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TAKING THE PULSE OF OUR PLANET FROM SPACE

EUMETSAT ECMWF EUSPA

ESA/NASA cooperation towards Mass Change and Geosciences International Constellation (MAGIC) mission

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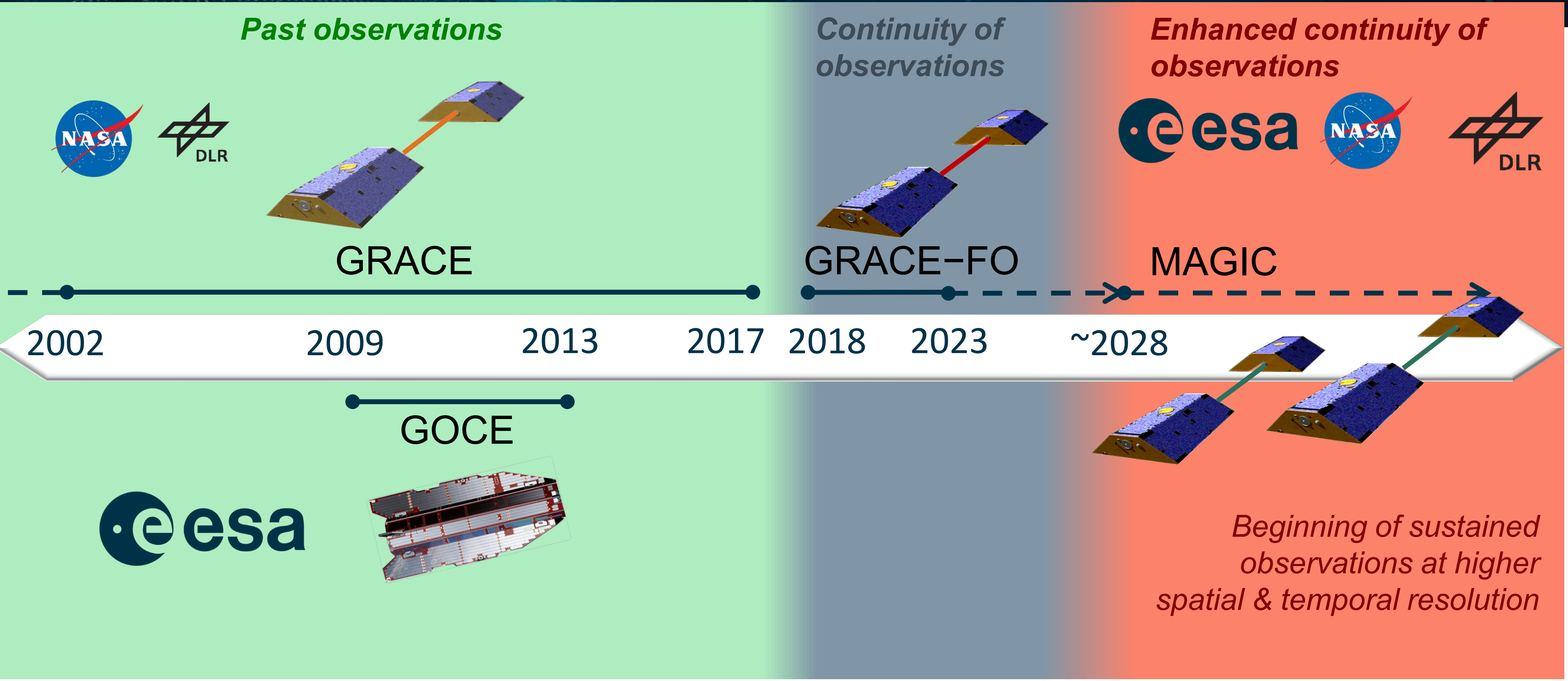
24 May 2022

1. History and Background
2. Latest Updates (MAGIC Status)
3. Way Forward

Timeline of Satellite Gravimetry



NASA/ESA cooperation background

- ESA and NASA have been involved in cooperation discussions on **satellite gravimetry** constellation concepts since more than a decade (GOCE Workshop, Munich 2011)

- **J**oint **P**rogramme **P**lanning **G**roup (**JPPG**) established between NASA and ESA for cooperation in the field of Earth Observation. **JPPG Sub-Group 1** is coordinating the activities for a collaborative mass change mission

- Over the past years, discussions between the two agencies led to articulating a strong interest in exploring a joint future mission and was captured in communications at highest levels (ESA letter February 15, 2019, NASA letter February 27, 2019, NASA letter November 15, 2019, ESA and NASA exchange letters August 2020).

