Earth Science and future Satellite Gravity Missions

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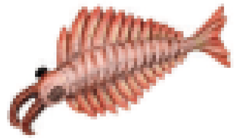
Towards a Roadmap for Future Satellite Gravity Missions

Graz, 30.9. to 2.10.2009



CAMBRIAN HUNTER DEFANGED
Anomalocaris didn't have the chops to chew up trilobites.
www.nature.com/news

Satellite data show Indian water stocks shrinking

Unsustainable water use in India is threatening agricultural production and raising the spectre of a major water crisis.

Matthew Rodell of NASA's Goddard Space Flight Center in Greenbelt, Maryland, and colleagues used data from the Gravity Recovery and Climate Experiment (GRACE) satellites — operated by NASA and the German Aerospace Center (DLR) — to determine how groundwater levels are changing in the Indian states of Rajasthan, Punjab and Haryana, which includes the national capital of New Delhi.

Their research, published online in *Nature* this week (M. Rodell *et al. Nature* doi:10.1038/nature08238; 2009), found gravity anomalies suggesting a net loss of 109 cubic kilometres of water — equivalent to a mass of 109 billion tonnes — from August 2002 to October 2008. The amount lost is double the capacity of India's largest surface-water reservoir, the Upper Wainganga, and almost three times the capacity of Lake Mead in Nevada, the largest reservoir in the United States.

> "If farmers could shift away from water-intensive crops and implement more efficient irrigation methods, that would help."

A second study using GRACE data, by scientists at the University of Colorado and the National Center for Atmospheric Research in Boulder, has found that the most intensively irrigated areas in northern India, eastern Pakistan and parts of Bangladesh are losing groundwater at an overall rate of 54 cubic kilometres per year, consistent with Rodell's results (V. M. Tiwari *et al. Geophys. Res. Lett.* doi:10.1029/2009GL039401; in the press).

Groundwater depletion in northwest India is a known problem, but Rodell's data suggest that the loss rate is around 20% higher than the Indian authorities have previously estimated.

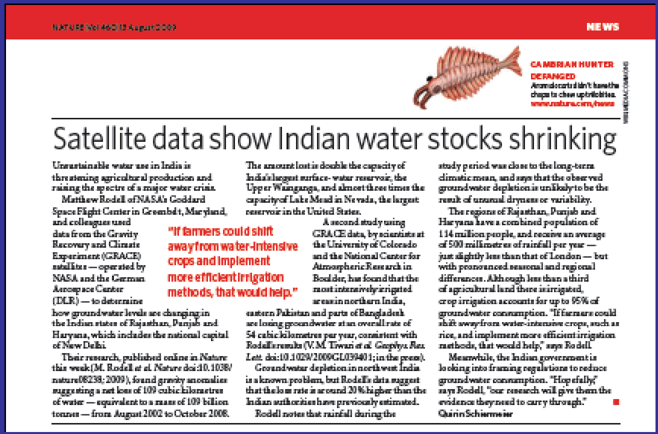
Rodell notes that rainfall during the study period was close to the long-term climatic mean, and says that the observed groundwater depletion is unlikely to be the result of unusual dryness or variability.

The regions of Rajasthan, Punjab and Haryana have a combined population of 114 million people, and receive an average of 500 millimetres of rainfall per year — just slightly less than that of London — but with pronounced seasonal and regional differences. Although less than a third of agricultural land there is irrigated, crop irrigation accounts for up to 95% of groundwater consumption. "If farmers could shift away from water-intensive crops, such as rice, and implement more efficient irrigation methods, that would help," says Rodell.

Meanwhile, the Indian government is looking into framing regulations to reduce groundwater consumption. "Hopefully," says Rodell, "our research will give them the evidence they need to carry through."

Quirin Schiermeier

nature, 460, 2009



NATURE|Vol 460|13 August 2009

NEWS

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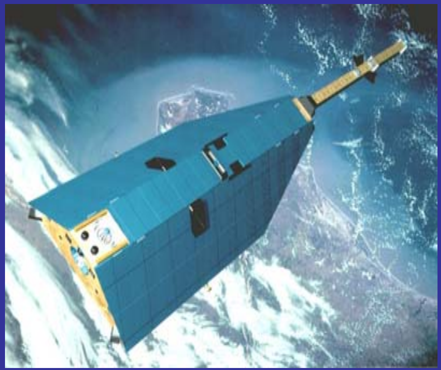
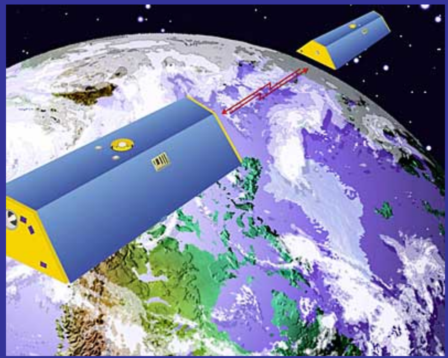
What does it tell us?

