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

SIRGAS annual meeting 2012. Concepción, Chile. October 31, 2012

WG on Vertical Datum Standardisation

A common initiative of

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

Initial members

L. Sánchez (Germany), chair

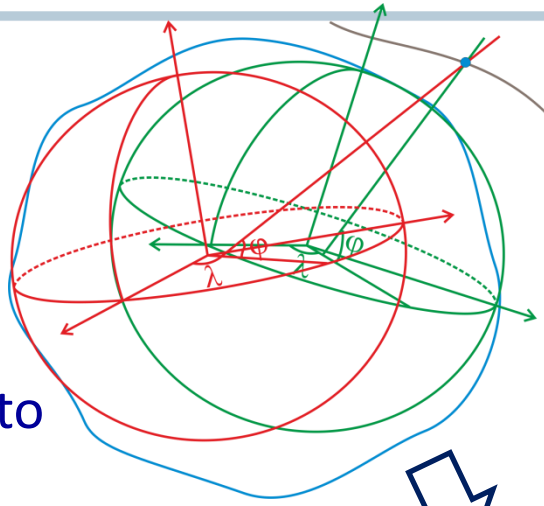
R. Čunderlík (Slovakia)
Z. Faskova (Slovakia)
K. Mikula (Slovakia)
N. Dayoub (Syria)
P. Moore (United Kingdom)
Z. Šima (Czech Republic)
V. Vatrt (Czech Republic)
M. Vojtiskova (Czech Republic)
J. Huang (Canada)
D. Roman (USA)
Y. Wang (USA)
J. Ågren (Sweden)

Introduction

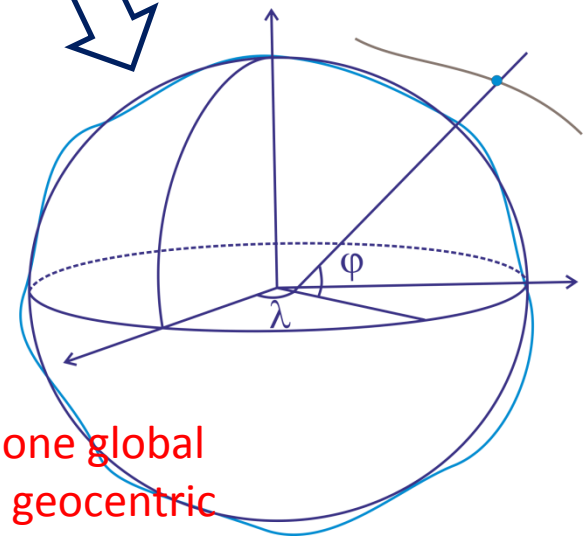
Studying (understanding and modelling) global change requires geodetic reference frames with

