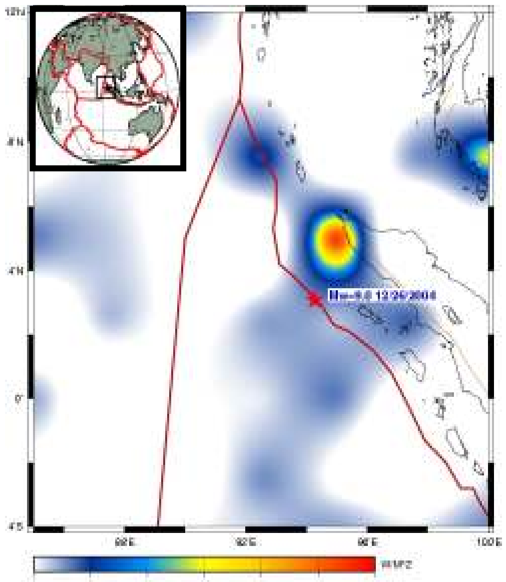
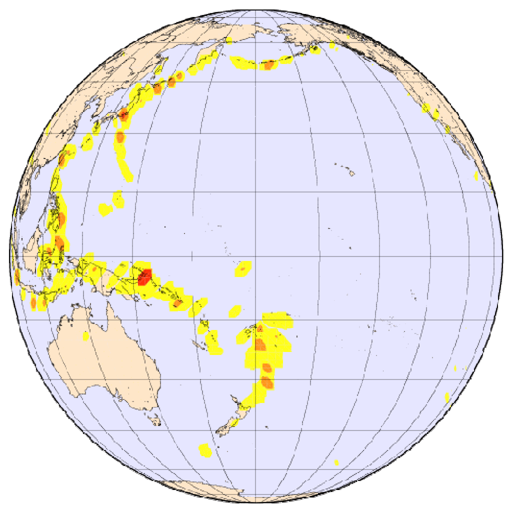
RECENT RESEARCH IN MONITORING EARTHQUAKES
by using multisenssor satellite and ground data
(a preliminary report)

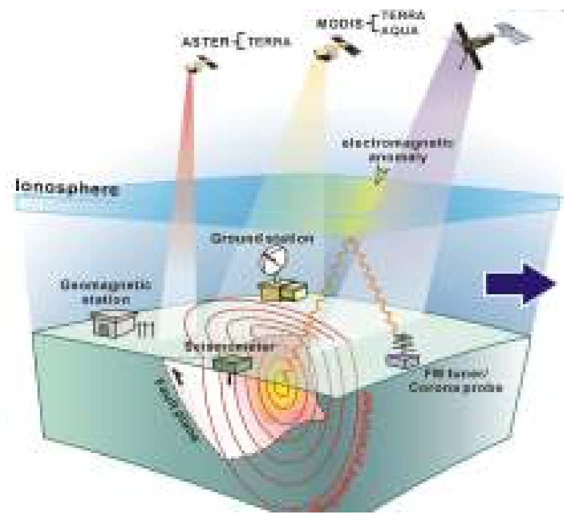


TIR anomaly prior to Sumatra
(Dec 26,2004)



Global Hotspot Map

(John Rundle, UCD)



Sensor Web Approach
(J.Liu,Taiwan)

Dimitar Ouzounov

Team Members

NASA team

D. Ouzounov, NASA/GFSC/SSAI/GMU
P. Taylor, NASA/GSFC
S. Habib, NASA/GSFC
F. Policeli, NASA/GSFC
N. Bryant, NASA JPL/Caltech

GMU team

G. Cervone, George Mason University, EGGS
M. Kafatos, George Mason University, COS

International Partners

S. Pulinets , UNAM, Mexico
M.Parrot , DEMTER,CNES, France
K. Hattori, Chiba University, Japan
V.Tramutoli, University of Basilicata,Italy
G.Ciarlo, CNRS, Florence, Italy
D. Liu, China Earthquake Administration , China
J.Y.Liu, National central University, Taiwan

Motivation

The complex and dynamic nature of the earthquake precursor phenomena requires spatial, spectral, and temporal coverage that is ***far beyond any mission****.*

Any possible links between the seismo-tectonic processes in the ground and atmosphere/ionosphere and earthquake precursors ***still are not well understood by the science community***

Objective

Sharing the knowledge *by providing new evidence about the connections between near space atmospheric and ionospheric signals related to the active faulting and earthquake processes.*

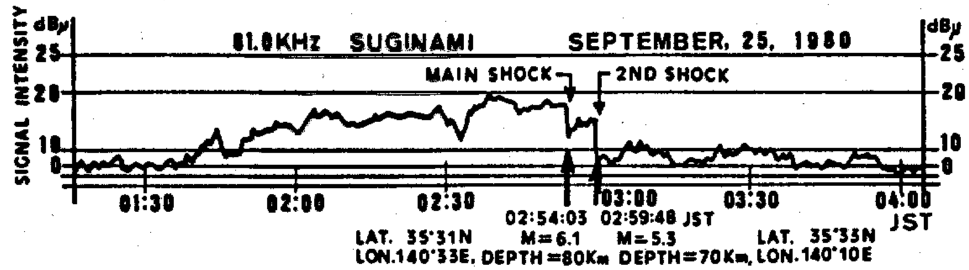
Outline of Presentation

- Science Background of EM Earthquake phenomena
- Lithosphere – Atmosphere-Ionosphere Coupling (LAIC)
- Sensor Web Approach
- Case studies of detected eartquake precurors -Sumatra, Kashmir, Peru
- Conclusions

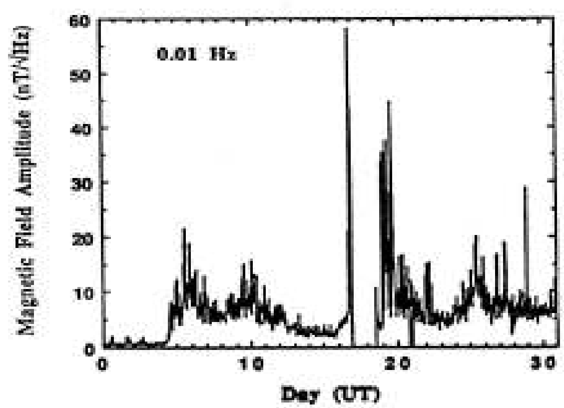
Ground EM earthquake precursors in historical order

First scientific paper on the seismo-electromagnetic effects by Milne in 1890

Gokhberg et al. (1982)



Loma Prieta, A.F.Smith (1994)



Kobe Earthquake, Uyeda (1995)

Satellite EM earthquake precursors in historical order

1. *Ionospheric precursors (large scale) (60-70th)*
2. *Optical emissions (beginning of 80th)*
3. *VLF emissions (middle of 80-th)*
4. *Particle precipitation (end of 80-90th)*
5. *Ion mass changes (middle of 90th)*
6. *ELF emissions (middle of 90th)*
7. *Small-scale irregularities (middle of 90th)*
8. *Thermal precursors (end of 90th)*

Pulinets, 2004

Earthquake precursors

- Planetary positions
- Ground deformations
- Geomagnetic methods
- Energy accumulation rate
- Earthquake clouds
- Gravity anomalies
- Ground water level
- Radon concentrations
- Meteorological conditions
- Thermal infrared
- Infrasound
- Crustal stress
- Abnormal behaviour of animals
- Geo-electric pulse
- Historical/statistical data
- Ground-based EM field
- Tilt meters
- GPS
- TGFR
- MS-Double Time Method
- Geo-electricity
- Micro-vibration
- Earth resistivity
- Geochemistry
- Seismic gap
- Foreshocks
- Geodesy
- Micro-changes
- Ionosphere

Vandergeden(2005)

Earthquake precursors

- *Planetary positions*
- *Ground deformations*
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- *Geochemistry*
- *Seismic gap*
- *Foreshocks*
- *Geodesy*
- *Micro-changes*
- ***Ionosphere***

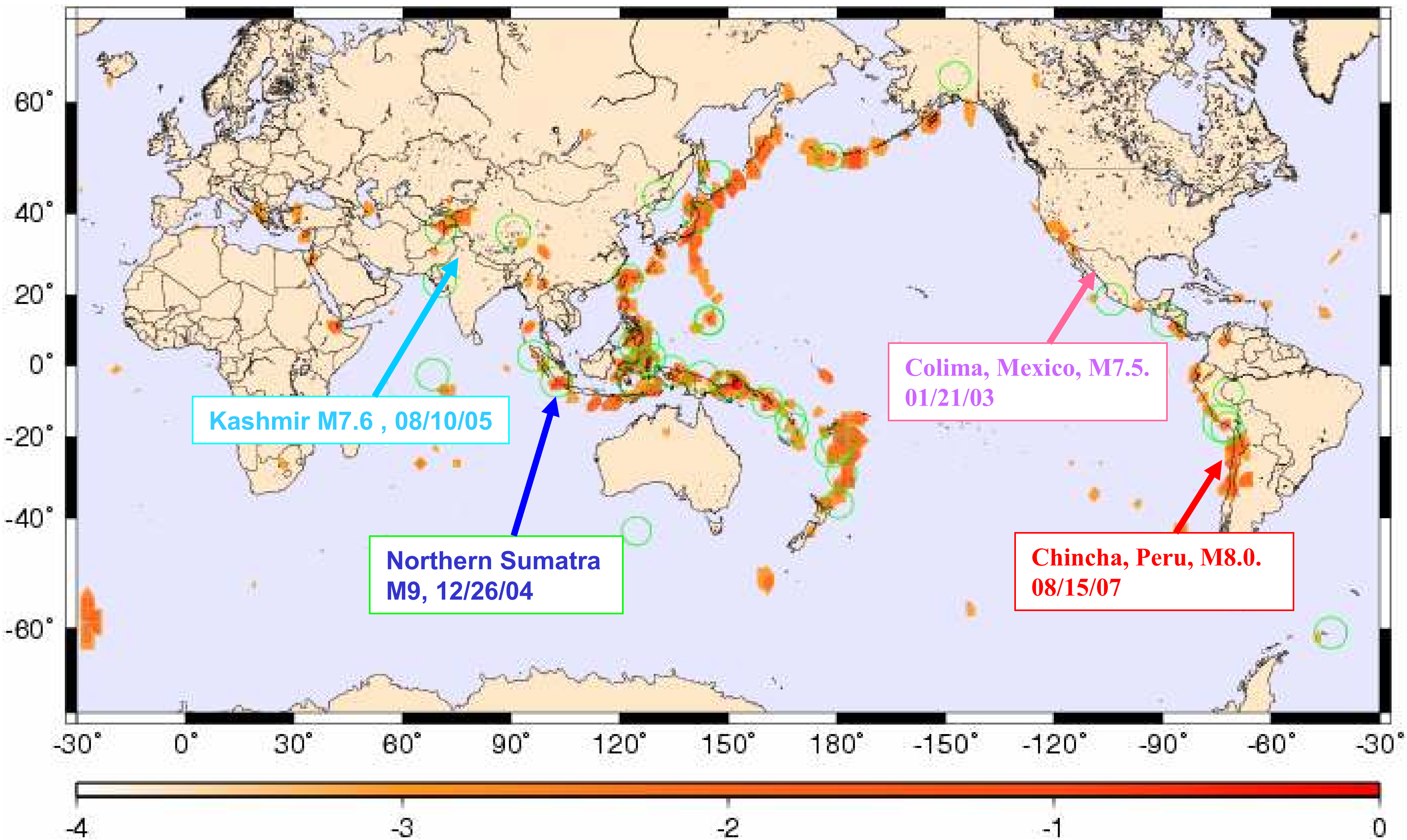
Vandergeden(2005)

Earthquake prediction in US: Probabilistic seismic hazard models running at the Southern California Earthquake Center

- *Jackson-Kagan Null Hypothesis*
- *Short-term Forecasts Based On Past Seismicity And Earthquake Clustering*
- *Keillis Borok (UCLA) identifying patterns of small earthquakes as precursors to large ones*
- *Pattern Informatics (PI) Method – J.Rundle (UCD)*

World-Wide Forecast Hotspot Map for Likely Locations of Great Earthquakes $M \geq 7.0$ For the Decade 2000-2010(Rundle, 2004)

Green Circles = Large Earthquakes $M \geq 7$ from Jan 1, 2000 – Dec 1, 2004



Earthquake Early Warning system
(by seismological observation)

Purpose: Actions to be taken with 10 and 50 seconds of warning

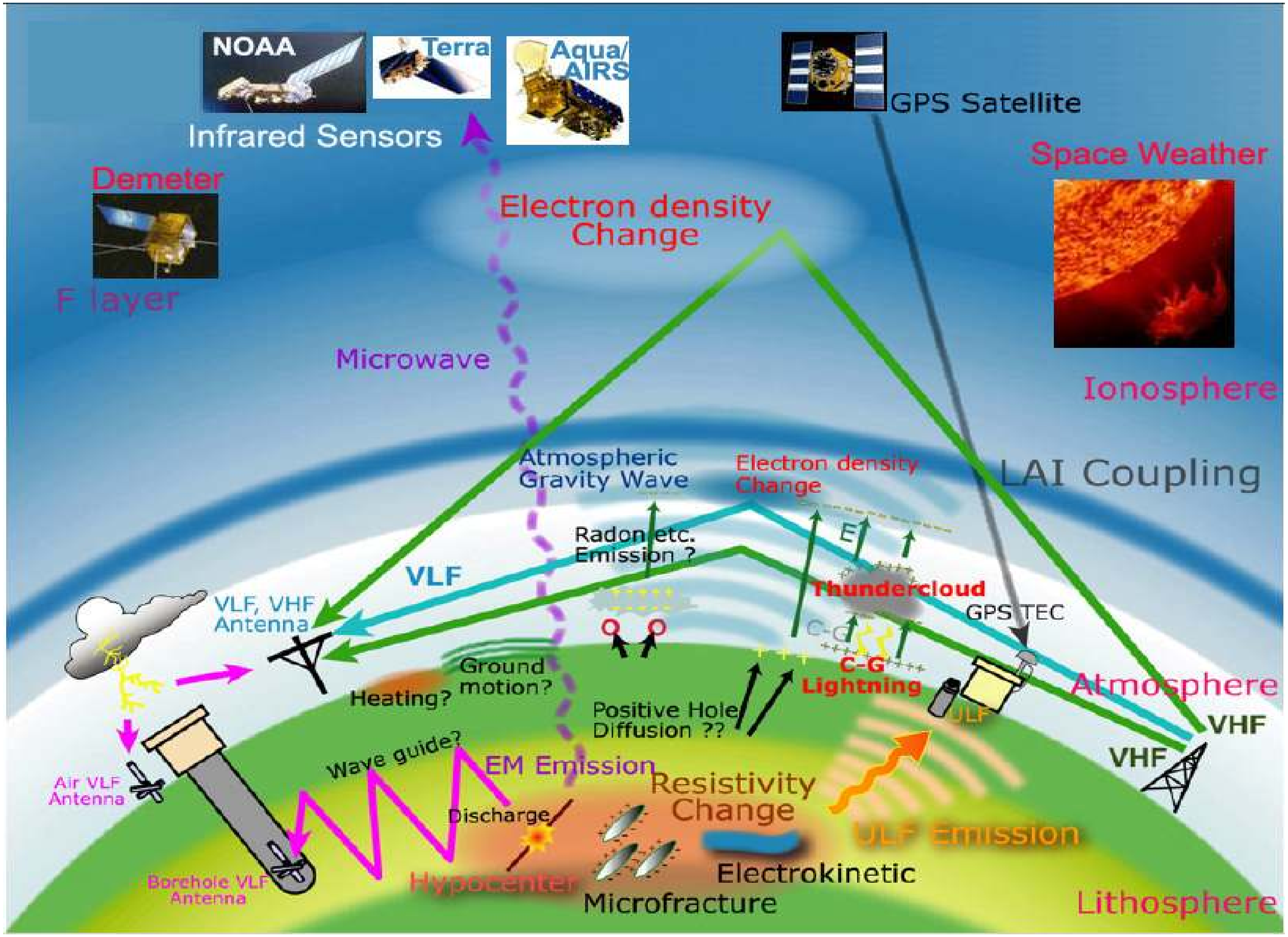
Users: Education, Health Care, Emergency Services Utilities & Transportation

Existing pilot systems:

1. *California , USA (TRInet, USGS)*
2. *Mexico City*
3. *Japan*
4. *Turkey*
5. *Taiwan*

Concept of Lithospheric - Atmosphere-Ionosphere Coupling (LAIC)