- scientific importance of (Rodell, Velicogna & Famiglietti, 2009) and others for climate change studies
- high societal relevance
- enormous value of GRACE time series
- necessity of continuity
- great responsibility

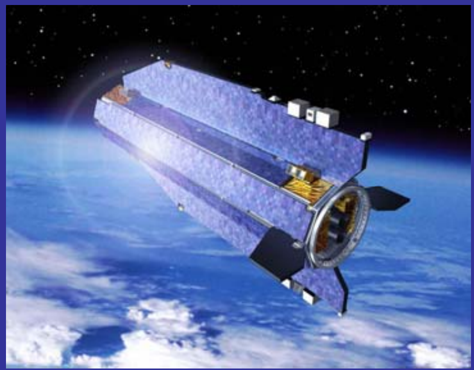
Satellite Gravimetry: a new element of Earth studies



CHAMP (2000)



GRACE (2002)



GOCE (2009)

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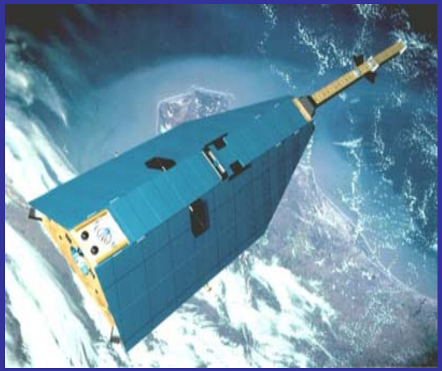
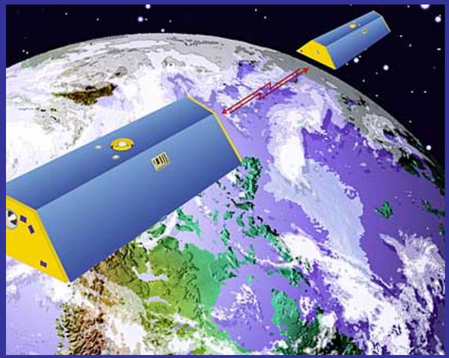
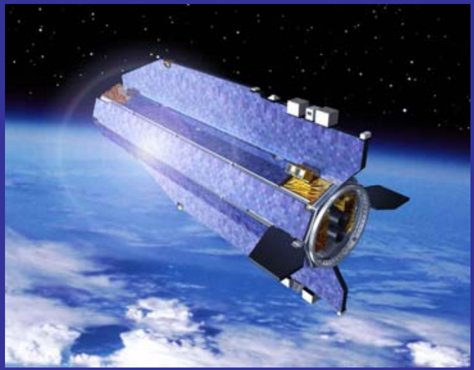






Three areas of application:

- mass distribution of solid Earth (geophysics)
- global height reference (ocean circulation, engineering)
- temporal mass redistribution (climate change)

