

Conventional reference level for a global unified height system

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On behalf of the

WG on Vertical Datum Standardisation

Working Group on “Vertical Datum Standardisation”

- Common initiative of
 - GGOS Theme 1:
Global Height System
 - International Gravity
Field Service (IGFS)
 - IAG Commission 2:
Gravity Field
 - IAG Commission 1:
Reference Frames
- **Main objective:** to provide a recommendation of the W_0 value to be appointed as the **reference level** of the global vertical reference system;
- **GGOS Theme 1** aims at the determination of a global vertical reference system, the **physical component** of which is given by **geopotential numbers** referring to the same **equipotential surface**;
- The equipotential surface appointed as the zero-height level
 - **is defined by a certain geopotential value called W_0 ;**
 - **shall be realised by a global geoid model;** i.e. geometric representation of the zero-height surface with respect to a reference ellipsoid.

Examples of “W₀-Values”

Recent estimations



W₀ [m²s⁻²]

- 854,2 Sea surface: DNSC08, Gravity: EGM2008 (Dayoub et al. 2012)
854,3 Sea surface: CLS01, Gravity: EIGEN-GC03 (Čunderlík and Mikula 2009)
854,4 Sea surface: KMS04, Gravity: EGM96 (Sánchez 2007)
854,6 Sea surface: J1 (2003-2005), Gravity: EGM96 (Burša et al. 2007)

~ 2 cm

Applied today
(best estimate
1999)



856,0

- Sea surface: T/P (1993-1998), Gravity: EGM96 (Burša et al. 1999)
IERS Conventions 2003, 2010

~ 15 cm

856,85

- IERS Conventions 1996

~ 10 cm

856,88

- Best fitting ellipsoid for T/P sea surface (Rapp 1995)

~ 43 cm

Which value shall be selected?

860,0

- IERS Standards 1992

62 636 860,850

- GRS80 (Moritz 2000)

Agreements regarding the W_0 estimation

- The reference W_0 value is to be selected arbitrarily, per convention (like any vertical datum). However, it is desirable that the appointed W_0 value is commensurate with present models of the Earth's geometry and gravity field;
- A new “best estimate” for a global W_0 value is necessary;
- Empirical estimation based on the convention that the geoid is that equipotential surface coinciding with the mean sea level;
- **Strategy:** combination of recent mean sea surface models and gravity global models.

Input data

Mean sea surface models:

- MSS_CNES_CLS11 (Schaeffer et al. 2012)
- DTU10 (Andersen 2010)
- mean yearly models individually computed by
 - Dayoub et al. (2012),
 - Burša et al. (2012),
 - Savcenko and Bosch (2012) - DGFI Altimetry Group.

Global gravity models:

- EGM2008 (Pavlis et al. 2012)
- EIGEN-6C2 (Förste et al. 2012)
- GOCO03S (Mayer-Gürr et al. 2012)
- GO_CONS_GCF_2_DIR_R4 (Bruinsma et al. 2013)

Empirical estimation of the vertical reference level

First approach: average potential over ocean areas.

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

Within the WG applied by two teams:

N. Dayoub (Syria)

P. Moore (United Kingdom)

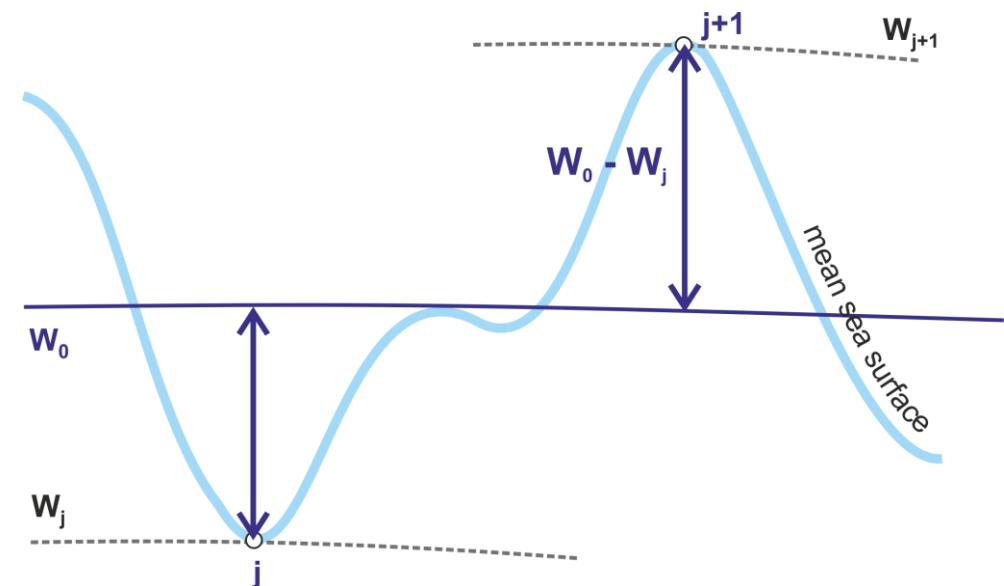
Z. Šima (Czech Republic)

