Correlation between ionospheric activities with earthquakes by monitoring Very Low Frequency (VLF) signals.

Prof. Sandip K. Chakrabarti

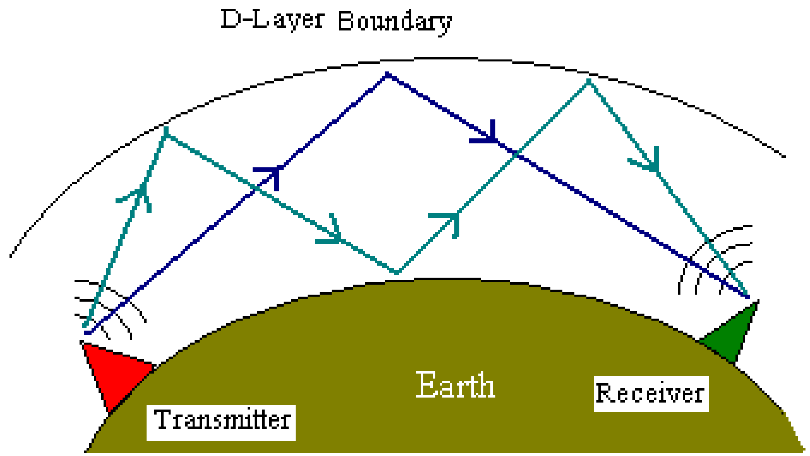
S.N. Bose National Centre for Basic Sciences
and
Centre for Space Physics, Kolkata

Paper presented at the Ninth Workshop on Non-Linear Dynamics and Earthquake Prediction
(1-13th October, 2007) SMR-1864

VLF is Very Low Frequency (10KHz-30KHz) Electromagnetic wave which propagates almost attenuation-free in between the earth and the lower ionospheric boundary.

In the night time the E-layer reflects the waves, but in the day time the D-layer reflects the waves.

Day-time VLF Propagation



No. of hops decides the amplitude and the actual propagation path decides the phase

In presence of terrestrial or extra-terrestrial ionospheric disturbances, the VLF propagation between the receiver and the transmitter is affected.

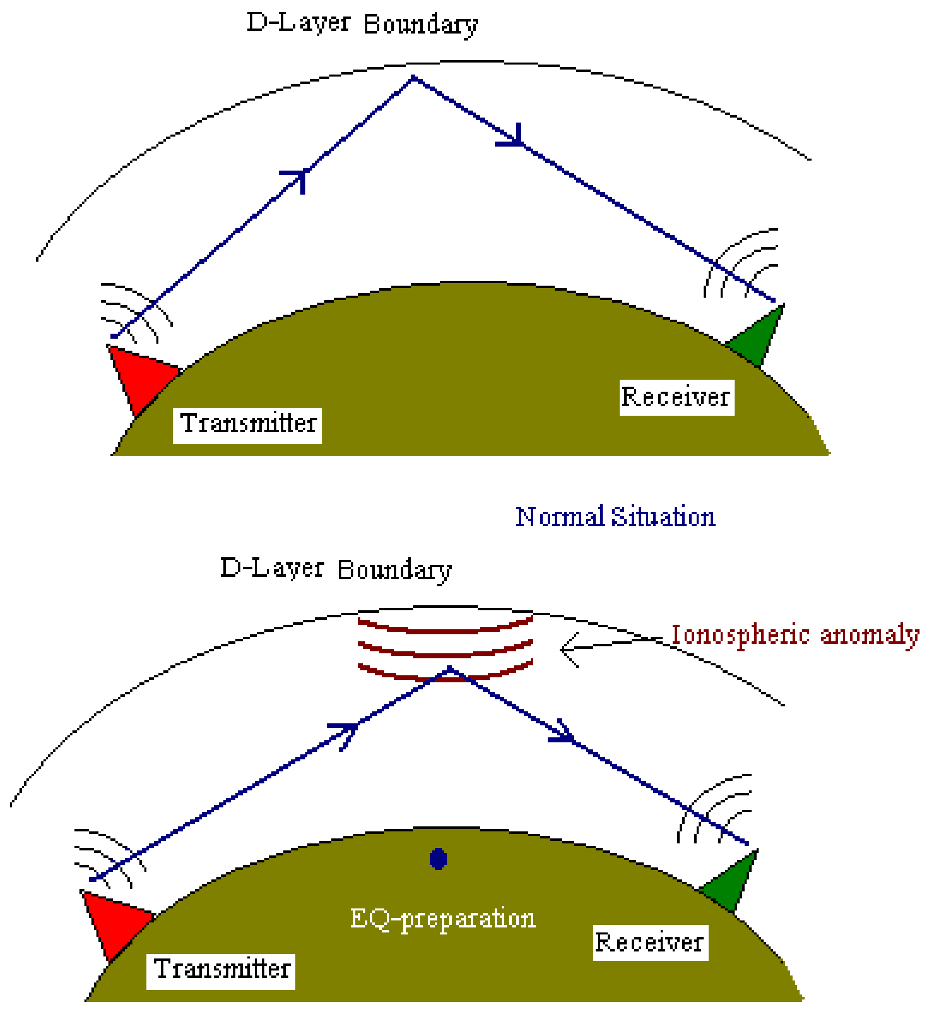
Causes of ionospheric anomalies
(Extra-terrestrial origin)

- Solar flares
- Gamma-ray bursts
- Strong pulsars

Causes of ionospheric anomalies (Terrestrial origin)

- Electric discharge during plate movements
- Electric field variations in the ionosphere causing heating of the ionosphere
- Excess radioactive gas (Radon) is discharged which decays and ionizes the ionosphere
- Magnetic field oscillation due to earthquake causing VLF generation
- Earthquake lights (also produce UVs), Sonoluminiscence, Triboluminisence etc.

These processes could start much before the actual earthquake.



Cartoon diagram of how Earthquakes will change VLF amplitude and phase.

The antenna has been installed at CSP (in Collaboration with Stanford University) to have the information about the electric and magnetic components

