



living planet BONN 23-27 May 2022

TAKING THE PULSE OF OUR PLANET FROM SPACE









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

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> > 24 May 2022

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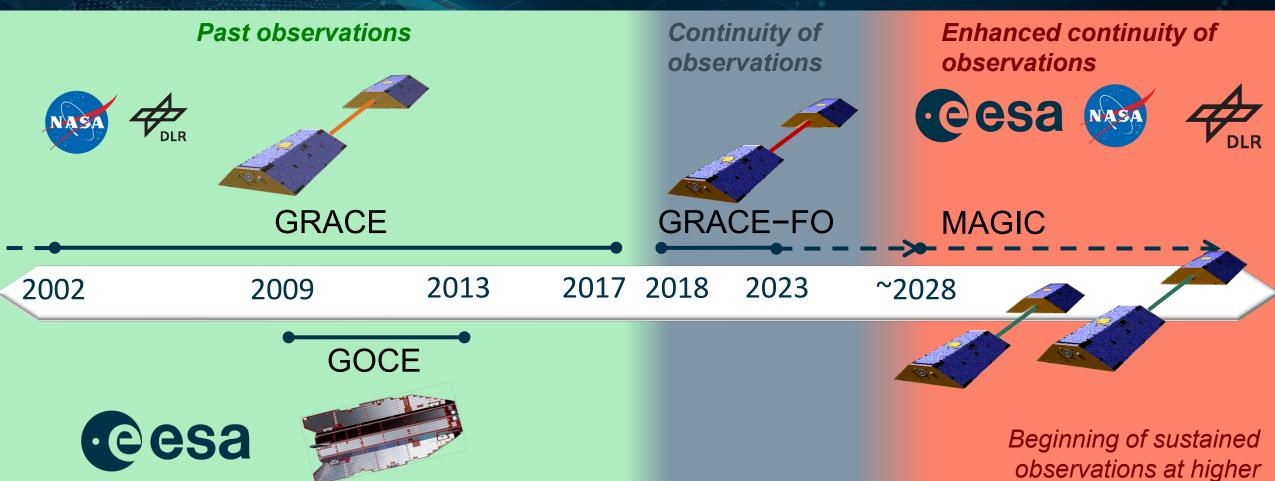




- 1. History and Background
- 2. Latest Updates (MAGIC Status)
- 3. Way Forward

Timeline of Satellite Gravimetry





spatial & temporal resolution

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)
- □ Joint Programme Planning Group (JPPG) established between NASA and ESA for cooperation in the field of Earth Observation. JPPG Sub-Group 1 is coordinating the activities for a <u>collaborative</u> 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 <u>communications at highest levels</u> (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
- Continuity after GRACE-FO ensured to continue the program of record and preserve the climate series, per US Decadal Survey 2017
- MAss-change and Geosciences International Constellation (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 Ad-hoc Joint Science Study Team (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 Mission Requirement Document (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 Joint Engineering Team (JET) and the Joint Mass Change Mission Expert Group (JMCMEG)
- ☐ March 2021 DLR GRACE I Phase 0 kicks off
- ☐ June 2021 NASA/JPL MC pre-Phase A kicks off

Satellite gravity user needs





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

Urge

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:









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

- An international multi-disciplinary initiative for IUGG -

Roland Pail

Rory Bingham, Carla Braitenberg, Annette Eicker, Martin Horwath, Eric Ivins, Laurent Longuevergne, Isabelle Panet, Bert Wouters, Gianpaolo Balsamo, Melanie Becker, Decharne 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, Junfi Guo Shin-Chan Han Edward Hanna Kosuke Heki György Hetényi Steven Jayne Weining Jiang, Shuangen Jin, Georg Kaser, Matt King, Armin Khi, Harald Khusthana, Georg Kaser, Matt King, Armin Khi, Harald Khusthanan, Gilgen Kusche, Thorne Lay, Anno Löcher, Scott Luthcke, Marta Marcos, Mark van der Meijle, Valentin Mikhailov, Christian Ohlwein, Fred Politiz, Yadu Pokhrel, Ruir Ponte, Matt Rodel, Gecille Rotstad-Denby. Himanshu Save, Bridget Scanlon, Sonia Seneviratne, Frederique Seyler, Andrew Shepherd, Tong, Song, Wim Spakman, C.K. Shum, Holger Steffen, Wenke Sun, Qiuhong Tang, Virendra Tiwari, sabella Velicogna, John Wahr, Wouter van der Wal, Lei Wang, Hua Xie, Hsien-Chi Yeh, Pat Yeh, Ben Zaitchik, Victor Zlotnicki