- 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

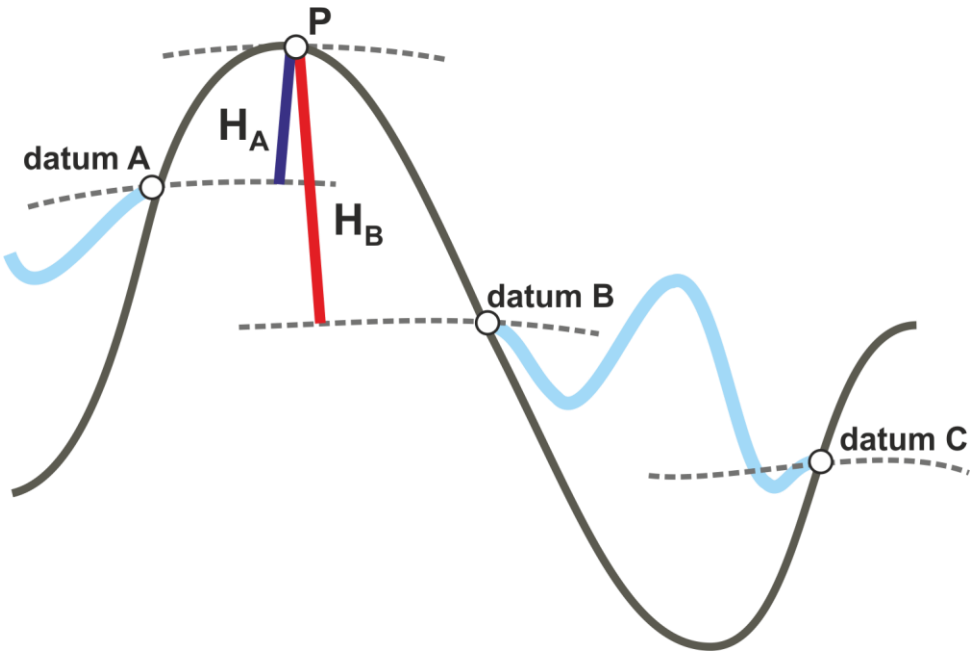


Today: one global unified geocentric reference system

Physical height systems

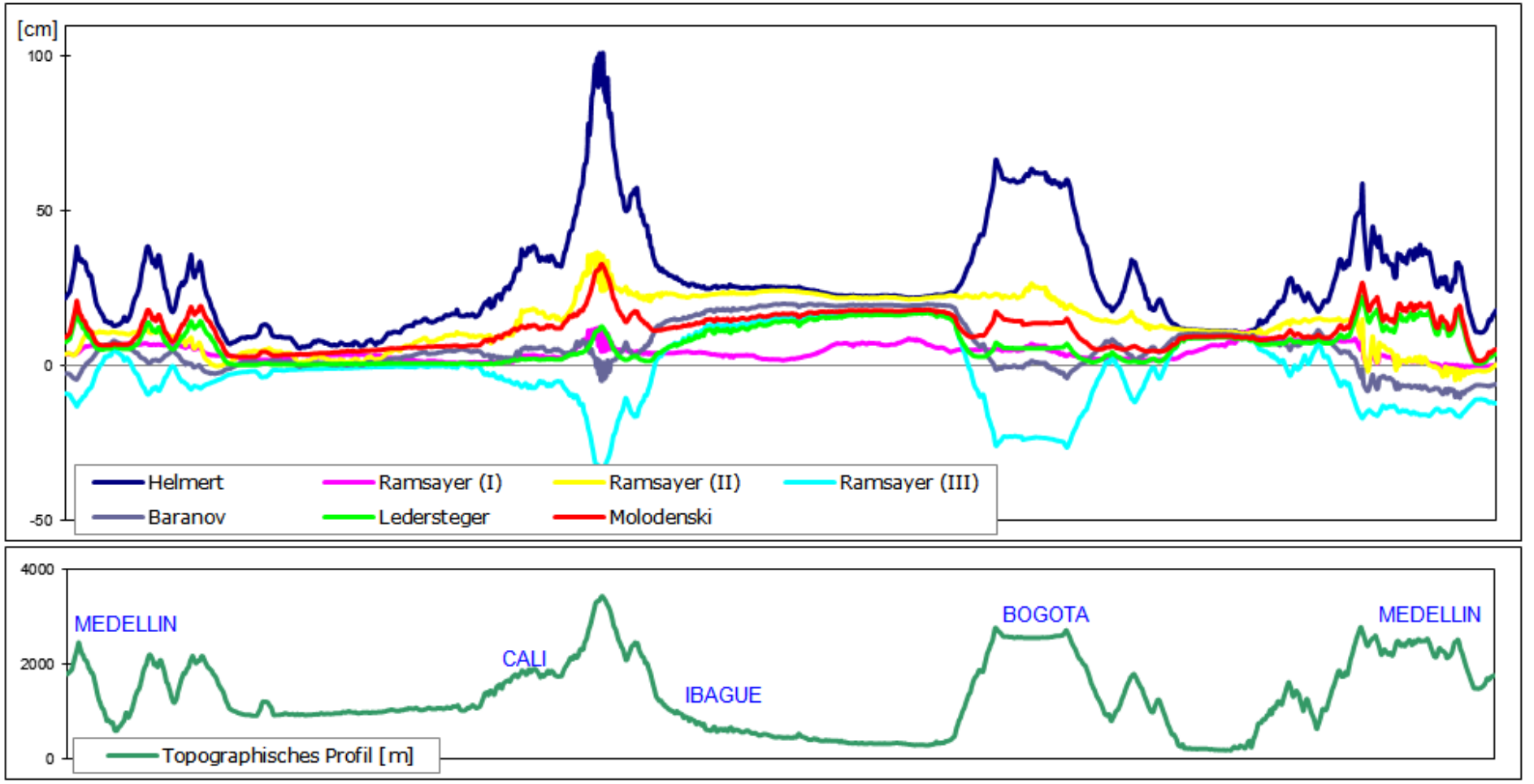
Today

- 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]

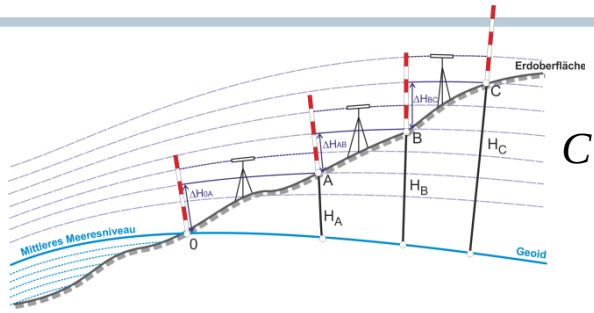
Physical heights in different systems



Consistent height determination

Today

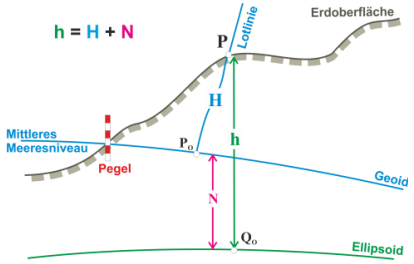
Levelling in combination with gravity reductions



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

Desired

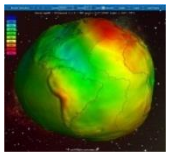
Disturbing potential in combination with a reference ellipsoid



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

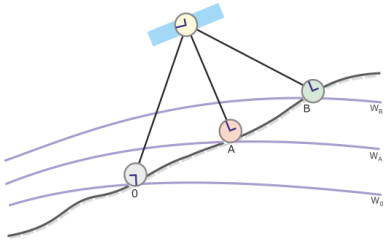
In the future

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



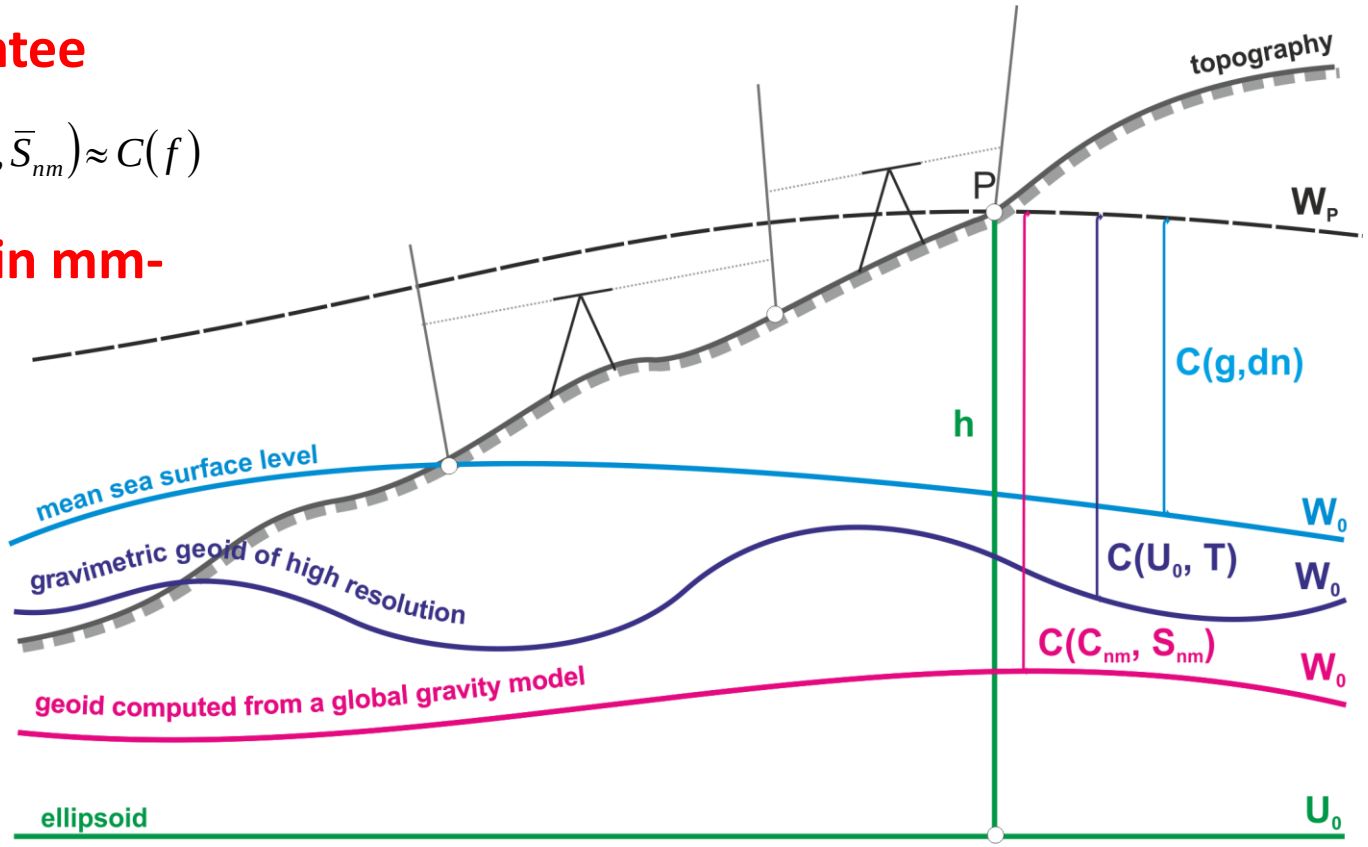
$$C(f) = c^2\left(\frac{f - f_0}{f_0}\right)$$

