DEMETER Spacecraft

Summary

František Němec

Faculty of Mathematics and Physics
Charles University
Prague, Czech Republic

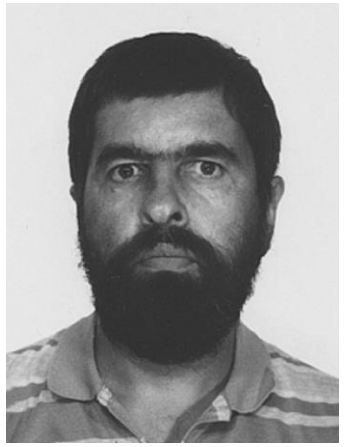
Short Personal Remark / Introduction

Me and DEMETER

- Started university in 2001
- Space physics project ~2003 (Cluster spacecraft, Equatorial noise)
- 2 summer stays in LPC2E/CNRS Orléans, France (2004, 2005) supervised by Michel Parrot
- PhD in co-tutelle (2007-2009)

Michel Parrot

- Principal investigator of DEMETER
- PI of IMSC (search-coil magnetometers)
- Natural & artificial electromagnetic wave signals
- Always willing to try new things
- Always up-to-date with literature



Scientific Motivation

DEMETER (Detection of Electro-Magnetic Emissions Transmitted from Earthquake Regions)

Scientific objectives

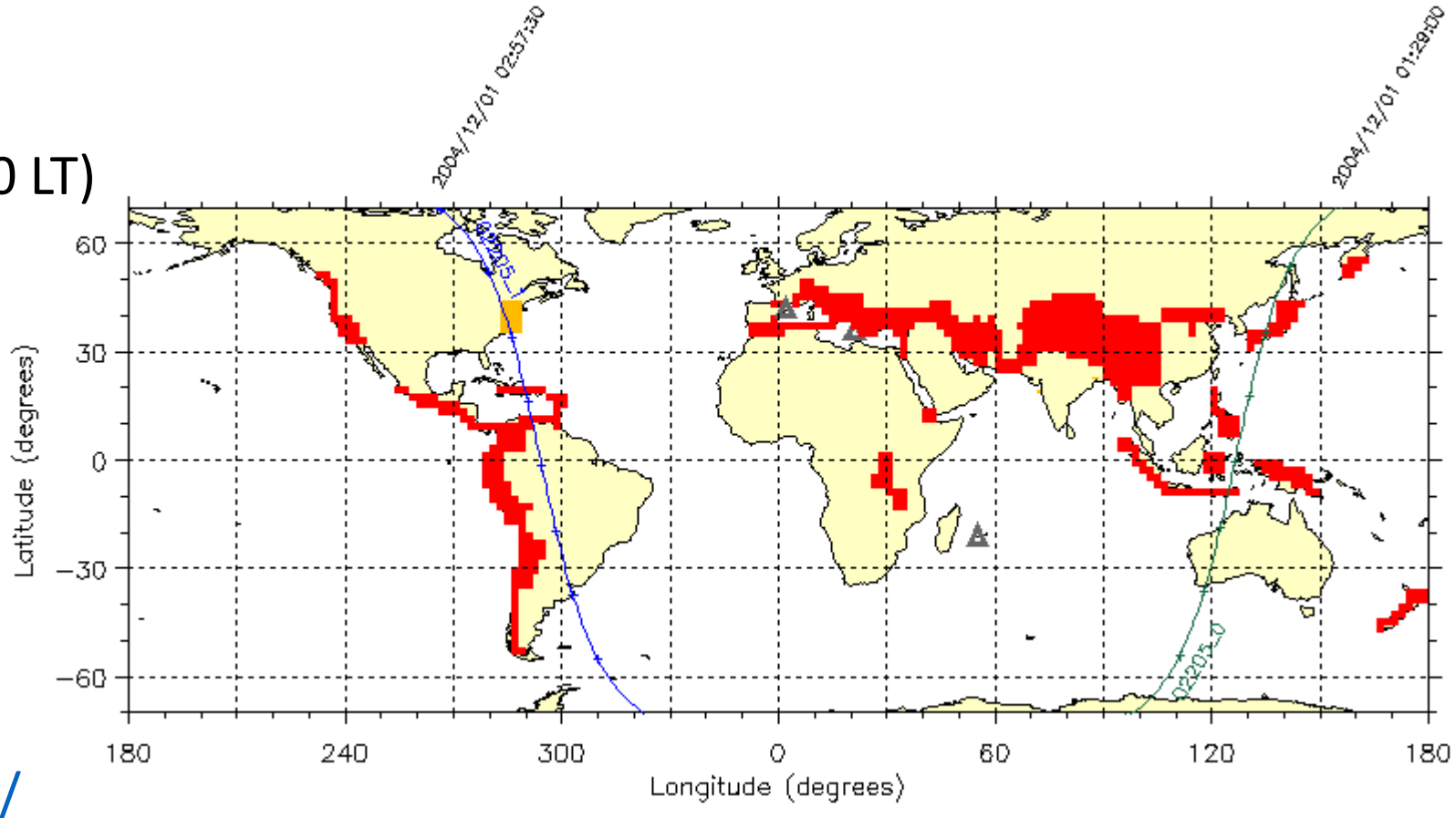
- to study the ionospheric disturbances in relation to the seismic activity and to examine the pre- and post-seismic effects,
- to study the ionospheric disturbances in relation to the volcano activity,
- to survey the ionospheric disturbances in relation to the anthropogenic activity,
- to contribute to the understanding of the generation mechanism of these disturbances,
- to give a global information on the Earth electromagnetic environment

Note:

Although seismic effects were the “primary goal”, many obtained results are related to anthropogenic activity – and many to lightning-related whistlers and natural plasma waves

Spacecraft Parameters

- Launched on 29 June 2004
- Mission ended in December 2010
- Microsatellite (~130 kg)
- Sun-synchronous orbit
  (13 orb./day; ~10:30 and 22:30 LT)
- Half-orbits:
  42 – 35865
- Measurements limited to
  λ_m < ~65°
- Two modes of operation
  ("Burst", "Survey")
- http://demeter.cnrs-orleans.fr/
- https://sipad-cdpp.cnes.fr/



Instruments Onboard

- **ICE**
  three electric sensors from DC up to 3.5 MHz
- **IMSC**
  three magnetic sensors from a few Hz up to 18 kHz
- **IAP**
  ion analyzer
- **IDP**
  energetic particle detector
- **ISL**
  Langmuir probe
- **RNF**
  Neural network for whistler detection

Electromagnetic Wave Measurements

- **ULF (0-15 Hz)**
  Burst + Survey: waveforms of 3 electric field components

- **ELF (up to 1250 Hz)**
  Burst: waveforms of 3 electric and 3 magnetic field components
  detailed wave analysis possible

