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Strategy for the Realization of the International Height Reference System (IHRS)

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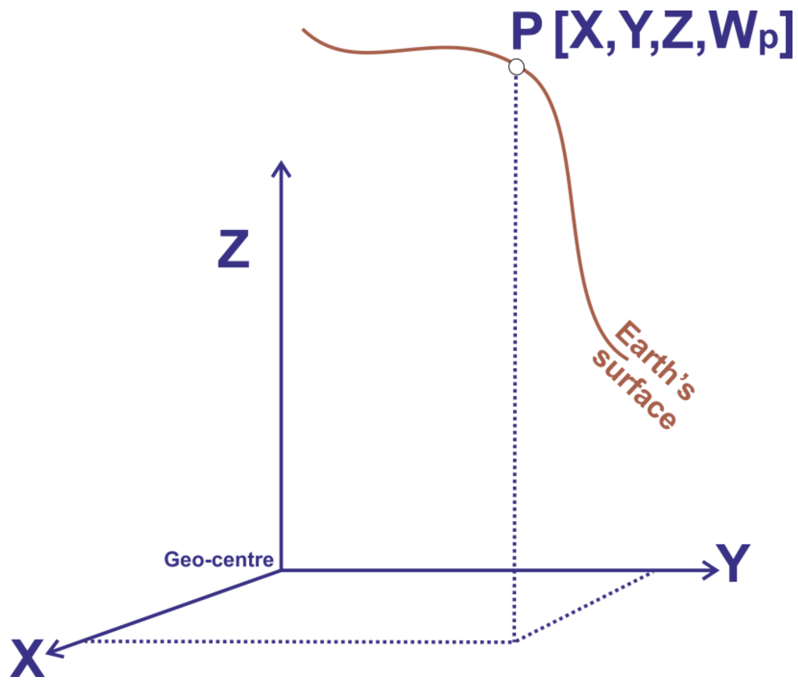
International Height Reference System (IHRS)
IAG Resolution No. 1, Prague, July 2015

1) Geopotential reference system co-rotating with the Earth.

2) Coordinates of points attached to the solid surface of the Earth are given by

   - geopotential values $W(\mathbf{X})$ (and their changes with time $\dot{W}$), and

   - geocentric Cartesian coordinates $\mathbf{X}$ (and their changes with time $\dot{\mathbf{X}}$) in the ITRS.



3) Parameters, observations and data in mean-tide system/mean crust (to support the combination of oceanic and continental realizations).

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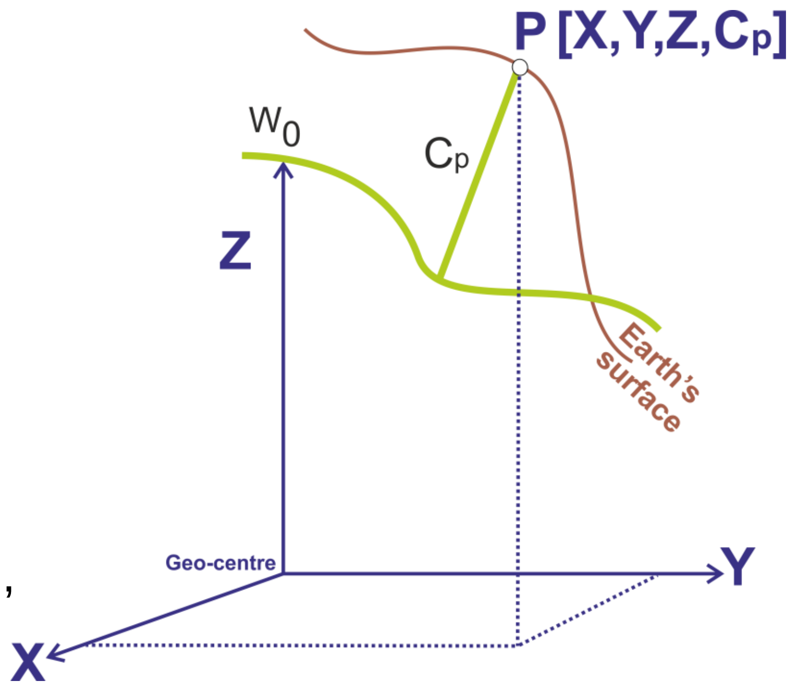
For practical purposes, potential values $W(\mathbf{X})$ are to be transformed into potential differences with respect to a conventional W_0 value:

- $-\Delta W = C_P = W_0 - W_P$
- $C_p(t_0,\mathbf{X}); dC_p(\mathbf{X})/dt$
- conventional fixed value
  $W_0 = const. = 62\,636\,853.4 \text{ m}^2\text{s}^{-2}$
- geopotential numbers are preferred, as they may be converted to any type of physical heights.



