*, Technische Universität München, Germany, 31 March – 1 April.
- [2] Bezděk A, 2011. Časové řady a modely gravitačního pole z inverze drah družic CHAMP, GRACE a GOCE. *Seminář Astronomického ústavu UK*, 9. listopadu 2011.
- [3] Bezděk A, Sebera J, Klokočník J, Kostecký J, 2011. Globální model gravitačního pole z dráhových dat družic CHAMP, GRACE a GOCE. *Seminář Výzkumného centra dynamiky Země*, Třešť, 16. listopadu 2011.

3. Comparison of detailed satellite and terrestrial data.

(prepared by P. Novák)

Formulations and numerical experiments in the field of forward modeling of selected gravitational effects were summarized in an article published in *Surveys in Geophysics*. Related numerical aspects were later analyzed in another contribution published in *Acta Geodynamica at Geomaterialia*. The methodology is based on spectral representation of Newtonian potential integrals with numerical coefficients of a global height function. Results were presented namely at the *7th General Assembly of the European Geosciences Union (EGU)* in Vienna, May 2010, and at the *Fall Meeting of the American Geophysical Union* in San Francisco, December 2010.

Methods based on harmonic representations of parameters used for description of the Earth's gravitational field require stable and efficient algorithms for harmonic analysis and synthesis. The key role in these computational steps play algorithms for computing Legendre functions of the first/second kind. A new algorithm for their evaluation was developed, tested and presented at the *7th General Assembly of the European Geosciences Union (EGU)* in Vienna, May 2010. The algorithm was described in an article submitted to *Studia Geophysica et Geodaetica* (after the first review, small modifications suggested).

The mathematical model for combined processing of local ground, airborne and global spaceborne data is based on the theory of potential and its boundary-value problems, namely the Dirichlet (first) boundary-value problem for the Laplace equation. The solution is based on Greens's surface integrals over the unknown potential function at some simple, closed and connected surface (geocentric reference ellipsoid). Observation equations in the form of surface integrals can be formulated for all types of currently available gravity field

observables. Due to the observation noise, a linear system of inconsistent equations must be solved with the solution estimated through some criterion (such as minimizing the quadratic form of the vector of residuals). Details of this model presented at *7th Hotine-Marussi* symposium in Rome, July 2009, were described in the article submitted and accepted for publication in the proceedings from the *7th Hotine-Marussi symposium (IAG Series to be published soon by Springer)*.

Besides solving for geographically-limited values of the gravity potential, methods based on global parametrization of the gravity potential were also tested. Namely a method of 2-D Fourier representation of the Earth's gravity potential at the surface of a geocentric sphere was tested because of the approximate spherical symmetry of the Earth's gravity field. Numerical coefficients in this series can be estimated directly from observed data, however, this approach requires some stable algorithms for the spherical harmonic analysis and synthesis. These methods were also investigated and results were presented at the *7th European Sciences Union* in Vienna, April 2010.

A possible application of GOCE data for definition and establishment of a global height system was tested within the Inter-Commission project "World Height System (WHS)" of the International Association of Geodesy (IAG). A preliminary study was presented at the *2nd Symposium of the International Gravity Field Service (IGFS)* held in Fairbanks, September 2010. The project is also based on combination of heterogeneous gravity data: spaceborne data locally enhanced by ground or airborne gravity data.

Published or submitted contributions:

