Three-corner representation of earthquake source spectra at Kamchatka

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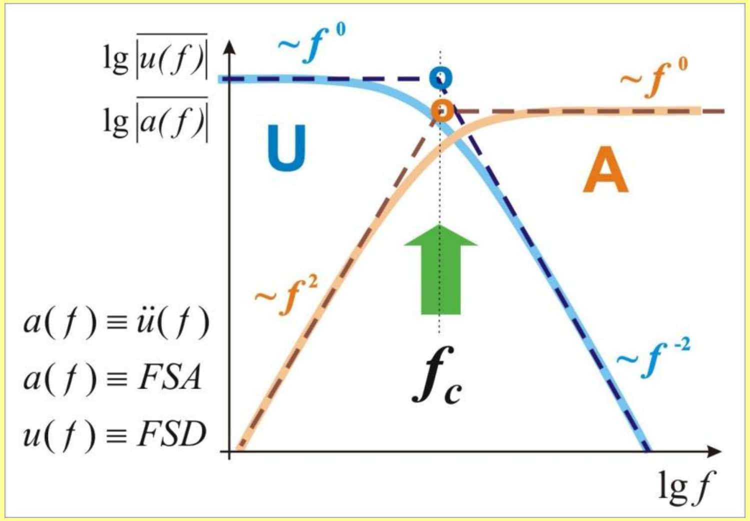
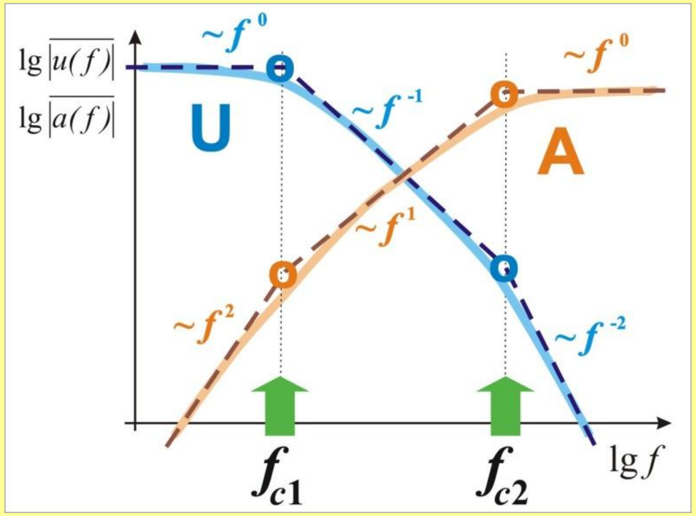
Starting point: "ω^{-2}" or "omega-square" model

for the shape of far-field earthquake source spectrum

Single corner: ***Brune 1970 ε=1*** ***Double corner:*** ***Aki 1967, Brune 1970 : ε<1***



Single-corner displacement *u*(*f*) spectrum: the simpler standard variant after (Brune 1970); ε=1 single corner frequency f_c



Two-corner *u*(*f*) spectrum, original by Aki 1967, also advanced, non-standard variant after (Brune 1970) ; ε<1 two corner frequencies f_{c1}, f_{c2}

Key points:

1. ***flat (f^0) source acceleration spectrum***
2. ***f_{c2} is commonly seen in observed spectra***

“Source-controlled f_{max}”, or 3rd corner frequency, f_{c3} :

HISTORY:

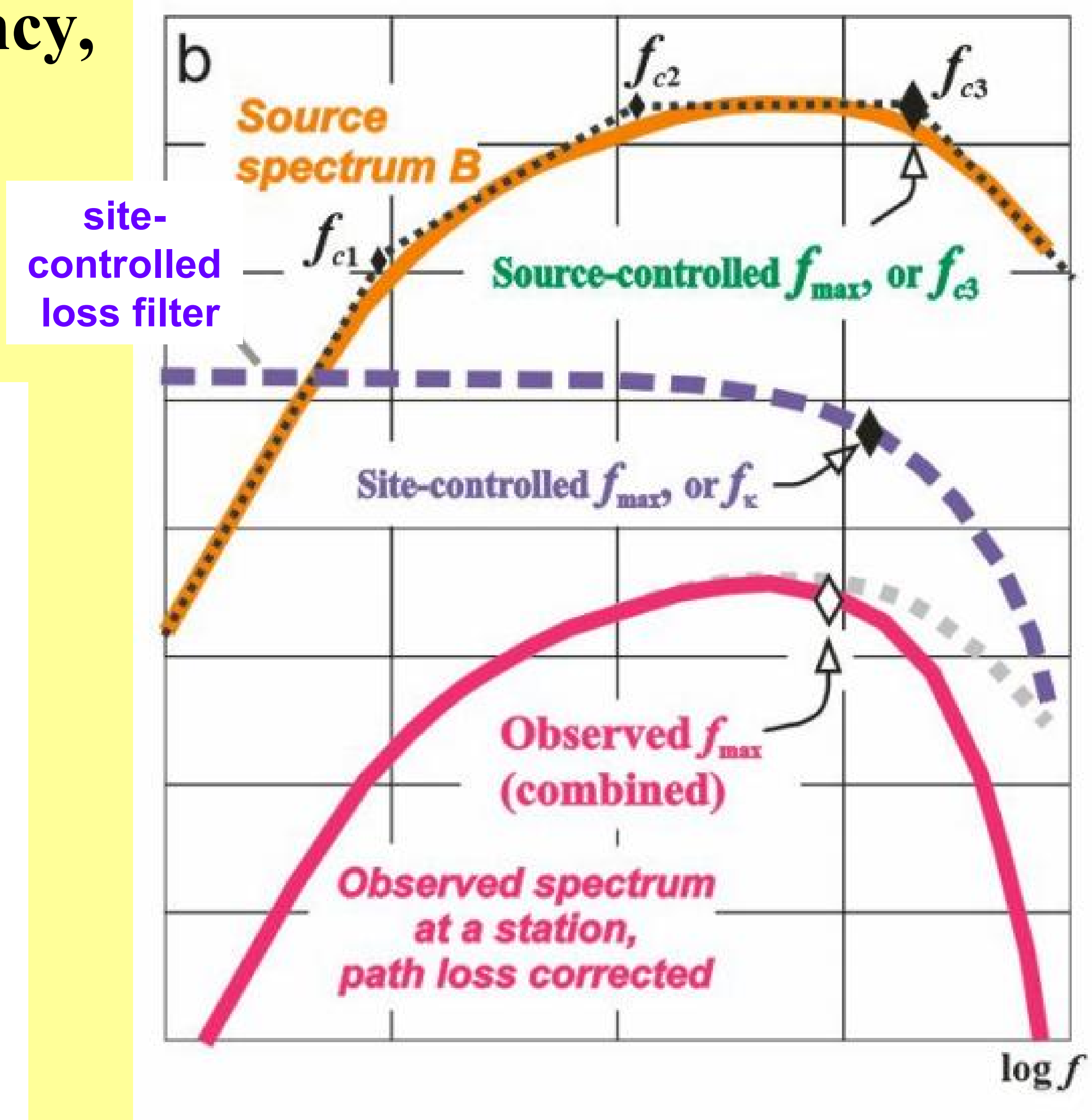
Hanks (1982) “f_{max}” *a*(*f*) shows **HF cutoff**.

