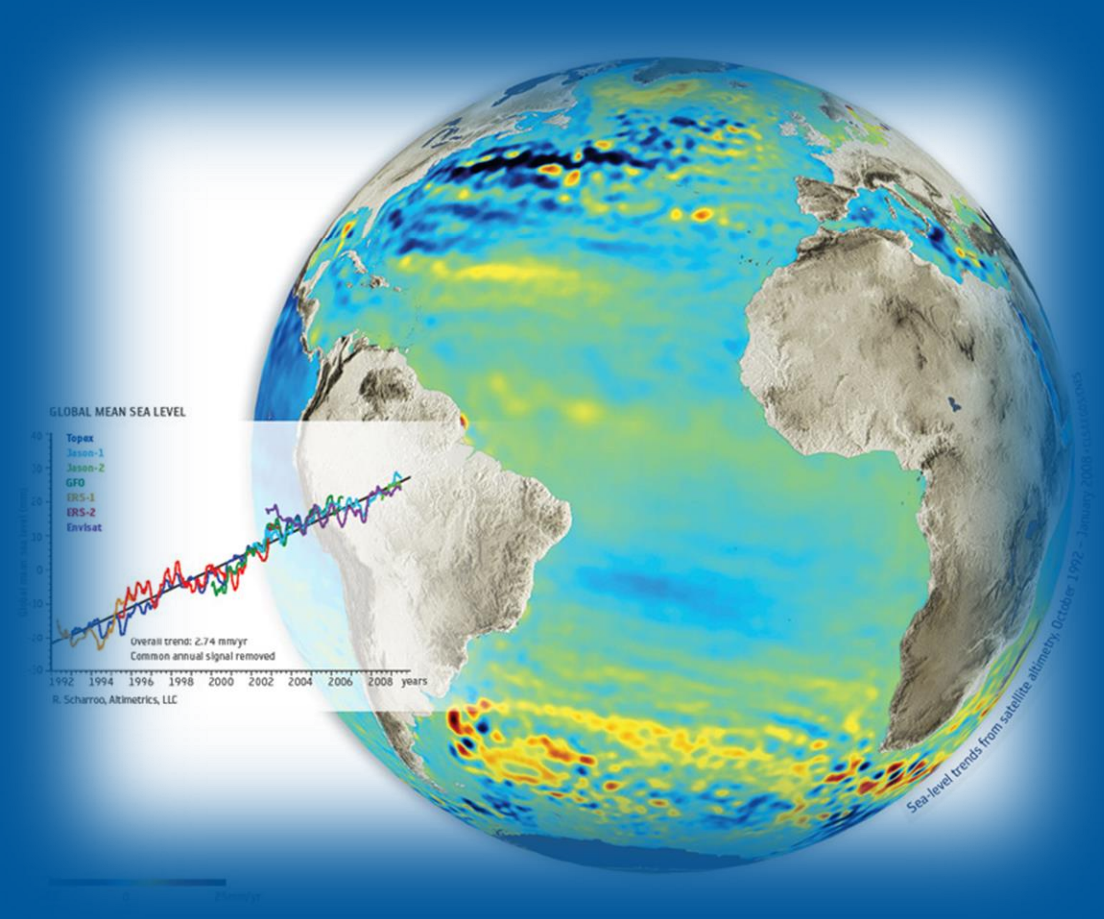
Geodätische Satellitenmessungen von Naturgefahren und des Globalen Wandels



Prof. Dr. Harald Schuh

Direktor Department 1: Geodäsie

Deutsches GeoForschungsZentrum Helmholtz-Zentrum Potsdam

Potsdam, 12. Februar 2021

Kolloquium der Leibniz-Sozietät

Die Geodäsie innerhalb der Geowissenschaften

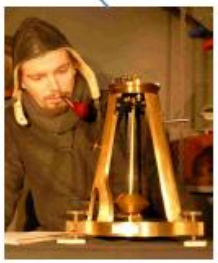
Geologie | Geophysik | Geodäsie | Geochemie | Geographie

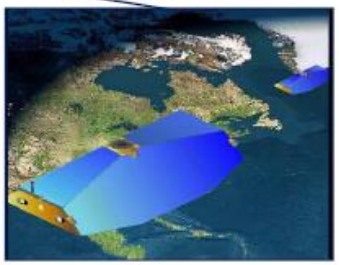
(Beschreibung, phys. Modelle) (Stoffbestand, graph. Darstellung)

Ausmessung und Abbildung der Erdoberfläche





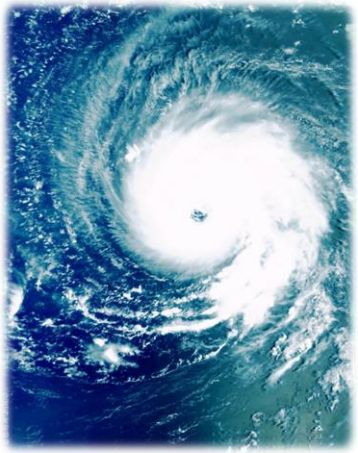


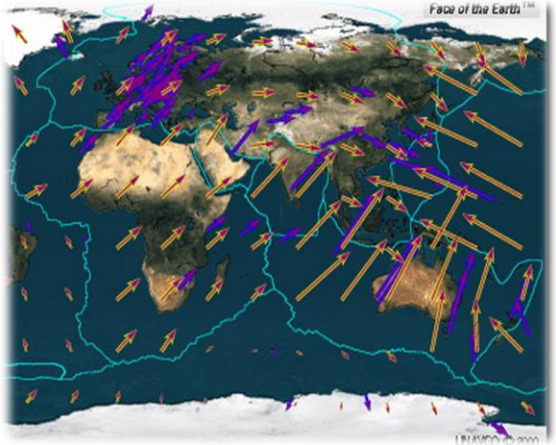


geometrisch	gravimetrisch
Theodolit, Radioastronomie, Laser, GPS	Pendel, Freifall, Radaraltimetrie, Satelliten

Voraussetzung: Ein eindeutiges, festes Bezugssystem (Archimedes: „Gebt mir einen festen Punkt im All und ich heble euch die Welt aus den Angeln“)

Herausforderungen an die Geodäsie: Veränderungen in Bruchteilen von Sekunden bis zu Millionen Jahren





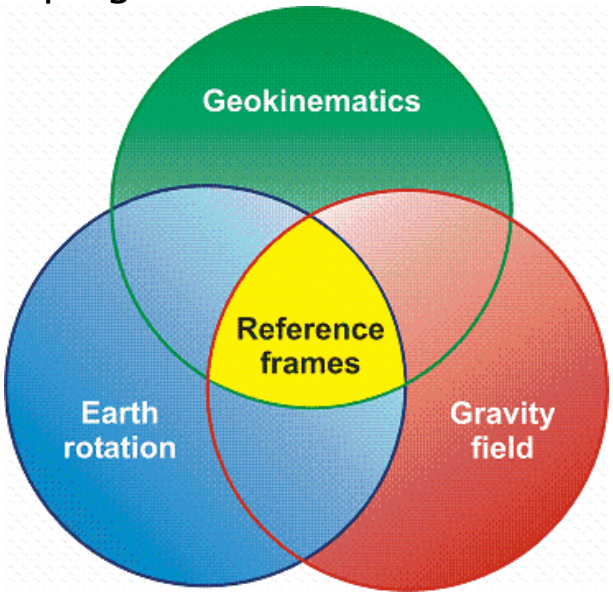
Aufgaben der Geodäsie

Geodäsie beschäftigt sich mit der Ausmessung, Darstellung und Untersuchung der

1. **Geometrie der Erde**
   Topographie, Bathymetrie, Eisoberfläche, Meeresspiegel

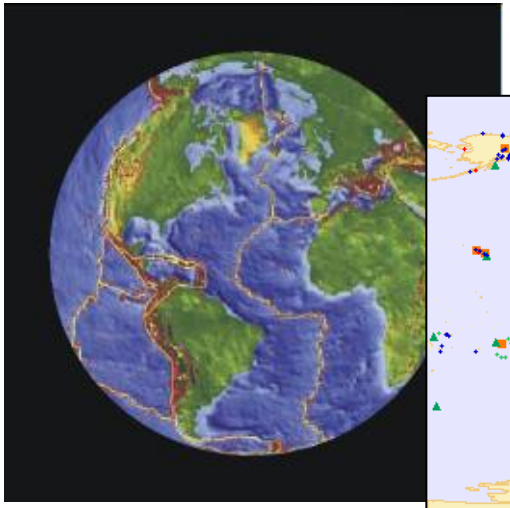
2. **Erdrotation und -orientierung**
   Polbewegung, Erdrotation, Nutation, Präzession

