Focus Area "Unified Height System" and JWG 0.1.2 "Strategy for the Realization of the International Height Reference System (IHRS)"

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Activities

The objectives and planned activities of the GGOS-FA "Unified Height System" for the 2015-2019 period are described in the Geodesist's Handbook 2016 (Drewes H. et al., 2016). The main goal at present is the implementation of the International Height Reference System (IHRS) defined by the IAG 2015 Resolution No. 1 (ibid. page 981). The progress is summarized as follows:

- In Dec 2015, the joint working group (JWG) *Strategy for the Realization of the IHRS* was installed with the objective of developing a scheme for the realization of the IHRS; i.e., the establishment of the International Height Reference Frame (IHRF). This JWG is supported by *the International Gravity Field Service* (IGFS), the IAG Commissions 1 and 2 (*Reference Frames* and *Gravity field*), the *Inter-commission Committee on Theory* (ICCT), the *regional sub-commissions for reference frames and geoid modelling*, and both *GGOS Bureaus* (*Networks and Observations* and *Products and Standards*). In particular, there is a strong cooperation with
  - IAG JWG 2.2.2: *The 1 cm geoid experiment* (chair: Y.M. Wang, USA)
  - IAG SC 2.2: *Methodology for geoid and physical height systems* (chair: J. Ågren, Sweden)
  - ICCT JSG 0.15: *Regional geoid/quasi-geoid modelling - Theoretical framework for the sub-centimetre accuracy* (chair: J. Huang, Canada)
  - IAG JWG 2.1.1: *Establishment of a global absolute gravity reference system* (chair: H. Wziontek, Germany)
  - J. Mäkinen, *tide systems in the IHRS* (Finnland).

- A brainstorming and definition of action items took place at a JWG meeting carried out during the *International Symposium on Gravity, Geoid and Height Systems 2016* (GGHS2016) in Thessaloniki (Greece) in Sep 2016. This JWG meeting was attended by 70 colleagues and allowed us to identify the activities to be faced immediately (Sánchez, 2016a). A main output of this meeting are the criteria for the selection of IHRF reference stations:

- GNSS continuously operating reference stations to detect deformations of the reference frame;
- Co-location with fundamental geodetic observatories to ensure a consistent connection between geometric coordinates, potential and gravity values, and reference clocks (to support the implementation of the GGRF);
- Co-location with reference stations of the *International Gravity Reference Frame* (IGRF): the IGRF and IHRF station selection for the co-location of this two reference frames is a contribution of IAG JWG 2.1.1;
- Preference of stations belonging to the ITRF and the regional reference frames (like SIRGAS, EPN, APREF, etc.);
- Co-location with reference tide gauges and connection to the national levelling networks to facilitate the vertical datum unification;
- Availability of terrestrial gravity data around the IHRS reference stations as main requirement for high-resolution gravity field modelling (i.e., precise estimation of potential values).

• During the *GGOS Days 2016* (Boston (MA), USA, Oct 2016), a preliminary station selection for the IHRF was performed (Sánchez, 2016b). This selection was based on a global network with worldwide distribution, including a core network (to ensure sustainability and long-term stability of the reference frame) and regional/national densifications (to provide local accessibility to the global frame).

• Based on the conclusions of the meetings in Thessaloniki and Boston, regional and national experts were asked
  - to evaluate whether the preliminary selected sites are suitable to be included in the IHRF (availability of gravity data or possibilities to survey them), and
  - to propose additional geodetic sites to improve the density and distribution of the IHRF stations in their regions/countries.

• After the feedback from the regional/national experts (see Table 1), the first approximation to the IHRF is based on about 170 reference stations. This station selection is regularly refined in agreement with changes/updates of other geodetic reference frames (ITRF and IGRF and their densifications). Figure 1 shows the IHRF station distribution (as of Apr 2019) and the co-location with SLR, VLBI, DORIS, IGRF, tide gauges and levelling networks' stations.

• With the preliminary station selection, following efforts concentrated on the computation of station potential values and the assessment of their accuracy. Different approaches were evaluated (Sánchez et al., 2017):
  - As national/regional experts provided the JWG with terrestrial gravity data around some IHRF sites, a direct computation of potential values was performed using a combination of terrestrial gravity data and different global gravity models (GGM) as well as different mathematical formulations (least-squares collocation, FFT, radial basis functions, etc.).
  - Computation of potential values by national/regional experts responsible for the geoid modelling using their own data and methodologies.
  - Computation of potential values based on GGM of high-degree (like XGM2016, EIGEN-6C, EGM2008, etc.).
  - Recovering potential values from existing local (quasi-)geoid models.
  - Table 2 lists the colleagues contributing to this first experiment.

