Deutsches Geodätisches Forschungsinstitut (DGFI-TUM)
Technische Universität München

GGOS Bureau of Products and Standards

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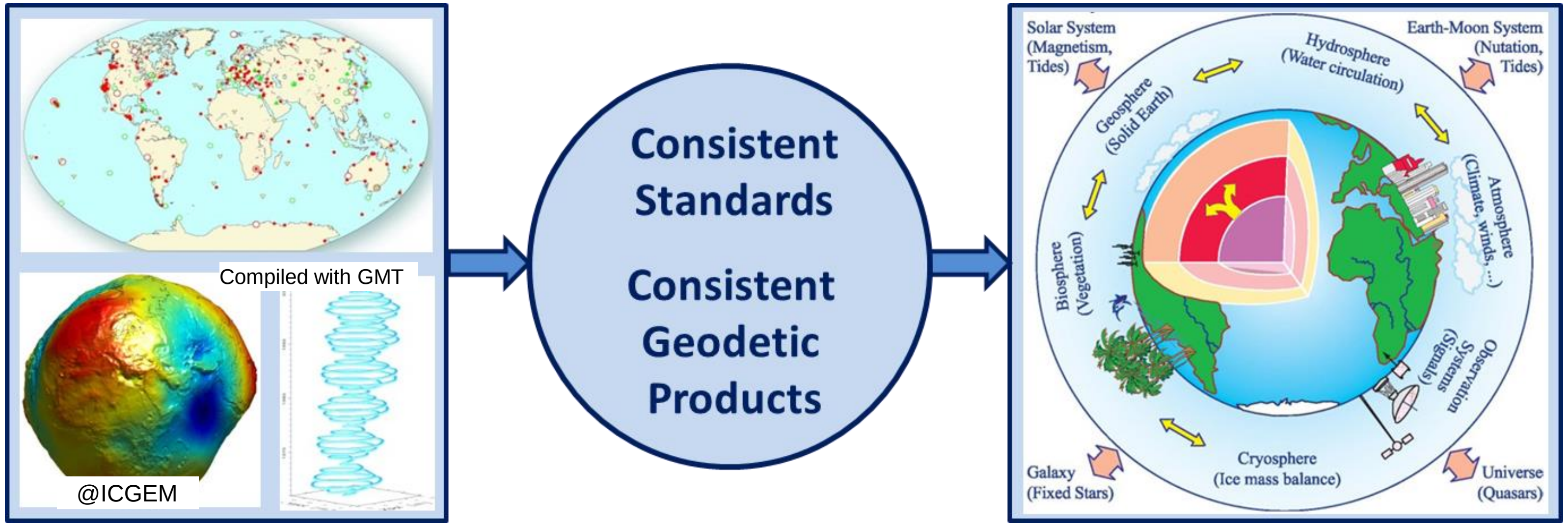
GGOS Days 2022, Munich, Germany, November 14-15, 2022

Bureau of Products and Standards (BPS)

The BPS supports GGOS in its key goal to provide consistent products describing the geometry, rotation and gravity field of the Earth.

Objectives

- contact and coordinating point for homogenization of IAG standards and products
- keep track of the adopted geodetic standards and conventions across all IAG components
- stimulate the development of new geodetic products, needed for Earth sciences and society
- describe and promote geodetic products, and contribute to GGOS outreach activities



After Drewes (2007), IAG Symposia 130

BPS organizational structure

- The BPS is chaired by Technical University of Munich
- BPS staff:
  - D. Angermann (Director), T. Gruber (Deputy Director), M. Gerstl (retired), R. Heinkelmann (GFZ), U. Hugentobler (TUM), L. Sánchez (TUM), P. Steigenberger (DLR)
- GGOS components associated to the BPS
  - Committee “**Contributions to Earth System Modelling (ESM)**” (Chair: M. Thomas)
  - Committee “**Definition of Essential Geodetic Variables (EGVs)**” (Chair: R. Gross)
  - Working Group **“Towards a consistent set of parameters for the definition of a new GRS**” (Chair: U. Marti)
- Associated members of the BPS:
  - ~ 15 representatives designated by the IAG Services and other relevant entities involved in geodetic standards and products

