Towards a first realization of the International Height Reference System (IHRS)

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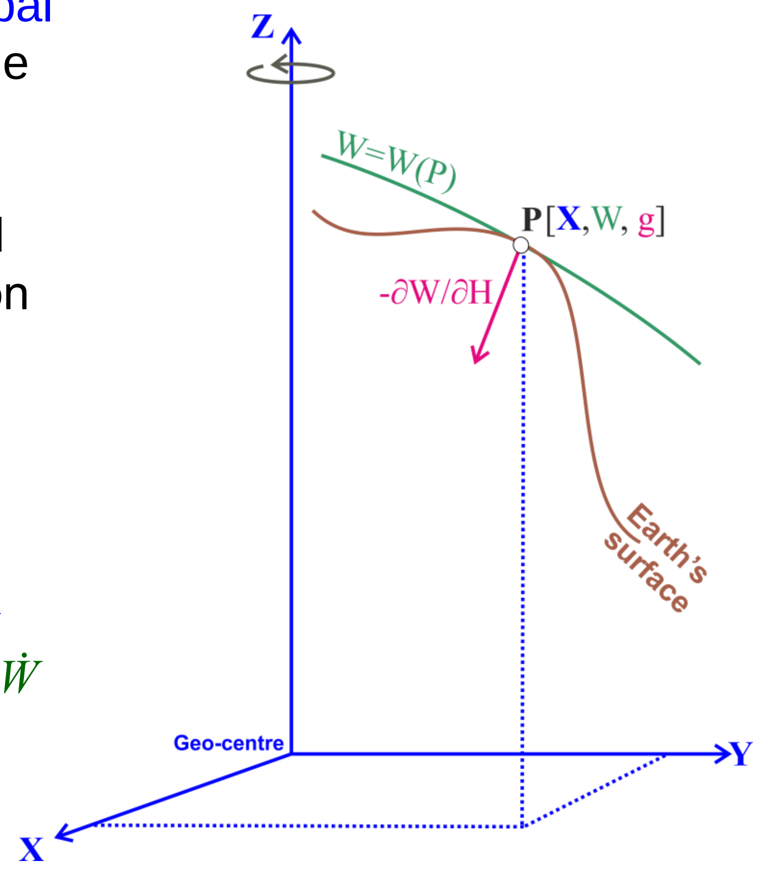
Motivation

A main objective of the International Association of Geodesy (IAG) and its Global Geodetic Observing System (GGOS) is the implementation of an integrated Global Geodetic Reference Frame (GGRF) that supports the consistent determination and monitoring of the Earth's geometry, rotation and gravity field with high accuracy worldwide.



The GGRF includes:

– Geocentric Cartesian coordinates $\mathbf{X}$, $\dot{\mathbf{X}}$
– Potential of the Earth's gravity field W, $\dot{W}$
– Gravity vector $\mathbf{g}$, $\dot{\mathbf{g}}$
– Physical height H, $\dot{H}$

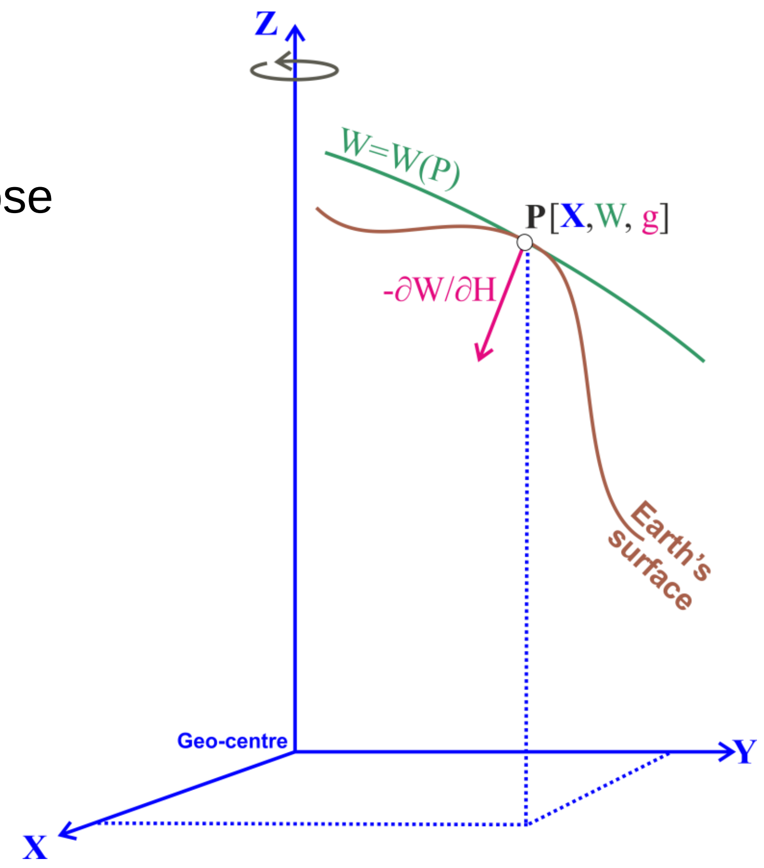
See: Description of the Global Geodetic Reference Frame; position paper adopted by the IAG Executive Committee, April, 2016, http://iag.dgfi.tum.de/fileadmin/IAG-docs/GGRF_description_by_the_IAG_V2.pdf

