Emissioni electromagnetiche ELF registrate dal satellite DEMETER in Abruzzo prima del terremoto dell'Aquila del 6 Aprile 2009

ELF EMISSIONS REGISTERD BY DEMETER OVER THE ABRUZZI REGION PRIOR TO THE 6 APRIL 2009 L'AQUILA EARTHQUAKE

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OUTLINE

- 1. DEMETER
- 2. WHAT IS A TURBULENCE
- 3. METHODOLOGY
- 4.RESULTS
- 5 CONCLUSIONS

Demeter

- DEMETER is a low-altitude microsatellite (710 km) launched in June 2004 onto a polar and circular orbit which measures electromagnetic waves all around the Earth except in the auroral zones (Parrot, 2006). In December 2005, the altitude of the satellite was decreased to 660 km. The ELF/VLF range for the electric field is from DC up to 20 kHz. There are two scientific modes: a survey mode where spectra of one electric and one magnetic component are onboard computed up to 20 kHz and a burst mode where, in addition to the onboard computed spectra, waveforms of one electric and one magnetic field component are recorded up to 20 kHz. The burst mode allows performing a spectral analysis with higher time and frequency resolution. Details of the wave experiment can be found in Parrot et al. (2006) and Berthelier et al. (2006). During the burst mode, the waveforms of the six components of the electromagnetic field are also recorded up to 1.25 kHz. This allows performing a detailed wave analysis.

Measured Parameters

Frequency band, E	DC – 4MHz
• Frequency band , B	10 Hz - 18 kHz
• Sensitivity B :	2 10-5 nT Hz-1/2 at 1 kHz
• Sensitivity E :	0.2 µV Hz-1/2 at 500 kHz
• Ion density:	$5\ 10^{2}$ - $5\ 10^{6}$ /cm3
• Ion temperature:	1000 K - 5000 K
• Electron density:	10^{2} - $5\ 10^{6}$ cm-3
• Electron temperature:	500 K - 3000 K
• Energetic electrons	30 keV - 10 MeV
• Ion composition	H^+, He^+, O^+, NO^+

What is turbulence

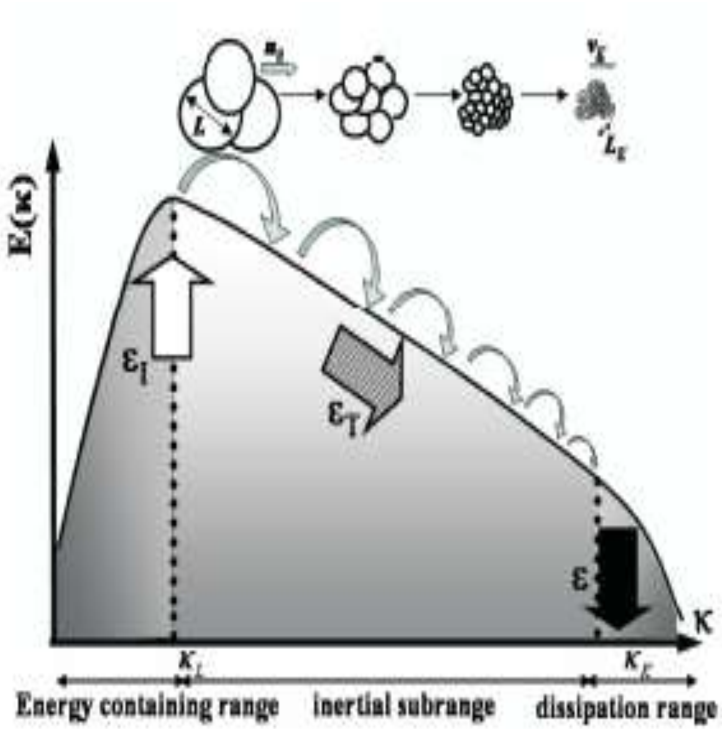


Fig. 1.7 Sketch of the energy cascade. In physical space, the large eddies are broken into smaller and smaller eddies. The energy is injected into the flow by the driving mechanisms at the rate ε_I, transferred to smaller scales at the rate ε_T and dissipated into heat at the rate ε. The local equilibrium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

This question has no clear answer. 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

Wavelet Analysis

- *Criteria for wavelet function and form of Morlet wavelet*

$$\int_{-\infty}^{+\infty} \psi(t) = 0$$

$$\int_{-\infty}^{+\infty} /\psi/^2 \, dt < \infty$$

$$\psi(t) = \exp(i\omega_0 t - t^2/2) - \sqrt{2}\exp(i\omega_0 t - t^2 - \omega_0^2/4)$$

$$\int_{-\infty}^{+\infty} x(t)\psi^*\left(\frac{t-\tau}{a}\right)dt = CWT(\tau, a)$$

Any localized function

$$\psi(t)$$

can be chosen as mother wavelet, if it satisfies the given on the left criteria

The complex Morlet wavelet is representing by this function

Continuous Wavelet Transform (a is scaling parameter)

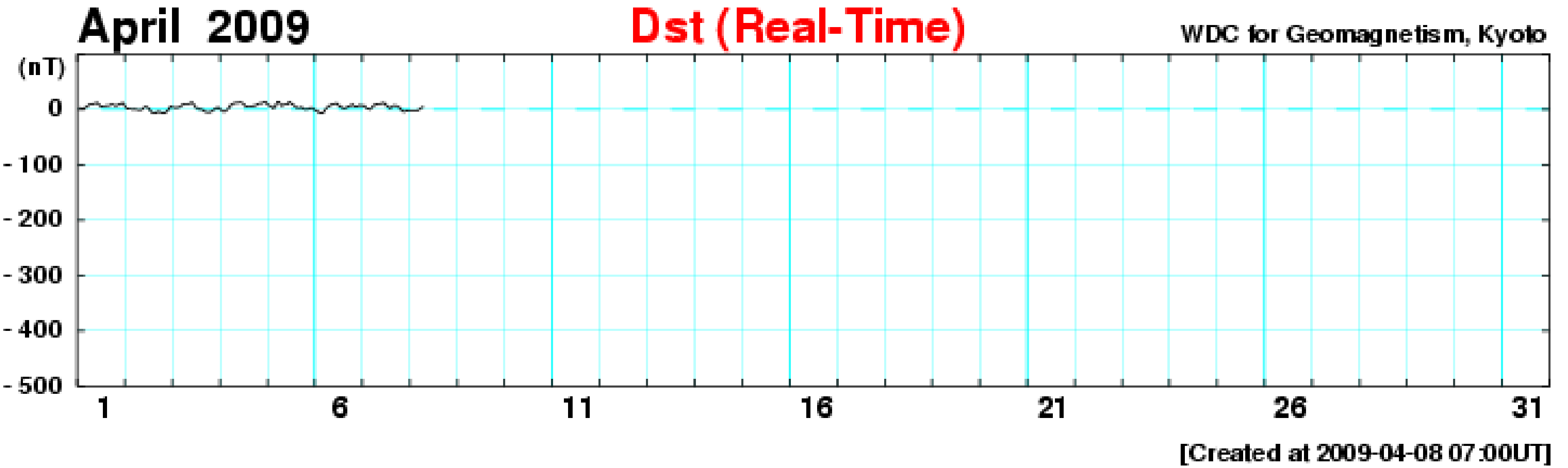
Bispectral analysis

- This method allows us to find the wave modes nonlinearly interacting by 3 waves processes.
- The resonance conditions for these processes are:
- $\omega_1+\omega_2 = \omega_3$
- $\mathbf{k}_1+\mathbf{k}_2 = \mathbf{k}_3$
- Verification of these conditions is possible by computing the bispectrum for 3 wave modes *k,l* and *k+l* which is defined as below:
  - $B(k,l)= E[X_k \; X_l \; X_{k+l}{}^*]$
- where X are the spectral components of signals *k,l* and *k+l* respectively. Averaging is over the time.
- A quantitive measure of the phase coherency may be made by computing of the bicoherence spectrum which is defined in terms of the bispectrum as

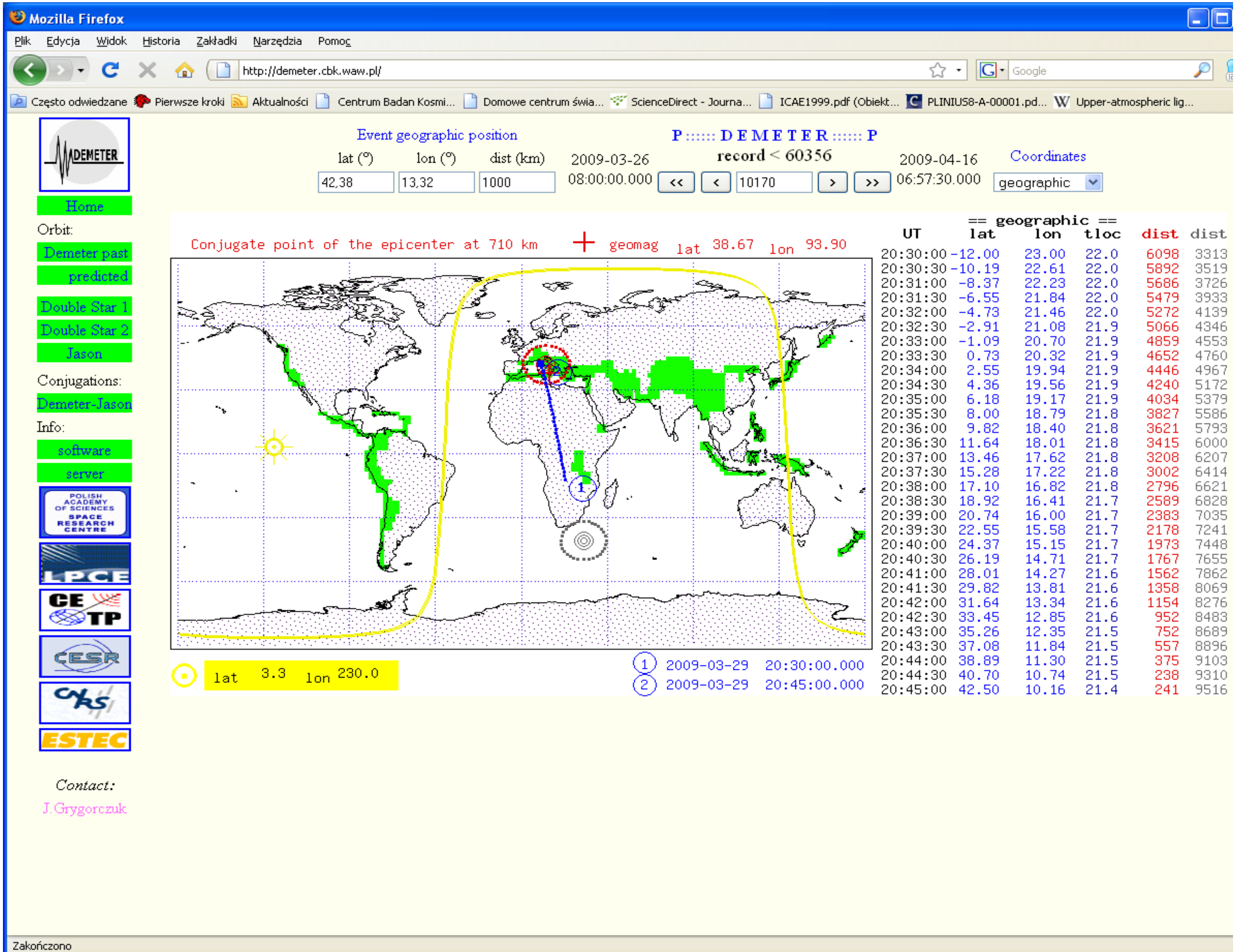
$$b^2(k,l) = \lim \frac{1}{T} \frac{/B(k,l)/^2}{P(k)P(l)P(k+l)}$$

