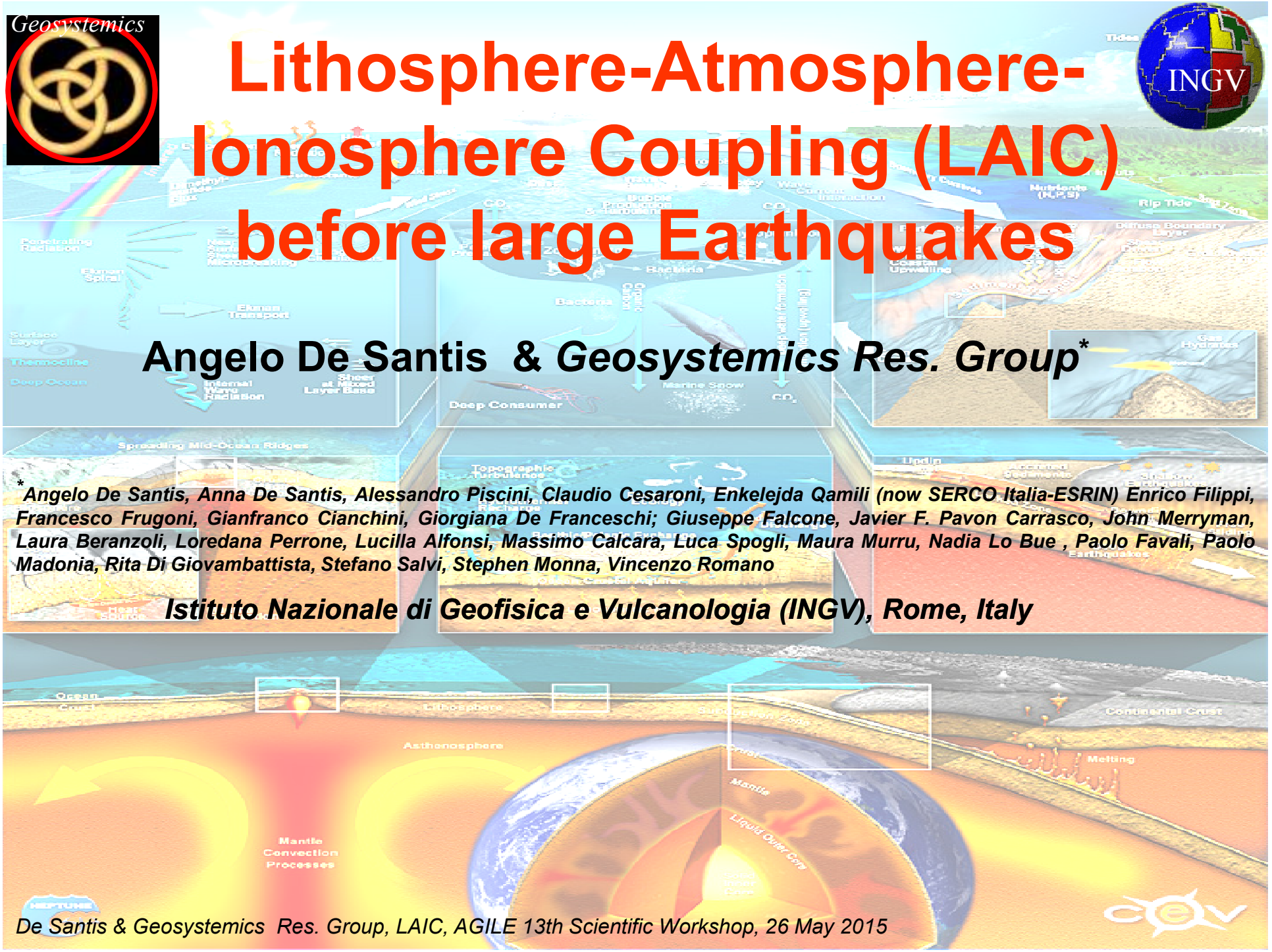

Geosystemics
INGV
Lithosphere-Atmosphere-Ionosphere Coupling (LAIC) before large Earthquakes
Angelo De Santis & Geosystemics Res. Group*
*Angelo De Santis, Anna De Santis, Alessandro Piscini, Claudio Cesaroni, Enkelejda Qamili (now SERCO Italia-ESRIN) Enrico Filippi, Francesco Frugoni, Gianfranco Cianchini, Giorgiana De Franceschi; Giuseppe Falcone, Javier F. Pavon Carrasco, John Merryman, Laura Beranzoli, Loredana Perrone, Lucilla Alfonsi, Massimo Calcara, Luca Spogli, Maura Murru, Nadia Lo Bue , Paolo Favali, Paolo Madonia, Rita Di Giovambattista, Stefano Salvi, Stephen Monna, Vincenzo Romano
Istituto Nazionale di Geofisica e Vulcanologia (INGV), Rome, Italy
Ocean Crust
Lithosphere
Asthenosphere
Mantle
Liquid Outer Core
Continental Crust
Melting
Mantle Convection Processes
De Santis & Geosystemics Res. Group, LAIC, AGILE 13th Scientific Workshop, 26 May 2015

Outline

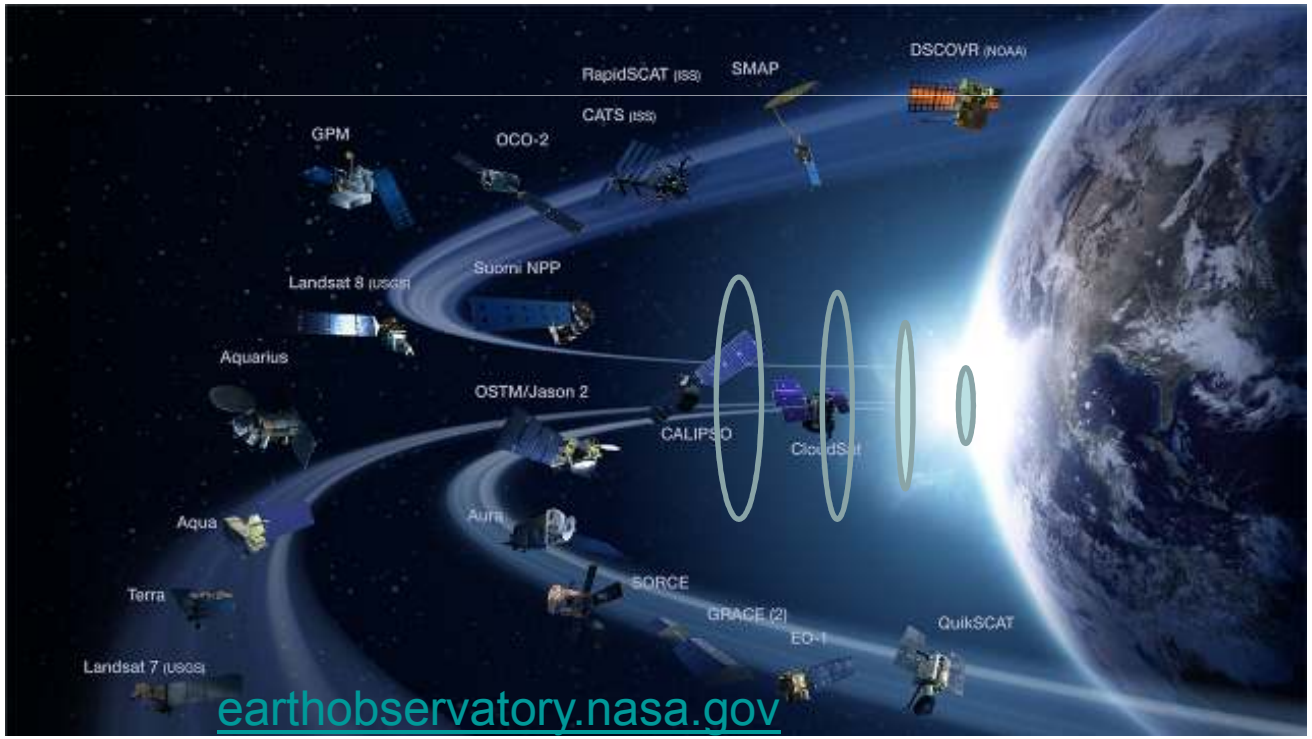
1. Why this presentation
2. What is an Earthquake (**EQ**)?
3. Litho-Atmo-Ionosphere Coupling (LAIC): An overview
4. Geosystemics: a multi-attack strategy to **EQ**
5. **EQ**s from space
6. LAIC Models
7. Present Satellite-based Projects
8. Conclusions