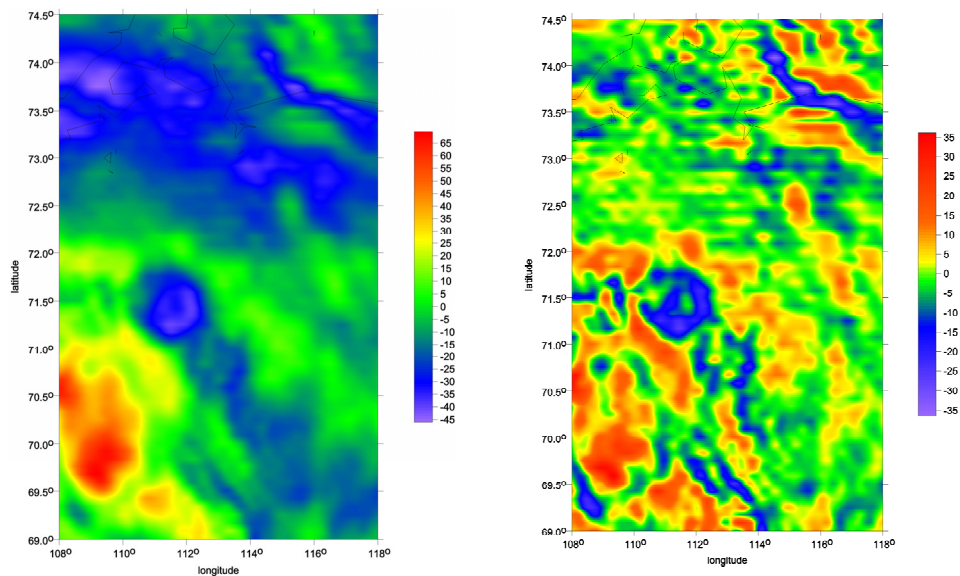
- Novák P (2010). High resolution constituents of the Earth gravitational field. *Surveys in Geophysics* 31(1): 1-21, doi: 10.1007/s10712-009-9077-z.
- Novák P (2010). Direct modeling of the gravitational field using harmonic series. *Acta Geodynamica et Geomaterialia* 157(1): 35-47.
- Vajda P, Ellmann A, Meurers B, Vaníček P, Novák P, Tenzer R (2010). Harmonic continuation and gravimetric inversion of gravity in areas of negative geodetic heights. In Mertikas SP (ed.) *Gravity, Geoid and Earth Observation*: 25-30, Springer-Verlag Berlin Heidelberg, ISBN: 978-3-642-10633-0.
- Vajda P, Vaníček P, Novák P, Tenzer R, Ellmann A, Meurers B (2010). On ambiguities in definitions and applications of Bouguer gravity anomaly. In Mertikas SP (ed.) *Gravity, Geoid and Earth Observation*: 19-24, Springer-Verlag Berlin Heidelberg, ISBN: 978-3-642-10633-0.
- Tenzer R, Novák P (2010). Effect of the long-wavelength topographical correction on the low-degree Earth's gravity field. In Mertikas SP (ed.) *Gravity, Geoid and Earth Observation*: 355-360, Springer-Verlag Berlin Heidelberg, ISBN: 978-3-642-10633-0.
- Douša J, Filler F, Šimek J, Kostelecký J, Kostelecký J (jr), Novák P (2011). New implementation of ETRS89 in the Czech Republic: Campaign EUREF-Czech-2009. *Geodetický a kartografický obzor* 55(99): 25-35.

4. Detection of hidden impact (meteoritic) structures on the Earth surface.

(prepared by J. Klokočník)

We continued in a survey of the Earth's special structures with the 2160×2160 gravitational potential model EGM08 using both its computed gravity anomalies in spherical approximation and second radial derivatives. Recently we tested 3 new gravity models based also (or solely) on the GOCE data.

Over most of the well known impact crater sites we find the second derivatives offer finer discrimination of the circular features than the anomalies themselves (see enclosed figures for the impact crater Popigai). We also find indications for double or multiple impact craters in close vicinity of the “original” well-known single craters verified by geologists (ibid). We published [1] and [2] about the impact craters. These findings were tested by geophysicists and geologists. Popigai remains as a clear candidate for a double or multiple crater [2]. We developed special method how to model double/multiple impact craters with point mass models [1], [2], [3]. This method [3] can be extended for any gravity feature of interest, provided that some elementary data about its size, shape and density contrast are known. The application of EGM08 for searching the impact craters has also been presented at [4]. Recently we employed for this purpose also EIGEN 6C, which is the first combined gravity model based on GOCE measurements.

