Deutsches Geodätisches Forschungsinstitut (DGFI-TUM)
Technische Universität München

Activities and plans of the GGOS Focus Area Unified Height System

L. Sánchez[1], M. Sideris[2], J. Ihde[3]

[1] Deutsches Geodätisches Forschungsinstitut,
Technische Universität München (DGFI-TUM), Germany
[2] Schulich School of Engineering, University of Calgary, Canada
[3] Helmholtz-Zentrum Potsdam, Deutsches GeoForschungsZentrum, Germany

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GGOS Focus Area Unified Height System

The GGOS Focus Area Unified Height System (formerly Theme 1) was established during the *GGOS Planning Meeting 2010* (February 1 - 3, Miami/Florida, USA) to continue the activities initiated by the *IAG ICP1.2: Vertical Reference Systems*, 2003-2011 (Ihde et al. 2007, 2011).

Objective: *Unification of the existing height systems* through the *definition and realization of a global vertical reference system* that

- supports *geometrical* (ellipsoidal) and *physical* (normal, orthometric, geoid) heights world-wide with *centimetre precision in a global frame*;
- enables the *unification of all existing physical height systems* (i.e., all geopotential differences shall be referred to one and the same reference equipotential surface with potential W_0); and
- provides *high-accuracy and long-term stability* of the vertical coordinates.

Goals of the GGOS FA-UHS
(as in Geodesist's Handbook 2012)

- Short-term goals:
  - To establish a *global vertical reference level* and its potential value W_0.
  - Refinement of standards and conventions for the *definition and realization of a world height system*.

- Mid-term goals:
  - To develop *GGOS products* for the *realization of a world height* system: reference frame, global height system unification, registry and metadata of existing height systems.

- Long-term goals:
  - To *maintain and use in practice* the world height system: temporal changes, update of definition and realization according to new geodetic developments, servicing the vertical datum needs to other geosciences.

GGOS FA-UHS: activities 2011 - 2015

- Conventional global reference level:
  → WG *Vertical Datum Standardisation*: Estimation of a W_0 value based on the newest geodetic models and including reliability assessment (Sánchez et al. 2017)
- Standards and conventions for the definition and realization of a world height system.
  → Main contributions:
  - Recommendations of the *IAG Ad-hoc group on an International Height Reference System – IHRS* (Ihde et al. 2015, 2017)
  - *BPS Inventory of Standards and Conventions* used for the IAG Products (Angermann et al. 2016).
  - Activities under the *ESA project "HSU with GOCE"* (Rummel et al. 2014).

Main result: IAG Resolution for the Definition and Realization of an International Height Reference System (IHRS) released in July 2015.

International Height Reference System (IHRS)
IAG Resolution No. 1, Prague, July 2015

1) Coordinates of points attached to the solid surface of the Earth are given by *potential differences* with respect to a *conventionally fixed* W_0 value:

$$C_P = C(P) = W_0 - W(P) = -\Delta W(P)$$

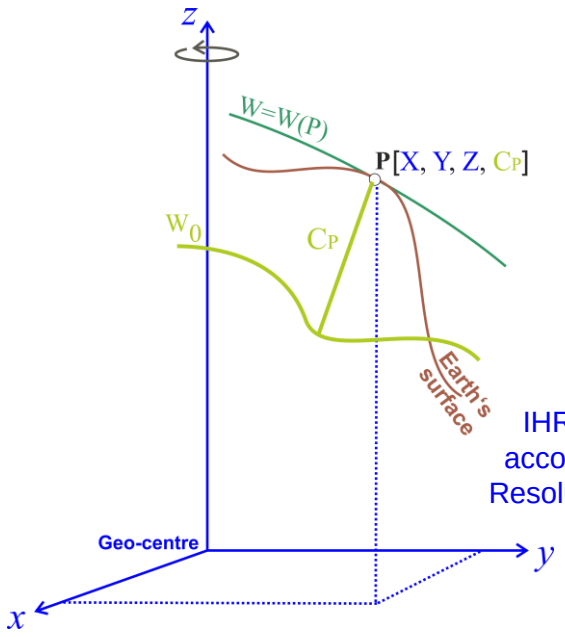
$$W_0 = const. = 62\,636\,853.4\ \mathrm{m^2 s^{-2}}$$

2) The position *P* is given in the ITRF

$\mathbf{X}_P\,(X_P, Y_P, Z_P)$; i.e., $W(P) = W(\mathbf{X}_P)$

3) The estimation of $\mathbf{X}(P)$, $W(P)$ (or $C(P)$) includes their variation with time; i.e., $\dot{\mathbf{X}}(P)$, $\dot{W}(P)$ (or $\dot{C}(P)$).