- The comparison of the results showed discrepancies up to the dm-level (Sánchez et al., 2017). The main conclusions of this experiment were:
  - The use of only GGMs is (at present) not suitable for the estimation of precise potential values. GGMs may be used if there is *no other way* to determine potential values.
  - A *standard* procedure for the computation of potential values may be not appropriate as
    - different data availability and different data quality exist around the world
    - regions with different characteristics require particular approaches (e.g. modification of kernel functions, size of integration caps, geophysical reductions like GIA, etc.)
  - A *centralized* computation (like in the ITRF) is complicated due to the restricted accessibility to terrestrial gravity data

- To overcome these inconveniences, during the *IAG-IASPEI Joint Scientific Assembly* (Kobe, Japan, Aug 2017) was agreed to initiate a new experiment towards:
  - the computation of IHRF coordinates using exactly the same input data and the own methodologies (software) of colleagues involved in the gravity field modelling, and
  - the comparison of the results, to identify a set of standards that allow to get as similar and compatible results as possible.

- In the same IAG-IASPEI 2017 Assembly, J. Ågren (Chair of IAG SC 2.2) and J. Huang (Chair of ICCT JSG 0.15) proposed to establish an interaction with the JWG 2.2.2 (chaired by Y.M. Wang). Aim of JWG 2.2.2 is the computation and comparison of geoid undulations using the same input data and the own methodologies/software of colleagues involved in the geoid computation. The comparison of the results should highlight the differences caused by disparities in the computation methodologies. In this frame, it was decided to extend the "geoid experiment" to the computation of station potential values as IHRS coordinates. With this proposal, the US NGS/NOAA agreed to provide terrestrial gravity data, airborne gravity, and digital terrain model for an area of about 500 km x 800 km in Colorado, USA (Fig. 2). With these data, different groups working on the determination of IHRF coordinates should compute potential values for some virtual geodetic stations located in that region. Afterwards, the results individually obtained should be compared with the *Geoid Slope Validation Survey 2017* (GSVS17), which will provide potential differences inferred from first order levelling measurements and gravity corrections along a validation line (see red line in Fig. 2).

- The Colorado data were distributed in Feb. 2018, together with a document summarising a minimum set of basic requirements (standards) for the computations. Ten different groups delivered solutions (Table 3) and the results were discussed during the *Gravity, Geoid and Height Systems (GGHS2018) Symposium* (Copenhagen, Denmark, Sep 2018). Main conclusions are (Wang et al., 2018; Sánchez et al. 2018a):
  - Two solutions were declared as outliers. They present large discrepancies (at the 1.5 m level) in (quasi-)geoid heights as well in the potential numbers with respect to the other solutions.
  - In the geoid comparison, six solutions agree within 3 cm to 10 cm in terms of standard deviation with respect to the mean value.
  - In the quasi-geoid comparison, the same six solutions agree within 1 cm to 4 cm in terms of standard deviation with respect to the mean value.
  - In the comparison of the potential values, four solutions agree within 1 cm to 2 cm in terms of standard deviation with respect to the mean value.

  - The discrepancies present a high correlation with the topography.
  - Possible sources of discrepancy:
    - Different handling of terrain corrections/reductions
    - Inconsistent use of the zero-degree term
    - Precision degradation due to the conversion of quasi-geoid heights to geoid heights and vice versa
    - Uncertainties in the processing of the airborne gravity data.

- To continue the Colorado experiment, following action items were formulated:
  - Participants in the experiment should provide a description with the main features of their computations in order to identify possible sources of discrepancies.
  - Participants should follow the basic standards/specifications distributed with the data, especially in the handling of corrections/reductions like the effect of the atmosphere, the consistent use of the zero-term, the global gravity models, etc.
  - The document with the standards/specifications was modified/extended to present more clearly some confusing issues like the handling of the zero degree term and the conversion from quasi-geoid to geoid (Sánchez et al., 2018b).
  - NGS/NOAA provided a pre-processed (cleaned) version of the GRAV-D data (down sampling 20 Hz data, de-biased data) by the end of 2018 in order to facilitate the use of these data in the individual solutions.

