Time Periods, Spatial Resolution, and Accuracy: From Geophysical Requirements to Mission Scenarios

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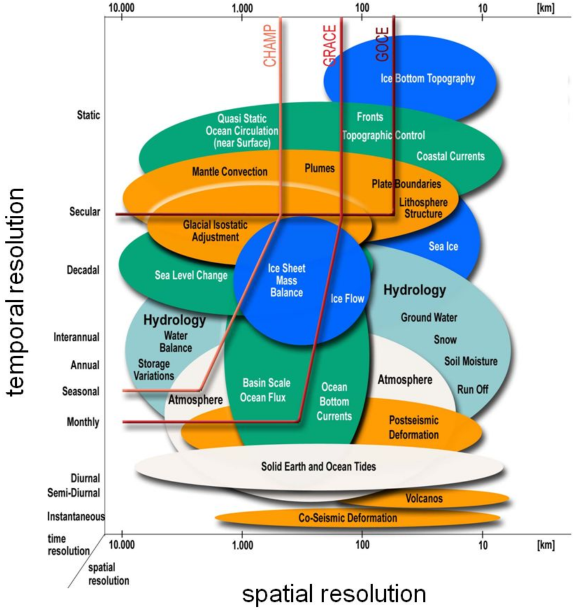
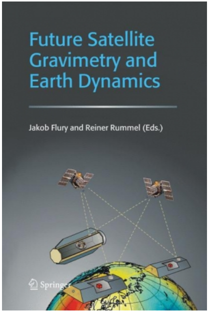
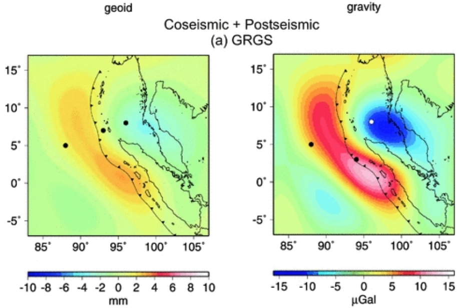




Earth, Moon, and Planets

Sneeuw et al (2005) *Science Requirements (...) and Simulated Mission Scenarios*

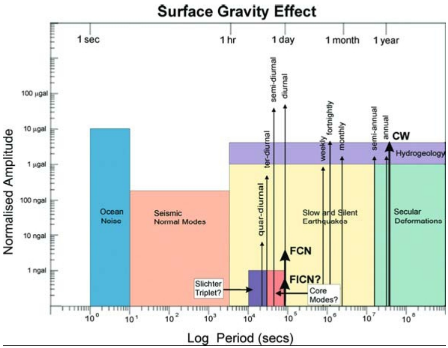
solid Earth



de Linage et al 2009

Science Area Theme	Required Resolution (km)	Main Periods	Required Accuracy Geoid or gravity	Comment
Solid Earth				
Glacial isostatic adjustment	> 500	10 000–100 000 y	1–10 μm/y	total geoid effect: 1–2 mm/y
Co-/post-seismic deformation, slow/silent earthquakes	regional	instantaneous—decadal	sub-mm	requires monitoring mission
Plate tectonics, mantle convection, volcanos	> 10	secular, instantaneous	< 1 mm/y	requires monitoring mission
Core motion (nutation, Slichter), seismic normal modes	> 5000	10 s–18 y	1 nGal – 1 μGal	

solid Earth



Crossley et al 1999

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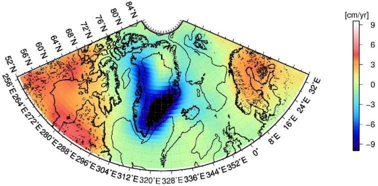
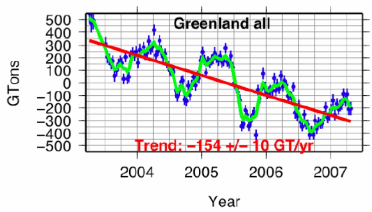
ice



