VLF Research in India and setup of AWESOME Receivers

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ADVANCING VLF SCIENCE THROUGH THE GLOBAL AWESOME NETWORK, 30-May to 01-Jun 2009, Tunis, Tunisia
Outline of talk

- Introduction
- The earlier VLF research work in India, highlights and limitations
- The motivation of set up of new AWESOME installation and IHY UNBSS initiation
- Importance of VLF stations, other supported data from multi instrument observatories
- Initial observations and results of using present VLF AWESOME receivers at India
- Future plans
**Whistlers and VLF emissions:**

- **Main whistler mode waves include:** Lightning whistlers, Triggered emissions, Hiss, Chorus, etc.
- **Generated either by lightning strikes or by wave-particle interaction in the magnetosphere**

![Diagram showing whistlers generated by lightning propagating along the geomagnetic field line and dispersed](image)

- By analyzing dispersion curve of the VLF whistler waves, plenty of information about the magnetospheric medium can be obtained viz.:
  - Electron density
  - Total electron content in a flux tube
  - Electric field

![Graph showing whistler spectrum](image)
How Important are VLF signals in Indian Low latitude region?

- India is a very interesting location for several reasons like:
  - conjugate region of the India lies in Indian Ocean
    - less lightning activity expected
  - Also the height of the magnetic field lines (~ 800 km max.) connecting conjugate regions lies in the ionosphere
    - Probable absorption of signals

Not enough VLF activity expected
Even though very interesting records of whistlers/VLF waves at Indian Low latitude locations has been observed like:

- Whistlers
- VLF emissions like – continuous and pulsing hiss
- Periodic emissions
- Hiss triggered emissions
- Whistler triggered emissions
- Hissler, etc.

**VLF emissions** like whistlers is also a class of natural radio phenomena, whose origin is in magnetospheric sources or in man made sources such as VLF transmitters.

Generation mechanism of VLF emissions are poorly understood, and they remain the focus of intense research activity.
Importance of source location of VLF signals in low latitude

- Because of curvature of magnetic field line at low latitude, it is difficult to get down coming whistler mode (WM) wave inside the WM transmission cone.

- As a result, quite a bit of activity seen at low latitudes may have exited at an ionospheric exit point at somewhat higher latitudes and then propagated in the Earth-ionosphere waveguide to the observation point.

- Furthermore at low latitude we expect WM waves exciting ionosphere both in the North and South to reach the observation location.
VLF Research in India - Status

Soon after the usage of whistlers and VLF waves was gaining importance in 1950’s at mid and high latitudes, for the study of ionosphere/magnetosphere

VLF research activity In 1963’s at B.H.U., Varanasi

First Whistler recording at station Gulmarg (1965-72) (24° N)
(Somayajulu et al., 1965)

Subsequent stations setup at: Nainital (1970-75) (20° N)
Varanasi (1975..) (14° N)
(Singh et al., Nature, 1977)

Also at: Agra (1980’s), Srinagar (1980’s) and Bhopal (1990’s)

These studies have emphasized occurrence & importance of Whistlers/VLF phenomena in low latitude region

- Synoptic mode for couple of months every year
- Study of naturally occurring phenomena
Some examples of observation

Fig. Spectrogram of Hissler (Ref: Singh et al., GRL, 2004)

Fig. Spectrogram of Pulsing Hiss
Important observations

Different whistlers like short, diffused, multifalsh, multipath, twin synchronized etc.

Emissions like hiss, pulsing hiss, risers, triggered, periodic, quasi periodic etc were observed at low latitudes of Indian sector (Somayajulu et al., 1972, Singh R P., 1993)

Also rare phenomena of hissslers also reported (Singh et al., 2004)

Propagation mechanisms are well discussed and good number of review papers published.

Used analog Experimental set up consists of T type antenna, pre and main amplifier, magnetic cassette tape recorder.

