CURRENT ACTIVITIES OF THE NEWLY ESTABLISHED IAG/IGFS IHRF COORDINATION CENTER FOR THE REALIZATION AND MAINTENANCE OF THE IHRS/IHRF

IAG WORKSHOP2024 ON ASIA PACIFIC GRAVITY, GEOID AND VERTICAL DATUMS, MANILA, PHILIPPINES, NOVEMBER 6-8, 2024

GS VERGOS, L SÁNCHEZ & R BARZAGHI & THE IHRF TEAM

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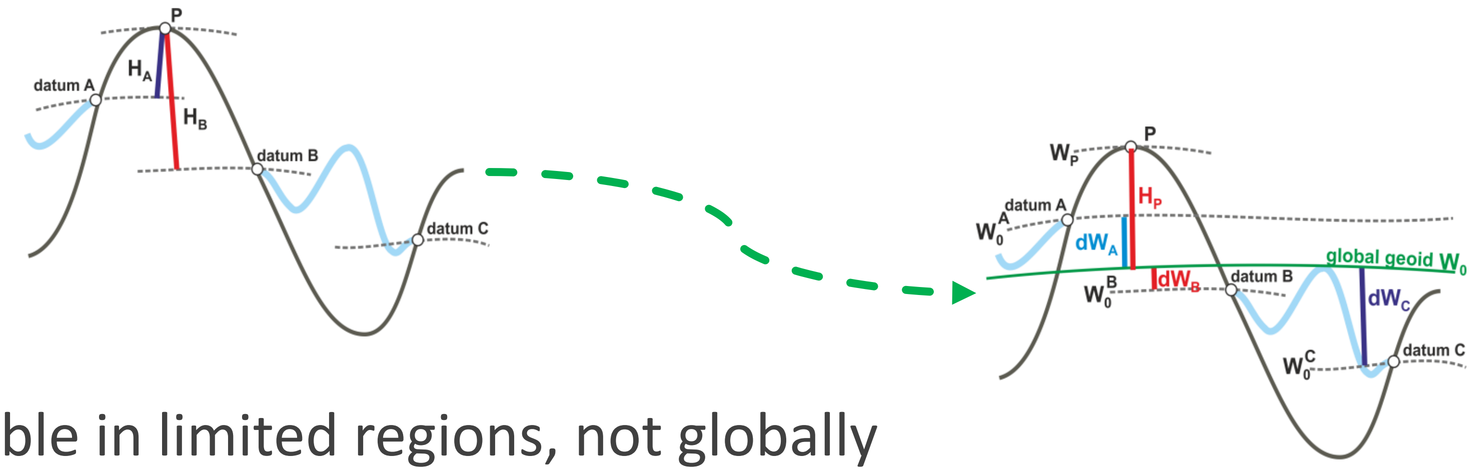
[3]Politecnico di Milano, Italy

WHY THE IHRF



- Existing height systems are usable in limited regions, not globally
- Existing height systems are not connected to each other, hence offsets (at the best-case scenario) exist even in neighboring countries
- Reliable physical heights are needed in a wide spectrum of (geo)scientific and engineering applications
- The vertical datum unification problem (all physical heights referring to the same equipotential surface) is a topic with long tradition in the IAG

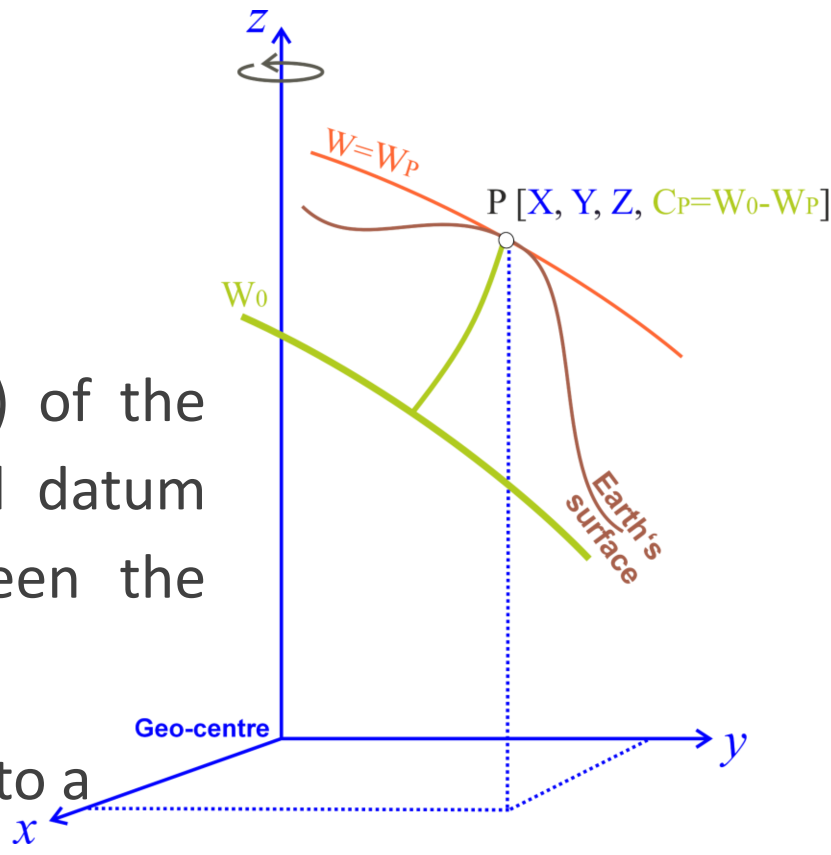
IHRS (IAG RESOLUTION NO. 1, PRAGUE, JULY 2015)

IHRF WITHIN IAG

- …..the development of theory and methods for the continuous improvement of the IHRS/IHRF should be promoted by the IAG Commissions and the Inter-Commission Committee on Theory (ICCT), while the operational performance should be ensured by the IAG Services.
- In that respect, the IHRF Coordination Centre (IHRF CC) has been proposed and accepted by the IAG EC as a central coordinating body under the responsibility of the International Gravity Field Service (IGFS) with direct adherence to the IGFS Central Bureau (IGFS CB), composed of individual modules taking care of the main components of the IHRF.

IHRF SCOPE

- responsibility to deliver the IHRF coordinates (X, Y, Z, C) of the IHRF reference stations and a catalogue of the vertical datum parameters, i.e., the transformation parameters between the existing local height systems and the IHRF
- Vertical coordinates are potential differences with respect to a conventionally fixed W_0 value:



$$C_P = C(P) = W_0 - W(P) = -\Delta W(P) \rightarrow H = \frac{C(P)}{\bar{g}}$$
$$W_0 = const. = 62\,636\,853.4\; m^2 s^{-2}$$

