Studying seismic events from ground and space

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Outline

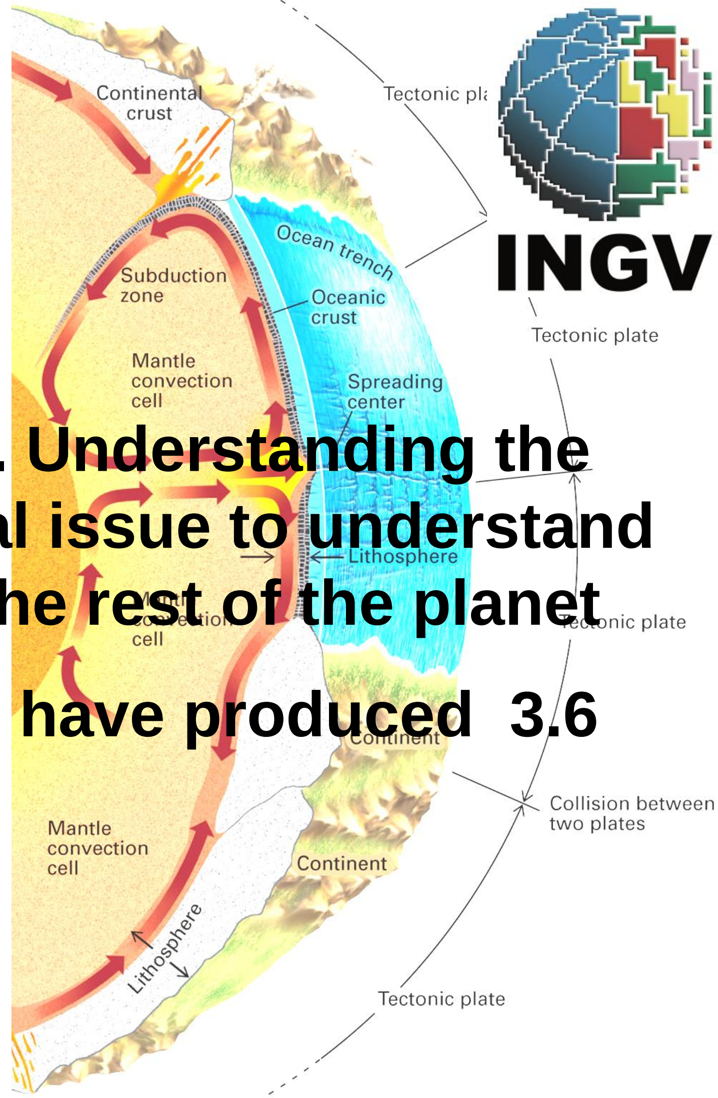
1. Why this talk
2. Earthquake Laws
3. Forecast vs. prediction
4. Geosystemics:
   a multi-attack strategy
5. Earthquakes from ground
   to space
6. LAI coupling Models
7. Conclusions

1. Why this talk

o. EE Project will deal with this topic

i. For Science: Lithosphere is complex. Understanding the Earthquake process is a fundamental issue to understand lithosphere and its interaction with the rest of the planet

ii. For the Society: Earthquakes effects have produced 3.6 Million deaths in the last century



Understanding the Earthquake Process (and its eventual forecast) is one of the greatest challenges of science

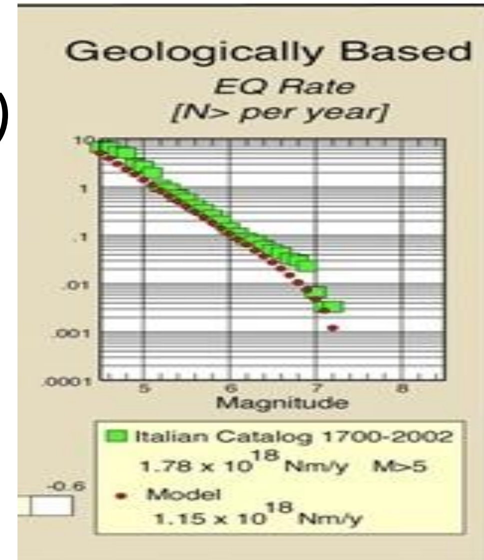
Geosystemics

2. Earthquake laws

INGV

2.1 Gutenberg-Richter Law (1944)

N earthquakes in a given region follows an exponential law of M: $\log N = a - bM$ $(b \cong 1)$



2.2 Omori –Utsu Law (1894; 1961):

Inverse power law of the aftershocks rate

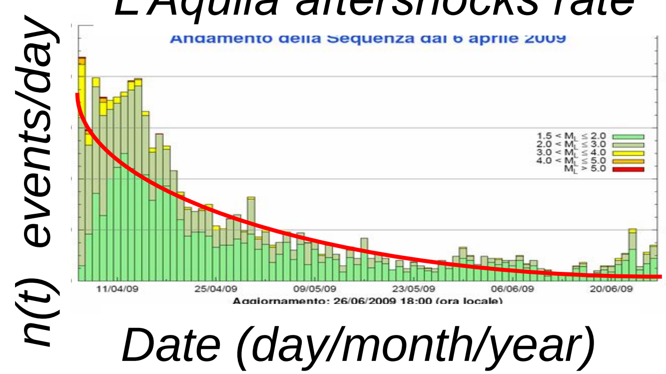
$n(t) = K/(c+t)^p$ with $p \cong 1$

2.3 Båth Law (1965):

$\Delta M = M_{main} - maxM_{after} \cong 1.2 \pm 0.2$

For 2009 M6.2 L'Aquila Eq.: $\Delta M = 1.0$

L'Aquila aftershocks rate



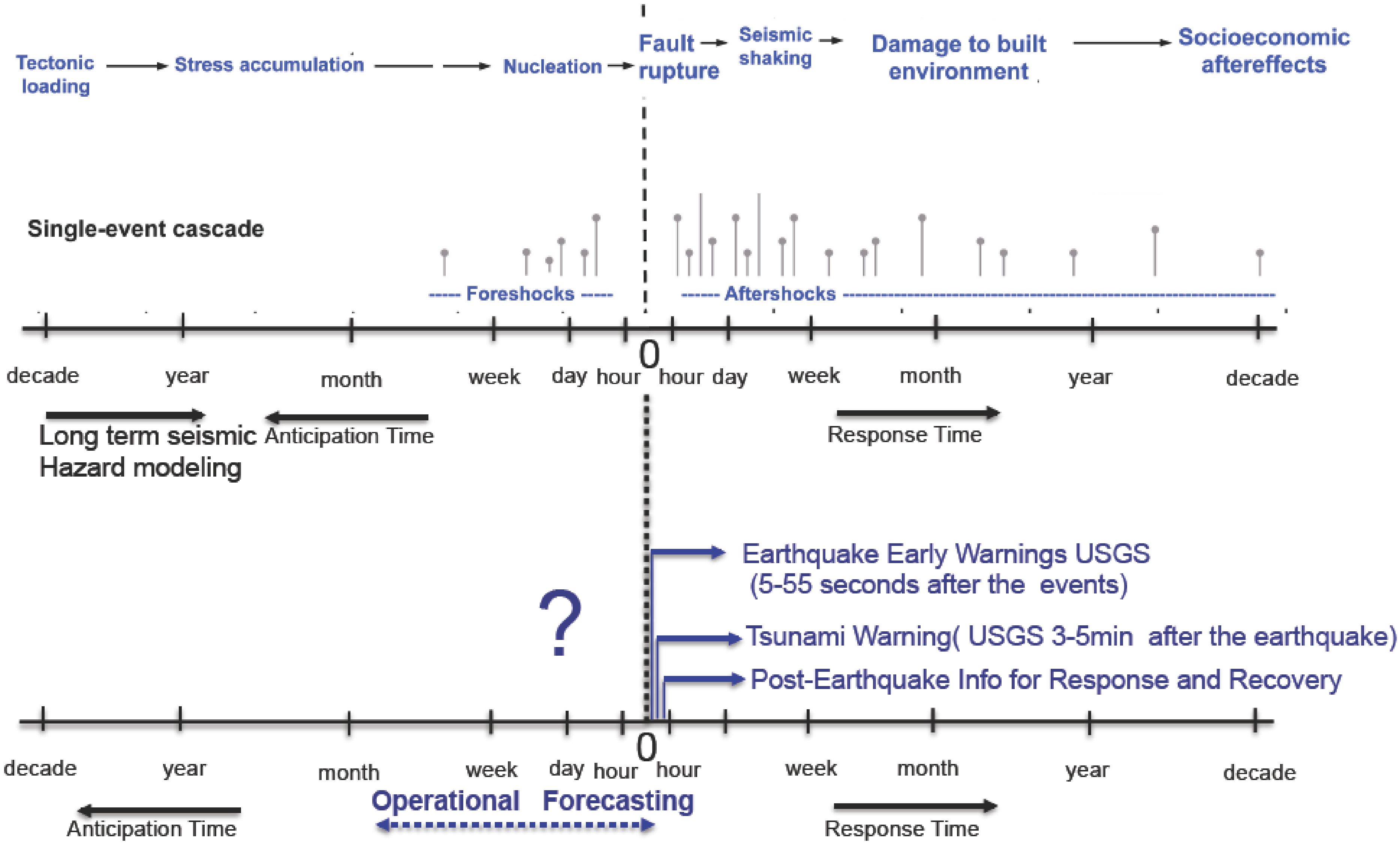
2.4 Felzer & Brodsky (2006):