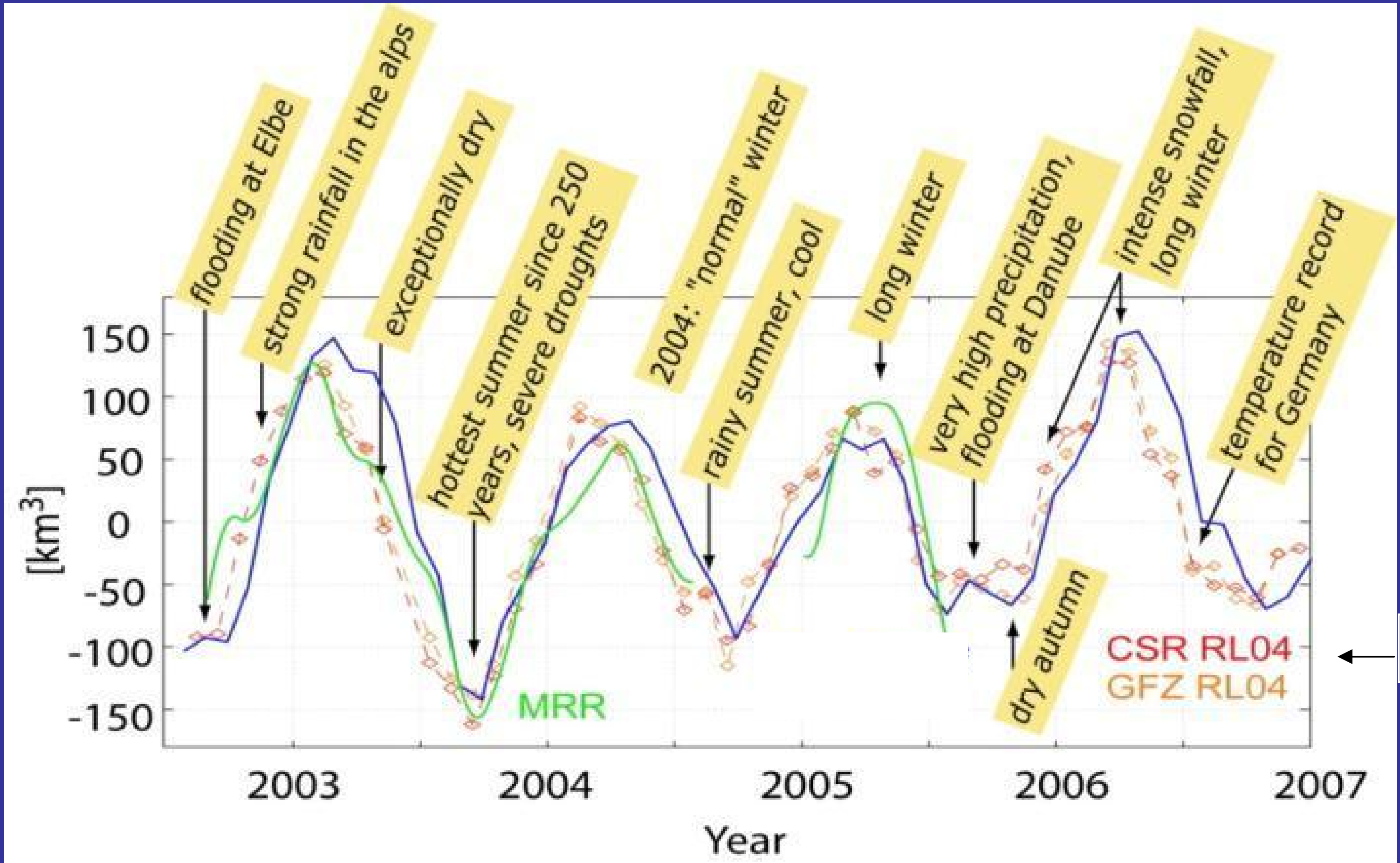
„puts masses on a scale“

temporal mass redistribution:

- continental water cycle
- ice mass balance
- sea level: steric versus mass gain/ loss
- glacial isostatic adjustment

GRACE and continental water cycle

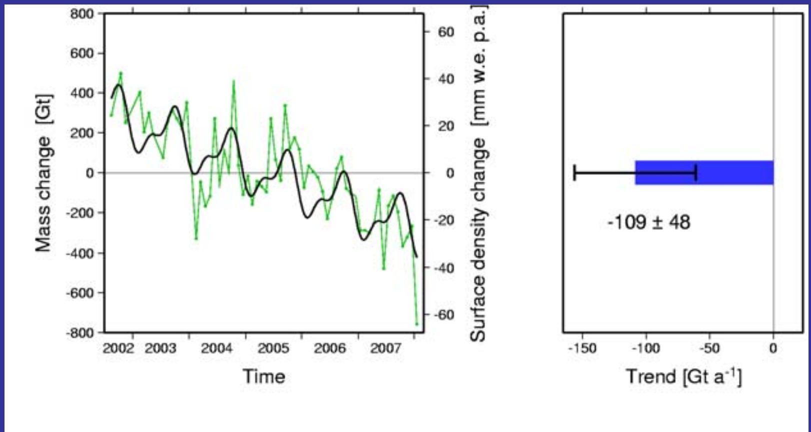
(Sub-)saisonal variability in Central Europe

