Some observations of data quality at global seismic stations

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Global CMT Project "Waveform Quality Center"

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Lamont-Doherty Earth Observatory
Columbia University | Earth Institute

IRIS

NSF

1. Data quality control using signals

    1a. Sensor response stability
    1b. Sensor orientation

2. Data quality control using noise

3. Key points, and challenges for instrumentation

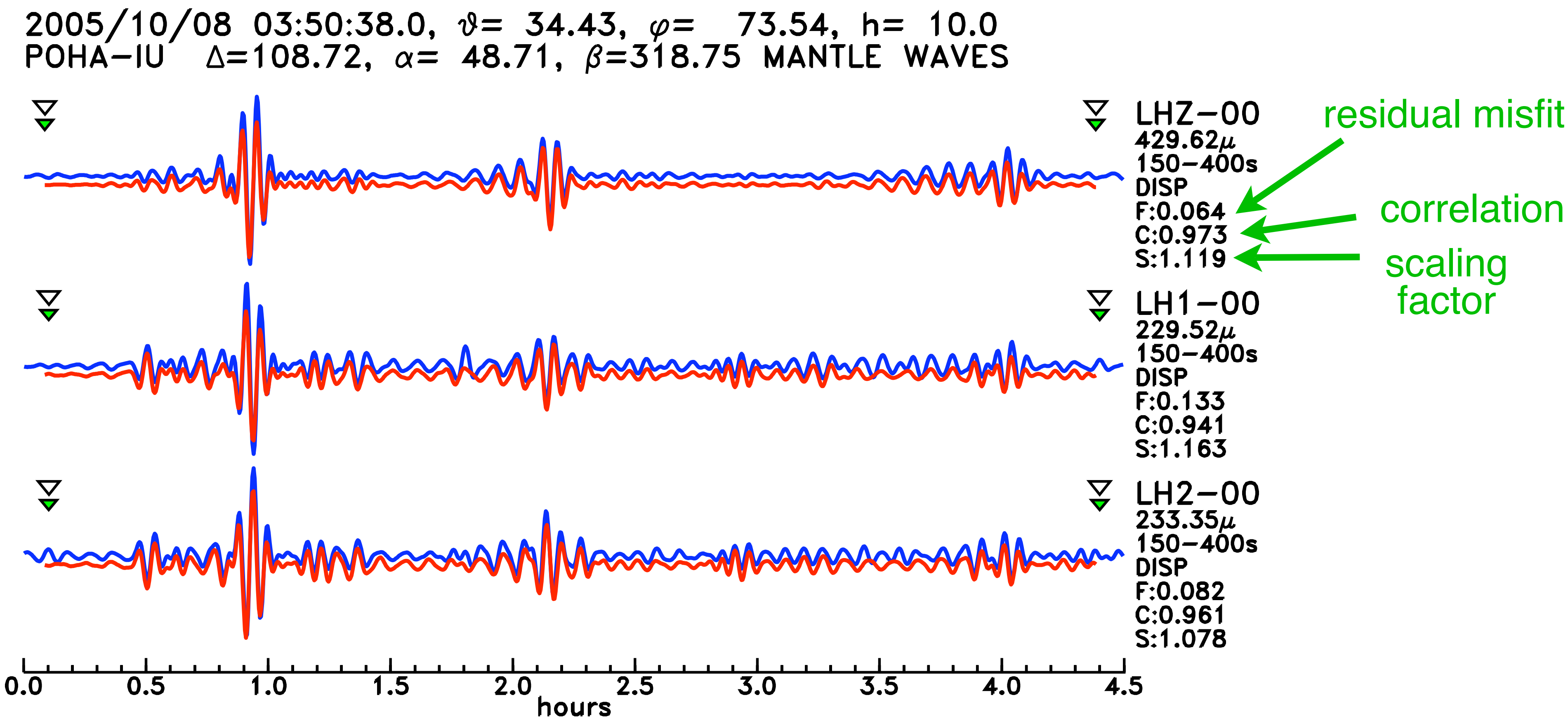
Assessment of reported gain in two frequency bands

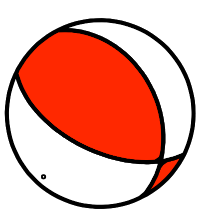
1. M>6.5 events in CMT catalog
2. Deconvolve instrument responses from dataless SEED volumes from IRIS DMC
3. Calculate optimal scaling for body waves (~60 s) and mantle waves (~175 s) for all well-fit seismograms
4. Calculate annual average and range of central quartiles

Initial results in Ekström et al. (2006); here, results for IC network updated through 2008.

Blue - observed seismograms

Red - synthetic seismograms

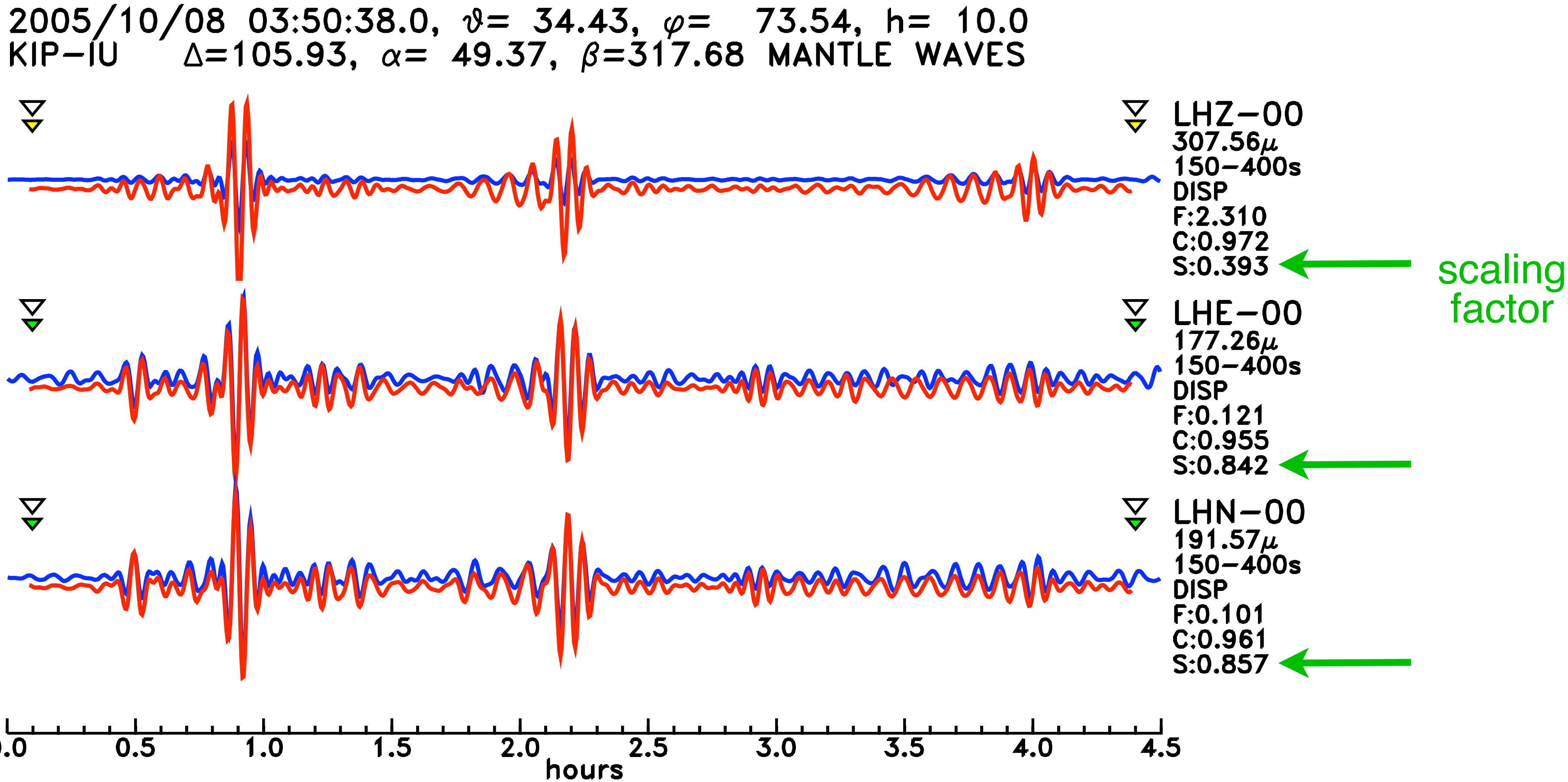


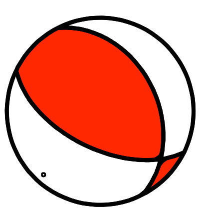


$$S = \frac{\sum_{i=1}^{N} o_i s_i}{\sum_{i=1}^{N} s_i^2}$$

Blue - observed seismograms

Red - synthetic seismograms





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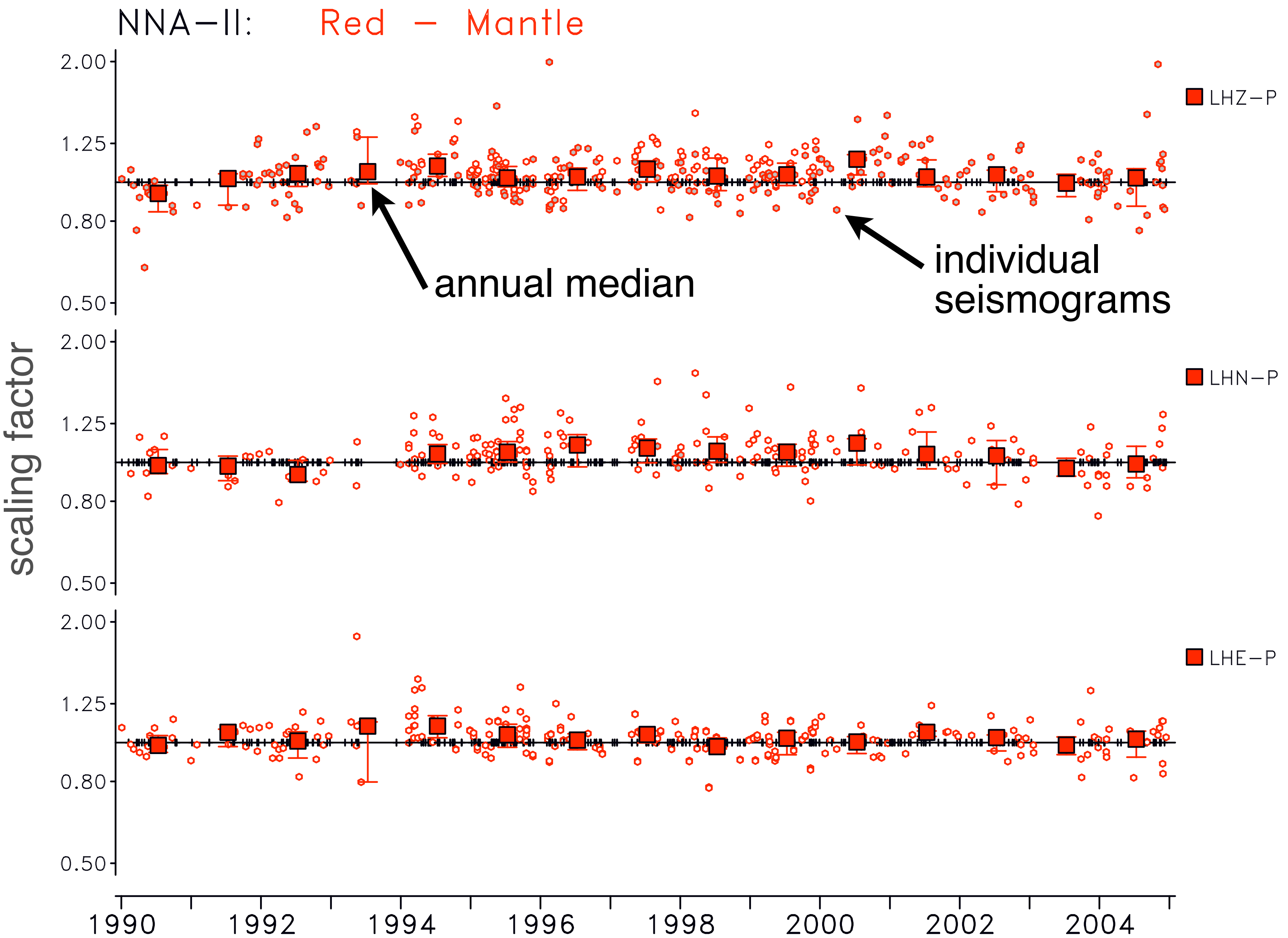
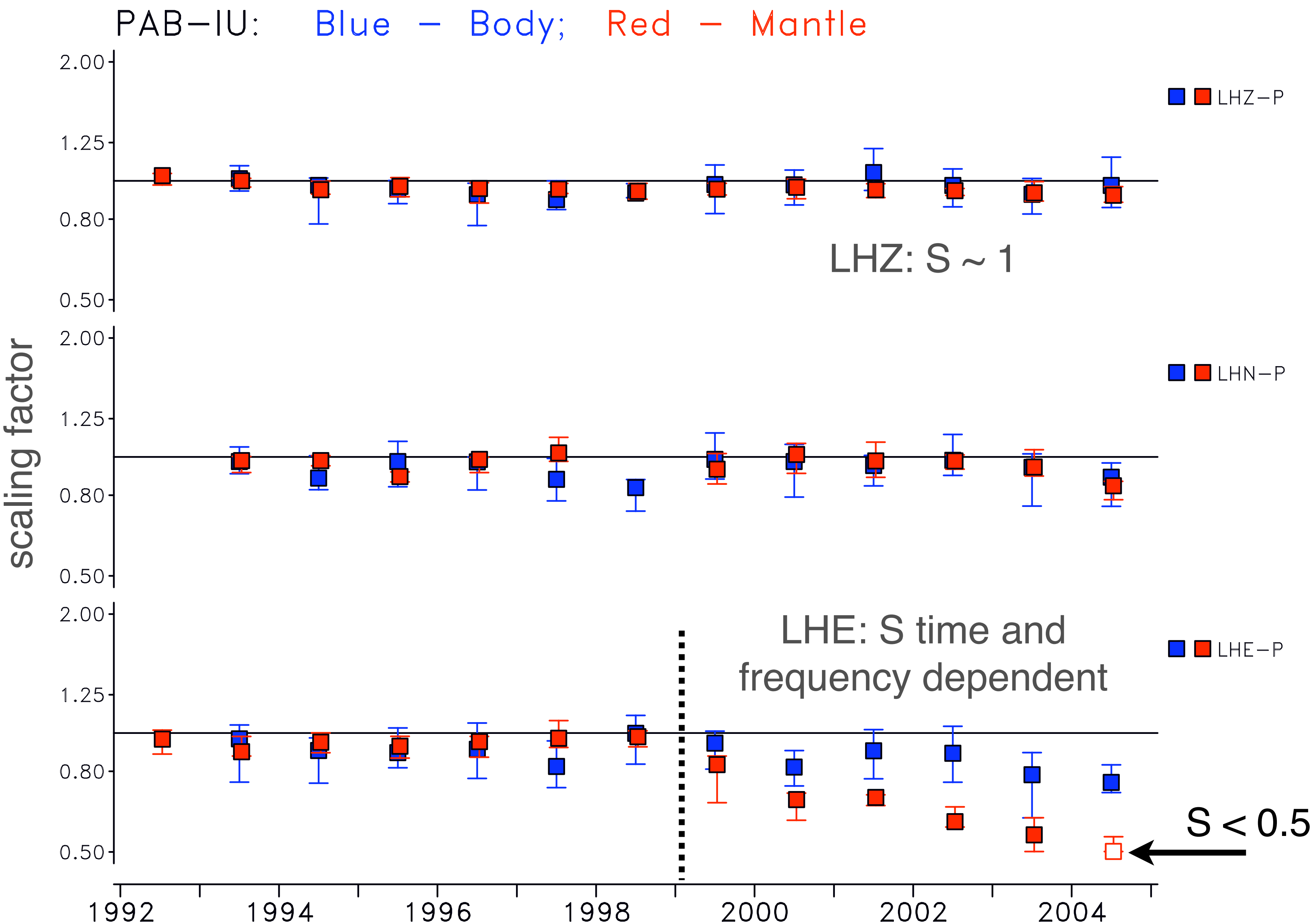
Scaling factors at NNA-II, 1990-2004



