Final Technical Report

Project title: Upgrading the Lamont Cooperative Seismographic Network and Modernization of the Advanced National Seismic System –Northeast Region.

Network name: **Lamont-Doherty Cooperative Seismographic Network (LCSN)**

USGS Cooperative Agreement number: G09AC00491

Principal Investigator: Won-Young Kim
Lamont-Doherty Earth Observatory of Columbia University
61 Route 9W, PO Box 1000
Palisades, NY 10964

Phone 845-365-8387, Fax: 845-365-8150
Email Address: wykim@ldeo.columbia.edu

Project Web Site: http://www.ldeo.columbia.edu/LCSN

Term covered by this report: **September 15, 2009 – September 15, 2011**

Upgrading the Lamont Cooperative Seismographic Network and Modernization of the Advanced National Seismic System –Northeast Region.

USGS Cooperative Agreement Number: G09AC00491

Won-Young Kim
Lamont-Doherty Earth Observatory of Columbia University
Palisades, NY 10964
Telephone: 845-365-8387, Fax: 845-365-8150, E-mail: wykim@ldeo.columbia.edu

Summary

Upgrading the seismographic stations of the Lamont Cooperative Seismographic Network (LCSN) and modernizing the Advanced National Seismic System (ANSS)–Northeast under the auspices of the American Recovery and Reinvestment Act (ARRA) of 2009 is the main goal of this project. We upgraded 24 broadband seismographic stations and deployed eight (8) new broadband stations during the spring of 2009 and September 2011 – a two-year seismic upgrades campaign. We also upgraded eight (8) short-period legacy stations with analog RF telemetry. Four of the short-period legacy stations were upgraded to broadband seismographic stations using Ethernet radios. Hence, LCSN now operates 32 broadband seismographic stations and 11 short-period stations in the northeastern United States monitoring earthquakes that occur in seven states: Connecticut, Delaware, Maryland, New Jersey, New York, Pennsylvania and Vermont. LCSN also monitors earthquakes in Washington, D.C. and northeastern Ohio. Six strong-motion instruments are also deployed around metropolitan New York City as part of the ANSS urban ground motion network.

The LCSN network operations center was upgraded with two (2) of the Real Time Servers and one (1) of the Post-Processing Server computers in the spring of 2010. And in June 2010, the AQMS (ANSS Quake Monitoring System) software was installed on the new server computers. Currently, AQMS is the primary earthquake data processing system at LCSN. AQMS is used for earthquake data acquisition, automatic processing, interactive analysis, and earthquake information distribution at the LCSN data collection and processing center at Lamont-Doherty Earth Observatory (LDEO) campus in Palisades, NY.

Through the seismic upgrades during 2009-2011, the seismographic station uptime and data recovery rates of the LCSN stations have been drastically improved. In particular, the third generation digital recorders being employed allow: 1) stable and robust data transfer with no data drop-offs and versatile telemetry via the steady Ethernet TCP/IP protocol; 2) remotely mass-center the broadband sensors, thereby reducing significantly the station service and maintenance trips; 3) very low power consumption of the dataloggers – typically a 6-channel unit with GPS clock consumes about 0.20 Ampere, allowing most of the remote stations powered by solar panels and batteries to operate with high station uptime (over 92%); 4) stable digitization and regularly, remotely calibrated sensors provide high quality digital seismic data that will allow us to detect and locate local and regional earthquakes with high confidence.

For real-time data exchange, integration and archive, LCSN exceeds the "ANSS Performance Standard (APS) v2.4". For rapid generation of earthquake parameters, LCSN performs slightly under the target outlined in the category, Mod-High Hazard Area. In particular, hypocenter and magnitude are usually posted in 15 – 30 minutes. We are working towards ~5 minutes latency for accurate hypocenter and magnitude information. Moment tensor and ShakeMap have similar latency to the ANSS performance standard, and LCSN is trying to meet the APS target, that is, ~10 –15 minutes posting time.

1. Upgrade of Broadband Seismographic Stations of the LCSN

We upgraded 24 broadband seismographic stations of the LCSN and deployed 8 new broadband stations during Sept. 2009-Sept. 2011 as listed in Table 1. These stations are plotted in Figure 1 with *red triangles*. The upgrade of broadband stations includes: 1) 6-channel datalogger for existing 3-component broadband sensor and 3-component strong-motion sensor; 2) improved seismic vault condition and construction of new concrete vaults; 3) upgrade digital serial spread-spectrum radios with Ethernet bridges with efficient TCP/IP protocol; 4) upgraded medium-period broadband sensors that have a natural period of T_0=20-30 sec and high instrument noise with the ANSS standard broadband sensor with longer natural period T_0= ~120 sec and low sensor noise; and 5) replaced aging power supply system which consists of solar panels and deep-cycle rechargeable batteries at many sites.

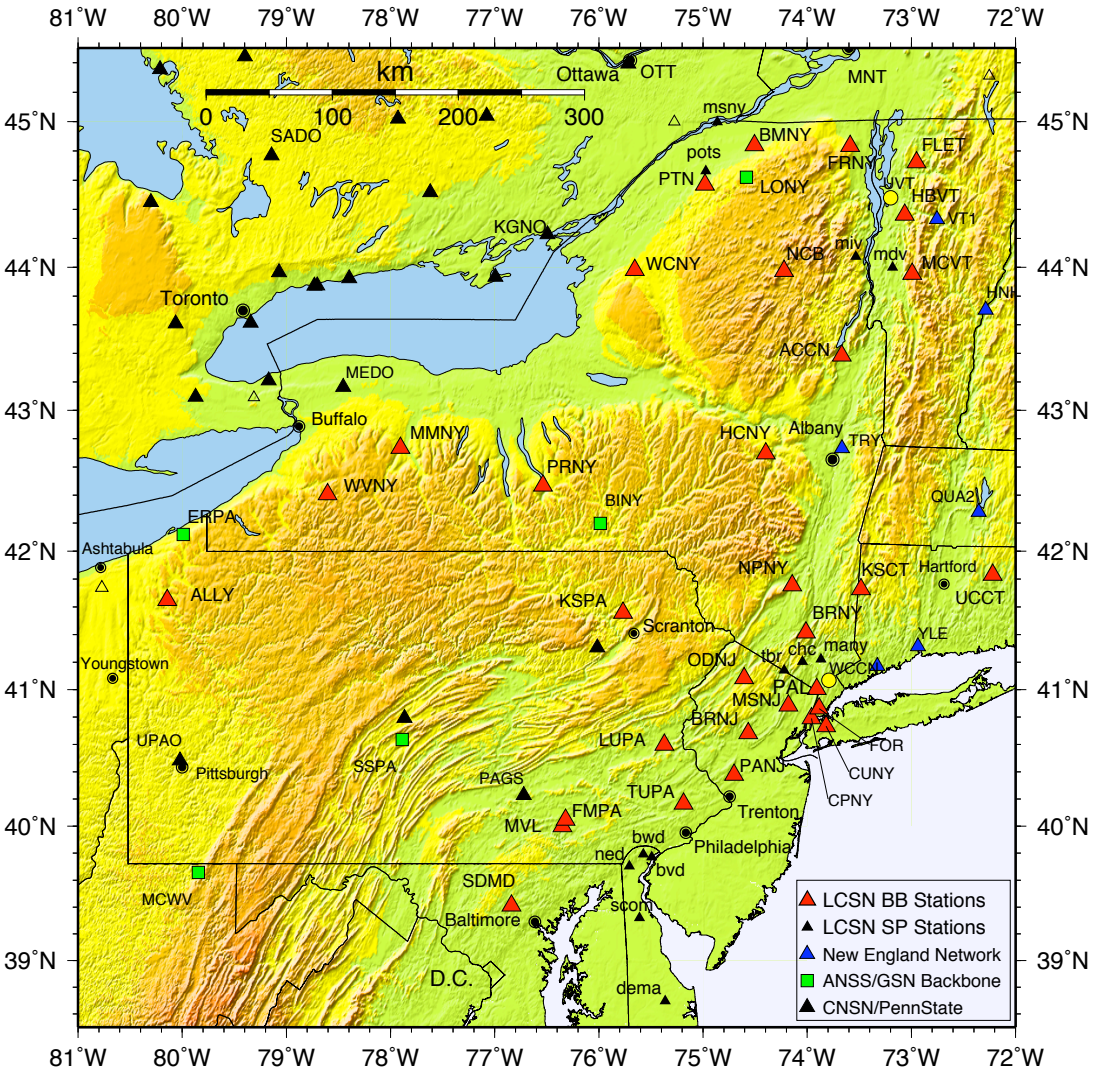

Figure 1. Map showing the upgraded broadband and short-period seismographic stations of the Lamont Cooperative Seismographic Network (LCSN). There are 32 broadband stations (*red triangles*), 11 short-period stations (*filled triangles*), and two strong-motion instrument sites upgraded during Sept. 2009–Sept. 2011. The strong-motion instrument sites at Westchester Community College, NY (WCCN) and University of Vermont, Burlington are plotted with *yellow circles*. Stations of the USNSN (*green squares*), NESN (New England Seismic Network; *blue triangles*) in northeastern United States and stations in southeastern Canada (CNSN, *solid triangles*) are plotted for reference.

Table 1. Broadband stations of LCSN upgraded and new deployments during Sept. 2009-Sept. 2011.

