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) † 2022
- H. Abd-Elmotaal (Egypt)
- C. Hwang (Chinese Taipei)

In the period 2019-2023, ISG has been involved in the Joint Working Group JWG 2.2.1 of IAG Sub-Commission 2.2 “Error assessment of the 1 cm geoid experiment”.

Overview

In the period 2019-2023, ISG research has been mainly related to local geoid computation and height datum unification. In addition to that, 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 and the development of other services for clipping and merging models;
- the distribution of the Colorado experiment and the Auvergne test datasets 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. According to tradition, ISG organized an International School on "The Determination and Use of the Geoid" during this four-year period. For the first time, the school was held online due to the Covid-19 limitations.

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. In the next future it is planned to improve both the repository and the website, storing models and information into a database and adding WebGIS functionalities into a more modern website.

Research activities

Most of the research studies were devoted to local/regional geoid determination and the height datum unification problem. The former mainly consists in the refinement of the collocation approach that is the technique traditionally applied for the geoid determination by the research group managing ISG. In this framework, it has to be mentioned the provided contribution to the Colorado experiment and the support to the results assessment and publication.
As for the latter issue, namely the height datum unification problem, the large availability of local/regional geoid/quasi-geoid models in the ISG repository fosters the study of a merging strategy to produce unified models between neighbour countries. The proposed method consists of first estimating biases and systematic effects by a least-squares adjustment of the local geoid residuals with respect to a satellite-only global gravity model, and then correcting the remaining distortions along the national borders to better join the local geoid models. This investigation was initially performed in the framework of the JWG2.2.1 "Integration and validation of local geoid estimates" of IAG Commission 2 in the period 2015-2019 and then continued during this period, also leading to a prototype of web-service implemented in Python.
Among the contributions to the realization of an International Height Reference System/Frame (IHRS/IHRF), it has to be mentioned the study performed in Ecuador (Carrion et al., 2023). The vertical offset between the official Ecuador Vertical Datum (EVD) at "La Libertad" tide gauge and the IHRF was estimated based on the fixed geodetic boundary value problem approach. The determination of the anomalous potential at the EVD point, which in turn enables the determination of the corresponding geopotential value, was carried out by applying the remove-compute-restore methodology based on gravity disturbance data and considering the GO_CONS_GCF_2_DIR_R5 satellite model at d/o 200 and 300. Thus, two estimates of the EVD offset with respect to the IHRF were obtained that amount to 0.911 m and 0.901 m, respectively. Furthermore, a computation were performed and presented at EGU2022 General Assembly concerning the IHRF estimation over the Matera (Italy) and AUT1 (Greece) EUREF stations using local gravity data and geoid models.

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, also providing 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 webpage 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 webpage in the ISG repository. On the other side, the ISG model webpage 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 webpages.
At the date of 31 May 2023, DOIs were assigned to 64 models stored in the ISG repository, that is about 30% 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.