Scaling factors at PAB-IU, 1992-2004

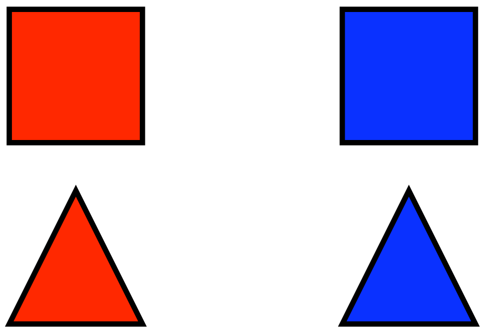
Example from Ekström et al. (2006)



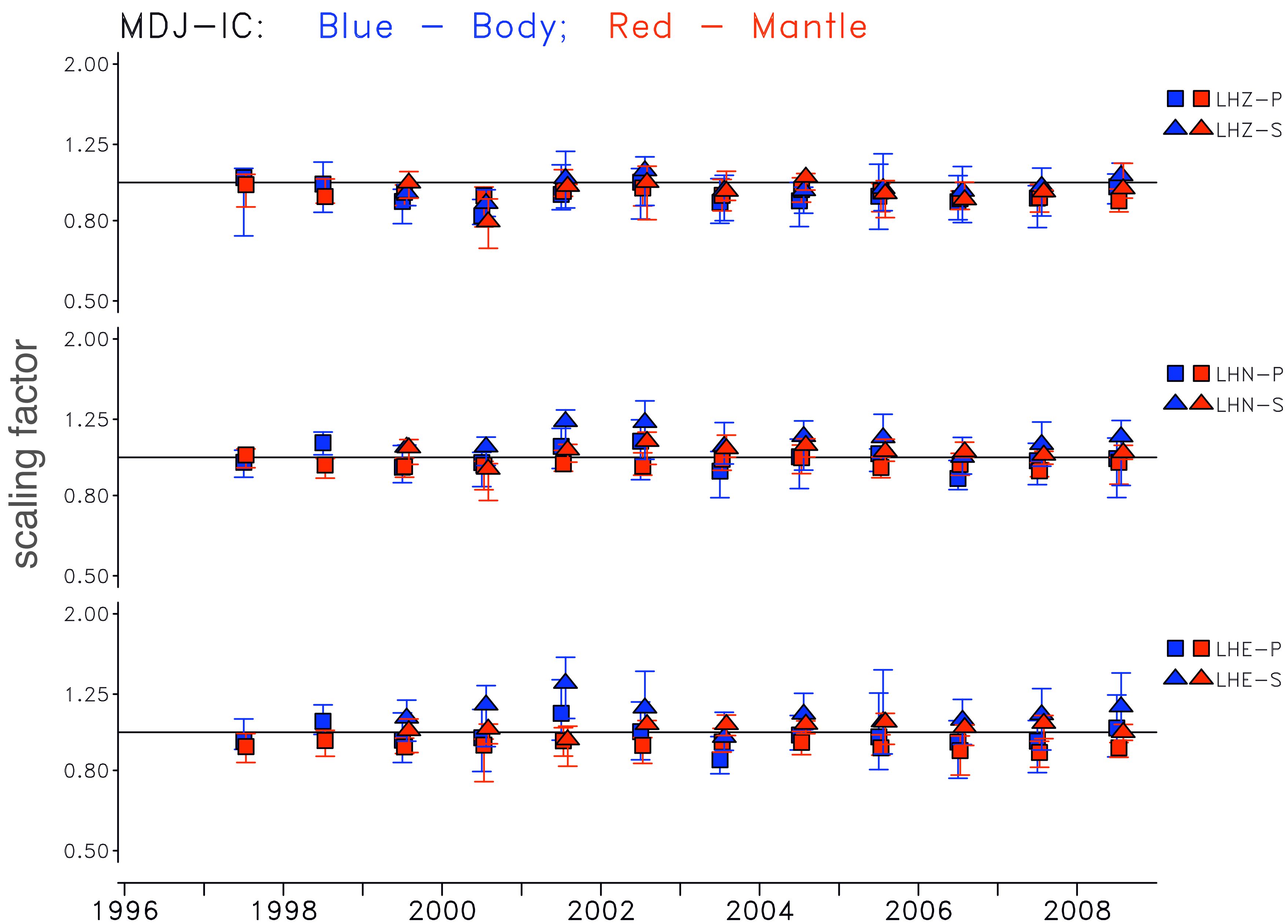
Mantle Body

Primary sensor: STS-1

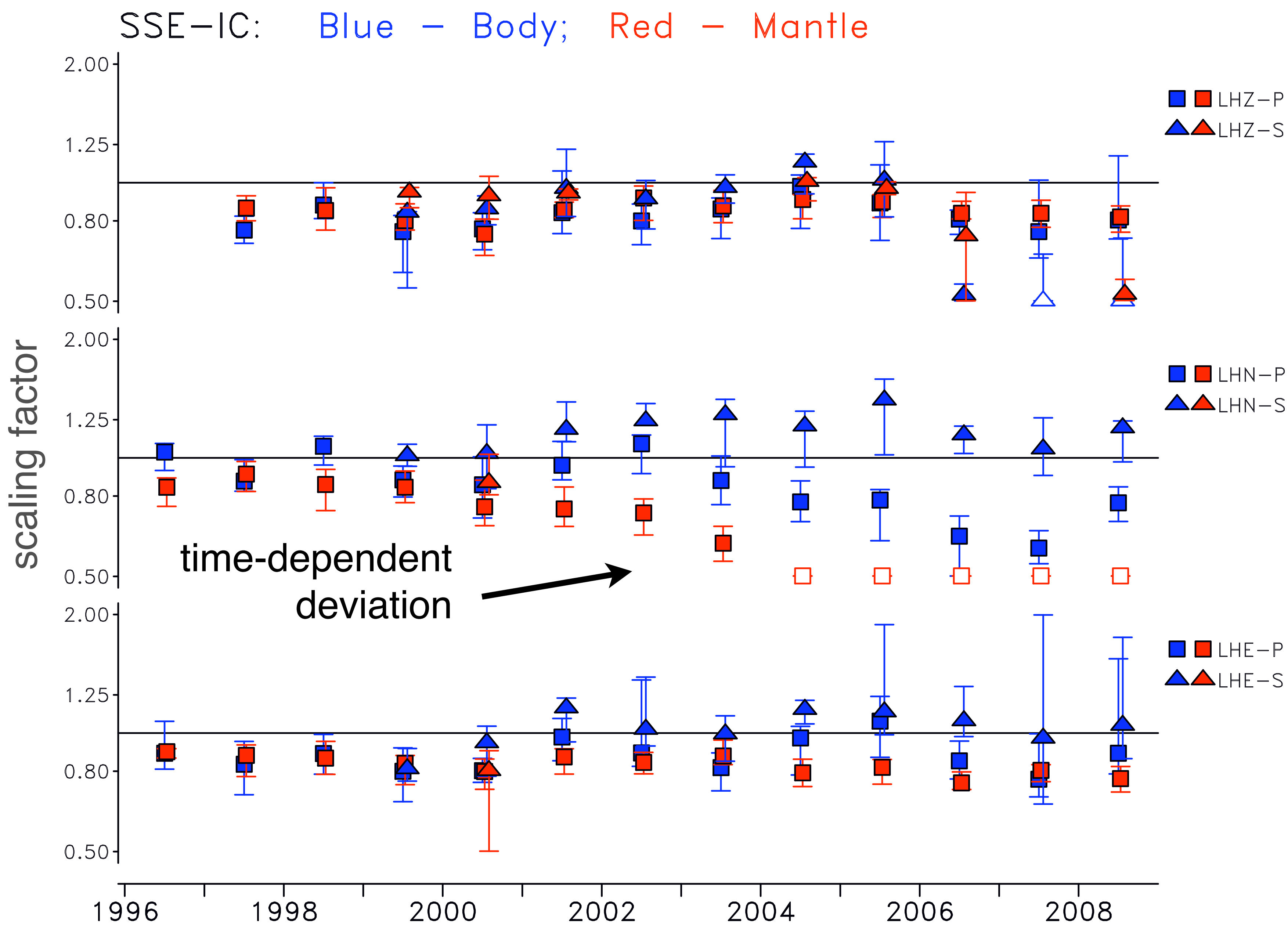
Secondary sensor: mostly STS-2



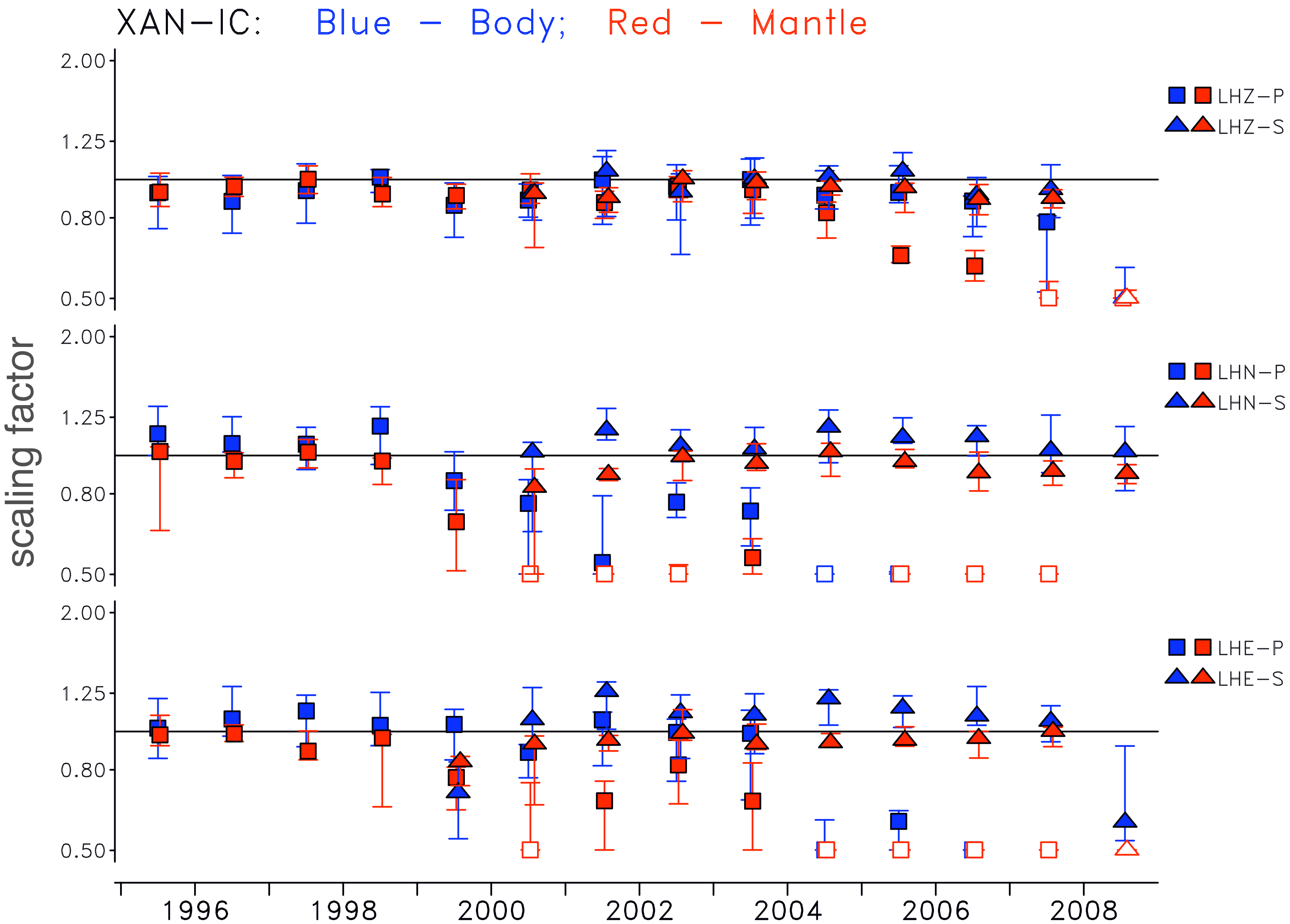
Scaling factors at MDJ-IC, 1997-2008



Scaling factors at SSE-IC, 1996-2008

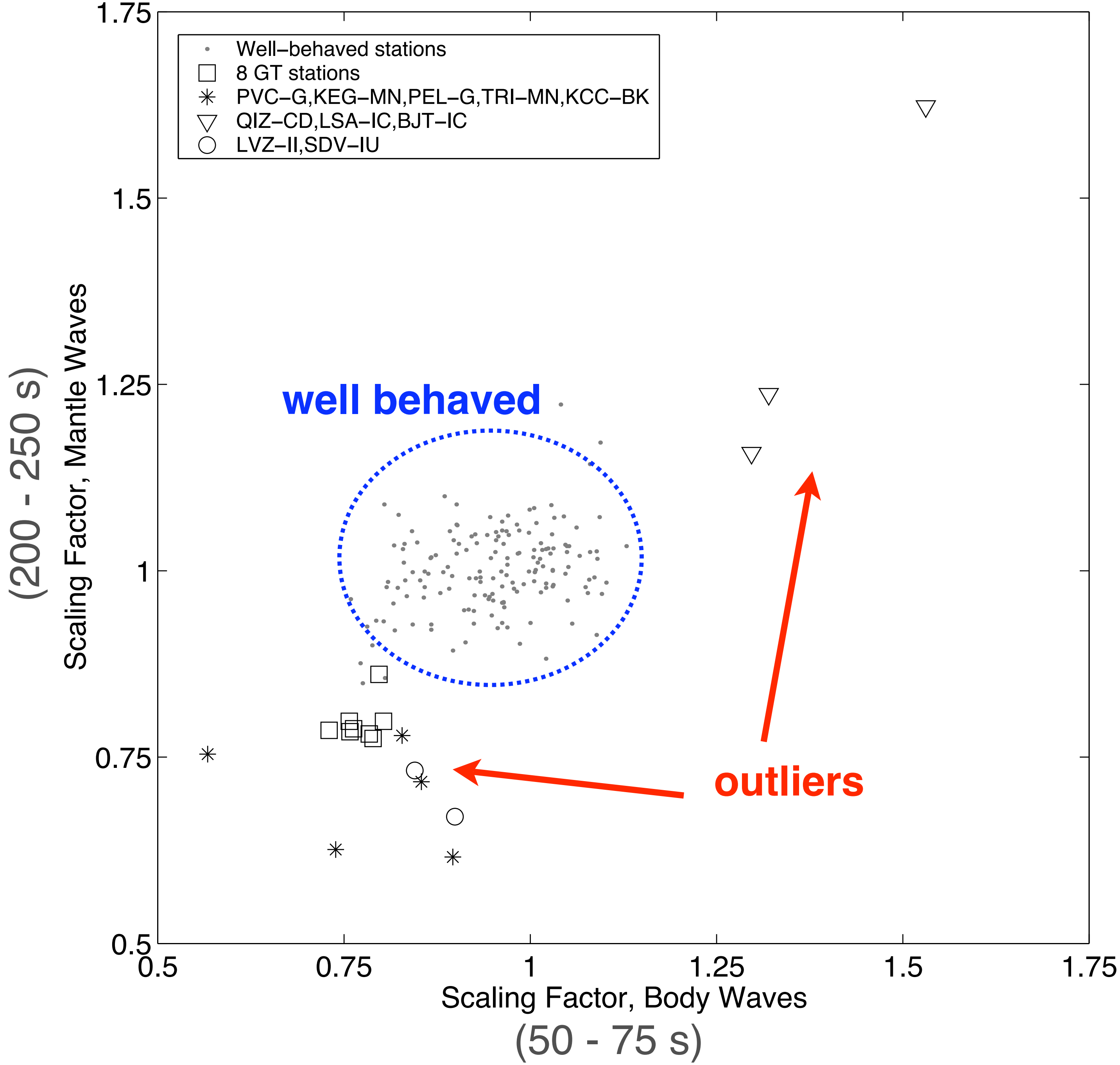


Scaling factors at XAN-IC, 1995-2008



secondary sensor okay; what has happened to the primary?

Most stations are well behaved, but not all



Stability of sensor (STS-1) gain

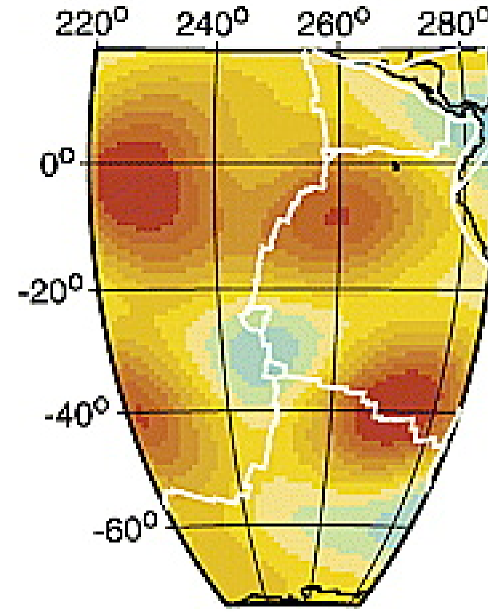
- Most stations show no, or small, deviations from the reported response
- A few stations (e.g., GTSN) show constant offsets in gain of 10-20%