V. Vatrt (Czech Republic)

M. Vojtiskova (Czech Republic)

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

E : Sea surface topography



Empirical estimation of the vertical reference level

Second approach: solution of the fixed geodetic boundary value problem.

$$\nabla^2 \delta W(\mathbf{X}) = 0 \quad \mathbf{X} \in \Omega$$

$$\delta W(\mathbf{X}) \rightarrow 0 \quad \mathbf{X} \rightarrow \infty$$

$$\delta g(\mathbf{X}) = g(\mathbf{X}) - \gamma(\mathbf{X}) \quad \mathbf{X} \in \Sigma$$

- Boundary surface Σ known;
- Unknown: datum discrepancy $\delta W (=W_0 - U_0)$
- Boundary condition: gravity disturbances δg

$\Sigma \leftrightarrow$ sea surface from satellite altimetry

$g(\mathbf{X}) \leftrightarrow$ global gravity model

$\gamma(\mathbf{X}), U_0 \leftrightarrow$ GRS80

Within the WG applied by two teams:

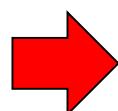
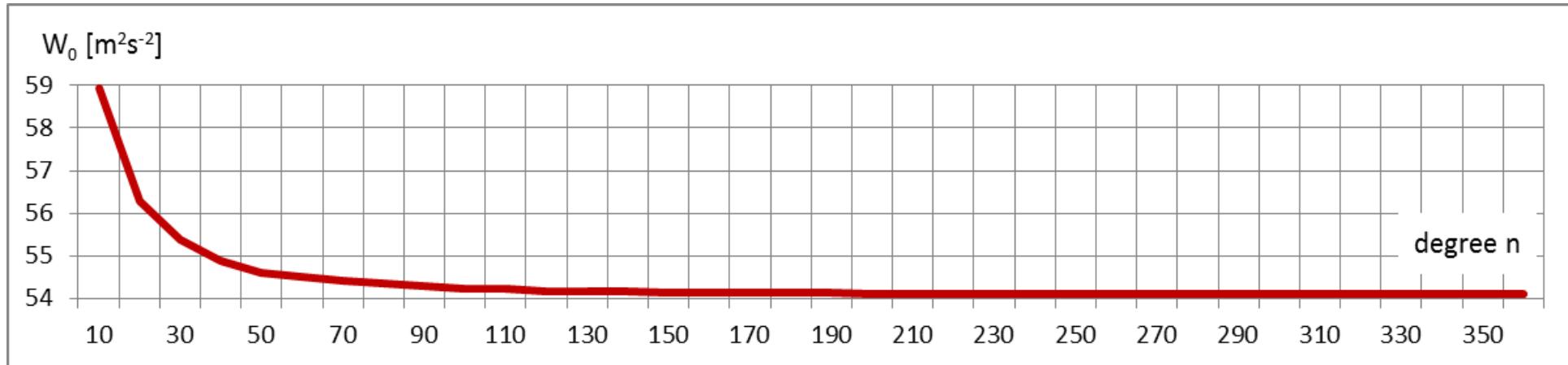
L. Sánchez (Germany)

R. Čunderlík (Slovakia)

Z. Faskova (Slovakia)

K. Mikula (Slovakia)

Dependence of the W_0 -estimate on the spectral resolution of the gravity model (n,m)

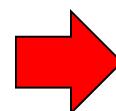


The use of a satellite-only gravity model is suitable.
After $n,m = 200$ the largest differences are $0,001 \text{ m}^2\text{s}^{-2}$, which are totally negligible.

Note: Computations carried out in zero tide system, the MSS-CNES-CLS11 sea surface model and the EIGEN-6C2 gravity model.

