THE LAMONT COOPERATIVE SEISMIC NETWORK AND THE ADVANCED NATIONAL SEISMIC SYSTEM: EARTHQUAKE HAZARD STUDIES IN THE NORTHEASTERN UNITED STATES.

Annual Project Summary

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Investigations undertaken

The operation of the Lamont-Doherty Cooperative Seismographic Network (LCSN) to monitor earthquakes in the northeastern United States is supported under this award. The goal of the project is to compile a complete earthquake catalog for this region to assess the earthquake hazards, and to study the causes of the earthquakes in the region. The LCSN now operates 40 seismographic stations in seven states: Connecticut, Delaware, Maryland, New Jersey, New York, Pennsylvania and Vermont. During October 2003 through September 2004, scientists and staff at the Lamont-Doherty Earth Observatory of Columbia University (LDEO) satisfactorily carried out three main objectives of the project: 1) continued seismic monitoring for improved delineation and evaluation of hazards associated with earthquakes in the Northeastern United States, 2) improved real-time data exchange between regional networks and the USNSN for development of an Advanced National Seismic System (ANSS) and expanded earthquake reporting capabilities, and 3) promoted effective dissemination of earthquake data and information.

A significant amount of associated research effort was related to determining seismic moment tensor and focal depth of small to moderate-sized earthquakes in the eastern United States by using three-component, broadband seismic waveform data. We studied the 6 June 2003, Mw 4.0 Bardwell, Kentucky, earthquake sequence which occurred at a shallow focal depth ($\approx$ 2 km) and indicates that the nearly horizontal P axis rotated about 45°clockwise from the average direction (ENE) for eastern North America. This suggests a locally perturbed stress field (Horton, Kim and Withers, 2004). We also analyzed waveform data from the 9 December 2003, Mw 4.3 central Virginia earthquake, which was a compound earthquake consisting of two nearly identical events separated by 12 seconds in the central Virginia seismic zone (Kim and Chapman, 2004).

The most significant results of these and other earlier studies were the distribution of deep and shallow earthquakes in the Central and northeastern US and their implications on the thickness of the seismogenic layer. This in turn yields information on the seismic potential of a seismic zone in the region.

We implemented rapid generation of instrumental ground motion and intensity maps – ShakeMaps. A ShakeMap is a representation of ground shaking produced by an earthquake.

Results

Network Operation

In operating the Lamont-Doherty Cooperative Seismographic Network (LCSN) during Oct. 2003–Sept. 2004, we accomplished: 1) Deployed a new broadband, 3-component seismograph at Flat Rock, Altona, New York. A total of 16 broadband seismographic stations are now operated directly by LCSN or affiliated to LCSN (Figure 1); 2) deployed four ANSS strong-motion instruments in the metropolitan New York City area as part of the ANSS-NE (Northeast) urban monitoring network. These modern digital accelerometers record 3-component ground motion at 100 samples/sec and transfer continuous data to a data concentrator (PC and a hard disk drive) at the Department of Civil Engineering and Engineering Mechanics (CEEM), Columbia University; 3) Continuous waveform data from 12 stations (vertical-component) are now sent to NEIC/USNSN in Golden, CO in real time; 4) All waveform data from 39 seismographic stations of the LCSN are now sent to IRIS-DMC in real time and are made available to the sesimological community in real time. Data are found in BUD (Buffer of Uniform Data) with network id "LD" at <http://www.iris.washington.edu/bud_stuff/dmc>; 5) Rapid earthquake information dissemination system under ANSS is implemented. It is called "recenteqs" and is accessible at <http://www.ldeo.columbia.edu/LCSN/recenteqs>; 6) Waveform data distribution system based on email request and automatic processing is implemented. Data are accessible at <http://almaty.ldgo.columbia.edu:8080/data.request.htm>; 7) Waveform data for earthquakes in the finger quake list are now provided as assembled SEED volumes for each event via WWW.

In addition, we established a new LCSN Lake Champlain subnetwork node at the William H. Miner Agricultural Research Institute in West Chazy, NY. The new broadband seismographic station at the Flat Rock, NY (FRNY) is telemetered to the Miner Institute using spread-spectrum radios. The short-period stations, HBVT, FLET, and PNZ are sending seismic data to the Miner Institute using analog FM radios in UHF/VHF band. For a second node at the Middlebury College, VT, a 24-bit A/D datalogger is installed to digitize signals from MIV and MDV.

