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

Andy Nyblade
Department of Geosciences, Penn State University
May 19, 2017
Shale Network Workshop

PennState

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DEPARTMENT OF CONSERVATION
AND NATURAL RESOURCES

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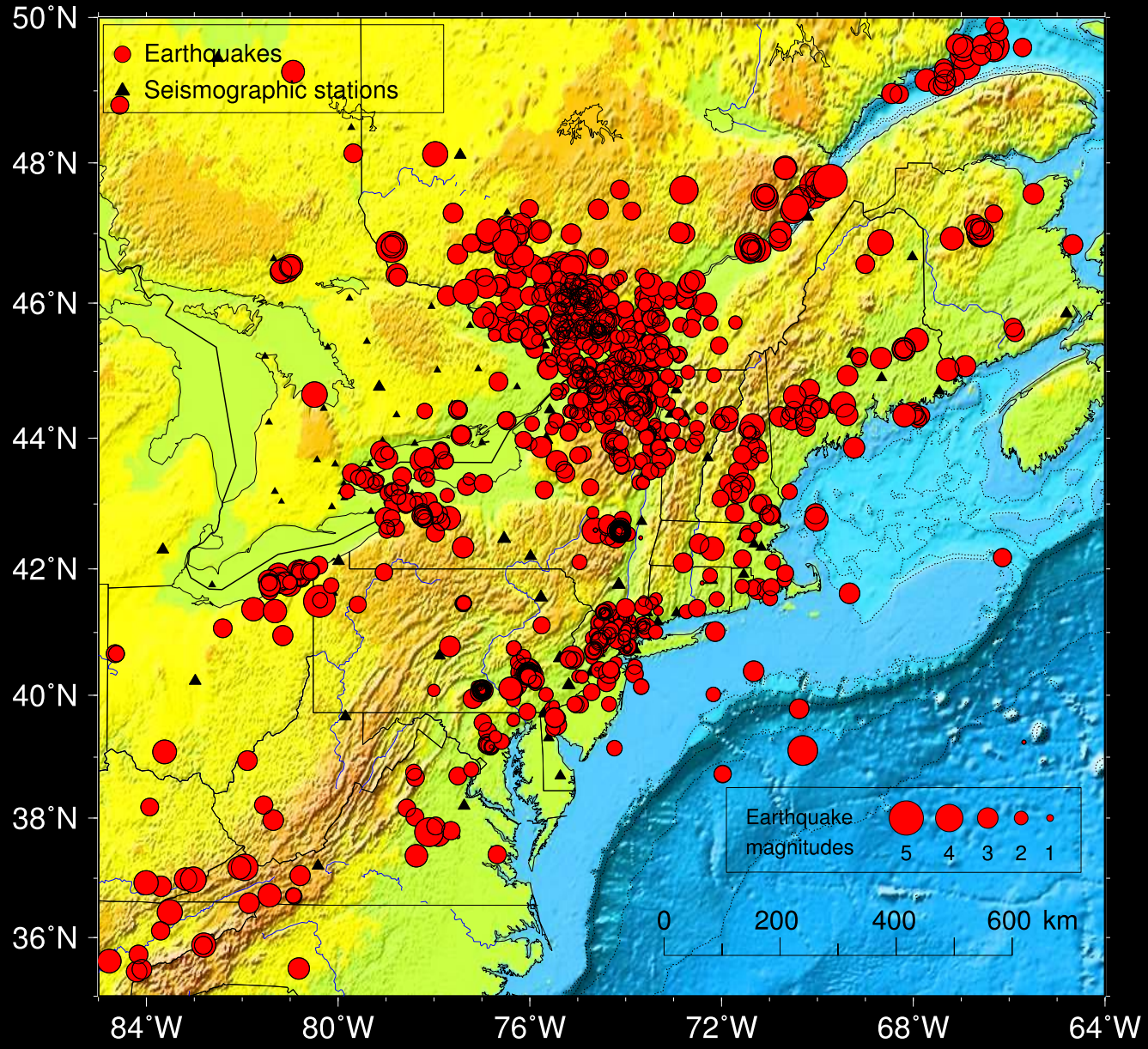
DEPARTMENT OF ENVIRONMENTAL PROTECTION

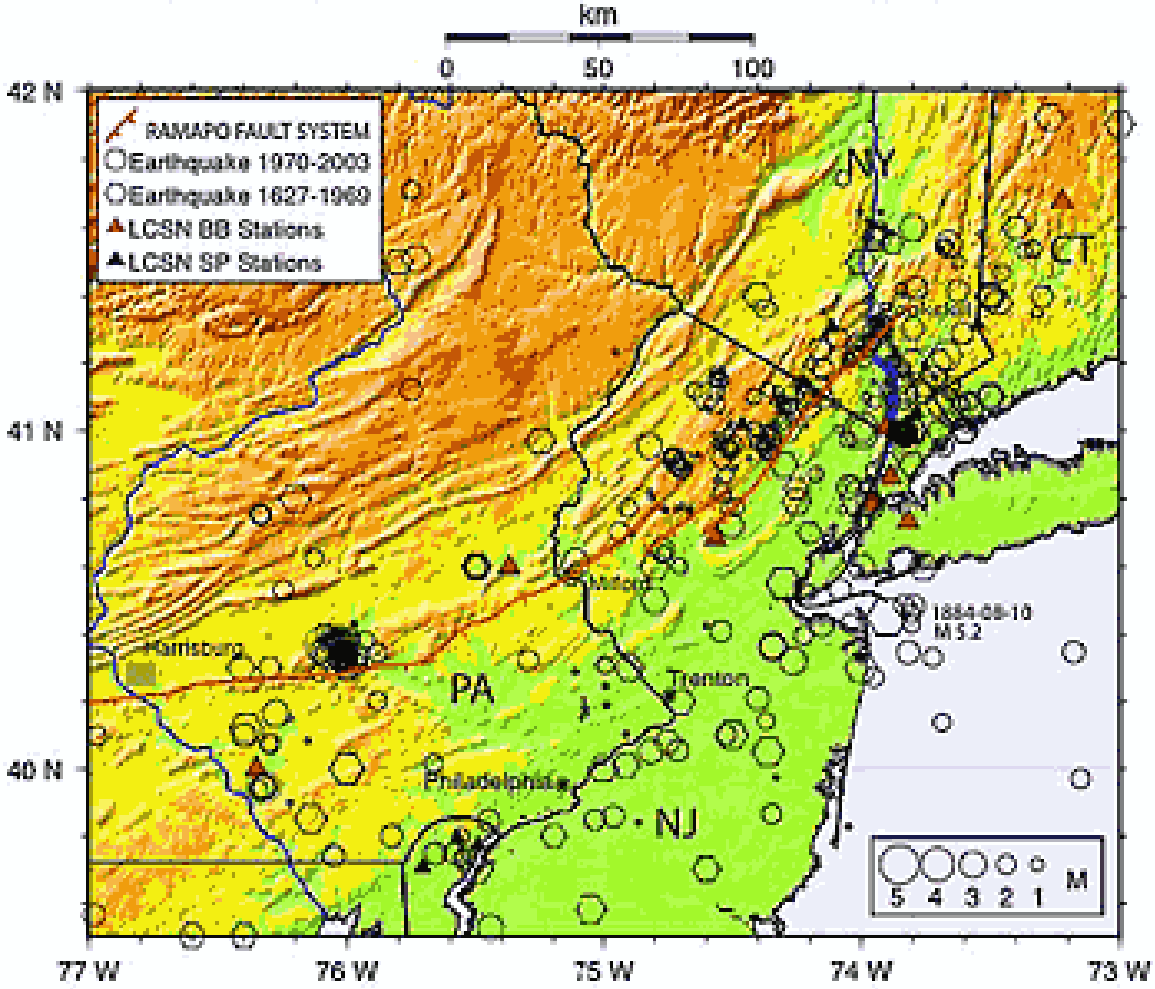
Introduction

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

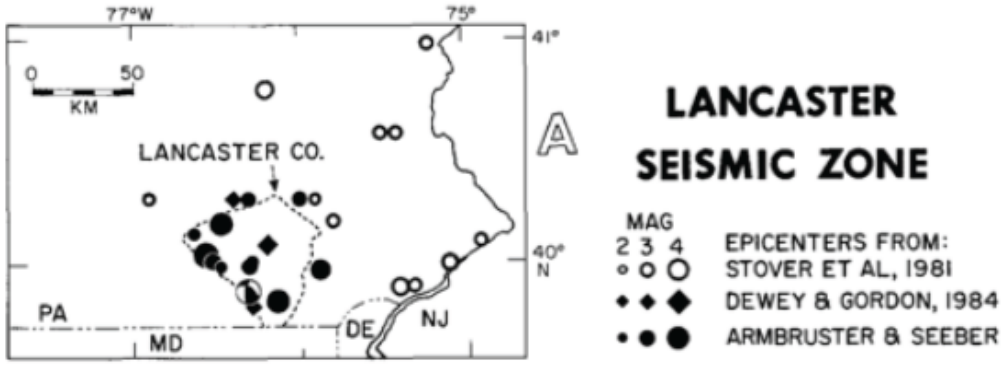
Earthquakes in NE United States and Canada 1990 - 2010



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>.

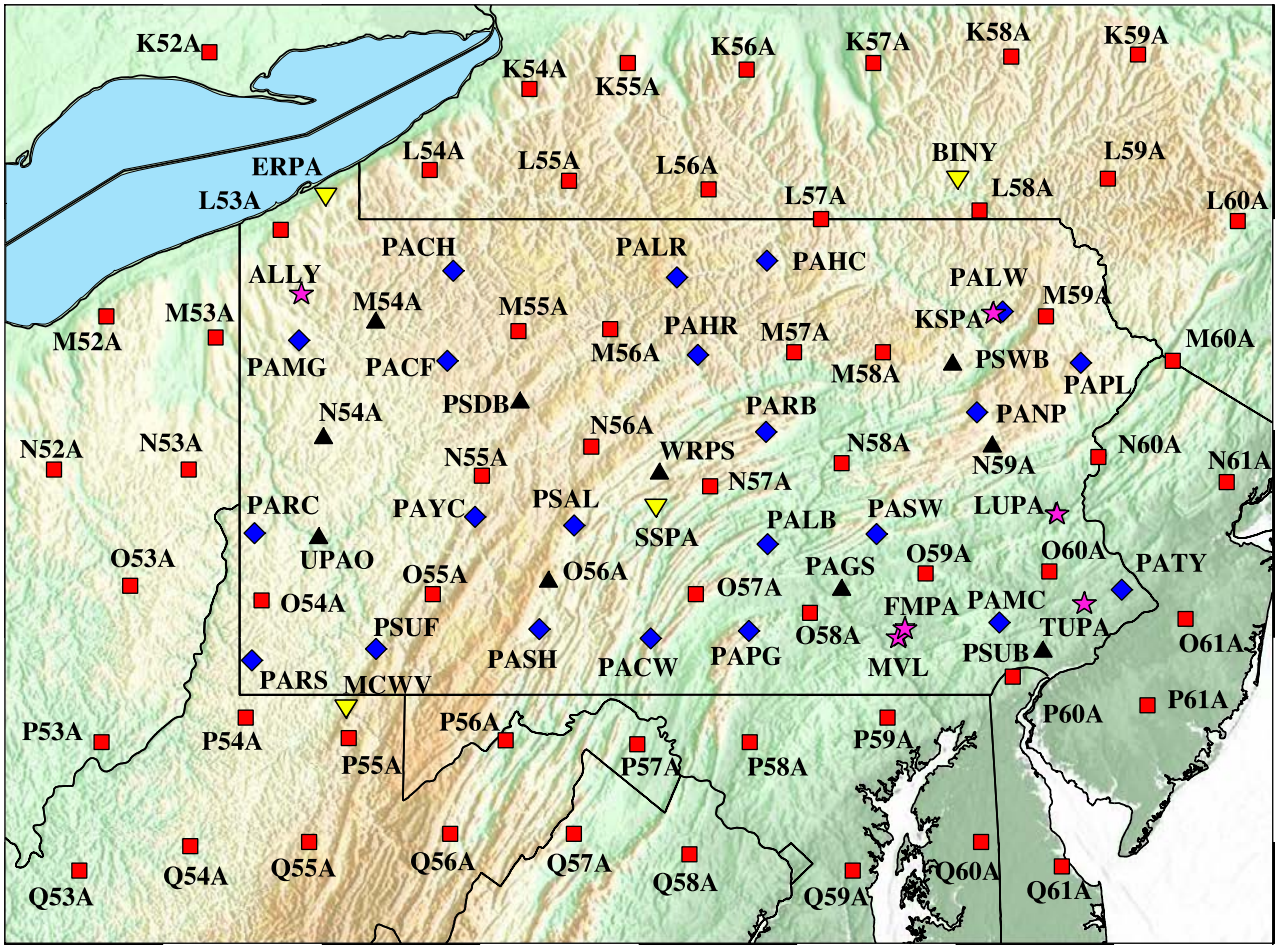


www.earthinstitute.columbia.edu/news/2004/story04-30-04b.html)



Armbruster and Seeber (1987)

