# The Comparison of the ionospheric plasma turbulence in the polar cusp and over seismic regions- Analysis of the DEMETER's measurements

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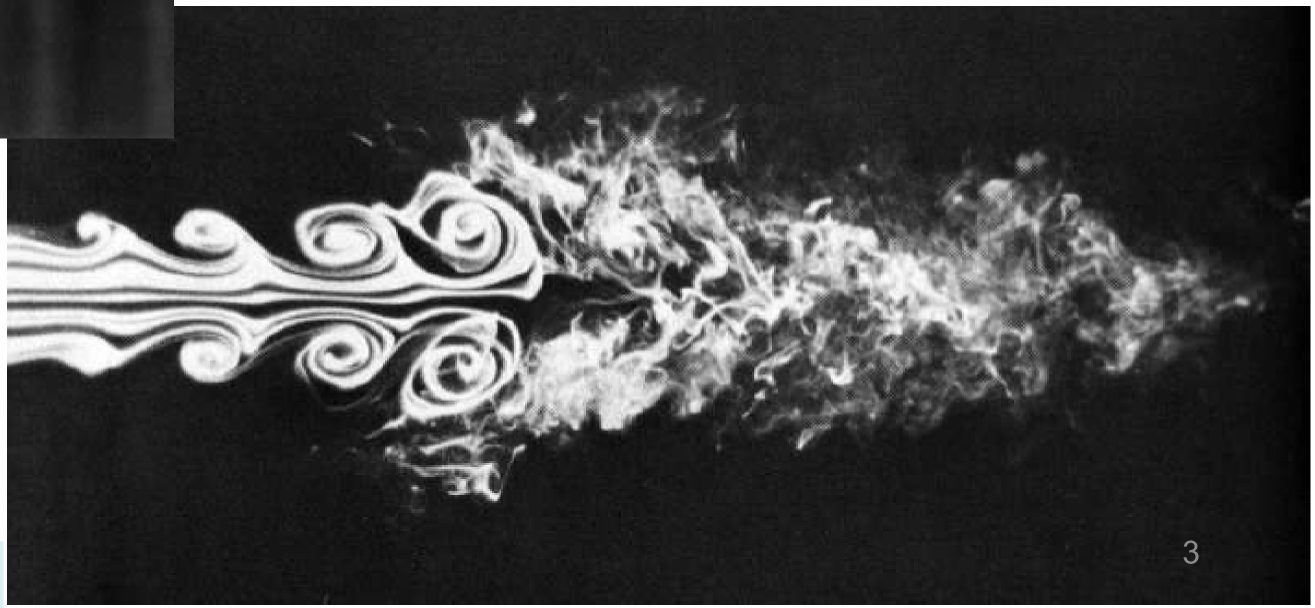
# *OUTLINE*

- MOTIVATION
- METHODOLOGY
- REGISTRATIONS: L'AQUILA, CHILE, POLAR CUSP.
- SUMMARY AND CONCLUSIONS

## What is turbulence ?

Turbulent  is a complex, nonlinear multiscale phenomenon, which poses some of the most difficult and fundamental problems in classical physics. It is also of tremendous practical importance in making predictions—for example, about heat transfer in nuclear reactors, drag in oil pipelines, the weather, and the circulation of the atmosphere and the oceans. ***But what is turbulence?*** Why is it so difficult to understand, to model, or even to approximate with confidence?



# How to describe turbulence?

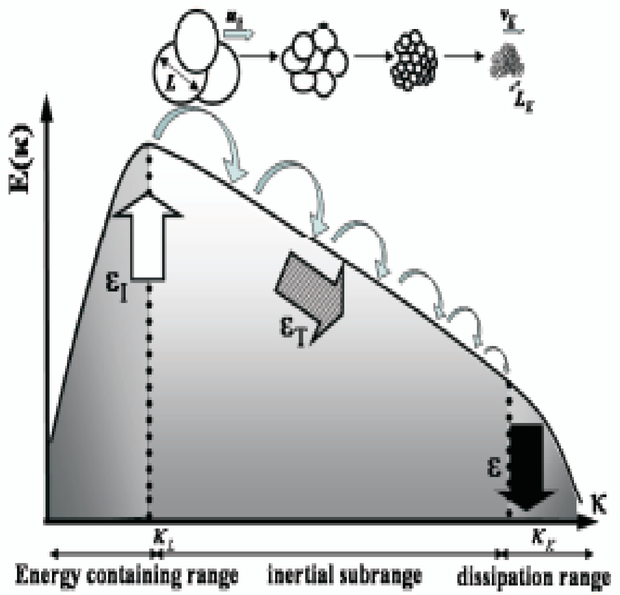



Fig. 1.7 Sketch of the energy cascade. In physical space, the large eddies are broken into smaller and smaller eddies. The energy is injected into the flow by the driving mechanisms at the rate $\varepsilon_I$, transferred to smaller scales at the rate $\varepsilon_T$ and dissipated into heat at the rate $\varepsilon$. The local equilibrium assumption is expressed by the equality $\varepsilon_I = \varepsilon_T = \varepsilon$. Both scales are logarithmic.

The definition of the turbulence in the fluids, gases and plasmas is still under discussion, but some *essential features of the turbulence* are out of the discussion.

They are :

Many degrees of freedom (***different scales***)

All of them in ***non -linear*** interaction (cross-scale couplings)

***Main characterization:***

Shape of the ***power spectrum*** and higher spectral features

Statistical methods of the turbulence description : PDF, skewness and kurtosis , intermitency, structural function.

Theory of the turbulence predicts the different slope of the spectra for the different types of the turbulence

Noncompressible turbulence (K-1941) $\Rightarrow k^{-5/3}$
Kolmogorow

Noncompressible isotropic MHD (IK-1965) $\Rightarrow k^{-3/2}$
Iroshnikov-Kraichnan

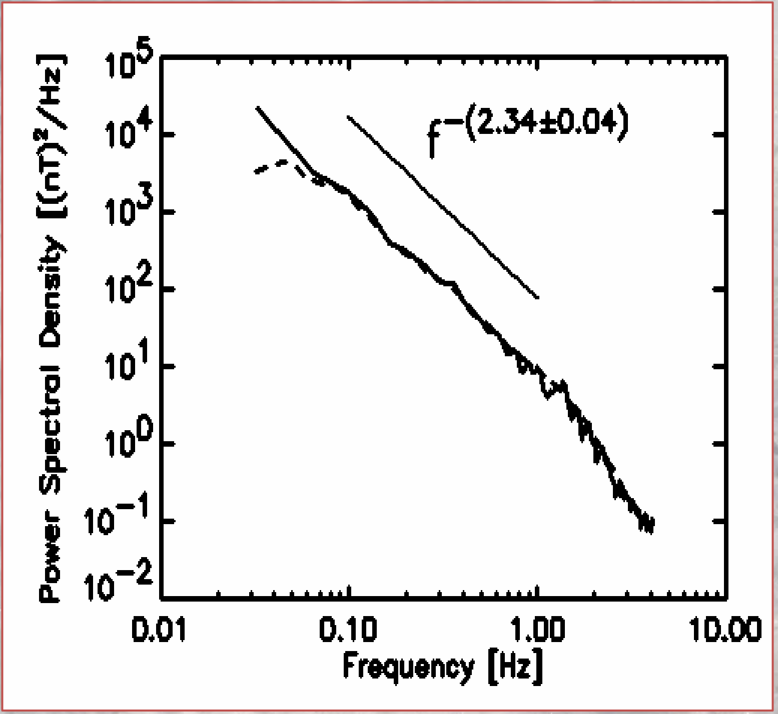
Noncompressible anisotropic MHD (SG-2000) $\Rightarrow k_{\perp}^{-2}$

Sridhar and Goldreich

Whistler turbulence (DB-1997) $\Rightarrow k^{-7/3}$

## Examples of power spectra of the magnetic field fluctuations, measured in the cusp (POLAR satellite)

**By110497_1**

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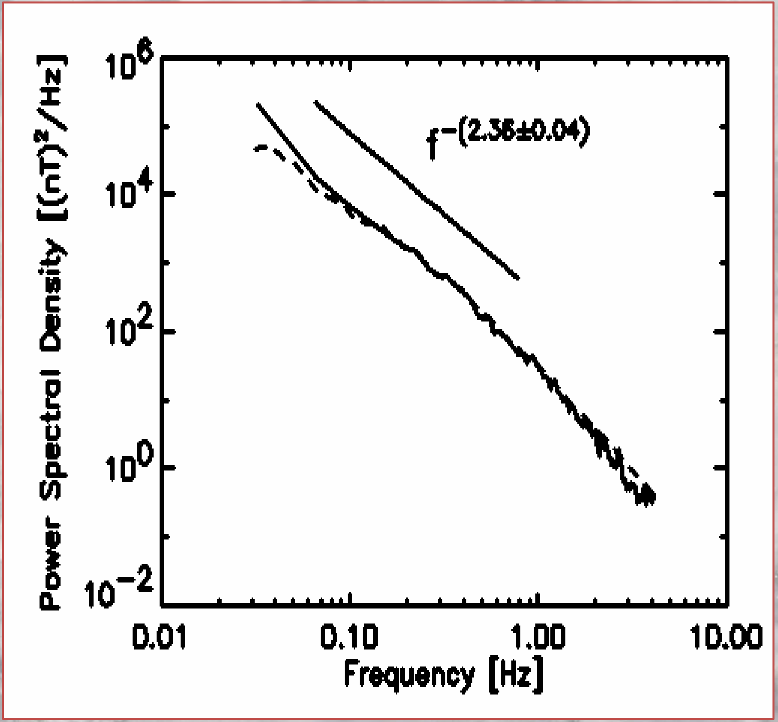



Yordanova, 2005

# *METHODOLOGY*

**The Fourier spectrum –for identification of disturbed areas**

**The complex Morlet wavelet- to study time evolution with high resolution**

**The bispectral analysis allows us to find the wave modes nonlinearly interacting by 3 waves processes.**

The resonance conditions for these processes are:

- $\omega_1+\omega_2 = \omega_3$
- $\mathbf{k_1}+\mathbf{k_2} = \mathbf{k_3}$

A quantitative measure of the phase coherency may be made by computing of the bicoherence spectrum which is defined in terms of the bispectrum as

$$b^2(k,l) = \lim \frac{1}{T} \frac{/ B(k,l) /^2}{P(k)P(l)P(k+l)}$$

Where *P(k)*,*P(l)* and *P(k+l)* are auto power spectra,

$B(k,l)= E[X_k \; X_l \; X_{k+l}^*]$

# *Statistics for the turbulence*

***Turbulence is non-Gaussian. The seemly random and intermittent nature of*** turbulence causes its probability density distribution not to be characterized by the bell-shaped curve. Instead it is skewed and kurtotic.