- Based on these action items, a second computation for the Colorado experiment was completed in Apr 2019. In total, 14 solutions were delivered (Table 4). At present, we are working on the comparison of geoid heights, height anomalies and potential values. The results will be discussed in the next *IUGG General Assembly* (Montreal, Canada, July 2019). It is expected to present all the results in a special issue of the *Journal of Geodesy*.

Outlook

To close the term 2015-2019, an executive report will be presented to the IAG and GGOS at the IUGG General Assembly 2019. It is expected to support this executive report with a peer-reviewed paper describing the strategy for the realization of the IHRS and a first solution for the IHRF. Aim of this first solution is to evaluate the achievable accuracy under the present conditions (data availability, computation methods, etc.) and to identify key actions to improve the determination of the IHRS/IHRF coordinates. These key actions should be faced in the next 2019-2023 period. For the same term, a joint working group of the GGOS FA-UHS, the IAG Commission 2 and the IGFS should investigate the best way to establish an *IHRS/IHRF element* within the IGFS to ensure the maintenance and availability of the IHRF. This implies regular updates of the IHRFyy to take account for new stations, coordinate changes with time, improvements in the estimation of coordinates (more observations, better standards, better models, better computation algorithms, etc.), geodetic products associated to the IHRF (description and metadata), and the organizational and operational infrastructure to ensure the IHRF sustainability.

