Very Low Frequency (VLF) studies of ionospheric-magnetospheric electromagnetic phenomena in Indian low latitude region using AWESOME receivers

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VLF Research in India - Status

- Soon after the usage of whistlers and VLF waves was gaining importance in 1950's for the study of ionosphere/magnetosphere

VLF research activity → In 1960's at B.H.U., Varanasi

First Whistler recording station → Gulmarg (1965-72) (24^o N)
(Somayajulu et al., 1965)

Subsequent stations setup at: Nainital (1970-75) (20^o N)
Varanasi (1975..) (14^o 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

- We plan to monitor natural and sub-ionospheric VLF signals continuously with AWESOME receivers. This will help us in better understanding of VLF wave phenomena in low latitude region

The AWESOME receivers will be setup at

- Dr KS Krishnan GRL, IIG, Allahabad (16.05^0N)

- ARIES, Nainital (20.29^0 N)

- B.H.U., Varanasi (14.55^0N)

- ELF/VLF range – 300 Hz to 45 kHz

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.

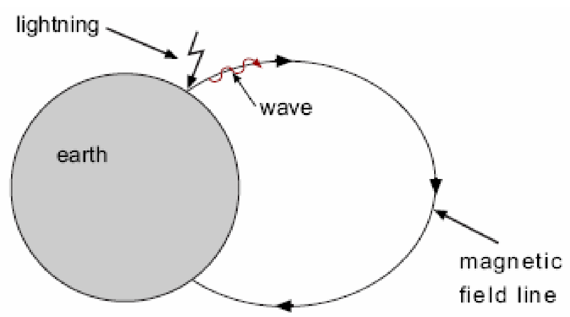
- One of the most widely studied wave mode is the whistler mode waves. The aim is to use this as a diagnostic tool for the study of Earths magnetosphere.

- 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, 1962).

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



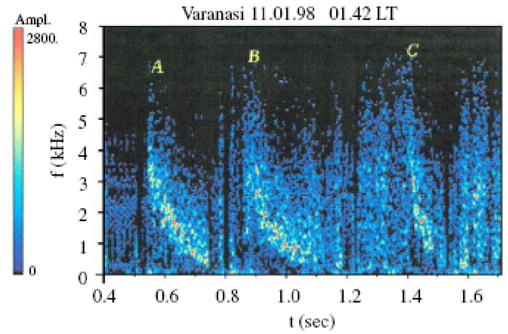


Fig. 1. Dynamic spectrum of diffused whistlers recorded at Varanasi on January 11, 1998 at 0142 h LT.

Whistler Spectrum

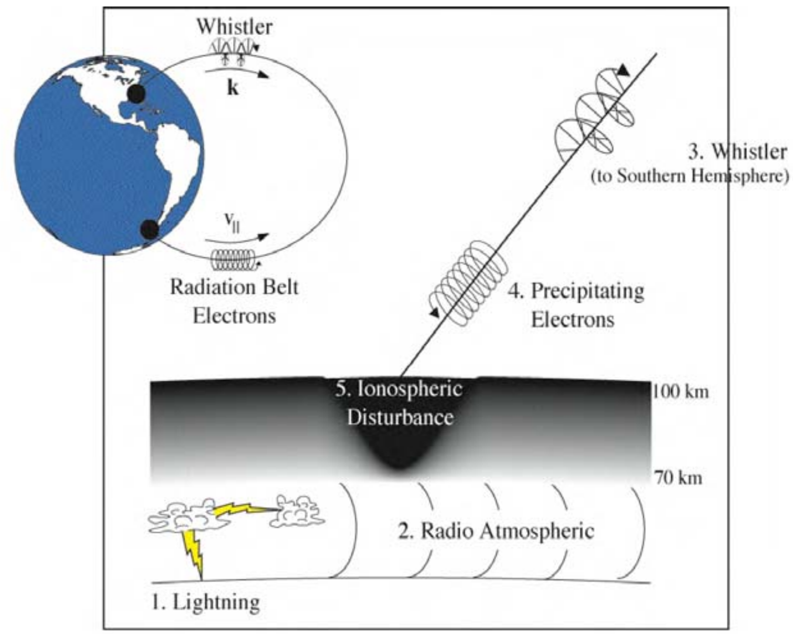
Whistlers Generated by → Lightning → Propagate along geomagnetic field line → Dispersed

