Von Wasser, Eis und Satelliten — und was uns die Schwerkraft über Umweltveränderungen verrät

Adrian Jäggi

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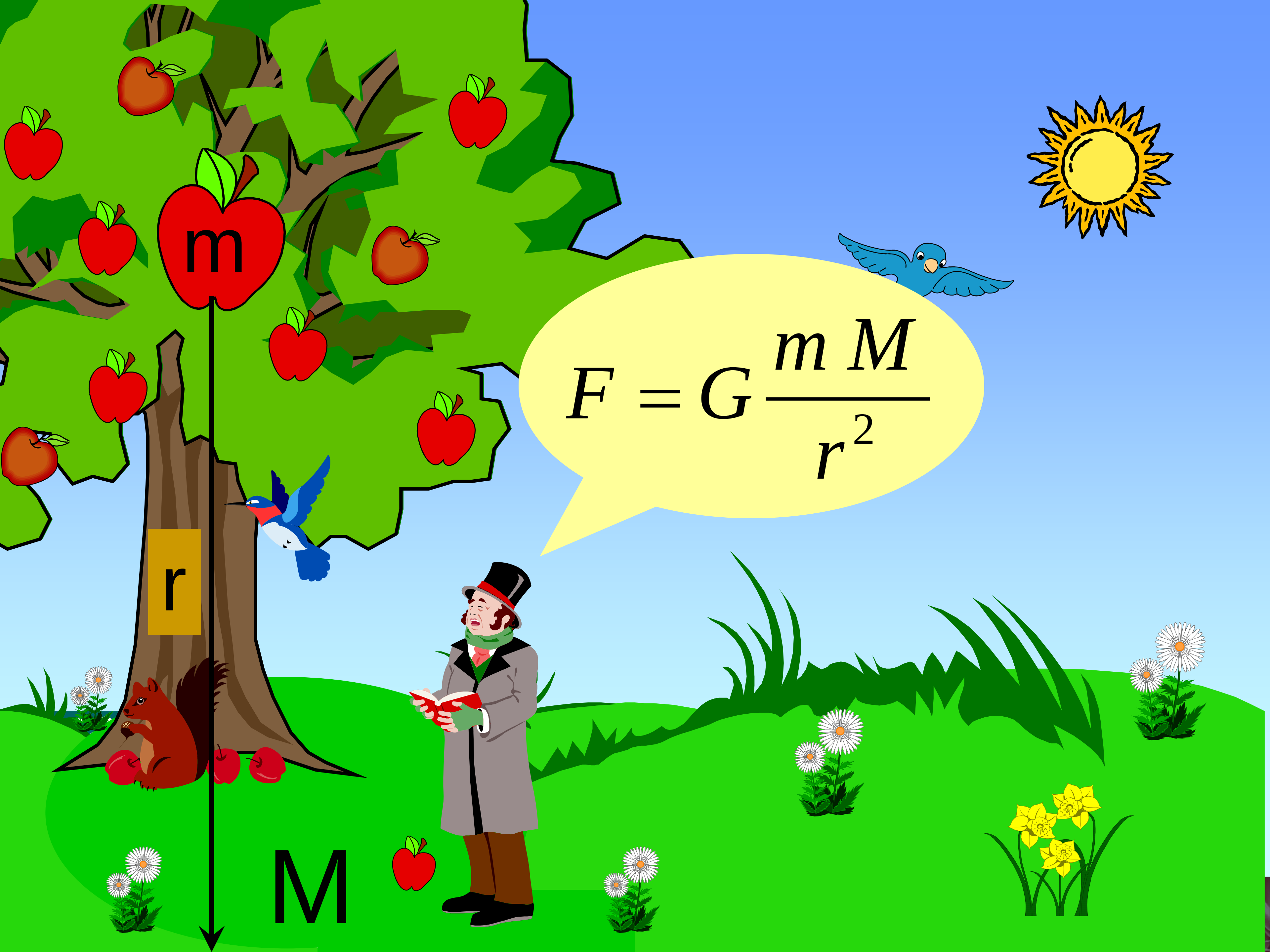
Universität Bern

PHYSIK AM FREITAG

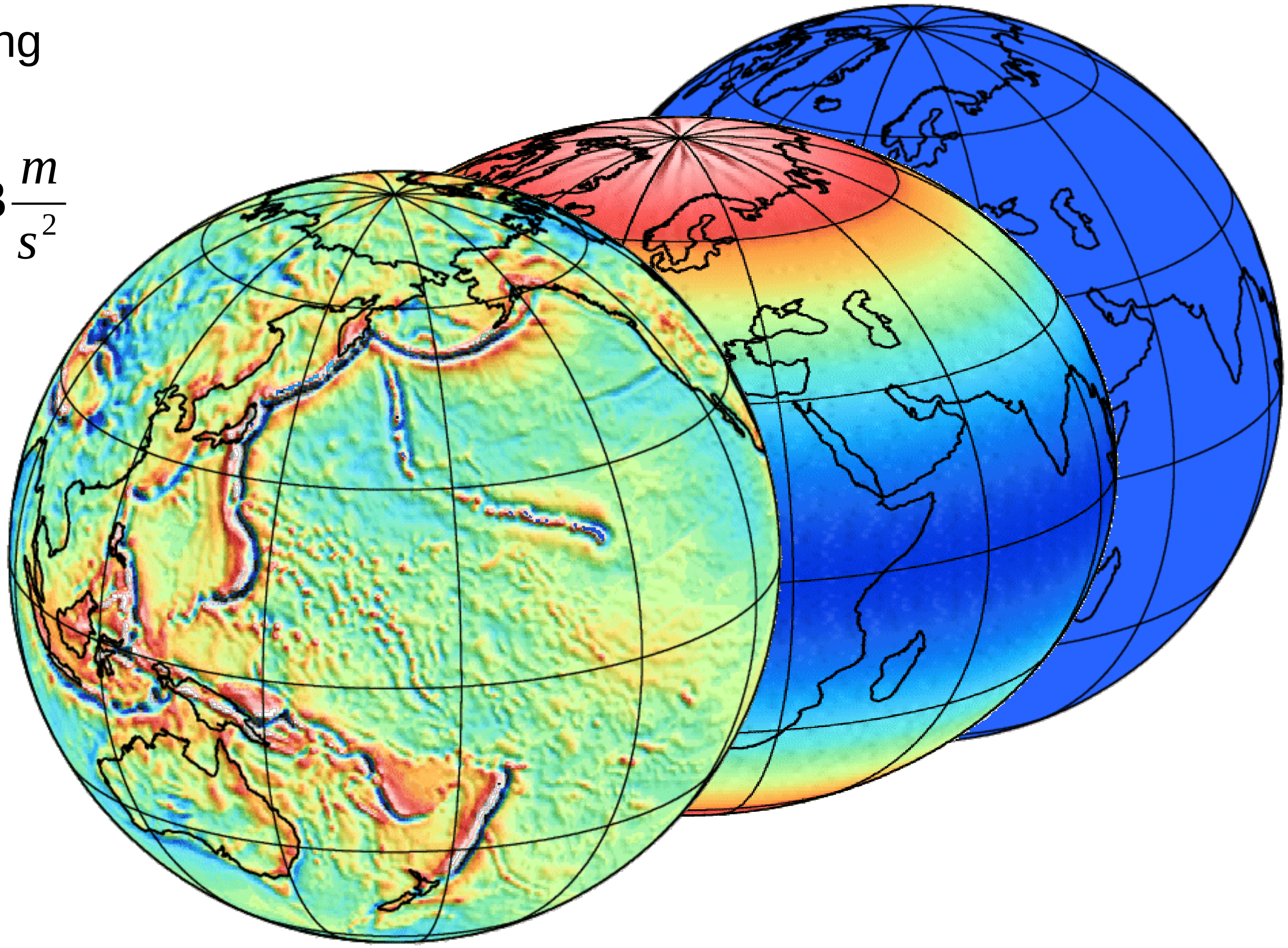

m
r
M
$$F = G\frac{m\,M}{r^2}$$

Schwerkraft

Schwerebeschleunigung
an der Erdoberfläche

$$g = 9{,}78\frac{m}{s^2}\ldots 9{,}83\frac{m}{s^2}$$

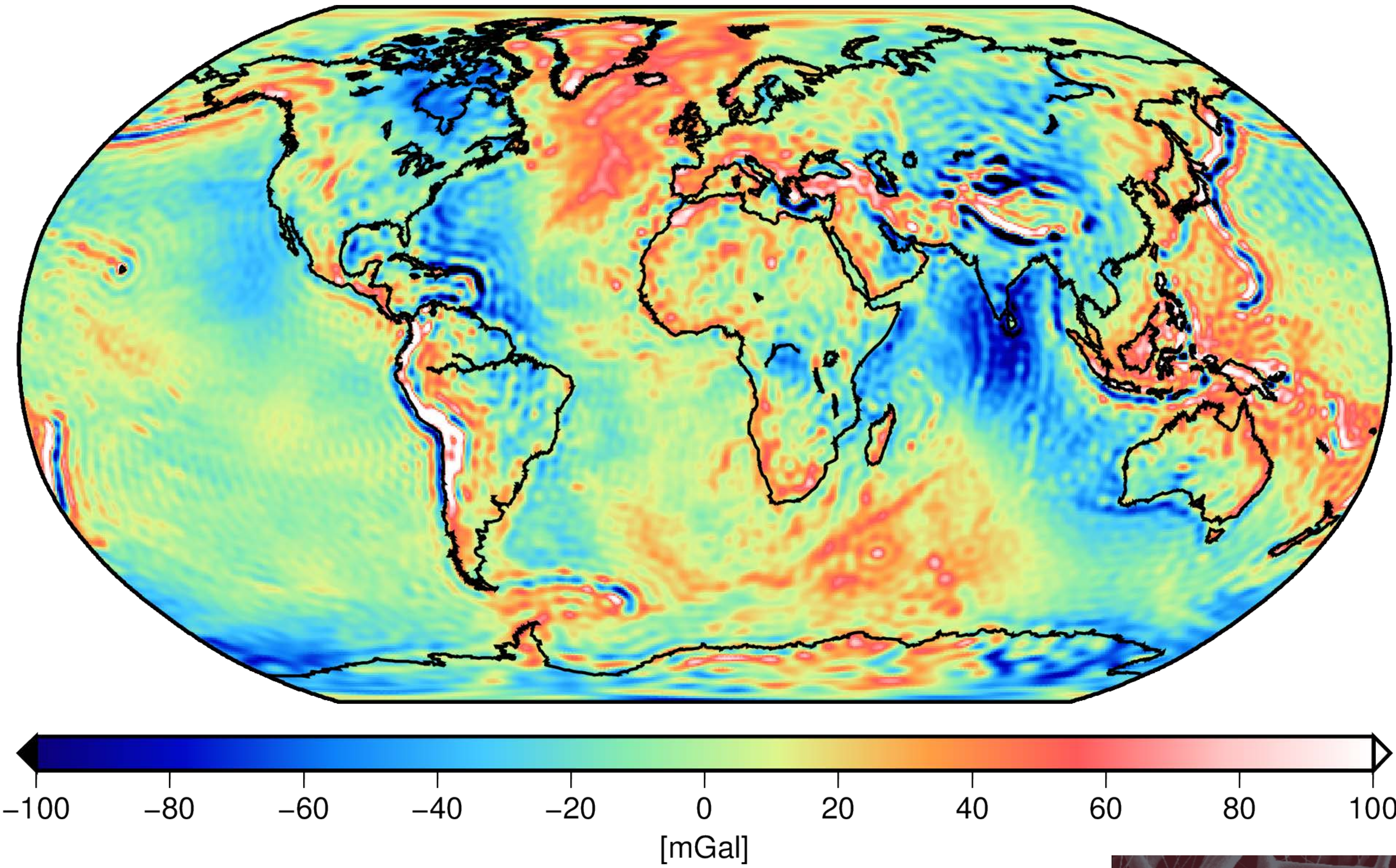
$$\pm 0{,}0004\frac{m}{s^2}$$



$$\left[1\,\mathrm{mGal} = 0{,}00001\frac{m}{s^2}\right]$$

1 Millionstel der
Schwerebeschleunigung

Schwerefeld März 2008



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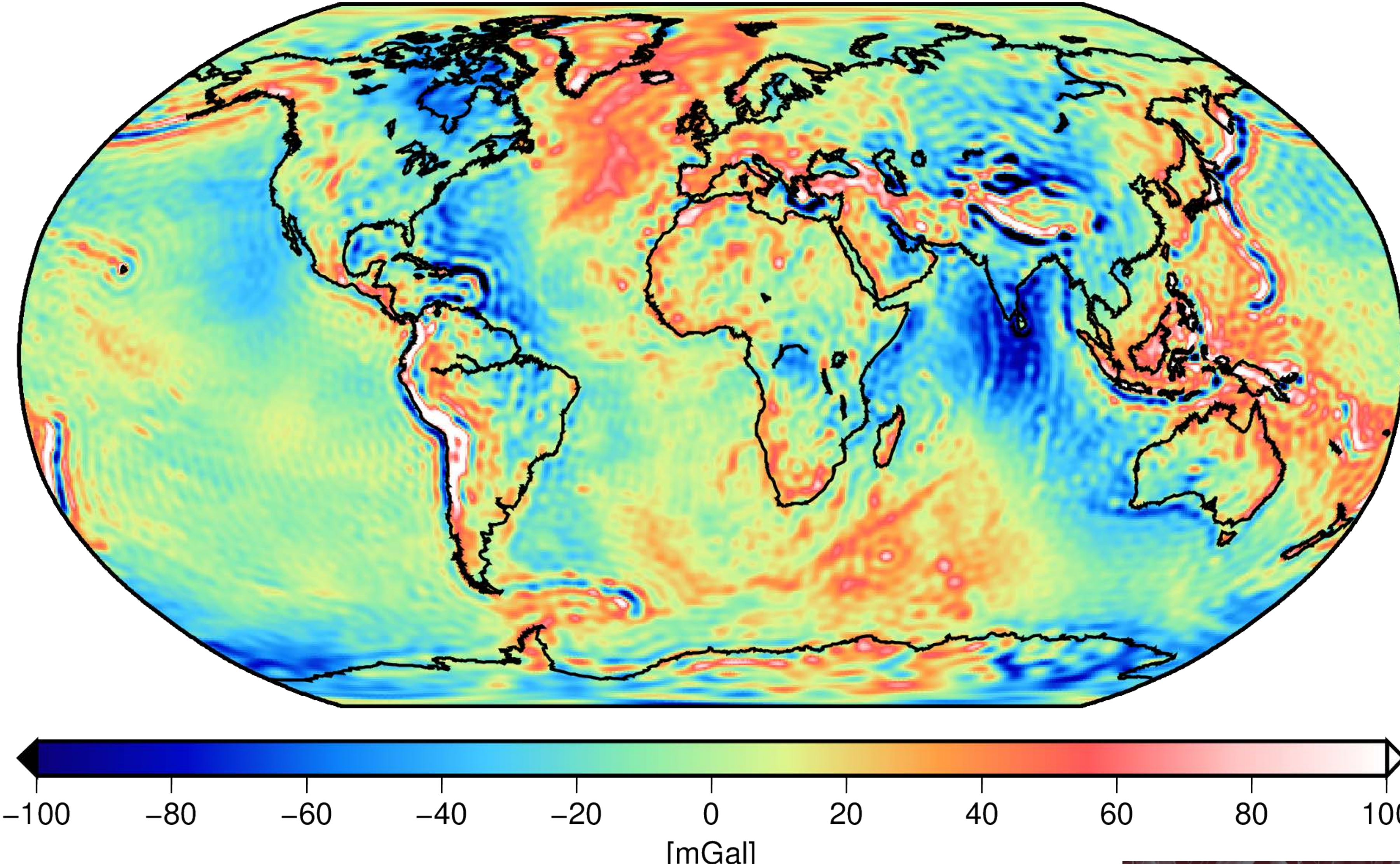
Schwerefeld September 2008



