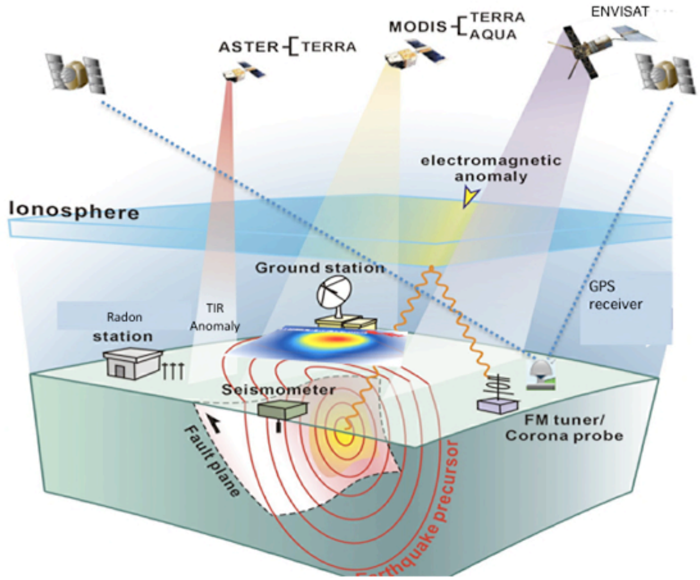
Application of Remote Sensing Technologies for Disaster Risk Management:

Multi sensor approach of analyzing atmospheric signals associated with major earthquakes

Dimitar Ouzounov

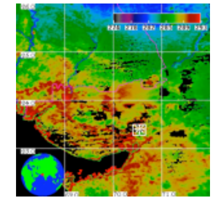
Chapman University and NASA/GSFC/SSAI

Sergey Pulinets, IAG,Russia, **Tiger Liu**, NCU, Taiwan, **Katsumi Hattori**, Chiba, Japan, **Michel Parrot**, LPC2E/CNR, France, **Menas Kafatos**, Chapman, CA, **Patrick Taylor**, NASA/ GSFC, MD, **A.Alonso-Baesa,** University of Santiago de Chile, Chile

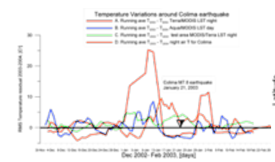


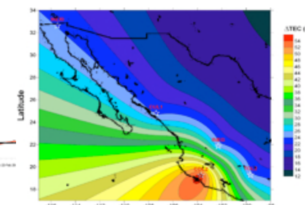
What we have learned about EQ precursors 2002-2010?

1. *2004 –Laboratory tests and TIR analysis*

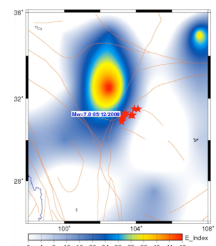


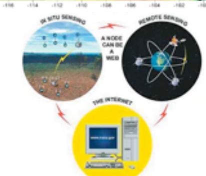
2. *2005 – First multi parameter analysis*



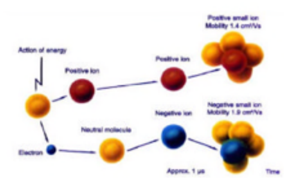


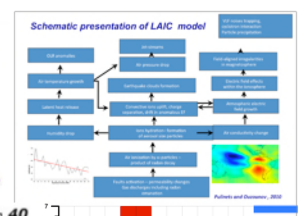
3. *2007- LWR analysis and Sensor Web*



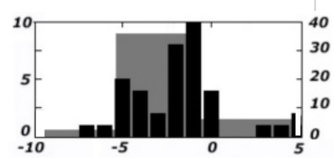


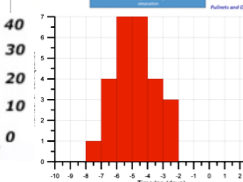
4. *2009- LAIC model testing*





5. *2010- Validation and statistical studies*





Mutisensor approach of analyzing atmospheric signals and search for possible earthquake precursors

- *The **purpose** of this study is to utilize existing global remote-sensing satellite data (thermal infrared observations from Terra, Aqua, GOES, POES, METEOSAT, space plasma parameters from DEMETER), simultaneously with ground observations to detect and understand atmospherics signals prior to major earthquakes.*

- *Our **approach** is integrated analysis, a Sensor Web approach based on using model estimates from the Land Atmosphere Ionosphere Coupling Model (LAIC) with data fusion of satellite and ground data.*

- *Our **rationale** for using the Sensor Web approach is that **the complex and dynamic nature of the earthquake hazard risk on global scale requires spatial, spectral, and temporal coverage that is far beyond any single satellite mssion and approach.***

- *Our **results** show that the new framework based on Joint Model - Space - Terrestrial Framework (JMSTF) used as integrated web, could provide an **Earthquake early-warning capabilities (days).** JMSTF is reviling an early change detection for the ensemble of geophysical signatures sensitive to the electro-chemical and thermodynamic processes in the Earths crust and atmosphere prior to major earthquakes (M>5.5).*

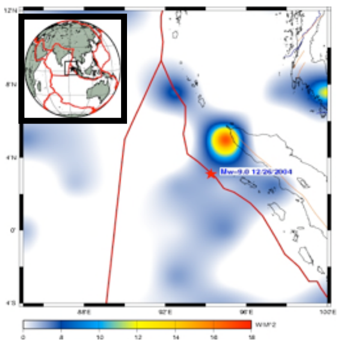
- *Our **validation** work is underway and is based on historical multi-year (10-20 years) time series baseline by continuous (i) monitoring; (ii) retrospective and **(iii) hot spots alerts** (location, time and intensity) by using ensemble of atmospheric and ionospheric signals (precursors) over different seismo-tectonic background.*

Where we are now

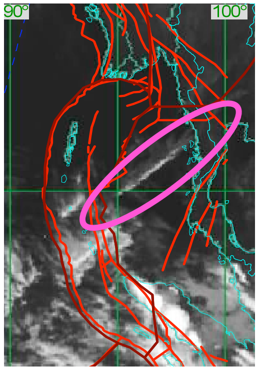
Methodology of the precursory signals we are investigating

Understanding the relationship ship between several Geophysical signature

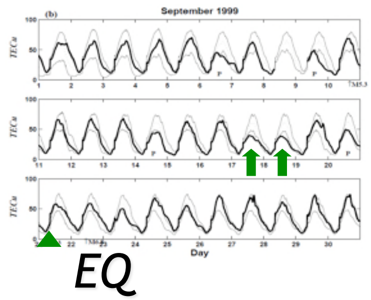
Long Wave Radiation
NOAA/AVHRR,AQUA/AIRS OLR



