GGOS Bureau of Products and Standards

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Workshop for the Implementation of the GGRF in Latin America
Buenos Aires, Argentina, Sep 16-20, 2019

Motivation

Remember the Mars Climate Orbiter incident from 1999?

https://www.simscale.com/blog/2017/12/nasa-mars-climate-orbiter-metric/

- The Mars Climate Orbiter, built at a cost of 125 USD million, was a 338-kilogram robotic space probe launched by NASA on Dec 11, 1998 to study the Martian climate, Martian atmosphere, and surface changes.
- In Sep 1999, after almost 10 months of travel to Mars, the Mars Climate Orbiter burned and broke into pieces.
- The navigation team at the Jet Propulsion Laboratory (JPL) used the metric system of kilogram and meter in its calculations, while Lockheed Martin Astronautics in Denver, Colorado, which designed and built the spacecraft, provided crucial acceleration data in the English system of inches, feet, and pounds.
- The acceleration readings were given in English units of pound-seconds^2; the control software was programmed in metric units of newton-seconds^2.

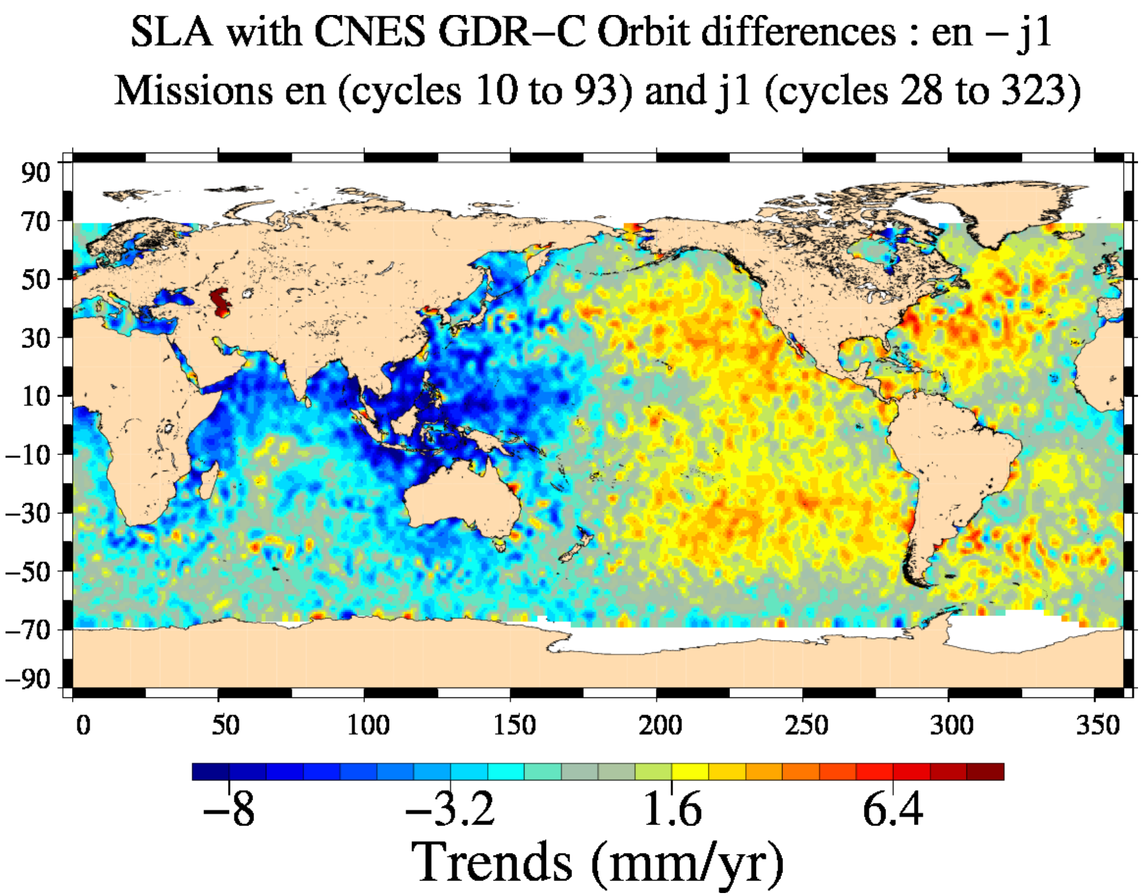
Outline

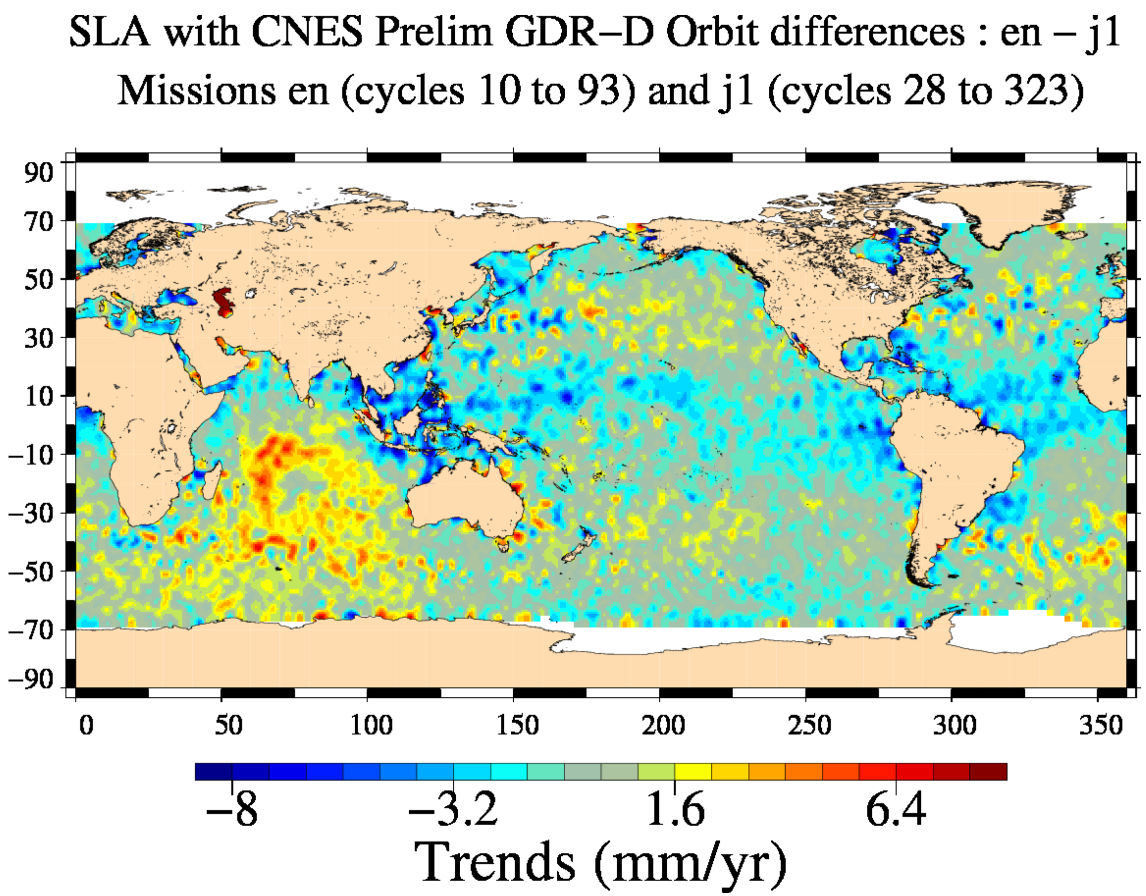
- Motivation
- Definition of the International Height Reference System (IHRS)
- Realisation of the IHRS: the International Height Reference Frame (IHRF)
  - Station selection for the reference network
  - Some considerations for the determination of IHRS/IHRF coordinates
- Colorado experiment: comparison of potential values and learnings from a successful international cooperation initiative
- Participation of Latin America in the implementation of the IHRS/IHRF

Motivation

- Geodesy focuses on determining, monitoring, mapping and understanding changes in the Earth's shape (geometry), rotation and gravity field.
- Geodetic observations and products are the metrological basis for measuring and interpreting changes of the Earth as a System. For instance,
  - Mass transport processes and mass variations (due to geophysical signals) can be observed by gravimetric measurements directly.
  - The description of very small changes associated with those processes, is only possible if a high-accuracy and long-term stable geodetic reference frame is available; e.g. to determine changes of magnitudes lower than 1 mm, the certainty of the reference frame has to be ideally at least ±0.1 mm.
- As the geodetic observations are becoming more precise and offer a higher resolution in space and time, the geodetic products are very much more sensible to data processing strategies (methods, standards, models, etc.).

