Height datum unification within a global vertical reference system

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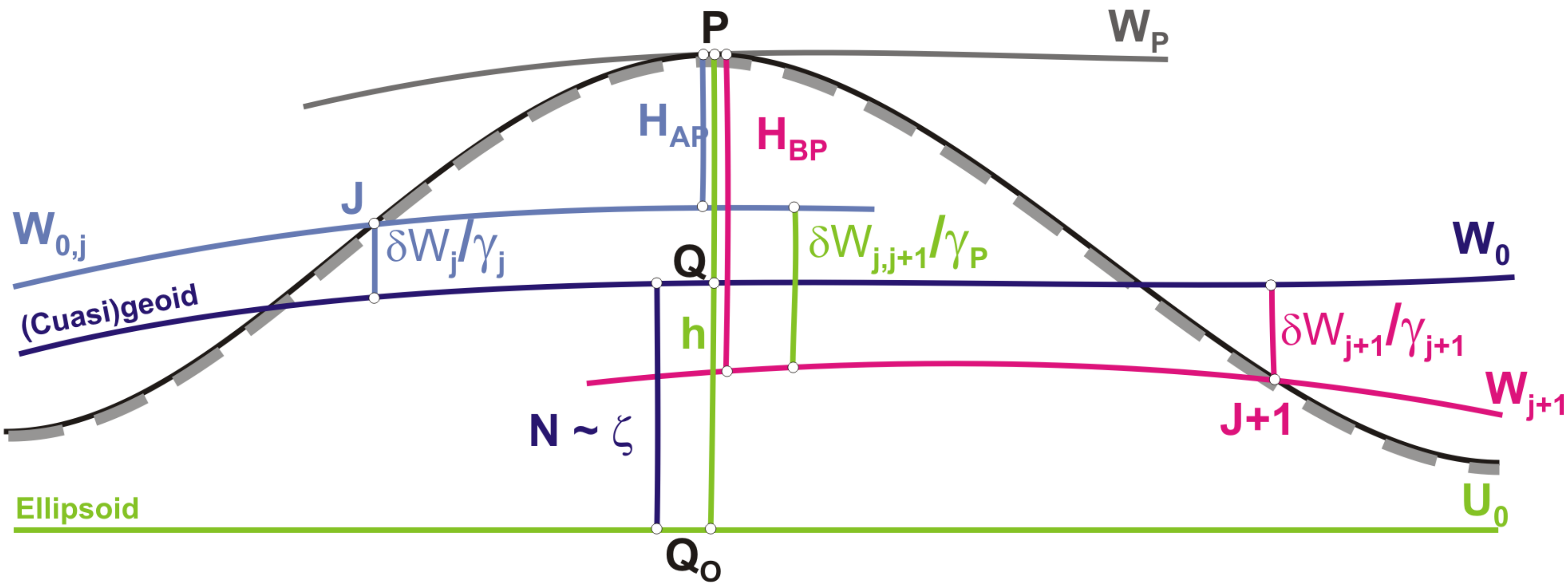
Objectives



1. To satisfy $H = h - \zeta$ with high precision world-wide;
2. To define and realize a global vertical reference system supporting geometric and physical heights;
3. To integrate the existing local height systems into the global one.

Basic approach

Definition
type of coordinates, reference surfaces, consistency between geometric and physical heights

→ **Realization**

- Conventions to realize the definition (W_0, tide system, reference epoch, etc.)
- Establisment of a global reference frame (similar to ITRF)
- Determination of (vertical) coordinates for the reference frame according to the definition and conventions
- Unification of the existing local height systems into the global one
  - SSTop at and around reference tide gauges
  - Connection of the local levels to the ITRS/ITRF
  - Connection of neighbouring local height systems
  - Connection parameters at epoch of local level definitions
    - Time variations of sea level at the reference tide gauges
    - Separation of crustal movements from sea level changes
    - Vertical movements of height benchmarks
- Re-calculation of the height related observables and iteration of the realization procedure until getting a mm-level accuracy

