Risques telluriques vus de l'espace

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SOMMAIRE

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- Introduction
- Satellite data to study the dynamic Earth
- State of the art and current challenges
- Case study: Nepal Earthquake
- Conclusions

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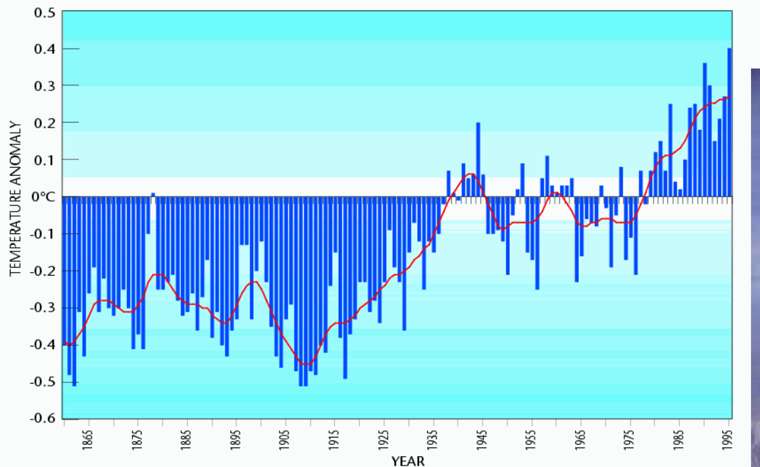
Introduction

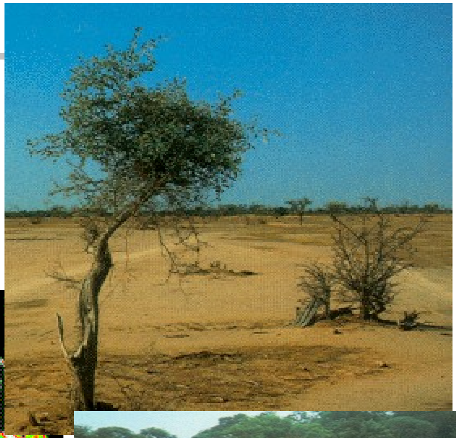
Satellite missions make it possible to improve both static and dynamic knowledge of the Earth system by providing:

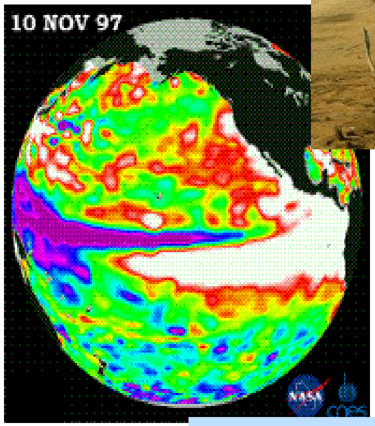
- geophysical measurements complementary to measurements acquired on the ground, at sea or by air (topography, bathymetry, gravimetry, magnetism, etc.) for a better static characterization of the Earth system;

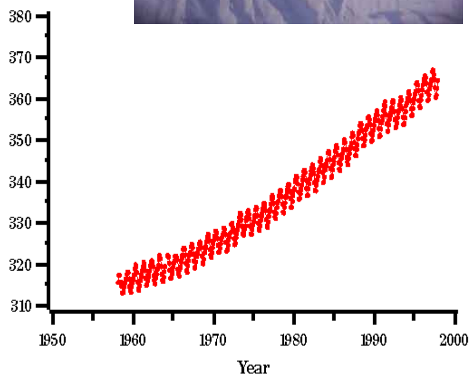
- continuous observations - during the life of one or more missions (magnetism, gravimetry, geodesy, surface imaging) perennial, complementary to those obtained in situ, in order to follow the dynamics of the Earth system.

Earth's system

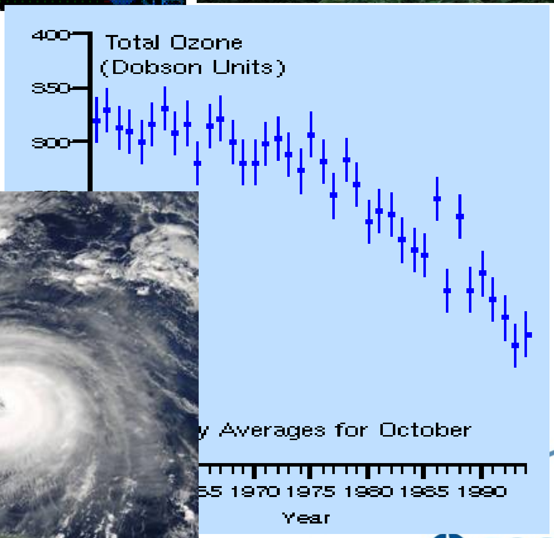




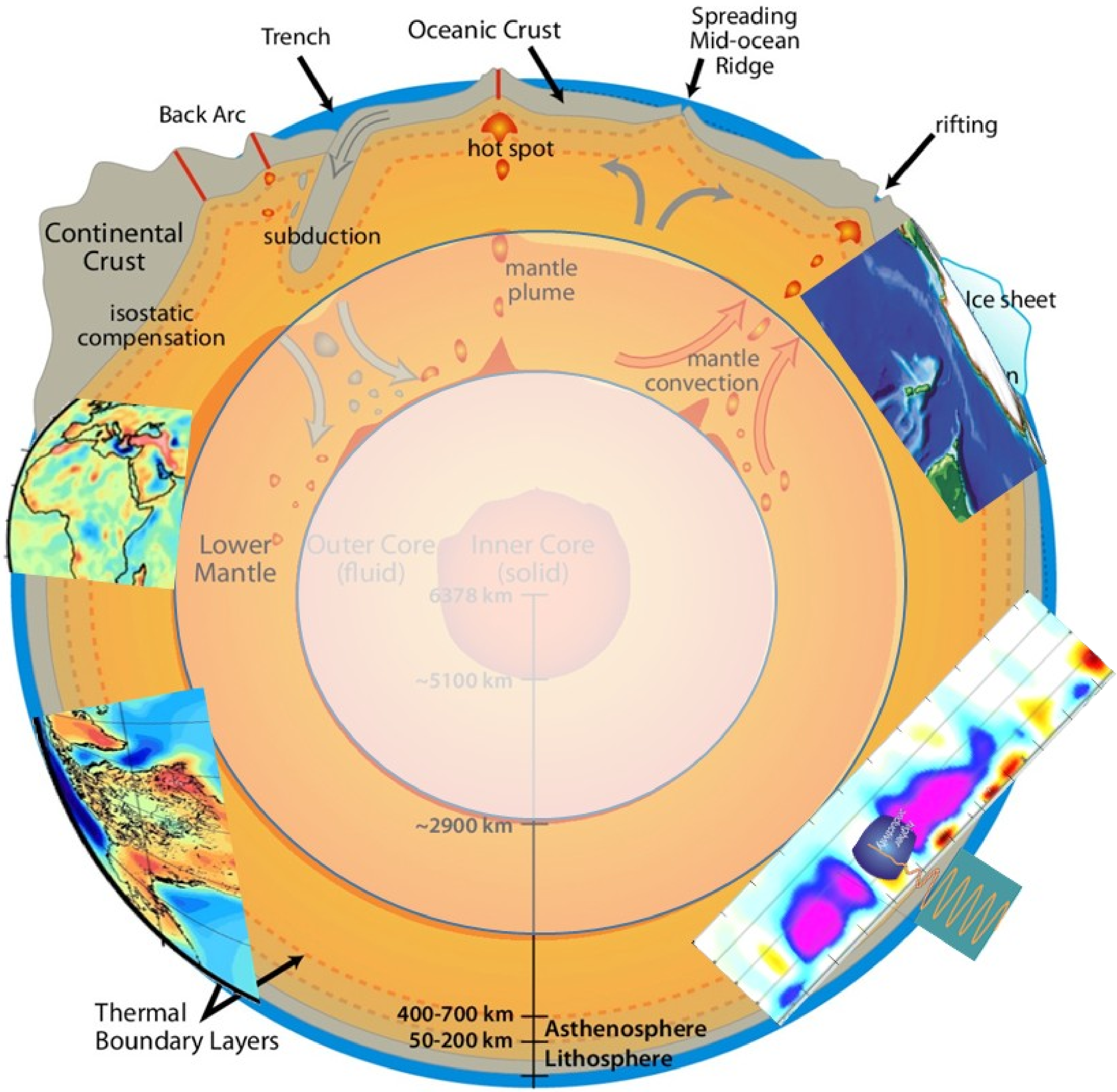




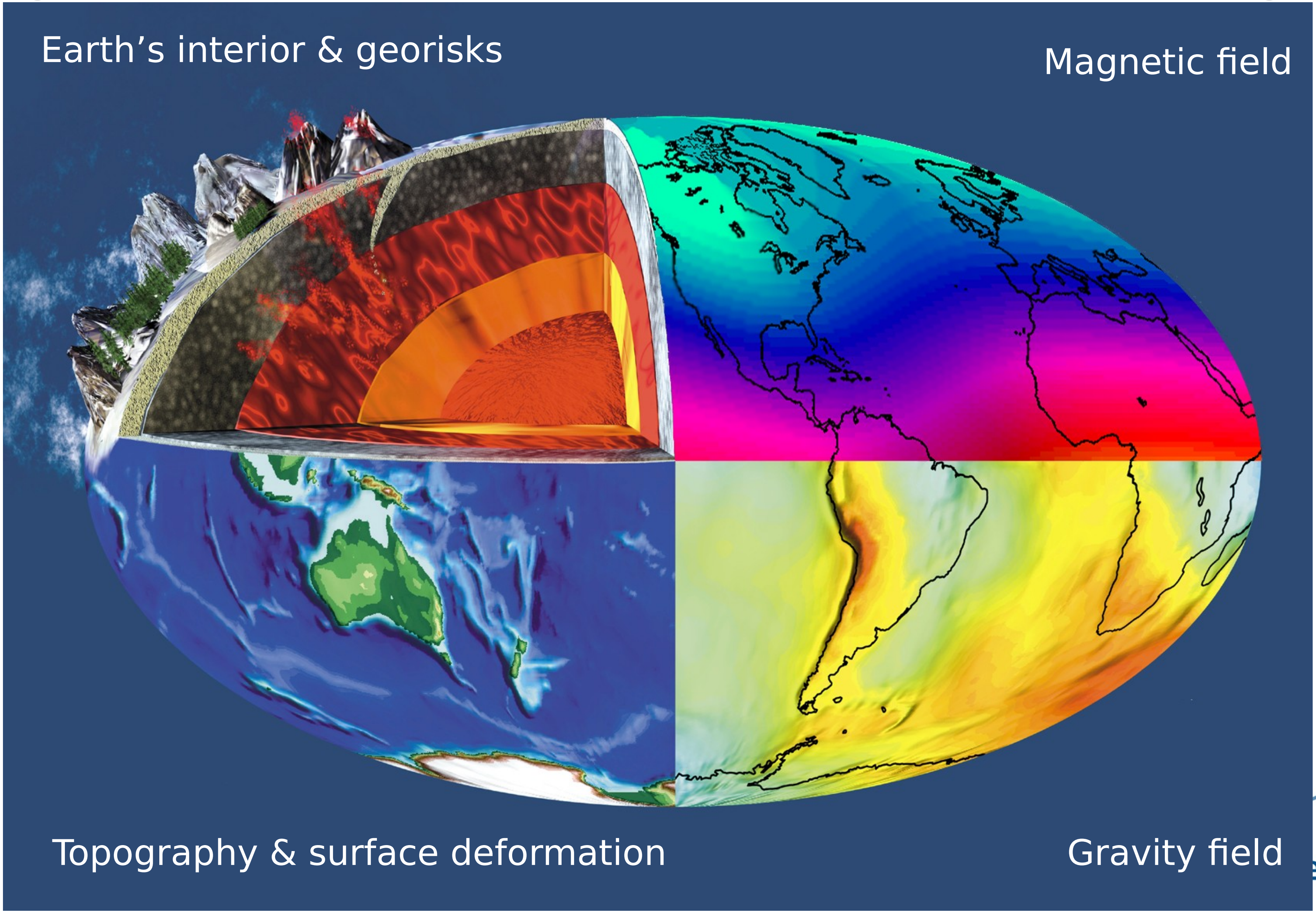
Source: Dave Keeling and Tim Whorf (Scripps Institution of Oceanography)



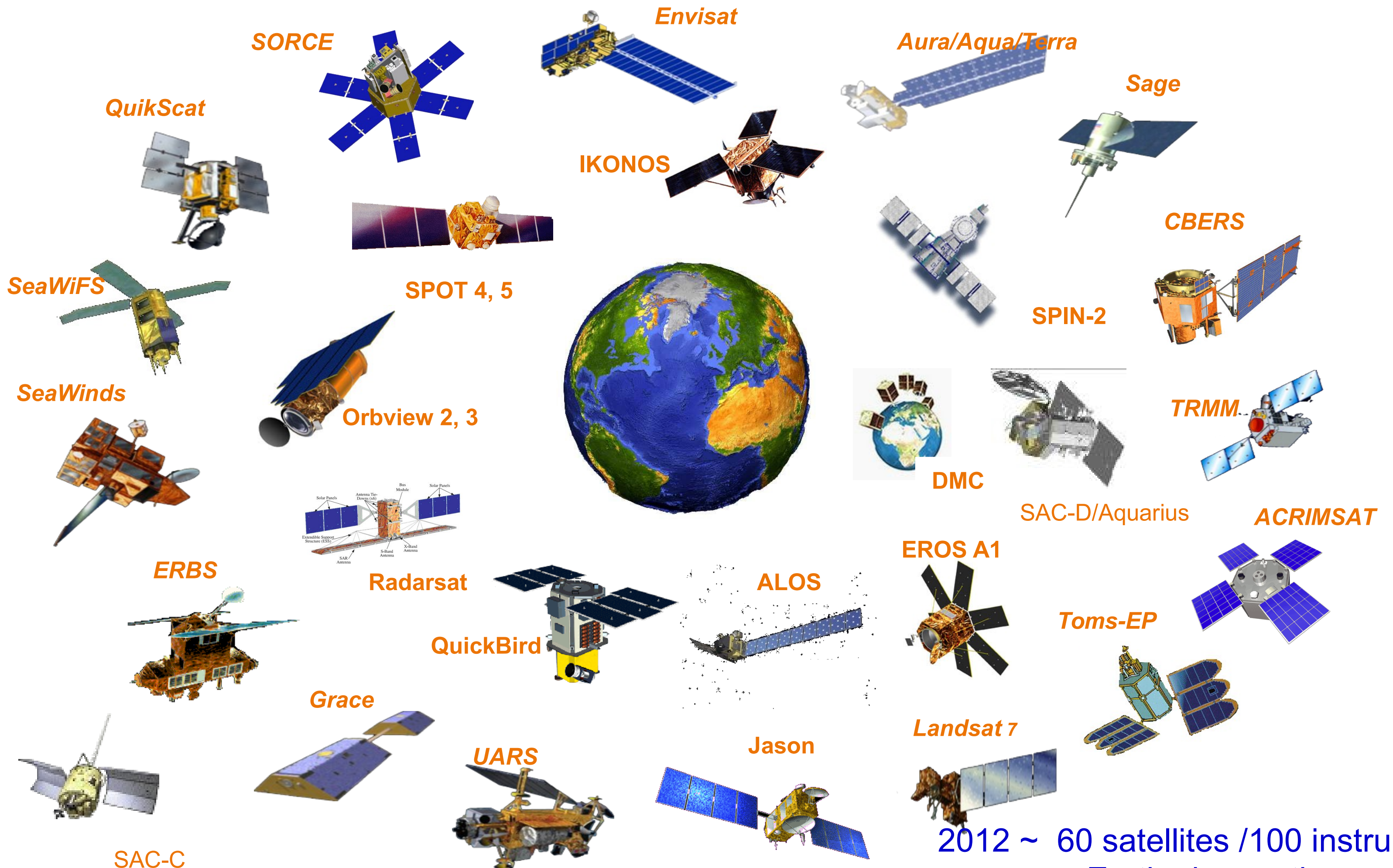
Introduction



Introduction



Introduction



2012 ~ 60 satellites /100 instruments for Earth observation

2015 ~ 150 satellites / 300 instruments

Global Earth observation System of systems

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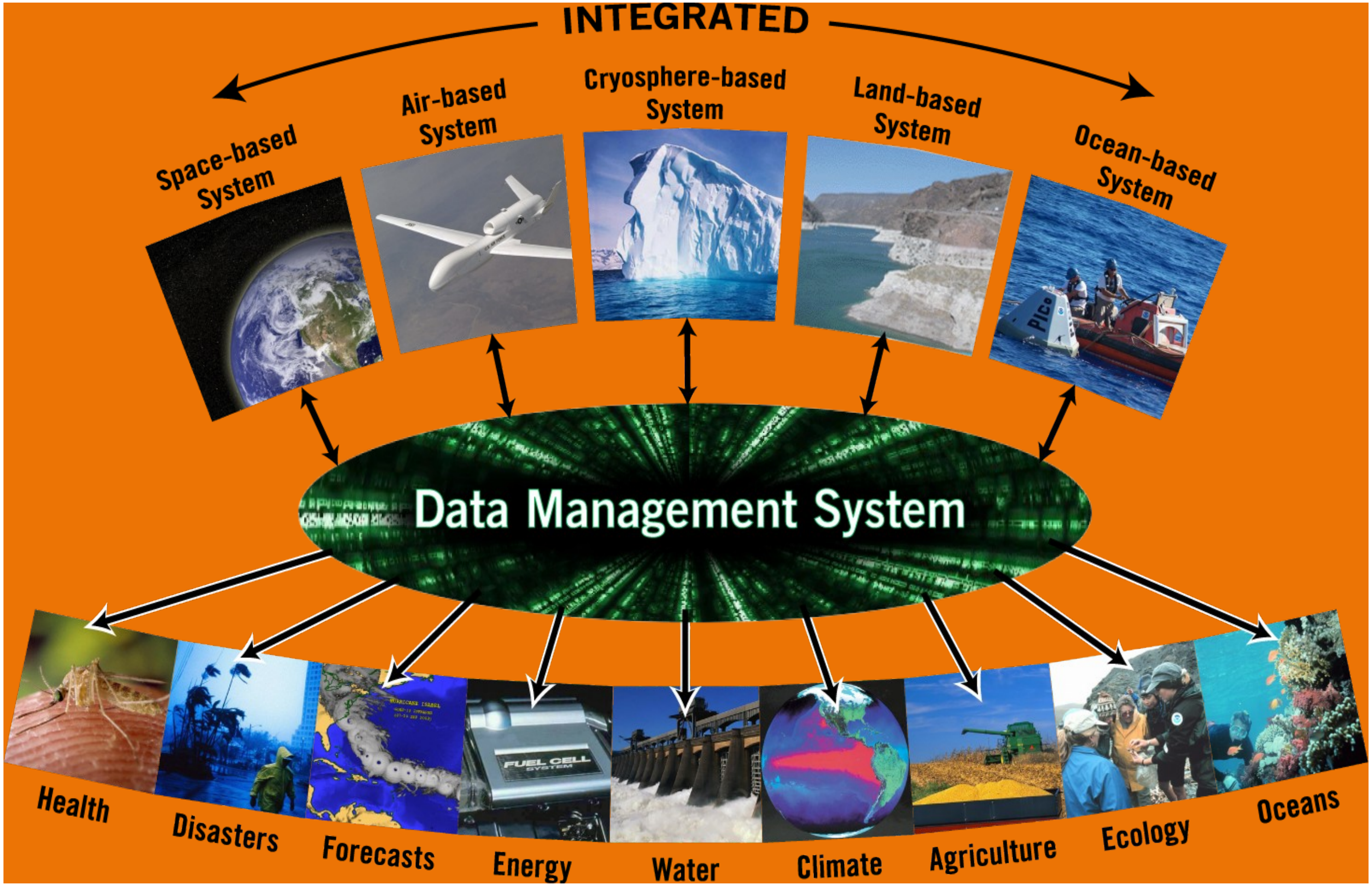
Introduction