MAGIC – An opportunity for MC constellation

- ❑ **GRACE**, **GOCE**, **GRACE-FO** → very successful series of gravity field missions, which established the importance of Earth's gravity field monitoring and mass change supporting a rich spectrum of science and applications

- ❑ Strong user demand expressed by **IUGG, IAG, GGOS** for <u>improved temporal and spatial resolutions</u> for enhanced continuity of observations, paving the way to future sustained observations and services

- ❑ <u>Continuity</u> after **GRACE-FO** ensured to continue the program of record and preserve the climate series, per US Decadal Survey 2017

- ❑ **MA**ss-change and **G**eosciences **I**nternational **C**onstellation (**MAGIC**) is the joint NASA/ESA constellation concept based on NASA's MCDO and ESA's NGGM studies.

- ❑ Goal is to implement <u>a (pre-) operational mission</u> with improved observations to meet science and application objectives defined in ESA/NASA MAGIC Mission Requirement Document (MRD).

- ❑ Necessity of <u>staggered approach</u> (development and launch) with two pairs of satellites, taking advantage of heritage and experience in order to meet enhanced continuity objectives with affordable budget.

Milestones (1)

- **2007 - 2011** – User Community Workshops: Noordwijk, NL (2007), Graz, AT (2009), Munich, DE (2011)
- **2007**– US Decadal Survey planning for a GRACE-II with wider goals and improved instruments than GRACE
- **2013 - 2016** – Inter-agency Gravity Science Working Group (**IGSWG**) works on a possible future NASA/ESA cooperation scenario for mass change mission ➔ IGSWG Report
- **2017**– US Decadal Survey planning for continuity to GRACE (Follow On) via international cooperation
- **March 2020** – Establishment of the **A**d-hoc **J**oint **S**cience **S**tudy **T**eam (**AJSST**) with the mission to support the definition of jointly agreed global user and science needs and to prepare a Mission Requirement Document (MRD)
- **October 2020** – ESA/NASA MAGIC **M**ission **R**equirement **D**ocument (**MRD**) Issue 1.0 released including AJSST recommendations

Milestones (2)

- **May 2021** - **ESA NGGM/MAGIC** Phase A kicks off with planned end in November 2022

- **May - June 2021** – Establishment of the ESA/NASA **J**oint **E**ngineering **T**eam (**JET**) and the **J**oint **M**ass **C**hange **M**ission **E**xpert **G**roup (**JMCMEG**)

- **March 2021** – **DLR GRACE I** Phase 0 kicks off

- **June 2021** – **NASA/JPL MC** pre-Phase A kicks off

Satellite gravity user needs

UGGI
IUGG

International Union of Geodesy and Geophysics

Resolutions

ADOPTED BY THE COUNCIL
AT THE XXVI GENERAL ASSEMBLY
PRAGUE, CZECH REPUBLIC
(22 JUNE – 2 JULY 2015)

- ✓ IUGG (International Union of Geodesy and Geophysics) embodies all geophysical and geodetic disciplines
- ✓ Represents about 100,000 users worldwide
- ✓ **Resolution 2** is the only resolution which makes explicit mention of **satellite constellations** beyond GRACE/GRACE-FO, GOCE & Swarm

Resolution 2:

Future Satellite Gravity and Magnetic Mission Constellations

The International Union of Geodesy and Geophysics

Considering

- The interest and need of the IUGG scientific community to understand processes of global mass transport in the Earth system, and the interaction among its subsystems including continental hydrology, cryosphere, atmosphere, ocean and solid Earth, in order to close the global water budget and to quantify the climate evolution of the Earth,
- The long lead time required to bring an earth observation system into operation,