Lithosphere-Atmosphere-Ionosphere (LAI) Coupling



D. Ouzounov: Recent Research in Monitoring Earthquakes … Sept 12, 2007

Mechanism of Lithosphere -Atmosphere -Ionosphere (LAI) Coupling Model

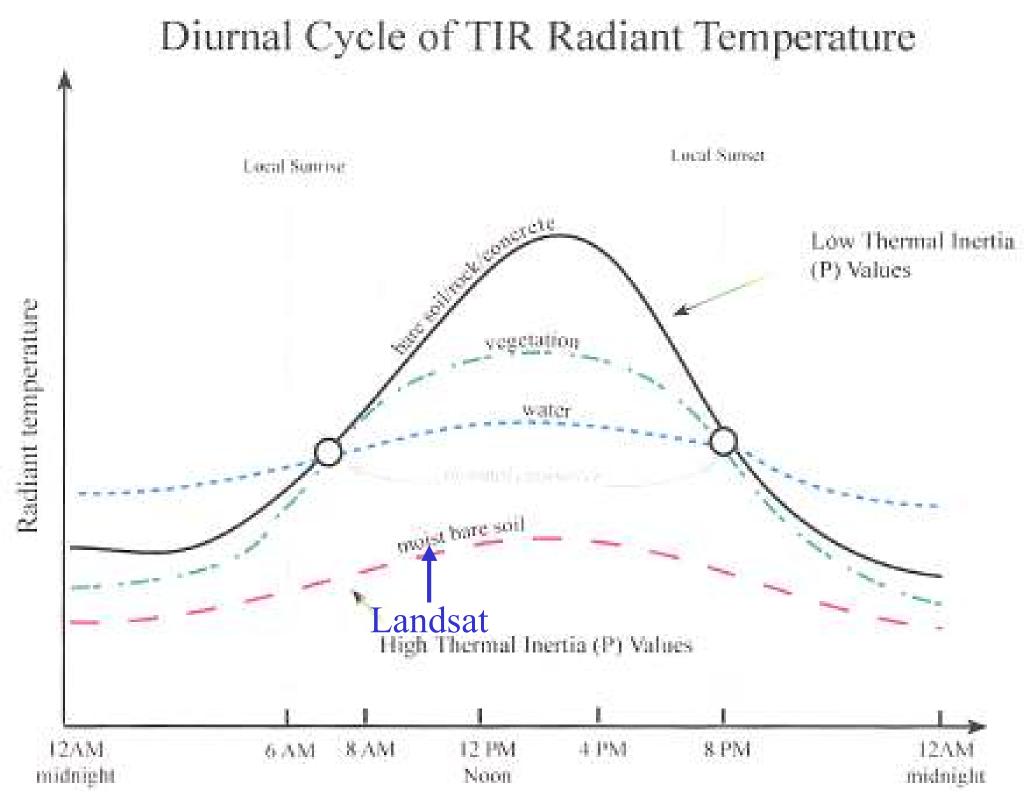
L-A

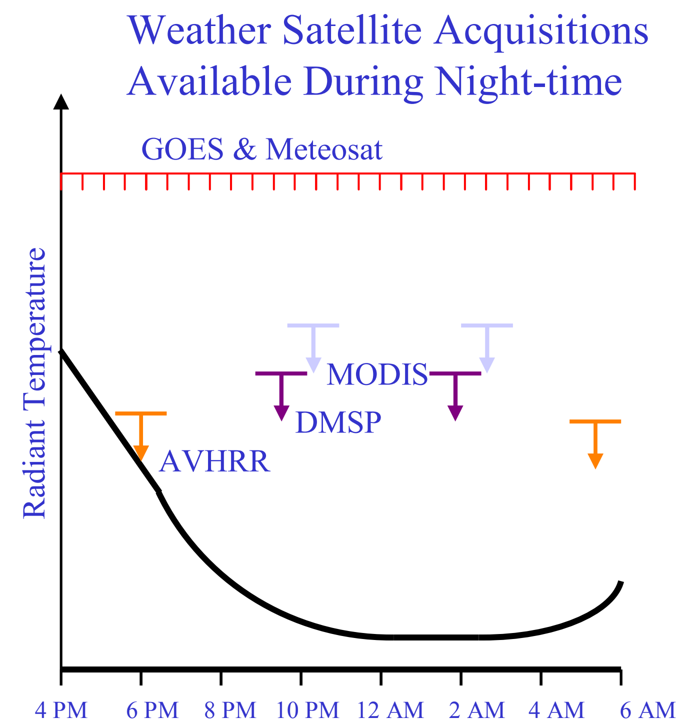
- Gas (Rn) emanation variations
  - Ionization
  - Complex ion clusters formation
  - Hydration
  - Latent heat release
  - Changes of air temperature and humidity

A-I

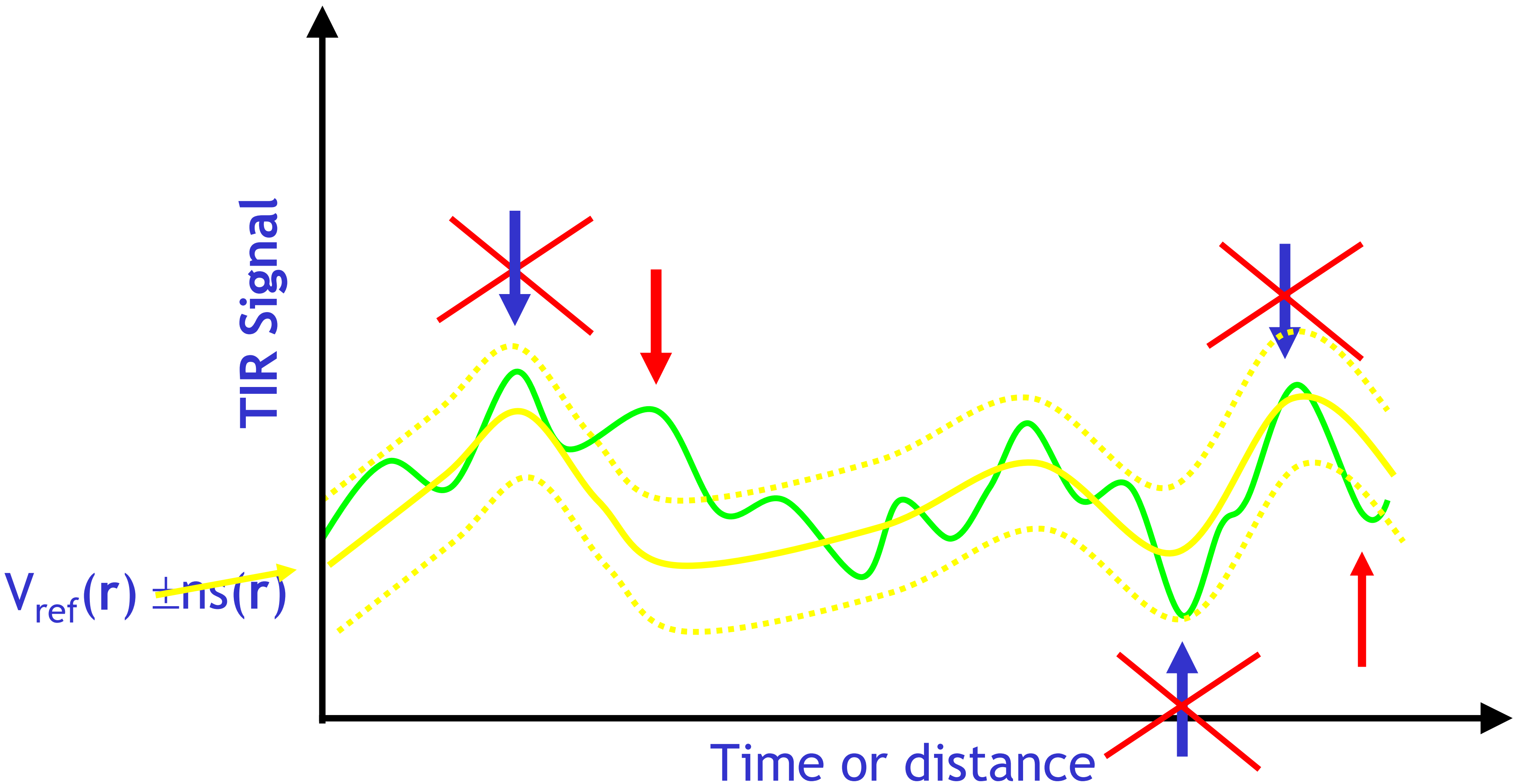
- Charged ion clusters – atmospheric plasma
  - Charge separation
  - Anomalous electric field generation
  - Electric field penetration into ionosphere
  - Sporadic E-layers formation
  - Large scale irregularities in F-region
  - Effects in magnetosphere ducts formation, VLF guiding stimulated particle precipitation
  - Modification of D-region

Normal TIR Diurnal Temperature Cycle and Satellite Acquisitions





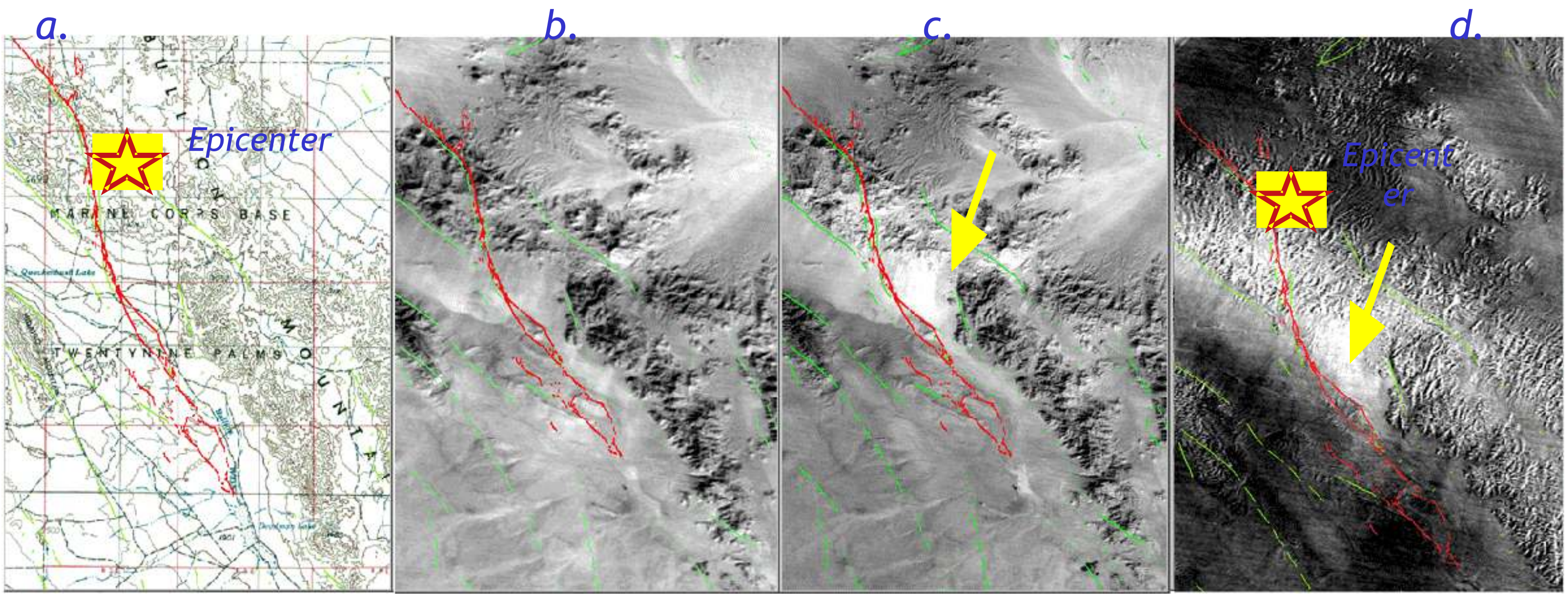
What "anomaly" means ?



[Tramutoli, 2004]

M5.7, 10/16/1999, Hector Mine (CA)
Landsat Acquisitions, band 6, μ10.4-12.5

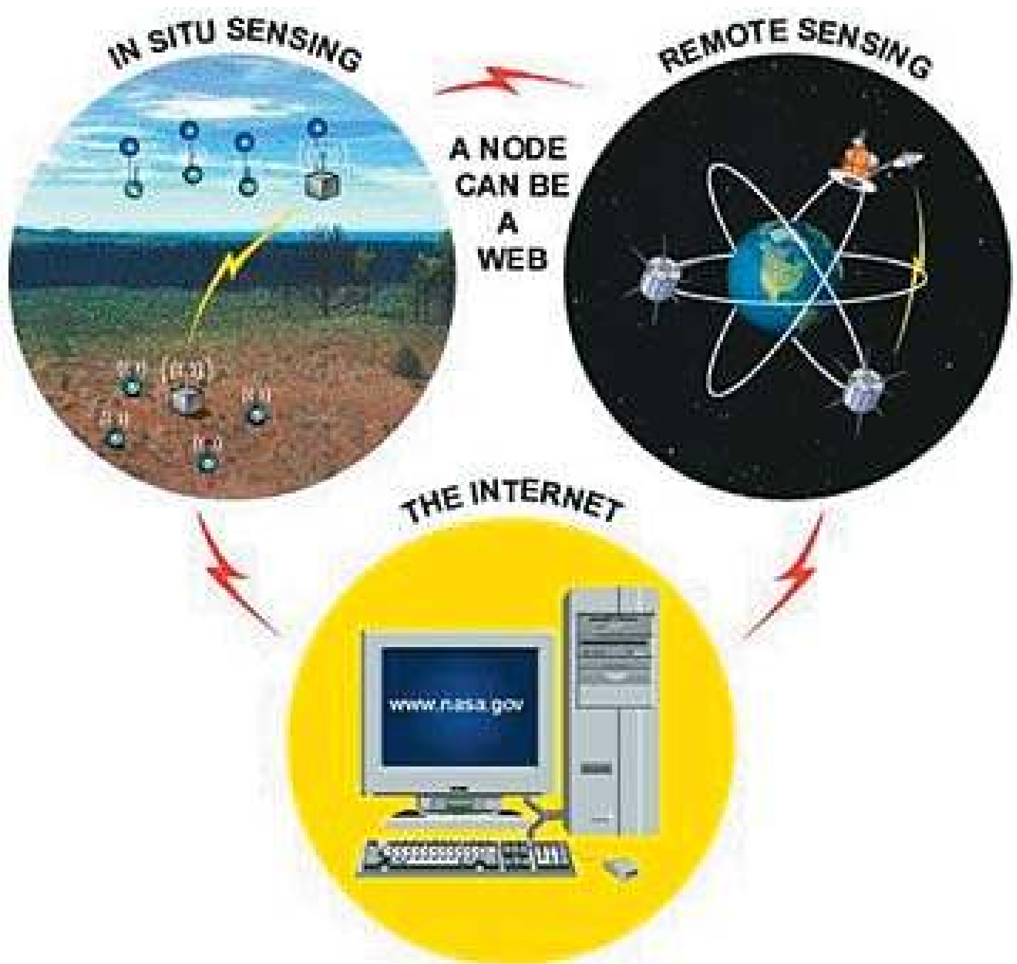
Thermal Anomaly Observed on 15 October 1999, Fifteen Hours Prior to the Hector Mine, CA Earthquake.
(Note : Landsat thermal band is not directly calibrated with temperature, images are relative temperatures)
a. Location Map provides orientation with an overlay graphic (in red) of the surface trace of the fault.
b. 20 October 1998 Landsat Image (one year prior to the earthquake)
c. 15 October 1999 Landsat image acquired 15 hours prior to earthquake. Bright pixels relatively hotter.
d. Difference image of Landsat images taken 1 year apart. Brighter areas are warmer in 1999.



