Report to the GSN-SC on GSN data quality

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Global CMT Project Waveform Quality Center

Washington, D.C., 2010/04/08

Lamont-Doherty Earth Observatory
COLUMBIA UNIVERSITY | EARTH INSTITUTE

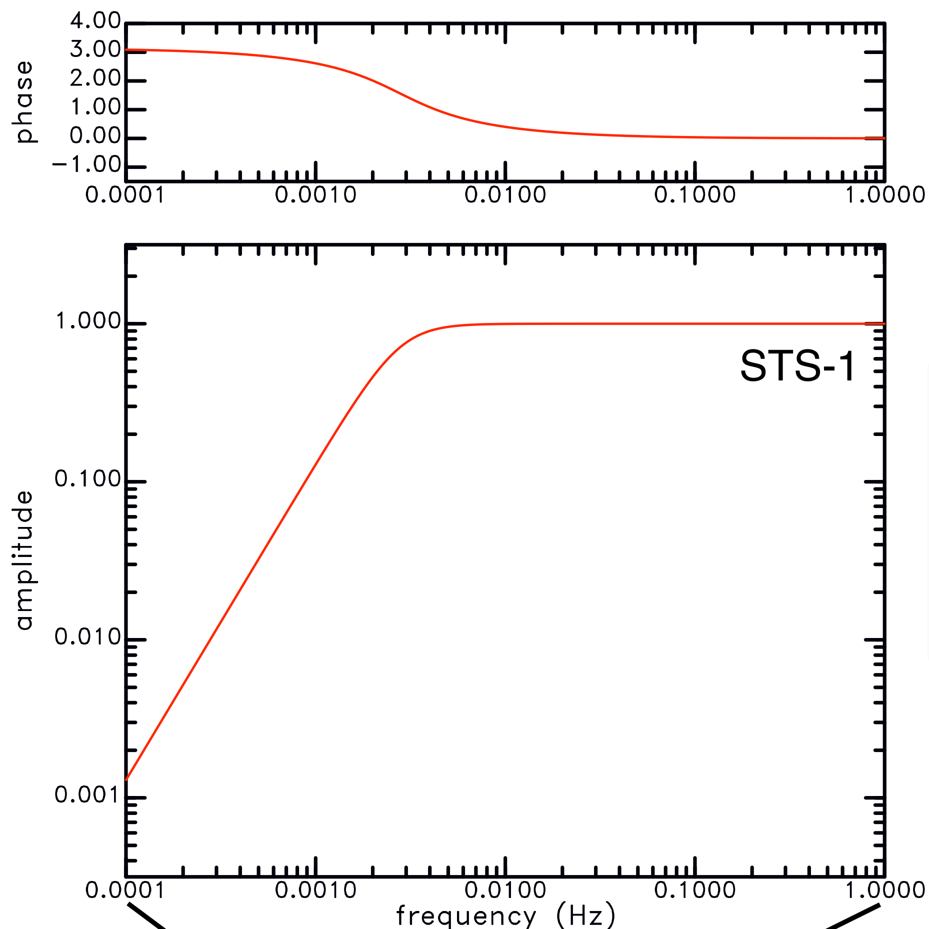
IRIS NSF

- Problems with GSN data quality; symptoms:
    - station frequency response
    - noise levels
    - secondary-sensor quality
- Impact on science and operations
- Need new focus on defining GSN success:
    - *quality*
    - *transparency*
- Opportunities for our science from “gold-standard” data

3 types of analysis

1. Scaling analysis
2. Intersensor coherence analysis
3. Noise analysis

Seismometer frequency response



$$T(s) = K \frac{\prod_{i=1}^{N} (s - z_i)}{\prod_{j=1}^{M} (s - p_j)}$$

ground motion → seismometer → seismogram

1. Scaling analysis:

Assessment of reported gain in two frequency bands

1. M > 6.5 events in CMT catalog

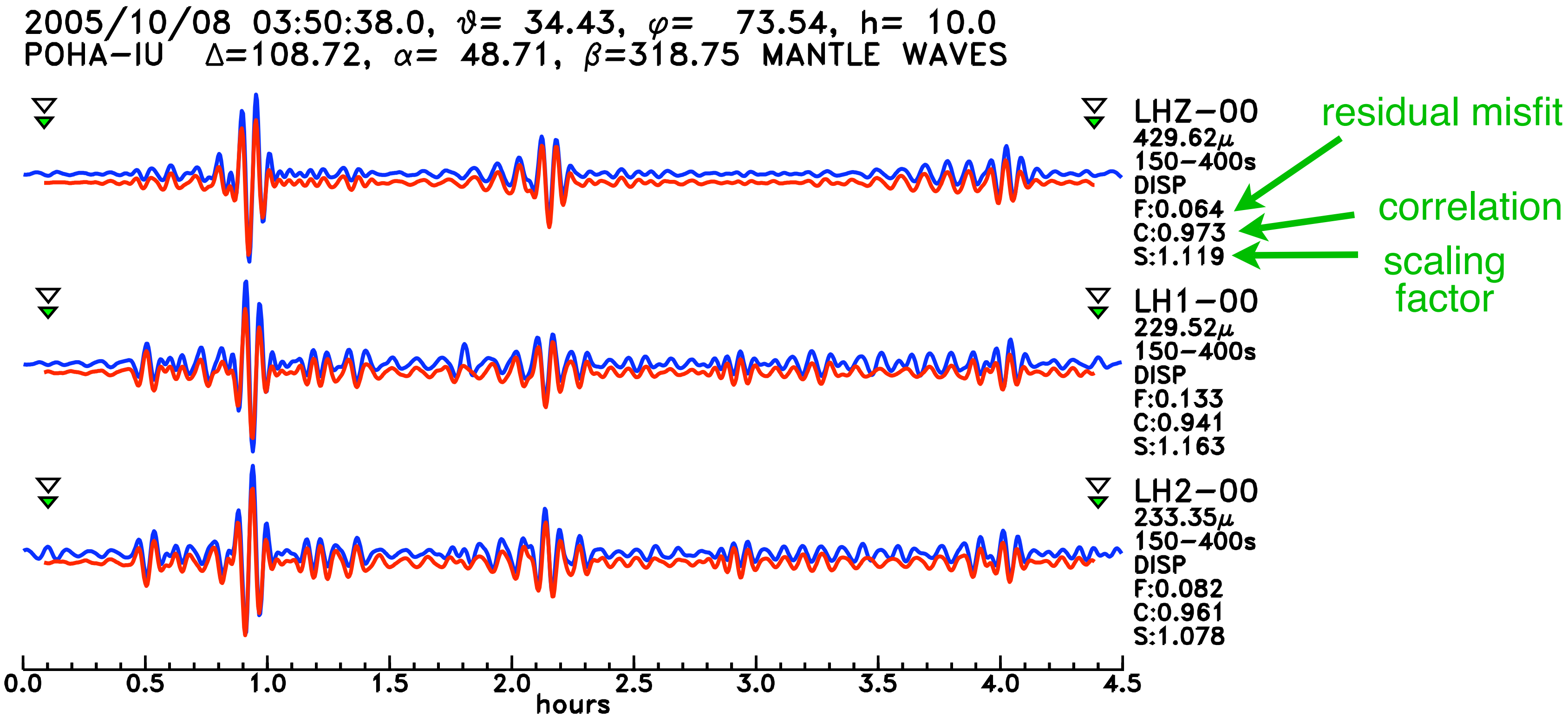
2. Deconvolve instrument responses from dataless SEED volumes from IRIS DMC

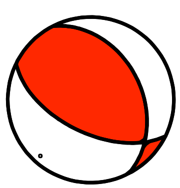
3. Calculate optimal scaling for body waves (~60 s) and mantle waves (~175 s) for all well-fit seismograms

4. Calculate annual average and range of central quartiles

Initial results in Ekström, Dalton, Nettles (2006).

Blue - observed seismograms
Red - synthetic seismograms

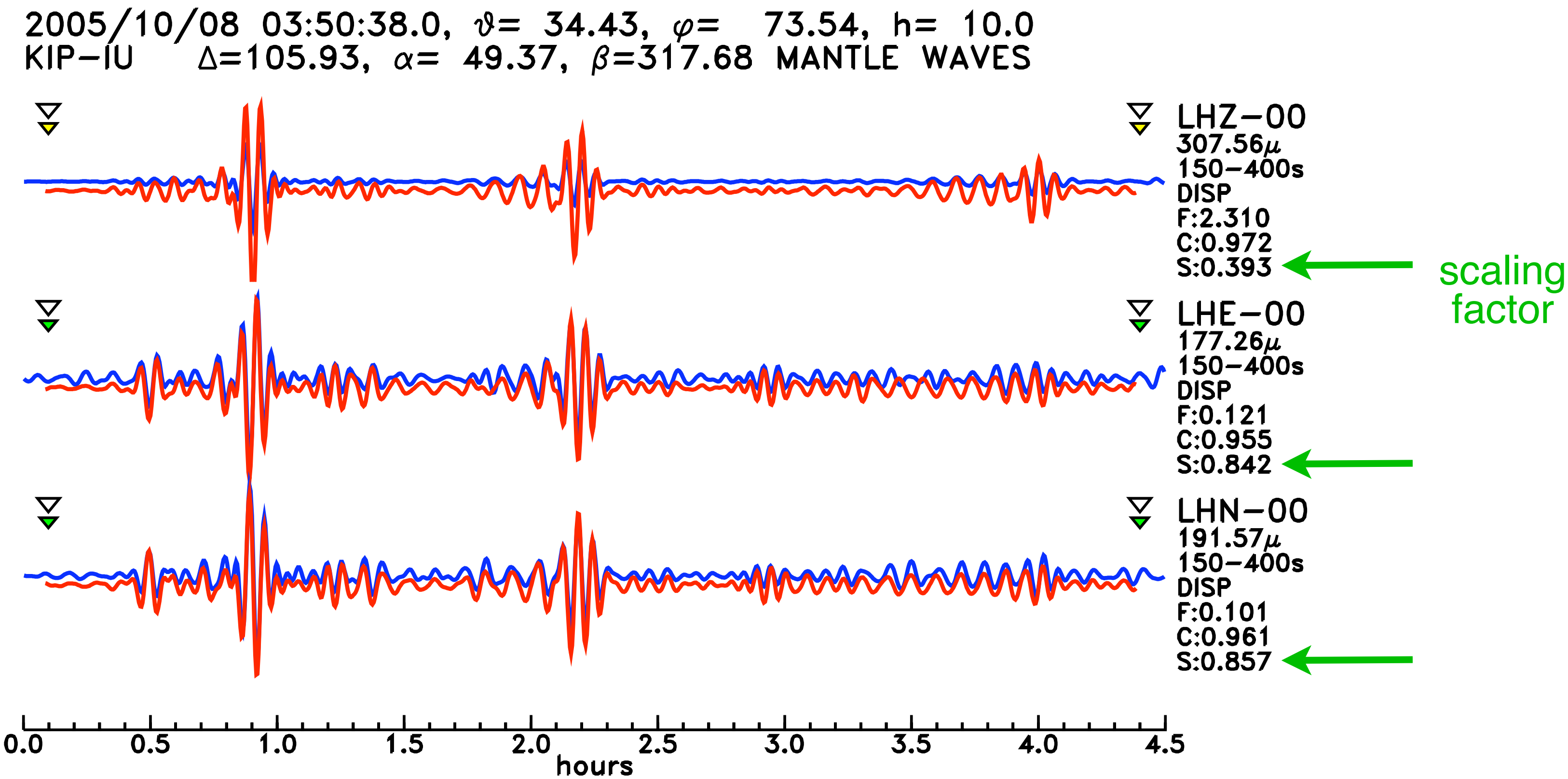


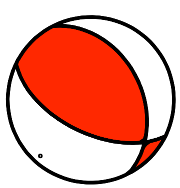


$$S = \frac{\sum_{i=1}^{N} o_i s_i}{\sum_{i=1}^{N} s_i^2}$$

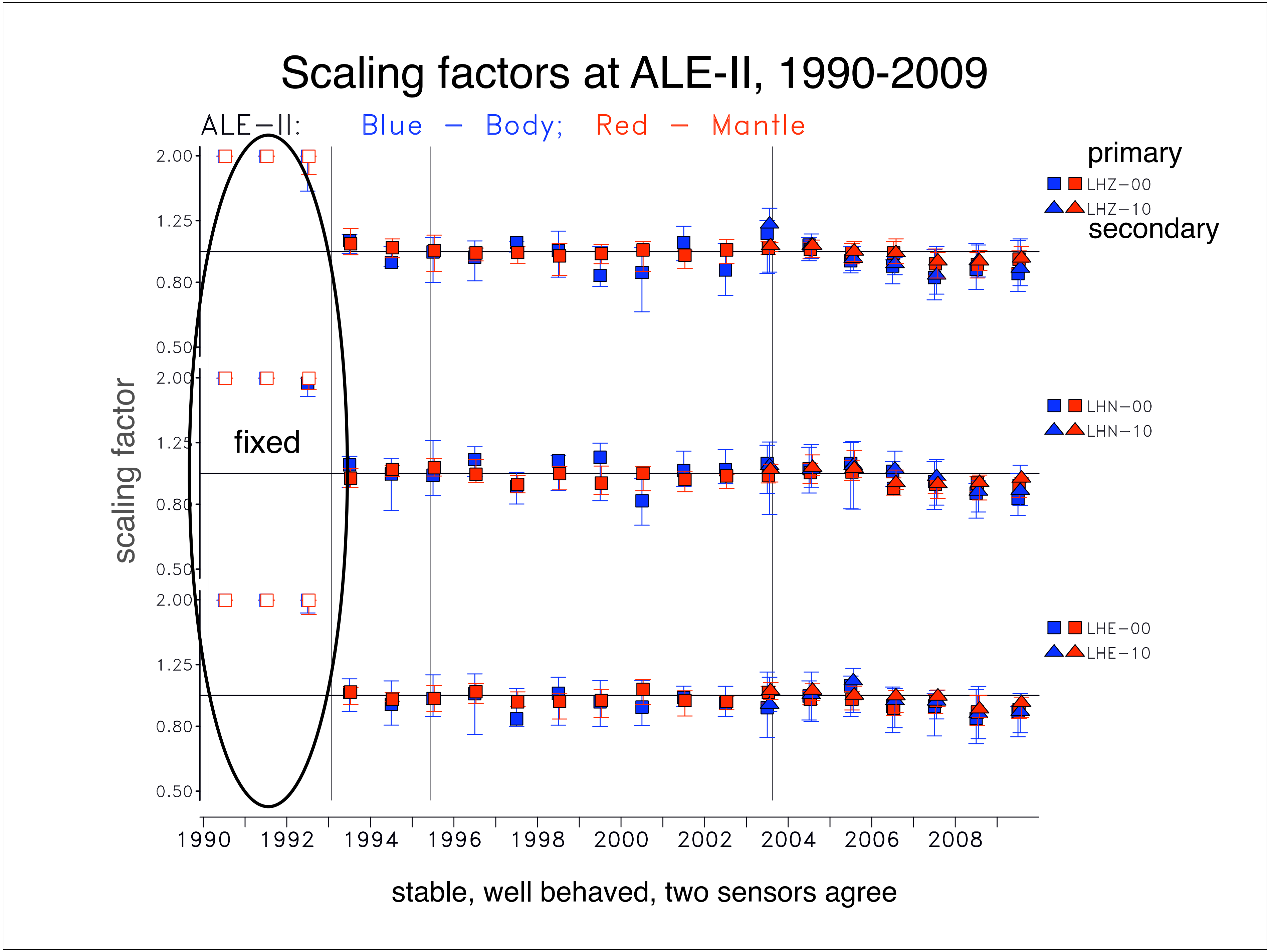
Blue - observed seismograms

Red - synthetic seismograms

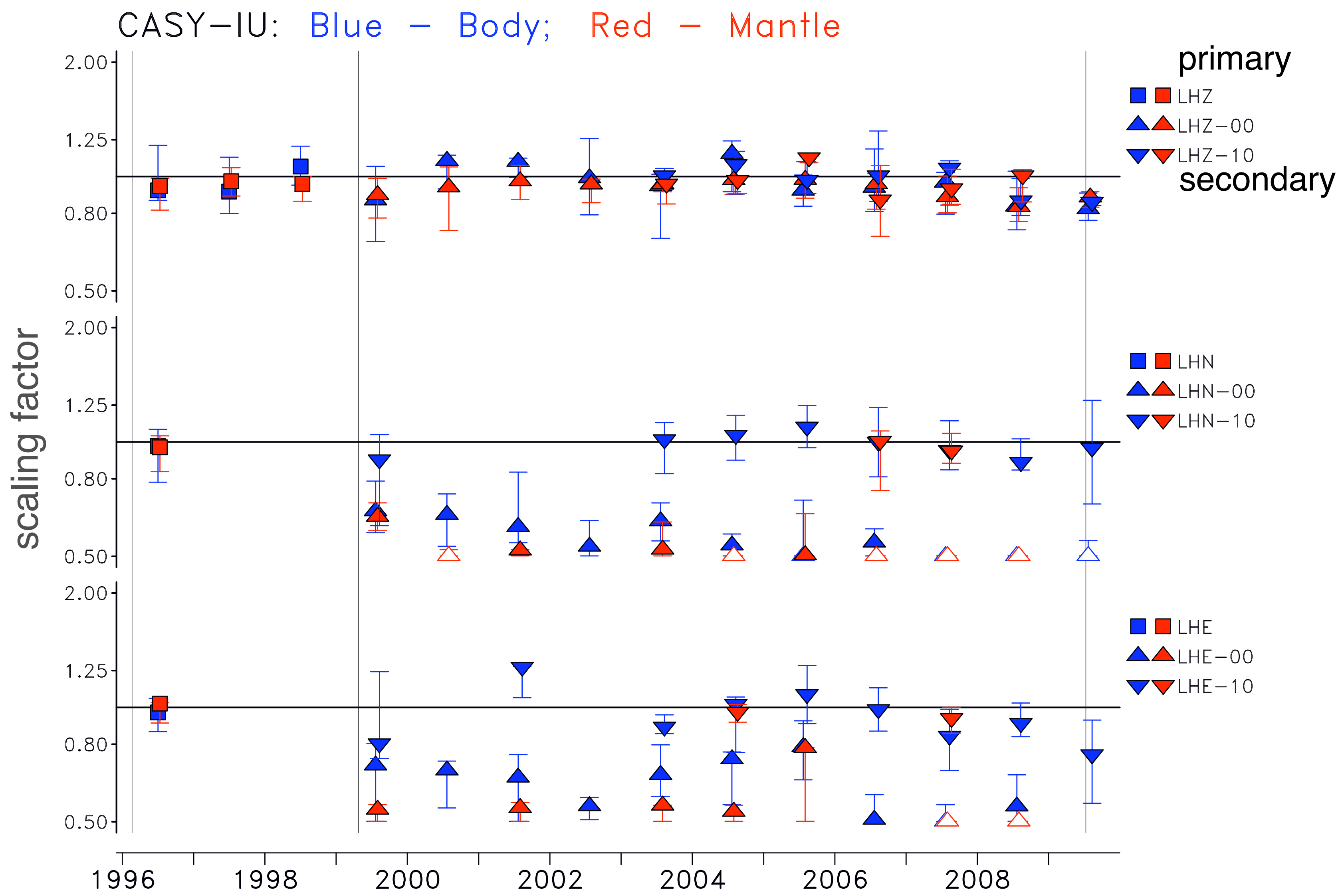




$$\boxed{S = \frac{\sum_{i=1}^{N} o_i s_i}{\sum_{i=1}^{N} s_i^2}}$$

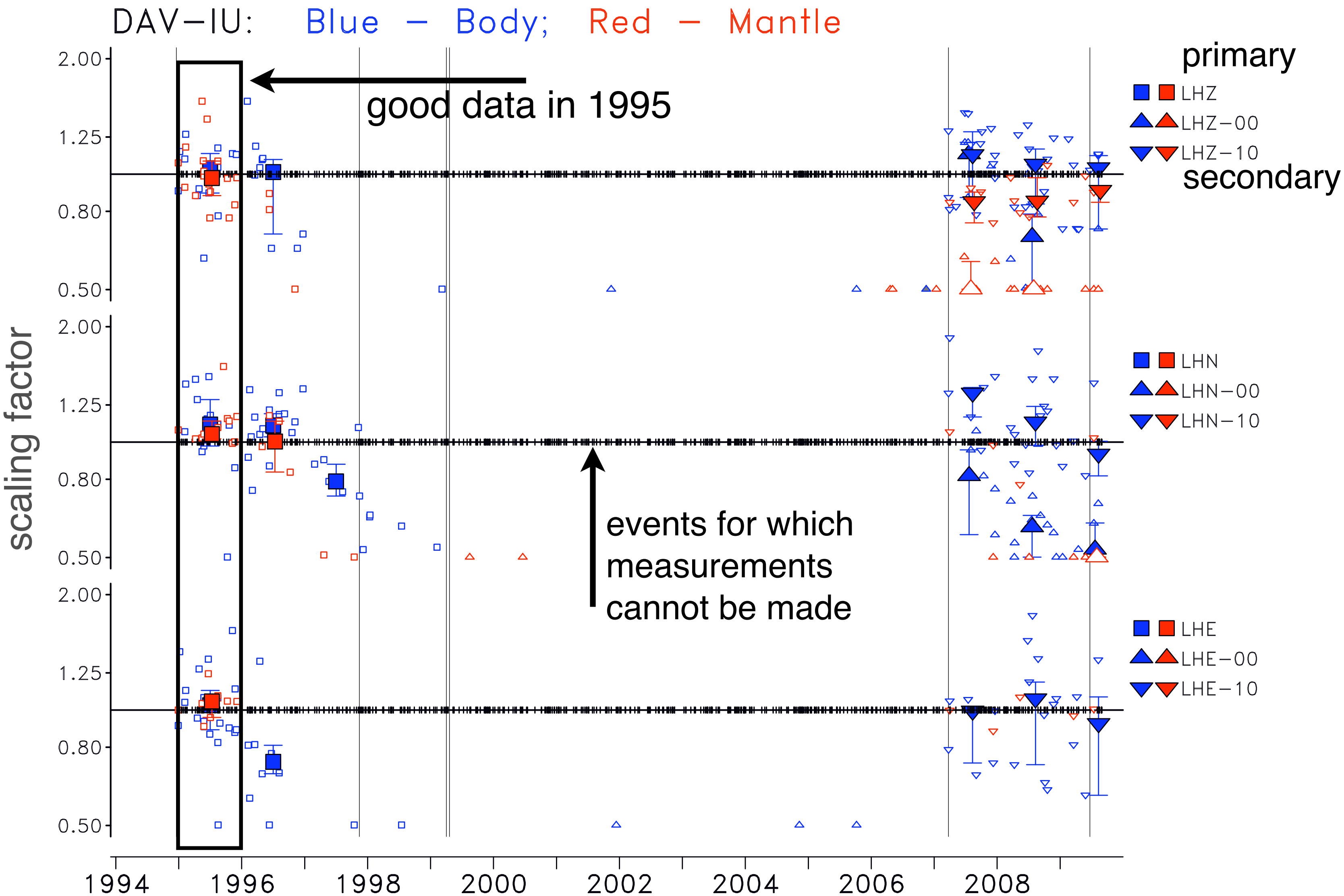

Scaling factors at ALE-II, 1990-2009
ALE−II: Blue − Body; Red − Mantle
primary
LHZ−00
LHZ−10
secondary
LHN−00
LHN−10
LHE−00
LHE−10
fixed
scaling factor
2.00
1.25
0.80
0.50
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
stable, well behaved, two sensors agree

