Geodesy
What is it, and why do I like it?

AVN Training School, HartRAO, 20.03.2018

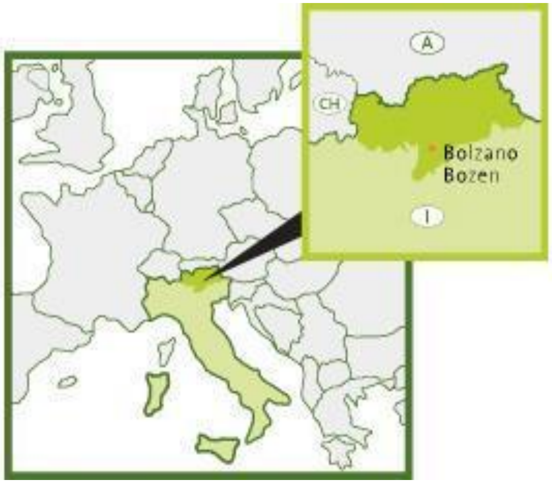
Maria Karbon

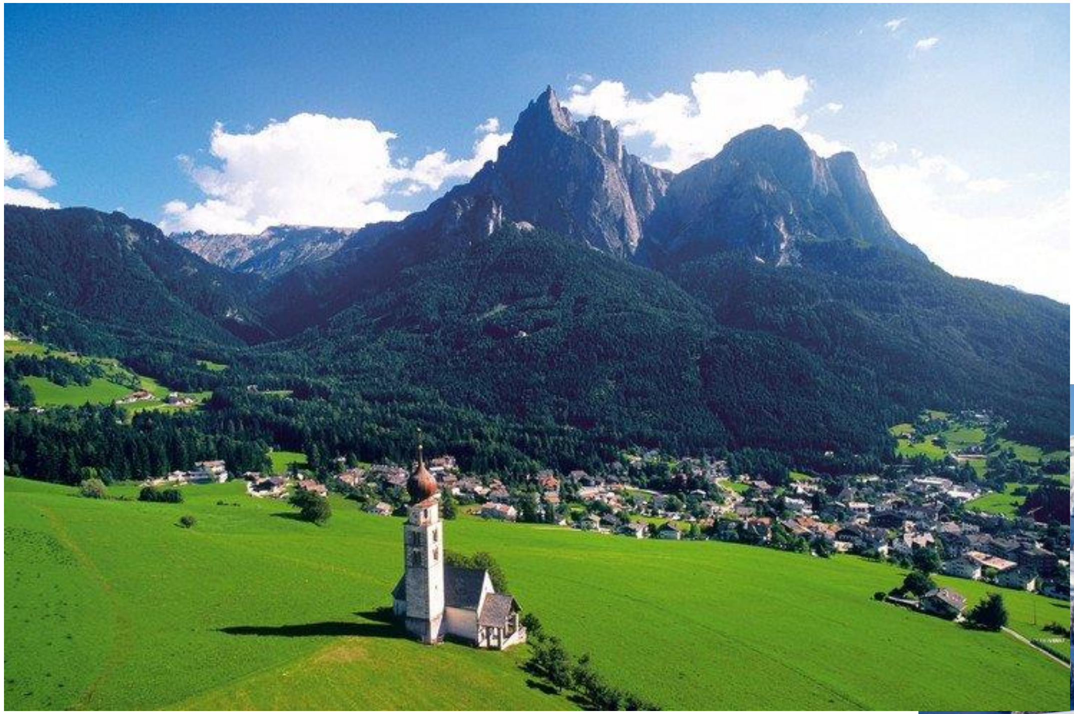
Institut für Geodäsie und Geoinformation
Uni Bonn

Introducing myself

I am…

- Maria Karbon
- from Seis am Schlern, South Tyrol, Italy





I studied…

- Informatics in high school (2003)

Max VALIER Gewerbeoberschule

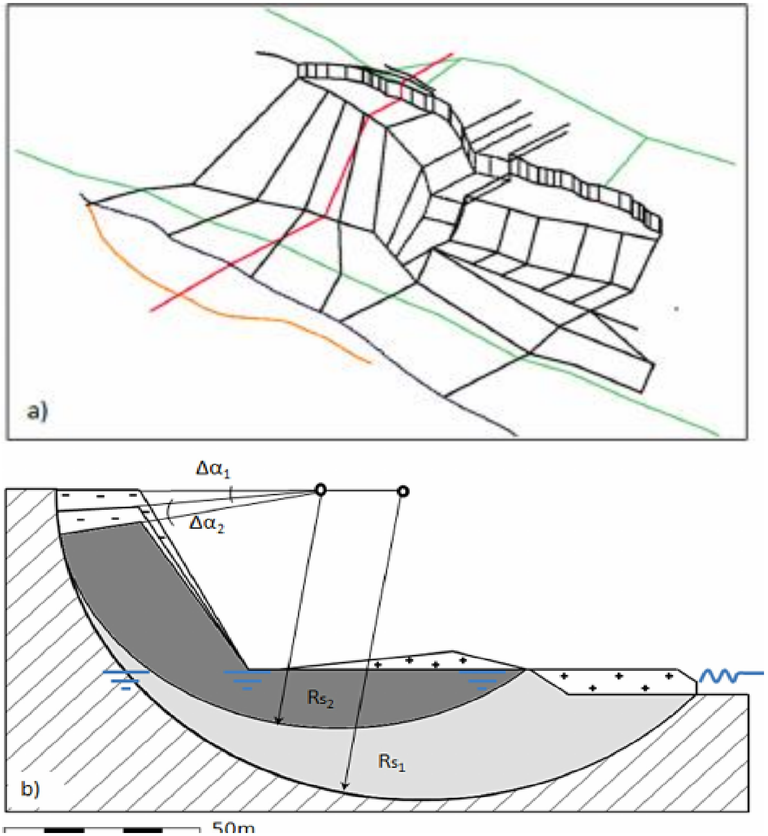
I studied…

- Informatics in high school
- Diploma in Geodesy

TECHNISCHE UNIVERSITÄT WIEN
Vienna | Austria

Diploma thesis (2009)

- Kinematics of a mass movement constrained by sparse and inhomogeneous data

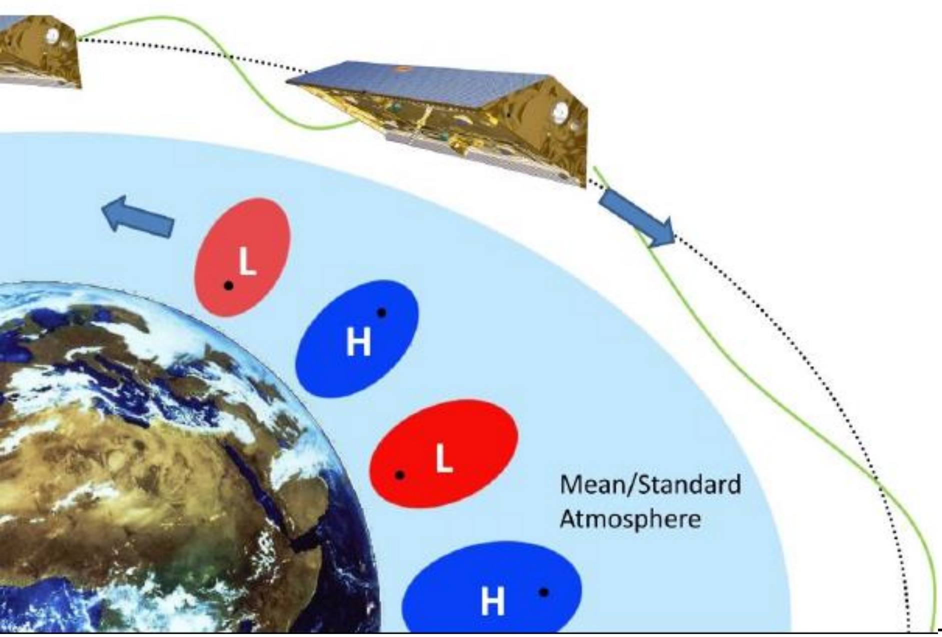


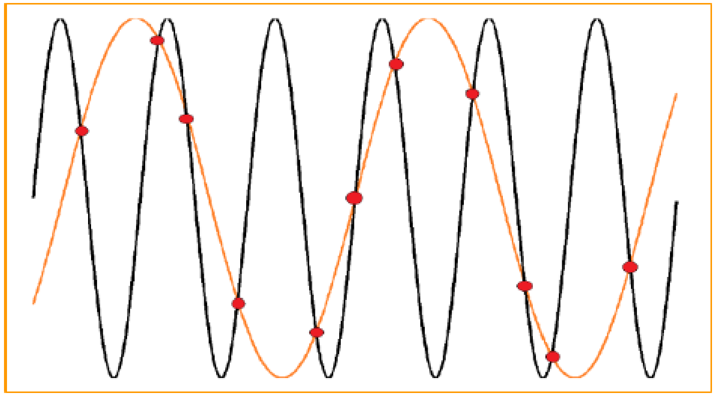
I studied…

- Informatics in high school
- Diploma in Geodesy
- PhD

PhD (2013)

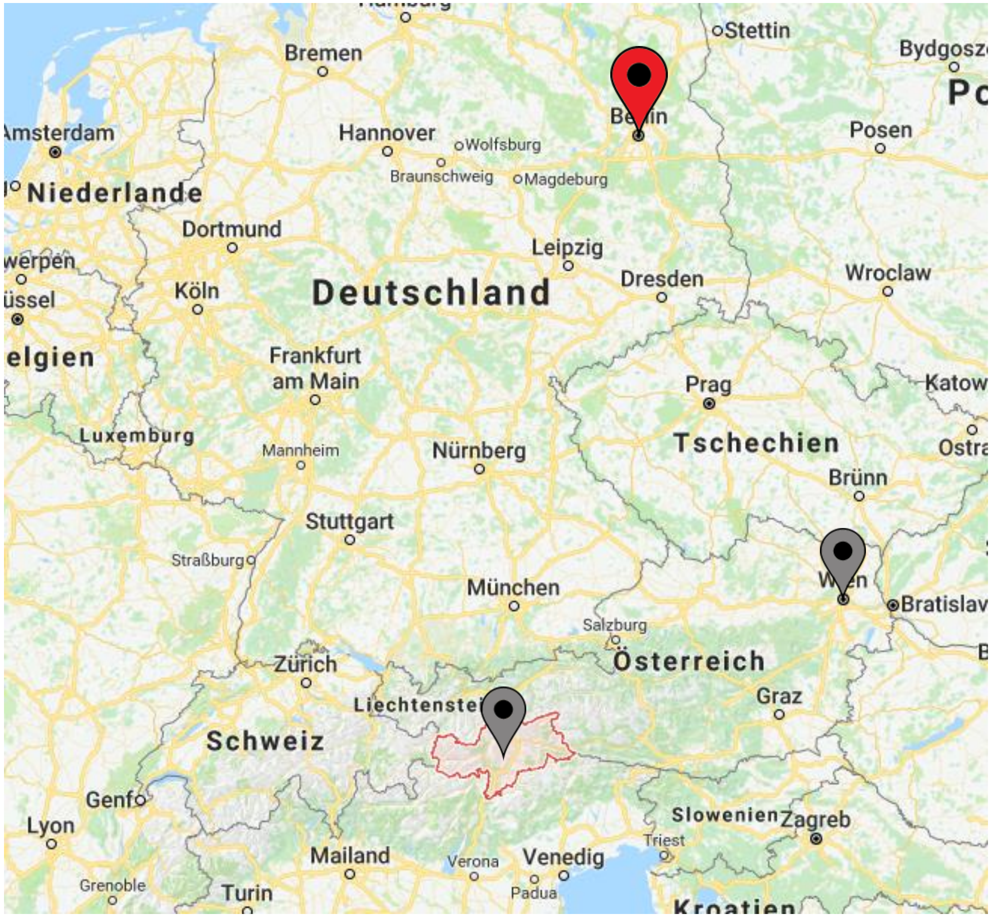
- Atmospheric effects on measurements of the Earth gravity field





I studied…

- Informatics in high school (2003)
- Diploma in Geodesy
- PhD
- PostDoc



GFZ
Helmholtz Centre
POTSDAM

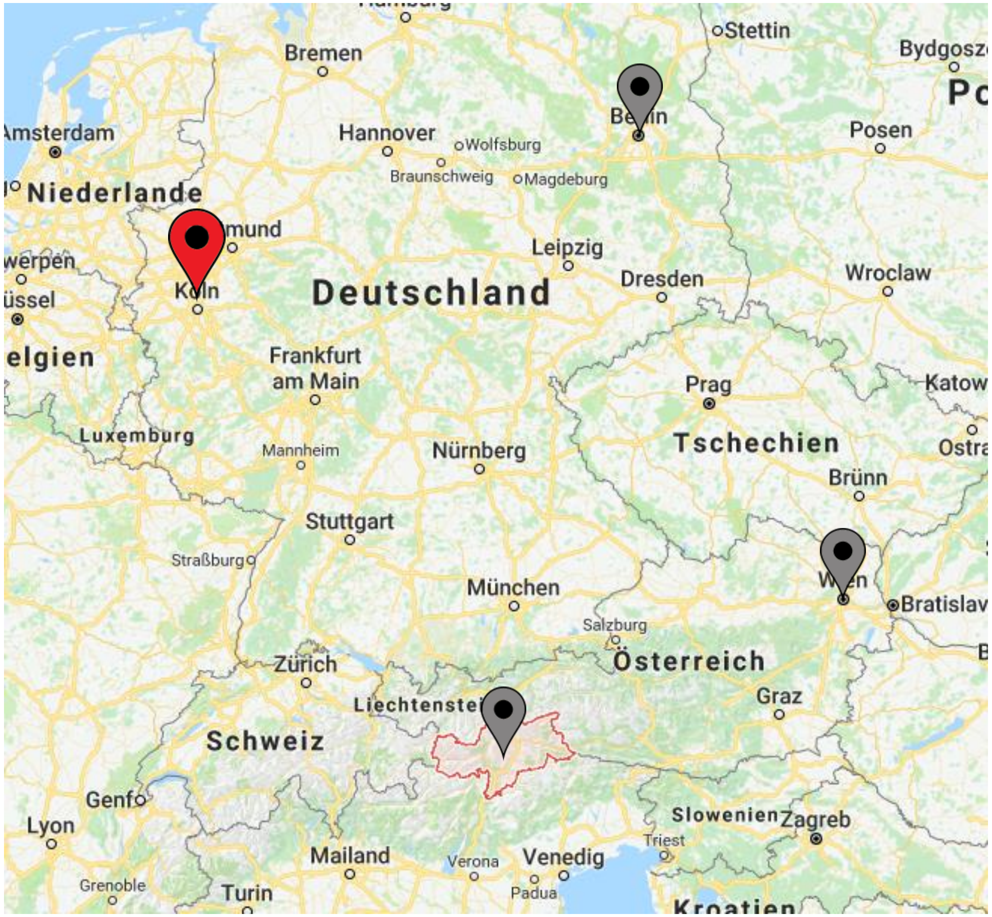
TU berlin

PostDoc (2013- May 2017)

- Earth orientation parameters from VLBI determined with a Kalman filter
- The extension of the parametrization of the radio source coordinates in geodetic VLBI and its impact on the time series analysis.
- Long term evaluation of ocean tidal variation models of Earth rotation

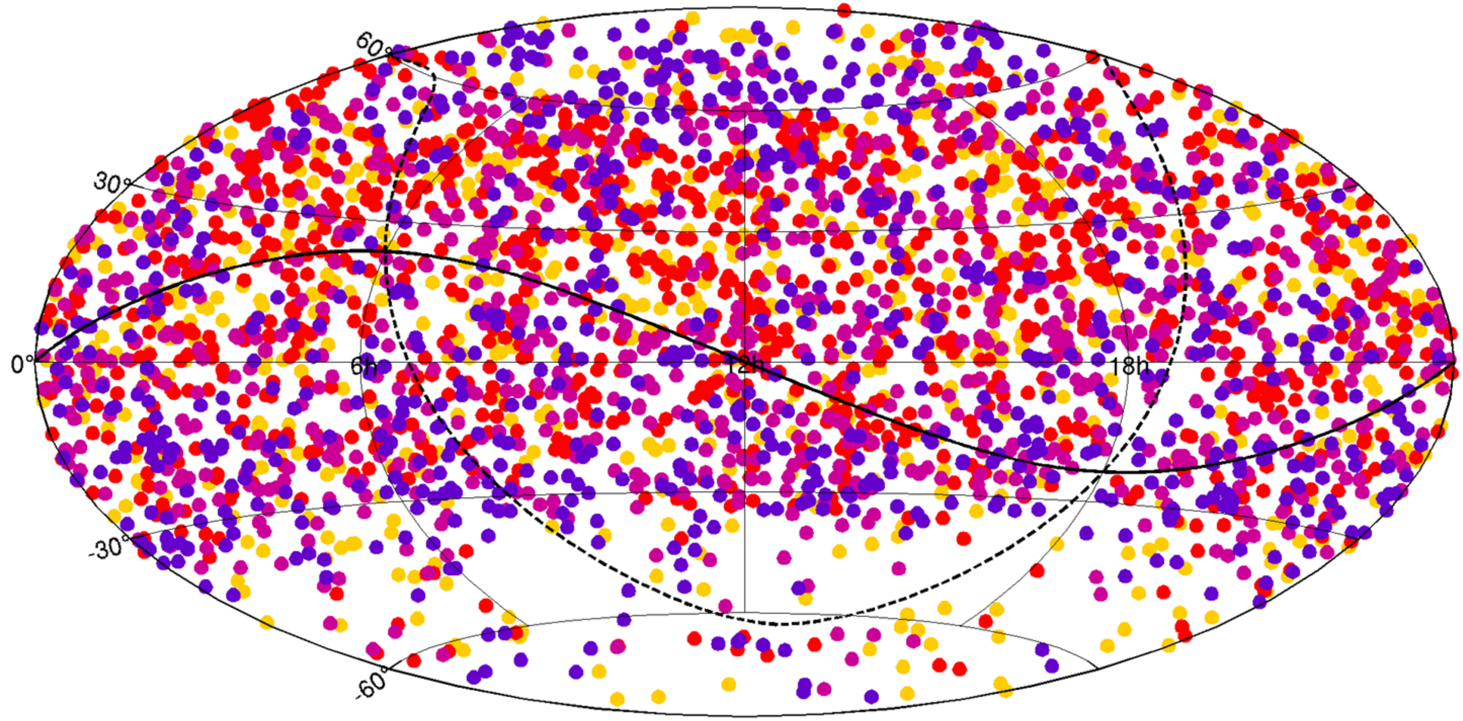
I studied…

- Informatics in high school (2003)
- Diploma in Geodesy
- PhD
- PostDoc



PostDoc (October 2017 – March 2018)

- Combination of celestial reference frames on normal equation level



What is Geodesy?

What does it mean?

- Geo – desy = Earth – dividing
- geo (← γη)
  - Gaia, goddess of the Earth
  - Earth, land, town, acre, soil, estate
- desy (← δαιομαι, δαιεσθαι) = divide, allot, distribute

- Example: Nile valley
  - border demarcation
  - surveying
  - mapping
  - cadaster
  - real estate regulation

What is it?

- Geodesy is the science of measuring and mapping the Earth surface.

Friedrich Robert Helmert
1843 - 1917

What is it?

- The objective of geodesy is the determination of the potential function W(x,y,z).

Ernst Heinrich Bruns
1848 - 1919

What is it?

- Geodesy is what geodesists do for their living.

Helmut Moritz
1933-

What is it?

- Geodesy is a discipline that deals with measurement and representation of the Earth, including its gravity field, in a three-dimensional time varying space.