IAG Resolutions 2015

The establishment of such a GGRF demands the implementation of a worldwide-unified (standardized) physical reference system.

A first concrete step oriented to this purpose was the release of two IAG resolutions during the IUGG2015 General Assembly (Prague, July 2015):

- one for the definition and realization of an International Height Reference System (IHRS), and
- the second one for the establishment of an International Gravity Reference System (IGRS) based on absolute gravity measurements (as replacement of the IGSN71).



See: Drewes et al.: The Geodesist's Handbook 2016, Journal of Geodesy. 2016.

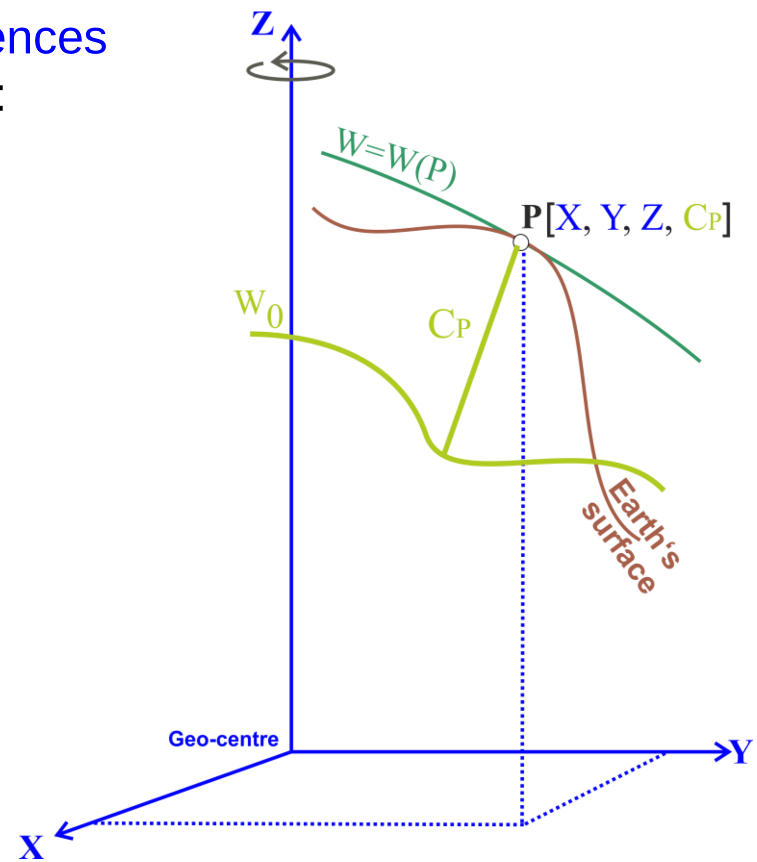
International Height Reference System (IHRS)
IAG Resolution No. 1, Prague, July 2015

1) Vertical coordinates are potential differences with respect to a conventional W_0 value:
   - $C_P = C(P) = W_0 - W(P) = -\Delta W(P)$
   - conventional fixed value
     $W_0 = const. = 62\,636\,853.4\ \mathrm{m^2 s^{-2}}$

2) The position P is given by the coordinate vector $\mathbf{X}_P$ (X_P, Y_P, Z_P) in the ITRF; i.e., $W(P) = W(\mathbf{X}_P)$

3) The determination 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) The determination of $\mathbf{X}$, $\dot{\mathbf{X}}$ follows the standards (and conventions) adopted within the IERS for the ITRS/ITRF. Similar standards for the determination of W, $\dot{W}$ are (still) missing.