Stations 2/2013 to 6/2015



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

Equipment

RefTek RT130 Datalogger

- Guralp CMG3T seismometer
- Nanometrics Compact Trillium seismometer

Broadband 3-component seismometers

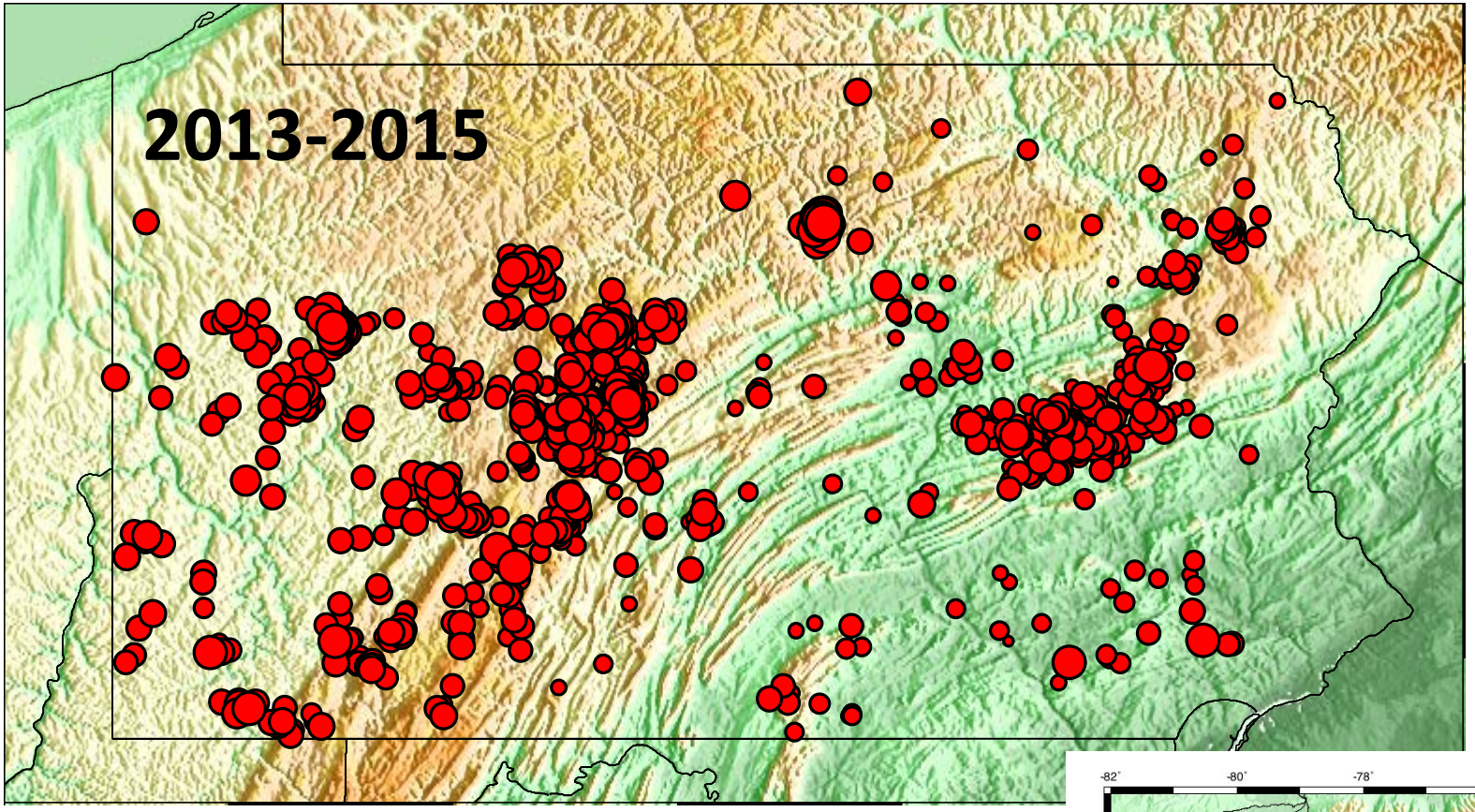
GPS Clock

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

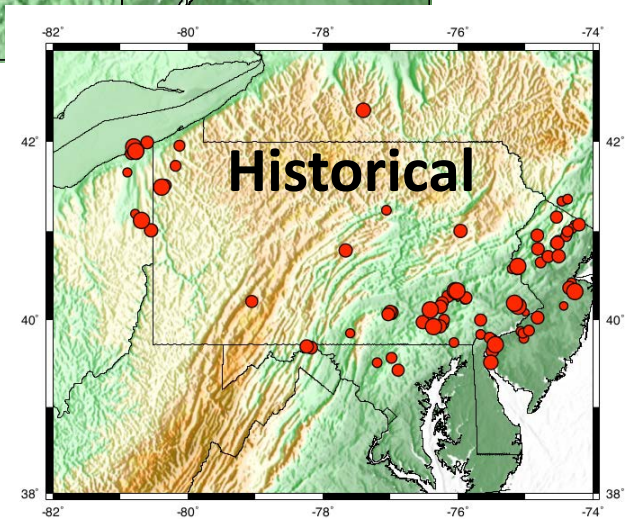
- 1761 events with 1544 located in Pennsylvania

Report can be downloaded from:

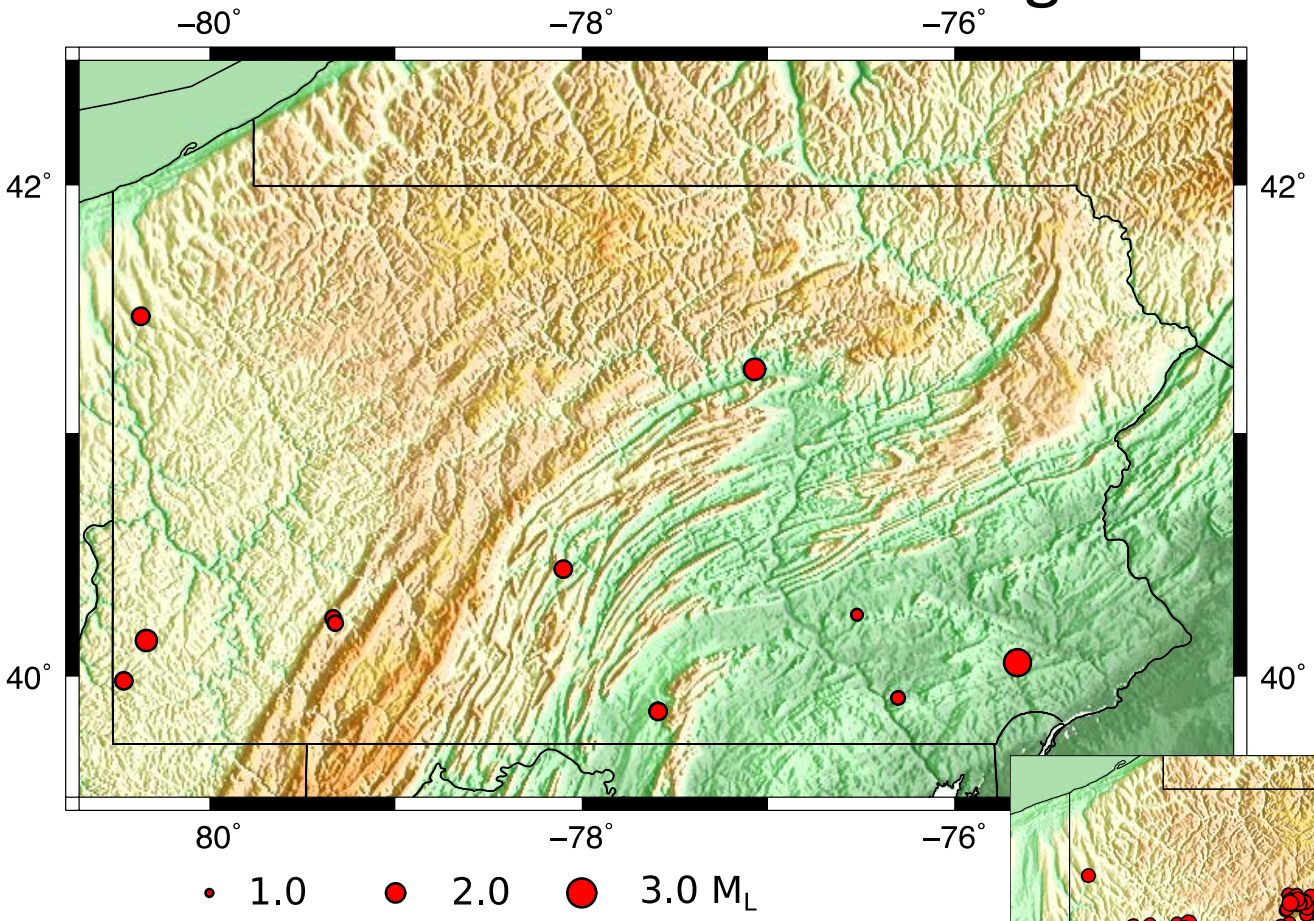
http://paseis.geosc.psu.edu/background.html

