Barometric Pressure Measurements and Corrections for Low Frequency Seismology

IRIS Seismic Instrumentation Technology Symposium
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Palm Springs, CA

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QUANTERRA

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US 4866442
Japan 2787445
EPO 0293780
Germany P3883081.7-08
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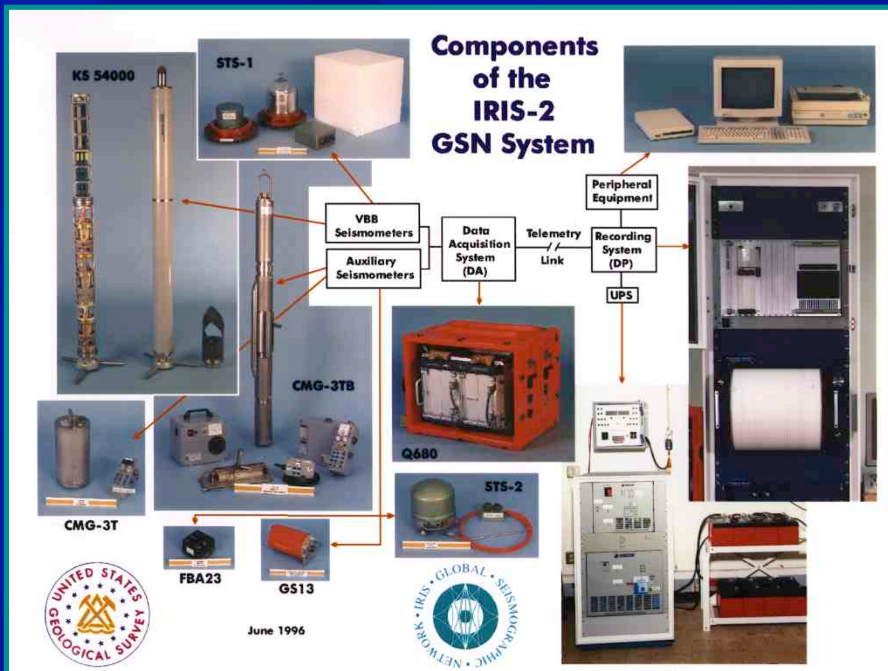
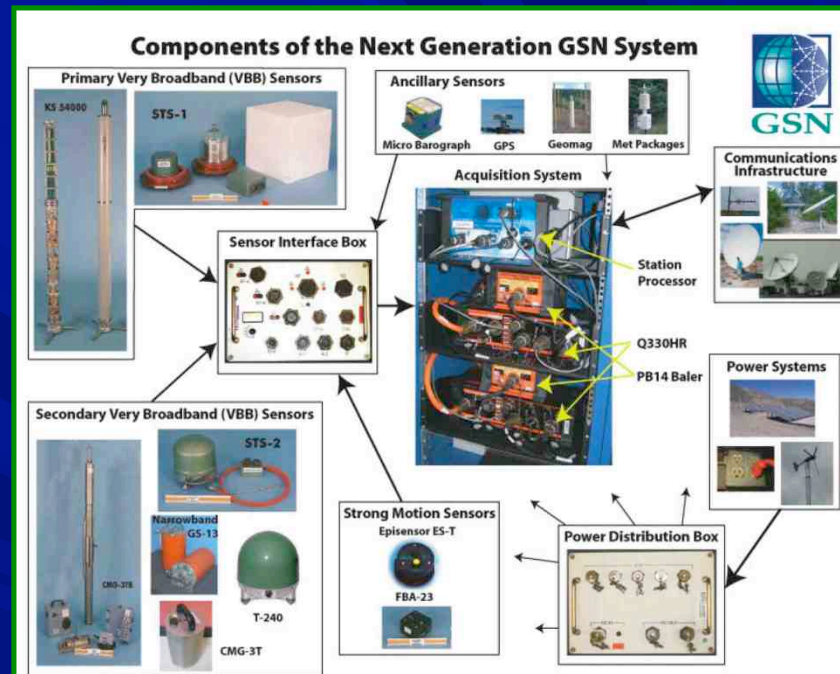
Singapore P9790690

Jun 15, 1987

1990

2009





Q330HR
The IRIS-GSN data system

25+ year R&D effort in VBB instrumentation

Performance: Noise, Dynamic Range, Bandwidth
Data Completeness [….”continuous” digital data stream…]
Time Accuracy
Operational Longevity and Reliability
Minimum Power to enable science-driven siting
Survivability, Physical Size, and Robustness
Environmental Ingress protection
Consistency
Communications, Monitoring, Control, and Calibration
Cost

VBB Technology Objective:

Acquire and record as faithfully as possible in a single continuous digital data stream the teleseismic spectrum encompassing ~5 decades in frequency and ~140dB dynamic range. Do this for years in challenging environments with minimal maintenance and cost to enable wide usage.

VBB technology is a powerful instrumentation technique, but what's the target?

Faithful measurement of minimum ambient seismic noise, and large signals over a wide frequency range.

Is the goal achieved in present instrument networks, and what can be done to improve data quality?

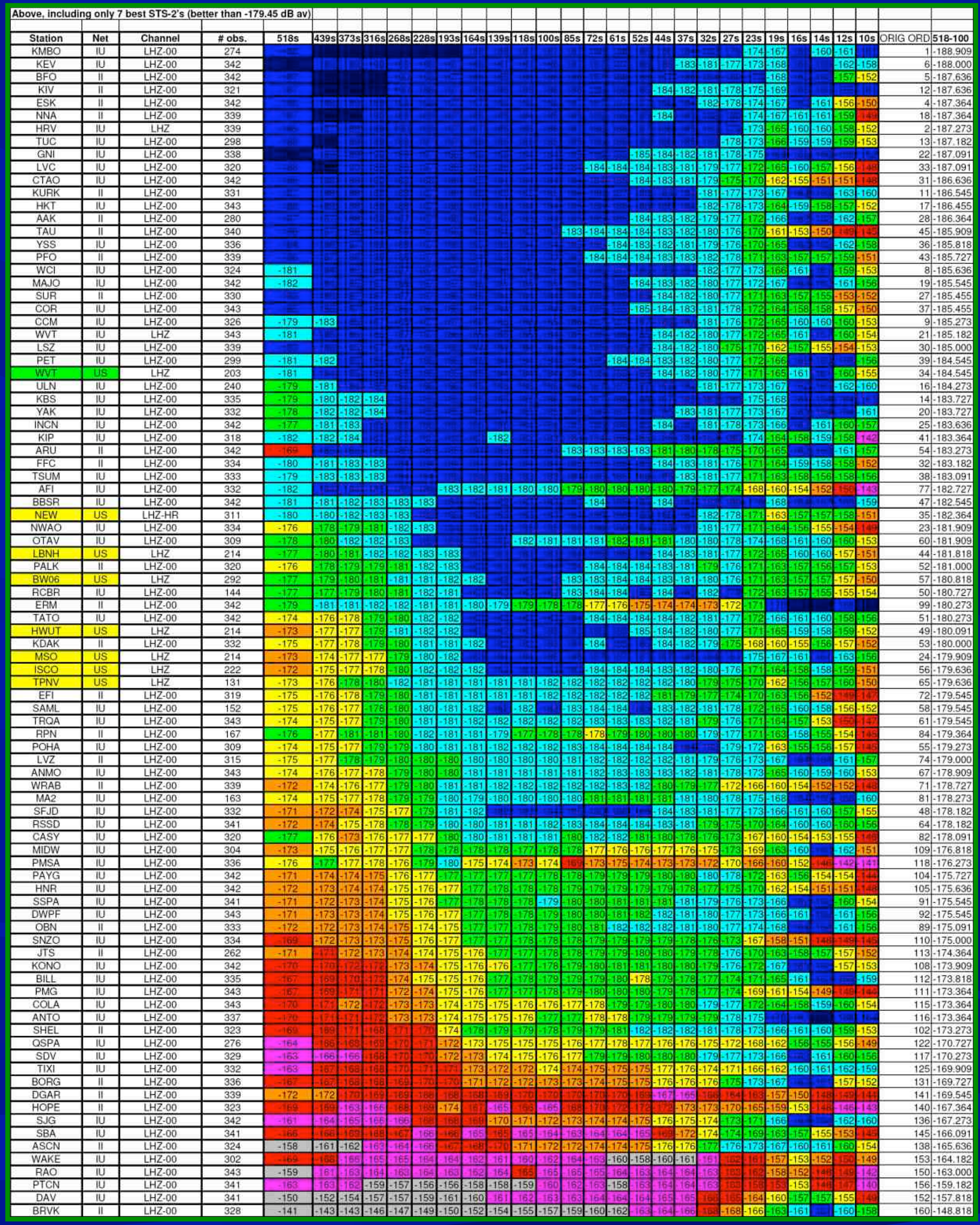
Noise & Networks

2-weeks in the life of the GSN
2006-05-17 - 2006/05/31

HRV #2 in the GSN?

…hmmm

www.seismology.harvard.edu/~ekstrom/...RADB_network_spectrum.html



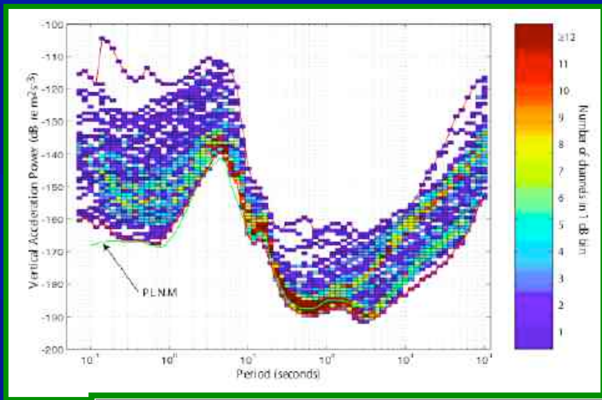
2-weeks in the life of the GSN
2006-05-17 - 2006/05/31

Ekstrom's binned spectra for II & IU stations rearranged by arithmetic averages of 11 518s-100s bins. This weights low-frequencies preferentially, and shows more organized ranking by VLP noise.

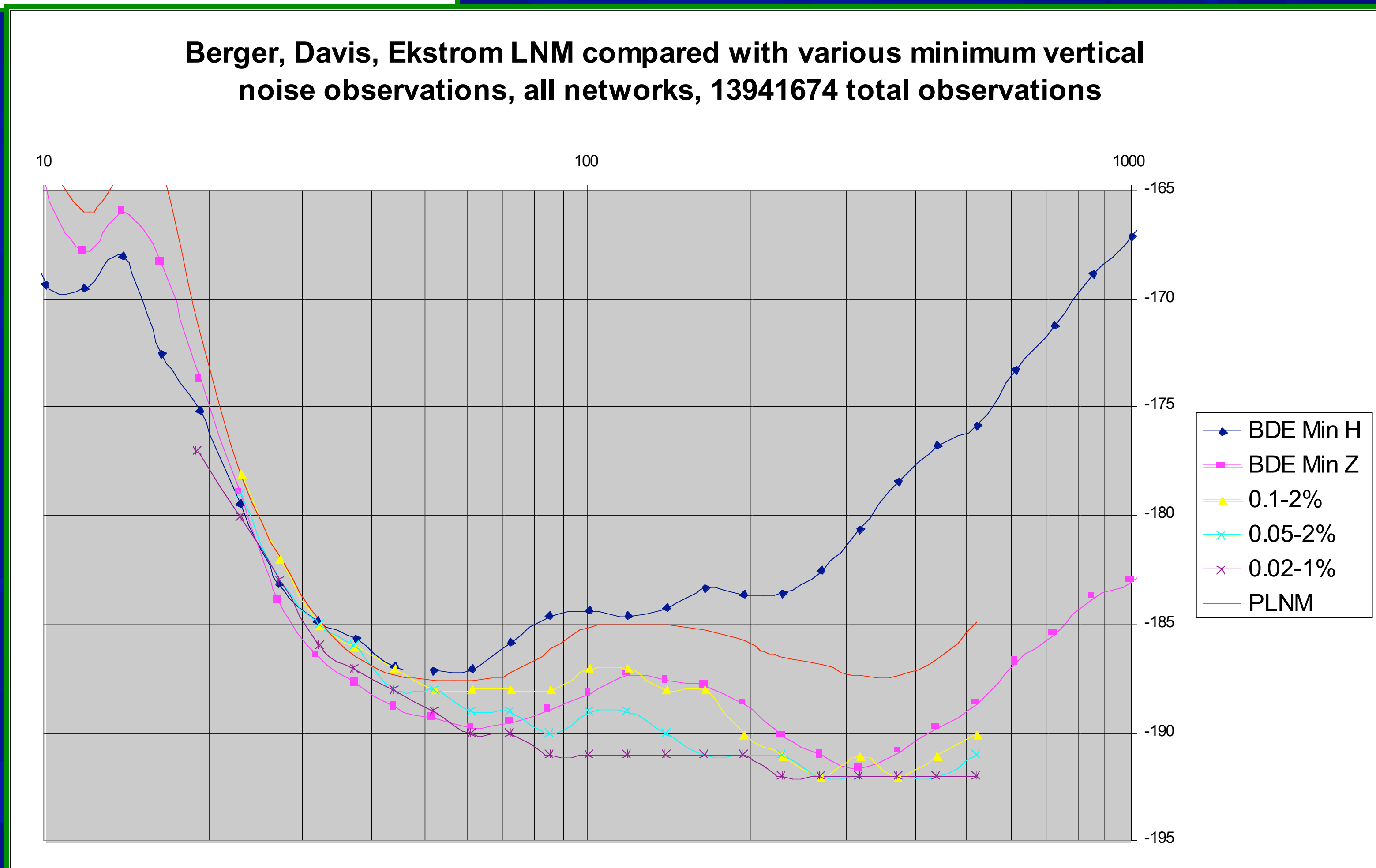
Is this general picture consistent over time, stations, or sensor type?

Example of Ekstrom's average month spectra from each station covering the period 1993/01 through 2006/07

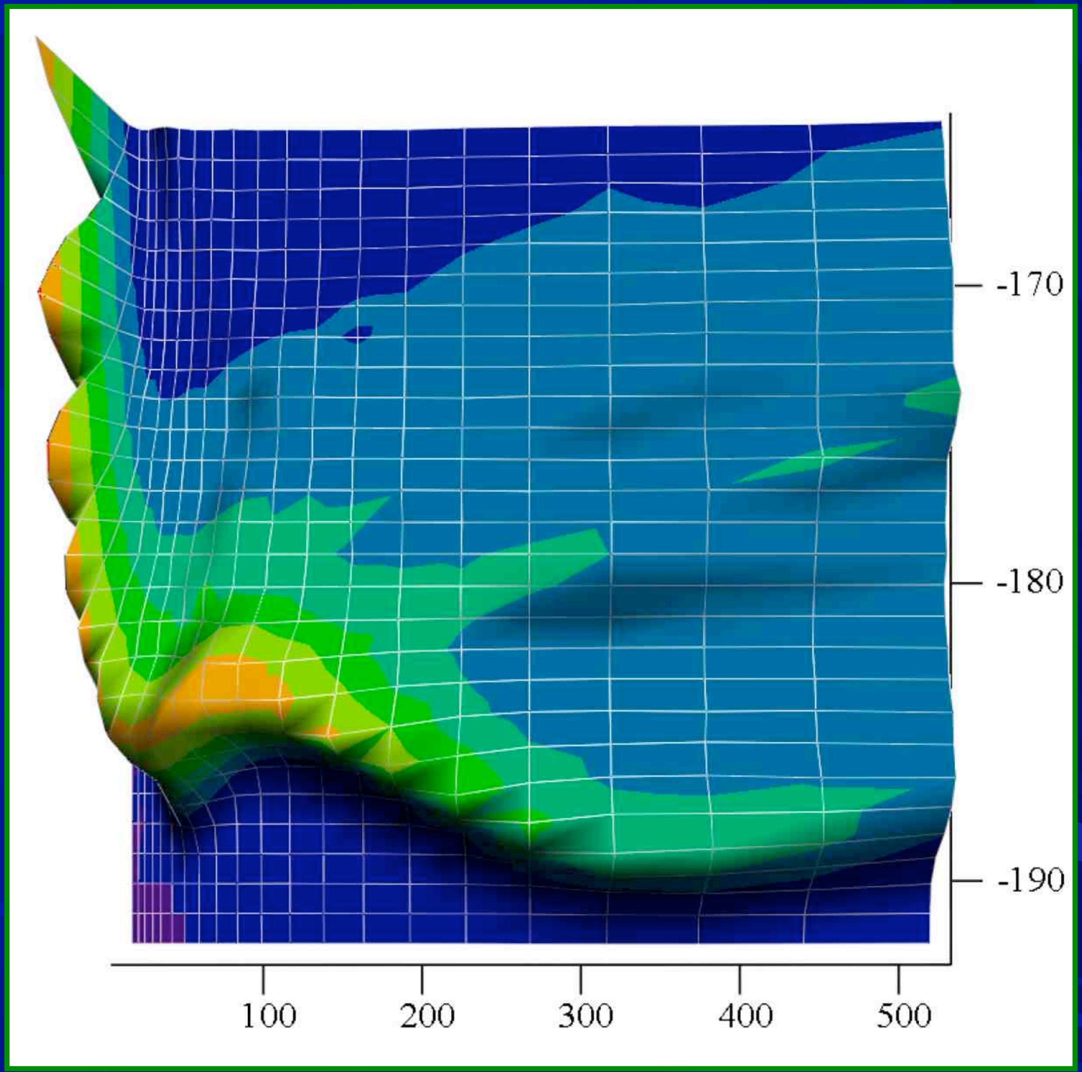
The entire data set comprises 355 stations and ~14M 1hr spectra.



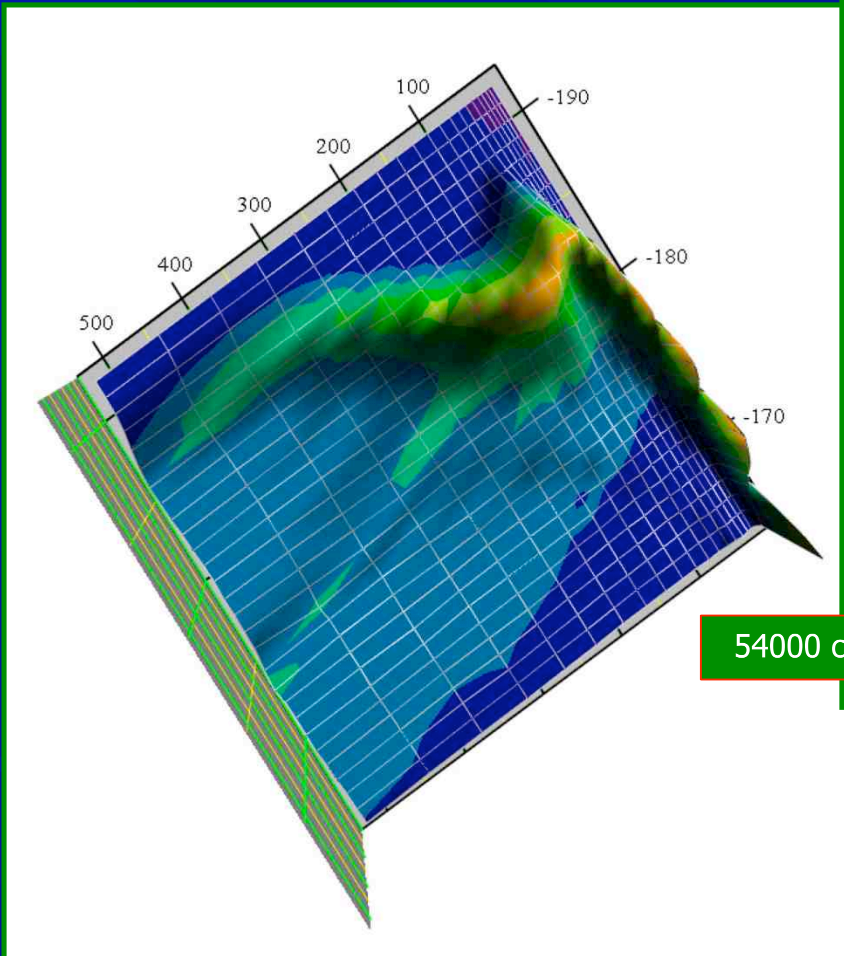
Does this data set reproduce the newest LNM?

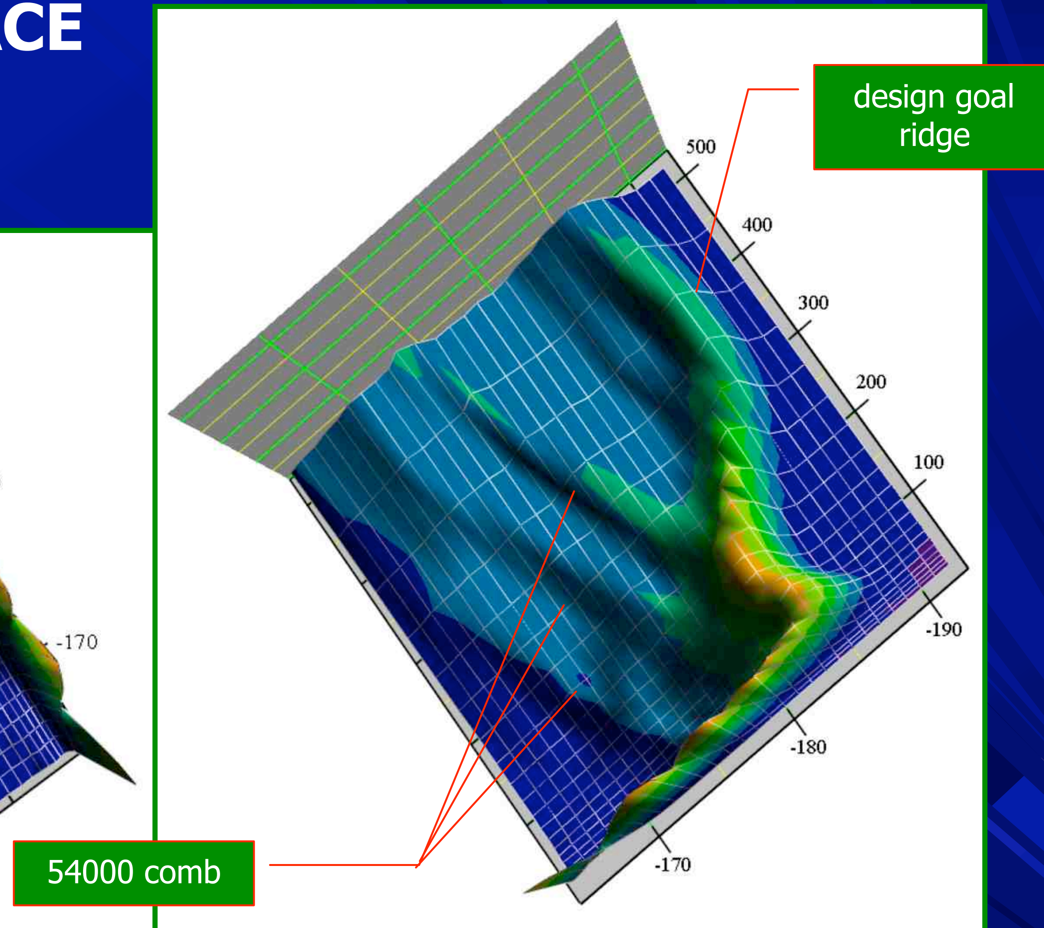


IRIS/GSN NOISE SURFACE – 1993-present

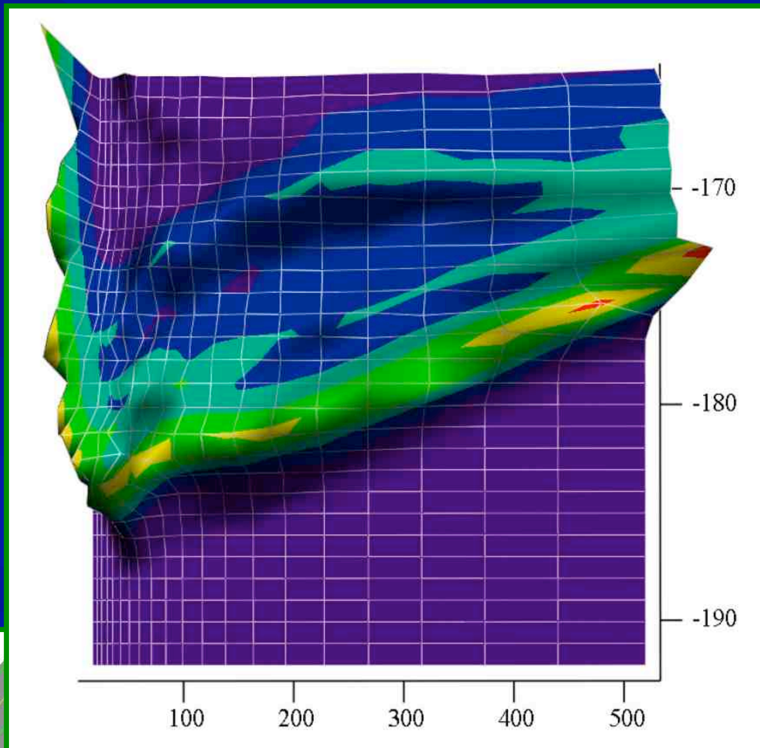


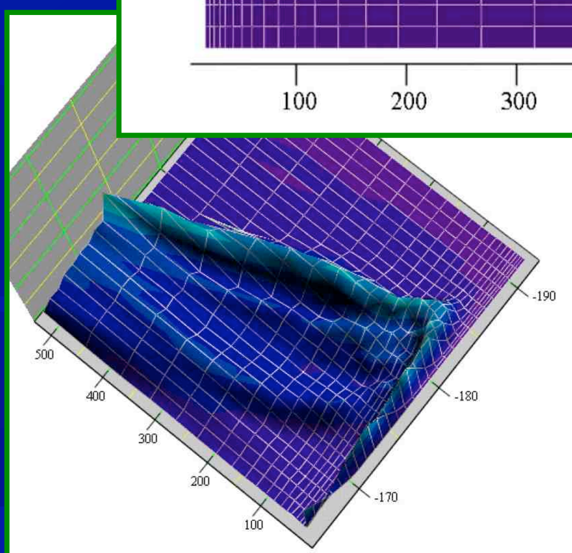
IRIS/GSN NOISE SURFACE
1993-present



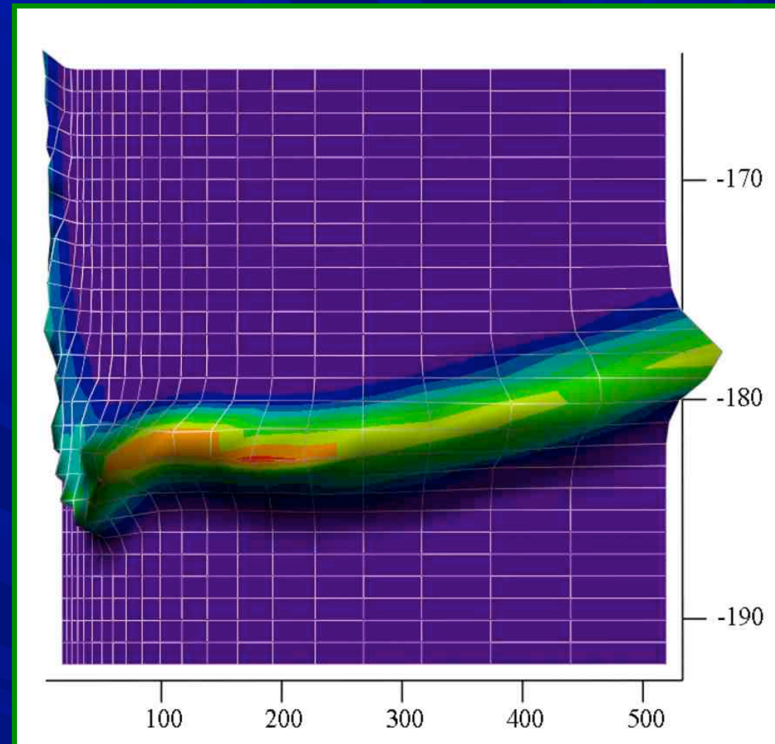


KS-54000





GE & US SELECT STS-2



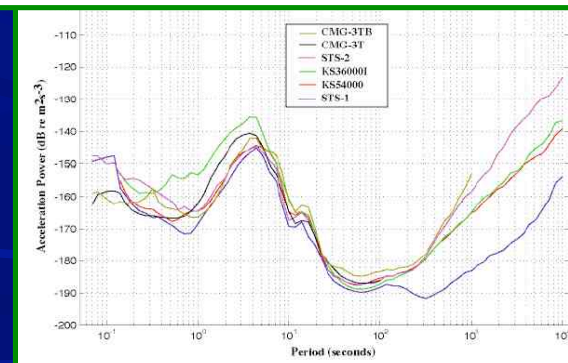
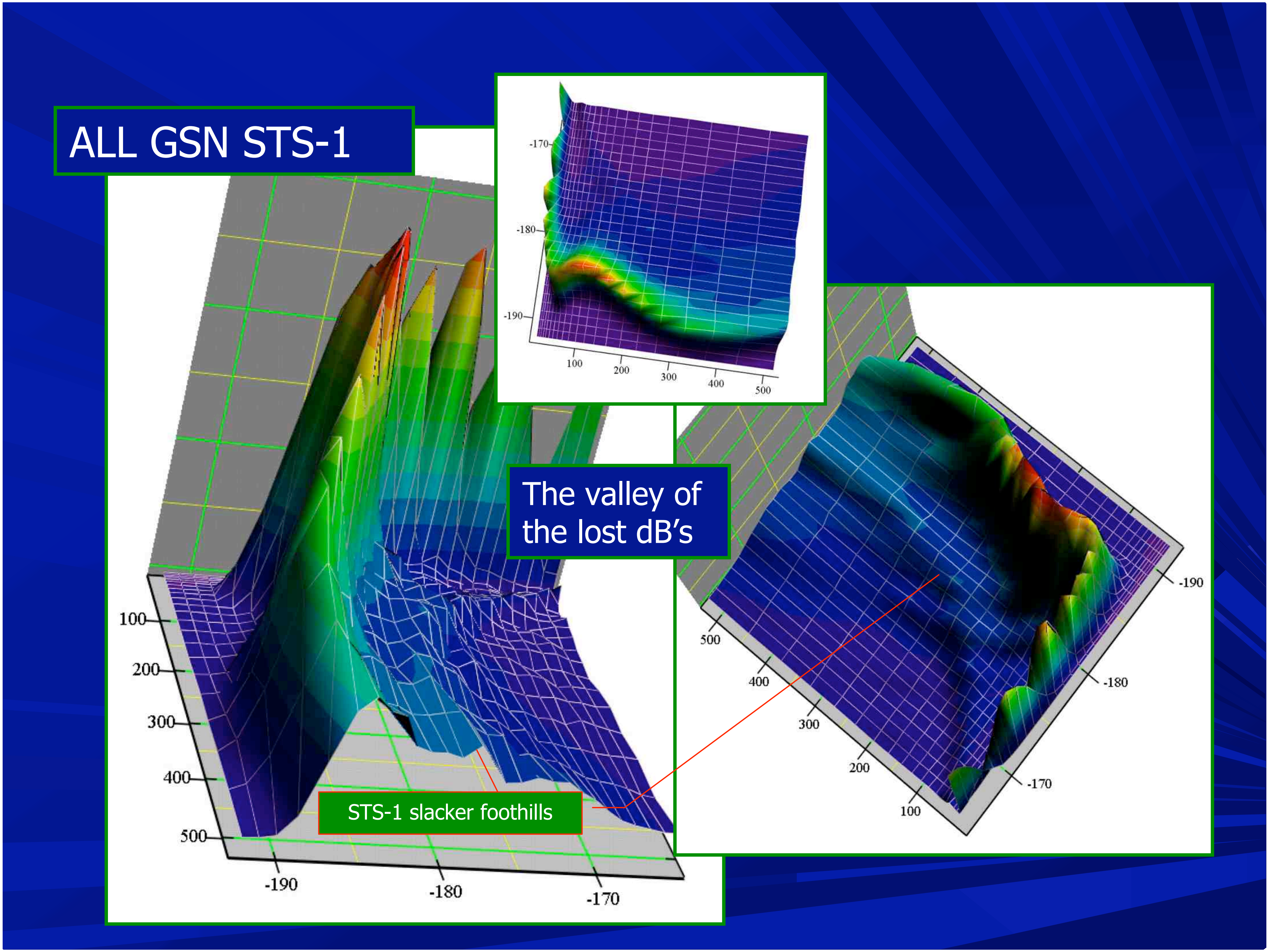


Figure 9.