See: Ihde J. et al.: Definition and proposed realization of the International Height Reference System (IHRS). Surveys in Geophysics 38(3), 549-570, 10.1007/s10712-017-9409-3, 2017

Realization of the IHRS

A reference frame realizes a reference system in two ways:

- physically, by a solid materialization of points (or observing instruments),
- mathematically, by the determination of coordinates referring to that reference system.
- The coordinates of the points are computed from the measurements, but following the definition of the reference system.

Immediate objectives regarding the IHRS:

- Establishment of an International Height Reference Frame (IHRF) with high-precise primary coordinates X_P, $\dot{X}_P$, W_P, $\dot{W}_P$.
- Identification and compilation/outlining of the required standards, conventions and procedures to ensure consistency between the definition (IHRS) and the realization (IHRF); i.e., an equivalent documentation to the IERS conventions is needed for the IHRS/IHRF.

Advances in the IHRS/IHRF implementation

1) Activities faced by the Joint Working Group on the Strategy for the Realization of the International Height Reference System (IHRS), (http://ihrs.dgfi.tum.de).

2) Coordinated work between:
   - GGOS Focus Area Unified Height System
   - International Gravity Field Service (IGFS)
   - IAG Commission 2 (Gravity field)
   - IAG Commission 1 (Reference Frames)
   - IAG Inter-commission Committee on Theory (ICCT)
   - Regional sub-commissions for reference frames and geoid modelling
   - GGOS Bureau for Networks and Observations
   - GGOS Bureau for Products and Standards.

3) First meeting of the WG at GGHS2016 (Thessaloniki, Sept. 2016): Brainstorming and definition of action items; criteria for the selection of IHRF stations.

4) GGOS Days 2016 (Cambridge, MA, Oct. 2016): Preliminary station selection for the IHRF.

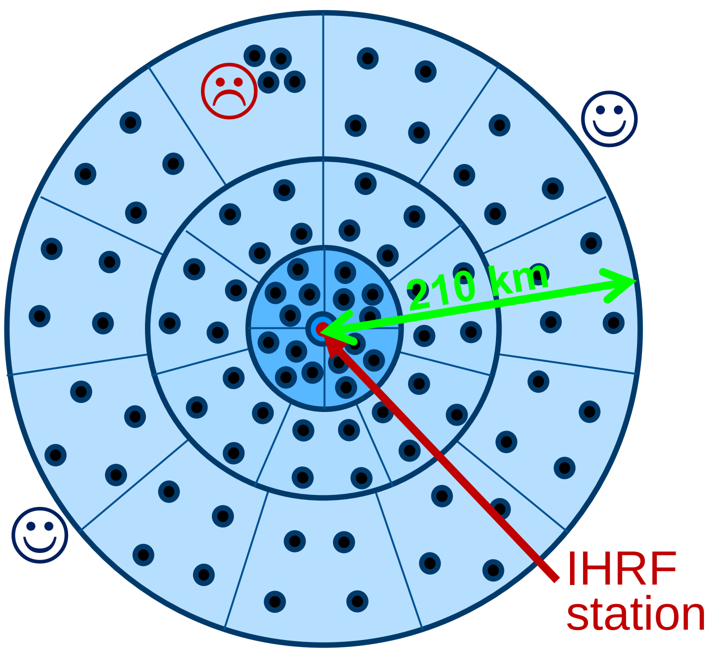
5) Nov. 2016 – March 2017: Interaction with regional/national experts about the preliminary station selection and proposal for further geodetic sites.

Criteria for the IHRF reference network configuration

1) Hierarchy:
   - A global network → worldwide distribution, including
   - A core network → to ensure sustainability and long term stability
   - Regional and national densifications → local accessibility
2) Collocated with:
   - fundamental geodetic observatories → connection between $\mathbf{X}$, W, $\mathbf{g}$ and time realization (reference clocks) → to support the GGRF;
   - continuously operating reference stations → to detect deformations of the reference frame;
   - reference tide gauges and national vertical networks → vertical datum unification;
   - reference stations of the new Global Absolute Gravity Reference System (see IAG Resolution 2, Prague 2015).
3) Main requirement: availability of terrestrial gravity data around the IHRS reference stations for high-resolution gravity field modelling (i.e., precise estimation of W).