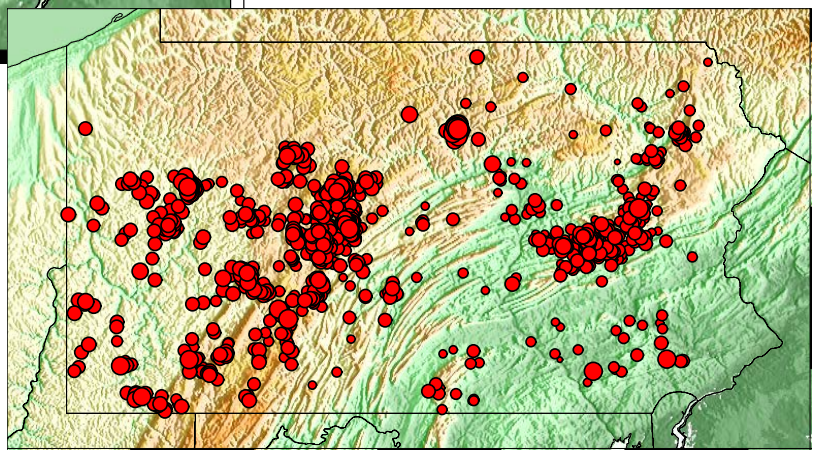


1.0 2.0 3.0 M_L

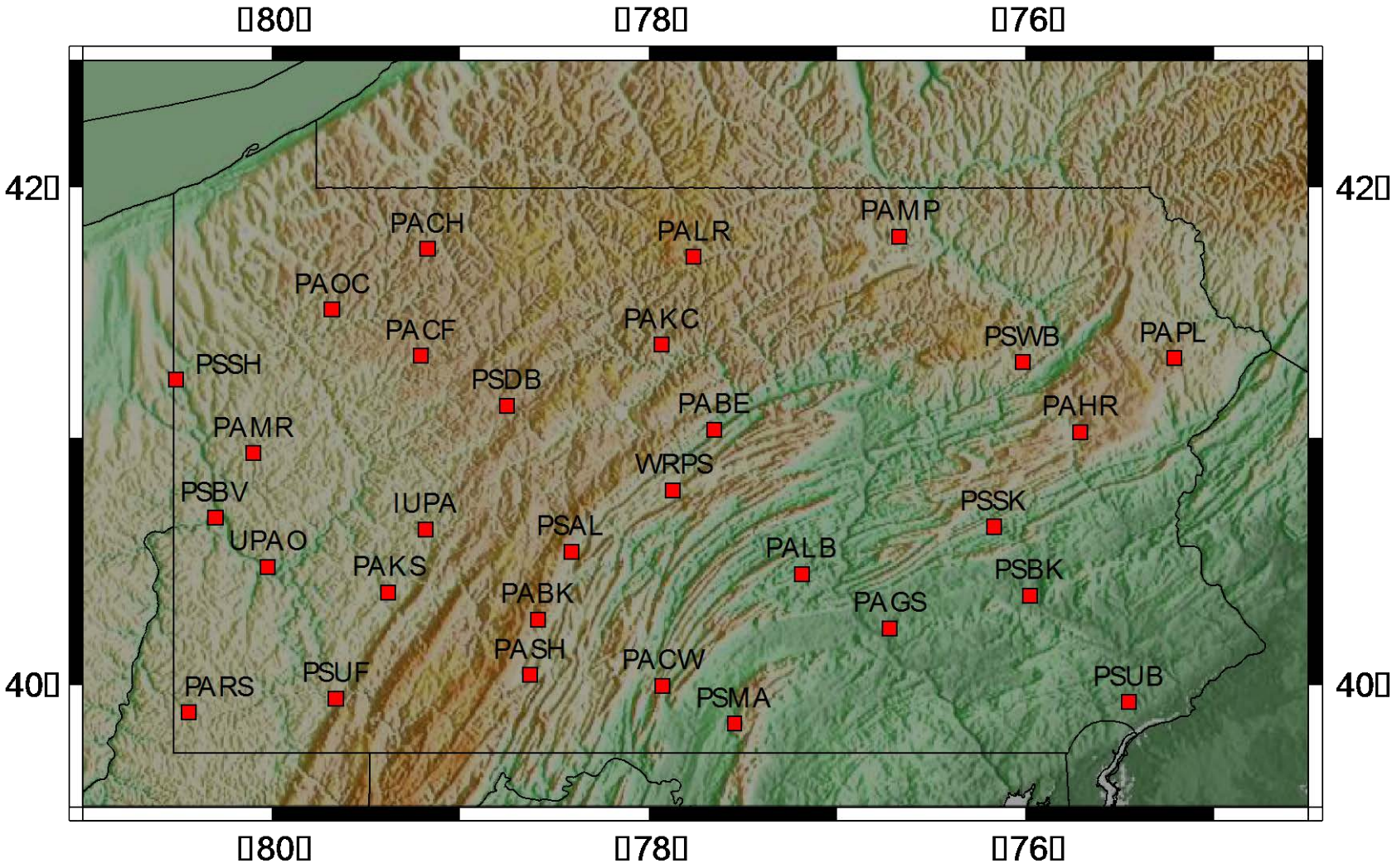


14 Non-mining events – probably all earthquakes (no evidence for oil and gas activity)



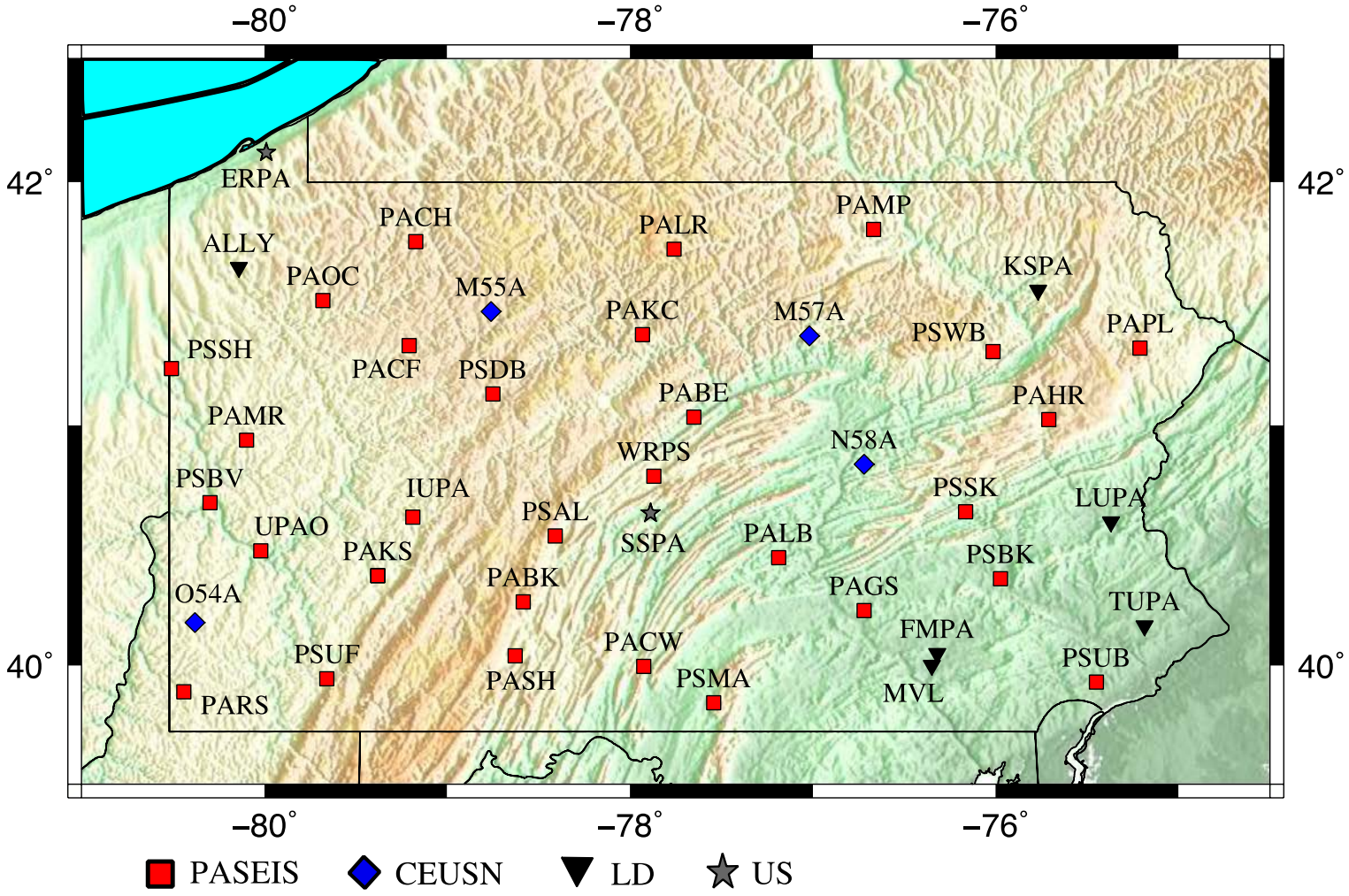


PASEIS Network Sept. 2016



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



Technical specifications; Network code = PE

IRIS MDA Usage

IRIS DMC MetaData Aggregator

Network summary (1 time span)

Network	PE :: Penn State Network :: PE Network Map :: DOI
Start Year	2004
End Year	2500

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

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

	Station	Site	Latitude	Longitude	Elevation	First start	Last end
R A	PABE	Bald Eagle State Park, Howard, PA	41.034715	-77.651590	204	2016/05/30	2599/12/31
R A	PACF	Cook Forest State Park, Cooksburg, PA	41.332515	-79.208278	398	2016/05/09	2599/12/31
R A	PACH	Chapman State Park, Clarendon, PA	41.756660				
R A	PACW	Cowans Gap State Park, Fort Loudon, PA	39.995013				
R A	PAGS	PA Geological Survey, Middletown, PA	40.230000				
R A	PAHR	Hickory Run State Park, White Haven, PA	41.024130				
R A	PAKC	Kettle Creek State Park, Renovo, PA	41.374710				
R A	PAKS	Keystone State Park, Derry Township, PA	40.376097				
R A	PALB	Little Buffalo State Park, Newport, PA	40.458910				
R A	PALR	Lyman Run State Park, Galeton, PA	41.725095				

IRIS MDA Usage

IRIS DMC MetaData Aggregator

Station summary (1 time span)

Network	PE :: Penn State Network :: PE Network Map :: DOI
Station	PABE :: Bald Eagle State Park, Howard, PA :: Penn State Network :: PABE Station Map :: RESP :: SAC PZs :: XML
Latitude	41.034715
Longitude	-77.651590
Elevation	204
Start	2016/05/30 (151) 00:00:00
End	2599/12/31 (365) 23:59:59
Epoch	**2016/05/30 (151) 00:00:00 - 2599/12/31 (365) 23:59:59**
Instrument	Nanometrics Trillium Compact/Reftek 130 Datalogger
Channels (Hz)	Location --: HHE (100) R A, HHN (100) R A, HHZ (100) R A, LHE (1), LHN (1), LHZ (1)
MetaData Load	2016/08/15 (228) 09:38:00

Virtual network affiliations:

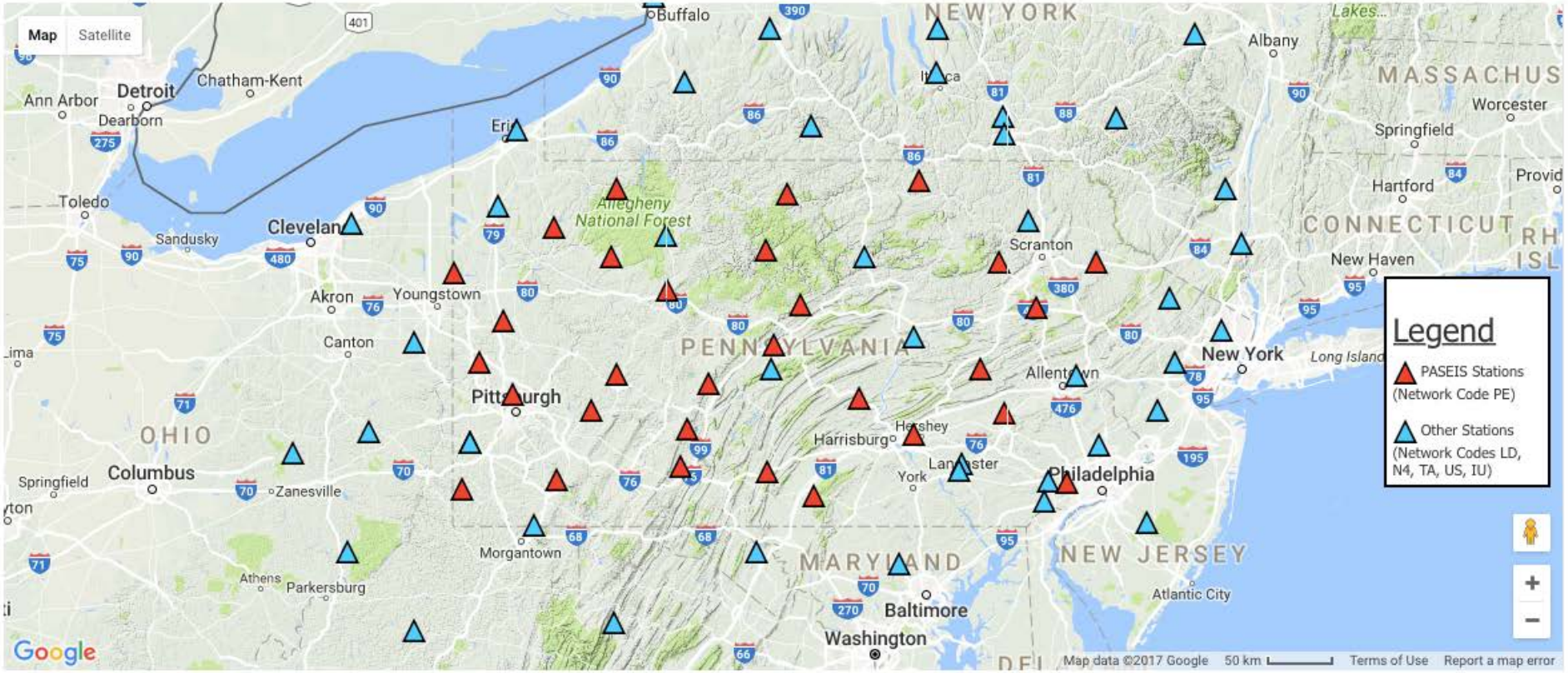
Name	Description	Primary DC	Secondary DC
_PENN	Pennsylvania State Geological Survey	PENN	IRIS DMC
_REALTIME	Stations collected and served in real time at the DMC	IRIS DMC	IRIS DMC
.UNRESTRICTED	All unrestricted stations, generated via cron	IRIS DMC	IRIS DMC
_US-REGIONAL	US Regional Networks	PSU	IRIS DMC

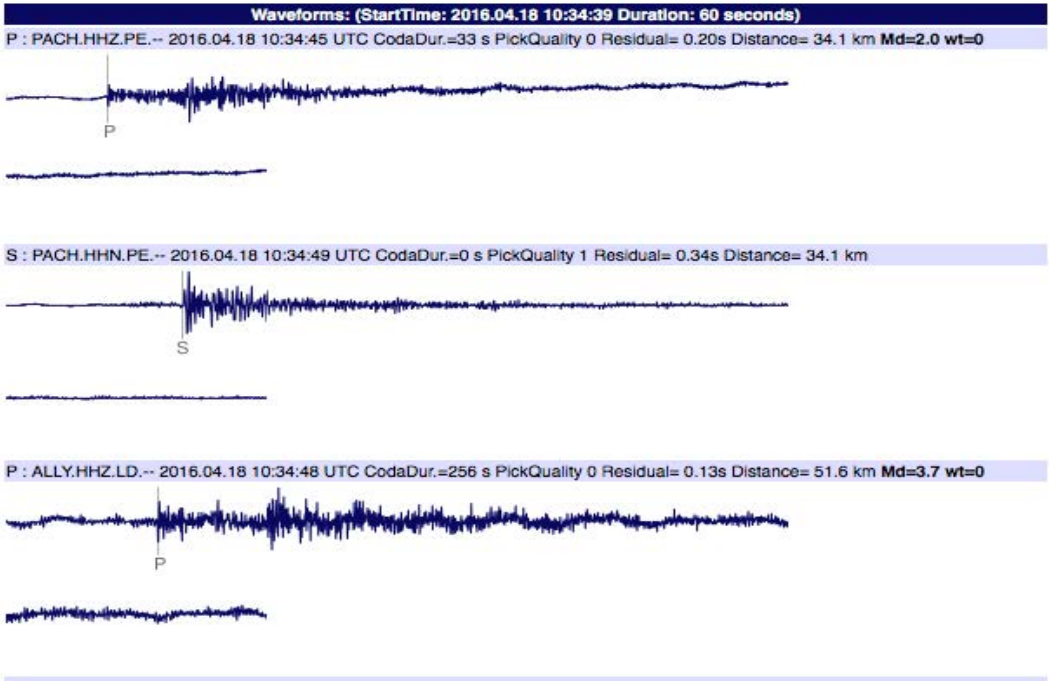
Real-time data availability (view Station Monitor)

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

Archive data availability - Make a batch request for data (breq_fast) - (data access overview)

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





Email Alert received for:
Magnitude 2.2
Time: 2016/04/18 Depth 3.3 miles (5.2 km)
Near Titusville, PA

Minor earthquake measures near city

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

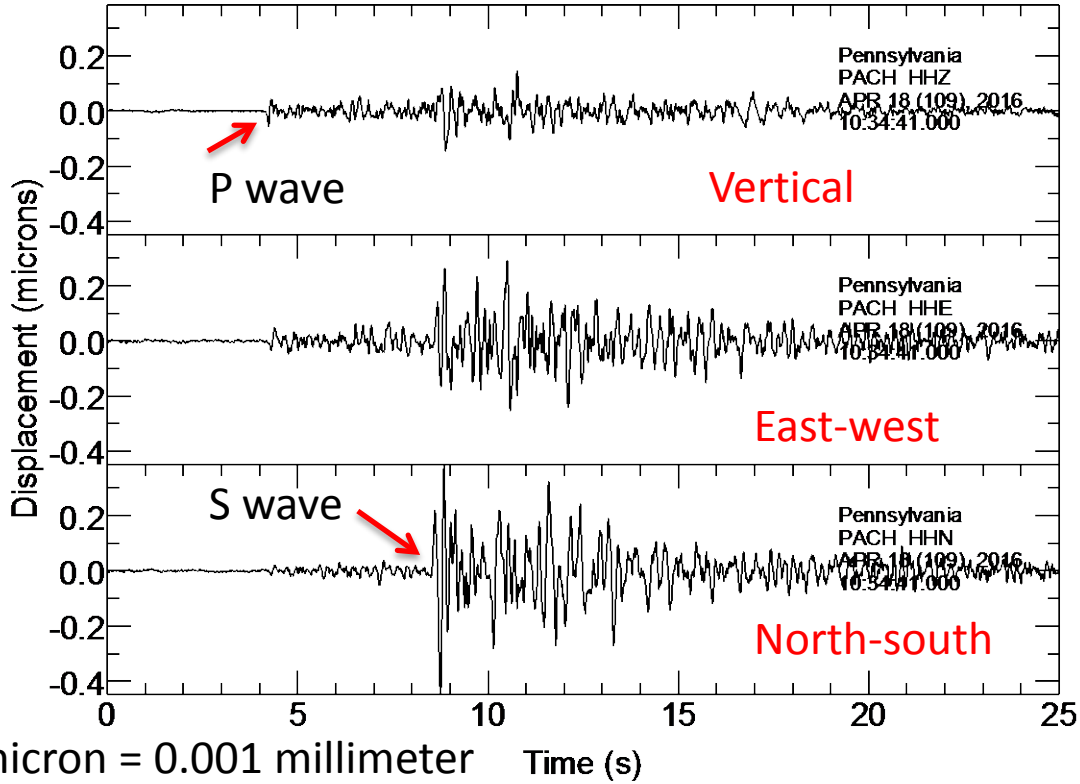
By Stella Ruggiero sruggiero@titusvilleherald.com | 0 comments

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.