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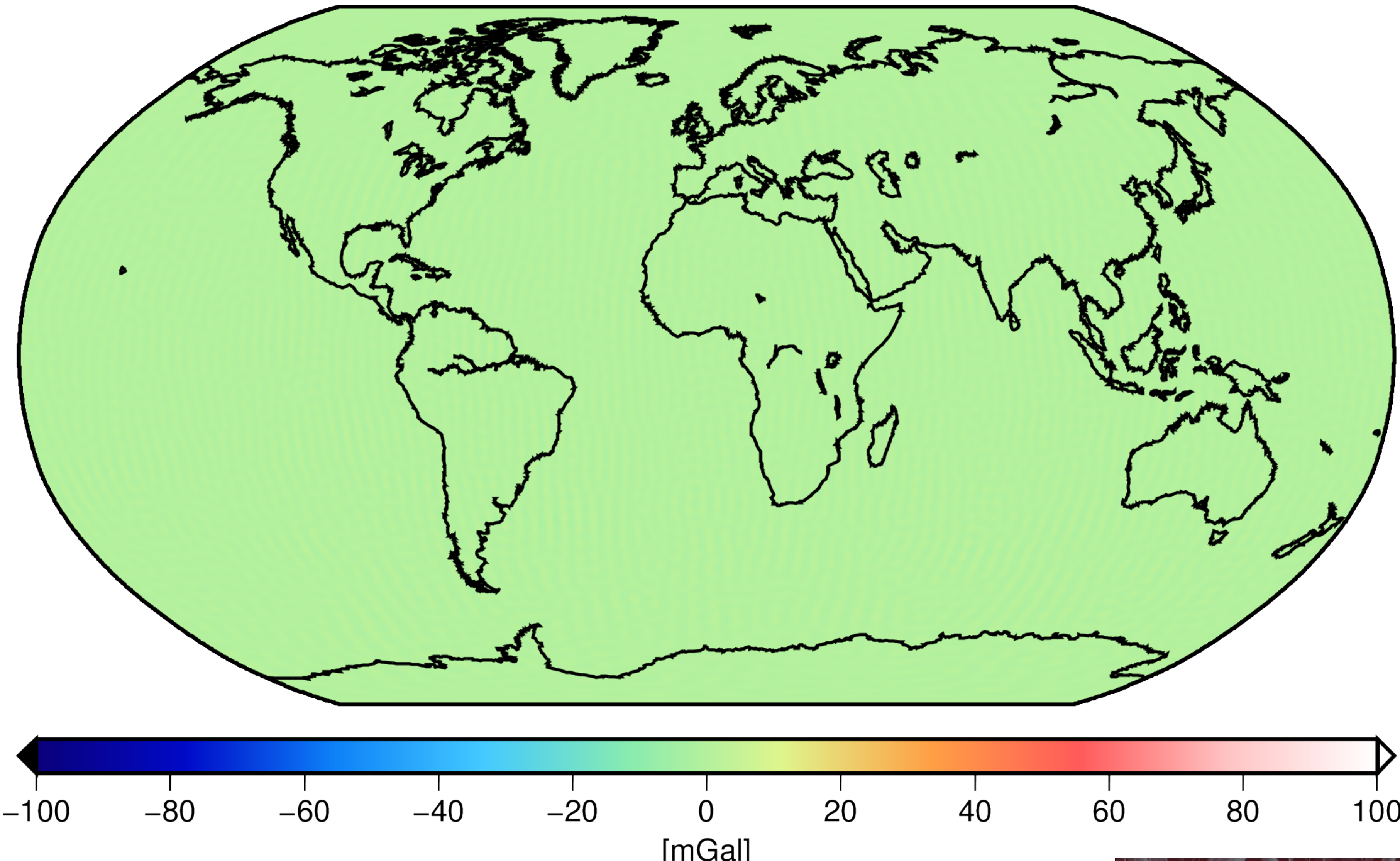
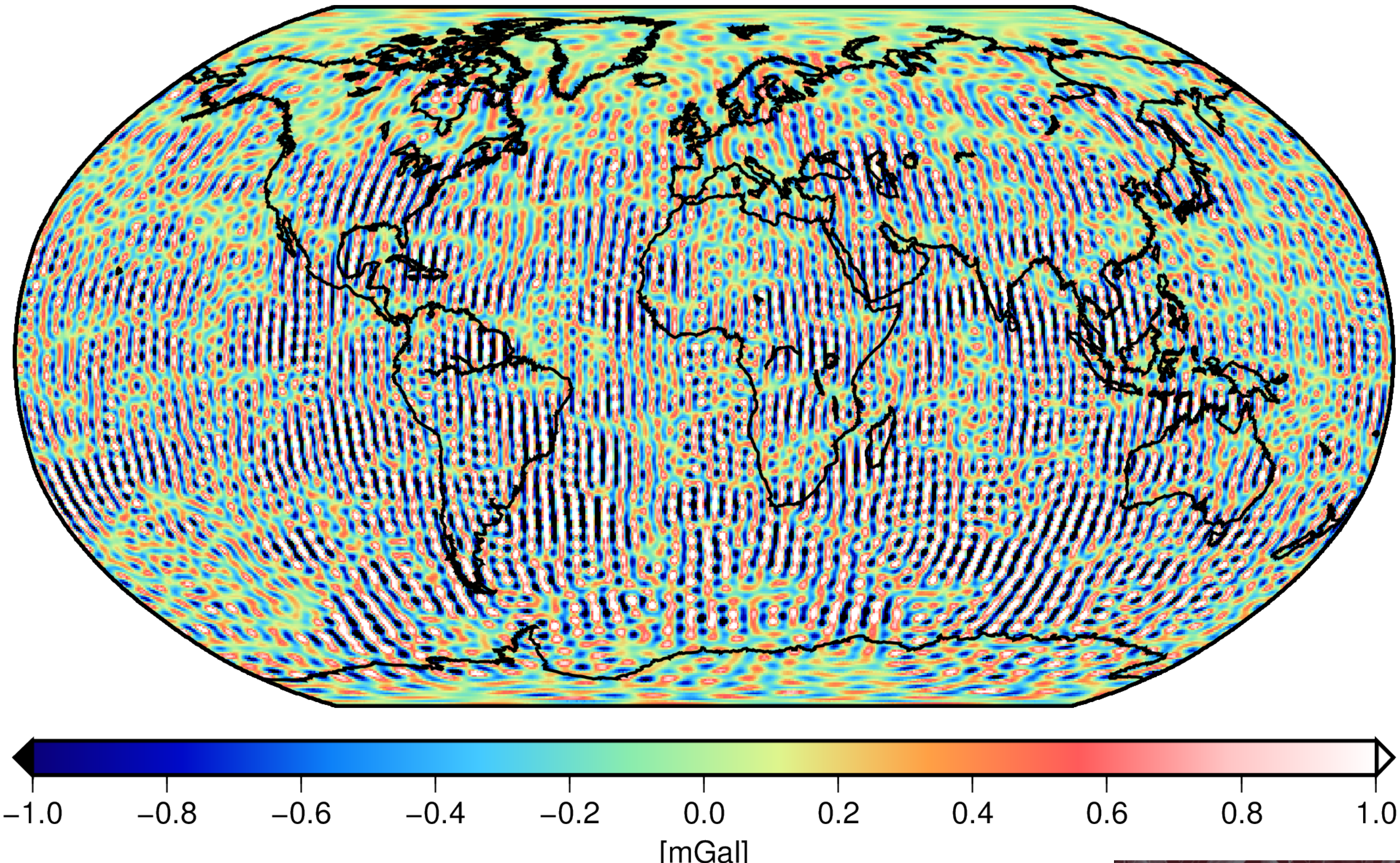
September – März 2008



September – März 2008



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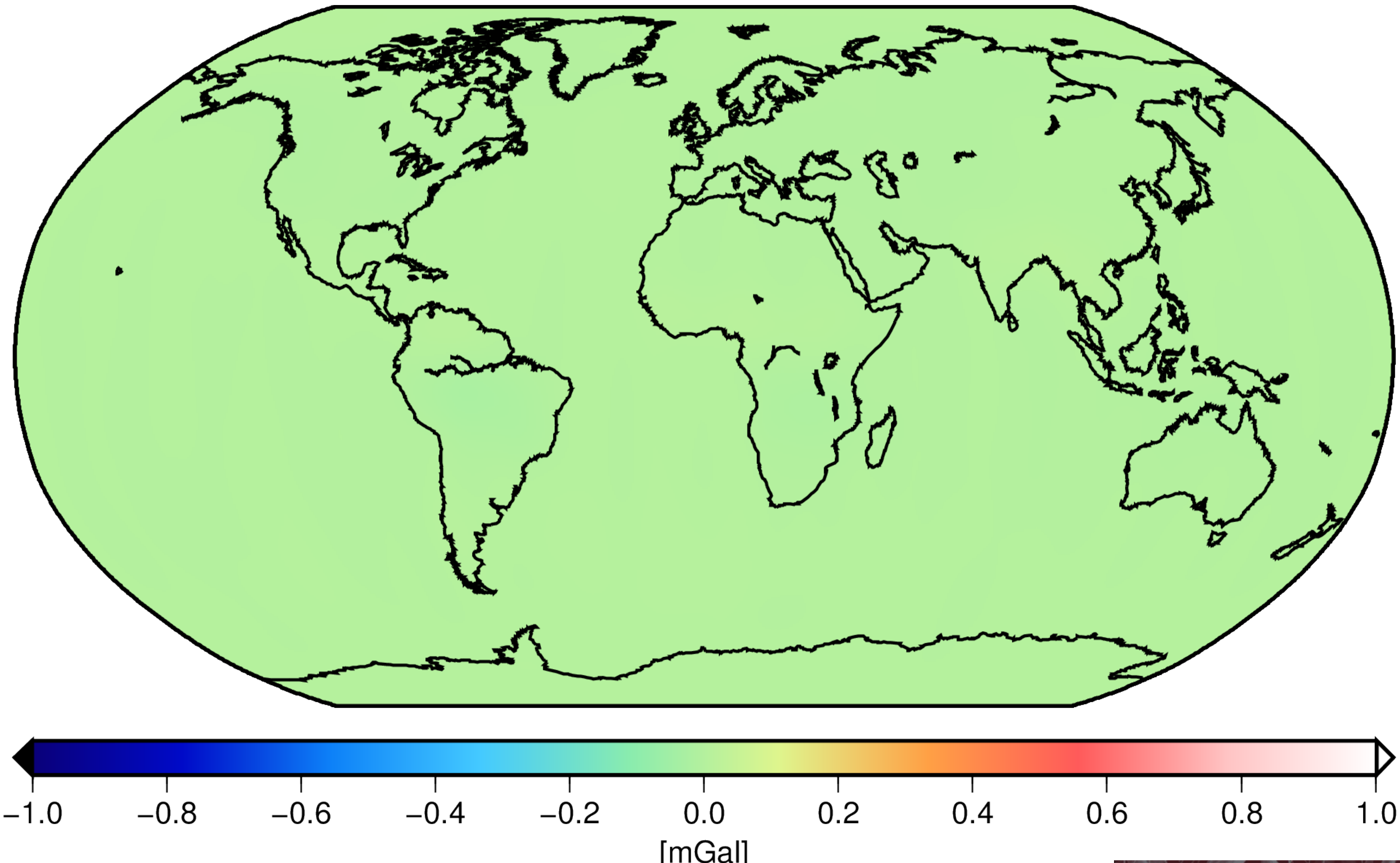

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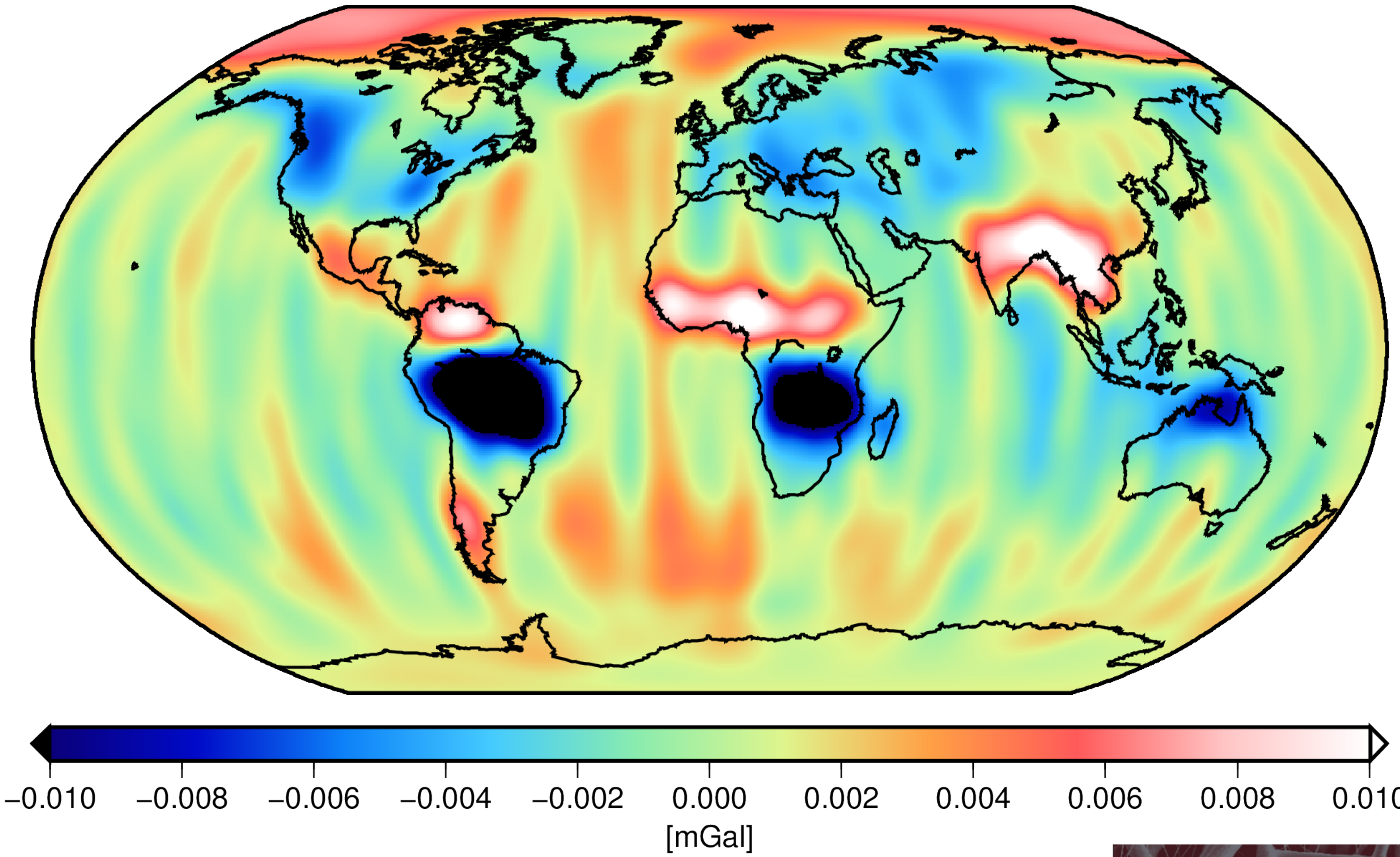
September – März 2008