➢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

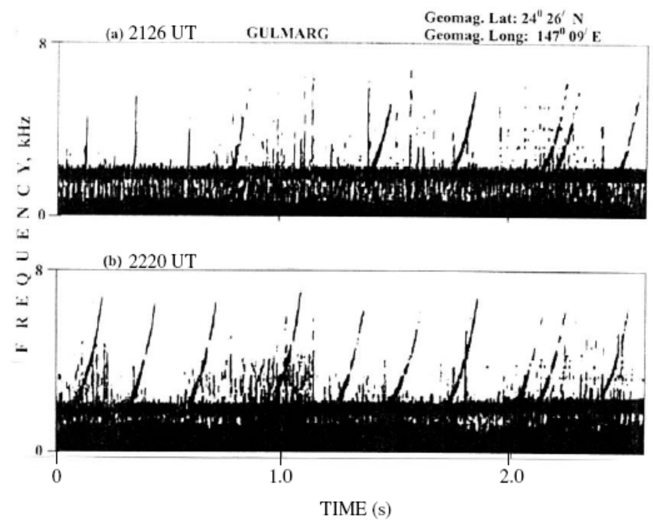
➢Understanding of whistler mode emissions in magnetosphere is important to infer the dynamics of radiation belt electrons. The high-energy belt particles and electromagnetic waves in the frequency range interact strongly (Inan et al., 1989).

➢Whistler mode waves can perturb the underlying ionosphere by scattering radiation belt electrons from the orbit through wave-particle interactions. The ionospheric perturbations produced include X-rays, optical emissions and density enhancements (Paschmann et al., 2003).



➢**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.



VLF emissions

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

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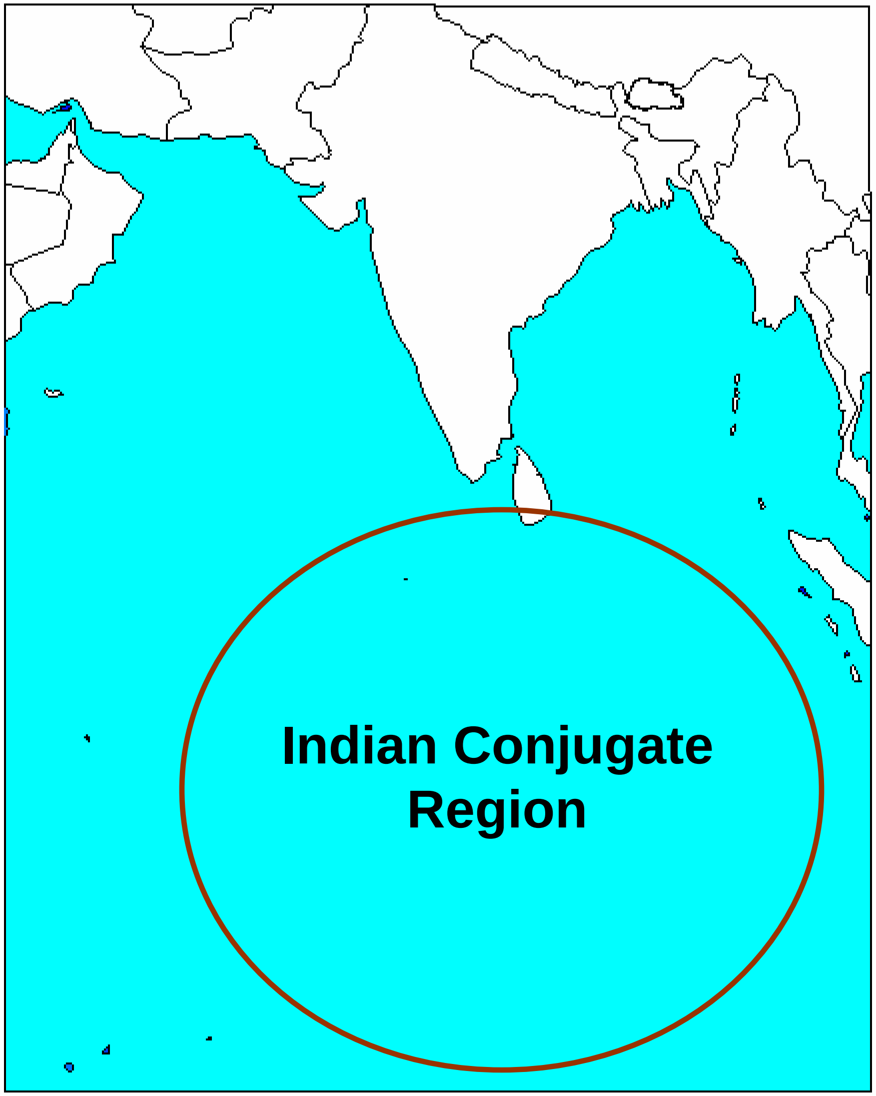
Not enough VLF activity expected



