VLF Science at Indian Centre for Space Physics
and
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ICSP is monitoring signals from various stations.
The old VLF-receiver at ICSP, Kolkata

- Loop antenna (RC circuit) capable of observing only one station
- Receiver (made at ICSP)
- DAC card connected to a computer for continuous data acquisition
Examples of VLF Observations of VTX at ICSP in 2002:
Collaboration with Stanford University STAR (VLF) laboratory started in 2005.

Stanford Star Laboratory Receiver
Antenna setup with preamp and GPS

Stanford University line receiver

GPS system
Subsequently, in 2007 we procured one more for our Antarctica station. Presently both are at ICSP.
Originally, the signal was very good. For ‘some reason’ not understood, the amplitude and phases currently are worse than those obtained by loop antennas.
We placed loop antennas and tested signals at various places in India.
Few others are being built at ICSP
Comparison between the solar flare data from two receivers and with the GOES satellite data.
Dec. 3\textsuperscript{rd}, 2005

ICSP observation of VLF-ionospheric interaction

NASA X-ray observation (GOES satellite) directly looking at the sun
Typical daytime observations from a given station

Note:

1. Classical quite sun shape in most of the days due to solar minimum.

2. Shift in sunrise/set

3. Mode conversion effects

4. Scintillation at night

5. Weak flares could also be seen on some days.
VTX signal amplitude is stable. Here is one year of data (~260 days the transmitter was on)
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 (under a totally new condition)
- Gamma-ray bursts (most exciting to observe during winter time; may be discovery is possible)
- Strong Pulsar (Same as GRB)
- Meteorite impact
Leonid Meteor Shower of 2002

![Graph of Leonid Meteor Shower of 2002](image-url)
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.
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.
Example of an actual data acquisition

Great Circle Path between the ICSP receiver and the VLF station at Vijayanarayananam
ICSP 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)
Our Antarctica trip:

• Mr. Sudipta Sasmal went to Maitri Station, Antarctica. Little did we realize that Indian Govt. the expedition would be so short lived.

• got very great data for few weeks (2007-2008). [I especially thank Morris for helping us a lot.]
Locations of Maitri and Palmar stations and the transmitting antenna at the South Pole.
Tectonic plate movements from Antarctica can be monitored using our D-Layer ionization and de-ionization time respectively.
Mr. Sasmal at Maitri, Antarctica
Narrowband Data of Maitri
VLF Campaign

• In order to understand the nature of signals we made a campaign in which we collected data from 13 different places in India in December (one week), and from 10 places in Summer (one week)

• This would help us better model the signals theoretically as already presented by my fresh students Tamal Basak and Sujay Pal yesterday
VTX Signals obtained by ICSP Receivers during Winter Campaign (18.2KHz)

Confused
Strange

Groundwave (skip zone)

Great (cf. Pune)!
Noisy but OK!

Strange (Weak?)

Great!
Superb!

Noisy but OK!

Great (low GML) effect!

Weak Signal?

Very noisy but understandable.
Our data (images) from various sites could be accessed at http://csp.res.in
Our Theoretical efforts

• We can now understand why signals at different places look totally different
• We can reproduce many features, though we need more improvements of the model.
Data hunting during 22\textsuperscript{nd} July, 2009
Total Eclipse
ICSP balloon payload on TSE90
Shadow of the moon on the white cloud background as seen from 22km above ground by our Payload.
Raw data at Malda on 21\textsuperscript{st}, 22\textsuperscript{nd} and 23\textsuperscript{rd} (5dB shifted for clarity)
Observed difference of VTX signal amplitude at three places during the total eclipse.
Observed difference of NWC signal amplitude at three places during the total eclipse.
Some more raw data of 22\textsuperscript{nd} July, 2010
15th January, 2010 (ASE-10)
From Kolkata we saw partial eclipse
Near the maximum obscuration a solar flare occurred! Perhaps in the first time in history, we see solar flare by lunar occultation!
Our data of NWC on that day clearly showed the solar eclipse effect as well as solar flare during eclipse.
Experiment with submerged antenna

(results being analysed)
Other science

- Soft Gamma Ray repeaters/Gamma ray burst observations (Sushanta Mondal)
- Earthquake correlation with VLF signal anomaly for VTX-ICSP baseline (Sudipta Sasmal)
- Same for VTX-Malda baseline (Asit Choudhury)
COME TO VELFRATO-10
Conference in Kolkata in Three weeks time (14\textsuperscript{th}-18\textsuperscript{th} March, 2010)

• Major invitees are: M. Hayakawa, Y. Tanaka, Y Hobara, Ken Lynn etc.
• $200 registration fee includes all expenses (accommodation plus food plus transportation plus trip to Sundarban)
• No fund for travel is available any more. All fund has been committed.
Thank you!