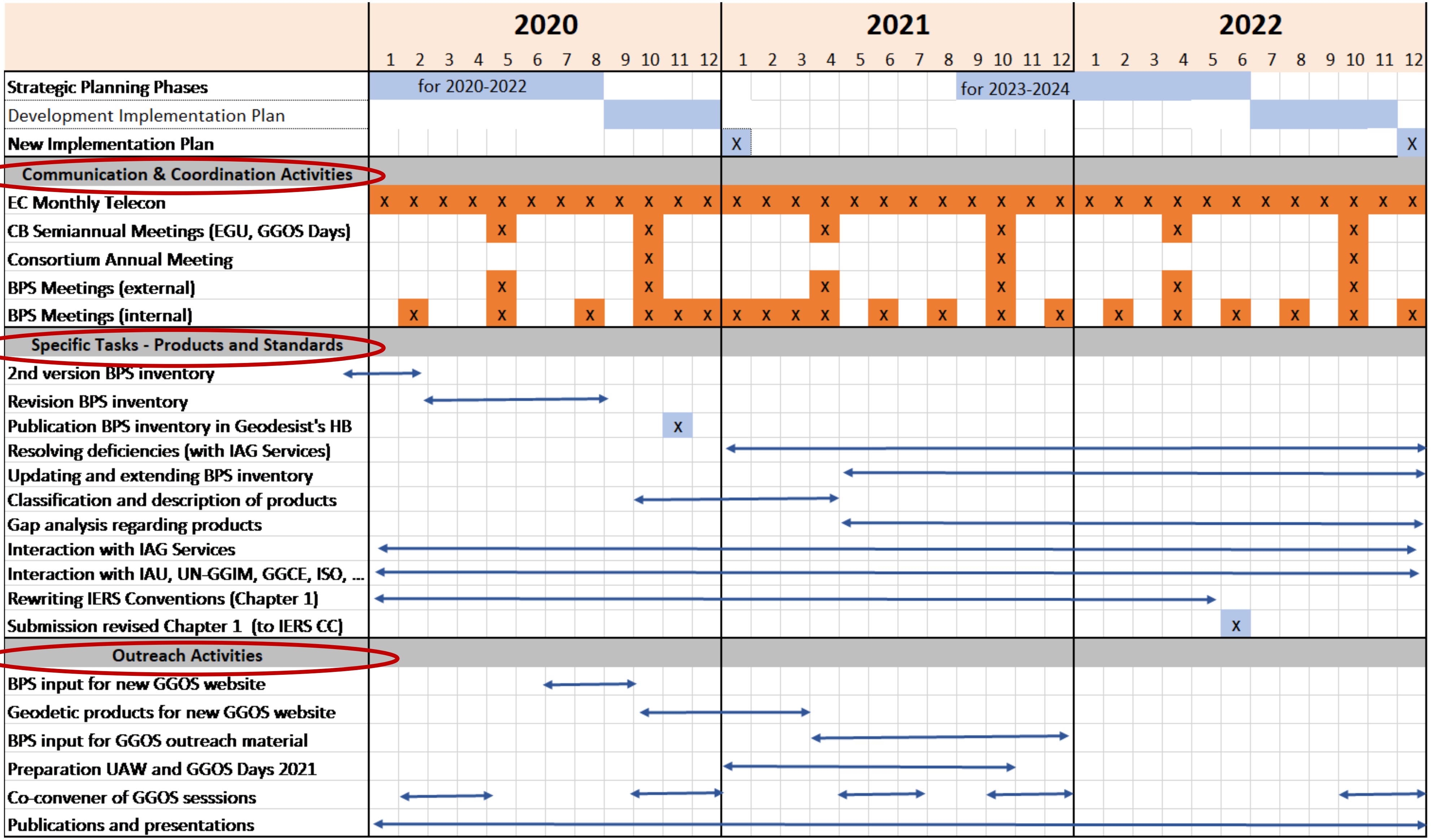
Representatives of IAG Services and other entities

R. Heinkelmann, Germany	International Earth Rotation and Reference Systems Service (IERS)	geometry
N. Stamatakos, USA	International Earth Rotation and Reference Systems Service (IERS)	
U. Hugentobler, Germany	International GNSS Service (IGS)	
E. Pavlis, USA	International Laser Ranging Service (ILRS)	
J. Gipson, USA	International VLBI Service for Geodesy and Astrometry (IVS)	
P. Štěpánek, Czech Republic	International DORIS Service (IDS)	
R. Barzaghi, Italy	International Gravity Field Service (IGFS)	gravity
S. Bonvalot, France	Bureau Gravimétrique International (BGI)	
M. Reguzzoni, Italy	International Service for the Geoid (ISG)	
E. S. Ince, Germany	International Center for Global Earth Models (ICGEM)	
K. M. Kelly, Germany	International Digital Elevation Model Service (IDEMS)	
H. Wzointek, Germany	International Geodynamics and Earth Tide Service (IGETS)	
J. Kusche, Germany	Representative of gravity community	
To be defined	IAU Commission A3 Representative	other entities
M. Craymer, USA	Chair of Control Body for ISO Geodetic Registry Network	
L. Hothem, USA	Vice-Chair of Control Body for ISO Geodetic Registry Network	
S. Rózsa, Hungary	IAG Communication and Outreach Branch	
M. Sehnal, Austria	GGOS Coordinating Office	

Interaction within IAG and with external stakeholders (IAU, ISO, UN GGIM)

- IAG Services (Analysis Coordinators and other Service representatives)
- IERS Conventions Centre (IERS CC)
  - IERS CC representative to BPS: N. Stamatakos (USNO)
  - BPS representative to IERS CC: D. Angermann
- International Astronomical Union (IAU)
  - IAU Commission A3 “Fundamental Standards” representative to BPS: to be defined
  - BPS representative to IAU: R. Heinkelmann
- International Standards Organization (ISO)
  - Control Body for ISO Geodetic Registry representative to BPS: M. Craymer (Canada), L. Hothem (USA)
  - IAG representative to ISO: D. Angermann
- UN GGIM Subcommittee on Geodesy (SCoG) and Global Geodetic Centre of Excellence (GGCE)
  - IAG representative to UN GGIM SCoG “Working Group: Data sharing and development of standards”: D. Angermann
  - SCoG/GGCE representative to BPS: to be defined

BPS Implementation Plan 2020-2022



BPS Inventory of Standards and Conventions

Inventory of standards and conventions used for the generation of IAG products (*Angermann et al, 2016 and 2020*)