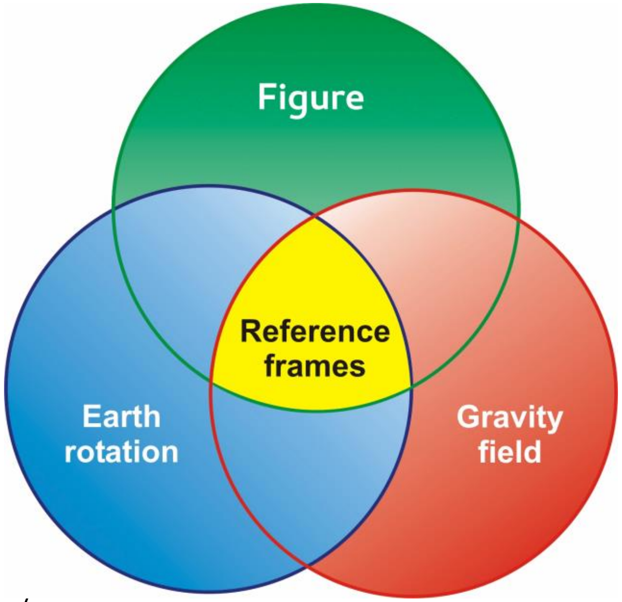
National Research Counci of Canada, 1973
Vanicek & Krakiwsky, 1982

What is it?

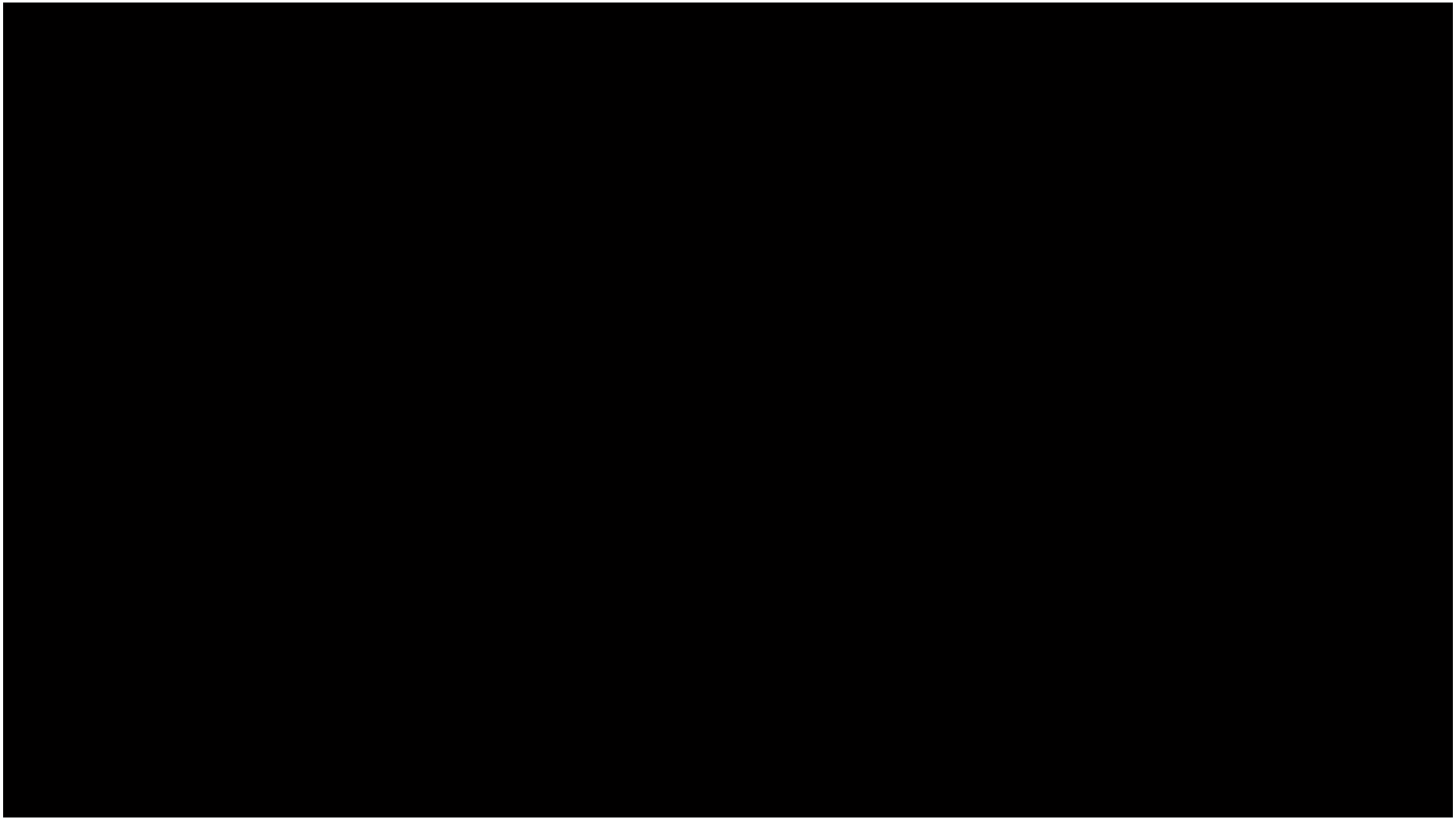
- Geodesy is a discipline that deals with the measurement and representation of the **shape** of the Earth, its **orientation in space** and its gravity field, in a 3D time varying space.

Three pillars of Geodesy

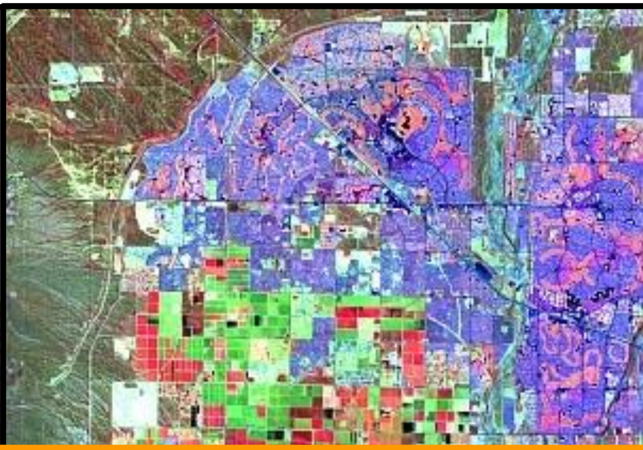
- **Figure of the Earth**
  - topography, bathymetry, ice surface, sea level
- **Earth rotation and orientation**
  - polar motion, Earth rotation, nutation, precession
- **Gravity field of the Earth**
  - gravity, geoid



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



Geodesy

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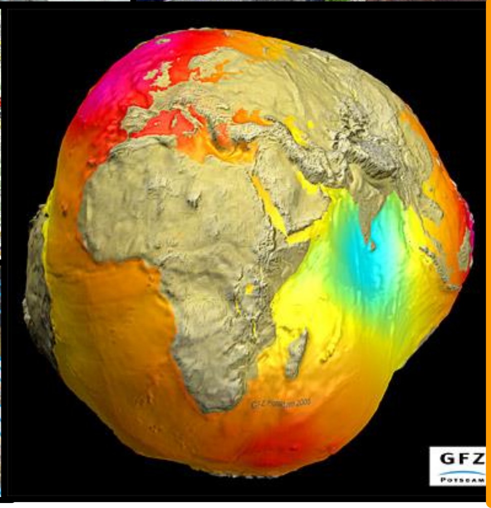
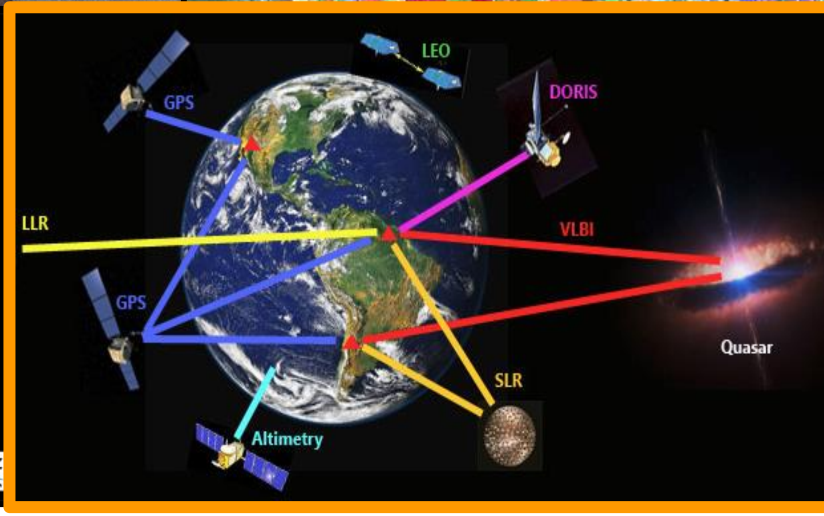
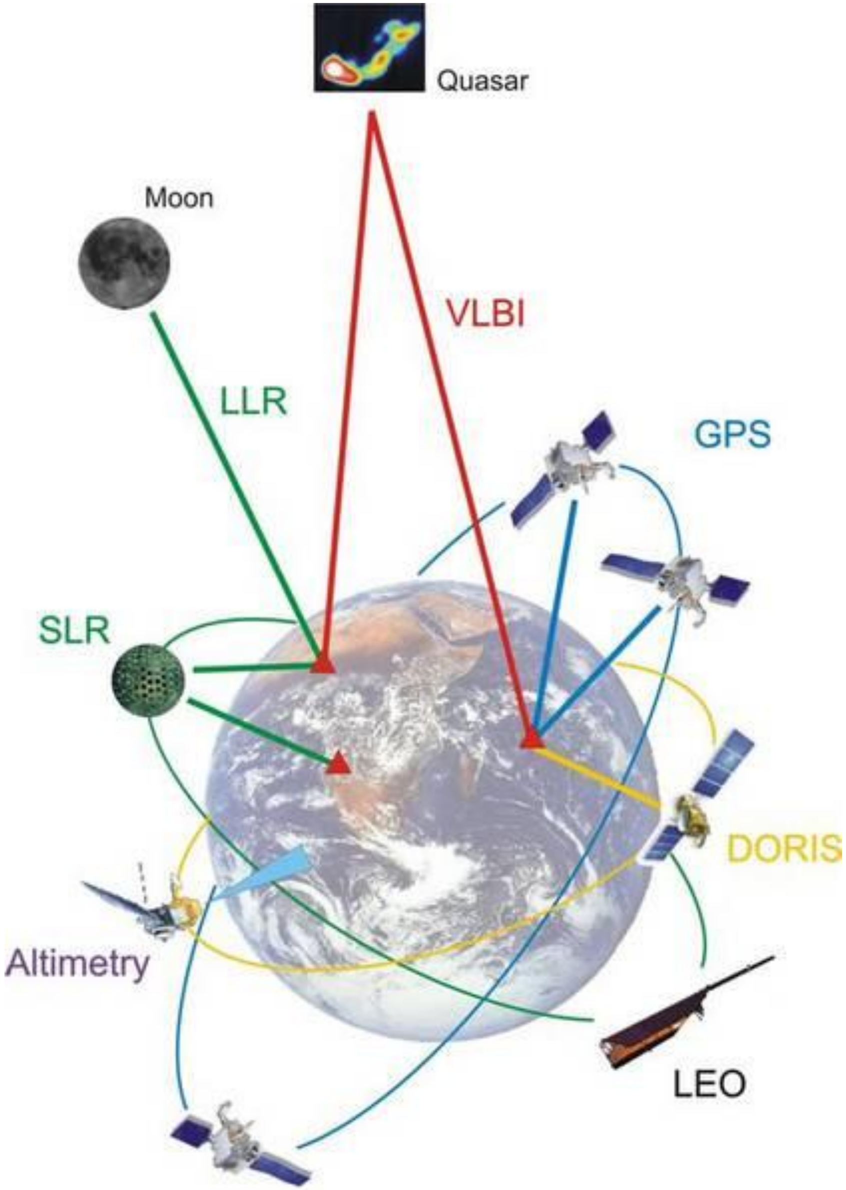
FRECHEN
KERPEN
RÖSRATH
HÜRTH
LOHMAR


GFZ


LEO
GPS
DORIS
LLR
VLBI
GPS
Quasar
SLR
Altimetry

Space geodesy…

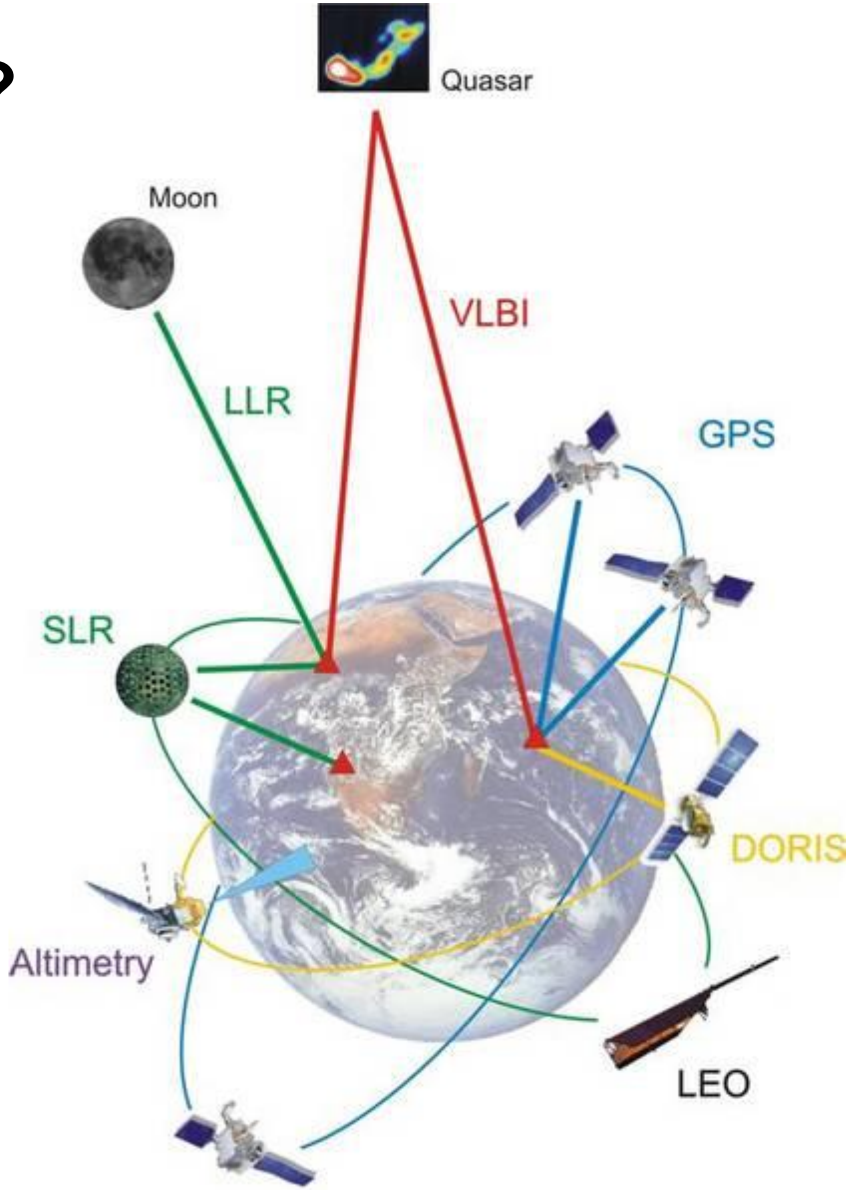
- studies the aspects of geodesy by using **natural** or **artificial celestial bodies** as observed objects or as observing platforms.



Space geodesy…what for?

- studies the aspects of geodesy by using **natural** or **artificial celestial bodies** as observed objects or as observing platforms.

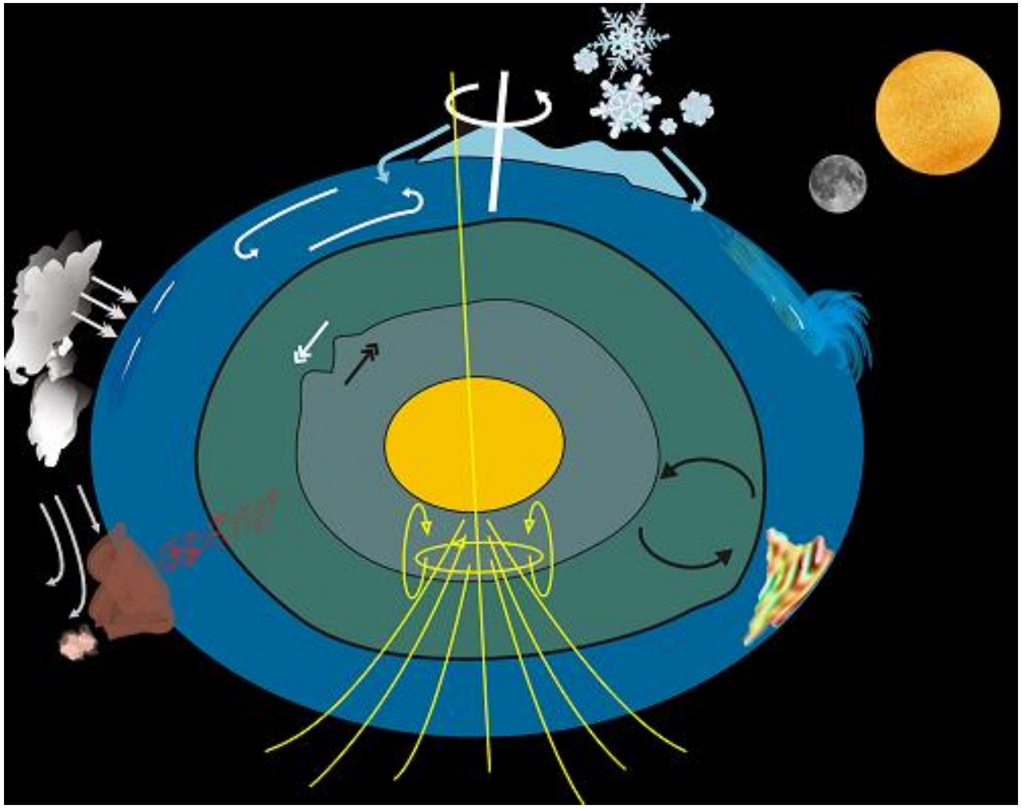
Global monitoring of the System Earth



Subsystems of the Earth

- Geodetic parameters are closely related to changes of mass distributions within and between the Earth‘s subsystems and the related interactions.

- Solid Earth
- Atmosphere
- Hydrosphere
- Cryosphere
- Biosphere
- Anthroposphere
- (Space)



Everything moves, everything changes!

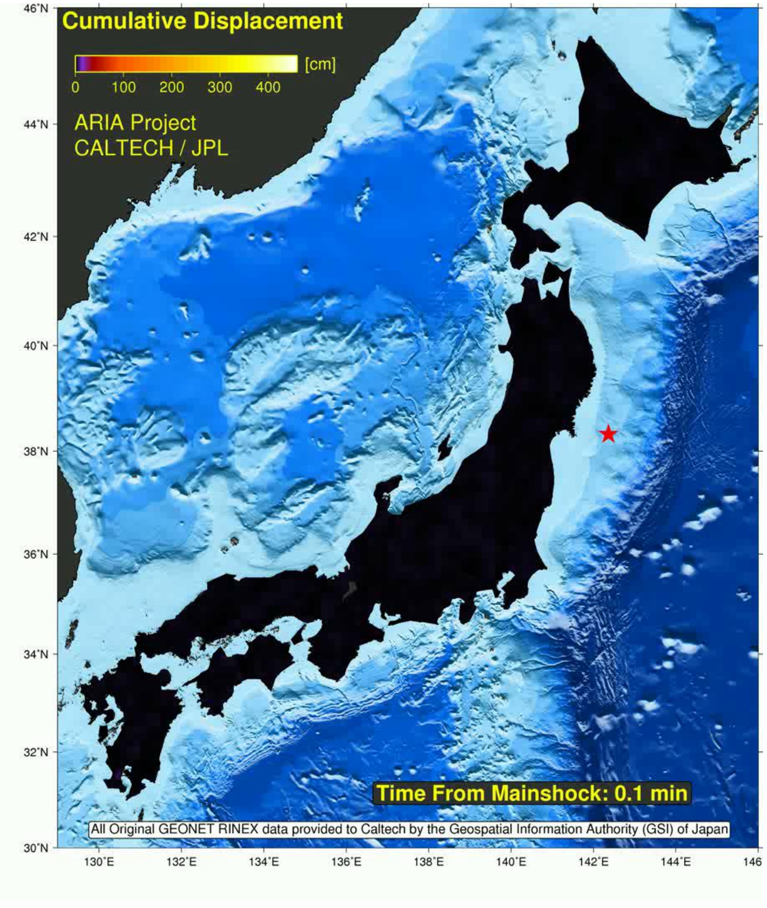
- **Examples:**
  - Earth rotation
  - Solid Earth tides
  - Plate tectonics
  - Earthquakes
  - Global weather
  - Sea level change
  - Loading (ice, ocean, atmosphere)

Christchurch, New Zealand,M: 7.1, 04.10.2010.

