Definition of Essential Geodetic Variables (EGV)

Contribution of Geodesy to Earth Observation

White Paper by
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Foreword

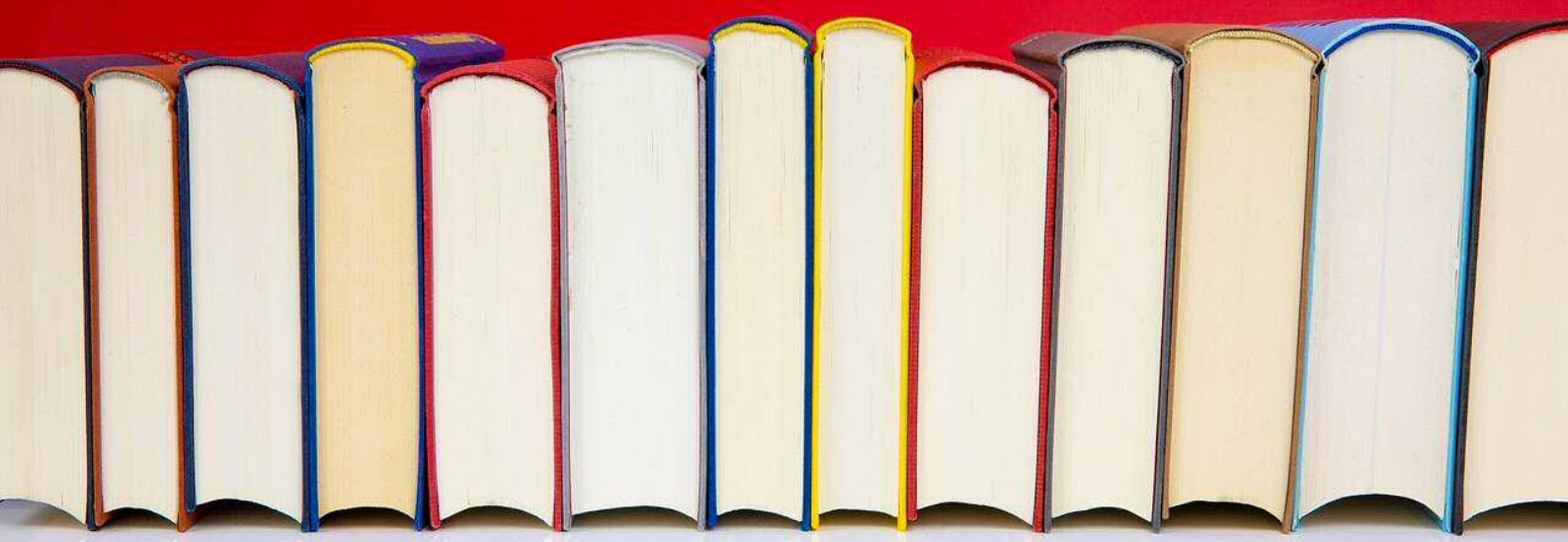
A cornerstone in the implementation of the GGOS Strategic Plan 2024-2034 is the definition of Essential Geodetic Variables (EGVs) to highlight the contribution of geodesy to Earth system monitoring. Essential Variables (EVs) are specific measurements or observations that are critical for understanding, monitoring and predicting changes in complex systems such as the Earth's climate, environment or socio-economic conditions. These variables are selected on the basis of their significant impact on these systems, their ability to provide actionable information and their usefulness in supporting scientific research, decision-making and policy development.

The Global Climate Observing System (GCOS) was the first community to introduce the concept of EVs, the Essential Climate Variables (ECVs), which have been widely adopted by the scientific and policy communities. Subsequently, the Global Ocean Observing System (GOOS) defined a complementary set of Essential Ocean Variables (EOVs) with standards aligned with the ECVs. Similarly, the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), a partner of the Biodiversity Observing Network of the Group on Earth Observations (GEO BON), has initiated the definition of Essential Biodiversity Variables (EBVs). There are currently other ongoing initiatives to introduce additional sets of EVs, not only to describe the Earth System, but also the socio-economic system, including for example urban development, energy and minerals, health, agriculture, etc.

Following the same arrangement of GCOS and GOOS, which defined the ECVs and EOVs, respectively, the Global Geodetic Observing System (GGOS) of the International Association of Geodesy (IAG) is working on the definition of the essential geodetic variables. This document presents the first concept for the definition of EGVs. This concept considers 18 EGVs based on 54 geodetic products. The products represent measurable parameters needed to evaluate the EGVs. As the different observing systems GGOS, GCOS and GOOS observe components of the same Earth, there are some essential variables that are common to all three. In such cases, geodesy makes a significant contribution to the characterization of these variables and complements or underpins the products provided by the other observing systems. Another set of essential variables are of a purely geodetic nature and are therefore defined for the first time in this document.