Code	Recorder	Sensor	Telemetry	Station name	Operation
ACCN	RT130	CMG-3T	Ethernet radio	Adirondack Community College, New York	1999-11-10
ALLY	RT130	CMG-3ESP	Direct Ethernet	Allegheny College, Meadville, PA	2002-05-30
BRNJ	Q730	Trillium-120PA	Direct Serial	Basking Ridge, New Jersey	1999-11-08
BRNY	Q730	CMG-3T	Direct Serial	Black Rock Forest, Cornwall, NY	2006-06-16
CPNY	RT130	Trillium-120PA	Direct Ethernet	Central Park, New York City	2002-02-21
CUNY	RT130	CMG-3ESP	Direct Ethernet	Queens College, CUNY, Queens, NYC	2002-06-02
FMPA	Q730	CMG-40T	Direct Serial	Franklin and Marshall College, PA	2005-02-22
FOR	RT130	CMG-3T	Direct Ethernet	Fordham University, the Bronx, NYC	2002-04-18
FRNY	Q330S	STS-2	Ethernet radio	Flat Rock, Altona, NY	2003-11-13
HCNY	RT130	CMG-3T	Direct Ethernet	Howe Caverns, Cobleskill, NY	2006-03-01
LUPA	RT130	CMG-3T	Ethernet radio	Lehigh University, PA	2001-01-01
MMNY	RT130	CMG-3ESP	Direct Ethernet	Mount Morris Dam, NY	2008-08-06
MSNJ	RT130	Trillium40	Ethernet radio	Montclair State University, NJ	2007-11-02
MVL	RT130	CMG-3ESP	Serial radio	Millersville University, PA	2001-02-12
NCB	Q330S	STS-2	Ethernet radio	Newcomb, New York	1992-01-01
NPNY	Q330-3	STS-2	Ethernet radio	Mohonk Preserve, New Paltz, NY	2007-09-07
ODNJ	Q330S	STS-2	Ethernet radio	Ogdensburg, New Jersey	2007-06-23
PAL	Q330HR	STS-2	Ethernet radio	Palisades, New York	1980-01-01
PANJ	Q330-3	STS-2	Ethernet radio	Princeton, NJ	2008-02-16
PRNY	Q730	CMG-40T	Direct Serial	Paleontological Research Institution, Ithaca, NY	2006-03-30
PTN	RT130	CMG-3ESP	Ethernet radio	Potsdam, NY	1971-01-01
SDMD	DM24	CMG-3T	Serial radio	Soldier's Delight, Maryland	2001-11-01
UCCT	RT130	CMG-3ESP	Ethernet radio	University of Connecticut, Storrs, CT	2005-03-04
WCNY	RT130	Trillium-120PA	Ethernet radio	West Carthage, New York	2007-06-27
New stations deployed during 2009- Sept. 2011.					
BMNY	RT130	Trillium-120PA	Ethernet radio	Brushton-Moira, New York	2011-07-29
FLET	RT130	CMG-3ESP	Ethernet radio	Fletcher, VT	2011-07-09
HBVT	RT130	CMG-3ESP	Ethernet radio	Hinesburg, VT	2011-07-19
KSCT	RT130	CMG-3ESP	Direct Ethernet	Kent School, Kent, CT	2011-08-22
KSPA	RT130	Trillium-120PA	Ethernet radio	Keystone College, La Plume, PA	2009-07-09
MCVT	RT130	Trillium-120PA	Direct Ethernet	Middlebury College, VT	2011-08-04
TUPA	RT130	Trillium-120PA	Ethernet radio	Temple University, PA	2010-05-07
WVNY	RT130	Trillium-120PA	Ethernet radio	West Valley, New York	2010-08-05

At several host institutions, a PC with the Earthworm data acquisition system acquires seismic data from the remote site and sends the data to the central data collection and processing site at LDEO in Palisades, NY via the Internet in real time. All of these PCs at the host institutions were upgraded with newer model and installed with a UPS (Uninterruptible Power Supply).

We compared ambient noise power spectral density (PSD) at stations before and after the upgrade (Figure 2). At station BRNJ (Basking Ridge, NJ) seismometer with natural period T_0=20s is upgraded to a broadband seismometer with T_0=120s, and a concrete vault is constructed to house the sensor. At WCNY (West Carthage, NY) seismometer with T_0=30s is upgraded to one with T_0=120s. For station, BRNJ the improvement is very obvious and at all period band (Figure 2), for WCNY, the improvement is obvious at long period (Figure 2).

Table 2. Short-period stations upgraded during 2009-Sept. 2011

Code	Datalogger	Sensor	Telemetry	Station name	Operation
MANY	Q730	HS-10	RF/VHF	Mount Airy, NY	1993-01-08
TBR	Q730	HS-10	RF/VHF	Table Rock, NY	1975-01-01
MIV	RT130	HS-10	RF/VHF	Mineville, NY	1984-01-01
MDV	RT130	HS-10	RF/VHF	Middlebury, VT	1970-03-01
MSNY	Q730	HS-10	RF/VHF	Massena, NY	1976-01-01
POTS	RT130	S-13J	Direct Ethernet	SUNY Potsdam, NY	2006-05-22
BVD	Q730	HS-10	T1 – dedicated phone line	Bellevue State Park, Delaware	1985-02-01
BWD	Q730	HS-10	T1 – dedicated phone line	Brandywine State Park, Delaware	1985-02-01
DEMA	Q730	HS-10	Microwave	Delaware Emergency Management Agency	1999-10-01
NED	Q730	HS-10	T1 – dedicated phone line	Newark, Delaware	1972-11-01
SCOM	Q730	HS-10	Microwave	Sussex County Emergency Operation Center	1999-10-01

Table 3. Strong-motion stations

Code	Datalogger	Sensor	Telemetry	Station name	Operation
WCCN	CMG-5TD	CMG-5TD	Serial digital radio	Westchester Comm College, NY	2007-04-05
UVM1	NetQuake	NetQuake	Direct Ethernet	University of Vermont, Burlington, VT	2011-08-19
UVM3	NetQuake	NetQuake	Direct Ethernet	University of Vermont, Burlington, VT	2011-08-19

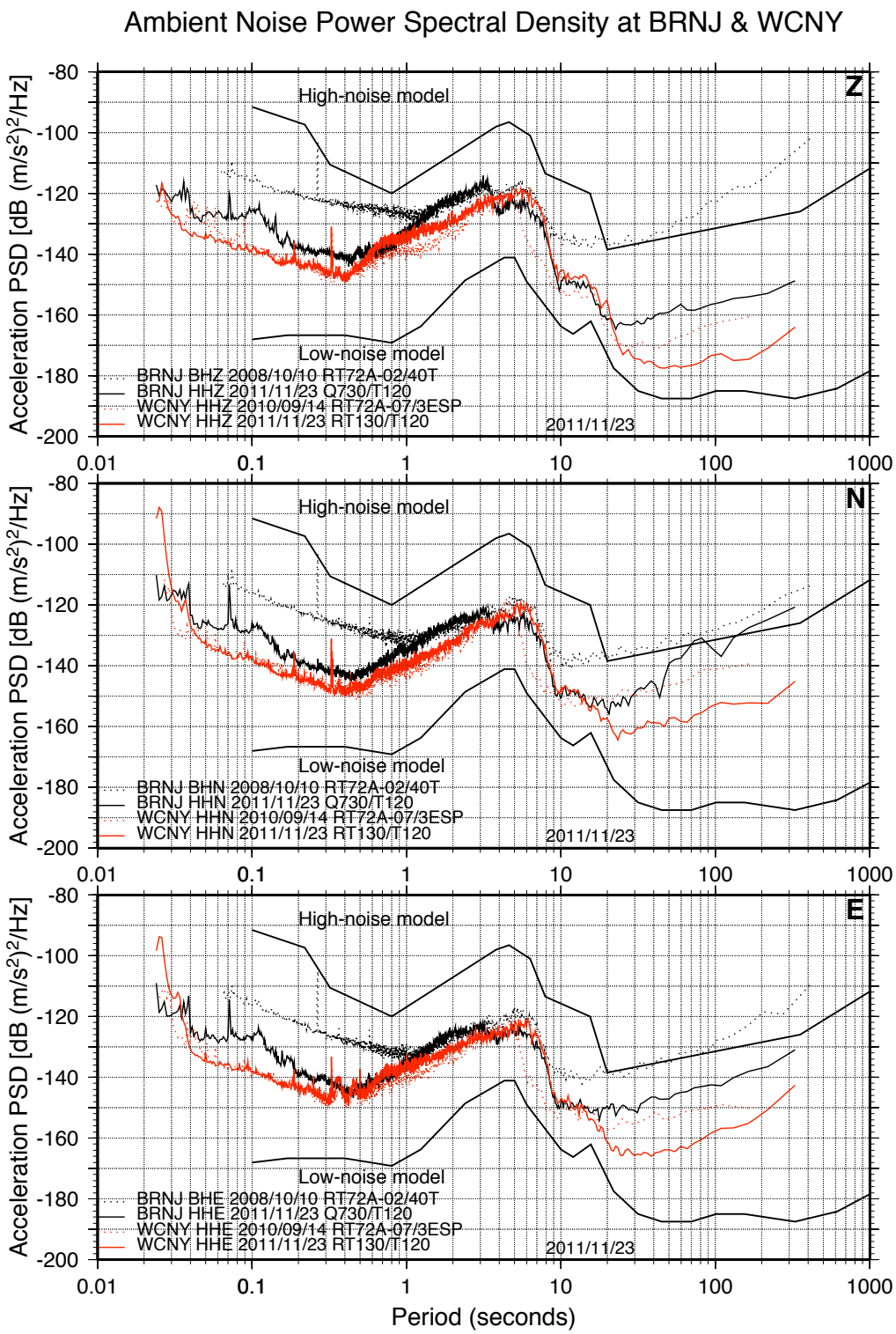

Figure 2. A comparison of 3-component ambient noise power spectral density (PSD) at two stations before (*dotted lines*) and after (*solid lines*) the seismic upgrade under ARRA 2009. At station BRNJ (*black lines*) seismometer with natural period T_0=20s is upgraded to a seismometer with T_0=120s, and a concrete vault is constructed to house the sensor. At WCNY seismometer with T_0=30s is upgraded to one with T_0=120s.