Time scales of changes

- **Sudden**
  - Earthquake (*local, regional)*
  - Rockslide and -avalanche *(local)*
  - Land slide *(local)*
  - Mud slide *(local)*
- **Emerging**
  - Volcanic eruption *(regional, global)*
  - Tsunami *(local to trans regional)*
  - Hurricane, Storm *(regional)*
  - Flood *(regional)*
- **Long term**
  - Climate change (sea level, temperature, weather activity, atmospheric structure, etc.) *(global)*
  - Tectonic plate motion *(global)*

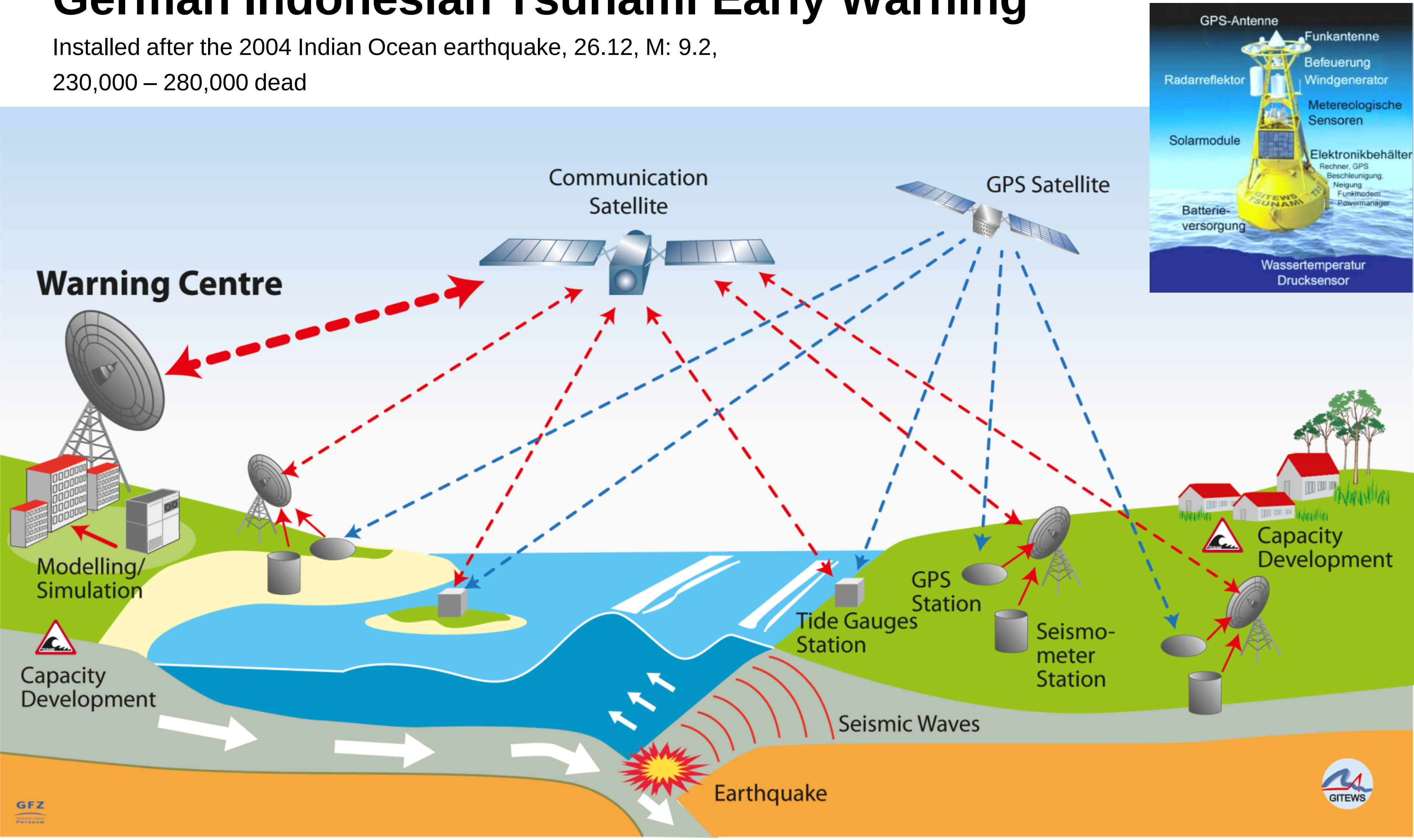
Sudden: M 9.0 Tohoku earthquake ,11. March 2011



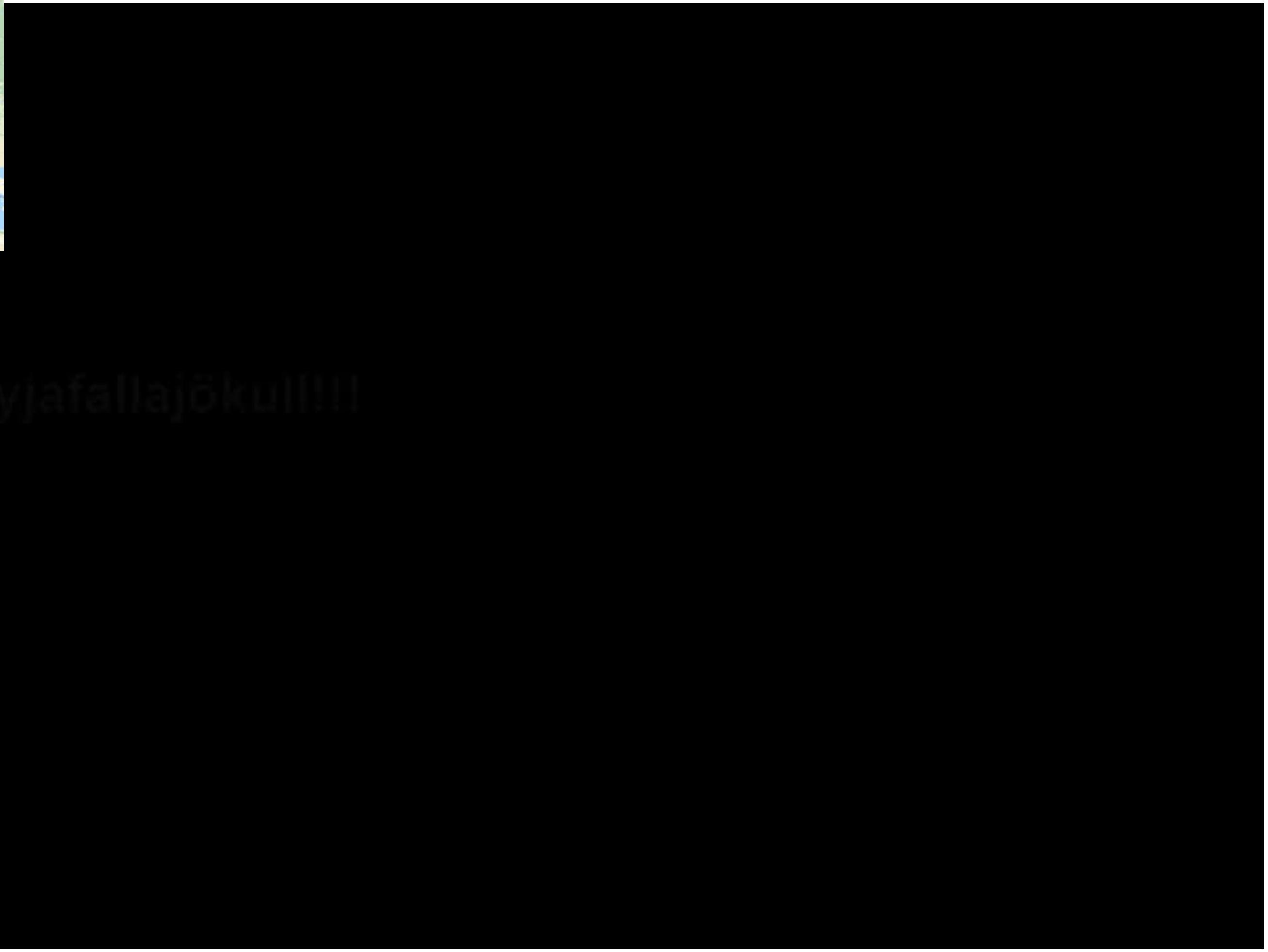
Sudden: M 9.0 Tohoku earthquake ,11. March 2011

German Indonesian Tsunami Early Warning

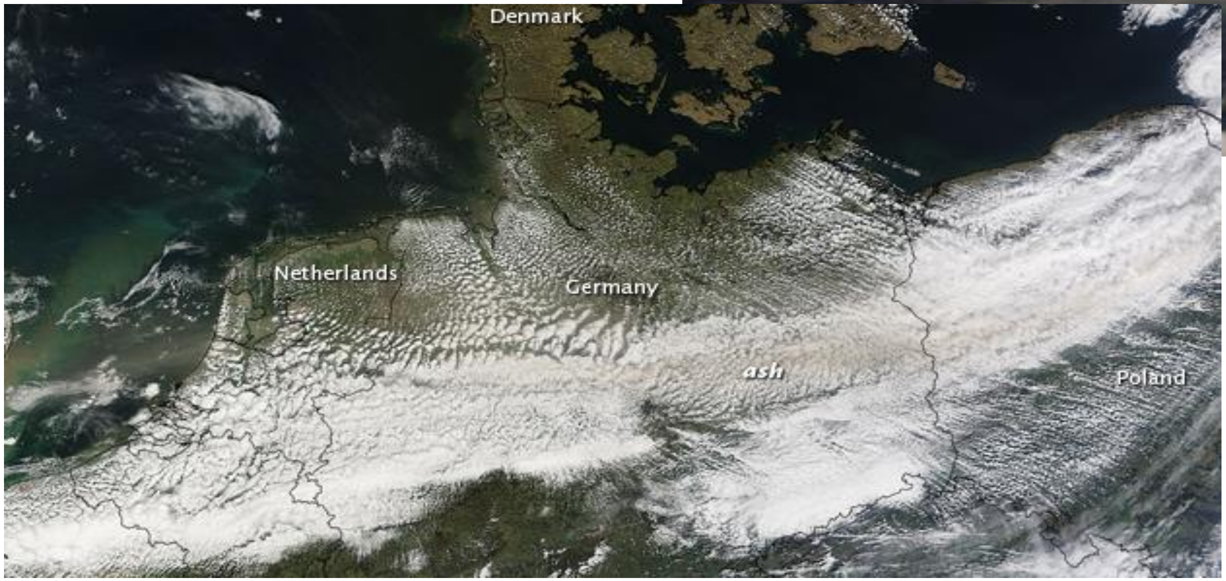
Installed after the 2004 Indian Ocean earthquake, 26.12, M: 9.2,
230,000 – 280,000 dead



Emerging: Eyjafjallajökull, March-April 2010



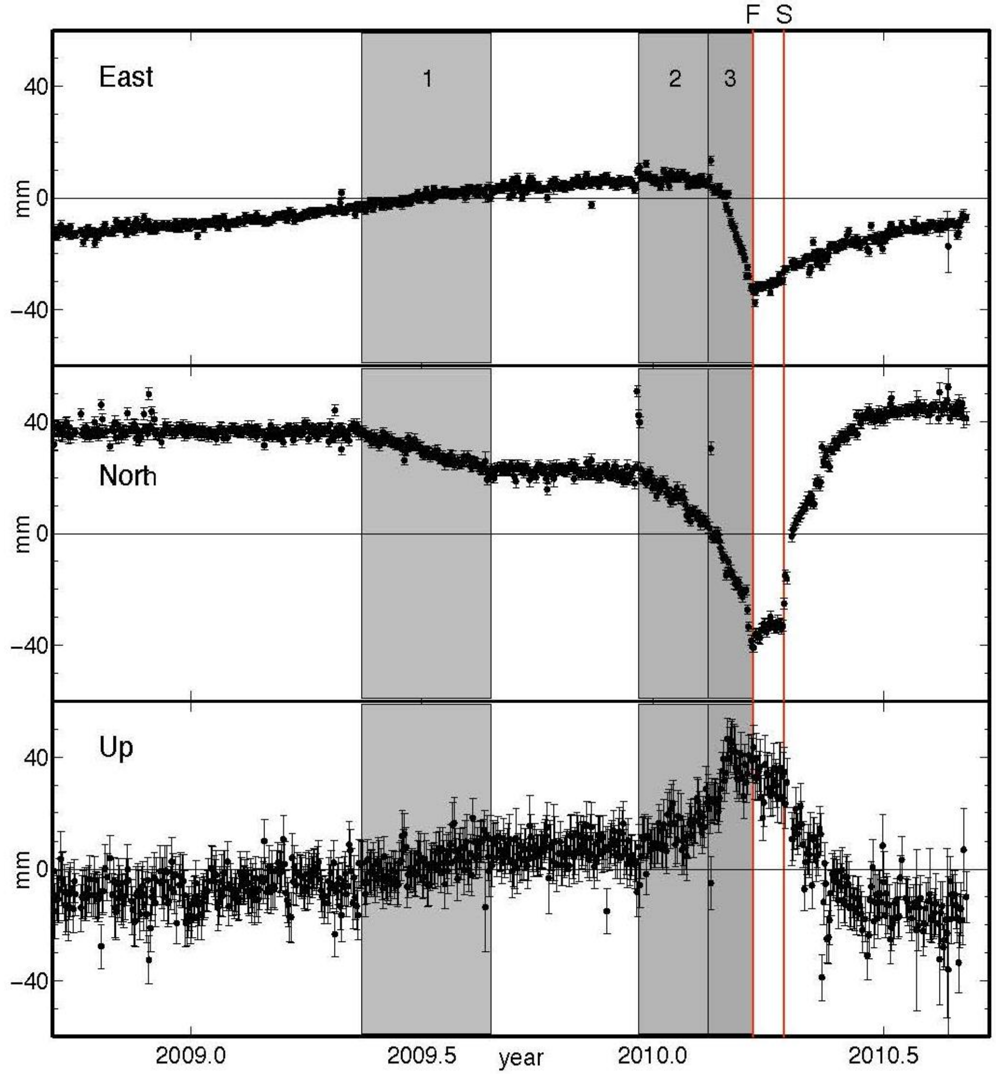
Emerging: Eyjafjallajökull, March-April 2010



[NASA image courtesy Jeff Schmaltz, MODIS Rapid Response Team at NASA GSFC]

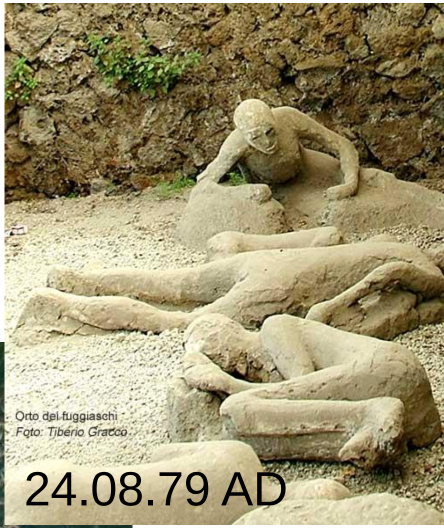
Emerging: Eyjafjallajökull, March-April 2010

- GPS time series of the station THEY
  - (south of the Eyjafjallajökull)
  - Relative to station REYK (Reykjavík)
- Grey areas (intrusions phases)
- Red line F (lateral eruption)
- Red line S (peak eruption)

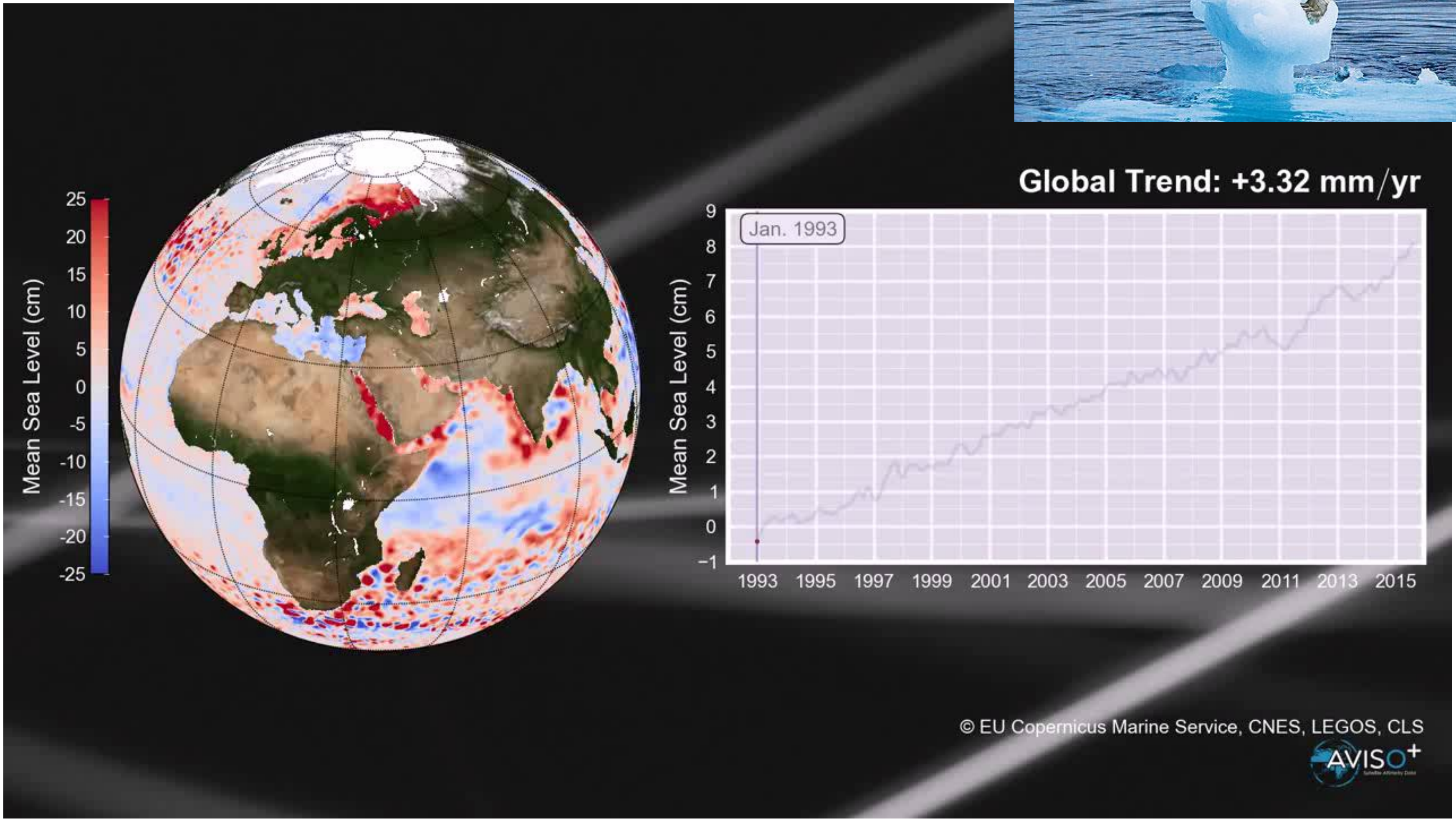


F Sigmundsson *et al. Nature* **468**, 426-430 (2010)

