International Centre for Global Earth Models (ICGEM)

Director: **E. Sinem Ince** (Germany)

http://icgem.gfz-potsdam.de

Terms of Reference

The determination of Earth's global gravity field is one of the main tasks of geodesy: it serves as a reference for geodesy itself and provides essential information about the Earth, its interior and its fluid envelope for all geosciences. Thus, it is important to model the gravity field globally and make the state-of-the-art models available to public as geodetic products. With accurate satellite measurements, it is now possible to map the static gravity field as well as its variations with much higher spatial and temporal resolutions compared to the first of its kinds. The list of such models is continuously growing and requires dedicated maintenance.

International Centre for Global Earth Models (ICGEM) is one of the five services coordinated by the International Gravity Field Service (IGFS) of the International Association of Geodesy (IAG). The primary objective of the ICGEM service is to collect and archive all existing static and temporal global gravity field models and provide an online interactive calculation service for the computation of gravity field functionals freely available to the general public. The calculation of the different functionals of the geopotential (e.g. geoid, gravity anomaly, gravity disturbance, equivalent water height) from a defined global model, on a specified grid or points with respect to a defined reference system, is not trivial for science and scientists and is a responsibility of geodesy too. Additionally, it is important to visualize the spatial and temporal distribution of the global gravity field and therefore interactive visualization is also provided by ICGEM.

Development

With the initiation of IGFS and the commitment for hosting and financial support by German Research Centre for Geosciences (GFZ), the ICGEM service was established in 2003 and aimed to collect and archive static gravity field models initially. Due to the increasing interest of the users and model developers, temporal gravity field models have also been made available on the same platform after the launch of GRACE mission. The service has been extensively used and promises further developments to serve multidisciplinary research.

Objectives

ICGEM is designed as a web-based service and comprehends:

- collecting and long-term archiving of existing static global gravity field models, solutions from dedicated shorter time periods (e.g. monthly GRACE/GRACE-FO models), and topographic gravity field models,
- making the above-mentioned models available on the web in a standardized format as described in Barthelmes and Förste (2011),
- since late 2015, the possibility of assigning Digital Object Identifiers (DOIs) to the models,
- a web interface to calculate gravity field functionals from the spherical harmonic models on freely selectable grids and user-defined points,
- a 3-D interactive visualization of the models (geoid undulations and gravity anomalies),
- quality checks of the static gravity field models via comparisons with other models in the spectral domain and w.r.t. GNSS/levelling-derived geoid undulations,
- the visualization of surface spherical harmonics as tutorial,
- the theory and formulas of the calculation service documented in GFZ's Scientific Technical Report STR09/02 (Barthelmes, 2013),
- manuals and tutorials for global gravity field modelling and usage of the service (Barthelmes, 2014) and

scientific journal papers for educational and reference purposes (Ince et al. 2019) and finally,

- the ICGEM web-based gravity field discussion forum for questions on ICGEM and its products and to request knowledge exchange.

Services

The Models

ICGEM relies on other centres and institutes who develop static and temporal gravity field models that are made available on ICGEM. By February 2020, 176 static gravity field models are listed in ICGEM (http://icgem.gfz-potsdam.de/tom_longtime). Apart from 17 older models, all other models are available in the form of spherical harmonic coefficients. Models from dedicated time periods (e.g. monthly solutions from GRACE) of Science Data System Centres CSR, JPL, and GFZ, and various other solutions such as from CNES/GRGS and ITSG are also available. Recently, the combined monthly models produced based on the COST-G standards have been made available (http://icgem.gfz-potsdam.de/series). Finally, topographic gravity field models have been made available for the first time in 2014 as requested by users and model developers (http://icgem.gfz-potsdam.de/tom_reltopo). Such models can enhance the benefit from the gravity field products in high frequency components and in multidisciplinary studies.

Digital Object Identifiers (DOI)

In order to support open science and open data, ICGEM does not only provide free access to the models but supports the assignment of Digital Object Identifiers (DOI) to make the models citable. Since 2016, ICGEM together with the GFZ Library and Information Services, provides a service to assign a DOI to the models, i.e. to the datasets of the coefficients. Currently, over 30 models have been assigned DOIs. ICGEM encourages the model developers to request DOI at http://pmd.gfz-potsdam.de/panmetaworks/metaedit.

The 3D Visualization

An online interactive service for the visualization of the models (in terms of height anomalies and gravity anomalies) as illuminated projection on a freely rotatable sphere is available (http://icgem.gfz-potsdam.de/vis3d/longtime, see also Fig. 1). Differences of two models, arbitrary degree windows, zooming in and out, are possible. The visualization of spherical harmonics is also possible for tutorial purposes (see Fig. 2).

