Vertical Reference Framework Update on IAG Inter Commission Project 1.2

The document attached to this paper is the latest information issued by the Chair of IAG ICP 1,2 in January 2011.

The TWLWG is invited to note this information and take any action it considers appropriate.

IAG Inter-Commission Project 1.2
Vertical Reference Frames

Pilot Project
Realization of a World Height System (WHS)

Opening Remarks

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.

We look forward to a wide acceptance and feedback to this Pilot Project (PP) over the next year.

Johannes Ihde
Chairman of IAG-ICP1.2

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1. ICP1.2-WHS-PP: Description of the Pilot Project

1.1 Objectives

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, especially the International Association of Hydrological Sciences (IAHS), the International Association for the Physical Sciences of the Oceans (IAPSO), UNESCO Global Sea Level Observing System (GLOSS), the International Hydrographic Organisation (IHO), the International Federation of Surveyors (FIG), and the Interservice Geospatial Working Group (IGEOWG) of NATO Standardization Agency (NSA).

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.

1.2 Organizational Aspects

The pilot project will gather and distribute information and data sets about national and regional vertical reference frames and its relationships to a global vertical datum. The results of the WHS-PP will be freely available to participants for any purpose in accordance with the IAG open data policy. An important theme of the pilot project will be to support and promote the development of WHS applications.

The pilot project will operate for a period of up to 1 year. Partial reviews will be conducted by the ICP1.2 for the purpose of assessing the project's progress towards achieving its goals and objectives.

All participants will be required to provide each four months feedback on their experience with the project. The following timelines have been established:

- July 15, 2010: Distribution of Pilot Project description
- August 15, 2010: Deadline for information about planned contributions
- 05/2011 Deadline for final contributions Survey of WHS-PP results
- 07/2011 Recommendations for implementation and continuation.

The Deutsches Geodätisches Forschungsinstitut (DGFI) will host 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.

1.3 Project Committee

The ICP1.2 WHS Pilot Project Committee is responsible for managing the pilot project. The proposed members are:

Laura Sánchez, Johannes Ihde, Urs Marti, Tilo Schöne, Gunter Liebsch, Michael Sideris.

The Pilot Project Committee will review proposals and provide a summary report to the IAG Commissions 1 and 2. The summary report will include recommendations for acceptance or rejection of proposals. The WHS Pilot Project Committee will decide which proposals are accepted, provisionally accepted, or declined.

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

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.

Mandatory elements for a WHS:

(1) Numerical Standards (mean Earth ellipsoid – mEe, ...)
(2) Global gravity model (GGM) with continental and/or national densifications

For existing local and regional height systems – RHS (chart datums and levelling networks)

(3) GNSS/levelling stations with coordinate time series in the current ITRF and geo-potential numbers referring to the RHS at a defined epoch with derived relationship (transformation parameters) between the global WHS and the regional RHS

Optional elements for a WHS:

(4) Monitored relationship between a conventional W_0 and the potential of the Earth gravity field level surface closely coinciding with the mean sea surface
(5) GNSS/tide gauge stations to monitor vertical movements in the current ITRF
(6) Tide gauge records for selected stations
(7) Absolute and superconducting gravity measurement at selected stations
(8) Information system (registry) providing relevant meta data.

2. Project work items

The pilot project (WHS-PP) will start with a case study consisting of the following elements:

(1) The numerical standards of the IERS conventions
(2) The global gravity model EGM2008 and a satellite only GGM (tbd) with continental and national densifications
(3) Monitored relationship between a conventional W_0 and the potential of the Earth gravity field level surface closely coinciding with the mean sea surface
(4) GNSS/levelling stations with coordinate time series in the current ITRF linked to TIGA stations (co-located GNSS stations and tide gauges) and geo-potential numbers referred to a RHS at defined epochs
(5) GNSS/tide gauge stations of TIGA to identify vertical movements of the tide gauges with respect to the ITRF
(6) Tide gauge registrations at the TIGA stations to separate sea level changes from vertical crustal movements and to derive the actual mean sea level at the given epoch of the sea surface topography model
(7) Absolute and superconducting gravity measurements at selected GGP stations linked by GNSS to TIGA stations
(8) Information system (registry) providing relevant data and meta data.