Motivation





Source: ESA Document: CLS-DOS-NT-12-52 - Validation Report: WP2200 Orbit Calculation, 2012

Motivation

- Additionally, the same signals of the System Earth are measured using different techniques with particular/individual properties. For instance:
  - Deformations on the Solid Earth (caused by e.g. tectonic activity or loading effects) are detected by
    - Precise station positioning (VLBI, SLR, DORIS, GNSS)
    - Surface scanning (SAR techniques)
    - Gravimetry (changes in the mass distribution)
  - Changes in the sea surface are detected by
    - Satellite altimetry (geometric variations of the sea surface)
    - Satellite gravimetry (mass displacements, ocean currents)
- To ensure a reliable and coherent interpretation of the Earth System changes detected by geodesy, it is necessary
  - high-precise and long-term stable reference frames for the Earth's geometry and gravity field, and
  - consistent and consistently used standards and conventions in the geodetic data processing and product generation over all geodetic fields (geometry, gravity, Earth orientation modelling).

Lexicon

- Standards:
  - Accepted specifications and measures for quantitative and qualitative values and their comparisons. They should guarantee compatibility between products.
  - Developed and promulgated by international, regional, and national organizations. Most important for geodesy outside the International Association of Geodesy (IAG) are:
    - International Organization for Standardization (ISO), mainly TC 211 “Geographic Information/ Geomatics” https://www.iso.org/
    - Open Geospatial Consortium (OGC), http://www.opengeospatial.org/

- Standardized units:
  - To express the value of a quantity by the product of a number and a unit. Units are used quite heterogeneously in science (e.g., mgal ↔ ms^{-2}) and society (km ↔ miles).
  - Internationally unified units are promulgated in the
    - International System of Units (SI) by the
    - International Bureau of Weights and Measures (BIPM), https://www.bipm.org/en/measurement-units/.
  - Most relevant for geodesy are metre (length), kilogram (mass), second (time); all other units are derived from these three *primary* units.

Lexicon

- Fundamental physical constants:
  - Physical quantities that are generally believed to be universal in nature and constant in time.
  - A complete list is given by the US National Institute of Standards and Technology (NIST, https://www.nist.gov/).
  - An internationally accepted set of values for the fundamental physical constants are regularly provided by the Committee on Data for Science and Technology (CODATA, http://www.codata.org/) of the International Science Council (ISC)
  - Some important fundamental constants for geodesy are
    - Universal values
      - the gravitational constant G (6.674 28 e^{-11} m^3 kg^{-1} s^{-2})
      - the speed of light in vacuum (299 792 458 m s^{-1})
    - Adopted values (as mean values at sea level)
      - the standard acceleration of gravity (9.806 65 m s^{-2})
      - the standard atmosphere (101 325 Pa)

Lexicon

- Resolutions:
  - Written motions adopted by a deliberating body. Resolutions are not binding like laws of a legislature, but they are more binding than recommendations. In non-legal bodies, which cannot pass laws, they form the highest level of commitment and shall be respected by all institutions/persons affiliated with the adopting body.

- Resolutions important for geodesy are those adopted by the
  - International Union of Geodesy and Geophysics (IUGG)
  - International Association of Geodesy (IAG)
  - International Astronomical Union (IAU)

- Examples are
  - IUGG Res 7 (1979) and IAG Res 1 (1980): Geodetic Reference System 1980 (GRS80)
  - IAG Res 16 (1983): Handling of permanent tide effects
  - IAU Res B2 (1997), Res B3 (2009), Res B2 (2018): International Celestial Reference System
  - IAG Res 1 (2015): W_0 value, International Height Reference System
  - IAG Res 1 (2019): ITRF as the standard terrestrial reference frame for positioning, satellite navigation and Earth science applications, as well as for the definition and alignment of national and regional reference frames.

