Geodetic Requirements for Next Generation Gravity Field Missions in the Context of Essential Geodetic Variables

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Mass change
And
Geosciences
International
Constellation

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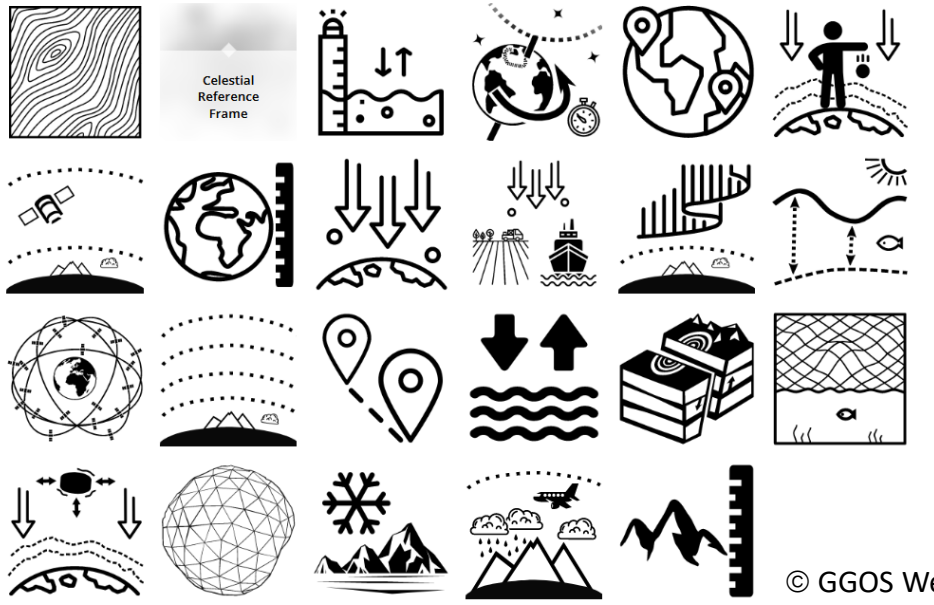

GGOS
Geodetic
Product
List

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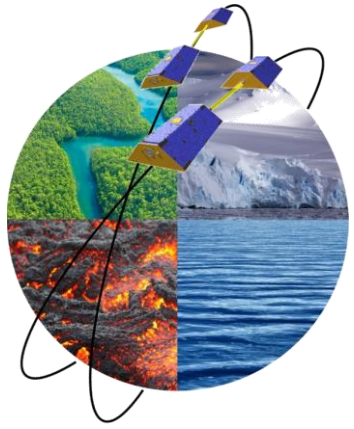
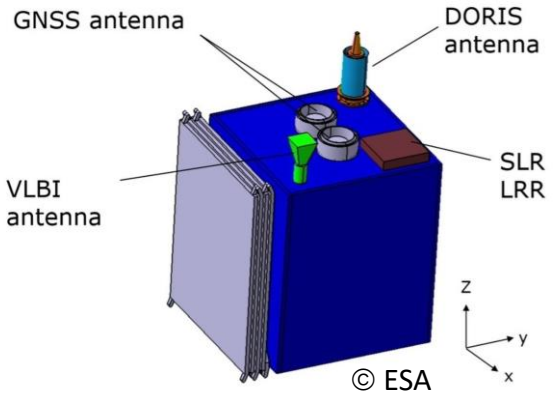
Questions to be addressed in this Presentation

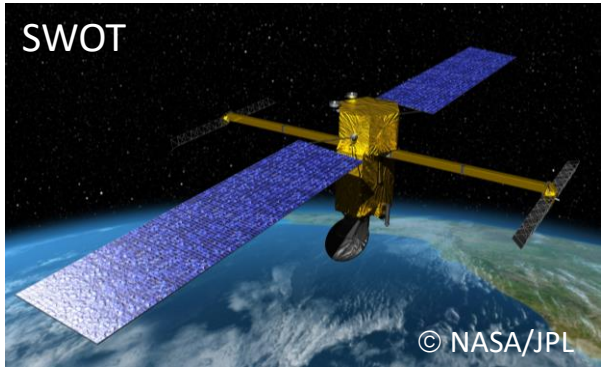
1. ***Do we need to define requirements for geodetic applications for designing future Earth Observation missions?***



Gravity field (NGGM/MAGIC)