Inverse power law of the probability for an aftershock at distance r from mainshock epicenter

$P(r) = K/r^s$ with $s \cong 1.4$-1.8

Earthquakes progress as chain reactions

Jordan, 2011; Ouzounov, 2013



Earthquakes progress as chain reactions

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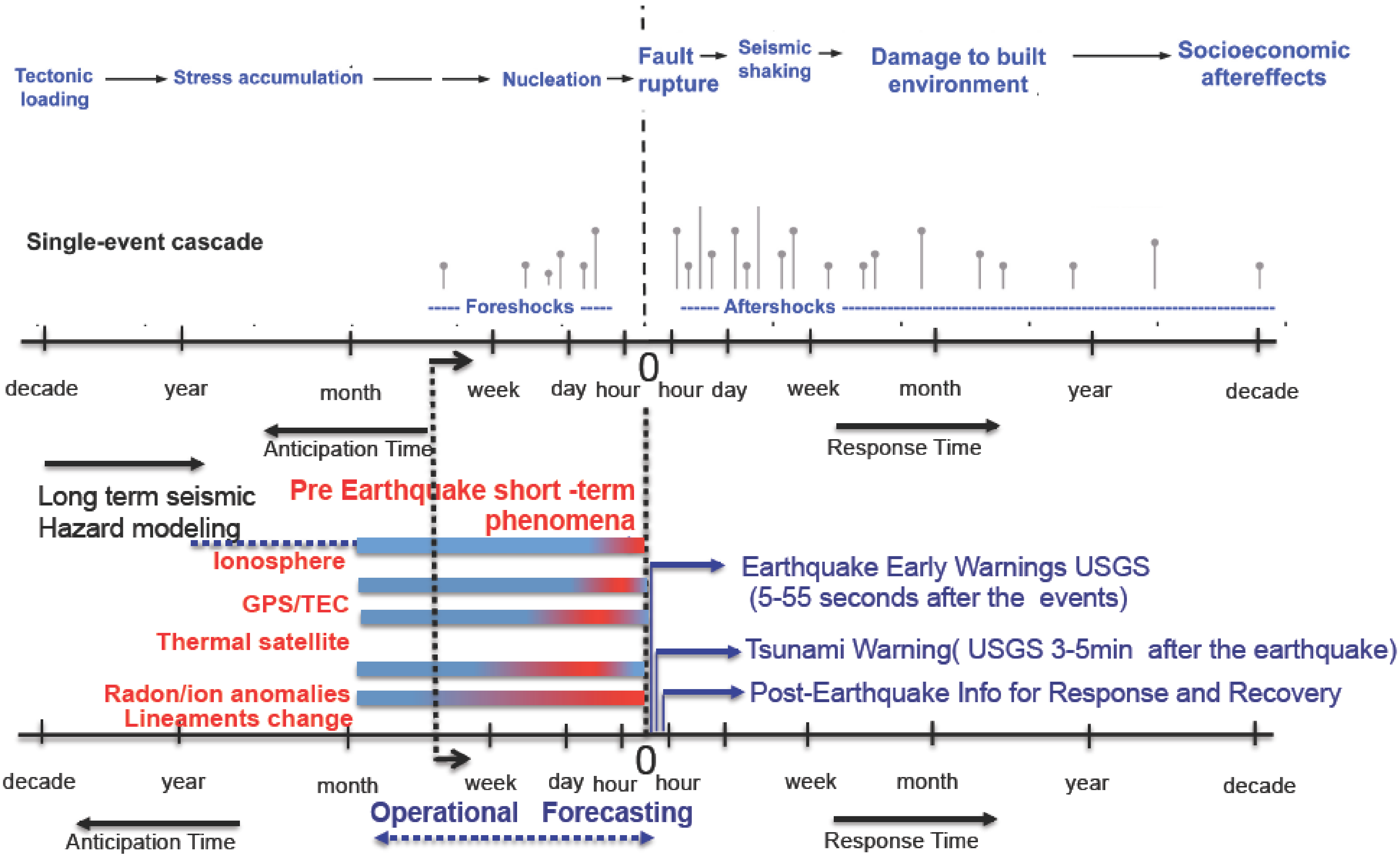
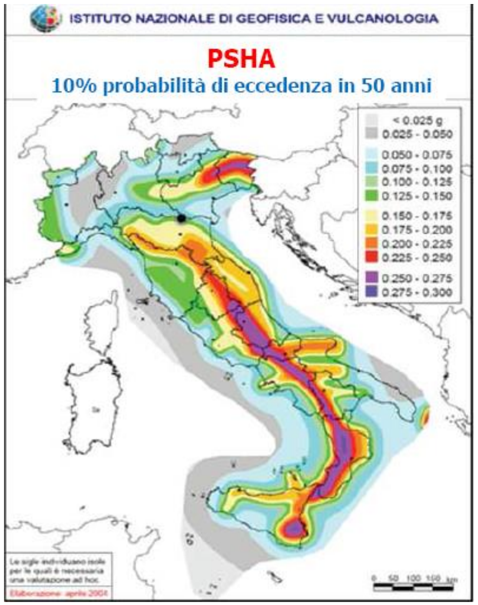
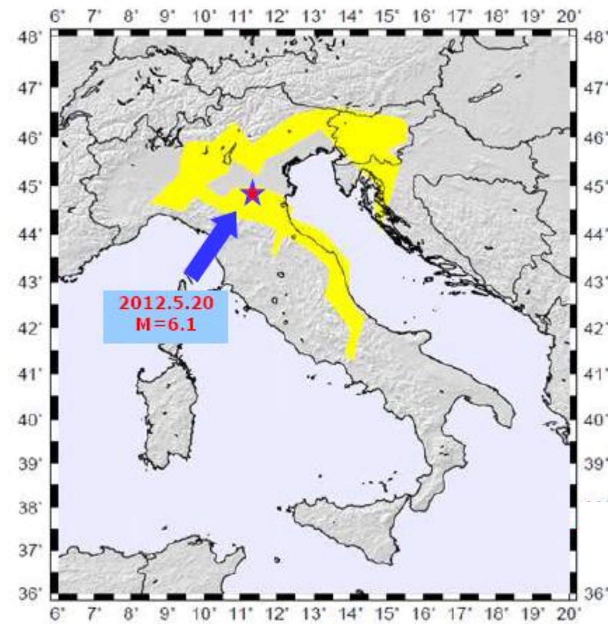


3. Probabilistic Forecasting vs. Deterministic Prediction

• *An **earthquake forecast** gives a probability that a target event will occur within a space-time domain*



Probabilistic Hazard Map for Italy (INGV, 2004)



Alarm for Italy M ≥ 5.5, 1 Mar – 30 Jun 2012 (Peresan, 2013)

• *An **earthquake prediction** is a deterministic statement that a target event will occur within a space-time domain*

E.g.: CN Algorithm (Keilis-Borok & Rotwain, 1990): First adaption of M8 Algorithm to California & Nevada

Probabilistic Forecasting

"Brick-by-Brick Approach"

- ***Statistical models***

– *Time-independent stationary Poisson process*
– *Long-term Reid renewal process*
– *Short-term Omori-Utsu clustering process*

- ***Physics-based models***

– *Tectonic fault loading, earthquake nucleation, slip-mediated stress transfer, rupture radiation damping*

Forecasting Time Scales *(Tom Jordan, SCEC, Monterey CA,2011)*

Long-term (centuries to decades)	Medium-term (years to months)	Short-term (weeks to minutes)
Probabilistic Seismic Hazard Analysis (PSHA)	⟷	***Operational Earthquake Forecasting (OEF)***
"Seismic Climate Forecasting"		***"Seismic Weather Forecasting"***

Deterministic Prediction

"Silver Bullet Approach"

A precursory change is diagnostic if it can predict the location, time, and magnitude of an impending event with high probability and low error rates (false alarms and failures-to-predict) *(Jordan et al., AoG, 2011)*

Proposed methods include:

– ***foreshocks & seismicity patterns***
– ***strain-rate acceleration***
– ***electromagnetic precursors***
– ***thermal anomalies***

