Recent Studies on Future Gravity Field Missions in Europe: e.motion vs. NGGM

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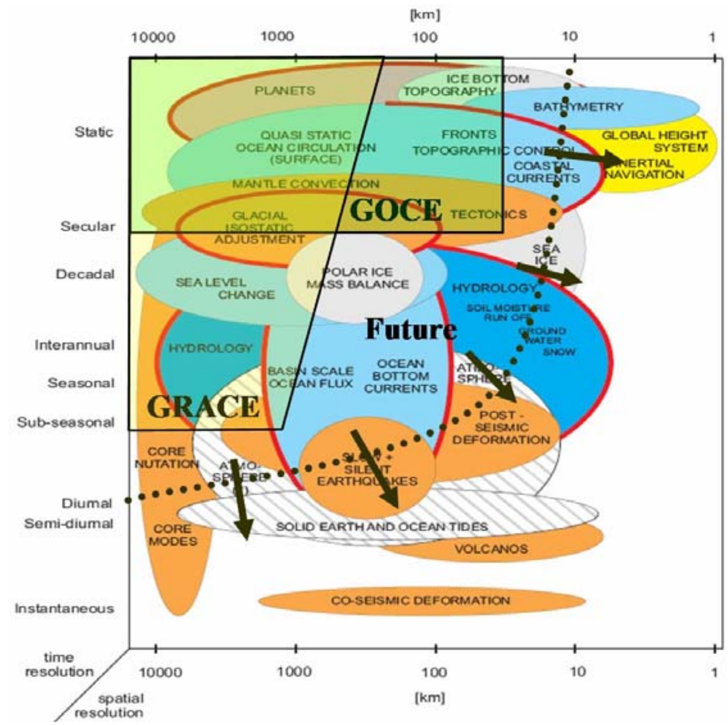


Outline

1. **Introduction**

2. **Identification of Science Requirements**
   - ➢ **e.motion ESA Earth Explorer 8 Proposal (Opportunity Mission)**
   - ➢ **ESA Studies: Next Generation Gravity Field Missions (NGGM)**
   - ➢ **e.motion vs. NGGM**

3. **Sensor Requirements / Simulations**

4. **Conclusions & Recommendations**

Introduction

Workshop: The Future of Satellite Gravimetry, ESTEC, April 2007

- Priority 1: Uninterrupted time series.
- Priority 2: Higher precision, higher resolution.
- Priority 3: New sensors (clocks, quantum sensors, etc.).

The Future of Satellite Gravimetry

Report from the

Workshop on The Future of Satellite Gravimetry

12-13 April 2007, ESTEC, Noordwijk, The Netherlands

Radboud Koop and Reiner Rummel (Eds.)

GGOS Workshop: Roadmap towards Future Satellite Gravity Field Missions, TU Graz, October 2009

- Multi-decade, continuous series of space-based observations of changes in the Earth's gravity field as a contribution to an integrated, sustained operational observing system for mass redistribution, global change, and natural hazards.
- Roadmap with 4 activities:
  - Science challenges
  - Technology development
  - Mission Implementation
  - Processing & Modeling

Towards a Roadmap for Future Satellite Gravity Missions

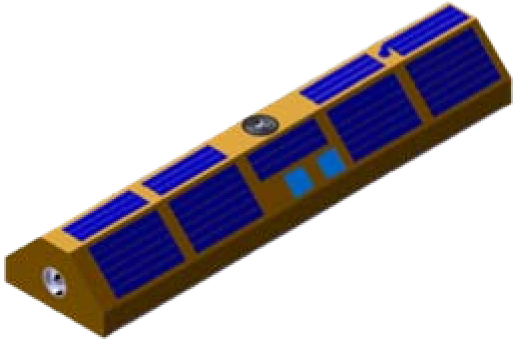
September 30 - October 2, 2009, Graz, Austria

GROUP ON EARTH OBSERVATIONS

http://www.iag-ggos.org/workshops/Graz

Introduction

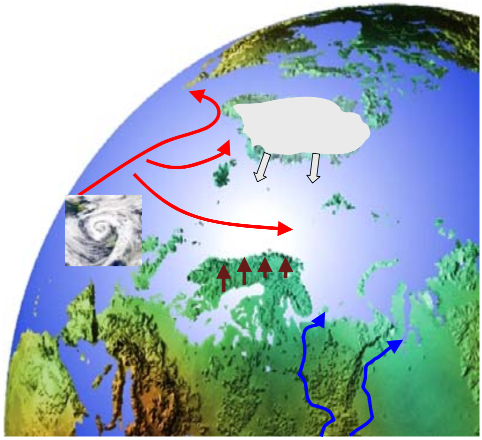
GFZ/STI Studies (2008-2011)



- GRAF: Lessons learned from GRACE; Simulations and investigation on possible gain in accuracy and spatial/temporal resolution.
- 3M4C: Laser SST requirements; S/C operation; Simulation
- 3M4C-FPS: Refinement and design of pointing concept; Technical requirements.

