AVLF DEMETER

Anthropogenic – Very Low Frequency - DEMETER

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Electromagnetic VLF sounding - Method and applications

- VLF method utilizes EM radio communication signal for geophysical applications
- Apparent resistivity (Roa)
- Surface impedance
- Electromagnetic Sounding
  Characterization of vertical variation of apparent resistivity
- Skin depth

$$\delta = \sqrt{\frac{2\rho}{\omega\mu}}$$

ρ ← resistivity
μ ← magnetic permeability
ω ↑ Angular frequency

- Depth about some tens of meters, continental résistivity

Applications

- Navigation
- Geophysical Research

Electromagnetic VLF sounding - Application to DEMETER

- Geophysical VLF method

At surface → ↓ ← **Synchronous**

E_θ & B_φ

↓

Resistivity

$Z_{calculated}$ → (E_θ, B_φ) **Antenna's field**

$Z_{measured}$ → (E_{12}, B_2) **Measured field**

- DEMETER & VLF Antennas

At height h → ↓ ← **Synchronous**

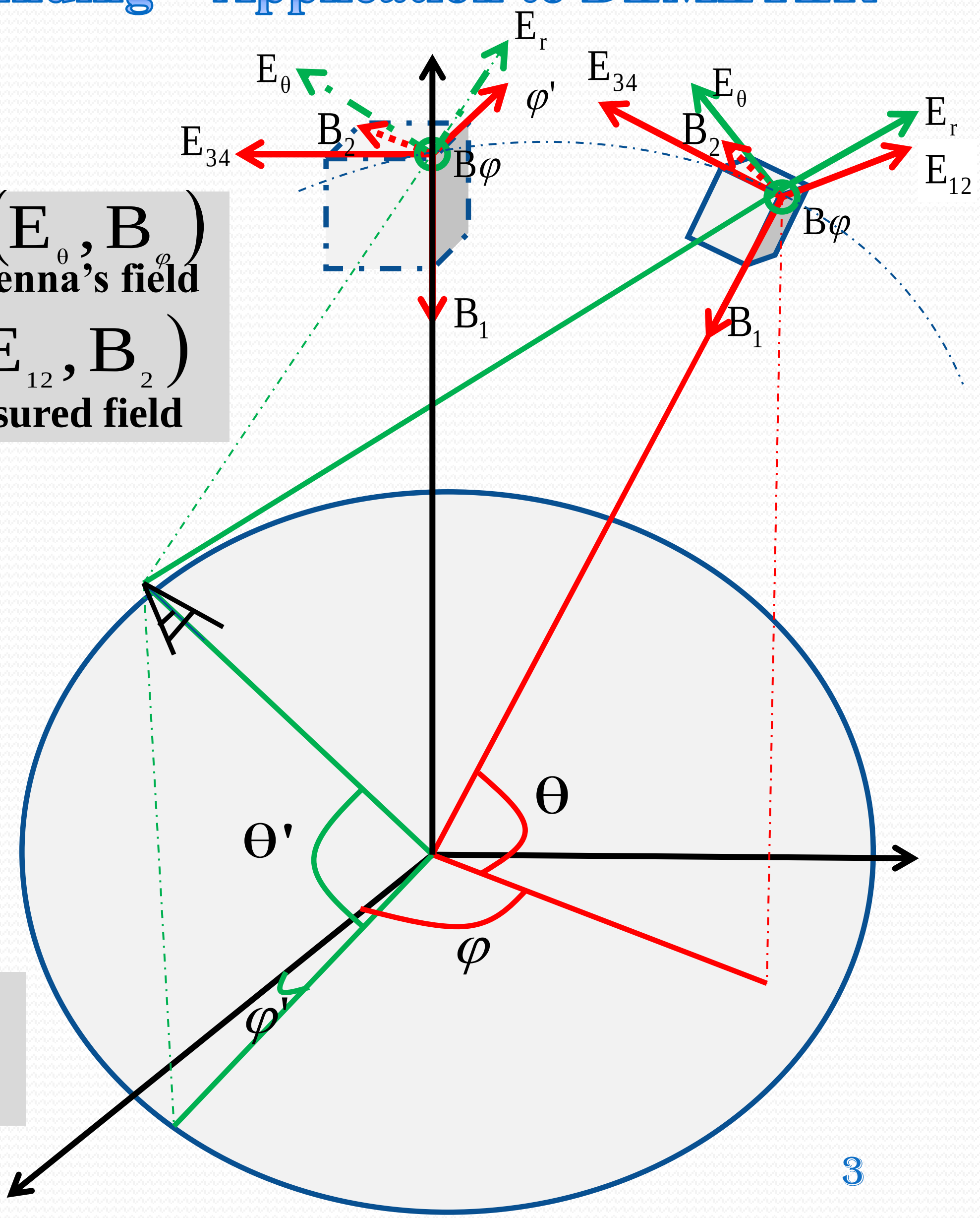
ICE Sensor	E* & B*	**IMSC Sensor**

↓ **?**

Resistivity

- Comparison

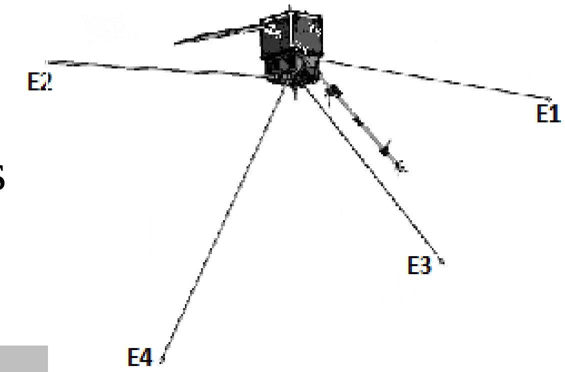
$$Z_{measured} \longleftrightarrow \frac{2Z_{calculated}}{\sqrt{2}} \frac{\cos(\theta)\sin(\varphi)}{\cos(\theta')\cos(\varphi')}$$

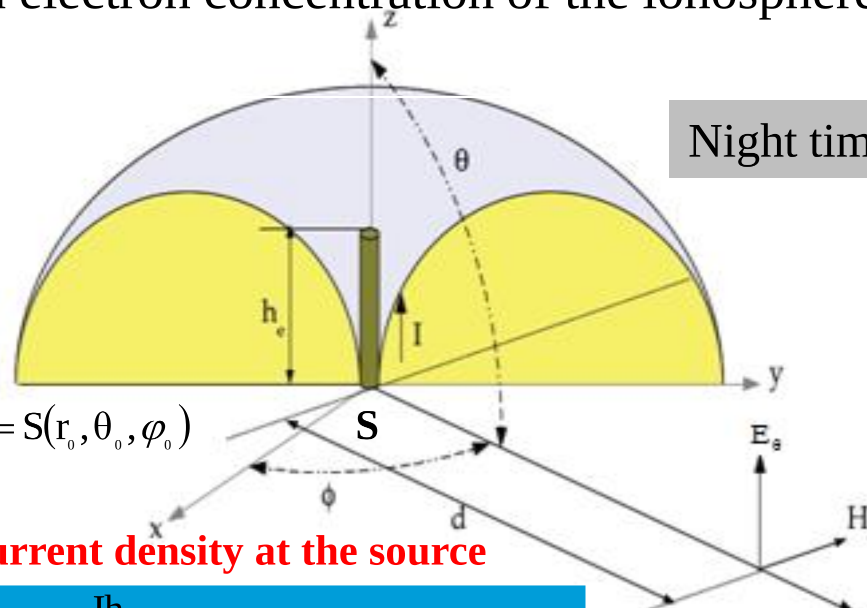


EM Field of VLF Antennas – Theoritical calculation

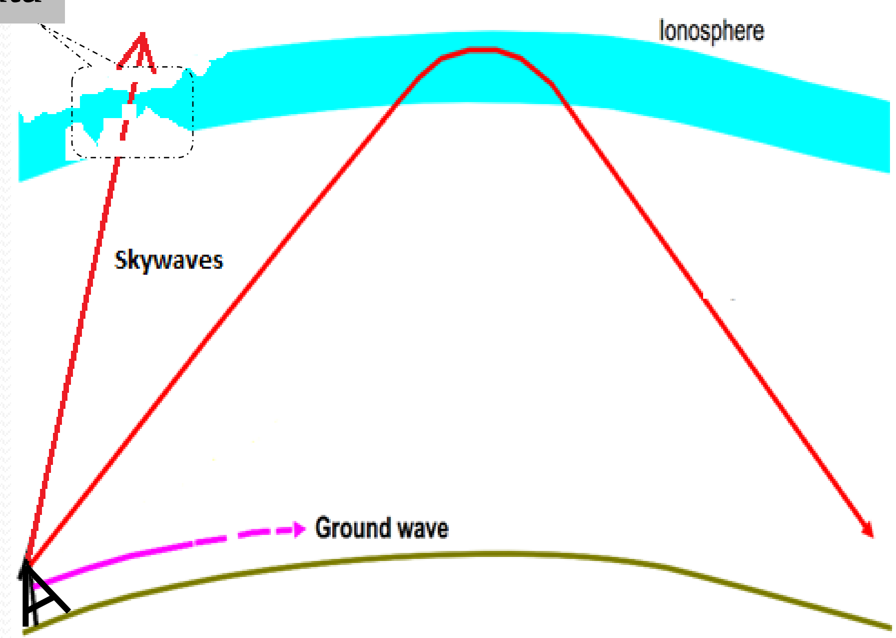
Ground wave propagates along the surface of the earth and depends on the property of the ground