International framework for Earth observation coordination

European Copernicus contribue to GEOSS

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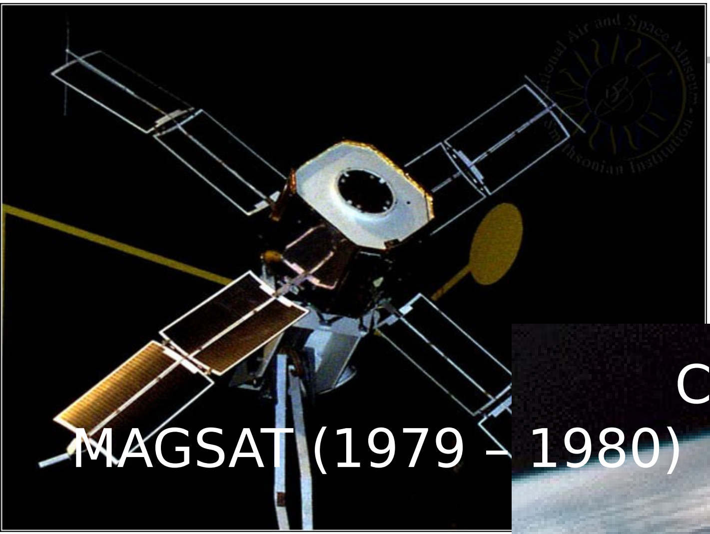
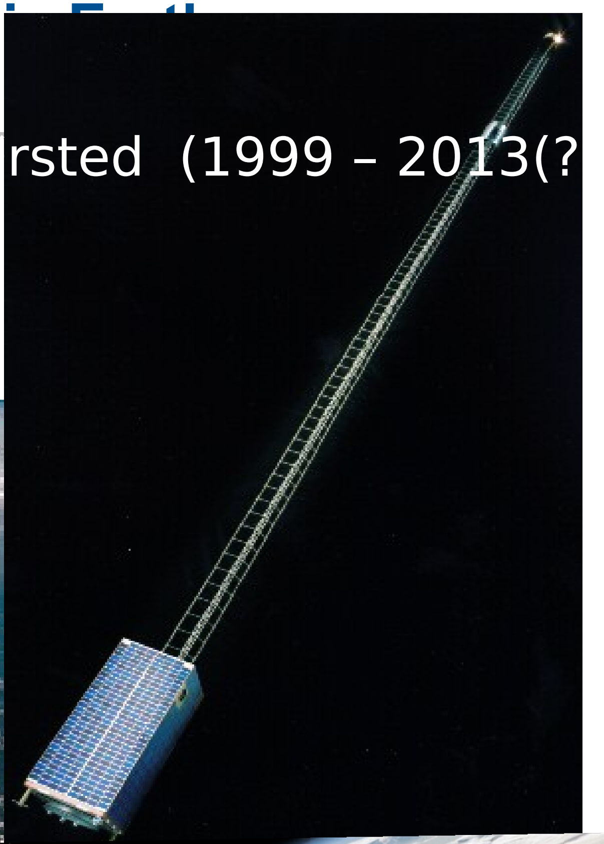
Satellite data to study the dynami



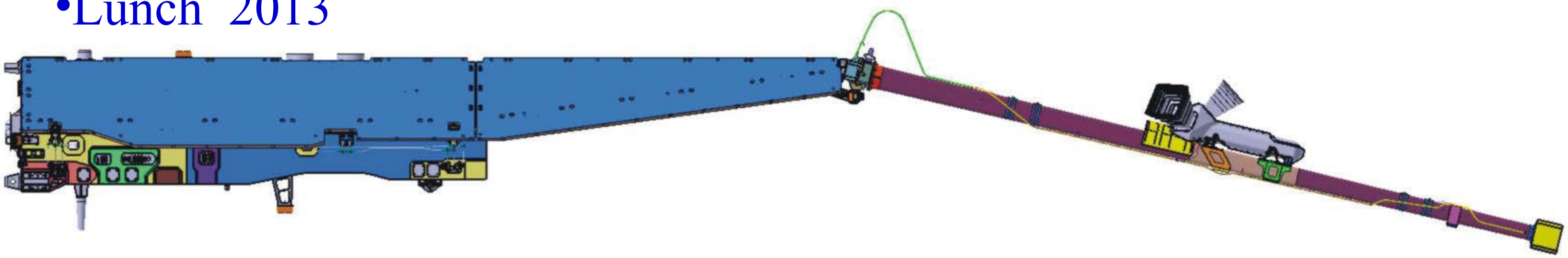


Satellite data to study the dynamic Earth

Swarm

- Cooperation ESA/CNES
- 3 satellites
- 2 altitude orbits
- Lunch 2013

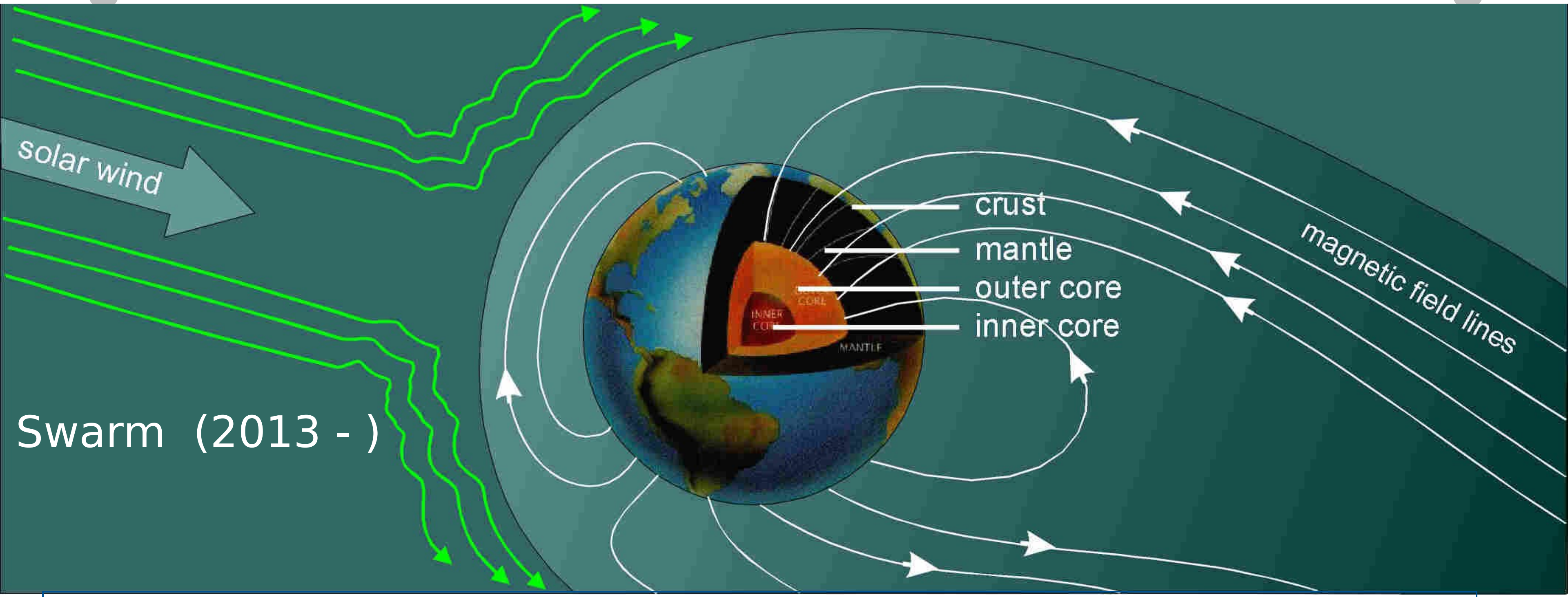
DC Mag Random Error
at VFMS < 1.0 nT



Long & slim body
9m, 1m², 400kg + 100kg fuel

DC Mag Random Error
at ASMS < 0.3 nT

Satellite data to study the dynamic Earth

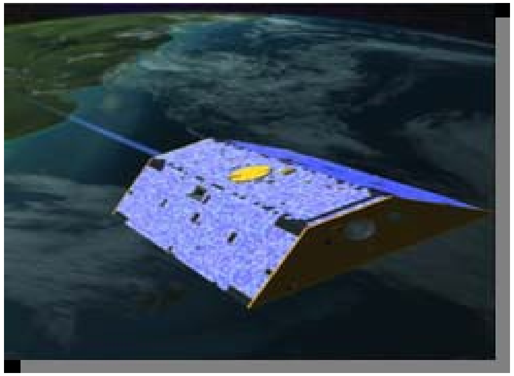


- provide the best survey ever of the geomagnetic field and its temporal evolution

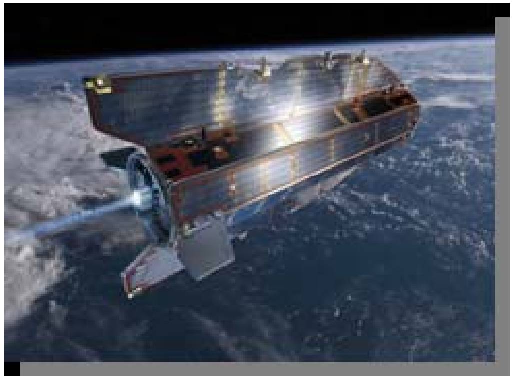
- gain new insights into the Earth system by improving our understanding of the Earth's interior and its physical environment

Satellite data to study the dynamic Earth

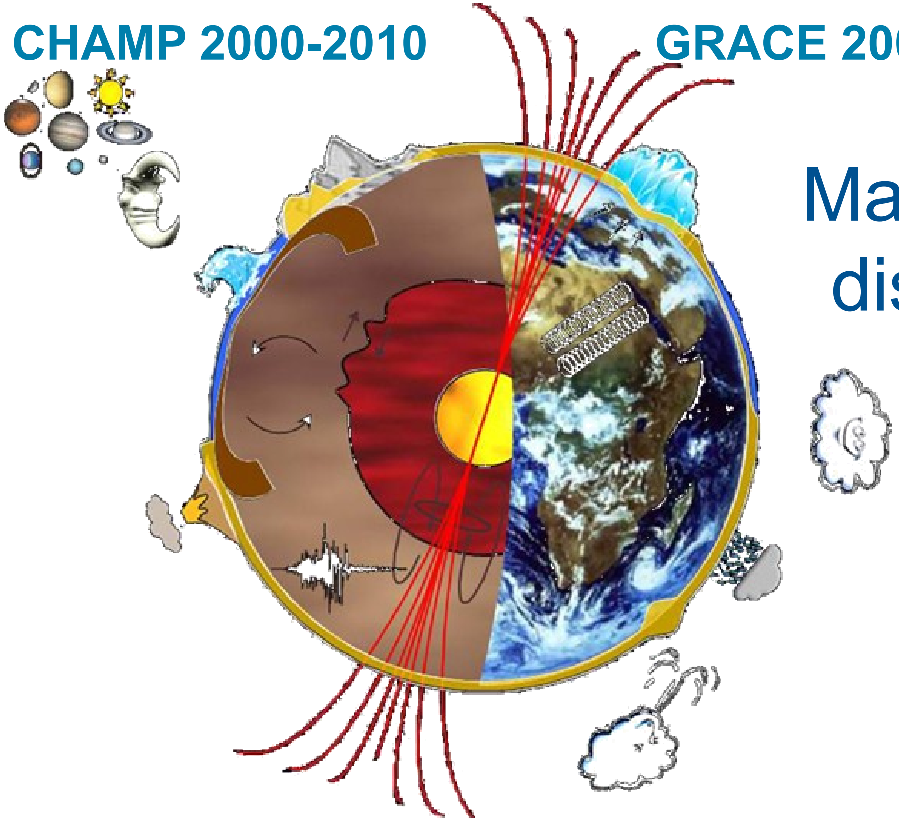
CHAMP 2000-2010



GRACE 2002-?



GOCE 2009-2013



Masses (re-) distribution

Satellite missions

CHAMP ***g***

GRACE → ***g(t)***

GOCE ***g***

Satellite data to study the dynamic Earth

Mission GRACE : 2002

- *Temporal resolution : 1 month - 10 days (solutions GRGS)*
- *Spatial resolution: 300 km*

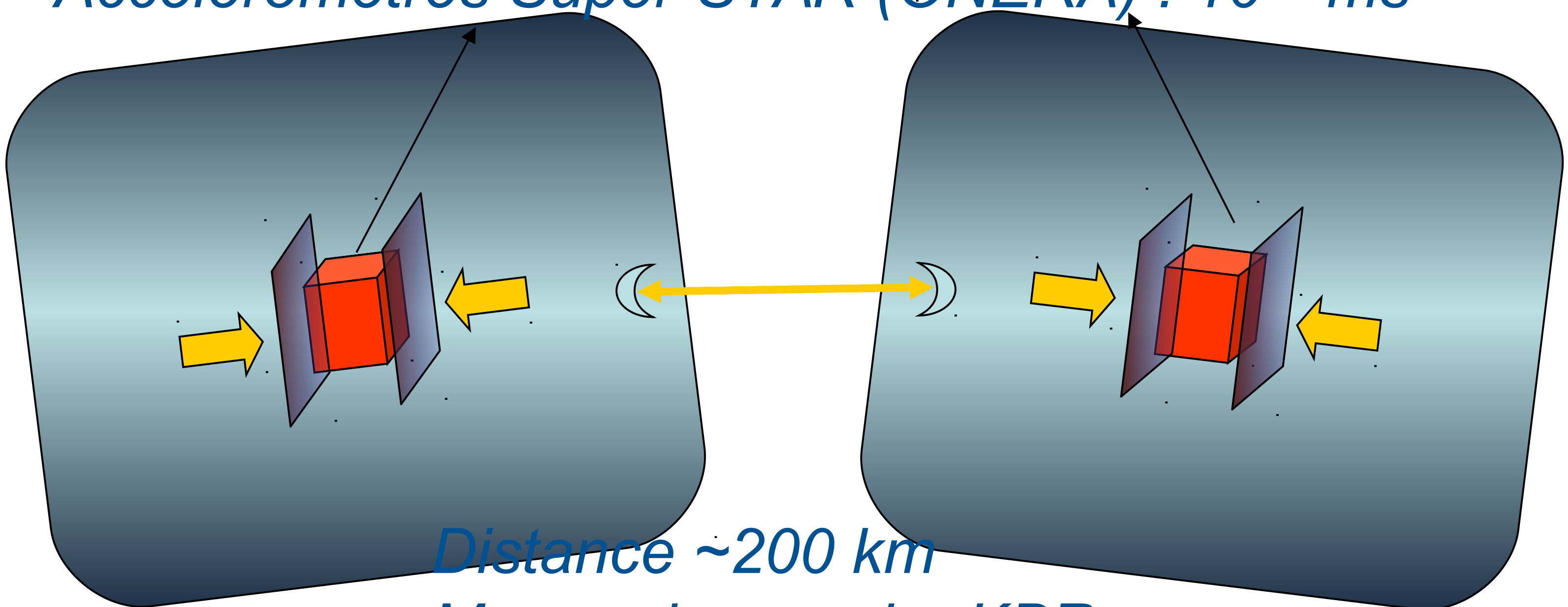
Altitude ~ 485 km (start)
~300 km (…end)

Distance inter-satellite ~ 200 km

Satellite data to study the dynamic Earth

Orbits (GPS) : prrcision ~1 cm

Accelerometres Super-STAR (ONERA) : 10^{-10} ms^{-2}



Distance ~200 km

Mesured par radar KBR

speed relative ~0.1 µm/s !!!)

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Satellite data to study the dynamic Earth

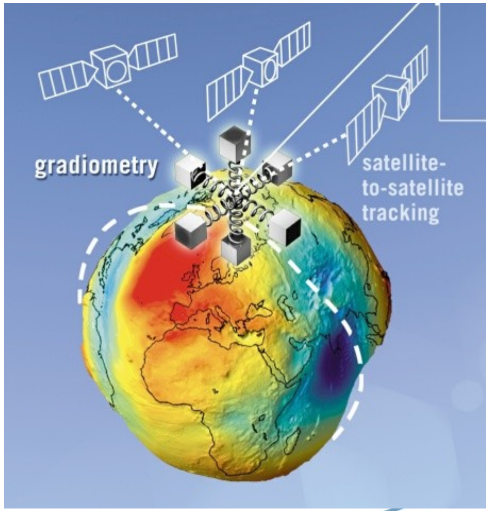
Original objectives:

*high resolution geoid to determine **ocean currents** and study the **lithosphere***

Gravity gradients V_{ij} from:

$$V_{ij} = \frac{\partial^2 V}{\partial x_i \partial x_j}$$

- *low orbit (250 km) - GPS*
- *gradiometry at scales < 750-1000 km*
- *compensation of atmospheric drag*



Mass anomalies geometry

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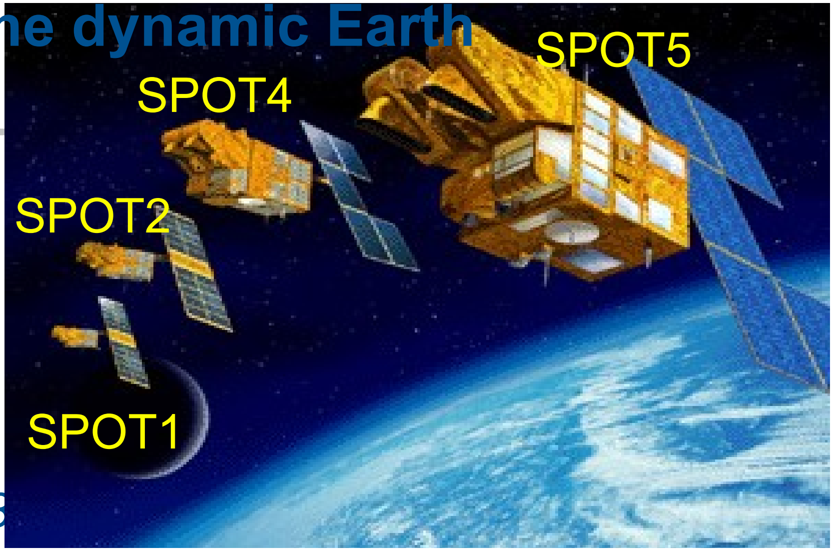
Satellite data to study the dynamic Earth



SPOT 1 : launched in1986 – orbit down en 2003

SPOT 2 : launched in1990 – stopped operations in 2009

SPOT 3 : launched in1993 – stopped operations in 1996

SPOT 4 : launched in1998 – new band IR; Passenger : instrument Vegetation 1

SPOT 5 : launched in2002 – Passengers: VEGETATION-2 et HRS (High resolution stereo camera)

SPOT 6 : launched in 20012

SPOT 7 : launched in 2014

Pléiades 1 & 2 (2011/2012 –)

Satellite data to study the dynamic Earth

The Pléiades constellation is composed of two very-high-resolution optical Earth-imaging satellites. Pléiades 1A and Pléiades 1B provide the coverage of Earth's surface with a repeat cycle of 26 days.