$$\langle x^n \rangle = \int_{-\infty}^{\infty} c^n B_x(c)\, dc$$

$$S = \frac{\left\langle (x - X)^3 \right\rangle}{\left\langle (x - X)^2 \right\rangle^{3/2}}$$

Skewness, says about deviation of PDF from Gaussian distribution

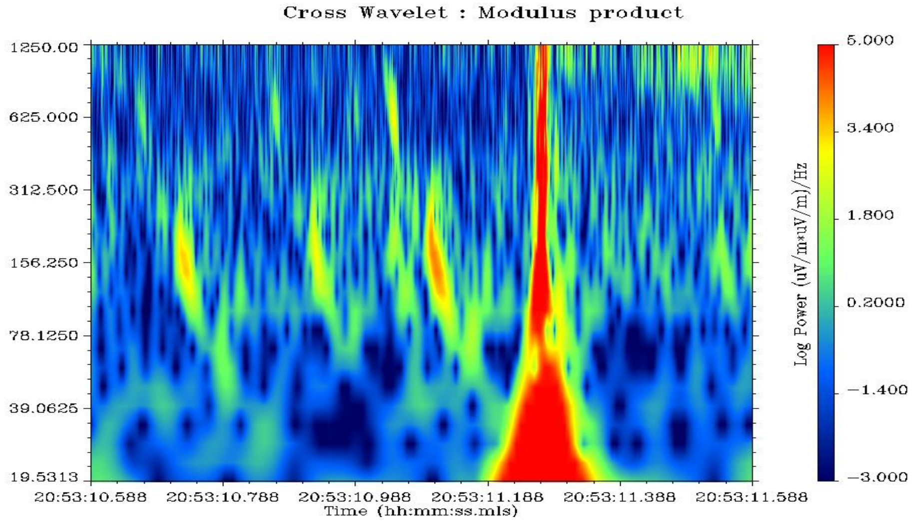
$$K = \frac{\left\langle (x - X)^4 \right\rangle}{\left\langle (x - X)^2 \right\rangle^{2}}$$

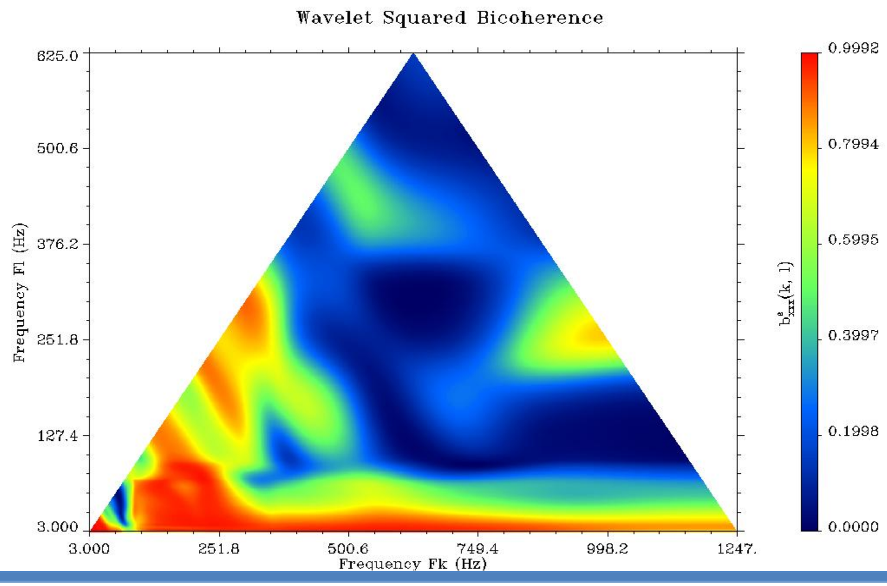
kurtosis

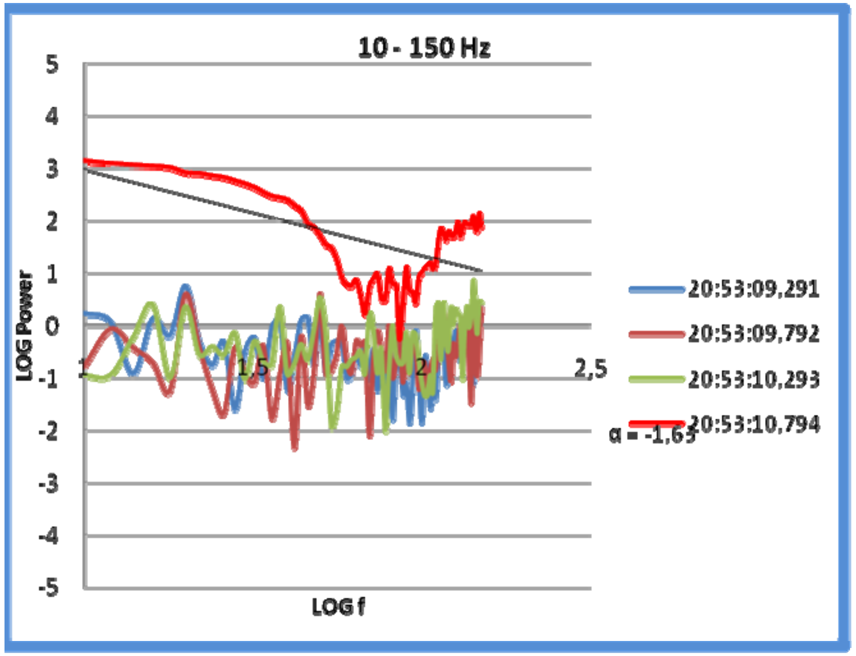
the kurtosis is a measure of intermittence in flows and is the parameter that controls the shape of PDF.

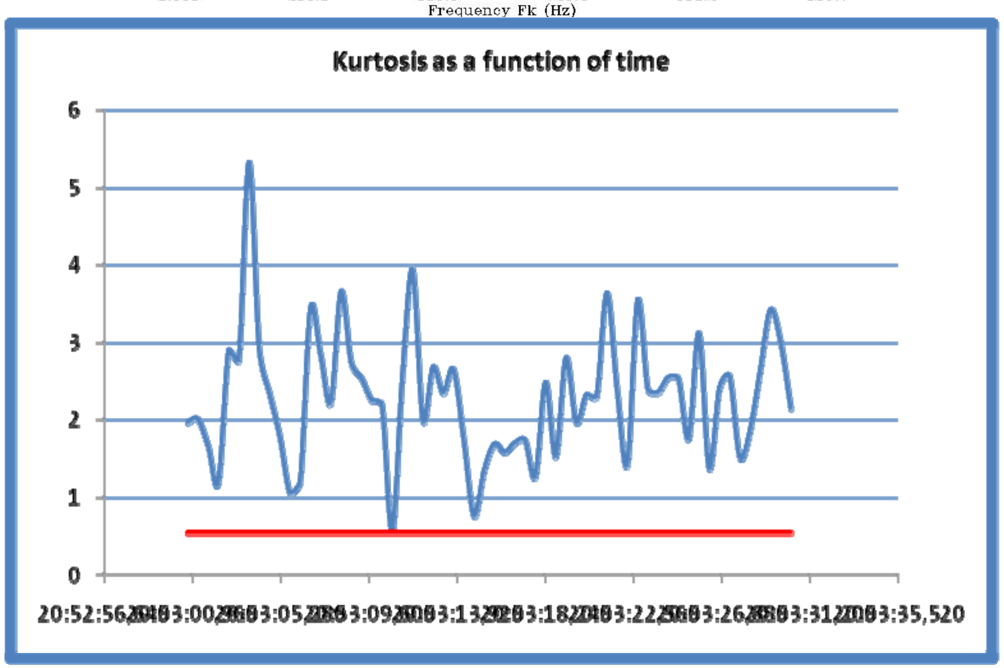
L’Aquila Earthquake 2009-04-06
at 01:32:41.4UTC
Magnitude Mw 6.3
Location:42.38 N ; 13.32 E
Depth: 2 km

