

International Service for the Geoid (ISG)

<http://www.isgeoid.polimi.it/>

President: Mirko Reguzzoni (Italy)

Director: Daniela Carrion (Italy)

Structure

The Service is hosted by the Department of Civil and Environmental Engineering at Politecnico di Milano (Italy).

In addition to the president and the director, the ISG staff is composed by other scientists (F. Sansò, R. Barzaghi, G. Sona, A. Albertella, C.I. De Gaetani, L. Rossi, K. Batsukh and J.F. Toro Herrera), as well as a secretary (C. Vajani).

The ISG advisory board is composed by the following scientists with expertise in the field of geoid determination:

- N. Pavlis (USA)
- M. Sideris (Canada)
- J. Huang (Canada)
- R. Forsberg (Denmark)
- J. Ågren (Sweden)
- U. Marti (Switzerland)
- H. Denker (Germany)
- L. Sánchez (Germany)
- K. Elger (Germany)
- I. Tziavos (Greece)
- D. Blitzkow (Brazil)
- W. Featherstone (Australia)
- H. Abd-Elmotaal (Egypt)
- C. Hwang (Chinese Taipei)

ISG is currently involved in the Joint Working Groups JWG 2.2.1 of IAG Sub-Commission 2.2 “Error assessment of the 1 cm geoid experiment”.

Overview

In the period 2019-2021, most activities have been devoted to standardise the information and increase the offer of services on the available archive of geoid and quasi-geoid models, namely:

- the update of the ISG data format, which is common to all models;
- the establishment of a DOI service, in cooperation with GFZ;
- the establishment of a (preliminary) web-service for height conversion;
- the distribution of the Colorado experiment data and results, through the ISG website.

ISG activities have been disseminated through the participation to international events with oral and poster presentations. A paper on ISG has been published on Earth System Science Data, as well. The traditional activities on school organization and scientific support to researchers on geoid estimation have been suspended due to the advent of the Covid-19 pandemic.

Last but not least, the ISG geoid repository has been continuously updated, significantly increasing the number of collected models. The ISG website has been modified accordingly.

Update of the ISG data format

ISG manages and preserves a repository of regional, national and continental geoid models at a worldwide scale. The repository aims at storing and redistributing geoid models in a standardised data format, providing also ancillary information useful for gravity related analysis. To this aim, the geoids are collected both in the format provided by the owners and in ISG format, a standardised ASCII format with the .isg extension. The first version of the ISG ASCII format was released in 2015 and updated in 2018 (version 1.01). In July 2020, a major new release, version 2.0, was published, mainly introducing more metadata to better characterize the content of the file, and also allowing to store sparse point data. All the new models will be published with version 2.0.

Each individual data file consists of three sections: a) the optional comment section; b) the header section, which contains textual and numerical parameters; c) the data section, which contains the undulation values. To increase data interoperability, section (a) and (b) were designed with the same scheme of the .gfc file, distributed by ICGEM and providing global model coefficients.

In the comment section (a), three paragraphs are strongly recommended, the first one with the licence under which the data are distributed, the second one with the reference to cite when using the data, the third one indicating the data provider and the institution distributing the model.

In ISG format, the header section (b) is composed by structured metadata. It can be conceptually divided into three parts. The first contains textual metadata that are required to characterize the model, such as:

- the name of the model and the year of computation,
- the type of the model (gravimetric, geometric or hybrid),
- the classification between geoid and quasi-geoid,
- the fact that the data are sparse or gridded, and in case the ordering of the gridded data,
- the reference ellipsoid and datum, the reference frame, and the tidal system,
- the fact that the coordinates are geodetic or projected and, in case, the type of projection,
- the units of the undulation data and the coordinate units.

The second part contains numerical metadata that are mainly required to georeferencing the undulation values, such as

- the bounding box of the undulation dataset, i.e. minimum and maximum coordinates,
- the grid step and the number of rows and columns if the data are gridded (the number of rows can be used in sparse data to specify the number of points),
- the no-data value for missing points inside the grid structure.

Finally, the third part contains information about the file, such as the creation date and the format version. Metadata and their keywords depend on the format version. The file format specifications for all the possible versions are available at a dedicated page on the ISG website (https://www.isgeoid.polimi.it/Geoid/format_specs.html).

