Seismic Observations during September 11, 2001, Terrorist Attack

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Summary

Since the time of plane impact at the Pentagon had often been reported with large scatter, the United States Army contacted us to inquire whether we could obtain an accurate time of the Pentagon attack on September 11, 2001 based upon our seismic network. We analyzed seismic records from five stations in the northeastern United States, ranging from 63 to 350 km from the Pentagon. Despite detailed analysis of the data, we could not find a clear seismic signal. Even the closest station (Δ= 62.8 km) at Soldier's Delight, Baltimore County, Maryland (SDMD) did not record the impact. We concluded that the plane impact to the Pentagon generated relatively weak seismic signals. However, we positively identified seismic signals associated with United Airlines Flight 93 that crashed near Shanksville, Somerset County, Pennsylvania. The time of the plane crash was 10:06:05$\pm$5 (EDT).

Introduction

Following the September 11, 2001 terrorist attack on the World Trade Center (WTC) towers, scientists at the Lamont-Doherty Earth Observatory of Columbia University were able to determine accurate times of the plane impacts and building collapses using the seismic signals recorded at numerous seismographic stations in the Northeastern United States. The collapse of the WTC towers generated large seismic waves observed in five states and up to 428 km away. The North Tower collapse was the larger seismic source and had a magnitude M_L 2.3 (Kim et al., 2001).

The time of plane impact at the Pentagon was reported with large scatter. For instance, Cable News Network (CNN) reported 09:43 (EDT), the Washington Post reported 09:40 (EDT), and the New York Times reported 09:38 (EDT).

If the plane impact to the Pentagon generated strong enough ground motion that could be propagated through the Earth's crust as elastic waves (seismic waves) and recorded at sensitive seismographic stations around the source, we could determine absolute time of the impact by using the arrival times of P, S or surface seismic waves. The accuracy of the measured time would depend upon the clarity and strength of the seismic wave arrivals and our knowledge of crustal structure between the source and seismographic stations. This method can provide accurate and absolute time of a seismic event, since most of the modern seismographic stations are equipped with GPS

(Global Positioning System) satellite receivers that can provide absolute time usually within one thousandth of a second accuracy.

In case of the WTC attack, the impacts of the two planes could be determined with an accuracy of about ± 2 seconds. Although the impact times are inferred from oscillatory surface wave arrivals, the nearest station, PAL (Palisades, NY), was only about 34 km away from the WTC.

Analysis of Seismic Records for Pentagon Attack

It was reported by the New York Times (B9, 10/06/2001) that at 09:36 (EDT) the crew of a military C-130 plane identified a Boeing 767 moving low and very fast, and that the plane crashed into the southwest side of the Pentagon at 09:38 (EDT). We collected seismic records from all available seismographic stations in the Northeastern United States around the Pentagon (Table 1; Figure 1) in the hope of verifying or accurately pinpointing the time of impact.

The nearest station to the Pentagon is SDMD (Soldier's Delight) in Baltimore County, Maryland (Δ= 62.8 km) that has been operational since the late summer of 2001. The station was installed and is operated by the Maryland Geological Survey. It is part of the Lamont-Doherty Cooperative Seismographic Network (LCSN) that monitors earthquakes in the Northeast. The second closest station to the Pentagon is CBN (Corbin, Virginia, Δ= 78.9 km). However, this station did not produce useful waveform data for the time window, because this seismographic station records data only when seismic signals are detected.

Figure 2 shows seismic records at the three nearest stations around the Pentagon with distance ranges from 63 to 208 km. Three minutes of vertical-component seismic records from 09:36:30 (EDT) to 09:39:30 (EDT) are plotted. There appears to be strong seismic signals around 09:38:52 at station MVL (Millersville, Pa; Δ= 139 km), but the signals are too high frequency (5-10 Hz) and too high amplitude (328 nm/s at 139 km). Hence, it appears be noise perhaps due to electrical disturbances. Otherwise, there are no clear and consistent seismic wave arrivals in this time window. Figure 3 shows seismic record section for records shown in Figure 2. These displays facilitate analysis of seismic signals by displaying a suite of records in order by distance. Hence, the seismic phase Pg (P waves propagating through Earth's crust) would propagate with nearly constant speed of about 6 km/s over the record section, where as the phase Pn (critically refracted P waves propagating through top of the uppermost mantle) propagates with an apparent speed of about 8 km/s. Hence, the consistency of seismic phases across a seismograph network is the key to discern if there are any seismic signals generated during the plane impact into the Pentagon. These waveform data indicate that we could not identify seismic signals associated with the plane impact into the Pentagon on September 11, 2001.