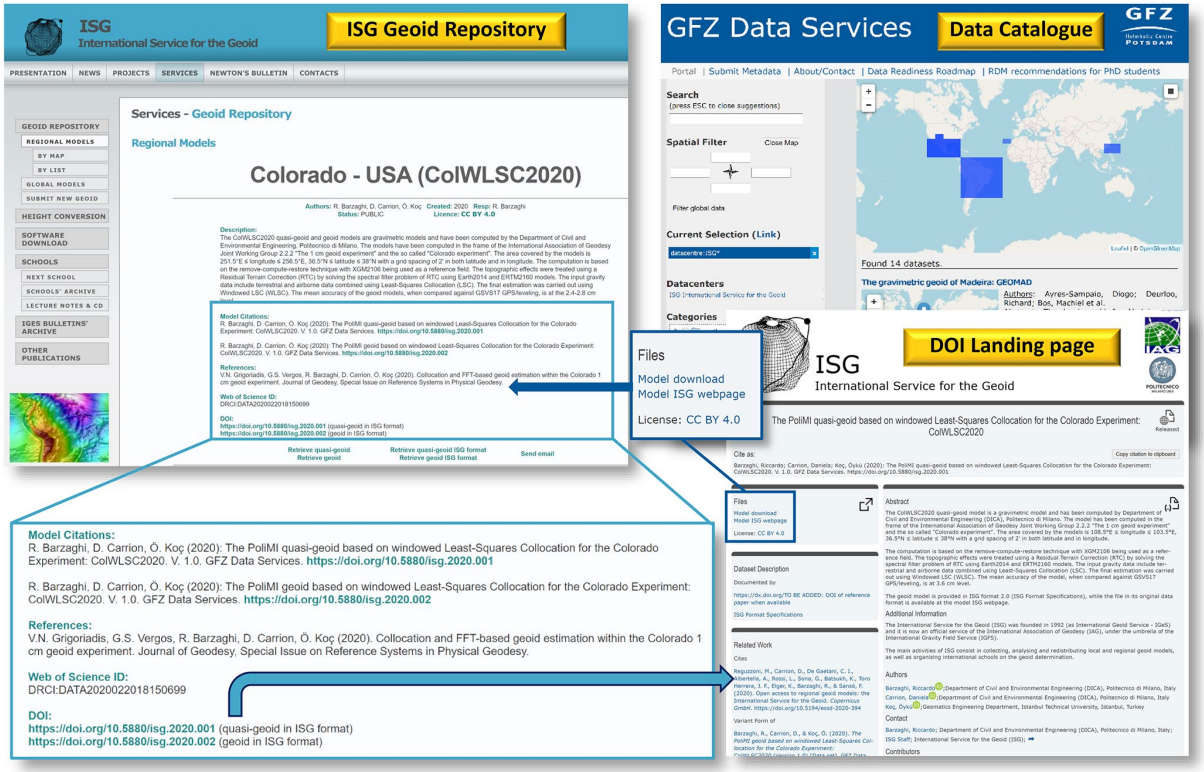

Figure 1: Overview on the relation between the ISG and the GFZ Data Services for an example of DOI-referenced model.

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.

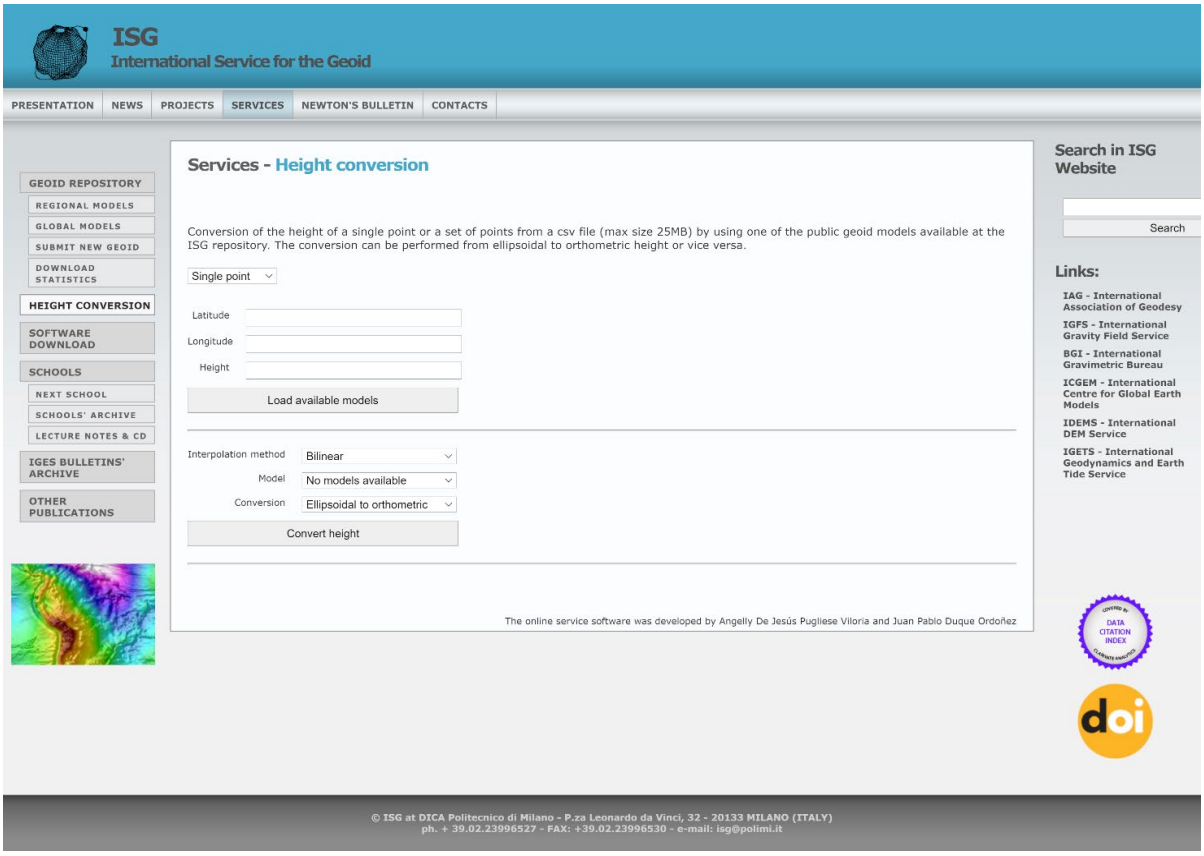

Figure 2: Webpage to access the ISG height conversion web-service.

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.
The service is currently being updated to work with models stored in the version 2.0 of the ISG format. Since this new version gives the possibility of discriminating between geoid and quasi-geoid models from the header information, the service will inform users whether the conversion is between ellipsoid and orthometric heights, or between ellipsoidal and normal heights.

