Inter-Commission Project 1.2
Vertical Reference Frames

Report for the Period 2003 – 2007

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Terms of Reference of ICP1.2

The Earth's surface may be described by its geometry and the potential of the Earth's gravity field. The determination of heights includes both of these aspects - the geometric part and the geopotential part. Presently, space geodetic techniques allow an accuracy in geometric positioning of about 10-9 of the Earth´s radius in global and continental scales. Gravity field parameters, including the physical height components, can at present be determined only 2 to 3 orders of magnitude less accurately than the geometric parameters. Moreover, the current height reference frames around the world differ in their vertical datums (e.g., the mean sea-level at the fundamental tide gauges) and in the theoretical foundations of the height systems. There is no global height reference system defined or realized, as with the International Terrestrial Reference System (ITRS). Considerable progress in the definition and realization of an unified, global vertical reference system will be achieved from the data of the new satellite gravity field and altimetry missions.

Based on the classical and modern observations, the ICP1.2 on Vertical Reference Frames shall study the consistent modelling of both, geometric and gravimetric parameters, and provide the fundamentals for the installation of a unified global vertical reference frame.

Objectives

- To elaborate a proposal for the definition and realization of a global vertical reference system (World Height System – WHS);
- To derive transformation parameters between regional vertical reference frames;
- To establish an information system describing the various regional vertical reference frames and their relation to a world height frame (WHF).

Program of Activities

- Harmonization of globally used height data sets;
- Study of combination procedures for height data sets from different techniques;
- Study of information on regional vertical systems and their relations to a global vertical reference system for practical applications;
- Unification of regional (continental) height systems.

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Meetings and workshops

- European Vertical Reference System Workshop, 5-6 April 2004 in Frankfurt on Main, Germany (draft minutes);
- Business Meeting of ICP1.2, 31 August 2004, on GGSM2004 in Porto, Portugal (minutes);

- Business Meeting of ICP1.2, 22 August 2005, on the IAG Scientific Symposium in Cairns, Australia (minutes);
- ICP 1.2 Workshop, 11-12 April 2006 in Prague, Czech Republic (minutes);
- ICP1.2 Splinter/Business Meeting, 28 August 2006 at the 1st IGFS Symposium in Istanbul, Turkey

Status and Results

The results of the work of the Inter-commission Project 1.2 are documented in "Conventions for the Definition and Realization of a Conventional Vertical Reference System (CVRS)" - File VRS_conventions_3.0_2007-05-01. 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. Parts of the IERS 2003 conventions are the basis for the CVRS conventions.

A global unified vertical reference system for an International Vertical Reference System (IVRS) can be realized by:

- A global network of stations with coordinates in ITRF and geopotential numbers referred to a conventional global reference level. This network should include co-location of permanent GNSS, tide gauges, permanent (SG) and periodical (AG) gravity stations.
- A global reference level derived from a conventional global gravity model (CGGM) from satellite gravity missions only in combination with a global sea level model from satellite altimetry.
- Both based on a set of consistent conventional numerical standards
- In addition local and regional gravity observations around the IVRS stations are required.

Regional and national height reference systems can be integrated into an IVRS by GNSS/levelling aligned to ITRF and using the CGGM and the numerical standards.

Changes of the solid and fluid Earth surface can be observed with respect to the conventional IVRF level by relevant observation techniques. The IVRS level is defined by a conventional W_0. The conventional IVRS level has to be related to the instantaneous mean sea surface level (MSSL).

Deficiencies

In view to a planned ISO registry for geodetic parameters, the establishment of an information system describing the various regional vertical reference frames and their relation to an IVRS was not realized. This includes the determination of transformation parameters between regional vertical reference frames and the unified global height system.

Further open topics are the relationships between an IVRS and the International Terrestrial Reference System (ITRS) (Basic relations between ITRS and IVRS conventions, parameters, realization, models).

Proposed continuation

The realization of an IVRS is a typical item of the IAG project GGOS, mainly as a combination of different products of IAG services.