Scaling factors at CASY-IU, 1996-2009



STS-1 horizontals bad; secondary noisy

Scaling factors at DAV-IU, 1994-2009



no good STS-1 data since 1997; secondary N,E noisy

2. Coherence analysis:

Comparison of signals recorded on two sensors

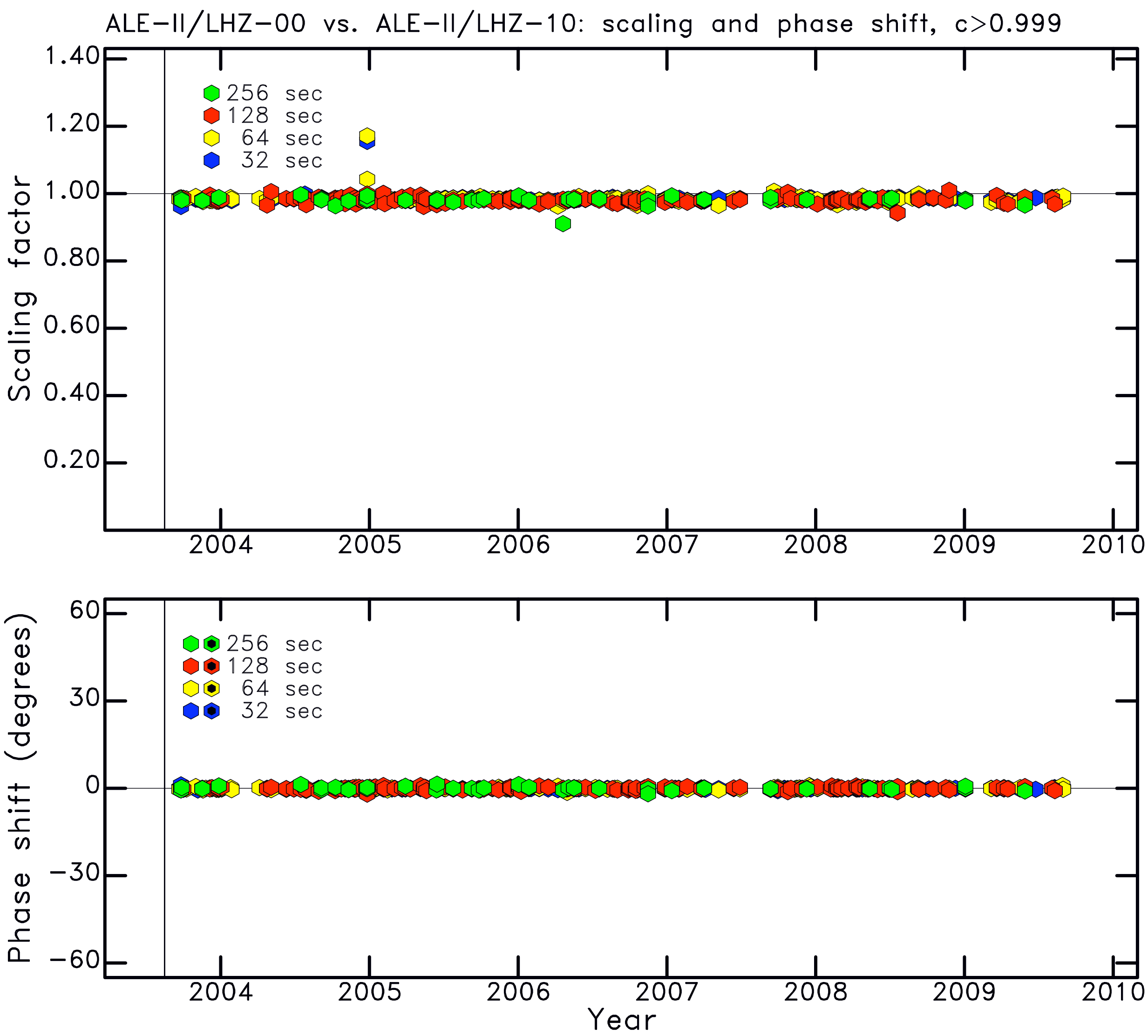
1. M > 6.5 events in CMT catalog (or continuous signal)

2. Deconvolve instrument responses from dataless SEED volumes from IRIS DMC

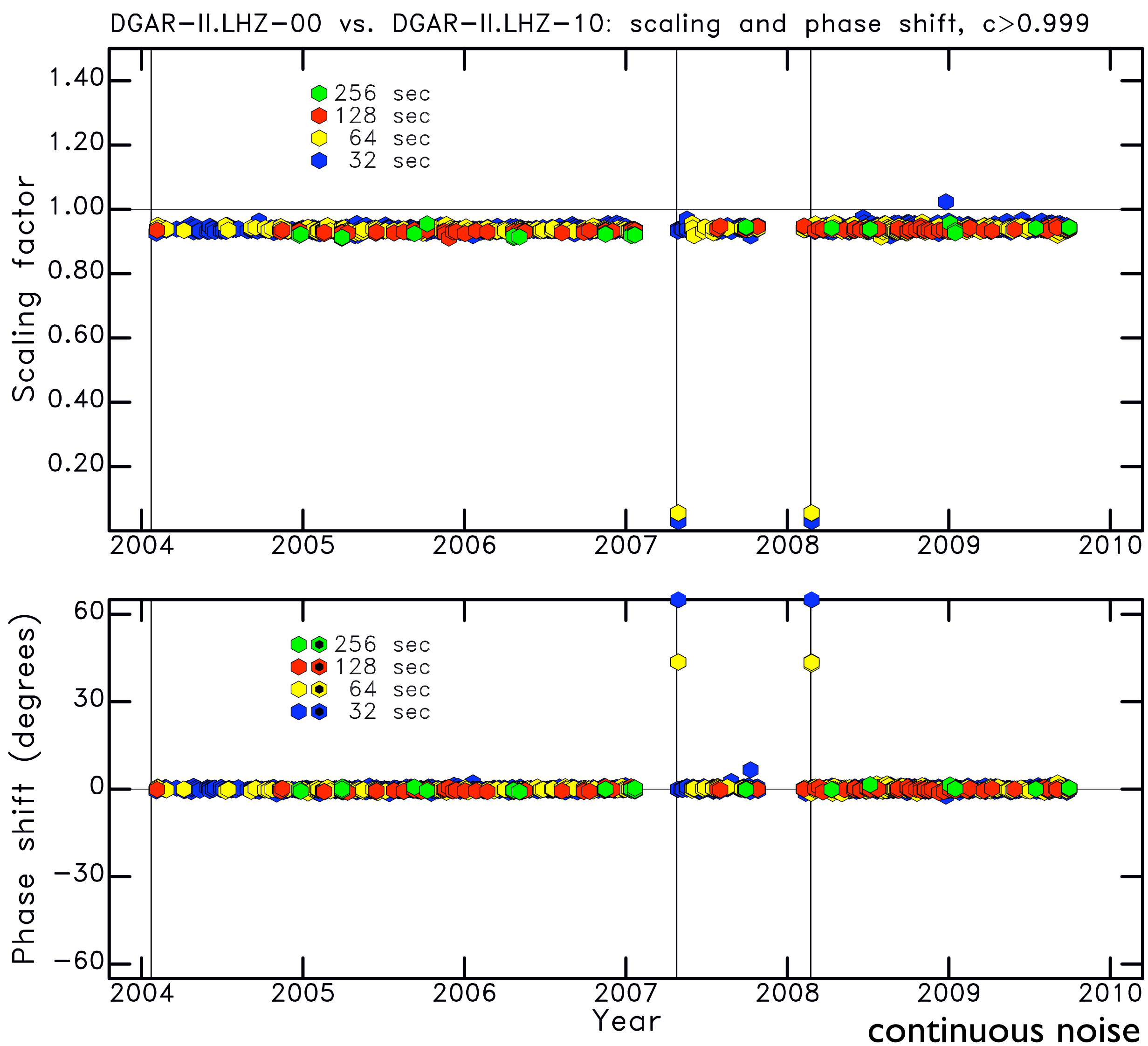
3. Calculate coherence in narrow frequency bands

4. When coherence is high, calculate scaling factor and phase shift that maximizes trace agreement

Intersensor coherence, ALE-II LHZ, 2003-2009



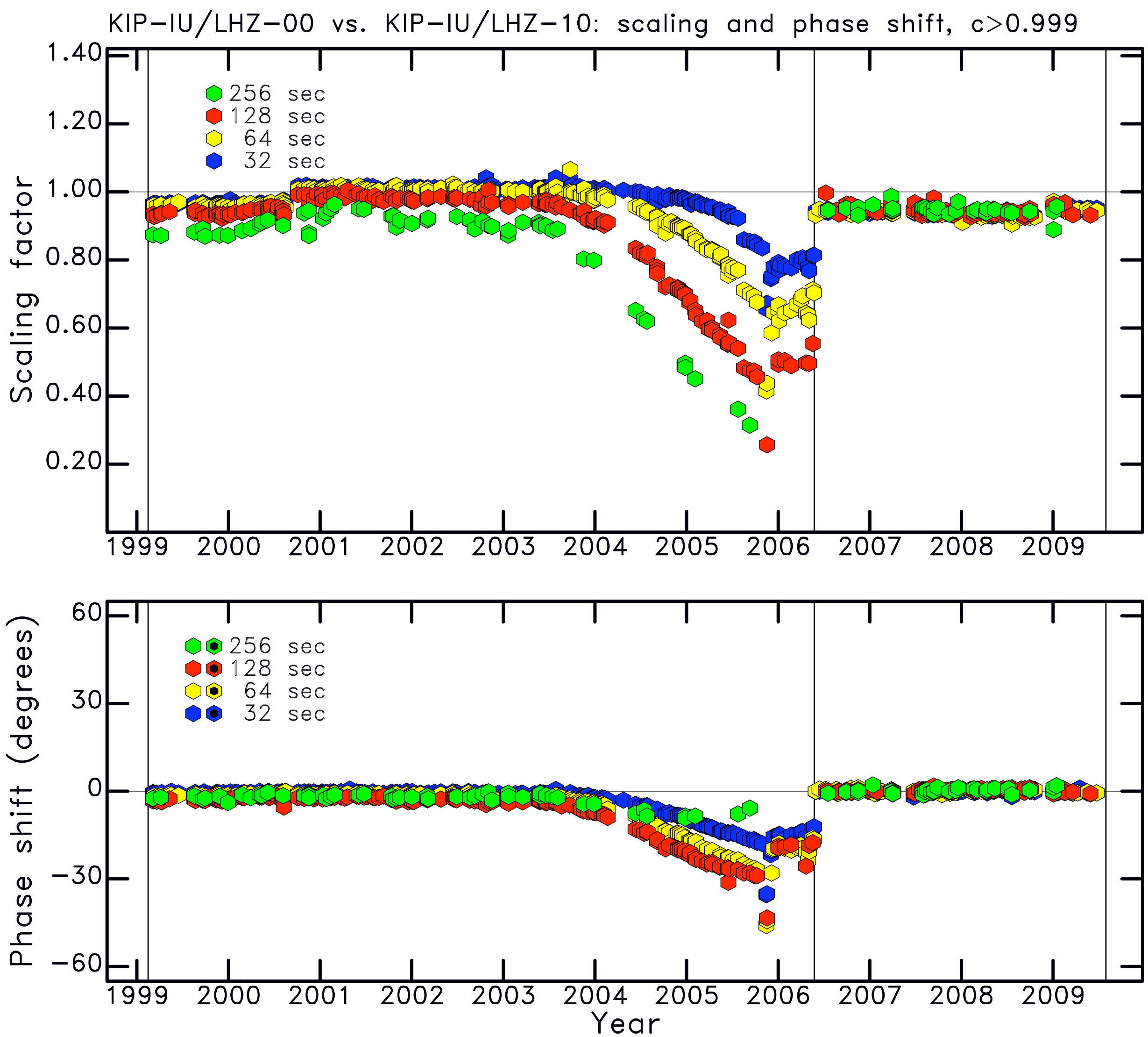
Intersensor coherence, DGAR-II LHZ, 2003-2009



~5% gain error

continuous noise

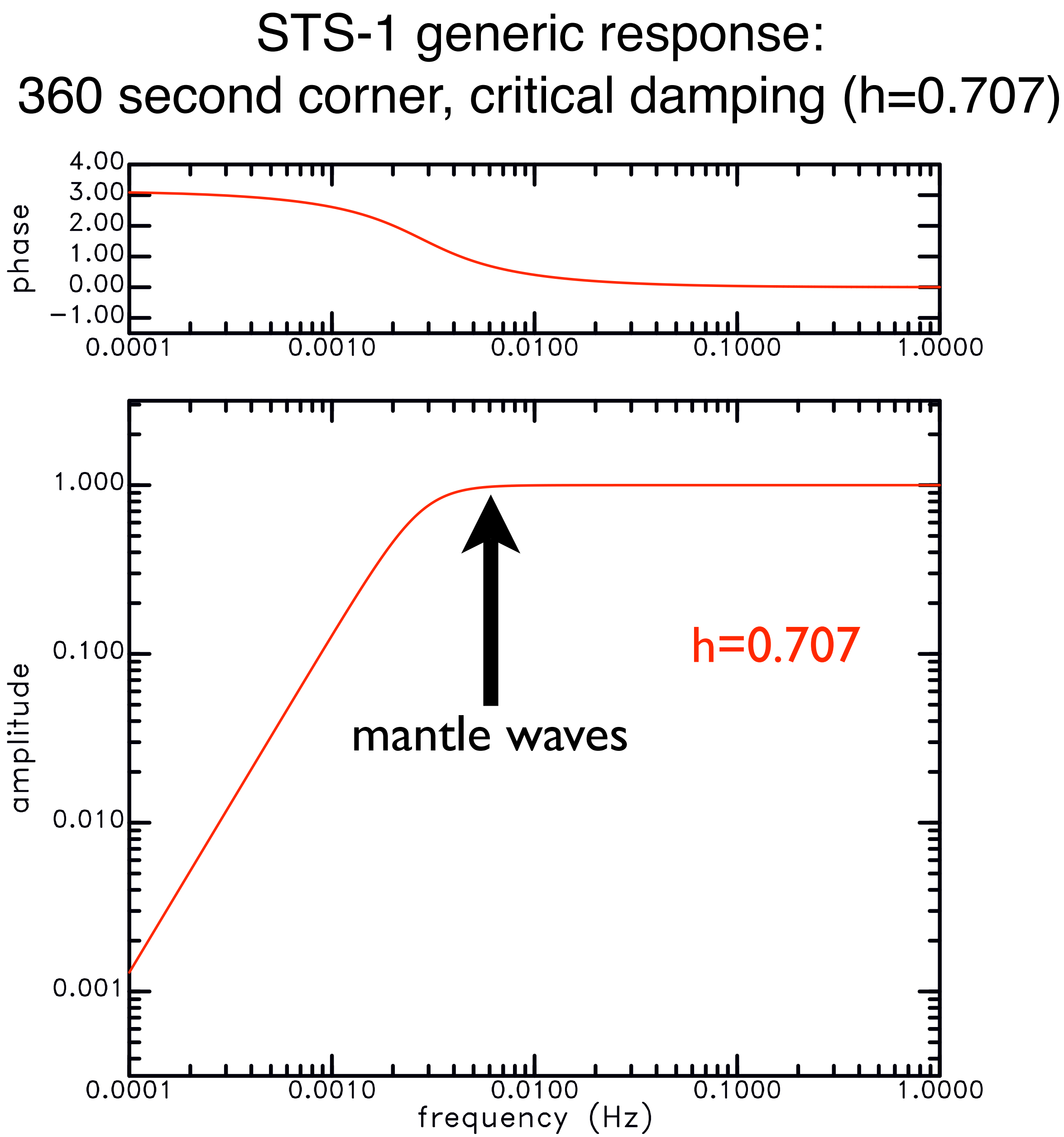
Intersensor coherence, KIP-IU LHZ, 1999-2009



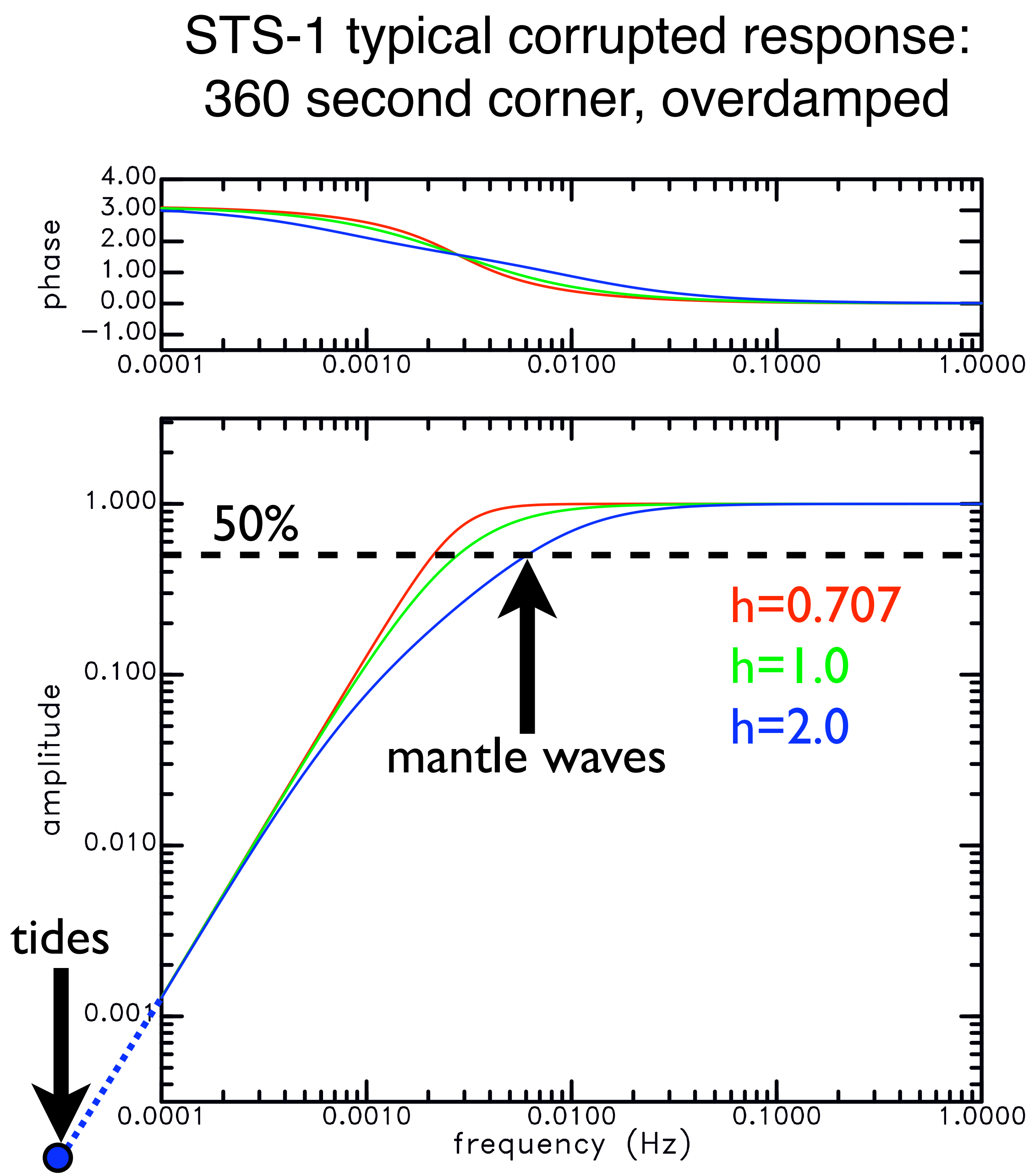
~5% gain error

STS-1 decay pattern

STS-1 response decay



STS-1 response decay

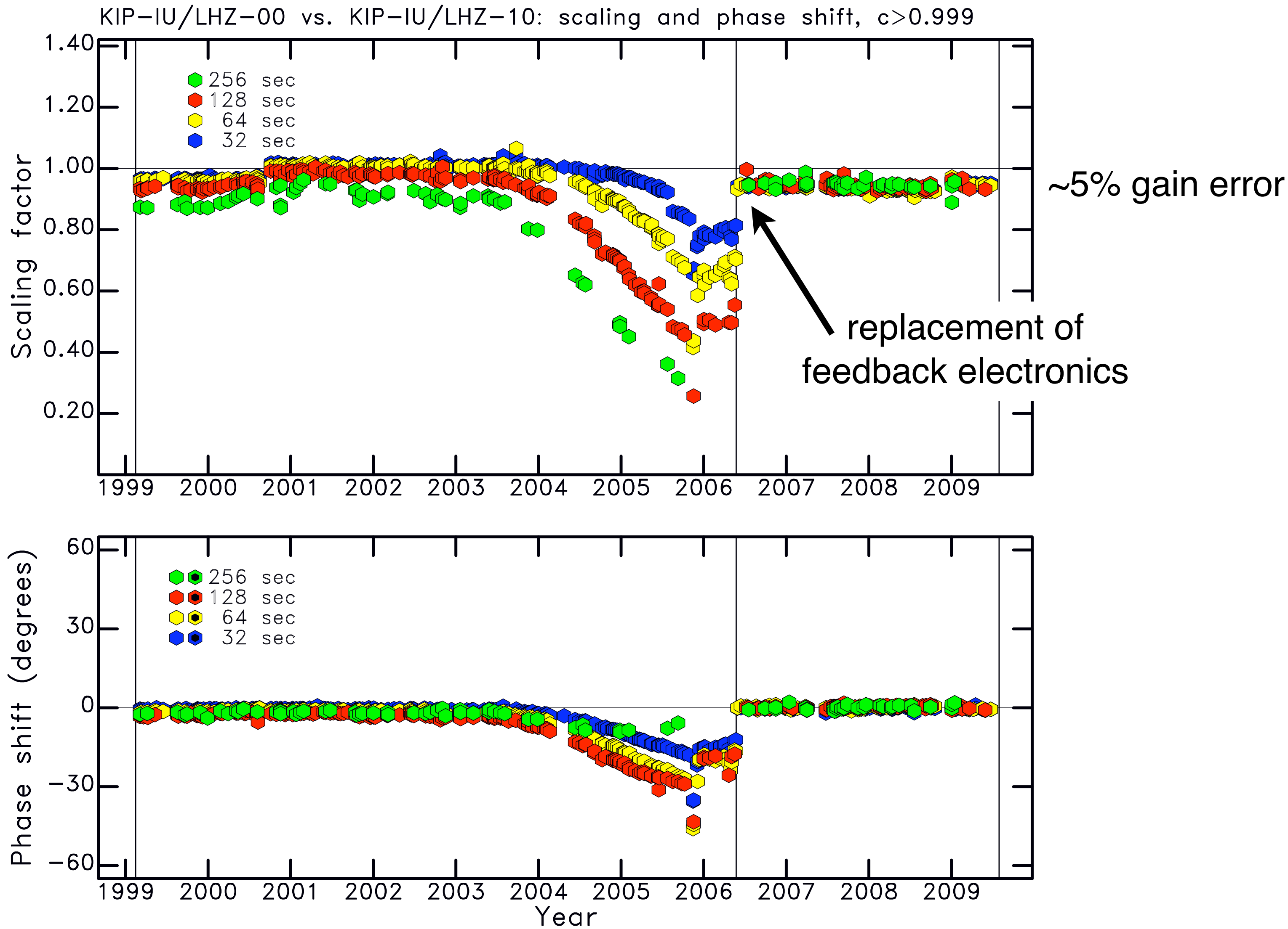


Hutt & Ringler:
moisture in FBEs

Yuki & Ishihara:
moisture in cable connectors

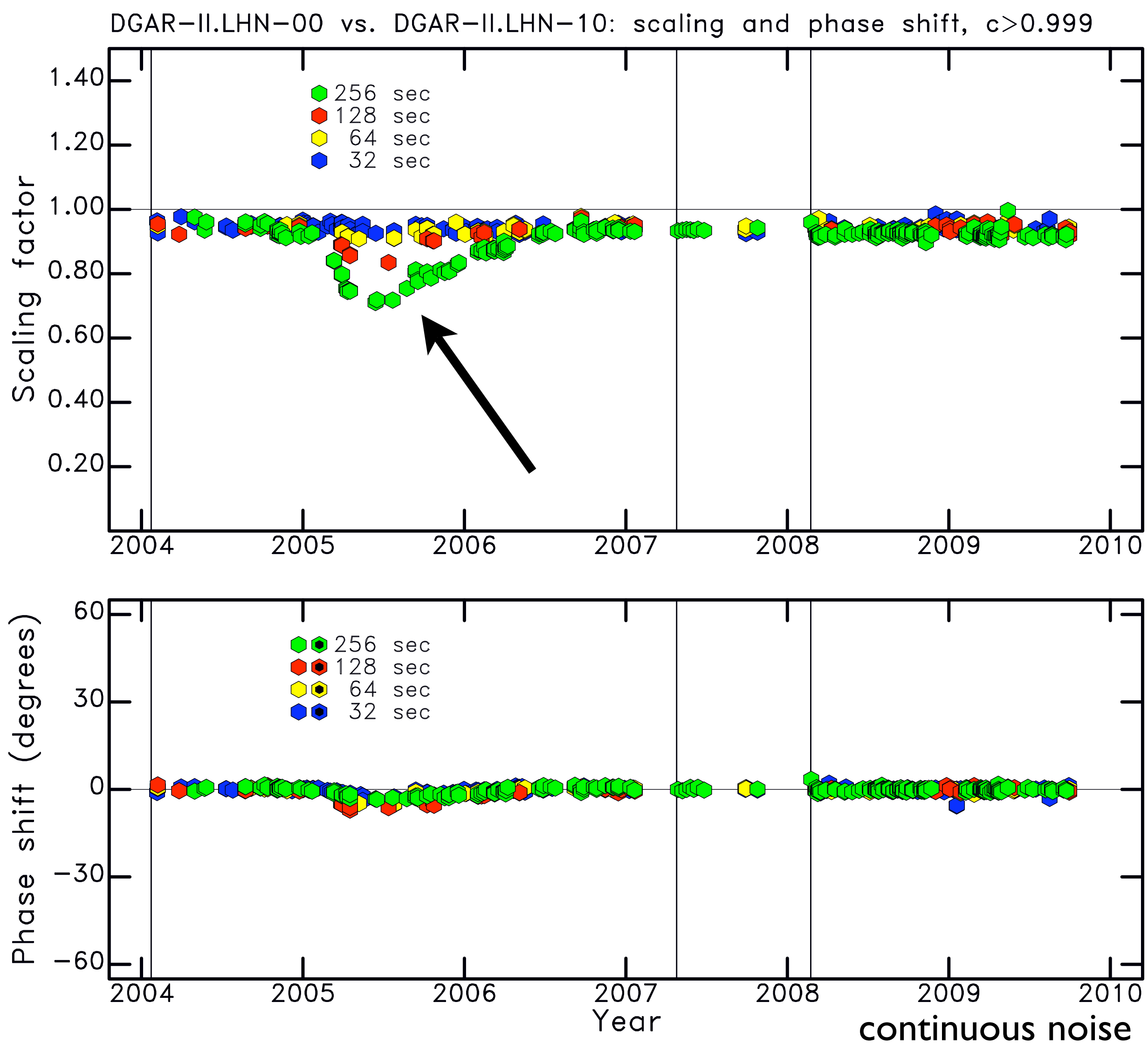
Hutt & Steim:
too-short mechanical free period