Development of a service for extracting geoid subsets

In the last year, ISG developed (but not yet made available online) a service to select a data subset from an existing local, regional or continental geoid model, among those that are stored in the ISG repository and are publicly available to users. The selection is performed through a graphical user interface and implies a data resampling by interpolation techniques. Finally, a file format conversion can be performed to import the selected and potentially clipped geoid models into commercial GNSS/GPS receivers or GIS software.
The tool has been developed in Python language by means of the Django framework. In particular, the implementation has been designed to provide static html pages from the backend and to manage the interaction with the user completely on the client side through asynchronous AJAX calls with JavaScript.
As for the area selection, three options are available: 1) to take the entire grid, 2) to extract a sub-grid from corners, 3) to cut the grid along a contour line given by a shapefile. In the latter case, no-data values are attributed to points belonging to the exported sub-grid but laying outside the shapefile contour (see Figure 3). As for the data interpolation, when required to change the original grid step, again three resampling options are available: 1) nearest-neighbor, 2) bilinear, 3) bicubic (see Figure 4). As an example, the EGG97 European model has been cut along the Italian border shapefile, then resampling the extracted grid at higher spatial resolution by bilinear interpolation (see Figure 5).

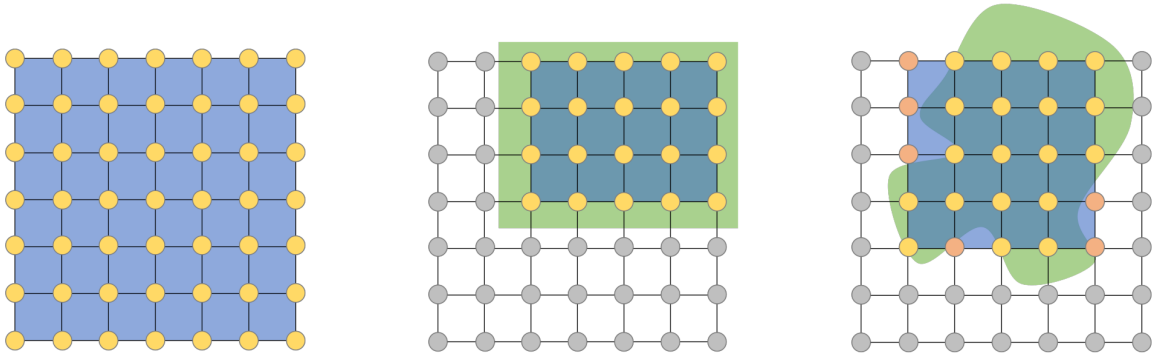

Figure 3: Subset selection options: entire grid (on the left), sub-grid from corners (in the center), sub-grid from georeferenced shapefile setting no-data values externally (on the right).

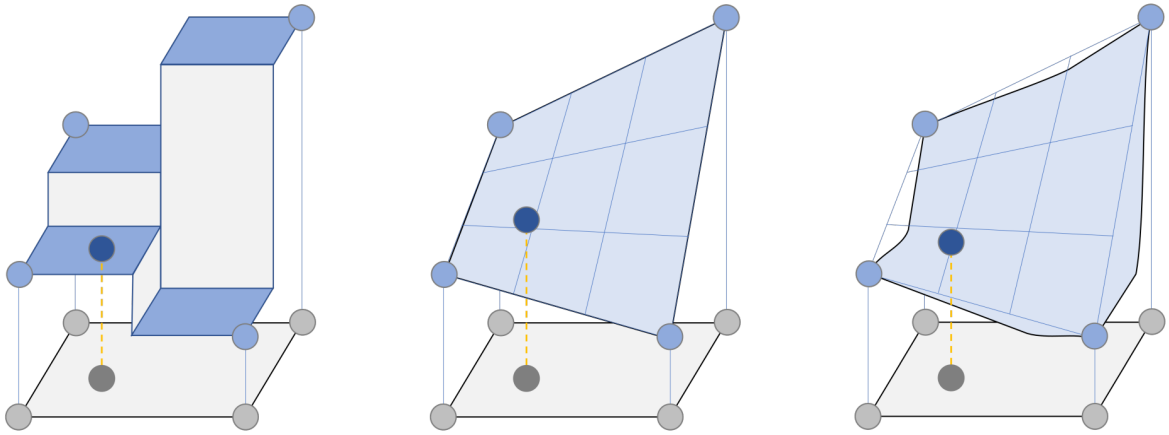

Figure 4: Resampling options: nearest-neighbor (on the left), bilinear (in the center), bicubic (on the right).