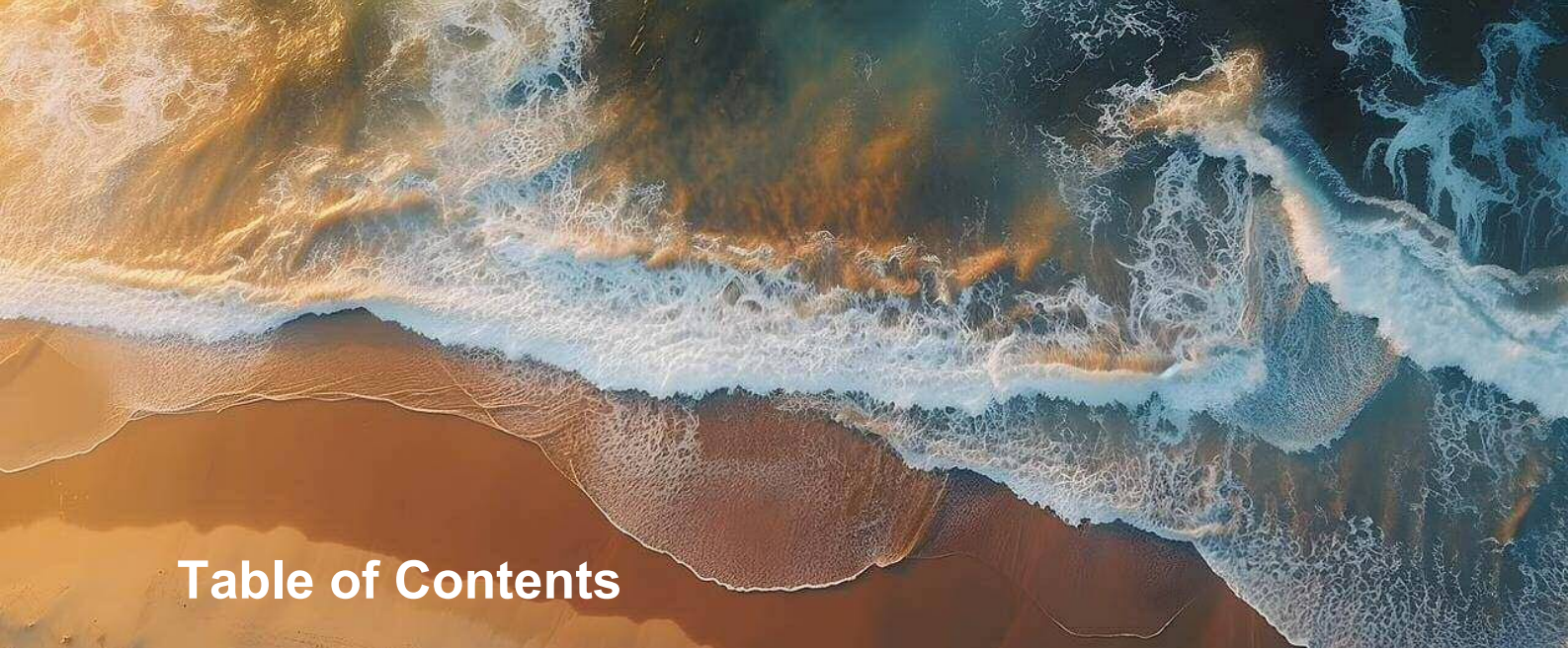
To clearly define essential variables, it is important to first understand the terms *essential* and *variable*. *Essential* means something that is absolutely necessary, indispensable, or fundamental to the core of a concept. A *variable* is considered essential if it significantly enhances the reliability and accuracy of desired outcomes. It may also be deemed essential if it provides critical insights relevant to a specific objective, even if it is not directly measurable. The *essentiality* of a variable may vary according to the needs of different communities or audiences, such as those in the scientific or policy-making communities. Any variable may be considered essential by someone or for the achievement of a particular goal, making the definition of essential variables inherently subjective. Developing these definitions requires a structured process that balances collective interests and ideally secures international recognition. To this end, it is imperative to circulate this document widely and gather feedback from the geodetic community as a whole. The first step in this process is to establish a consensus on a catalogue of Essential Geodetic Variables (EGVs) and their supporting products. Once broad agreement is reached, the next phase will involve defining the requirements for geodetic products to support the EGVs. This effort will also include identifying responsible stewards for each EGV.

Community participation is being encouraged through review by or consultation with the GGOS Science Panel, the GGOS Governing Board, the IAG Executive Committee and the IAG key components (Services, Commissions, Inter-Commission Committees, Projects). Following their feedback, a broader public review will be initiated, taking into account relevant stakeholders and the global geodetic community to achieve a general consensus on the EGVs. This document already includes feedback from the GGOS Science Panel and the GGOS Governing Board. It is now time for review by the IAG Executive Committee and IAG Components.



Document History

Version	Date	Changes
1.0	02-02-2024	▪ Initial version.
2.0	19-02-2024	▪ Minor update of chapters 1 to 3.2. ▪ Chapter 3.3 added.
3.0	08-04-2024	▪ Minor update of all chapters with inclusion of some new geodetic products. ▪ Version given to the GGOS Science Panel for review.
4.0	01-08-2024	▪ Update including feedback from the GGOS Science Panel Members.
5.0	01-10-2024	▪ Minor edits. ▪ Version given to the GGOS Governing Board for review.
6.0	08-01-2025	▪ Update including feedback from the GGOS Governing Board Members. ▪ References (footnotes) added. ▪ EGV icons added. ▪ Version given to the Executive Committee and key components of the International Association of Geodesy (IAG) for review.



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1. Introduction

The purpose of this document is to initiate the definition of essential variables provided by geodesy, which are capable of describing and monitoring the Earth in a systematic and a sustainable way. Geodesy observes the Earth as a whole, from the interior to the surface, including the atmosphere, with regional and local refinements, and provides a large number of products for this purpose. Moreover, geodetic products are needed for all ground and space bound positioning, navigation and timing (PNT) tasks, and thus play a fundamental role in modern society[1]. So far, however, these products suffer from a lack of visibility for the global society (non-geodetic communities, administration, decision makers, science and others) and in some cases they are also not easy to understand for non-experts. In addition, geodesy as a discipline is also not well known to the public and therefore, there is a need to better promote these geodetic products[2,3].

For these reasons, a set of essential geodetic variables shall be identified and requirements for them shall be specified. In order to clearly state that such geodetic variables observe the Earth it is proposed to name these variables as:

Essential Geodetic Variables:

Contribution of Geodesy to Earth Observation

with the acronym

EGV

[1] *More details on the contribution of Geodesy to science and society may be found in Plag, H. P.; Pearlman M. (Eds.) (2009): Global Geodetic Observing System: Meeting the Requirements of a Global Society on a Changing Planet in 2020, Springer Verlag, https://doi.org/10.1007/9783642026874_3.*

[2] *GGOS, the Global Geodetic Observing System of the International Association of Geodesy (IAG), envisions a future where geodetic data and products are not a scientific asset only, but an essential resource guiding decision-making across diverse fields, see Sánchez, L.; Miyahara, B.; Craddock, A.; Sehnal, M.; Angermann, D.; Gross, R.; Schuh, H. (2024b): GGOS Strategic Plan 2024-2034. GGOS Coordinating Office, https://doi.org/10.5281/zenodo.10571157.*

[3] *The United Nations, through its Global Geodetic Centre of Excellence (UN-GGCE), recognises the significant vulnerabilities in the global geodetic supply chain and calls for action to ensure long-term and reliable geodetic products, see UN-GGCE (2024): Hidden Risk: How weaknesses in the global geodesy supply chain could have catastrophic impacts on critical infrastructure and national economies. Background report for decision-makers, Version 1.1, https://ggim.un.org/UNGGCE/documents/20240620-Hidden_Risk_Report.pdf, accessed 2024-12-17.*

An EGV is a geometric or a physical variable or a group of linked variables that critically contributes to the characterization of the geometric and physical shape of the Earth and to its orientation in space.