München 2015

Verlag der Bayerischen Akademie der Wissenschafter

IUGG



IGSWG



e.motion²

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

SCIENCES ENGINEERING THE NATIONAL ACADEMIES PRESS



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

716 pages | ISBN 978-0-3

CONTRIBUTO GET THIS BOOK Committee Space Studies Academies of FIND RELATED TITLES

SUGGESTED

National Ac Changing Plan Washington,

US Decadal Survey



Mass Change Designated Observable Science and Applications Traceability Matrix

SHARE (f) (in)

The Mass Change Study Team^{1,2,3,4,5} February 13, 2020

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



MCDO - NASA ←







Gravitational seismology - ESA study

2015

2016

2017

2018

2019

2020



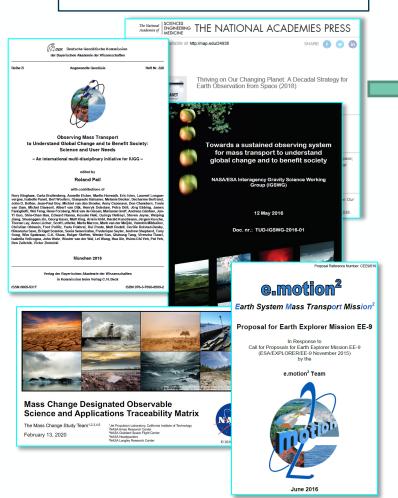


- 1. History and Background
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MAGIC Mission Requirement Document (MRD)



Global user requirements



Consolidation of user requirements

Ad hoc Joint Science Study Team (AJSST)

Coordination

ESA/NASA

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stec

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Next Generation Gravity Mission as a Masschange 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

JMCMEG supports MRD evolution

Prepared by Reference

Issue/Revision
Date of Issue
Status
Document Typ
Distribution

30 October 2020 Issued Mission Requirements Document (MRD)

Mission Re Public

Earth and Mission Science Division ESA-EOPSM-FMCC-MRD-3785

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

European Space Age

Agence spatiale européen

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.

- 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

Ref: MAGIC MRD Issue 1.0

MAGIC MRD SATM table



•		•		to gravity changes	References: IUGG-interpolated, IUGG specific requirement, DS+MCDO, IGSWG, Grav. Seismo.; Wiese et al. 2016, Metivier & Conrad, 2008; Marquart et al.,2005 + Dumberry, 2010				
Science and Applications Traceability Matrix (SATM) Current status Vs. MCDO Vs. Joint constellation (MAGIC)					N.A. = Not Applicable/Not Available (e.g. due to lack of measurements/capabilities)				
	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)	MCDO	Joint constellation (MAGIC)				
Thematic field			Resolution & Accuracy	Resolution & Accuracy	Resolution & Accuracy		Scientific/societal Questions & Objectives		
					Threshold	Target			
	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			
		MCI		quiremer	arget-a: 400 km @ 0.05 cm; arget-b: 150 km @ 5.0 cm	Q: H1, H2, H3, CL2; O: H-1a, H-1c; H2-b, H2-c; H-3a; H4-a; CL-2a			
			uded in	arget-a: 350 km @ 0.01 cm/yr; arget-b: 150 km @ 0.5 cm/yr; arget-c: 200km @ 0.1 cm/yr					
						N.A.			
	Soil moisture	М	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	Q: H1, H2, H3, CL2; O: H-1a, H1-c; H2-b, H2-c; H-3a; H4-a; CL-2		
		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			
Hydrology	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			