Analyzed on advanced VLF data analysis system (AVDAS) at BHU, varanasi

Later used loop antenna was better to avoid back ground noise.
Main limitations

- The T type antenna records Ez components of the waves and vertical antennas are heavily masked by local noises compared to loop antenna.
- All sites used analog systems and single channel Ez measurements which limits the scientific application and interpretation of data.
- Not possible for direction finding which is essentially considered at mid and high latitude.
- Further traditional system used forbade the use of VLF transmitter signal as there was no facility to monitor those signals.
- Because of these limitations, probing of D region ionospheric have not been given due attention at low latitudes.
- The solar flare effects and magnetic storms studies on D region ionosphere have not been possible because of non availability of Narrow band data.
With the association of IHY UNBSS program, a collaboration between Stanford University and Indian Institute of Geomagnetism has made during 2007.

Three AWESOME VLF receivers were installed and monitoring natural and sub-ionospheric VLF signals continuously. This will help us in better understanding of VLF wave phenomena in low latitude region.

The AWESOME receivers are deployed at Dr KS Krishnan Geophysical Research Laboratory, IIG, Allahabad (16.49°N), also (in collaboration with)

- ARIES, Nainital (20.29° N)
- B.H.U., Varanasi (14.91°N)
Experimental Setup:

- **VLF Receiver installed**
  - AWESOME VLF Receiver – Stanford University
  - Capable of collecting Narrowband + Broadband VLF data
  - Amplitude and Phase of Transmitter signal
  - Saves entire VLF signal spectrum

- Crossed loop antenna – 10 x 10 meter
- Frequency response – 300 Hz to 47.5 kHz
- Sampling – 100 kHz
- 10-microsecond time resolution
Locating the source of observed VLF signals in India was always a problem, because of the absence of Direction Finding measurements.

The VLF receiver used was very simple – T-type antenna, pre- and main- amplifiers and a magnetic cassette tape recorder.

Direction Finding (DF) Study by AWESOME

Three Channel - AWESOME can measure
- X-component (North-South)
- Y-component (East-West)
- Ez – Vertical E-field (interested to install at one site at least)

Ez measurement is useful for studying near ionospheric exit signal and also to remove 180 degree ambiguity.
Location of Indian VLF Stations in AWESOME Network

- **Nainital**
  - Lat. 20.48 N Long. 153.34 E
  - May, 2007

- **Allahabad**
  - Lat. 16.49 N Long. 155.34 E
  - March, 2007

- **Varanasi**
  - Lat. 15.41 N Long. 156.37 E
  - October, 2007

Under IHY/UNBSSI program
Network of Indian Geomagnetic Observatories

- VLF receivers sites
Importance of VLF sites

Allahabad (16.490N) – multi parameter observatory
- Digital flux gate magnetometer
- Digital CADI Ionosonde
- Air glow optical experiments
- VHF Scintillation receivers, TEC measurements
- Search coil magnetometer for ULF observations

Nainital (20.290 N) : A high altitude observatory with lower Atmospheric observations, Solar observations are monitored regularly and best location for sprites observations in future

Varanasi (14.910N) : The most active group in VLF research in India and very good VLF events were observed in past. Also, Scintillation and TEC measurement experiments are going on.
Monitor natural and sub-ionospheric VLF signals continuously with AWESOME receivers.
Matlab codes are developed for data analysis.
Data Storage: 250 GB pocket external hard disks are used to store the data at sites and final data is stored in server at IIG head quarters (Mumbai).

Objectives:

- Understand the generation and propagation mechanism of naturally occurring VLF waves in low latitude region.

- To investigate long-term trends of magnetospheric parameters such as electron density, total electron content in a flux tube and electric fields during quiet and active solar periods.

- Correlation between VLF wave activity and geomagnetic activity.

- Remote sensing of the lower ionosphere, lightning and thunderstorms.