[Bryant 2003,
Ouzounov et al., 2005]

joint EQ precursors analysis-Sensor Web Approach

Sensor Web



Sensormag.com

What is sensor Web (SeWeb):

- *SeWeb a coordinated observation infrastructure employing multiple sensors that are distributed on one or more platforms.*
- *SeWeb it facilitates maximal use of existing multiple and already validated physical measurements*
- *SeWeb can integrate data and model in one framework and to provides feedback on data gaps which may then be acquired from other sources.*

Possible earthquake precursory signals we are investigating

Geophysical signature	*Source*	*Data*
Thermal infrared	*MODIS, AIRS*	*LST, SST*
	NOAA/AVHRR 15,16,17	*OLR*
Surface heat flux	*NCAR-data center*	*SLHF*
Total Electron Content	*GPS*	*Dual frequencies*
Ionospheric variability	*DEMETER*	*VLF/ELF, Te, Ne, Ni, Ti,*
Radon concentrations	*ground measurements*	*Gamma*
Meteorological information	*MODIS,GOES, METEOSAT*	*RGB, Cloud data*

* ***VLF*** *– very low frequency,* ***SLHF-*** *surface latent heat flux,* ***TEC****- total electron content,* ***TIR-*** *thermal infrared,* ***LST-****Land surface temperature,* ***SST****- Sea surface temperature,* ***OLR*** *– Ongoing long wave radiation,* ***NCAR*** *- National Center for Atmospheric Research.*

Elements of the joint EM analysis

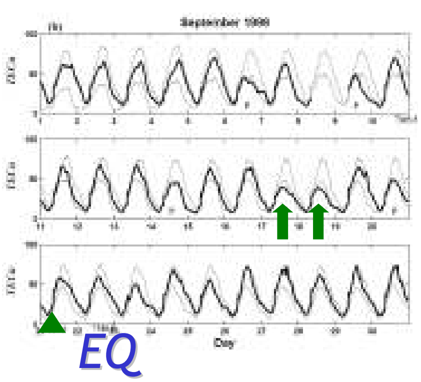
(i) GPS Total Electron Content (TEC) – Liu et al, 2000,2004, Pulinets et al, 2006;

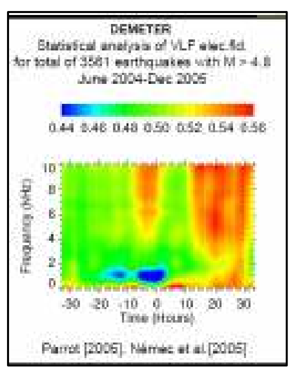
(ii) Ionospheric electromagnetic plasma measurements from the DEMETER satellite- Parrot et al 2005,Nemec et al, 2005;

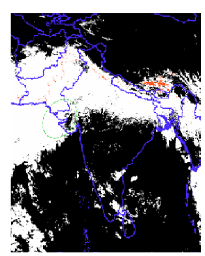
(iii) TIR and emitted long-wavelength radiation – Tramutoli et al., (2004, 2007),Ouzounov et al, 2007;

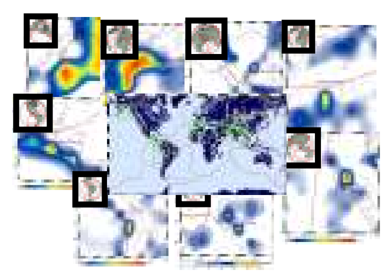
(iv) Surface latent heat flux (SLHF) from NOAA/NCEP – Cervone et al, 2005;

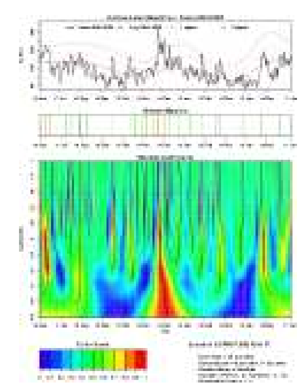
(v) MODEL: Lithosphere-Atmosphere-Ionosphere Coupling (LAIC) – Pulinets et al, 2004, 2006











Temporal sequence of short-term EM precursors

(i) ***Ground surface thermal anomaly appears*** *2 weeks – few days before the seismic shock (radon from underground to surface)*

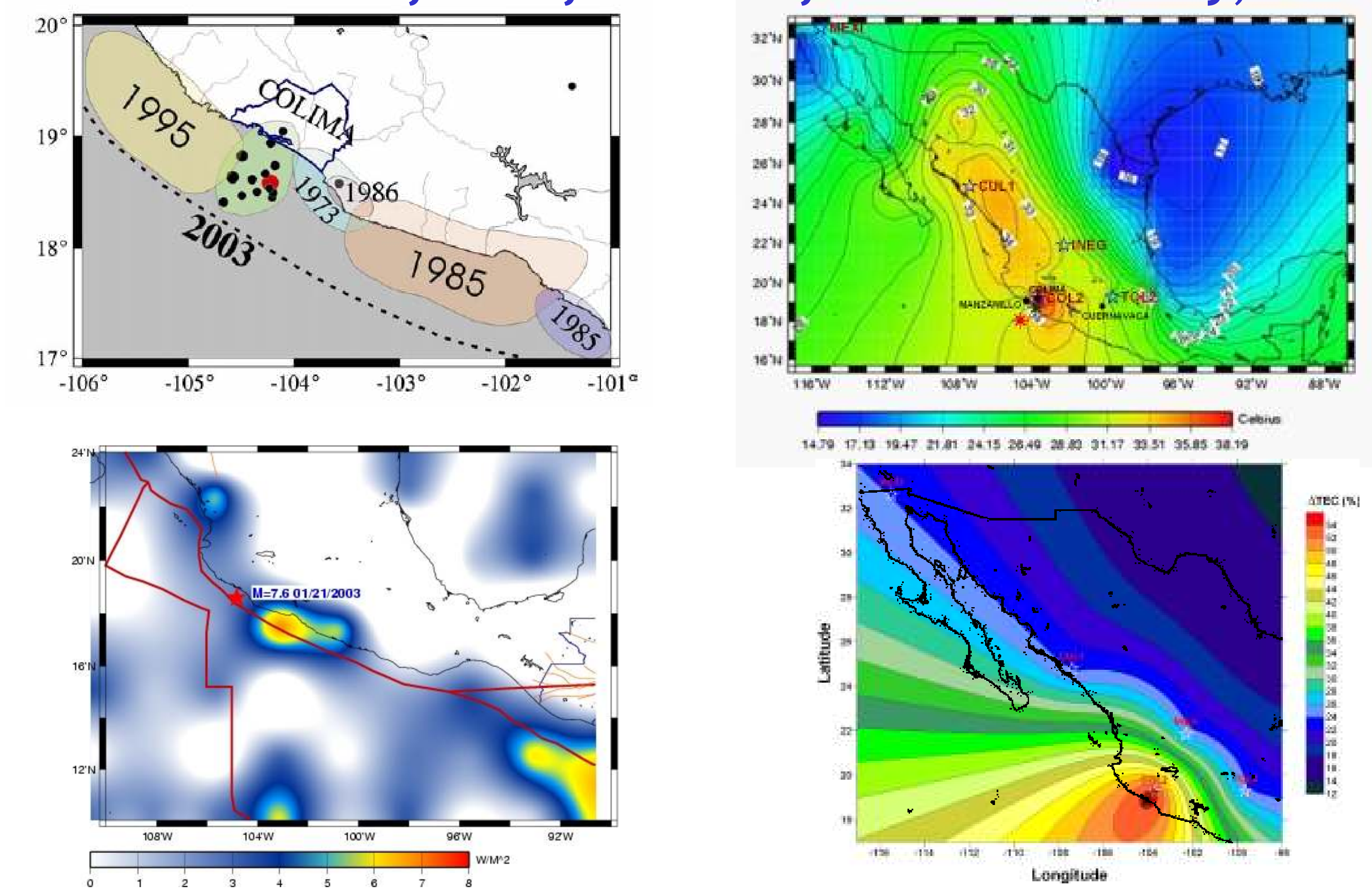
(ii) ***Negative trend of air humidity*** *(Radon flux increase over the ground surface)-positive trend of the air temperature and daily temperature range (up to two weeks before the seismic shock)*

(iii) ***Humidity minimum*** *(Radon maximum), maximum of daily temperature range – 1 week – 5 days before the seismic shock, formation of neutral clusters*

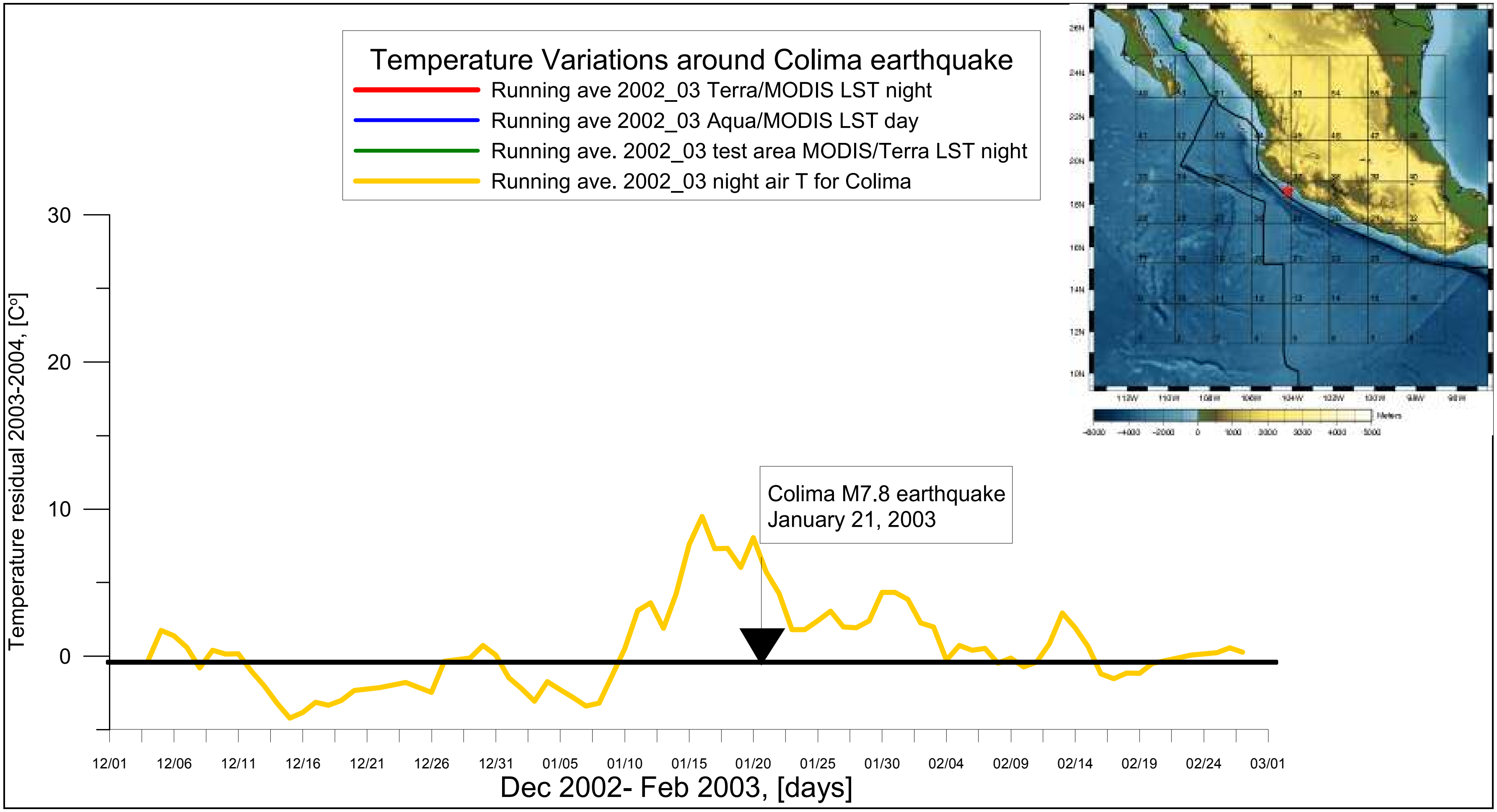
(iv) ***Increase of the air humidity*** *(Radon decreases), anomalous SLHF, neutral clusters break, generation of anomalous electric field – ionospheric anomalies (5 days – 1 day before the seismic shock)*

M7.6 Colima (Mexico) 01.22.2003

(1)Seismo-tectonics settings;(2) Surface temperature at Mexico on January,14 2003 at 1410 LT; (3) Earth radiation for Dec/Jan 2003; (4) Spatial distribution of ΔTEC from INEGI for 1010 LT January, 18 2003



Joint temperature variations (A, B, and C) satellite, and ground air temperature (D) variations around M7.6 Colima (Mexico) 01.22.200



Running average of the difference T2003 – T2004 of Nighttime MODIS/Terra LST (A-red), Daytime MODIS/Aqua LST (B-blue), Night time MODIS/terra LST for tested area (300 km south form Colima epicenter) computed in 50x50 km area around the epicenter. D. Running average of the difference T2003 – T2004 of air nighttime temperature (D -orange) distribution in the time of MODIS/Terra satellite local time passing. (Pulinets, Ouzounov, et al, 2006)

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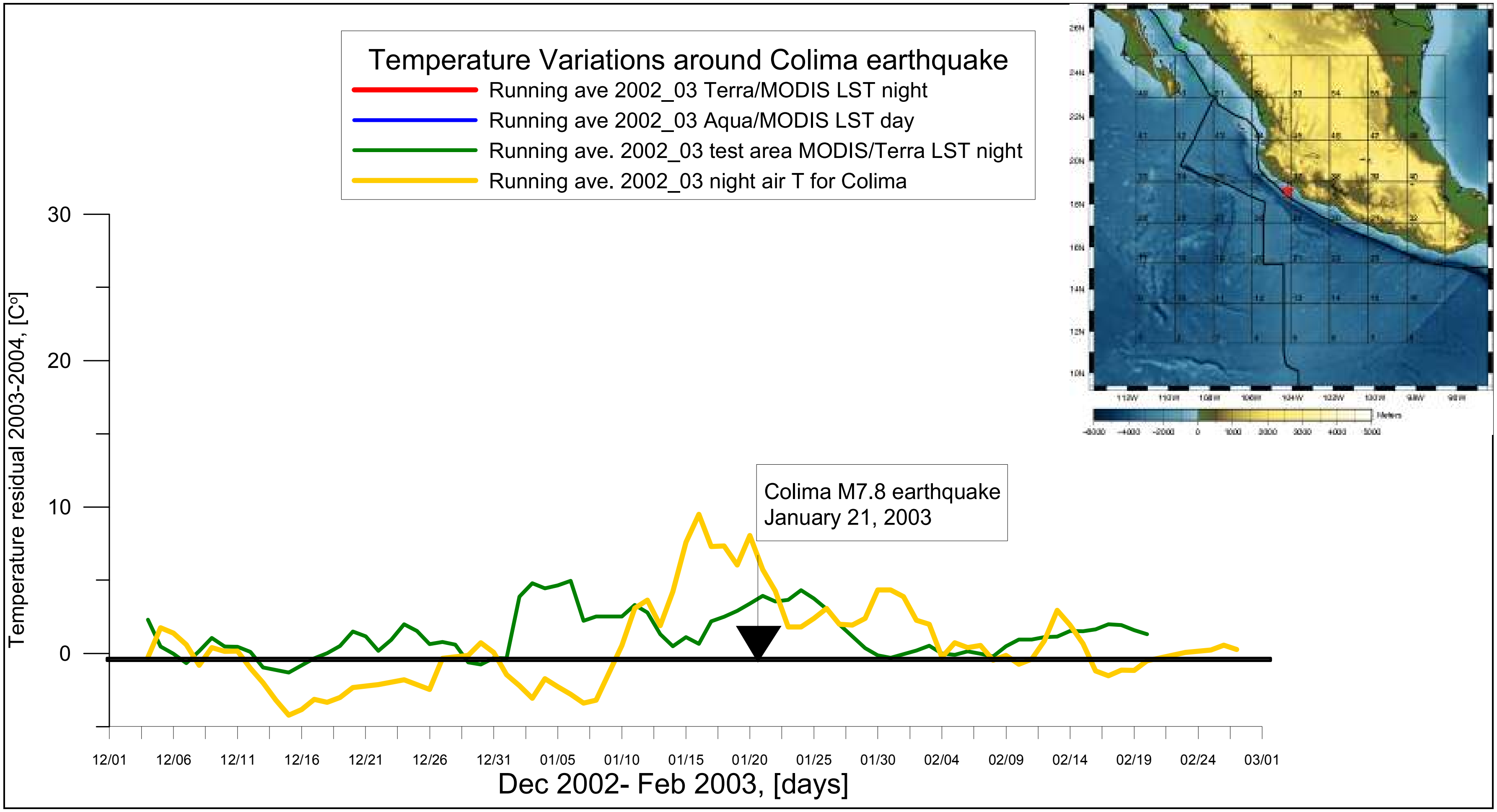

