OBSERVER LE CHAMP MAGNETIQUE TERRESTRE: QUAND LA THEORIE SUIT LA MESURE

MIOARA MANDEA - CNES

European Research Council

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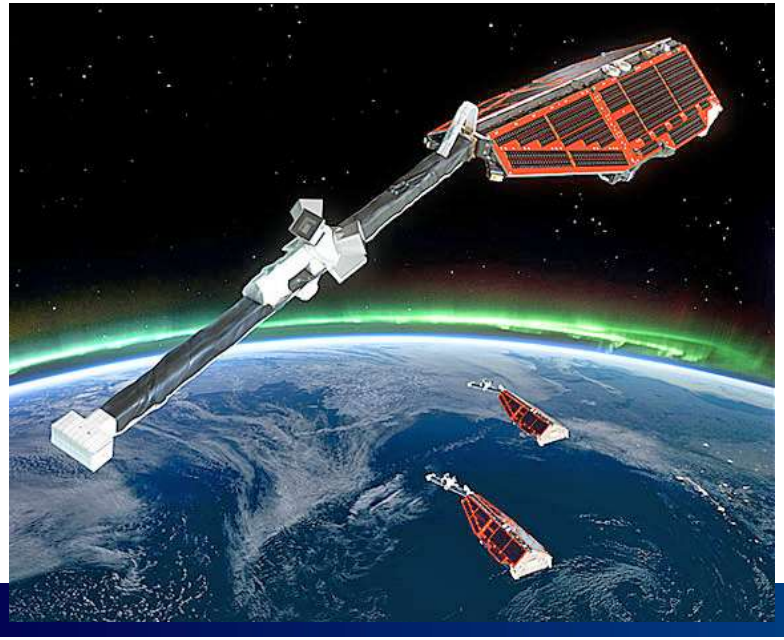
cnes

GRACEFUL



Outline

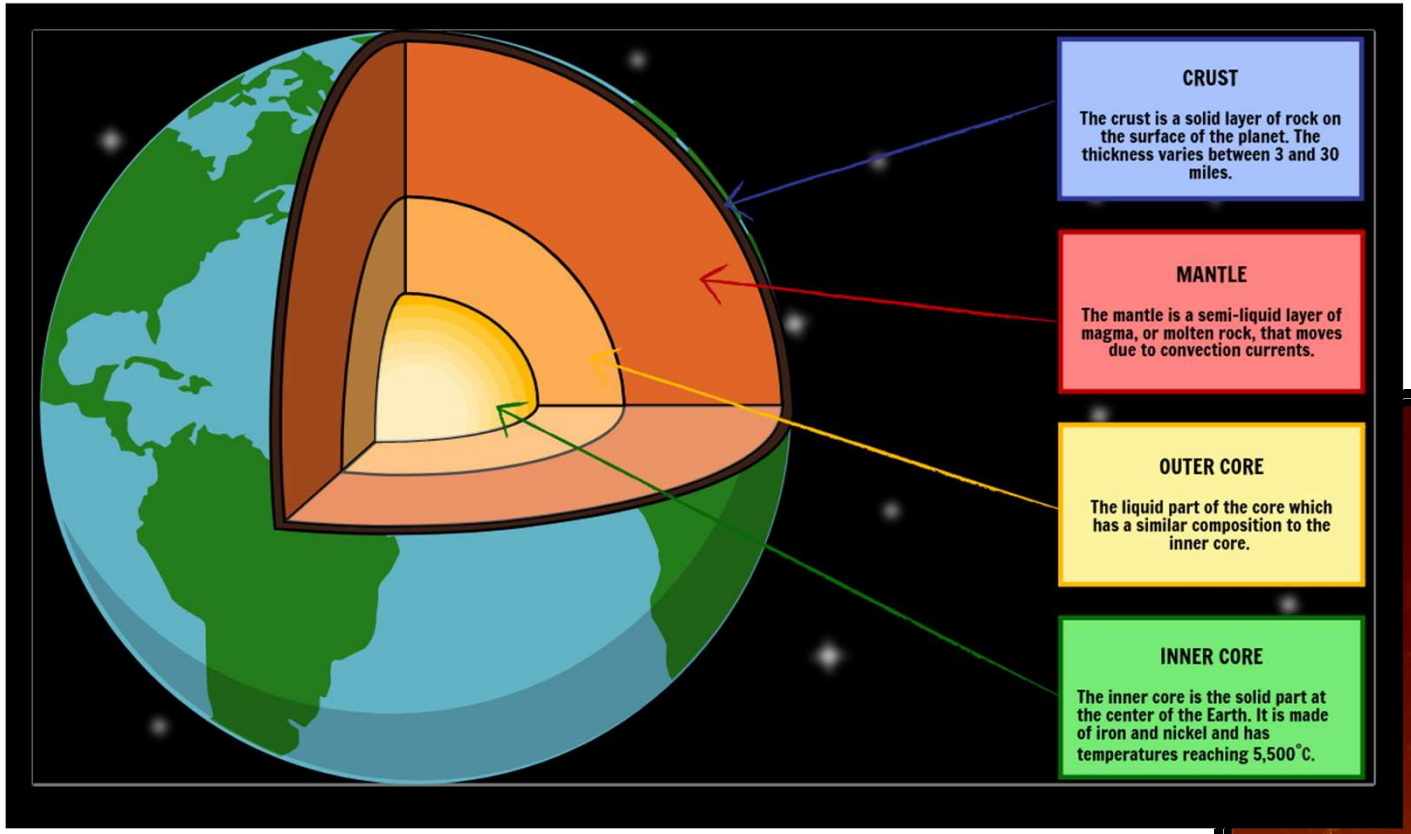
Introduction & history

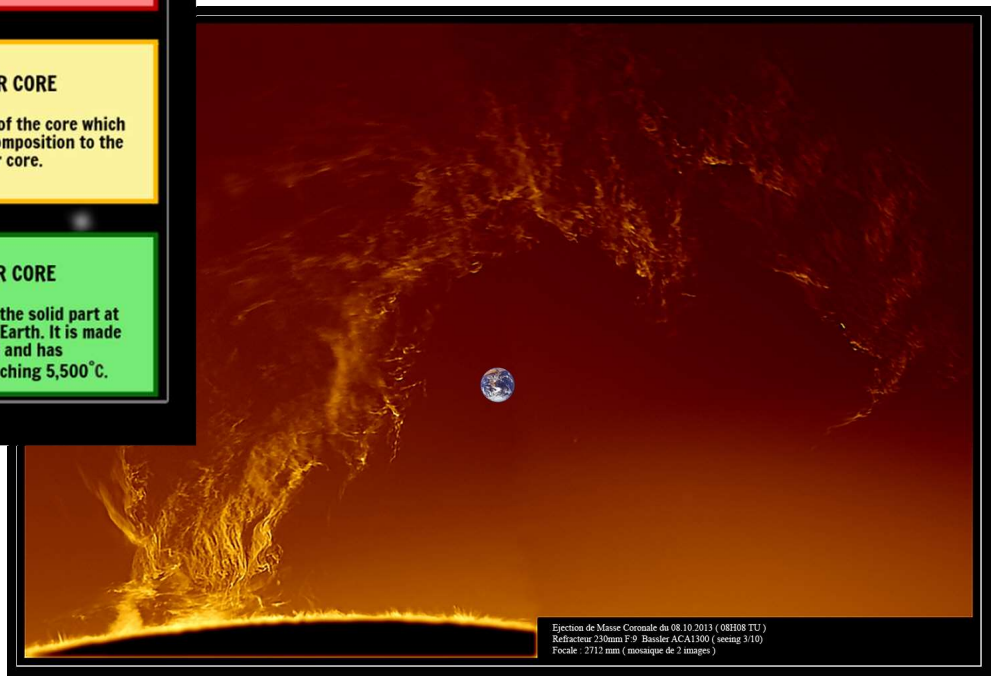
Measurements & models

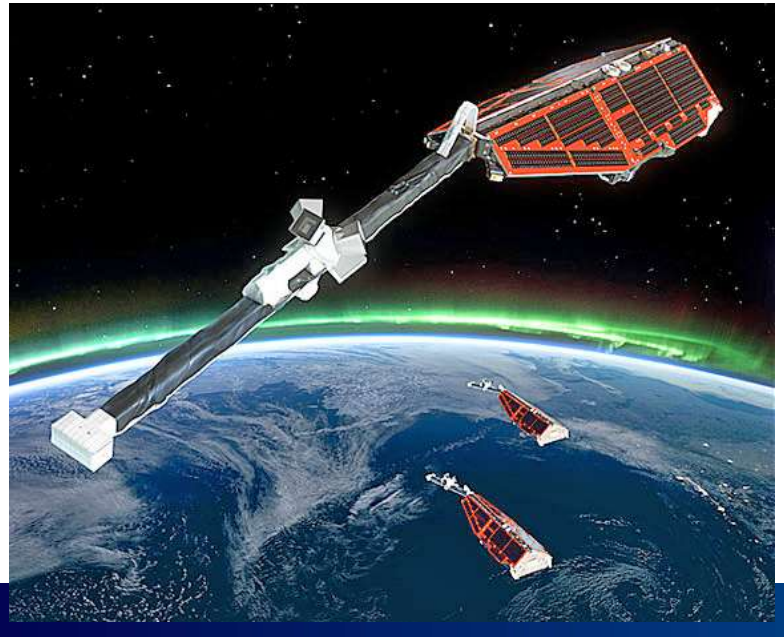
When measurements precede theory...

- Geomagnetic jerks – core dynamics
- Magnetic and gravity anomalies – irregularities of the core-mantle boundary

Conclusions


CRUST
The crust is a solid layer of rock on the surface of the planet. The thickness varies between 3 and 30 miles.
MANTLE
The mantle is a semi-liquid layer of magma, or molten rock, that moves due to convection currents.
OUTER CORE
The liquid part of the core which has a similar composition to the inner core.
INNER CORE
The inner core is the solid part at the center of the Earth. It is made of iron and nickel and has temperatures reaching 5,500°C.


