VLF remote sounding of the upper and lower ionosphere above seismic regions

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In the recent years the field of seismo-electromagnetic has acclaimed specific attention in the scientific community in particular since the launch in July 2004 of the DEMETER micro-satellite. In this contribution, we intend to discuss the variation of the VLF emission recorded around the date of large earthquakes. We use the electric field measurements recorded by the ICE experiment onboard DEMETER. This study enables us a remote sounding of the upper and lower ionosphere using, respectively, the whistler mode emissions and the VLF ground-based transmitters.

We apply two methods to estimate the VLF flux density variation above seismic regions. We find a decrease of the VLF intensity level several days before the earthquakes occurrence. This decrease is due to the presence of pre-seismic ionospheric anomalies which disturb the propagation of the VLF radio wave before its detection by the DEMETER/ICE experiment. This ionospheric anomaly has an effect on the plasma which refracts and scatters the radio wave along its path to the satellite. We believe that the model proposed by Molchanov et al. (*Nat. Hazards Earth Syst. Sci*., **6**, 2006) provides a good explanation on the way the atmospheric gravity waves, induced by the gas-water release from the earthquakes preparation zone, disturb the ionosphere.

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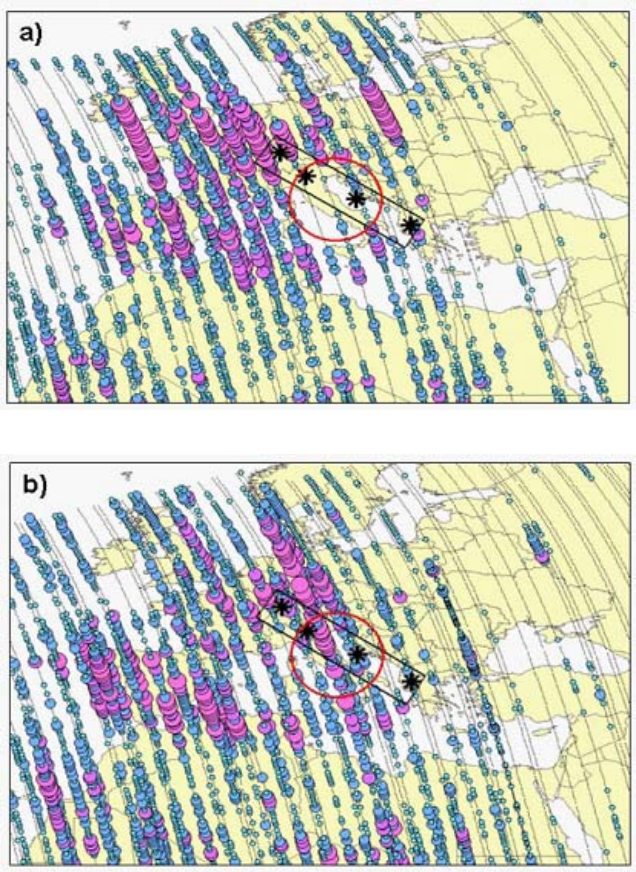
Molchanov et al. (2006) found a drop of VLF-transmitter signal before EQ occurrence



- Several events have been considered by Molchanov et al. (2006).

- Earthquakes in the Adriatic region:
  a) 23, 24 and 25 Nov. 2004.
  b) 05 Dec. 2004.

- Magnitude ~ 5.5.

- Main Results:
  The VLF transmitter signal is less observed/absent before the earthquake occurrence.

