GOCE, satellite gravimetry and a subjective view on the role of satellite laser ranging

Reiner Rummel

Institute of Astronomical and Physical Geodesy

Technische Universität München

rummel@bv.tum.de

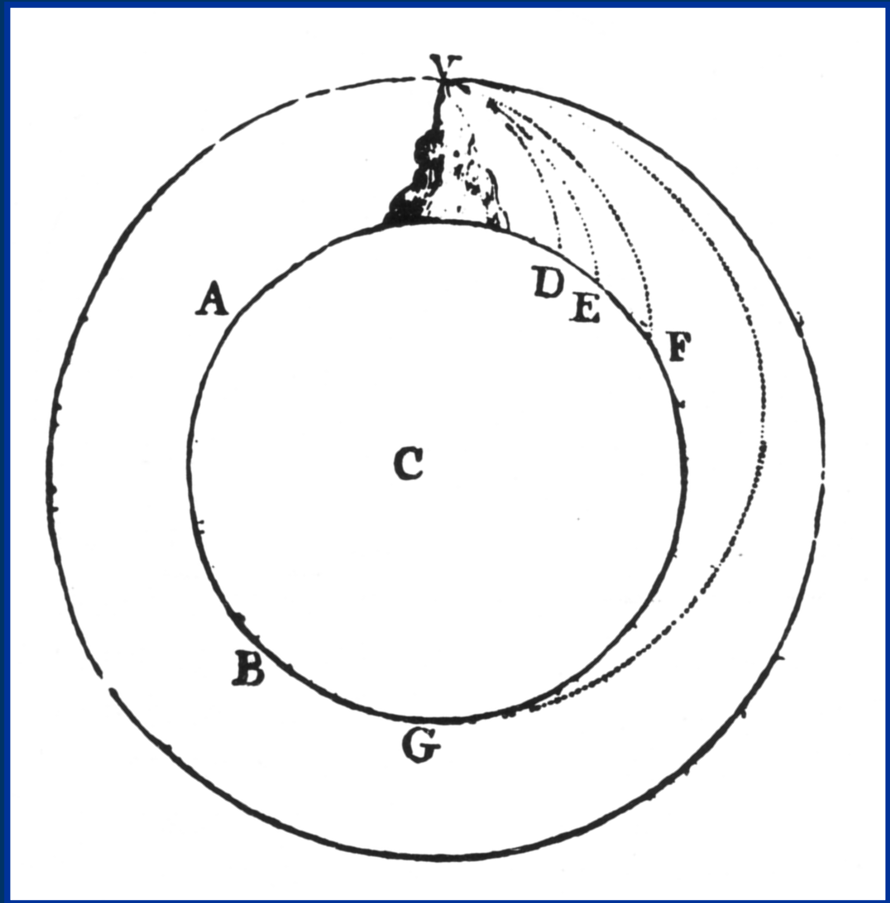
International Laserworkshop, Wettzell, 16.5.2011

How to connect to the theme of this workshop?

- laser tracking of GOCE?
- the connection of geometry and gravity?
- future gravimetric satellite missions and laser technology?
- …

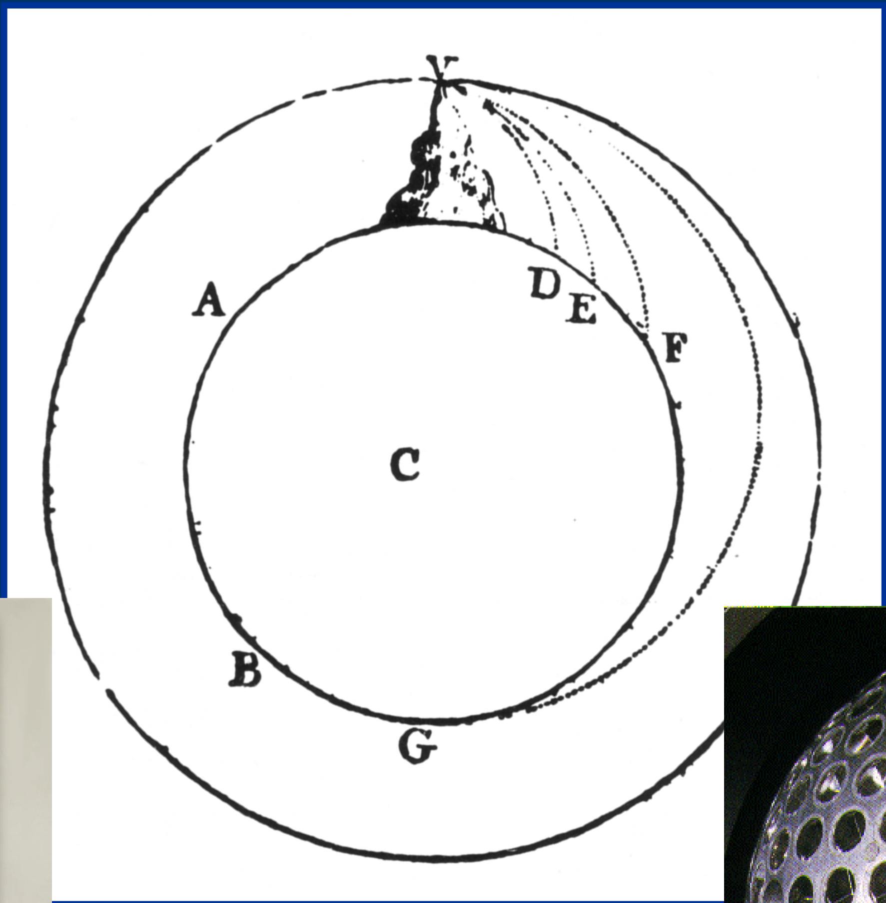
- first principle of satellite gravimetry
- satellite gravimetry – a short history
- GOCE versus GRACE
- GRACE and GRACE follow-on
- GOCE gravity gradiometry and its sensor system
- GOCE and the role of its orbits
- satellite gravimetry and fundamental physics