However, very interesting records of whistlers/VLF waves at Indian Low latitude locations have been observed e.g.:

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

Some examples of observation

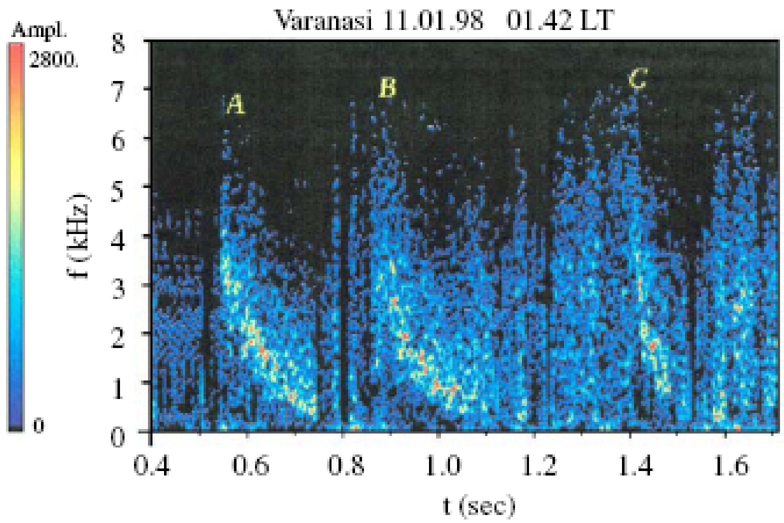


Fig. 1. Dynamic spectrum of diffused whistlers recorded at Varanasi on January 11, 1998 at 0142 h LT.

