Lithosphere-Atmosphere-Ionosphere Coupling (LAIC) before large Earthquakes

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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. EQs 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?

earthobservatory.nasa.gov
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
EQs are not random in time

Earthquakes occur in clusters

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Deadliest EQs from 1900

2010 Haiti  M7  300,000

<table>
<thead>
<tr>
<th>YEAR</th>
<th>LOCATION</th>
<th>MAGNITUDE</th>
<th>ESTIMATED DEATH TOLL</th>
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<tr>
<td>1</td>
<td>Tangshan, China</td>
<td>7.5</td>
<td>255,000</td>
</tr>
<tr>
<td>2</td>
<td>Gansu, China</td>
<td>8.6</td>
<td>200,000</td>
</tr>
<tr>
<td>3</td>
<td>Qinghai, China</td>
<td>7.9</td>
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<td>4</td>
<td>Kanto, Japan</td>
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<td>5</td>
<td>Turkmenistan</td>
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<td>8</td>
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<tr>
<td>9</td>
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<td>30,000</td>
</tr>
</tbody>
</table>


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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).

**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.*

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5.1 Study from space: Some studies from DEMETER

(Detection of Electro-Magnetic Emissions Transmitted from Earthquake Regions) in orbit 2004-2010

Plasma Analyser

Electronic module

Magnetic sensors

Langmuir probe

Electric sensor

Energetic Particle Analyser

Courtesy of M. Parrot

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5.1 Study from space: Statistical study from DEMETER

Night time VLF Electric field **Attenuation** at \( \sim 1.7 \text{kHz} \)

**Method of the Superimposed Epochs**

- DEMETER satellite
- \( \sim 9000 \) EQs
- \( M \geq 5 \) and \( h < 40 \) km
- (2004-2010)

At a given frequency \( (\sim 1.7 \text{kHz}) \)

At a given distance \( (\sim 150 \text{ km}) \)

**2-4 hours in advance**

*Pisa et al. (2012, 2013)*

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17 days before the EQ

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
11 days before the EQ

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

Green=Foreshocks
Red=Mainshock & Aftershocks

M. Parrot, Erice -2012
7 days before the EQ

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

Green=Foreshocks
Red=Mainshock & Aftershocks

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

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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

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

- \( T(d)_i \): 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

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5.4 Study from space: ionospheric analyses

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

(a) M8 Wenchuan 12 May 2008

DTEC Signal

(b) Solar activity

Wavelet Spectrum

True

(a) M7 Lushan 20 April 2013

DTEC Signal

(b) Solar activity

Wavelet Spectrum

False

Wavelet Cross-spectrum
5.5 Study from ground: Two examples

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

\[
\tilde{s}(t) = \sum_{i=1}^{N(t)} \sqrt{E_i} \cdot G(R_i) = 10^B \sum_{i=1}^{N(t)} 10^{0.75M_i} G(R_i)
\]

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

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5.6 Study from seafloor: contribution by EMSO

European Multidisciplinary Seafloor and Water-Column Observatory

EMSO

INGV
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

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6. LAIC: an alternative EM model

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

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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


De Santis et al., Geosystemics and entropy of earthquakes, Proceedings APSCO Symposium, Beijing, China, Sept. 2011

De Santis et al., Accelerating Moment Release Revisited: examples of application to Italian seismic sequences, Tectonophysics, 2015.

De Santis et al., Geosphere perturbations induced by the Earth: the state of the art and future trends, Phys. Chem. Earth, 2015.