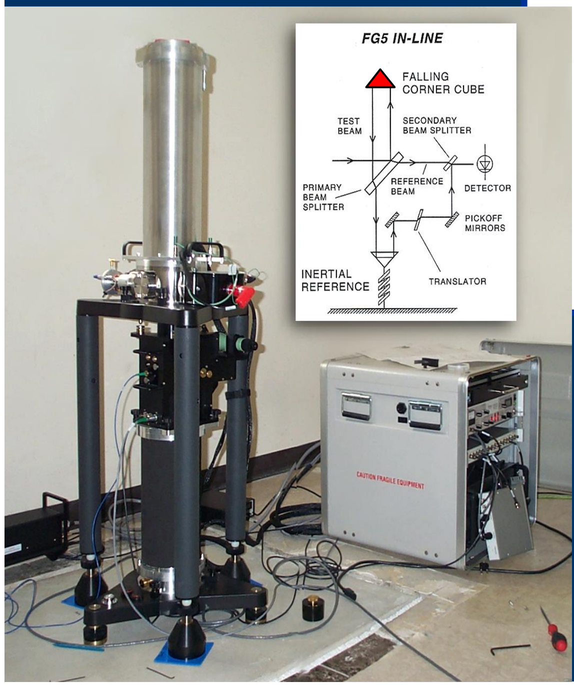
test mass in free fall

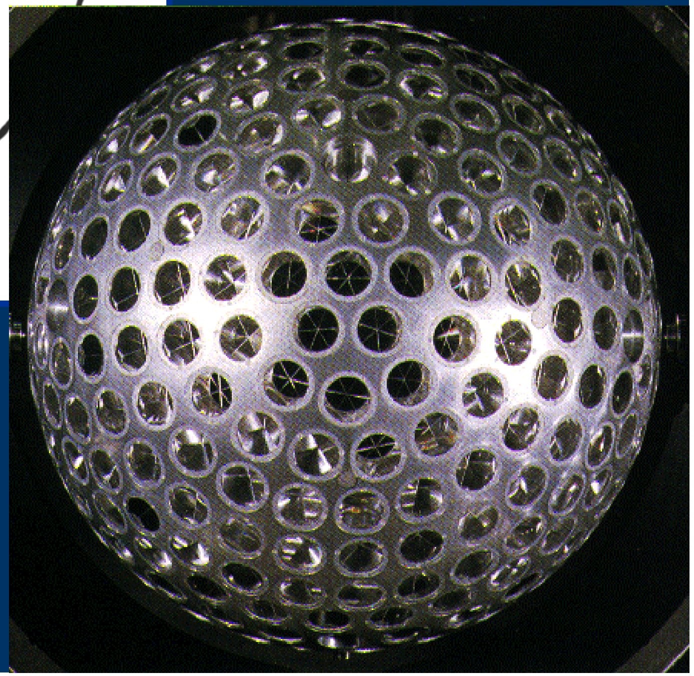


I. Newton “De mundi systemate“ 1715

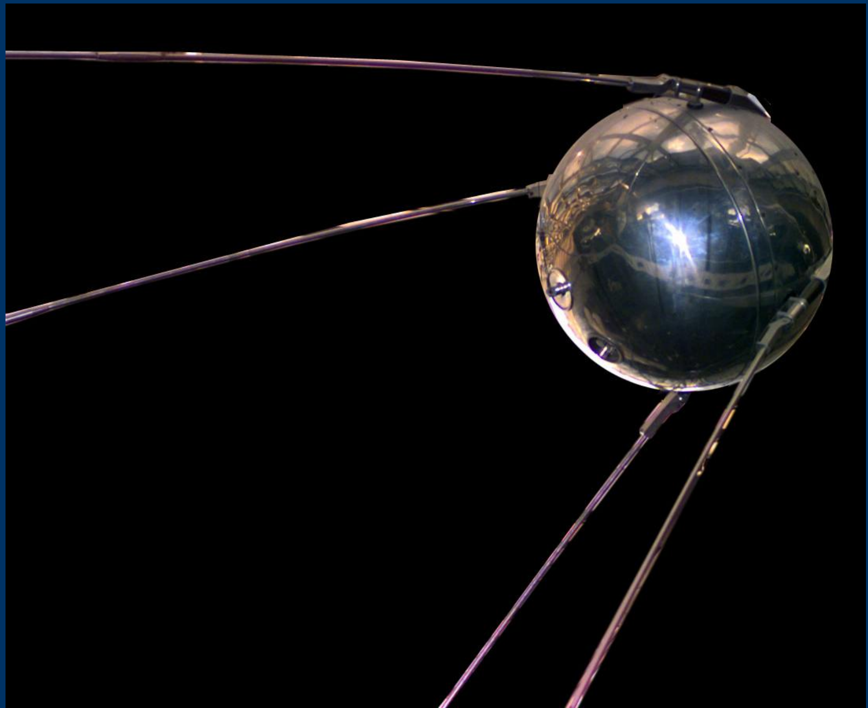
test mass in free fall



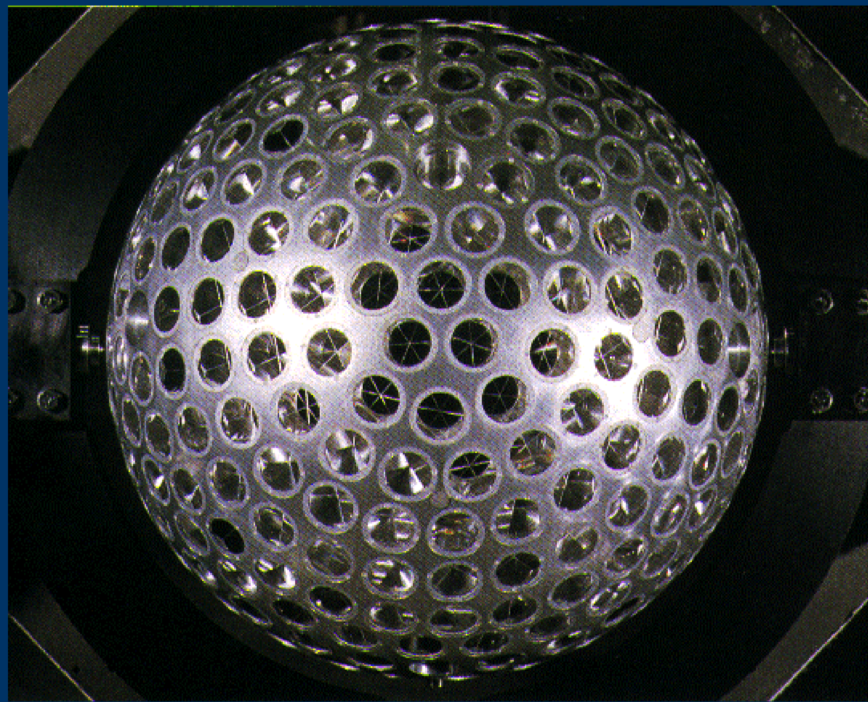




test mass in free fall



1957: Sputnik 1

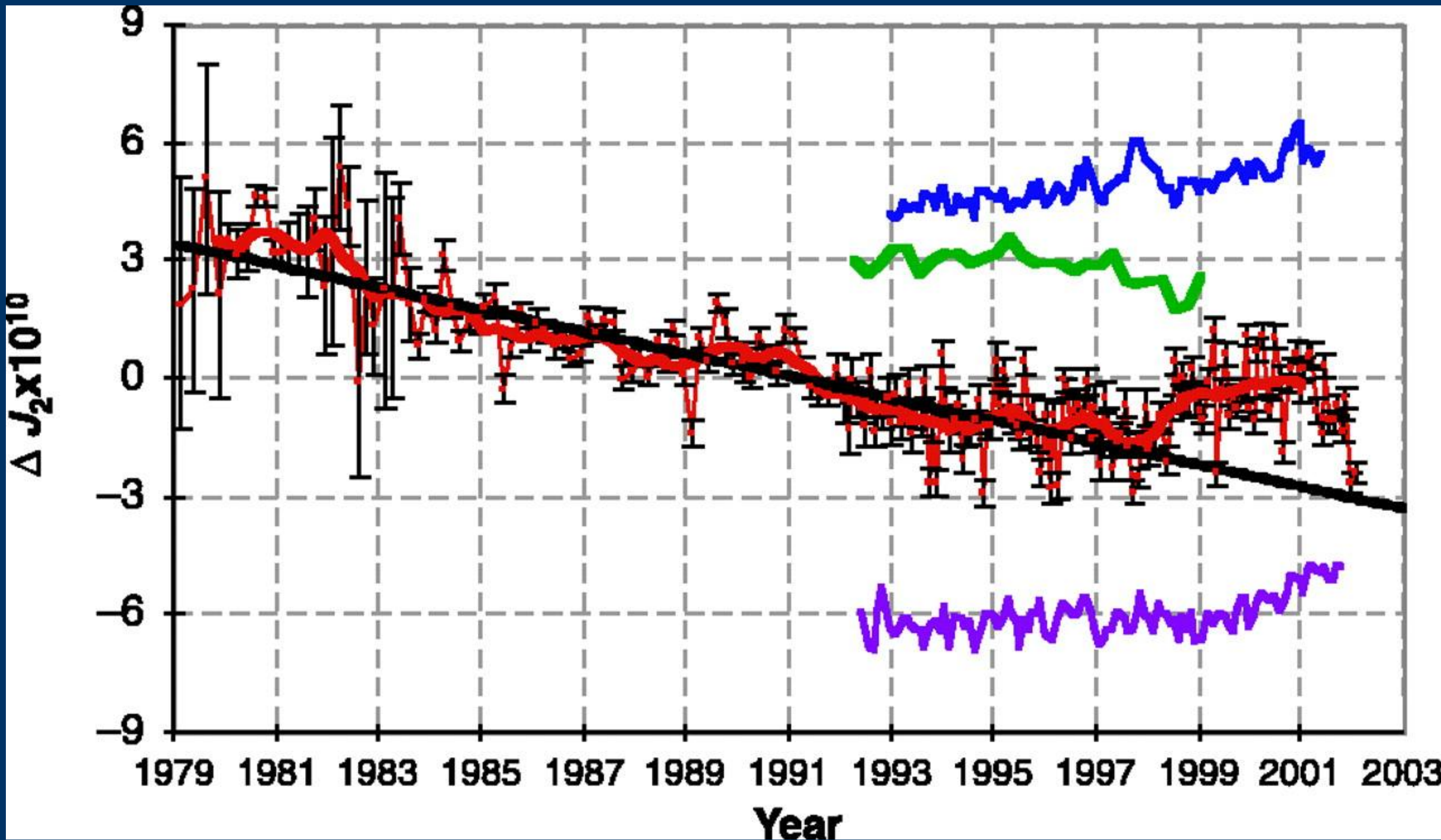


today: LAGEOS I and II

test mass in free fall

steady decrease of earth flattening

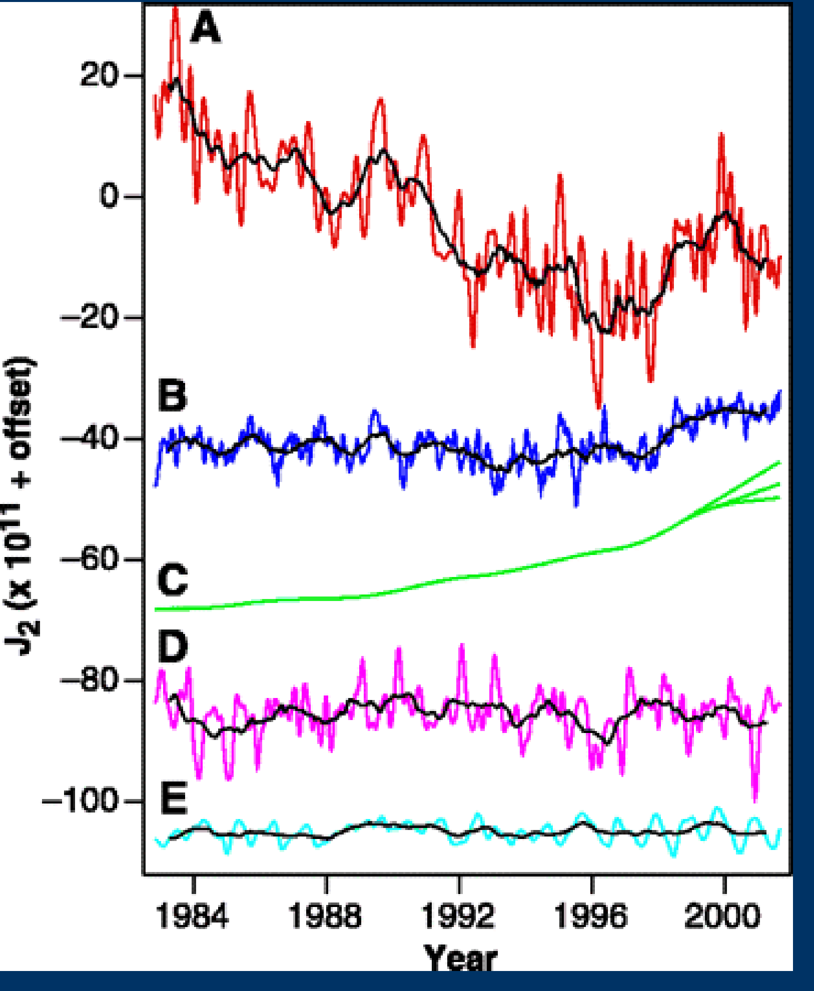
change of trend in recent years



Cox & Chao, Science, 297, 2002

test mass in free fall

temporal changes of the earth's flattening:
what are the causes?



Dickey, Marcus, de Viron, Fukumori, 2002

candidates:

- ocean masses
- melting ice caps
- atmospheric masses
- hydrology

test mass in free fall

alliance of geodesy and fundamental physics

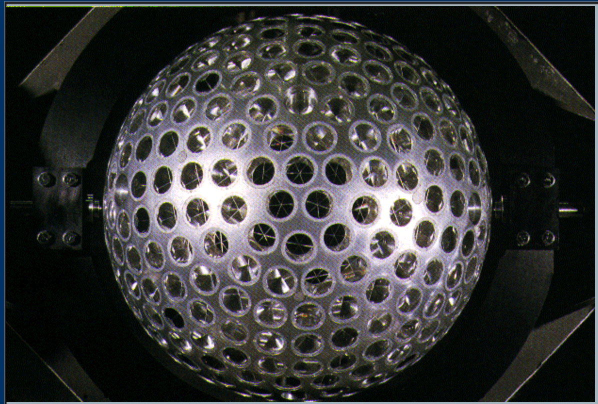
Ciufolini I, A Paolozzi, EC Pavlis, JC Ries, R König, RA Matzner, G Sindoni, H Neumayer: Towards a One Percent Measurement of Frame Dragging by Spin with Satellite Laser Ranging to LAGEOS, LAGEOS 2 and LARES and GRACE Gravity Models in: Probing the Nature of Gravity by Everitt CWF et al. (eds.) 2010

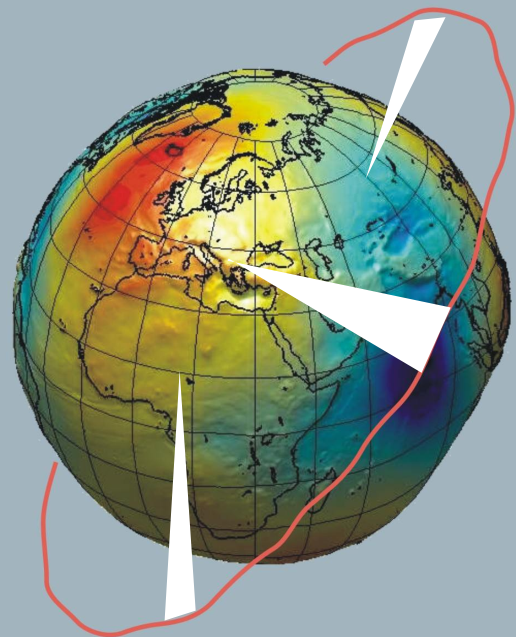
Ciufolini I: Phys. Rev. Lett. 56, 278–281 (1986) Measurement of the Lense-Thirring drag on high-altitude, laser-ranged artificial satellites