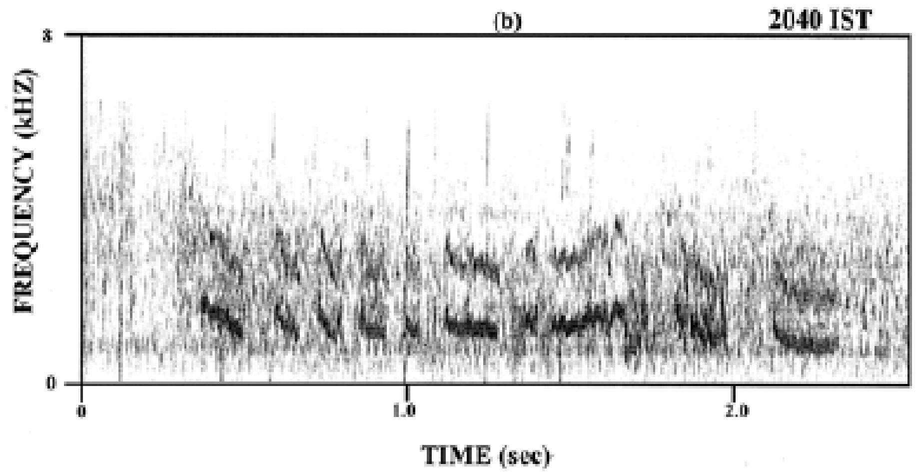
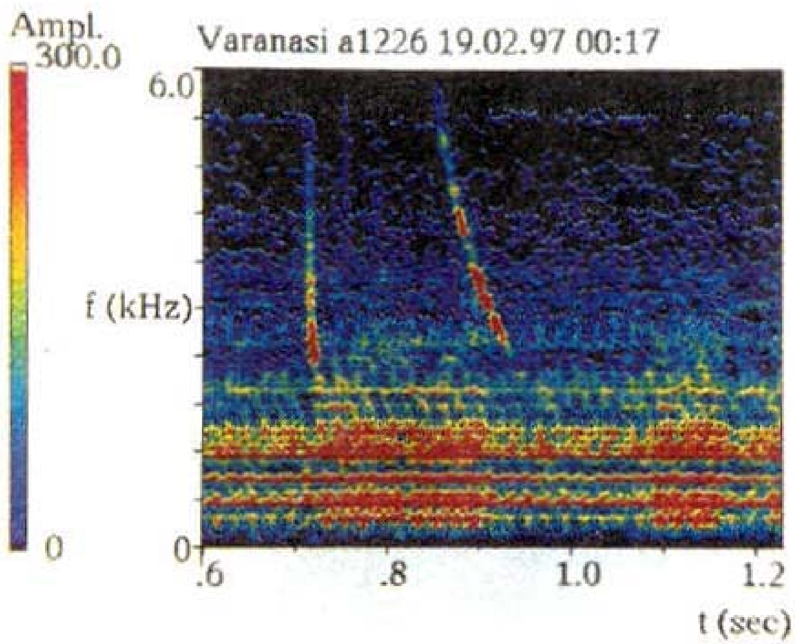


Fig. Spectrogram of Hissler



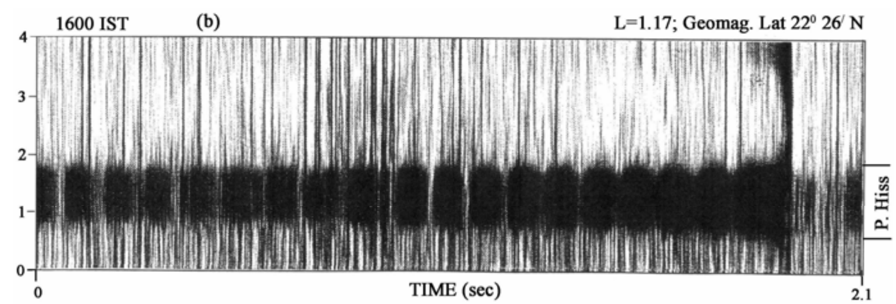


Fig. Spectrogram of Pulsing Hiss

Importance of source location of VLF signals in low latitude

- Due to 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, quiet a bit of activity seen at low latitudes may have exited at an ionospheric exit point at some what higher latitudes and then propagated in the Earth-ionosphere waveguide to the observation point

- Furthermore at low latitude, we expect WM waves exiting ionosphere both in the North and South to reach the observation location

- Locating the source of observed VLF signals in India was always a difficulty, because of the absence of Direction Finding measurements.
- The VLF receiver used was simple – T-type antenna, pre- and main- amplifiers and a magnetic cassette tape recorder