Since the spring of 2002, LCSN has been cooperating with POLARIS (Portable Observatories for Lithospheric Analysis and Research Investigating Seismicity) Consortium of Canada, for improved earthquake monitoring along the well developed and highly populated eastern US-Canada border region. In the spring of 2004, a new POLARIS station MEDO (Medina, NY) was deployed in western NY. The new station improved significantly the earthquake monitoring along the Toronto-Niagara Falls-Buffalo region.

The primary emphasis was on implementing automatic, prompt data processing and distribution system. We will continue to work for improving accuracy of earthquake location and timely dissemination of earthquake message.

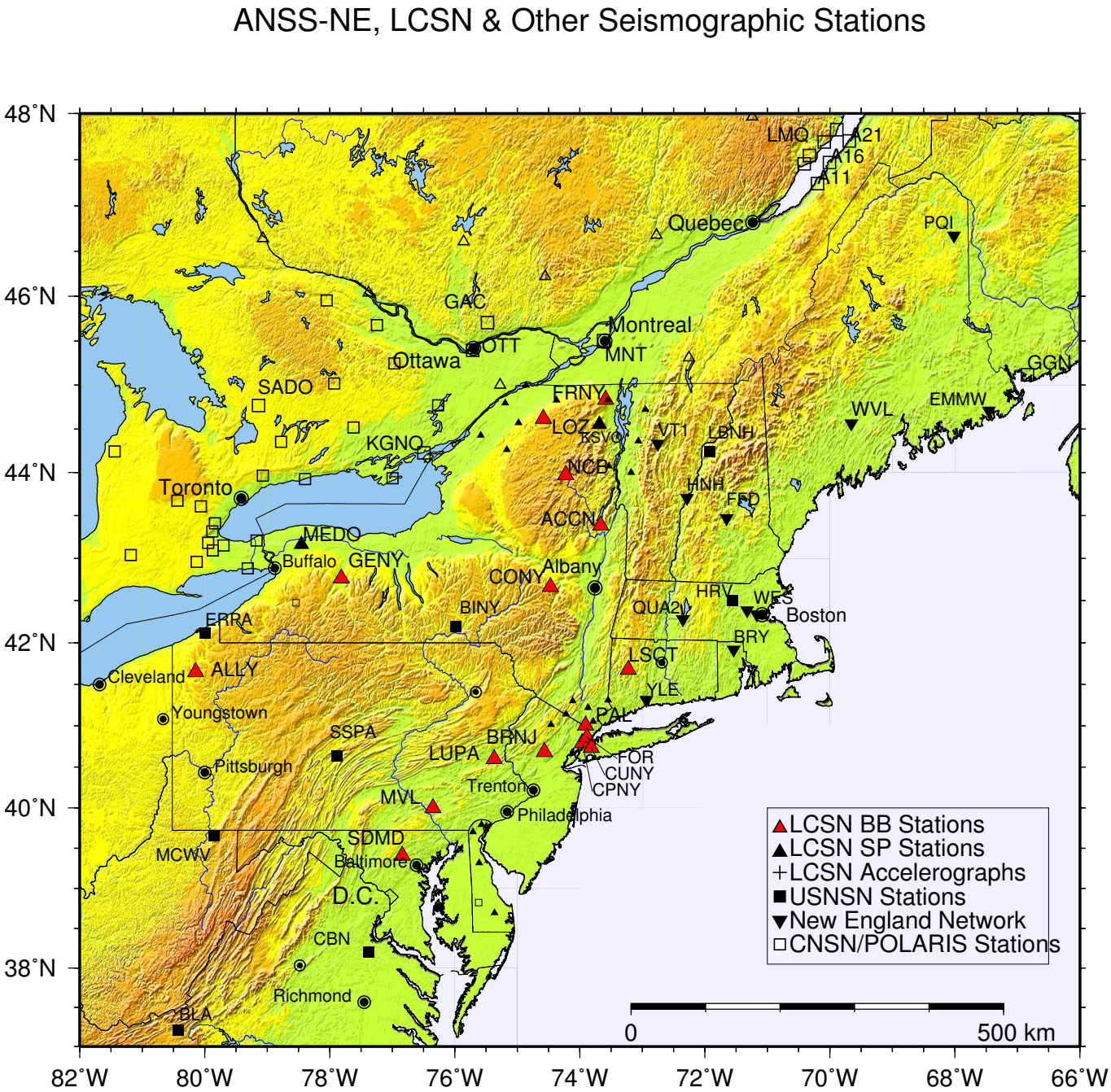

Figure 1: Seismographic stations in the Northeastern United States and Southeastern Canada. LCSN broadband sites (*red triangles*), short-period sites (*filled triangles*), New England Seismic Network sites (Weston Observatory; *inverted triangles*) are plotted. Broadband stations of the USNSN (*squares*) and broadband stations of the Canadian National Seismograph Network (CNSN), Southern Ontario seismic network (SOSN) and POLARIS consortium stations *open squares*) are plotted for reference.

Seismicity

About 20 local and regional earthquakes with magnitude greater than about 2 that have occurred in the northeastern United States and southern Canada were detected and located by the LCSN during October 1, 2003 through September 30, 2004. These earthquakes range from magnitude m_b(Lg) 1.8 to 4.6 (Table 1). A general seismicity pattern during this period indicates that the seismicity was very low compared to previous years. In particular, a relatively lower level of seismicity in Adirondacks and in Western Quebec seismic zone in southern Canada.