Pléiades 1A
December 17, 2011

Pléiades 1B
December 2, 2012

Satellite data to study the dynamic Earth

- *two "small satellites" (mass of one ton) offering a spatial resolution at nadir of* **0.7 m and a field of view of 20 km**

- *great agility enables a daily access all over the world, which is a critical need for defence and civil security applications, and a coverage capacity necessary for the cartography kind of applications at scales better than those accessible to SPOT family satellites.*

Satellite data to study the dynamic Earth

Rotterdam Harbor acquired in 2013

19 January 2015, shows a new island that has formed from the eruption of the Hunga Tonga underwater volcano, in Tonga

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State of the art and current challenges

In spite of all these measurements, the great spatio-temporal variability of the geodynamic processes complicates singularly the study of the "Solid Earth" system. Thus, time scales and spatial characteristics vary over several orders of magnitude:

-*from the second (earthquakes) to million years (plate tectonics)*

- *from the centimeter (fault) to the tens of thousands of kilometers (oceanic mid-dorsal).*

Specific methods and analyzes are therefore necessary to characterize the phenomena related to land-based risks.

State of the art and current challenges

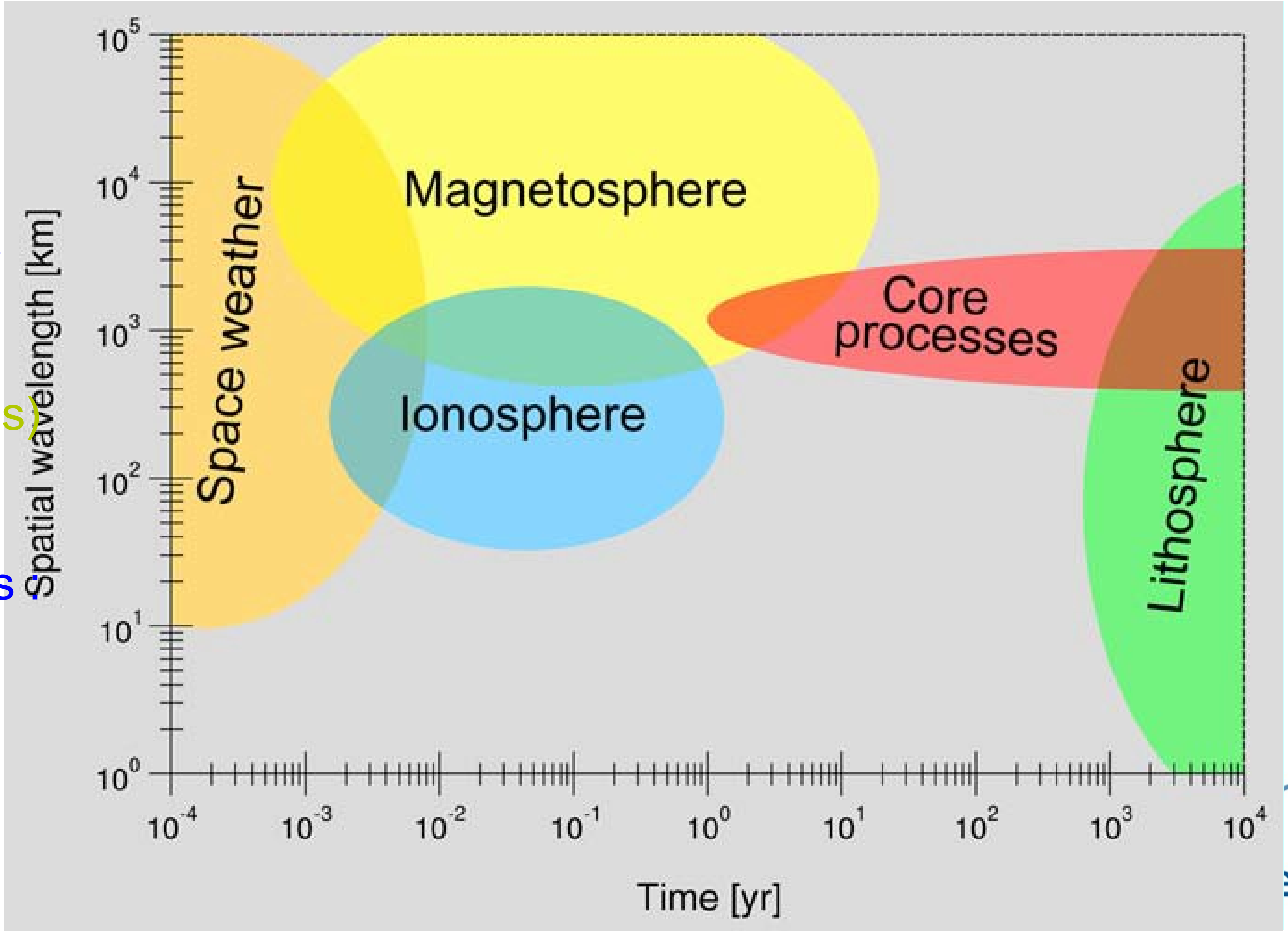
A superimposition of sources

Variability in space and time

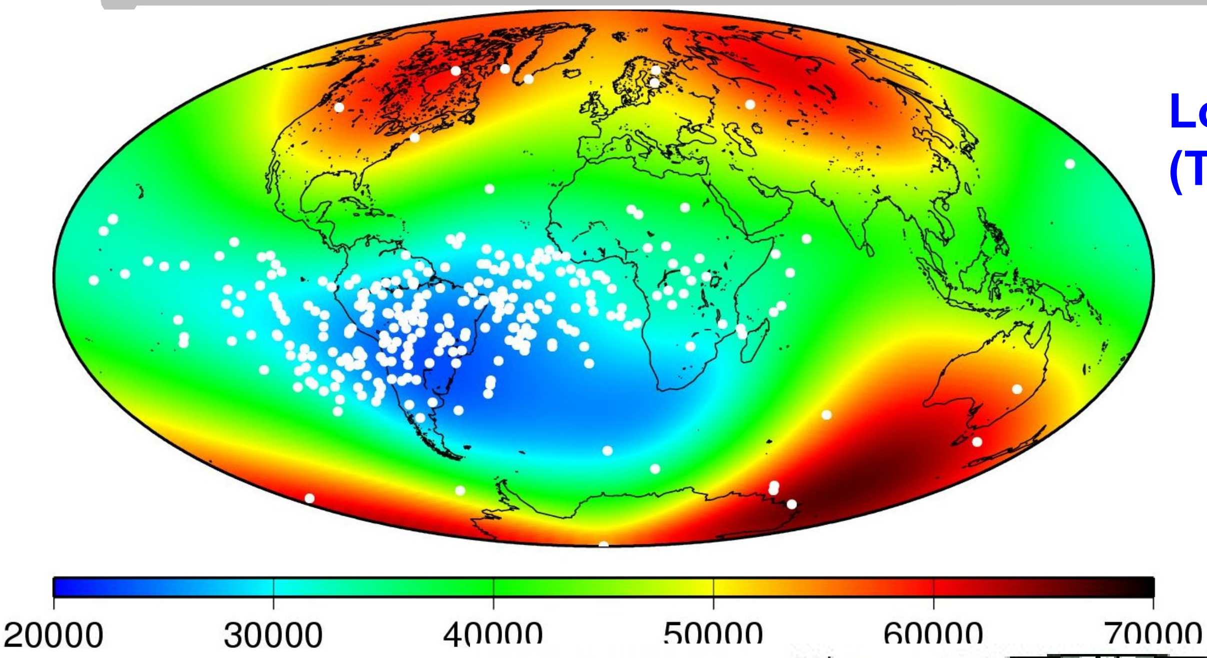
- Contributions internes
  - – Noyau
  - – Lithosphère

- Contributions externes
  - – Ionosphère
  - – Magnétosphère
  - – Curents alignés (FACs)

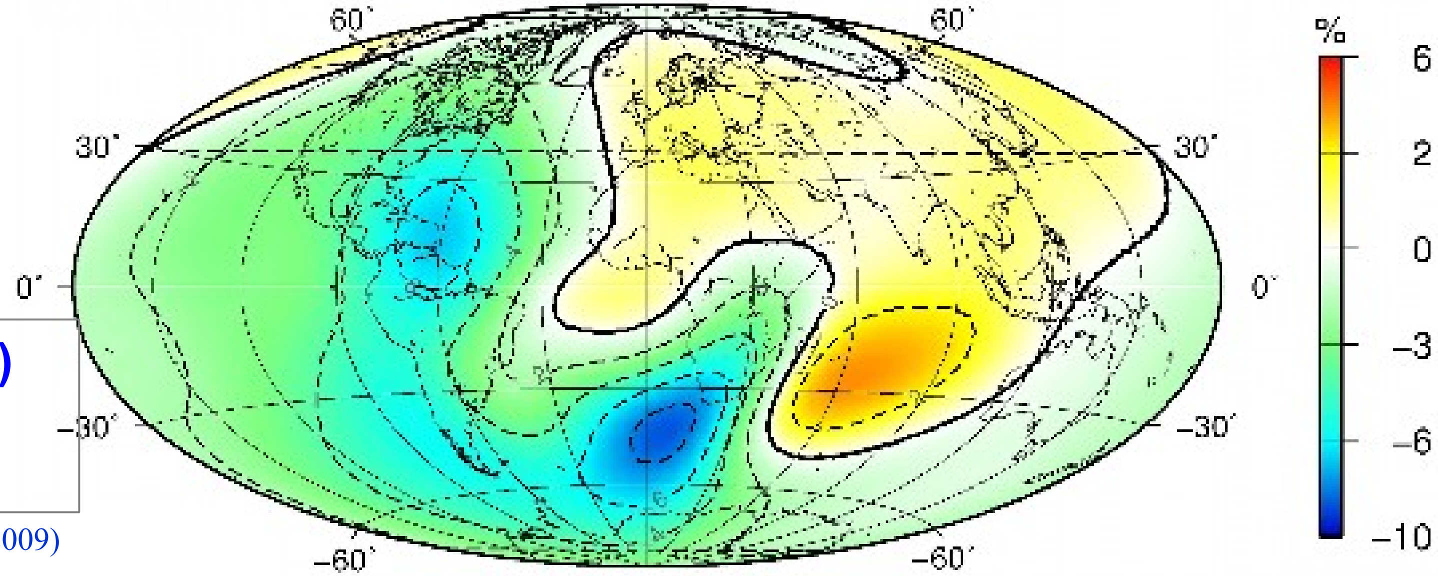
- Contributions mineures :
  - – Curents induits
  - – Curents océaniques



State of the art and current challenges



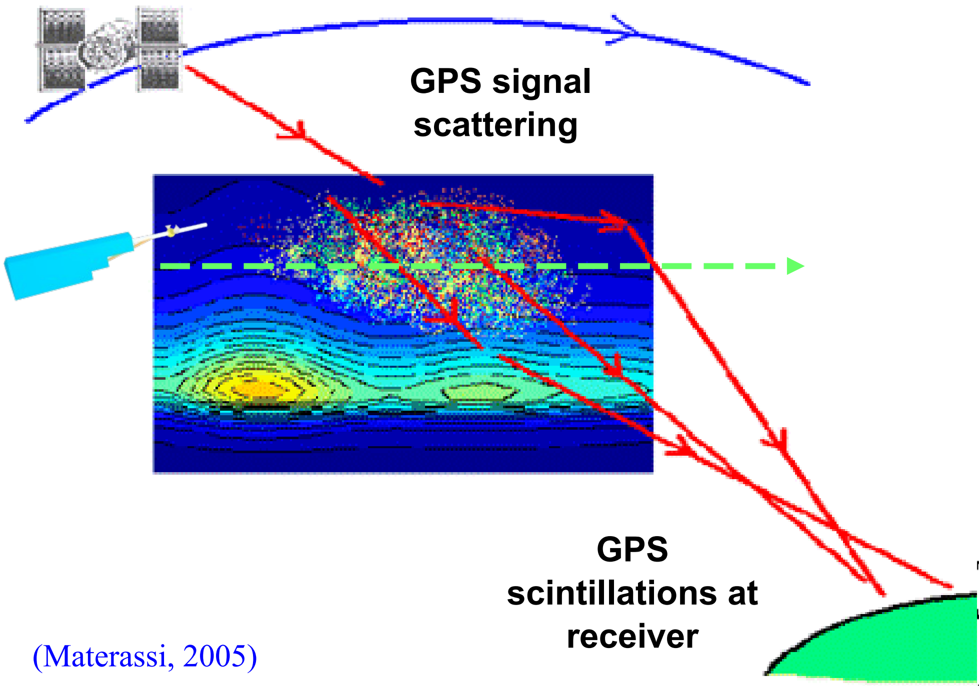
Lost connection (Topex/Possidon 1992-2006)



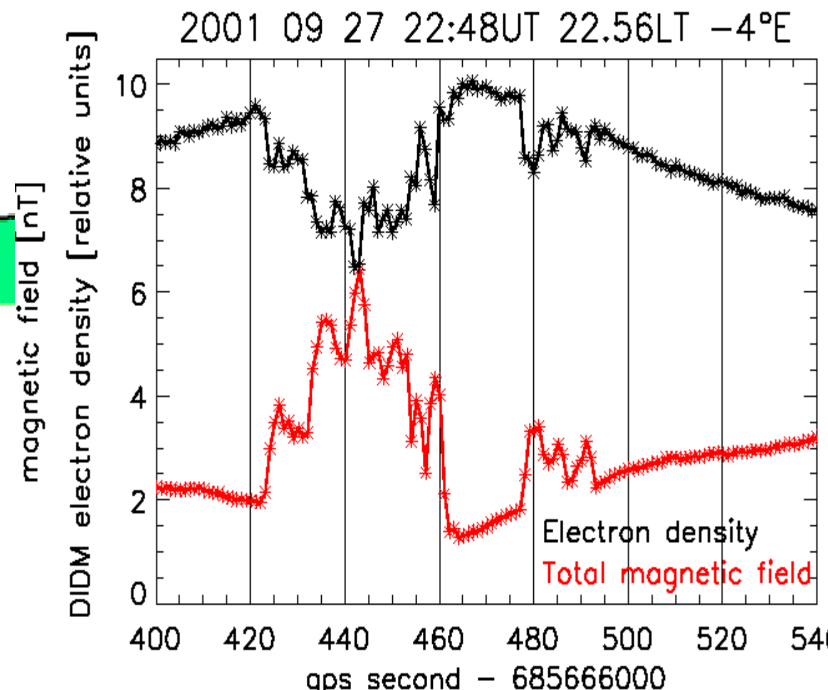
ΔF (MAGSAT (1980) – CHAMP (2005)

(Mandea et al., 2009)

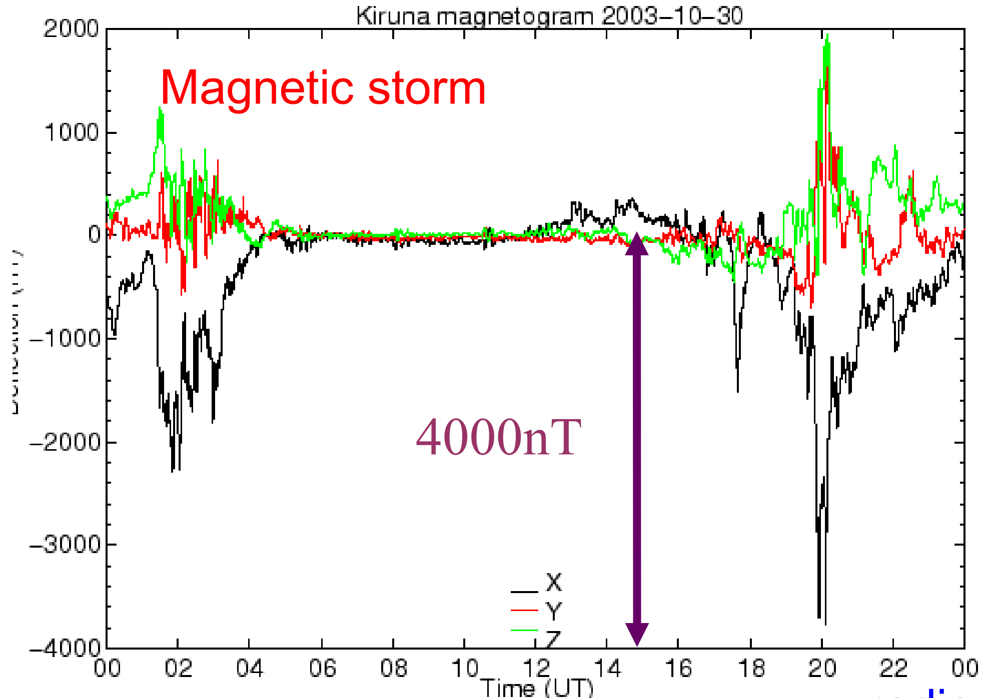
State of the art and current challenges



(Materassi, 2005)