Ejection de Masse Coronale du 08.10.2013 (08H08 TU)
Refracteur 230mm F/9 Bassler ACA1300 (seeing 3/10)
Focale : 2712 mm (mosaique de 2 images)



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The compass

- created around the Qin Dynasty era (255 BC – 206 BC) & pointed South

- long before it was used for navigation, the compass was actually used by fortune tellers on their boards to make predictions

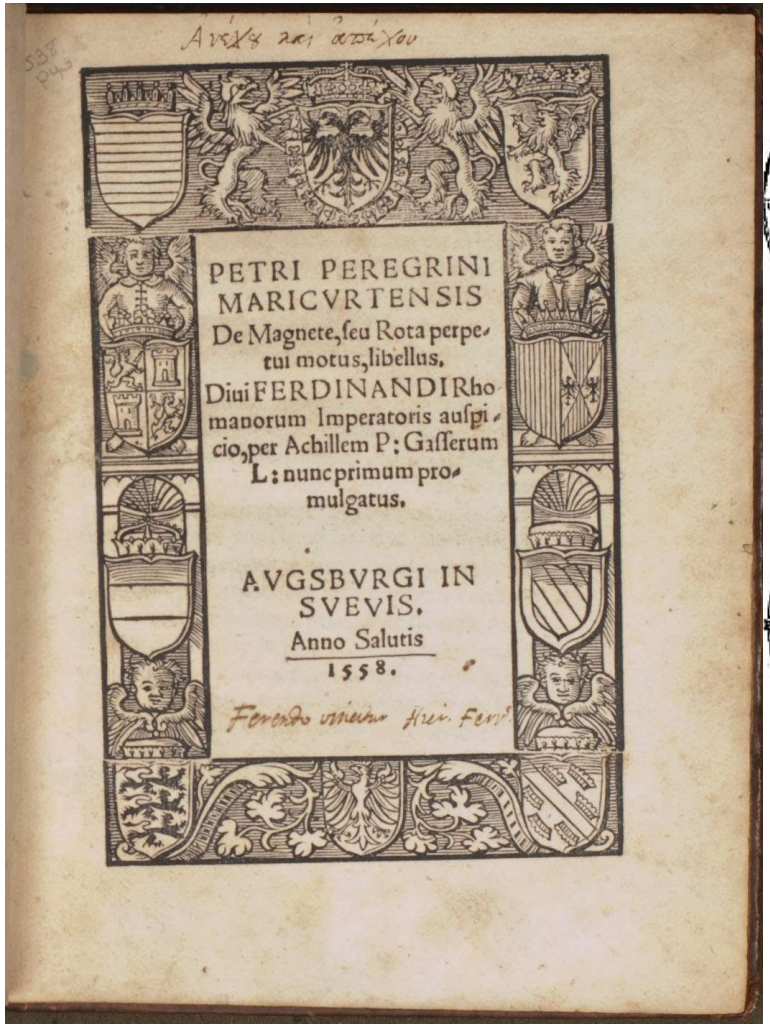
- primitive compasses showed people the way not literally, but figuratively, helping them to order and harmonize their environments and lives

Introduction & history

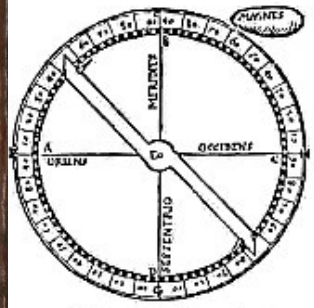
Petrus Peregrinus [1240–?]

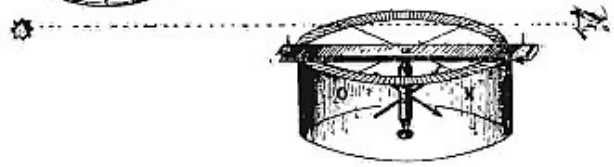
1269 – *Epistola de Magnete*

- *Actum in castris in obsidione Luceriæ anno domini 1269 8 die augusti* ("Done in camp during the siege of Lucera, August 8, 1269")
- described 2 kinds of compass
  - ✓ one in which an oval lodestone floated in a bowl of water
  - ✓ the first dry compass with the needle mounted on a pivot


PETRI PEREGRINI
MARICVRTENSIS
De Magnete, seu Rota perpetui motus, libellus.
Diui FERDINANDI Romanorum Imperatoris auspicio, per Achillem P: Gasserum L: nunc primum promulgatus.
AVGSBVRGI IN SVEVIS.
Anno Salutis
1558.

a





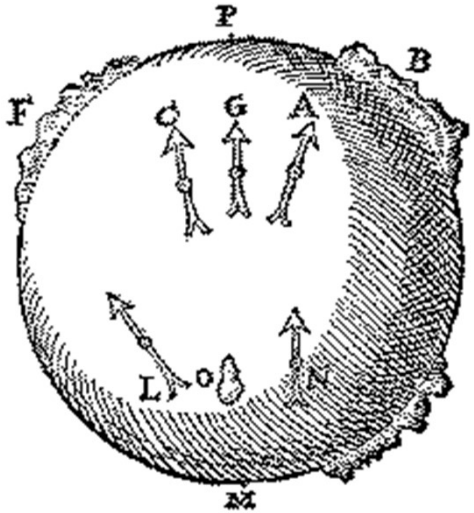
b

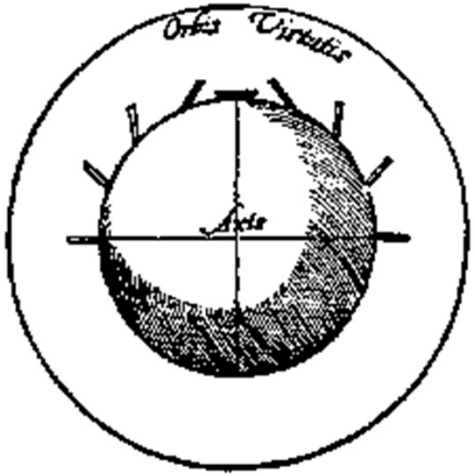
Introduction & history

William Gilbert [1544-1603]

1600: *DE MAGNETE*
(On the Magnet and Magnetic Bodies, and on the Great Magnet the Earth)

- described many of his experiments with his model Earth called the terrella
- investigated the reason compasses point North





Guillaume le Nautonier sieur de Castelfranc [1560 – 1620]

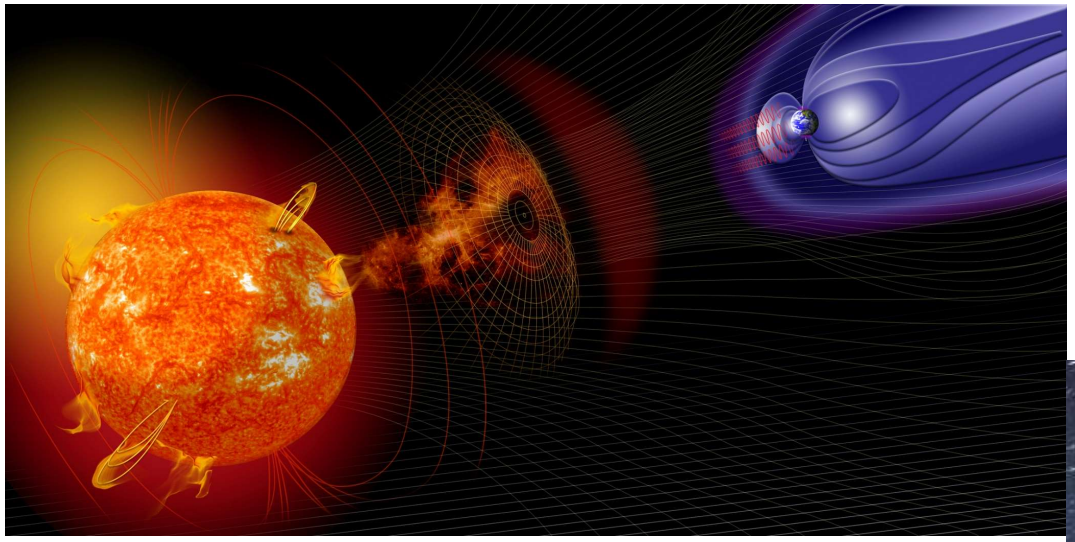
1601: "*MECOMETRIE DE LEYMANT* CEST A DIRE LA MANIERE DE MESURER les longitudes par le moyen de l'eymant. Par laquelle est enseigné, vn trescertain moyen, au paravant inconnu, de truuer les longitudes Geographiques de tous lieux, aussi facilement comme la latitude…"

(Mandea and Mayaud, 2002)

Auec Priuilege du Roy, Fontaine Bleau, le quinziesme jour d'octobre 1601"

Some 750 years
after Petrus Pelegrinus' *Epistola*
we are still astonished by the magnetic field