Acknowledging

- The experience acquired in the last decade within the IUGG in analyzing data from dedicated satellite missions such as CHAMP, GRACE, GOCE and Swarm for the purpose of estimating the gravity and magnetic fields and their time variations,
- The clear expression of need from the user communities so far, and the definition of joint science and user requirements for a future satellite gravity field mission constellation by an international working team under the umbrella of IUGG,

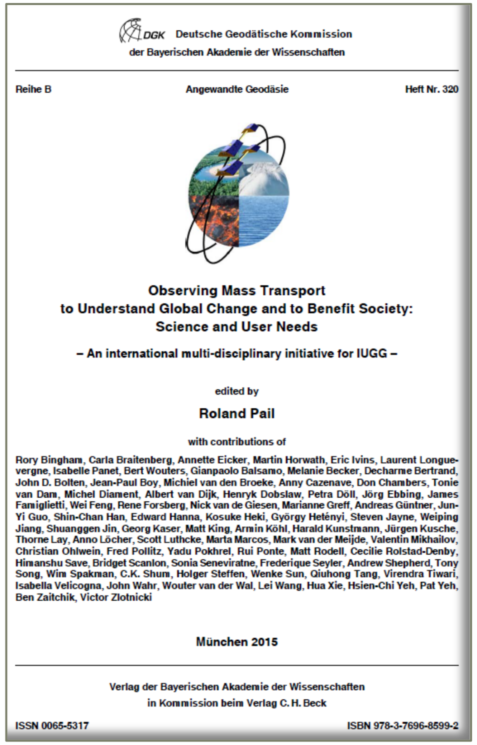
Noting

- The need for a long-term sustained observation of the gravity and magnetic fields and related mass transport processes of the Earth beyond the lifetime of GRACE and the GRACE Follow-On planned for the 2017 - 2022 period, and beyond the lifetime of Swarm, currently 2013 to 2018,
- The demonstrated need for satellite constellations to improve temporal and spatial resolution and to reduce aliasing effects,

Urges

International and national institutions, agencies and governmental bodies in charge of supporting Earth science research to make all efforts to implement long-term satellite gravity and magnetic observation constellations with high accuracy that respond to the aforementioned need for sustained observation.

Past studies & documents:


DGK Deutsche Geodätische Kommission
der Bayerischen Akademie der Wissenschaften

Reihe B Angewandte Geodäsie Heft Nr. 320

Observing Mass Transport
to Understand Global Change and to Benefit Society:
Science and User Needs

– An international multi-disciplinary initiative for IUGG –

edited by

Roland Pail

with contributions of

Rory Bingham, Carla Braitenberg, Annette Eicker, Martin Horwath, Eric Ivins, Laurent Longuevergne, Isabelle Panet, Bert Wouters, Gianpaolo Balsamo, Melanie Becker, Decharme Bertrand, John D. Bolten, Jean-Paul Boy, Michiel van den Broeke, Anny Cazenave, Don Chambers, Tonie van Dam, Michel Diament, Albert van Dijk, Henryk Dobslaw, Petra Döll, Jörg Ebbing, James Famiglietti, Wei Feng, Rene Forsberg, Nick van de Giesen, Marianne Greff, Andreas Güntner, Jun-Yi Guo, Shin-Chan Han, Edward Hanna, Kosuke Heki, György Hetényi, Steven Jayne, Weiping Jiang, Shuanggen Jin, Georg Kaser, Matt King, Armin Köhl, Harald Kunstmann, Jürgen Kusche, Thorne Lay, Anno Löcher, Scott Luthcke, Marta Marcos, Mark van der Meijde, Valentin Mikhailov, Christian Ohlwein, Fred Pollitz, Yadu Pokhrel, Rui Ponte, Matt Rodell, Cecilie Rolstad-Denby, Himanshu Save, Bridget Scanlon, Sonia Seneviratne, Frederique Seyler, Andrew Shepherd, Tony Song, Wim Spakman, C.K. Shum, Holger Steffen, Wenke Sun, Qiuhong Tang, Virendra Tiwari, Isabella Velicogna, John Wahr, Wouter van der Wal, Lei Wang, Hua Xie, Hsien-Chi Yeh, Pat Yeh, Ben Zaitchik, Victor Zlotnicki

