Definition of Essential Geodetic Variables (EGVs)

Contribution of Geodesy to Earth Observation

Thomas Gruber[(1)], Detlef Angermann[(2)], Laura Sánchez[(2)]

[(1)] Institute of Astronomical and Physical Geodesy (IAPG), Technical University of Munich

[(2)] Deutsches Geodätisches Forschungsinstitut (DGFI-TUM), Technical University of Munich

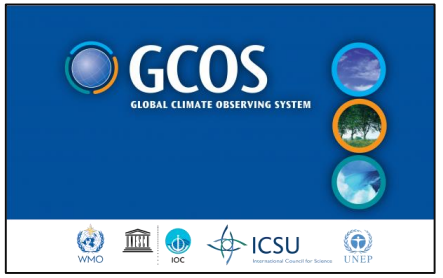
Introduction – Why to define Essential Variables?

Essential Variables: Variables that are capable of describing and monitoring the climate (ECVs), the oceans (EOVs) and **geodetic properties of the Earth (EGVs)** in a systematic and sustainable way.

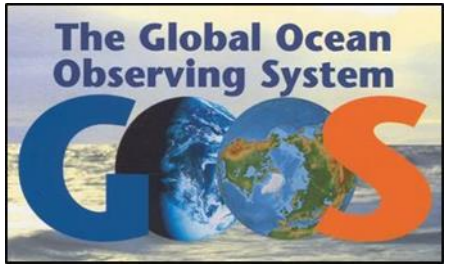
- Encourage **scientists and observing systems** to put more emphasis to these variables.
- Stimulate engagement of **national and international organizations** and **funding agencies to support provision of these variables**.
- Help decision makers to commit the **support of systematic and sustained Earth observation with Satellites and Earth-based systems**.
- Support **GEO Societal Benefit Areas (SBAs)** and **UN Sustainable Development Goals (SDGs)** including the **UN-GGCE** (United Nations Global Geodetic Centre of Excellence).

Introduction – Who defines Essential Variables?

- First Essential Variables have been defined by the Global Climate Observing System (**GCOS**) in 2011: **55 Essential Climate Variables (ECVs)** have been defined so far.



- Global Ocean Observing System (**GOOS**) follows in 2014: **31 Essential Ocean Variables (EOVs)** have been defined so far.



- Global Geodetic Observing System (**GGOS**) is working on the **definition of Essential Geodetic Variables (EGVs)**.
- Under the GGOS Bureau of Products and Standards **(BPS)** the **Committee on Essential Geodetic Variables** has been established (Chair since 2023: Thomas Gruber following Richard Gross).

Introduction – Development and Current Status

- **2017 GGOS Days**: Initial gap analysis (R. Gross).
- **2018 GGOS Days**: Committee on EGVs established and definition of tasks. Initial thoughts presented.
- **2019 IUGG**: Talks about EGV requirements, EGVs for Earth geometry and gravity field.
- **2022 GGOS Days**: Target audience and first list of EGVs.
- **2023 IUGG**: Status & Plans; Identification of a basic set of EGVs; Definition of criteria, levels and requirements of EGVs.
- **2024 White Paper**: “Definition of Essential Geodetic Earth Observation Variables”. Review by GGOS Science Panel completed. Next revision under preparation.

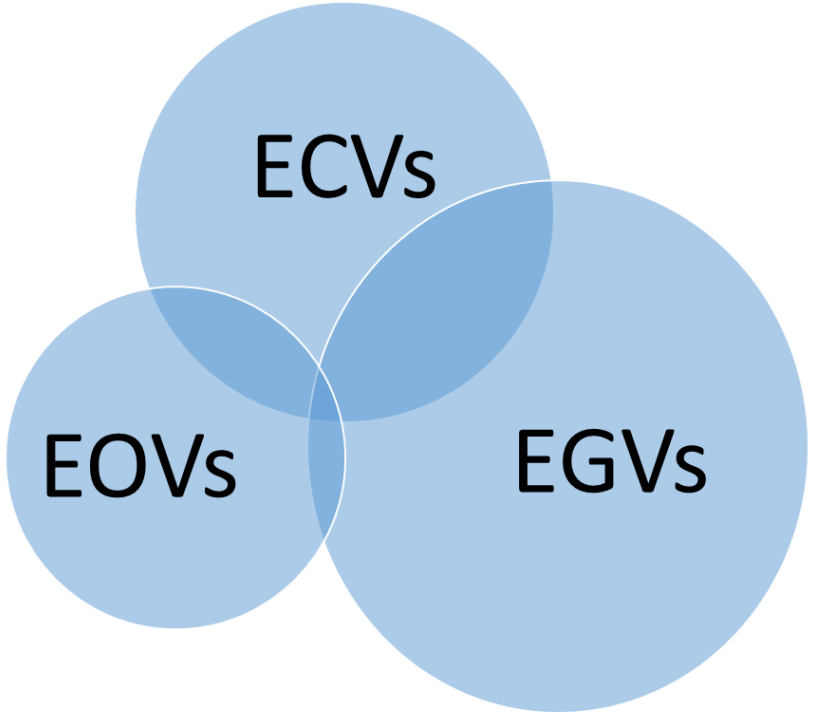
White Paper – Naming of Essential Variables