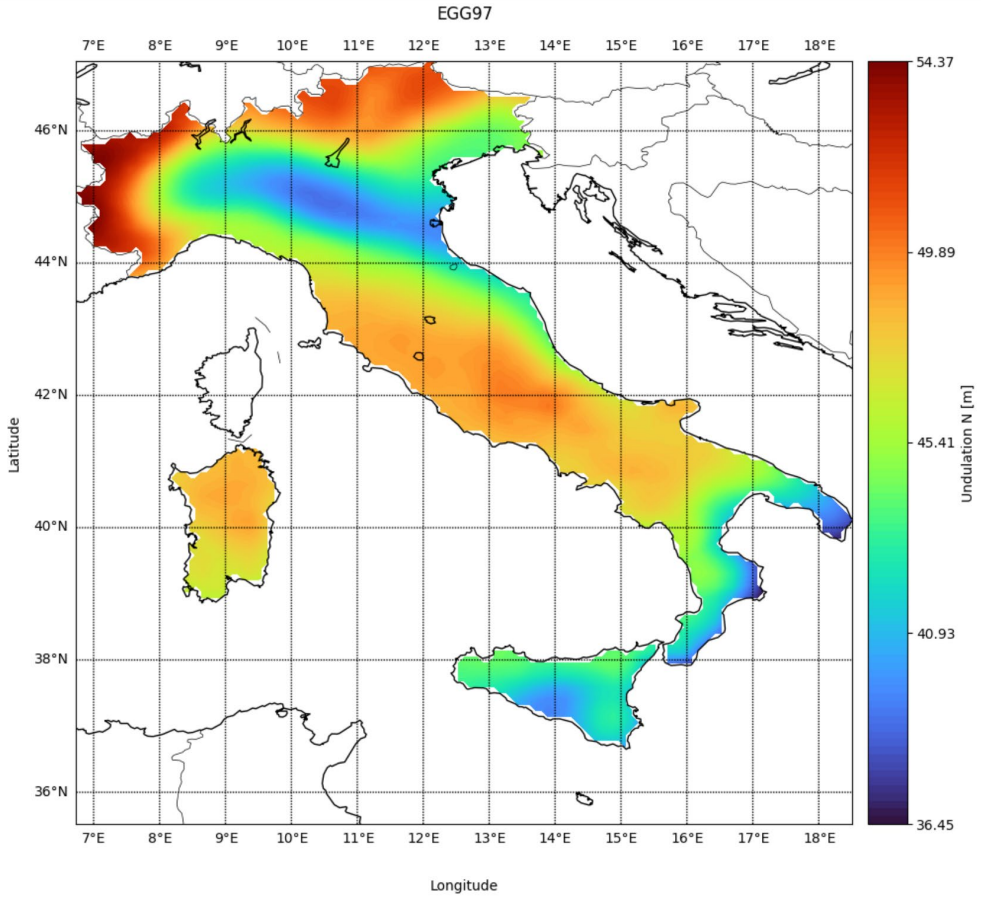

Figure 5: Extracted model from shapefile contour with a bilinear resampling.

Finally, it has to be mentioned that the currently implemented format conversions allow to export the extracted grids in one of the following formats:

- Internal format (.isg) - version ISG1.01 and ISG2.00
- Comma Separated Values (.csv)
- Carlson Geoid Separation File (.gsf)
- GeoTIFF Elevation (.tif)
- GEOCOL (.gri)

Further formats will be implemented in the next future. Along with the data file, a .png image files is also generated and made available to the user.

Development of a service for merging geoid models

ISG also developed a service to merge geoid models at national borders. The tool consists of the following steps:
- reading two or more models from the existing ISG repository;
- removing the contribution of a global model to all of them to setup the long wavelengths;
- removing also a bilinear surface for each model to manage differences in their reference frames;
- merging the geoid residuals by an inverse distance weighting (IDW) in the surroundings of the national borders;
- applying a suitable resampling technique to generate a unique grid of geoid residuals;
- adding back the contribution of the global model;
- if one of the model is taken as reference, adding back its removed bilinear surface over the whole extension of the merged grid to restore the corresponding reference frame.

The tool is developed in Python language through the Django framework. It is still at a prototype level and, therefore, it has not yet been made available online.

Distribution of the Colorado experiment data and results

In the period 2015-2019, 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 terms 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 are assigned to almost all 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, 15 solutions have been published on the ISG website, all but one 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".

Distribution of the Auvergne test data and results

In 2004, the French Institut Géographique National (IGN), upon the request of the steering committee of the European Gravity and Geoid Project (EGGP), prepared a dataset to test geoid determination methods and software. The Auvergne region, located in the centre of France, was selected as the target area. The dataset consists of about 240,000 gravity points, a digital terrain model and 75 GPS/levelling points, allowing for the computation and evaluation of a 3°×2° geoid is feasible. At that time, it was agreed that IGeS (now ISG) would have published both input data and results on its website. After renewing the agreement with IGN, some webpages on the Auvergne test dataset have been setup, also considering that some research groups are still using it for evaluation purposing. Similarly to the Colorado experiment, users can find a homepage providing input and validation data with the information required for their use, as well as webpages dedicated to each solution that is available in the ISG repository.