EGVs shall be defined by GGOS (Global Geodetic Observing System[4]), which is a component of the IAG (International Association of Geodesy)[5]. This is a similar arrangement to that used for the definition of ECVs (Essential Climate Variables[6,7]), which were defined in 2011 by GCOS (Global Climate Observing System[8]), and for the definition of EOVs (Essential Ocean Variables[9,10]), which were defined in 2014 by GOOS (Global Ocean Observing System[11]). All essential variables shall be continuously monitored and shall meet specific requirements in terms of spatial and temporal resolution and in terms of latency and consistency[12,13]. Since the different observing systems GGOS, GCOS and GOOS observe components of the same Earth, there are essential variables that are common to all three[14]. In such cases, geodetic products provide significant additional contributions to characterize these variables and complement the products from other organizations. Another set of essential variables is of purely geodetic nature and therefore, they are newly defined by GGOS.

The subsequent chapters define the criteria to declare a variable as essential and identifies possible levels of EGVs (chapter 2). Further, a first classification is provided for high level EGVs identifying the domain, subdomain, scientific area and the related geodetic products (chapter 3). Finally, requirements needed to be met by these geodetic products in order to become or contribute to an EGV must be identified and described. This will be the next step as soon as a broad agreement has been reached on the catalogue of EGVs described in sections 3.1 and 3.2.

[4] *https://ggos.org/*

[5] *Main characteristics and on-going activities of GGOS are summarised in Sánchez L., Riddell A., Angermann D., Rodríguez J., Sehnal M., Gruber T., Gross R., Lidberg M., Craddock A., Ferrándíz J.M. (2024). The Global Geodetic Observing System (GGOS) – Harnessing Geodesy for the Benefit of Science and Society, allgemeine vermessungsnachnichten, 06-06/2024: 256-269, https://doi.org/10.14627/avn.2024.5-6.4.*

[6] *https://gcos.wmo.int/en/essential-climate-variables*

[7] *Bojinski, S.; Verstraete, M.; Peterson, T.C.; Richter, C., Simmons, A.; Zemp, M. (2014): The Concept of Essential Climate Variables in Support of Climate Research, Applications, and Policy, Bulletin of the American Meteorological Society 95: 1431–1443, https://doi.org/10.1175/BAMS-D-13-00047.1.*

[8] *https://gcos.wmo.int/en/home*

[9] *https://goosocean.org/what-we-do/framework/essential-ocean-variables/.*

[10] *Fischer, A.; Grimes, S. (2012): Definition of Ecosystem Essential Ocean Variables. Technical Report, GEOWOWWP6-IOU-I6.1.1, GEOSS Interoperability for Weather, Ocean and Water, IOC-UNESCO, 24 pp.*

[11] *https://goosocean.org/*

[12] *Bombelli A., Serral I., Blonda P., Masó J., Plag H.-P., Jules-Plag S., McCallum I. (2015), EVs current status in different communities and way to move forward, ConnectinGEO, https://ddd.uab.cat/pub/worpap/2015/146882/D2_2_EVs_current_status_in_different_communities_and_way_to_move_forward.pdf*

[13] *Patias, P., Verde, N., Mallinis, G., Georgiadis, C., Giuliani, G., Serral, I., McCallum, I., Kussul, N., Lehmann, A., Masó, J. (2018), Best practice white paper on use of EVs for UN programs. GEOEssential Deliverable 8.1, https://www.geoessential.eu/wp-content/uploads/2019/10/D8.1_v5.pdf*

[14] *There are currently other ongoing initiatives to introduce additional sets of EVs, not only to describe the Earth system, but also the socio-economic system, including for example biodiversity, urban development, energy and minerals, health, agriculture, etc., see e.g. Lehmann, A.; Mazzetti, P.; Santoro, M.; Nativi, S.; Masò, J.; Serral, I.; Spengler, D.; Niamir, A.; Lacroix, P.; Ambrosone, M.; McCallum, I.; Kussul, N.; Patias, P.; Rodila, D.; Ray, N.; Giuliani, G. (2022): Essential earth observation variables for high-level multi-scale indicators and policies, Environmental Science & Policy, vol 131, 105-117, https://doi.org/10.1016/j.envsci.2021.12.024*

2. Definition and criteria of EGVs

EGVs are observed variables that are crucial to characterize the geodetic properties of the Earth and are needed to understand the dynamics of the Earth system in all its components and their interplay. They are essential to continuously monitor the Earth system, to assess possible risks, to develop mitigation strategies and to underpin the availability of sustainable geodetic services. They are required to support the work of the UN-GGCE (United Nations Global Geodetic Centre of Excellence[15,16]) and other high level international organizations like the UN-FCCC (United Nations Framework Convention on Climate Change[17]), the IPCC (Intergovernmental Panel on Climate Change[18]), the Committee on Earth Observation Satellites (CEOS[19]) and GEO (Group on Earth Observations[20]) together with its Global Earth Observation System of Systems (GEOSS[21]) and Knowledge Hub[22].

EGVs shall be identified based on the following main criteria, which are adapted from criteria for the definition of ECVs[7], and extended by two additional criteria specifically applicable to geodetic products (sustainability and consistency).

Relevance:	The variable is critical for characterizing the geometric and physical properties of the system Earth and its temporal changes.
Feasibility:	Observing or deriving the variable on a global scale is technically feasible using proven and scientifically understood methods.

[15] *https://ggim.un.org/UNGGCE/*

[16] *United Nations Global Geodetic Centre of Excellence, Strategy and Operating Plan, V.1.0, https://ggim.un.org/UNGGCE/documents/UN_GGCE_Strategy_%20and_Operating_Plan_v1.0.pdf*

[17] *https://unfccc.int/*

[18] *https://www.ipcc.ch/*

[19] *https://ceos.org/*

[20] *https://earthobservations.org/*

[21] *https://old.earthobservations.org/geoss.php*

[22] *https://gkhub.earthobservations.org/*

Cost effectiveness: Generating and archiving data about the variable is affordable, mainly relying on coordinated observing systems using proven technology, taking advantage of historical datasets (when possible).

Sustainability: The variable shall be made available over decades and the tools for observing it shall be sustainable.

Consistency: The variables shall be consistent in terms of reference systems and standards/conventions so that they can be easily combined or used together.