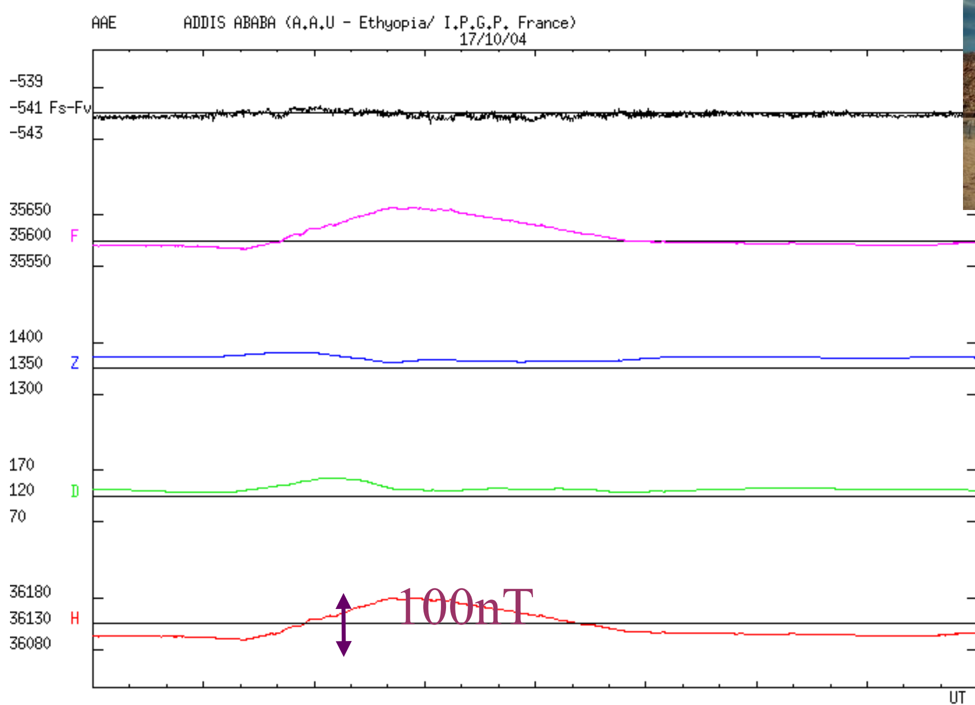
In < 8 min after a CME - effets on radio communications and GPS



aurorale

navigation

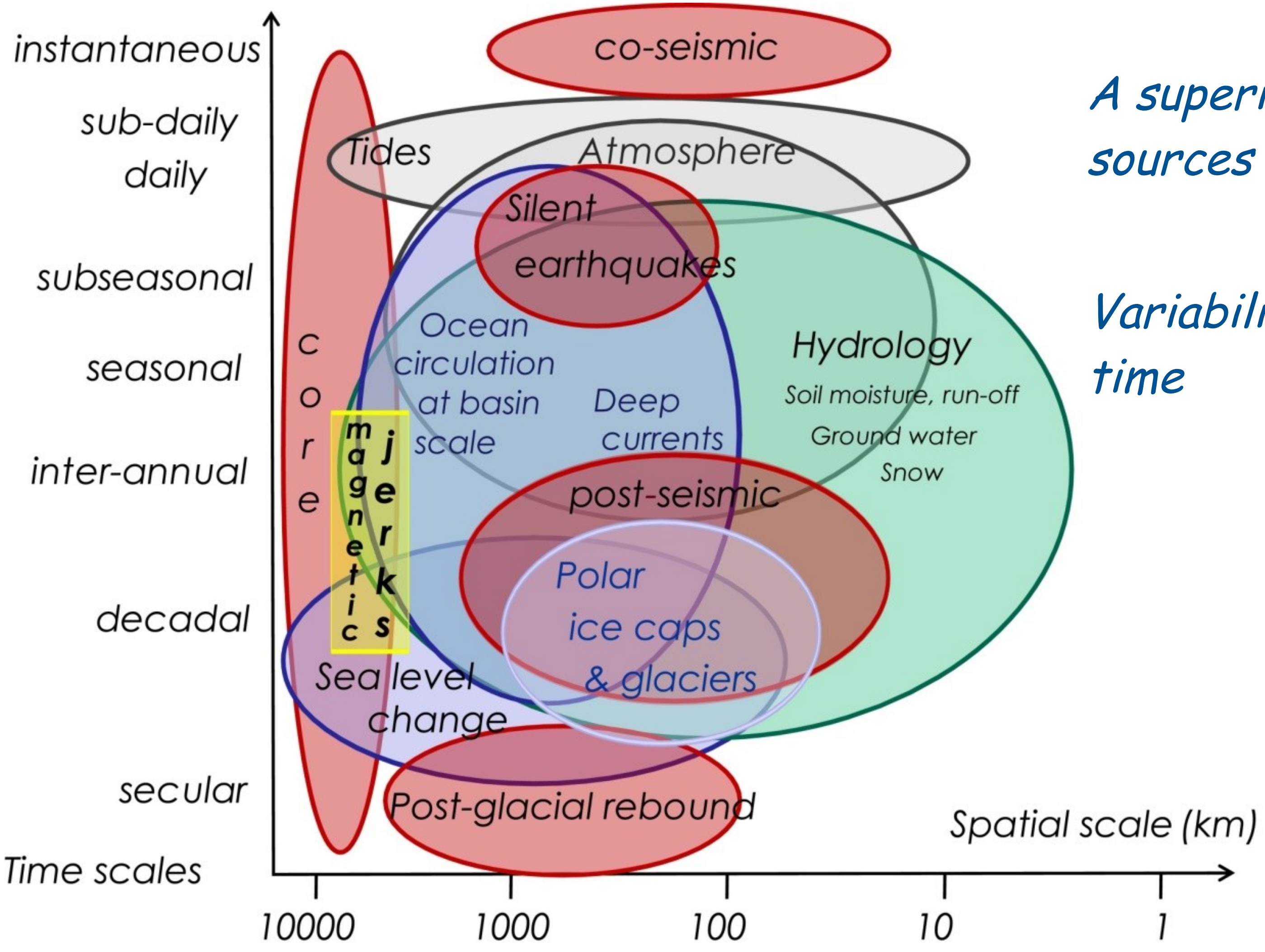
radio



transport of electricity

Satellites operation

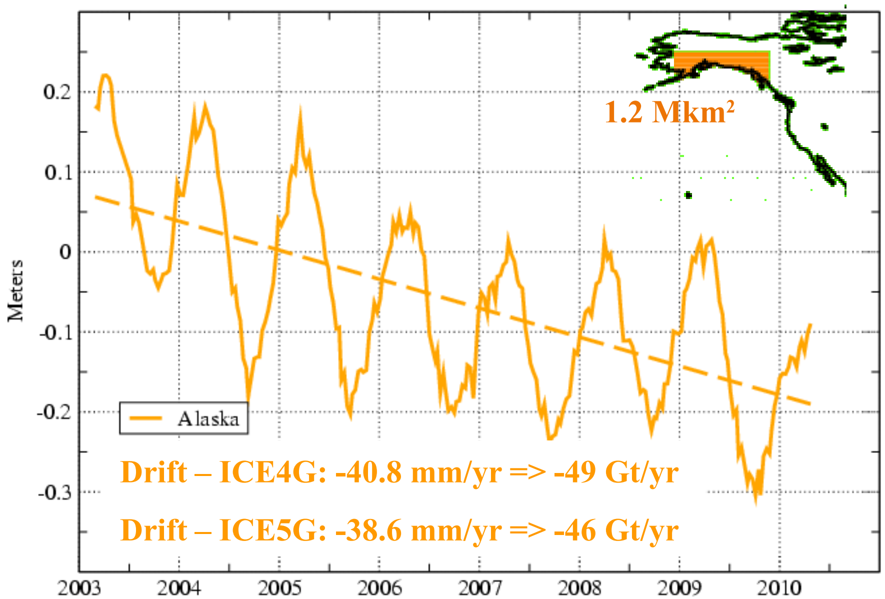
State of the art and current challenges

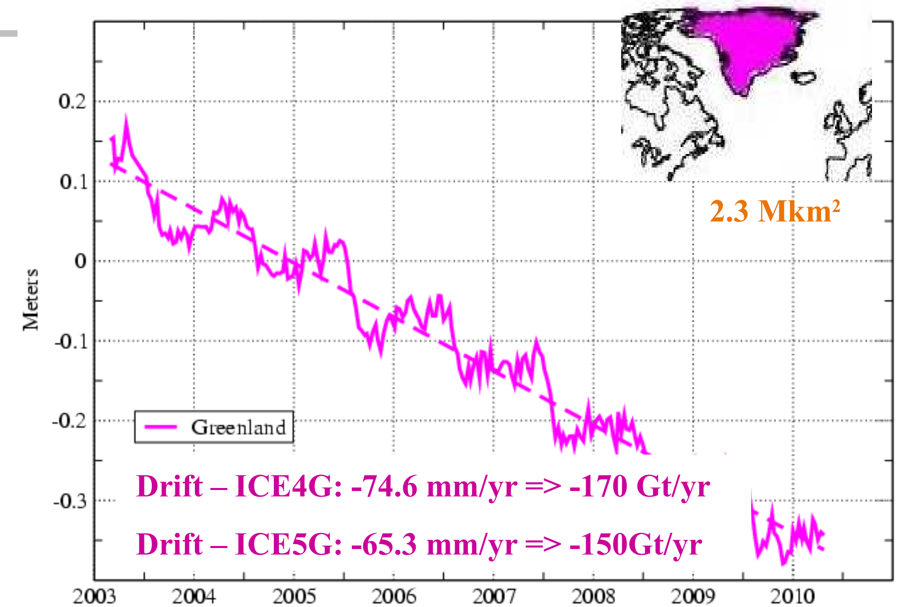


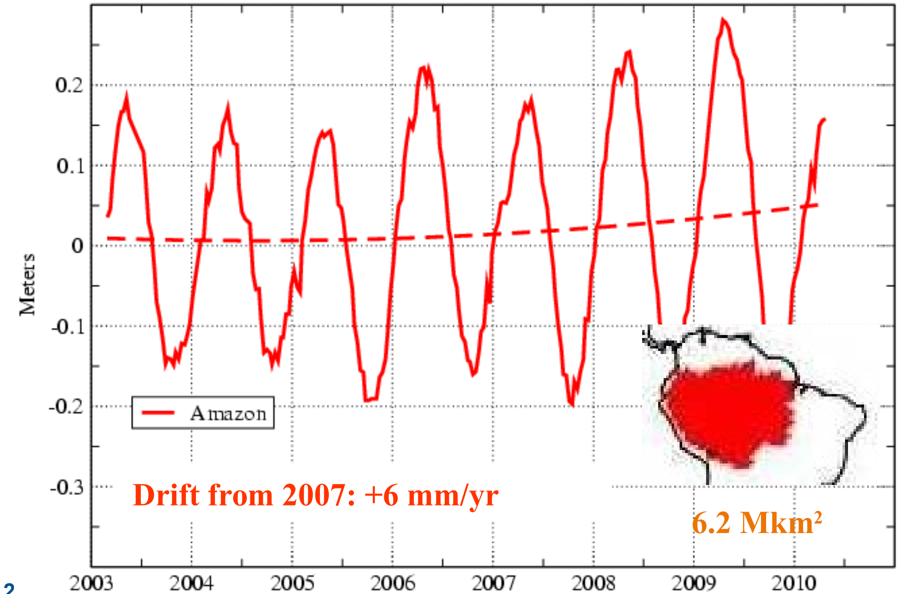
A superimposition of sources

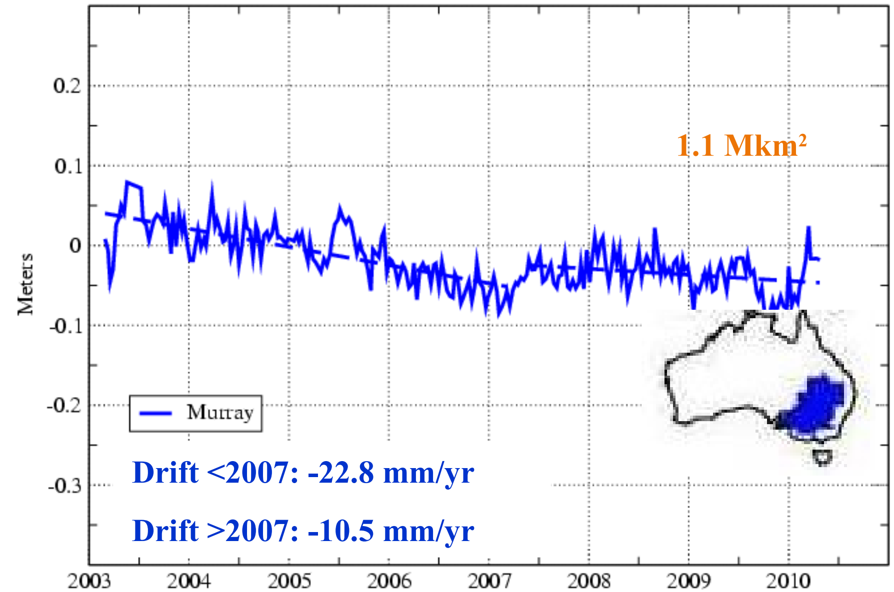
Variability in space and time

State of the art and current challenges









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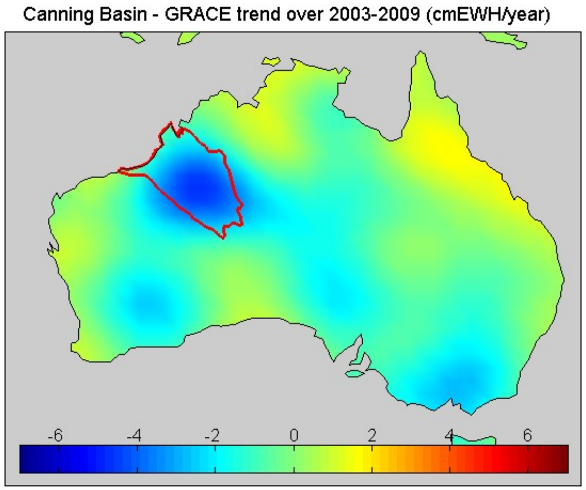
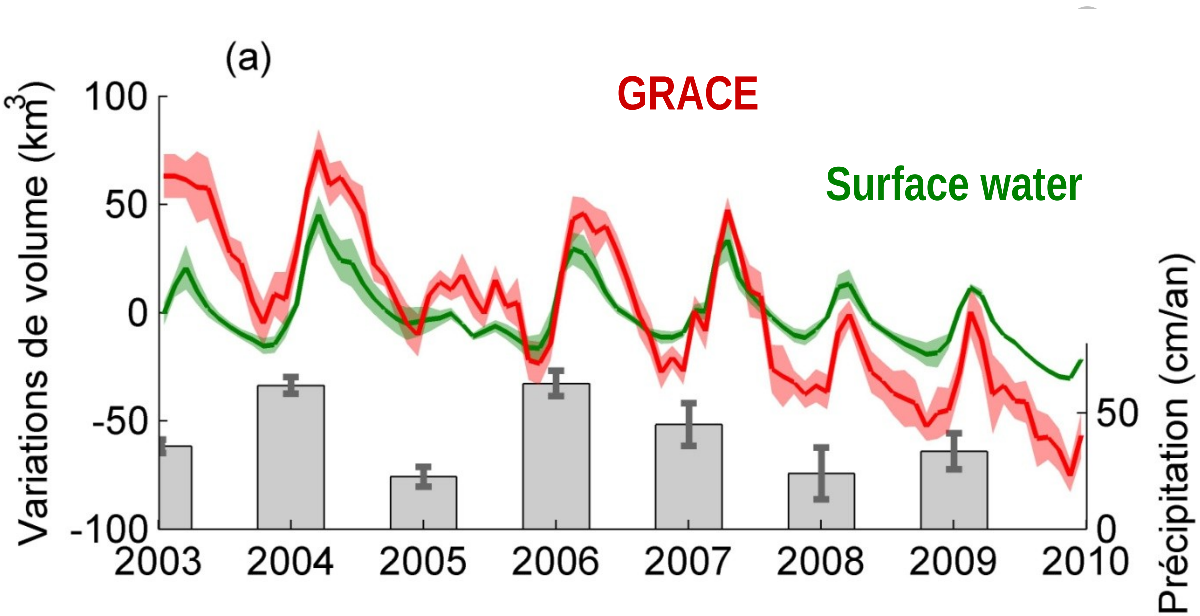
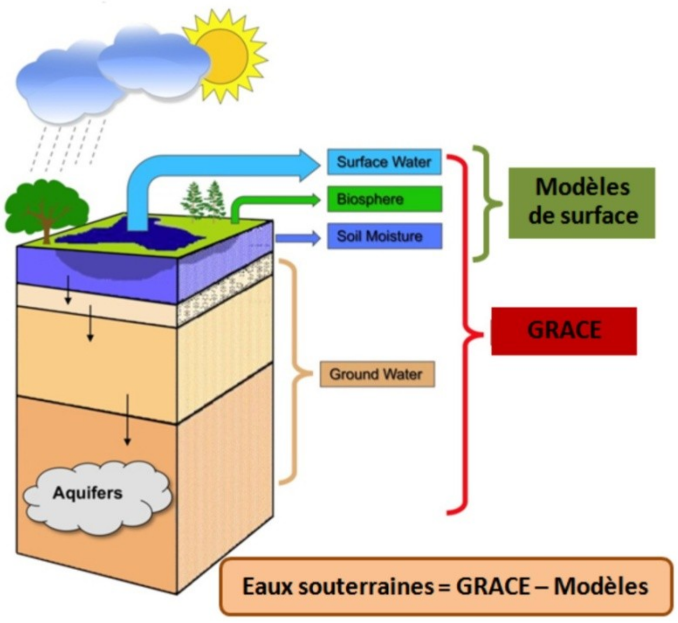
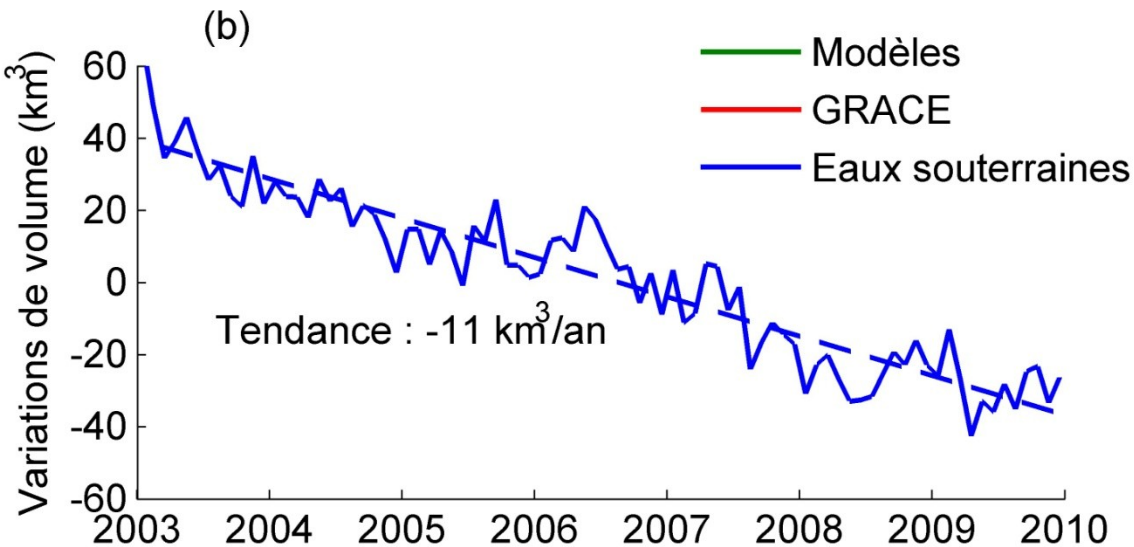
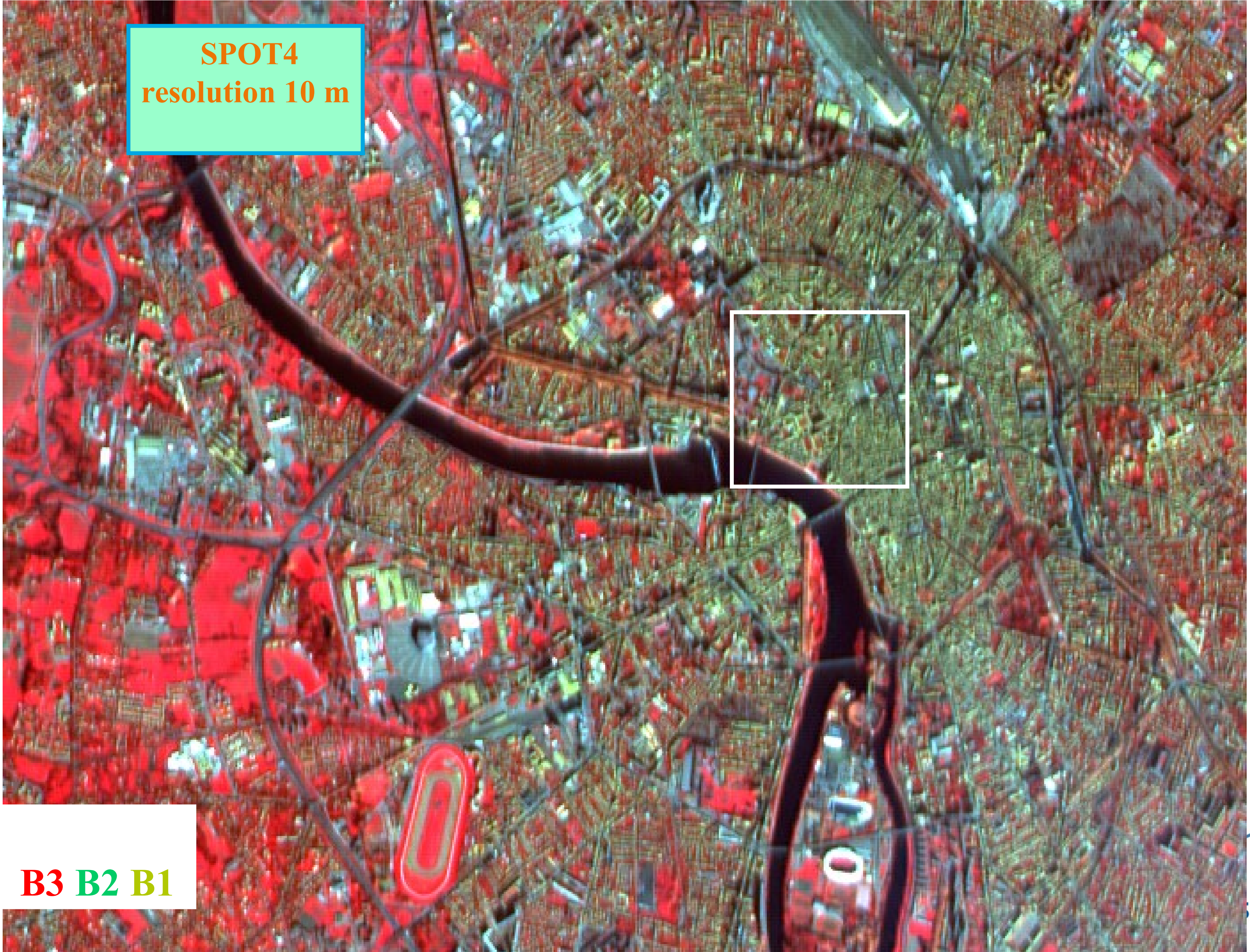