Spatial re	solutions and t	emporal so	ales associated	to gravity changes ix (SATM) ion (MAGIC)	References \$300 interpulated, \$20	B specific requirement, 08+MCDO, II Connect, 2006, Marquart et al., 2005 +	ESSO, Grav. Selamo.; Wires et al. 2016, Metho Dumbery, 2010
Cu	rent status Vs.			ion (MAGIC)	N.A. + Not Application Not Available (e.g. due to look of reseasements/capabilities)		
		Time scale (D: Daily to	Current state of the art (e.g. GRACE, GRACE-FO)	мсро	Joint constellation (MAGIC)		
Thematic field	Signal	Time scale (D: Daily to weekly, M: Monthly (Seasonal to inter-annual); L: Long-term trend)	Resolution & Accuracy	Resolution & Accuracy	Resolution		Scientificisocietal Questions & Object
_		bend) D	NA.	NA.	Threshold Threshold-ir 600 km @ 3.2 cm; Threshold-ir 300 km @ 5.9 cm;	Target or 600 km @ 0.3 cm; Target or 500 km @ 0.6 cm; Target < 200 km @ 0.6 cm	
Hydralogy	Groundwater storage	M	450 km @ 2.5 cm	Baseline: 450 km @ 2.5 cm; Goal: 50 km @ 1.0 cm	Threshold-c: 200 km @ 6.0 cm Threshold-a: 400 km @ 0.5 cm; Threshold-b: 150 km @ 50.0 cm	Target -c: 200 km @ 0.6 cm Target -c: 400 km @ 0.05 cm; Target -b: 150 km @ 5.0 cm	Q; H1, H2, H3, CL2; Q; H-1a, H-1c; H2-b, H3-c; H-3a; HI-a; Q;
		L	250 km @ 1 cmlyr	TEO	Threshold-a: 250 km @ 0.1 cmlyr; Threshold-b: 150 km @ 5.0 cmlyr	Target-ix 350 km @ 0.01 onlyr; Target-ix 150 km @ 0.5 onlyr; Target-ix 200km @ 0.1 onlyr	
	Soi moisture	D M	NA 450 km @ 2.5 cm	NA Baseline: 450 km @ 2.5 cm Goal: 200 km @ 2.5 cm	NA Threshold-a: 400 km @ 0.5 cm; Threshold-b: 150 km @ 50.0 cm	N.A. Target-ix 400 km @ 0.05 cm; Target-ix 150 km @ 5.0 cm	Q: H1, H0, H0, CL2; O: H-1a, H1-c; H2-b, H0-c; H-3a; H1-a; O
		L	250 km @ 1 cmlyr	TEO	Threshold-a: 250 km @ 0.1 cmlyr; Threshold-b: 150 km @ 5.0 cmlyr	Target-is: 150 km @ 0.01 cm/yr; Target-is: 150 km @ 0.5 cm/yr	
	Extreme events: warning (e.g. drought, flood)	D	NA.	Goal: 50 km @ 1.5 mm	Threshold-a: 600 km @ 3.2 cm; Threshold-b: 300 km @ 5.9 cm; Threshold-c: 290 km @ 6.0 cm	Target or 200 km (g 0.5 cm; Target or 200 km (g 0.6 cm; Target or 200 km (g 0.6 cm	Q: H1, H0, H6; Q: H-1a; H-3a; H-3a; HH-a
		M.	450 km @ 2.5 cm	Baseline: 450 km @ 2.5 cm; TBD	Threshold-o: 400 km @ 0.5 cm; Threshold-b: 150 km @ 50.0 cm Threshold-o: 250 km @ 0.1 cmlyr; Threshold-b: 150 km @ 5.0 cmlyr	Target-ix 400 km @ 0.05 cm; Target-ix 150 km @ 5.0 cm Target-ix 350 km @ 0.01 cmlyr; Target-ix 150 km @ 0.5 cmlyr	