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

Geomagnetic conditions prior to the L’Aquila earthquake

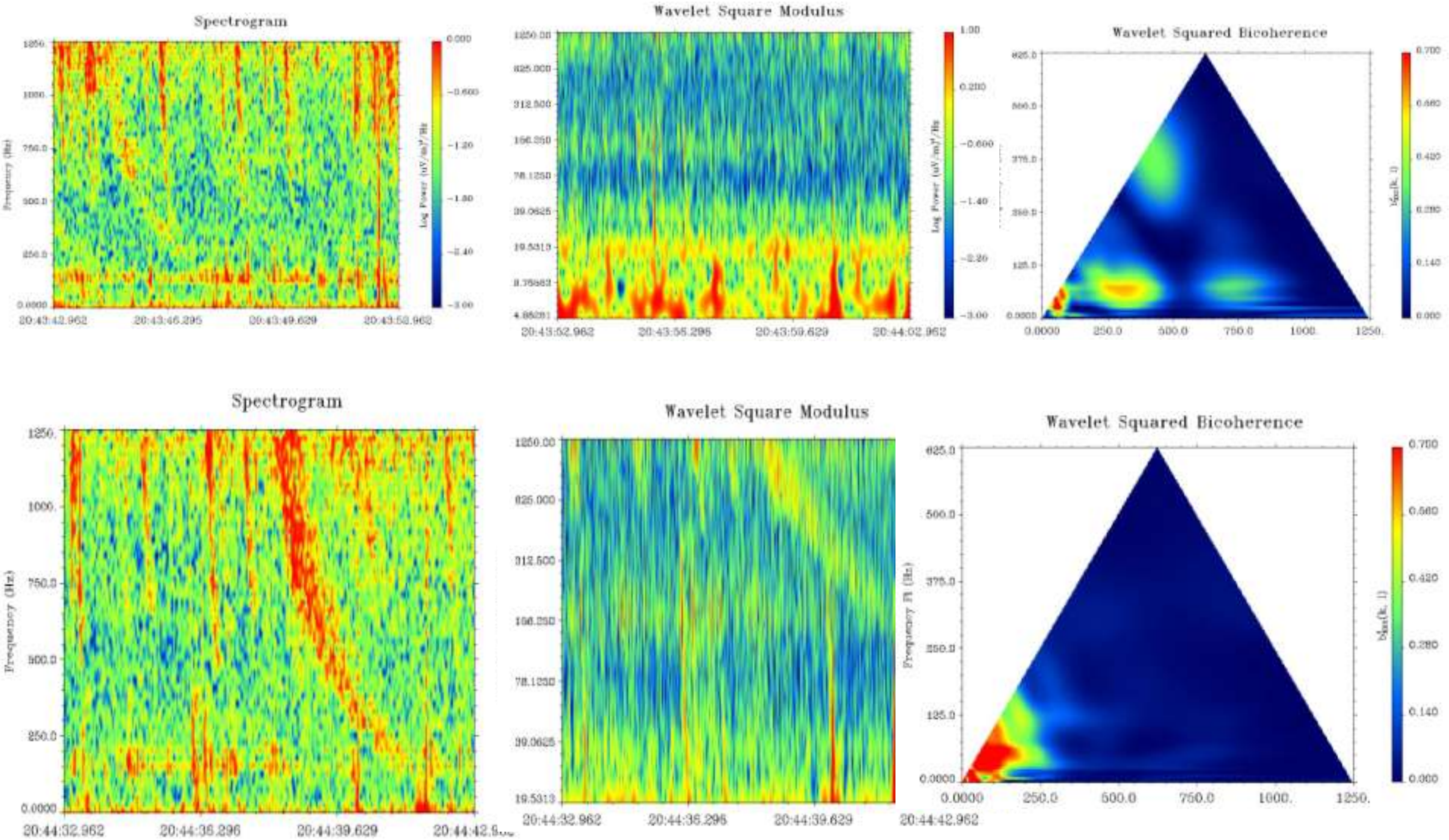


Demeter’s orbit on March 29-8 days to the earthquake

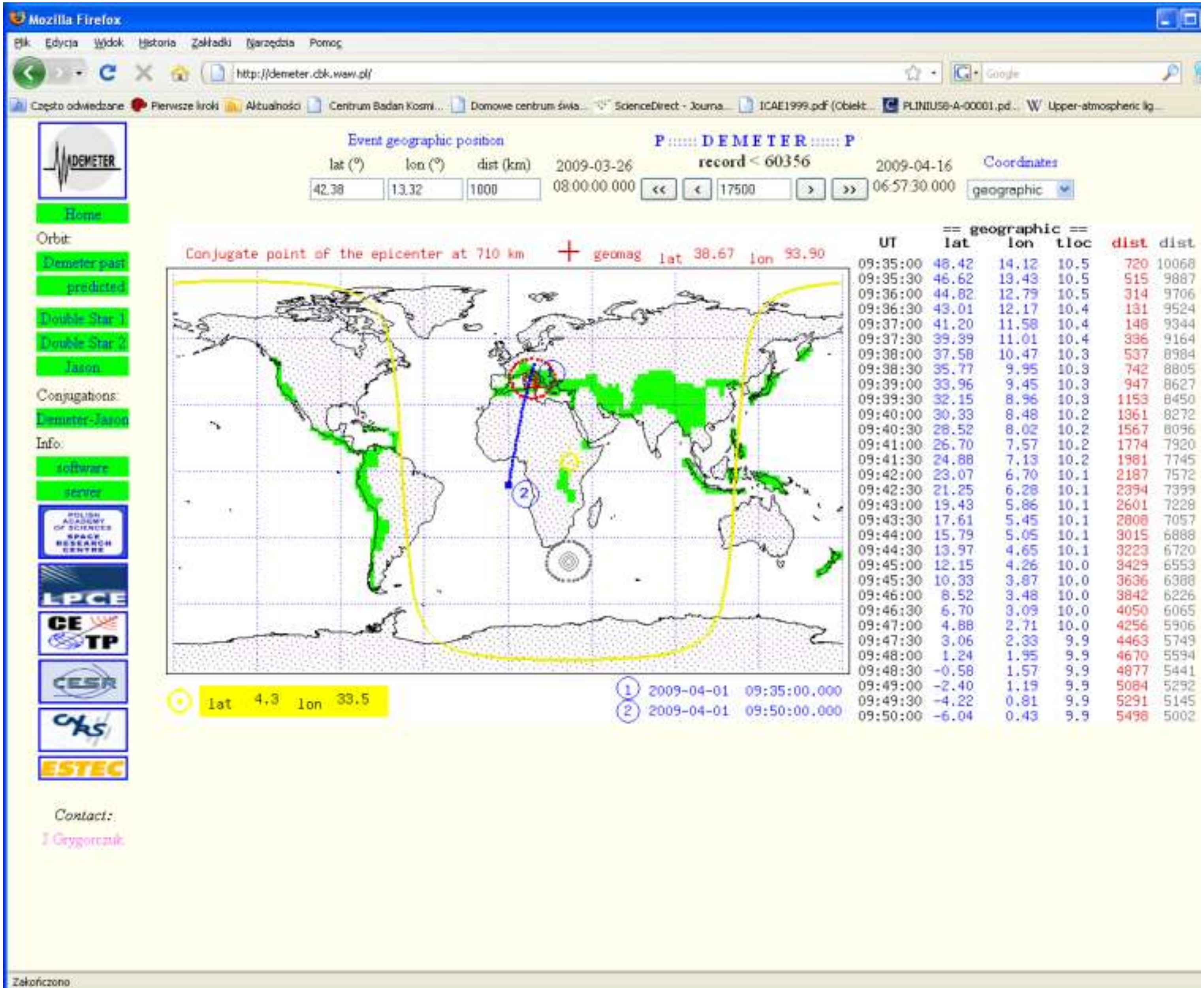


UT	lat	lon	tloc	dist	dist
20:30:00	-12.00	23.00	22.0	6098	3313
20:30:30	-10.19	22.61	22.0	5892	3519
20:31:00	-8.37	22.23	22.0	5686	3726
20:31:30	-6.55	21.84	22.0	5479	3933
20:32:00	-4.73	21.46	22.0	5272	4139
20:32:30	-2.91	21.08	21.9	5066	4346
20:33:00	-1.09	20.70	21.9	4859	4553
20:33:30	0.73	20.32	21.9	4652	4760
20:34:00	2.55	19.94	21.9	4446	4967
20:34:30	4.36	19.56	21.9	4240	5172
20:35:00	6.18	19.17	21.9	4034	5379
20:35:30	8.00	18.79	21.8	3827	5586
20:36:00	9.82	18.40	21.8	3621	5793
20:36:30	11.64	18.01	21.8	3415	6000
20:37:00	13.46	17.62	21.8	3208	6207
20:37:30	15.28	17.22	21.8	3002	6414
20:38:00	17.10	16.82	21.8	2796	6621
20:38:30	18.92	16.41	21.7	2589	6828
20:39:00	20.74	16.00	21.7	2383	7035
20:39:30	22.55	15.58	21.7	2178	7241
20:40:00	24.37	15.15	21.7	1973	7448
20:40:30	26.19	14.71	21.7	1767	7655
20:41:00	28.01	14.27	21.6	1562	7862
20:41:30	29.82	13.81	21.6	1358	8069
20:42:00	31.64	13.34	21.6	1154	8276
20:42:30	33.45	12.85	21.6	952	8483
20:43:00	35.26	12.35	21.5	752	8689
20:43:30	37.08	11.84	21.5	557	8896
20:44:00	38.89	11.30	21.5	375	9103
20:44:30	40.70	10.74	21.5	238	9310
20:45:00	42.50	10.16	21.4	241	9516

March 29-8 days to the earthquake Kp index 20090329 1 1-1 1-1-1+1-1 Σ 7

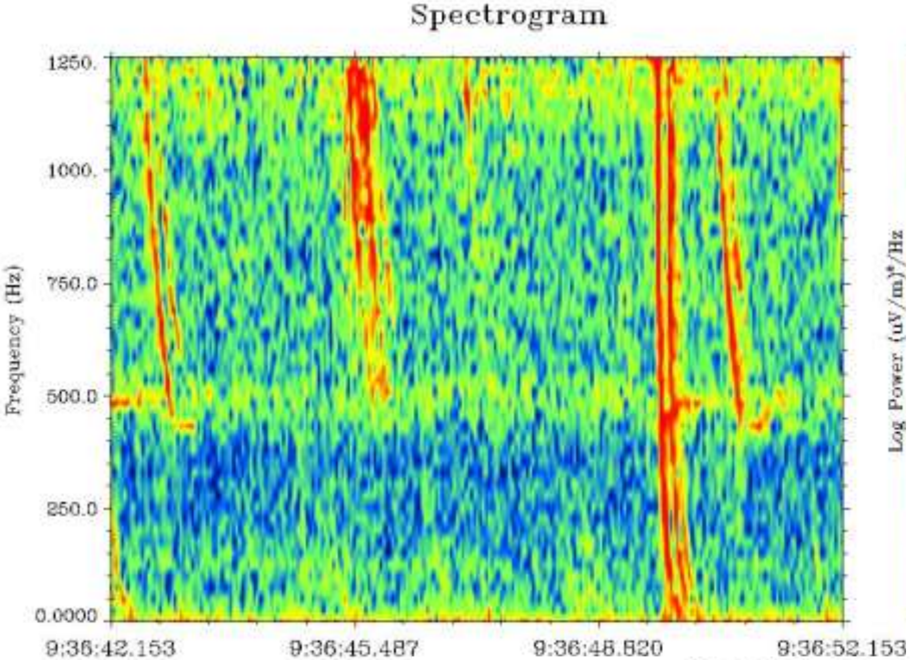


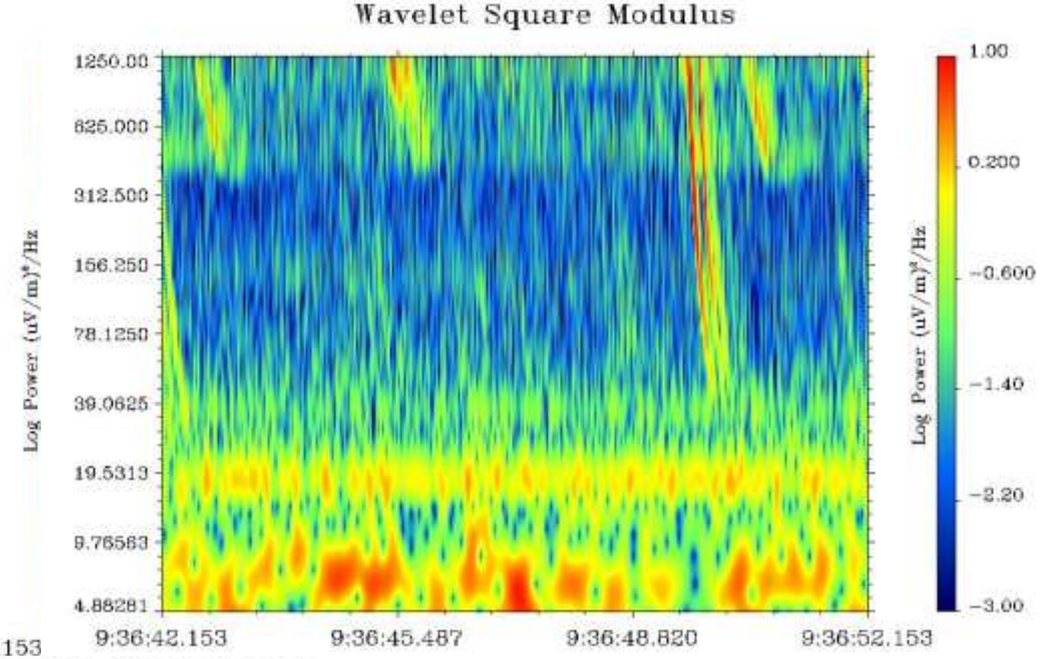
Demeter's orbit on April 1 -5 days to the earthquake