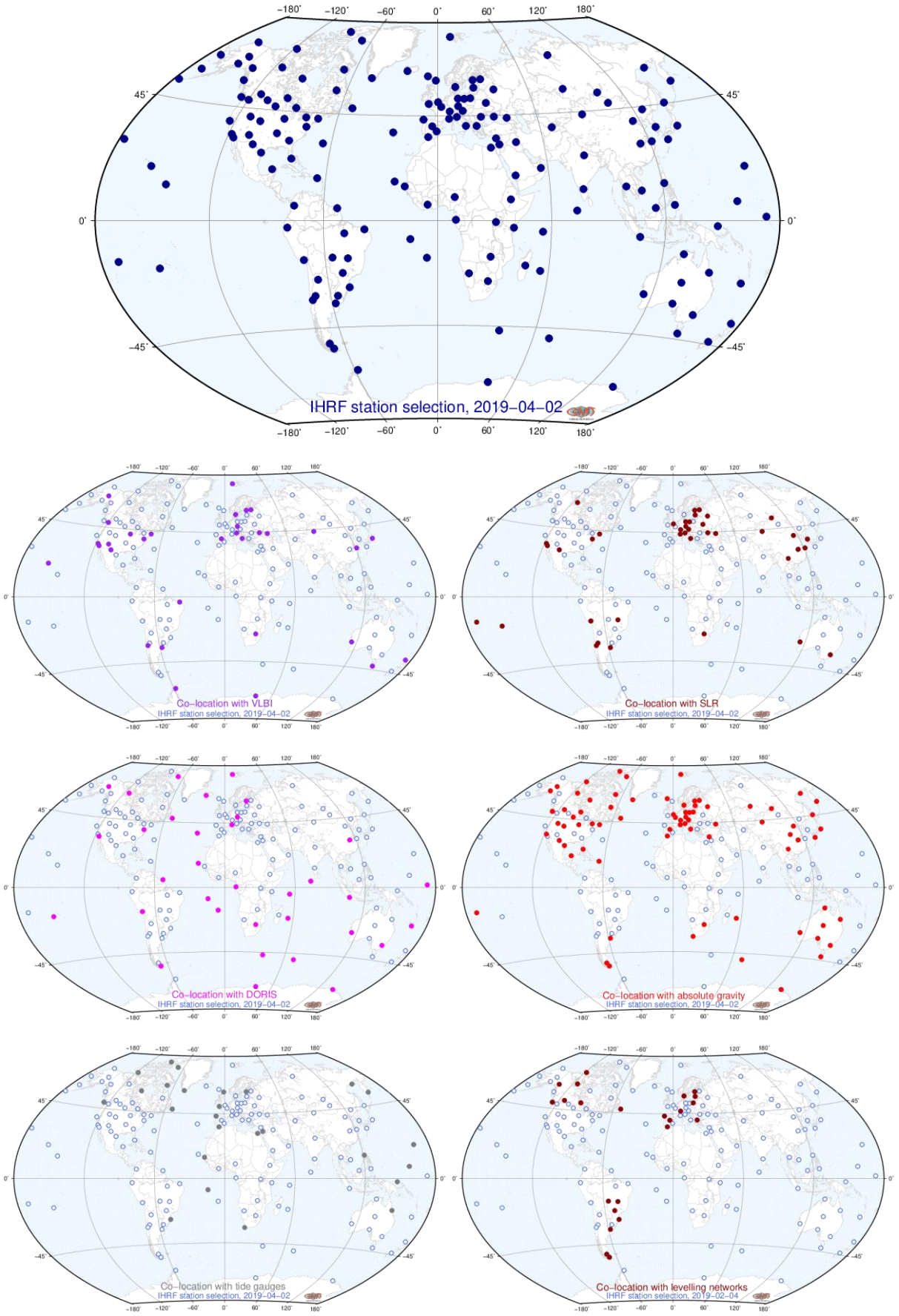

Fig. 1. IHRF stations as of April 2019 and the co-location with VLBI, SLR, DORIS, absolute gravity (IGRF), tide gauges and levelling networks' stations.

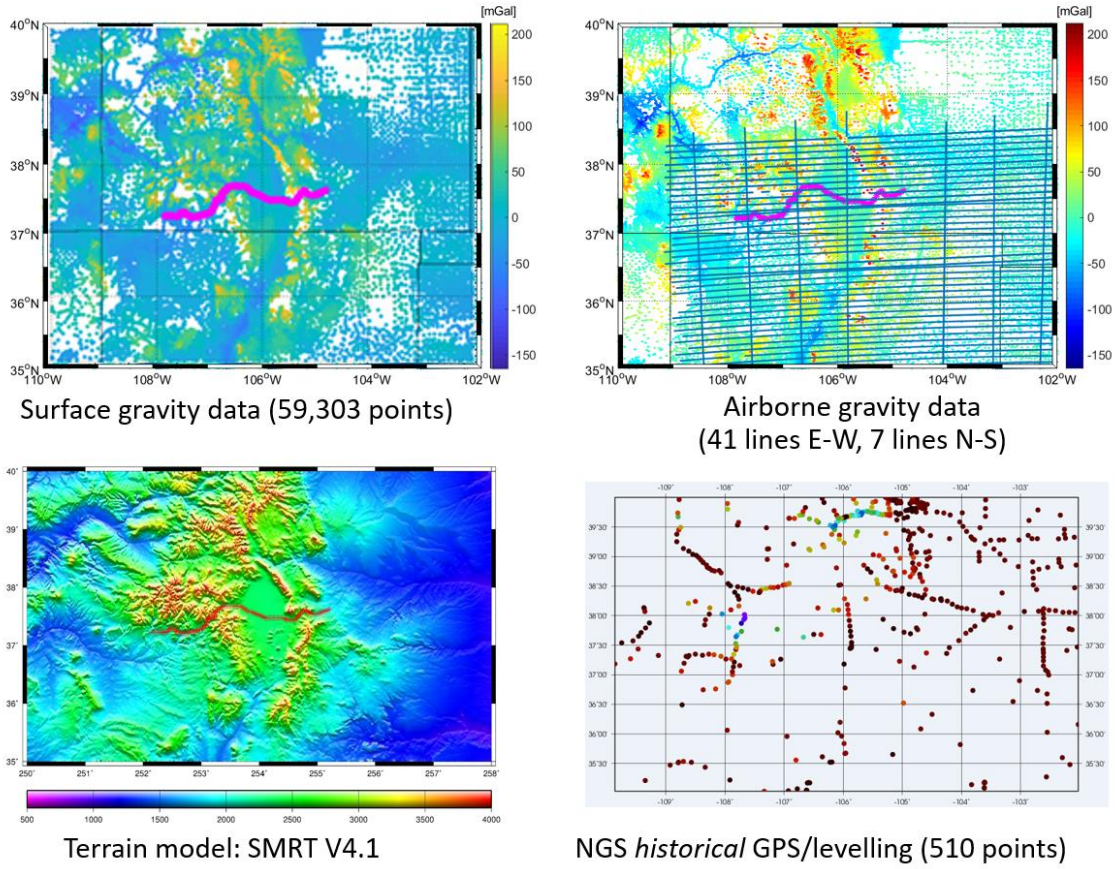

Fig. 2. Data provided by the US NGS/NOAA for the Colorado experiment. The red line represents the validation profile of the Geoid Slope Validation Survey 2017 (GSVS17). For validation, potential differences inferred from first order levelling and gravity corrections along this line will be compared with potential differences inferred from the different Colorado solutions (see Tables 2 and 3).