Requirements on the terrestrial gravity data

- Homogeneously distributed gravity points around the IHRF reference stations up to 210 km (~ 2°).
- The gravity data may exist or have to be observed.
- Mean accuracy of the gravity values better than ±100 μGal.
- Gravimetry referred to an absolute gravity station is desired.
- Gravity point positions with GPS (some cm accuracy is sufficient).
- In mountain areas ~50% more gravity points.
- Of course, the more terrestrial gravity points the merrier.



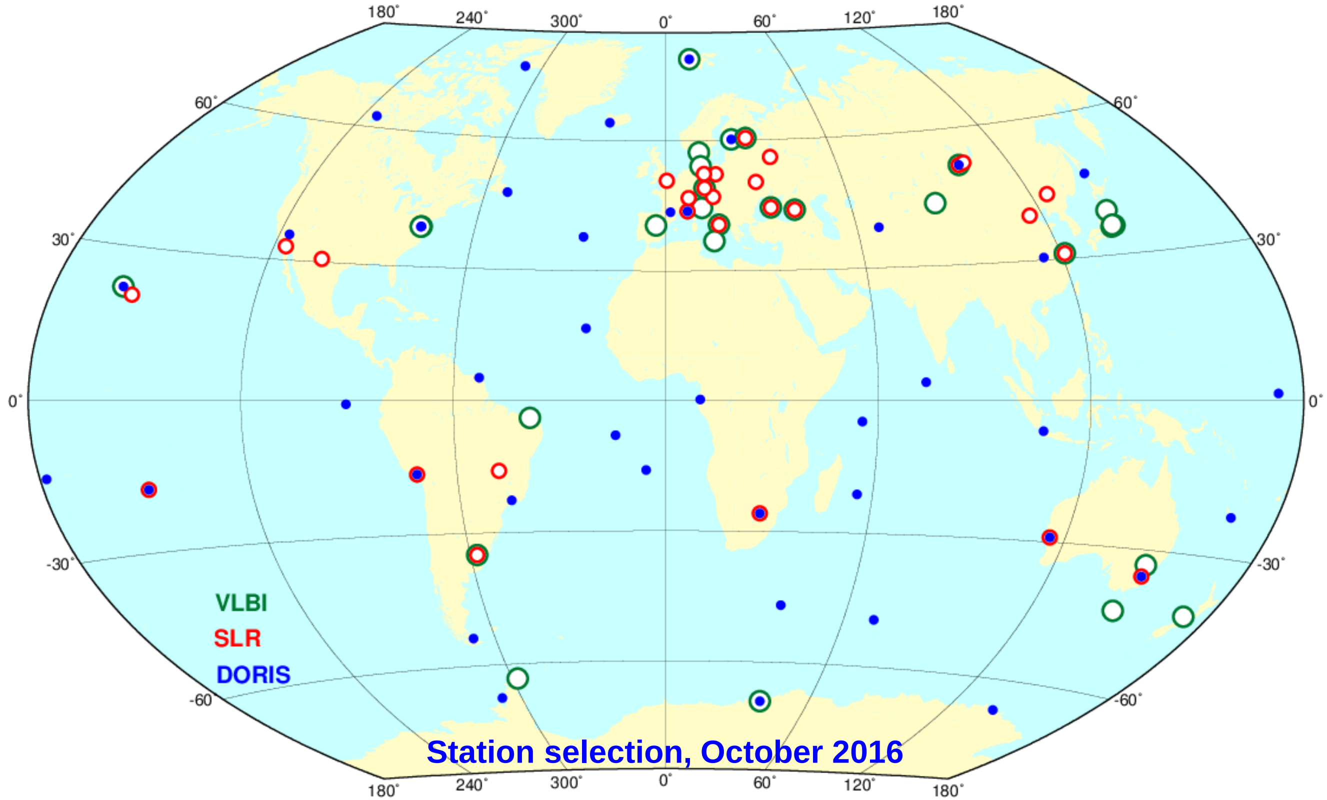
Template according to the gravity effect on the geoid ($\Delta g = 1 \cdot 10^{-6}\ ms^{-2} \rightarrow 1\ mm$)

Distance	Compart ments	# of points flat/mountain
10 km	1	**4/8**
50 km	4	**20/30**
110 km	7	**30/45**
210 km	11	**50/75**
Sum	23	**104/158**

Preliminary selection of IHRF reference stations (Oct. 2016)

A preliminary station selection based on VLBI, SLR and DORIS reference sites co-located with GNSS was performed in October 2016.