- Introduction (Chapter 1)
- GGOS Bureau of Products and Standards (Chapter 2)
- Evaluation of numerical standards (Chapter 3)
- Product-based review (Chapter 4)
  - Six geodetic products/topics have been reviewed (see right)
  - Consideration of other products (e.g., atmosphere products, sea level, ice melting, terrestrial water storage, …) (open for discussion)
- Assess the present status, identify gaps and deficiencies, provide recommendations (interaction with IAG Services, IERS Conventions Center, UN-GGIM SCoG, GGCE, IAU, ISO, …)
- Goal: Improve consistency of geodetic products

Contents

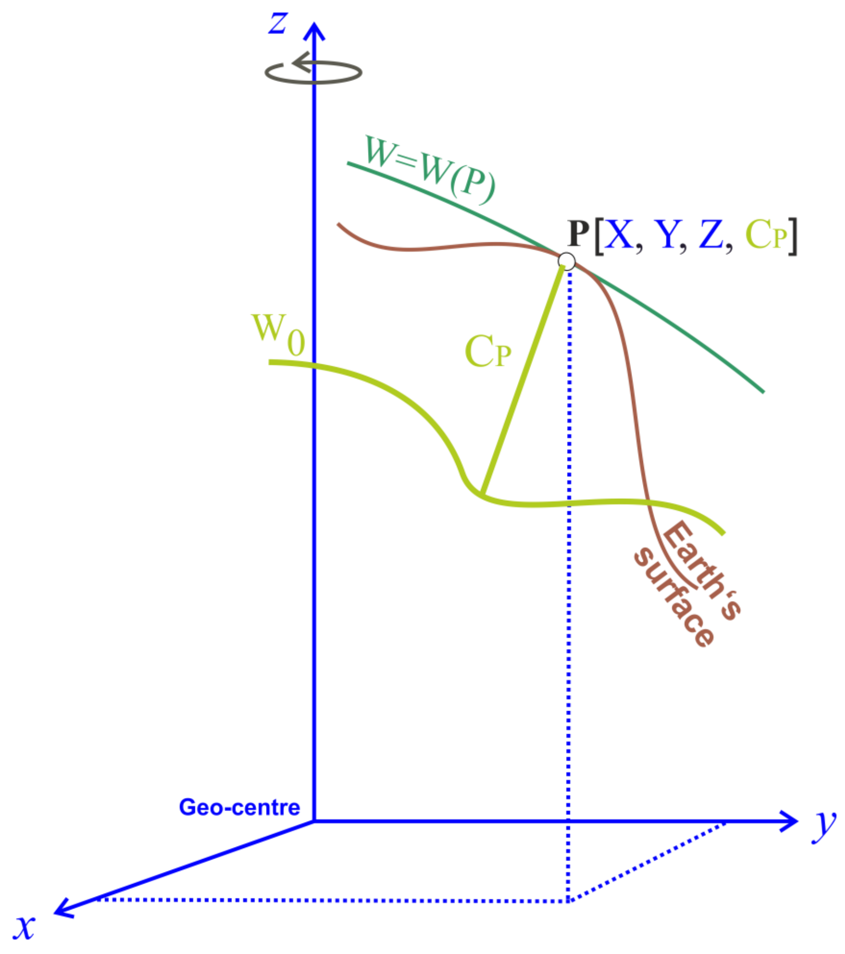
Angermann D., Gruber T., Gerstl M., Heinkelmann R., Hugentobler U., Sánchez L., Steigenberger P. (2020): **GGOS Bureau of Products and Standards: Inventory of standards and conventions used for the generation of IAG products**. The Geodesist's Handbook 2020, Eds: Poutanen M., Rózsa S., Journal of Geodesy, https://doi.org/10.1007/s00190-020-01434-z.