The data section was originally developed to contain the gridded undulation values, but from the format version 2.0 it is also possible to store sparse data by providing the point coordinates along with the undulation values. In case of gridded data, the point coordinates are defined in the header section and the undulation values are always stored row by row, being the default ordering from North to South, each row going from West to East.

Establishment of a DOI service

Geoid models that are collected by ISG are validated and standardized by converting them into a unique ASCII file format. In order to further improve interoperability and reusability of these models, it is crucial to univocally identify the data file (also by stable links), to assign metadata, to grant proper credit to research authors, and to allow for data citation.

In the framework of the GGOS working group “DOIs for Geodetic Data Sets”, ISG and GFZ are cooperating for developing a DOI minting service for local/regional geoid/quasi-geoid models collected and published via the International Service for the Geoid. The service includes the DOI assignment to the models, the collection and provision of standardised metadata and an additional backup of the models through GFZ Data Services, guaranteeing a persistent data access (the rights for publication of the models have been addressed by ISG and the data are already available for public download via the ISG geoid repository).

Since summer 2020, when the service was activated, the geoid/quasi-geoid distribution has been changed as follows:

- ISG geoid and quasi-geoid models in standardised ISG format (ASCII) can be labelled by DOIs. It is not foreseen to apply DOIs to the models in “original” format (as provided by the authors).
- The models that are labelled by DOIs are published under the Creative Commons Attribution 4-0 International Licence (CC BY 4.0) unless otherwise stated.
- The models that are labelled by DOIs are additionally publicly accessible via machine-readable DOI landing pages and the data catalogue of GFZ Data Services.
- The DOI landing pages have a specific layout for ISG.
- The geoid repository at ISG remains the first access point of ISG geoid models.
- A copy of the models will be archived at GFZ (backup).

Figure 1 provides an overview on the relation between the ISG and the GFZ Data Services for an example of DOI-referenced model. Both the quasi-geoid and geoid solutions, constituting the example model, can be accessed via the dedicated web page in the ISG geoid repository (on the left) and via the DOI landing pages in the GFZ Data Services (on the right). The “File” section of the DOI landing page includes the links to the model file and the corresponding web page in the ISG repository. On the other side, the ISG model web page is enhanced with the recommended citations of the DOI-assigned models and the links to the DOI landing pages at the GFZ Data Services. The arrows show the cross-references between the two web pages.

At the date of 31 May 2021, DOIs were assigned to 20 models stored in the ISG repository, that is about 11% of the total number of open-access models.

In addition to the DOI assignment, the agreement between ISG and Clarivate is still active, thus indexing all ISG geoid and quasi-geoid models in the Data Citation Index and providing the corresponding accession number on the ISG website of the model website