Sky wave due to ionosphere refraction depends on electron concentration of the ionosphere.





$$S = S(r_0, \theta_0, \varphi_0)$$

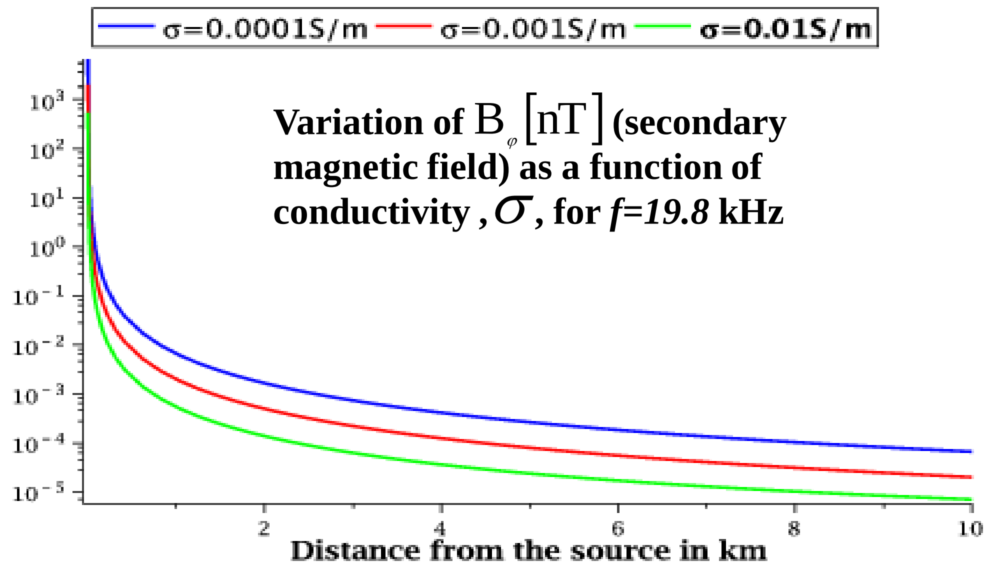


Current density at the source

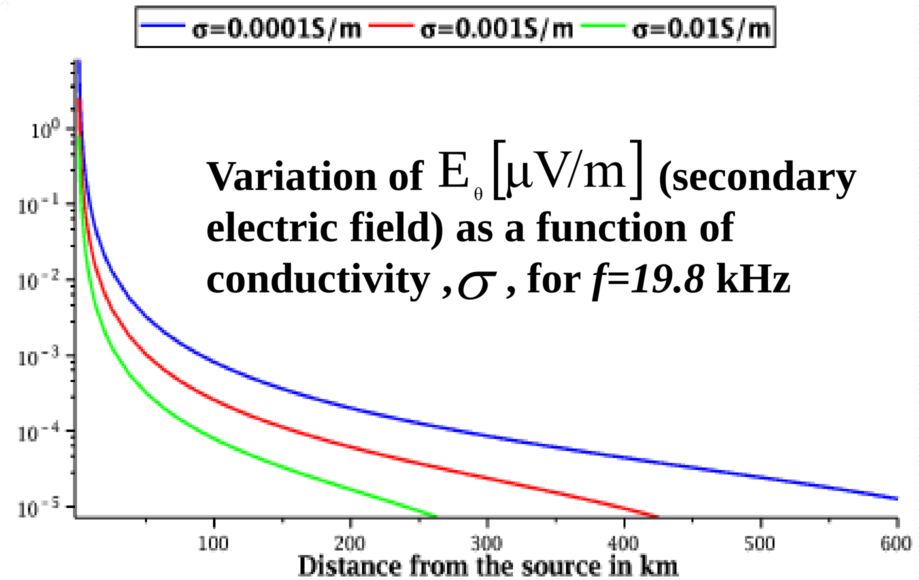
$$\vec{J}(r') = \frac{I h_e}{r'^2 \sin(\theta')} \delta(r'-r_0)\delta(\theta'-\theta_0)\delta(\varphi'-\varphi_0)\vec{u}_r$$

$$|Z| = \left|\frac{E_\theta}{H_\varphi}\right| \quad \& \quad |Z| \propto \frac{1}{\sigma^{1/2}}$$