		0	NA.	NA.	Threehold-b: 150 km @ 5.0 cm/yr NA	Target-is: 150 km @ 0.5 cmlyr N.A.	
	Water balance closure	м	1000 km @ 1.0 cm	Baseline: 1000 km @ 1.0 cm; Goal: 3 km @ 1.0 cm	Threshold-o: 400 km @ 0.5 cm; Threshold-b: 150 km @ 50.0 cm	Target-ix 400 km @ 0.05 cm; Target-ix 150 km @ 5.0 cm; Target-ix 200 km @ 1 cm	Q: H1, H2, H3, CL2; Q: H-1s, H-5c; H-3s, H-3c; H-3s; CL2+
		L D	1000 km @ 1.0 mmlyr NA	TEO N.A.	Threshold-s: 250 km @ 0.1 cmlyr; Threshold-b: 150 km @ 5.0 cmlyr NA	Target-ix 250 km @ 0.01 cmlyr; Target-ix 150 km @ 0.5 cmlyr N.A.	
	Global change impact on water cycle	м	1000 km @ 1.0 cm	Sassine: 1000 km @ 1.0 cm; Goal: 3 km @ 1.0 cm	Threshold-a: 400 km @ 0.5 cm; Threshold-b: 150 km @ 50.0 cm	Target-ix 400 km @ 0.05 cm; Target-ix: 150 km @ 5.0 cm	Q: H1, H2, H3, CL2; Q: H15a, H15c; H26a, H3-c; H43a; CL-2a
	Cycle	L	1000 km @ 1.0 mm/r NA	TEO N.A.	Thresholder 250 km @ 0.1 cm/yr; Thresholder 150 km @ 5.0 cm/yr. NA	Target-b: 150 km @ 0.5 onlyr;	
	Crycephere mass balance	м	200-500 km @ 4.0- 5.0 cm	Baseline: 300 km @ 4.0 cm; Goal: 100 km @ 1.0 cm	Threshold-o: 250 km @ 5.5 cm; Threshold-b: 150 km @ 50.0 cm Threshold-b: 150 km @ 50.0 cm	Target-ix 250 km @ 0.55 cm; Target-ix 150 km @ 5.0 cm	Q: C1, C2, C3, C12; O: C-9s; C4s, C4s, C4s, C4s; C3-s; C3-s; C4s
		L D	250 km @ 1 cmlyr NA	TEO NA	Threshold to 120 km @ 15.0 cm/yr NA	Target-b: 120 km @ 1.5 onlyr NA	
	Global and regional sea level	M L	300 km @ 1.5 cm	Baseline: 200 km @ 1.5 cm; Goal: 100 km @ 1.5 cm TBD	Threshold-is: 250 km @ 5.5 cm; Threshold-is: 150 km @ 50.0 cm Threshold-is: 170 km @ 2.6 cm/yr; Threshold-is: 130 km @ 15.0 cm/yr;	Target-ix 250 km @ 0.55 cm; Target-ix 150 km @ 5.0 cm Target-ix 170 km @ 0.26 cm/y; Target-ix 130 km @ 1.5 cm/y	Q; C1, C2, C11, C12; C: C-1a, C-1c; C-2a; C1-1a, C1-1b; C1.
Crycephere		D	NA	N.A.	NA.	N.A. Tarpet-x 250 km d2 0.55 cm:	Q: C1, C2, C12; Q: C-1a, C-1c; C-lar, C1-lar, C1-lar
	GIA		300 km @ 2.5 cm	Baseline: 300 km @ 2.5 cm; Goal: 200 km @ 1.0 cm	Thresholder 250 km @ 5.5 cm; Threshold-b: 150 km @ 50.0 cm	Target-b: 150 km @ 5.0 cm; Target-c: 200 km @ 1.0 cm Target-x: 170 km @ 0.26 cm/y;	
		L D	250 km @ 1 cmlyr NA	TEO N.A.	Threshold-s: 170 km @ 2.6 cmlyr; Threshold-b: 120 km @ 15.0 cmlyr NA	Target-ix 170 km @ 0.26 cm/yr; Target-ix 130 km @ 1.5 cm/yr; Target-ix 150 km @ 0.2 cm/yr N.A.	
	Mass changes of ice sheet and glaciers	*	350 km @ 10.0 cm	Baseline: 300 km @ 4.0 cm; Goal: 200 km @ 1.0 cm (100 km globally)	Threshold-or 250 km @ 5.5 cm; Threshold-b: 150 km @ 50.0 cm	Target-ix 250 km @ 0.55 cm; Target-ix 150 km @ 5.0 cm	Q: C1, C2, CL2; O: C-1s; C4s, C4s, C4s, C4s; C CL4s