Reference level depending on input data?

How can we guarantee

$$C(g,dn) \approx C(U_0,T) \approx C(\bar{C}_{nm},\bar{S}_{nm}) \approx C(f)$$

in cm-level (better in mm-level), globally?

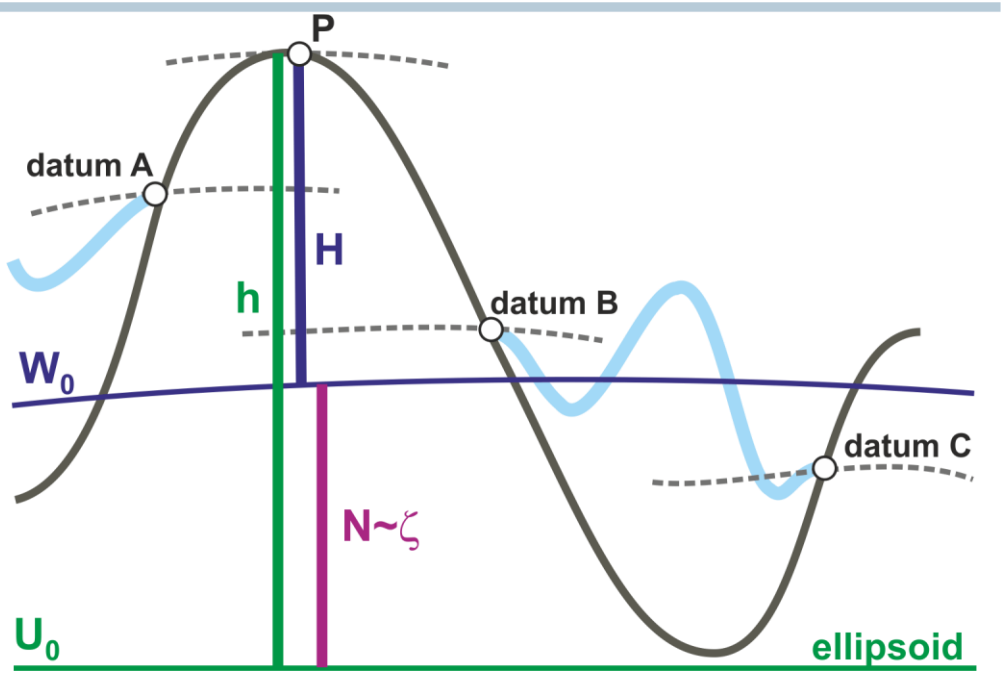


- The same W_0 value for all existing (regional) geoids?
- The same geoid with different (regional) W_0 values?
- Only one geoid with only one W_0 value?

Solution

A global vertical reference system

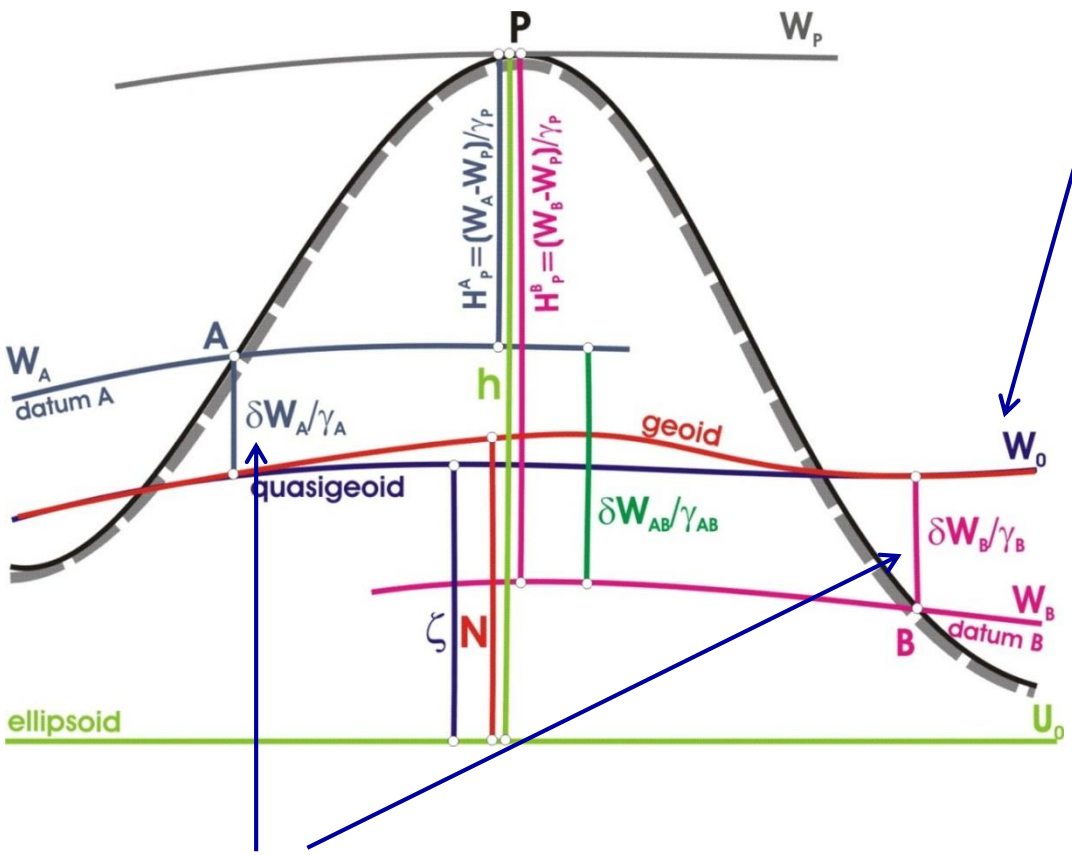
- To solve the **discrepancies** between the **existing height systems** and
- To support the **different** techniques for **height determination**.