2. Upgrade of Short-Period Stations of the LCSN

We upgraded 11 short-period stations of the LCSN with mostly vertical sensors and analog RF telemetry. These are *legacy* stations deployed since early 1970s and hence, some of their instruments deteriorated over decades and make them increasingly difficult to repair, in particular, the telemetry equipment such as VCO (voltage controlled oscillator) and discriminator pair. Most of these short-period stations are deployed as clusters in areas of higher seismicity than surroundings or around urban population centers such as, Palisades sub-network in Greater NYC region (a in Figure 3) and Delaware sub-network around Philadelphia, PA–Wilmington, DE (d in Figure 3). These sub-networks were harder to upgrade than the broadband stations mainly due to switchover from the analog RF telemetry to digital spread-spectrum radio telemetry, which requires line-of-sight between the remote seismic station and receiving data collection centers/host institutions. In the following subsections, we will describe our seismic upgrades of 11 short-period stations in four sub-networks.

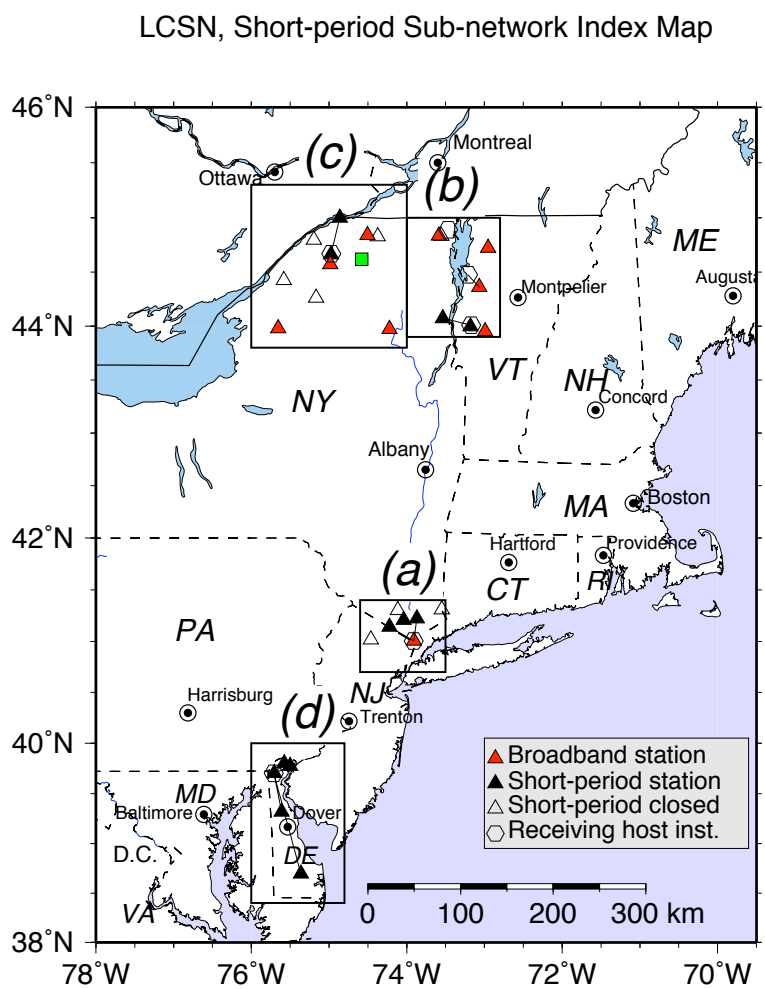

Figure 3. Map shows short-period stations (*solid triangles*) and sub-network data acquisition nodes (*hexagons*) of LCSN in 2009-2011. Sub-networks are: (a) Palisades, NY; (b) Lake Champlain sub-network with nodes at University of Vermont, Burlington and Middlebury College, VT; (c) SUNY-Potsdam sub-network, and (d) Delaware Geological Survey (DGS) sub-network covering Philadelphia, PA–Wilmington, DE region.

2.1. Upgrade of Palisades Sub-network of LCSN in Greater New York City Region

Prior to the ARRA seismic upgrades, five short-period seismographic stations of the LCSN monitored earthquakes in southern New York, northern New Jersey and western Connecticut. Though seismicity is relatively low in this region compared with more active Adirondacks and other seismic zones, earthquake risk is very high due to high population density and densely built lifelines and infrastructure in the area. The Palisades sub-network covers the Greater New York City region and acquired seismic data in real time using five RF (radio frequency) telemetry links. Seismic data from these stations were sent to receivers at the Lamont-Doherty Earth Observatory (LDEO) campus in Palisades, NY in real time.

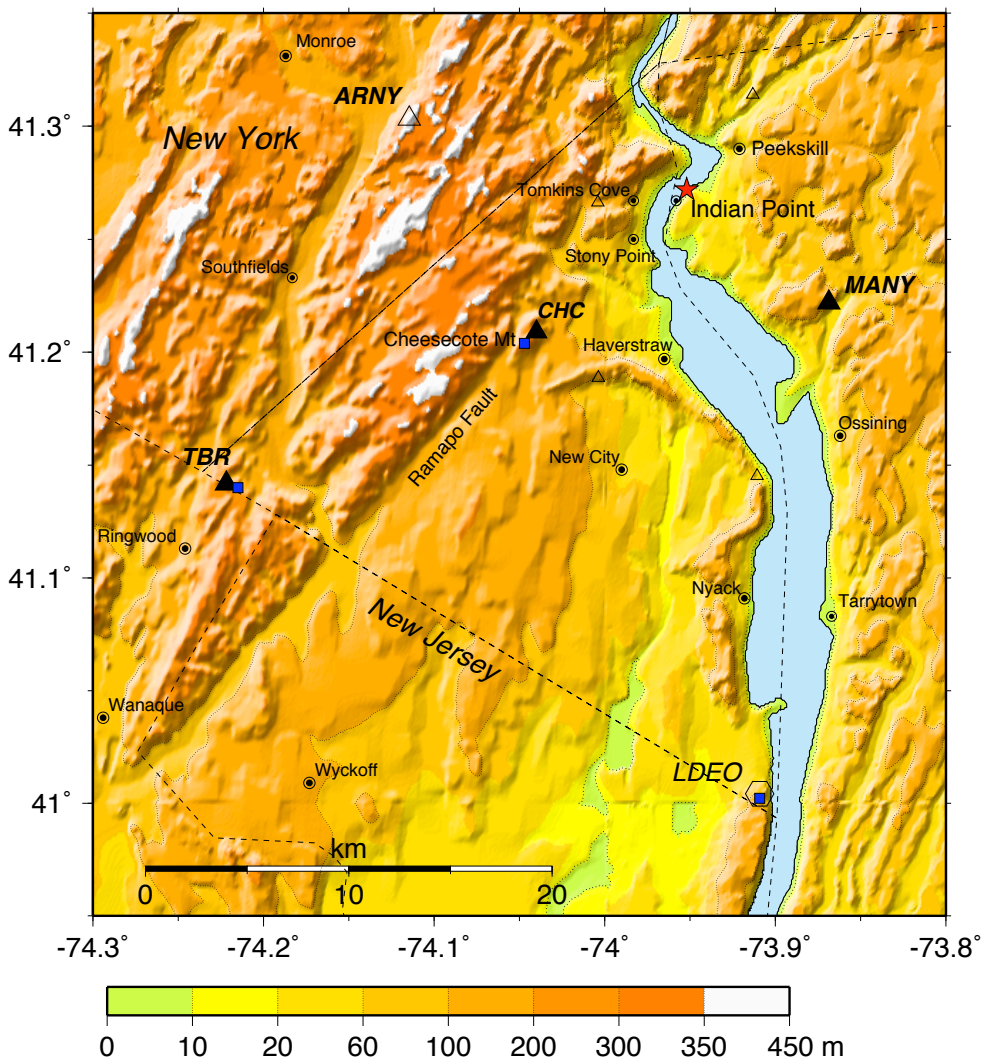

Figure 4. Upgraded seismographic stations in and around Palisades, NY (*solid triangles*) and Rockland County emergency communication microwave towers (*blue squares*). TBR remained at the existing site; ARNY is relocated to Cheesecote Mountain site (CHC) and MANY remained at the existing site. Seismic data from TBR, CHC and MANY are being configured to transmit to Lamont via Rockland County's microwave communication network, which will be completed during the summer of 2012.

Since the fall of 2008, LCSN has been working with Rockland County, NY to allow the county to build a microwave tower at the Lamont campus and utilize the newly built Rockland County (RC) microwave emergency communication network to carry seismic signals from the short-period seismic stations to LCSN data collection and processing center at Lamont campus. We planned to upgrade following:

1) TBR (Table Rock, NY): The RC microwave tower site is located close to the existing seismographic station. The RC microwave communication network will carry the data on TCP/IP to the microwave receiver at Lamont campus. The RC microwave communication network will be completed by August 2012.
2) ARNY (Arden House, NY): Relocated the seismic station to Cheesecote Mountain where the RC microwave tower is close to the seismic station site (see Figure 4).
3) MANY (Mount Airy, NY): It is configured to transfer data by using the RC microwave communication network tower near West Haverstraw, NY (Figure 4).
4) CRNY (Cross River, NY): It is relocated to the Kent School, Kent, Connecticut (KSCT). The seismic data is sent to Lamont by using Internet communication.

The upgrade of Palisades sub-network short-period stations will be completed in August 2012 when the Rockland County's microwave communication network will be completed. These relocations will improve monitoring earthquakes around Indian Point nuclear power plant in Buchanan, Westchester County, NY.

2.2. Upgrade of Lake Champlain Sub-network in Western Vermont–Adirondacks

Lake Champlain sub-network consisted of five short-period seismic stations around eastern Adirondacks along Lake Champlain and western Vermont (Figure 5). The stations cover active Adirondacks and western Quebec seismic zones in the region. For instance, the Mw 5.0 Au Sable Forks, NY earthquake of 20 April 2002 occurred in this region. A short-period seismic station PNZ (Plattsburgh, NY) was upgraded into a broadband instrument in the fall of 2003. The broadband station, FRNY (Flat Rock, Altona, NY) sends digital data to the Miner Institute of Agricultural Research in West Chazy, NY.