1. Why this presentation

Questions

1. Is there any Litho-Atmo-Ionosphere Coupling (LAIC) before large EQs?

2. If yes, can the LAIC effects be detected from space?



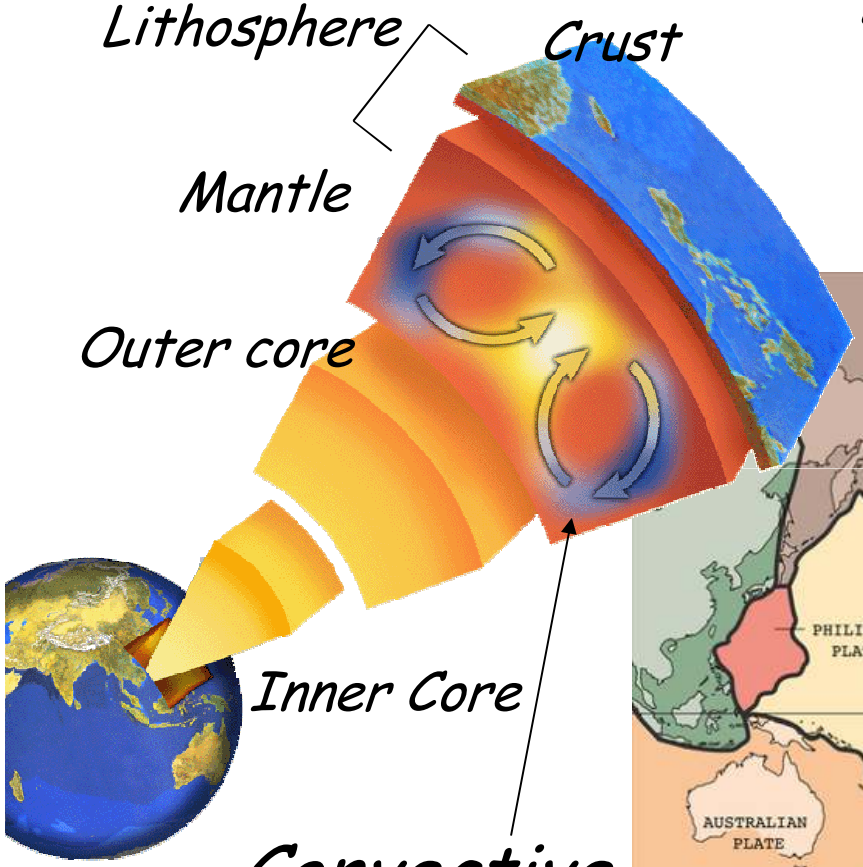
2. What is an EQ

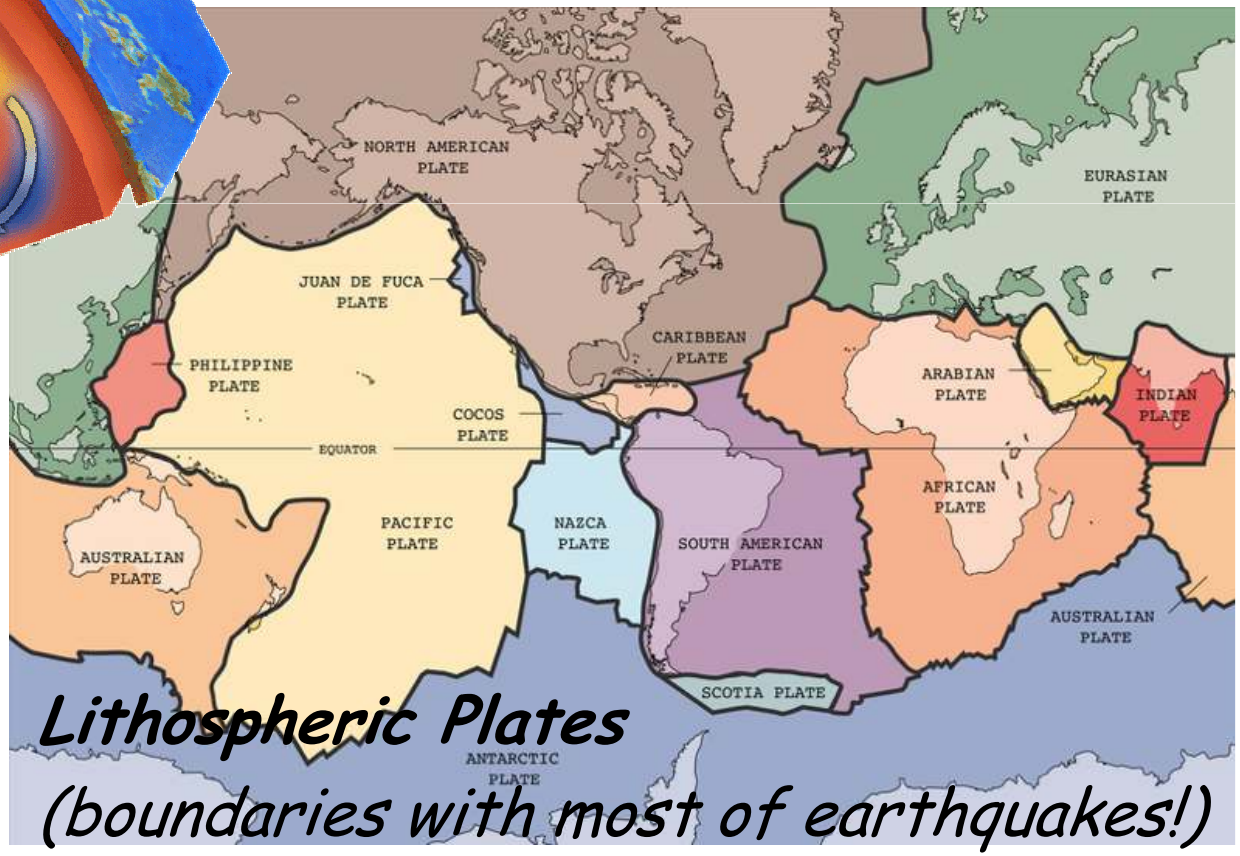
- ***Rapid Movement of the ground*** *caused by the rupture in the* ***lithosphere*** *(down to 700km depth)*
- *Expression of our planet* ***vitality*** *(Tectonics, rotation and heat by the Earth)*
- ***EQ is a Natural*** *Phenomenon:*

  " EQs do not kill people, buildings do!"

- ***Measure*** *of an EQ:* ***Magnitude*** *(real number, Richter) or* ***Intensity*** *(degrees from I to XII* ***Mercalli*** *scale)*

EQs are not random in space

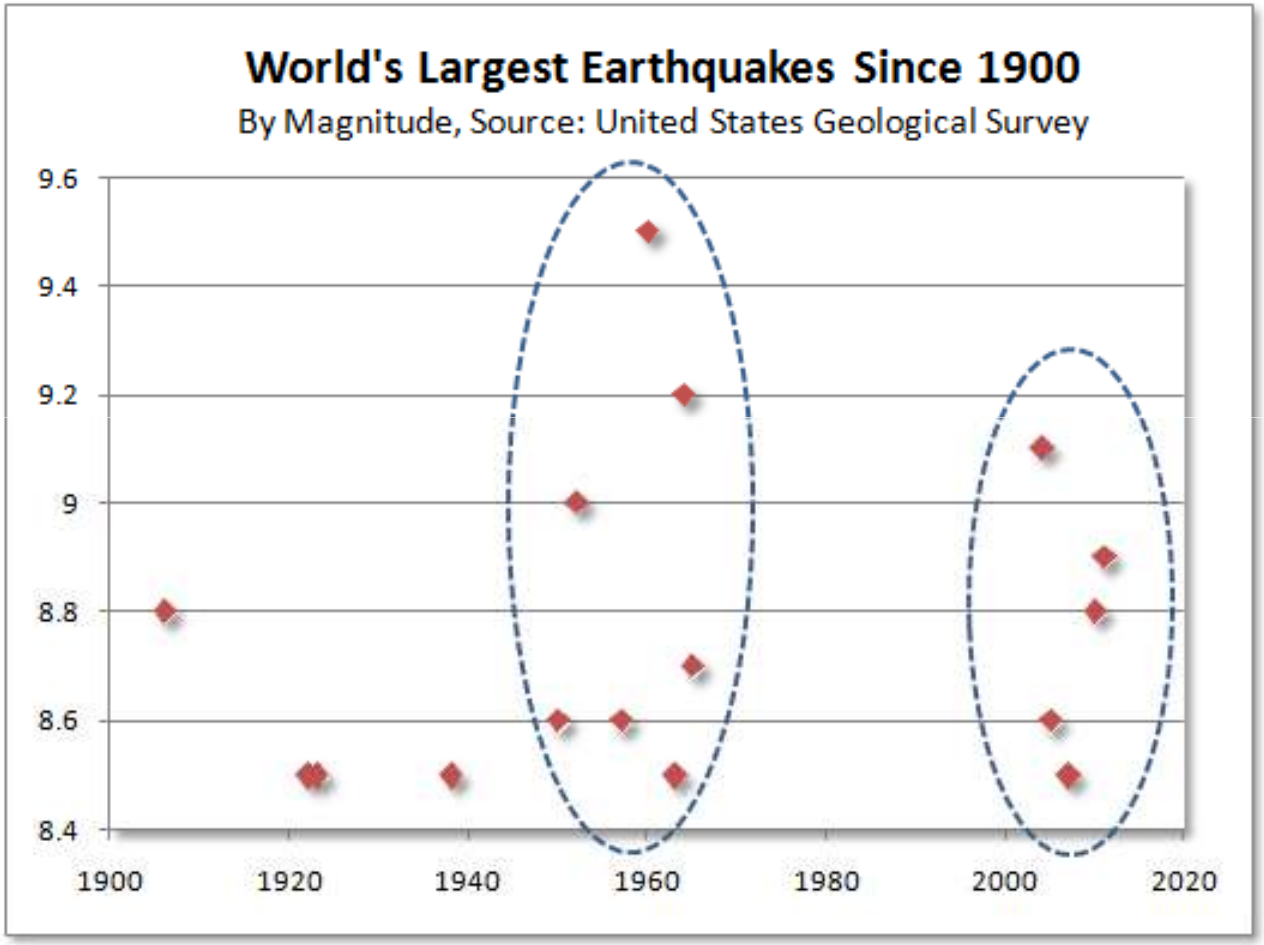




Lithospheric Plates

(boundaries with most of earthquakes!)

EQs are not random in time



Earthquakes occur in clusters

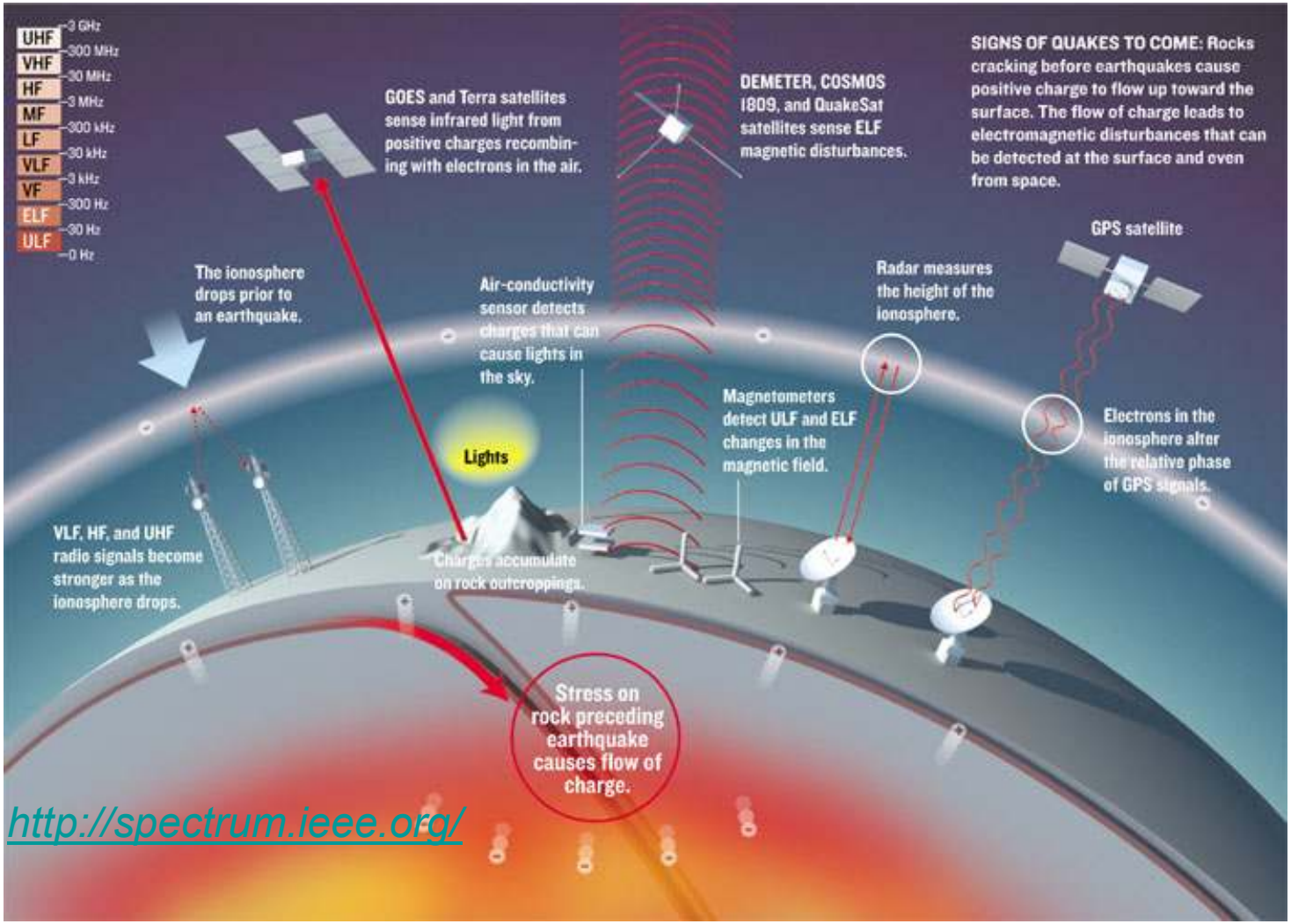
Deadliest EQs from 1900

2010 Haiti M7 300,000

	YEAR	LOCATION	MAGNITUDE	ESTIMATED DEATH TOLL
1	1976	Tangshan, China	7.5	255,000
2	1920	Gansu, China	8.6	200,000
3	1927	Qinghai, China	7.9	200,000
4	1923	Kanto, Japan	7.9	143,000
5	1948	Turkmenistan	7.3	110,000
6	1908	Messina, Italy	7.2	70,000
7	1932	Gansu, China	7.6	70,000
8	1970	Peru	7.9	66,000
9	1990	Iran	7.7	40,000
10	1935	Quetta, Pakistan	7.5	30,000