ALL GSN STS-1
The valley of the lost dB's
STS-1 slacker foothills
100
200
300
400
500
-190
-180
-170

Is higher noise associated with particular stations, or is it randomly present across the entire station population?

Net	Station	Sensor	hrs <-178	hrs >-178	% BETTER
IU	MAJO	STS-1	108700		100%
IU	TUC	STS-1	105859		100%
IU	CCM	STS-1	96094		100%
II	BFO	STS-1	84445		100%
IU	HKT	STS-1	77988		100%
…					
II	PALK	54000	28488		100%
…					
IU	SAML	54000	15531		100%
IU	CTAO	STS-1	105159	724	99%
IU	KEV	STS-1	92080	717	99%
…					
IU	ANMO	54000	95497	18911	83%
II	NNA	STS-1	71075	15648	82%
IU	FURI	STS-1	39340	8940	81%
…					
IU	PMSA	STS-1	9519	100146	9%
IU	SDV	STS-1	6202	74392	8%
IU	GUMO	54000	4148	104551	4%
…					
IU	BILL	STS-1	1838	71108	3%
IU	FUNA	STS-1		5529	0%
…					
IU	RAO	STS-1		14302	0%
IU	TRIS	STS-1		14786	0%
II	NRIL	STS-1		14819	0%
IU	RAIO	CMG3-T		15244	0%

Method:

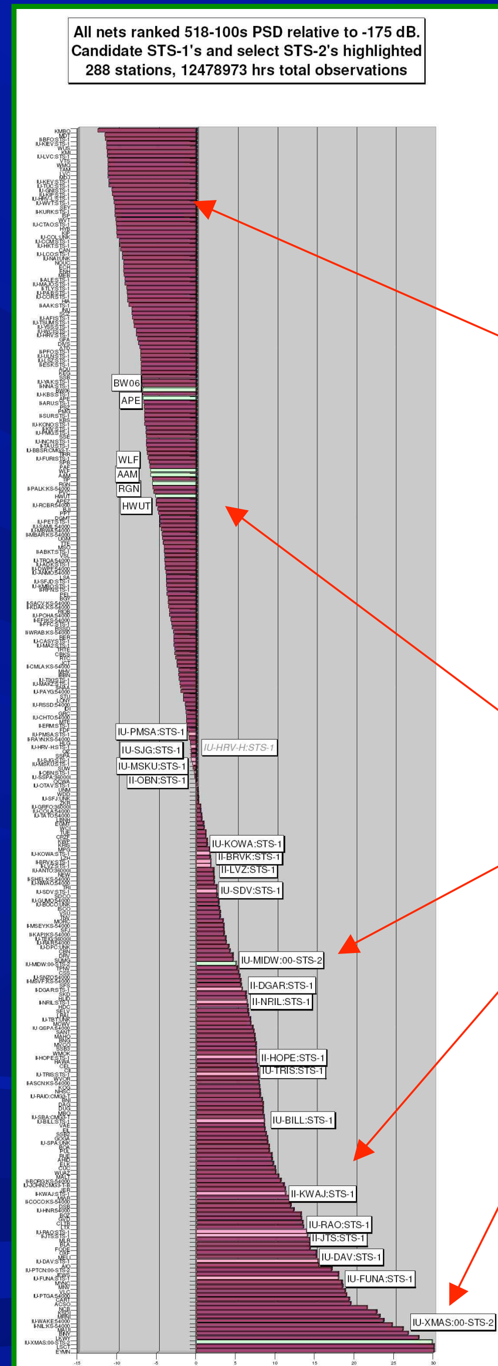
Consider average PSD in 11 1/14 decade bands 518-100s. Rank stations by fraction better than a target: -178dB. The results do not depend strongly on the particular band, or the particular "cutoff" of -178dB. We'll see why -178dB is a reasonable figure.

partial table of GSN stations

All-network ranking:

-187dB

Better



-175dB

Worse

-145 dB

HRV

288 stations comprising IU & II GSN, GE, US,MN,G,CD stacked by mean PSD 518-100s.

GE,US STS-2’s

IU-MIDW (STS-2)

10 GSN STS-1 with high mean PSD

XMAS

IU

Station	Sensor	Total obs		518 <-175	518-100 <-178
BBSR	*CMG3-T-B*	34212		100%	100%
CCM	*STS-1*	96094		100%	100%
COL	*UNK*	27327		100%	100%
GNI	*STS-1*	59827		100%	100%
HKT	*STS-1*	77988		100%	100%
KIEV	*STS-1*	57950		98%	100%
LCO	*STS-1*	35604		100%	100%
LVC	*STS-1*	36554		100%	100%
MAJO	*STS-1*	108700		96%	100%
NAI	*UNK*	5315		100%	100%
SAML	*54000*	15531	**SAML**	31%	100%
TRQA	*54000*	43059	**TRQA**	27%	100%
TSUM	*STS-1*	76079		96%	100%
TUC	*STS-1*	105859		100%	100%
WVT	*STS-1*	45526		99%	100%
CTAO	*STS-1*	105883		99%	99%
KEV	*STS-1*	92797		99%	99%
KIP	*STS-1*	97015		98%	98%
RCBR	*54000*	49789		85%	97%
LSZ	*STS-1*	48718		88%	96%
MBWA	*54000*	17481		68%	96%
ULN	*STS-1*	77310		87%	96%
AFI	*STS-1*	58277		97%	95%
COR	*STS-1*	94461		96%	95%
DWPF	*54000*	60532	**DWPF**	7%	95%
PMG	*STS-1*	95408		62%	95%
PAB	*STS-1*	87604		92%	94%
KBS	*STS-1*	88863		89%	93%
YAK	*STS-1*	94106		84%	88%
INCN	*STS-1*	75782		67%	87%
KMBO	*STS-1*	60782		86%	86%
KONO	*STS-1*	108408		81%	86%
YSS	*STS-1*	107708		84%	86%
ANMO	*54000*	114408		49%	83%
FURI	*STS-1*	48280		81%	81%
SFJD	*STS-1*	10587	**SFJD**	7%	80%
HRV	*STS-1*	98287		81%	77%
WCI	*STS-1*	41290		76%	76%
ADK	*STS-1*	69383		41%	75%
CASY	*STS-1*	58021		93%	73%
MAKZ	*STS-1*	44315		61%	69%
TIXI	*STS-1*	62768		42%	69%
PET	*STS-1*	96642		65%	68%

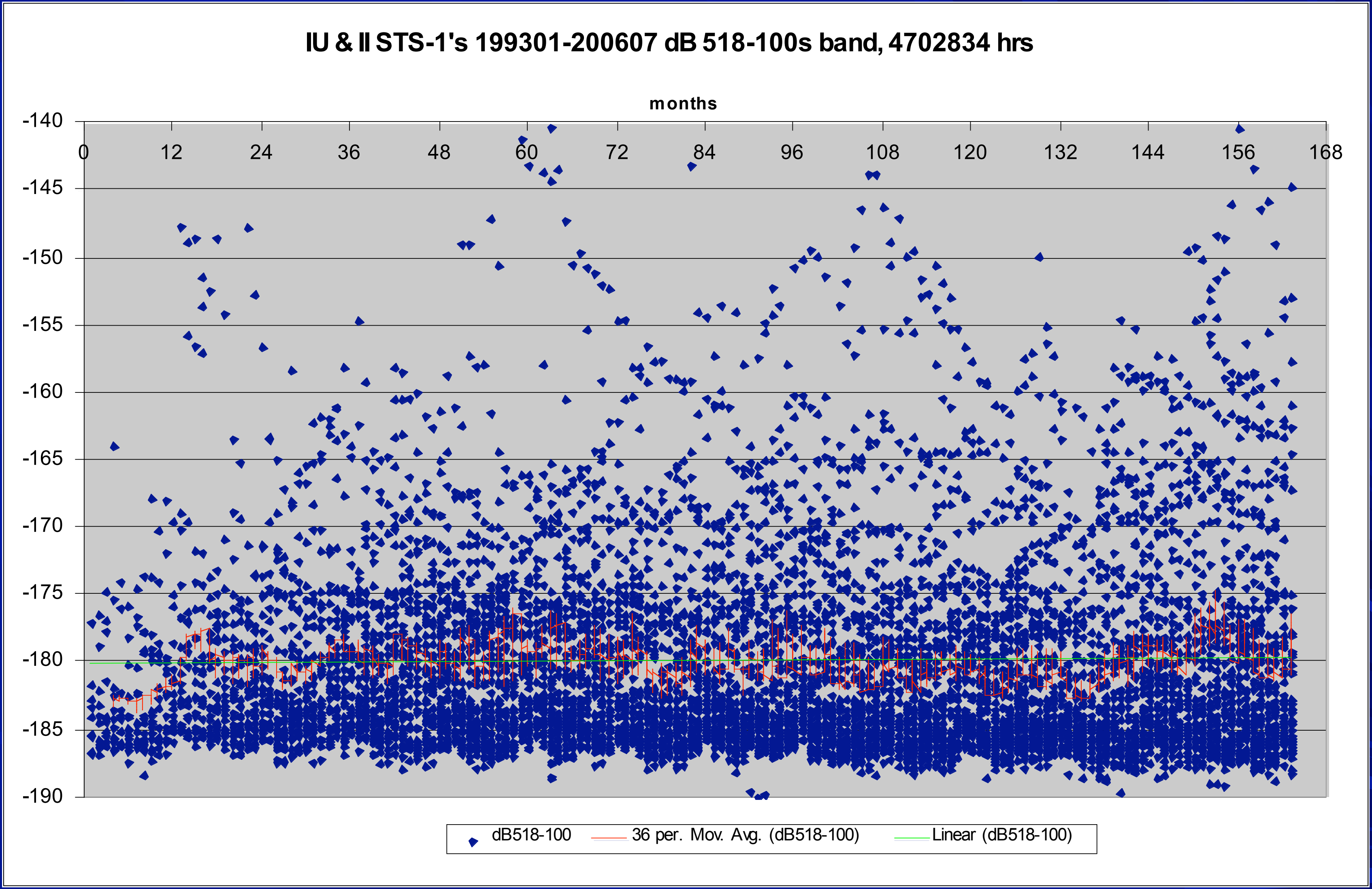
Station	Sensor	Total obs		518 <-175	518-100 <-178
POHA	*54000*	47611	**POHA**	20%	67%
MA2	*STS-1*	83218		54%	58%
MEAN	*IU-MEAN*	5189544	**MEAN**	49%	56%
OTAV	*STS-1*	30472	**OTAV**	32%	46%
NWAO	*54000*	99752		37%	39%
TATO	*54000*	103345	**TATO**	26%	38%
MSKU	*STS-1*	8141	**MSKU**	30%	37%
SJG	*STS-1*	105924	**SJG**	2%	34%
KOWA	*STS-1*	1898	**KOWA**	30%	30%
RSSD	*54000*	51155	**RSSD**	4%	19%
SFJ	*UNK*	58386	**SFJ**	1%	18%
MIDW	*00-STS-2*	39598	**MIDW**	7%	16%
TBT	*UNK*	15596	**TBT**	15%	15%
PAYG	*54000*	61146	**PAYG**	0%	9%
PMSA	*STS-1*	109665	**PMSA**	15%	9%
SDV	*STS-1*	80594	**SDV**	5%	8%
CHTO	*54000*	86055	**CHTO**	0%	7%
GUMO	*54000*	108699	**GUMO**	1%	4%
SPA	*UNK*	87258	**SPA**	1%	4%
BILL	*STS-1*	72946	**BILL**	1%	3%
ANTO	*36000I*	56524	**ANTO**	0%	0%
BOCO	*UNK*	13924	**BOCO**	0%	0%
COLA	*54000*	78607	**COLA**	0%	0%
DAV	*STS-1*	75506	**DAV**	0%	0%
DPC	*UNK*	743	**DPC**	0%	0%
FUNA	*STS-1*	5529	**FUNA**	0%	0%
GRFO	*36000I*	76719	**GRFO**	0%	0%
HNR	*54000*	72314	**HNR**	0%	0%
JOHN	*CMG3-T-B*	42938	**JOHN**	0%	0%
PTCN	*00-STS-2*	65811	**PTCN**	0%	0%
PTGA	*54000*	27739	**PTGA**	0%	0%
QSPA	*54000*	25232	**QSPA**	0%	0%
RAIO	*CMG3-T*	15244	**RAIO**	0%	0%
RAO	*STS-1*	14302	**RAO**	0%	0%
RAR	*54000*	97601	**RAR**	0%	0%
SBA	*CMG3-T*	63018	**SBA**	0%	0%
SNZO	*54000*	98885	**SNZO**	0%	0%
SSPA	*36000I*	70522	**SSPA**	0%	0%
TEIG	*36000I*	31490	**TEIG**	0%	0%
TRIS	*STS-1*	14786	**TRIS**	4%	0%
WAKE	*54000*	71314	**WAKE**	0%	0%
XMAS	*00-STS-2*	28807	**XMAS**	0%	0%

II

	SENSOR	Total obs		518s <-175	518-100s <-178
ALE	*STS-1*	46488		100%	100%
BFO	*STS-1*	84445		100%	100%
KURK	*STS-1*	64540		100%	100%
PALK	*KS-54000*	28488		76%	100%
MBAR	*KS-54000*	29147		43%	98%
AAK	*STS-1*	65206		89%	93%
SACV	*KS-54000*	19991	**SACV**	26%	93%
TLY	*STS-1*	56179		88%	88%
PFO	*STS-1*	67523		94%	86%
NNA	*STS-1*	86723		100%	82%
EFI	*KS-54000*	69845	**EFI**	25%	80%
KIV	*STS-1*	84292		80%	80%
KDAK	*KS-54000*	60580	**KDAK**	25%	79%
RPN	*STS-1*	44995		76%	78%
ARU	*STS-1*	80000		73%	77%
SUR	*STS-1*	80550		100%	77%
TAU	*STS-1*	97774		100%	77%
ABKT	*STS-1*	33037		60%	76%
WRAB	*KS-54000*	95525	**WRAB**	5%	71%
ESK	*STS-1*	102564		100%	60%
RAYN	*KS-54000*	49586	**RAYN**	0%	59%
CMLA	*KS-54000*	47058	**CMLA**	9%	56%
FFC	*STS-1*	95721		68%	56%
II-MEAN	*II-MEAN*	2377285	**MEAN**	47%	53%
BRVK	*STS-1*	76814	**BRVK**	27%	31%
ERM	*STS-1*	68444	**ERM**	32%	30%
LVZ	*STS-1*	70661	**LVZ**	15%	19%
OBN	*STS-1*	87203	**OBN**	12%	10%
NIL	*KS-54000*	33051	**NIL**	3%	7%
ASCN	*KS-54000*	70909	**ASCN**	0%	0%
BORG	*KS-54000*	81652	**BORG**	0%	0%
COCO	*KS-54000*	59156	**COCO**	0%	0%
DGAR	*STS-1*	20139	**DGAR**	3%	0%
HOPE	*STS-1*	56060	**HOPE**	1%	0%
JTS	*STS-1*	50303	**JTS**	0%	0%
KAPI	*KS-54000*	14164	**KAPI**	0%	0%
KWAJ	*STS-1*	42497	**KWAJ**	0%	0%
MSEY	*KS-54000*	53611	**MSEY**	0%	0%
MSVF	*KS-54000*	26862	**MSVF**	0%	0%
NRIL	*STS-1*	14819	**NRIL**	0%	0%
SHEL	*KS-54000*	60683	**SHEL**	0%	0%

Consider the STS-1's in pink

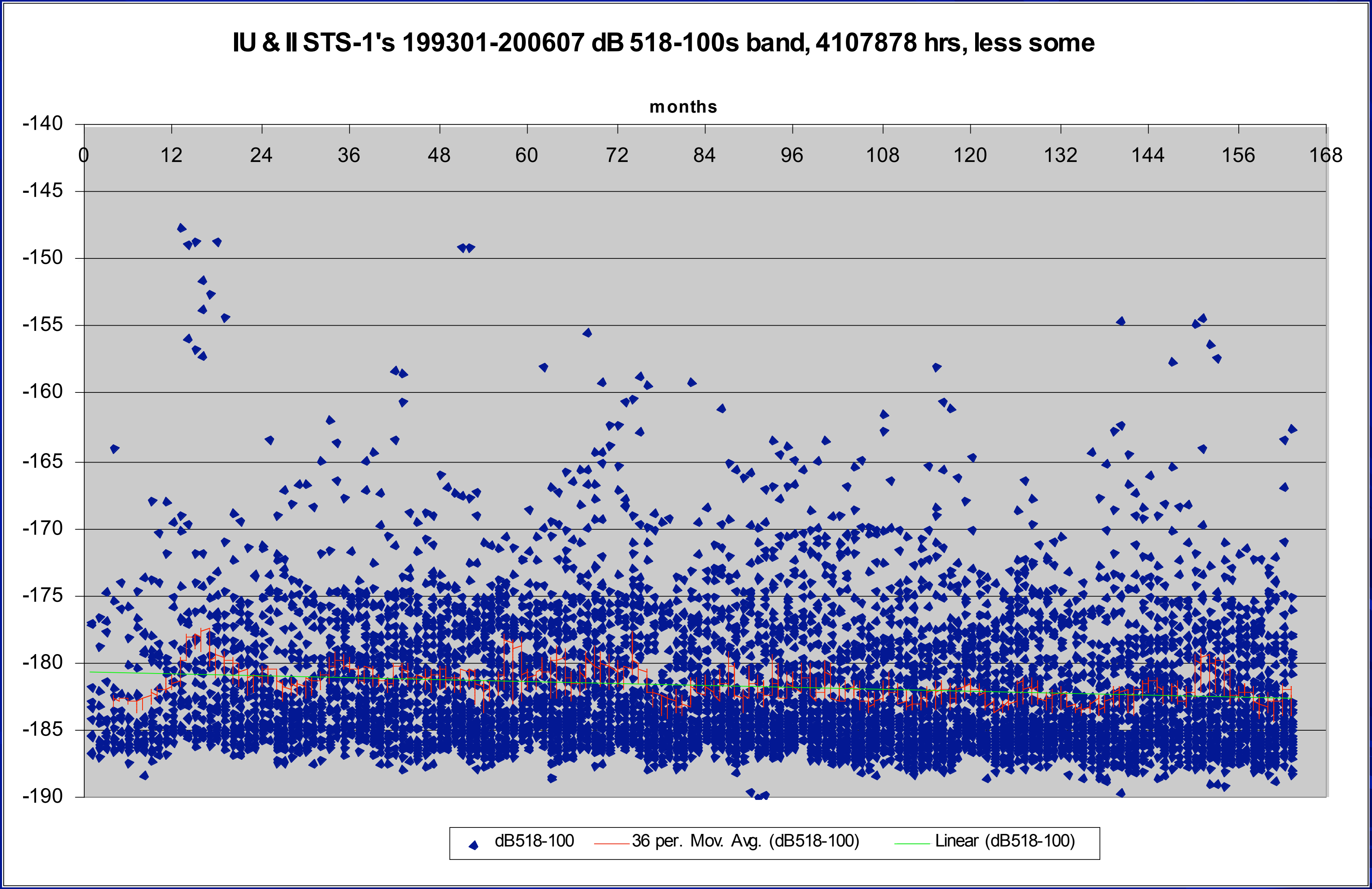
Is the STS-1 “fleet” performance deteriorating?



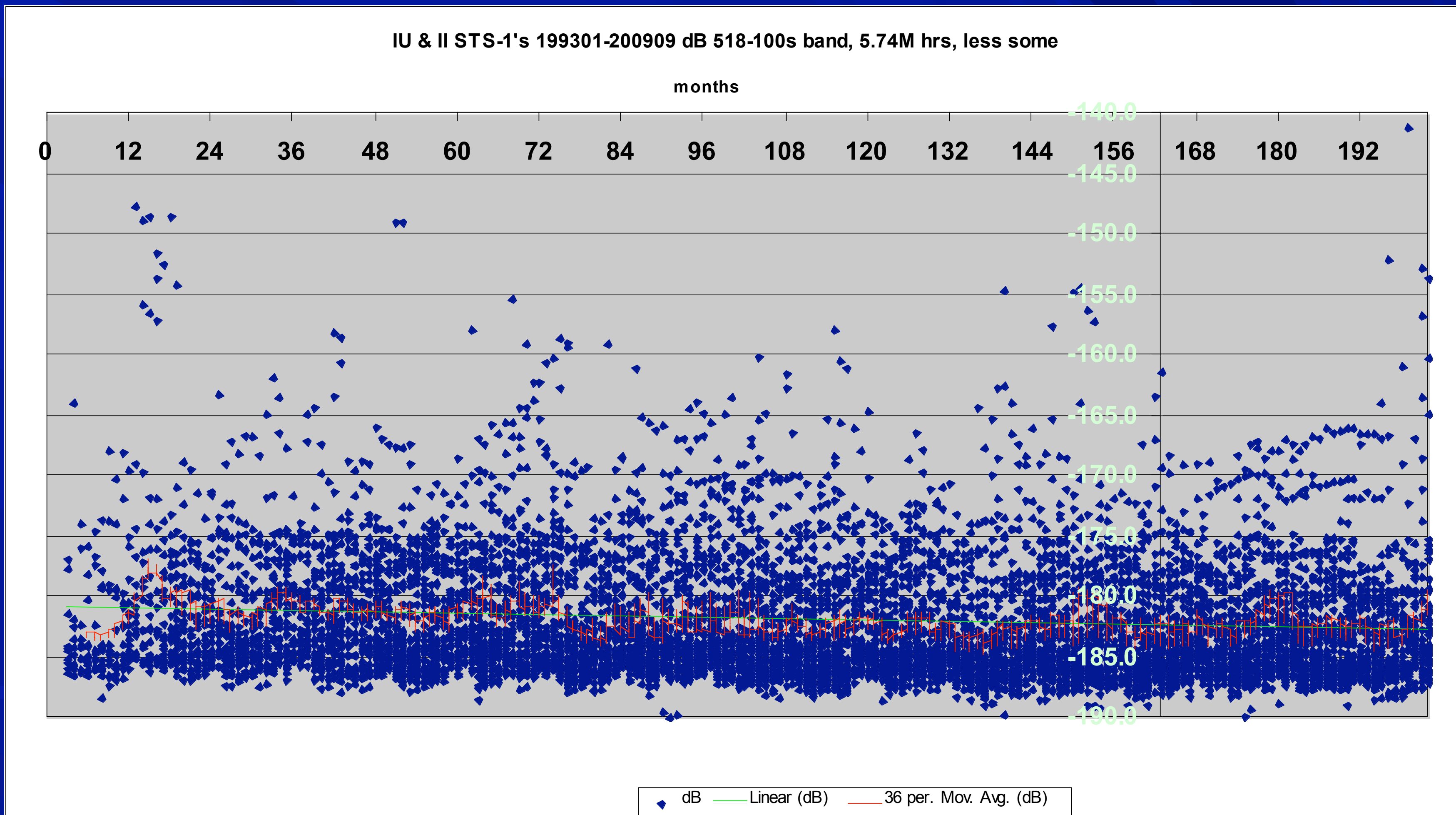
IU & II STS-1's 199301-200607 dB 518-100s band, 4702834 hrs
months
-140
-145
-150
-155
-160
-165
-170
-175
-180
-185
-190
0
12
24
36
48
60
72
84
96
108
120
132
144
156
168
dB518-100
36 per. Mov. Avg. (dB518-100)
Linear (dB518-100)

Mean -180.0

If it ain't broke, don't fix it.



Mean -181.8


IU & II STS-1's 199301-200909 dB 518-100s band, 5.74M hrs, less some
months
0
12
24
36
48
60
72
84
96
108
120
132
144
156
168
180
192
-140.0
-145.0
-150.0
-155.0
-160.0
-165.0
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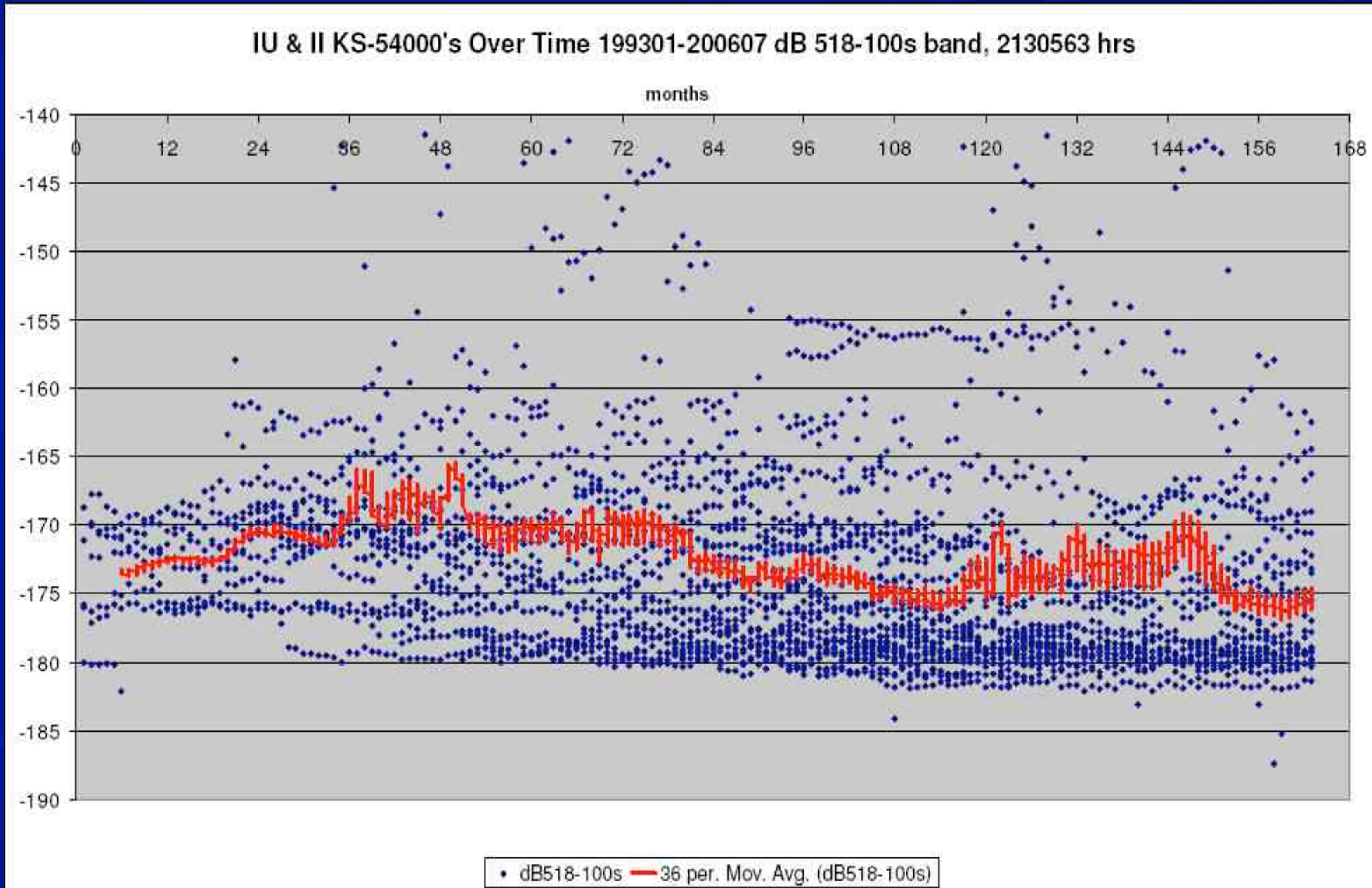
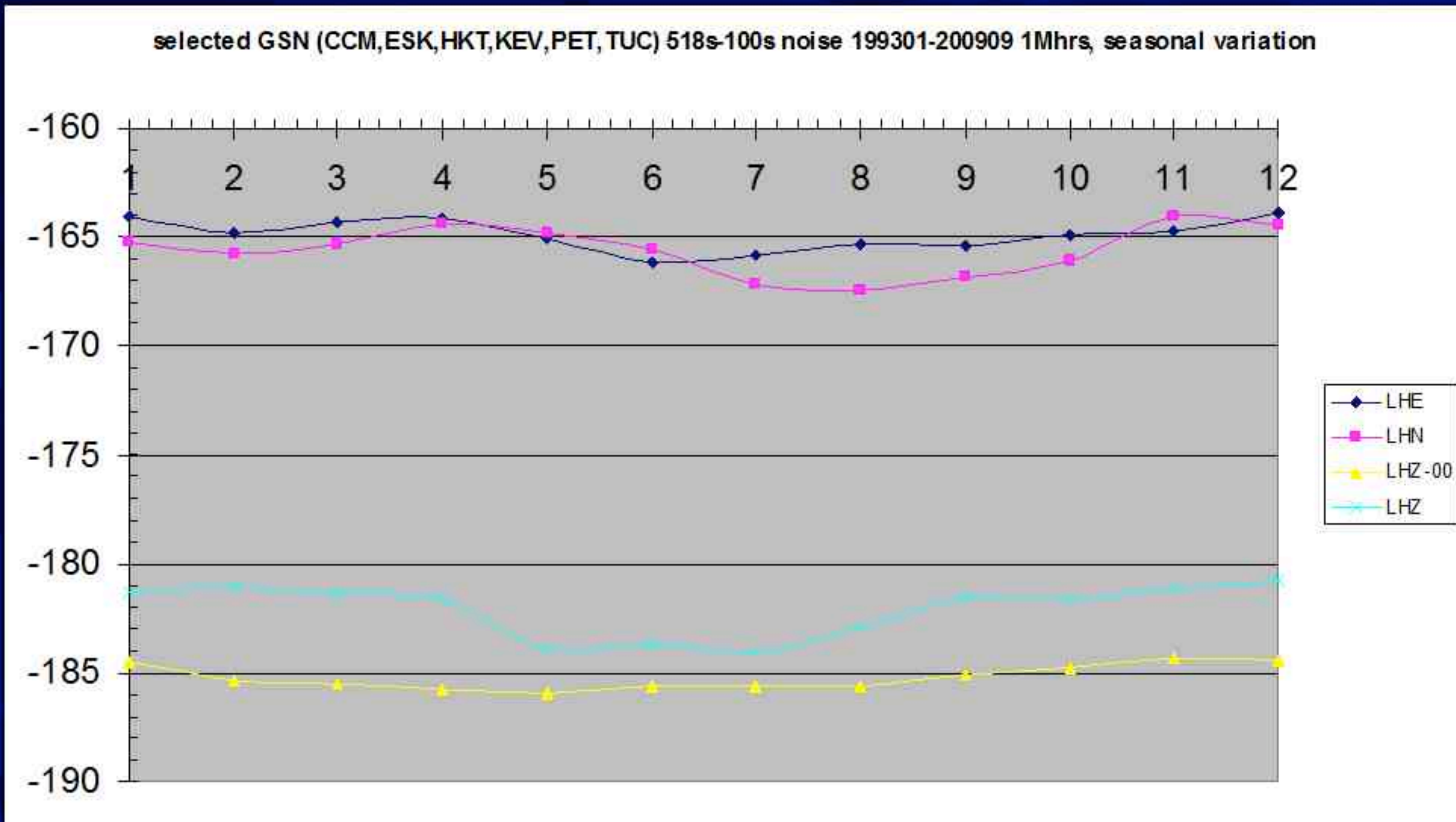
-175.0
-180.0
-185.0
-190.0
dB
Linear (dB)
36 per. Mov. Avg. (dB)