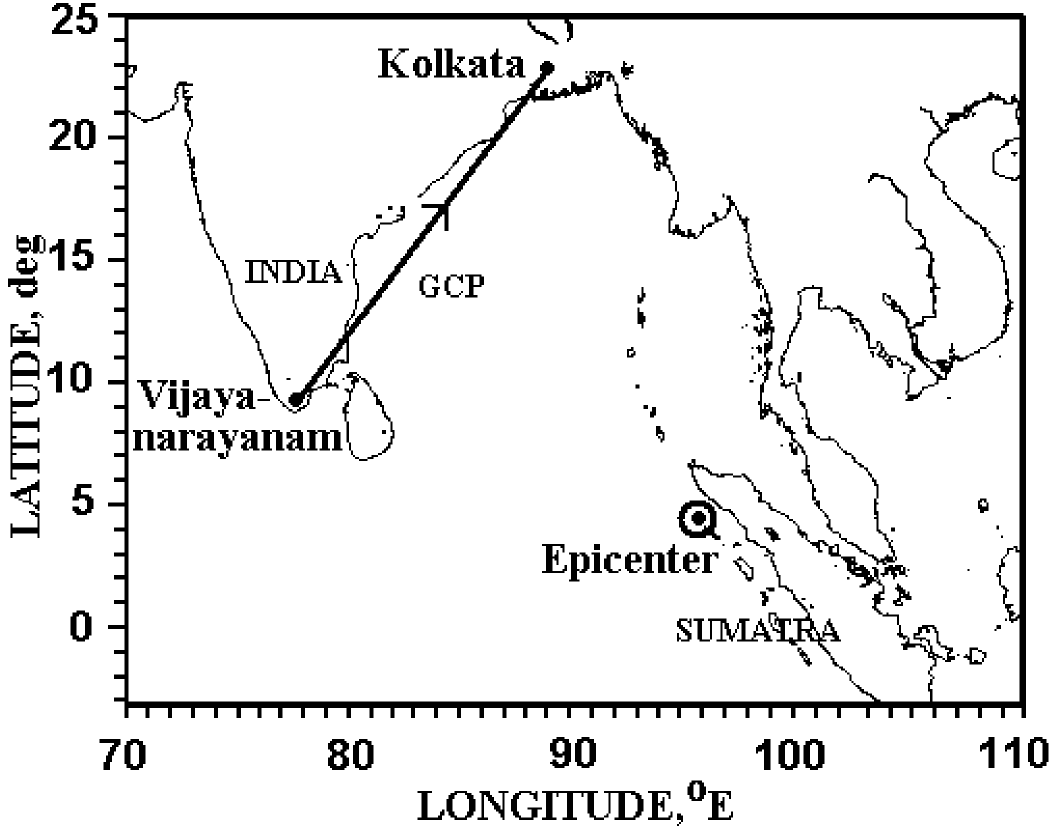
Antenna setup with preamp and GPS

Pre-amplifier

Stanford University line receiver

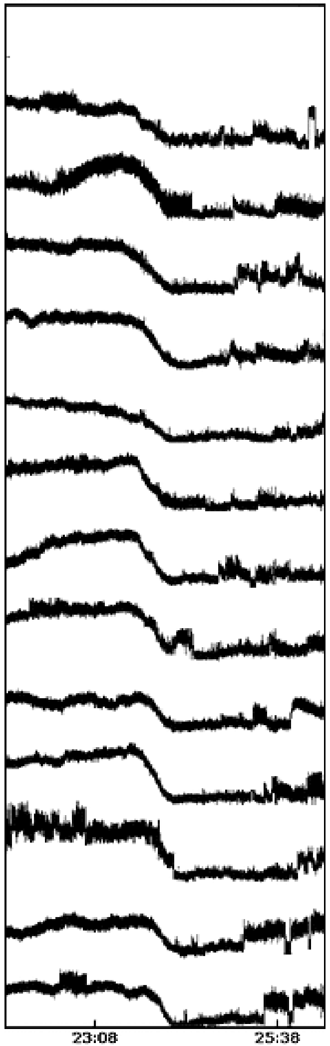
GPS system

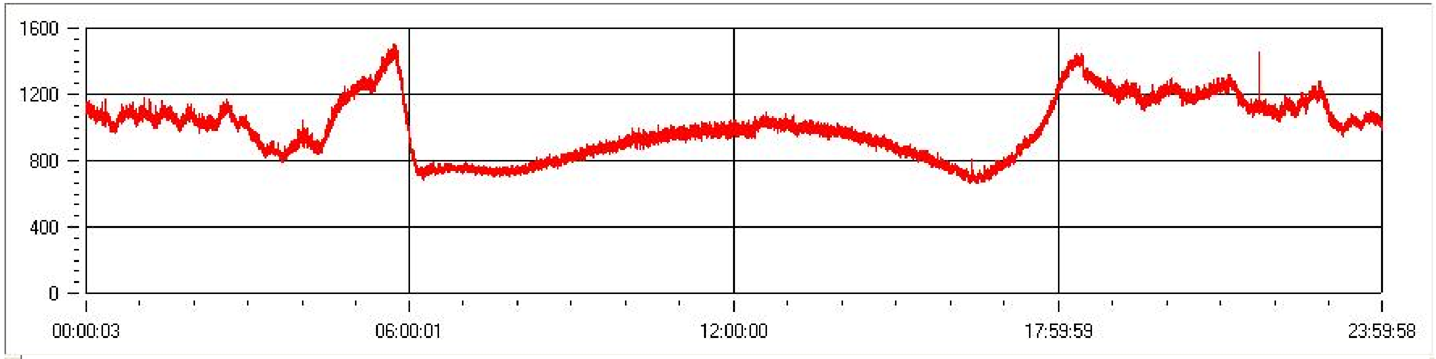
Example of an actual data acquisition

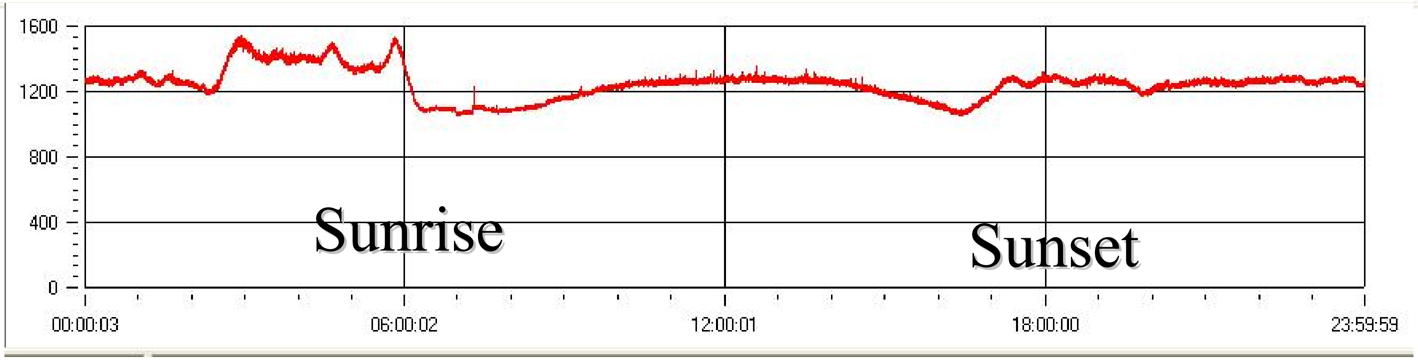


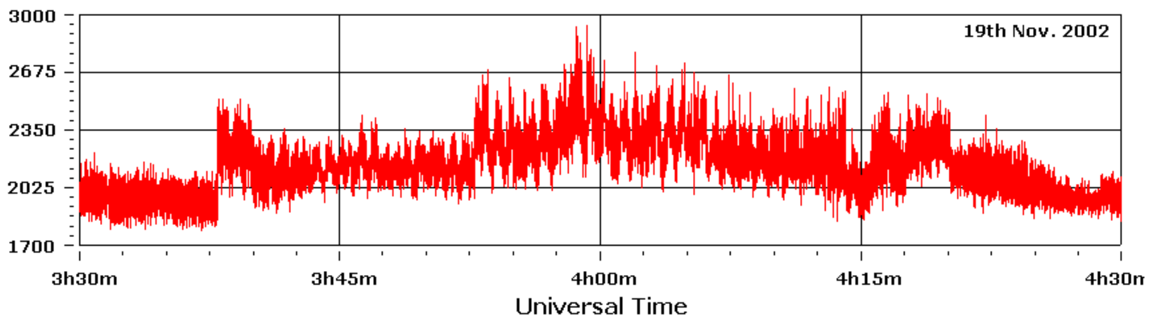
Great Circle Path between the CSP receiver and the VLF station at Vijayanarayanam

VLF Observations at CSP is going on last few years: Meteor Shower in Day time (below), Variation of D-Region formation at Sun-rise (left) and 24 Hr. Classic profile of Sunrise and Sunset (bottom two panels).