BPS activities concerning IERS Conventions update

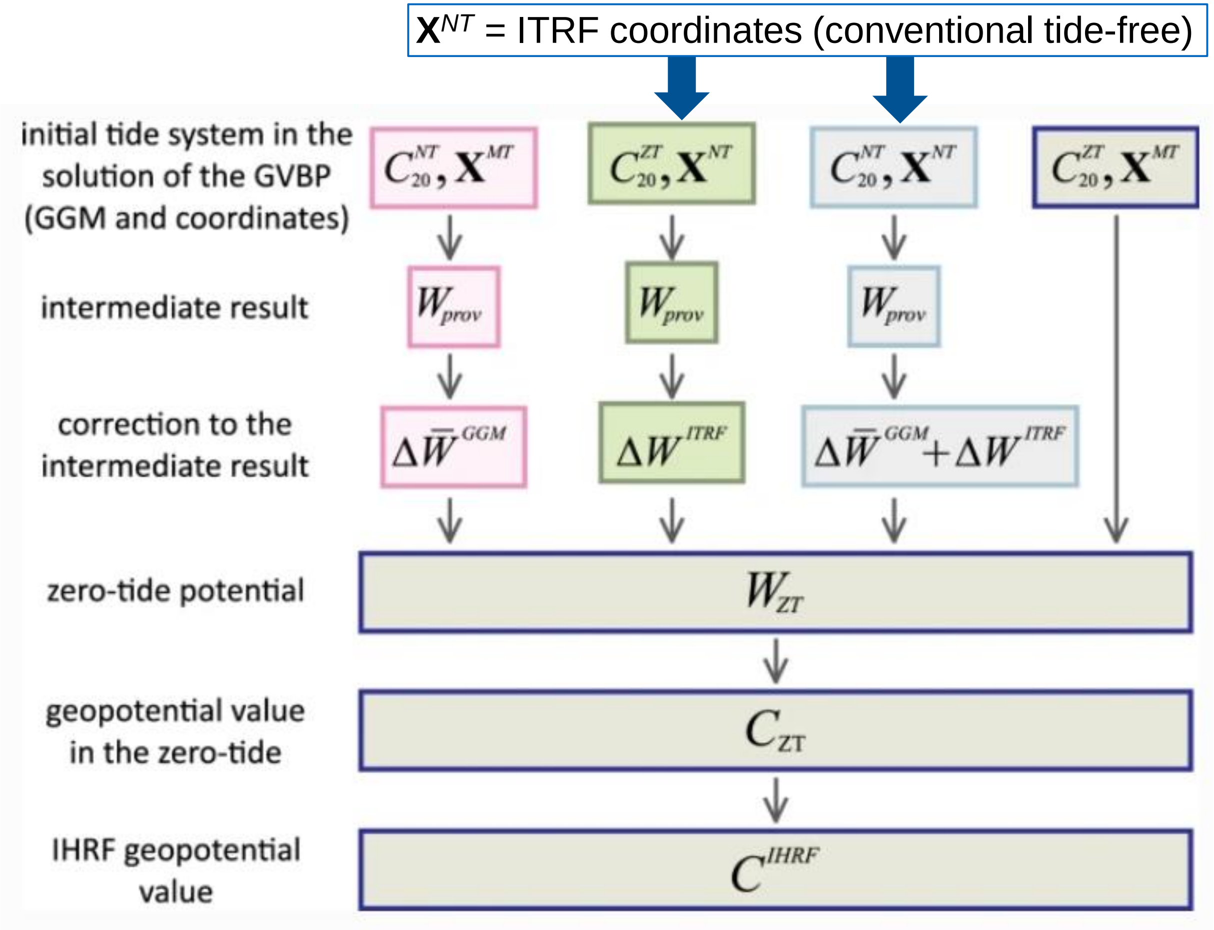
- Together with the IERS Conventions Center (Nick Stamatakos), the BPS organized a Session "**Standards, Conventions, and Formats**" in the framework of the Unified Analysis Workshop 2022 (Thessaloniki, Greece, October 21-23, 2022)
- The focus of this session was on the updating of the IERS Conventions
- Five presentations on various chapters/topics of the IERS Conventions, followed by fruitful discussions
- The BPS contributes to the rewriting/revising of the IERS Conventions, mainly in the function as *Chapter Expert* for Chapter 1
- Chapter 1 "**General definitions and numerical standards**"
  - Section 1.1 Permanent Tide
  - Section 1.2 Numerical Standards

Section 1.1 Permanent Tide

- **Some facts:**
  - **ITRF coordinates** are in the ***conventional tide-free*** system
  - **Global gravity models** can be in the ***tide-free*** or the ***zero-tide*** system
  - The **gravity potential** can be computed either in the ***tide-free*** or the ***zero-tide system***, but not in the mean-tide system
  - The new International Height Reference System (IHRS) prescribes **IHRF coordinates** in the ***mean-tide system*** (see IAG Resolution 2015, No. 1), to support oceanographic and hydrographic modelling (essential for monitoring global change phenomena such as sea level rise)
- **Principle of the IHRS/IHRF**:
  - Precise determination of gravity potential values at positions defined by ITRF coordinates (see figure)
- **Solution for IHRF coordinates:**
  - Defining a conventional procedure to get IHRF coordinates in the ***mean-tide system*** using ***conventional tide-free ITRF coordinates*** as input and computing the gravity potential in the ***tide-free*** or in ***zero-tide system***



Treatment of the permanent tide in heights



Correction to gravity potential when using tide-free ITRF coordinates:

$$\Delta W^{ITRF}(\varphi) \approx \left(-\gamma_0(\varphi)\right) \cdot h_T(\varphi) = -0.5901 + 1.7475 \cdot \sin^2\varphi + 0.0273 \cdot \sin^4\varphi \left[\mathrm{m^2 s^{-2}}\right]$$

Correction to gravity potential when using tide-free global gravity models:

$$\Delta \bar{W}^{GGM}(\varphi, h) = k_{20} \cdot \left(1 - \frac{3h}{a}\right) \cdot (0.9722 - 2.8673 \cdot \sin^2\varphi - 0.0690 \cdot \sin^4\varphi) \left[\mathrm{m^2 s^{-2}}\right]$$

Conversion of geopotential values from the zero-tide to the mean-tide system:

$$C_{MT} := C_{ZT} - W_{T0}$$

$$W_{T0} \approx \bar{W}_T(\varphi, 0) = 0.9722 - 2.8841 \cdot \sin^2\varphi - 0.0195 \cdot \sin^4\varphi \left[\mathrm{m^2 s^{-2}}\right]$$

More details in:

→ Mäkinen, J. (2021). *The permanent tide and the International Height Reference Frame IHRF*. J Geod 95, 106, https://doi.org/10.1007/s00190-021-01541-5

→ Sánchez et al. (2021), *Strategy for the realisation of the IHRS*, J Geod 95, 33 (2021). https://doi.org/10.1007/s00190-021-01481-0

Section 1.2 Numerical Standards

(Table taken from IERS Conventions)

Table 1.1: IERS numerical standards.