3. **Schwerefeld der Erde**
   Schwere, Geoid

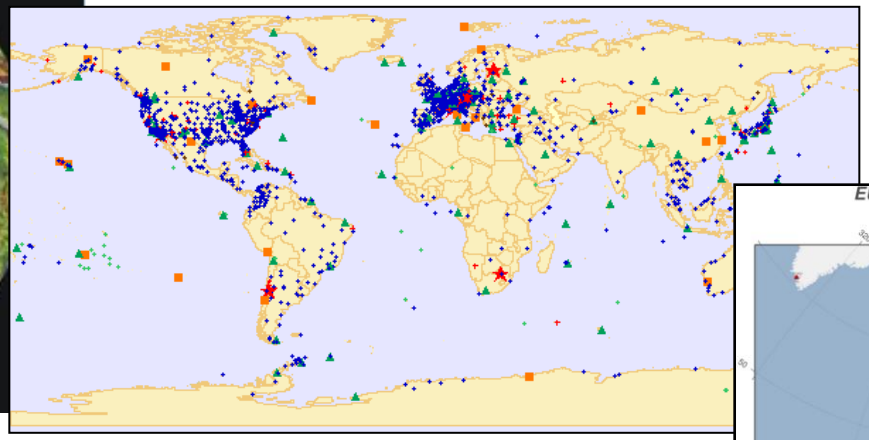


http://www.iag-aig.org/

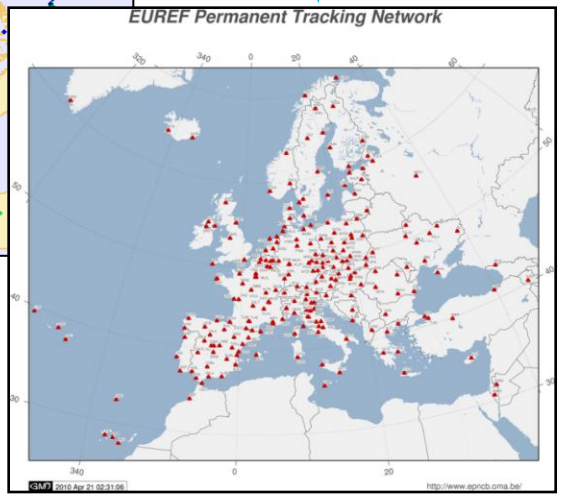
Referenzrahmen, vom Großen ins Kleine



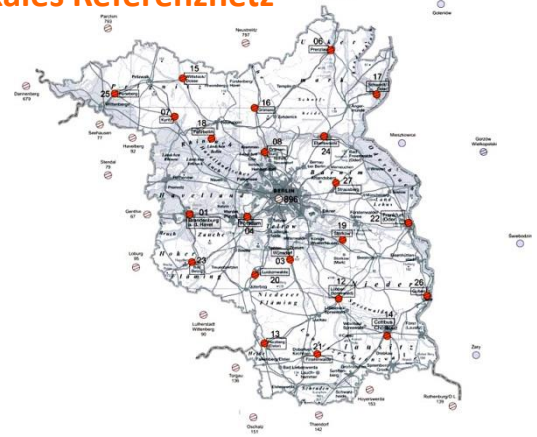
ITRF2014



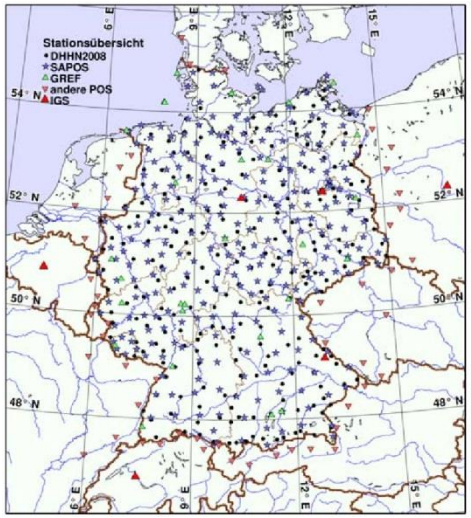
ETRS89



Lokales Referenznetz



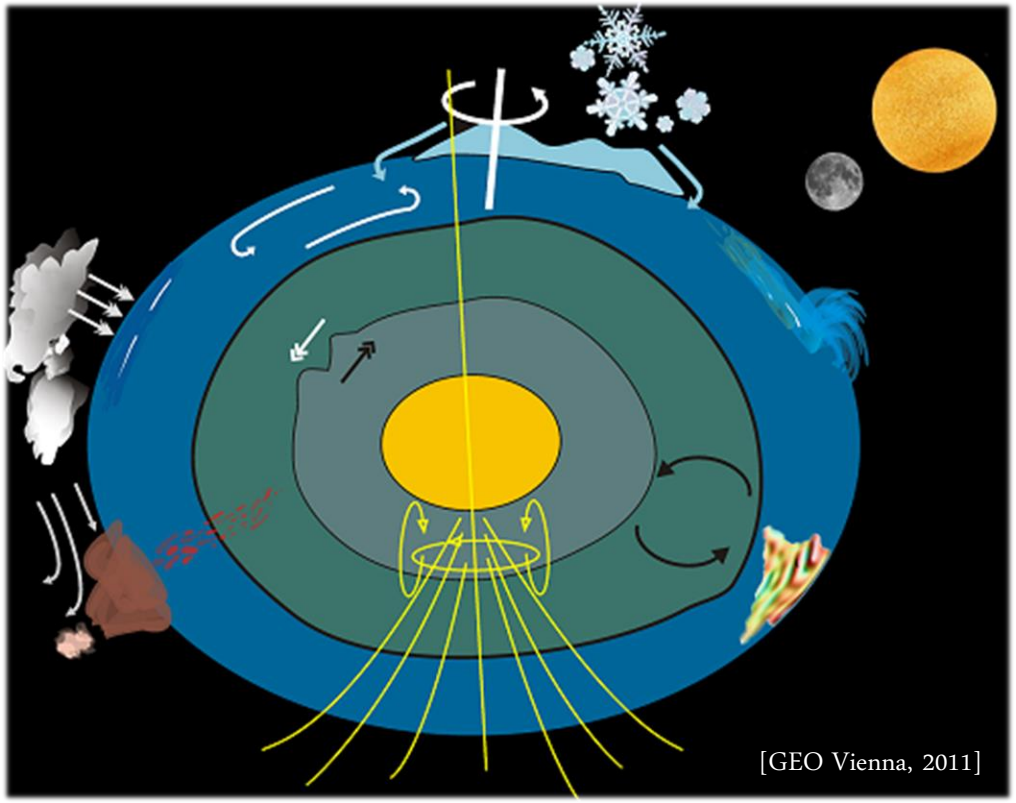
GREF



Teilsysteme der Erde (I)

Geodätische Messgrößen sind eng mit den Massenverlagerungen zwischen den Teilsystemen der Erde und den jeweiligen Wechselwirkungen verknüpft:

- feste Erde
- Atmosphäre
- Hydrosphäre
- Kryosphäre
- Biosphäre
- Anthroposphäre
- (Weltall)



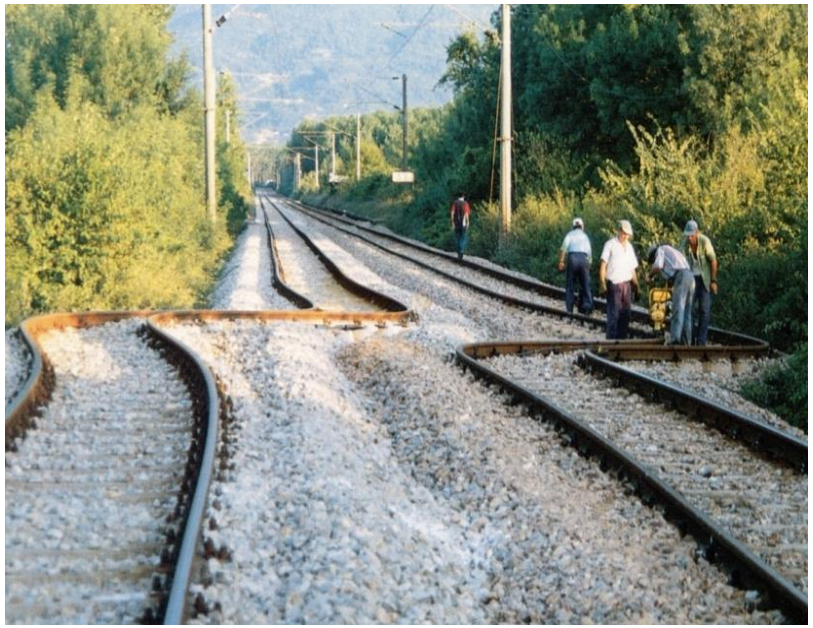
Geometrie und Deformation der Erde

Alles ist in Bewegung!

Problem und Faszination der Geodäsie

Beispiele:

- Erdrotation
- Gezeiten der festen Erde
- Tektonische Plattenbewegung
- Erdbeben
- Globales Wettergeschehen
- Meeresspiegeländerung
- Auflasteffekte (Eis, Ozean, Atmosphäre)

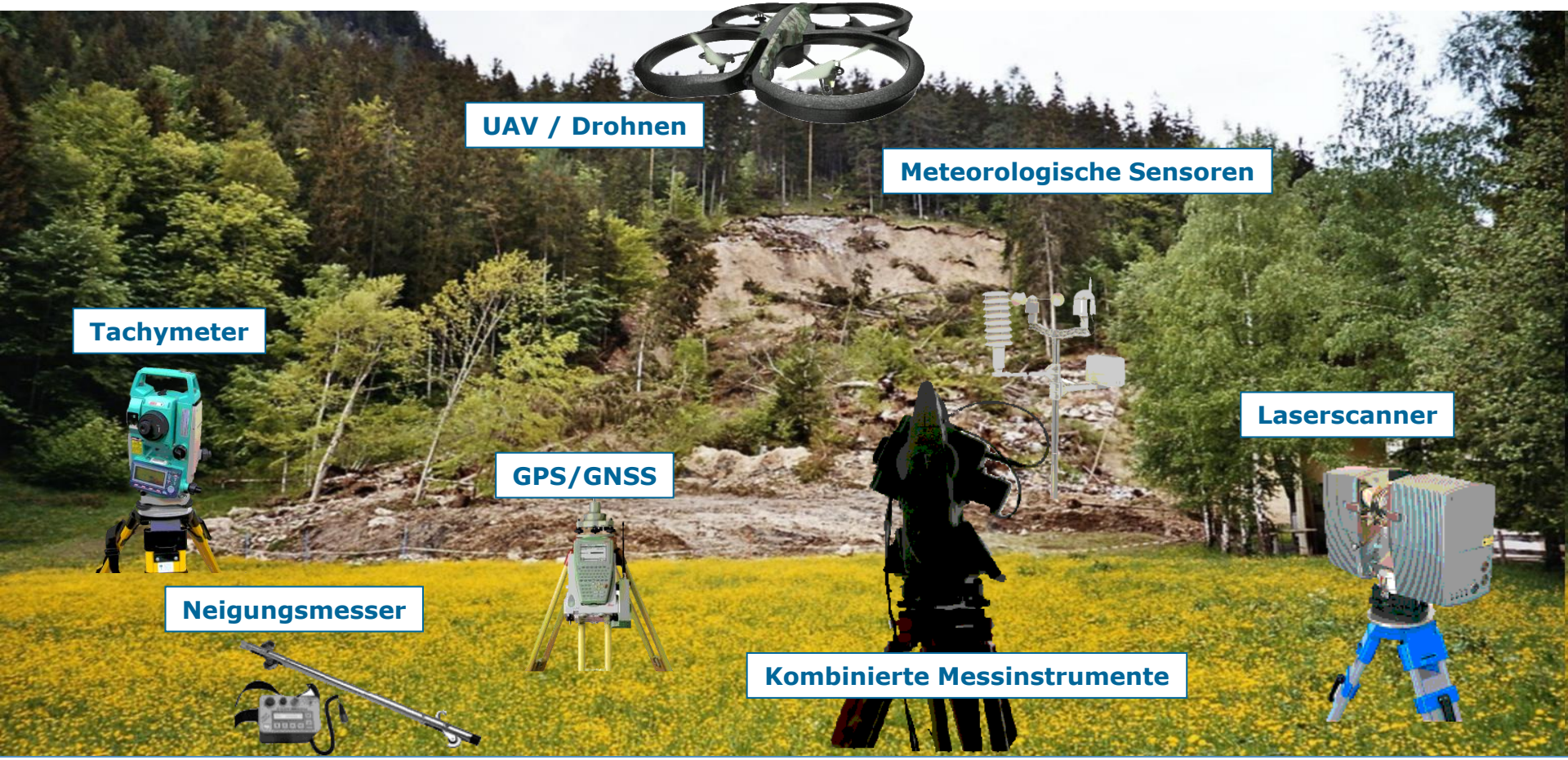


(Türkei, 2007)