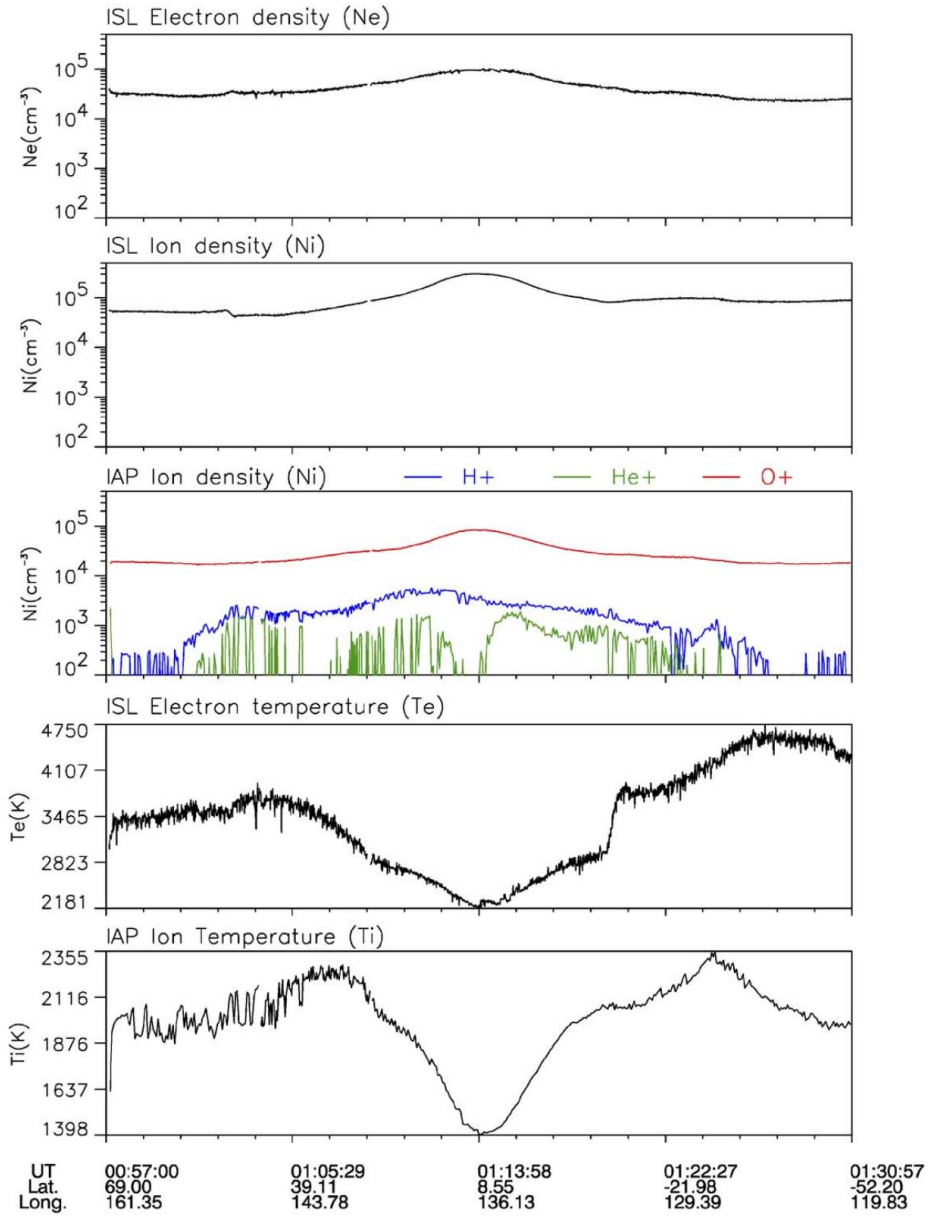
- **VLF (up to 20 kHz; strong transmitter signals above detectable due to aliasing)**
  Burst: waveform of 1 electric and 1 magnetic field component
  Survey: spectra of 1 electric and 1 magnetic field component ($\Delta f \sim 20$ Hz, $\Delta t \sim 2$ s)
  magnetic field data suffer from onboard interferences

- **HF (up to 3.175 MHz)**
  Burst: ~0.6 ms long waveforms at selected times
  Survey: on-board calculated spectra ($\Delta f \sim 3.25$ kHz, $\Delta t \sim 2$ s)

Plasma Measurements

- **IAP:**
  ion density (H^+, He^+, O^+)
  ion temperature
  ion velocity
  $\Delta t \sim 4$ s

- **ISL:**
  electron density
  electron temperature
  $\Delta t \sim 1$ s

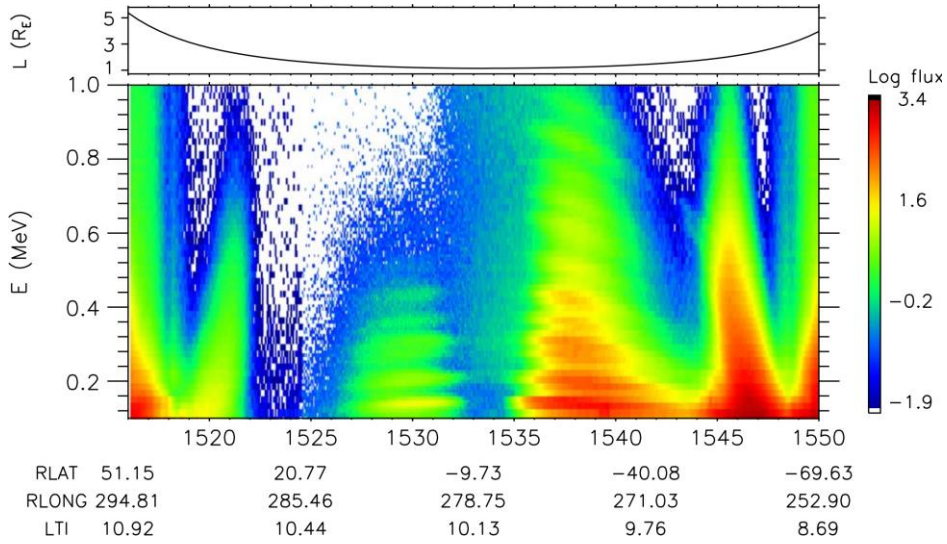


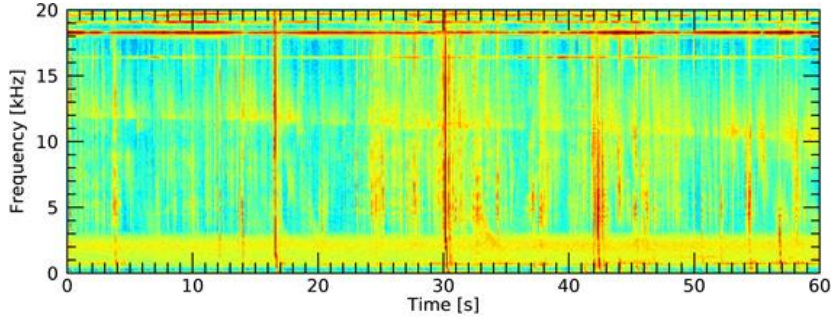
Energetic Particle Measurements

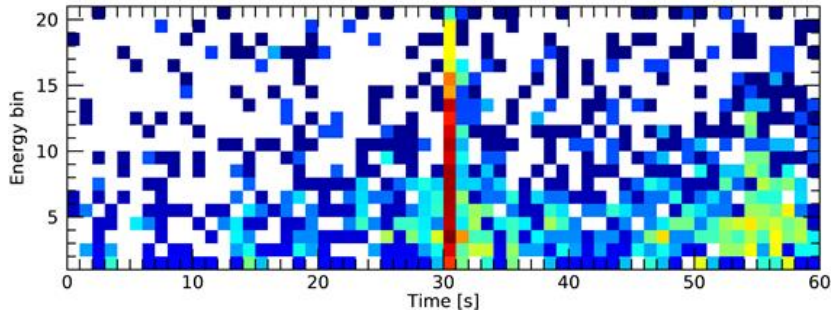
- 70 keV – 2.5 MeV

- *Burst:*
  256 energy channels (linear)
  Δt ~ 1 s

- *Survey:*
  128 energy channels (linear)
  Δt ~ 4 s
  counts in 3 predefined energy ranges (Δt ~ 1 s)