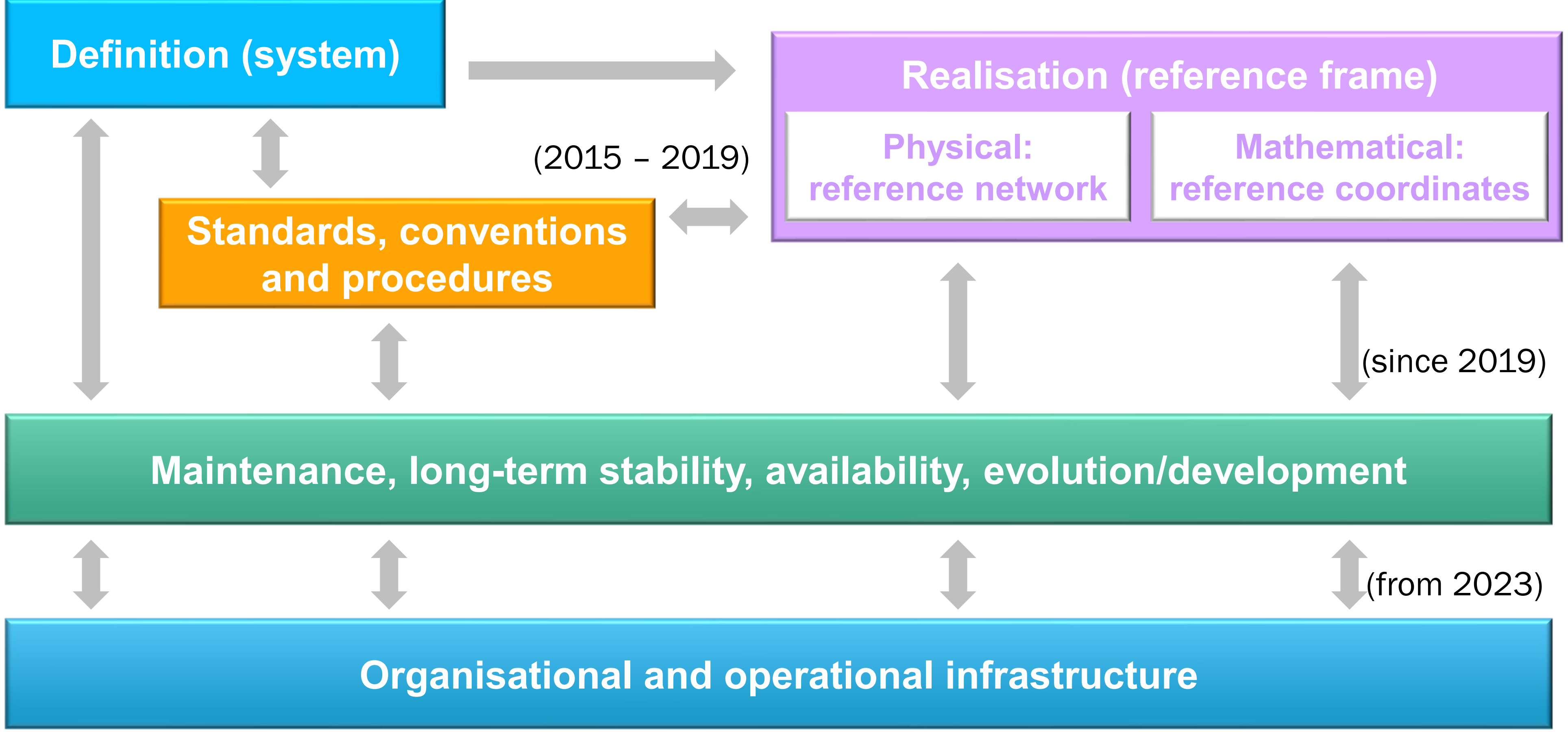
Convention: geopotential-based height system

Realisation: the International Height Reference Frame (**IHRF**)

IHRF EVOLUTION

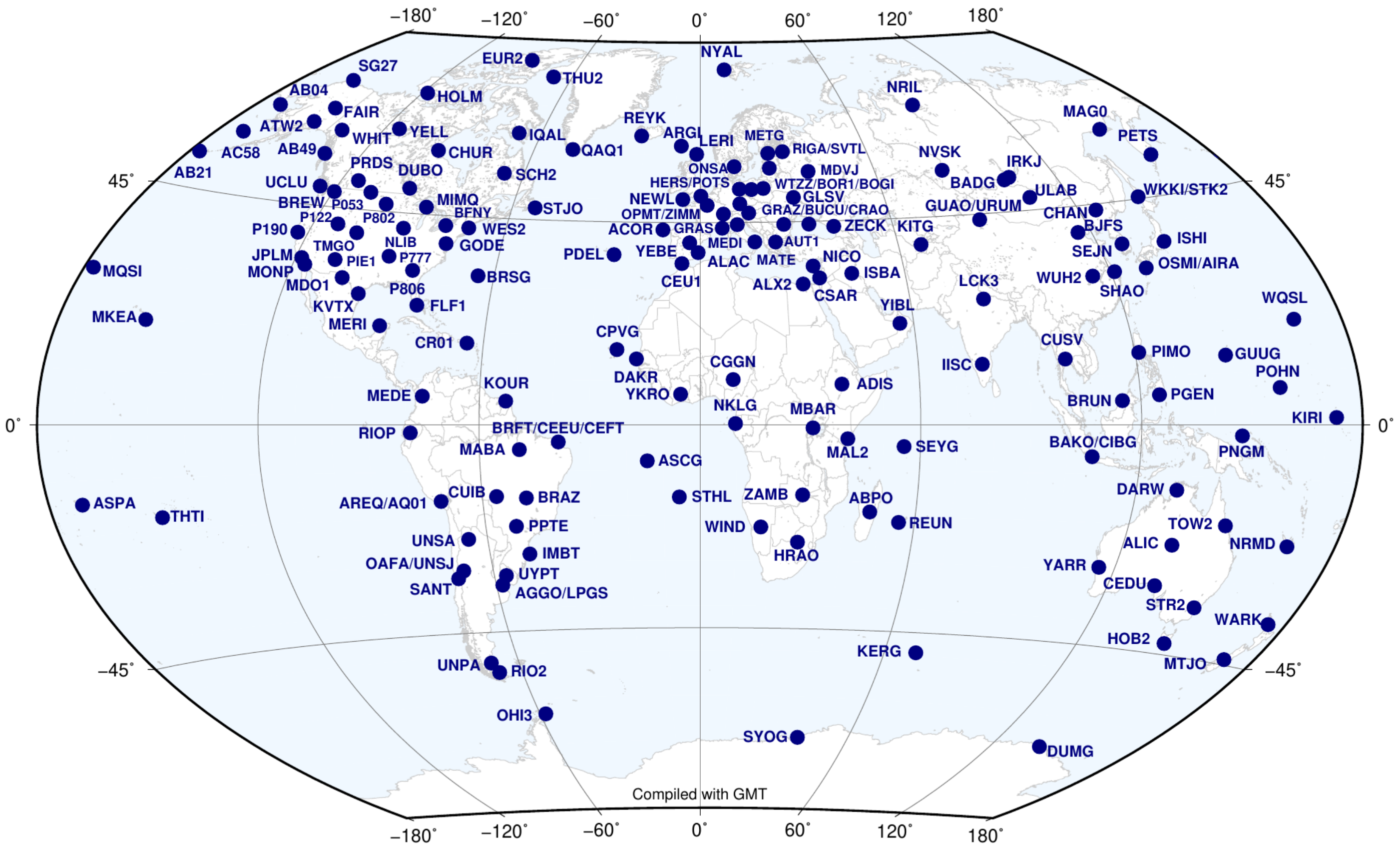
Objective: to provide an international standard for the precise determination of physical heights worldwide: the *International Height Reference System*

(2011 – 2015)



Sánchez et al. (2023) A first solution for the International Height Reference Frame (IHRF). IUGG 2023

IHRF – FIRST PROPOSAL



1) Global network with regional/national densifications

2) Core network materialised by GNSS continuously operating stations and co-located with the ITRF (and its regional densifications), ITGRF, reference clocks, national vertical frames

3) First proposal for the IHRF reference network (~170 stations) in coordination with the GGOS-BNO, IERS, BGI/IGFS and the IAG regional sub-commissions for reference frames and gravity field modelling.