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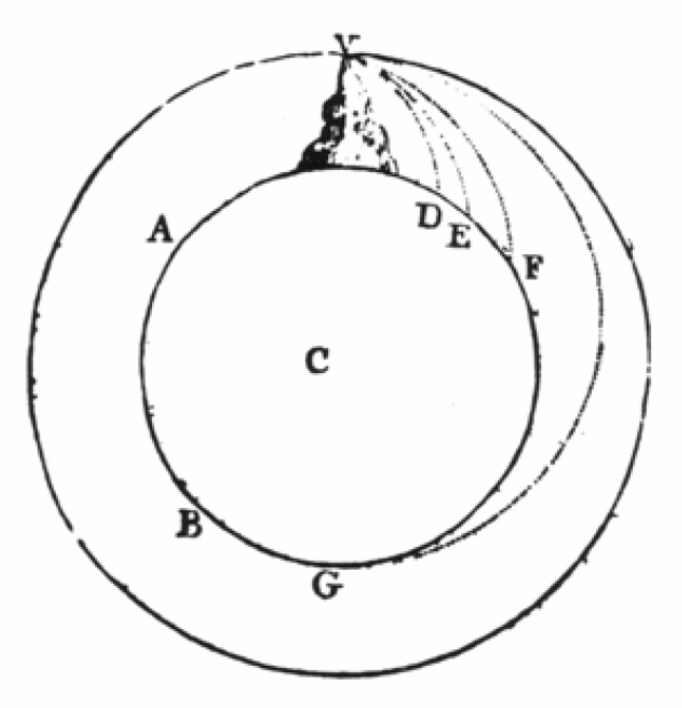
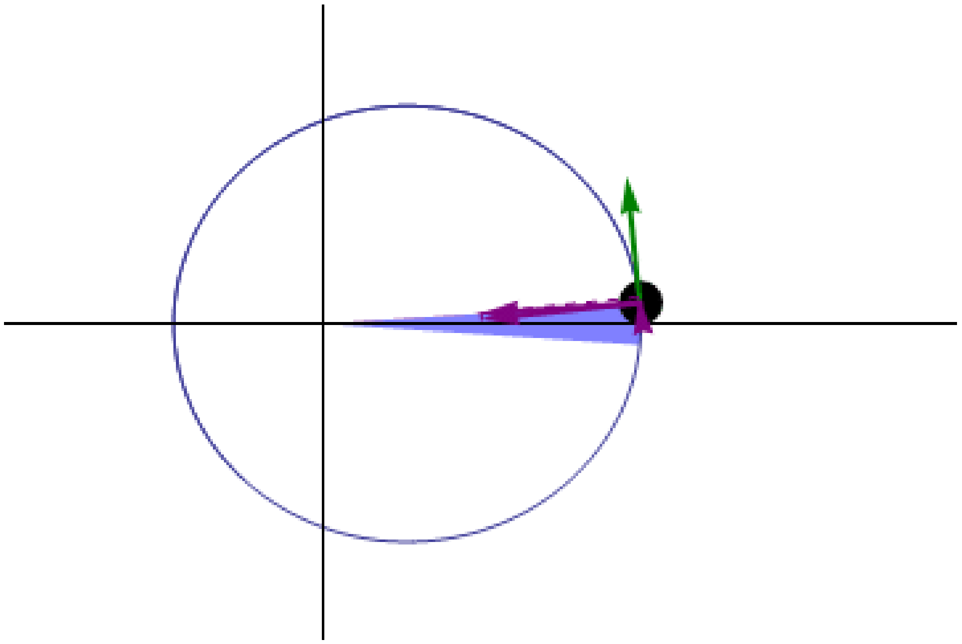
Wie misst man diese Veränderungen?

Vom Steinwurf zur Satellitenbewegung





Newton (1715):

„De mundi systemate“

Vermessung der Flugbahn, oder

- der Geschwindigkeit
- der Beschleunigung

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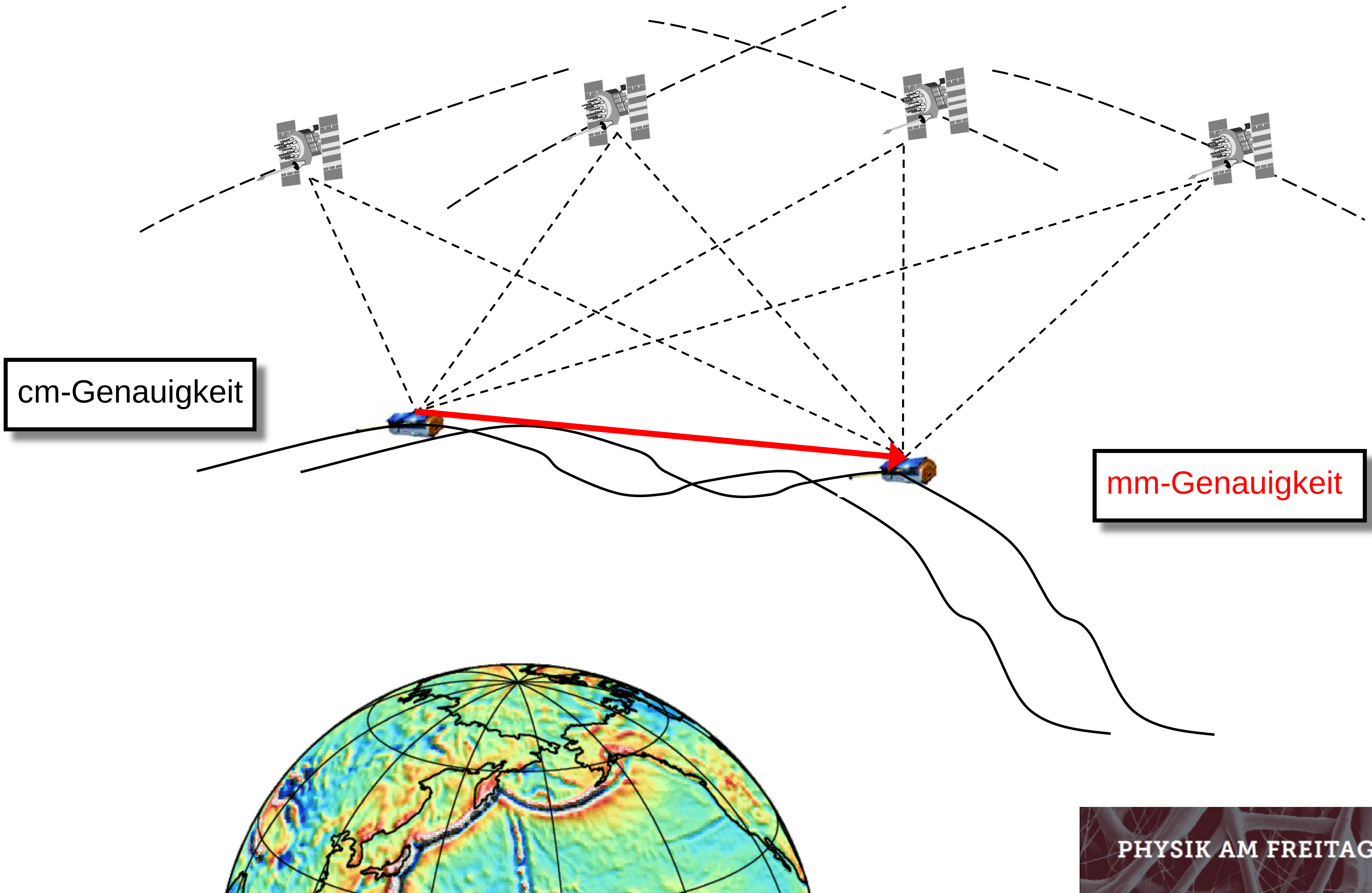
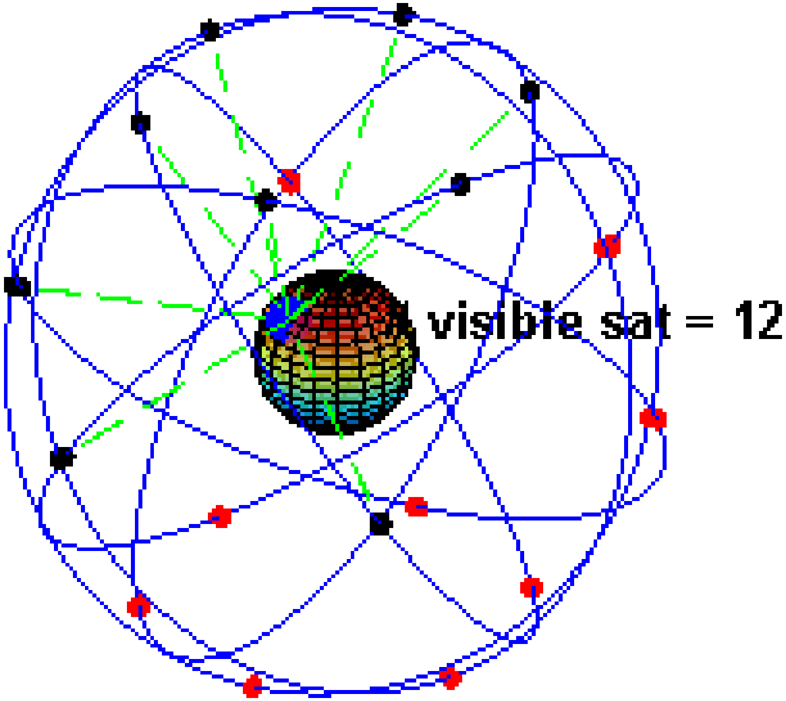
Vermessung der Flugbahn mit GPS

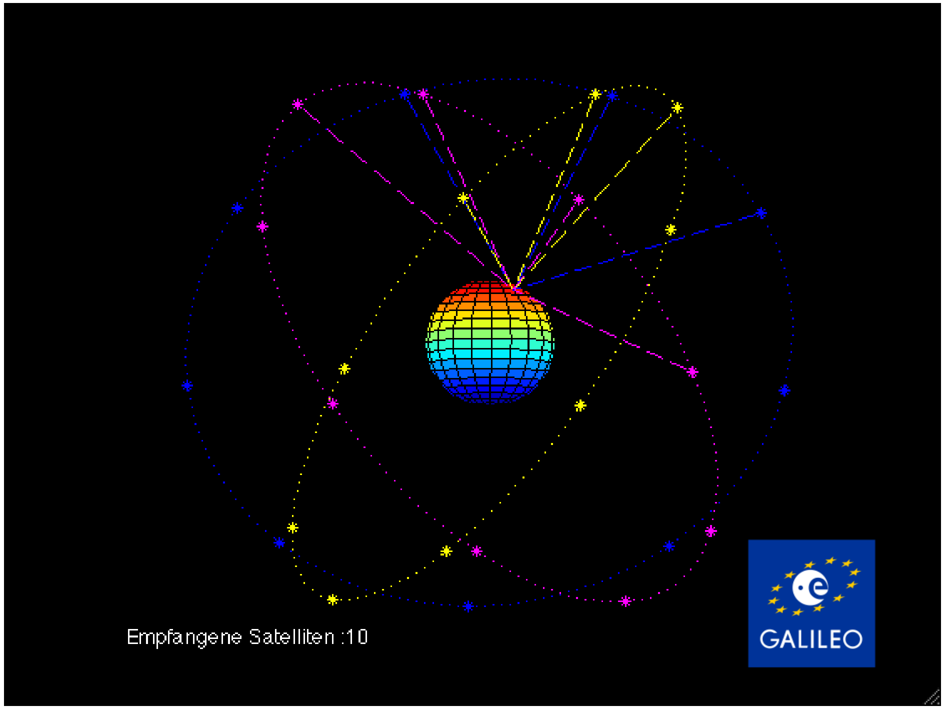


GPS & Co.

Global Positioning System (GPS)



Galileo



GPS, Galileo und weitere Systeme, z.B. aus Russland, werden unter dem Begriff Global Navigation Satellite Systems (GNSS) zusammengefasst.

Bernese GNSS Software

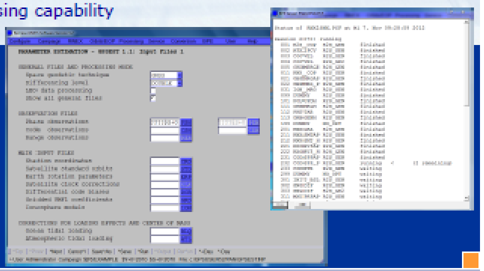
Bernese GNSS Software Version 5.2

The Bernese GNSS Software, Version 5.2, continues in the tradition of its predecessors as a high performance, high accuracy, and highly flexible reference GPS/GLONASS (GNSS) post-processing package. State-of-the-art modeling, detailed control over all relevant processing options, powerful tools for automatization, the adherence to up-to-date, internationally adopted standards, and the inherent flexibility due to a highly modular design are characteristics of the Bernese GNSS Software.

Features and Highlights

- Available on UNIX/Linux, Mac, and Windows platforms
- **User-friendly GUI**
- Built-in HTML-based **help system**
- Multi-session parallel processing for **reprocessing** activities
- **Ready-to-use BPE** examples for different applications:
  - PPP (basic and advanced versions)
  - RINEX-to-SINEX (double-difference network processing)
  - Clock determination (zero-difference network processing)
  - LEO precise orbit determination based on GPS-data
  - SLR validation of GNSS or LEO orbits

  All examples are designed for **combined GPS/GLONASS** processing. Some of them are prepared for an **hourly processing scheme.**
- Program for automated coordinate **time series analysis** (FODITS)
- **Ambiguity resolution** also for GLONASS
- Improved troposphere and ionosphere modeling
- Estimation of **scaling factors** for crustal deformation models (grids)
- Real kinematic analysis capability
- **IERS 2010** conventions compliance
- Support of GNSS-specific receiver antenna models
- Full verification of serial number for individually calibrated antennas
- Galileo processing capability



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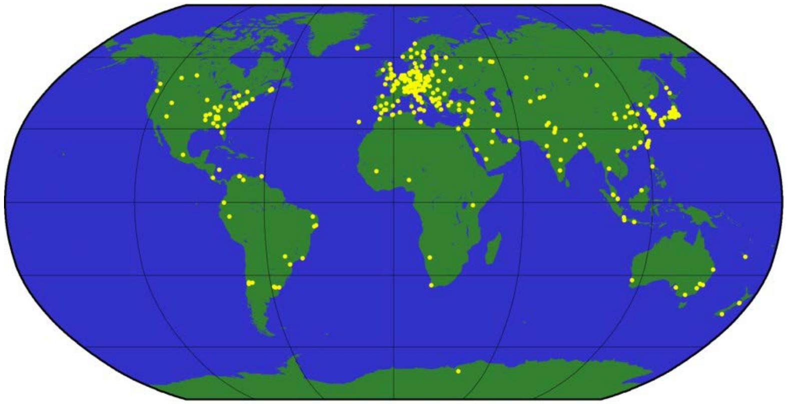
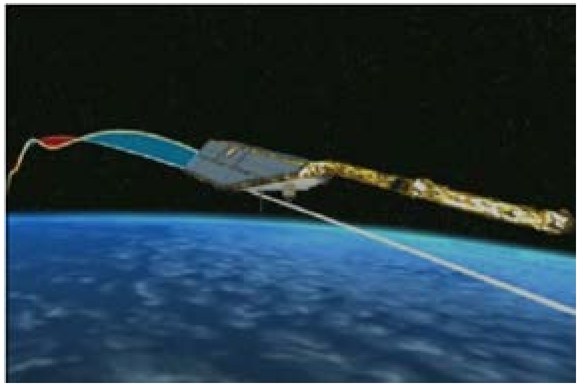


Die Bernese GNSS Software ist ein wissenschaftliches Software-paket zur hochpräzisen Analyse von GNSS Daten. Es wird hier in Bern am Astronomischen Institut entwickelt und mittlerweise von mehr als 600 Institutionen weltweit eingesetzt.