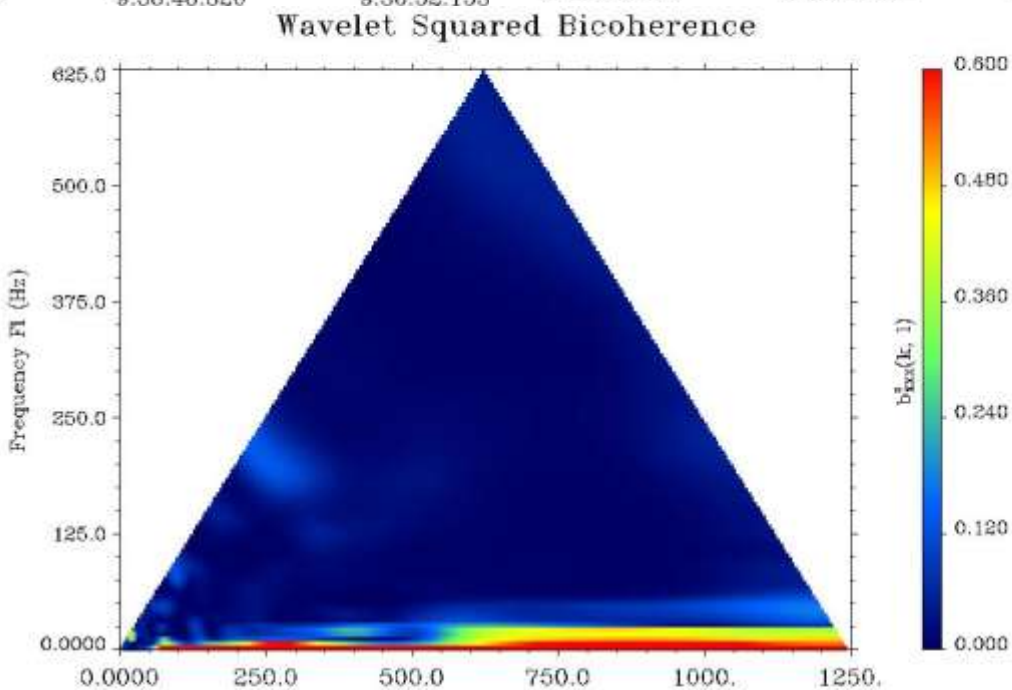


UT	lat	lon	tloc	dist	dist
	== geographic ==				
09:35:00	48.42	14.12	10.5	720	10068
09:35:30	46.62	13.43	10.5	515	9887
09:36:00	44.82	12.79	10.5	314	9706
09:36:30	43.01	12.17	10.4	131	9524
09:37:00	41.20	11.58	10.4	148	9344
09:37:30	39.39	11.01	10.4	336	9164
09:38:00	37.58	10.47	10.3	537	8984
09:38:30	35.77	9.95	10.3	742	8805
09:39:00	33.96	9.45	10.3	947	8627
09:39:30	32.15	8.96	10.3	1153	8450
09:40:00	30.33	8.48	10.2	1361	8272
09:40:30	28.52	8.02	10.2	1567	8096
09:41:00	26.70	7.57	10.2	1774	7920
09:41:30	24.88	7.13	10.2	1981	7745
09:42:00	23.07	6.70	10.1	2187	7572
09:42:30	21.25	6.28	10.1	2394	7399
09:43:00	19.43	5.86	10.1	2601	7228
09:43:30	17.61	5.45	10.1	2808	7057
09:44:00	15.79	5.05	10.1	3015	6888
09:44:30	13.97	4.65	10.1	3223	6720
09:45:00	12.15	4.26	10.0	3429	6553
09:45:30	10.33	3.87	10.0	3636	6388
09:46:00	8.52	3.48	10.0	3842	6226
09:46:30	6.70	3.09	10.0	4050	6065
09:47:00	4.88	2.71	10.0	4256	5906
09:47:30	3.06	2.33	9.9	4463	5749
09:48:00	1.24	1.95	9.9	4670	5594
09:48:30	-0.58	1.57	9.9	4877	5441
09:49:00	-2.40	1.19	9.9	5084	5292
09:49:30	-4.22	0.81	9.9	5291	5145
09:50:00	-6.04	0.43	9.9	5498	5002

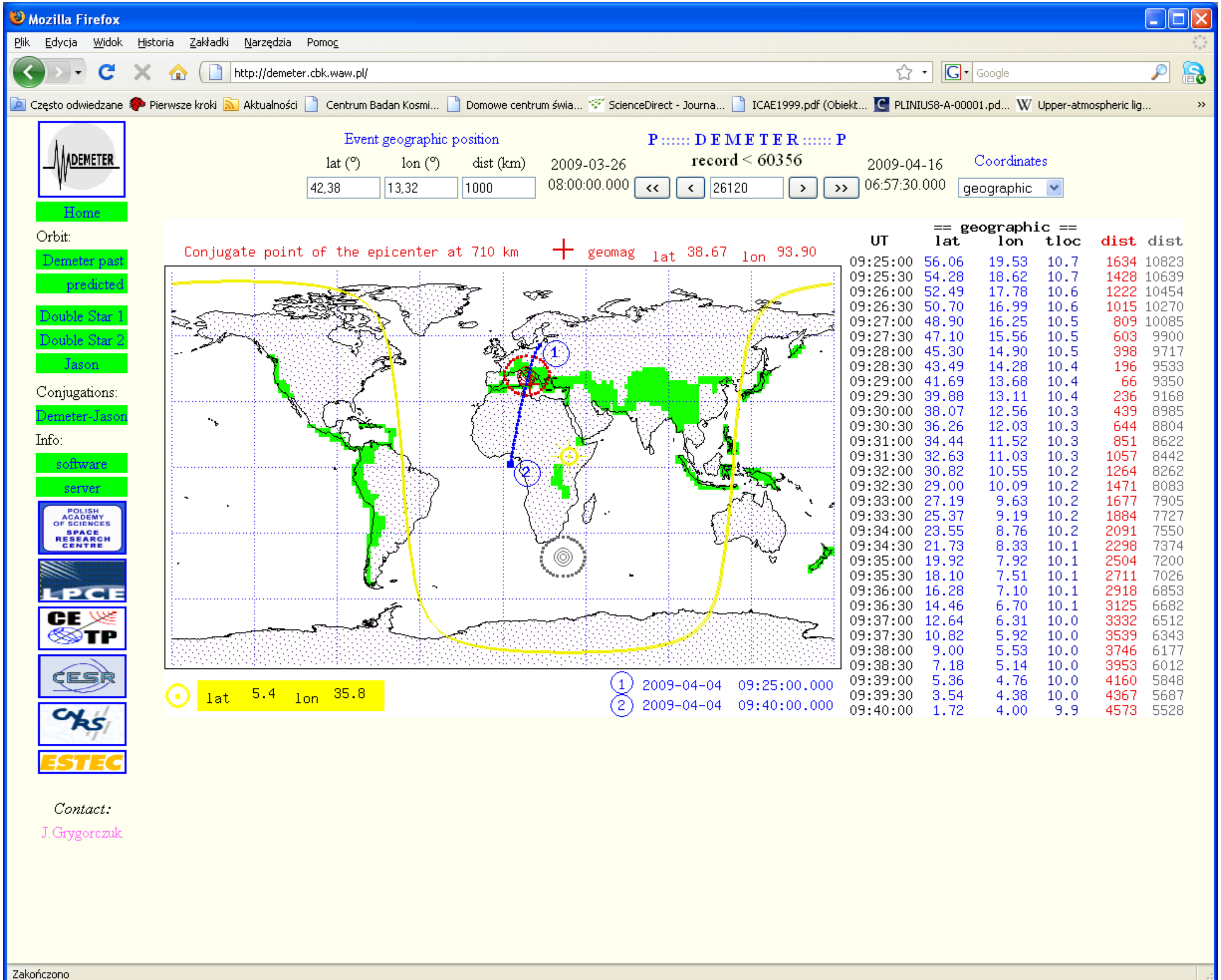
5 days to the earthquake 2009 04 01 Kp1 0 0+1 1-1-1+2 Σ 7





