Towards a Vertical Datum Standardisation

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on behalf of

Vertical Datum Standardisation

Joint Working Group JWG 0.1.1 of

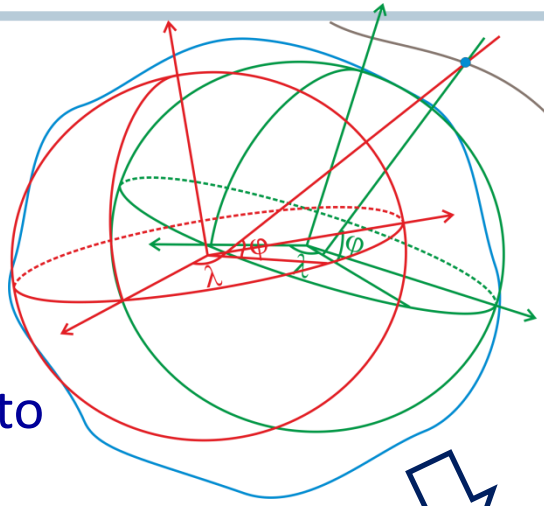
GGOS Theme 1: Unified Global Height System
IAG Commission 1: Reference Frames
IAG Commission 2: Gravity Field
International Gravity Field Service

Introduction

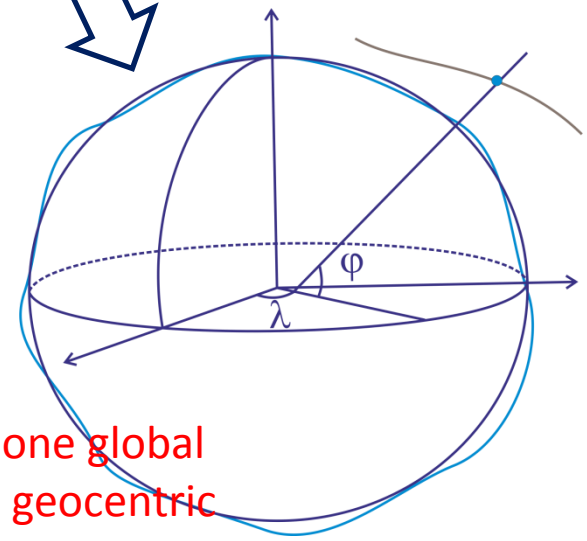
Studying (understanding and modelling) global change requires geodetic reference frames with

- Order of **accuracy higher** than the magnitude of the effects we want to study;
- **Consistency** and **reliability worldwide**;
- **Long-term stability**.

Definition, realisation, maintenance and **use** of the ITRS/ITRF guarantees a worldwide unified geometric reference frame with reliability in the mm-level.



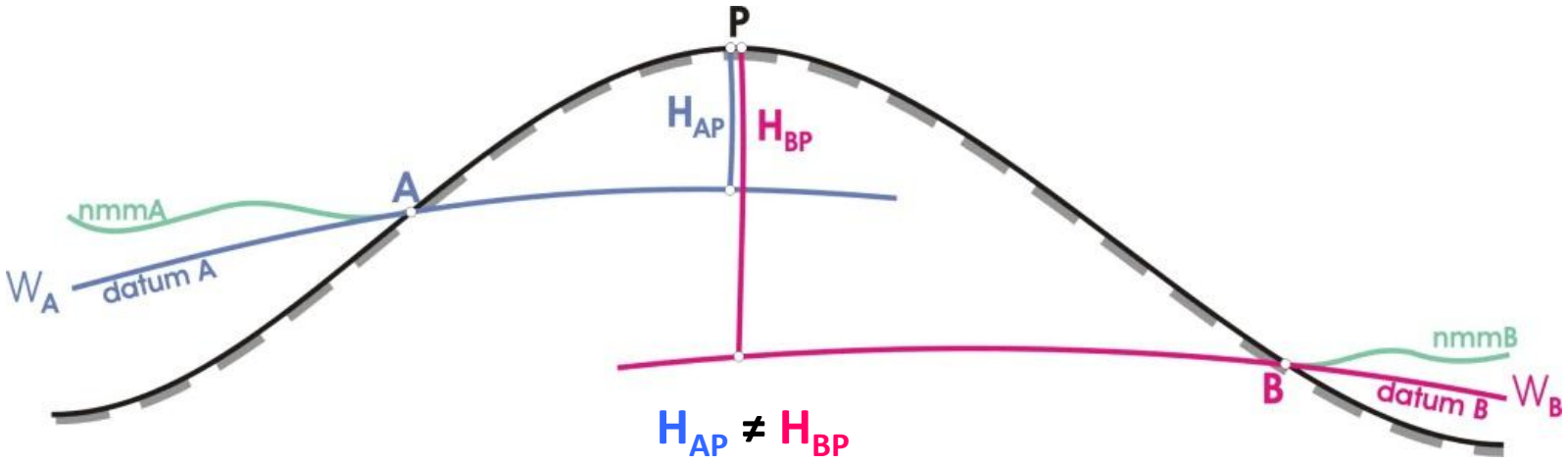
Before: many individual (local) horizontal reference systems