Table 1: Colleagues contributing to the station selection for the International Height Reference Frame (see Fig. 1)

- M Véronneau, J Huang - Natural Resources Canada, Canada
- I Oshchepkov - Center of Geodesy, Cartography and SDI, Russia
- D Roman, K Choi, K Ahlgren - US National Geodetic Service - NOAA, USA
- R Ruddick - Geoscience Australia, Australia
- M Amos - Land Information New Zealand, New Zealand
- SRC de Freitas - Universidade Federal do Parana, Brazil
- JR Chire Chira - Instituto Geográfico Nacional, Peru
- DA Piñón - Instituto Geográfico Nacional, Argentina
- C Estrella - Instituto Geográfico Militar, Ecuador
- A Álvarez - Instituto Geográfico Nacional, Costa Rica
- A Echalar Rivera - Instituto Geografico Militar, Bolivia
- D Avalos-Naranjo - Instituto Nacional de Estadística y Geografía, Mexico
- S Costa, R Luz - Instituto Brasileiro de Geografia e Estatística, Brazil
- D Blizkow, ACOC de Matos - Universidade de São Paulo, Brazil
- N Suárez - Servicio Geográfico Militar, Uruguay
- J Krynski - Institute of Geodesy and Cartography, Poland
- U Marti - Federal Office of Topography, swisstopo, Switzerland
- K Matsuo - Geospatial Information Authority of Japan, Japan
- H Abd-Elmotaal - Minia University, Egypt
- G Vergos - Aristotle University of Thessaloniki, Greece
- M Poutanen - Finnish Geospatial Research Institute, Finland
- PA Vaquero Fernández - Instituto Geográfico Nacional, Spain
- J Ågren - Lantmäteriet, Swedish mapping, cadastral and land registration authority, Sweden
- H Wziontek - Bundesamt für Kartographie und Geodäsie, Germany
- V Mackern, W Martínez - SIRGAS
- R Forsberg - National Space Institute, Denmark

- I Liepinš - Latvian Geospatial Information Agency, Latvia - T Jiang - Chinese Academy of Surveying and Mapping, China

Table 2: Colleagues contributing to the first experiment for the determination of IHRS coordinates (Sánchez et al. 2017)

- M Véronneau, J Huang - Natural Resources Canada, Canada - G Vergos - Aristotle University of Thessaloniki, Greece - D Blizkow, ACOC de Matos - Universidade de São Paulo, Brazil - JL Carrión-Sánchez, SRC de Freitas - Universidade Federal do Parana, Brazil - H Denker - Leibniz Universität Hannover, Germany - R Pail - Technische Universität München, Germany - V Lieb - Technische Universität München, Germany - L Sánchez - Technische Universität München, Germany

Table 3: Colleagues contributing to the first computation for the Colorado experiment (Wang et al., 2018; Sánchez et al., 2018b)

- VN Grigoriadis, GS Vergos, DA Natsiopoulos - Aristotle University of Thessaloniki, Greece - H Abd-Elmotaal - Minia University, Egypt - B Erol, M Serkan Isik - Istanbul Teknik Üniversitesi, Turkey - YM Wang, X Li, K Ahlgren - US National Geodetic Survey - NOAA, USA - M Véronneau, J Huang - Natural Resources Canada, Canada - J Ågren - Lantmäteriet, Swedish mapping, cadastral and land registration authority, Sweden - S Claessens, M Filmer - Curtin University, Australia - EL Nicacio, JL Carrión, SRC de Freitas, R Dalazoana, VG Ferreira, Universidade Federal do Parana, Brazil - D Blizkow, ACOC de Matos - Universidade de São Paulo, Brazil - L Sánchez - Technische Universität München, Germany