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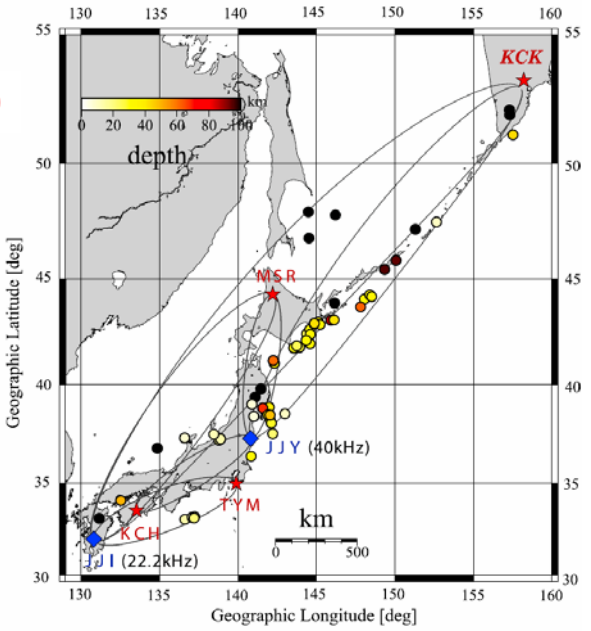
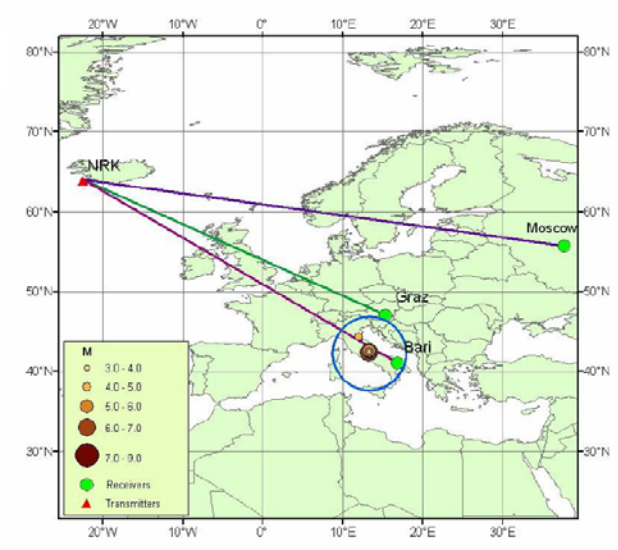
Later on, several investigations reported drop of VLF-transmitter signals as observed by Molchanov et al. (2006):

- Groud-based studies
  - Hayakawa et al. (2010, 2011)
  - Kasahara et al. (2010)
  - Motu et al. (2008)
  - Rozhnoi et al. (2007, 2009, 2010)