Direction Finding (DF) Study by AWESOME

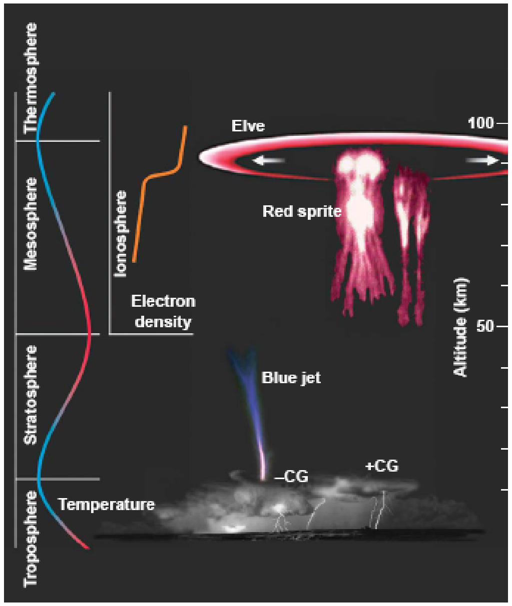
Three Channel - AWESOME can measure

- X- component (North-South)
- Y- component (East-West)
- Ez – Vertical E-field

- Ez measurement is useful for studying nearby ionospheric exit signal and also to remove 180 degree ambiguity

VLF remote sensing of the lower ionosphere:

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



The pantheon of transient luminous emissions of the stratosphere and mesosphere: sprites, jets, and elves.

Source: Neubert T., Science, vol 300, 2003

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

➢Night-time electron densities in D-region are typically ~ 1 to 10 el/cc.

➢Powerful VHF or HF radar cannot measure the D-region at night-time - >1000 el/cc for useful echoes.

➢Reflection height of the VLF waves propagating in the earth ionosphere wave guide is ~ 85 km.

➢Amplitude/phase of the VLF signal is highly sensitive to conductivity.

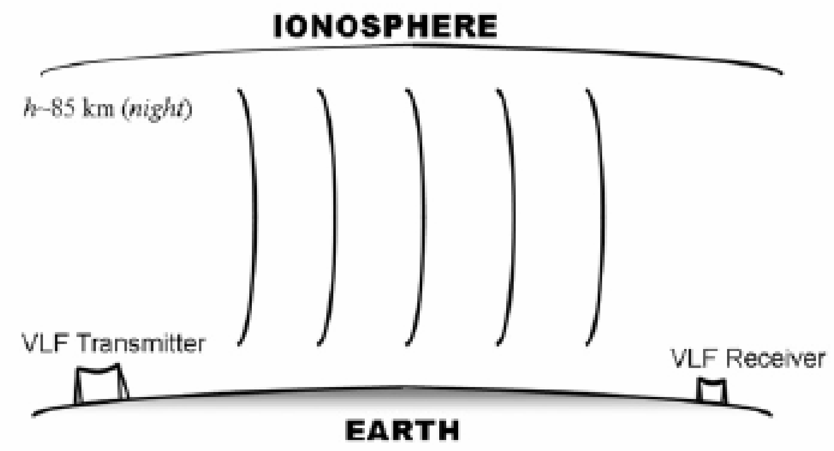


Fig. 1. Schematic of subionospheric VLF propagation.

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.**

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.

Experimental Setup:

The receivers will be setup at
Allahabad (16.04^{0}N), Nainital (20.29^0 N) and Varanasi (14.55^0 N)

VLF Receiver to be installed → **AWESOME VLF Receiver**

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Capable of collecting → Narrowband → Amplitude and Phase of Transmitter signal

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Broadband VLF data → Saves entire VLF signal spectrum