Implicit characteristics:

- One reference level (W_0 or geoid) to be used globally;
- All existing geo-potential numbers (physical heights) referring to one and the same global level;
- Precise combination with geometric heights and geoid models of high resolution, i.e. h-H-N=0.

Strategy

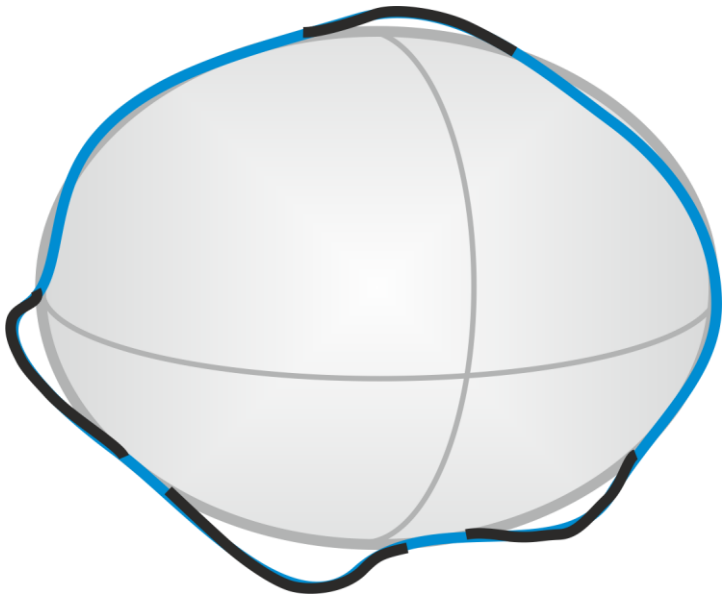


1. Selection (**Definition and realisation**) of a global reference level W_0
   - W_0 = potential of the geoid
   - Geoid = equipotential surface best fitting the global mean sea (Gauss definition)

2. **Connection** of the individual reference levels with the global W_0

Empirical estimation of W_0

In the 1990s and before:



- Determination of the parameters for a best fitting ellipsoid

$$U_0 = U(a, f, \omega, GM); \text{ or } U_0 = U(a, J_2, \omega, GM)$$

Then by definition:

$$W_0 \overset{!}{=} U_0$$

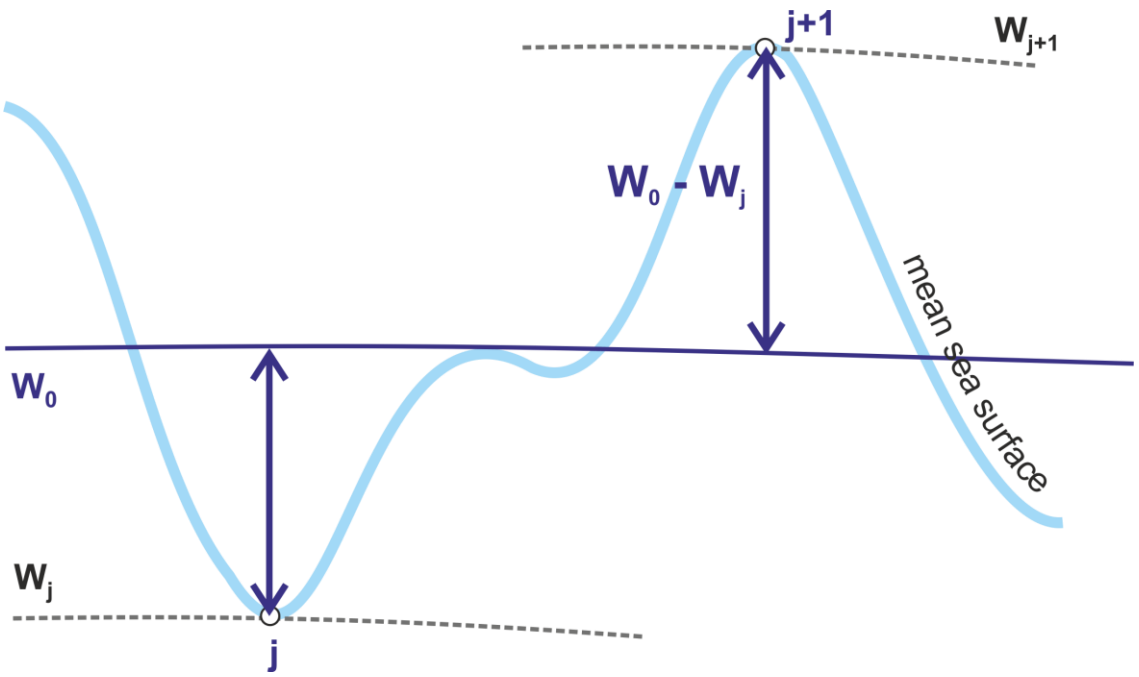
Empirical estimation of W_0

Late 1990s and 2000s:

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

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



Empirical estimation of W_0

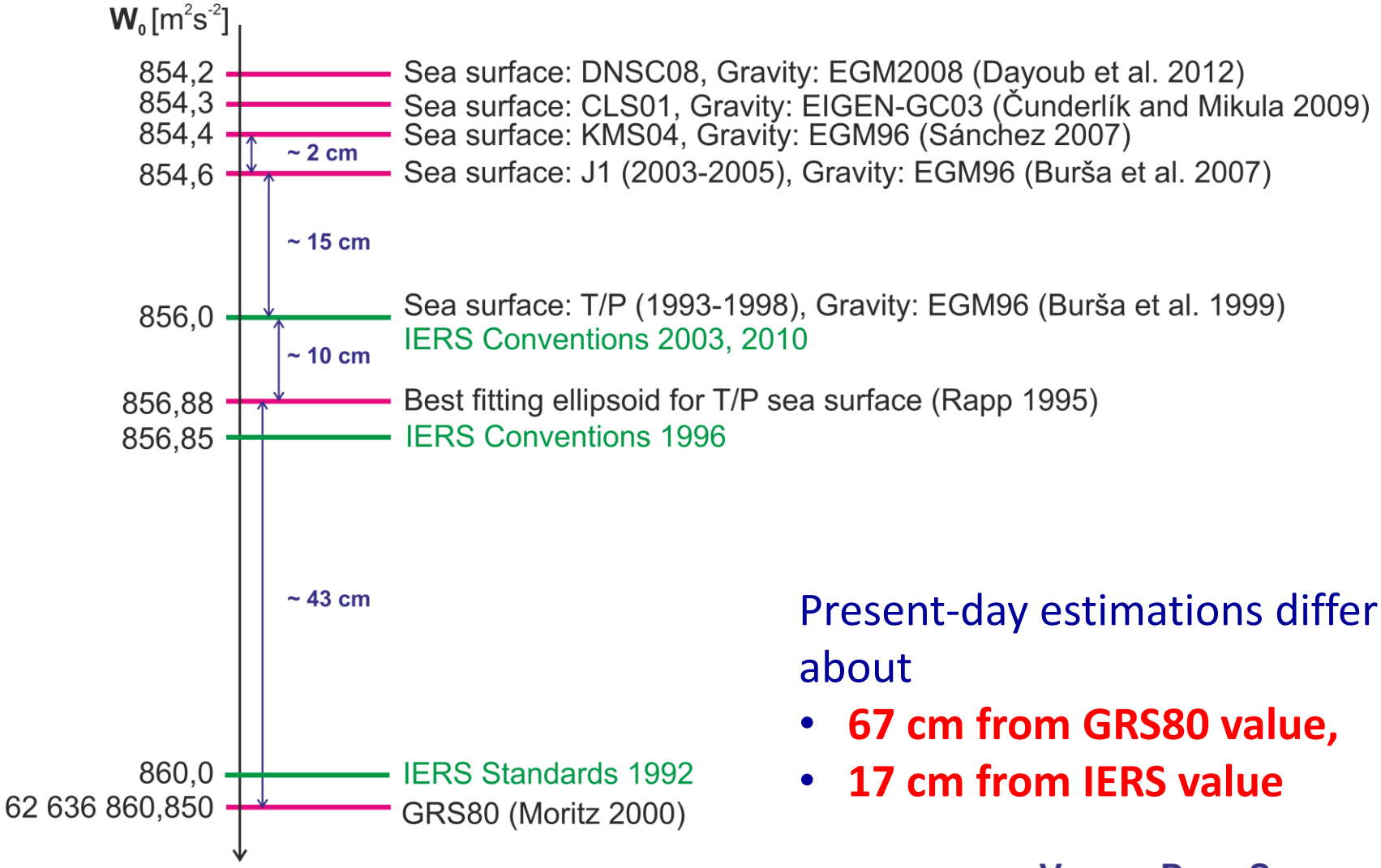
Today: solution of the fixed geodetic boundary value problem:

$$\nabla^2 \delta W(\mathbf{X}) = 0 \qquad \mathbf{X} \in \Omega$$
$$\delta W(\mathbf{X}) \to 0 \qquad \mathbf{X} \to \infty$$
$$\delta g(\mathbf{X}) = g(\mathbf{X}) - \gamma(\mathbf{X}) \qquad \mathbf{X} \in \Sigma$$

Boundary surface Σ known;
Unknown: disturbing potential δW ($=W_0-U_0$)
Boundary condition: gravity disturbances δg
Regularisation: δW vanishes at infinity

$\mathbf{X} \leftrightarrow$ sea surface from satellite altimetry, continental surfaces from SMRT
$g(\mathbf{X}) \leftrightarrow$ global gravity model
$\gamma(\mathbf{X})$, $U_0 \leftrightarrow$ GRS80