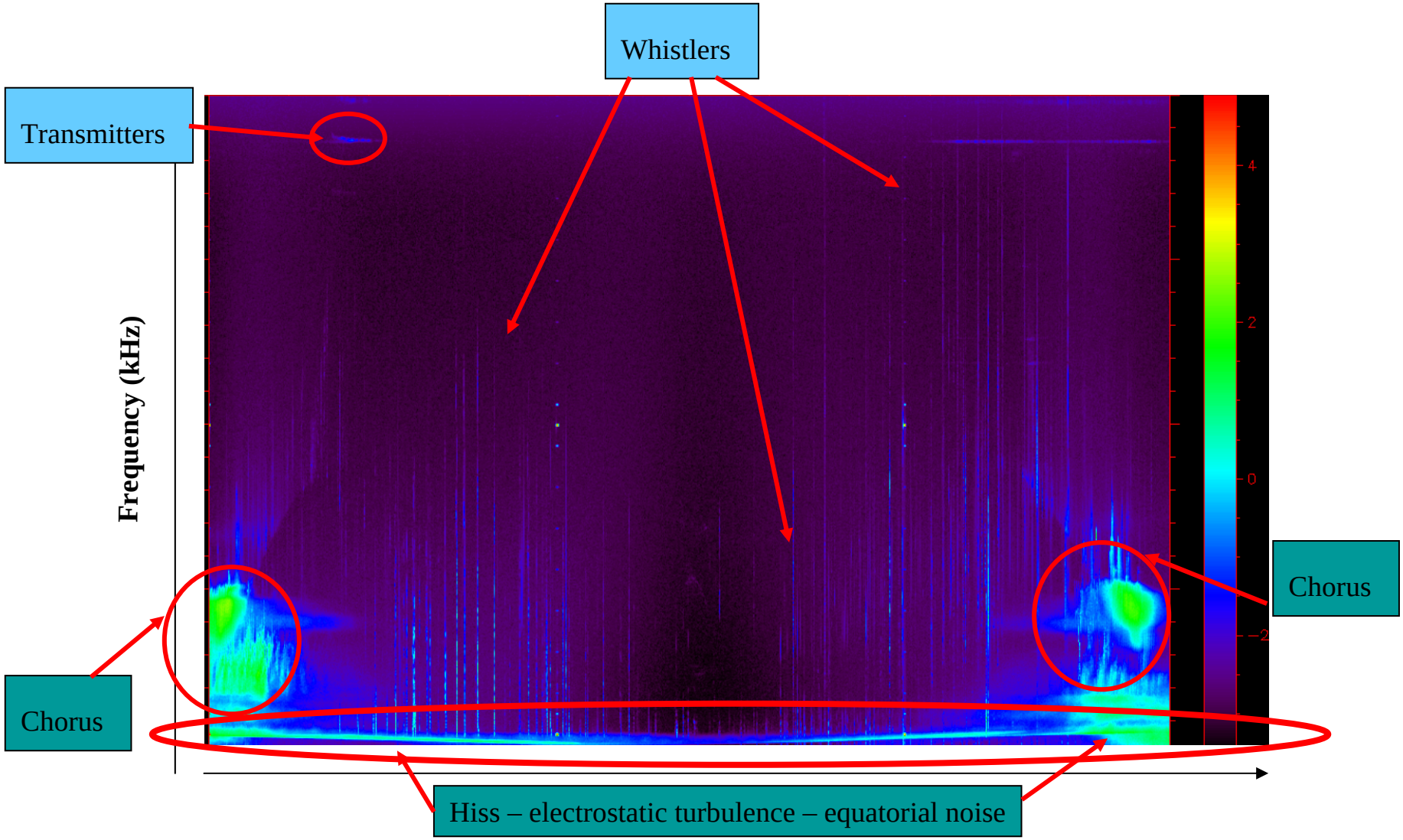
Hayakawa et al., 2010



Rozhnoi et al., 2009

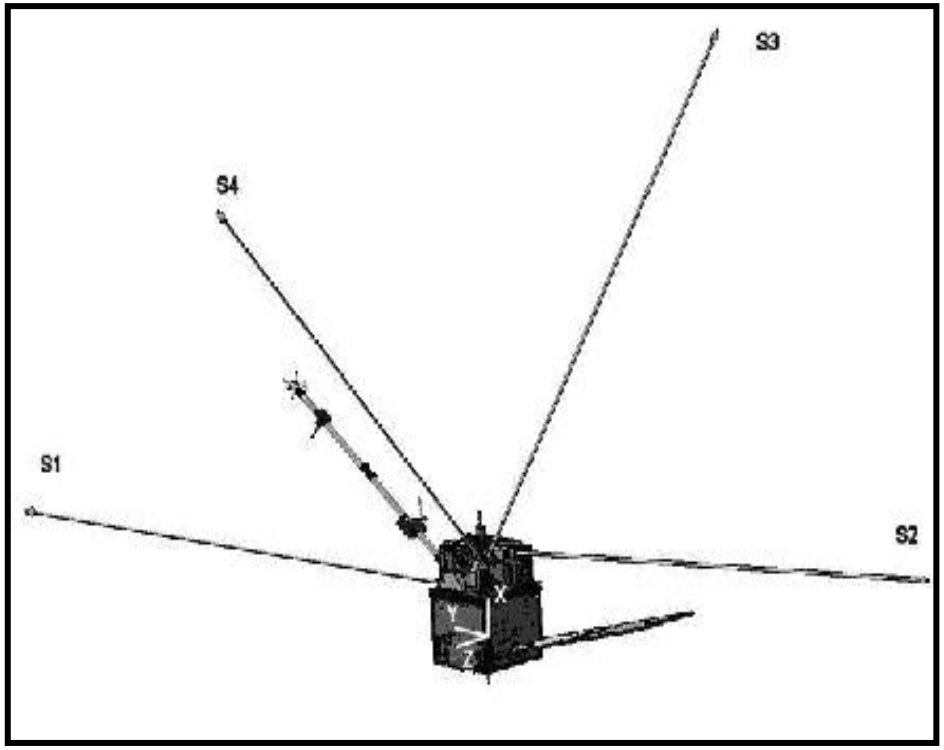


Spectral method: ELF/VLF ionospheric components



DEMETER micro-satellite (Parrot, 2003)