Satellitenbahnen



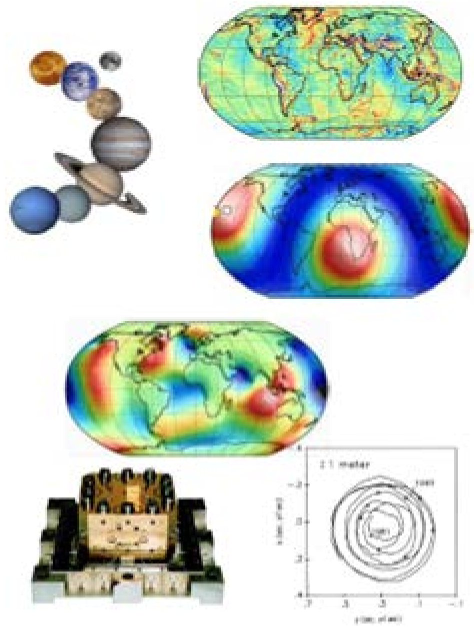
Bewegungsgleichung

$$m \cdot \ddot{\vec{x}} = \vec{F}(t, \vec{x}, \ldots)$$

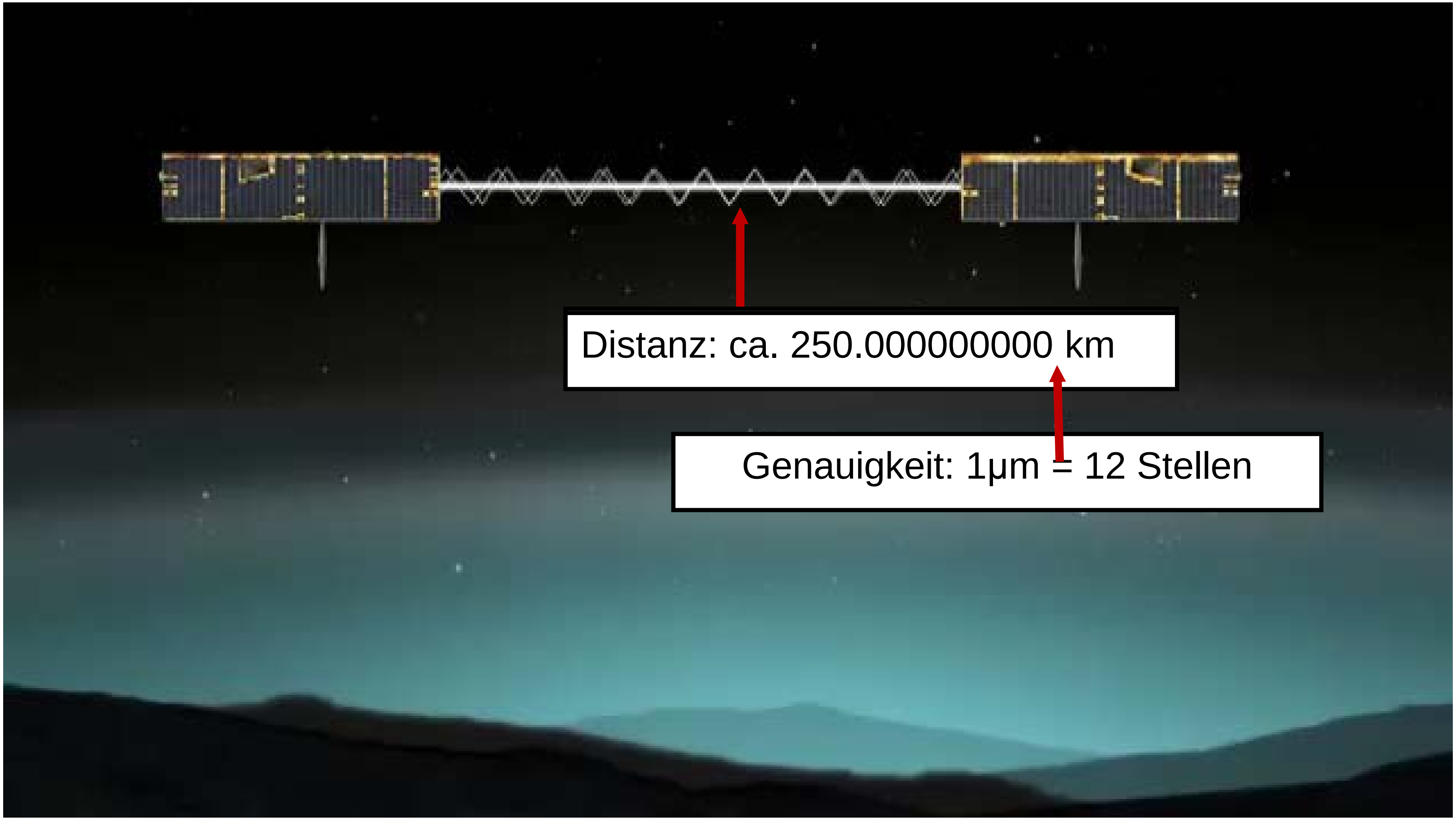
=> Numerische Integration der Bahn

Kräfte:

- Statisches Schwerefeld
- Weitere Himmelskörper (Sonne, Mond, Planeten)
- Festerdegezeiten
- Ozeangezeiten
- Polgezeiten
- Ozeanpolgezeiten
- Atmosphärische Gezeiten
- Dealiasing (Atmosphäre, Ozeane)
- Nicht-gravitative Kräfte
- Relativistische Effekte



GRACE Messprinzip



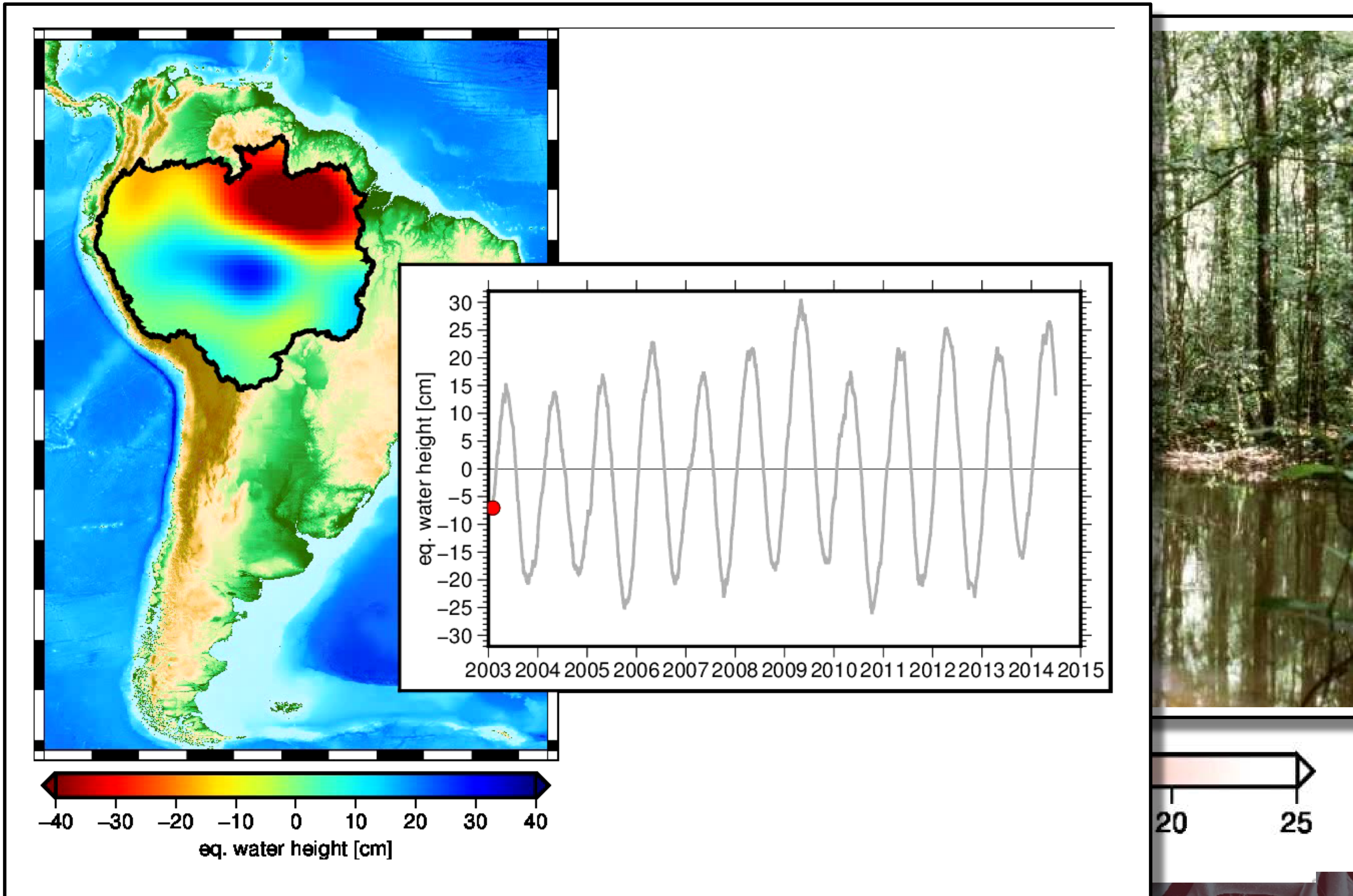
Dies ist viel genauer als man die absolute oder relative Position mit GPS messen kann (cm bzw. mm).

und in Zukunft mit Laser

LISA: Laser Interferometer Space Antenna, Start vorgesehen für 2017

Welche Veränderungen messen wir nun genau?

Zeitliche Variationen



[1km^3 = 1gt Wasser]

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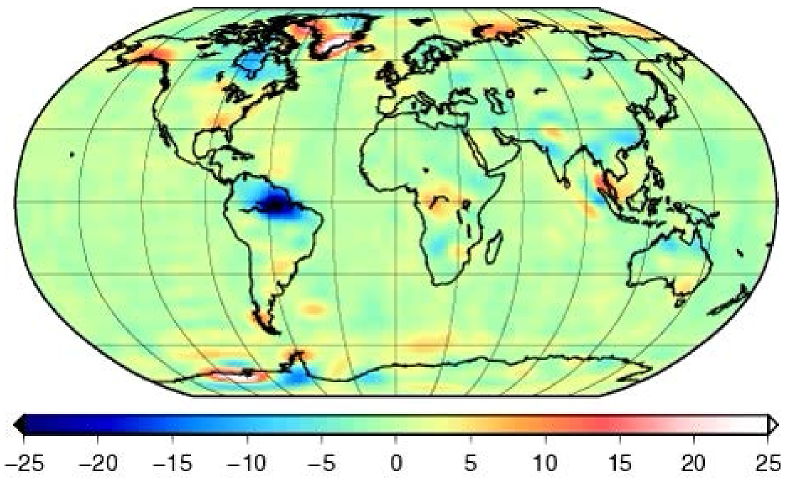
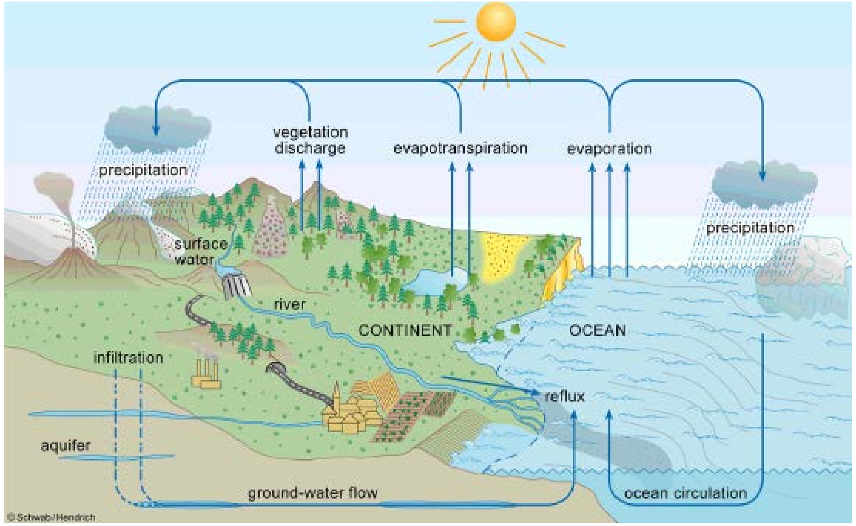
Globaler Wasserkreislauf



[cm EWH]



ΔTWS(t) = ΔGW(t) + ΔSW(t) + ΔSWE(t) + ΔSM(t) - ΔRO(t)

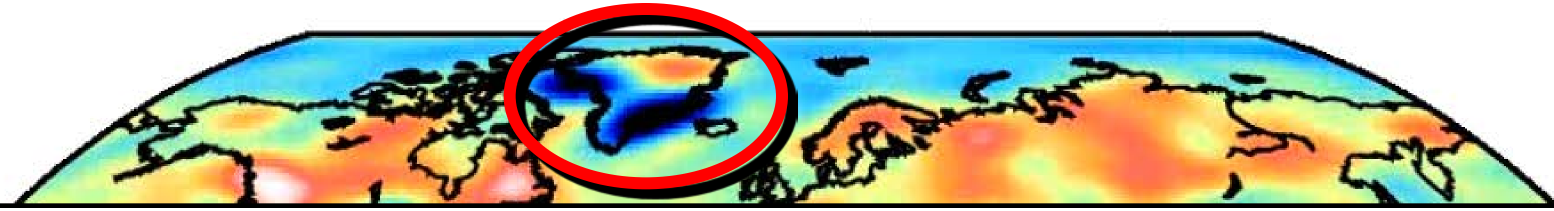
ΔTWS(t) = Total Water Storage **kann nur GRACE liefern!**