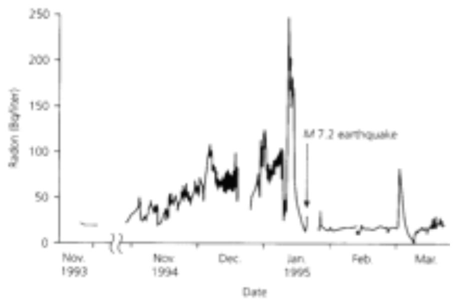
Clouds information
MODIS,GOES, METEOSAT



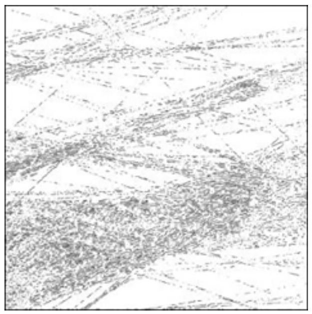
Total Electron Content
GPS, COSMIC



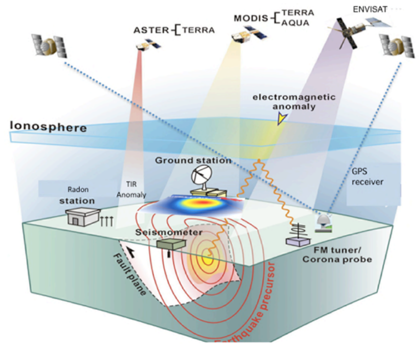
Radon/ Gas variations



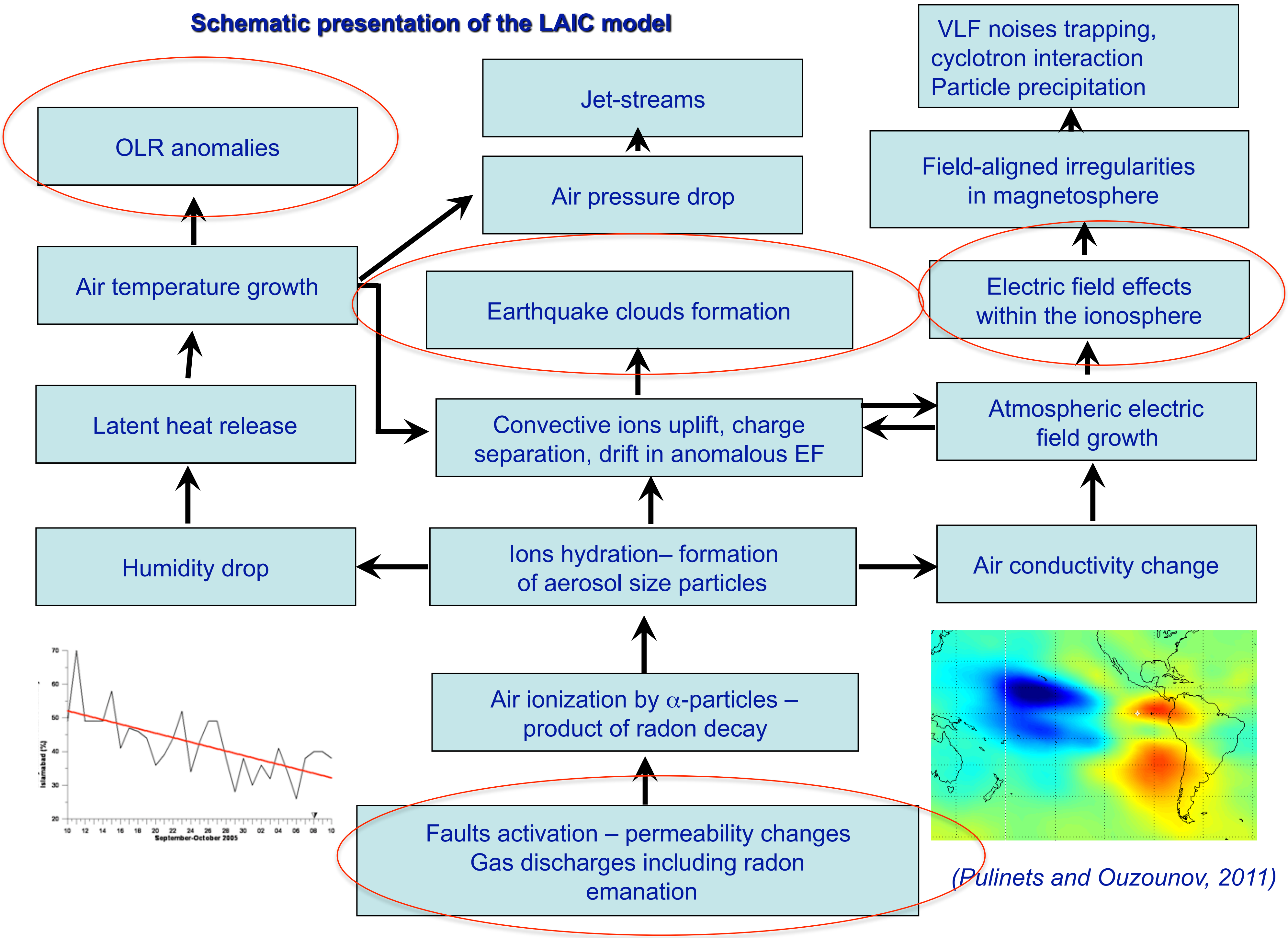
Change in tectonic lineaments
ASTER , MODIS



Data Integration
Sensor Web



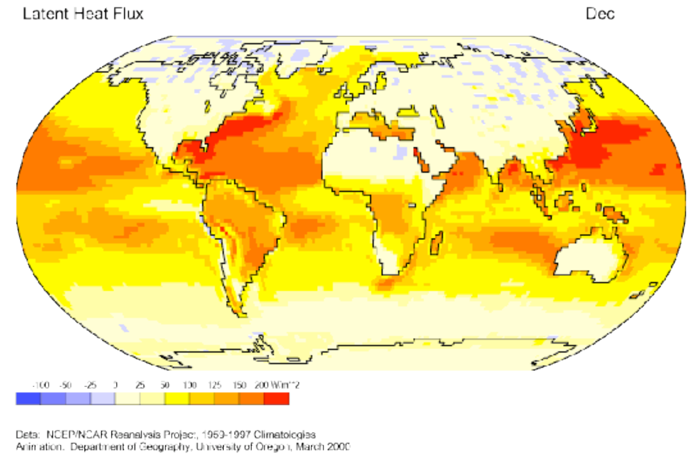
Schematic presentation of the LAIC model



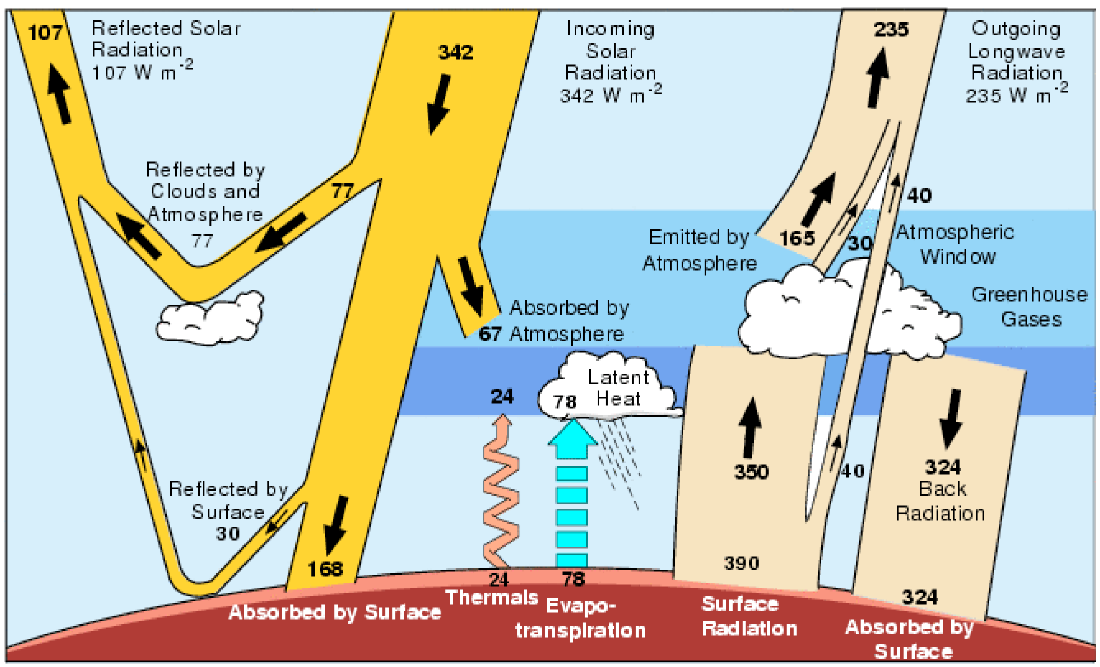
(Pulinets and Ouzounov, 2011)