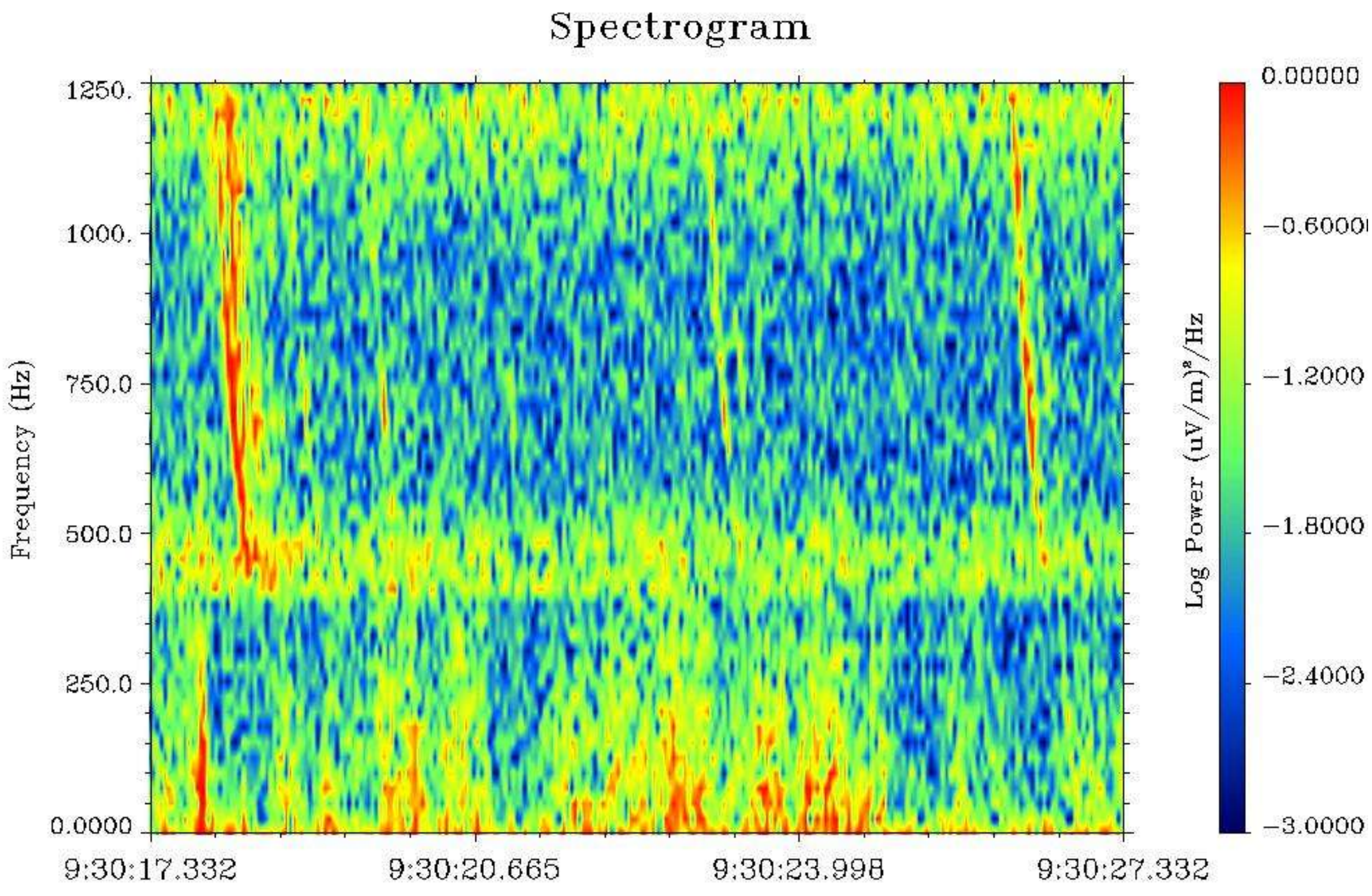


2 days to the earthquake 2009 04 04 morning

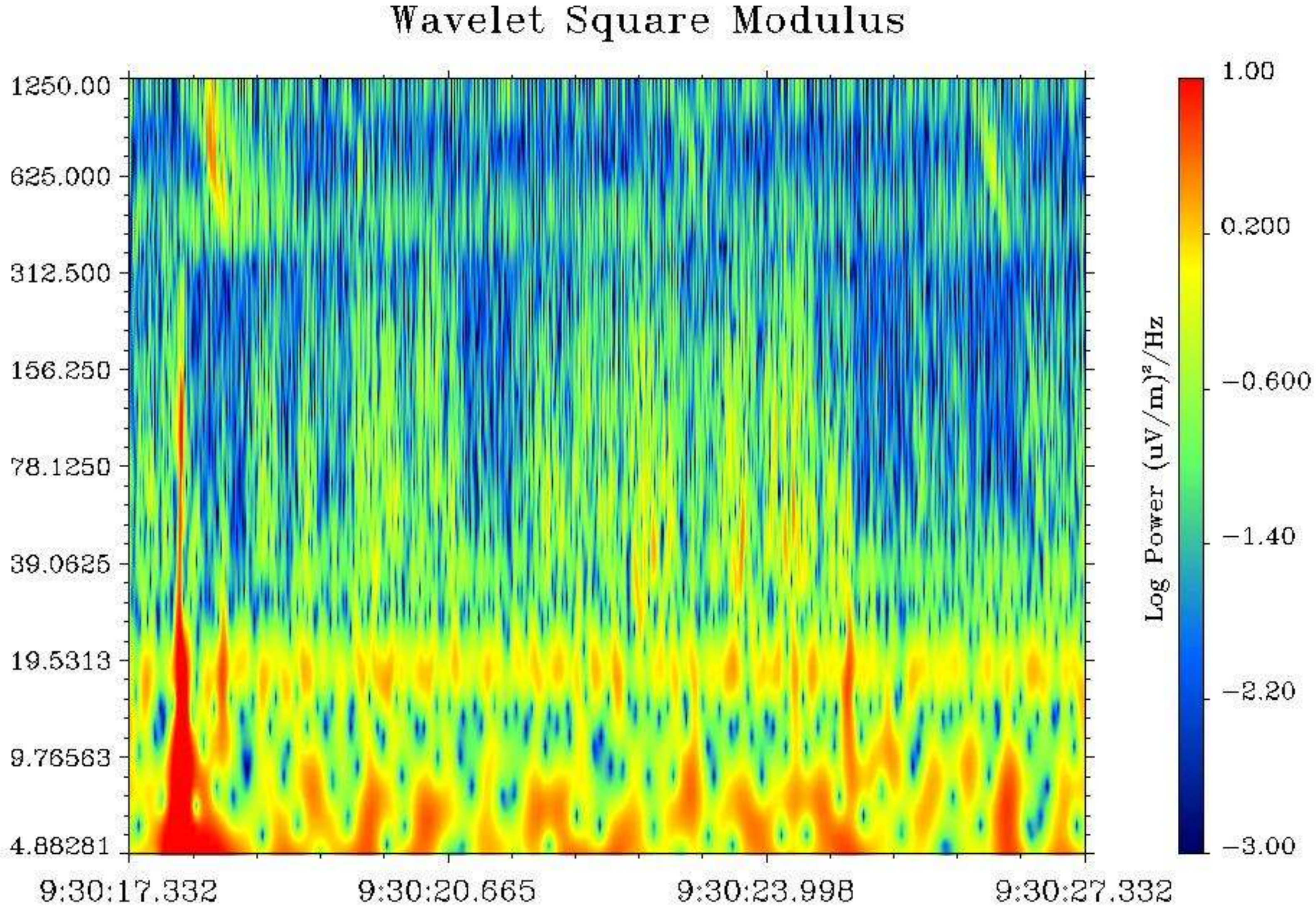


UT	== geographic == lat	lon	tloc	dist	dist
09:25:00	56.06	19.53	10.7	1634	10823
09:25:30	54.28	18.62	10.7	1428	10639
09:26:00	52.49	17.78	10.6	1222	10454
09:26:30	50.70	16.99	10.6	1015	10270
09:27:00	48.90	16.25	10.5	809	10085
09:27:30	47.10	15.56	10.5	603	9900
09:28:00	45.30	14.90	10.5	398	9717
09:28:30	43.49	14.28	10.4	196	9533
09:29:00	41.69	13.68	10.4	66	9350
09:29:30	39.88	13.11	10.4	236	9168
09:30:00	38.07	12.56	10.3	439	8985
09:30:30	36.26	12.03	10.3	644	8804
09:31:00	34.44	11.52	10.3	851	8622
09:31:30	32.63	11.03	10.3	1057	8442
09:32:00	30.82	10.55	10.2	1264	8262
09:32:30	29.00	10.09	10.2	1471	8083
09:33:00	27.19	9.63	10.2	1677	7905
09:33:30	25.37	9.19	10.2	1884	7727
09:34:00	23.55	8.76	10.2	2091	7550
09:34:30	21.73	8.33	10.1	2298	7374
09:35:00	19.92	7.92	10.1	2504	7200
09:35:30	18.10	7.51	10.1	2711	7026
09:36:00	16.28	7.10	10.1	2918	6853
09:36:30	14.46	6.70	10.1	3125	6682
09:37:00	12.64	6.31	10.0	3332	6512
09:37:30	10.82	5.92	10.0	3539	6343
09:38:00	9.00	5.53	10.0	3746	6177
09:38:30	7.18	5.14	10.0	3953	6012
09:39:00	5.36	4.76	10.0	4160	5848
09:39:30	3.54	4.38	10.0	4367	5687
09:40:00	1.72	4.00	9.9	4573	5528

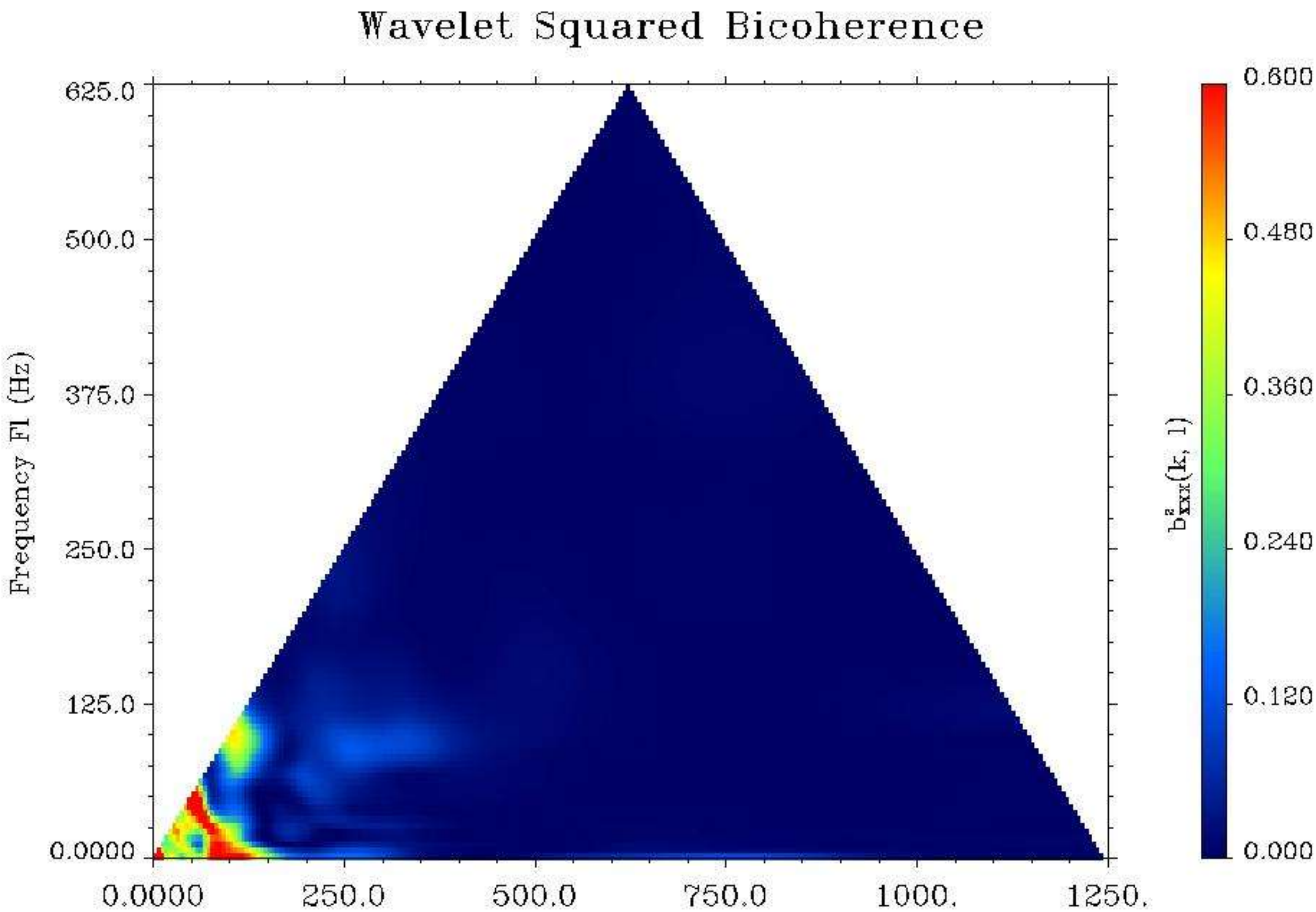
2 days to the earthquake 2009 04 04 Kp 0 0 0 0+0+0+0+0+ Σ 2- morning



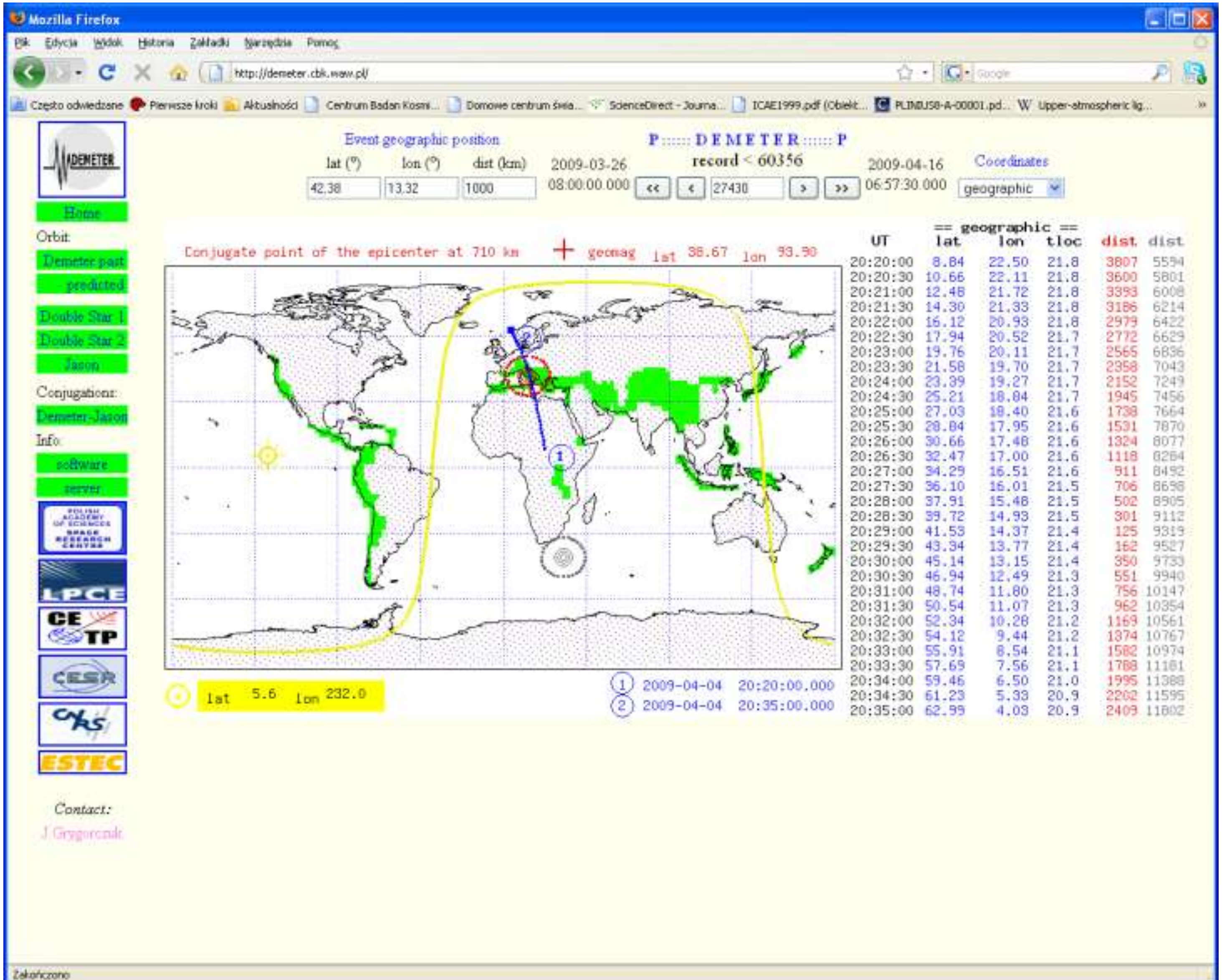
2 days to the earthquake 2009 04 04 Kp 0 0 0 0+0+0+0+0+ Σ 2- morning



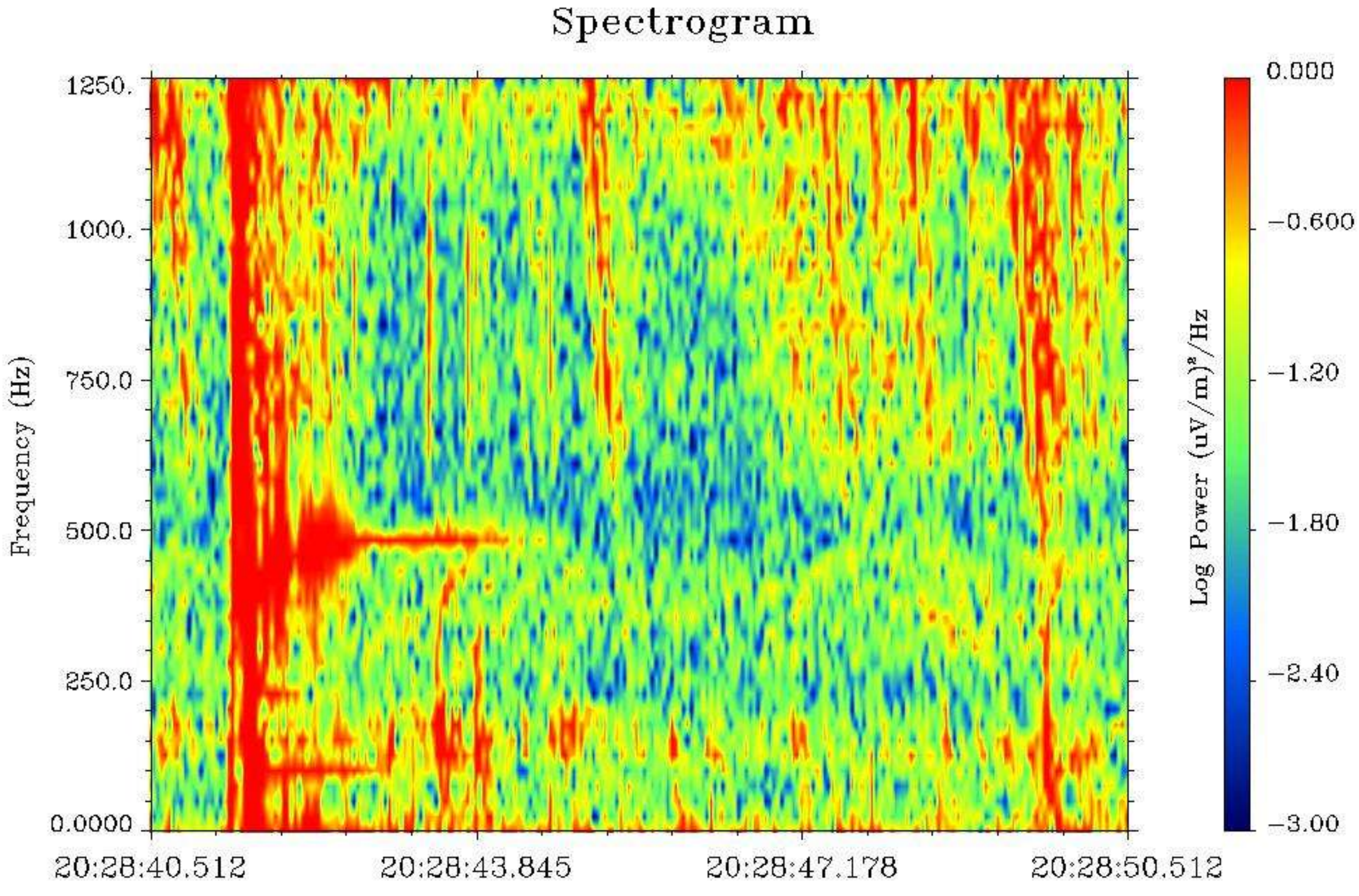
2 days to the earthquake 2009 04 04 Kp 0 0 0 0+0+0+0+0+ Σ 2- morning