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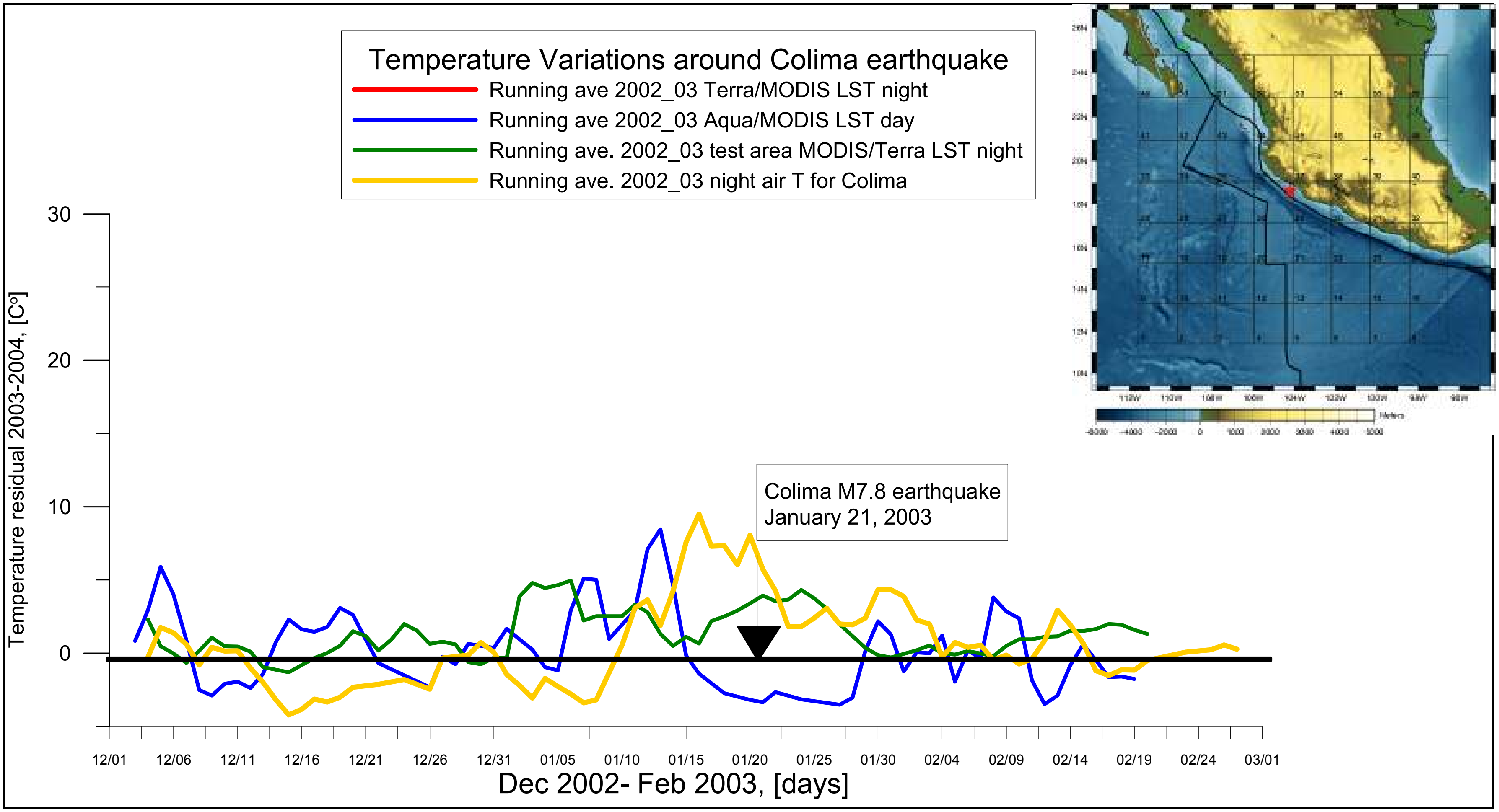

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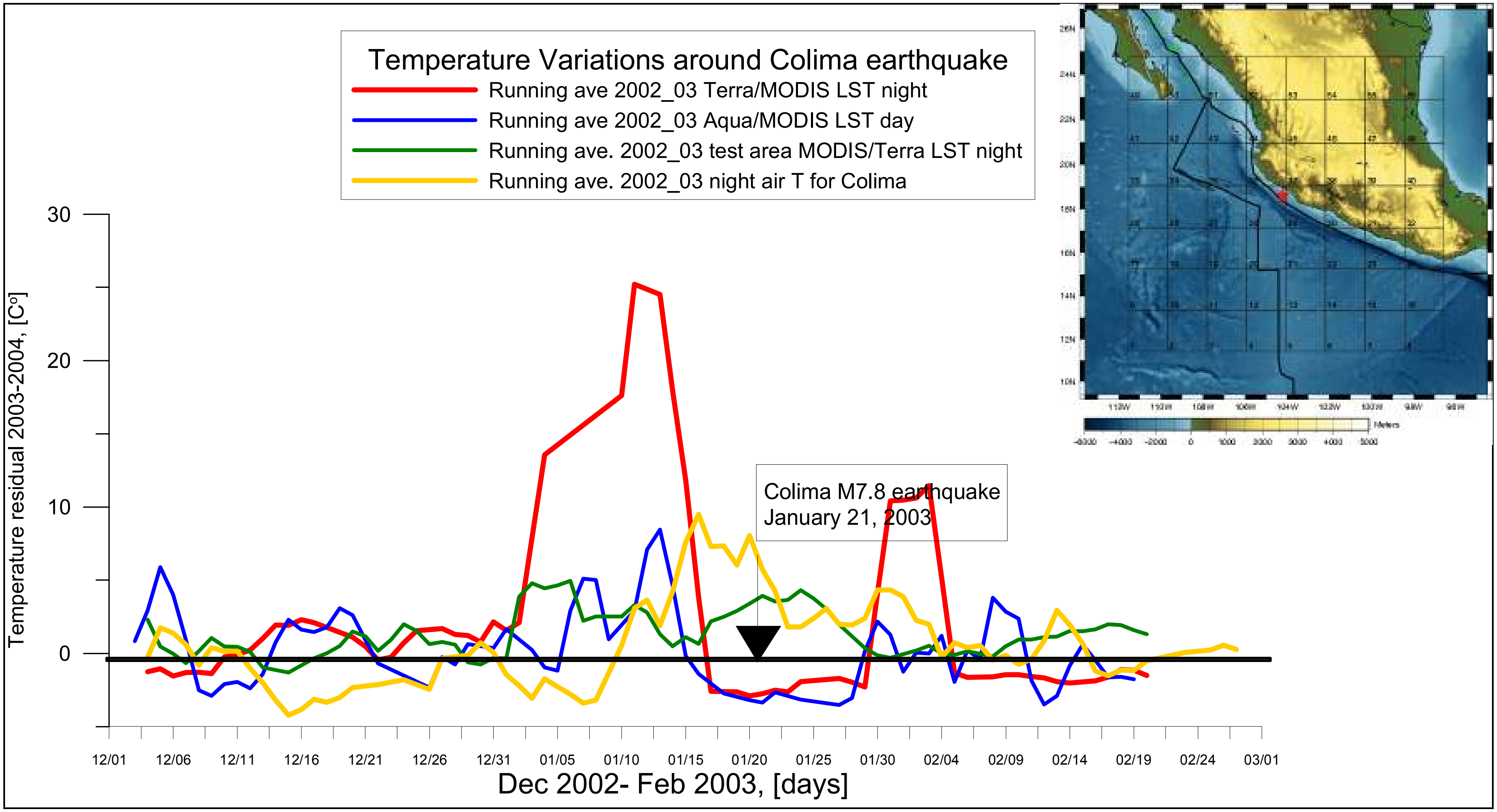

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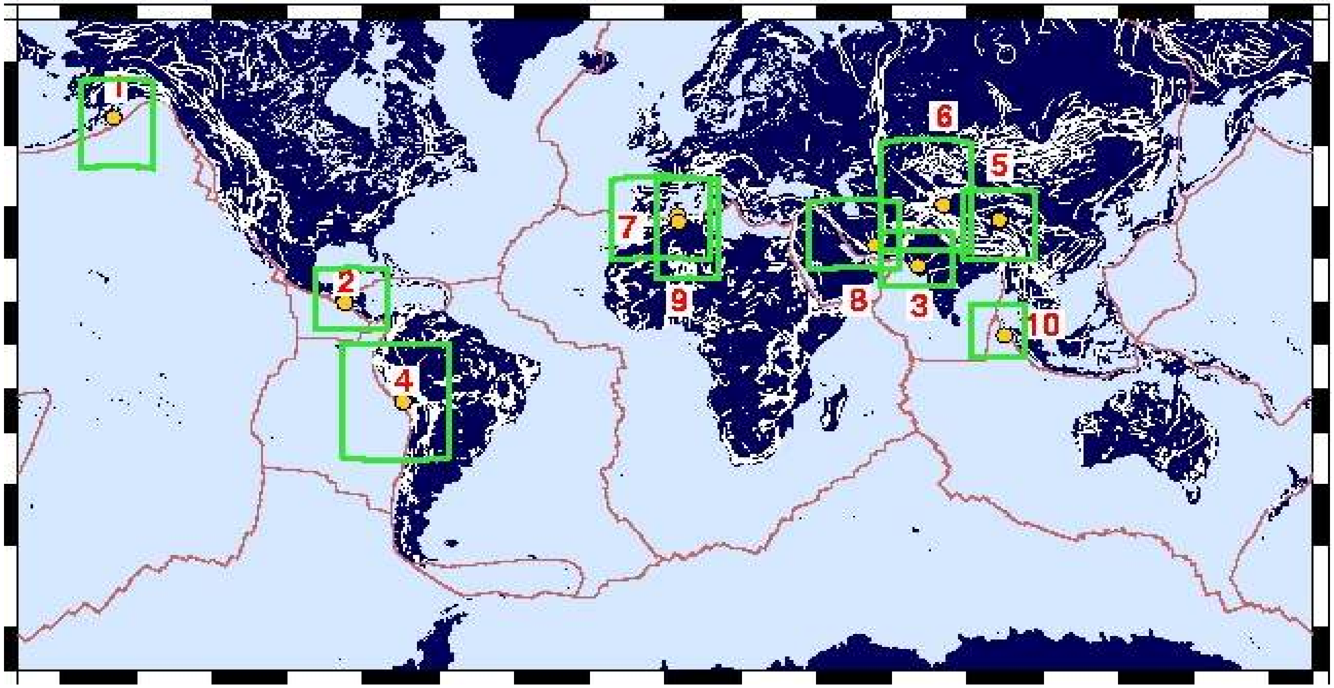
Case studies of world-wide earthquake analysis

Up to today were analyzed more then
150 M>5.0 (TIR,OLR,GPS/TEC, OLR, SLHF,T/H,DEMETER)
4,000 M>5.0 earthquakes (SLHF)

Global analysis of OLR variability prior to major earthquakes 2001-2005



Name	Date	Location	Time	Mw	H (km)	Type	Toll
3. Bhuj, Gujarat, India	01/26/2001	23.63N/70.24E	03:16:41	7.9	23.6	Thrust Fault	20,000
7. Boumerdes, Algeria	05/21/2003	36.93 N/3.58E	18:44:19	6.8	10.0	Thrust Fault, Strike slip	2,300
8. Southeastern Iran	12/26/2003	29.10N/58.24E	01:56:58	6.6	15.0	Strike-slip fault	31,000
10.Sumatra,Indonesia	12/26/2004	3.09N/ 94.26E	01: 1:9.0	9.0	28.6	Mega trust	284,000
11. Kashmir,Pakistan	10/08/2005	34.43N/73.54E	03:50:38	7.6	10.0	Strike-Slip	100,000

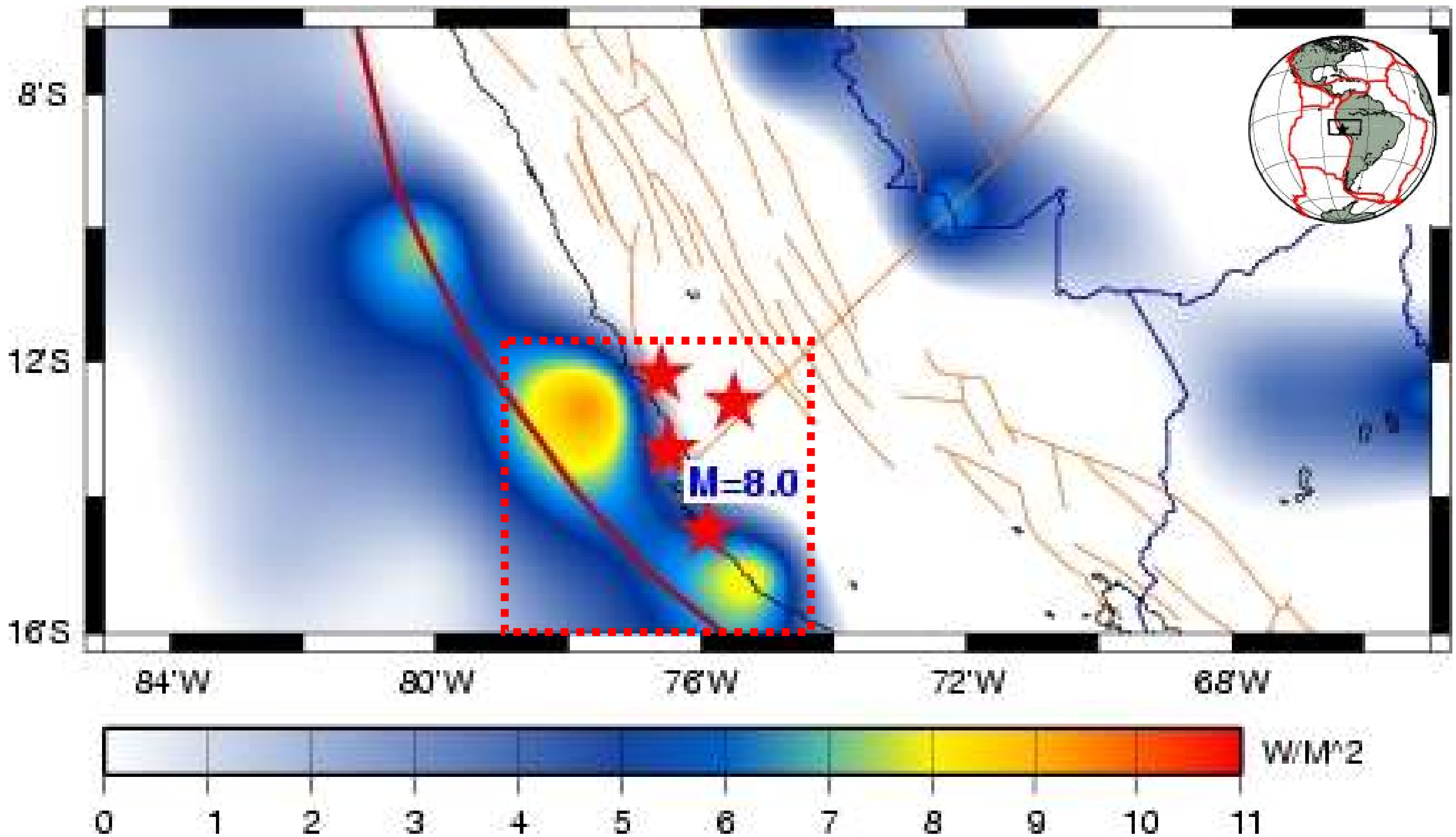
Peru M8.0 08.15.2007

2001	*06*	*23*	*-16.26*	*-73.64*	*33*	*8.40*
2001	*06*	*26*	*-17.75*	*-71.65*	*24*	*6.70*
2001	*07*	*07*	*-17.54*	*-72.08*	*33*	*7.60*
2006	*10*	*20*	*-13.46*	*-76.68*	*23*	*6.70*
2007	***08***	***15***	***-13.41***	***-76.61***	***39***	***8.00***

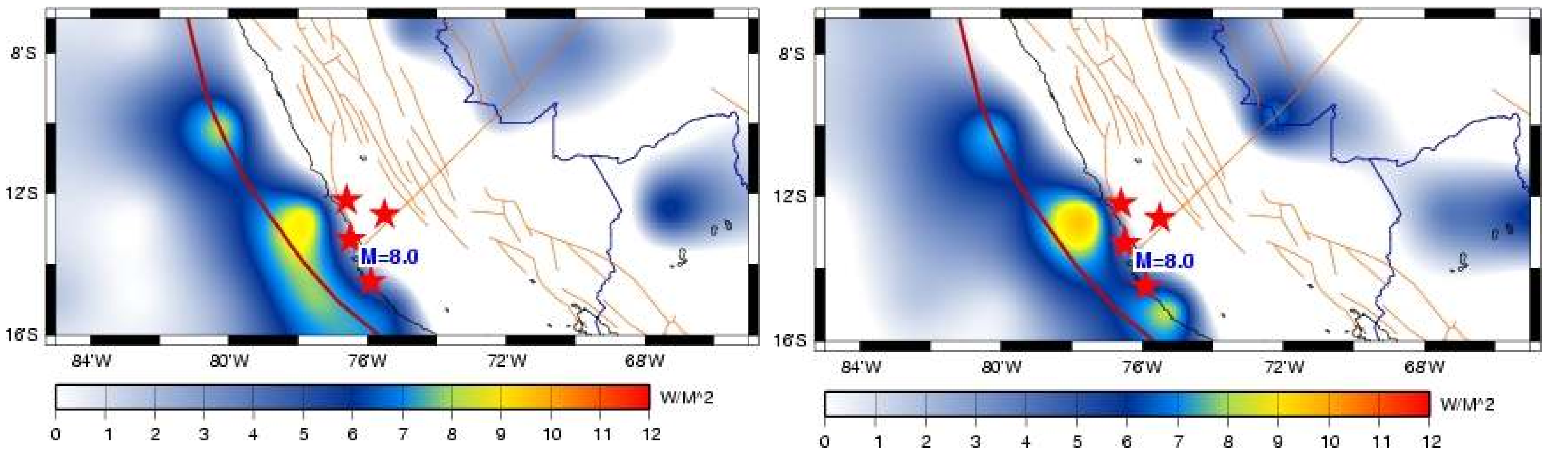
M 8.0 Peru 08.15.2007.MODIS RGB Terra (left) and Aqua (right) on 08.09.2007

