VLF electromagnetic wave attenuation measured by DEMETER above earthquake epicentres

Pisa, D. (1,2,3), F. Nemec (2), M. Parrot (1), O. Santolik (3,2)

(1) LPC2E/CNRS, Orléans, France
(2) Faculty of Mathematics and Physics, Charles University in Prague, Prague, Czech Republic (3) IAP /ASCR, Prague, Czech Republic

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Motivation

"Is there a correlation between seismic activity and wave intensity observed by a low-altitude satellite?" Němec et al., 2008 and 2009

Yes, a very small, but statistically significant decrease of wave intensity 0-4 hours before the time of the main shock (only during the night time, using a very large data set).

Can we observe the same effect using the full Demeter data set?

Pisa, D., F. Nemec, M. Parrot, O. Santolik (2011)
Attenuation of electromagnetic waves at the frequency $\sim$ 1.7 kHz in the vicinity of earthquakes observed in the upper ionosphere by the DEMETER satellite; Annals of Geophysics. (in press)

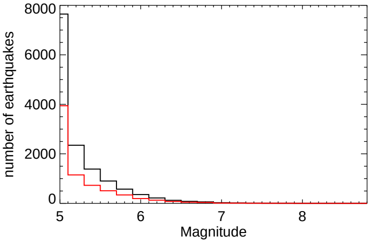
Measured data

- DEMETER spacecraft (circular orbit, altitude $\sim$ 700 km)
- Sun-synchronous orbit: always in local day (10:30 LT) or local night (22:30 LT)
- launched in June, 2004, we use data till the end of mission (December, 2010)
  about 6.5 years of data
- VLF wave data (up to 20 kHz) obtained during the "Survey" mode used: electric field component (Δ f$\sim$ 19.5 Hz, Δ t $\sim$ 2 s)
- **only night time data used**

Earthquake Data

- USGS earthquake catalogue (http://neic.usgs.gov/)
  - magnitude
  - latitude
  - longitude
  - depth

- $\sim$ 13811 earthquakes between 2004 and 2010
- M$\geq$5.0 : 9859 (7190 unique ones)
- M$\geq$5.5 : 2843 (2098)
- M$\geq$6.0 : 896 (676)
- depth $\leq$20 km : 5789 (4297)
- depth $\leq$10 km : 4663 (3468)



Method (1/3) - background activity

Emission map – a six dimensional matrix

- geomag. lat: $< -65^\circ, 65^\circ >$, resolution 2 degrees
- geomag. lon: $< 0^\circ, 360^\circ)$, resolution 10 degrees
- local time: nightime, daytime
- kp: $(0 \div 1o, 1+ \div 2+, > 3-)$
- frequency: 16 bands (up to 10 kHz)
- season: Apr – Sep, Oct – Mar

A histogram accumulated in each cell represents the probability density function $f(\mathrm{E})$

$$\text{Cumulative probability: } F_i = \int_{-\infty}^{E_i} f(E)dE$$

Method (2/3) - collecting data

- all available data of wave intensity during seismic events have been used
- data measured during more than one seismic event have been excluded
- obtained cumulative probabilities are organized in bins:
  - frequency – 16 bands (up to 10 kHz)
  - time to/from an earthquake: 120 hours before - 72 hours after, resolution 1 hour
  - distance from an earthquake: <10 degrees, resolution 1 degree
- cumulative probabilities F_i are uniformly distributed between 0 and 1
- for each of the bins, we calculate "probabilistic intensity":

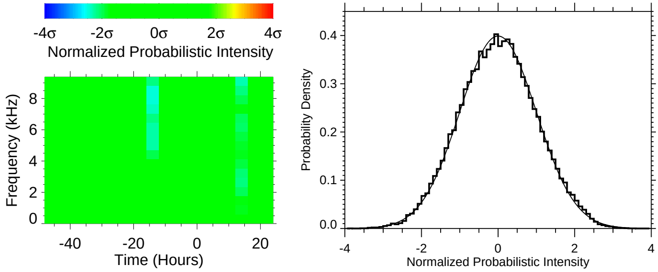
$$I = \frac{\sum_{i=1}^{M} F_i}{M} - 0.5 \text{ (tends to the normal distribution)}$$