Intersensor coherence, KIP-IU LHZ, 1999-2009



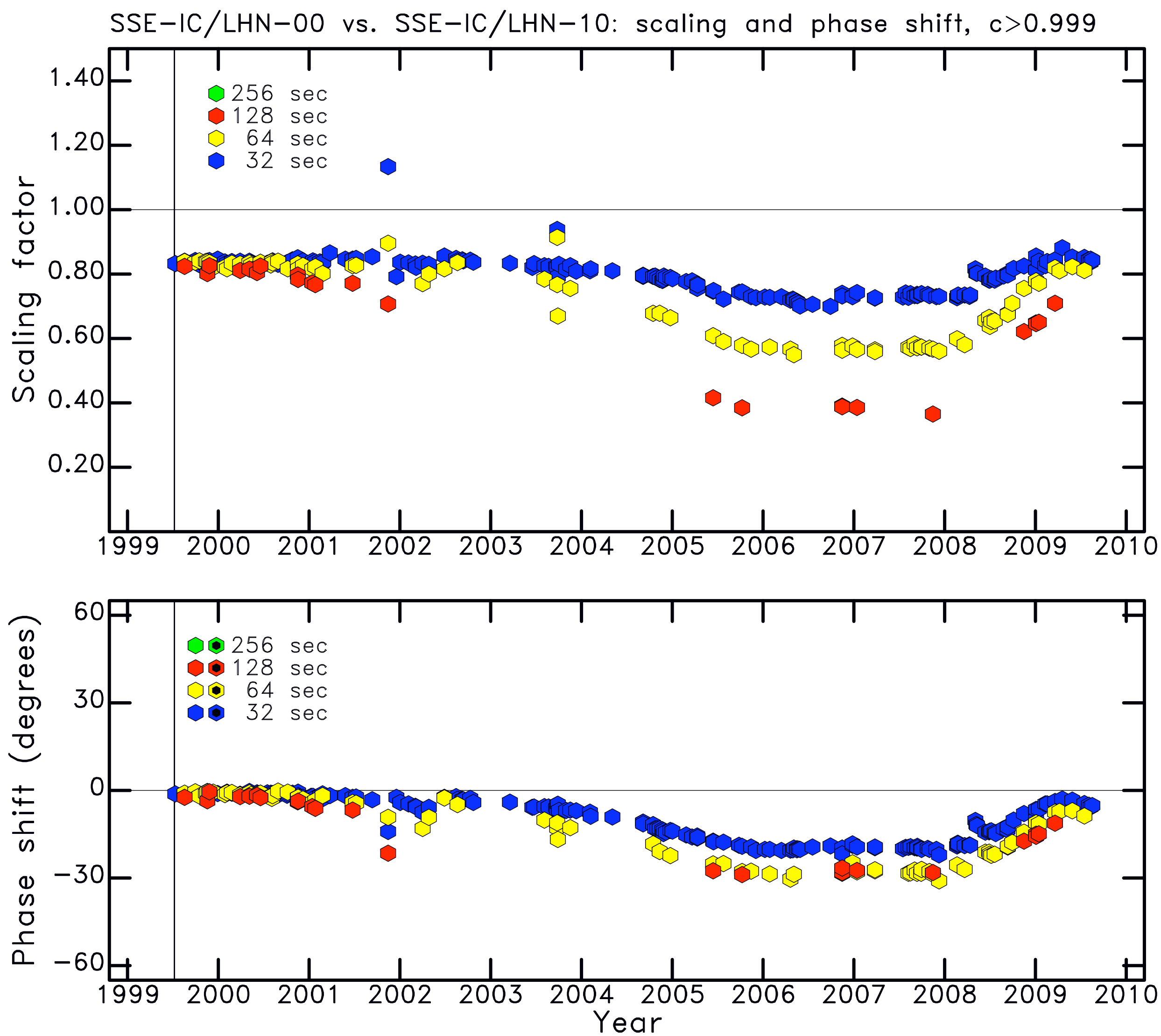
STS-1 decay pattern

Intersensor coherence, DGAR-II LHN, 2003-2009



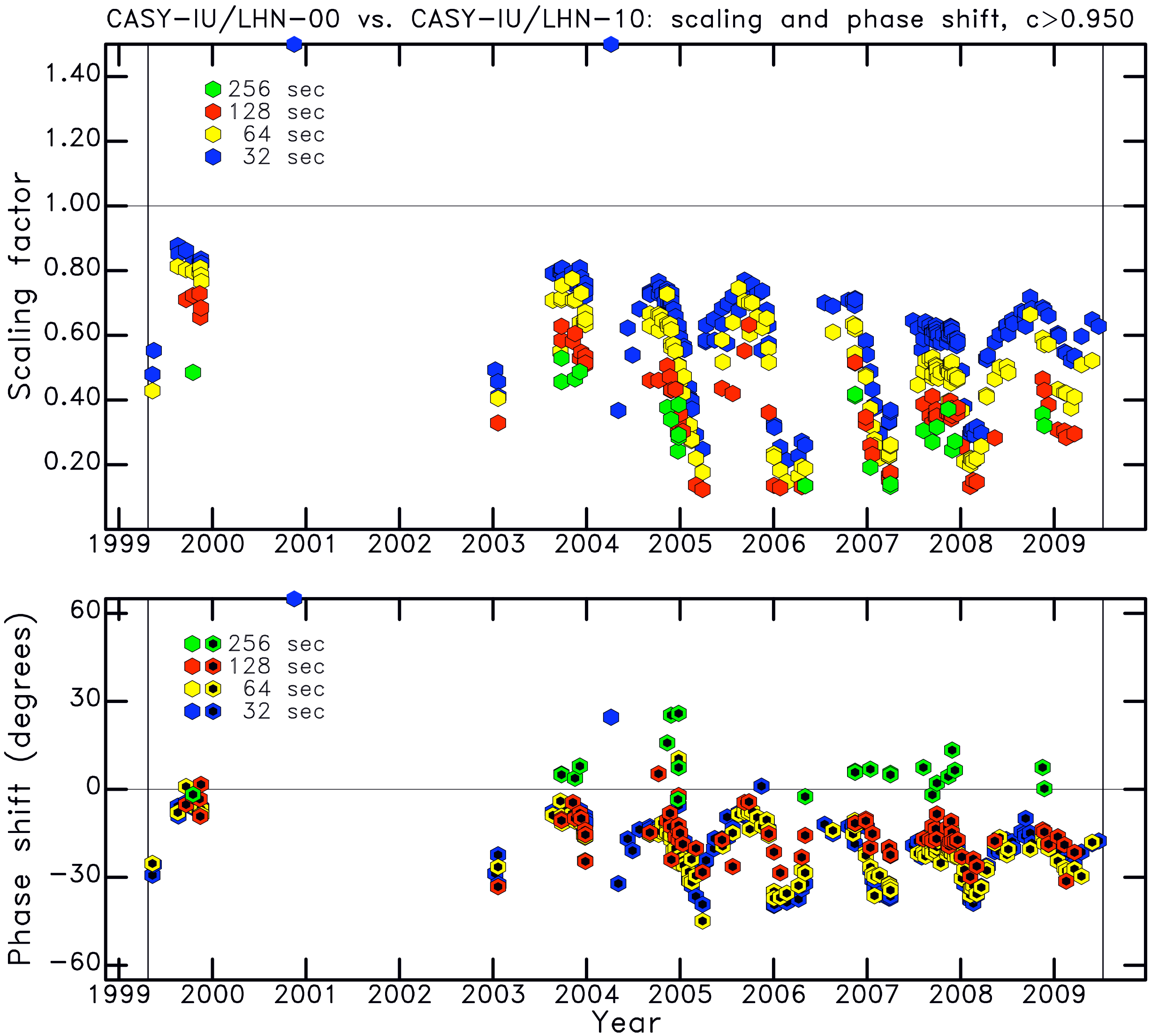
transient problem missed by infrequent calibration

Intersensor coherence, SSE-IC LHN, 1999-2009



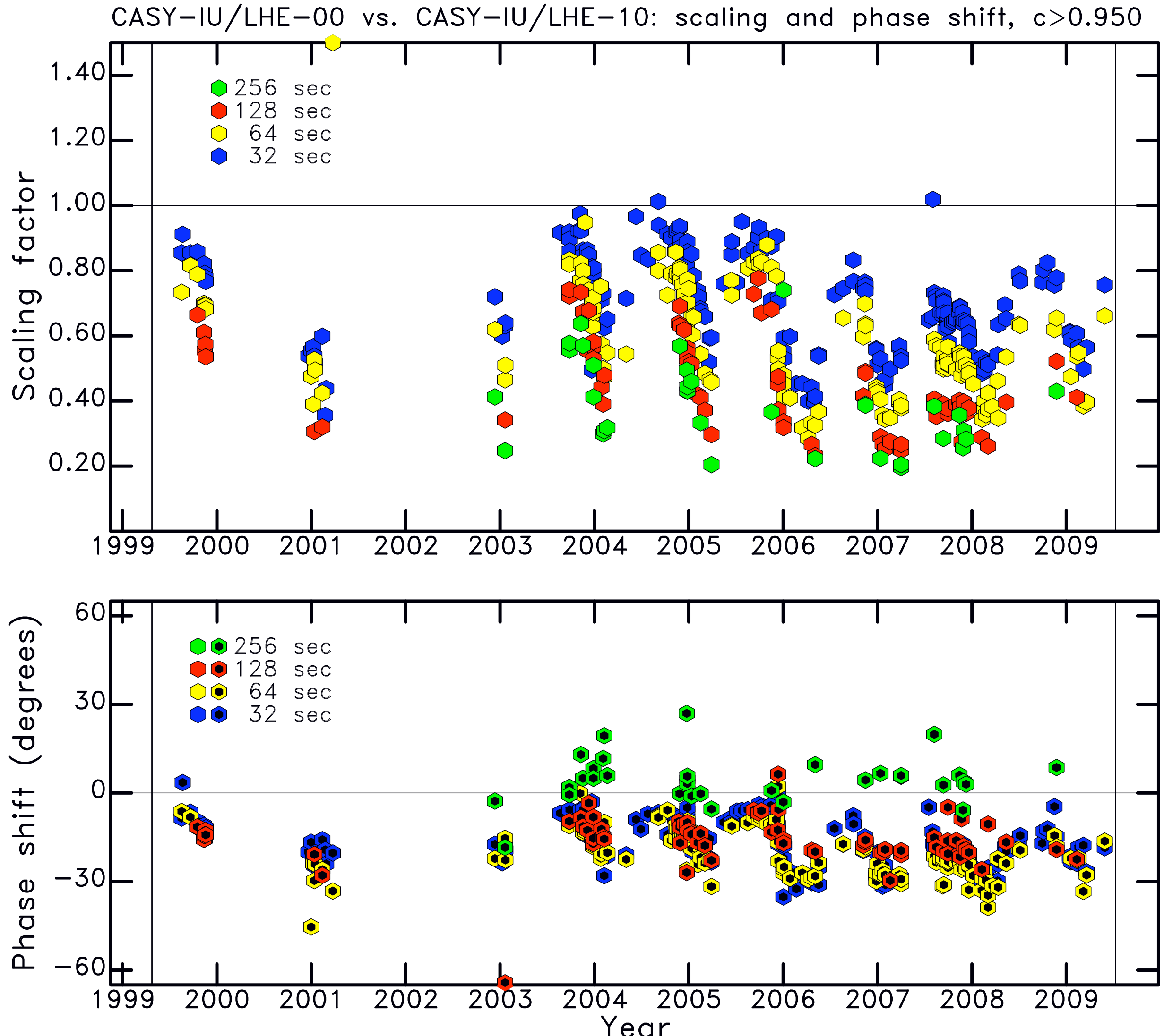
time- and frequency-dependent response error

Intersensor coherence, CASY-IU LHN, 1999-2009



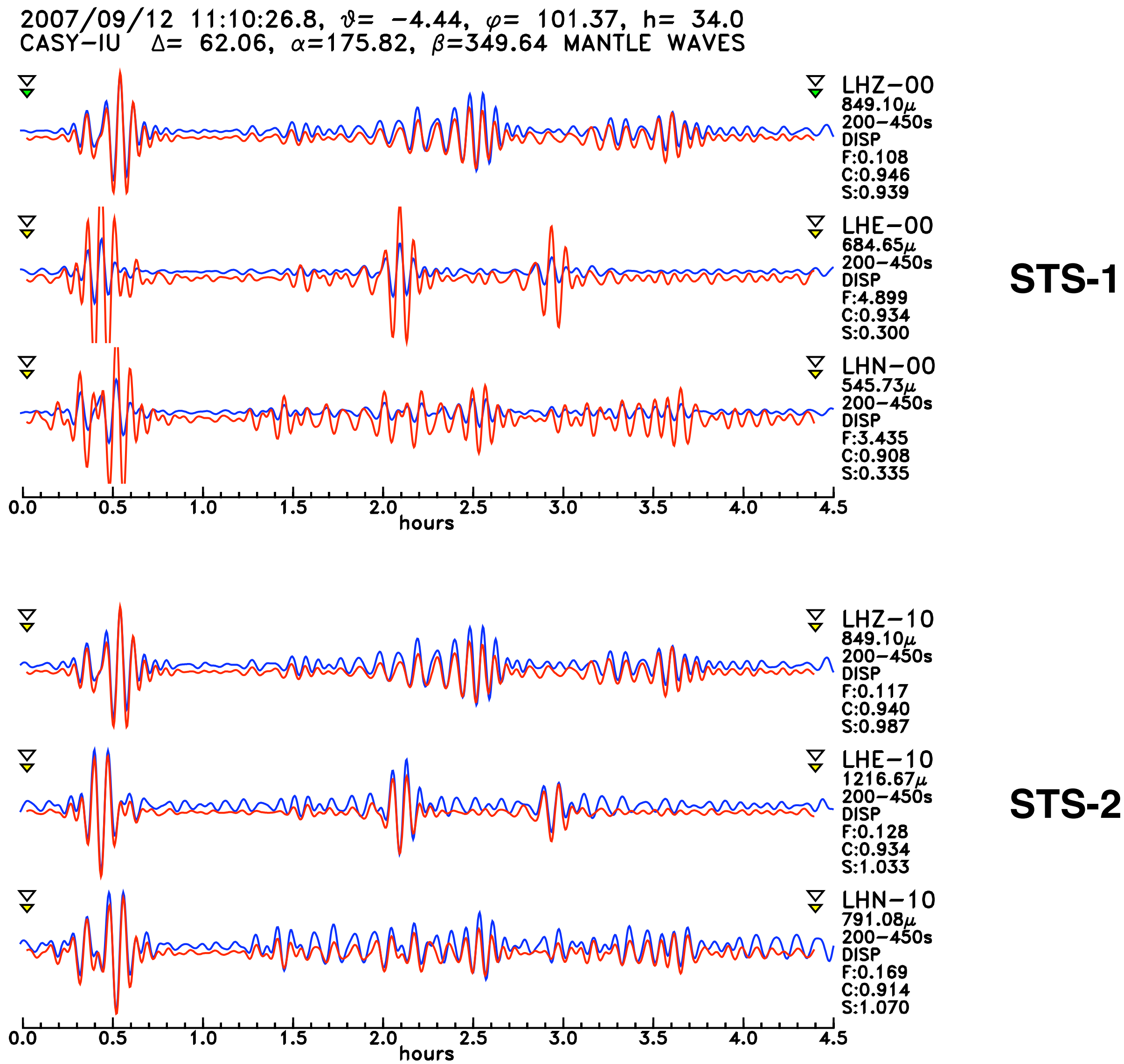
severe time- and frequency-dependent response error

Intersensor coherence, CASY-IU LHE, 1999-2009

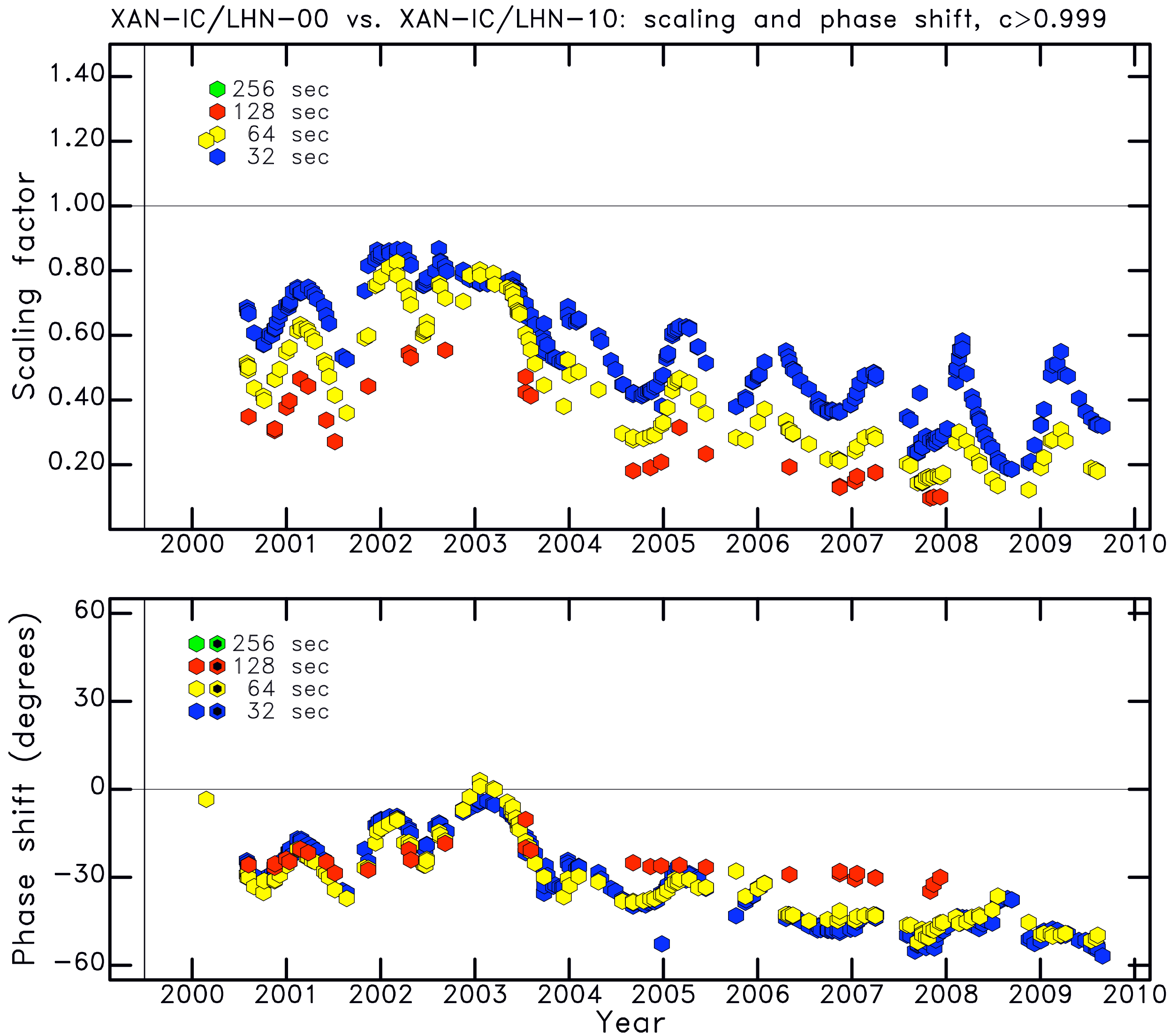


severe time- and frequency-dependent response error
(also compromises orientation estimates)

Seismograms from CASY-IU



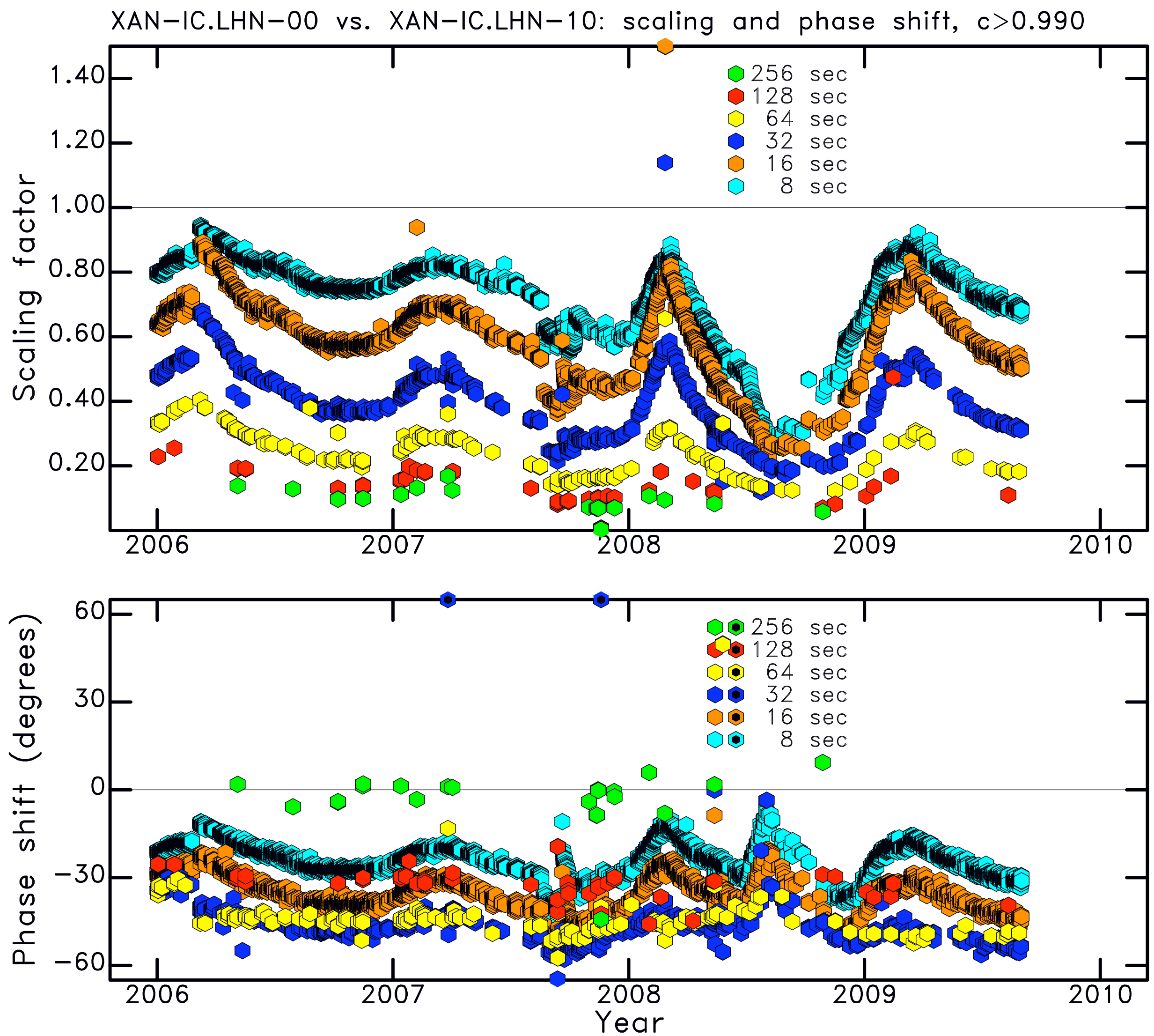
Intersensor coherence, XAN-IC LHN, 1999-2009