Data: ICE experiment onboard DEMETER (Berthelier et al., 2006)



• The 4 sensors, labeled S1, S2, S3 and S4 are spherical aluminum electrodes.

• Each mounted at the end of a 4 meter deployable boom.

•Four frequency ranges have been defined, DC / ULF [0-15 Hz], ELF [15 Hz-1 kHz], VLF [15 Hz-17.4 kHz] and HF [10 kHz-3.175 MHz].

•Investigated the emissions in the frequency range from 15 Hz to 20 kHz.

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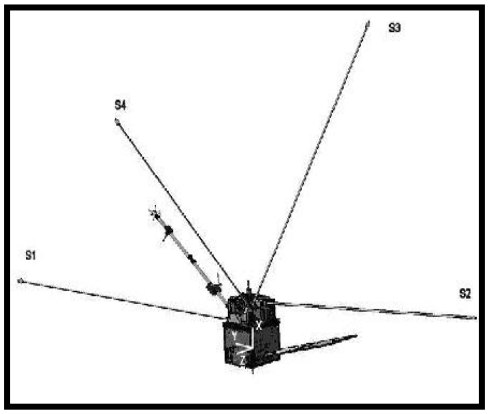
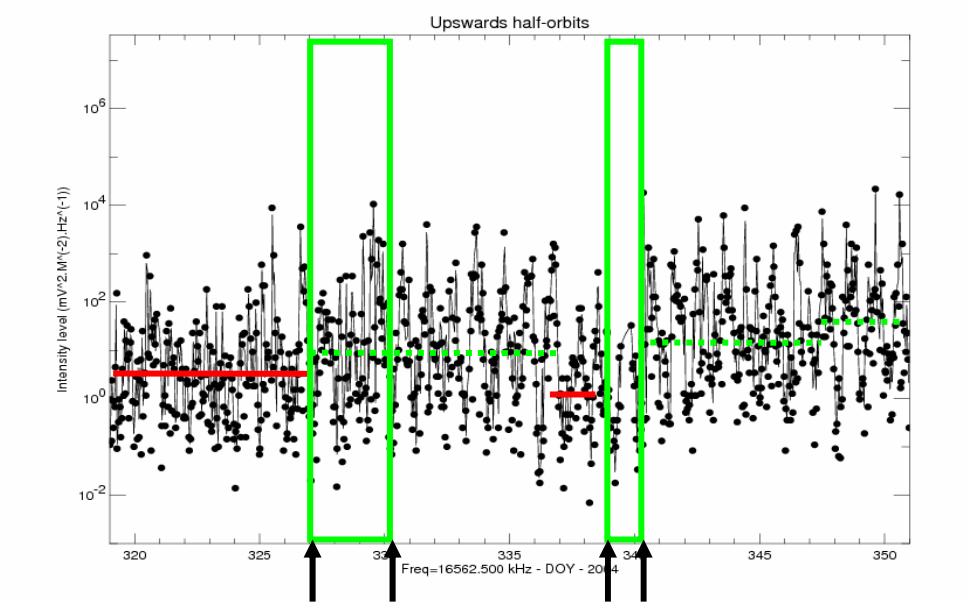
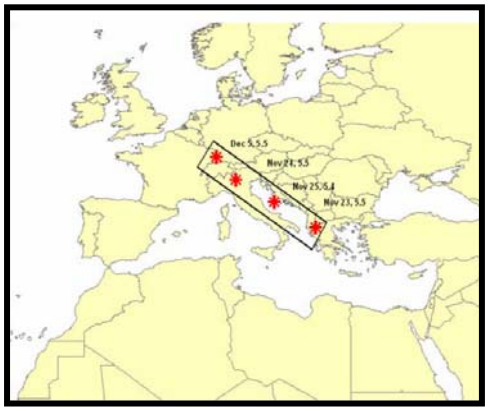
Berthelier et al., 2006