# March 26, 11 days before the earthquake distance ≈245km

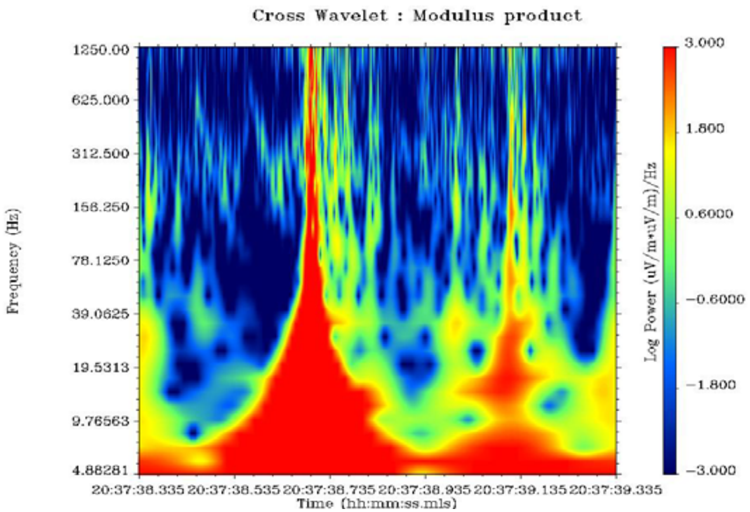


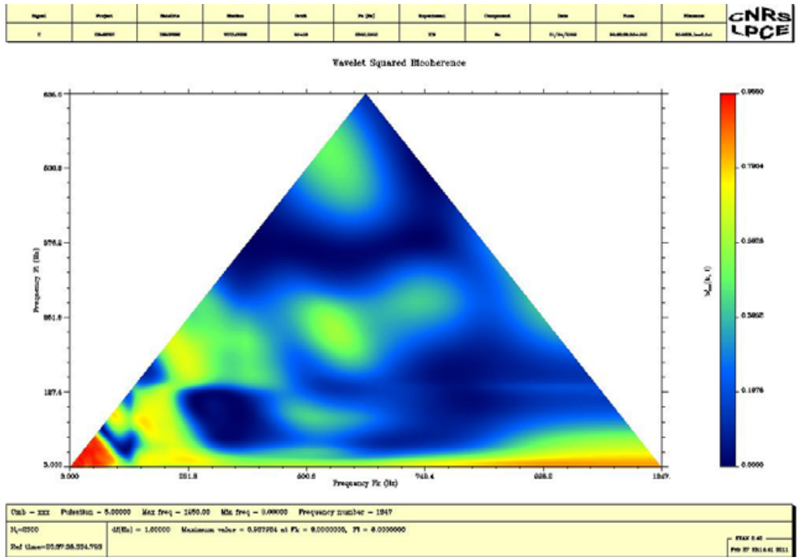



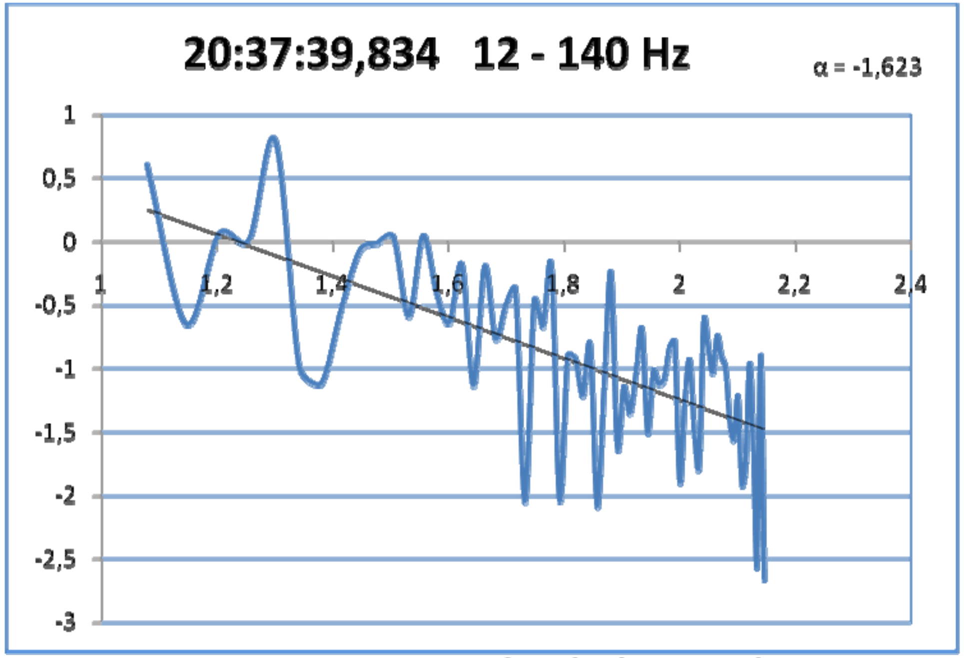



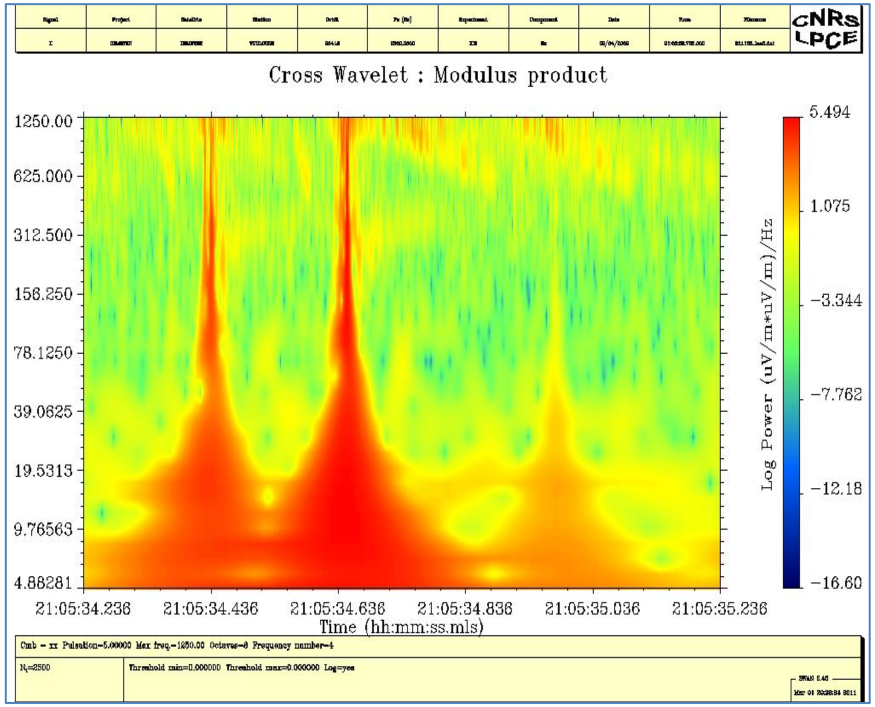
# April 1 20:37 5 days to the earthquake d≈60km