In case of the plane impacts to the WTC towers, the observed peak amplitudes on the vertical-component record at PAL (Palisades, NY; Δ = 34 km) are 230 and 260 nanometers/sec for the first (North Tower) and the second (South Tower) impacts, respectively. A nanometer is 10^{-9} meters.

Figure 4 shows seismic record section of vertical seismic records from the WTC South Tower

collapse at 11:59:39 (EDT) (13:59:04 UTC). It generated strong seismic waves equivalent to an earthquake of local magnitude M_L =2.1 (Richter scale; see Kim, 1998). The seismic signals, Lg and Rg waves, are discernible up to about 500 km from the WTC site. Stations MVL, SDMD and SSPA that we examined for the Pentagon case, also recorded useful signals and indicate that these stations were working normally on September 11, 2001.

Analysis of Seismic Records for United Airlines Flight 93 Crash near Shanksville, Pa

Figure 5 shows seismic record section of vertical-component records from four stations around the United Airlines Flight 93 crash site near Shanksville, Somerset County, Pennsylvania. The location of the site is taken from the web site for the Flight 93 Memorial,
URL http://www.shanksvillememorial.com. The four closest stations range in distance from 92 to 218 km (Table 1). Two minutes of vertical-component seismic records starting from estimated origin time of 14:06:05 (10:06:05 EDT) are plotted.

The seismic signals are relatively weak compared with the background noise level. For instance, at stations MCWV and SDMD, the signal (portion of signals just after Sg) to noise (portion of records just before Pg arrivals) ratios are about 1:1, whereas, at station SSPA the ratio is about 2.5:1 and at MVL it is about 2:1 (Figure 5).

Although, seismic signals across the network are not as strong and clear as the WTC case (see Kim et al., 2001), three component records at station SSPA (Δ= 107.6 km) shown in Figure 6 are quite clear. The three-component records at SSPA are dominated by strong Lg arrivals, whereas the Pg waves are difficult to discern and have amplitudes comparable to the noise level. This is typical for seismic waves generated by airplane impacts and crashes. The seismic signals marked as Sg in Figure 5 propagated from the Shanksville crash site to the stations with approximately 3.5 km/s. Hence, we infer that the Flight 93 crashed around 14:06:05$\pm$5 (UTC) (10:06:05 EDT). The uncertainty is only due to seismic velocity at the uppermost crust near the surface in which the Lg waves propagated.

Acknowledgments

We thank the many individuals and institutions that collaborated with us in operating the seismographic stations in the Northeastern United States. In particular, Richard Ortt and Robert Conkwright at the Environmental Geology and Mineral Resources, Maryland Geological Survey installed and operate the station SDMD (Soldier's Delight, Maryland) and provided the digital waveform data for the analysis. Professor Charles Scharnberger at the Millersville University, Pennsylvania operates the station MVL (Millersville, Pennsylvania) and provided the data. These modern broadband, digital seismographic stations form the backbone of the Lamont-Doherty Cooperative Seismographic Network (LCSN). We appreciate LCSN staff Jeremiah Armitage, John Armbruster and John Contino at Lamont-Doherty Earth Observatory for their efforts. Dr. Martin Chapman at Virginia Tech provided the waveform data from BLA (Blacksburg, Virginia). The analysis carried out for this report is sponsored by the Department of Natural Resources, State of Maryland under contract number SMGS/AG1-01-075.

References

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Table 1: Seismographic Stations in the Northeastern United States

Seismographic stations				Pentagon[1]		Shanksville, Pa[2]	
Station code	Station name	Lat. (°N)	Long. (°W)	Distance (km)	Az (°)	Distance (km)	Az (°)
SDMD	Solder's Delight, Md	39.410	76.840	62.8	17.4	190.6	111.4
CBN	Corbin, Va	38.205	77.373	78.9	200.5	244.3	146.8
MVL	Millersville, Pa	39.999	76.351	139.3	25.7	217.8	90.8
SSPA	Standing Stone, Pa	40.636	77.888	208.5	340.3	107.6	52.8
MCWV	Mont Chateau, WVa	39.658	79.846	255.9	290.8	92.1	241.7
BLA	Blacksburg, Va	37.211	80.421	347.9	239.1	342.3	203.2

[1] Epicentral distance and azimuth between the Pentagon (approximately at 38.871°N, 77.058°W), and stations; [2] Epicentral distance and azimuth between the UA Flight 93 crash site (40.055°N, 78.901°W) and the stations.