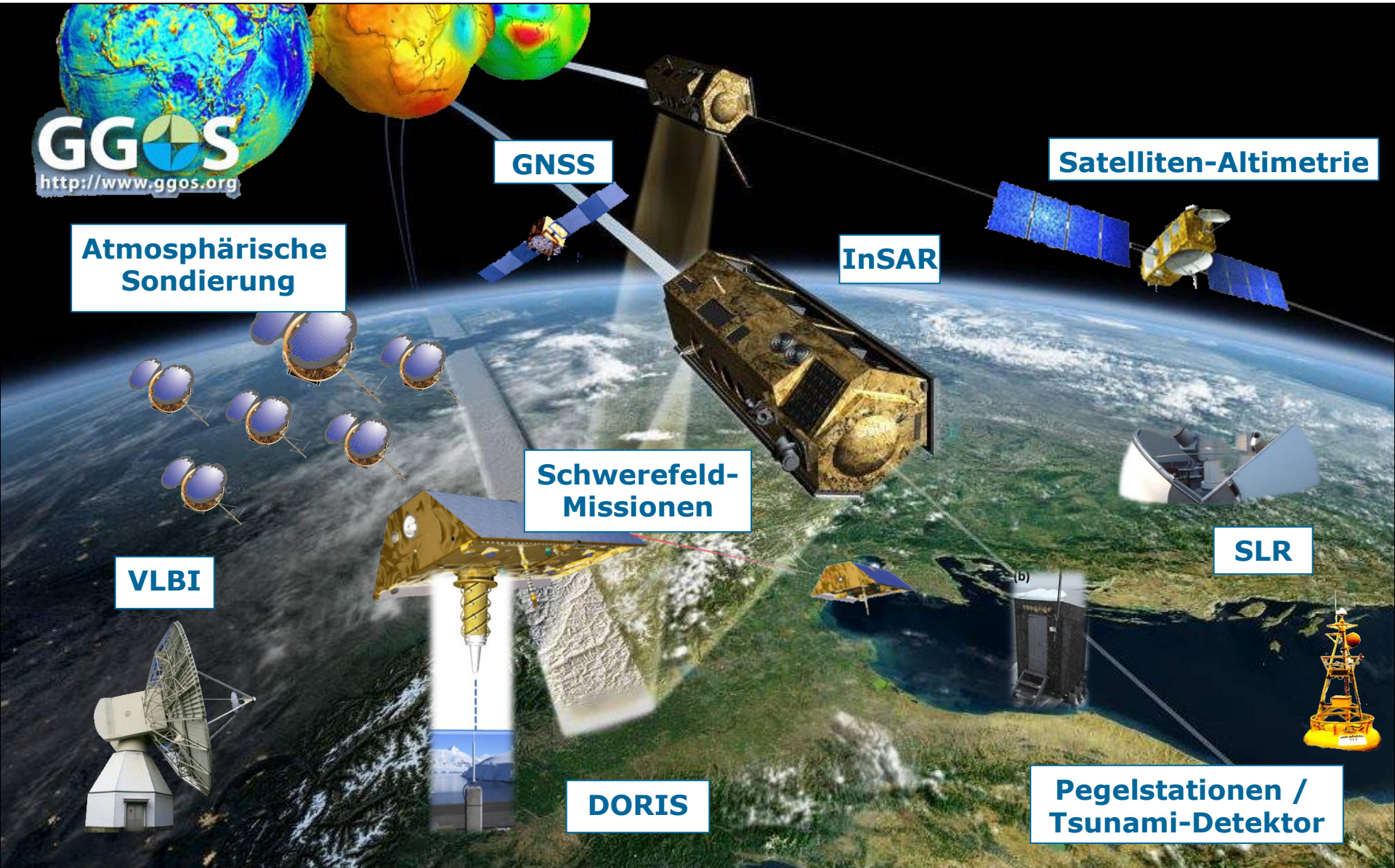
Kontinuierliches Monitoring ist unabdingbar!

Geodätisches Monitoring: lokal & regional

Zuverlässige Bestimmung von Veränderungen der Geometrie, Position und Orientierung von Objekten im Raum



Geodätisches Monitoring: global



GGOS (Global Geodetic Observing System) – Ziele

- **1 mm für Positionen und 0.1 mm/Jahr für Geschwindigkeiten** auf globalen Skalen (für den ITRF)
- **Kontinuierliche Messungen** (Zeitreihen für Erdrotationsparameter, Stationspositionen und Entfernungen)
- Messungen in **genäherter Echtzeit**
- **Höchste Zuverlässigkeit** und **Redundanz**
- **Geringe Kosten für** Bau und Betrieb der **geodätischen Infrastruktur**

First geospatial UN resolution

Photo: Kyoung-Soo Eom

UN General Assembly, 26 February 2015

Global Geodetic Reference Frame for Sustainable Development (GGRF) resolution

- *No. A/69/266 –*

- adopted by the United Nations (UN) General Assembly on 26th of Feb, 2015
- co-sponsored by 52 Member States:

  *Argentina, Australia, Belgium, Brazil, Bulgaria, Canada, China, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Ethiopia, **Fiji**, Finland, France, Georgia, Germany, Greece, Hungary, Ireland, Jamaica, Japan, Lithuania, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Papua New Guinea, Philippines, Poland, Portugal, Republic of Korea, Samoa, Slovenia, Solomon Islands, Spain, Sweden, Tunisia, Tuvalu, United Kingdom and Great Britain and Northern Ireland, United States of America and Vanuatu*

UN resolution no. 69/266 on the '*importance of geodetic reference frames*'

United Nations A/RES/69/266

General Assembly

Distr.: General
11 March 2015

Sixty-ninth session
Agenda item 9

Resolution adopted by the General Assembly on 26 February 2015

[*without reference to a Main Committee (A/69/L.53 and Add.1)*]

69/266. A global geodetic reference frame for sustainable development

…

Recognizing also the economic and scientific importance of and the growing demand for an accurate and stable global geodetic reference frame for the Earth…

…

Encourages Member States and relevant international organizations to enhance global cooperation …

…

2015 TIME FOR GLOBAL ACTION FOR PEOPLE AND PLANET

PRESS RELEASE

UN General Assembly urges sharing of geospatial data to benefit people and planet

26 February, New York – The science that supports the precise pinpointing of people and places should be shared more widely, according to the United Nations General Assembly as it adopted its first resolution recognizing the importance of a globally-coordinated approach to geodesy – the discipline focused on accurately measuring the shape, rotation and gravitational field of planet Earth.

Geodesy plays an increasing role in people's lives, from finding disaster victims to finding directions using a smart phone

… first resolution recognizing the importance of a globally-coordinated approach to geodesy – the discipline focused on accurately measuring the shape, rotation and gravitational field of planet Earth.

standards and conventions.

Co-sponsored by 52 Member States, the resolution was originally put forward by Fiji. Ambassador Peter Thomson, Fiji's Permanent Representative to the United Nations, explained that, as a Small Island Developing State, Fiji is vulnerable to increasingly severe natural disasters, sea-level rise and other problems triggered by climate change, but uses geodesy data to plan as best as it can. "We fully realize the importance of critical geospatial infrastructure and information in helping countries and decision-makers make more informed, evidence-based decisions on mitigation and preparedness," Ambassador Thomson stated.

Fiji also highlighted the power of precise positioning for United Nations peacekeeping, for

2016: New UN permanent **Sub-Committee on Geodesy**

"The International Association of Geodesy (IAG) welcomes and unreservedly appreciates the establishment of a United Nations Sub-Committee on Geodesy. This advancement will augment the impacts of geodesy on the political level as well as its visibility in society.

IAG and its Global Geodetic Observing System (GGOS) as promoting geodetic science and coordinating the international geodetic services will strongly support the new Sub-Committee whenever necessary and wherever possible."

Prof. Dr. Dr. h.c. Harald Schuh, President of the IAG

Roadmap for the Global Geodetic Reference Frame

- a principle-based briefing document for national governments
- aims to enhance the GGRF and make it more sustainable

follow the

UN-GGIM Global Geodetic Reference Frame Working Group

on twitter: @unggrf - and check out www.unggrf.org

Kategorien von Naturereignissen

Plötzlich

- Erdbeben (*lokal, regional)*
- Fels- und Bergsturz *(lokal)*
- Hangrutschung *(lokal)*
- Muren *(lokal)*

Sich abzeichnend

- Vulkanausbruch *(regional, global)*
- Tsunami *(lokal bis überregional)*
- Hurrikan, Sturm *(regional)*
- Hochwasser *(regional)*

Langfristig

- Klimaveränderungen (Meeresspiegel, Temperatur, Wettergeschehen, Atmosphärenaufbau, etc.) *(global)*
- Tektonische Plattenbewegung *(global)*

Neue Entwicklungen in der Geodäsie

Fachübergreifende Themen

- *Seismo-geodesy*
- *Volcano-geodesy*
- *Atmosphere geodesy*
- *Marine geodesy*
- *Cryosphere geodesy*
- *Geodesy for climate research*

Neue Technologien

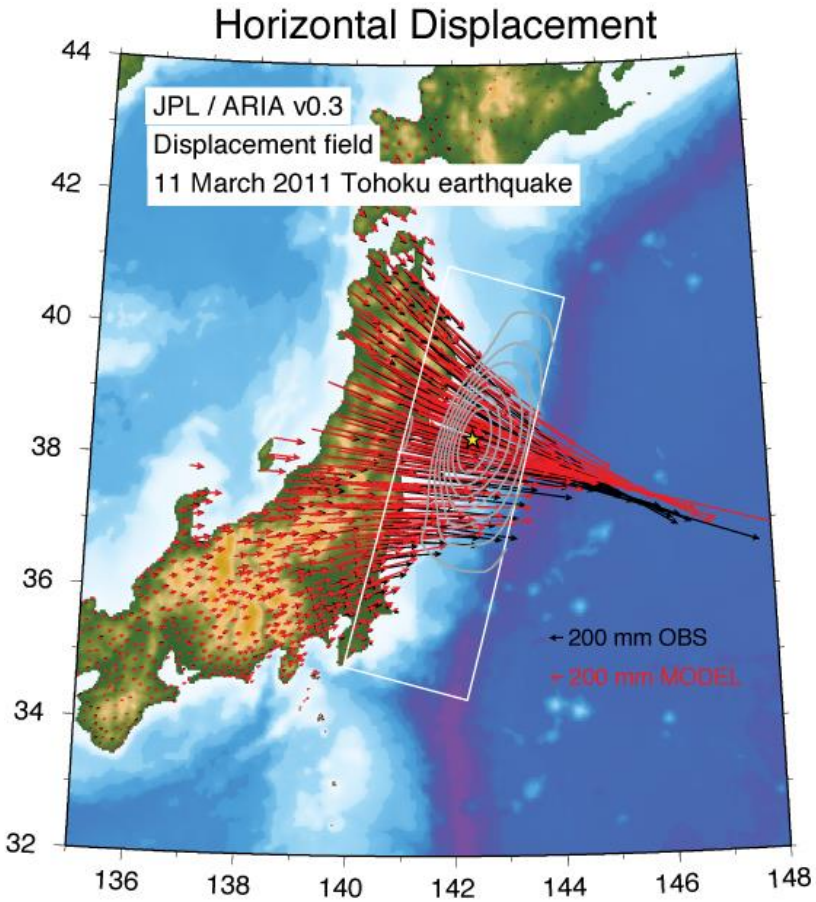
- *Use of quantum technology*
- *Low cost mass sensors (cell phones, U-BLOX, MEMS, …)*
- *Cloud computing ('Big Data')*