Two short-period seismic stations – FLET (Fletcher, VT) and HBVT (Hinesburg, VT), were upgraded into 3-component broadband and 3-component strong-motion sensors by installing a 6-channel datalogger. For HBVT, we were able to establish digital Ethernet radio telemetry to the University of Vermont in Burlington, but for FLET, we had to use a private Internet access point (Figure 5).

Two short-period, high-gain seismographic stations – MIV and MDV send seismic data using analog RF radio telemetry to the data collection center at Middlebury College, VT. In September 2004, datalogger at Middlebury College was upgraded to digital recording using Reftek DAS (model RT72-07).

We upgraded MDV into 3-component broadband seismometer and 3-component strong-motion sensor by installing a 6-channel datalogger. We were able to relocate the station to a quiet location with bedrock outcrop at Bread Loaf campus of the Middlebury College about 15 km east of the existing site. The new site is named MCVT (Middlebury College, VT; see Figure 5) and has direct Ethernet access. The legacy station MDV is still operational because the host institution wishes to have it running until it is no longer serviceable.

MIV short-period station sends data by using a analog RF radio to Middlebury College where an Earthworm system exports waveform data to LCSN data processing center via the Internet. We were unable to upgrade the station in time due to delayed permission from the landowner. It will be upgraded to short-period, 3-component station and data will be sent to data collection center at Middlebury College, VT by using the Ethernet radios as soon as we receive the permission.

(b) LCSN, Lake Champlain Sub-network

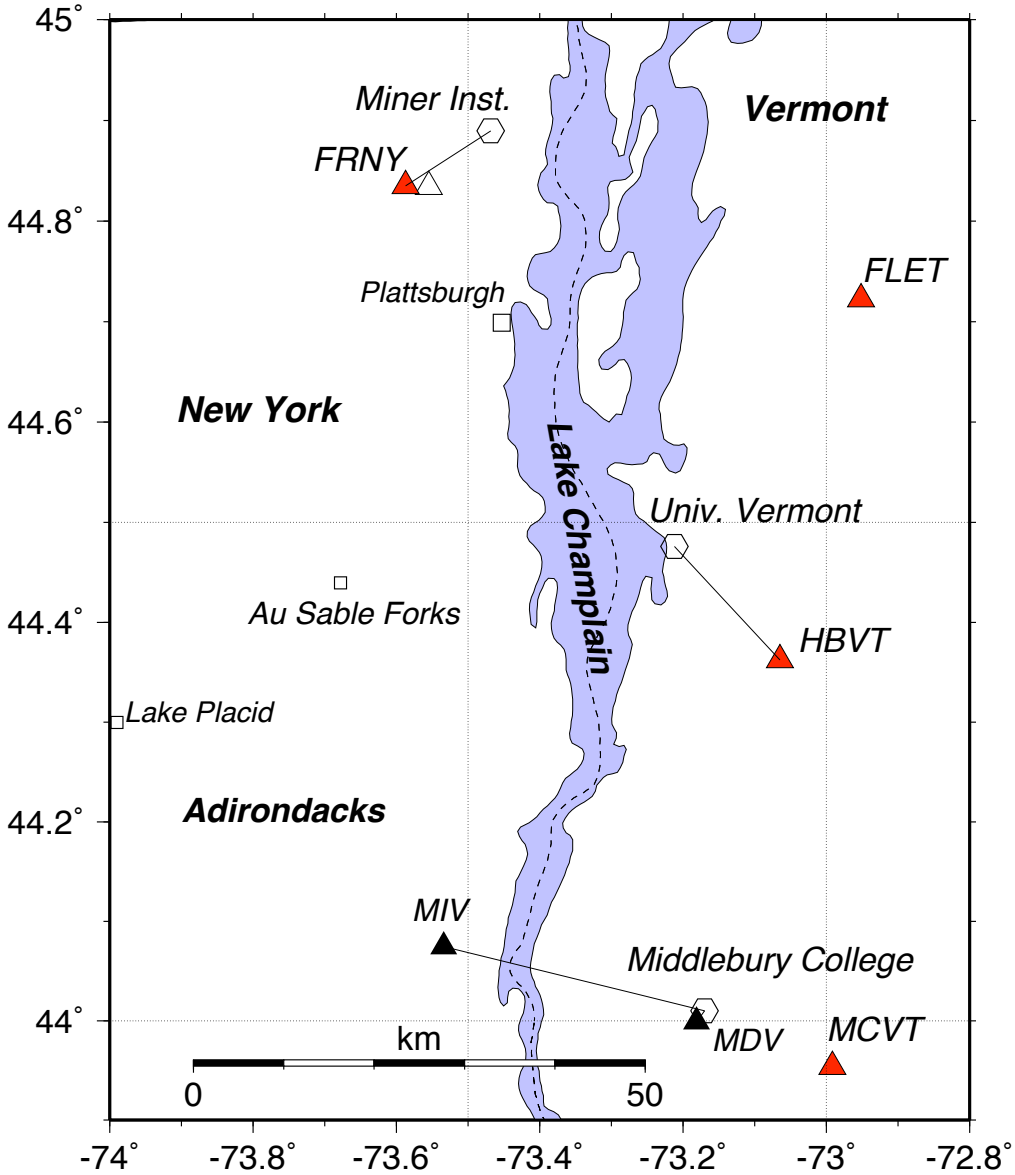

Figure 5. Lake Champlain sub-network consisted of five stations located on both sides of the lake. It is an area of higher seismicity in the northeastern US. Note the town of Au Sable Forks, NY, where Mw 5.0 earthquake occurred on 20 April 2002. We upgraded three short-period, high-gain seismographic stations with broadband sensors and digital Ethernet radio telemetry to the Internet access point at the University of Vermont in Burlington, and to Internet access point at Middlebury College, VT (*red triangles*). The data is transferred to the LCSN data processing computer for event detection and location in real time. Two short-period stations still in operation are plotted with *solid triangles* (MIV & MDV). Two NetQuake units are also installed at the University of Vermont campus.

2.3. Upgrade of Potsdam Sub-network in Northwestern Adirondacks

Prior to the ARRA 2009 seismic upgrades, there were five vertical short-period seismic stations in the Potsdam sub-network in northwestern Adirondacks along the St. Lawrence River. SUNY–Potsdam College operated these stations in cooperation with LCSN (Figure 6). Two stations in the region have been upgraded into broadband seismographic stations in the fall of 2005, LONY (Lake Ozonia, NY; ANSS backbone) and PTN (Potsdam, NY; broadband station of LCSN). We upgraded three broadband stations in the region: NCB, WCNY and PTN in the region under the 2009 ARRA seismic upgrades, and a short-period station BGR (Bangor, NY) was relocated to BMNY (Brushton-Moira, NY) and upgraded into broadband seismographic station with 3-component strong-motion sensor under the ARRA 2009 seismic upgrades.

The short-period station MSNY (Massena, NY) is located inside the Long Sault Dam operated by New York Power Authority (NYPA). We have been working with NYPA staff since the summer of 2011 to upgrade the seismographic station. So far, the upgrade is incomplete because NYPA facility could not complete bringing the AC power supply and the Internet access cable to the site. As soon as the cabling work is done, we will install ANSS standard 3-component accelerometer with ±2g full-scale along with a 6-channel datalogger at the site to ensure high quality data acquisition.

(c) LCSN, Potsdam Subnetwork Stations and Telemetry

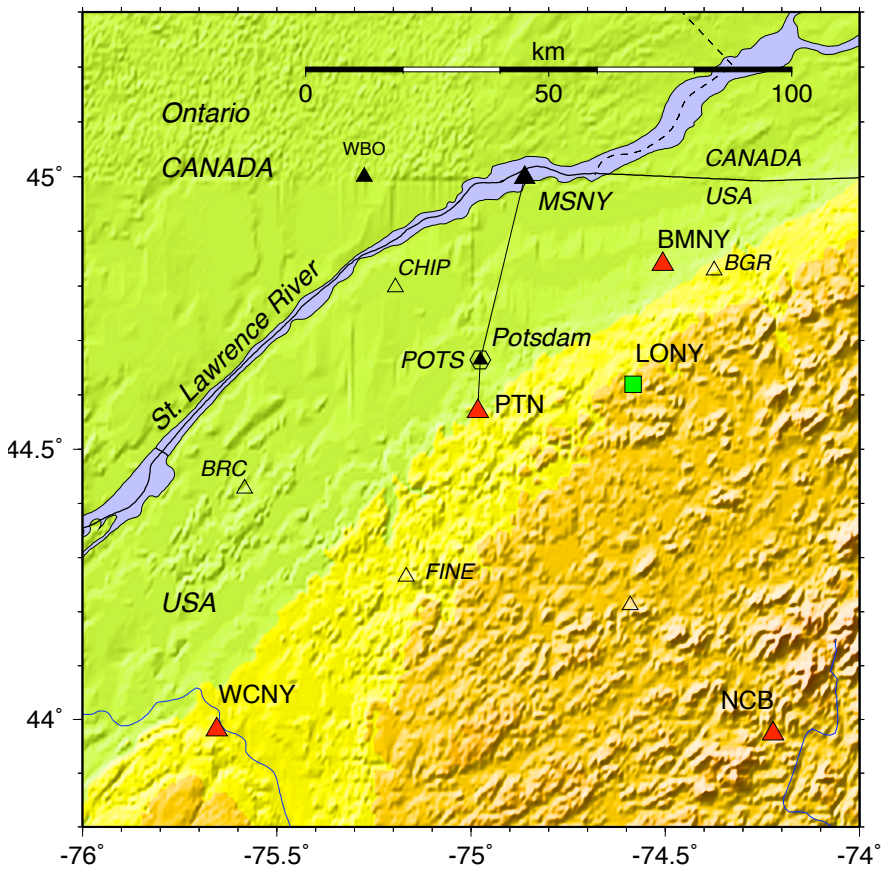

Figure 6. Potsdam sub-network around northwestern Adirondacks along the St. Lawrence River. Two short-period, high-gain seismographic stations POTS and MSNY (*solid triangles*) send seismic data using radio telemetry to the data collection center at SUNY–Potsdam College where data are digitized by Q730 datalogger. An Earthworm system at the data collection center transfers data to the LCSN data processing center for event detection and location. New broadband stations deployed since 2000 that use Internet communication are plotted with *red triangles.* BGR is upgraded to a broadband station BMNY.