Today: one global unified geocentric reference system

Physical height systems

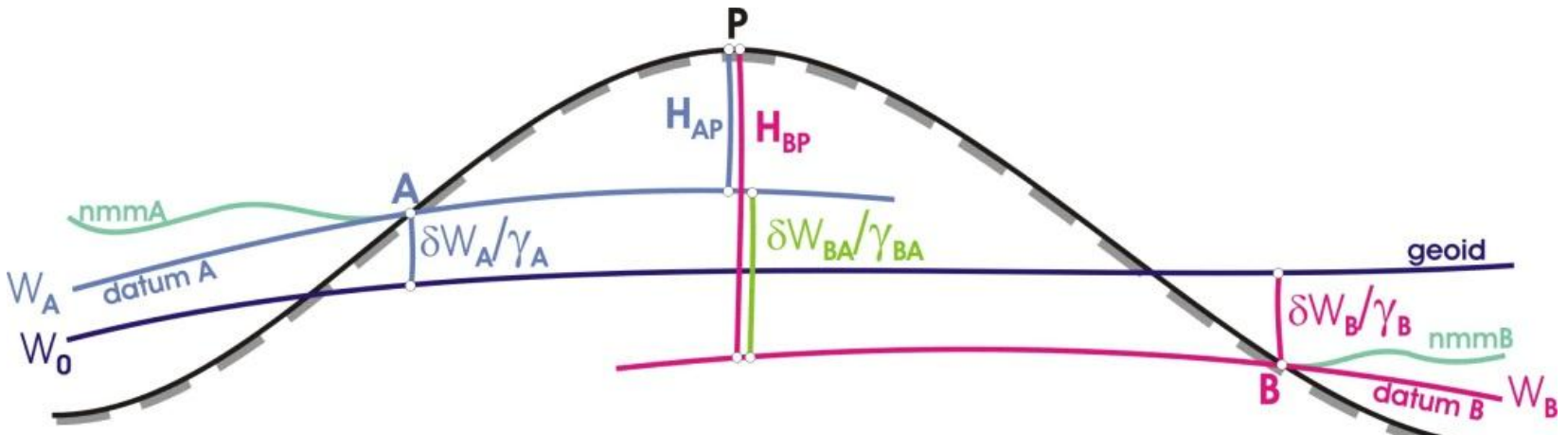
Today



- As many reference levels as reference tide gauges;
- Different types of heights (normal, normal-orthometric, orthometric …);
- Omission of height variations with time;
- Inconsistencies of many [dm] at borders between datum zones;
- Low reliable comparison of height-dependent observables (gravity anomalies, (quasi-)geoid heights, etc.);
- Imprecise [cm … dm] combination with the geometric reference [h-H-N≠0]

Unified reference level W_0

Desired



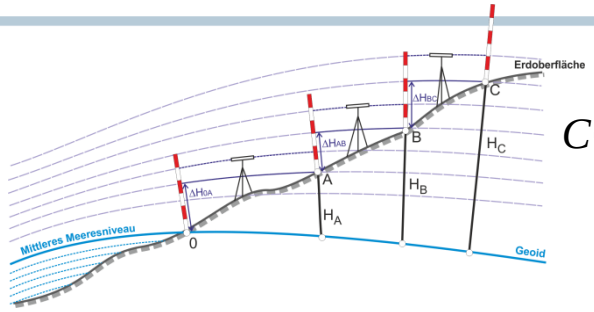
$$H_{AP} + (\delta W_A/\gamma_P) = H_{BP} + (\delta W_B/\gamma_P)$$

- One global unified reference level (W_0 or global geoid);
- All existing geopotential numbers (physical heights) referring to one and the same global level;
- Precise combination with geometric heights and geoid models of high resolution.