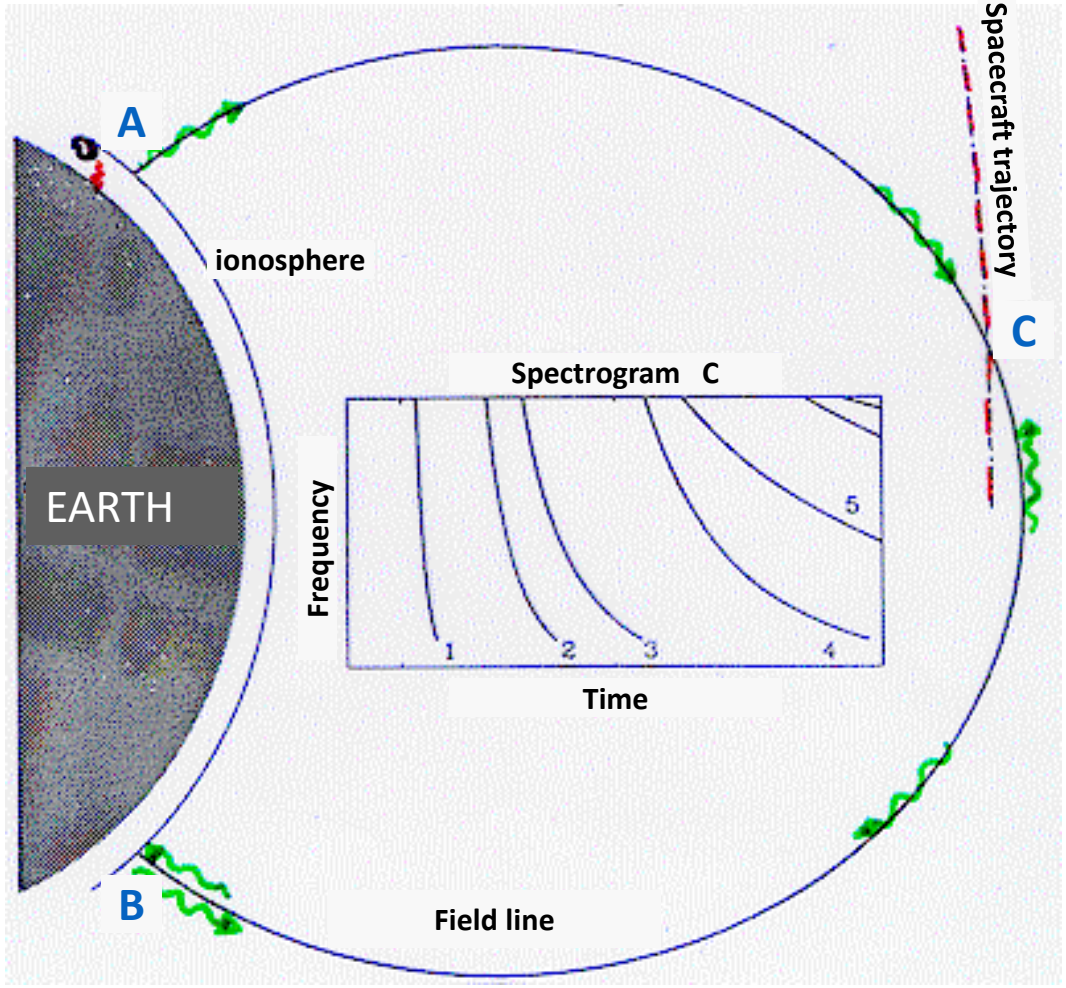


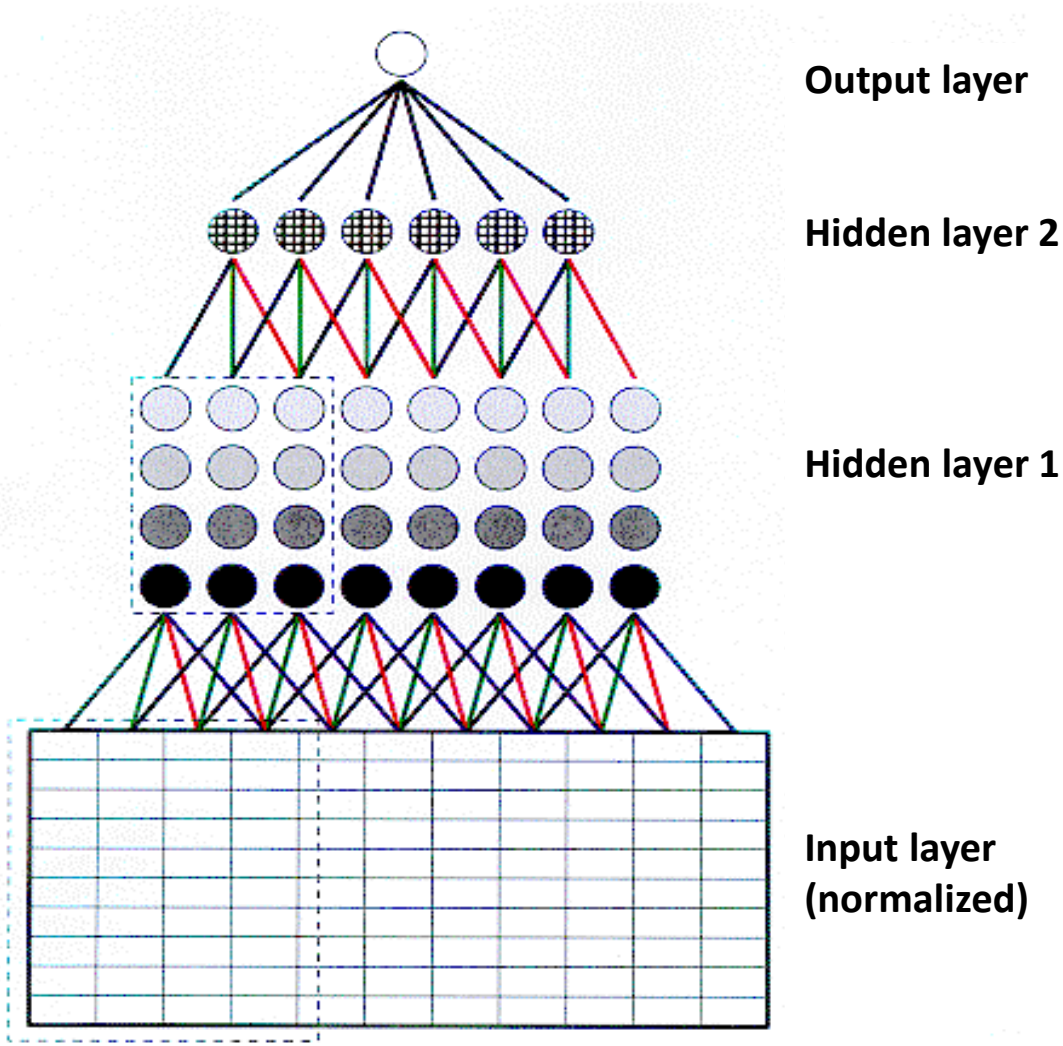




Automatic Whistler Identification

- Number of identified whistlers in a given time-interval (Δt ~ 0.1 s) and dispersion class
- Runs on-board, uses high-resolution data which are not transmitted to the ground