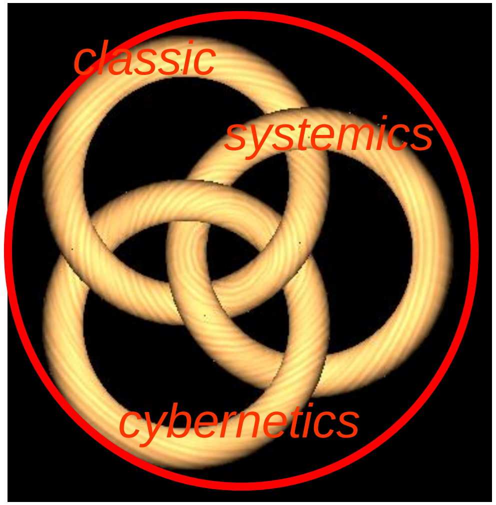
– *ground deformation*
– *material property changes*
– *hydrologic changes*
– *geochemical signals*
– *animal behavior*

4.1 Geosystemics

Geosystemics is a trans-disciplinary approach that consists of integrating the knowledge from "classic" disciplines
MATHEMATICS, PHYSICS (GEOPHYSICS), CHEMISTRY (GEO CHEMISTRY), BIOLOGY, GEOLOGY, INFORMATICS (GEOINFORMATICS)
with more recent disciplines such as SYSTEMICS[1] and CYBERNETICS[2]

[1] *Systemics is the science of complex systems studied from a holistic point of view (in their wholeness) (e.g. Klir, 1991).*
[2] *Cybernetics is the science that studies phenomena of self-regulations and communications among natural and artificial systems (Wiener, 1948).*

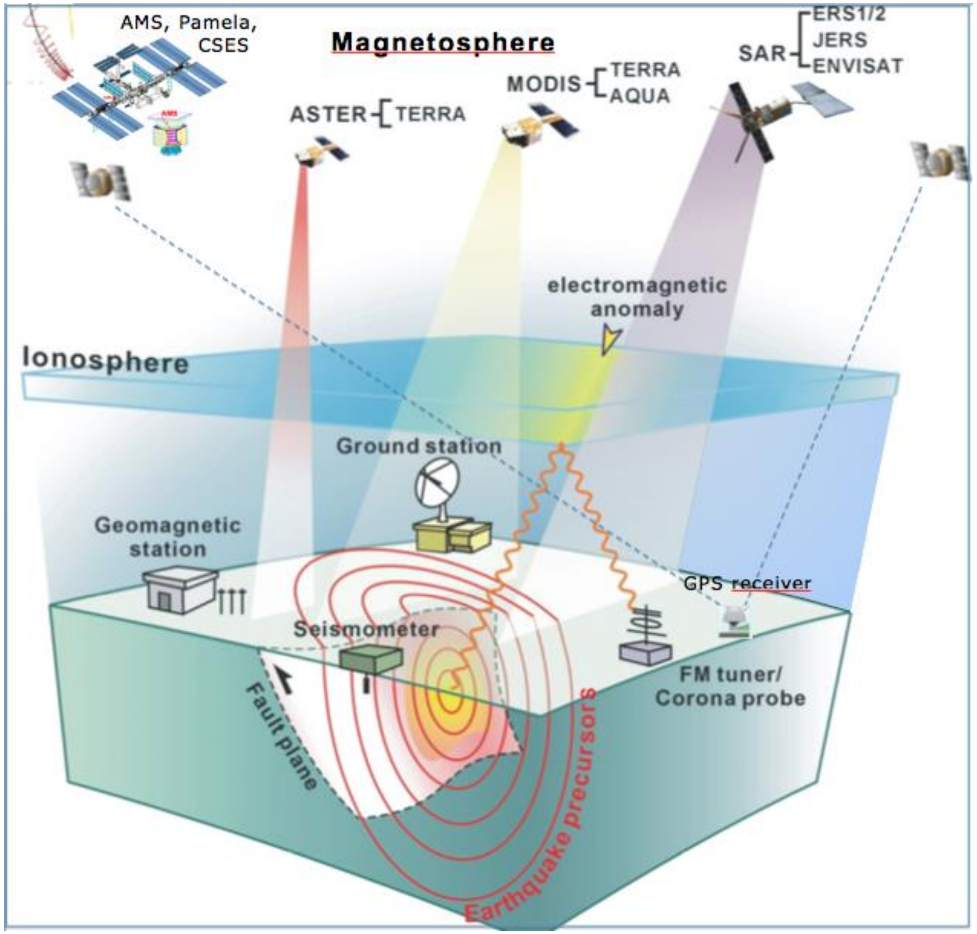
***Geosystemics** studies Earth system from the holistic point of view, looking with particular attention at self-regulation phenomena and relations among the parts composing Earth (De Santis, WSEAS, 2009 & NATO Book, 2014*) as approaching **a critical state** or persisting its **trend of evolution**.*



Importance of ***<u>Universal Tools</u>*** *(e.g. fractal dimension, phase space, degrees of freedom,* ***information and entropy) & <u>Multi-attack strategy</u> (Multi-scale/parameter/platform observations)***.

* ***Blue References*** *are by the Geosystemics Group*

4.2 Multi-attack strategy



Patterns in the earthquake 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*

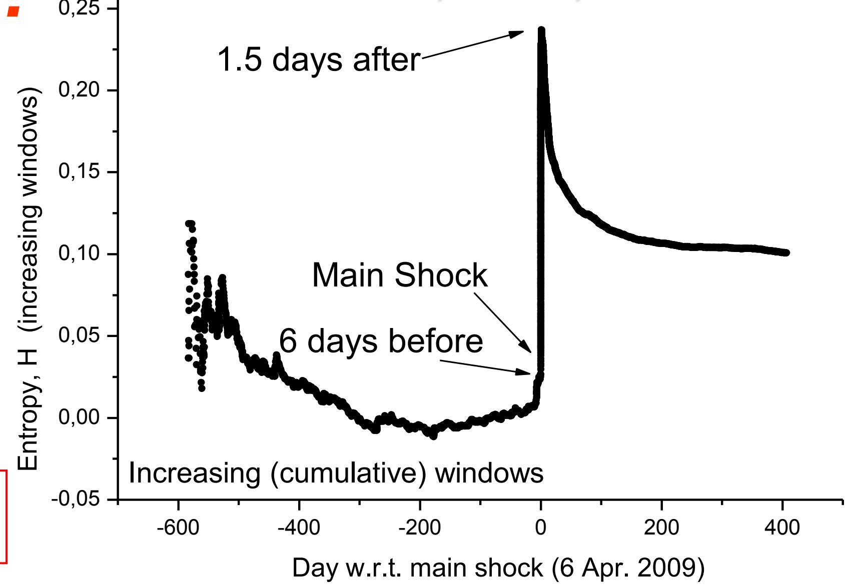
1. ***Seismic fore-patterns***
   (from seismic and magnetic data)
   - *Acceleration* ***(interm. term)***
   - *non linear pdf* ***(short term)***

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

5.1 Study from ground: Seismic analyses

Geosystemics

De Santis et al., BSSA, 2011



Shannon Entropy

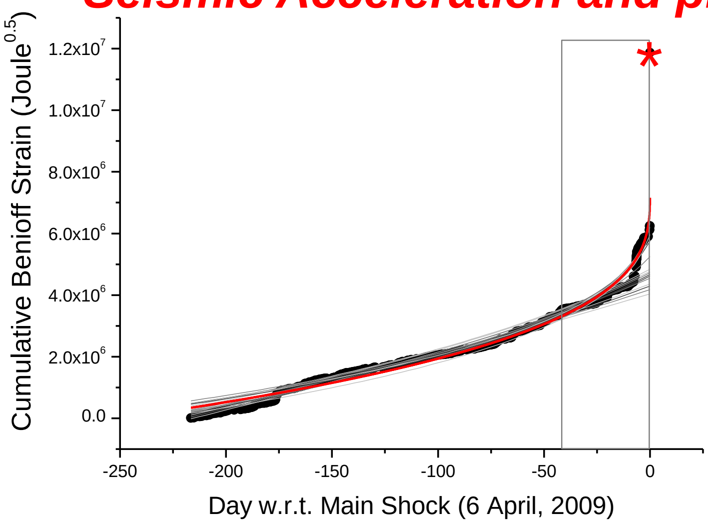
$$H(t) = -\int_{M_c}^{\infty} p(t,M)\cdot \log p(t,M)\,dM$$