- Space investigations
  - Boudjada et al. (2008, 2010)
  - Stangl et al. (2010)





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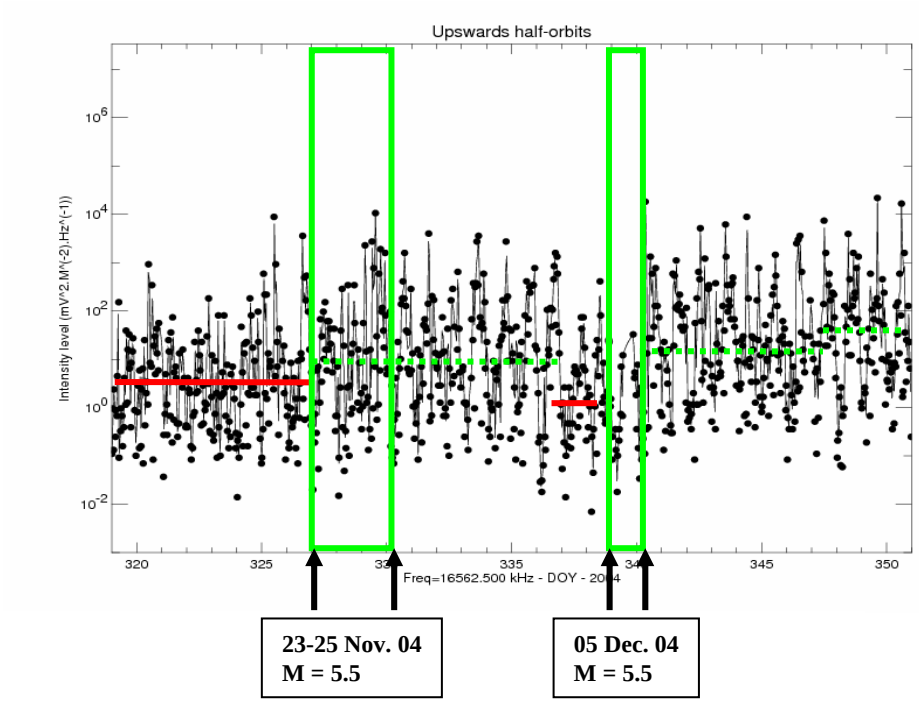
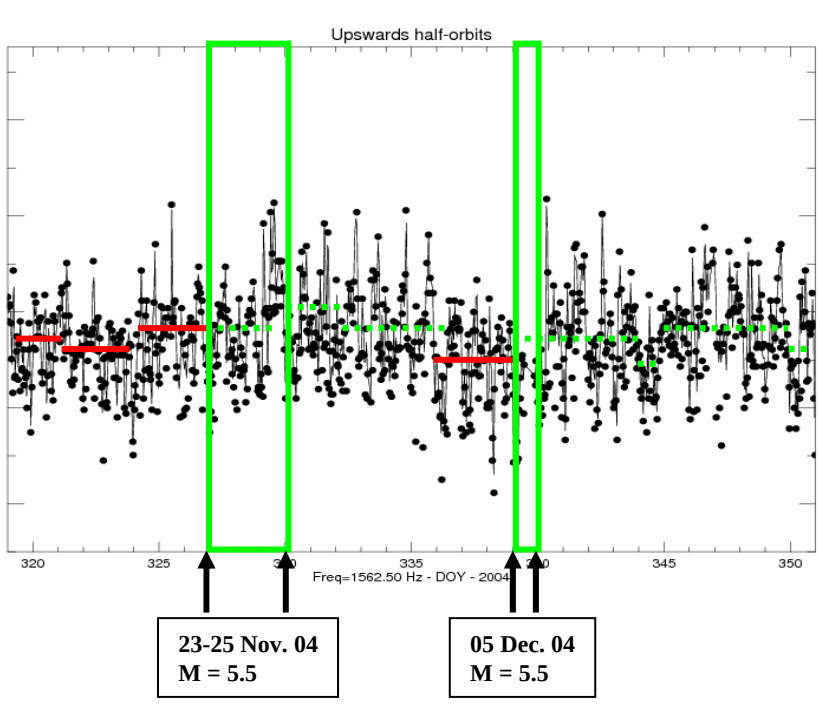
Drop of VLF-transmitter signals and also of VLF whistler emissions (i.e. chorus)