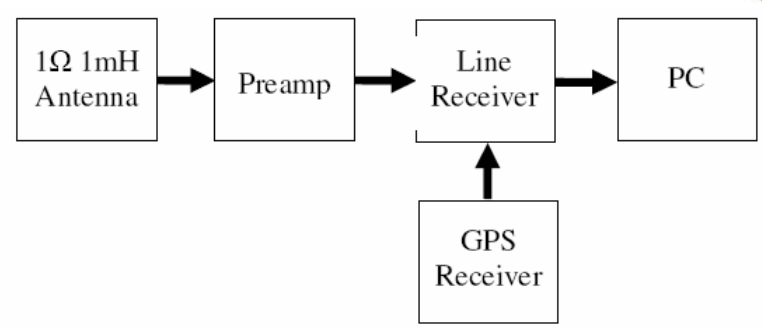
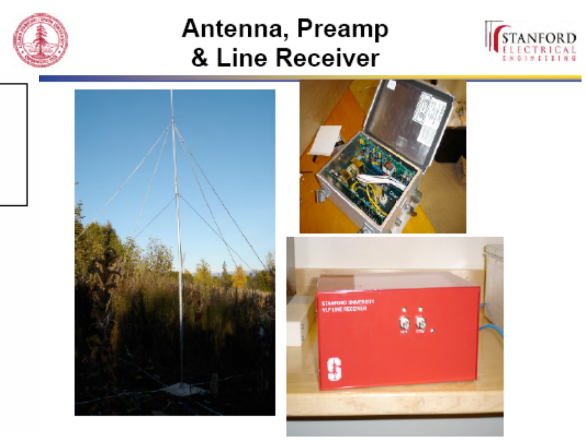
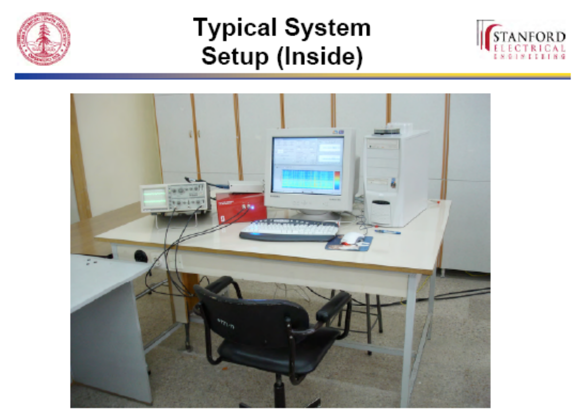
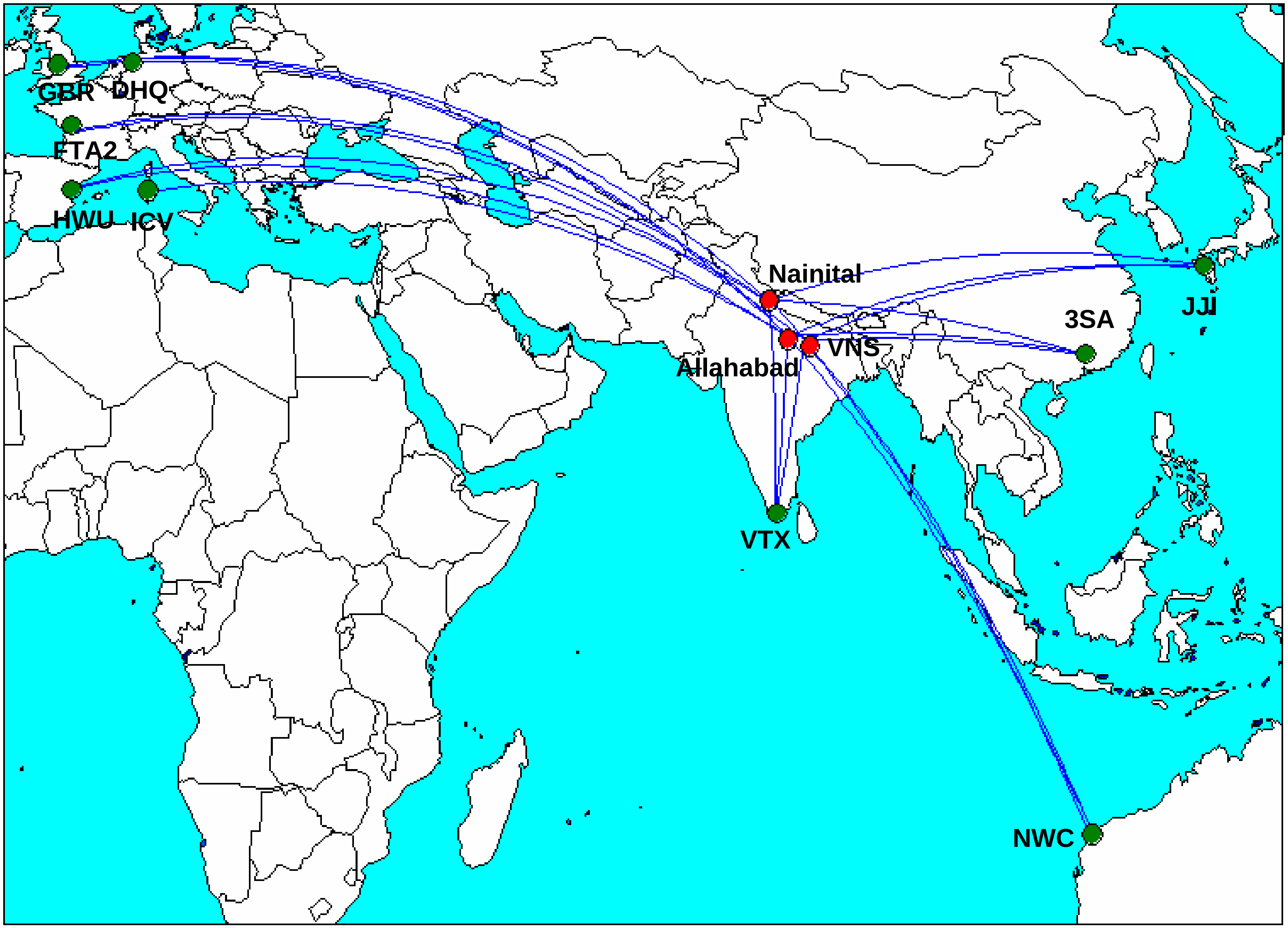


