GSN Review of WQC Station Performance Reports

The Lamont Waveform Quality Center (WQC) has issued a series of reports, beginning in January 2010, documenting the status of the Global Seismographic Network. These reports focus on station performance as observed by the WQC over the years, and include scaling analysis based upon CMT waveforms, noise assessment, inter-sensor coherence, and polarization evaluation.

The ten reports to date have been distributed to the GSN and members of the IRIS community. The sites include CASY, KIP, ALE, XAN, DGAR, WCI, DAV, RPN, KONO, and SSE. This document will review the historical problems noted in these reports and address specific issues raised by the WQC.

Background

In the mid-2000s, the WQC observed scaling problems at some sites with STS-1 seismometers, based on the Centroid Moment Tensor (CMT) analysis of waveforms with period ranges from 50-250 seconds, and speculated these problems were associated with the aging of the sensor (Ekstrom et al, 2006). In 2007, an analysis by the WQC identified orientation problems at a small number of GSN stations (Ekstrom and Busby, 2008). These observations by the WQC motivated a number of efforts by IRIS, IDA, and the USGS to investigate and address data quality issues:

- In 2006, IRIS funded a joint proposal from Metrozet and UC Berkeley to develop a new FBE (feedback electronics) system to replace aging STS1 boxes. This successful project led to the introduction of the Metrozet STS1-E300 in 2008.
- Davis *et al.* (2005) and Davis and Berger (2007) published two studies testing GSN responses using normal mode and tidal amplitudes. Their analyses indicated there were sensitivity issues at several GSN stations, though many problem sites reported by the WQC behaved normally at very long periods. Similarly, comparisons between primary and secondary sensors in the microseismic band at a number of sites generally indicated normal performance (Hutt, unpublished, 2008).
- Field kits were developed to provide an independent measure of sensor orientation, absolute calibration, and location. These SensOrLoc (Sensitivity, Orientation, and Location) kits are now routinely deployed by the ASL and IDA during upgrade or maintenance visits and are described in ftp://ftpext.usgs.gov/pub/cr/nm/albuquerque/ASL/pub/users/GSN_data_quality/SensOrLoc Procedure.doc. The SensOrLoc kits were deployed at 27 sites during the 2009 field season.
- A new calibration policy was developed and submitted to the GSNSC in 2009 for their review and a network-wide calibration effort was initiated to refine the accuracy of current metadata.
- Bob Hutt began a series of experiments on STS-1 FBEs in 2008 and reported on the results at the 2009 Fall AGU meeting (Hutt and Ringler, 2009; ftp://ftpint.usgs.gov/pub/cr/nm/albuquerque/ASL/pub/users/Hutt/Posters/BOB_AGU_POSTER_comp.pdf). These experiments suggest humidity may be responsible for some of the apparent variation in STS-1 sensitivity at long-periods. These effects are not substantial in the microseism band nor at tidal frequencies, but are very apparent in the long-period

surface-wave band used in CMT solutions by the Lamont Global CMT Project. Additional information about the effect of the humidity is included ftp://ftpext.usgs.gov/pub/cr/nm/albuquerque/ASL/pub/users/GSN_data_quality/Effects of high humidity on STS-1.doc

Station performance reports

The WQC reports present an in-depth view of the station performance since installation. The tools used by WQC provide valuable insight and are important contributions to the data quality process.

In reviewing the reports, we summarize the observed problems and describe our efforts to investigate and rectify them. In some cases, multiple WQC observations stem from a single problem and we have tried to consolidate the response. We briefly mention results from calibrations and provide information on whether these problems were reported through Data Problem Reports (DPR) s and other mechanisms. We also provide details about the specific stations in terms of logistics and operational environment.

Thus far, our assessment is that the problems observed by the WQC generally fall into two categories. The first is problems associated with the degradation of the STS-1 sensors. In many sites, we believe that this loss of sensitivity is associated with humidity in the FBEs. In other cases, there may be mechanical or other problems and this is an area of active investigation. It is only in the last year that the research by Bob Hutt and others has illuminated the cause of some of the problems observed by the WQC, allowing the ASL and IDA to design plans for remediation. And it is only in the last year that the GSN has been able to purchase significant quantities of the equipment necessary to replace the electronics. There was little that could be done to address the problems identified by the WQC until very recently.

The second category of problems appears (thus far) to be related to sites where access is limited or difficult for some reason or another. This is the challenge of operating a global network with limited resources. The GSN has not had sufficient funding to visit all sites on a regular basis.