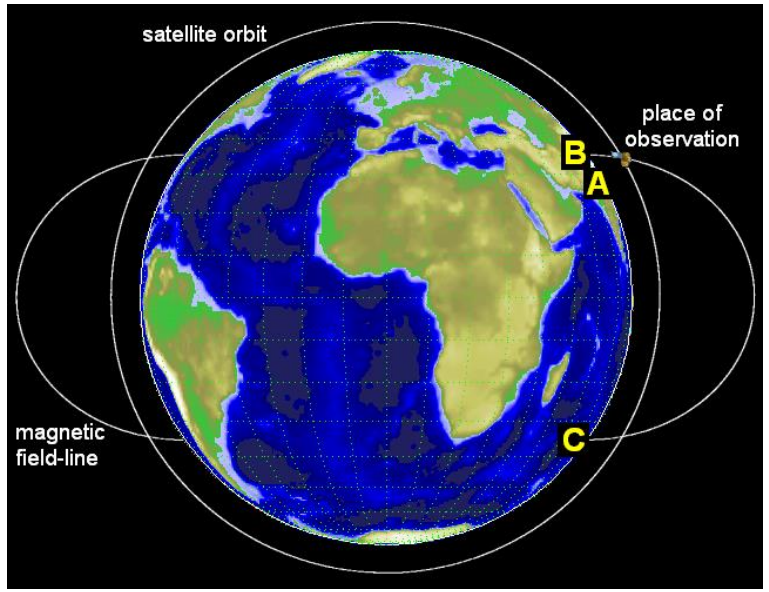


Seismic-Related Effects: General Thoughts

- Existence, as well as a possible mechanism of generation, are still unclear
- A case study cannot confirm/deny such effects => statistics (still) needed

- Spacecraft can cover the entire Earth's surface, getting into the vicinity of many earthquakes
- Problems:
    1. Strong natural background
    2. Signal should propagate through multiple layers

- What point on the Earth’s surface does the spacecraft “see”?



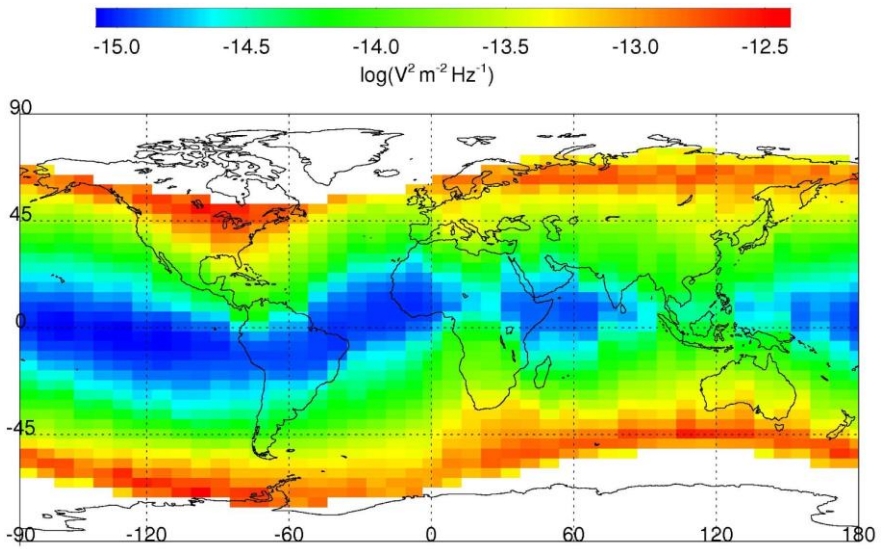
How to Account for Natural Variability (1)

- Situation “close to” vs. “far from” earthquakes
  - problematic when the “natural background” depends on the position
- Number of values exceeding predefined thresholds
  - the threshold definition is rather arbitrary
- Control orbits
  - difficult to be aware of possible biases (e.g., it is never exactly the same location)
- Difference from mean larger than (some number of) standard deviations
  - “when we want to find out what is exceptional, we must know what is normal”
  - requires data processing in two steps and large amount of data measured
    1. calculate mean value and standard deviation at a given place under given conditions
    2. evaluate data measured at the time of earthquakes
  - the distribution of values is hardly ever Gaussian-like

How to Account for Natural Variability (2)

- Probability ("**normalized intensity**")
- Represents the distribution of values in the form of a histogram (not only 1st+2nd moments)

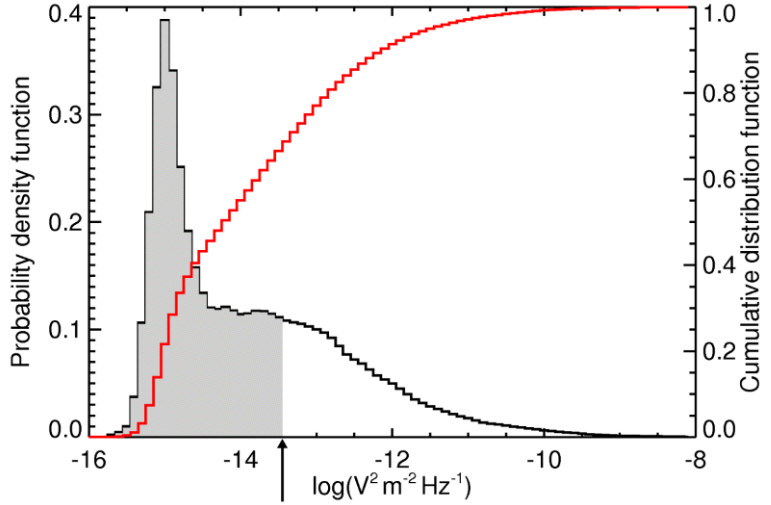
- **Step 1:**
  - Values at a given place under given conditions
  - All data used when constructing this distribution
  - Represented by a multi-dimensional matrix
  - Possible parameters: wave frequency, latitude/longitude, magnetic local time, geomagnetic activity, season, …
  - In each cell there is a <u>histogram of measured values</u>



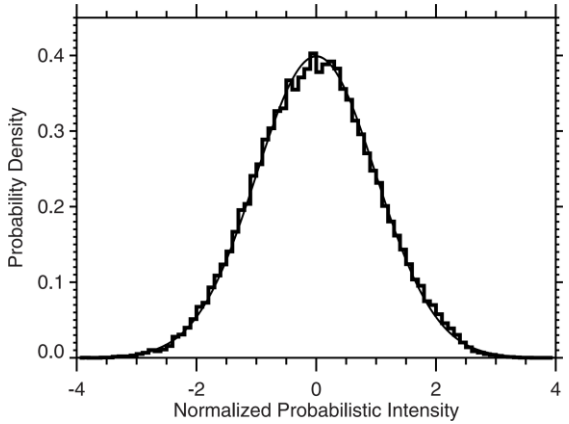
How to Account for Natural Variability (3)

- **Step 2:**
  - Measured value => value of cumulative distribution function (i.e., probability of occurrence of values less than or equal to the measured one)
  - Obtained "cumulative probabilities" organized wrt:
    - ✓ time to/from an earthquake
    - ✓ distance from an earthquake
  - For each bin we calculate:

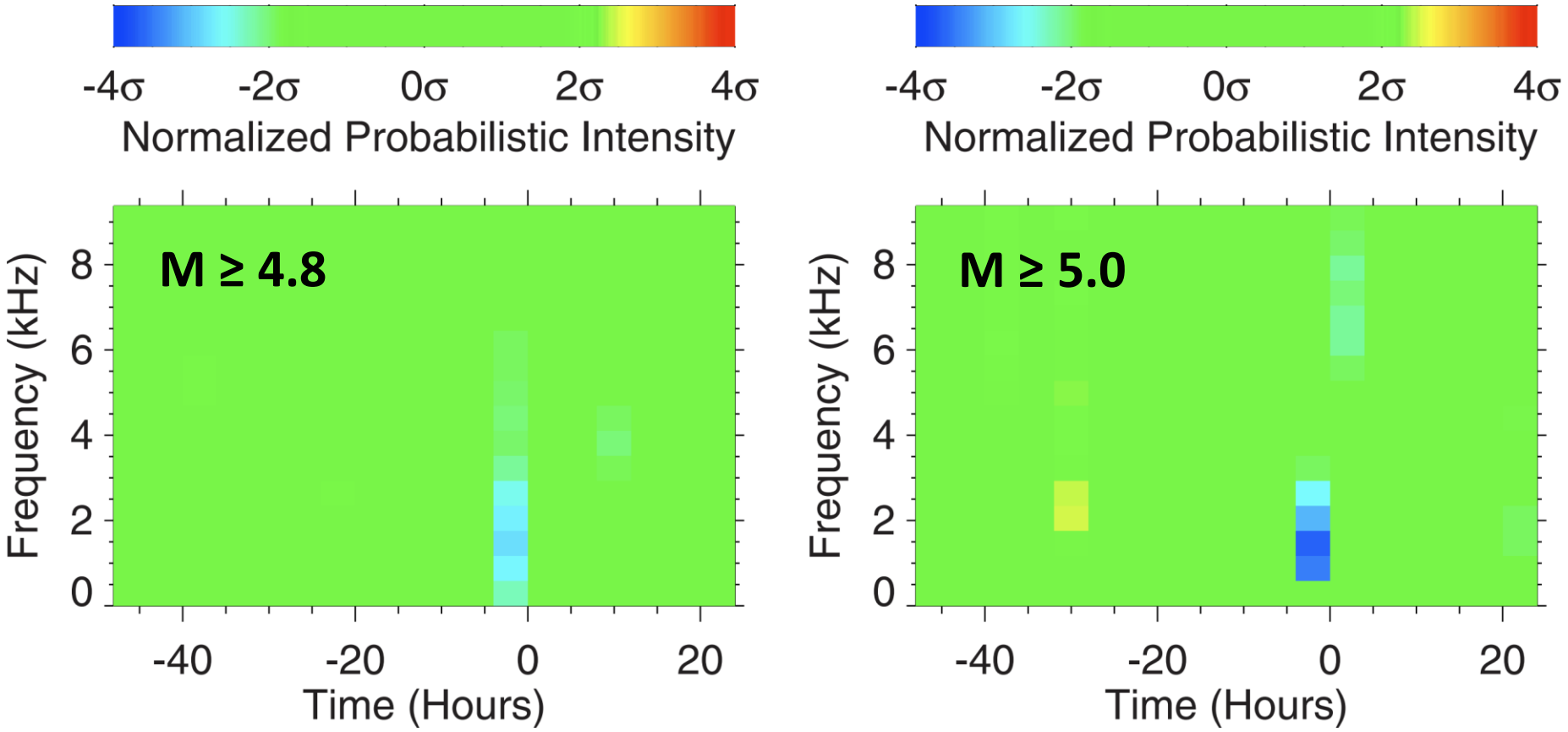
$$\mathrm{I} = \sum_{i=1}^{M} F_i - 0.5 = N(0;\sigma)$$



  - σ depends on the number of "independent" samples (~#orbits) => Monte Carlo
  - Normalization (separately for each bin) => "**normalized probabilistic intensity**", N(0;1)
  - Changes related to seismic activity and their statistical significance can be evaluated
  - Only data occurring nearby a single earthquake used



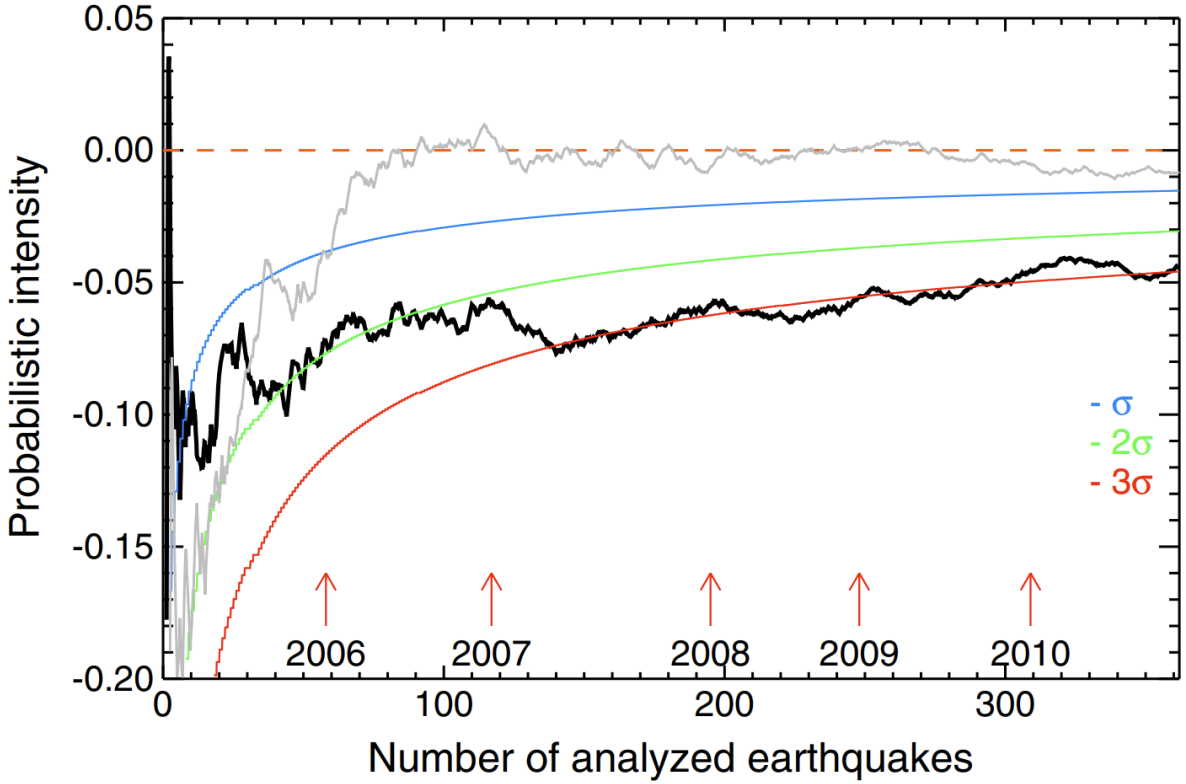
Seismic Effects: VLF Wave Intensity (1)