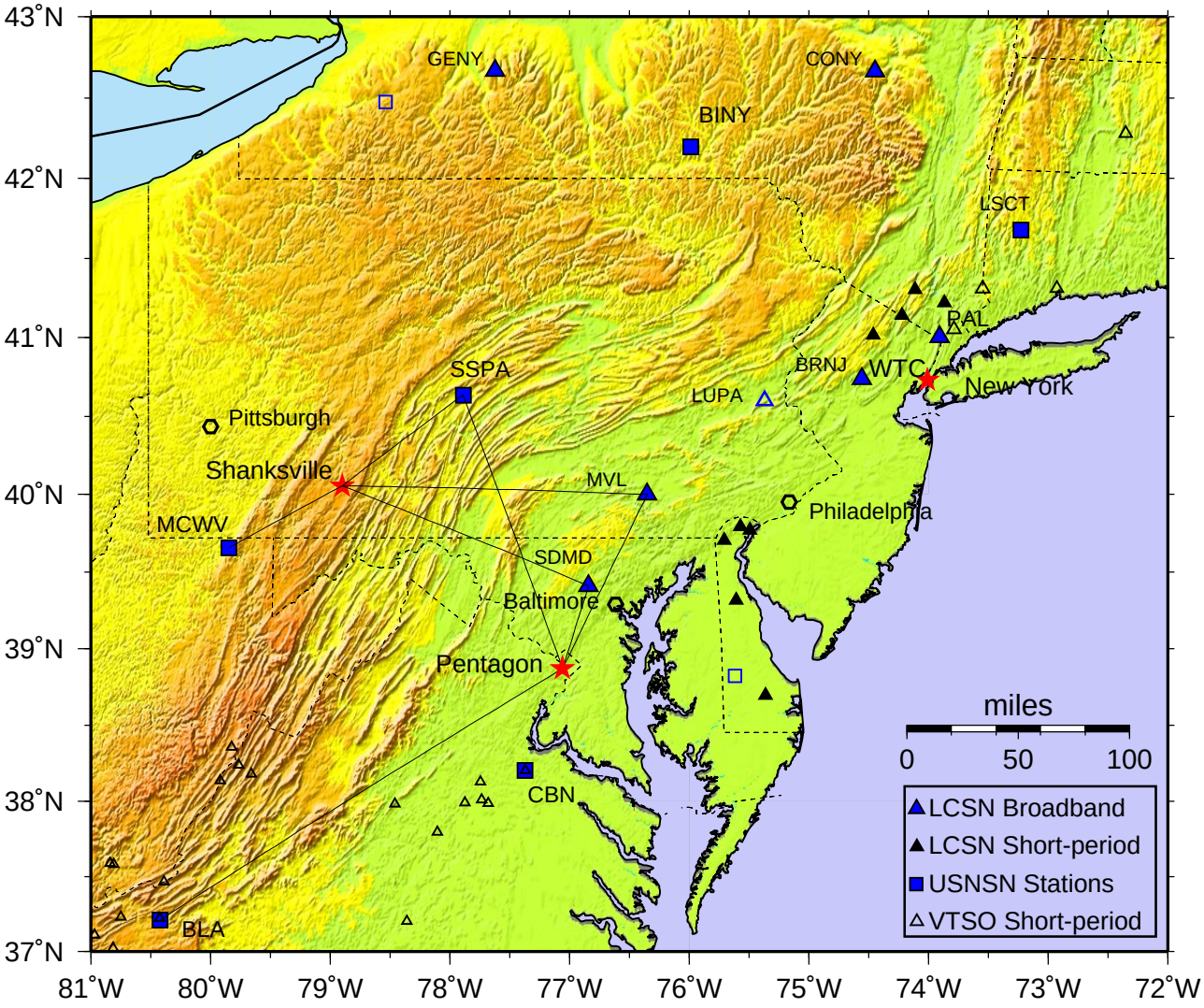

Figure 1: Seismographic stations and topography for Northeastern United States. Impacts and crashes of aircrafts during the terrorist attack on Sept. 11, 2001 are indicated by solid stars. Solid triangles and squares indicate stations that recorded seismic signals from WTC, Pentagon and Shanksville, Pa, whereas the open triangles and squares indicate stations either closed or recorded no data. Waveform data used for the analysis are indicated by source-receiver path.