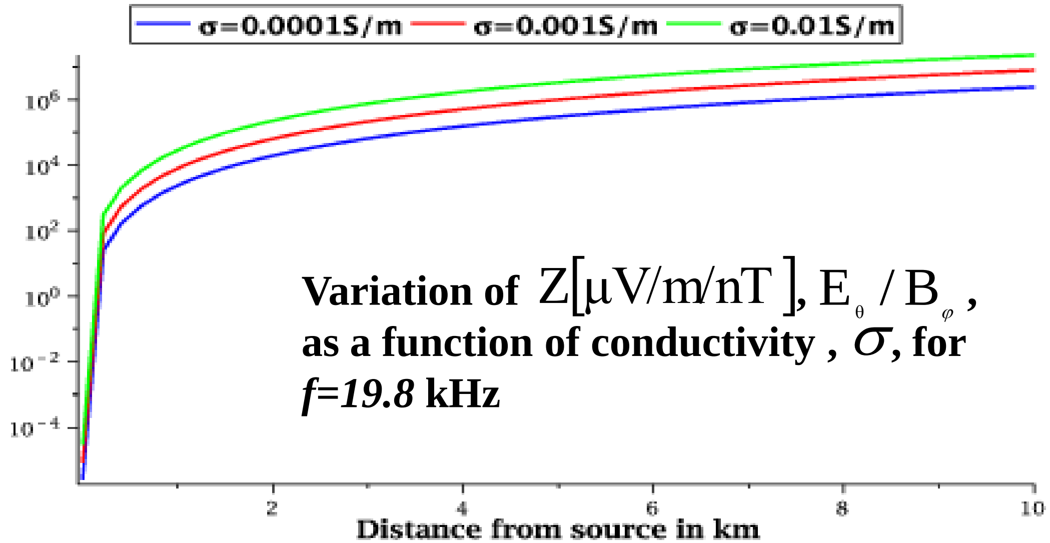
Electromagnetic Field of VLF Antennas



Variation of $B_{\varphi}\,[nT]$ (secondary magnetic field) as a function of conductivity , σ, for *f=19.8* kHz



Variation of $E_{\theta}\,[\mu V/m]$ (secondary electric field) as a function of conductivity , σ , for *f=19.8* kHz



Variation of $Z[\mu V/m/nT]$, E_{θ}/B_{φ} , as a function of conductivity , σ, for *f=19.8* kHz

Solution without ionosphere !

EM field = Primary field + Secondary field

resistivity

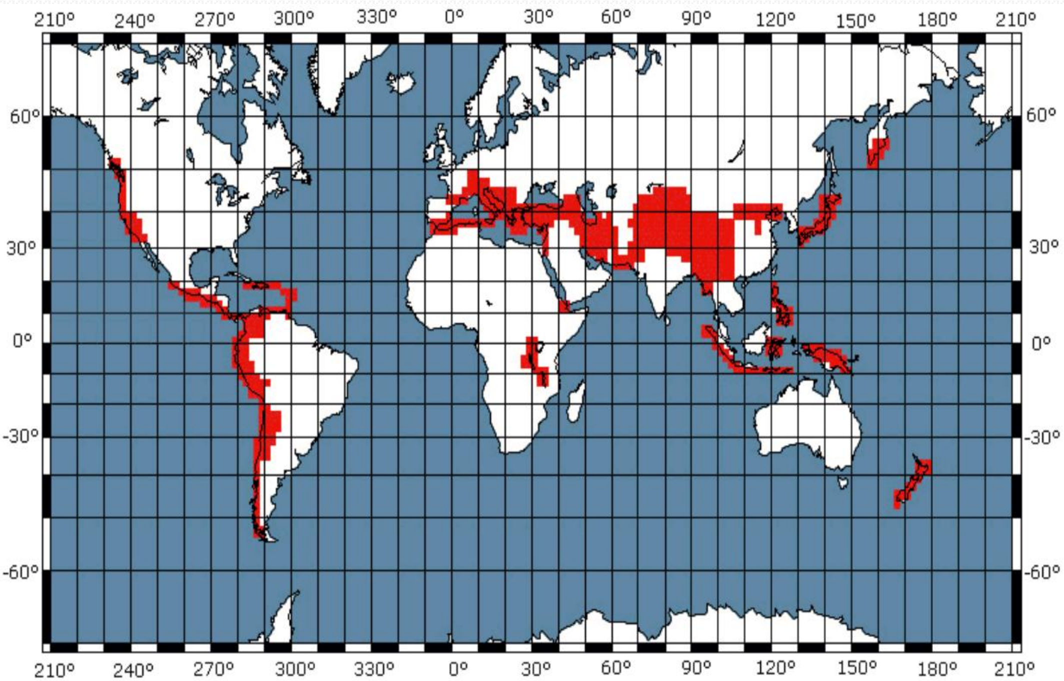
VLF DATA & DEMETER

3kHz < f < 30kHz (100km > λ > 10km)