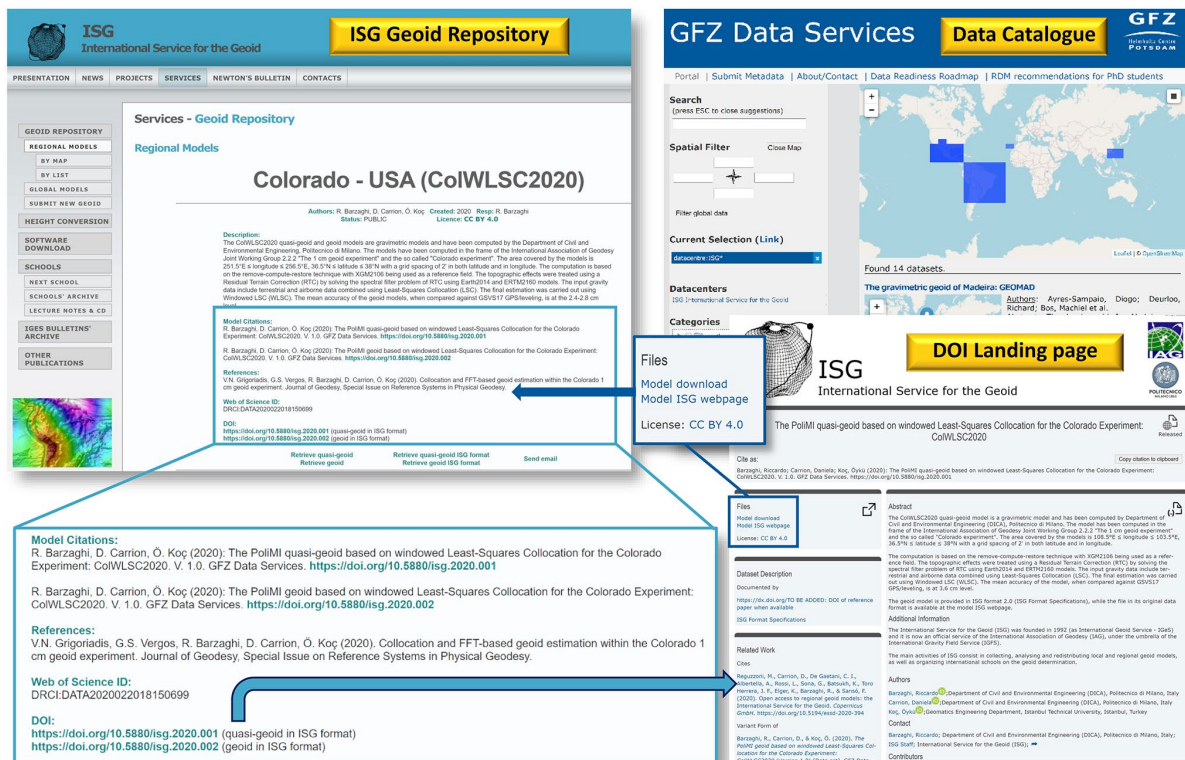


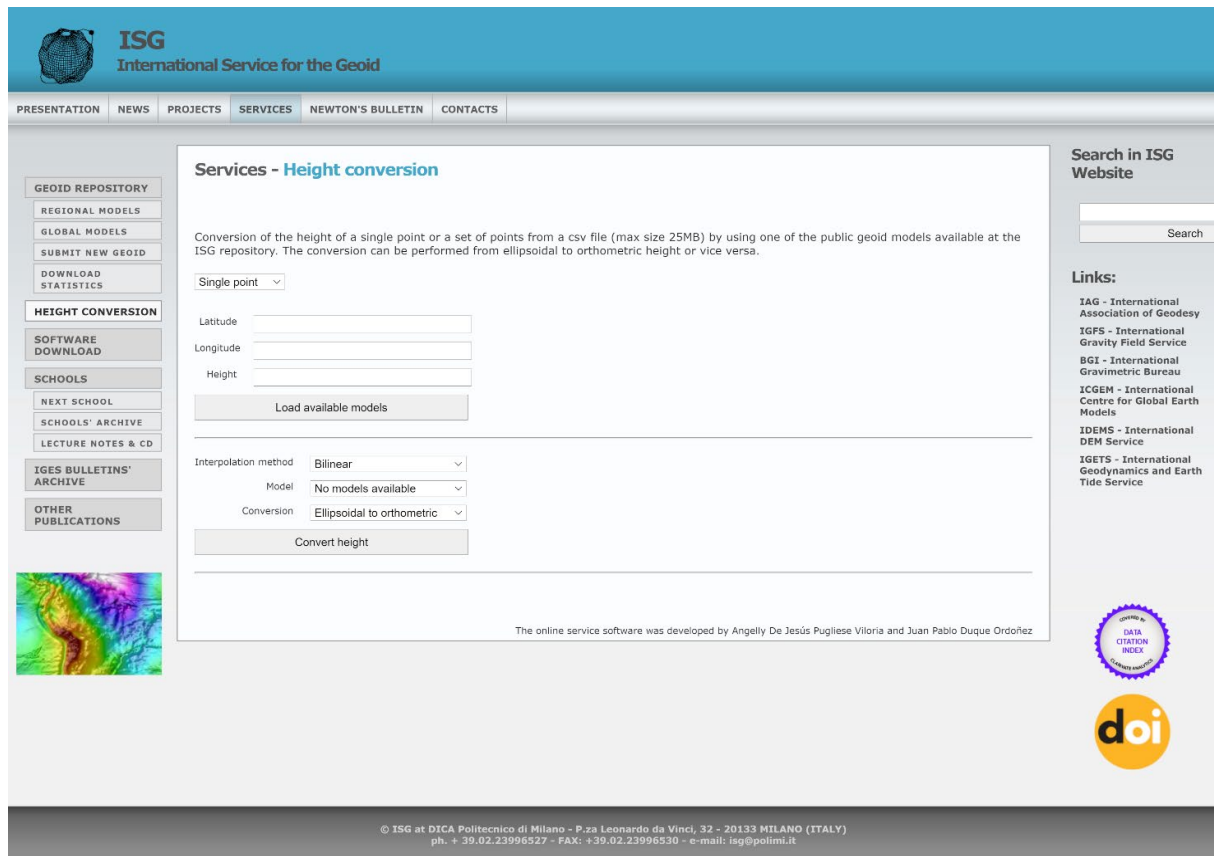
Figure 1: overview on the relation between the ISG and the GFZ Data Services for an example of DOI-referenced model.