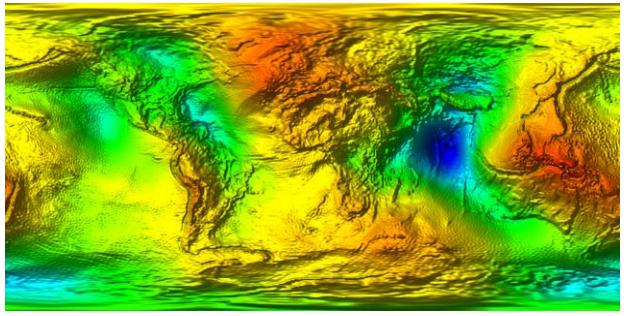
Reference frames (GENESIS)

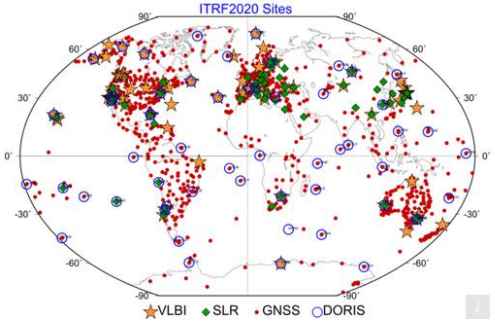


Earth geometry (Ocean, Land, Ice)

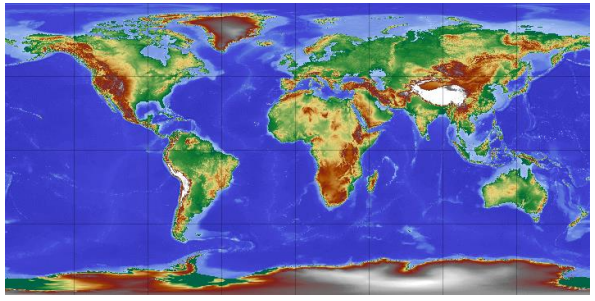
2. ***Do we need to define Essential Geodetic Variables (EGV's)? What are EGV's?***

"Observed variables that are crucial (essential) to characterizing the geodetic properties of the Earth and that are key to sustainable geodetic observations." (R. Gross)





ITRF station distribution [Source: Altamimi et al.]



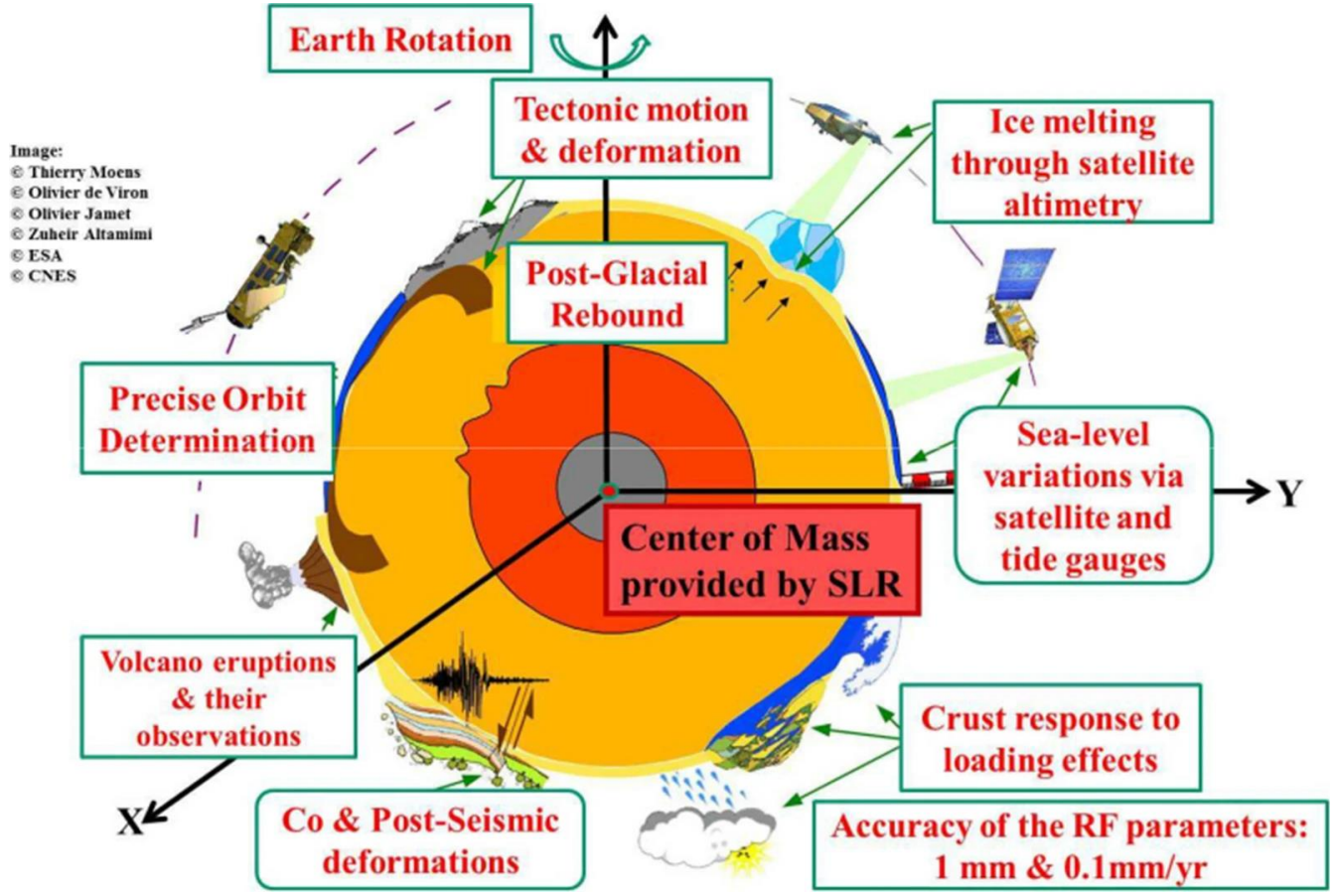
Geodetic Requirements for future EO Missions