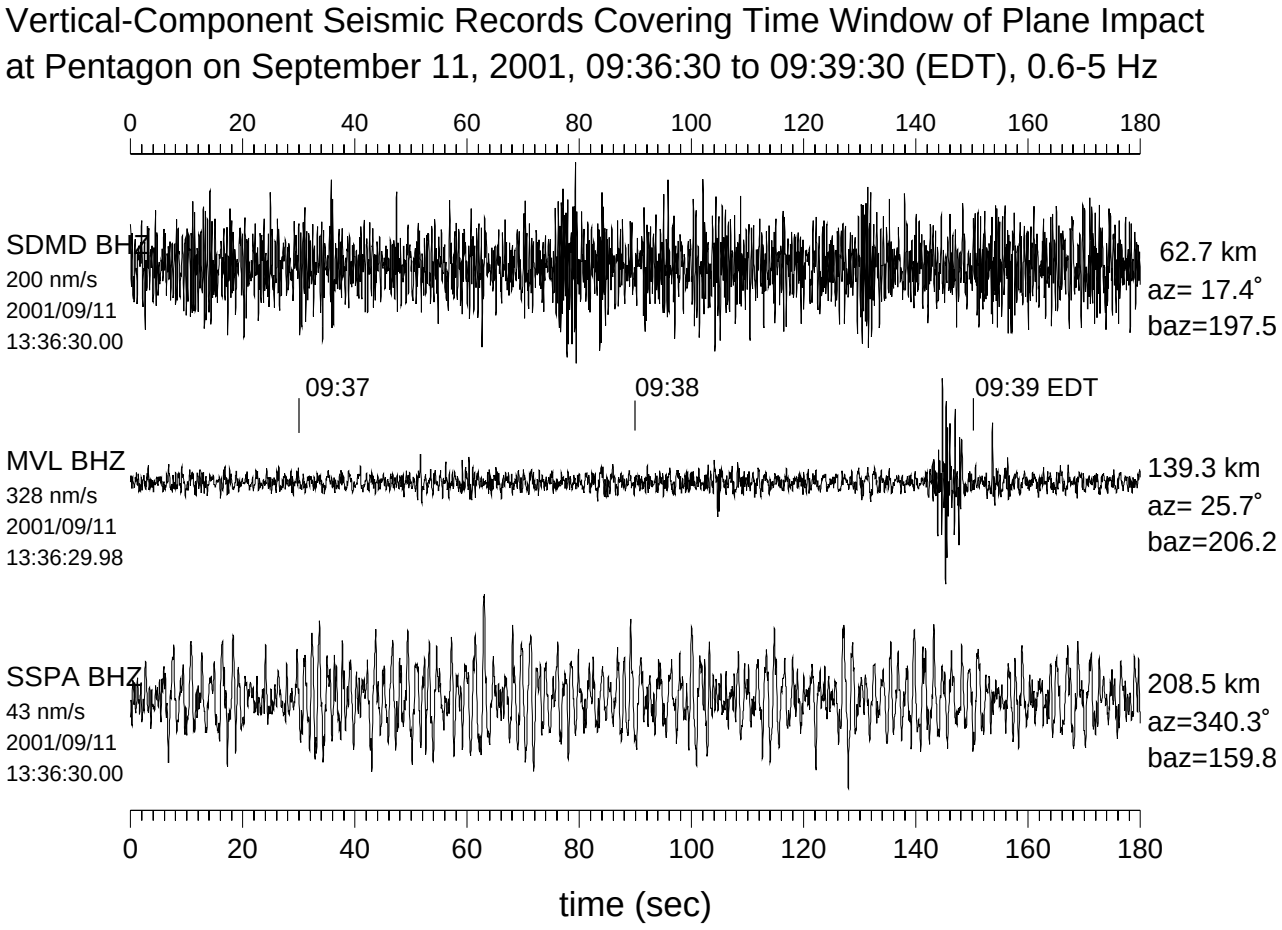

Figure 2: Vertical-component seismic records at three stations around Pentagon. Three minutes of continuous data shown starting at 09:36:30 EDT (13:36:30 UTC). Data were sampled at 40 times/s and passband filtered from 0.6 to 5 Hz. The maximum amplitudes of traces ranges from 200 nanometer/seconds (nm/s) at SDMD (Δ=63 km) to 43 nm/s at SSPA (Δ =208 km) The largest signal at MVL at around 09:38:50 is probablly generated by electrical disturbance. Eastern Daylight Time (EDT) is UTC minus 4 hours.