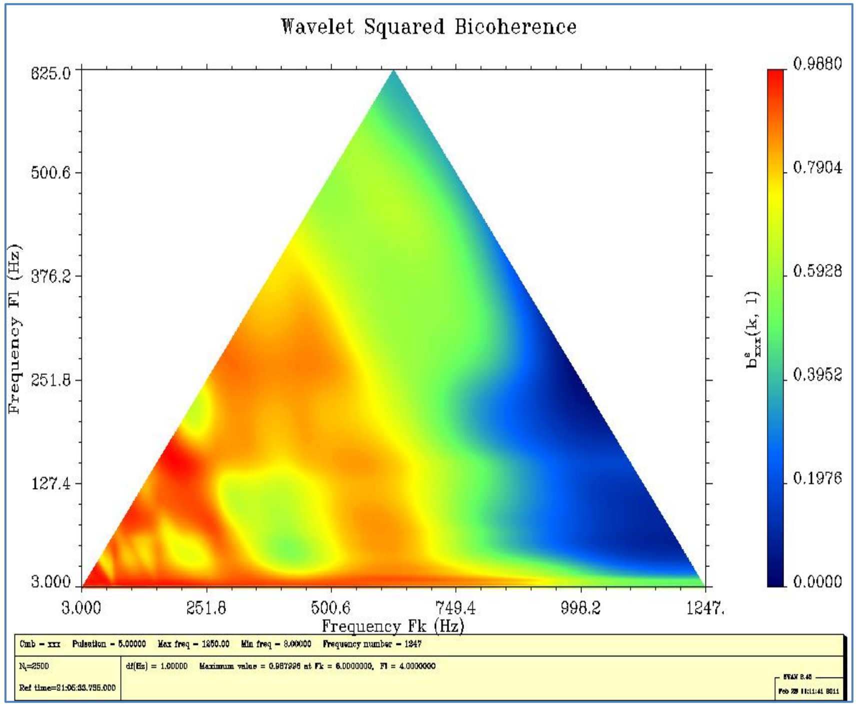


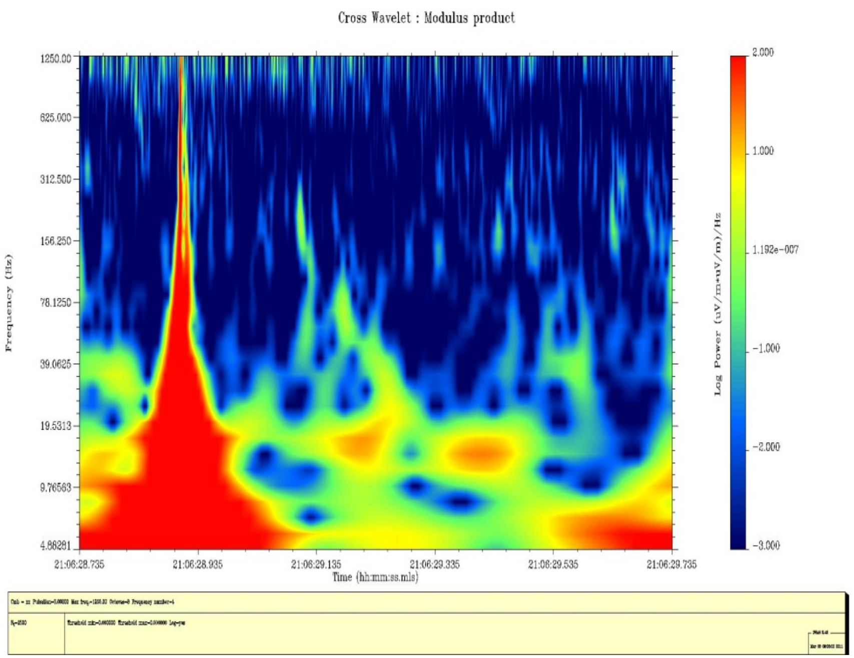



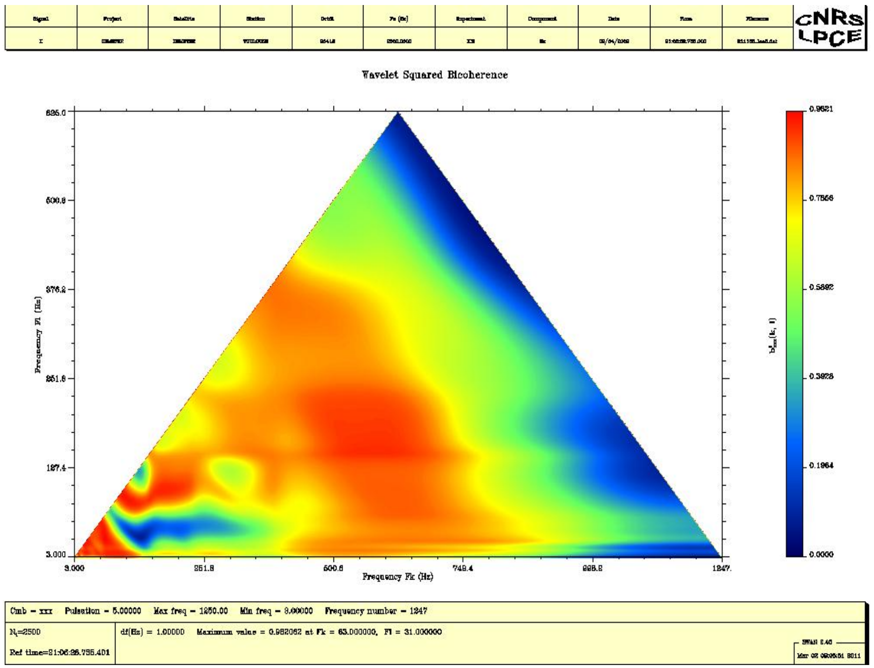



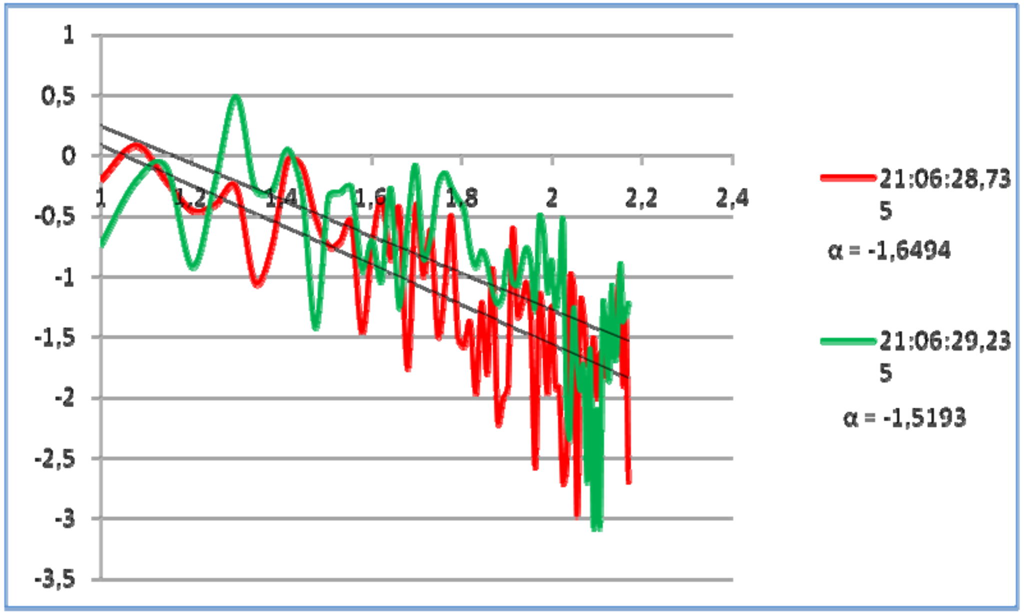
# April 2  4 days to eq d≈700km

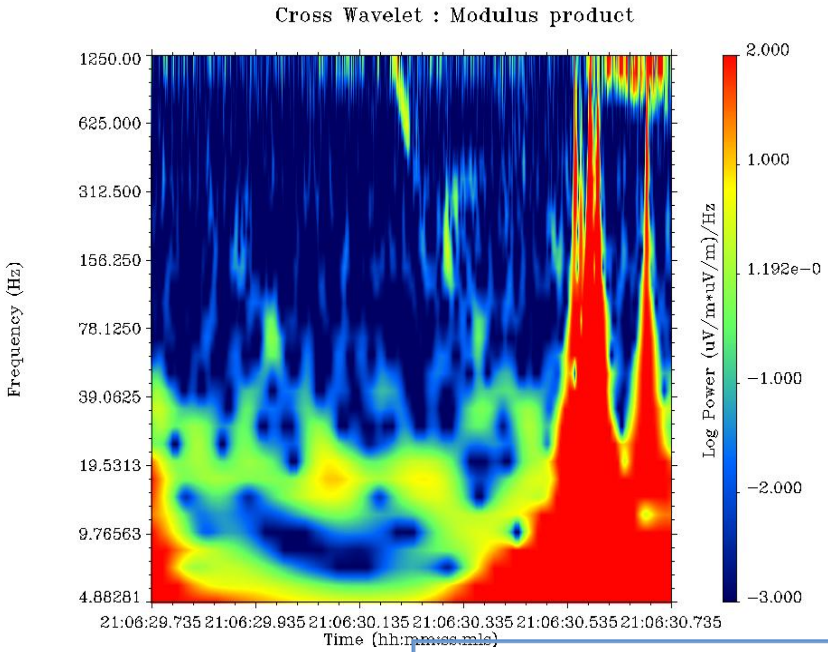


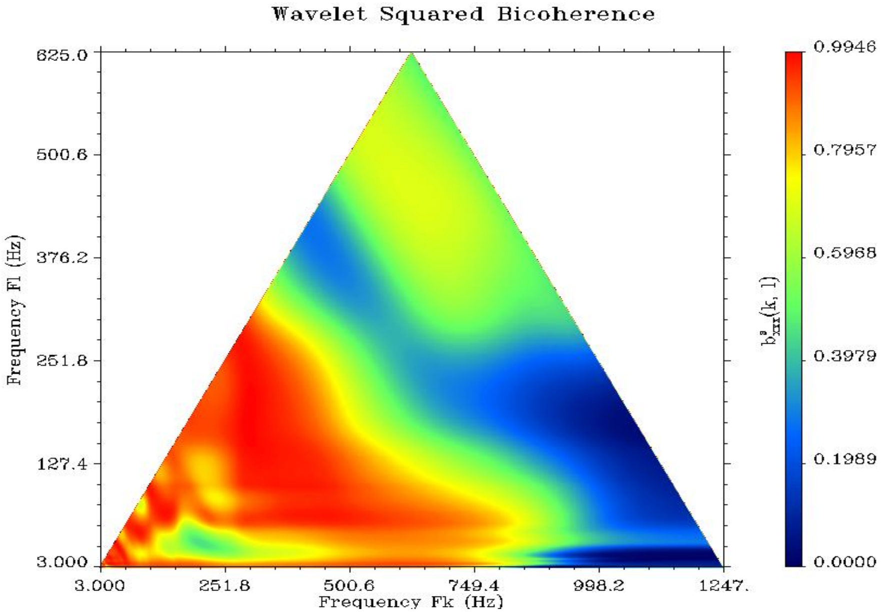



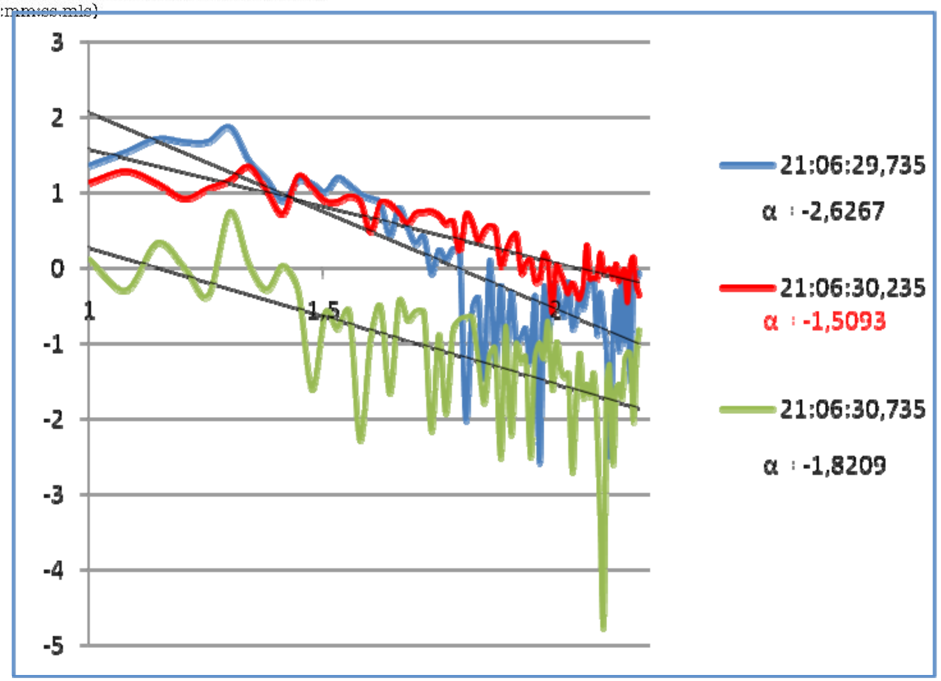

Cross Wavelet : Modulus product
Frequency (Hz)
Time (hh:mm:ss.mls)
Log Power (uV/m*uV/m)/Hz


Wavelet Squared Bicoherence
Frequency Fl (Hz)
Frequency Fk (Hz)