4) Mean tide system and SI units.



IHRS coordinates according to the IAG Resolution No. 1, 2015

→ The name *International Height Reference System* unifies/ standardizes all the names used previously: World Height System, Global Vertical Reference System, Global Height System, Unified Height System, Global Vertical Datum, etc.

GGOS FA-UHS: activities 2015 - 2019

Objective: Realization of the IHRS

- Establish a global reference network for the IHRS realisation: the International Height Reference Frame (IHRF)
- Evaluate different strategies for the determination of reference coordinates at the reference stations
- Identify required standards, conventions and procedures needed to ensure consistency between the definition (IHRS) and the realisation (IHRF).

GGOS FA-UHS: activities 2015 - 2019

- Reference network

  → Criteria for the station selection (Sep 2016, GGHS2016, Thessaloniki)

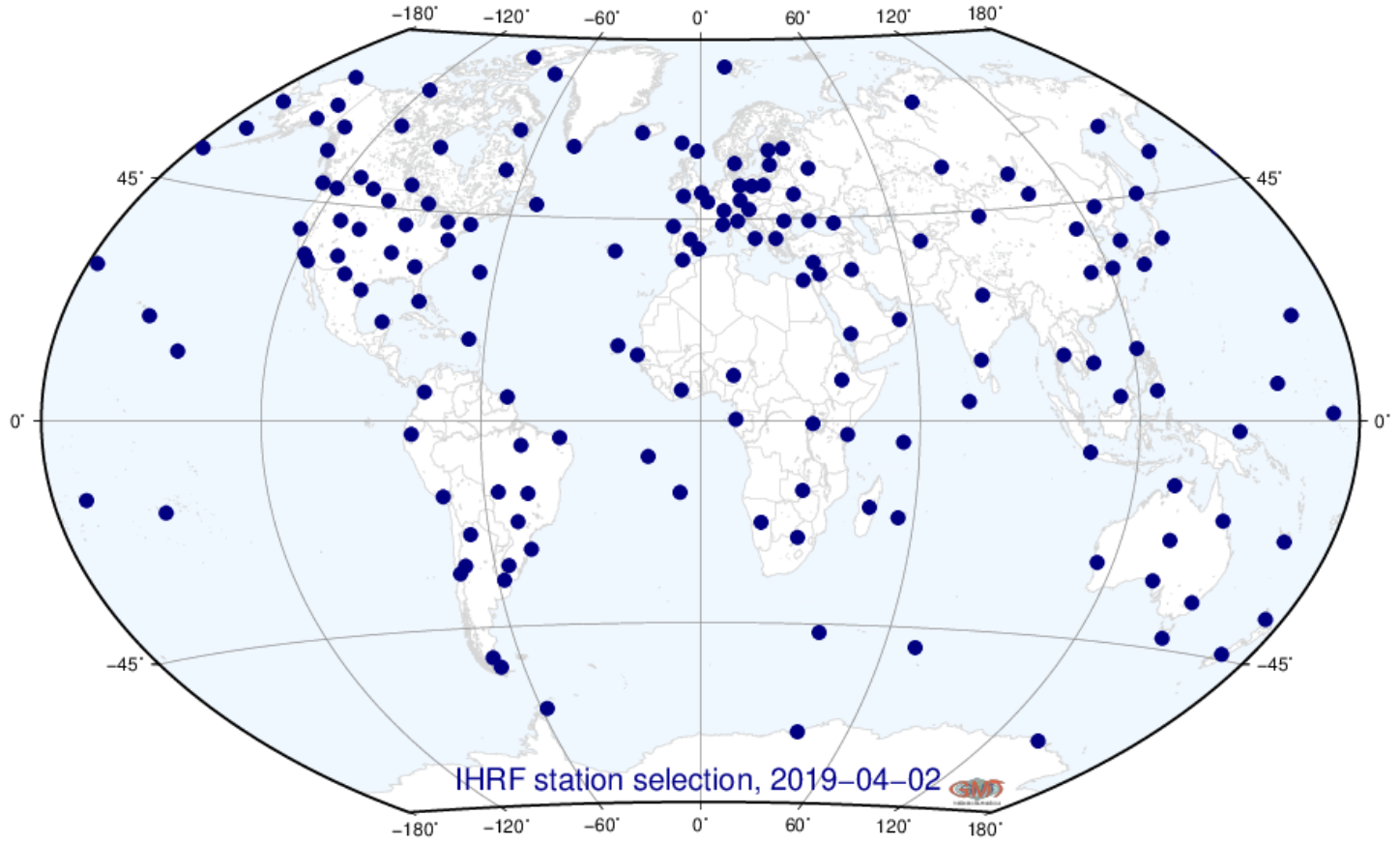
  → Preliminary reference network for the IHRF based on the contribution of the GGOS-BNO, the IAG Services and regional/national experts on reference frames and geoid modelling (started in Oct 2016, GGOS Days 2016, Cambridge, MA, still open)