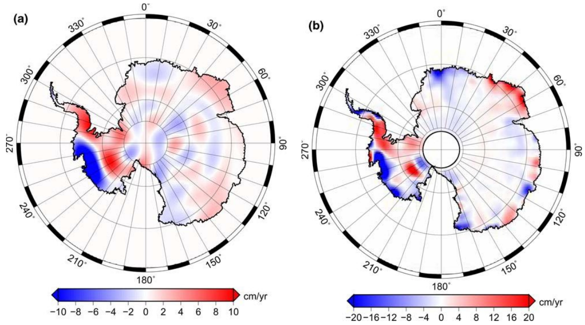
Wouters et al 2008



Luthcke et al 2007

Science Area Theme	Required Resolution (km)	Main Periods	Required Accuracy Geoid or gravity	Comment
Ice				
Ice mass balance	100–4000	seasonal – secular	<0.01 mm/y	monitoring mission desired
Bottom topography, ice compaction	20–50	quasi-static	0.01–0.1 mGal	
Geoid for sea ice thickness	10–100	static	100 mm	

ice



Gunter et al 2009

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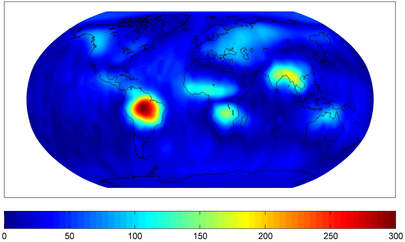
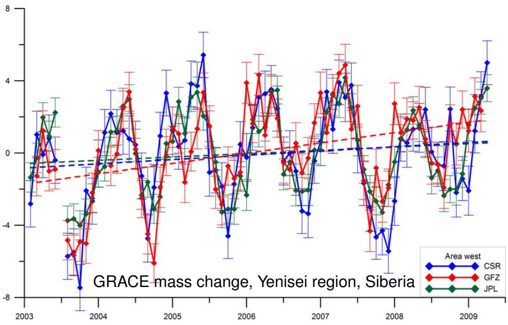
continental hydrology



annual signal amplitude

Science Area Theme	Required Resolution (km)	Main Periods	Required Accuracy Geoid or gravity	Comment
Hydrology				
Snow, precipitation, ground water, dams, soil moisture, run-off, evapo-transpiration	10–5000	1 h–secular	0.5–1 mm monthly	high spatial resolution more important than accuracy

continental hydrology



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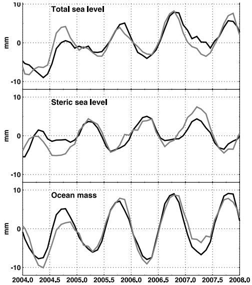
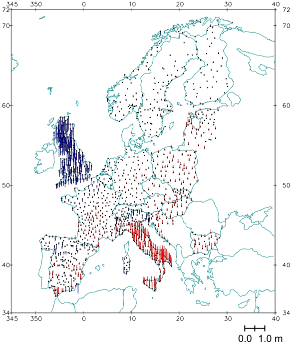
ocean



Leuliette et al 2008/
Willis et al 2008

Science Area Theme	Required Resolution (km)	Main Periods	Required Accuracy Geoid or gravity	Comment
Ocean				
Mean flow: narrow currents, topographic control	20–50	quasi-static	5–10 mm	
Coastal currents along shelf edges	10–50	quasi-static	5–10 mm	
Interaction mean and eddy flow, ocean fronts position	10–100	quasi-static	5–10 mm	
Bathymetry	1–10	static		
Basin scale mass change, deep water formation	1000–5000	months – decades	10 mm	sea level, oscillations
Bottom currents	10–200	months – decades	0.1–1 mm	
Sea Level				
Global sea level change monitoring	> 2000	interannual, secular	0.1 mm/y	monitoring mission desired

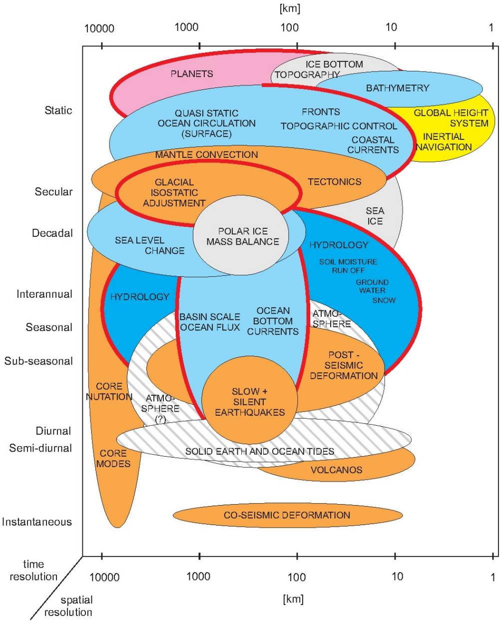
geodesy



residuals GPS/leveling vs. EGG07 geoid (Denker et al 2008)