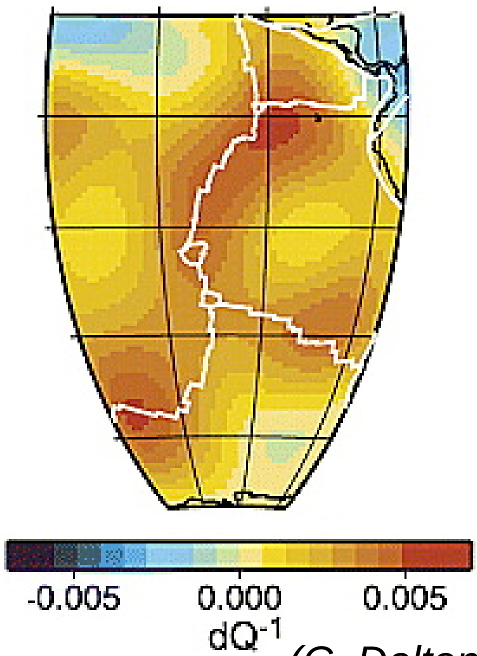
severe time- and frequency-dependent response error

Intersensor coherence, XAN-IC LHN, 1999-2009

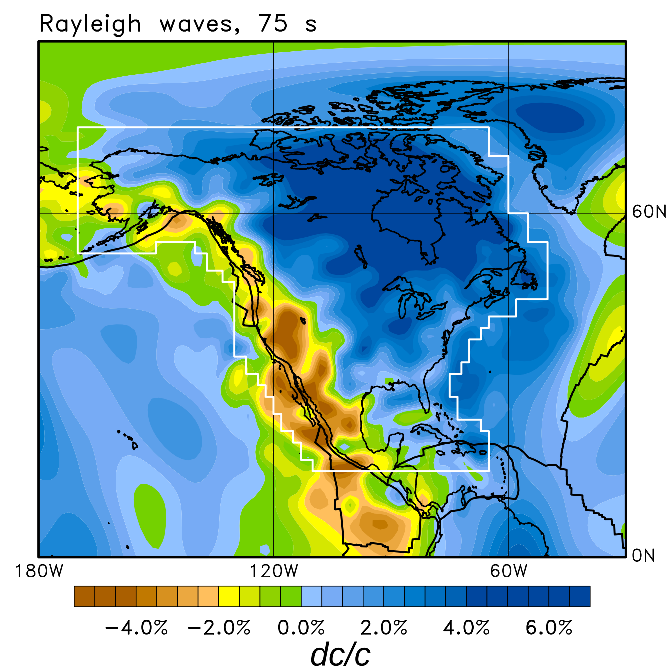
*phase and amplitude at 8 sec affected -- **no** flat part of response*

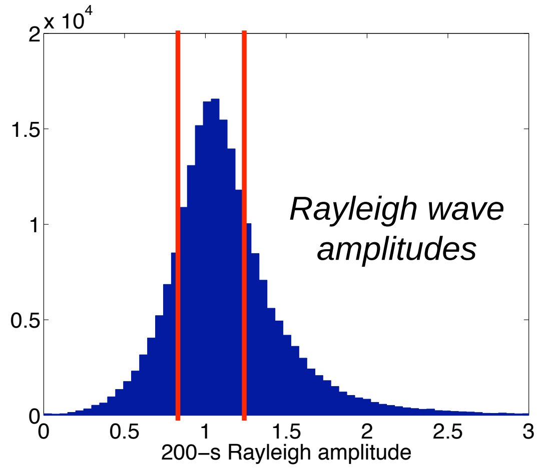


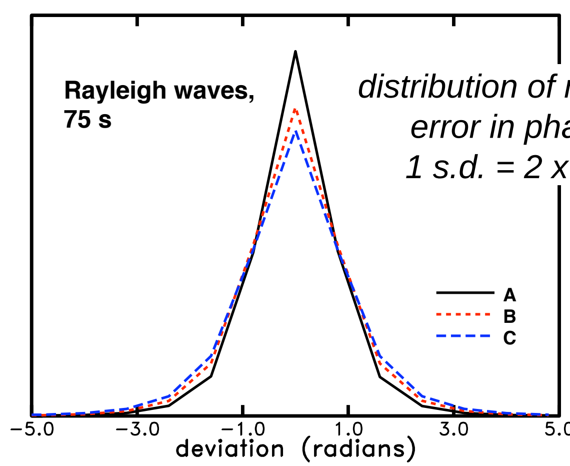
Design goals: aggregate data error an order of magnitude smaller than measured/ modeled signal



(C. Dalton)





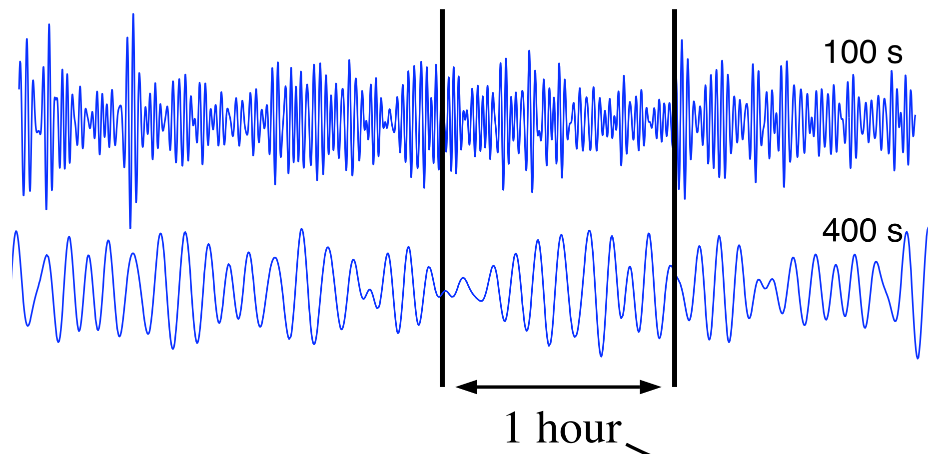


distribution of measurement error in phase angle: 1 s.d. = 2 x obs. error

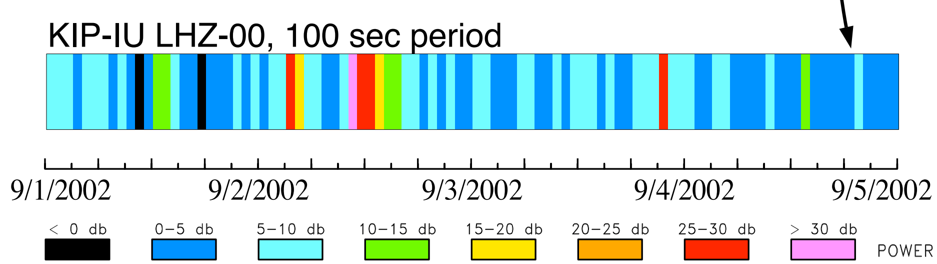
3. Noise analysis

Calculation of signal power of long-period GSN data

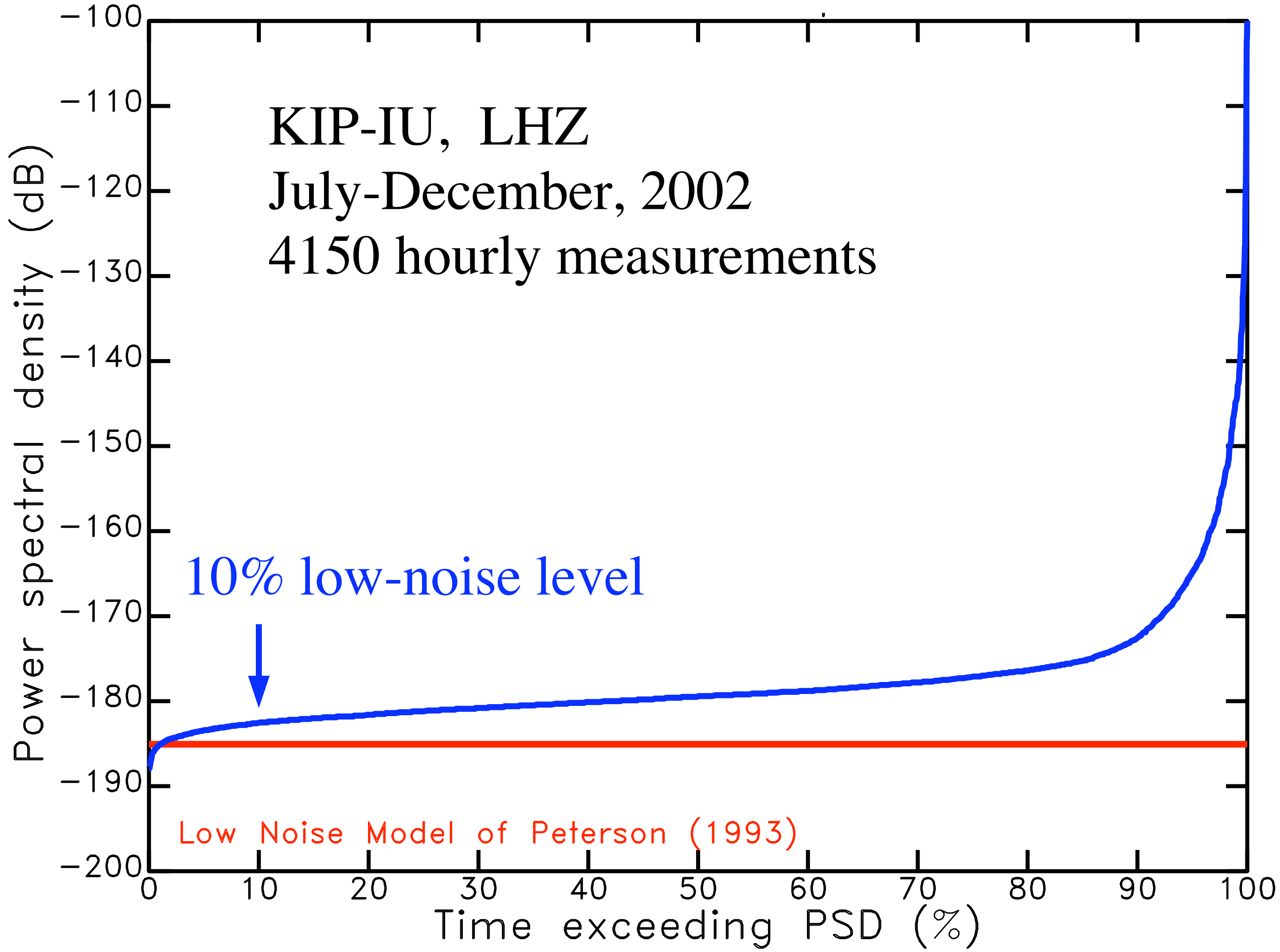
continuous filtered time series:



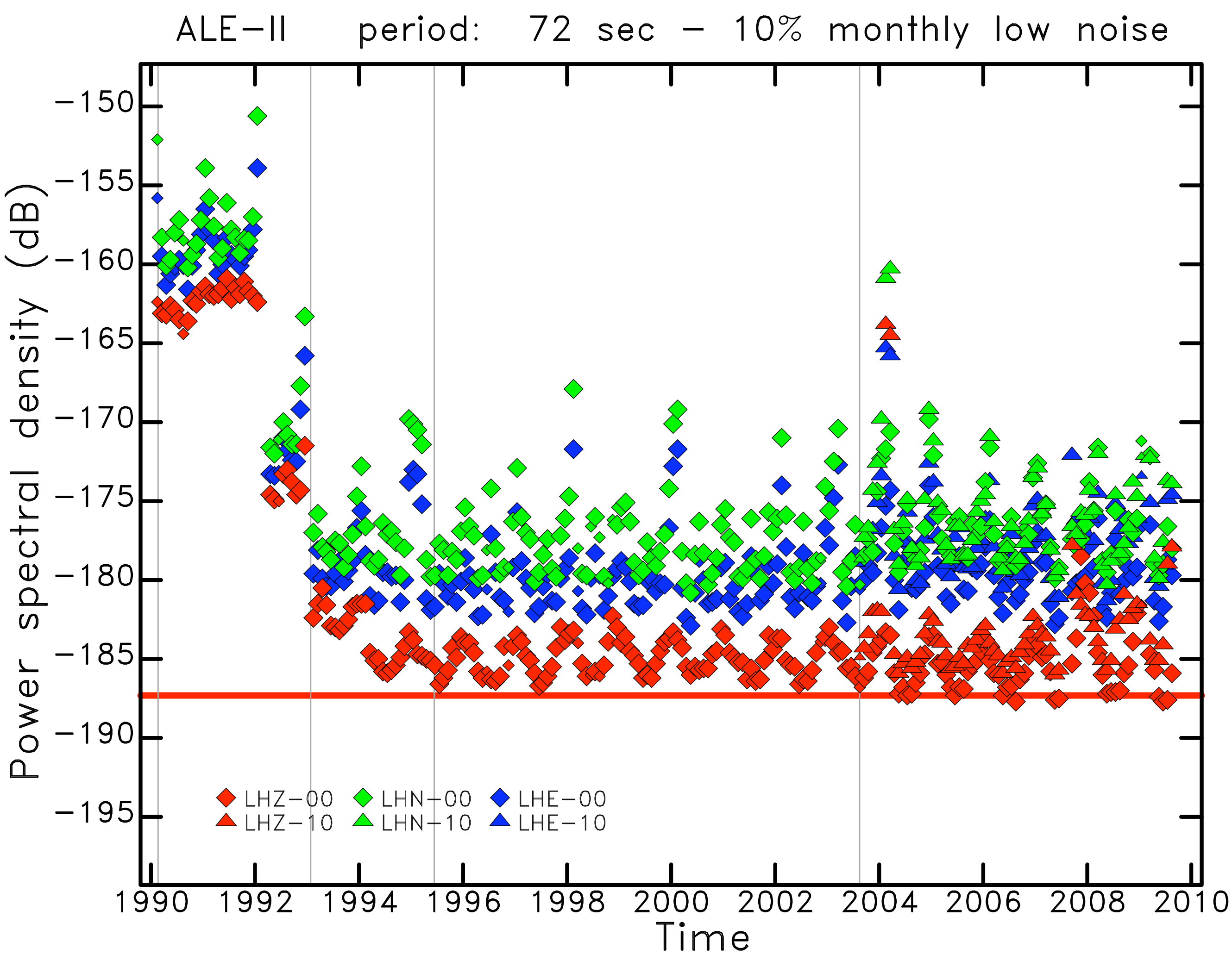
1. calculate rms
2. convert to power spectral density
3. store as hourly samples of signal level



100 sec period - distribution of PSD

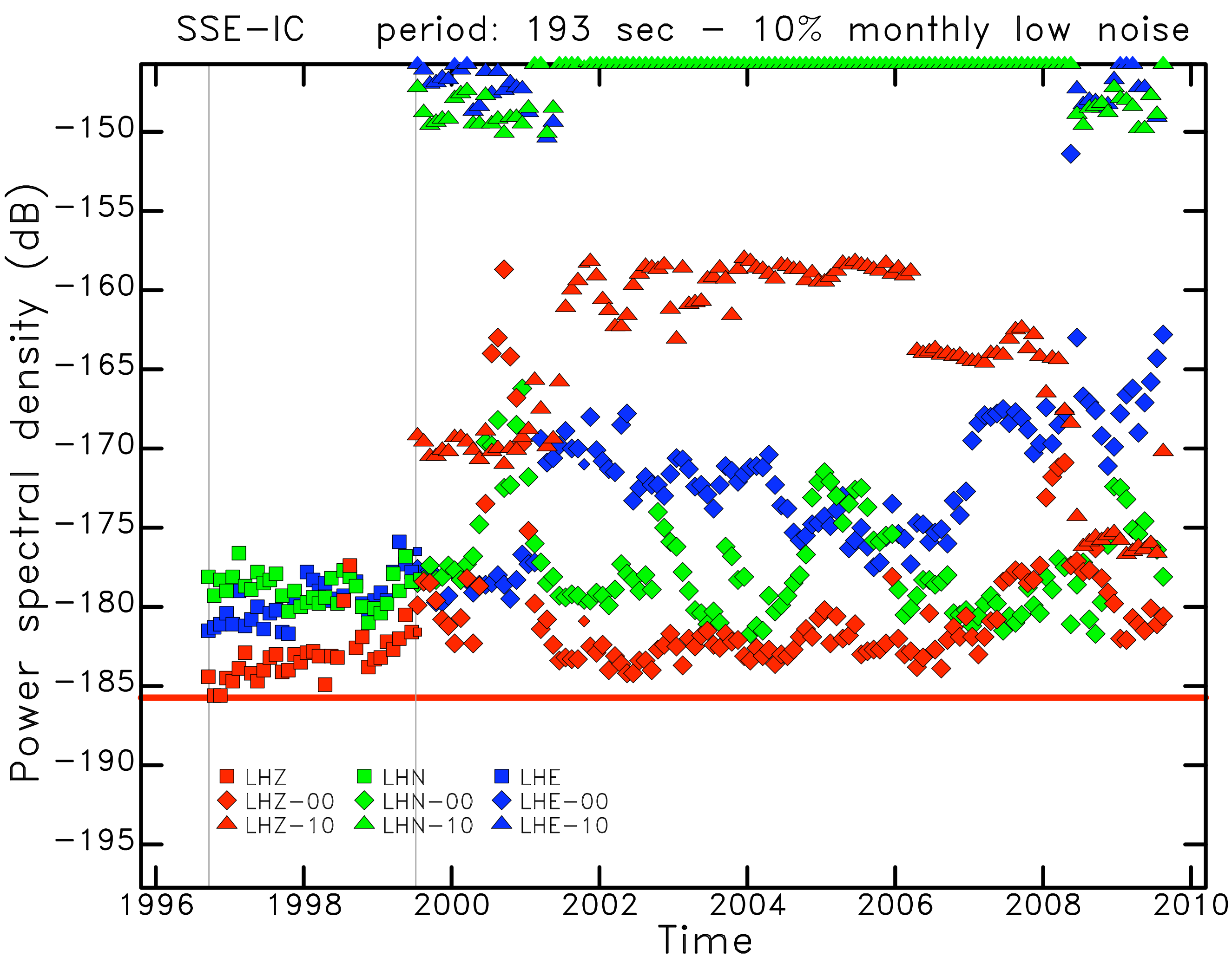


Noise, ALE-II, 72 sec



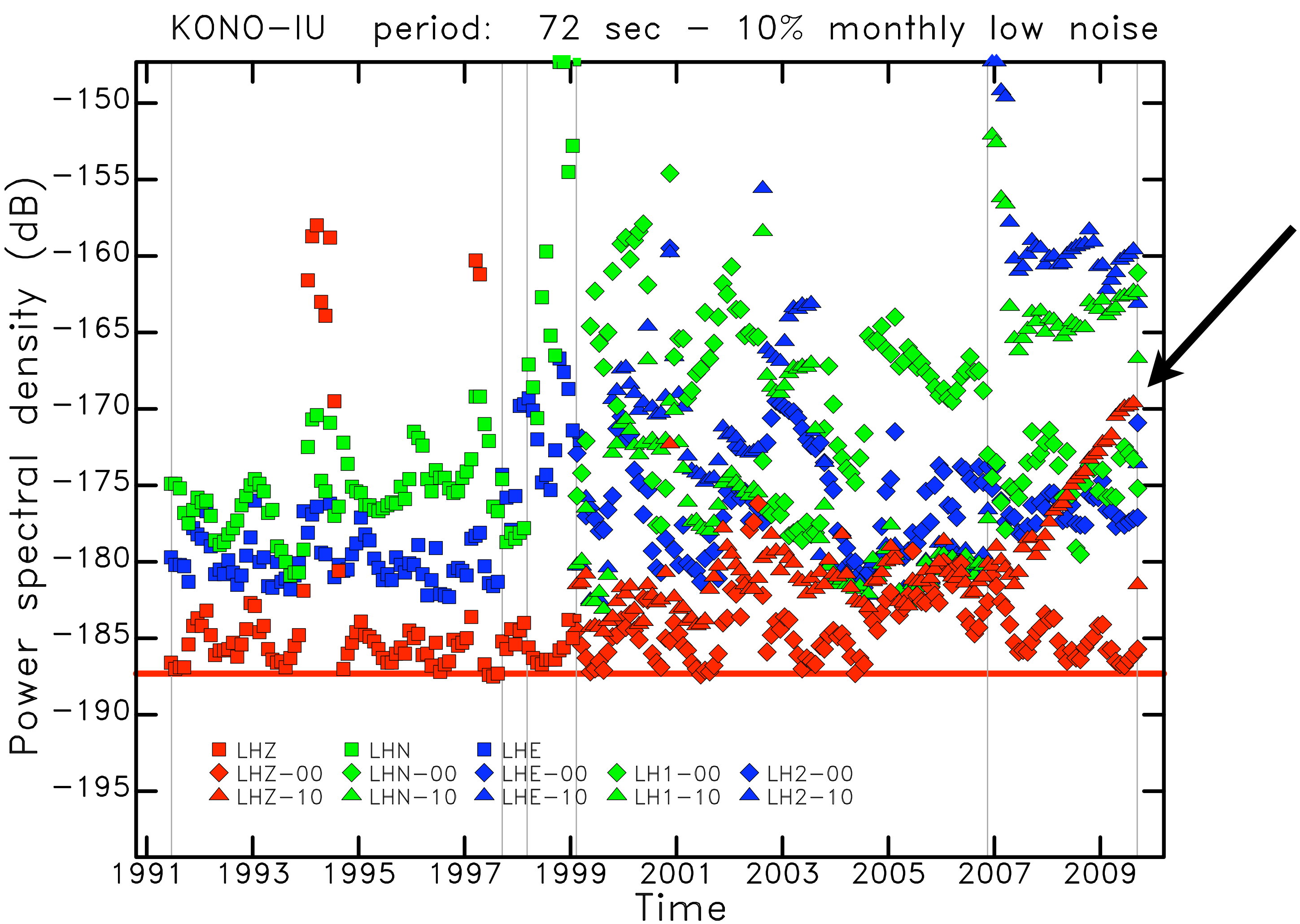
seasonal signal, well behaved

Noise, SSE-IC, 193 sec



primary sensor unstable
secondary not providing quality backup data

Noise, KONO-IU, 72 sec



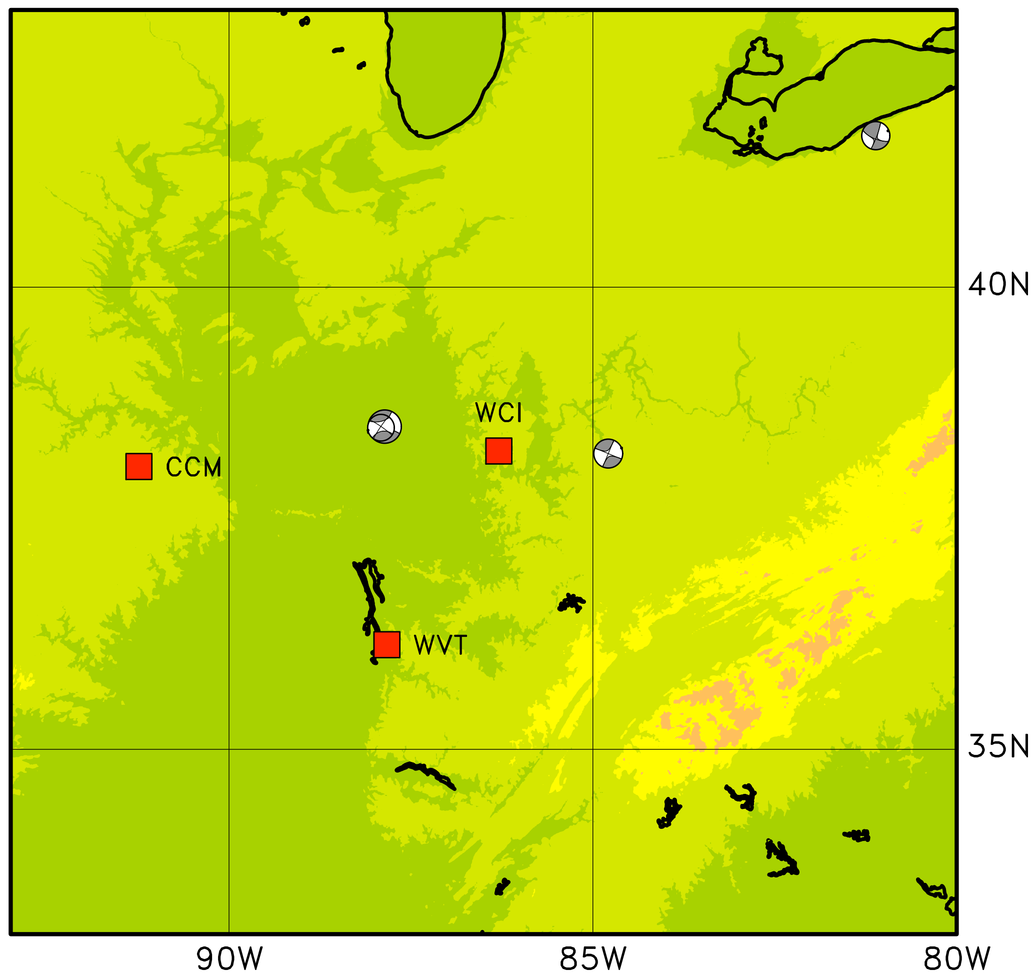
early data + Z-00: can be a good, quiet site