Bertotti B: Generation of geodesic motion by the twin probe method, 1974

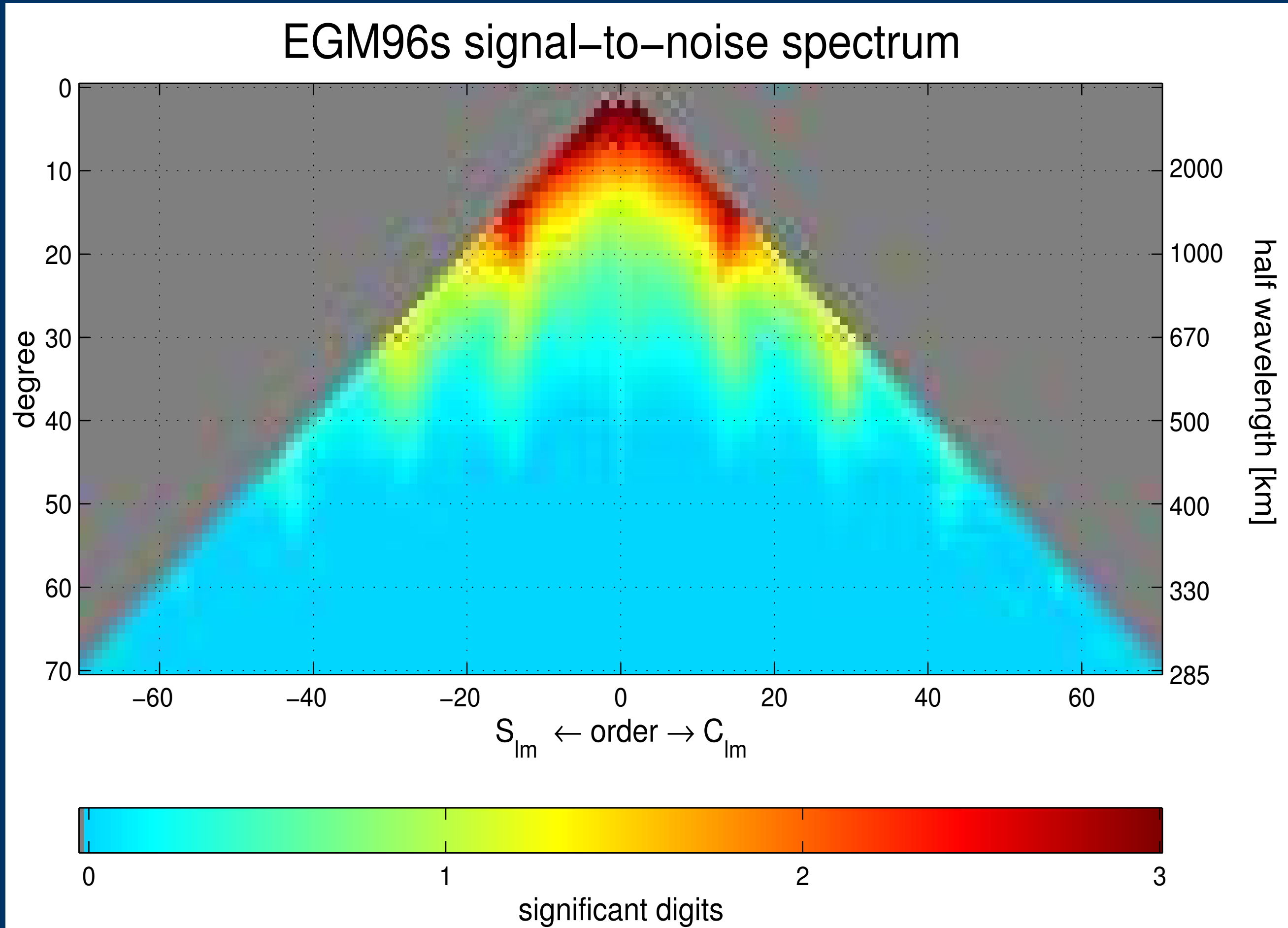
test mass in free fall

observatories “see” only
short arc segments





test mass in free fall

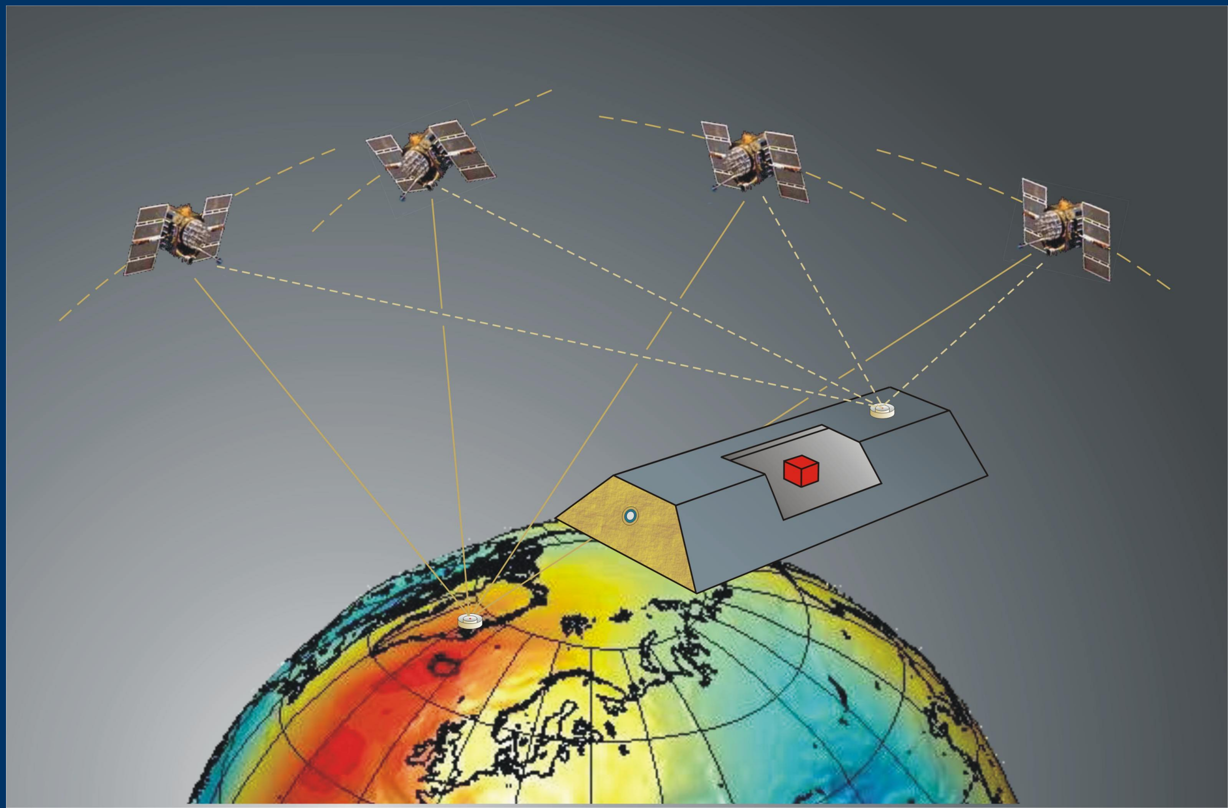


many satellites, many orbit characteristics, many arcs

test mass in free fall

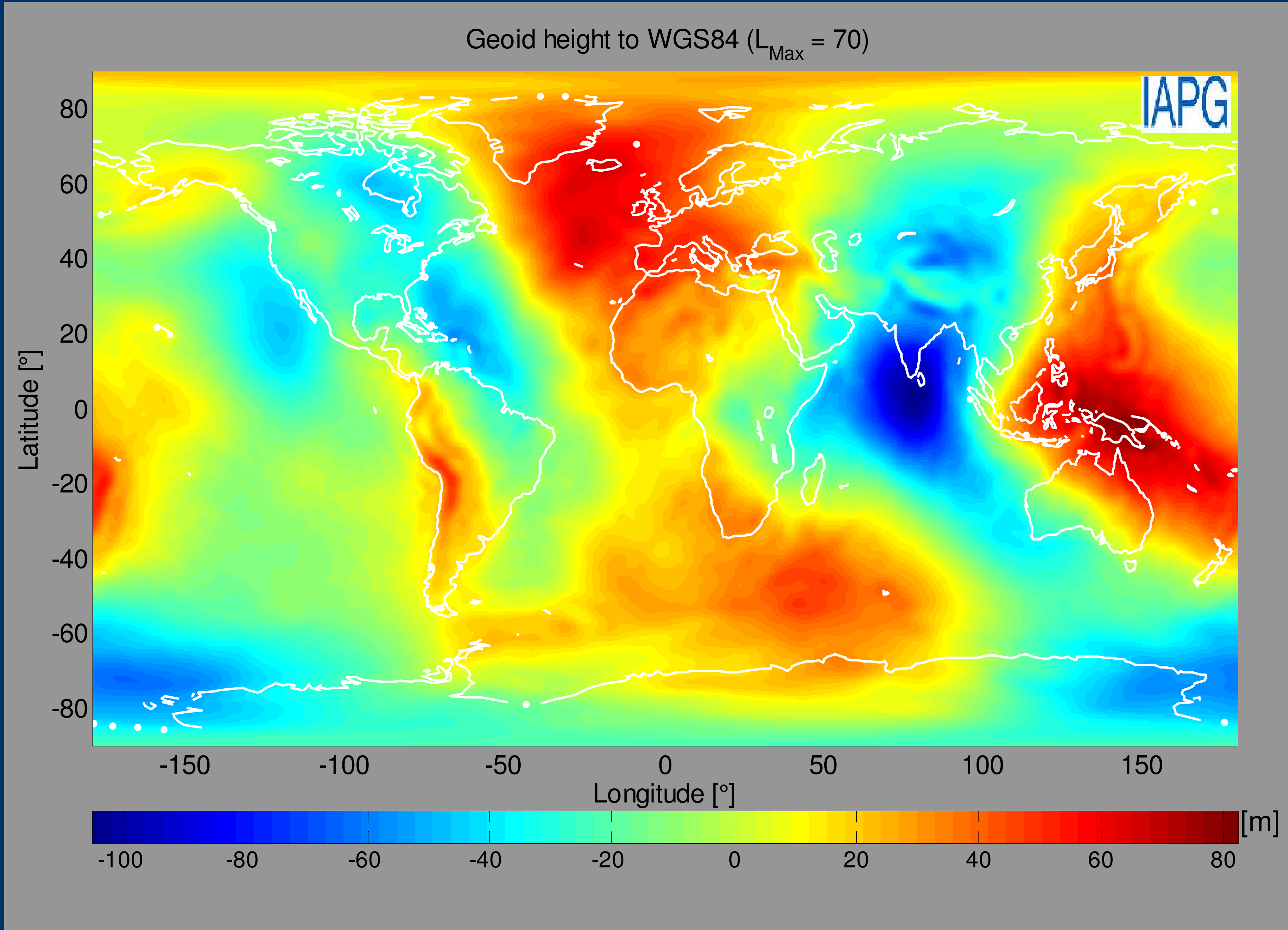
a new era:

1. uninterrupted tracking in 3D (GNSS)
2. low earth orbiters (LEOs)
3. ultra precise accelerometers



satellite-to-satellite tracking in high-low mode

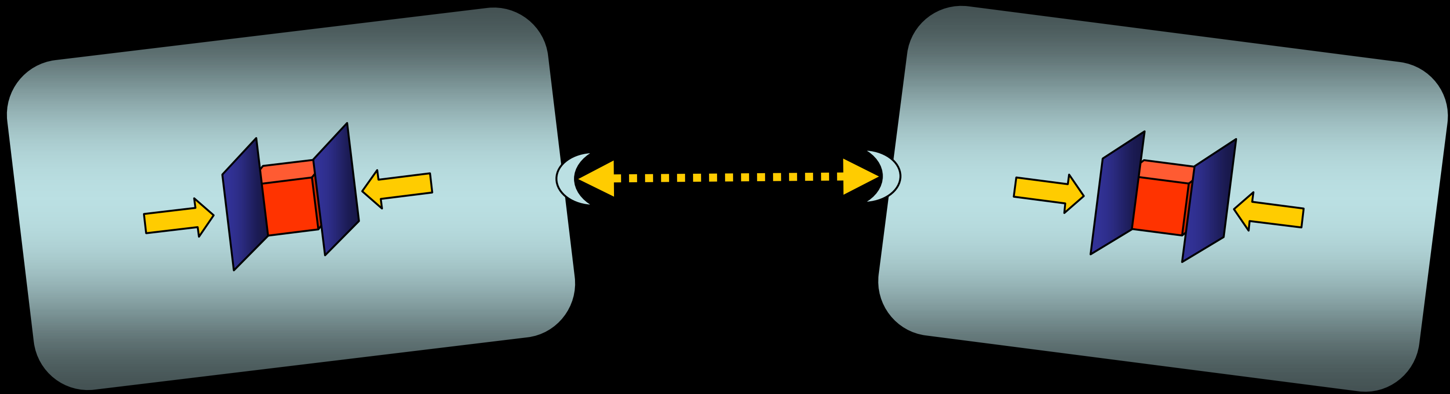
geoid model derived from high-low satellite-to-satellite tracking



several test masses in free fall

several test masses in free fall

from absolute to differential measurement

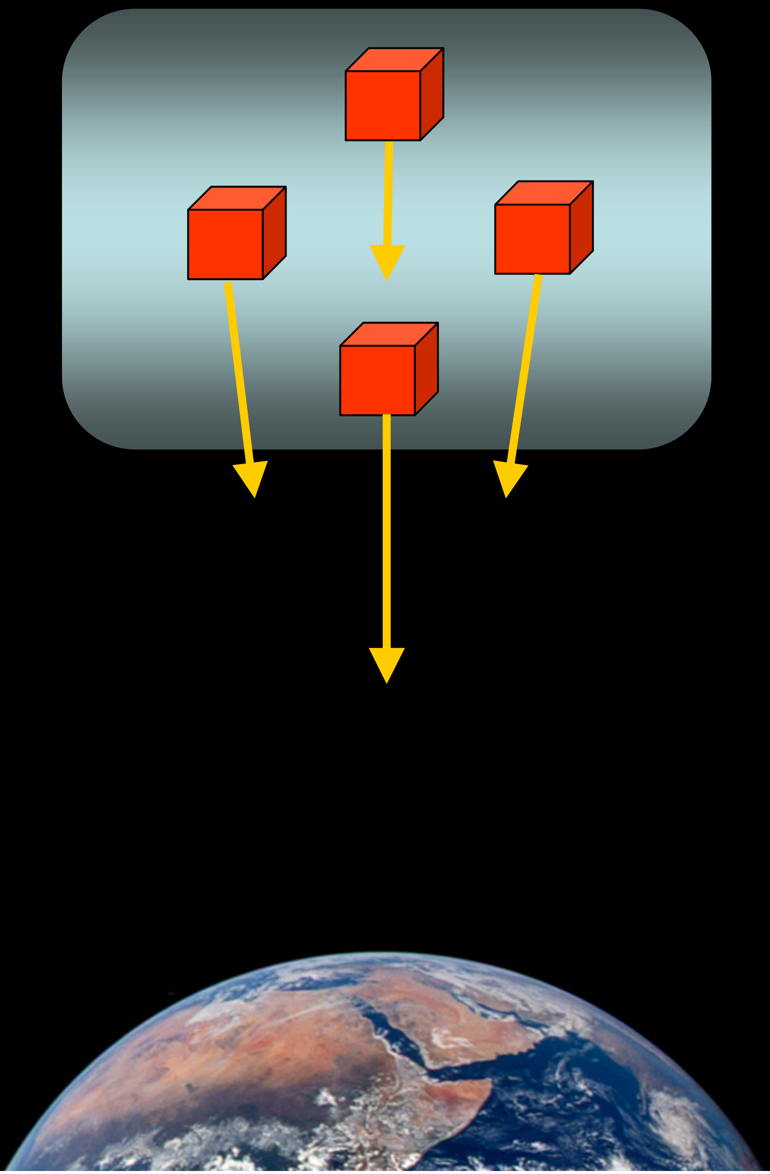


baseline: 200km

concept:

GRACE

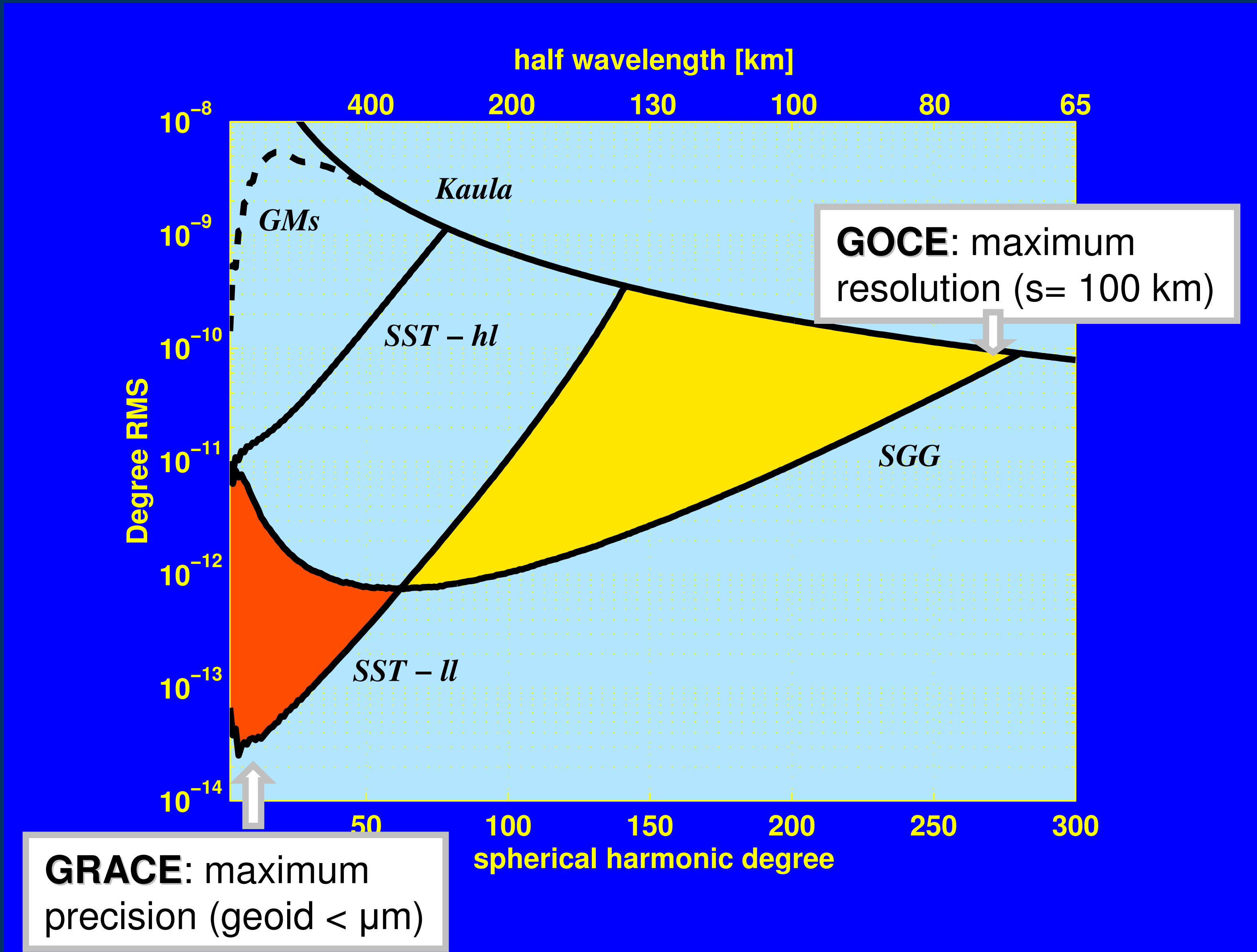
several test masses in free (?) fall



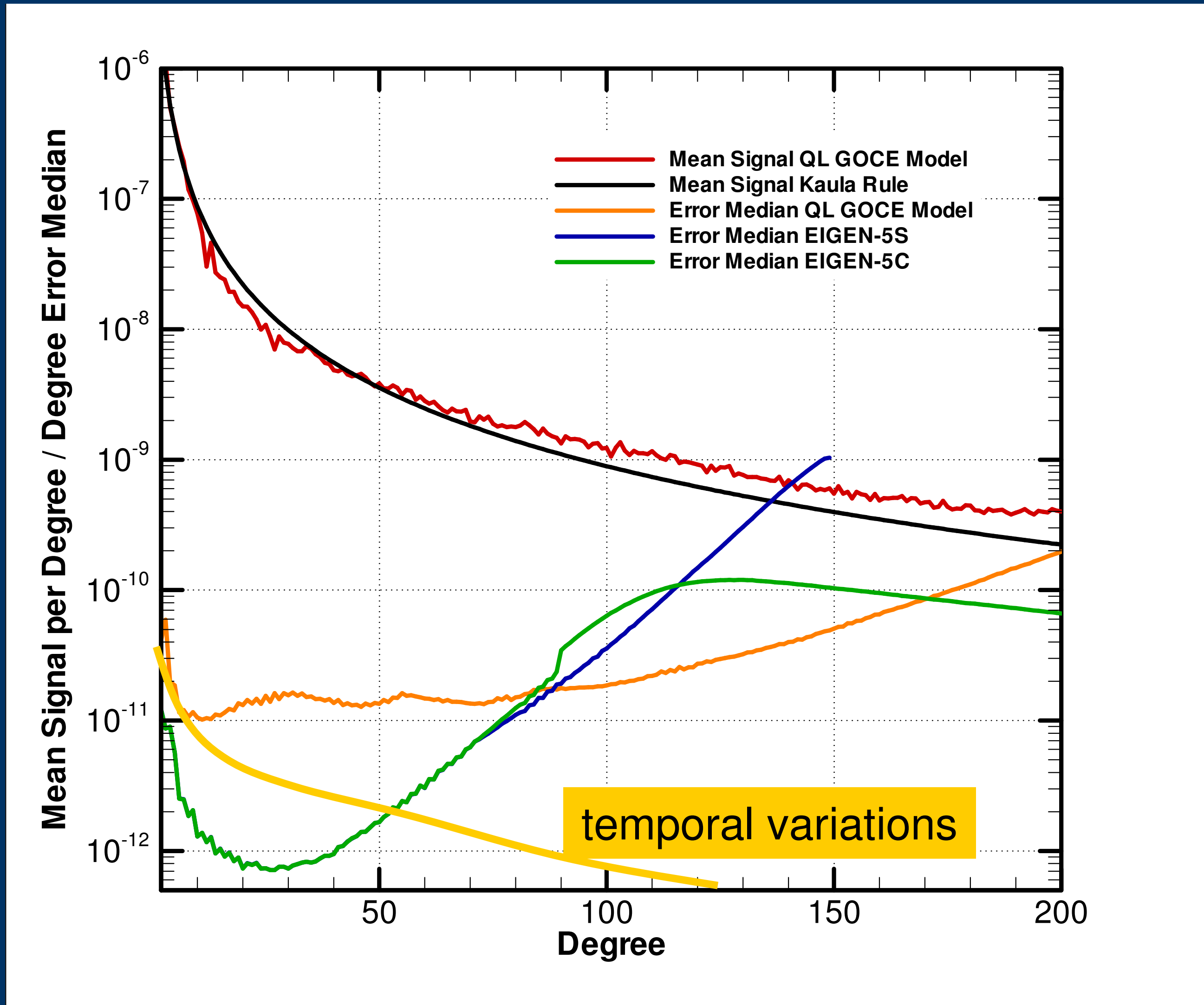
baseline: 50 cm

concept:
GOCE

GOCE versus GRACE

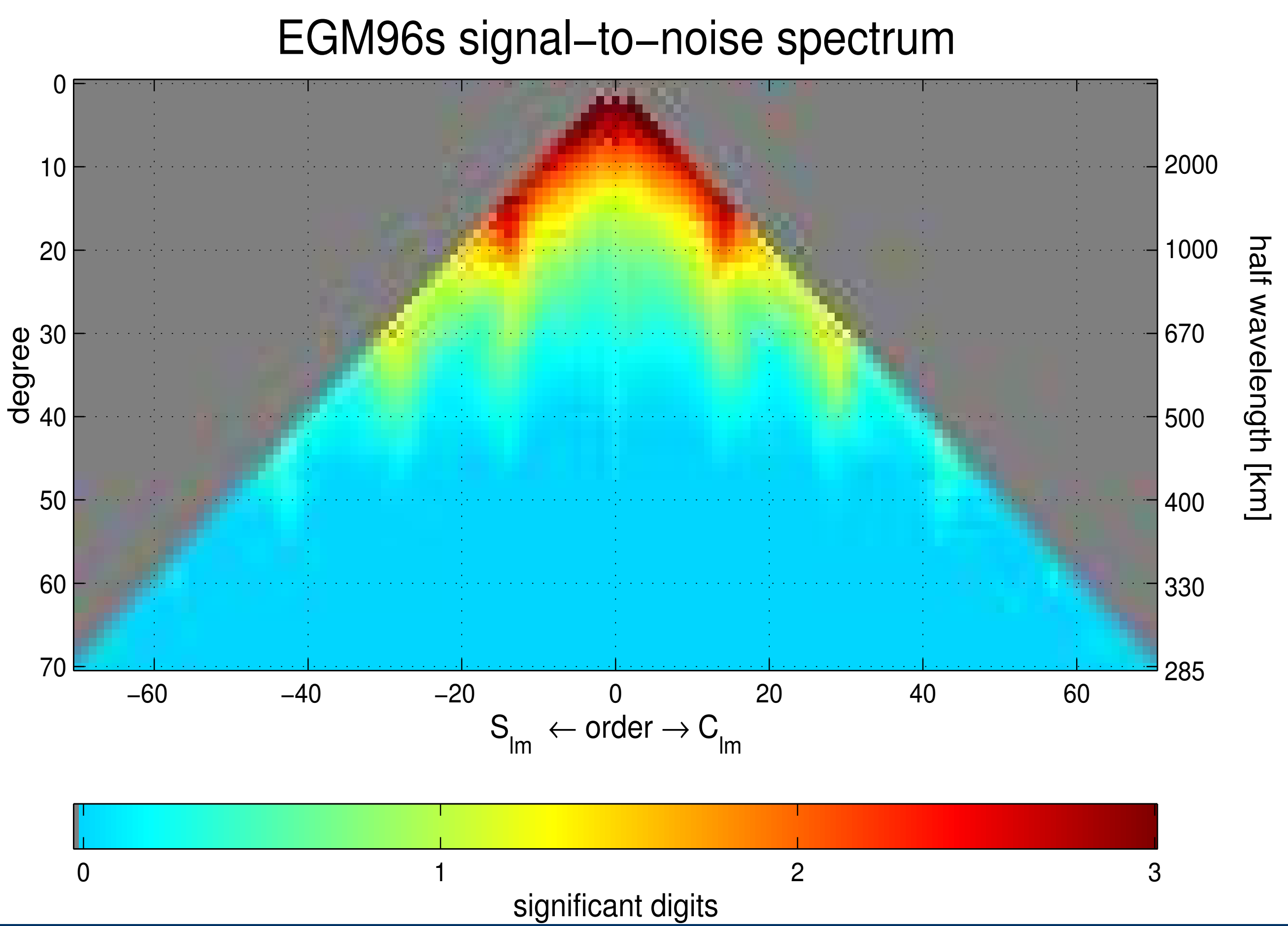


GOCE versus GRACE



degree variances (median) of signal and noise

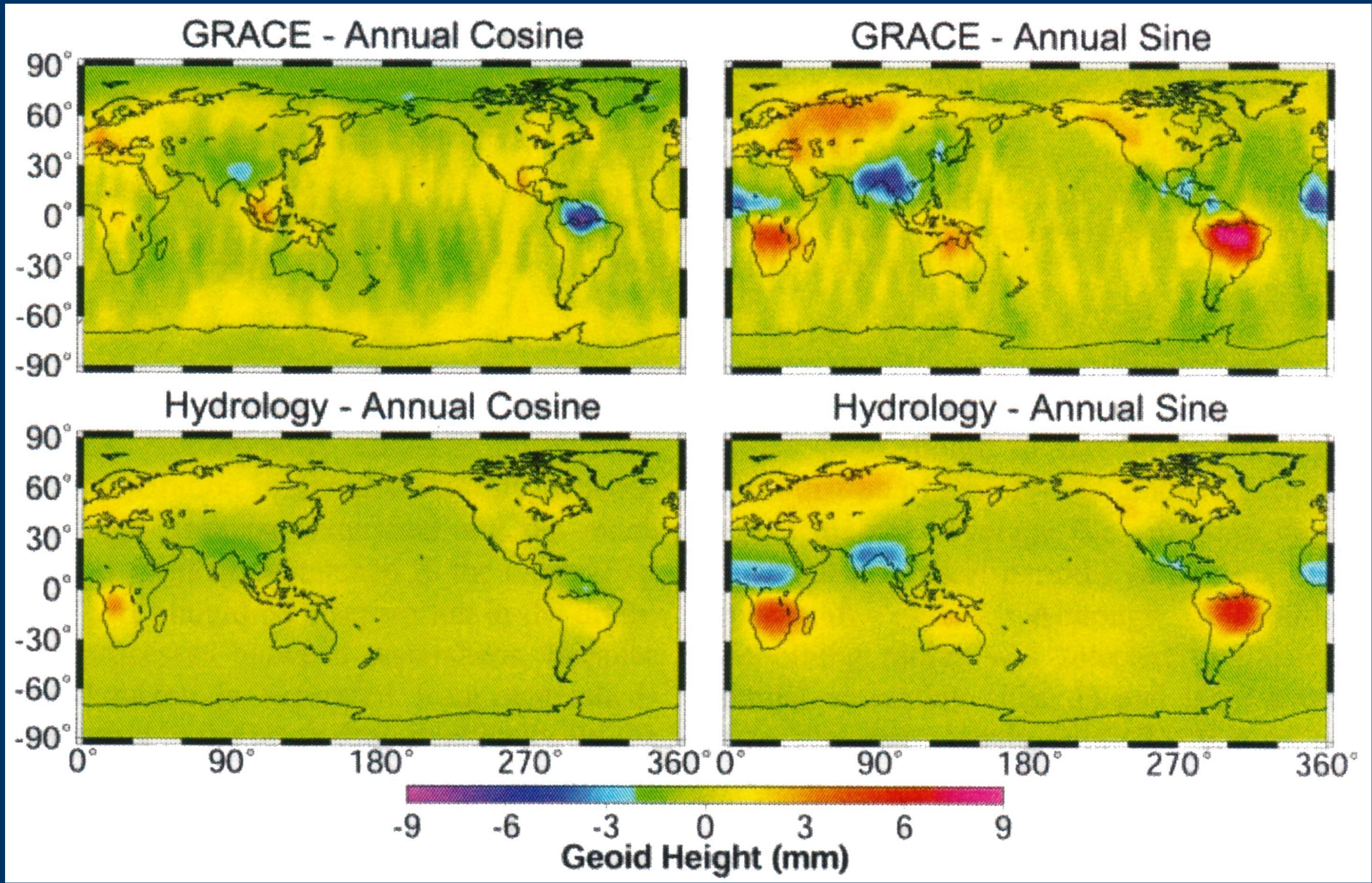
GOCE versus GRACE



problem with degree/order zero, one, two and low harmonics

GOCE versus GRACE

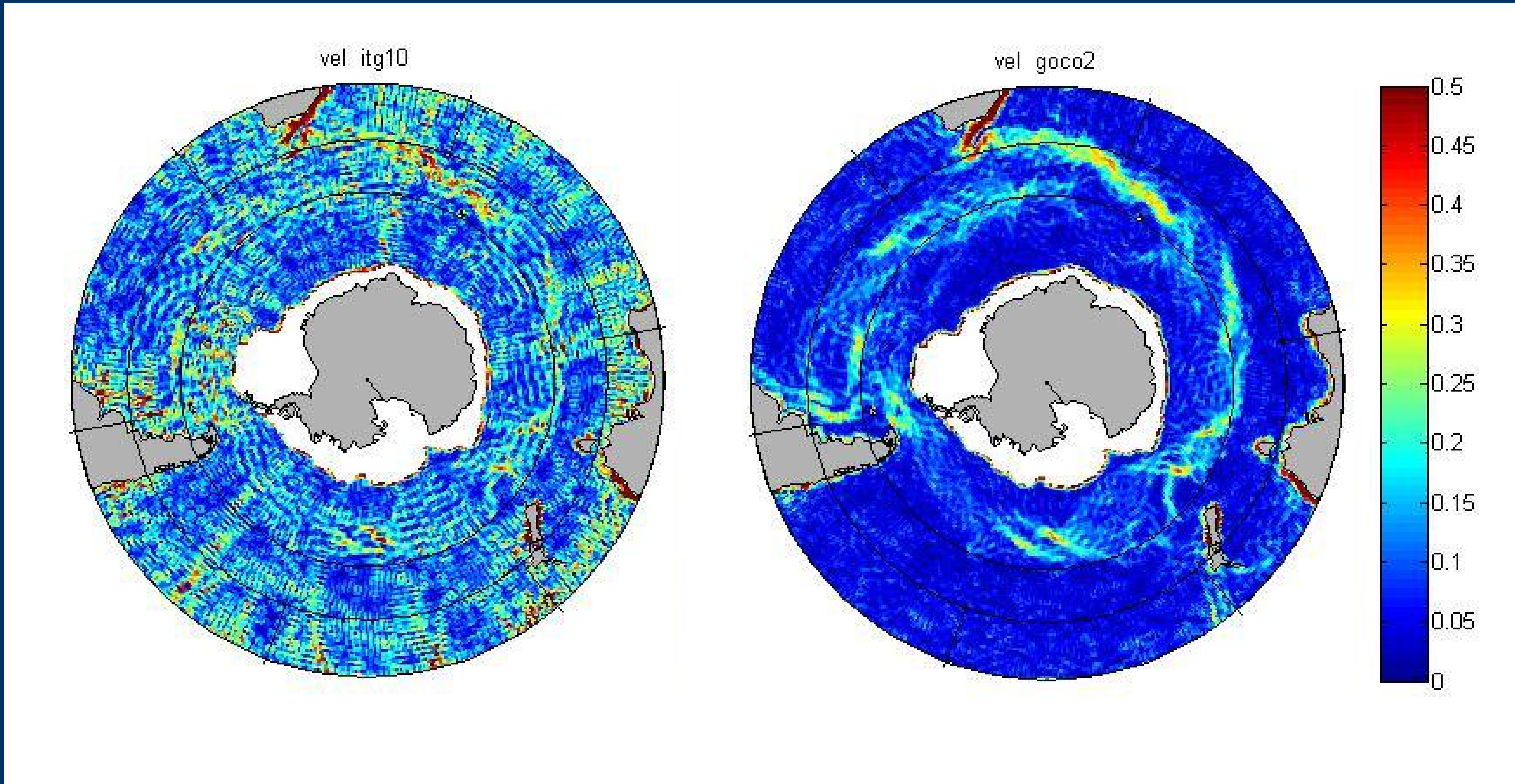
GRACE measures temporal gravitational changes
example: seasonal changes of continental hydrology