ESA Study: Monitoring and Modeling individual Sources of Mass Distribution and Transportin the Earth System by Means of Satellites(2007-2008)

- Forward modeling of time variable gravity field by coupled geophysical models.
- Simulation of orbit scenarios, gravity field retrieval & signal separation.
- Forward model update in 2010. Publication on-line.

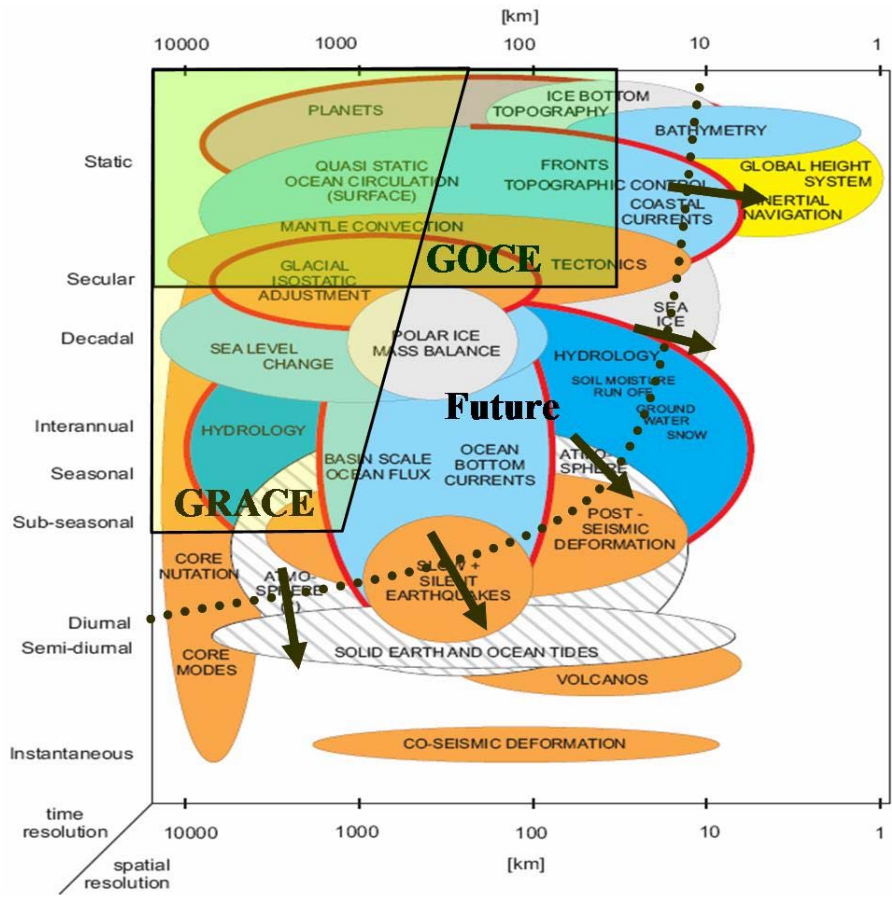


See: Gruber, T.; Bamber, J. L.; Bierkens, M. F. P.; Dobslaw, H.; Murböck, M.; Thomas, M.; van Beek, L. P. H.; van Dam, T.; Vermeersen, L. L. A.; Visser, P. N. A. M.: *Simulation of the time-variable gravity field by means of coupled geophysical models*; Earth System Science Data Discussions, Vol. 4, Nr. 1, pp 27-70, Copernicus Publications, ISSN 1866-3591, DOI: 10.5194/essdd-4-27-2011, 2011

Introduction

ESA Studies NGGM: Next Generation Gravity Field Mission (2009-2011)

- Establish a mission architecture concept aimed at the optimal recovery of the Earth variable gravity field by means of SST.
- Review of requirements for the mission.
- Set-up of a modular and flexible mission performance simulation tool using the variable Earth gravity model and including models for the satellite and the instruments.
- Preliminary design of the selected mission and perform an error analysis. Ídentification of critical technologies.
- Study 1 led by Thales-Alenia with science support from ULUX, TUM, Univ. Stuttgart, TU Delft
- Study 2 led by Astrium with science support from GFZ, Univ. Bonn.