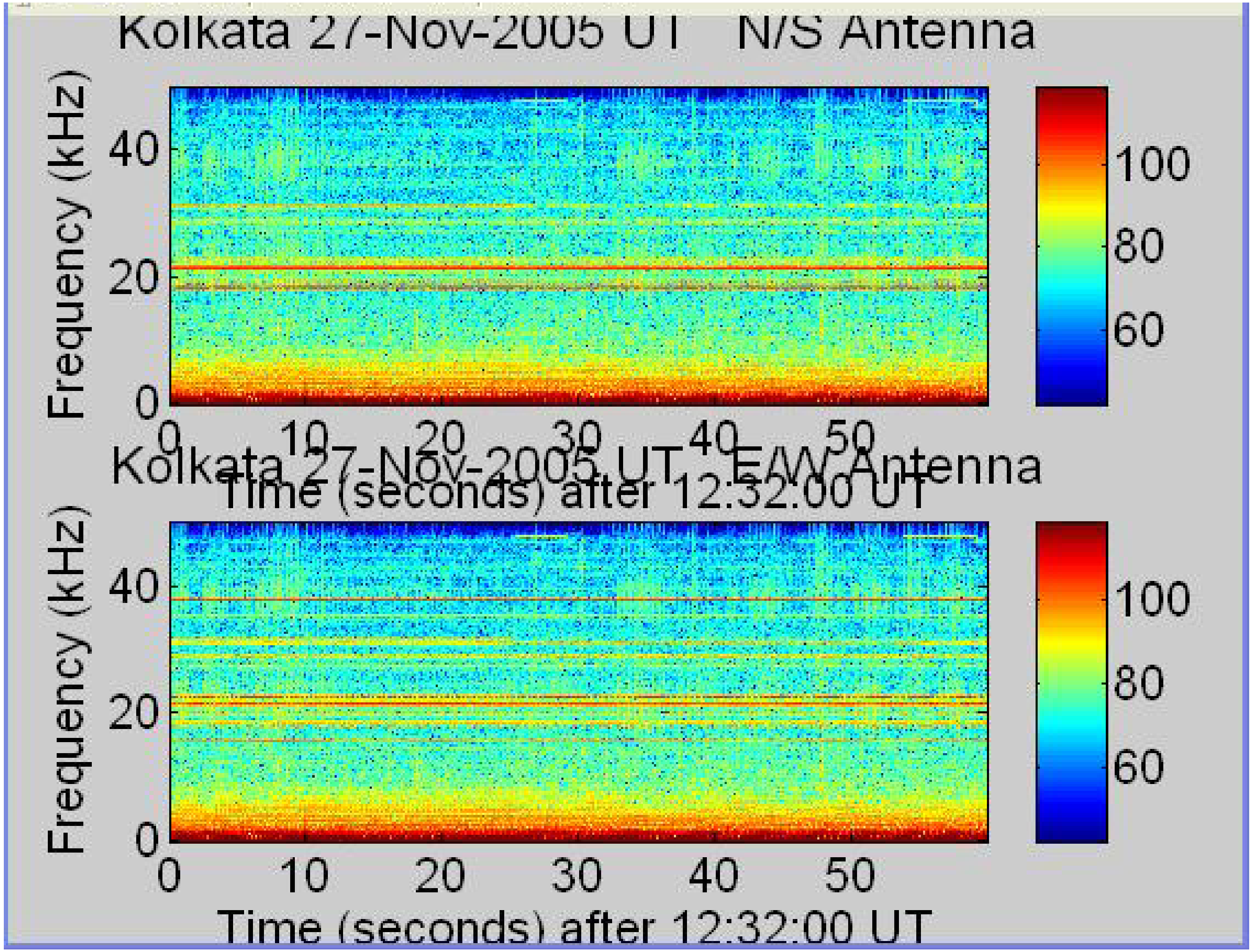




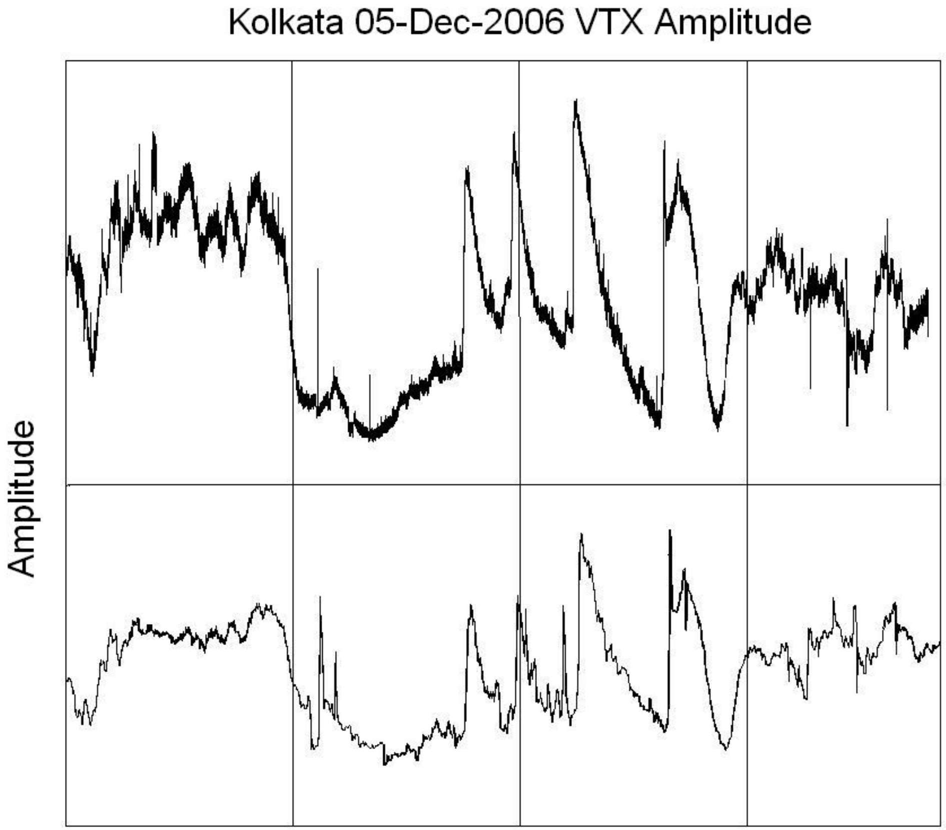




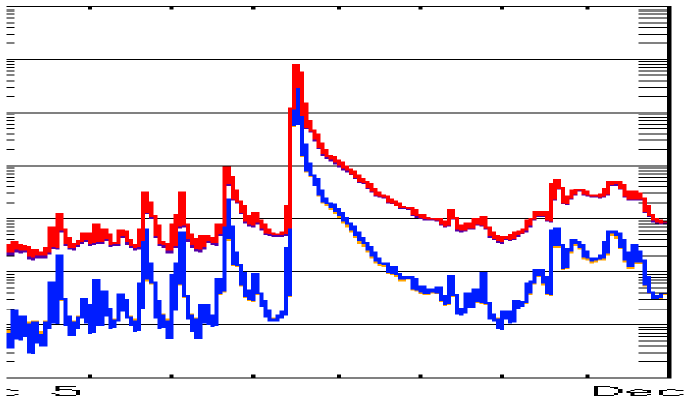
Broadband data is also coming every day and it is kept in the data bank and also at Stanford site