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.

WHS-PP Work Items:

1. ***Analysis centres for determining and monitoring the relationship between a conventional W0 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 Wp 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.

3. Instructions for Submitting Proposals

Information about planned contributions should contain a description of the activities proposed by the organization, not exceeding ten pages.

Send proposals to:

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Proposals shall submitted by e-mail, please include the completed proposal form (see below).

Proposal Form

INFORMATION ABOUT PLANNED CONTRIBUTIONS TO THE INTERCOMMISSION PROJECT 1.2 VERTICAL REFERENCE FRAMES – WORLD HEIGHT SYSTEM – PILOT PROJECT (WHS-PP)

Proposing Organization:

Point of Contact:
Name:
Address:
Telephone:
FAX:
E-mail:

Proposal for:

- *Analysis centres for determining and monitoring the relationship between a conventional W0 and the potential of the Earth gravity field level surface closely coinciding with the mean sea surface*
- *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*
- *Investigations on the accuracy of computing point values Wp of the gravity potential by means of high resolution gravity field models and regional densifications of gravity data*
- *Operative determination of physical WHS heights in regions with a weak geodetic infrastructure including and development of an information system (registry) providing relevant data*

For Joint proposals:

Collaborating institutions:
Contacts:

Detailed proposal information:

IAG Inter-Commission Project (ICP) 1.2 Vertical Reference Frames

World Height System - Pilot Project (WHS-PP)

WI1. 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.

Author: Laura Sánchez

A main request for the establishment of a World Height System (WHS) is to refer all physical heights (or geo-potential numbers) to one and the same vertical datum world-wide. According to the *Conventions for the definition and realization of a Conventional Vertical Reference System* (Ihde et al. 2007), this datum shall correspond to a level surface of the Earth's gravity field with a given potential value W_0 = const. This definition is based on a fixed conventional value which can arbitrarily be chosen. However, it is expected that this value is consistent with other defining parameters of geometrical and physical models of the Earth.

W_0 is the geo-potential value of the geoid. The geoid is characterized, from the theoretical point of view, by the ideal surface of the oceans. Therefore, the empirical estimation of W_0 is associated with the analysis of the mean sea level and global gravity data. Traditionally, W_0 was defined to be equal to the normal potential U_0 generated by a best fitting ellipsoid. Today, modern geodetic space techniques with high accuracy and resolution, and improved analysis strategies provide advanced tools for the estimation of W_0 based on precise parameters of the geometry and physics of the Earth. Especially, the detailed representation of the Earth's surface by GNSS positioning and SAR on land, and satellite altimetry in marine areas, and the improved gravity field models provided by the new satellite missions, allow the empirical evaluation of theoretical approaches with much higher accuracy.

The subject of the WI1 is the empirical estimation of a W_0 value to be adopted as the conventional reference level of a WHS, and to be included as a defining parameter for the computation of an improved mean Earth ellipsoid. The determination of a reference W_0 value within the WHS-PP must be appropriately documented and completely reproducible. Its uniqueness, reliability, and repeatability shall be guaranteed by clear conventions, which are also a component of its realization. In this context, the objectives comprise:

1. The detailed description of the theoretical approach applied for the W_0 computation, explaining the constraints included to derive this value as an absolute potential quantity;
2. The complete list of all models, constants, and numerical standards included in the empirical evaluation of the theoretical approach described in (1);
3. The statement about the time-dependency of W_0 and how this dependence shall be considered in the long-term stability of W_0 as a reference value;

4. The formulation about the procedure to globally realize the reference level given by the estimated W_0;
5. A proposal about new conventions or modification of the existing ones to make the estimated W_0 compatible with the standardization promoted by the IAG.