Tapley et al., Science, 2004

GOCE versus GRACE

GOCE measures spatial details
of geoid



geostrophic velocities up to d/o 180

the future

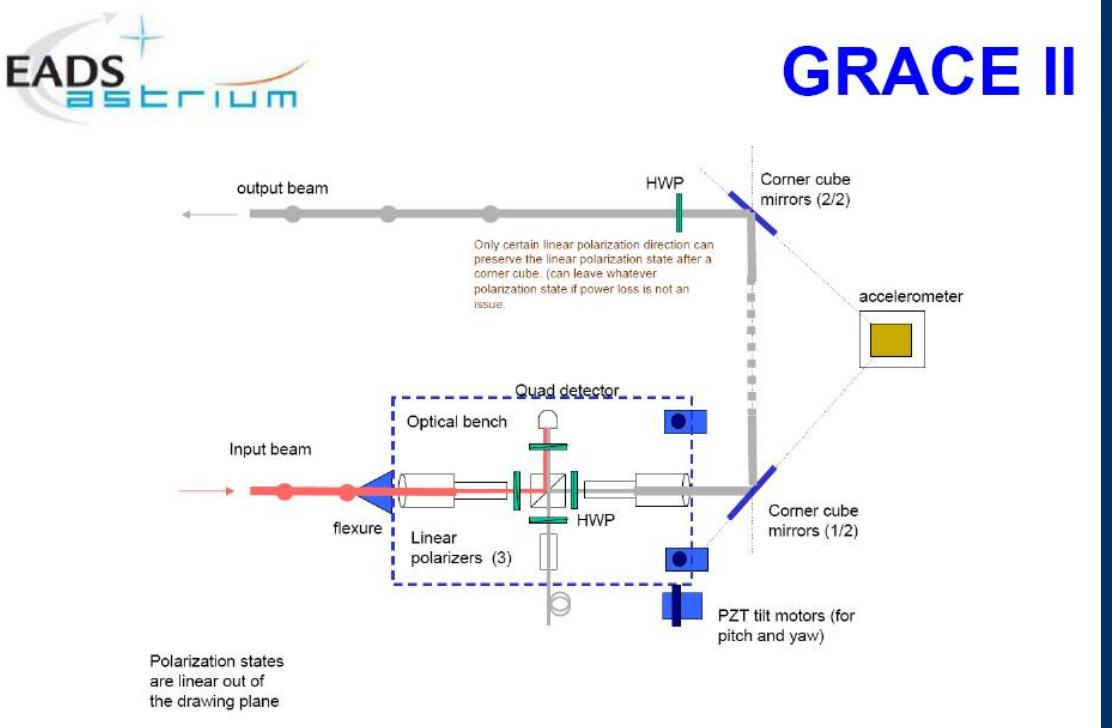


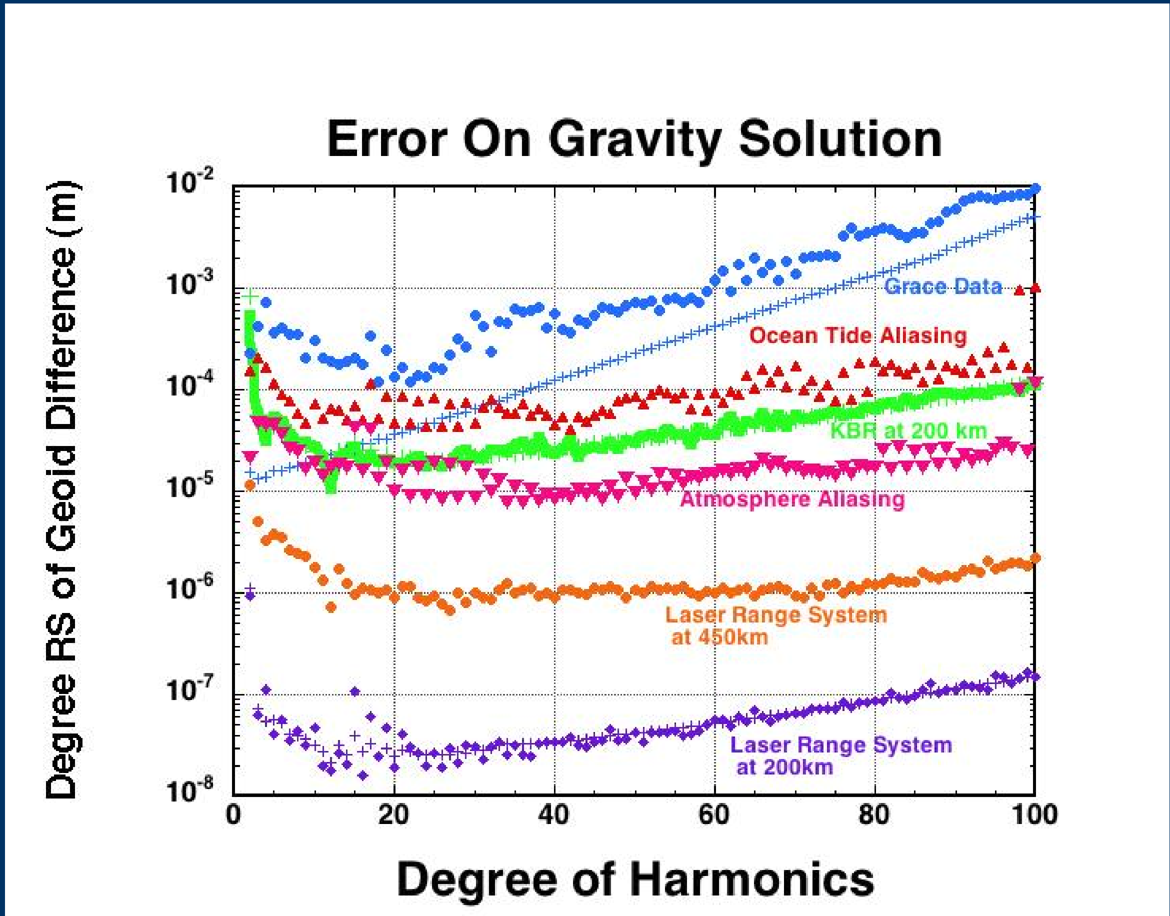
Figure 4-2: GRACE II Laser Ranging Experiment Schematics

see also, e.g.:

Bender PL, RS Nerem, JM Wahr: possible future use of laser gravity gradiometers, Space Sci Rev 108, 2003

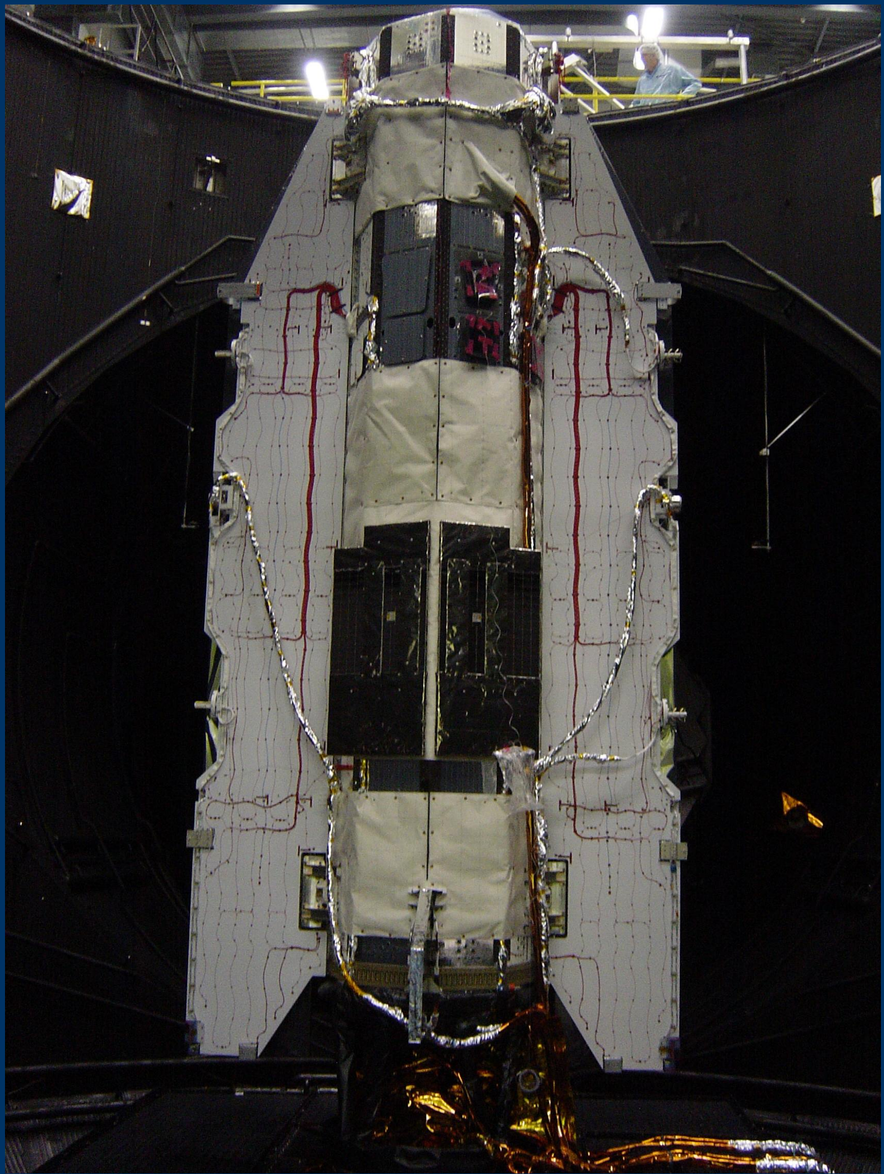
the future

„how to make use of very high precision?“



Watkins, M, 2007

GOCE



GOCE

Gravity and steady-state

Ocean **C**irculation

Explorer

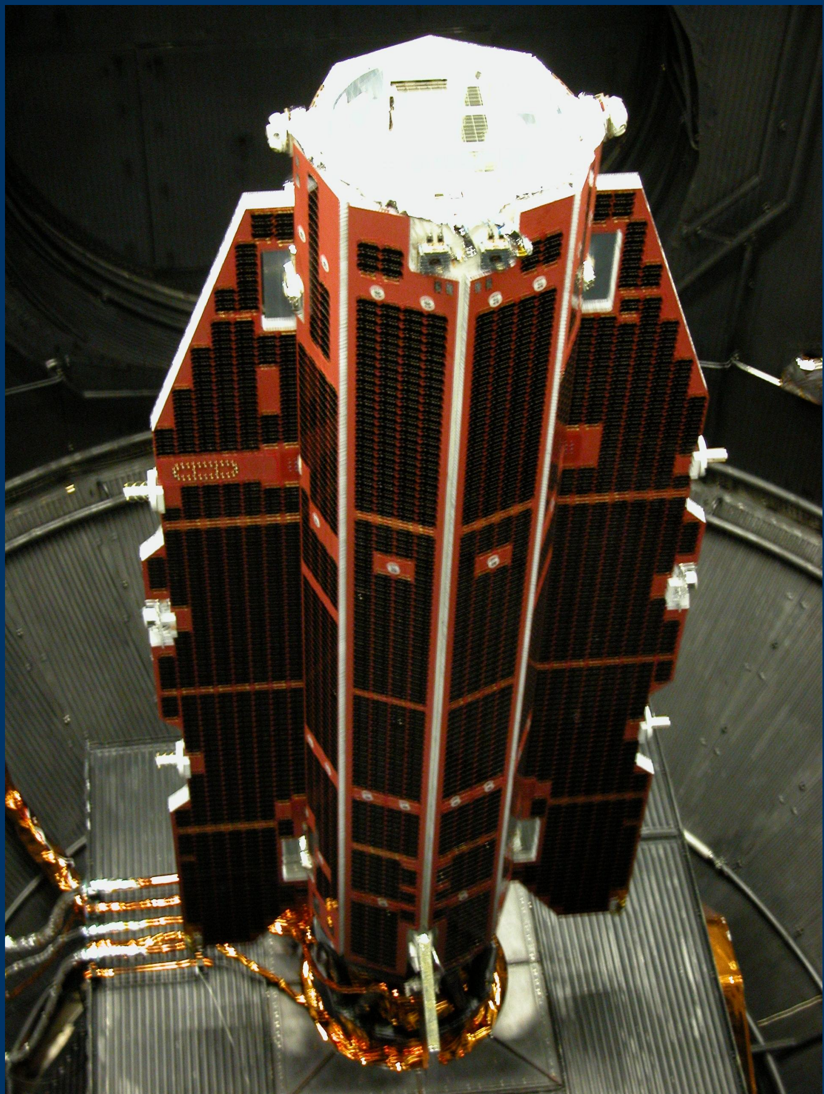
launched on 17 March 2009

first mission of

“Living Planet Programme”

of ESA

GOCE



GOCE

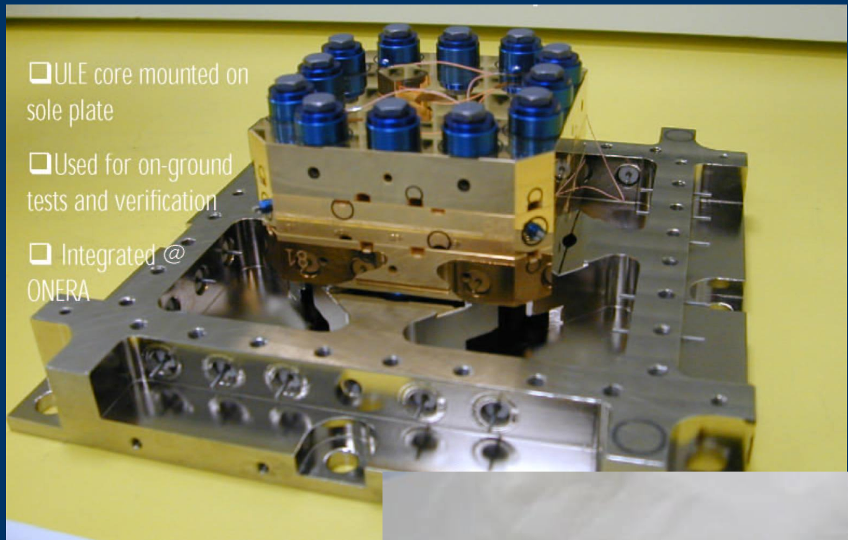
- inclination 96 degrees (sun synchronous)
- circular orbit
- altitude 259 km
- duration > 18 months

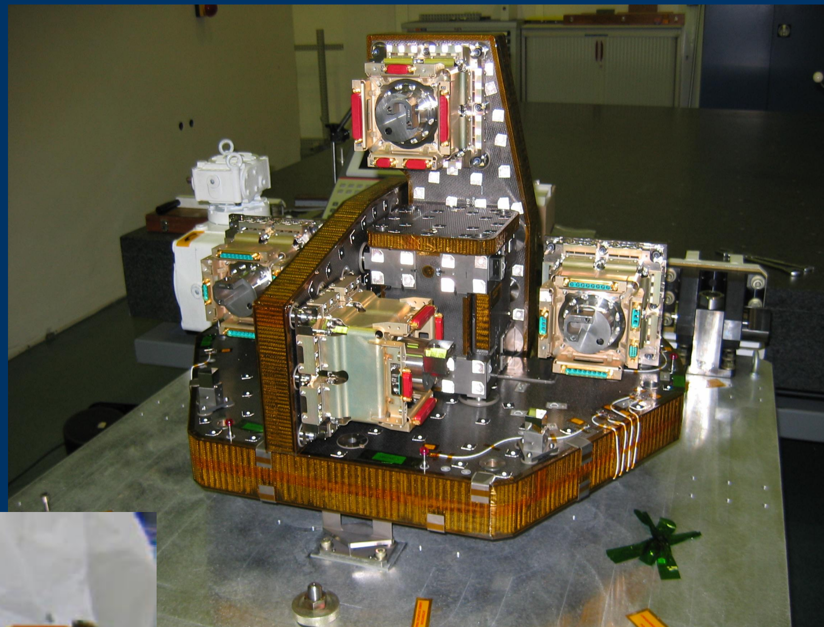
mission objectives:

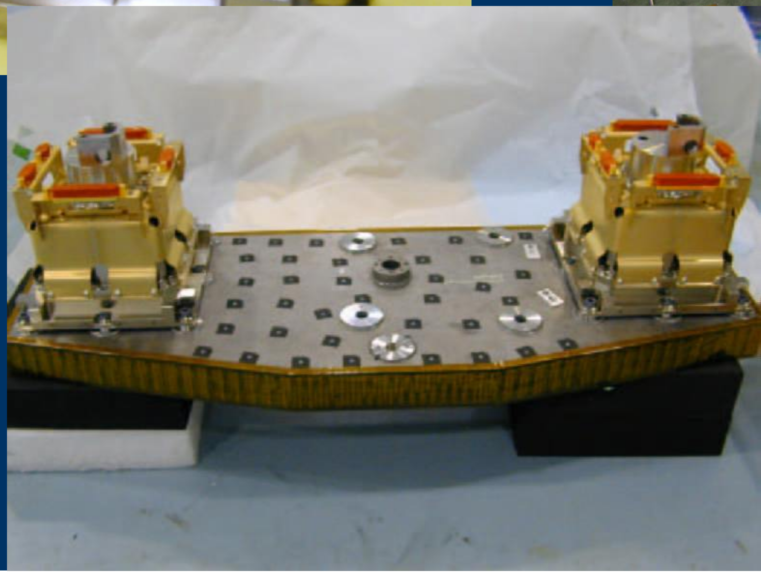
- spatial details (100km)
- gravity to 1 ppm
- geoid 1-2-cm