Examples for Science & Mission Objectives and derived Mission Requirements

GENESIS: Co-location of Geodetic Techniques in Space

"The GENESIS mission's primary goal is a significant improvement of the International Terrestrial Reference Frame (ITRF). The ITRF is recognized to be the metrological foundation for all space- and ground-based observations in Earth Science and Navigation, and therefore this mission will potentially have a major impact in a large number of GNSS and Earth Observation applications"

→ Geodetic Product: ITRF



Geodetic Requirements for future EO Missions

Examples for Science & Mission Objectives and derived Mission Requirements

NGGM/MAGIC (Mission Requirements Document, Issue 1.0, Oct. 2020 and presented at ESA Living Planet Symposium 2022)

Table 1. Thematic fields and signals investigated by MAGIC

Thematic field	Signals/Quantities of interest
Hydrology	• Ground-water storage • Soil moisture • Extreme events warning (e.g. drought, flood) • Water balance closure • Global change impact on water cycle
Cryosphere	• Mass balance of ice sheets and glaciers • Contribution to global and regional sea level • Glacial isostatic adjustment (GIA)
Oceanography	• Ocean bottom pressure • Antarctic Circumpolar Current (ACC) and Atlantic Meridional Overturning Circulation (AMOC) variability • Tidal models • Heat and mass observations • Ocean circulation models
Solid Earth	• Geohazards • Deep interior properties and dynamics • Reshaping of Earth surface under external or internal forcing • Natural resources
Climate Change	• Sea-level change • Separation of contributors to the global water cycle
Neutral atmosphere	• Thermospheric neutral density • Thermospheric wind

→ **Geodesy not mentioned as thematic field and no requirements were defined (initially)**

Table 4. MAGIC user requirements for Hydrology (Ground-water storage, Soil moisture, Extreme events warning, Water balance closure, Global change impact on water cycle). Values are obtained from IUGG user requirements [RD1] and the e.motion2 proposal [RD6]. At the bottom of the table a few additional requirements are obtained from specific references which are available in the STM table at the end of the document (Annex-A).

Thematic field	Time scale **D**: Daily to weekly; **M**: Monthly; **L**: Long-term trend	Threshold: Resolution & Accuracy [EWH]	Target: Resolution & Accuracy [EWH]
Hydrology	**D**	Threshold-a: 600 km @ 3.2 cm; Threshold-b: 300 km @ 5.9 cm; Threshold-c: 280 km @ 6.0 cm	Target-a: 600 km @ 0.3 cm; Target-b: 300 km @ 0.6 cm; Target-c: 280 km @ 0.6 cm
	M	Threshold-a: 400 km @ 0.5 cm; Threshold-b: 260 km @ 4.8 cm	Target-a: 400 km @ 0.05 cm; Target-b: 260 km @ 0.48 cm
	L	Threshold-a: 350 km @ 0.1 cm/yr; Threshold-b: 150 km @ 5.0 cm/yr	Target-a: 350 km @ 0.01 cm/yr; Target-b: 150 km @ 0.5 cm/yr
Thematic sub-field			
Ground-water storage	**L**	See Hydrology	Target: 200 km @ 0.1 cm/yr
Water balance closure	**M**	See Hydrology	Target: 200 km @ 1 cm
Global change impact on water cycle	**L**	See Hydrology	Target: 200km @ 0.1 cm/yr