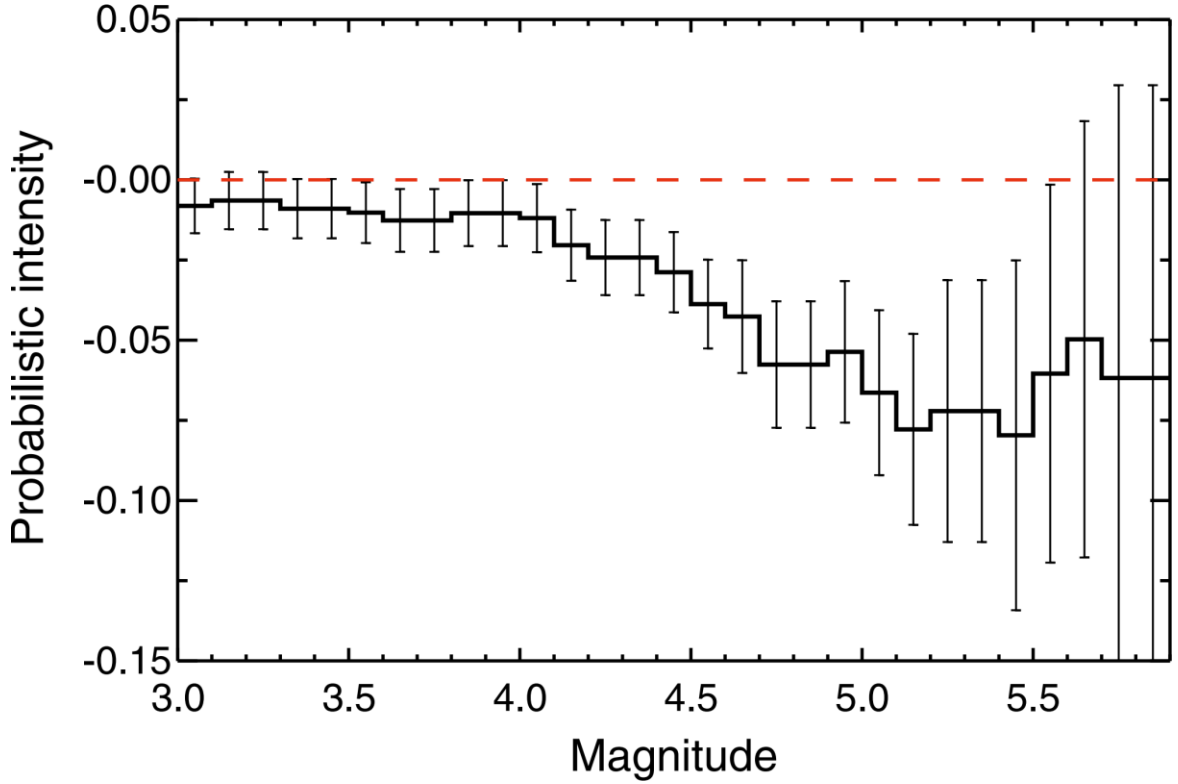


- Within 330 km of the earthquakes shallower than 40 km
- Nighttime only

Němec et al., GRL, 2008

Seismic Effects: VLF Wave Intensity (2)



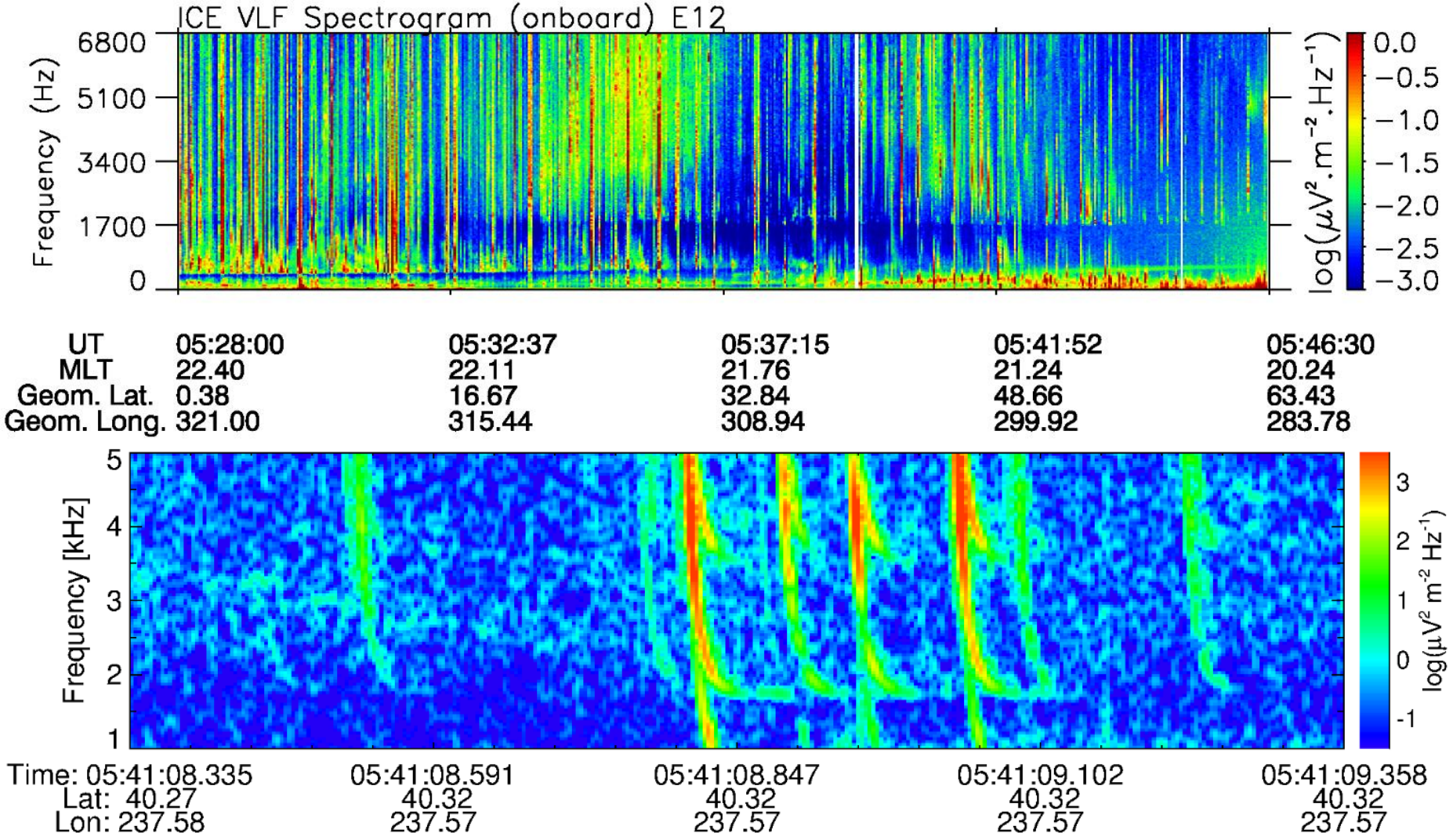


- frequency ~ 1.7 kHz
- black curve: 0 – 4 hours before
- gray curve: 24 – 28 hours before

Píša et al., JGR, 2013

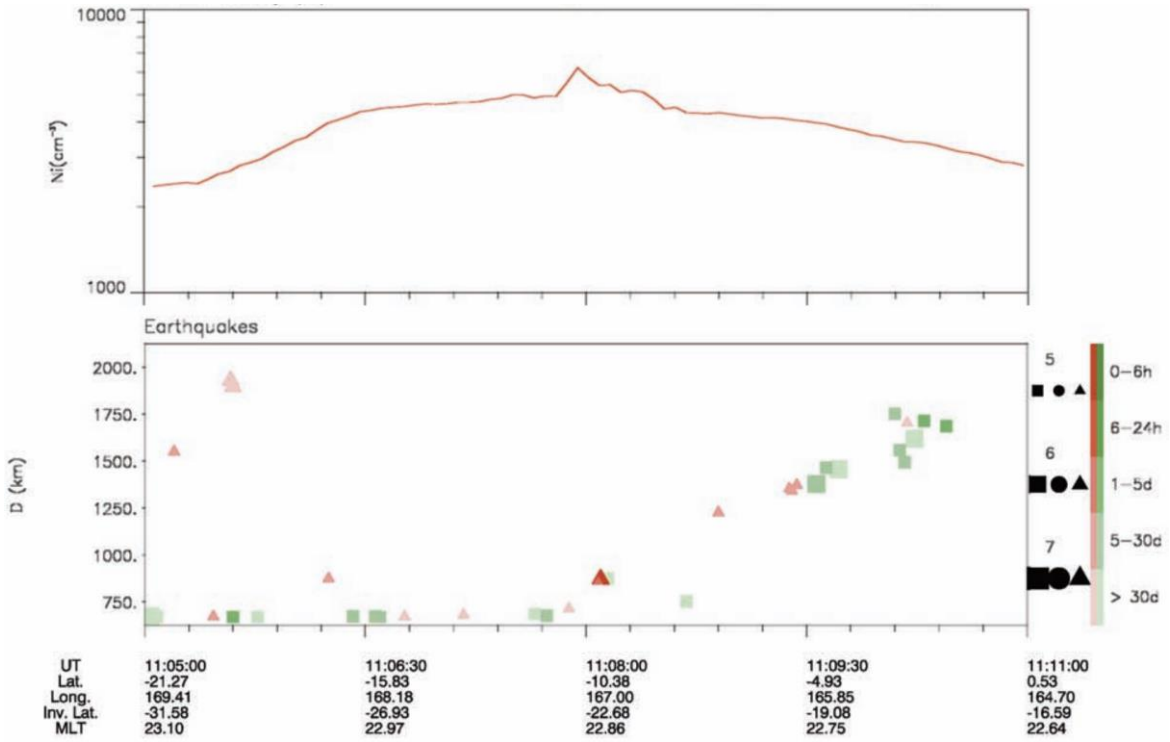
Seismic Effects: VLF Wave Intensity (3)