GOCE gravitational gradiometry

single accelerometer



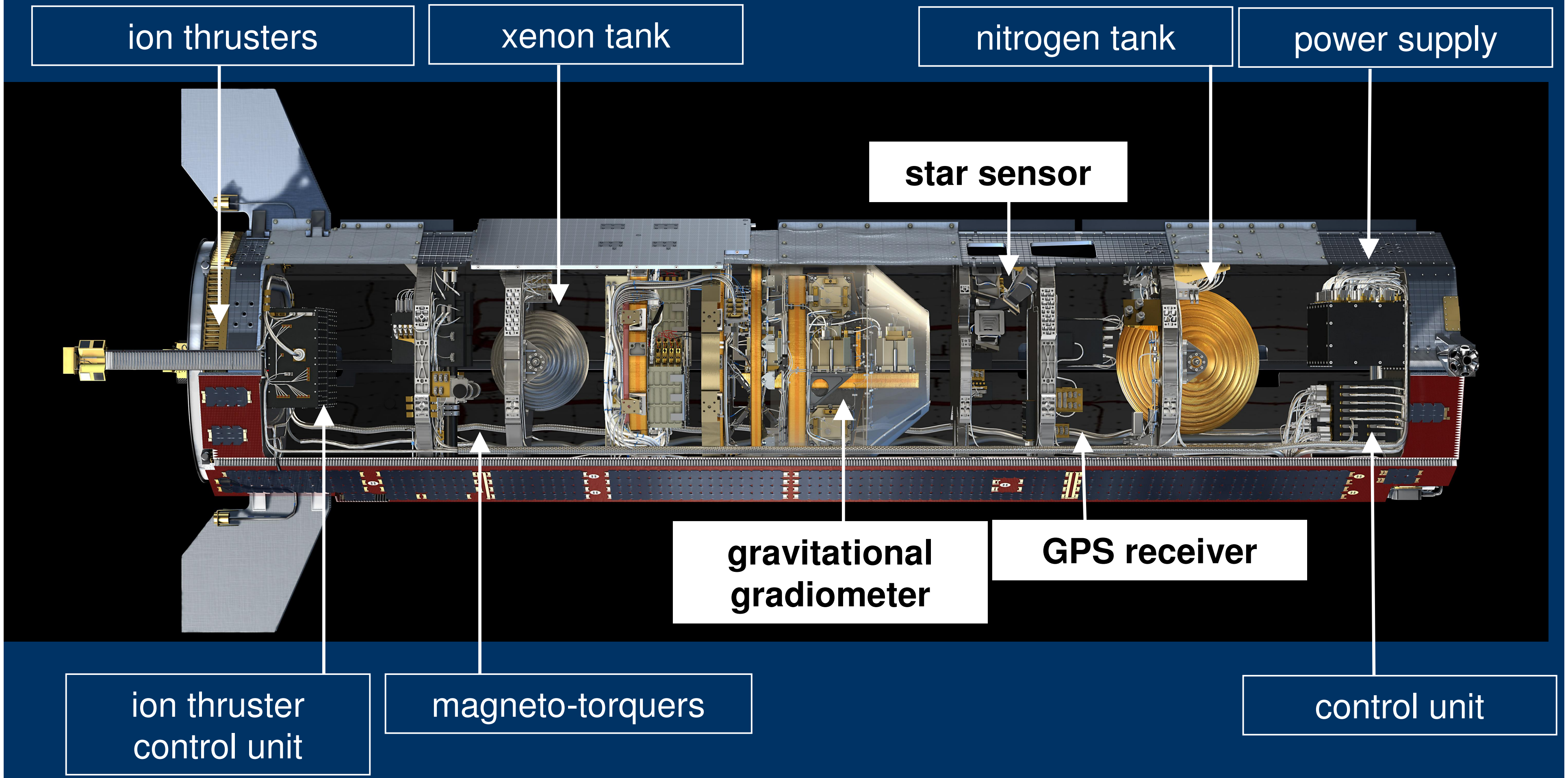




one axis gradiometer

three axes gradiometer consisting of 6 accelerometers

GOCE sensor system

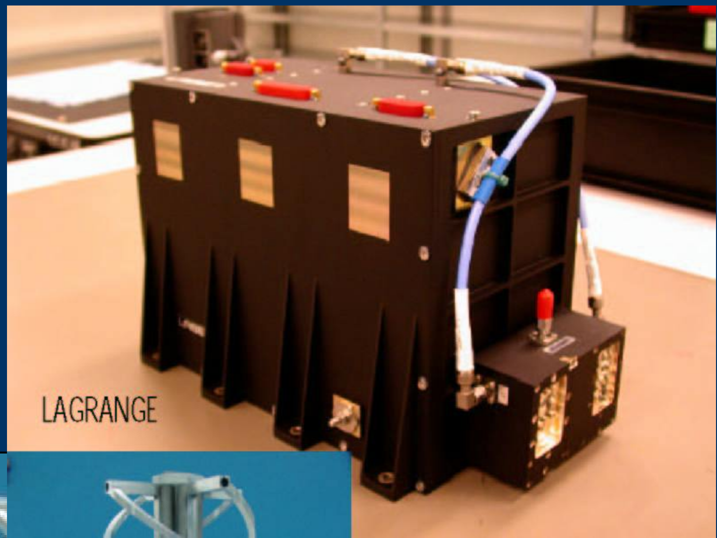


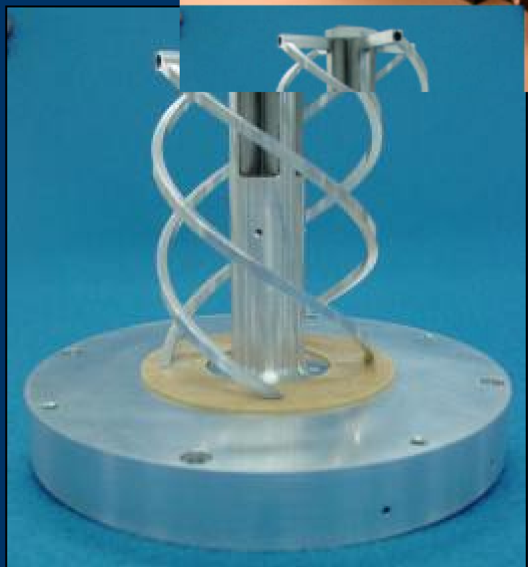
source: ESA

GOCE sensor concept

orbit and gravity field determination from GPS

independent control via satellite laser ranging (SLR)