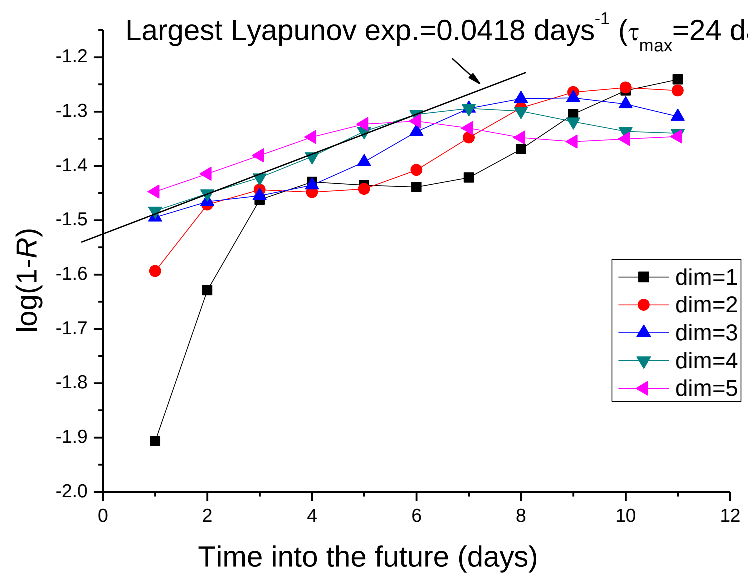
b-value and Entropy

$$H(t) = \log(e \cdot \log e) - \log b = k' - \log b$$

Seismic Acceleration and phase space analysis

6 Apr. 2009
M6.2 L'Aquila EQ





De Santis et al., Tectonophysics, 2010

5.2 Study from ground and space: magnetic analyses

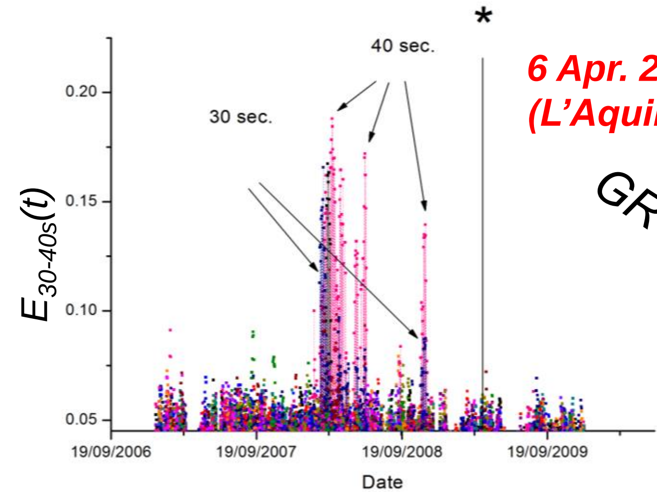
Magnetic TF Entropy

$$\mathbf{Z}(\omega) = A(\omega)\,\mathbf{X}(\omega) + B(\omega)\,\mathbf{Y}(\omega)$$

$A(\omega)$, $B(\omega)$: magnetic Transfer Functions (TF)

The (normalised) entropy contribution of the harmonic ω_i is given by :

$$E_i(t) = -\frac{p(\omega_i,t)\cdot \log p(\omega_i,t)}{\log N}$$



6 Apr. 2009 (L'Aquila EQ, M6.2)

GROUND

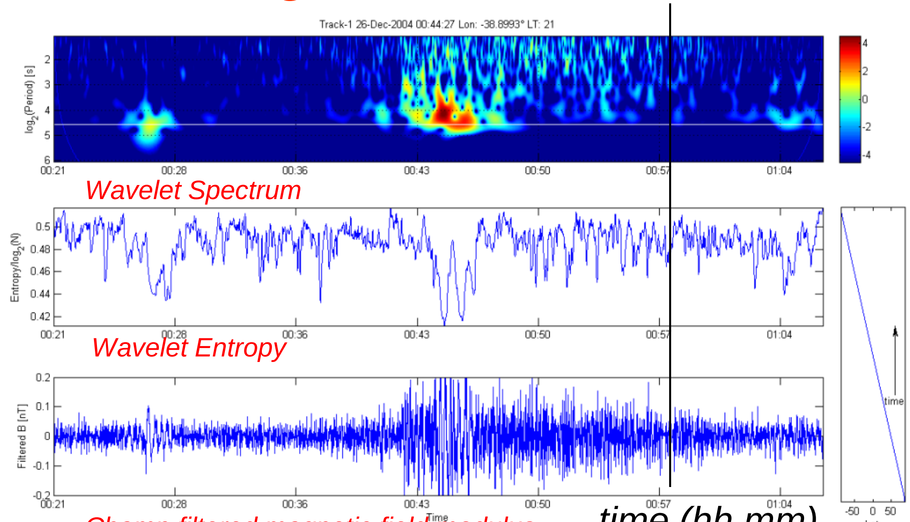
Cianchini et al., NPG, 2012

Wavelet Entropy of satellite magnetic data

Example 26th Dec, 2004 (Sumatra EQ, M9)

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

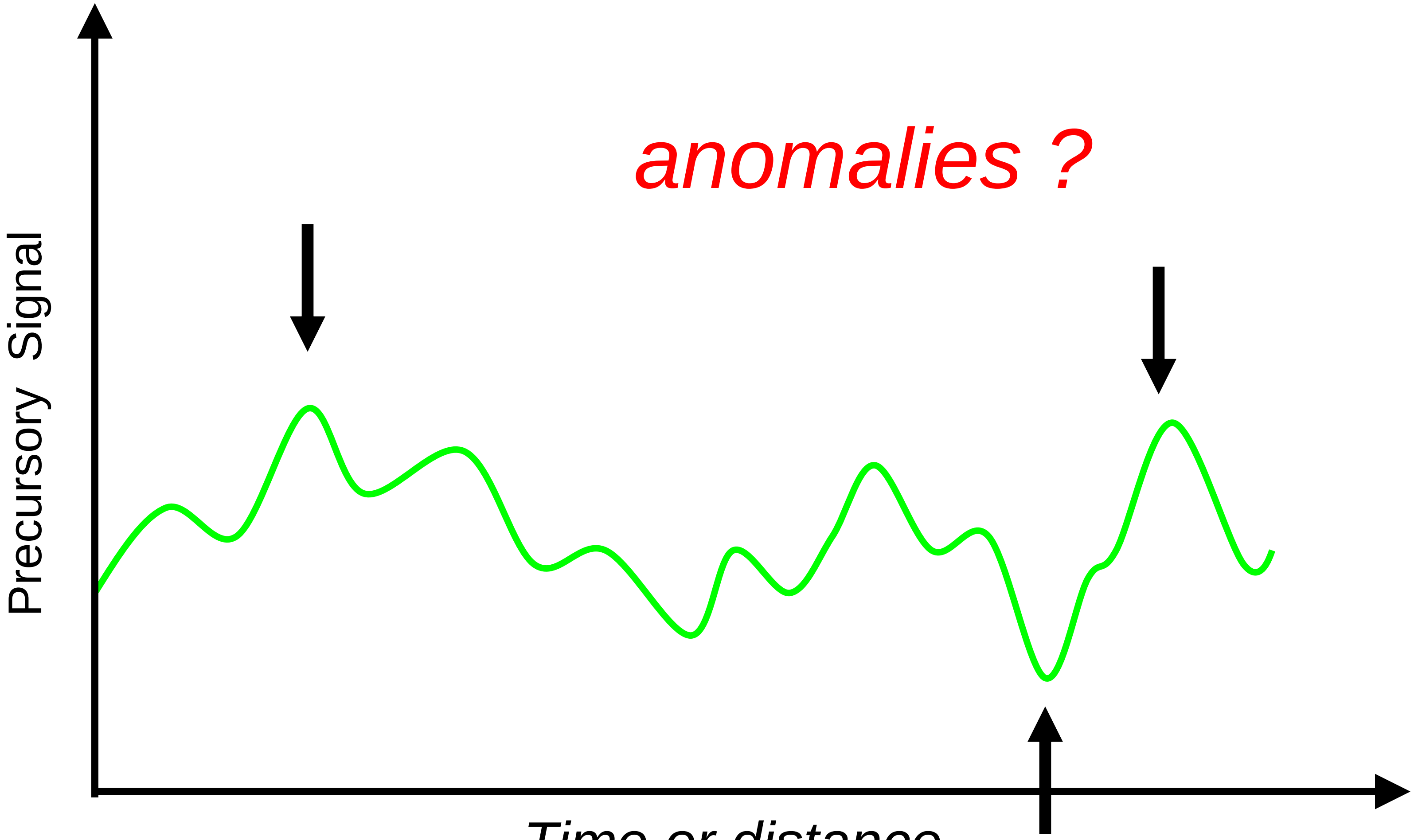
Cianchini et al.,IASME, 2009



time (hh.mm)