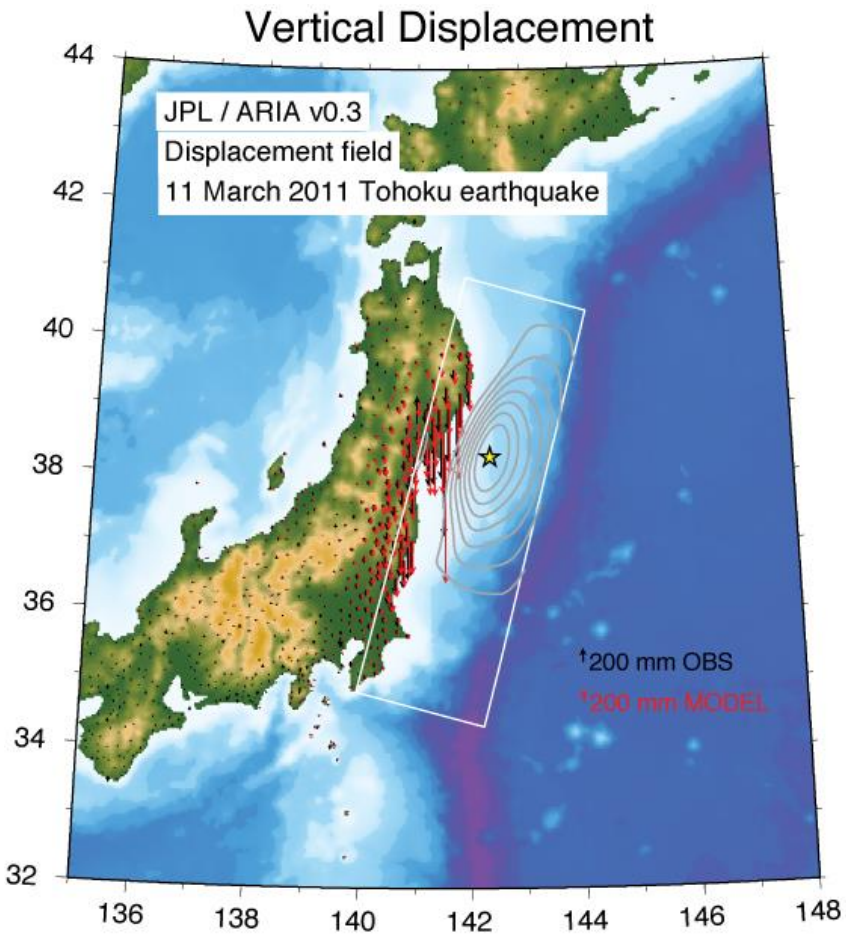
Neue Satellitenkonzepte

- *Rapid development in satellite technology, swarms of low cost mini-, micro-, nano-, pico-, and even smaller satellites*
- *Integration of MEOs (like GPS, Galileo) with GEOs and LEOs*

Plötzlich …

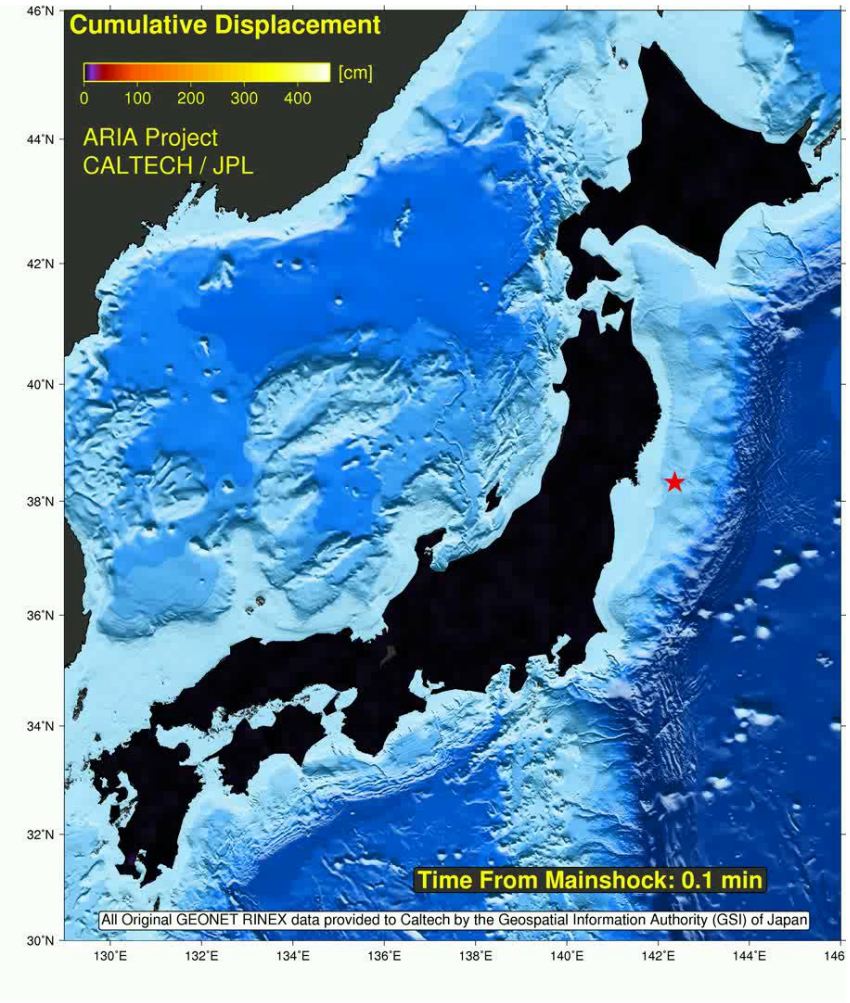
M9.0 Erdbeben Tōhoku – 11. März 2011 (I)





Datenquelle: GEONET, Geospatial Information Authority (GSI) Japan
Prozessiert von: Jet Propulsion Laboratory (JPL) und Caltech

M9.0 Erdbeben Tōhoku – 11. März 2011 (II)



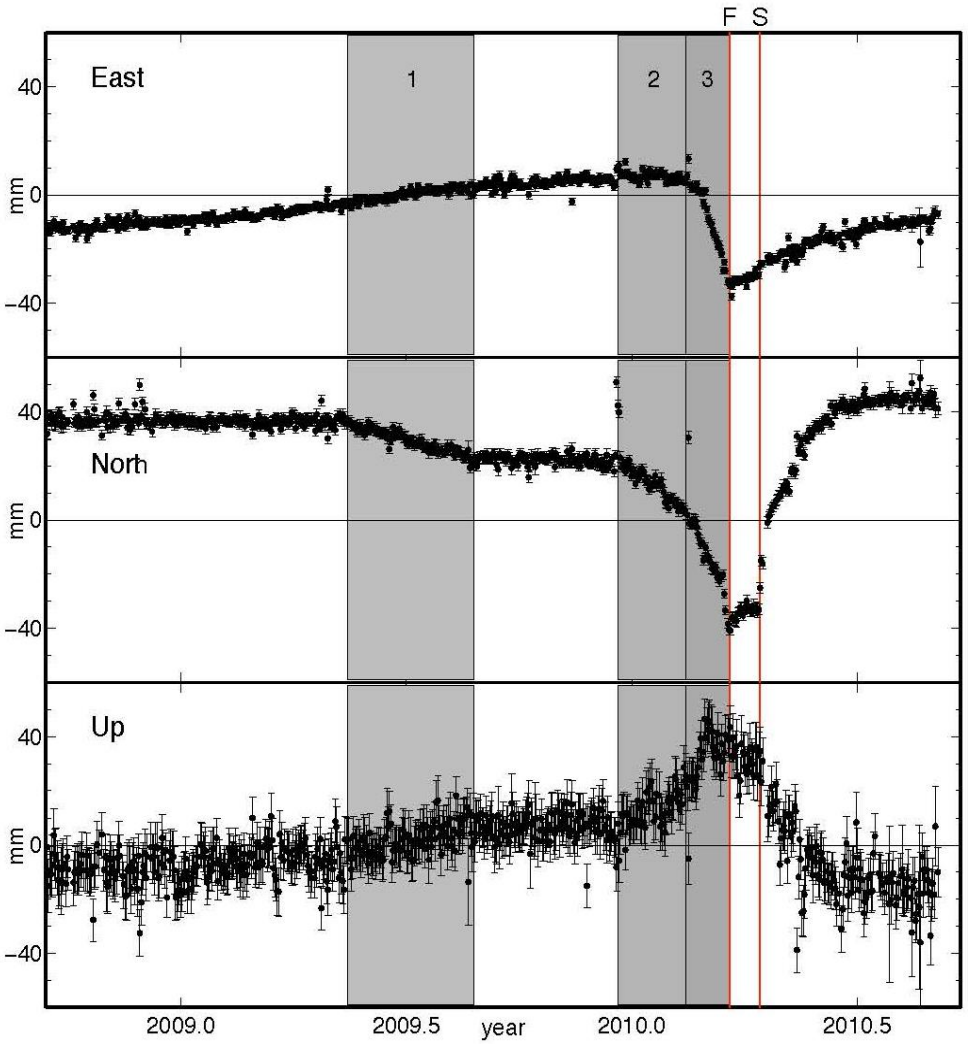
ftp://sideshow.jpl.nasa.gov/pub/usrs/ARIA/

Sich abzeichnend …

Monitoring des Eyjafjallajökull mit GPS (II)

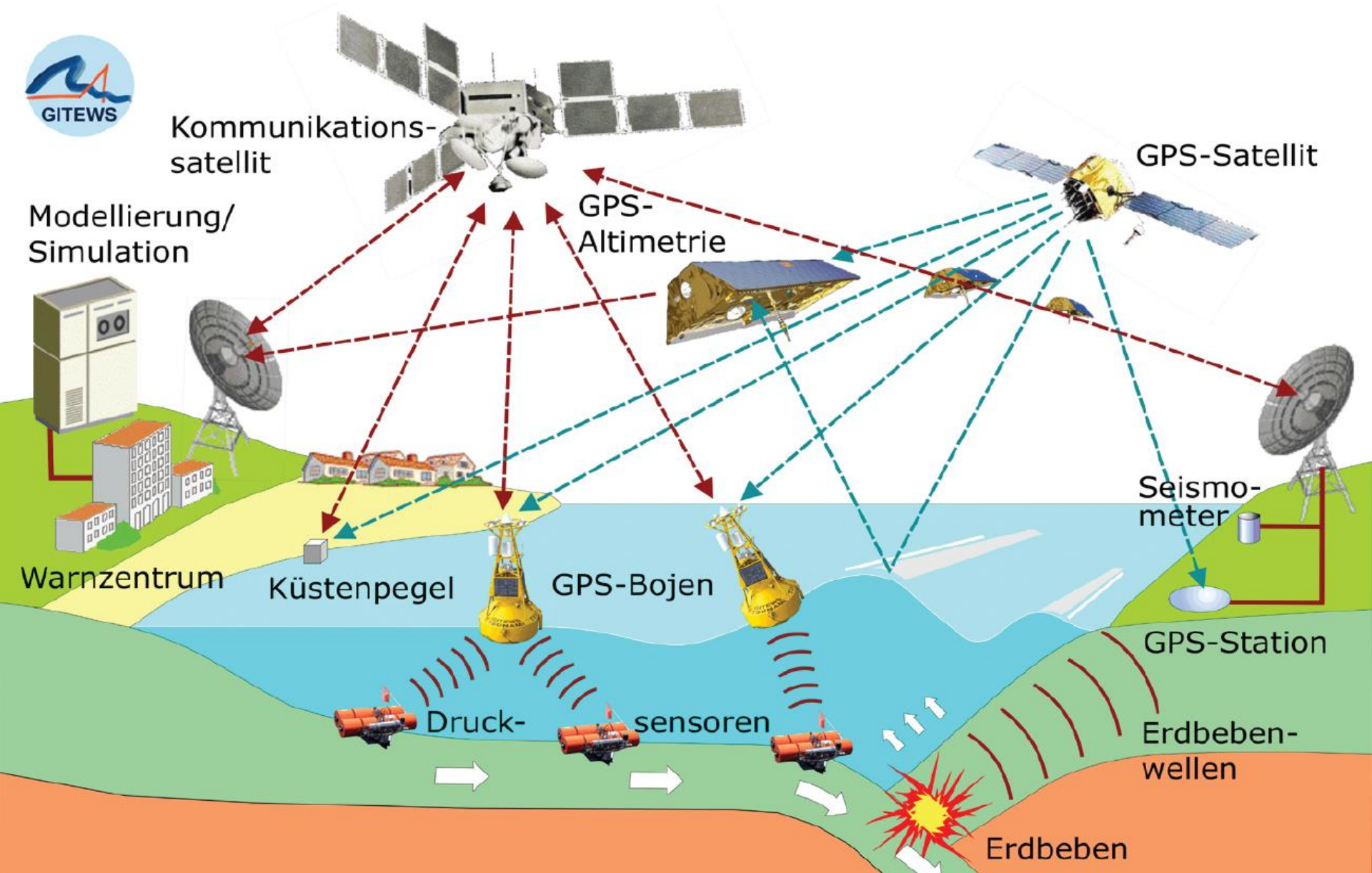
- GPS-Zeitreihe der Station THEY (südwestlich des Eyjafjallajökull)
- relativ zur Station REYK (Reykjavík)