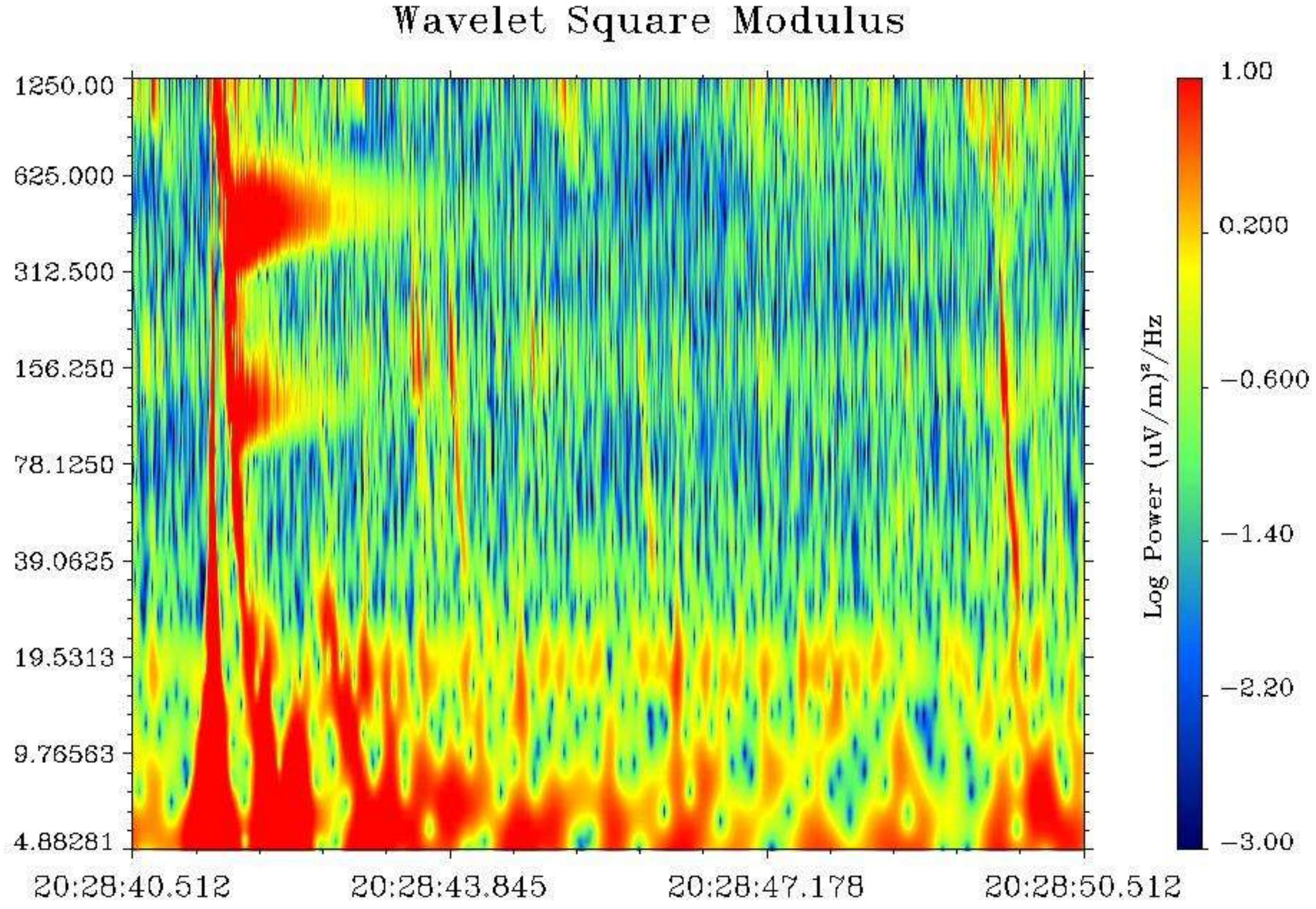
2 days to the earthquake 2009 04 04



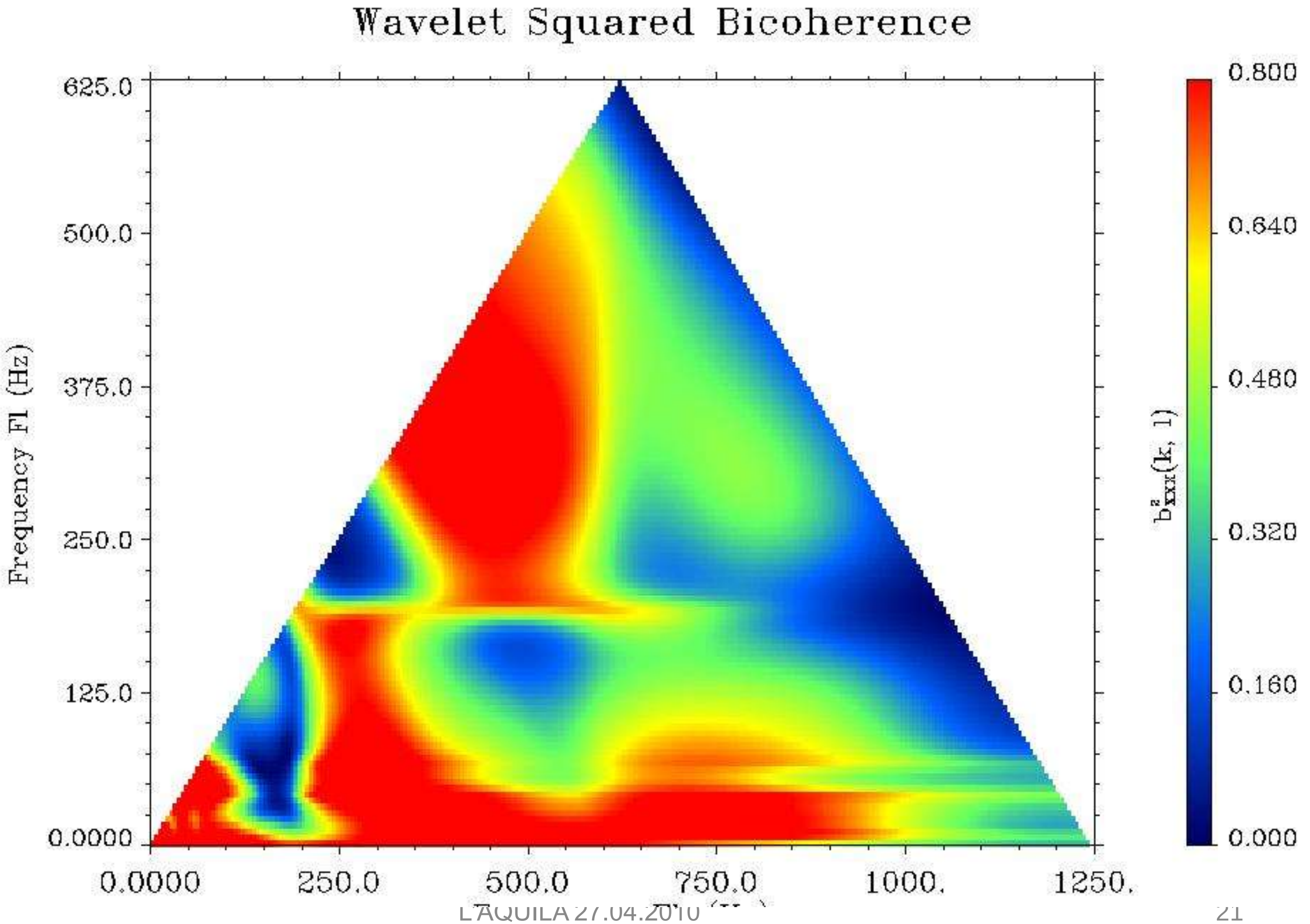
2 days to the earthquake 2009 04 04 Kp 0 0 0 0+0+0+0+0+ Σ 2- night



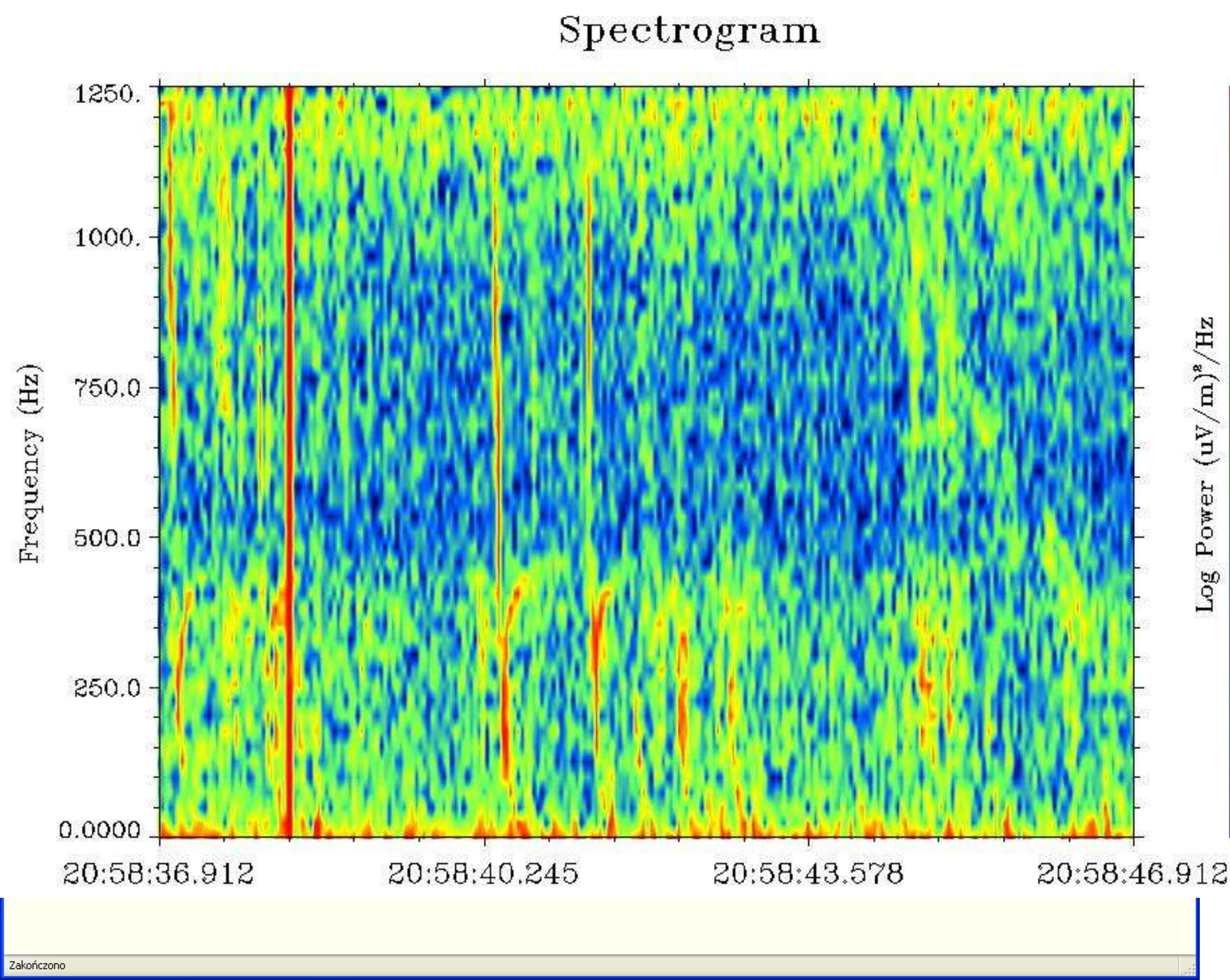
2 days to the earthquake 2009 04 04 Kp 0 0 0 0+0+0+0+0+ Σ 2- night