SOURCES: United States Geological Survey, Associated Press THE WASHINGTON POST

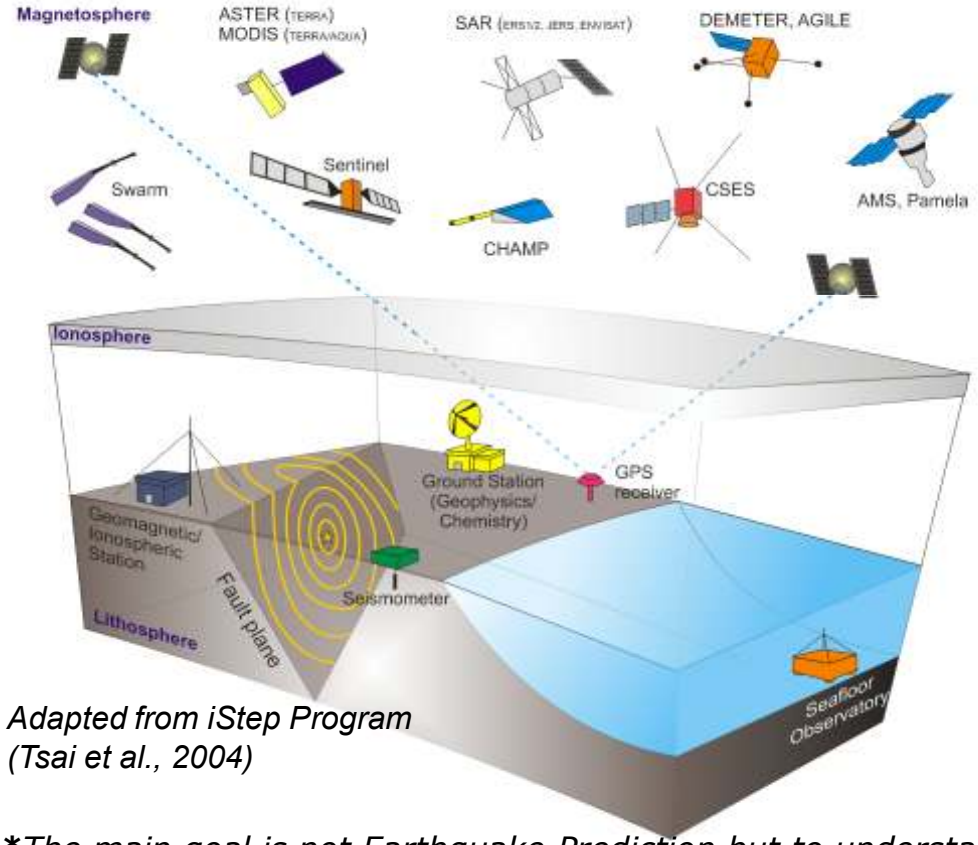
3. LAIC:
An Overview



http://spectrum.ieee.org/

4. Geosystemics: a Multi-attack strategy to EQ

Geosystemics *studies Earth system from the holistic point of view, looking with particular attention at self-regulation phenomena and relations among the parts composing Earth as approaching* ***a critical state*** *or persisting its* ***trend of evolution*** *(De Santis, 2009 & 2014) .*



Adapted from iStep Program (Tsai et al., 2004)

Patterns in the ***EQ preparation phase****

3. ***Ionospheric anomalies (short term)***

(from satellite or ionosondes or GPS networks)

- *ionospheric density*
- *em field*
- *TEC*

2. ***Atmospheric anomalies (short term)***

- *Thermal anomalies*
- *Clouds anomalies*

1. ***Seismic fore-patterns***

(from seismic and magnetic data)

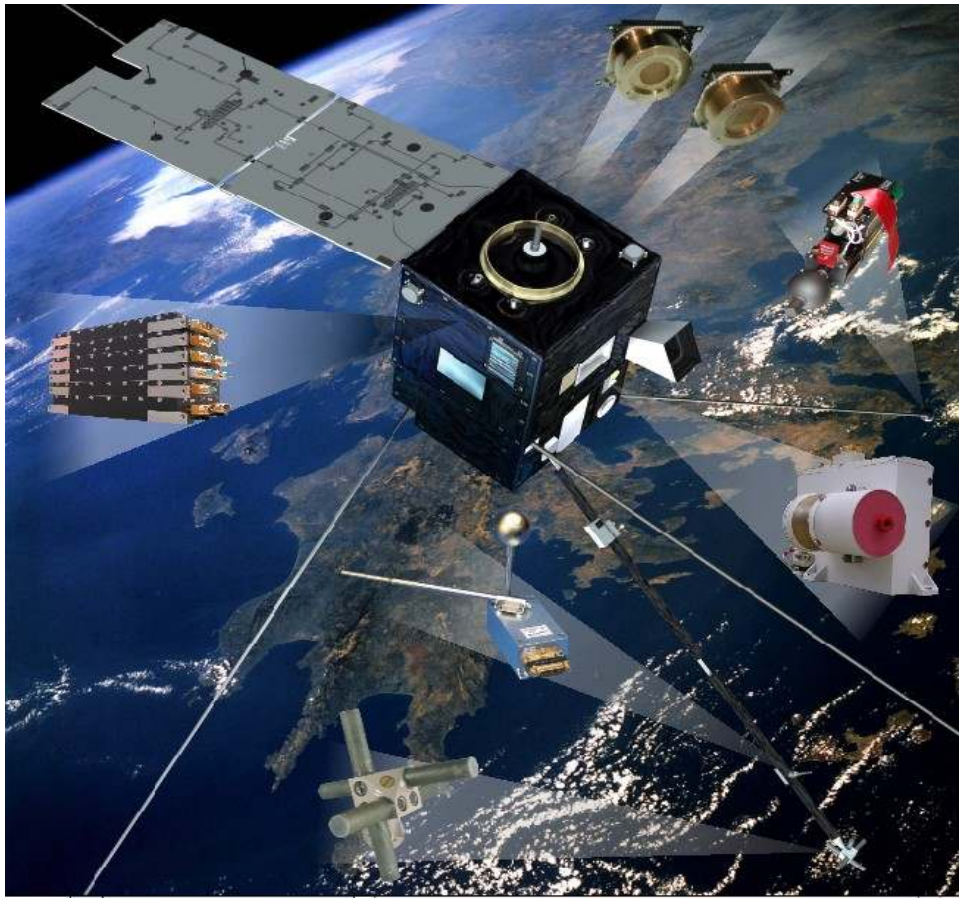
- *Acceleration* ***(interm. term)***
- *non linear pdf* ***(short term)***

******The main goal is not Earthquake Prediction but to understand* ***the process of earthquake preparation*** *and* ***geospheres coupling****.*

5.1 Study from space: Some studies from DEMETER

(**D**etection of **E**lectro-**M**agnetic **E**missions **T**ransmitted from **E**arthquake **R**egions) in orbit 2004-2010

Plasma Analyser



Electric sensor

Electronic module

Energetic Particle Analyser

Magnetic sensors

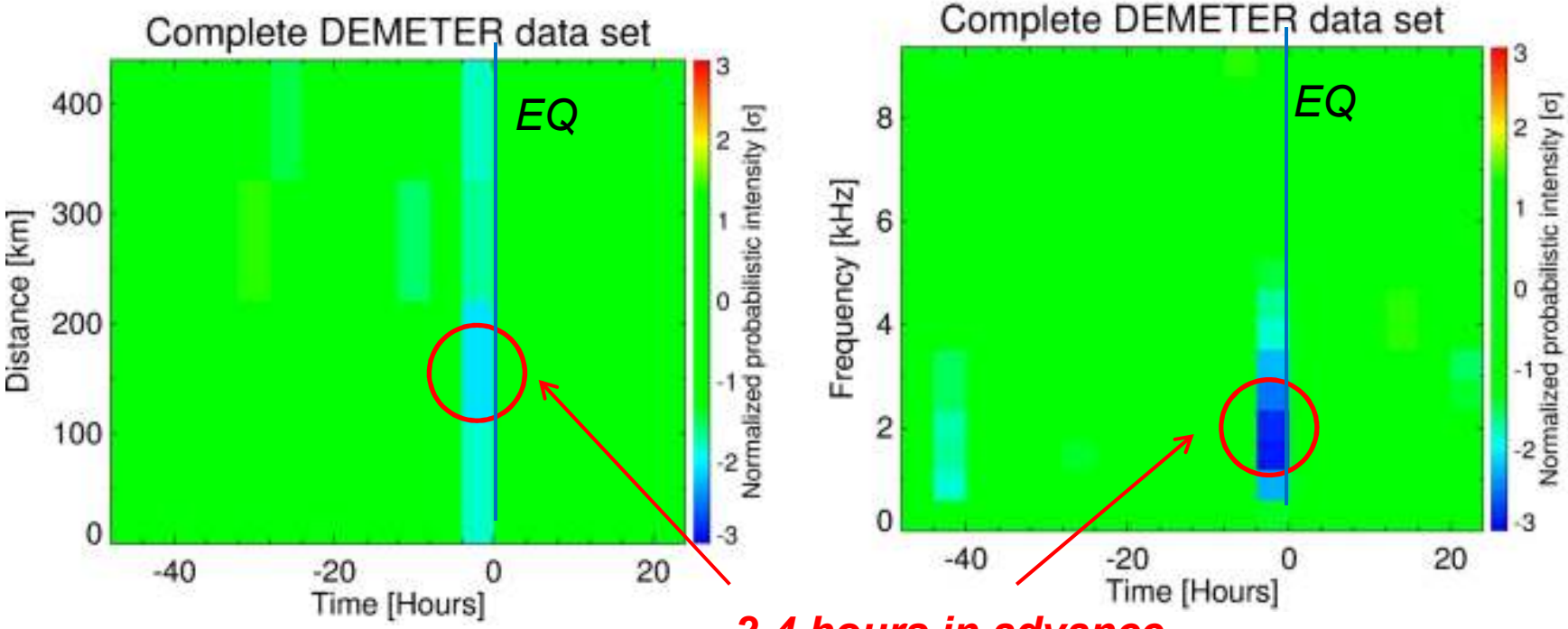
Langmuir probe

Courtesy of M. Parrot

5.1 Study from space: Statistical study from DEMETER

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

*Night time VLF Electric field **Attenuation** at ~1.7kHz*
*Method of the **Superimposed Epochs***



2-4 hours in advance

At a given frequency (~1.7kHz)

At a given distance (~ 150 km)

Pisa et al. (2012, 2013)