	Constant	Value	Uncertainty	Ref.	Description
		Natural defining constants			
CODATA	c	$299792458\ \mathrm{ms}^{-1}$	Defining	[1]	Speed of light
		Auxiliary defining constants			
IAU	k	$1.720209895 \times 10^{-2}$	Defining	[2]	Gaussian gravitational constant
IAU	L_G	$6.969290134 \times 10^{-10}$	Defining	[3]	1−d(TT)/d(TCG)
IAU	L_B	$1.550519768 \times 10^{-8}$	Defining	[4]	1−d(TDB)/d(TCB)
IAU	TDB_0	-6.55×10^{-5} s	Defining	[4]	TDB−TCB at JD 2443144.5 TAI
IAU	θ_0	0.7790572732640 rev	Defining	[3]	Earth Rotation Angle (ERA) at J2000.0
IAU	$d\theta/dt$	1.00273781191135448 rev/UT1day	Defining	[3]	Rate of advance of ERA
		Natural measurable constant			
CODATA	G	$6.67428 \times 10^{-11}\ \mathrm{m^3kg^{-1}s^{-2}}$	$6.7 \times 10^{-15}\ \mathrm{m^3kg^{-1}s^{-2}}$	[1]	Constant of gravitation
		Body constants			
DE421	$GM_\odot{}^{\#}$	$1.32712442099 \times 10^{20}\ \mathrm{m^3s^{-2}}$	$1 \times 10^{10}\ \mathrm{m^3s^{-2}}$	[5]	Heliocentric gravitational constant
DE421	$J_{2\odot}$	2.0×10^{-7}	(adopted for DE421)	[5]	Dynamical form factor of the Sun
DE421	μ	0.0123000371	4×10^{-10}	[6]	Moon-Earth mass ratio
		Earth constants			
Groten 2004	$GM_\oplus{}^{\dagger}$	$3.986004418 \times 10^{14}\ \mathrm{m^3s^{-2}}$	$8 \times 10^{5}\ \mathrm{m^3s^{-2}}$	[7]	Geocentric gravitational constant
Groten 2004	$a_E{}^{\dagger\ddagger}$	6378136.6 m	0.1 m	[8]	Equatorial radius of the Earth
Groten 2004	$J_{2\oplus}{}^{\ddagger}$	1.0826359×10^{-3}	1×10^{-10}	[8]	Dynamical form factor of the Earth
Groten 2004	$1/f^{\ddagger}$	298.25642	0.00001	[8]	Flattening factor of the Earth
Groten 2004	$g_E{}^{\dagger\ddagger}$	$9.7803278\ \mathrm{ms^{-2}}$	$1 \times 10^{-6}\ \mathrm{ms^{-2}}$	[8]	Mean equatorial gravity
2017/11/06 IAG 2015	W_0	$62636853.4\ \mathrm{m^2s^{-2}}$	$0.02\ \mathrm{m^2s^{-2}}$	[10]	Potential of the geoid
	$R_0{}^{\dagger}$	6363672.6 m	0.1 m	[8]	Geopotential scale factor ($GM_\oplus/W_0$)
	H	3273795×10^{-9}	1×10^{-9}	[9]	Dynamical flattening
		Initial value at J2000.0			
	ϵ_0	84381.406″	0.001″	[4]	Obliquity of the ecliptic at J2000.0
		Other constants			
IAU	$au^{\dagger\dagger}$	$1.49597870700 \times 10^{11}$ m	3 m	[6]	Astronomical unit
IAU	L_C	$1.48082686741 \times 10^{-8}$	2×10^{-17}	[3]	Average value of 1−d(TCG)/d(TCB)

TCB-compatible value, computed from the TDB-compatible value in [5].

† The value for $GM_\oplus$ is TCG-compatible. For a_E, g_E and R_0 the difference between TCG-compatible and TT-compatible is not relevant with respect to the uncertainty.

‡ The values for a_E, $1/f$, $J_{2\oplus}$ and g_E are "zero tide" values (see the discussion in Section 1.1 above). Values according to other conventions may be found in reference [8].

†† TDB-compatible value. An accepted definition for the TCB-compatible value of au is still under discussion.

[1] Mohr *et al.*, 2008.
[2] Resolution adopted at the IAU XVI General Assembly (Müller and Jappel, 1977), see http://www.iau.org/administration/resolutions/general_assemblies/
[3] Resolution adopted at the IAU XXIV General Assembly (Rickman, 2001), see http://www.iau.org/administration/resolutions/general_assemblies/
[4] Resolution adopted at the IAU XXVI General Assembly (van der Hucht, 2008), see http://www.iau.org/administration/resolutions/general_assemblies/
[5] Folkner *et al.*, 2008.
[6] Pitjeva and Standish, 2009.
[7] Ries *et al.*, 1992. Recent studies (Ries, 2007) indicate an uncertainty of $4 \times 10^5\ \mathrm{m^3s^{-2}}$.
[8] Groten, 2004.
[9] Value and uncertainty consistent with the IAU2006/2000 precession-nutation model, see (Capitaine *et al.*, 2003).
2017/11/06 [10] Resolution No. 1 adopted at the IAG (2015), see https://iag.dgfi.tum.de/fileadmin/IAG-docs/IAG_Resolutions_2015.pdf

BPS recommendations for updates:

- IAU Res. B1.9 (2000): $\boldsymbol{L_G}$ declared as defining constant => $\boldsymbol{L_G}$ should not change with new updates of $\boldsymbol{W_0}$ ($L_G=W_0/c_2$)
- IAU Res. B2 (2012): Gaussian gravitational constant ***k*** to be deleted from the system of astronomical constants
- IAU Res. B2 (2012): astronomical unit (**au**) => exact value
- $\boldsymbol{L_C}$ is a derived quantity => should be deleted from the table
- CODATA (2018): New value ***G*** = $6.67439 \times 10^{-11}\ \mathrm{m^3\ kg^{-1}\ s^{-2}}$
- New JPL planetary and lunar ephemerides (DE440 and DE441, Park et al. 2021)
- New value: $\boldsymbol{GM_O} = 1.32712440042 \times 10^{20}\ \mathrm{m^3\ kg^{-1}\ s^{-2}}$ (Piteva 2015)

Section 1.2 Numerical Standards

*Table 1.2: Parameters of the Geodetic Reference System **GRS80*** *(taken from IERS Conventions 2010)*

Constant	Value	Description
$GM_\oplus$	3.986005×10^{14} m^{3}s^{-2}	Geocentric gravitational constant
a_E	6378137 m	Equatorial radius of the Earth
$J_{2\oplus}$	1.08263×10^{-3}	Dynamical form factor
ω	7.292115×10^{-5} rads^{-1}	Nominal mean Earth's angular velocity
$1/f$	298.257222101	Flattening factor of the Earth

- GRS80 (still) provides the conventional values (IUGG 1979 / IAG 1980)
- GRS80 is widely used in many geodetic applications and it is adopted by many countries

	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

Table: Comparison of numerical standards

(taken from BPS Inventory; Angermann et al. 2020)

- Geodetic work is based on different numerical standards (e.g., GRS80, WGS84, IERS Conventions, EGM2008, …)
- A unique set of numerical standards **does not exist**, also different time and tide systems are in use within IAG
- These inconsistencies are a potential source of errors when combining different products
- GGOS WG "Towards a consistent set of parameters for the definition of a new GRS" (=> presentation Urs Marti)

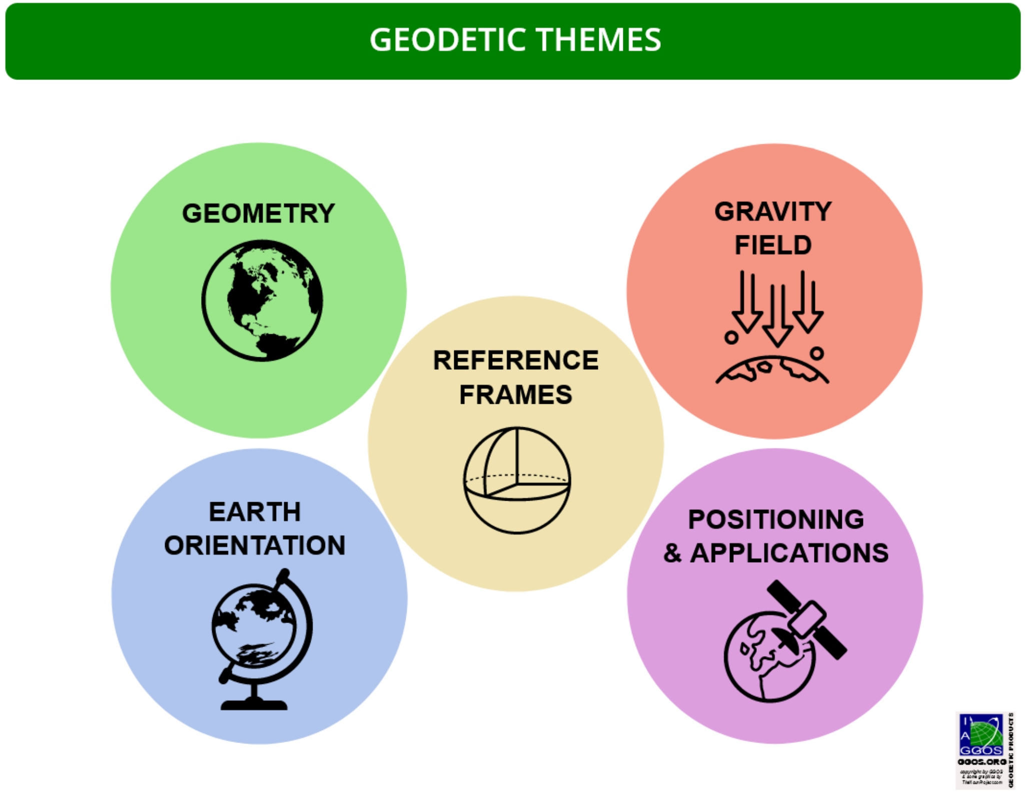
BPS recommendations for IERS Conventions Chapter 1 updates