Introduction & history

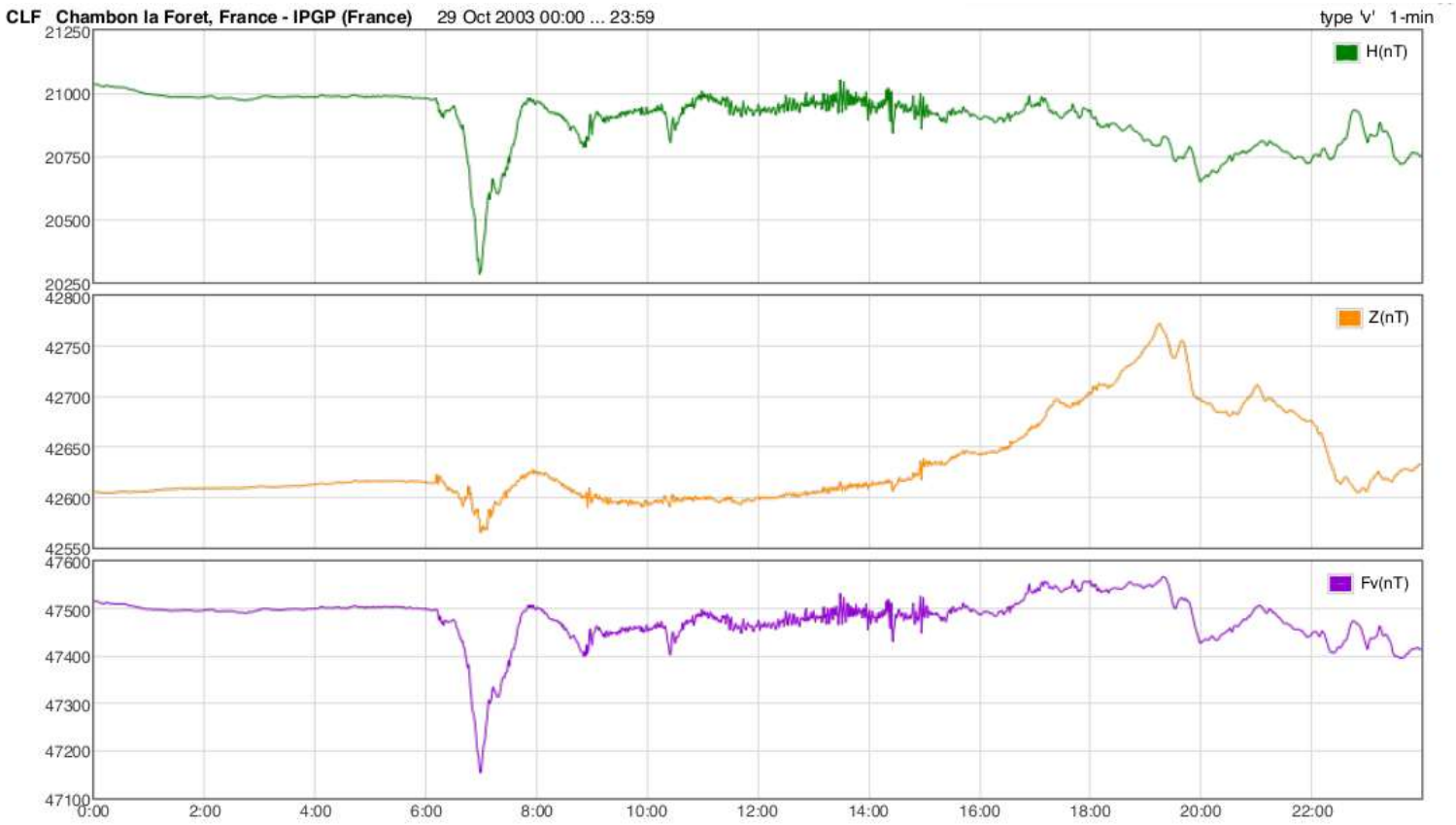


Understanding…

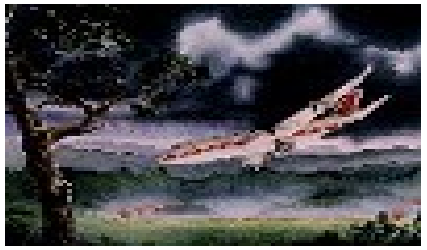
- Earth – Sun environment
- Near-Earth space
- Earth's deep interior

(Friis-Christensen et al., 2004)

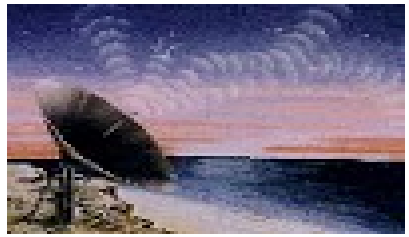
Introduction & history



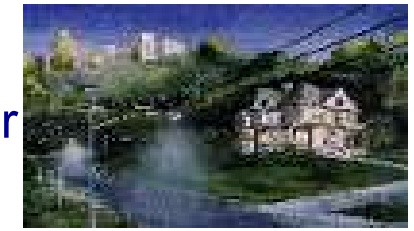
navigation



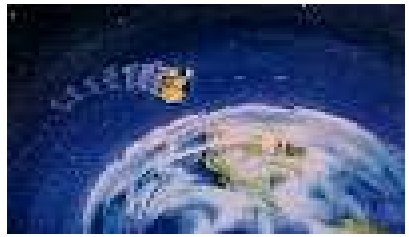
radio



electric power



satellite operations



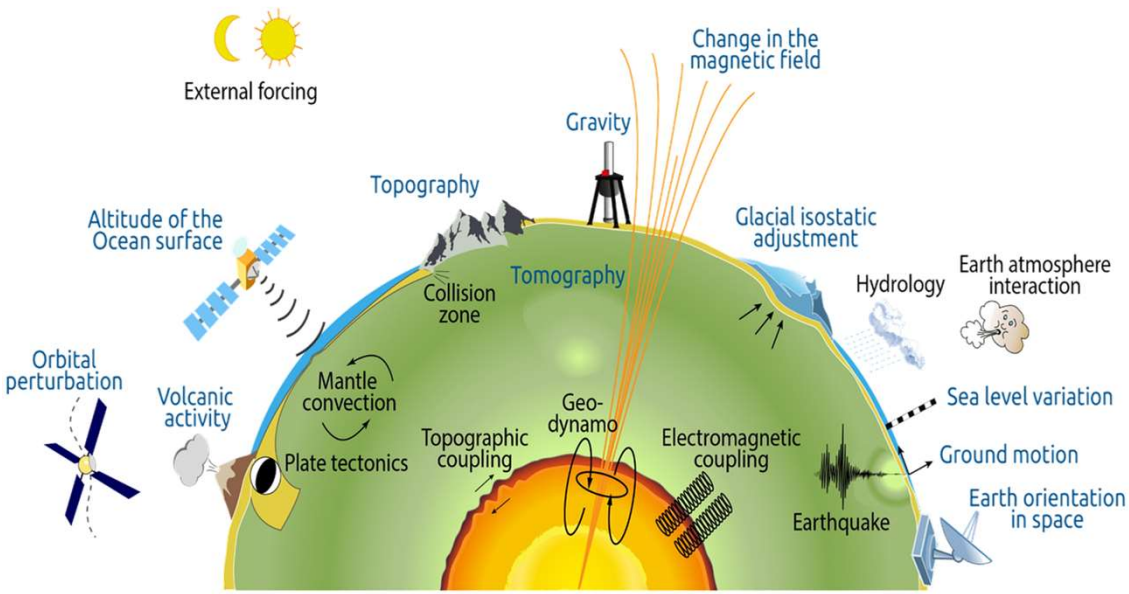
Introduction & history

Why measuring the Earth's magnetic field?

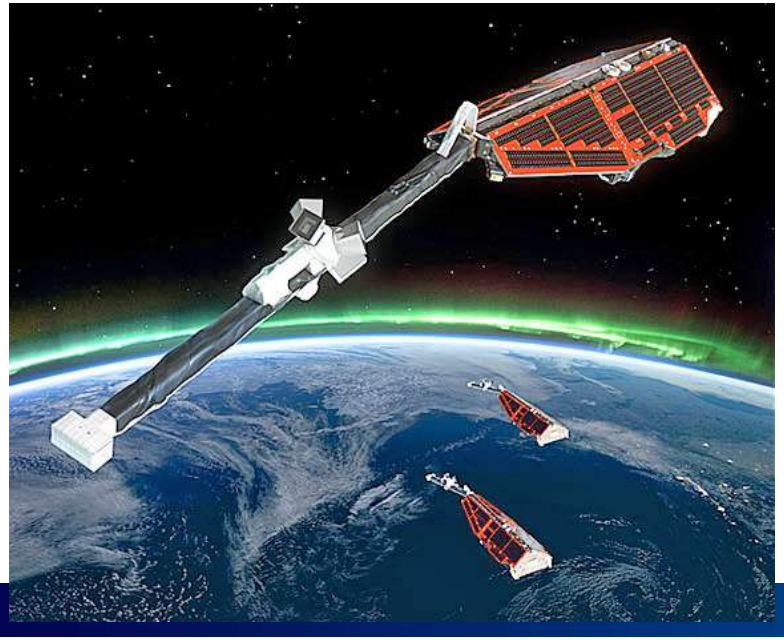
- Fundamental science
- Society-driven applications

STUDY THE EARTH'S SYSTEM

Magnetic measurements
- ground observatories
- space platforms



Observing the Earth's system dynamics (©Guyot, 2020)



Outline

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Measurements & models

Observations - direct

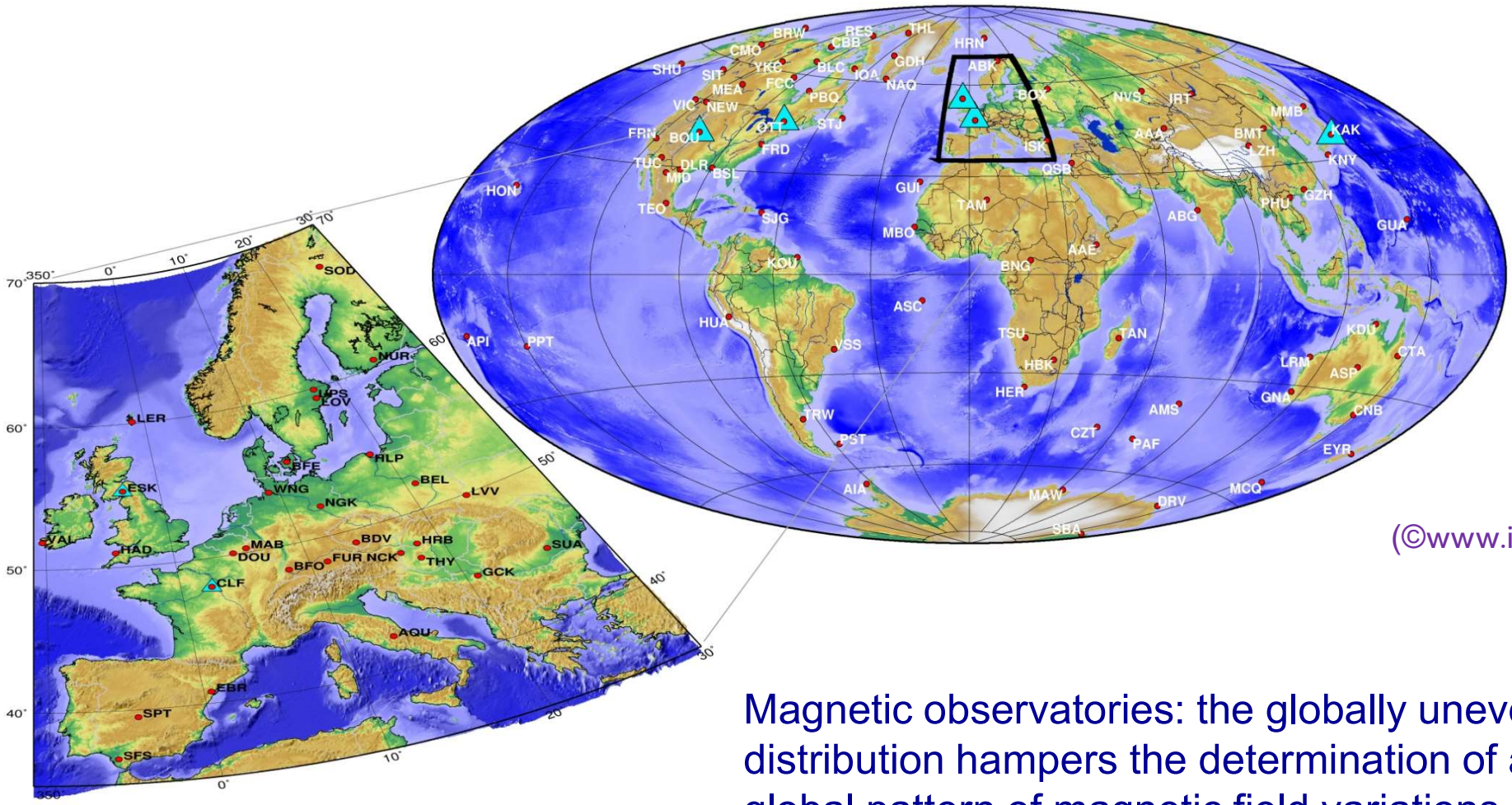
- Declination < 500 yrs
- Inclination < 400 yrs
- Intensity < 200 yrs
- Magnetic observatories ~ 100 yrs
- Satellites (nearly continuously ~ 20 yrs)