IU CASY

Overview: With the exception of JOHN and KNTN, CASY has been one of the more difficult IU sites to visit. Until recently, access was limited to a supply vessel, which requires 8-10 days transit time, plus a potential for 8-10 weeks on site until the supply vessel returns and then another 8-10 days transit back. Because of these difficulties, ASL personnel have not visited the site since its installation in 1996.

STS-1

1. Horizontal components show scaling and stability problems beginning in 1998 and continuing through the present.

   No DPRs issued identify this problem. We are not certain what occurred in 1998; however, we believe that this scaling problem is related to humidity in the FBEs. Recent experiments with amplitude-variable calibrations are consistent with what we expect to see from a humidity problem on the horizontal sensors.

To address this problem in the interim, we are working with the station operator to install desiccant in the FBEs. As soon as the station operator is able to do this, we will run calibrations to see if drying out the boxes resolves the problem.

To improve the communication about this problem, we have issued a DPR. We have also issued a ticket on our tracking system, which will generate a problem report and associated map symbol on the ASL Web pages for station status.

2. Horizontals have reversed polarity 1997-1998.

   The QC team caught the polarity problem and corrected it in 1999. However, the person who corrected the azimuth in the metadata failed to carry the correction all the way back to the installation of the sensor – which is why it is not correct in 1997 and 1998. This error has been corrected and new dataless generated as of January 2010.

3. Horizontals are extremely noisy, beginning in 1999 and continuing.

   The vault flooded in 1999 and the DPRs indicate that it took quite awhile for the sensors to return to operation. We believe that the flooding resulted in corrosion in the connectors and that may explain the increased noise levels.

STS-2

1. Problems with STS-2 data from 1999-2003

   There are several DPRs starting at 2/10/1998 that document the STS-2 with poor data quality. On 2003,230 the seismometer is reported as once again operating properly. One DPR covering 2/19/96 – 4/13/2004 noted that the horizontal sensor values were assigned new values in the dataless based on a cooperative study with Harvard that the STS-2 horizontals were only producing half of the double-ended output. These values remain in use.

   DPRs also note high noise for the secondary sensor due to environmental noise in the vault. As was typical in early installations of secondary sensors, this STS-2 is not well-installed. This will be addressed during the station upgrade.

2. Misorientation angle of -7^{o}

   A single DPR on orientation states the STS-2 was re-oriented by the station operator with changes made in the dataless 1996,235. It is certainly possible that during this effort, a misorientation occurred. We believe STS-1s and STS-2 orientations are in error (between the two sensors) by around 1.5 degrees. We will not have a good way to determine the absolute orientations of these instruments until we deploy a SensOrLoc kit to CASY.

FBA-23

1. N/S component of the FBA did not detect the Haitian or Chilean earthquakes

   Although not part of the WQC review, we noted problems with the N/S component of the FBA as part of the recent earthquake review. A trouble ticket has been opened for this problem.

Site issues: The WQC report identifies an annual signal in the coherence analysis of the horizontal components and attributes it to the STS-1. There are a number of DPRs for CASY indicating changes in mass positions, suggesting that there are vault stability issues common to permafrost environments. Our analysis suggests that the signal on the coherence plots originates in the STS-2.

Calibrations: Station calibrations for CASY were run in 1996, 1998, 2006, 2008, 2009, and 2010. The 1996 calibration did not include a random telegraph calibration, only sine and step calibrations. During the 1998 calibration there was a problem with the instrument and thus no reliable calibration was recorded. The last four calibrations (2006-2010) indicate that all three components of the primary sensor are showing lowered long-period response corners. The horizontal components see more severe damping than the vertical, which is in agreement with the WQC report. Finally, we have verified that the damping of the long-period corner is amplitude dependent, indicating a possible humidity effect.

Comments: There have been a number of DPRs opened on CASY over the years, although the ASL had not opened DPRs indicating the seriousness of the problems on the STS-1 until recently. Through our own cal analysis and other comparisons we concur with the finding of this report. Trouble tickets have been opened and DPRs have been issued.

It is certainly clear that we let CASY go, focusing on other stations that were easier and more cost-effective to reach. Tying up a field engineer for 2-3 months is quite expensive and that was a consideration. Although the budget situation improved in FY09, we've been focused on Q330 upgrades.