		L	200 km @ 10 cm/yr	TEO	Threshold-a: 170 km @ 2.6 cmlyr; Threshold-b: 130 km @ 15.0 cmlyr	Target-ic 170 km @ 0.26 cm/yr; Target-ic 120 km @ 1.5 cm/yr; Target-ic 200 km @ 0.1 cm/yr	0.46
	Sea-level change	D M	NA 200-500 km @ Few mm - 1.5 cm	N.A. Baseline: 300 km @ 1.5 cm; Goal: 100 km @ 1.5 cm	NA Threshold-a: 1000 km @ 0.2 cm; Threshold-b: 400 km @ 0.5 cm;	N.A. Target-o: 1000 km @ 0.00 cm; Target-o: 400 km @ 0.05 cm;	0: 01; 0.1; 0.2; 0: 0-1s; 0-1s; 0-1s; 0-1s; 0.1-s; 0 086
		L	200 km @ 1.5 cmlyr	TEO	Threshold-a: 800 km @ 0.015 cmlyr: Threshold-b: 400 km @ 0.05 cmlyr: Threshold-b: 180 km	Target-a: 800 km @ 0.0015 cmyr; Target-b: 600 km @ 0.005 cmyr; Target-b: 600 km @ 0.005 cmyr; Target-c: 180 km @ 0.18	
	Ocean bottom pressure	D	NA.	NA Baseline: 200 km @ 1.5 cm:	© 1.8 cm/yr. NA Threshold-a: 1000 km @ 0.2 cm;	NA Target-a: 1000 km @ 0.00 cm;	Q; Q1; Q; Q-1c, Q-1e
		M L	300-600 km @1.5 cm 300 km @ 1.5 cm/yr	Baseline: 200 km @ 1.5 cm; Goal: 50 km @ 1.0 cm	Threshold-b: 400 km @ 0.5 cm; Threshold-c: 250 km @ 5.5 cm. Threshold-a: 800 km @ 0.015 cm/v: Threshold-b: 400 km @	Target-0: 400 km @ 0.05 cm; Target-0: 250 km @ 0.55 cm. Target-0: 800 km @ 0.0015 cmlyr; Target-0: 400 km @ 0.005 cmlyr; Target-0: 180 km @ 0.18	
			NA NA	NA.	cmlyr: Threshold-b: 400 km @ 0.05 cmlyr: Threshold-c: 180 km @ 1.8 cmlyr. NA	onlyr, Target-c: 180 km @ 0.18 onlyr. NA	
	ACC and AMOC		200-500 km/NA @ 1.5 cm	Baseline: 300 km @ 1.5 cm; Goal: 50 km @ 1.0 cm	Threshold-o: 1000 km @ 0.2 cm; Threshold-b: 400 km @ 0.5 cm; Threshold-c: 250 km @ 5.5 cm.	Target-o: 1000 km @ 0.02 cm; Target-o: 400 km @ 0.05 cm; Target-o: 250 km @ 0.55 cm;	Q: O1; Q: O-1s, O-1s, O-1s
	usiability	L	300 km @ 1.5 cmlyr	TEO	Threshold-a: 600 km @ 0.015 cmlyr; Threshold-b: 600 km @ 0.05 cmlyr; Threshold-c: 190 km	Target-of: 200 km @ 1.5 cm Target-or: 800 km @ 0.0015 cmlyr; Target-b: 400 km @ 0.005 cmlyr; Target-or: 180 km @ 0.18	0: 0-1a, 0-1c, 0-1d
Oceanography		D	NA 200-500 km/ll 1 0-2 5	NA Danalina William (b.15 cm)	@ 18 onlys. Threshold: 400 km @ 5 cm Threshold: a: 1000 km @ 62 cm;	Target 400 km @ 0.5 cm	
	Tidal models		200-500 km@ 1.0-2.5 om	Baseline: 300 km @ 1.5 cm; Goal: 50 km @ 1.0 cm	Threshold-a: 1000 km @ 0.2 cm; Threshold-b: 400 km @ 0.5 cm; Threshold-c: 250 km @ 5.5 cm. Threshold-a: 800 km @ 0.015 cmlor. Threshold-b: 400 km @	Target-ix 1000 km @ 0.00 cm; Target-ix 400 km @ 0.05 cm; Target-ix 250 km @ 0.55 cm. Target-ix 800 km @ 0.050 cm. Target-ix 800 km @ 0.0015	Q: O1; Q: O-1d