Surlari (SUA)

Chambon-la-Foret (CLF)

Niemegk (NGK)

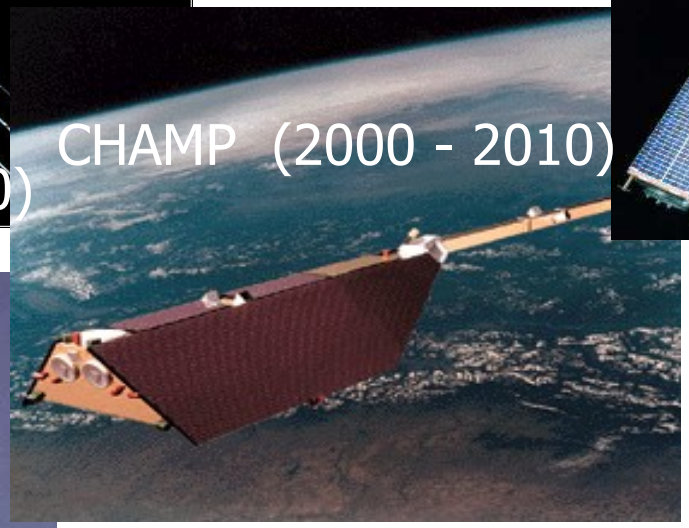
Measurements & models



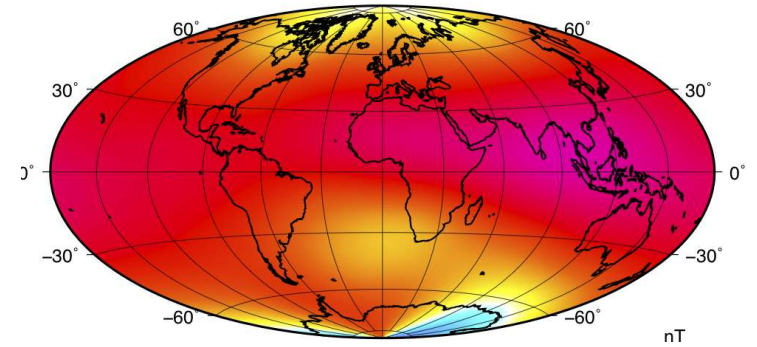
(©www.intermagnet.org)

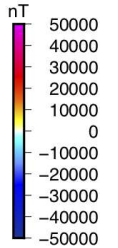
Magnetic observatories: the globally uneven distribution hampers the determination of a detailed global pattern of magnetic field variations