ASL personnel have been in contact with Geoscience Australia to begin planning a visit. Because of the remoteness of the location and the limitations associated with access, the earliest we expect to visit the site is 2010-2011. We plan to deploy a SensOrLoc kit to CASY when the station is upgraded and confirm the orientation of all the sensors.

IU KIP:

Overview: KIP is a former WWSSN station that has continued to operate as a collaborative Geoscope and GSN station. It is easily reached for maintenance from NOAA's Pacific Tsunami Warning Center, which provides support in operating the station. The location is also convenient for visits while a field engineer is in transit to other sites in the Pacific.

STS-1

1. All channels show change of scaling factor beginning in 2003 through 2006. Anomalously low noise on the vertical channel corresponds to reduced scaling.

   No DPRs issued identify this problem. However, an anomalous calibration in 2006 informed us of the problem and we replaced the FBEs on all three sensors. This fixed the problem with the reduced scaling.

   KIP is the station which first alerted us to the humidity problem in the STS-1 FBEs. Although the response was anomalous at periods of several hundred seconds, it was normal in the tidal and microseismic bands.

   We have issued a DPR for the anomalous time period in order to notify the user community about the problem.
2. STS-1 Horizontals show high noise since 2008

   We have observed long-period pulses that have raised the noise levels since sometime in late 2007. These actually started earlier but have become worse over time. We believe these pulses are from moisture "somewhere" in the system, most likely cable connectors or the feedback electronic box capacitors. We have issued a DPR and opened a trouble ticket.

3. E/W STS-1 shows reduced scaling 2008-present

   This problem was identified in the fall of 2009, based on the annual calibration, and a trouble ticket was opened. Subsequent calibrations have shown that the effect is amplitude dependent, suggesting a recurrence of the humidity problem. However, the problem has not been resolved by the addition of desiccant and efforts to dry out the connectors. We also see this problem on the N/S component and are continuing to investigate. A new set of FBEs has been shipped for installation by the station operator

   We have issued a DPR to document the problem.
4. Polarity problems 1988—1990

   Previously we had a polarity reversal documented for the horizontal STS-1 channels from 1988,228 through 1990,276. We have now confirmed the vertical STS-1 had correct polarity from 1988,228 through 1989,300. The N/S STS-1 polarities were also good for this same time frame. The E/W polarities were correct from 1988,228 through 1988,350 but reversed from 1988,350 through 1989,300. All STS-1 polarities were reversed from 1989,300 through 1990,276. These changes have been made in the dataless as of Feb 2010.

STS-2

No problems reported by the WQC.

Calibrations: Station calibrations for KIP were run in 1995, 1998, 2004, 2005, 2006, 2007, 2009, and 2010. The 1998 calibration did not include a random telegraph calibration. The 2004 calibration did not yield useable data for analysis of the long-period corner. After the feedback boxes were replaced in 2006, calibrations were done on the primary sensor. These calibrations indicate a slightly lowered response although this was not identified at that time. The more recent calibrations indicate the instrument's response is lower than nominal on both horizontals. Multiple amplitude calibrations indicate that the long-period corner is amplitude dependent on the horizontal sensors (but not the vertical), even after the feedback box has been dried out and the desiccant has been replaced. This problem is still under investigation.

Comments: As noted above, KIP was the station that led to the investigations of the effect of humidity on the FBE boxes. At this point, we do not know whether we will be able to recover the full non-linear response of the STS-1 from 2003-2006 although we are continuing to investigate this issue. We intend to replace the FBEs with E300s when a field team goes through Hawaii.

When the station is upgraded, we will improve the installation of the STS-2 through the use of granite baseplate and "stock pot" cover.

II ALE

Early instrument response

The WQC ALE report notes problems with the published system response covering ALE data recorded prior to 1993. When we investigated the system response problem, we discovered that an error was introduced into the ALE metadata in 2001 when IDA transitioned between response information database systems. Since the old information was still available, we were able to correct the data and send an update to the DMC within one week. Lamont has made a preliminary check of the revised metadata and found that the change addressed the problem

exemplified in Figure 8 of their report. An example is provided in the IDA annual report and proposal.

STS-2
The report notes transients in recent STS-2 streams that mar the quality of the data. To correct the quality of the STS2 data may require replacement of the sensor. We expect to upgrade ALE this year and may take the opportunity to make a switch at that time. Alternatively, we may opt for installing better thermal insulation foam if no new sensor is available.