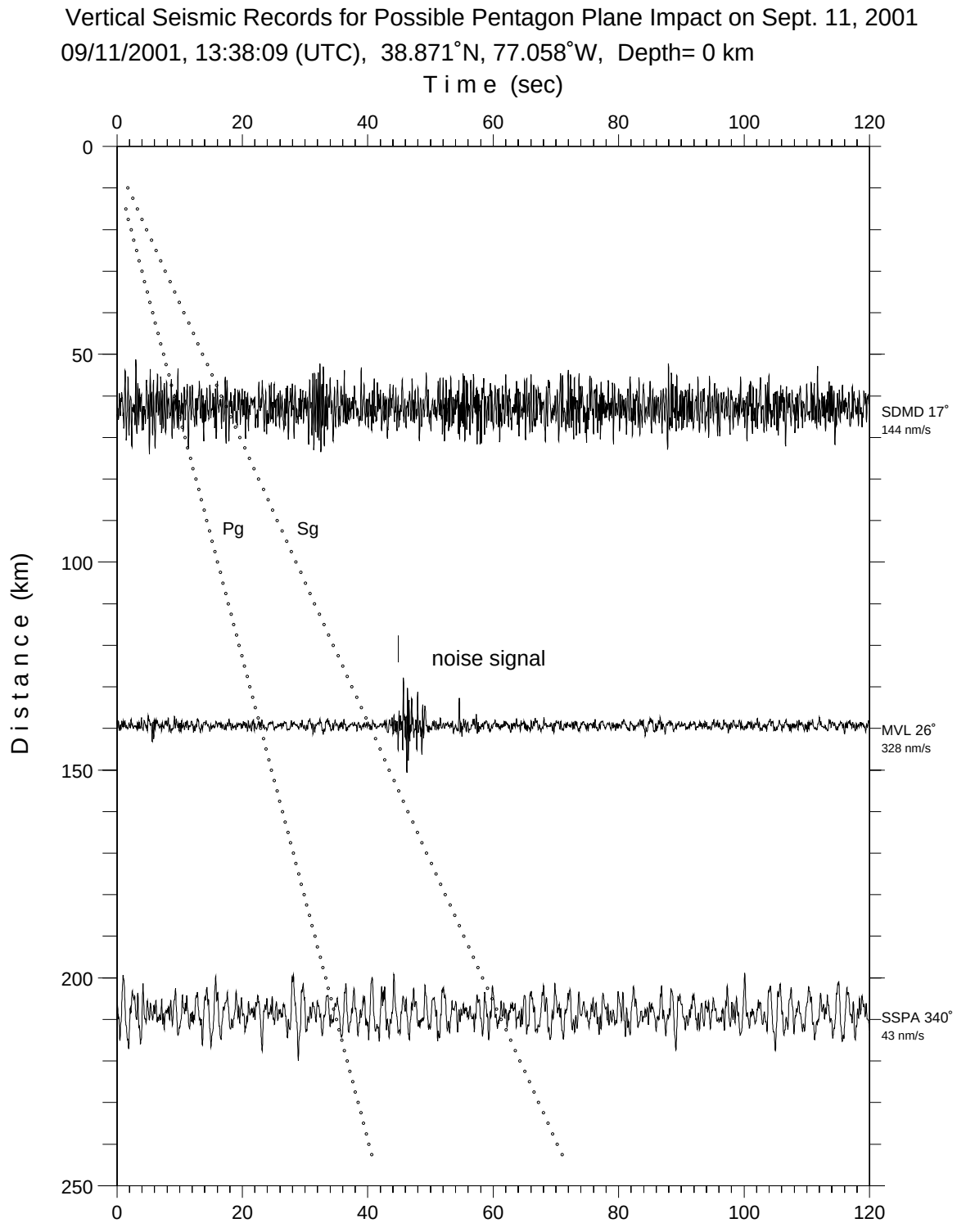

Figure 3: Vertical-component records from three stations in Fig. 2. Possible seismic signals from the airplane crash into the Pentagon may be very weak, but examination of seismic data recorded across network of three stations would help identify the signals. Predeicted P- and S-wave arrivals across the network are indicated by dotted lines for a presumed origin time of 13:38:09 EDT. There is no clear seismic signals which can be associated with the airplane crash into the Pentagon.