Notable earthquakes during the period are: October 1, 2003, M_L 2.4 aftershock of the August 26, 2003 earthquake in Milford, NJ-Upper Black Eddy, PA; December 9, 2003 m_b(Lg) 4.5 Central Virginia earthquake near Goochland west of Richmond, VA; a M 3.3 earthquake occurred at Ashtabula, Ohio, on June 30, 2004; and August 4, 2004, M_L 3.3 Lake Ontario earthquake. (see Figure 2).

Table 1: Earthquakes recorded by LCSN for period Oct. 1, 2003 through Sept. 30, 2004

Date Year/Mo/Dy	Time (hr:mn:s)	Lat (°N)	Long (°W)	h (km)	Mag* (M_L)	Location
2003/10/01	08:07:57.4	40.57	75.12	3	2.4c	3 km NE of Milford, NJ
2003/10/07	01:32:03.2	41.73	71.57	6	1.8n	SW of Providence, RI (WES)
2003/10/12	08:26:06.0	47.05	76.27	18	4.6n	76 km NW Maniwaki, Que (OTT)
2003/10/15	04:13:14.0	45.08	66.91	18	3.1n	21 km E St.Stephen, NB(OTT)
2003/10/18	16:25:07.0	46.94	67.19	18	3.5n	99 km SE Edmundston, NB(OTT)
2003/11/04	13:37:31.8	40.25	75.88	1	2.7c	10 km SE of Reading, PA
2003/12/09	20:59:18.7	37.774	78.100	10	4.3w	Goochland, central Virginia
2004/01/20	17:11:54.1	43.20	71.77	9	2.5n	19 km W of Concord, NH
2004/02/24	01:54:42.4	41.55	70.98	5	2.0n	S of New Bedford, MA (WES)
2004/03/14	05:05:10.3	41.77	81.24	5	2.4n	NE of Cleveland, OH
2004/03/17	01:44:44.4	43.20	70.58	5	2.1n	SSW of Biddeford, ME (WES)
2004/03/17	12:38:15.0	45.05	75.66	18	2.5	NW of Ogdensburg, NY
2004/03/17	22:01:58.2	44.90	74.91	8	2.8	4 km S of Massena, NY
2004/03/22	15:21:39.0	39.87	75.06	2	2.2c	12 km SW of Ramblewood, NJ
2004/06/16	06:31:27.0	42.79	79.08	18	3.1n	18 km SE of Port Colborne, ON
2004/06/22	10:17:53.0	45.17	69.12	9	2.0n	NW of Bangor, ME (WES)
2004/06/30	04:03:14.6	41.78	81.08	5	3.3n	NE of Cleveland, OH
2004/08/04	23:55:26.6	43.69	78.25	5	3.3	Lake Ontario, Medina, NY
2004/08/28	12:38:37.9	43.16	71.61	5	2.1n	16 km W of Concord, NH
2004/09/04	02:05:32.0	44.90	74.89	3	2.9c	3 km S of Massena, NY

* c = Mc coda duration magnitude determined by LDEO, n = Nuttli's mb(Lg) reported by Geological Survey of Canada, Ottawa or by the Weston Observatory, Boston College, MA; default is the local Richter magnitude determined and reported by Lamont-Doherty Earth Observatory of Columbia University.