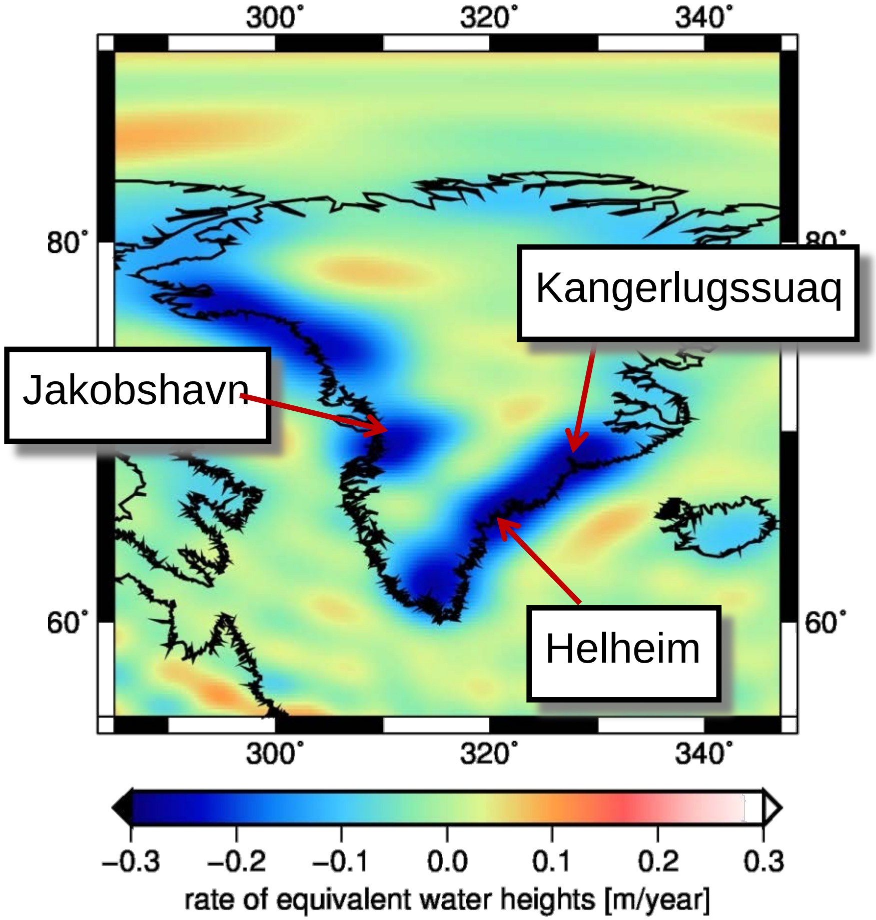
ΔGW(t) = Ground Water
ΔSW(t) = Surface Water } ΔAW(t) = Accessible Water
ΔSWE(t) = Snow Water Equivalent

ΔSM(t) = Soil Moisture
ΔRO(t) = Run Off

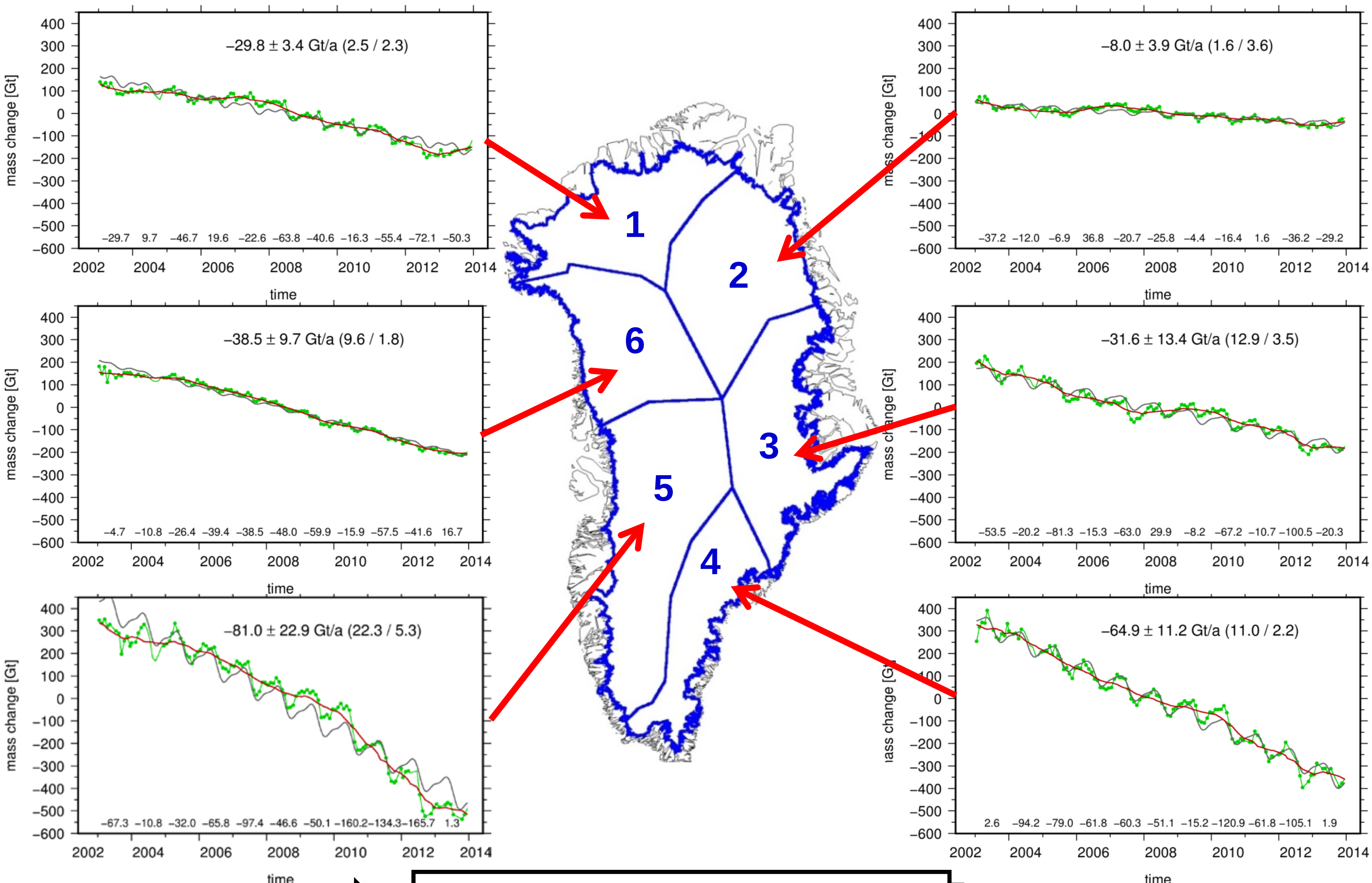
} **Auftrennung benötigt zusätzliche Messungen**

Zeitliche Variationen





Schmelzendes Eis in Grönland



Massen Verlust: ~250 gt/Jahr

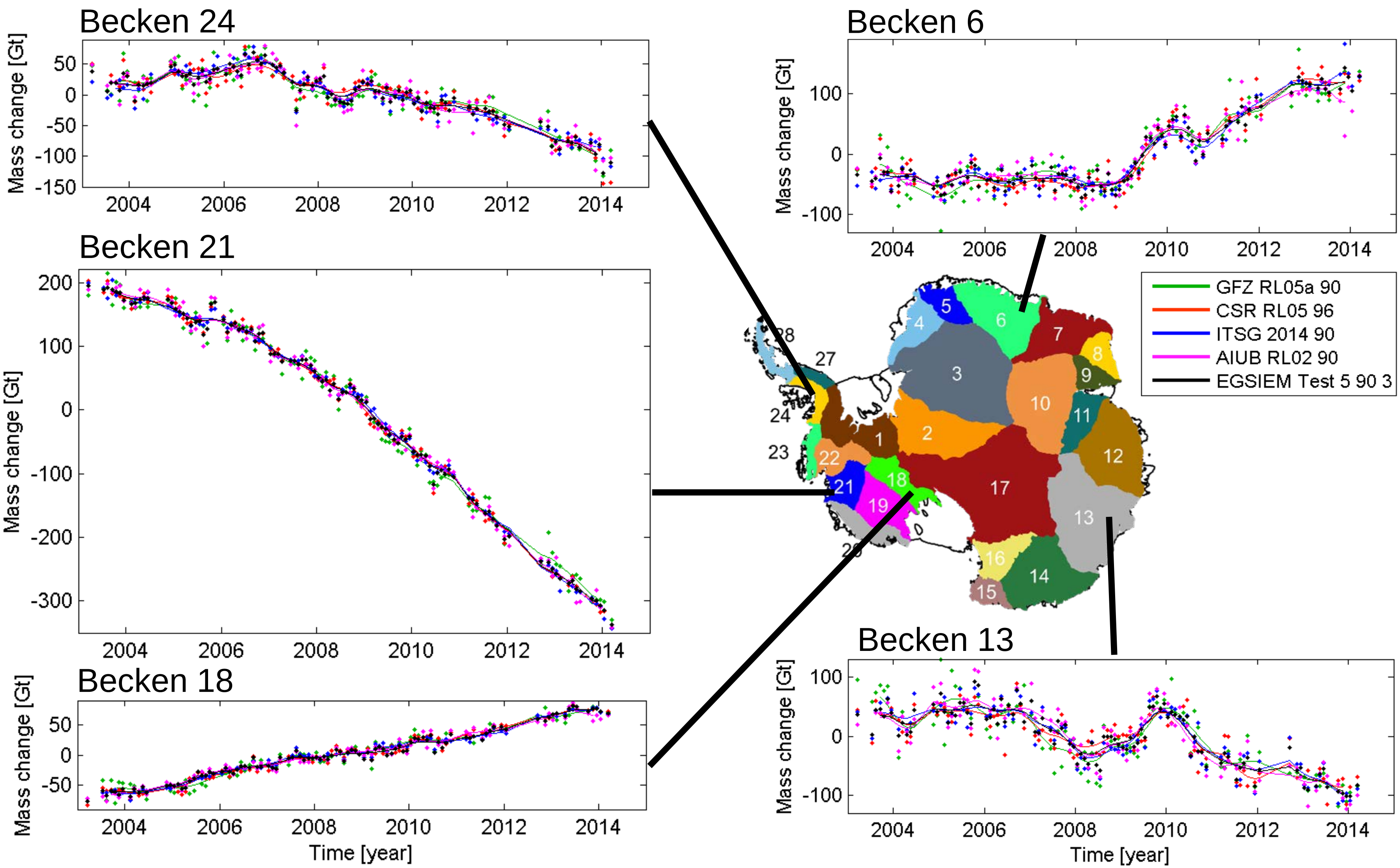
Schmelzendes Eis in Grönland

150´000

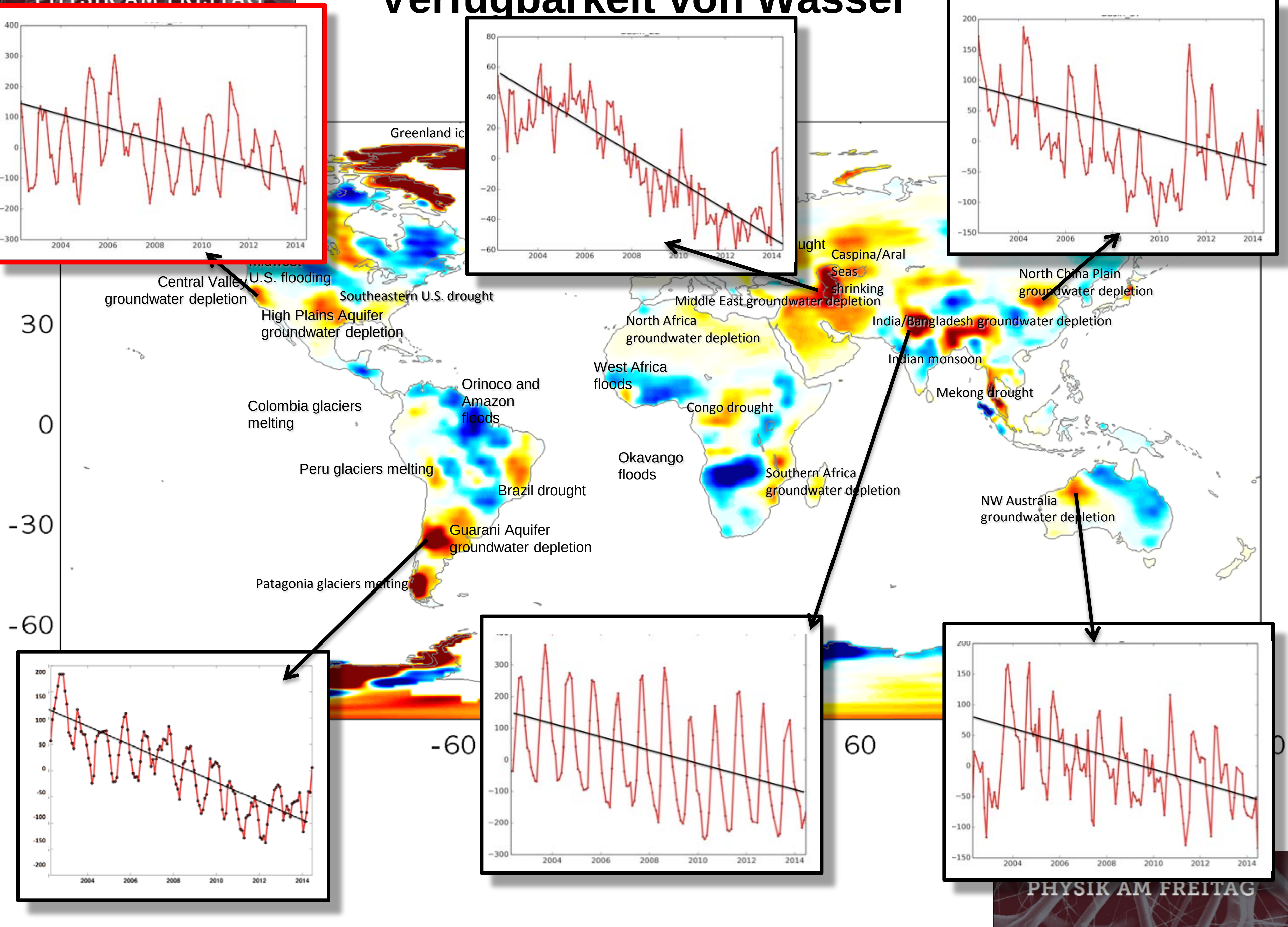
dieser Blöcke schmelzen
in Grönland

jede Sekunde

Schmelzendes Eis in der Antarktis



Verfügbarkeit von Wasser



Beispiel: Dürre in Kalifornien

The drought you can't see

The Western Hemisphere is experiencing a drought of crisis proportions. In Central America, crops are failing, millions are in danger of starvation, and if the drought doesn't break soon, even vessels transiting the Panama Canal will need to lighten their loads, which will increase prices for goods transported globally. In the western United States, the drought-stricken region spans a vast area responsible for much of the nation's fruits, vegetables, and beef. As the drought's grip has tightened, water users have turned to tapping groundwater aquifers to make up the deficit for people, crops, livestock, and industry. But even when the rain does return, regreening the landscape and filling again the streams, lakes, and reservoirs, those aquifers will remain severely depleted. It is this underground drought we can't see that is enduring, worrisome, and in need of attention.