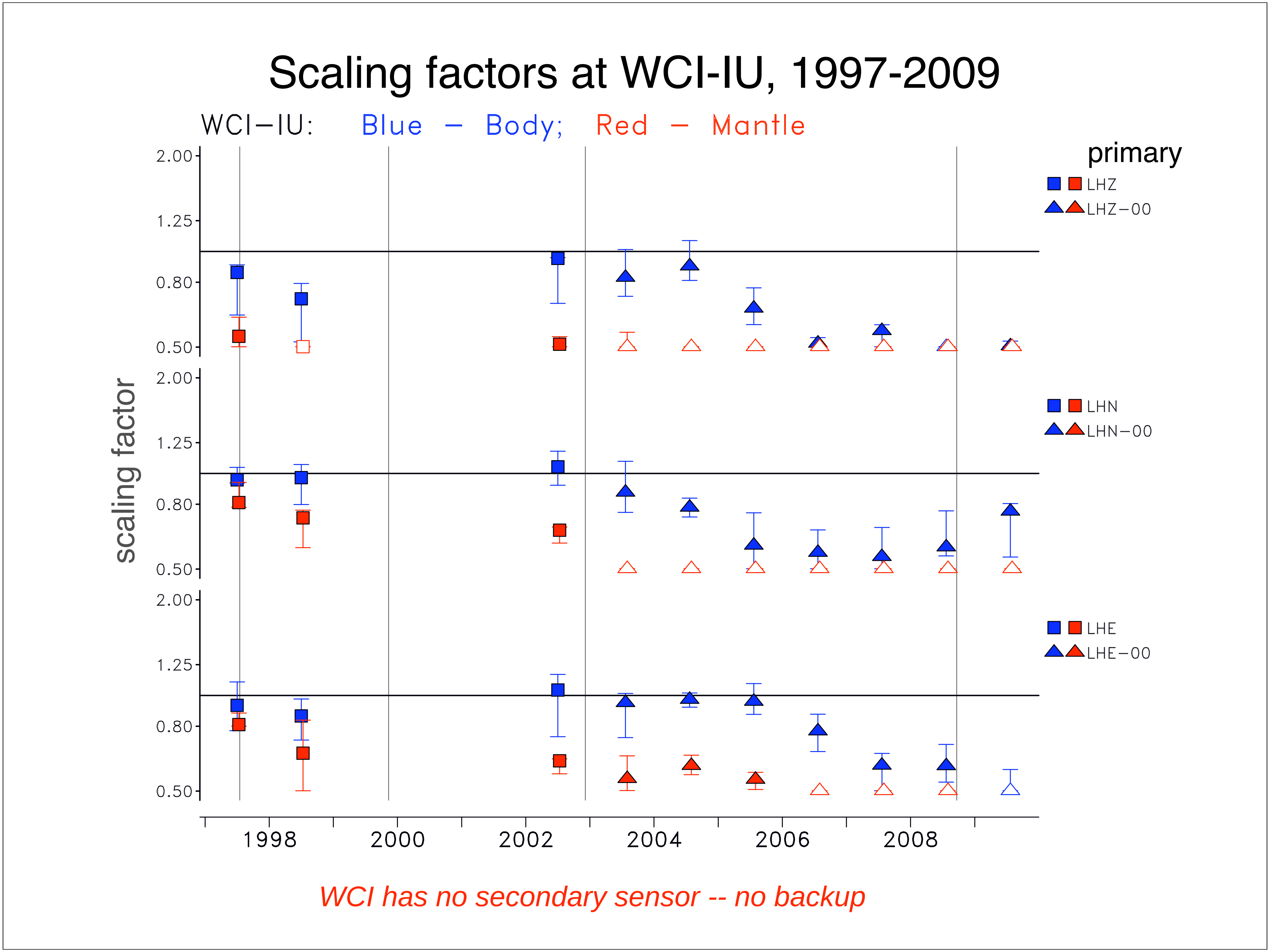
horiz. noise variable; current secondary bad

Problems like these need to be communicated to the community

- Science
- Operational (hazards) data use

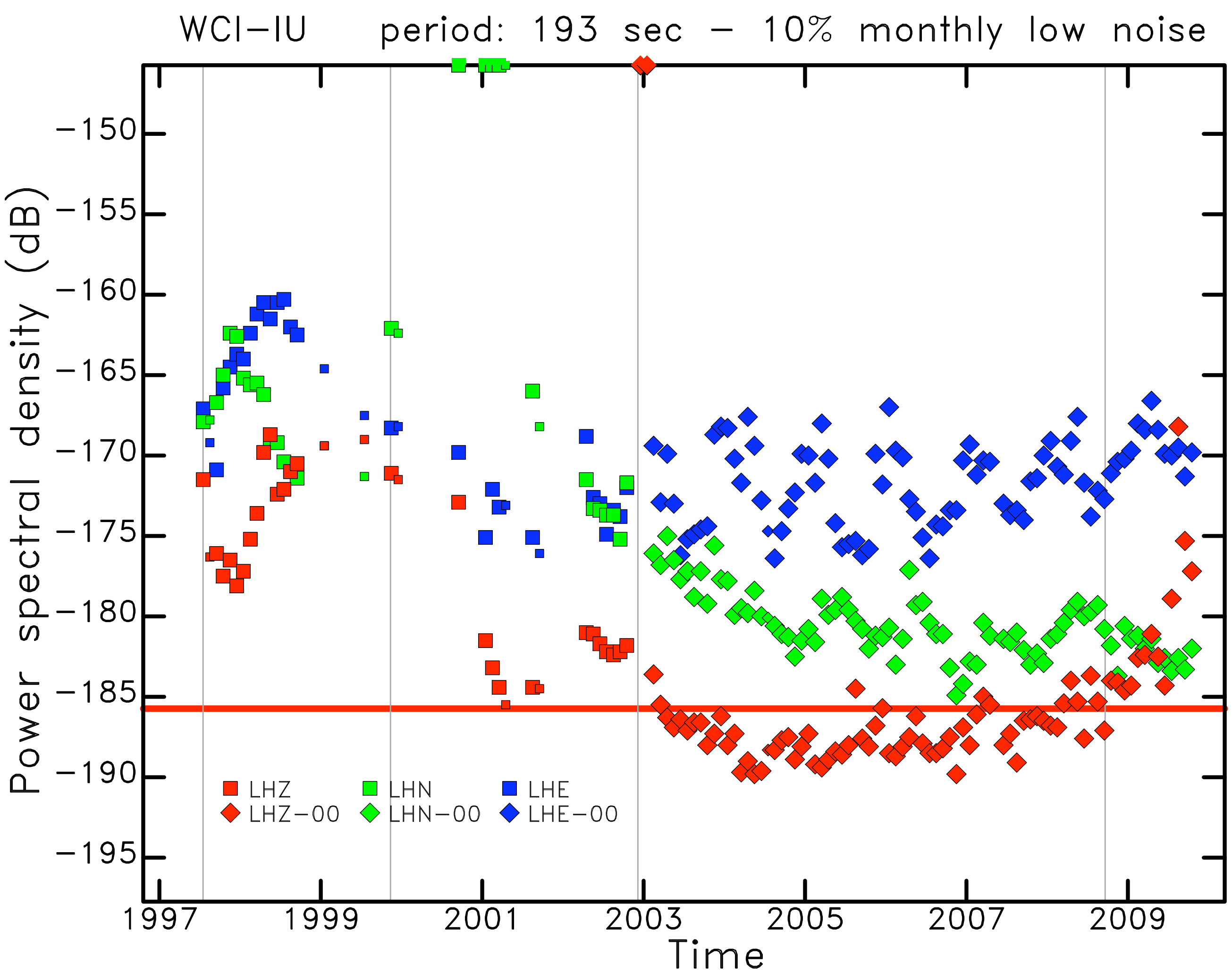
Case study: WCI-IU has never operated properly



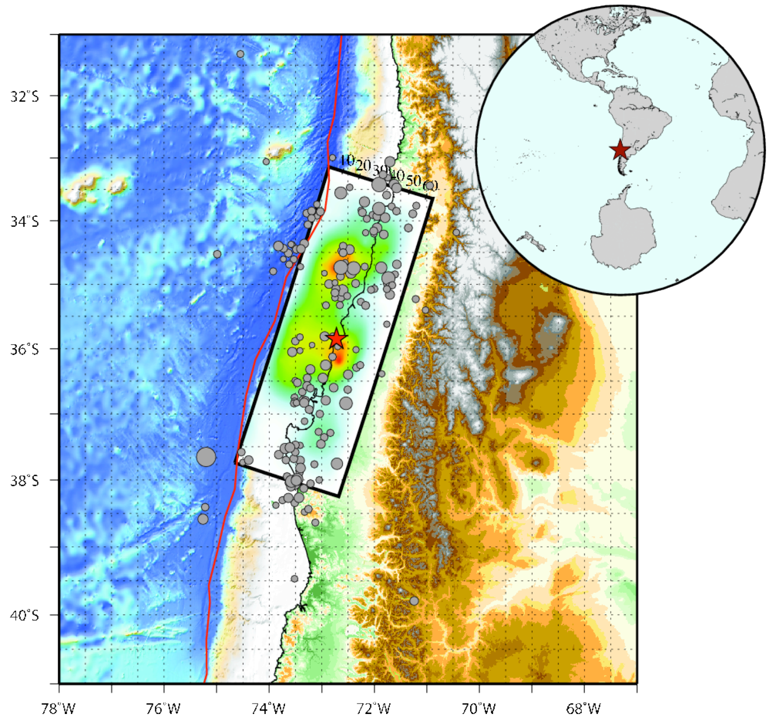


Scaling factors at WCI-IU, 1997-2009
WCI–IU: Blue – Body; Red – Mantle
primary
LHZ
LHZ–00
LHN
LHN–00
LHE
LHE–00
scaling factor
2.00
1.25
0.80
0.50
1998
2000
2002
2004
2006
2008
WCI has no secondary sensor -- no backup

Noise, WCI-IU, 193 sec

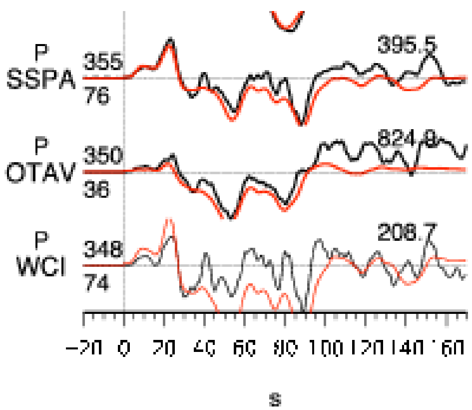


noise is never stable;
apparent decay followed by rapid increase in noise

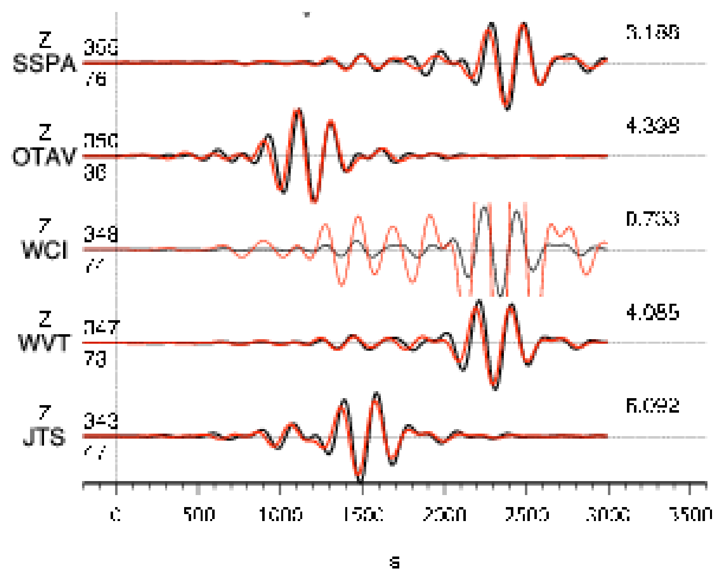



```
10/02/27  6:34:17
 OFFSHORE MAULE, CHILE
 Epicenter: -35.826  -72.668
 MW 8.8

 USGS/WPHASE CENTROID MOMENT TENSOR
 10/02/27 06:34:17.00

                 ----###
            --------########-
          ----------##########-
        -----------############--
      ------------##############--
     ------------################--
     ------------################--
    -------------#################--
    ----   -------#######   #######--
    ---- P -------####### T #######--
    ----   -------#######   #######--
    -------------################---
     ------------################--
     ------------###############---
      -----------##############---
        ----------###########---
          ---------#########---
            -------######----
                 ###----
```

WCI is one of the most-often used stations for W-phase analysis

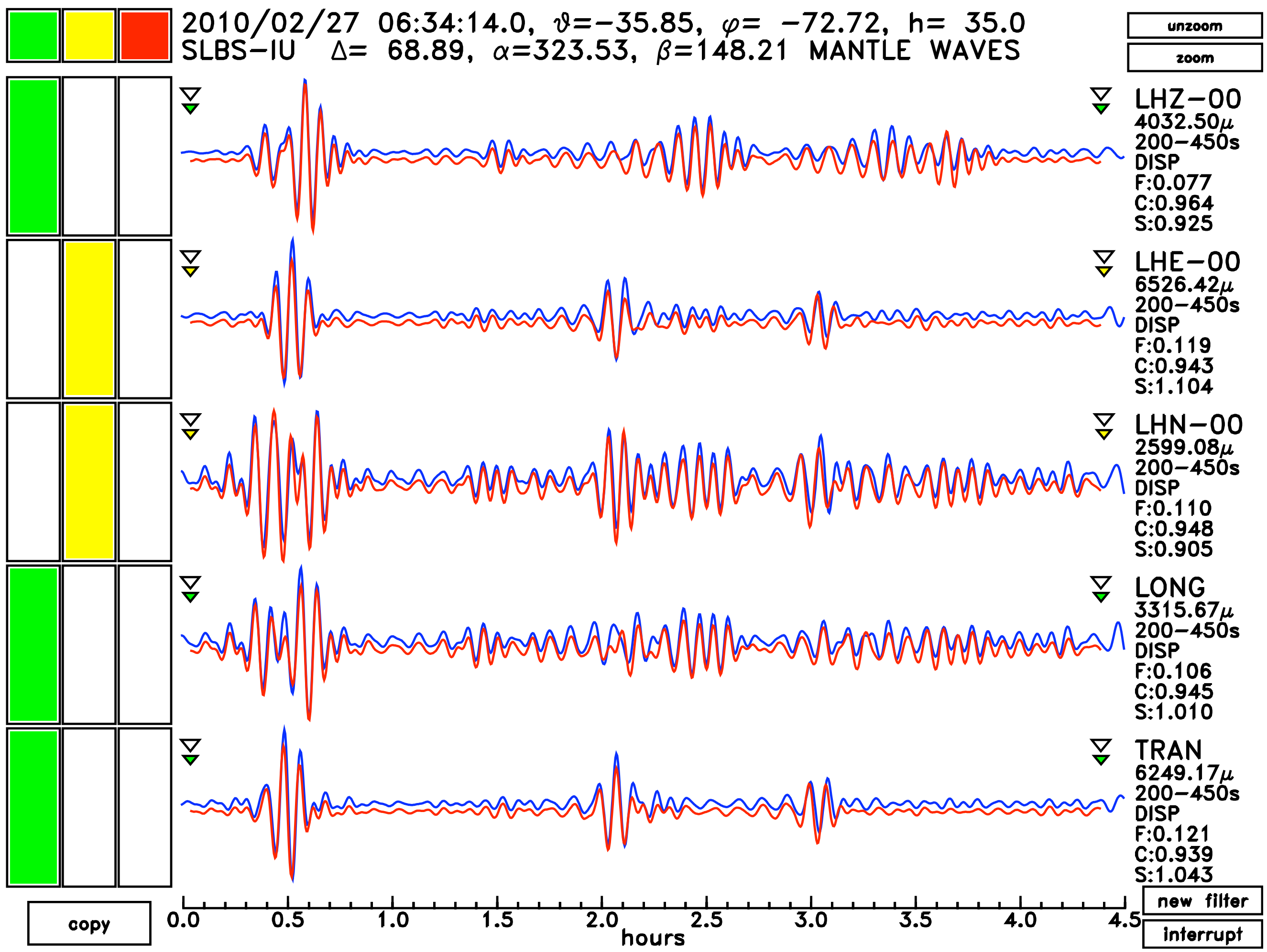


NEIC finite-fault model, Chile Mw 8.8

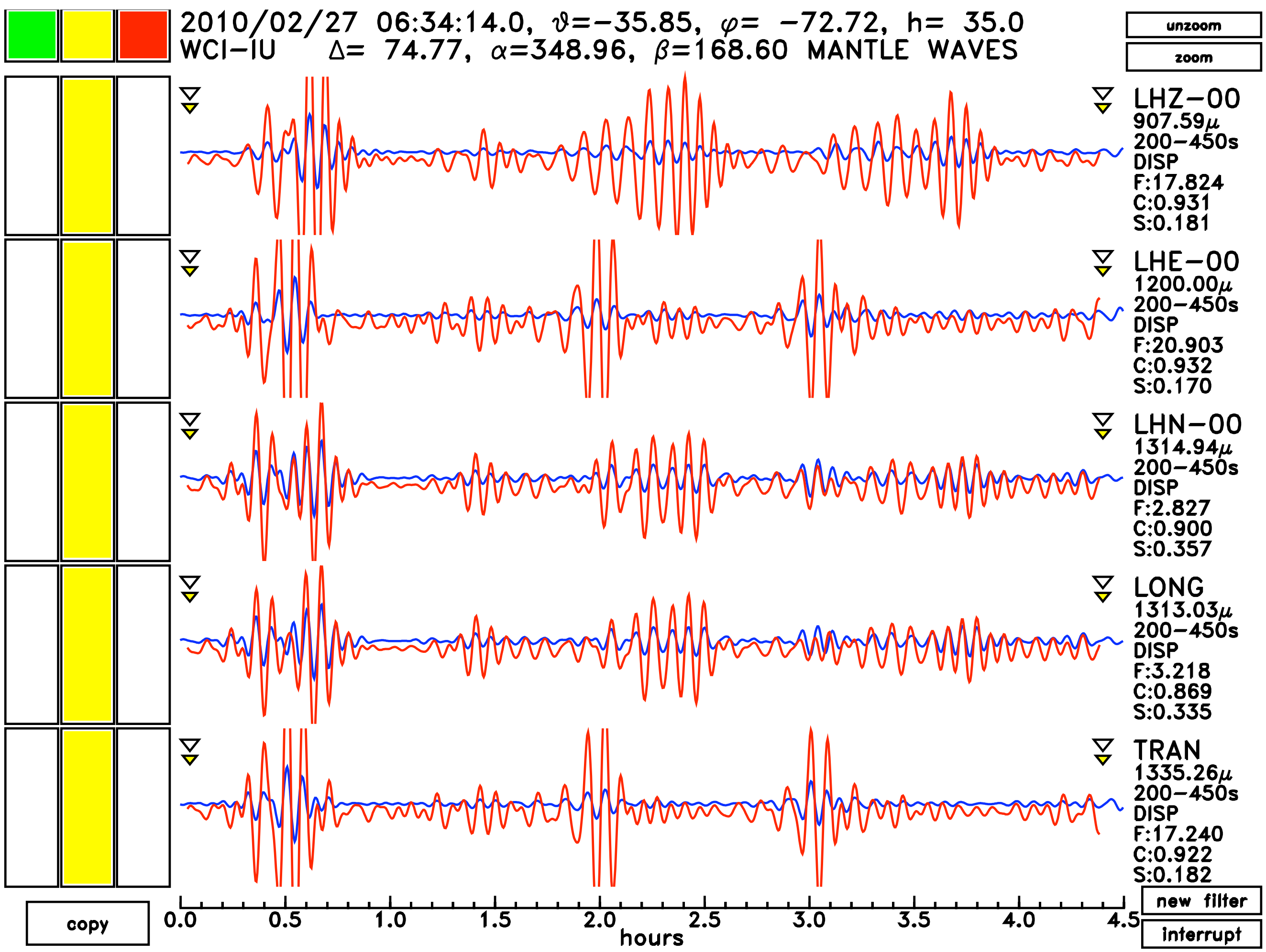


WCI is also an ANSS Backbone/ USArray Reference station

Good data from Chile earthquake

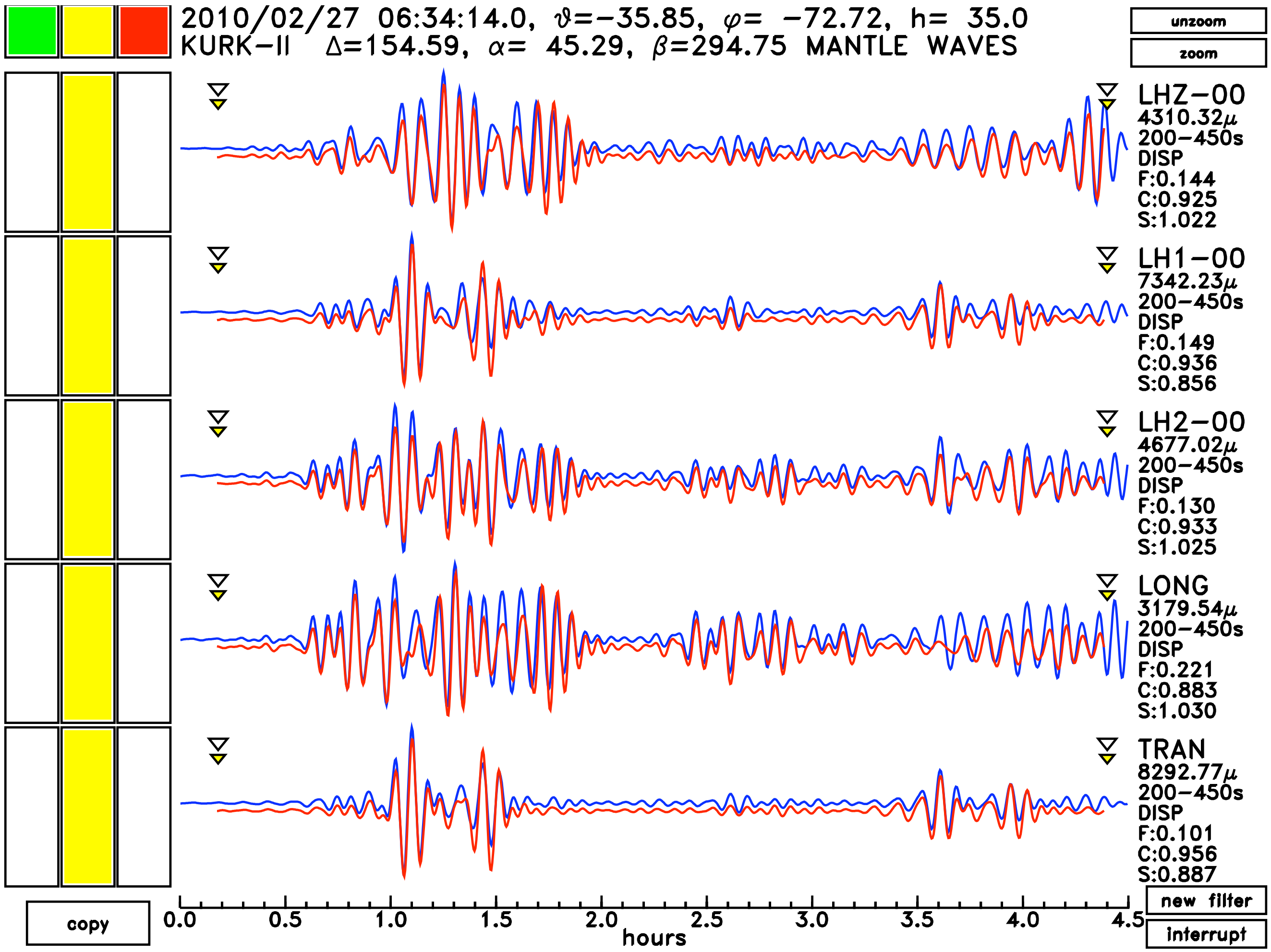


Not good.