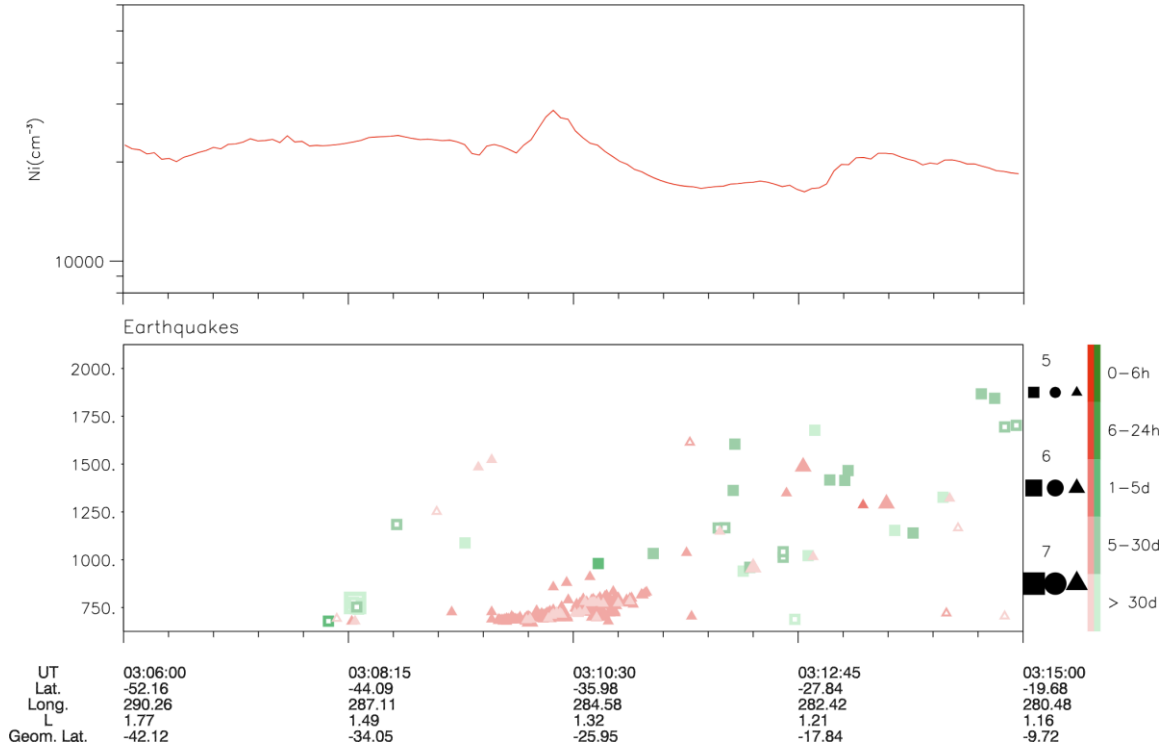
- 1.7 kHz ~ Earth-ionosphere waveguide cut-off frequency => changes in the waveguide (?)



Píša et al., JGR, 2013

Seismic Effects: Ionospheric Density (1)

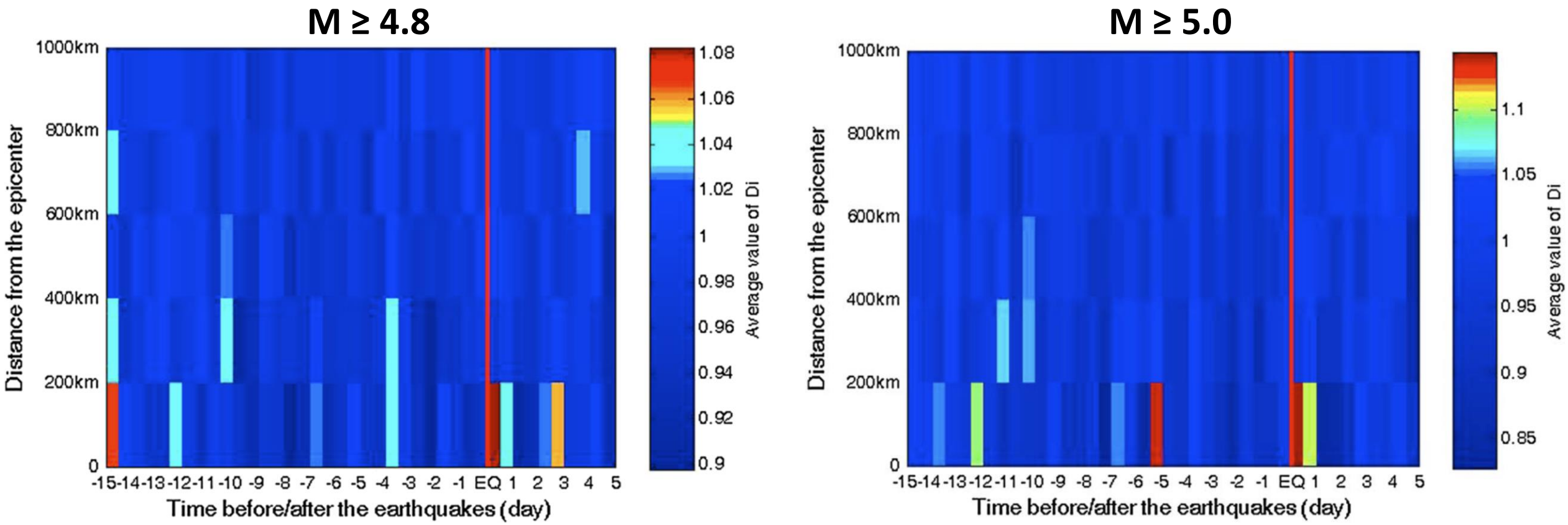




Parrot et al., AG, 2012

Píša et al., JGR, 2011

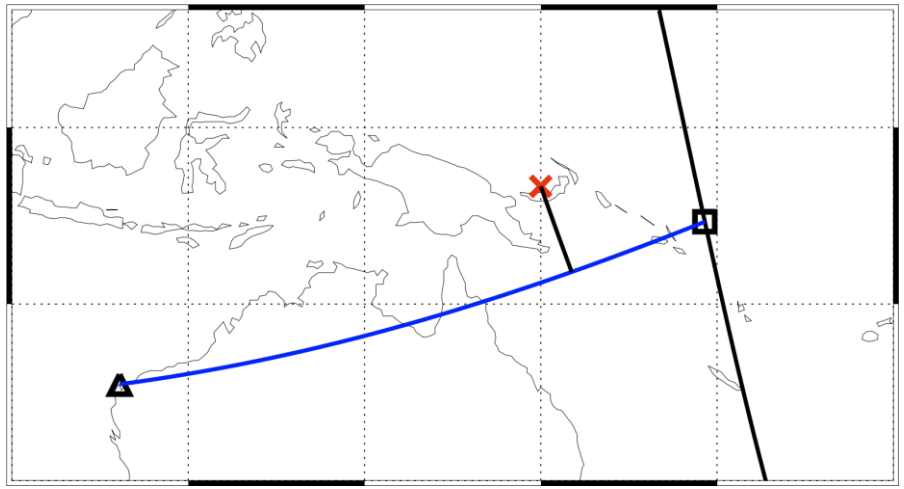
Seismic Effects: Ionospheric Density (2)

