General Information

Standards and Conventions for Geodesy

D. Angermann (Germany)

Preface

Unified standards and conventions are the basis for the generation of consistent and reliable geodetic products based on geometric and gravimetric observations. The use of identical standards and conventions is crucial for the modelling and processing of the different geodetic observations as well as for the parameter estimation and representation in all fields of geodesy, in order to ensure consistent results for the geometry, the rotation and gravity field of the Earth along with its variations in time. It is equally important that users of geodetic products are aware of the standards and conventions these products are based on, to fully exploit their accuracy and to allow for a coherent interpretation. Standards and conventions are widely used in a broad sense and various international organizations and entities are involved in this subject. In the first part of this document the relevant nomenclature is introduced. We shall distinguish standards, standardized units, fundamental physical standards, resolutions and conventions (Drewes 2008). The second part focuses on the Bureau for Standards and Conventions, which has been installed as a GGOS component in 2009.

1. Nomenclature

1.1 Standards

Various international, regional and national organizations are involved in the development, coordination, revision, maintenance, etc. of standards that address the interests of a wide area of users. Important for geodesy is the ***International Organization for Standardization*** (ISO, http://www.iso.org), an international standard-setting body composed of representatives from a network of national standards institutes of more than 150 countries. ISO was founded in 1947 and promulgates worldwide priority, industrial and commercial standards to enable a consensus to be reached on solutions that meet the requirements needed in science and society. IAG has two representatives to ISO and there is one representative of ISO to IAG. The ***Technical Committee ISO/TC 211*** (http://www.isotc211.org), was formed within ISO to cover the areas of digital geographic information and geomatics. Also relevant for geodesy is the ***Open Geospatial Consortium*** (OGC, http://www.opengeospatial.org), an international voluntary consensus standards organization, originating in 1994. In OGC, more than 400 commercial, governmental, non-profit and research organizations worldwide collaborate in a consensus process encouraging development and implementation of open standards for geospatial content and location-based services, mainstream IT, GIS data processing and data sharing. There is a close cooperation between OGC, ISO/TC211 and IAG institutions.

1.2 Standardized units

The terms “quantities and units” are defined in the ***International Vocabulary of Basic and General Terms in Metrology*** (ISO/IEC Guide, 2007; Bureau International des Poids et Mesures, 2006) . The value of a quantity is generally expressed as the product of a number and a unit. The unit is simply a particular example of the quantity concerned which is used as a reference, and the number is the ratio of the value of the quantity to the unit. Many different units may be used for a particular quantity. For example, the speed may be expressed in the form of v = 25 m/s = 90 km/h. However, because of the importance of a set of well defined and easily accessible units universally agreed for the multitude of measurements that support today's complex society, units should be chosen so that they are readily available to all, are constant throughout time and space, and are easy to realize with high accuracy.

Most relevant for geodesy is the ***International System of Units*** (SI, www.bipm.org/ en/si/si_brochure), which was adopted by the 11th General Conference on Weights and Measures (1960). It is hosted by the ***International Bureau of Weights and Measures*** (Bureau International des Poids et Mesures, BIPM). In order to establish a system of units, it is necessary first to establish a system of quantities, including a set of equations defining the relations between those quantities. This is necessary because the equations between the quantities determine the equations relating the units. The units are divided into two classes – base units and derived units. In a similar way the corresponding quantities are described as base quantities and derived quantities. There are seven base units, each representing, by convention, different kinds of physical quantities. Three of them most relevant for geodesy are:

- Length (standardized unit metre, [m]),

- Mass (standardized unit kilogram, [kg]), and
- Time, duration (standardized unit second [s])

The number of derived units and derived quantities of interest in science and technology can be extended without limit. For example, the derived unit speed is metre per second [m/s], or centimetre per second [cm/s] (in the SI). The kilometre per hour [km/h] is a measurement unit of speed outside the SI but accepted for use with the SI. The knot, equal to one nautical mile per hour, is a measurement unit of speed outside the SI.