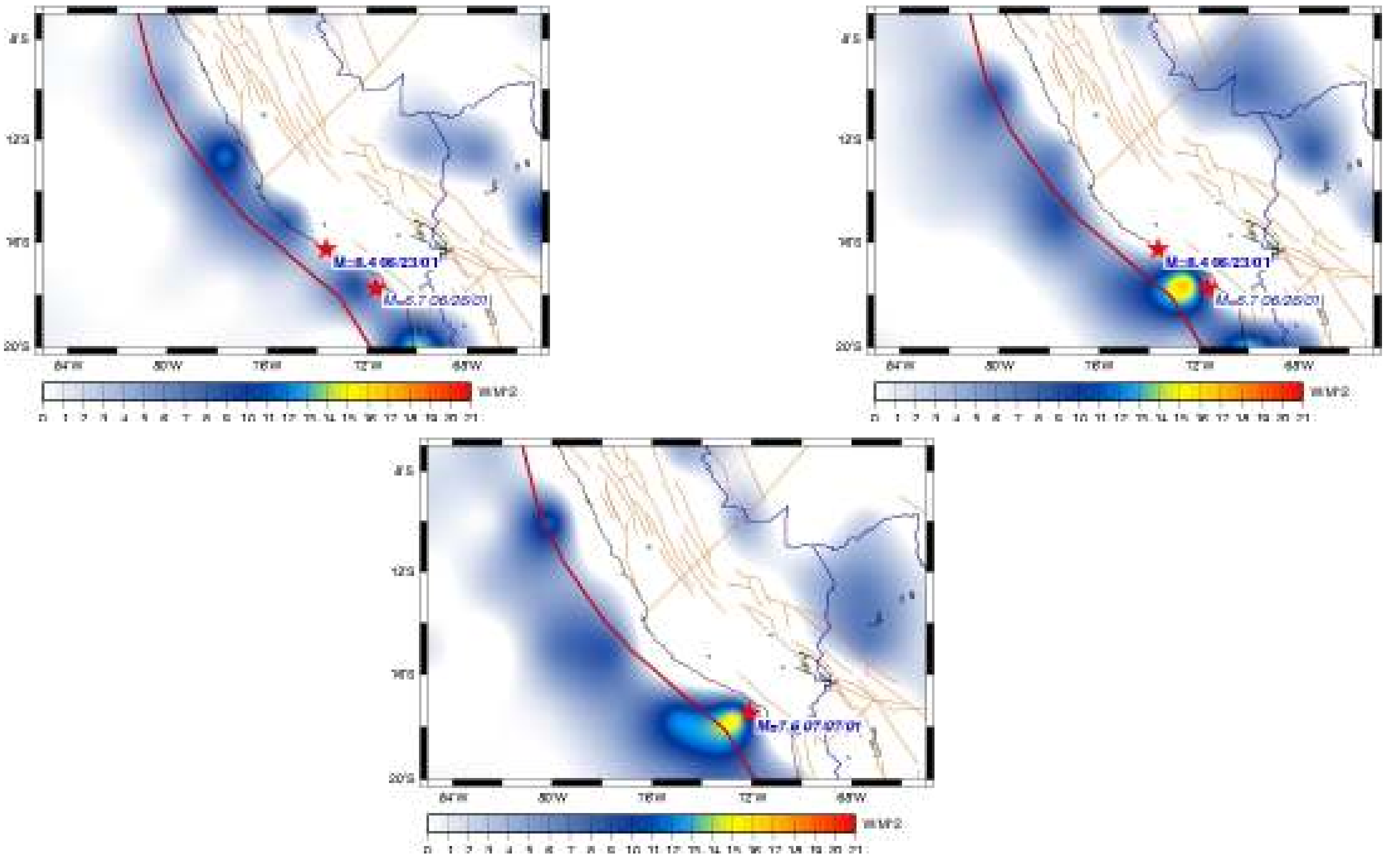
M 8.0 Peru 08.15.2007.**Monthly (August 2007) Earth radiation anomalies over Peru. The "Anomalous" level was defined for period of 1980-2007** (tectonic plate boundaries are with red line, main tectonic faults are with brown line)



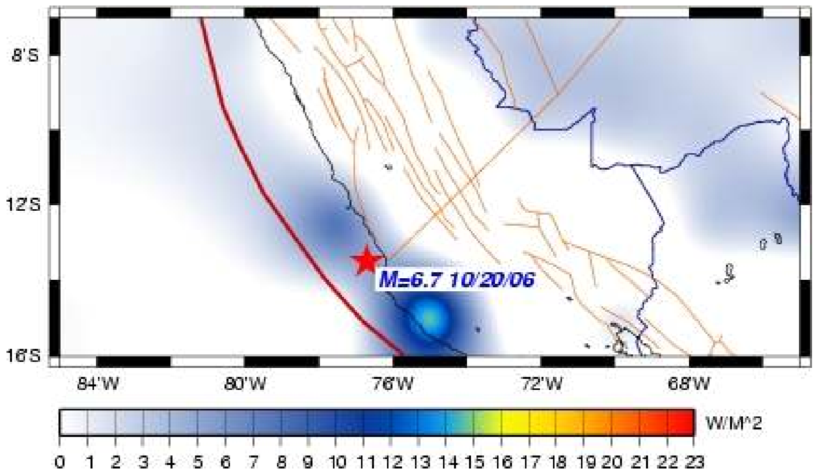
Monthly July 2007 and August 2007 Earth radiation Eddy field over Peru. The "Anomalous" level was defined for period of 1980-2007 (tectonic plate boundaries are with red line, main tectonic faults are with brown line)

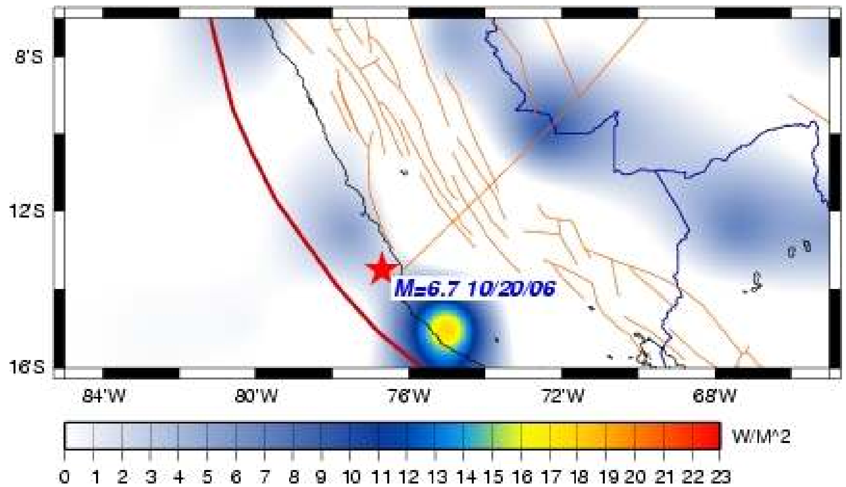


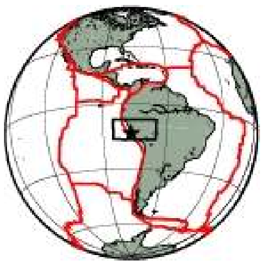
Monthly May, June and July 2001 Earth radiation Eddy field over Peru. The "Anomalous" level was defined for period of 1980-2007 (tectonic plate boundaries are with red line, main tectonic faults are with brown line)



Monthly July 2007 and August 2007 Earth radiation Eddy field over Peru. The "Anomalous" level was defined for period of 1980-2007 (tectonic plate boundaries are with red line, main tectonic faults are with brown line)

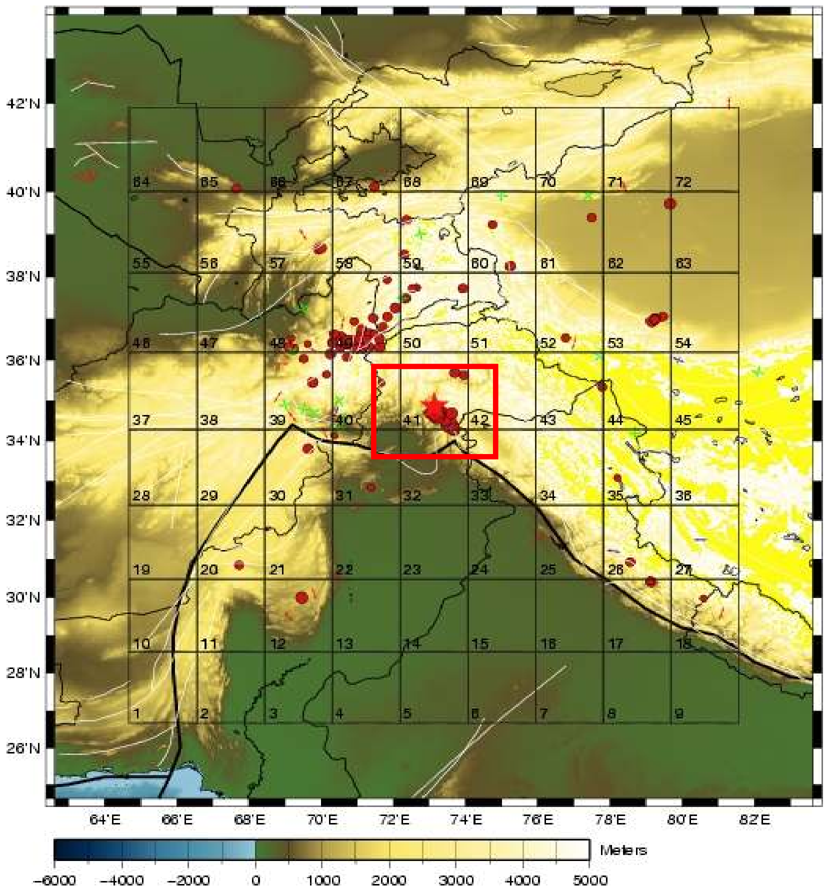


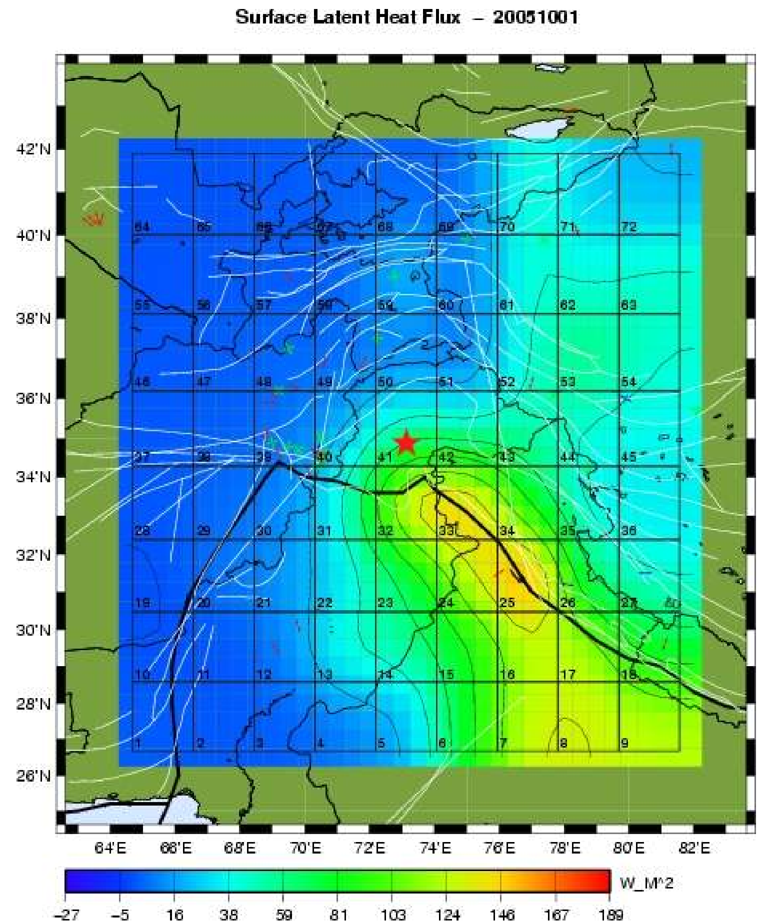




M7.6 – Kashmir /PAKISTAN, 2005 October 8 03:50:40 UTC

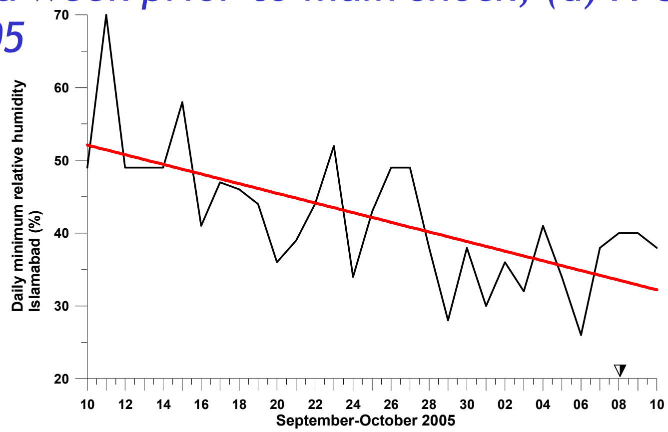
(1) Sesimo-tectonic settings (2) Anomaly of surface latent heat flux on Oct 1. 2005

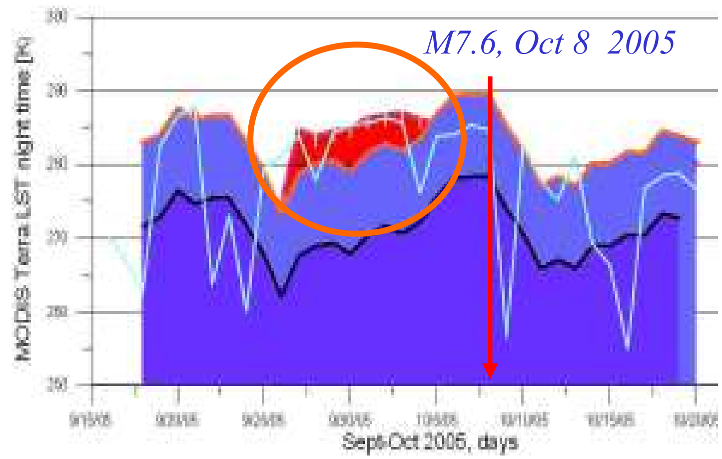




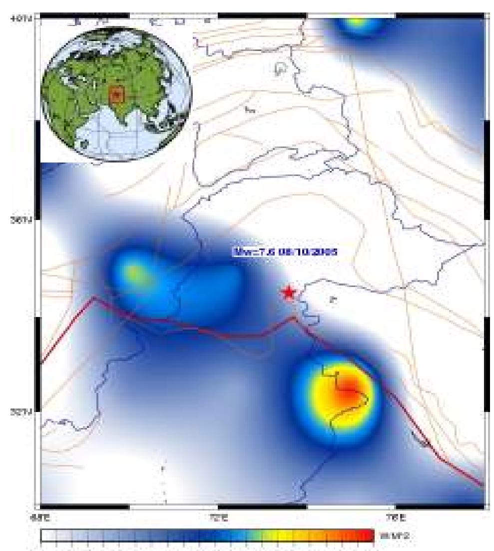
M7.6 Kashmir /PAKISTAN, 2005 October 8 03:50:40 UTC

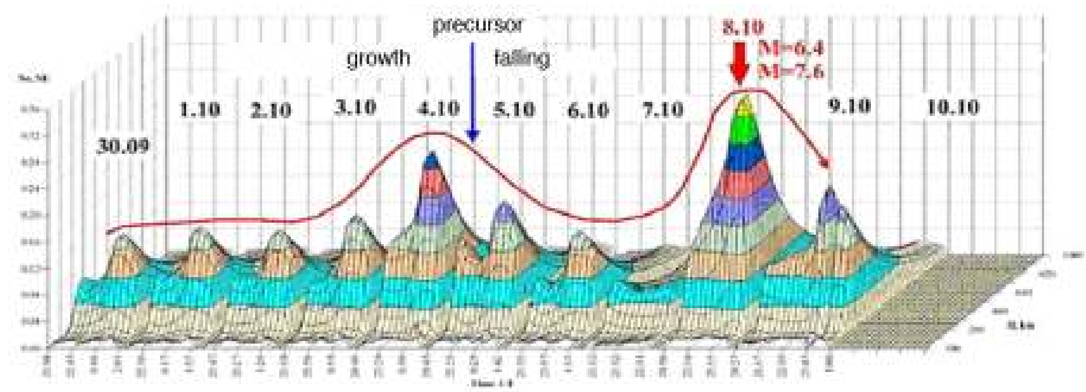
Thermal earthquake precursors associated with M7.6 Kashmir of October 8, 2005. (a) Atmospheric pre earthquake effects of diminishing the relative humidity prior to the Oct 2005 event ; (b) Occurrence of MODIS TIR anomaly prior to Oct 8,2005 earthquake (c); OLR anomaly build a week prior to main shock; (d) A GPS/TEC type phenomena was shown in advance to Oct 8, 2005



