Multi-parameter observations of atmospheric pre-earthquake signals and their validation: Potential for Future

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Some Perspectives

- We should remember some lessons learned from other fields, principally weather forecasting (numerical weather prediction, NWP, and climate change):
  - Forecasting in these fields did not exist decades ago
  - Now we take for granted such weather forecasts
  - For weather, physics is well known. But non-linear effects limit forecasts beyond ~ 10 days
  - However, for climate change, global decadal to centennial forecasting is still problematic. We know the basic physics, e.g. how temperature varies, but still a lot of physics are unknown (such as water cycle, cloud physics, and aerosol effects)
  - For climate, hindcast modeling is very important. The availability of global satellite data (extending now over ~ 30 years) has proven extremely important to test model runs
  - Satellites may prove similarly important for EQ hindcasting and forecasting

- Similarly, for EQ forecasting, hindcasting has to be understood first, before we have confidence in forecasting specific events

- For EQ forecasting science, as in NWP, data availability is extremely important, data-driven science

- Climate change, as EQ science, are by their nature interdisciplinary fields, and in fact even transdisciplinary (i.e. beyond natural sciences, involving social sciences, decision making, policy, etc.)

- Different physical theories of forecasting EQ’s will have to predict energy budgets and parameters (e.g. TIR, Magnitude, time change, etc.)
Team and collaborators

AGU Fall Meetings 2002-2012

Collaborative Framework

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VESTO 2009, Japan
Our progress in Atmospheric pre-EQ phenomena (2002-2012)
Lessons learned...

1. 2004 - Satellite TIR anomalies and Lab tests
   Pro: Thermal phenomena exist
   Cons: Lab experiments were not enough

2. 2005 - First multi parameter atmospheric analysis
   Pro: Detecting possible pre-EQ signals from space and in situ
   Cons: Single observations are not enough to understand process

3. 2008 - Sensor Web Approach for EQ studies
   Pro: Multi parameter approach is more reliable
   Cons: The physical link was not there

4. 2009 - LAIC model update
   Pro: Gain better knowledge about pre-EQ phenomena
   Cons: Models guide, experiments decide. More data needed

5. 2011 - Validation and statistical studies
   Pro: Retrospective validation established
   Cons: No prospective tests. Testing has recently begun.
Where we are now
Methodology of the precursory signals we are investigating
Understanding the relationship ship between several Geophysical signature

Long Wave Radiation for 2004 Sumatra
NOAA/AVHRR,AQUA/AIRS OLR

Data Integration
Sensor Web

Total Electron Content
GPS, COSMIC

Clouds information
MODIS,GOES, METEOSAT

Radon/ Gas variations

CSEP Workshop, May 5-7-, 2013: Validation of atmospheric pre-earthquake signals
Earth radiation anomalies (long wave)

- OLR refers to the sum total of all the long wave EM energy infrared radiation that escapes from the Earth back to space
- measured on the top of the Earth's atmosphere
- at wavelengths ranging from 5 to 100 micrometers.

Global OLR (NASA/AIRS)
~ 9-14 microns

Pre-earthquake OLR anomaly
Dec 19, Sumatra 2004

TOA

Earth Energy budget

CSEP Workshop, May 5-7, 2013: LAIC Validation
2013: What we have learned from the 2011 M9 Tohoku Earthquake?  
Multi - Precursors panel

**NOAA OLR Anomaly**  
(-1-3 days)

**GPS/TEC Anomaly**  
(-3 days)

**LEO tomography**  
(-3 days)

**Radon counts anomaly**  
(-10 days)

**Foreshock analysis**  
(-1-2 days)

**Air Temperature/Humidity**  
(-3 days)

Ouzounov et al, 2011

Papadopoulos, 2011
Alert contents:
- Time of alert;
- Location (+/- error)
- Time interval (1-30 days)
- Magnitude (Approx.)
- Confidence (if exists)
Retrospective statistical studies of thermal signals

2006-2008 – 14 major events in Kamchatka (M>5.8)  
2003-2008 - 9 major events in Taiwan, 15 major events in Japan (M>5.8)
Retrospective statistical studies of thermal signals

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Thermal Analysis False Alarms

1. We have systematically analyzed (retrospected) the False alarm ratio (FAR) transient features of thermal radiation field associated with the 100 major earthquakes (M>5.9) in Taiwan, Japan, Kamchatka and the world by using NOAA POES and NASA EOS Aqua Thermal data continuously for the period of 2003-2009.