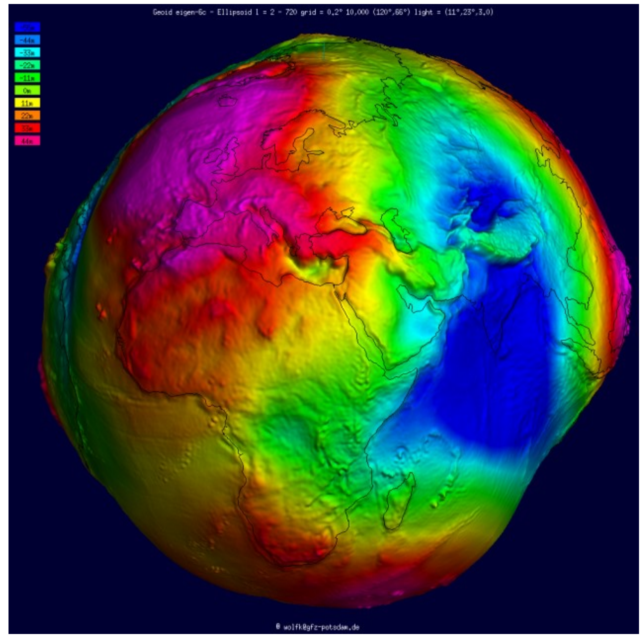

Fig. 1 Visualization (geoid) of a global gravity field model.

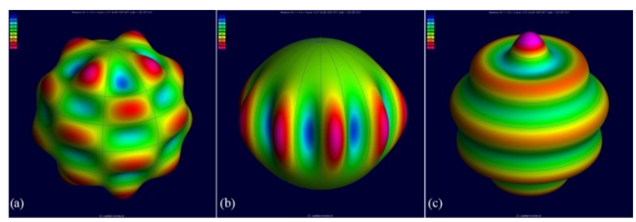

Fig. 2 3D visualization of spherical harmonics as a tutorial. The images show (a) tesseral (l = 9, m = 4), (b) sectorial (l = 9, m = 9), and (c) zonal (l = 9, m = 0) spherical harmonics (Ince et al. 2019).

The Calculation Service

A web-interface to calculate gravity field functionals from the spherical harmonic models on freely selectable grids or at user-defined points with respect to a reference system of the user's choice is provided. The following functionals are available in the grid calculation (http://icgem.gfz-potsdam.de/calcgrid):

- pseudo height anomaly on the ellipsoid (or at arbitrary height above the ellipsoid)
- height anomaly (on the Earth's surface)
- geoid height (height anomaly plus spherical shell approximation of the topography)
- gravity disturbance

- gravity disturbance in spherical approximation (at arbitrary height above the ellipsoid)
- gravity anomaly (classical and modern definition)
- gravity anomaly (in spherical approximation, at arbitrary height above the ellipsoid)
- simple Bouguer gravity anomaly
- gravity at the Earth's surface (including the centrifugal acceleration)
- gravity on the ellipsoid (or at arbitrary height above the ellipsoid, including the centrifugal acceleration)
- gravitation on the ellipsoid (or at arbitrary height above the ellipsoid, without centrifugal acceleration)
- second derivative in spherical radius direction (at arbitrary height above the ellipsoid)
- equivalent water height (water column)

Beside the functionals listed above, deflections of vertical can be computed at user-defined points (http://icgem.gfz-potsdam.de/calcpoints).

In the calculation setting, filtering is possible by selecting the range of used coefficients or the filter length of a Gaussian averaging filter. The calculated grids together with the calculation settings included in the header part can be downloaded once the calculation is completed. For grid calculations, the corresponding plots created using GMT (in Postscript or Portable Network Graphics format) are available for download (see Fig. 3). Since 2018, calculations on user-defined points are available (see Fig. 4) and the results can be downloaded in ASCII format as well.