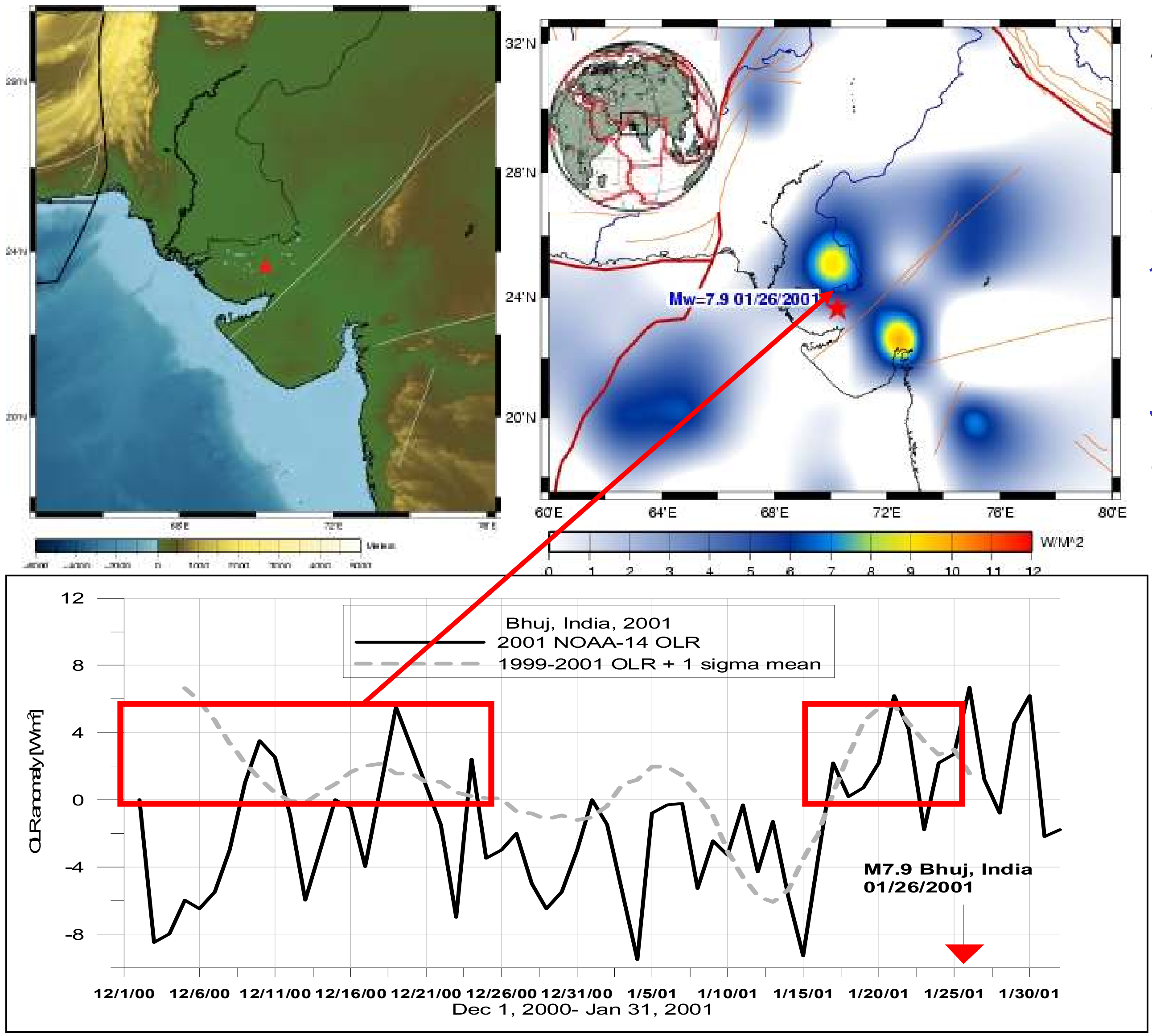


Bondur,2006





M7.9 Bhuj, India, Jan 26, 2001

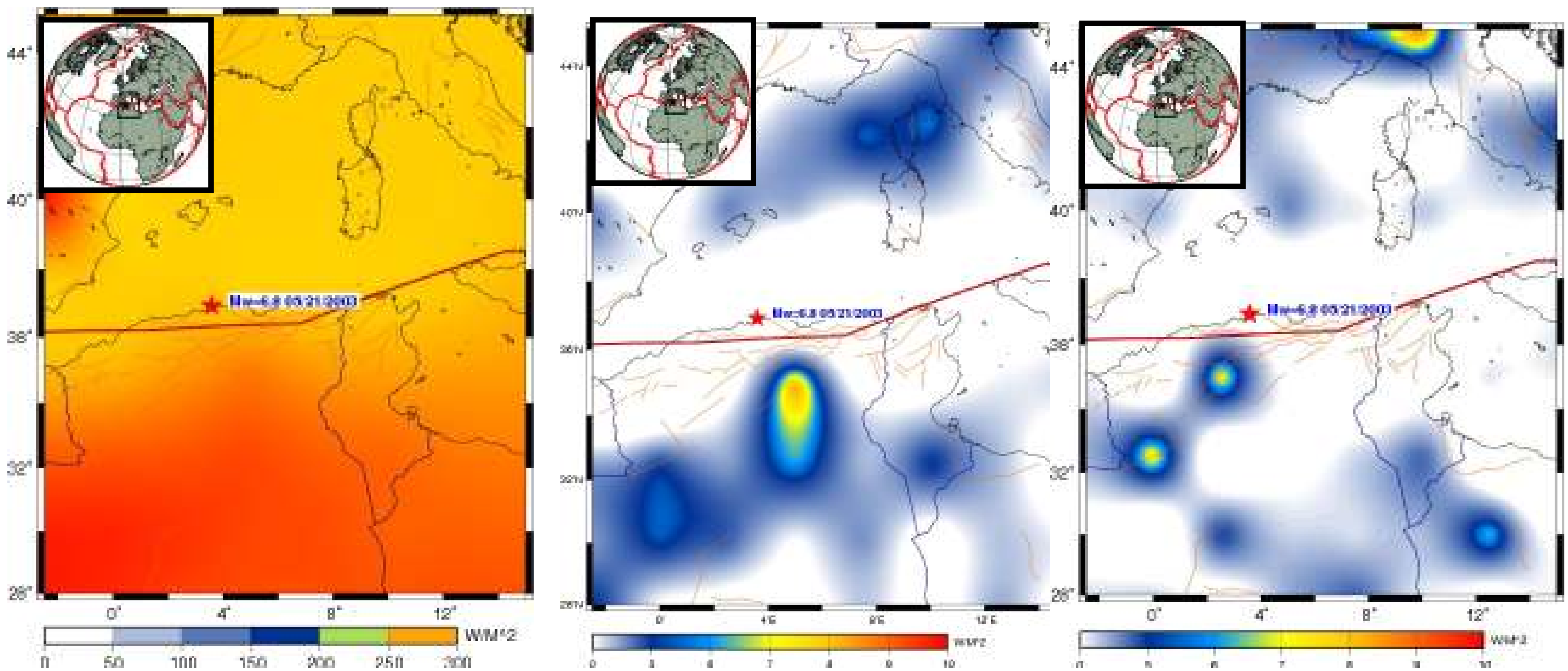


Map of OLR monthly variations for December 2000, for M 7.9 Bhuj, India earthquake of January 26, 2001

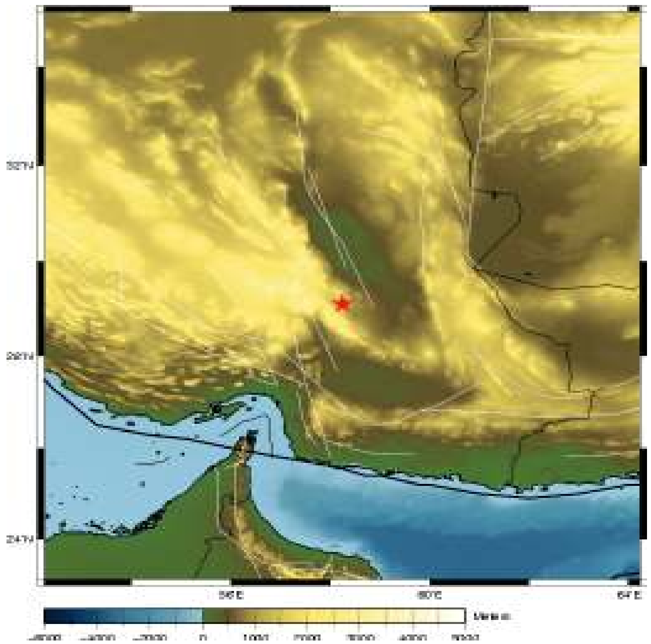
Time-series of daily OLR anomaly for December 1, 2000 - January 31, 2001 over the epicenter (23.63N/ 70.24E)

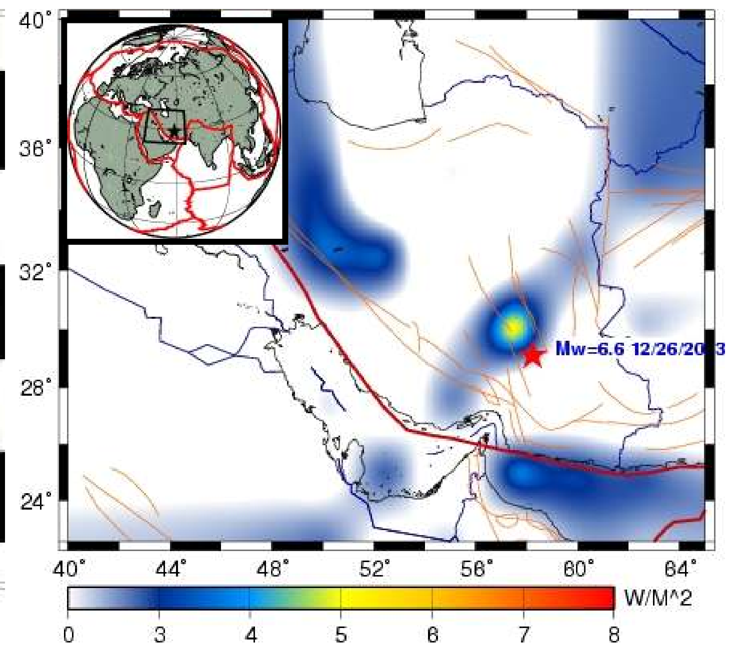
M6.8, Boumerdes, Algeria 2003

Map of OLR monthly normal field for April 2003 (a) eddy OLR for April 2003 (b) and (c) eddy OLR for May 2004,for M6.8 Boumerdes, northern Algeria earthquake of May 23, 2003

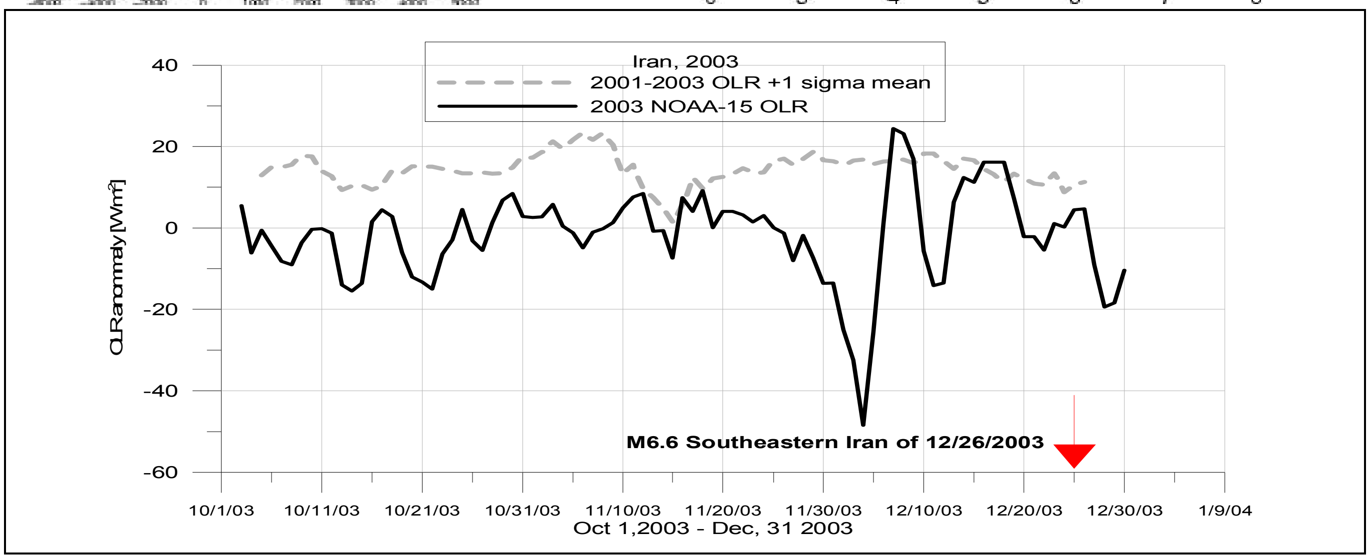


M6.6 Southeastern Iran, Dec 25 2003





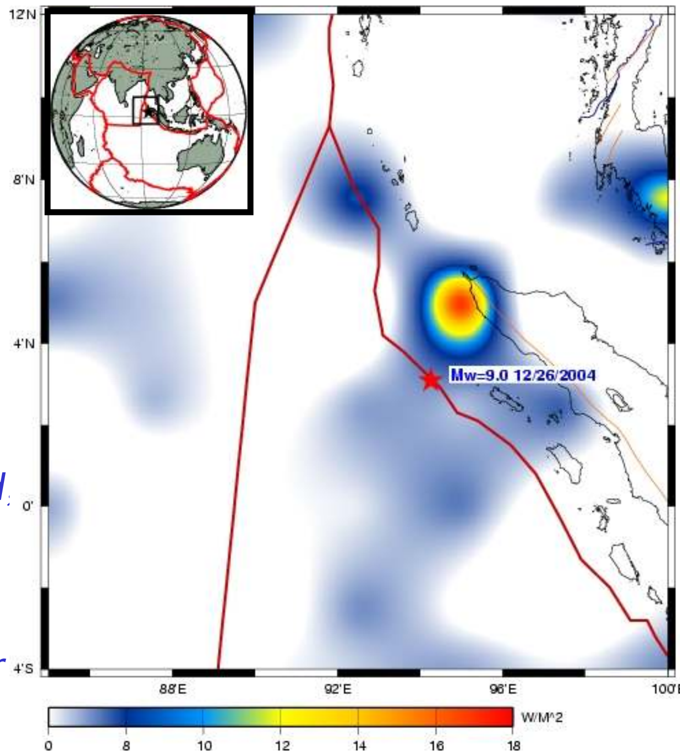
Map of OLR monthly variations for November 2003



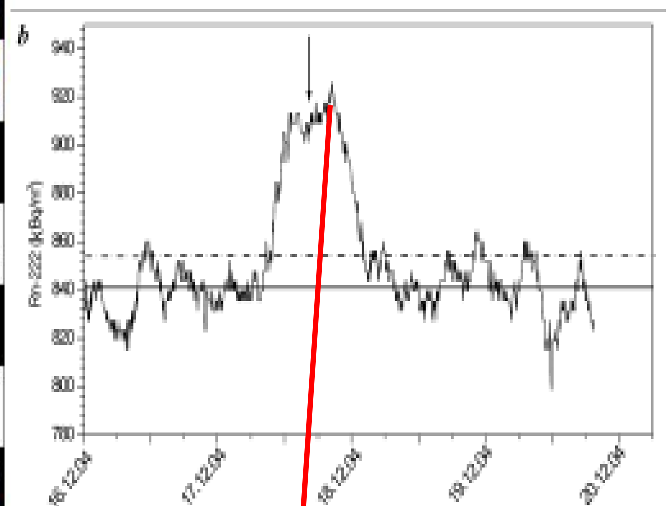
Time-series of daily OLR anomaly for October 1, 2003 - December 31, 2003 over the epicenter of (29.1N/ 58.2E)