4) A living network: new stations and decommission of stations.

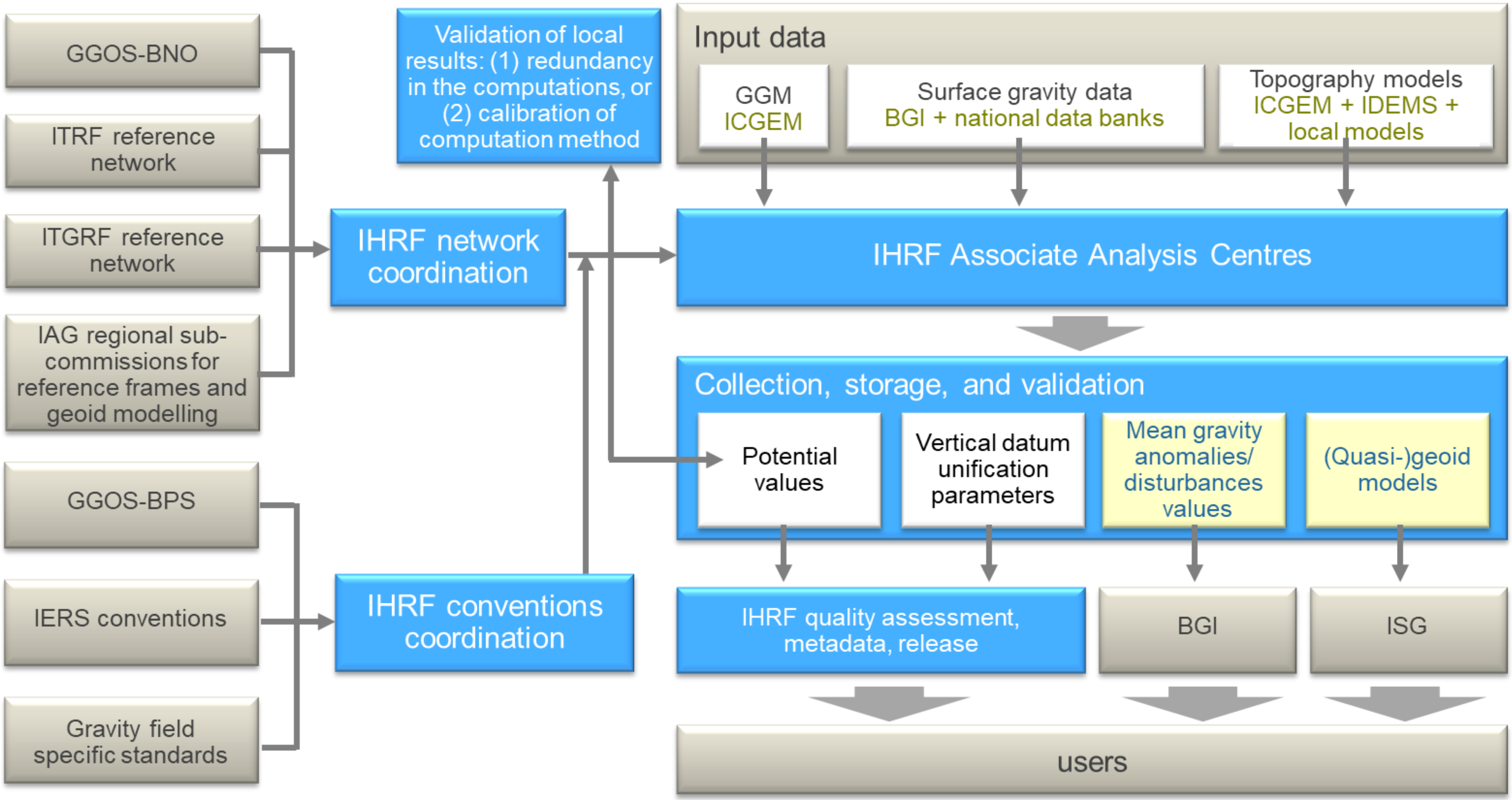
Sánchez et al. (2024) Towards a first solution for the International Height Reference Frame (IHRF). GGHS2024

IHRF COORDINATES

1) The IHRS/IHRF is
   - a combination of a geometric component given by the coordinate vector $\mathbf{X}$ in the ITRS/IHRF and
   - a physical component given by the determination of potential values W at $\mathbf{X}$
2) The determination of X follows the IERS Conventions and it is well established in practice (IERS and associated data, analysis, combination and product centres)
3) The determination of W is only possible by means of gravity field modelling (so far without standard procedures)
4) To be in agreement with the ITRF, the expected accuracy of W is
   - Positions: $\approx \pm 3\times10^{-2}$ m^2s^{-2} (about 3 mm)
   - Velocities: $\approx \pm 3\times10^{-3}$ m^2s^{-2}/a (about 0.3 mm/a)
5) For the moment, our goal is $\pm 1\times10^{-1}$ m^2s^{-2} (about 1 cm)
6) The IHRS/IHRF coordinates include the determination of time variations. For the moment, we consider static coordinates only

Sánchez et al. (2024) Towards a first solution for the International Height Reference Frame (IHRF). GGHS2024