2.4. Upgrade of Delaware Sub-network of the LCSN

Delaware Geological Survey (DGS) operates five short-period vertical seismographic stations in Delaware in cooperation with LCSN since the 1980s. These stations are: NED (White Clay Creek State Park), DEMA (Delaware Emergency Management Agency), SCOM (Sussex County Emergency Operations Center), BWD (Brandywine Creek State Park) and BVD (Bellevue State Park) and are shown in Figure 7. The analog seismic data from DEMA and SCOM are transferred to DGS building via the State of Delaware Microwave Communication system, whereas the analog seismic data from the stations –BVD, BWD and NED, are transferred via dedicated phone lines to DGS building. At DGS, a 6-channel Q730 digital recorder is installed in May 2010 under ARRA 2009 and Earthworm sends data in real time to LCSN processing center at Lamont via the Internet.

A proposal to upgrade these stations with a three-component short-period sensor or 3-component shallow borehole accelerometer with ±2g full scale was not recommended by the USGS/ANSS under ARRA 2009. Shallow borehole accelerometer may be useful for these stations, because there is lack of bedrock outcrops and the earth surface is covered by thick sediment (Atlantic Coastal Plain).

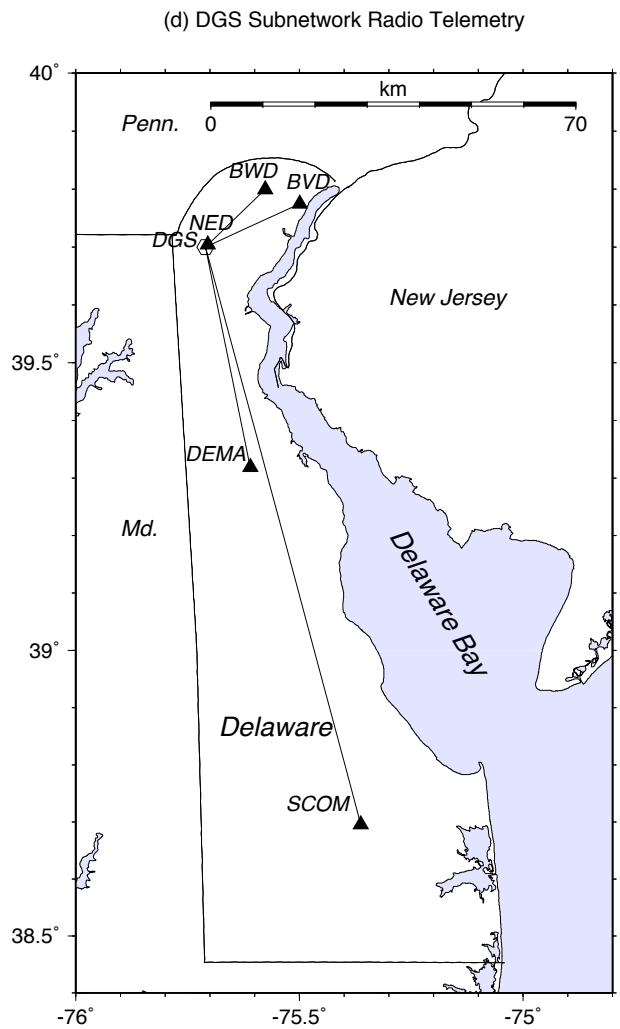

Figure 7. Delaware sub-network stations and radio telemetry links. DGS is the data collection and processing site at the Delaware Geological Survey building in Newark, DE. Earthworm system with Q730 datalogger is the data acquisition system.

3.1. Upgrade of LCSN Network Operations Center

In March 2007, IPT/USGS proposed that the ANSS regional network operations explicitly be organized around a two-tier structure. This was considered the most cost effective way for regional networks to meet the ANSS Performance Standards. LCSN has been classified as Tier 1 regional network. In the spring of 2010, two (2) of the Real Time Servers and one (1) of the Post-Processing Server computers and an external RAID disk drive were installed at the LCSN data collection and processing center at Lamont-Doherty Earth Observatory (LDEO) campus in Palisades, NY. And in May-June 2010, the AQMS (ANSS Quake Monitoring System) software was installed on the new server computers. The AQMS is a standardized earthquake data processing system to be used at the ANSS Tier I regional seismic networks. Currently, the AQMS is used for earthquake data acquisition, automatic processing, interactive analysis, and earthquake information distribution at LCSN. The standard software is the *CISN software* developed by the California Integrated Seismic Network (CISN), which is open source software.

AQMS at LCSN is implemented as the following:

- The Earthworm seismic phase detection module (*pick_ew*) is working on vertical-component broadband and short-period channels recorded at 100 sample/s from LCSN stations (network code: LD) and vertical-component data stream from selected stations of the neighboring regional networks such as, New England Seismic Network, Canadian National Seismic Network, Virginia Tech Seismic Network, OhioSeis and Puerto Rico Seismic Network,

- Detected phase arrivals are handled by the event association/trigger module (*binder_ew*) and the associated event is passed to *hypoinverse* for location,

- *Carlstatrig/carlsubtrig* Earthworm modules provide some backup to this event detection and association system where *binder_ew* has difficulty detecting small events in a sparse network such as LCSN,

- Initial magnitude estimation is determined from Earthworm module *localmag*,

- Reporting via email of initial locations is handled by the automated system,

- Relocation and final magnitude determination are accomplished through the *Jiggle* interface to the database and *hypoinverse*,

- An event SEED volume is compiled, and *Cube* format message is generated on the post-processing machine. Our process does not yet automatically push the event to EIDS when the event is finalized, but it is only one extra step to copy the *Cube* message to our legacy script,

- Finger Quake list, event web page creation, updates to our user-searchable database and informational emails are sent via our legacy post-processing scripts.

3.2. Improved Quality of the Waveform Data.

The global centroid moment tensor (GCMT) project group at LDEO has evaluated quality of waveform data and associated metadata for several LCSN stations, and begun to use LCSN data on their routine analysis to determine GCMT solutions. We were told that the LCSN data from many stations were of high quality and that they are very useful for determining GCMTs for earthquakes in Caribbean and North America (person. comm., Meredith Nettles of LDEO). The data analyses shown in Figures 8 & 9 indicate that data are in high quality and that its metadata are also correct. It is a good way to verify response function for a station.

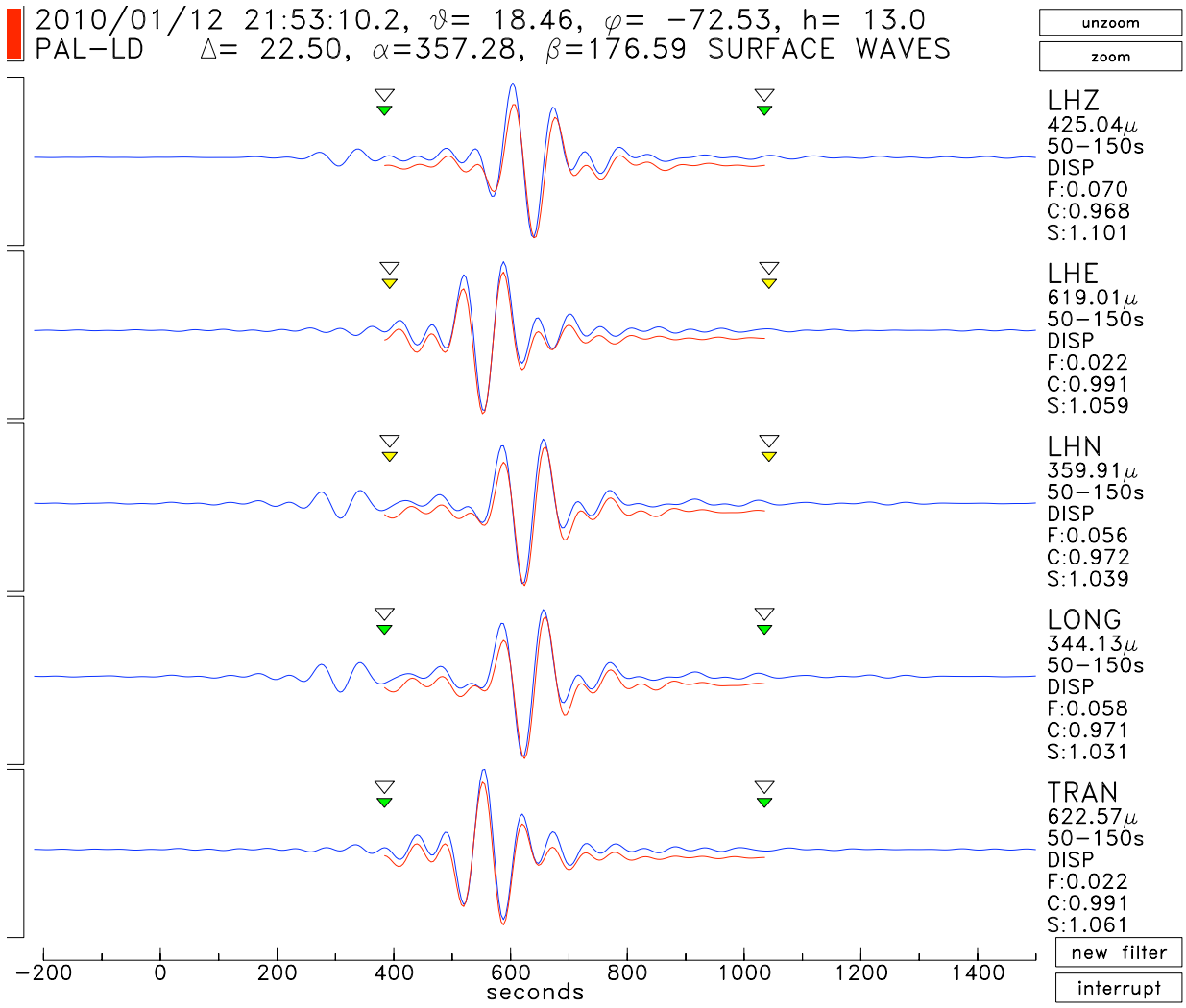

Figure 8. Surface-wave analysis of data from PAL (Palisades, NY), which has STS-2 seismometer (T_0 =120s) and Quanterra Q330-HR datalogger. Signals are filtered between 50-150s. Good fit between the data (*blue lines*) and corresponding synthetic seismograms (*red lines*) indicate that the data is of high quality and that the response function (metadata) is correct. It is a good way to verify response function of the stations and the data quality. The records are from the disastrous earthquake (magnitude 7) that occurred on January 12, 2010 in Haiti. [the figure courtesy of Meredith Nettles of LDEO].