		L D	200 km @ 1.5 cmlyr NA	TBD Goat 100 km @ 1.5 cm	cmlyr, Threshold-b: 400 km @ 0.05 cmlyr, Threshold-c: 180 km @ 1.8 cmlyr. Threshold: 400 km @ 5 cm	conlyr, Target-0: 400 km @ 0.005 conlyr, Target-c: 180 km @ 0.18 conlyr. Target: 400 km @ 0.5 cm	
	Heat and mass.		000-500 km @ 1.5 cm	Baseline: 300 km @ 1.5 cm	Threshold-o: 1000 km @ 0.2 cm; Threshold-o: 400 km @ 0.5 cm; Threshold-o: 250 km @ 5.5 cm.	Target-or 1000 km (§ 0.00 cm; Target-or 400 km (§ 0.05 cm; Target-or 250 km (§ 0.55 cm;	Q: 01, Q1, Q2; Q: 0-1s, 0-1s, 0-1s, 0-1s, 0-1s; Q: Q: ds, Q: ds
	observations	L	300 km @ 1.5 cmlyr	TBD	Threshold-a: 800 km @ 0.015 cmlyr: Threshold-b: 400 km @ 0.05 cmlyr: Threshold-c: 180 km	Target-d: 200 km @ 1.0 cm Target-x: 800 km @ 0.0015 cmlyr; Target-b: 400 km @ 0.005 cmlyr; Target-c: 180 km @ 0.18	
	Ocean circulation models	0	NA.	N.A.	∯ 18 owlyr. NA	onlyr. N.A	
			000-500 km @ 1.5 cm	Baseline: 300 km @ 1.5 cm; Goal: 50 km @ 1.0 cm	Threshold-is: 1000 km @ 0.2 cm; Threshold-is: 400 km @ 0.5 cm; Threshold-is: 200 km @ 5.5 cm. Threshold-is: 800 km @ 0.015	Target -c 400 km @ 0.05 cm; Target -c 200 km @ 0.05 cm; Target -c 200 km @ 0.55 cm. Target -c 800 km @ 0.0015	Q: O1; Q: O-1a, O-1b, O-1c, O-1d, O-1e
		L	300 km @ 1.5 cmlyr	TEO	cmlyr, Threshold-6: 400 km @ 0.05 onlyr, Threshold-c: 180 km @ 1.8 omlyr. Threshold-a: 200 km @ 6.0 cm;	naget-is soo kin gi 0.0075 onlyr; Target-b: 400 kin gi 0.005 onlyr; Target-c: 180 kin gi 0.18 onlyr. Target-is: 300 kin gi 0.6 on;	
	Natural hazards	D	NA.	NA	Threshold-b: 200 km @ <10.0 cm Mar 8 earthquakes) Threshold-a: 200 km @ 1.0 cm; Threshold-b: 100 km @ 1.0 cm;	Target-o: <250 km @ 10.0-1.0 on Target-o: 250 km @ 0.1 on; Target-o: 180 km @ 0.1 on;	O: 51, 52, 54; O: 5-1a, 5-1b; 5-3c; 5-4c
			300 km @ 2.5 cm	Baseline: 300 km @ 2.5 cm; Goal: 200 km @ 1.2 cm	Threshold-b: 180 km @ 18 cm; Threshold-c: 200 km @ 1-2 cm Mar 8 earthquakes; Threshold-a: 250 km @ 0.5 cm/c:	Target-b: 180 km @ 1.8 cm; Target-c: 200 km @ 1.0 cm (Mw 7 earthquakes) Target-s: 250 km @ 0.05 cm/s:	
		L D	300 km @ 1.5 cmlyr	TEO NA	Threshold-a: 250 km @ 0.5 cm/yr, Threshold-b: 150 km @ 5.0 cm/yr, Threshold-c: 200 km @ 1 cm/yr	Target-ix: 250 km @ 0.05 cm/yr; Target-ix: 150 km @ 0.5 cm/yr; Target-ix: 100 km @ 1.0 cm/yr NA	