Papageorgiou and Aki(1983) and *Gusev* (1983): **source** origin of f_{max}

Aki (1988) f_{max} vs M_0 trend

Hough and Anderson (1984): **site-related loss** controls f_{max}

Accumulated evidence suggests: f_{max} incorporates **both** components



Outline of the study

1. Reduce observed S-wave spectra to the source by means of a *reliable* attenuation model ($Q(f)$, κ_0) (*cross-checked* by 2 techniques: *spectral* and multi-band *amplitude decay*)

2. From corrected spectra, extract *f*c1 *f*c2 *f*c3

3. Cross-check the existence of fc3

4. Discuss scaling and other properties of spectra

Data set used

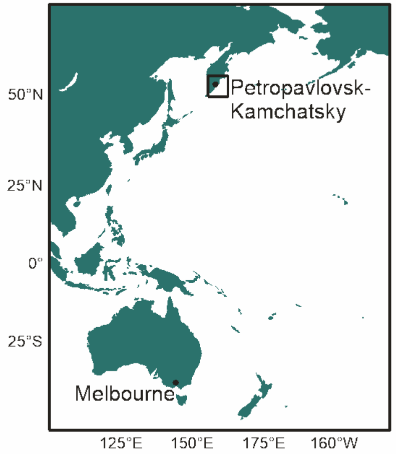
7 rock-ground stations
accelerometers **CMG5T** and **CMG5TD**
Digitization rate: 100 sps
Work bandwidth: **0.2–35 Hz**

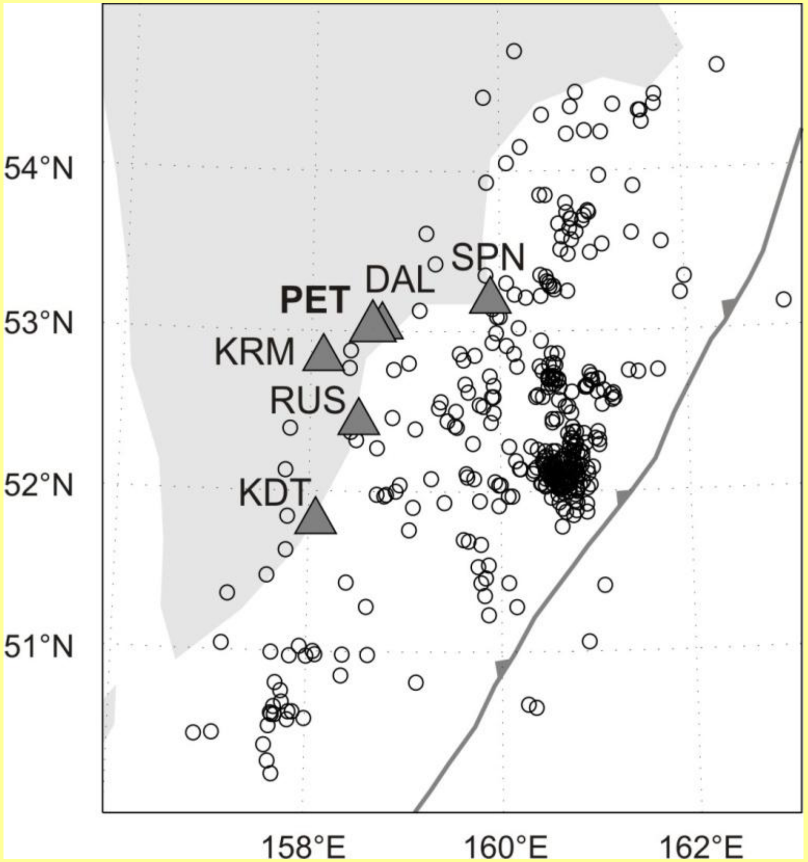
Magnitude ***Mw**** range: **3.5–6.5**
Hypo distance range: **55–270 km**
Depth range: **3–170 км**

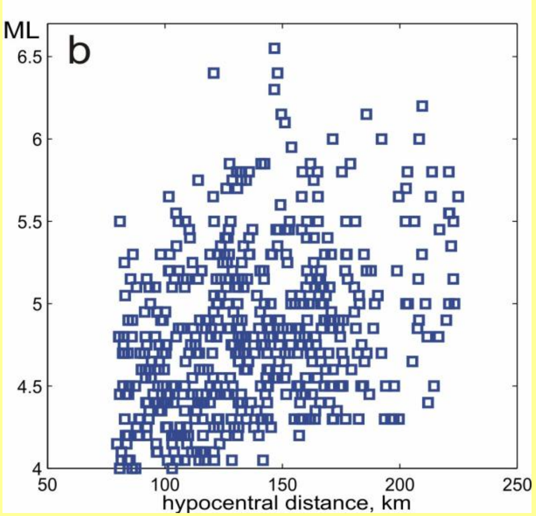
***S* waves**

372 earthquakes (2011–2014):
1 252 source spectra

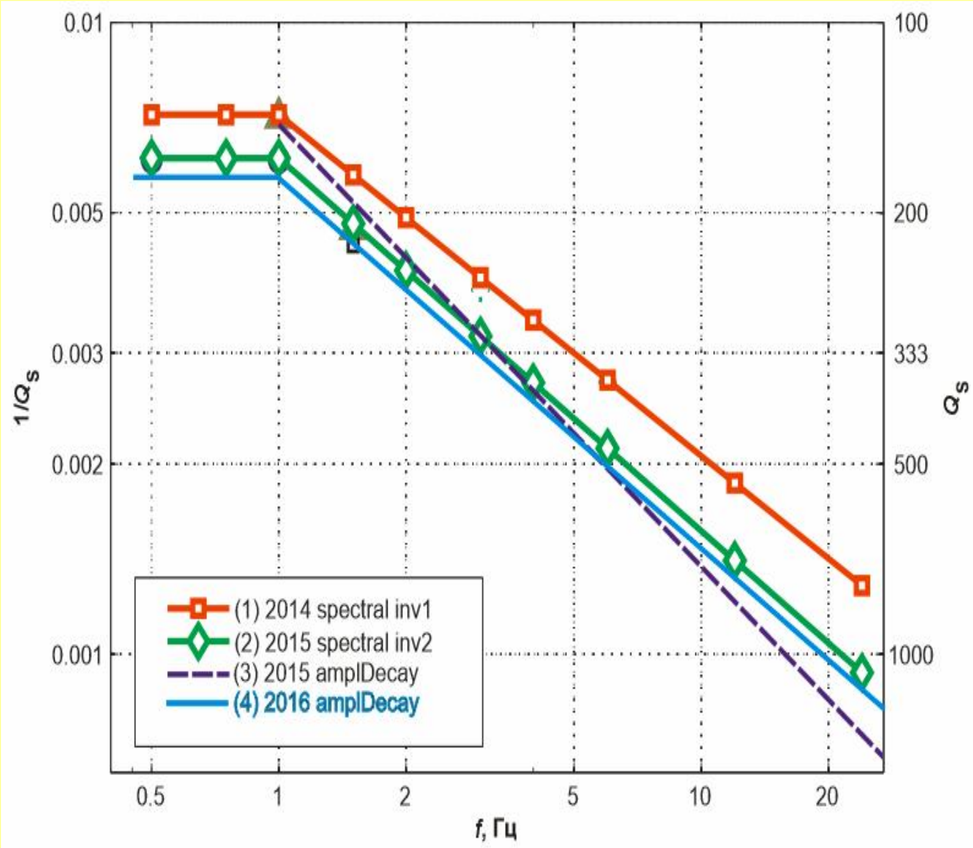
and more







Loss models by two techniques: agree



Technique 1: **spectral**

assume spectrum to be ω^{-2} between fc2 and fc3

observe how spectral shape deforms with distance; derive Q(f),κ_0

pilfalls: local station conditions;

fc3 pick needed

Technique 2: **multiband amplitude decay, with coda normalization**

assume geometric spreading known

observe how band amplitude decays with distance; derive Q(f)

pilfalls: geometric spreading hypothesized; κ_0 cannot be estimated

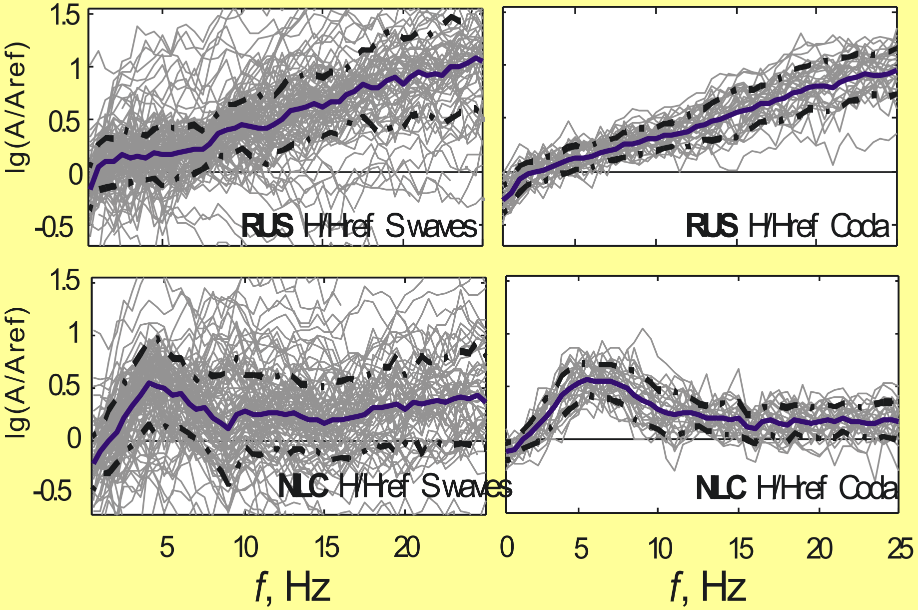
Station spectral corrections (empirical)