[RD1] Pail R. et al., Observing Mass Transport to Understand Global Change and to Benefit Society: Science and User Needs – An international multi-disciplinary initiative for IUGG.
[RD6] T. Gruber, I. Panet et al, Earth System Mass Transport Mission2 - e.motion2, Proposal for Earth Explorer Mission EE-9 (Proposal Reference Number: CEE9/019), June 2016.

Geodetic Requirements for future EO Missions

NGGM/MAGIC – Proposal for Geodetic Applications & Requirements

The story behind the scene:

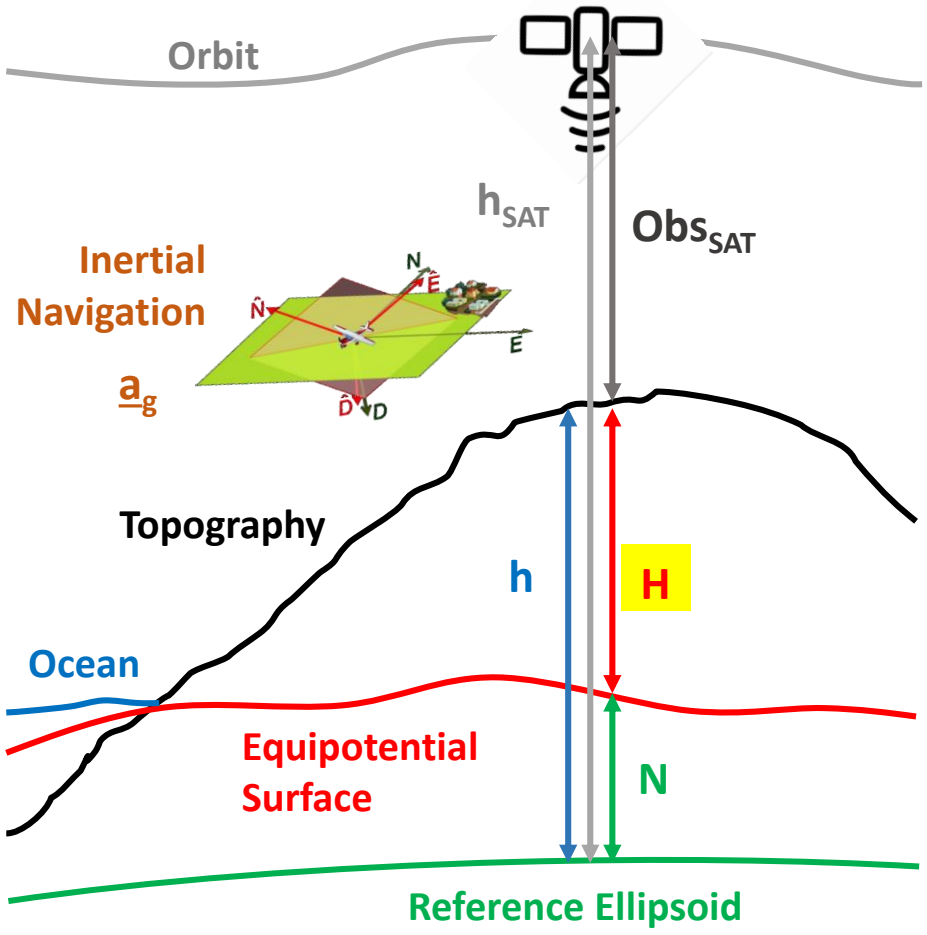
- At ESA Living Planet Symposium I asked the presenter why no requirements for geodetic applications are included?
- Initial answer: Somehow it is assumed that it is granted that the geodetic product are anyhow available.
- My conclusion: Obviously geodesy suffers from visibility in this context. This needs to be improved!

What happened:

- I was asked by ESA to prepare a chapter with requirements for geodetic applications (be aware - this happens when you ask a question like this!)
- Result is shown on next slides.