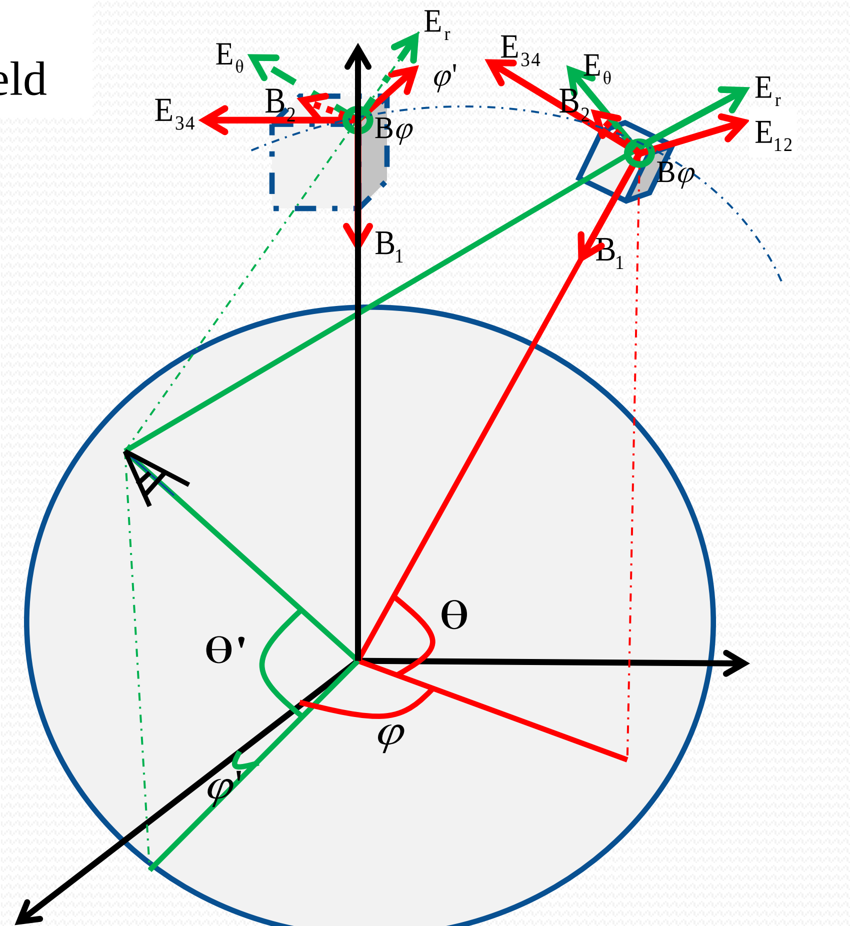
ICE sensor (Burst) → Waveform of electric field