The Gravity Recovery And Climate Experiment (GRACE) satellites have provided a global look at groundwater depletion by monitoring small temporal changes in Earth's gravity field. GRACE confirmed massive losses of groundwater from the aquifer underlying California's agriculturally important Central Valley since the 1980s.* In the decade between 2003 and 2012, the drawdown was equivalent to the entire water storage volume of Lake Mead, the nation's largest surface reservoir.† The extraction of groundwater has caused wells to run dry and produced detectable regional uplift or rebound of the land due to water displacement (see Borsa *et al.*, p. 1587).

Underground reservoirs are a natural long-term water storage solution. Taking advantage of aquifers avoids the expense and environmental issues of dam construction. Unlike surface reservoirs, aquifers are not subject to evaporative loss, but under natural conditions they are only recharged slowly as excess precipitation percolates into the aquifer. In some cases, the average age of groundwater can be many thousands of years old, dating back to a time when the climate was wetter. But when water is withdrawn through pumping at prodigious rates, hydrologic processes are not sufficient to fully recharge the reservoirs, especially when land development has created impervious surfaces.

Forty years ago, the state of Arizona reached a critical juncture that called for action, with rapidly falling water tables, dry wells, subsiding land surface, and deteriorating water quality. Now, in the Tucson area for example, water from the Colorado River is used to artificially recharge the aquifers with excess water in wet years that can later be tapped during dry years. The statewide 1980 Groundwater Management Act guarantees that over a 10-year period, the aquifer cannot be overdrawn. The current crisis has prompted the legislature of California—the last state in the west without groundwater regulation—to pass a series of bills that establish state-level oversight of pumping from aquifers.

Surface- and groundwater are all part of one coupled system, responding on different time scales to changes in precipitation. Five years ago when I was director of the U.S. Geological Survey (USGS), an Arizona congressman had some concerns about a USGS report on the impact of overpumping of groundwater on surface stream flows. The congressman declared, "You all should be aware that according to Arizona state law, surface water and groundwater flows are decoupled." Jim Leenhouts, the USGS associate director for the Arizona Water Science Center responded, without hesitation, "Thank you, congressman. Here at the USGS we follow the laws of nature, not the laws of man." It is high time we started managing our precious water supplies in harmony with the laws of nature.

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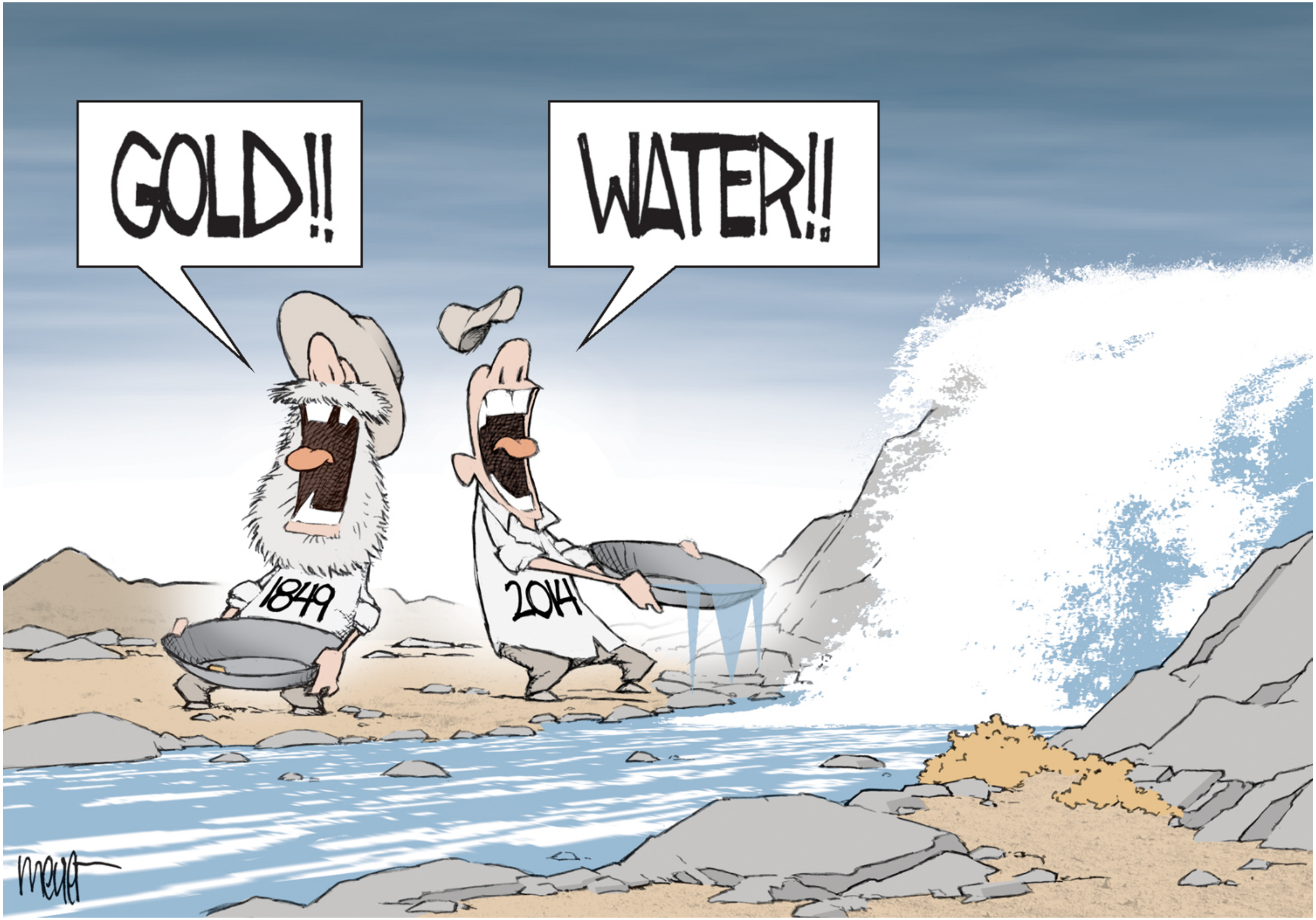
Beispiel: Dürre in Kalifornien



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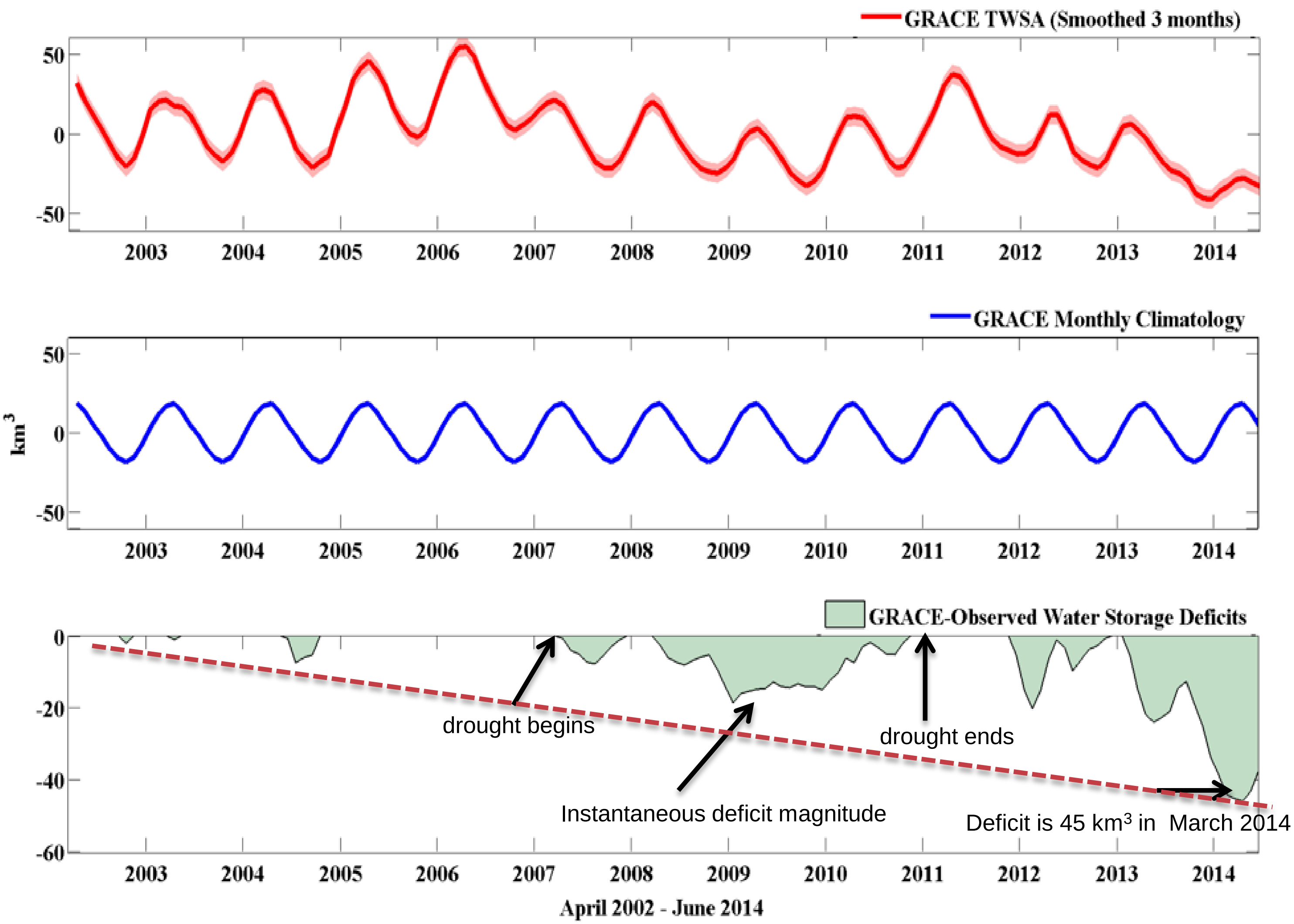
Beispiel: Dürre in Kalifornien

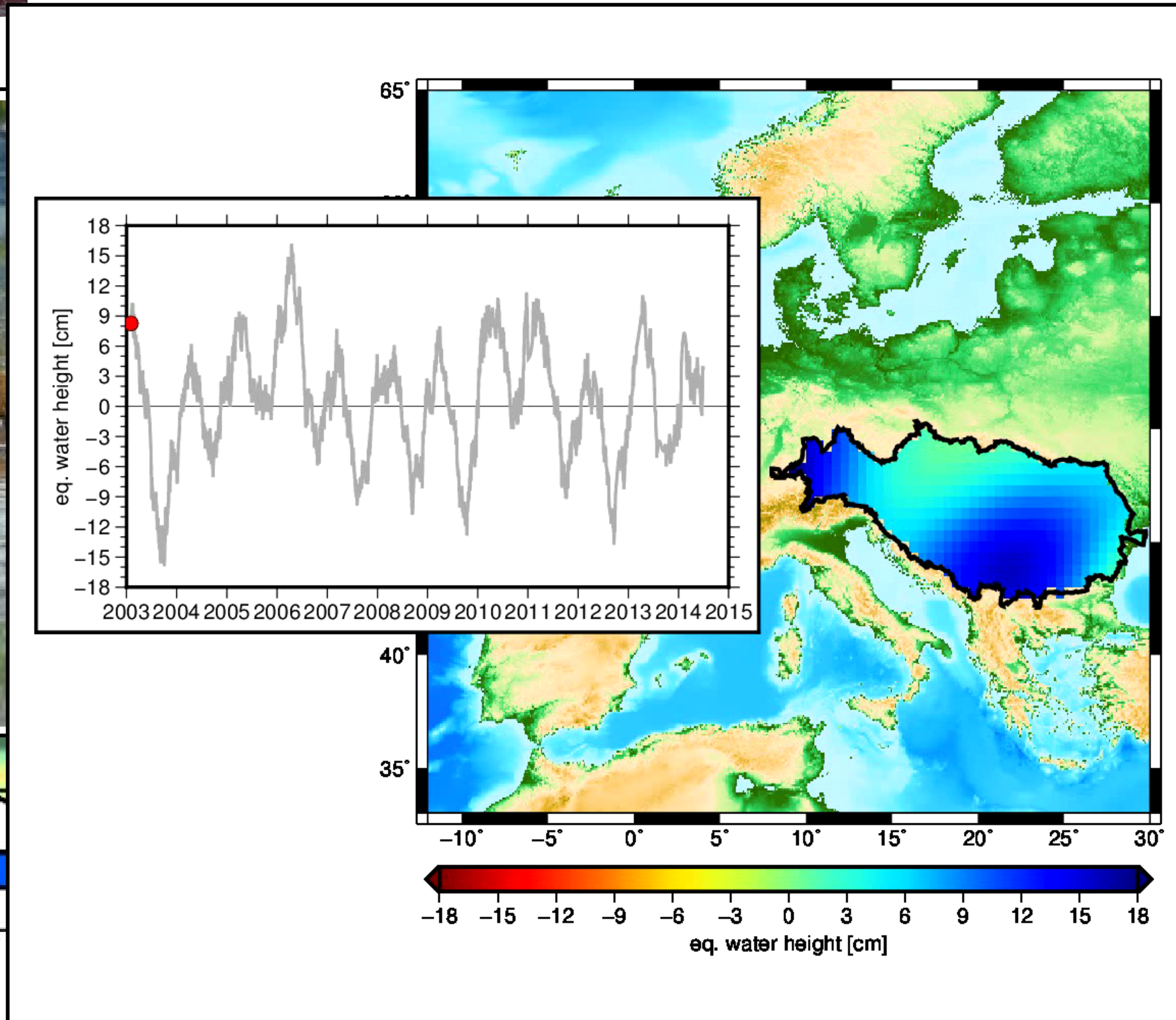
Tatsächliche Water Storage Variationen

‘Normaler’ Bereich der Water Storage Variationen

Unterschied zu ‘normal’ trockenen Bedingungen



Beispiel: Überschwemmung



Helfen diese Daten für die Frühwarnung?