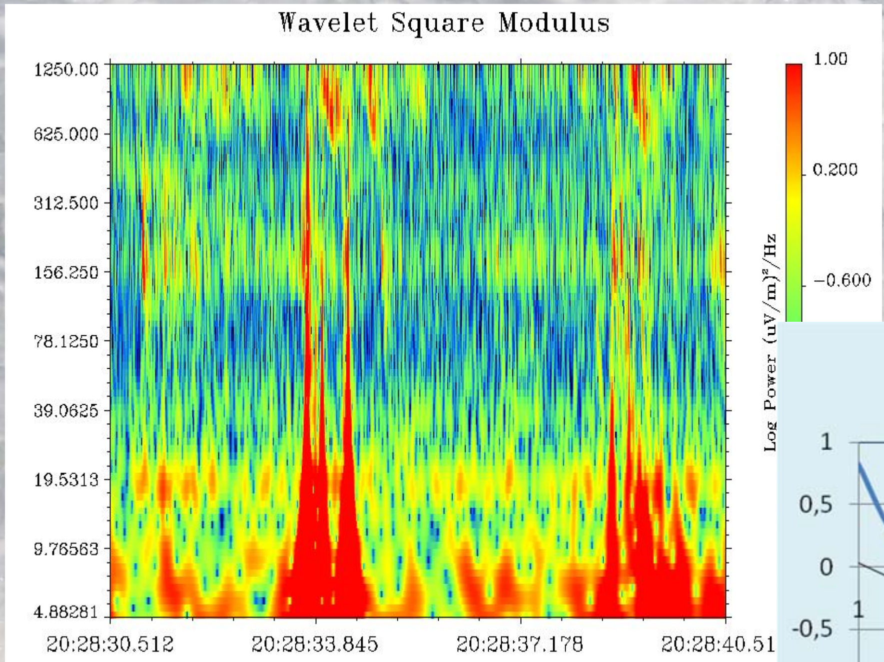

21:06:28,735
α = -1,6494
21:06:29,235
α = -1,5193

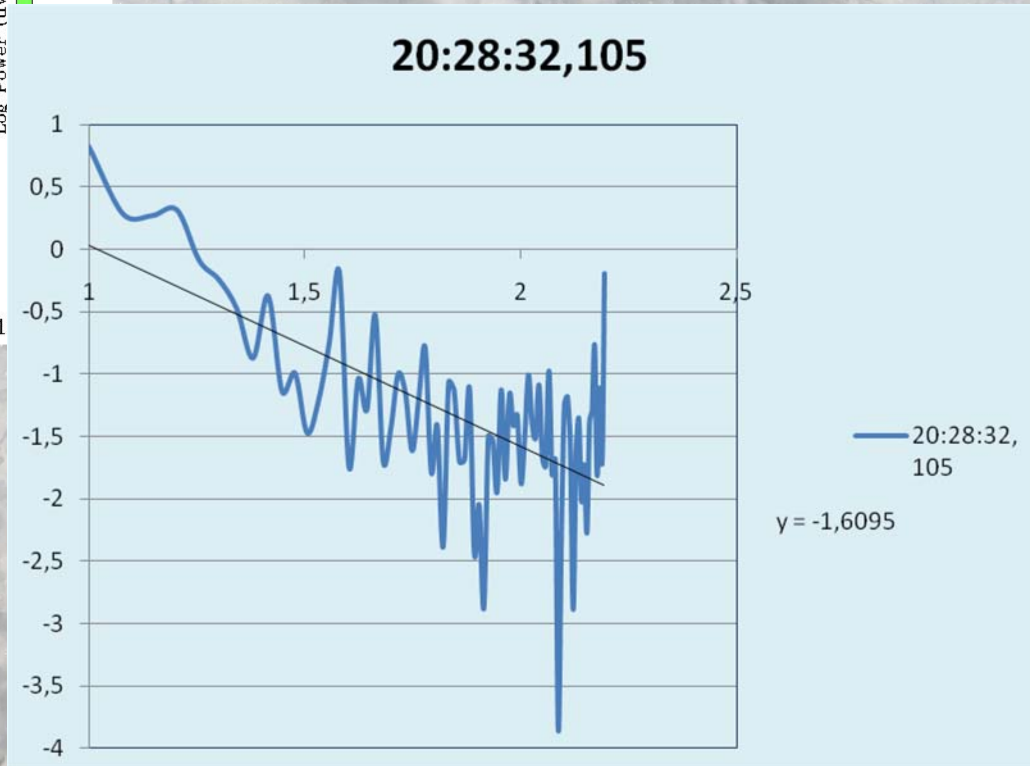

Cross Wavelet : Modulus product
Frequency (Hz)
1250.00
625.000
312.500
156.250
78.1250
39.0625
19.5313
9.76563
4.88281
21:06:29.735 21:06:29.935 21:06:30.135 21:06:30.335 21:06:30.535 21:06:30.735
Time (hh:mm:ss.mls)
Log Power (uV/m*uV/m)/Hz
2.000
1.000
1.192e-0
-1.000
-2.000
-3.000


Wavelet Squared Bicoherence
Frequency Fl (Hz)
625.0
500.6
376.2
251.8
127.4
3.000
3.000 251.8 500.6 749.4 998.2 1247.
Frequency Fk (Hz)
0.9946
0.7957
0.5968
0.3979
0.1989
0.0000


3
2
1
0
-1
-2
-3
-4
-5
1
1,5
2
21:06:29,735
α : -2,6267
21:06:30,235
α : -1,5093
21:06:30,735
α : -1,8209