Long wave Radiation Data (OLR)

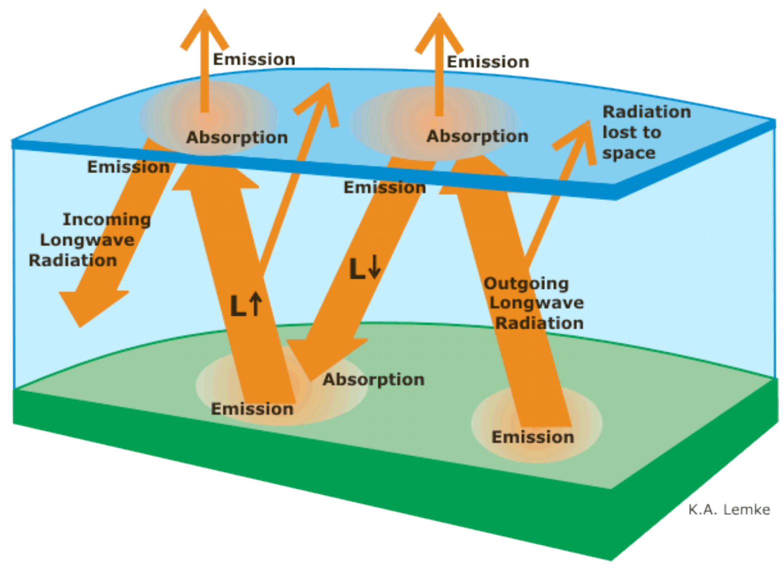
- OLR refers to the sum total of all the long wave EM energy infrared radiation that escapes from the Earth back to space
- measured on the top of the Earth's atmosphere
- at wavelengths ranging from 5 to 100 micrometers



Global Heat Flows

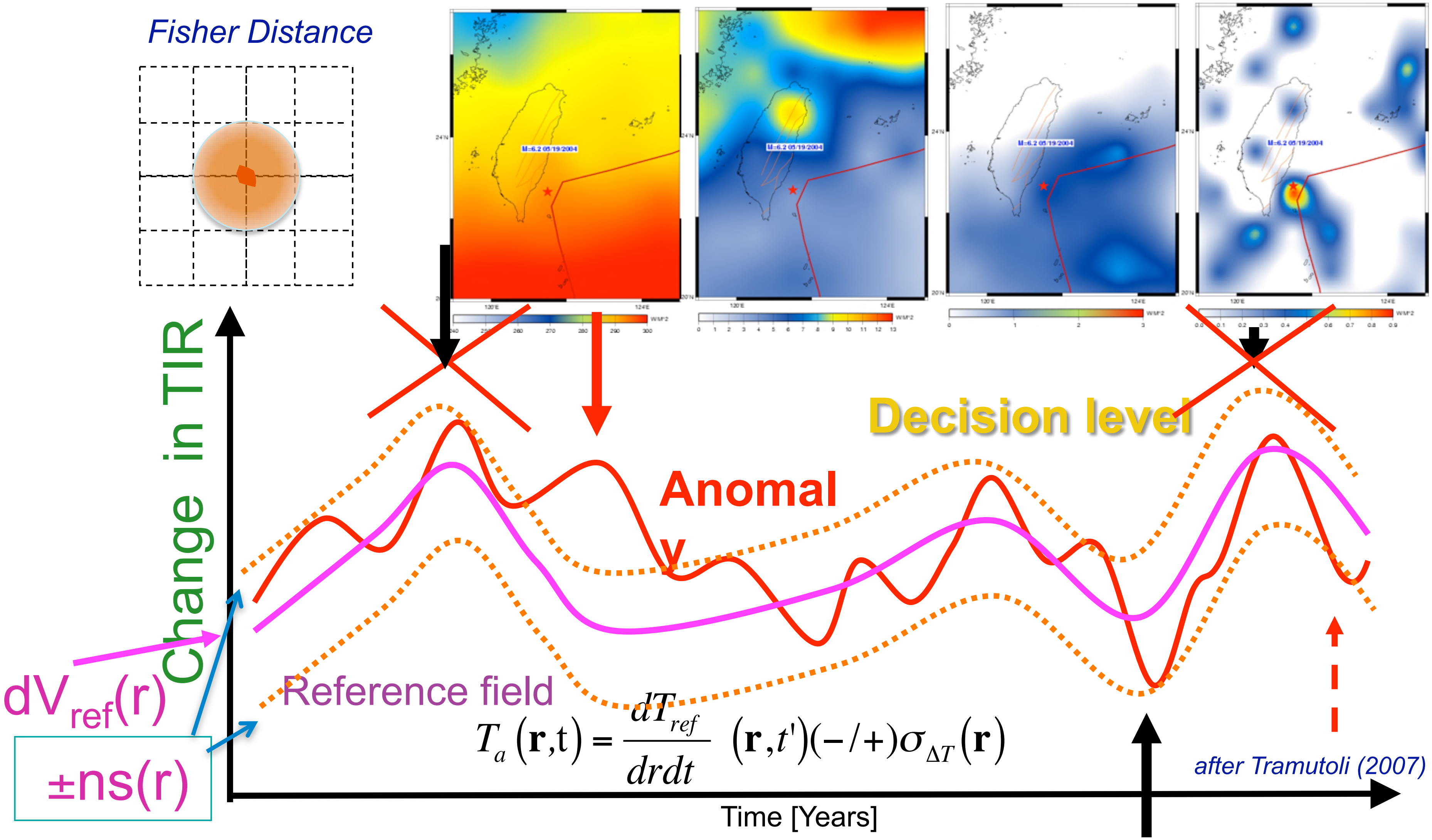


Kiehl and Trenberth 1997



Methodology->

How we do the detection of the transient radiation field



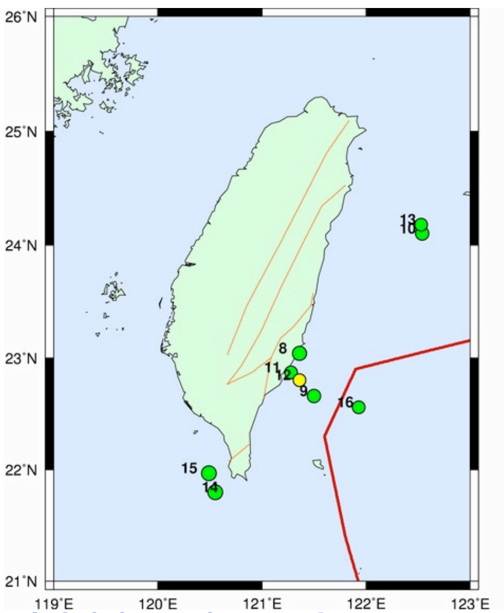
$$T_a(\mathbf{r},t) = \frac{dT_{ref}}{drdt}(\mathbf{r},t')(-/+)\sigma_{\Delta T}(\mathbf{r})$$

