# DEVELOPMENT OF A MULTIBAND MAGNITUDE SCALE FOR KAMCHATKA

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# Multiband magnitude concept

**(1)** ***body wave, peak amp.: Zapolskiy 1961-1964***

***later work: Tsujura 1967, Duda&Yanovskaya 1993-95***

**(2)** ***coda waves: [Aki&Chouet 1975],***
***Rautian and Khalturin 1972-1978***

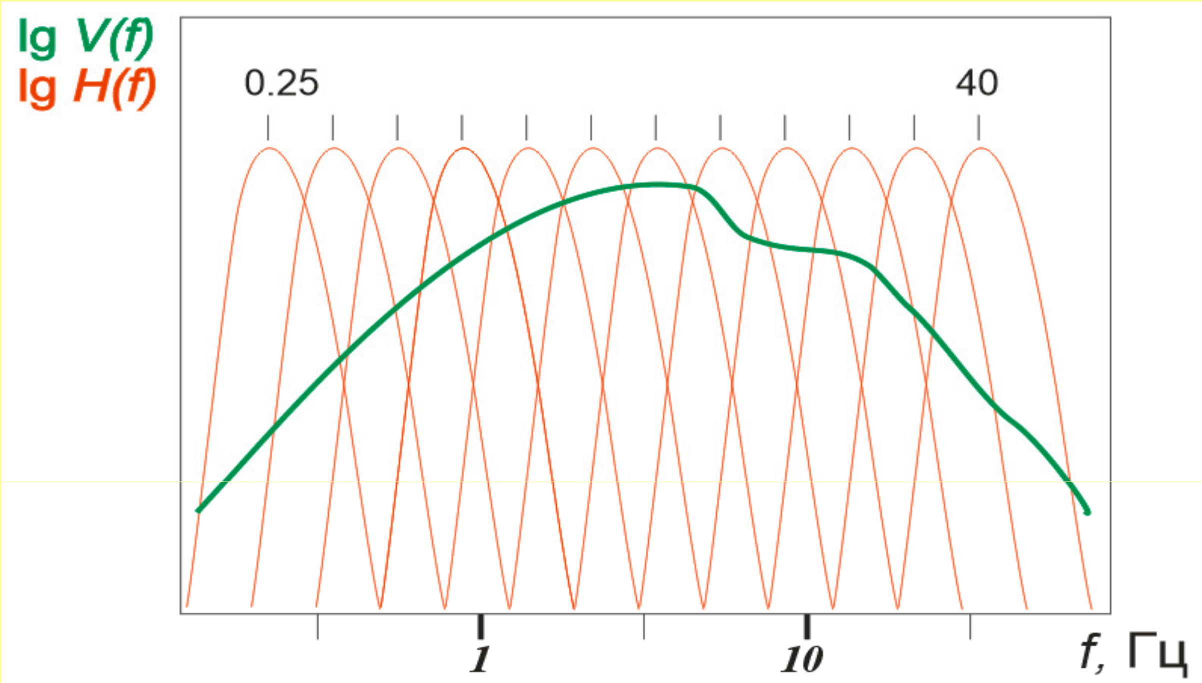
***later work: Mayeda&Walter***

**(3)** ***body wave, energy: unexplored***

***Main approach to follow: Rautian and Khalturin 1972-1978***

# Multiband magnitude concept (2)

## *the concept of data processing: sketch view*



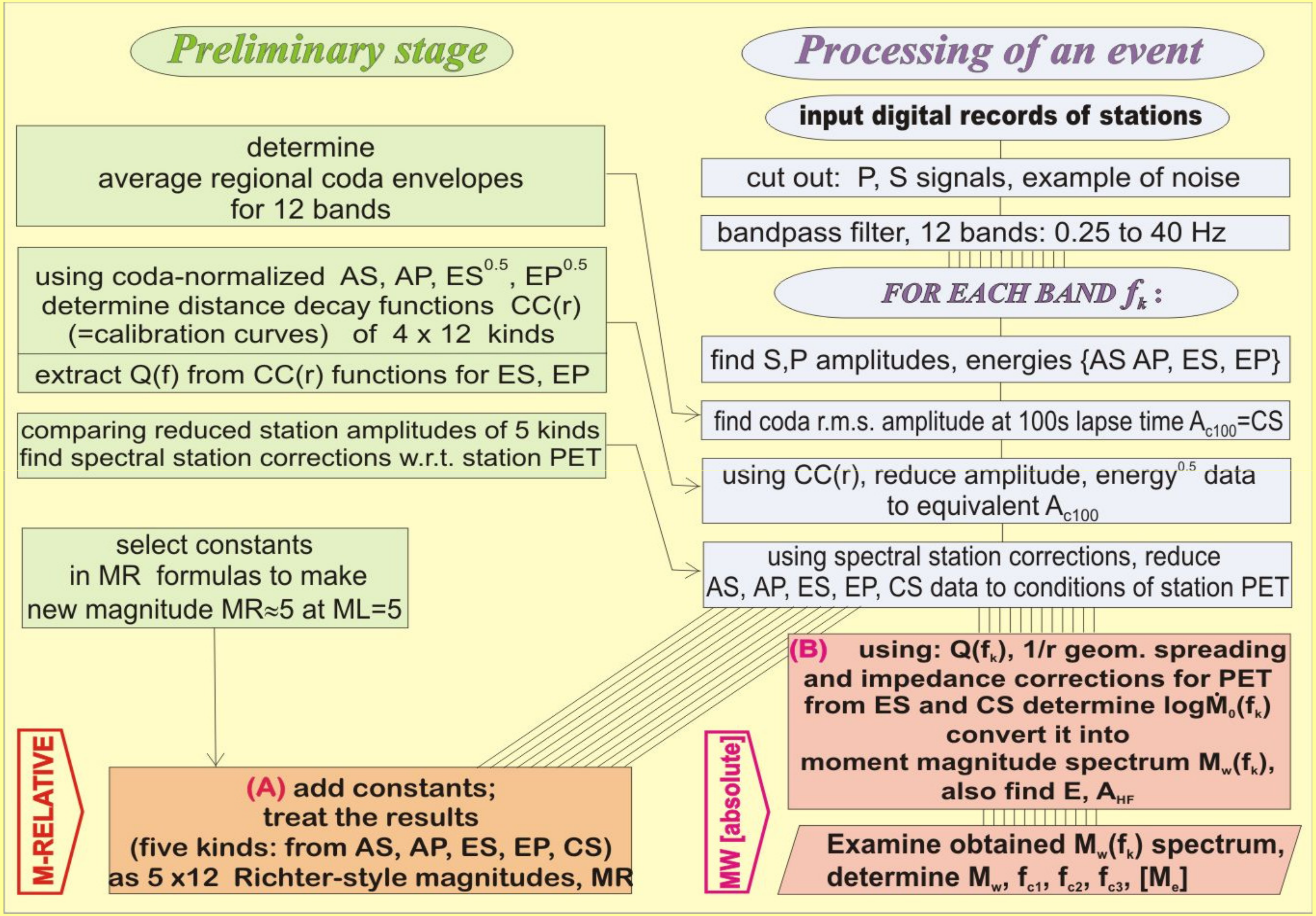

The version employed here

------ 2/3-octave/
0.2 decade filters,
with central frequencies:

**0.25, 0.4, 0.63, 1, 1.6, 2.5,**
**4, 6.3, 10, 16, 25, 40 Hz**

----- velocity spectrum of S-wave
----- filters: octave, 2/3-octave or like
----- with log-uniform set
----- of central frequencies

# Flow-chart of processing



# Flow-chart of processing: preparatory stage

## *Preliminary stage*

determine
average regional coda envelopes
for 12 bands

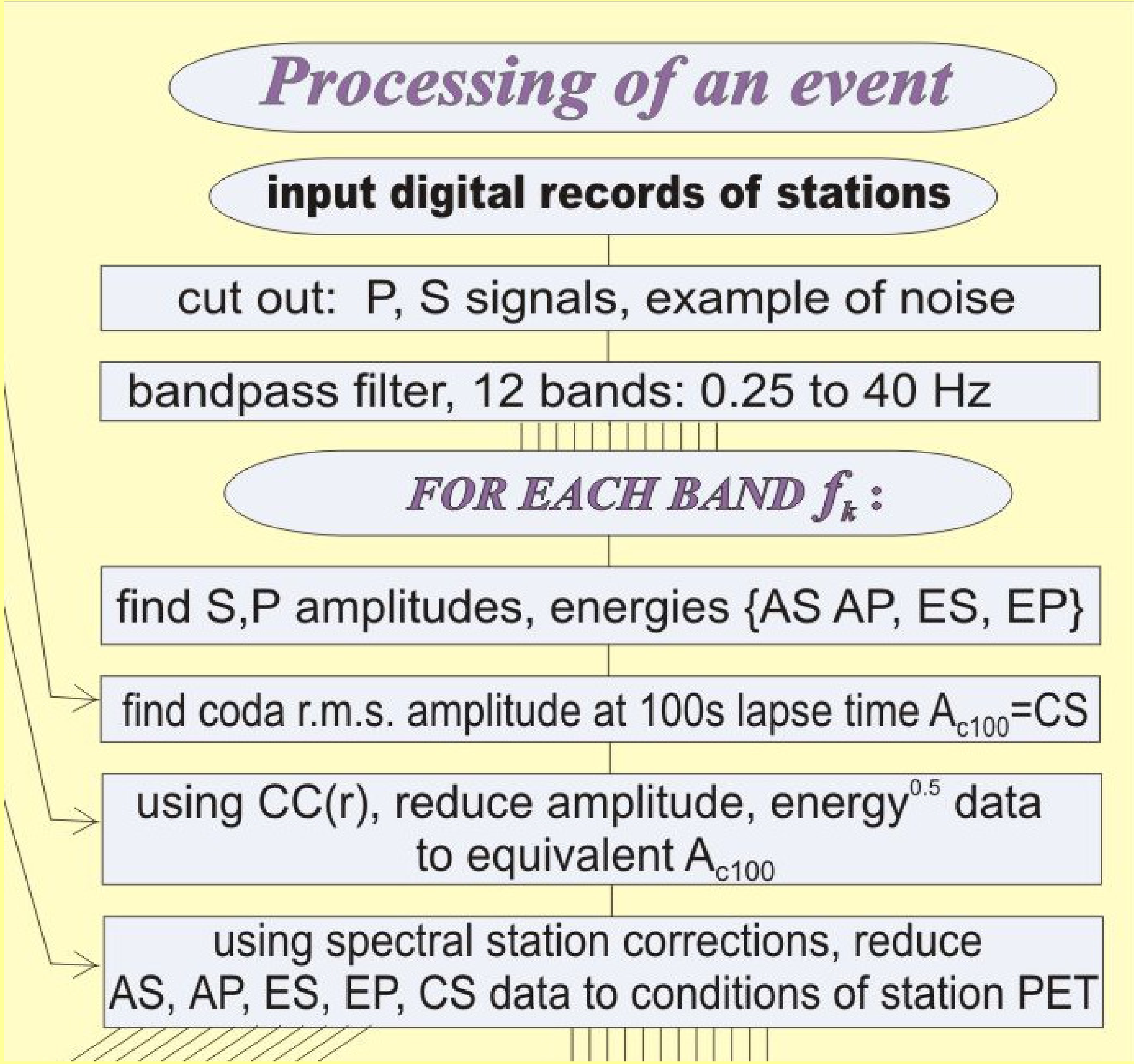
using coda-normalized AS, AP, $ES^{0.5}$, $EP^{0.5}$
determine distance decay functions CC(r)
(=calibration curves) of 4 x 12 kinds