# 2 days to the earthquake 2009 04 04 Kp 0 0 0 0+0+0+0+0+ Σ 2- Distance to epicenter ≈300km



# CHILE Earthquake

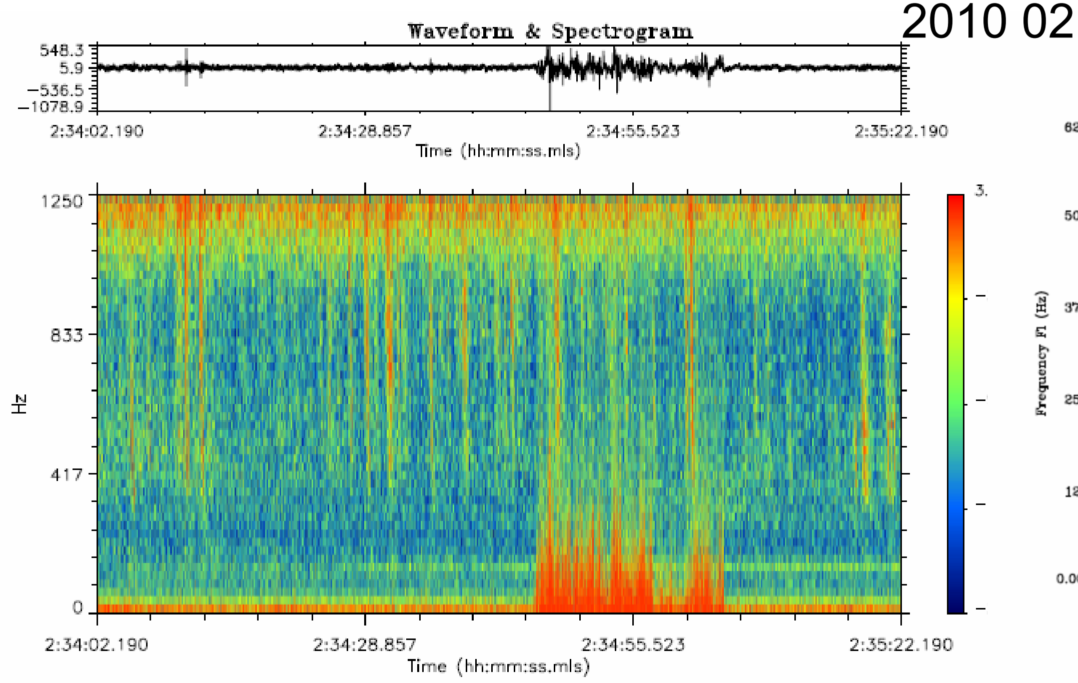
Magnitude: Mw 8.8

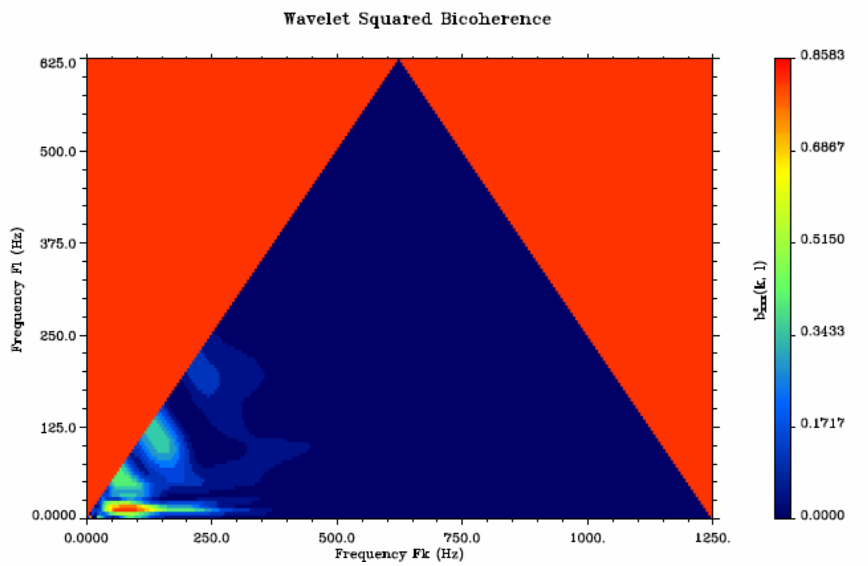
Time: 2010-02-27 at 06:34:14.1 UTC

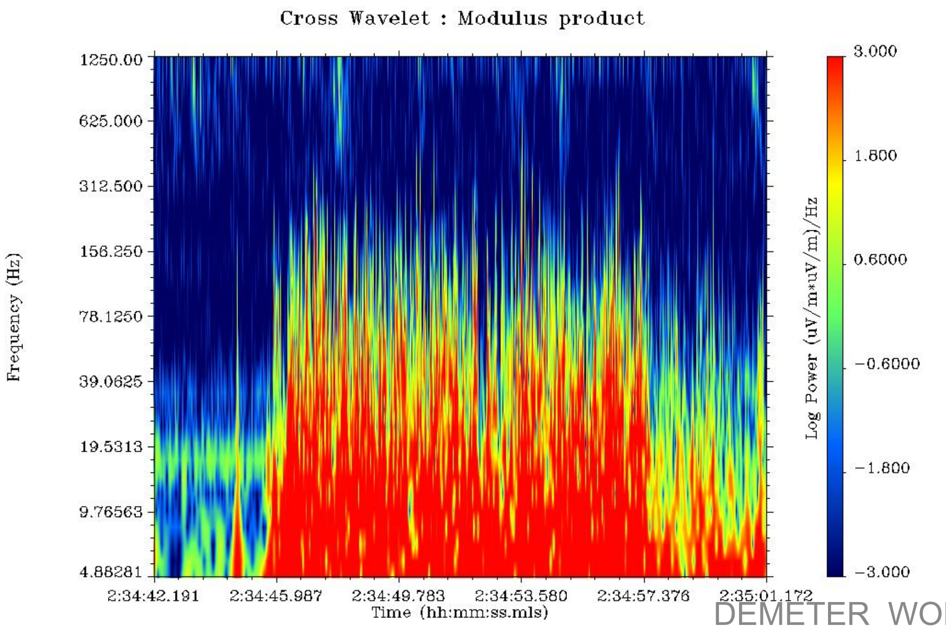
Location: 35.89 S ; 73.04 W

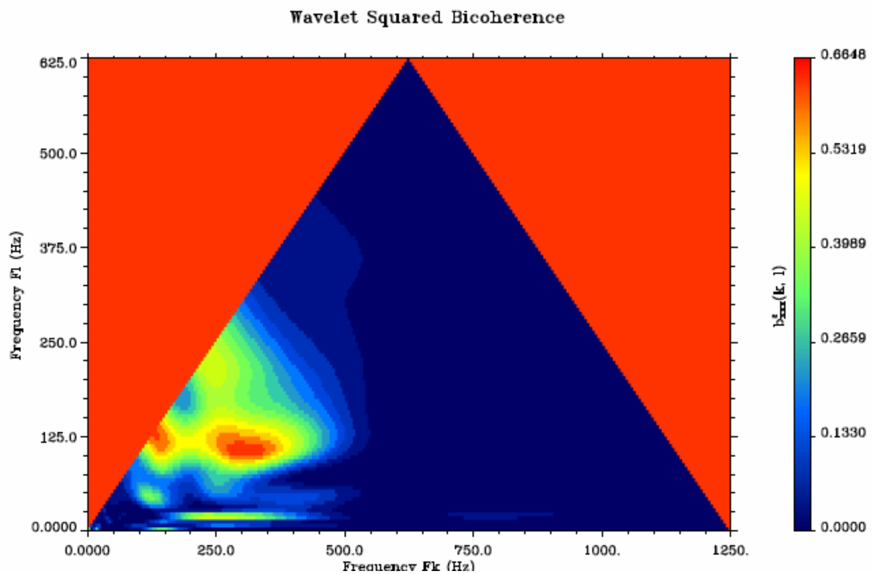
Depth: 30 km

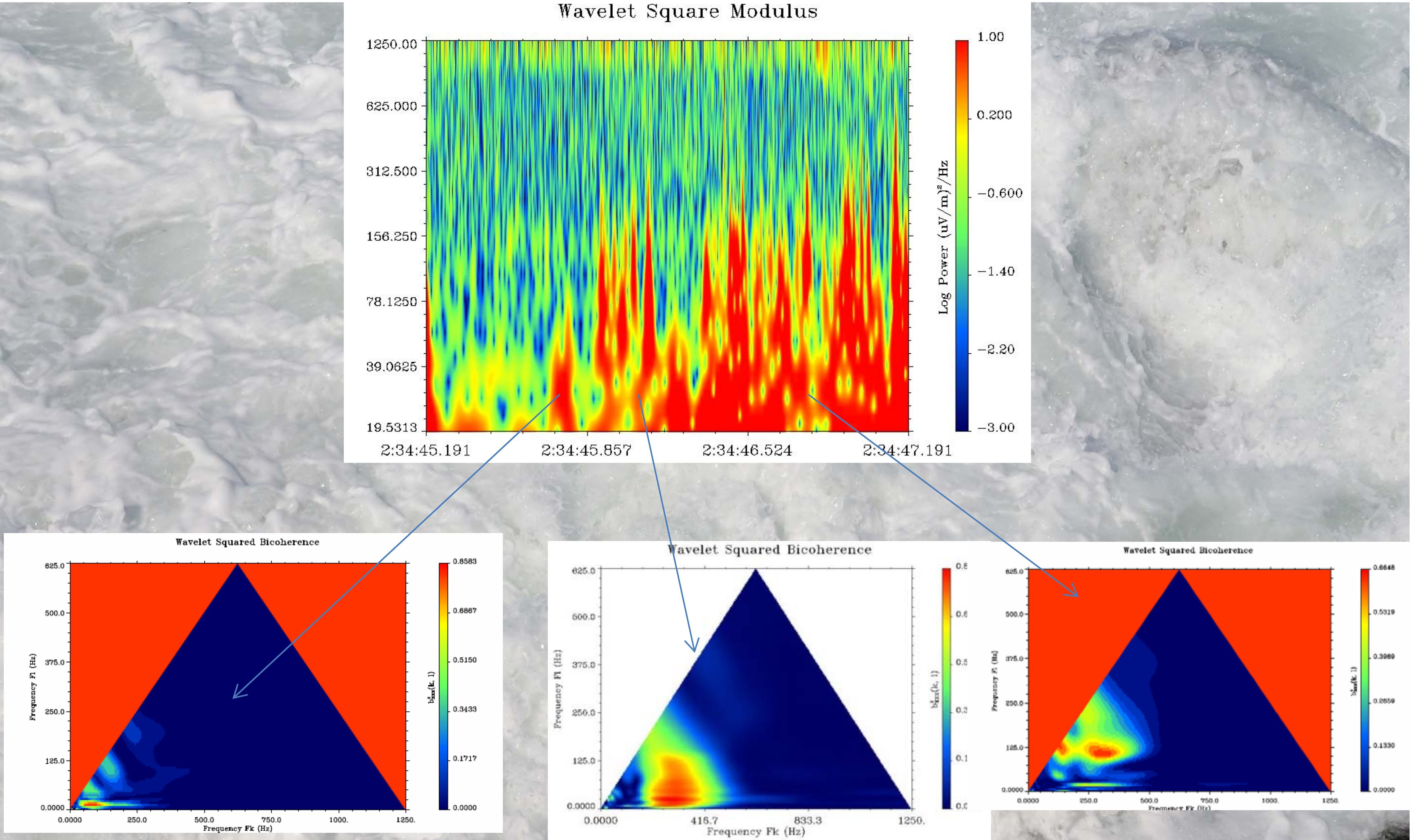
# 2010 02 18 Kp 0+0 0+1 2 3 2 0 Σ+ 9 d≈630km