Why calling them **”Essential Geodetic Variables (EGV): Contribution of Geodesy to Earth Observation”?**

- **Geodesy observes the Earth as a whole**, from the interior to the surface including the atmosphere, with regional refinements and provides a **large number of products**.
- So far, however, these **products suffer from a lack of visibility for the global society** and in some cases they are also not easy to understand for non-experts.
- **Geodesy as a discipline is also not well known to the public** and therefore, there is a need to better promote these geodetic products
- In order to **clearly state that such geodetic variables observe the Earth** this name is proposed.

White Paper – Classification, Criteria and Levels of EGVs

- **Classification**
- EGVs may overlap with ECVs or EOVs



- **ECVs:** Atmosphere, Land, Ocean
- **EOVs:** Physical, Biogeochemical, Biological/ecosystems

Options for EGVs following GGOS Products:

- **Geodetic Fields:** Geometry, Gravity, Earth Rotation, Reference Frames, Positioning & Applications
- **Earth System Components:** Solid Earth, Oceans, Cryosphere, Hydrosphere, Atmosphere

Proposed classification for EGVs:
Global, Land, Ocean

White Paper – Classification, Criteria and Levels of EGVs

- **Criteria to become an EGV**
  - **Relevance effectiveness (ECV, EOV, EGV)**: The **variable is critical** for characterizing the properties of the Earth system and its temporal changes.
  - **Feasibility effectiveness (ECV, EOV, EGV)**: Observing or deriving the variable on a global scale is **technically feasible** using proven, scientifically understood methods.
  - **Cost effectiveness (ECV, EOV, EGV)**: **Generating and archiving data on the variable is affordable**, mainly relying on coordinated observing systems using proven technology.
  - **Sustainability (EGV)**: The variable shall be made **available over decades** and the tools for observing it shall be sustainable.
  - **Consistency (EGV):** The variables shall be **consistent in terms of reference systems and standards/conventions** so that they can be easily combined or used together.

White Paper – Classification, Criteria and Levels of EGVs

EGVs Level Definition (as it is commonly used in EO satellite missions)

- **Level 0: Calibrated instrument data** collected by satellites, airborne or ground-based campaigns annotated with geo-location and epoch.
- **Level 1: Earth observation data sets based on agreed standards and conventions** with geophysical corrections **as geo-located time series**.
- **Level 2:** Products determined from a **combination of various Earth observation data sets** describing specific parameters of the Earth system in space and time domain.
- **Level 3:** Accumulated **products describing the geometrical and physical shape of the Earth** or its orientation in space. These variables are application-oriented.

Currently **EGVs are defined at level 3 and partially at level 2** for variables that are relevant to a large user community.

White Paper – Proposed EGVs

EGV	Level	Domain	Subdomain
Global Reference Frames	L3	Global	Geometric/Physical
Land Geometry	L3	Land	Geometric
Sea Surface	L3	Ocean	Geometric
Sea Level	L3	Ocean	Physical
Sea Ice	L3	Ocean	Geometric
Ice Sheets	L3	Land	Geometric/Physical
Glaciers	L3	Land	Geometric/Physical
Global Earth Gravity Field	L3	Global	Physical
Terrestrial Water Storage	L3	Land	Physical
Inland Water Level	L3	Land	Geometric/Physical
Earth Orientation Parameters	L3	Global	Geometric
Neutral Atmosphere and Ionosphere	L3	Global	Physical
Station Positions and Variations	L2	Land	Geometric
Tide Gauge Records	L2	Ocean	Geometric
Land and Marine Gravity Data	L2	Land/Ocean	Physical
Regional Gravity Field Model	L2	Land/Ocean	Physical
Regional Reference Frames	L2	Land/Ocean	Geometrical/Physical
Satellite Orbits	L2	Global	Geometric