Some examples of W_0 estimates



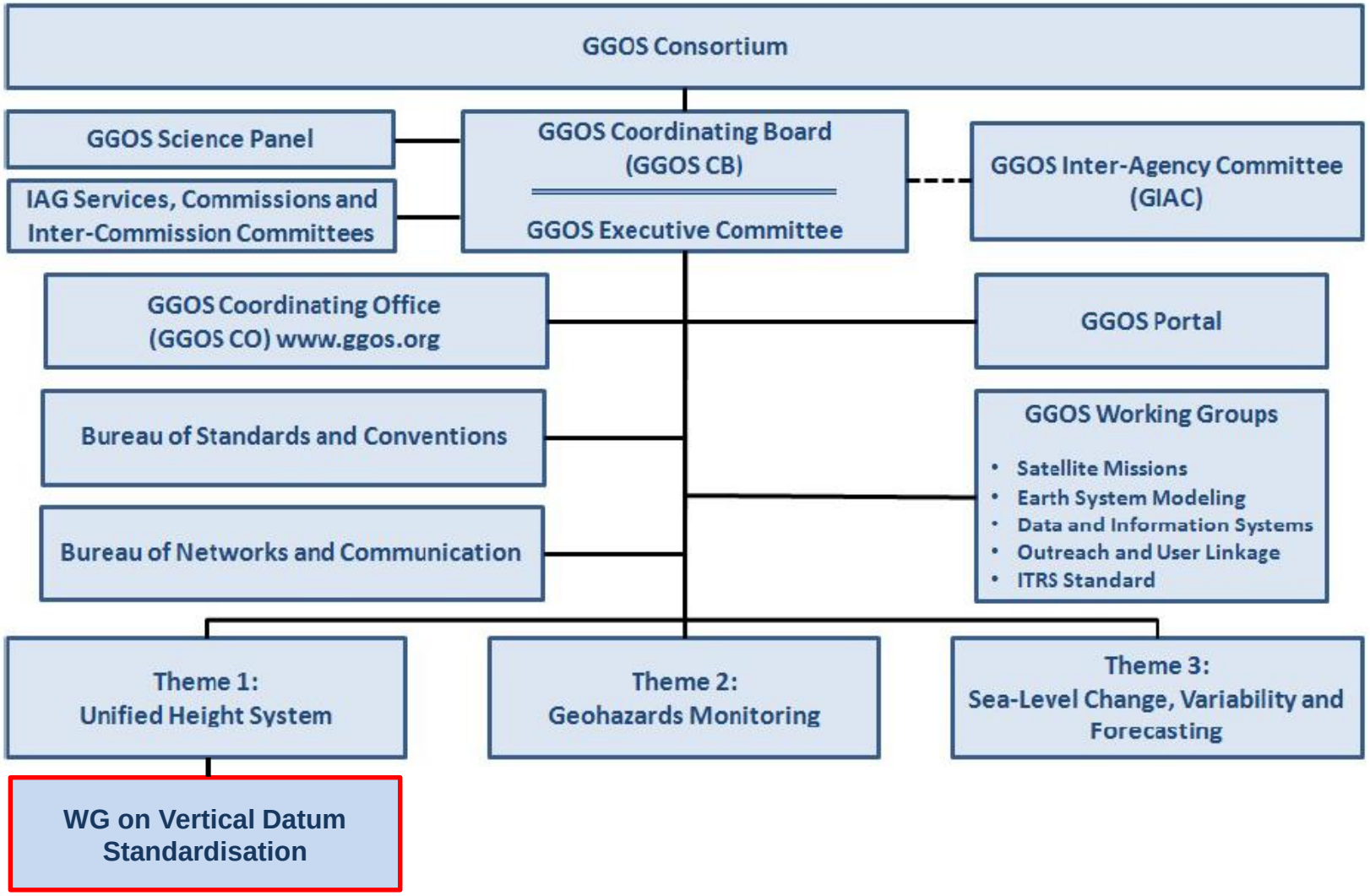
Present-day estimations differ about

- **67 cm from GRS80 value,**
- **17 cm from IERS value**

Remarks on W_0

- The reference level W_0 for potential differences **can arbitrarily be appointed**. However, to get the worldwide consistency desired within a global vertical reference system, the selected **W_0 value must be realisable** with **high-precision at any time and anywhere** around the world.
- Since W_0 represents only one quantity and it is not sufficient to estimate position and geometry of the equipotential surface it is defining; **the main problem to solve here is not the determination of the W_0 value *per se*, but its realisation**.
- Therefore, it is necessary to estimate it from **real observations** of the Earth's gravity field and surface.
- The **uniqueness**, **reliability** and **repeatability** of the global reference level W_0 (or global geoid) can only be guaranteed by introducing **specific conventions** (like any other reference system!). On the contrary, there will exist as many height systems as W_0 computations.

A Unified Height System: a GGOS challenge



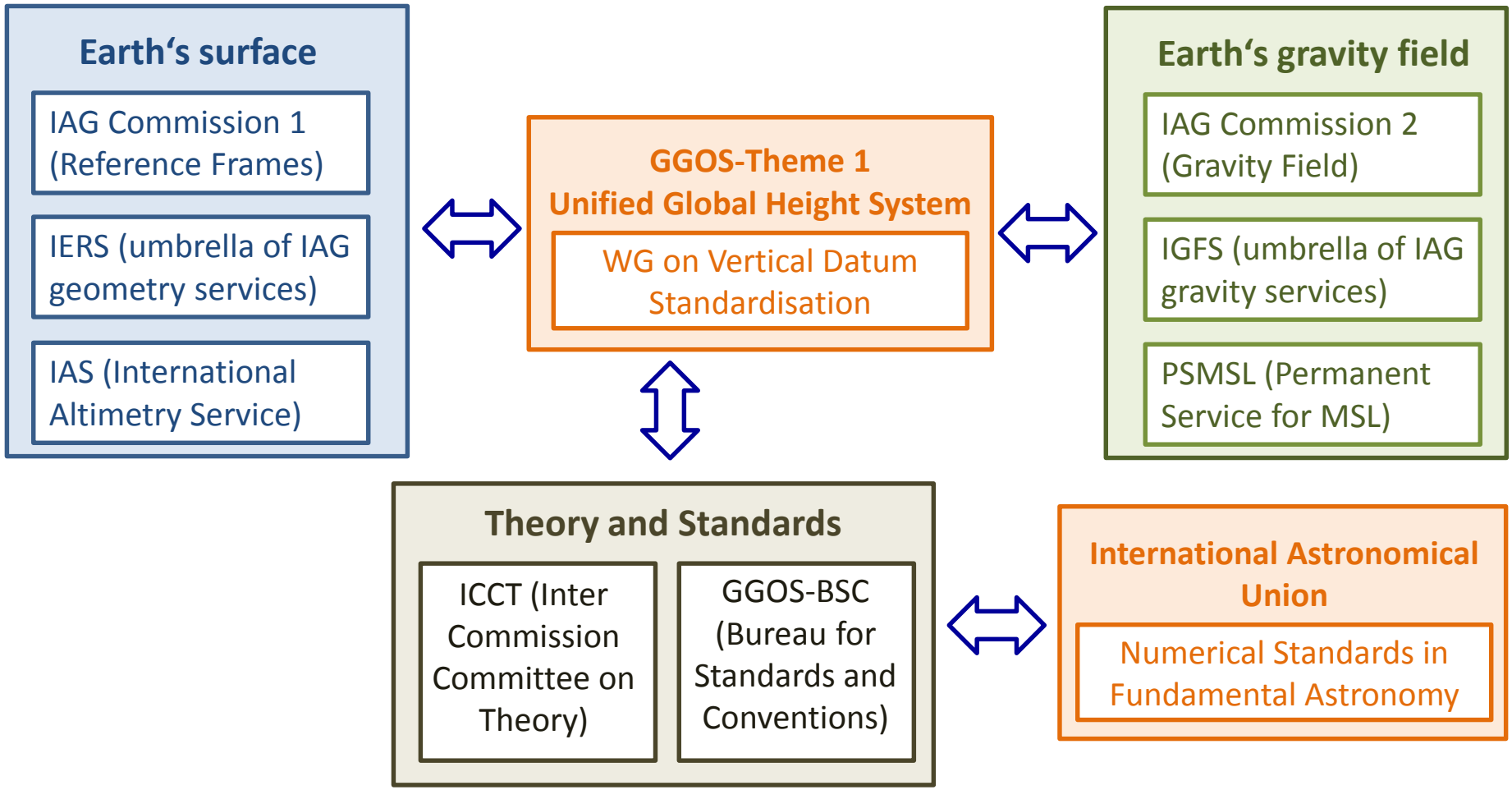
WG on Vertical Datum Standardization

- 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 an appropriate strategy to connect (unify, transform) any local height system with the global W_0 reference level.