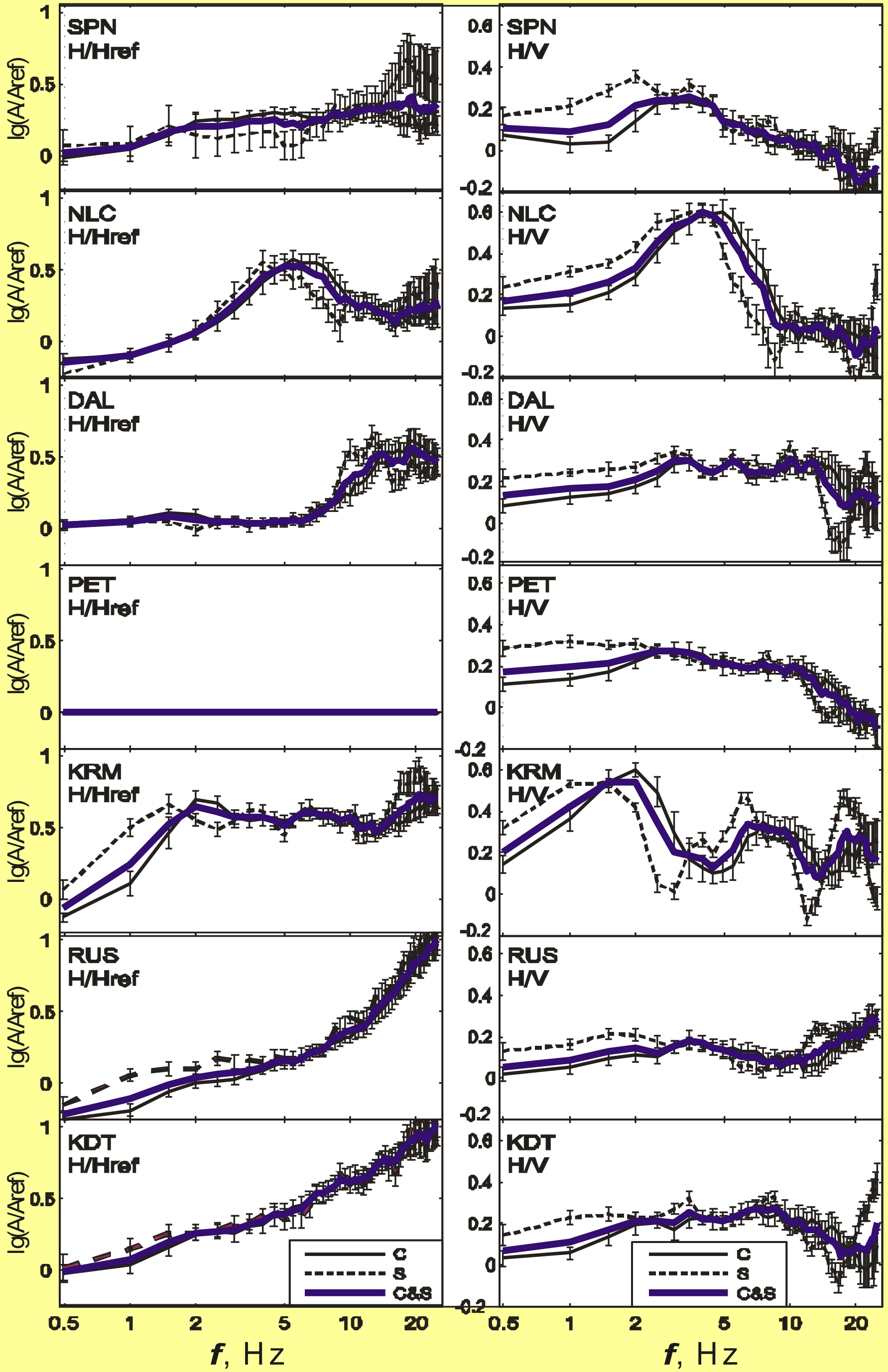
H/Href (main mode, ref.sta.:PET)

H/V(to compare)

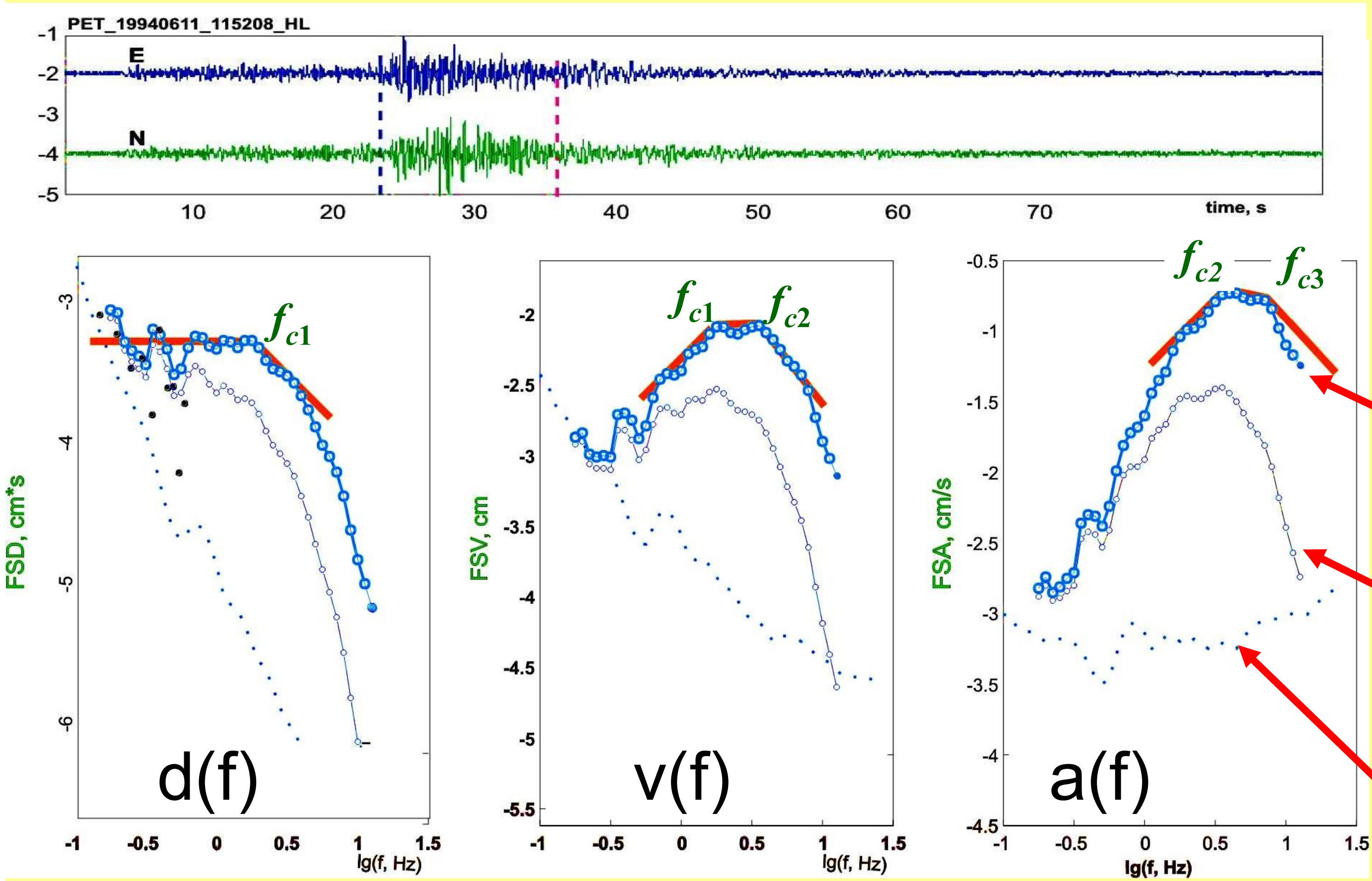
Using S-wave spectra and coda in parallel