Consistent height determination

Today

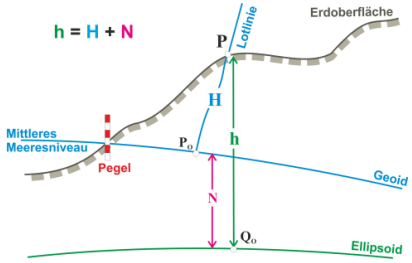
Levelling in combination with gravity reductions



$$C(g,dn) = W_0 - W_P = \int_0^P g\,\delta n \cong \sum_0^P g\,dn$$

Desired

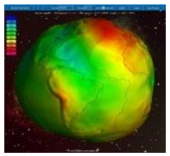
Disturbing potential in combination with a reference ellipsoid



$$C(U_0,T) = -(U_0 - W_0) + \bar{\gamma}(\varphi)h - T(\varphi,\lambda,h)$$

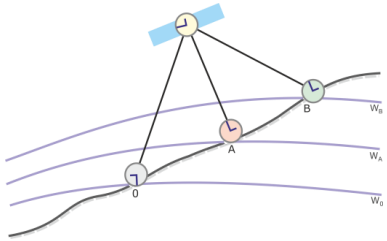
In the future

Global gravity field models in combination with ITRS/ITRF coordinates



$$C(\bar{C}_{nm},\bar{S}_{nm}) = W_0 - [V(r,\theta,\lambda) + Z(r,\theta)]$$

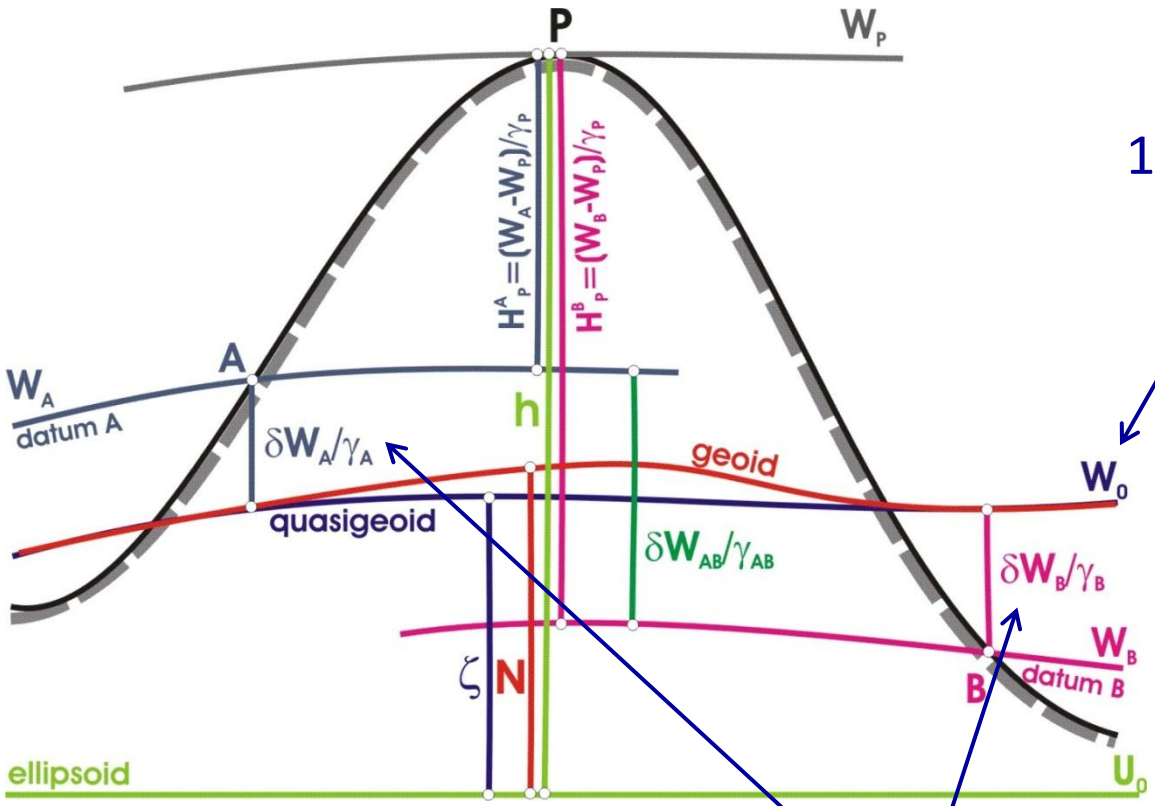
Comparison of clock frequencies of high-precision