Sustainability requires availability of observation systems providing all observables needed for an EGV continuously over decades and with similar quality. To achieve this, the geodetic infrastructure providing the observables has to be operated and further developed continuously. *Consistency* is a major requirement for EGVs and the underlying geodetic products. All products defining an EGV shall be processed based on agreed standards and conventions. Processing centers shall follow specific conventions released or adopted by the IAG[23,24,25,26] and the recommendations provided by the GGOS Bureau of Products and Standards[27,28].

Different levels of EGVs are defined, mainly representing the level of detail or complexity of a variable. Following the conventions usually applied to Earth observation satellite data[29,30], the lowest level represents raw observations, while the highest level is defined by combined products providing relevant Earth system parameters. In more detail, the following scheme for data levels is proposed:

Level 0 Variables: Calibrated instrument data collected by satellites, airborne or ground-based campaigns annotated with geo-location and epoch.

Level 1 Variables: Earth observation data sets based on agreed standards and conventions with geophysical corrections as geo-located time series, possibly determined from a combination of instrument data.

[23] *Petit, G., Luzum, B. Eds. (2010): IERS Conventions (2010). IERS Technical Note No. 36. Verlag des Bundesamtes für Kartographie und Geodäsie, Frankfurt a. M., https://www.iers.org/IERS/EN/Publications/TechnicalNotes/tn36.html*

[24] *Sánchez, L., Ågren, J., Huang, J., Wang, Y.M., Mäkinen, J., Pail, R., Barzaghi, R., Vergos, G.S., Ahlgren, K., Liu, Q. (2021): Strategy for the realisation of the International Height Reference System (IHRS), J Geod, 95, 3, https://doi.org/10.1007/s00190-021-01481-0.*

[25] *Wziontek, H., Bonvalot, S., Falk, R., Gabalda, G., Mäkinen, J., Pálinkáš, V., Rülke, A., Vitushkin, L. (2021): Status of the International Gravity Reference System and Frame. J Geod 95, 7, https://doi.org/10.1007/s00190-020-01438-9.*

[26] *Hohenkerk, C. (2011), Standards of Fundamental Astronomy. Scholarpedia, 6(1):11404, http://www.scholarpedia.org/article/Standards_of_Fundamental_Astronomy.*

[27] *Angermann D., Gruber T., Gerstl M., Heinkelmann R., Hugentobler U., Sánchez L., Steigenberger P. (2016), 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., Rózsa S. (Eds.), The Geodesists' Handbook 2016, Journal of Geodesy, 90(10), 1095-1156, https://doi.org/10.1007/s00190-016-0948-z*

[28] *Angermann D., Gruber T., Gerstl M., Heinkelmann R., Hugentobler U., Sánchez L., Steigenberger P. (2020), Bureau of Products and Standards: Inventory of standards and conventions used for the generation of IAG products. In: Poutanen M., Rózsa S. (Eds.), The Geodesists' Handbook 2020, Journal of Geodesy, 94(11), 221–292, https://doi.org/10.1007/s00190-020-01434-z*

[29] *https://www.earthdata.nasa.gov/learn/earth-observation-data-basics/data-processing-levels*

[30] *https://help.marine.copernicus.eu/en/articles/5046705-which-levels-are-used-for-data-processing*

Level 2 Variables: Products determined from a combination of various Earth observation data sets describing specific parameters of the Earth system in the space and time domains.

Level 3 Variables: High-level accumulated products describing the geometric and physical shape of the Earth or its orientation in space, after performing a significant data processing and/or data combination. These variables are application-oriented and shall be directly applicable to multidisciplinary Earth system monitoring.

Currently it is considered to define EGVs at level 3 and partially at level 2 for variables that are relevant to a large user community and that need to be understandable to non-experts. Level 0, level 1 and some level 2 variables are more specific and require more expert knowledge to be used. They are useful to assess availability and quality of the geodetic infrastructure in a given region. Therefore, these EGVs are considered to be more relevant for the geodetic community but are required for the determination of level 2 and level 3 EGVs. Nevertheless, these lower level EGVs shall be specified in the future as well, but with a different purpose.

Fundamental numerical standards or conventions provided by geodesy, which are essential requirements for geodetic Earth observation and product generation, such as the geocentric gravitational constant (GM), the potential value of the geoid (W_0), the Earth's dynamical form factor (J_2), the reference level ellipsoid, etc., are not considered in this document so far.

2. Classification of EGVs

The classification of EGVs defines for each variable the domain, the subdomain, the scientific area, a person or organization who takes care about the variable, i.e., the steward (to be identified in a later stage) and the related geodetic products contributing to the EGV. The domain is defined as “Global”, “Land” and “Ocean”, while the subdomain specifies whether the variable relates to the “Geometry” or “Physics” of the Earth. Table 1 shows the list of proposed EGVs and their classification according to the level, domain and subdomain. Table 2 identifies the main geodetic products associated to the definition of the EGVs. Section 3.3 provides an overview about the specific geodetic products contributing to the EGVs.

Table 1. List of proposed EGVs

EGV	Level	Domain	Subdomain	ECV*	EOV**
Earth Orientation Parameters	L3	Global	Geometric		
Global Reference Frames	L3	Global	Geometric/Physical		
Global Earth Gravity Field	L3	Global	Physical		
Regional Reference Frames	L3	Land/ Ocean***	Geometric/Physical		
Regional Gravity Field Model	L3	Land/ Ocean***	Physical		
Land Geometry	L3	Land	Geometric		
Sea Surface	L3	Ocean	Geometric	X	X

	Sea Level	L3	Ocean	Physical	X	X
	Sea Ice	L3	Ocean	Geometric	X	X
	Ice Sheets	L3	Land	Geometric/Physical	X	
	Glaciers	L3	Land	Geometric/Physical	X	
	Inland Water Level	L3	Land	Geometric/Physical	X	
	Terrestrial Water Storage	L3	Land	Physical	X	
	Atmosphere	L3	Global	Physical	X	
	Satellite Orbits	L2	Global	Geometric		
	Station Positions and Variations	L2	Global	Geometric		
	Sea Water Level Records	L2	Ocean	Geometric		
	Land and Marine Gravity Data	L2	Land/ Ocean***	Physical		

** Essential Geodetic Variables common to Essential Climate Variables*
*** Essential Geodetic Variables common to Essential Ocean Variables*
**** For regional applications at land and ocean*