Comparison between the solar flare data from two receivers

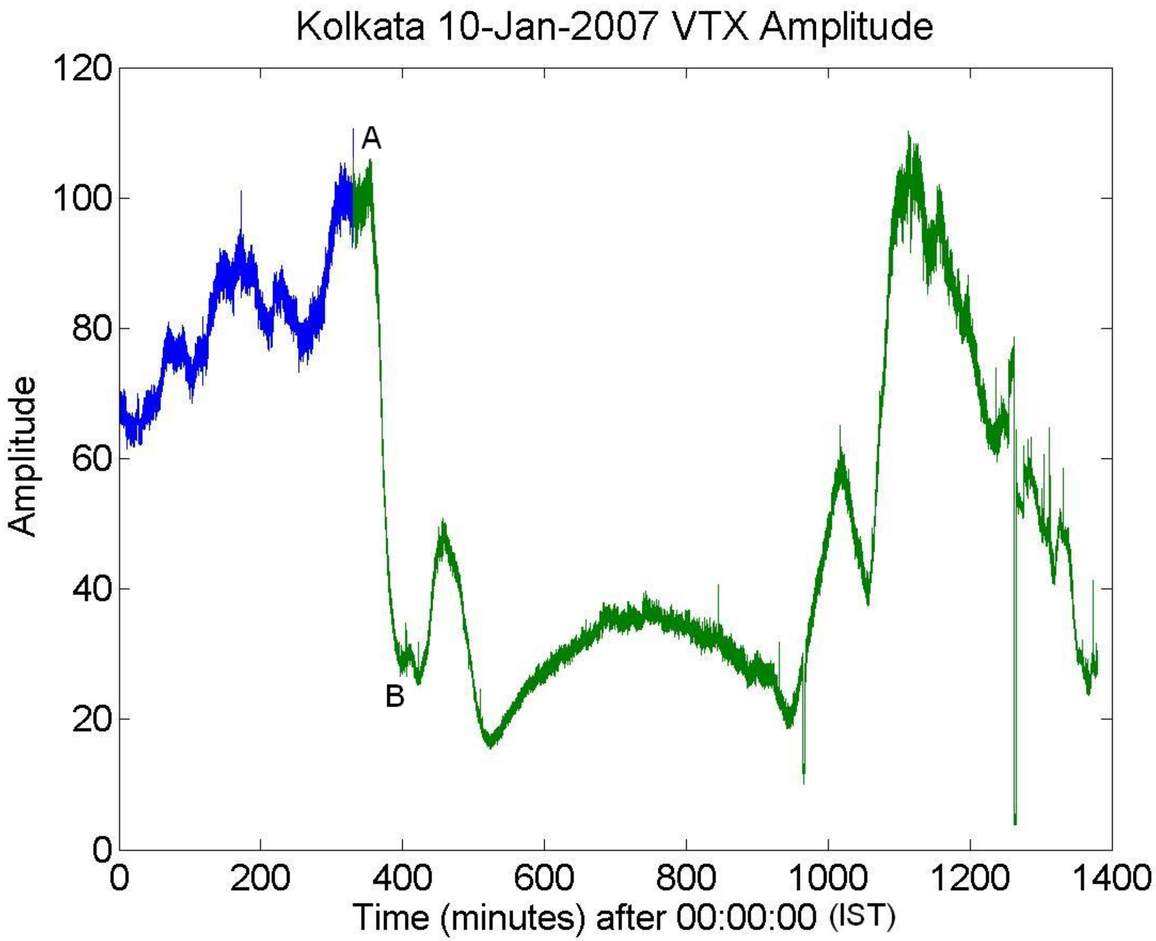


and with the GOES satellite data



What effects are we looking at?

Classical data from VT station using Stanford receiver at our Centre showing sunset and sunrise terminators very clearly



Observation of terminator shifts before Kobe earthquake of 1995 by Hayakawa's group