- graue Flächen (Intrusions-Phasen)
- rote Linie F (Flankeneruption)
- rote Linie S (Gipfeleruption)



F Sigmundsson *et al. Nature* **468**, 426-430 (2010) doi:10.1038/nature09558

Tsunami Frühwarnsystem GITEWS (II)



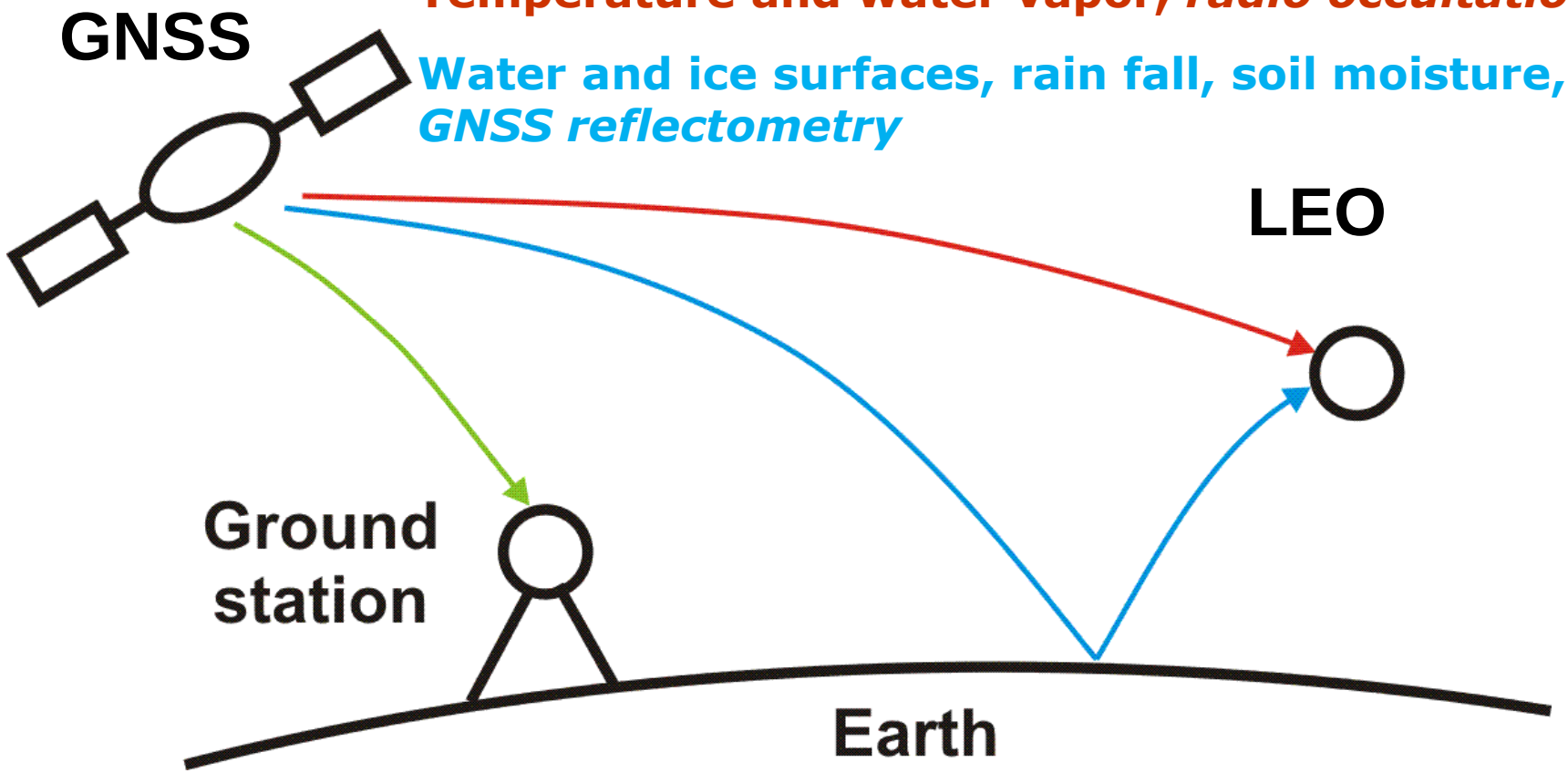
Atmosphere geodesy: GNSS remote sensing

Three applications:

Water vapor, *GNSS ground-based measurements*

Temperature and water vapor, *radio occultation*

Water and ice surfaces, rain fall, soil moisture, *GNSS reflectometry*



Operationelles Wasserdampfmonitoring mit GNSS

Automatisierte Prozessierung von stündlichen GNSS-Daten von ~330 Stationen in Deutschland

Ergebnisse < 30 min nach Eingang der letzten Epoche ('near real time')

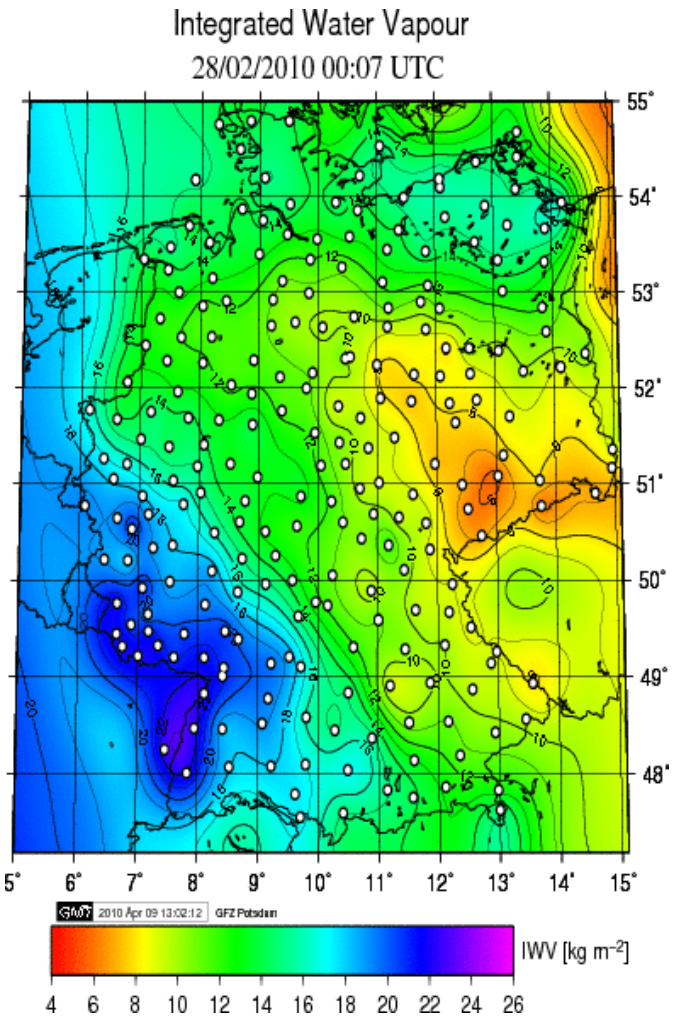
Hauptprodukt: *Zenith Wet Del*ay, integrierter Wasserdampf mit 15 min Auflösung

Neues Produkt: *Slant Total Delay* für 3D Wasserdampftomographie und Assimilation (MeteoFrance, UK MetOffice, Wetterdienste der Niederlanden, Dänemark & Deutschland)