Northern Sumatra Dec 26,2004, M9.0

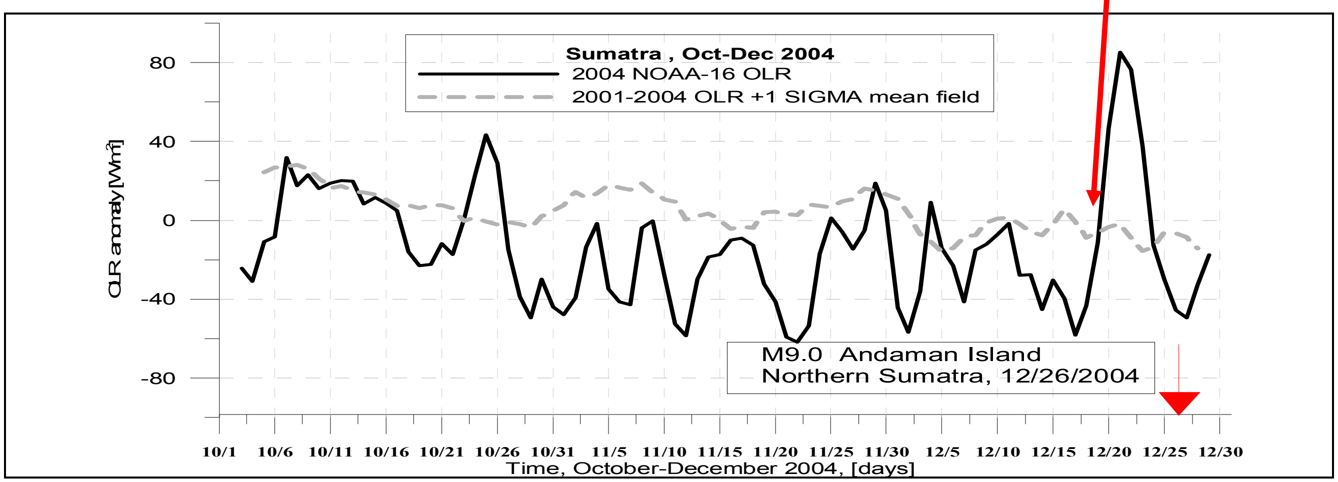
A/ Map of OLR monthly variations for November 2004, month prior to M9.0 Sumatra Andaman Island, Northern Sumatra of December 26, 2004. Epicenter (3.09N/94.26E)



Rn-222



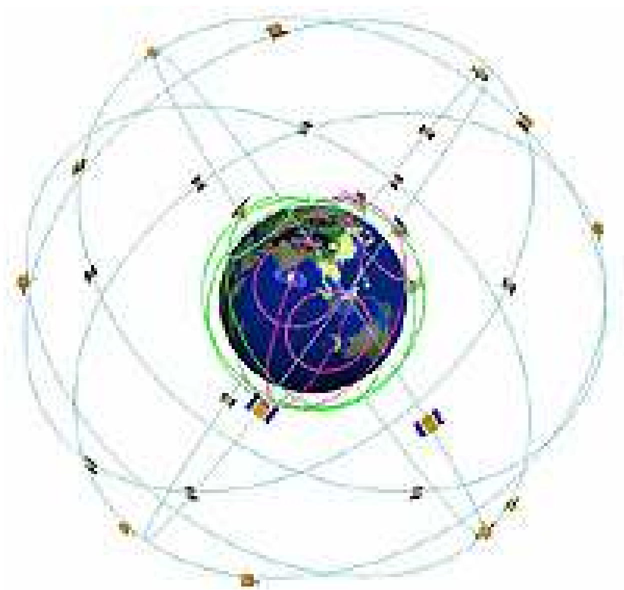
B/ Variation of Rn-222 during 16 to 20 December 2004, (23°52N; 87°02E), Birbhum District, West Bengal, India.

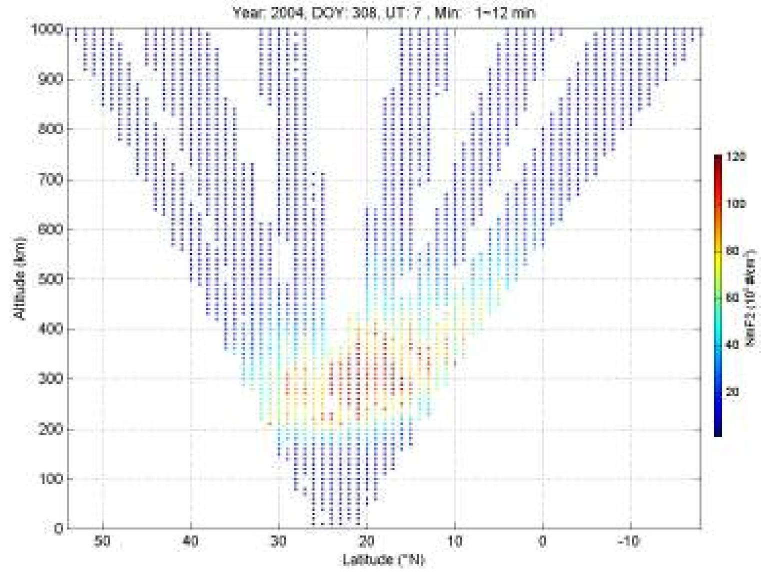


C/ Time-series of daily OLR anomaly for October 1, 2004 - December 31, 2004 over the epicenter of (3.09N/ 94.26E)

Major international dedicated missions to study earthquake precursors in atmosphere and ionosphere

- *DEMETER, CNES/France, Detection of Electro-Magnetic Emissions Transmitted from Earthquakes (2004-2008)*
- *COSMIC – Taiwan/USA, 2006-2010*
- *Kompass-2, CANOPUS, Russia (2006-2010)*
- *UNAMSAT-3, Mexico (2007-2009)*
- *SESS, China (2008-2010)*
- *Kazakhstan, (2008-2010)*





SUMMARY

What we know:

*1.EM satellites can detect “**anomalies**” over the land and ocean connected with impending strong earthquakes over major faults;*

2.Lithosphere-Atmosphere-Ionosphere coupling was observed prior to the main earthquakes and involves multiple geophysical parameters.

Work is in progress:

(i) Practical applications for Global Monitoring of TIR,OLR,GPS/TEC, OLR, SLHF,T/H anomalies;

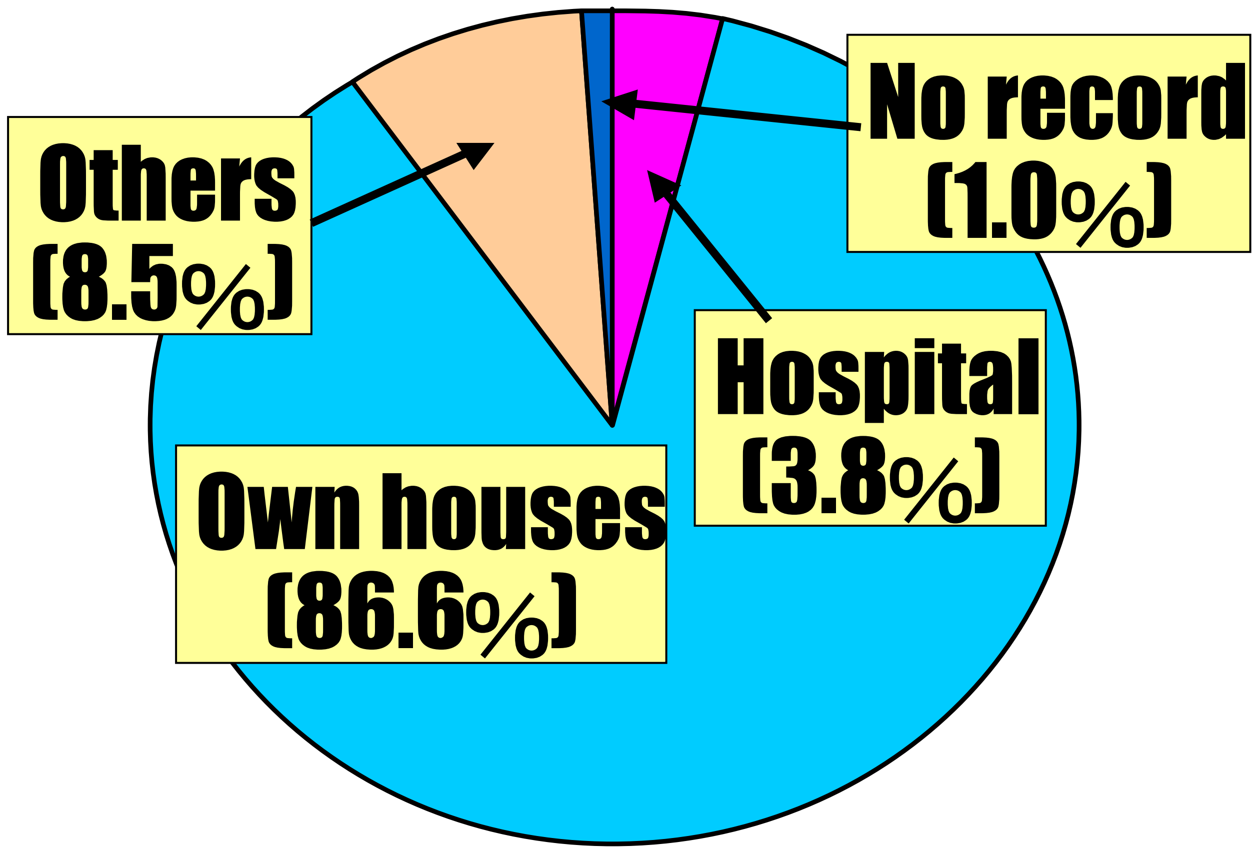
(ii) The quantitatively connection between EM precursors, TIR anomalies and earthquake parameters.

“Unless we launch a concentrated interdisciplinary effort, we will always be surprised by the next major earthquake.” Ari Ben-Menahem

Questions?

Places where casualties were killed
by the 1995 Kobe Earthquake (in Kobe City)

(after Hyogo Medical Examiners)



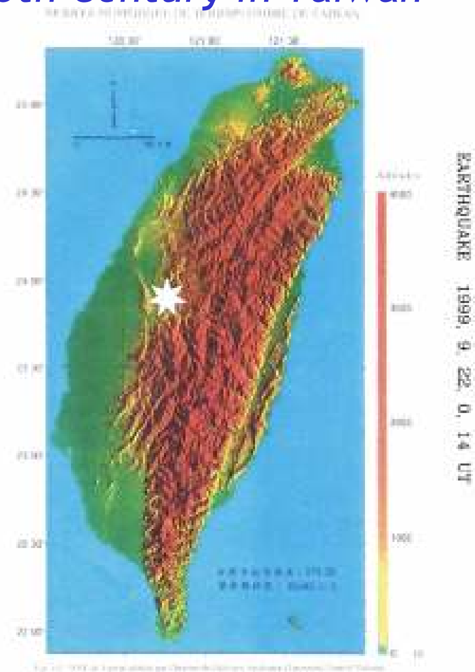
Examples of atmospheric EM phenomena related to EQ

The Chi-Chi Earthquake 09/ 21, 1999, Mw 7.6

21 days before

20 days after

The Largest Earthquake during 20th Century in Taiwan



2,415 deaths (including missing people)
1,441 severely wounded
US$9.2 billion worth of damage
44,338 houses completely destroyed
41,336 houses severely damaged

The 1995, Jan 17 Kobe Earthquake (M=7.2).More than 5,500 were killed and over 26,000 injured. The economic loss about $US 200 billion.

Rotate upward tornado-type cloud and bright horizontal striped cloud (similar to water vapor trails). Picture is taken around 1700 JST on Jan 9 1995, eight days before M7.2 Kobe Earthquake, Japan (K.Ongon)

Latest publications

- *Ouzounov D., D. Liu, C. Kang , G.Cervone, M. Kafatos, P. Taylor, 2007. Outgoing Long Wave Radiation Variability from IR Satellite Data Prior to Major Earthquakes, Tectonophysics, Volume 431, Issues 1-4 , 20 February, pp. 211-220*
- *M.Parrot and D.Ouzounov, 2006.Surveying the Earth's Electromagnetic Environment From Space, EOS, Transactions of American Geophysical Union,26 December,Vol.87, 52, pp.595*
- *Pulinets S., D. Ouzounov, A. Karelin, K. Boyarchuk, L. Pokhmelnykh, 2006. The Physical Nature of Thermal Anomalies Observed Before Strong Earthquakes, Physics and Chemistry of the Earth, 31, 143-153*
- *Pulinets S., D. Ouzounov L. Ciraolo, R. Singh, G. Cervone, A. Leyva, M.Dunajecka, Karelin, K. Boyarchuk, 2006. Thermal, Atmospheric and Ionospheric Anomalies Around the time of Colima M7.8 Earthquake of January 21, 2003, Annales Geophysicale, 24, 835-849*

The ESPERIA mission

An ***equatorial*** space mission

LEO small-satellite

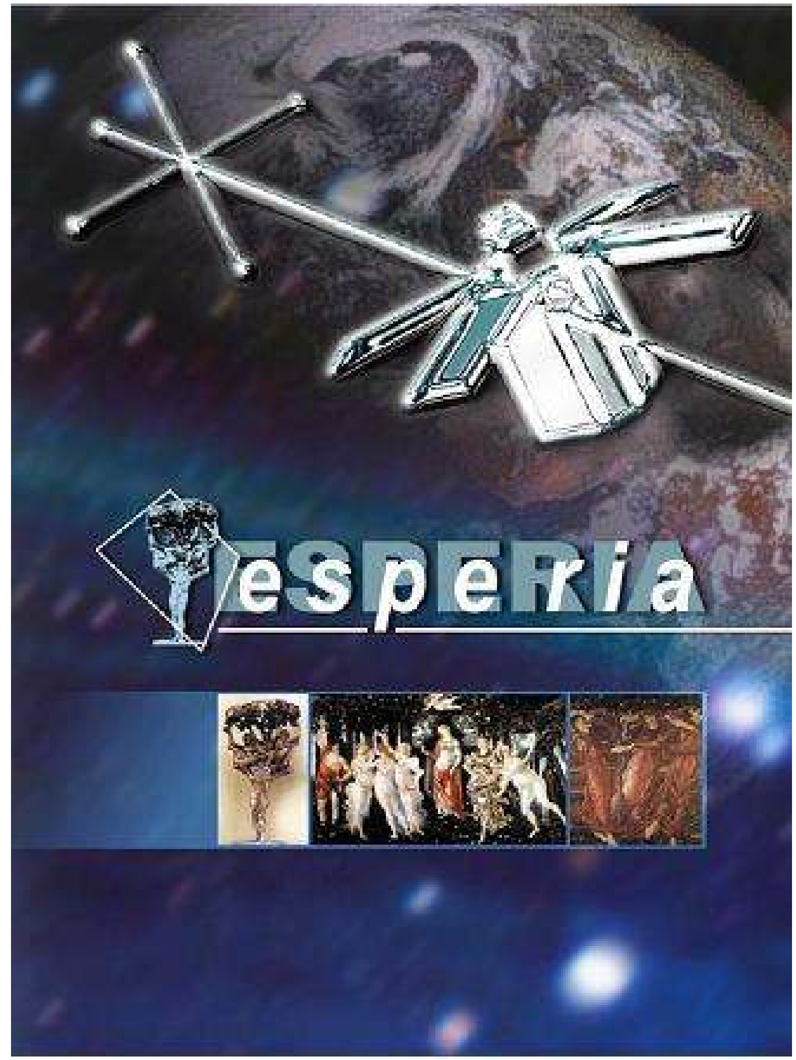
Multi-instrument payload

Study of ***seismic*** & ***anthropogenic*** electromagnetic effects in the near-Earth space.

Scientific objectives

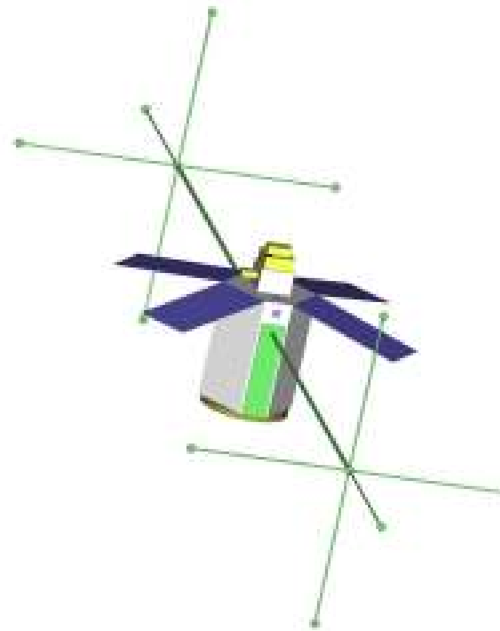
Primary: **pre-earthquake EME**
a contribution to earthquake forecasting

Secondary: **man-made EME**
VLF÷HF-transmitters)
anthropogenic impact



(Sgrigna, 2004)

Payload Instruments:



Electric Field Analyser (EFA)

- frequency range: ~DC ÷ 10 MHz
- accuracy: 300 nV/m
- dynamic range: 120 dB

Magnetic Field Analyser (MAFA)

FLUX – GATE:
- frequency range: ~DC ÷ 10 Hz
- accuracy: a few (6-8) pT
- resolution: 24 bit

SEARCH – COIL:
- frequency range: ~10 Hz ÷ 100 kHz
- sensitivity: 10^{-2} pT /(Hz)½ (at 1 kHz)

Langmuir Probe & Retarding Potential Analyser (LP&RPA)

LP:
- electron temperature: 300 ÷ 15000 K
- electron density: $10^2 \div 10^7$ cm^{-3}

RPA:
- ionic temperature: 300 ÷ 10000 K
- ionic density: $10^2 \div 10^7$ cm^{-3}

Particle Detector Analyser (PDA).