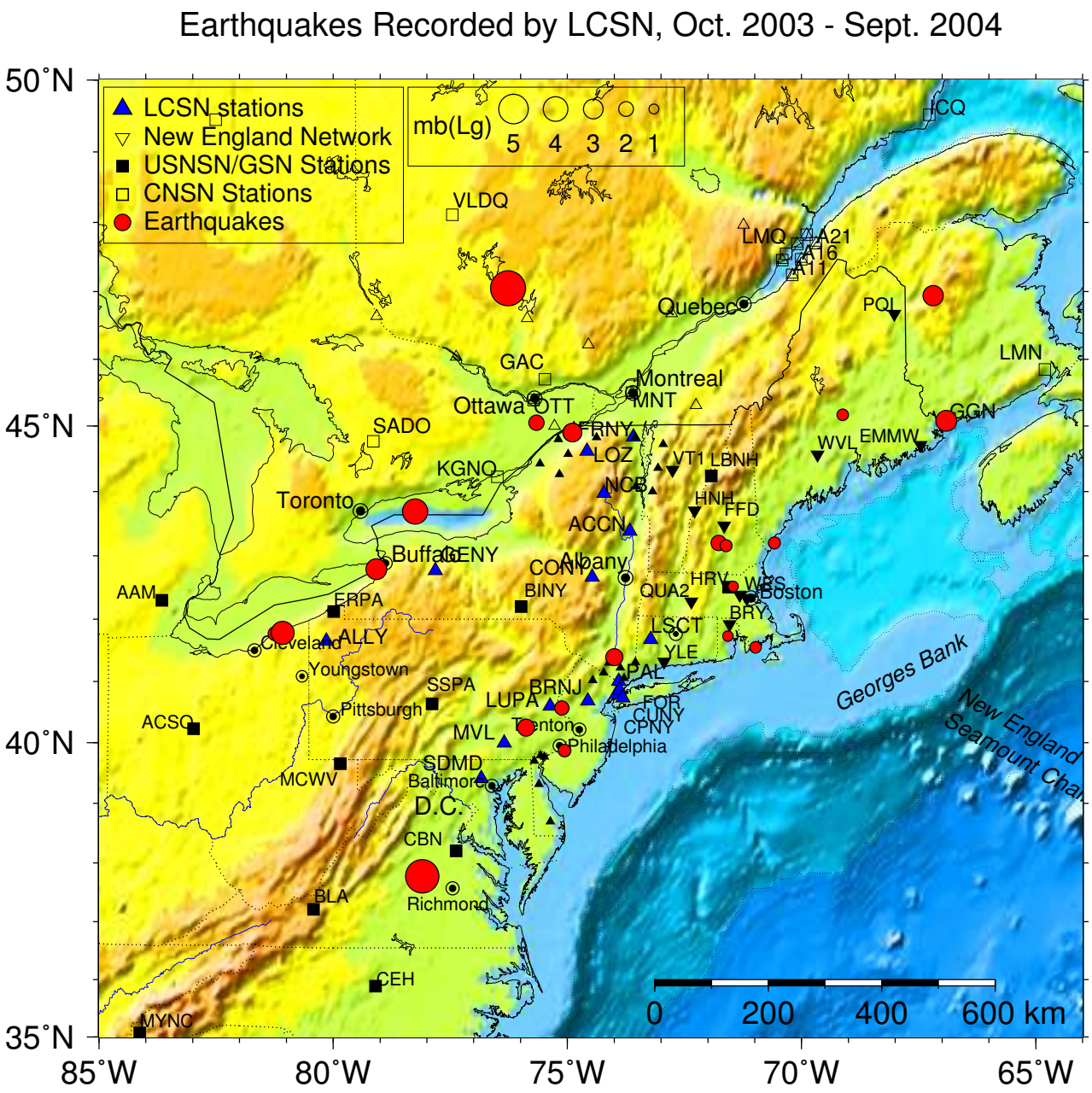

Figure 2: Earthquakes which have occurred in the northeastern United States and southeastern Canada in the time period of Oct. 1, 2003 through Sept. 30, 2004 recorded by the LCSN. Symbol size is proportional to magnitude. Broadband stations of the LCSN, USNSN, NESN, and CNSN are plotted for reference.