Science Area Theme	Required Resolution (km)	Main Periods	Required Accuracy Geoid or gravity	Comment
Geodesy				
Precise heights for engineering, GNSS levelling, coastal height reference, sea level monitoring	20–50	static	5–20 mm	for some areas also geoid time variation
Inertial navigation	5–10	static	0.1 mGal, 0''1 deflection of vertical	combination with terrestrial data required
Atmosphere	gravity field improvement may be interesting for future atmospheric modeling			
Planets	dedicated autonomous gravity field missions with very high spatial resolution			

priorities


[km]
10000
1000
100
10
1
Static
Secular
Decadal
Interannual
Seasonal
Sub-seasonal
Diurnal
Semi-diurnal
Instantaneous
PLANETS
ICE BOTTOM TOPOGRAPHY
BATHYMETRY
GLOBAL HEIGHT SYSTEM
INERTIAL NAVIGATION
QUASI STATIC OCEAN CIRCULATION (SURFACE)
FRONTS
TOPOGRAPHIC CONTROL
COASTAL CURRENTS
MANTLE CONVECTION
GLACIAL ISOSTATIC ADJUSTMENT
TECTONICS
SEA ICE
SEA LEVEL CHANGE
POLAR ICE MASS BALANCE
HYDROLOGY
SOIL MOISTURE
RUN OFF
GROUND WATER
SNOW
HYDROLOGY
BASIN SCALE OCEAN FLUX
OCEAN BOTTOM CURRENTS
ATMO-SPHERE
POST - SEISMIC DEFORMATION
CORE NUTATION
ATMO-SPHERE (?)
SLOW + SILENT EARTHQUAKES
SOLID EARTH AND OCEAN TIDES
CORE MODES
VOLCANOS
CO-SEISMIC DEFORMATION
time resolution
spatial resolution
10000
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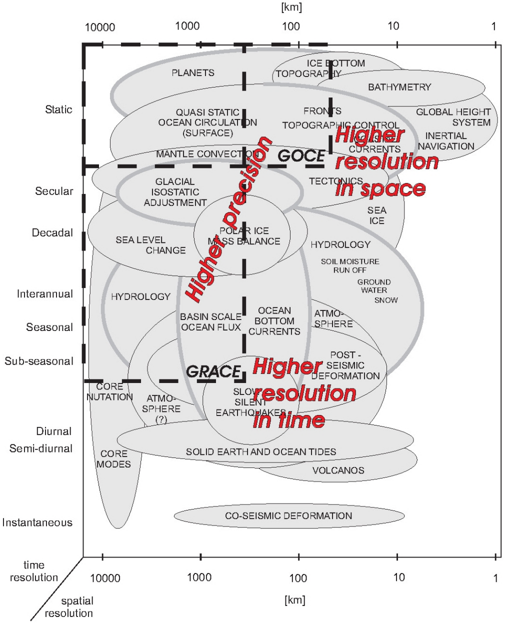
[km]