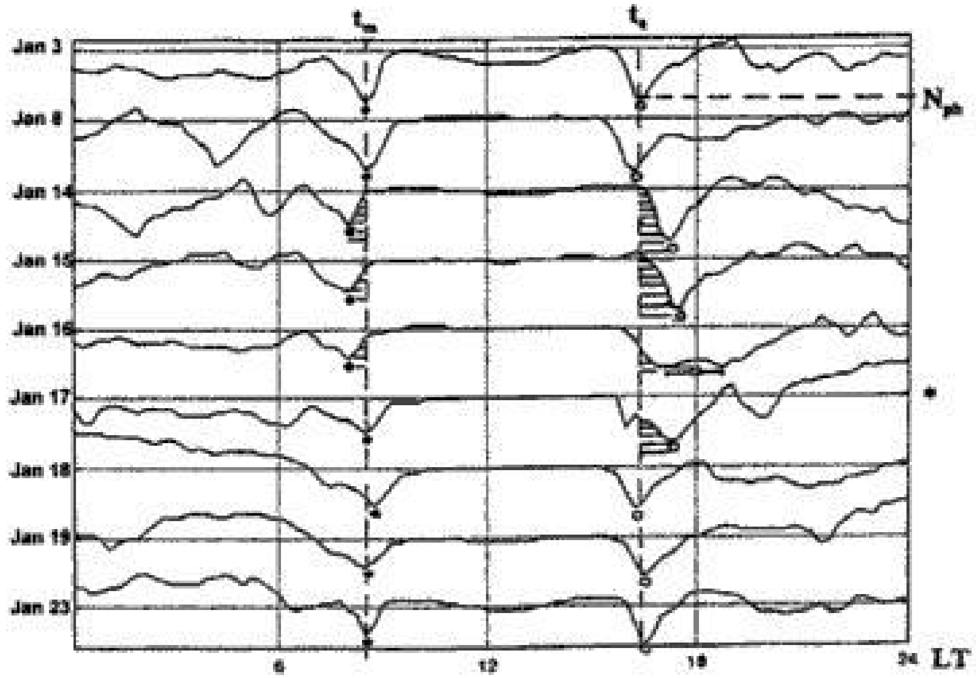
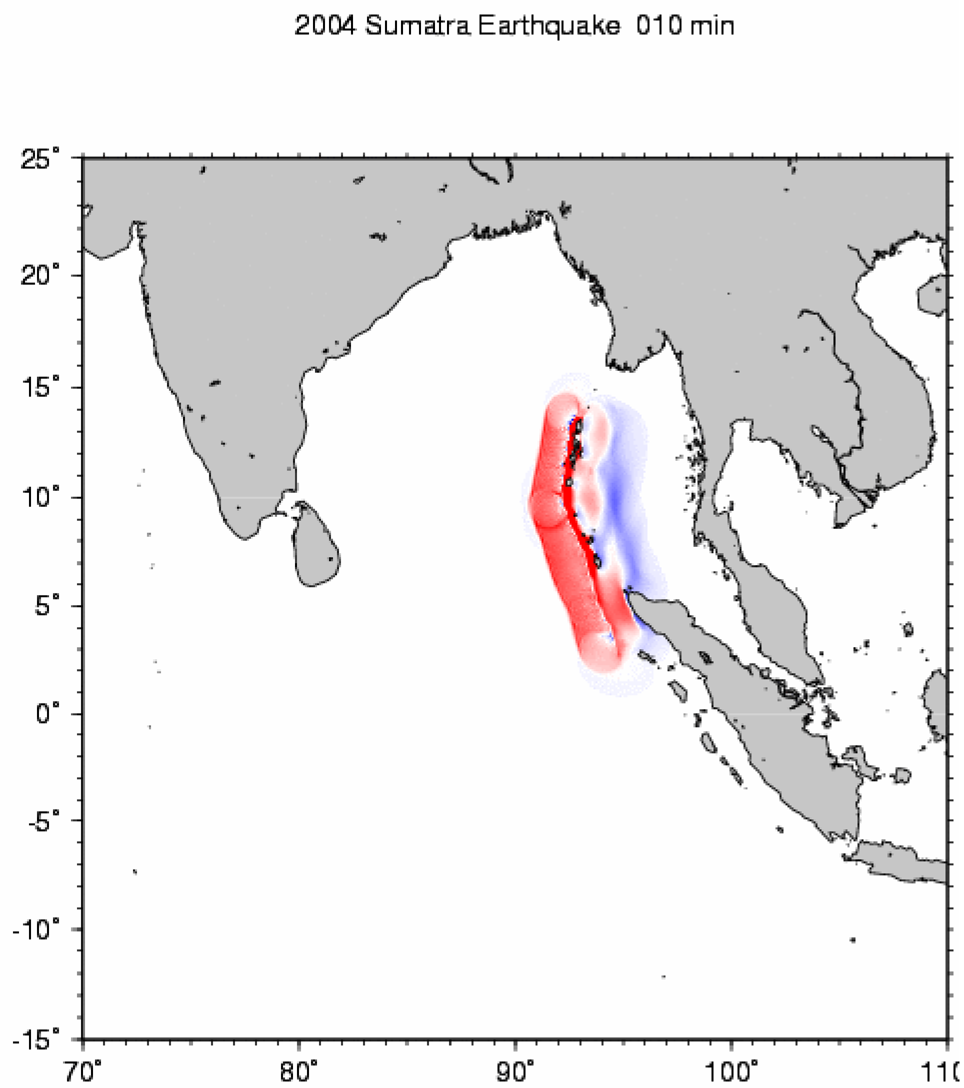
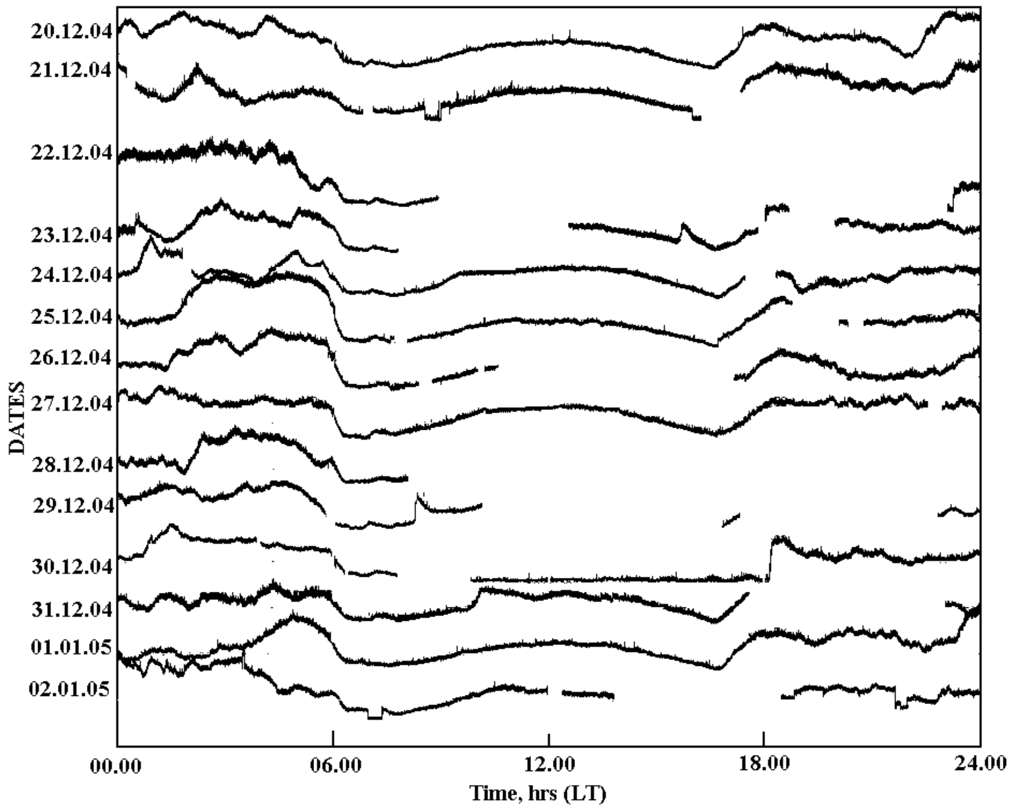


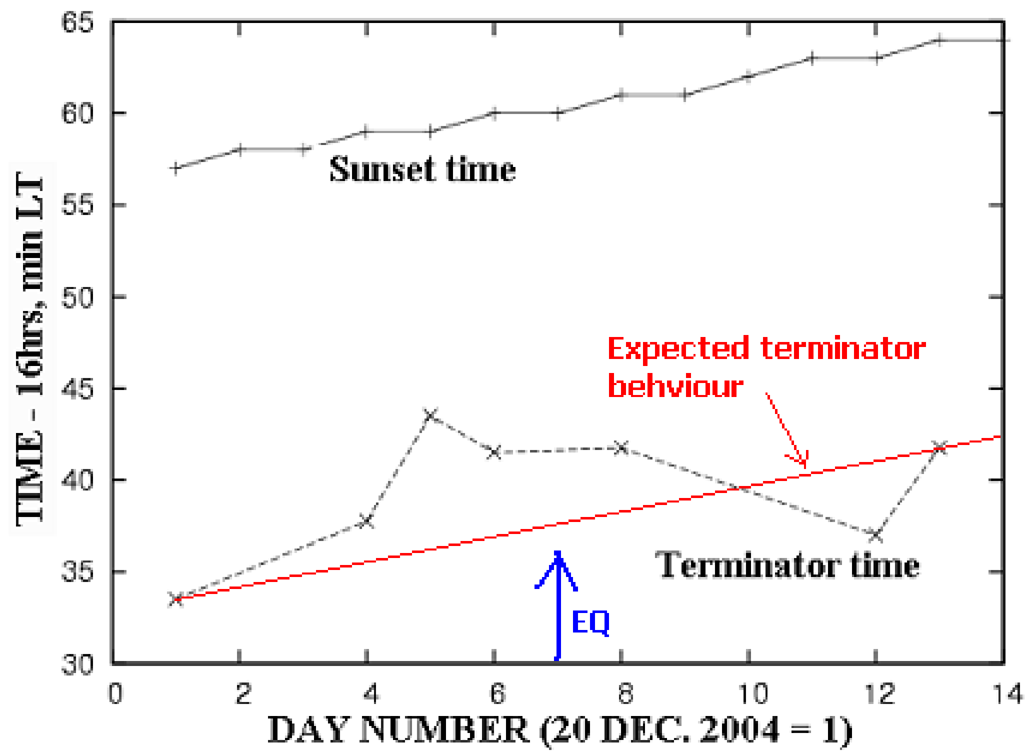
Fig. 1: Sequential plots of the terminator time variations of the Inubo (10.2 kHz) receiving station signal phase before the Kobe earthquake of 17th January, 1995 (*asterisk*). The time of sunrise and sunset is designated by t_m, and t_e. The shift of the terminator time is marked by *shadowing*.