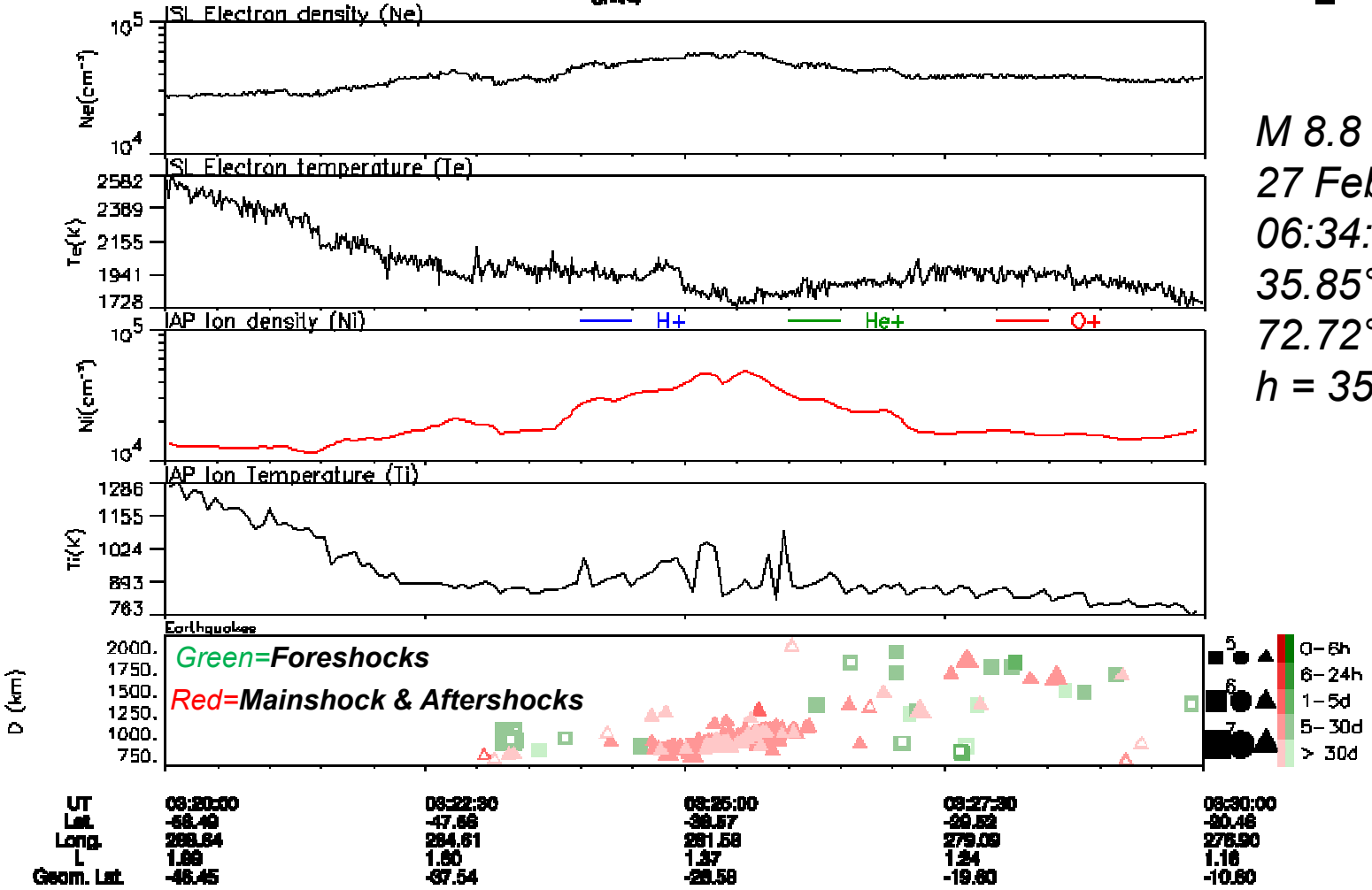
Geosystemics

17 days before the EQ

DEMETER

Date (y/m/d): 2010/02/10

Orbit: 30021_1



M 8.8 ***CHILI EQ***
27 Febr. 2010
06:34:14 UT
35.85°S
72.72°W
h = 35 km

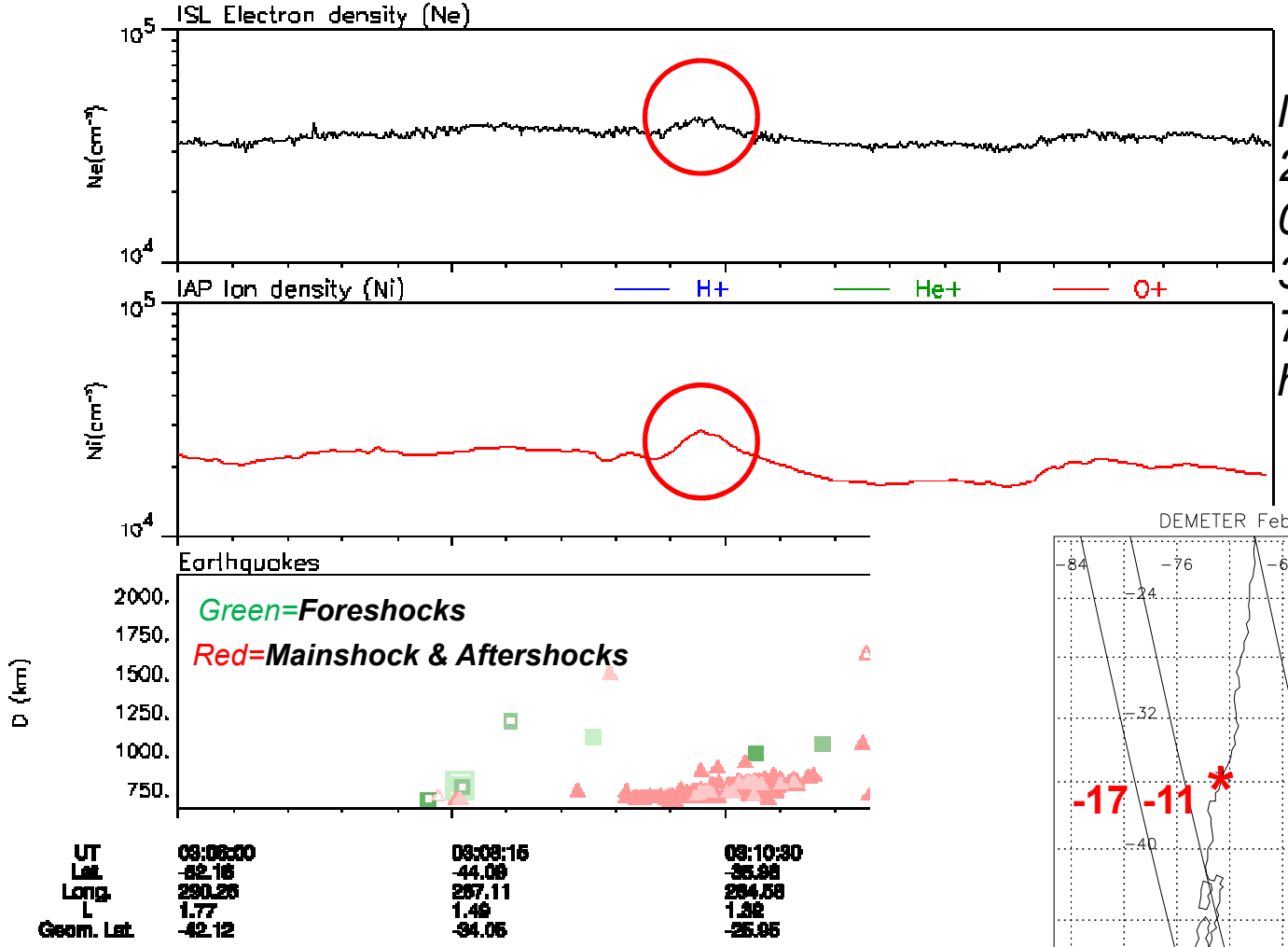
M. Parrot, Erice -2012

Geosystemics

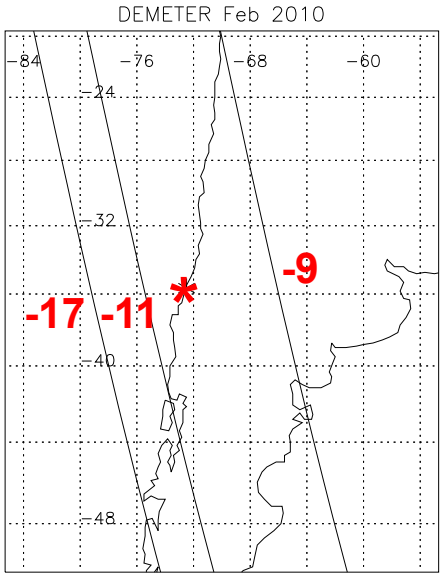
11 days before the EQ

DNEPR DEMETER CNES CNRS

DEMETER **Date (y/m/d): 2010/02/16** **Orbit: 30109_1**

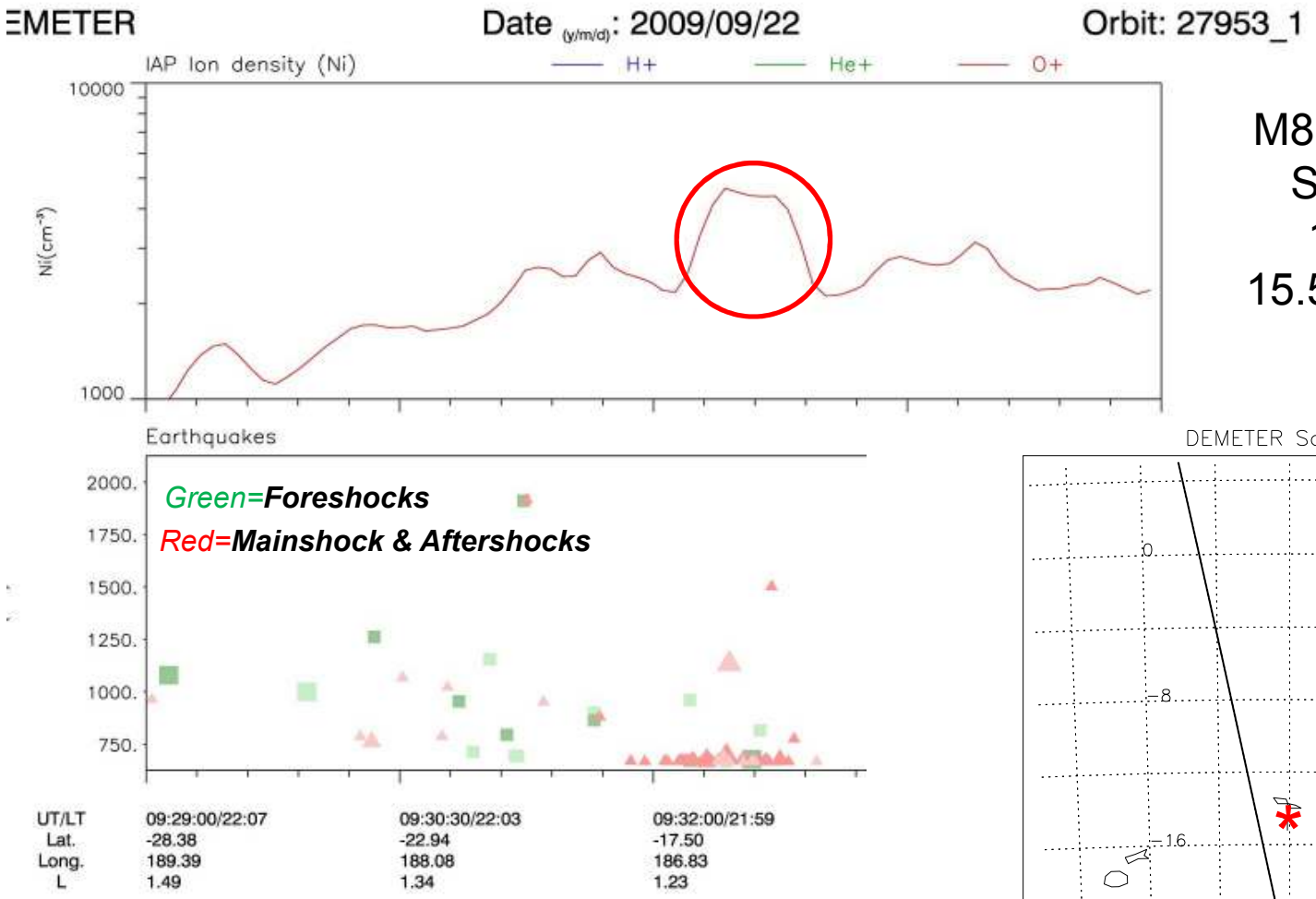


M 8.8 ***CHILI EQ***
27 Febr. 2010
06:34:14 UT
35.85°S
72.72°W
h = 35 km

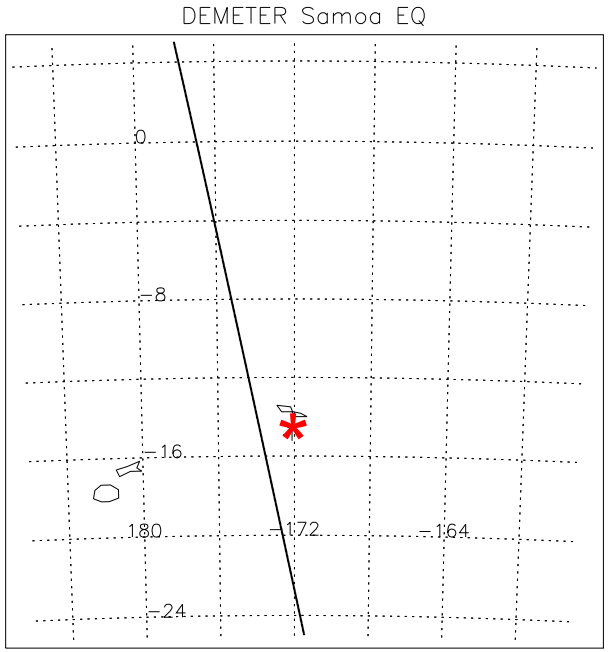


M. Parrot, Erice -2012

7 days before the EQ

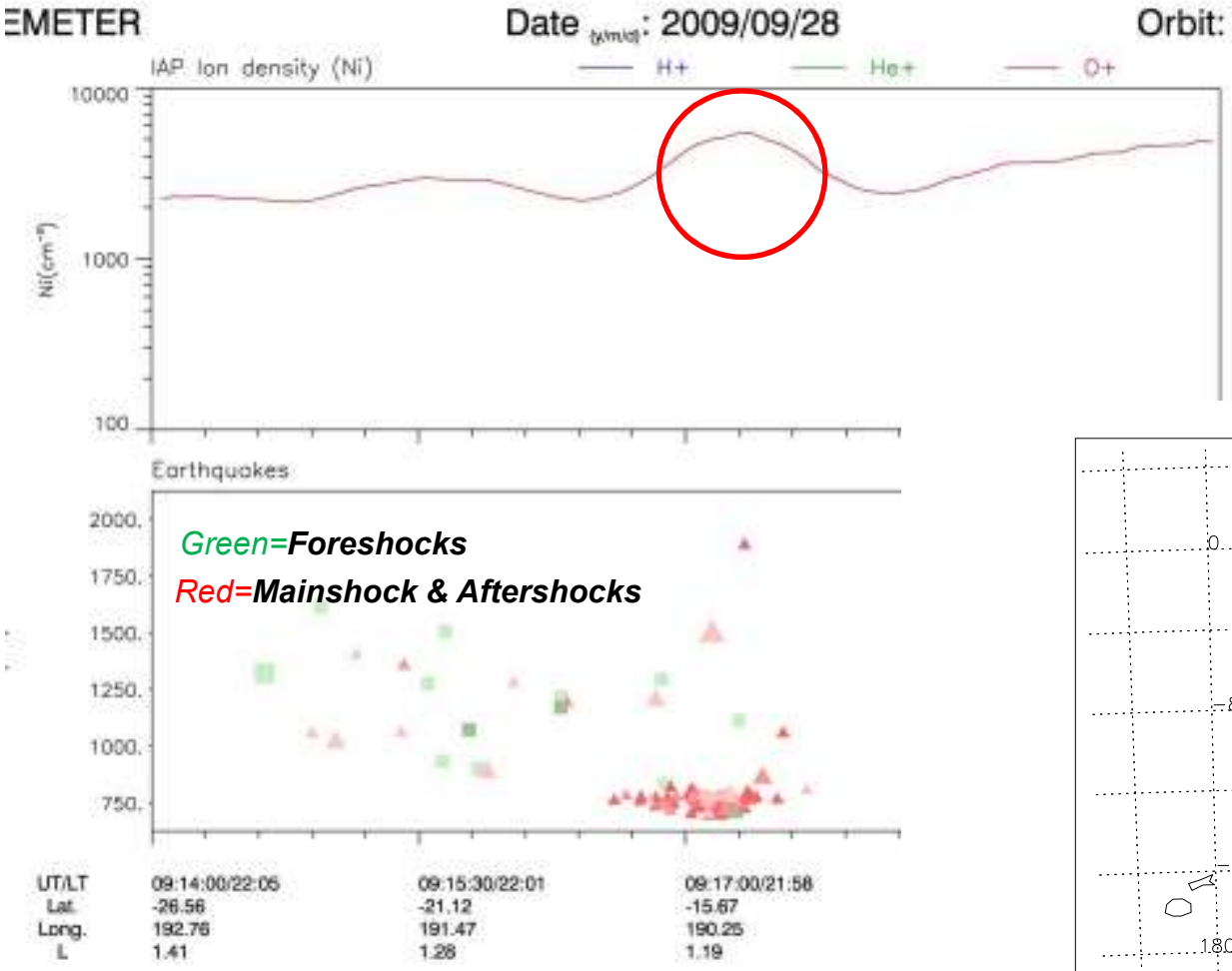


M8.1 **SAMOA EQ**
Sep. 29, 2009
17:48:11 UT
15.51°S 172.03°W
h=18km

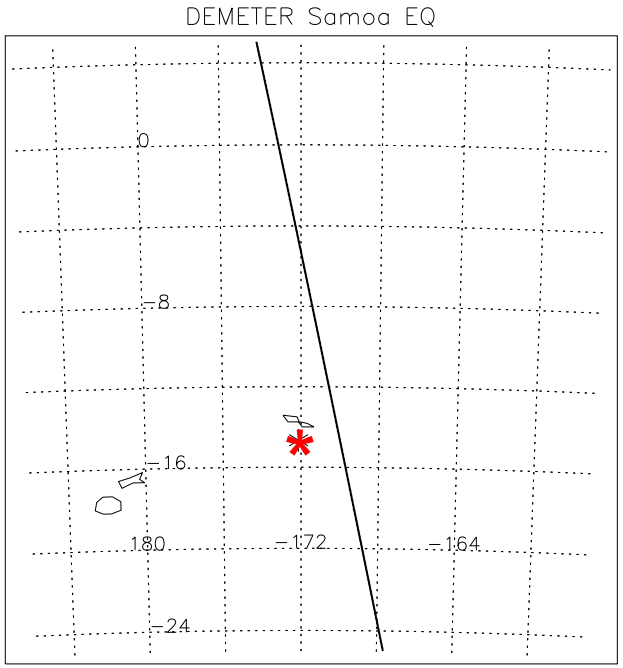