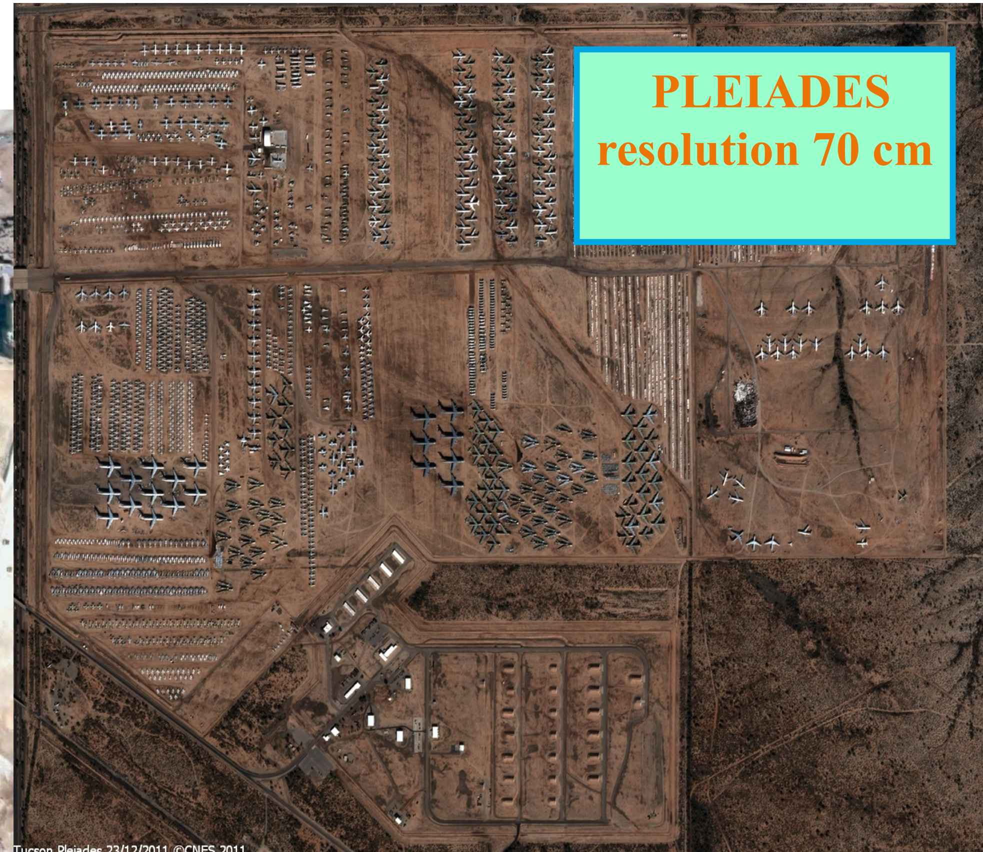


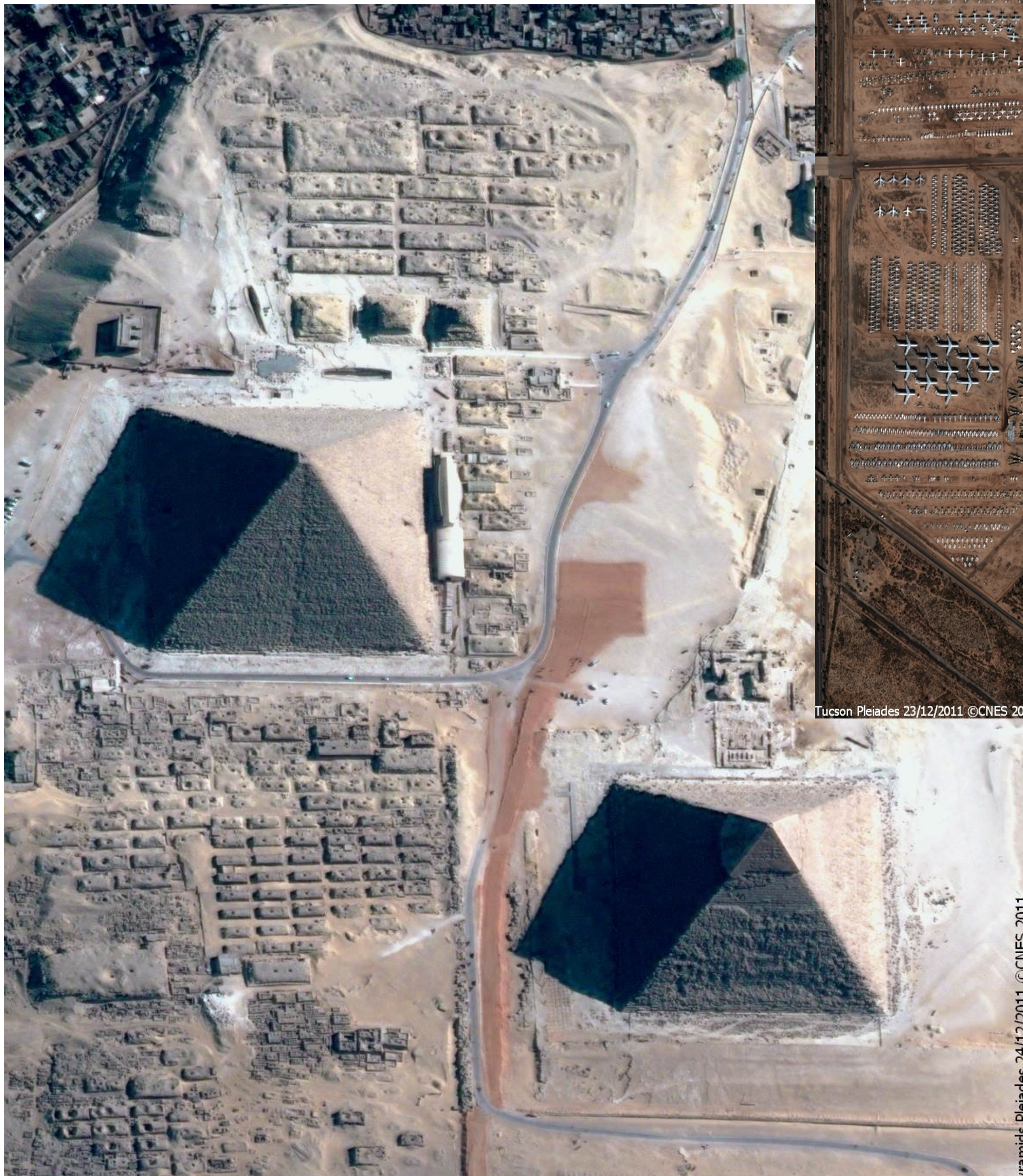


(Cazenave et al., 2011)


SPOT4
resolution 10 m
B3 B2 B1

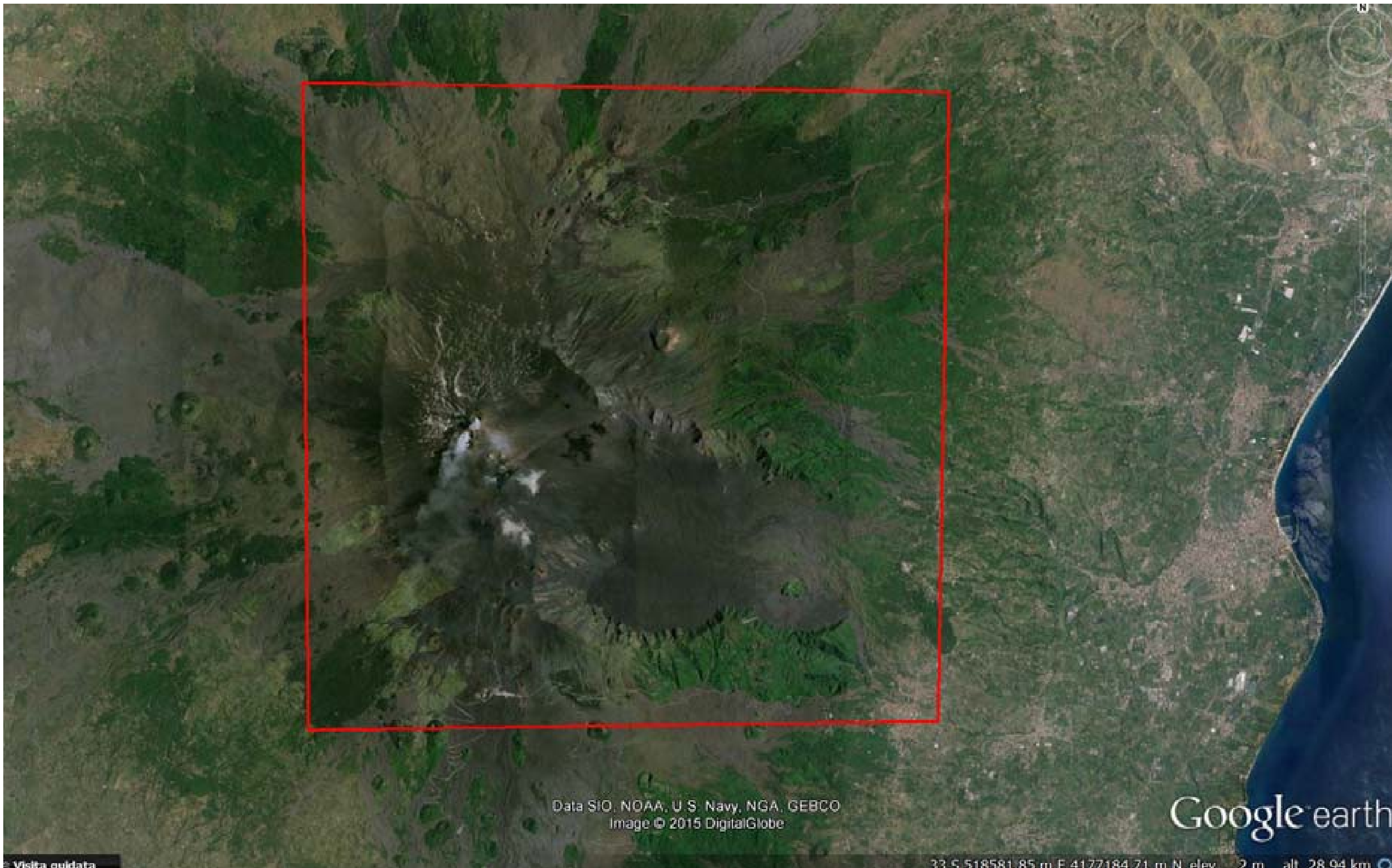
PLEIADES resolution 70 cm





State of the art and current challenges

ETNA – Pleiades acquisition



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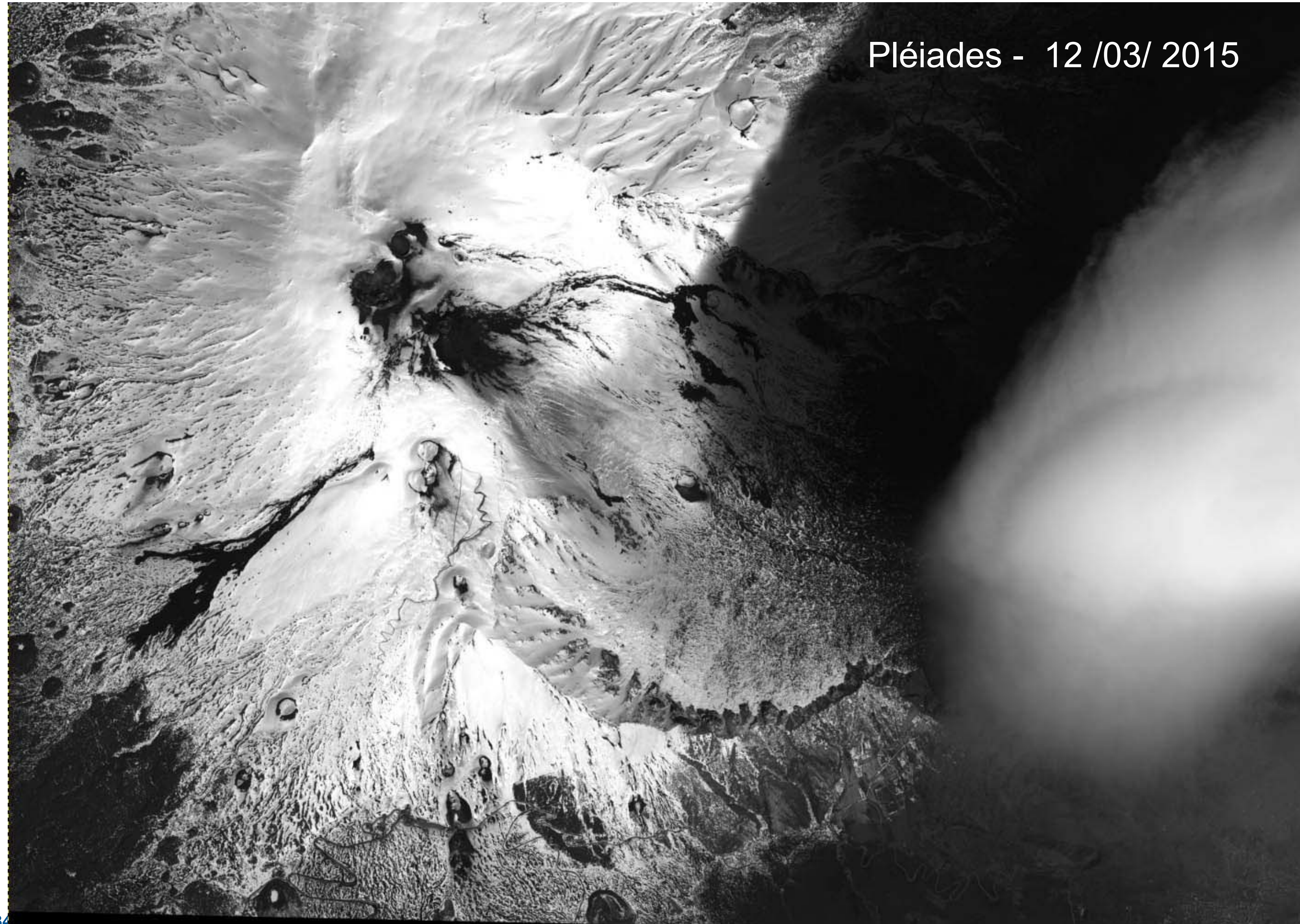
State of the art and current challenges