Interaction with other IAG/GGOS components



WG on Vertical Datum Standardization

On going-activities

L. Sánchez (Germany)	⇨	W_0-computation based on fixed-GBVP, analytical solution
R. Čunderlík (Slovakia) Z. Faskova (Slovakia) K. Mikula (Slovakia)	⇨	W_0-computation based on fixed-GBVP, Boundary Element Method (BEM), Finite Element Method (FEM) and Finite Volume Method (FVM).
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. Ågren (Sweden)	⇨	Regional realisation of a global W_0

WG on Vertical Datum Standardization

First results

The different teams computed W_0 using the same input data, but their own methodologies.

Estimates provided by N. Dayoub

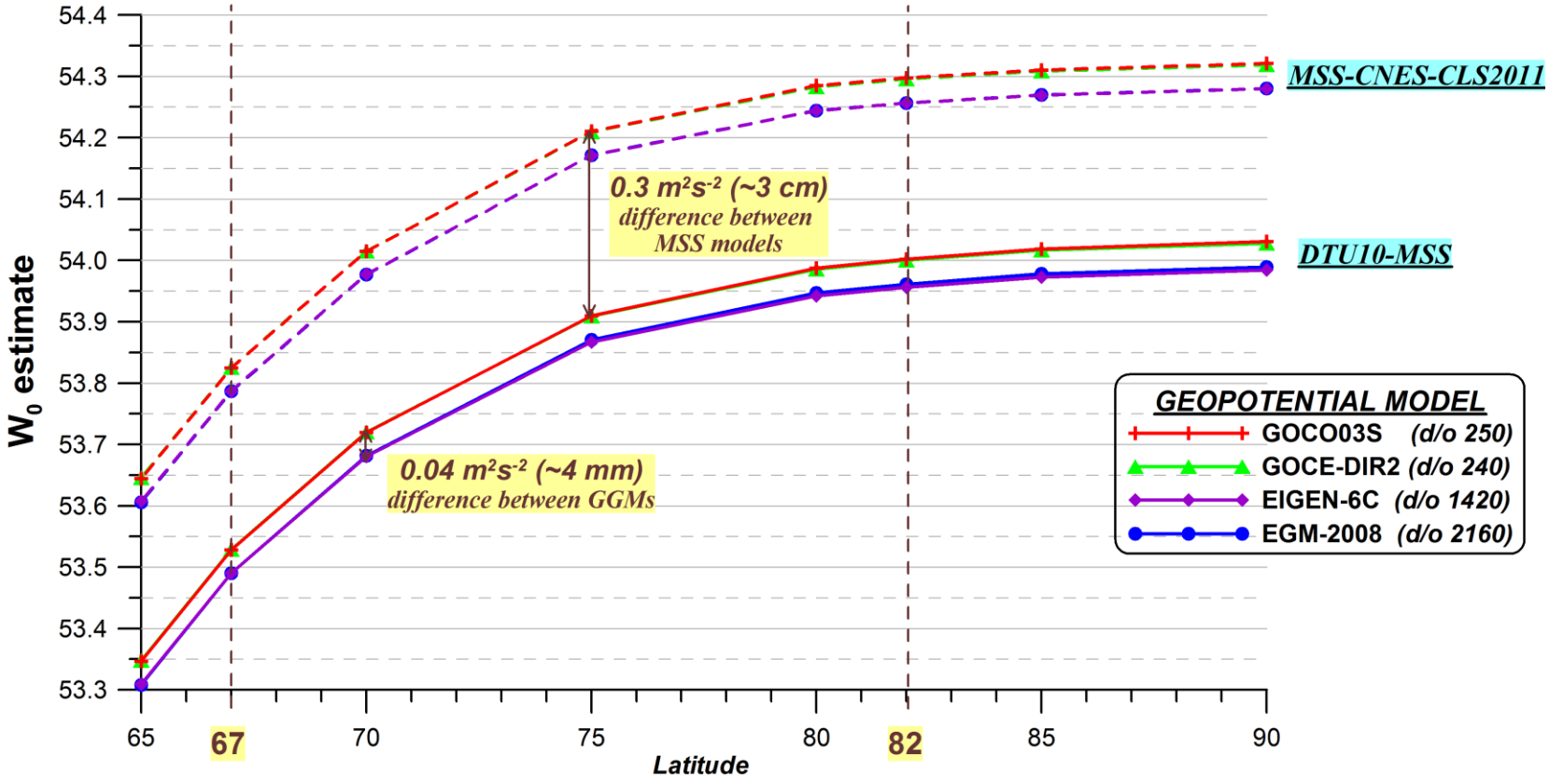
MSS	Domain N/S	GGM	Max degree	$W_0(m^2s^{-2})$		
				1996.0	2001	2005
CLS11	82°/82°	EIGEN6C	n=200	62636854.43		62636854.19
		GOCO03S		62636854.43		62636854.19
	67°/67°	EIGEN6C		62636854.06		62636853.82
		GOCO03S		62636854.06		62636853.82
DTU10	82°/82°	EIGEN6C			62636854.11	62636854.00
		GOCO03S			62636854.11	62636854.00
	67°/67°	EIGEN6C			62636853.75	62636853.64
		GOCO03S			62636853.75	62636853.64

- W_0-dependence on the latitude coverage.
- W_0-dependence on the reference epoch of the mean sea surface model and potential coefficients.