Milford, NJ–Upper Black Eddy, PA earthquake on October 1, 2003
A small earthquake of M_L =2.4 occurred on 10/01/2003 at 08:07 (08:07 EDT) close to the town of Milford, NJ along the Delaware River. The shock was felt by residents with high intensity and residents around the Milford reported hearing an explosion-like sound associated with the shock. This is the largest aftershock of the earthquake of M_L =3.5 occurred on 08/26/2003 at 18:24 (14:24 EDT) in the area. Aftershocks recorded by a local network deployed in October 2003 indicated that main- and after-shocks must have very shallow depths. Focal depth of about 40 aftershocks are clustered at around 1.5 to 2 km depth. The earthquake occurred close to the boundary fault between the Precambrian Reading prong and the Mesozoic Newark basin, but the lineation of the aftershocks seems nearly perpendicular to the orientation of the boundary fault. It is a significant event for its implication on seismic hazards in the region and on the seismotectonic setting.

Lake Ontario earthquake on August 4, 2004
A small earthquake of M_L =3.3 occurred on 08/04/2004 at 23:55 (19:55 EDT) in the center of Lake Ontario about 20 km South of Port Hope, Ontario, Canada. Although the event is small, the shock is very well recorded by broadband stations recently deployed at Medina, NY (MEDO) and other stations of the POLARIS stations in Ontario, Canada. Preliminary analysis of the data indicates that the shock occurred at a shallow depth of about 4 to 5 km.