Dependence of the W_0 -estimate on the choice of the gravity model

EGM2008 n/m = 2159	ITG-GRACE03S 5-min mean free air anomalies (terrestrial, altimetry, aerial data, topography)	62 636 8 54,26
GOCO03S n/m = 250	GOCE 1 year CHAMP 8 years GRACE 7 years Lageos 5 years	54,18
EIGEN-6C2 n/m = 1949	GOCE 350 days GRACE 7,8 years Lageos 25 years DTU10 gravity anomalies and ocean geoid EGM2008 continental geoid	54,12
GO_CONS_GCF_2_ DIR_R4 n/m = 260	GOCE 837 days GRACE 9 years Lageos 25 years	54,12

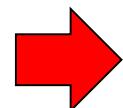


Models including GRACE, GOCE and Satellite Laser Ranging data are preferred. Recent models deliver maximal differences of **0,06 m²s⁻²** (\sim 6 mm vertical distance).

Note: Computations carried out in zero tide system and the MSS-CNES-CLS11 sea surface model.

Dependence of the W_0 -estimate on the choice of the sea surface model

MSS_CNES_CLS11	16 years altimetry data (T/P, T/P TDM, J1, ERS1 ERM+GM, ERS2 ERM, ENVISAT, GFO) Reference period: 1993 – 1999 Coverage: 80°S – 84°N Mean tide system	62 636 8 54,12
DTU10	17 years altimetry data (T/P, T/P TDM, J1, ERS1 ERM+GM, ERS2 ERM, ENVISAT, GEOSAT GM, ICESAT, GFO) Reference period: 1993 – 2009 Coverage: 84°S – 90°N Mean tide system	53,81



There is a difference of $0,31 \text{ m}^2\text{s}^{-2}$, which reflects the mean discrepancy of $\sim 3 \text{ cm}$ between both models. Possible causes:

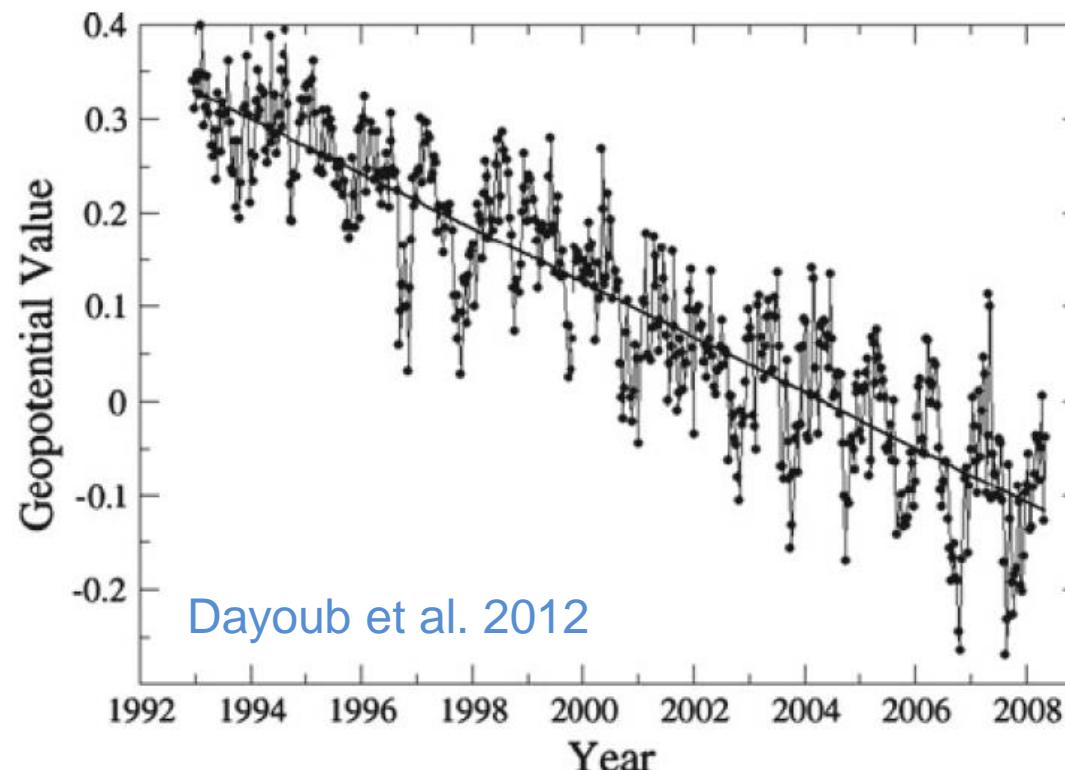
- Different strategies to process the altimetry data;
- Different reductions taken into account in each model;
- Different periods (inter-annual ocean variability).