from M. Parrot, Rome - May 2014

1 day before the EQ

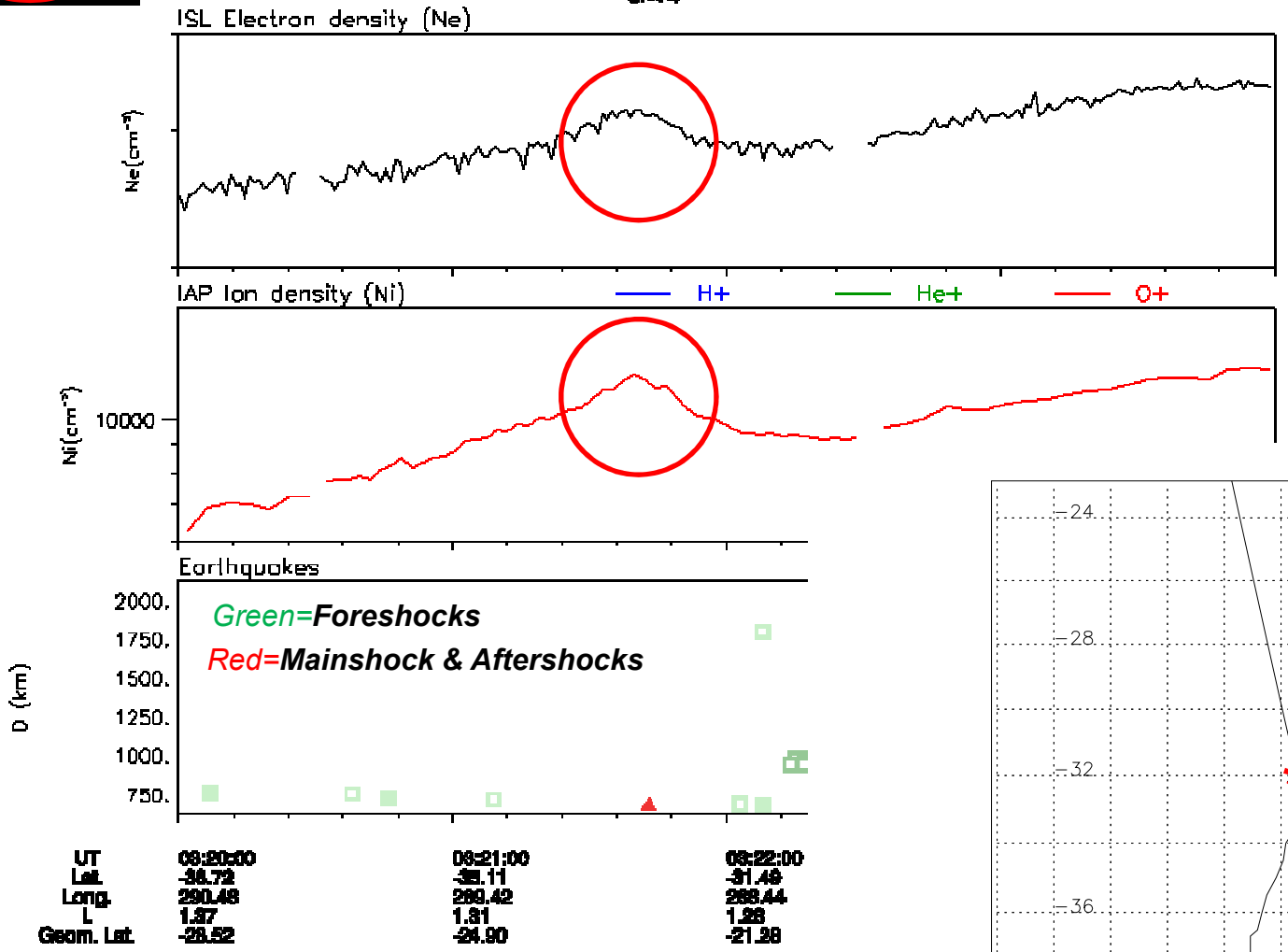


M8.1 **SAMOA EQ**
Sep. 29, 2009
17:48:11 UT
15.51°S 172.03°W
h=18km

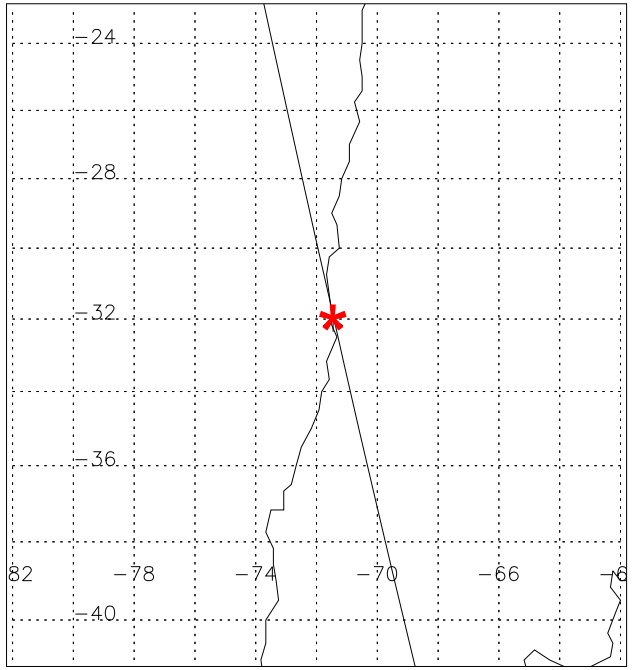


from M. Parrot, Rome - May 2014

A few hours before



M5.1 Feb. 10, 2006
17:51:54 UT
32.52°S 288.61°E

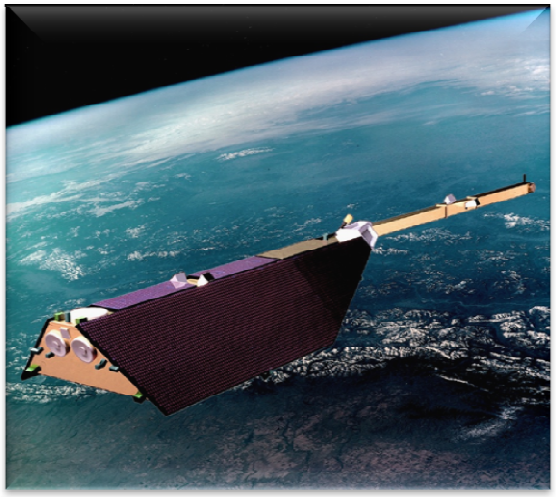


from M. Parrot, Rome - May 2014

5.2 Study from space: magnetic analyses

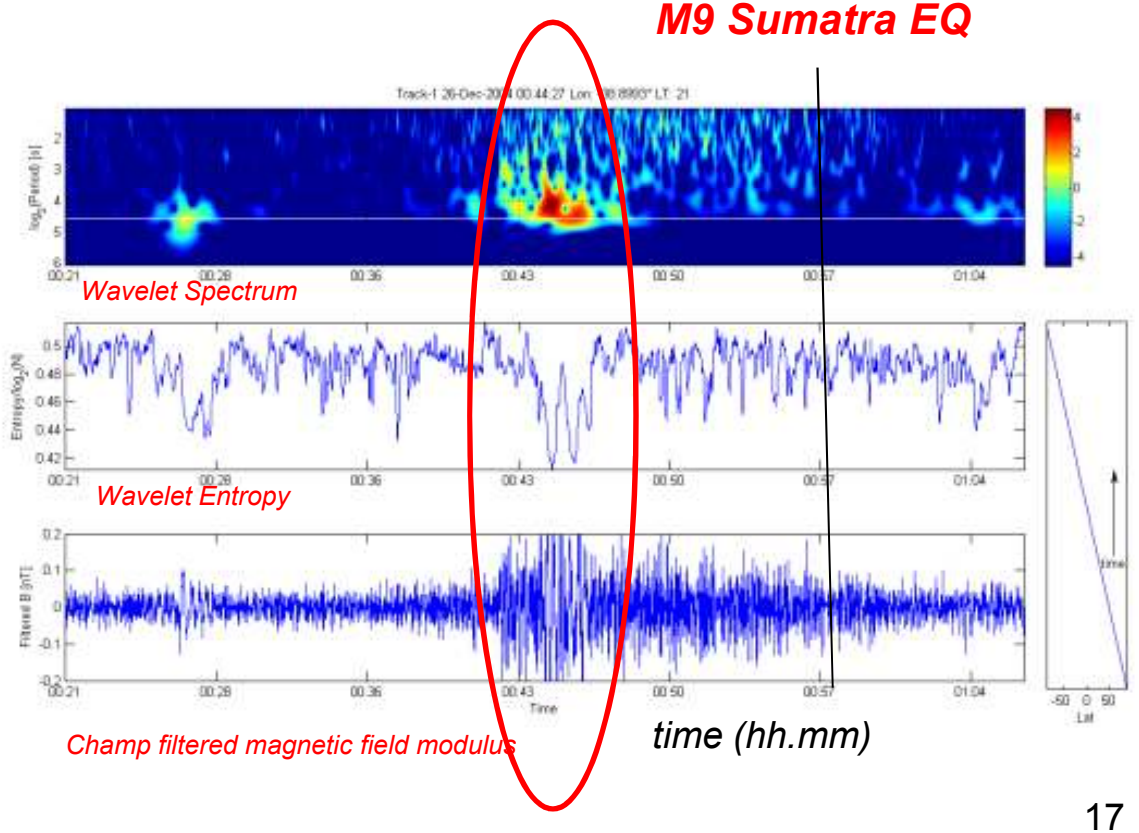
Wavelet Entropy of satellite magnetic data

The case of magnetic signal from CHAMP satellite (in orbit 2000-2010) →



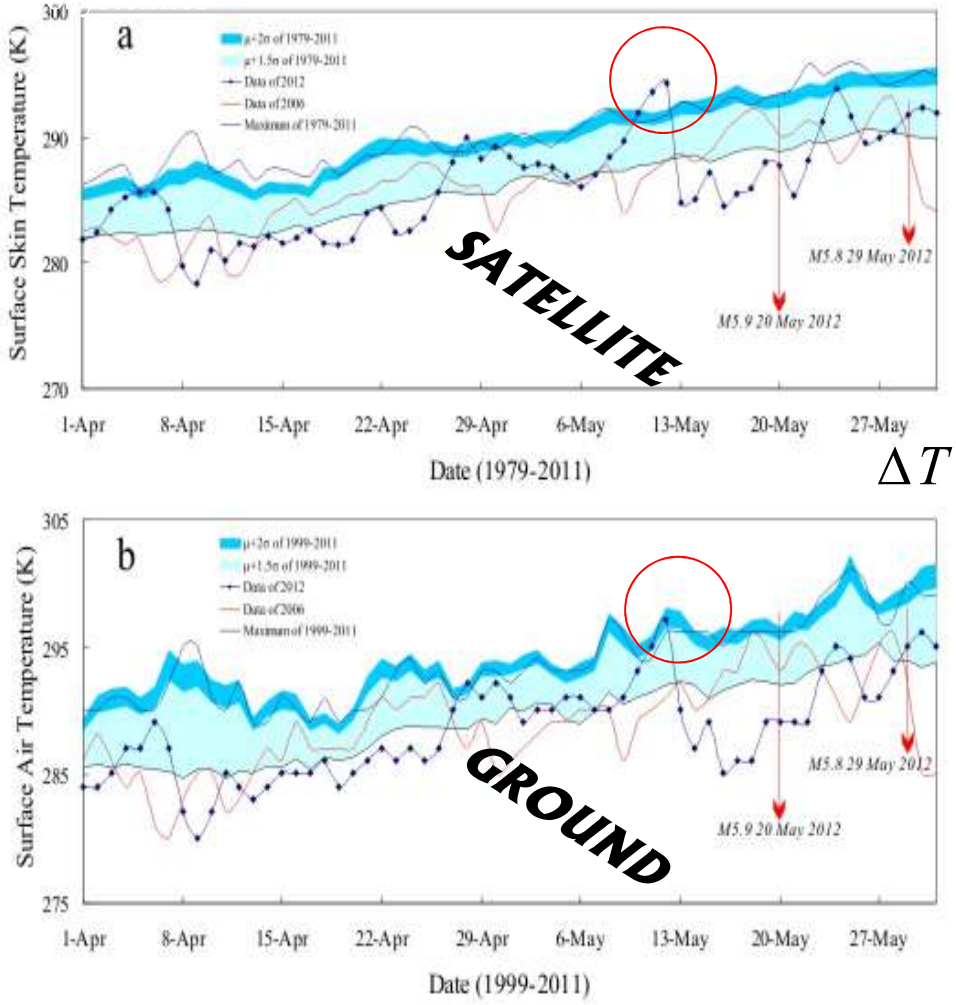
Cianchini et al.,IASME, 2009

26th Dec. 2004
M9 Sumatra EQ



5.3 Study from space (& ground): atmospheric analyses

Thermal anomalies before May 2012 M6 EMILIA (Italy) major earthquakes