Remark:

- 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.

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.

Requirements on W_P

The GGOS terms of reference do not include physical heights or potential values but state:

- Accuracy of the geoid (geometry of any equipotential surface)
  - Static geoid: 1 mm, spatial resolution: 10 km.
  - Time-dependent geoid: 1 mm, spatial resolution of 50 km, temporal resolution of 10 days
- Accuracy of the ITRF coordinates:
  - Positions: 1 mm horizontal, 3 mm vertical.
  - Velocities: 0.1 mm/a horizontal, 0.3 mm/a vertical.
- Inferred (expected) accuracy for W_P:
  - Positions: ~ $3\times10^{-2}\ m^2s^{-2}$ (about 3 mm).
  - Velocities: ~ $3\times10^{-3}\ m^2s^{-2}$ (about 0.3 mm/a).

The GGOS requirements are very ambitious. More realistic target values may be around

- Positions: $10 \times 10^{-2}\ m^2s^{-2}$ (about 1 cm).
- Velocities: $10 \times 10^{-3}\ m^2s^{-2}$ (about 1 mm/a).

Possibilities for the determination of W_P

- Levelling + Gravimetry:

$$W_P = W_0 - C_P; \quad C_P = \int_0^P g\,dn$$

- High-resolution gravity field modelling:

$$W_P = W_{P,satellite-only} + W_{P,high-resolution}$$

Satellite-only gravity field modelling:
Satellite orbits and gradiometry analysis
Satellite tracking from ground stations (SLR)
Satellite-to-satellite tracking (CHAMP, GRACE)
Satellite gravity gradiometry (GOCE)
Satellite altimetry (oceans only)

+

High-resolution gravity field modelling:
Stokes or Molodensky approach
Satellite altimetry (oceans only)
Gravimetry, astro-geodetic methods, levelling,etc.
Terrain effects

- Combined (high-resolution) gravity field models:

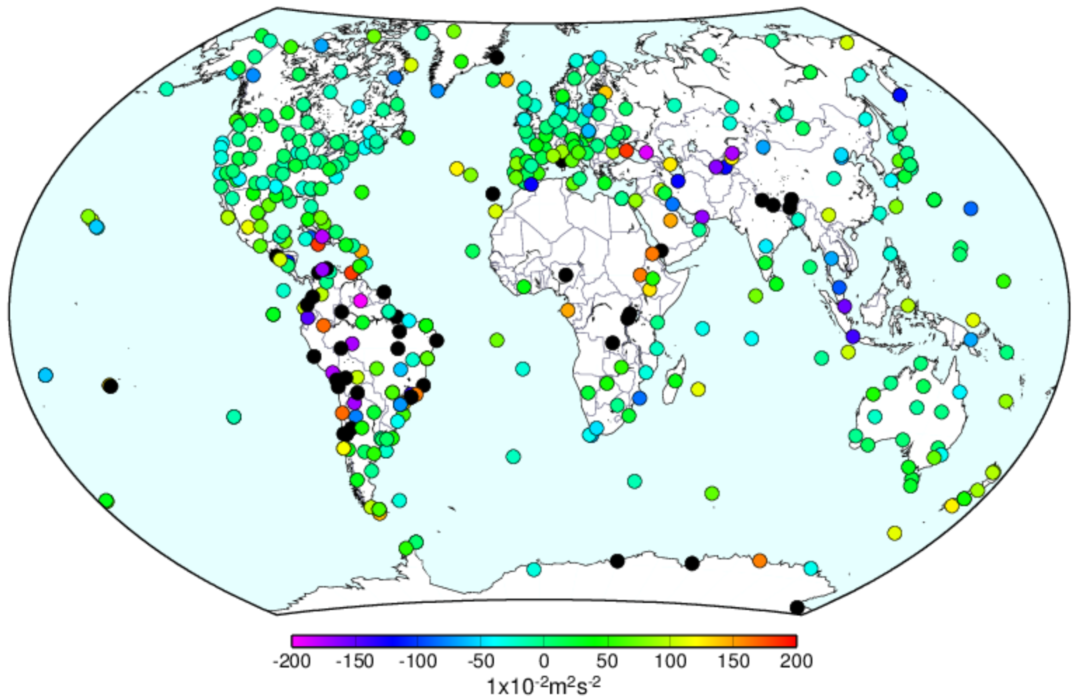
$$W_P = f\left(X_P, GGM\right)$$

W_P from combined (high-resolution) GGMs

- This method is not (yet) suitable.
- Main drawback: incomplete gravity signal due to lack of data and restricted accessibility to terrestrial gravity data.