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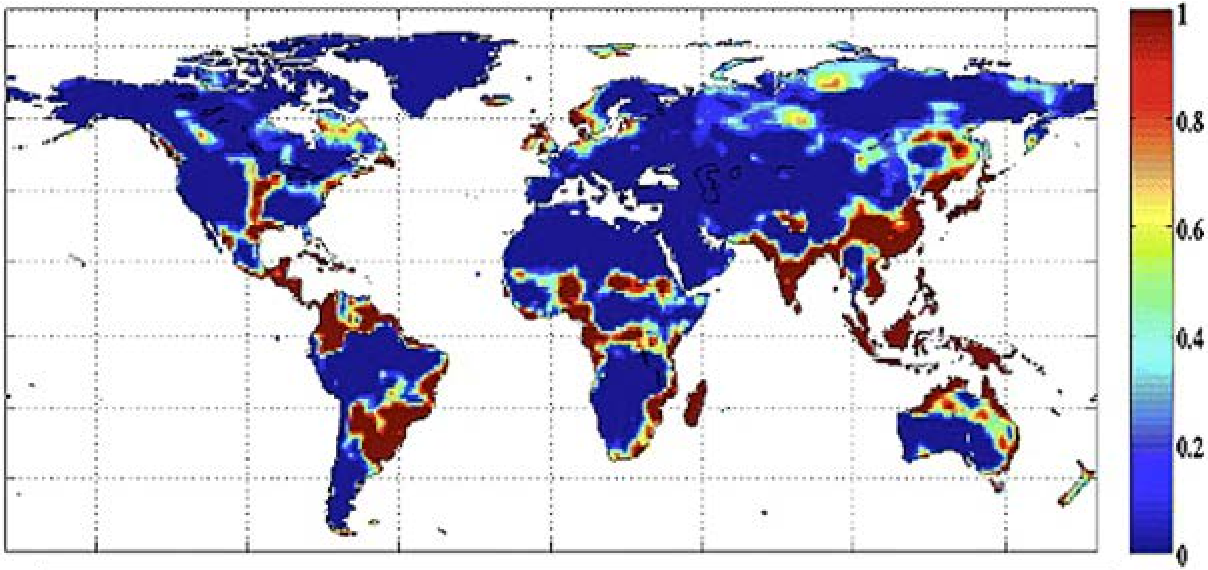
Vermutlich ja, …

Gesättigte Böden ⇨ Ein Faktor, der das Entstehen von Hochwasser begünstigt

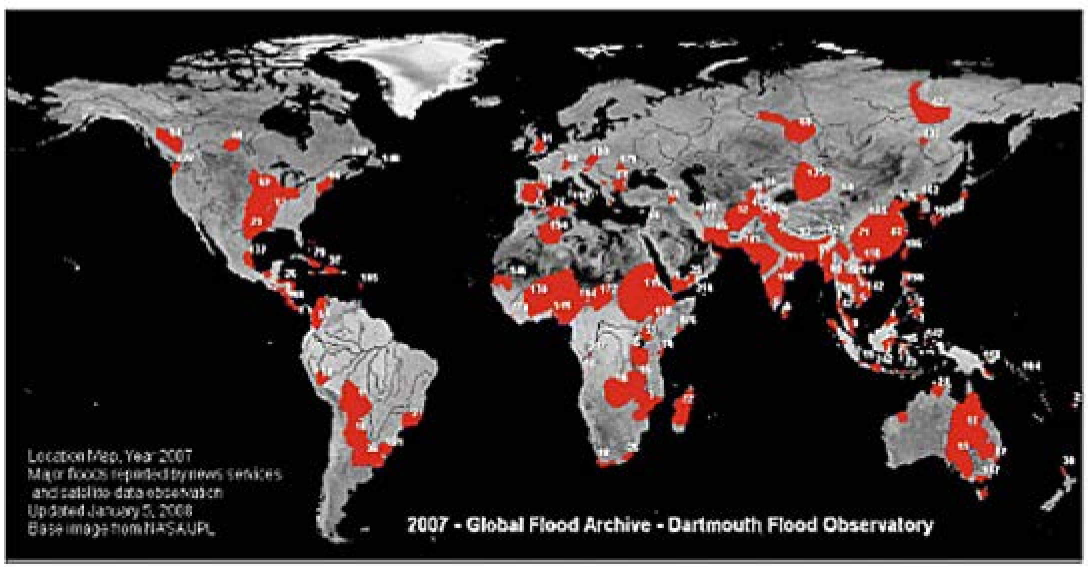
Ungewöhnliche Entwicklungen im Total Water Storage könnten zukünftig als Indiz für das Entstehen von Hochwasser dienen.

Vermutlich ja, …



Aus GRACE abgeleitete Flut-Index Maxima für den Mai 2007.

Diese Information steht erst zwei Monate später zur Verfügung, und bloss mit monatlicher Auflösung.

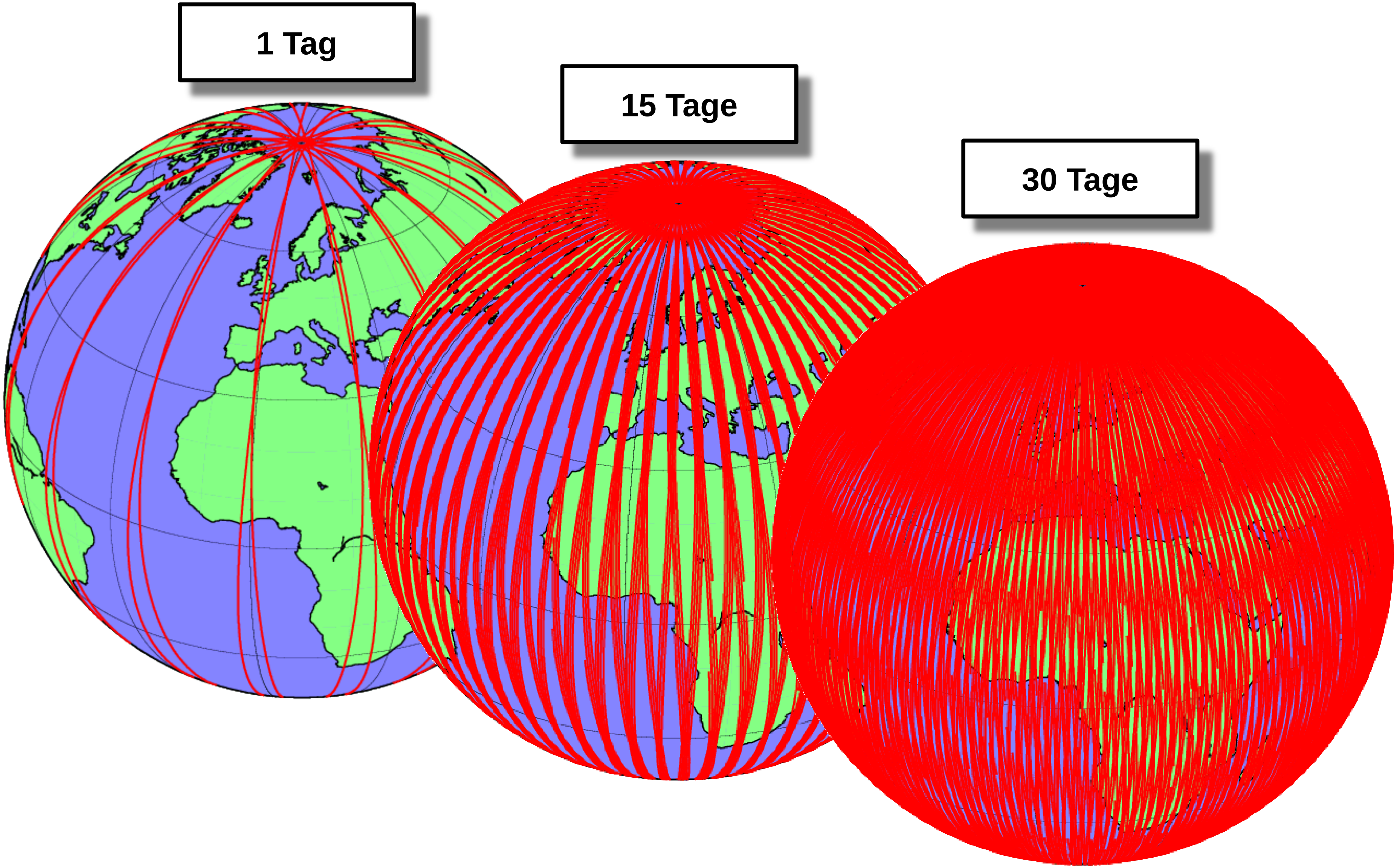


Im Mai 2007 tatsächlich aufgetretene Überflutungen.

Um nützlich zu sein, muss diese Information in naher Echtzeit und mit wesentlich höherer (täglicher) Auflösung vorliegen.

Reager and Famiglietti (2009)

Tägliche Auflösung, geht das … ?



EGSIEM

European Gravity Service for Improved Emergency Management

ist ein Projekt zwischen 8 europäischen Partnern

finanziert durch

European Commission

zur Erstellung bestmöglicher Schwerefeldprodukte und zur Untersuchung auf deren Eignung für Frühwarnsysteme

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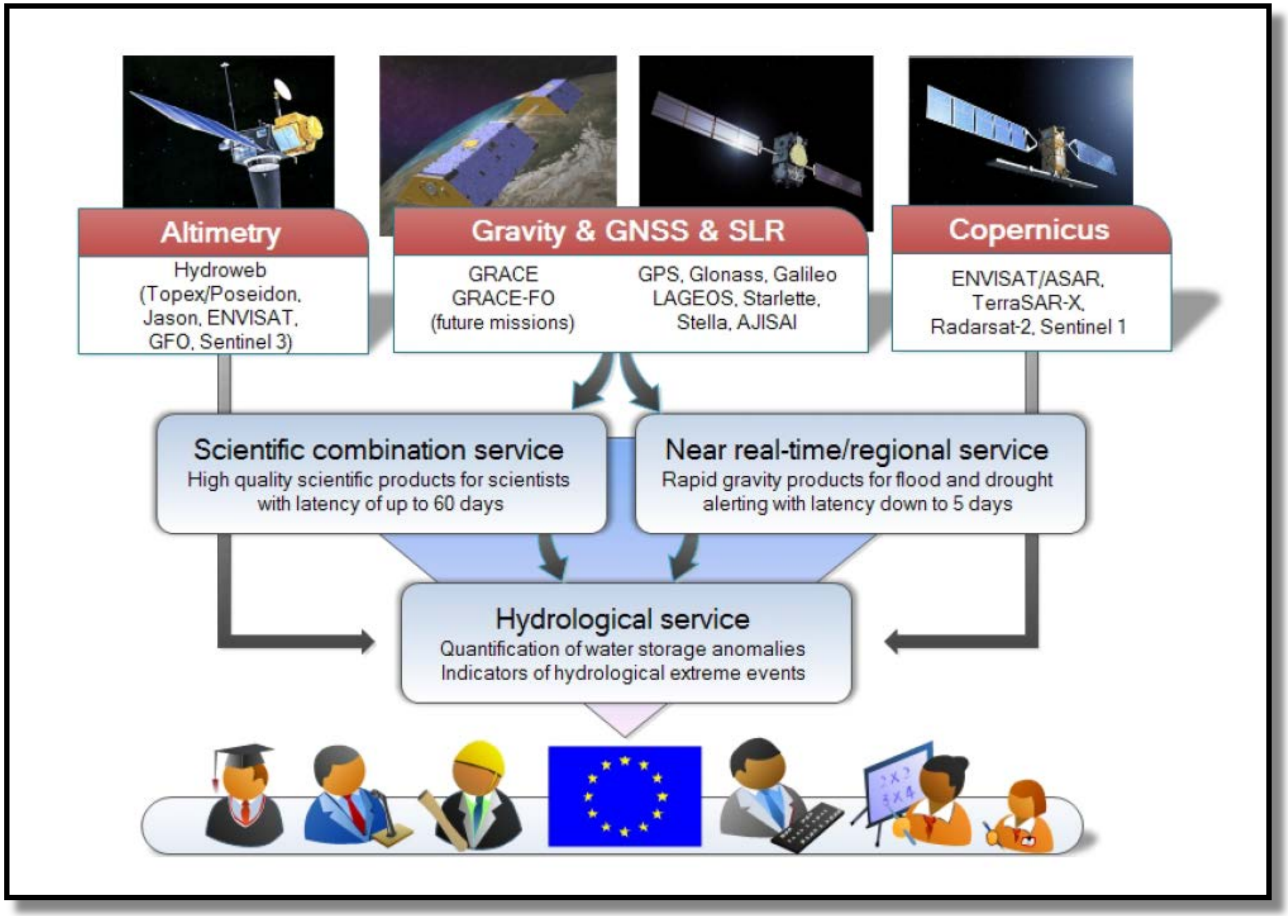
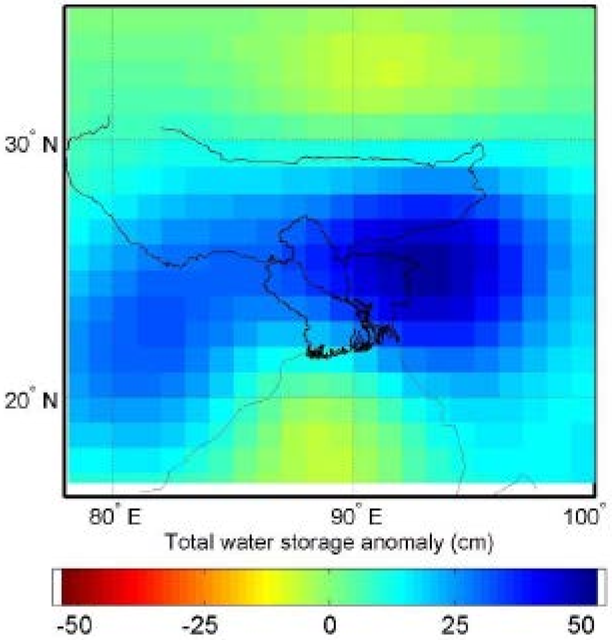
EGSIEM

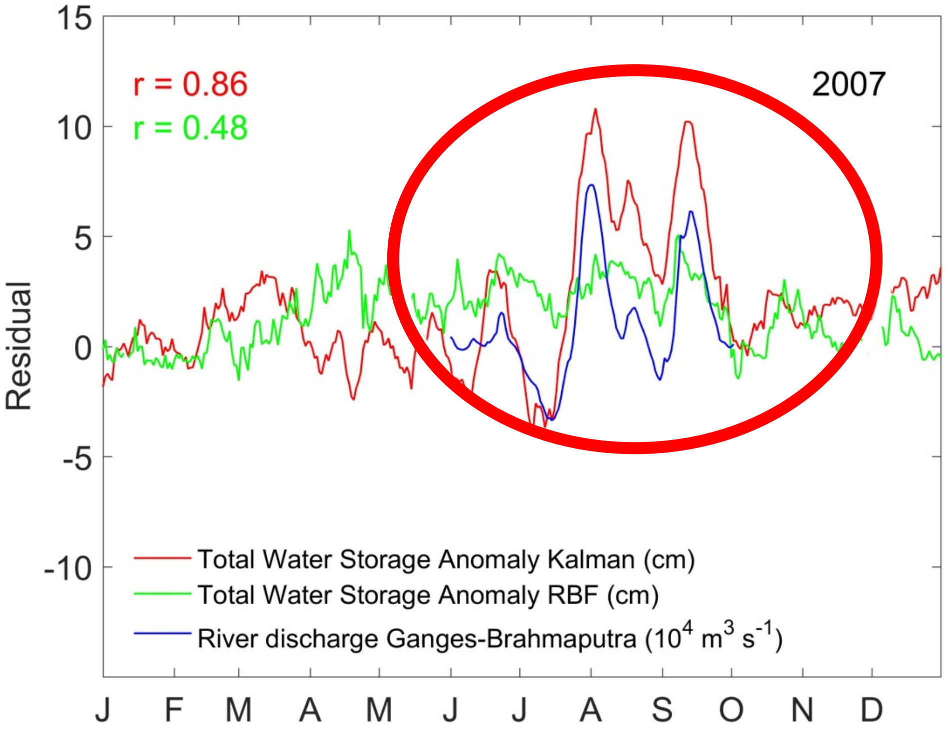
European Gravity Service for Improved Emergency Management