- VLF waves as precursors to Earthquakes.
Electromagnetic effects

- Solar Flare Detection
- Cosmic Gamma Rays
- Chorus Emissions
- Lightning
- Whistler waves
- LEP Events, hurricane studies
- Early/fast Events
- Mesospheric lightning discharges
  - Sprites, elves, blue jets, TGFs
Examples of some spectrograms

Varanasi

VTX (18.2 kHz) Sferics

VLF transmitter signals

Allahabad

North-South

Allahabad: 04-Jun-2008

East-West

Plot Generated: 04-Jun-2008 (local)
Studies in Progress

Dynamic spectrograms of tweeks observed simultaneously at Allahabad and at Nainital on 13 June, 2007

Dynamic spectra of First Whistler recorded at Allahabad on 17 June, 2008
Dynamic spectrum of chorus between 0.75 and 3.2 kHz recorded at Allahabad on 12 August 2007

- Earthquake precursor study for China EQ on 12 May, 2008
- The JJI signals which are received at Indian sites are analyzed during pre and post EQ period
Objectives of Solar Eclipse campaign period:
(19 – 25 July, 2009)

- Study of ionospheric D-region variability i.e. electron density, ionospheric reflection height, etc.

- Effect of Solar Eclipse on Marine VLF communication by monitoring VLF transmitter signals operated by several countries globally. Special emphasis on VTX – Indian and NWC – Australian transmitters.

- Since solar eclipse creates nighttime conditions during daytime, an attempt will also be made to record naturally occurring magnetospheric VLF emissions.

- Such eclipse time emissions will provide opportunity to study the complex VLF emissions generation and propagation mechanism involved in low latitude region.
Location of VLF stations

Allahabad (16.04°N), Nainital (20.29°) and Varanasi (14.91° N)

(In Geomagnetic Latitude)
Future plans

- Total solar eclipse provides a rare opportunity to study the Electro-Dynamic processes in the D-region of the ionosphere and magnetosphere.
- As solar cycle 24 is in progress, expecting intense solar flares and geomagnetic storms, best use the supporting data from other multi instruments for campaign periods.
- Coupling of D, E and F region studies during quiet and disturbed periods.
- Interested in collaborative studies with other AWESOME VLF community for some event studies or campaign plans.
Allahabad - Site

Thank You for your kind Attention!
VLF Presentation at Libya

History of VLF studies in India: Earlier work, some Whistlers, tweeks and emission examples, importance of Indian stations

Present AWESOME installation and importance of Narrowband data (first study) and reason of choosing ALD, BHU, NAI. VF project initiated during 2007 which low solar activity period, good time to study quite time D region night time electron density variations.

Allahabad station, the multi instruments observatory which is useful to supplement other data of gravity waves, pulsation data and Ionosonde to study F and D region coupling (??)

Maintaining the VLF stations and storage system of huge VLF data.

Developing Matlab codes for various VLF studies

Narrowband data especially NWC etc which receive at Indian stations cover the seismological areas like Aandamon, Sumatra and China: pre signatures of Earthquake and any anomalies, new IIG observatory functioning at Andamon.

Significance of IIG magnetic data for SFE events and these effects can be seen in Narrowband data, expected good solar flares during high solar activity period.

Geomagnetic storms

Some typical VLF events noticed during 2007 and 2008 (Details by Dr. Rajesh)

Future plan, mention solar eclipse campaign during July 2009
- Lightning discharges
- Whistlers
- ELF/VLF emissions
- Lightning induced electron precipitation (LEP)
-Sprites, Elves, Blue jets, etc.
- Solar flares
- Geomagnetic storms
- Earthquake precursors etc.
Sources of ELF / VLF waves

ELF/VLF waves has various Natural and Artificial origin:

- **Natural sources of ELF/VLF waves:**
  - Includes Lightning discharge from thunder storms, volcanic eruptions, dust storm and tornadoes, etc.

- **Man Made Sources of ELF and VLF Radio Waves:**
  - HF heating
  - Fixed frequency VLF transmitters
  - Nuclear explosions

- **However, on a global basis, by far the most significant source of wave at ELF/VLF is that generated by lightning discharges from thunderstorms.**

  - **Global Lightning Flash rate ~ 50-100 sec^{-1} km^{-2}**
Introduction:

- The Earth’s magnetosphere is capable of sustaining wide variety of wave phenomena. These waves are important partly because they influence the behavior of the magnetosphere and partly because they can be used as an experimental tool to investigate the upper atmosphere.