Introduction

e.motion: Earth System Mass Transport Mission (2009-2010)

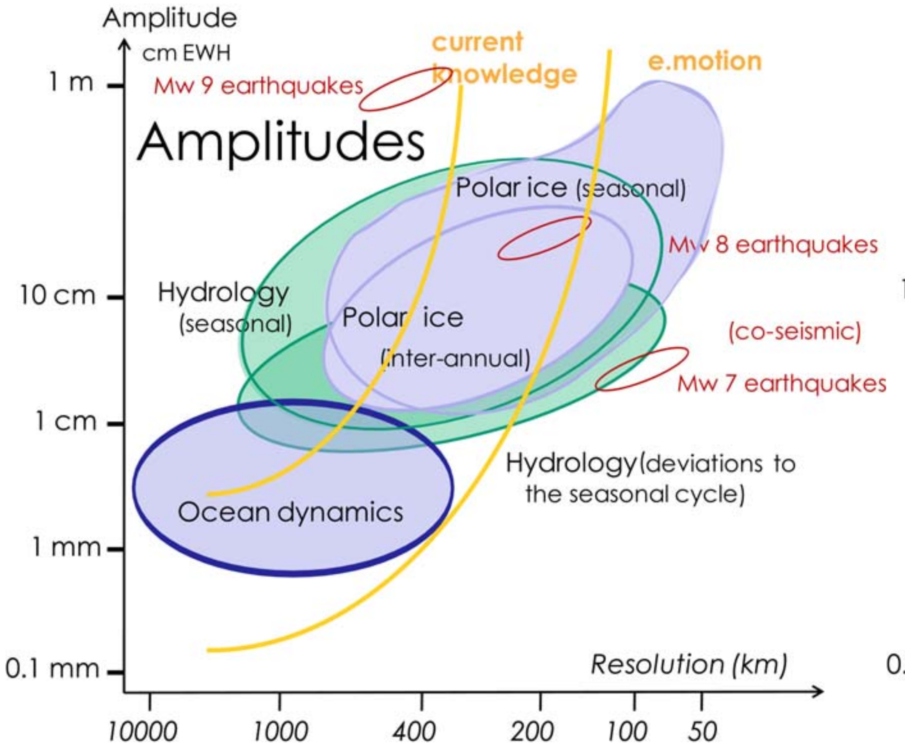
- Mission proposal submitted to ESA's EE8 call.
- EE Opportunity Mission with a ceiling of 100 M€ industrial cost for space and mission specific ground segment.
- 2 mission candidates out of 30 proposals were selected in Nov. 2010.
- e.motion was rated high for science questions to be addressed.
- Technology was rated as not mature enough to proceed into pre-phase A.
- Budget estimation was rated as unrealistic due to technical complexity.

- In conclusion e.motion was not selected, but it was recommended to:
  - further investigate the performance that can be achieved without the need for smoothing filters, and
  - analyze the synergies offered by a constellation with 2 pairs, one being GRACE-C and the other being e.motion.