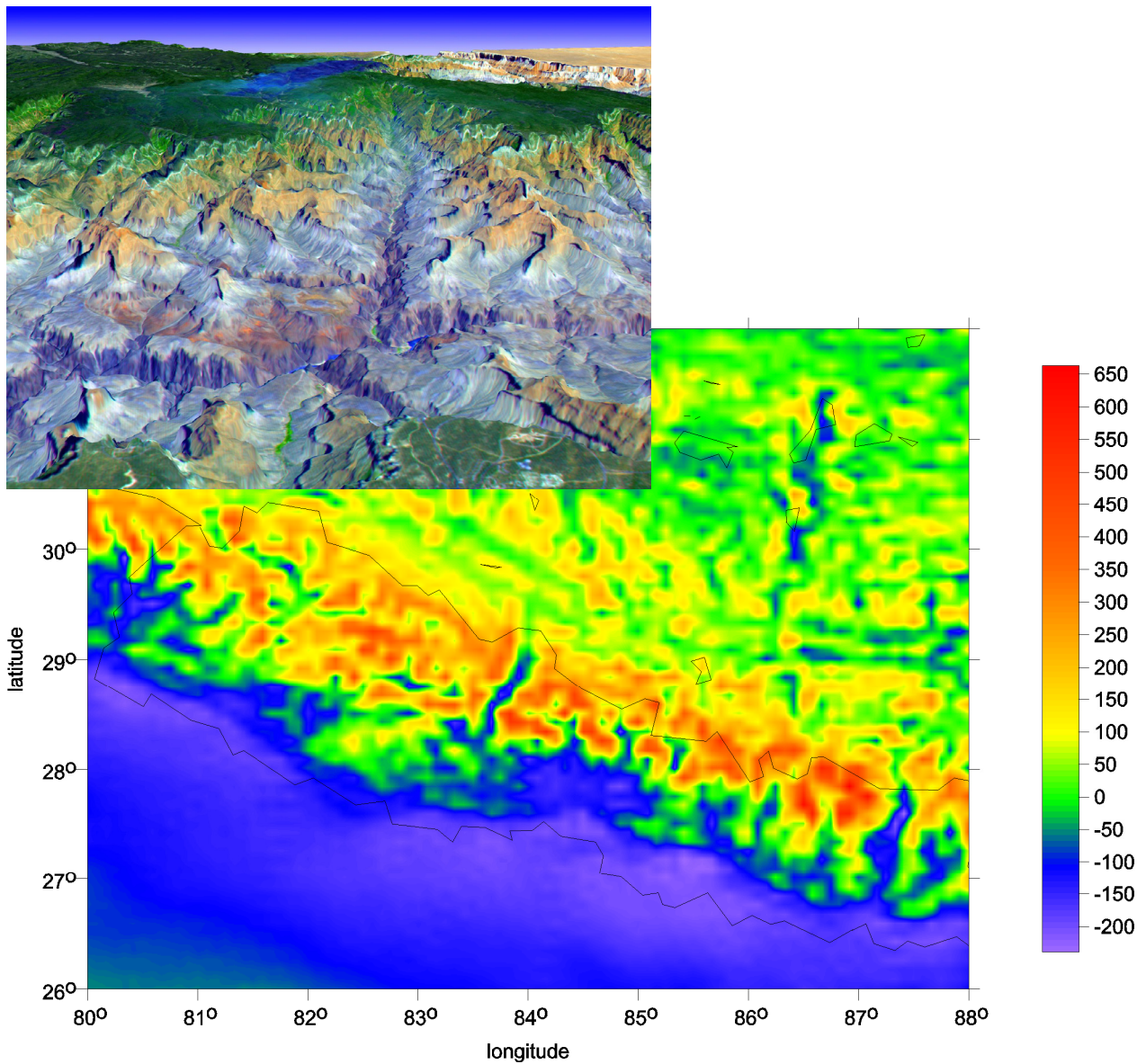


Gravity anomalies Δg (in miligals) [above] and second radial derivatives of the disturbing potential T_{zz} (in Eötvös) [below], represented by the combined gravity field model EGM 2008 up to degree/order 2160 (5 arcmin resolution) in the area of large impact crater Popigai, Siberia, Russia.

There is another, unexpected application of EGM 08 (and all new gravity models forthcoming now with the GOCE data included), namely the study of geomorphology of recently active zones like Himalaya and the second radial derivatives. First study is in [5], further are in progress.

We can now compute full the Marussi tensor of the second derivatives, the invariants of the gravity field from them and other quantities interesting for geophysical interpretation of

various features on the Earth and we are able to do a service for geologists and geophysicists interested in such data for their own analyses.



Gravity anomalies, represented by EGM 2008 up to degree/order 2160, for Himalaya, put into a contrast with a digital topography model (smaller figure).

Published or presented contributions:

(if not listed in preceding items)

[1] Klokočník J., Novák P., Kostelecký J., Wagner C.A., Detecting impact craters using the EGM 08, *Acta Geodyn. Geomater.* 2010, 7, #1 (157), 71-97.

[2] Klokočník J., Kostelecký J., Pešek I., Novák P., Wagner C.A., Sebera J., Candidates for multiple impact craters?: Popigai and Chicxulub as seen by the global high resolution

gravitational field model EGM08, *Solid Earth EGU* 2010, 1, 71-83, DOI: 10.5194/se-1-71-2010.