DATA: *Modern Era Retrospective-analysis for Research and Applications (MERRA) of GEOS -5 (NASA) mainly from Aqua and Terra* ***satellites***

$$\Delta T(d)_{2012} = T(d)_{2012} - \frac{1}{n} \sum_{i=1979(1999)}^{2011} T(d)_i$$

$T(d)_i$ multiple years mean of daily temperature
$T(d)_{2012}$ daily temperature of the year of earthquake
n number of years (satellite: 33 years; ground 13 years)

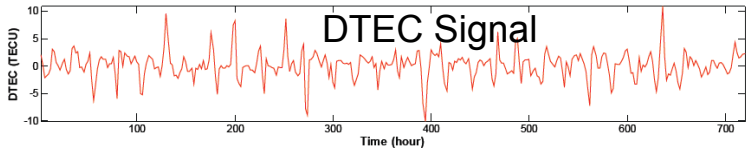
Qin et al., Annals Geoph., 2012

5.4 Study from space: ionospheric analyses

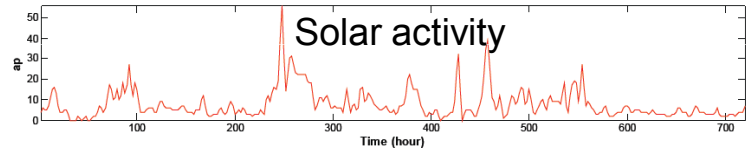
Total Electron Content (TEC): ***contrasting results for two Chinese EQs (because of Coversphere?)*** *(He et al. 2014)*

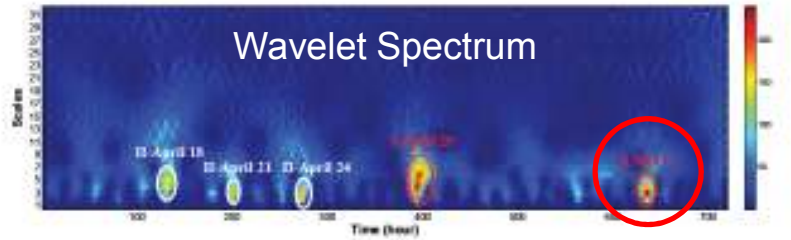
M8 Wenchuan 12 May 2008

(a)

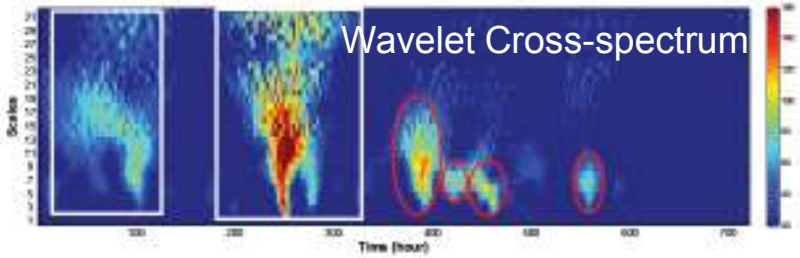


(b)