Establishment of a web-service for height conversion

In summer 2020, ISG activated a height conversion web-service to the users. They can provide the coordinates of one or more points (in the latter case through a CSV file containing three columns, namely latitude, longitude and height to be converted) and, after selecting the geoid model and the interpolation method, the web-service returns the conversion from ellipsoidal to orthometric height or vice versa. Once the user provides the point coordinates, only the geoid models containing at least one of these points are listed and can be selected by the user for the height conversion. This is possible by exploiting the model bounding box information that is available in the model file header as defined according to the ISG format.

As for the algorithmic point of view, the conversion is based on the formula $H = h - N$, relating the ellipsoidal height h and the orthometric height H through the geoid undulation N . Due to the fact that geoid models used by this service are given on a grid, the currently available interpolation methods are a bilinear interpolation among the four closest grid knots to the input point and the inverse distance weighting interpolation. Other interpolation methods may be made available in the future. The distinction between geoid and quasi-geoid will be performed soon, also mentioning the different reference systems/frame involved in the conversion. In this respect, the implemented web-service has to be considered as a preliminary solution.

As for the software implementation point of view, the web-service is divided into front-end and back-end, the former providing a user interface and the latter performing the calculations. The front-end is the "visible" part of the application (see Figure 2), it is implemented by using an HTML page and JavaScript. The HTML page contains a form with all the needed fields for the height conversion according to the web-service created on the back-end. The interface is designed to change as the user interacts with the application and selects the different options (single or multiple point coordinates). There are also checks on the input file size and format when the user asks for the conversion of more than one point.



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Services - Height conversion

Conversion of the height of a single point or a set of points from a csv file (max size 25MB) by using one of the public geoid models available at the ISG repository. The conversion can be performed from ellipsoidal to orthometric height or vice versa.

Single point

Latitude

Longitude

Height

Interpolation method

Model

Conversion

The online service software was developed by Angelly De Jesús Pugliese Viloria and Juan Pablo Duque Ordoñez

Search in ISG Website

Links:

- IAG - International Association of Geodesy
- IGFS - International Gravity Field Service
- BGI - International Gravimetric Bureau
- ICGEM - International Centre for Global Earth Models
- IDEMS - International DEM Service
- IGETS - International Geodynamics and Earth Tide Service

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Figure 2: Webpage to access the ISG height conversion web-service.

The back-end is the core of the web-service, performing the required computation without increasing the burden of the front-end. In this way the web-service can be modified or updated without interfering with the front-end. In order to implement the back-end, a REST API (Representational State Transfer Application Programming Interface) was created in Django, a high-level Python web framework that allows performing mathematical calculations using Python with the NumPy library. Four different endpoints were created for the geoid model research and the height conversion, both for a single point and a set of points.

All requests from the front-end to the back-end rely on the HTTP POST method, i.e. enclosing the data in the body of the request messages instead of storing it, while the answers from the back-end are transmitted through a JSON file, which is directly visualized in the HTML page.