	Evolution of Earth's crust under external or internal	м	NA 300 km @ 2.5 cm	Baseline: 300 km @ 2.5 cm; Goat: 200 km @ 1.0 cm	Threshold-or 250 km @ 1.0 cm; Threshold-b: 180 km @ 18 cm.	Target-ix: 350 km @ 0.1 cm; Target-ix: 180 km @ 1.8 cm.	Q: 52, 53, 54; Q: 5-2x; 5-3x, 5-3x, 5-3x; 5-4;
Solid Earth	Socieg Natural resources	L	300 km @ 1.5 cmlyr	TEO	Threshold-a: 250 km @ 0.5 cmlyr; Threshold-b: 150 km @ 5.0 cmlyr	Target or 250 km (2 0.05 cm/yr, Target or 150 km (2 0.5 cm/yr, Target or 4100 km (2 10 cm/yr, Target or 200 km (2 0.6 cm/	
		D M	NA 000-450 km @ 2.5 cm	NA Sassine: 450 km @ 2.5 cm; Goat: 100 km @ 1.0 cm	Threshold-is: 200 km @ 6.0 cm; Threshold-is: 200 km @ 10.0 cm Threshold-is: 250 km @ 1.0 cm; Threshold-is: 250 km @ 1.0 cm;	Target-ic <250 km @ 10.0-1.0 km Target-ic 250 km @ 0.1 cm; Target-ic 180 km @ 0.1 cm;	Q: S4, Q: S4a, S-4a, S-4c
	exploitation	L	300 km @ 1.5 cmlyr	Goal: 100 km @ 1.0 cm	Threshold-b: 180 km @ 18 cm. Threshold-a: 250 km @ 0.5 cm/yr, Threshold-b: 150 km @ 5.0 cm/yr	Target-is: 180 km @ 1.8 cm. Target-is: 250 km @ 0.05 cm/yr; Target-is: 150 km @ 0.5 cm/yr	
	Deep interior properties and dynamics	D M	NA 300 km @ 2.5 cm	N.A. Baseline: 300 km @ 2.5 cm	NA Threshold-a: 250 km @ 1.0 cm;	Sody (dee) Target-x 250 km @ 0.1 cm;	
			200 km @ 2.5 cm 200 km @ 1.5 cmlyr	Goat 200 km (§ 1.2 cm	Threshold-i: 180 km @ 18 cm. Threshold-i: 250 km @ 0.5 cm/yr, Threshold-i: 150 km @ 5.0 cm/yr	Target-o: 180 km @ 1.8 cm. Target-x: 250 km @ 0.05 cm/yr; Target-c: 150 km @ 0.5 cm/yr; Target-c: 2000-6000 km @ 0.05- 0.1 mm in 10 yr; Target-d: 220-	O: 52, 53; O: 52x; 53x; 53b; 53b; 53c; 53d
						2.1 mm in 10 yr; Target d: 230- 230 km (j): 1 mm in 10 yr	



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

MAGIC MRD way forward

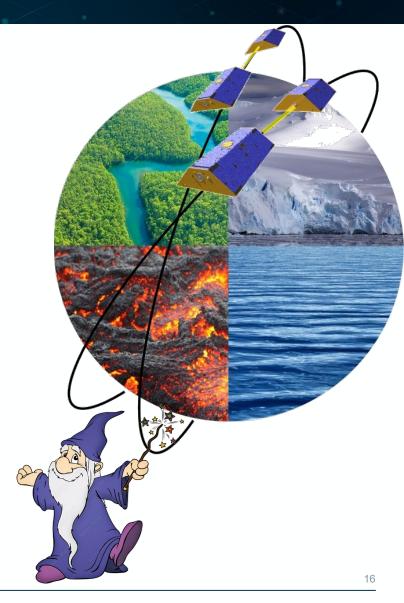


- □ ESA, NASA and DLR have reached an agreement on the main pillars of the baseline implementation scenario for MAGIC, with some details currently still under discussion
- □ The **MRD** will remain a **reference** document defining the mission requirements achievable by an optimized Bender constellation
- 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 <u>precursor of future operational</u> <u>system</u>
- ☐ 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)



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 Laser Tracking Instrument (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