Modern definition of a vertical reference system

Consistent modelling of geometric and physical parameters, i.e.
$h = H^N + \zeta$ ($\approx H + N$) in a global frame with high accuracy (**$> 10^{-9}$**)

Geometrical Component

Coordinates:

h (t), dh/dt

Definition:

ITRS + **Level ellipsoid ($h_0 = 0$)**

a. (**a**, J2, ω, GM) **or**

b. (**W_0**, J2, ω, GM)

Realization:

1. Related to the **ITRS** (ITRF)
2. Conventional ellipsoid

Conventions:

IERS Conventions

Ellipsoid constants, W_0, U_0 values, reference tide system have to be aligned to the physical conventions!

Physical Component

Coord.: Potential differences

$-\Delta W_P(t) = W_0(t) - W_P(t)$; $d\Delta W_0/dt$

Definition:

W_0= *const.* (as a convention)

Realization:

1. Selection of a global **W_0** value
2. Determination of the local **$W_{0,j}$** values
3. Connection of **$W_{0,j}$** with **W_0**
4. Geometrical representation of **W_0** and **$W_{0,j}$** (i.e. geoid comp.)
5. Potential differences into physical heights (**H** or **H^N**)

Zero tide system

Realization of W_0 ($W_{0,j}$) by solving GBVP

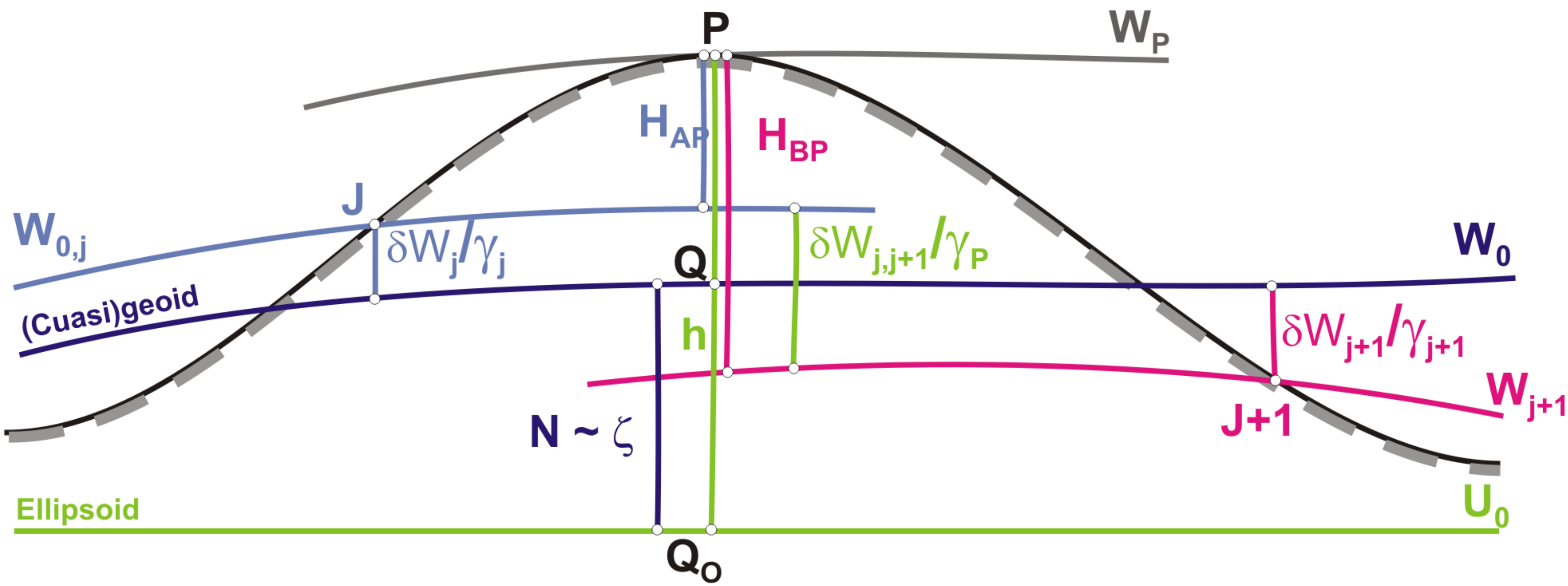
	Ocean areas	Land areas
	Fixed gravimetric GBVP provides the global reference level (W_0)	**Scalar-free GBVP** provides the local reference levels (W_j)
Formulation	$\nabla^2 T = 0$ *outside boundary surface* ; $T = W - U$	
	$-\frac{\partial T}{\partial r} = \delta g$	$-\frac{\partial T}{\partial r} - \frac{2}{r} T = g_j - \frac{2}{r}\delta W_j$ $\delta W_j = W_{0,j} - U_0 = W_0 - W_{0,j}$
Constraints	$T = 0\ at\ \infty\ ;\ \int_{sea} T\, d\sigma = k_i\ ;\ \int_{land} T\, d\sigma = k_j\ ;\ \int k_i + \int k_j = 0 \Rightarrow T_{00} \equiv \int T\, d\sigma = 0$	
Solution	$T = \frac{\Delta GM}{R} + \frac{R}{4\pi}\iint_\sigma B_j\ S(\psi) d\sigma + \sum_{n=1}^{\infty} \frac{R}{4\pi}\iint_\sigma G_n\ S(\psi) d\sigma$	
	$j = 1\ ;\ B_1 = \delta g$ (gravity disturbances)	$j = 1 \dots J\ ;\ B_j = g_j - \frac{2}{r}\delta W_j$ $g_1 = \Delta g\ ;\ g_2 = \Delta C\ ;$ etc.