Geodetic Requirements for future EO Missions

NGGM/MAGIC – Proposal for Geodetic Applications & Requirements



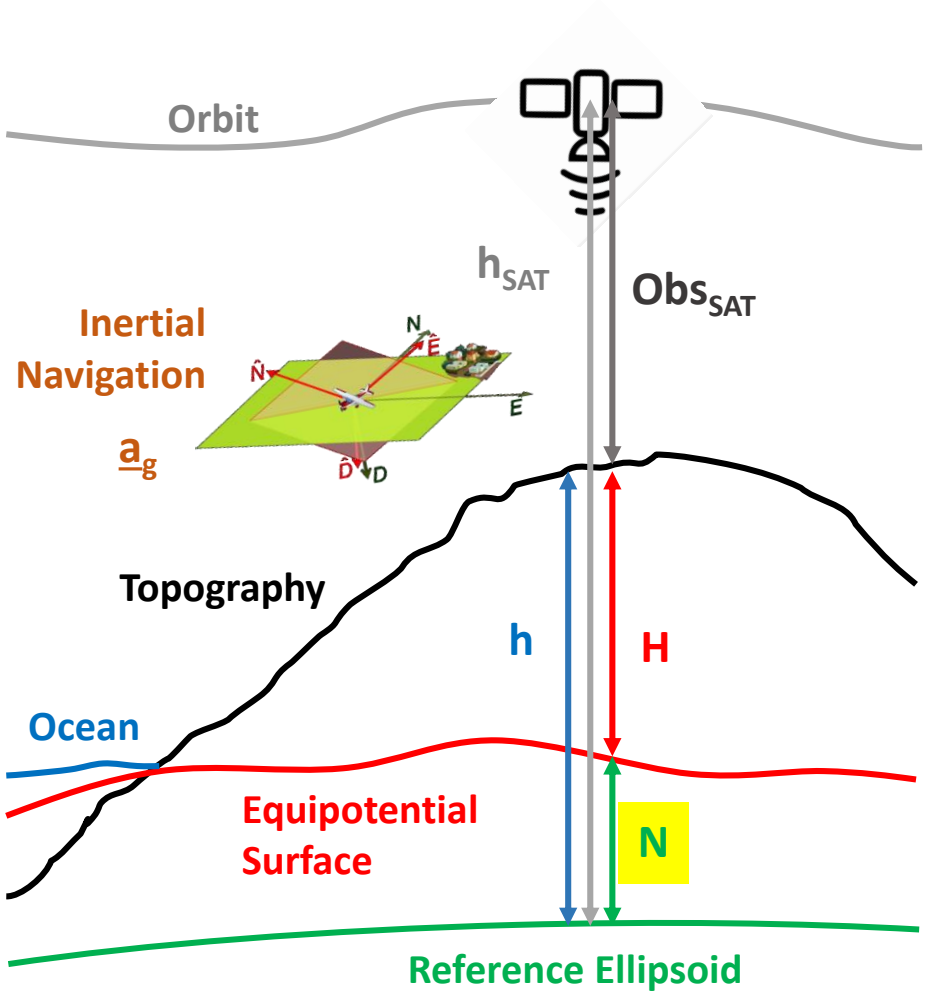
Physical Heights & Height System Unification: H

- Equipotential surface needs to be known with highest spatial resolution and temporal variability needs to be considered.
- Height systems have major impact on water management and cross-border engineering projects (with different height systems).
- NGGM/MAGIC provides a better reference global equipotential surface. Better quantification of residual omission error possible.
- NGGM/MAGIC also will provide temporal changes of the equipotential surface and correspondingly of physical heights.
- Temporal changes of height reference stations contributes to regional sea level change observations (absolute and relative).

→ **Geodesy shall provide a description of the equi-potential reference surface (in space & time domain)**