- One of the most widely studied wave mode is the whistler mode waves. The aim is to use this as a diagnostic tool for the study of Earths magnetosphere.

- Whistler mode radiation consists of electromagnetic waves whose upper frequency cutoff is either the local electron plasma frequency \(f_p\) or gyrofrequency \(f_g\), which ever is less (Stix, 1992).
VLF remote sensing of the lower ionosphere:

- Solar flares
- Giant cosmic $\gamma$-ray flares
- Lightning induced electron precipitation (LEP)
- Effects of lightning discharge
  - Sprites, elves, blue jets, TGFs

Subionospheric VLF observations allow the measurement of the D-region of the lower ionosphere, normally not accessible with other instruments.

The ambient nighttime electron densities in D-region are typically ~ 1 to 10 el/cc. Even the most powerful VHF or HF radar cannot measure the D-region at nighttime - >1000 el/cc for useful echoes. Precipitating electrons with >100 keV energy penetrate to altitudes < 85 km, creating secondary ionization therein. The additional ionization produced is typically < 100 el/cc. The reflection height of the VLF waves propagating in the earth ionosphere wave guide is ~ 85 km at night. Amplitude/phase of the VLF signal is highly sensitive to conductivity.

VLF radio remote sensing is the technique suited for detection of disturbances in D-region.

Subionospheric VLF signals are also helpful in the study of VLF waves as a precursor to earthquakes.
Network of Indian Geomagnetic Observatories

- **IIG Headquarters**
- **Observatories operated by IIG**
- **Observatories operated by other Institutes (NGRI, IIA & SOI)**
- **New observatories to be opened**
- **Observatories discontinued**
- **Digital Magnetometer**
Table 1. The details of ground geomagnetic stations in India.

<table>
<thead>
<tr>
<th>Station/Code</th>
<th>Geographic Latitude</th>
<th>Geographic Longitude</th>
<th>Geomagnetic Latitude</th>
<th>Geomagnetic Longitude</th>
<th>Dip. Latitude</th>
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<tbody>
<tr>
<td>Tirunelvelli (TIR)</td>
<td>8.7 N</td>
<td>77.8 E</td>
<td>0.17 S</td>
<td>149.97 E</td>
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<td>Trivandrum (TRD)</td>
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<td>76.95</td>
<td>0.31 S</td>
<td>149.1</td>
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<td>Ettaiyapuram (ETT)</td>
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<td>0.28 N</td>
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<td>Kodaikanal (KOD)</td>
<td>10.23</td>
<td>77.47</td>
<td>1.39 N</td>
<td>149.78</td>
<td>2.86</td>
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<td>Pondicherry (PON)</td>
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<td>79.92</td>
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<tr>
<td>Hyderabad (HYD)</td>
<td>17.42</td>
<td>78.55</td>
<td>8.45</td>
<td>151.5</td>
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<td>Visakhapatnam (VSK)</td>
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<td>Alibag (ABG)</td>
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<td>Nagpur (NGP)</td>
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<td>Ujjain (UJJ)</td>
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<td>18.83</td>
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<td>Silchar (SIL)</td>
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<td>Jaipur (JAI)</td>
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<td>Hanle (HAN)</td>
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<td>78.95</td>
<td>23.69</td>
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<td>30.81</td>
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</table>
10 April 2001: X2.3 Solar flare (sfe) at 05:25 UT modified the ionospheric current and affected the magnetic field within a few minutes.

11 April: Pre-noon Quiet day condition prevails showing a steady geomagnetic field.

11-12 April: Effect on the ground magnetic variation following the flare and earth directed Halo CME on 10 April, which impacted the earth’s magnetosphere almost 34 hours after the solar burst.