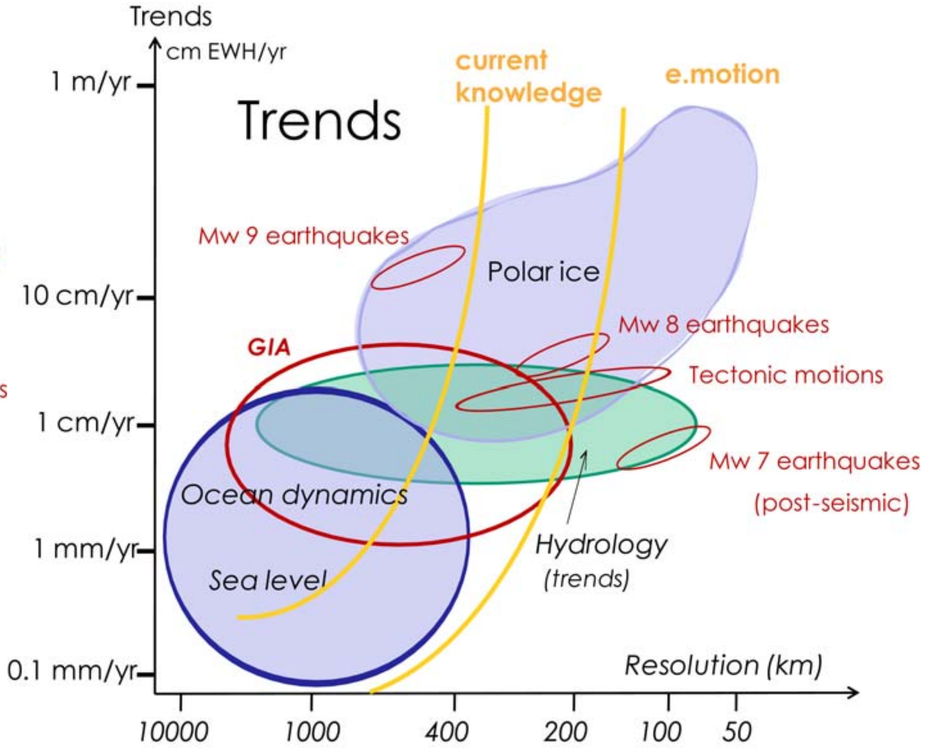
Science Requirements

e.motion

- Temporal gravity with spatial resolution of 200 km or better and global coverage
- Amplitudes with 10 times increased sensitivity compared to current knowledge;
- Mass variations at seasonal to decadal time scales, by extending the existing record of satellite data by a time series of 7 years or more with enhanced quality, with a temporal resolution of 1 month or better.



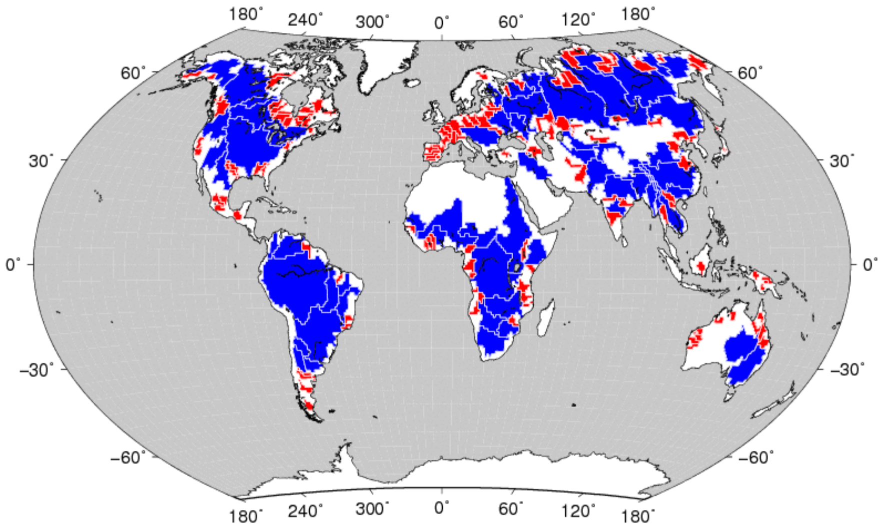
seasonal to interannual variations



long-term trends

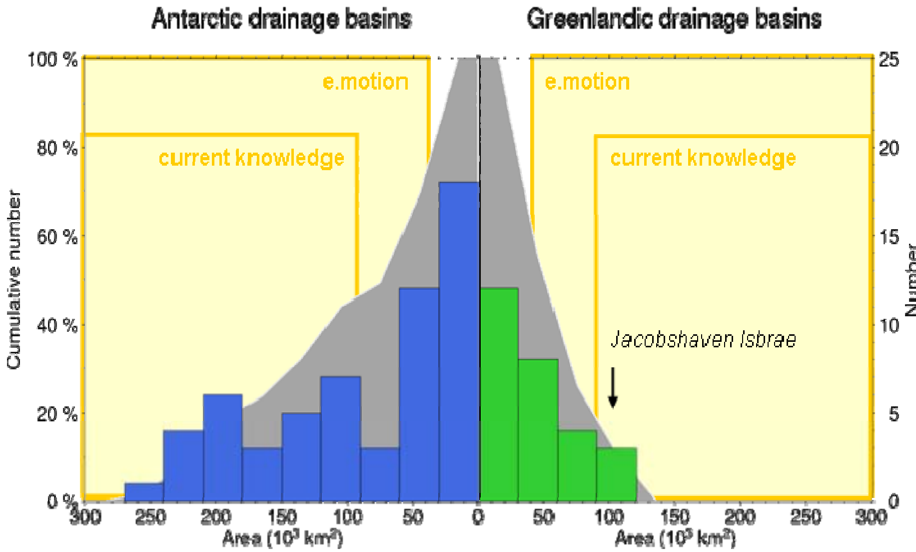
Science Requirements
e.motion

Hydrology



River drainage basins with a size between 40000 km^2 and 200000 km^2 (red) which will be resolved by e.motion, as well as basins larger than 200000 km^2 (blue) which corresponds to the present day resolution.
Source: Oki, T. & Sud, Y.1998, Earth Interactions; Rodell, M. and Famiglietti, J., 1999, Wat. Res. Research.