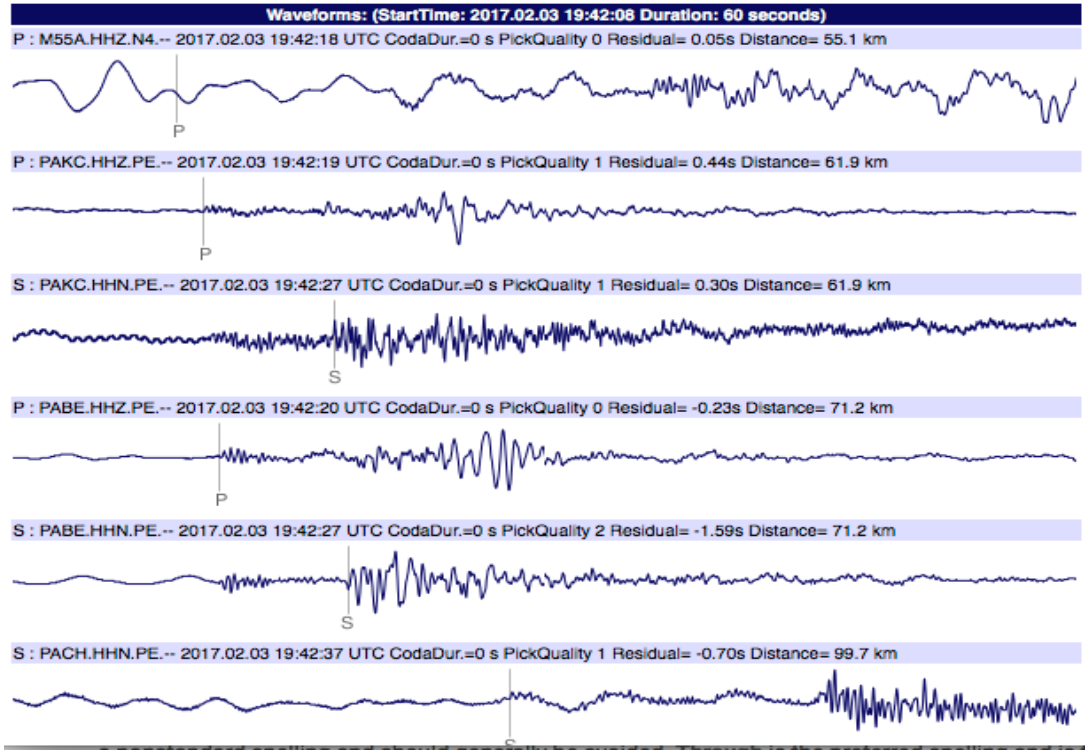
Magnitude 2.2
Time: 2016/04/18 06:34:40 local
Depth 3.3 miles (5.2 km)
Near Titusville, PA

What do the data look like? (Chapman State Park)

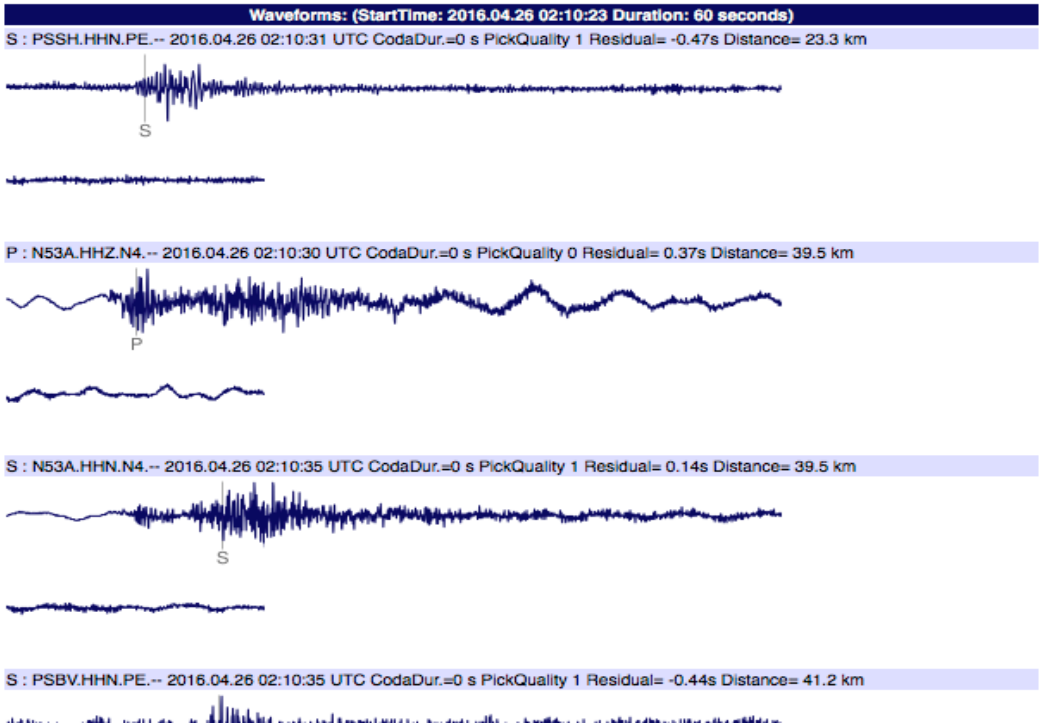


1 micron = 0.001 millimeter

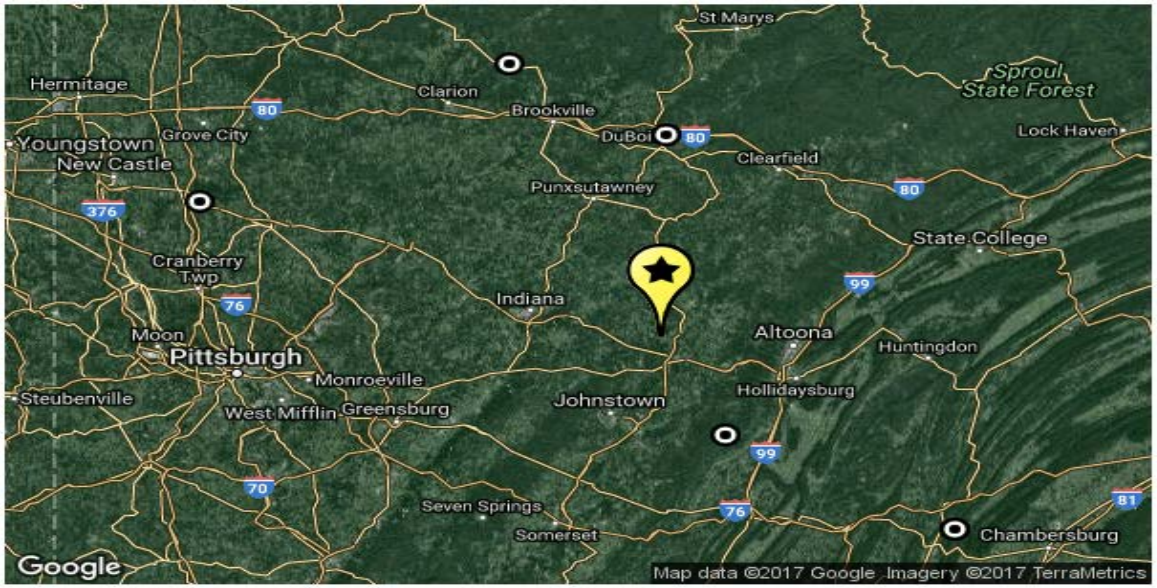
Figure courtesy of C. Ammon

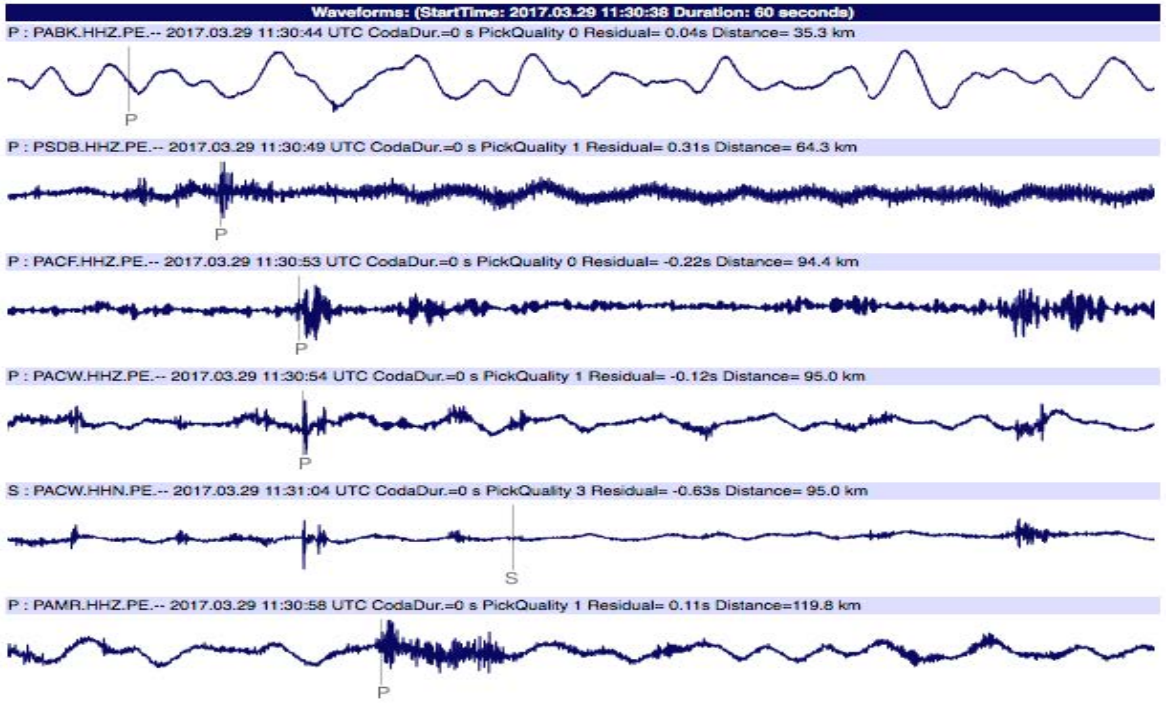


Example Email alert for a mining blast. Note characteristic long period surface wave.



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





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

PASEIS

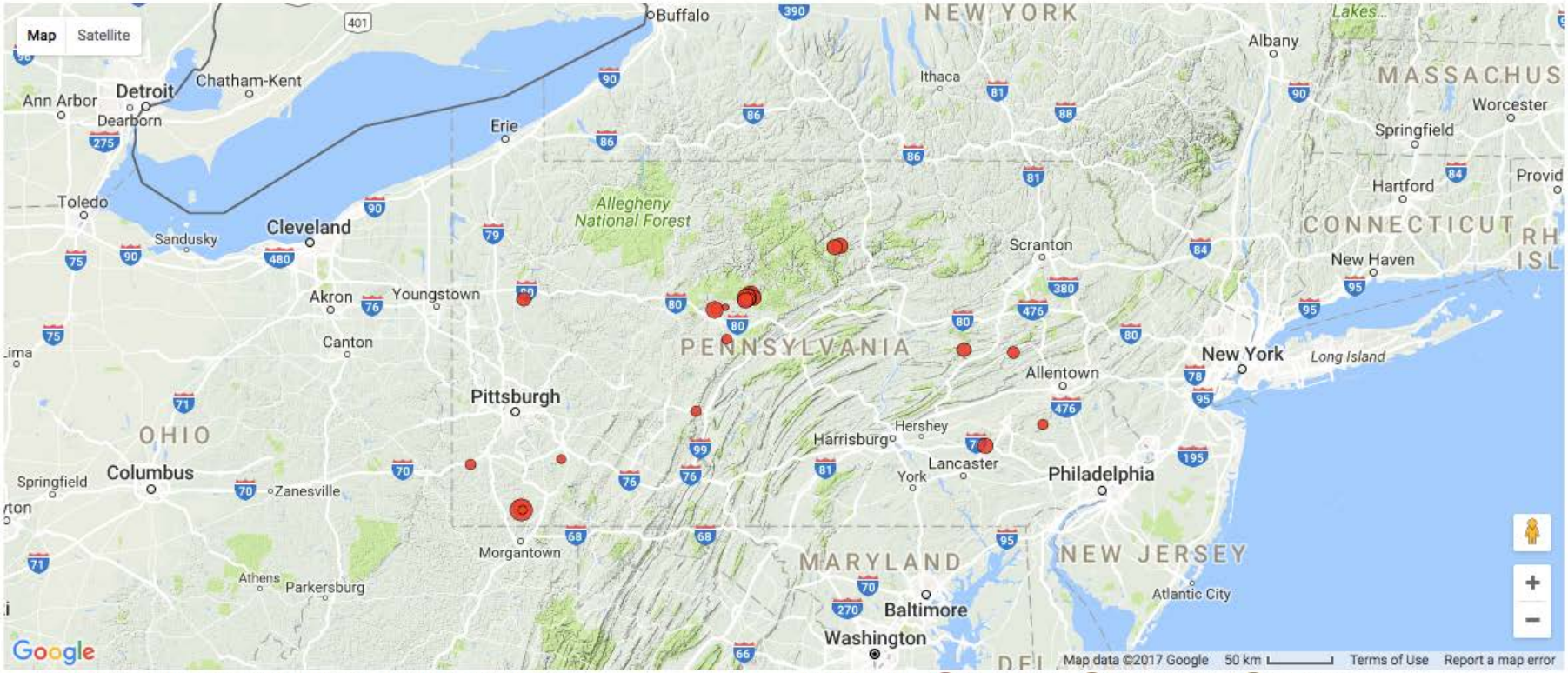
The Pennsylvania State Seismic Network

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.