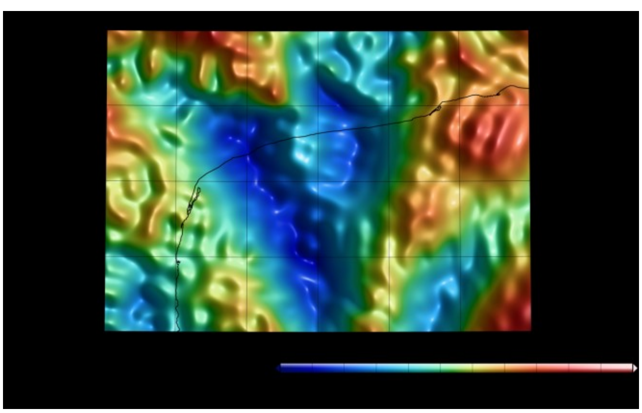

Fig. 3 Example of grid and plot generation by the calculation service: gravity disturbances of the Chicxulub crater region from the model XGM2019e_2159.

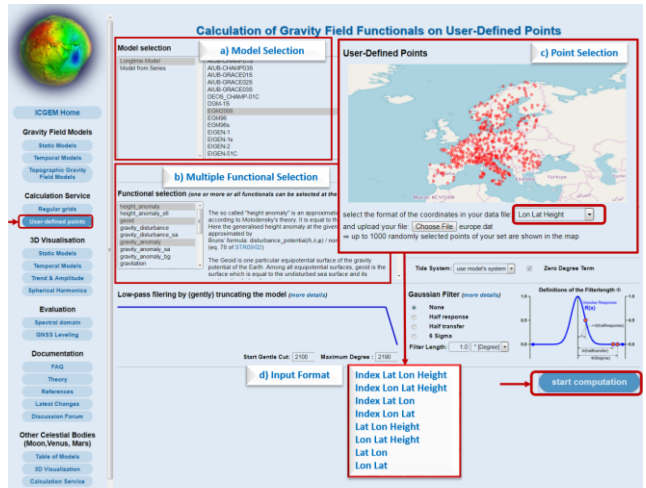

Fig. 4 User-defined point calculation interface and settings (Ince et al. 2019)

The table is interactively re-sortable for all columns by clicking in the header cells.

Nr	Model	Nmax	Australia (201 points)	Brazil (1112 points)	Canada (2691 points)	Europe (1047 points)	Japan (816 points)	USA (6169 points)	All (12036 points)
176	XGM2019	760	0.217 m	0.44 m	0.151 m	0.14 m	0.125 m	0.264 m	0.2494 m
176	XGM2019e_2159	2,190	0.215 m	0.438 m	0.128 m	0.127 m	0.09 m	0.248 m	0.2361 m
175	GO_CONS_GCF_2_TIM_R6e	300	0.318 m	0.502 m	0.29 m	0.34 m	0.431 m	0.396 m	0.3832 m
174	ITSG-Grace2018s	200	0.404 m	0.545 m	0.387 m	0.504 m	0.573 m	0.496 m	0.4837 m
173	EIGEN-GRGS.RL04.MEAN-FIELD	300	0.327 m	0.507 m	0.298 m	0.345 m	0.447 m	0.404 m	0.391 m
172	GOCO06s	300	0.318 m	0.503 m	0.292 m	0.341 m	0.43 m	0.398 m	0.3847 m
171	GO_CONS_GCF_2_TIM_R6	300	0.317 m	0.501 m	0.29 m	0.34 m	0.431 m	0.396 m	0.383 m
170	GO_CONS_GCF_2_DIR_R6	300	0.313 m	0.503 m	0.292 m	0.339 m	0.432 m	0.396 m	0.3838 m
169	IGGT_R1C	240	0.388 m	0.529 m	0.427 m	0.457 m	0.574 m	0.464 m	0.4689 m
168	Tongji-Grace02k	180	0.432 m	0.592 m	0.475 m	0.587 m	0.661 m	0.525 m	0.5357 m
167	SGG-UGM-1	2,159	0.217 m	0.446 m	0.13 m	0.121 m	0.076 m	0.245 m	0.2353 m
166	GOSG01S	220	0.359 m	0.518 m	0.373 m	0.426 m	0.526 m	0.442 m	0.4392 m
165	IGGT_R1	240	0.317 m	0.513 m	0.348 m	0.387 m	0.483 m	0.412 m	0.4111 m
164	IfE_GOCE05s	250	0.337 m	0.512 m	0.329 m	0.385 m	0.48 m	0.414 m	0.4081 m
163	GO_CONS_GCF_2_SPW_R5	330	0.33 m	0.511 m	0.299 m	0.346 m	0.442 m	0.396 m	0.3873 m
162	GAO2012	360	0.293 m	0.531 m	0.309 m	0.453 m	0.759 m	0.366 m	0.4177 m
161	XGM2016	719	0.218 m	0.44 m	0.151 m	0.14 m	0.125 m	0.263 m	0.2489 m
160	Tongji-Grace02s	180	0.452 m	0.605 m	0.478 m	0.596 m	0.669 m	0.53 m	0.5417 m
159	NULP-02s	250	0.351 m	0.512 m	0.375 m	0.413 m	0.508 m	0.427 m	0.4284 m
158	HUST-Grace2016s	160	0.489 m	0.658 m	0.594 m	0.69 m	0.837 m	0.596 m	0.6273 m

Fig. 5 Comparison of the models w.r.t. GNSS-levelling: Root mean square (rms) about mean of GNSS / levelling minus gravity field model derived geoid heights [m]. Note the XGM2019 is evaluated for two different N_{max}.