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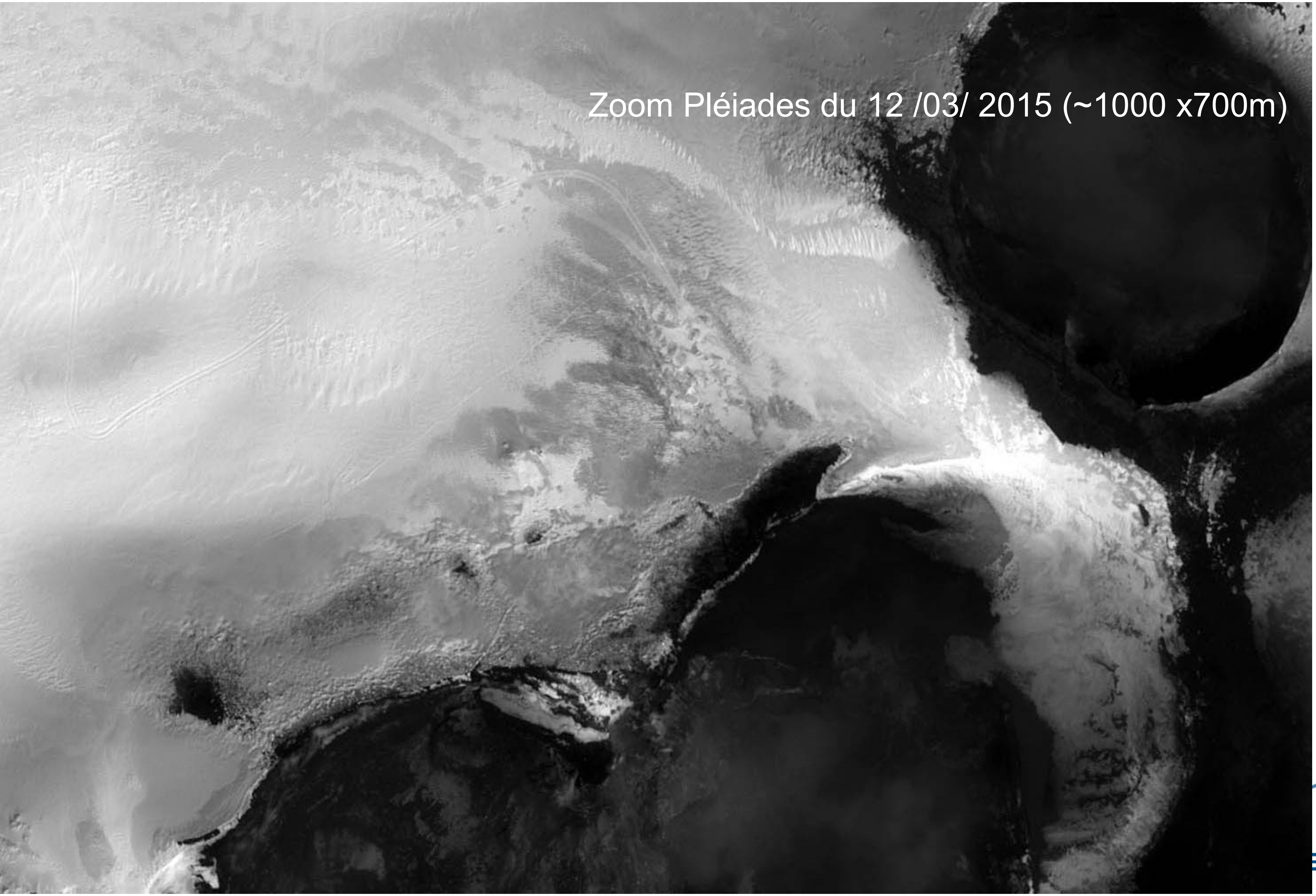

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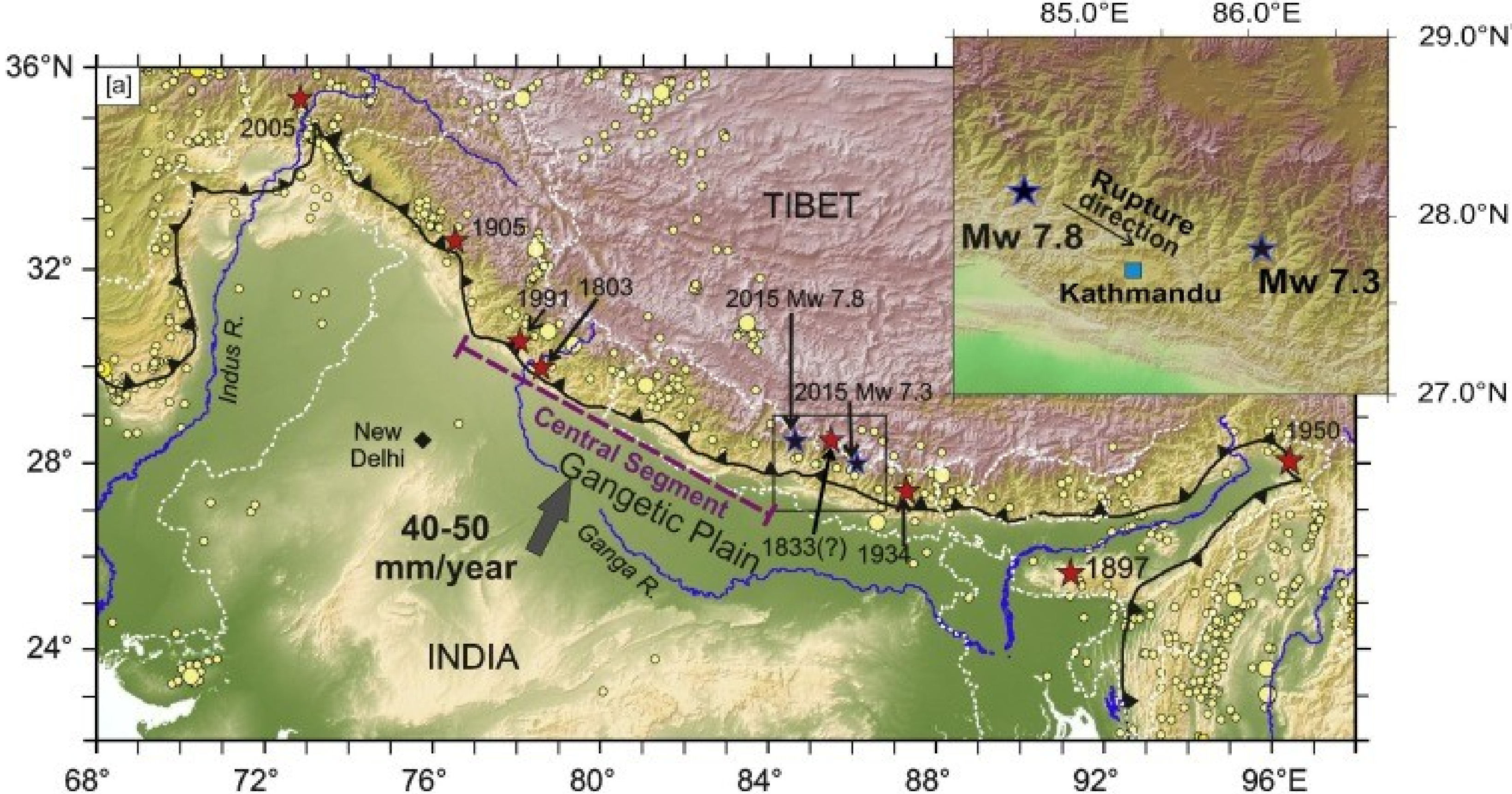
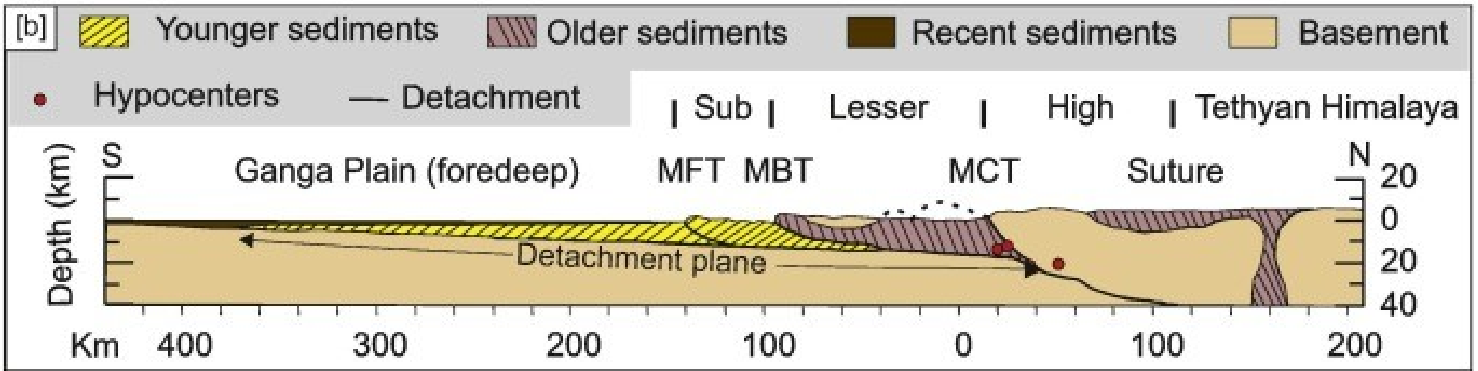
- Conclusions

Case study: the Nepal EQ

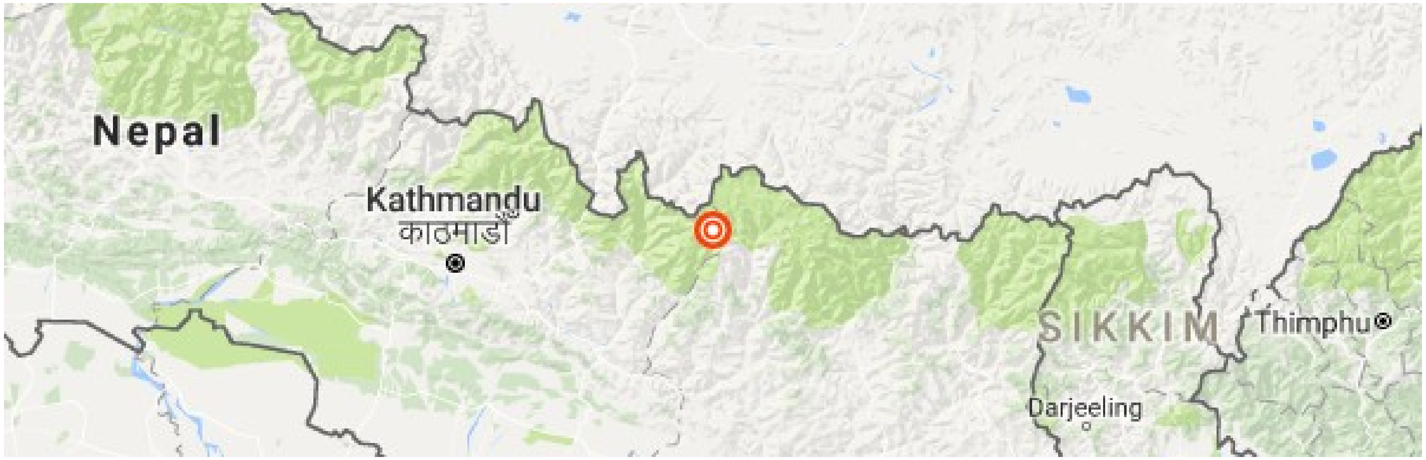


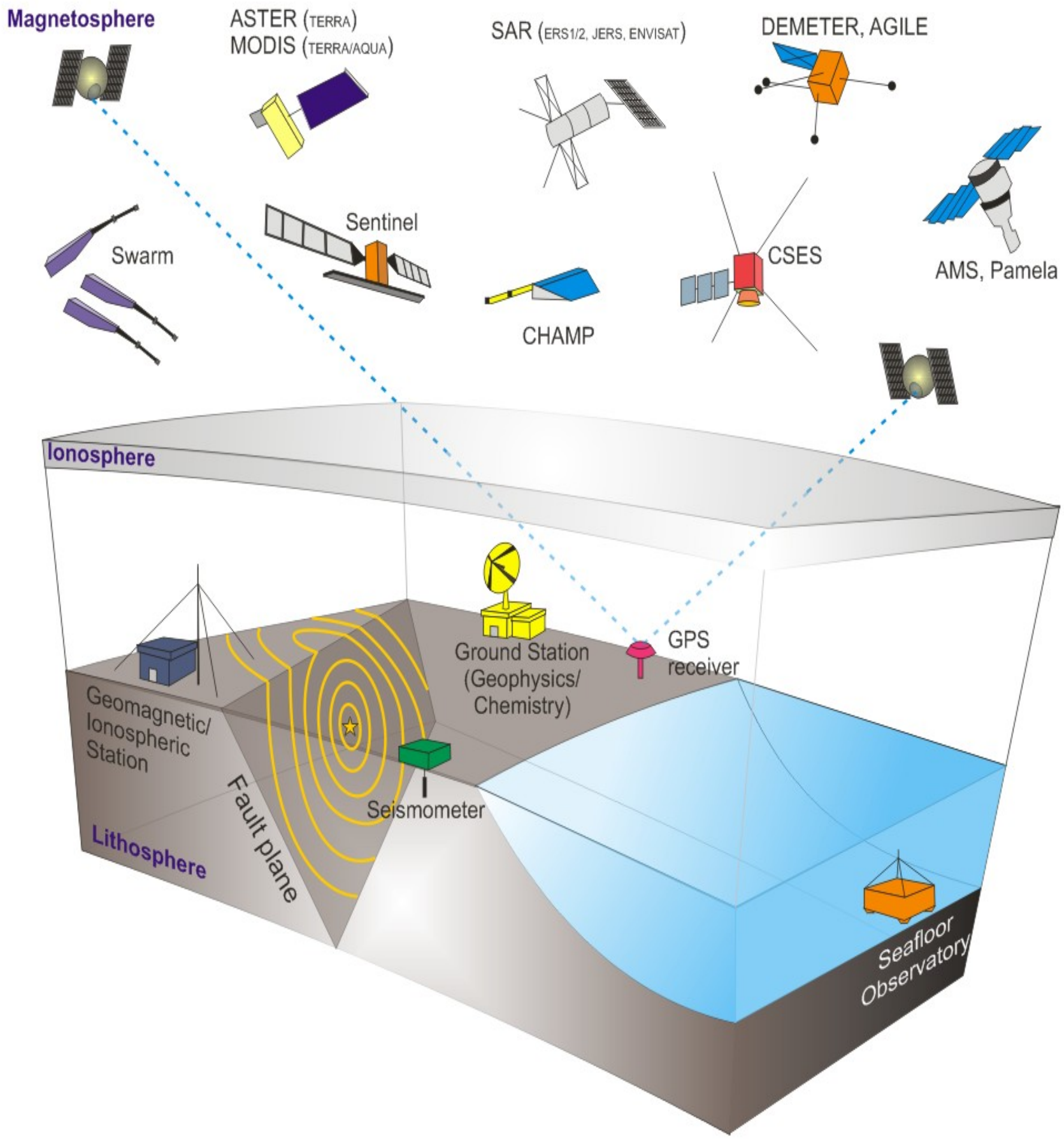


Case study: the Nepal EQ

Gorkha EQ followed by 475 aftershocks with magnnitude >4 until Nov 28

Magnitude 5.4 earthquake
16 km from Gumdel, Nepal · Nov 28, 12:35 AM





The goal is not an EQ prediction, but to understand the process of earthquake preparation and the geospheres coupling.

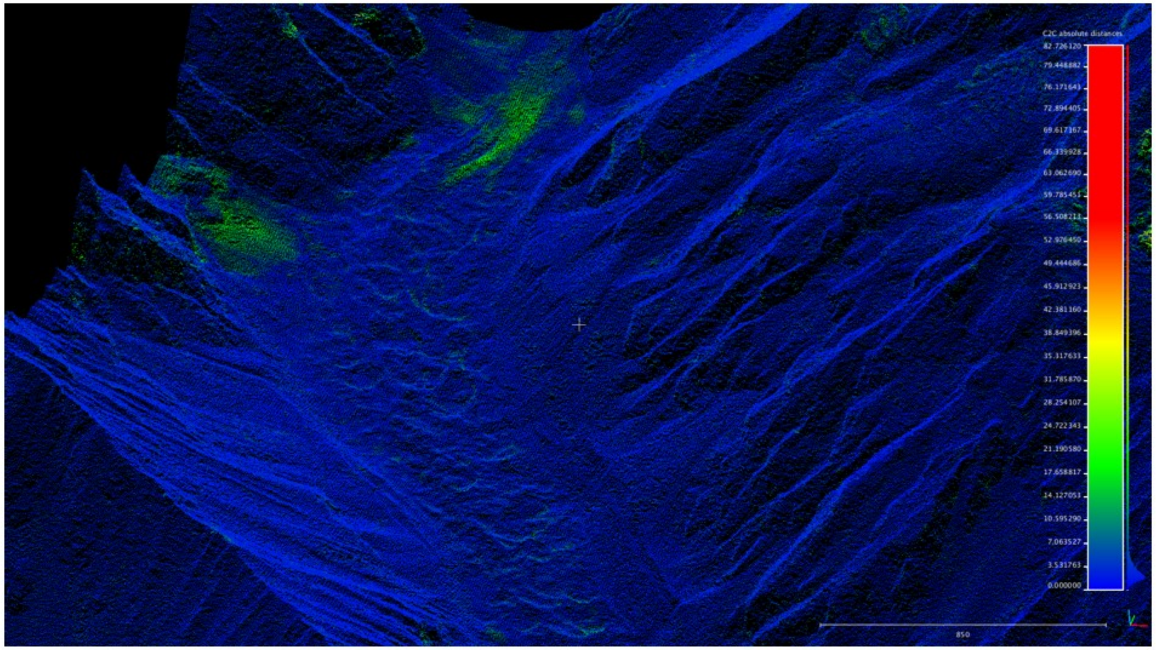
Interest Lithosphere-Atmosphere-Ionosphere Coupling (LAIC).

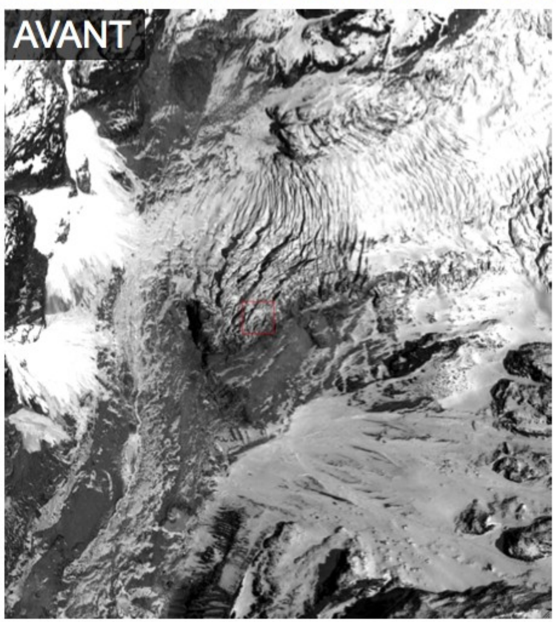
Case study: the Nepal EQ

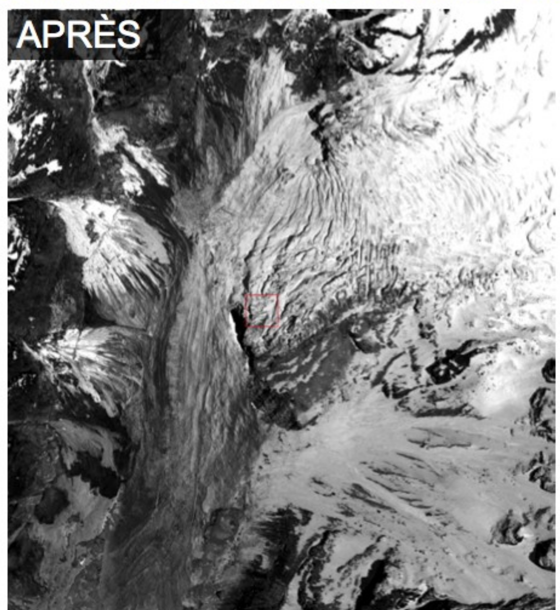
La place Durbar à Katmandou, classée au patrimoine mondial de l'UNESCO avant et après le séisme d'avril 2015
Satellite Pleiades - Images du 29 novembre 2014 et du 27 avril 2015. Copyright CNES - Distribution Airbus DS

Two days after the earthquake that struck Nepal, the Pleiades satellites, developed by CNES, have captured an image of the capital city, Kathmandu.