Measurements & models



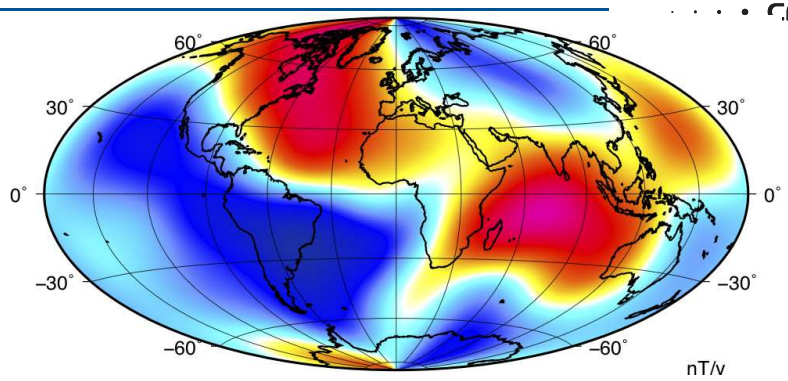
Measurements & models



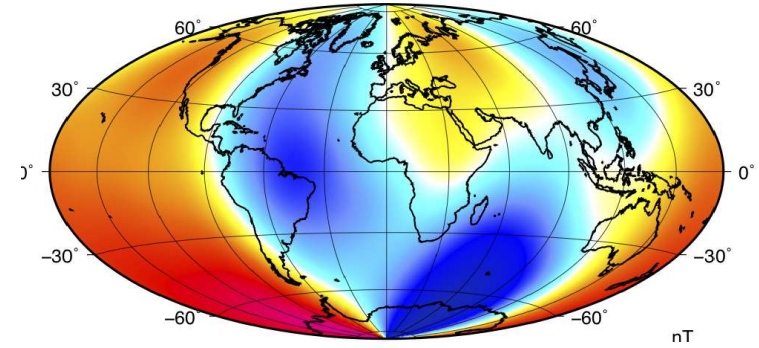


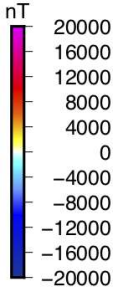
North Component

X



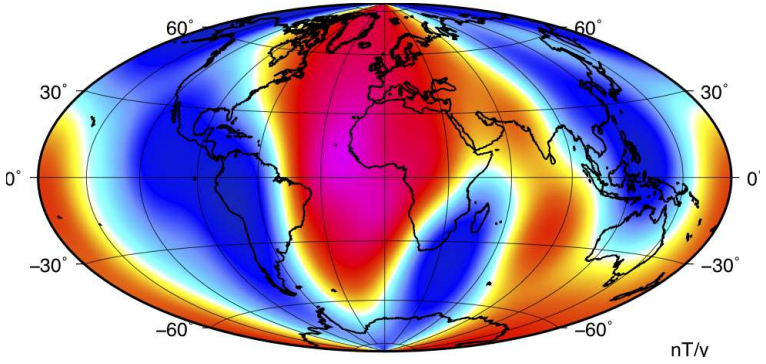
dX/dt



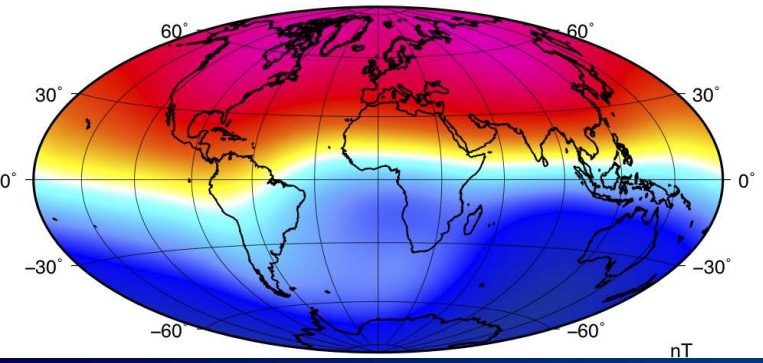


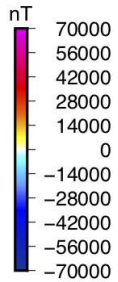
East Component

Y



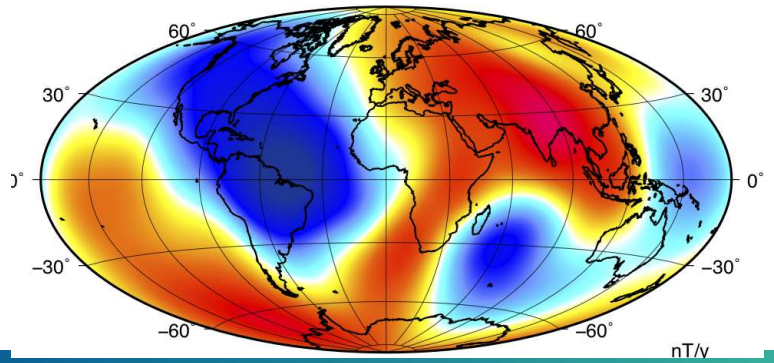
dY/dt





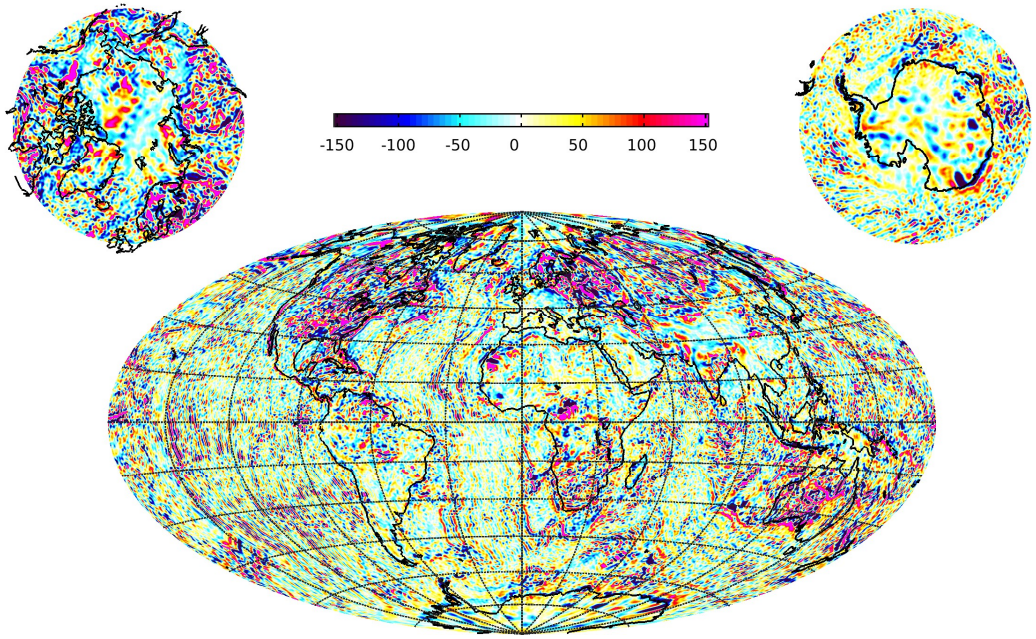
Vertical Component

Z

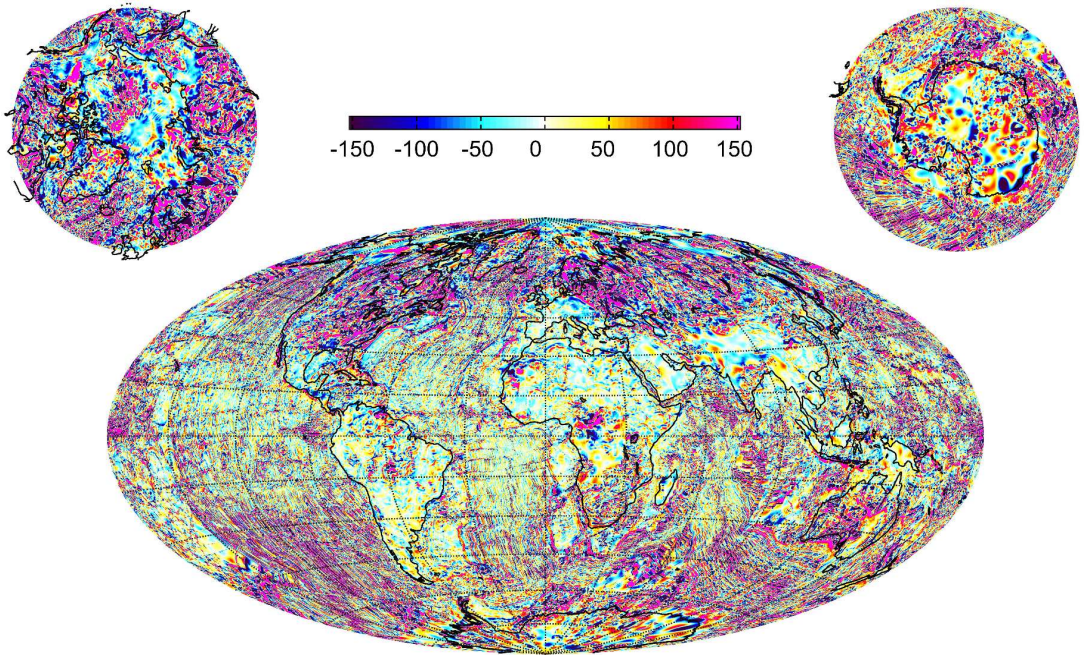


dZ/dt

Measurements & models

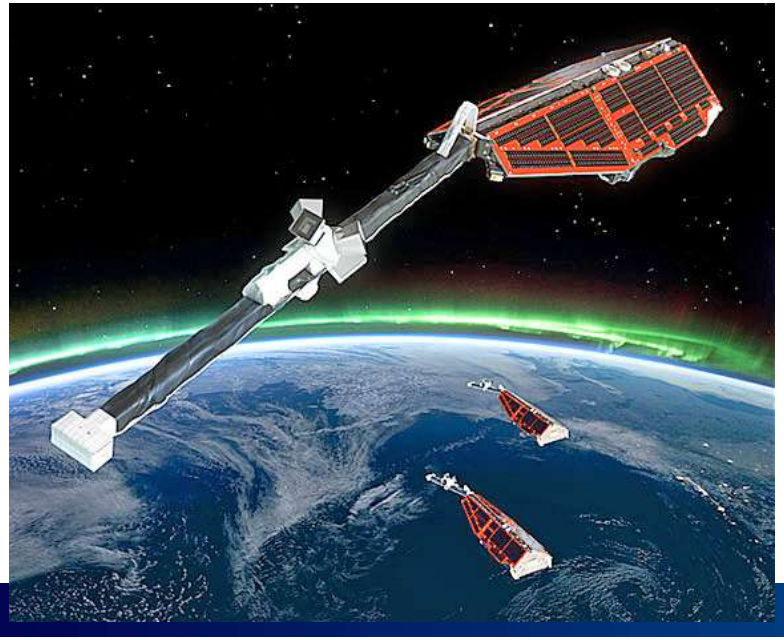


Lithospheric field → SH = 350



Lithospheric field → SH = 1100

(Thébault et al., 2021)



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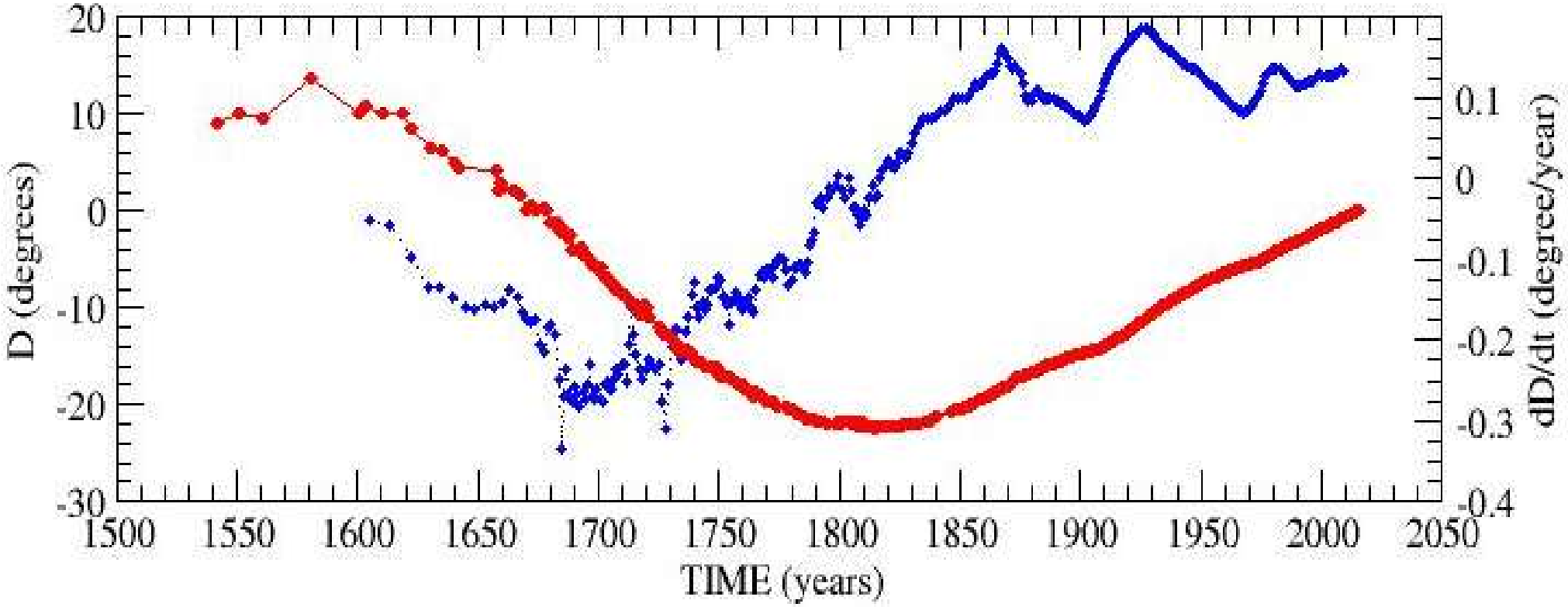
Geomagnetic jerks – core dynamic

THE STORY
Chambon-la-Foret observatory



(Alexandrescu et al., 1996; Mandea & Le Mouel, 2016)

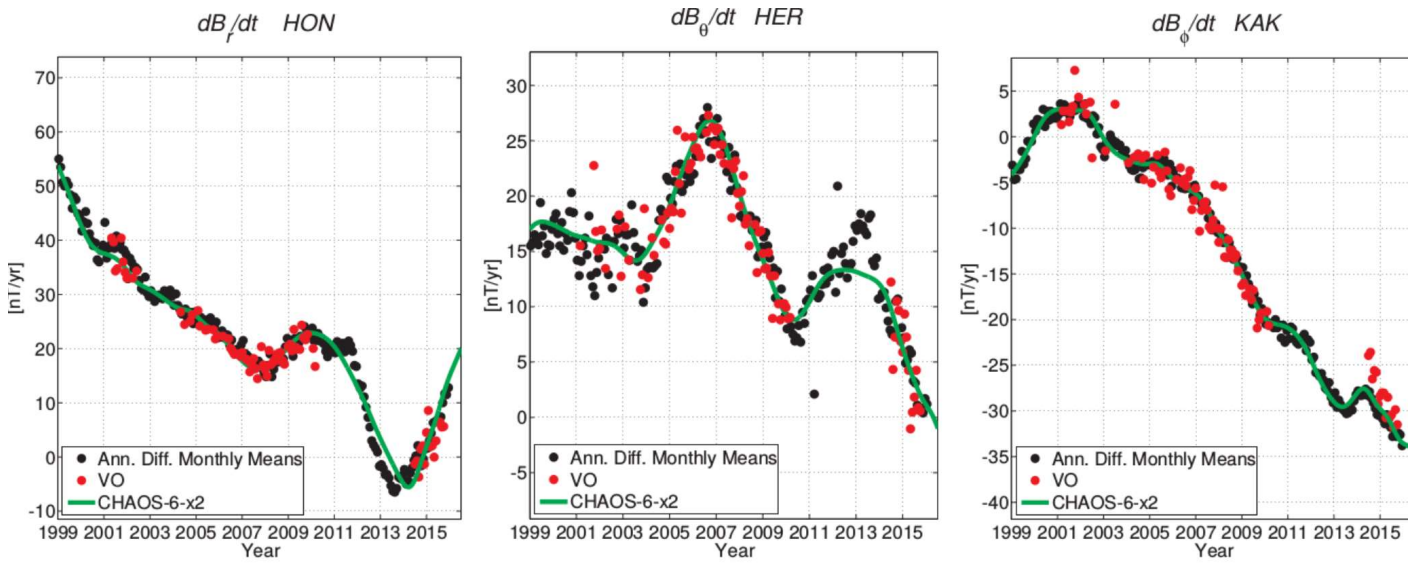
Geomagnetic jerks – core dynamics

VO approach has been developed and used in different studies
(Mandea and Olsen, 2006; Olsen and Mandea, 2007; Beggan et al., 2009; Whaler and Beggan, 2015; Saturnino et al., 2018; Finley et al., 2017; Barrois et al., 2017; Domingos et al., 2019; Magnus et al., 2020;)

Advantages:

- time series with high temporal resolution and uniform global coverage
- CHAMP and Swarm: series over more 2 decades
- VOs compare well with ground observatory records