Table 4: Colleagues contributing to the second computation for the Colorado experiment (results to be presented at the IUGG General Assembly 2019)

- VN Grigoriadis, GS Vergos, DA Natsiopoulos - Aristotle University of Thessaloniki, Greece and R Barzaghi, D Carrion - Politecnico de Milano, Italy - T Jiang - Chinese Academy of Surveying and Mapping, China - M Véronneau, J Huang - Natural Resources Canada, Canada - S Claessens, M Filmer - Curtin University, Australia - Q Liu, M Schmidt, L Sánchez - Technische Universität München, Germany - R Forsberg - National Space Institute, Denmark - K Matsuo - Geospatial Information Authority of Japan, Japan and R Forsberg - National Space Institute, Denmark - M Willberg, R Pail - Technische Universität München, Germany - B Erol, M Serkan Isik, S Erol - Istanbul Teknik Üniversitesi, Turkey - J Ågren - Lantmäteriet, Swedish mapping, cadastral and land registration authority, Sweden - YM Wang, X Li, K Ahlgren, US National Geodetic Survey - NOAA, USA - M Varga, T Bašic - University of Zagreb, Republic of Croatia and M Pitonák, P Novák - University of West Bohemia, Czech Republic - R Barzaghi, D Carrion - Politecnico de Milano, Italy - D Blizkow, ACOC de Matos, Escola Politécnica da Universidade de São Paulo, Brazil

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Matos, N. Suárez, J. Krynski, U. Marti, K. Matsuo, H. Abd-Elmotaal, M. Poutanen, P.A. Vaquero Fernández, H. Wziontek, V. Mackern, W. Martínez, R. Forsberg, I. Liepinš, T. Jiang, J.L. Carrión-Sánchez, X. Li, E.L. Nicacio, R. Dalazoana, V.G. Ferreira...

References

Drewes H., Kuglitsch F., Ádám J., and Rózsa S.: *The Geodesist's Handbook 2016*, J Geod, 90(10): 981 - 982, 2016.

Sánchez L.: *Working Group on the Strategy for the Realization of the International Height Reference System (IHRS): Brainstorming and definition of action items*. Splinter meeting at the International Symposium on Gravity, Geoid and Height Systems 2016 (GGHS2016), https://ihrs.dgfi.tum.de/fileadmin/JWG_2015/SP_WG_IHRS_Realization_with_Comments_from_the_Splinter_Meeting.pdf, 2016a.

Sánchez L: *International Height Reference System (IHRS): Required measurements and expected products*. GGOS Days 2016, Cambridge (MA), USA, https://ihrs.dgfi.tum.de/fileadmin/JWG_2015/Sanchez_IHRS_Obs_Prod_GGOS2016_2.pdf, 2016b.

Sánchez L., Denker H., Pail R., Lieb V., Huang J., Roman D., Ågren J., Amos M., Ihde J., Barzaghi R., Sideris M., Oshchepkov I., Blitzkow D., Matos A.C.O.C., Piñon D., Avalos D., Freitas S.R.C., Luz R.: *A first approximation to the International Height Reference Frame (IHRF)*. Joint Scientific Assembly of the International Association of Geodesy and the International Association of Seismology and Physics of the Earth's Interior (IAG-IASPEI 2017), Kobe, Japan, https://ihrs.dgfi.tum.de/fileadmin/JWG_2015/Sanchez_et_al_A_first_IHRF_IAG2017_v2.pdf, 2017.

Sánchez L., Ågren J., Huang J., Véronneau M., Wang Y.M., Roman D., Vergos G., Abd-Elmotaal H., Amos M., Barzaghi R., Blitzkow D., Matos A.C.O.C., Denker H., Filmer M., Claessens S., Oshchepkov I., Marti U., Matsuo K., Sideris M., Varga M., Willberg M., Pail R.: *Advances in the establishment of the International Height Reference Frame (IHRF)*. International Symposium on Gravity, Geoid and Height Systems 2018 (GGHS2018), Copenhagen, Denmark, 2018a.

Sánchez L., Ågren J., Huang J., Wang Y.M., Forsberg R.: *Basic agreements for the computation of station potential values as IHRS coordinates, geoid undulations and height anomalies within the Colorado 1 cm geoid experiment*, https://ihrs.dgfi.tum.de/fileadmin/JWG_2015/Colorado_Experiment_Basic_req_V0.5_Oct30_2018.pdf, 2018b.