Lexicon

- Conventions:
  - Set of agreed, stipulated and generally accepted norms, standards or criteria. Quantities are called conventions, if they do not represent a natural property, but originate in an agreement. For instance,
    - Greenwich as the meridian of origin for longitude, or the equatorial plane as the origin for latitude, etc.
    - The geo-centre as origin of the ITRS/ITRF (X=Y=Z=0)
    - $W_0 = 62\ 636\ 853.4\ m^2s^{-2}$
  - Conventions are normally adopted by the international bodies, in geodesy, usually the components of the International Association of Geodesy (Services, Commissions, GGOS)
  - In geodesy, the most established and common are the conventions of the International Earth Rotation and Reference Systems' Service (IERS). They are regularly updated and they are the basis for the analysis of the geometric observations and for the generation of IERS products (e.g. the ITRF).

GGOS Bureau of Products and Standards (GGOS-BPS)

- Installed in 2009 as the "GGOS Bureau for Standards and Conventions"
- In 2014, it becomes "GGOS Bureau of Products and Standards"
- Objectives:
  - To support the IAG in its goal to obtain geodetic products of highest accuracy and consistency;
  - To act as the contact and coordination point for the harmonization of the standards and products used/generated by the different IAG components;
  - To promote the integration of geometric and gravimetric parameters and the development of new products, required to address geophysical questions and societal needs.
  - To keep track of adopted geodetic standards and conventions across all IAG components as a fundamental basis for the generation of consistent geometric and gravimetric products. This implies
    - to review and evaluate all standards, constants, resolutions and conventions adopted by IAG and its components,
    - to identify gaps, inconsistencies and deficiencies,
    - to propose updates or new standards if necessary,
    - to propagate standards and conventions to the wider scientific community.
  - The work is primarily build on the IAG Services and their support is fundamental to achieve the BPS goals.

GGOS Bureau of Products and Standards (GGOS-BPS)

- It is jointly operated by the Deutsches Geodätisches Forschungsinstitut (DGFI-TUM) and the Lehrstuhl für Astronomische und Physikalische Geodäsie (APG) of the Technische Universität München (TUM) within the Forschungsgruppe Satellitengeodäsie (FGS).
- Director: Detlef Angermann, deputy director: Thomas Gruber
- Staff:
  - Geometry, orbits, TRF: D Angermann, U Hugentobler, P Steigenberger (as associated member, GSOC/DLR)
  - Earth orientation, CRF: M Gerstl, R Heinkelmann (as IAU representative, GFZ Potsdam)
  - Gravity, geoid, physical heights: T Gruber, L Sánchez
- To fulfil its mission, the BPS works closely together with all the IAG Services and Commissions and international bodies involved in the adoption of standards, resolutions, and conventions (IERS, IAU, BIPM, CODATA, NIST, ISO/TC211, UN-GGIM Sub-committee of Geodesy).

Representatives of IAG Services and other entities

Position (IAG Service, other entity)	Representatives	Affiliation, Country
IERS Conventions Center	Gérard Petit (until 2016) Nick Stamatakos (since 2017)	BIPM (France) USNO (USA)
IERS Analysis Coordinator	Thomas Herring R. Heinkelmann (since 2019, BPS)	MIT (USA) GFZ (Germany)
IGS Representative	Urs Hugentobler (BPS staff)	TUM (Germany)
ILRS Analysis Coordinator	Erricos Pavlis	UMBC/NASA (USA)
IVS Analysis Coordinator	John Gipson	GSFC/NASA (USA)
IDS Representatives	Frank Lemoine, John Ries, Jean-M. Lemoine, H. Capdeville	GSFC/CSR (USA) CNES/GRGS (France)
IGFS Chair	Riccardo Barzaghi	Politec. Milano (Italy)
BGI Chair	Sylvain Bonvalot	IRD (France)
ISG President	Mirko Reguzzoni	Politec. Milano (Italy)
ICGEM Chair	Franz Barthelmes (until 2017) E. Sinem Ince (since 2018)	GFZ (Germany) GFZ (Germany)
IDEMS Director	Kevin M. Kelly	ESRI (USA)
IGETS Chair	Hartmut Wziontek	BKG (Germany)
Gravity Comm. (corresp. Member)	Jürgen Kusche	Univ. Bonn (Germany)
IAG Representative to ISO	Johannes Ihde (until 2017) Detlef Angermann (since 2018)	BKG, GFZ (Germany) TUM (Germany)
IAG Communication and Outreach	Josef Ádám	Univ. Budapest (Hungary)
IAU Commission A3 Representative	Catherine Hohenkerk (until 2018) James L. Hilton (since 2018)	United Kingdom USNO (USA)
IAU Representative	Robert Heinkelmann (BPS staff)	GFZ (Germany)
Control Body for ISO Geodetic Registry	Michael Craymer (Chair) Larry Hothem (Vice Chair)	NRCan (Canada) USA