IC XAN
Overview: Like other GSN stations in China, XAN is maintained by personnel of the China Earthquake Administration and the USGS has no remote access to the acquisition systems. Data from XAN are not transmitted in real time and are received on tape.

From 1986 to 2000, installation and maintenance of the China network was provided by Brian Brizzell, a contract engineer based in Asia. Brian worked directly with Mr. Liu of the CEA to address problems identified by ASL personnel. When Brian left in 2000, the ASL worked directly with CEA personnel. Mr. Liu left the CEA in 2004 and his technical skills are missed.

In late 2007, this situation was exacerbated when the established path of shipping through the US Embassy was eliminated. As a result, spare and replacement parts shipments were backed up awaiting a resolution of Customs problems, but parts are now being shipped.

STS-1
1. Scaling problems initiate for the horizontals in 1999 and for the vertical in 2005.
   The ASL had not issued any DPRs related to the sensitivity problem, which may be related to a FBE humidity problem. We have issued a DPR in order to document the problem and opened a trouble ticket.
2. The STS-1 noise levels increased significantly in 1999.
   A DPR on the long-period noise at XAN was opened in 1999. We are uncertain about the source of the problem. It appears contemporaneous with the replacement of the STS-2, suggesting that the some problem was introduced during that site visit.
3. Vertical component is extremely noisy starting in 2008
   The vertical component of the STS-1 has been pegged since 2/25/2008, as reported in our ticketing system. We requested that the station operator recenter the seismometer and have included a replacement STS-1 sensor in one of the current shipments.

STS-2
1. Poor coherence is observed until 2000.
   A DPR in 1999 indicated that the STS-2 had failed. It was replaced with a new sensor later that year.
2. The STS-2 vertical noise levels were high in 1999.
   While high vertical noise levels were not expressly stated, a 1999 DPR indicates the STS-2 was producing digitizer noise.
3. The Vertical and E/W components of the sensor appear to begin malfunctioning in 2008.

A trouble ticket issued in 2008 indicates problems with the scaling horizontal components of the STS-2. This problem had not been submitted as a DPR. A problem with the vertical component was not identified. A replacement STS-2 had been held up because of the shipping problems but we hope to see it installed within a few weeks.

Site issues: The WQC report indicates that noise increased at the site in 2004 as well as a seasonal signature. We believe the annual signature is associated with the STS-2, similar to what was going on at CASY.

Calibrations: The USGS does not have access to the datalogger and is not able to perform calibrations directly.

Comments: The politics of working in China has complicated the maintenance of this station, particularly with regard to getting equipment into the country. We had put together a large shipment of equipment for the stations in 2007, which was delayed because of the change in shipping protocol. We are relieved that the shipping problems are resolved for the moment.

We will be working with the CEA in the coming months to address other data quality issues. We hope to engage the CEA in running calibrations as well as work with them to install E300s. We also plan to begin discussions about the Q330 upgrades.

II DGAR

The DGAR report shows compelling evidence of a problem with the STS1-NS long period sensitivity during 2005. That problem has since disappeared. We expect that this kind of behavior may be identified and compensated for with more frequent calibration tests. This will be possible with the new data systems, which support remote calibrations. DGAR is scheduled for upgrade late in the campaign. We will also check the station orientation and sensitivity with a SensOrLoc kit at that time.

IU WCI

*Overview***:** WCI (Wyandotte Caves State Park) was originally installed and operated by St. Louis University. The USGS GSN project became involved in 2002 through a coordinated effort among IRIS, the USGS, and St. Louis University. Today, the station is considered part of the ANSS backbone network as well as the GSN. ANSS personnel provide support for the communications system.

Although the site is located in the United States, access to the caves is limited because of the risk of spreading the bat white-nose fungus to uninfected areas. There is no secondary sensor or accelerometer at WCI.

STS-1

1. The STS-1 has serious scaling problems on all components since 1998. Body and mantle wave scalings differ.

   We suspect that the problems with the site may stem from the humidity problem in the FBEs, although the development of problems so soon after installation may indicate some

issues with the initial installation. A trouble ticket was opened for the STS-1 in August 2009. A DPR was not issued at the time, but has been issued now.

2. Noise levels on Z and E/W sensors increased dramatically immediately after installation.
   The ASL was not performing QC on the station at that time. We are not sure what occurred.
3. Little data recovered from late 1998 to early 2002
   The GSN program assumed responsibility for the station in 2002. We do not know what problems caused the low data return.
4. Noise levels on Z and E/W sensors increased in 2008.
   We also see a gradual increase of noise level on the order of approximately 8 dB. The increased long-period noise is coming from instrument pulses that are showing gradually increased amplitudes.