IAG Inter-Commission Project (ICP) 1.2 Vertical Reference Frames

World Height System - Pilot Project (WHS-PP)

WI2. Regional processing centres and global combination centres for GNSS/levelling stations with coordinate time series in the respectively valid ITRF linked to IGS TIGA stations and geo-potential numbers referred to the RHS at defined epochs

Author: Tilo Schöne

Traditionally, almost all regional height systems (RHS) are defined by referencing the levelling network to a specific tide gauge at a coast, with a datum defined to an epoch from an arbitrarily selected time period. Herewith a direct, but not perfect link to the physical shape of the Earth is made through tide gauge observations. The sea level at these points does not necessarily coincident with the equipotential surface but departs by the mean dynamic topography. Linking the tide gauge reference by levelling to the RHS, establishes the physical link to the equipotential only if the dynamic topography can be taken into account.

There are numerous representations of RHS with height inconsistencies (offsets) to a global datum definition (WHS) due to the historical selection of different reference tide gauges and reference epochs. These RHS can be aligned by connecting the RHS to the WHS through ITRF-referenced levelling control points with known geo-potential numbers. To establish this, a common datum epoch needs to be specified. In a first step, GNSS-derived time series at Tide Gauge Sites (IGS TIGA) and GNSS/levelling control points need to be evaluated for their eligibility, consistency, and time series continuity. Regional processing centres should provide the analysis of current sets of GNSS solutions of, e.g. the TIGA and IGS reprocessing (repro1) campaigns and their respective combinations. The result should be time series with epoch information in the most recent ITRF (note: IGS TIGA reprocessing and IGS repro1 are in ITRF2005). Other centres should study the combination of these results with those stations, where GNSS/levelling heights and geo-potential numbers are available. Steps should be undertaken with the IGFS to establish more control points, if necessary (see WI3).

Responses to WI2 of the WHS CfP should emphasize on

- analyzing data of IGS TIGA GNSS/tide gauge stations to identify vertical movements of the tide gauges with respect to the ITRF,
- establishing the physical connection between the ITRF defined points, the levelling network (RHS), and the points where geo-potential numbers are defined,
- analyze GNSS (GPS) derived time series to allow establishing a commonly defined epoch of a WHF realization for both TIGA and GNSS/levelling stations with geo-potential numbers
- analyze tide gauge records at TIGA stations to separate sea level changes from any vertical tectonic or artificial movement and to derive the local mean sea level at the given epoch of a sea surface topography model

IAG Inter-Commission Project (ICP) 1.2 Vertical Reference Frames

World Height System - Pilot Project (WHS-PP)

WI3. Investigations on the accuracy of point values Wp of the gravity potential computed by means of high resolution gravity field models and regional densifications of gravity data

Author: Urs Marti

The gravity potential Wp, the disturbing potential Tp, and the height anomaly ζp can approximately be calculated by means of a global gravity field model (GGM) such as the EGM2008. As a derived quantity, geo-potential numbers Cp (=Wp-Wo) can be determined as well. A necessary input for this computation is an accurate position in a global reference system.
These results can be compared with physical heights derived from levelling and gravity or from densified regional/local gravity field models.
Depending on the region and the available data, these differences contain various components:

- Commission error of the GGM (regional effects; mostly in regions with poor data coverage)
- Omission error of the GGM (local effects; mostly significant in mountainous regions)
- Random and systematic errors of the ellipsoidal heights (due to GNSS measurements and inconsistent or different reference systems)
- Random and systematic errors in the physical heights (levelling problems, offset and systematic errors of local height systems)
- Errors in the local gravity field models (geoid models; offsets, tilts, long wavelength errors)

A central role in this comparison play the GPS/levelling points, where theoretically all the necessary input data is available. There have already been many studies in this field for a lot of different data sets. Most of these studies aimed at the quality evaluation of the GGMs and were conducted under the umbrella of a joint working group, lead by J. Huang of the International Gravity Field Service (IGFS) and the Commission 2 of IAG. A good overview of the results is presented in the Special Issue No. 4 of the "Newton's Bulletin" (2009).

In this pilot project, we expect similar studies and tests but more focused on the problems of local and regional height systems and their relationship to a GGM and, subsequently also, to a conventional global height system. In this WI3 we basically limit the investigations to the study of GPS/levelling points, to comparisons with local/regional gravity field models and local/regional gravity data. Other methods (e.g. tide gauges, altimetry, ...) are covered by the other work items.