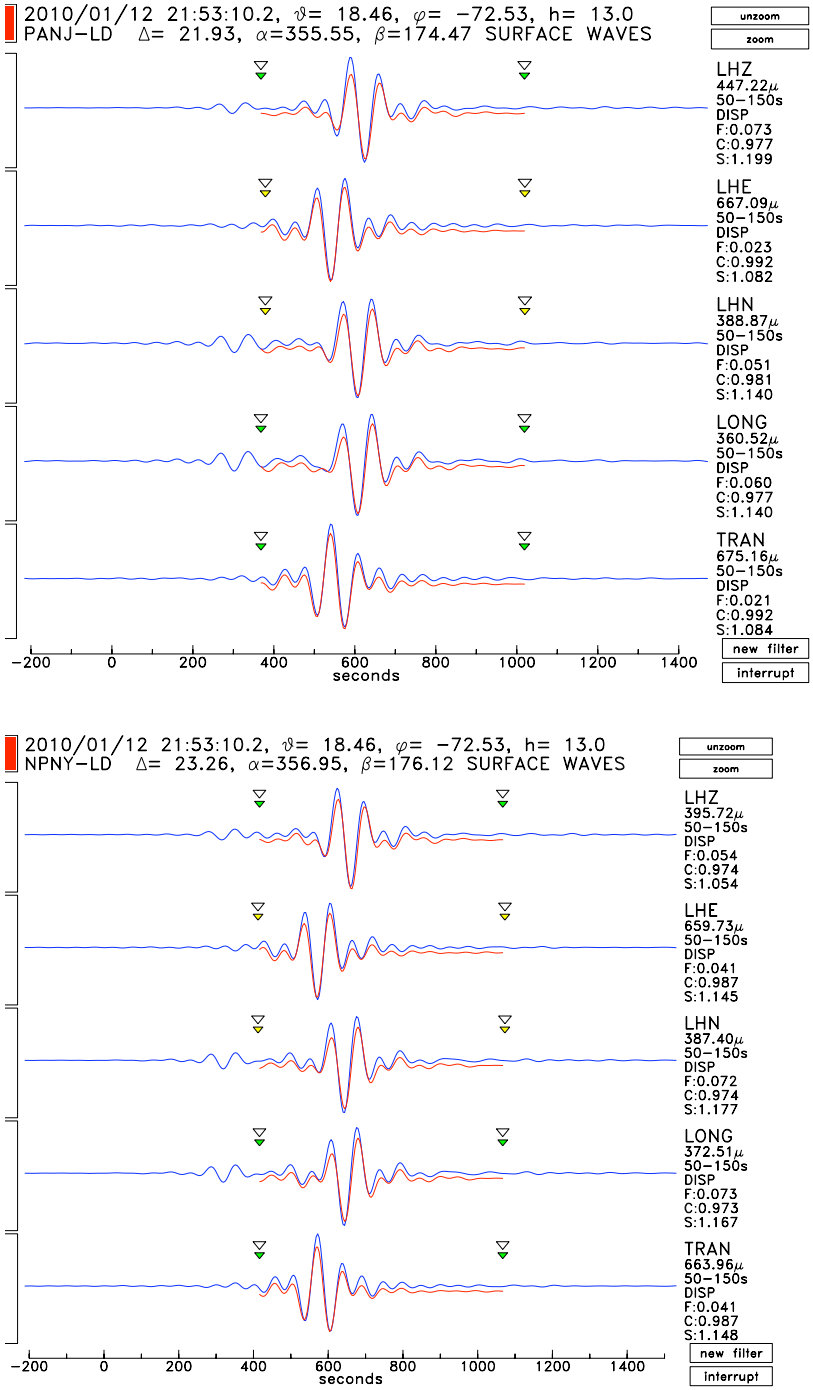

Figure 9. (***Top***) Surface-wave analysis of data from PANJ (Princeton, NJ), which has STS-2 seismometer (T_0=120s) and Quanterra Q330-3 datalogger. Signals are filtered between 50-150s. Good fit between the data (*blue lines*) and corresponding synthetic seismograms (*red lines*) indicate that the data is of high quality and that the response function (metadata) is correct. It is a good way to verify response function for a station. The records are from the magnitude 7 disastrous earthquake that occurred on January 12, 2010 in Haiti; (***Bottom***) the same as the top traces, but for data from the station NPNY (New Paltz, NY), which has STS-2 seismometer (T_0=120s) and Quanterra Q330-3 datalogger. [the figure courtesy of Meredith Nettles of LDEO].

3.3. Ambient Noise Analysis for Site Condition and Data Quality Control

To evaluate quality of broadband seismographic stations, we calculate power spectral density (PSD) of ambient noise samples at each station and compare the PSDs with global high– and low–noise models as well as each other. Three-component acceleration power spectral density of six stations equipped with STS-2 seismometer (T_0=120s) and digital recorder (Q330) are plotted in Figure 10 for comparison. On vertical-component records, the ambient noise at 100s range between -180 and -170 dB except at PAL (Palisades, NY; see Figure 10). All six stations have been upgraded to LCSN vault and the seismometers (except PAL) were serviced and calibrated by the manufacturer. Higher noise level between 0.4–1s (1–2.5 Hz) at PAL is perhaps due to freight train passing by the station within about 2 km. The noise at 10 Hz ranges between -145 and -130 dB. The consistency of PSDs at long periods (10–100s) and at high frequencies (1–40 Hz) at all stations indicates that the sites are very quiet and the instruments have high fidelity.

Three-component acceleration PSD of eight stations equipped with Trillium-120PA seismometer (T_0=120s) and digital recorder (RT130-01/6) are plotted in Figure 11 for comparison. On vertical-component records, the ambient noise at 100s ranges between -172 and -165 dB except at BRNJ (Basking Ridge, NJ) and CPNY (Central Park, New York City; see Figure 11). A very high noise level on vertical-component at CPNY at period longer than 20s is not well understood at the moment. The ambient noise at 10 Hz ranges from -145 dB to -110 dB on all three components (see Figure 11).

Three-component acceleration PSD of six stations equipped with CMG-3T seismometer (T_0 =100–120s) and digital recorder (RT130-01/6) are plotted in Figure 12 for comparison. On vertical-component records, the ambient noise at 100s ranges between -180 and -140 dB. The ambient noise at 10 Hz ranges from -140 dB to -105 dB on all three components (see Figure 12). The north-south (N) component PSDs at stations LUPA (Lehigh University, PA) and BRNY (Black Rock Forest, NY) are not correct, because the mass of the broadband sensor is not centered [the mass centering motor is not working]. On east-west (E) component, PSD of the station BRNY is not correct due to the mass is not being properly centered (see Figure 12).

Three-component acceleration PSD of seven stations equipped with CMG-3ESP seismometer (T_0 =30s) and digital recorder (RT130-01/6) are plotted in Figure 13 for comparison. The ambient noise PSD at the stations ALLY (Allegheny College, PA), CUNY (Queens College, Queens, NYC) and MVL (Millersville University, PA) are very poor (see Figure 13). The seismometers at these stations are installed on surface level with very little thermal insulation. We need to re-site these stations with proper concrete vault.