Detailed view





Example of interactive processing mode



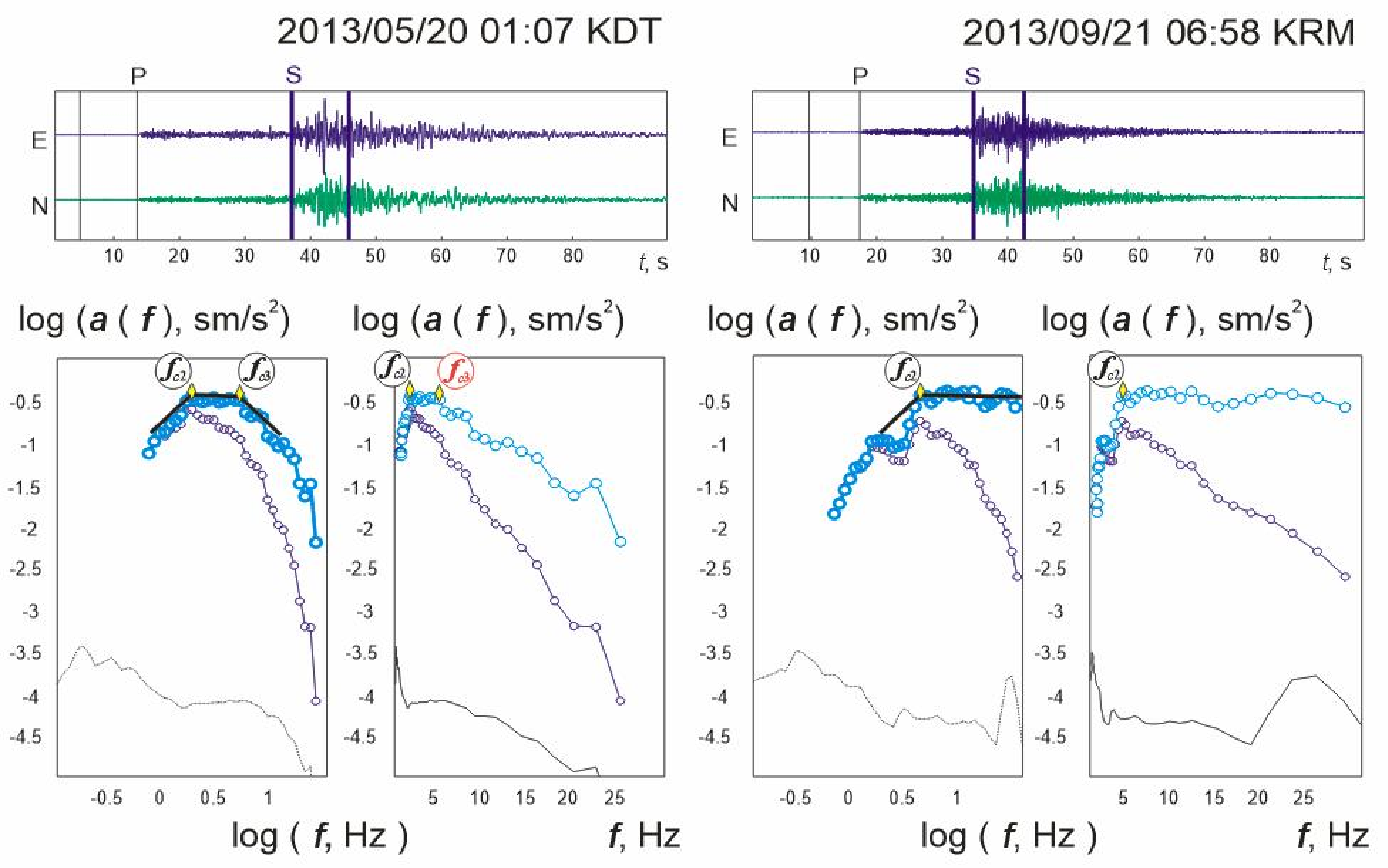
loss-corrected S wave spectrum

observed S wave spectrum

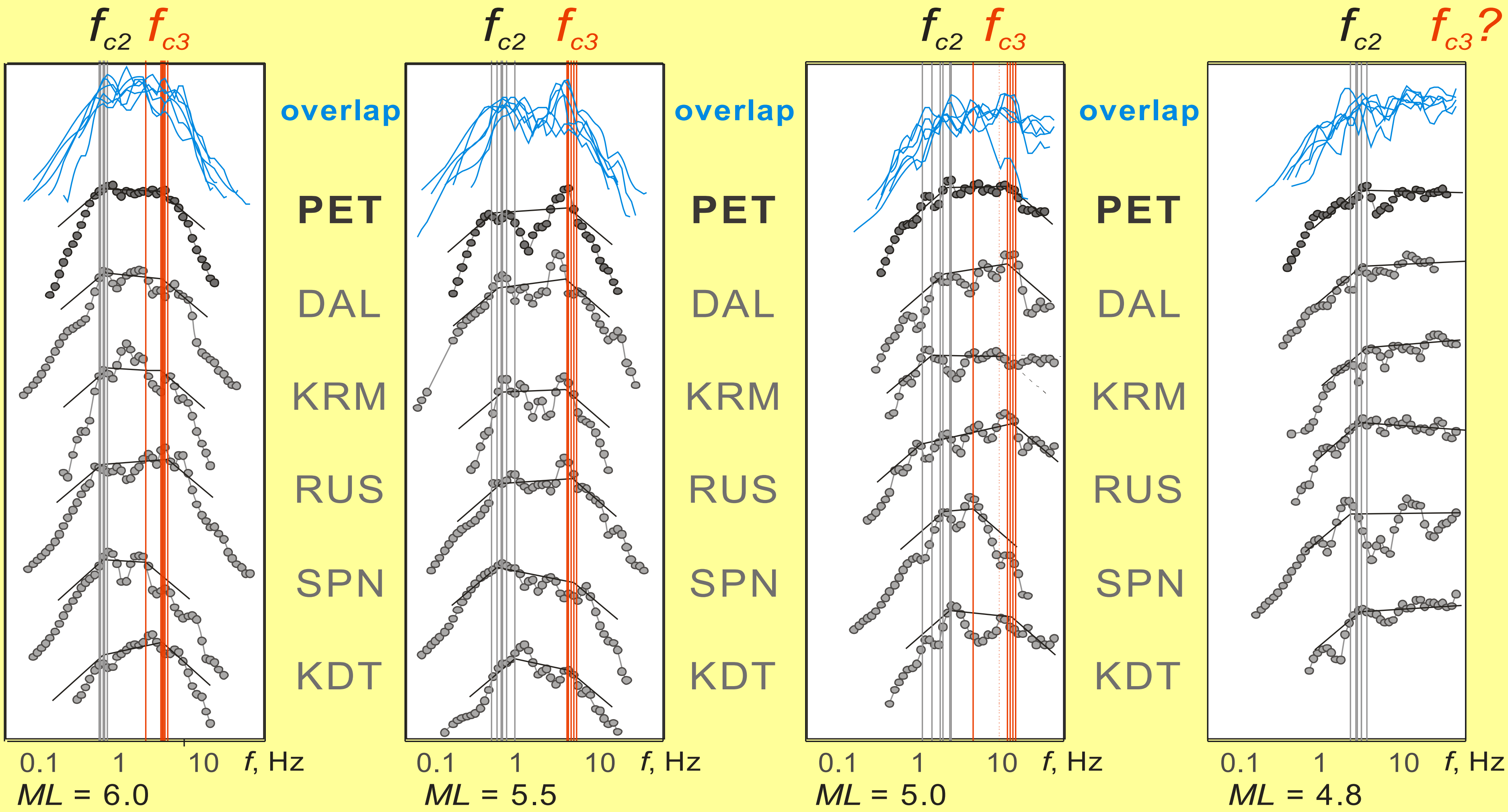
noise

spectral smoothing window used:
0.15 log units (1/2 octave)