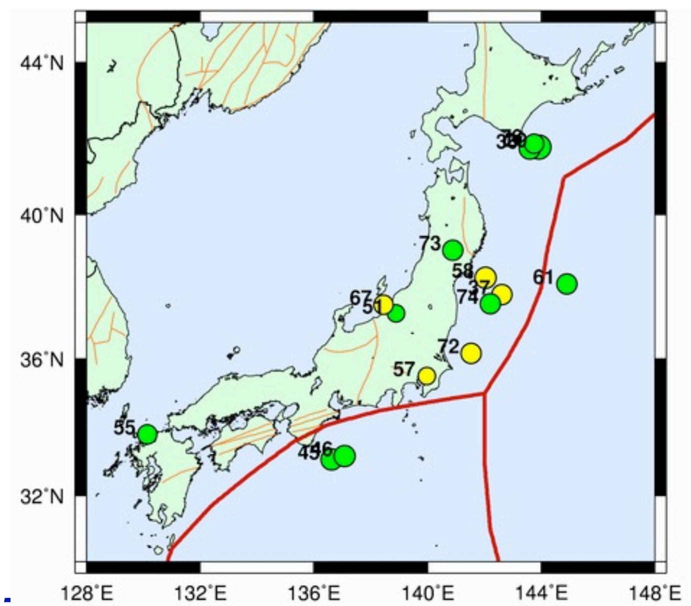
Validation studies of atmospheric anomalies

The main goal was to check if the earthquake associated atmospheric signals appeared systematically prior to the major events worldwide.
The areas of interests are Taiwan and Japan and the most recent 2009/2010 major earthquakes.

To Catch a Fish . . . You Need to Go where the Fish Are!

Taiwan *Japan*



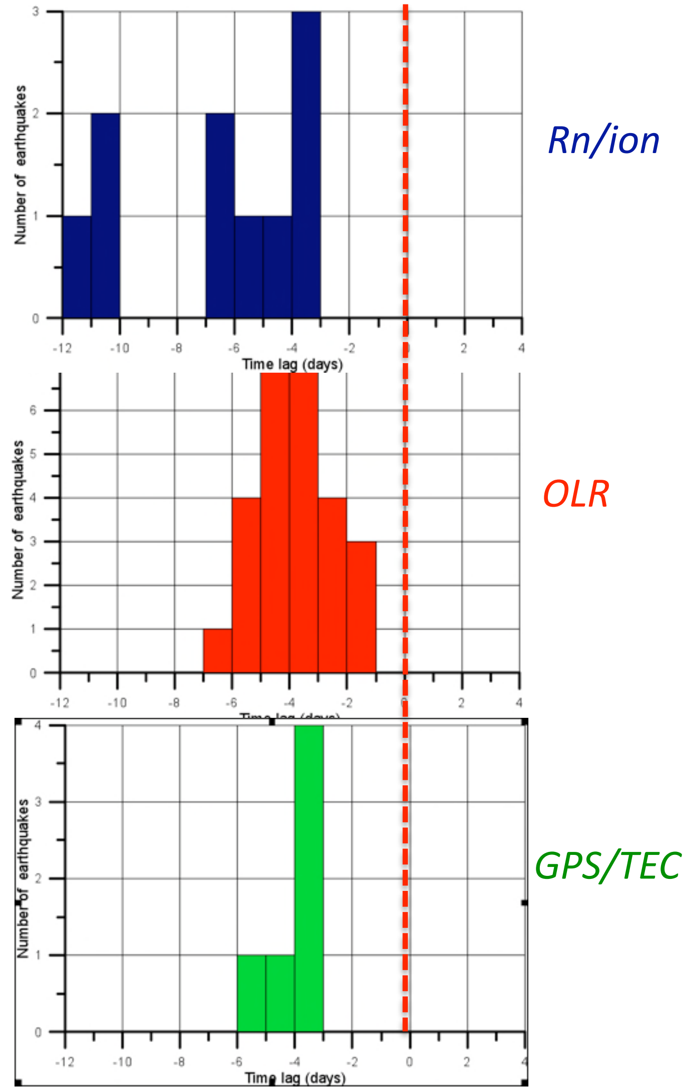


2003-2009 – 9 major events in Taiwan, 15 major events in Japan and most recent 2009-2010 earthquakes been selected - total of 24 earthquakes (M>5.9)

Ouzounov et al, 2010

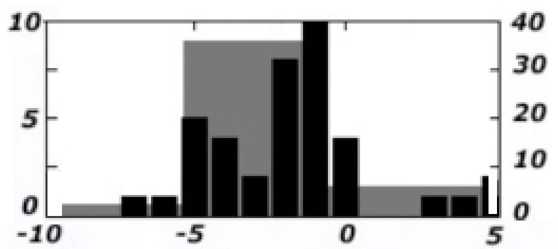
Summary of the OLR ,GIM-GPS/TEC and radon/gas anomalies associated with major earthquake activities for (2003-2009) over Taiwan (9), Japan (15)

#	Region	##	Year/Date	Lat/Lon	M	Depth	Thermal anomaly	GIM GPS/TEC	DEMETER	Radon /Ion
							Lag Time (days)			
1	Taiwan	8	2003/12/10	23.04/121.36	6.8	10	-6	-5,-2		CL: -12.5
2	Taiwan	9	2004/5/19	22.66/121.5	6.2	20	-7	-6		CL: -7.4
3	Taiwan	10	2004/11/8	24.1/122.54	6.3	29	-2	-2		CL: -7.5
4	Taiwan	11	2006/4/1	22.87/121.28	6.1	9	-2	-4(p), -2?		TPT: -7.2 CL: -2.0
5	Taiwan	12	2006/4/15	22.8/121.36	5.9	18	-5	—(storm)		TPT: -11 CL: -2.0
6	Taiwan	13	2006/7/28	24.18/122.53	5.9	33	-5	0(p)		TPT: -11 CL: no data
7	Taiwan	14	2006/12/26	21.8/120.55	7.1	10	-5	-2?	-.2	TPT,CL: none
8	Taiwan	15	2006/12/26	21.97/120.49	6.9	10	-5	-2?	-.2	TPT,CL none
9	Taiwan	16	2007/1/25	22.56/121.93	6	36	-5	0(p)		TPT,CL: none MS: -6.2
10	Japan	29	2003/9/25	41.81/143.91	8.3	27	-6	-1(p)		
11	Japan	30	2003/9/25	41.77/143.59	7.4	33	-6	-1(p)		
12	Japan	37	2002/10/31	37.81/142.62	7	10	-6	-4,-3-2(p)		
13	Japan	46	2004/9/5	33.07/136.62	7.2	14	-4	—(storm)		
14	Japan	47	2004/9/5	33.18/137.07	7.4	10	-4	—(storm)		-4
15	Japan	51	2004/10/27	37.28/138.88	6	14	-3	-2(p),-1(p)、0(p)		-3
16	Japan	56	3/20/05	33.81/130.13	6.6	10	-5	-2(p),-1(p)、0(p)		-5
17	Japan	58	7/23/05	35.5/139.98	5.9	61	-4	—		-4
18	Japan	59	8/16/05	38.28/142.04	7.2	36	-5	-4,-3		-4
19	Japan	62	11/14/05	38.11/144.9	7	11	-4	—		
20	Japan	68	7/16/07	37.53/138.45	6.6	12	-3	-2	-.2	
21	Japan	73	5/7/08	36.16/141.53	6.9	27	-4	-2,-1,0		
22	Japan	74	6/13/08	39.03/140.88	6.9	7	-4	-3,-2		
23	Japan	75	7/19/08	37.55/142.21	7	22	-4	-5(p),-4(p)		
24	Japan	77	9/11/08	41.89/143.75	6.8	25	-2	-3,-2		