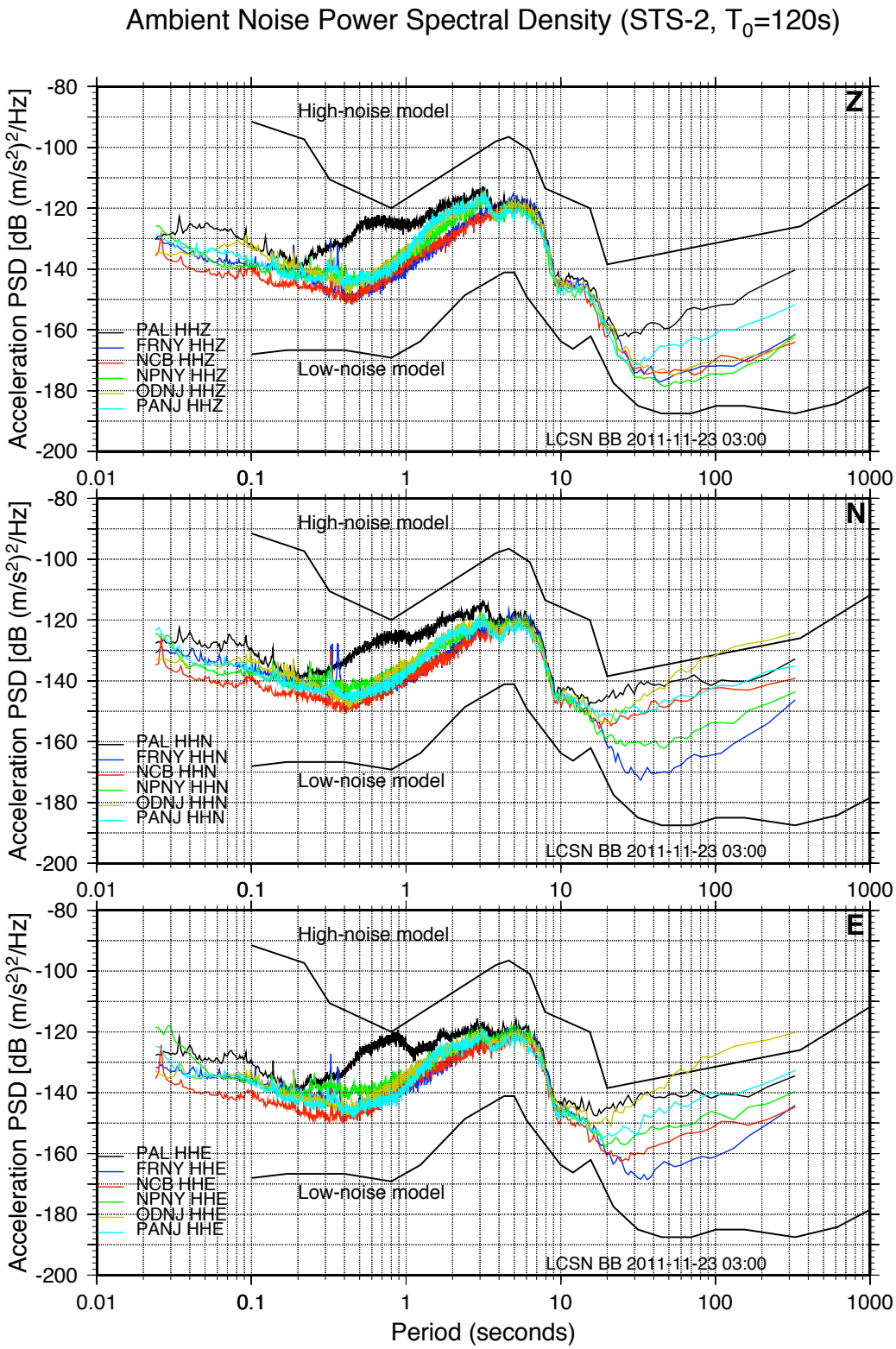

Figure 10. Acceleration power spectral density of 3-component records from 6 broadband stations with STS-2 seismometer having natural period T_0=120s. The sensors are installed in concrete vaults and hence, have low ambient noise at long-period bands. High noise at PAL is due to passing freight train about 2 km from the station.

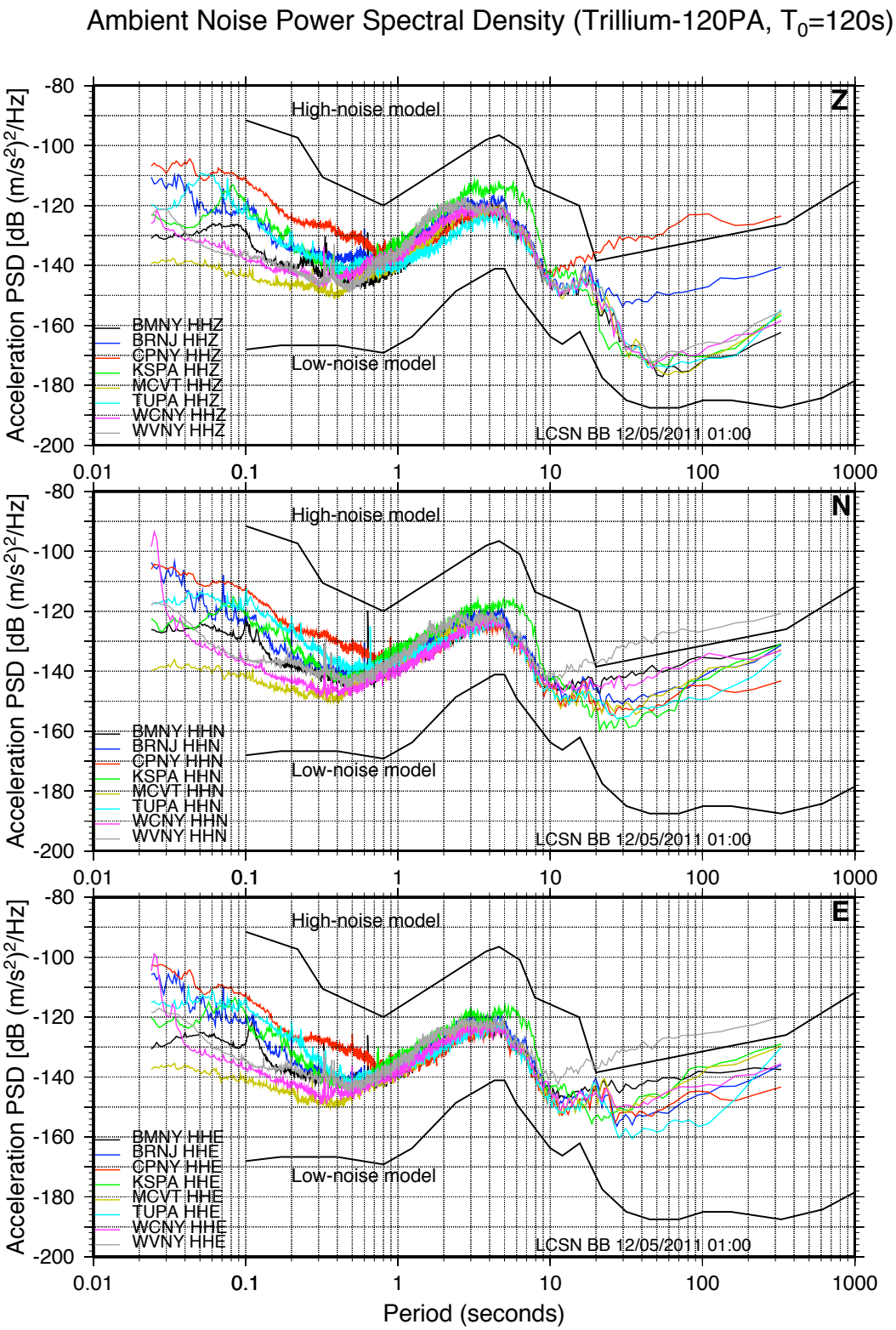

Figure 11. Acceleration power spectral density of 3-component ambient noise records from 8 broadband stations with Trillium-120PA seismometer having natural period T_0=120s.

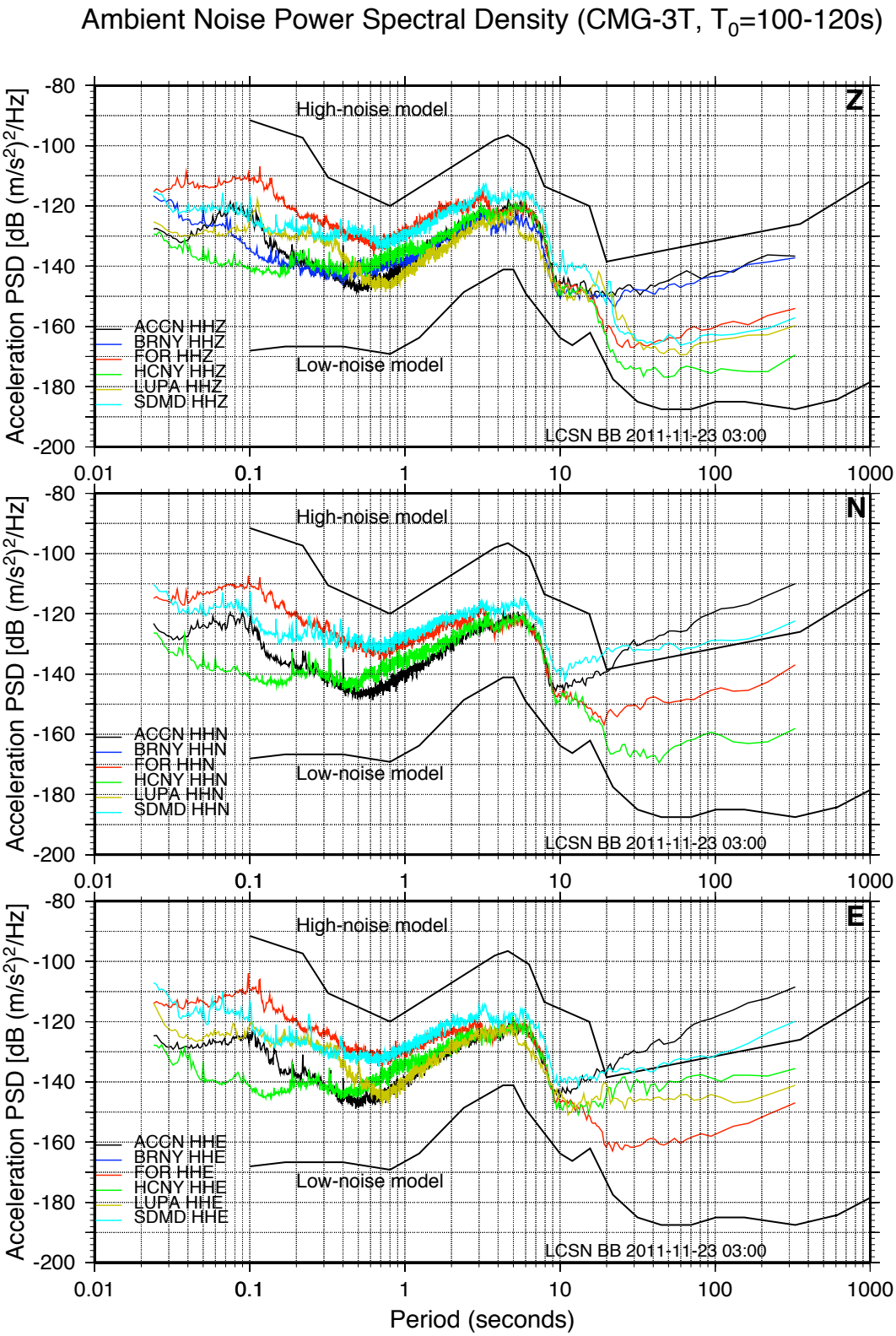

Figure 12. Acceleration power spectral density of 3-component ambient noise records from 6 broadband stations with CMG-3T seismometer having natural period T_0=100–120s. North-south (N) component PSDs at stations LUPA and BRNY are not plotted, and on east-west (E) component, PSD of the station BRNY is not plotted due to the mass of those components are not being properly centered.