2. We have found OLR anomalous behavior before all of hindcasted events with no false negatives. Each OLR anomaly been seen in the vicinity of the epicenter, within one 1.5 pixel radius around the epicenter. FAR for false positives are less then 25% from all of the hindcasted events.

3. Origin of the existing false alarms: Data quality, short time-series, definition of the “normal” field, etc.
Prospective Tests
Supersites and areas of prospective testing
Instrument measures the gamma emitted from Radon daughters ($^{214}\text{Pb}$ and $^{214}\text{Bi}$) with energy of 351 and 609 KeV.

The new methodology can reduce significantly the integral background radioactivity by a factor of 3 in the energy window of 250-700 KeV.
Increase in the Gamma counting rate hours in advance and related to the local seismic activity within a radius of 100 km from the sensor.
Prospective testing: Southern California

Aug 14, 2012, Chapman Gamma sensor, Internal Alert #1 was issued for M>5, >200km from Chapman

Aug 15, 2012, Satellite thermal detection Internal alert #2 was issued for M>5, near Southern California/Mexico, 32N/117W

Aug 26, 2012 Satellite thermal detection 07.30 LT Internal alert #3

Prospective testing: Southern California

Aug 15, 2012 - Aug 26, 2012

Preparation phase for a strong EQ far over 300 km and more from Orange next 24-48 hours. Local increase of EQ in a range of 30-80 km from Chapman M: 3.0-3.5.

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Prospective EQ analysis: Southern California

Aug 15, 2012, Satellite thermal detection Internal alert #2 was issued for M>5, near Southern California/Mexico, 32N/117W

Aug 26, 2012 Satellite thermal detection 07.30 LT Internal alert #3

M 5.5 - SOUTHERN CALIFORNIA - 2012-08-26 20:58:01 UTC


#2 #3
Summary

1. **Retrospective testing:** We have systematically analyzed the transient features of thermal radiation field, GPS/TEC, and Gas/Ion data associated with 25 (100 total number) earthquakes (M>5.9) in Taiwan and Japan (2003-2009) and the latest event M9.0 Tohoku earthquake in Japan. We have found anomalous behavior before all of hind casted events no false negatives. False alarm ratio has been calculated for the same month of the earthquake occurrence for the entire period of analysis 2003-2009. Only for 2 events the false positive been found. The lead time for thermal anomalous signals before the earthquake occurrence varies between 2 and 20 days, for GPS/TEC 1-5 days and Radon-Ion 3-25 days.

2. **Prospective Testing:** Testing has begun in the last year in Southern California integrating satellite thermal monitoring with gamma observations at Chapman. Global tests started in 2012 mostly with satellite thermal data and GPS/TEC data over 5 regions of collaborative precursor testing: Japan, Taiwan, Italy, Russia(Kamchatka, Sakhalin, Kurils), and California. Next steps are to expand the collaboration for new regions and apply independent methods for validation.

3. **Model Validation:** Need to understand the energetics and specific values of observed parameters associated with LAIC.
Lithosphere-Atmosphere-Ionosphere Coupling (LAIC) model development and validation by natural processes

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CSEP Workshop, May 5-7, 2013
Chapman Earth Observing Remote System is ON!

http://eos.chapman.edu/
Outline

1. LAIC model schematic presentation
2. The nature of the thermal radiation anomalies
3. Connection with Global Electric Circuit and Ionosphere
4. LAIC validation
5. Summary
Faults activation – permeability changes
Gas discharges including radon emanation

Faults activation

Air ionization by $\alpha$-particles – product of radon decay

Ions hydration – formation of aerosol size particles

Convective ions uplift, charge separation, drift in anomalous EF

Earthquake clouds formation

Air pressure drop

Latent heat release

Humidity drop

Air temperature growth

OLR anomalies

Jet-streams

Air conductivity change

Atmospheric electric field growth

Field-aligned irregularities in magnetosphere

VLF noises trapping, cyclotron interaction
Particle precipitation

(Pulinets and Ouzounov, 2011)
Middle and short-term pre-earthquake signals

Radon observations Kobe, Japan
1994-1995

Middle term

Short Term pre-EQ phenomena

- Radon observations Kobe, Japan
- 1994-1995
- Middle and short-term pre-earthquake signals
- CSEP Workshop, May 5-7, 2013: LAIC Validation
What are criteria to explain the atmospheric thermal radiation anomalies?