ICGEM continues to evaluate the static gravity field models w.r.t. GNSS/levelling derived geoid undulations (see the list in Fig. 5) and in the spectral domain w.r.t. already reliable models (see Figs. 6). Visualization of the improvement of the satellite-only models w.r.t. EIGEN-6C4 over the years are shown as a function of spatial resolution in Fig. 7.Apart from the gravity field models of the Earth, ICGEM hosts similar models for other celestial bodies (Moon, Mars, Venus and Ceres). A 3D visualization of the Moon's geoid is shown in Fig. 8

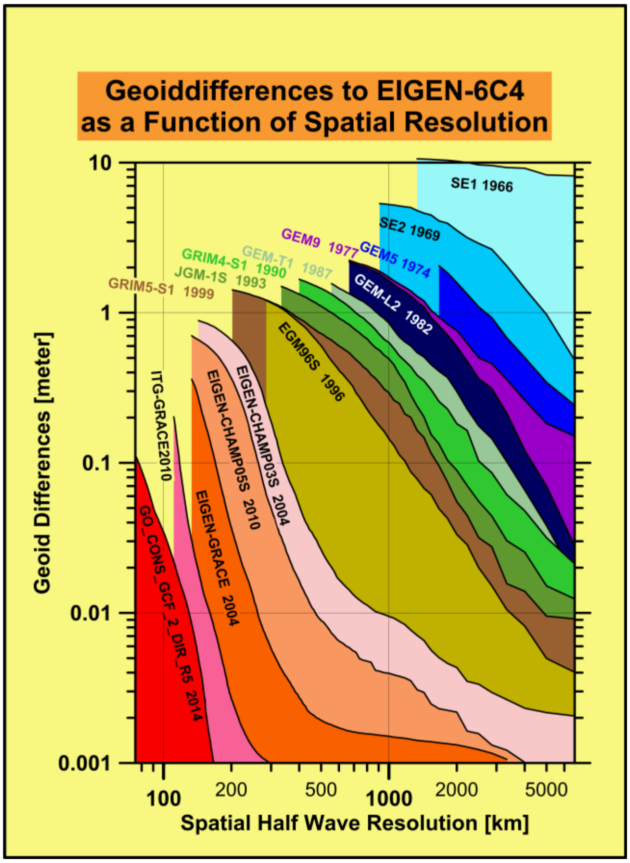

Fig. 6 Comparison of the satellite-only model GO_CONS_GCF_2_DIR_R6 in the spectral domain with one of the most recent models that combines satellite and terrestrial data (EIGEN-6C4).

FAQs and Discussion Forum

In May 2017, to support the users from different disciplines and levels, ICGEM introduced the Frequently Asked Questions (FAQs) and their short and detailed answers. Such answers are expected not only to help students and researchers for educational purposes, but also to understand the background of the ICGEM products. Moreover, to increase the knowledge exchange with and among the users ICGEM's discussion forum is expanded and it is encouraged to be used to share gravity field related questions and information.