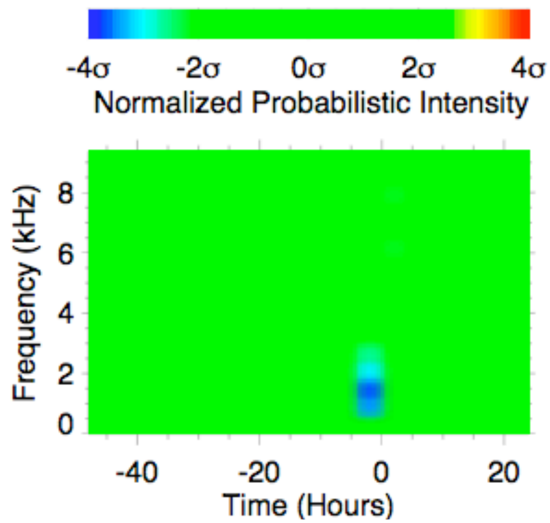


Statistical studies for EQ atmospheric precursors. A- GPS/TEC; B- VLF; C- Thermal OLR

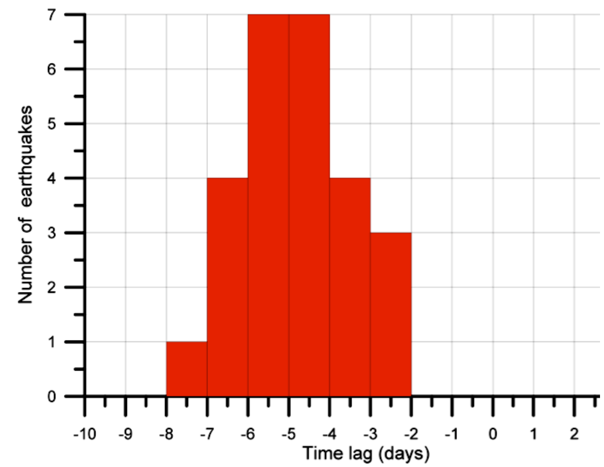
A



B



C



A. GPS/TEC over Taiwan (1996-2000) show a systematic TEC enhancement 2-5 days in advance (Liu et al., 2003); B. DEMETER data electric field in the VLF range (1-10 KHz) showing a systematic decrease of the intensity during nighttime, 4-6 hours prior to 3500 earthquakes of (M> 5) for period 2004-2008(Parrot, 2009); and C. Thermal radiation anomalies appearance within 2-5 days in advance to M>5.9 (2003-2008) over Japan and Taiwan. (Ouzounov et al., 2009)

OLR 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 hind casted events 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 10% from all of the hind casted events.

3. Origin of the existing false alarms : Data quality, short time-series, definition of the "normal" field, etc.

4. How to minimize FAR? Perform regional statistical validation to improve the reference field; Use joint satellite and terrestrial data fusion; Use of Ensemble Precursor Analysis (EPA) can minimize FAR.

The Atmospheric-Ionospheric Response to M9 Tohoku Earthquake Revealed by Joined Satellite and Ground Observations

1. Satellite Thermal radiation
2. GPS/TEC variations
3. LEO Tomography
4. Air Temperature/RH
5. Ion concentration

Since May 15,2011 our paper is available online on Cornell ARXIVE
http://arxiv.org/abs/1105.2841

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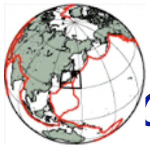
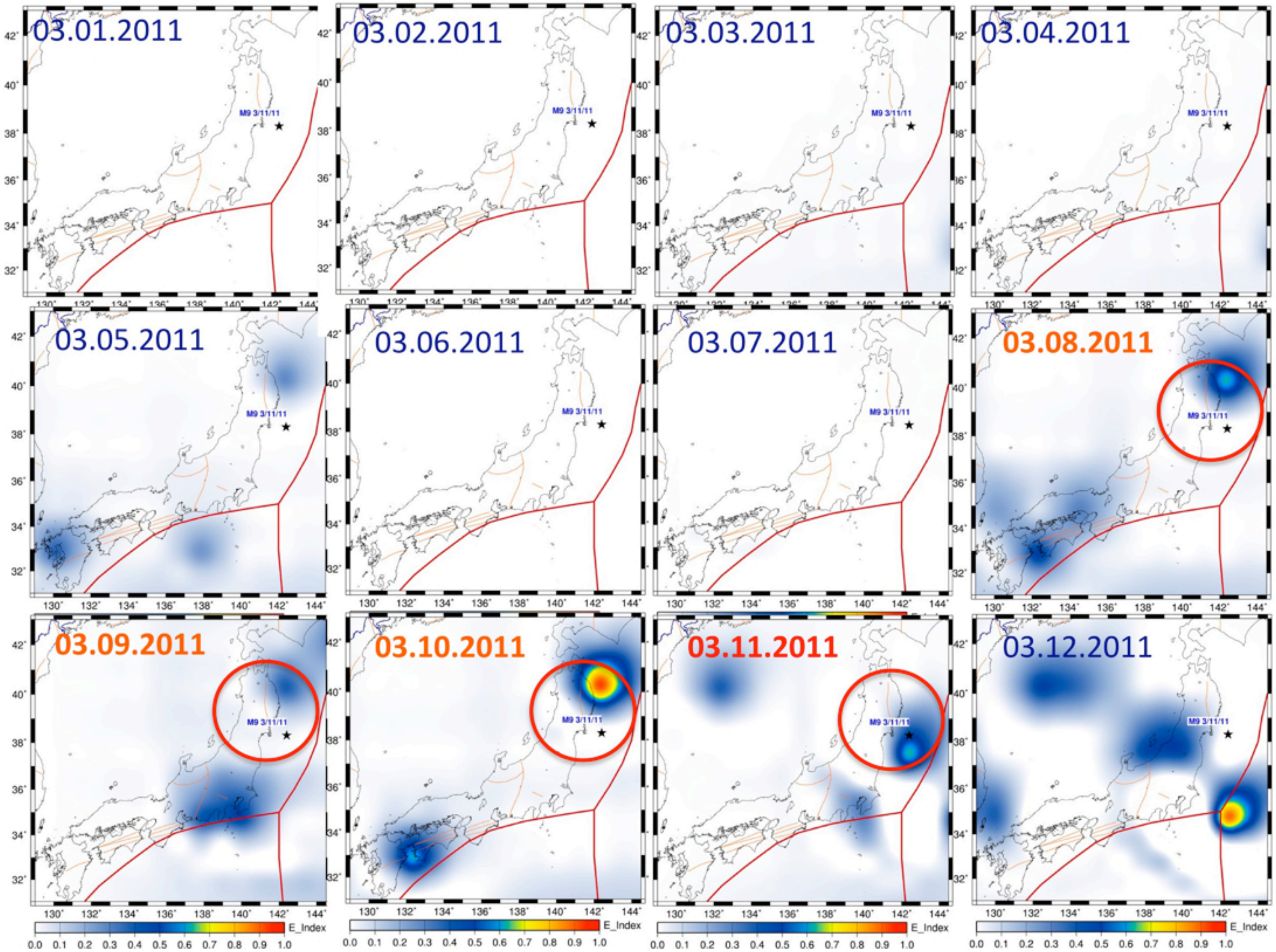
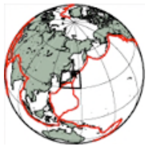
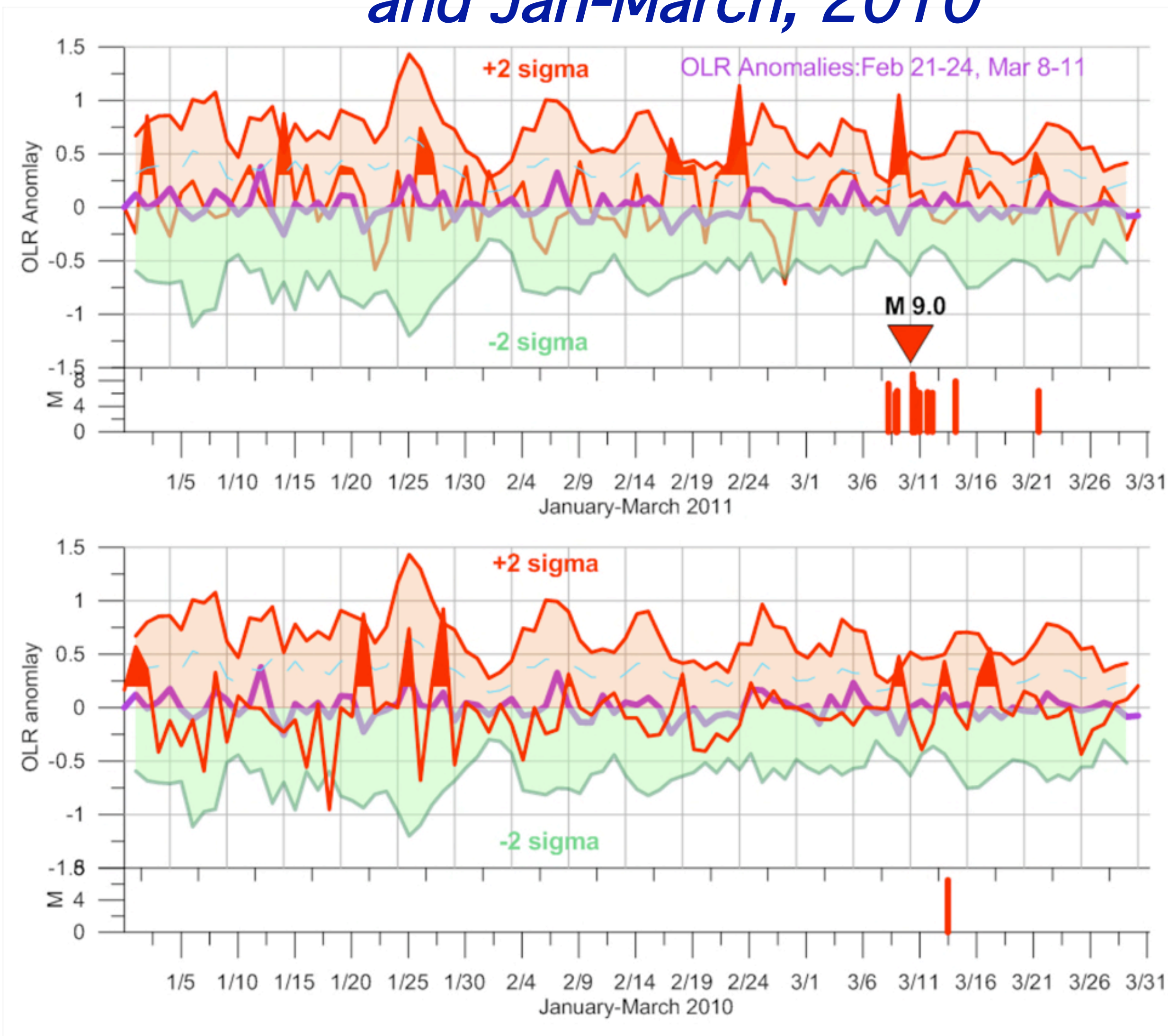