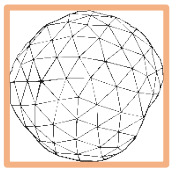
Table 2. Geodetic products associated to the definition of an EGV

Acronym	Definition	Acronym	Definition
AGM	Absolute Gravity Measurements	MRWL	Mean Regional Water Level
CPO	Celestial Pole Offset	MSL	(Global) Mean Sea Level
CRF	Celestial Reference Frame	MSS	Mean Sea Surface
DEM	Digital Elevation Model	PKM	Plate Kinematic Model
DOT	Dynamic Ocean Topography	PM	Polar Motion
DTM	Digital Terrain Model	RGFQ	Regional Gravity Field Quantities
EOT	Empirical Ocean Tide Model	RGM	Regional Geoid Model
ESD	Earth Surface Deformation	RGRF	Regional Gravity Reference Frame
ESO	Earth Observation Satellite Orbits	RHRF	Regional Height Reference Frame
GFQ	Gravity Field Quantities	RMSL	Relative Mean Sea Level
GFV	Glacier Flow Velocities	RSLC	Relative Sea Level Change
GGM	Global Gravity Field Model	RTRF	Regional Terrestrial Reference Frame
GIM	Global Ionosphere Maps	RWLC	Regional Water Level Change
GIT	Glacier Ice Thickness	SES	Sea State
GMC	Glacier Mass Change	SIE	Sea Ice Extension
GRF	Gravity Reference Frame	SIV	Sea Ice Volume
GSC	GNSS Satellite Clocks	SLA	Sea Level Anomaly
GSO	GNSS Satellite Orbits	SLC	(Global) Sea Level Change
HRF	Height Reference Frame	SLWR	Sea Level Water Records
IMC	Ice Mass Change	SPTS	Station Position Time Series
IST	Ice Sheet Thickness	TDM	Thermosphere Density Model
IWV	Integrated Water Vapor	TGFM	Topographic Gravity Field Model
LGM	Land Gravity Measurements	TGM	Time Series Gravity Measurements
LOD	Length of Day	TRF	Terrestrial Reference Frame
MDT	Mean Dynamic Topography	TWSA	Terrestrial Water Storage Anomaly
MGC	Mean Geostrophic Currents	UT1	Universal Time
MGM	Marine Gravity Measurements	VDP	Vertical Datum Parameter

3.1 Level 3 EGVs

	**Earth Orientation Parameters**
Domain	Global
Subdomain	Geometric
Scientific Area	Change of the orientation of the Earth with respect to a global reference frame (celestial pole offsets, UT1, LOD, polar motion).
EGV Stewards	
Products	▪ Celestial Pole Offset (CPO): *Differences with respect to the conventional celestial pole position defined by precession and nutation models with respect to the CRF*. ▪ Universal Time (UT1): *Computed from a measure of the Earth's angle with respect to the CRF, called the Earth Rotation Angle*. ▪ Length of Day (LOD): *Time series of LOD variations*. ▪ Polar Motion (PM): *Time series of pole coordinates relative to the TRF and rates of PM*.

	**Global Reference Frames**
Domain	Global
Subdomain	Geometric/Physical
Scientific Area	Geometric reference frames for the determination of the positions of astronomical objects in the celestial system and of points on or above the Earth surface in the terrestrial system. Physical reference frames for determining the gravity acceleration and the equipotential surface as a height reference.
EGV Stewards	
Products	▪ Celestial Reference Frame (CRF): *Catalog of precise equatorial coordinates of extragalactic radio sources*. ▪ Terrestrial Reference Frame (TRF): *Concrete points (markers) attached to the solid Earth crust with precisely determined coordinates (mean 3D positions of the stations and their motions)*. ▪ Gravity Reference Frame (GRF): *Absolute gravity measurements traceable to the International System of Units (SI) that contain conventional temporal gravity corrections*. ▪ Height Reference Frame (HRF): *Reference stations homogeneously distributed over the world and with known geopotential numbers or height values with respect to a global common reference surface.*

	**Global Earth Gravity Field**
Domain	Global
Subdomain	Physical
Scientific Area	Global Earth gravity field in the spectral and spatial domains including derived quantities with respect to a reference (ellipsoidal) gravity field.
EGV Stewards	
Products	▪ Global Gravity Field Models and its variation (GGM): *Spherical or ellipsoidal harmonic series of gravity potential either as mean or as a temporal series (low degree harmonics from satellite-only combined models)*. ▪ Topographic Gravity Field Models (TGFM): *Spherical or ellipsoidal harmonic series of gravity potential originated by the attraction of the Earth's topographic masses*. ▪ Gravity Field Quantities (GFQ): *Calculated gravity functionals on grids or selected points either with reference to an ellipsoidal reference field (height anomaly, geoid, gravity disturbance, gravity anomaly, deflections of the vertical, equivalent water height) or as full signal (gravitation, gravitational potential, gravity, gravity potential, normal gravity, normal potential, gravity gradient)*.

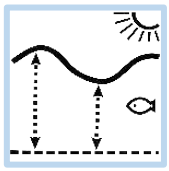
	**Regional Reference Frames**
Domain	Land/Ocean
Subdomain	Geometric/Physical
Scientific Area	Regional densification of global reference frames to improve the station distribution and provide access to the global TRF, GRF and HRF at regional/national scales. A regional height system is not necessarily a regional densification of the HRF, as the reference surface of most of the existing physical height systems is linked to the mean sea level determined at a tide gauge and consequently to the regional geoid model (RGM). The link between the regional height systems and the global HRF is provided by vertical datum parameters (VDP).
EGV Stewards	
Products	▪ Regional Terrestrial Reference Frame (RTRF)*: Concrete points (markers) attached to the solid Earth crust with precisely determined coordinates (mean 3D positions of the stations and their motions) for regional networks*.

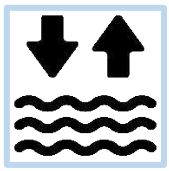
	▪ Regional Gravity Reference Frame (RGRF)*: Absolute gravity measurements traceable to the SI that contain conventional temporal gravity corrections*. ▪ Regional Height Reference Frame (RHRF)*: Reference stations regionally distributed with known geopotential numbers or height values with respect to the global HRF reference surface*. ▪ Vertical Datum Parameter (VDP)*: Connection of the regional height system to the global height reference frame (HRF)*.