- *Approximately 15% of stations equipped with STS-1 seismometers show a time- and frequency-dependent deterioration of the true gain. This is still true, though investigations at individual stations have identified site-specific problems, as well.*

➡ Cause of problem is not known

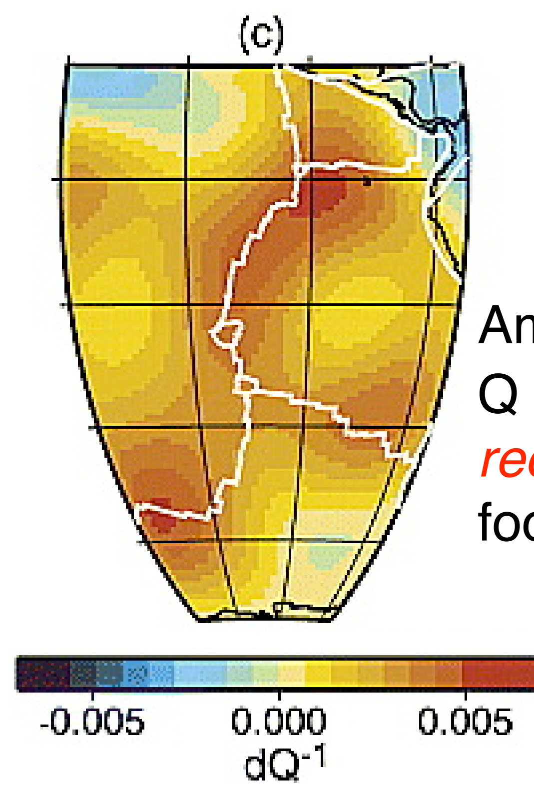
➡ Need regular instrument calibration (our approach is ad hoc)

Why does it matter?

- Amplitudes carry critical information for improving models of elastic and inelastic structure
- Also important for improvements in source modeling



Amplitude ➞ Q



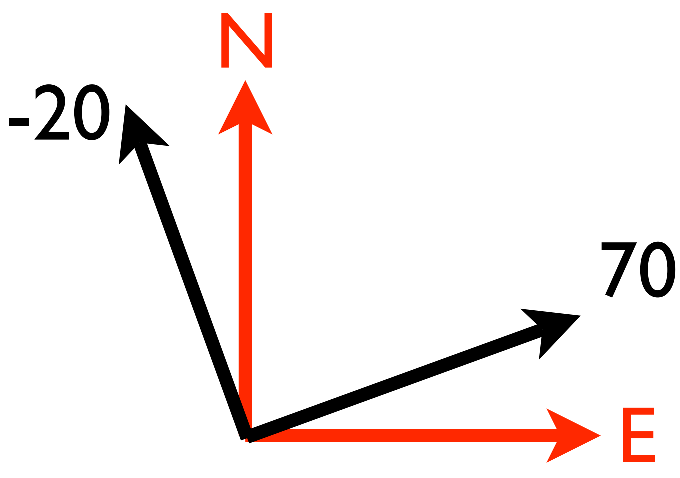
Amplitude ➞
Q + source factor + *receiver factor* +
focusing

(Dalton and Ekström, 2006)

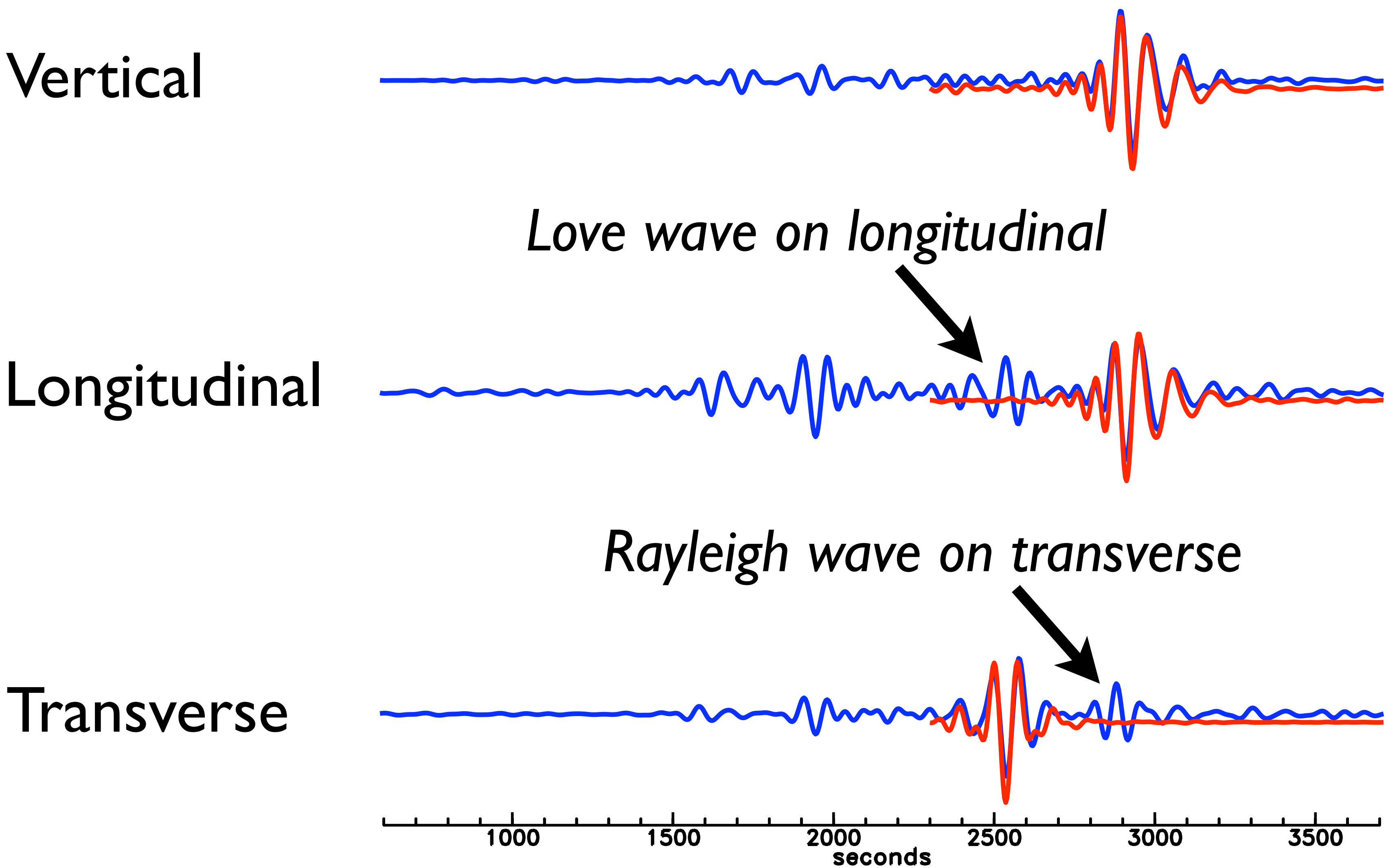
Assessment of Reported Horizontal Sensor Orientations