Case study: the Nepal EQ





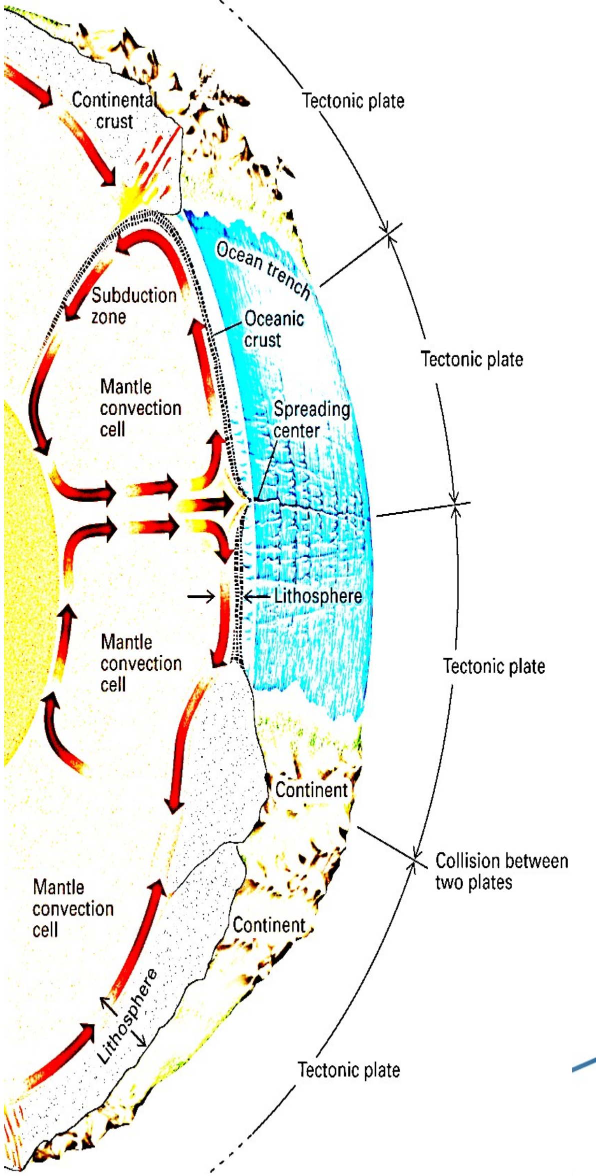


Images Spot 6/7

DEM model computed before and after the Nepal EQ.

Case study: the Nepal EQ

For Science: Lithosphere is complex. Understanding the (EQ) process is a fundamental step to know lithosphere and its interaction with the rest of the planet



For society: Understanding the EQ Process (and its eventual forecast) is one of the greatest challenges of science for which we need both ground and space observations

Case study: the Nepal EQ

Patterns in the EQ possible signature

Ionospheric anomalies

(short term– observed from satellites or ionosondes or GPS networks)

- ionospheric density
- EM field
- TEC

Atmospheric anomalies

(short term)

- Thermal anomalies
- Clouds anomalies

Seismic fore-patterns

(from seismic and magnetic data)

- Acceleration (interm. term)
- non linear pdf (short term)

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Case study: the Nepal EQ

On April 25, 2015 (06.26 UTC) a large earthquake occurred in Nepal Himalaya 77km NW of Kathmandu:

- ✓ magnitude Mw 7.8
- ✓ epicenter 28.15^{o}N, 84.71^{o}E
- ✓ depth of 15 km

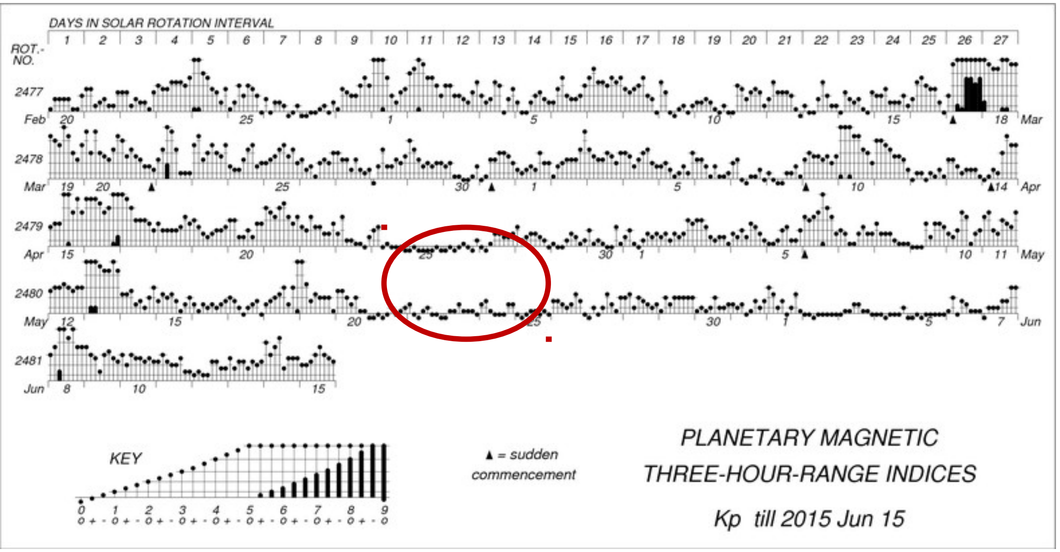
According to USGS

fault rupture plane @295o and the dip 10oNNE

the rupture surface @~100km along the strike &80 km along the downdip

17 days later (May 12, 2015), a strong aftershock followed approximately 77km NE of Kathmandu, with a smaller estimated magnitude of Mw 7.3

Case study: the Nepal EQ



Swarm data

- ➢VFM (Low Resolution)
- ➢ASM Level1B 1Hz
- ➢electron density Ne 2 Hz

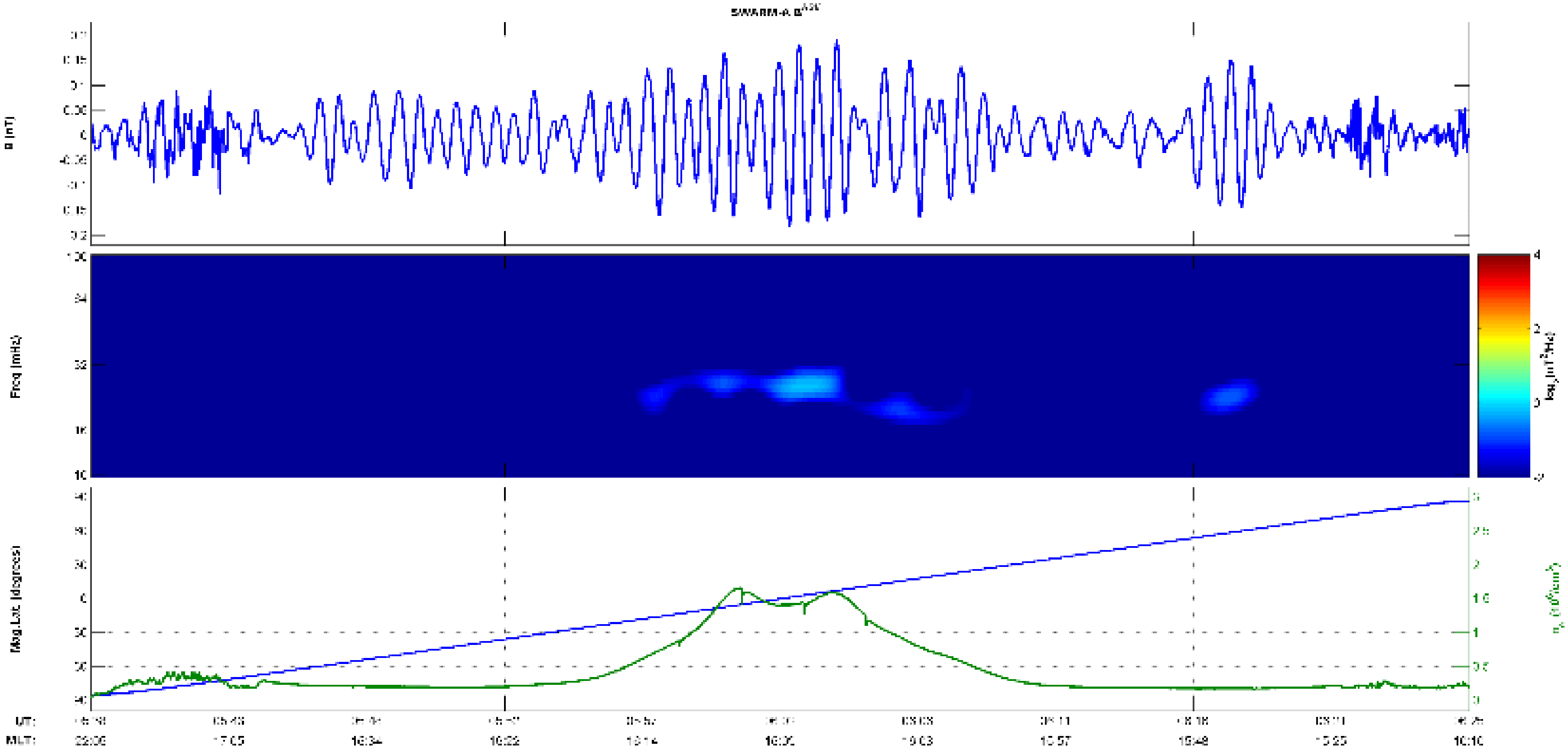
along the tracks that flew in a circular region within R=2750 km (Dobrovolsky radius strain $R=10^{0.43M}$) to be more conservative → a slightly larger area with a magnitude M=8.

Data Analysis

wavelet analysis of Swarm data for the same day of the earthquake

- ✓magnetically calm period around the EQ occurrence
- ✓intense ULF anomaly detected by the wavelet analysis
- ✓solar activity magnetic indices are rather low → probability that this anomaly is due to the very last phase of preparation of the impending EQ.

Case study: the Nepal EQ



ULF anomalous and persisting signal (from around 3 to 6 UTC) is clearly detected before the earthquake.

Case study: the Nepal EQ

After this single-spot analysis → a more extensive analysis for two months around the earthquake occurrence, to confirm or refute the cause-effect relationship.

Two-step analysis:

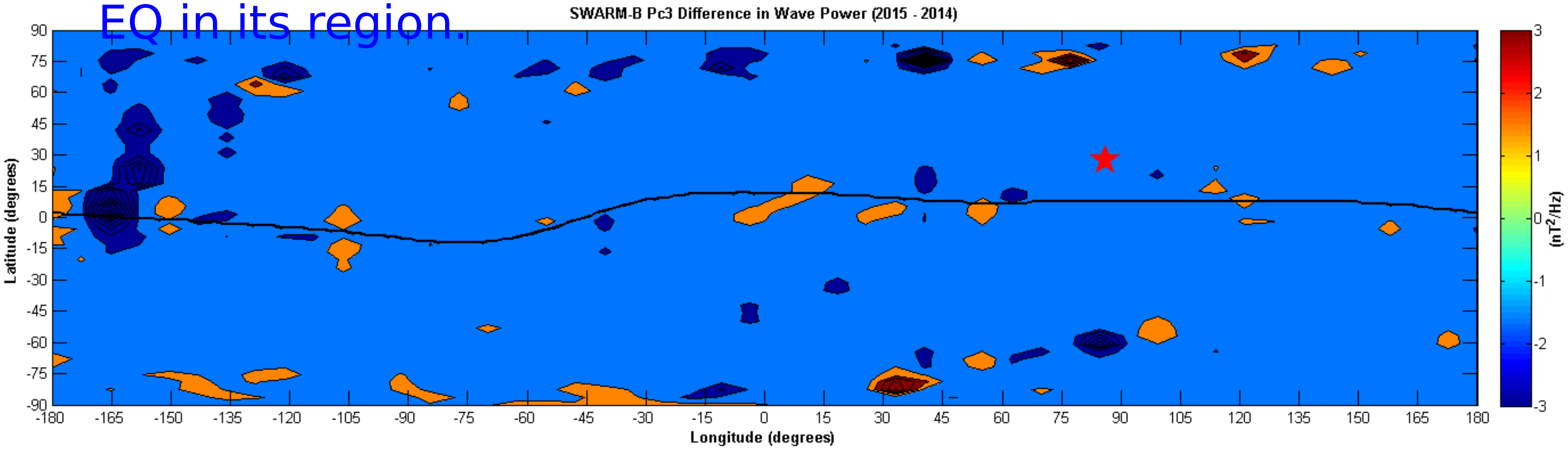
i)the comparison of the average power in Pc3 frequency band (0.022-0.1 Hz) for a 2-month period in 2015 with that of the previous year, when no large earthquake occurred in the area of interest

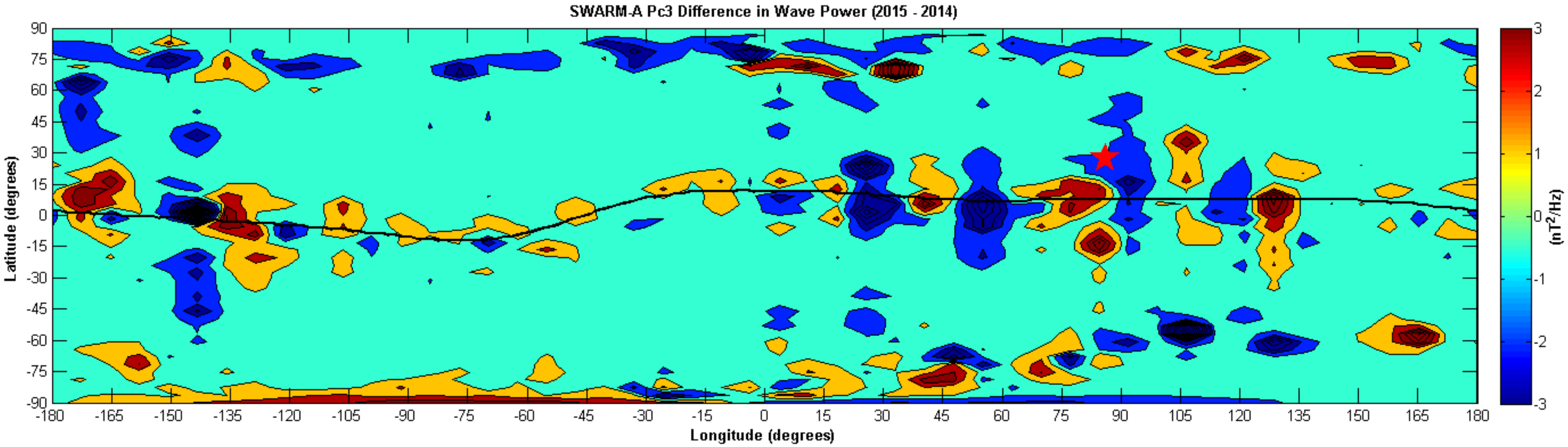
ii) the search for the single “anomalies” and then of the temporal behavior of the cumulative number of anomalies in

- Swarm data
- Ground data extracted from the USGS Catalog (1 April to 10 May 2015 with magnitude M4+)

Case study: the Nepal EQ

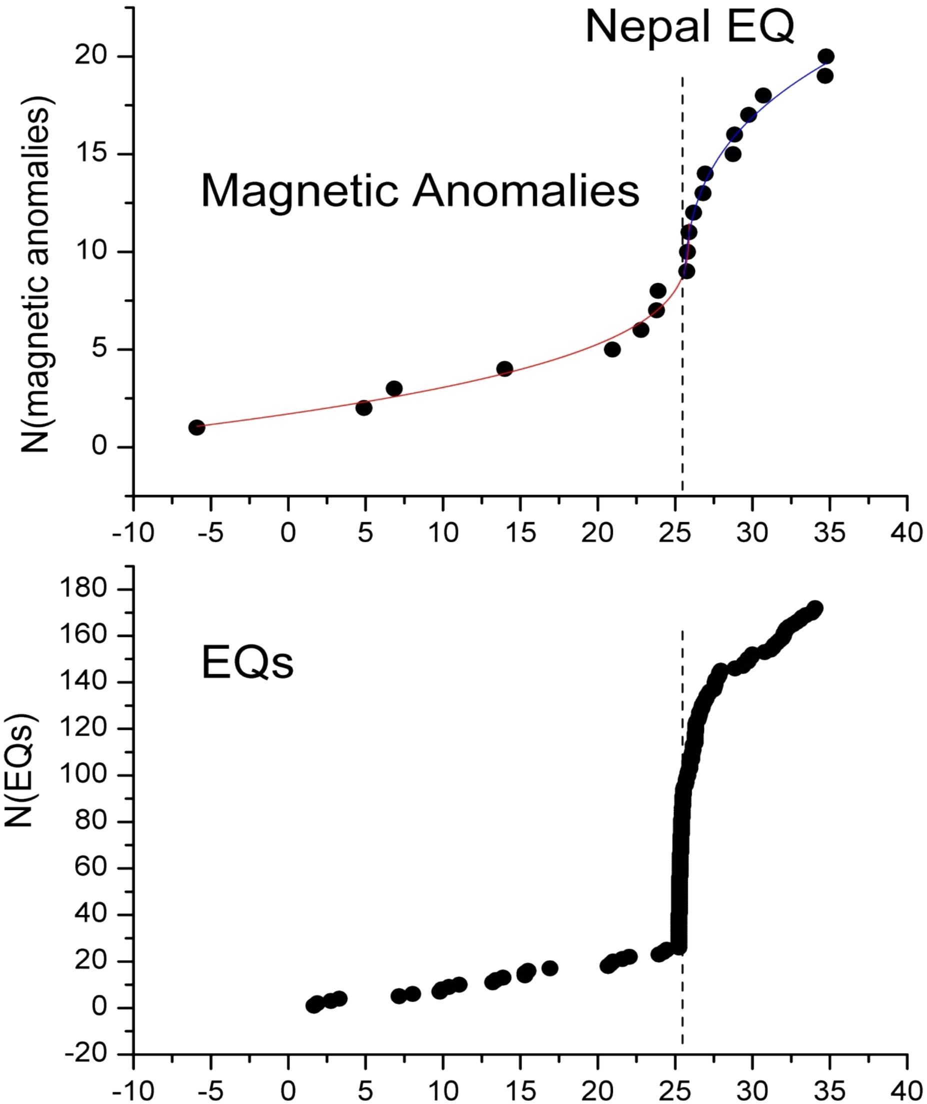
Pc3 difference in wave power 2015-2014 for Swarm B satellite, suggesting an ionospheric contribution for the Nepal EQ in its region.