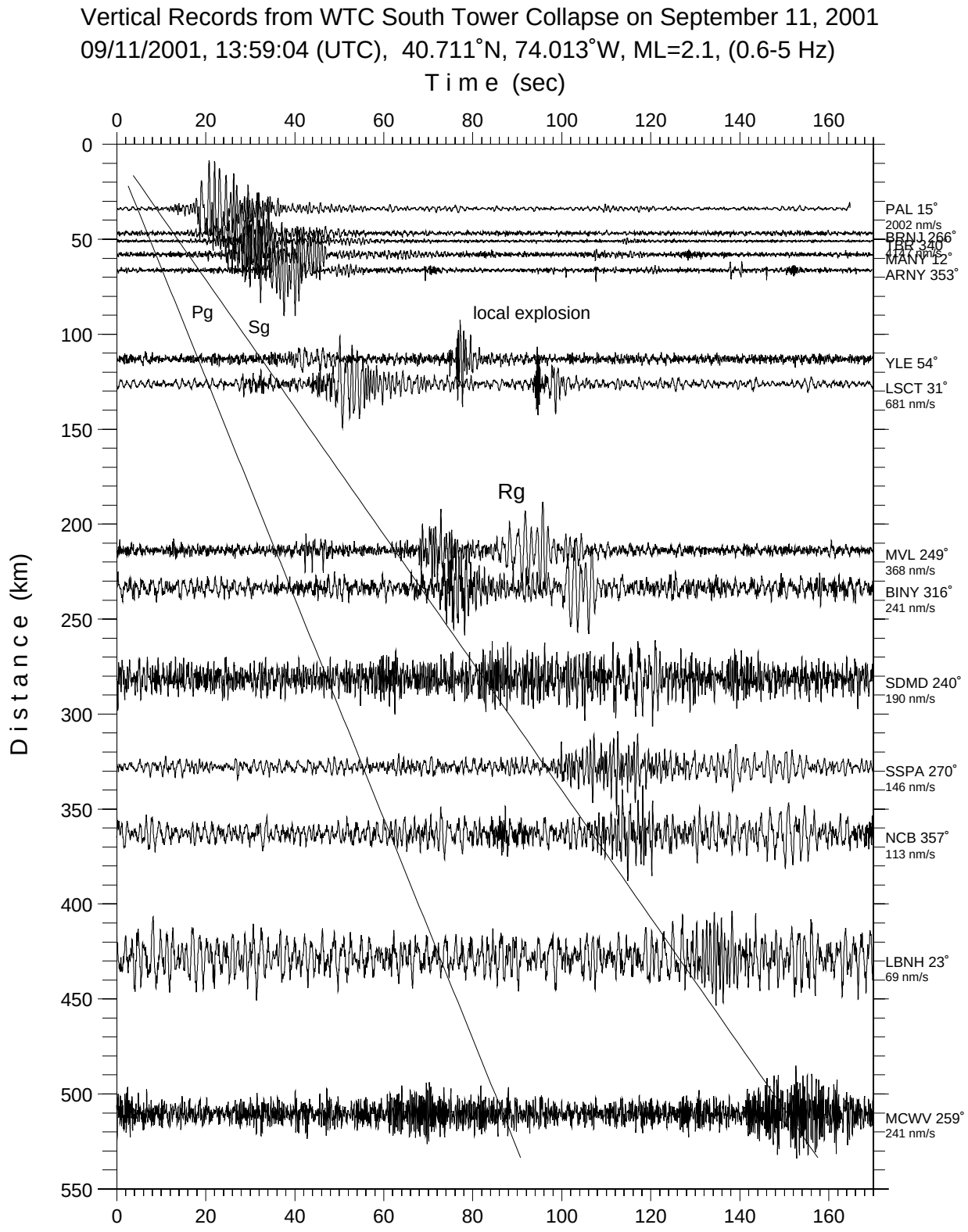

Figure 4: Vertical component record section from WTC South Tower collapse. S wave arrivals with 3.5 km/s are indicated by solid line, which is usually the beginning of Lg waves.