Reported orientation of seismometer

True orientation of seismometer

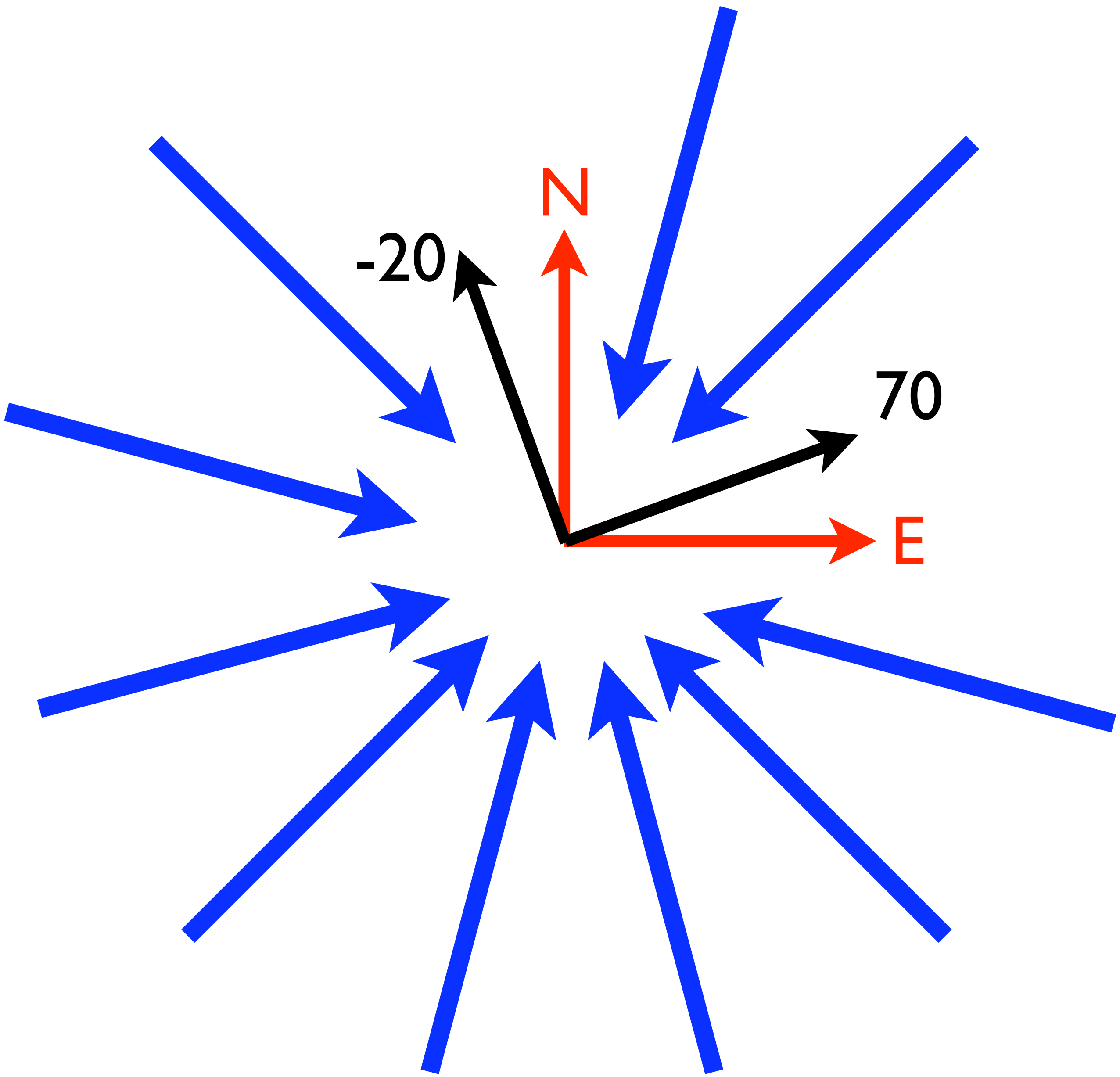


Symptoms of a misoriented sensor



Station D09A, earthquake on 08/20/2007

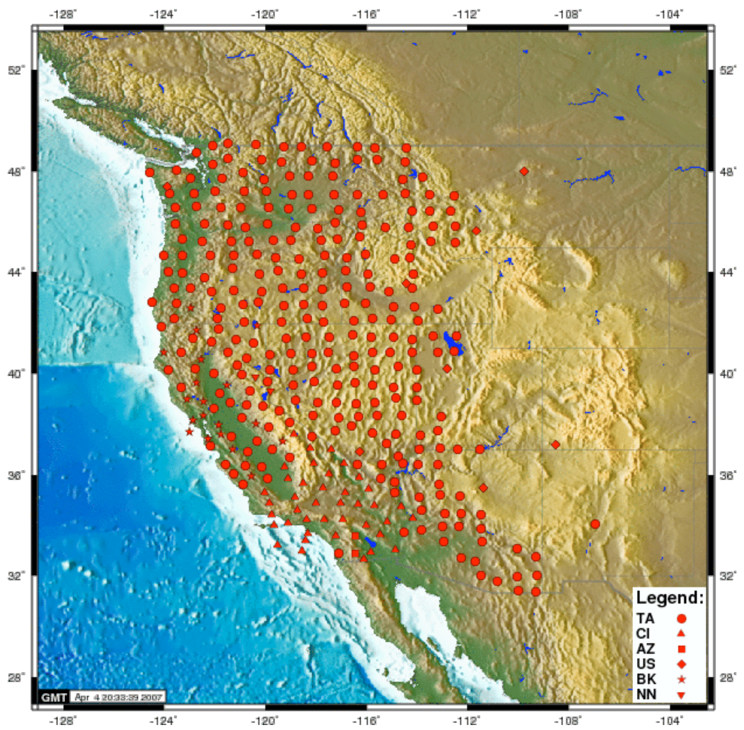
Many earthquake signals --
invert for orientation of sensor



Validation of approach: USArray data using earthquake signals recorded in 2006-2007

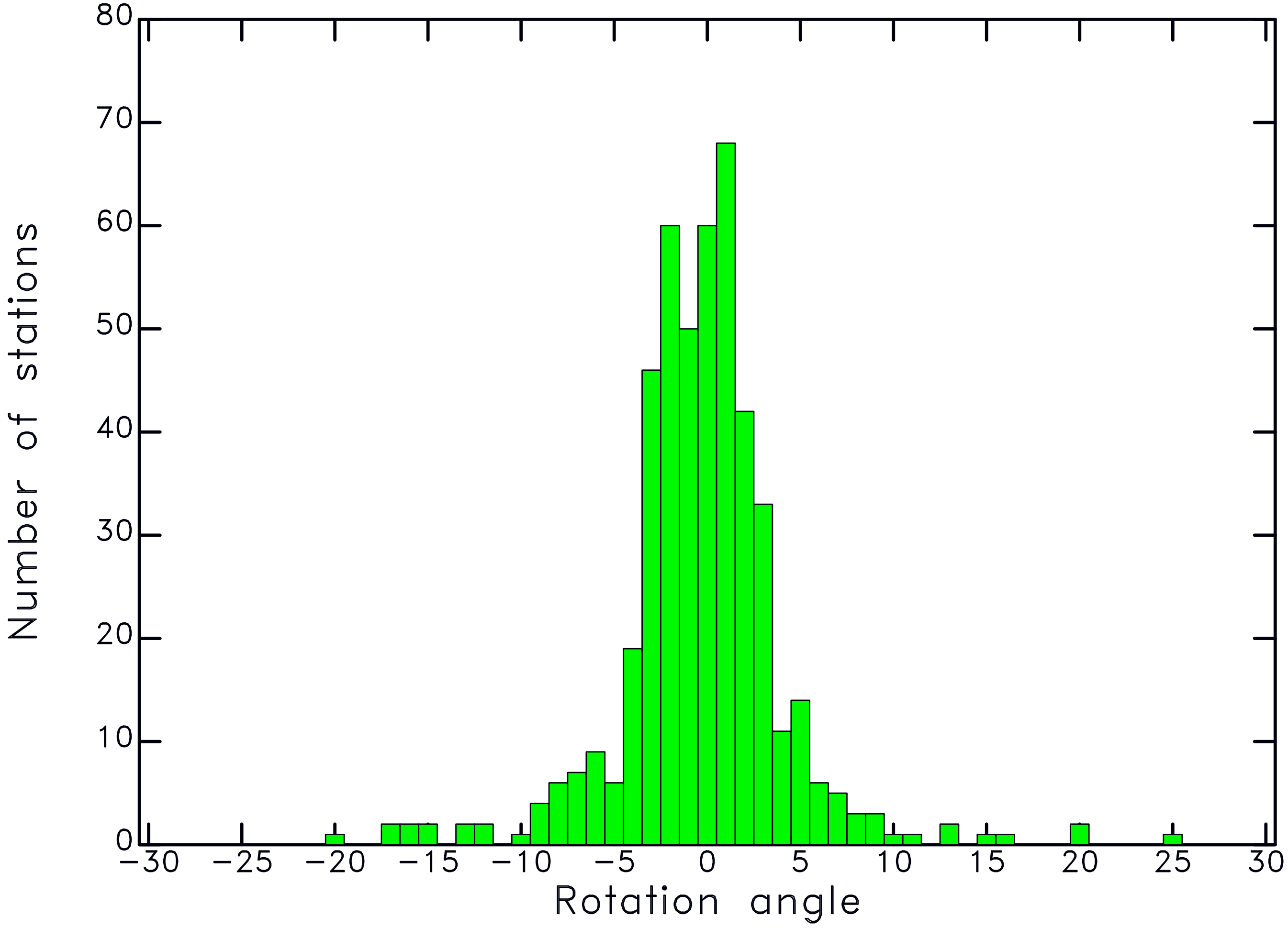
400+ USArray stations

Result:
> 5% misoriented > 10 degrees
> 10 % misoriented > 5 degrees

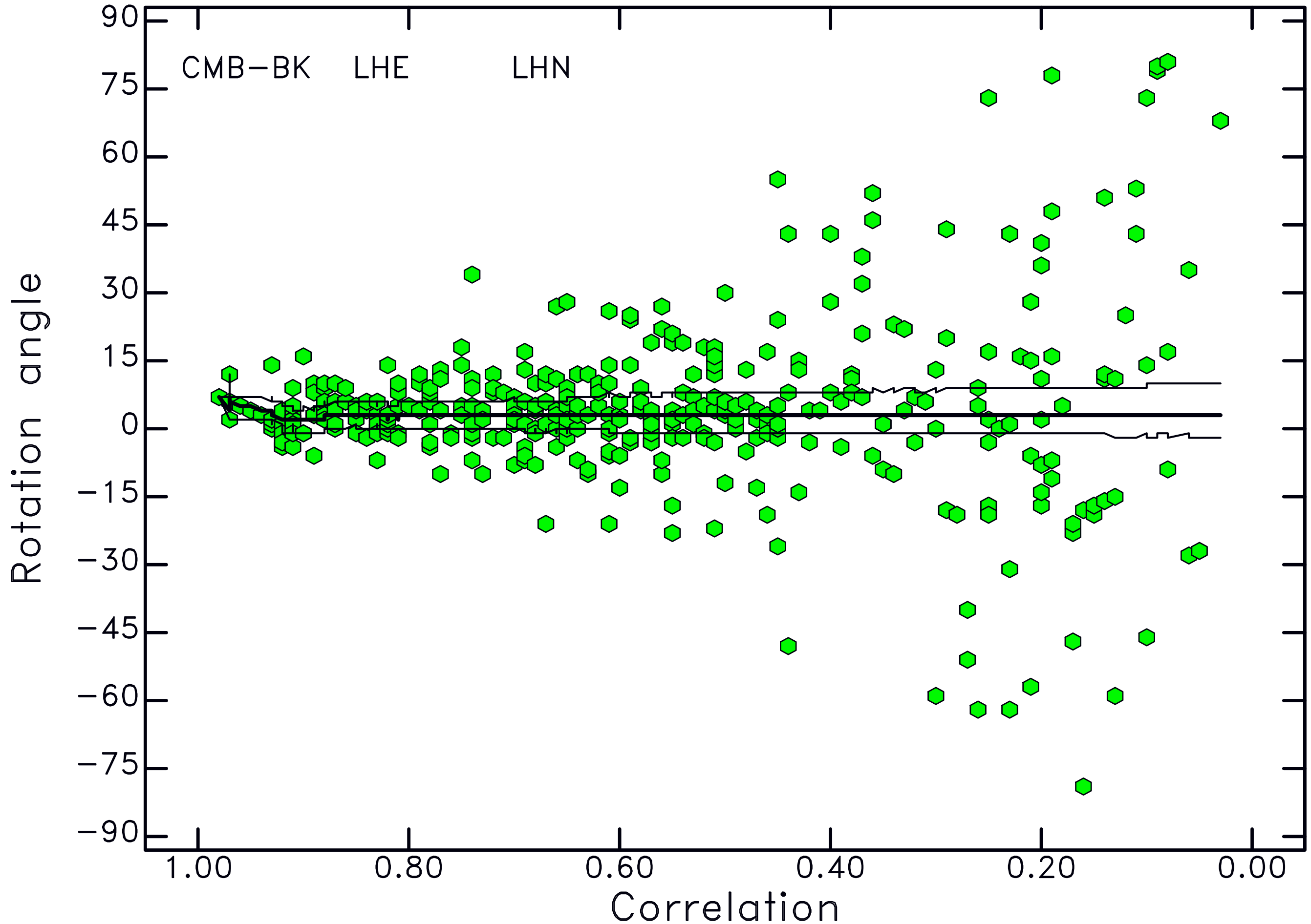


(see Ekström and Busby, 2008)