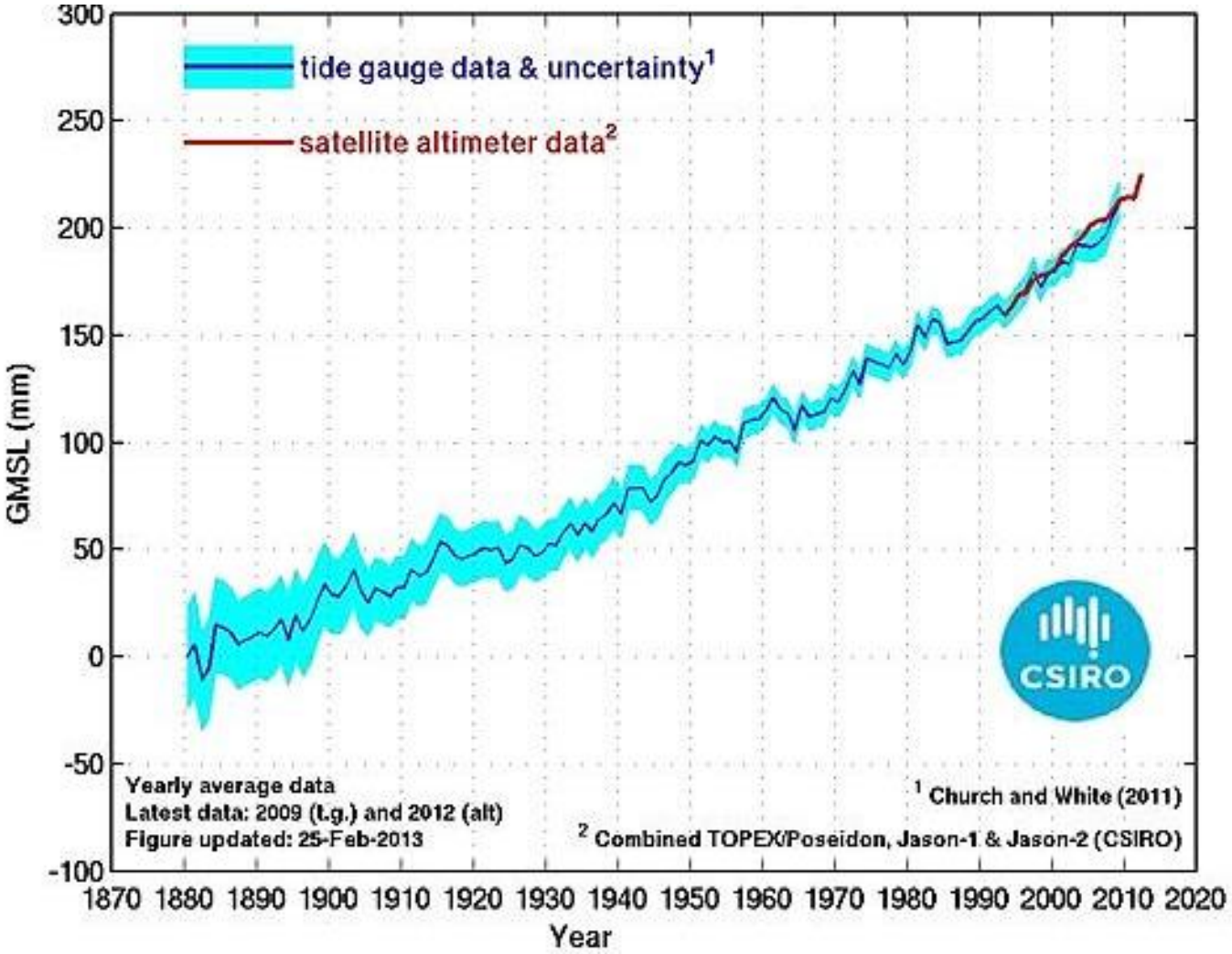
Genauigkeit: ~1-2 mm IWV

Anwendungen:
Wettervorhersage (um 30% verbessert), Atmosphärenmodellierung, Klimaforschung

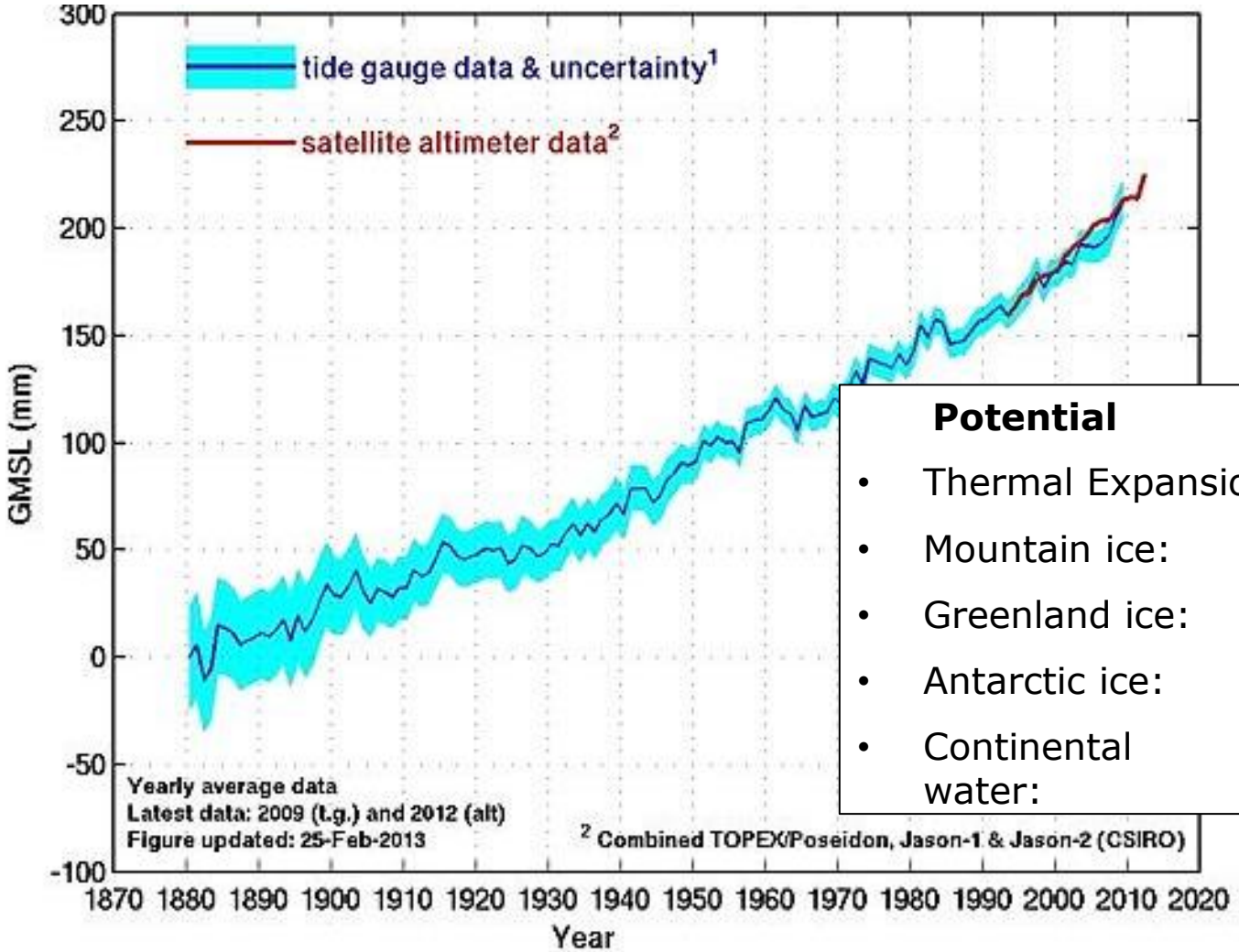
Weather Front Xynthia 28.02.2010



Marine Geodesy:
Anstieg des globalen Meeresspiegels von 1880 bis heute



Globaler Meeresspiegelanstieg
potentielle Beiträge (z.B. Schmelzen des Eises)



Potential

- Thermal Expansion (t): < 1 m
- Mountain ice: 0.5 m
- Greenland ice: 7 m
- Antarctic ice: 65 m
- Continental water: < 0.5 m

Satellitenaltimetrie

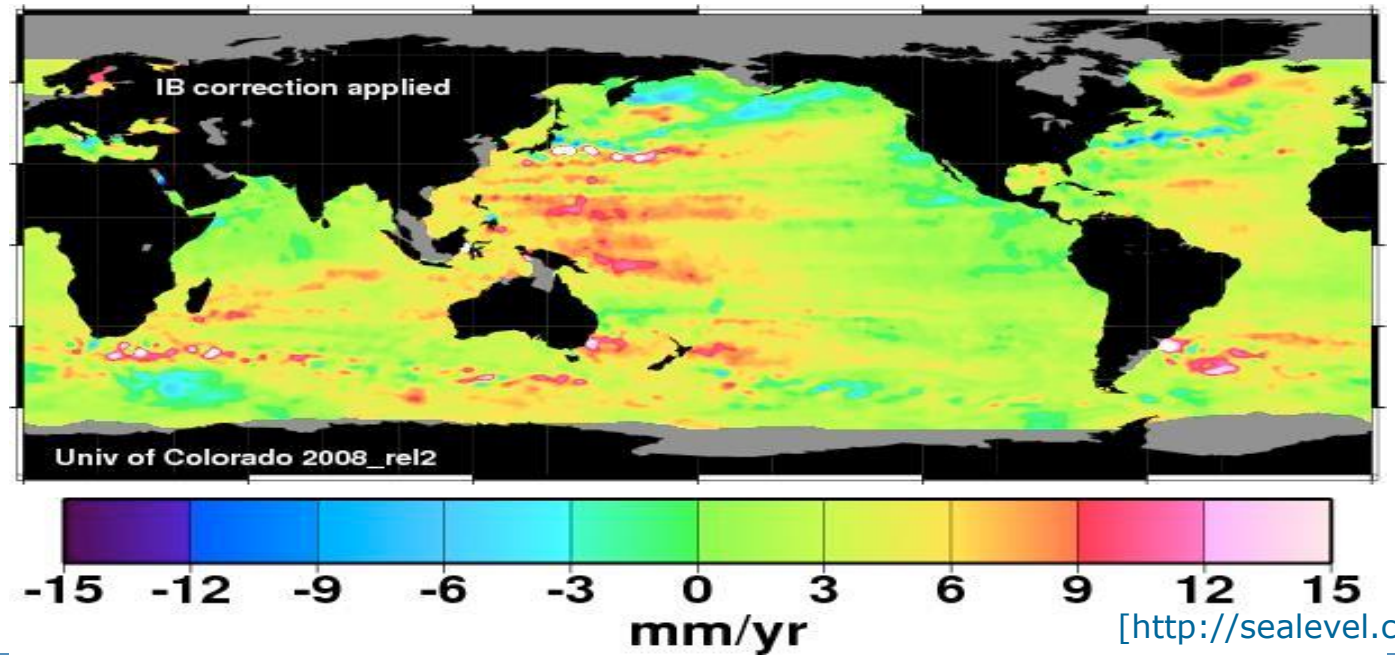
Messen der Meeresoberfläche mittels Radar-Altimeter

+ nahezu globale Abdeckung mit hoher Genauigkeit (~ cm)

- kurze Zeitserien (> 1993)

± Jason-1 hat eine Wiederholungsrate von 10 Tagen

- Kalibrierung der Altimeter-Drift mittels Pegelmessungen

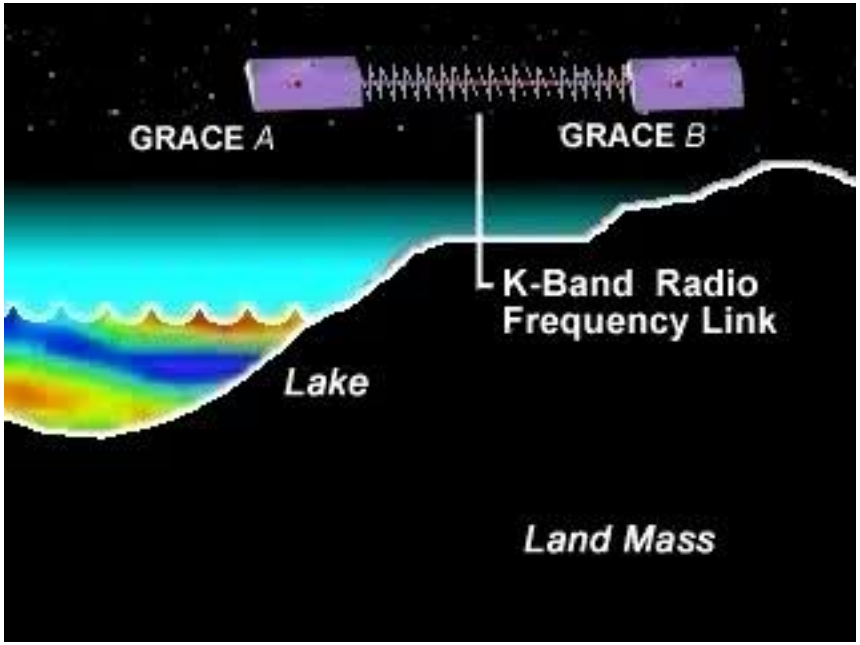


[http://sealevel.colorado.edu]