Calibration: The system installed at WCI does not allow the system to be remotely calibrated. Remote calibrations will be possibly when a Q330 system is installed.

Comments: The USGS GSN program has been involved in the maintenance of this station since 2002. Although USGS personnel have visited the site to install and maintain the communications network, no one has actually visited the cave and performed maintenance on the station. Instead, the USGS has worked with staff from St. Louis University to support the station.

We are investigating the possibility of getting special permission to enter the cave.

The USGS is expecting to upgrade the station in the next year or so. The upgrade will include the installation of a secondary sensor and an accelerometer as well as replacement of the STS-1 FBE. A full calibration will be run before the upgrade and a SensOrLoc deployment will take place.

IU DAV

Overview: DAV is another WWSSN site and the station has been operated by personnel of the Philippine volcano and seismology organization PHIVOLCS since installation.

Maintenance of the station has been complicated by the fact that the island of Mindanao was off-limits to all US citizens for a number of years. In 2009, the State Department changed their advisory to allow US citizens to visit, although serious warnings are provided: “Some foreigners who reside in or visit Mindanao and the Sulu Archipelago hire their own security”. As a result, no one from the ASL has visited since 1995, although occasional maintenance has been performed by CTBTO staff (for example, they installed the STS-2 in 2007).

STS-1

1. The STS-1 scaled well only in 1995. By 1997, all three components no longer match synthetics.
   A number of DPRs indicate problems with the STS-1 (and improvements) although the overall problem was not identified. We have opened a trouble ticket and a DPR to document the problem.

2. The STS-1 had variable noise levels over the entire installation.
   There are no specific DPRs on the noise levels, although a number of DPRs indicate poor performance.

STS-2

1. All aspects of the STS-2 appear to be operating normally over the entire installation. The problem in performing analysis is due to the high noise levels for the STS-2.
   The STS-2 was installed by the CTBTO, before we had improved our installation of secondary sensors. We intend to improve the installation during the upgrade.
2. Polarization analysis shows a median rotation angle of -4º
   This sensor was installed by the CTBTO. The orientation will be checked when we are able to deploy a SensOrLoc kit.

Calibrations: Calibrations at DAV have been run in 1994, 1995, 1996, 1997, 2006, and 2009. We were not able to estimate the long-period corner during the last two calibrations because of the excessive site noise during these calibration times. With the lack of good calibration data as well as the largely variable noise levels we have been unable to fit the long-period response to the STS-1 at this station. We have scheduled another calibration for this site in order to obtain a good recording.

Comments: DAV has been a difficult site to maintain well because of the limitations on travel by US citizens. We have been fortunate to work with the CTBTO for the installation of the STS-2. We are awaiting the results of the scheduled calibration to determine the next steps in improving the performance of the STS-1s.

II RPN

The RPN report indicates the station is operating satisfactorily. There is a gain difference between the STS1 and STS2 that can be resolved with the absolute gain test we are using in our current calibration campaign. This test will probably be conducted when the station is upgraded and a technician uses the SensOrLoc kit at the site.

Immediately following the Maule, Chile, event in February, the metadata for the STS1-N's sensitivity was incorrect. On March 29th, we published a new dataless SEED with this value adjusted based upon the co-located STS-2.

IU KONO:

Overview: The station, formerly a WWSSN site, is deep inside an old silver mine that is used now only for tourist excursions. Unfortunately, the instruments are only a few feet from the mine's rail line, and tilt pulses from the passing trains are dramatic though not constant. Otherwise, it is a quiet and stable site.

STS-1

1. Polarization study shows median angle of 2 to 3 degrees.
   The SensOrLoc deployment in the fall of 2009 found 1.2 degrees. The metadata were updated in Sept 2009.
2. The synthetic fit shows a loss of E/W LP gain in 2006.
   No DPRs address this issue directly.

CMG-3T (not an STS-2)

1. The noise level increased in 2007.
   The CMG was replaced in late 2006 to fix a problem with high-frequency noise. The high-frequency problem appears to have been fixed, with slightly elevated long period noise.
2. The CMG-3T has a median rotation angle of 3 degrees.
   The SensOrLoc deployment in the fall of 2009 found 2.2 degrees. The metadata were updated in Sept 2009.