Pc3 difference in wave power 2015-2014 for Swarm A satellite;

Case study: the Nepal EQ



✓define as "anomaly" that value exceeding some sigmas along track only

- occurred during magnetic quiet times
- within the Dobrovolsky circular area around the epicenter with a radius of $R=10^{0.43M}$ (=2750 km for Nepal M8)

(Dobrovolsky et al., 1979)

✓Compute cumulative number of them, *N(magnetic anomalies)*, at the exact time they occur is given

✓agreement with the corresponding curve deduced from M4+ earthquakes (EQs) analysis

Case study: the Nepal EQ

Cumulative numbers of anomalies

✓follows the same typical power-law behavior of a critical system approaching its critical time → the large seismic event of 25 April, 2015

✓recovers as the typical recovery phase after a large earthquake.

The impressive similarity of this behavior with the analogous of seismic data analysis, provides strong support to the lithospheric origin of the satellite magnetic anomalies, as due to the LAI coupling during the preparation phase of the Nepal earthquake

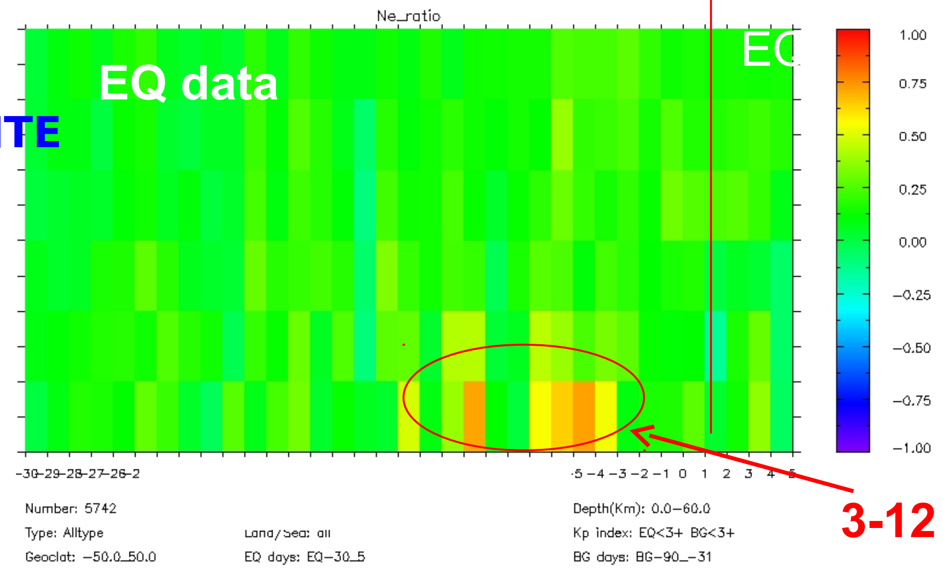
cnes

Conclusions

Space data – a possible source of information on **EQ**

1) DEMETER SATELLITE (2004-2010)

Ionospheric Electronic Density



DEMETER satellite (2004-2010)
~ 9000 EQs
M≥5 and h< 40 km

3-12 days in advance

(Li & Parrot, 2013)

2) CHAMP SATELLITE – wavelet analysis of data with respect of Sumatra EQ - some specific (2000- 2009) features are observed after the two Sumatra EQ, with periods of about 16 and 30 s.

(Balasis & Mandea 2007)

3) PLEIADES SATELLITES – active faults & EQ - unified view of the EQ cycle

(Klinger, 2016)

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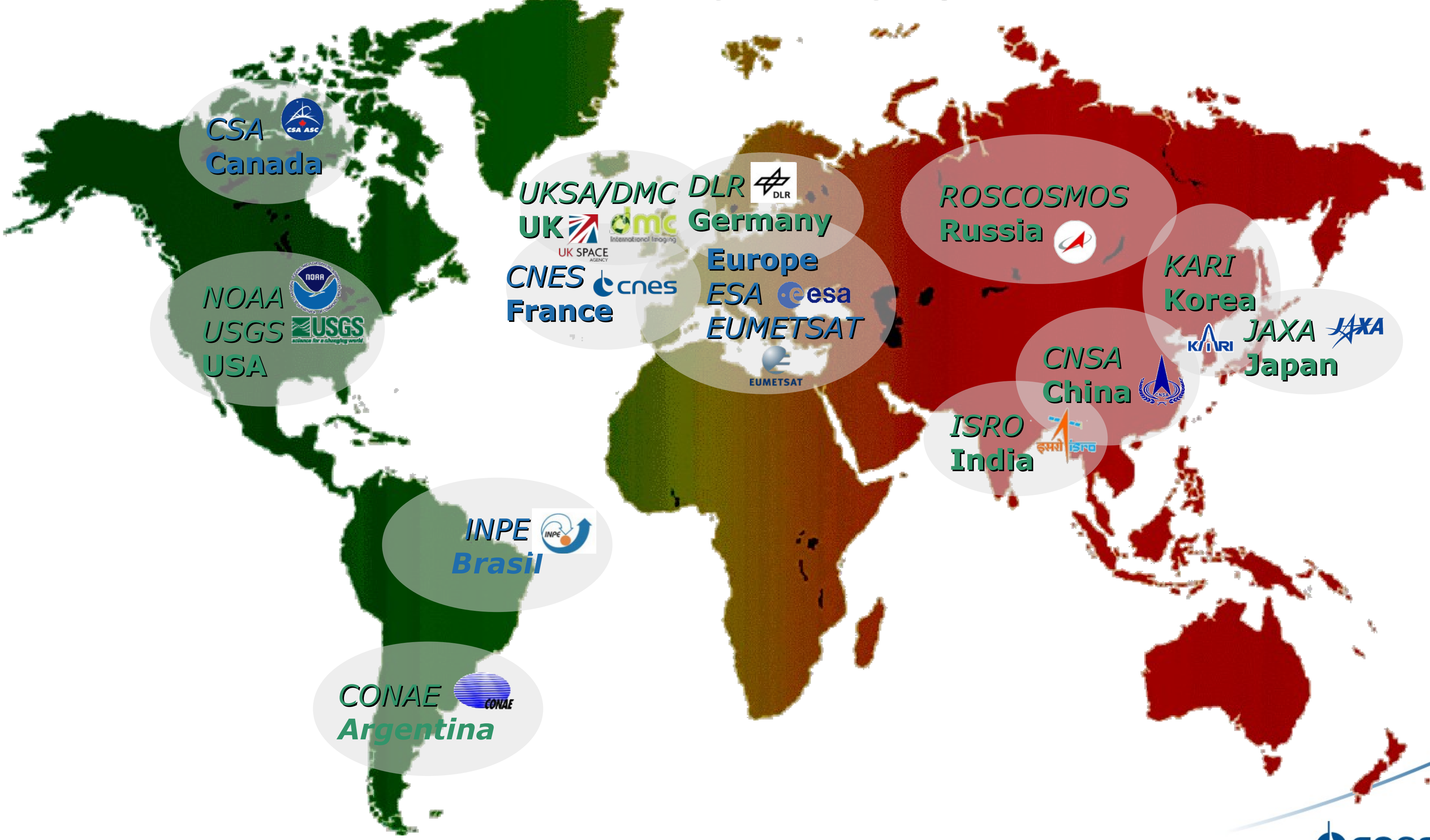
SOMMAIRE

cnes

International Charter 'Space and Major Disasters'

Members



International Charter 'Space and Major Disasters'

Process

Authorised User sends a request for Charter activation

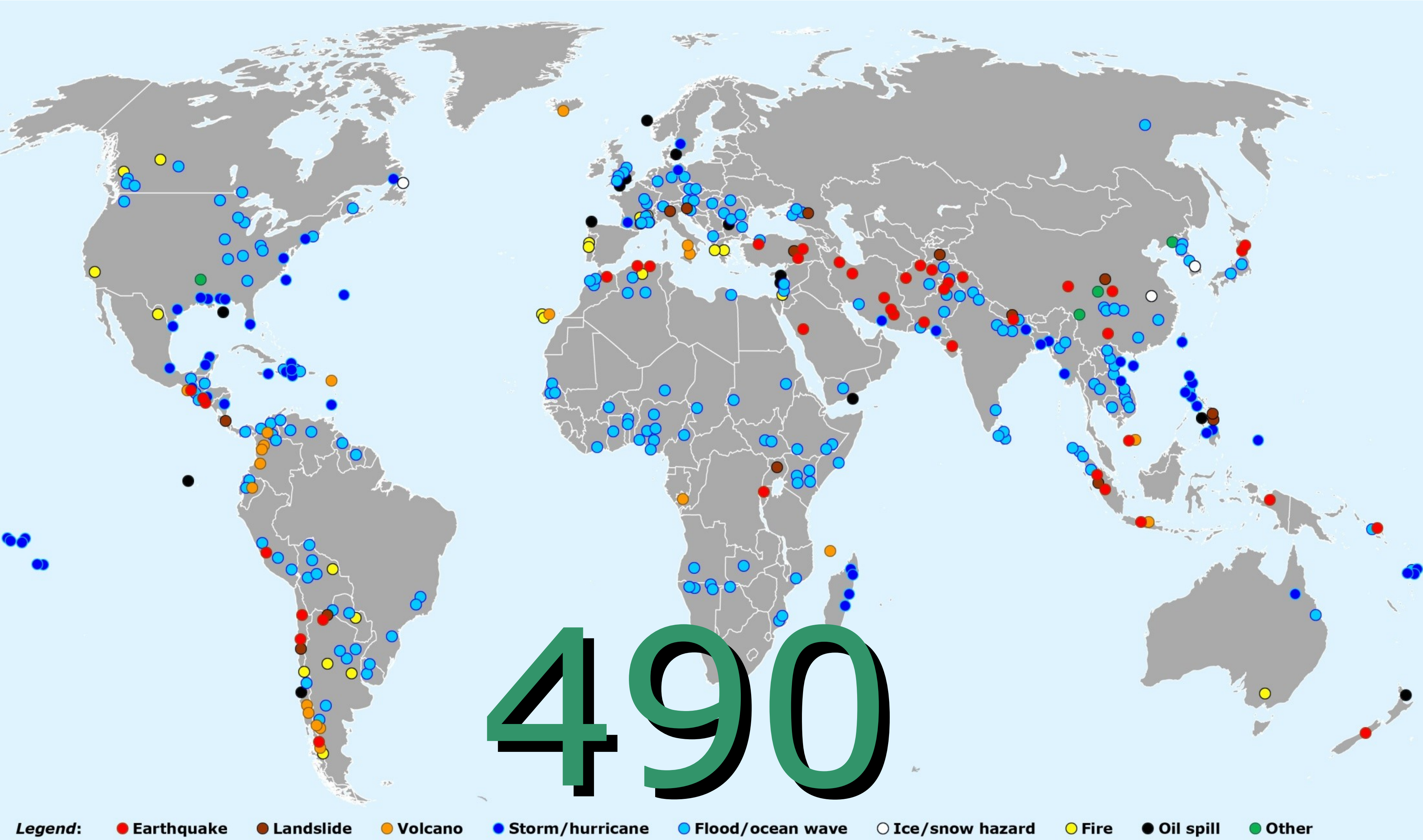
Direct link to the user/response community who will use the maps

24/7 operators respond to requests by quickly tasking satellites

Satellite images received and turned into useful maps

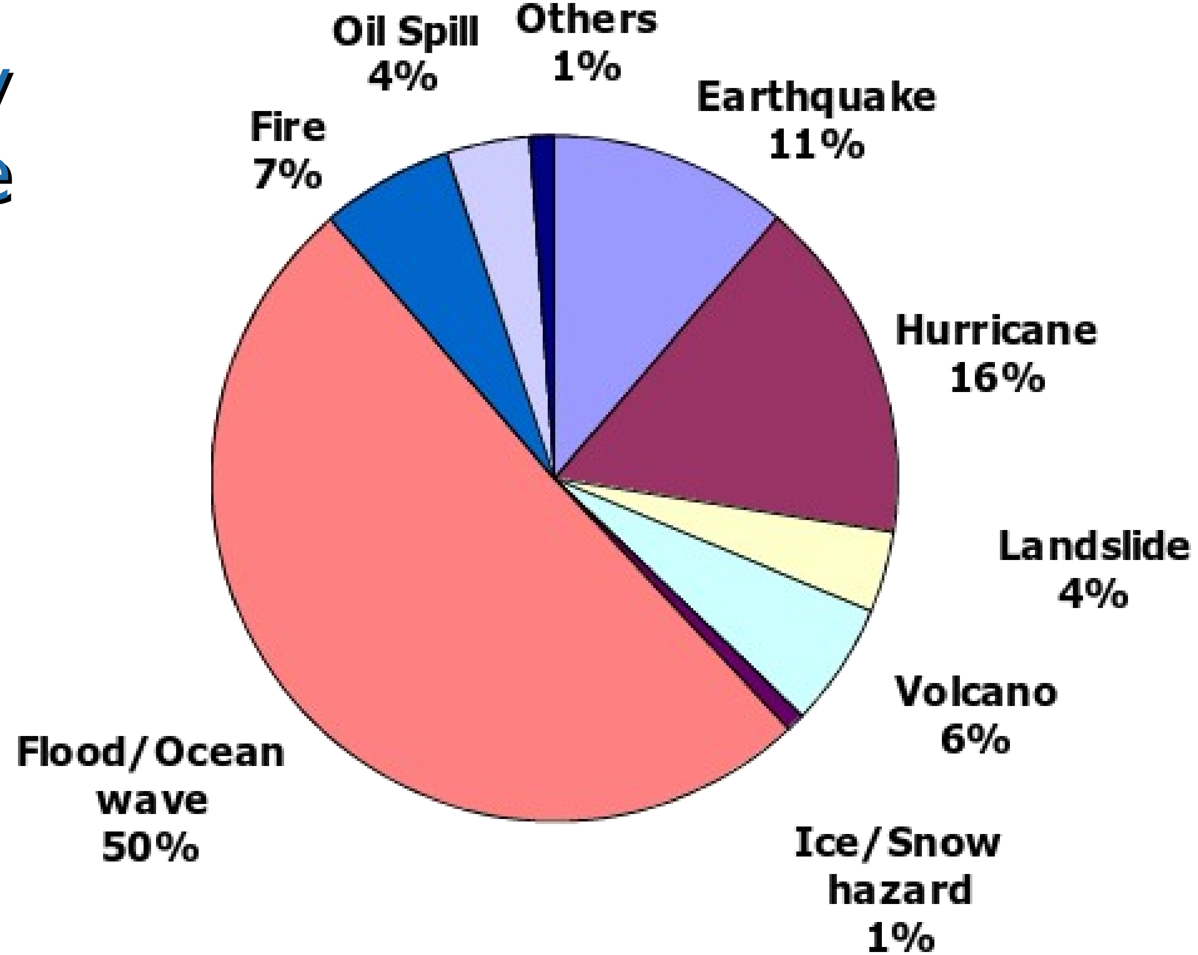
International Charter 'Space and Major Disasters'

Map of activations



International Charter 'Space and Major Disasters'

Activations by disaster type



For 490 activations – July 2016

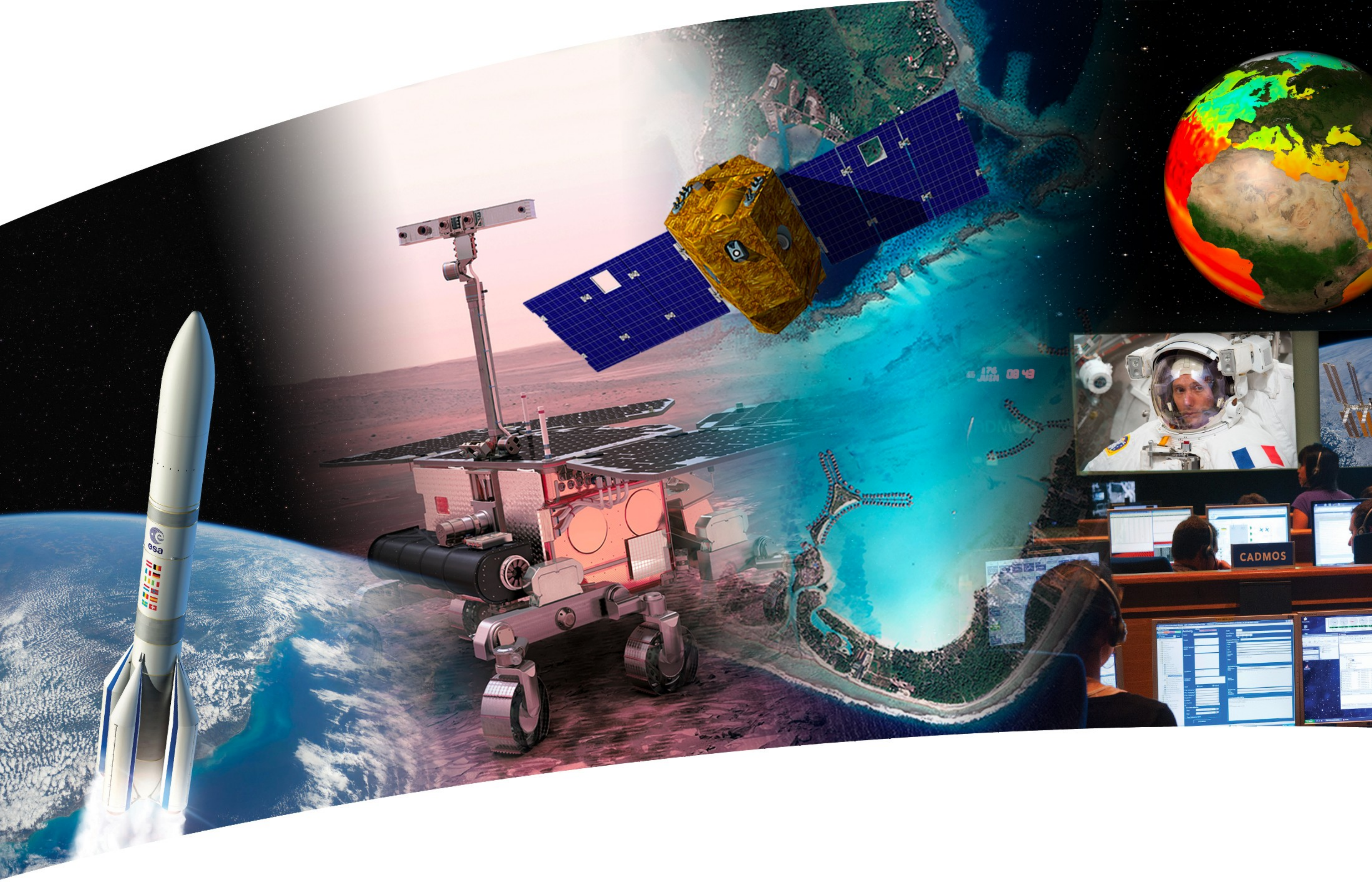
Mechanisms to activate the Int. Charter

Direct activation by an Authorised User

Activation via an Authorised User on behalf of a user from another country without AU

Activation via the UN for UN users

Activation for Asia Pacific users via Sentinel Asia (Asian Disaster Reduction Centre)



MERCI POUR VOTRE ATTENTION