- Energy range: 300keV÷2GeV
- Pitch angle accuracy < 4^o with particle identification

(Sgrigna, 2004)

"COMPASS-VULCAN" space system

Measured Parameters

- Quasi constants an electrical and magnetic fields
- Electron and ionic concentration
- Ion-mass structure
- ELF-VLF and HF electromagnetic emissions
- Temperature of electrons and ions
- Power spectrum both flows of electrons and ions > 15 keV
- Emissions in range of lengths of waves 727-1103 nm
- Intensity of the IR radiation in several lines

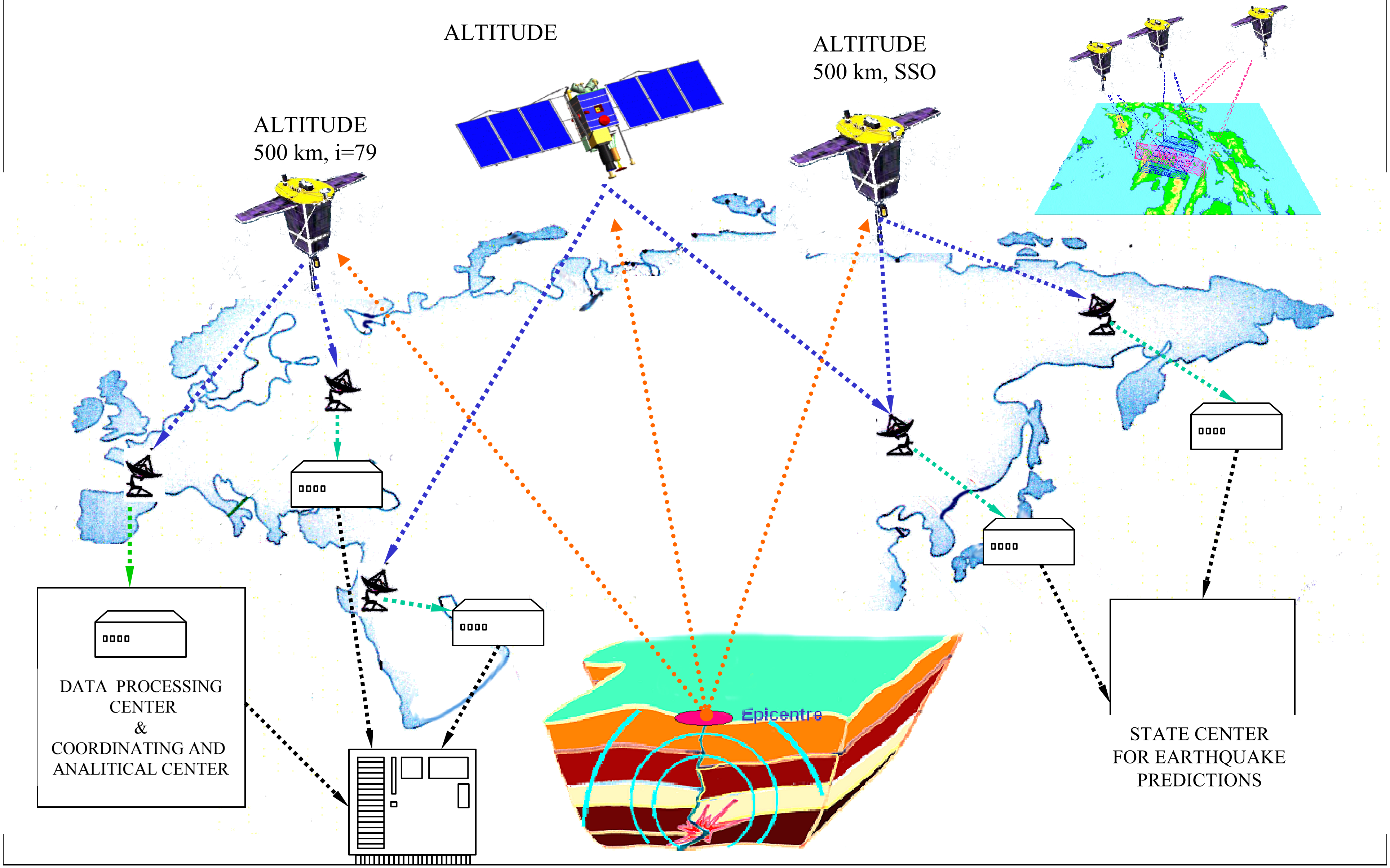
(Pulinets, 2005)

THE MAIN STAGES OF THE "COMPASS-VULCAN" project

THE 1-ST STAGE:	**2005** (March 2006)	- Launch of "Compass-2" experimental space vehicle. Flight qualification of space equipment and ground equipment tests.
THE 2-ST STAGE:	**2005-2006**	- Launch of "COMPASS" satellites into LEO-1 (400-500 km.) and "VULCAN" satellites into LEO-2 (900-1100 km.). Putting into operation of Situation Center for collecting and processing of earthquakes forerunners data
THE 3-ST STAGE:	**2007-2009**	- Launch of 6 (six) "COMPASS" and "VULCAN" satellites into LEO-1 & LEO-2 (three on each orbit). Completion of the creation basic satellite constellation.

(Pulinets, 2005)

SPACE & GROUND SEGMENT CONCEPT

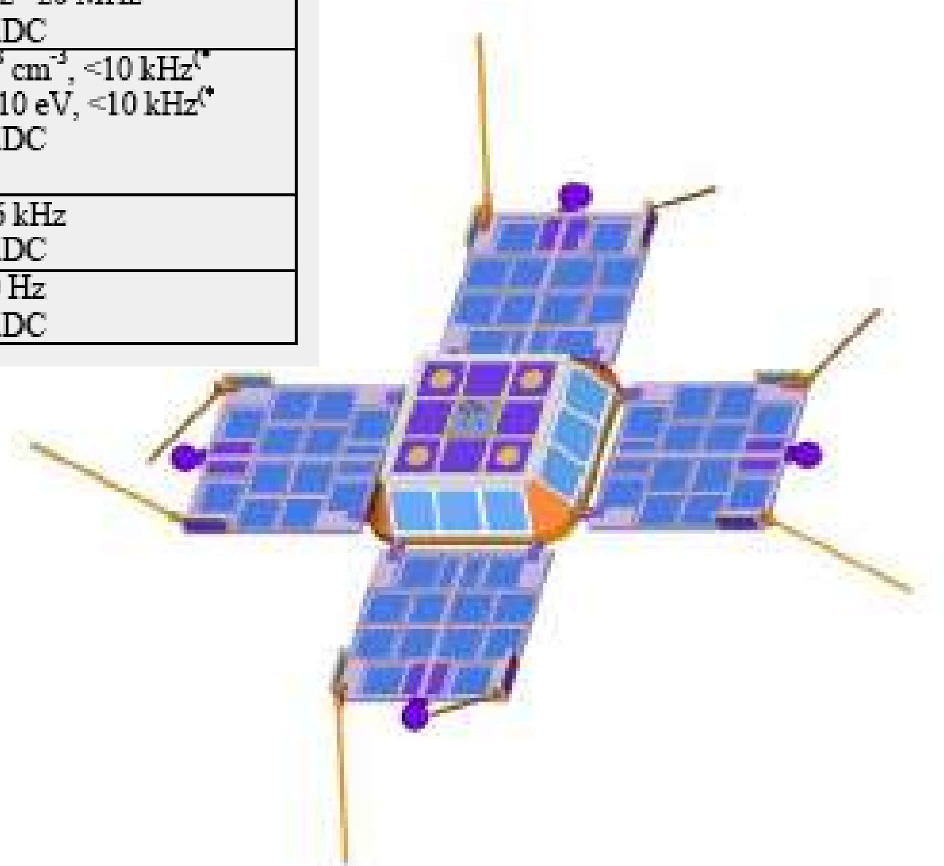


UNAMSAT-3

Langmuir probe	variations of the electron density and temperature
Particle detectors	110 keV - 80 MeV
HF radiospectrometer	0.1 – 15 MHZ
GPS receiver	

Swedish nanosatellite

Instrument	Measured Quantities	Range
EFVS	*Electric field* (3D vector)	Few kHz– 20 MHz 14 bit ADC
LP	*Plasma density* *Electron temperature*	$10 - 10^{8}$ cm^{-3}, <10 kHz(* 0.001 - 10 eV, <10 kHz(* 18 bit ADC
ARM	*Magnetic field* (3D vector)	DC – 16 kHz 16 bit ADC
FGM	*Magnetic field* (3D vector)	DC-100 Hz 22 bit ADC

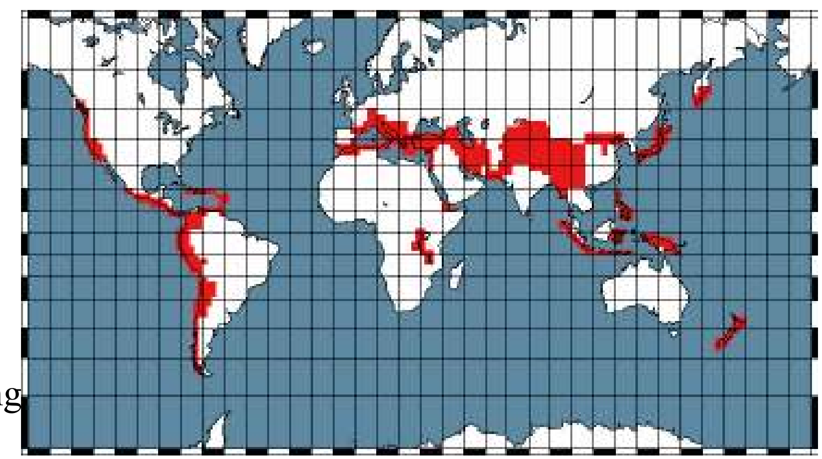


Detection of Electro-Magnetic Emissions

Transmitted from Earthquakes (DEMETER)

The operations

The orbit of DEMETER is polar, circular with an altitude of 710 km.
DEMETER record data in two modes: a survey mode all around the Earth with low resolution, and a burst mode with high resolution above main seismic zones.



Measured Parameters

Frequency range, B — 10 Hz - 20 kHz

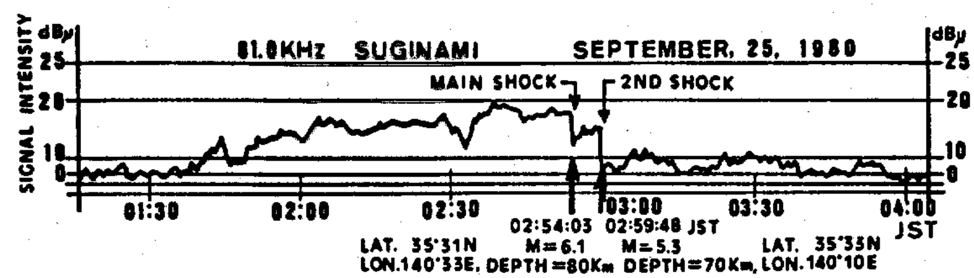
Frequency range, E — DC – 3.5 MHz

Sensibility B : — 1. 10^{-5} nT $Hz^{-1/2}$ at 1 kHz

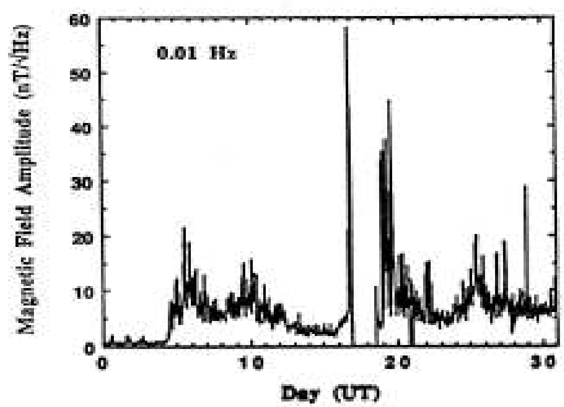
- Sensibility E : — 0.2 μV $Hz^{-1/2}$ at 500 kHz
- Particles: electrons — 30 keV - 10 MeV
- Ionic density: — 5 10^{2} - 5 10^{6} ions/cm^{3}
- Ionic temperature: — 1000 K - 5000 K
- Ionic composition: — H^{+}, He^{+}, O^{+}, NO^{+}
- Electron density: — 10^{2} - 5 10^{6} cm-3
- Electron temperature: — 500 K - 3000 K

First scientific paper on the seismo-electromagnetic effects by Milne in 1890

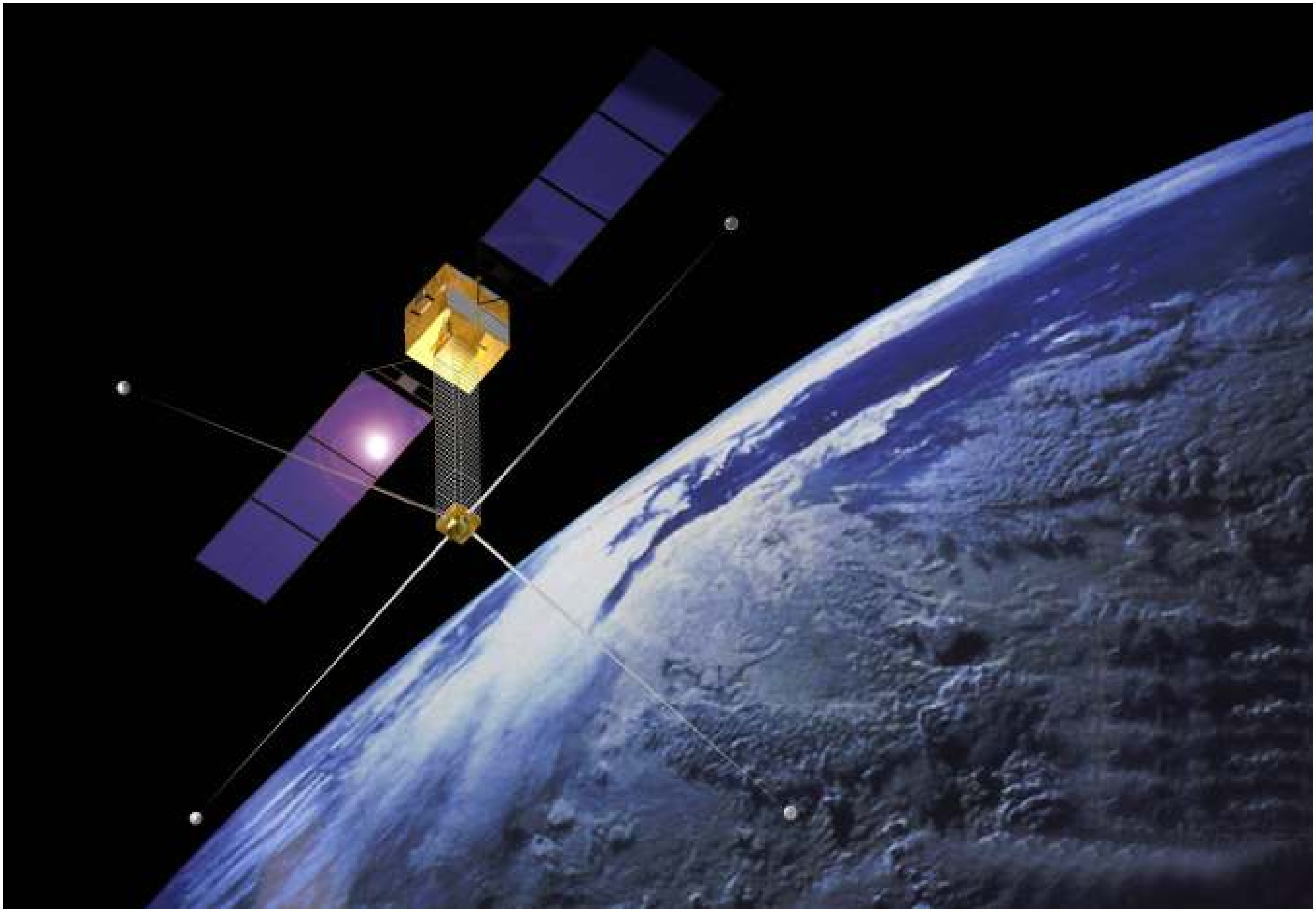
Gokhberg et al. (1982)



Loma Prieta, A.F.Smith (1994)



CHINA SEISMO-ELECTROMAGNETIC SATELLITE (CSES)



CHINA SEISMO-ELECTROMAGNETIC SATELLITE (CSES)

Payloads	Physical parameter	Specification
Search coil magnetometer	3 components of magnetic field	10Hz—20kHz
Electric field detector	3 components of electric field	DC—3.5MHz
fluxgate magnetometer	3 components of basic magnetic field	DC—10Hz
GPS receiver	Ionospheric TEC; Electron density Ne	
Plasma Analysis	Ion density	10^2~10^7cm^{-3}
	Ion temperature	500~5000K
	Ion components	
	Ion velocity	
Langmuir probe	Electron density	5×10^2~5×10^6cm^{-3}
	Electron temperature	500~10000K
Energetic Particle Detector	Proton flux	1.5MeV～200MeV
	Electron flux	≥100keV
Overhause magnetometer	The total magnetic field intensity	18000～65000nT