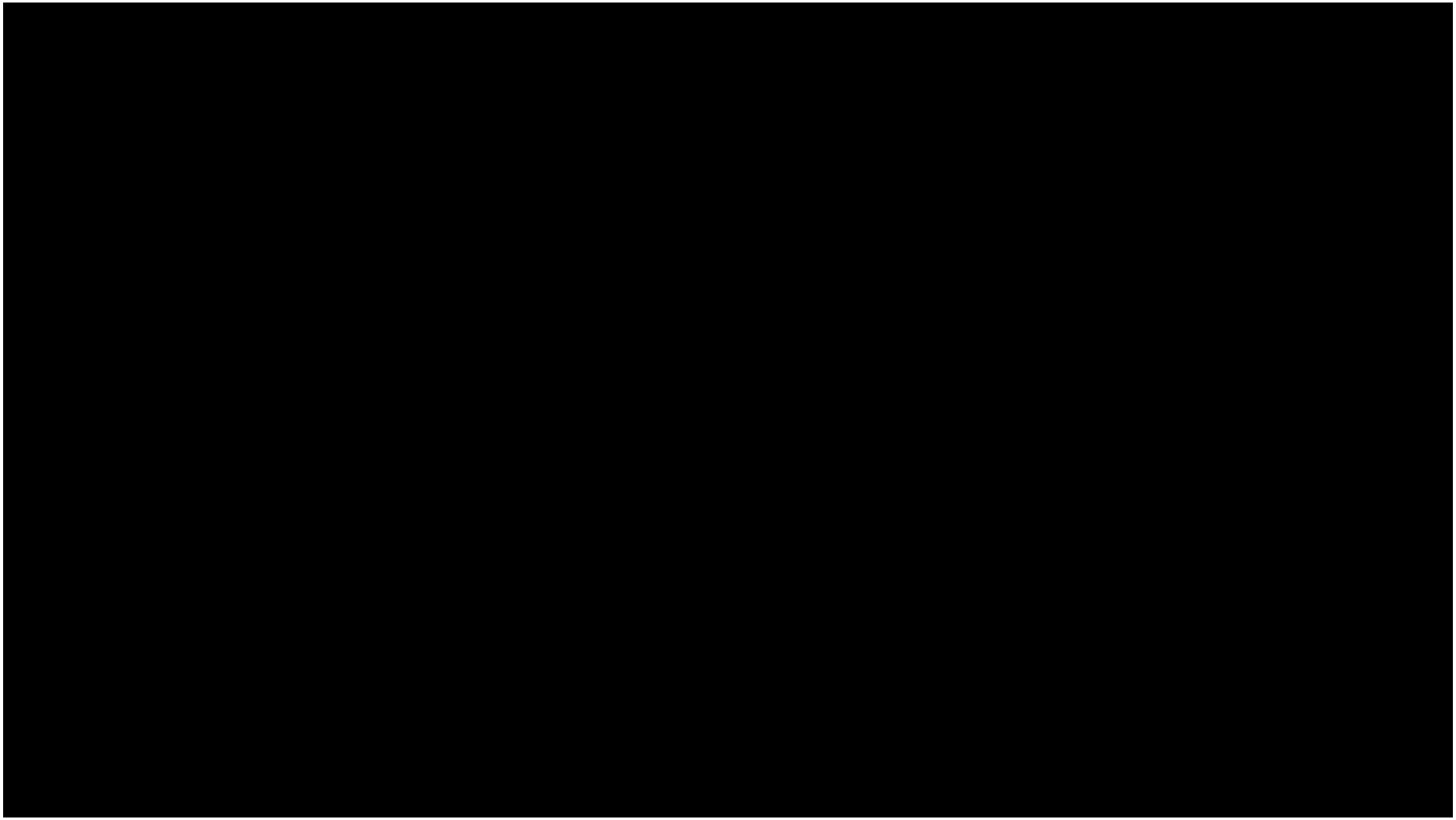
Emerging: Mount Vesuvius ?



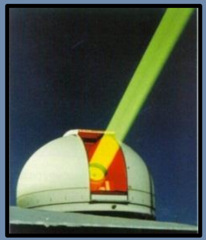
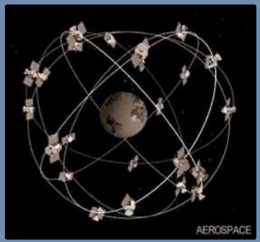
Long term: Sea level rise

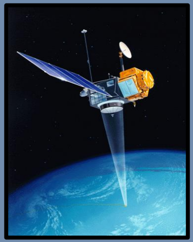


Why geodetic VLBI?



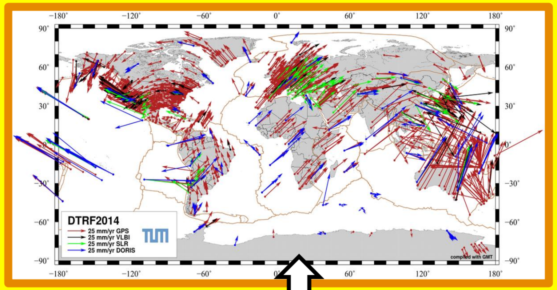
Geodetic observation techniques

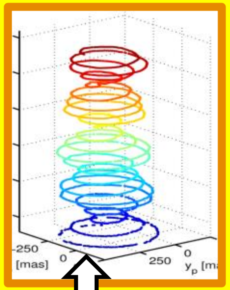




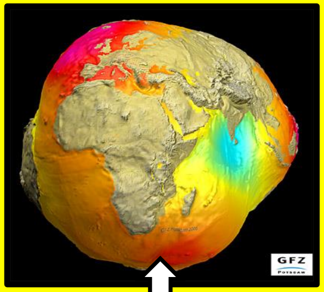


Standards and Models | Analysis Centres | Combination Centres

Geodetic products







Geodetic reference frames

IAG GGOS Bureau for Products and Standards (Angermann et al, 2016)

The role of VLBI for space geodesy

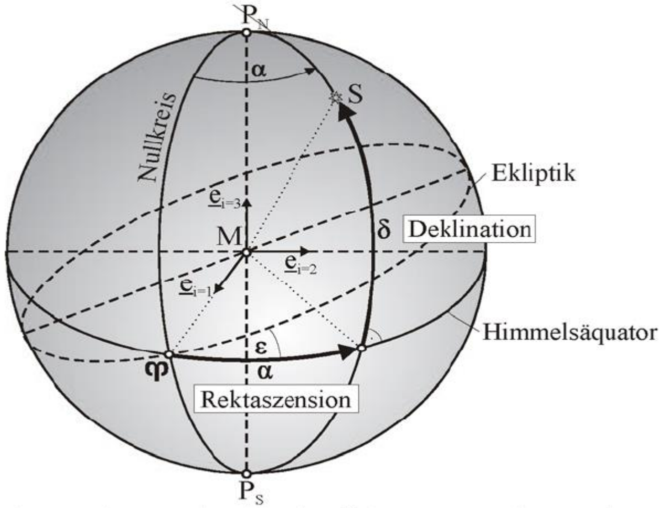
Parameter Type	VLBI	GNSS	DORIS	SLR	LLR	Altimetry
ICRF (Quasars)	X					
Nutation, Precession	X	(X)		(X)	X	
Polar Motion	X	X	X	X	X	
UT1	X					
Length of Day	(X)	X	X	X	X	
ITRF (Stations)	X	X	X	X	X	(X)
Geocenter		X	X	X		X
Gravity Field		X	X	X	(X)	X
Orbits		X	X	X	X	X
LEO Orbits		X	X	X		X
Ionosphere	X	X	X			X
Troposphere	X	X	X			X
Time Freq./Clocks	(X)	X		(X)		

Fields involved

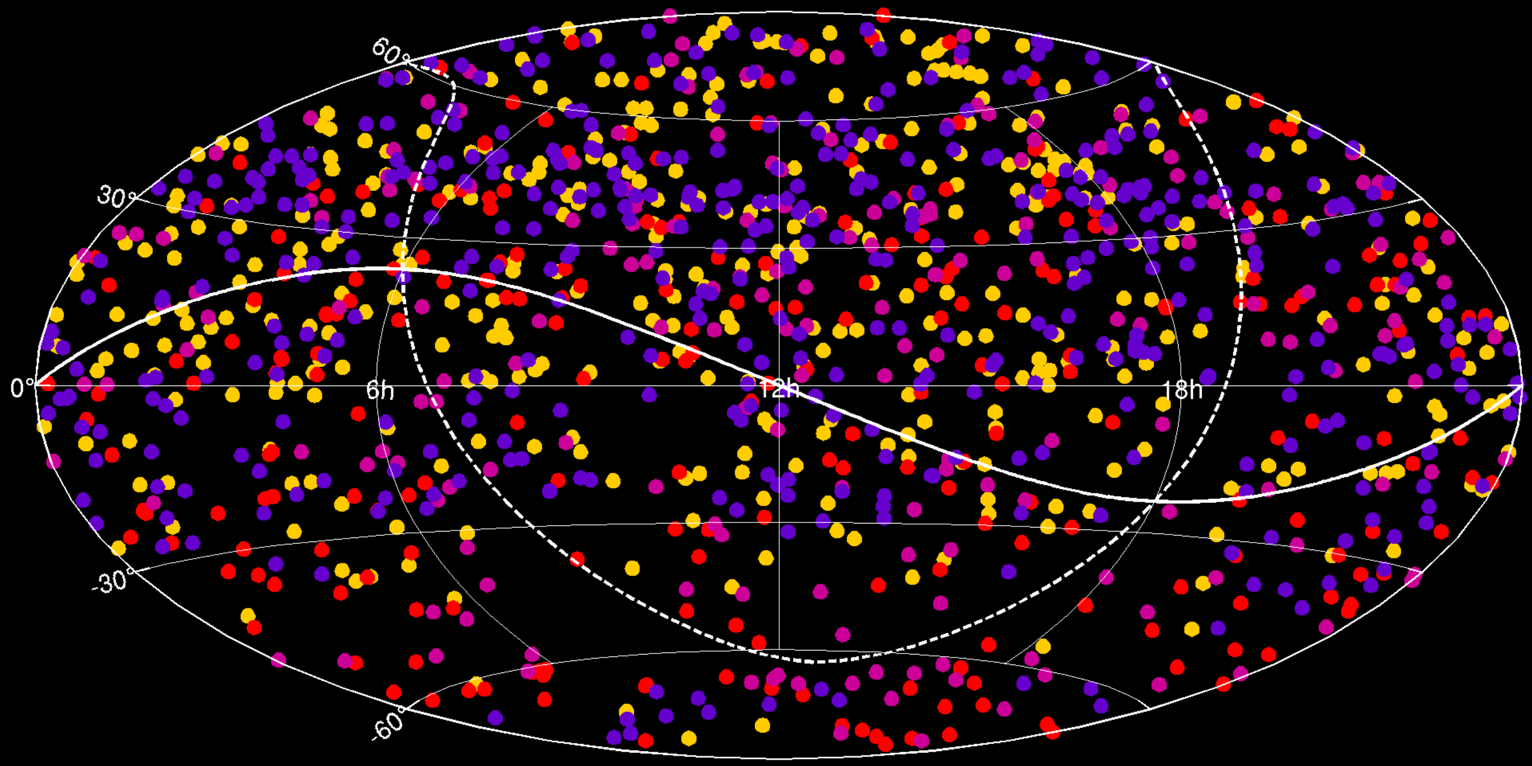
- astronomical objects, radio sources (**astrophysics, radio astronomy**),
- propagation of radio in space-time (**gravitational physics**) and in the atmosphere (**atmosphere physics**)
- the antenna- and receiver, mechanical and electronical components of the instrumentation (**radio-frequency engineering**),
- Earth as being the carrier of the interferometer baselines formed by antenna pairs (**geodynamics**),
- correlator (**signal processing**), and analysis of VLBI observations, application of physically motivated mathematical models through the software based on the objective and subjective decisions of the operator(s)
- (**space geodesy**)

Quasi-inertial system realized by VLBI

- **Origin**
  - Solar System Barycenter (SSB), i.e. the center of mass of the solar system bodies (solar system dynamics)
- **Time scale, metric**
  - Barycentric coordinate time (TCB), BCRS
- **Orientation, principal plain**
  - True celestial equator at J2000.0 defined by precession (Lieske et al, 1977) and nutation (Seidelmann et al., 1982) models
- **Coordinates**
  - **Right ascension**
    - Clockwise hour angle α, Zero = vernal equinox ♈ (intersection of the mean ecliptic with the true celestial equator at J2000.0 (solar system dynamics)
  - **Declination**
    - Angle w.r.t. the principal plane δ, positive towards celestial north pole P_N
- **Orientation stability**
  - The stability of the axes is given by the constant positions of the quasar coordinates (kinematically non-rotating)



(Arias, E.F., et al., Astron. Astrophys. 303, 604, 1995)


60°
30°
0°
-30°
-60°
6h
12h
18h

Why do we need the ICRF?

- For geodesy, the radio sources are the most stable remote targets.
- They provide the external orientation of Earth **(Earth Orientation Parameters).**

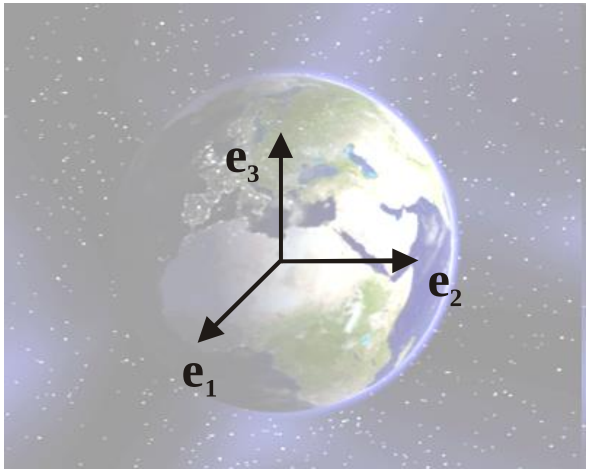
- ICRF2 (Fey et al., 2015) is the most precise and stable orientational frame available
- (IAU 2009, IUGG 2011). It is realized by **VLBI** observations of extragalactic radio sources.

- Other (celestial) reference frames, such as
  - the galactic reference frame (GalRF),
  - other radio reference frames (e.g. at other radio frequencies),
  - the optical star catalogs (FK5, Hipparcos, FK6, etc.),
  - the planetary ephemerides (JPL, IAA, etc.) and
  - the **orbits of satellites**

…are **referred** to ICRF.

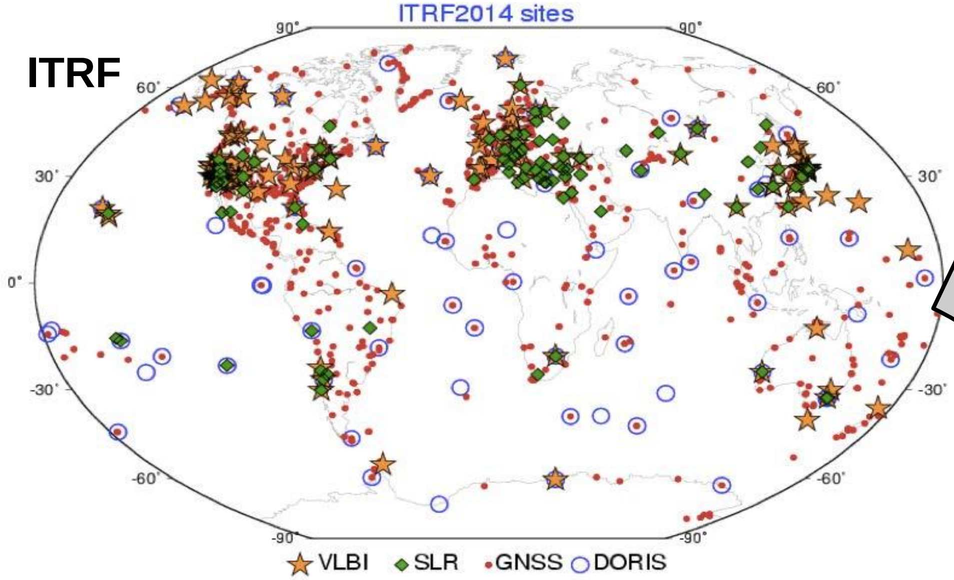
Geocentric co-rotationg body-fixed system

- **Origin**
  - Center of mass of system Earth, including solid Earth, oceans, atmosphere, cryosphere, …
- **Time scale, metric**
  - Geocentric coordinate time (TCG), GCRS
- **Orientation, principal plane**
  - BHI 1984.0 reference pole
  - Equatorial system: e_1 intersection of equator and Greenwich meridian, e_3 mean pole, e_2 orthogonal wrt. e_1/e_3
- **Coordinates**
  - Geocentric 3D-cartesian
- **Orientation stability**
  - NNR (kinematically non rotating) on Earth crust model