München 2015

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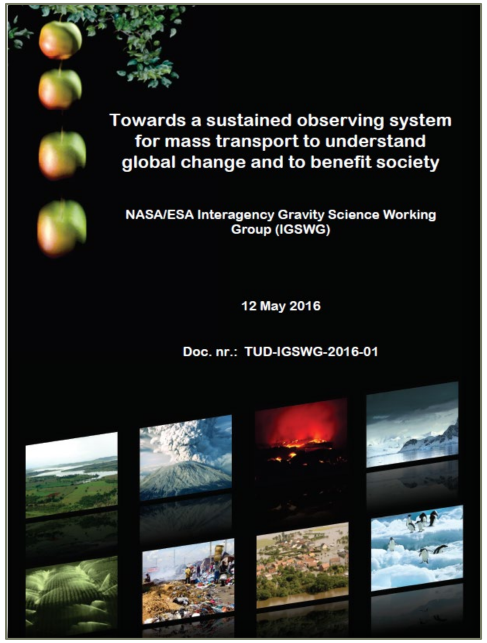
Towards a sustained observing system for mass transport to understand global change and to benefit society

NASA/ESA Interagency Gravity Science Working Group (IGSWG)

12 May 2016

Doc. nr.: TUD-IGSWG-2016-01


Proposal Reference Number: CEE9/019

e.motion²

Earth System Mass Transport Mission²

Proposal for Earth Explorer Mission EE-9

In Response to
Call for Proposals for Earth Explorer Mission EE-9
(ESA/EXPLORER/EE-9 November 2015)
by the

e.motion² Team

June 2016


The National Academies of SCIENCES ENGINEERING MEDICINE THE NATIONAL ACADEMIES PRESS

This PDF is available at http://nap.edu/24938 SHARE

Thriving on Our Changing Planet: A Decadal Strategy for Earth Observation from Space (2018)

DETAILS
716 pages | 8.
ISBN 978-0-3

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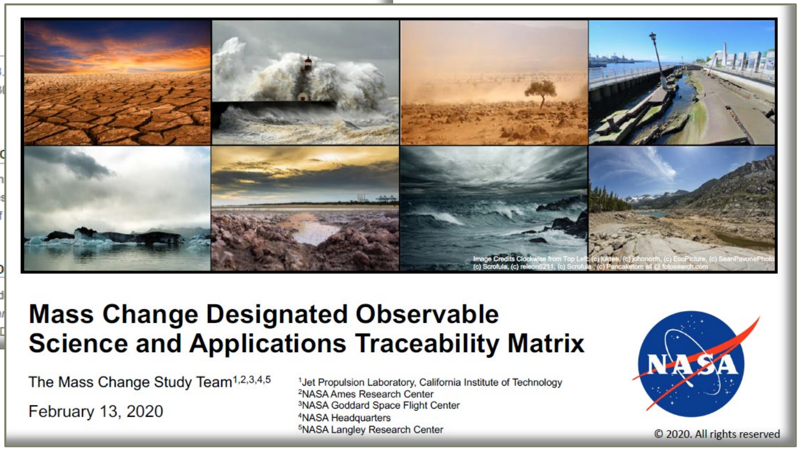
Mass Change Designated Observable Science and Applications Traceability Matrix

The Mass Change Study Team[1,2,3,4,5]

February 13, 2020

[1]Jet Propulsion Laboratory, California Institute of Technology
[2]NASA Ames Research Center
[3]NASA Goddard Space Flight Center
[4]NASA Headquarters
[5]NASA Langley Research Center

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MCDO - NASA

UNIVERSITÀ DEGLI STUDI DI MILANO · ThalesAlenia Space · GIS

Gravitational seismology - ESA study

IUGG

IGSWG

e.motion²

2015 2016 2017 2018 2019 2020

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MAGIC Mission Requirement Document (MRD)