Distribution of the Colorado experiment data and results

In the past 4 year period, the 1-cm geoid experiment (also called Colorado experiment) was setup as a joint effort of the Focus Area Unified Height System of the Global Geodetic Observing System (GGOS), the IAG Sub-commission 2.2, IAG Inter-Commission Committee on Theory (ICCT), and many related studies and working groups. The main objective of the experiment was the estimation and comparison of geoid undulations and height anomalies in Colorado using the same input data (provided by the US National Geodetic Survey, NGS) and different methodologies for the gravity field modelling. ISG offered the possibility of publishing both input data and results (in term of geoid and quasi-geoid models) on its website. To this aim, dedicated webpages are now online, one for each solution computed in the frame of the Colorado experiment. A homepage summarizing the project and providing input and

validation data is available too. As it is done for any other model in the ISG repository, information about names and institutions of the authors, the publication year of the model, key reference publication(s) and a brief description on the computational method of the model is provided for the Colorado solutions too. Moreover, DOIs can be assigned to these solutions, making it possible to directly cite geoid and quasi-geoid models in scientific publications. Finally, the availability of the input data and possible comparisons with the already existing solutions can foster other researchers to test their own algorithm on this dataset, even if the official experiment is closed. ISG will also publish these additional results.

For the moment, ten solutions have been published on the ISG website, four of them have been already labelled with DOIs (geoid and quasi-geoid models have different DOIs even if they refer to the same solution). This activity has been carried out in the frame of Joint Working Groups JWG 2.2.1 of Sub-Commission 2.2 “Error assessment of the 1 cm geoid experiment”.

Participation to conferences and publications

ISG members took part to some international conferences/events, presenting the activities performed by the service. In particular, the following two oral presentations were given:

- “The International Service for the Geoid and its role in South America” at the workshop on the “Implementation of the United Nations’ Resolution on the Global Geodetic Reference Frame (UN-GGRF) for Sustainable Development in Latin America” held in Buenos Aires, Argentina, 16-20 September 2019.
- “The International Service for the Geoid: focus on Asia-Pacific region” at the first Asia Pacific geoid workshop for IAG-Sub-Commission 2.4e, held in Taiwan, 29 October 2020.

Moreover, ISG contributed to the presentation entitled “The IGFS gravity field observations and products contributions to GGOS infrastructure” at EGU General Assembly in 2020. Finally, an abstract entitled “Assigning Digital Object Identifiers to Geoid Models in the ISG Repository” was submitted and accepted as a poster presentation at IAG Scientific Assembly in 2021.

As for the publications, a paper focussing on ISG and mainly on its geoid repository has been recently published, please see M. Reguzzoni, D. Carrion, et al. (2021). Open access to regional geoid models: the International Service for the Geoid. *Earth System Science Data*, 13, pp. 1653–1666. DOI: 10.5194/essd-13-1653-2021. ISG users are encouraged to cite this paper when using ISG services.

School organization and scientific support to researchers on geoid estimation

One of the main tasks of ISG consists in organizing schools on geoid estimation and related topics. The last international school was held in Mongolia in 2016, at the Geodesy Department of Mongolian University of Science and Technology (MUST), Ulaanbaatar. The planning was to organize a new edition in 2020, but the advent of the Covid-19 pandemic led to postpone the school organization when the worldwide health situation will make travelling and hosting safer.

Traditionally, ISG also provides tailored training courses on geoid estimation at Politecnico di Milano. Again, this activity became unfeasible because of the Covid-19 pandemic. However, the possibility of organizing online training activities is being considered.

ISG geoid repository and website update

In the last two years, the ISG archive of local, regional and continental geoid and quasi-geoid models has been continuously updated. Not only the latest release of a model is stored in the archive, but also outdated versions are collected to keep memory of the work done in the past and to allow for comparisons. The full (or almost the full) series of the official geoid models are available for many countries. Three possible policy rules are considered for the model distribution: “public” if it can be freely downloaded from the website, “on demand” in case the authors asked to be informed before distributing the model, and “private” if it is just included in the archive but it cannot be distributed to the users. Therefore, the aim of the “private” policy is to inform users that a model exists without publishing any data through the ISG service. Almost 250 models are currently available in the ISG database, whose composition is reported in Tables 3, 4 and 5 (last update of the statistics was on 31 May 2021). The global coverage of the available gridded geoid models, together with their spatial resolution, is shown in Figure 3.

Europe	81
North America	65
Asia	33
Oceania	22
Africa	19
South America	14
Antarctica	4
Arctic	4
Total	242

Table 3: Number of models per continent in the ISG archive.

< 1991	4
1991 – 1995	15
1996 – 2000	41
2001 – 2005	30
2006 – 2010	56
2011 – 2015	51
2016 – 2020	44
> 2020	1
Total	242

Table 4: Number of models per year in the ISG archive.

