Correlation Between Ionospheric Anomaly With Seismic Activities

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The first attempt was done by Russian colleagues (Gokhberg et al. in 1989 and Gufeld et al. in 1992.

They studied for a long distance vlf propagation from Reunion (omega transmitter) to Omask. They have succeeded to find out a significant propagation anomaly a few days before the famous Spitak earthquake in 1992.
The most convincing result on the seismo-ionosphere coupling with VLF was obtained by Hayakawa et al. in the 1996 for the Kobe earthquake in 1995 (with a magnitude of 7.3 and with a depth of 20 Km).
The Transmitter and Receiver

The GCP between Kolkata and VTX is 1932 Km.

(Lat. 22º34‘N, Long. 88º24‘E)

(Lat. 08º26‘N, Long. 77º44‘E)
The Instruments

The Stanford AWESOME Receiver
The ICSP VLF Receiver
The 18.2 kHz signal amplitude
Observation of terminator shifts before Kobe earthquake of 1995

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.

Hayakawa et al., 1996
The procedure of studying earthquake precursors by VLF propagation

Hayakawa et al. used the terminator shifting method
Thought to be the causes of ionospheric anomalies

- 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 light/sonoluminiscence/triboluminiscence
  These processes could start much before the actual earthquake.
ICSP data (with one loop antenna) before and during the Sumatran Earthquake

Chakrabarti et al., 2005
A “Quiet” day signal

Kolkata 19–Jan–2007 VTX Amplitude

SRT

TA

TB

SST

Time (minutes) after 00:00:00 IST ( = UT+05:30:00)

Amplitude
An “Active” day signal
Variation of sunrise & sunset terminators throughout the year

The "CLASSIC PICTURE"

Sasmal & Chakarbarti, 2009
The variation of sunrise and sunset terminators for a longer period of time

Sasmal & Chakarbarti, 2009
The Standardized Calibration Curve (SCC)

Sasmal & Chakarbarti, 2009
The VLF Day Length

The D-Layer Preparation Time (DLPT) and the D-Layer Disappearance Time (DLDT)
Earthquakes in Indian neighboring zone & seismic circles (M>3.5)
Variation of the number of seismic events with the seismic circles
Energy of The Earthquake

\[
\log_{10} E = 4.4 + 1.5 Ms
\]
(for earthquake less than 5.0 magnitude)

\[
\log_{10} E = 5.24 + 1.44 Ms
\]
(for earthquake greater than 5.0 magnitude)

where,

\[
E = \text{Energy of the earthquake in Jules}
\]
\[
Ms = \text{surface wave magnitude (Lowrie, 2007).}
\]
Variation of effective earthquake magnitude with respect to the “Middle Point” with days
Variation of the VLF Day-length

Sasmal & Chakarbarti, 2009
Correlation between daylength & seismic activity

Sasmal & Chakarbarti, 2009
The DLPT & DLDT Method
The first attempt of this method and the success

Variation of DLPT and DLDT using CSP data. The earthquake dates coincide with the anomalous ionization and de-ionization times. The effect is observed beyond $2\sigma$ level (some times $5\sigma$)

Chakrabarti et al. 2007
<table>
<thead>
<tr>
<th>Date</th>
<th>Earthquake Magnitude</th>
<th>Observed DLPT in minutes</th>
<th>Deviation in $\sigma$</th>
<th>Country of the Earthquake</th>
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<tbody>
<tr>
<td>7/11/06</td>
<td>5.0</td>
<td>42</td>
<td>1.0</td>
<td>Pakistan</td>
</tr>
<tr>
<td>30/11/06</td>
<td>6.2</td>
<td>29</td>
<td>1.9</td>
<td>Indonesia</td>
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<td>95</td>
<td>4.2</td>
<td>Myanmar</td>
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<tr>
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<td>85</td>
<td>3.5</td>
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<td>5.7</td>
<td>112</td>
<td>5.2</td>
<td>North Sumatra</td>
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<tr>
<td></td>
<td>(17/12/06)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>17/01/07</td>
<td>5.9</td>
<td>69</td>
<td>2.04</td>
<td>South Sumatra</td>
</tr>
<tr>
<td>*25/01/07</td>
<td>4.0</td>
<td>70</td>
<td>2.05</td>
<td>India</td>
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<td>(24/01/07)</td>
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<tr>
<td>11/02/07</td>
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<td>79</td>
<td>2.6</td>
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<td>74</td>
<td>2.2</td>
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<tr>
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<td>4.8</td>
<td>33</td>
<td>2.5</td>
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<td>(15/02/07)</td>
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<td></td>
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</tr>
<tr>
<td>21/02/07</td>
<td>3.6</td>
<td>75</td>
<td>2.3</td>
<td>India</td>
</tr>
<tr>
<td>1/04/07</td>
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<td>67</td>
<td>3.0</td>
<td>Solomon Islands</td>
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<tr>
<td>21/04/07</td>
<td>6.1</td>
<td>71</td>
<td>2.5</td>
<td>Papua New Guinea</td>
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<td>27/04/07</td>
<td>6.0</td>
<td>70</td>
<td>2.3</td>
<td>North Sumatra</td>
</tr>
</tbody>
</table>

Comparison of the earthquake dates with the DLPT anomaly

Chakrabarti et al. 2007
DLPT variation with days
DLDT variation with days
Correlation between DLPT & seismic activity
Correlation between DLDT & seismic activity
Correlation with Effective Magnitude
Correlation with DLDT
Correlation with DLPT
Conclusion & Future Plan

- The VLF signal anomaly and the Seismic activities are correlated for the kolkata-VTX baseline.
- The maximum anomaly occurs two days before the seismic activities for the VLF daylength method.
- The maximum anomaly occurs one day before the seismic activities for the DLPT & DLDT method.
- To obtain better correlation and to improve the predictability of the seismic events the data are being analyzed for the Malda-VTX baseline.
- The signal form other receiving places and other transmitting frequencies will be analyzed in future.
Thank You