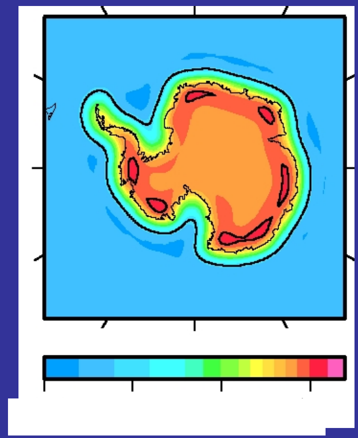


ΔS (GRACE)

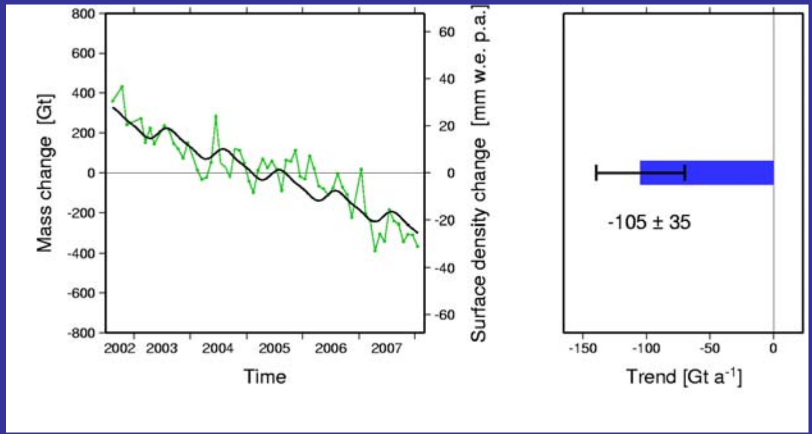
Seitz et al., EPSL, 2008

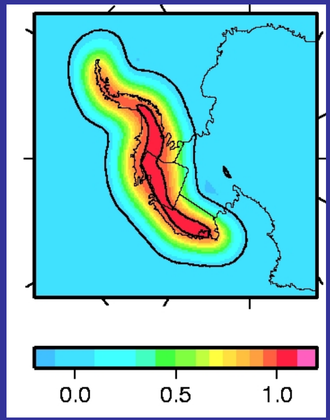
GRACE and ice mass balance





weight function

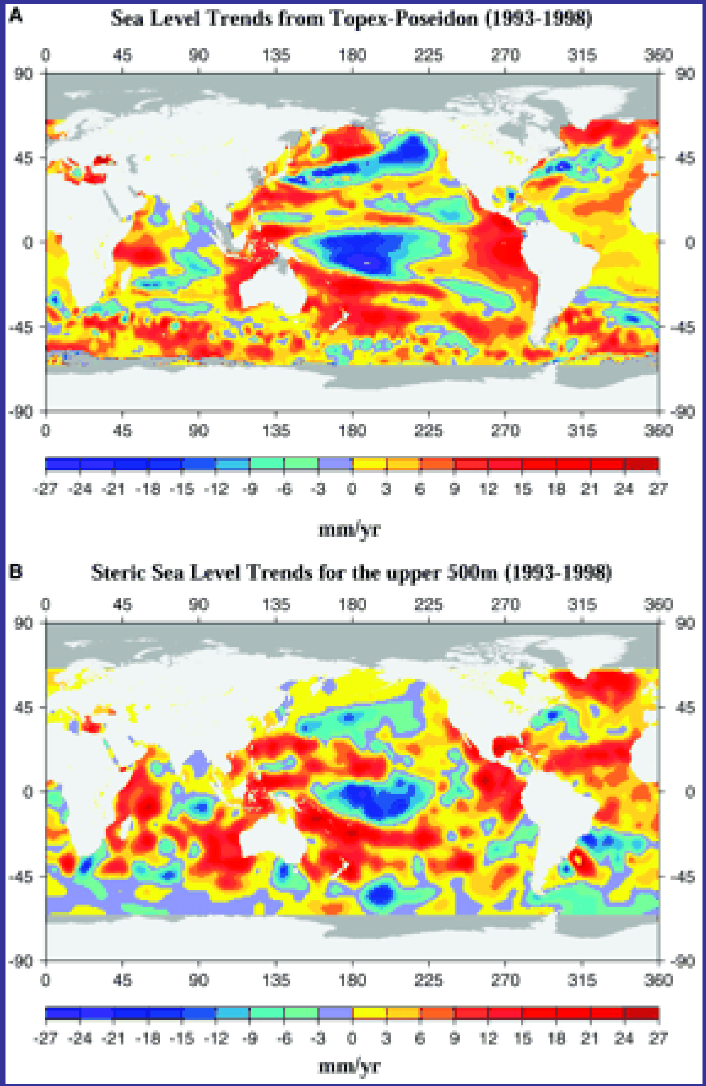




weight function

Horwath and Dietrich (2009) Geophys. J. Int.