$$C(f) = c^2\left(\frac{f - f_0}{f_0}\right)$$

GOAL: $C(g,dn) \approx C(U_0,T) \approx C(\bar{C}_{nm},\bar{S}_{nm}) \approx C(f)$ **in cm-level (better in mm-level), globally.**

Vertical datum standardisation



1. Definition and realisation of a global W_0-value

2. Connection of the local reference levels with the global W_0

Empirical estimation of W_0

In the 1990s and before: $W_0 = U_0$; $U_0 = U(a, f, \omega, GM)$; $U_0 = U(a, J_2, \omega, GM)$

Late 1990s and 2000s

$$\int_S \Xi^2 ds = \min; \quad \Xi = \frac{W_0 - W_j}{\gamma_j}$$

Ξ : Sea surface topography

- Points *j* with coordinates from satellite altimetry describe the mean sea surface;
- Potential values *W* are derived from a global gravity model

Today: solution of the fixed geodetic boundary problem

$$\nabla \delta W(\mathbf{X}) = 0 \qquad \mathbf{X} \in \Omega$$
$$\delta W(\mathbf{X}) \to 0 \qquad \mathbf{X} \to \infty$$
$$\delta g(\mathbf{X}) = g(\mathbf{X}) - \gamma(\mathbf{X}) \qquad \mathbf{X} \in \Sigma$$

Boundary surface Σ known;
Unknown: disturbing potential **δW**
Boundary condition: gravity disturbances **δg**
Regularisation: **δW** vanishes at infinity

X ↔ sea surface from satellite altimetry, continental surfaces from SMRT
g(**X**) ↔ global gravity model
γ(**X**), U_0 ↔ GRS80

Some estimations of W_0

W_0 [m^2/s^2]	Comments
62 636 860,850	GRS80, Moritz (2000)
856,88	Best fitting ellipsoid for the mean sea surface from T/P, Rapp (1995)
856,2	Mean sea surface: **T/P** (1993-2001), Global gravity model: **EGM96**, Burša et al. (2002)
854,6	Mean sea surface: **CLS01** (φ = 80°N/S), Global gravity model: **EIGEN-GC03C** Reference epoch: 2000.0, Sánchez (2009)
854,3	Mean sea surface: **CLS01** (φ = 80°N/S), Global gravity model: **EIGEN-GC03C** Reference epoch: 2000.0, Čunderlík and Mikula (2009)
854,4	Mean sea surface: **DNSC08** (φ = 80°N/S), Global gravity model: **EGM2008**, Reference epoch: 2005.0, Dayoub et al. (2012)
854,6	Mean sea surface: **T/P, J1** (1993-2009), Global gravity model: **EGM2008**, Burša et al. (2011)