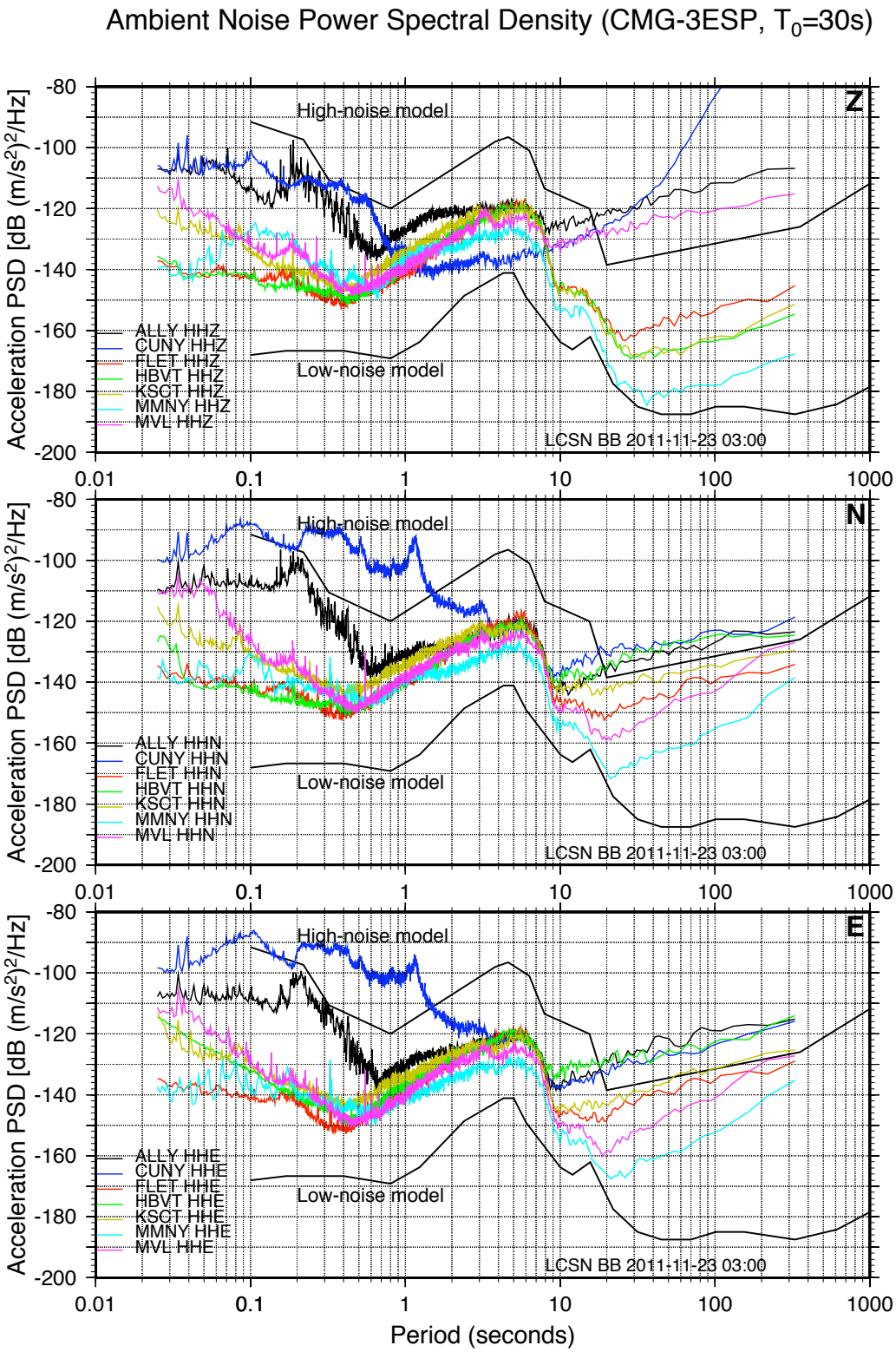

Figure 13. Acceleration power spectral density of 3-component ambient noise records from 7 broadband stations with CMG-3ESP seismometer having natural period T_0=30s. Stations ALLY and CUNY show extremely high noise level at high frequencies and long periods. The sensors at these stations are installed inside school buildings and lack thermal insulation. We need to relocate these stations.

3.4. Data Management Practices

Current state of progress toward meeting the ANSS data management performance standards 4.1 – 4.3 Data Exchange Between ANSS Networks, and 5.1 – 5.4 Data Archiving and Public Distribution are briefly described below for Mod-High Hazard Area.

Performance Area	Metric (explanations below)	Units	Mod-High Hazard Area (ANSS-NorthEastern US)
Data Exchange Between ANSS Networks			
4.1	Waveform Availability Timeliness	10 sec.	Real-time between NESN, CNSN, PRSN
4.2	Amplitude Availability Timeliness	60 sec.	Working to make real-time feed from New England Seismic Network for ANSS-NE ShakeMaps
4.3	Phase Picks Availability Timeliness	60 sec.	We are ready to import/export to ANSS Networks, ~60 sec
Data Archiving and Public Distribution			
5.1	Availability of Waveforms to External Users	0 min.	100 % Real-time via IRIS-DMC and LCSN AutoDRM http://almaty.ldgo.columbia.edu:8080/data.request.htm
5.2	Availability of Event Bulletin (parametric data)	15 min.	we are meeting the goal via Finger Quake list http://www.ldeo.columbia.edu/cgi-bin/quake.cgi
5.3	Metadata availability (current)	100 %	downloadable via web site at http://www.ldeo.columbia.edu/LCSN/Metadata/DATALESS.LD.seed
5.4	Data import into archive	0 min.	100% in real-time (permanent archive at IRIS-DMC)

3.5. Progress on Metadata Development

LCSN has complete metadata for station characteristics and instrument responses since the early 1980s. Hence, event oriented SEED volumes were routinely generated and archived. Current, LCSN DATALESS SEED volume is available at IRIS-DMC and at the LCSN web page.

From LCSN home page at URL:
http://www.ldeo.columbia.edu/LCSN/Metadata/DATALESS.LD.seed
Click to download the file (8.9 Megabytes, 12/01/2011)

From Lamont-Doherty public ftp site:
ftp://ftp.ldeo.columbia.edu/archive/LCSN/DATALESS.LD.seed

From IRIS-DMC in Seattle, WA.
ftp://ftp.iris.washington.edu/pub/RESPONSES/DATALESS_SEEDS/LD.dataless

Since 2008, ANSS urban strong-motion instruments (CMG-5TD) with 100 samples/sec continuous and 200 samples/sec triggered system responses are included with location codes "(blank)" and "10" respectively, as well as new dataloggers such as Güralp DM-24/3 mk3. Decimation filter blockette is added to the analog short-period stations to conform to SEED V2.4.

3.6. LCSN Broadband Station Data Recovery Rate in 2011

A major component of the ARRA seismic upgrades was to replace the old serial communication only dataloggers with those dataloggers with Ethernet communication that allow multiple functions such as, data recording and telemetry and remote mass centering of the sensor. The new dataloggers provided significantly improved telemetry and hence the data recovery rate across the network as well as the quality of the data. For 31 LCSN broadband stations, 26 stations had data recovery rate greater than 90% during 2011 (see Figure 14). The station PTN (Potsdam, NY) had a massive power and telemetry failure during much of 2011, and LUPA (Lehigh University, PA) had similar problem in 2011. All stations with data recovery rate less than 90% – PTN, LUPA, HBVT and UCCT (not plotted here), had intermittent power failure. These stations use Ethernet radios to telemeter the data to the Internet access point, so the power consumptions at the remote station sites are high, and the solar panels at remote site provided insufficient power.

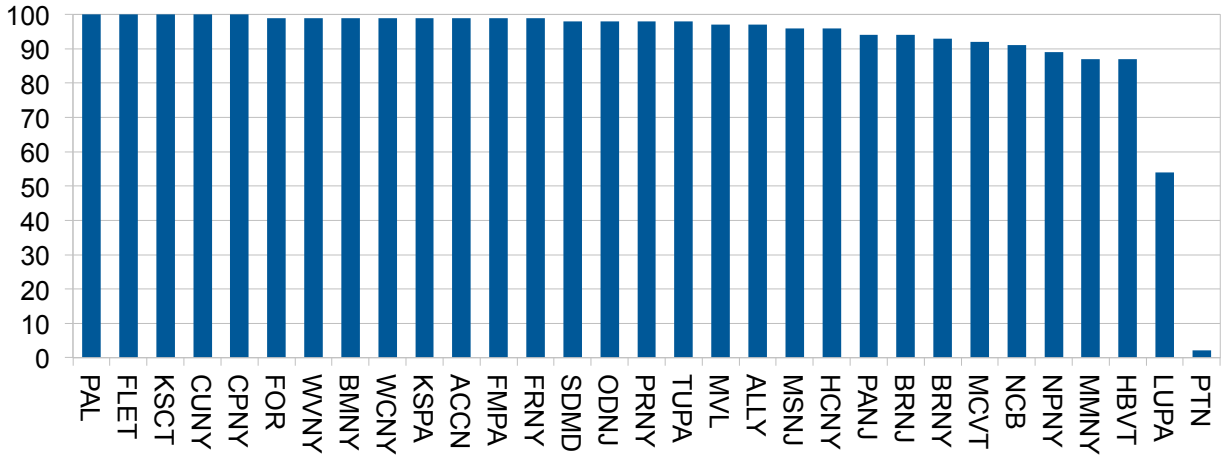

Figure 14. Histogram showing station data recovery percentage of 31 LCSN broadband stations in 2011. Only 5 stations have recovery percentage less than 90%. All stations with data recovery rate less than 90% – PTN, LUPA, HBVT and UCCT (not plotted here), had intermittent power failure. This statistics is from the average daily percentage availability at IRIS-DMC in Seattle, WA.