Public	181
On-Demand	22
Private	39
Total	242

Table 5: Number of models per policy-rule in the ISG archive.

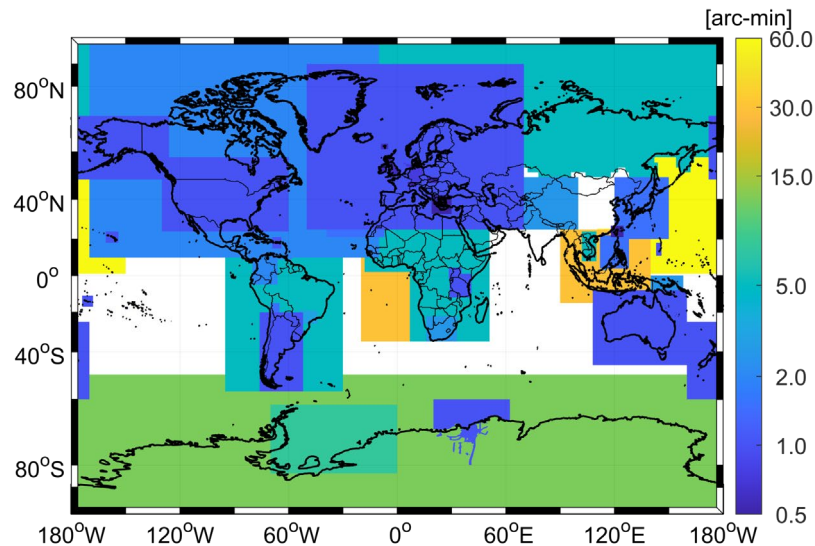


Figure 3: Spatial coverage of the gridded geoid models available at ISG. Colour-bar shows the highest spatial resolution per location (log10 scale, unit: arc-minutes).

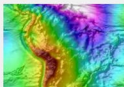
The ISG website is updated simultaneously to the ISG archive. For each geoid model that is stored in the archive a dedicated webpage is available on the website, containing information about the model name, year, authors, contact person, type (gravimetric, geometric or hybrid, geoid or quasi-geoid) and policy rule. There is a short description of the model characteristics, at least one bibliographic reference and a model figure. When a DOI is attributed to the model, the corresponding citation is provided, along with the data license (CC BY 4.0), see Figure 4. If the model is classified as “public”, the corresponding data file can be downloaded from the webpage in a unique ASCII format (.isg), whose specifications are provided in the website. After authors’ authorization, the “on demand” models can be distributed to users in the same ASCII file format. The webpage of each model can be reached from a complete list of available geoids or by clicking on a geographical map.

Apart from the geoid repository, the website has been updated in the home page and in the section dedicated to the software, adding some Matlab functions to read and write geoid and quasi-geoid models in ISG format. News section has been continuously kept up-to-date. No papers have been submitted to Newton’s Bulletin in the last two years. The current home page of the ISG service is shown in Figure 5. Some statistics on the website access are displayed in Figure 6.


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 SCHOOLS' ARCHIVE
 LECTURE NOTES & CD
 IGES BULLETINS' ARCHIVE
 OTHER PUBLICATIONS



Services - Geoid Repository
 Regional Models

Colorado - USA (CoWLSC2020)

Authors: R. Barzaghi, D. Carion, Ö. Köp Created: 2020 Resp: R. Barzaghi
Status: PUBLIC Licence: CC BY 4.0

Description:
 The CoWLSC2020 quasi-geoid and geoid models are gravimetric models and have been computed by the Department of Civil and Environmental Engineering, Politecnico di Milano. The models have been computed in the frame of the International Association of Geodesy Joint Working Group 2.2.2 "The 1 cm geoid experiment" and the so called "Colorado experiment". The area covered by the models is 251.5°E ≤ longitude ≤ 256.5°E, 36.5°N ≤ latitude ≤ 38°N with a grid spacing of 2" in both latitude and in longitude. The computation is based on the remove-compute-restore technique with XGM2106 being used as a reference field. The topographic effects were treated using a Residual Terrain Correction (RTC) by solving the spectral filter problem of RTC using Earth2014 and ERTM2160 models. The input gravity data include terrestrial and airborne data combined using Least-Squares Collocation (LSC). The final estimation was carried out using Windowed LSC (WLSC). The mean accuracy of the geoid models, when compared against GSV17 GPS/leveling, is at the 2.4-2.8 cm level.