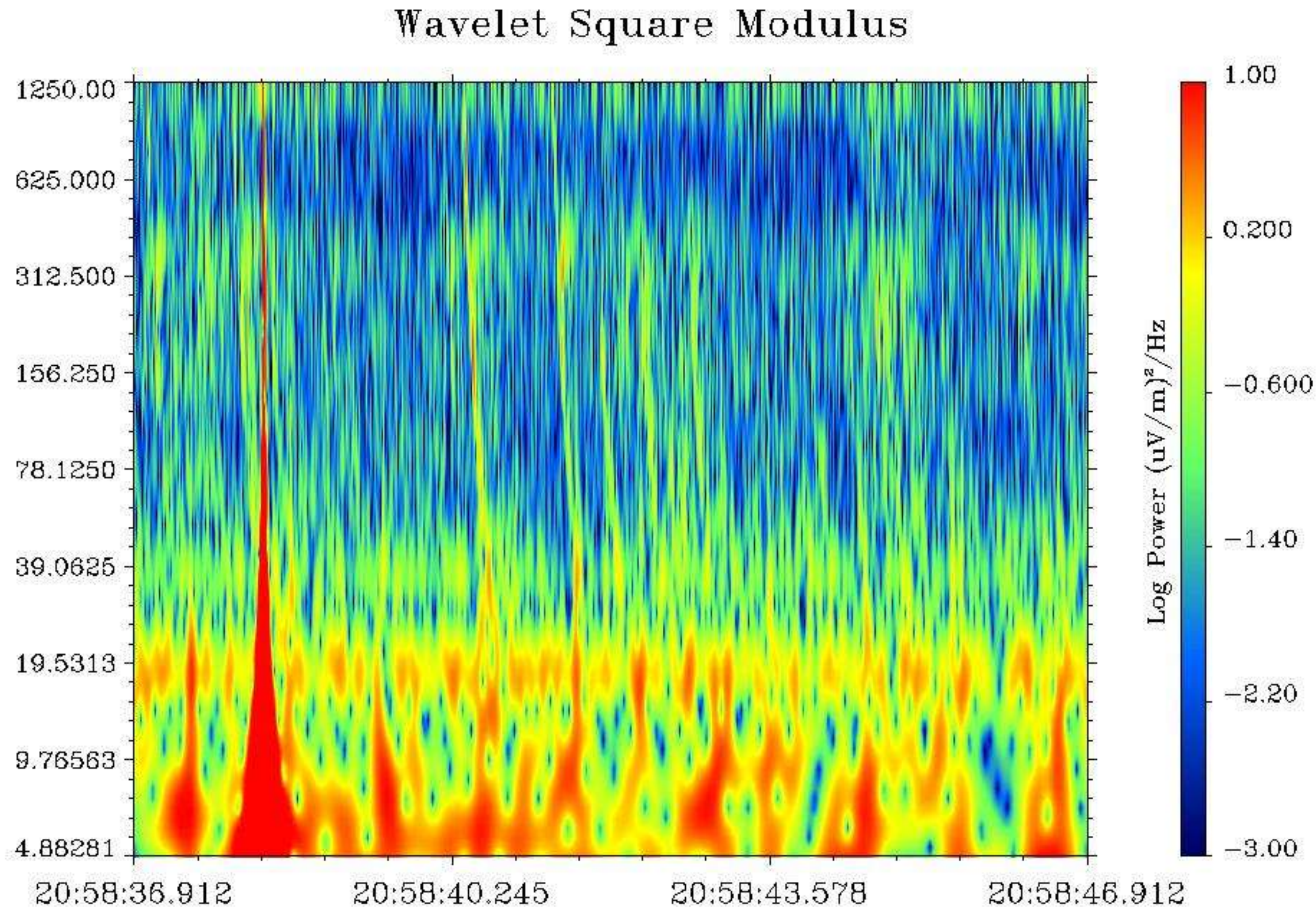


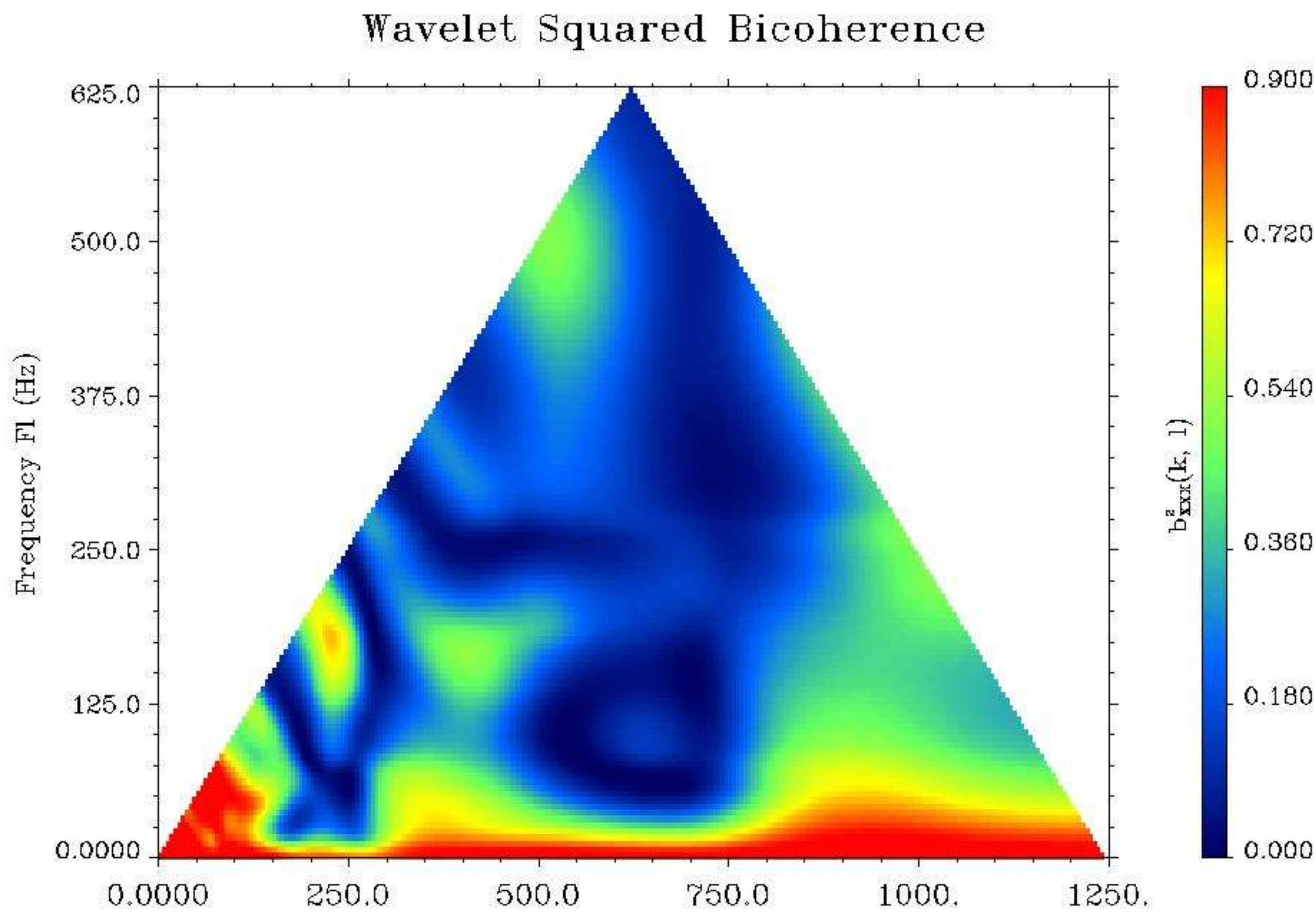
2 days to the earthquake 2009 04 04 Kp 0 0 0 0+0+0+0+0+ Σ 2- night



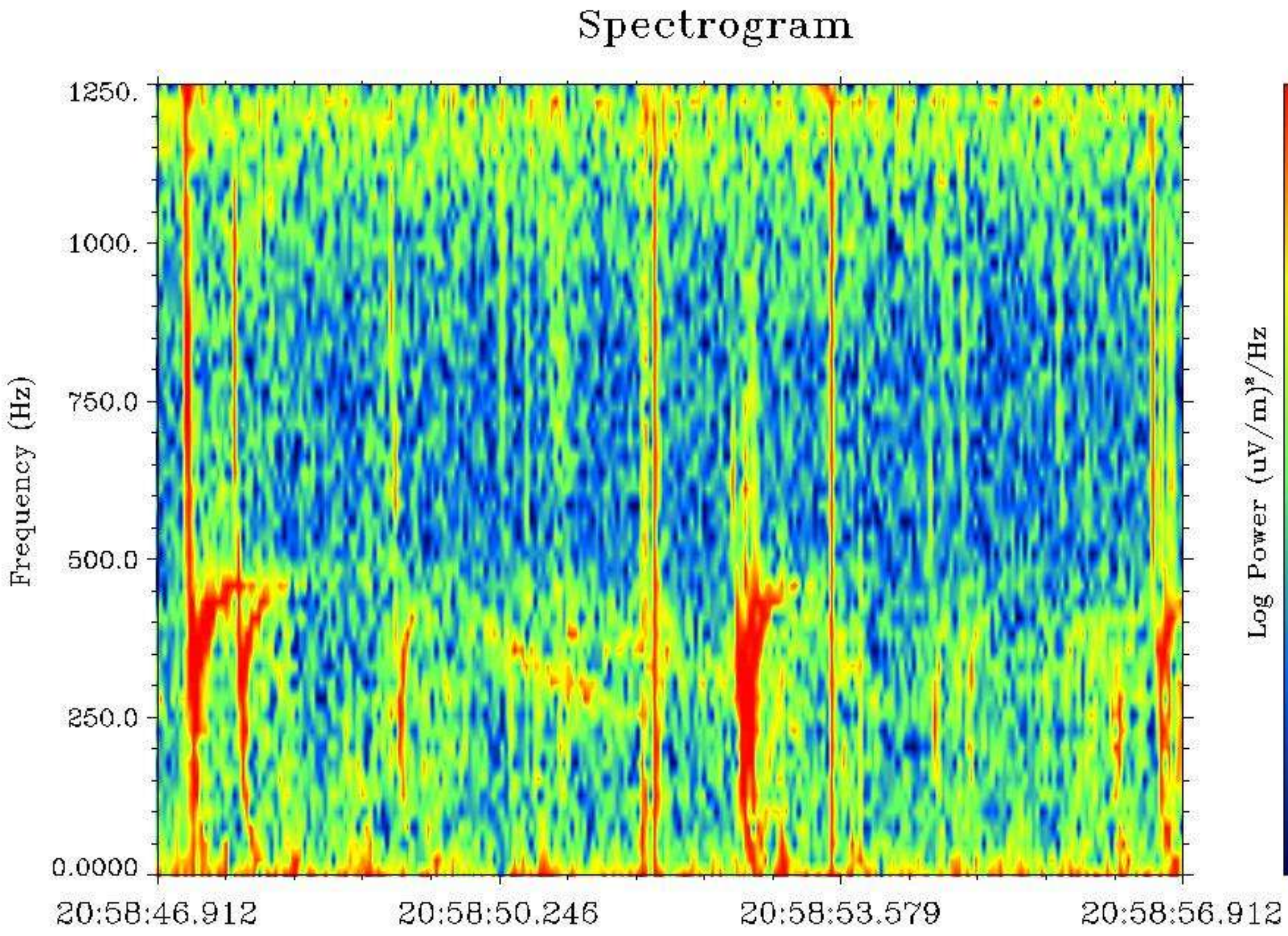
-1 day 2009 04 05 Kp 1+2-2-1 1-1+1-0+ Σ 9-



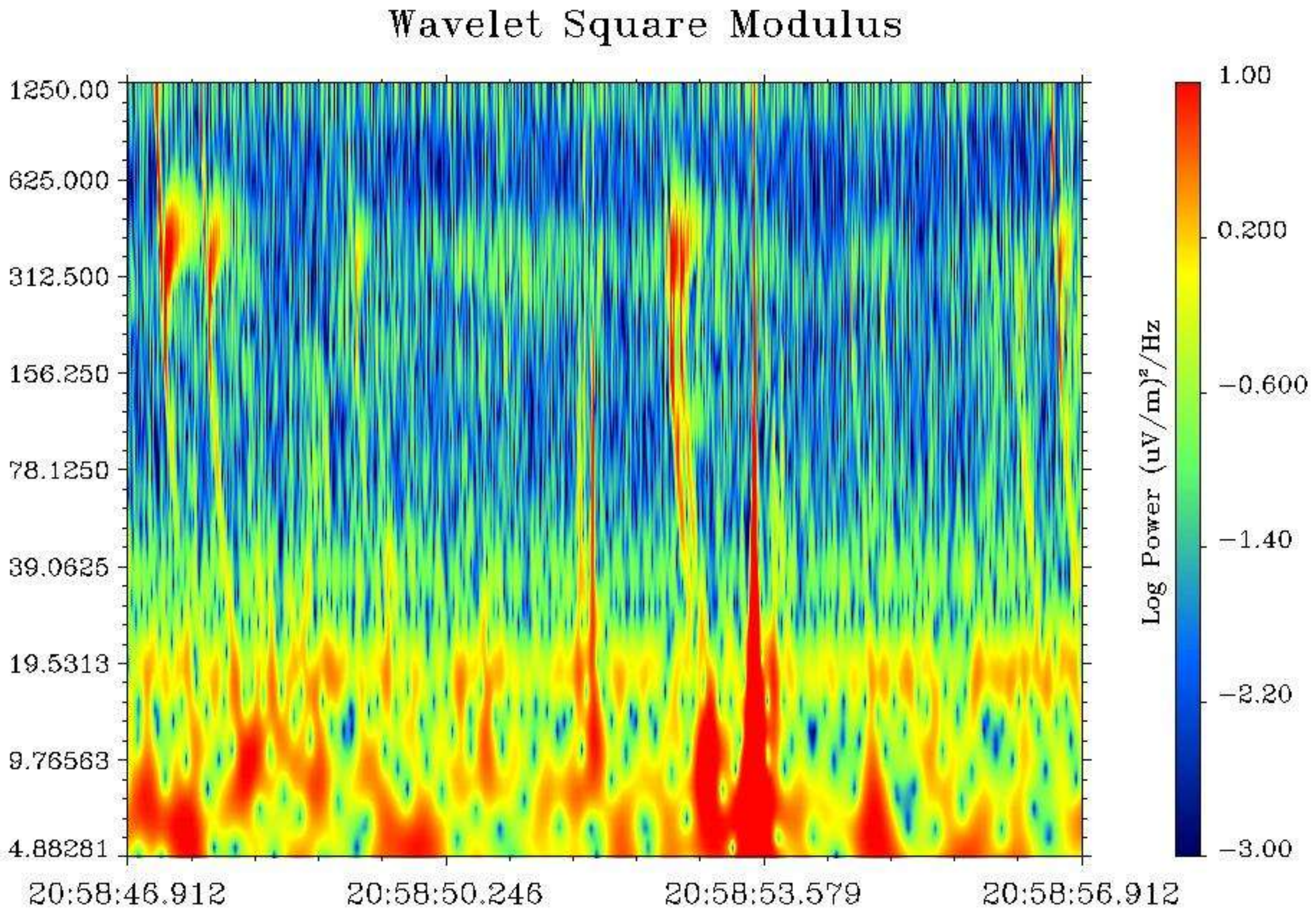

Wavelet Square Modulus
1250.00
625.000
312.500
156.250
78.1250
39.0625
19.5313
9.76563
4.88281
20:58:36.912
20:58:40.245
20:58:43.578
20:58:46.912
Log Power (uV/m)²/Hz
1.00
0.200
−0.600
−1.40
−2.20
−3.00