German transmitter signal



VLF whistler chorus emissions



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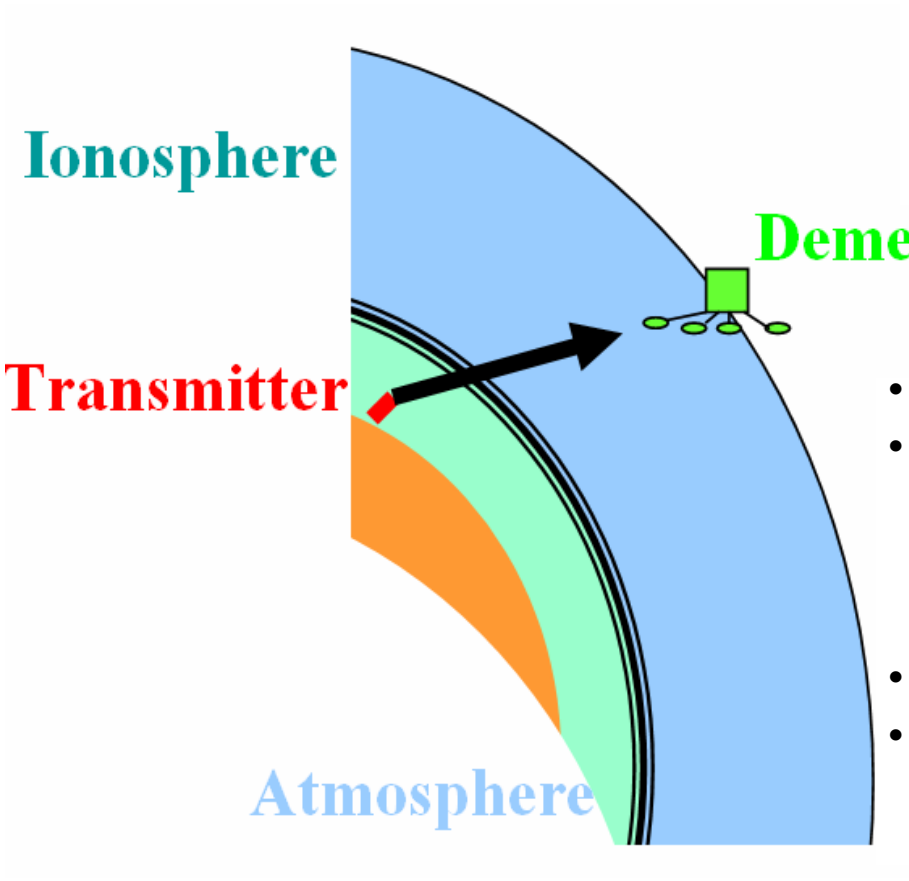
Qualitative model



Part 1:
In the absence of seismic preparation zone

First key region
- Boundary Atmosphere-Ionosphere
- The transmitter signal is detected by Demeter satellite without a drop in intensity level

Second key region
- At the altitude of Demeter satellite
- The VLF whistler emissions are mainly ducted radiation following the Earth's magnetic field line