Day time OLR anomalous map for March 1- 12 , 2011
Over Japan. Anomaly represents the maximum acceleration in the earth radiation.



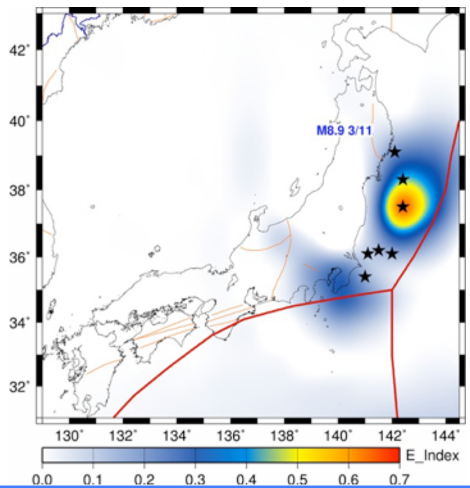


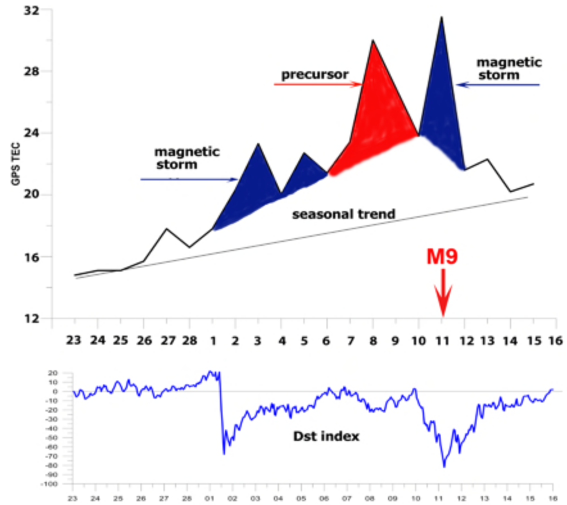
Day time OLR time series for Jan - March , 2011 and Jan-March, 2010

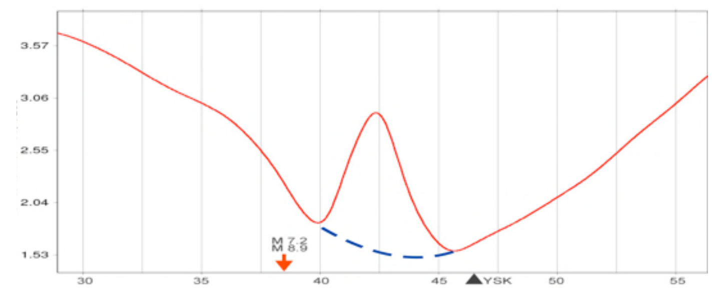


The Atmospheric-Ionospheric Response to M9 Tohoku Earthquake Revealed by Joined Satellite and Ground Observations

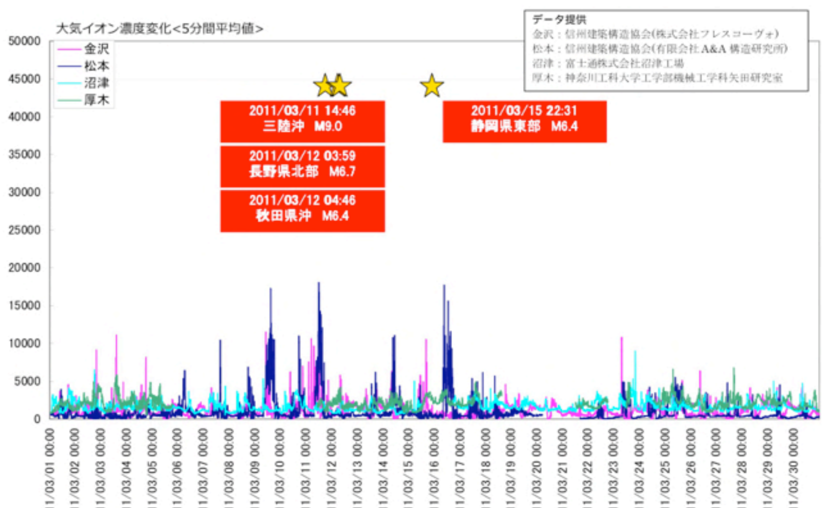
NOAA OLR Anomaly | *GPS/TEC Anomaly* | *LEO tomography*