Wavelet Squared Bicoherence
Frequency F1 (Hz)
625.0
500.0
375.0
250.0
125.0
0.0000
0.0000
250.0
500.0
750.0
1000.
1250.
$b^2_{xxx}(k, l)$
0.900
0.720
0.540
0.360
0.180
0.000

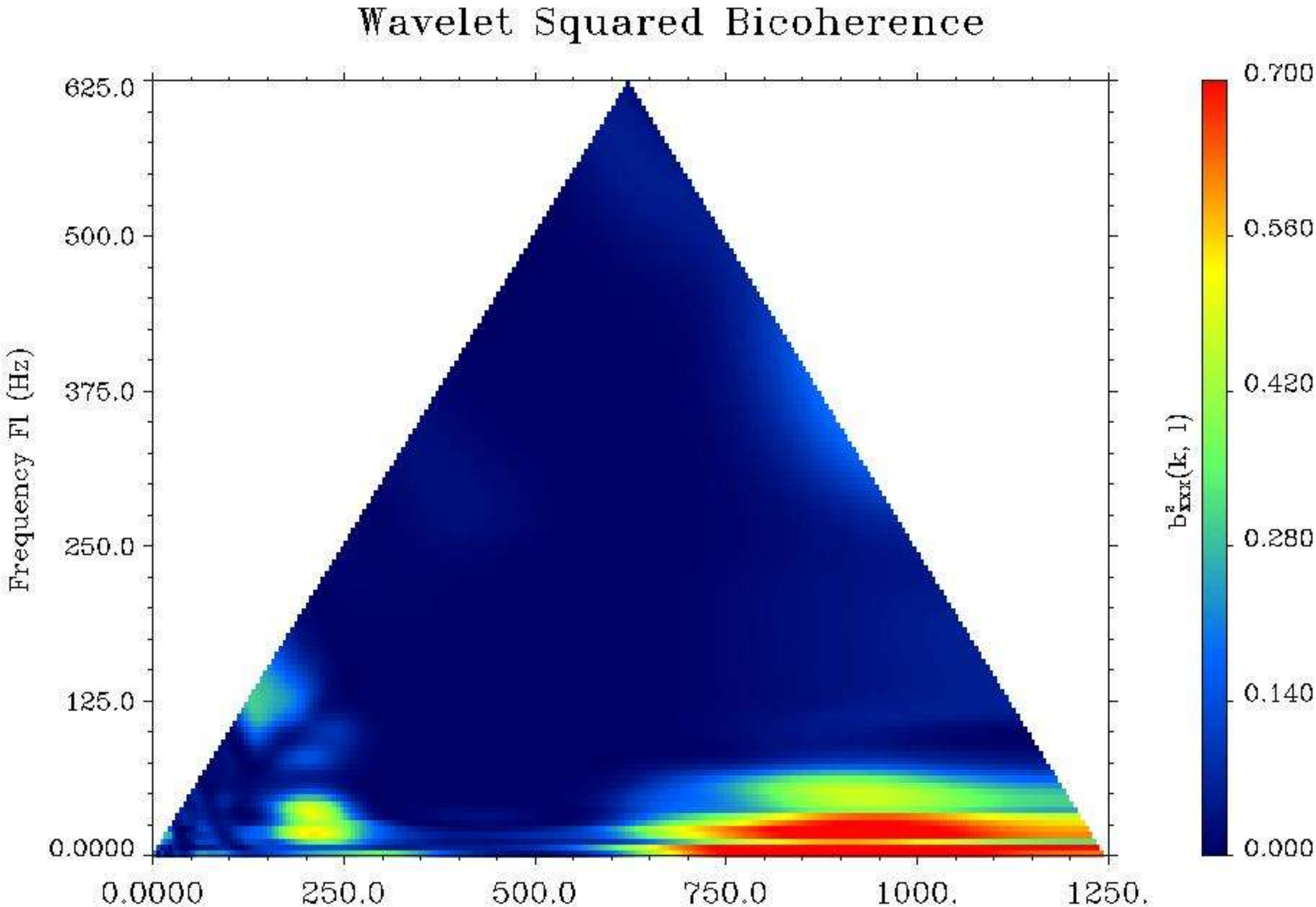
-1 day 2009 04 05 Kp 1+2-2-1 1-1+1-0+ Σ 9-

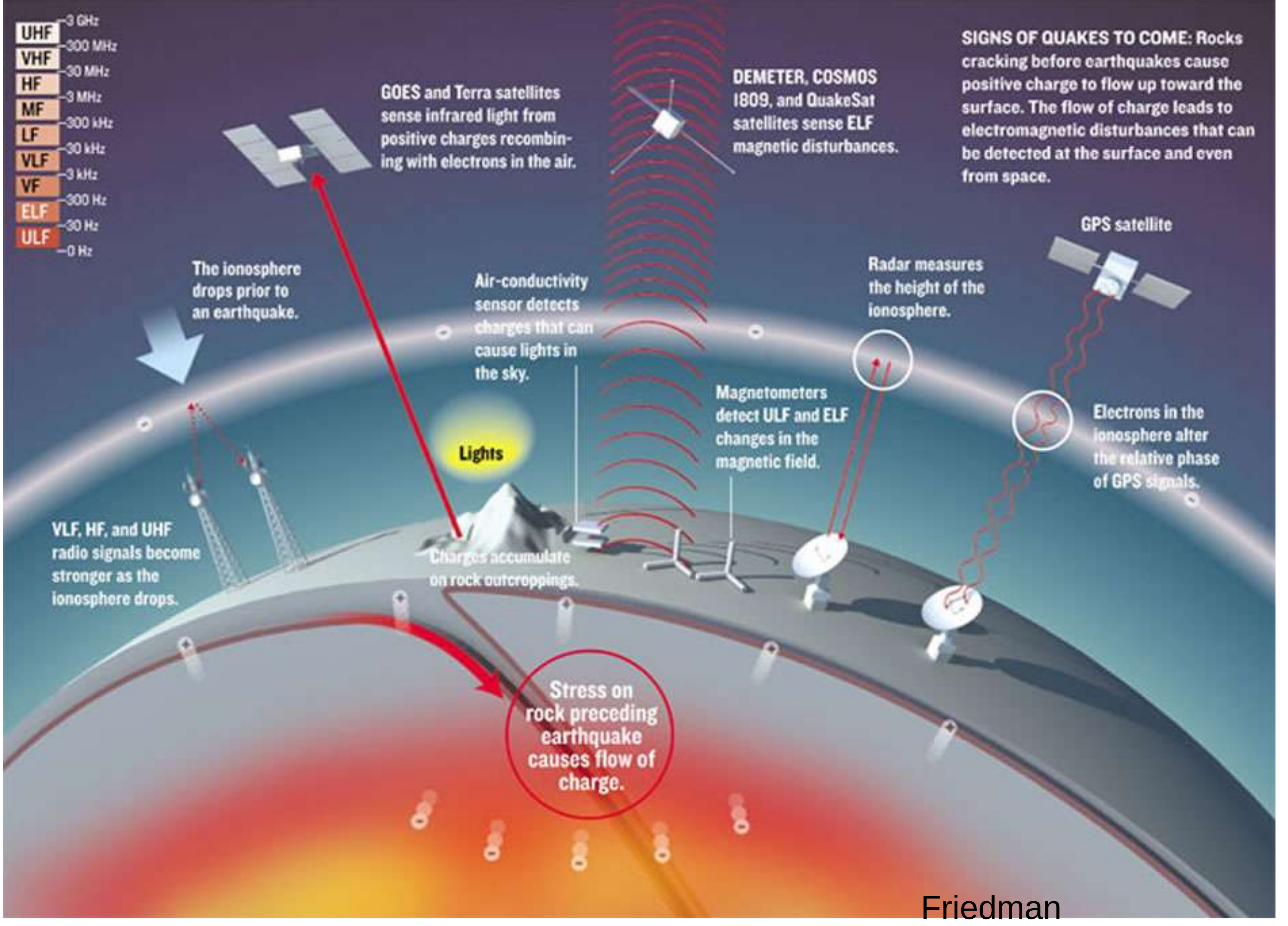


-1 day 2009 04 05 Kp 1+2-2-1 1-1+1-0+ Σ 9-



-1 day 2009 04 05 Kp 1+2-2-1 1-1+1-0+ Σ 9-



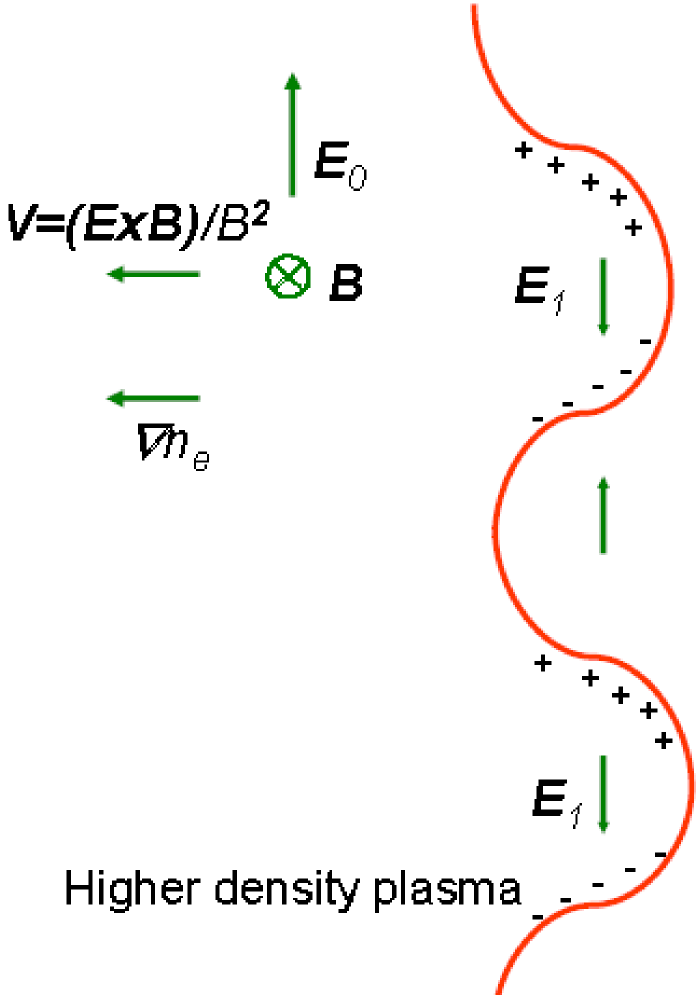

UHF
VHF
HF
MF
LF
VLF
VF
ELF
ULF
3 GHz
300 MHz
30 MHz
3 MHz
300 kHz
30 kHz
3 kHz
300 Hz
30 Hz
0 Hz
GOES and Terra satellites sense infrared light from positive charges recombin-ing with electrons in the air.
DEMETER, COSMOS 1809, and QuakeSat satellites sense ELF magnetic disturbances.
SIGNS OF QUAKES TO COME: Rocks cracking before earthquakes cause positive charge to flow up toward the surface. The flow of charge leads to electromagnetic disturbances that can be detected at the surface and even from space.
GPS satellite
The ionosphere drops prior to an earthquake.
Air-conductivity sensor detects charges that can cause lights in the sky.
Radar measures the height of the ionosphere.
Lights
Magnetometers detect ULF and ELF changes in the magnetic field.
Electrons in the ionosphere alter the relative phase of GPS signals.
VLF, HF, and UHF radio signals become stronger as the ionosphere drops.
Charges accumulate on rock outcroppings.
Stress on rock preceding earthquake causes flow of charge.