Sumatran earthquake and the subsequent Tsunami was a wake-up call for all of us!





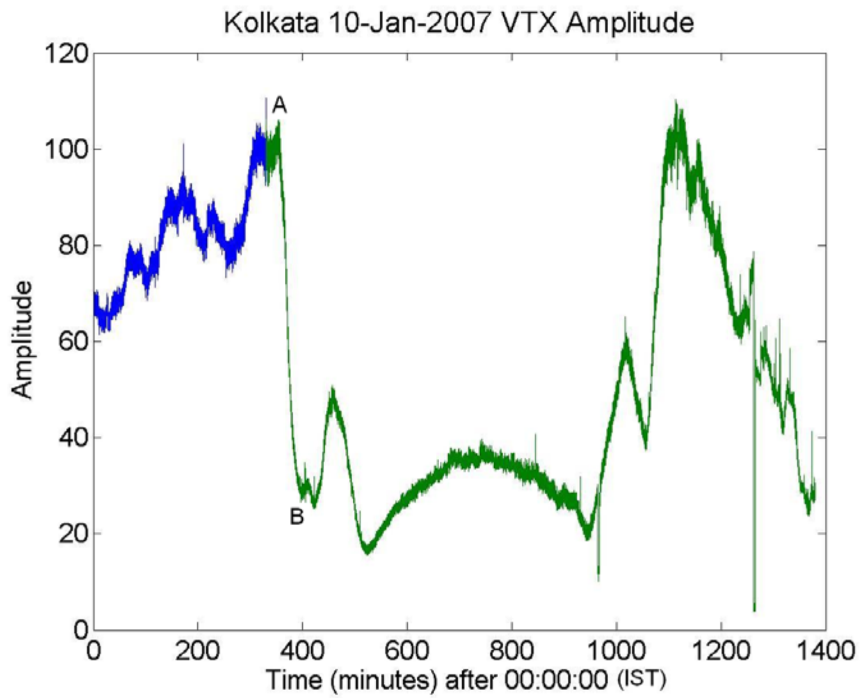
CSP data (with one loop antenna) before and during the Sumatran Earthquake



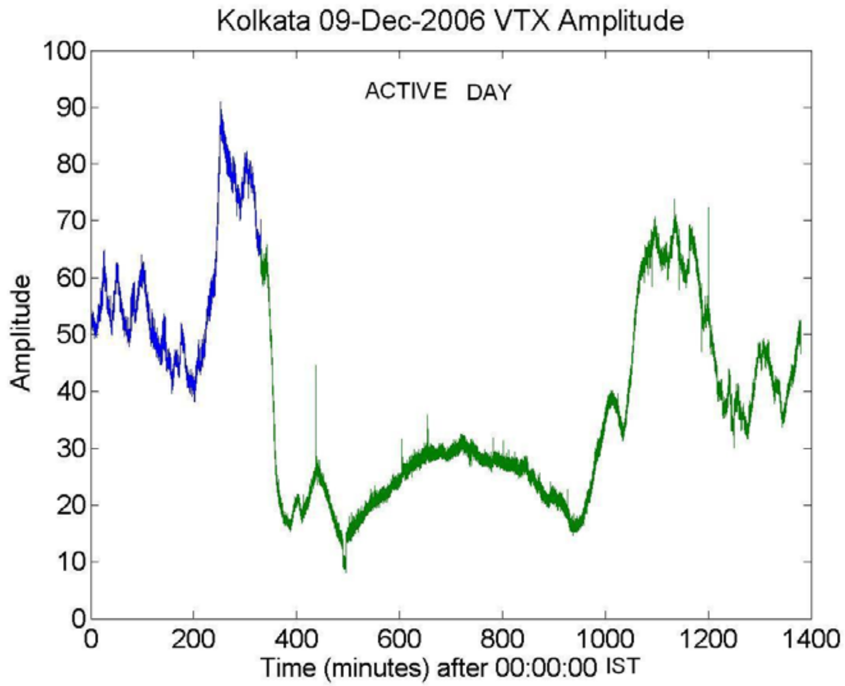
Anomalous shift of the terminator time. Instead of following the sunset time, we observe a shift of 9 minutes on the 24th of December, 2004 (Chakrabarti et al. 2005)

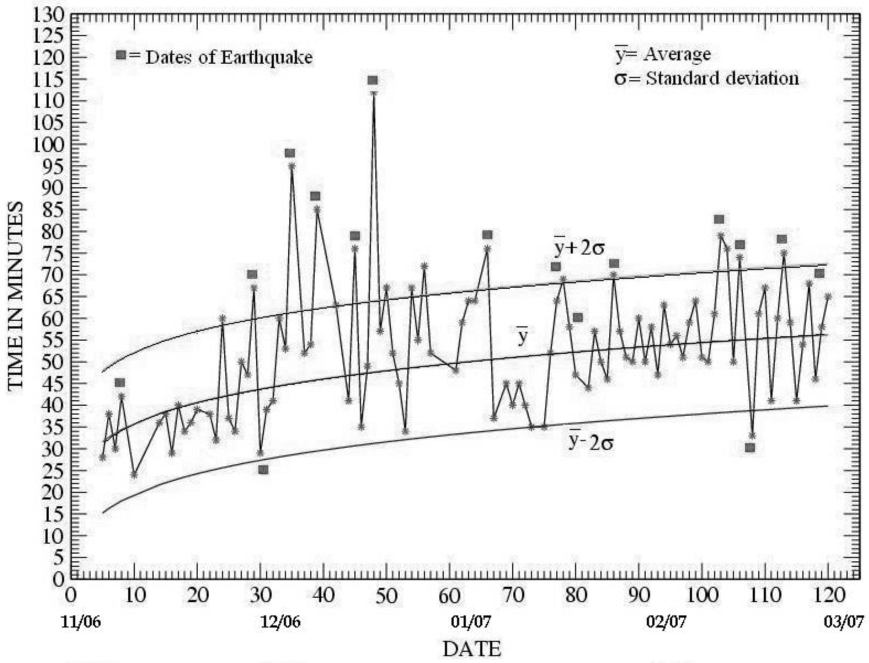
Another effect: Totally new! The formation time of D-Layer and the recombination time of D-layer are anomalous just before earthquake