Geodetic Requirements for future EO Missions

NGGM/MAGIC – Proposal for Geodetic Applications & Requirements



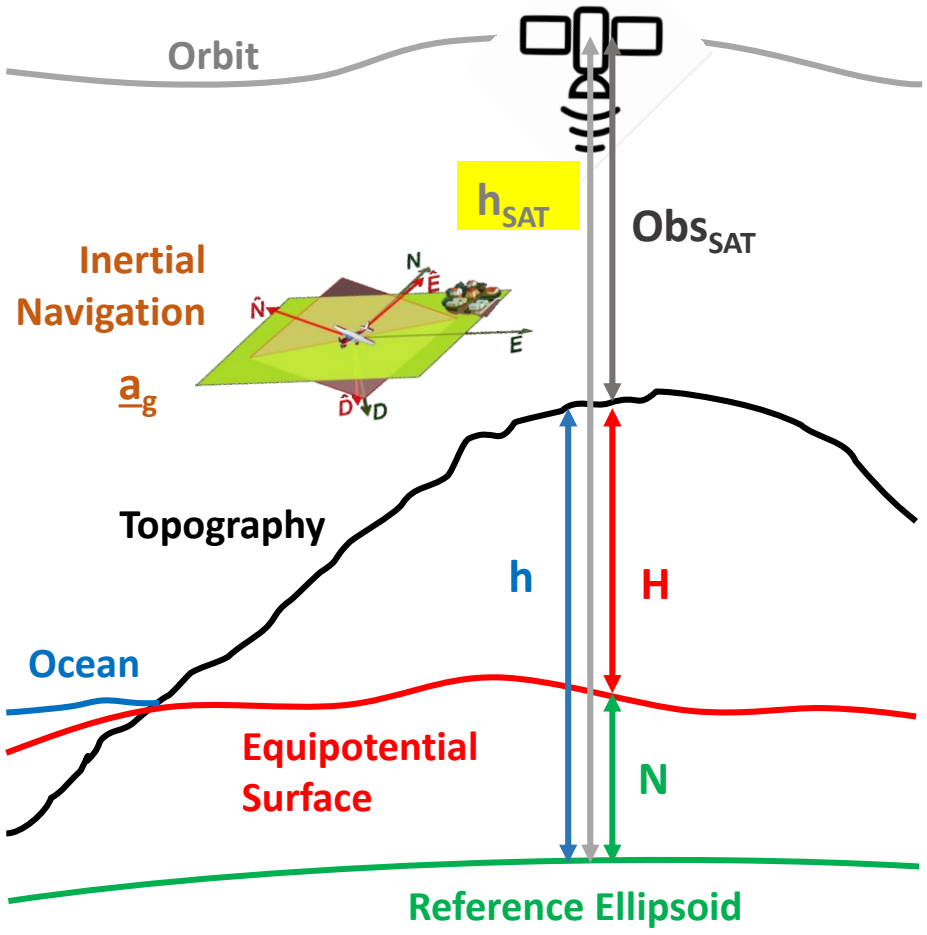
GNSS Levelling: H = h - N

- GNSS levelling is used by national geodetic authorities in many countries for determination of physical heights.
- It has high economic potential and is of great interest for countries with a less advanced geodetic infrastructure.
- NGGM/MAGIC provides enhanced information of the geoid in particular by providing its temporal variations (e.g. GIA signal 1 mm/yr).
- For precise GNSS levelling (at mm level) the geoid variations need to be considered together with geometric GNSS height variations.

→ **Geodesy shall provide regional geoid and its variations to enable GNSS Levelling**

Geodetic Requirements for future EO Missions

NGGM/MAGIC – Proposal for Geodetic Applications & Requirements



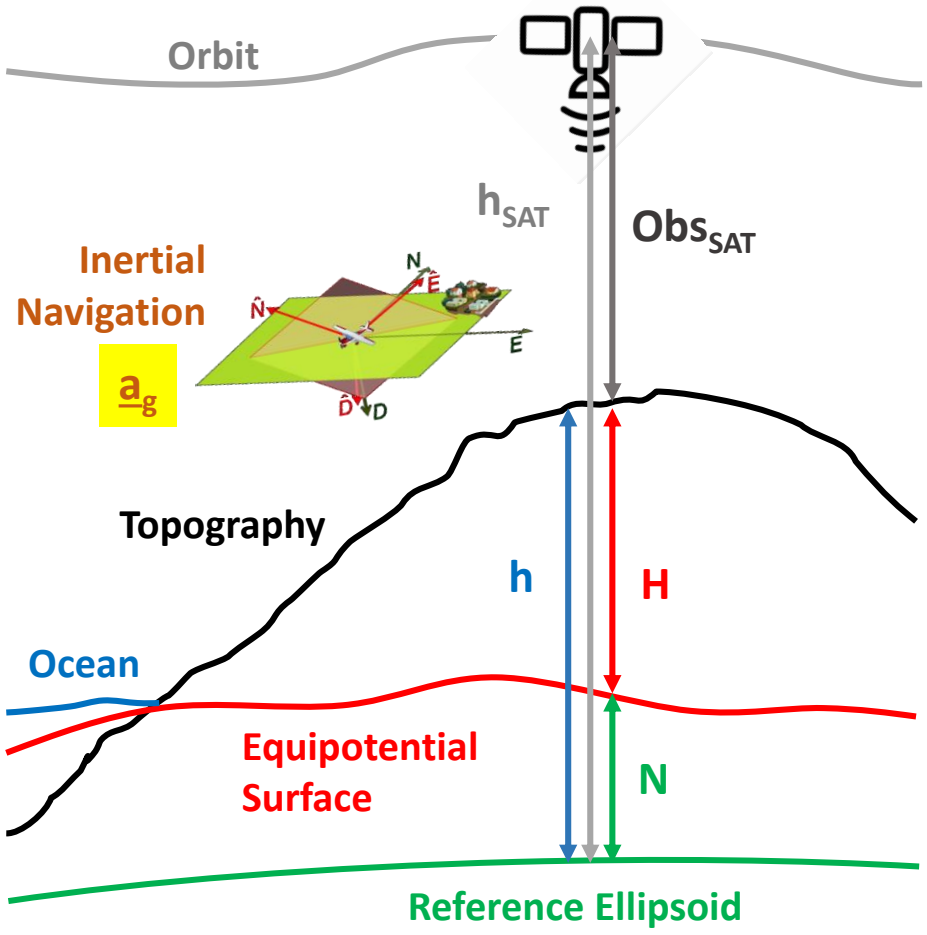
Geometric Heights & Orbit Accuracy: h_{SAT}