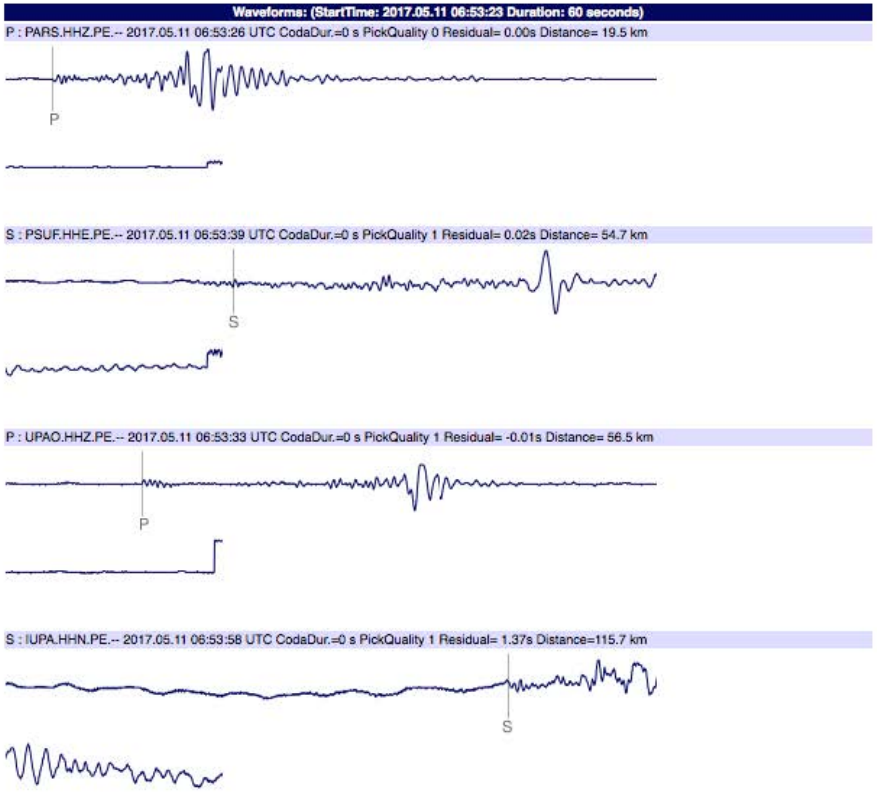
The sources of the seismic events displayed are not analyzed. Possible sources include natural earthquakes, mining blasts, and induced seismicity.



Depth uncertainties of 31.6km indicate a fixed hypocentral depth

Depth Scale 0 - 2.5 km | 2.5 - 5.0 km | > 5.0 km

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



Example event with an undetermined source

May 11, 2017 Mag. 2
Time: 2:54 am

Source depth = 1 km

No active fracking or wastewater disposal nearby

Waveforms look like a blast

Active coal mines in area but coal seam is at ~200-250 m depth

Acknowledgments

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

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IRIS provides data management (data archiving and distribution)

the IRIS CONSORTIUM

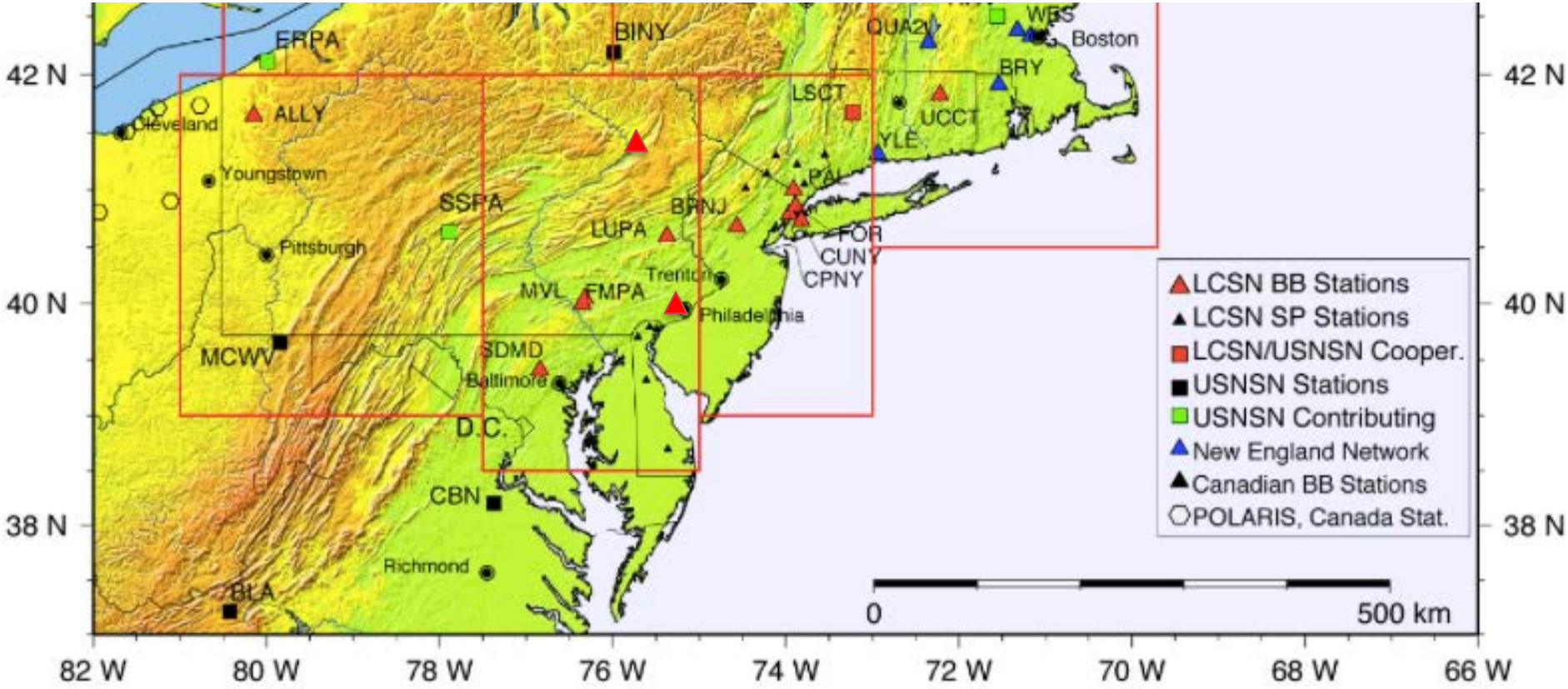
NSF

PennState

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

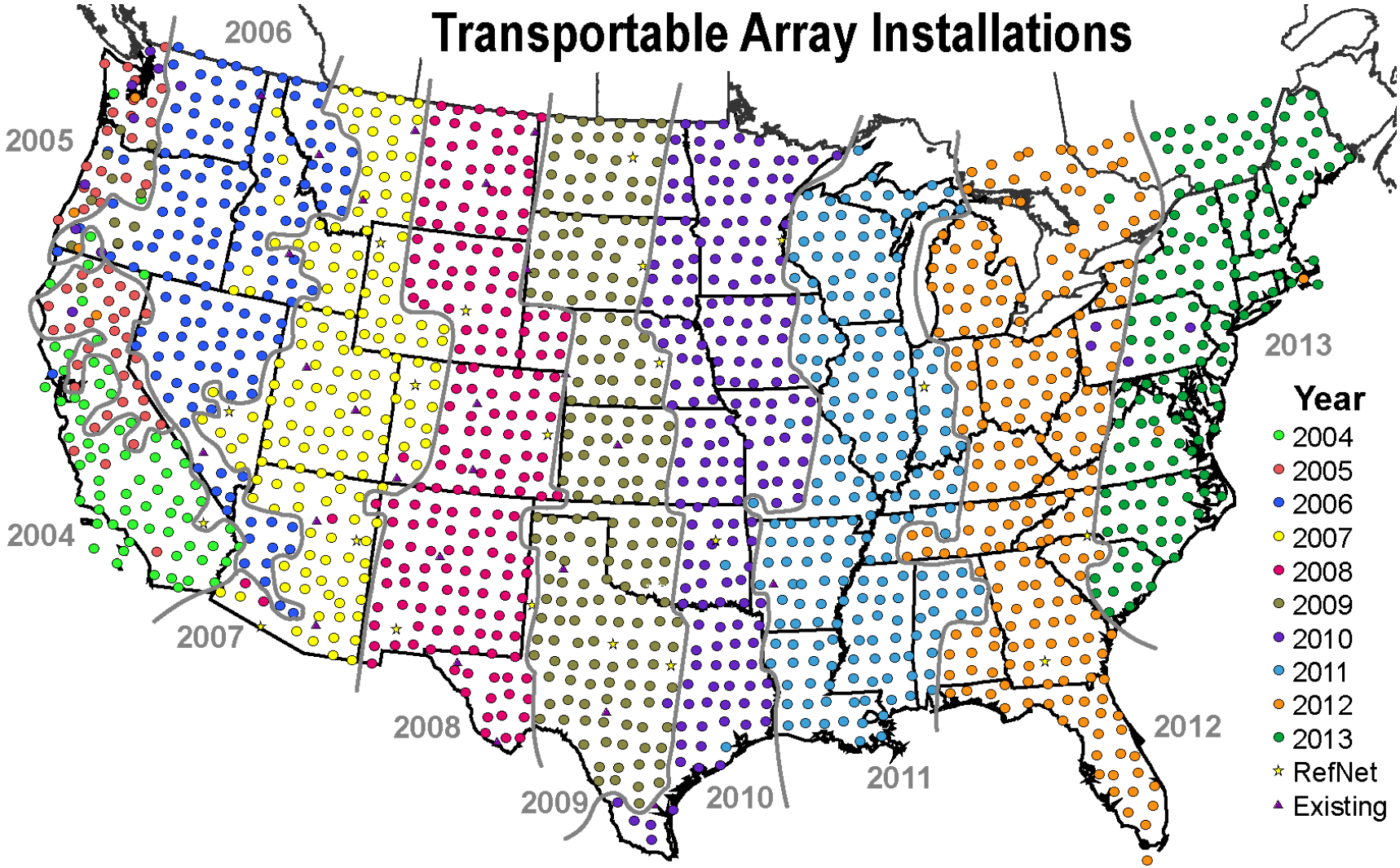
USGS and LCSN Stations



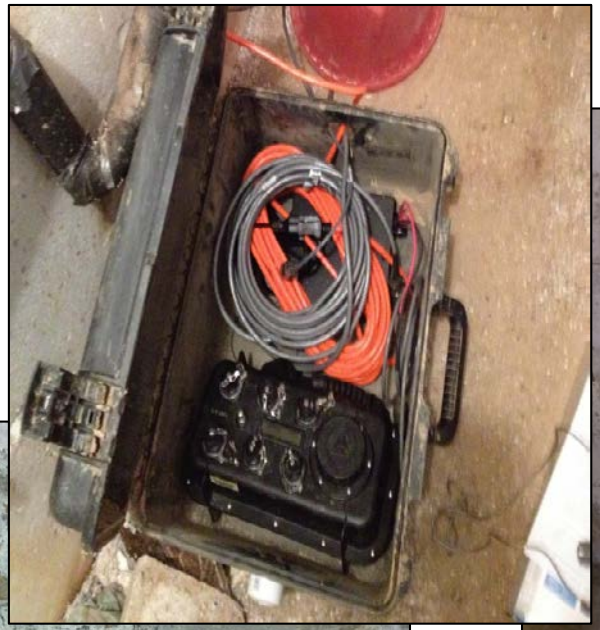
History of building a PA state seismic network

- 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

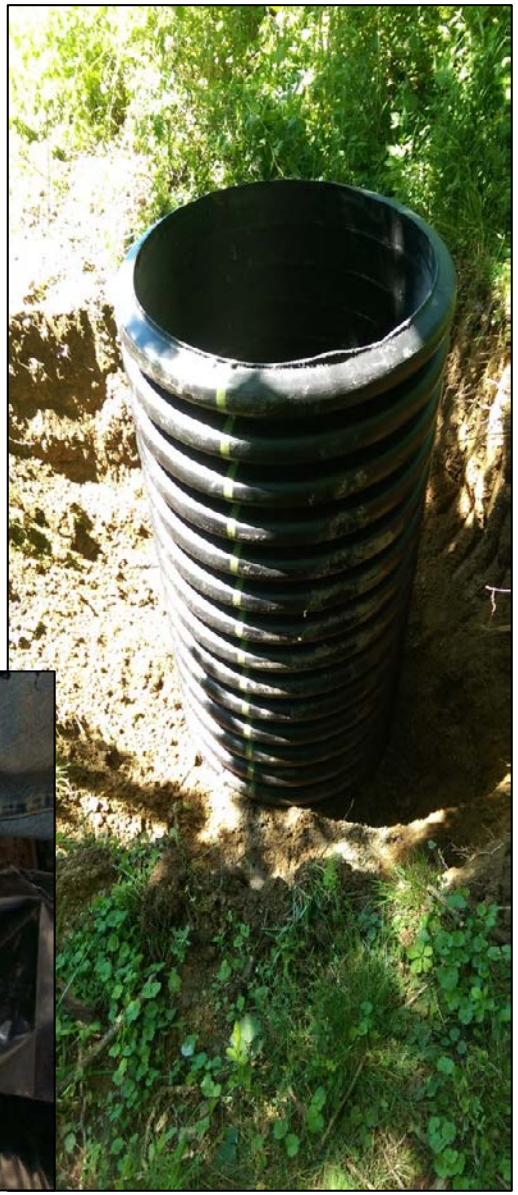
USArray


Transportable Array Installations
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
Year
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
RefNet
Existing

Basement deployments – mostly at university locations



Outside vault deployments – mostly at state park locations



Network summary (1 time span)

Network	PE :: Penn State Network :: PE Network Map :: DOI
Start Year	2004
End Year	2500

Overview of network

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

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

List of station names, locations, and start times

Station summary (1 time span)

Network	PE :: Penn State Network :: PE Network Map
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 A, HHN (100) R A, HHZ (100) R A, LHE (1), LHN (1), LHZ (1)
MetaData Load	2016/04/15 (106) 14:10:37

Virtual network affiliations:

Name	Description	Primary DC	Secondary DC
_PENN	Pennsylvania State Geological Survey	PENN	IRIS DMC
_REALTIME	Stations collected and served in real time at the DMC	IRIS DMC	IRIS DMC
.UNRESTRICTED	All unrestricted stations, generated via cron	IRIS DMC	IRIS DMC
_US-REGIONAL	US Regional Networks	PSU	IRIS DMC