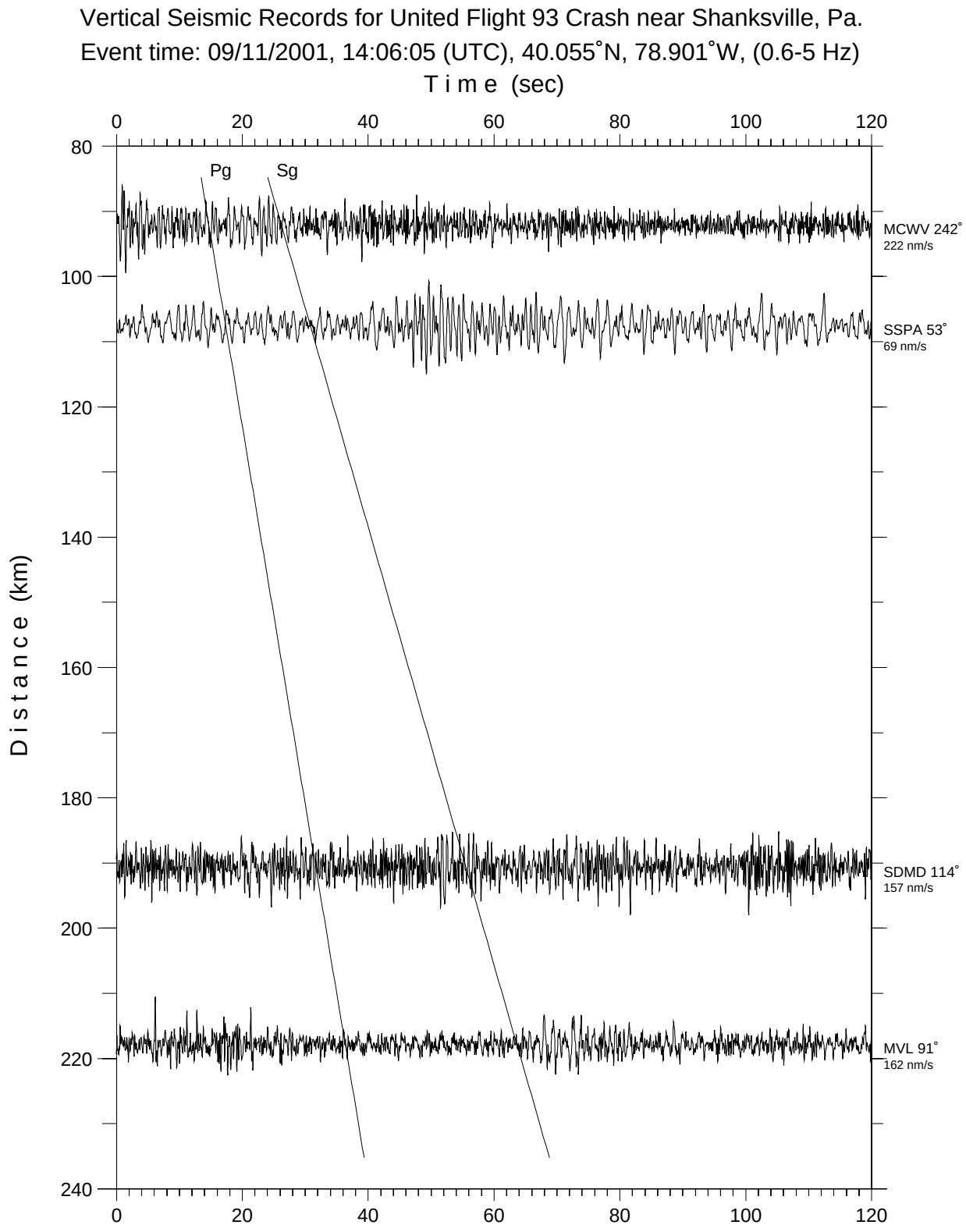

Figure 5: Seismic record section of vertical records from the United Airlines Flight 93 crash near Shanksville, Pa on Sept. 11, 2001. Relatively consistent seismic signals arrivals are discernible at stations, SSPA and MVL. Maximum zero-to-peak amplitude at SSPA is about 140 nm/s.