IU & II KS-54000's Over Time 199301-200607 dB 518-100s band, 2130563 hrs
months
0
12
24
36
48
60
72
84
96
108
120
132
144
156
168
-140
-145
-150
-155
-160
-165
-170
-175
-180
-185
-190
dB518-100s
36 per. Mov. Avg. (dB518-100s)

Mean -172.5

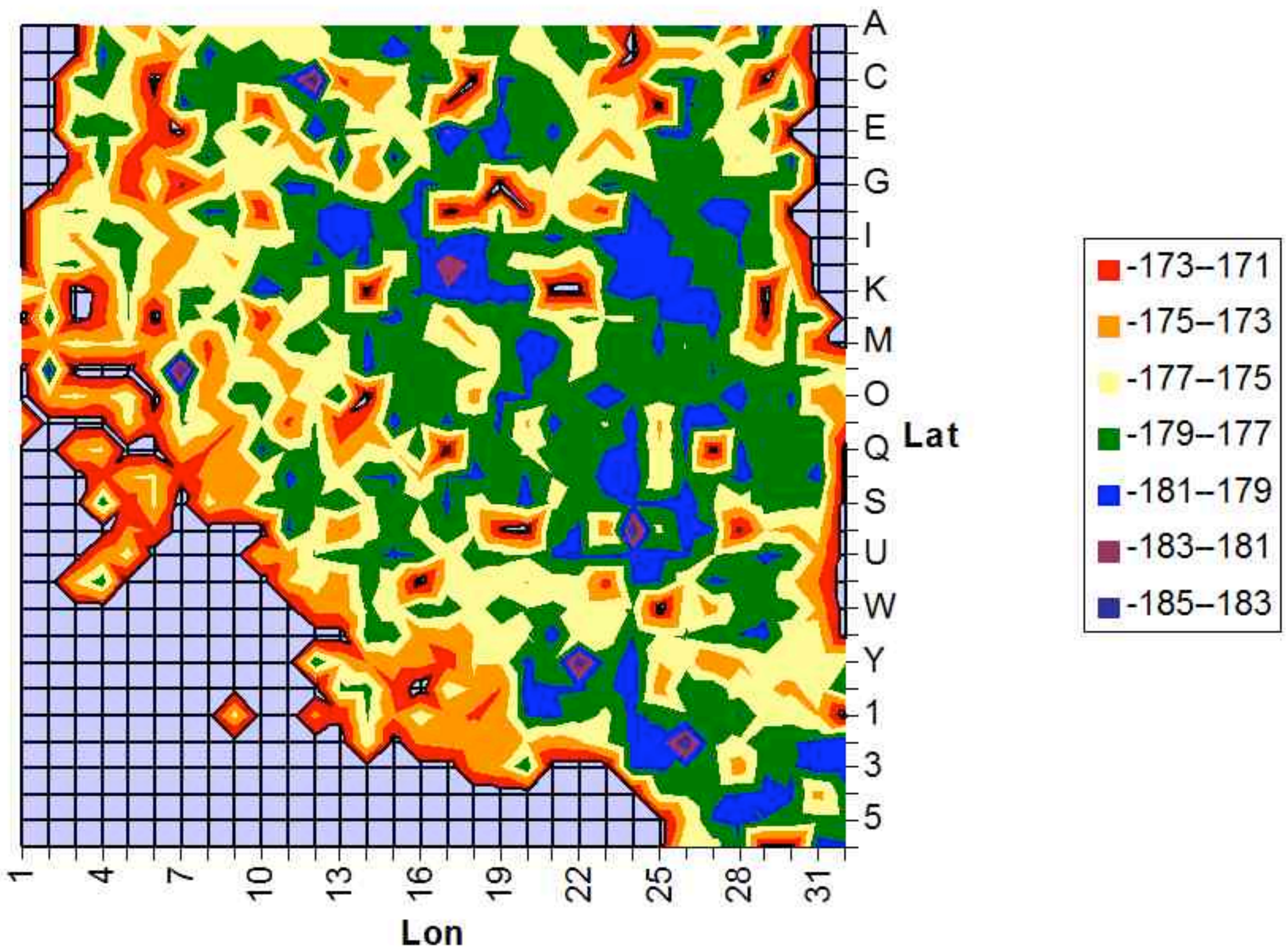
High-Quality GSN stations, seasonal variation

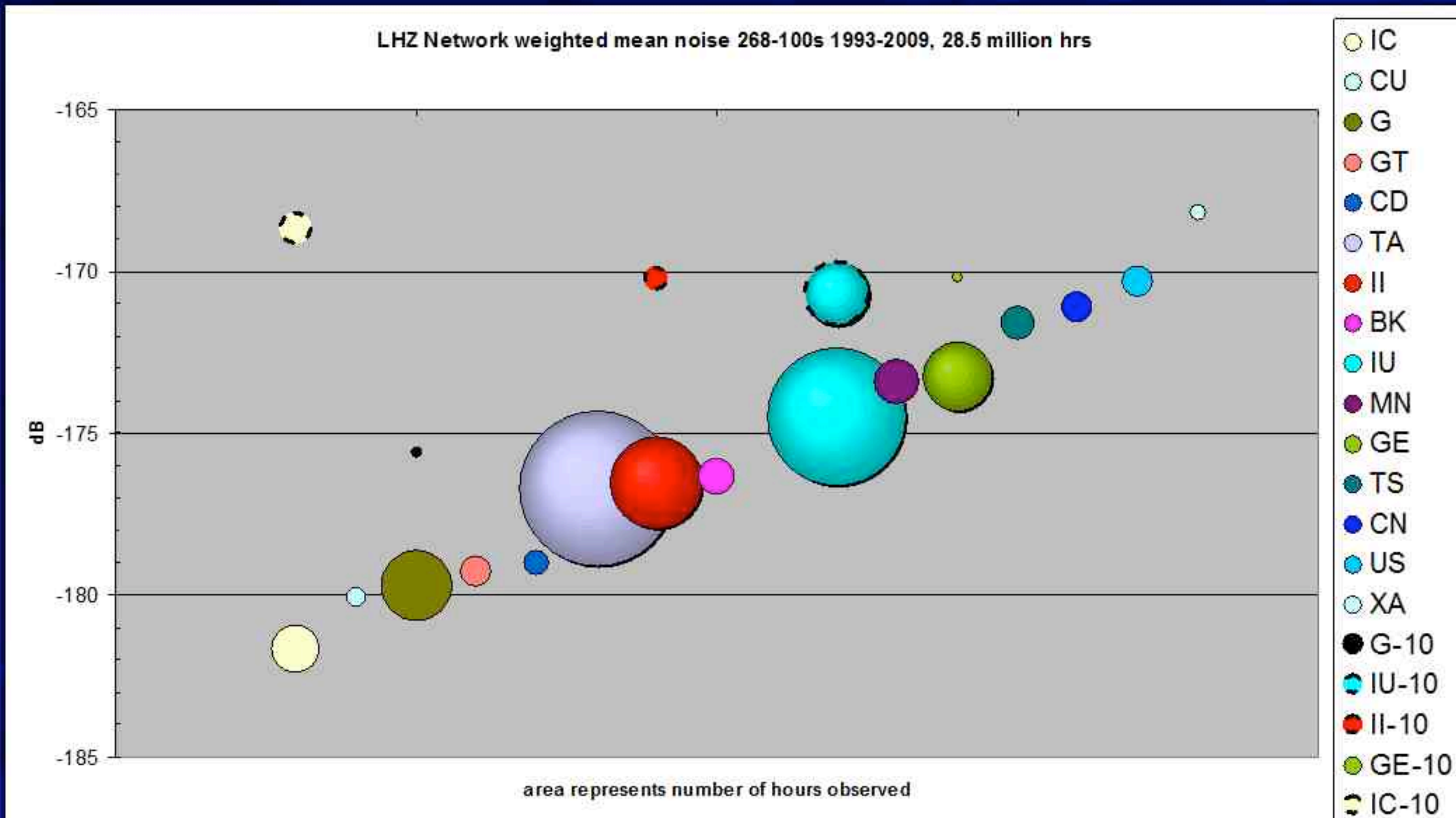


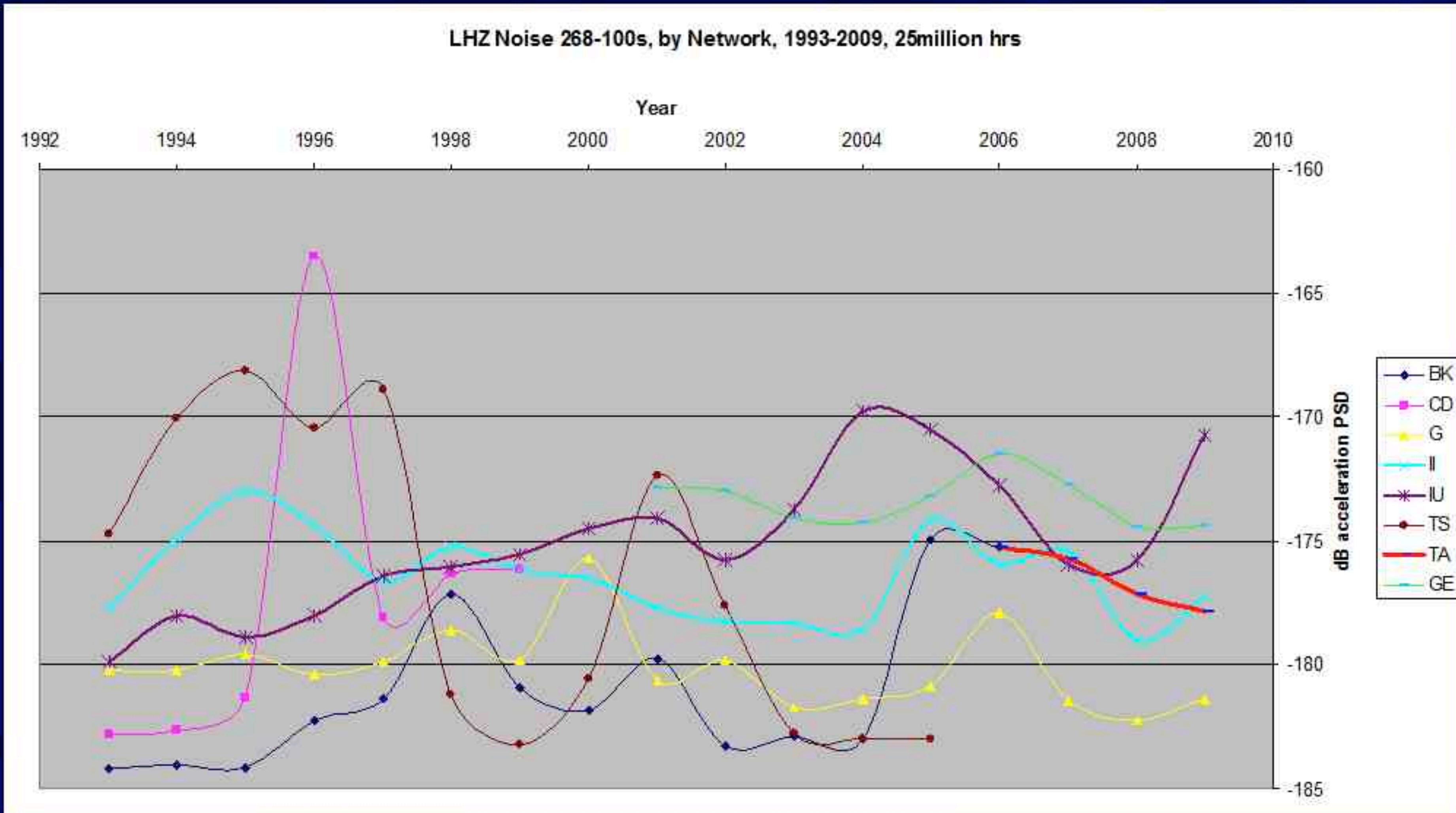
month stack (1993-2009)

USArray TA Oct 2009

TA weighted LHZ noise 200601-200909 (9.2 million hrs) vs. location



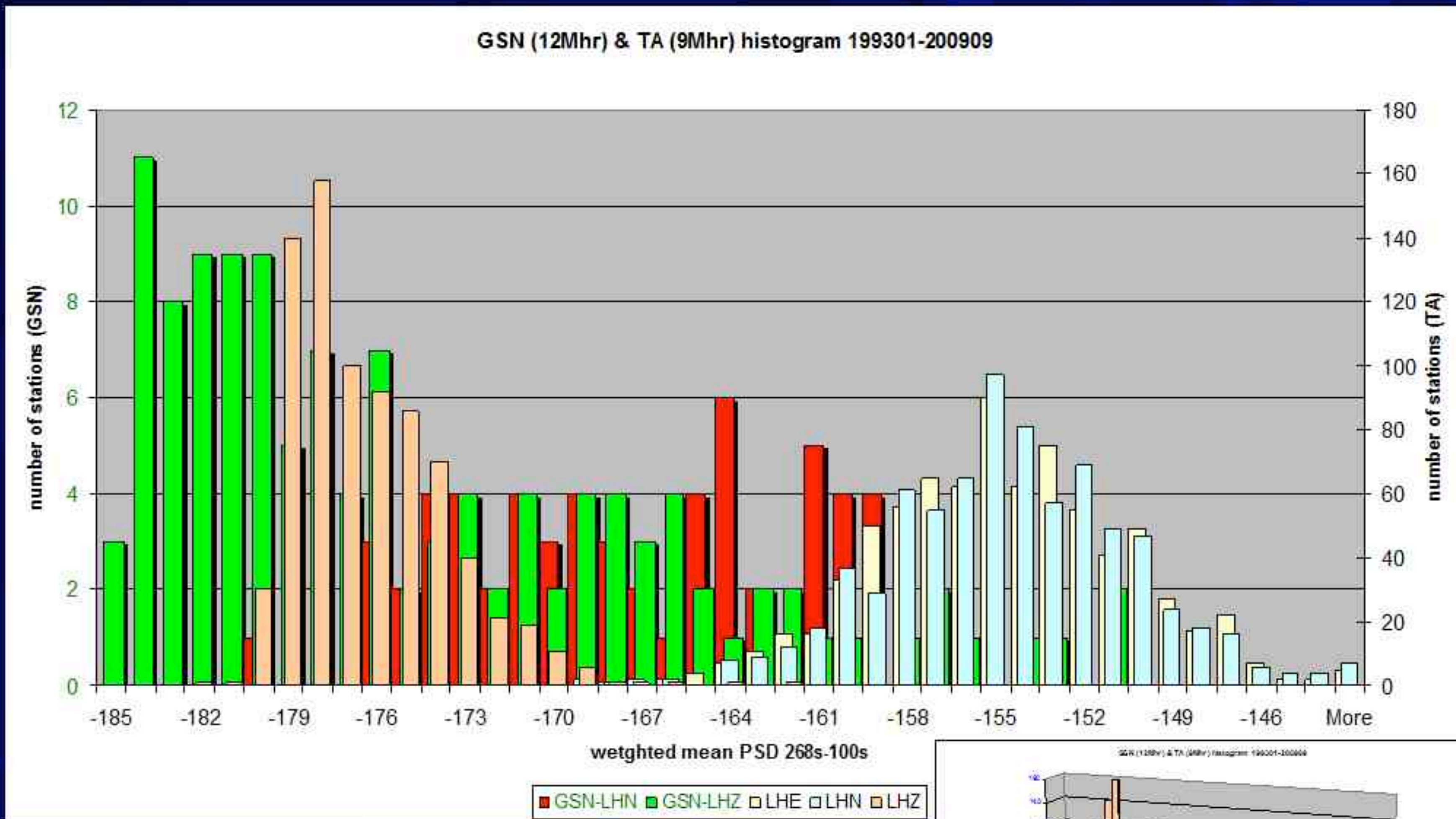

LHZ Network weighted mean noise 268-100s 1993-2009, 28.5 million hrs
dB
-165
-170
-175
-180
-185
area represents number of hours observed
IC
CU
G
GT
CD
TA
II
BK
IU
MN
GE
TS
CN
US
XA
G-10
IU-10
II-10
GE-10
IC-10

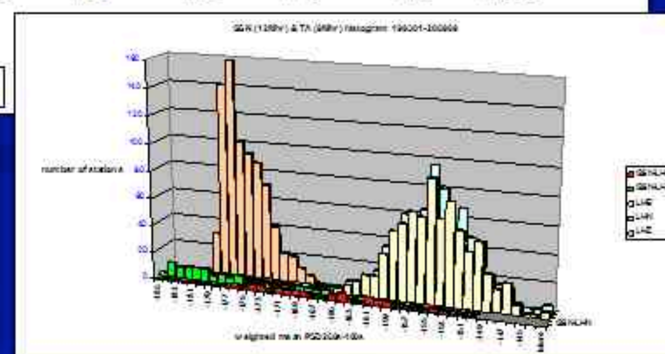


LHZ Noise 268-100s, by Network, 1993-2009, 25million hrs
Year
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
-160
-165
-170
-175
-180
-185
dB acceleration PSD
BK
CD
G
II
IU
TS
TA
GE

Horizontal Noise, by network

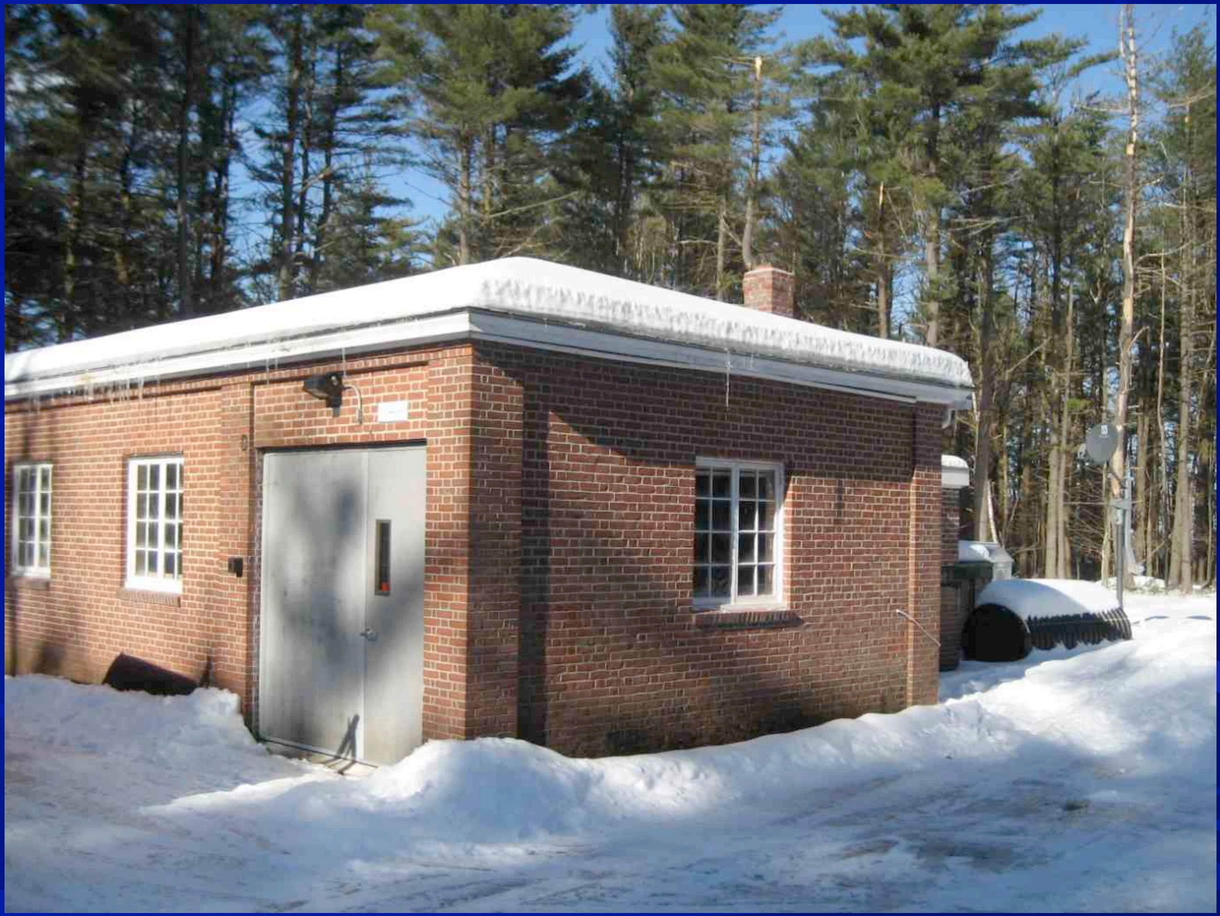
(month stack 1993-2009)


GSN (12Mhr) & TA (9Mhr) histogram 199301-200909
number of stations (GSN)
number of stations (TA)
wetghted mean PSD 268s-100s
GSN-LHN
GSN-LHZ
LHE
LHN
LHZ
More

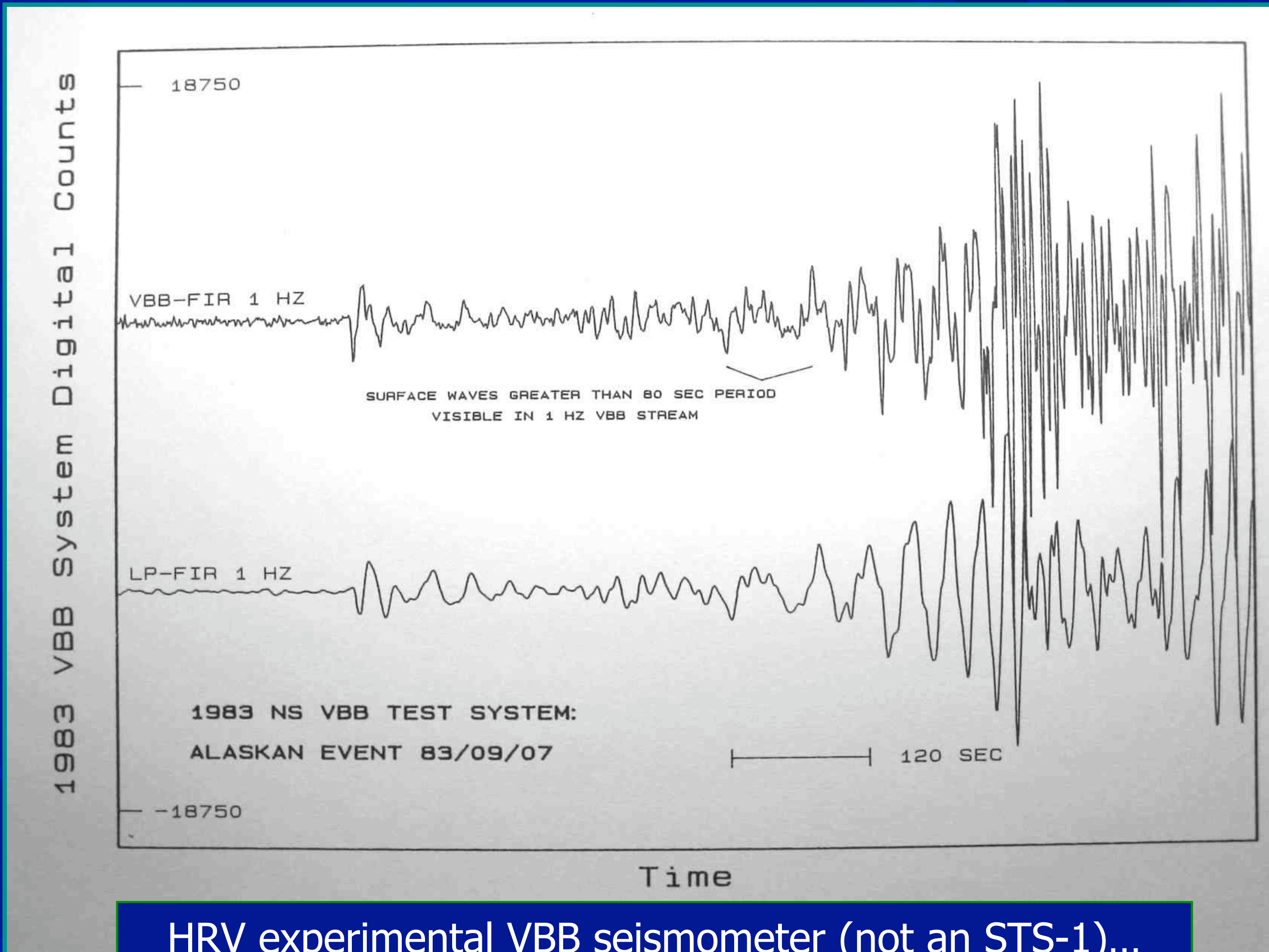


Pressure

Harvard University HRV GSN station and development facility Adam M. Dziewonski Observatory



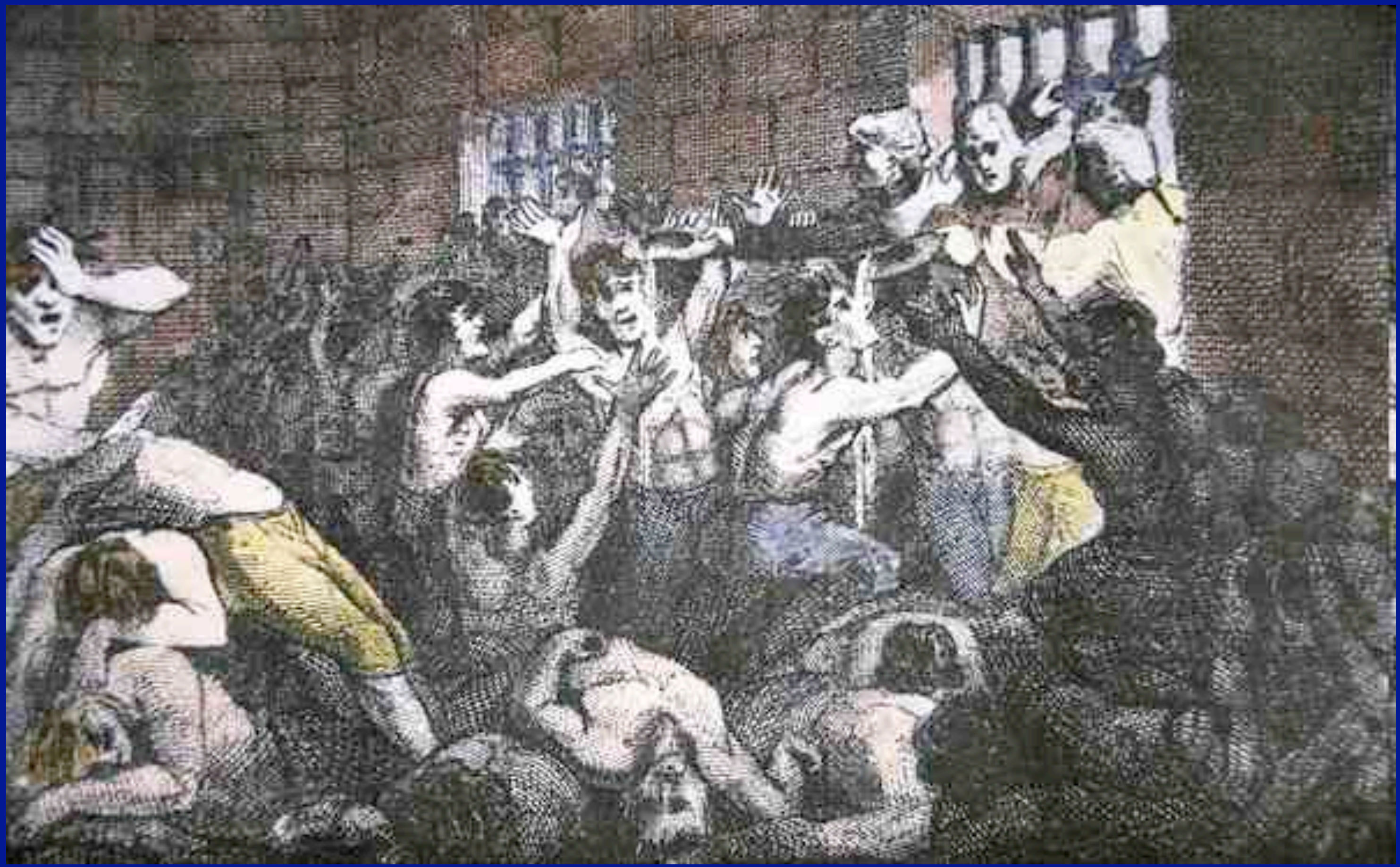
World's first digital VBB seismogram



HRV experimental VBB seismometer (not an STS-1)…

…this was revolutionary stuff!

