

## Inter-Commission Project 1.2: Vertical Reference Frames

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### Introduction

At present, there are some hundred physical height systems realized worldwide. The realization of a unified global reference surface for physical height systems, the relation of individual tide gauge records with respect to this reference surface, the separation of sea level changes and vertical crustal movements at tide gauges, and the connection with the terrestrial reference system are to at large unsolved problems. To proceed towards a unified physical height system we need at the centimetre accuracy level:

- a unified global height datum,
- consistent parameters, models and processing procedures for the Terrestrial Reference Frame (TRF) and gravity field,
- a closed theory for the combination of parameters (space techniques, gravity),
- consideration of time dependency, and
- a rigorous concept for the realization.

The definition and realization of a World Height System (WHS) is a fundamental requirement of GGOS (Global Geodetic Observing System). In the same way as the ITRS/ITRF provides a high precision geometrical reference frame, the WHS shall provide the corresponding high precision physical reference frame for studying the system Earth.

ICP 1.2 is a common project of IAG Commission 1 and 2. From beginning of 2010 the activities of ICP1.2 were integrated in GGOS as Theme 1.

### 1. The ICP1.2 Vertical Reference Frames in the Period 2007 - 2011

The Inter-Commission Project 1.2 – World Height System-Pilot Project (ICP1.2 – WHS-PP) is an initiative of IAG ICP1.2.

The results of the work of the Inter-Commission Project 1.2 in the first term 2003 – 2007 are documented in **Conventions for the Definition and Realization of a Conventional Vertical Reference System (CVRS)**, Ihde et al. 2007. In the CVRS conventions a general concept for the definition and realization of a unified, global vertical reference system is described. The CVRS conventions are aligned to the IERS 2003 Conventions. The conventions for a Global Vertical Reference System (GVRS) are a step forward to the realization of a WHS.

The main objective for the second term 2007 – 2011 is the initiation of a pilot project for a WHS realization (WHS-PP). The project continuation shall be realized in cooperation with other organizations.

This pilot project will provide an opportunity for the IAG Commission 1 (Reference Frames) and 2 (Gravity Field) to further expand and refine its existing reference frame infrastructure, to provide users with information about worldwide vertical reference frames, and to relate the regional height systems to a global datum.

The Deutsches Geodätisches Forschungsinstitut (DGFI) hosts the web site: <http://whs.dgfi.badw.de>. It will be used to convey further information about the project as required and as the project develops.

The main objectives in the period 2007 – 2011 are

- Considering the open topics of the period 2003 - 2007
- Further development of the CVRS conventions
- Preparation of decision about numerical standards as task in cooperation with International Astronomical Union (IAU) and international hydrological associations.
- Initiation of a pilot project for an WHS realization

## 2. The Realization Concept of a WHS

The realization of a WHS can be achieved mainly through the combination of different products of IAG services. The general case for realization of a WHS and unification of continental VRS is the combination of GNSS points and, if possible of GNSS/levelling points, with a global gravity model (GGM) which is named as the geodetic boundary value problem (GBVP) approach. This approach requires the following components:

- A global permanent GNSS network of stations connected with levelling networks, optionally supplemented by permanent (superconducting) and/or periodical (absolute) gravity observations at selected stations
- A global gravity model (GGM) with continental and regional densifications.

As result of this approach, we have available physical heights or geo-potential numbers related to a geoid/quasigeoid  $T_p \text{ RRT}$  which is related to a conventional zero level of the potential of the Earth gravity field  $W_0$ .

The WHS can be realized by two classes of points with two different procedures:

- GNSS points:  $c_P = W_0 - W_P$  and  $W_P = U_{p \text{ GPS}} + T_p \text{ RRT}$ , and
- points of levelling networks k:  $c_P = c_{P k} + W_0 - W_{0k}$ . By this,  $c_{P k}$  will be transformed from the regional level  $W_{0k}$  to the conventional global level  $W_0$ . The difference  $W_0 - W_{0k}$  can be determined by GNSS/levelling in selected co-location points by

$$W_0 - T_p \text{ RRT} - U_{p \text{ GPS}} - c_{P k}.$$

An alternative approach which can be used for the unification of vertical reference frames is based on the combination of tide gauge observations with a global sea surface topography model. It is necessary that the tide gauge stations are linked to the regional levelling network and to the geometrical reference system ITRS/ITRF. (This approach will not further be considered).

In general, the realization of a WHS and the unification of the existing height systems into the global one require a combination of different elements based on a set of consistent conventional numerical standards. The accuracy of the WHS realization depends in the first order on the resolution of the gravity field model and the appropriate regional densification with gravity data. A service providing all relevant information would be useful.

### 3. WHS Pilot Project

In July 2010 the description of the of WHS Pilot Project with a call for information about planned contributions was send out. The deadline for final contributions Survey of WHS-PP results is May 2011 and the final report will be given at IAG General Assembly 2011.

The four WHS-PP Work Items are:

1. *Analysis centres for determining and monitoring the relationship between a conventional  $W_0$  and the potential of the Earth gravity field level surface closely coinciding with the mean sea surface*
2. *Regional processing centres and global combination centres for GNSS/levelling stations with coordinate time series in the current ITRF linked to TIGA stations and geo-potential numbers referred to the RHS at defined epochs*
3. *Investigations on the accuracy of computing point values  $W_p$  of the gravity potential by means of high resolution gravity field models and regional densifications of gravity data*
4. *Operative determination of physical WHS heights in regions with a weak geodetic infrastructure including and development of an information system (registry) providing relevant data*

It is assumed that the results of TIGA (i.e. land vertical velocities at tide gauges derived from GNSS positioning) are available.

Partners for the WHS-PP are inside the IAG: the IGFS (International Gravity Field Service) for GGM, absolute and super conducting gravity meter measurements, IGS (International GNSS Service) for TIGA, SC2.4 (Sub-Commission 2.4) for continental and regional densification of a GGM, PSMSL (Permanent Service for Mean Sea Level) for tide gauge measurements, and the IAS (International Altimetry Service) for a global sea surface topography model.

### 4. Proposed continuation

At the end of the second term of ICP1.2 and after the work of the various WIs is completed, the ICP will prepare a final report and recommendations on how to best realize the WHS (including all relevant issues such as the computation and adoption of a "best"  $W_0$  value, an optimal global geoid surface, etc.) This report will be presented at the IAG General Assembly in Melbourne. Then the ICP will be dissolved.

In the future, the work of ICP should continue in the form of a GGOS Integrated Product (i.e., Theme 1) for the establishment and maintenance of a WHS. The International Gravity Field Service (IGFS) should take the leading role there and report directly to GGOS. GGOS has to clarify inconsistencies in the numerical parameters for integrated geodetic applications. Conventions for the definition and realization of the parameters of the MSSSL have also to be agreed.