WG on Vertical Datum Standardization

First results

Estimates provided by R. Čunderlík, Z. Faskova, K. Mikula

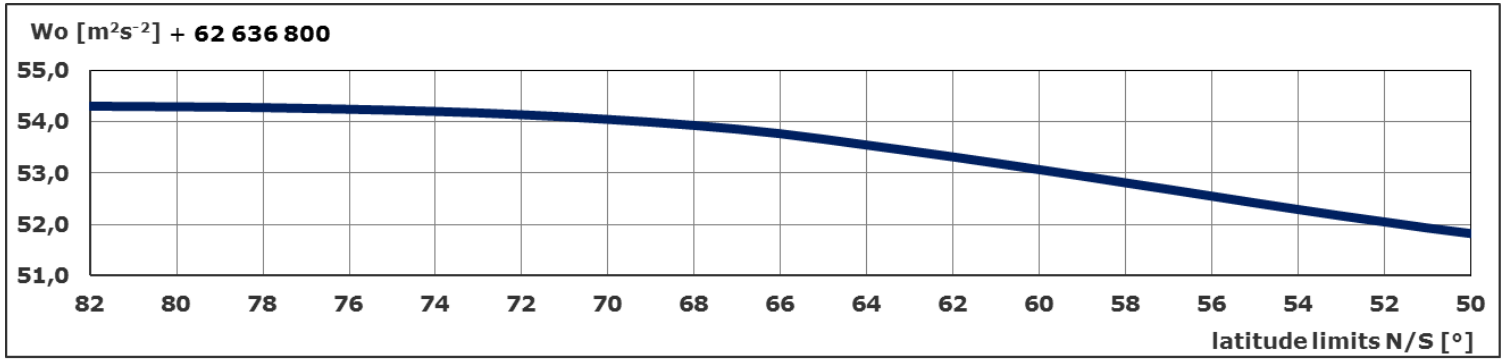


- W_0-dependence on the spectral resolution of the gravity model.

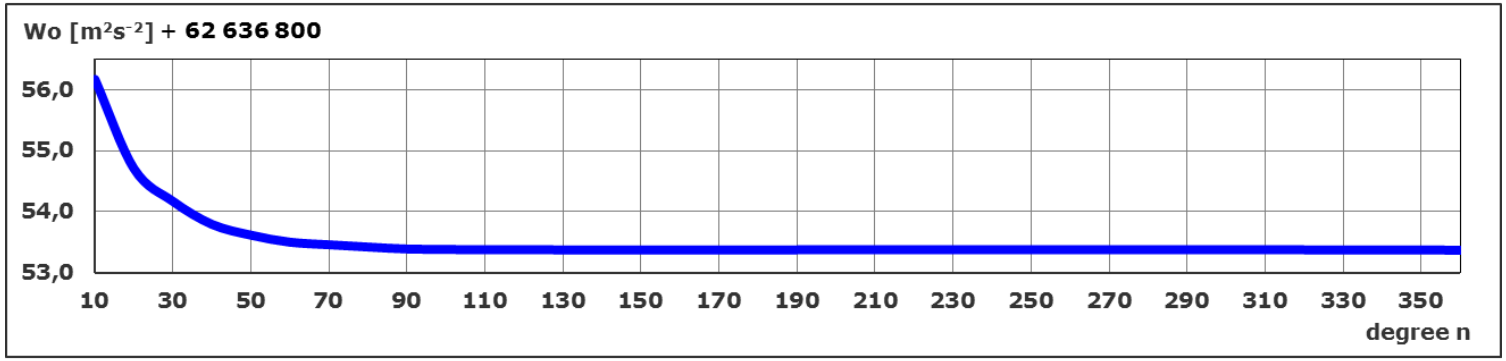
WG on Vertical Datum Standardization

First results

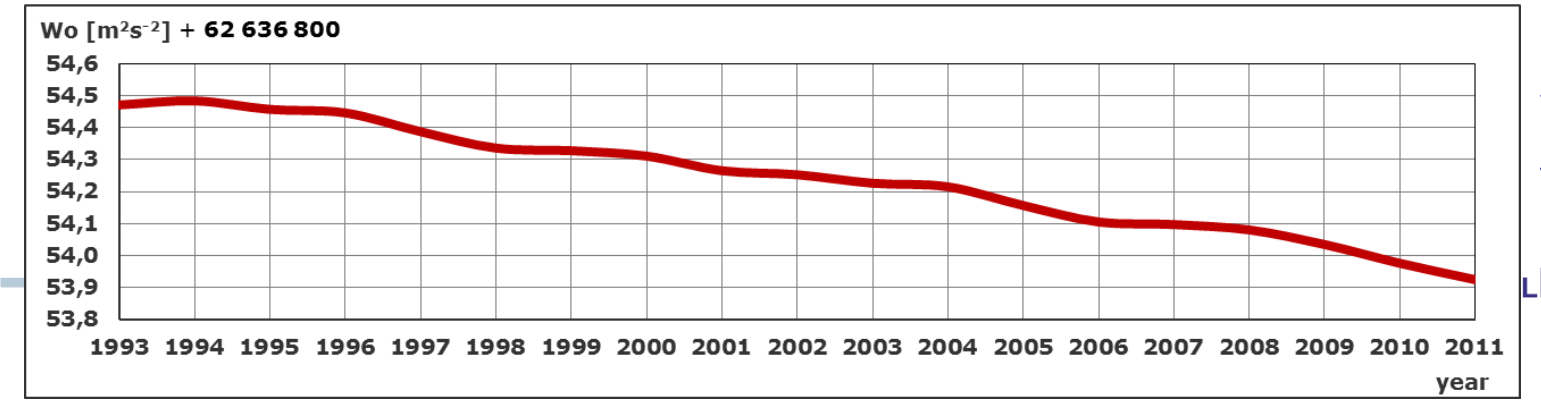
Estimates provided by L. Sánchez



W_0-variation with latitudinal coverage.



W_0-variation with degree *n* of the GGM.



W_0-variation with time.

First results

First WG meeting GGHS 2012, Venice, Italy, October 11, 2012

One year ago

- Three very close W_0 estimations (~0,2 m^2s^{-2}): Čunderlik et al., Dayoub et al., Sánchez et al. (computations started in 2005)
- One W_0 estimation far away (~2 m^2s^{-2}): Burša et al. (computations from 1999 thru 2011 produce the same value)

Today

- Burša et al. estimation came close to the others.
- IERS includes the “old” Burša value, but this value has not been formally adopted or recommended by the IAG (nor IUGG).

Next steps

What to do? WG members agreed on:

- To recommend a (new) “best present estimate” for W_0 to be included as the reference for a global vertical reference system and be the reference value for time transformation;
- This value will be an agreement between (signed by) the four groups (Čunderlik et al., Dayoub et al., Sánchez et al., Burša et al.)
- This recommendation will be supported by four papers describing models and methods applied in the individual estimations and by a common position paper summarizing the WG agreement.

Open questions to be solved in the close future

Planned activities by the individual groups to refine their estimations: (still open questions)

- Combination of a “geodetic” sea surface model and an “oceanographic” DOT-model to reproduce a sea surface closer to an equipotential surface (geoid);
- 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.

More information at http://whs.dgfi.badw.de/ **or** sanchez@dgfi.badw.de