objectives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10000
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FRONTS
TOPOGRAPHIC CONTROL
CURRENTS
GLOBAL HEIGHT SYSTEM
INERTIAL NAVIGATION
MANTLE CONVECTION
GOCE
Higher resolution in space
Higher precision
GLACIAL ISOSTATIC ADJUSTMENT
TECTONICS
SEA ICE
SEA LEVEL CHANGE
POLAR ICE MASS BALANCE
HYDROLOGY
SOIL MOISTURE RUN OFF
GROUND WATER
SNOW
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OCEAN BOTTOM CURRENTS
ATMO-SPHERE
POST - SEISMIC DEFORMATION
GRACE
Higher resolution in time
CORE NUTATION
ATMO-SPHERE (?)
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SOLID EARTH AND OCEAN TIDES
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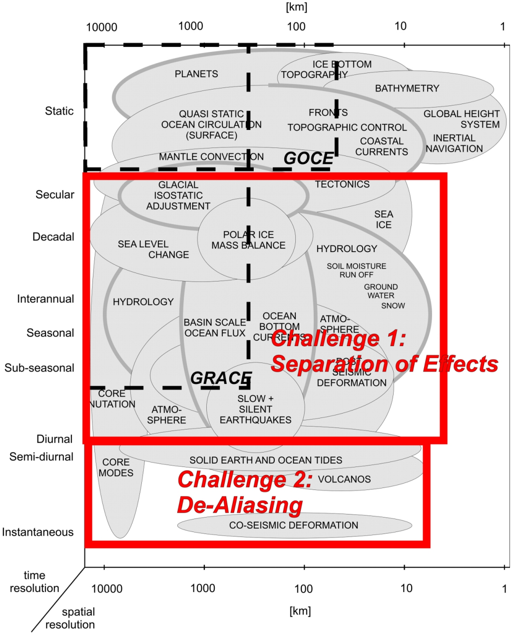
VOLCANOS
CO-SEISMIC DEFORMATION
time resolution
spatial resolution
10000
1000
100
10
1
[km]

challenges


[km]
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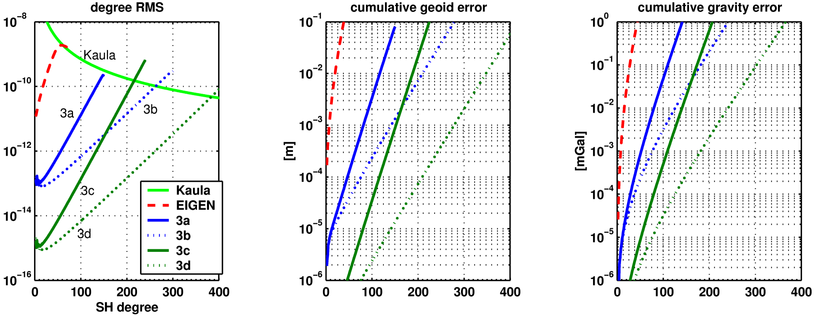
OCEAN BOTTOM CURRENTS
ATMO-SPHERE
Challenge 1: Separation of Effects
POST SEISMIC DEFORMATION
GRACE
CORE NUTATION
ATMO-SPHERE
SLOW + SILENT EARTHQUAKES
SOLID EARTH AND OCEAN TIDES
CORE MODES
Challenge 2: De-Aliasing
VOLCANOS
CO-SEISMIC DEFORMATION
time resolution
spatial resolution
10000
1000
100
10
1
[km]

basic scenarios

Numbers of Observable		PSD (unit/$\sqrt{\text{Hz}}$)	h (km)	L	ρ_0 (km)	Comment
1. Very High AltitudeMonitoring Missions						
1a	$\Delta \underline{x}$	1 cm	6000	30	–	hi–lo SST at LAGEOS altitude
1b	$\Delta \rho$	0.1 μm	6000	30	1000	lo–lo SST at LAGEOS altitude
2. Gradiometry Missions						
2a	T_{xx}, T_{yy}, T_{zz}	1 mE	180	400	–	
2b	T_{xx}, T_{yy}, T_{zz}	0.1 mE	180	600	–	
2c	T_{xx}, T_{yy}, T_{zz}	1 mE	100	600	–	represents high e mission
2d	T_{xx}, T_{yy}, T_{zz}	0.1 mE	100	720	–	
2e	full tensor	10 mE	50	600	–	planetary mission
3. Low–Low SST Missions						
3a	$\Delta \rho$	10 μm	400	150	50	current GRACE, short ρ_0
3b	$\Delta \rho$	10 μm	200	300	50	very low GRACE
3c	$\Delta \rho$	0.1 μm	400	300	50	3a 100× better (laser)
3d	$\Delta \rho$	0.1 μm	200	500	50	3b 100× better (laser)
3e	$\Delta \rho$	0.1 μm	200	500	200	3d with larger baseline
3f	$\Delta \rho$	0.1 μm	200	500	1000	3d with very large baseline
4. ConfigurationFlights						
4a	T_{xx}, T_{xz}, T_{zz}	10 μE	400	400	0.1–1	CartWheel-like (coplanar)
4b	full tensor	10	400	400	0.1–1	LISA-like (non-coplanar)