Wang Y.M., Forsberg R., Sánchez L., Ågren J., Huang J.: *Report on Colorado geoid comparisons*. International Symposium on Gravity, Geoid and Height Systems 2018 (GGHS2018), Copenhagen, Denmark, https://ihrs.dgfi.tum.de/fileadmin/JWG_2015/Wang_report_GGHS2018ColoradoGeoidReportMod.pdf, 2018.

Further reading

Web site

A web site summarizing the main characteristics, achievements and challenges of the GGOS-FA "Unified Height System" is available at http://ihrs.dgfi.tum.de/. This information is mirrored at http://ggos.org/en/focus-areas/unified-height-system/.

Selected publications and presentations

Altiparmaki O.N., Vergos G.S.: *Potential determination at coastal stations from the synergy of SAR/SARin altimetry and local gravity data towards the IHRS*. International Symposium on Gravity, Geoid and Height Systems 2018 (GGHS2018), Copenhagen, Denmark, 2018.

Andritsanos V., Vergos G., Gruber Th., Fecher T.: *GOCE variance and covariance contribution to height system unification*. GGHS2016: International Symposium on Gravity, Geoid and Height Systems 2016, Thessaloniki, Greece, 2016-09-22.

Blitzkow D., de Matos A.C.O.C, de Carvalho Carneiro C., Costa S.M.C.: *First efforts for the IHRF establishment in Brazil*. International Symposium on Gravity, Geoid and Height Systems 2018 (GGHS2018), Copenhagen, Denmark, 2018.

Erol B., Serkan Işık M.: *Methodology Assessment of High Resolution Geoid Modeling Using The GRAV-D Data Over Colorado*. International Symposium on Gravity, Geoid and Height Systems 2018 (GGHS2018), Copenhagen, Denmark, 2018.

Gerlach C., Gruber Th., Rummel R.: *Höhensysteme der nächsten Generation*; in: Freeden, W.; Rummel, R. (eds.) Handbuch der Geodäsie, Vol. 2016, Springer, ISBN (Online) 978-3-662-46900-2, DOI: 10.1007/978-3-662-46900-2_7-1, 2016.

Grigoriadis V.N., Vergos G.S., Natsiopoulos D.A.: *Geoid/Quasi-geoid modeling based on the remove-restore approach with the JWG2.2.2 Colorado dataset and contributions to the IHRF*. International Symposium on Gravity, Geoid and Height Systems 2018 (GGHS2018), Copenhagen, Denmark, 2018.

Gruber Th., Willberg M., Pfaffenzeller N.: *Geodetic Space Sensors for Height System Unification and Absolute Sea Level Determination*. International Symposium on Gravity, Geoid and Height Systems 2018 (GGHS2018), Copenhagen, Denmark, 2018.

Gruber Th.: *Geodetic space sensors for height system unification and absolute sea level determination*. Fourth Swarm Science Meeting & Geodetic Missions Workshop, Banff, Canada, 2017-03-22.

Gruber Th.: *GOCE and Heights - How does the 3rd Coordinate benefit from it?* ESA Living Planet Symposium 2016, Prag, Czech Republic, 2016-05-11.

Ihde J., Sánchez L., Barzaghi R., Drewes H., Foerste Ch., Gruber Th., Liebsch G., Marti U., Pail R., Sideris M.: *Definition and proposed realization of the International Height Reference System (IHRS)*. Surveys in Geophysics, 10.1007/s10712-017-9409-3, 2017.

Ihde J., Sánchez L.: *Physical Height and the GGRF, Earth Gravity Field and the GGRF, GGRF an Integrated Approach*. GGOS Days 2015, Frankfurt a.M., Germany, 2015-10-22.

Mäkinen J.: *The permanent tide in the International Height Reference System IHRS*. International Symposium on Gravity, Geoid and Height Systems 2018 (GGHS2018), Copenhagen, Denmark, 2018.

Marti U., Sánchez L.: *Le système de référence altimétrique global*. Commission Géopositionnement, Conseil national de l'information géographique, Paris, France, 2017-03-15.

Nicacio E.L., Carrión J.L., de Freitas S.R.C., Dalazoana R., Ferreira V.G.: *Strategy for calculating local potential values as IHRS coordinates – a case study on the Colorado empirical experiment*. International Symposium on Gravity, Geoid and Height Systems 2018 (GGHS2018), Copenhagen, Denmark, 2018.

