Essential Gravimetric Variables – Identification and Initial Assessment

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Geometry and Kinematic

Reference Systems

Gravity Field

Earth Rotation

DORIS
GNSS
RS
Altimetry
VLBI
SLR
GRACE-FO
GOCE
## Essential Variables

<table>
<thead>
<tr>
<th>System</th>
<th>Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global Climate Observing System (GCOS)</td>
<td>Essential <strong>Climate Variables</strong> <em>(ECV)</em>&lt;br&gt;“Physical, chemical or biological variable or a group of linked variables that critically contributes to the characterization of Earth’s climate.”</td>
</tr>
<tr>
<td>Global Ocean Observing System (GOOS)</td>
<td>Essential <strong>Ocean Variables</strong> <em>(EOV)</em></td>
</tr>
<tr>
<td>Group on Earth Observations Biodiversity Observation Network (GEO BON)</td>
<td>Essential <strong>Biodiversity Variables</strong> <em>(EBV)</em></td>
</tr>
<tr>
<td>Global Geodetic Observing System (GGOS)</td>
<td>Essential <strong>Geodetic Variables</strong> <em>(EGV)</em>&lt;br&gt;“Observed variables that are crucial (essential) to characterizing the geodetic properties of the Earth and that are key to sustainable geodetic observations.” (R. Gross)</td>
</tr>
</tbody>
</table>
The BPS supports GGOS in its key goal to obtain consistent products describing the geometry, rotation and gravity field of the Earth.

- Homogenization of IAG standards and products;
- Keep track of the adopted geodetic standards and conventions across IAG components,
- Integration of geometric and gravimetric parameters and to develop new geodetic products, needed for Earth sciences and society.
- Coordinate the Committee on “Essential Geodetic Variables (EGVs)” whose task is apart from others the definition of “Essential Gravimetric Variables (EGrVs)”

after Drewes (2007), IAG Symposia 130
## Links between Essential Variables and EGrVs

<table>
<thead>
<tr>
<th>Land</th>
<th>Ocean Surface</th>
<th>Ocean Sub-Surface</th>
<th>Atmosphere Surface</th>
<th>Atmosphere Upper-air</th>
<th>Atmosph. Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>River discharge</td>
<td>Temperature</td>
<td>Temperature</td>
<td>Temperature</td>
<td>Temperature</td>
<td></td>
</tr>
<tr>
<td>Water use</td>
<td>Salinity</td>
<td>Salinity</td>
<td>Wind speed &amp; dir.</td>
<td>Wind speed &amp; dir.</td>
<td></td>
</tr>
<tr>
<td>Ground water</td>
<td>Sea level</td>
<td></td>
<td>Water vapour</td>
<td>Water vapour</td>
<td></td>
</tr>
<tr>
<td>Lakes</td>
<td>Sea state</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soil moisture</td>
<td>Sea ice</td>
<td></td>
<td>Precipitation</td>
<td>Lightning</td>
<td></td>
</tr>
<tr>
<td>Snow cover</td>
<td>Surface Current</td>
<td>Sub-surface current</td>
<td>Surface radiation</td>
<td>Earth radiation</td>
<td></td>
</tr>
<tr>
<td>Glaciers &amp; ice caps</td>
<td>Ocean colour</td>
<td></td>
<td>Cloud properties</td>
<td>Cloud properties</td>
<td></td>
</tr>
<tr>
<td>Ice sheets</td>
<td>Carbon dioxide</td>
<td>Carbon dioxide</td>
<td></td>
<td>Carbon dioxide</td>
<td></td>
</tr>
<tr>
<td>Permafrost</td>
<td>Ocean acidity</td>
<td>Ocean acidity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Land cover</td>
<td>Phytoplankton</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FAPAR</td>
<td>Stress</td>
<td>Oxygen</td>
<td></td>
<td></td>
<td>Methane</td>
</tr>
<tr>
<td>Leaf area index</td>
<td>Heat flux</td>
<td>Nutrients</td>
<td></td>
<td></td>
<td>Ozone</td>
</tr>
<tr>
<td>Biomass</td>
<td></td>
<td>Tracers</td>
<td></td>
<td></td>
<td>Aerosols properties</td>
</tr>
<tr>
<td>Soil carbon</td>
<td></td>
<td>Nitrous oxide</td>
<td></td>
<td></td>
<td>Greenhouse gas</td>
</tr>
<tr>
<td>Fire disturbance</td>
<td></td>
<td>Carbon isotopes</td>
<td></td>
<td></td>
<td>Precursors</td>
</tr>
<tr>
<td>Albedo</td>
<td></td>
<td>Organic carbon</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