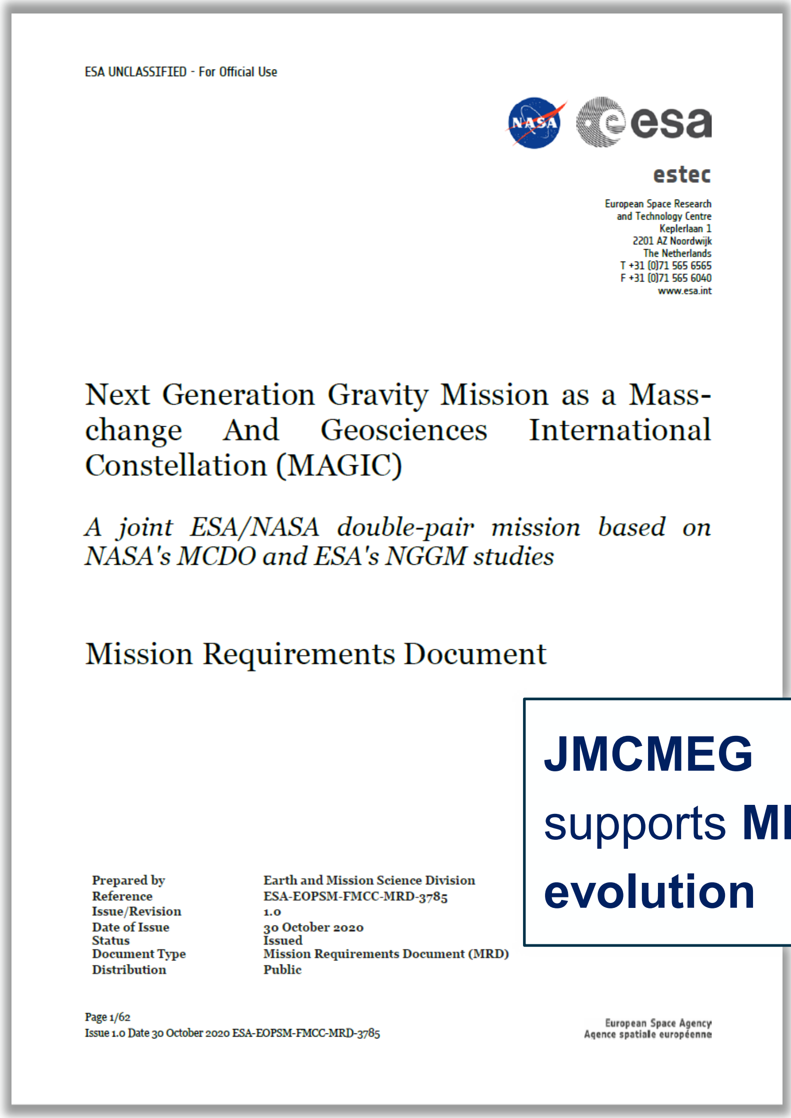
Global user requirements

Consolidation of user requirements

Ad hoc Joint Science Study Team (AJSST)

Coordination

ESA/NASA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Next Generation Gravity Mission as a Mass-change And Geosciences International Constellation (MAGIC)

A joint ESA/NASA double-pair mission based on NASA's MCDO and ESA's NGGM studies

Mission Requirements Document

Prepared by	Earth and Mission Science Division
Reference	ESA-EOPSM-FMCC-MRD-3785
Issue/Revision	1.0
Date of Issue	30 October 2020
Status	Issued
Document Type	Mission Requirements Document (MRD)
Distribution	Public

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Issue 1.0 Date 30 October 2020 ESA-EOPSM-FMCC-MRD-3785