Most relevant for geodesy in the BIPM is the Section ***Time, Frequency and Gravimetry,*** a Service of the IAG. IAG is represented among the Section members. Thus, a very close connection and cooperation between them is ensured.

1.3 Fundamental Physical Constants

The formulations of the basic theories of physics and their applications are based on so-called fundamental physical constants. These quantities, which have specific and universally used symbols, are of such importance that they must be known as accurately as possible. A physical constant is generally believed to be both universal in nature and constant in time. In contrast a mathematical constant is a fixed numerical value, which does not directly involve any physical measurement. A complete list of all fundamental physical constants is given by the ***National Institute of Standards and Technology*** (NIST, *http://physics.nist.gov/constants*). NIST publishes regularly a list of the constants. The most relevant for geodesy among them are the gravitational constant, the speed of light in vacuum, the standard acceleration of gravity, and the standard atmosphere.

The ***Committee on Data for Science and Technology*** (CODATA, *http://www.codata.org*) is an interdisciplinary Scientific Committee of the International Council for Science (ICSU). IUGG is a member Union of CODATA. The Committee works to improve the quality, reliability, management and accessibility of data. CODATA is concerned with all types of data resulting from measurements and calculations in all fields of science and technology, including physical sciences, astronomy, engineering, and others. The ***CODATA Task Group on Fundamental Physical Constants*** has recently announced the public release of the 2010 Least Squares Adjustment of the values of the set of fundamental physical constants (CODATA Newsletter 101, August 2011). The values for them are given in http://www.physics.nist.gov/cuu/Constants/index.html. The 2010 values for the most relevant fundamental constants for geodesy are:

- Newtonian constant of gravitation: $6.67384\ 10^{-11} \pm 0.00080\ 10^{-11}$ [$m^3\ kg^{-1}\ s^{-2}$]
- Speed of light in vacuum: 299792458 m/s (exact)
- Standard acceleration of gravity: 9.80665 m/s^2 (exact)
- Standard atmosphere: 101325 Pa (exact)

Please note, that the 2010 value for the Newtonian constant of gravitation differs from the previous estimation of 2006, being $6.67428\ 10^{-11} \pm 0.00067\ 10^{-11}$ [$m^3/kg/s^2$].

1.4 Resolutions

A resolution is a written motion adopted by a deliberating body. The substance of the resolution can be anything that can normally be composed as a motion. In this context we refer to the motion for adopting standards, constants or any parameters to be used by institutions and persons affiliated with the adopting body. Most important resolutions for geodesy are those adopted by the Councils of the ***International Union of Geodesy and Geophysics*** (IUGG, *http://www.iugg.org*), the ***International Association of Geodesy*** (IAG; *http://www.iag-aig.org*), and the ***International Astronomical Union*** (IAU, *http://www.iau.org*).

Resolutions are non-binding laws of a legislature, but more binding than recommendations. In non-legal bodies, such as IUGG, IAG and IAU, which cannot pass laws, they form the highest level of commitment. Resolutions shall be respected by all institutions and persons affiliated with the adopting body. Important resolutions of IUGG/IAG/IAU with respect to standards and conventions are, e.g.,

- IUGG 1979 Resolution No. 7 and IAG 1980 Resolution No. 1 on the Geodetic Reference System 1980 (GRS80, Moritz 2000). The adopted values for the four defining constants of the GRS80 are:
  - Equatorial radius (a): 6378137 [m]
  - Geocentric gravitational constant (GM): $3.986005\ 10^{14}$ [$m^3\ s^{-2}$]
  - Dynamical form factor of the Earth (J_2): $1.08263\ 10^{-3}$ (free of tides)
  - Angular velocity of rotation (ω): $7.292115\ 10^{-5}$ [$rad\ s^{-1}$]
- IAG Resolutions No. 16 (1983) on the tide system. It is recommended to use "zero-tide" values associated with the geopotential and "mean-tide" values for quantities associated with station displacements.
- IUGG Resolution No. 2 (2007) on the Geocentric and International Terrestrial Reference System (GTRS and ITRS).
- IAU2000/2006 Resolutions on the precession-nutation model (Capitaine et al., 2009).
- IAU 2009 Resolution No. B3 on the Second Realization of the International Celestial Reference Frame (Ma et al., 2009)