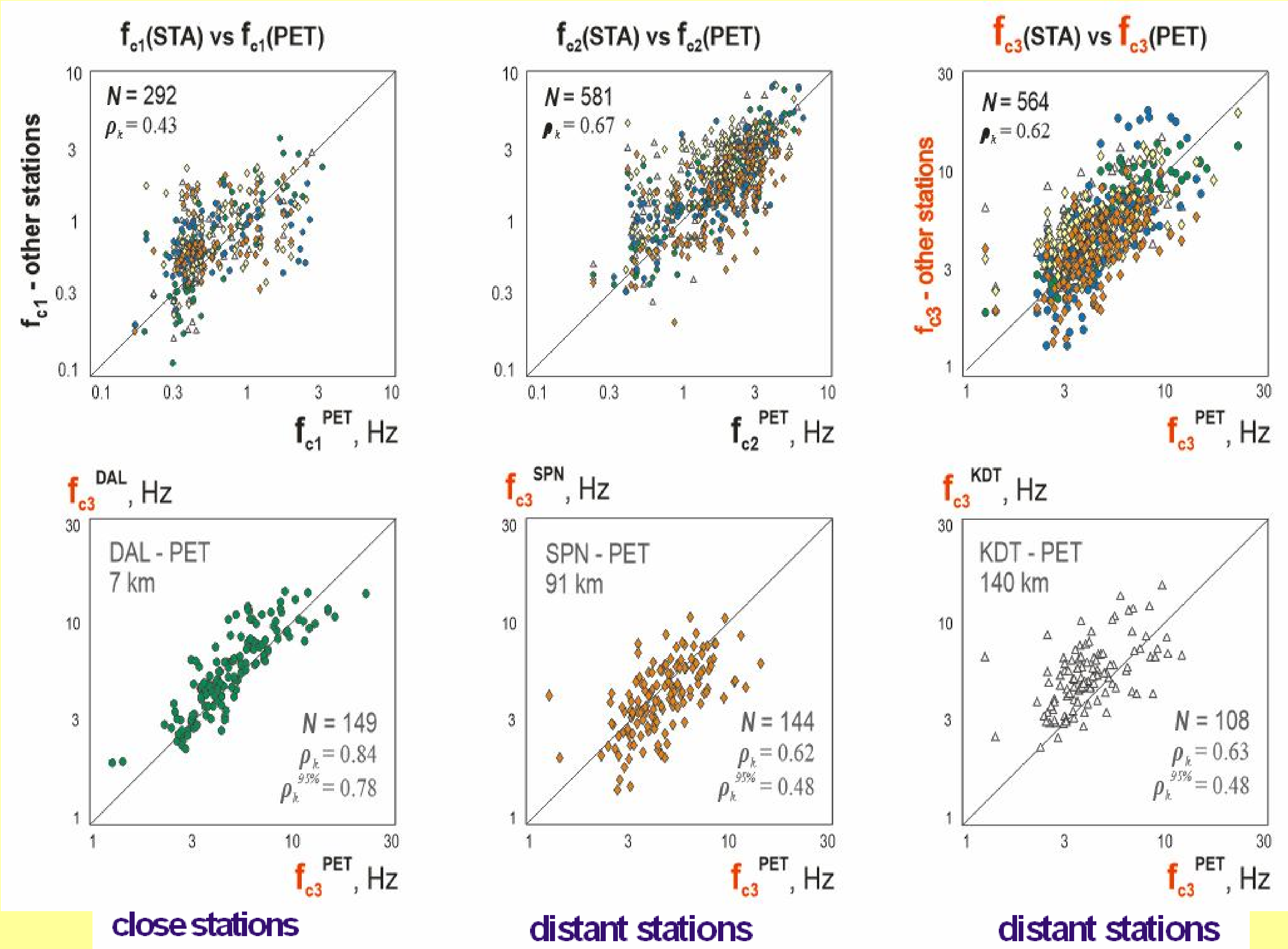
More example cases: f_{c3} may be observable or unobservable/absent



Can one observe fc3 (and fc2) in parallel in recovered spectra of several stations (4 cases)



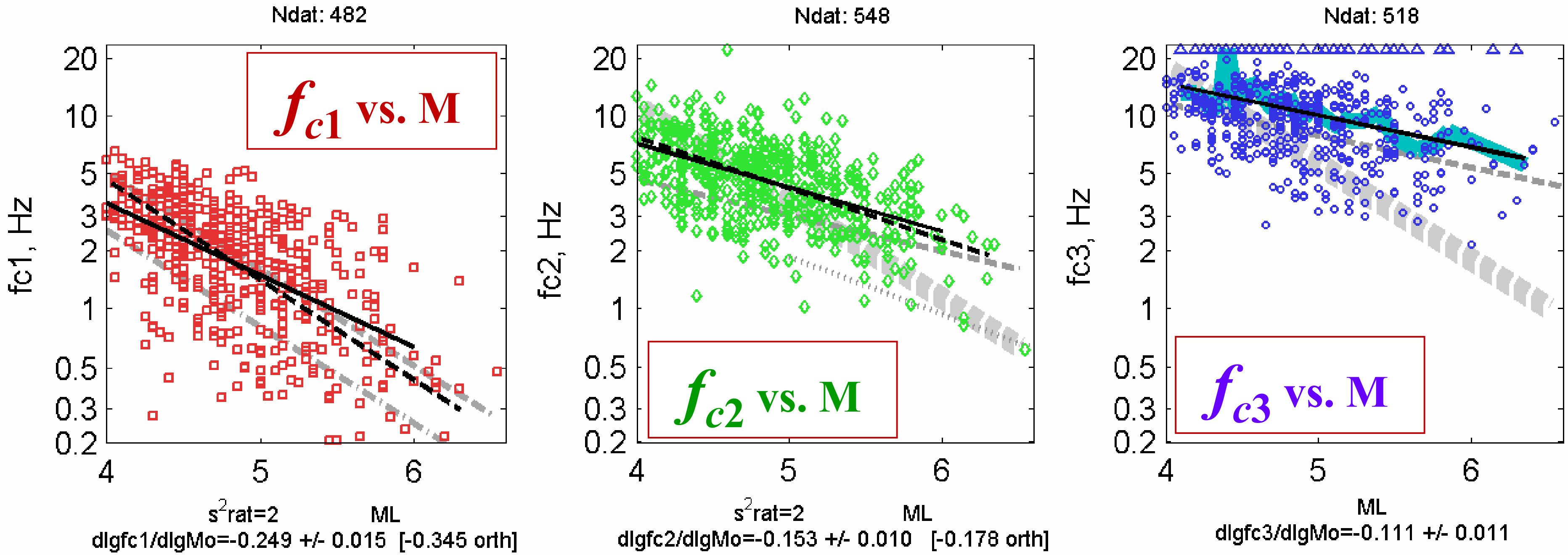
Pair correlation analysis: f_{ci}(*sta1*) vs f_{ci}(*sta2*)



Existence of f_{c3}

is thought to be proven

fc1 – fc2 –fc3 trends side by side, PET data 1993-2005



(1) Each of the 3 trends is different

(2) Assumption of *similarity*:

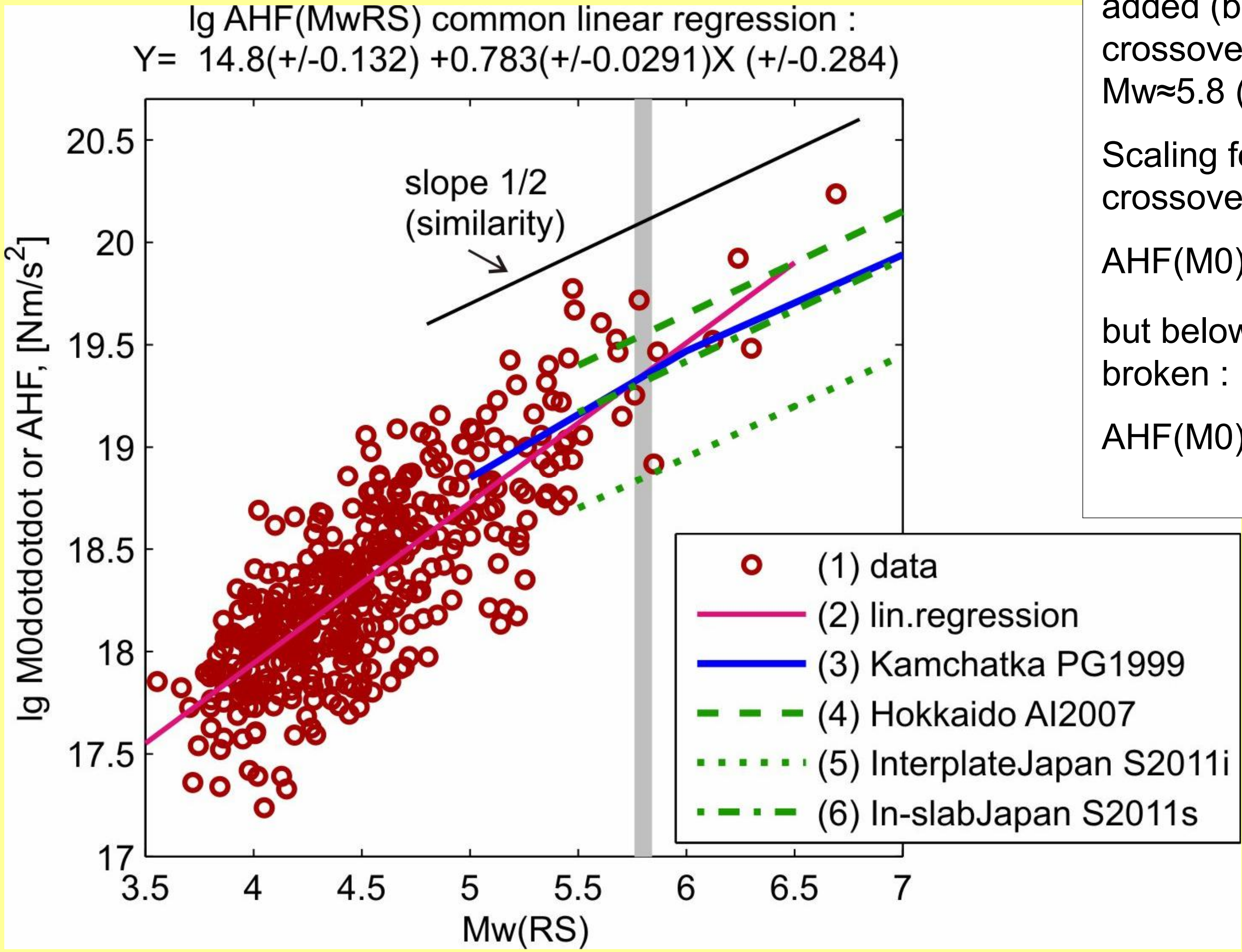
≈holds for f_{c1};