GRACE and mass component of sea level change



sea level change
from satellite altimetry
(T/P altimetry, 1993-1998)

steric sea level change
thermal expansion
(temperature, 500m, 1993-1998)

Cabanes, Cazenave & LeProvost, 2001

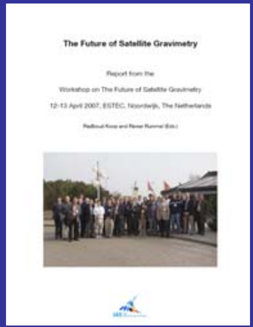
The Future of Satellite Gravimetry

Report from the

Workshop on The Future of Satellite Gravimetry

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

Radboud Koop and Reiner Rummel (Eds.)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Resolutions:

…

3a In view of science achievements and the current performance of GRACE the participants of the workshop strongly support the idea of a GRACE follow-on mission based on the present configuration, with emphasis on the uninterrupted continuation of time series of global gravity changes. This should be short-term (Launch ~2011 TBD) priority one.

3b In parallel, investigations into the reduction of the aliasing problem offers even greater science benefits by increased spatial resolution and accuracy and should therefore have high priority.

…

GRACE limitations:

- aliasing (e.g. ocean tide models)
- systematic distortions

  striations → Gauss type filters

  leakage → affects mass estimates
- separation of effects

  (quality of background models)

strategic elements before the background of GGOS

A) Work towards Thematic (Geodetic) Observing Systems (and models)