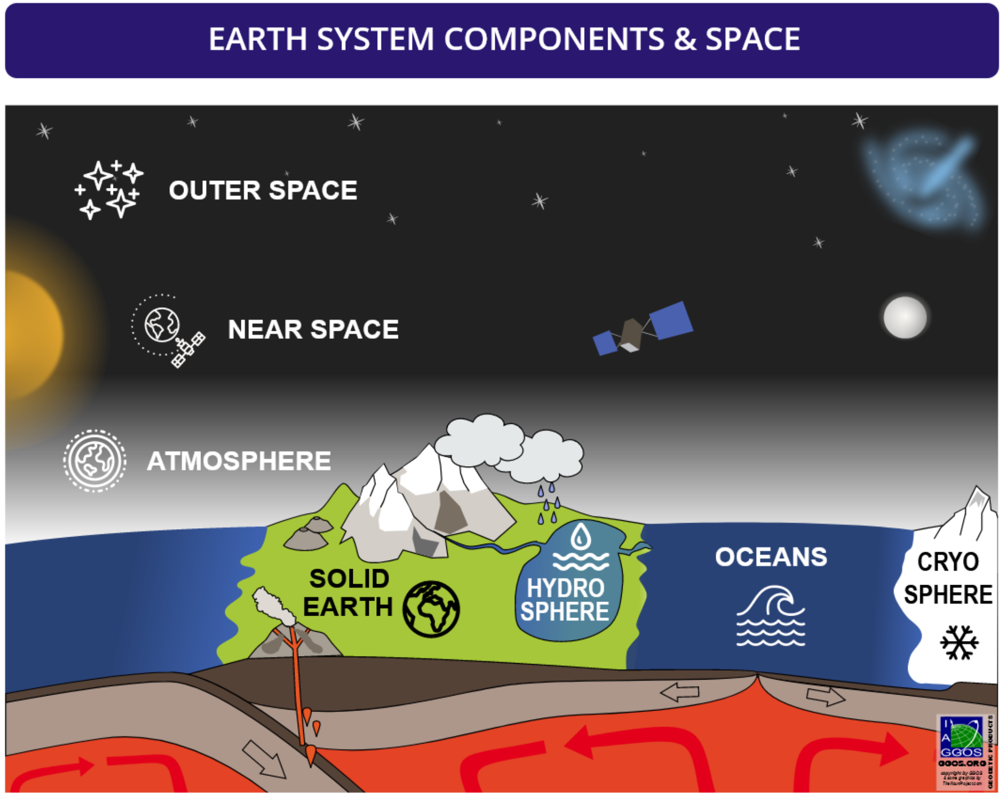
- Section 1.1 Permanent Tide
  - Include the IAG Resolution (2015) on the International Height Reference Frame (IHRF) demanding the mean-tide system for heights
  - Update references (e.g., Drewes et al., 2016; Ihde et al., 2017; Mäkinen, 2021; Sanchez et al., 2021
  - Add a short paragraph or a footnote summarizing the strategy for the implementation of the IHRF concerning the handling of the permanent tide (needs to be discussed within the IERS)
- Section 1.2 Numerical Standards
  - Update Table 1.1 “IERS numerical standards“ (see slide 11), íncluding the corresponding descriptions
  - Update resolutions (e.g., IAG 2015, IAU 2012) and references (e.g., Piteva 2015, CODATA 2018, Park et al., 2021)
- General recommendations of the BPS
  - **REC-1**: The used numerical standards including time and tide systems must be clearly documented for all geodetic products (*IAG/GGOS*)
  - **REC-2**: The BPS recommends that the necessity of a new Geodetic Reference System (GRS) should be further clarified (WG: *Urs Marti*)

Classification and description of geodetic products

Two classifications for geodetic products:

- ***Geodetic themes***: Reference frames, geomety, Earth orientation, gravity field, positioning and applications
- ***Earth system components and space***: Outer and near space, atmosphere, hydrosphere, oceans, cryosphere, and solid Earth





Angermann D., Gruber T., Gerstl M., Heinkelmann R., Hugentobler U., Sánchez L., Steigenberger P., Gross R., Heki K., Marti U., Schuh H., Sehnal M., Thomas M.: **GGOS Bureau of Products and Standards: Description and Promotion of Geodetic Products**. In: (Eds. J. Freymueller, L. Sánchez), IAG Symposia, 10.1007/1345_2022_144, 2022

List of geodetic products and “appetizer“ questions (some examples)

Reference Frames

- Height Reference Frame
- Celestial Reference Frame
- Gravity Reference Frame
- Terrestrial Reference Frame

How can we link Earth and space?

How can we provide a stable reference for measuring changes of our planet?

Geometry

- Surface Deformation Models
- Ocean Topography Models
- Sea Level Change
- Digital Elevation Model
- Ice Sheets & Glaciers – Variations
- Station Positions & Variations
- Tide Gauge Records
- Sea Surface Heights

Why is the Earth‘s surface in constant change?

How fast is the sea level rising?

How fast is the ice being lost in Greenland and Antarctica?

How can the height of oceans be observed?

Earth Orientation

- Earth Orientation Parameters

Why are the days getting longer and the Earth is wobbling?

Gravity Field

- Global Gravity Field – Models
- Gravity Field – Temporal Variations
- Terrestrial Gravity Data
- Regional / Local Geoid Models
- Ice Sheets & Glaciers – Variations
- Height Systems

Why is the Earth‘s gravity field variable?

What is a geoid and why is it needed?

Why are height systems so important?

Positioning & Applications

- Thermosphere
- Ionosphere
- Lower Neutral Atmosphere
- Atmospheric Products
- GNSS Satellite Orbits and Clocks

How does the atmosphere influence low-flying satellites?

How can geodesy contribute to weather prediction?