Beispiel: Ganges-Brahmaputra Delta

12. Sept. 2007

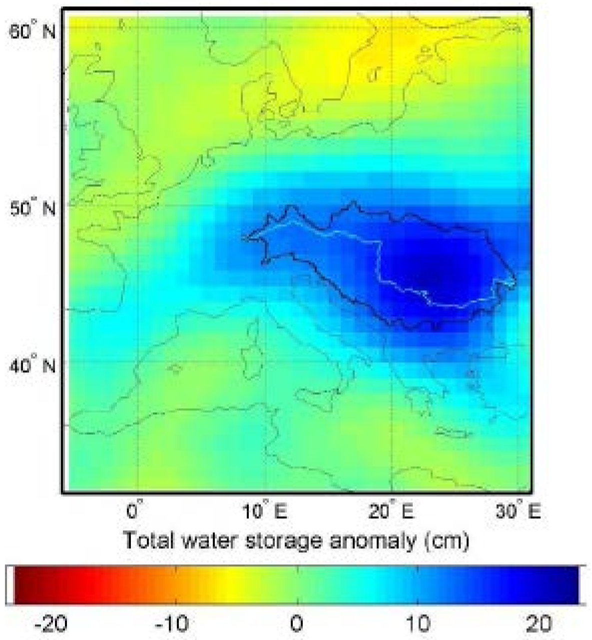


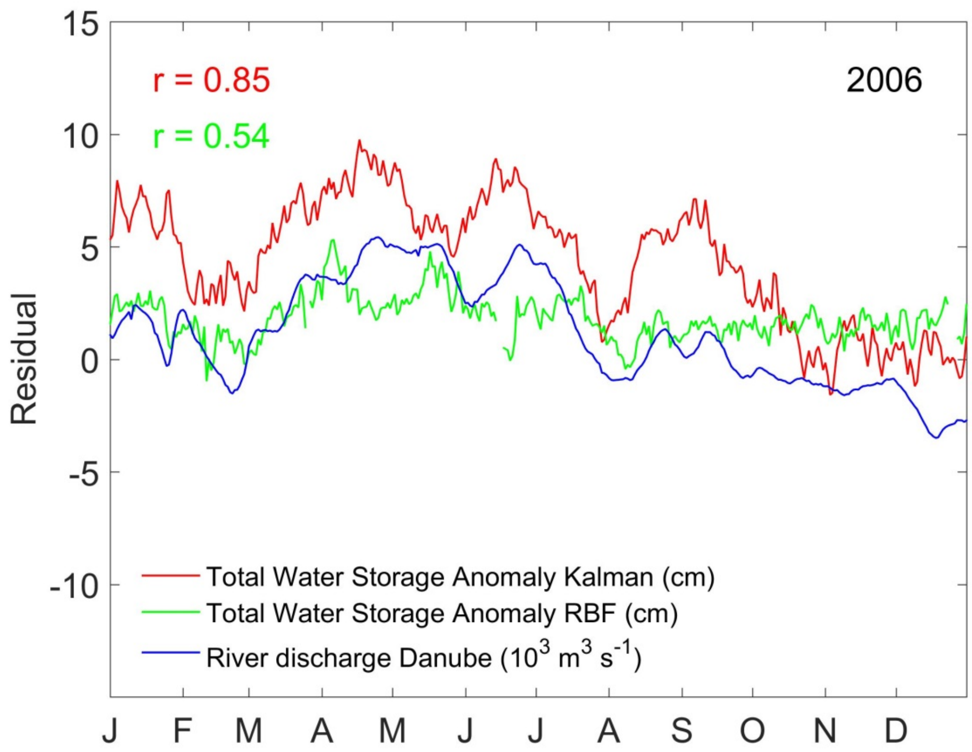


Tägliche Schwerefeldlösungen (Kalman Lösung) korrelieren gut mit terrestrischen Abfluss Messungen.

Beispiel: Donau Becken

17. April 2006





Tägliche Schwerefeldlösungen (Kalman Lösung) korrelieren gut mit terrestrischen Abfluss Messungen.

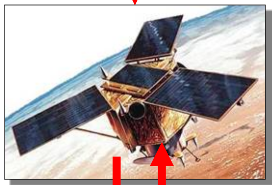
Rapid Mapping

ZKI: Zentrum für satelliten-gestützte Kriseninformation

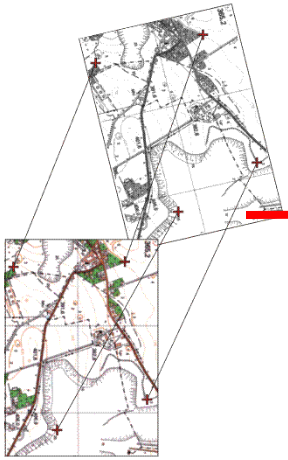
ZKI

Alarm

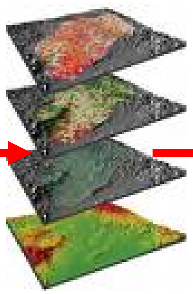
Idee für die Zukunft:
Frühere Alarmierung dank Gravity Indikatoren



Datenbeschaffung



Vorverarbeitung



Analyse

Kartenerstellung

Weitergabe

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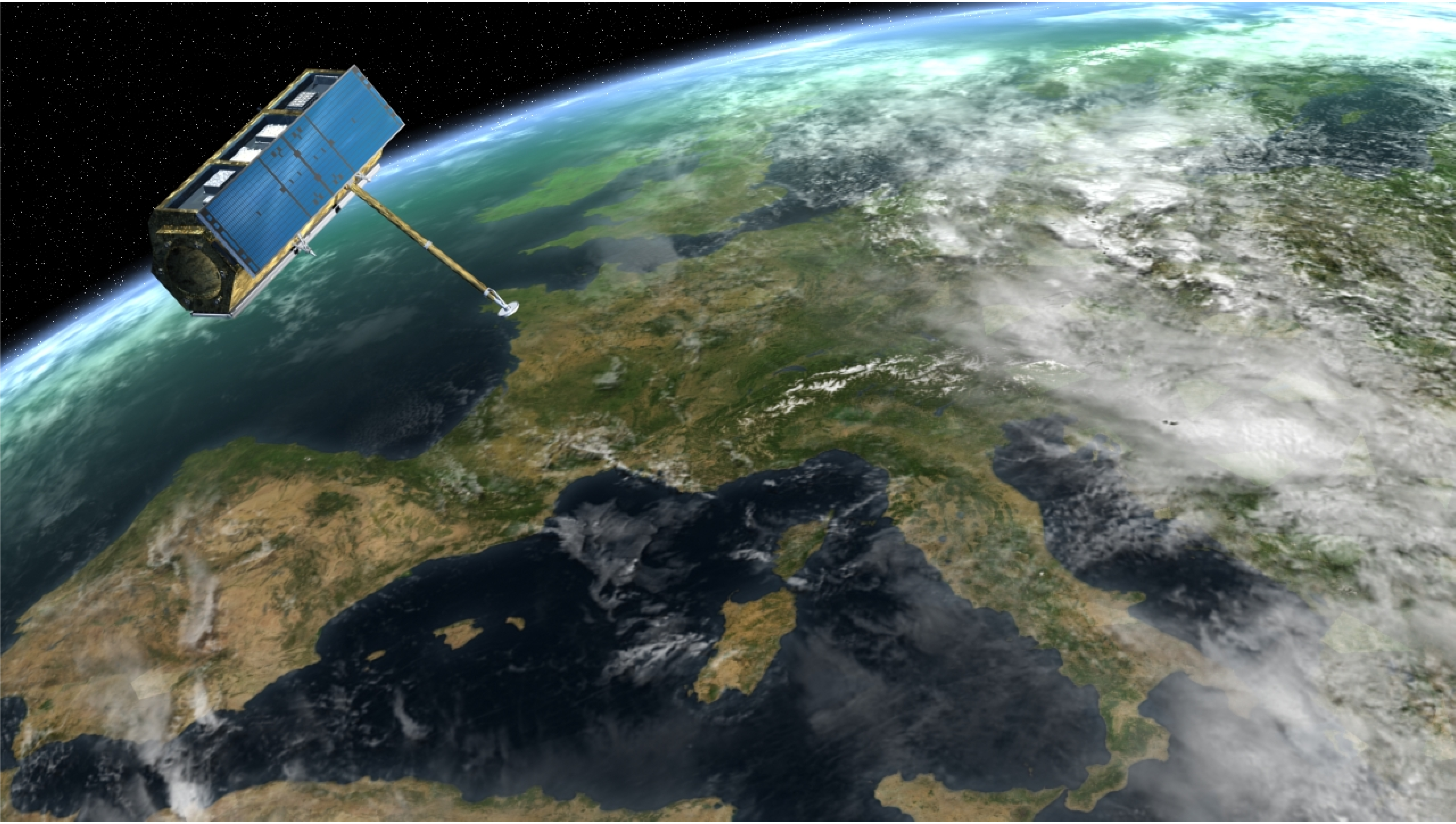
Rapid Mapping



Beispiel: England

Beispiel einer aus TerraSAR-X Satellitendaten abgeleiteten Hochwasserfläche

Hochwasser England, Tewkesbury

hellblau: Hochwasserfläche
dunkelblau: Normalwasserpegel

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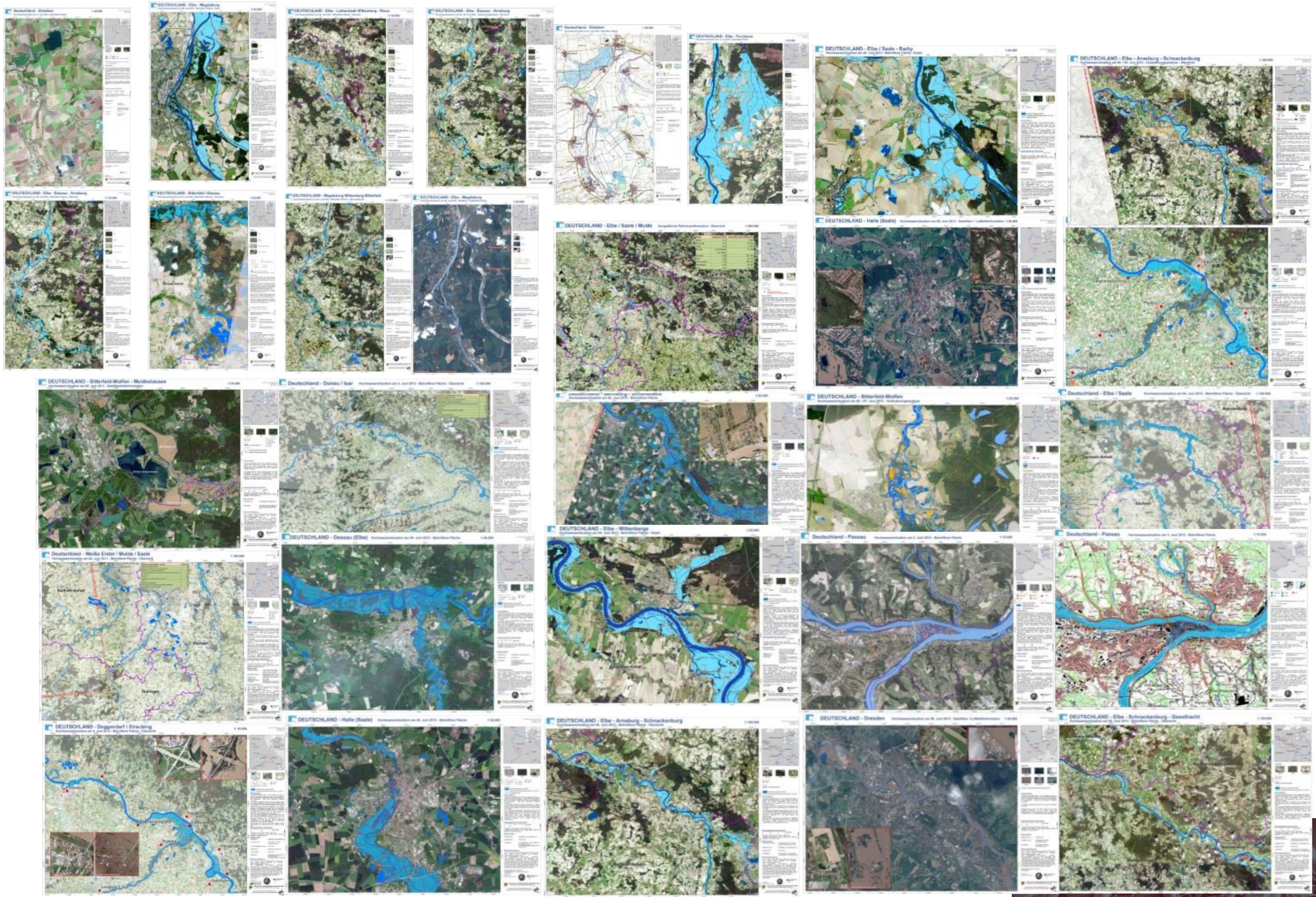
Über 50 Kartenprodukte für 2013



Informationen zu EGSIEM

Newsletter

No. 1
April 2015

EGSIEM

European Gravity Service for Improved Emergency Management

Courtesy NASA/JPL Caltech

Inside this issue:

WELCOME TO EGSIEM

The **European Gravity Service for Improved Emergency Management (EGSIEM)** project, which is funded by the Horizon2020 Framework Program for Research and Innovation of the European Union, aims at using gravity field analysis for forecasting and mapping of hydrological extremes like large-scale droughts and flood events. The project is funded for three years, from 2015 to 2017. The leader of the project is the Astronomical Institute of the University of Bern.

EGSIEM CONSORTIUM
- Universität Bern, Switzerland
- Université du Luxembourg, Luxembourg
- Helmholtz-Zentrum Potsdam Deutsches GeoForschungsZentrum, Germany
- Technische Universität Graz, Austria
- Leibniz Universität Hannover, Germany
- Centre National d'Études Spatiales, France
- Deutsches Zentrum für Luft- und Raumfahrt e.V., Germany
- Géode & Cie, France

Photo: M.Tognola
EGSIEM kick-off meeting, 13.-14.January 2015, Bern

Goals and Ambitions

At the heart of the EGSIEM project is the idea that *better knowledge yields better decision-making.* Towards this idea the 8 consortium members of EGSIEM aim to derive improved products from the **Gravity Recovery and Climate Experiment** (GRACE) satellite mission. The current latency and complex nature of the data derived from the GRACE mission (a dual satellite mission of NASA and the German Aerospace Center, which has been making detailed measurements of Earth's gravity field variations since March 2002) makes the data of limited value for monitoring and forecasting applications. Currently Geodesists need to wait approximately 2 months from observation by GRACE until the data is processed for access and examination. EGSIEM will improve the data latency, will perform the complex processing, and will provide a simple to use web interface (based on the ***EGSIEM plotter*** provided by Géode & Cie). The data will be freely available for users.

The impact of EGSIEM

The main goal of the project is to improve the availability of data for users, especially in terms of better drought and flood forecasting. EGSIEM will reduce the timeframe to 5 days. As the data is going to be made freely available (via our project website egsiem.eu), the users may use them also for other applications as well. EGSIEM aims to improve existing monitoring products. The improvement in flood and drought monitoring will benefit Europe and also other countries. For example the impact of the 2009 flood in Namibia which claimed 131 lives and displaced 445,000 people could have been better anticipated by the existence of concise warning products.

News und Updates über das Projekt werden regelmässig über den 4x pro Jahr heraus-gegebenen EGSIEM Newsletter publiziert. Sämtliche Ausgaben sind erhältlich auf der Website www.egsiem.eu

EGSIEM ist in den social media:
https://twitter.com/EGSIEM
www.facebook.com/egsiem
https://egsiem.wordpress.com

Vielen Dank für die Aufmerksamkeit!