former HRV vault - site visit



HRV GSN station and development facility

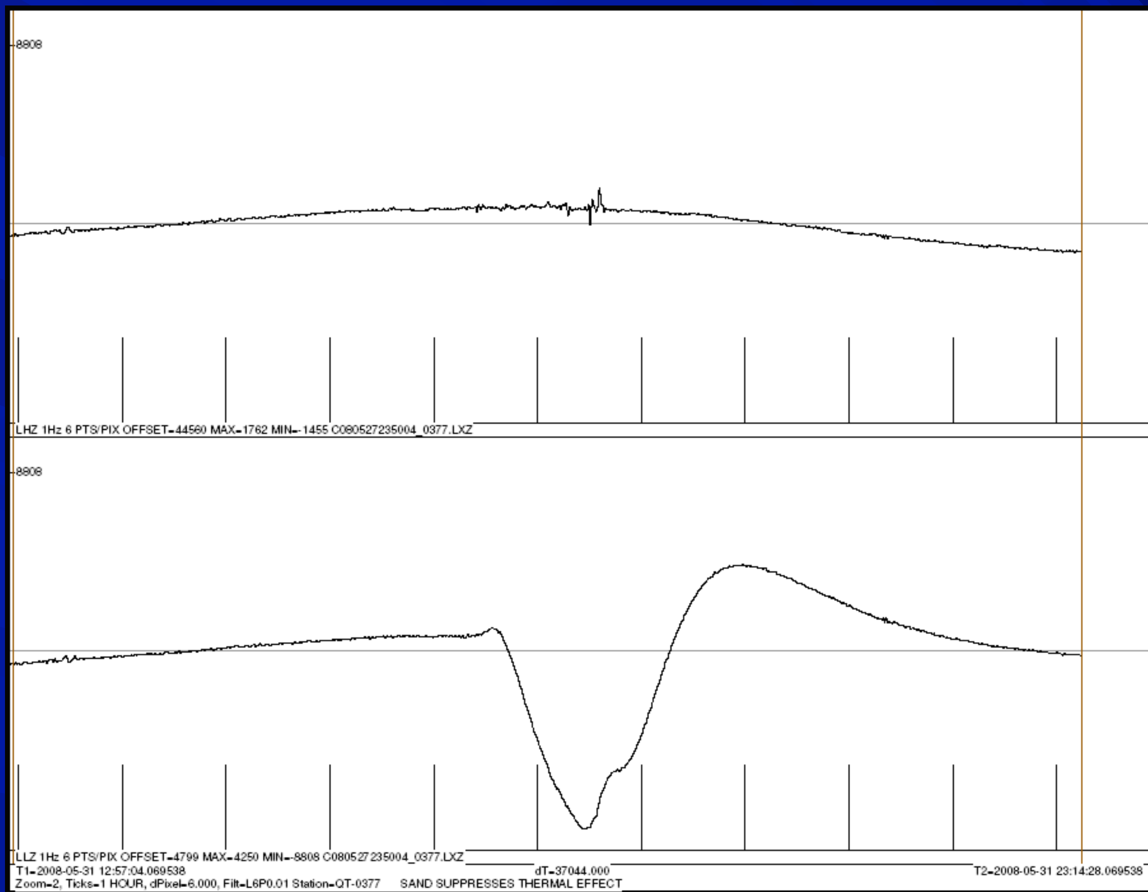
Major Effects on low-frequency vertical instruments:

Thermal, Thermal, Thermal

Pressure

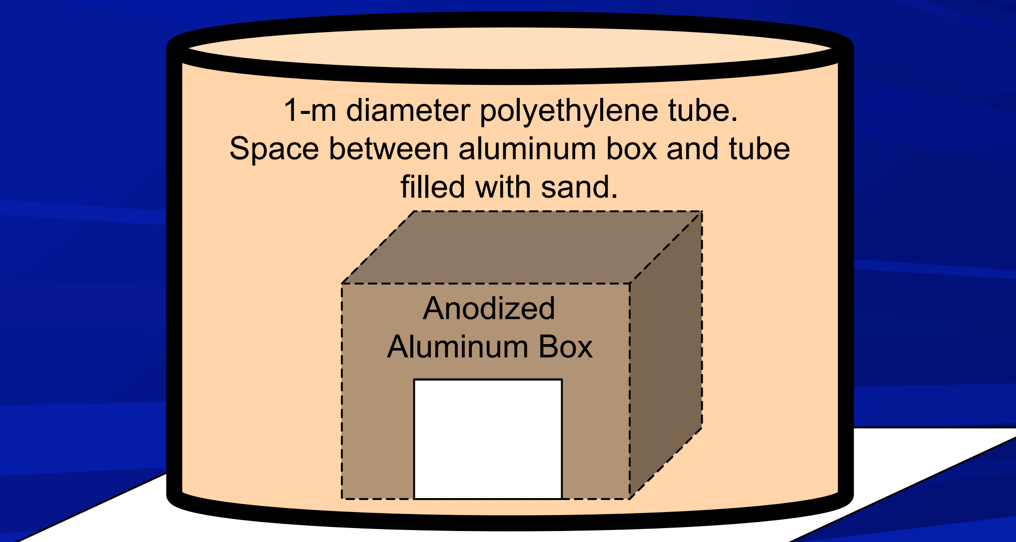
- gravitation of atmosphere
- deformation of surface
- deformation of instrument housing
- adiabatic temperature changes
- buoyancy

Thermal Time Constant

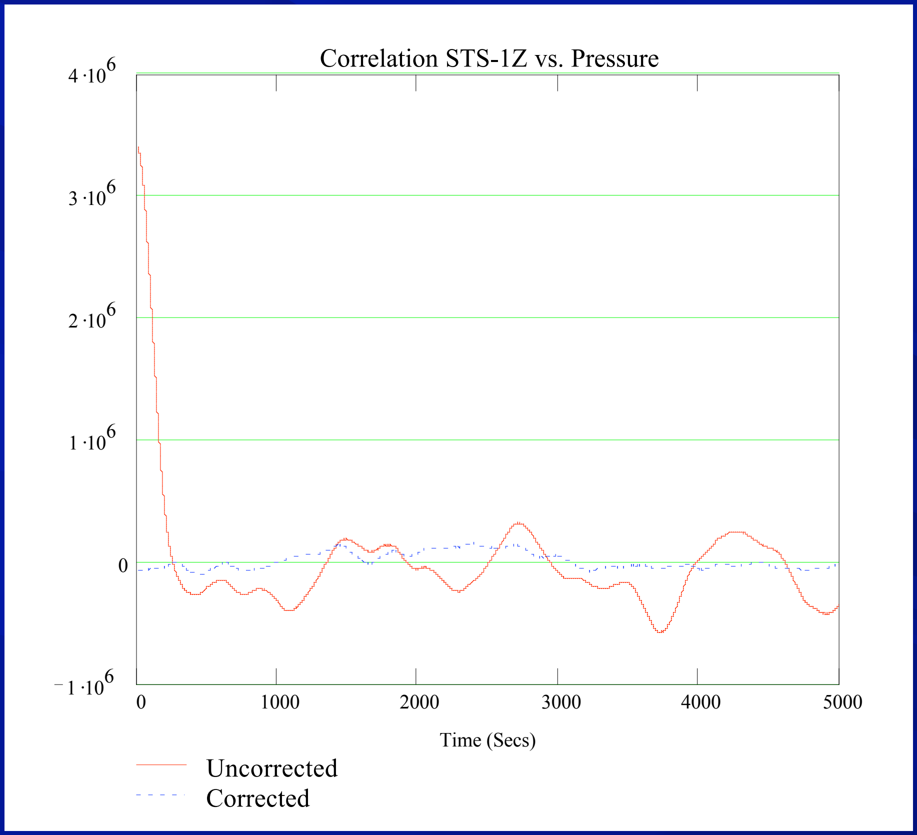


With this isolation, previously large thermal disturbances such as caused by opening the vault door are not visible in the very long period records. The figure below shows the effect of a similar installation on an STS-2. In the top panel, the low-frequency data from an STS-2 installed inside a similar 1-m sand-filled tube is shown. On the bottom panel, an STS-2 is installed in a more typical manner inside a Styrofoam box with 3-in thick walls. The tick marks are hours. The thermal effect of walking in the vault room and working for about 2 hours in the vault, although not directly on these seismometers, is clearly seen as a mainly thermally-induced pulse on the no-sand STS-2. This behavior seen on STS-2's suggested that an STS-1 may also benefit from the thermal mass of a large volume of sand isolating the sensor from ambient temperature changes.

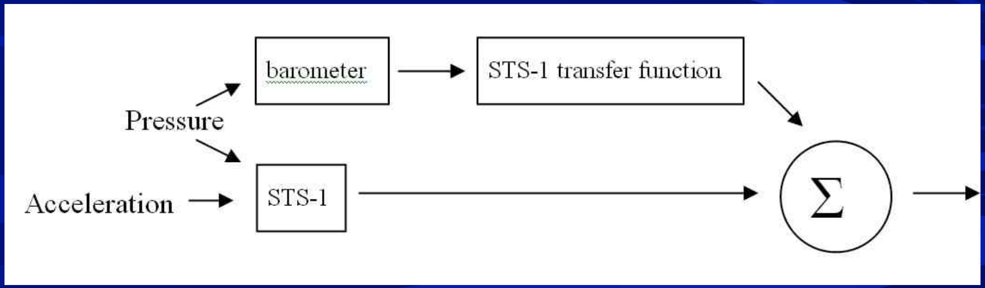
Thermal Mass



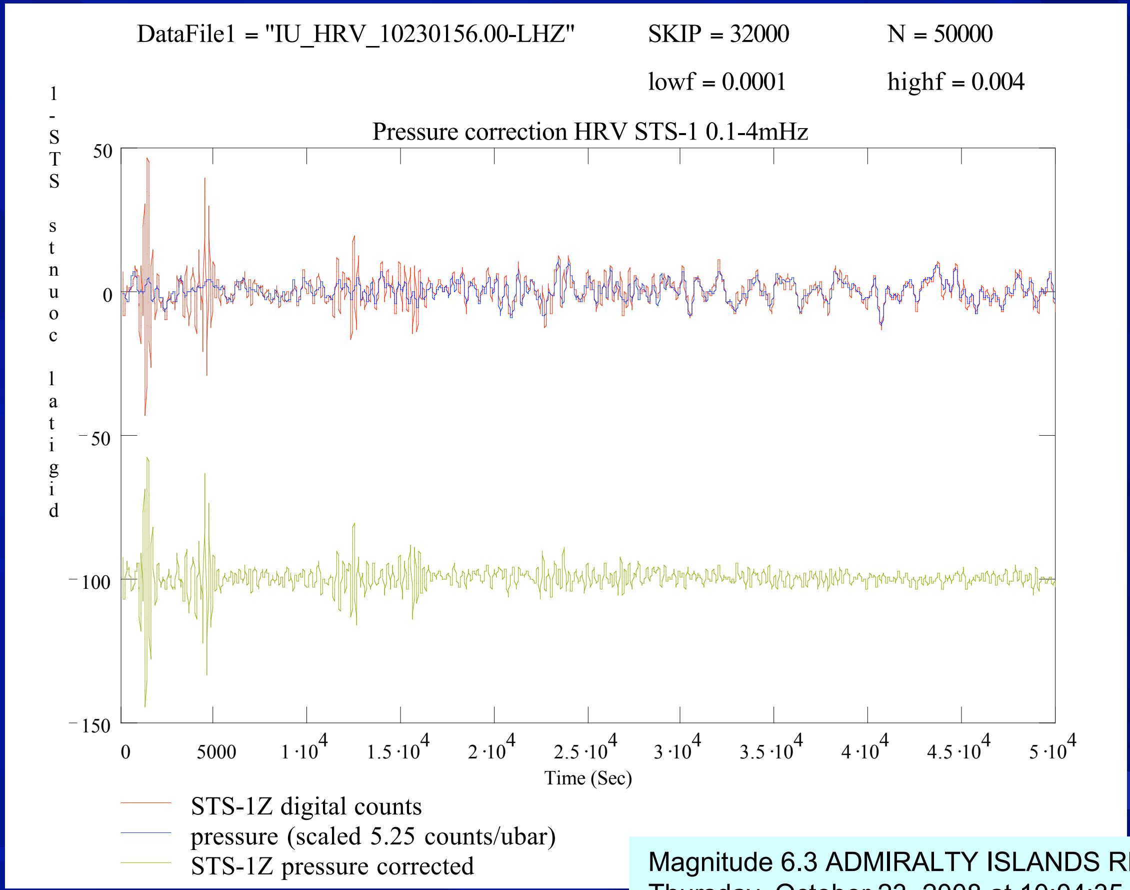
Vertical Correlation w/ Pressure seen on STS-1



These results are consistent with results, e.g. shown by Zürn and E. Wielandt, *Geophys. J. Int.*,**142**, 2006 for correction of the predominant air-mass gravitational effect. The present results perhaps show greater improvement in the corrected data.



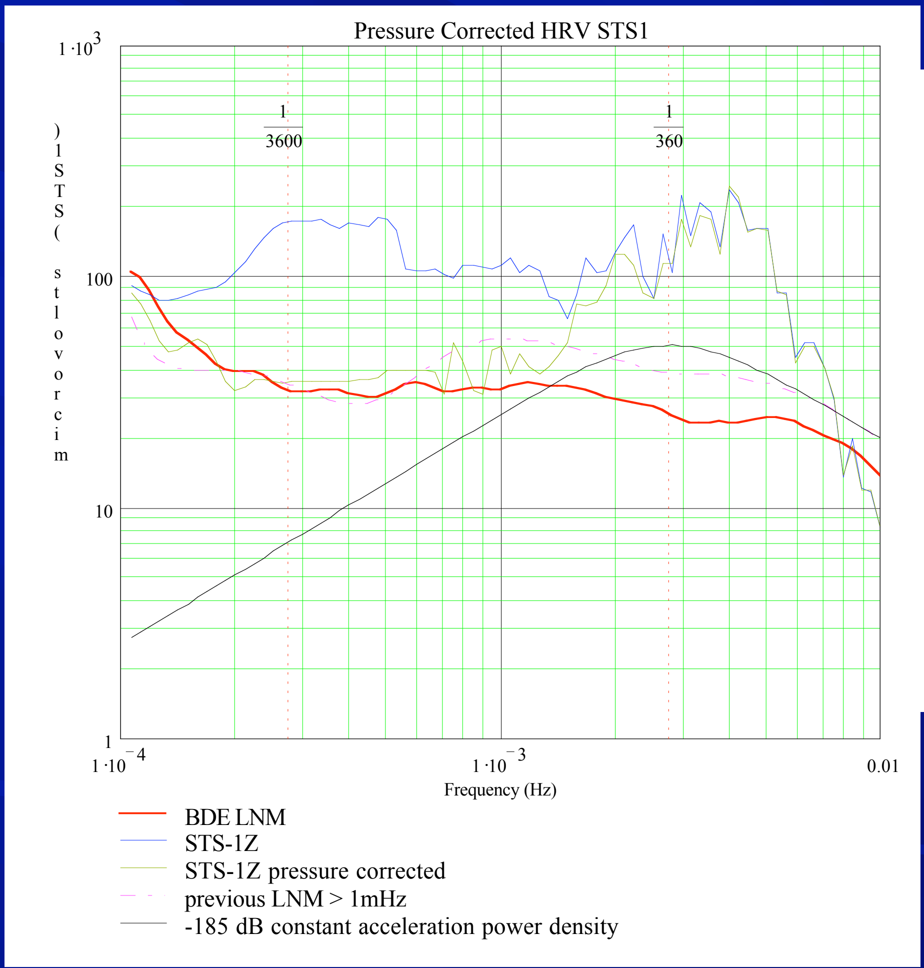
Pressure Corrected

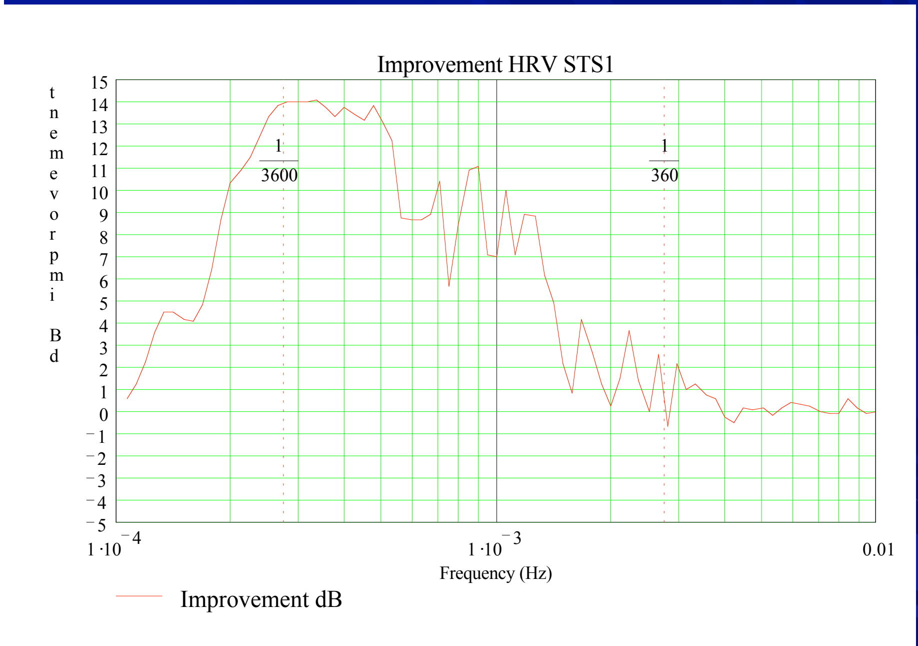


Magnitude 6.3 ADMIRALTY ISLANDS REGION, P.N.G.
Thursday, October 23, 2008 at 10:04:35 UTC

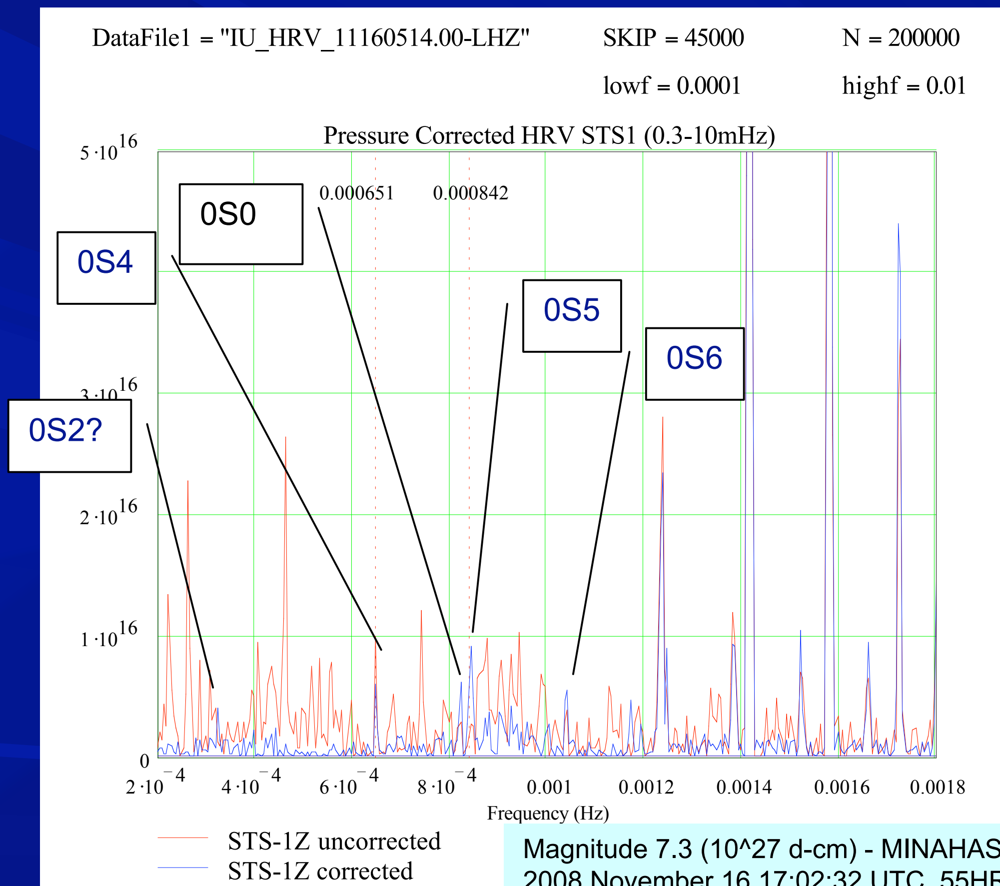
The vertical scale is digital counts on a Q330 24-bit digitizer (~1.1 nm/count in the flat-velocity response region of the sensor from 0.3mHz to the limit of the bandpass filter in this example, 33 mHz). The pressure is scaled at 5.25 counts/μbar, equivalent to 5.25 nm/s^2/hPa. The pressure data are corrected with a recursive digital filter, an approach that may be adapted to continuous real-time correction in a data acquisition system.

Pressure Corrected STS-1 HRV GSN station





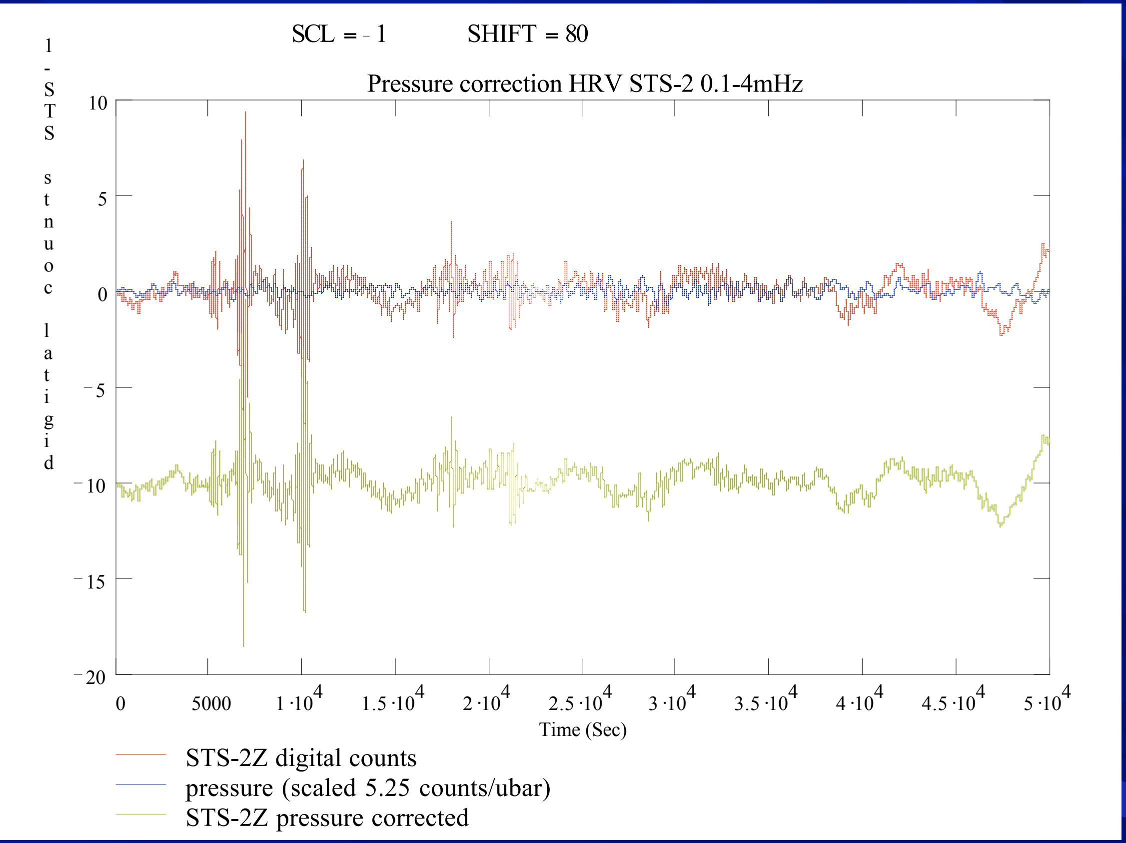
Pressure Corrected STS-1 HRV



Magnitude 7.3 (10^27 d-cm) - MINAHASA, SULAWESI, INDONESIA
2008 November 16 17:02:32 UTC. 55HRS DATA

text

STS-2 vertical



The method effective on the highly-isolated STS-1 vertical was applied to a quiet STS-2 operating without external pressure shielding. This STS-2 is installed in a typical way, using a styrofoam box placed on the pier in the HRV vault. The same event is shown in the STS-1 data above.

The simple zero-phase correlation with pressure is now absent. A correlation is seen with an 80s phase shift, and negative sign. Further low-frequency correlation persists however. There are likely thermal, possible adiabatic, effects and direct distortion of the STS-2 pressure case. Effective usage of the pressure data therefore requires external physical isolation of thermal and pressure effects on the STS-2.

Pressure Instruments

what do you need to do this at home?

VTI SCP1000 MEMS

Few ubar resolution below 4mHz. Size ~ 5mm x 5mm

Bare sensor cost ~ $10, Cost ~$100 with a pressure port

Setra 270 Precision Analog

~ 1 to a few ubar resolution up to some Hz . Size ~ 2.5in diameter

Cost <$1000 - convenient if analog sampling already available

Quanterra "Environmental Processor"

- Digital MEMS barometer
- Phase lock to Q330
- Sampling of Analog barometers
- Being deployed in TA