extract Q(f) from CC(r) functions for ES, EP

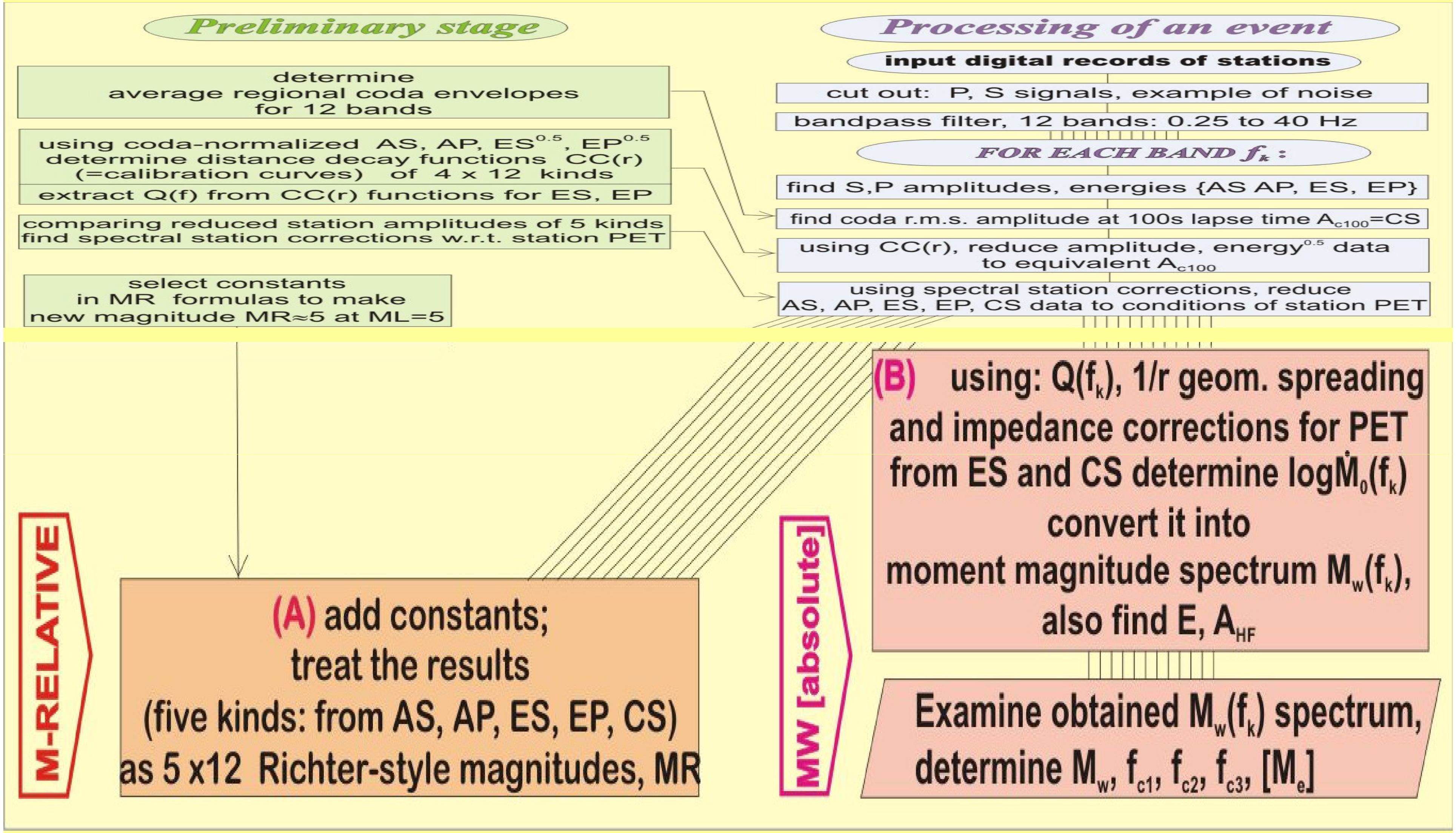
comparing reduced station amplitudes of 5 kinds
find spectral station corrections w.r.t. station PET

select constants
in MR formulas to make
new magnitude MR≈5 at ML=5

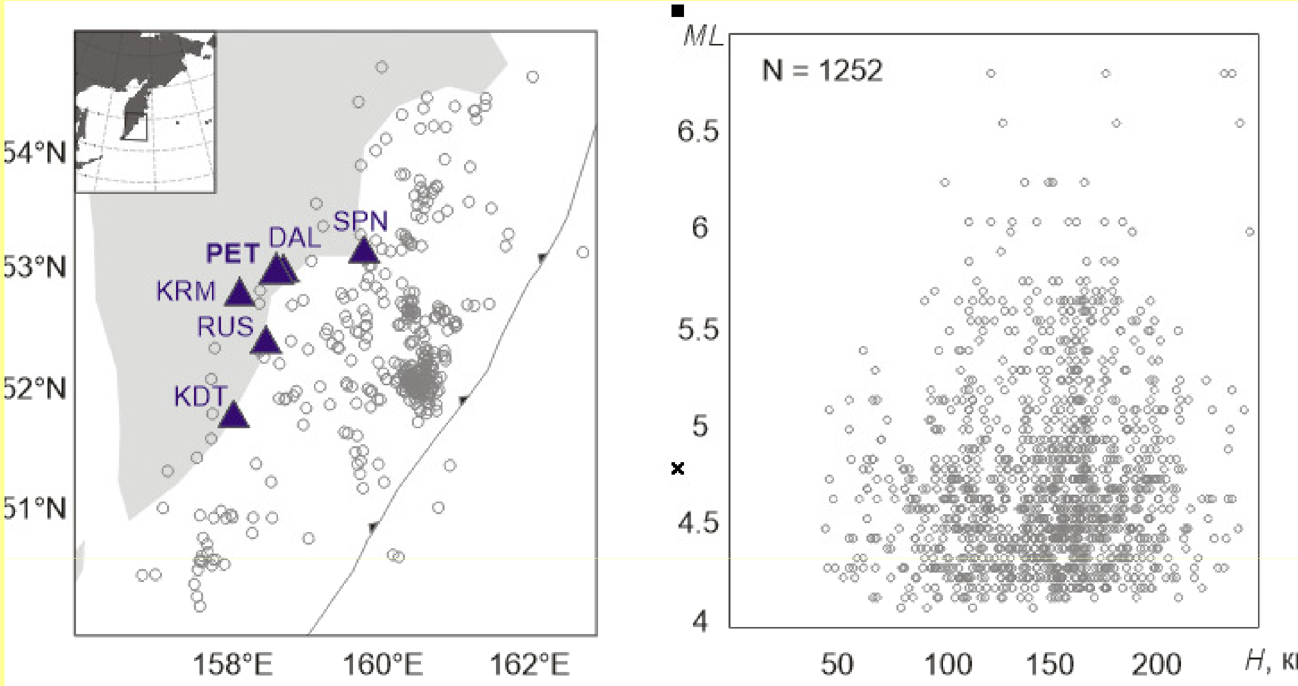
## Flow-chart of processing: single event reduction stage



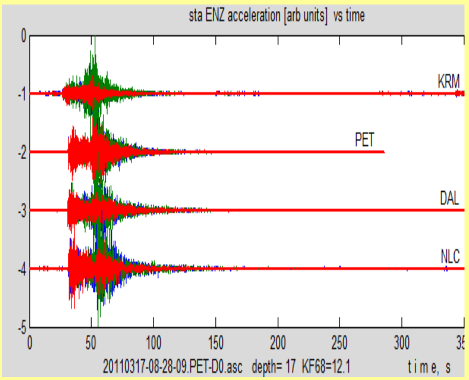
# Flow-chart of processing: single-event M calculation

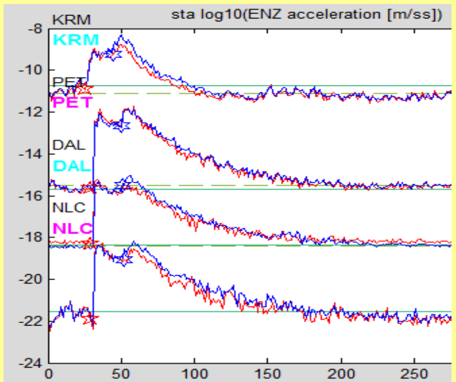


# Main dataset used



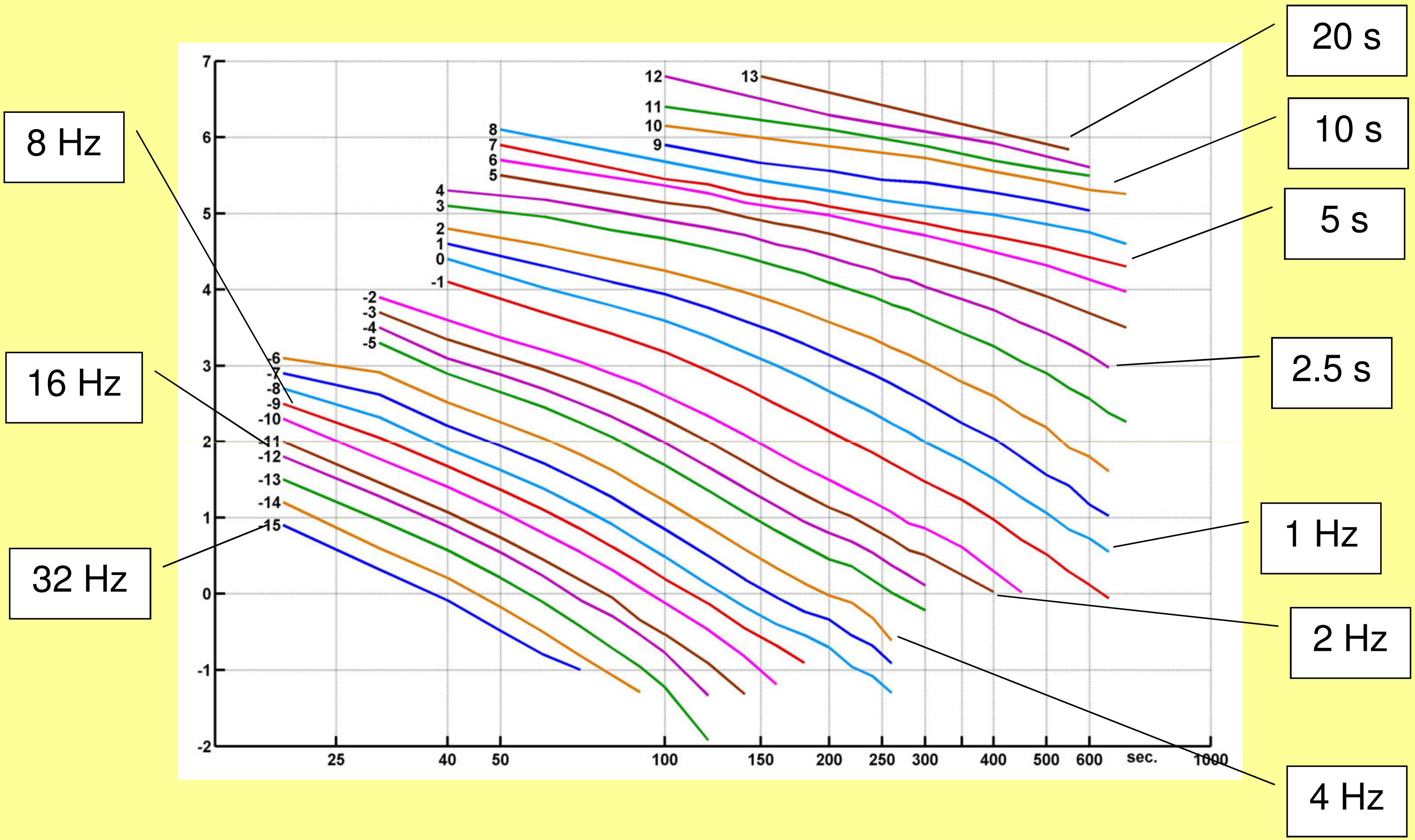

Data description:
7 rock-like stations
accelerometers
CMG5T and CMG5TD
Digitization: 100 sps
372 earthquakes,
Depth: 5 - 170 km