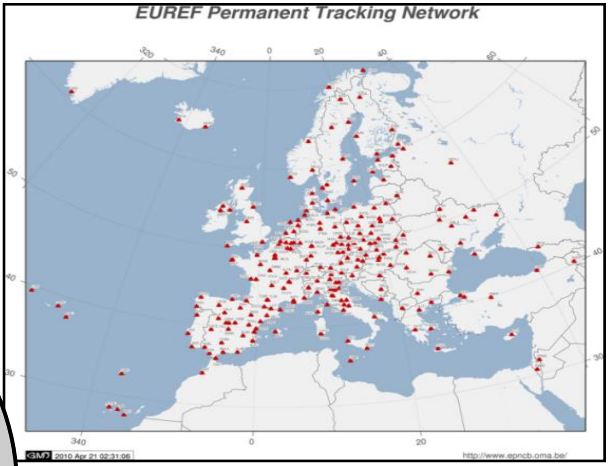


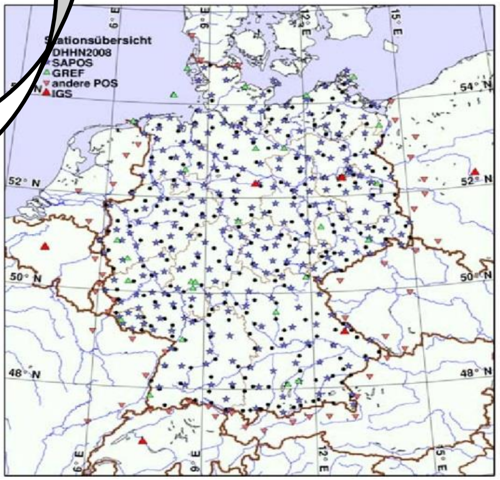
From large scale to the smallest detail

ITRF



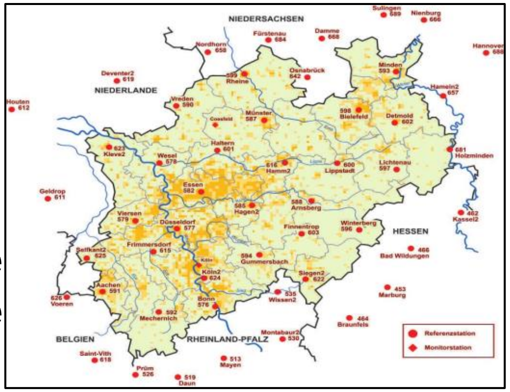
ETRS98





DREF

Local reference frame



VLBI contribution to the ITRF: scale

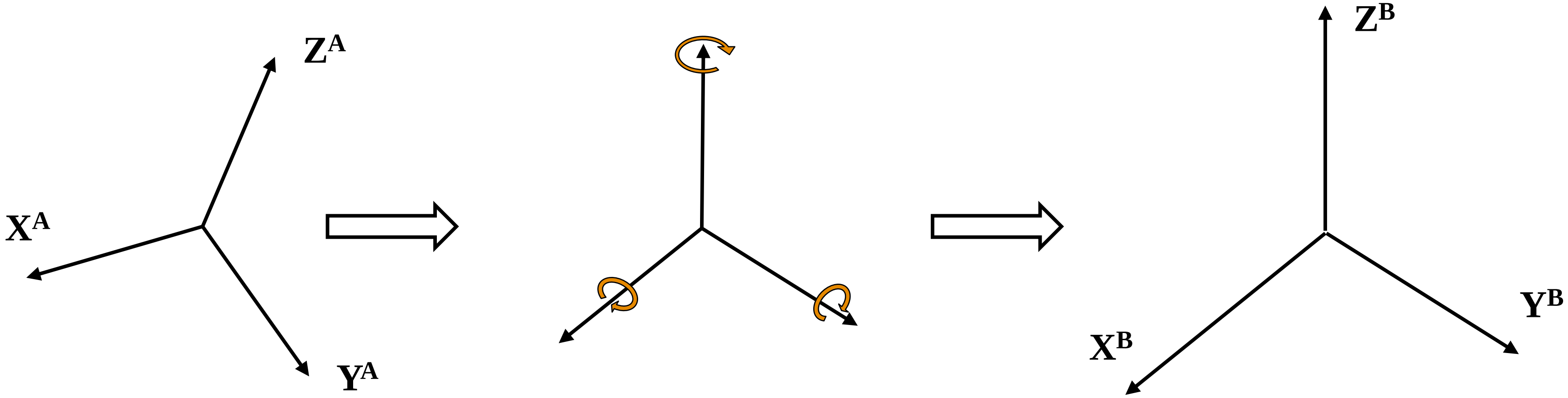
VLBI contribution to the ITRF: scale

- HELMERT-transformation between two frames

VLBI contribution to the ITRF: scale

- HELMERT-transformation between two frames

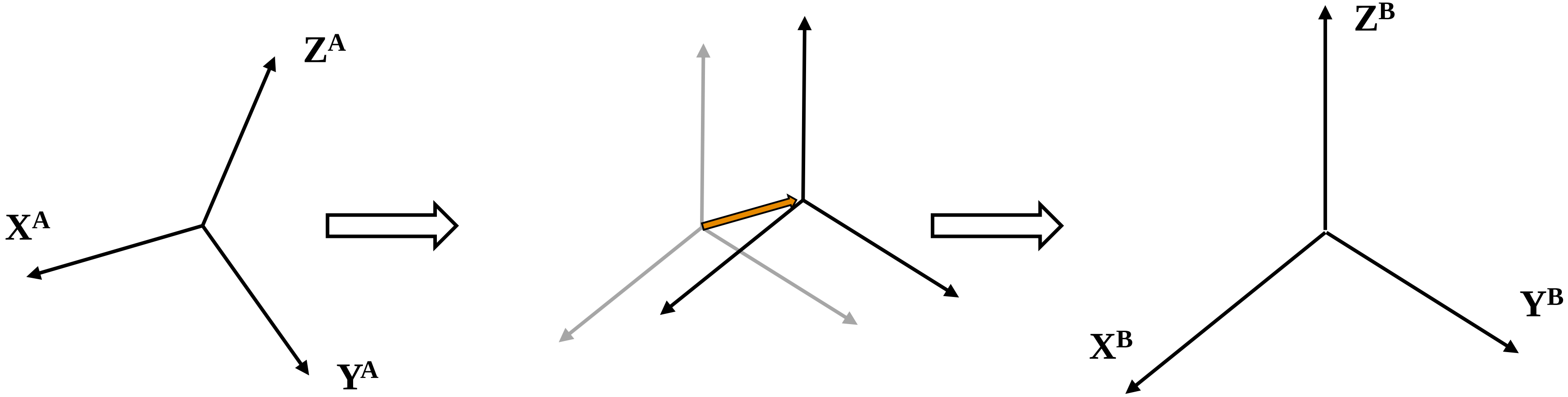
$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}^B = \begin{bmatrix} c_x \\ c_y \\ c_z \end{bmatrix} + (1 + s \times 10^{-6}) \cdot \begin{bmatrix} 1 & -r_z & r_y \\ r_z & 1 & -r_x \\ -r_y & r_x & 1 \end{bmatrix} \cdot \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}^A$$



VLBI contribution to the ITRF: scale

- HELMERT-transformation between two frames

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}^B = \begin{bmatrix} c_x \\ c_y \\ c_z \end{bmatrix} + (1 + s \times 10^{-6}) \cdot \begin{bmatrix} 1 & -r_z & r_y \\ r_z & 1 & -r_x \\ -r_y & r_x & 1 \end{bmatrix} \cdot \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}^A$$



VLBI contribution to the ITRF: scale

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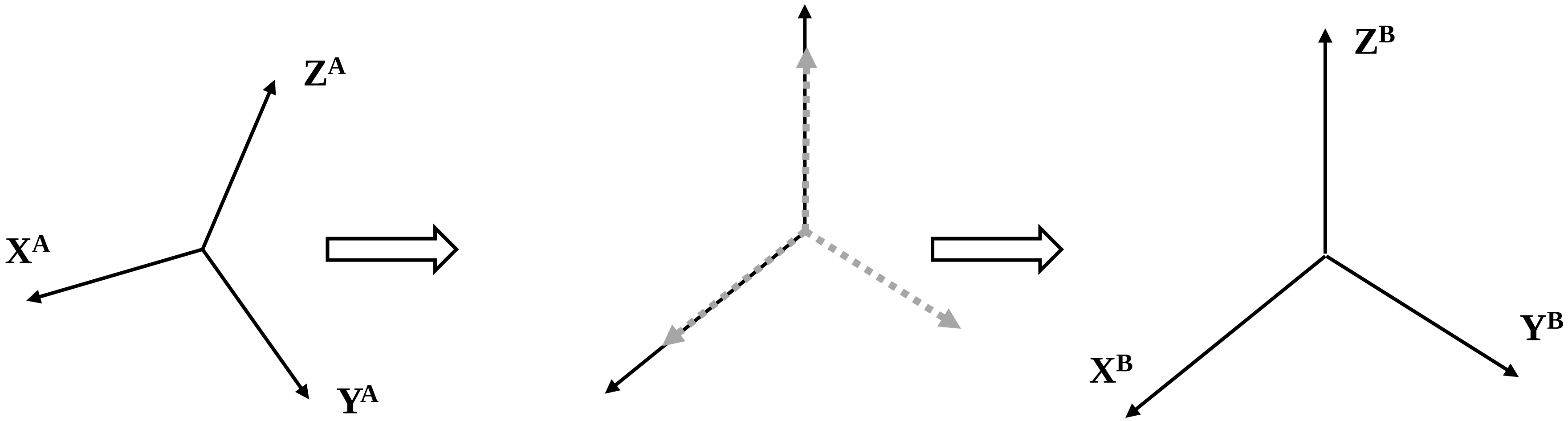


VLBI contribution to the ITRF: scale

- **Definition**
- The ***geodetic datum*** is the fixation of the degree of freedom of a reference frame. It relates the reference frame to the reference system through defining/specifying the **external geometry**.

- **Scale**
- The **VLBI scale** only depends on the speed of light (in vacuum) *c*, no other physical constant is involved. is the best known physical constant, a defining constant (no uncertainty).

- All observations obtained by the space geodetic techniques (**DORIS, GNSS, SLR, VLBI**) measure time differences. Together with the speed of light the observations realize a polyhedron of metric baselines that fully determines the **inner geometry** of the station networks. The lengths of the involved baselines realize the **scale**.

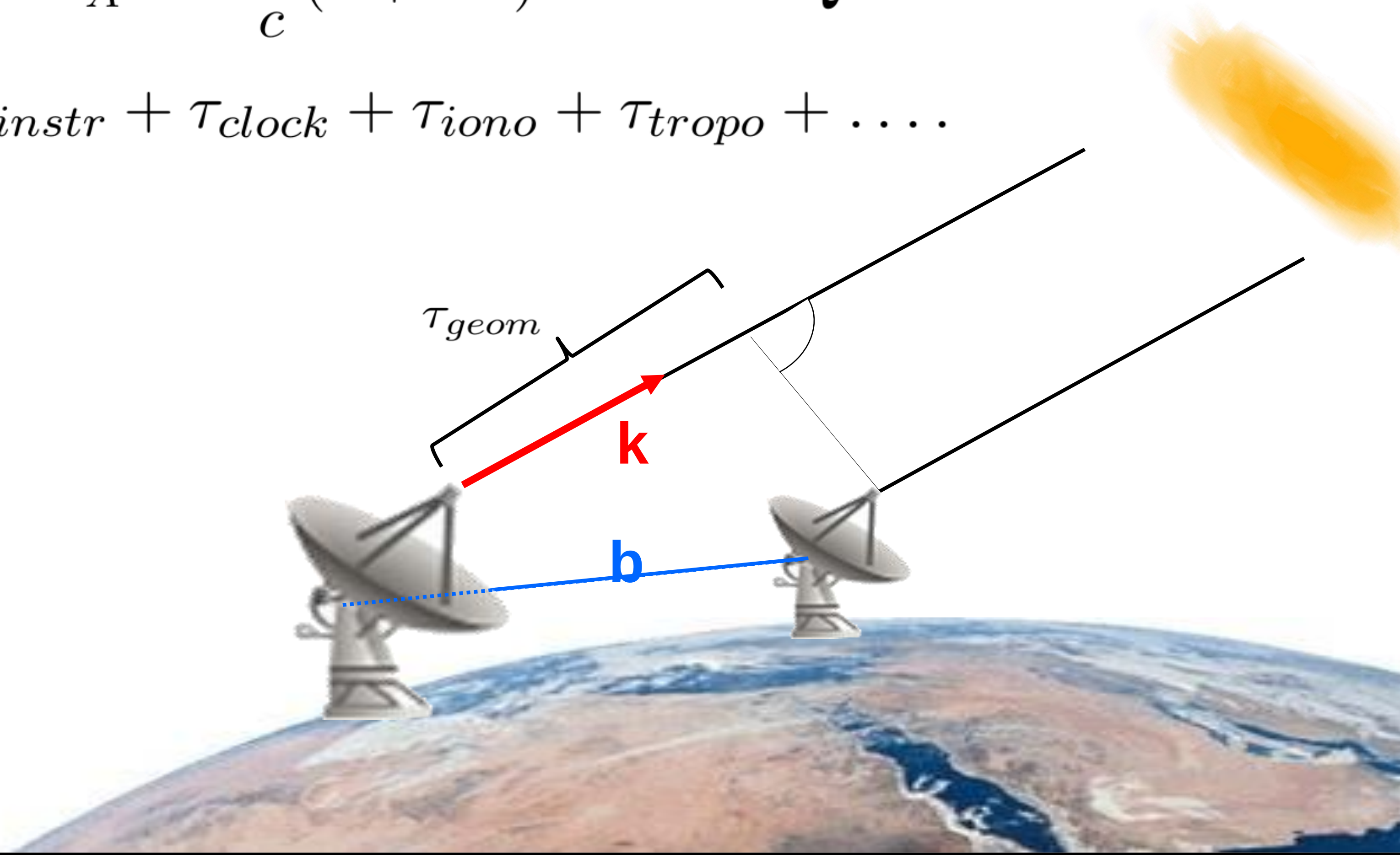
- The **scale** of ITRF is defined by **VLBI** and **SLR**.

The VLBI observable

- **Geometrical delay**

$$\tau_{geom} = t_B - t_A = -\frac{1}{c}(\boldsymbol{b} + \Delta\boldsymbol{b}) \cdot \boldsymbol{W} \cdot \boldsymbol{R} \cdot \boldsymbol{Q} \cdot \boldsymbol{k}$$

$$+ \tau_{instr} + \tau_{clock} + \tau_{iono} + \tau_{tropo} + \ldots .$$

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OF THE
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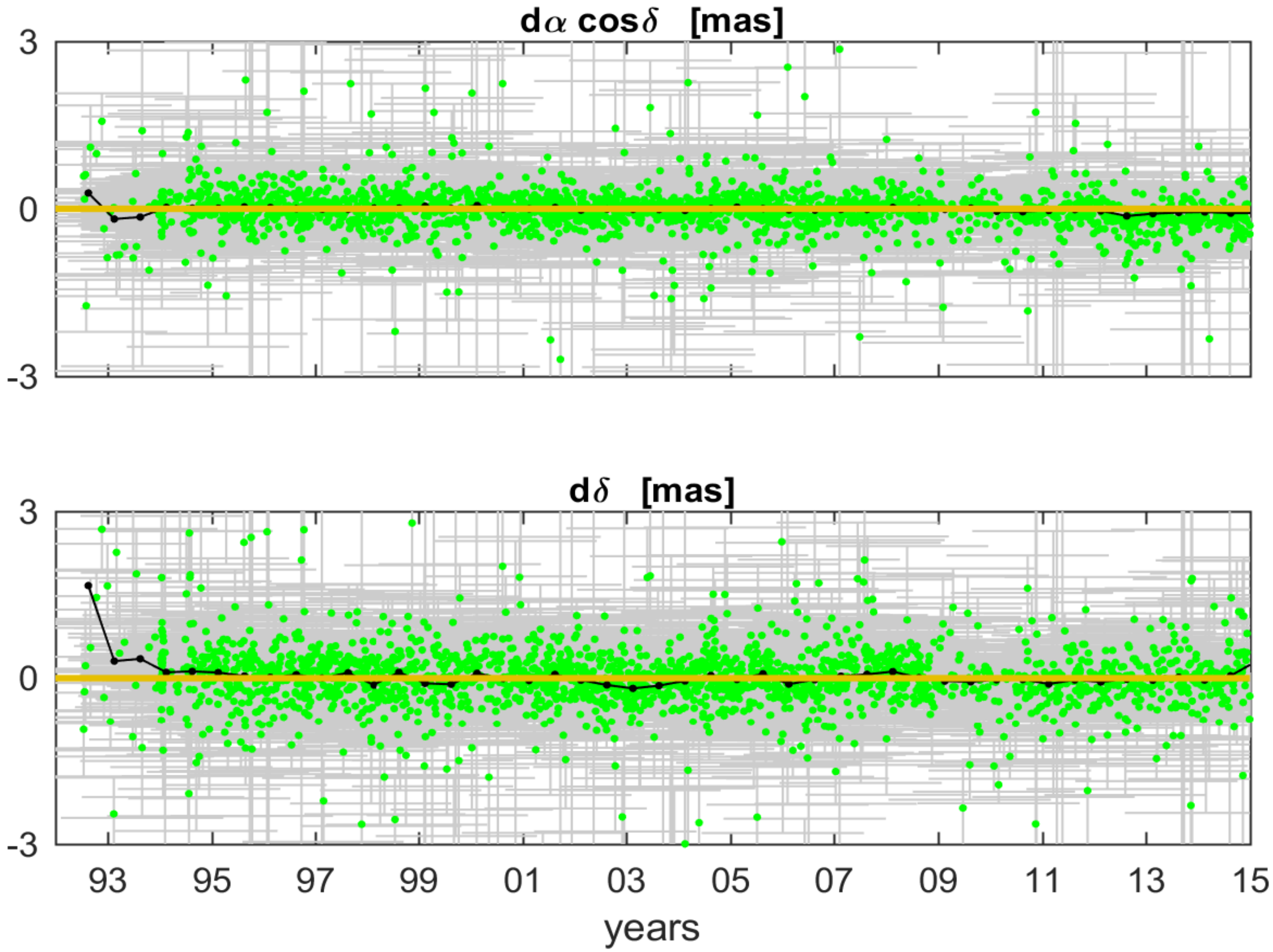