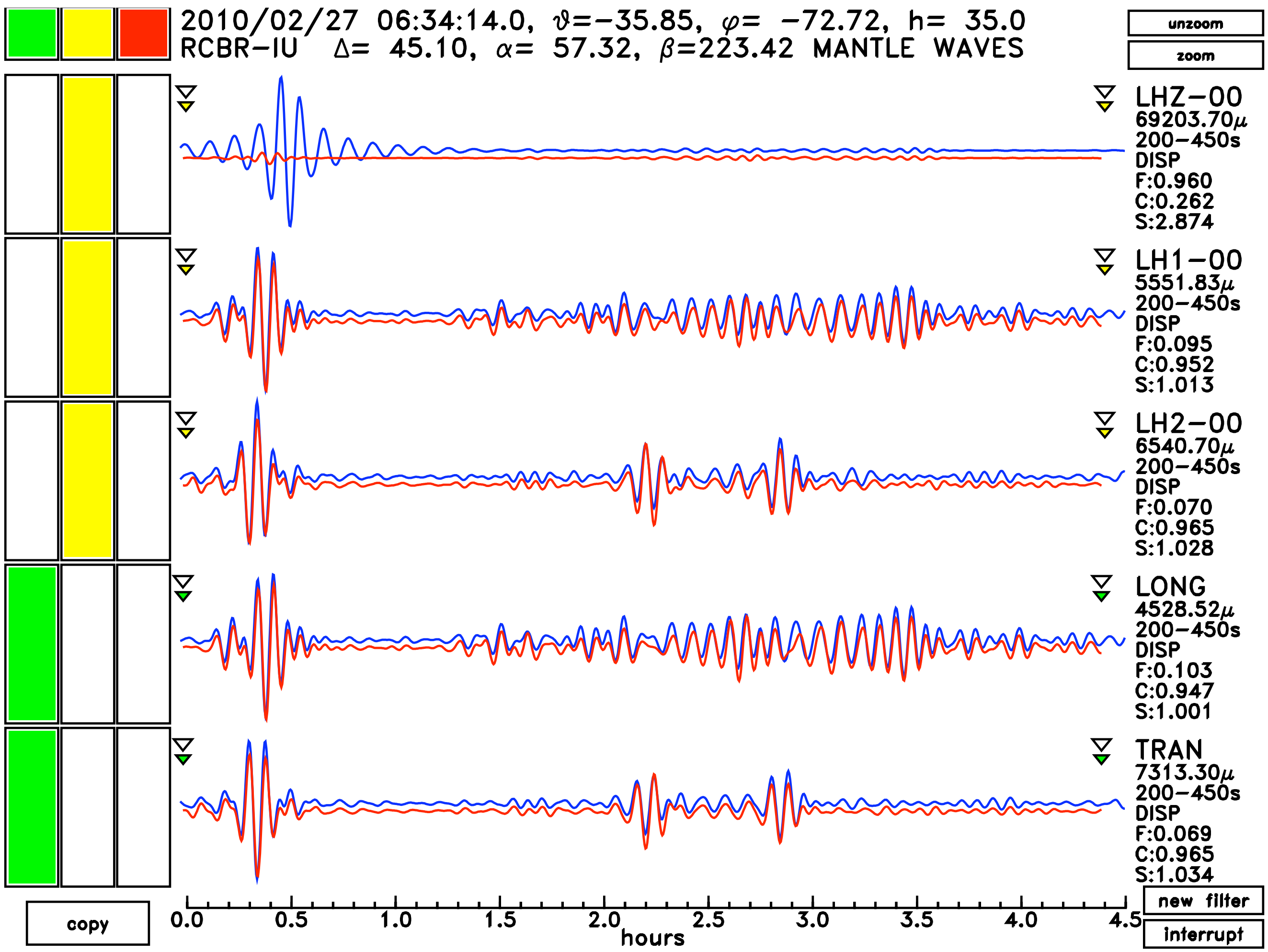


2010/02/27 06:34:14.0, ϑ=−35.85, φ= −72.72, h= 35.0
WCI−IU Δ= 74.77, α=348.96, β=168.60 MANTLE WAVES
unzoom
zoom
LHZ−00
907.59μ
200−450s
DISP
F:17.824
C:0.931
S:0.181
LHE−00
1200.00μ
200−450s
DISP
F:20.903
C:0.932
S:0.170
LHN−00
1314.94μ
200−450s
DISP
F:2.827
C:0.900
S:0.357
LONG
1313.03μ
200−450s
DISP
F:3.218
C:0.869
S:0.335
TRAN
1335.26μ
200−450s
DISP
F:17.240
C:0.922
S:0.182
copy
0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5
hours
new filter
interrupt

This one is good now.



Not good.



2010/02/27 06:34:14.0, ϑ=−35.85, φ= −72.72, h= 35.0
RCBR−IU Δ= 45.10, α= 57.32, β=223.42 MANTLE WAVES
unzoom
zoom
LHZ−00
69203.70μ
200−450s
DISP
F:0.960
C:0.262
S:2.874
LH1−00
5551.83μ
200−450s
DISP
F:0.095
C:0.952
S:1.013
LH2−00
6540.70μ
200−450s
DISP
F:0.070
C:0.965
S:1.028
LONG
4528.52μ
200−450s
DISP
F:0.103
C:0.947
S:1.001
TRAN
7313.30μ
200−450s
DISP
F:0.069
C:0.965
S:1.034
new filter
interrupt
copy
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
hours

Not good.

Nearly 1/3 of IU, IC, II realtime stations had at least one unusable channel (primary sensor) for the Mw = 8.8 Chile earthquake.

What has happened?

- **Technical problems:**
  - STS-1 sensor stability (8/10 stations)
  - incorrect response functions (few channels meet design goals)
  - poor secondary-sensor data quality (6/10 stations)
- **Not a hardware problem:**
  - lack of consistent policies and procedures
  - lack of clear metrics for data quality
- **Need new focus** on defining GSN success:
  - *quality*
  - *transparency*

Current operation plan:

1. Replace FBEs with Metrozet E300 boxes

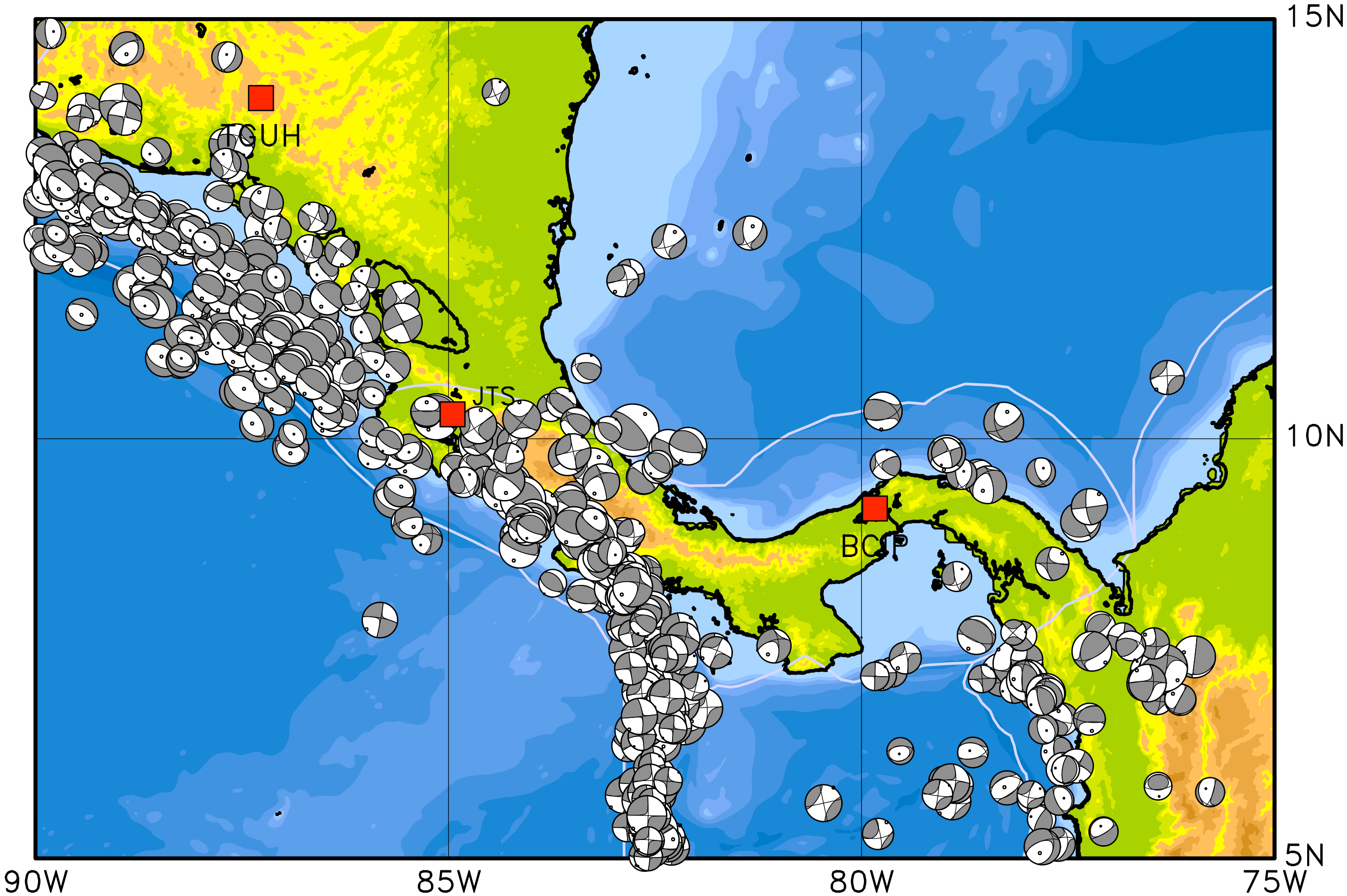
2. Install secondary broadband sensor on scheduled site visits

3. Upgrade to Q330HR datalogger (easier remote calibration)

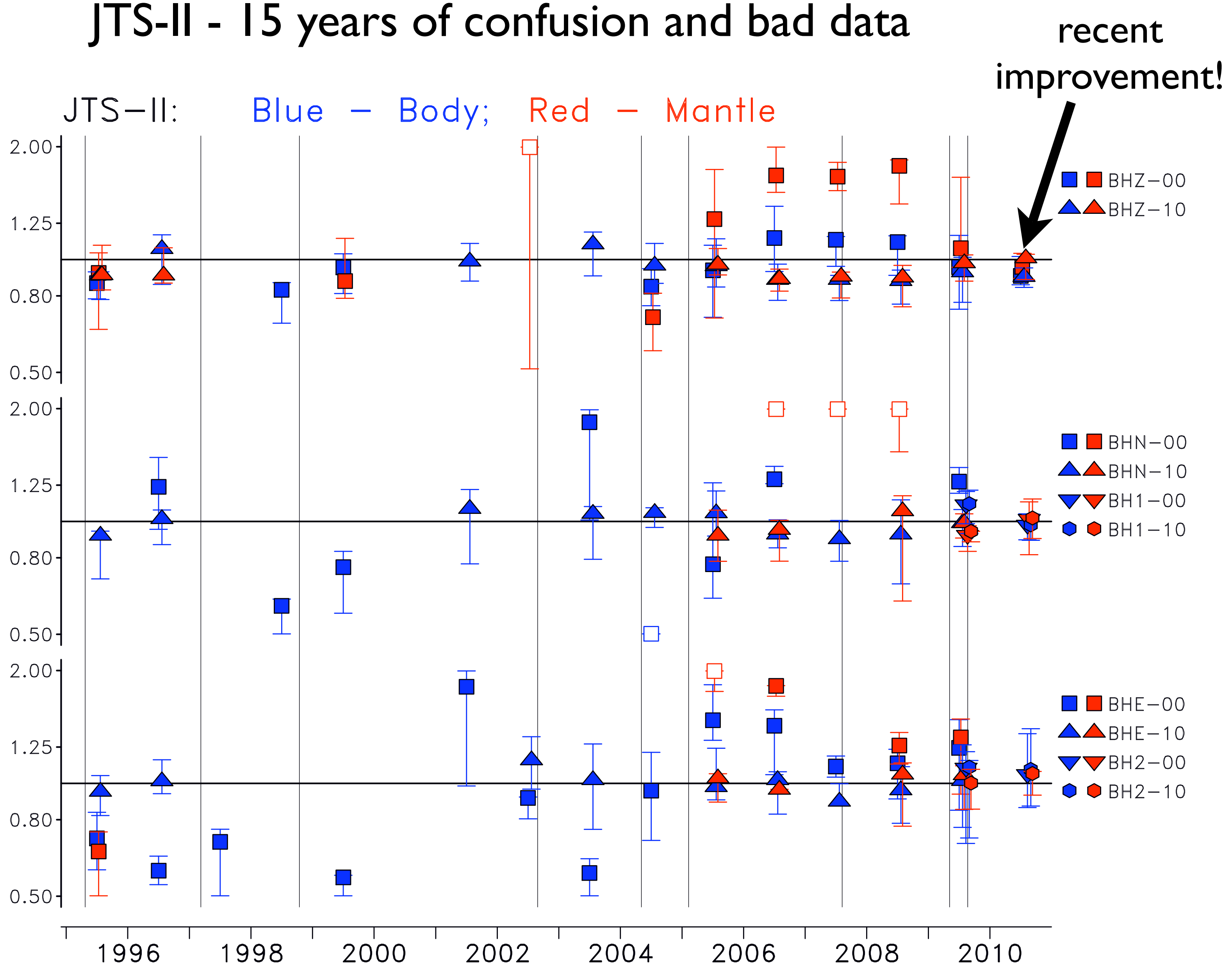
4. Annual calibration cycle

Some successes so far. Many problems not solved.

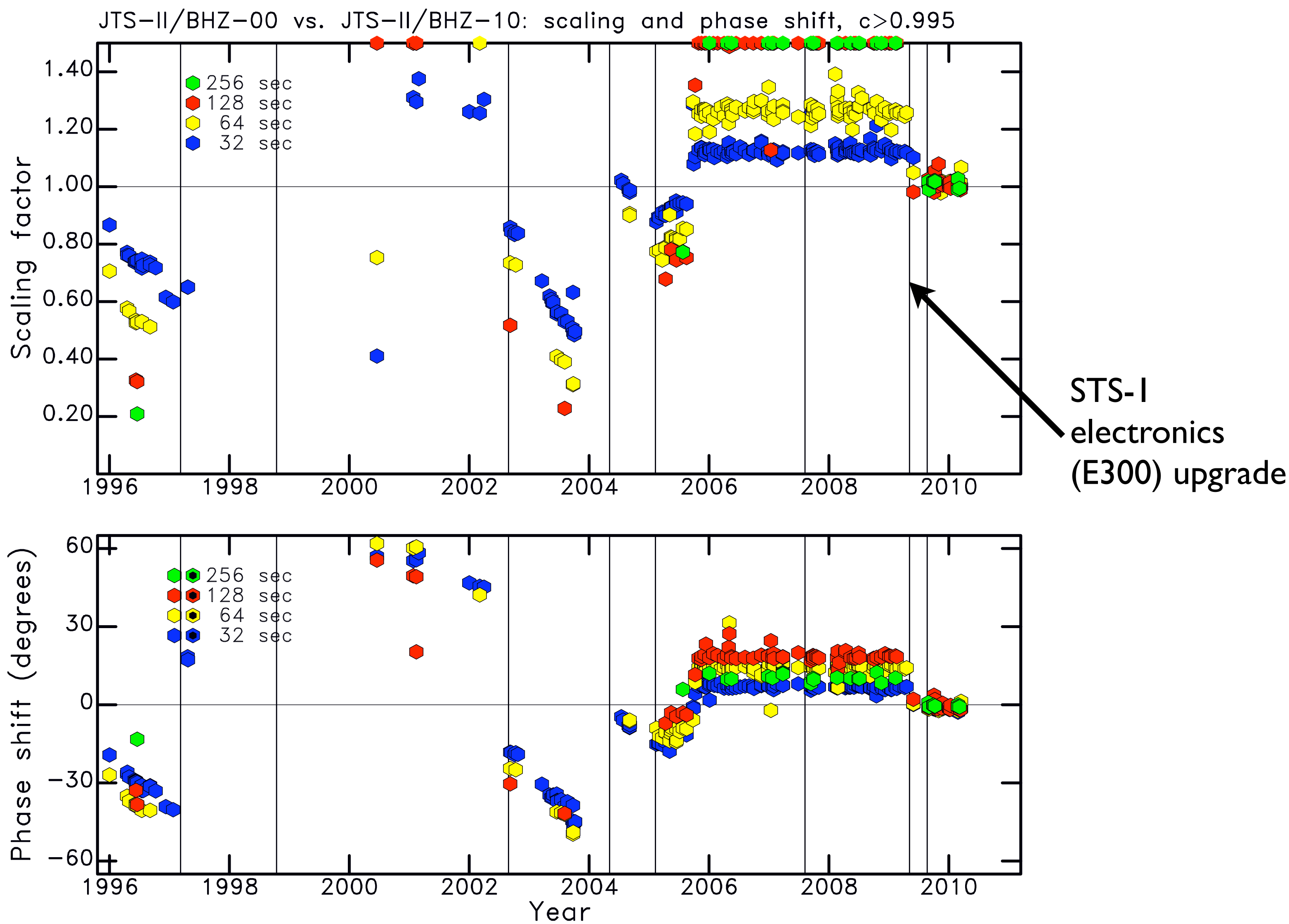
JTS-II - recent site visit and upgrade



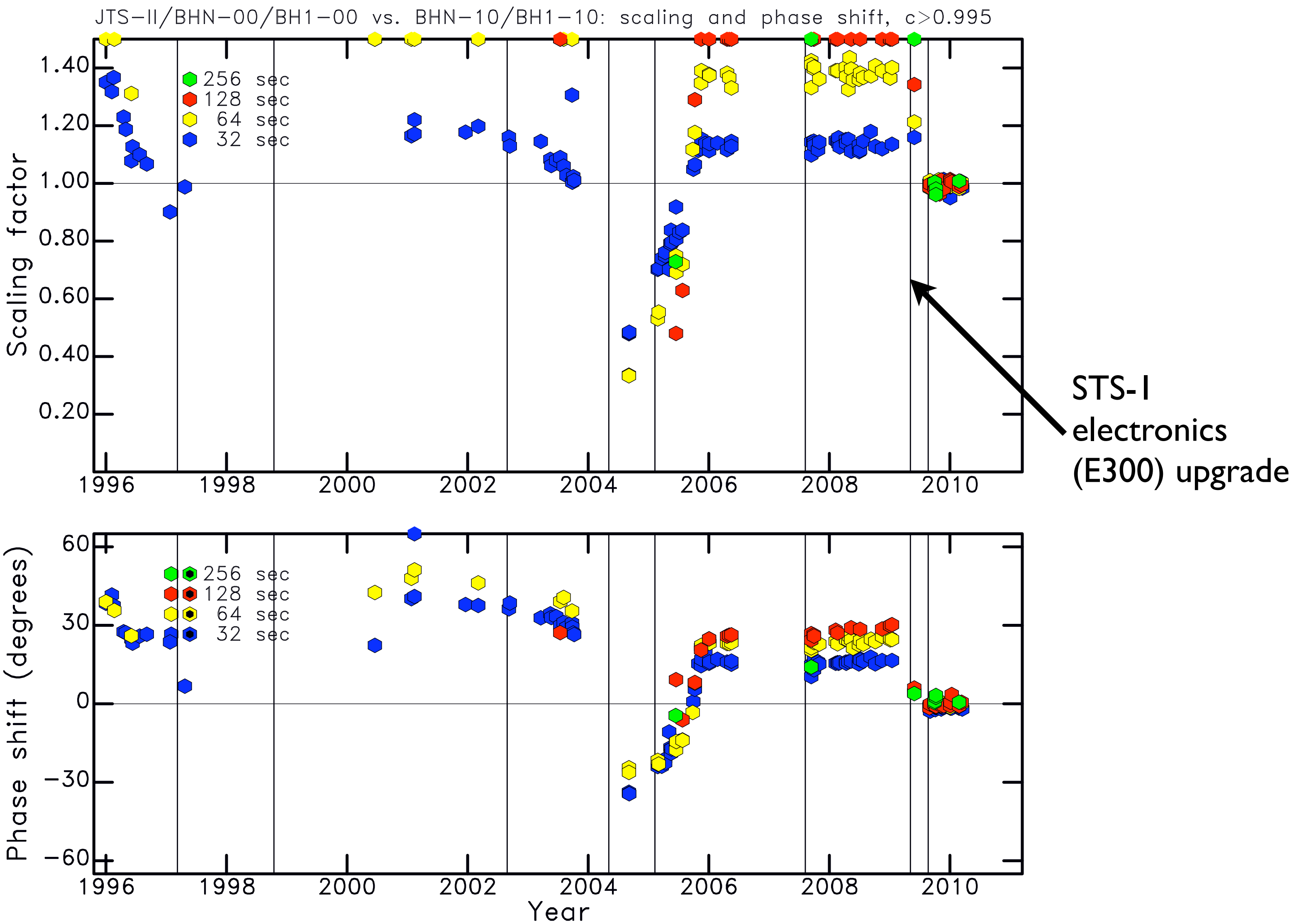
JTS-II - 15 years of confusion and bad data



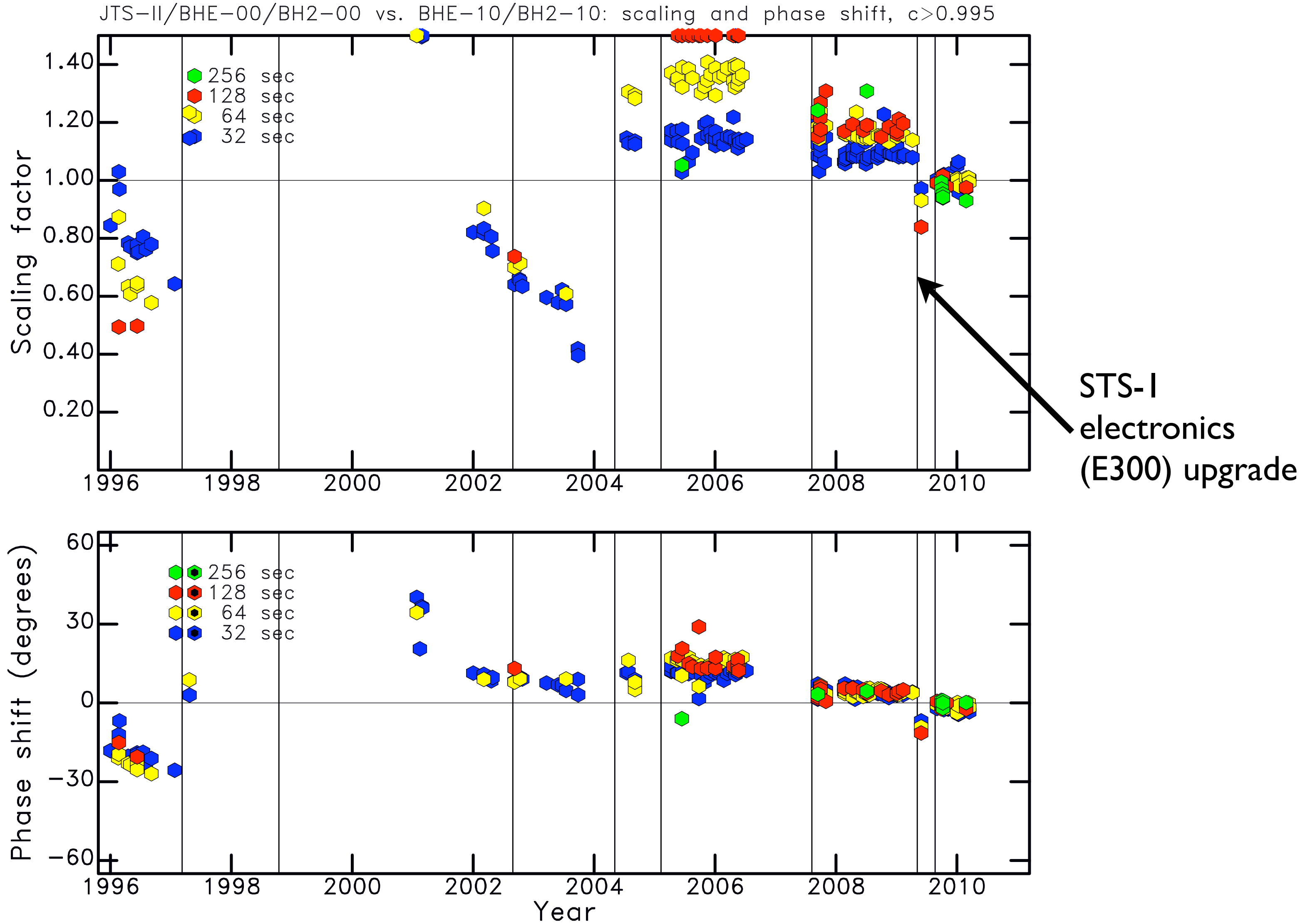
JTS-II - 15 years of confusion and bad data - possibly solved?