- Radial orbit accuracy is crucial for EO missions observing geometric heights (GNSS, Altimetry, SAR).
- Orbit heights enter one-to-one into the total error budget.
- Satellite orbit determination needs to consider the time variable component of the gravity field. .
- NGGM/MAGIC will further contribute by providing observations of the gravity field with higher temporal resolution.
- NGGM/MAGIC possibly contributes to further improved orbits of GNSS satellites and GNSS positioning.

→ **Geodesy shall provide a time variable gravity field with higher temporal resolution for POD.**

Geodetic Requirements for future EO Missions

NGGM/MAGIC – Proposal for Geodetic Applications & Requirements



Inertial Navigation: $\underline{a}_g$

- Improved knowledge of gravity field directly has impact on inertial navigation accuracy (correction for gravitational accelerations).
- Importance for navigation applications where no access to satellite navigation signals is possible.
- NGGM/MAGIC might improve high precision inertial navigation positioning for specific applications with high demands on positioning accuracy.

→ **Geodesy shall provide high resolution gravity field model and its temporal variations.**

Geodetic Requirements for future EO Missions

NGGM/MAGIC – Geodesy Societal and Science Questions and Objectives

G1 - Societal & Science Questions – Height Systems:

- How to achieve a global unification of height systems with sufficient accuracy?
- How can regional and national height systems be unified independently of local datums?
- How can we complement local terrestrial and airborne gravimetry surveys?

NGGM/MAGIC Objectives – Height Systems:

- **G1-a**. Develop a global reference geoid as an optimum combination of satellite and ground/airborne gravity data covering all relevant spatial wavelength.
- **G1-b**. Develop a global satellite-only reference geoid with highest possible resolution, which serves as basis for computing the omission error at height reference stations from local gravity observations.
- **G1-c**. Generate a reference geoid which accounts for temporal changes of gravity field with improved spatial resolution and accuracy particularly needed in regions with strong gravity variations.

Geodetic Requirements for future EO Missions

NGGM/MAGIC – Geodesy Societal and Science Questions and Objectives

G2 - Societal & Science Questions – GNSS Levelling:

- How can we improve GNSS levelling to benefit national geodetic control networks and surveying applications, in particular in countries with a less developed geodetic infrastructure?
- Can GNSS levelling substitute costly and time-consuming traditional spirit levelling techniques?
- How do physical heights vary with redistribution of mass in the Earth system?
- How do changes in frequency and magnitude of the time variable gravity field affect the reference geoid used as zero-height level from which physical heights are measured?

G2 – NGGM/MAGIC Objectives – GNSS Levelling:

- Resolve temporal variations of physical heights induced by gravity variations originating from geophysical signals by including temporal gravity field variations of sufficient spatial resolution and accuracy.

Geodetic Requirements for future EO Missions

NGGM/MAGIC – Geodesy Societal and Science Questions and Objectives

G3 - Societal & Science Questions – Geometric Heights & Orbits:

- How are satellite-derived geometric heights affected by redistribution of mass in the Earth system?
- How can we improve the determination of geometric heights to derive enhanced products of Earth Observation missions such as SAR and altimetry missions?