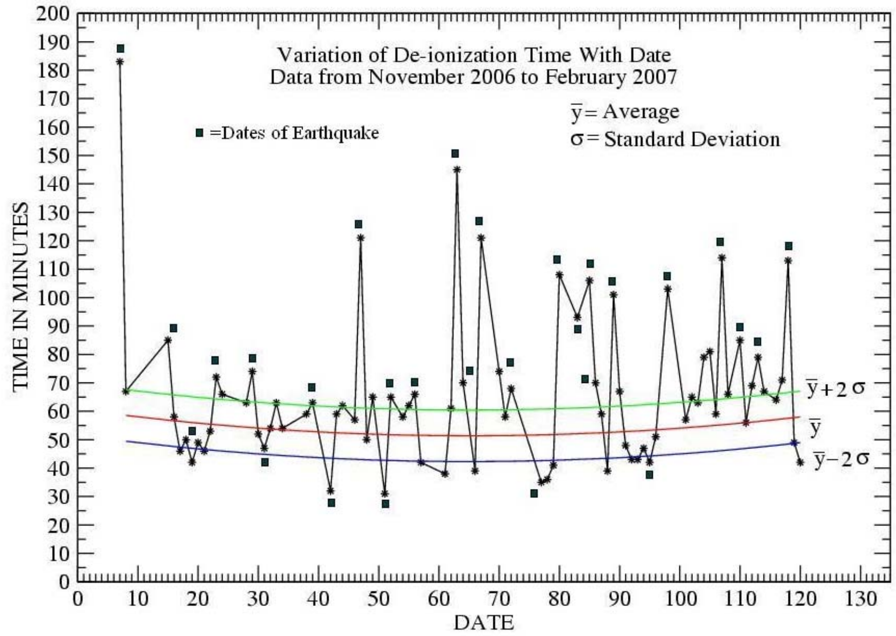
Seismically quiet day: normal DLPT



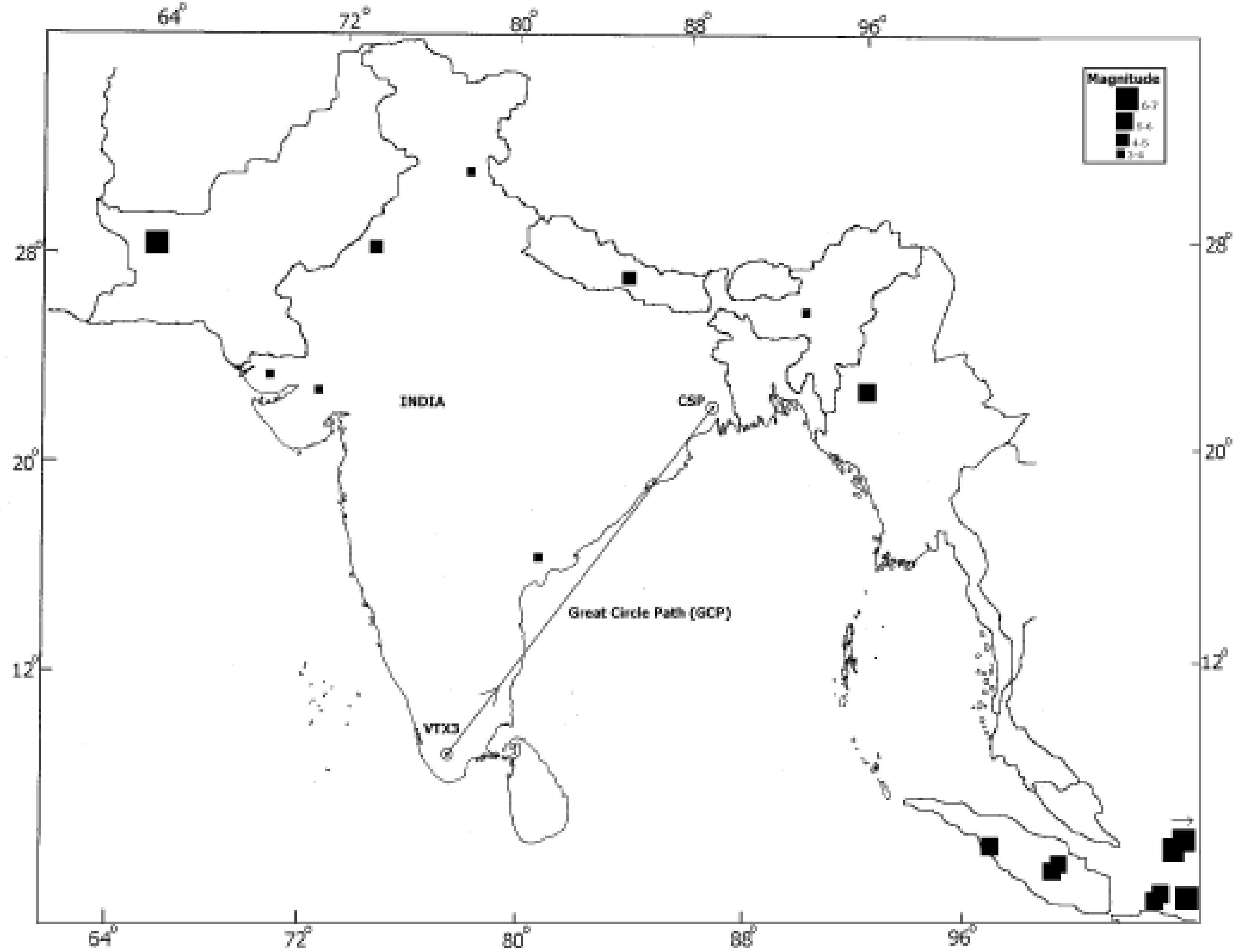
Seismically active day: abnormal DLPT/DLDT







Variation of Ionization (left) at sunrise and de-ionization time (right) at sunset using CSP data. The earthquake dates coincide with the anomalous ionization and de-ionization times (Chakrabarti et al. 2007). The effect is observed beyond 2σ level (some times 5 σ)



64°
72°
80°
88°
96°
28°
20°
12°
Magnitude
6-7
5-6
4-5
3-4
INDIA
CSP
VTX3
Great Circle Path (GCP)

Only strongest earthquakes have been written in the Table

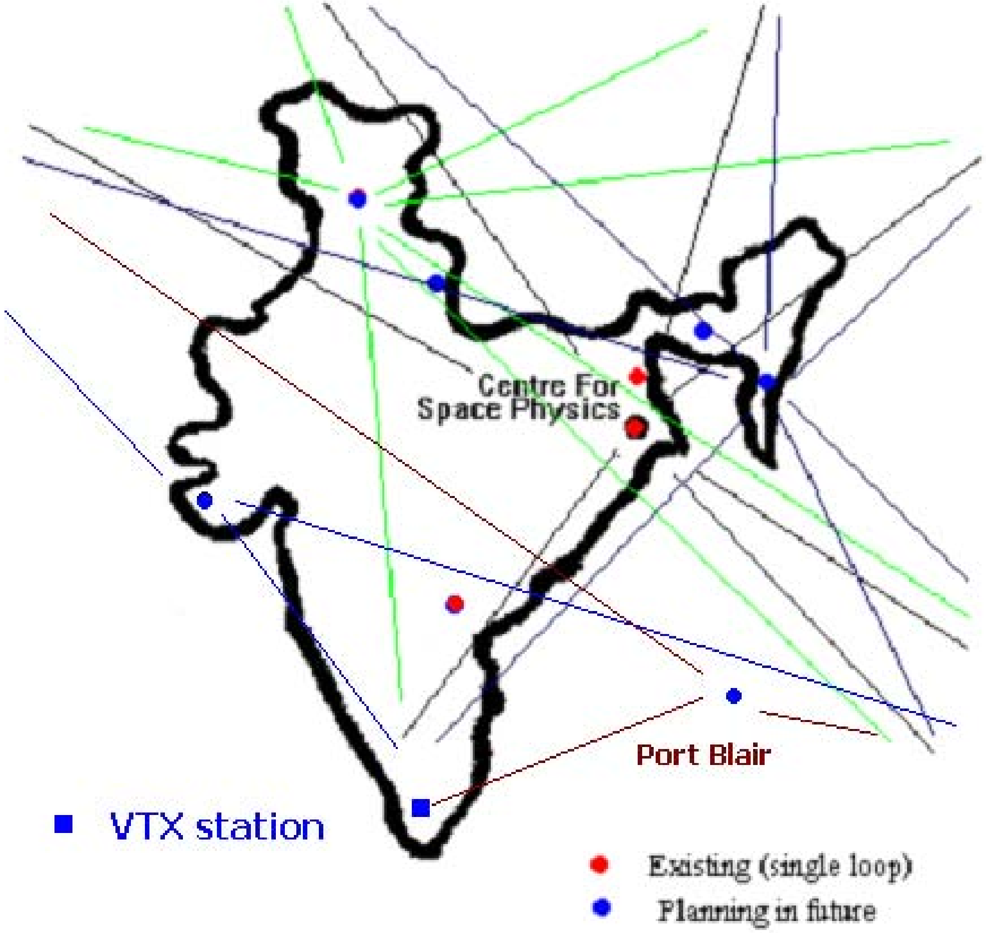
Table 1: The observed deviation of DLPT from the mean around seismically active days.