18 EGVs in total

- Level 3: 12
- Level 2: 6

Domain

- Global: 5
- Land/Ocean: 3
- Land: 6
- Ocean: 4

Subdomain

- Geometrical
- Physical
- Geometrical/Physical

ECV linked to Physical Shape	ECV linked to Geometrical and Physical Shape
ECV linked to Geometric Shape	

White Paper – Geodetic Products for EGVs

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

Example: Gravity Field Products

- 53 Geodetic Products in total being part of EGVs.
- 24 out of 53 Geodetic Products are linked to observations or models of the Earth gravity field.
- 12 out of 24 gravity field related products are primary gravity field observations or models.

Primary Gravity Field Geodetic Product
Link to Gravity Field Geodetic Product

White Paper – Examples Primary Gravity Field EGV Description

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 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.** ▪ **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).**

White Paper – Examples Linked Gravity Field EGV Description

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.
EGV Stewards	
Products	▪ **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.* ▪ **Sea Level Change / Dynamic Ocean Topography (SLC/DOT)**: *Time series of geo-located deviations of the instantaneous sea surface height from the geoid*. ▪ **Regional Mean Sea Level (RMSL)**: *Geo-located deviation of MSS with respect to local equipotential surface defined by a regional height reference system*. ▪ **Regional 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*.

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 for glaciers (physical method)***. ▪ Glacier Ice Thickness (GIT): *Temporal changes of the thickness of glaciers from radar and laser altimeters (geometric method)*. ▪ Glacier Flow Velocities (GFV): Ice volume changes by *glacier flow velocities from interferometric SAR and net snow accumulation from atmospheric models*.

White Paper – Selected Geodetic Products Contributing to EGV

Products	Global Reference Frames	Land Geometry	Sea Surface	Sea Level	Sea Ice	Ice Sheets	Glaciers	Global Earth Gravity Field	Terrestrial Water Storage	Inland Water Level	Earth Orient. Param.	Neutral Atmosph. and Ionosph.	Station Positions and Variations	Tide Gauge Records	Land and Marine Gravity Data	Regional Gravity Field Model	Regional Reference Frames	Satellite Orbits
EGV	L3	L3	L3	L3	L3	L3	L3	L3	L3	L3	L3	L3	L2	L2	L2	L2	L2	L2
ECV			X	X	X	X	X		X	X		X						
EOV			X	X	X													
Domain	Global	Land	Ocean	Ocean	Ocean	Land	Land	Global	Land	Land	Global	Global	Land	Ocean	Land/ Ocean	Land/ Ocean	Land/ Ocean	Global
GRF																		
HRF																		
GGM																		
TGFM																		
GFQ																		
MSL																		
MDT																		
MGC																		
SLC																		
DOT																		
RMSL																		
RSLC																		
GMC																		

EGV Global Reference Frames

- Gravity Reference Frame (GRF)
- Height Reference Frame (HRF)

EGV Glaciers

- Glacier Mass Change (GMC)

EGV Global Earth Gravity Field

- Global Gravity Field Models and its variation (GGM)
- Topographic Gravity Field Models (TGFM)
- Gravity Field Quantities (GFQ)

EGV Sea Level

- Mean Sea Level / Mean Dynamic Topography (MSL/MDT)
- Mean Geostrophic Currents (MGC)
- Sea Level Change / Dynamic Ocean Topography (SLC/DOT)
- Regional Mean Sea Level (RMSL):
- Regional Sea Level Change (RSLC)

Primary Geodetic Product directly related to EGV

Geodetic Products providing important information to EGV

Geodetic Products indirectly linked to EGV

White Paper – Selected Geodetic Products Contributing to EGV

Products	Global Reference Frames	Land Geometry	Sea Surface	Sea Level	Sea Ice	Ice Sheets	Glaciers	Global Earth Gravity Field	Terrestrial Water Storage	Inland Water Level	Earth Orient. Param.	Neutral Atmosph. and Ionosph.	Station Positions and Variations	Tide Gauge Records	Land and Marine Gravity Data	Regional Gravity Field Model	Regional Reference Frames	Satellite Orbits
EGV	L3	L3	L3	L3	L3	L3	L3	L3	L3	L3	L3	L3	L2	L2	L2	L2	L2	L2
ECV			X	X	X	X	X		X	X		X						
EOV			X	X	X													
Domain	Global	Land	Ocean	Ocean	Ocean	Land	Land	Global	Land	Land	Global	Global	Land	Ocean	Land/ Ocean	Land/ Ocean	Land/ Ocean	Global
GRF																		
HRF																		
GGM																		
TGFM																		
GFQ																		
MSL																		
MDT																		
MGC																		
SLC																		
DOT																		
RMSL																		
RSLC																		
GMC																		