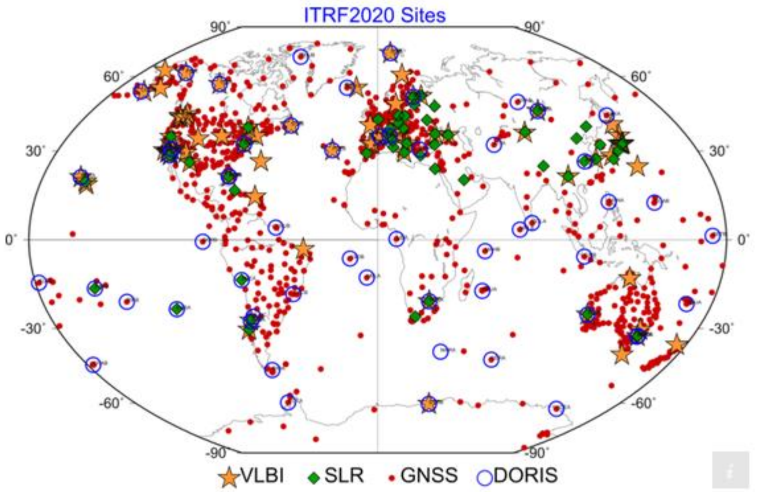
GFZ Helmholtz-Zentrum Potsdam DLR

Product descriptions at GGOS Website (www.ggos.org)

Terrestrial Reference Frame

How can we provide a stable reference for measuring changes of our planet?

The International Association of Geodesy (IAG) recommends the International Terrestrial Reference Frame (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 (see IAG Resolution No. 1, 2019). The importance of geodetic reference frames has been recognized by the United Nations, too. In February 2015, the UN General Assembly adopted its first geospatial resolution "A Global Geodetic Reference Frame for Sustainable Development".



ITRF station distribution [Source: Altamimi et al.]

Read More ...

- 23 product descriptions finished
- Further descriptions will follow

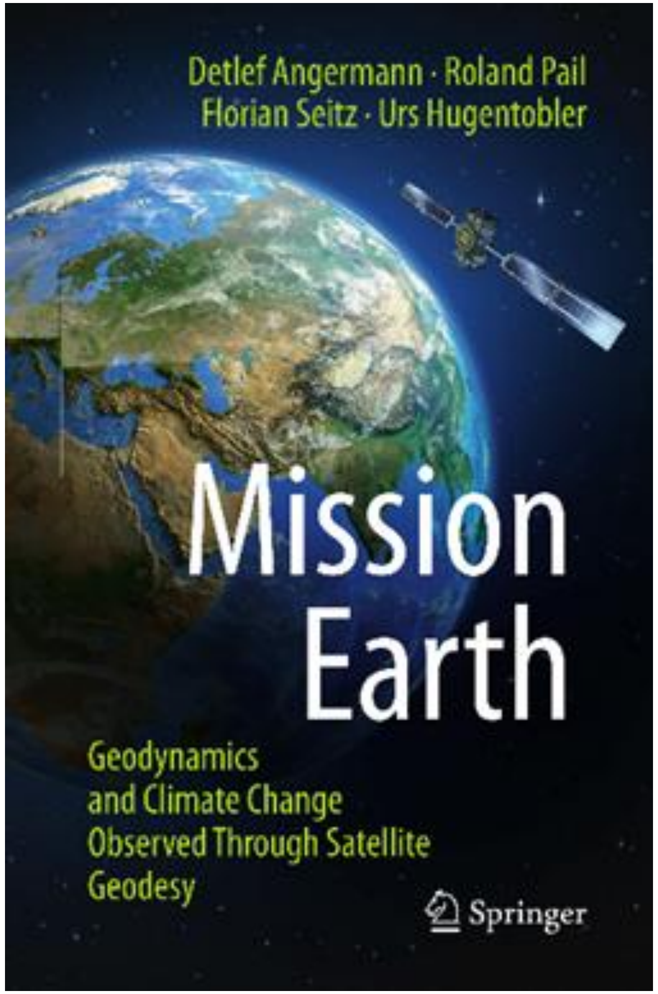
Status: Oct. 2022

Top Products	Visits
Sea Surface Heights	2147
EOP – Earth Orientation Parameters	1980
CRF - Celestial Reference Frame	1711
TRF – Terrestrial Reference Frame	1668
GNSS Satellite Orbits and Clocks	1312
GRF - Gravity Reference Frame	934
DEM – Digital Elevation Model	896
Height Systems	871

Final remarks

- The work of the BPS, and of GGOS in general, is built upon the foundation provided by the IAG Services and the other IAG Components.
- The BPS serves as a GGOS component to identify and harmonize discrepancies between the standards and conventions used within IAG for the generation of geodetic products.
- It supports IAG in its goal to obtain geodetic products of highest accuracy and consistency, and in making them easier findable and more visible to other disciplines and to society.
- Thanks to a strong collaborative work between the BPS, the GGOS Coordinating Office, the GGOS Science Panel, and the IAG Services, it has been possible to create a comprehensive description of the different geodetic products for the GGOS website.
- With such an information platform and central access point for geodetic products, GGOS contributes to make geodesy more visible for its beneficial products.
- And finally, the classification and description of geodetic products could also be a first step towards the definition of Essential Geodetic Variables (=> presentation: Richard Gross)

Mission Earth – Geodynamics and Climate Change Observed Through Satellite Geodesy



- **Geodesy - The science of measuring the Earth, presented in an exciting and easy to understand way**
- **Illustrative examples from satellite navigation to climate change**
- **How geodesy has become an integral part of our daily life**

With interview contributions by Günter Hein, Harald Lesch and Stefan Rahmstorf

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