ECV

EOV

ECV & EOV

Link to EGrV

EOV's for Biology & Ecosystems and EBV's not connected to EGV's
Essential Gravimetric Variables (EGrVs)

Geodetic Product Levels = EGrV Levels

Level 0 EGrVs: Geodetic Standards
- Reference Frames: e.g. Center of Mass
- Gravity Standards

Level 1 EGrVs: Observations
- Gravity Potential (Geoid)
- Gravity Acceleration (1st derivative radial)
- Deflections of the Vertical (1st derivatives horizontal)
- Gravity Gradients (2nd derivatives)

Level 2 EGrVs: Geopotential Models
- Global Models (Mean and Time-variable)
- Global Geoid (Mean and Time-variable)
- Regional Geoid (Mean and Time-variable)

Level 3 EGrVs: Application Variables
- Mass Distribution in Earth System
- Mass Transport in Earth System

Contributions to ECV’s & EOV’s
- River discharge
- Water use
- Ground water
- Lakes
- Soil moisture
- Snow cover
- Glaciers
- Ice caps
- Ice sheets
- Permafrost
- Sea level
- Surface currents
- Sub-surface currents
- Pressure
**Example: L0 EGrV – Geodetic Standards**

**IGFS – Central Bureau** is implementing a set of standards related to gravity field observations to secure consistency and to promote their use within the geoscientific community (Geoid Metadata Editor (v0.1.3) and Gravity Metadata Editor (v0.2.6)).

<table>
<thead>
<tr>
<th>Section</th>
<th>Geoid</th>
<th>Gravity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Reference Information</td>
<td>Organisation, Contact, Creation Date</td>
<td></td>
</tr>
<tr>
<td>2. Identification</td>
<td>Reference System, Citation, Description, Status, Point of Contact, Spatial Extent Geographic Bounding Box Coordinates</td>
<td></td>
</tr>
<tr>
<td>3. Distribution</td>
<td>Distributor, Order Process, Constraints</td>
<td></td>
</tr>
<tr>
<td>4. Standard and Conventions</td>
<td>GM, a, f, Tide System, Reference Ellipsoid, Standard Density of the Earth</td>
<td>GM, a, f, normal gravity reference ellipsoid, Tide System, EOP’s, Tidal Conventions, Station Coordinates and Corrections</td>
</tr>
<tr>
<td>5. Data and Data Quality Information</td>
<td>Data and Data Quality Information; Accuracy, Consistency, Completeness, Data Distribution, Geoid Data, Gravity Data, Position and Height Accuracy</td>
<td>Accuracy, Consistency, Completeness, Data Distribution, Gravity Data, Position and Height Accuracy, Time Period of Content</td>
</tr>
</tbody>
</table>
Example: L1 EGrV - Observations

Ground based, Airborne and Satellite Observations & Integration Area

<table>
<thead>
<tr>
<th>Observation Type</th>
<th>Derivative</th>
<th>Height</th>
<th>Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>GRACE (FO)</td>
<td>$1^{st}$</td>
<td>500 km</td>
<td>200 km</td>
</tr>
<tr>
<td>GOCE</td>
<td>$2^{nd}$</td>
<td>250 km</td>
<td>80 km</td>
</tr>
<tr>
<td>Airborne Gravimetry</td>
<td>$1^{st}$</td>
<td>&lt;10 km</td>
<td>2-5 km</td>
</tr>
<tr>
<td>Geoid (Levelling)</td>
<td>0</td>
<td>Ground</td>
<td>In-situ</td>
</tr>
<tr>
<td>Gravimetry</td>
<td>$1^{st}$</td>
<td>Ground</td>
<td>In-situ</td>
</tr>
<tr>
<td>Deflections of the Vertical</td>
<td>$1^{st}$</td>
<td>Ground</td>
<td>In-situ</td>
</tr>
</tbody>
</table>

(According to Rummel, van Gelderen, 1995)
Mean Ocean Geoid as Reference Surface for Ocean Circulation – Geodetic MDT

Improved ocean geoid leads to improved MDT

Improved MDT leads to improved geostrophic current velocities

Improved geostrophic current velocities lead to improved transport

Meridional overturning circulation at 26°N as observed by the RAPID array, depending on depth, and applying geodetic MDTs.