Estimated rotation angles for 473 USArray stations

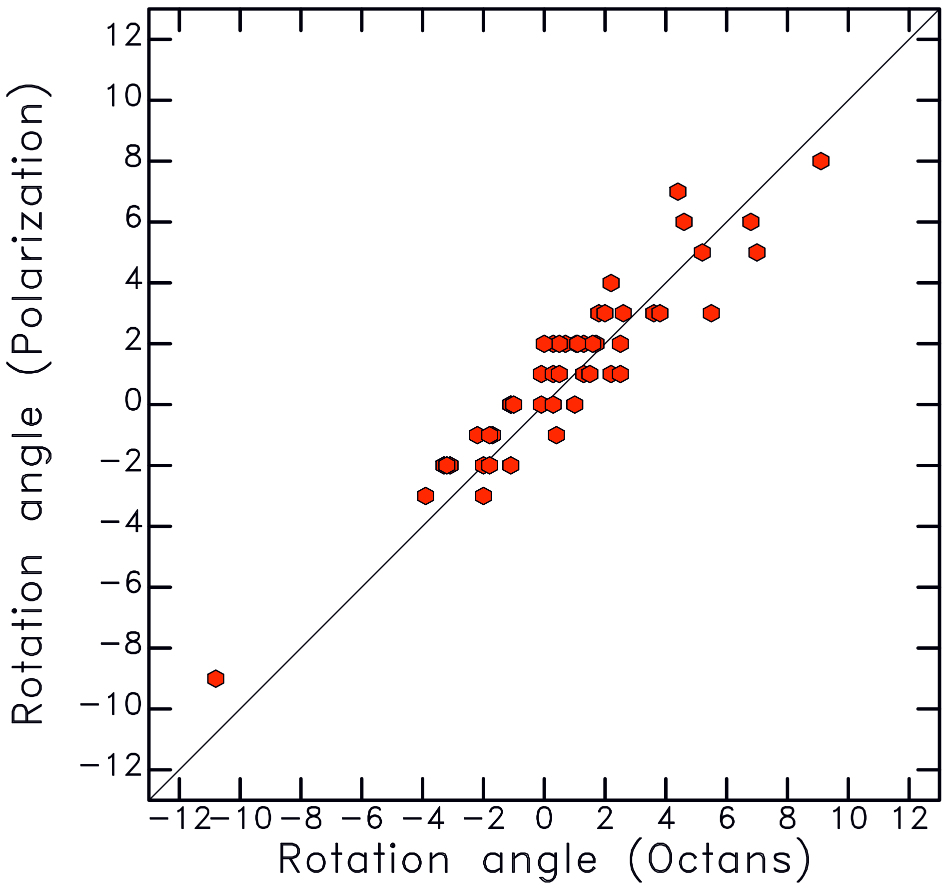


Rotation angle estimates

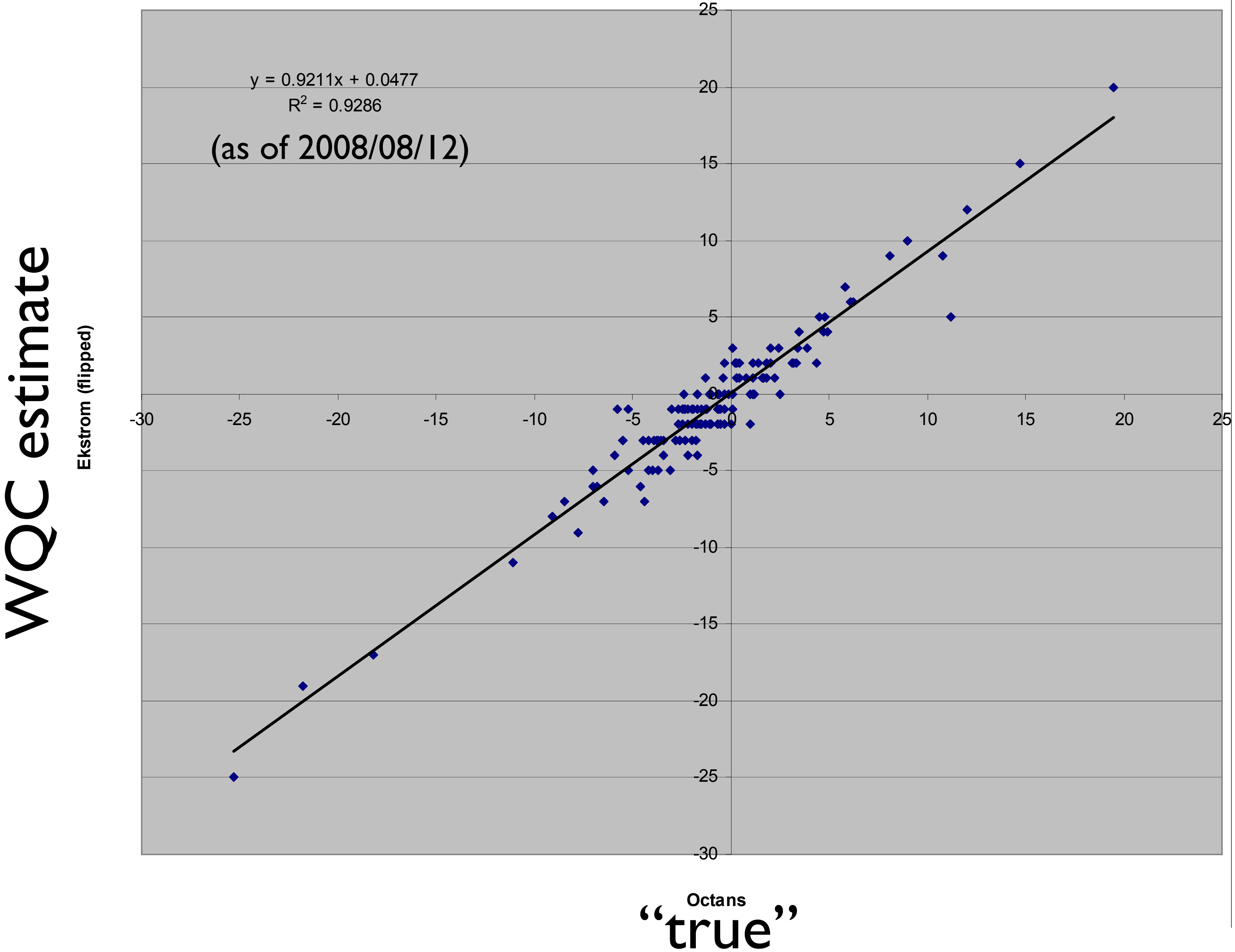


Octans interferometric laser gyro

Agreement of field (Octans) and polarization angles

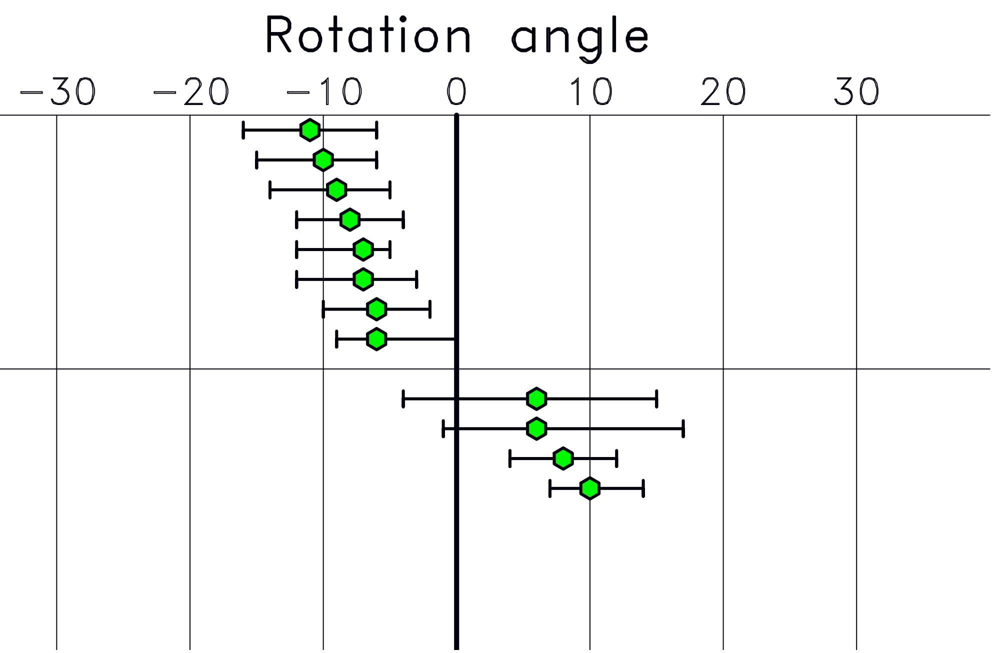


TA update from B. Busby -- 144 stations



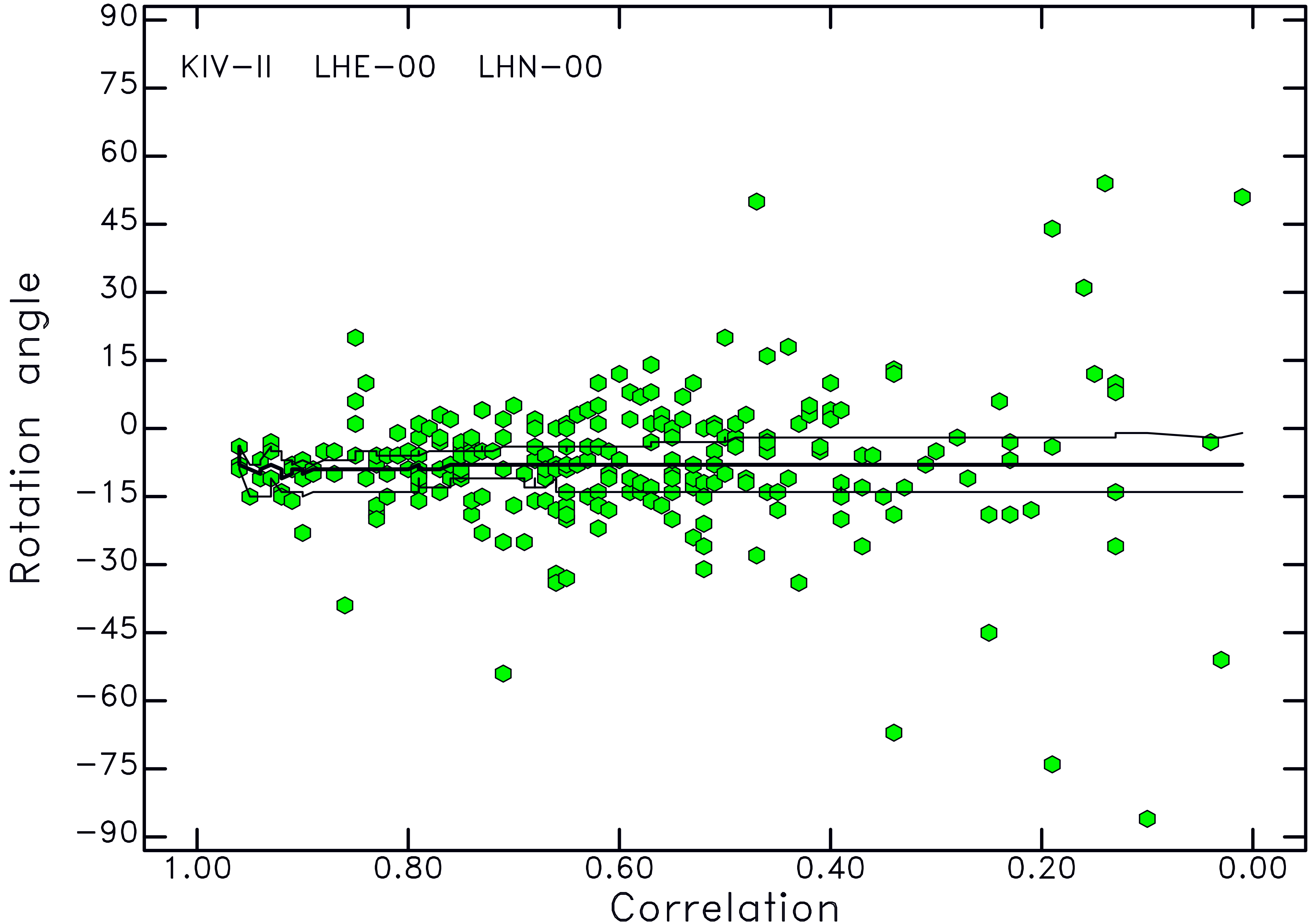
Outliers (>5 deg)
II, IU, IC
as of 2009/11/08

KDAK−II	LHE−00	LHN−00	84.1	354.1	389	−11
MIDW−IU	LHE−00	LHN−00	90.0	0.0	55	−10
KIV−II	LHE−00	LHN−00	90.0	0.0	169	−9
AAK−II	LHE−00	LHN−00	90.0	0.0	232	−8
KMBO−IU	LHE−00	LHN−00	90.0	0.0	27	−7
TLY−II	LHE−00	LHN−00	90.0	0.0	301	−7
CASY−IU	LHE−00	LHN−00	270.0	180.0	45	−6
SNZO−IU	LH1−00	LH2−00	271.0	1.0	395	−6
LSA−IC	LHE−00	LHN−00	90.0	0.0	205	6
TIXI−IU	LHE−00	LHN−00	90.0	0.0	48	6
PALK−II	LH1−00	LH2−00	6.5	96.5	202	8
SSPA−IU	LHE−00	LHN−00	90.0	0.0	198	10

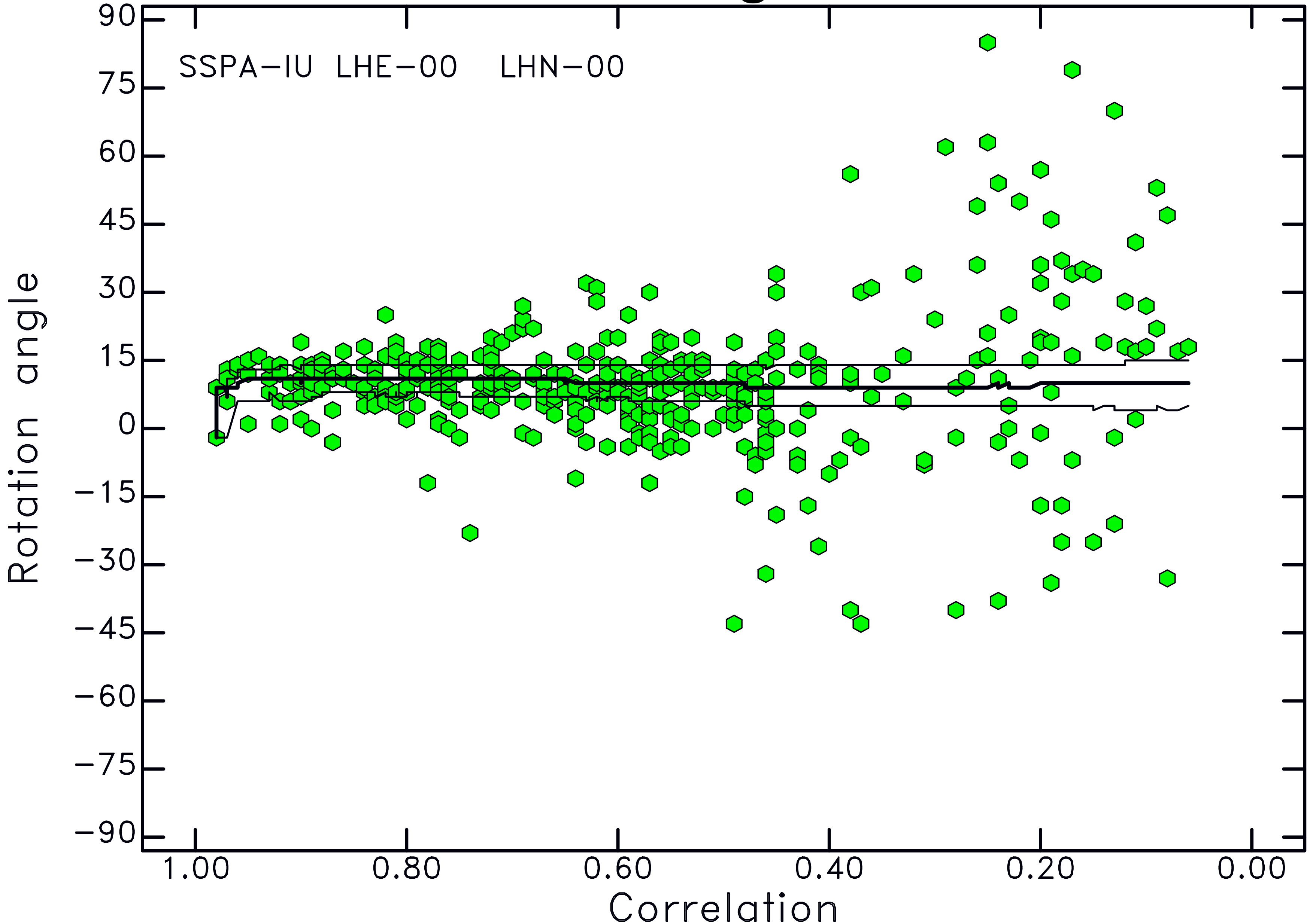


several GSN outliers have been eliminated in the last year or so by updates to metadata or (for secondary sensors) re-orientation of the sensor

KIV-II -8 degrees



SSPA-IU +10 degrees

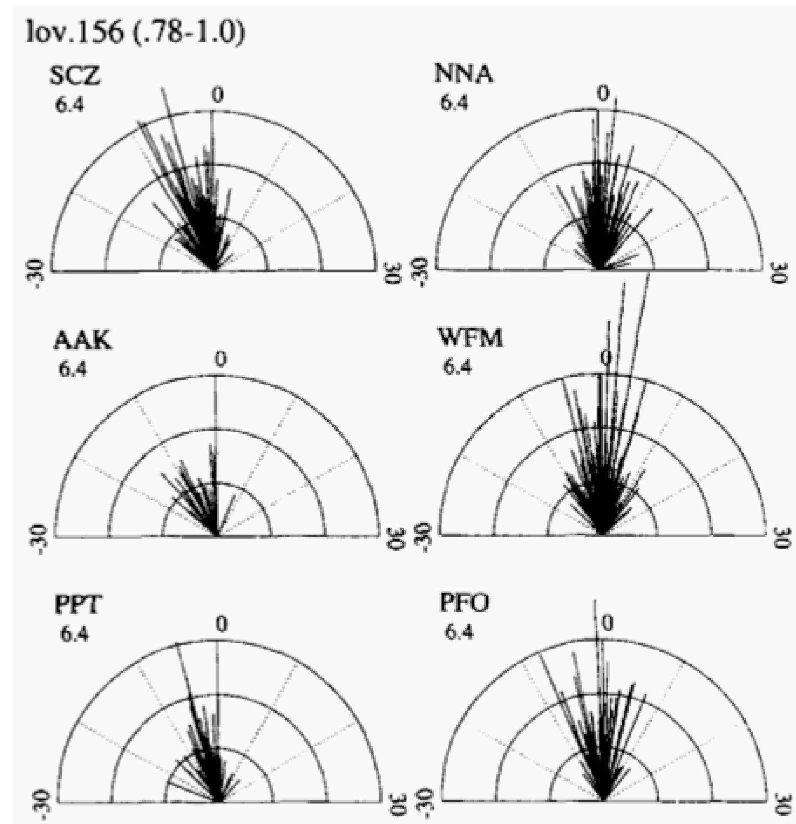


Sensor orientation

Most GSN and USArray TA stations are well oriented, but not all.