**Example unfiltered data: traces and log envelopes**

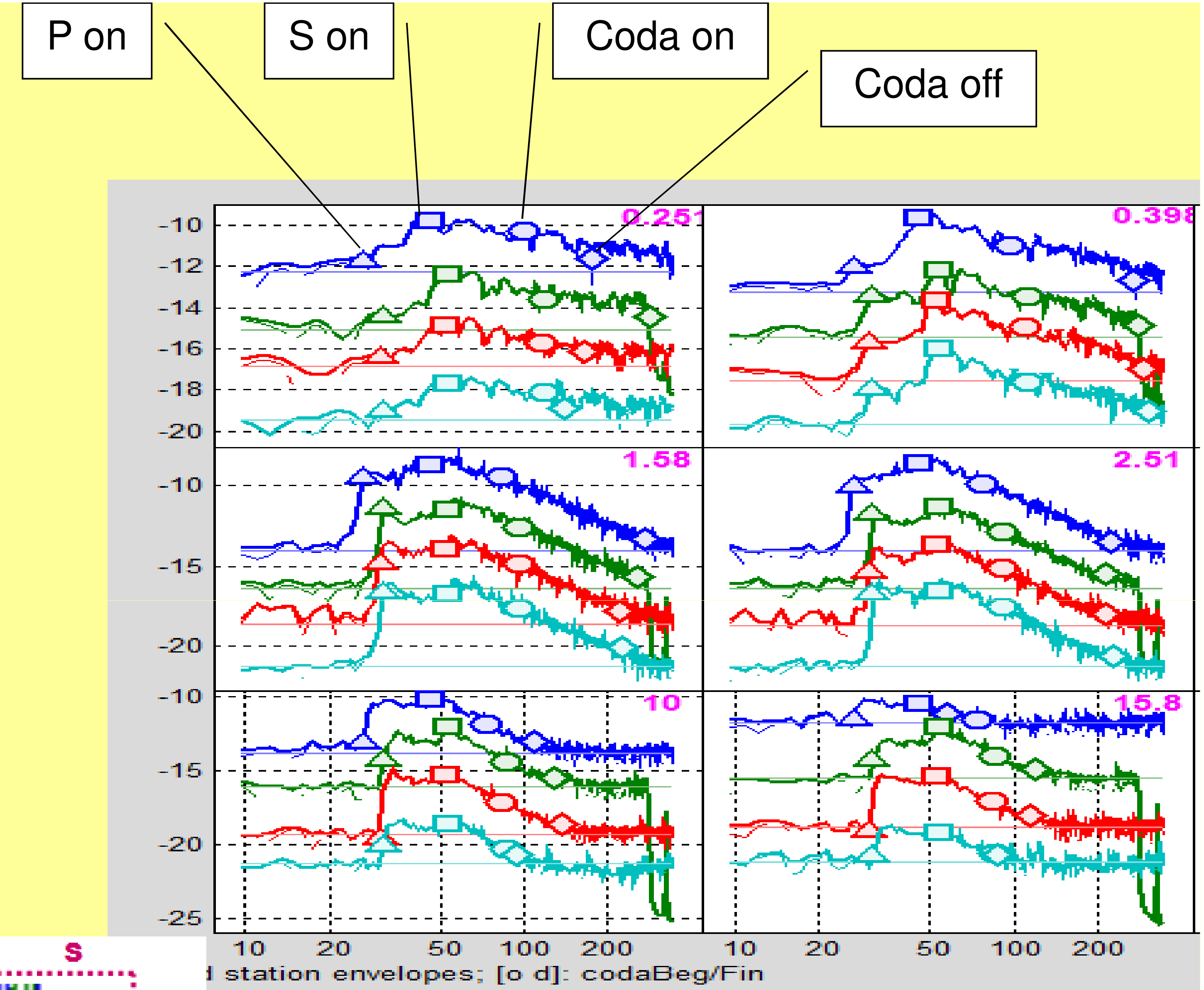
# Average regional coda envelopes

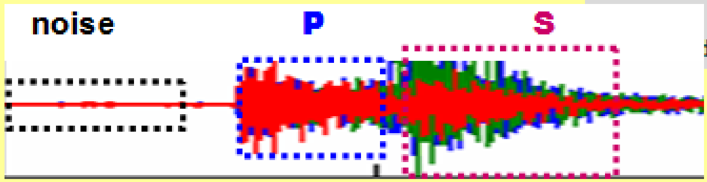



**Preliminary work: determination of average regional coda envelopes for a set of frequency bands. The range of central frequencies from 0.05 to 32 Hz, with step 0.1 along log f. Filter bandwidth 0.2 decade=2/3 octave**

**Example band envelopes**

**4 stations, 6 bands of total 12**




P, S spectrum calculation windows

# Measurement procedures

*Measured entities (per each band):* *code*

•S wave peak ……………………………………………“AS”
•P wave peak ……………………………………………“AP”
•S wave energy over: (onset to onset+1.8*ttime) ……… “ES”
•P wave energy over: (onset to onset+1.6*ttime)……… “EP”
•Coda rms amplitude at 100 s lapse time ……………… “CS”

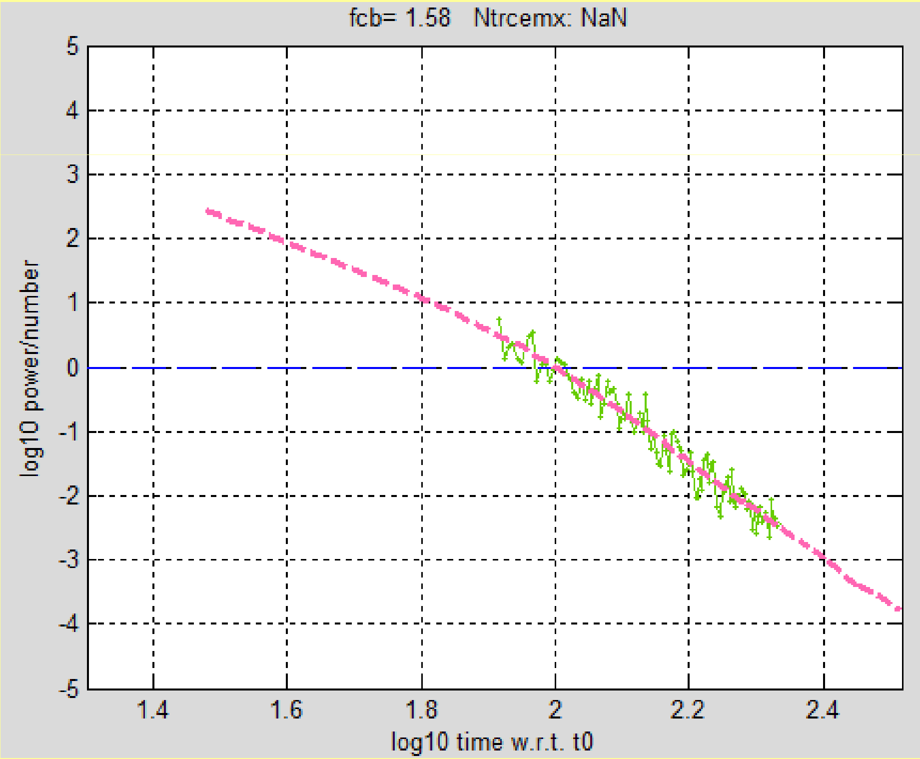



Illustration for the procedure of determination of rms amplitude of coda.

Red: regional standard coda shape of the 1.6 Hz band, power

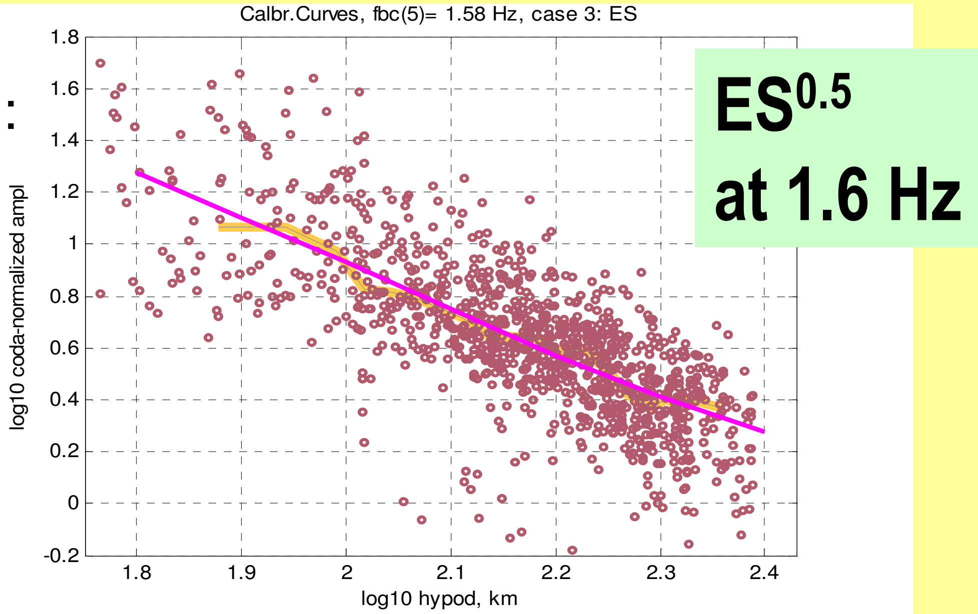
Green: the residual of fitting the instant square amplitude of individual coda (sum of 3 traces) by the red line.