European Space Agency
Agence spatiale européenne

JMCMEG supports MRD evolution

MAGIC MRD objectives

- **OBJ-1.** to measure and monitor the mass change and improve current estimations of ground-water storage, soil moisture, water balance closure, global change impacts on water cycle, providing the capability to raise extreme events warning (e.g. drought, flood).
- **OBJ-2.** to measure and monitor the cryosphere mass balance, the global and regional sea level, the Glacial Isostatic Adjustment (GIA), including the estimation of mass changes for ice sheet and glaciers.
- **OBJ-3.** to provide mass and sea level change and heat estimates for oceanography to improve tidal and ocean circulation models. Such information will also serve as critical input to operational oceanography and marine forecasting services as well as sea ice monitoring in the polar oceans.
- **OBJ-4.** to measure and monitor the mass change on Earth's deep interior properties and dynamics, Earth's crust under internal or external forcing, including observations for improvements in natural resources exploitation and assessment of effects of geohazards (e.g. earthquakes, tsunamis and volcanic activities).
- **OBJ-5.** to measure and monitor the mass change and its trends for climate change applications.
- **OBJ-6.** to provide measurements of mass change for ground-water storage and global change impact on water cycle applications for extreme events warnings and soil moisture.
- **OBJ-7.** to provide measurements of mass change for estimations of cryosphere mass changes including ice sheet and glaciers.
- **OBJ-8.** to support monitoring applications of geo-hazards (including Mw 8 earthquakes and Mw 7 as target) over few hundred kilometres areas and deep interior properties and dynamics over large spatial scales (e.g. 6.000 km) for estimating Body tides at millimetre accuracy.
- **OBJ-9.** to provide measurements of thermosphere neutral density and wind.
- **OBJ-10.** to provide new atmospheric parameters to separate atmospheric signals from the mass variation measurements.

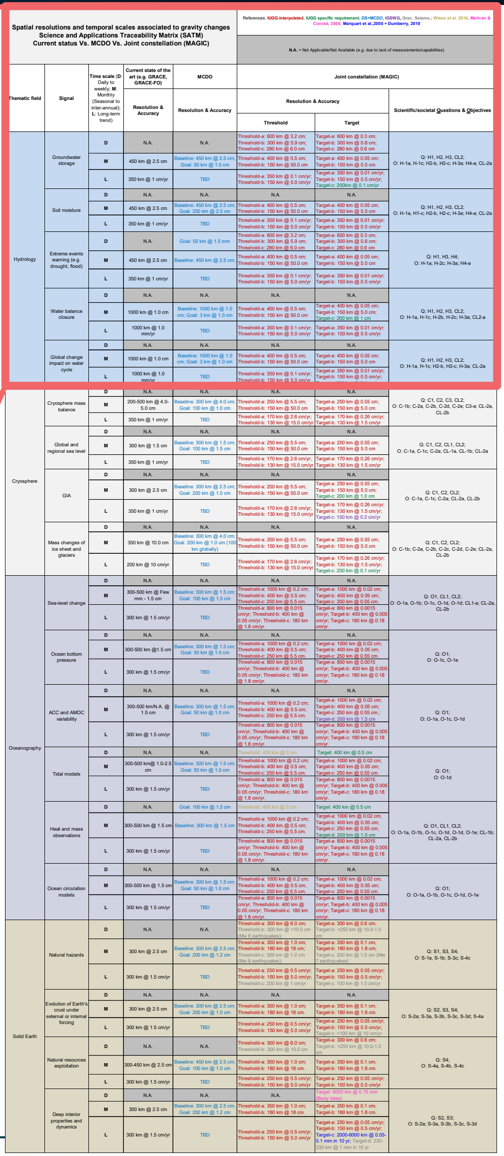
***Ref:** MAGIC MRD Issue 1.0*

- **10 mission objectives** spanning different times scales (daily to weekly, monthly to seasonal & long-term) and thematic fields
- The **mission requirements** of MAGIC are derived from these **mission objectives**
- All objectives address specific scientific and technical aspects and are connected to **societal & science questions**