For the moment, 5 solutions have been published on the ISG website, including the original one by Duquenne (2006). Further solutions will be collected in the next future and we will continue to encourage researchers to share their results on the Auvergne test through the ISG website to have a wide comparison among different computation methods.

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 three 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.
• "The International Service for the Geoid" at the IAG Joint Working Group 2.2.1 meeting, held online, 8 December 2021.

ISG contributed to the presentation entitled "The IGFS gravity field observations and products contributions to GGOS infrastructure" at EGU General Assembly in 2020. Two posters entitled "Assigning Digital Object Identifiers to Geoid Models in the ISG Repository" and "The International Service for the Geoid and its repository of regional geoid models" were presented at IAG Scientific Assembly in 2021 and GGHS Symposium in 2022, respectively. Finally, the design of the new ISG database was presented at the ISPRS Congress in 2022.

As for the publications, a paper focussing on ISG and mainly on its geoid repository has been published on Earth System Science Data, please see M. Reguzzoni, D. Carrion, et al. (2021). Users are encouraged to cite this paper any time they download geoid models from the ISG repository or in general when using ISG services. Other published papers in journal special issues containing conference proceedings are those by De Gaetani et al. (2022) and Toro Herrera et al. (2022).

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. In 2016 an international school was held in Mongolia, 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 would have improved to make travelling and hosting safer. To overcome these limitations, it was decided for the first time to offer the school online. In cooperation with the Dept. of Geodesy and Geodynamics Research and Development in Ethiopian Space Science and Technology Institute (ESSTI) of Addis Ababa (Ethiopia), the 13th International School on "The Determination and Use of the Geoid" was held online on Microsoft Teams platform, from 13 October to 17 November 2021. Overall, 35 people attended the School, including PhD students, researchers and professionals. Among the attendees, a group of 13 people was hosted in Addis Ababa at ESSTI premises, for local support; 8 attendees were connected from Europe; 6 from the USA; 3 from Peru; 2 from Argentina; 2 from Morocco and 1 from Nepal. All participants received a certificate of attendance at the end of the school. The programme was in accordance with that of the most recent schools and the schedule was planned with the aim of matching the different time zones (see Table 1).

Wednesday 13/10/2021	14:00	18:00	Prof. Fernando Sansò	General theory on gravity field
Friday 15/10/2021	14:00	18:00	ISG staff	Check of software installation on attendee's computers
Monday 18/10/2021	14:00	18:00	Prof. Nikos Pavlis	Global geopotential models
Tuesday 19/10/2021	14:00	18:00	Prof. Nikos Pavlis	Practical exercises: global geopotential models
Wednesday 20/10/2021	14:00	18:00	Prof. Rene Forsberg	Terrain effect computation and remove/restore, including practical exercises
Thursday 21/10/2021	14:00	18:00	Prof. Riccardo Barzaghi	Residual geoid estimation
Friday 22/10/2021	14:00	18:00	Prof. Riccardo Barzaghi	Practical exercises: residual geoid estimation
Tuesday 26/10/2021	14:00	18:00	Prof. Hussein Abd-Elmotaal Prof. Yan Wang Prof. George Vergos	The African Geoid project The Colorado experiment The computation of the Mediterranean Geoid
Wednesday 17/11/2021	14:00	18:00	Prof. Laura Sanchez	The height datum unification

Table 1: Schedule, programme and teachers of the 13th International School on "The Determination and Use of the Geoid".

As for the future, the 14th edition of the school has been already organized in cooperation with SIRGAS and will take place at Instituto Geográfico Nacional in Buenos Aires, Argentina, from 13 to 17 November 2023.
Finally, it has to be mentioned that ISG traditionally provides also tailored training courses on geoid estimation at Politecnico di Milano. Again, this activity became unfeasible because of the Covid-19 pandemic. Although the online option was considered, no training course was organized in the period 2019-2023, but we expect that the currently improved situation should give the possibility of restarting this activity as well. In this context, a visit of researchers and technicians from Jordan for their national geoid computation is planned for the end of this year.

ISG geoid repository and website update

In the last four 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 previous 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. Currently, 275 models are available in the ISG database, whose composition is reported in Tables 2, 3 and 4 (last update of the statistics was on 31 May 2023). The global coverage of the available gridded geoid models, together with their spatial resolution, is shown in Figure 6.

Europe	90
North America	72
Asia	43
Oceania	22
Africa	21
South America	19
Antarctica	4
Arctic	4
Total	275

Table 2: Number of models per continent in the ISG archive.