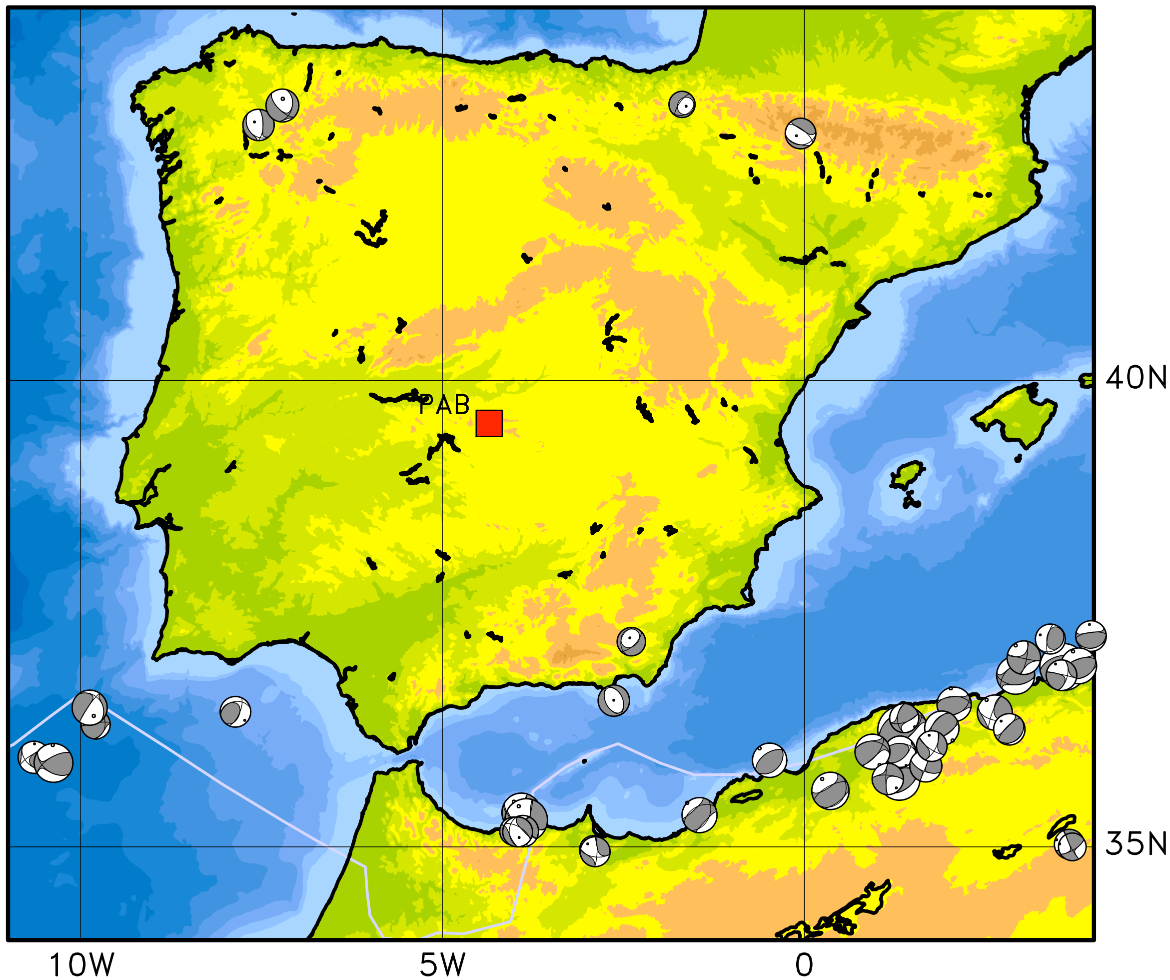
JTS-II - 15 years of confusion and bad data - possibly solved?



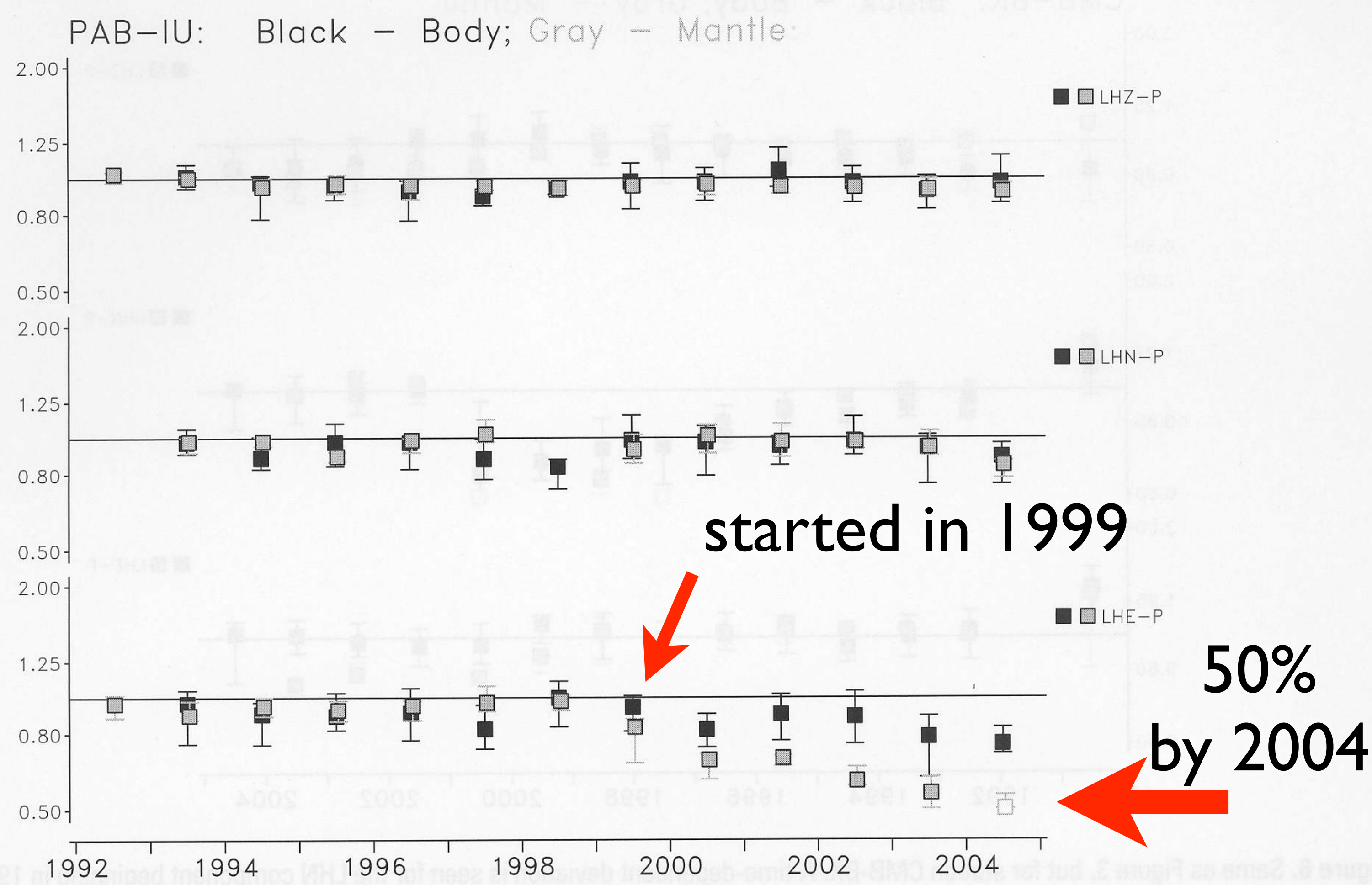
JTS-II - 15 years of confusion and bad data - possibly solved?



PAB-IU - recent site visit and upgrade

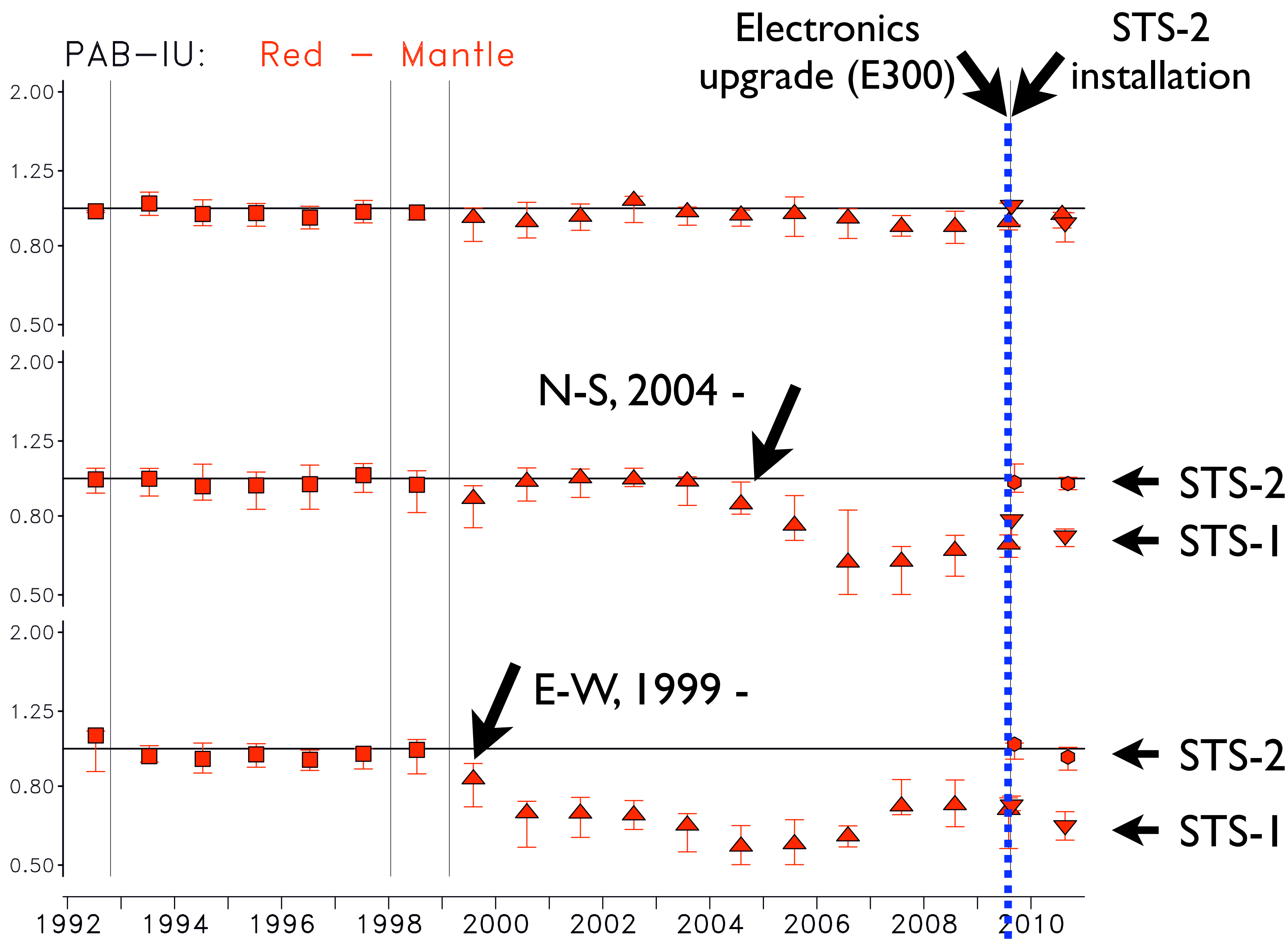


PAB-IU - loss of gain on E-W reported in SRL, 2006

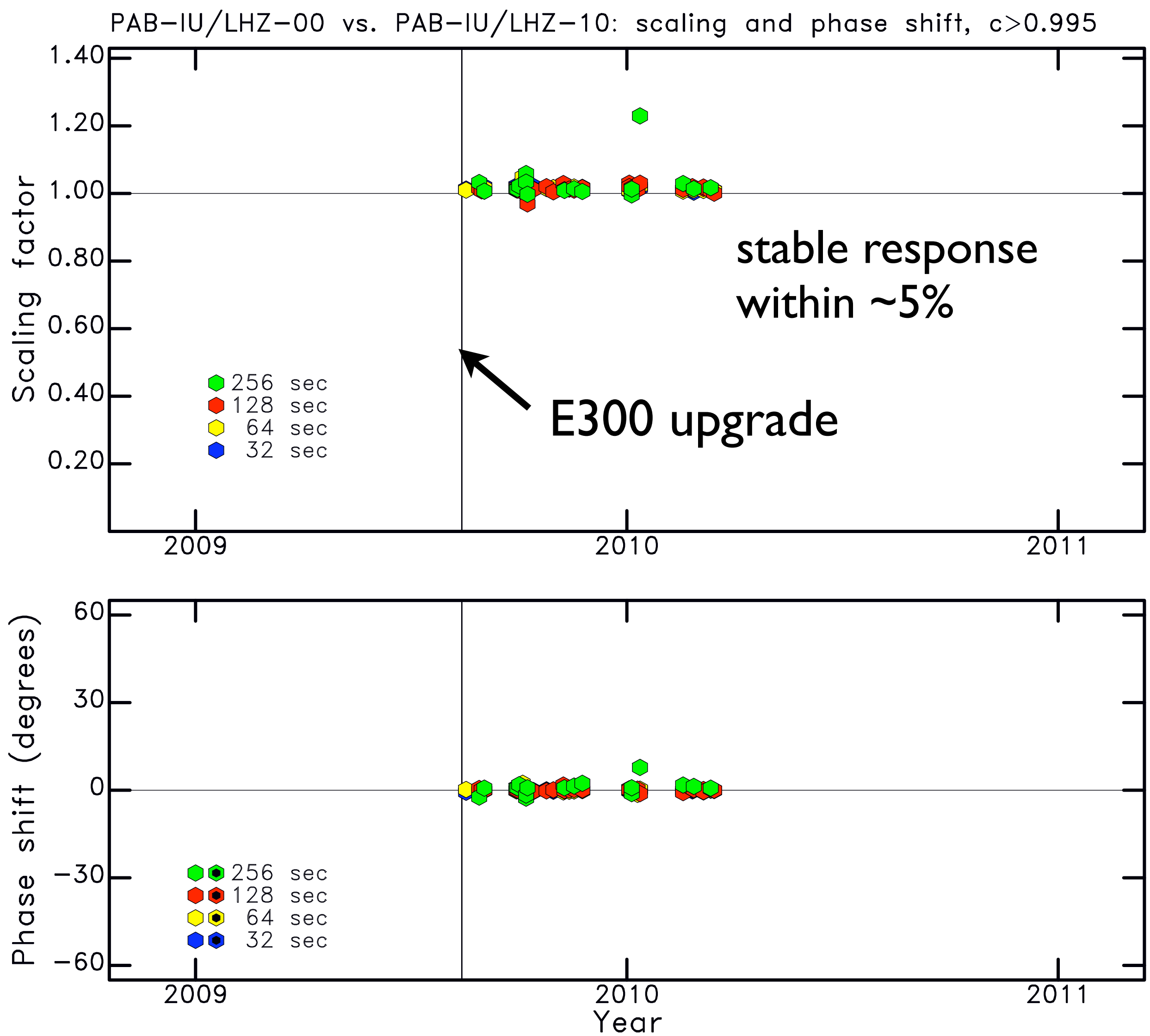


▲ **Figure 4.** Same as Figure 3, but for station PAB-IU. Beginning in 1999, the LHE-P component shows a time-dependent deviation of the observed gain from the reported gain. The deviation is larger for the longer-period (mantle-wave) data. The open square for year 2004 indicates that the scaling factor was smaller than 0.5.

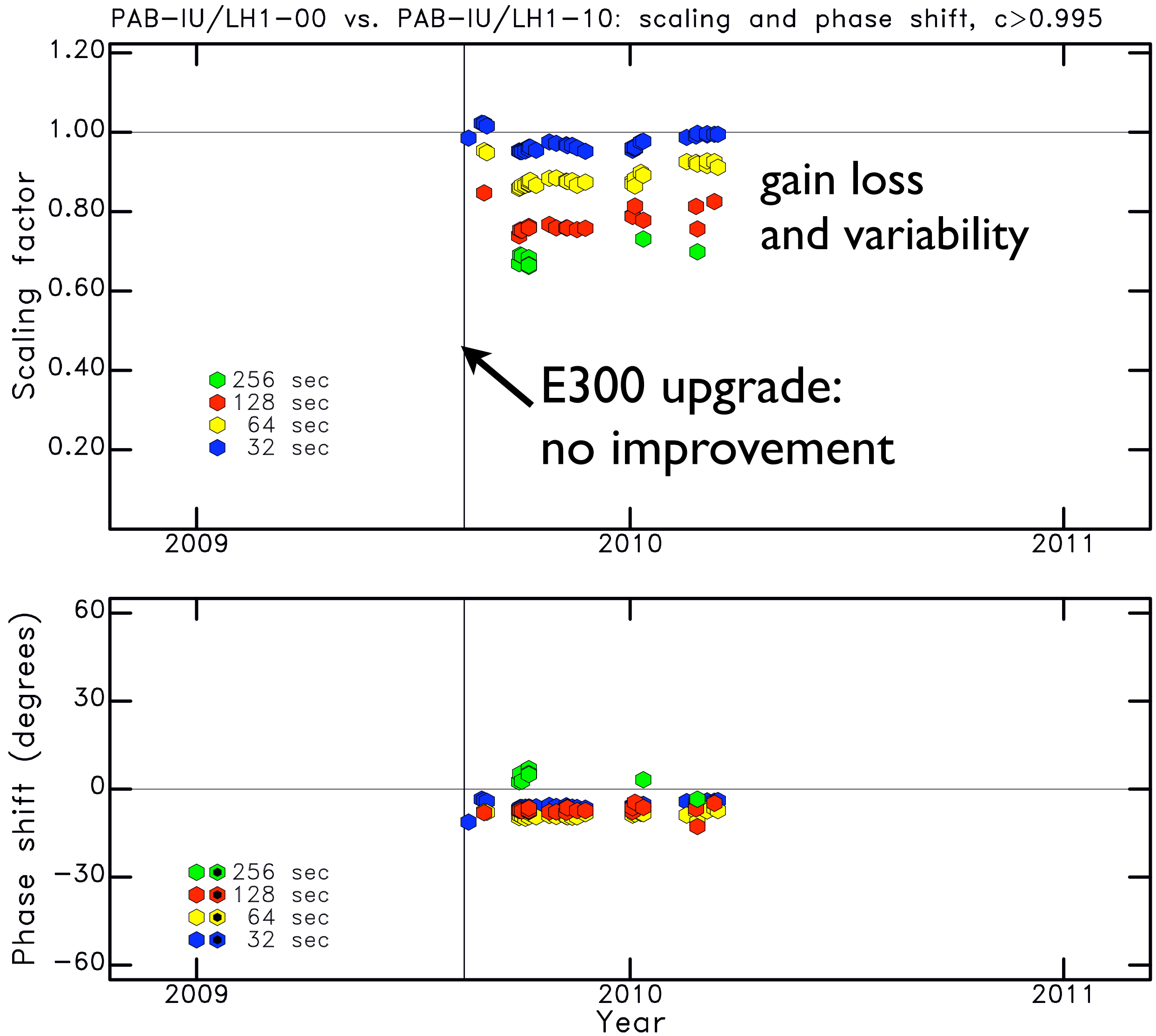
PAB-IU - current status (after upgrade)



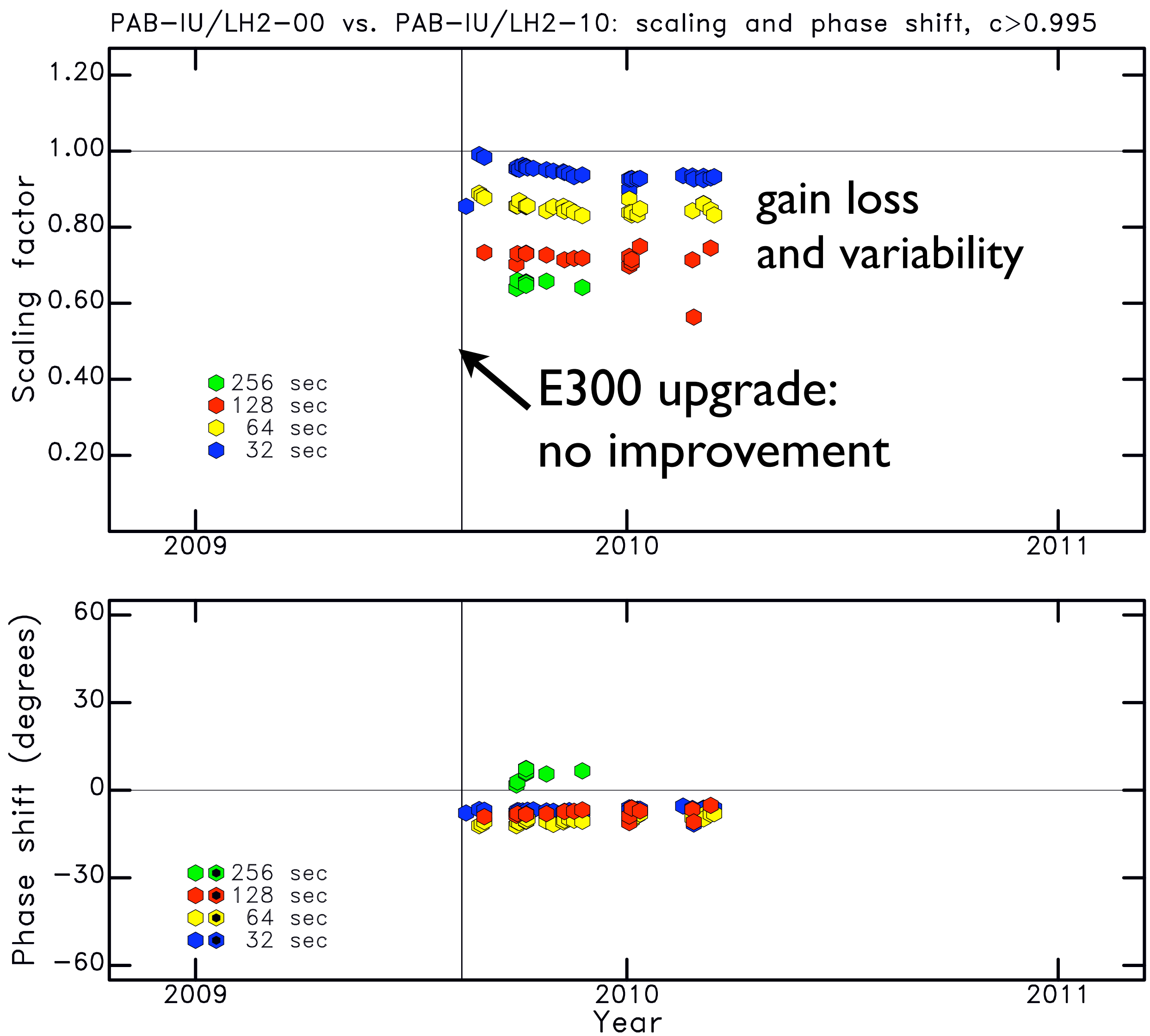
PAB-IU - STS-1/STS-2 coherence, vertical component



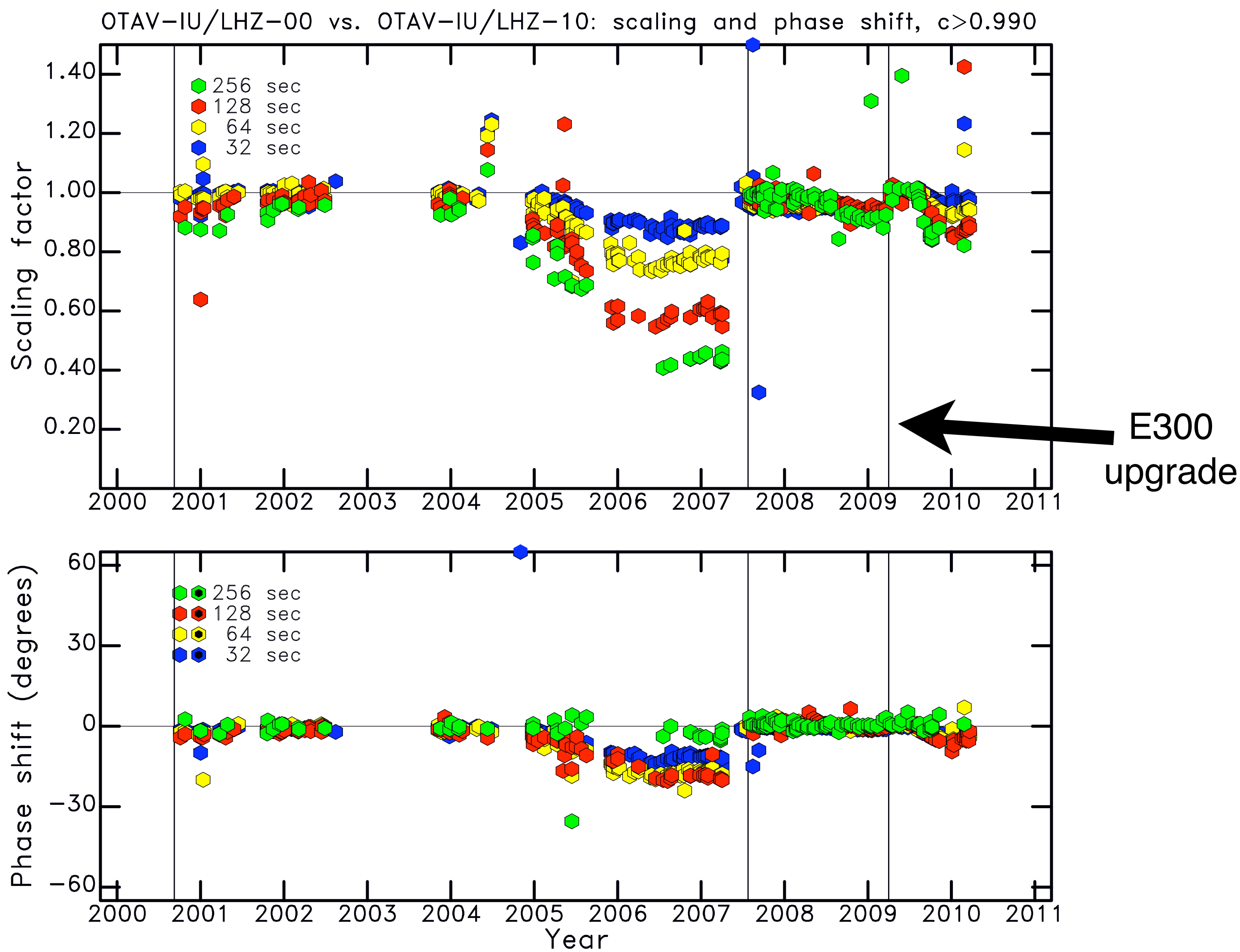
PAB-IU - STS-1/STS-2 coherence, N-S component