MAGIC MRD SATM table

Spatial resolutions and temporal scales associated to gravity changes Science and Applications Traceability Matrix (SATM) Current status Vs. MCDO Vs. Joint constellation (MAGIC)					References: IUGG-interpolated, IUGG specific requirement, DS+MCDO, IGSWG, Grav. Seismo.; Wiese et al. 2016, Metivier & Conrad, 2008; Marquart et al.,2005 + Dumberry, 2010 N.A. = Not Applicable/Not Available (e.g. due to lack of measurements/capabilities)		
Thematic field	Signal	Time scale (D: Daily to weekly; M: Monthly (Seasonal to inter-annual); L: Long-term trend)	Current state of the art (e.g. GRACE, GRACE-FO) Resolution & Accuracy	MCDO Resolution & Accuracy	Joint constellation (MAGIC) Resolution & Accuracy Threshold	Target	Scientific/societal Questions & Objectives
Hydrology	Groundwater storage	D	N.A.	N.A.	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	Q: H1, H2, H3, CL2; O: H-1a, H-1c; H2-b, H2-c; H-3a; H4-a; CL-2a
						rget-a: 400 km @ 0.05 cm; rget-b: 150 km @ 5.0 cm	
						rget-a: 350 km @ 0.01 cm/yr; rget-b: 150 km @ 0.5 cm/yr; rget-c: 200km @ 0.1 cm/yr	
	Soil moisture					N.A.	Q: H1, H2, H3, CL2; O: H-1a, H1-c; H2-b, H2-c; H-3a; H4-a; CL-2a
		M	450 km @ 2.5 cm	Baseline: 450 km @ 2.5 cm; Goal: 200 km @ 2.5 cm	Threshold-a: 400 km @ 0.5 cm; Threshold-b: 150 km @ 50.0 cm	Target-a: 400 km @ 0.05 cm; Target-b: 150 km @ 5.0 cm	
		L	350 km @ 1 cm/yr	TBD	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	
	Extreme events warning (e.g. drought, flood)	D	N.A.	Goal: 50 km @ 1.5 mm	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	Q: H1, H3, H4; O: H-1a; H-2c; H-3a; H4-a
		M	450 km @ 2.5 cm	Baseline: 450 km @ 2.5 cm;	Threshold-a: 400 km @ 0.5 cm; Threshold-b: 150 km @ 50.0 cm	Target-a: 400 km @ 0.05 cm; Target-b: 150 km @ 5.0 cm	
		L	350 km @ 1 cm/yr	TBD	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	

MCDO Requirements are included in the **MAGIC MRD**



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MAGIC MRD way forward

- **ESA**, **NASA** and **DLR** have reached an agreement on the main pillars of the **baseline implementation scenario for MAGIC**, with some details currently still under discussion

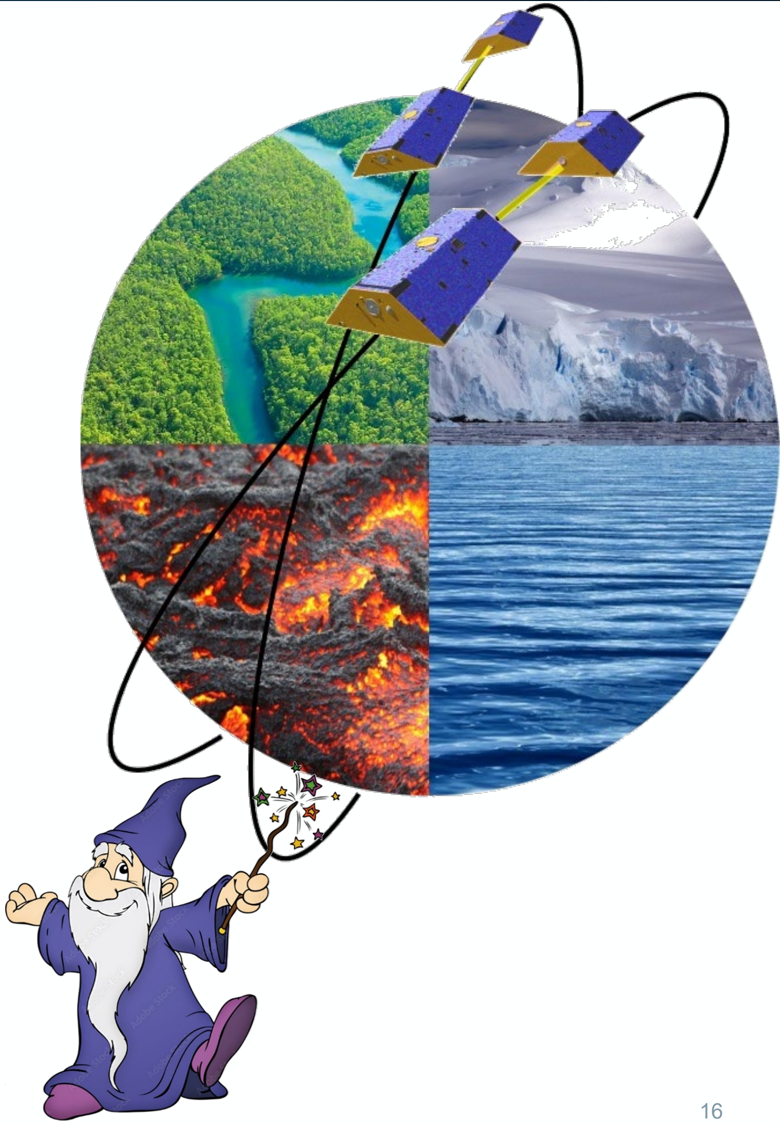
- The **MRD** will remain a **reference** document defining the mission requirements achievable by an optimized Bender constellation