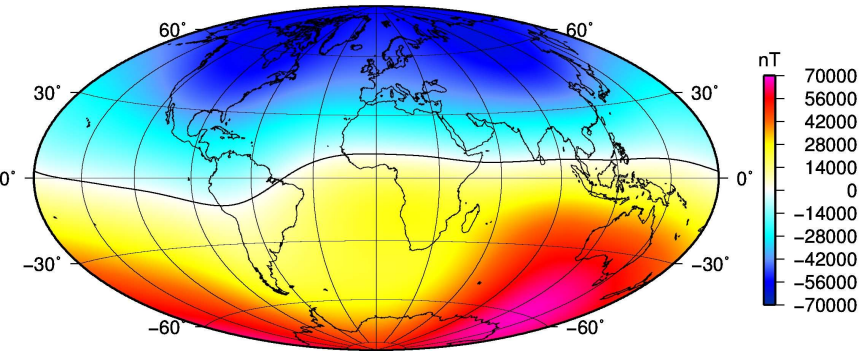
The cleaner the data analysis, the more likely we are to draw correct physical inferences



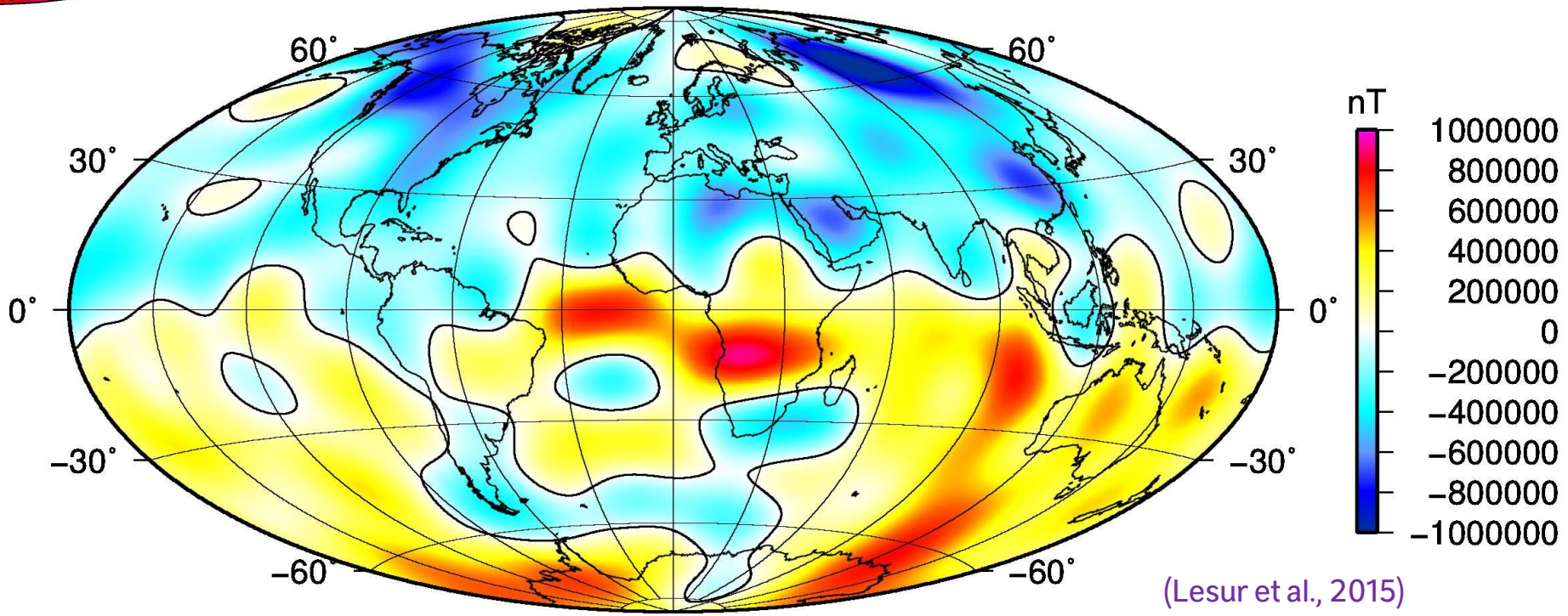
(Barrois et al., 2017)

WHICH MECHANISM?

Geomagnetic jerks – core dynamics

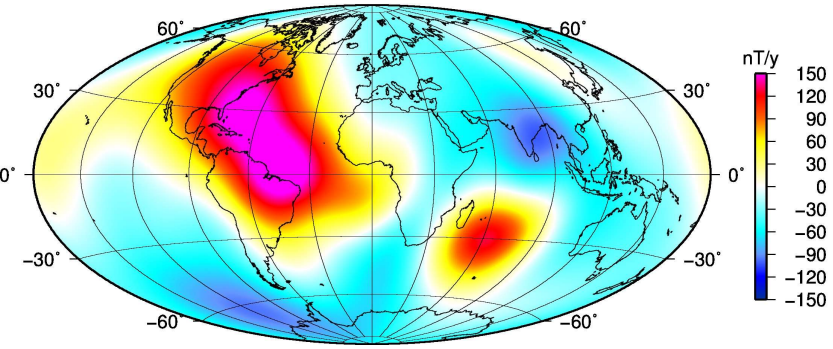


B_r magnetic field @ Earth's surface
@ Core-Mantle Boundary (CMB)

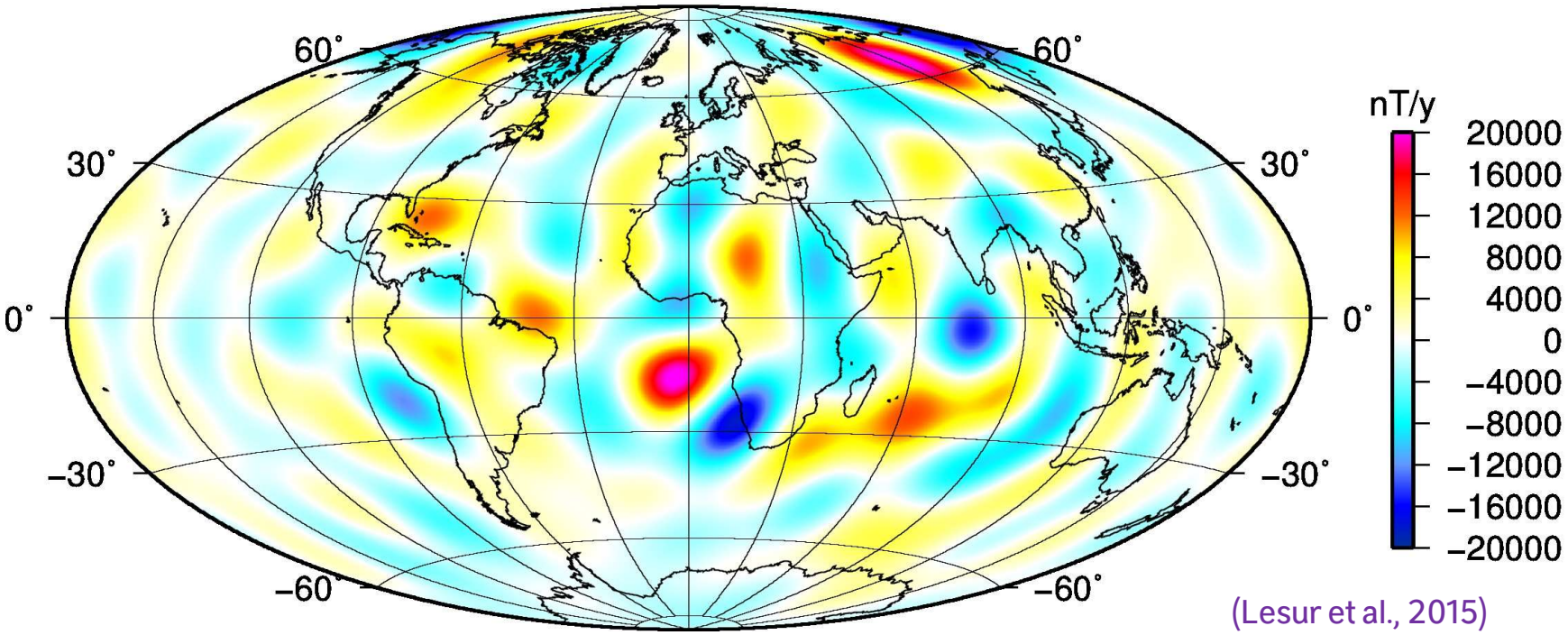


(Lesur et al., 2015)

Geomagnetic jerks – core dynamics

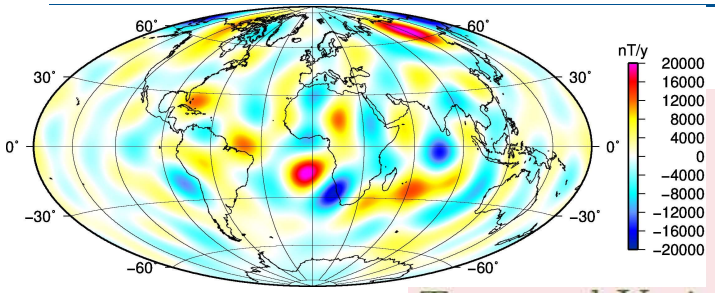


dBr /dt magnetic field @ Earth's surface
@ Core-Mantle Boundary (CMB)

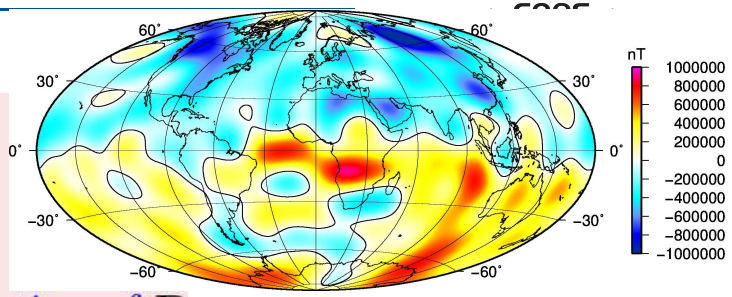


(Lesur et al., 2015)