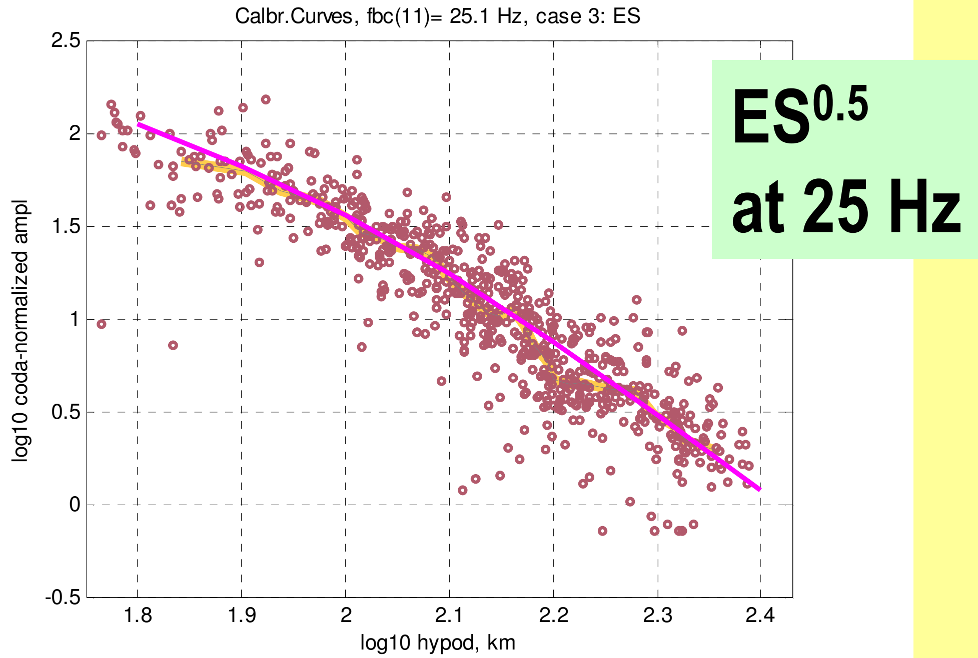
Note good accuracy of fitted level, i.e., of CS estimate

## Calibration curves: consrtucting by coda normalization

Normalized amplitudes
per each band of each station (dots):
aS=AS/CS,
aP=AP/CS,
yS=YS/CS, where YS=$ES^{0.5}$
yP=YP/CS, where YP=$EP^{0.5}$

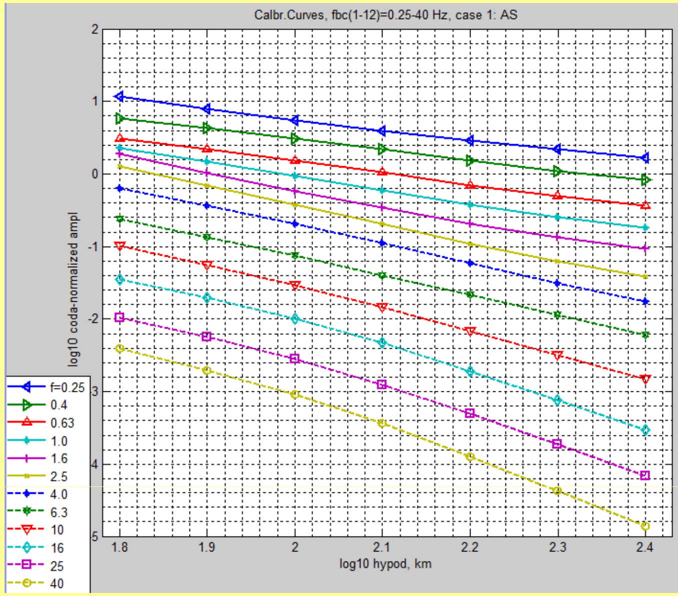
magnitude calibration curves
are smoothed normalized
amplitudes (pink lines):
CCAS(r)= <aS(r)>
CCPP(r)= <aP(r)>
CCYS(r)= <yS(r)>
CCYP(r)= <yP(r)>