- Model should be connected with the processes of water evaporation and condensation (anomalous latent heat fluxes are observed)
- Extremely high energy effectiveness producing the effects at meteorological scales
- Air humidity drop should be explained
- The process is very dynamic in space and time
- Does not depend on land or ocean epicenter position
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TOA

Earth Energy budget
Anomalous thermal radiation and latent heat flux in advance (days) to the Kashmir M7.6 earthquake of 08 Oct, 2005

OLR anomaly

SLHF anomaly

Ouzounov et al, 2008

Cervone et al., 2007
Estimates of produced thermal energy

(physics requires such estimates)

1. Each $\alpha$-particle emitted by $^{222}$Rn with the average energy of $E_\alpha=5.46$ MeV can produce $\sim 3 \cdot 10^5$ electron-ion pairs.

2. Radon activity before earthquake is $\sim 2000$ Bq/m$^3$ (from obs. Inan, 2008)

3. The ion production rate is $\sim 6 \cdot 10^8$ s$^{-1}$

4. The H20 particle $\sim 1000$ nm size contains $0.4 \cdot 10^{12}$ water molecules

5. During water vapor condensation process the latent heat release is $U_0 \sim 40.68 \cdot 10^3$ J/mol (1 mol $= 6.022 \cdot 10^{23}$)

6. The given radon activity with formation of particles of 1000 nm size gives the thermal energy output $16 \text{ W/m}^2$

Thermal radiation anomaly before Tonga M6.3 – 22 Oct, 2008
What is the source of this huge energy?

✓ The energy is contained in the water vapor present in atmosphere, and this vapor is created by solar radiation

✓ Ionization does not create thermal energy, it produces the means for the thermal energy release (ions)

✓ It is a phase transition process characteristic of the synergetic processes
Humidity drop - an atmospheric indicator

Colima station
- Colima, Mexico
- 21 Jan 2003

Kashmir, Pakistan
- 08 Oct 2005

Wenchuan, China
- 12 May 2008

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Tonga M6.3 – 22 Oct, 2008
Oct 5-8 2008 (-12 days)

Samoa M8.0 - Sept 29, 2009
09.26 Sept 2009 (-3 days)

Tohoku M9.0 - March 11, 2011
11.09 Mar 2011 (-3 days)
What about ionosphere?

$M=7.3$, New Guinea Islands, $\Delta f_{oF2}$ 16.07.1980, INTERCOSMOS-19

M9.3 Sumatra, electron temperature 26.12.2004, DMSP satellite
Increase of conductivity of the boundary layer of atmosphere before Wenchuan 2008 earthquake, China
GPS/TEC map, TEC anomaly

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Decrease of conductivity of the boundary layer of atmosphere before the Wenchuan 2008 earthquake, China
GPS/TEC map, TEC anomaly
LAIC Validation

Non seismic sources of Atmospheric anomalies
LAIC Physical Validation

1. Man-made disaster - radioactive release
2. Natural fossil nuclear radiation
3. Sand storms effects in ionosphere
Validation# 1 Thermal anomalies registered over NPP disaster areas from satellite (Non seismic source LAIC)

1. Radioactive components – products of Nuclear Power Plant disaster ionize atmospheric gases
2. New formed ions undergo hydration
3. Hydration is equivalent to ionization, hence latent heat is exerted
4. Anomalous fluxes of heat can be registered by satellite infrared sensor

Chernobyl
USSR, 1986

Fukushima, Japan, 2011

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Validation# 2 - Natural fossil nuclear reactor, Oklo, Gabon Africa

July 2004-2010

Strong thermal anomalies as effect of air ionization

Geology Map

Smellie, 1995
Validation #3. Changes of conductivity of the boundary layer of atmosphere during sand storms
Ionospheric effect of Aug 12-13/2012
Saharan sand storms
LAIC is using fundamental principles of atmospheric physics and we suggest LAIC is a valid model for studying specific variations in atmosphere, which we found are connected with the earthquake preparation process.

LAIC has no limitation regarding the place and mechanisms of earthquake. It works over the land and over the sea, for inland and coastal earthquakes.

LAIC also can explain some processes driven by atmospheric ionization and related to atmospheric chemistry, atmospheric electricity and atmospheric thermodynamics.

NEXT: Numerical simulation of LAIC model to obtain quantitative estimates and correspondence of thermal and ionospheric features in relation to pre-earthquake sources. Energy budget calculations are needed for different EQ events.