- VLBI and SLR sites guarantee a long-term perdurability/maintenance of the geodetic facilities.
- DORIS and GNSS guarantee a homogeneous distribution worldwide.
- The GGOS Bureau for Networks and Observations supports this task by implementing an inventory about further co-located observables at each site (e.g. absolute gravity, superconducting gravity-meter, reference clocks involved in the TT realization, etc.).



Refined station selection for the IHRF

Based on the preliminary station selection of Oct. 2016, national/regional experts were asked to

1) evaluate whether these sites are suitable to be included in the IHRF: Are gravity data around these sites available? If not, is it possible to survey gravity around them?

2) propose additional geodetic sites to improve the density and distribution of the IHRF stations in their regions/countries:

   - proposed sites shall be materialized by a continuous operating GNSS station;
   - stations belonging to the regional reference frames (like SIRGAS, EPN, APREF, etc.) are preferred;
   - gravity data around the proposed stations must be available;
   - GNSS stations co-located with the reference tide gauges and connected to the national levelling networks is desirable.

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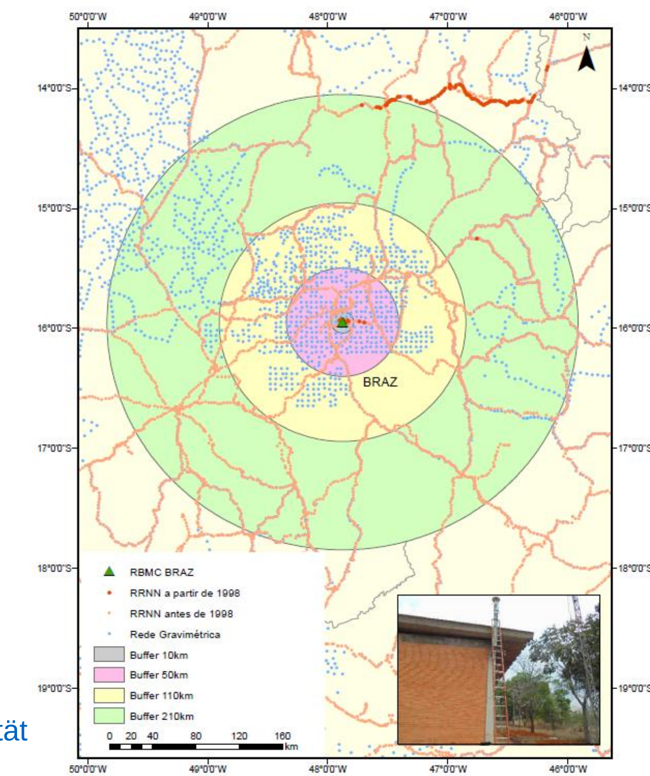
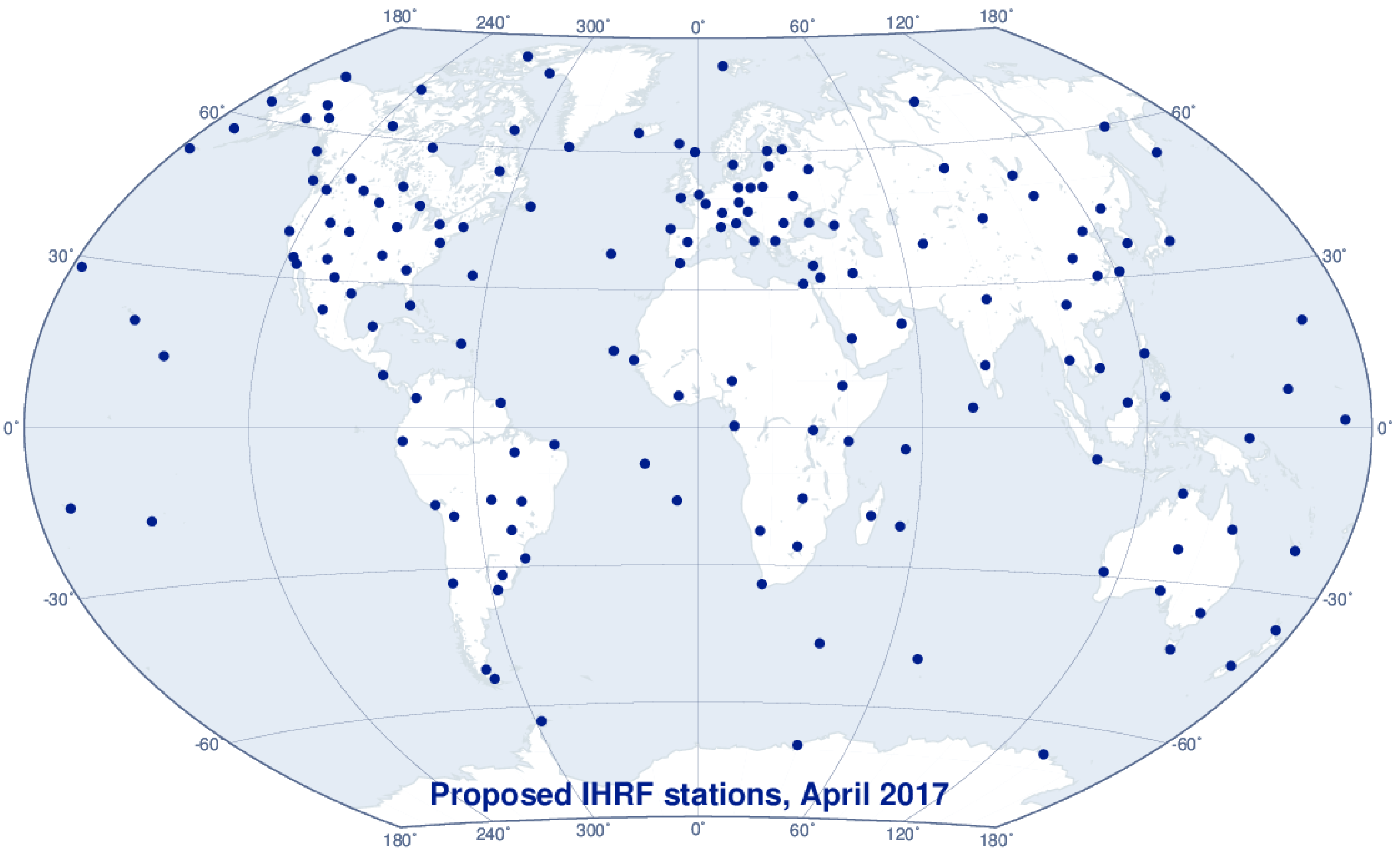


First proposal for the IHRF reference network (Apr. 2017)

163 proposed stations after the feedback from the regional/national experts. In those regions with poor coverage (specially in Africa and Asia), other IGS stations were added.