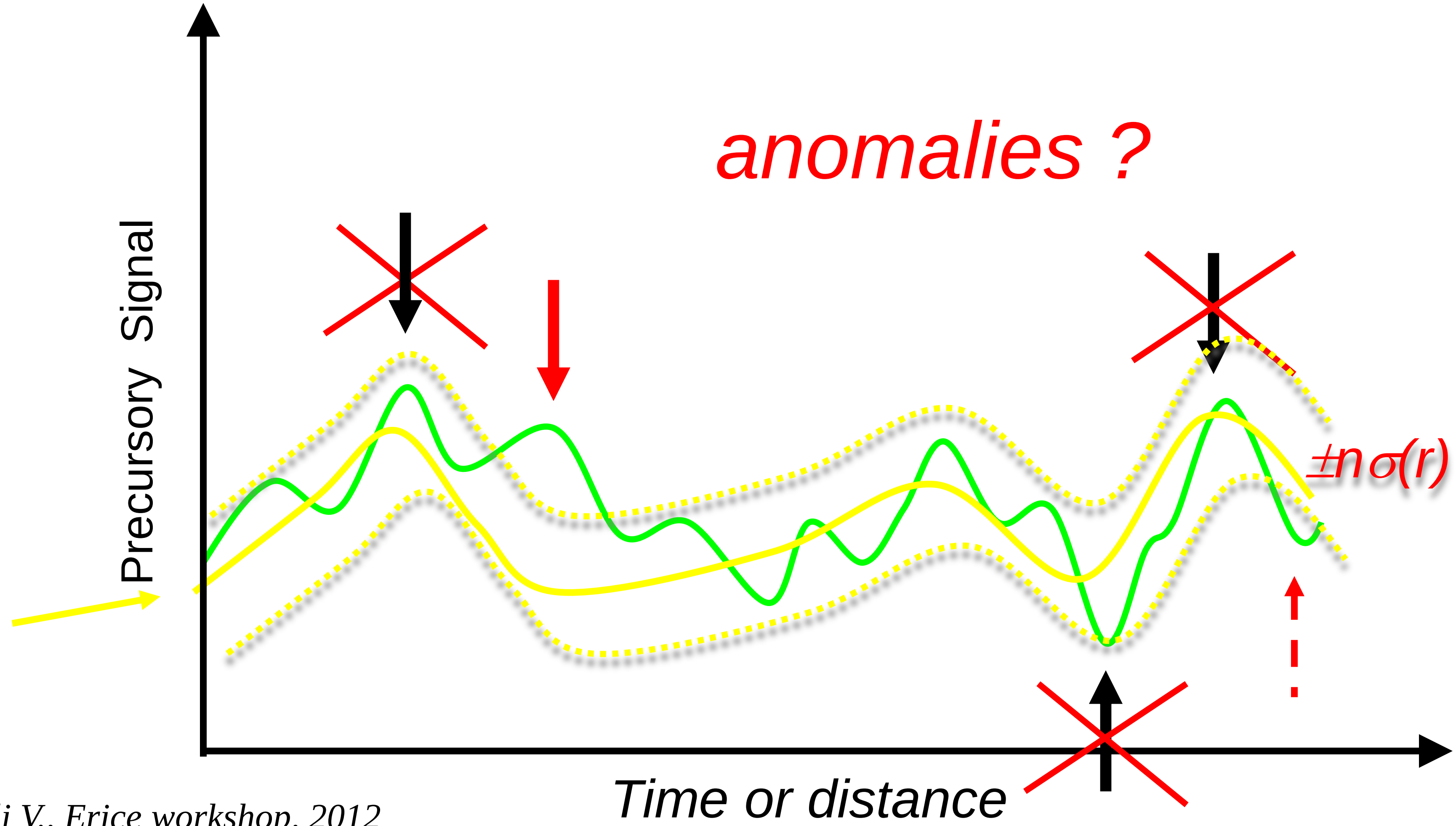
SATELLITE

What "anomaly" means ?



After Tramutoli V., Erice workshop, 2012

What “anomaly” means ?

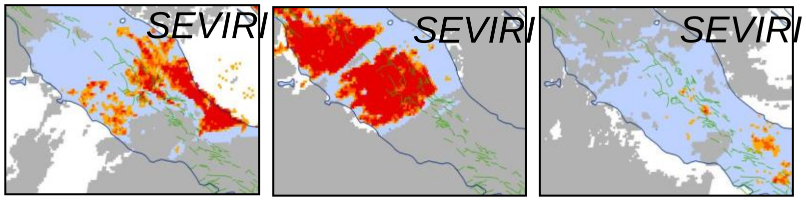


Tramutoli V., Erice workshop, 2012

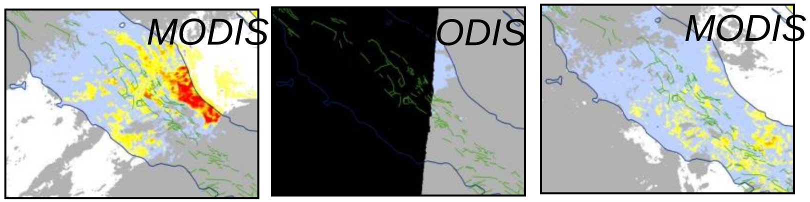
5.3 Study from ground and space: atmospheric analyses

6 April, 2009 M6.2 L'AQUILA (Italy) earthquake

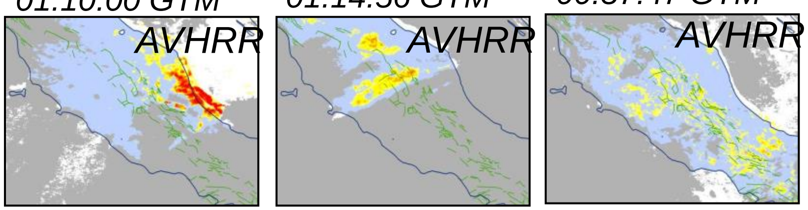
TIR (Thermal InfraRed) anomalies



30 March 2009 00:00:00 GMT | *31 March 2009 00:00:00 GMT* | *01 April 2009 00:00:00 GMT*



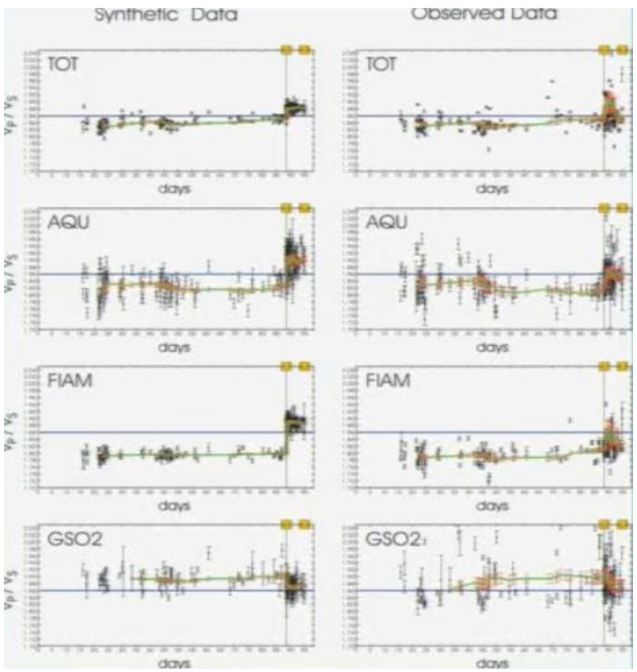
30 March 2009 01:10:00 GTM | *31 March 2009 01:14:56 GTM* | *01 April 2009 00:57:47 GTM*



30 March 2009 00:22:57 GMT | *31 March 2009 01:57:31 GMT* | *01 April 2009 01:46:49 GMT*

SATELLITE

Comparison with Seismological observation (Vp/Vs) (Lucente et al, Geology, 2010)