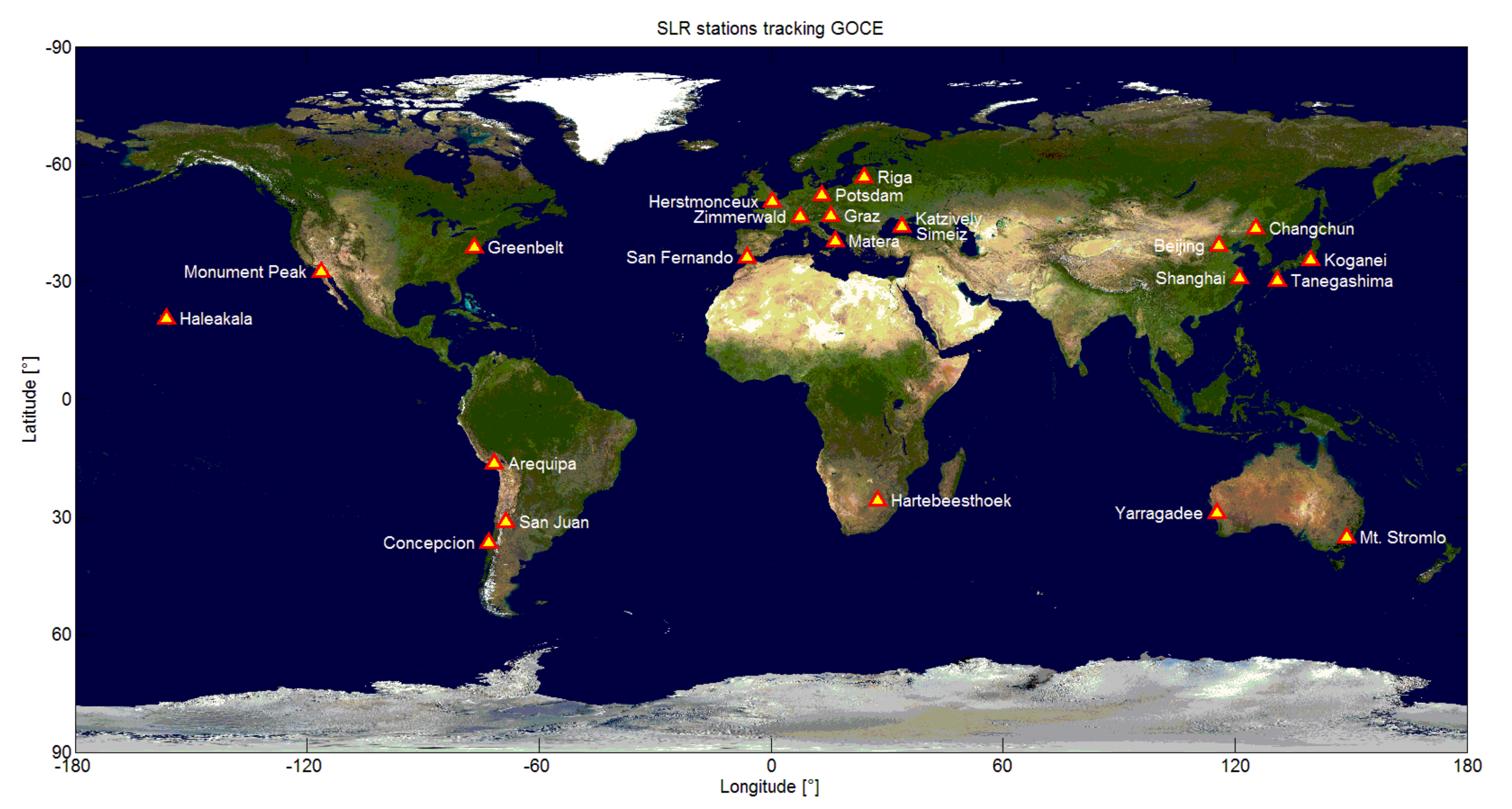




newly developed
European
space qualified
GPS receiver

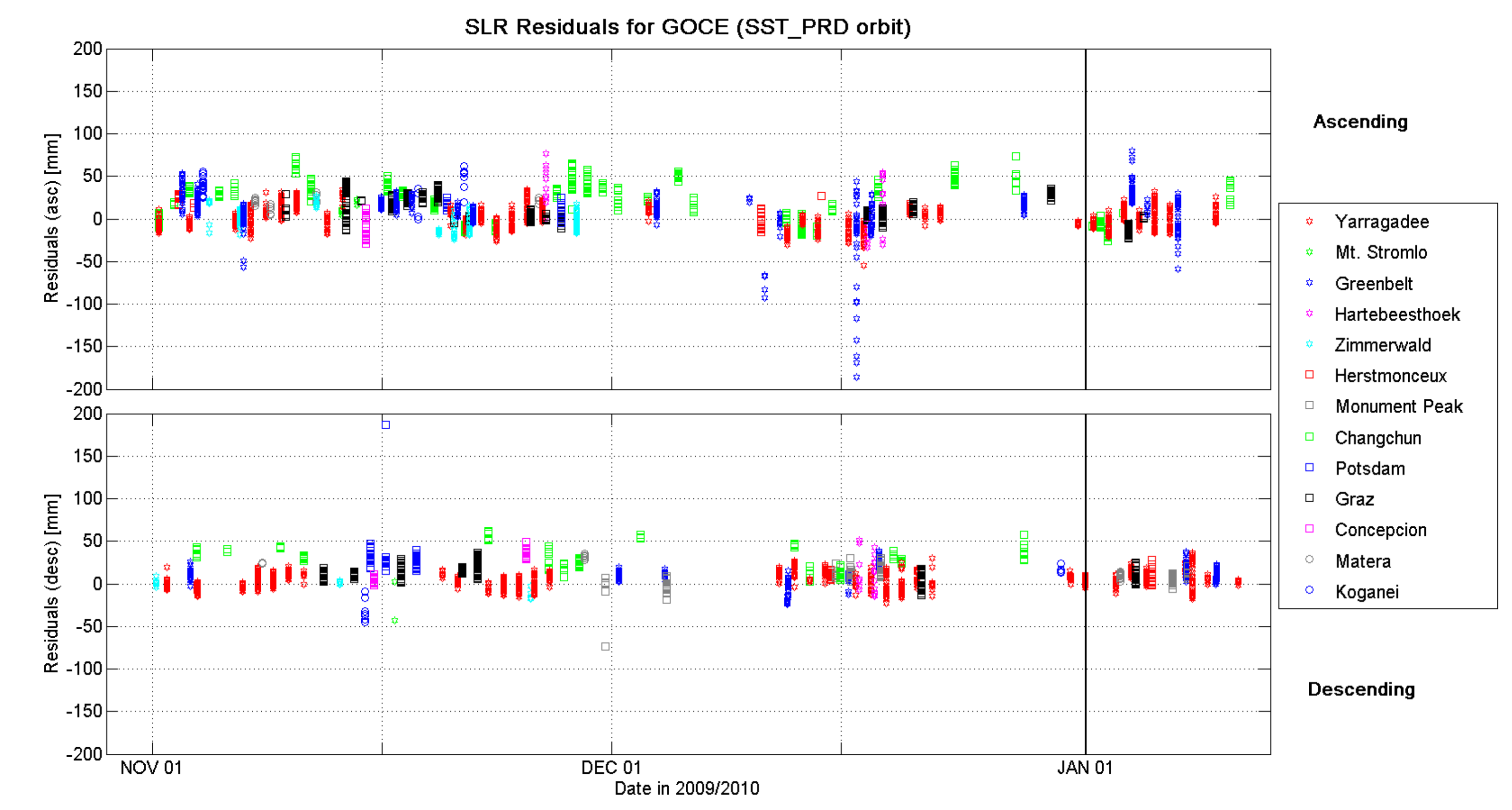
laser
retro-
reflectors

GOCE orbits



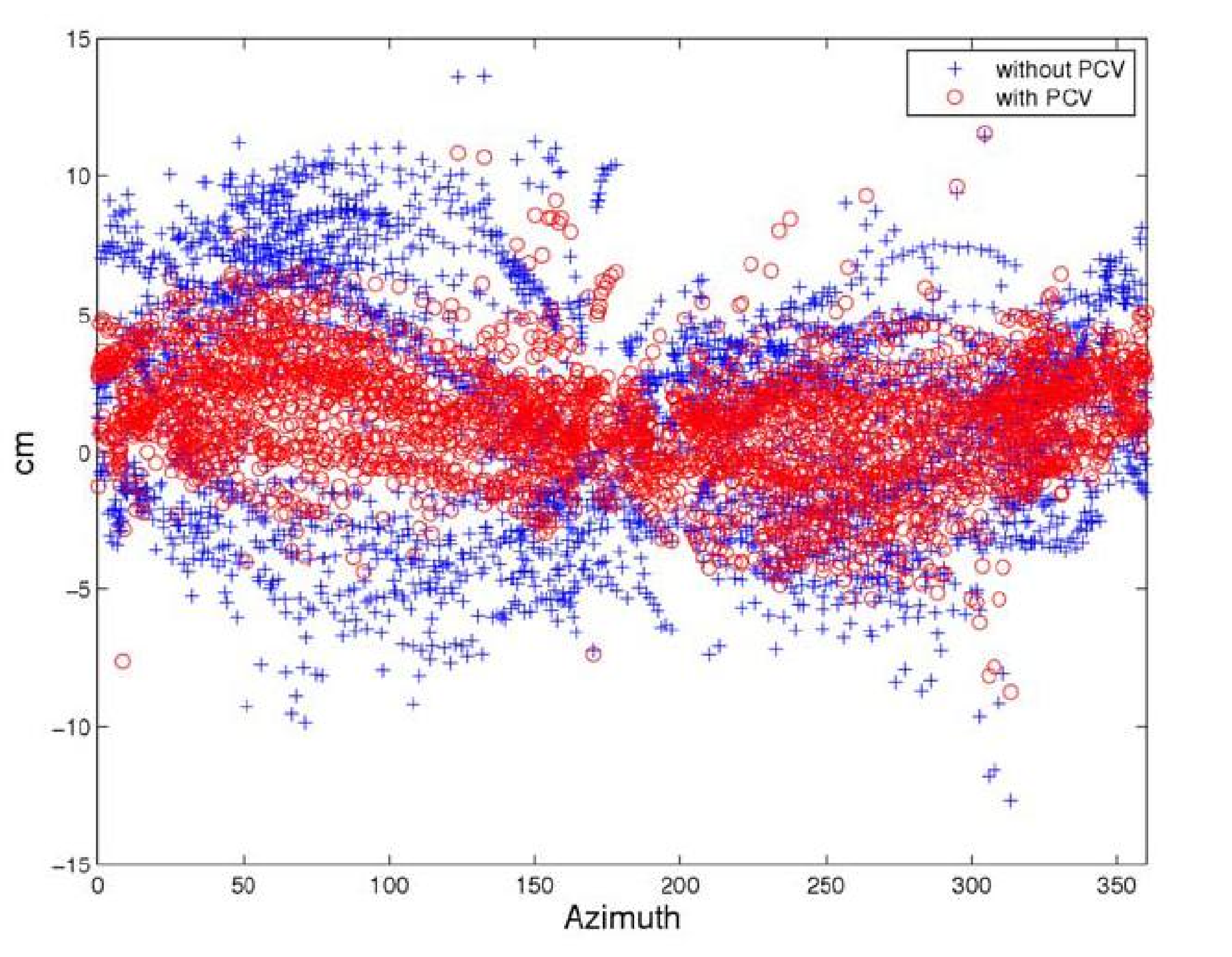
comparison with satellite laser ranging

GOCE orbits



RMS differences 2cm

GOCE orbits

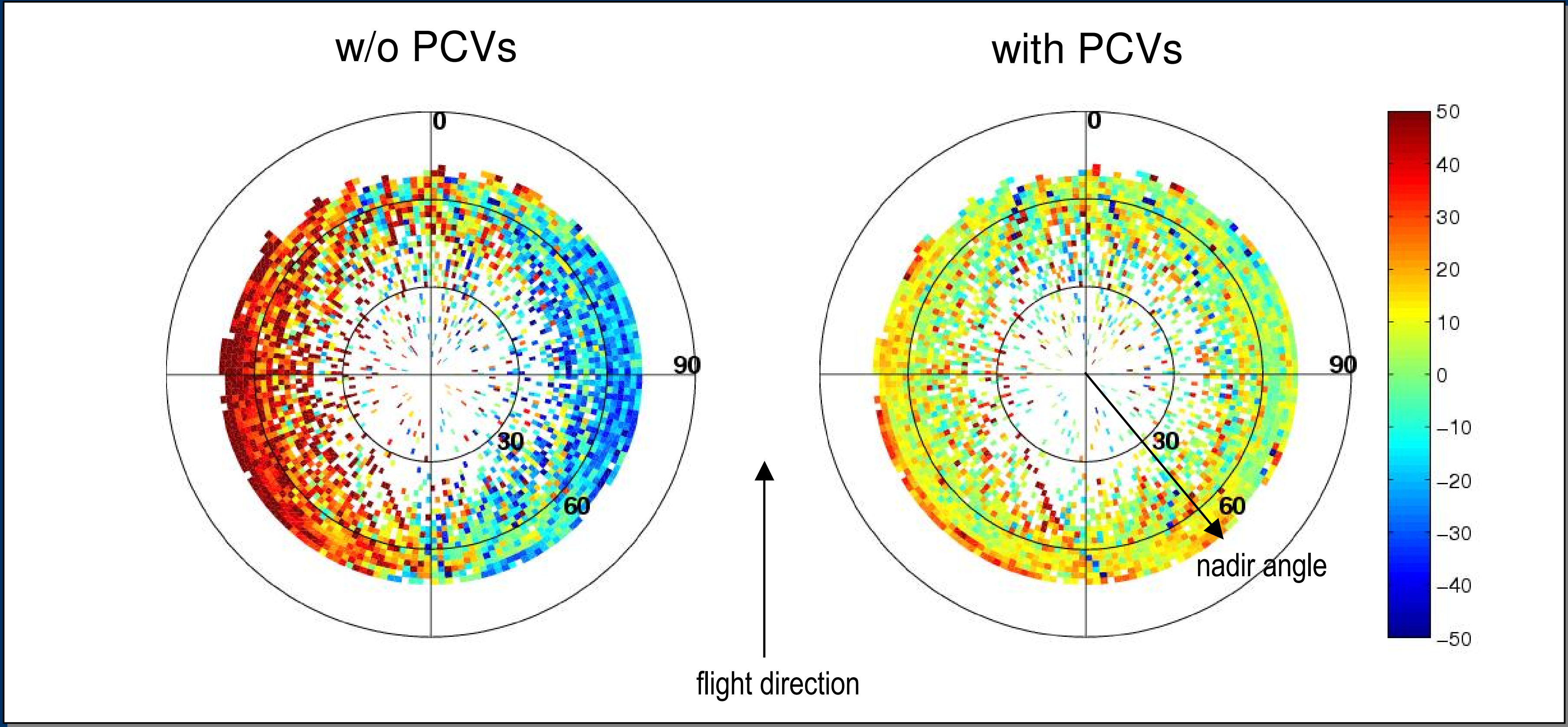


Jäggi et al., 2010

orbit validation with SLR

PSO: validation with SLR

SLR residuals, as derived from GOCE tracking



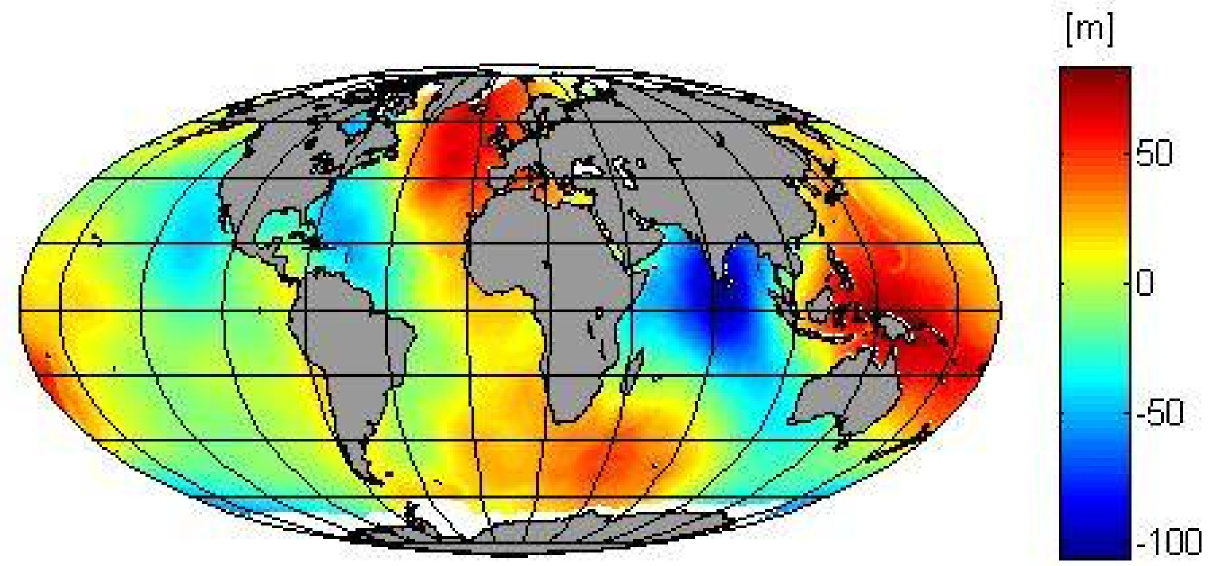
Jäggi et al., 2010

systematic cross-track orbit errors are directly observed by SLR

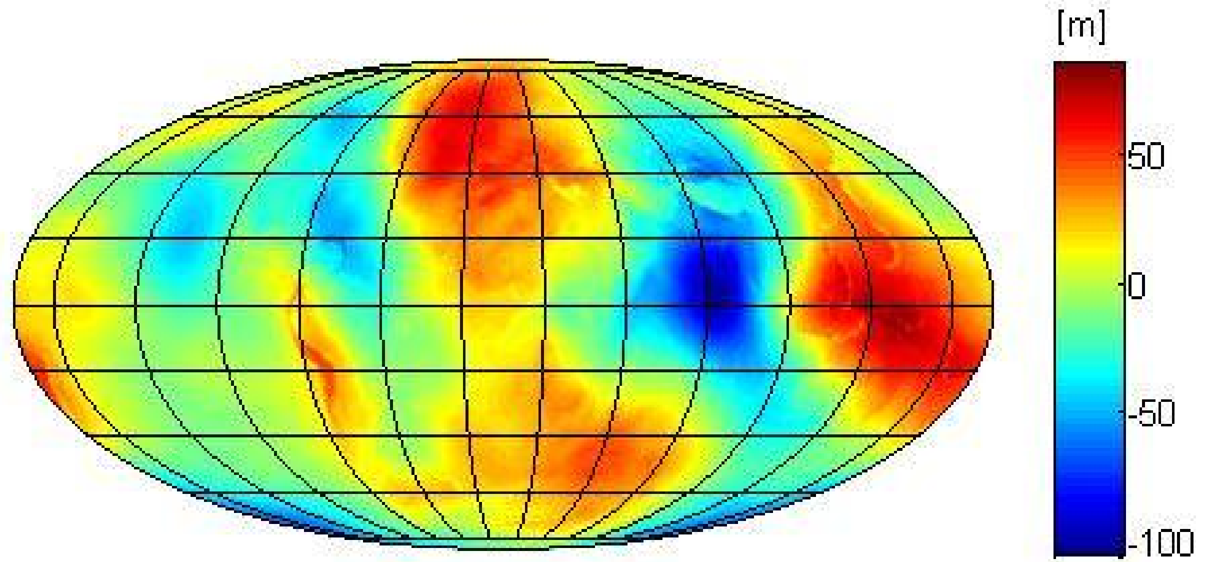
a novelty

GOCE and oceanography

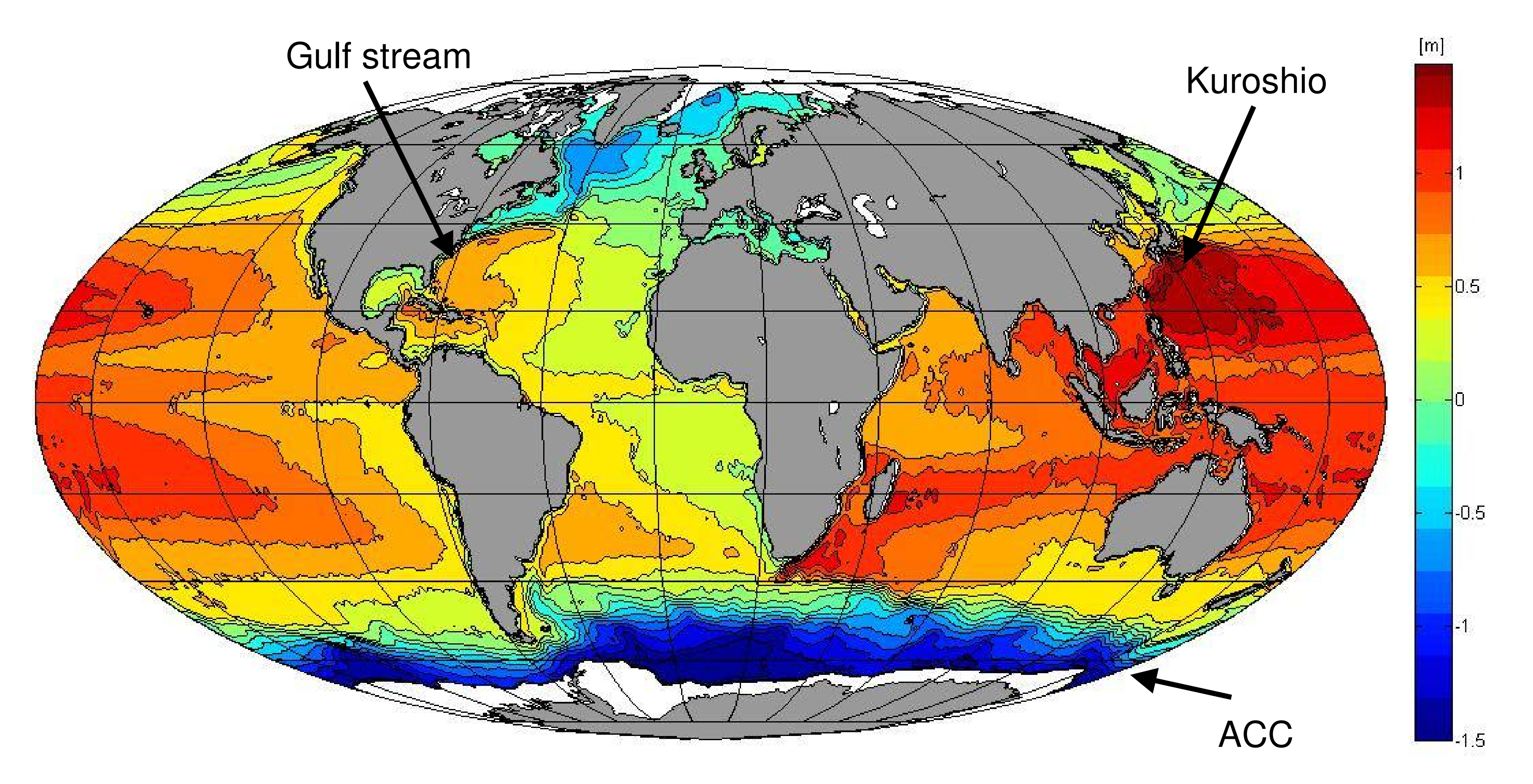
mean sea surface
1992- 2010
from multi mission
radar altimetry