1.5 Conventions

A convention is a set of agreed, stipulated or generally accepted norms, standards or criteria. In physical sciences, numerical values such as constants or quantities are called conventional if they do not represent a measured property

of nature, but originate in a convention. A conventional value for a constant or a specific quantity (e.g., the potential of the geoid W_o) can be for example an average of measurements, agreed between the scientists working with these values.

In geodesy conventions may be adopted by IAG and its components (Services, Commissions and GGOS). The most established and widely used conventions are those of the ***International Earth Rotation and Reference Systems Service*** (IERS, http://www.iers.org). The latest versions are the IERS Conventions 2010 (Petit and Luzum, 2010). Equivalent conventions will have to be released by the ***International Gravity Field Service*** (IGFS, *http://www .igfs.net*), to serve as the basis for gravity field related data and products. For the gravity field missions (e.g., CHAMP, GRACE, GOCE) different standards or conventions are currently in use (e.g., GOCE Standards; released by the European GOCE gravity consortium, 2010).

Below are the values of the IERS Conventions 2010 for some important geodetic constants:

- Newtonian constant of gravitation (G): $6.67428\ 10^{-11} \pm 0.00067\ 10^{-11}$ [$m^3\ kg^{-1}\ s\text{-}^2$]
- Geocentric gravitational constant (GM): $3.986004418\ 10^{14} \pm 8\ 10^5$ [$m^3\ s^{-2}$]
- Equatorial radius (a): 6378136.6 ± 0.1 [m]
- Flattening factor (1/f): 298.25642 ± 0.00001
- Dynamical form factor of the Earth (J_2): $1.0826359\ 10^{-3} \pm 1\ 10^{-10}$
- Angular velocity of rotation (ω): $7.292115\ 10^{-5}$ [$rad\ s^{-1}$]
- Potential of the geoid (W_0): 62636856.0 ± 0.5 [$m^2\ s^{-2}$]

2. GGOS Bureau for Standards and Conventions

The Bureau for Standards and Conventions (BSC) has been established as a GGOS component in 2009. It is the successor of the GGOS Working Group on Conventions, Modelling and Analysis that was chaired by Hermann Drewes. The BSC is jointly operated by the Deutsches Geodätisches Forschungsinstitut (DGFI), and the Institut für Astronomische und Physikalische Geodäsie (IAPG) of Technische Universität München, both in Munich, Germany, under the umbrella of the Forschungsgruppe Satellitengeodäsie (FGS).

2.1 Mission and goals

The implementation of common standards and conventions for the generation of geometric and gravimetric products is of crucial importance for GGOS. The BSC supports GGOS in its goal to obtain products of highest accuracy, consistency, temporal and spatial resolutions, and referring to a unique reference frame stable over decades.

GGOS shall keep track of the strict observance of adopted geodetic standards, standardized units, fundamental physical constants, resolutions and conventions in all official products provided by the geodetic community, identify gaps and deficiencies in standards and conventions, to initiate steps to close them, and to propagate geodetic standards and conventions in the geodetic and general scientific community and promote their use.

To fulfil its mission the BSC works closely together with experts in the field and maintains regular contact and establishes a strong interface with all the IAG Services and Commissions and international bodies involved in the adoption of standards, physical constants, resolutions and conventions.