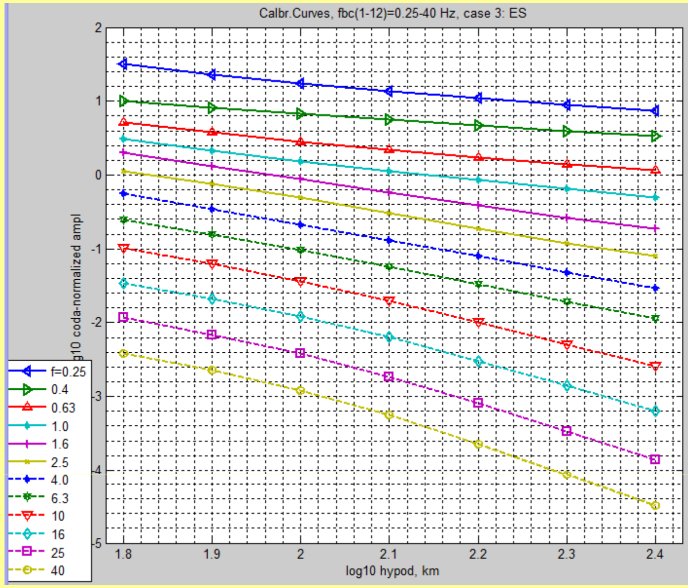


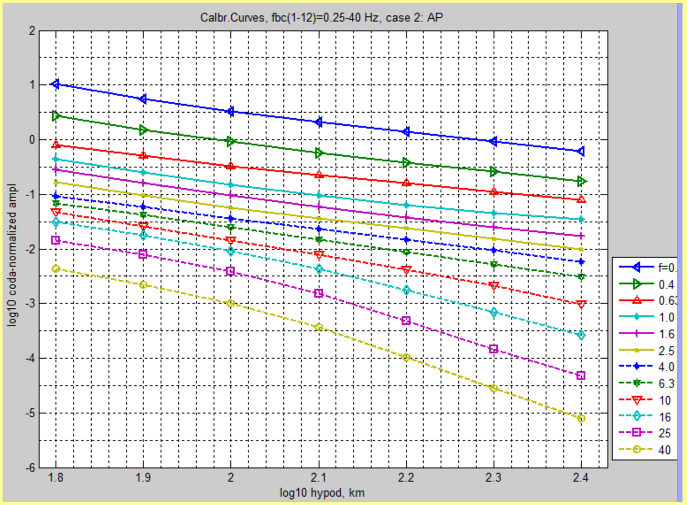



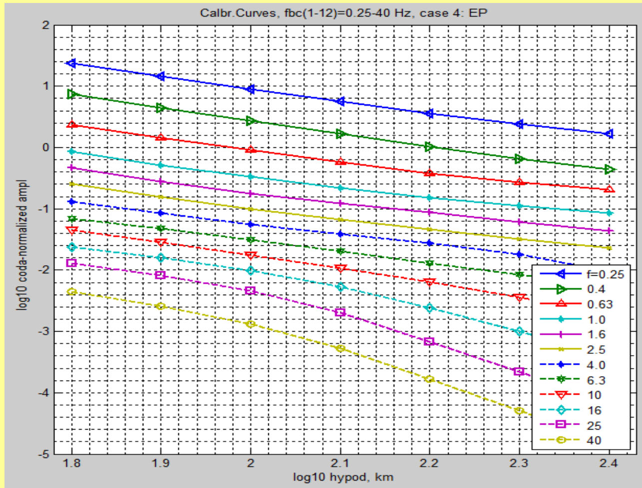

examples shown: YS, 1.6 and 25 Hz

# calibration curves:
# shapes for *AS, AP, YS=ES$^{0.5}$, YP=EP$^{0.5}$ , 12 bands*

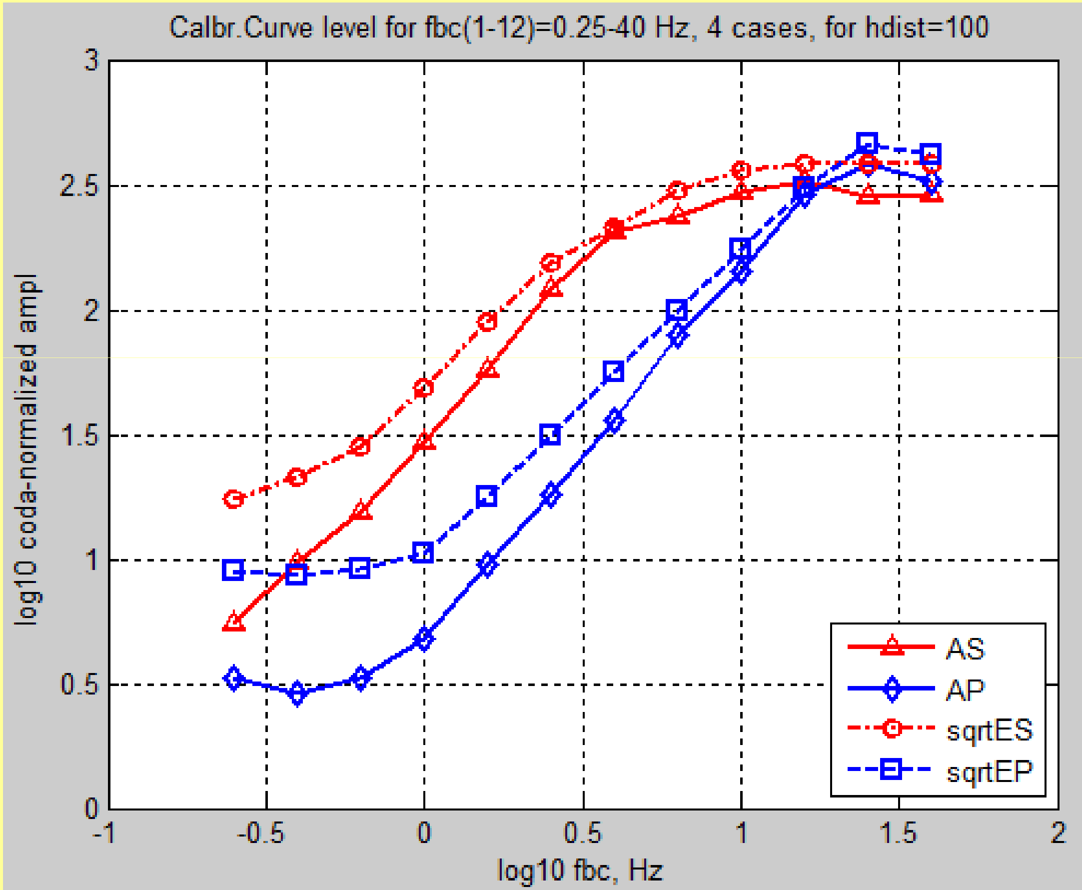


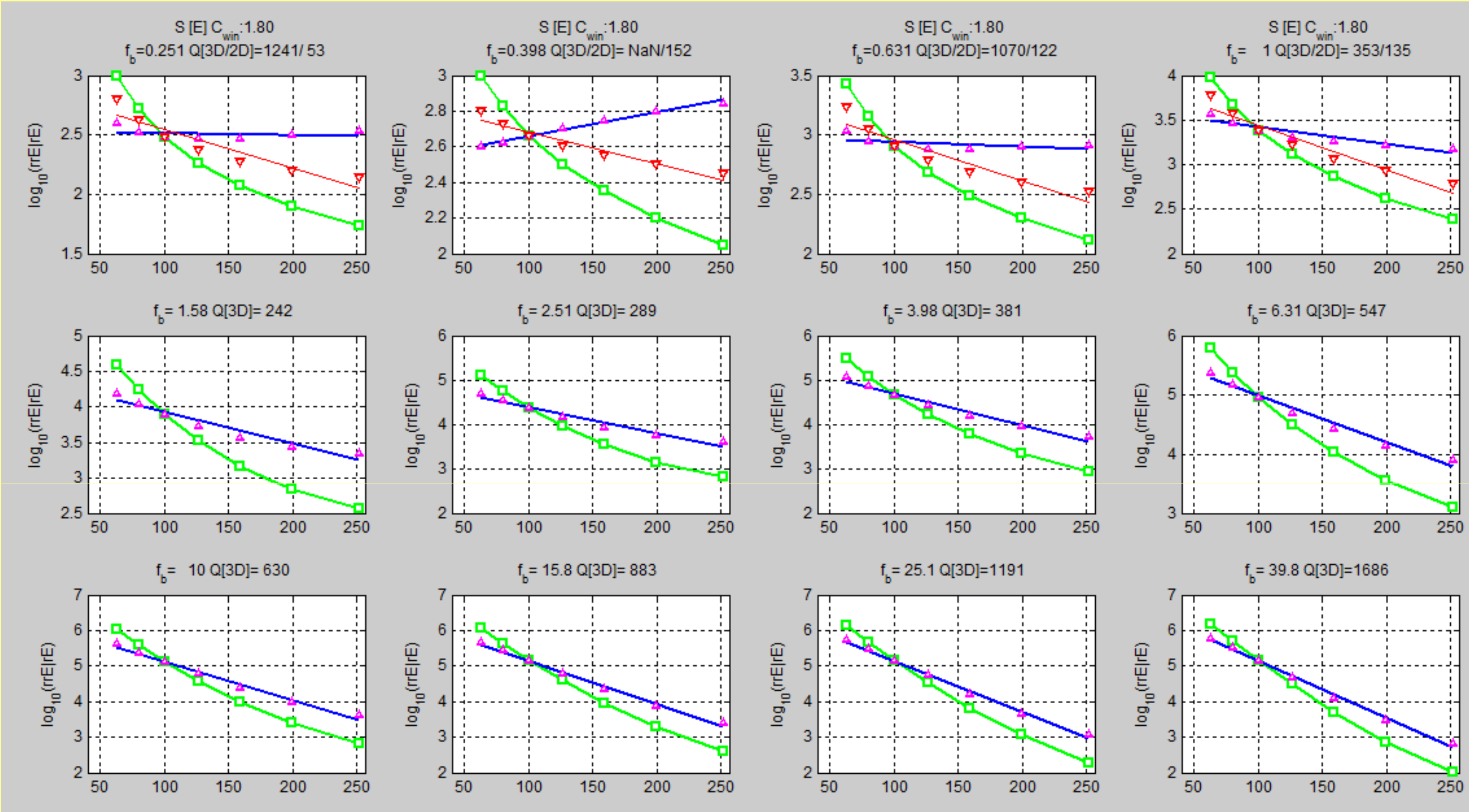



# Calibration curves: their level at 100 km, anchored by Ac(100 s)



# S wave loss determination

# using the shape of Calibration Curves for ES

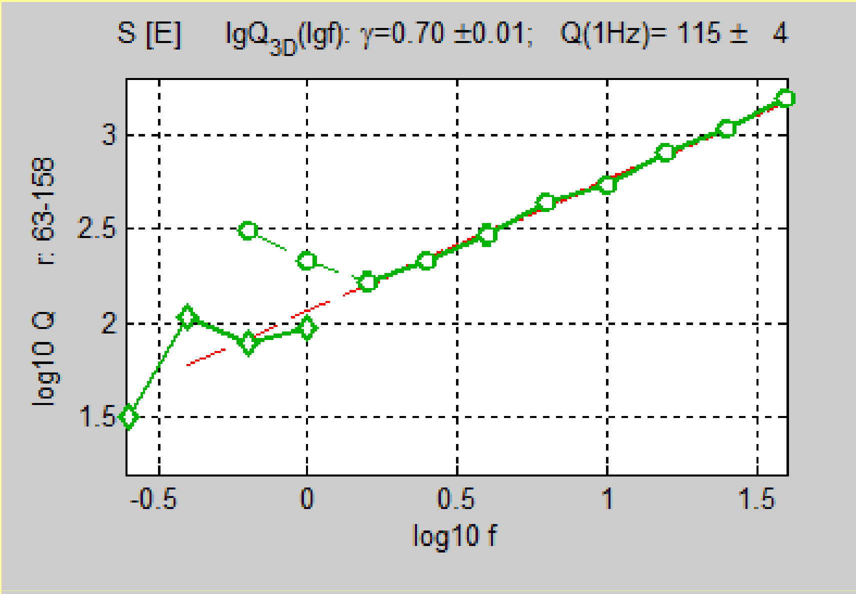


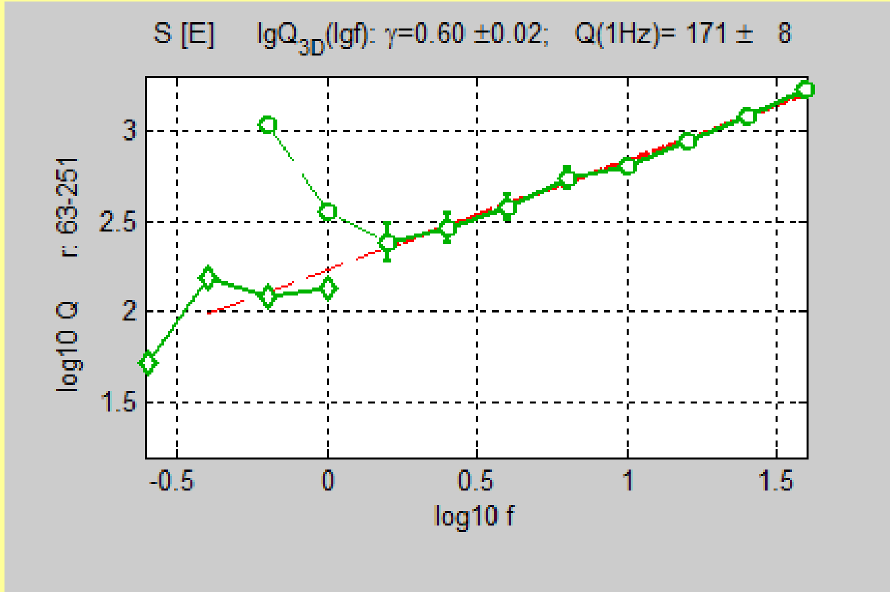

CCES

---Δ---- $r^2$ * CCES (pure loss effect 3D, amplitude decay 1/r assumed)

----Δ--- $r$ * CCES (pure loss effect 2D, amplitude decay 1/$r^{0.5}$ assumed)

# Q(f) from S wave envelopes, 12 bands



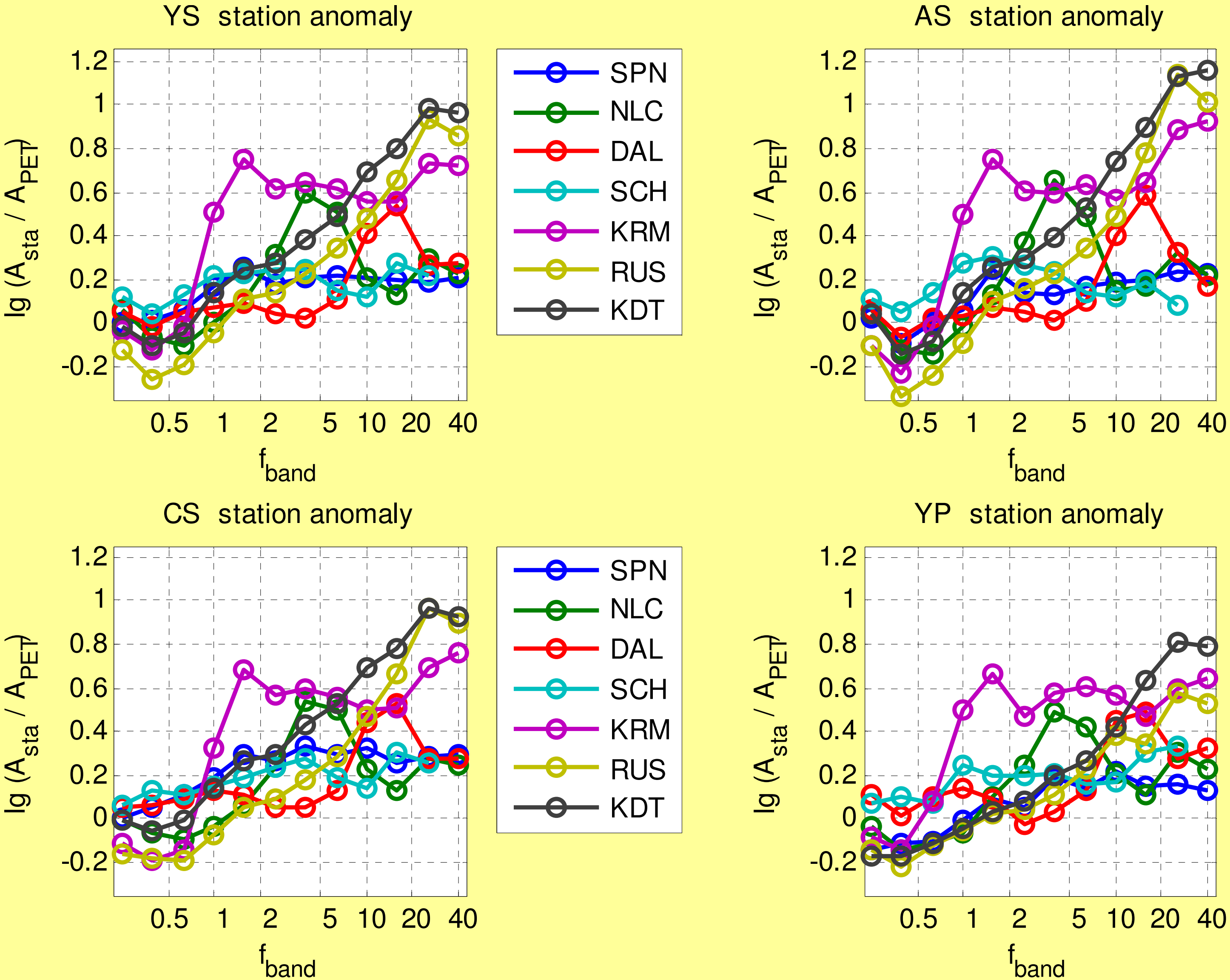




Distance base: 63-125 km 63-250 km

accepted quality factor for the r=1-50 km range

$$Q(f) = \begin{cases} 110 f^{0.6} & f \geq 1\,\mathrm{Hz} \\ 110 & f < 1\,\mathrm{Hz} \end{cases}$$