IMSC sensor (Burst) → Waveform of magnetic field

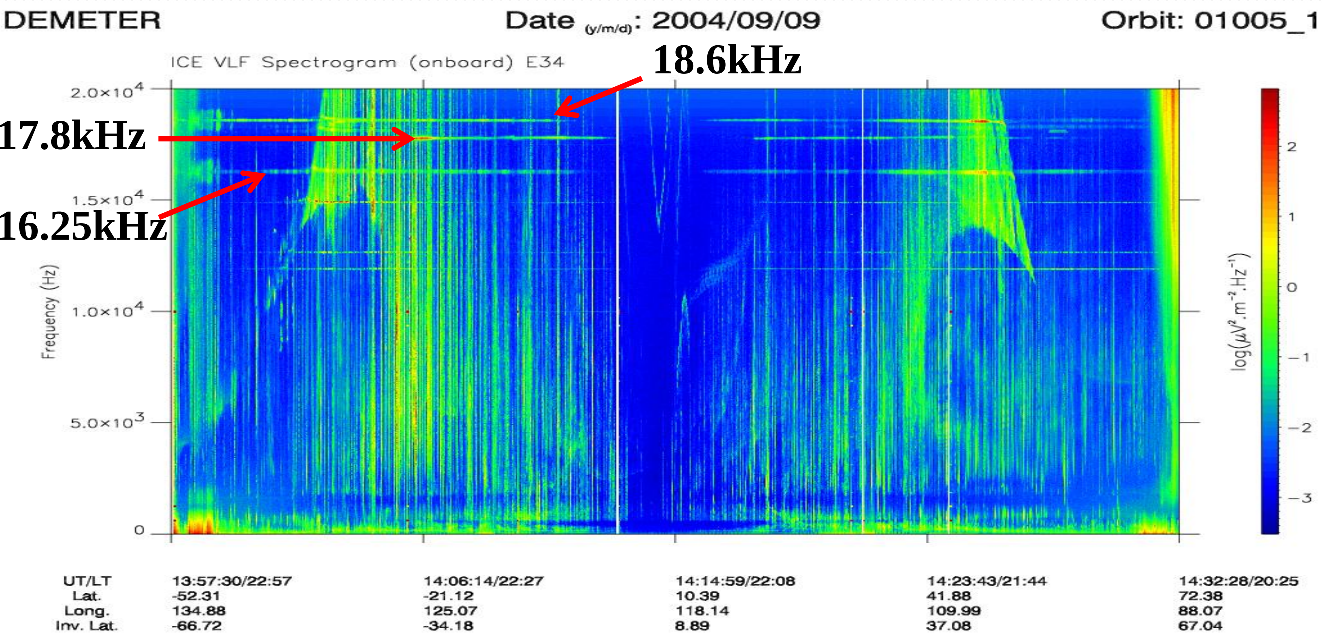
Noise & other field's sources



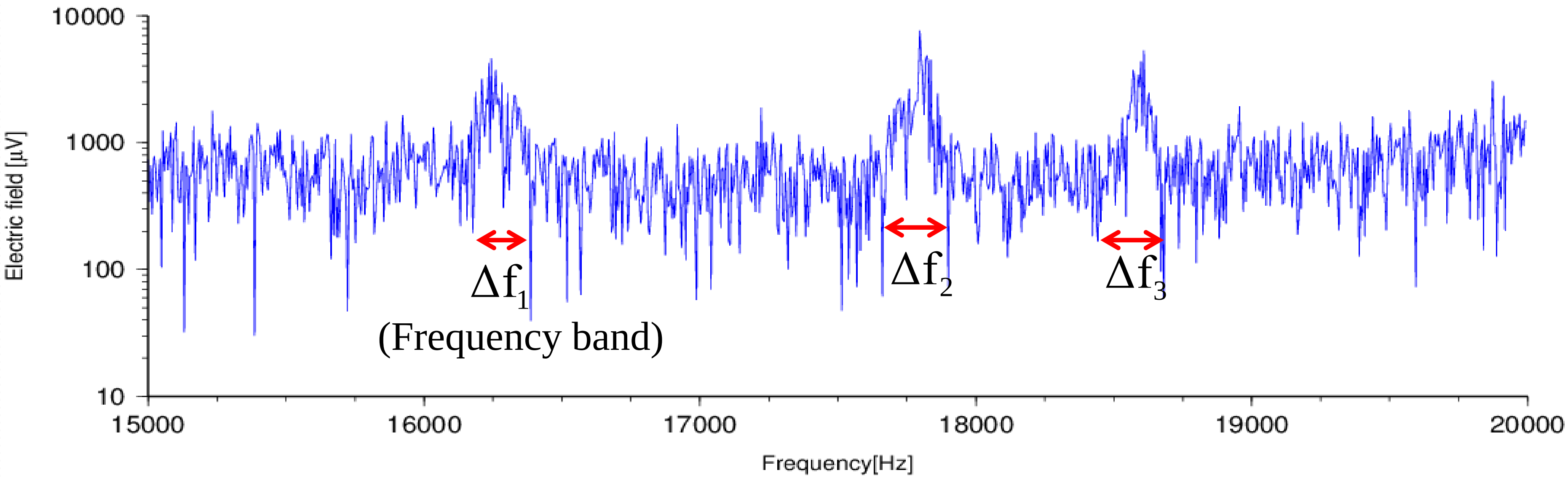
DEMETER's burst zone



VLF Data and DEMETER – Dispersion by ionosphere

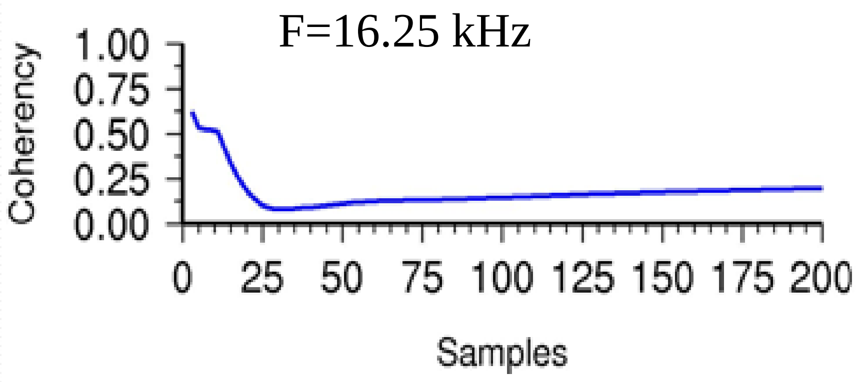


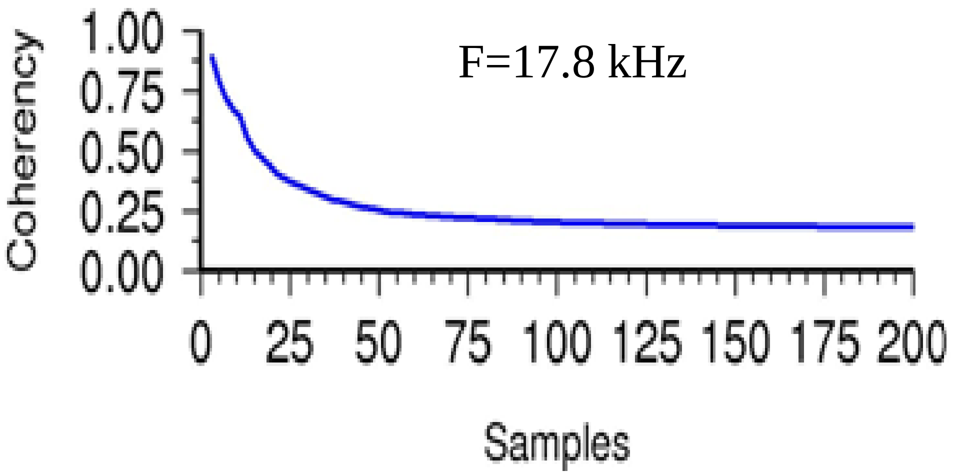
- **Spectogram of electric field**
- **3 Antennas in the 15 – 20 kHz frequency band**