Figure 1: 2004 VLF Receiver Block Diagram





Location of planned observation sites and VLF transmitters



Simultaneous Satellite and Ground measurement

Canadian satellite CASSIOPE – with Radio Receiver instrument

- RRI instrument can measure up to 18 MHz and can make wideband measurements at VLF

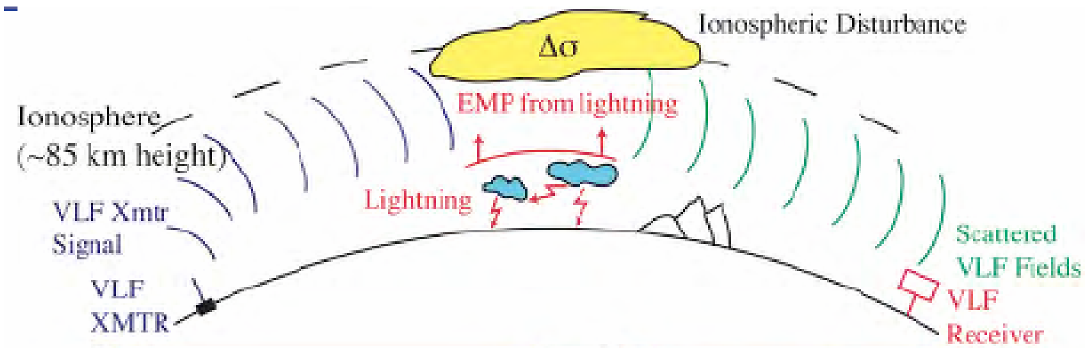
Details of satellite orbit
Inclination: 80 Degrees
Orbit: 325 × 1500 km
Lifetime: > 1 year
Launch: Early 2008

- Stanford Alaska Array and IIG, Mumbai sites

- Prof VS Sonwalkar, University of Alaska-Fairbanks

THANK YOU

➢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.**

Significance of the study:

For Space weather studies the analysis of VLF data provides a powerful tool for remote sensing of the processes in the magnetosphere.

- VLF whistler waves provide us with valuable information regarding physical structure of upper atmosphere eg. Electron density, Total electron content, Electric field.
- The VLF waves play an active role in the dynamics of the Earths ionosphere and the magnetosphere through their interaction with the plasma and radiation belt energetic particles.
- The wave-particle interaction leads to amplification of waves, triggering of emissions and precipitation of electrons in the radiation belt.

Precipitating electrons → { enhanced ionization, optical emissions, X-rays }

- The VLF waves pose a radio interference in the VLF range which is used for marine navigation and communication.

Proper understanding of VLF phenomena is important, to know how they are generated and propagate such a long distance and effect the dynamics of the magnetosphere.