Method (3/3) - normalization

- normalize by the standard deviation (determined separately for each bin) and define a "normalized probabilistic intensity":

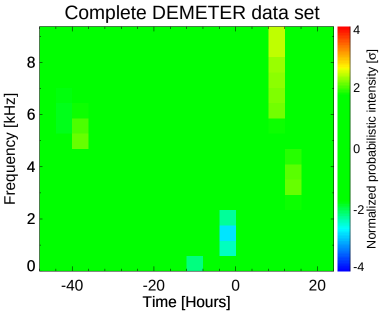
$$I_n = \frac{I}{\sigma} \longrightarrow N(0;1)$$

- if there were no seismic effects, the normalized probabilistic intensity would have a normal distribution with $\sigma = 1$

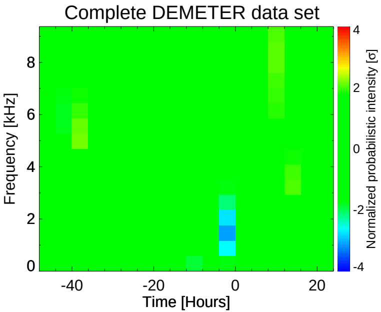


Random data selection, from *Němec et al., 2008*.

Time-frequency spectrogram

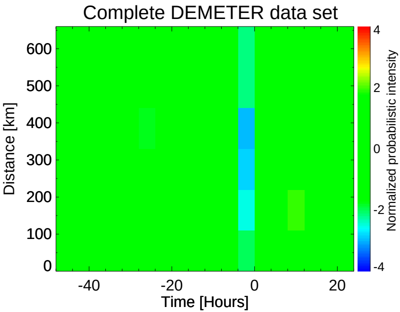


Normalized probabilistic intensity,
distance ≤330 km, M≥5, depth < 40 km

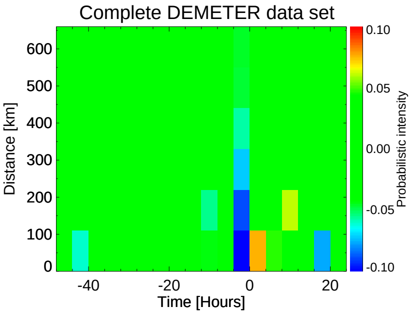


Normalized probabilistic intensity,
distance ≤440 km, M≥5, depth < 40 km

Time-distance spectrograms



Normalized probabilistic intensity,
$M \geq 5, \ depth < 40 \ km, f \sim 1.7 \ kHz$



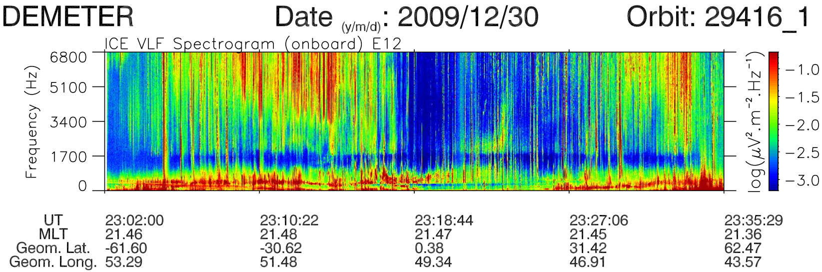
Probabilistic intensity (without normalization)

Wave guide cutoff

A shift of the effective position of the lower boundary of the ionosphere can cause changes of the waveguide properties.
This would modulate the waveguide cutoff frequency f_c,

$$f_c = \frac{c}{2h},$$

where h is the effective height and c the speed of light *[Budden, 1962]*.



Our results suggest a decrease of the lower ionospheric boundary, *[Harrison et al., 2010]*.

Conclusion

Statistical analysis of the seismic activity and wave intensity shows:

- a very small decrease of wave intensity shortly (0-4 hours) before the main shock
- the attenuation effect corresponding to a decrease by 2 dB of the wave intensity, compared with random variations of the background intensity corresponding to ± 7.5 dB $\longrightarrow$ a large data set is necessary
- the effect is observed only during the night
- the effect is observed at frequency ~ 1.7 kHz
- possible explanation by an increase of the ionospheric waveguide cutoff frequency

Thank you for your attention