< 1991	4
1991 – 1995	15
1996 – 2000	41
2001 – 2005	31
2006 – 2010	57
2011 – 2015	52
2016 – 2020	63
> 2020	12
Total	275

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

Public	209
On-Demand	21
Private	45
Total	275

Table 4: Number of models per policy-rule in the ISG archive.

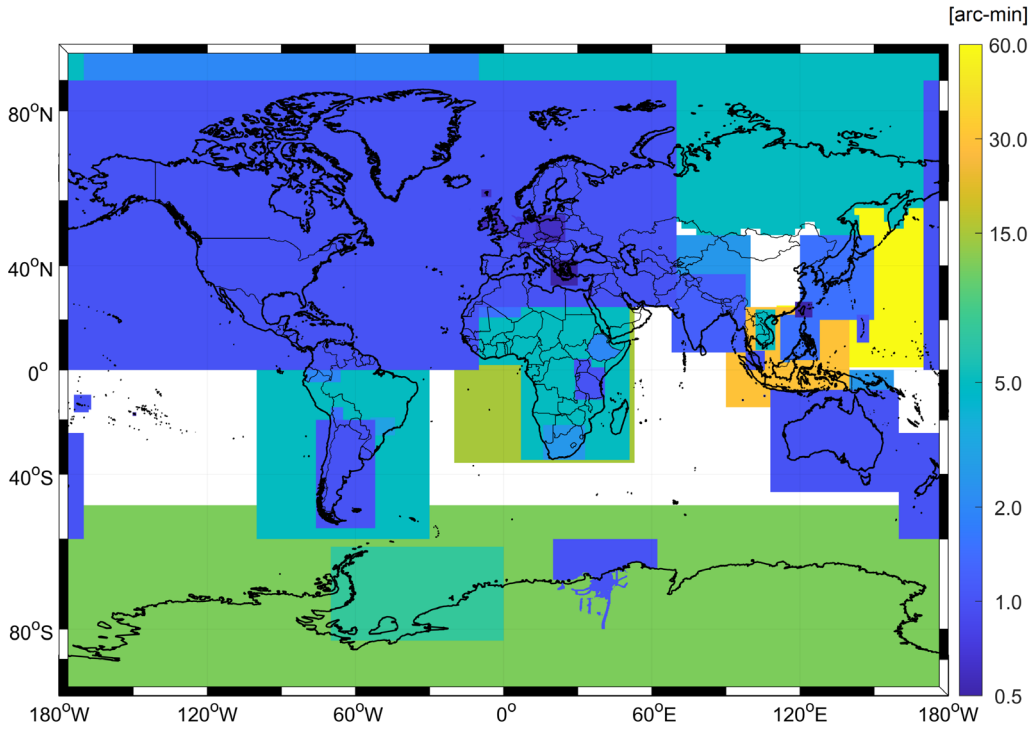

Figure 6: Spatial coverage of the gridded geoid models available at ISG. The colour-bar shows the highest spatial resolution per location (log10 scale, unit: arc-minutes).

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 7.
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 homepage 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. Since no papers were submitted to Newton's Bulletin, a new editorial collocation will be investigated to make the journal more appealing for geodesists. The current homepage of the ISG service is shown in Figure 8. Some statistics on the website access are displayed in Figure 9.