vertical datum unification strategies

Strategies for the vertical datum unification

A global vertical reference system has to be connected to the geometric terrestrial reference system (TRS) to satisfy $h = H + \zeta$ world-wide. This is possible by constraining the determination of the δW_j terms to:

$$\gamma_P h_P - \left(W_0^j - W_P^j\right) - T_P^j - 2\delta W_j = 0$$



Strategies for the vertical datum unification

Oceanic approach
(SStop around gauges)
Satellite altimetry and satellite-only GGM, SSTop at coast lines including also tide gauge records.

$$T_P^j - T_0 = \delta W^j$$

Coastal approach
(reference tide gauges)
GPS positioning at tide gauges, (geopotential numbers), terrestrial gravity and satellite-only GGM.

$$\frac{1}{2}T_P^j - \frac{1}{2}h_P\gamma_P = \delta W^j$$

Terrestrial approach
(geometrical reference stations)
GPS positioning at reference stations (including border points), geopotential numbers, terrestrial gravity and satellite-only GGM.

$$\frac{1}{2}\left(T_P^j + \Delta C_P^j\right) - \frac{1}{2}h_P\gamma_P = \delta W^j$$

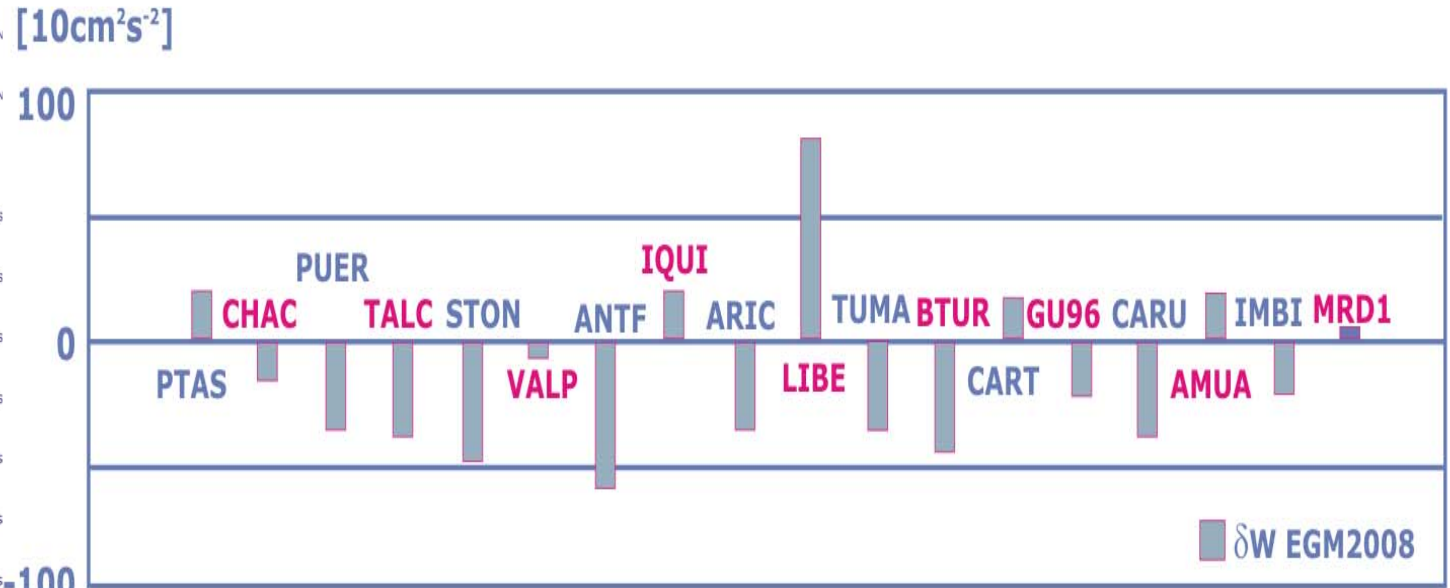
$$\frac{1}{2}\left(T_P^j + \Delta C_P^j\right) - \frac{1}{2}\left(T_P^{j+1} + \Delta C_P^{j+1}\right) = \delta W^{j+1} - \delta W^j$$

Solution of observation equations by a combined adjustment !

Numerical tests: coastal approach

Solution of the fixed GBVP on ocean areas: W_0 **= 62 636 853,1** $m^2\ s^{-2}$
Geometry of the mean sea surface: **CLS01** model (Hernandez, Schaeffer 2001),
Gravity disturbances from **CHAMP-GRACE GGM**, n=150, coefficients @ 2000.0

Solution of the scalar-free GBVP at reference tide gauges
SIRGAS coordinates, EGM2008 model (coefficients @ 2000.0), zero tide system.