Major activities of the GGOS-BPS

- Inventory of constants, standards, conventions used across all IAG Services, i.e., numerical standards, resolutions of IAG, IAU and IUGG, IERS conventions, conventions of gravity missions (CHAMP, GRACE, GOCE), satellite altimetry, …
- Focus on IAG/GGOS products: CRS/CRF, TRS/TRF, EOP, GNSS orbits, gravity field, vertical reference systems and heights, …
- Assessment of the present status, identification of deficiencies, recommendations to resolve inconsistencies and gaps, …

  → Angermann D., Gruber T., Gerstl M., Heinkelmann R., Hugentobler U., Sánchez L., Steigenberger P.: GGOS Bureau of Products and Standards: Inventory of standards and conventions used for the generation of IAG products. In: Drewes H., Kuglitsch F., Adám J. (Eds.) The Geodesist's Handbook 2016. Journal of Geodesy 90(10), 1095-1156, 10.1007/s00190-016-0948-z, 2016

- Presently, an updated version of the BPS inventory in preparation: Update on general issues and numerical standards, ICRF2 → ICRF3, ITRF2008 → ITRF2014, EOP08C04 → EOP14C04, updates on GNSS orbits, components of the International Gravity Field Service (IGFS), and the International Height Reference System and Frame (IHRS/IHRF).

Numerical standards used within IAG

	semi-major axis a [m]	Geocentric Grav. Constant GM [10^{12}m^{3}s^{-2}]	Dyn. form factor J_2 [10^{-6}]	Earth's rotation ω [rad s^{-1}]	Normal potential U_0 or W_0 [m^{2}s^{-2}]
GRS80 (1979)	6 378 137	398.600 5	1 082.63	7.292 115	62 636 860.850
EGM2008	6 378 136.3	398.600 4415$^{(1)}$	1 082.635 9	7.292 115	62 636 856.0 (1998)
IERS Conv. (2010)	6 378 136.6$^{(2)}$	398.600 4418$^{(3)}$	1 082.635 9	7.292 115	62 636 856.0 (1998)
IERS Conv. (update 2017)	6 378 136.6$^{(2)}$	398.600 4418$^{(3)}$	1 082.635 9	7.292 115	62 636 853.4 (2015)
IAG Resol. No. 1 (2015)					62 636 853.4 (2015)

$^{(1)}$TT-compatible value; $^{(2)}$value given in zero-tide system; $^{(3)}$TCG-compatible value

BPS recommendations on numerical standards

- **REC 1**: The used numerical standards including time and tide systems must be clearly documented for all geodetic products.
- **REC 2**: The W_0 value issued by the IAG resolution No. 1 (2015) should be used as the conventional reference value for geodetic work.
- **REC 3**: The development of a new Geodetic Reference System GRS20XX based on best estimates of the major parameters is desired.

Endorsed as recommendations of the Unified Analysis Workshop 2017 (Paris)