GRACE and GRACE-FO Twin Satellite Missions

GRACE Measurement Principle

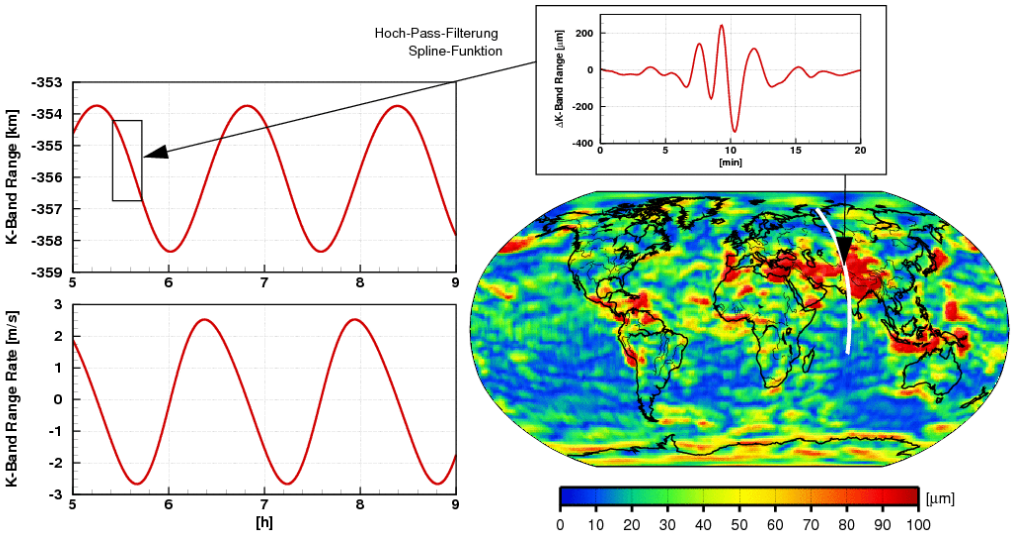
s = 220±50km



σ_s = few µm
(a tenth of the thickness of a human hair)
resp. temporal change
σ_s/dt = 100 nm/sec

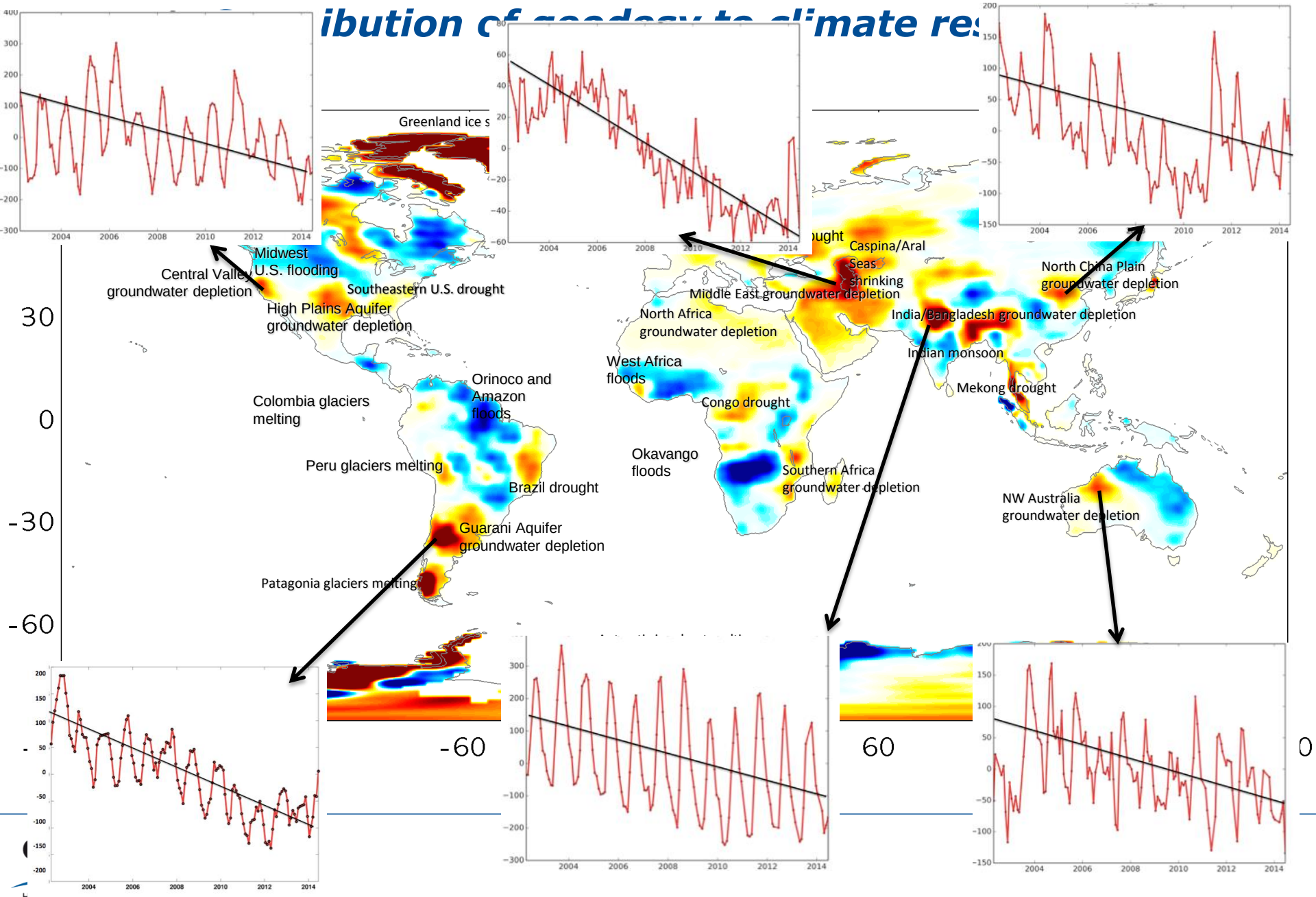
Left: 1/rev separation change (primarily flattening of the Earth): ±2km

Right: Observed mass change related distance variation: ±200 µm

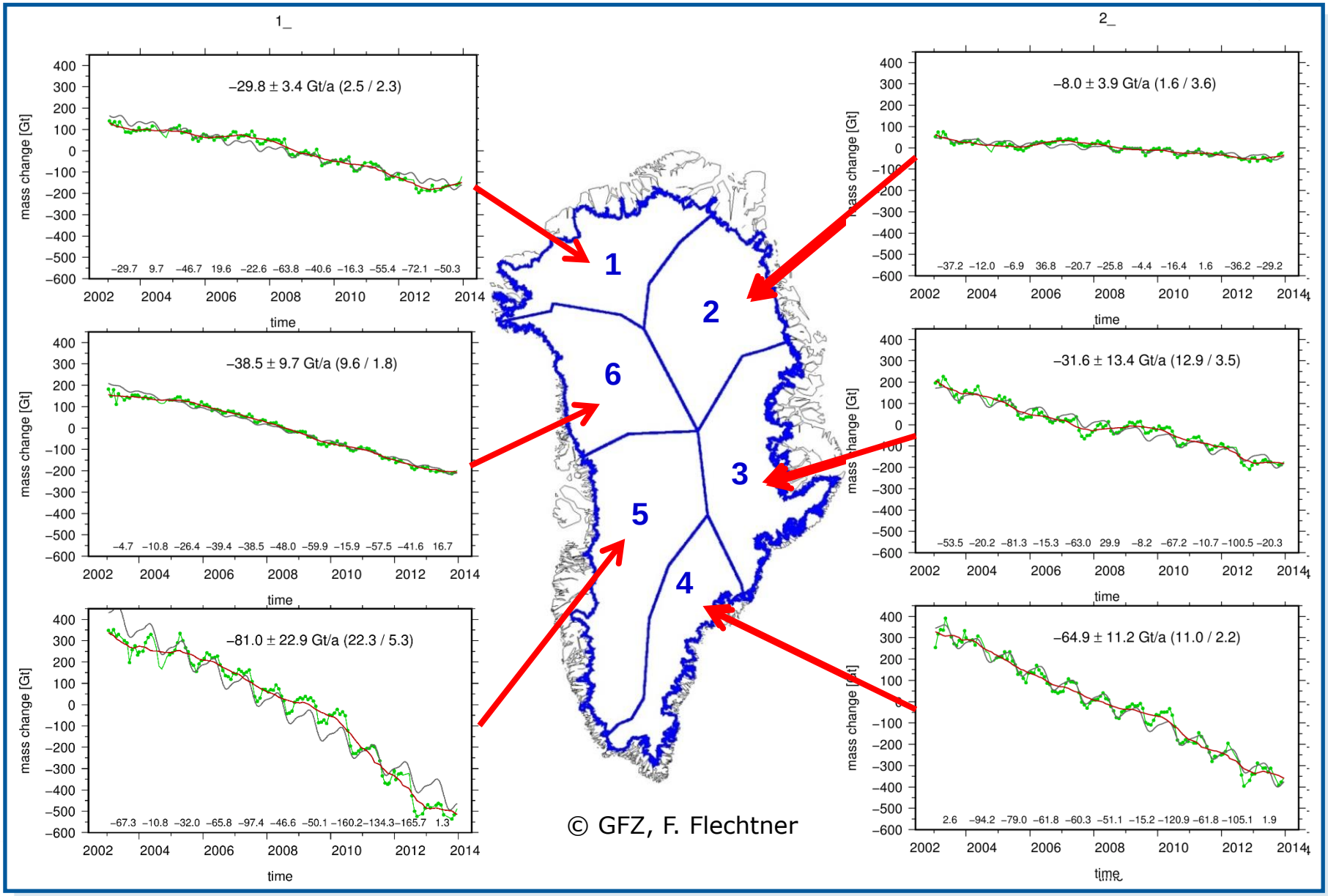


Trends in freshwater availability from GRACE (2002-2017)