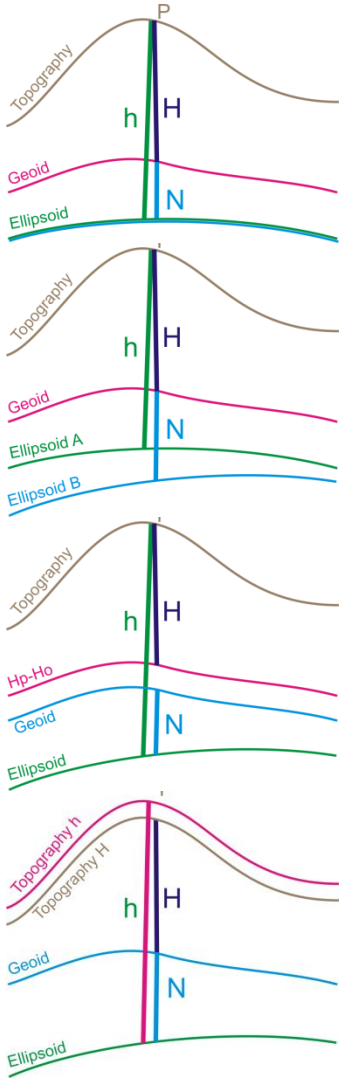
W_0 = 62 636 856,0 included in AGU and IERS Conventions from Burša et al. (2002),
It differs about ~ 4 x 10^{-8} (~ 3 m^2s^{-2} , ~ 30 cm) from recent computations.

Vertical datum unification

Basic approach: $h - H - N = \frac{\delta W}{\gamma}$

But:

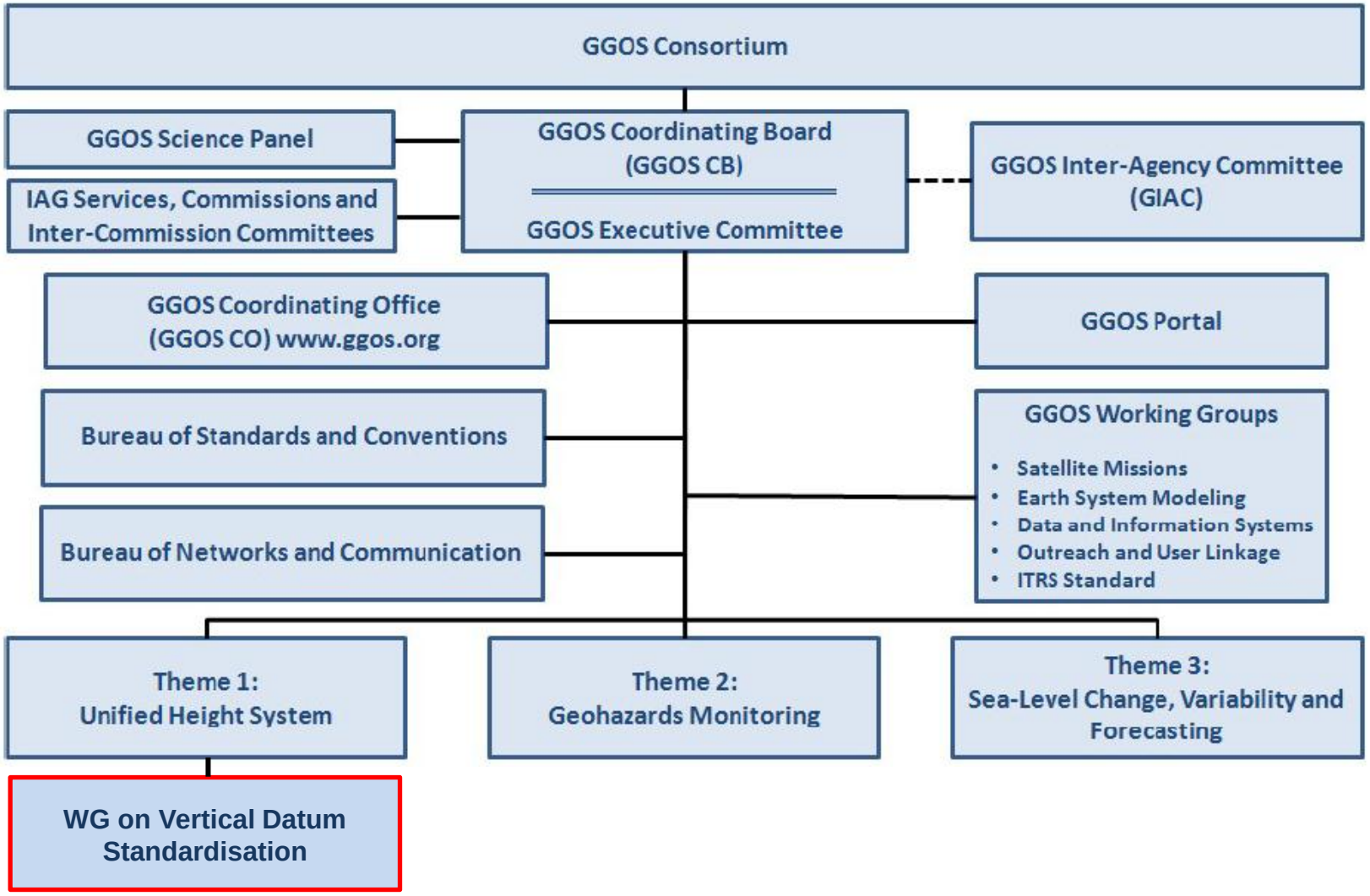
- Usage of different ellipsoid parameters
- Heights (h, H, N) in different tide systems
- Mixture of orthometric hypothesis (heights and geoids)
- Omission of levelling error accumulation
- Different reference epochs (unknown dH/dt)
- Different reductions (Earth-, ocean-, atmospheric tides, ocean and atmospheric loading, post-glacial rebound, etc.)
- Not appropriate error propagation analysis in the combination of satellite and terrestrial gravity data.