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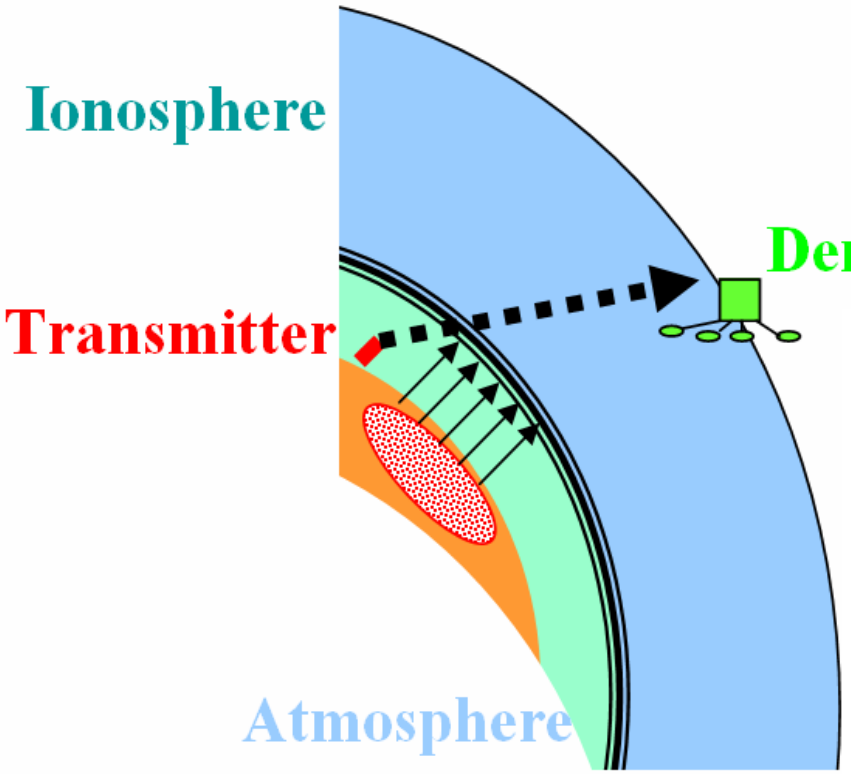
Qualitative model



Part 2:
In the presence of seismic preparation zone

First key region
- Boundary Atmosphere-Ionosphere
- The transmitter signal is attenuated and only part of the emission detected by the satellite

Second key region
- At the altitude of Demeter satellite
- The VLF whistler emissions are mainly non-ducted radiation; only part of the emission is observed

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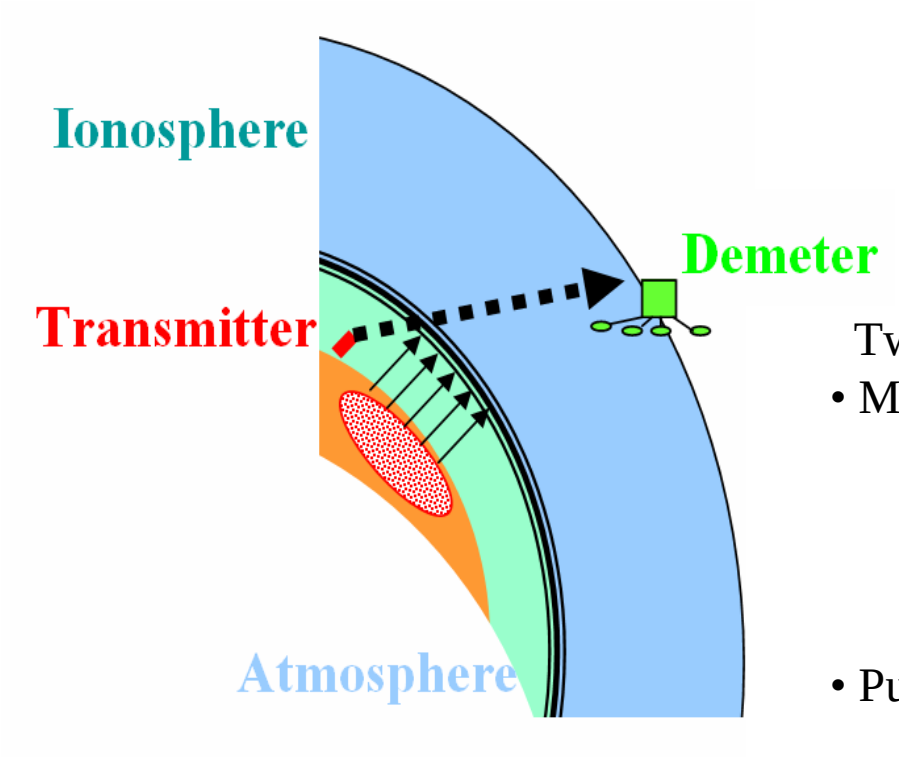