IAG Inter-Commission Project (ICP) 1.2 Vertical Reference Frames

World Height System - Pilot Project (WHS-PP)

WI4. Operative determination of physical WHS heights in regions with a weak geodetic infrastructure including and development of an information system (registry) providing relevant data

Author: Gunter Liebsch, Johannes Ihde

Currently, various national and regional physical height reference frames are used for the vertical geo-refencing of data sets. These reference frames differ in their vertical datum, in the theoretical background, etc. Differences between the vertical reference frames may reach decimetre to meter level.

The most practicable concept for the determination of physical heights H_{phys} with relation to the sea level in a world height system is the reduction of GNSS heights $h_{GNSS,\ ellips}$ by geoid heights N_{GGM} of a global gravity field model (GGM). The derivation of the physical height is then carried out according to the simple formula: $H_{phys} = h_{GNSS,\ ellips} - N_{GGM} + A_{dd}$, being A_{dd} the discrepancy between the local reference level of H_{phys} and a global conventional level.

The accuracy of the height determination depends on the accuracy of the gravity field model and the GNSS measurements. For pure global gravity field models an accuracy of some decimetres results depending on the gravity measurements and the topography. In general, the GNSS measurements are in the height component two to three times less accurate as in the horizontal position. For the combination of a global gravity field model with a regional one, one can reach an accuracy up to few centimetres.

According to a study of the worldwide stage of development of the geodetic data bases, no geo-data infrastructure and no geodetic data bases are available in more than 100 states. Furthermore, the development of geodetic reference networks needs to be viewed in the context, since only about 30 countries of the world dispose of well-trained qualified staff and up-to-date geodetic data bases. Thus, realizations of development aid projects are considerably hindered or delayed in many countries of the world. For persons involved in the development aid projects, the knowledge of the country status with regard to geodetic developments and infrastructure is of fundamental importance.

In the context of the ICP1.2 Vertical Reference Frames, the scientific concepts for the realization of a world height system essentially assume the availability of a developed geodetic infrastructure. To support developments of aid projects an implementation concept should be worked out for different development stages under special consideration of the question “What is geodetically possible for countries with a weak infrastructure?"

The following division seems sensible:

1. For areas with no geo-data or geodetic data bases. Approach: Combination of a GGM with GNSS height determination without regional improvements. Accuracy potential: Sub-meter to 50 cm.
2. Weakly developed infrastructure, like e.g. few permanently working GNSS stations including Internet connection, no information about height systems. Approach: GGM and GNSS positioning by means of DGNSS (Differential GNSS Positioning). Accuracy potential: decimetre level, depending on GGM accuracy in the area of operation.
3. A height reference system is available in single components that are also basis for existing geo-data, e.g. a working sea gauge coupled with a GNSS permanent station and/or heights determined by levelling. Approach: Use of a global gravity field model and of DGNSS measurements, use of the existing height information for validation or transformation into a national height reference system. These data are the origin for further development of the national height system or the transformation of existing data into a WHS, respectively. Accuracy potential: Sub-dm.

Currently, the global gravity field model EGM08 allows the derivation of physical heights globally, with an accuracy between 0.1 m and 0.5 m.

The design and establishment of a web based information system which provides information about national and regional vertical reference frames and their relation to a unique global vertical reference frame to the users is an integrated part of this work. The information system should support the gathering and distribution of data as well as meta data describing height reference frames.

Generally, the realization process of such an information system could be structured in the following steps:

- Description of the functionality of the information system
- Definition of a data structure for the description of the metadata and data on the basis of ISO standards
- Realization of a prototype of the information system
- Test mode of the information system with a limited number of users
- Start of the open service

Proposals to this work item should contain details about

- Steps for the realization of the information system
- Basic concepts for the functionality of information system and data structure
- Possibilities to verify the content of the information system
- Possible time schedule
- IT environment

Subject of WI4 is the formulation of a handbook in which the necessary processes for the single development stages 1 to 3 are described and integrated a web based information system. The handbook and information system can internationally be provided to the working groups operating in developing countries. Furthermore, shortfalls have to be identified and proposals for its removal are requested.