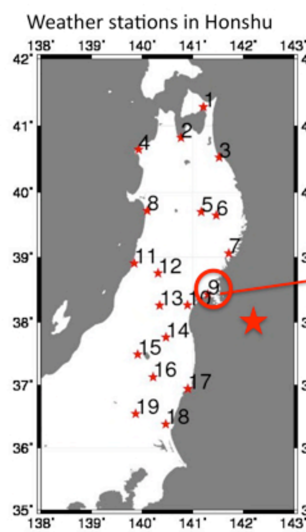


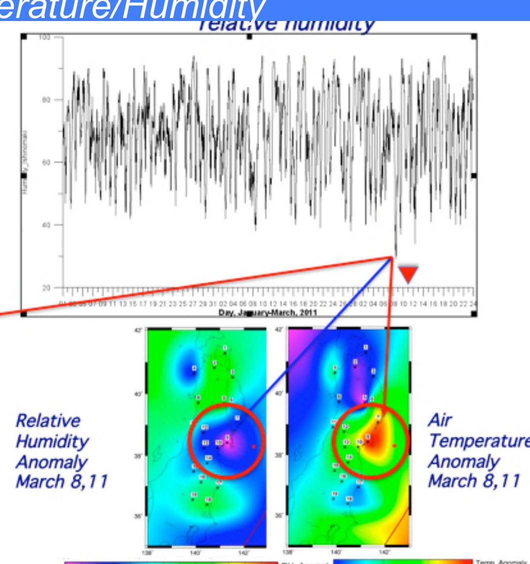




Ion Content (E-Pisco) | *Air Temperature/Humidity*







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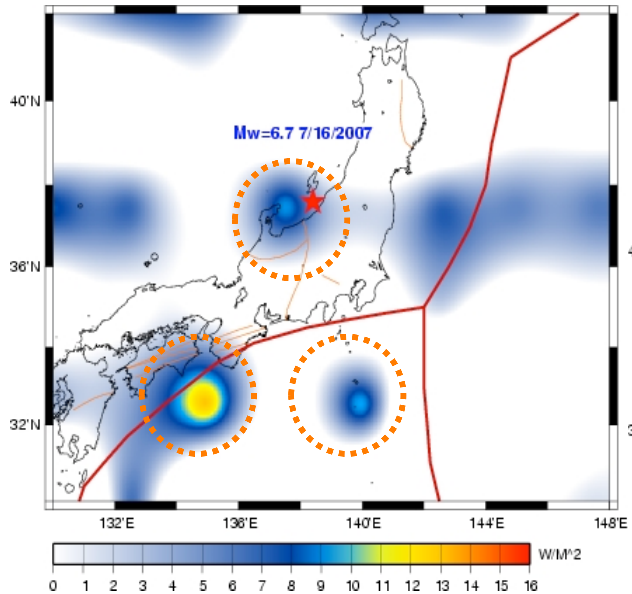
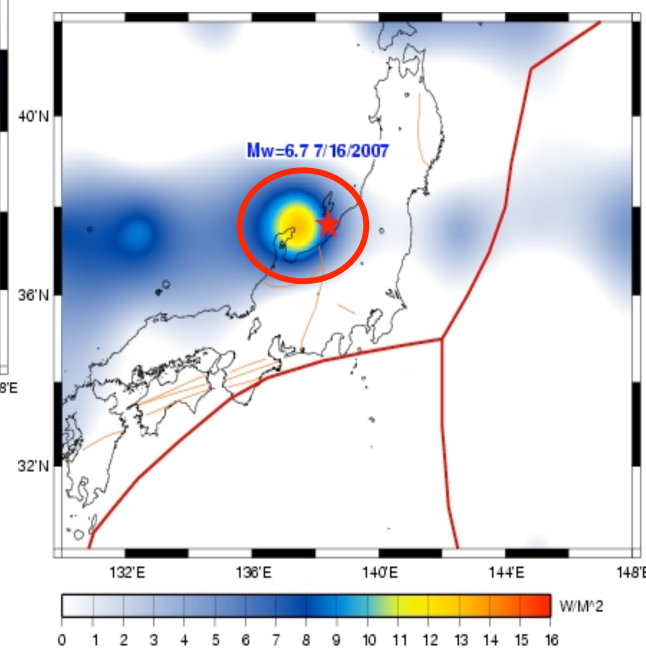
Hot-spot alerts around Niigata-ken Chuetsu-oki earthquake 2007-07-16 01, Mw 6.7 near west coast of Honshu, Japan

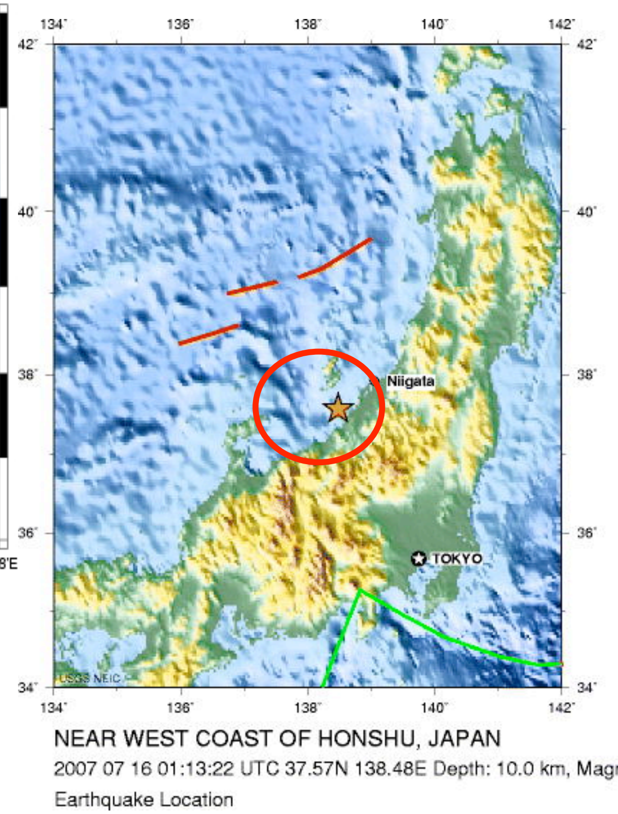
(Prospective mode)



July 4, 2007



July 14, 2007



July 16, 2007, USGS

Time evolution:

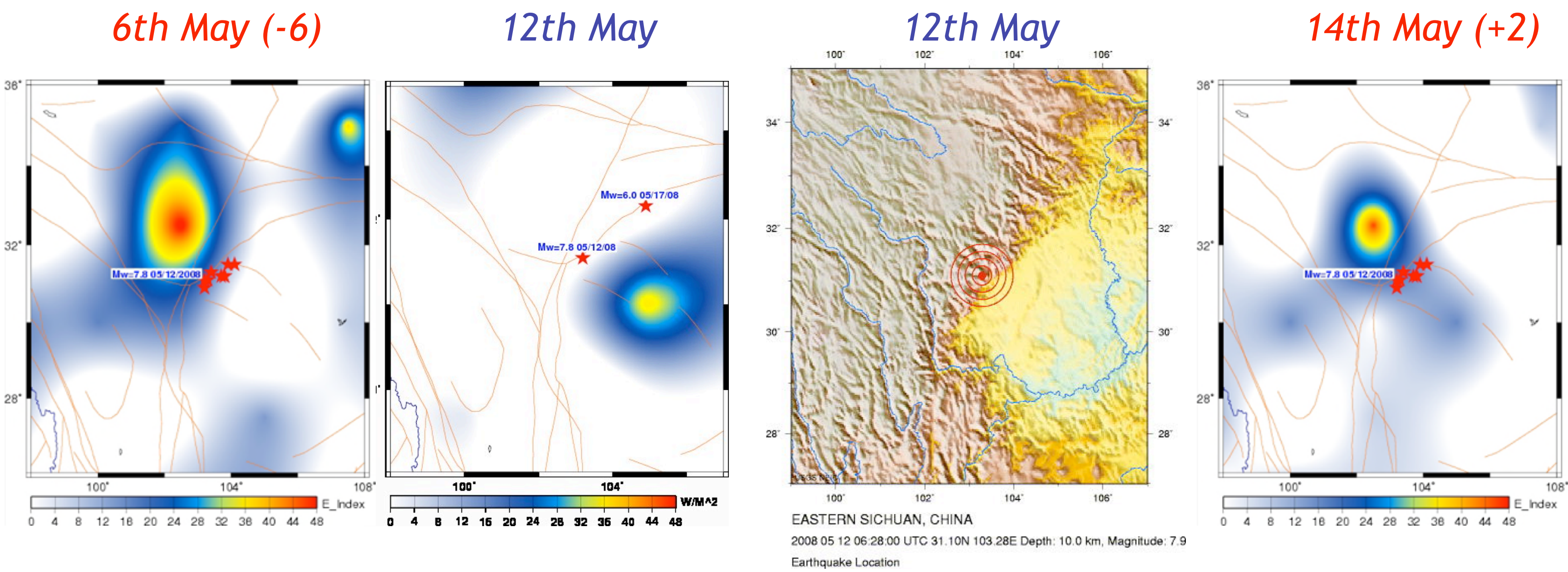
July 4 – EQ Alert

July 14- EQ Warning

July 16- EQ Event

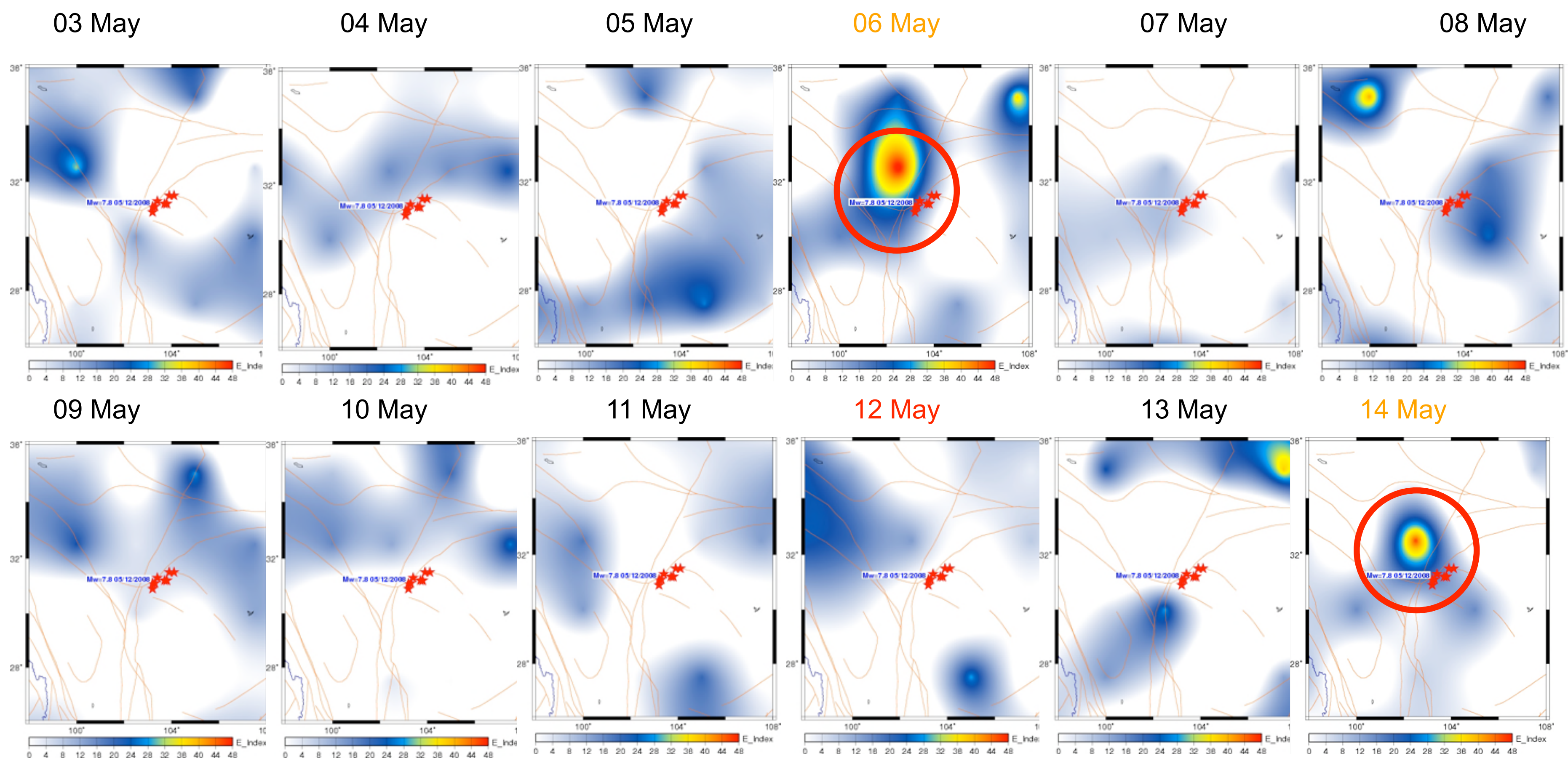
Thermal Infrared alerts around M7.9 Wenchuan Earthquake, China 2008 (Retrospective & Prospective)

- *May 6th (-6 days)- TIR signal detected , M7.9 has occurred on May 12th*
- *May 14th (-3 days) – EQ Alert#2, M6.0 has occurred on May 17th*
- *May 23rd (-2 days) – EQ Alert#3, M5.8 has occurred on May 25th*



Time-series of daily day-time radiation for (left to right) -(1)May 6th,(2)12th, (3) USGS map for (4)16th of May over the West Sichuan province (Ouzounov et al, 2008)

Hot-spot alerts around M7.9 Wenchuan Earthquake Thermal Infrared maps of daily night-time earth outgoing radiation over epicenter of M7.8 Eastern Sichuan, China May 3- May 14, 2008,



Ouzounov et al, 2008

Summary

1. *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.*
2. *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.*
3. *The lead time for thermal anomalous signals before the earthquake occurrence varies between 2 and 7 days, for GPS/TEC 1-3 days and Radon-Ion 3-10 days;*
4. *For all events we have analyzed multiple parameters including: radon counts/ions, thermal radiation, GPS/TEC and ionosphere variability. Our findings demonstrate the presence of related variations of these parameters implying their connection with the earthquake preparation process .*
5. *Next is to expand the collaboration for new regions and apply independent statistical hypothesis for validation.*

References

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- **Ouzounov D.,** S. Pulinets, K,.Hattori, M. Kafatos and P. Taylor (2011) Atmospheric Response to Fukushima Daiichi NPP (Japan) Accident Reviled by Satellite and Ground observations*,* *http://arxiv.org/abs/1107.0930*
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