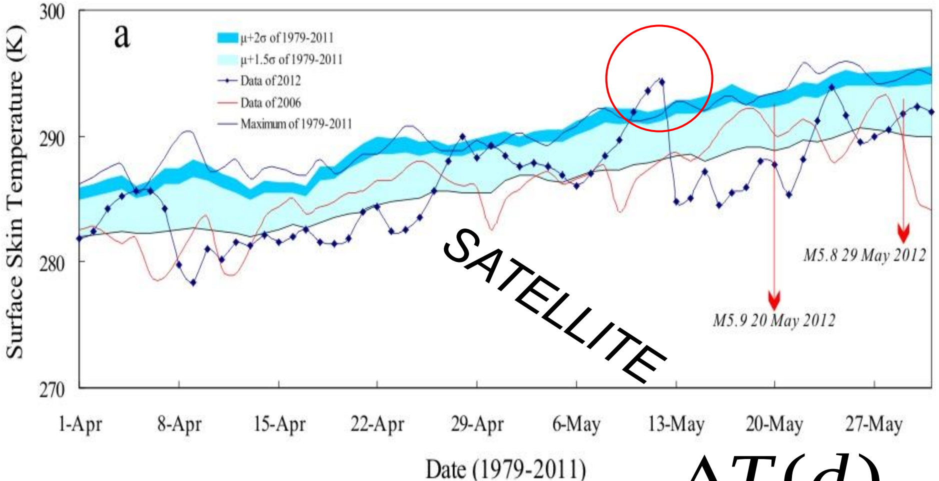


GROUND

Tramutoli V., Erice workshop, 2012

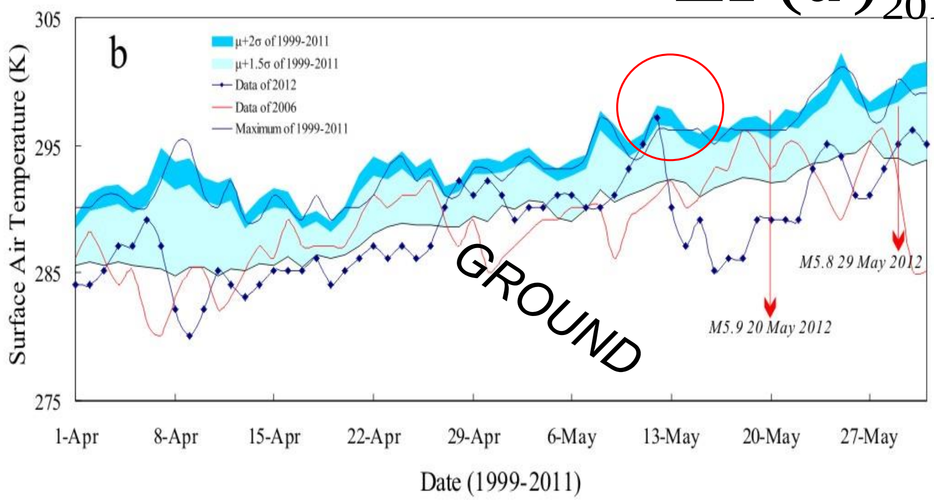
5.3 Study from ground and space: atmospheric analyses (cont.d)

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: 32 years; ground 12 years)

Qin et al., Annals Geoph., 2012

5.4 Study from ground (with ionosondes): ionospheric analyses

"Seismic" Ionospheric Anomalies detected by ionosondes when they satisfy the following conditions:

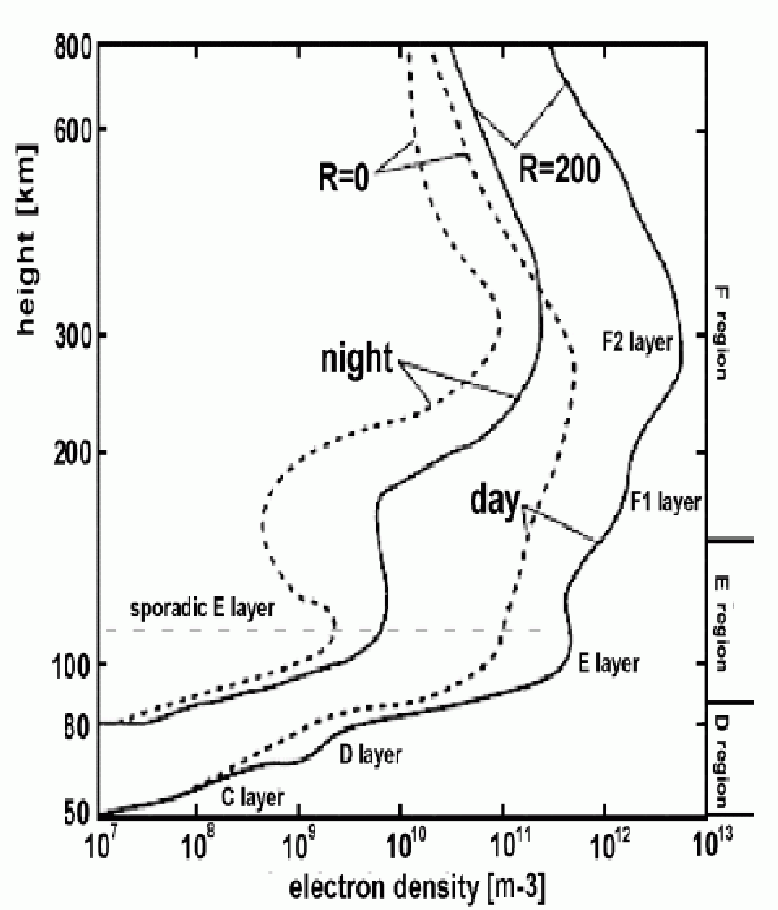
1. The occurrence of abnormally high Es layer with
$\Delta h'Es = (h'Es - (h'Es)med) \geq 10$ km

2. $\delta fbEs = fbEs - (fbEs)med / (fbEs)med \geq 20\%$

3. $\delta foF2 = foF2 - (foF2)med / (foF2)med \geq 10\%$

Following each other within one day for 2-3 hours. ($\delta fbEs$ follows $\Delta h'Es$, but $\delta foF2$ shift depends on M)

where (..)med=27 day running median calculated over quiet days (Ap≤15)

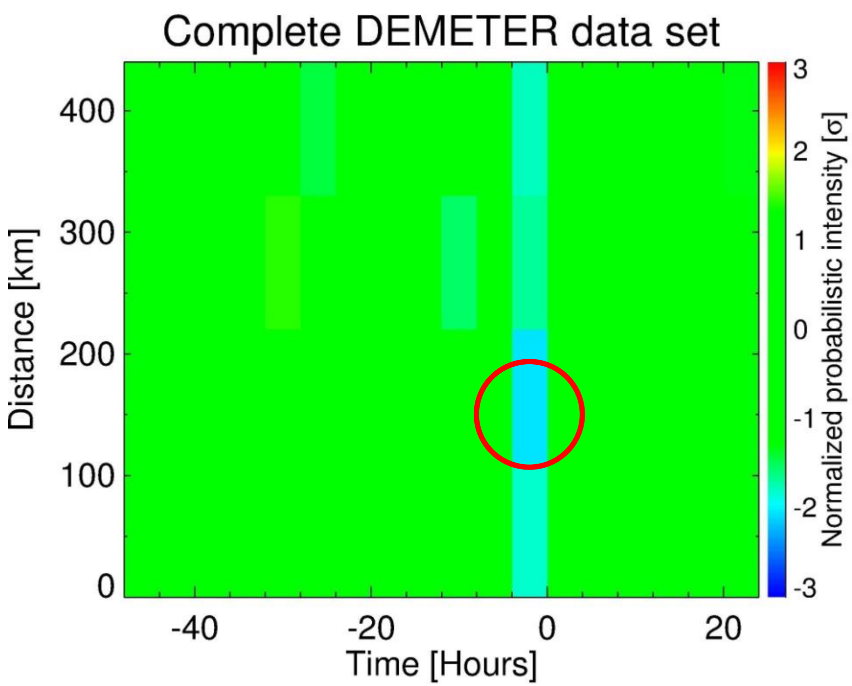


In Italy 36% true alarms
64% false alarms
***(**Perrone et al., AG, 2010)*

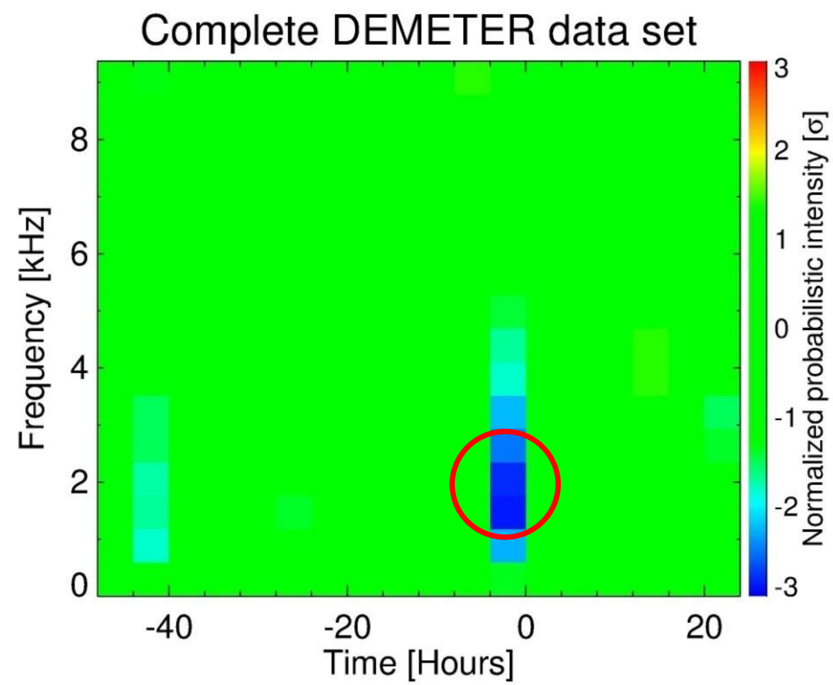
5.5 Study from space: ionospheric (statistical) analyses