breaks for f_{c2} and f_{c3}

grey trends:
(1) Taiwan, globe
(2) ENA WUSA
(3) Aki 1988

The slope of the trend of high-frequency source spectral level vs. M0 shows prominent deviation from one expected for the case of similarity

$$AHF = \dddot{M}_0(f)_{\max}$$



The AHF(M_0) trend (pink line) is approximately linear at Mw=3.5-6, but when data on larger events are added (blue line), the crossover can be seen around Mw≈5.8 (grey line)

Scaling follows similarity above the crossover:

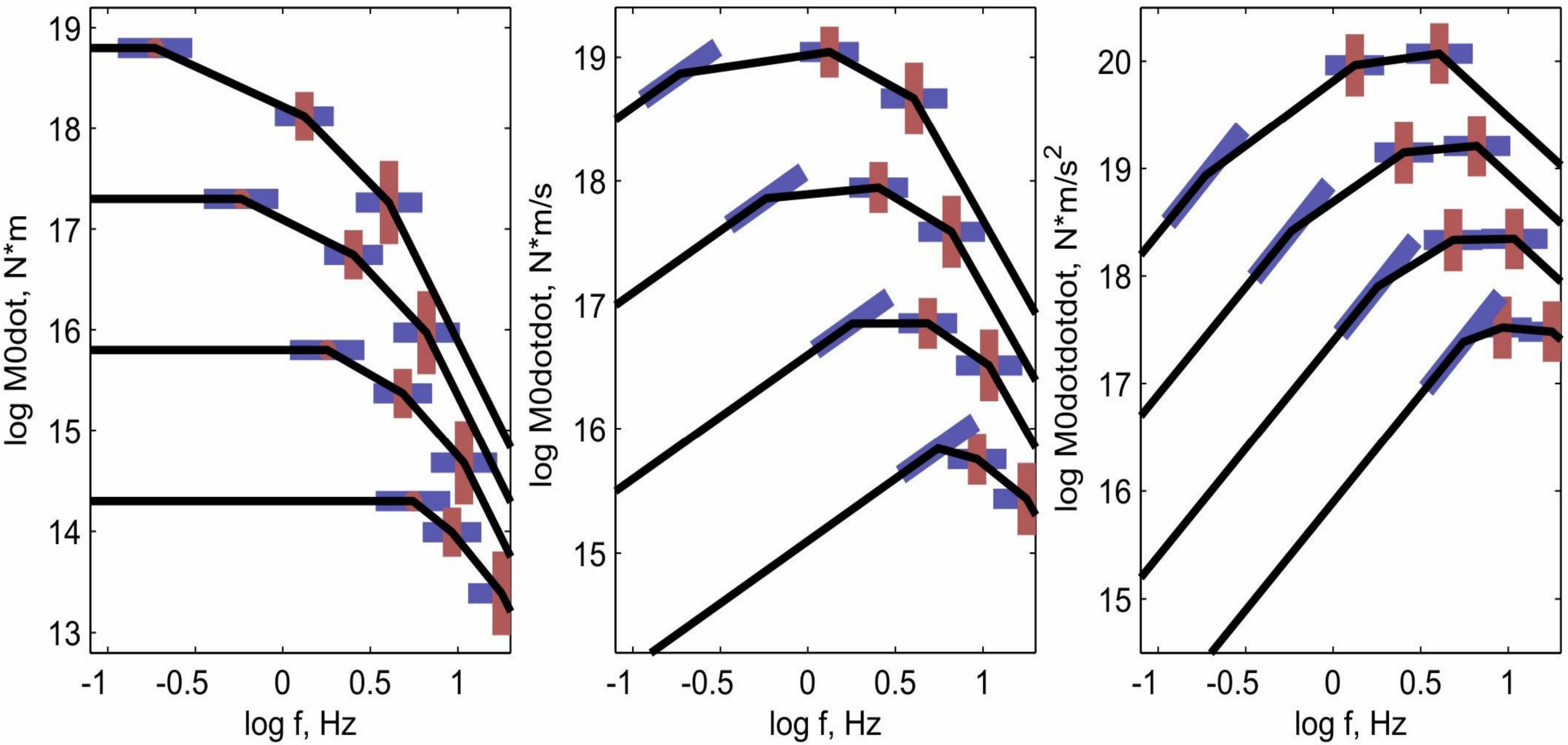
AHF(M0)~$M0^{1/3}$

but below it, similarity is radically broken :

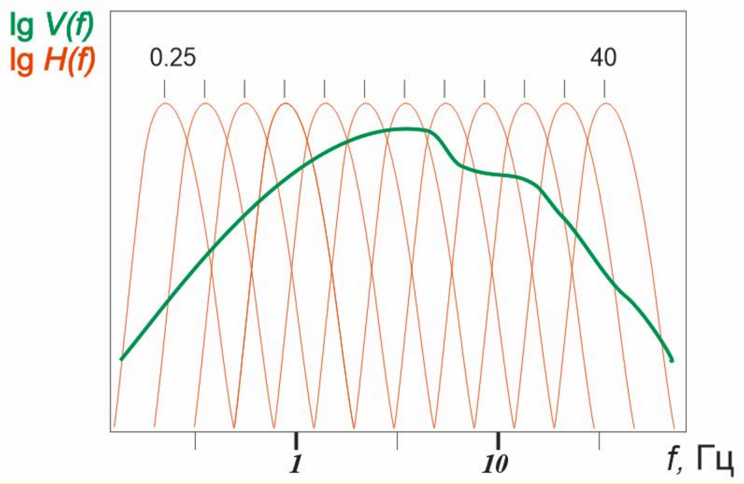
AHF(M0)~$M0^{0.52}$

EMPIRICAL SCALING LAW OF SOURCE SPECTRA, WITH UNCERTAINTY
for moderate earthquakes of Avachinsky Gulf, Kamchatka

at Mw= 3.50 4.50 5.50 6.50



Multiband spectra and automatic picking of M0 and fci



2/3-octave/ 0.2 decade filters,
12 bands centered at:
0.25, 0.4, 0.63, 1, 1.6, 2.5,
4, 6.3, 10, 16, 25, 40 Hz