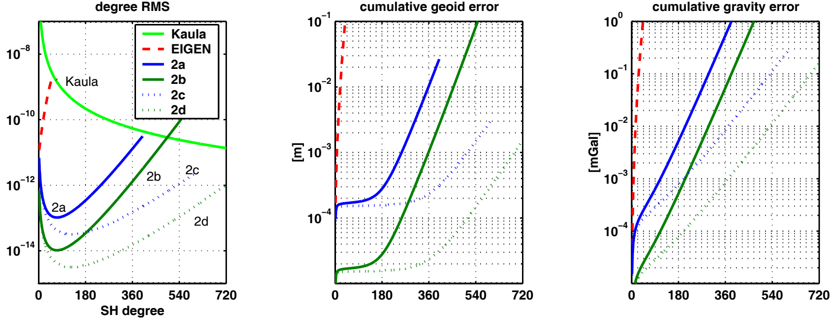
basic scenarios lo-lo SST



3a: 10μm SST @400km
3b: 10μm SST @200km
3c: 0.1μm SST @400km
3d: 0.1μm SST @200km

very promising for GIA, core, ocean mass change, ...

basic scenarios gradiometry



2a: 1mE gradio @180km
2b: 0.1mE gradio @180km
2c: 1mE gradio @100km (ecc.)
2d: 0.1mE gradio @100km (ecc.)

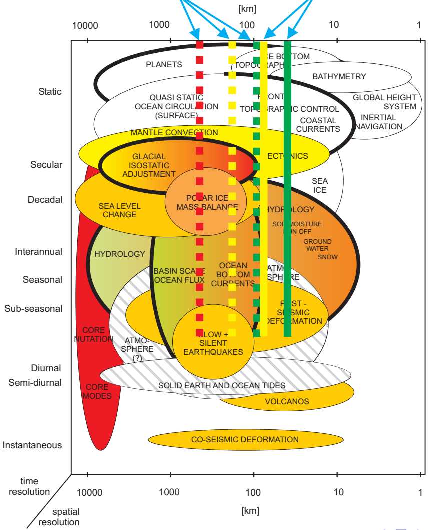
simulation vs. requirements

accuracy levels from mission simulations (geoid):

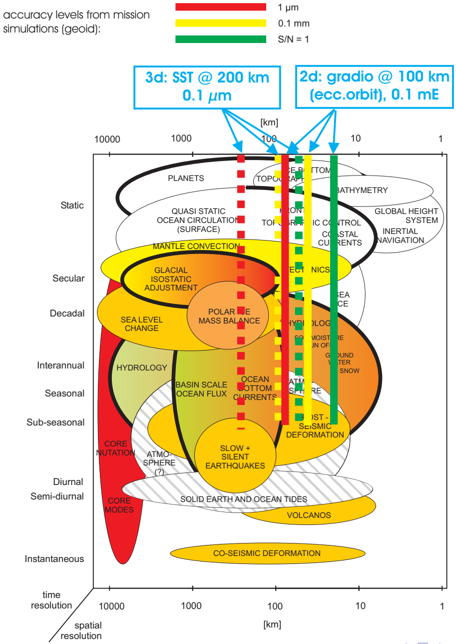
- 1 μm
- 0.1 mm
- S/N = 1

3c: SST @ 400 km 0.1 μm

2b: gradio @ 180 km 0.1 mE



simulation vs. requirements



conclusions

- GRACE (GOCE) results (achievements, limitations): good starting point for future requirements,
- science expectations/requirements beyond GRACE/GOCE are well established:
  - more spatial resolution
  - more time resolution
  - better accuracy
- increased priority since GRACE launch: ice melting, sea level, ocean circulation, hydrology, water management, tectonic hazards, ...
- length of time series is critical for quality of results,

  $\Rightarrow$ quick GRACE-2 desirable

  $\Rightarrow$ long term funding (e.g., mission operations cost)?
- enough papers?