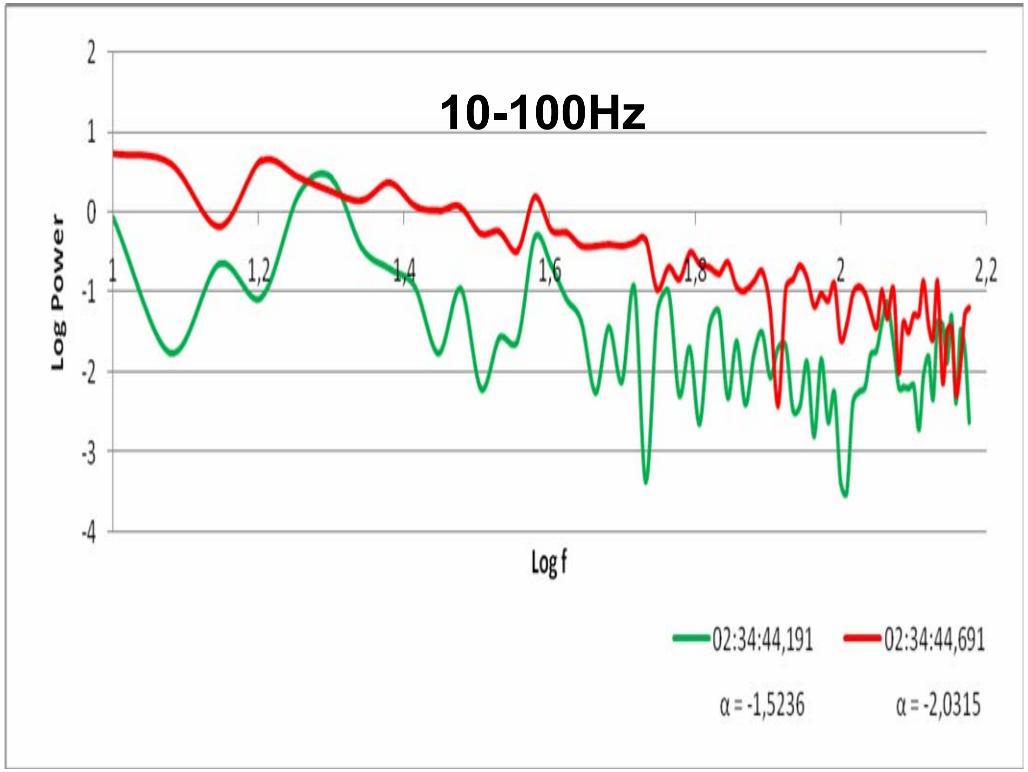


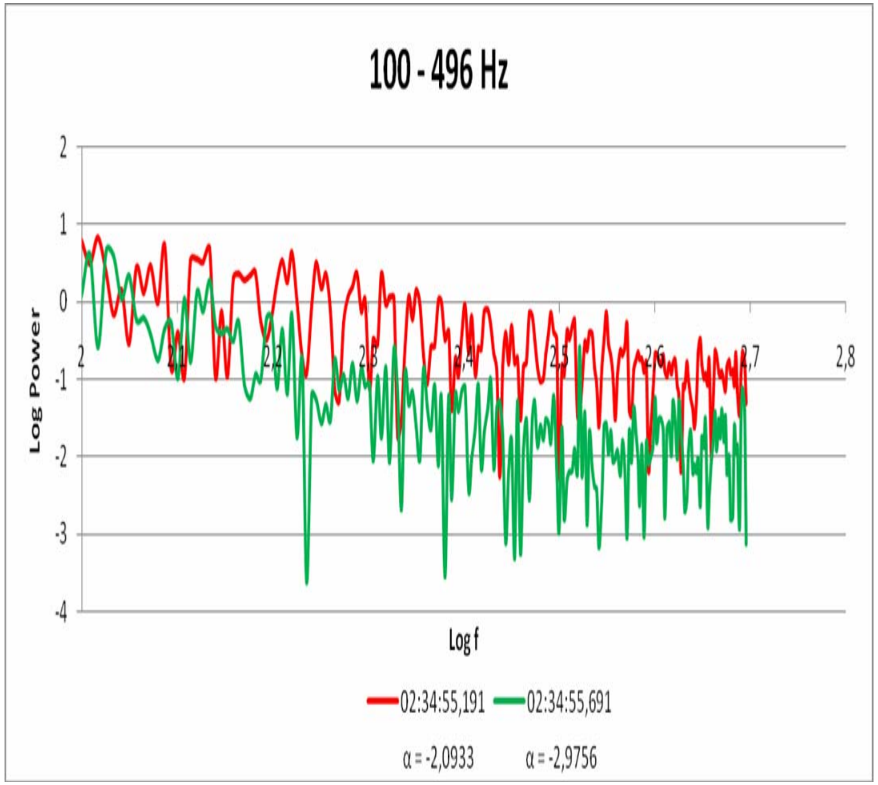



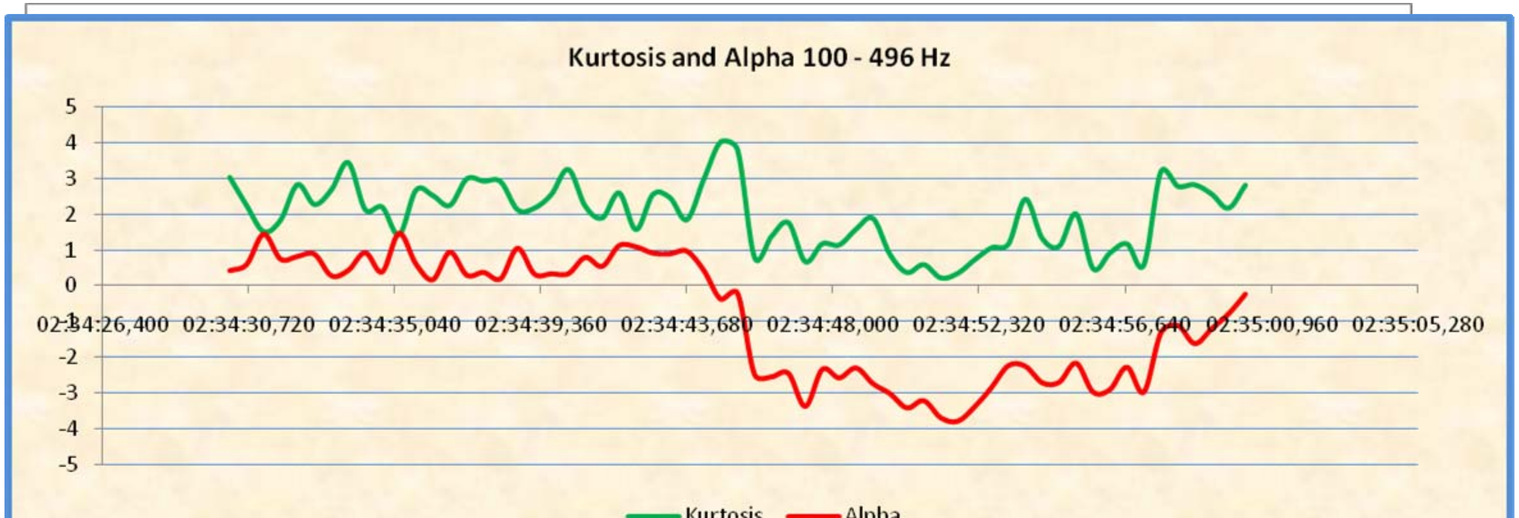



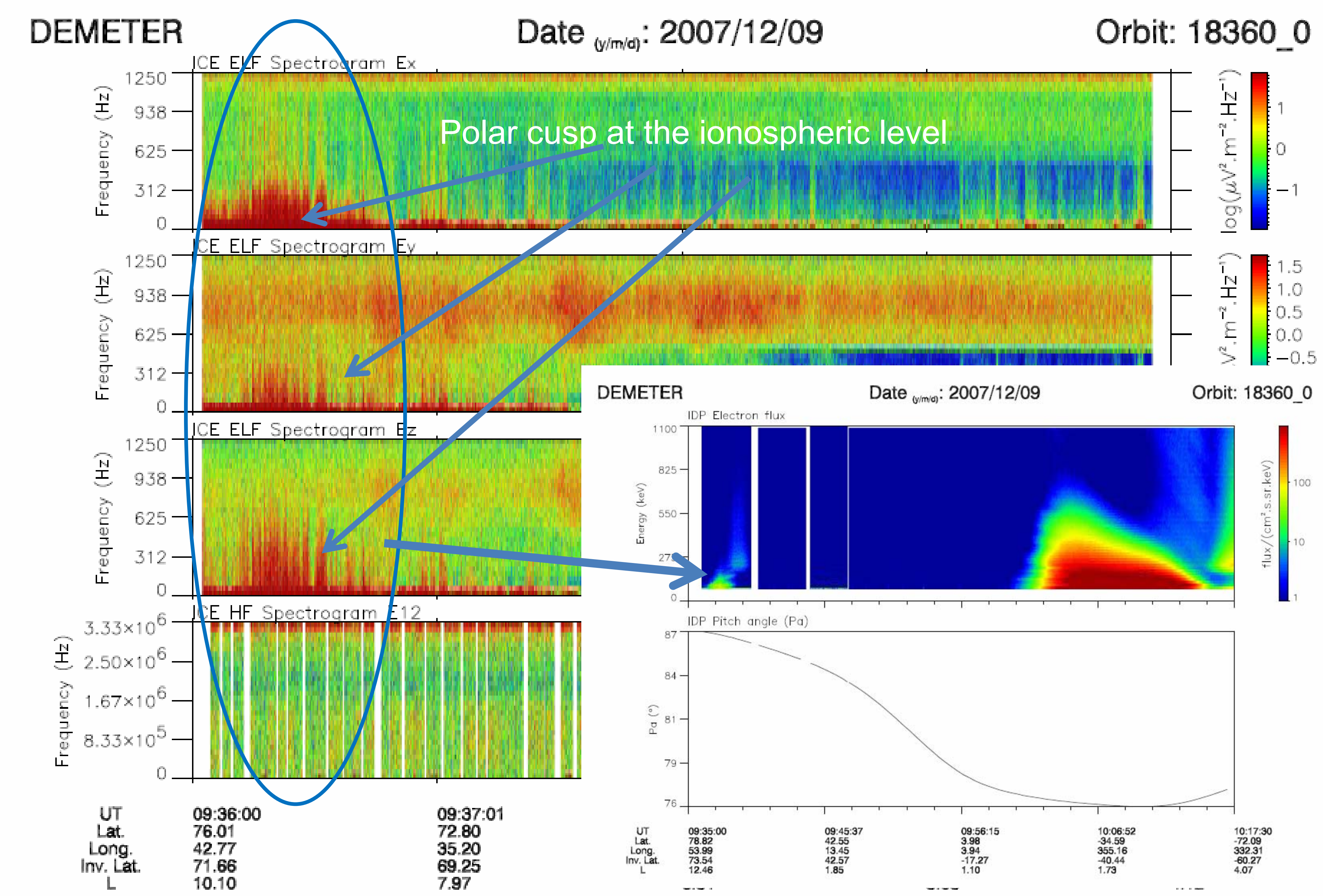



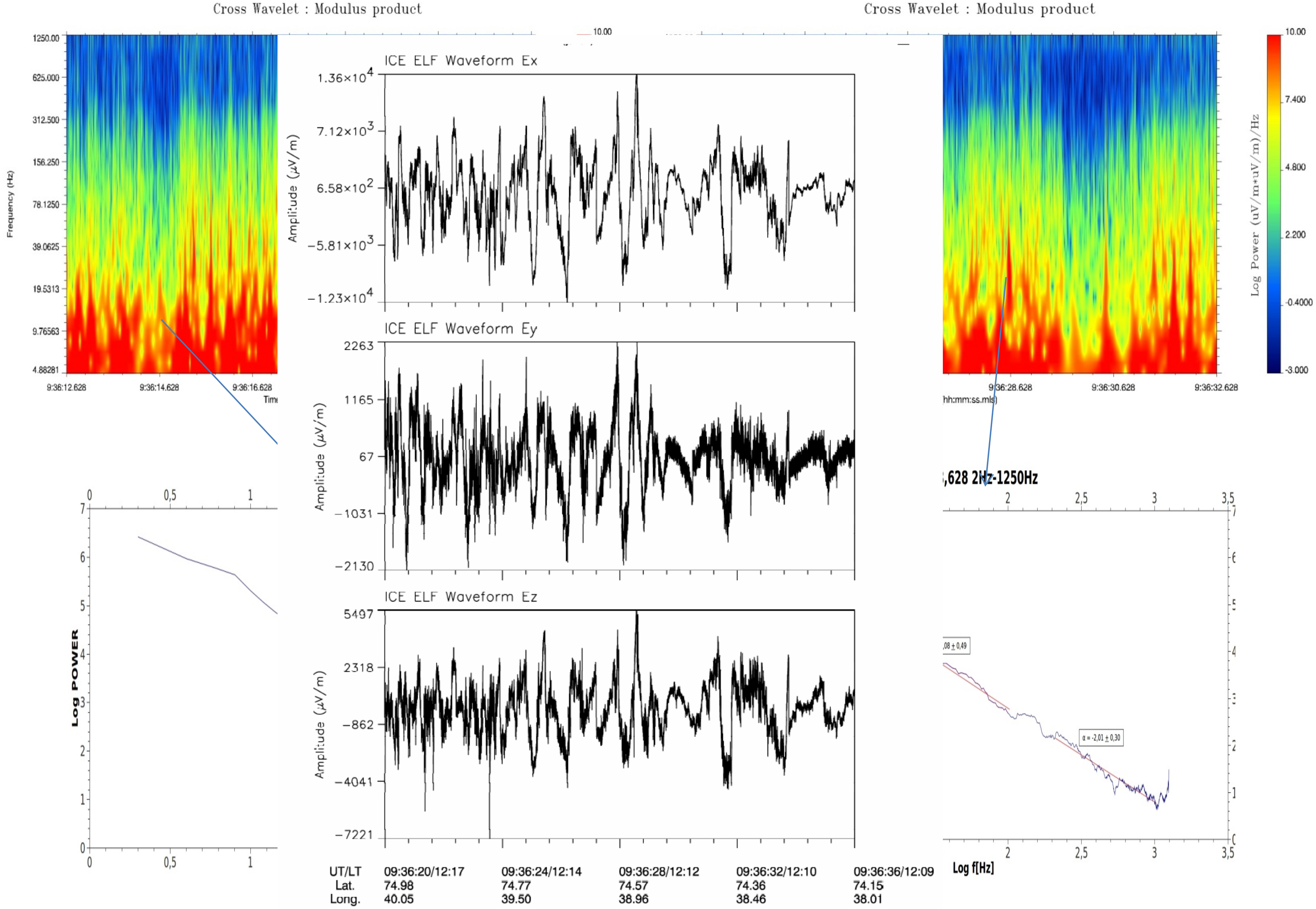

Wavelet Square Modulus
1250.00
625.000
312.500
156.250
78.1250
39.0625
19.5313
2:34:45.191
2:34:45.857
2:34:46.524
2:34:47.191
Log Power (uV/m)²/Hz
1.00
0.200
−0.600
−1.40
−2.20
−3.00
Wavelet Squared Bicoherence
Frequency Fk (Hz)
Frequency Fl (Hz)
0.0000
416.7
833.3
1250.