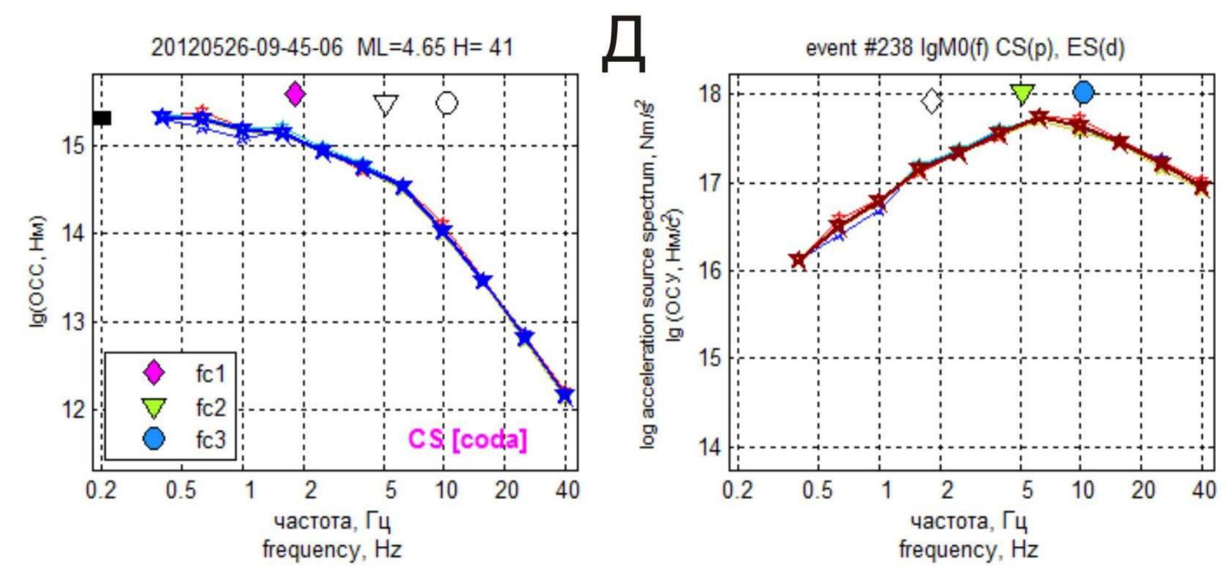
Sequence of processing:

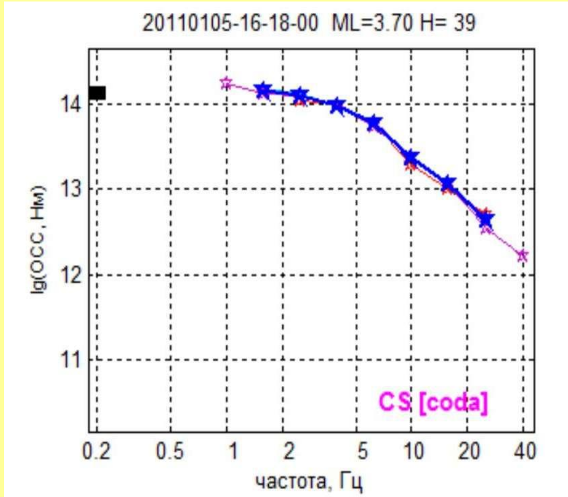
1. Cut out S & coda (C) & noise; BANDFILTER
2. Find energy of S; rms amplitude of C, reduce to reference distance/time
3. Convert reduced band amplitudes into source spectrum (S-based + C-based)
4. Pick M0/Mw, fc1, fc2, fc3,

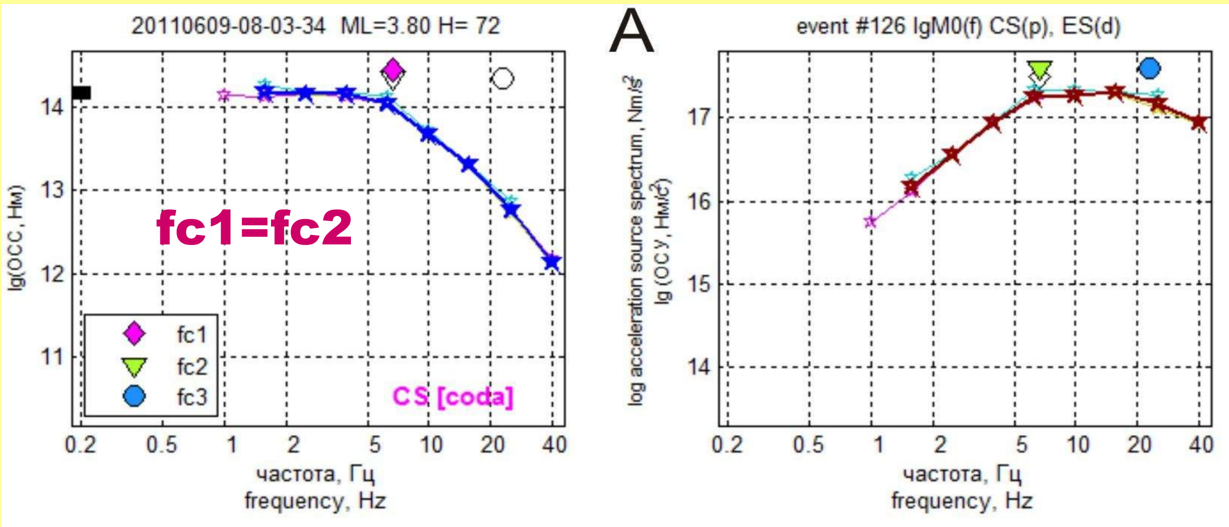
Supporting info (per band):

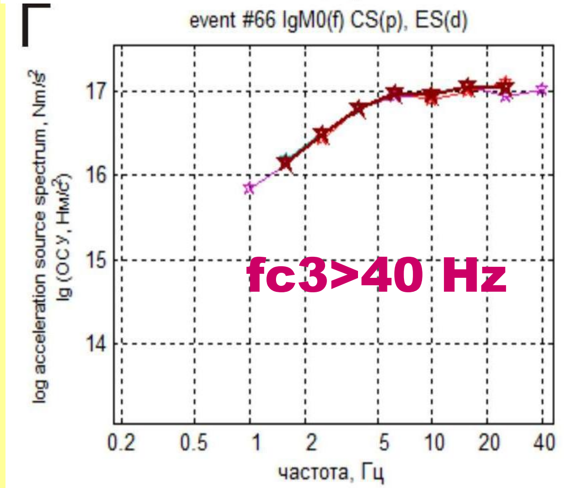
1. Standard coda shapes Standard amplitude decay functions
2. Q(f)
3. Spectral station corrections
4. Reference station impedance correction (for effects of layered medium)

Example source spectra and auto picked M0 and fci (1)



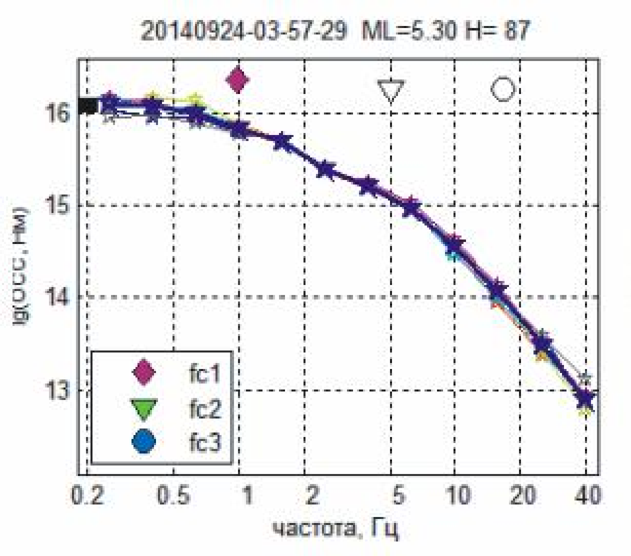


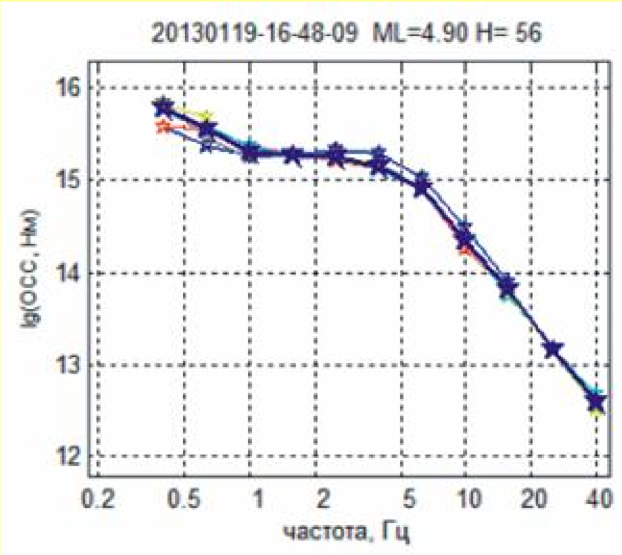




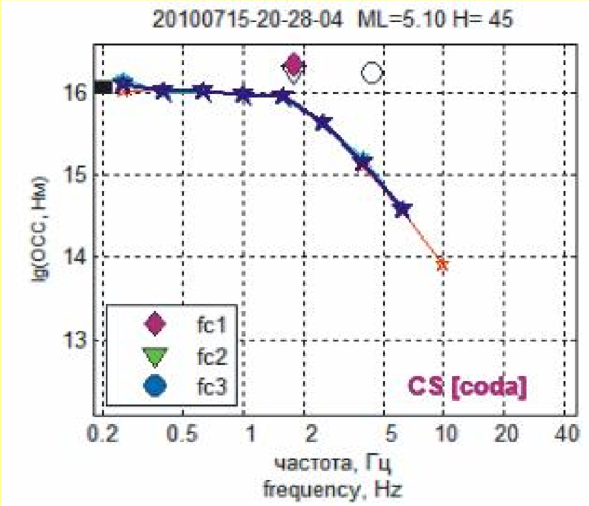
Example source spectra and auto picked M0 and fci (2)