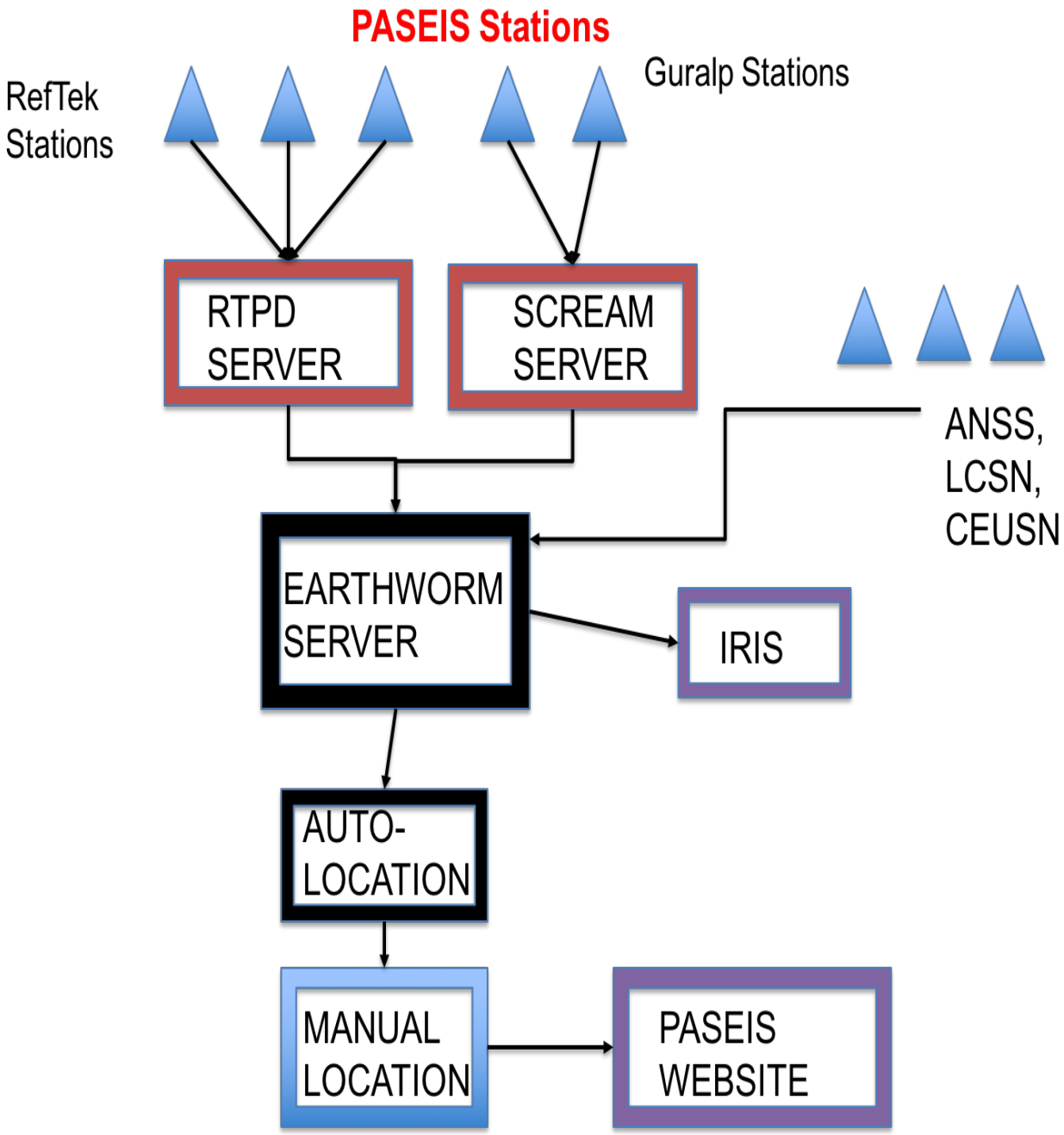
Real-time data availability (view Station Monitor)

View some of the data

	Earliest	Latest
R	2016/05/06 (127) 00:00:00	2016/05/18 (139) 00:00:00

Archive data availability - Make a batch request for data (breq_fast) - (data access overview)

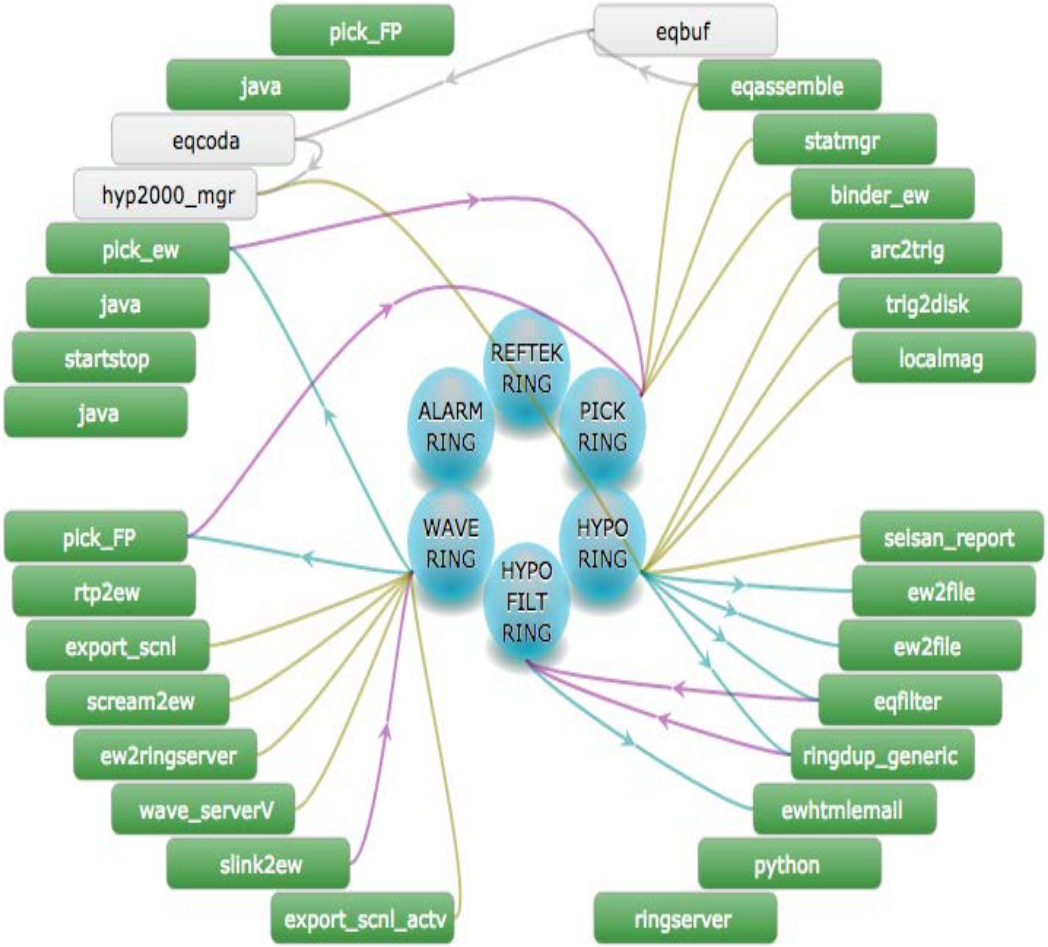
Information on how to request the data


PASEIS Stations
RefTek Stations
Guralp Stations
RTPD SERVER
SCREAM SERVER
ANSS, LCSN, CEUSN
EARTHWORM SERVER
IRIS
AUTO-LOCATION
MANUAL LOCATION
PASEIS WEBSITE

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

Modules | Rings | Graph | System | Penn State Seismic



Last Updated: Fri Mar 24 2017 10:17:48 GMT-0400 (EDT)

Update Now

EZW v1.5.2 by isti, 2016; Licensed to Penn State

Module Legend:

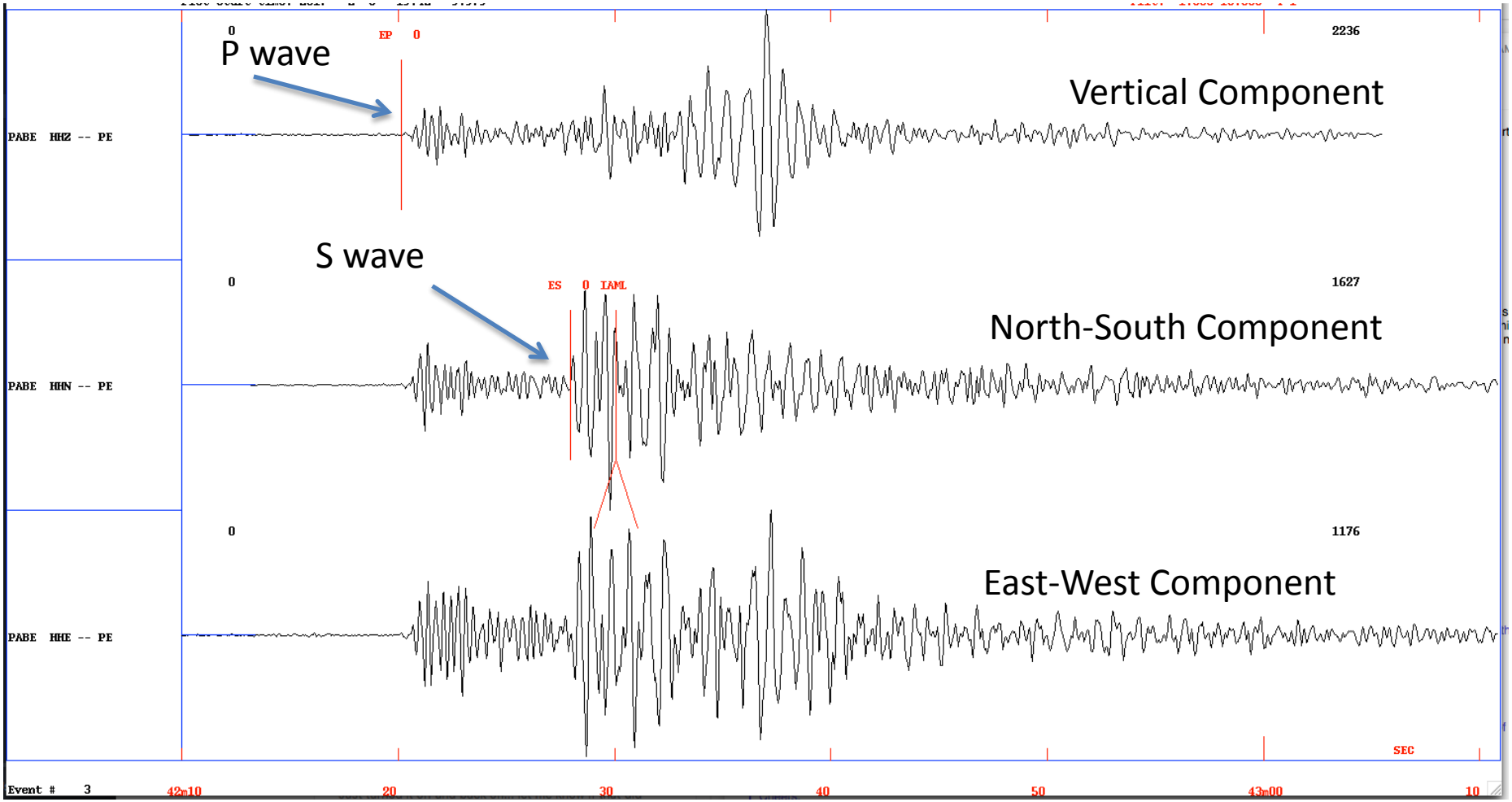
Analysis of Automatic Locations

- 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 event might be an earthquake, then the event is manually relocated

Manual Event Locations

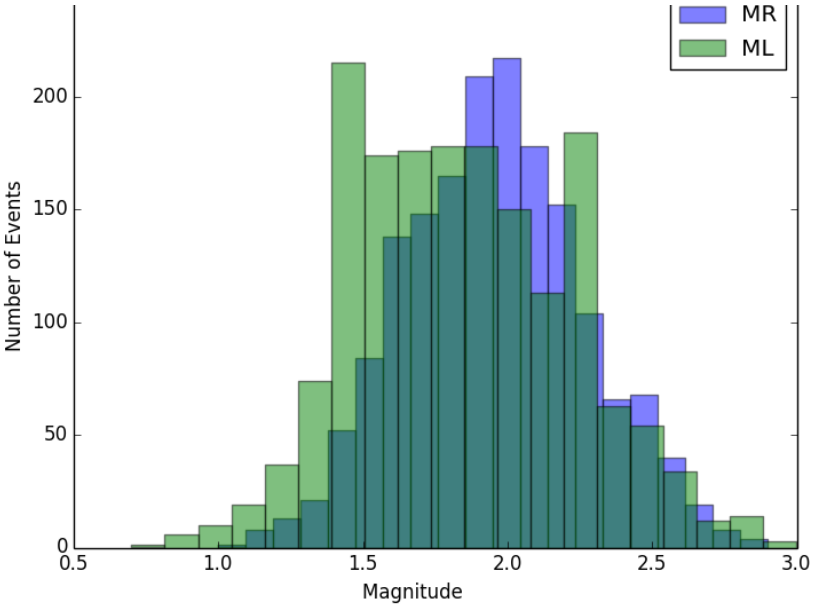
- Pull data from Earthworm server
- Refine arrival time picks by hand using SEISAN
- Relocate event using HYPOINVERSE and same velocity model as used for automatic solution
- Add event information to database and post on the website