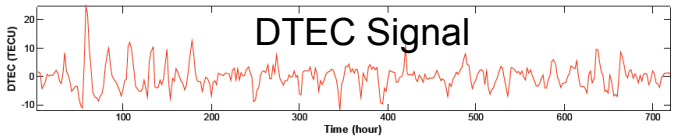


True

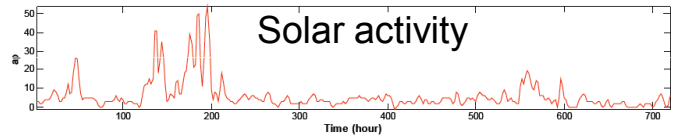


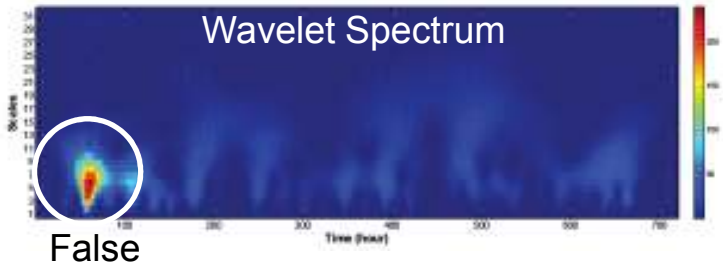
M7 Lushan 20 April 2013

(a)

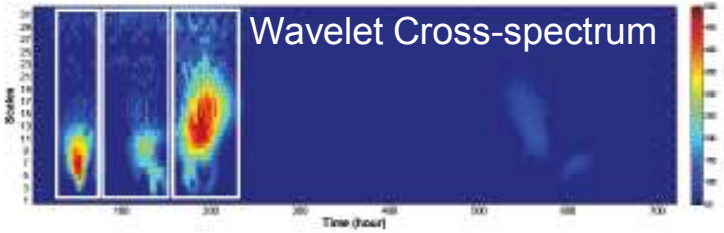


(b)





False

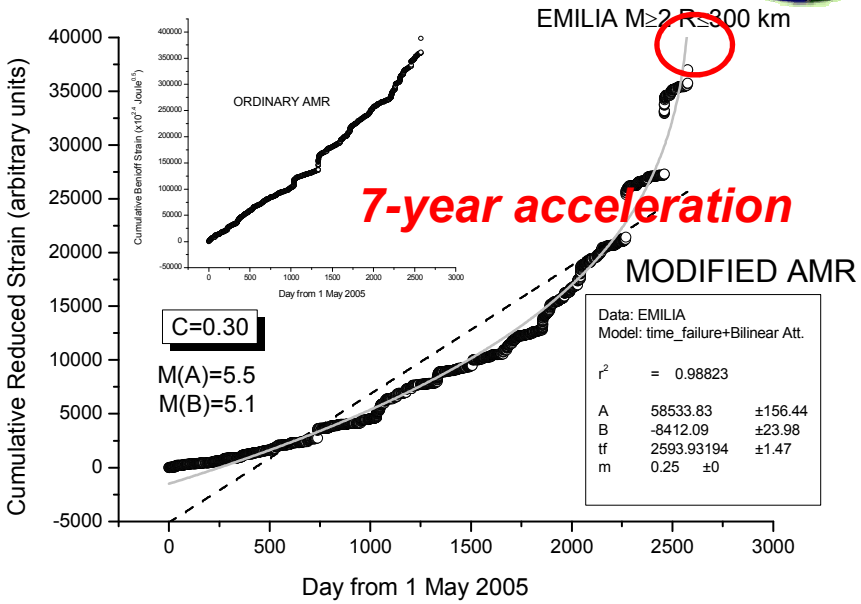


5.5 Study from ground: Two examples

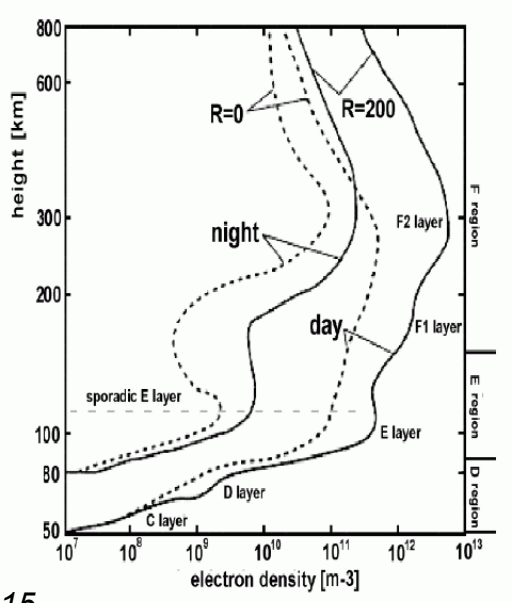
- Seismic Anomalies *identified by the modified Cumulative Benioff strain (De Santis et al., 2015)*

$$\tilde{s}(t\ ) = \sum_{i=1}^{N(t_i)} \sqrt{E_i} \cdot G(R_i) = 10^{\beta'} \sum_{i=1}^{N(t_i)} 10^{0.75 M_i} G(R_i)$$

EQ at the critical point
(power-law with infinite time derivative)



- Ionospheric EQ-related anomalies *detected by ionosondes when they satisfy 3 simultaneous conditions on Es & F2 layers.*
(Perrone et al., AG, 2010)

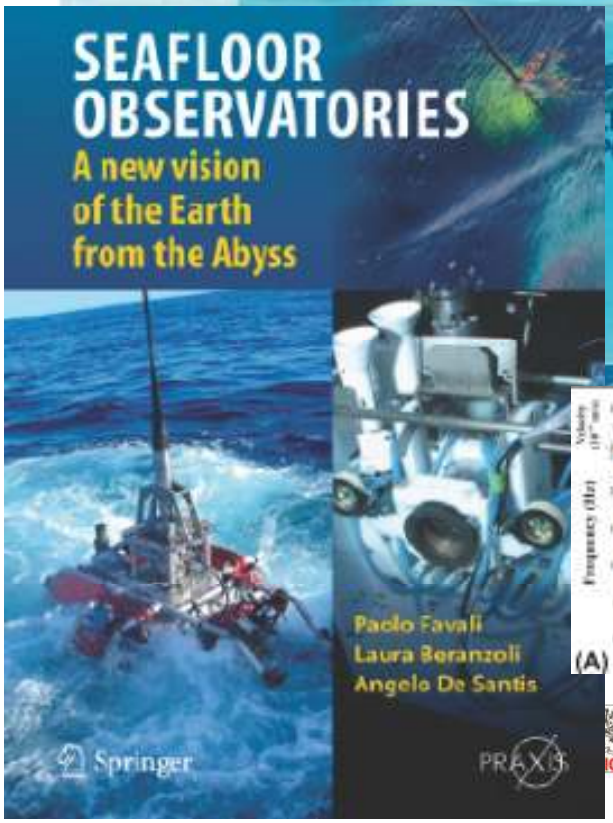


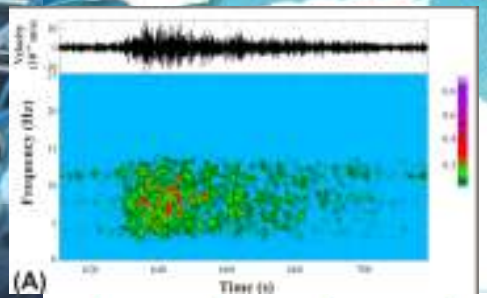
In Italy, period 1980-2009)
36% true alarms
64% false alarms

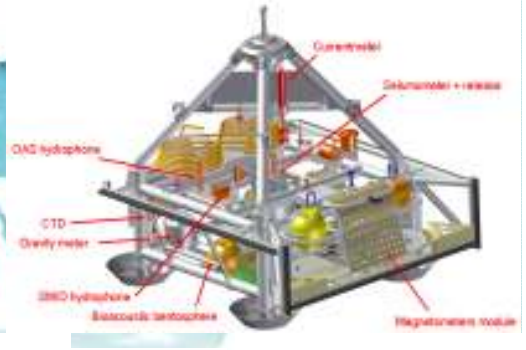
5.6 Study from seafloor: contribution by EMSO

EMSO

European Multidisciplinary Seafloor and Water-Column Observatory



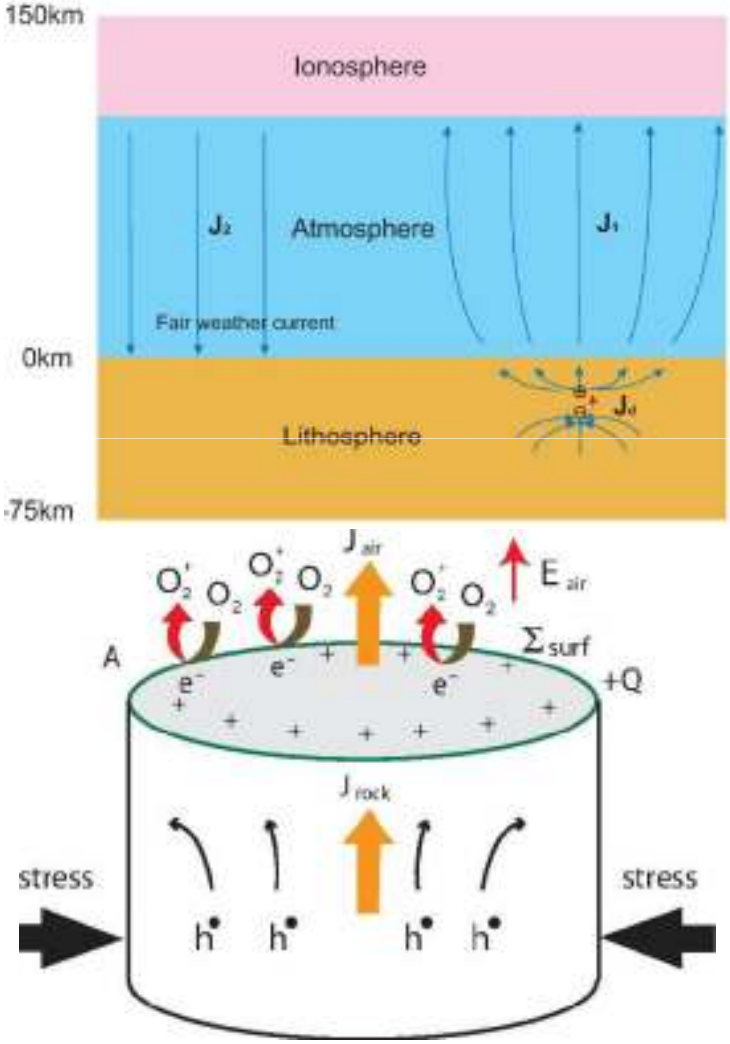




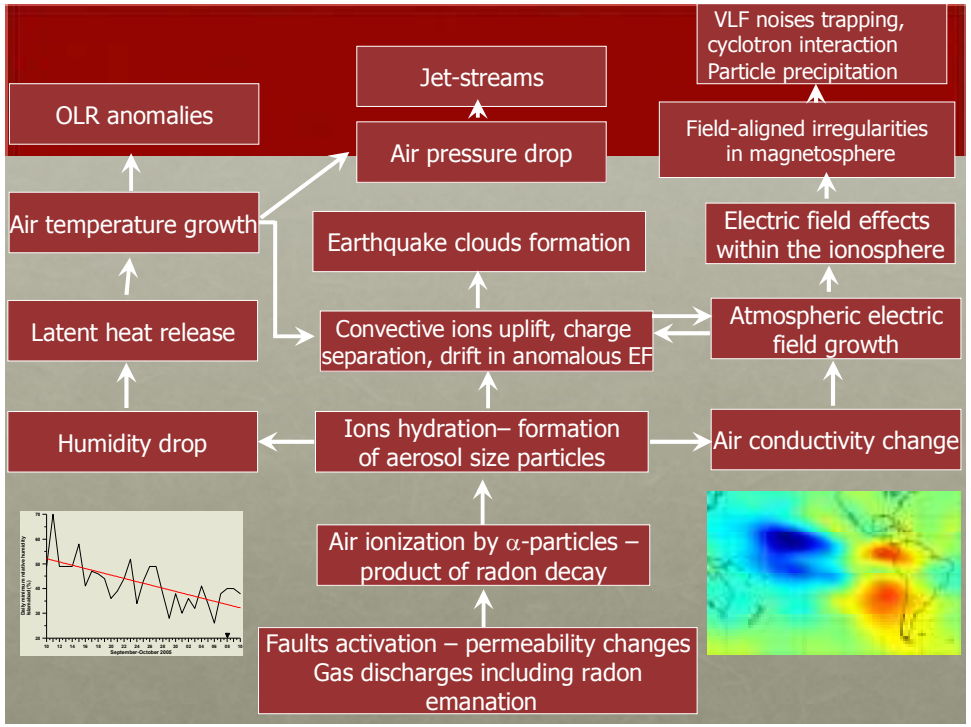
6. LAIC Models

Current Dynamos for LAIC coupling

1. *Dynamo from stressed rocks (Freund, JAES, 2011)*
2. *Dynamo from injection of radon and charged aerosols (Sorokin and Hayakawa, MAS 2013; Pulinets & Ouzounov, JAES 2011)*