Why does it matter?

- Modeling of earthquake sources
- Measurement of Love wave / toroidal mode parameters
- Estimates of anisotropy
- Estimates of off-great-circle arrival angle, for both elastic and anelastic structure

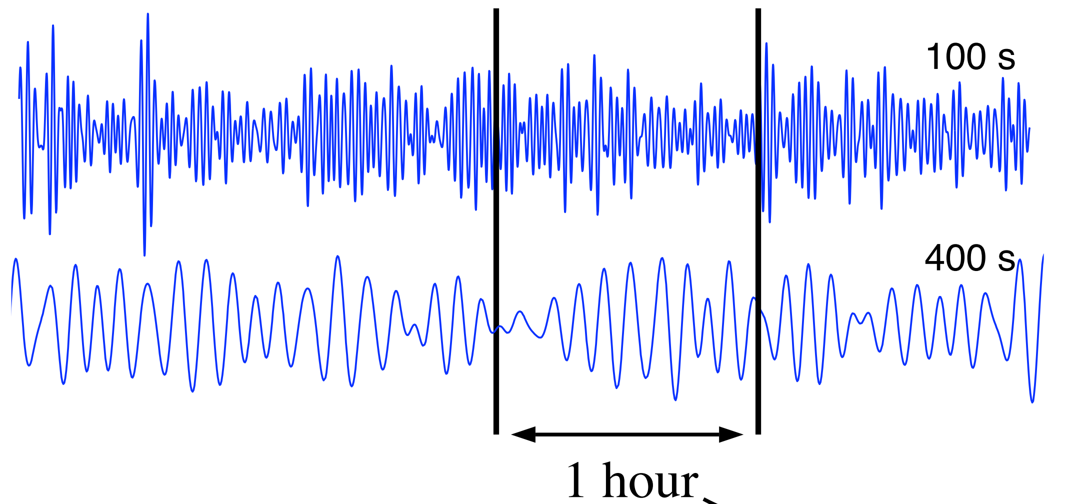


(Laske, 1995)

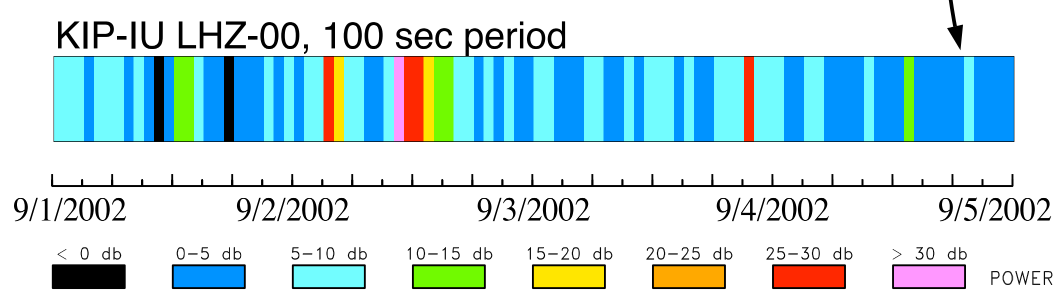
Assessment of noise levels

Calculation of signal power of
long-period GSN data

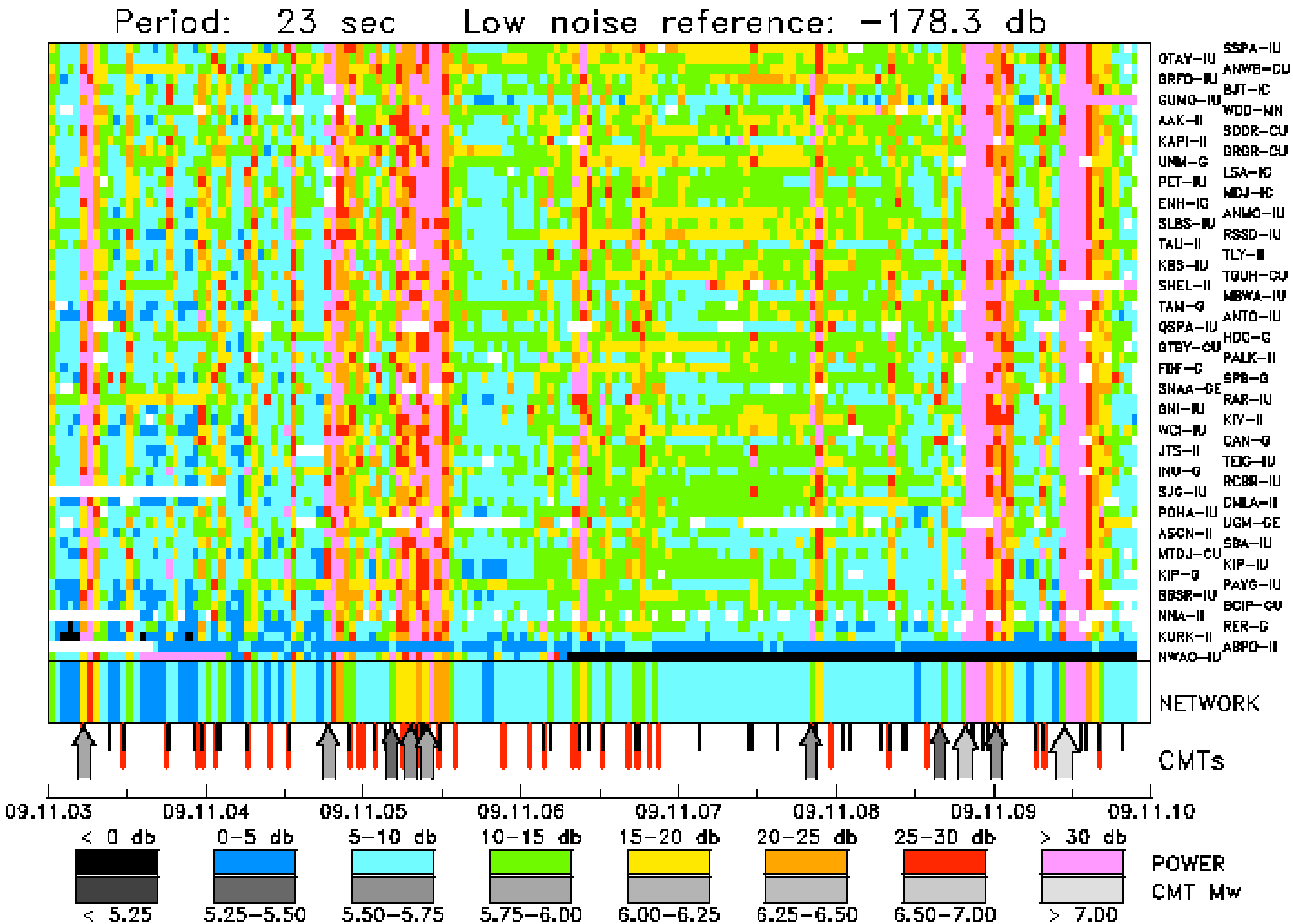
continuous filtered time series:



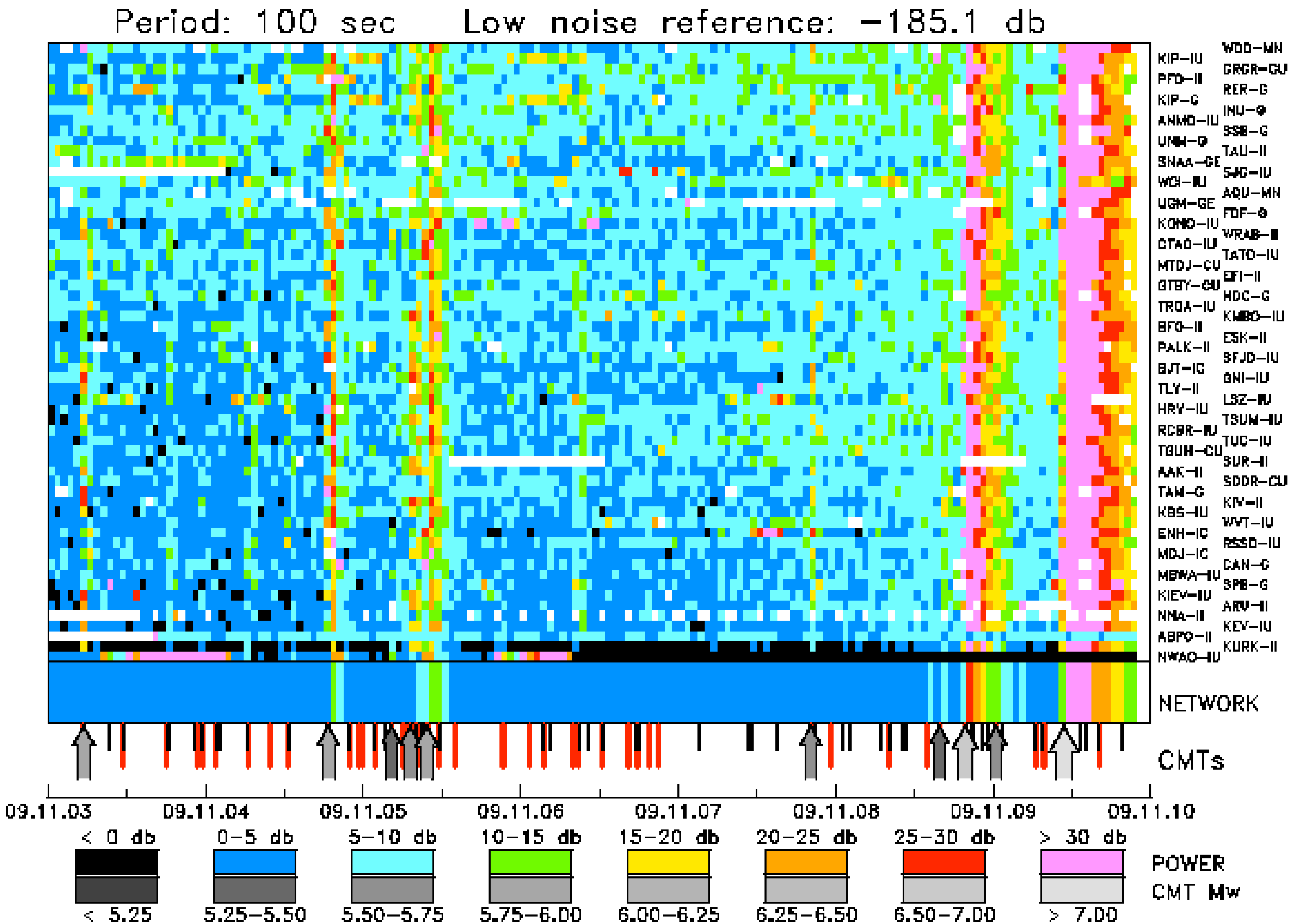
1. calculate rms
2. convert to power spectral density
3. store as hourly samples of signal level