G3 – NGGM/MAGIC Objectives – Geometric Heights & Orbits:

- Improve the accuracy of Earth Observation satellite orbits by including the time variable gravity field information in the precise orbit determination process.
- G3-b. Improve the accuracy of geometric heights by benefiting from improved orbits and generate enhanced products from Earth Observation missions such as altimetry and SAR missions.

Geodetic Requirements for future EO Missions

NGGM/MAGIC – Geodesy Mission Requirements (Proposal)

Thematic field	**Time scale** **D**: Daily to weekly; **M**: Monthly; **L**: Long-term trend; **A**: Long-term average	**Threshold:** Resolution & Accuracy [Geoid] *Resolution & Accuracy [EWH]*	**Target:** Resolution & Accuracy [Geoid] *Resolution & Accuracy [EWH]*
Geodesy	**D**	N.A.	N.A.
	M	Threshold-a: 400 km @ 50 µm *Threshold-a: 400 km @ 0.7 cm;* Threshold-b: 200 km @ 500 µm *Threshold-b: 200 km @ 13 cm*	Target-a: 400 km @ 5 µm *Target-a: 400 km @ 0.07 cm;* Target-b: 200 km @ 50 µm *Target-b: 200 km @ 1.4 cm*
	L	Threshold-a: 400 km @ 5 µm/yr *Threshold-a: 400 km @ 0.07 cm/yr;* Threshold-b: 200 km @ 50 µm/yr *Threshold-b: 200 km @ 1.4 cm/yr*	Target-a: 400 km @ 0.5 µm/yr *Target-a: 400 km @ 0.01 cm/yr;* Target-b: 200 km @ 5 µm/yr *Target-b: 200 km @ 0.14 cm/yr*
	A	Threshold-a: 100 km @ 0.5 cm *Threshold-a: 100 km @ 264 cm;* Threshold-b: 30 km @ 1 cm *Threshold-b: 30 km @ 1740 cm*	Target-a: 100 km @ 0.1 cm *Target-a: 100 km @ 53 cm;* Target-b: 30 km @ 0.5 cm *Target-b: 30 km @ 870 cm*

Essential Geodetic Variables (EGV's)

What are EGV's?

"Observed variables that are crucial (essential) to characterizing the geodetic properties of the Earth and that are key to sustainable geodetic observations." (R. Gross)

M. Rothacher (IUGG 2019)

ETH zürich

Criteria for Essential Variables (ECVs, EOVs, EGVs, …)

- **Relevance:** The variable is critical for characterizing the climate system / ocean system / ??? and its changes.
- **Feasibility:** Observing or deriving the variable on a global scale is technically feasible using proven, scientifically understood methods.
- **Cost effectiveness:** Generating and archiving data on the variable is affordable, mainly relying on coordinated observing systems using proven technology, taking advantage where possible of historical datasets.

My addition:

- **Sustainability:** The variable should be made available over decades (reference frame stability, chains of satellite missions, …)

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Essential Geodetic Variables (EGV's)

What are EGV's?

M. Rothacher (IUGG 2019)

ETH zürich

Definition of Essential Geodetic Variables (EGVs)

- Essential for what ? For geodesy ? Essential for the monitoring of the **Earth system as a whole**
- We should define real geometrical and physical quantities (clear meaning and clear methods to measure them), not like "Lakes", "Glaciers", "Ground water", etc.
- We should try to define quantities that are independent of the Earth component it is used for (hydrology, solid Earth, ocean, cryosphere, …)
- We have three important pillars: geometry, Earth rotation, gravity field, but we should add the atmosphere, snow, soil moisture, etc. Where do they fit ?
- Only variables should be chosen that are continuously produced and are sustainable …

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Essential Geodetic Variables (EGV's)

Do we need to EGV's?

Yes !

If we would have had EGV's NGGM/MAGIC requirements for geodetic applications would have been defined also in the initial version.

To be Done by the Geodetic Community:

- Identify a basic set of EGV´s (either classiefied by geodetic pillars or by applications).
- Define criteria to become an EGV: Relevance, Feasibility, Cost effectiveness, Sustainability, others.
- Define the right level for EGV's: Should it be at Level 2 or 3 to be relevant? Should lower level variables be considered?
- Identification of requirements for EGV's: Driven by applications? Driven by geodetic techniques?

Conclusions

1. ***Do we need to define requirements for geodetic applications for designing future Earth Observation missions?***

- Done for NGGM/MAGIC
- In future EGV's shall be defined and used for defining requirements for EO satellite missions.

2. Do we need to define Essential Geodetic Variables (EGV's)? What are EGV's?

- Yes, absolutely
- To be defined by the geodetic community.