Seismicity in Pennsylvania and the Pennsylvania State Seismic Network (PASEIS)

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Introduction

- Review of seismicity in PA
- Review of seismic networks in PA
- Seismicity in Pennsylvania 2013-2015
- Building the Pennsylvania State Seismic Network (PASEIS)
- Event detection and location
- PASEIS web site

Earthquakes in NE United States and Canada 1990 - 2010



Earthquake locations by the Lamont Cooperative Seismographic Network, US Geological Survey and the Geological Survey of Canada. June 2010, Won-Young Kim, Lamont-Doherty Earth Observatory of Columbia University, <www.ldeo.columbia.edu/LCSN>.



Permanent seismic stations in PA through 2015

- USGS National Network (2 stations)
- Lamont Doherty Earth Observatory Cooperative Seismic Network (LCSN) (supported as a regional network by the USGS) (6 stations)
- Initial 10 PASEIS stations



History of building a PA state seismic network

- 2006-2009 Establishment of the first 6 permanent PASEIS stations DCNR (data archived and distributed using the PE Network code)
- 2009 Carbon sequestration technical assessment DCNR
 - 25 portable seismic stations
- 2010 Purchase of 4 USArray stations from IRIS DCNR
- 2013 Earthquake monitoring during USArray DCNR
 - Support for temporary network to densify the USArray network, develop seismicity catalog
- 2015 Expand the 10-station permanent

network to 30 stations and provide seismic event information – DCNR and DEP





Stations 2/2013 to 6/2015



- 101 3component high quality (broadband) stations
- Recording continuously



PA seismicity 2/2013 to 06/2015 (from Kyle Homman's MS thesis, PSU)

- Average number of stations used for each event: 10
- Minimum number of stations used was 4
- 1761 events with 1544 located in Pennsylvania



Magnitudes and Depths

 Local magnitudes range from 1.0 to 2.9



Catalog is complete to magnitude 1.8

- Depths 0 -5 -10 -15 (km) -20 -25 -30 -35 -40-45 L____0 100 200 300 400 500 600 700 800 900 Number of Events
- Depths mostly < 1 km



Non-mining events



Are there spatial and temporal correlations with well activity?



-No correlation has been found with either injection wells or fracked wells for the 2013-2015 time period

Summary of findings: 1530 mining related events 14 Non-mining events – they are all probably tectonic earthquakes



Historical

2/2013-6/2015

PASEIS Station Map Sept. 2016



Equipment

RefTek RT130 Datalogger

- Guralp CMG3T seismometer
- Nanometrics Compact Trillium seismometer



Broadband 3-component seismometers



GPS Clock





Basement deployments – mostly at university locations





Outside vault deployments – mostly at state park locations



Technical specifications; Network code = PE



Network summary (1 time span)

IRIS

Usage

Network	PE :: Penn State Network :: <u>PE Network Map</u> :: <u>DOI</u>
Start Year	2004
End Year	2500

http://ds.iris.edu/mda/PE

Stations for PE network (28 stations) :: Click column title to sort

	Station A-	Site Av	Latitude A-	Longitude Av	Elevation A-	First start Av	Last end Av	
RA	PABE	Bald Eagle State Park, Howard, PA	41.034715	-77.651590	204	2016/05/30	2599/12/31	
RA	PACF	Cook Forest State Park, Cooksburg, PA	41.332515	-79.208278	398	2016/05/09	2599/12/31	
RA	PACH	Chapman State Park, Clarendon, PA	41.756660	DIC				IDIC DMC MataData Acamagtan
RA	PACW	Cowans Gap State Park, Fort Loudon, PA	39.995013	Usage				IKIS DMC MetaData Aggregator
RA	PAGS	PA Geological Survey, Middletown, PA	40.230000			58		
RA	PAHR	Hickory Run State Park, White Haven, PA	41.02413(St	tation summ	nary (1 tim	e span)		
RA	PAKC	Kettle Creek State Park, Renovo, PA	41.374710	Notwork	DE u Donn St	ata Naturark u DE	Notwork Mon	" DOI
RA	PAKS	Keystone State Park, Derry Township, PA	40.376097	Station	PE :: Penn St	Legele State Park	Howard PA	Pann State Naturek .: DARE Station Man .: DESD .: SAC DZs .: VML
RA	PALB	Little Buffalo State Park, Newport, PA	40.458910	Latitude	41 034715	Lagie State Faix	, nowald, IA	renii State Network <u>FABE Station Map</u> <u>KESF</u> <u>SAC FZS</u> <u>AME</u>
RA	PALR	Lyman Run State Park, Galeton, PA	41.725095	Longitude	-77.651590			
				Elevation	204			
				Start	2016/05/30 (151) 00:00:00		

MetaData Load 2016/08/15 (228) 09:38:00

<u>US-REGIONAL</u> US Regional Networks

Description

Real-time data availability (view Station Monitor)

.UNRESTRICTED All unrestricted stations, generated via cron

Latest R 2016/08/18 (231) 00:00:00 2016/08/28 (241) 00:00:00

Virtual network affiliations:

2599/12/31 (365) 23:59:59

2016/05/30 (151) 00:00:00 - 2599/12/31 (365) 23:59:59

Channels (Hz) Location --: HHE (100) R A, HHN (100) R A, HHZ (100) R A, LHE (1), LHN (1), LHZ (1)

Stations collected and served in real time at the DMC IRIS DMC

Primary DC Secondary DC

IRIS DMC

IRIS DMC

IRIS DMC

IRIS DMC

PENN

PSU

IRIS DMC

Nanometrics Trillium Compact/Reftek 130 Datalogger

Pennsylvania State Geological Survey

End

Epoch

Name

PENN

Earliest

REALTIME

Instrument



Overview of network

Network summary (1 time span)

 Network
 PE :: Penn State Network :: PE Network Map :: DOI

 Start Year
 2004

 End Year
 2500

Stations for PE network (30 stations) :: Click column title to sort

	Station A-	Site AT	Latitude A-	Longitude Av	Elevation AT	First start Av	Last end Av
RA	<u>IUPA</u>	Indiana University of Pennsylvania, Indiana, PA	40.606670	-79.169670	398	2016/11/14	2599/12/31
RA	PABE	Bald Eagle State Park, Howard, PA	41.034715	-77.651590	204	2016/05/30	2599/12/31
RA	PABK	Blue Knob State Park, Imler, PA	40.266520	-78.583680	482	2016/09/13	2599/12/31
RA	PACF	Cook Forest State Park, Cooksburg, PA	41.332515	-79.208278	398	2016/05/09	2599/12/31
RA	PACH	Chapman State Park, Clarendon, PA	41.756660	-79.171430	431	2016/03/18	2599/12/31
RA	PACW	Cowans Gap State Park, Fort Loudon, PA	39.995013	-77.924788	394	2016/05/10	2599/12/31
RA	PAGS	PA Geological Survey, Middletown, PA	40.230000	-76.720000	120	2012/02/12	2599/12/31
R A	PAHR	Hickory Run State Park, White Haven, PA	41.024130	-75.709870	364	2016/07/18	2599/12/31
RA	PAKC	Kettle Creek State Park, Renovo, PA	41.374710	-77.932530	294	2016/05/04	2599/12/31
RA	PAKS	Keystone State Park, Derry Township, PA	40.376097	-79.379512	336	2016/06/13	2599/12/31
RA	PALB	Little Buffalo State Park, Newport, PA	40.458910	-77.167830	145	2015/12/21	2599/12/31
RA	PALR	Lyman Run State Park, Galeton, PA	41.725095	-77.760062	537	2016/04/17	2599/12/31
RA	PAMP	Mt. Pisgah State Park, Troy, PA	41.805900	-76.668890	348	2016/04/28	2599/12/31
RA	PAMR	Moraine State Park, Slippery Rock, PA	40.939800	-80.097300	393	2016/08/01	2599/12/31
RA	PAOC	Oil Creek State Park, Oil Creek, PA	41.515960	-79.681090	337	2016/08/01	2599/12/31
RA	PAPL	Promised Land State Park, Greentown, PA	41.299015	-75.021400	572	2016/06/01	2599/12/31
RA	PARS	Ryerson Station State Park, Wind Ridge, PA	39.886320	-80.445220	305	2016/04/15	2599/12/31
RA	PASH	Shawnee State Park, Schnellsburg, PA	40.026000	-78.635690	393	2016/04/22	2599/12/31
RA	PSAL	PSU Altoona Campus, Altoona, PA	40.543700	-78.414500	402	2015/11/16	2599/12/31
RA	PSBK	PSU Berks Campus, Reading, PA	40.363210	-75.973800	83	2016/02/16	2599/12/31
RA	PSBV	PSU Beaver Campus, Monaca, PA	40.679950	-80.297500	307	2016/01/26	2599/12/31
RA	PSDB	PSU Dubois Campus, Dubois, PA	41.130000	-78.750000	437	2010/01/01	2599/12/31
RA	PSMA	PSU Mont Alto Campus, Mont Alto, PA	39.843010	-77.543400	299	2016/02/24	2599/12/31
RA	PSSH	PSU Shenango Campus, Sharon, PA	41.235000	-80.507600	265	2015/11/25	2599/12/31
R A	PSSK	PSU Schuylkill Campus, Schuylkill Haven, PA	40.642587	-76.164978	227	2016/04/25	2599/12/31
RA	PSUB	PSU Brandywine Campus, Media, PA	39.930000	-75.450000	110	2009/01/30	2599/12/31
RA	PSUF	PSU Fayette Campus, Uniontown, PA	39.944200	-79.658800	373	2016/01/07	2599/12/31
RA	PSWB	PSU Wilkes-Barre Campus, Wilkes-Barre, PA	41.305475	-76.015183	398	2009/11/13	2599/12/31
RA	UPAO	University of Pittsburgh, Pittsburgh, PA, USA	40.480000	-80.020000	274	2009/07/30	2599/12/31
RA	WRPS	PSU, University Park, PA, USA	40,790000	-77.870000	320	2009/09/29	2599/12/31

List of station names, locations, and start times



Station summary (1 time span)