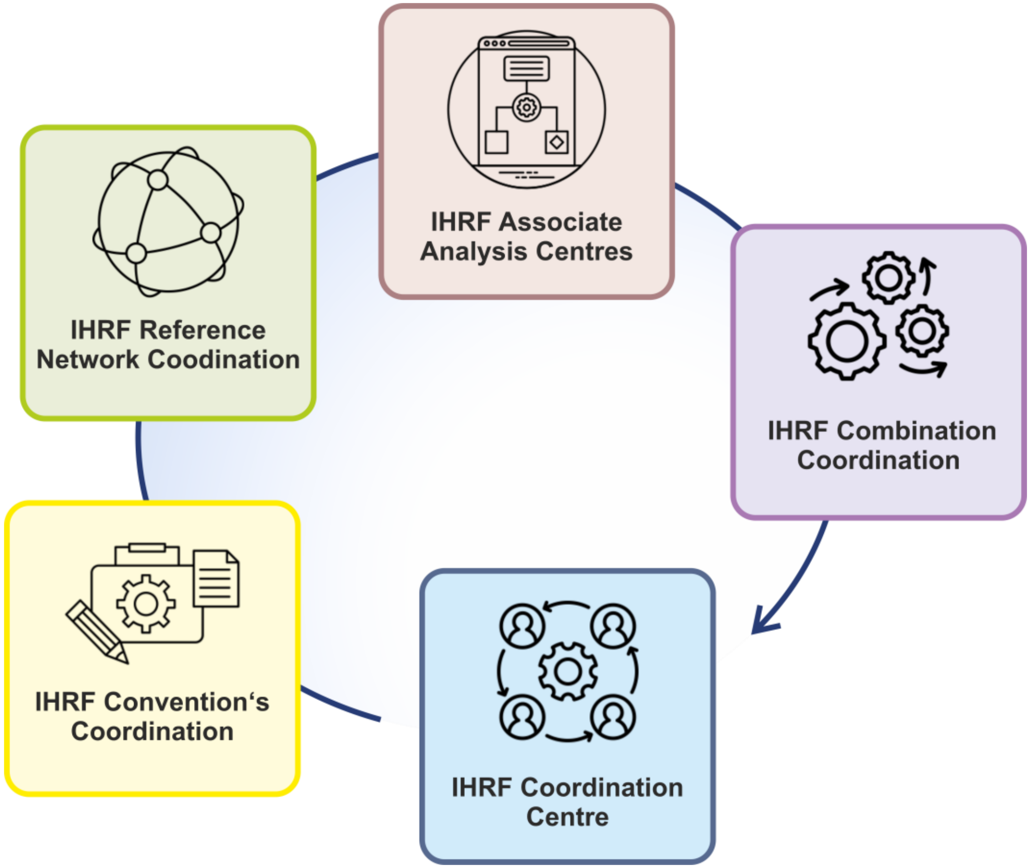
THE IHRF & IGFS SERVICES

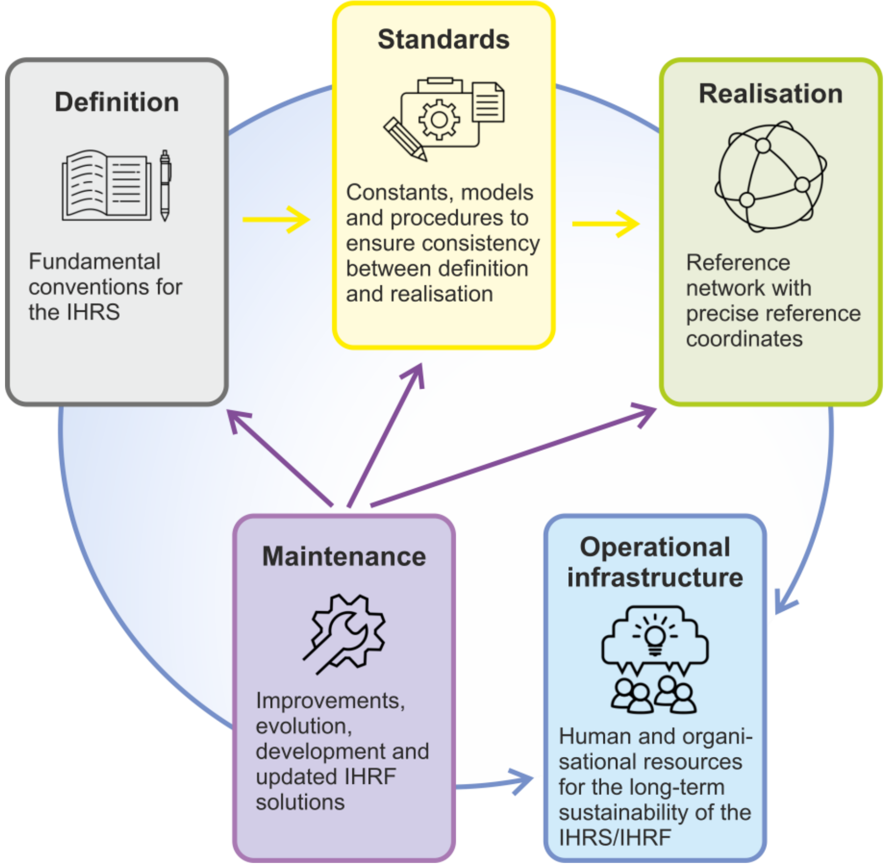


HOW TO DEPENDS ON THE AREA/REGION

- A **"centralised" computation** (like in the ITRF) is not possible due to the restricted accessibility to surface gravity data
  - Regional/national experts involved in the determination of W in their regions/countries
- To standardise as much as possible in a world-wide distributed computation
  - Basic standards on numerical constants, reference ellipsoid, degree zero and mass centre convention, handling of permanent tide effects.
- Determination of W depending on the data gravity availability and quality
  - For regions without surface gravity, data use GGM + topographic gravity signals
  - For regions with some surface gravity data, but with poor data coverage or unknown data quality, improve data availability and quality and solve the GBVP.
  - For regions with good surface gravity data coverage and quality, use precise regional geoid or height anomaly.

IHRF CC PERMANENT COMPONENTS - DUTIES





IHRF PERMANENT COMPONENTS - DUTIES

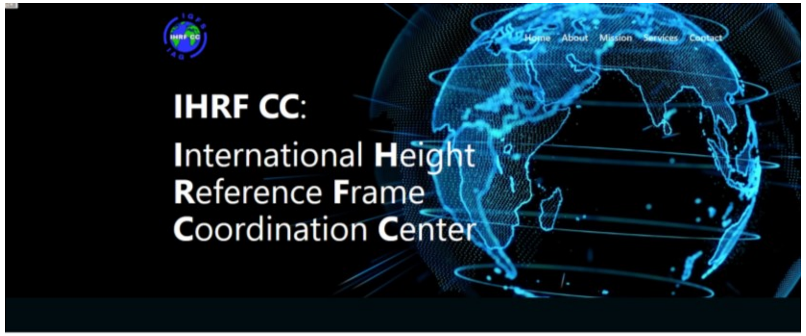
- IHRF Associate Analysis Centers (IHRF ASCs)
  - The main driving force of the IHRF, based on a voluntary effort
  - The IHRF ASCs are national/regional agencies/bodies that contribute to the realization of the IHRF by providing the potential values at the IHRF stations located in their countries/regions and the vertical datum parameters.
  - These ASCs will strictly follow the conventions outlined by the IHRF CVC, use the ITRF input coordinates provided by the IHRF RNC, and provide detailed descriptions about their calculations.

IHRF PERMANENT COMPONENTS – IHRF ASC PEOPLE

- Africa **Hussein Abd-Elmotaal**
- America North **Yan Ming Wang, Jianliang Huang**
- America South **Ana Cristina Oliveira Cancoro de Matos, Claudia Tocho, Gabriel do Nascimento Guimarães, Walter Subiza**
- Oceania **Sten Claessens & Neda Darbeheshti**
- Europe **Joachim Schwabe, Heiner Denker**

- India **Ropesh Goyal**
- Japan **Koji Matsuo**
- China **Tao Jiang**
- KSA/Arabia **Rossen Grebenitcharksy, Abdullah Theeb Hassan Al-Qahtani**
- Iran **tbd**
- Turkey **Bihter Erol**
- Greenland **Rene Forsberg, Hergeir Teitsson**
- Antarctica **tbd**