  → The present proposal of the IHRF reference network is a start point of implementation; the station selection is not finished or closed. New stations can be added or some stations may be decommissioned.

  → This network is globally distributed and should be extended by means of regional and national densifications.

Preliminary IHRF reference network (as of Apr 2019)

170 stations well-distributed world-wide, materialized by GNSS continuously operating stations and co-located with *VLBI (30 sites)*, *SLR (40 sites)*, *DORIS (35 sites)*, *absolute gravity – IGRF (77 sites)*, *tide gauges (26 sites)*, *national levelling networks (23 sites)*.



Interaction with regional/national experts for the IHRF station selection

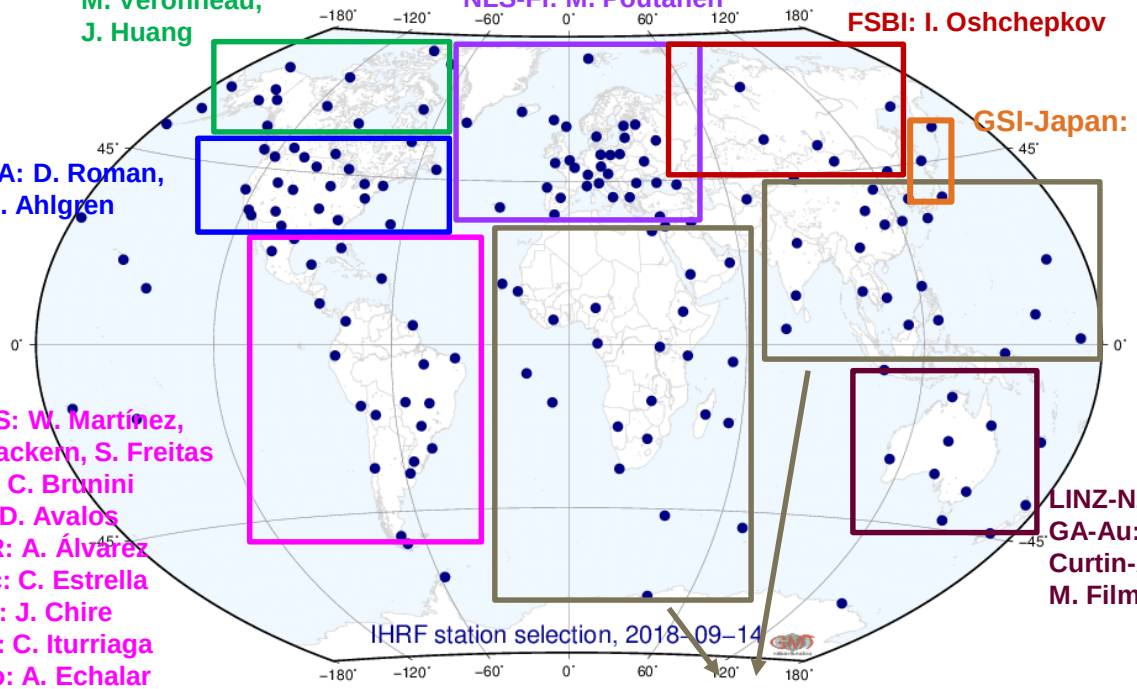
IGIK-Pl: J. Krinsky
DTU-Dk: R. Forsberg
AUTH-Gr: G. Vergos
LGIA-LV: I. Liepins
LM-Se: J. Ågren, Nordic Geodetic Commission (NGK)
Swisstopo-Ch: U. Martí
IGN-Es: P. Vaquero
NLS-Fi: M. Poutanen