Major activities of the GGOS-BPS

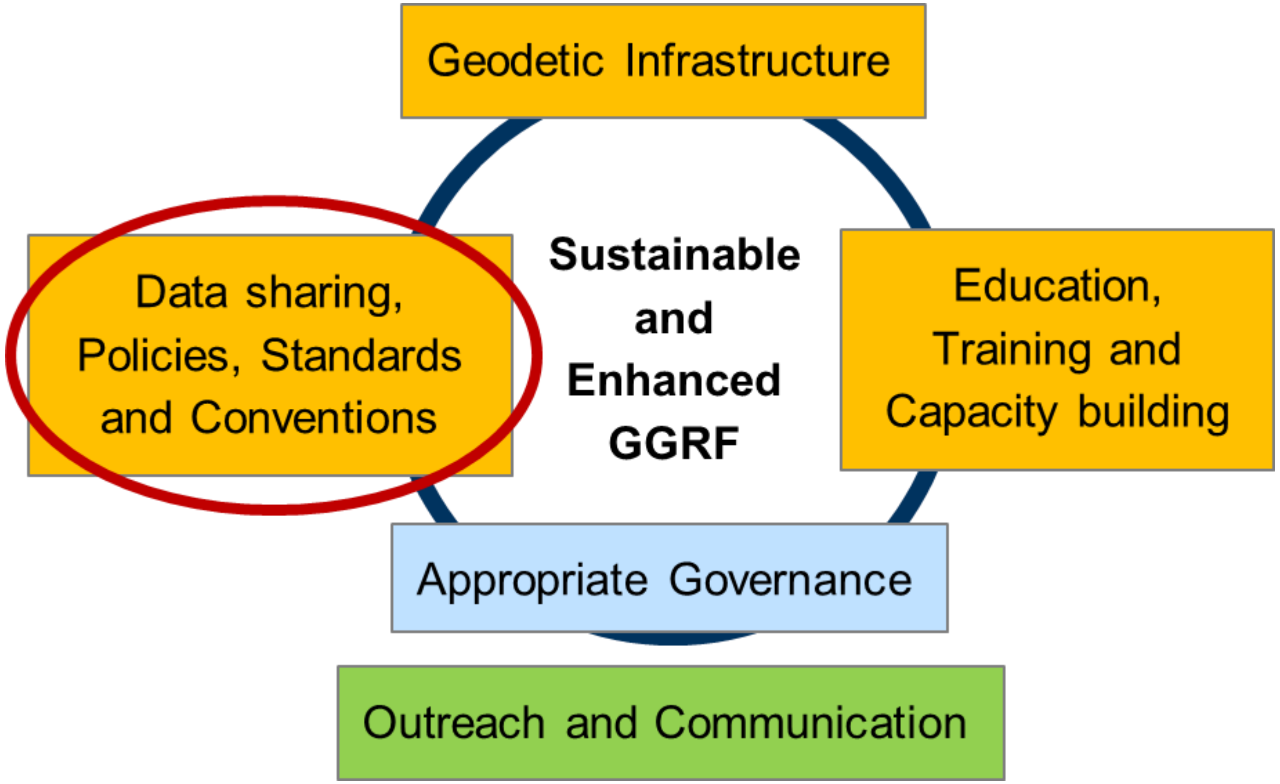
- Contribution to updating/re-writing/revising of the IERS Conventions, mainly to Chapter 1 “General definitions and numerical standards”
- IGFS contributes to Chapter 1
- Session on IERS Conventions at UAW Workshop in Paris, Oct 2019
- Re-writing scheduled 2019-2021, using web-based tools (GitLab)
- Updated chapters should be submitted to IERS Conventions Centre by June 2022
- Final version should be ready by Sep 2022

Chapter	Old Chapter #	Title	Position	Applicant
1	1	General definitions and numerical standards	Chapter Editor-in-Chief	Nick Stamatakos
			Chapter Expert	Detlef Angermann
			Assistant Chapter Expert	George Vergos^^ Riccardo (riccardo.barzagl
2	9	General relativistic models for space-time coordinates and equations of motion	Chapter Editor-in-Chief	Michael Efroimsky
			Chapter Expert	Sergei Klioner
			Assistant Chapter Expert	Sergei Kopeikin **
			Software Editor	Maria Davis
3	2	Celestial reference system and frame	Chapter Editor-in-Chief	Jean Souchay, Bryan Dorland
			Chapter Expert	Sebestian Lambert*
			Assistant Chapter Expert	Dmitry Pavlov
4	4	Terrestrial reference systems and frames	Chapter Editor-in-Chief	Dennis McCarthy, Frank Lemoine**.
			Chapter Expert	Zuheir Altamimi
			Assistant Chapter Expert	Xavier Collilieux
5	5	Transformation between the International Terrestrial Reference System and the Geocentric Celestial Reference System	Chapter Editor-in-Chief	José Ferrandiz, Nick Stamatakos
			Chapter Expert	
			Assistant Chapter Expert	Nick Stamatakos, Dennis McCarthy
			Software Editor	Maria Davis
6	5	Geopotential	Chapter Editor-in-Chief	John Ries, Srinivas Bettadpur, Erricos Pavlis
			Chapter Expert	Jean Paul Boy
			Assistant Chapter Expert	Dmitry Pavlov
7	7	Displacement of reference points	Chapter Editor-in-Chief	Erricos Pavlis
			Chapter Expert	Jean Paul Boy
			Assistant Chapter Expert	Nick Stamatakos, Dennis McCarthy
			Software Editor	Maria Davis
8	8	Tidal variations in the Earth's rotation	Chapter Editor-in-Chief	
			Chapter Expert	John Gipson.
			Assistant Chapter Expert	Christian Bizouard
			Software Editor	Maria Davis
9	9	Models for atmospheric propagation delays	Chapter Editor-in-Chief	
			Chapter Expert	
			Assistant Chapter Expert	Johannes Boehm^; Erricos Pavlis^
			Software Editor	Maria Davis
10	11	General relativistic models for propagation	Chapter Editor-in-Chief	
			Chapter Expert	Sergei Klioner
			Assistant Chapter Expert	Sergei Kopeikin **
			Software Editor	Maria Davis