	**Regional Gravity Field Model**
Domain	Land/Ocean
Subdomain	Physical
Scientific Area	Regional gravity field models representing gravity field quantities with high resolution. These models are determined from a combination of satellite gravimetry with ground, airborne and marine gravity data providing highest possible spatial resolution.
EGV Stewards	
Products	▪ Regional Geoid Model (RGM): *Grid of regional geoid estimates describing the geopotential surface serving as the height reference surface for a country or a specific region*. ▪ Regional Gravity Field Quantities (RGFQ): *Point values or grids of regional gravity anomalies, gravity disturbances, deflection of the vertical*.

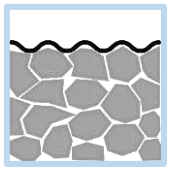
	**Land Geometry**
Domain	Land
Subdomain	Geometric
Scientific Area	Geometry of land surface with respect to the reference Earth ellipsoid or the geoid and its variations.
EGV Stewards	
Products	▪ Digital Elevation Model (DEM): *Geo-located heights of land surface with respect to the reference ellipsoid or the geoid*. ▪ Digital Terrain Models (DTM): *Heights of terrain of the solid Earth (including bathymetry and bedrock) with respect to the reference ellipsoid or the geoid as geo-located data or spherical harmonic expansion*. ▪ Plate Kinematic Model (PKM): *Velocity vectors representing the motion of tectonic plates*.

	▪ Earth Surface Deformation (ESD): *Regional models of 3D geometric surface deformation and deformation changes (gradients) over long distances (strain field).*

	**Sea Surface**
Domain	Ocean
Subdomain	Geometric
Scientific Area	Geometry of ocean surface with respect to the reference Earth ellipsoid.
EGV Stewards	
Products	▪ Mean Sea Surface (MSS): *Geo-located long-term average sea surface heights.* ▪ Sea Level Anomaly (SLA): *Time series of geo-located deviations of the instantaneous sea surface from the MSS.* ▪ Sea State (SES): *Characterization of waves in terms of height.* ▪ Empirical Ocean Tide Model (EOT): *Sea surface variations due to luni-solar tides.*

	**Sea Level**
Domain	Ocean
Subdomain	Physical
Scientific Area	Height of ocean surface with respect to the geoid, which is defined as the global equipotential surface of the Earth's gravity field that is most closely approximated by the global MSS, or with respect to the local equipotential surface at the height reference station of a regional height reference system. The former is known as absolute or global sea level, the latter as relative sea level.
EGV Stewards	
Products	▪ Global Mean Sea Level / Mean Dynamic Topography (MSL/MDT): *Geo-located deviation of MSS with respect to the geoid.* ▪ Mean Geostrophic Currents (MGC): *Geostrophic currents derived from MSL/MDT.* ▪ Global Sea Level Change / Dynamic Ocean Topography (SLC/DOT): *Time series of geo-located deviations of the instantaneous sea surface height from the geoid.*

	▪ Relative Mean Sea Level (RMSL): *Geo-located deviation of MSS with respect to a local equipotential surface defined by a regional height reference system*. ▪ Relative Sea Level Change (RSLC): *Time series of geo-located deviations of the instantaneous sea surface height from the local equipotential surface defined by a regional height reference system*.

	**Sea Ice**
Domain	Ocean
Subdomain	Geometric
Scientific Area	Sea ice coverage in the oceans and ice volume estimation of sea ice.
EGV Stewards	
Products	▪ Sea Ice Extension (SIE): *Time series of sea ice coverage in the oceans*. ▪ Sea Ice Volume (SIV): *Volume of sea ice from heights of sea ice above the ocean surface*.

	**Ice Sheets**
Domain	Land
Subdomain	Geometric/Physical
Scientific Area	Temporal changes of the volume and mass of ice sheets grounded on land surface or seafloor.
EGV Stewards	
Products	▪ Ice Mass Change (IMC): *Temporal gravity changes from satellite gravimetry missions caused by ice mass change and transport (physical method)*. ▪ Ice Sheet Thickness (IST): *Temporal changes of the thickness of ice sheets from radar and laser altimeters (geometric method). IST is also known as ice grounding line location*.

	**Glaciers**
Domain	Land
Subdomain	Geometric/Physical
Scientific Area	Temporal changes of the volume and mass of glaciers.
EGV Stewards	
Products	▪ Glacier Mass Change (GMC): *Temporal gravity changes from satellite gravimetry missions caused by ice mass change and transport (physical method).* ▪ Glacier Ice Thickness (GIT): *Temporal changes of the thickness of glaciers from radar and laser altimeters (geometric method). GIT is also known as glacier elevation change.* ▪ Glacier Flow Velocities (GFV): *Ice volume changes by glacier flow velocities from interferometric SAR (Synthetic-Aperture Radar) and net snow accumulation from atmospheric models.*

	**Inland Water Level**
Domain	Land
Subdomain	Geometric/Physical
Scientific Area	Water levels of inland lakes and rivers for estimating water mass variations and water runoff into the oceans.
EGV Stewards	
Products	▪ Mean Regional Water Level (MRWL): *Mean water level of inland lakes and rivers.* ▪ Regional Water Level Change (RWLC): *Time series of water level of inland lakes and rivers.*

	**Terrestrial Water Storage**
Domain	Land
Subdomain	Physical
Scientific Area	Total amount of water stored in all continental storage compartments (ice caps, glaciers, snow cover, soil moisture, groundwater, surface water bodies, water in biomass). The change of TWS over time balances

	the budget of the water fluxes precipitation, evapotranspiration, and runoff; i.e., it closes the continental water balance.
EGV Stewards	
Products	▪ Terrestrial Water Storage Anomaly (TWSA): *Calculated from a time series of global gravity field models relative to the long-term mean in terms of equivalent water heights*.

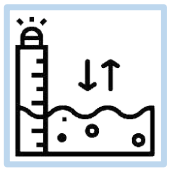
	**Atmosphere**
Domain	Global
Subdomain	Physical
Scientific Area	Determination of the non-hydrostatic refractive effect of the lower atmosphere on radio signals. Electron content of the ionosphere for considering delays of radio waves. Assimilation of geodetic observations to physically driven thermosphere density models.
EGV Stewards	
Products	▪ Integrated Water Vapor (IWV): *Neutral atmosphere zenith and slant wet delays as well as gradients describing the integrated water vapor content*. ▪ Global Ionosphere Maps (GIM): *Global maps of the vertical total electron content*. ▪ Thermosphere Density Model (TDM): *Time and space dependent scale factors determined from geodetic data for physical thermosphere density models*.