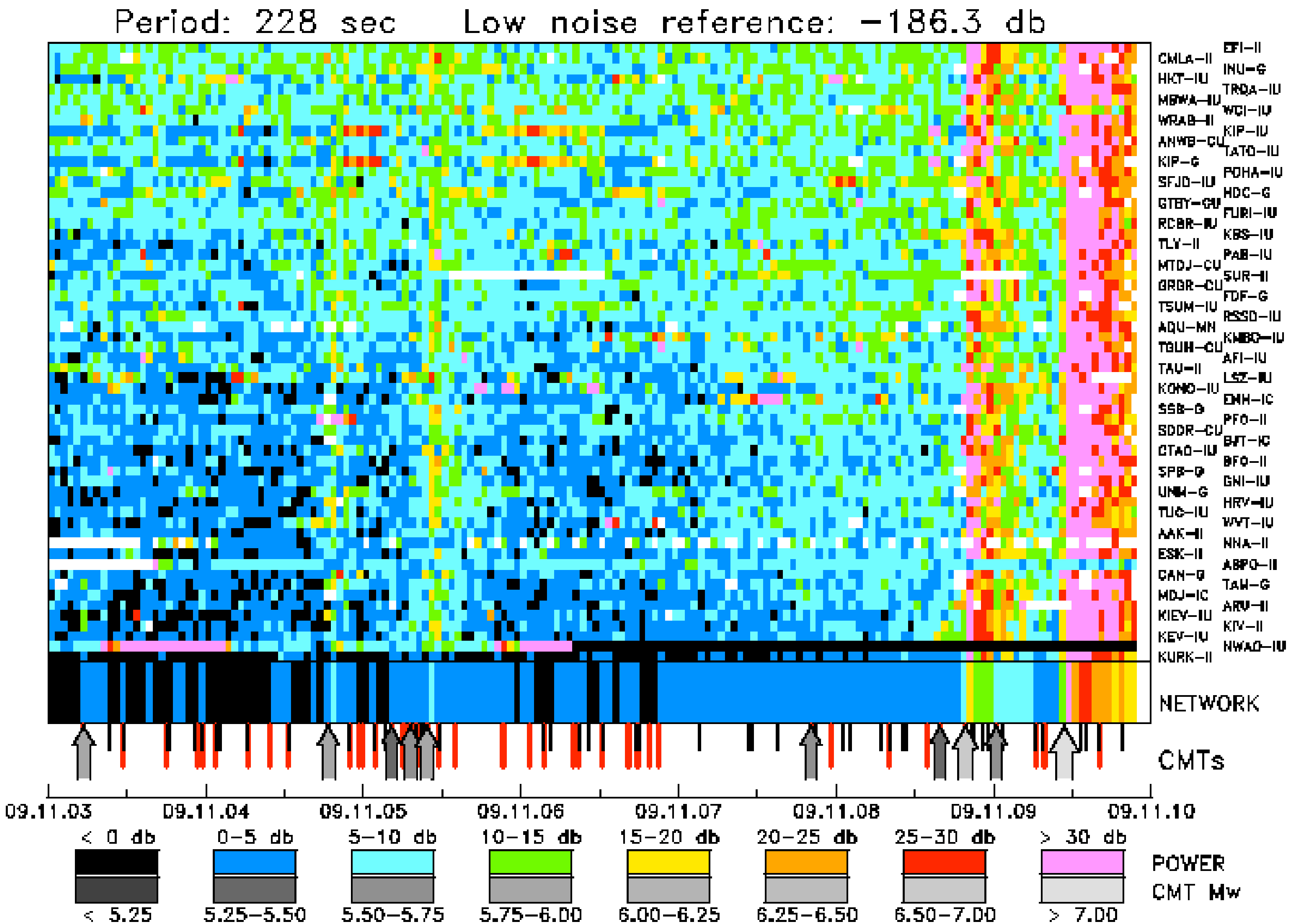
One week of noise at 23 seconds period



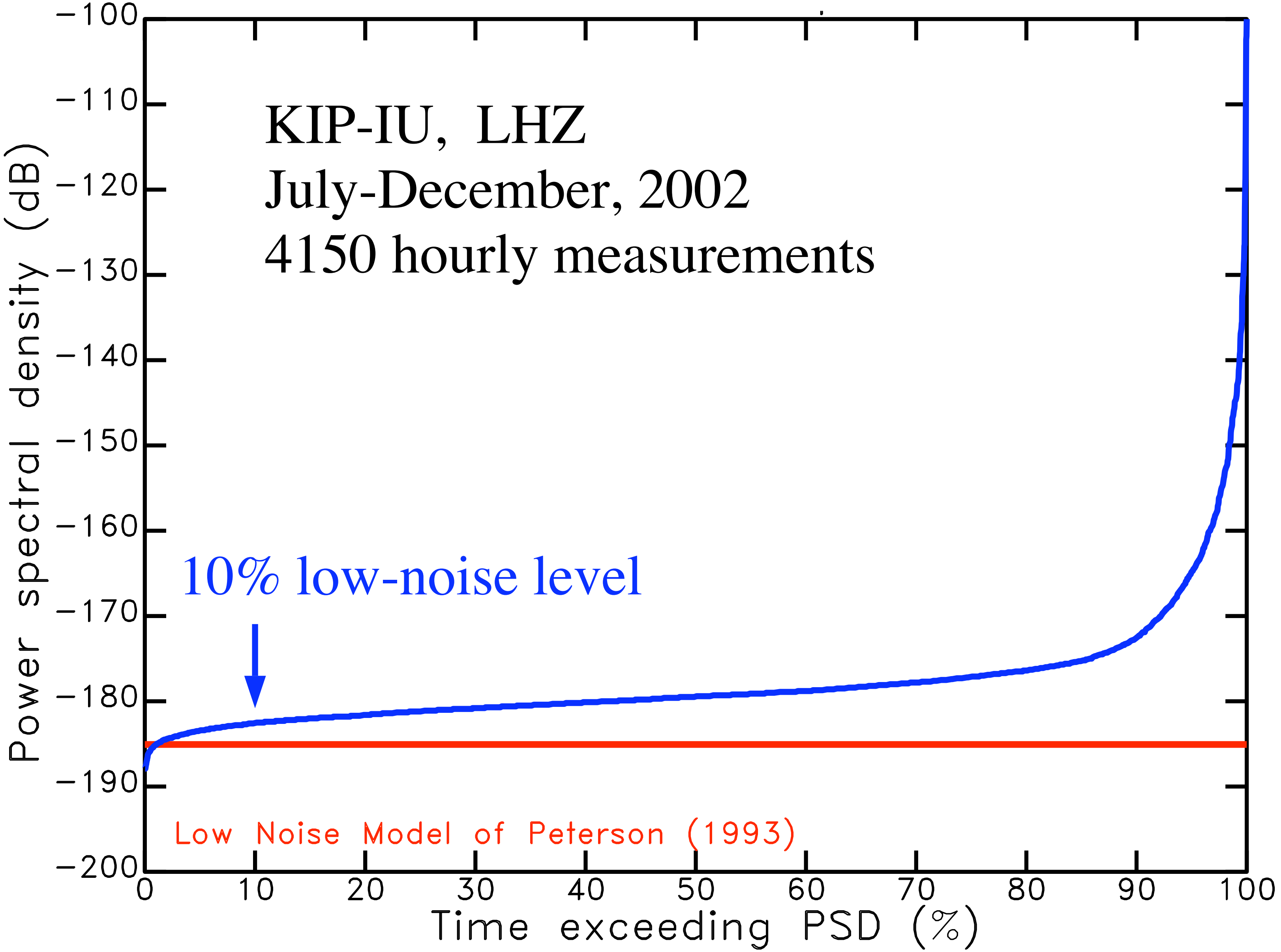
One week of noise at 100 seconds period



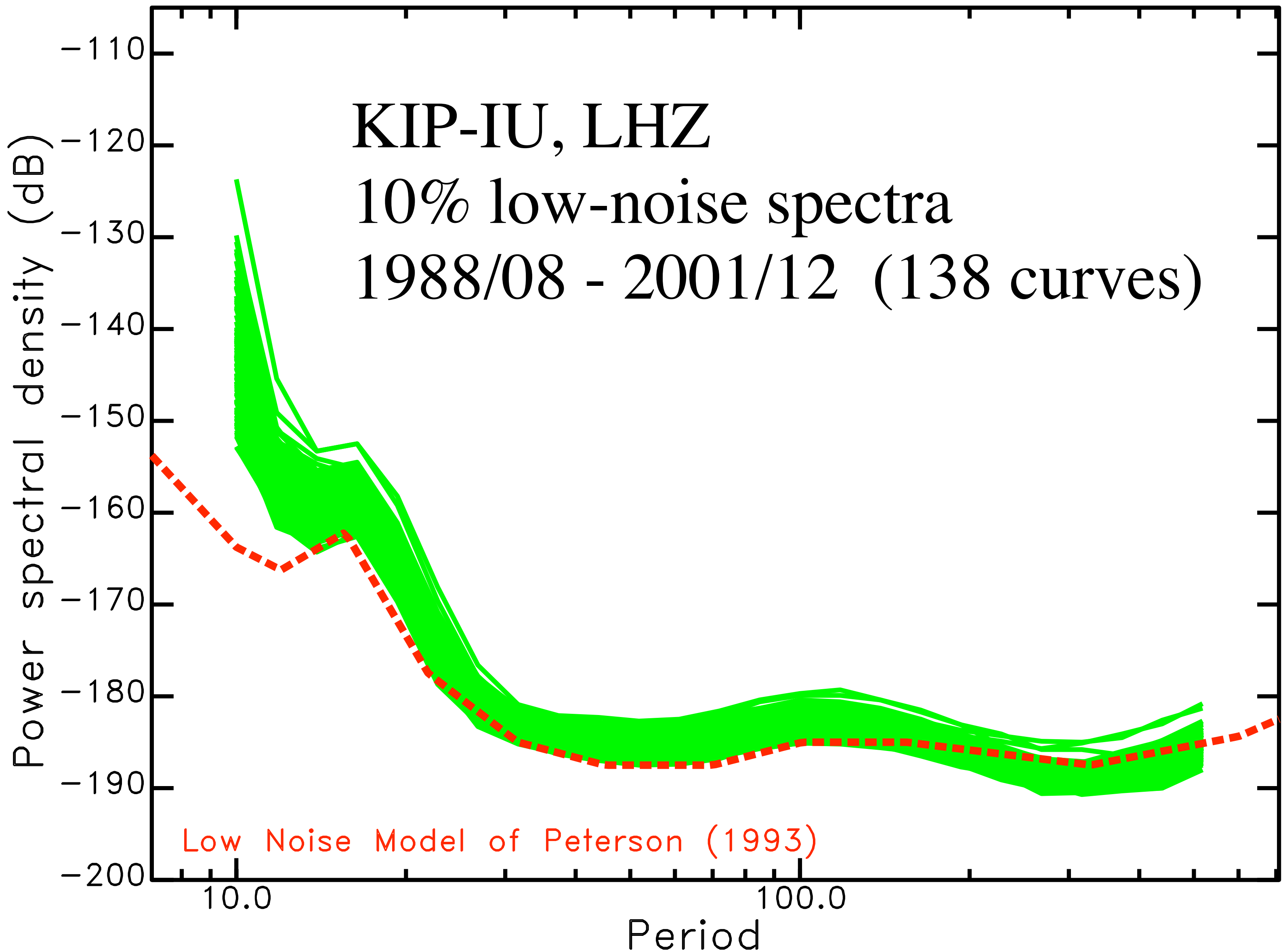
One week of noise at 228 seconds period



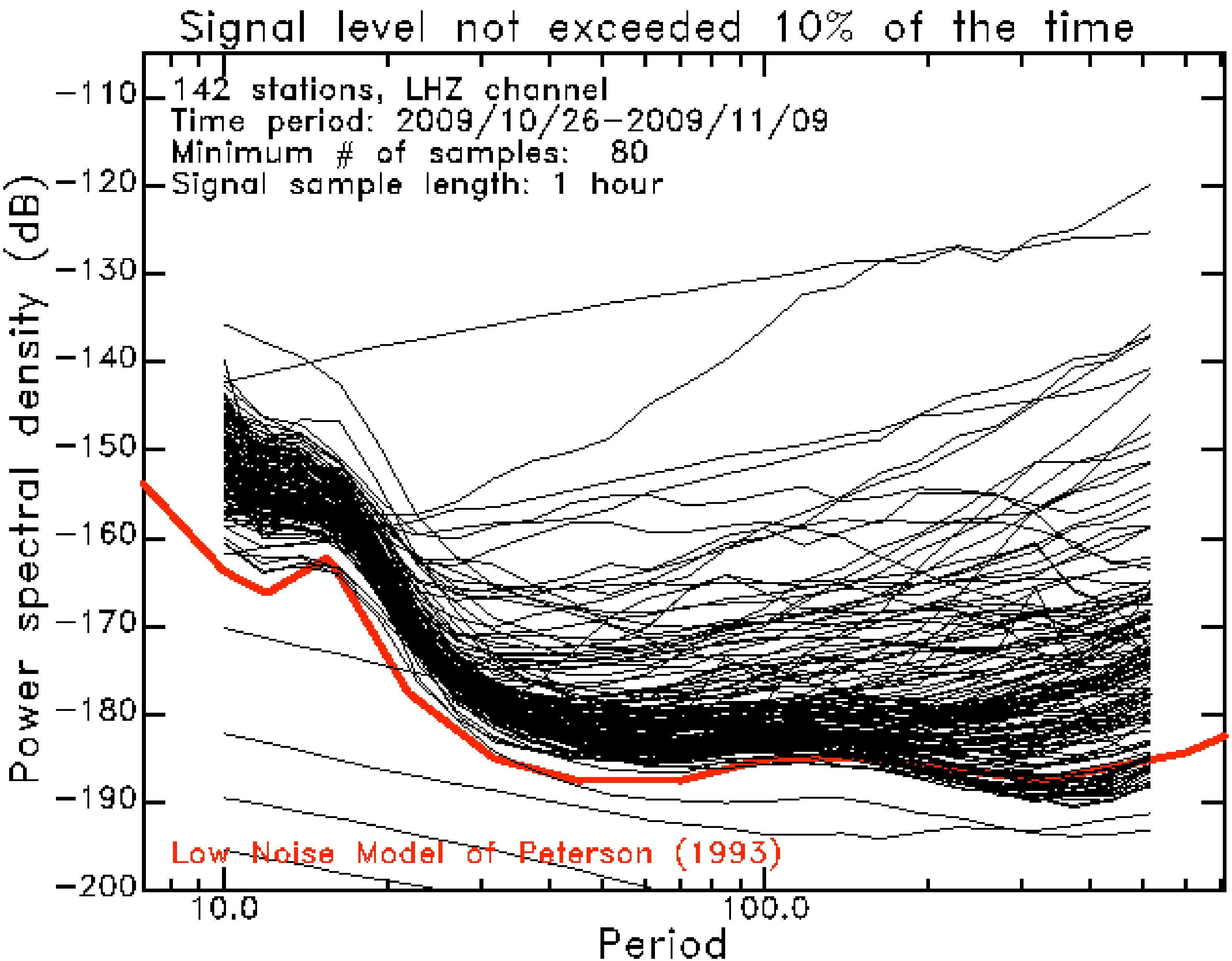
100 sec period - distribution of PSD



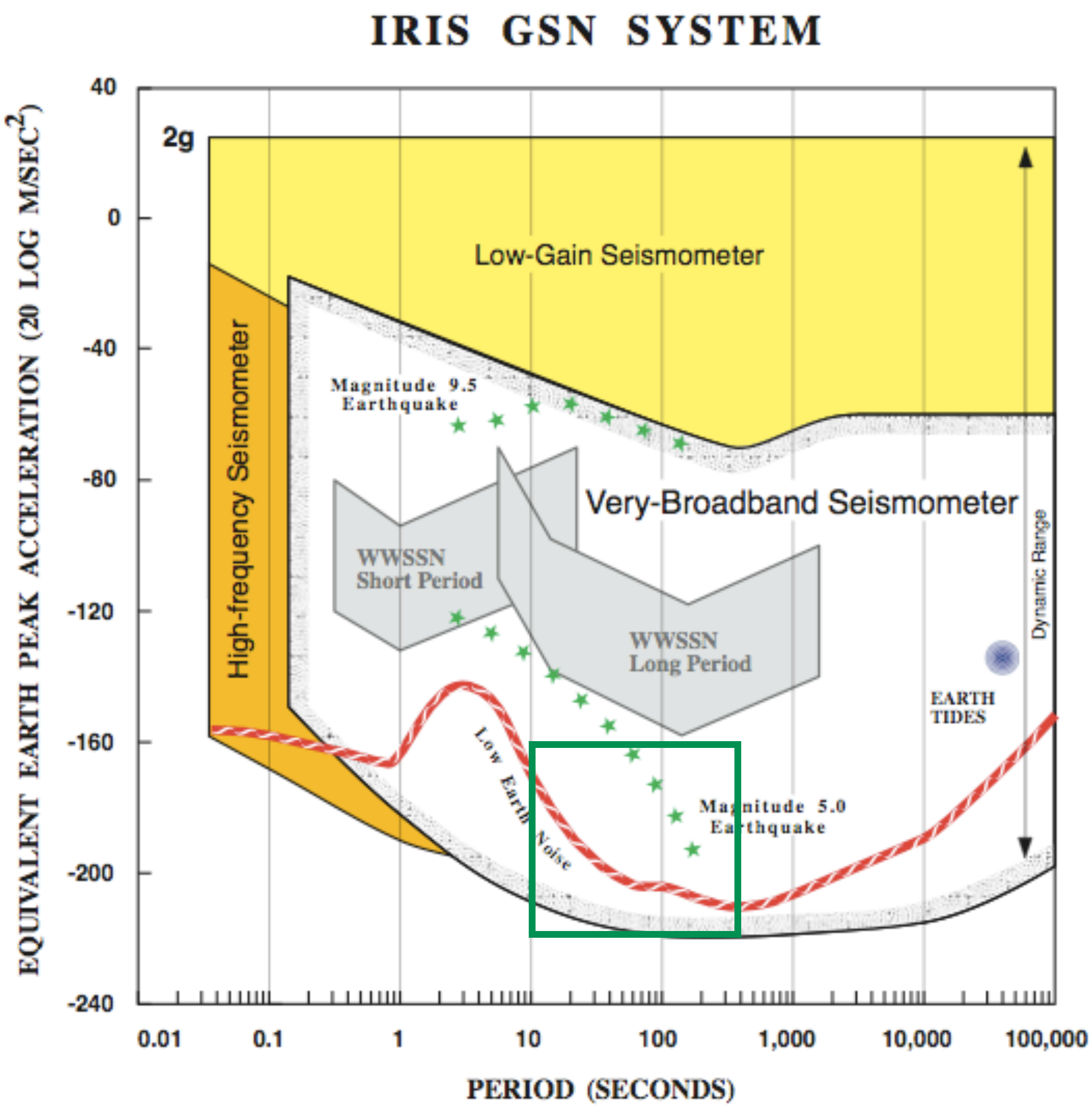
Stability of low-noise spectra



Noise spectra from the Global Seismic Network



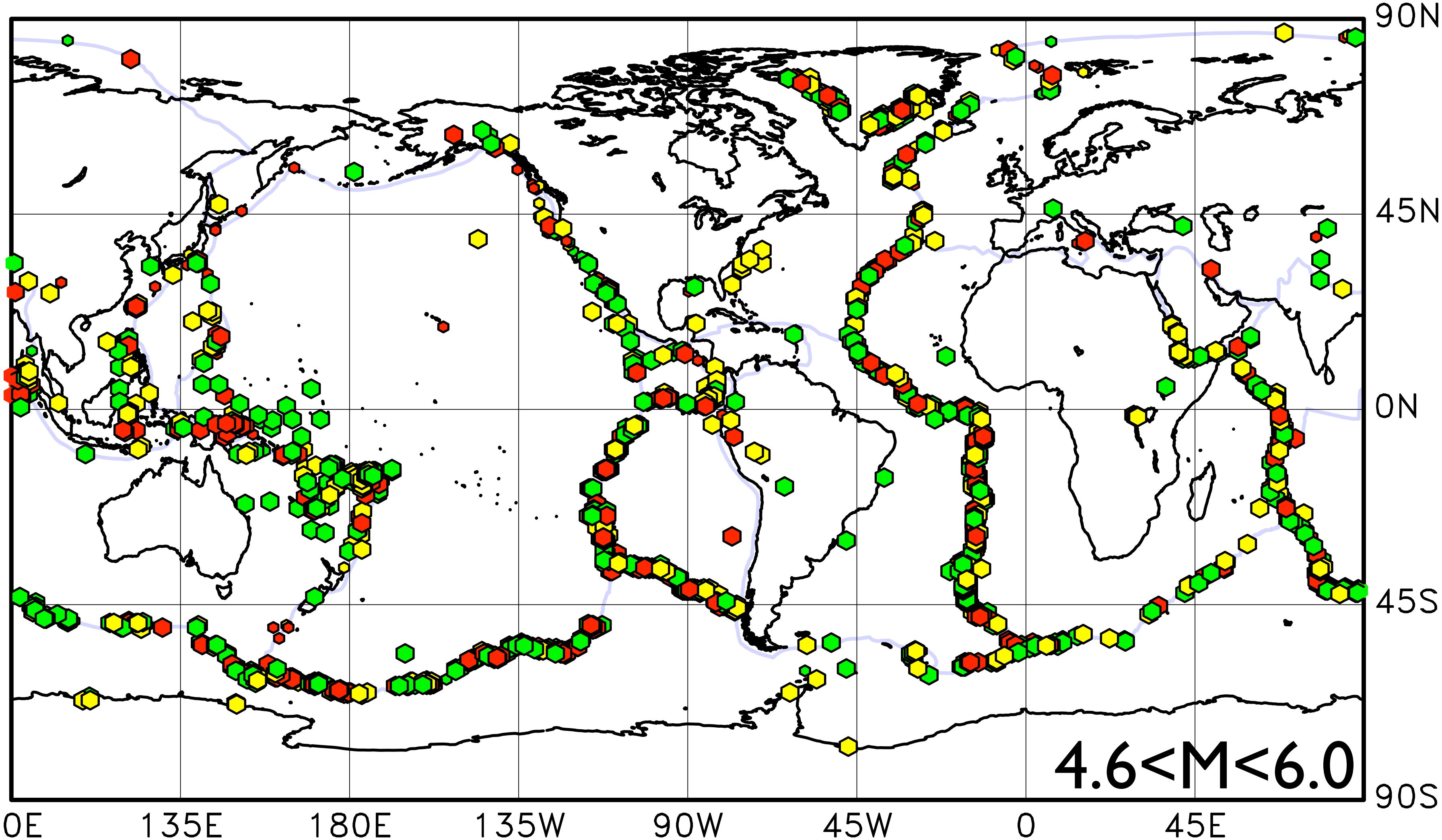
Maintaining and improving station quietness in the low-Earth-noise band is important



allows detection and analysis of small-moderate earthquakes globally

New earthquakes - not in other global catalogs (detected at 35-150 s, but not at 1 Hz)

New earthquakes (~1800)
1991-2006

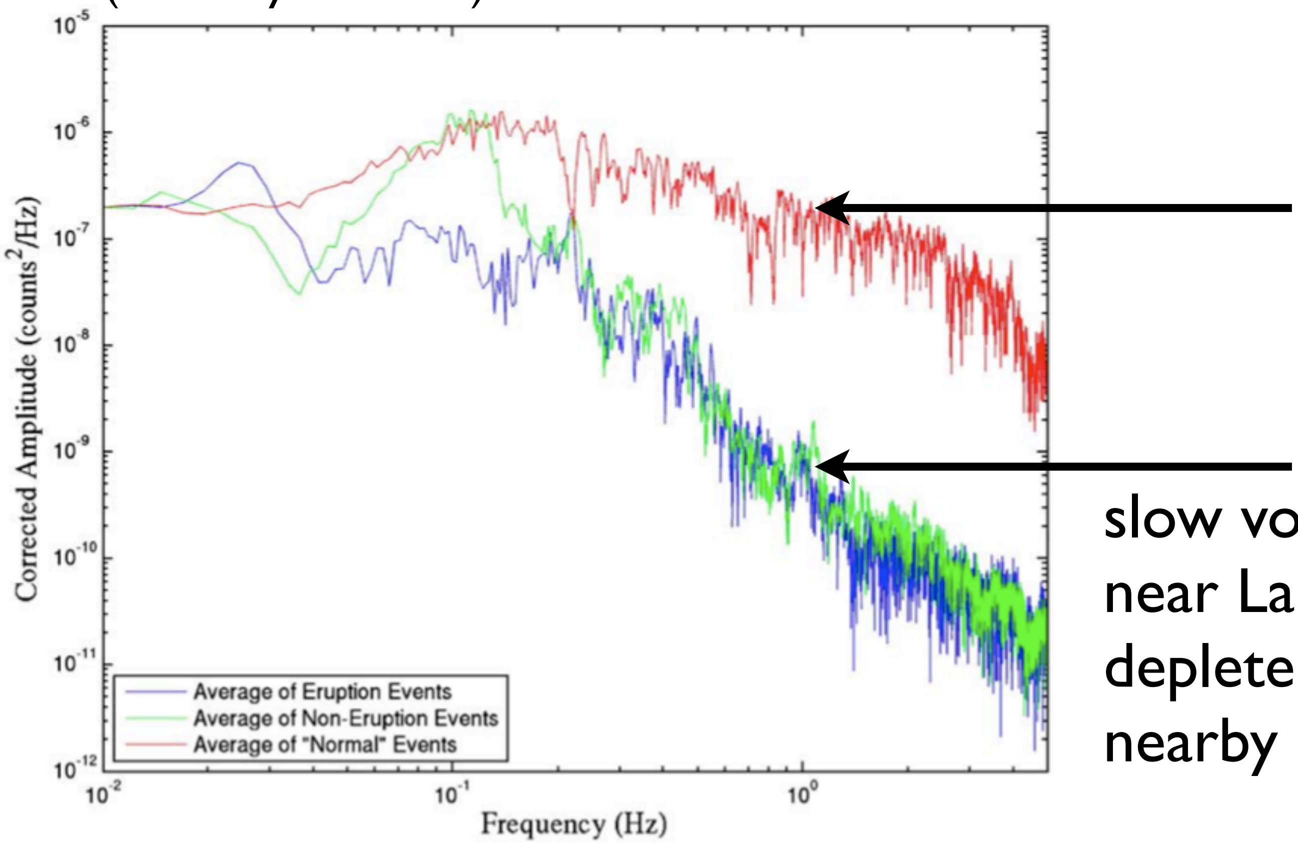


Best / Very good / Good

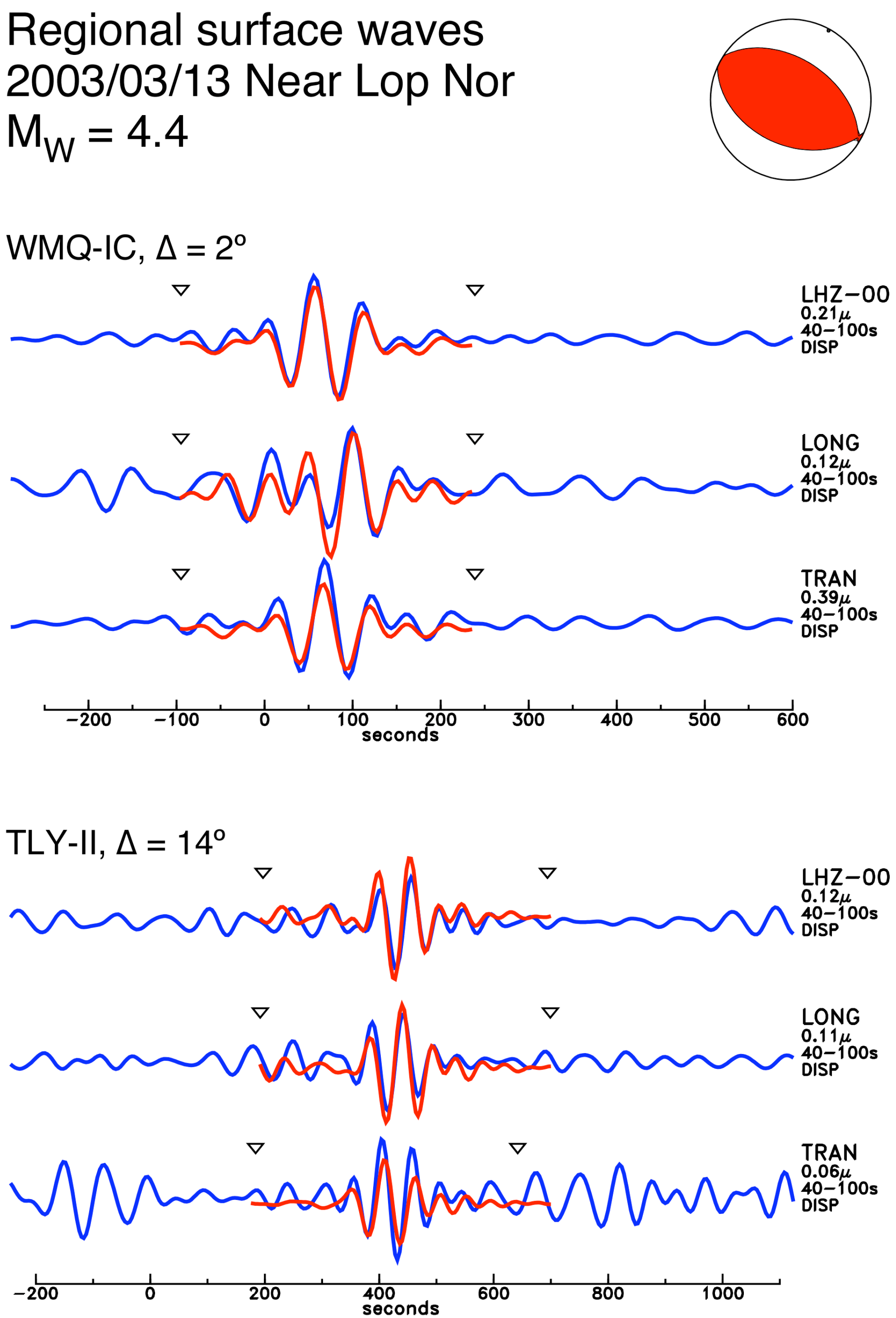
(small symbols - previously detected earthquakes with new M more than one unit greater than reported)

Detection and analysis of events with little high-frequency energy

(courtesy A. Shuler)



slow volcano-tectonic earthquakes near Lake Kivu have 1-Hz energy depleted by more than 10^2 wrt nearby earthquakes



(Sykes and Nettles, ISS meeting, 2009)

And events in regions of special interest for earthquake and explosion monitoring

Summary, and challenges

- Quantitative waveform analysis requires highly accurate instrument response information. GSN Design Goals Update (2002): need errors to be one order of magnitude smaller than the level at which we can model signal. This means, e.g., response accurate to 1%.

- We are not there yet! Need to do better with both transfer functions and sensor orientation.

- Need stations quiet in low-noise band

➡ Self-aware seismographs that know their own response functions? And orientations? And report them?

➡ Autonomous, low-power stations for quiet siting?

➡ How can the horizontal channels be made quieter?