Date	Earthquake Magnitude	Observed DLPT in minutes	Deviation in σ	Country of the Earthquake
7/11/06	5.0	42	1.0	Pakistan
29/11/06	3.9	67	2.8	India
30/11/06	6.2	29	1.9	Indonesia
05/12/06	5.0	95	4.2	Myanmar
09/12/06	5.2	85	3.5	North Sumatra
*15/12/06	3.5 (16/12/06)	76	2.9	India
*18/12/06	5.7 (17/12/06)	112	5.2	North Sumatra
*05/01/07	3.4 (07/01/07)	76	2.6	India
17/01/07	5.9	69	2.04	South Sumatra
*25/01/07	4.0 (24/01/07)	70	2.05	India
11/02/07	5.0	79	2.6	North Sumatra
14/02/07	4.0	74	2.2	Indonesia
*16/02/07	4.8 (15/02/07)	33	2.5	Nepal
21/02/07	3.6	75	2.3	India
27/02/07	3.5	58	1.7	India
1/04/07	7.5	67	3.0	Solomon Islands
21/04/07	6.1	71	2.5	Papua New Guinea
27/04/07	6.0	70	2.3	North Sumatra

* Anomalous DLPT before or after the earthquake which occurs on dates in second column.

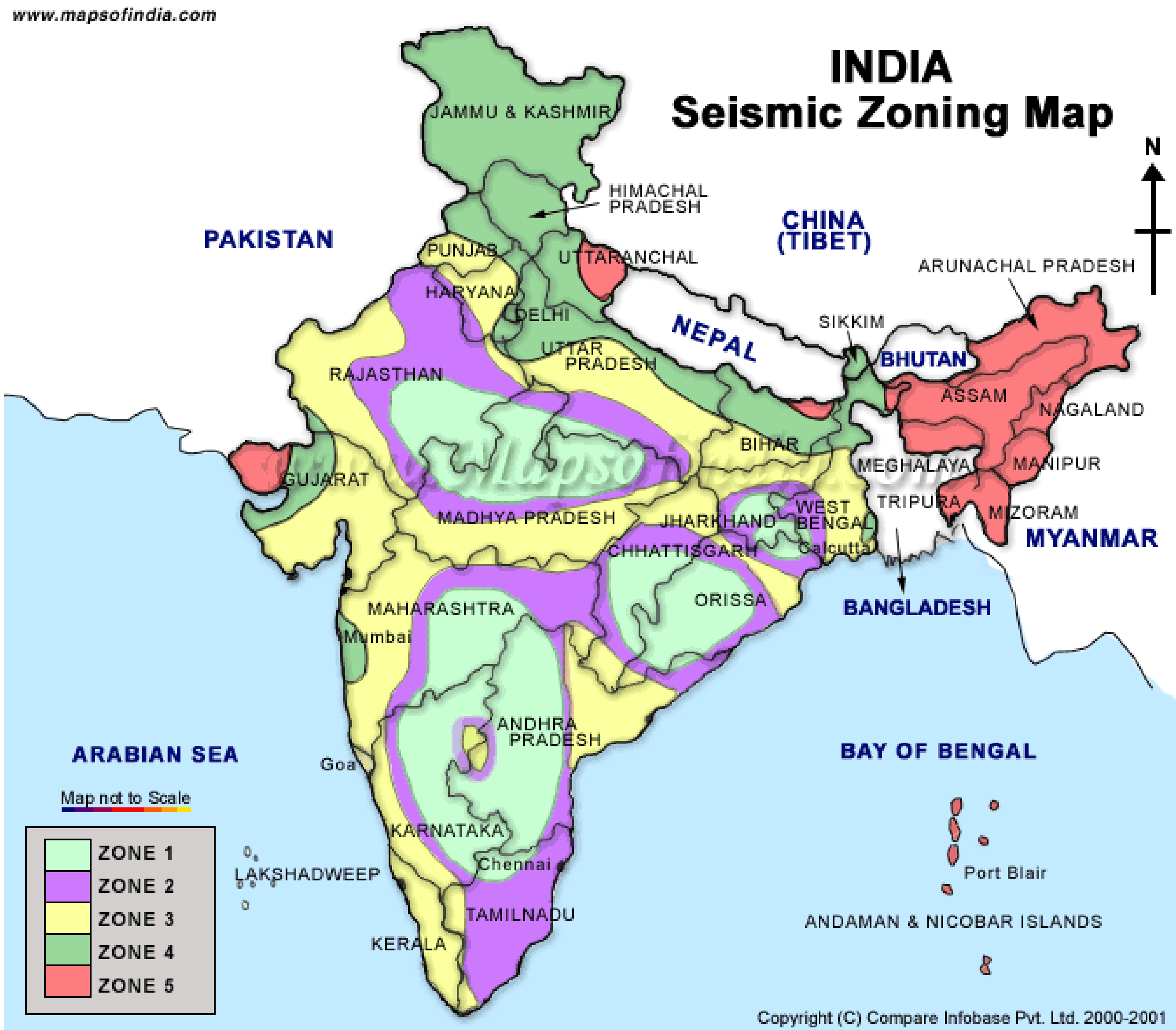
** The earthquake data is taken from the website **http://www.imd.ernet.in**.

CSP has now deployed a large number of atennas around India



Schematic picture of how the receiver / transmitter baselines would increase the chance to locate the Earthquake epicenter. In future, we wish to increase the number of receivers, the fast internet to transfer data from all the centers to the head office data bank.

Seismic zones in India



We have placed the antenna in Kashmir, Bhuj, Agartala and Port Blair. One receiver at Hyderabad TIFR/Balloon Facility and one at Malda have been installed some time back.

Few others are being built at CSP

References:

1 Possible detection of ionospheric disturbances during Sumatra-Andaman Island Earthquakes in December, 2005, Ind. J. Rad. & Space Phys., 34, 314.

2. Unusual behaviour of D-region Ionization time at 18.2KHz during seismically active days, Ind. J. Phys (in press).

Thank you!