Data Availability

1) *LCSN Data Retrieval from Standard IRIS-DMC Archive*: Continuous 40 samples/sec waveform data from broadband, three-component seismographs recorded at PAL (Palisades, NY) and other stations of the LCSN are archived at IRIS/DMC in Seattle, WA for further dissemination to other scientists and to public users. Waveform data in SEED formats have been submitted and current PAL data holdings at IRIS/DMC cover most of the data since the fall of 1999. Interested users can request the waveform data to IRIS/DMC by using E-mail requests and other means. In case of E-mail request, the network code is "LD". An example data request format is

```
PAL LD 2004 08 04 23 55 00.0 2004 08 05 00 05 00.0 3 BHZ BHN BHE
GENY LD 2004 08 04 23 55 00.0 2004 08 05 00 05 00.0 3 BHZ BHN BHE
ALLY LD 2004 08 04 23 55 00.0 2004 08 05 00 05 00.0 3 BHZ BHN BHE
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We will continue to submit the continuous, broadband waveform data recorded at PAL and other stations of the LCSN to IRIS/DMC.

Since January 2001, all broadband data are available from this method. and since January 2003, all short-period waveform data (100 samples/sec) are also available from here. The URL is:
<http://www.iris.edu/SeismiQuery>

2) *Real-time Retrieval of Waveform Data from BUD System at IRIS-DMC*: All waveform data from 40 seismographic stations of the LCSN are now sent to IRIS-DMC in real time and are available to sesimological community in real time. Data are found in BUD (Buffer of Uniform Data) with network id "LD" at: <http://www.iris.washington.edu/bud_stuff/dmc>

3) *Recent Earthquake Data from LCSN Local Archive*: Waveform data from selected significant earthquakes in northeastern United States can be retrieved from local archive. When felt earthquakes or significant events occurs in the northeastern United States, we put seismic phase arrival picks, short-period and broadband waveform data into the LCSN web site which can be easily downloaded by users via the Internet. Other event data requested by users, which includes neighboring seismographic network operators, Geological Survey of Canada, Ottawa, high school teachers and students, are also processed and written into SEED format for download by users. Our experience indicates that it is the most efficient method to disseminate to multiple users without additional effort. The URL for the LCSN web site is: <http://www.ldeo.columbia.edu/LCSN> or users can navigate from the LDEO home page at: <http://www.ldeo.columbia.edu>, then select "Research", "Databases and Repositories" and "Lamont-Doherty Cooperative Seismographic Network". Waveform data of the selected events in SEED format can be found in "Data Access & Archive" or from the webseismogram window.

3.1) *AutoDRM*: Waveform data can be obtained using AutoDRM E-mail response system by entering queries on the web page at: <http://almaty.ldeo.columbia.edu:8080/data.request.htm>

3.2) *Download LCSN Event SEED Volume*: Phase picks and waveform data from recent earthquakes in the northeastern US are easily downloadable via WWW. From the LCSN home page, clicking "Finger Quake for Recent Seismic Events in the Northeastern U.S." then clicking LAT or LON column allows user to choose an event and download data.

Contact person for additional inquiries and assistance:
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E-mail: goldm@ldeo.columbia.edu
Data format: SEED, AH, ASCII

Reports Published

Kim, Won-Young and M. Chapman (2004), The 9 December 2003, Mw 4.3 central Virginia earthquake: A Compound earthquake in the central Virginia seismic zone, Submitted to the *Bulletin of the Seismological Society of America*, September 2004.

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Non-Technical Summary

The primary objective of the Lamont-Doherty Cooperative Seismographic Network (LCSN) to monitor earthquakes in the northeastern United States and to gather data about eastern U.S. seismicity in order to understand the causes of earthquakes in the region, the identification of areas of high seismicity, and the resulting effects of seismic activity. This is a difficult problem, while eastern seismicity is significantly less than that of the western U.S., potentially damaging earthquakes have occurred, and it is important to assess the risk accurately.

The LCSN currently operates 40 seismographic stations in the Middle Atlantic States, ranging from the New York – Canada Border to south of Baltimore Maryland. 24 of these stations are organized in four subnetworks consisting of 5 to 7 short-period stations. The other 16 stations are stand-alone broadband seismographic stations. The LCSN is a cooperative operation, participants include State University of New York (SUNY) at Potsdam, at Plattsburgh, and at Cobleskill, as well as Adirondack Community College, and Westchester Community College; the Delaware Geological Survey and the Maryland Geological Survey; The William H. Miner Agricultural Research Institute in West Chazy, NY; Middlebury College, VT; Millersville and Lehigh Universities, PA and Allegheny College, PA; Fordham University, in the Bronx; Queens College, CUNY in Queens, and Central Park Conservancy, New York City. All data from these stations is transmitted to Lamont-Doherty Earth Observatory (LDEO) in real time for automatic event detection and location of seismic activity. During the time period included in this report, over 20 regional earthquakes with magnitude greater than 1.5 were recorded by the LCSN in the northeastern United States. This data, along with data gathered in earlier years, has helped us to define areas of relatively high seismicity, as well as determine the ground motion and the associated potential risk.

In the summer of 2003, we deployed four Advanced National Seismic System (ANSS) strong-motion instruments in the metropolitan New York City area as part of the ANSS-NE (Northeast) urban ground motion monitoring network. These modern digital accelerometers record 3-component ground motion at 100 samples/sec and transfers continuous data to a data concentrator.

A small shock of magnitude 2.4 occurred on October 1, 2003, following a damaging earthquake occurred on 26 August 2003 within a couple of kilometers from Milford, New Jersey. The mainshock was felt intensely by residents in New Jersey and Pennsylvania along the Delaware River. People at around the epicenter felt intensity VI (MMI) at close to the epicenter. The earthquake caused minor damage and very small aftershocks were occurring at a rate at about one event each day through fall of 2004.

Significant research efforts were made to determine accurately the earthquake faulting mechanism and focal depth of small to moderate-sized earthquakes in the eastern United States by using three-component, broadband seismic waveform data. We studied the 6 June 2003, magnitude 4 Bardwell, Kentucky, earthquake sequence which indicated that it occurred at a shallow focal depth about 2 km. The 9 December 2003, magnitude 4.3 central Virginia earthquake, suggested that it was a compound earthquake consisting of two nearly identical events separated by 12 seconds in the central Virginia seismic zone. Most significant results of these studies were distribution of deep and shallow earthquakes in the Central and northeastern US and their implications on the thickness of the seismogenic layer. This in turn yields information on the seismic potential of a seismic zone in the region.