Barometric Pressure Measurements and Corrections for Low Frequency Seismology

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Palm Springs, CA

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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 \(~140\)dB 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
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?

Berger, Davis, Ekstrom LNM compared with various minimum vertical noise observations, all networks, 13941674 total observations
IRIS/GSN NOISE SURFACE – 1993-present
IRIS/GSN NOISE SURFACE
1993-present
The valley of the lost dB’s

ALL GSN STS-1

STS-1 slacker foothills
Is higher noise associated with particular stations, or is it randomly present across the entire station population?
<table>
<thead>
<tr>
<th>Net</th>
<th>Station</th>
<th>Sensor</th>
<th>hrs &lt;-178</th>
<th>hrs &gt;-178</th>
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<td>RAIO</td>
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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.
All-network ranking:

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
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

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

<table>
<thead>
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<th>months</th>
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<td></td>
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dB  Linear (dB)  36 per. Mov. Avg. (dB)
Mean -172.5
High-Quality GSN stations, seasonal variation

month stack (1993-2009)
TA weighted LHZ noise 200601-200909 (9.2 million hrs) vs. location
Horizontal Noise, by network

(month stack 1993-2009)
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
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.
1-m diameter polyethylene tube. Space between aluminum box and tube filled with sand.

Anodized Aluminum Box

SAND FILLS THIS SPACE
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.
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/s²/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

DataFile1
"IU_HRV_10230156.00-LHZ"
= SKIP 27000 = N 32000 =
lowf 0.0001 = highf 0.004 =
1.10^4 1.10^3
0.01

Improvement dB

Improvement HRV STS1

Pressure Corrected HRV STS1

BDE LNM
STS-1Z
STS-1Z pressure corrected
previous LNM > 1mHz
-185 dB constant acceleration power density
Pressure Corrected STS-1 HRV

DataFile1 = "IU_HRV_11160514.00-LHZ"
SKIP = 45000
N = 200000
lowf = 0.0001
highf = 0.01

Pressure Corrected HRV STS1 (0.3-10mHz)

Magnitude 7.3 (10^27 d-cm) - MINAHASA, SULAWESI, INDONESIA
2008 November 16 17:02:32 UTC. 55HRS DATA
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
< 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
HRV performance 1993-present. “good” and “bad” intervals. A number of stations show similar patterns.
STS-1 winter chill down
large event
STS-3
(prototype with pressure-sensitive case)
STS-2

Pressure Corrected HRV STS2 (3.10GHz)

DataFile = "QT_0377_061000511LZ*"
SKIP = 47000
N = 200000
Φ = 0

DataFile2 = "IU_HRV_061000530_LDO*"
lowf = 0.0001
highf = 0.01812
Φ1 = 50

Pressure Corrected HRV STS1

DataFile = "QT_0377_061000511LZ*"
SKIP = 47000
N = 200000
SCL = 0.3
lowf = 0.0001
highf = 0.01812

Improvement HRV STS2

-18.5 dB constant acceleration power density

- STS-1Z uncorrected
- STS-1Z corrected
- STS-1Z pressure corrected
- previous LHC = limits
- previous LHC = limsup

Improvement HRV STS1

- HDE LHC
- STS-1Z
- STS-1Z pressure corrected
- previous LHC = limits
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)
Two NCPA Sensors

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

34 days Paroscientific Pressure HRV
34 days Quanterra EP MEMS Pressure HRV
Setra 270, MEMS, & Paroscientific

![Graph showing comparison of pressure HRV readings over 34 days for Paroscientific, Setra 270, MEMS, and Quanterra EP MEMS.]
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
Is the correlation with pressure, and resulting noise level, at HRV unusual?

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.
Thanks for the first 22 years!
Figure 9: Micro-baroms measured with two independent Nano-Barometers
### Network Averages 518s-100s

<table>
<thead>
<tr>
<th>Net</th>
<th>Stations</th>
<th>Total Obs</th>
<th>Hrs &lt; -178 dB per station</th>
<th>Network Mean</th>
<th>dB</th>
<th>Stations</th>
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<tbody>
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<td>CD</td>
<td>8</td>
<td>701164</td>
<td>87645.5</td>
<td>-182.2</td>
<td>10</td>
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<tr>
<td>G</td>
<td>17</td>
<td>1060311</td>
<td>62371.2</td>
<td>-180.3</td>
<td>30</td>
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<td>282619</td>
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<td>-173.6</td>
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<td>14017.7</td>
<td>-171.6</td>
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| 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  |

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.
Q: Could this performance goal be widely reproduced?

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

Steim, 1986

Berger, after Clinton, Heat 2002
Global Networks Today
VBB digital stations 1984
STS-1 10170330
(deconvolution of time series
sample – higher bandwidth, event)