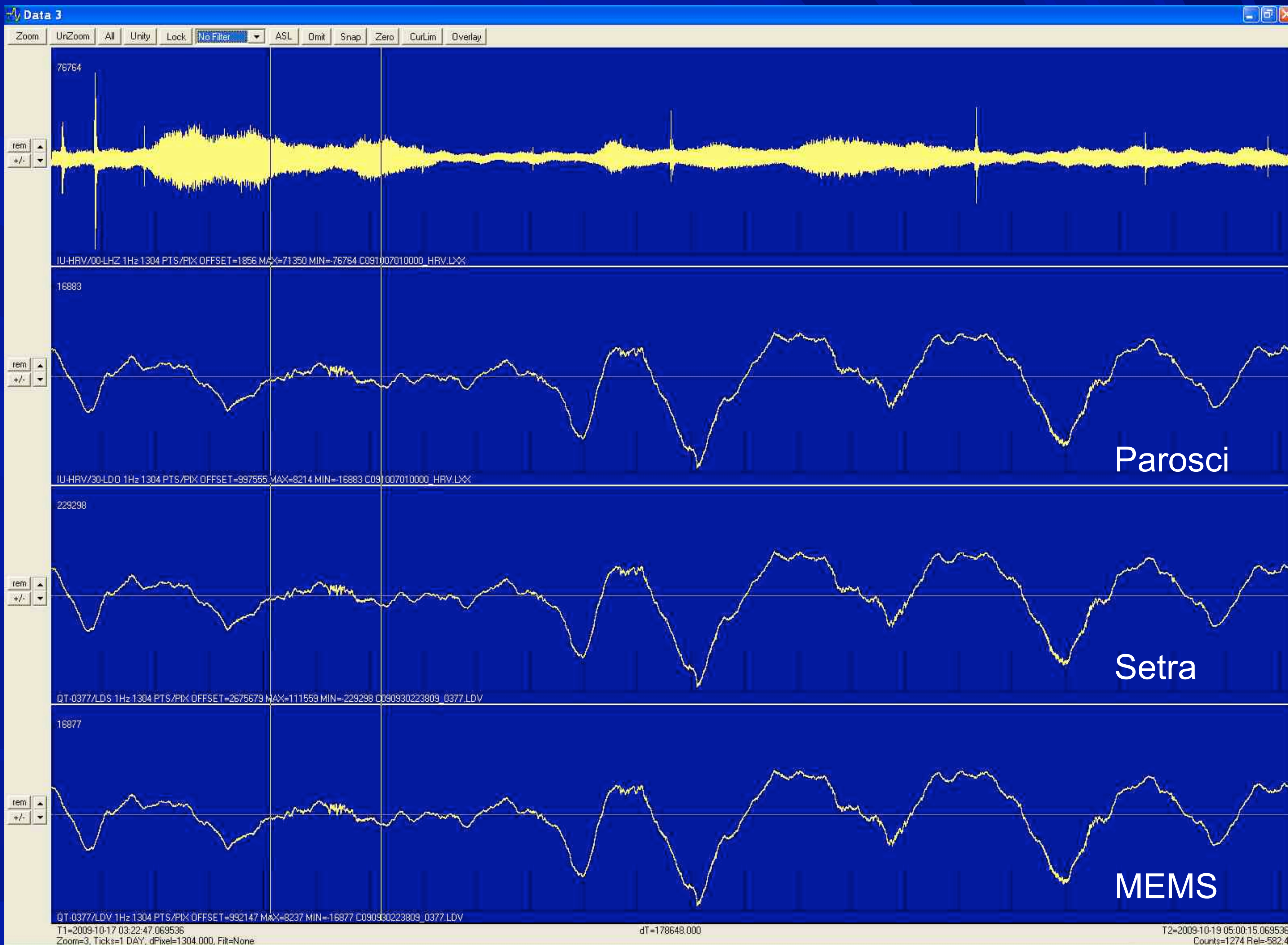
MEMS barometer with port

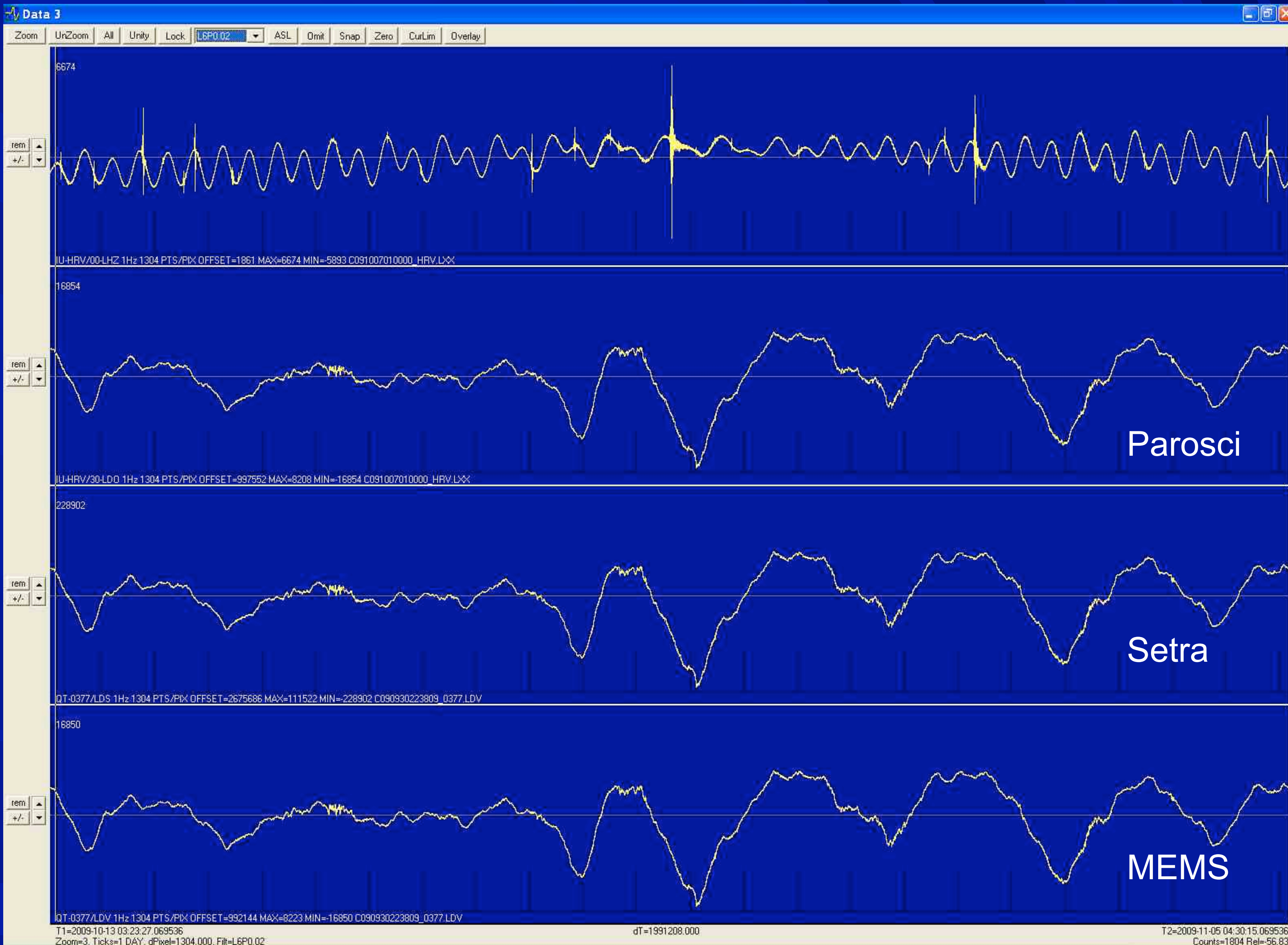
Paroscientific

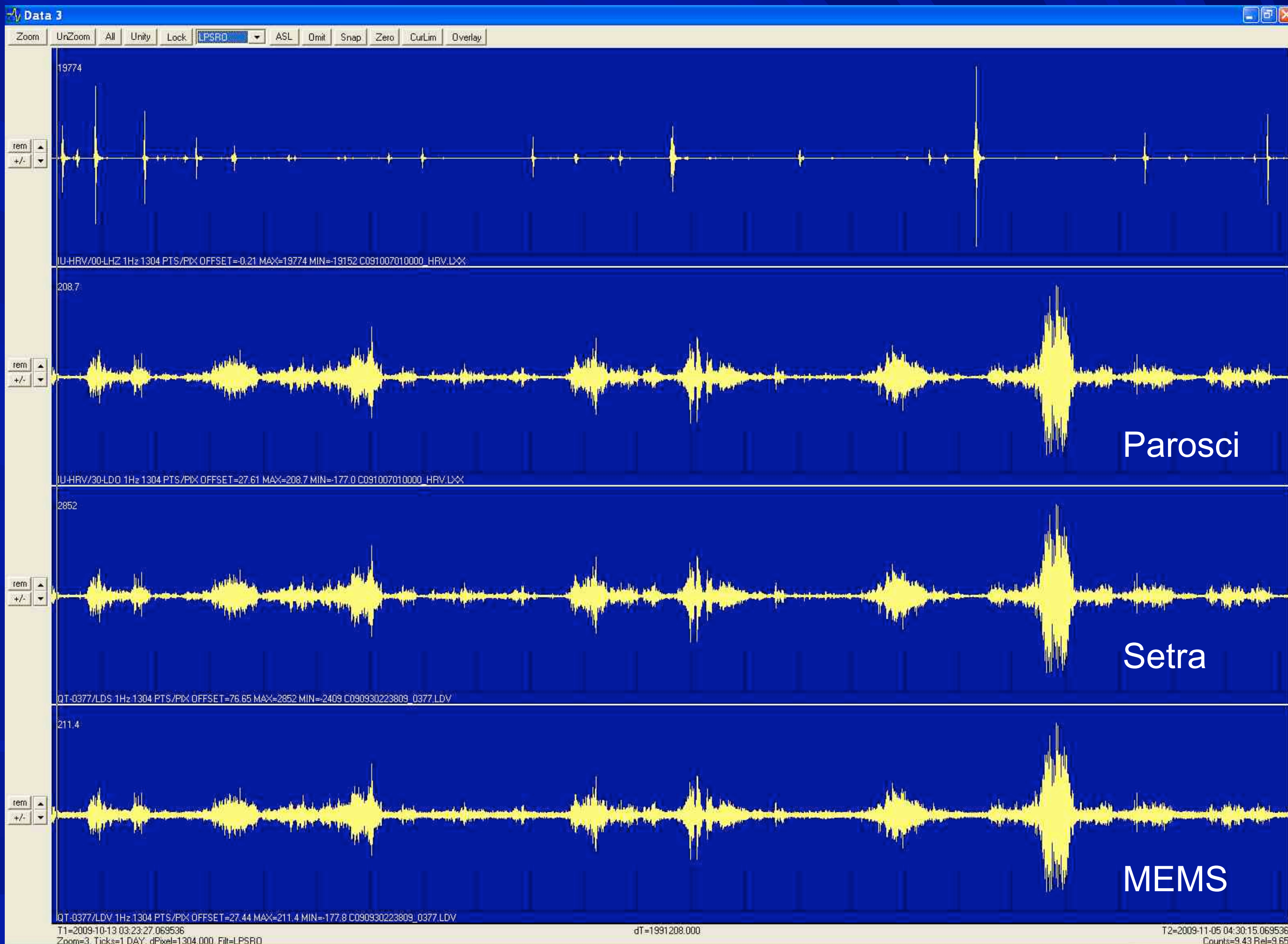
6000, 1000 & 9000 Series Transmitters*

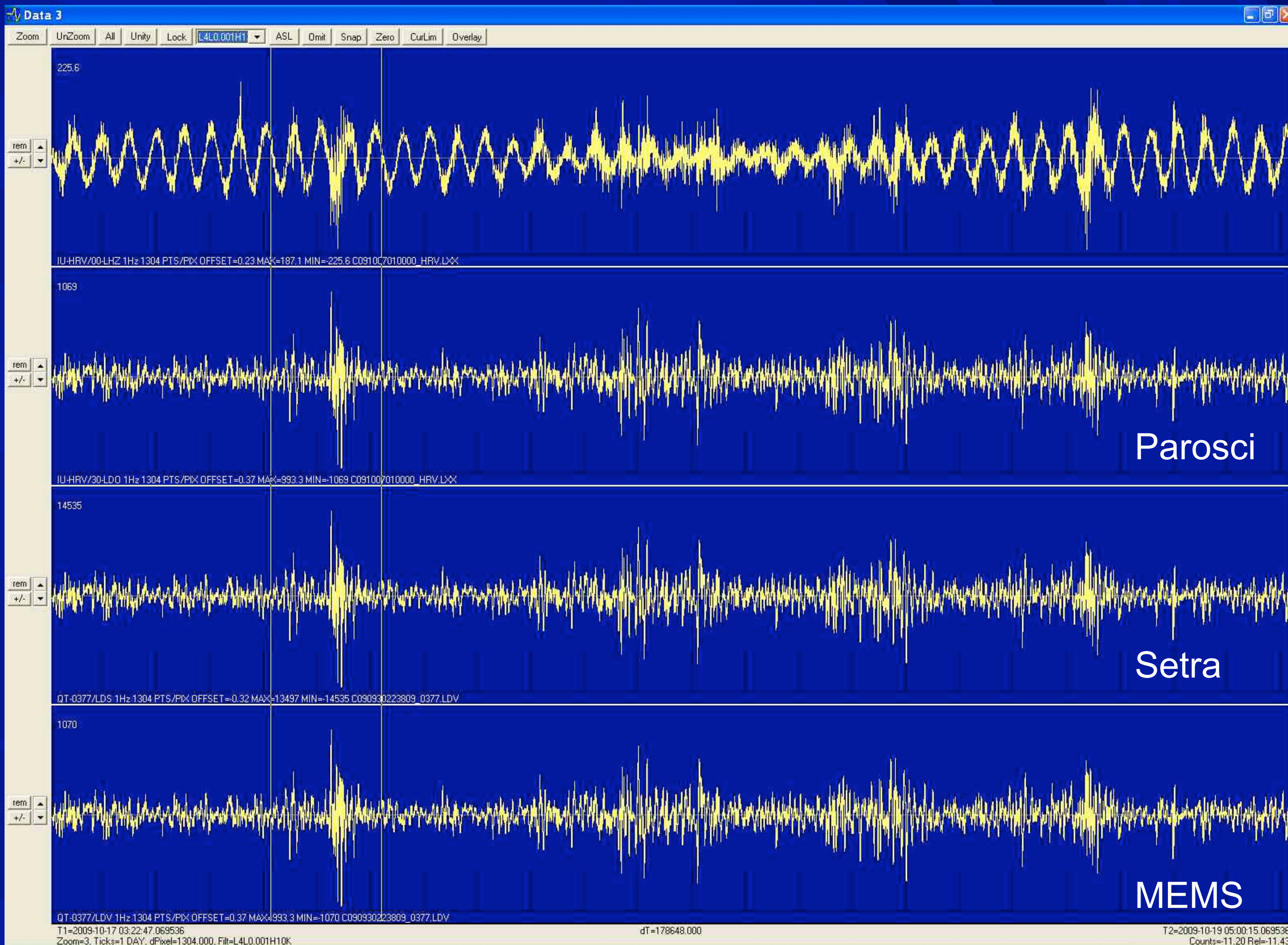
< 1 ubar resolution up to ~ 0.5 Hz . Size ~ 2.5in cube

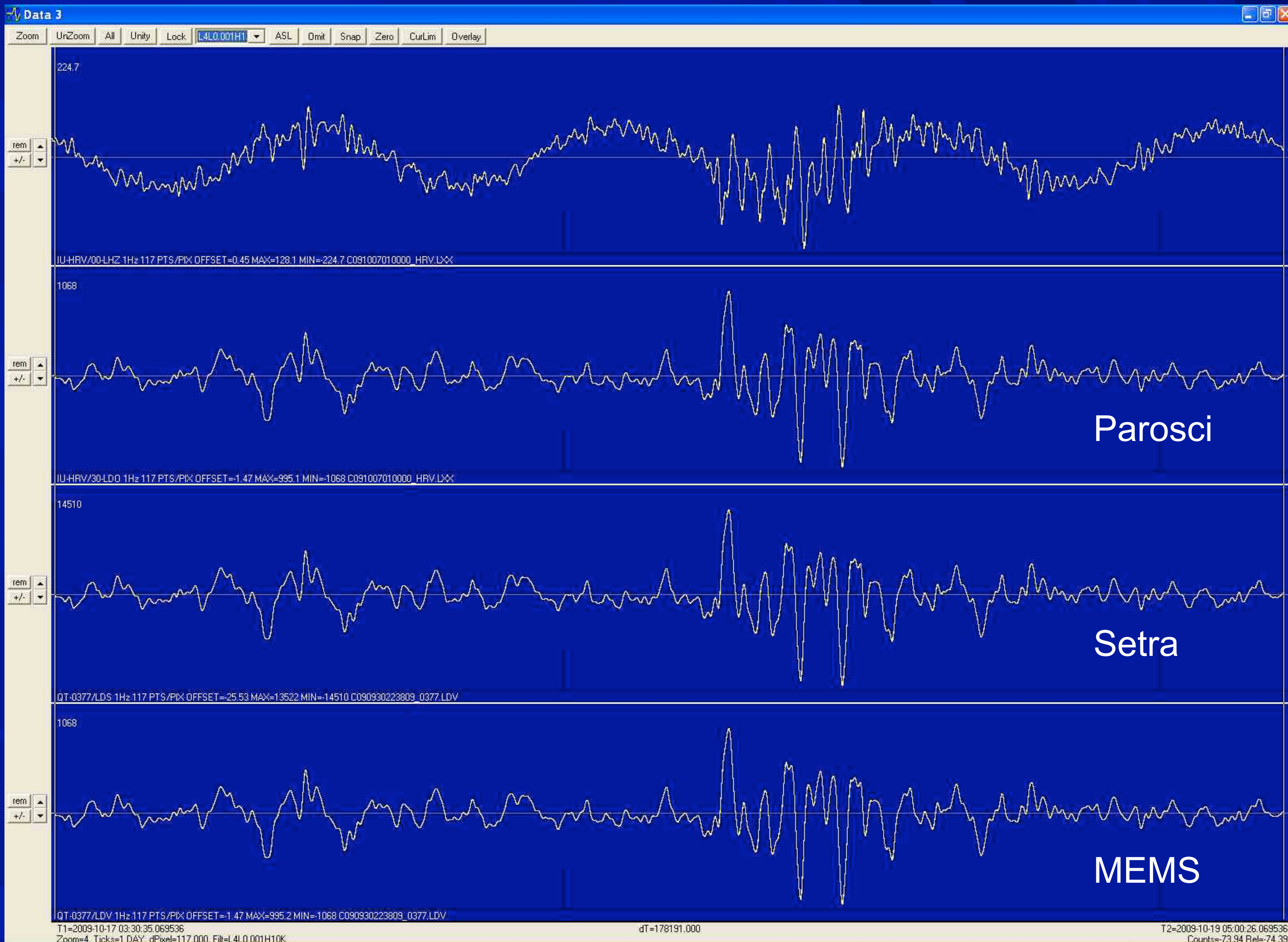
Cost ~$5000 - digital sampling non-trivial to time align, resolution diminishes as sample interval decreases


Data 3
Zoom
UnZoom
All
Unity
Lock
No Filter
ASL
Omit
Snap
Zero
CurLim
Overlay
76764
IU-HRV/00-LHZ 1Hz 1304 PTS/PIX OFFSET=1856 MAX=71350 MIN=-76764 C091007010000_HRV.LXX
16883
IU-HRV/30-LDO 1Hz 1304 PTS/PIX OFFSET=997555 MAX=8214 MIN=-16883 C091007010000_HRV.LXX
Parosci
229298
QT-0377/LDS 1Hz 1304 PTS/PIX OFFSET=2675679 MAX=111559 MIN=-229298 C090930223809_0377.LDV
Setra
16877
QT-0377/LDV 1Hz 1304 PTS/PIX OFFSET=992147 MAX=8237 MIN=-16877 C090930223809_0377.LDV
MEMS
T1=2009-10-17 03:22:47.069536
Zoom=3, Ticks=1 DAY, dPixel=1304.000, Filt=None
dT=178648.000
T2=2009-10-19 05:00:15.069536
Counts=1274 Rel=-582.4


Data 3
Zoom UnZoom All Unity Lock L6P0.02 ASL Omit Snap Zero CurLim Overlay
6674
IU-HRV/00-LHZ 1Hz 1304 PTS/PIX OFFSET=1861 MAX=6674 MIN=-5893 C091007010000_HRV.LXX
16854
IU-HRV/30-LDO 1Hz 1304 PTS/PIX OFFSET=997552 MAX=8208 MIN=-16854 C091007010000_HRV.LXX
Parosci
228902
QT-0377/LDS 1Hz 1304 PTS/PIX OFFSET=2675686 MAX=111522 MIN=-228902 C090930223809_0377.LDV
Setra
16850
QT-0377/LDV 1Hz 1304 PTS/PIX OFFSET=992144 MAX=8223 MIN=-16850 C090930223809_0377.LDV
MEMS
T1=2009-10-13 03:23:27.069536
Zoom=3, Ticks=1 DAY, dPixel=1304.000, Filt=L6P0.02
dT=1991208.000
T2=2009-11-05 04:30:15.069536
Counts=1804 Rel=-56.83

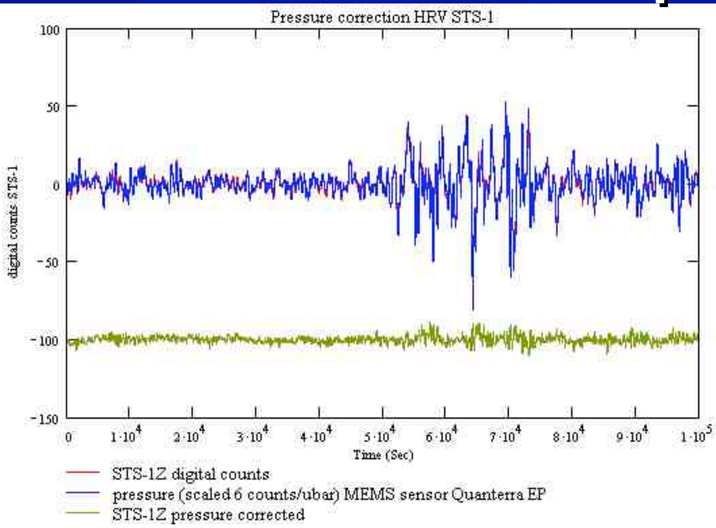

Data 3
Zoom
UnZoom
All
Unity
Lock
LPSRO
ASL
Omit
Snap
Zero
CurLim
Overlay
19774
IU-HRV/00-LHZ 1Hz 1304 PTS/PIX OFFSET=-0.21 MAX=19774 MIN=-19152 C091007010000_HRV.LXX
208.7
Parosci
IU-HRV/30-LDO 1Hz 1304 PTS/PIX OFFSET=27.61 MAX=208.7 MIN=-177.0 C091007010000_HRV.LXX
2852
Setra
QT-0377/LDS 1Hz 1304 PTS/PIX OFFSET=76.65 MAX=2852 MIN=-2409 C090930223809_0377.LDV
211.4
MEMS
QT-0377/LDV 1Hz 1304 PTS/PIX OFFSET=27.44 MAX=211.4 MIN=-177.8 C090930223809_0377.LDV
T1=2009-10-13 03:23:27.069536
Zoom=3, Ticks=1 DAY, dPixel=1304.000, Filt=LPSRO
dT=1991208.000
T2=2009-11-05 04:30:15.069536
Counts=9.43 Rel=9.65


Data 3
Zoom
UnZoom
All
Unity
Lock
L4L0.001H1
ASL
Omit
Snap
Zero
CurLim
Overlay
225.6
IU-HRV/00-LHZ 1Hz 1304 PTS/PIX OFFSET=0.23 MAX=187.1 MIN=-225.6 C0910C7010000_HRV.LXX
1069
Parosci
IU-HRV/30-LDO 1Hz 1304 PTS/PIX OFFSET=0.37 MAX=993.3 MIN=-1069 C091007010000_HRV.LXX
14535
Setra
QT-0377/LDS 1Hz 1304 PTS/PIX OFFSET=-0.32 MAX=13497 MIN=-14535 C090930223809_0377.LDV
1070
MEMS
QT-0377/LDV 1Hz 1304 PTS/PIX OFFSET=0.37 MAX=993.3 MIN=-1070 C090930223809_0377.LDV
T1=2009-10-17 03:22:47.069536
Zoom=3, Ticks=1 DAY, dPixel=1304.000, Filt=L4L0.001H10K
dT=178648.000
T2=2009-10-19 05:00:15.069536
Counts=-11.20 Rel=-11.43


Data 3
Zoom
UnZoom
All
Unity
Lock
ASL
Omit
Snap
Zero
CurLim
Overlay
224.7
IU-HRV/00-LHZ 1Hz 117 PTS/PIX OFFSET=0.45 MAX=128.1 MIN=-224.7 C091007010000_HRV.LXX
1068
IU-HRV/30-LDO 1Hz 117 PTS/PIX OFFSET=-1.47 MAX=995.1 MIN=-1068 C091007010000_HRV.LXX
Parosci
14510
QT-0377/LDS 1Hz 117 PTS/PIX OFFSET=-25.53 MAX=13522 MIN=-14510 C090930223809_0377.LDV
Setra
1068
QT-0377/LDV 1Hz 117 PTS/PIX OFFSET=-1.47 MAX=995.2 MIN=-1068 C090930223809_0377.LDV
MEMS
T1=2009-10-17 03:30:35.069536
Zoom=4, Ticks=1 DAY, dPixel=117.000, Filt=L4L0.001H10K
dT=178191.000
T2=2009-10-19 05:00:26.069536
Counts=-73.94 Rel=-74.39

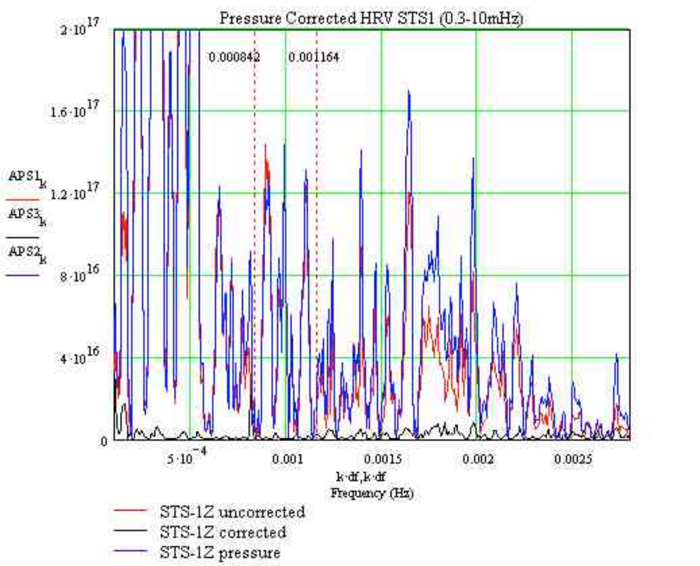
STS-1 pressure removal

10170330



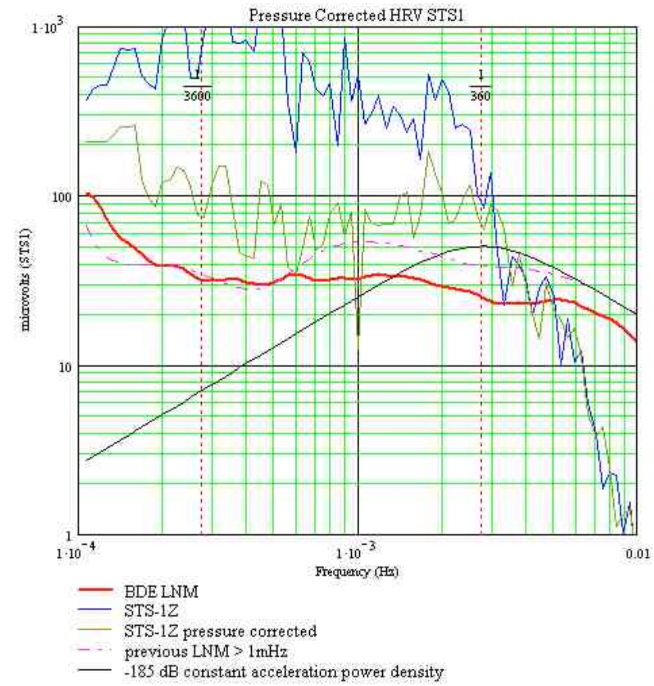
DataFile1 = "IU_HRV_10170330.00-LHZ" SKIP = 44000 N = 200000 Φ = 0

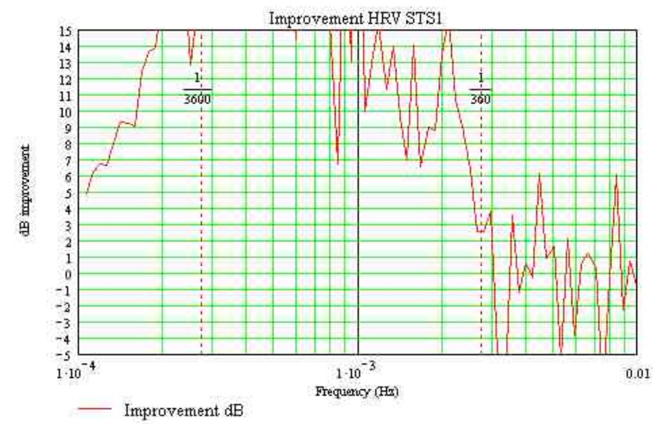
DataFile2 = "QT_0377_10170330.LDV" lowf = 0.0001 highf = 0.004



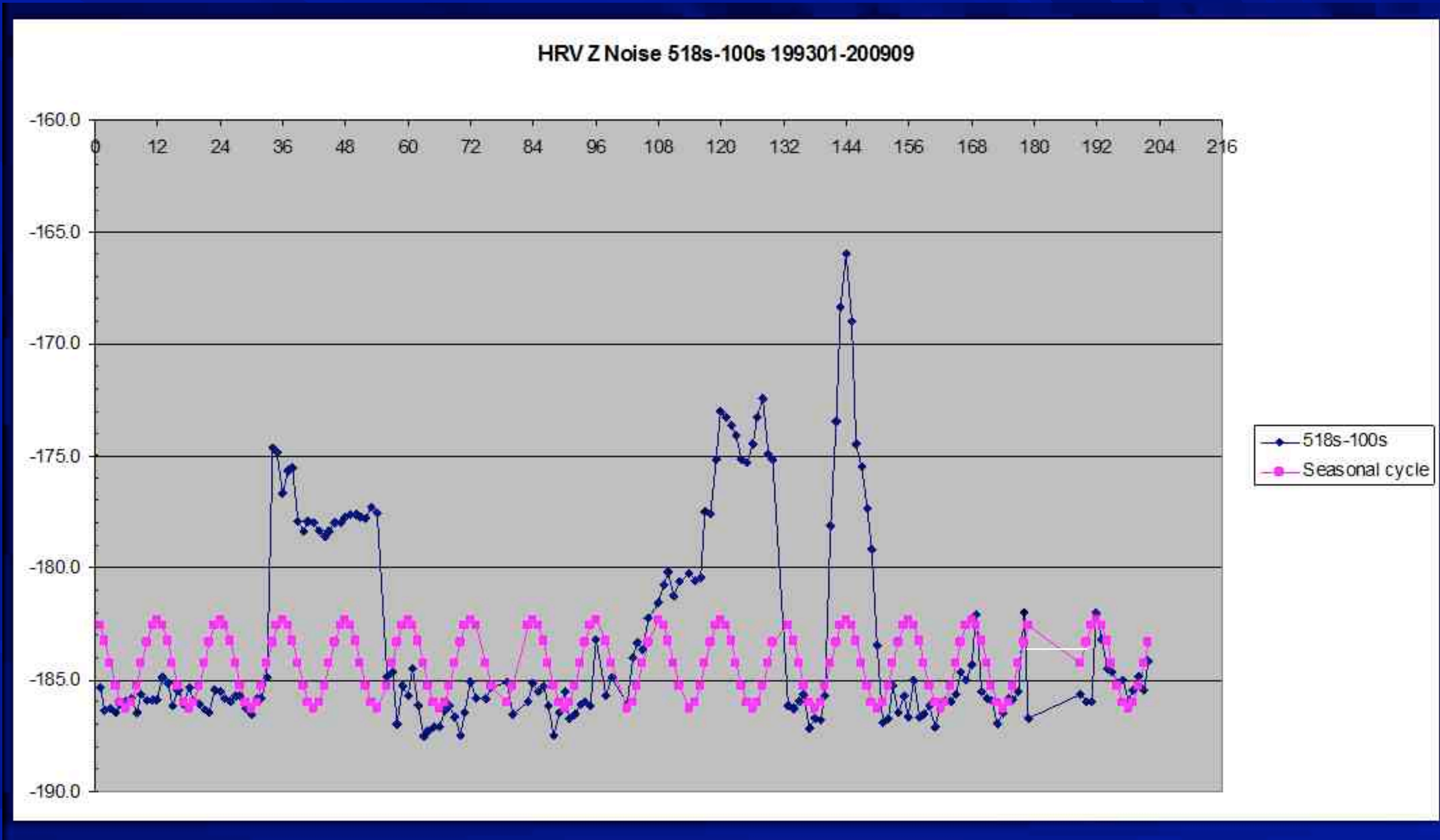
DataFile1 = "IU_HRV_10170330.00-LHZ" SKIP = 44000 N = 200000

lowf = 0.0001 highf = 0.004



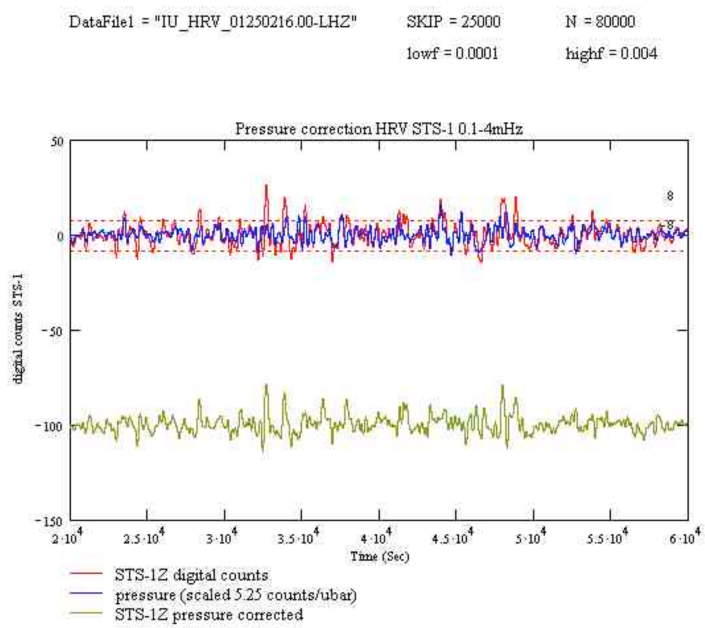


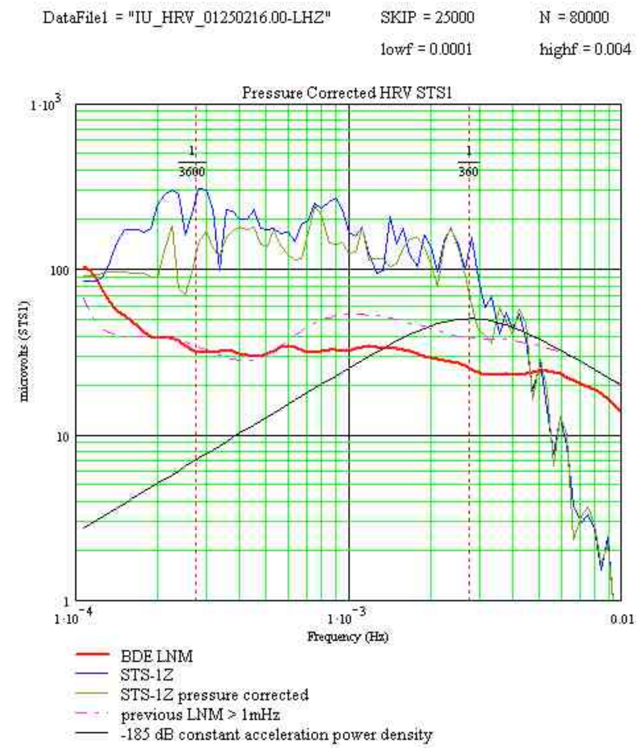
HRV performance 1993-present. “good” and “bad” intervals.
A number of stations show similar patterns