IHRF WEBSITE, COMMUNICATION & VISIBILITY

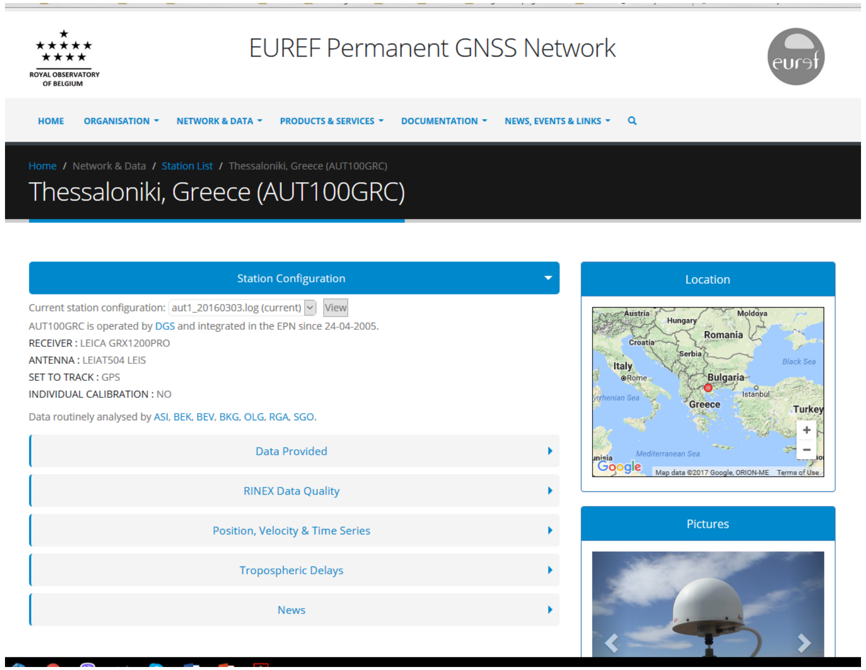


- Website already developed (https://ihrfcc.topo.auth.gr/)
- Main IHRF e-mail alias is ready and working (ihrf@topo.auth.gr)
- IHRF documents repository to the website (minutes, material, presentations, notes, etc.)
- IHRF cookbook as a how-to guide for ASCs already prepared

IHRF as a realization of IHRS

Why AUT1?

- EUREF Station (Class A Station)



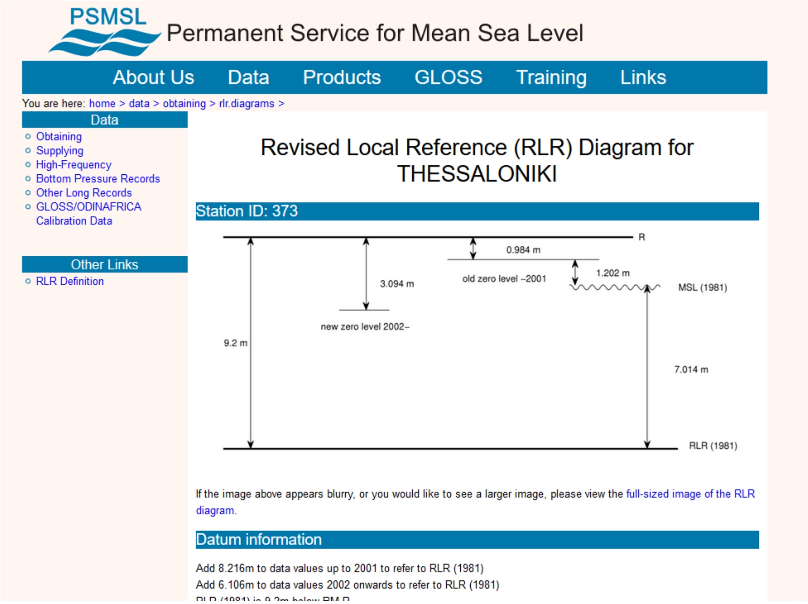

The AUT1 EUREF Class A station (© EUREF)

PROXIMITY OF TG FOR REFERENCE TO THE LVD

IHRF as a realization of IHRS

Why AUT1?

- EUREF Station (Class A Station)
- HNHS TG station in proximity (9.2 km)



Thessaloniki SONEL TG station (© PSMSL)

COLLOCATION WITH ABSOLUTE GRAVITY

IHRF as a realization of IHRS

Why AUT1?

- EUREF Station (Class A Station)
- HNHS TG station in proximity (9.2 km)
- GravLab A10(#027) station in proximity (8 km)

GravLab A10 (#027) (© GravLab)

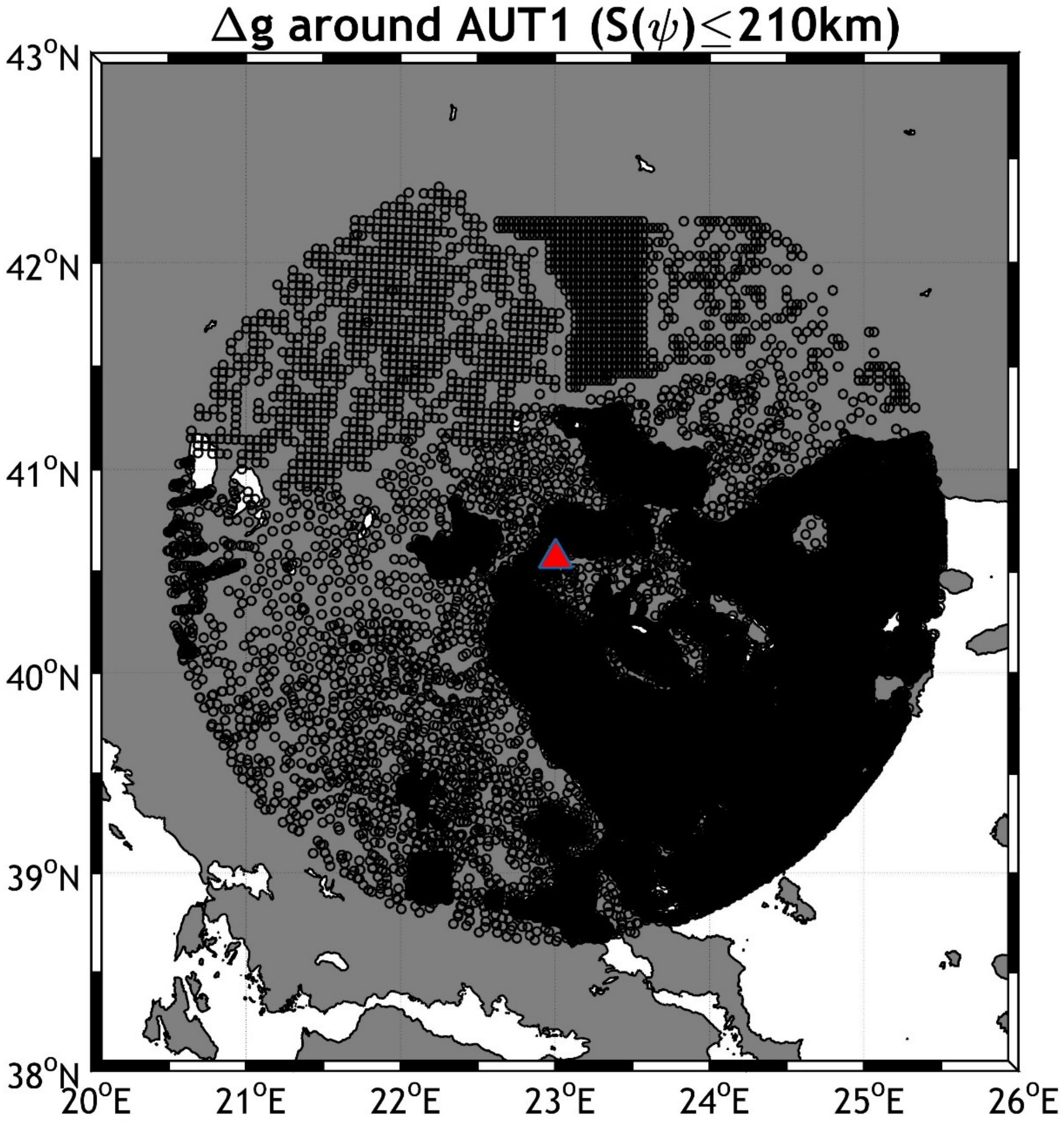
LOCAL GRAVITY DATA TO SUPPORT W_P COMPUTATION

IHRF as a realization of IHRS

Why AUT1?