The IAG has to clarify inconsistencies in the numerical parameters for integrated geodetic applications. Conventions for the definition and realization of the parameters of the MSSL have also to be agreed.

Proposed items for continuation:

- Discussion of the results of ICP1.2 (GGOS action)
- Initiation of a pilot project for an IVRS realization on the basis of the IGS TIGA-PP, GGP and IGFS for AG and a CGGM (call for participation as an IGFS action)
- Further development of the CVRS conventions
- Decision about numerical standards as task of GGOS in cooperation with International Astronomical Union (IAU) and international hydrological associations.

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), the International Hydrographic Organisation (IHO), the International Federation of Surveyors (FIG), and. the Inter-service Geospatial Working Group (IGeoWG) of NATO.

Annex: Numerical Standards

The Geodetic Reference System 1980 (GRS 80, 1980) defines major parameters for geodetic reference systems related to a level ellipsoid. It is agreed by the International Union of Geodesy and Geophysics (IUGG), International Association of Geodesy (IAG) and International Astronomical Union (IAU). The GRS80 parameters are recommended by IAG for the conversion of ITRF Cartesian coordinates to ellipsoidal coordinates. It is used worldwide for many map projections and million of coordinates are related to it.

At the IUGG General Assembly 1991 in Vienna new values for the geocentric gravitational constant GM and the semi-major axis a of the level ellipsoid were recommended. Since this time these parameters have been used in global gravity models e.g. EGM96. The two other defining parameters were not changed.

In the IERS 2003 conventions (Mc Carthy and Petit, 2004) numerical standards are listed (Table 1.1). These conventions have the effect of standards and when read with chapters 4.1.4 and 4.2.5 recommended the use of

GRS80 for transformations. The value of the geocentric gravitational constant (GM) has not changed since 1991. The parameters in Table 1.1 have the status of standards. In parallel in chapters 4.1.4 and 4.2.5 the GRS80 is recommended for transformations.

Table 1 contains parameters of different level ellipsoids. The gravitational constants GM of GRS80 and IERS 2003 conventions differ in the metric system by about 0.9 m. The semi-major axis of both standards differs by 0.4 m. It has to be stated, that the IERS 2003 conventions recommends different level ellipsoid parameters for different applications.

GRS80 is recommended (and generally used) for geometrical applications. For global gravity models, various inconsistent values are used in practice.

The IAG needs to remove this inconsistency to enable the development of integrated geodetic applications (cf., Hipkin, 2002). The geoid potential parameter W_0 of a Global Vertical Reference System defines the relationship of the physical heights to the Earth body. The parameter W_0 must be consistent between systems to ensure the relations to be reproducible.

Table 1: Level ellipsoid parameters

Ellipsoid	Semi-major axis a [m]	Flattening f^{-1}	Geocentric gravitational constant GM [$10^8 m^3 s^{-2}$]	U_0/W_0 [$m^2 \cdot s^{-2}$]	γ_e [$m \cdot s^{-2}$]
International 1930 (Hayford)	6 378 388	297	3 986 329		
GRS 67	6 378 160	298.247	3 986 030		
GRS 80	6 378 137	298.2572221	3 986 005	62 636 860.850	9.78032677
IUGG 91	6378136.3 ± 0.5		3 986 004.41 ± 0.01		
IERS 2003 Conventions (zero tide)	6378136.6 ± 0.1	298.25642 ± 0.00001	3986004.418 ± 0.008	62 636 856.0 ± 0.5	(9.78032666)*
Angular velocity of the Earth rotation ω		10^{-11} rad s^{-1}	7 292 115		

In addition to the existing IERS numerical standards other parameters shall be calculated and included in the IERS conventions e.g.

γ_e normal gravity at equator
γ_p normal gravity at pole
* not consistent with IERS 2003 Conventions

(Remark: The numerical value of W_0 has to be revised in view of recent work done at the DGFI)

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