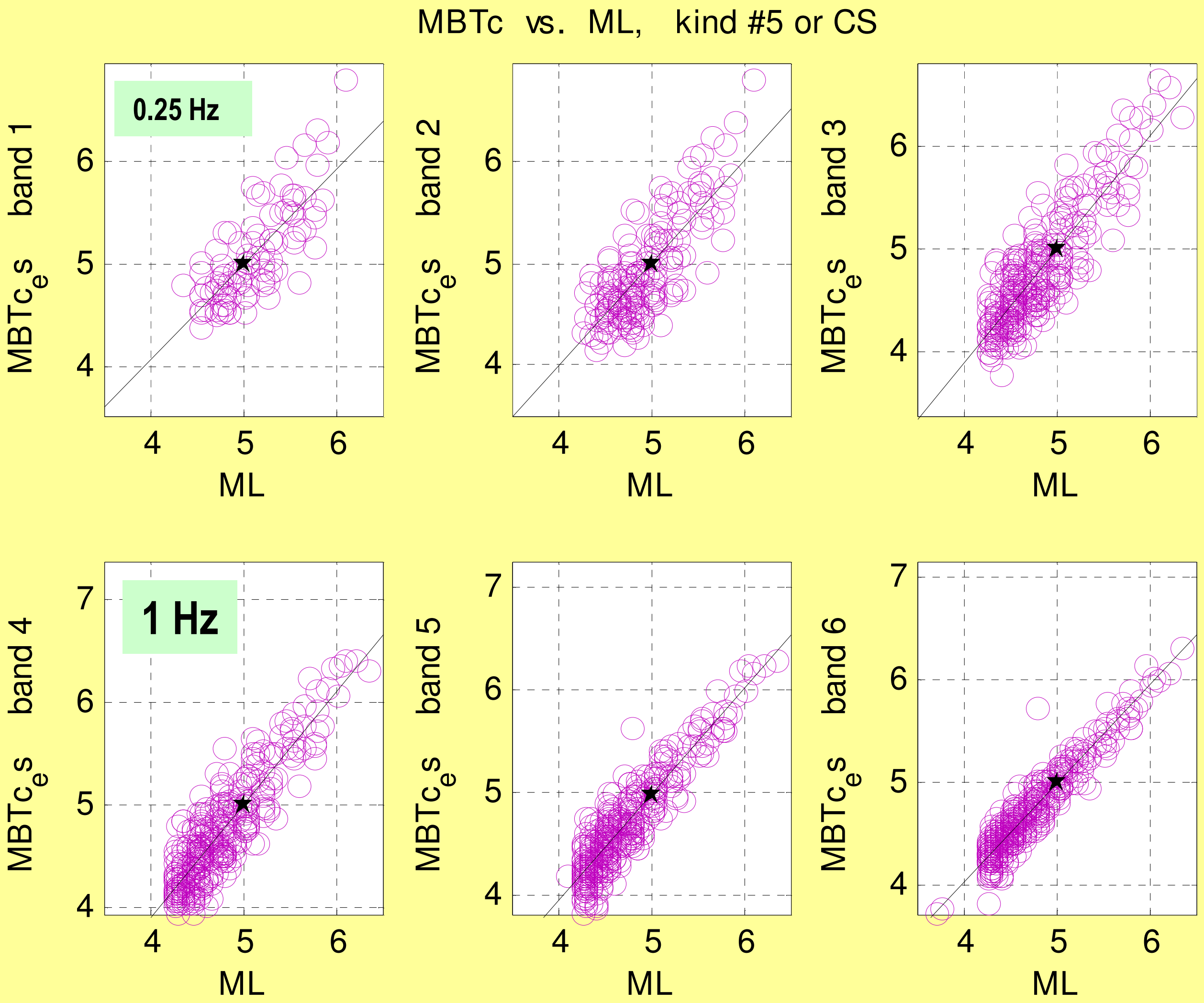
# Deriving station corrections as –(resudual w.r.t. PET)



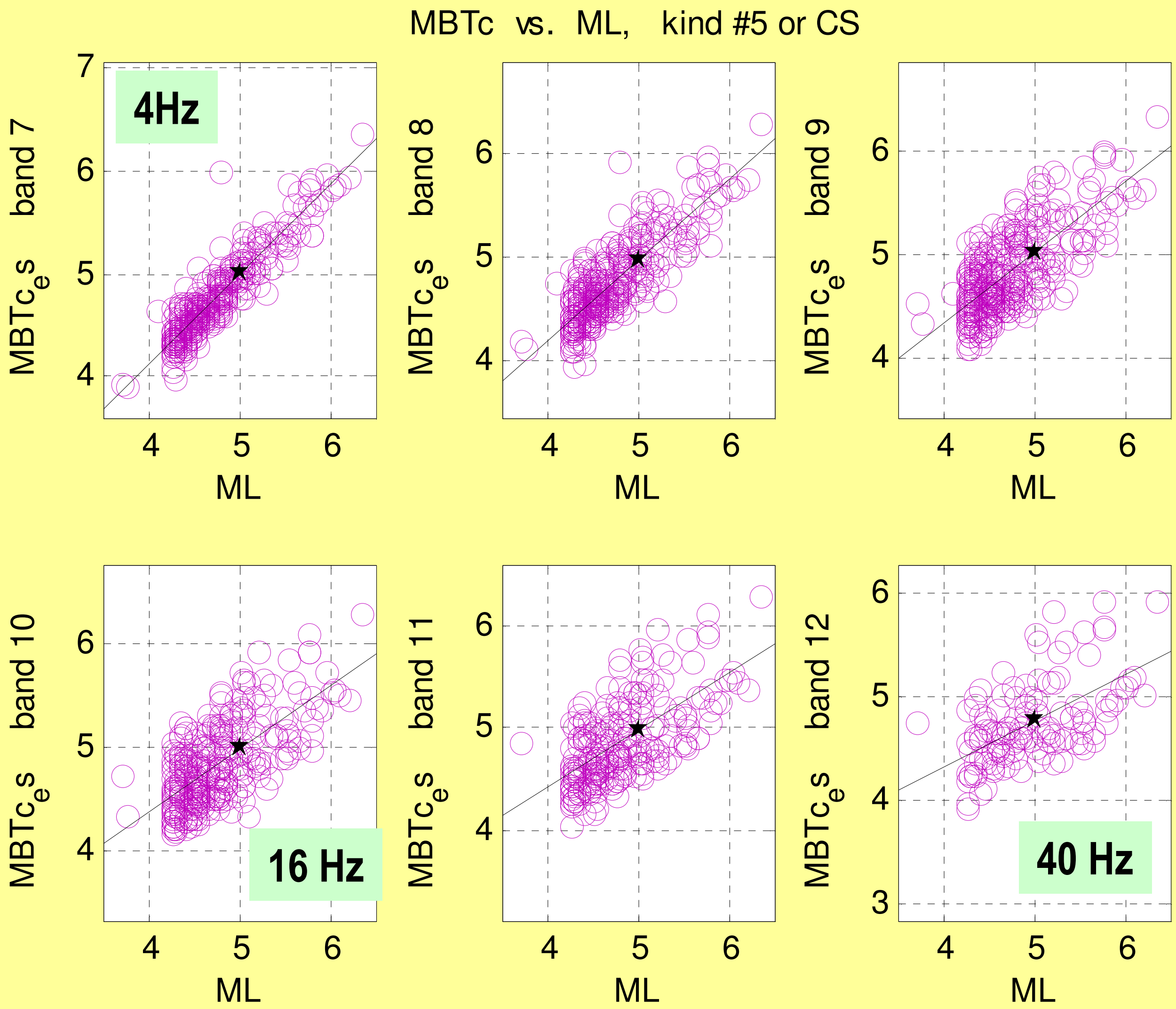

Note: resonance peaks at NLC, DAL, KRM; powerful amplification at HF at KDT, RUS

**(A) Richter-style (no absolute calibration) multiband magnitudes MRCS for 6 bands 0.25-2.5 Hz coda-level-based, determined by CS=$\log_{10}(A_{c100})$, vs. ML**