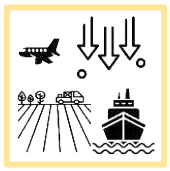
3.2 Level 2 EGVs

	**Satellite Orbits**
Domain	Global
Subdomain	Geometric
Scientific Area	GNSS satellite orbits provide the basis for precise positioning on ground, for precise orbit determination of satellites and for navigation and timing applications. They are essential for Earth system studies. Together with precise satellite clocks, they allow for a precise point positioning for single stations with a precision on the several millimeter level in the agreed terrestrial reference frame (TRF). Precise orbits of Earth observation satellites are needed for optimally exploiting their

	instrument data. Consistently recomputed precise orbit information is essential for geodetic products.
EGV Stewards	
Products	▪ GNSS Satellite Orbits (GSO): *Ephemerides of GNSS satellites*. ▪ GNSS Satellite Clocks (GSC): *Clock solution for GNSS satellite clocks aligned to UTC time scale*. ▪ Earth Observation Satellite Orbits (ESO): *Orbits of Earth observation satellites as state vector time series*.

	**Station Positions and Variations**
Domain	Global
Subdomain	Geometric
Scientific Area	3D station positions (referred to a reference epoch), constant velocities, seasonal variations and discontinuities of points observed by space geodetic techniques (completed by acoustic ranging seafloor stations in ocean areas).
EGV Stewards	
Products	▪ Station Position Time Series (SPTS): *Product contains lists of stations, plots of position coordinates, seasonal signals, non-tidal loading series, discontinuity data (e.g., earthquakes and instrument changes), station velocities, atmospheric integrated water vapor, quality assessment statistics, tables of data holdings*.

	**Sea Water Level Records**
Domain	Ocean
Subdomain	Geometric
Scientific Area	Height of the sea water level with respect to a local height reference recorded by a water level recorder (tide gauge). To obtain absolute sea level changes from these records, they have to be corrected by vertical land motions (see product ESD).
EGV Stewards	
Products	▪ Sea Water Level Records (SWLR): *Data per recording station: Monthly and annual local mean sea level values; local mean sea level trends; local mean sea level anomalies; sea level reconstructions (prediction of historical data)*.

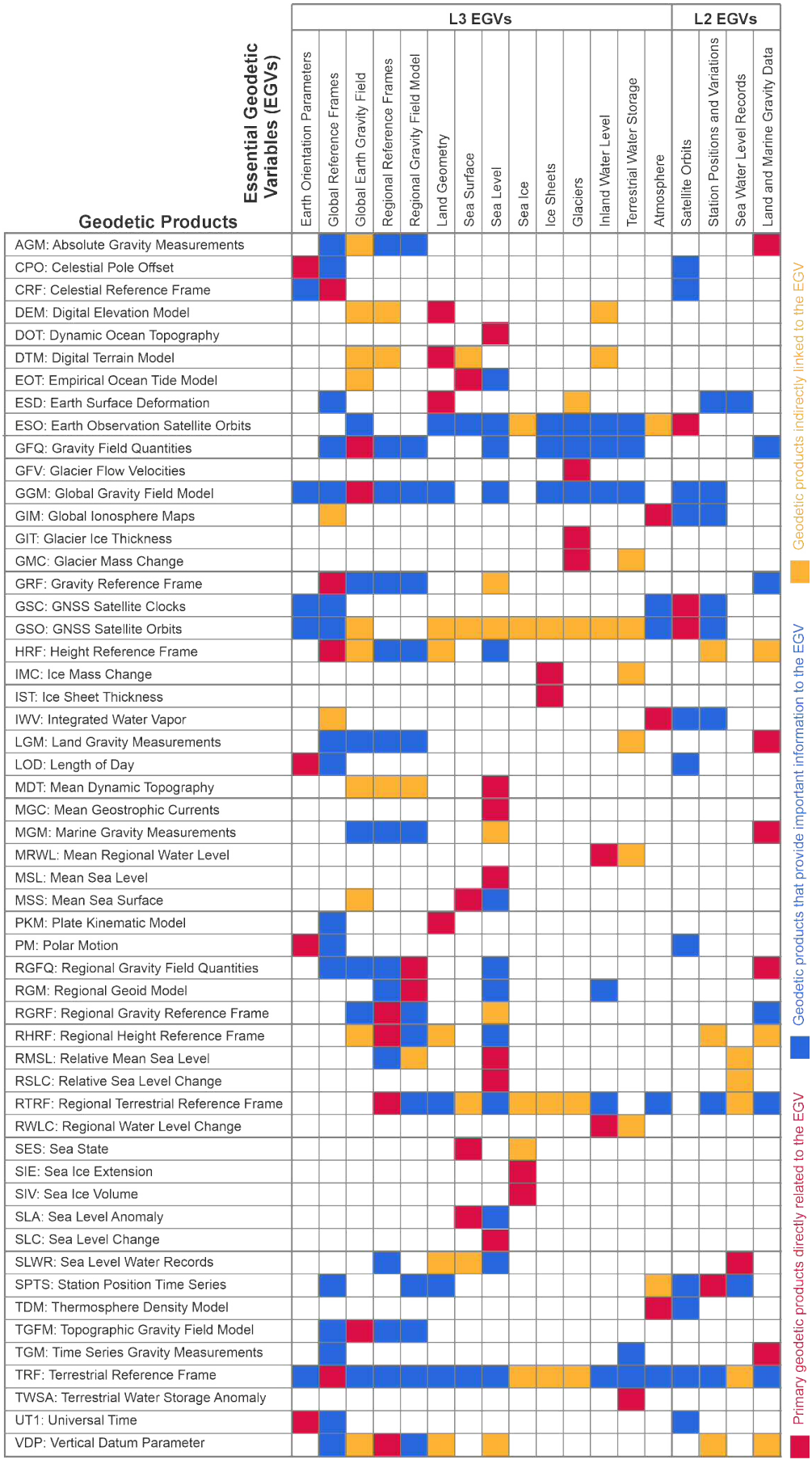
	**Land and Marine Gravity Data**
Domain	Land/Ocean
Subdomain	Physical
Scientific Area	Gravity measurements acquired at the Earth's surface or by airborne campaigns with different types of instruments (absolute, relative) on land or at the oceans as observation per epoch or as observation time series.
EGV Stewards	
Products	▪ Land Gravity Measurements (LGM): *Surface or airborne gravity measurements per country or per campaign over land or inland waters from relative gravimetry*. ▪ Marine Gravity Measurements (MGM): *Gravity measurements over the oceans by ship or airborne gravimetry from relative gravimetry*. ▪ Absolute Gravity Measurements (AGM): *Gravity measurements observed with absolute gravimetry instruments*. ▪ Time Series Gravity Measurements (TGM): *Gravity measurements at stations with continuously operating superconducting gravimeters or repeated absolute gravity measurements*.