NRCan:
M. Véronneau,
J. Huang

FSBI: I. Oshchepkov

GSI-Japan: K. Matsuo

NGS/NOAA: D. Roman,
K. Choi, K. Ahlgren



SIRGAS: W. Martínez,
M.V. Mackern, S. Freitas
AGGO: C. Brunini
INEGI: D. Avalos
IGN-CR: A. Álvarez
IGM-Ec: C. Estrella
IGN-Pe: J. Chire
IGM-Cl: C. Iturriaga
IGM-Bo: A. Echalar
IGN-Ar: D. Piñon
SGM-Uy: N. Suárez
IBGE: S. Costa, R. Luz
EPUSP: D. Blitzkow, A.C.O.C. Matos

LINZ-Nz: M. Amos
GA-Au: R Ruddick
Curtin-Au: W. Featherstone
M. Filmer, S. Claessens

IGS stations
H.A. Abd-Elmotaal (Egypt)

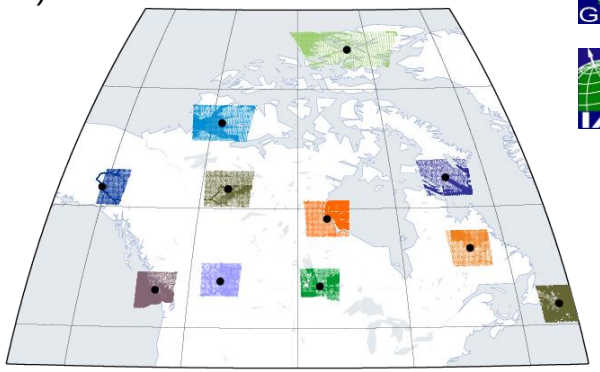
GGOS FA-UHS: activities 2015 - 2019

- Determination of potential values as IHRS/IHRF coordinates

→ Sep. 2016 to Mar. 2017: Strategy for the integration (transformation) of existing vertical datums into the IHRS/IHRF (Sánchez and Sideris 2017)

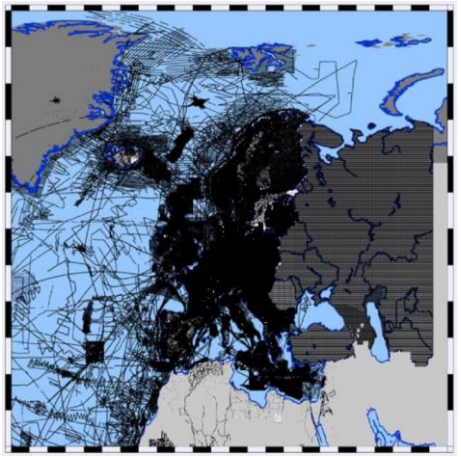
→ May to Aug. 2017:

a) Computation of potential values using the latest GGMs of high-resolution:
   - EGM2008 (Pavlis et al., 2012), lmax = 2190
   - EIGEN-6C4 (Förste et al., 2014), lmax = 2190
   - XGM2016 (Pail et al., 2017), lmax = 719, extended to lmax = 2190 with EIGEN-6C4



b) Comparison with potential values inferred from high-resolution gravity field modelling in Canada (NRCan, M. Véronneau, J. Huang) and Europe (IFE/LUH, Germany H. Denker)

c) Further numerical experiments in Greece (AUTH, G. Vergos), Brazil (EPUSP, D. Blitzkow, A.C.O.C. Matos) and Ecuador (UFPR, S. Freitas and J.L. Carrión-Sánchez)



GGOS FA-UHS: activities 2015 - 2019

- Determination of potential values as IHRS/IHRF coordinates
  - → Potential values W determined using *different approaches* present *discrepancies in the dm-level*.
  - → To assess the consistency between different computation methods, *fifteen approaches* were evaluated by *computing potential values using exactly the same input data* (Colorado experiment)
  - → To minimize discrepancies and to obtain as similar and compatible results as possible with the different methods, a set of basic standards was released (Sánchez, Ågren, Huang, Wang, Forsberg, 2019)
  - → Action conducted by
    - GGOS JWG: *Strategy for the realisation of the IHRS* (chair: L Sánchez)
    - IAG JWG 2.2.2: *The 1 cm geoid experiment* (chair: YM Wang)
    - IAG SC 2.2: *Methodology for geoid and physical height systems* (chair: J Ågren)
    - ICCT JSG 0.15: *Regional geoid/quasi-geoid modelling - Theoretical framework for the sub-centimetre accuracy* (chair: J Huang)