Example:

- Global network with known **X** coordinates
- Differences between the W_P values derived from EGM2008 (Pavlis et al. 2008) and EIGEN6C4 (Förste et al. 2014), both at n=2190
- Differences larger than $\pm 200 \times 10^{-2}\ m^2s^{-2}$ (~ ± 2 m)
- Desired accuracy for W_P: $\pm 10 \times 10^{-2}\ m^2s^{-2}$

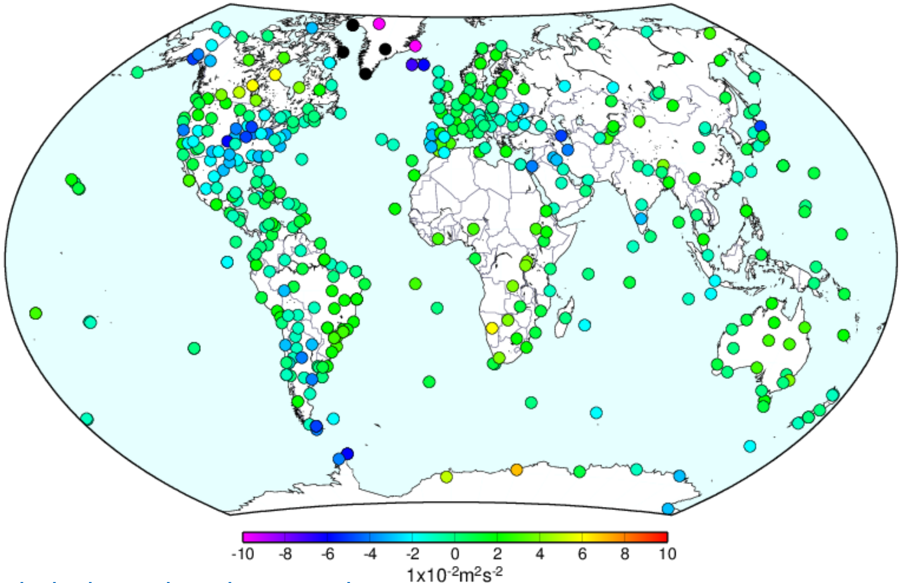


W_P from high-resolution gravity field modelling

- Accuracy: some cm up to dm.
- Advantages:
  - High-precise satellite-only GGMs (SLR+GRACE+GOCE).
  - In some cases, terrestrial gravity data is only available at (for) national agencies (but not for global geoid modelling).
- Main drawbacks:
  - Lack of terrestrial gravity data (in sparsely surveyed regions).
  - Different standards applied in the local gravity field modelling.
  - Discrepancies between gravity field observables derived from the satellite-only GGMs.

Example:

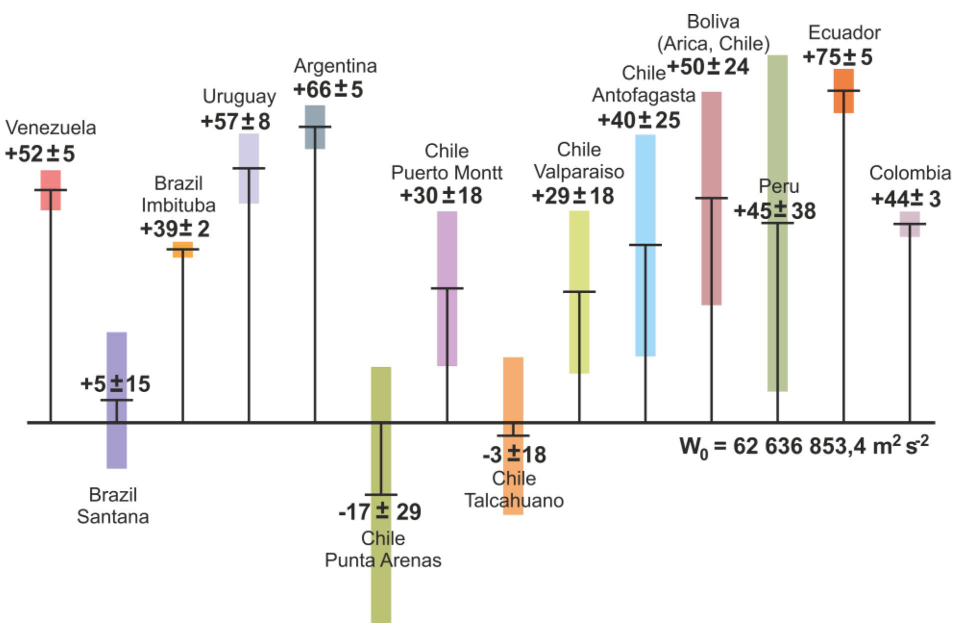
- Differences between the W_P values derived from EIGEN-6S4 (Förste et al. 2016) and GO_CONS DIR_R5 (Bruinsma et al. 2013)
- Differences -21×10^{-2} to $7 \times 10^{-2}\ m^2s^{-2}$
- Desired accuracy for W_P: $\pm 10 \times 10^{-2}\ m^2s^{-2}$