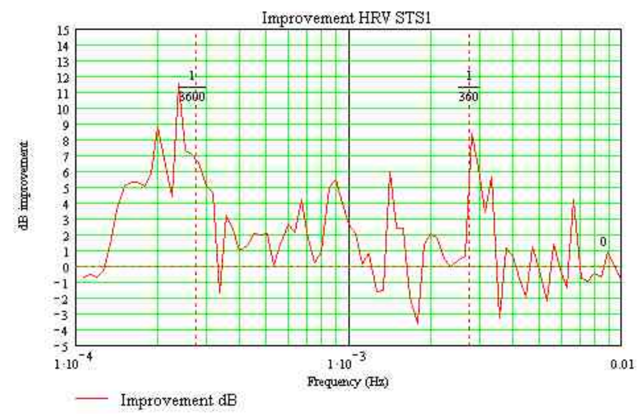


STS-1 winter chill down

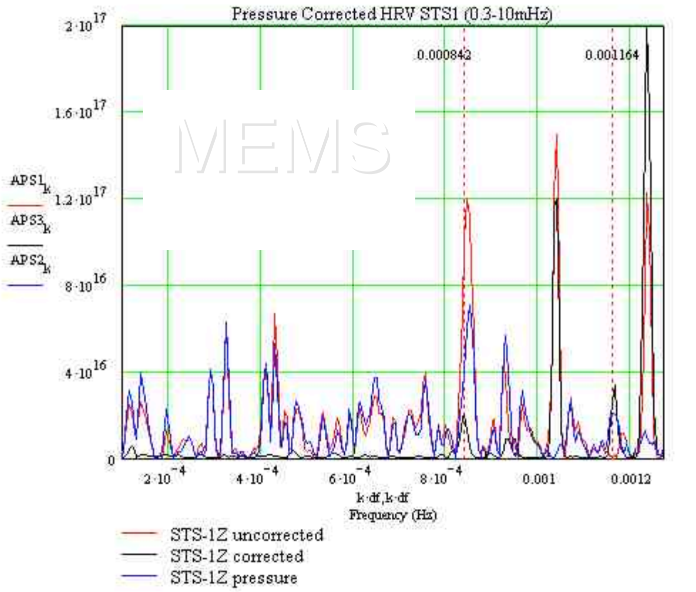
01250216





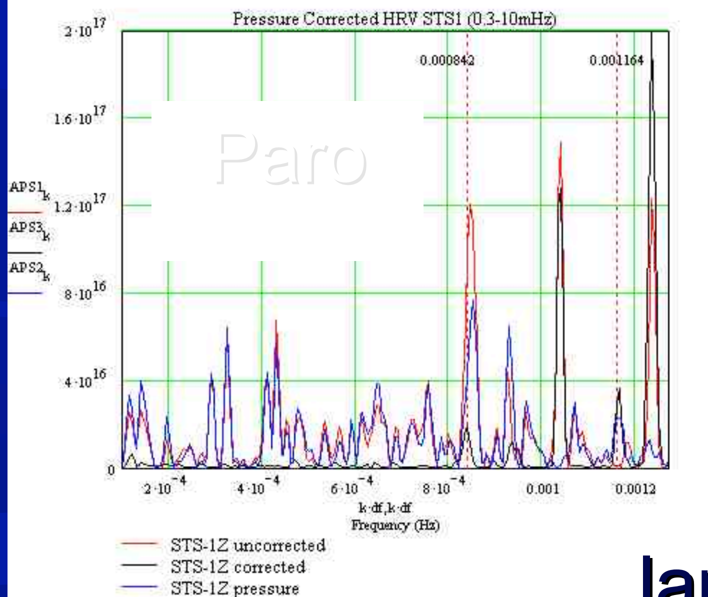


DataFile2 = "QT_0377_08100805.LDV" lowf = 0.0001 highf = 0.001818



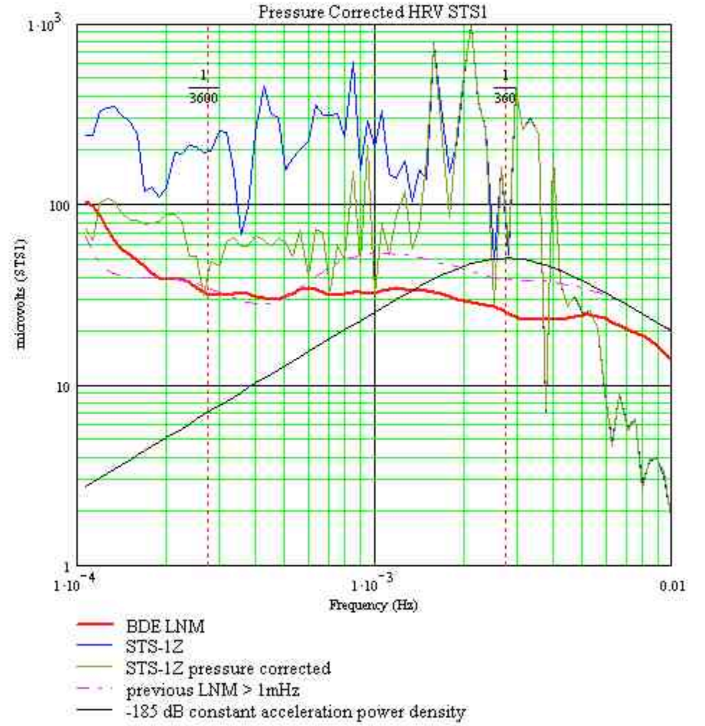
DataFile1 = "IU_HRV_08100803.00-LHZ" SKIP = 44000 N = 200000

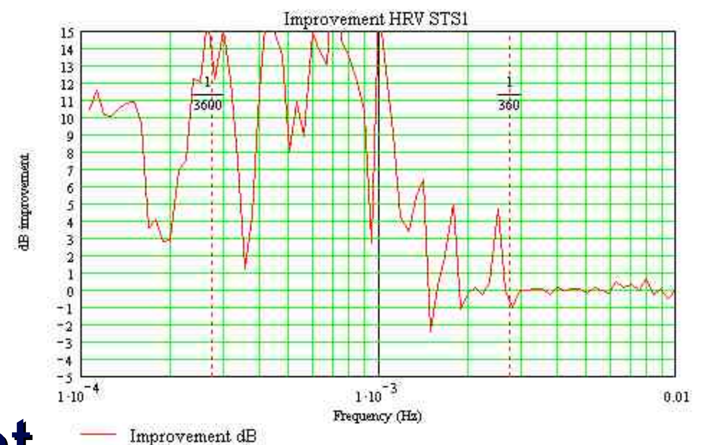
DataFile2 = "IU_HRV_08100803.30-LDO" lowf = 0.0001 highf = 0.001818



DataFile1 = "IU_HRV_08100803.00-LHZ" SKIP = 44000 N = 200000

lowf = 0.0001 highf = 0.001818



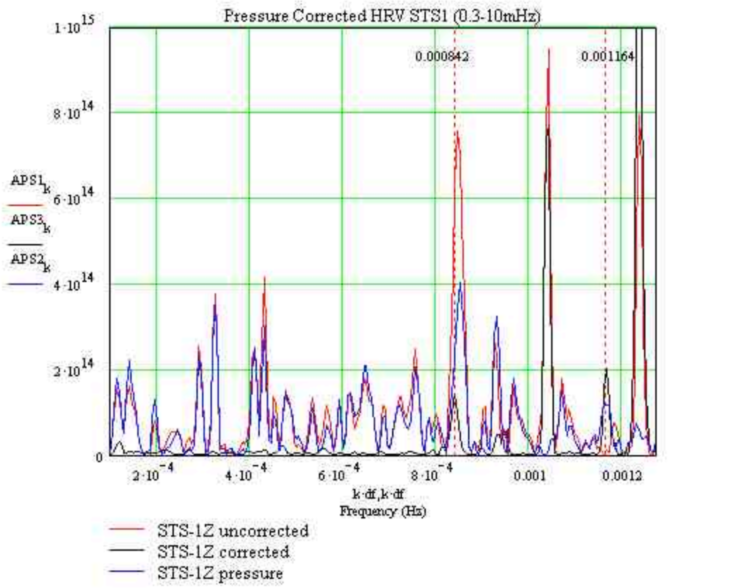


08100803

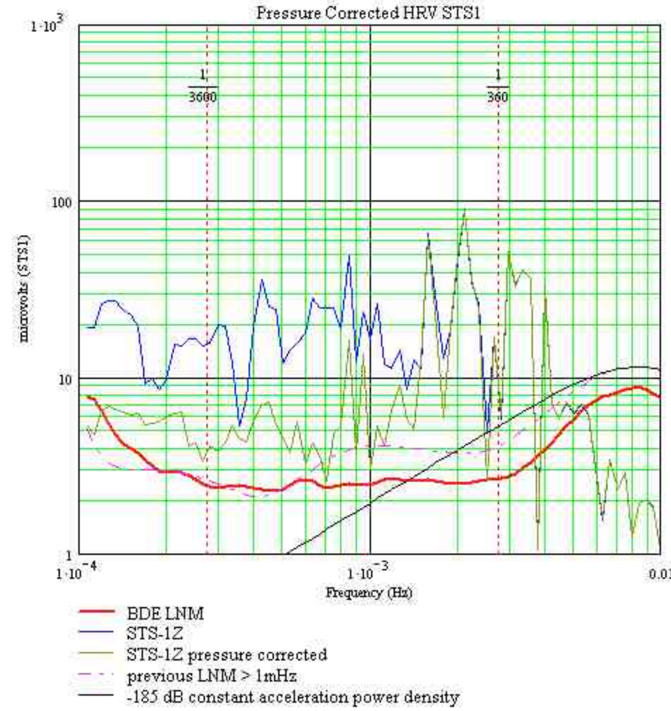
large event

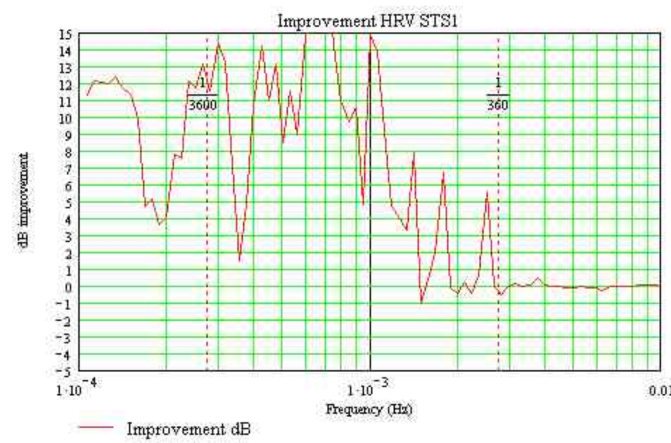
STS-1

DataFile1 = "IU_HRV_08100805.00-LHZ" SKIP = 44000 N = 200000 Φ = 24
DataFile2 = "QT_0377_08100805.LDV" lowf = 0.0001 highf = 0.001818



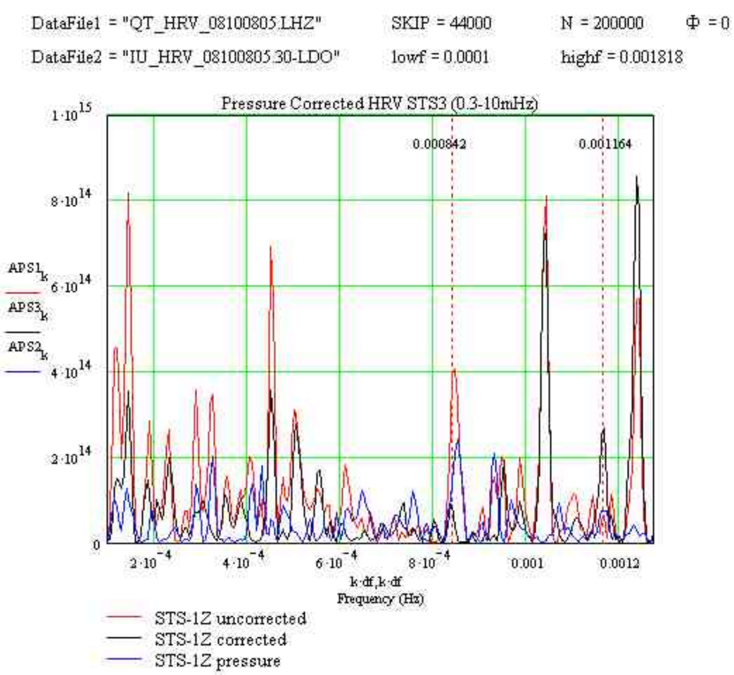
DataFile1 = "IU_HRV_08100805.00-LHZ" SKIP = 44000 N = 200000
lowf = 0.0001 highf = 0.001818

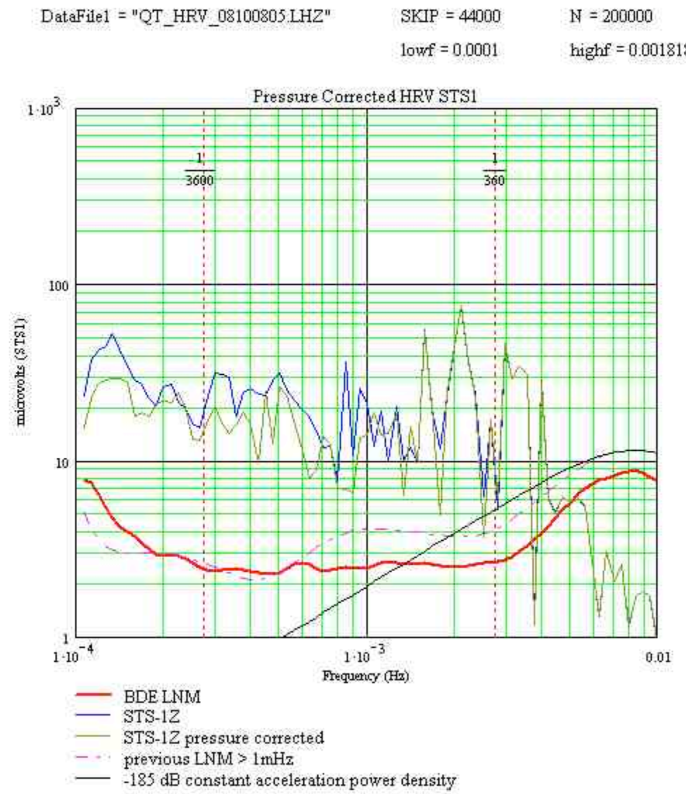


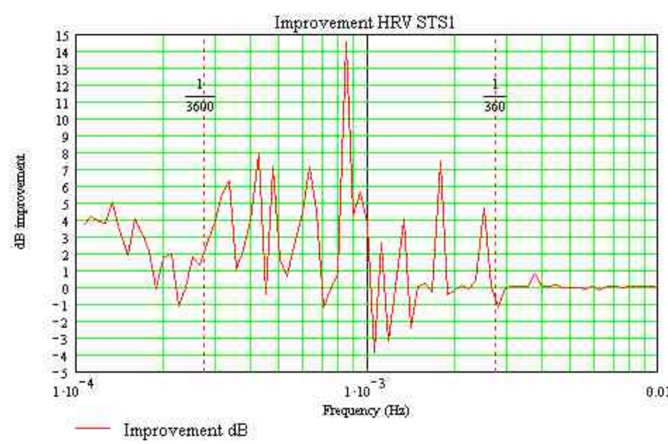


STS-3

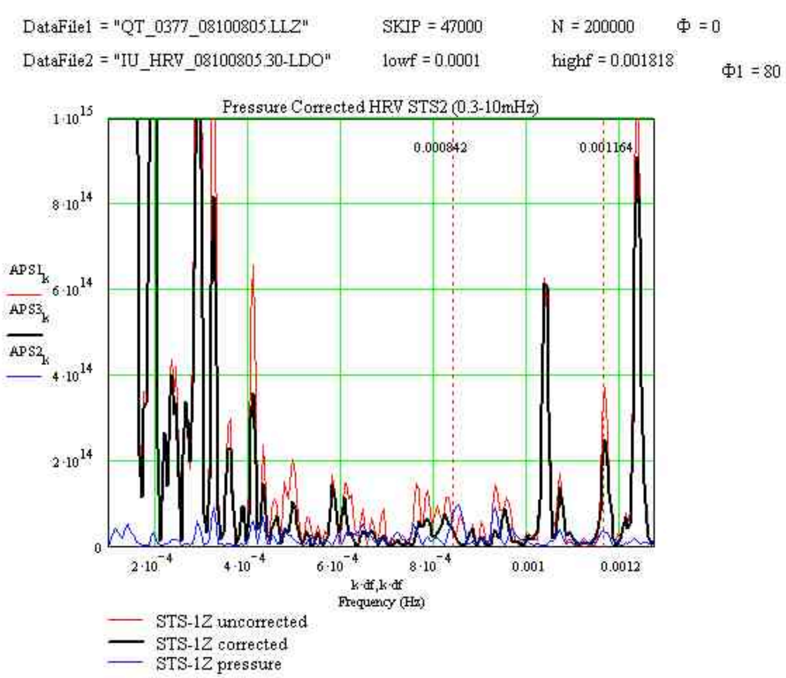
(prototype with pressure-sensitive case)



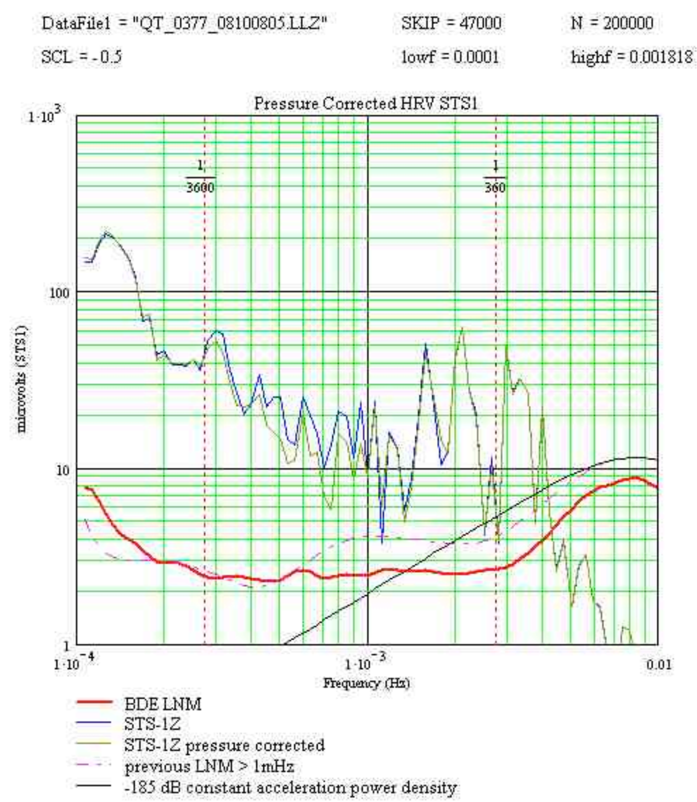




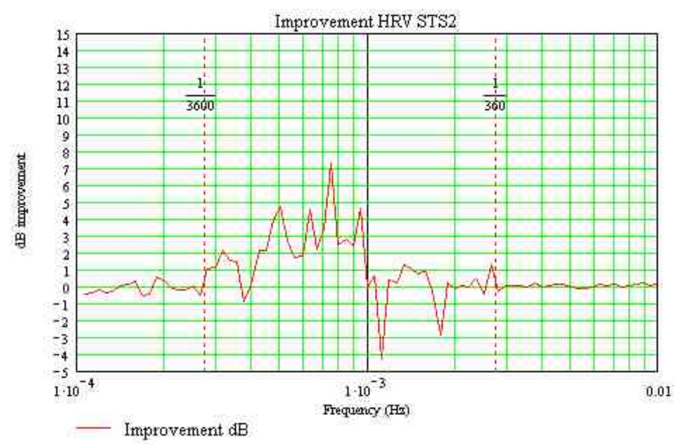
STS-2



DataFile1 = "QT_0377_08100805.LLZ"
SKIP = 47000
N = 200000
Φ = 0
DataFile2 = "IU_HRV_08100805.30-LDO"
lowf = 0.0001
highf = 0.001818
Φ1 = 80
Pressure Corrected HRV STS2 (0.3-10mHz)
0.000842
0.001164
APS1_k
APS3_k
APS2_k
k·df, k·df
Frequency (Hz)
STS-1Z uncorrected
STS-1Z corrected
STS-1Z pressure



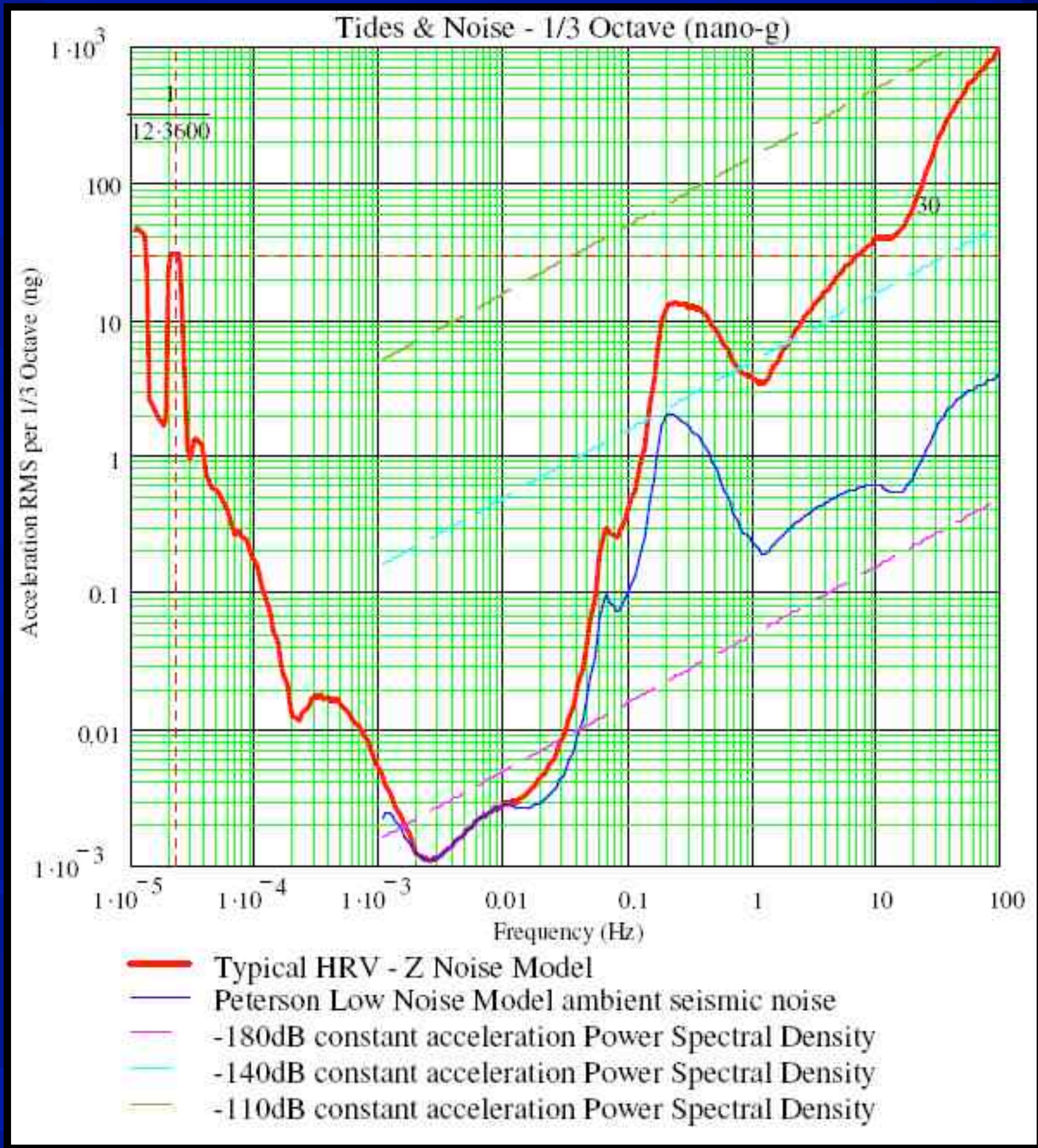
DataFile1 = "QT_0377_08100805.LLZ"
SKIP = 47000
N = 200000
SCL = -0.5
lowf = 0.0001
highf = 0.001818
Pressure Corrected HRV STS1
1/3600
1/360
microvolts (STS1)
Frequency (Hz)
BDE LNM
STS-1Z
STS-1Z pressure corrected
previous LNM > 1mHz
-185 dB constant acceleration power density



Improvement HRV STS2
1/3600
1/360
dB improvement
Frequency (Hz)
Improvement dB

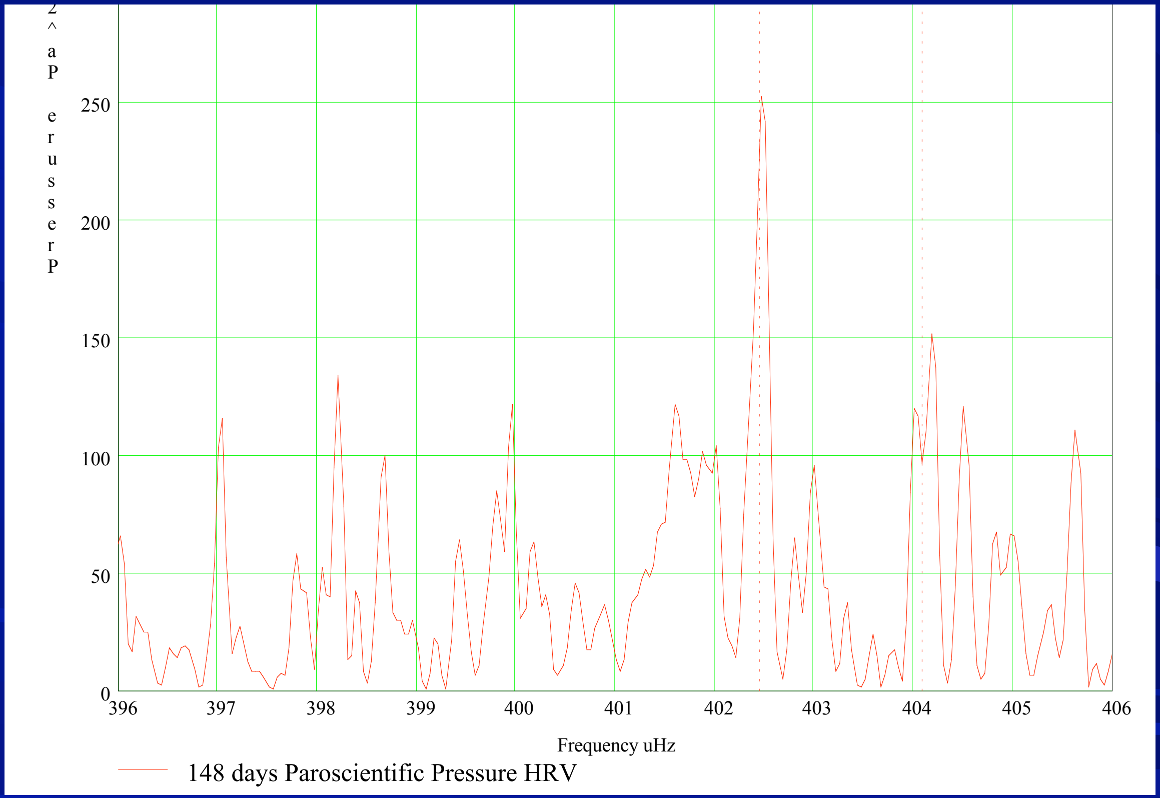
Barometric Noise Spectrum

bigger picture

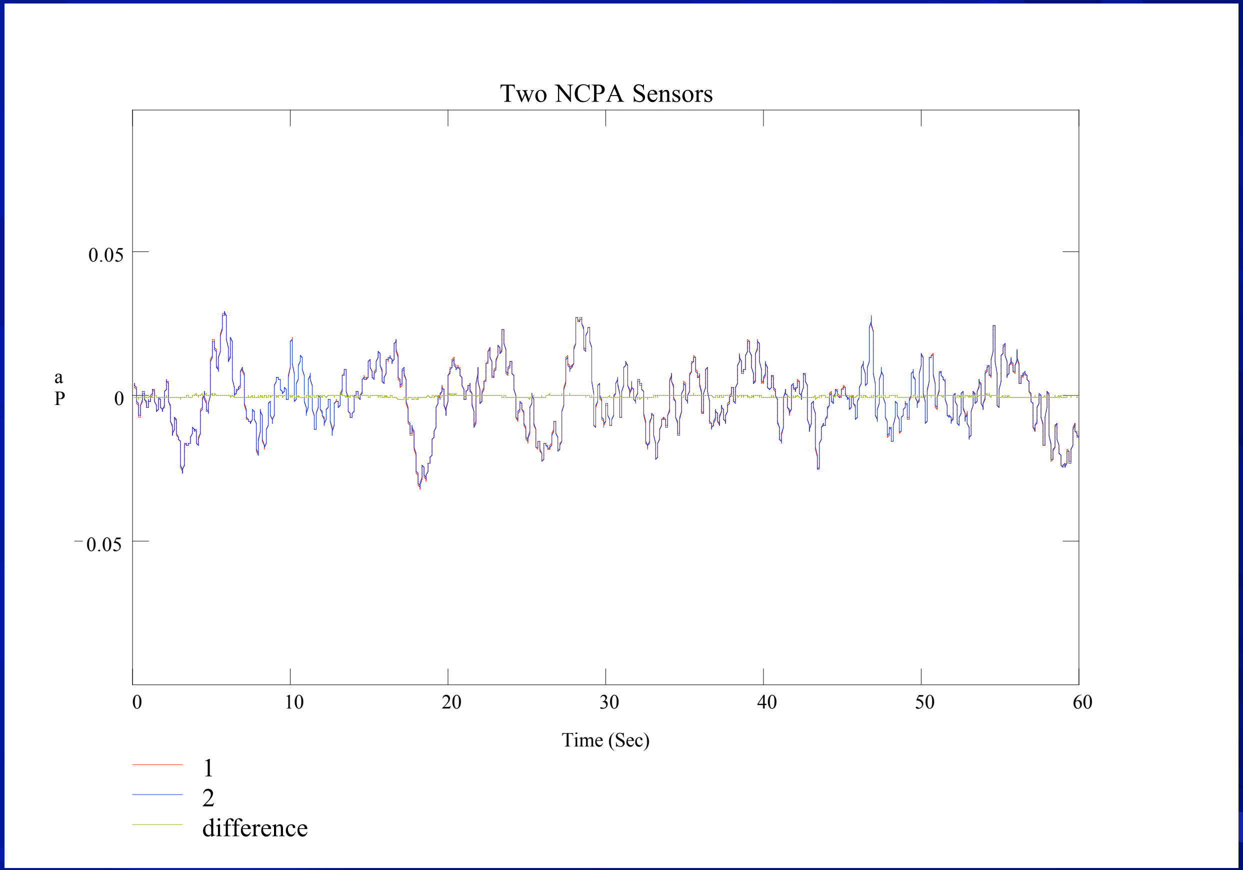


Wideband view of seismic noise

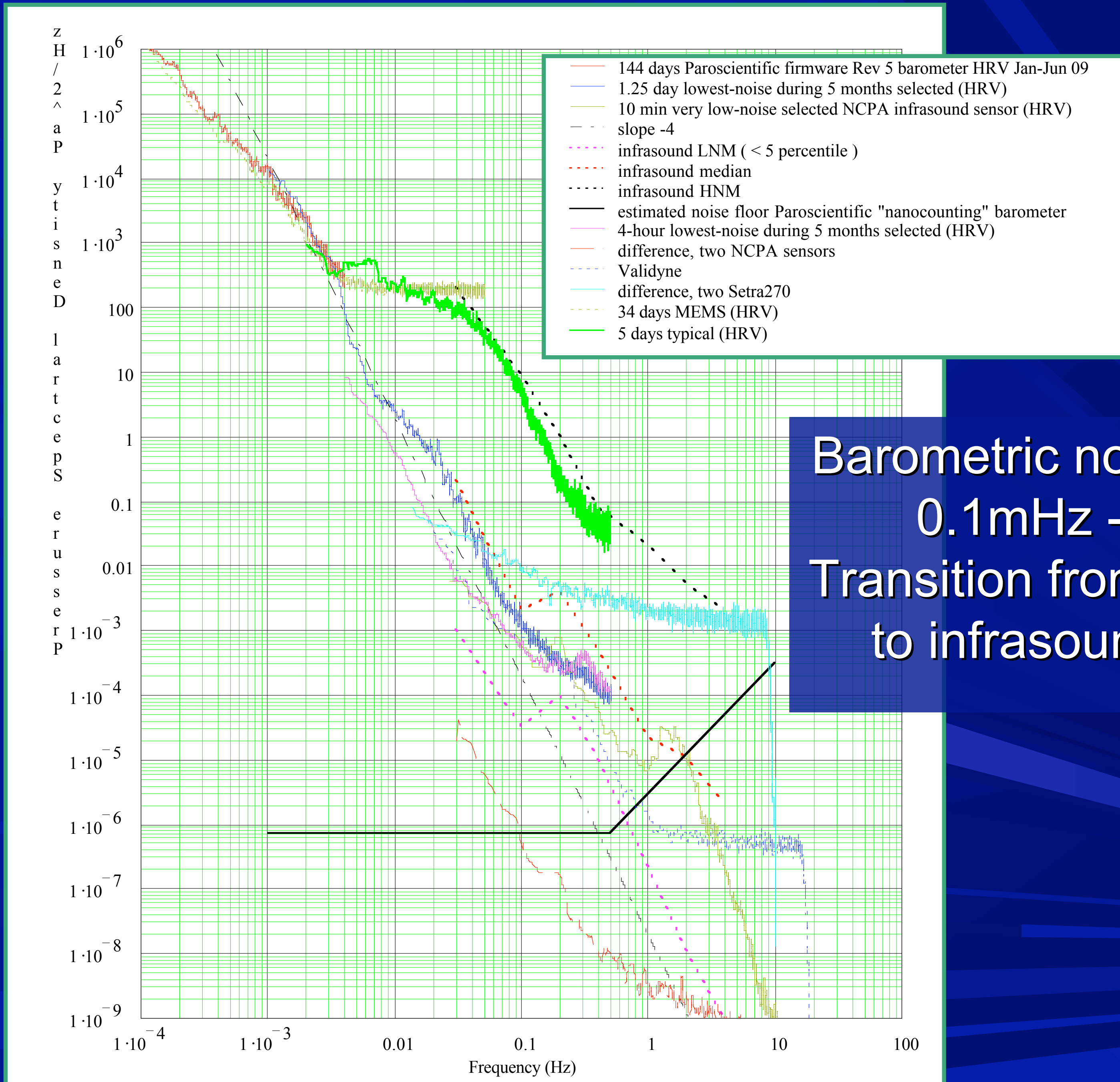
An application of long-duration barometric observations