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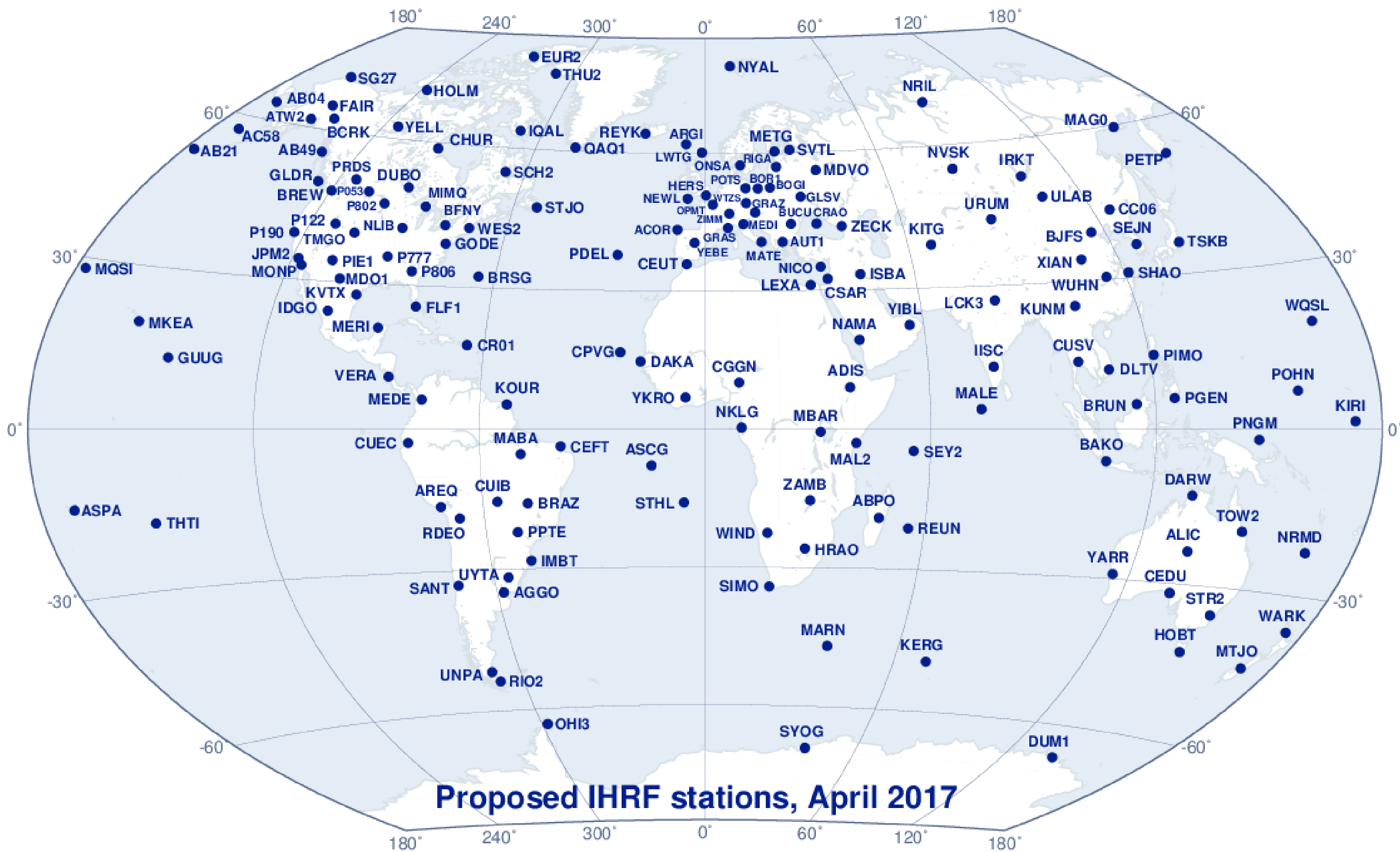

Next steps

With this preliminary selection, next efforts concentrate on the computation of the potential values $W(P)$ and the assessment of their accuracy. Different approaches are being evaluated:

1) As national/regional experts provided the WG on the IHRS Realization with terrestrial gravity data around some IHRF sites, a direct computation of potential values (and their accuracy) is being performed. In this case, following experiments are being conducted:
   - Simulations about the distribution and quantity of gravity points needed around the IHRF stations,
   - Simulations about the variation of potential values with time; i.e., $\dot{W}(P)$,
   - Comparison of different mathematical formulations (least-squares collocation, FFT, radial basis functions, etc.).
2) Computation of potential values (and their accuracy) by national/regional experts responsible for the geoid modelling using their own data and methodologies.
3) Computation of potential values (and their accuracy) based on global gravity models of high-degree (like XGM2016, EIGEN-6C, EGM2008, etc.).
4) Recovering potential values from existing local quasi-geoid models.

The comparison of the results obtained from these different approaches will provide a basis to outline further steps; especially, the identification of detailed standards and conventions for the IHRS realization and the implementation of a roadmap based on the available geodetic data.

Closing remarks

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Further reading:

– Ihde J., Sánchez L., Barzaghi R., Drewes H., Foerste Ch., GruberT., Liebsch G., Marti U., Pail R., Sideris M.: **Definition and proposed realization of the International Height Reference System (IHRS)**. Surveys in Geophysics 38(3), 549-570, 10.1007/s10712-017-9409-3, 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: **Poster EGU2017-17136, today, 17:30-19:00, Hall X3**

– http://ihrs.dgfi.tum.de, www.ggosdays.com/en/focus-areas/unified-height-system/

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