Link to ECV’s & EOV’s
Surface currents
Sub-surface currents

L3 EGrV Mass Transport in Earth System

Link to ECV’s & EOV’s

Sea level

L2 EGrV
Global Geoid (Mean)

Mass Transport in Earth System

Link to ECV’s & EOV’s
Surface currents
Sub-surface currents

L3 EGrV Mass Transport in Earth System

Link to ECV’s & EOV’s
Example: L2 EGrV – Regional Geoid (Mean)

Mean Regional Geoid as Reference Surface for Physical Heights on Land

GNSS-Levelling: \( H_G = h - N - N_0 - N_1 \approx h - N \)

Spirit Levelling: \( H_R \)

Ideal Case: \( H_G = H_R \)

L2 EGrV
- Global Geoid (Mean)
- Regional Geoid (Mean)

Link to ECV’s
- River Discharge
- Lakes
- Sea Level
Mean Geoid as Reference Surface for Absolute Sea Level

Sea Level wrt. Local Datum
\[ SL_A = TG_A \quad SL_B = TG_B \]
\[ \Delta SL_{AB} \neq TG_A - TG_B \]

Absolute Sea Level wrt. Global Geoid
\[ SL_A = TG_A + N_A \]
\[ SL_B = TG_B + N_B \]
\[ \Delta SL_{AB} = SL_A - SL_B = TG_A - TG_B + (N_A - N_B) \]

In Case of Vertical Land Motion:
\[ \Delta SL_{AB} = TG_A - TG_B + (N_A - N_B) + (h_A - h_B) \]

Tide Gauge Benchmark
Earth Surface (Geometry)
Ocean Surface (Geometry)
Tide Gauge Height
Tide Gauge Reading

L2 EGrV
Global Geoid (Mean)
Regional Geoid (Mean)

Link to ECV’s Sea Level
## EGrVs Requirements

<table>
<thead>
<tr>
<th>EGrV</th>
<th>Current Resolution, Accuracy</th>
<th>Required Resolution, Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>L0: CoM Gravity Standards (Constants)</td>
<td>? high</td>
<td>1 mm 3-axes high</td>
</tr>
<tr>
<td>L1: Land Gravimetry</td>
<td>Point Obs., µGal m to km, mGal 100-200km, mGal Point Obs. mm/km, cm/km</td>
<td>Point Obs., µGal m to km, &lt;mGal 100km, &lt;mGal Point Obs., mm/km</td>
</tr>
<tr>
<td>L2: Global Models Mean Geoid</td>
<td>8km, cm to dm 200km, 1mo, mm 1-100km, cm to dm -</td>
<td>8km, 1cm 100km, 1d-1mo, 1mm 1km, 1cm ?, 1 cm/decade</td>
</tr>
<tr>
<td>L3: Mass Distribution (Satellites)</td>
<td>100km, 50cm EWH 200km, 1mo, 10km³(Gt)</td>
<td>100km, 10cm EWH 100km, 1d-1mo, 1Gt</td>
</tr>
</tbody>
</table>
IUGG General Assembly, Montreal, 15.7.2019

Summary and Conclusions

- ECVs and EOVs well defined
- EGVs for Geometry, Earth Orientation and Gravimetry → Essential Gravimetric Variables (EGrVs).
- Different Levels of EGrVs are proposed:
  - Level 0: Geodetic (Gravimetric) Standards
  - Level 1: Gravity Observations of different kind with different integration areas.
  - Level 2: Geopotential Models (regional & global)
  - Level 3: Application Variables (mass distribution and mass transport)
- Requirements for EGrVs need to be fixed.