- When the programmatic implementation scenario is finalised, the plan is to review and develop a subset MRD accordingly. This subset shall include the mission requirements for the **implementation scenario**. **Staggered double pair realisations** shall be analysed until the original MRD objectives are reached and its requirements are fulfilled.

MAGIC – Baseline implementation scenario

- **Two-pair "Bender"** constellation acting as precursor of future operational system

- **First satellite pair (P1)** (currently under consideration)
  - Implemented via a DE-USA fast-paced cooperation programme to ensure continuity of observations with GRACE-FO, with some potential ESA in-kind contributions (e.g. MicroSTAR accelerometer family, linear cold gas thrusters)
- **Second satellite pair (P2)**
  - Implemented via a Europe-USA cooperation programme with some potential NASA in-kind contributions with target launch date compatible to maintain at least 4 years of combined operations
  - NASA potential contribution based on elements/units of the Laser Tracking Instrument (LTI)



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MAGIC – NASA Mass Change Pre-Phase A activities

- ❑ MC currently a component of NASA's Earth System Observatory (ESO) announced in 2021
- ❑ Working with Earth Science Directorate to define mission configuration options subject to ESO funding profiles
- ❑ Proceeding with schedule determined in March 2 & 3 NASA/DLR/ESA meetings:
  - ➢ Support DLR/GFZ Phase-A
  - ➢ Support Aerospace Programmatic Assessment (independent cost and schedule analysis)
  - ➢ Mission Concept Review (MCR) in June 1 - 2, 2022
  - ➢ Support Earth Science Observatory (ESO) Independent Review Team June-August 2022
  - ➢ KDP-A in August 2022 (TBD)
  - ➢ Official NASA Phase-A start in September 2022
  - ➢ Mission Design Review/System Requirements Review in December

MAGIC – P2 baseline configuration

System:

- Inclined orbit with a target altitude of **~400 km** and inclination between **65 deg** and **70 deg**
- Baseline launcher from **Vega** family, with other European and US launchers as back-up
- Two spacecraft embarking each of them a **L**aser **T**racking **I**nstrument (**LTI**), the next-generation accelerometers with performance consistent with LTI, and GNSS receivers
- Launch date no later than **2032**, with target to maintain **4 years minimum** of combined P1-P2 operations

Spacecraft:

- Three high-performance accelerometers based on **ONERA's MicroSTAR** family of accelerometers
- Redundant LTI: baseline concept based on the LTI version to be embarked in P1 with European and US units, with potential addition of laser acquisition systems. Back-up concept: fully European LTI.
- Geodetic-quality **GNSS** receiver
- **Hybrid propulsion** concept: electric propulsion for orbit maintenance and drag compensation/drag free and linear cold gas thrusters for fine attitude control/drag free
- Spacecraft units based on **maximum reuse** of existing units