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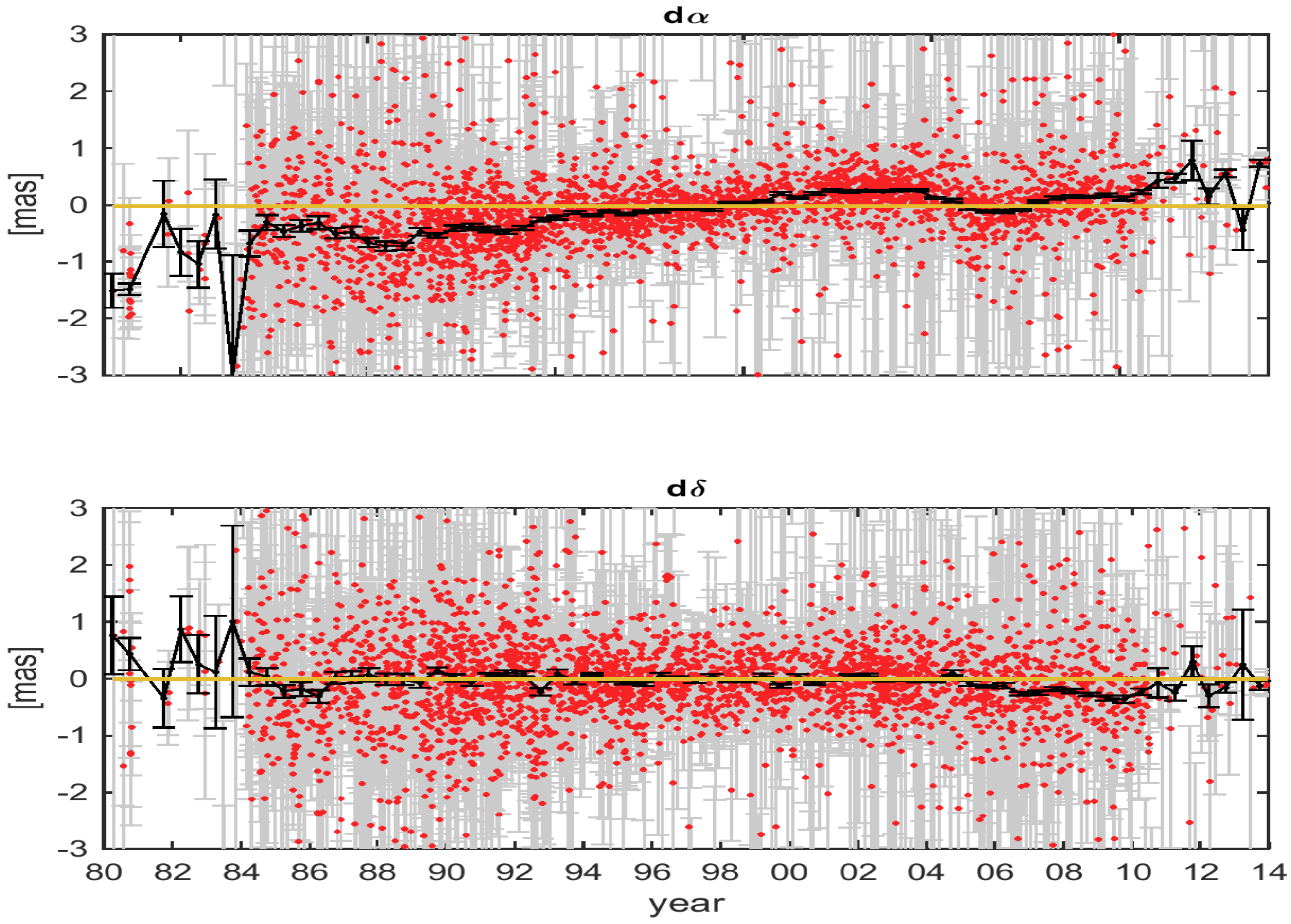
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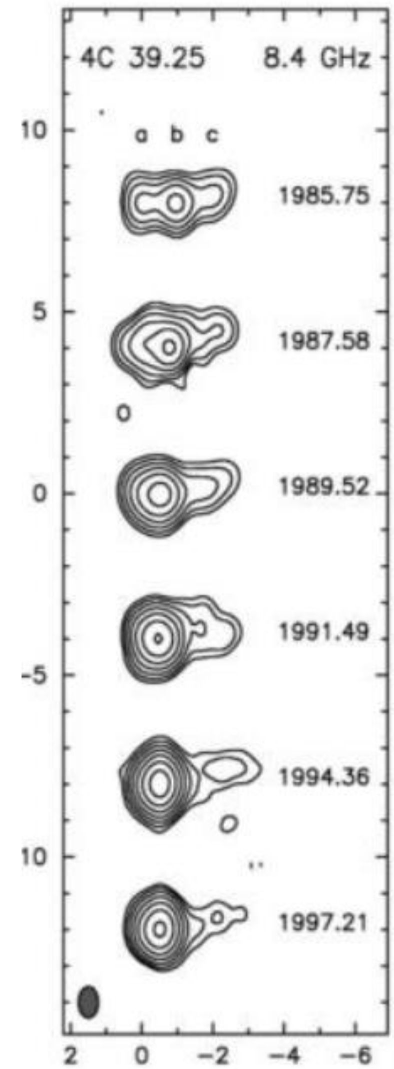
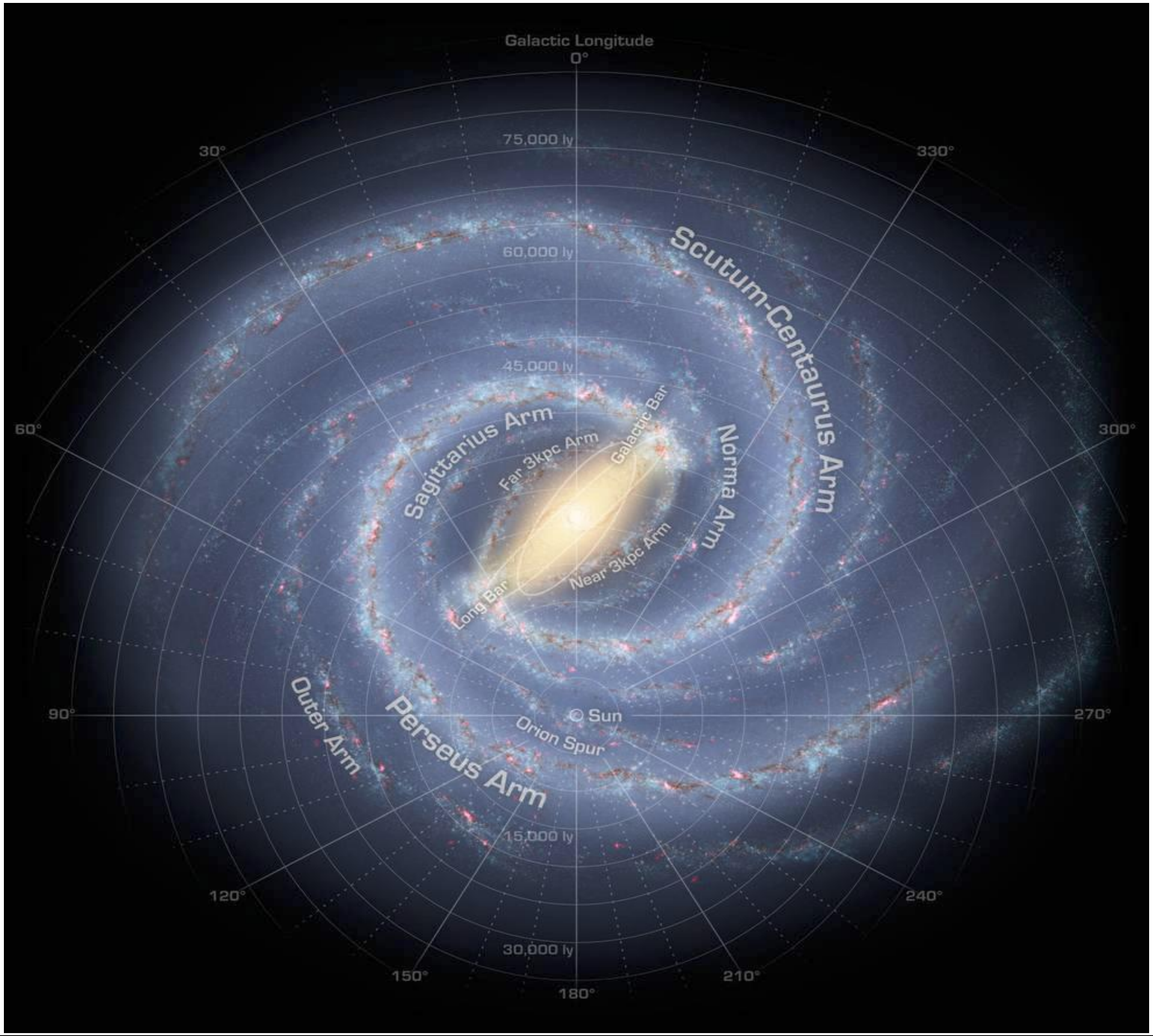
year
80 82 84 86 88 90 92 94 96 98 00 02 04 06 08 10 12 14


4C 39.25
8.4 GHz
a b c
1985.75
1987.58
1989.52
1991.49
1994.36
1997.21

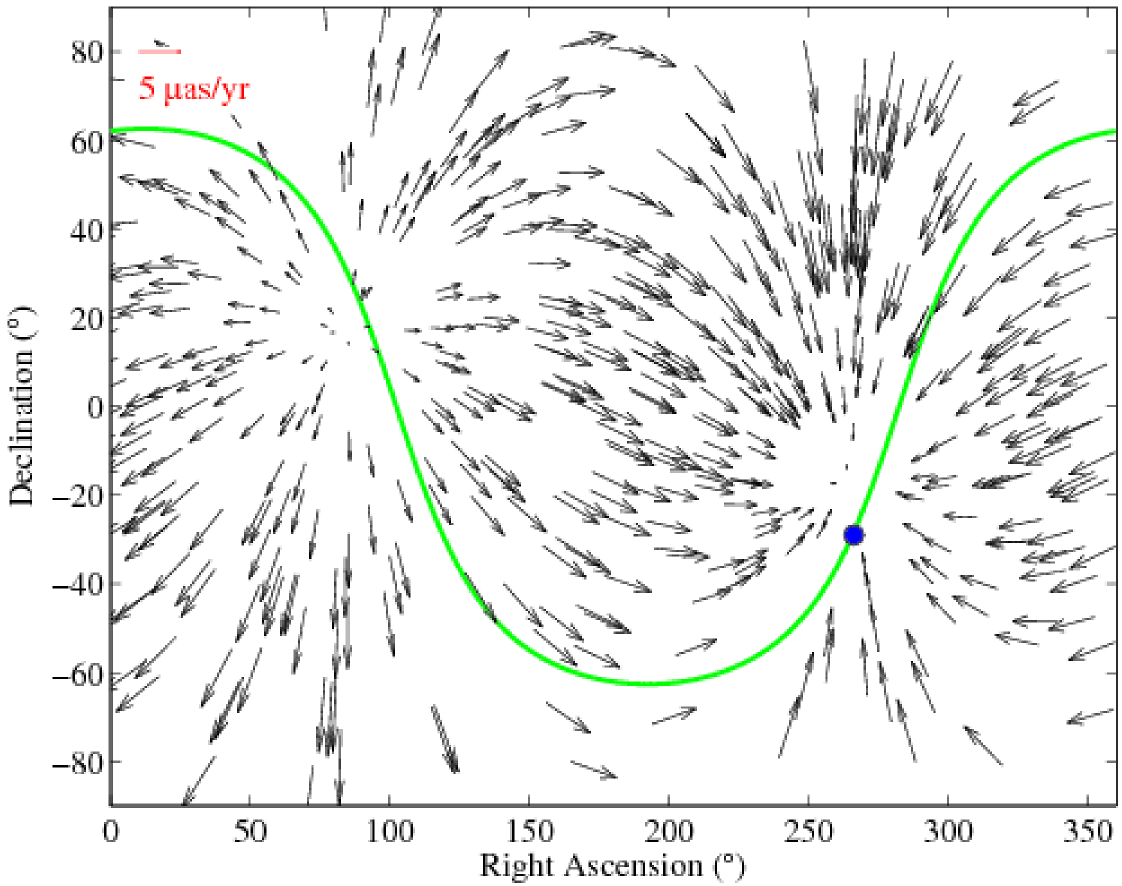
$$\tau_{geom} = -{}^{1}/_{c} \cdot (b - \Delta b) \cdot W \cdot R \cdot Q \cdot k$$

Secular abberation drift



- The gravitational attraction of the Galactic center leads to the **centrifugal acceleration** of the Solar system barycenter.
- It results in **secular aberration drift** which displaces the position of the distant radio sources.

Secular abberation drift



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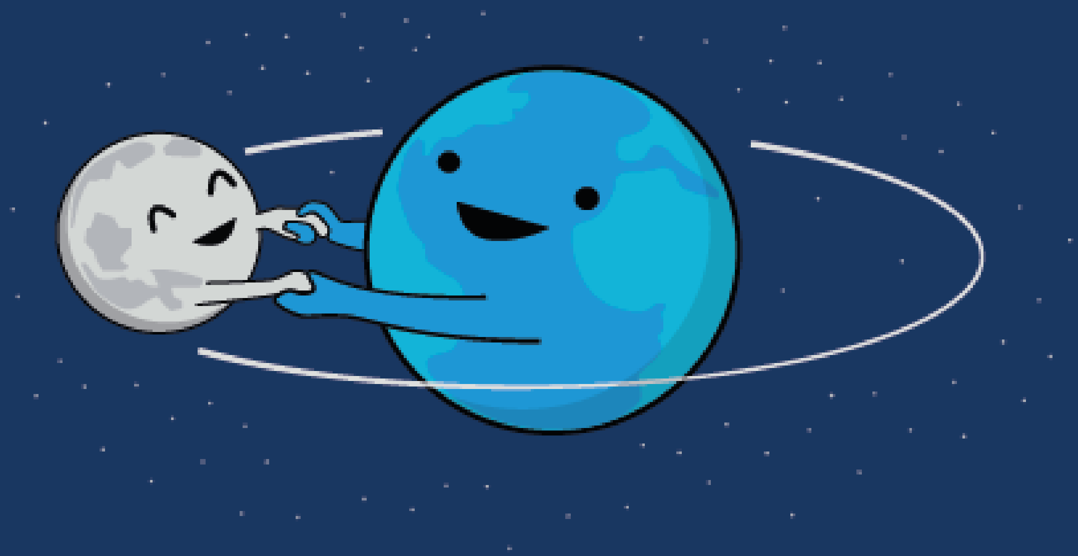
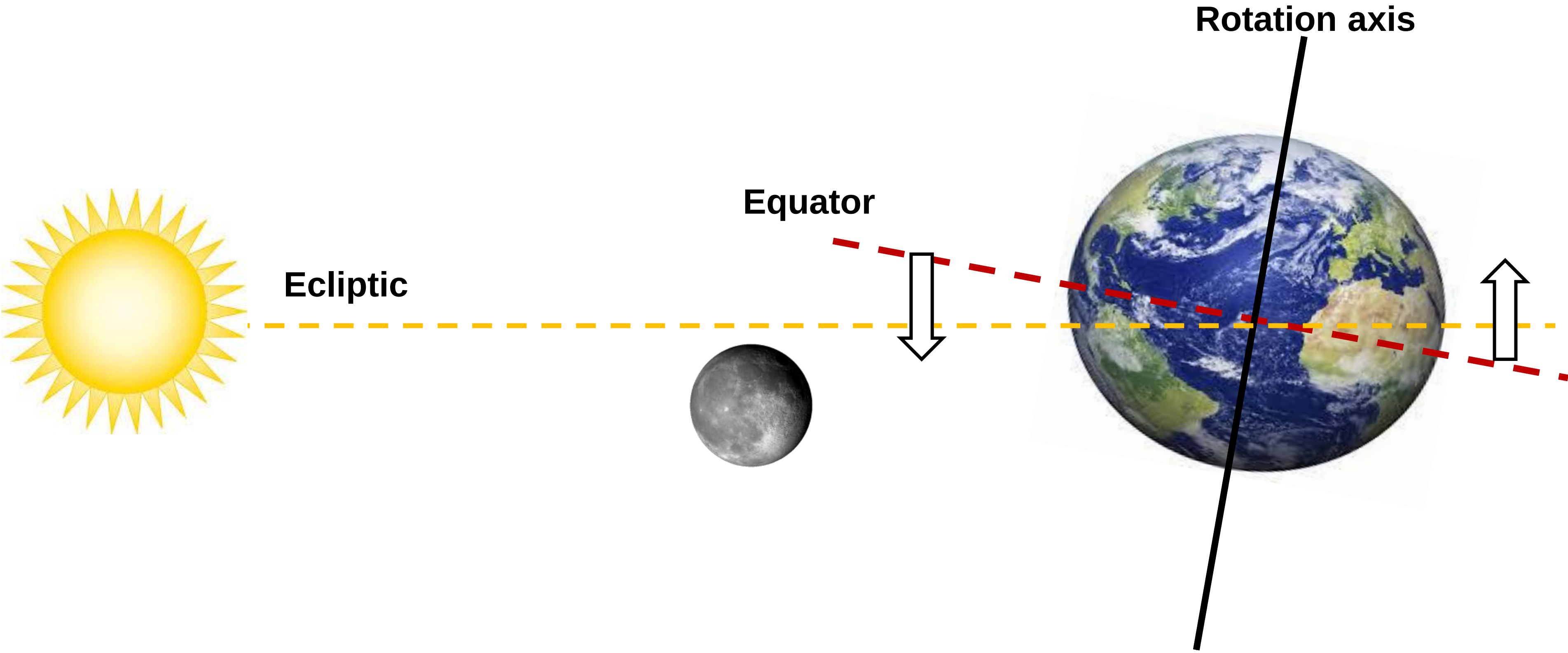
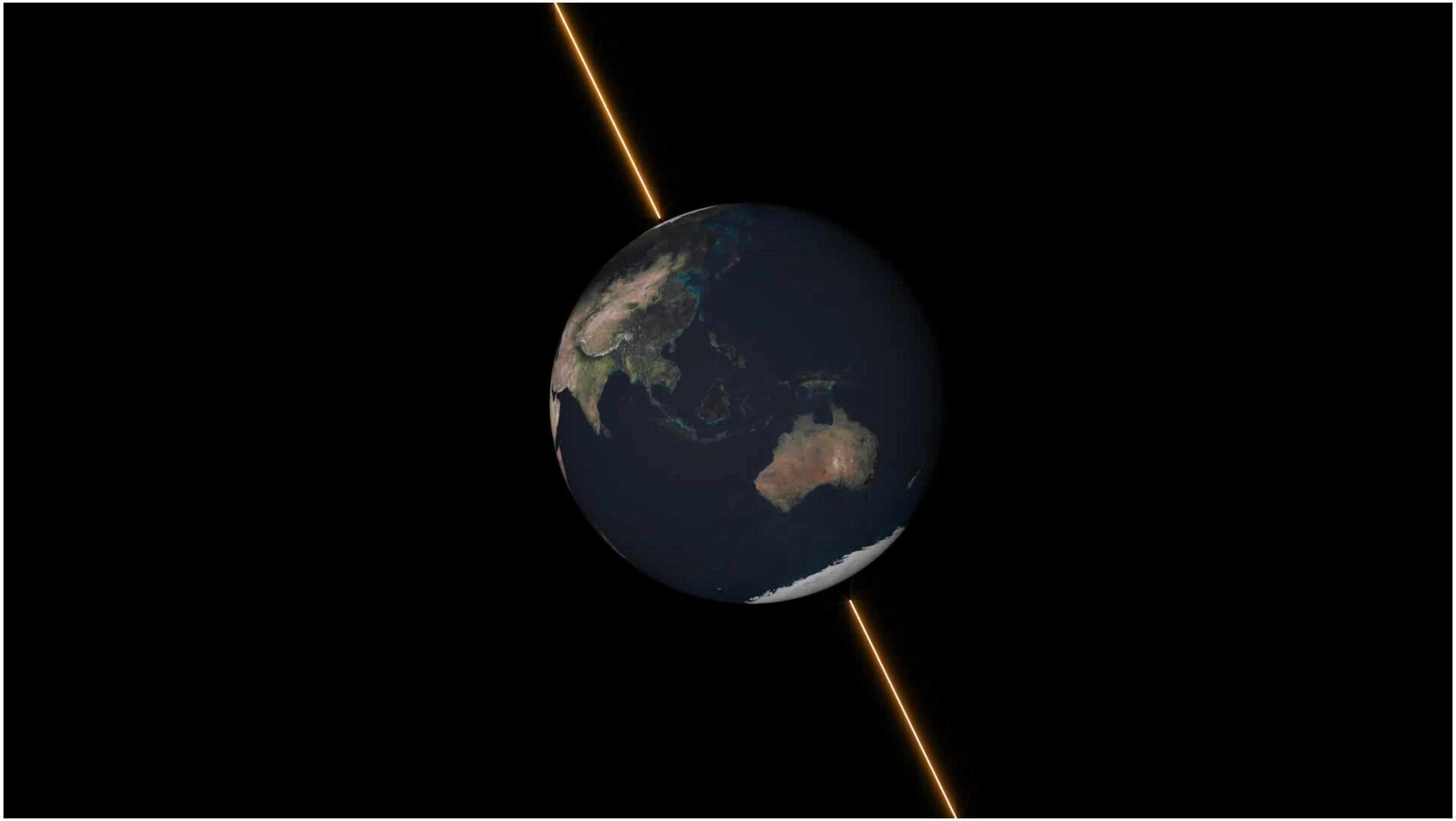