2.2 Tasks

The main objectives of the GGOS Bureau for Standards and Conventions (BSC) are:

- The BSC evaluates the geodetic standards and conventions currently in use by all the IAG Services for the generation of geodetic/geophysical products. It reviews official products of IAG with respect to the correct use of standards and conventions.
- The BSC propagates all geodetic standards and conventions to geodetic and general scientific communities and urges their common use. If necessary, the BSC proposes the adoption of new standards and conventions, changes and revisions.
- The BSC propagates most important standards to society in general and promotes their use. These outreach activities include the participation at relevant conferences and meetings and submission of papers to journals in neighbouring fields.
- The BSC maintains regular contact with all internal and external institutions involved in the adoption of standards, resolutions and conventions. It thereby takes advantage of representations in IAG Services, IAG Commissions, IUGG and IAU, as well as in other bodies involved in standards and conventions (e.g., BIPM, ISO, CODATA).
- The Bureau is in charge with administrative tasks, communications, data base and web support. For these tasks a close cooperation with the GGOS Coordination Office and the GGOS Portal is established.
- For specific issues dealing with particular fields of geodesy the BSC may set up dedicated Working Groups. Regional or national members may be included in such Working Groups.
- The BSC reports regularly to the GGOS Coordination Board and to the IAG Executive Committee, and – if necessary or appropriate – to the IUGG Executive Committee.

2.3 Staff members of the BSC

- Director: D. Angermann
- Deputy director: T. Gruber
- Geodetic fields and expertise of staff members:
  - Geometry, orbits, TRF: U. Hugentobler, P. Steigenberger, D. Angermann
  - Earth Orientation, CRF: M. Gerstl, R. Heinkelmann
  - Gravity: J. Bouman, T. Gruber
  - Vertical reference systems: L. Sánchez
- Associate members: J. Ádám, M. Craymer, J. Ihde, J. Kusche
- The representation of all IAG Services and other bodies involved in standards and conventions is in progress.

References

Bureau International des Poids et Mesures (2006), The International System of Units (SI), 8th edition, (http://www.bipm.org/en/si/si_brochure).

Capitaine, N., Mathews, P.,.M., Dehant, V., Wallace, P. T., Lambert, S. B. (2009). On the IAU 2000/2006 precession-nutation and comparison with other models and VLBI observations, Celest. Mech. Dyn. Astro., 103, 2, doi:10.1007/s10569-008-9179-9.

Drewes H. (2008). Standards and conventions relevant for geodesy. In: The Geodesist' s Handbook 2008, Drewes H., Hornik H., Ádám J., Rozsa Sz. (Eds.), J. Geodesy, Vol. 82, 833-835, Springer.

European GOCE gravity consortium (2010), GOCE High level Processing Facility GOCE Standards, Gruber, T., Abrikosov, O., Hugentobler, U (Eds.), Document No. GO-TN-HPF-GS-011.

Groten, E. (2004) Fundamental parameters and current (2004) best estimates of the parameters of common relevance to astronomy, geodesy, and geodynamics. J. Geodesy (77), 724-731, Springer.

ISO/IEC Guide 99-12:2007 (2007). International Vocabulary of Metrology – Basic and General Concepts and Associated Terms, VIM.

Ma C., Arias F., Bianco G., Boboltz D., Bolotin S., Charlot P., Engelhardt G., Fey A., Gaume R., Gontier A., Heinkelmann R., Jacobs C., Kurdubov S., Lambert S., Malkin Z., Nothnagel A., Petrov L., Skurikhina E., Sokolova J., Souchay J., Sovers O., Tesmer V., Titov O., Wang G., Zharov V. (2009). The second realization of the International Celestial Reference Frame by Very Long Baseline Interferometry. IERS Technical Note, No. 35, A. Fey and D. Gordon (Eds.), Verlag des Bundesamts für Kartographie und Geodäsie, Frankfurt a.M.

Moritz, H. (2000). Geodetic Reference System 1980, J. Geodesy (74), 128-134, Springer.

Petit, G. and Luzum, B. (2010). IERS Conventions (2010), IERS Technical Note, No. 36, Verlag des Bundesamts für Kartographie und Geodäsie, Frankfurt a.M.