Network	PE :: Penn State Network :: PE Network Map :: DOI
Station	PACH :: Chapman State Park, Clarendon, PA :: Penn State Network :: PACH Station Map :: RESP :: SAC PZs :: XML
Latitude	41.756660
Longitude	-79.171430
Elevation	431
Start	2016/03/18 (078) 00:00:00
End	2599/12/31 (365) 23:59:59
Epoch	2016/03/18 (078) 00:00:00 - 2599/12/31 (365) 23:59:59
Instrument	Reftek 130 Datalogger
Channels (Hz)	Location ::: LOG (0)
Instrument	Nanometrics Trillium Compact/Reftek 130 Datalogger
Channels (Hz)	Location:: HHE (100) R, HHN (100) R, HHZ (100) R, LHE (1), LHN (1), LHZ (1)
MetaData Load	2016/08/15 (228) 09:38:02

Virtual network affiliations:



Query archive for data day availability:

Open broadband seismic stations in PA with near real-time telemetry

- 30 stations in the PASEIS network
- 6 stations operated by LCSN (LD)
- 2 stations operated by the USGS (US)
- 4 stations in the CEUSN network operated by IRIS/USGS



Stations used to detect and locate seismic events by PASEIS (71 total)





Earthworm Process

- Automatic detection and location of seismic events
 - Arrival time picks (P and S waves)
 - STA/LTA algorithm
 - Frequency band algorithm
 - Location
 - HYPOINVERSE code with velocity model for PA
- Alerts

Records event information and sends email alerts







Analysis of Automatic Locations

- Determine whether an event is real or a false detection
 - Use information on email alert
 - Waveform characteristics
 - Location of stations
 - Location of event (near to known mine?)
- If there is any indication that the event might not be a false detection, then the event is manually relocated

Manual Event Locations

- Pull data from Earthworm server
- Refine arrival time picks by hand using SEISAN
- Relocate event using HYPOINVERSE and same velocity model as used for automatic solution
- Add event information to database and post on the website

Example P- and S-wave arrival time picks from SEISAN





Email Alert received for Magnitude 2.2 earthquake near Titusville PA on April 18, 2016



P: ALLY.HHZ.LD.-- 2016.04.18 10:34:48 UTC CodaDur.=256 s PickQuality 0 Residual= 0.13s Distance= 51.6 km Md=3.7 wt=0

Minor earthquake measures near

city

Posted: Tuesday, April 19, 2016 12:08 am

By Stella Ruggiero sruggiero@titusvilleherald.com | = 0 comments

A small earthquake, which was likely too weak to be noticed by anyone other than geologists, measured in the Titusville area on Monday, around 6:34 a.m.

The quake was magnitude 2.2, according to AccuWeather meteorologist Jordan Root. He said it was fairly weak on the scale, and not likely felt by many people, or maybe no one at all. As of late Monday afternoon, Root had received no reports of anyone experiencing the quake.





Example of an Email alert for a Teleseismic earthquake (a distant, M > 5 earthquake)



Example of an Email alert for a false detection on cultural noise (most alerts look like this!)



Example Email alert for a mining blast. Note characteristic long period surface wave.



Email alert for one of the Lawrence County events on April 25, 2016.



Seismic Events Seismic Stations Background About Data Contact (http://paseis.geosc.psu.edu)

The 25 most recent seismic events are shown here. The full event catalog from September 2016 may be downloaded here.

The sources of the seismic events displayed are not analyzed. Possible sources include natural earthquakes, mining blasts, and induced seismicity.



Date	UTC Time (HH:MM:SSS)	Latitude (Deg.)	Longitude (Deg.)	Depth (km)	Magnitude	Horizontal Uncertainty (km)	Depth Uncertainty (km)	Information
2017-03-30	19:17:57.3	41.167	-78.069	0.1	1.8	0.3	31.6	Download
2017-03-29	18:34:58.8	41.084	-78.347	0.1	1.5	0.6	31.6	Download
2017-03-29	16:15:00.4	39.826	-79.942	0.1	1.3	0.7	31.6	Download
2017-03-28	16:17:45.9	41.14	-78,107	0.1	1.9	0.7	31.6	Download

PE.PABKHHZ	2017-04-04T00:00:00 2017-04-05T00:00:00 UTC	€ 61:00
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N58A HE ES 0 1743 2.05 90 1.501053.50 288		
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M57A HN ES 0 1743 18.69 90 0.70010111.1 310		20.00
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PSBK HE IAML 1743 0.36 51.8 0.28 38.7 162		22:00
PAHR HN IAML 1743 5.92 52.6 0.70 49.9 43		
N58A HE IAML 1743 6.60 25.0 0.67 53.4 288		23.00
PALB HN IAML 1743 17.04 21.3 0.61 93.1 254		
M57A HN TAML 1743 23.56 13.4 0.48 111 310		80.00
SSPA B1 IAML 1743 32.90 15.1 0.74 150 268		
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Acknowledgments

Support for PASEIS comes from DCNR (Bureau of Topographic and Geologic Survey) and DEP





NSF

IRIS provides data management (data archiving and

distribution)