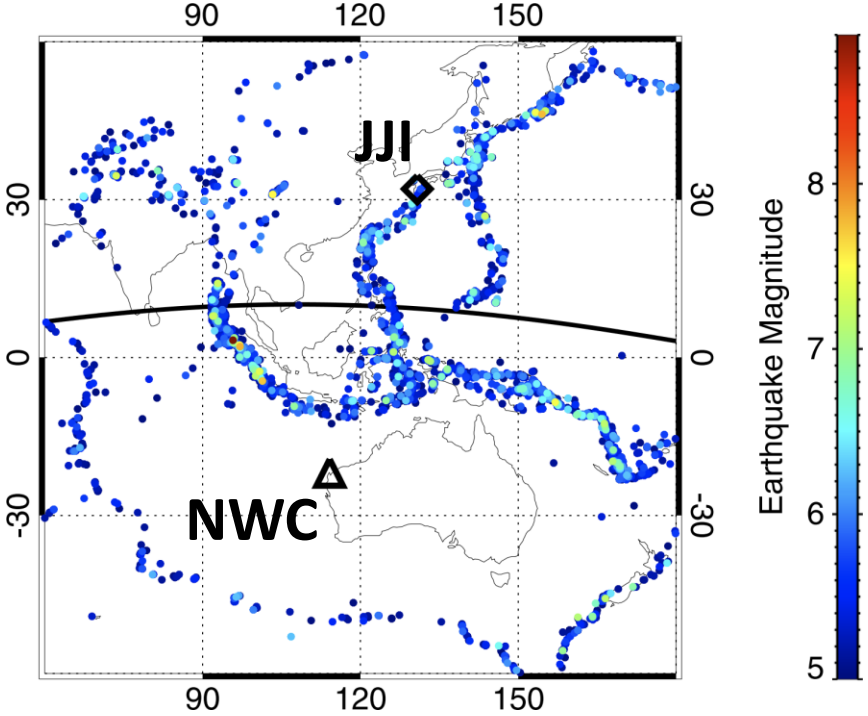


- Post-seismic effect observed

Yan et al., JGR, 2017

Seismic Effects: VLF Transmitter Signals

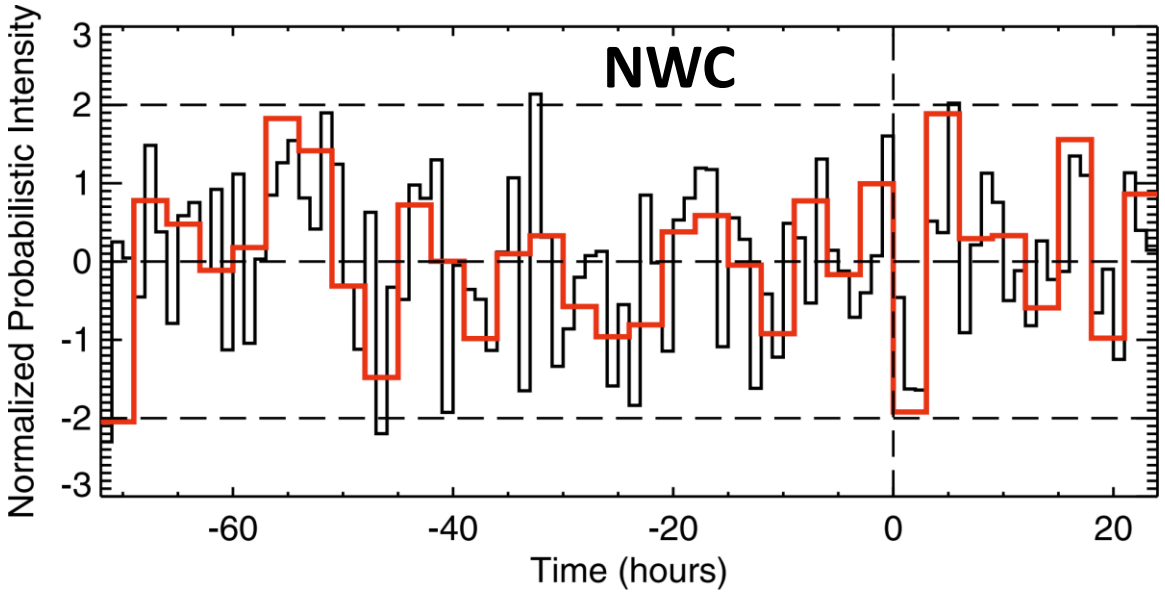


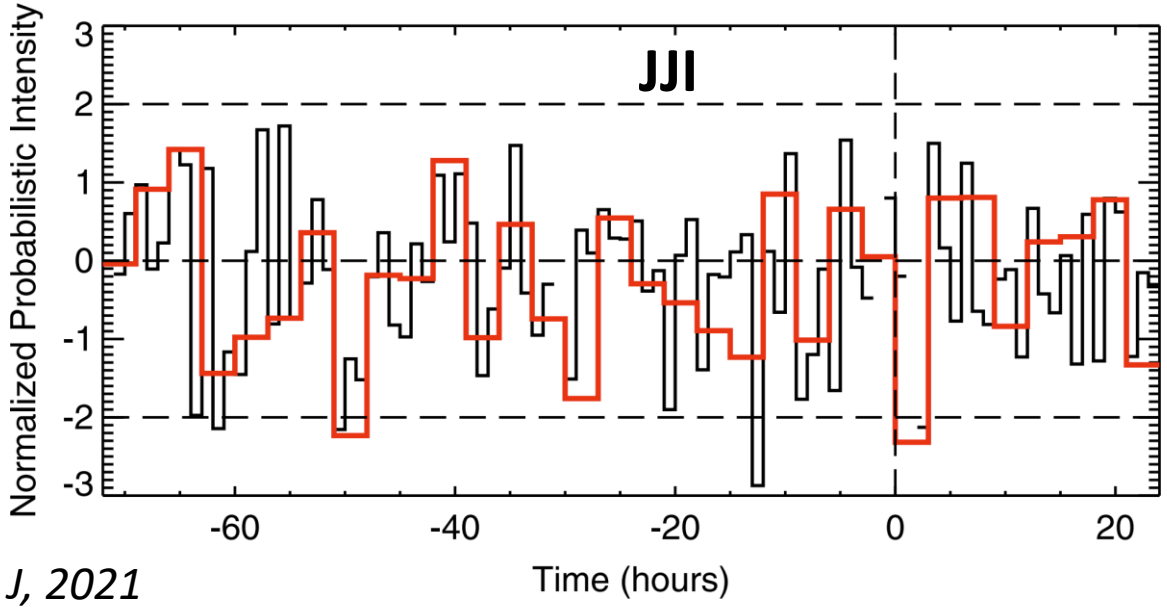


d < 4°

M ≥ 5

shallower than 40 km





Němec et al., E. Phys. J, 2021

Conclusions

- DEMETER spacecraft can be considered very successful
- Not only seismic-related phenomena but also anthropogenic + magnetospheric

- Natural “background” is highly variable and identification of (small) seismic effects is tricky
- Elaborated statistical analyses needed
- The existence of seismic-related effects (and particularly precursors) is still questionable (I think) – on the edge of statistical significance
- Scientifically tempting…