Precession & Nutation

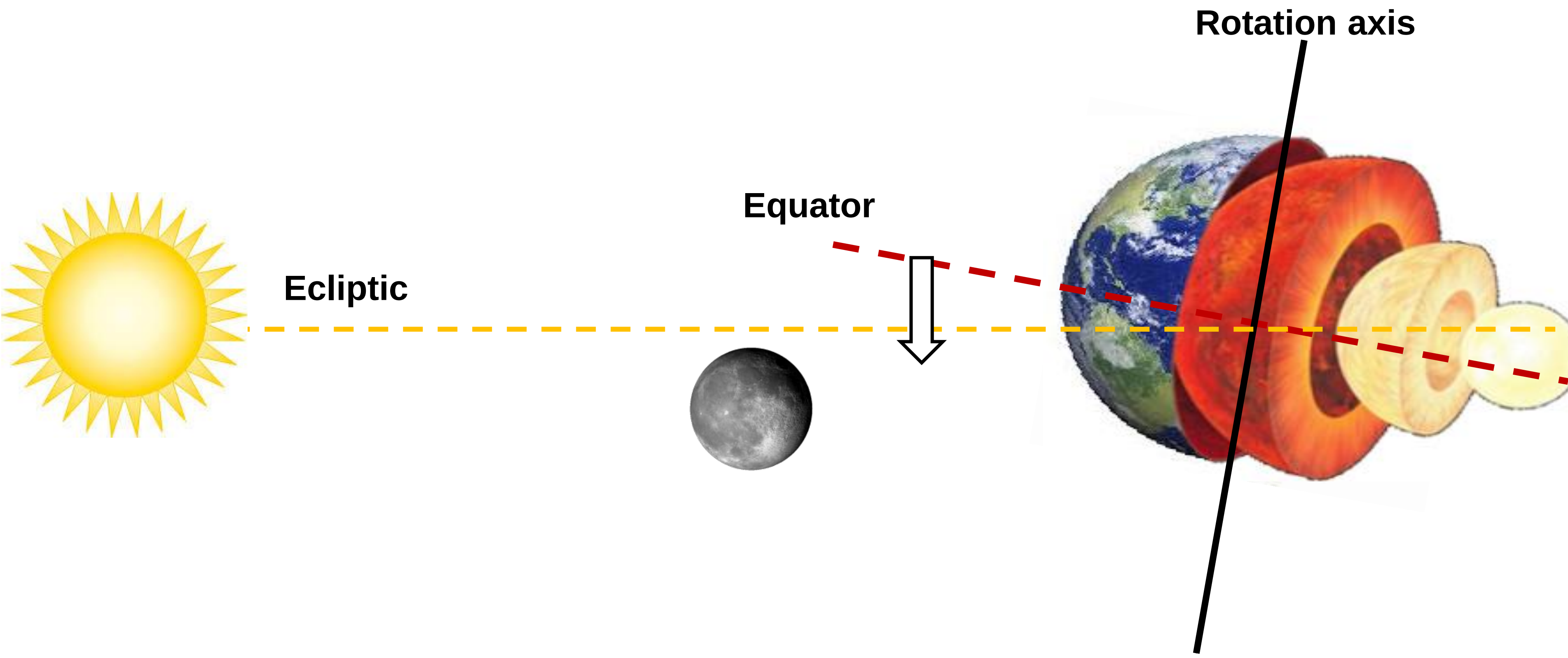


Precession & Nutation

NASA‘s GSFC Conceptual Image lab

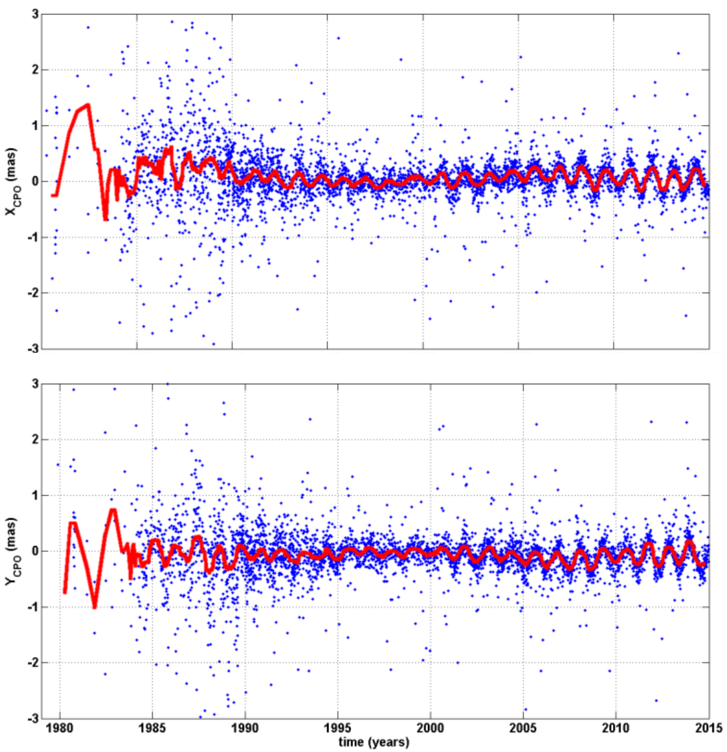


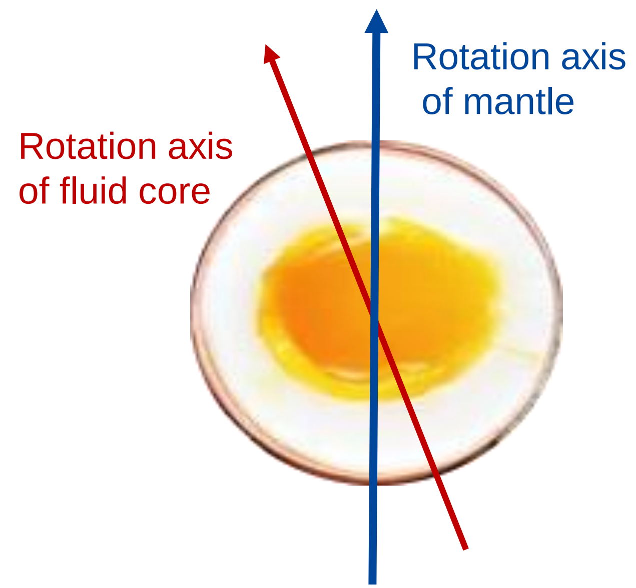
Precession & Nutation



Free Core Nutation

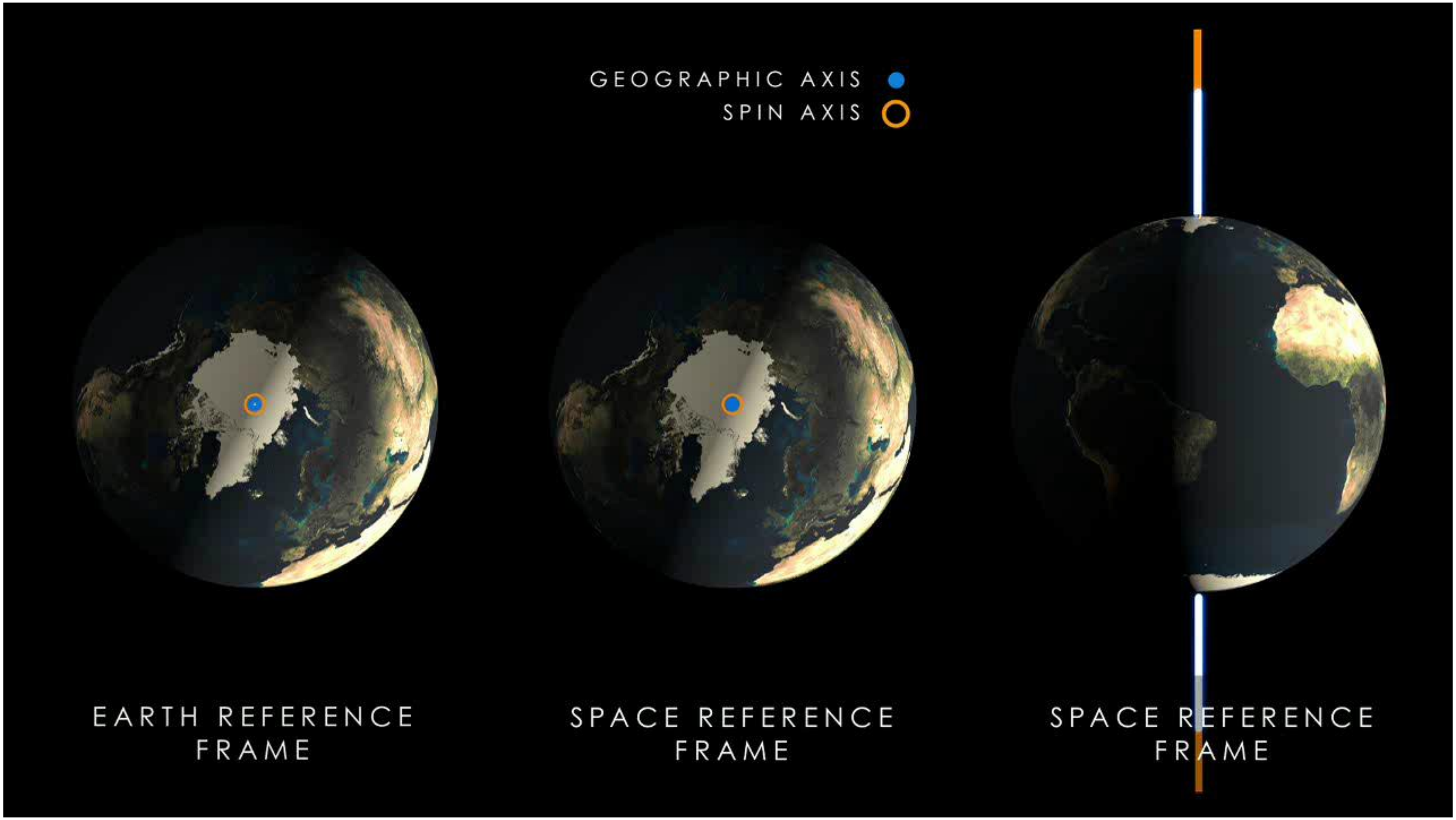
- Variations in free core nutation (FCN) are connected with various processes in the Earth's fluid core and core-mantle coupling, which are also largely responsible for the geomagnetic field variations, particularly the geomagnetic jerks. Period ~ 430 days



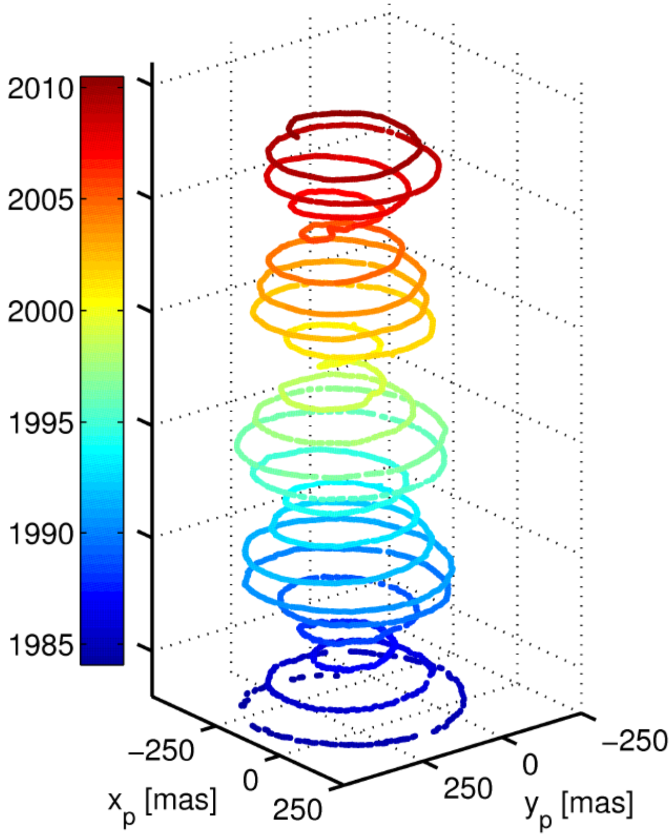


Polar motion

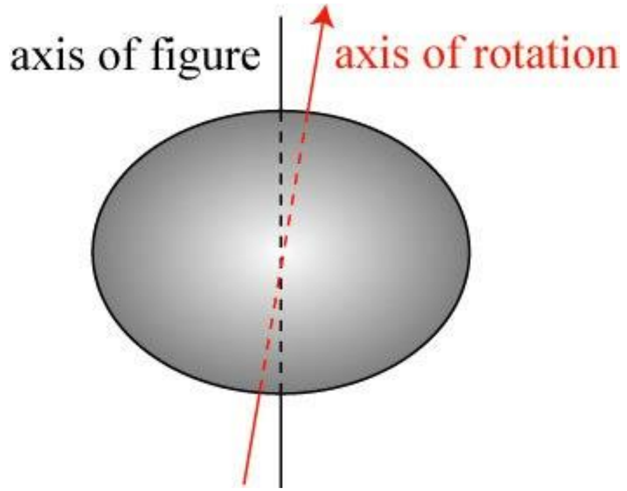
NASA's GSFC Conceptual Image lab



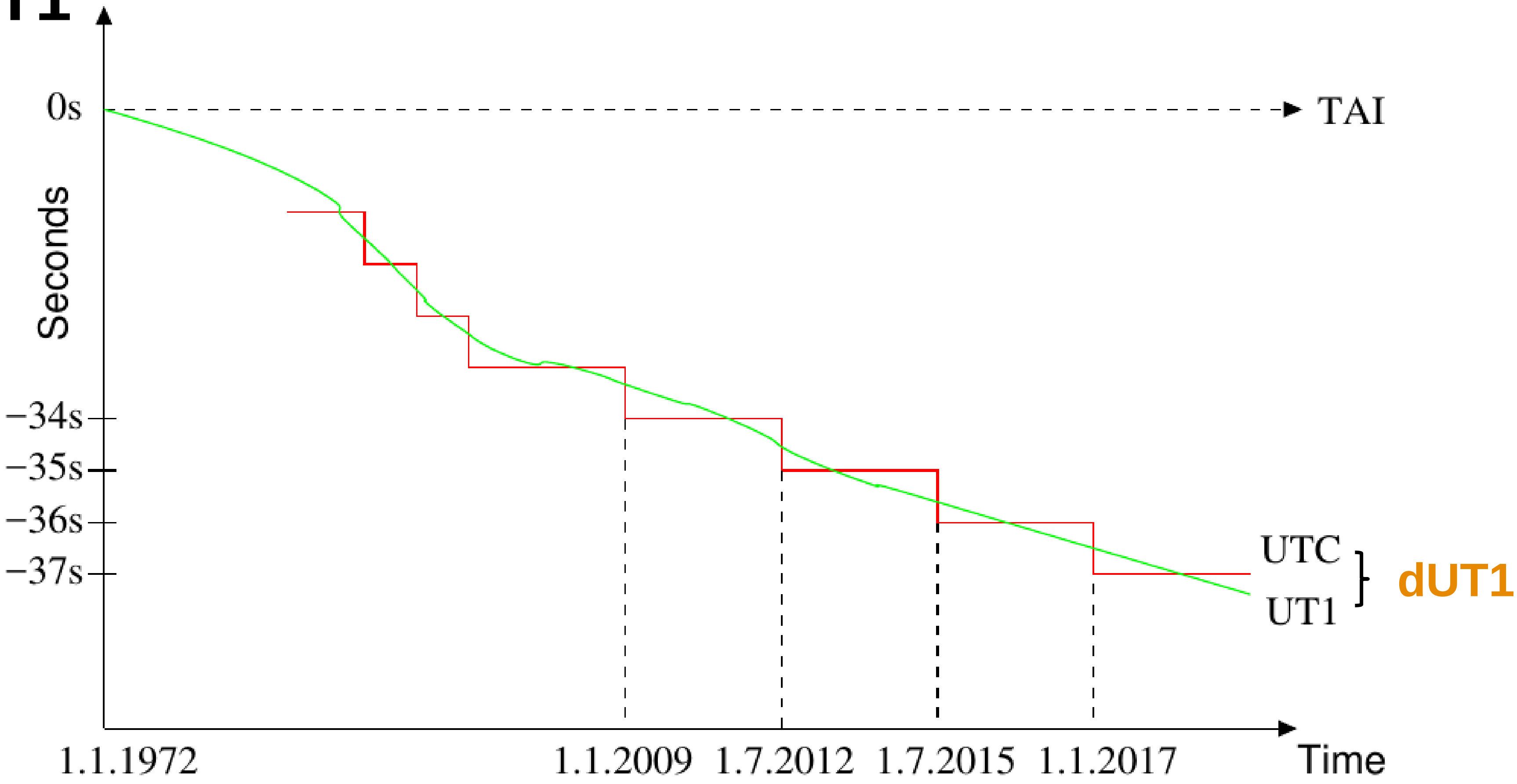
Polar motion



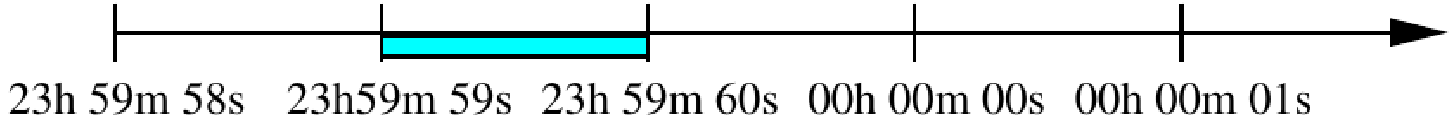
- Chandler wobble
  - Free oscillation
  - Amplitude ~6 m
  - Period ~430 d
- Yearly signal
  - forced oscillation (mainly atmosphere)
  - Amplitude ~3m
  - Pmeriod ~365 d



dUT1



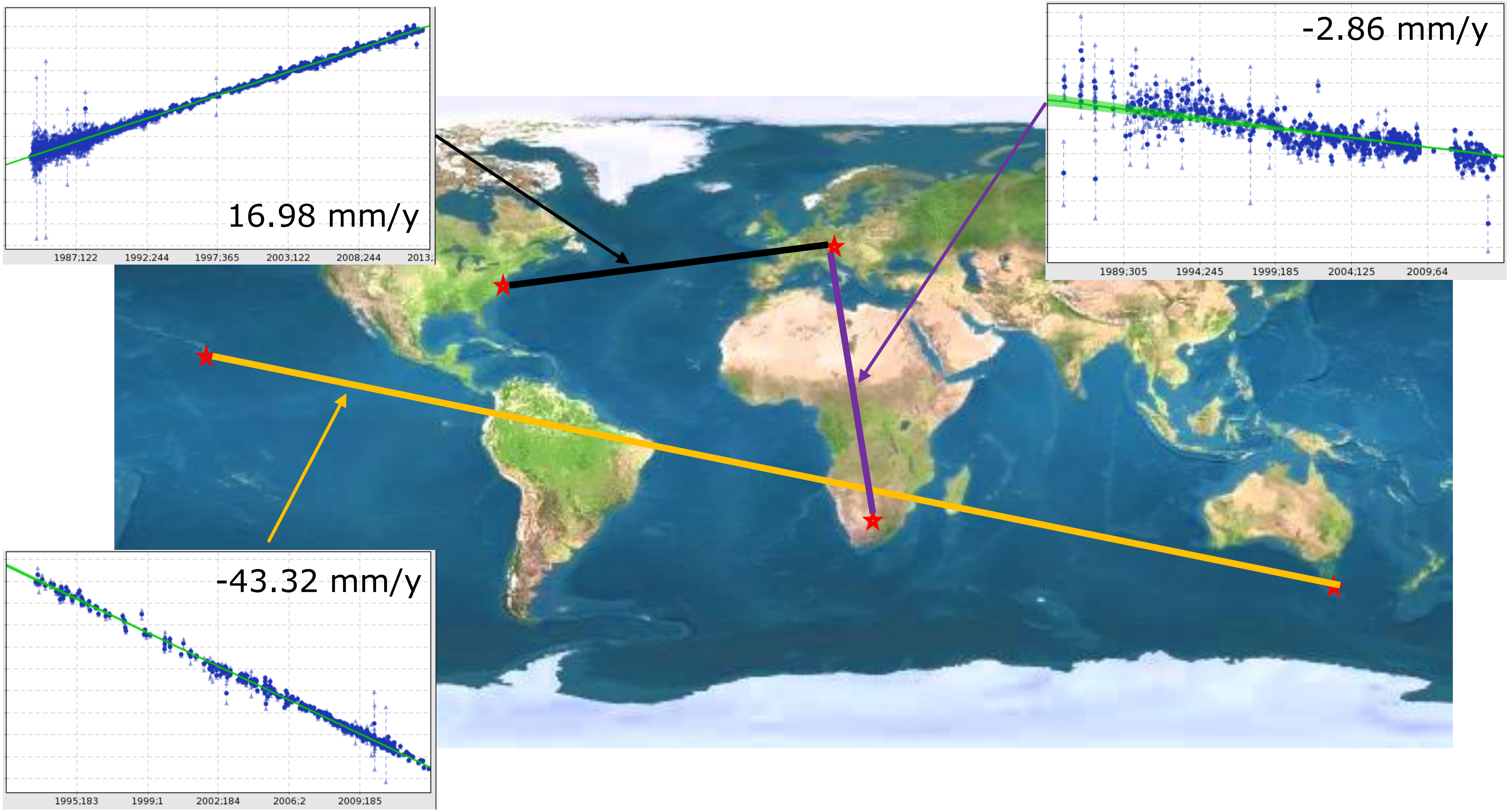
Seconds
0s
−34s
−35s
−36s
−37s
TAI
UTC
UT1
dUT1
1.1.1972
1.1.2009
1.7.2012
1.7.2015
1.1.2017
Time