DEMETER satellite
~ 9000 earthquakes
M≥5 and h< 40 km

*Night time VLF Electric field **Attenuation** at ~1.7kHz*



At a given frequency (~1.7kHz)



At a given distance (~150 km)

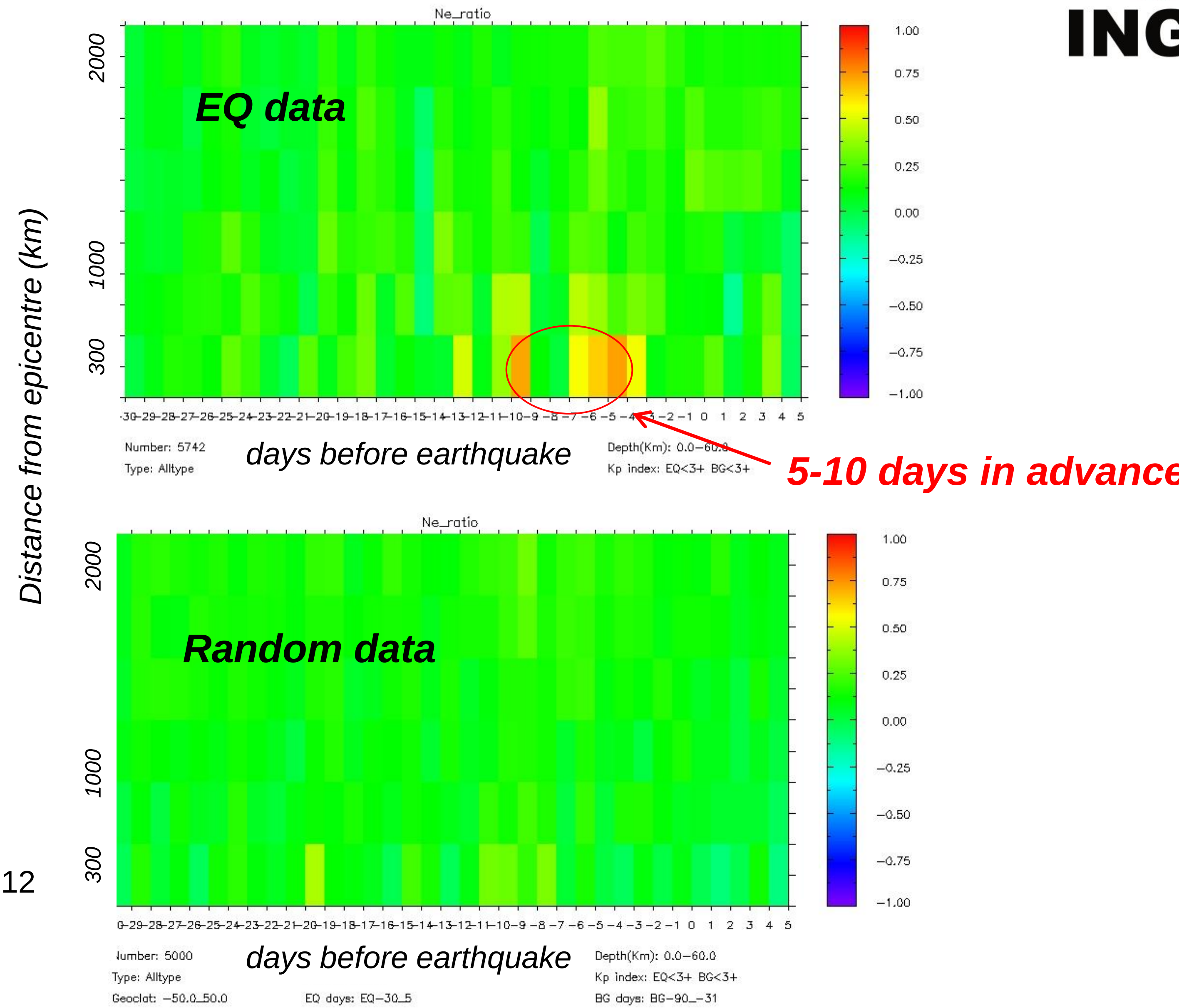
Pisa et al. (2012, 2013)

5.5 Study from space: ionospheric (statistical) analyses (cont.d)

Geosystemics

INGV

Ionospheric Electronic Density

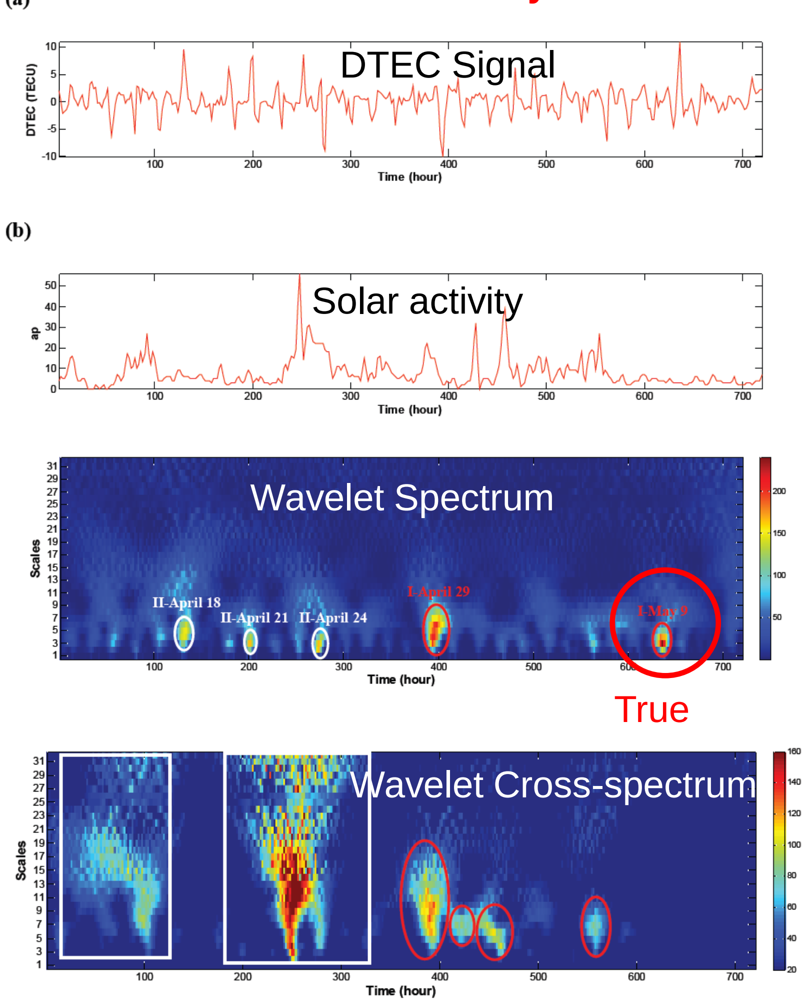


After Parrot M., Erice 2012

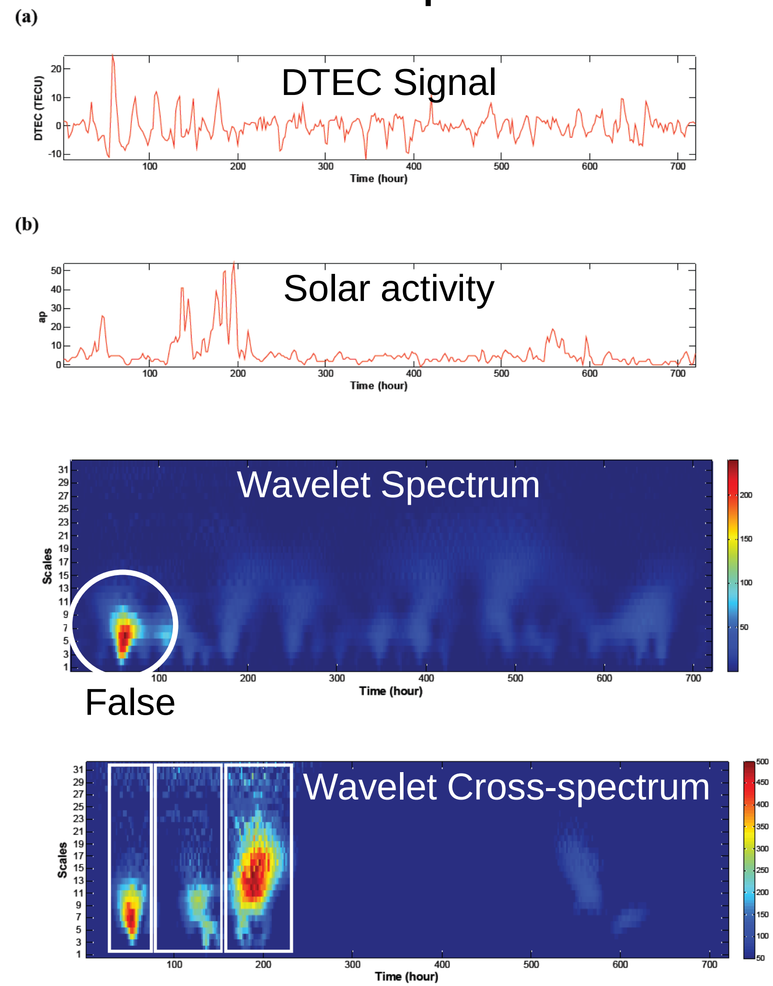
5.5 Study from space: ionospheric analyses