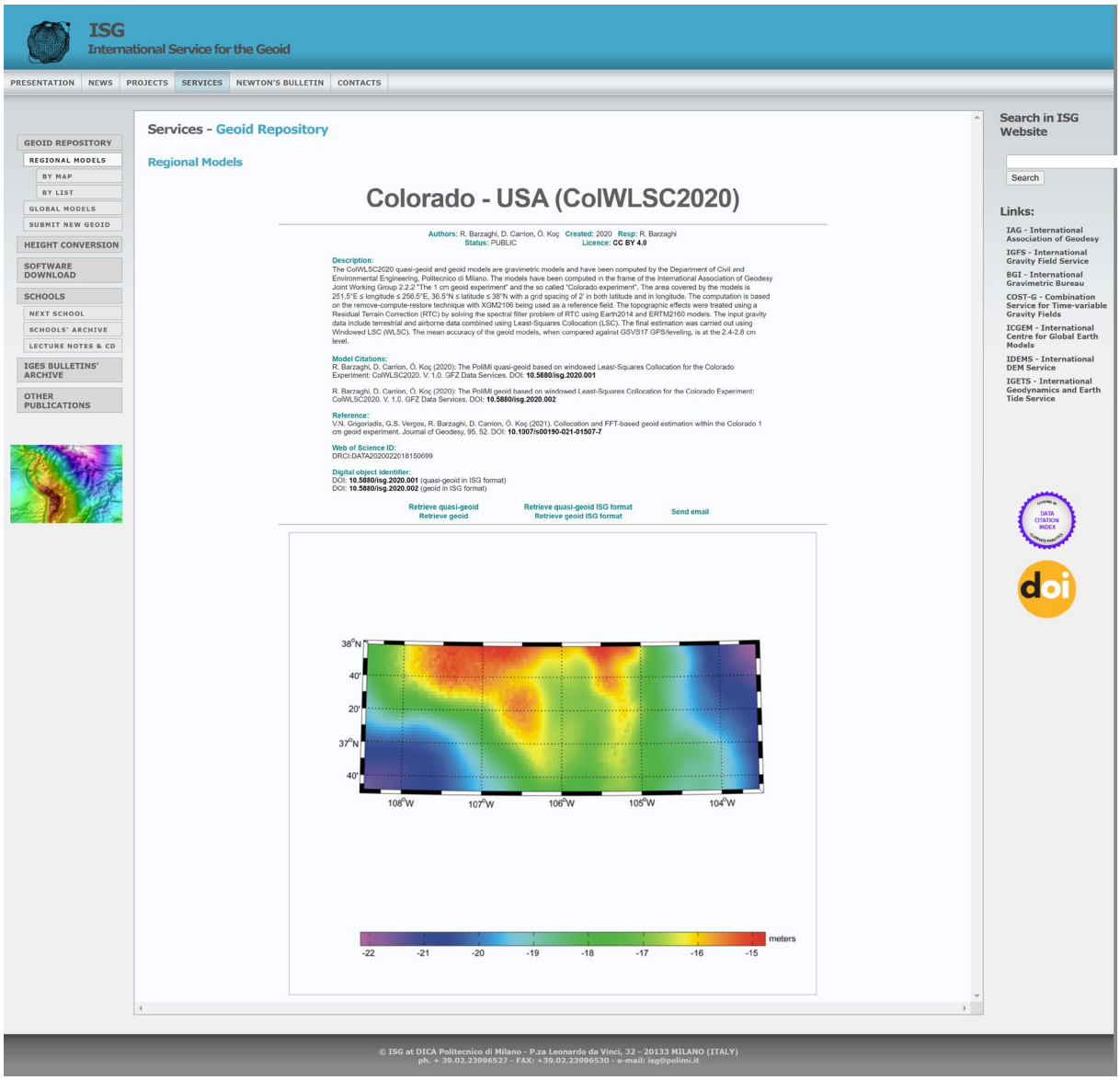

Figure 7: Example of a webpage describing a model stored in the geoid repository (https://www.isgeoid.polimi.it/Geoid/America/USA/Colorado20WLSC_g.html).