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



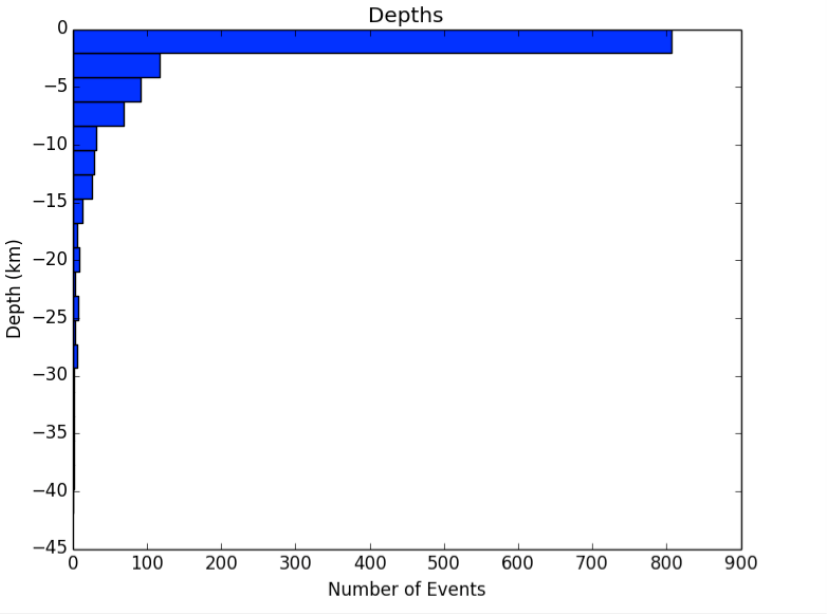
Magnitudes and Depths

- Local magnitudes range from 1.0 to 2.9

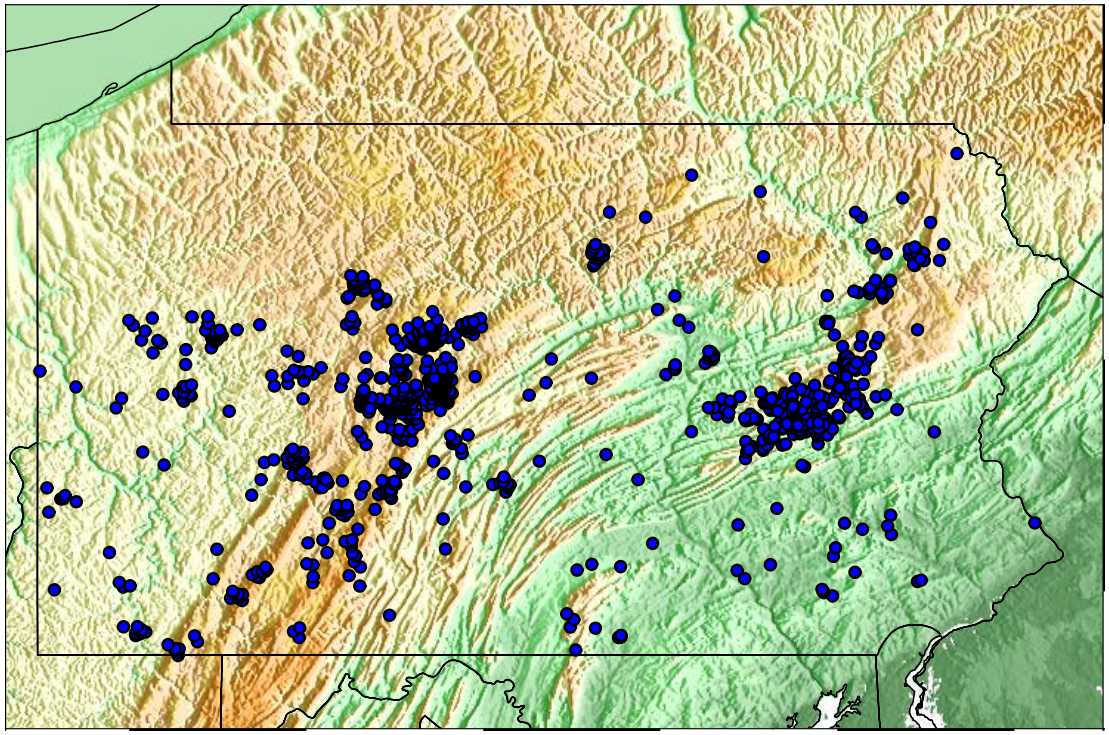


Catalog is complete to magnitude 1.8

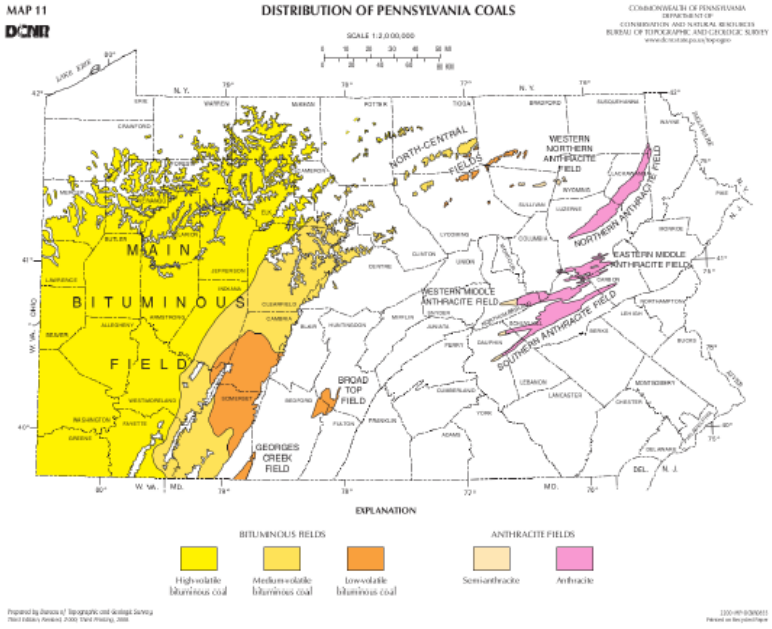
- Depths mostly < 1 km



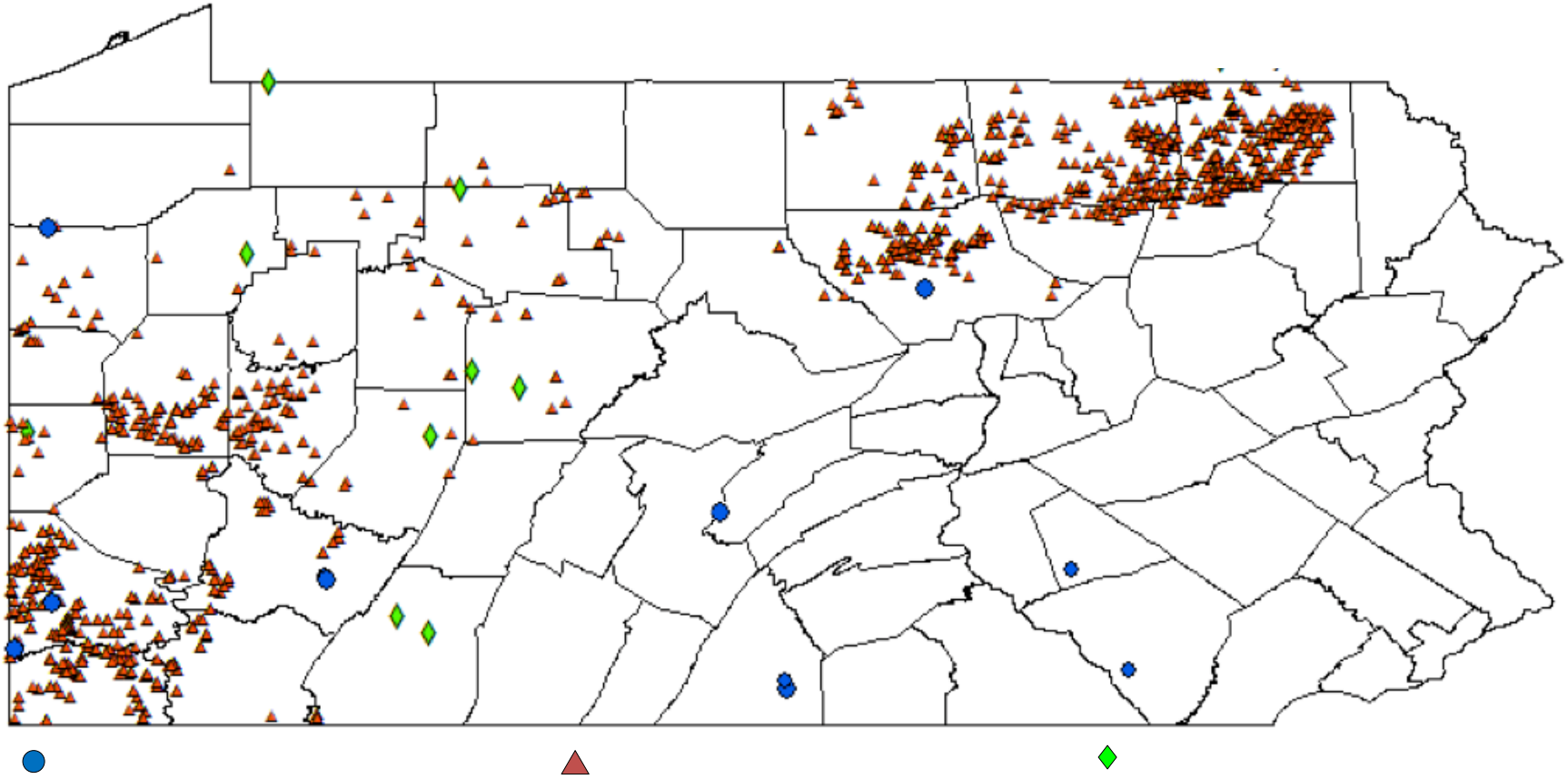
Mine or Quarry Blasts



asts



Are there spatial and temporal correlations with well activity?

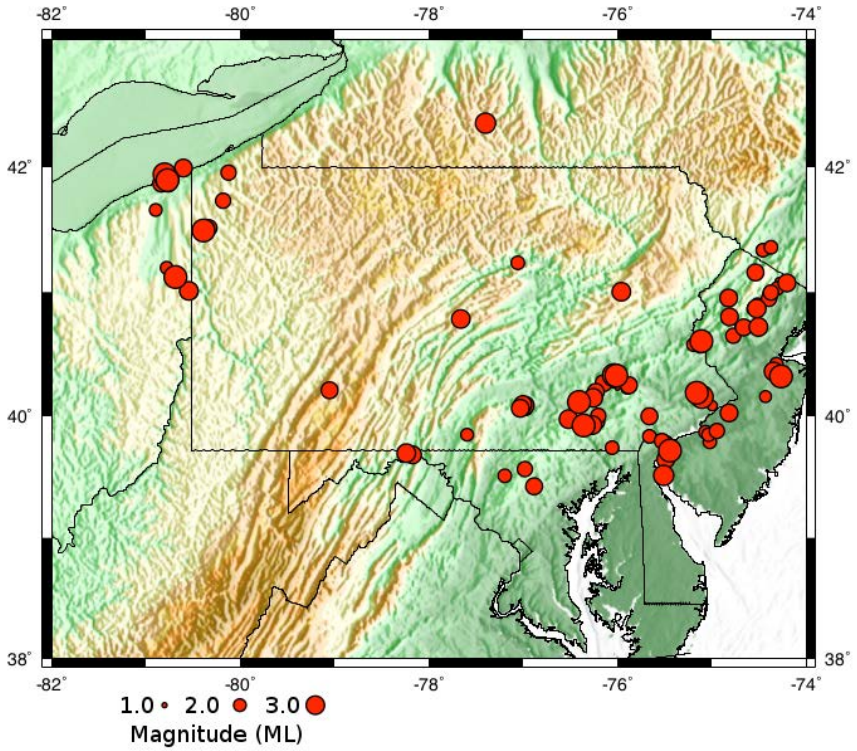


Non-mining events Production wells (2013/2015) Injection wells

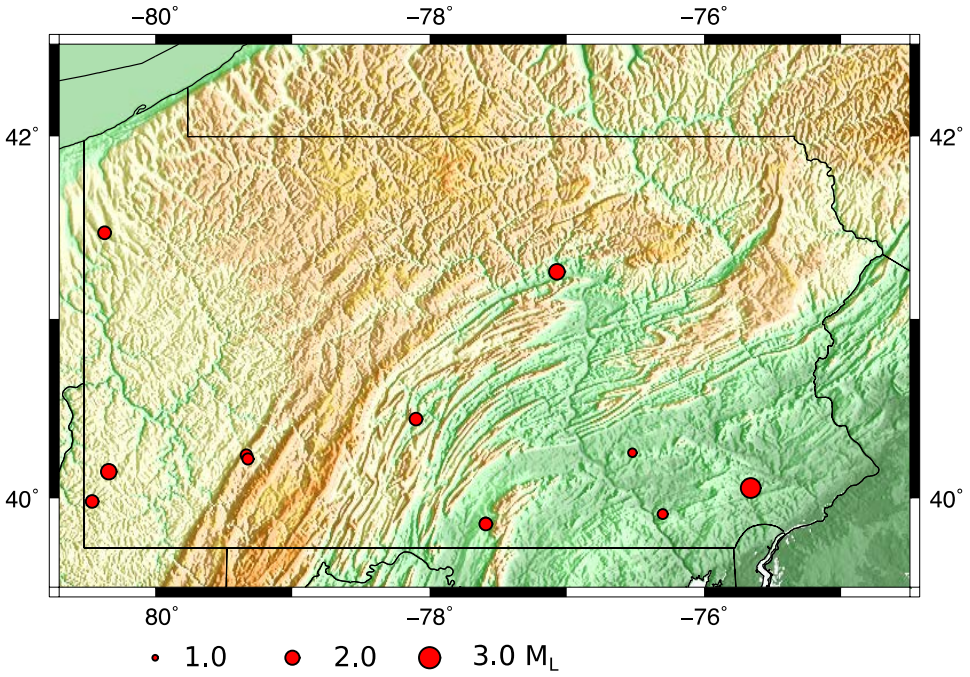
-No correlation has been found with either injection wells or fracked wells for the 2013-2015 time period