Note: Computations carried out in zero tide system and the EIGEN-6C2 gravity model 10

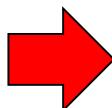
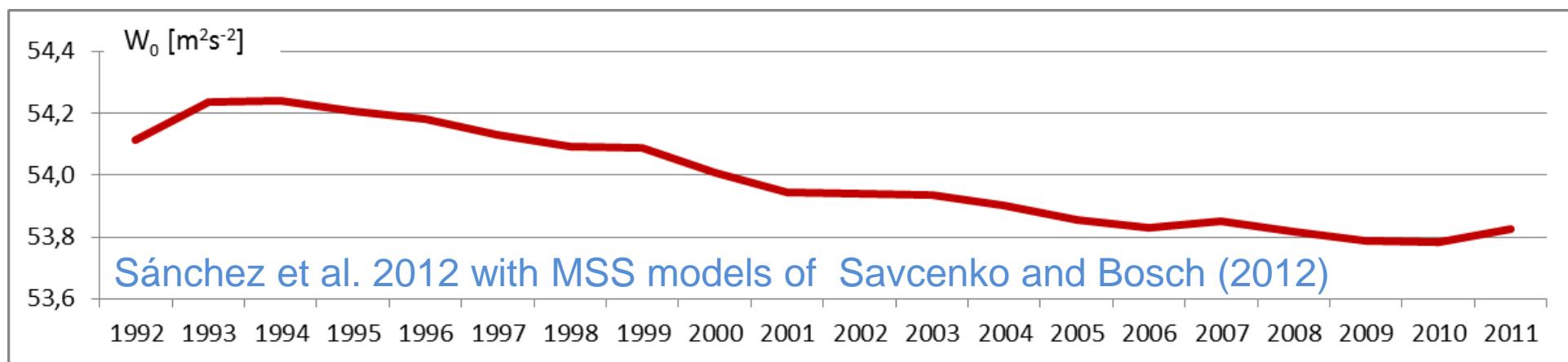
Dependence of the W_0 -estimate on the choice of the sea surface model

Computation of yearly mean sea surface models to refer the sea surface heights to a univocal reference epoch:

- 1) Dayoub et al. (2012): 1992 - 2009 (T/P and Jason 1)
- 2) Burša et al. (2012): 2003 - 2011 (Jason 1)
- 3) Savcenko and Bosch (2012): 1992 – 2011 (T/P, T/P-EM, ERS2, Jason 1, Jason 2, Envisat)

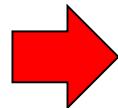
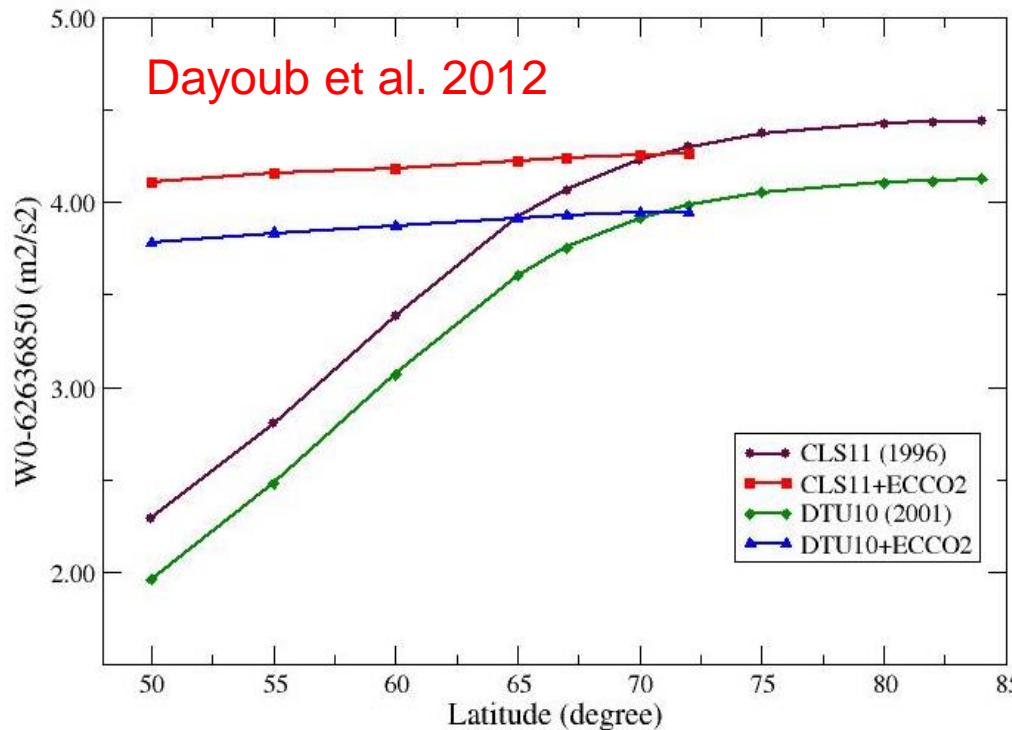


Dependence of the W_0 -estimate on the choice of the mean sea surface model



- The W_0 -estimates reflect (with opposite sign) the sea level rise measured by satellite altimetry;
- The extreme values occurred in 1993 (maximum) and 2010 (minimum), difference $0,46 \text{ m}^2\text{s}^{-2}$;
- These differences shall not be understood as a change in W_0 , but in the sea level; e.g. the geoid is not growing/decreasing with the mean sea level!
- This only means that the mean sea level coincides with a different equipotential surface depending on the period utilized for the average of the sea surface heights.