Timing: The WQC report mentions timing problems for both sensors. Vandalism resulted in the loss of the GPS clock signal in 2004. The problem was extensively documented with DPRs. It was a tricky problem to fix because of the long cable run required for the antenna.

Calibrations: Calibrations have been run at KONO during 1991, 1997, 1999, 2003, 2005, 2006, 2008, and 2009. All of the recent calibrations (2003-2009) indicate that the instrument's long-period corner matches the instrument's nominal response very closely. We are currently in the process of analyzing older calibration data.

Comments: The FBEs were replaced with an E300 during the Q330 upgrade. We were not able to replace the CMG-3T during the upgrade, but plan to install an STS-2 during a future maintenance trip.

IC SSE:

Overview: Like other GSN stations in China, SSE is maintained by staff of the China Earthquake Administration and the USGS has no remote access to the acquisition systems. Data from SSE are delayed by 30 minutes in transmission.

Many of the issues identified for XAN also apply to SSE (and to our other stations in China).

From 1986 to 2000, installation and maintenance of the China network was provided by Brian Brizzell, a contract engineer based in Asia. Brian worked directly with Mr. Liu of the CEA to address problems identified by ASL staff. When Brian left in 2000, the ASL worked directly with CEA staff. Mr. Liu left the CEA in 2004 and his technical skills are missed.

In late 2007, this situation was exacerbated when the established path of shipping through the US Embassy was eliminated. As a result, spare and replacement parts shipments were backed up awaiting a resolution of Customs problems, but parts are now being shipped.

STS-1:

1. Beginning to 2000 the N/S component shows problems with scaling.
   This problem was not identified in the QC process and there are no DPRs. Humidity in the FBE is a possible explanation but we cannot be certain without calibrations. A trouble ticket has been opened and a DPR issued to document that problem.
2. Noise has been increasing since 2002, especially N/S.
   A problem with increased noise in 2001 was resolved after a lengthy troubleshooting process with the station operator. We have not identified the source of the increased noise.

3. Polarization analysis shows median rotation angle of 7º.
   The orientation will be checked when we are able to deploy a SensOrLoc kit.

STS-2:

1. The STS-2 demonstrated a sharp loss of gain on the Z-component in 2006..
   There are no DPRs for the STS-2 at SSE. In addition, we have observed a loss of sensitivity in the horizontal components. A replacement STS-2 is part of the current shipments making their way to China.
2. The noise on the STS-2 was very low after the 1999 installation. In then increased up to 10 dB in 2000.
   No DPR records exist.
3. Polarization analysis shows a median rotation angle of 5º.
   The orientation will be checked when we are able to deploy a SensOrLoc kit.

Gain differences: The WQC notes a frequency-independent difference in gain (~15%) between the STS-1 and STS-2 components beginning in 1999. Analysis of the tidal data indicates that this problem originates in the STS-1 (at least in the Z-component, Davis and Berger (2007)) and may be in the sensor or in the digitizer board.

Calibrations: The USGS does not have access to the datalogger and is not able to perform calibrations directly.

Comments: The politics of working in China has complicated the maintenance of this station, particularly with regard to getting equipment into the country. We had put together a large shipment of equipment for the stations in 2007, which was delayed because of the change in shipping protocol. We are relieved that the shipping problems are resolved for the moment.

We will be working with the CEA in the coming months to address other data quality issues. We hope to engage the CEA in running calibrations as well as work with them to install E300s. We also plan to begin discussions about the Q330 upgrades.

Moving forward

Station upgrades

Federal stimulus funding from NSF and USGS in 2009 enabled the GSN to procure sufficient equipment to supply the upgrade process. The procurements include Q330s, secondary sensors, and Metrozet STS- E300 electronics for all sites. At the same time, the GSN accelerated the deployment and upgrade to NGS ("next generation" systems) throughout the GSN. This expanded field effort will enable the GSN to address many outstanding data quality, particularly with the STS-1 sensors.

As a part of its 2009 field season, the GSN performed 25 upgrades with the installation of Q330s. During these site visits, 12 E300 replacements of STS-1 FBEs were conducted and 12 broadband secondary sensors were replaced or installed.