Contributing solutions

Faculty of Engineering, Minia University, *Egypt*

İstanbul Teknik Üniversitesi, Istambul, *Turkey*

Department of Geodesy and Surveying, Aristotle University of Thessaloniki, Thessaloniki, *Greece*

National Geodetic Survey, *USA*

Natural Resources Canada, *Canada*

Lantmäteriet, Swedish mapping, cadastral and land registration authority, *Sweden*

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Escola Politécnica, Universidade de São Paulo; Centro de Estudos de Geodesia, *Brazil*

Deutsches Geodätisches Forschungsinstitut, Technische Universität München, *Germany*

Ingenieurinstitut für Astronomische und Physikalische Geodäsie, Technische Universität München, *Germany*

Chinese Academy of Surveying and Mapping, *China*

Politecnico de Milano, *Italy*

Faculty of Geodesy, University of Zagreb, *Croatia* - Research Institute of Geodesy, Topography and Cartography, *Czech Republic*

National Space Institute, Technical University of Denmark, *Denmark*

Geography and Crustal Dynamics Research Center, Geospatial Information Authority of Japan, *Japan*

GGOS FA-UHS: activities 2015 - 2019

- Determination of potential values as IHRS/IHRF coordinates
  - → The Colorado experiment *started in July 2017*
  - → *First results* were discussed GGHS2018 (Sep 2018, Copenhagen)
  - → A *second computation* was ready for the EGU2019 (Apr 2019, Vienna)
  - → Some refinements (*third computation*) were delivered in Jun 2019
  - → Results presented and extensively discussed at the *IUGG2019, Symposium G02: Static Gravity Field and Height Systems*
  - → Twelve of fifteen solutions agree within *1 cm to 2 cm in terms of standard deviation with respect to the mean value*

GGOS FA-UHS: planned activities 2019 - 2023

- Based on the Colorado experiment outcomes, to elaborate a document with *detailed standards and conventions* for the realization and maintenance of the IHRS.
- In agreement with the IGFS and the IAG Commission 2, to design a strategy *to install an operational infrastructure within the IGFS* to ensure the *maintenance and availability of the IHRF in a long-term basis*.
- Aspects to be considered are
  - Updates of the IHRS definition and realization according to future improvements in geodetic theory and observations.
  - Regular updates of the IHRF (e.g. IHRFyyyy) according to new stations, coordinate changes with time, improvements in the estimation of reference coordinates and modelling of the Earth's gravity field, etc.
  - Support in the realization and utilization of the IHRS/IHRF at regional and national level.
  - To guarantee an organizational and operational infrastructure to ensure the sustainability of the IHRF.

GGOS FA-UHS: planned activities 2019 - 2023

- With the support of the IAG Commission 2, the IGFS and the ICCT to promote the study of
  - quality assessment in the determination of potential values
  - determination of potential changes with time $\dot{W}$
  - realization of the IHRS in marine areas
  - ....

GGOS FA-UHS: planned activities 2019 - 2023

GGOS session dedicated to the Focus Area Unified Height System **Session G06j**

- Tuesday, **July 16, 4:30 – 6:00 pm, room 510BD**

  → Global gravity field modelling as a fundamental component for the precise height determination and the monitoring of the Earth System (R. Pail)

  → On the Need of Terrestrial Gravity Data and High-resolution Gravity Field Modelling for Realization of the International Height Reference System (J. Ågren)

  → Roadmap to a Mutually Consistent Set of On- and Offshore Vertical Reference Frames - the Dutch Approach (C. Slobbe)

  → The Treatment of the Permanent Tide in Geodetic Quantities: Past, Present, and the Future (J. Mäkinen)

  → 40 Years of the GRS80: Do We Need a New Ellipsoid? (I. Oshchepkov)

  → Geodesy and Earth Observation Based on Quantum Optics and Relativity (J. Müller)

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R Barzaghi, D Carrion - Politecnico de Milano, Italy
SRC de Freitas - Universidade Federal do Parana, Brazil
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D Avalos-Naranjo - Instituto Nacional de Estadística y Geografía, Mexico
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