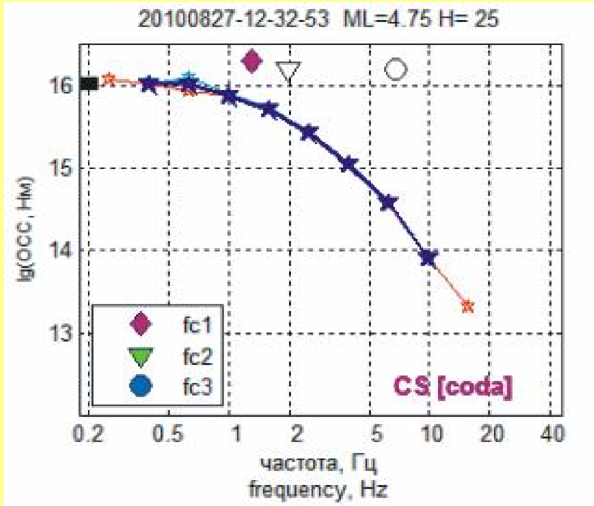
flat vs. growing LF spectrum

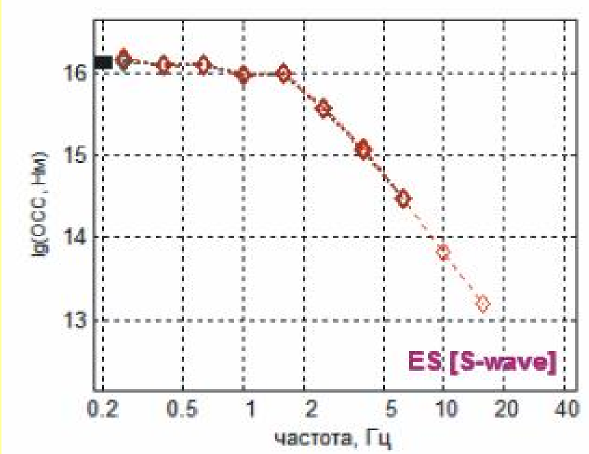


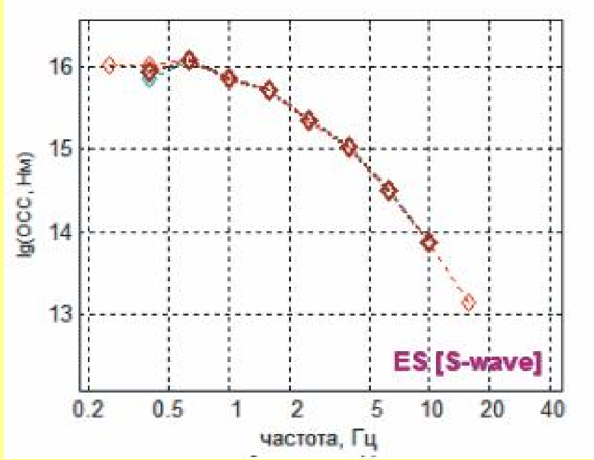


coda-derived vs. S-wave-derived spectrum



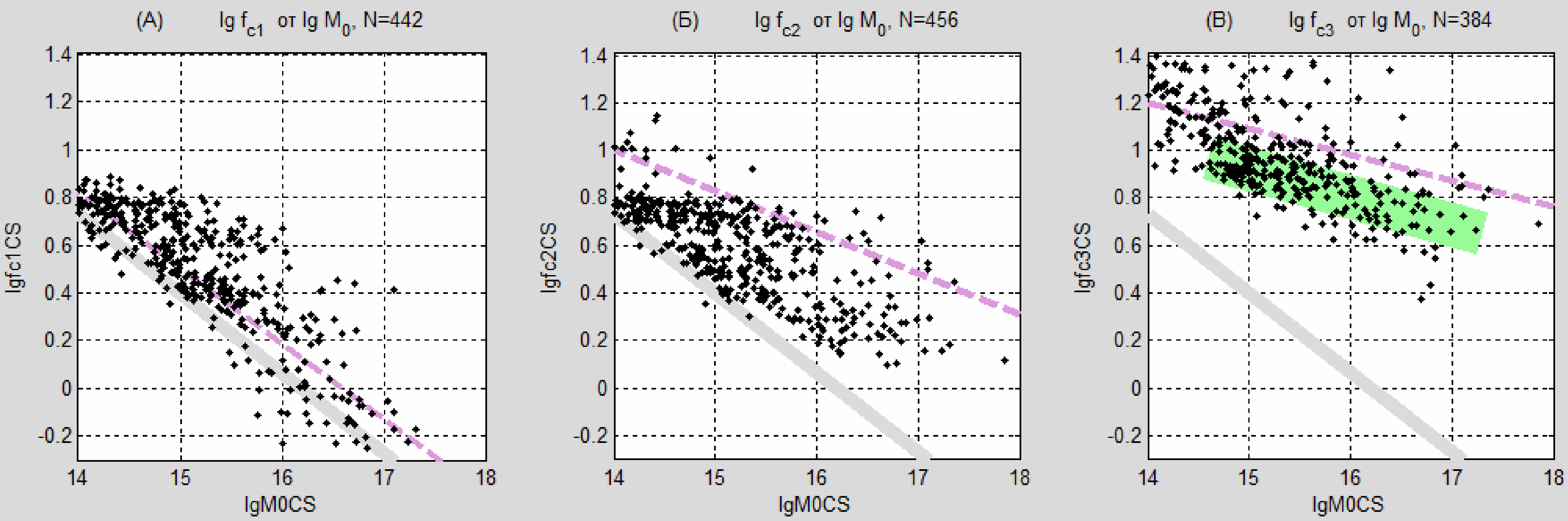






Hand-picked (-----) vs. auto-picked (•) f_{ci}

(procedures conceptually non-identical!)



Despite systematic shifts, the lack of similarity is confirmed for fc2, fc3:

fc1 appx $\propto M_0^{1/3}$

whereas fc2, and, probably, fc3 do not

Slow f_{c2} vs. M_0 trend (exponent<1/3),

as compared to that of f_{c1} (exponent≈1/3),,

is thought to be proven

Conclusions

1. Among hundreds of attenuation-corrected spectra of M=3.5-6 earthquakes, a large fraction (80%+) shows the source-controlled f_{max}, i.e. the third corner frequency f_{c3}.
2. For many spectra, the second corner frequency f_{c2} can be confidently identified.
3. Both for fc2 and fc3, scaling does not follow the standard $f_{ci} \propto M_0^{1/3}$ trend characteristic for the case of similarity.

Possible physics that underlies trends of f_{c2}, f_{c3}

- $\boldsymbol{f_{c2}}$ is probably related to **slip pulse width**;
the trend $f_{c2} \propto f_{c1}^{0.5\text{-}0.6}$ suggests that pulse width grows by some mechanism akin to random walk

- $\boldsymbol{f_{c3}}$ is probably related to the lower limit of the size of fault surface heterogeneity, (or else to cohesion zone width, or both) (compare Aki (1983)), ;
the trend $f_{c3} \propto f_{c1}^{0.2\text{-}0.3}$ suggests that these parameters increase with source size, however very slowly. Probably this trend reflect variations in fault surface maturity: the greater is distance the fault walls have slipped one over another, the larger is accumulated wear and the lower is the upper cutoff of heterogeneity spectrum. (compare Gusev 1990; Matsu'ura 1990,1992).

Thank you

for attention