While some problems with the STS-1 seismometers will be solved with the E300s, some will not as demonstrated by upgrades at HRV, INCN, and SDV. We are investigating the problems at these sites. As there is still no replacement for STS-1 mechanical assemblages, the GSN will have to rely upon a secondary broadband sensor installed on-site to assure adequate data quality in these cases. The extent of mechanical or other problems with the STS-1s is not yet resolved, but many problems are consistent with humidity issues in the FBE.

Challenges also remain with the primary borehole sensor, the KS-54000. There are GSN sites where the installed KS-54000 is noisy or operating with dead channels, in part, because of the lack of replacement equipment. Recently purchased KS-54000 have failed at an unacceptably high rate and the GSN decided against the purchase of additional sensors, relying upon repairs of existing units to keep sites operational. To ameliorate the problem, the GSN has procured secondary broadband sensors to be installed at the surface to provide for back-up broadband data. The GSN plans to procure and test new prototype replacements for the STS-1 and KS-54000 as they are developed.

Emergency Maintenance

Various issues sometimes preclude rapid response to specific sites, including shipping schedules, customs, and local/national political situations. In particular, the ASL currently has limited flexibility through the end of FY10 because of ARRA requirements. However, to the extent possible within the current effort in upgrading GSN stations, GSN will expedite efforts to rectify data quality issues.

Calibration

GSN will continue its active calibration program following the 2009 policy, and provide for both absolute and/or relative calibrations yearly at all sites either via field visits or remote telemetry links. In 2009, 66 relative calibrations were performed, at essentially all GSN sites with telemetry and remote calibration capability

IDA and the ASL have run numerous calibrations over the years. Although the IDA group has analyzed the results and updated metadata following every calibration, the ASL has not, in part due to limitations in staffing. In addition, the USGS had placed a lower priority on analyzing calibrations in the past because of their experience with the GTSN. Weekly calibrations were

performed on the KS-54000 and GS-21 sensors of the GTSN over a period of five years and the results were remarkably consistent, leading to confidence that feedback sensors were very stable.

The ASL has now rectified the staffing situation by the addition of Adam Ringler. Over the past several weeks, Adam Ringler and Bob Hutt have conducted tests to assess the accuracy of the ASL random binary and step calibrations. The occurrence of the Chilean earthquake provided a fortuitous large signal to verify their results. Their review recommends that ASL update metadata when the instrument's damping or corner period parameters differ by more than 1% of the currently published metadata.

All the GSN calibration data back to 2001 has been processed to fit the long-period poles. Each calibration analysis must be reviewed by hand to verify the results (some calibrations may be too noisy to produce a good result) before metadata are changed. We are currently assessing the tools used to update sensor metadata, in order to reduce the likelihood of introducing errors during the updating process. The older calibrations are currently being set up so those can be processed those as well. Metadata updates will begin in April.

In order to investigate the temporal dependence of station calibration more systematically for STS-1s and other sensors, the ASL is calibrating five GSN stations (PMG, POHA, SDV, TSUM, and GUMO) monthly for a six-month test period.

Enhanced quality control methods
IDA and ASL have been investigating tools to extend their data quality control procedures. The ASL has implemented methods to identify time-dependent changes in USGS operated stations using power levels, refined analysis of calibration signals and spectral techniques (see, for example, ftp://ftpint.usgs.gov/pub/cr/nm/albuquerque/ASL/pub/users/GSN_data_quality/ASL QC Tools.doc). Both groups are gearing up to incorporate synthetic seismograms into their analysis.

Communications
One of the primary criticisms of the WQC reports is the lack of communication about station problems to the community. We agree that this has been a problem and we look forward to working with the DMS SC and GSN SC to identify better means of communicating problems.

The current mechanism common to both IDA and ASL is the Data Problem Report tool available through a Web interface at the IRIS DMC. There is a general sense that this mechanism is not well used (or used at all) by the community, which led to some cynicism regarding the process. In fact, the ASL staff cut back on using DPRs to report problems in 2007.

Because DPRs remain the only common mechanism, the ASL has renewed its use of this tool. Both ASL and IDA also use the Web to communicate about problems, although not in a standard form.

Performance metrics
The GSN Network Operations Group (ASL, IDA, IRIS) is beginning to develop uniform performance metrics for the GSN in order to provide for objective measures of data quality. The

intention is for the metrics to be published, and applied routinely to GSN data. The performance measurements will guide decisions about repair/replacement/maintenance of GSN instrumentation, as well as providing a means for the scientific community to easily assess the known quality of a station and sensor channel. These metrics will be developed in collaboration with WQC, GSN SC, and DMS SC.