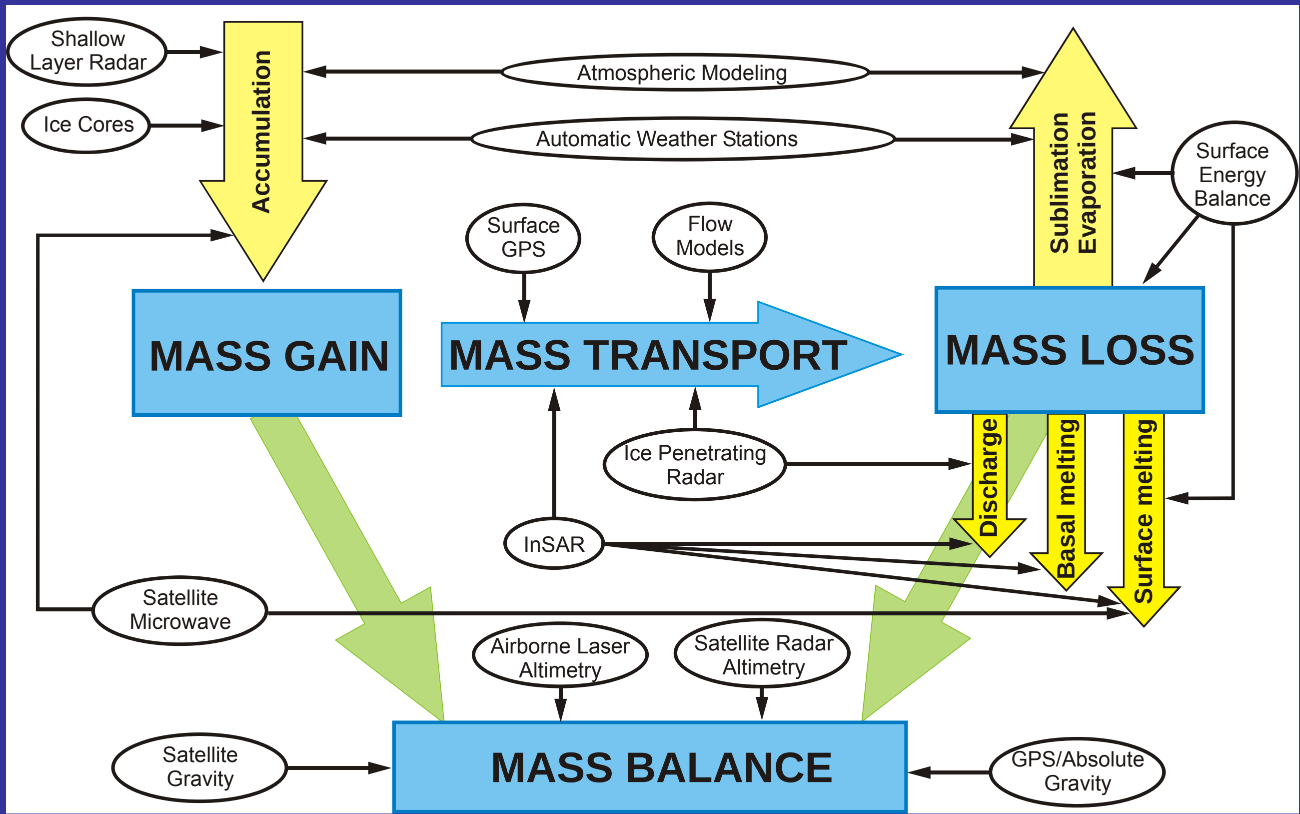
in order to be able

- to cope with the complexity of the Earth processes
- to get an independent control
- to become able to bridge a mission gap

strategic elements before the background of GGOS

Thematic (Geodetic) Observing System:

ice mass balance



Thomas, 2001, EOS

strategic elements before the background of GGOS

Thematic (Geodetic) Observing System:

continental water balance

NASA, GSFC

GRACE and GRACE-FO
terrestrial gravimetry
GNSS
persistent scatterers (SAR)
soil moisture (SMOS, …)
snow cover
groundwater monitoring
run off
precipitation
…

strategic elements before the background of GGOS

Thematic (Geodetic) Observing System:

Sea level change (also GLOSS, TIGO…)

tide gauges

GNSS and geodetic leveling

absolute gravimetry

satellite radar altimetry

GRACE and GRACE-FO

ARGO floats

STD/ CTDs along ship routes

sea surface temperature (from satellites)

…

strategic elements before the background of GGOS

B) Connect thematic geodetic observing systems
to global observing system

- for earth rotation studies on global mass balance (mass and motion)
- as patial systems of global Earth system studies

strategic elements before the background of GGOS

C) GRACE-FOs must become operational/ monitoring missions in the context of Climate Forecast activities

example: JASON-FO altimetry and InSAR are part of the Sentinel series of the European GMES

But how to get there?

International and Intergovernmental Programmes

• INSPIRE	Infrastructure for Spatial Information in Europe
• GEOSS	Global Earth Observing System of Systems
• IGOS	Integrated Global Observing Strategy mit GCOS, GOOS, GTOS
• CEOS	Committee on Earth Observing Satellites
• WCRP	World Climate Research Programme
• IPCC	Intergovernmental Panel on Climate Change

Domain	Essential Climate Variables ECV‘s
Atmospheric (over land, sea and ice)	Surface: air temperature, precipitation, air pressure, surface radiation budget, wind speed/ direction, water vapour Upper air: earth radiation budget, upper air temperature, wind speed/ direction, water vapour, cloud properties Composition: CO_2, methane, ozone, other long lived greenhouse gases, aerosol properties
Oceanic	Surface: sea-surface temperature, sea-surface salinity, sea level, sea ice, sea state, currents, ocean colour, CO_2 partial pressure Sub-surface: temperature, salinity, currents, nutrients, carbon, ocean tracers, phytoplankton
Terrestrial	River discharge, water use, ground water, lake levels, snow cover, glaciers and ice caps, permafrost and seasonally frozen ground, albedo, land cover (vegetation type, fraction of photosynthetically active radiation), leaf area index, biomass, fire disturbance

UNFCCC (UN Framework Convention on Climate Change)
und GCOS (Global Climate Observing System)