***for each band, constant shift is selected so as to set MRk=5 at ML=5***

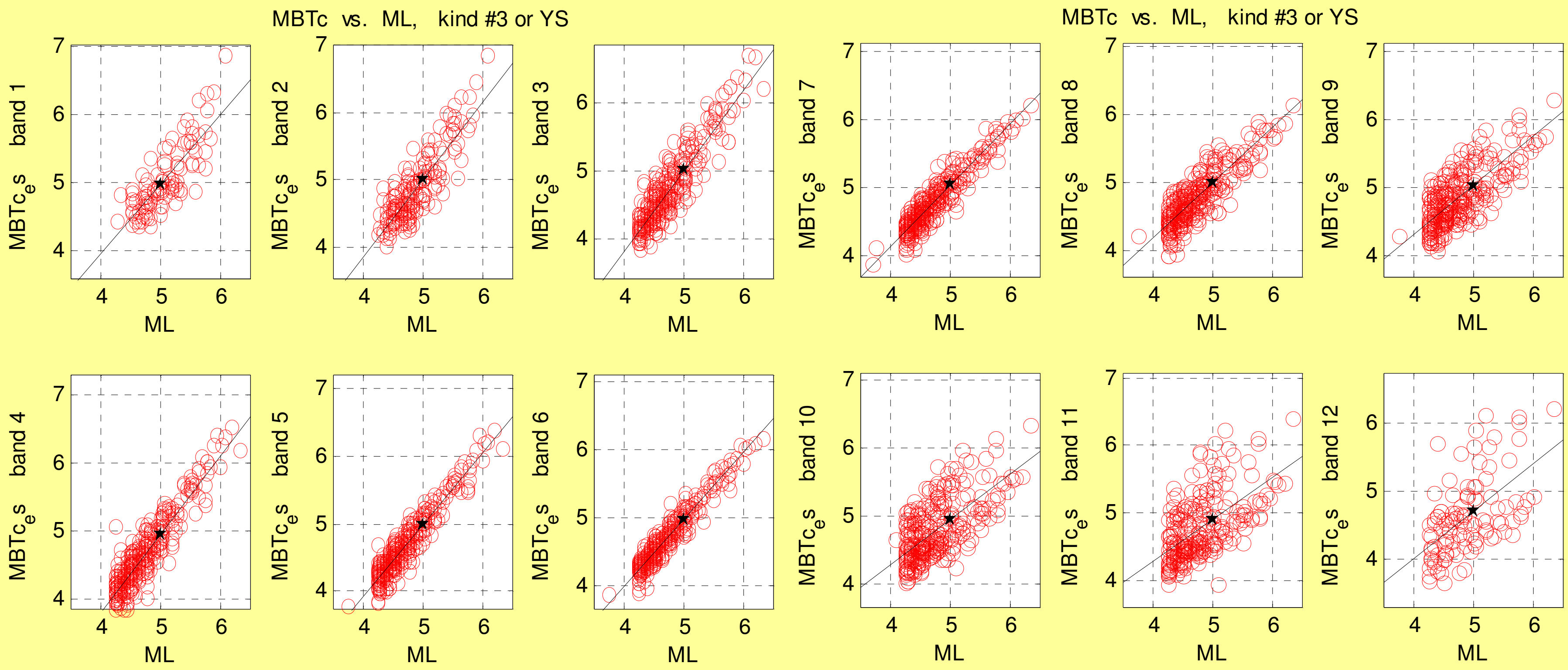


# Same, for 6 bands 4-40 Hz



# Richter-style multiband magnitudes MRES for 6 bands 0.25-2.5 Hz, vs. ML

## S-wave energy-based



## (2) Steps of absolute calibration of multiband magnitudes (only ES and CS kinds):

# making $\lg\dot{M}_0(f)$ or $M_W(f)$ spectrum

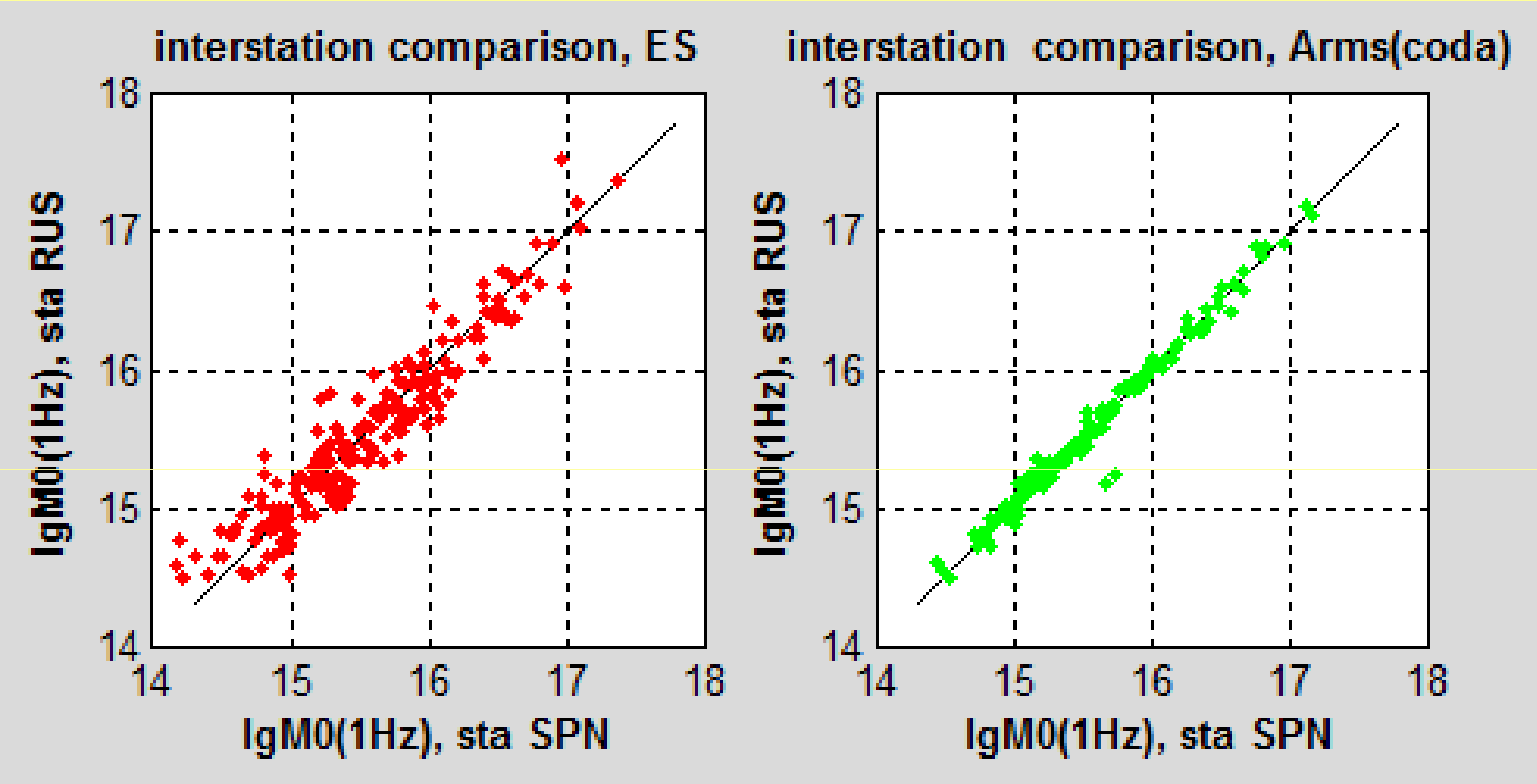
**Begin with uncalibrated 100s coda level of a station:**
**for CS: observed, for ES: reduced with calibration curve; reduce to PET using station corrections**

1. **Convert 100s coda level (real or converted) to ES level at r=50 km; transform ES to Fourier amplitude spectrum level**
2. **Using attenuation model and 1/r geometric spreading, convert r=50km spectra to r=1 km spectra**
3. **Introduce impedance corrections to reduce recorder conditions to the case of uniform half-space with mantle parameters.**
4. **Apply standard coefficients ($\mathcal{R}\, K_{surf}/4\pi c^3 \rho r)^{-1}$, and obtain:**

$$\dot{M}_0(f_k);$$

$$M_w(f_k) = \frac{2}{3}\log(\dot{M}_0(f_k) - 9.1)$$

# Accuracy comparison: ES vs. Coda




$\sigma$(single station)=**0.15**

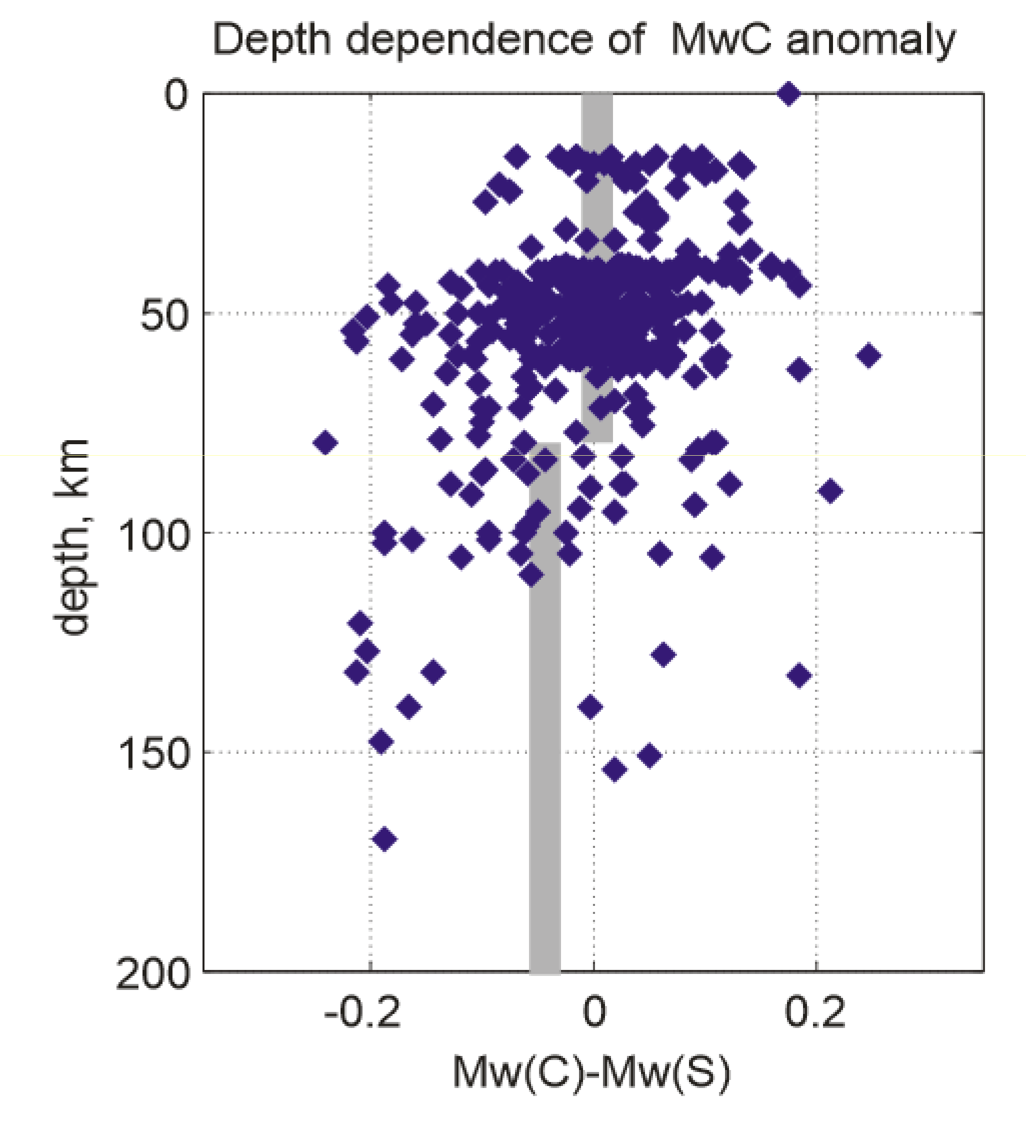
$\sigma$(single station)=**0.058**

***Interstation distance ~150 km***

Technical question:

Is $M_w$ from coda of deeper earthquakes correct?

may use $M_w$ from S-wave as a reference




***Plotted:***

***Mw(Coda)-Mw(S-wave)***

***Shows:***

***limited negative shift of about -0.1 below 80 km***

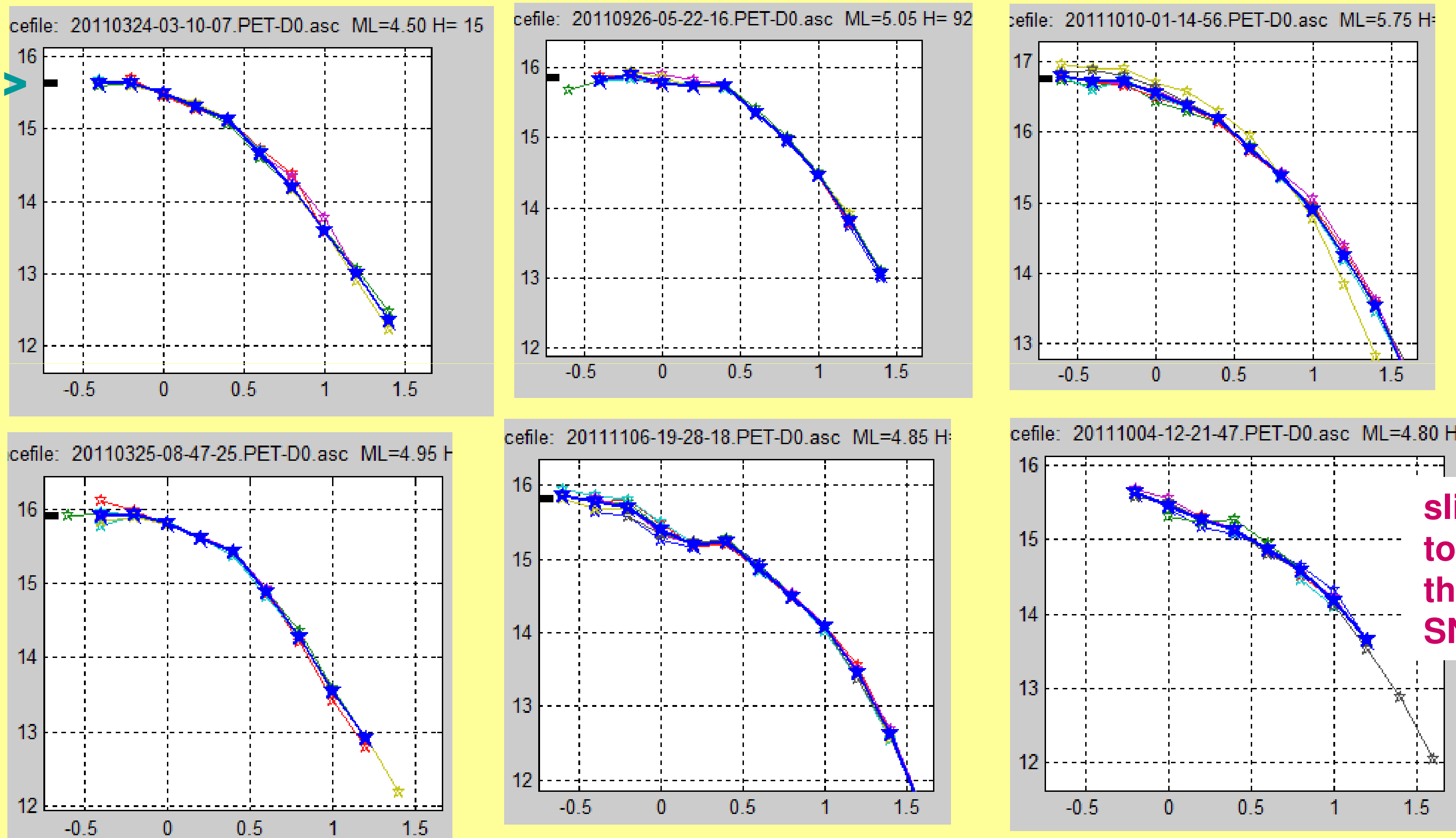
***Why?***

***Depressed coda generation at depth***

# Example source spectra $\dot{M}_0(f_k)$ from coda

**[stacks of single-station estimates (color-coded thin lines), the overlapping blue line is the median over 3$^+$ stations]**