Dependence of the W_0 -estimate on the latitudinal extension of the mean sea surface model



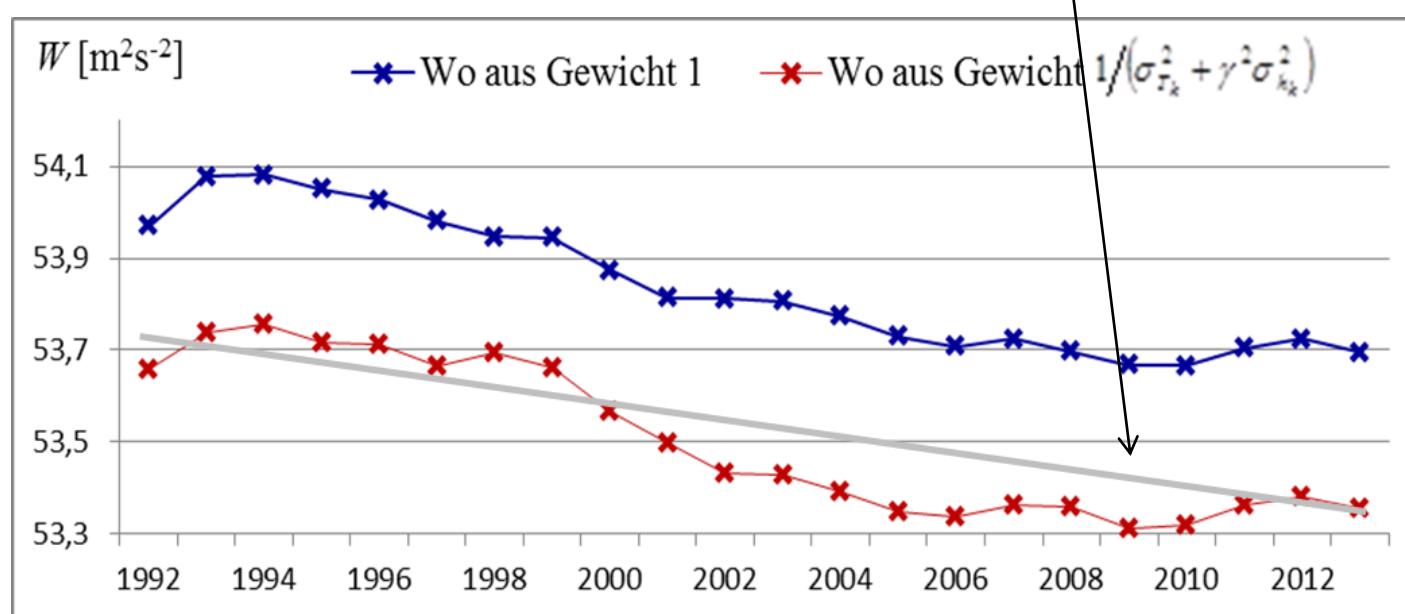
- The lower the considered latitude the lower the W_0 value;
- This dependence is caused by the omission of sea surface topography effects at high latitudes;
- Therefore, it should be considered the maximal latitudinal extension available.

Error propagation analysis in the estimation of W_0

- Present computations assume input data without error;
- If accuracy of mean sea level heights and global gravity models are taken into account in the computations, the W_0 -estimate changes about $-0,4 \text{ m}^2/\text{s}^2$ ($\sim +4\text{cm}$);
- It is recommended to adopt the W_0 value estimated after a linear regression for the year 2010.

Recommended value:

$$W_0 = 62\,636\,853,4 \text{ m}^2\text{s}^{-2} \pm 0,02 \text{ m}^2\text{s}^{-2}$$



Outlook

- To support this recommendation the WG on Vertical Datum Standardisation is
 - preparing a **position document** describing all the computations and error analysis;
 - working together with the **GGOS Bureau for Standards and Conventions** to outline the computation of a **new reference ellipsoid**;
 - defining **adequate strategies** for the realisation of this reference level in **global, regional and local frames**.