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

M8 Wenchuan 12 May 2008



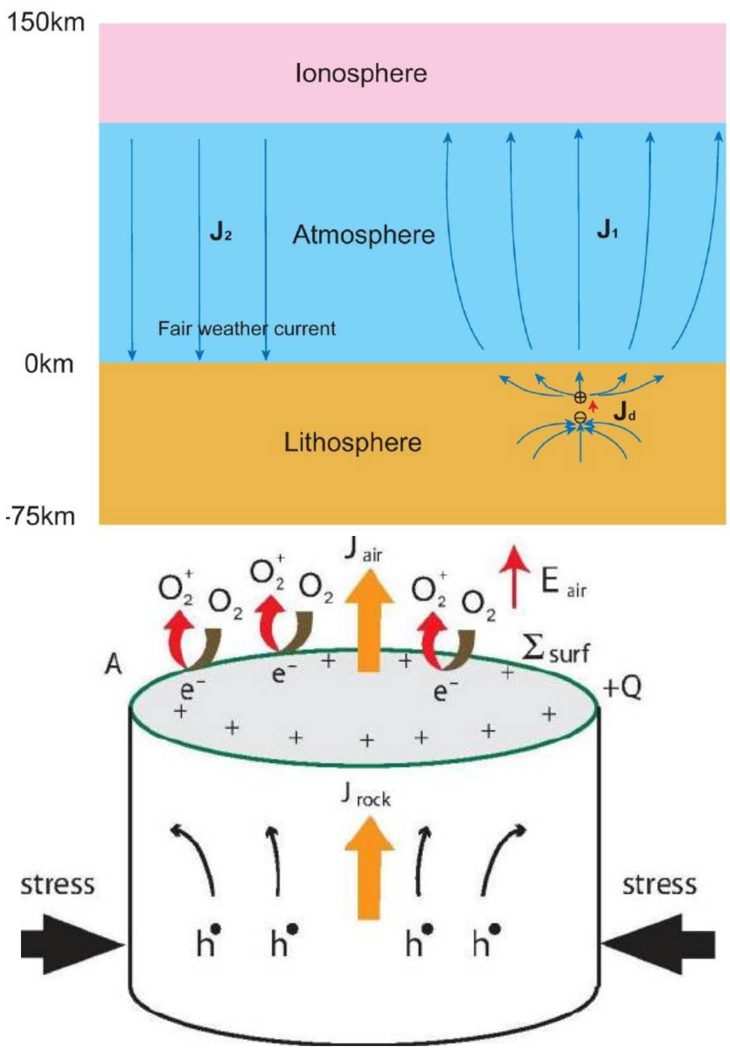
M7 Lushan 20 April 2013



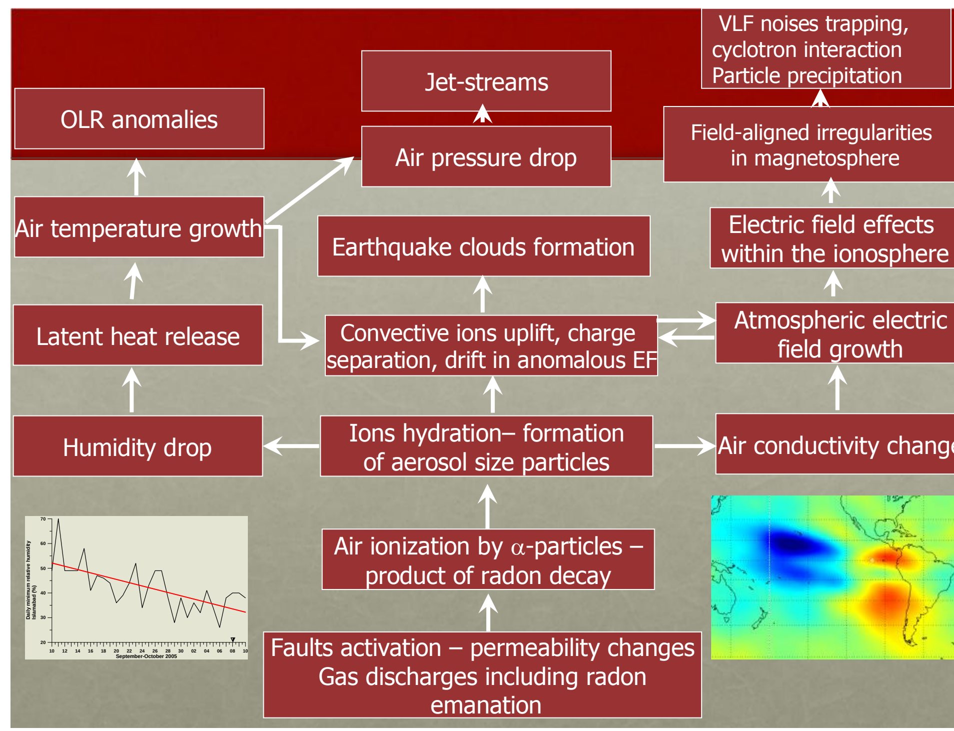
6. LAI Coupling Models

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)



Kuo et al., JGR 2014



Pulinets & Ouzounov, JAES 2011

7. Conclusions

1. Earthquake Physics is **complex**

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

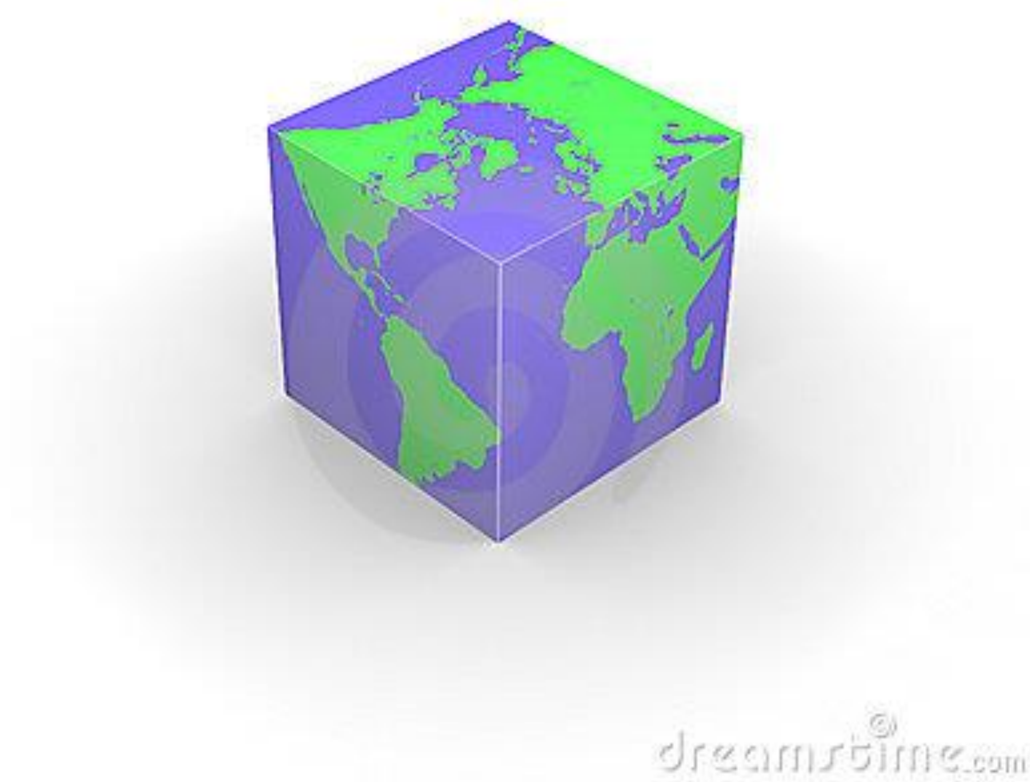
3. Combined **ground-satellite** data analysis is the best

4. We need to better **understand the physics** to verify which is the best model of **LAI coupling**

5. Only eventually **Earthquake Forecasting** will be possible.

6. More **case-studies and research** are necessary 

Thanks for your attention !



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