Summary of findings: 1530 mining related events

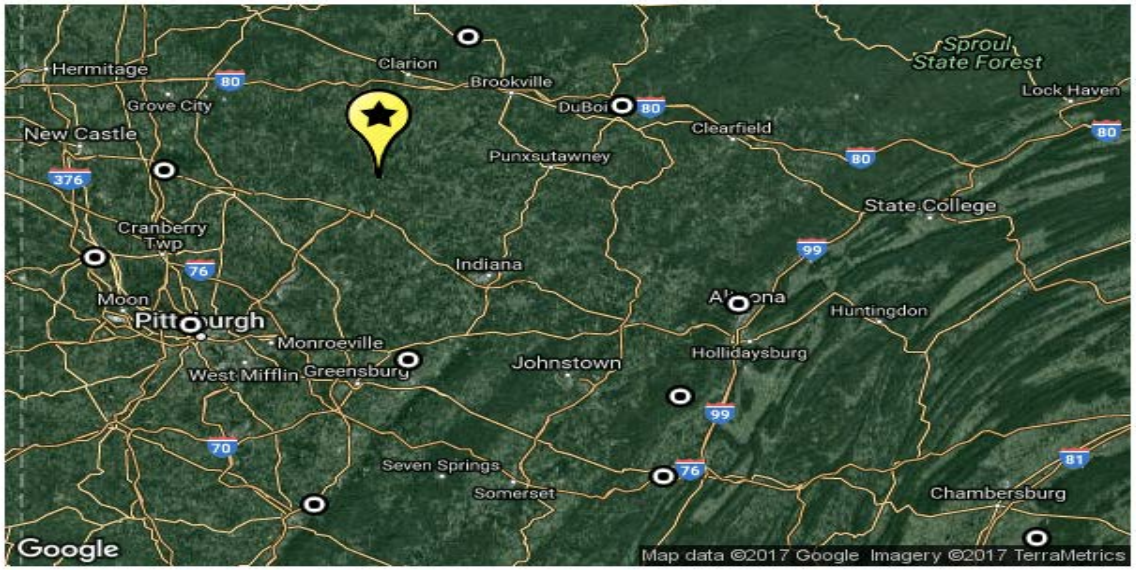
14 Non-mining events – they are all probably tectonic earthquakes

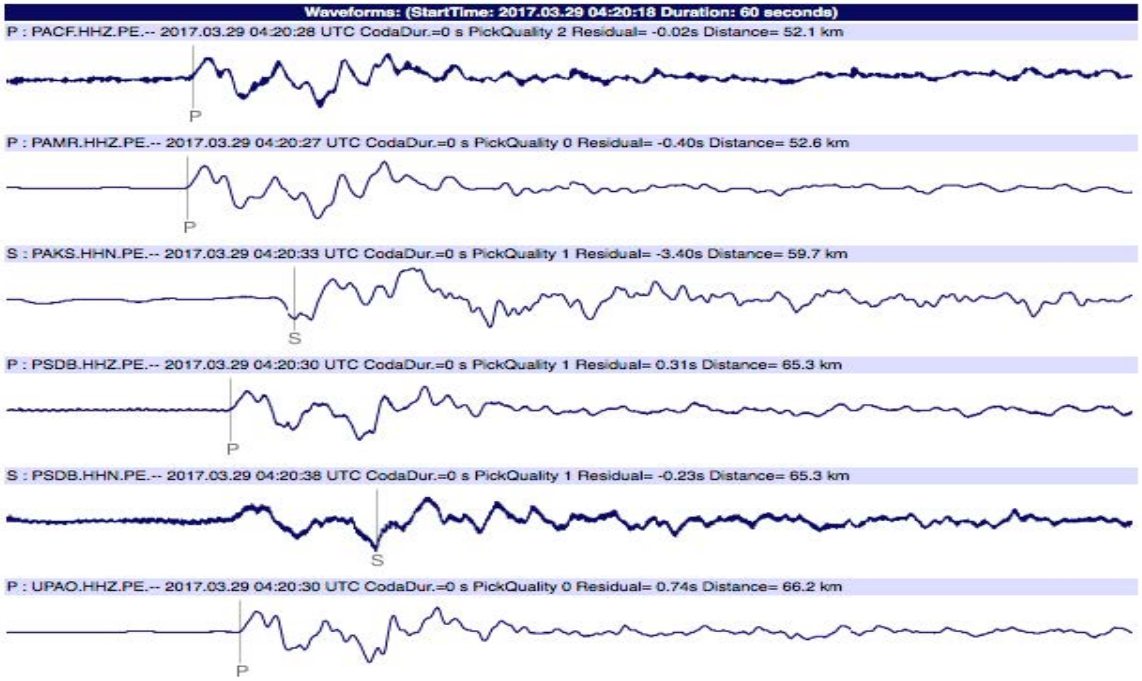


Historical

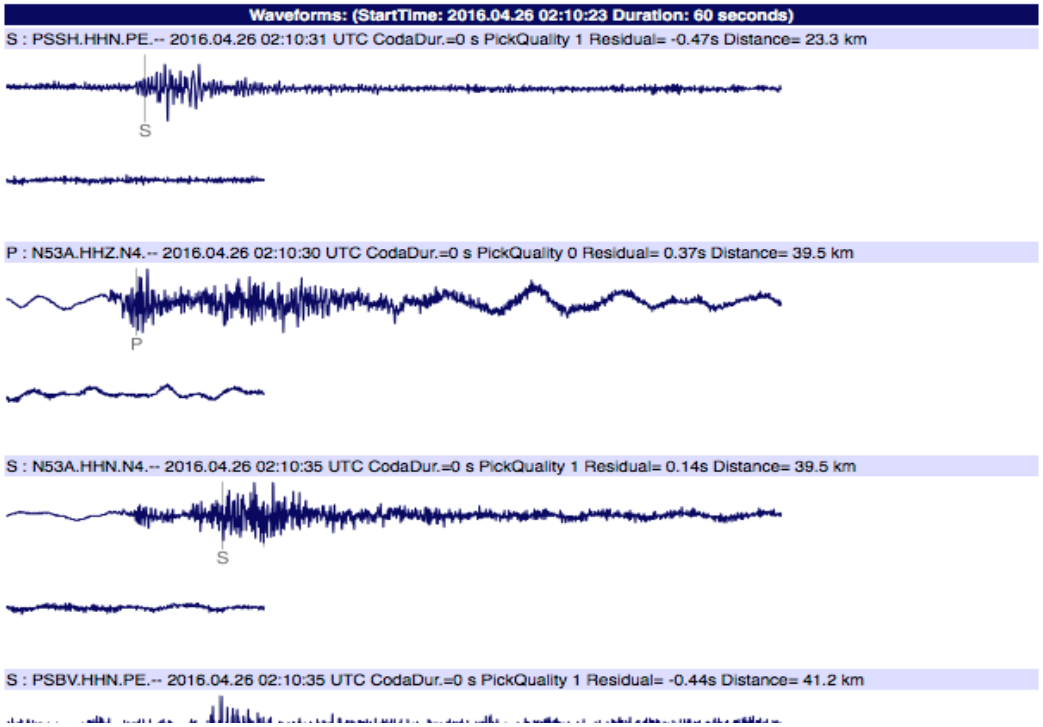


2/2013-6/2015





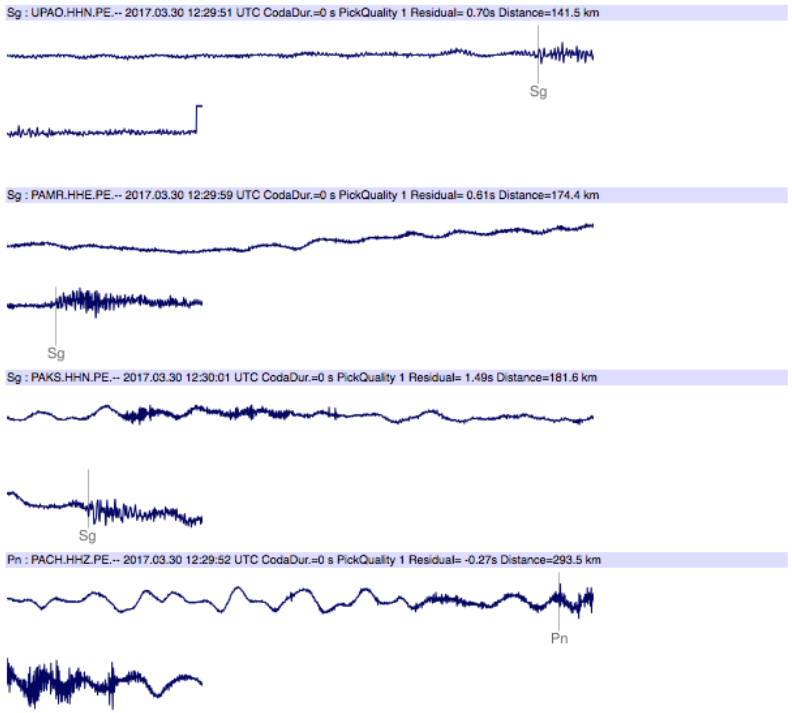
Example of an Email alert received for a Teleseismic event (large, M > 5)

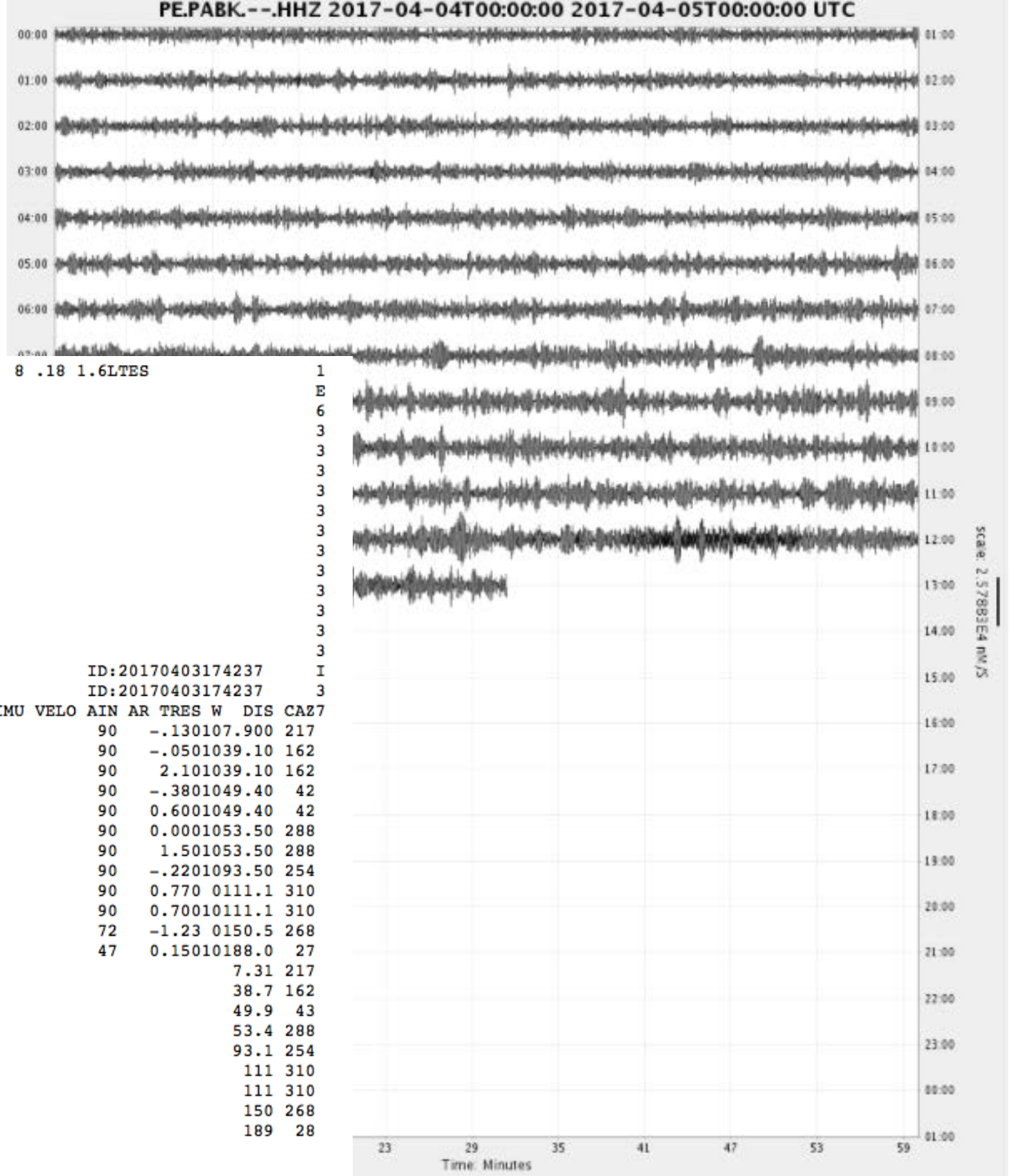


Email alert for one of the Lawrence County events of April 25, 2016.

Mag 3 event, SE Ohio, April 4, 2017

Mag 2 event, SE Ohio, March 30, 2017






```
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CHANNELID: N58A.HHZ.N4.--                                                        3
CHANNELID: PSSK.HHZ.PE.--                                                        3
CHANNELID: PABE.HHZ.PE.--                                                        3
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CHANNELID: PAHR.HHN.PE.--                                                        3
CHANNELID: WUPA.HHN.LD.--                                                        3
CHANNELID: ODNJ.HHN.LD.--                                                        3
CHANNELID: NPNY.HHZ.LD.--                                                        3
CHANNELID: PAMR.HHZ.PE.--                                                        3
ACTION:HIN 17-04-03 14:49 OP:kah  STATUS:               ID:20170403174237        I
OLDACT:HIN 17-04-03 14:48 OP:kah  STATUS:               ID:20170403174237        3
STAT SP IPHASW D HRMM SECON CODA AMPLIT PERI AZIMU VELO AIN AR TRES W  DIS CAZ7
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PSBK HZ EP    0   1742 52.86                              90   -.0501039.10 162
PSBK HN ES    0   1742 57.94                              90    2.101039.10 162
PAHR HZ EP    0   1742 54.24                              90   -.3801049.40  42
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N58A HZ EP    0   1742 55.31                              90   0.0001053.50 288
N58A HE ES    0   1743  2.05                              90    1.501053.50 288
PALB HZ EP    0   1743  1.76                              90   -.2201093.50 254
M57A HZ EP    0   1743  5.69                              90   0.770 0111.1 310
M57A HN ES    0   1743 18.69                              90   0.70010111.1 310
SSPA BZ EP    0   1743 10.07                              72   -1.23 0150.5 268
L59A HZ EP    0   1743 16.80                              47   0.15010188.0  27
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PSBK HE  IAML     1743  0.36         51.8 0.28                       38.7 162
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
PALB HN  IAML     1743 17.04         21.3 0.61                       93.1 254
M57A HE  IAML     1743 22.79         11.0 0.33                        111 310
M57A HN  IAML     1743 23.56         13.4 0.48                        111 310
SSPA B1  IAML     1743 32.90         15.1 0.74                        150 268
L59A HE  IAML     1743 41.17         17.5 0.47                        189  28
```