Possible Solar mode
see Thomson, Lanzerotti et al., IEEE Proceedings, No. 5, May 2007,
(don’t put too much stock in the vertical scale in this figure)

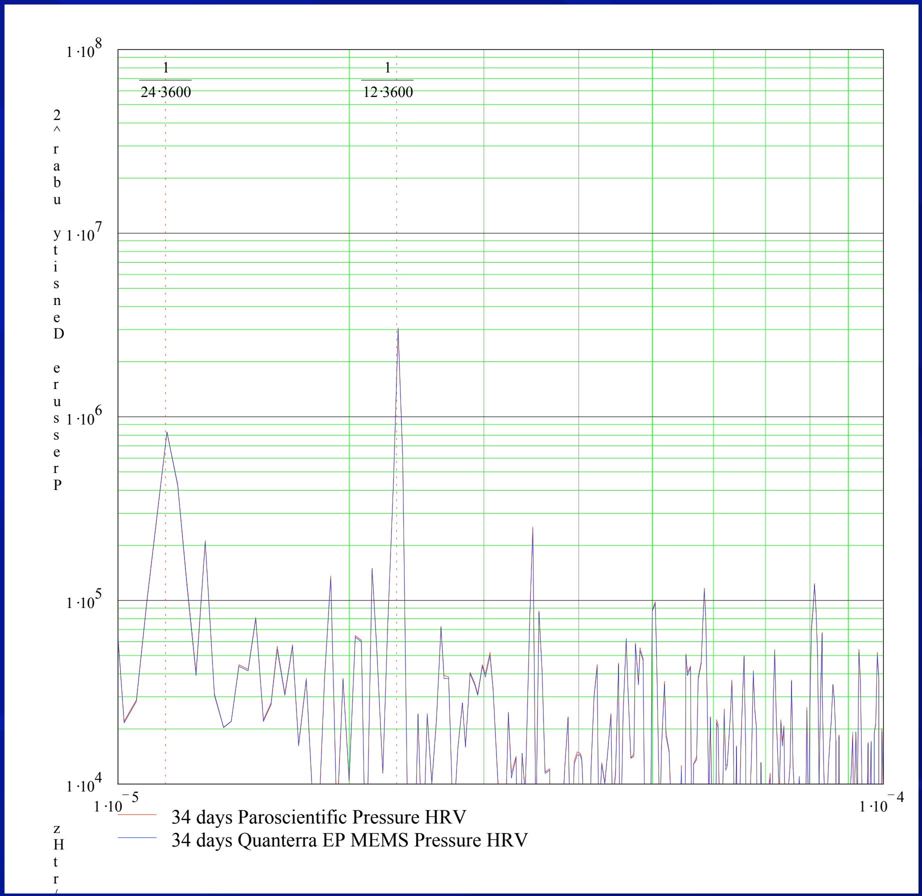


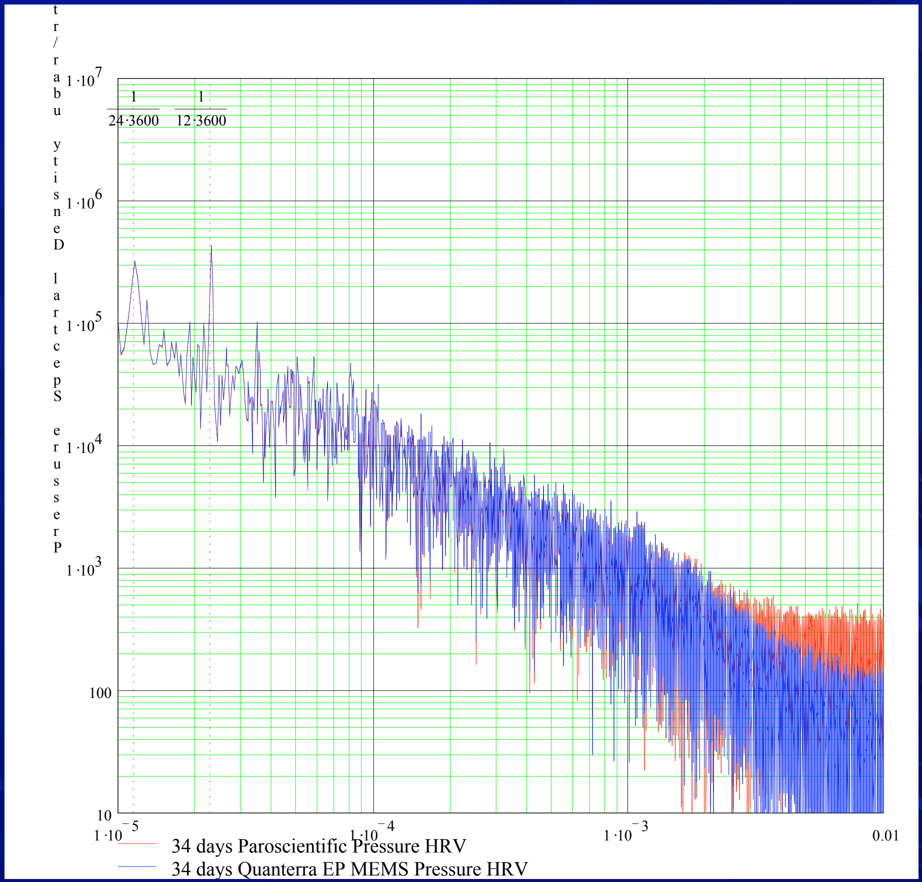
Microbaroms observed on NCPA sensors (bandpass filtered 0.1-16Hz)



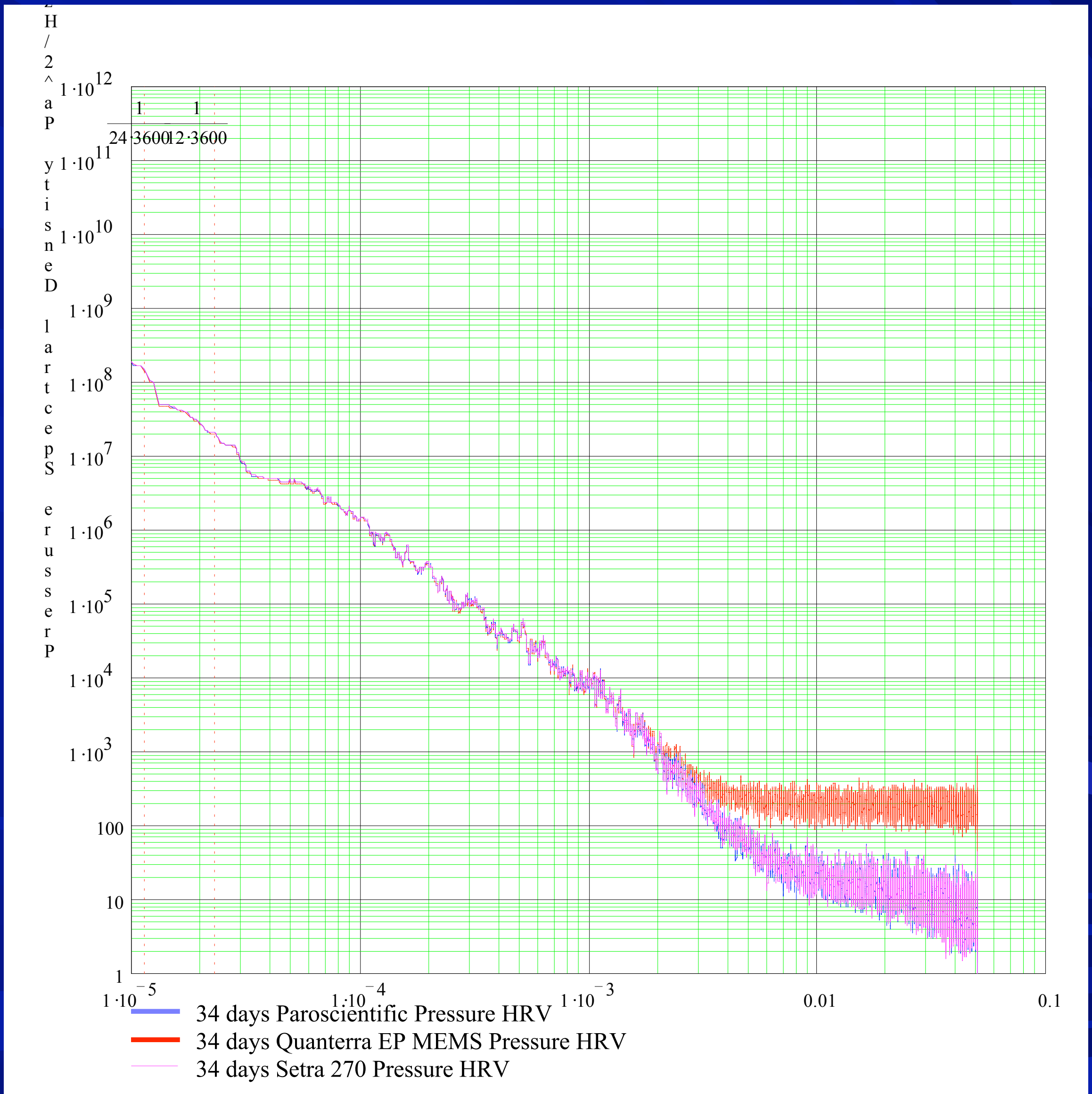
Barometric noise spectrum 0.1mHz - ~10 Hz.
Transition from barometers to infrasound sensors

MEMS & Paroscientific

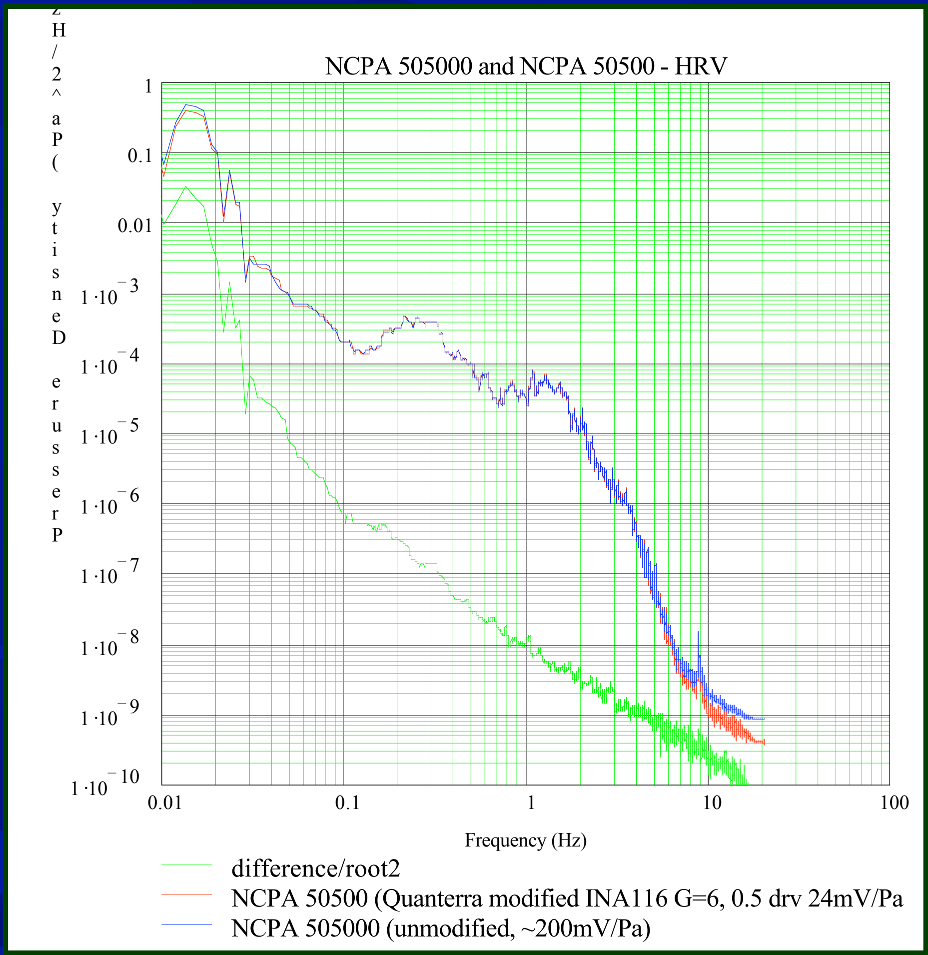




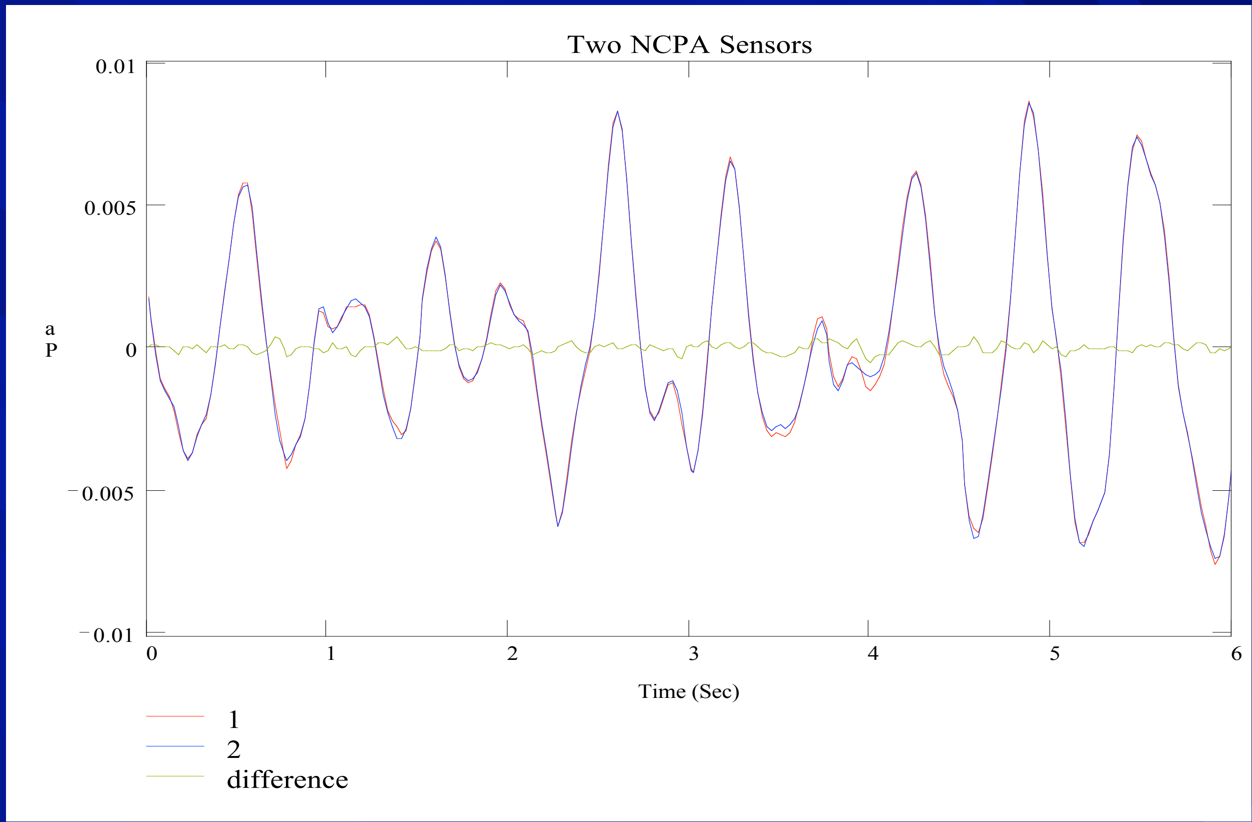
Setra 270, MEMS, & Paroscientific



Modification of NCPA sensor for low power, direct digitization



Power required for modified version ~40mW vs ~750mW



Two NCPA sensors bandpass filtered 1-16Hz.
Amplitude of difference =1mPa = 10nbar rms

Noise levels (PSD) in decibels

Station	Channel	# obs.	518s	439s	373s	316s	268s	228s	193s	164s	139s	118s	100s	85s	72s	61s	52s	44s	37s	32s	27s	23s	19s	16s	14s	12s	10s
ENH-IC	LHZ-00	315	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-184	-182	-180	-176	-171	-165	-159	-156	-157	-154
KIEV-IU	LHZ-00	340	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-183	-181	-180	-176	-172	-164	-160	-156	-155	-154
SPB-G	LHZ-00	332	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-182	-178	-172	-163	-156	-153	-153	-150
KEV-IU	LHZ-00	343	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-183	-181	-179	-176	-171	-165	-160	-156	-156	-154
TAM-G	LHZ-00	328	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-184	-183	-181	-176	-173	-164	-157	-155	-156	-152
BFO-II	LHZ-00	350	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-184	-183	-183	-181	-178	-172	-164	-157	-152	-152	-150
NNA-II	LHZ-00	140	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-173	-167	-160	-159	-158	-159
LSZ-IU	LHZ-00	337	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-184	-182	-180	-175	-170	-162	-156	-153	-152	-149
TUC-IU	LHZ-00	344	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-184	-183	-181	-176	-171	-162	-155	-153	-152	-149
MDJ-IC	LHZ-00	316	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-184	-184	-183	-182	-180	-177	-171	-164	-160	-157	-157	-153
ESK-II	LHZ-00	351	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-184	-185	-184	-183	-181	-179	-176	-170	-162	-155	-150	-149	-147
KONO-IU	LHZ-00	344	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-183	-181	-179	-175	-171	-163	-157	-153	-152	-151
TSUM-IU	LHZ-00	323	-179	-181	-183	-184	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-183	-181	-178	-172	-163	-157	-156	-156	-150
AAK-II	LHZ-00	351	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-184	-184	-184	-182	-180	-179	-177	-173	-165	-160	-158	-157	-157
ARU-II	LHZ-00	240	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-184	-184	-184	-183	-181	-179	-176	-171	-163	-159	-155	-154	-154
WVT-IU	LHZ	348	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-185	-184	-182	-180	-178	-175	-170	-162	-156	-153	-151	-149
CAN-G	LHZ-00	334	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-183	-184	-184	-184	-183	-182	-181	-177	-171	-162	-154	-151	-152	-150
HRV-IU	LHZ-00	343	-181	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-184	-184	-183	-181	-179	-176	-170	-161	-154	-151	-149	-146
KIP-IU	LHZ-00	343	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-182	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-173	-163	-157	-158	-155	-140

Is the correlation with pressure, and resulting noise level, at HRV unusual?

http://www.ldeo.columbia.edu/~ekstrom/Research/Noise/RADB_network_spectrum.html

Conclusions:

High-quality, thermally stable installations may be candidates for improvement of vertical data with barometric corrections.

Modest barometric resolution is required for corrections up to 3-4mHz, where correlation with seismic data diminishes sharply.

Large “improvement” (>15dB) is apparently possible in some cases.

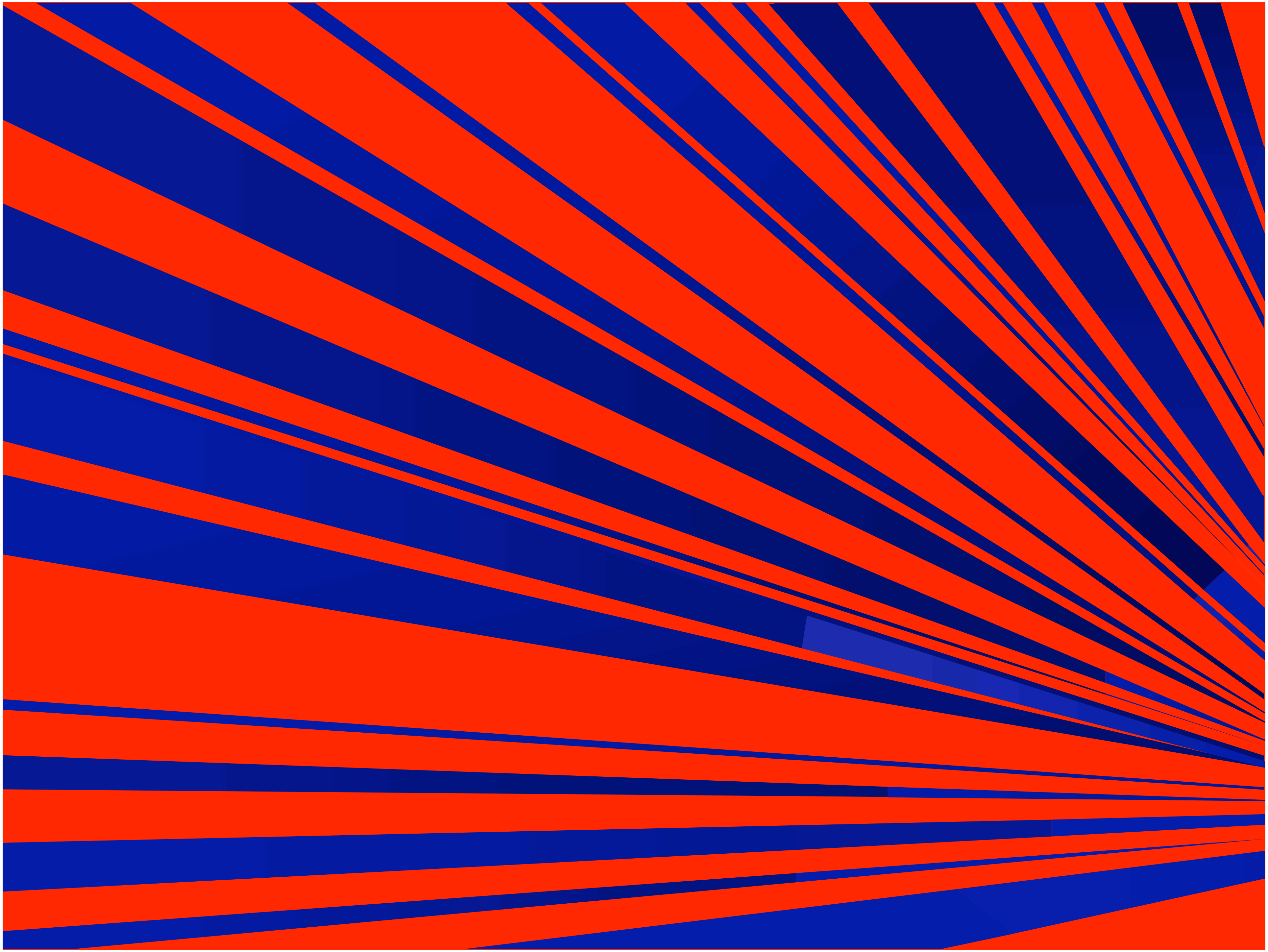
Horizontal data shows little correlation with single-station pressure. Work on-going.

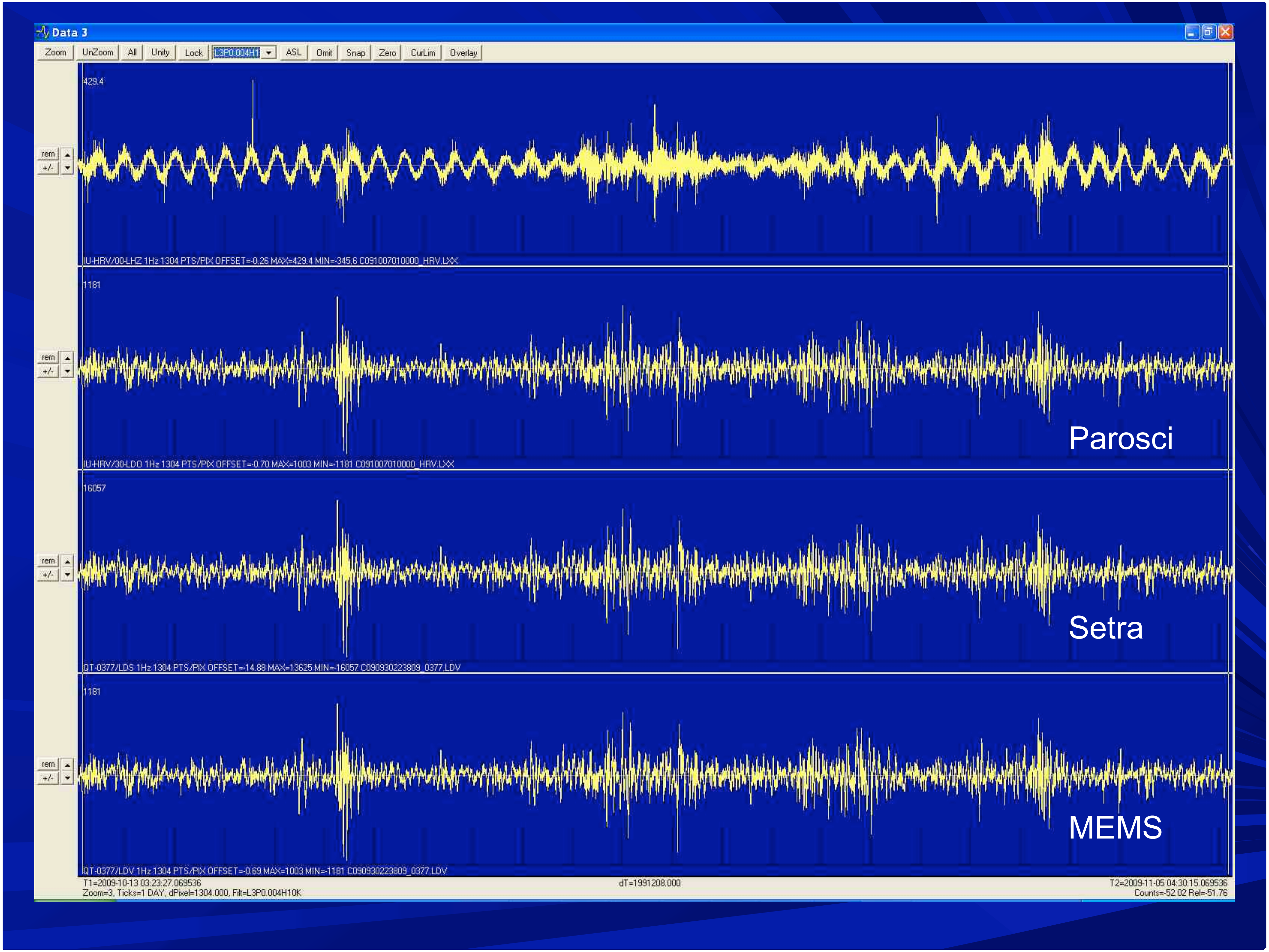
General-purpose BB sensors (STS-2 and similar class) show pressure effects, but not a simple relation

Effectiveness of pressure correction may vary seasonally at some sites.

QUANTERRA®

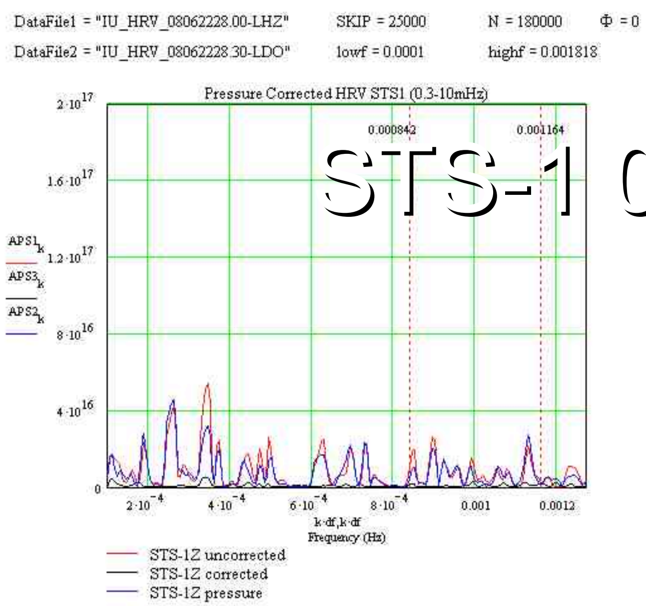
Thanks for the first 22 years!