See also: Is Chicxulub a double impact crater? Pres. at *6th EGU A. von Humboldt Internatl. Conf. on Climate Change, Natural Hazards, and Societies*, Mérida, México, section: The Cretaceous/Tertiary Boundary

- [3] Pešek I., Wagner C.A., Klokočník J., Kostecký J., Sebera J., EGM 08 searches for hidden impact craters, with support from point mass modelling, Pres. at EGU GA Vienna 2010, *Geophys. Res. Abstracts* 12, EGU2010-2121, 2010.
- [4] Kostecký J., Klokočník J., Pešek I., Kalvoda J.: Possible applications of detailed Earth's gravity field model. Pres. at the *11th Czech-Polish workshop „On recent geodynamics of the Sudeten and adjacent areas“*, Castle Třešť, 4 – 6 November 2010.
- [5] Kalvoda J., Klokočník J., Kostecký J. (in print): Regional correlation of the Earth Gravitational Model 2008 with morphogenetic patterns of the Nepal Himalaya. – *Acta Universitatis Carolinae, Geographica*, XLV, 2, 53 – 78, Prague. (2010) (SCOPUS)
- [6] Kostecký J., Klokočník J., Pešek I., Kalvoda J.: Některé možné aplikace modelů gravitačního pole Země. Předneseno na semináři s mezinárodní účastí „*Družicové technologie a súčasná geodézia*“, Stavebná fakulta STU Bratislava, 8.12.2010.
- [7] Kalvoda J., Klokočník J., Kostecký J. (in print): Comparison of morphogenetic features of the Nepal Himalaya with the Earth Gravitational Model 2008. *Sborník konferenčních příspěvků XXII. Sjezdu České geografické společnosti*, Ostrava 2010, 9 p., 8 figs. (ISI / *Proceedings – Conference Proceedings Citation Index*, Thomson / Reuthers).

Overview 2007–2011

We are very grateful to the programme ESA PECS, to our as well as European authorities for this grant. We got a chance to work with high quality data, within international community on a new level of quality. We were (and are) in contact with such people like the project manager Rune Floberghagen. His co-authorship is very useful for us – direct access to information – thanks to him we started a detailed study of the fine orbit tuning for GOCE by which we can intentionally change the orbit to a high order resonance to fulfil requirements of the experiment. Ten years ago it was beyond our dream to do something like that and to influence thinking of such people who directly decide about the orbit. And much more: work on GOCE inspired us to extend this type of analysis to interplanetary missions and for the Earth's remote sensing satellite GNSS-R (bistatic altimetry/reflectometry). We have publications about it.

Our group consists of older as well as young research workers. Our youngest co-worker Josef Sebera worked in DGF I Munich, where 20–30 years ago Jaroslav Klokočník repeatedly worked. We all were able to present our results and to gather inspiration face to face to specialists from all the world on various conferences and workshops, not only in Europe. Money of PECS C98056 grant help us to travel a lot. Younger colleagues had opportunity to read their papers for the first time at large lecture rooms for several hundred people (for example at ESA Living Planet Symposium 2010 in Bergen). Josef Sebera (our PhD student)

and Aleš Bezděk became first co-authors and now first authors of our common research papers, which is evidently important for their professional career.

For the first time in our country we tried to determine a gravity field model from satellite data, namely from kinematic orbits of GOCE (level L2 product). Before GOCE and before ~2000 it was well beyond our capabilities (data and computers). By this way we now belong to international society (USA, France and Germany – only these countries) where such computations are feasible.

Our research is interdisciplinary, from dynamics of the Earth's artificial satellites (applied celestial mechanics) to geo-applications (results potentially useful for geodesy, geology, geophysics, morphology, ocean science, etc).

It would be more than sad to interrupt such successful cooperation yielding evident results (see lists of our publications in international journals in the individual sections, as mentioned above) just because of money shortage. We applied for a grant to PRODEX, without any reply, and to the Grant Agency of Czech Republic (without any success); we will try it again.

Financial plan and its fulfilment

In table 1 below, there is the overview of the fulfilment of the Financial Plan for year 2011. The planned amounts come from the PECS Experiment Arrangement No 98056, App. 2, p. 5.

ITEM		AMOUNT (€)	
		planned	realized
Salaries incl. all insurances		46 400	43 510
Travel (incl. tickets, per diem, accommodation, fees, etc.)		10 000	14 215
Small equipment - smaller then 5000 Euro per piece		1 000	475
Large equipment		0	0
Miscellaneous	data GOCE, system eng. consultations	500	0
	publications of colour pages	500	0
	consumables	300	0
	services	0	0
Overheads		500	1 000
Total		59 200	59 200

Table 1. Financial Plan for year 2011 and its fulfilment

Appendix: List of publications

Published contributions 2008–2011 (in alphabetical order): 32

1. Bezděk A, Klokočník J, Kostecký J, Floberghagen R, Gruber Ch, 2009. Simulation of free fall and resonances in the forthcoming GOCE mission. *Journal of Geodynamics* 48(1), 47–53.
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