Geomagnetic jerks – core dynamics

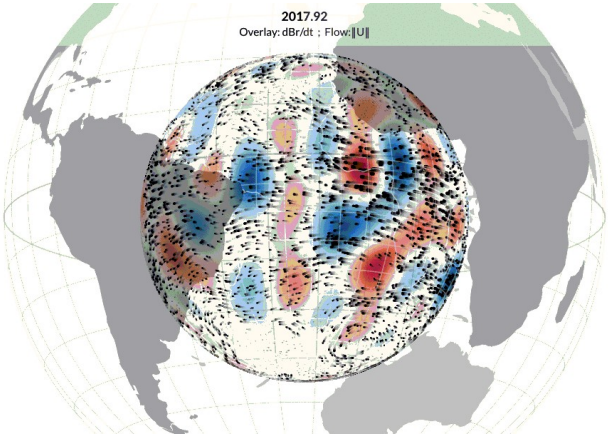


$$\underbrace{\frac{\partial \mathbf{B}}{\partial t}}_{\text{Temporal Variation of } \mathbf{B}} = \underbrace{\nabla \times (\boldsymbol{u} \times \mathbf{B})}_{\text{Induction of } \mathbf{B}} + \underbrace{\eta \nabla^2 \mathbf{B}}_{\text{Dissipation of } \mathbf{B}},$$



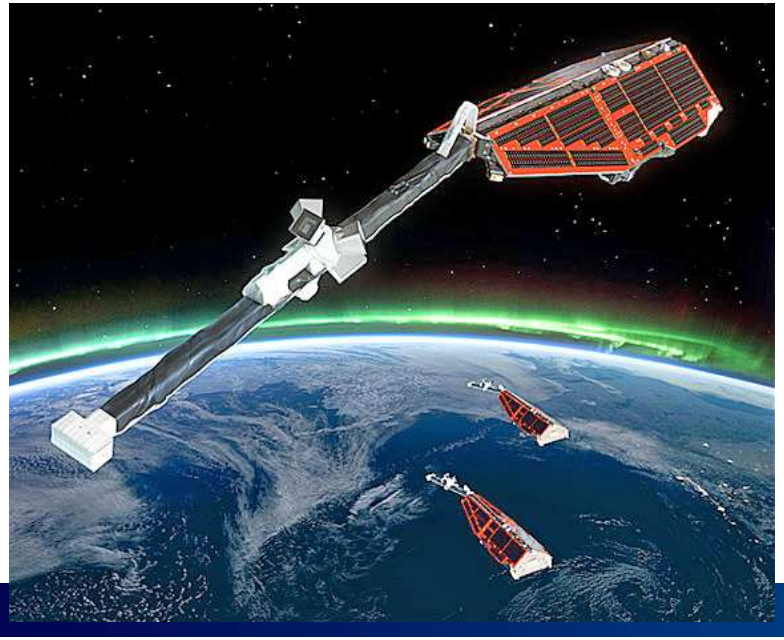
$$\partial_t B_r = -\nabla_H \cdot (B_r \mathbf{u}_H)$$

$$2\rho(\boldsymbol{\Omega} \times \mathbf{u})_H = -\nabla_H p$$



Something acts to disturb equilibrium in core; it shows up in flow patterns

(Barrois et al., 2017)



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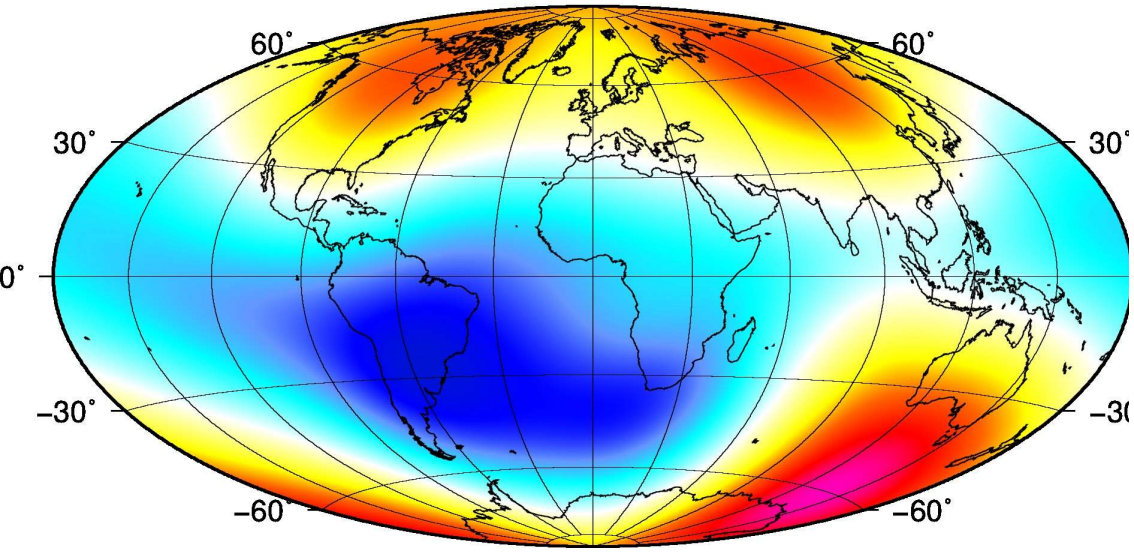
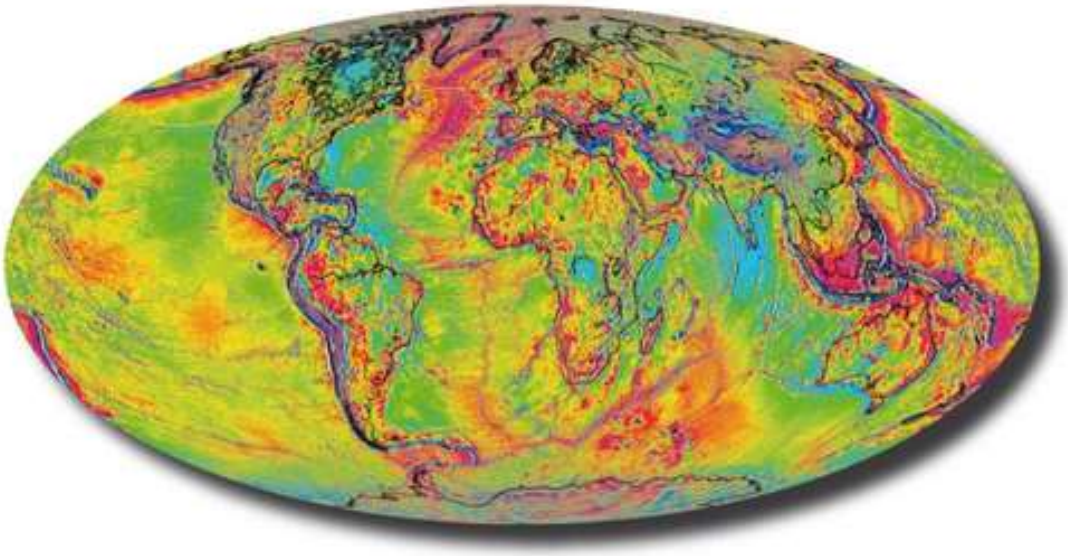
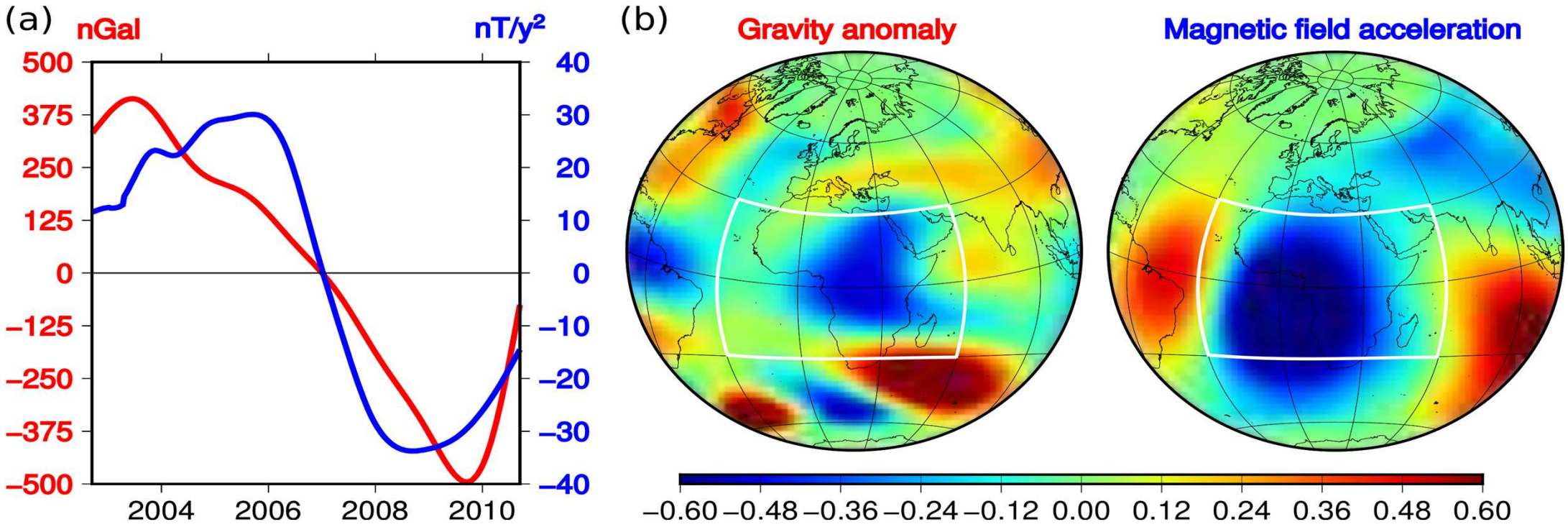
THE STORY
IPG Paris





Magnetic and gravity fields maps

Magnetic and gravity anomalies – irregularities of the CMB



Results of the SVD for magnetic and gravity time-series:

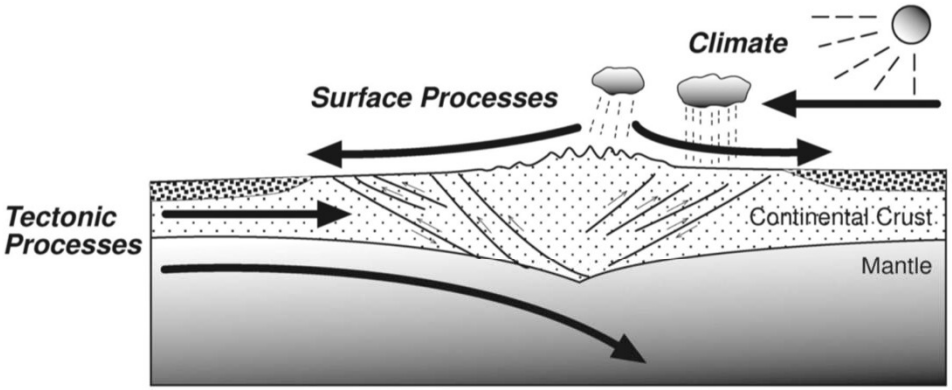
Left panel - temporal pattern **(60nT/yr² and 900 nGal)**
Right panels - spatial pattern for the magnetic and gravity data