Data 3
Zoom
UnZoom
All
Unity
Lock
L3P0.004H1
ASL
Omit
Snap
Zero
CurLim
Overlay
429.4
IU-HRV/00-LHZ 1Hz 1304 PTS/PIX OFFSET=-0.26 MAX=429.4 MIN=-345.6 C091007010000_HRV.LXX
1181
Parosci
IU-HRV/30-LDO 1Hz 1304 PTS/PIX OFFSET=-0.70 MAX=1003 MIN=-1181 C091007010000_HRV.LXX
16057
Setra
QT-0377/LDS 1Hz 1304 PTS/PIX OFFSET=-14.88 MAX=13625 MIN=-16057 C090930223809_0377.LDV
1181
MEMS
QT-0377/LDV 1Hz 1304 PTS/PIX OFFSET=-0.69 MAX=1003 MIN=-1181 C090930223809_0377.LDV
T1=2009-10-13 03:23:27.069536
Zoom=3, Ticks=1 DAY, dPixel=1304.000, Filt=L3P0.004H10K
dT=1991208.000
T2=2009-11-05 04:30:15.069536
Counts=-52.02 Rel=-51.76

STS-1 08062228 quiet



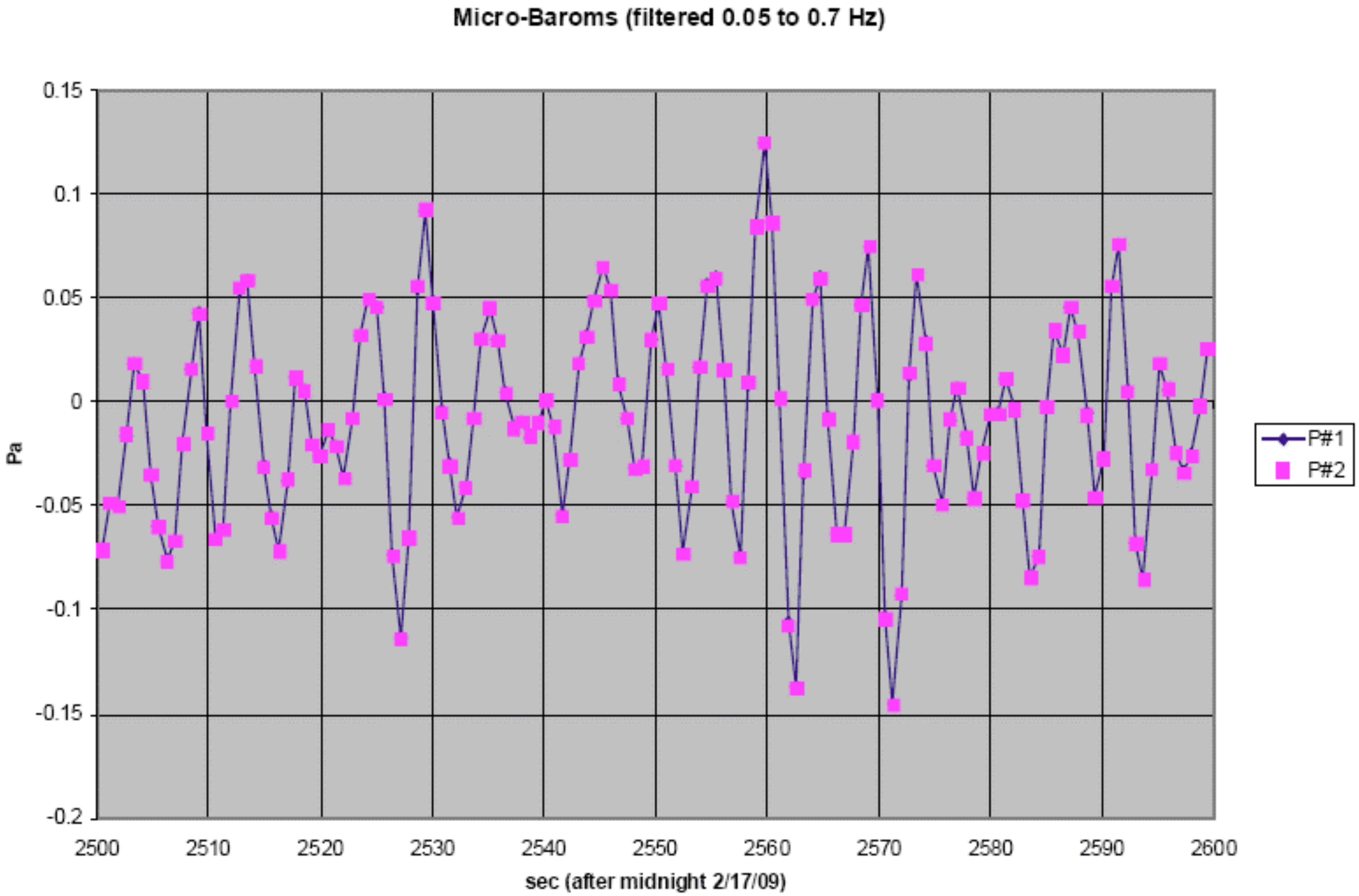
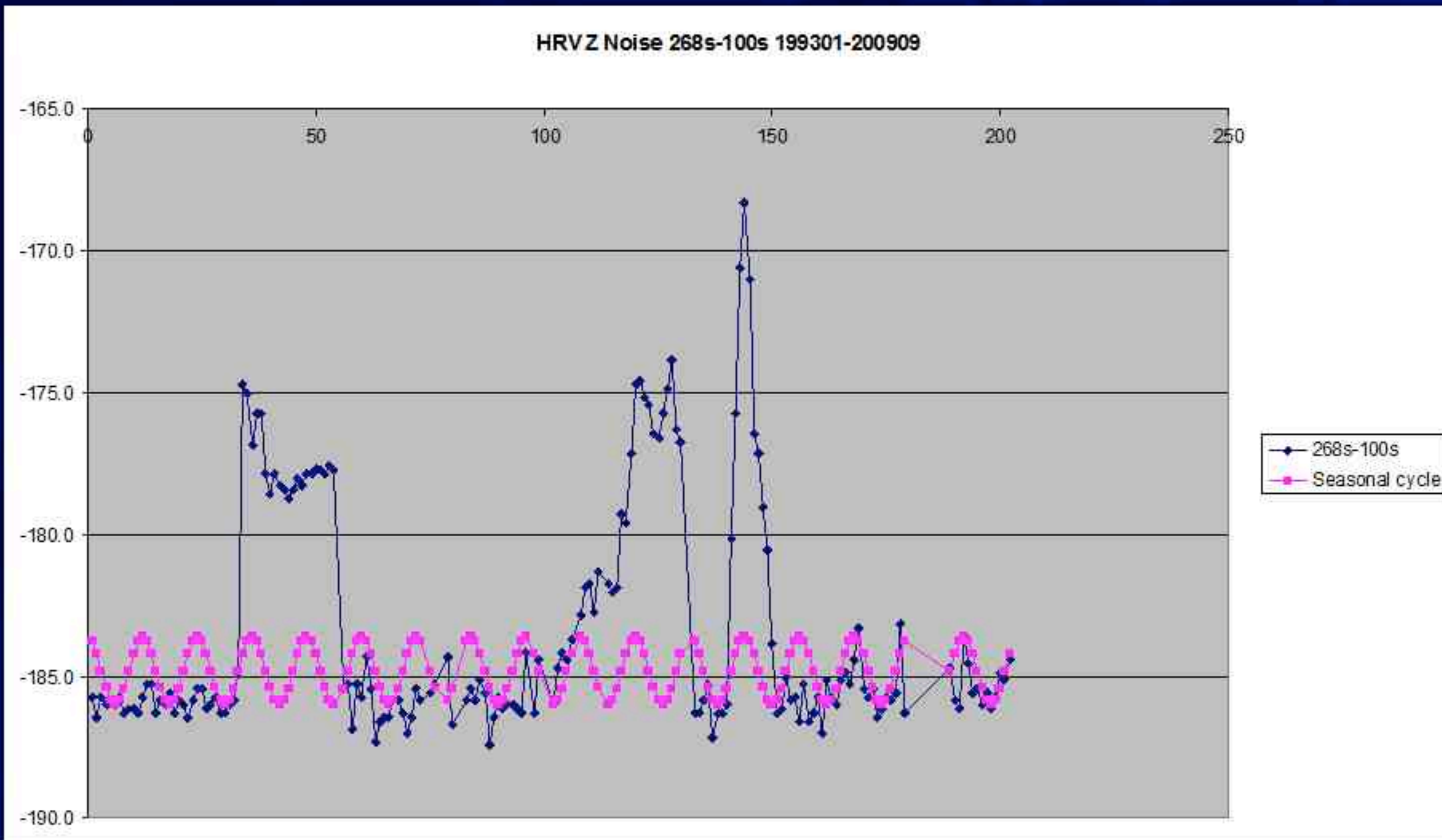


Figure 9: Micro-baroms measured with two independent Nano-Barometers

Network Averages 518s-100s

Total observations better than -178 dB 518-100s				Network Mean	
Net	Stations	Total Obs	Hrs < -178 dB per station	dB	Stations
CD	8	701164	87645.5	-182.2	10
G	17	1060311	62371.2	-180.3	30
GE	13	282619	21739.9	-173.6	50
II	20	1298088	64904.4	-177.3	40
IU	42	2841976	67635.0	-178.1	84
MN	11	232206	21109.6	-177.7	25
US	7	98124	14017.7	-171.6	47
	118	6514488		11908688 total obs	

The value -178dB average 518-100s turns out to be the GSN network mean, as well as somewhat worse than the capability of an STS-2

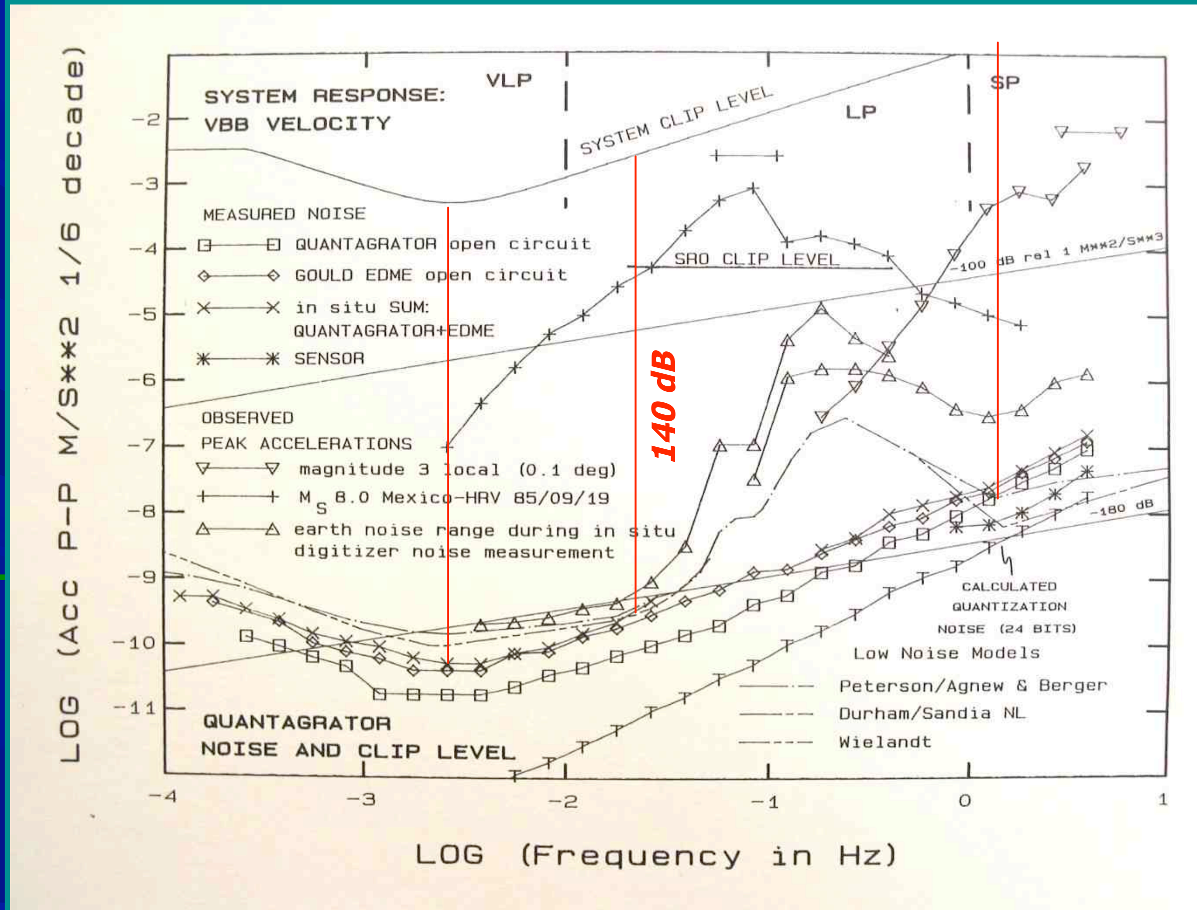


HRV Z Noise 268s-100s 199301-200909
-165.0
-170.0
-175.0
-180.0
-185.0
-190.0
0
50
100
150
200
250
268s-100s
Seasonal cycle

VBB System Design Document

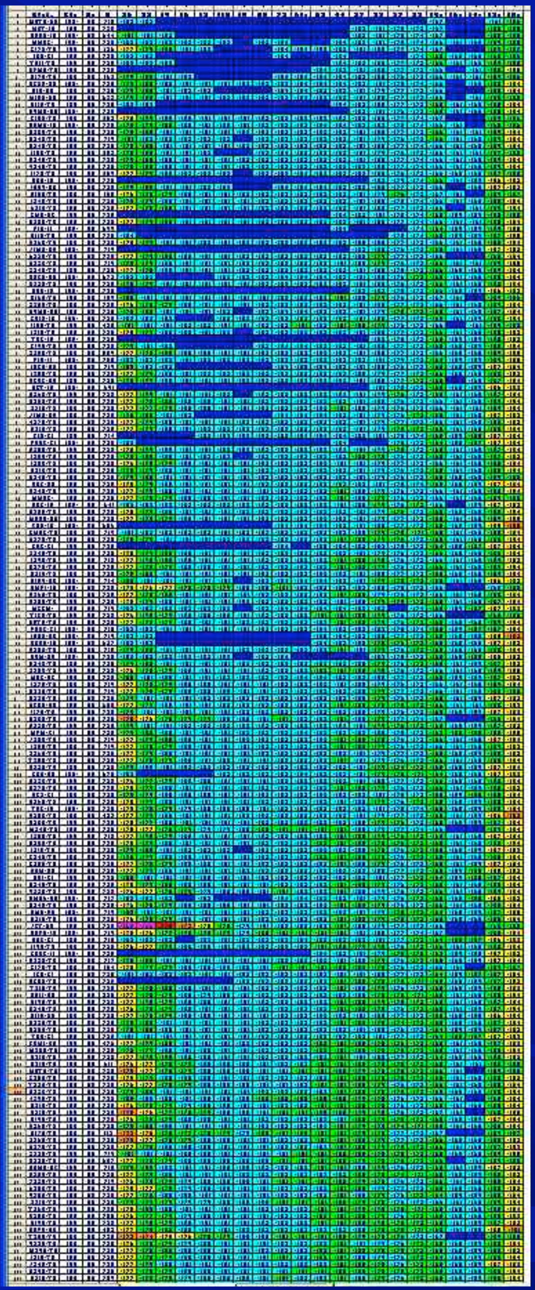
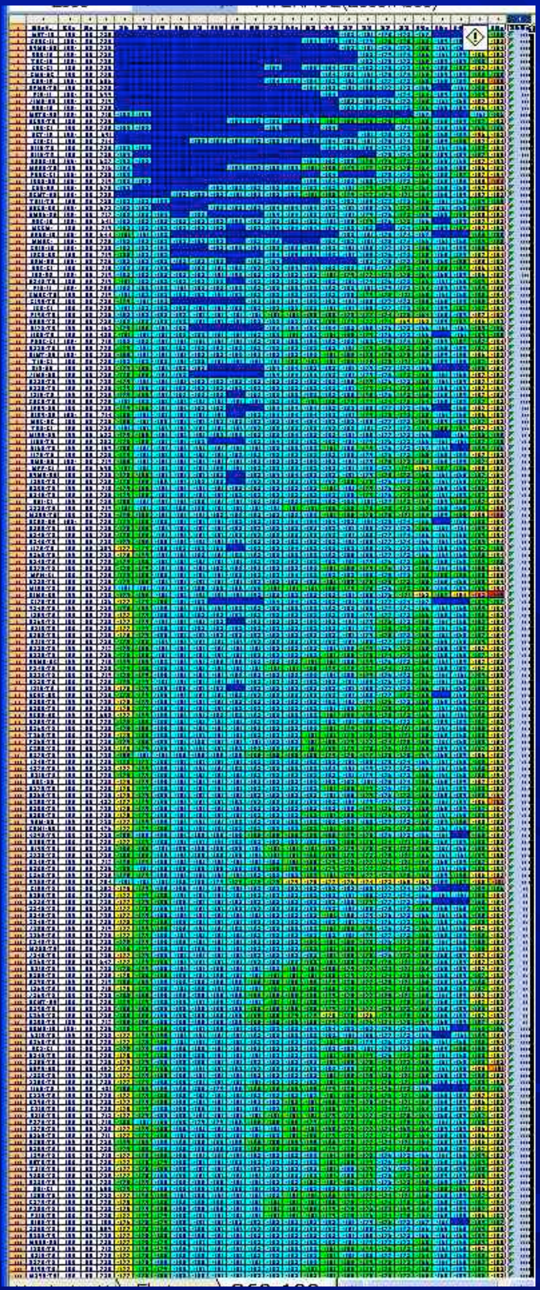
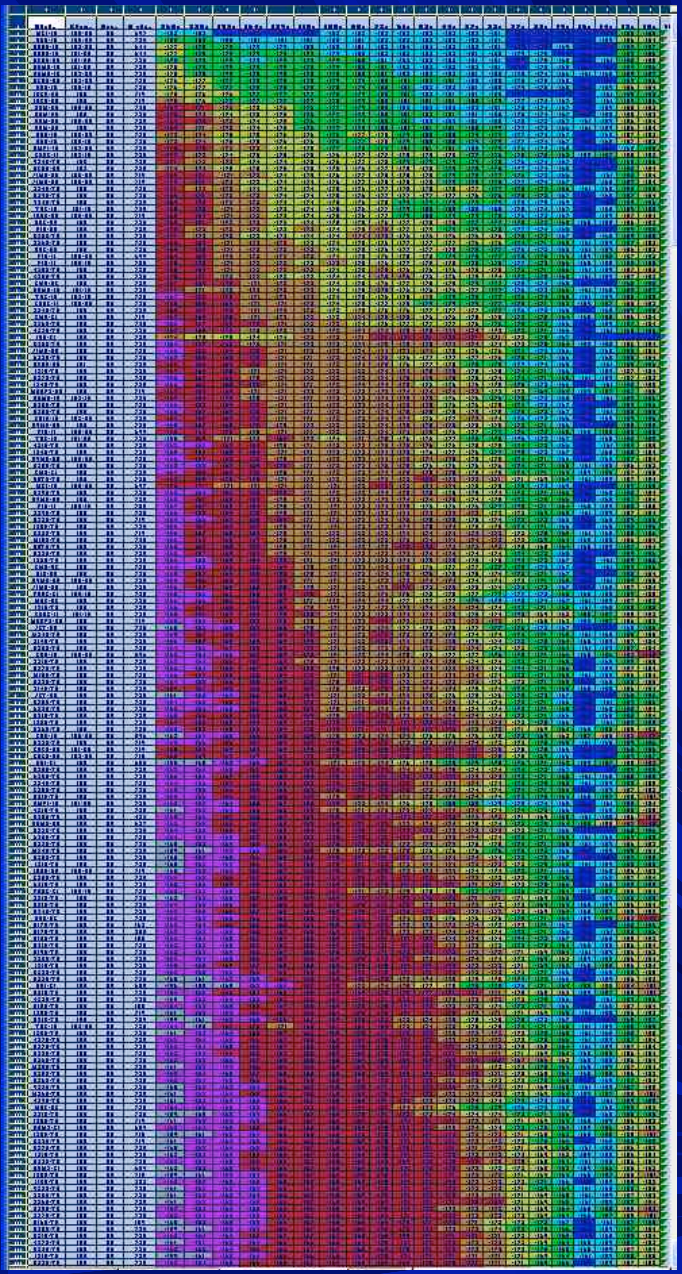
Q: Could this performance goal be widely reproduced?

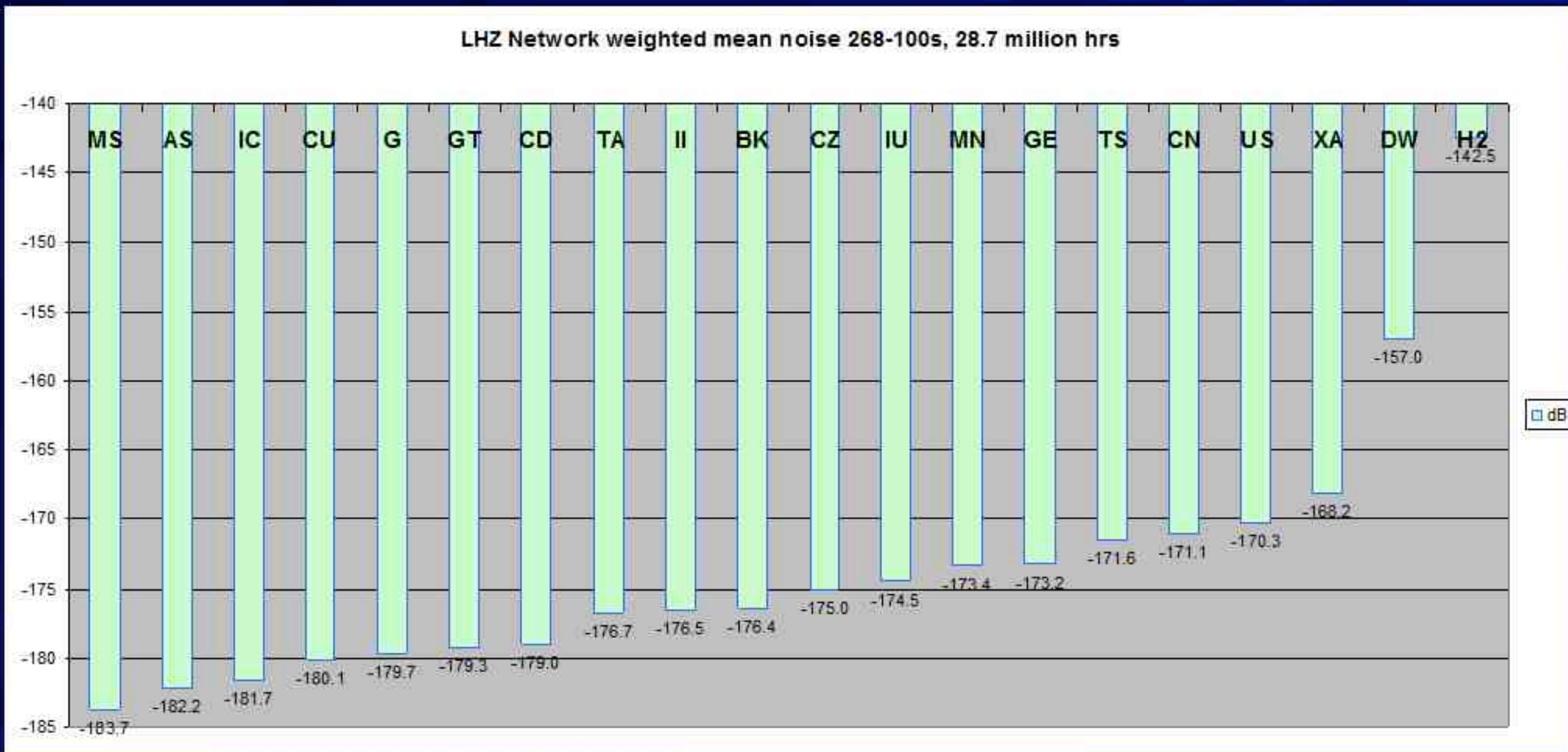
Q: How well does the GSN uniformly achieve this goal?



Steim, 1986

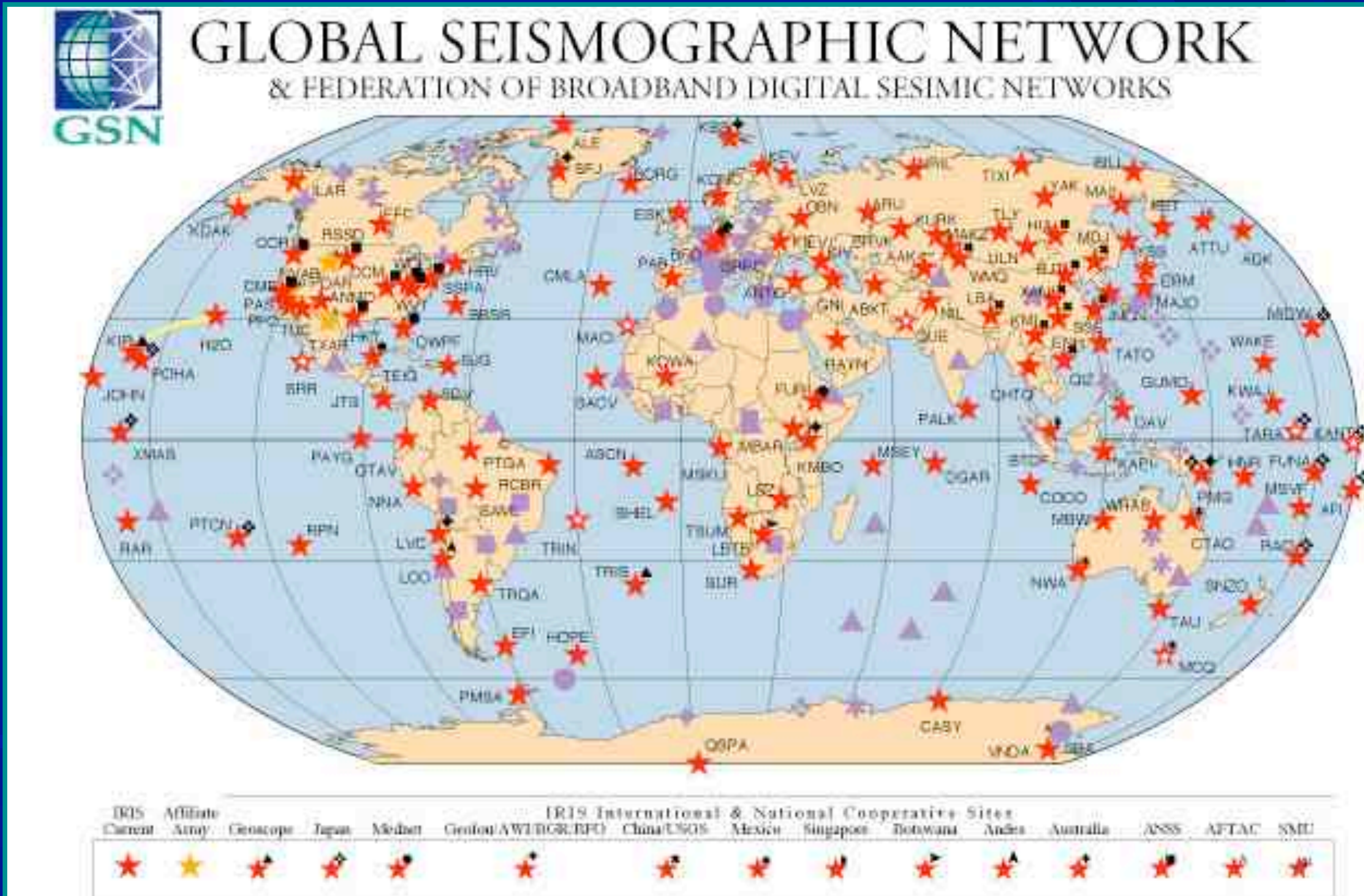
Berger, after Clinton, Heaton 2002



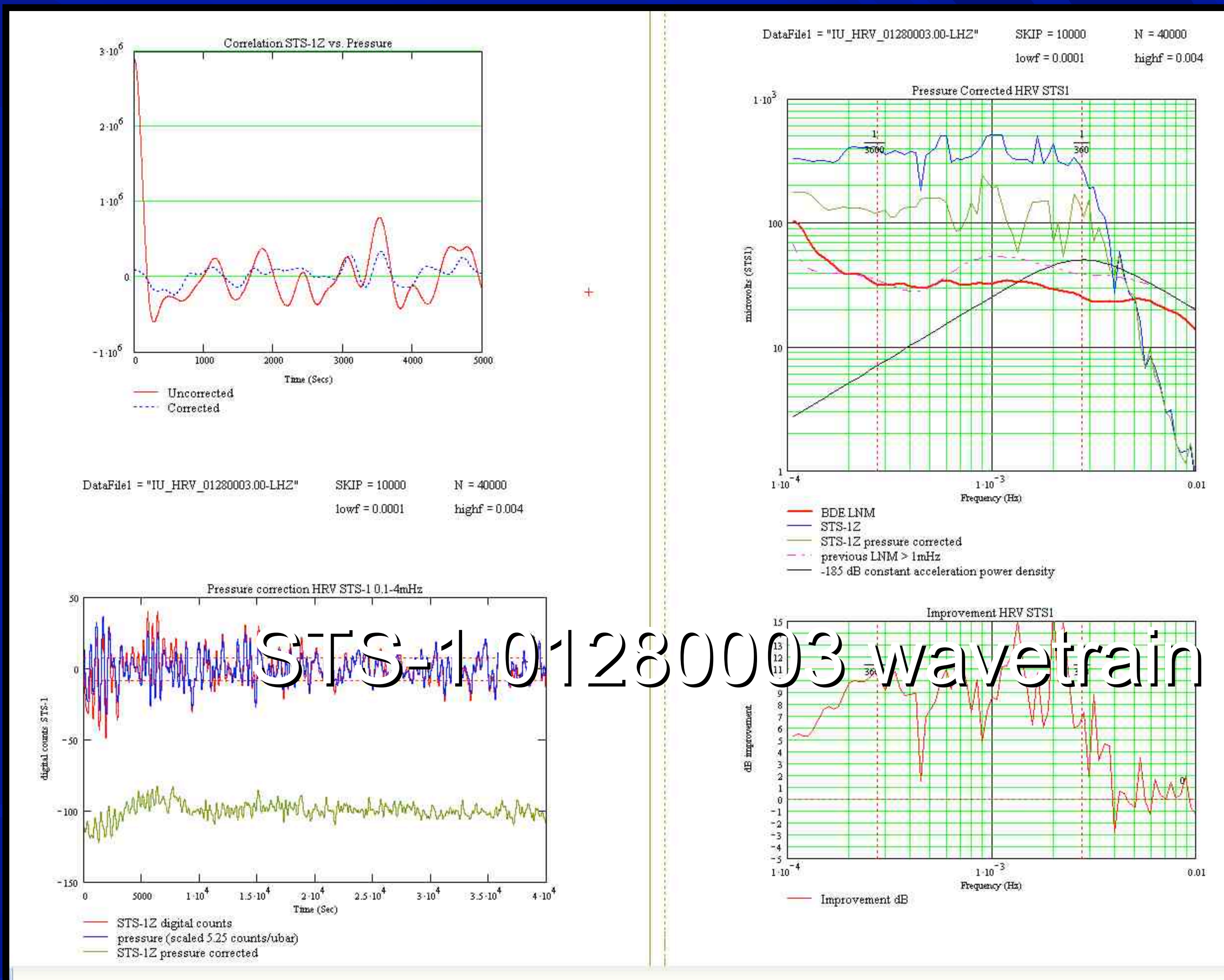
LHZ Network weighted mean noise 268-100s, 28.7 million hrs
-140
-145
-150
-155
-160
-165
-170
-175
-180
-185
MS
AS
IC
CU
G
GT
CD
TA
II
BK
CZ
IU
MN
GE
TS
CN
US
XA
DW
H2
-183.7
-182.2
-181.7
-180.1
-179.7
-179.3
-179.0
-176.7
-176.5
-176.4
-175.0
-174.5
-173.4
-173.2
-171.6
-171.1
-170.3
-168.2
-157.0
-142.5
dB

Global Networks Today



VBB digital stations 1984

STS-1 01280003 wavetrain



STS-1 10170330 (deconvolution of time series sample – higher bandwidth, event)