Continental Ice



Distribution of areas of continental hydrology drainage basins. Lines indicate recovery improvement of e.motion with regard to current knowledge. Grey area indicates the cumulative number of basins observable.
Source: Oki & Sud,1998, Earth Interactions.

Science Requirements

NGGM Study 1

- Translation of science requirements to observation requirements

	Description	Spatial resolution	Temporal resolution	Signal magnitude (geoid heights)
1	Melting of ice sheets (with separation of GIA)	100–1000 km	Seasonal – secular	0.01 mm/year (secular)
2	Non-steric comp. of sea-level var. at seasonal and shorter time scales	Global to basin level	Interannual – secular	0.1 mm/year (secular)
3	Ground water (soil moisture and snow) at higher spatial scales	10–200 km	Hourly – seasonal – secular	1 cm (seasonal)
4	Post-seismic deformation	10–200 km	Subseasonal	1 mm (subseasonal)

Science Requirements

NGGM Study 1

- Summary of observation requirements

	Wave-length	10000 km	1000 km	200 km	100 km	10 km
	SH degree	2	20	100	200	2000
CGE (cum. Geoid error)	10 mm			Ground Water		
	1 mm	Non-steric sea-level			Seismic	
	0.1 mm		Ice sheets			

SH degree	150	200	250
CGE [mm]	0.1	1	10
CGE requirements			

- Science requirements identified by NGGM study 2 are similar to the results obtained by NGGM study 1.

Science Requirements

e.motion vs. NGGM

- Science requirements derived from research objectives:

Resolution [km]	Resolution [d/o]	e.motion		NGGM	
		EWH [cm]	Geoid [mm]	EWH [cm]	Geoid [mm]
500	40	0.5	-	-	< 0.1
400	50	1	0.1	-	< 0.1
200	100	**10**	**1**	-	< 0.1
133	150	-	-	-	0.1
100	200	-	-	-	**1**
80	250	-	-	-	10

- Significant differences in science requirements mainly driven by budget = technology constraints (in case of e.motion).

- Different representations are used for science requirements analysis. EWH used by „water" people, geoid used by „geodesists". Conversion is needed.

Science Requirements

e.motion vs. NGGM

- Science requirements derived from research objectives:

Resolution [km]	Resolution [d/o]	e.motion		NGGM	
		EWH [cm]	Geoid [mm]	EWH [cm]	Geoid [mm]
500	40	0.5	-	-	< 0.1
400	50	1	0.15	**< 1**	< 0.1
200	100	**10**	**1**	**1**	< 0.1
133	150	-	-	-	0.1
100	200	-	-	**20**	**1**
80	250	-	-	-	10

- Conversion of EWH to Geoid Heights[1]:

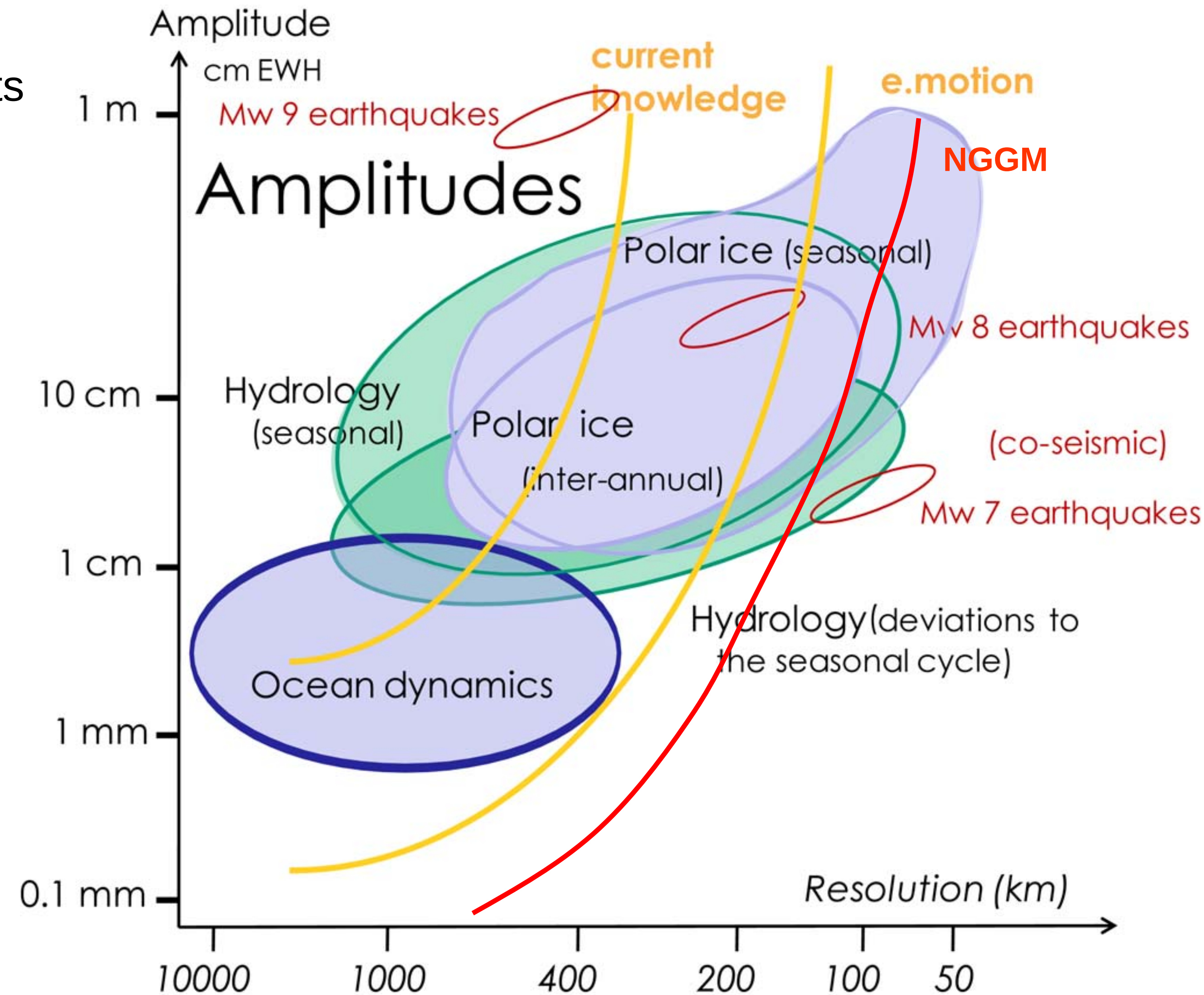
EWH	Spherical Cap	Amplitude Geoid Variation
1 cm	2000 km	0.5 mm
1 cm	800 km	0.3 mm
1 cm	400 km	0.15 mm
1 cm	200 km	0.08 mm
1 cm	100 km	0.04 mm

[1] from I. Panet

Science Requirements

e.motion vs. NGGM

Observation requirements for NGGM one order of magnitude higher as compared to e.motion.



Sensor Requirements

Semi-analytical Error Propagation

- Graphical representation of error PSD in terms of range rate

Reference scale values:

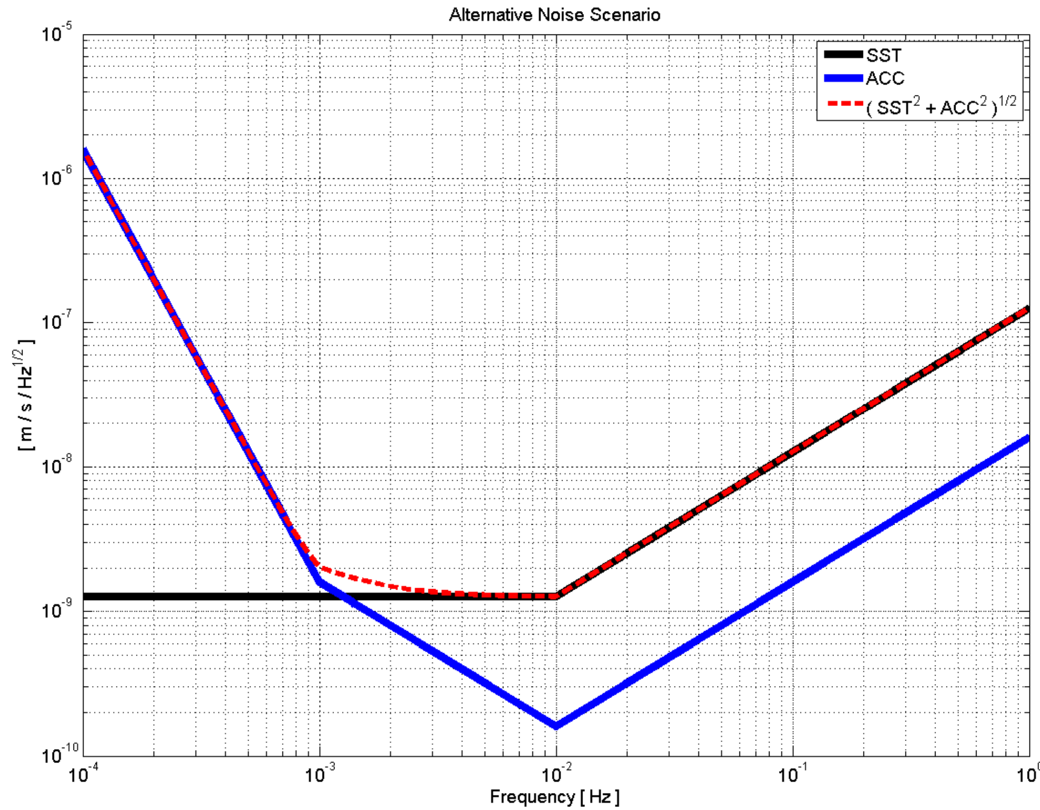
$$s_{k=0} = 2 \cdot 10^{-8}$$

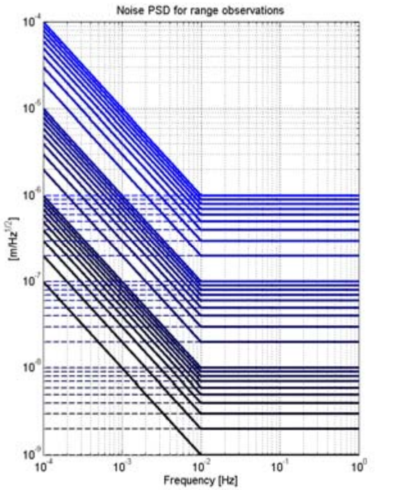
$$a_{k=0} = 1 \cdot 10^{-11}$$

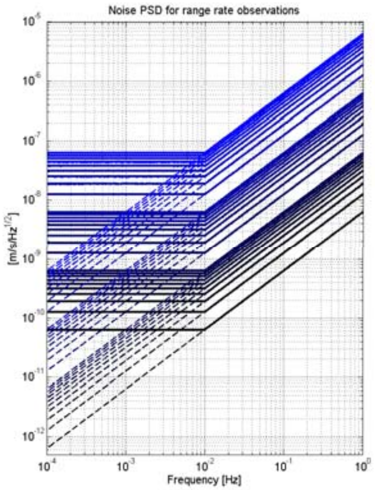
Minimum scale values:

$$s_{k=20} = 9 \cdot 10^{-11}$$

$$a_{k=20} = 8 \cdot 10^{-14}$$



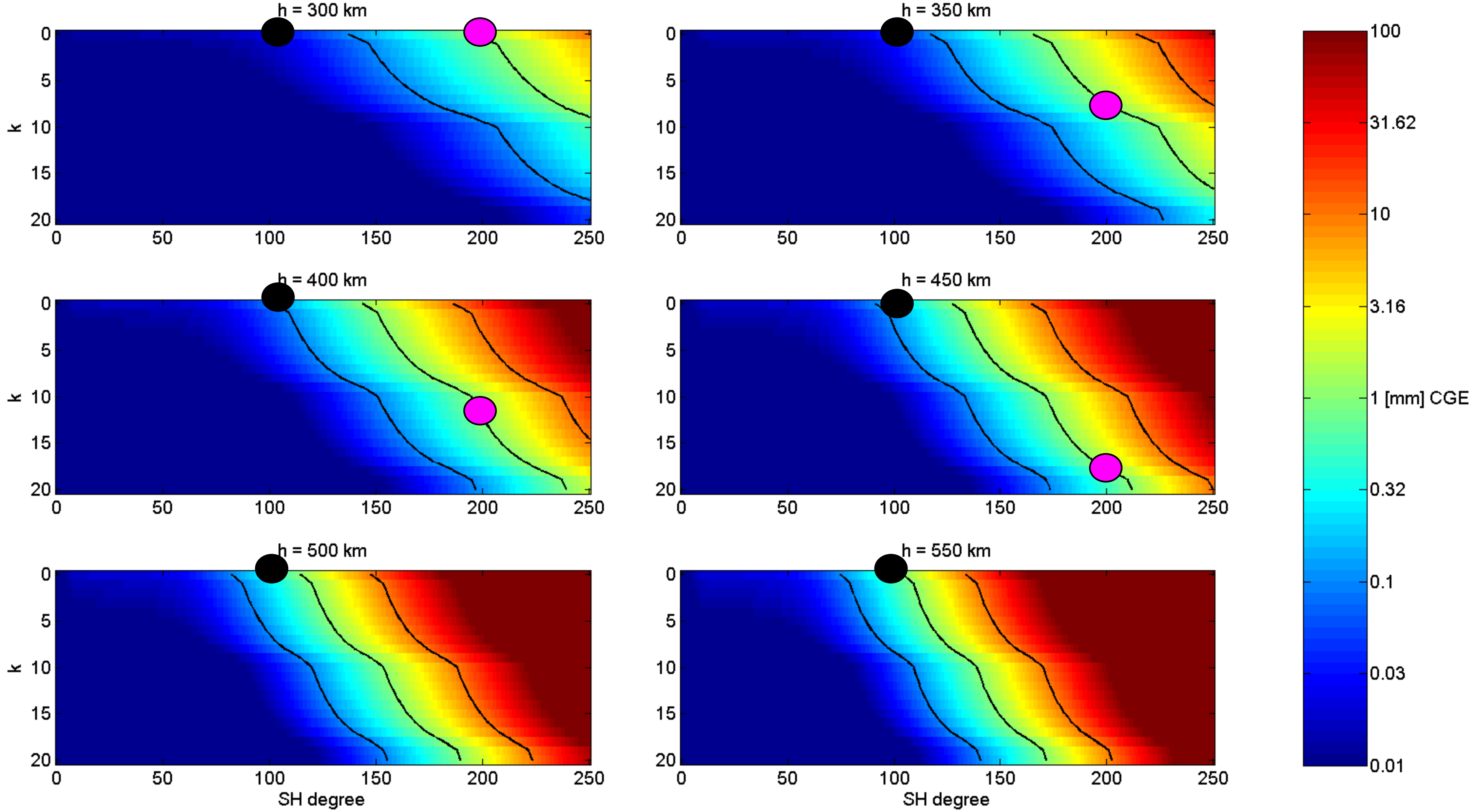




Sensor Requirements

Semi-analytical Error Propagation

- CGE for d = 75 km, black lines represent 0.1, 1 and 10 mm



● requ. e.motion (1 mm @ d/o 100) ● requ. NGGM (1 mm @ d/o 200)

Sensor Requirements
Full-scale Simulations

- A number of tandems and combination tandems was investigated in a full scale simulation (including pendulum and cartwheel).
- Observations were simulated using the ESA Mass Transport Srudy forward model.
- Simulated observation errors were generated in a mission simulator applying instrument error PSD's and coupling.
- Full scale retrievals were computed for all chosen scenarios. Errors were derived by comparison to forward model.
- Quick-look (semi-analytical) and full-scale simulation results were compared and quick-look errors were scaled accordingly.
- Preferred mission scenarios were identified taking into account science requ. and technological challenge. These are:
  - Dual tandem Bender formation (in-line).
  - Single-tandem high altitude pendulum.

Conclusions & Recommendations

- Since 2007 various workshops on future gravity field missions and studies have been conducted in Europe.
- Science requirements are strongly driven by mission assumptions and budget constraints (e.g. e.motion).
- Technology still needs to be developed and is not yet mature enough to implement sophisticated single tandem missions (e.g. pendulum).
- Several simulation tools are available at industry and science. This includes mission simulators, time variable gravity field forward model, quick-look analysis tools and full-scale simulators.
- Results indicate that dual tandem missions flying in different inclinations provide very good science return, are feasible, and do not need large technology development (for in-line formations).
- A consolidation of science requirements on both sides of the Atlantic (and further) is needed. What does science really need?
- There is an option to fly independently, but simultaneously two tandem pairs operated by different agencies. A strategy needs to be worked out in order to get optimal science return from such a configuration.
- This kind of mission has to become a monitoring tool (like altimetry).