10-100Hz
Log Power
Log f
02:34:44,191
02:34:44,691
α = -1,5236
α = -2,0315


100 - 496 Hz
Log Power
Log f
02:34:55,191
02:34:55,691
α = -2,0933
α = -2,9756

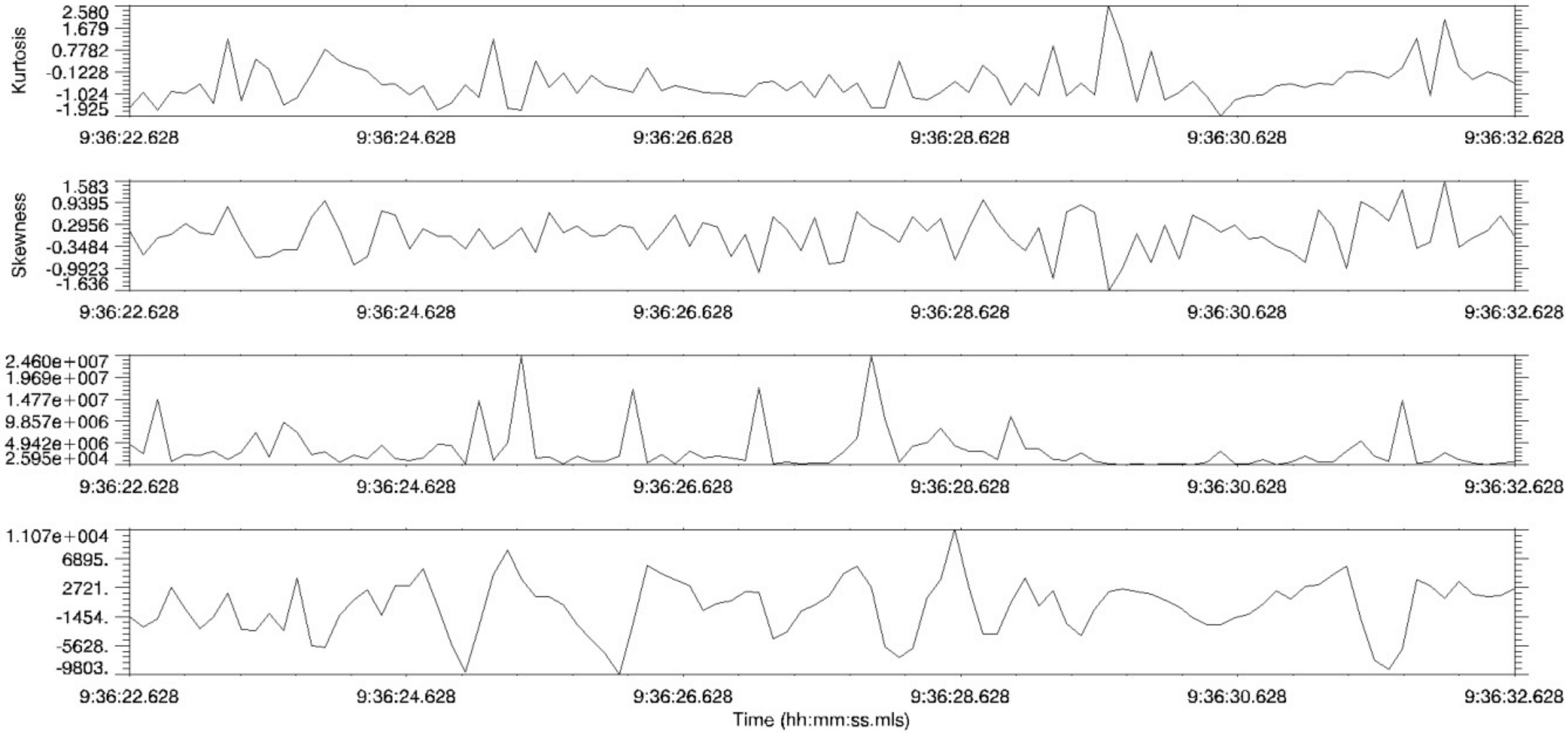

Kurtosis and Alpha 100 - 496 Hz
Kurtosis
Alpha

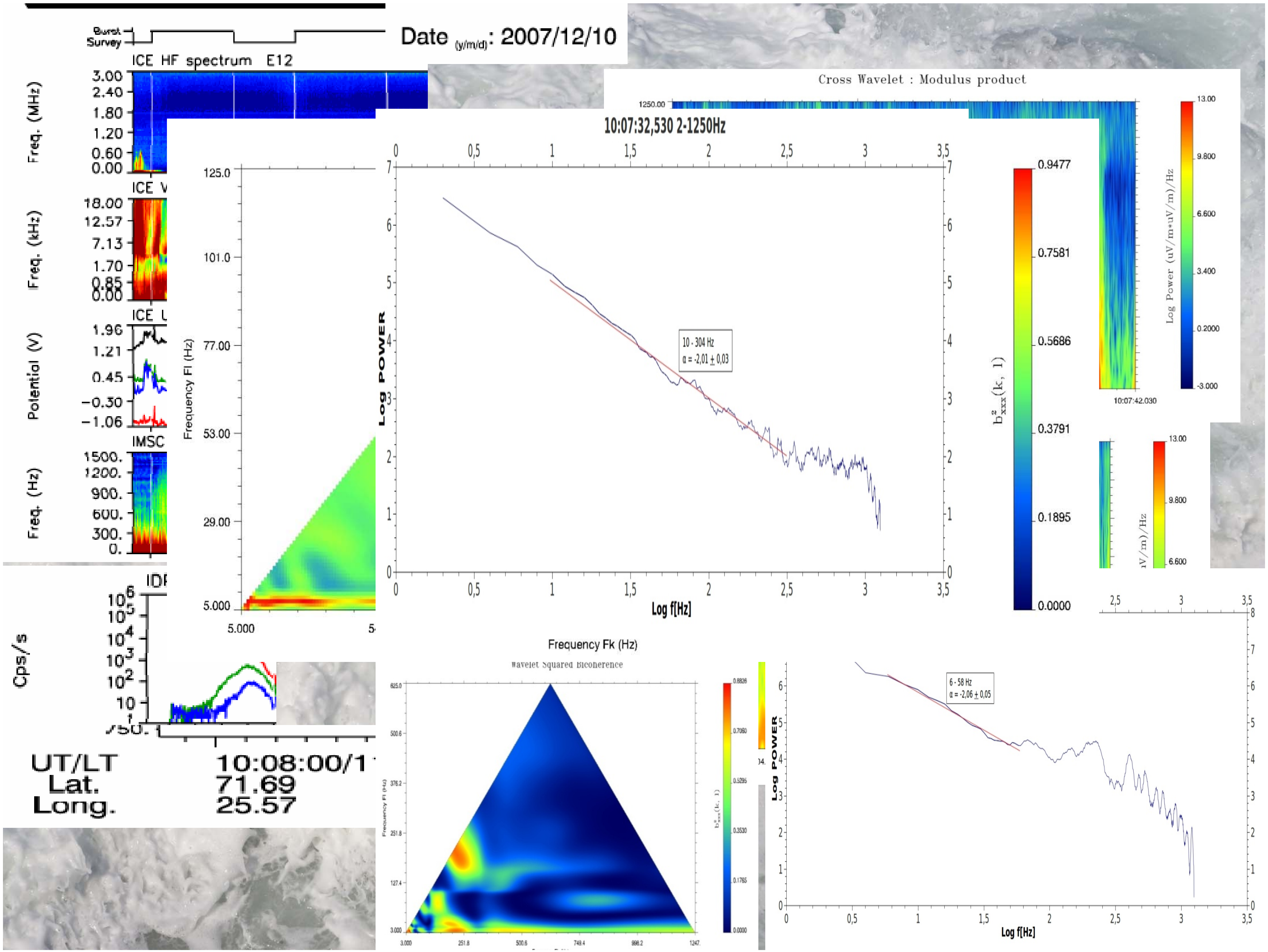

DEMETER
Date (y/m/d): 2007/12/09
Orbit: 18360_0
ICE ELF Spectrogram Ex
ICE ELF Spectrogram Ey
ICE ELF Spectrogram Ez
ICE HF Spectrogram E12
Frequency (Hz)
Polar cusp at the ionospheric level
UT 09:36:00 09:37:01
Lat. 76.01 72.80
Long. 42.77 35.20
Inv. Lat. 71.66 69.25
L 10.10 7.97
IDP Electron flux
Energy (keV)
flux/(cm².s.sr.keV)
IDP Pitch angle (Pa)
Pa (°)
UT 09:35:00 09:45:37 09:56:15 10:06:52 10:17:30
Lat. 78.82 42.55 3.98 -34.59 -72.09
Long. 53.99 13.45 3.94 355.16 332.31
Inv. Lat. 73.54 42.57 -17.27 -40.44 -60.27
L 12.46 1.85 1.10 1.73 4.07



Cross Wavelet : Modulus product
Cross Wavelet : Modulus product
Frequency (Hz)
1250.00
625.000
312.500
156.250
78.1250
39.0625
19.5313
9.76563
4.88281
9:36:12.628
9:36:14.628
9:36:16.628
9:36:28.628
9:36:30.628
9:36:32.628
hh:mm:ss.mls)
Log Power (uV/m*uV/m)/Hz
10.00
7.400
4.800
2.200
-0.4000
-3.000
ICE ELF Waveform Ex
ICE ELF Waveform Ey
ICE ELF Waveform Ez
Amplitude (µV/m)
$1.36\times10^4$
$7.12\times10^3$
$6.58\times10^2$
$-5.81\times10^3$
$-1.23\times10^4$
2263
1165
67
-1031
-2130
5497
2318
-862
-4041
-7221
UT/LT
Lat.
Long.
09:36:20/12:17
74.98
40.05
09:36:24/12:14
74.77
39.50
09:36:28/12:12
74.57
38.96
09:36:32/12:10
74.36
38.46
09:36:36/12:09
74.15
38.01
Log POWER
,628 2Hz-1250Hz
α = -2,01 ± 0,30
Log f[Hz]

Moment evolution





Date (y/m/d): 2007/12/10
Burst
Survey
ICE HF spectrum E12
Freq. (MHz)
Freq. (kHz)
Potential (V)
Freq. (Hz)
IMSC
Cps/s
UT/LT
Lat.
Long.
10:08:00/1
71.69
25.57
Cross Wavelet : Modulus product
Log Power (uV/m*uV/m)/Hz
10:07:42.030
10:07:32,530 2-1250Hz
Log POWER
Log f[Hz]
10 - 304 Hz
α = -2,01 ± 0,03
Frequency Fl (Hz)
Frequency Fk (Hz)
Wavelet Squared Bicoherence
6 - 58 Hz
α = -2,06 ± 0,05

# Conclusions

- We presented the electromagnetic effects observed by DEMETER satellite prior to the earthquakes in L'Aquila and Chile. These results are compared with obsevations  the polar cusp.
- The analysis of the wave form in ELF frequency range with Fourier, wavelet and bispectral methods has shown the presence of the strong emissions in this frequency range in the ionosphere before the earthquake.
- The discussed results  over seismic regions have been obtained during very quiet time and therefore no ionospheric and magnetospheric sources of perturbations were expected.
- The statistical analysis of the wave data shows (Polar cusp, L'Aquila and Chile) the intermittent  and non Gaussian character of the registered data what is the feature of the turbulence.
- The turbulence K41 type is dominating in the ionosphere over seismic regions, while in the polar cusp at ionospheric altitudes whistler and mhd turbulence is registered.


THANK YOU FOR YOUR ATTENTION
DEMETER WORKSHOP, PARIS,
OCTOBER 10 2011