- EUREF Station (Class A Station)
- HNHS TG station in proximity (9.2 km)
- GravLab A10(#027) station in proximity (8 km)
- Abundance of local gravity data (25208 pts. with S<210km)

ABUNDANCE OF GRAVITY



Distribution of available local gravity anomalies around AUT1

LEVELLING CONNECTION TO THE NATIONAL VRF

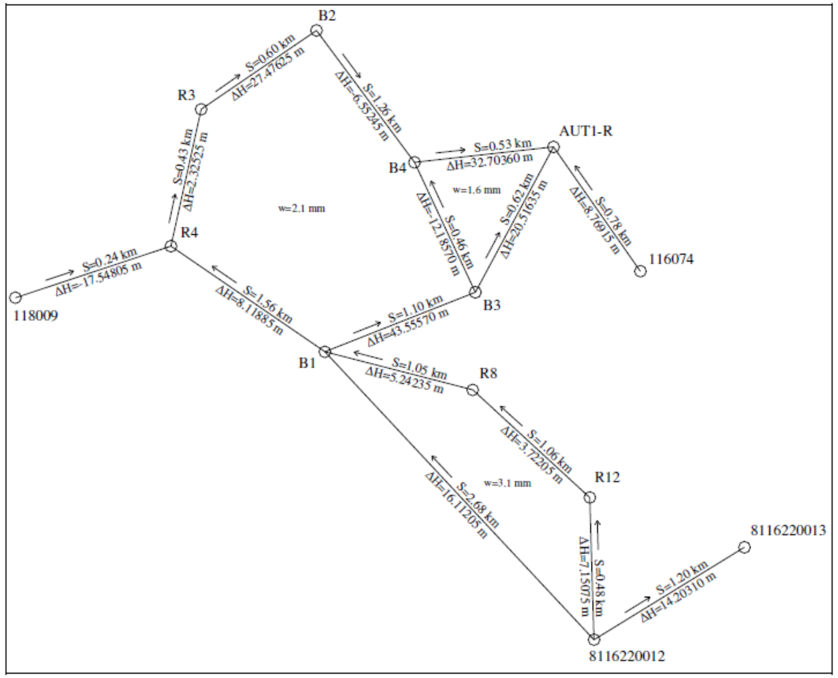
IHRF as a realization of IHRS

Why AUT1?

- EUREF Station (Class A Station)
- HNHS TG station in proximity (9.2 km)
- GravLab A10(#027) station in proximity (8 km)
- Abundance of local gravity data (25208 pts. with S<210km)
- Levelling connection with the Hellenic VRF through dedicated 1st order spirit leveling

CONNECTION WITH THE LOCAL VRF TO PROVIDE THE OFFSET

AUT1 dedicated spirit leveling



AUT1 1st order spirit leveling to connect to HVRF (Vlachakis et al. 2005)

METHODOLOGY

Estimate the potential @ AUT1 employing ellipsoidal, orthometric and geoid heights (synthesis of GOCE GGM + local data through RCR)

$$\widehat{W}_{AUT1} = W_o^{CVD} - \Delta C_{AUT1}^{CVD/LVD}$$

$$(h_{AUT1} - H_{AUT1} - N_{AUT1})\bar{g}_i = \Delta C_{AUT1}^{CVD/LVD}$$

$$\bar{g}_{AUT1} = g_{AUT1} + 0.0424 H_{AUT1}$$

From EUREF (088/2005)

1st order leveling

Dedicated relative gravity campaign

Determine N_{AUT1} using an RCR concept as:

$$N_{AUT1} = N_0 + N_{GOCE}\Big|_2^{n_1} + N_{RTM}\Big|_{n_{1+1}}^{216,000} + N_{res}\Big|_{216,000}^{\infty}$$

METHODOLOGY

Determine N_{AUT1} using an RCR concept as:

$$N_{AUT1} = N_0 + N_{GOCE/GRACE}\Big|_2^{n_1} + N_{GGM\ comp}\Big|_{n_1+1}^{n_2} + N_{RTM}\Big|_{n_2+1}^{216,000} + N_{res}\Big|_{216,000}^{\infty}$$

$$N_0 = \frac{GM - GM_o}{R\gamma} - \frac{W_o - U_o}{\gamma}$$

$N_{GOCE}\Big|_2^{n_1}$ GOCO05s to d/o e.g. 220, 250, ….

$N_{GOCE}\Big|_{n_1+1}^{n_2}$ Some combined GGM like XGM2019e

$N_{RTM}\Big|_{n_2+1}^{216,000}$ SRTM3″ DTM for the wider Hellenic area either with the classical RTM approach or the spectral one

$N_{res}\Big|_{216,000}^{\infty}$ From Δg_{res} employing numerical integration, LSC, FFT, Stokes modifications (WG), radial spherical basis functions

TOWARDS A FIRST SOLUTION

Input data: Disturbing potential computed for the local/regional geoid or height anomaly, without fitting to GNSS/Levelling data

$$W = U + T \quad \rightarrow \quad \Delta g = \delta g + \frac{1}{\gamma}\frac{\partial \gamma}{\partial h}T = -\frac{\partial T}{\partial h} + \frac{1}{\gamma}\frac{\partial \gamma}{\partial h}T \rightarrow \qquad N \sim \zeta = \frac{T}{\gamma}$$

Height anomaly

$$W(P) = U(P) + \zeta(P)\cdot\gamma_Q + \Delta W_0 \quad [\mathrm{m^2s^{-2}}] \rightarrow \quad W(P) = W_0 - \big(h(P) - \zeta(P)\big)\cdot\bar{\gamma}_{QQ_0} \quad [\mathrm{m^2s^{-2}}]$$

Geoid

$$W(P) = W_0 - \big(h(P) - N(P)\big)\cdot\bar{g}(P) \quad [\mathrm{m^2s^{-2}}] \text{ with}$$

$$\bar{g}(P) = g(P) + 0.424\times10^{-6}\cdot\big(h(P) - N(P)\big) + TC(P) \quad [\mathrm{ms^{-2}}]$$

Results: Potential values

Station	Latitude[°]	Longitude[°]	h [m]	W[m2m-2]
ACOR 13434M001	43.36438604	-8.39892871	66.874	62636739.38
ALAC 13433M001	38.33892293	-0.48122575	60.317	62636759.06
ALX2 30102M001	31.19706855	29.91099701	57.951	62636437.34
ARGI 10117M002	61.99737250	-6.78352091	110.239	62636330.26
AUT1 12619M002	40.56681956	23.00372276	150.053	62635796.03
BOGI 12207M003	52.47499384	21.03521983	139.917	62635784.52

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EVALUATION & CHALLENGES

- Quality assessment of the W values is very difficult because a proper error propagation and redundancy are practically impossible. External validation data (i.e. GNSS/levelling) are required and sometimes their quality is very poor. We recommend:

  → Evaluation of the calculation methods used by national/regional experts: determination of the geopotential model using a certain set of input data and comparison with results obtained by other approaches: Datasets available (e.g., Colorado data) at the International Service for the Geoid, https://www.isgeoid.polimi.it/.