EGV Global Reference Frames

- Gravity Reference Frame (GRF)
- Height Reference Frame (HRF)

EGV Glaciers

- Glacier Mass Change (GMC)

EGV Global Earth Gravity Field

- Global Gravity Field Models and its variation (GGM)
- Topographic Gravity Field Models (TGFM)
- Gravity Field Quantities (GFQ)

EGV Sea Level

- Mean Sea Level / Mean Dynamic Topography (MSL/MDT)
- Mean Geostrophic Currents (MGC)
- Sea Level Change / Dynamic Ocean Topography (SLC/DOT)
- Regional Mean Sea Level (RMSL):
- Regional Sea Level Change (RSLC)

Primary Geodetic Product directly related to EGV

Geodetic Products providing important information to EGV

Geodetic Products indirectly linked to EGV

White Paper – Selected Geodetic Products Contributing to EGV

Products	Global Reference Frames	Land Geometry	Sea Surface	Sea Level	Sea Ice	Ice Sheets	Glaciers	Global Earth Gravity Field	Terrestrial Water Storage	Inland Water Level	Earth Orient. Param.	Neutral Atmosph. and Ionosph.	Station Positions and Variations	Tide Gauge Records	Land and Marine Gravity Data	Regional Gravity Field Model	Regional Reference Frames	Satellite Orbits
EGV	L3	L3	L3	L3	L3	L3	L3	L3	L3	L3	L3	L3	L2	L2	L2	L2	L2	L2
ECV			X	X	X	X	X		X	X		X						
EOV			X	X	X													
Domain	Global	Land	Ocean	Ocean	Ocean	Land	Land	Global	Land	Land	Global	Global	Land	Ocean	Land/ Ocean	Land/ Ocean	Land/ Ocean	Global
GRF																		
HRF																		
GGM																		
TGFM																		
GFQ																		
MSL																		
MDT																		
MGC																		
SLC																		
DOT																		
RMSL																		
RSLC																		
GMC																		

EGV Global Reference Frames

- Gravity Reference Frame (GRF)
- Height Reference Frame (HRF)

EGV Glaciers

- Glacier Mass Change (GMC)

EGV Global Earth Gravity Field

- Global Gravity Field Models and its variation (GGM)
- Topographic Gravity Field Models (TGFM)
- Gravity Field Quantities (GFQ)

EGV Sea Level

- Mean Sea Level / Mean Dynamic Topography (MSL/MDT)
- Mean Geostrophic Currents (MGC)
- Sea Level Change / Dynamic Ocean Topography (SLC/DOT)
- Regional Mean Sea Level (RMSL):
- Regional Sea Level Change (RSLC)

Primary Geodetic Product directly related to EGV

Geodetic Products providing important information to EGV

Geodetic Products indirectly linked to EGV

White Paper – Selected Geodetic Products Contributing to EGV

Products	Global Reference Frames	Land Geometry	Sea Surface	Sea Level	Sea Ice	Ice Sheets	Glaciers	Global Earth Gravity Field	Terrestrial Water Storage	Inland Water Level	Earth Orient. Param.	Neutral Atmosph. and Ionosph.	Station Positions and Variations	Tide Gauge Records	Land and Marine Gravity Data	Regional Gravity Field Model	Regional Reference Frames	Satellite Orbits
EGV	L3	L3	L3	L3	L3	L3	L3	L3	L3	L3	L3	L3	L2	L2	L2	L2	L2	L2
ECV			X	X	X	X	X		X	X		X						
EOV			X	X	X													
Domain	Global	Land	Ocean	Ocean	Ocean	Land	Land	Global	Land	Land	Global	Global	Land	Ocean	Land/ Ocean	Land/ Ocean	Land/ Ocean	Global
GRF																		
HRF																		
GGM																		
TGFM																		
GFQ																		
MSL																		
MDT																		
MGC																		
SLC																		
DOT																		
RMSL																		
RSLC																		
GMC																		

EGV Global Reference Frames

- Gravity Reference Frame (GRF)
- Height Reference Frame (HRF)