Friedman

Categories of Plasma Instability

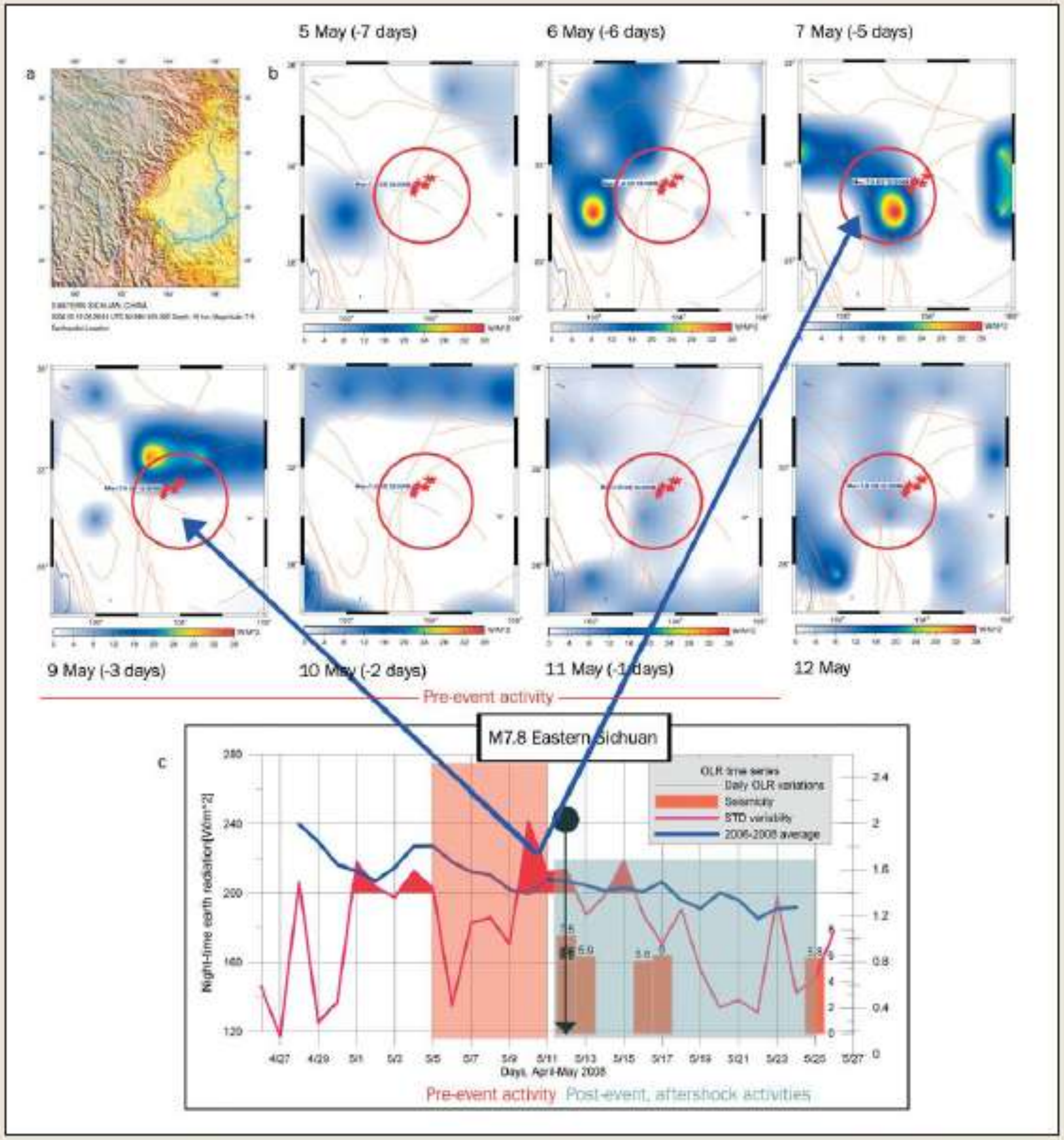
Source of Free Energy	**Type of Instability**
Streaming of one species relative to another	Streaming Instability
Gradient in plasma pressure plus external force	Gradient Instability
Gradient in plasma pressure without external force	Universal Instability
Non-Maxwellian particle distribution	Kinetic Instability

F-Region Gradient Drift Instability



- Electrons collisionless
- Ions almost collisionless
- Residual collisions cause ions to drift in direction of ambient electric field.
- $E = E_0 + E_1$

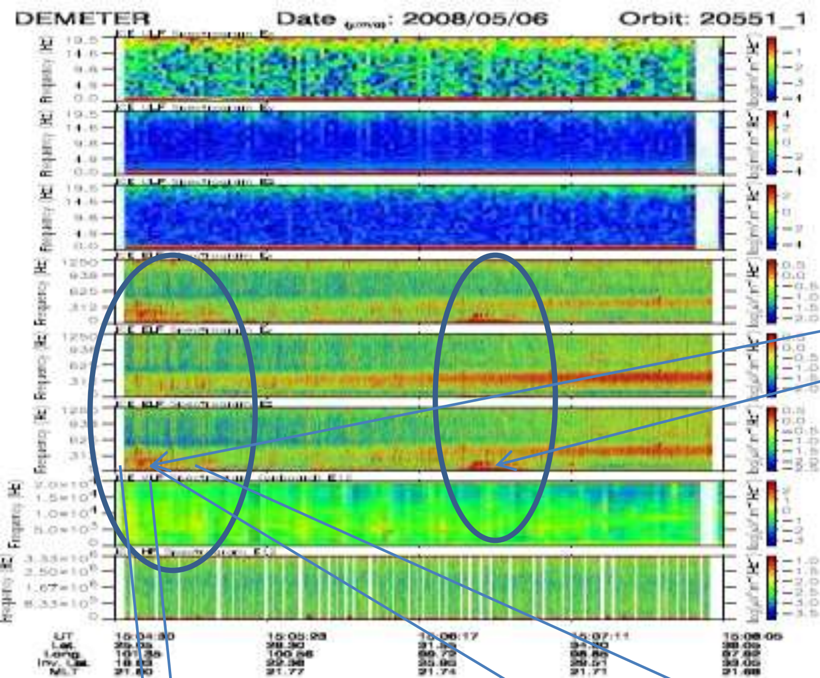
Variations of night-time outgoing earth radiation during the time of M 7.8 Sichuan earthquake of 12 May, 2008



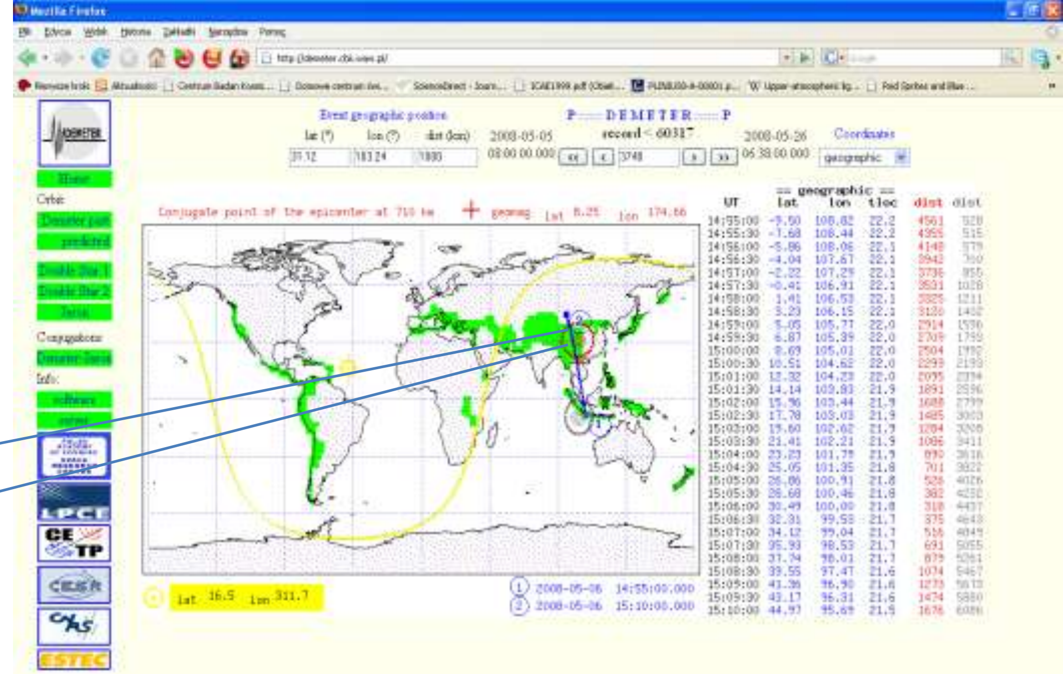
(a) USGS M 7.8 location map, 12 May 2008; (b) Maps of daily night-time OLR over Eastern Sichuan, China, for 5-12 May 2008, (NOAA/AVHRR); (c) Time-series of daily night-time OLR variability for 25 April-25 May 2008 over the epicentral area

Ouzunov et al. 2008

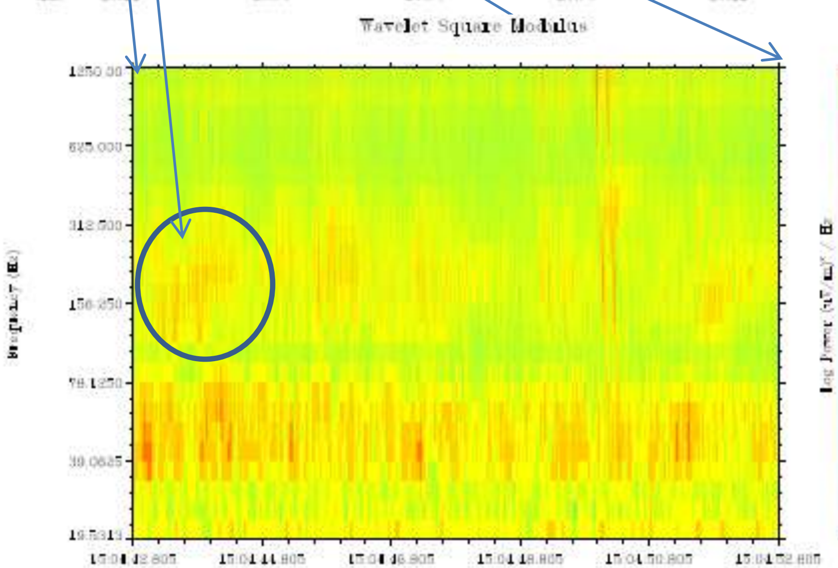
-6 days



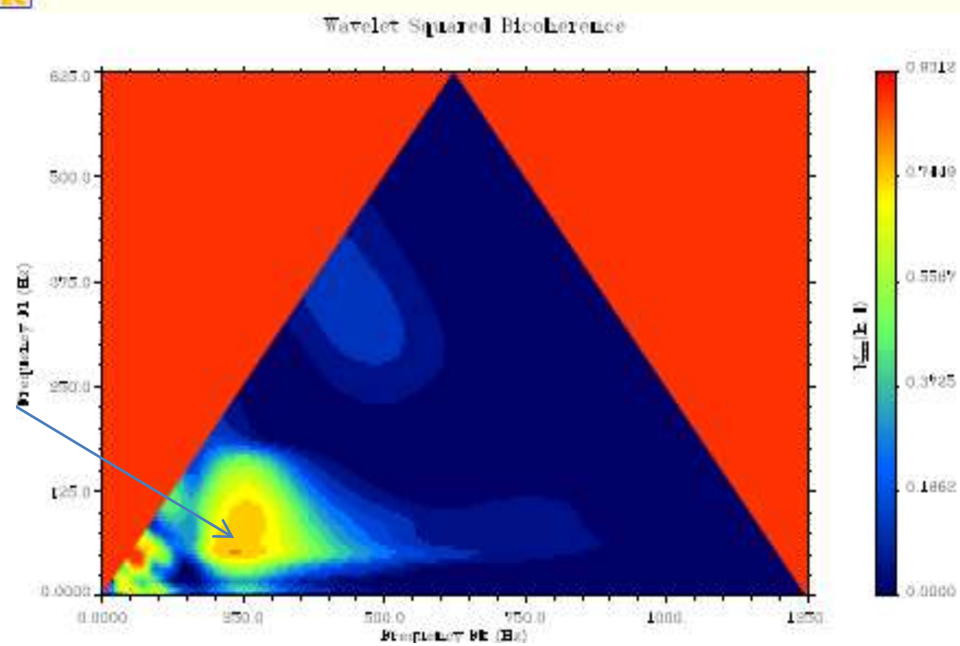
DEMETER
Date (y/m/d): 2008/05/06
Orbit: 20551_1



D E M E T E R
Conjugate point of the epicenter at 710 km



Wavelet Square Modulus



Wavelet Squared Bicoherence

Conclusions

- We presented the electromagnetic effects observed by DEMETER satellite prior to the earthquake in L'Aquila.
- 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 8-1 days before the earthquake.
- The discussed results were obtained during very quiet time and therefore no ionospheric and magnetospheric sources of perturbations were expected. However these turbulence behaviors are not specifically related to the occurrence of earthquakes and can be met in other regions of the ionosphere particularly at equatorial and high latitudes. But the closest occurrence in space and in time suggests that the observed effects at mid-latitudes are related to a perturbation of the ionosphere which could be associated with the preparation of the discussed earthquakes.

Grazie per Sua attenzione