W_P from Levelling + Gravimetry $\quad W_P = \left(W_0^{local} + \delta W\right) - C_P;$

- *Relative* accuracy: mm, *absolute* accuracy: up to ±2 m.
- Advantage: basis for the height determination during the last 150 years.
- Drawback: local vertical datums, systematic errors in levelling, omission of time-dependent changes, etc.
- Requirement: vertical datum unification within the IHRF: determination of the potential differences between the global vertical datum W_0 and the local ones W_{0i}.
- Expected accuracy of the vertical datum parameters: cm in well-surveyed regions, dm in sparsely surveyed regions, extreme cases up to 1 m.

Example: vertical datum parameters (in cm) for the South American height systems w.r.t. the IHRS W_0 value.



Present challenges:

- Establishment of a vertical reference network as the main component of the International Height Reference Frame (IHRF).
- Determination of potential values W_P at the reference network stations as accurate as possible.

Strategy for the IHRS realization (1)

1) To select a global reference network for the implementation of the IHRF (includes site specifications/characteristics)

- Hierarchy:
  - A global network → worldwide distribution
  - Regional and national densifications → local accessibility

- Collocated with:
  - fundamental geodetic observatories → connection between position vectors $\mathbf{X}$, gravity potential W, reference clocks, and absolute gravity $\mathbf{g}$;
  - continuously operating reference stations → to detect deformations of the reference frame;
  - geometrical reference stations of different densification levels → to allow access to the IHRF also in remote areas;
  - 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).

The IHRF is understood to be a component of the Global Geodetic Reference Frame (UN GGRF resolution 2015).

Strategy for the IHRS realization (2)

2) Compilation/generation of standards and conventions

- Identification of required standards and conventions for the IHRS realization:
  - Solid Earth/ocean/atmospheric tides,
  - Ocean/atmospheric/hydrological loading,
  - Plate tectonic motion, crustal deformation,
  - Precession, nutation,
  - LOD, polar motion,
  - Post-glacial rebound,
  - Is the precision of the reduction models sufficient?
- Handling of tide systems in vertical coordinates
  - Conventional conversion formulae between tide systems for consistent treatment.
- Modelling of non-linear motions
  - Conventional physical models
  - Can we assume dh/dt = dH/dt?
- Harmonization of analysis strategies, models, and products related to the Earth's geometry and gravity field (consistency between X_P and W_P).

Strategy for the IHRS realization (3)

3) Estimation of potential values
   - Strategies for the determination of W and $\dot{W}$ with high precision in accordance with the adopted standards and conventions
   - Specifications for procedures and computations
   - Molodensky approach to avoid disparities between orthometric hypothesis?
   - Fixed GBVP instead of scalar-free GBVP?
   - Which observational data are required?

4) Densification of the global network
   - by integration of the existing local height systems into the IHRF (vertical datum unification).

5) Maintenance and availability of the IHRF
   - Regular updates of the IHRF*yy* to take account for:
     - new stations;
     - coordinate changes with time $\dot{\mathbf{X}}$, $\dot{W}$;
     - improvements in the estimation of $\mathbf{X}$ and W (more observations, better standards, better models, better computation algorithms, etc.)
   - Geodetic products associated to the IHRF (description and metadata).
   - Organizational and operational infrastructure to ensure the IHRF sustainability.

On-going activities

Coordinated work between:

- GGOS Focus Area 1
- International Gravity Field Service (IGFS)
- IAG Commission 2 (Gravity field)
- IAG Commission 1 (Reference Frames)
- IAG Inter-commission Committee on Theory (ICCT)
- Regional/national vertical reference systems

1) Selection of core stations for the IHRF
   - in agreement with the GGOS Bureau for Networks and Observations, main requirement are gravity data around (~250 km) core stations for high-resolution gravity field modelling.

2) Identification of required standards and conventions
   - in agreement with the GGOS Bureau for Products and Standards, main requirement is the harmonization with the IERS conventions.

3) Estimation of potential values
   - Evaluation of different methodologies and compilation of guidelines for high-resolution gravity field modelling.

4) Vertical datum unification
   - Roadmap for the integration of the existing local height systems into the IHRF.

Working Group on the Strategy for the Realization of the International Height Reference System (IHRS), more information at **http://ihrs.dgfi.tum.de**