SIRGAS DGFI

Numerical tests: coastal approach

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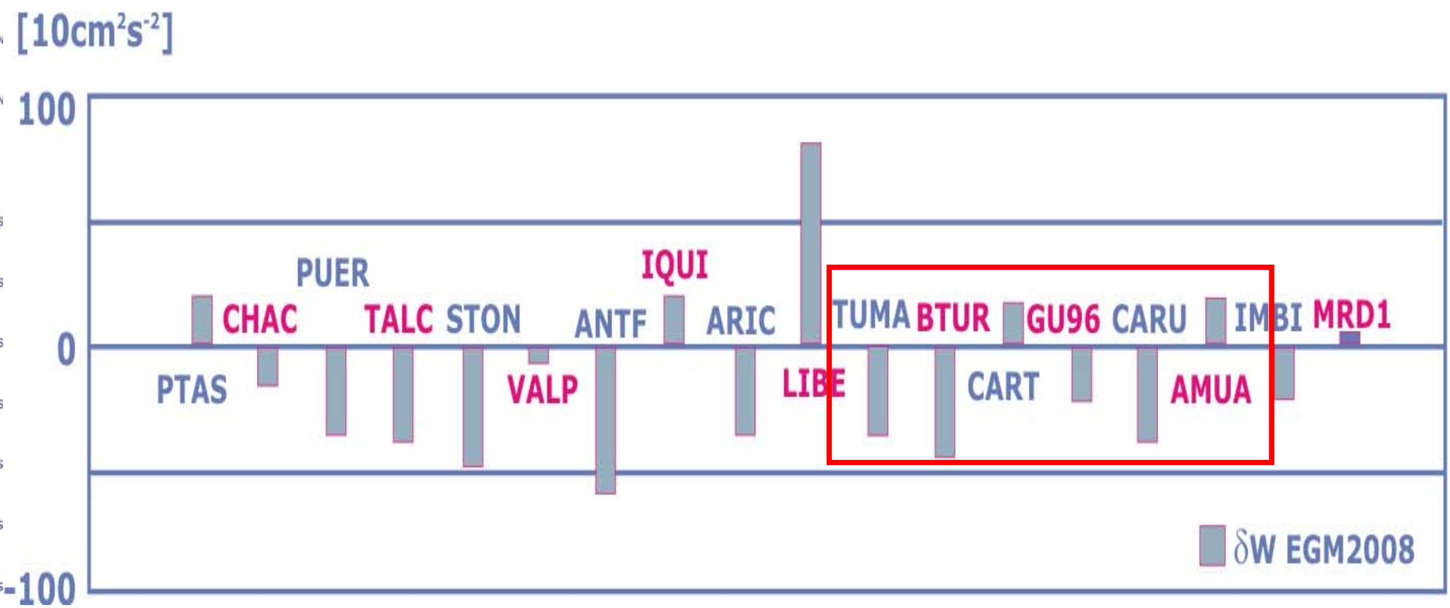
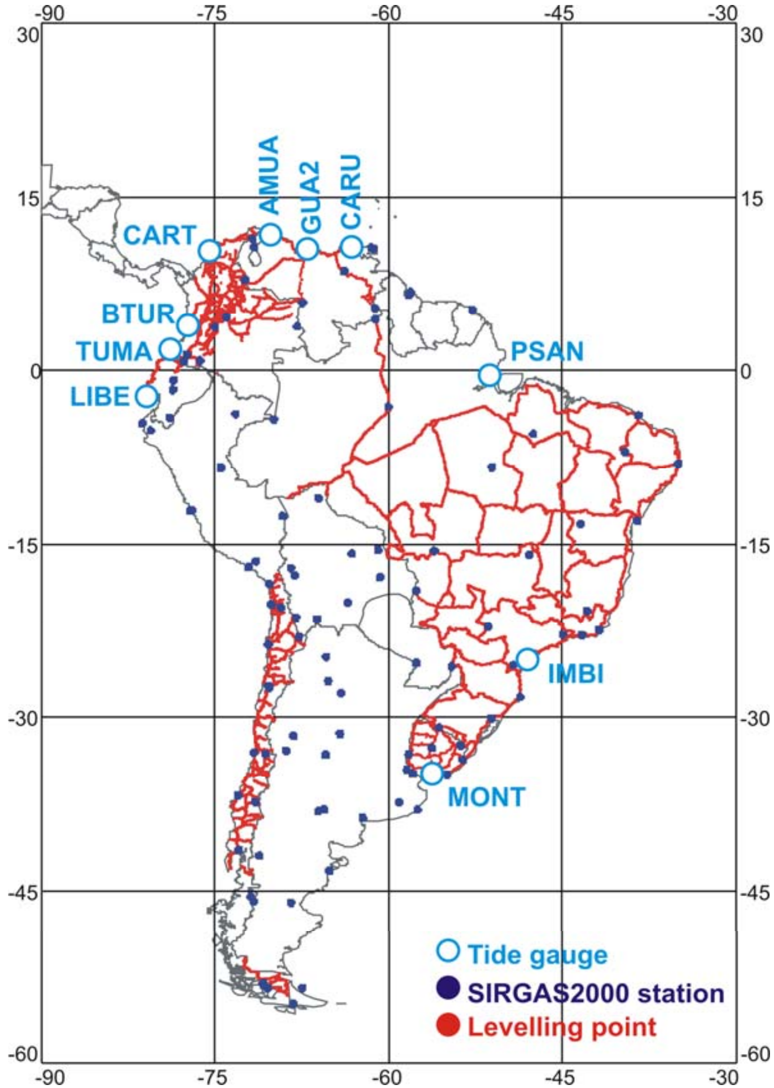