Oshchepkov I.: *Geodetic reference system consistent with the IHRF W_0 value*. International Symposium on Gravity, Geoid and Height Systems 2018 (GGHS2018), Copenhagen, Denmark, 2018.

Sánchez L., Čunderlík R., Dayoub N., Mikula K., Minarechová Z., Šíma Z., Vatrt V., Vojtíšková M.: *A conventional value for the geoid reference potential W_0.* Journal of Geodesy 90(9), 815-835, 10.1007/s00190-016-0913-x, 2016.

Sánchez L., de Freitas S.R.C, Martínez W., Mackern M.V., Cioce V., Pérez-Rodino R.: *Advances in the modernisation of the height reference systems in Latin America and their integration to the International Height Reference System (IHRS)*. International Symposium on Gravity, Geoid and Height Systems 2018 (GGHS2018), Copenhagen, Denmark, 2018.

Sánchez L., Ihde J., Pail R., Barzaghi R., Marti U., Ågren J., Sideris M., Novák P.: *Strategy for the Realization of the International Height Reference System (IHRS)*. GGHS2016: International Symposium on Gravity, Geoid and Height Systems 2016, Thessaloniki, Greece, 2016-09-22.

Sánchez L., Ihde J., Pail R., Gruber Th., Barzaghi R., Marti U., Ågren J., Sideris M., Novák P.: *Towards a first realization of the International Height Reference System (IHRS)*. European Geosciences Union General Assembly 2017, Vienna, Austria, 2017-04-25.

Sánchez L., Martí U., Ihde J.: *Le chemin vers un système de référence altimétrique global et unifié*. Association Française de Topographie, Revue XYZ 150: 61-67, 2017.

Sánchez L., Sideris M.G.: *Vertical datum unification for the International Height Reference System (IHRS)*. Geophysical Journal International 209(2), 570-586, 10.1093/gji/ggx025, 2017.

Sánchez L., Sideris M.G.: *Vertical datum unification for the International Height Reference System (IHRS)*. International Symposium on Gravity, Geoid and Height Systems 2018 (GGHS2018), Copenhagen, Denmark, 2018.

Sánchez L., Sideris M.G.: *Vertical datum unification for the International Height Reference System (IHRS)*. European Geosciences Union General Assembly 2017, Vienna, Austria, 2017-04-27.

Sánchez L.: *GGOS Focus Area 1: Unified Height System: Present activities*, GGOS Coordinating Board Meeting, TU Vienna, Vienna, Austria, 2016-04-16.

Sánchez L.: *Working Group on the Strategy for the Realization of the International Height Reference System (IHRS): Brainstorming and definition of action items*. Splinter meeting at the International Symposium on Gravity, Geoid and Height Systems 2016, 2016-09-21.

Sánchez, L. *International Height Reference System (IHRS): Required measurements and expected products*. GGOS Days 2016, Cambridge (MA), USA, 2016-10-26.

Slobbe D.C., Klees R., Verlaan M., Zijl F., Farahani H.H.: *Height system connection between island and mainland using a hydrodynamic model: a case study connecting the Dutch Wadden islands to the Amsterdam ordnance datum (NAP)*. International Symposium on Gravity, Geoid and Height Systems 2018 (GGHS2018), Copenhagen, Denmark, 2018.

Wang Y.M., Li X., Ahlgren K.: NGS *Geoid computation experiment in Colorado*. International Symposium on Gravity, Geoid and Height Systems 2018 (GGHS2018), Copenhagen, Denmark, 2018.

Willberg M., Gruber Th., Pail R.: *Geoid Requirements for Height Systems and their Unification*; Fourth Swarm Science Meeting & Geodetic Missions Workshop, Banff, Canada, 2017-03-22.

Willberg M., Gruber Th., Vergos G.: *Height systems in Greece and its islands - some experimental results*. GGHS2016: International Symposium on Gravity, Geoid and Height Systems 2016, Thessaloniki, Greece, 2016-09-21.

Willberg M., Zingerle Ph., Pail R.: *Least squares collocation with global model information for height systems*. International Symposium on Gravity, Geoid and Height Systems 2018 (GGHS2018), Copenhagen, Denmark, 2018.