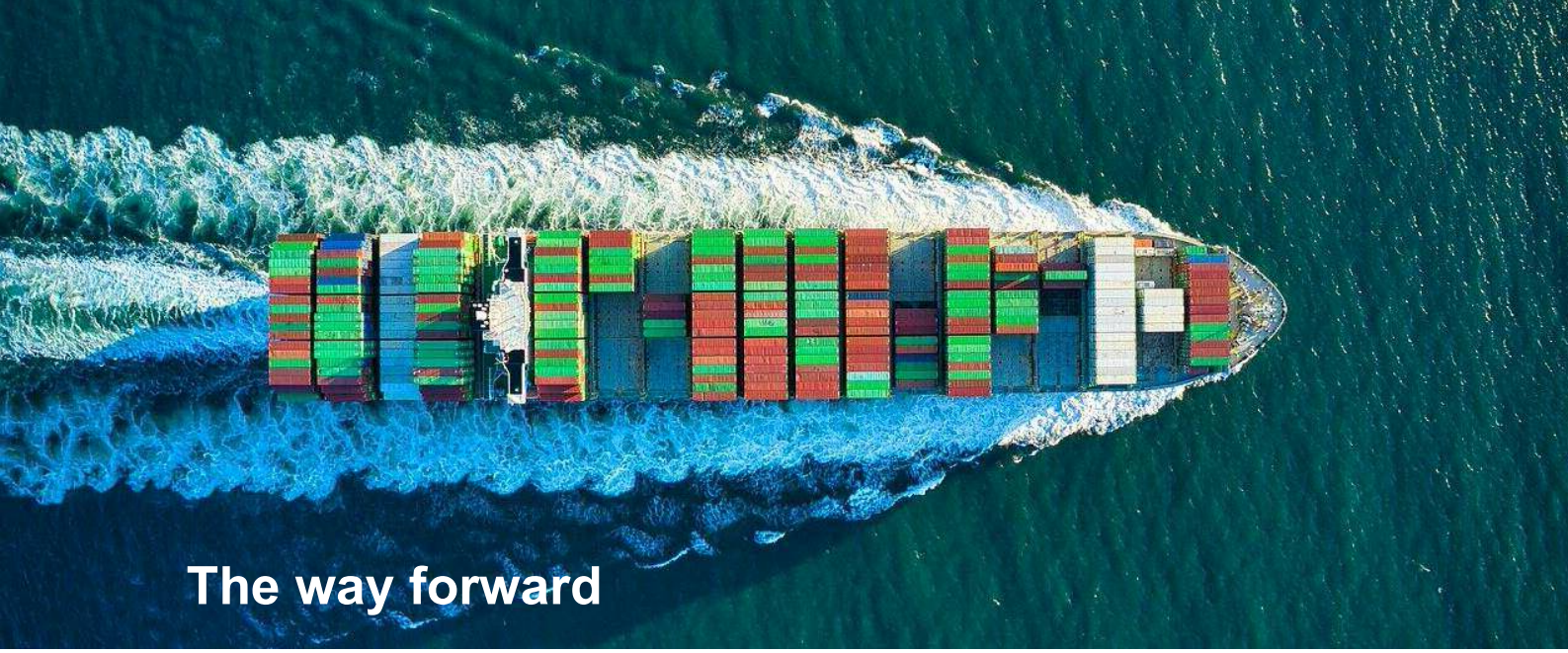
3.3 Overview EGVs and Geodetic Products

Table 3 provides an overview about the geodetic products contributing to the EGVs:

- **Red** indicates the primary geodetic products directly related to the EGV;
- **Blue** indicates the geodetic products that provide important information to the EGV;
- **Orange** indicates geodetic products indirectly linked to the EGV.

Table 3. Overview of geodetic products contributing to the EGVs





The way forward

A GGOS commitment is the definition of EGVs. This proposal is a concrete response to that commitment. However, the contribution of the international geodetic community is needed to obtain a widely accepted catalogue of EGVs. For this reason, GGOS turns to you, recognised experts in geodesy, to get your opinion on this concept. GGOS will certainly take into account all feedback provided (as already done with the GGOS Science Panel and GGOS Governing Board), but this is a multi-stakeholder process with clear objectives where compromises will be needed. This process includes:

1) Defining the list of essential geodetic variables and supporting products (current state);
2) Defining/outlining the specific requirements to be met by the geodetic products to support the assessment of the essential geodetic variables with confidence (next step);
3) Identification of stewards for the EGVs (next step);
4) Periodic evaluation/updating of EGVs and geodetic products according to improved geodetic observations, methods and results. This is a long-term activity, which means that everyone will have many opportunities to review and contribute to the definition and maintenance of the EGVs.

For now, we ask that you focus on the general picture before looking at the details (requirements and stewards). To help us process your feedback, we invite you to share your comments on the following topics:

- What is your opinion on the general definition and criteria (e.g. levels) proposed for the definition of the essential geodetic variables?
- What do you think about the classification into domains (e.g. Global, Land, Ocean) and sub-domains (Geometry, Physical)?
- What do you think about the list of geodetic products and the concept of how they relate to the different EGVs?
- We have focused on a general/broad definition of the essential variables, taking into account as many supporting products/data as possible, but keeping the number of EGVs small. Do you agree with this approach?

- Do you have any specific comments on the proposed EGVs and their description in sections 3.1 and 3.2?
- Are any EGVs or related products missing or redundant?
- What is your opinion on Table 3 showing the interaction between EGVs and geodetic products?
- Is there anything that is obviously missing or wrong?
- Do you have any other comments?

Many thanks for your time and valuable input! Your support is highly appreciated!

Please send your comments and suggestions to the GGOS Coordinating Office (co@ggos.org).