- **Dispersion by the ionosphere that involves some statistical analysis**

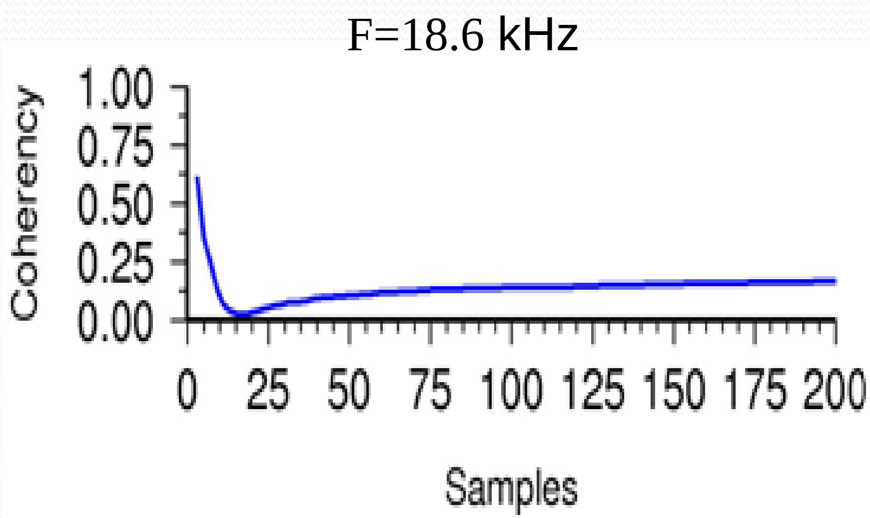


E & B - Coherency of 2 synchronous components

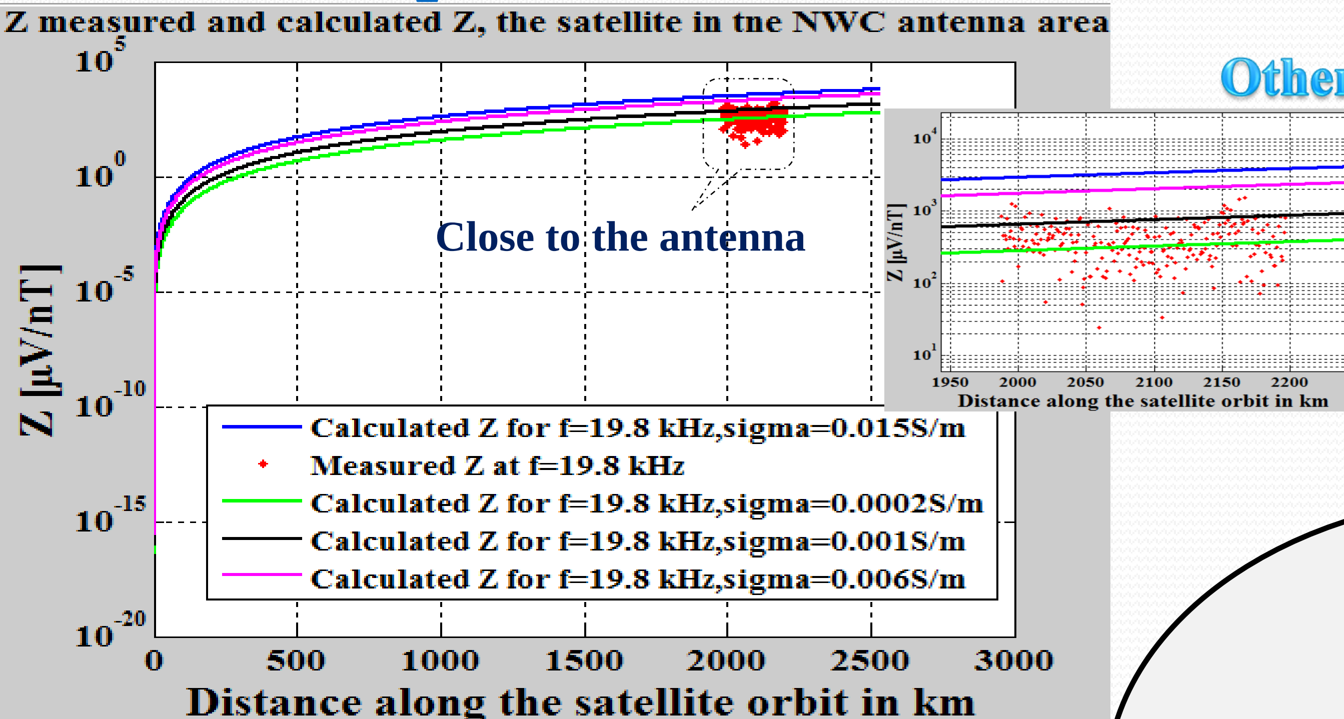
- **Coherency between 2 synchronous components electric and magnetic in DEMETER's data**
  - F=16.25 kHz
    11 sample for coherency > 0.5
  - F=18.6 kHz
    3 sample for coherency > 0.5
  - F=17.8 kHz
    15 sample for coherency > 0.5