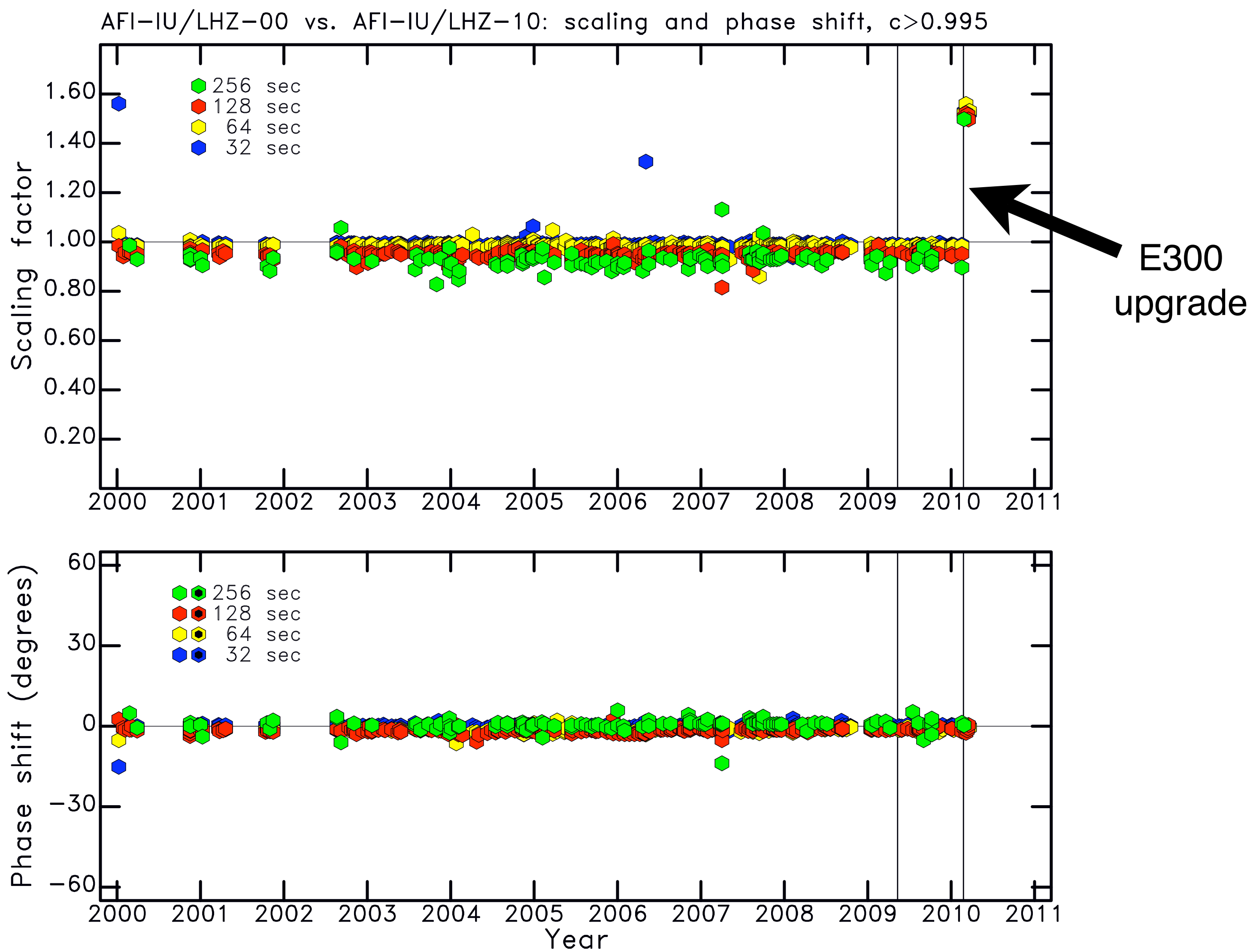
PAB-IU - STS-1/STS-2 coherence, E-W component



OTAV-IU, Z


OTAV-IU/LHZ-00 vs. OTAV-IU/LHZ-10: scaling and phase shift, c>0.990
Scaling factor
1.40
1.20
1.00
0.80
0.60
0.40
0.20
256 sec
128 sec
64 sec
32 sec
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011
E300
upgrade
Phase shift (degrees)
60
30
0
−30
−60
256 sec
128 sec
64 sec
32 sec
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011
Year

AFI-IU, Z



AFI-IU/LHZ-00 vs. AFI-IU/LHZ-10: scaling and phase shift, c>0.995
256 sec
128 sec
64 sec
32 sec
Scaling factor
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011
E300 upgrade
Phase shift (degrees)
60
30
0
−30
−60
Year

Technical problems

Current operation plan:

1. Replace FBEs with Metrozet E300 boxes.
   Solves problem in some cases; many not solved. Not a cure-all.

2. Install secondary broadband sensor on scheduled site visits.
   This is slow. Key sites should be prioritized (US Backbone??).
   Poor-quality installations should be fixed a.s.a.p.

3. Upgrade to Q330HR datalogger (easier remote calibration).
   Great - but need to get cal results into the metadata and ops plan.

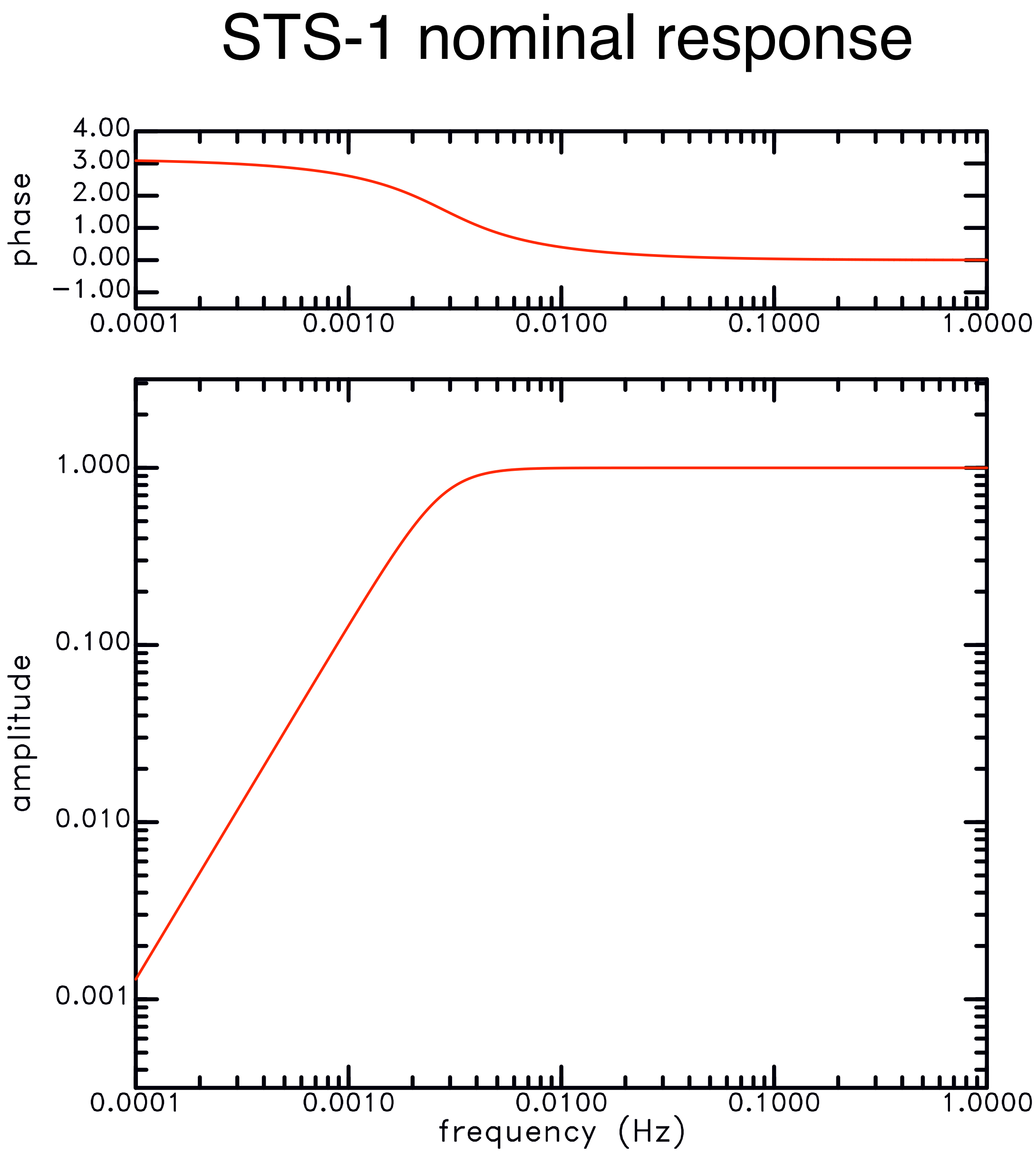
4. Annual calibration cycle.
   At stations with suspected problems, calibrate more frequently to characterize response evolution. Note: step cal sufficient for problem ID.

- Identify stations where cal input x response differs significantly from output
- Identify stations with secondary sensor significantly noisier than primary
- Target these for fixes
- Communicate status to IRIS community

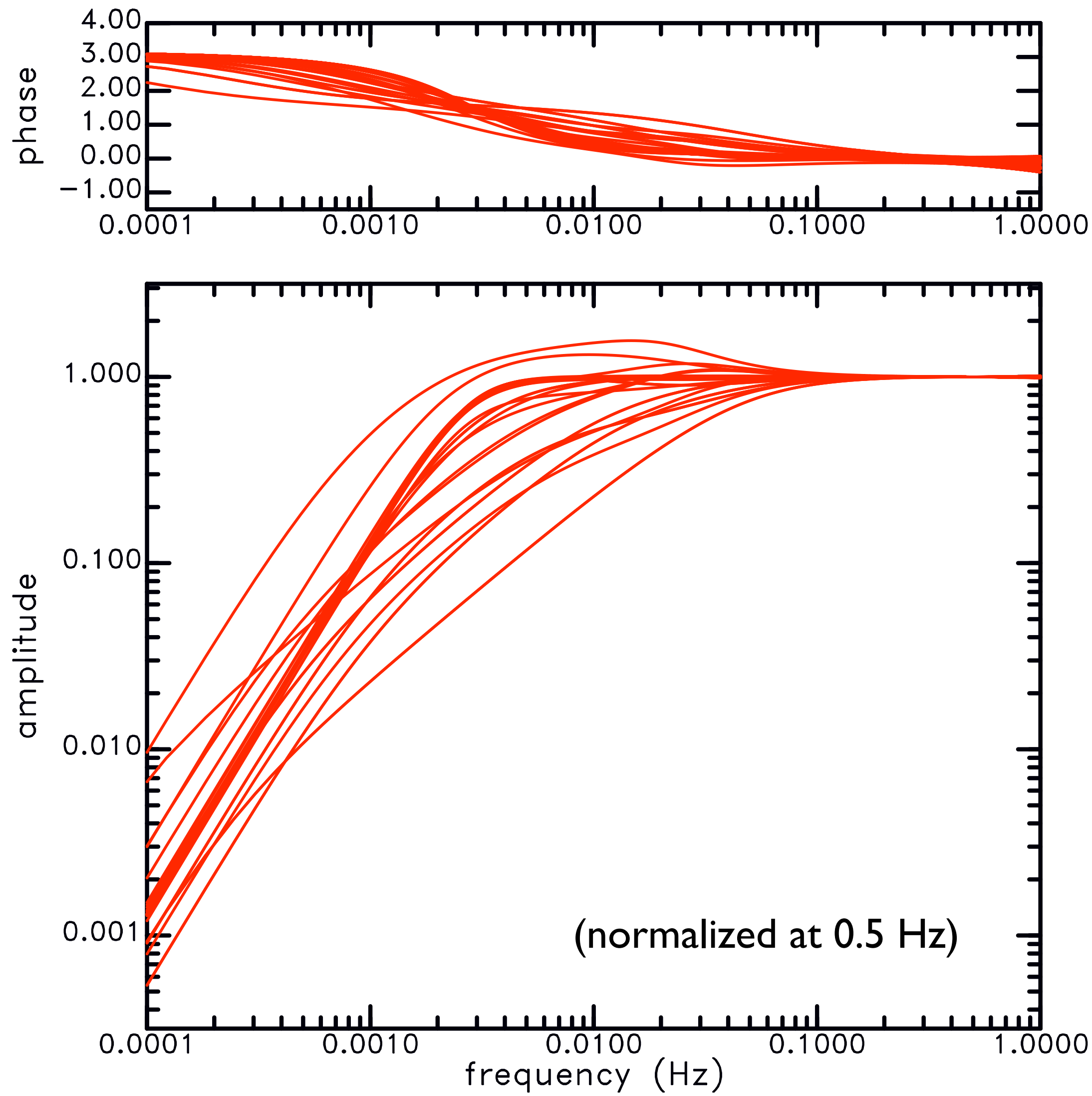
What has happened?

- **Technical problems:**
  - STS-1 sensor stability (8 of 10 stations examined)
  - incorrect response functions (few channels examined meet design goals)
  - poor secondary-sensor quality (6 of 10 stations examined)
- **Not a hardware problem:**
  - lack of consistent policies and procedures
  - lack of clear metrics for data quality
- **Need new focus** on defining GSN success:
  - *quality*
  - *transparency*

Policies / procedures: cal results



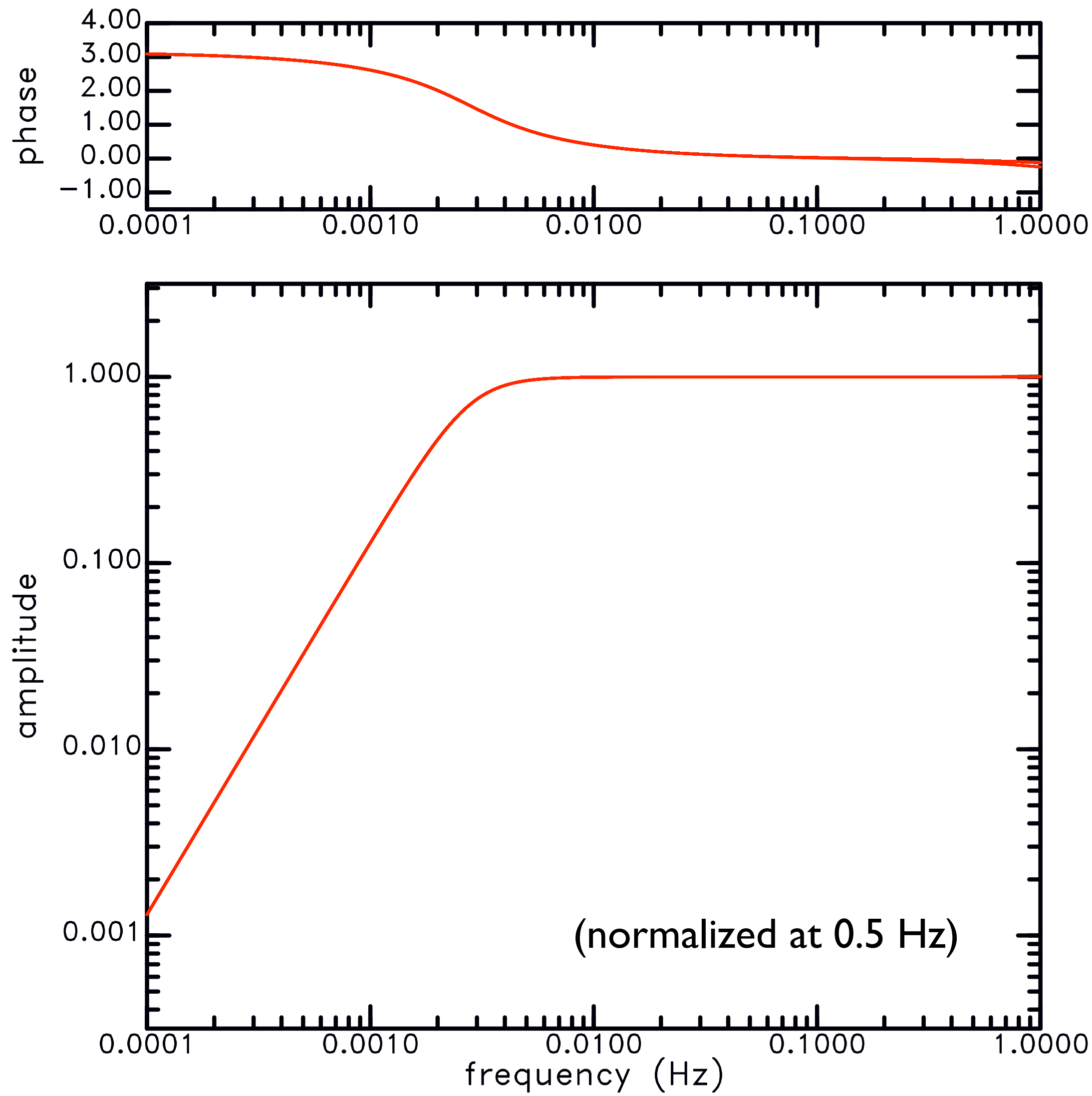
IDA network: STS-1 vertical component response functions 2001-2010



24 stations
78 epochs

AAK	KIV
ABKT	KURK
ABPO	KWAJ
ALE	LVZ
BFO	NNA
BRVK	NRIL
DGAR	OBN
ERM	PFO
ESK	RPN
FFC	SUR
HOPE	TAU
JTS	TLY

USGS network: STS-1 vertical component response functions 2001-2010

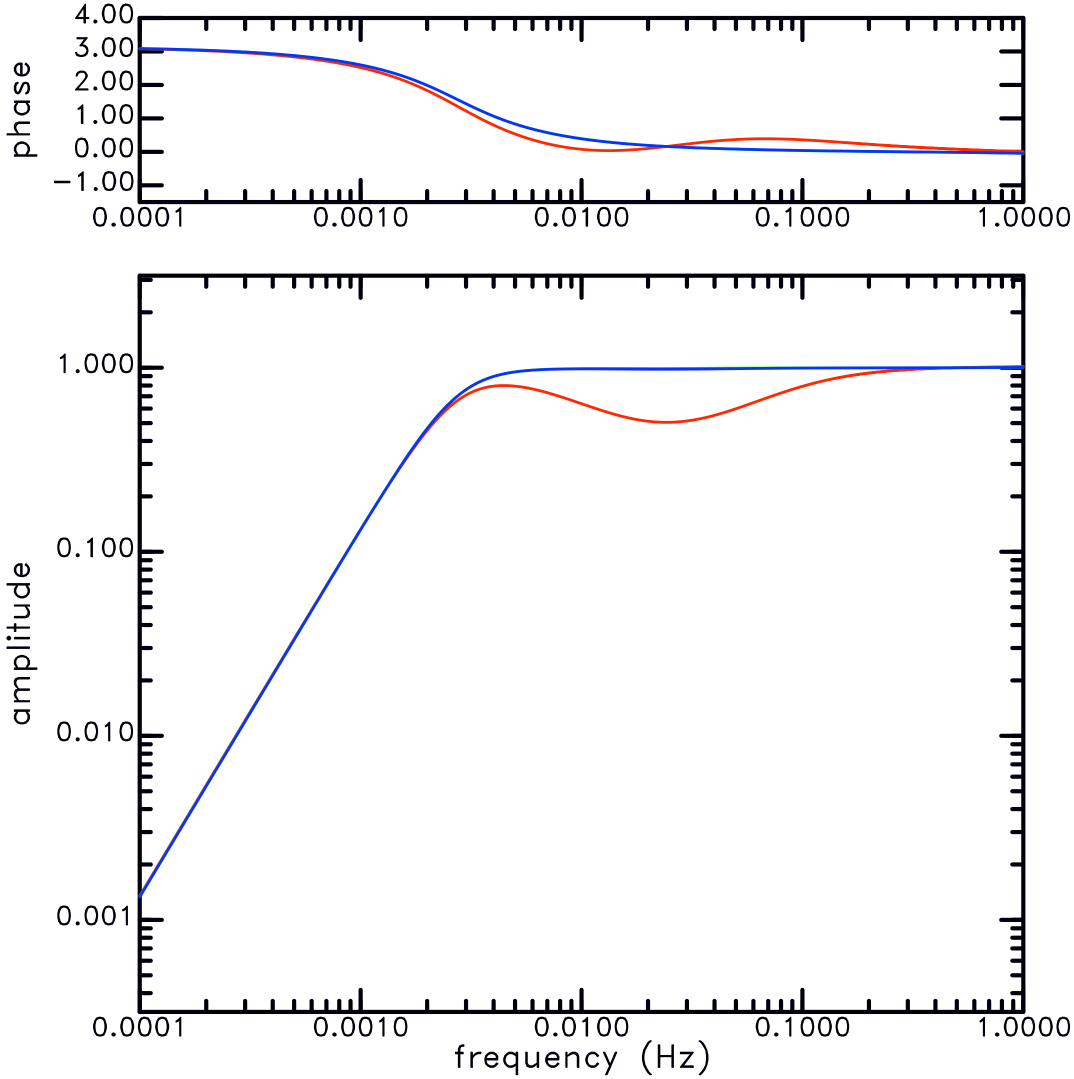


47 stations
99 epochs

ADK
AFI
BILL
CASY
CCM
COR
CTAO
DAV
FUNA
FURI
GNI
HKT
HRV
INCN
KBS
KEV
KIEV
KIP
KMBO
KONO
KOWA
LCO
LVC
MA2
MAJO
MAKZ
MSKU
OTAV
PAB
PET
PMG
PMSA
QSPA
RAO
SDV
SFJ
SFJD
SJG
TIXI
TRIS
TSUM
TUC
ULN
WCI
WVT
YAK
YSS

Policies / procedures: cal results

Current epoch at ESK-II



What has happened?

- **Technical problems**
- **Not fundamentally a hardware problem**

  Identification of problems + feedback to ops and users

- **Need new focus** on defining GSN success:
  - *quality*
  - *transparency*

  Not just design goals, but operational metrics and standards for *sustainable* high-quality data.

  Need to define policies and procedures that make this part of the core work plan.

Opportunities:
IRIS science is great. Imagine what could be done with truly "gold-standard" data!

We need this for the Grand Challenges...

Possible initial steps

1. Quality:
   a. station acceptance testing and certification using basic quality metrics (*e.g.*, relative response, orientation, timing)
   b. prioritize current data stream, then backfill quality certification
   c. longer-term quality review (*cf.* TA quality review)

2. Transparency:
   Giving data users knowledge of quality status
   a. public posting of certification status and other metrics at DMC
   b. user-queriable database of known station problems and metadata change dates, hosted at DMC

3. Communication with the IRIS community:
   How do we ensure sustained high-quality data production (a legacy of gold-standard GSN data)? strategies, resource allocation, etc.

Key questions for the GSN

1. How do we close the loop?
   - need the policies and procedures in place to make sure:
     - QC happens
     - info from lab QC and field gets into metadata, and to the user community
     - info from QC drives operational decisions
     - these activities are sustained (= core operational responsibilities)
     - *hardware cannot solve this alone*

2. How best to leverage IRIS resources for immediate and long-term action?
   - TA experience, products, metrics
   - Advance-deploy TA at/near problematic Backbone stations?
   - Personnel resources (fewer ARRA requirements)
   - We need some creative thinking!

3. How can the GSN Standing Committee do a better job?
   - Self-assessment session - what do we need to do differently to support charge #1?
   - Could be initiated at this meeting.

Доверяй, но проверяй !