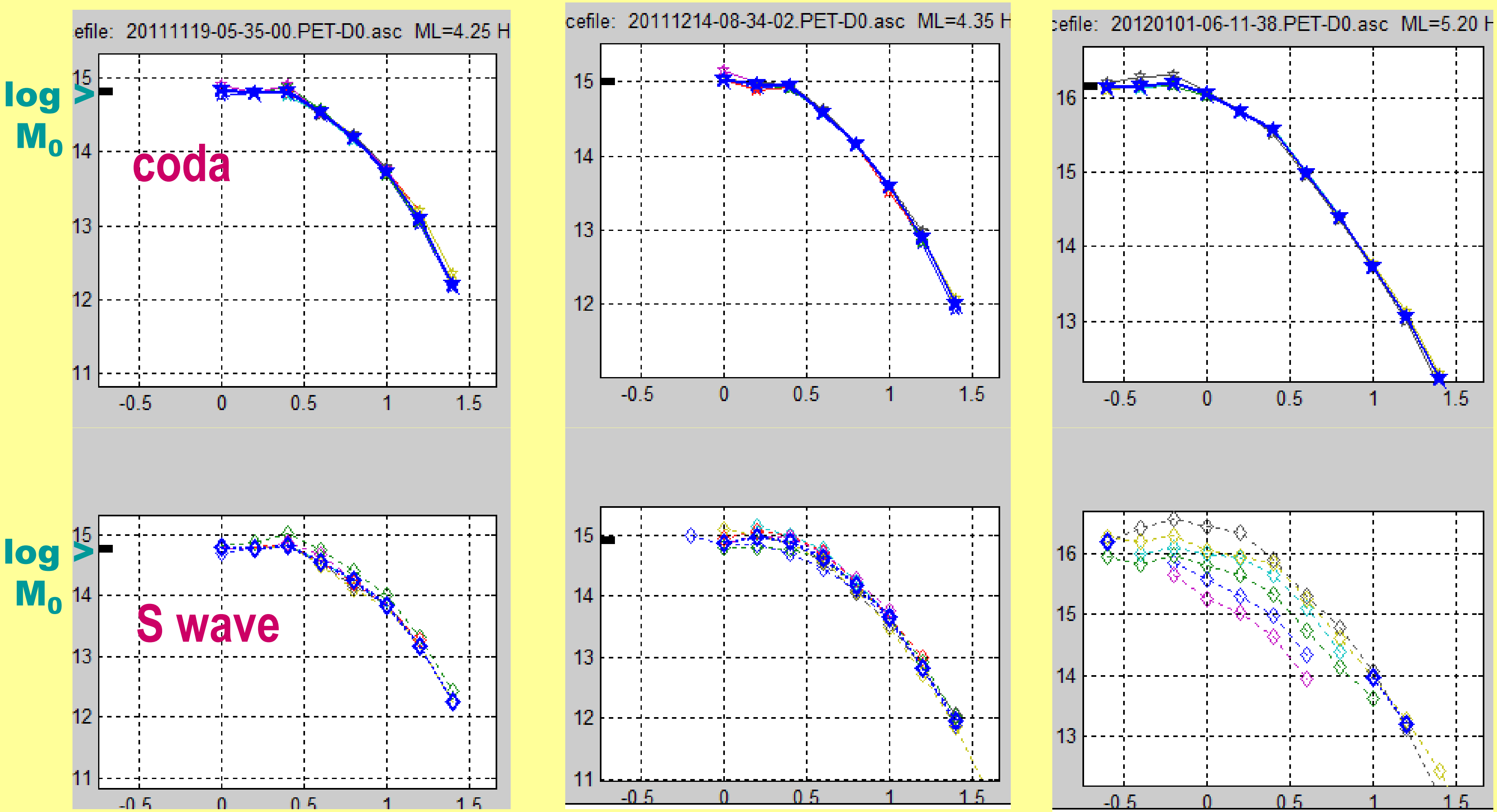
**log > $M_0$**




**slip too long to find M0 at the current SNR?**

≈ 80% of recovered spectra show clear LF shelf at 3$^+$ stations thus delivering **acceptable $M_0$ and $M_w$ estimates (-)**

## Example source spectra $\dot{M}_0(f_k)$ from coda (top) vs. from S-wave (bottom)



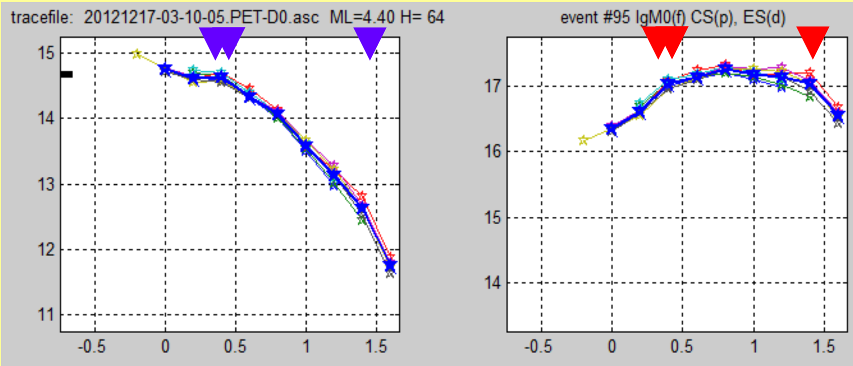

match of estimates *between coda and S-wave*: mostly good

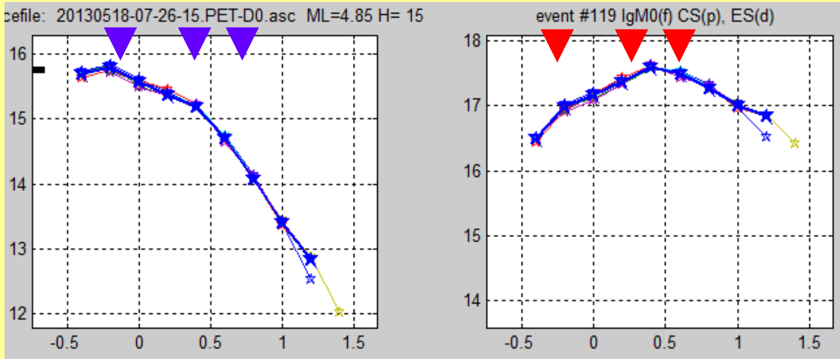
match *among stations*: good to excellent for coda
poor to good for S-wave

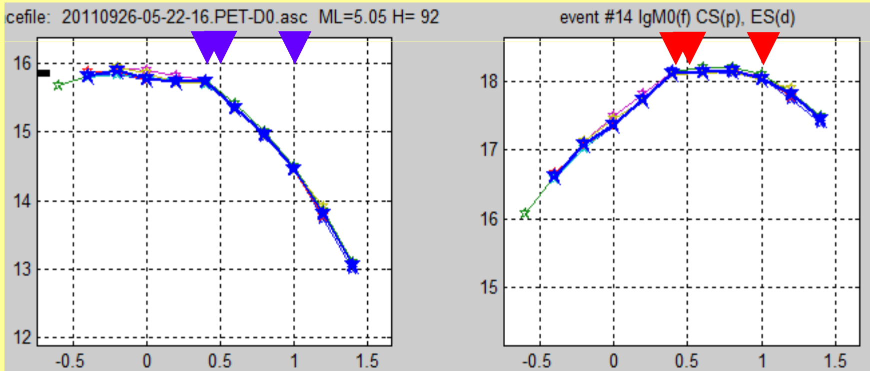
# Triples of corner frequencies

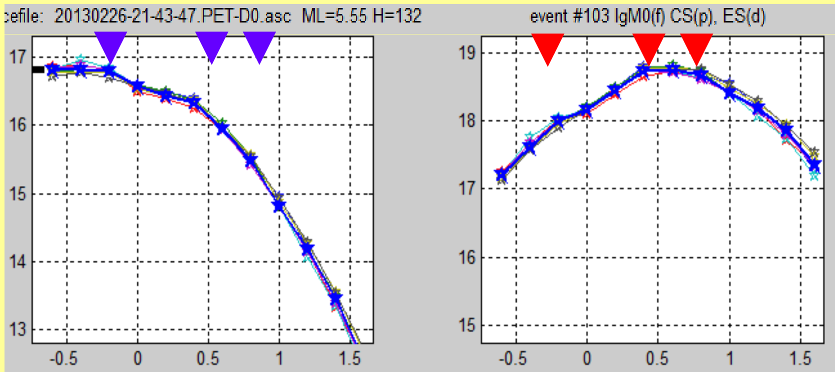
(automatically picked from source spectra using -3dB level w.r.t. plateau)

$\dot{M}_0(f_k)$ ("displacement", left) and $\dddot{M}_0(f_k)$ ("acceleration", right)




**More than 90% of spectra show "source-controlled" $f_{max}$, treated as "third corner frequency", $f_{c3}$**

**Many spectra show second corner frequency $f_{c2} > f_{c1}$**

# *Conclusions*

*(1) Foundations for Kamchatka regional multiband magnitude system are set. These include:*

*(a) standard coda shapes;*

*(b) AS, AP, ES, EP calibration functions; and*

*(c) station corrections*

*(2) A technique for Richter-style multiband magnitude determination is developed and tested, based on AS, AP, ES, EP , and CS data*

*(3) A technique for recovery, from ES and CS data in parallel, of calibrated (in N·m) source spectrum is developed and tested. On this basis, a technique for mass determination of* ***moment magnitude spectrum, $M_w(f)$,*** *is developed*

*(4) Almost all recovered source spectra show $f_{c3}$ feature.*

Thank you

for your attention