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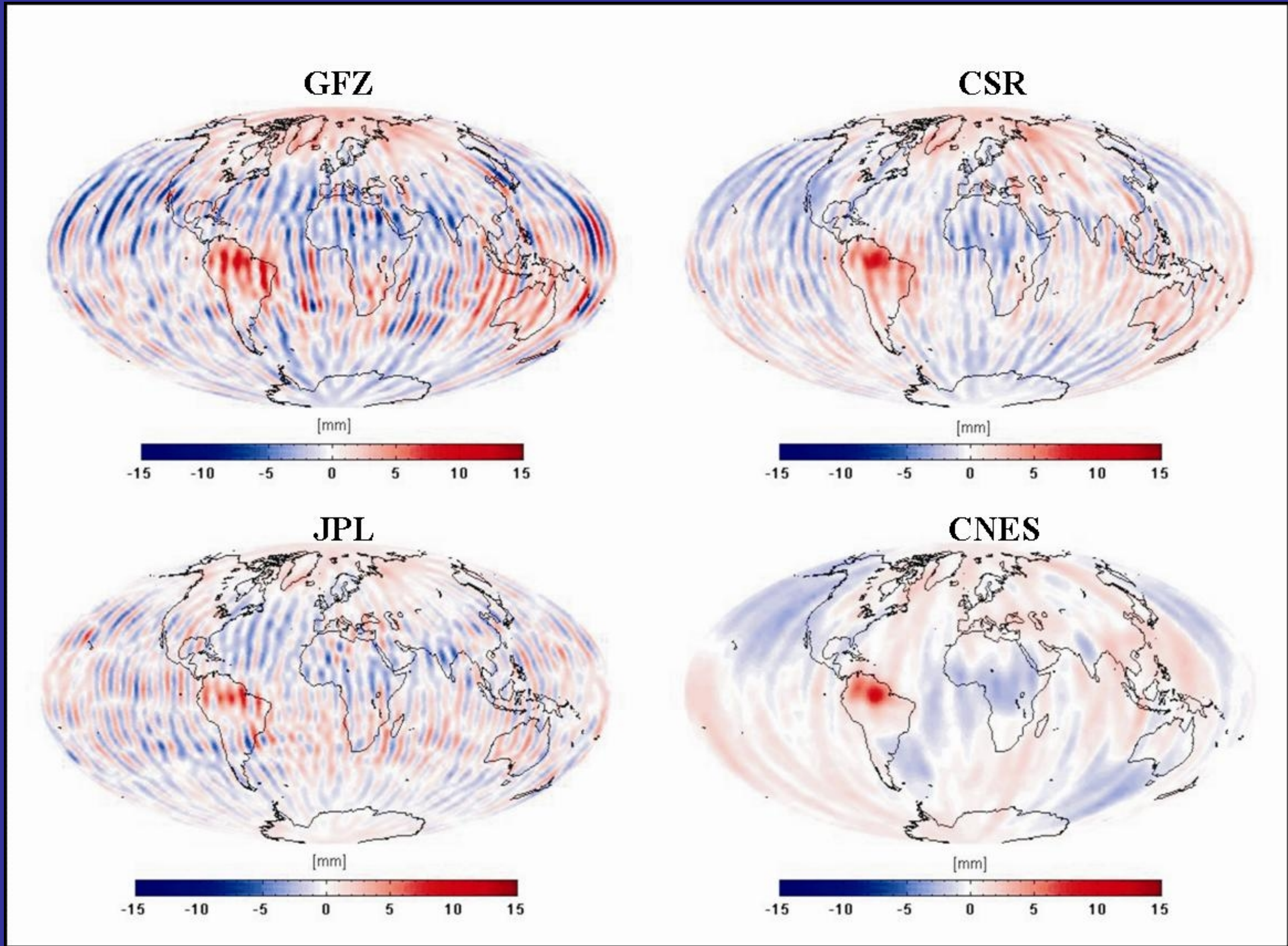
Summary:

- GRACE is highly successful
  (continental water cycle, ice mass balance, sea level, GIA,…)
- GRACE-FO is a necessity (but prepare also for a gap)
- recommendations to GGOS:
  - A) Establish thematic geodetic observing systems
  - B) Integrate them into GGOS (earth rotation and ESS)
  - C) Get GRACE-FO into operational Climate Forecast satellite program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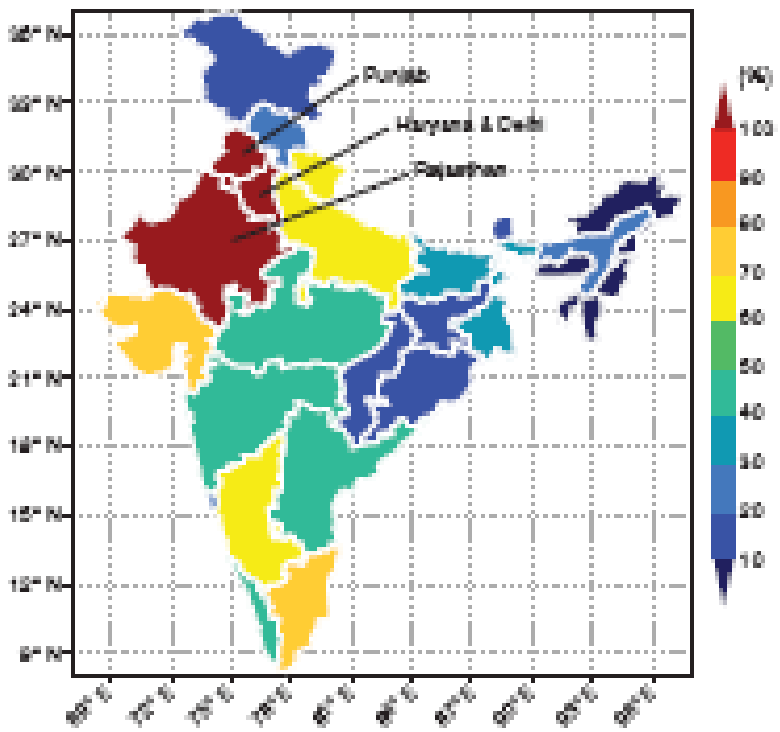

Figure 1 | Groundwater withdrawals as a percentage of recharge. The map is based on state-level estimates of annual withdrawals and recharge reported by the Indian Ministry of Water Resources[4]. The three states studied here are labelled.

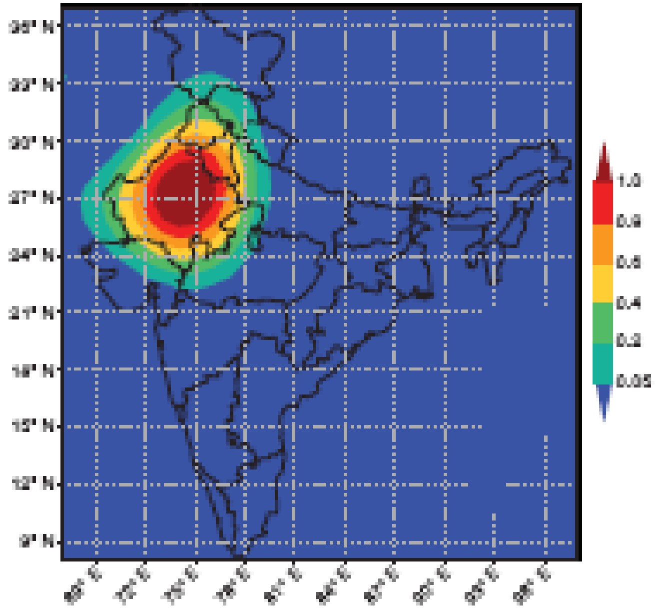

Figure 2 | GRACE averaging function. The unscaled, dimensionless averaging function used to estimate terrestrial water storage changes from GRACE data is mapped.

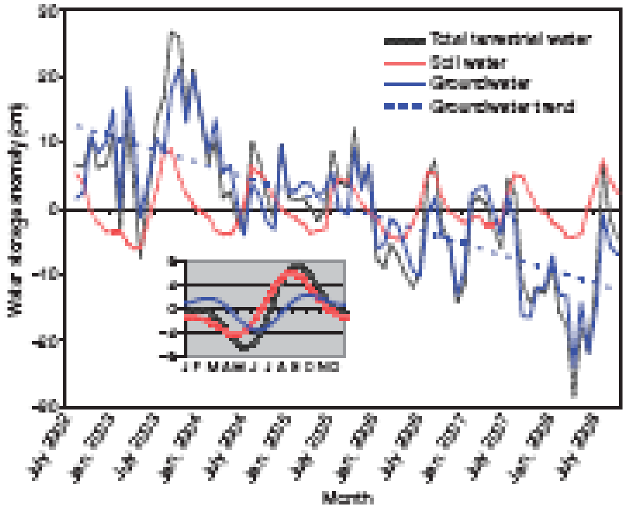

Figure 3 | Monthly time series of water storage anomalies in northwestern India. Monthly time series of anomalies of GRACE-derived total TWS, modelled soil-water storage and estimated groundwater storage, averaged over Rajasthan, Punjab and Haryana, plotted as equivalent heights of water in centimetres. Also shown is the best-fit linear groundwater trend. Inset, mean seasonal cycle of each variable.