geoid
from six months
GOCE data

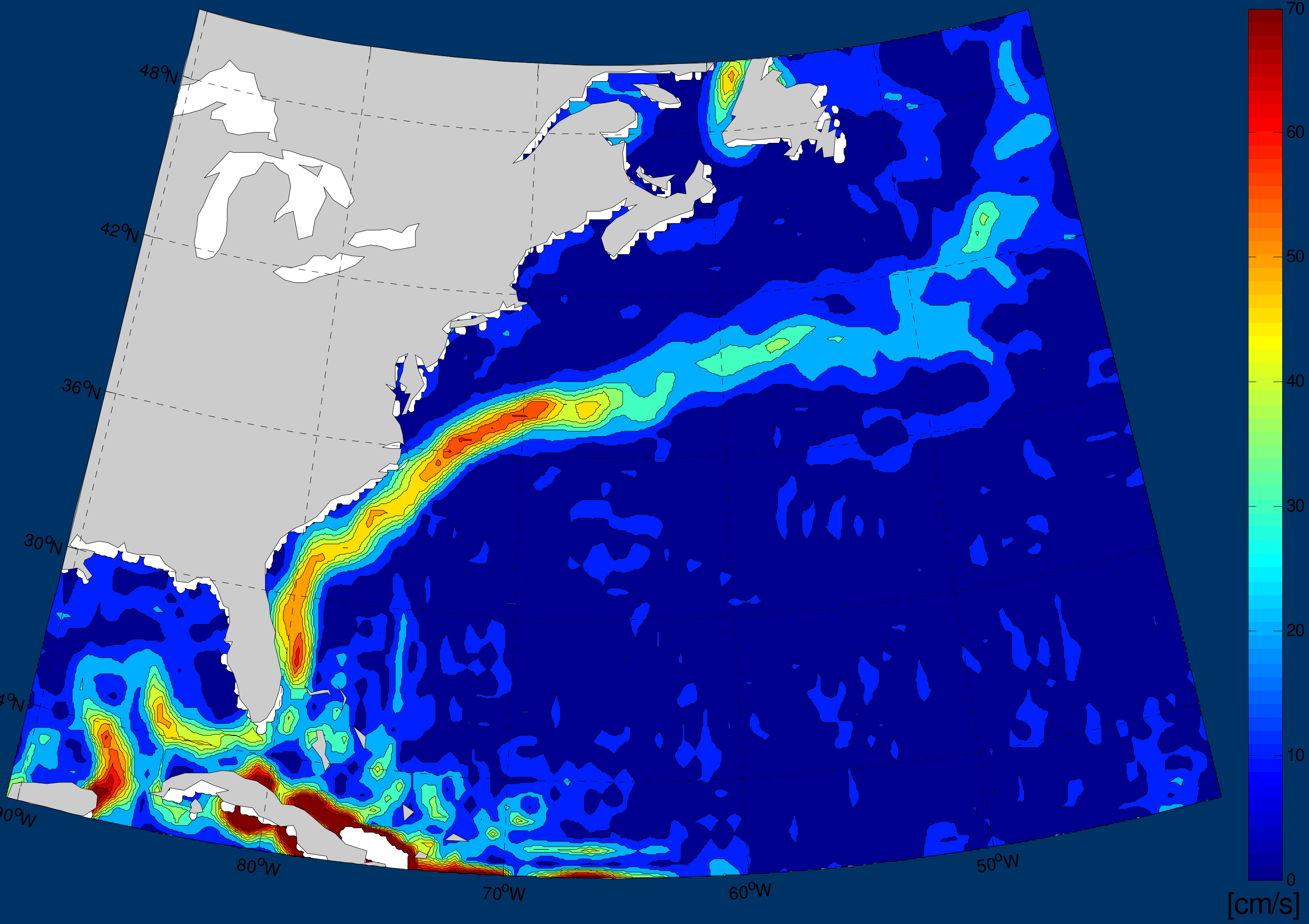


GOCE and oceanography



mean ocean topography (in m)

GOCE and oceanography

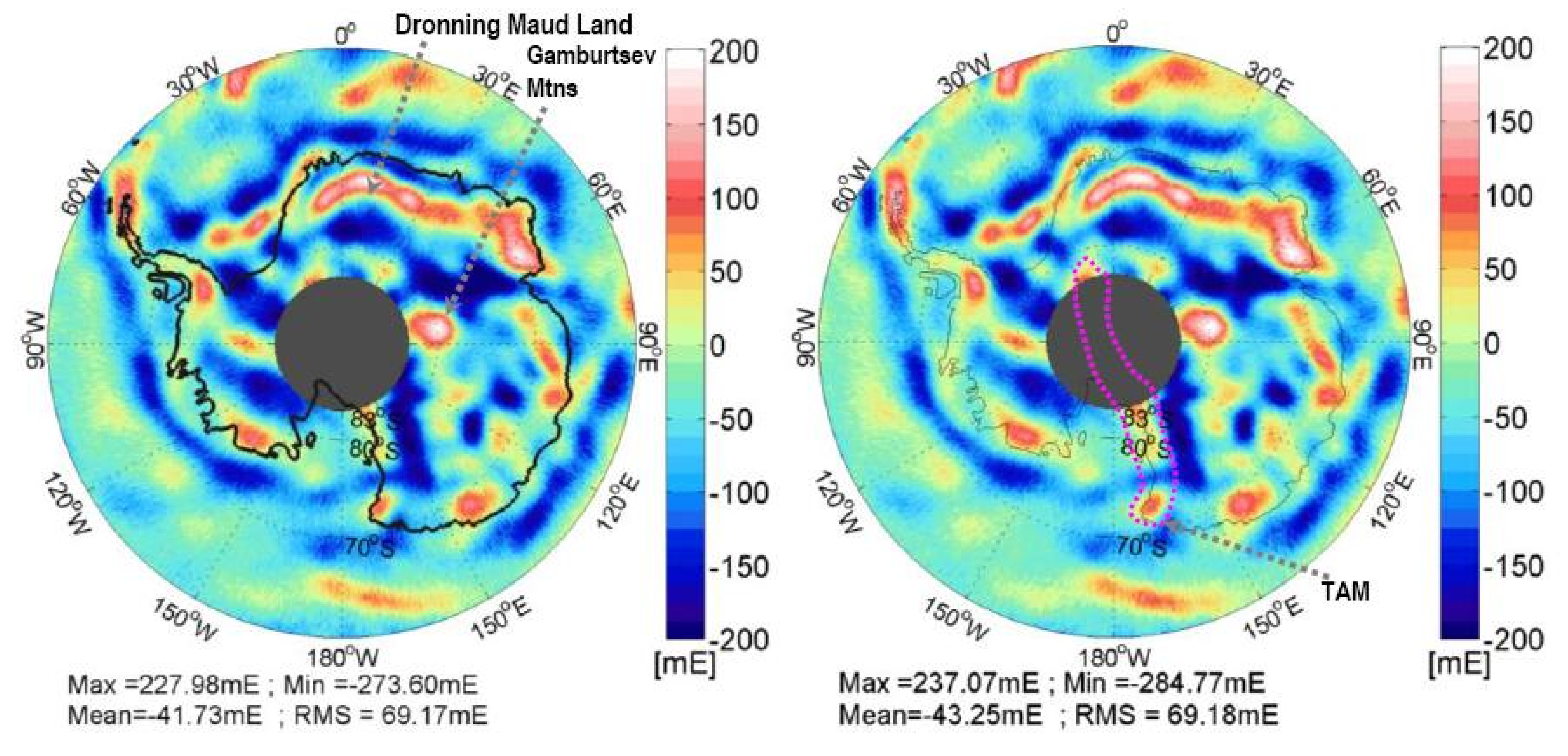


geostrophic velocities North Atlantic

from GOCE and satellite altimetry

IAPG/ TUM

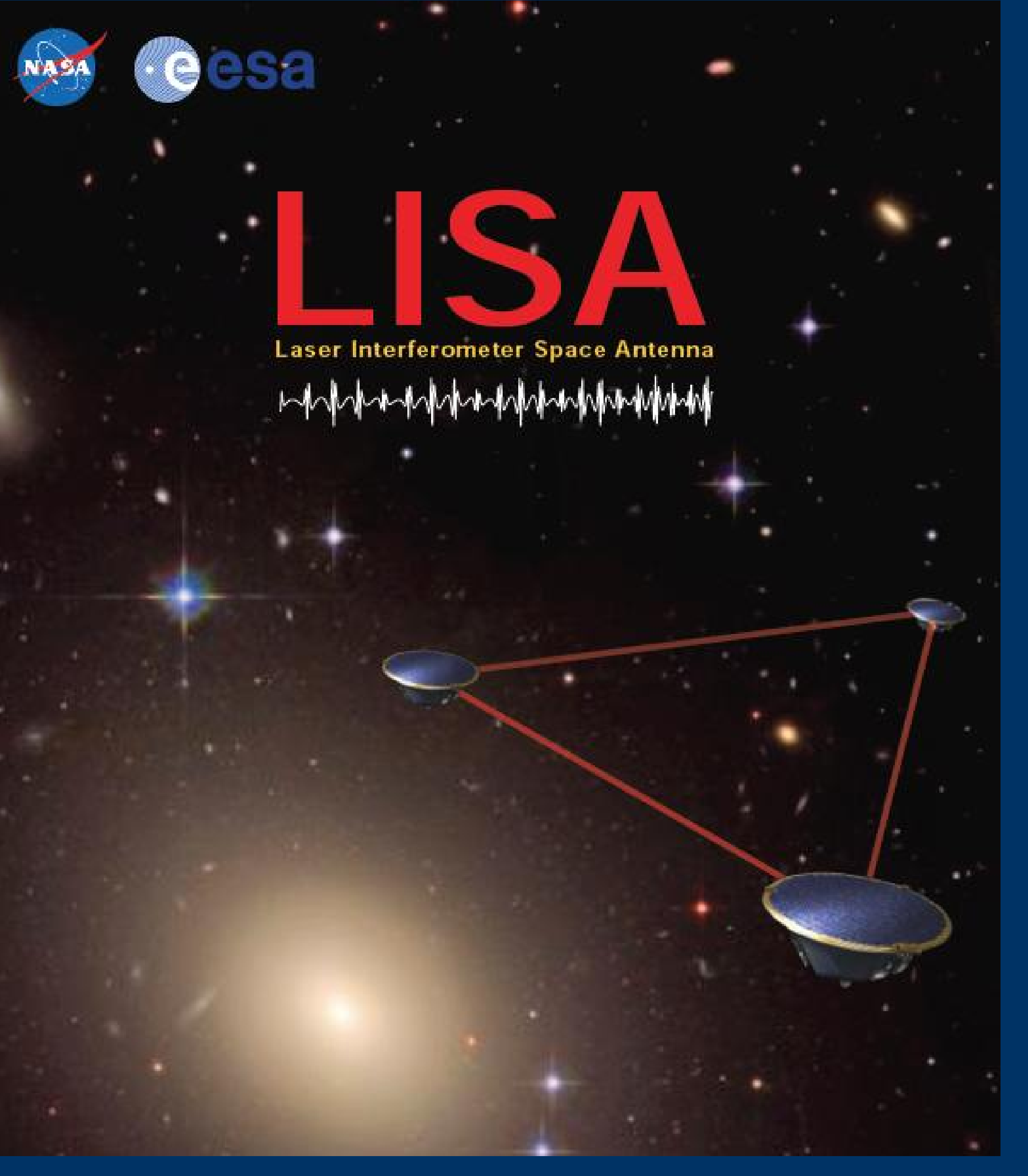
GOCE and geophysics



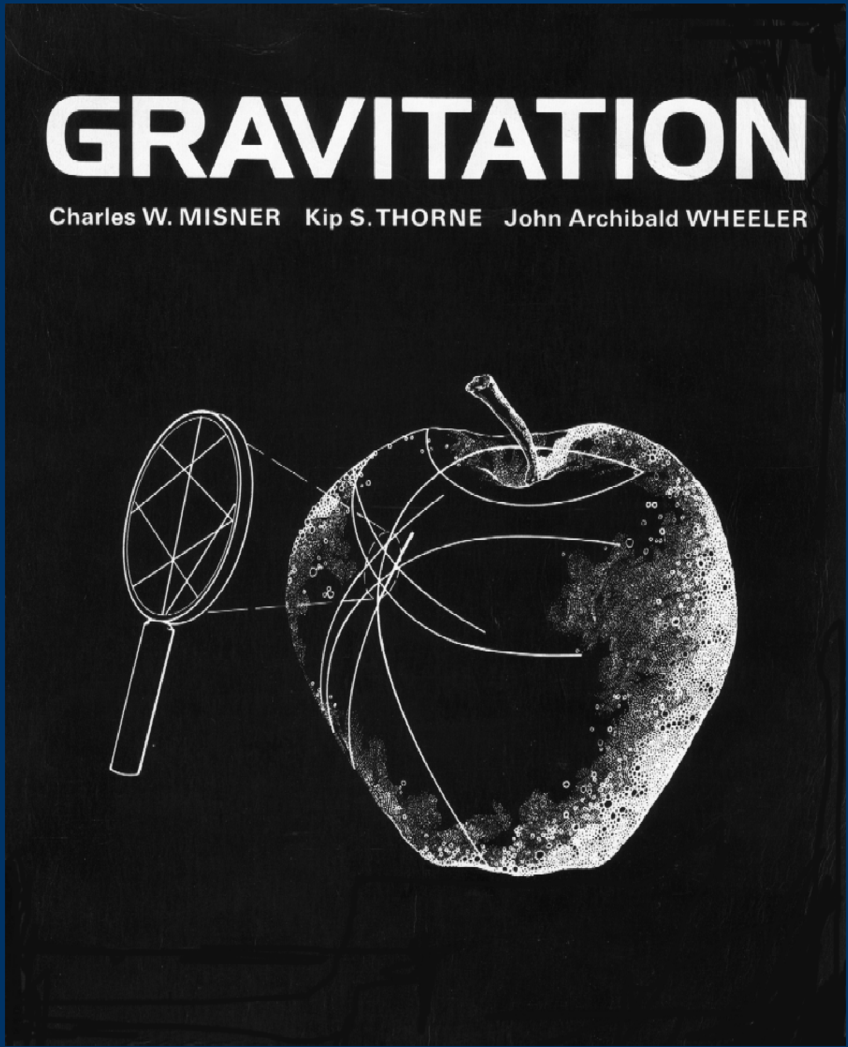
V_{zz}-component from two months GOCE

the future

The alliance with
fundamental physics:
LISA pathfinder
LISA
STEP
Microscope,
Beppi Colombo…



the future



[Misner, Thorne & Wheeler, 1973]

Geodesic

The story of two ants walking on an apple:
“They walk from two adjacent points A und B,
each taking the shortest distance, to two adjacent points A’ und B’.
We measure the distance between them, while they are walking.
From the measured distances we derive the local curvature of the apple”

gravity is geometry

concluding remarks

- SLR ties (geometric) co-ordinate system to spherical harmonic expansion of the gravitational field
- growing importance of consistency between geometry and gravity (think of studies of sea level rise, continental hydrology, ice mass balance, dynamic ocean topography,…)
- SLR as validation tool
- strengthen alliance with fundamental physics
- LAGEOS-3 counter orbiting: should one study it?
- laser gradiometry (Bender et al.)
- laser link between free falling proof masses

Level 2 processing: High Level Processing Facility (HPF)

GOCE End-to-End Simulation Scheme