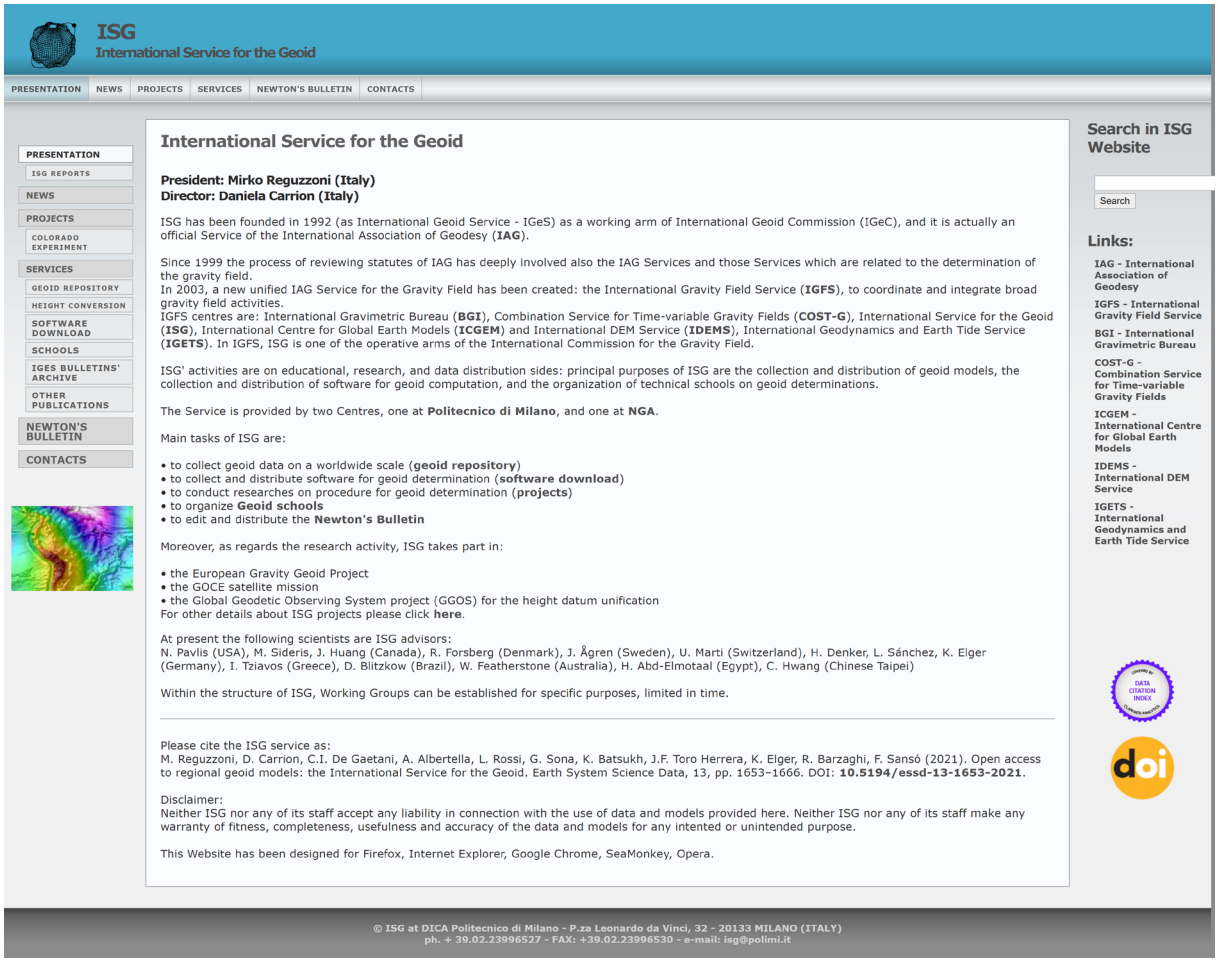

Figure 8: Homepage of the ISG website (https://www.isgeoid.polimi.it/).

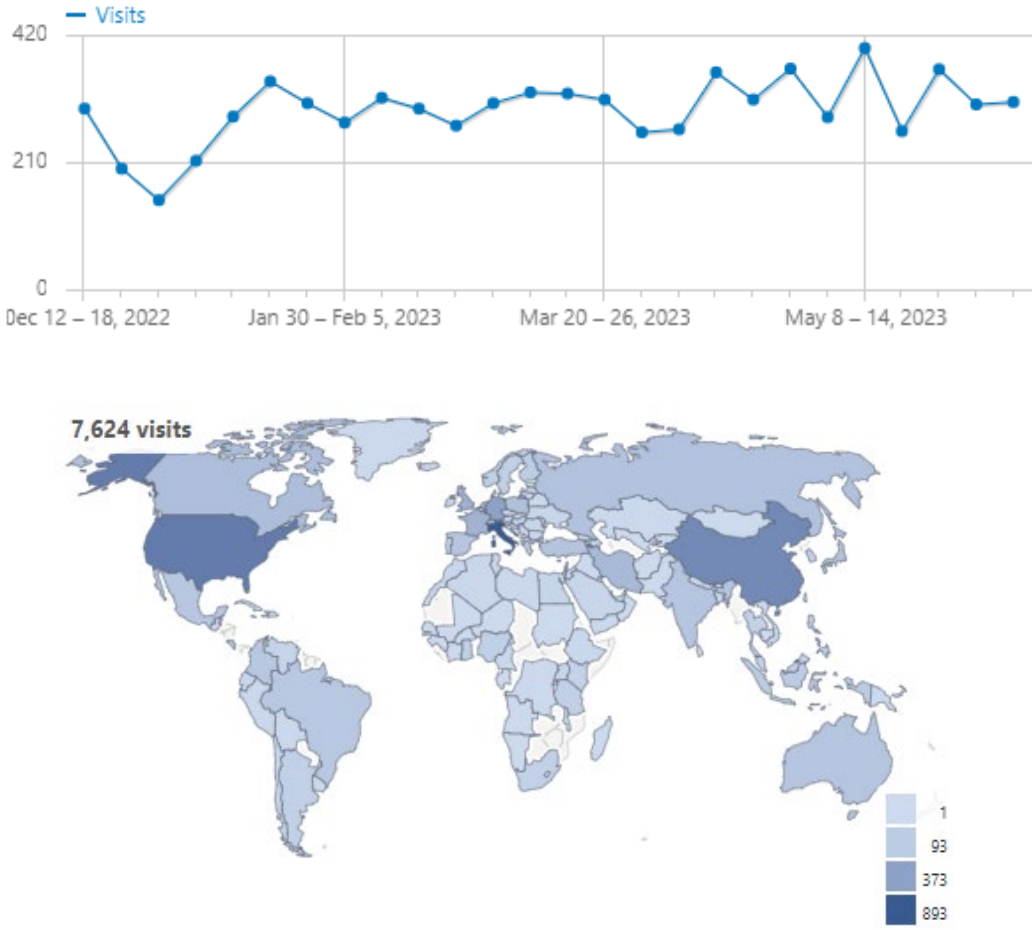

Figure 9: Statistics on the number of visitors per week (upper panel) and per country (lower panel) for the ISG website from December 2022 till May 2023 (last six months).

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