Disturbance of the ionosphere above seismic regions

Two main models

- Molchanov model:
  1. Water/gas release in preparation zone
  2. Generation of Atmospheric Gravitational Waves

- Pulinets model:
  1. Changes of atmospheric electricity due to the ionization produced by the emanating radon
  2. Conductivity changes in the near ground-layer

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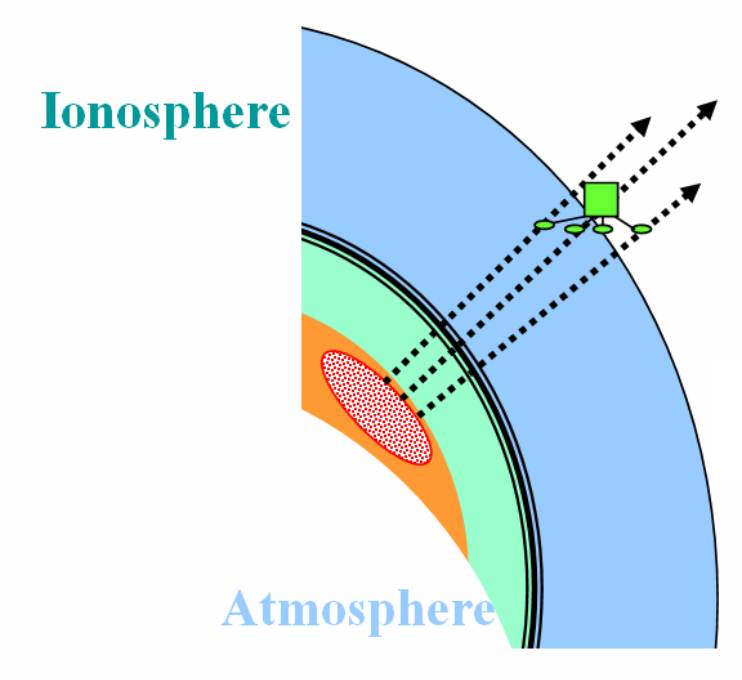
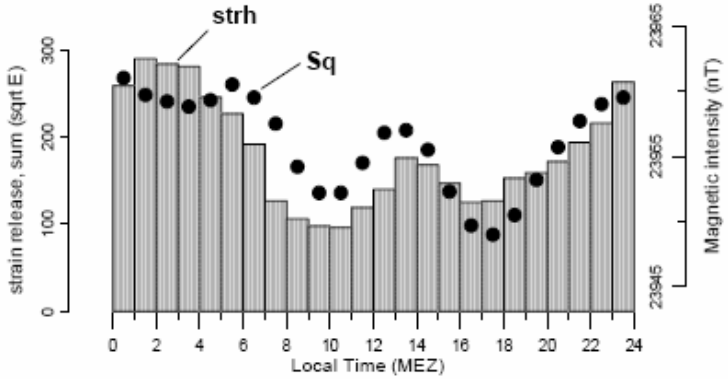


Duma and Ruzhin (2003)

- Statistic analyses over 100 years
- Probability of earthquake occurrence strongly depends on the time of day, or Local Time
- The regular diurnal variations of the Earth's magnetic field, commonly known as Sq-variations; related to Ionospheric current system (Chapman and Bartels, 1940)



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Conclusion:

1. VLF transmitter signal shows a drop in the intensity level above seismic regions

2. VLF whistler emissions have similar behavior

3. Further investigations will provide more constraints on the proposed models