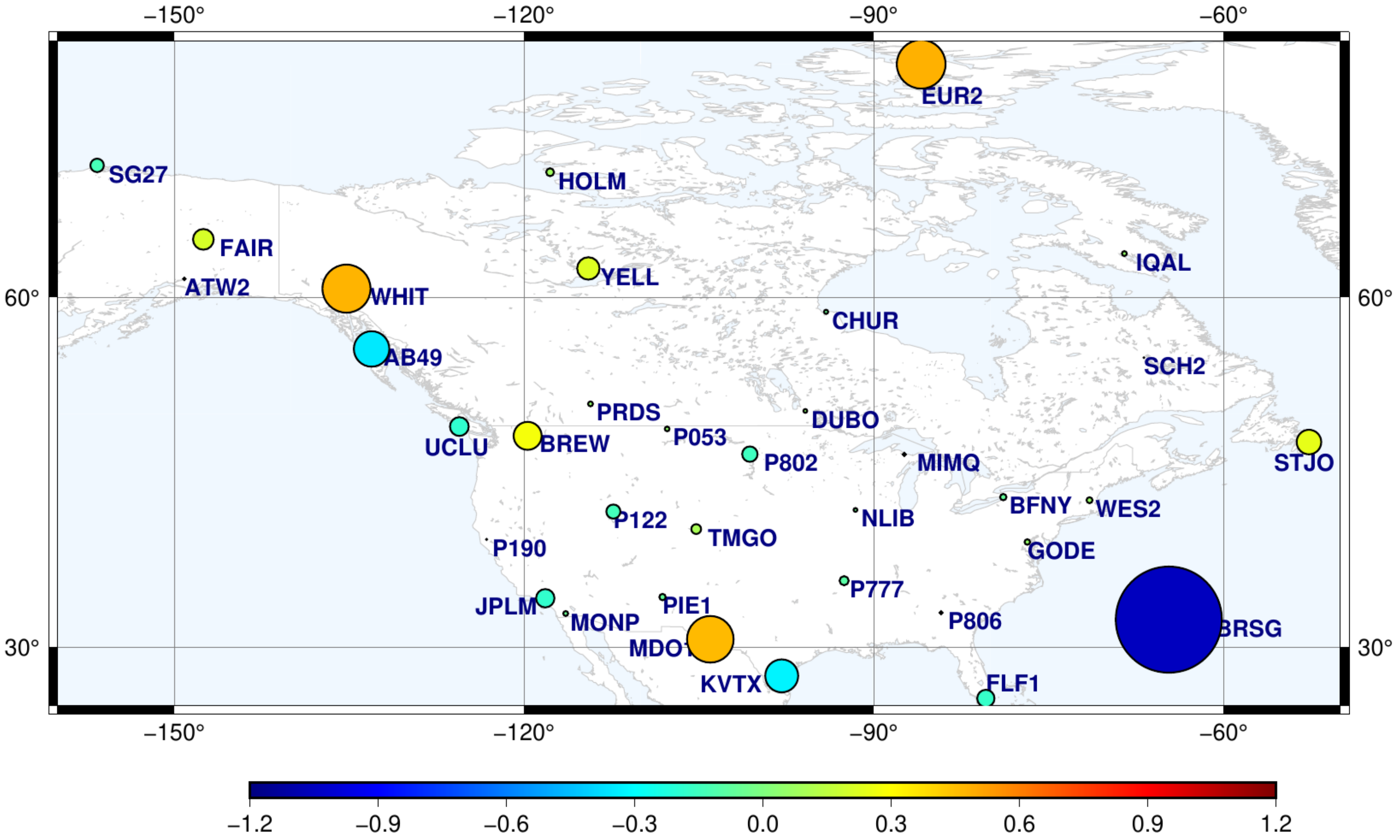
  → Within the IHRF CC, two datasets, one based on simulated data (GGM+topo effects) and one based on real data will be generated to be used as a test board (for new methods, approaches, etc.)

  → Redundancy is desired: Two calculations using the same input data and different software.

EVALUATION – TWO EXAMPLES

Differences between the potential values inferred from the Canadian geoid PCGG20_21A and the US height anomalies xG20B (thanks to M Véronneau, J Huang, YM Wang and K Ahlgren):

Mean: -0.01 m^2s^{-2} (~ -1 cm)
STD: 0.26 m^2s^{-2} (~ 3 cm)
Min.: -1.05 m^2s^{-2} (~ -10 cm)
Max.: 0.48 m^2s^{-2} (~ 5 cm)



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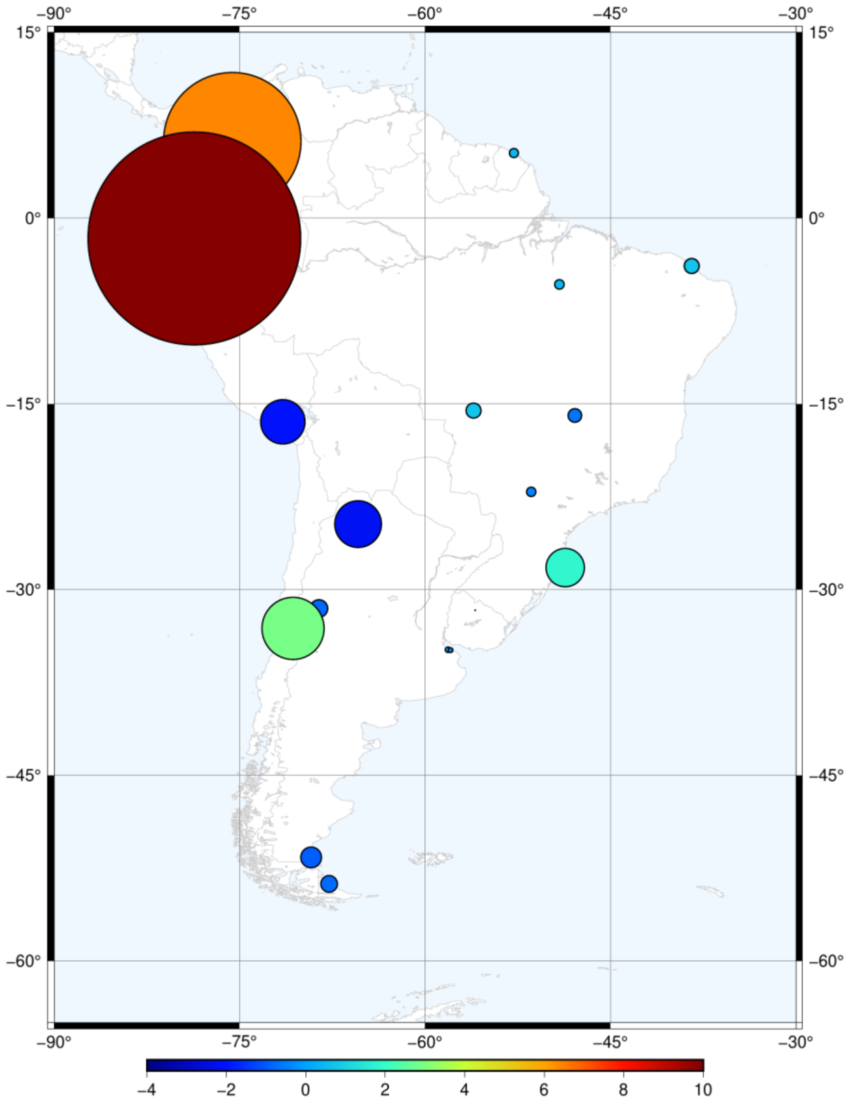
EVALUATION – TWO EXAMPLES