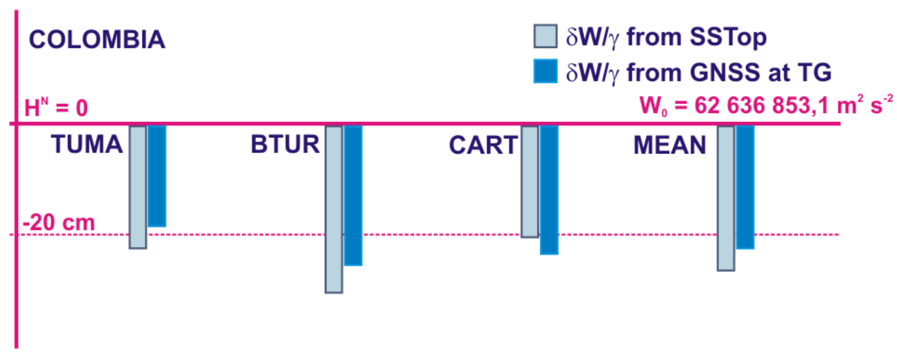
Numerical tests: coastal and oceanic approach

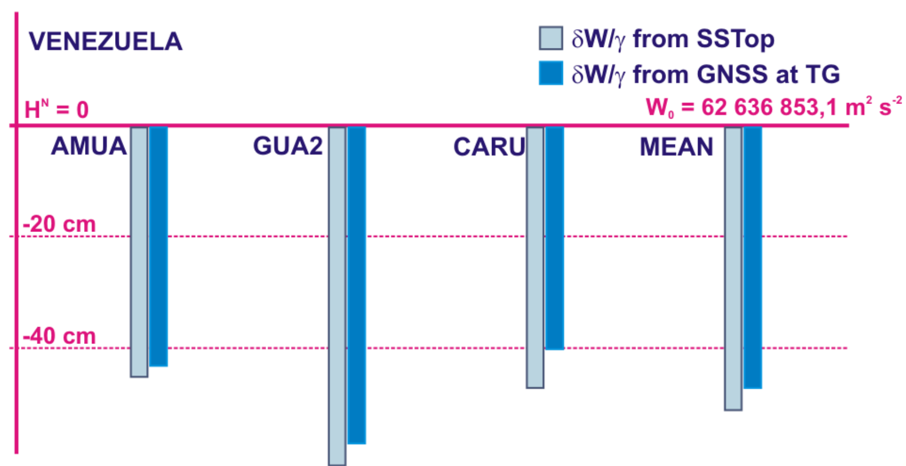


Input data:

- Local quasigeoid models
- GNSS positioning
- Geopotential numbers from levelling

H^N, h, ζ, SSTop at epoch 2000.0, zero tide system





Outlook

- To extend the numerical tests to the entire SIRGAS region. This implies:
  - Determination of SSTop at all the reference tide gauges;
  - GNSS positioning at the same tide gauges to distinguish sea level changes form vertical movements of the Earth's crust;
  - Continental adjustment of the first order vertical networks;
- To estimate the connection terms $\delta \mathbf{W_i}$ at the definition period of the local reference levels, i.e. all heights (**h, $\mathbf{H^N}$, ζ, SSTop**) must be reduced to a common reference epoch;
- To determine the $\delta \mathbf{W_i}$ using regional (or local) geoids of high resolution. The GGMs do not provide the required accuracy and resolution;
- To follow the IAG recommendations about a **reliable** and **precise** global reference level (a W_0 conventional value).