Status of IERS Conventions Centre re-write staff
(Credit, N. Stamatakos, presented at IERS Directing Board meeting, April 7, 2019)

Major activities of the GGOS-BPS

- Contribution to the GGRF Working Group “Data sharing and development of standards”
- BPS director (D Angermann) is the IAG representative to this WG
- BPS compiled a summary on IAG standards and conventions for this WG.



Major activities of the GGOS-BPS

- Initiation of a document with the standards and conventions required for the realization of the International Height Reference System (IHRF).
- Joint work with GGOS Focus Area Unified Height System, IAG Commission 2 (Gravity Field), Inter-commission Committee on Theory, International Gravity Field Service (IGFS).
- Main result should be a document similar to the IERS conventions.

Basic agreements for the computation of station potential values as IHRS coordinates, geoid undulations and height anomalies within the Colorado 1 cm geoid experiment

Contributors: L. Sánchez[1], J. Ågren[2], J. Huang[3], Y.M. Wang[4], R. Forsberg[5]

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[2]Lantmäteriet, Swedish mapping, cadastral and land registration authority, Sweden
[3]Natural Resources Canada, Canada
[4]NOAA's National Geodetic Survey, USA
[5]National Space Institute, Denmark

Version 0.5, October 30, 2018

Preamble

During the business meeting of the JWG 0.1.2[1] held at IAG-IASPEI 2017 (Kobe, Japan), J. Ågren[2] and J. Huang[3] proposed to establish a strong interaction with the JWG 2.2.2 (the 1 cm geoid experiment). Aim of JWG 2.2.2 is the computation and comparison of geoid undulations using the same input data and the own methodologies/software of colleagues involved in the geoid computation. The comparison of the results should highlight the differences caused by disparities in the computation methodologies. In this frame, it was decided to extend the "geoid experiment" to the computation of station potential values as IHRS coordinates. With this proposal, NGS/NOAA agreed to provide terrestrial gravity data, airborne gravity, and digital terrain model for an area of about 500 km x 800 km in Colorado, USA. With these data, the different groups working on the determination of IHRF coordinates should compute potential values for some *virtual* geodetic stations located in that region. Afterwards, the results obtained individually should be compared with the Geoid Slope Validation Survey 2017 (GSVS17). In the same meeting, it was also agreed to standardise as much as possible the data processing to get as similar and compatible results as possible with the different methods. However, the definition of a "standard or unified" processing procedure/strategy is not suitable, because regions with different characteristics apply particular approaches. Therefore, at this first stage, we agreed to outline a set of basic (minimum) requirements to initiate the experiments for the computation of the potential values. The choice of the processing method is up to the gravity field

Major activities of the GGOS-BPS

- To contribute to the Committee on Essential Geodetic Variables (EGVs), which is associated to the BPS

  → Richard Gross presentation

Summary

- Common standards and conventions are of crucial importance for the generation of consistent geodetic products and should be consistently applied for processing geometric and gravimetric observations.
- The use of different standards (e.g., numerical constants, time and tide systems, loading models…) is a source for errors and inconsistencies of geodetic products.
- Users (in particular those who are NOT specialized in geodesy) may have difficulties to use geodetic products correctly and to know exactly whereupon they refer to.
- The product-based inventory compiled by the BPS identifies some deficiencies regarding standards and conventions and provide recommendations how to resolve inconsistencies and gaps. This should be a living document and should be kept up-to-date.