Model Citations:
 R. Barzaghi, D. Carion, Ö. Köp (2020): The PoLiMi quasi-geoid based on windowed Least-Squares Collocation for the Colorado Experiment: CoWLSC2020, V. 1.0. GFZ Data Services, DOI: [10.5880/ing.2020.001](https://doi.org/10.5880/ing.2020.001)
 R. Barzaghi, D. Carion, Ö. Köp (2020): The PoLiMi geoid based on windowed Least-Squares Collocation for the Colorado Experiment: CoWLSC2020, V. 1.0. GFZ Data Services, DOI: [10.5880/ing.2020.002](https://doi.org/10.5880/ing.2020.002)

Reference:
 V.N. Gligoradis, G.S. Vergos, R. Barzaghi, D. Carion, Ö. Köp (2021) Collocation and FFT-based geoid estimation within the Colorado 1 cm geoid experiment. Journal of Geodesy, 95, 52, DOI: [10.1007/s00190-021-01507-7](https://doi.org/10.1007/s00190-021-01507-7)

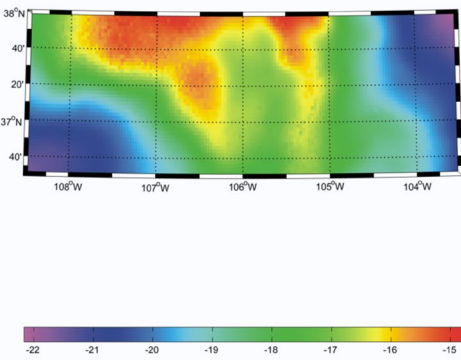
Web of Science ID:
 DRCI:DATA2020022018150699

Digital object identifier:
 DOI: [10.5880/ing.2020.001](https://doi.org/10.5880/ing.2020.001) (quasi-geoid in ISG format)
 DOI: [10.5880/ing.2020.002](https://doi.org/10.5880/ing.2020.002) (geoid in ISG format)

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 ICGEM - International Centre for Global Earth Models
 IDEMS - International DEM Service
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Figure 4: Example of a webpage describing a model stored in the geoid repository (https://www.isgeoid.polimi.it/Geoid/America/USA/Colorado20WLSC_g.html).

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CONTACTS

International Service for the Geoid

President: Mirko Reguzzoni (Italy)
Director: Daniela Carrion (Italy)

ISG has been founded in 1992 (as International Geoid Service - IGeS) as a working arm of International Geoid Commission (IGeC), and it is actually an official Service of the International Association of Geodesy (**IAG**).

Since 1999 the process of reviewing statutes of IAG has deeply involved also the IAG Services and those Services which are related to the determination of the gravity field.

In 2003, a new unified IAG Service for the Gravity Field has been created: the International Gravity Field Service (**IGFS**), to coordinate and integrate broad gravity field activities.

IGFS centres are: International Gravimetric Bureau (**BGI**), Combination Service for Time-variable Gravity Fields (**COST-G**), International Service for the Geoid (**ISG**), International Centre for Global Earth Models (**ICGEM**) and International DEM Service (**IDEMS**), International Geodynamics and Earth Tide Service (**IGETS**). In IGFS, ISG is one of the operative arms of the International Commission for the Gravity Field.

ISG' activities are on educational, research, and data distribution sides: principal purposes of ISG are the collection and distribution of geoid models, the collection and distribution of software for geoid computation, and the organization of technical schools on geoid determinations.

The Service is provided by two Centres, one at **Politecnico di Milano**, and one at **NGA**.

Main tasks of ISG are:

- to collect geoid data on a worldwide scale (**geoid repository**)
- to collect and distribute software for geoid determination (**software download**)
- to conduct researches on procedure for geoid determination (**projects**)
- to organize **Geoid schools**
- to edit and distribute the **Newton's Bulletin**

Moreover, as regards the research activity, ISG takes part in:

- the European Gravity Geoid Project
- the GOCE satellite mission
- the Global Geodetic Observing System project (GGOS) for the height datum unification

For other details about ISG projects please click [here](#).