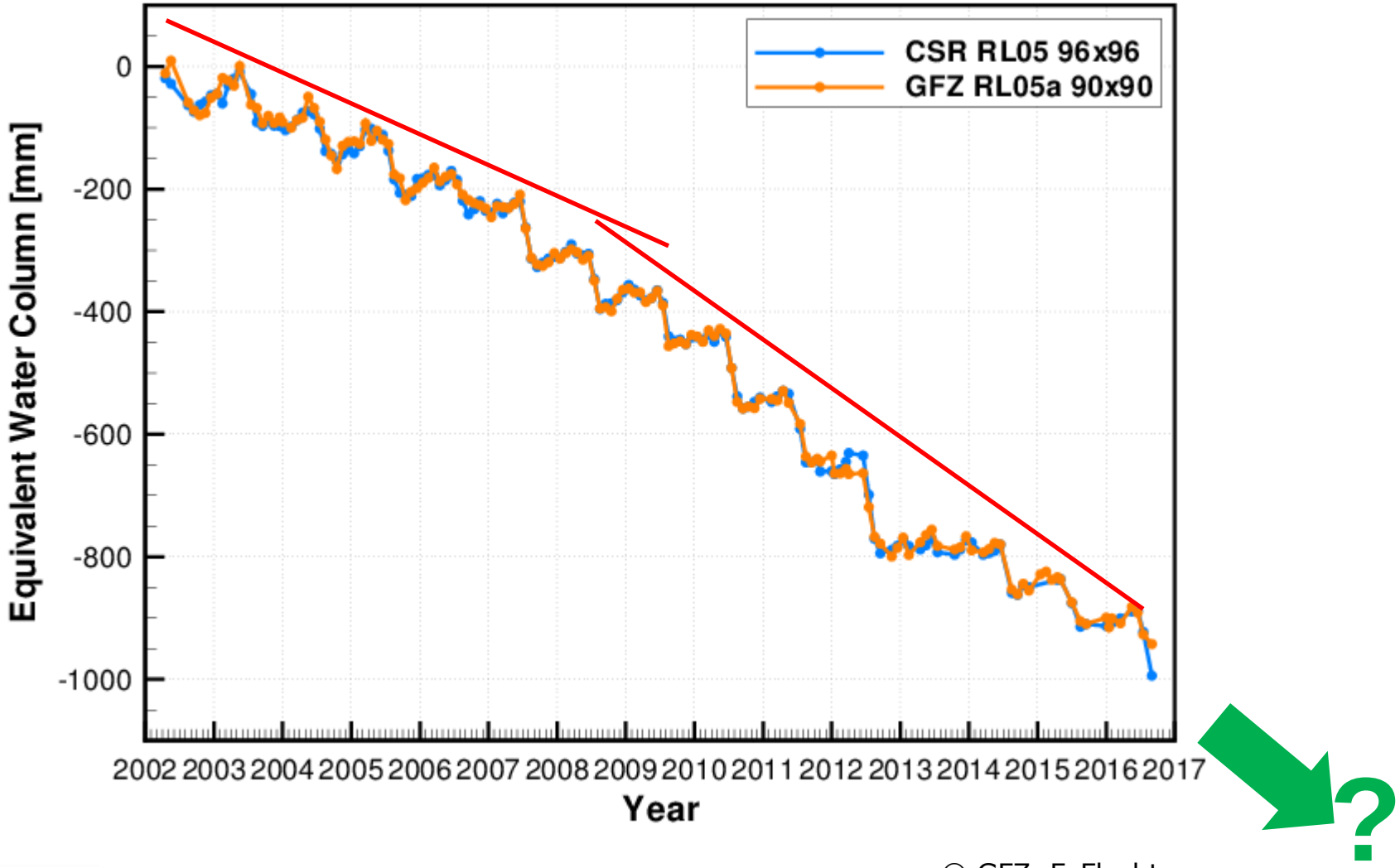
ibution c[illegible]ate re[illegible]



GRACE Anwendung: Eisbedeckung von Grönland



GRACE Applications
(Total) Greenland Ice Melting

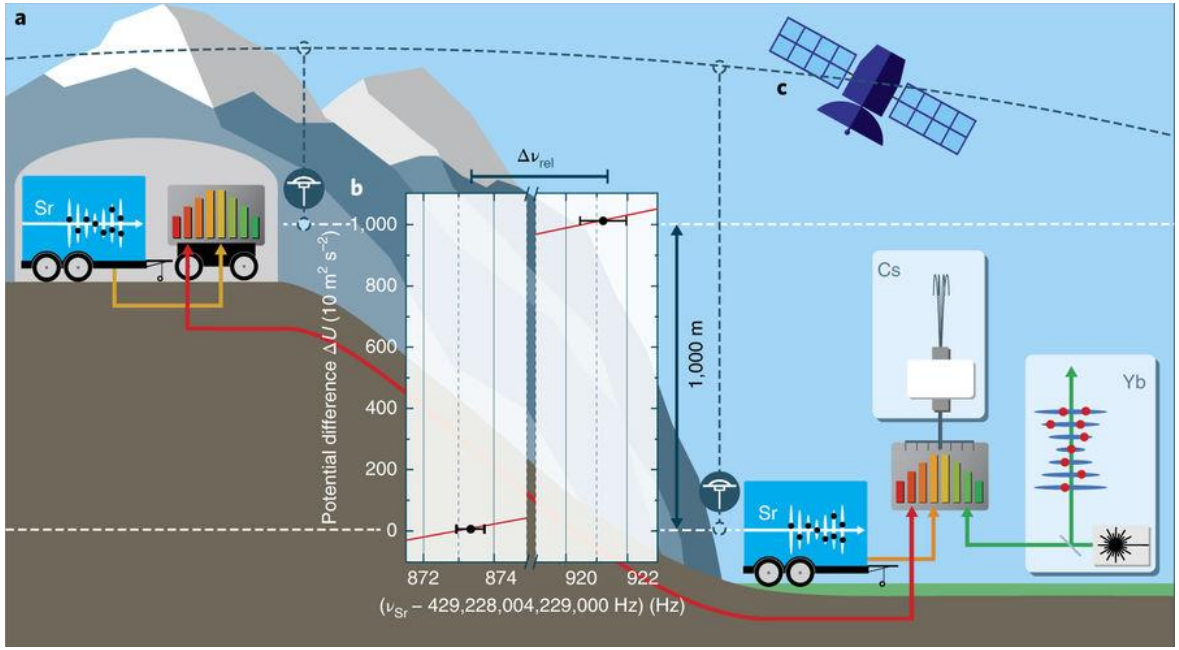


New technologies: use of quantum technology for geodesy

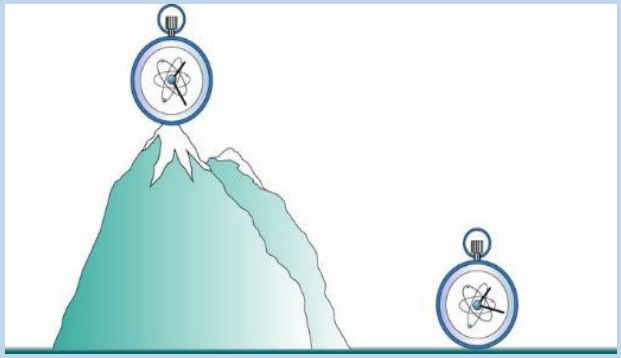
Transportable optical clocks for measuring height differences

Authors: Jacopo Grotti,…., Christian Voigt (GFZ), …

Nature Physics, 12 Feb 2018, doi:10.1038/s41567-017-0042-3



Excellent agreement between height differences from clock and from conventional geodesy: 0.19 m, but clock accuracy still two orders of magnitude below geodesy



From: **An optical clock to go**, summary on the article by Andrew D. Ludlow, *Nature Physics*, News & Views, published on 13 Feb 2018

New technologies (b)

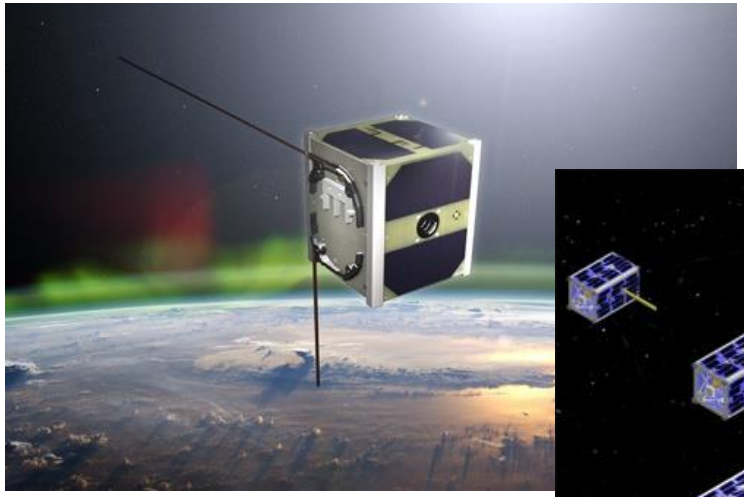
- Low cost mass sensors transmitting geodetic and geophysical data from billions of points to central units for continuous processing ('Big Data')

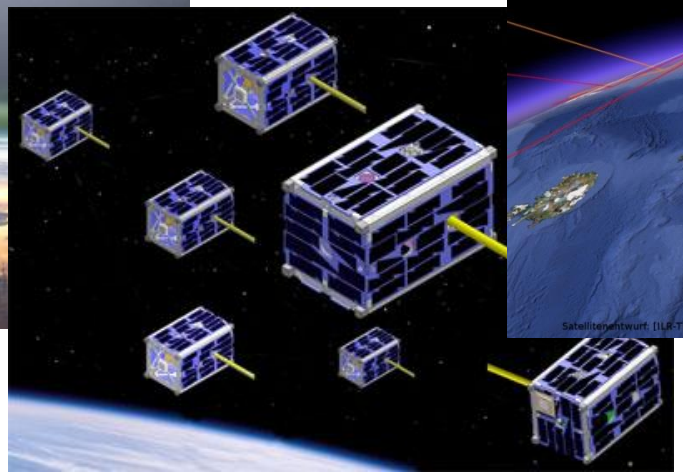
New technologies (c)

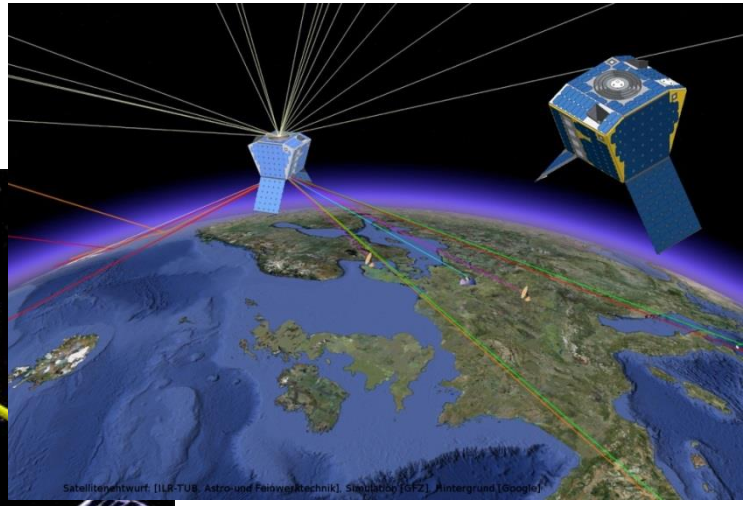
- **Distributed (cloud) computing** to manage the zettabytes (10^{21} bytes) of data ('**Big Data**') that are recorded daily
- Need for **Data Science** (novel methods in computer science)

New satellite concepts

- Rapid development in satellite technology
  - swarms of low-cost mini-, micro-, nano-, pico-, and even smaller satellites
  - soon thousands of commercial communication satellites (Samsung, Boeing, SpaceX, …) that can also be used for navigation, positioning, and remote sensing
  - proposals for next generation gravity missions







Zusammenfassender Ausblick

- Geodäsie liefert einen wichtigen Beitrag zum Verständnis von Klimaänderungen und Naturgefahren,

- erfordert hochgenaues Monitoring, präzise Messdaten, stabile und zuverlässige Referenzrahmen (terrestrisch und himmelsfest) …

… auf allen zeitlichen und räumlichen Skalen.

- Ergebnisse sind wichtig für eine Vielzahl von Nachbardisziplinen und …

- … in Anbetracht faszinierender technologischer Entwicklungen hat die Geodäsie hervorragende Perspektiven!


NORTH POLE
Thank you for your attention!
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