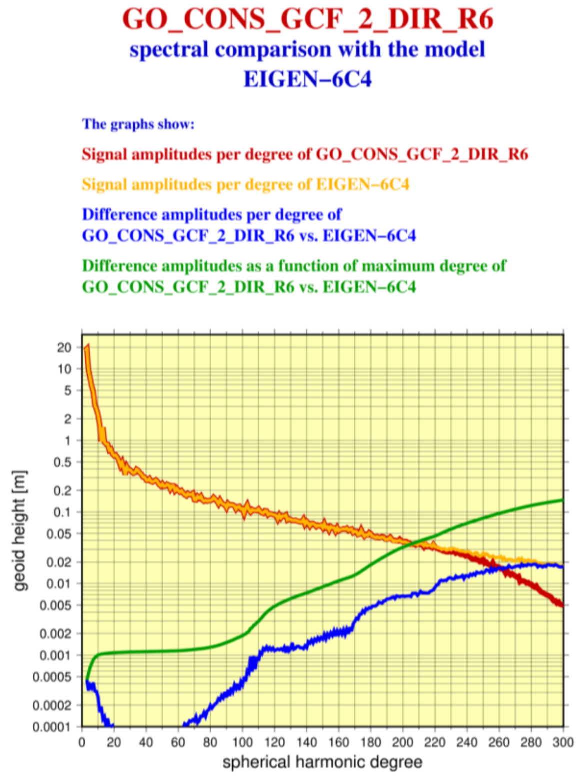

Fig. 7 Visualization of the improvement of satellite-only models over the past decades: Geoid differences to the model EIGEN-6C4 as a function of spatial resolution.

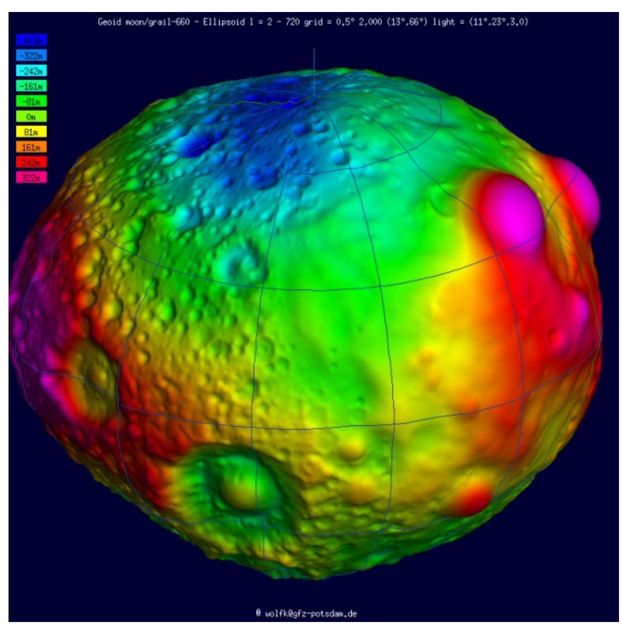

Fig. 8 Visualization of the "Geoid" of the Moon.

Outlook

ICGEM is a unique platform to collect and provide access to a comprehensive list of gravity field models that are of static, temporal and topographic kind. Beside the calculation and visualization services, complementary documentations about the models are made available. The ICGEM service is a worldwide service and is not aimed to a specific user community. It continues to update its content with new models and additional features as requested by users, and depending on availability. The coordination and communication of the ICGEM Service are made through the ICGEM's staff (icgem@gfz-potsdam.de) with input from international contributors.

Data Policy

Access to global gravity field models, derived products and tutorials, once offered by the center, shall be unrestricted for any external user.

Reference

Reference for ICGEM Service and its products is as follows:

Ince, E. S., Barthelmes, F., Reißland, S., Elger, K., Förste, C., Flechtner, F., and Schuh, H.: ICGEM – 15 years of successful collection and distribution of global gravitational models, associated services, and future plans, Earth Syst. Sci. Data, 11, 647–674, https://doi.org/10.5194/essd-11-647-2019, 2019.

Other references:

Barthelmes, F.: Definition of Functionals of the Geopotential and Their Calculation from Spherical Harmonic Models: Theory and formulas used by the calculation service of the International Centre for Global Earth Models (ICGEM), Scientific Techni- cal Report STR09/02, Revised Edition, January 2013, Deutsches GeoForschungZentrum GFZ, https://doi.org/10.2312/GFZ.b103-0902-26,2013.

Barthelmes, F.: Global Models, in: Encyclopedia of Geodesy, edited by: Grafarend, E., Springer International Publishing, 1–9, https://doi.org/10.1007/978-3-319-02370-0_43-1, 2014.

Barthelmes, F. and Förste, C: The ICGEM-format. Potsdam: GFZ German Research Centre for Geosciences, available at: http: //icgem.gfz-potsdam.de/ICGEM-Format-2011.pdf (last access: 25 February 2020), 2011.

Staff

ICGEM is hosted by GFZ Potsdam. After the long-time director of the ICGEM service *Franz Barthelmes'* retirement, current staff consists of
E. Sinem Ince
Sven Reißland
The staff is allocated part-time and responds to queries on a best-effort basis.

Point of Contact

E. Sinem Ince
Helmholtz Centre Potsdam
GFZ German Research Centre for Geosciences
Telegrafenberg,
D-14473 Potsdam,
Germany
E-mail: elmas.sinem.ince@gfz-potsdam.de