At present the following scientists are ISG advisors:
N. Pavlis (USA), M. Sideris, J. Huang (Canada), R. Forsberg (Denmark), J. Ågren (Sweden), U. Marti (Switzerland), H. Denker, L. Sánchez, K. Elger (Germany), I. Tziavos (Greece), D. Blizkow (Brazil), W. Featherstone (Australia), H. Abd-Elmotaal (Egypt), C. Hwang (Chinese Taipei)

Within the structure of ISG, Working Groups can be established for specific purposes, limited in time.

Please cite the ISG service as:
M. Reguzzoni, D. Carrion, C.I. De Gaetani, A. Albertella, L. Rossi, G. Sona, K. Batsukh, J.F. Toro Herrera, K. Elger, R. Barzaghi, F. Sansó (2021). Open access to regional geoid models: the International Service for the Geoid. Earth System Science Data, 13, pp. 1653–1666. DOI: **10.5194/essd-13-1653-2021**.

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Neither ISG nor any of its staff accept any liability in connection with the use of data and models provided here. Neither ISG nor any of its staff make any warranty of fitness, completeness, usefulness and accuracy of the data and models for any intended or unintended purpose.

This Website has been designed for Firefox, Internet Explorer, Google Chrome, SeaMonkey, Opera.

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BGI - International Gravimetric Bureau

COST-G - Combination Service for Time-variable Gravity Fields

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Figure 5: Home page of the ISG website (<https://www.isgeoid.polimi.it/>).

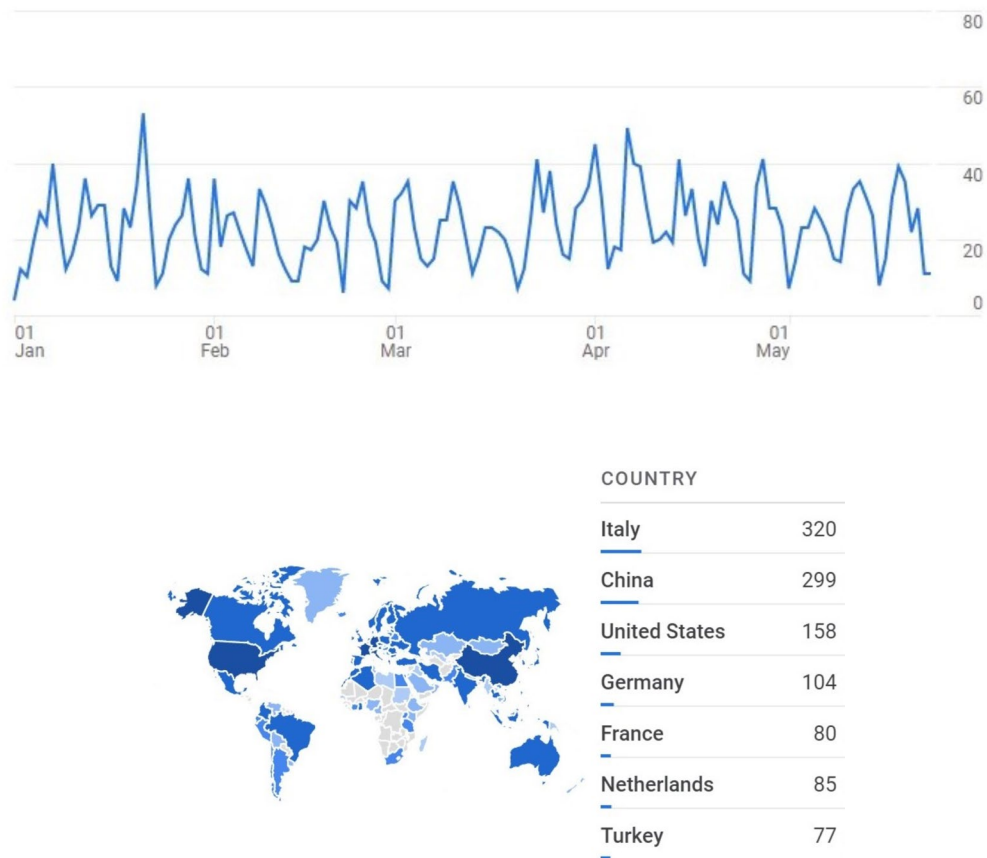


Figure 6: Statistics on the number of visitors per day (upper panel) and per country (lower panel) for the ISG website from the beginning of 2021 till end of May 2021.