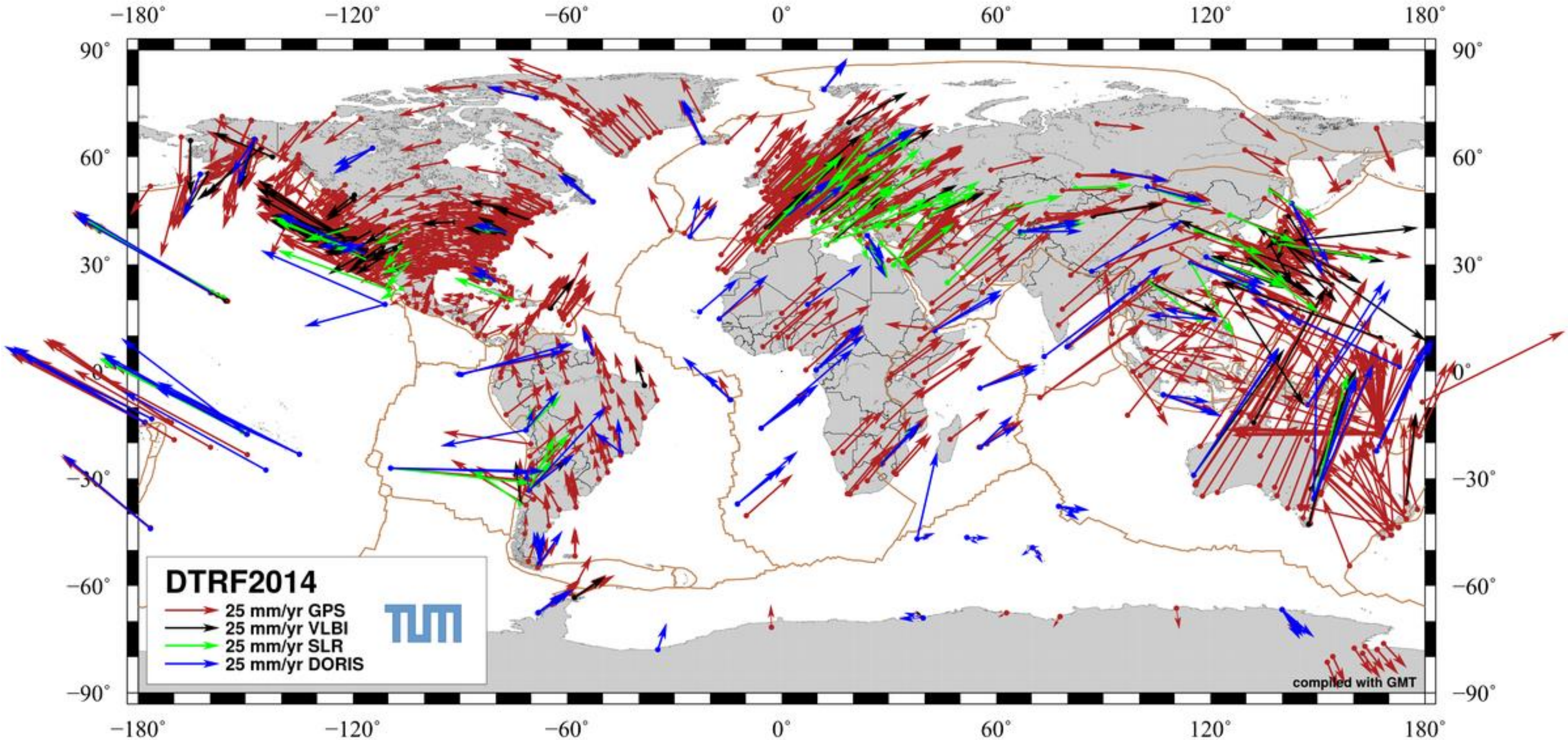
23h 59m 58s
23h59m 59s
23h 59m 60s
00h 00m 00s
00h 00m 01s

$$\tau_{geom} = -{}^{1}/_{c} \cdot (b - \Delta b) \cdot W \cdot R \cdot Q \cdot k$$

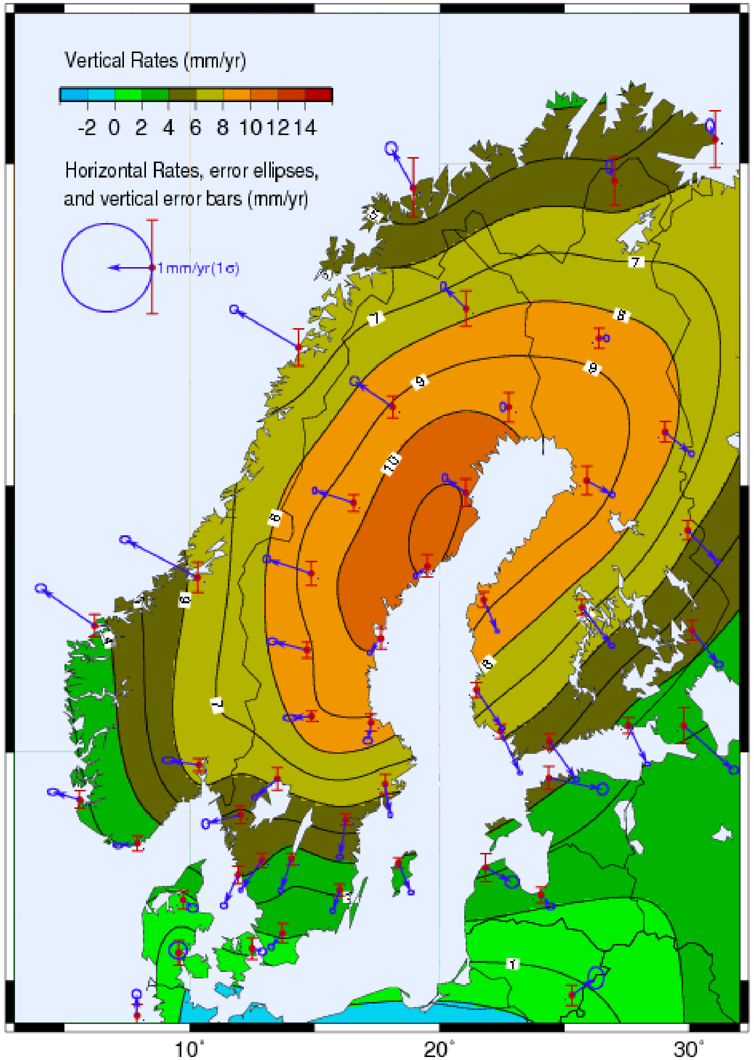
Plate techtonics



TRF velocities



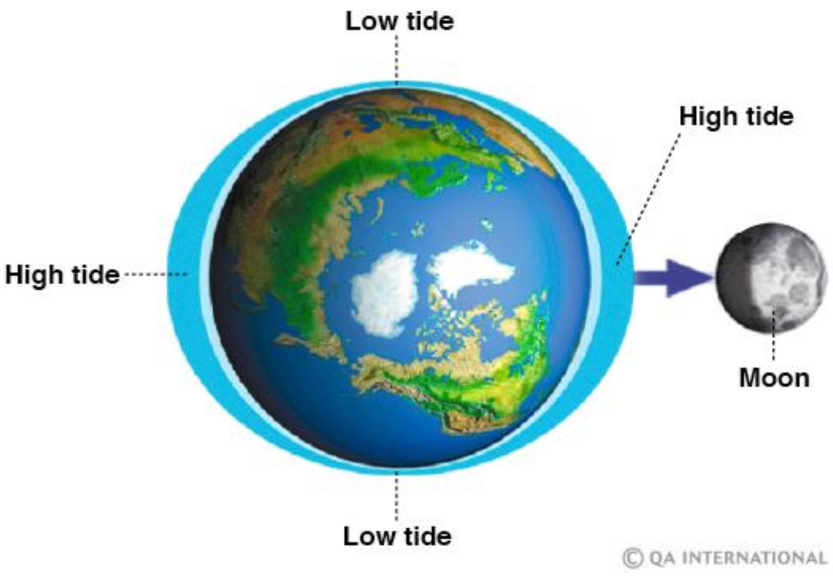
Post glacial rebound

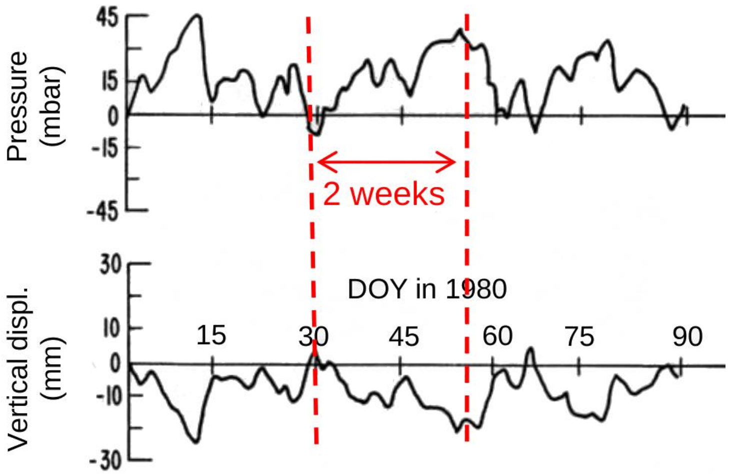


- Melting of ice sheets of last ice age:
  - Vertical up to 12 mm/y
  - Horizontal up to 3 mm/y

Tides

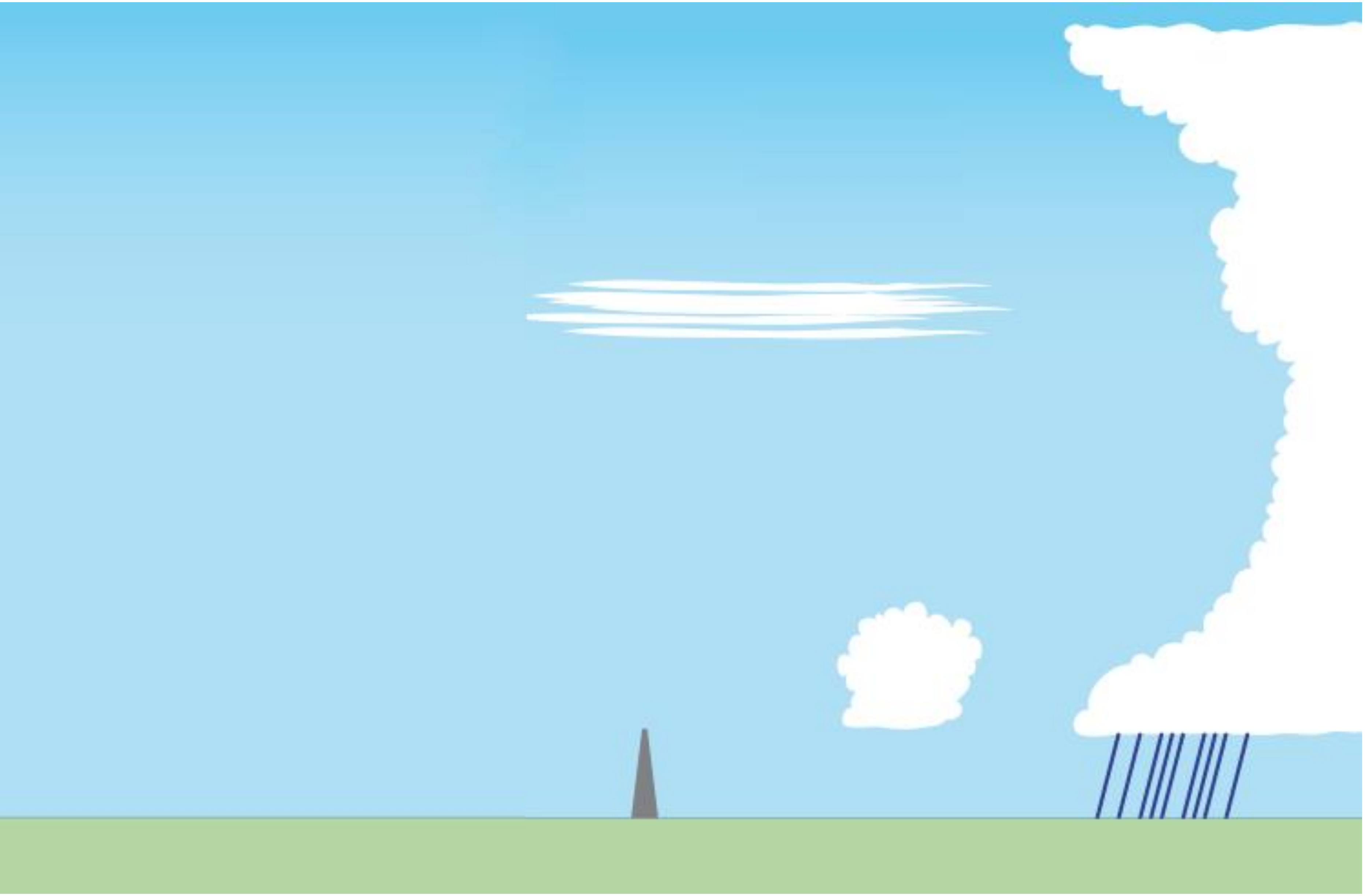
- **Solid Earth tides +/- 30 cm**
- **Atmospheric loading:**
  - tidal: 1-2mm
  - Non-tilal: up to 2 mm
- **Ocean tidal loading:**
  - Half of atmospheric effects
- **Effect also Earth rotation!**



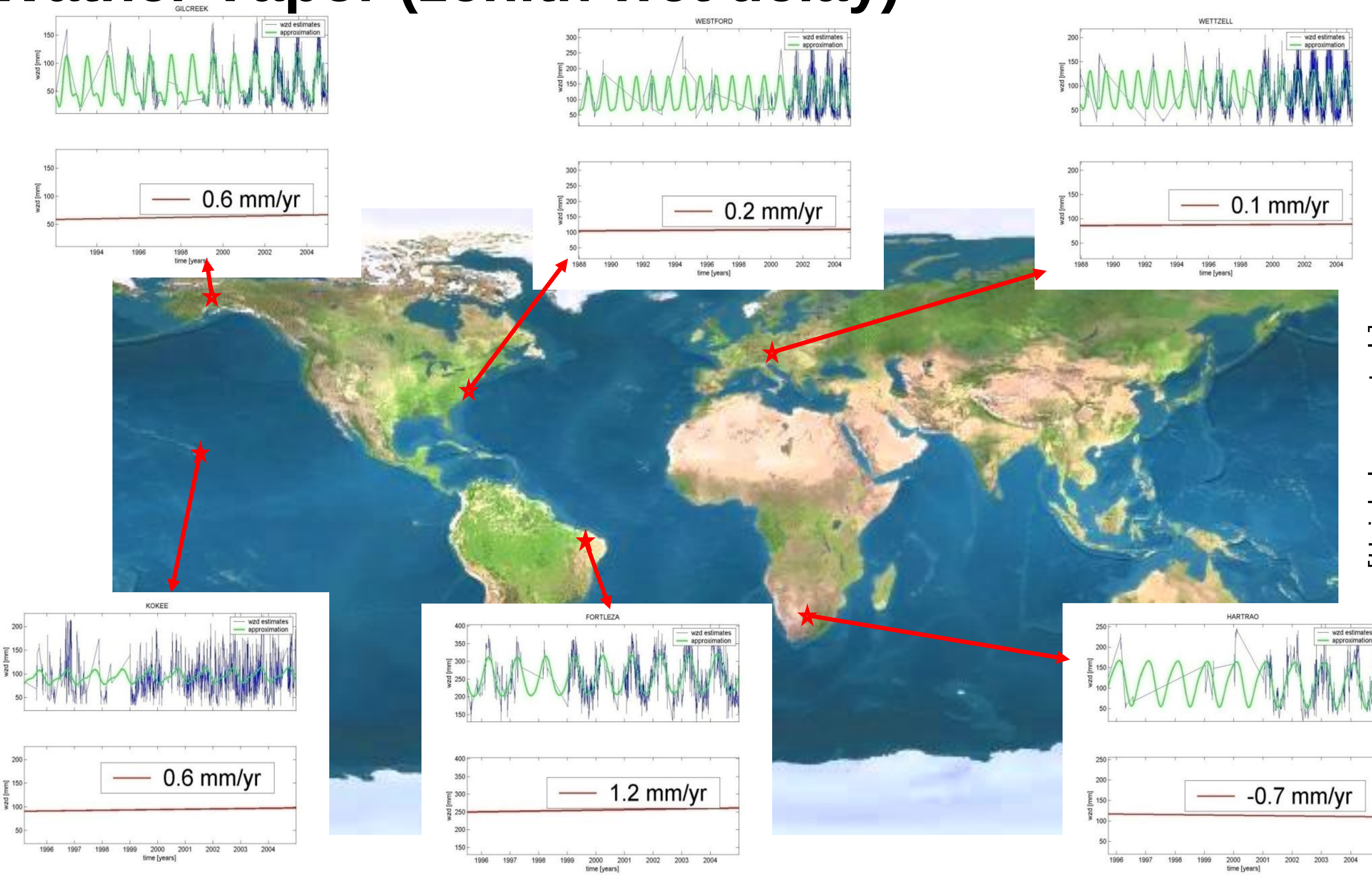


[VanDam & Wahr,1987]

$$\tau_{geom} = -{}^{1}/_{c} \cdot (b - \Delta b) \cdot W \cdot R \cdot Q \cdot k + \tau_{tropo}$$



Wather Vapor (zenith wet delay)



[Heinkelmann et al.]

What is geodetic VLBI good for?

- **Realizes** the conventional celestial reference system
- Is the only technique providing celestial pole offset estimates (**precession/nutation**) and the phase of Earth rotation: **UT1**
- This includes the **free core nutation** (FCN) signal
- Satellite techniques **rely** on the parameters provided by VLBI
- Provides the longest Earth-based baselines (up to 12,000 km) and thus **direct measurement** of tectonic plate motions, post glacial rebound, etc.
- Provides a **long-term stable infrastructure** that adds significant, precise, and robust information for the realization of the terrestrial reference system

Why di I like it?

- **Covers a wide range of topics**
  - From astrophysics down to the interior of the Earth
  - No chance to get bored
- **Advent of VGOS**
  - New & more data -> new results
- **International community**
  - …more like family

Need some money?

Germany:
This is a very nice link from the German Academic Exchange Service. There you can search for scholarships according your country and degree:
https://www.daad.de/deutschland/stipendium/datenbank/en/21148-scholarship-database/?status=&origin=&subjectGrps=&daad=&q=&page=1&back=1

The same thing, but from the German Ministry for Education and Science, unfortunately in German only...
http://www.foerderdatenbank.de/
But maybe you can find something interesting starting from the main page: https://www.bmbf.de

The DFG is the most important founding agency in Germany, but in most cases you must be affiliated with a German institution, or at least have a German collaborator. http://www.dfg.de/en/index.jsp

English master courses in Berlin, Bonn, Munich, Stuttgart,…

Travel funding for conferences: IAG, IVS, EGU, AGU,…

Austria:
This is the Austrian Academic Exchange Service:
https://oead.at/en/to-austria/grants-and-scholarships/

A grant database:
http://www.grants.at/

Austrian funding agency, same goes as for the DFG:
https://www.fwf.ac.at/en/research-funding/fwf-programmes/

Italy:
Scholarships from the Italian Ministry of foreign affairs:
http://www.esteri.it/mae/en/ministero/servizi/stranieri/opportunita/borsestudio_stranieri.html

Most of the funding agencies in Europe can be found here:
https://www.nsf.gov/od/oise/europe/science_funding.jsp

European Union programs, not sure how interesting they are, as usually they are limited to European citizen and very hard to get. But sometimes they have international programs:
http://ec.europa.eu/research/participants/portal/desktop/en/opportunities/h2020/topics/msca-if-2016.html

Thanks for your attention!