Remarks

- The **ITRS/ITRF** provides a highly precise **geometrical reference frame** (consistent in sub-cm level worldwide);
- An equivalent **highly precise physical reference frame is missing**, it must be given by realising a Global Unified Height System;
- The **uniqueness**, **reliability** and **repeatability** of the global reference level W_0 (or global geoid) can be guaranteed by introducing **specific conventions** only. On the contrary, there will exist as many height systems as W_0 computations.
- It is necessary to implement (and to follow) **standards**, **conventions** and the "**step by step**" for the usage of h-H-N in the vertical datum unification. Otherwise, there is no guarantee that only one and the same reference level is introduced as a global vertical datum anywhere and everywhere (GNSS-GGM is not sufficient).

A Unified Height System: a GGOS challenge



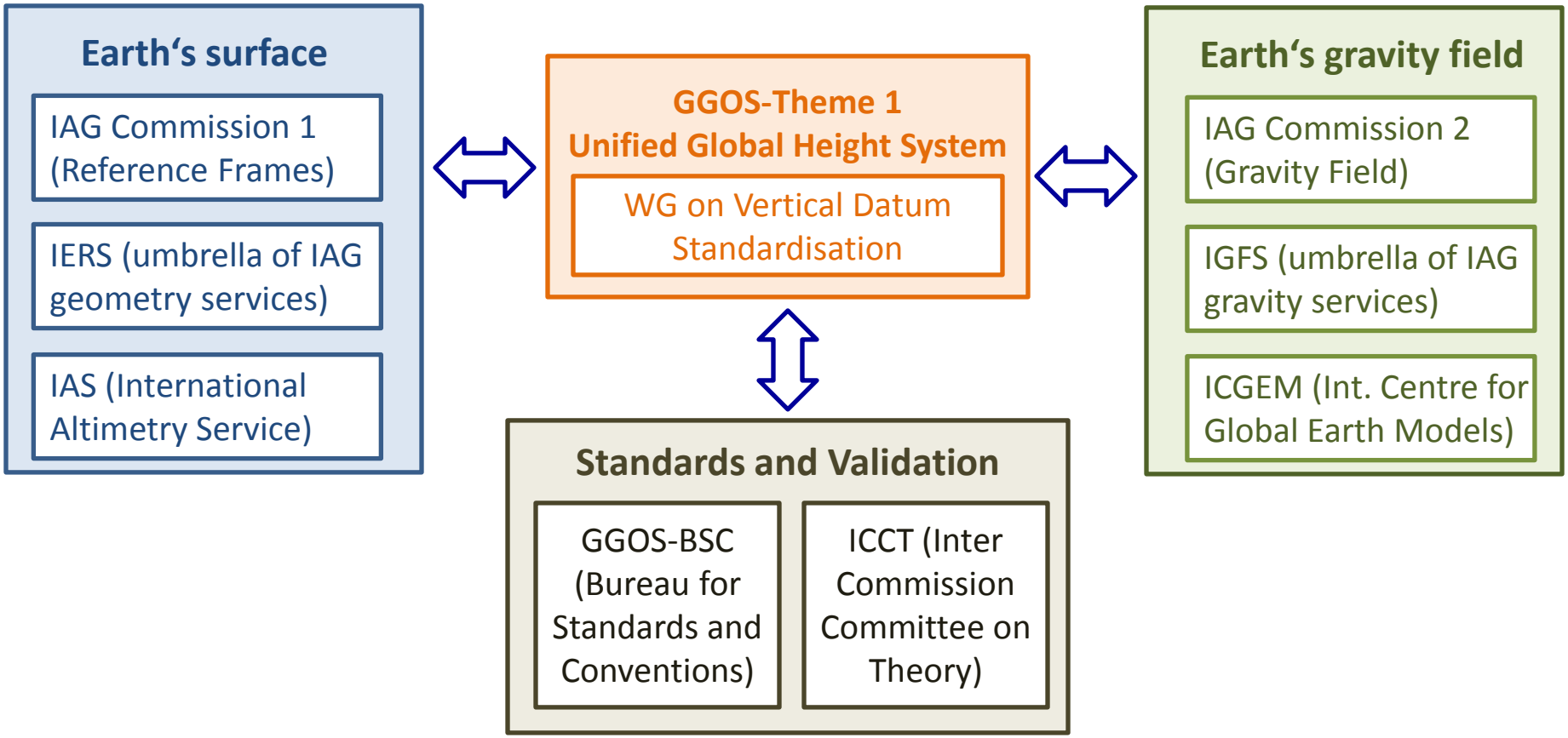
WG on Vertical Datum Standardization

- Initiated during the IUGG General Assembly in Melbourne, July 2011
- Approved by the IAG Executive Committee in December 2012
- Term: 2011 – 2015

Objectives

- To bring together all teams working on the computation of W_0 to elaborate an inventory describing individual methodologies, conventions, standards, and models presently applied;
- To implement a new W_0 computation following individual (own) methodologies, but applying the same input geodetic models;
- To make a proposal for a formal IAG/GGOS convention about W_0 supported by a document containing the detailed computation of the recommended value.
- To provide a standard about the usage of W_0 in the vertical datum unification describing a appropriate strategy to connect (unify, transform) any local height system with the global W_0 reference level.