Differences between the geopotential numbers inferred from the South American geoid models GEOIDE2021 and GEOIDE2023 (thanks to ACOC Matos, D Blitzkow, G Guimarães)

Differences @ 20 points	(@ 18 points)
Mean: **0.661 m^2s^{-2}**	**(-0.087** m^2s^{-2}**)**
STD: **2.748** m^2s^{-2}	(1.238 m^2s^{-2})
Min.: -2.175 m^2s^{-2}	(0.661 m^2s^{-2})
Max.: **9**.901 m^2s^{-2}	(2.896 m^2s^{-2})

- **Challenging topography (terrain effects)**
- **National geopotential models preferred (instead of continental)**
- **New calculations in Argentina, Brazil, Colombia and Uruguay (completed in August 2024)**



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A GLOBAL EFFORT

US main territory (30 stations):
Model NAPGD2022 - xG20B
Mean accuracy 0.45 m^2s^{-2}

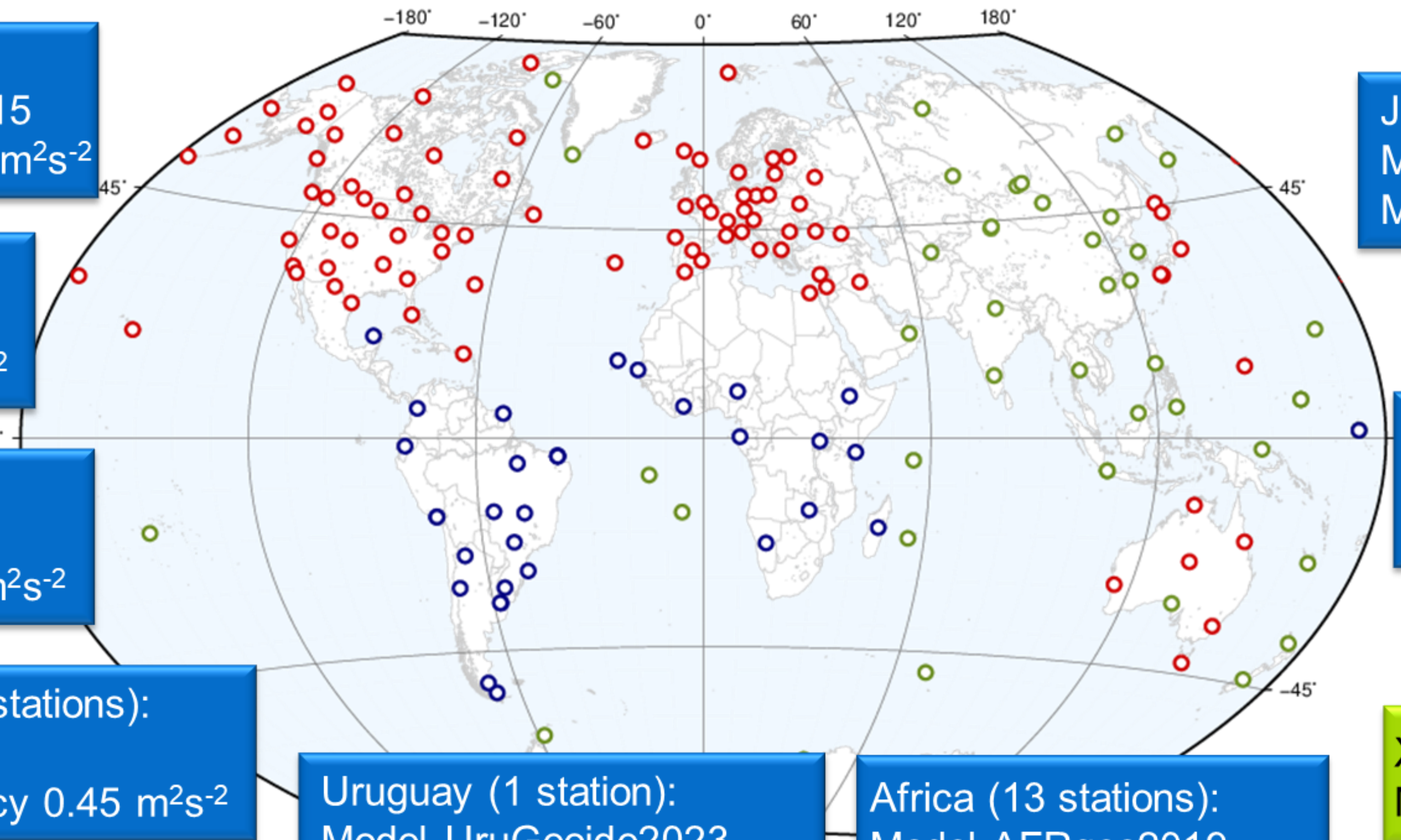
Canada (11 stations):
Model PCGG20_21A
Mean accuracy 0.35 m^2s^{-2}

Europe (40 stations):
Model EGG2016
Mean accuracy 0.40 m^2s^{-2}

Mexico (1 station):
Model GGM-CA 2015
Mean accuracy 2.0 m^2s^{-2}

Japan (5 stations):
Model JGEOID2019
Mean accuracy 0.57 m^2s^{-2}

Colombia (1 station):
Model QGeoidCOL2023
Mean accuracy 1.57 m^2s^{-2}



Brazil (6 stations):
Model GEOIDE2023
Mean accuracy 0.50 m^2s^{-2}

Australia (6 stations):
Model AGQG2017
Mean accuracy 0.62 m^2s^{-2}

Argentina (5 stations):
Point by point
Mean accuracy 0.45 m^2s^{-2}

Uruguay (1 station):
Model UruGeoide2023
Mean accuracy 0.35 m^2s^{-2}

Africa (13 stations):
Model AFRgeo2019
Mean accuracy 2.0m^2s^{-2}

XGM2019
Mean accuracy 4.0m^2s^{-2}

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IHRF DEVELOPMENTS

- A (short) white paper will be prepared on why the IHRF is needed + why the geoid and gravity are needed
- What are the benefits of having it and the pitfalls of not having it (similar to the GGOS Strategic Plan and Implementation Strategy)
- Simulated and GGM+topo based data on the IHRF web-reprository to test approaches, methods & algorithms
- First realization on-line as potential values, offsets to national VRFs and metadata (presented @ GGHS2024 – Thessaloniki, Greece)

IHRF THE WAY FORWARD

- Anyone working on the field is welcome to contribute
- No commitment(s) to provide local gravity data, as they are sensitive
- The IHRF CC depends on the ASCs, so membership and participation is free
- Establishment of ASC(s) at national or regional level in the Asia-Pacific area (??)

ACKNOWLEDGEMENTS

This work relies on the voluntary contribution of many colleagues. This support is greatly appreciated.

THANK YOU