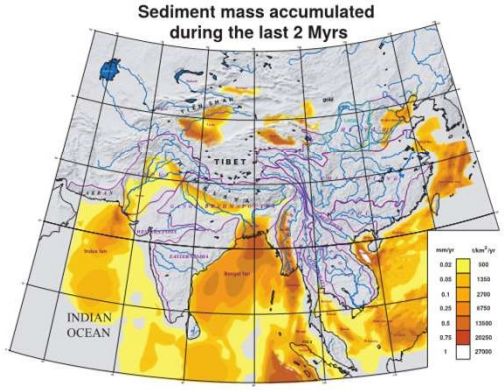
(Mandea et al., 2015)

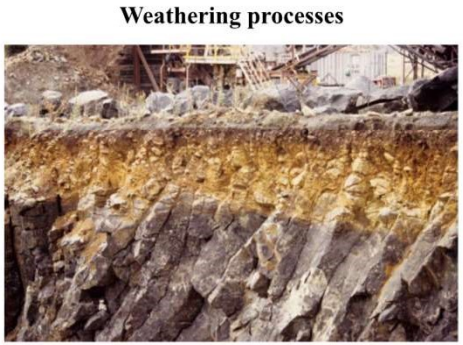
WHICH MECHANISM?

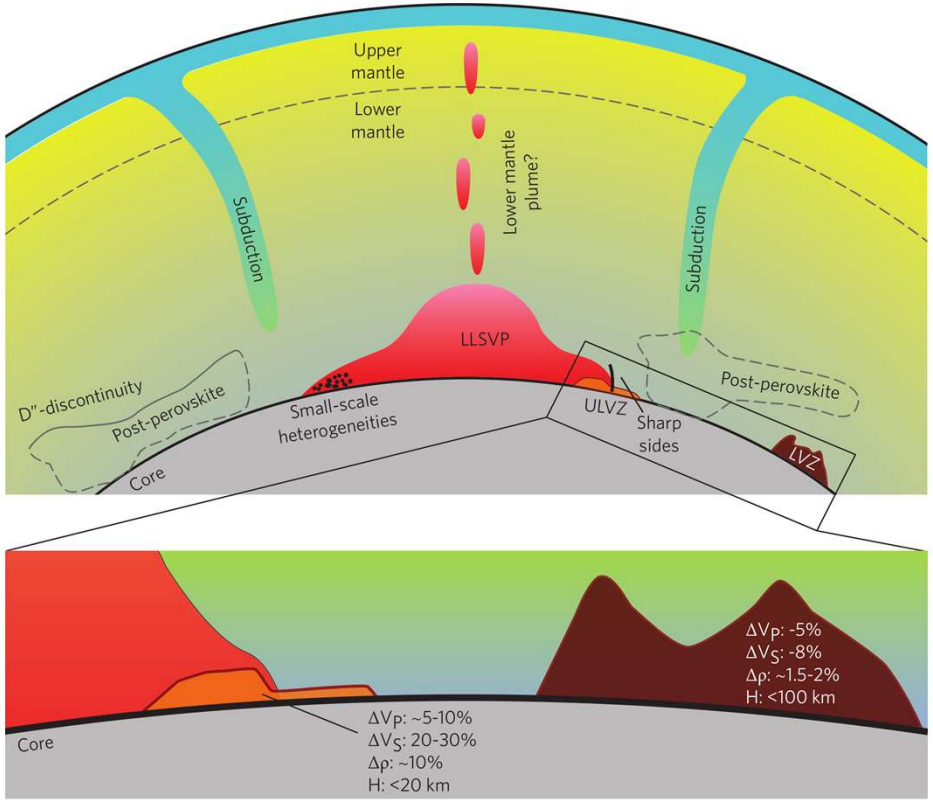
Magnetic and gravity anomalies – irregularities of the CMB

From the Earth's surface to the CMB – via geomorphology









(Métivier et al., 1997), Willett,1999; Selby, 1982)

(Rost, 2013)

What is the impact of geomorphic processes at the CMB on potential fields?

Probing the deep Earth interior by synergistic use of observations of the magnetic and gravity fields, and of the Earth's rotation

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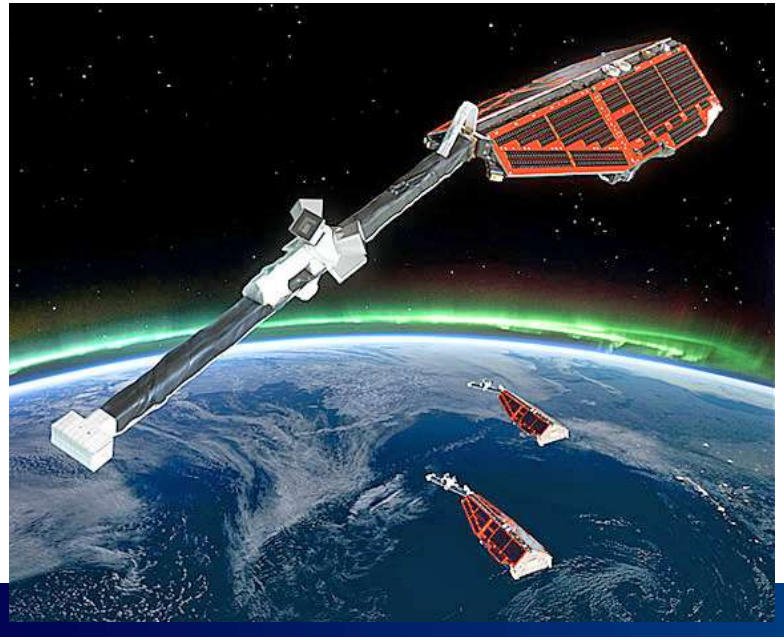
LEGOS



Outline

Introduction & history

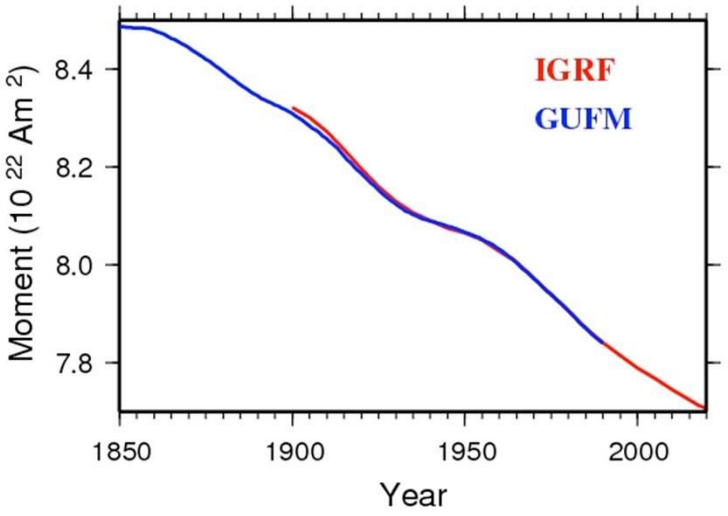
Measurements & models

When measurements precede theory...

- Geomagnetic jerks – core dynamics
- Magnetic and gravity anomalies – irregularities of the core-mantle boundary

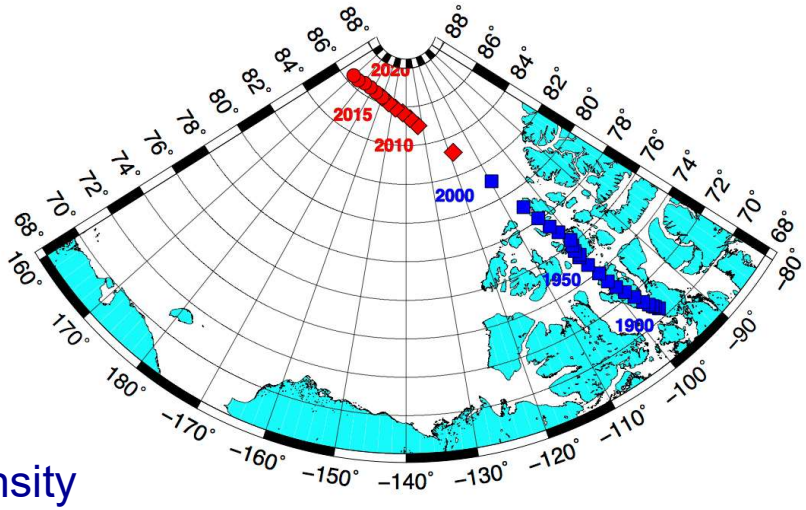
Conclusions

More intriguing features

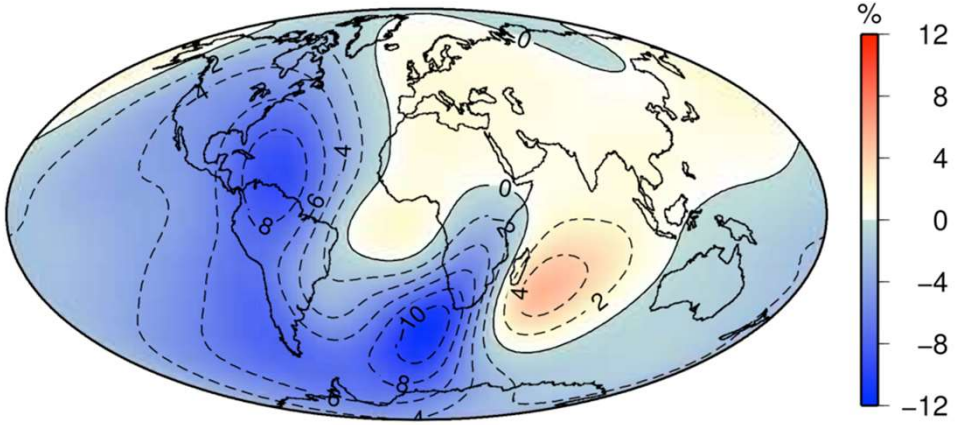


Earth's magnetic field features

- Dipole decay
- Magnetic poles velocity
- Rate of change of field intensity
- South Atlantic Anomaly



(Mandea & Chambodut, 2020)



(Mandea & Purucker, 2017)