Interaction with other IAG/GGOS components



(initial) Members and on-going activities

L. Sánchez (Germany), chair	⇨	W_0-computation based on fixed-GBVP, analytical solution
R. Cunderlík (Slovakia) Z. Faskova (Slovakia) K. Mikula (Slovakia)	⇨	W_0-computation based on fixed-GBVP, Boundary Element Method (BEM)
N. Dayoub (Syria) P. Moore (United Kingdom)	⇨	W_0-computation based on averaging W-values from a GGM on points describing the sea surface (MSS) W_0-computation based on a reference ellipsoid ($W_0 = U_0$)
Z. Šima (Czech Republic) V. Vatrt (Czech Republic) M. Vojtiskova (Czech Republic)	⇨	W_0-computation based on averaging W-values from a GGM on points describing the sea surface (MSS)
J. Huang (Canada) D. Roman (USA) Y. Wang (USA) J. Agren (Sweden)	⇨	Regional realisation of a global W_0

Further comments

- The different teams computing W_0 are using the same input data, but their own methodology.
- Since all the computations are delivering very close results, we can concentrate now on standards and conventions for a formal recommendation on W_0.
- We want to evaluate:
  - The combination of a “geodetic” sea surface model and an “oceanographic” DOT-model to reproduce a sea surface closer to an equipotential surface (geoid);
  - The integration of polar regions on the Earth’s surface representation;
  - Differences between W_0 values obtained from a long-term mean sea surface model and yearly mean sea surface models;
  - A formal procedure for the error propagation analysis .

First concrete results will be presented during the next International Symposium on Gravity, Geoid and Height Systems **GGHS 2012, Venice, Italy**