Freund, 2011; Kuo et al., JGR 2014



Pulinets & Ouzounov, JAES 2011

6. LAIC: an alternative EM model

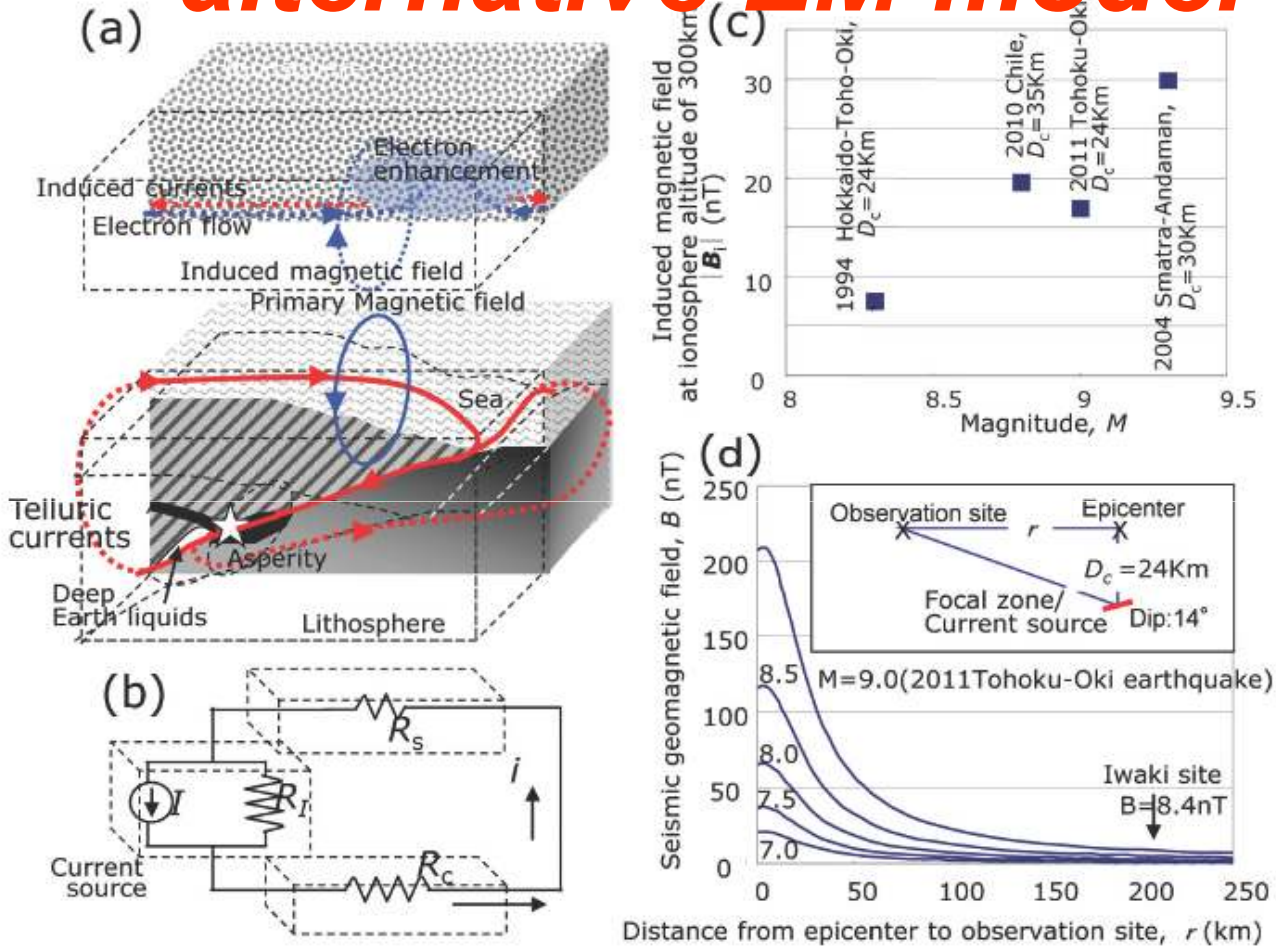


Figure 3. (a) Model of seismic L-I magnetic induction coupling for a strong offshore earthquake, (b) the equivalent electric circuit, and (c) the induc magnetic field at an F-layer altitude of 300 km caused by the seismic telluric current, as estimated using the present FEE model with $h = 100$ μm, for tl recent strong earthquakes. (d) The estimated seismic geo-magnetic field as a function of distance from the epicentre; FEE model, $D_c = 24$ km, dip = 14° ar $h = 100$ μm.

Attempt to explain why seafloor earthquakes show better seismo-em precursors (Enomoto, GJI, 2012)

7. Satellite-based Projects

SAFE – Swarm for EQ study

"Thus, em radiation significantly above the background noise prior to at least some EQs may be observable from space in carefully designed experiments." (Cicerone et al., 2009)

Swarm satellites

i. Three twin ESA satellites in quasi-polar orbits, appropriate combination of (em, particles & gps) sensors

ii. Satellite orbiting configuration: 2 satellites (460km) +1 satellite (510km)

The specific 3-satellite Swarm configuration is expected to favour discrimination between EQ-related and non-EQ-related anomalies

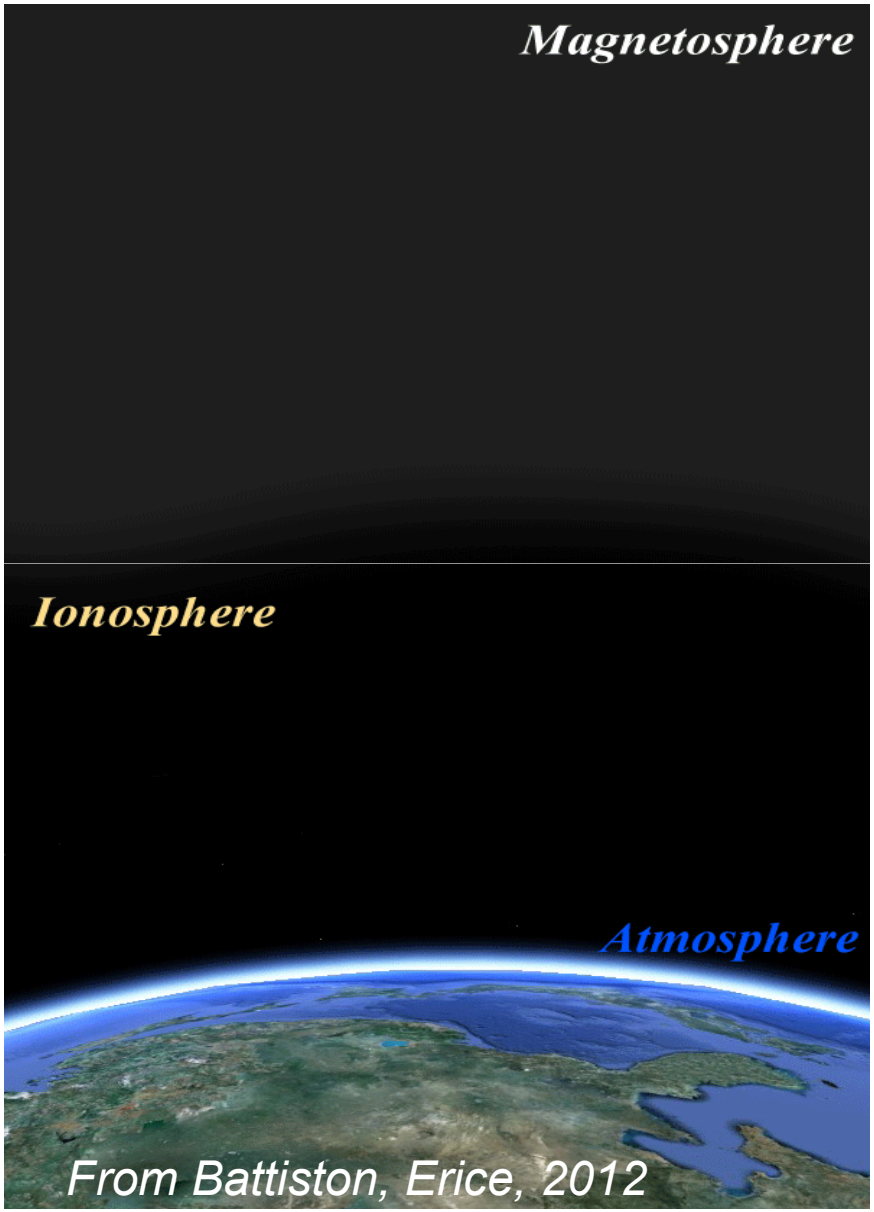
7. Satellite-based Projects

LIMADOU (MATTEO RICCI)
ITALY-CHINA PROJECT

CSES: Chinese Satellite FOR EM monitoring of possible lithosphere induced signals

INFN, ASI, UNIV. TRENTO, PERUGIA, TORVERGATA… &
CENTRE OF EARTHQUAKE ADMIN. (CHINA)
(with some little help from INGV)

Study of precipitation of energetic particles from the magnetosphere



8. Conclusions
Messages to take home

1. Earthquake Physics is **complex**

2. A **multi-attack** & **multi-community** strategy (multi-parameter and interdisciplinary approach) to the problem is fundamental → **Geosystemics**

3. LAI Coupling **exists** and it is possible to be detected by space (but with caution and together with ground data observations!)

4. However, we need to better **understand the physics** and identify the best model of **LAIC**

5. **Satellite** data analysis (e.g. SAFE esa-funded Project & LIMADOU… & AGILE?) will provide important insight

Thanks for your attention !

9. Selected Recent References by Geosystemics Group

Cianchini G., De Santis A., D. R. Barraclough, L. X. Wu, and K. Qin, Magnetic transfer function entropy and the 2009 Mw = 6.3 L'Aquila earthquake (Central Italy), Nonlin. Processes Geophys., 19, 2012, pp. 401-409, doi:10.5194/npg-19-401-2012.

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