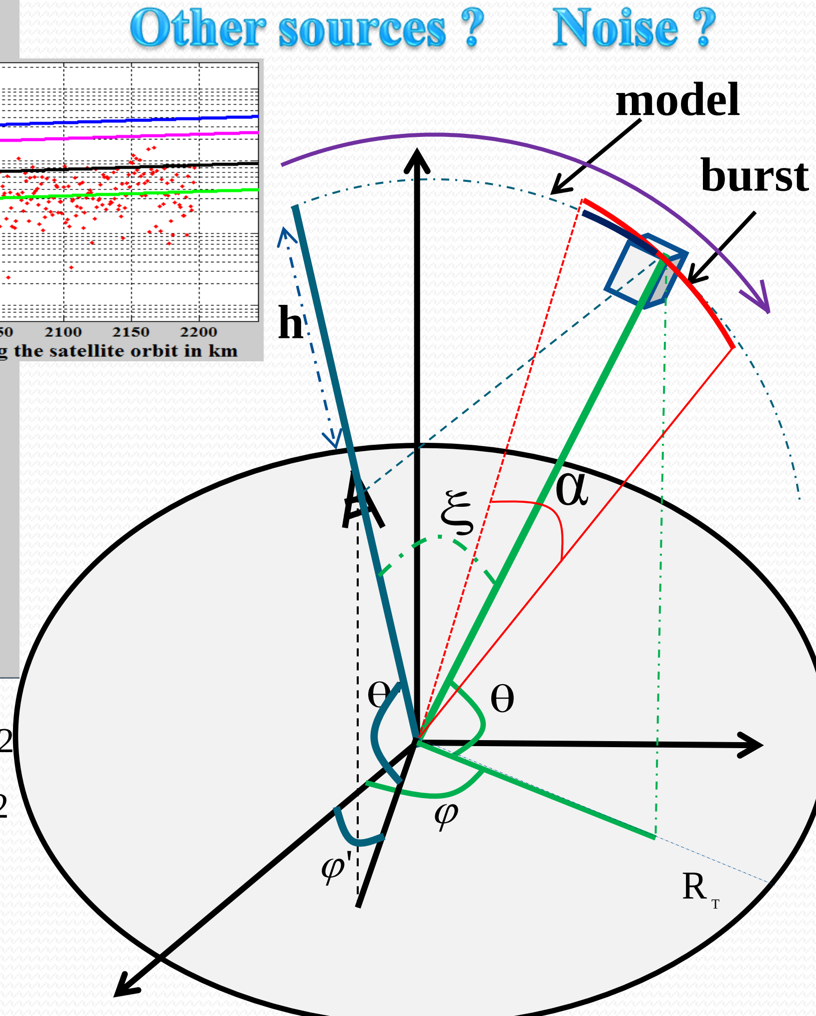






Comparison – Measured and calculated Z





- E_{12} measured field & E_θ calculated field from E_{12}
- B_2 measured field & B_φ calculated field from B_2
- Comparison : measured and calculated Z

$$Z_{\text{calculated}} \longleftrightarrow \frac{\sqrt{2}}{2}\,\frac{\cos(\theta')\cos(\varphi')}{\cos(\theta)\sin(\varphi)}\,Z_{\text{measured}}$$

Discussion

- The objective is to restitute the average conductivity of the Earth (over few tens of meter depth)

- We use impedance because it is independant of the dipole moment

- Near the geographical position of the antenna, observation and model are quite similar

- Some differences may be due to other VLF source field or noise or attenuation.

- Conductivity , $\left(\frac{1}{Roa}\right)$, may be obtained from VLF data by applying our approach

Thank you

Question…?