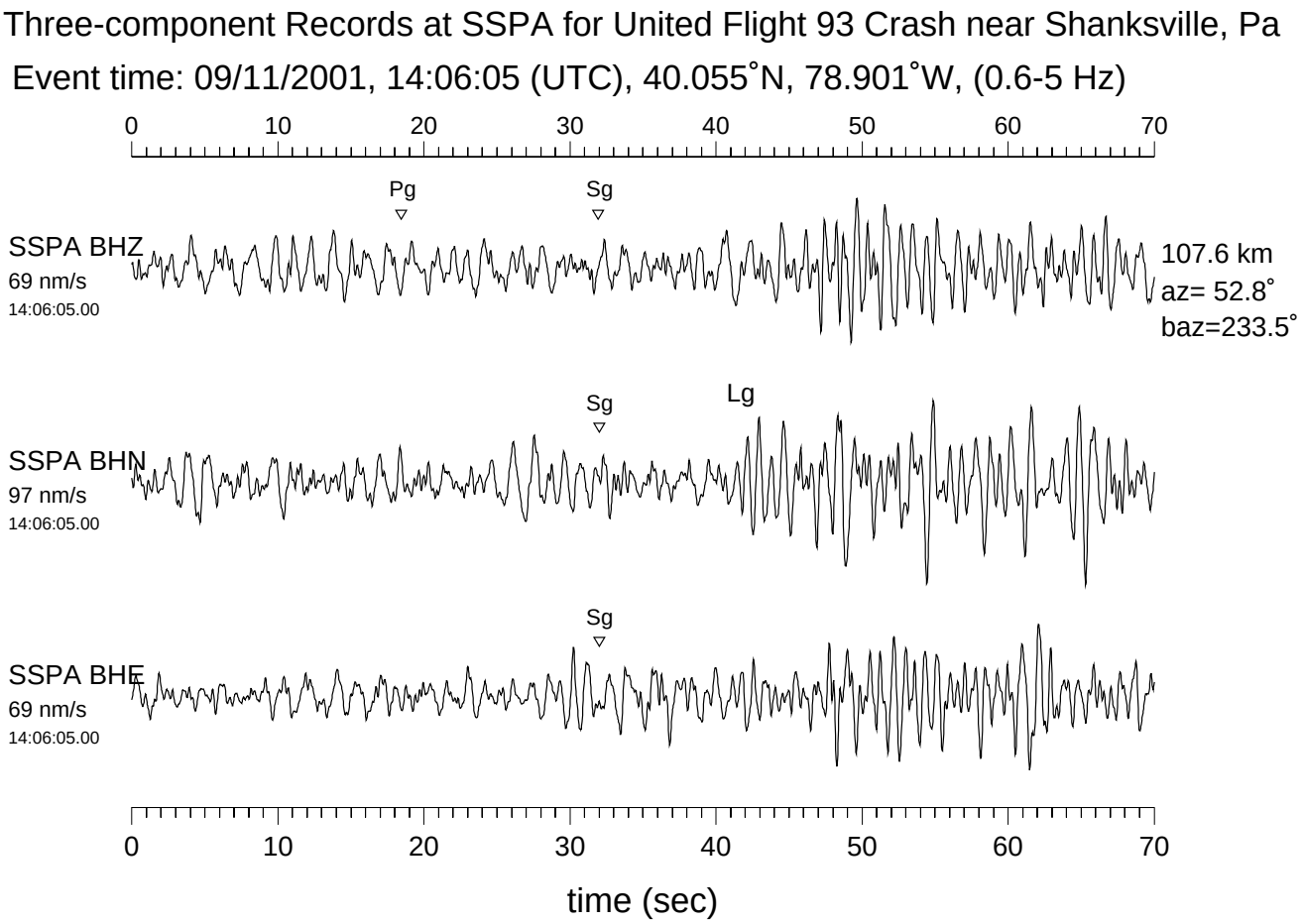

Figure 6: Three-component seismic records, vertical, North-South, and East-West components, at station SSPA from the United Airlines Flight 93 crash near Shanksville, Pa on Sept. 11, 2001. Short-period surface waves, Rg and Lg waves, are quite clear. Maximum zero-to-peak amplitudes on three-component ranges from 160 to 180 nm/s on NS-component.