EGV Glaciers

- Glacier Mass Change (GMC)

EGV Global Earth Gravity Field

- Global Gravity Field Models and its variation (GGM)
- Topographic Gravity Field Models (TGFM)
- Gravity Field Quantities (GFQ)

EGV Sea Level

- Mean Sea Level / Mean Dynamic Topography (MSL/MDT)
- Mean Geostrophic Currents (MGC)
- Sea Level Change / Dynamic Ocean Topography (SLC/DOT)
- Regional Mean Sea Level (RMSL):
- Regional Sea Level Change (RSLC)

Primary Geodetic Product directly related to EGV

Geodetic Products providing important information to EGV

Geodetic Products indirectly linked to EGV

White Paper – Overview Geodetic Products Contributing to EGV

Primary Geodetic Product directly related to EGV

Geodetic Products providing important information to EGV

Geodetic Products indirectly linked to EGV

Products	Global Reference Frames	Land Geometry	Sea Surface	Sea Level	Sea Ice	Ice Sheets	Glaciers	Global Earth Gravity Field	Terrestrial Water Storage	Inland Water Level	Earth Orient. Param.	Neutral Atmosph. and Ionosph.	Station Positions and Variations	Tide Gauge Records	Land and Marine Gravity Data	Regional Gravity Field Model	Regional Reference Frames	Satellite Orbits
EGV	L3	L3	L3	L3	L3	L3	L3	L3	L3	L3	L3	L3	L2	L2	L2	L2	L2	L2
ECV			X	X	X	X	X		X	X		X						
EOV			X	X	X													
Domain	Global	Land	Ocean	Ocean	Ocean	Land	Land	Global	Land	Land	Global	Global	Land	Ocean	Land/ Ocean	Land/ Ocean	Land/ Ocean	Global
AGM																		
CPO																		
CRF																		
DEM																		
DOT																		
DTM																		
EOT																		
ESD																		
ESO																		
GFQ																		
GFV																		
GGM																		
GIM																		
GIT																		
GMC																		
GRF																		
GSC																		
GSO																		
HRF																		
IMC																		
IST																		
LGM																		
LOD																		
MDT																		
MGC																		
MGM																		
MRLW																		
MSL																		
MSS																		
PKM																		
PM																		
RGM																		
RGRF																		
RHRF																		
RMSL																		
RSLC																		
RTRF																		
RWLC																		
SES																		
SIE																		
SIV																		
SLA																		
SLC																		
SPTS																		
TDM																		
TGFM																		
TGM																		
TGR																		
TRF																		
TWSA																		
UT1																		
VDP																		
WVC																		

White Paper – Requirements for EGVs

- After fixing the list of EGVs requirements for the Geodetic Products need to be specified.
- Requirements shall be specified such that the Geodetic Product will contribute to the EGV. This includes accuracy, temporal and spatial resolution, latency, needed observation systems, product provider, etc. (see example below)

EGV	Product	Accuracy	Temporal resolution	Spatial Resolution	Observations	Service/ Provider
Global or Land/Ocean						
Global Reference Frames	**CRF**	25 µs, stability 3µs/yr	Decades long-term?	Not specified	VLBI	IERS / ICRS Centre
	GRF					
	HRF					
	TRF	Origin: 1 mm, stability 0.1 mm/yr Scale: 0.1 ppb, stability 0.01 ppb/yr	Decades long-term?	Not specified	VLBI, SLR, GNSS, DORIS	IERS / ITRS Centre
Earth Orientation Parameters	**CPO**		1 hour, latency weekly to near real-time	Not specified	VLBI	IERS EOP Centre / Rapid Service Pred. Centre
	LOD				VLBI, SLR, GNSS, DORIS	
	PM	30 µs			VLBI, SLR, GNSS, DORIS	
	UT1	2 µs			VLBI	

Summary and Conclusions

- Proposed name: ”Essential Geodetic Variables (EGV): Contribution of Geodesy to Earth Observation”. Improve visibility to non-geodetic communities.
- A set of 18 EGVs has been defined partially overlapping with ECVs and EOVs.
- Currently only Level 3 and some Level 2 EGVs are considered as these have major impact for interdisciplinary users.
- So far 53 Geodetic Products have been identified contributing to an EGV.
- EGV Descriptions have been prepared and links between EGVs and Geodetic Products were identified.
- Requirements for Geodetic Products need to be defined after general concept has been reviewed and confirmed by GGOS and IAG bodies (GGOS Days 2024 as next milestone).