Some observations of data quality at global seismic stations

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SITS, 2009/11/10
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

2005/10/08 03:50:38.0, $\psi = 34.43$, $\varphi = 73.54$, $h = 10.0$
POHA-IU $\Delta = 108.72$, $\alpha = 48.71$, $\beta = 318.75$ MANTLE WAVES

\[
S = \frac{\sum_{i=1}^{N} O_i S_i}{\sum_{i=1}^{N} S_i^2}
\]
Blue - observed seismograms
Red - synthetic seismograms

$S = \frac{\sum_{i=1}^{N} O_i S_i}{\sum_{i=1}^{N} S_i^2}$
Scaling factors at NNA-II, 1990-2004

NNA-II: Red - Mantle

annual median
individual seismograms

scaling factor

Scaling factors at PAB-IU, 1992-2004

Example from Ekström et al. (2006)

PAB–IU: Blue – Body; Red – Mantle

LHZ: \( S \sim 1 \)

LHE: \( S \) time and frequency dependent

\( S < 0.5 \)
Primary sensor: STS-1

Secondary sensor: mostly STS-2
Scaling factors at SSE-IC, 1996-2008

SSE-IC: Blue - Body; Red - Mantle

Scaling factor vs time-dependent deviation

Scaling factors at XAN-IC, 1995-2008

XAN-IC: Blue — Body; Red — Mantle

secondary sensor okay; what has happened to the primary?
Most stations are well behaved, but not all

- Well-behaved stations
- 8 GT stations
- QIZ–CD, LSA–IC, BJT–IC
- LVZ–II, SDV–IU

Most stations are well behaved, but not all outliers.
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.

\[ \text{Amplitude} \rightarrow Q + \text{source factor} + \text{receiver factor} + \text{focusing} \]

(Dalton and Ekström, 2006)
Assessment of Reported Horizontal Sensor Orientations

Reported orientation of seismometer

True orientation of seismometer
Symptoms of a misoriented sensor

Vertical

Longitudinal

Transverse

Love wave on longitudinal

Rayleigh wave on transverse

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

Figure 1: Individual measurements of polarization angle $\alpha$ as a function of the corresponding optimal combined correlation coefficient $C_{\text{tot}}$ for the station CMB-BK. The thick line shows the median of the individual measurements above a given correlation coefficient, and the thin lines show the range of the second and third quartiles of this distribution of measurements.
Octans interferometric laser gyro
Figure 7: Comparison between two types of measurements of rotation angle. The horizontal axis corresponds to high-precision field measurements of seismometer orientation obtained at 49 Transport Array sites at the time of station removal. The measurements were obtained using an IXSEA Octans IV interferometric fiber-optic gyroscope. The vertical axis corresponds to the rotation angle obtained from the surface-wave-polarization measurements. The thin line indicates equal values of the two measurements. The difference between the two measurements is less than 3° for all stations.
TA update from B. Busby -- 144 stations

\[ y = 0.9211x + 0.0477 \]
\[ R^2 = 0.9286 \]

(as of 2008/08/12)

Robert Busby  Aug 12, 2008

Data evaluation since 2006, Octans measurements up to July 2008, 144 stations shown.

The standard deviation between the two sets is 1.4 degrees. The standard deviation of their set with reported azimuths is 5.1 degrees.

Four anomalous stations are shown in yellow in Table 1 which might be investigated for errors or unusual sensor multiply.

Figure 1.

WQC estimate

Ekstrom (flipped)

“true”
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.
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

KIP-IU LHZ-00, 100 sec period
One week of noise at 23 seconds period

Period: 23 sec  Low noise reference: -178.3 db
One week of noise at 100 seconds period

Period: 100 sec  Low noise reference: −185.1 db
One week of noise at 228 seconds period
100 sec period - distribution of PSD

KIP-IU, LHZ
July-December, 2002
4150 hourly measurements

10% low-noise level

Power spectral density (dB)

Time exceeding PSD (%)
Stability of low-noise spectra

KIP-IU, LHZ
10% low-noise spectra
1988/08 - 2001/12 (138 curves)
Noise spectra from the Global Seismic Network

Signal level not exceeded 10% of the time

142 stations, LHZ channel
Time period: 2009/10/26–2009/11/09
Minimum # of samples: 80
Signal sample length: 1 hour

Low Noise Model of Paterson (1993)
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

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

(courtesy A. Shuler)
Regional surface waves
2003/03/13 Near Lop Nor
$M_W = 4.4$

WMQ-IC, $\Delta = 2^\circ$

TLY-II, $\Delta = 14^\circ$

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

(Sykes and Nettles, ISS meeting, 2009)
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?