An algorithm for automatic picking of seismic S-wave arrivals and application to San Jacinto fault zone

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Background

- Data volumes presently increasing rapidly
- Manual identification and picking of phases is unfeasible
- Typically, auto S picks << in number than P
- Auto S picks have widespread applicability:
  - Tomography
  - Attenuation
  - Anisotropy
  - Improved locations
  - Enhanced detection rates
  - Source properties

Overview

- Description of picking algorithm
- Antelope/software implementation of algorithm
- Application to San Jacinto fault zone & Taiwan

The Algorithm

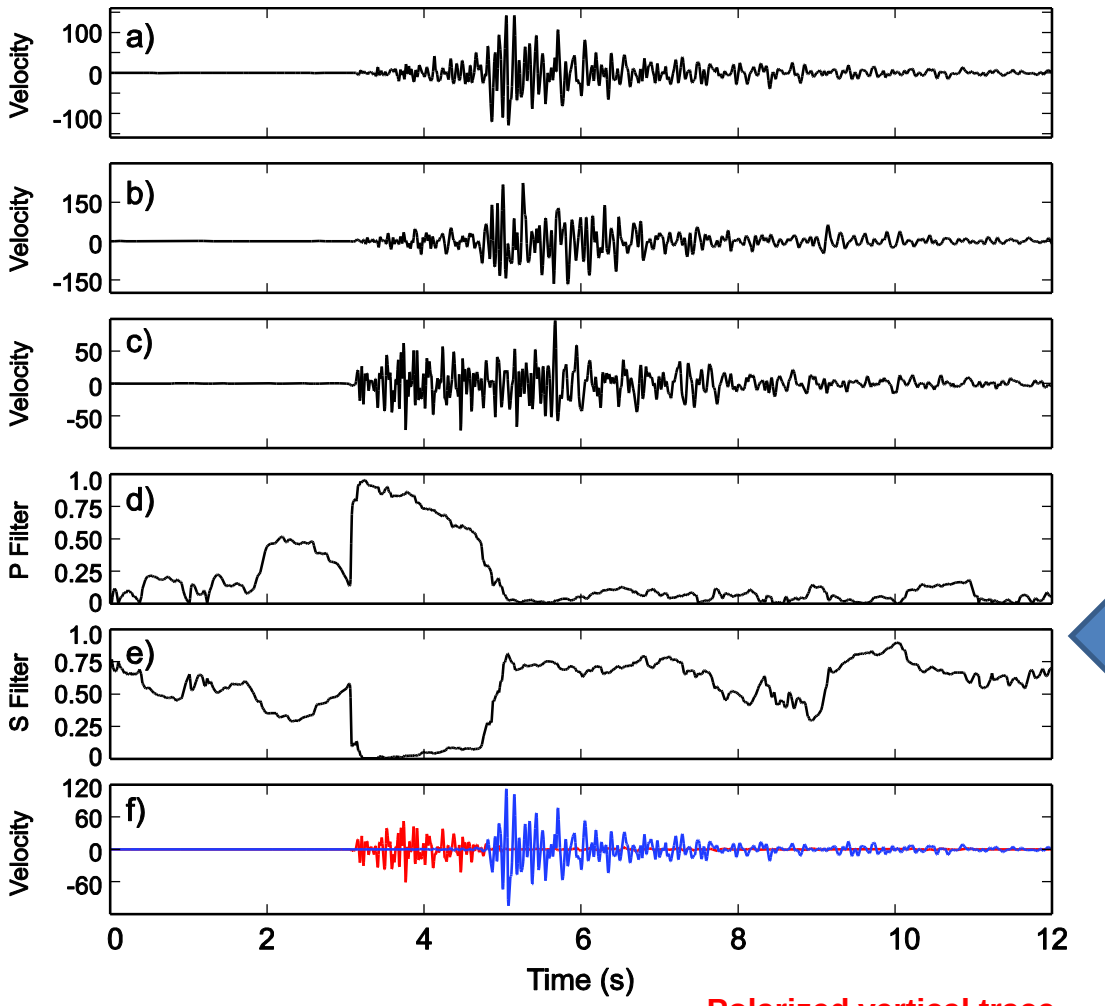
Three stages:

1) Polarization filter to remove P energy from horiz. traces

2) STA/LTA + processing to get trial S-pick

3) Kurtosis function near trial pick to lock in on S arrival

Stage 1



Sliding covariance matrix
w/ 3 sec window every sample

Calculate rectilinearity and incidence angle each sample

$$r = 1 - \left(\frac{\lambda_2 + \lambda_3}{2\lambda_1} \right) \qquad \varphi = \cos^{-1}(u_{11})$$

Take product at each time step to create polarization filters

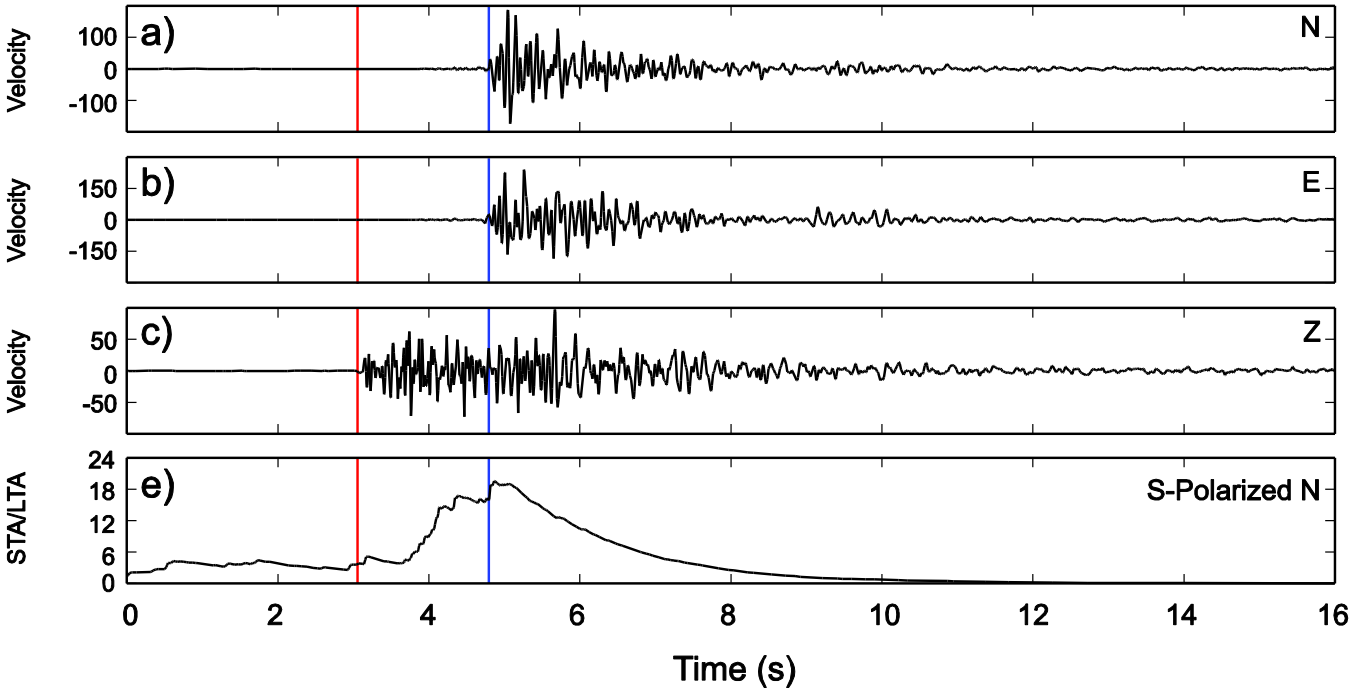
$$p = r\cos(\varphi) \qquad s = r(1 - \cos(\varphi))$$

Multiply horizontal traces by *s*-filter at each time step to remove
as much P energy as possible

From Ross & Ben-Zion (2014), GJI

Stage 2

-Run STA/LTA on “polarized” horizontal traces (STA=1s, LTA=10s, on=5, off=1)



-Smooth STA/LTA with moving average to remove high freq. signals

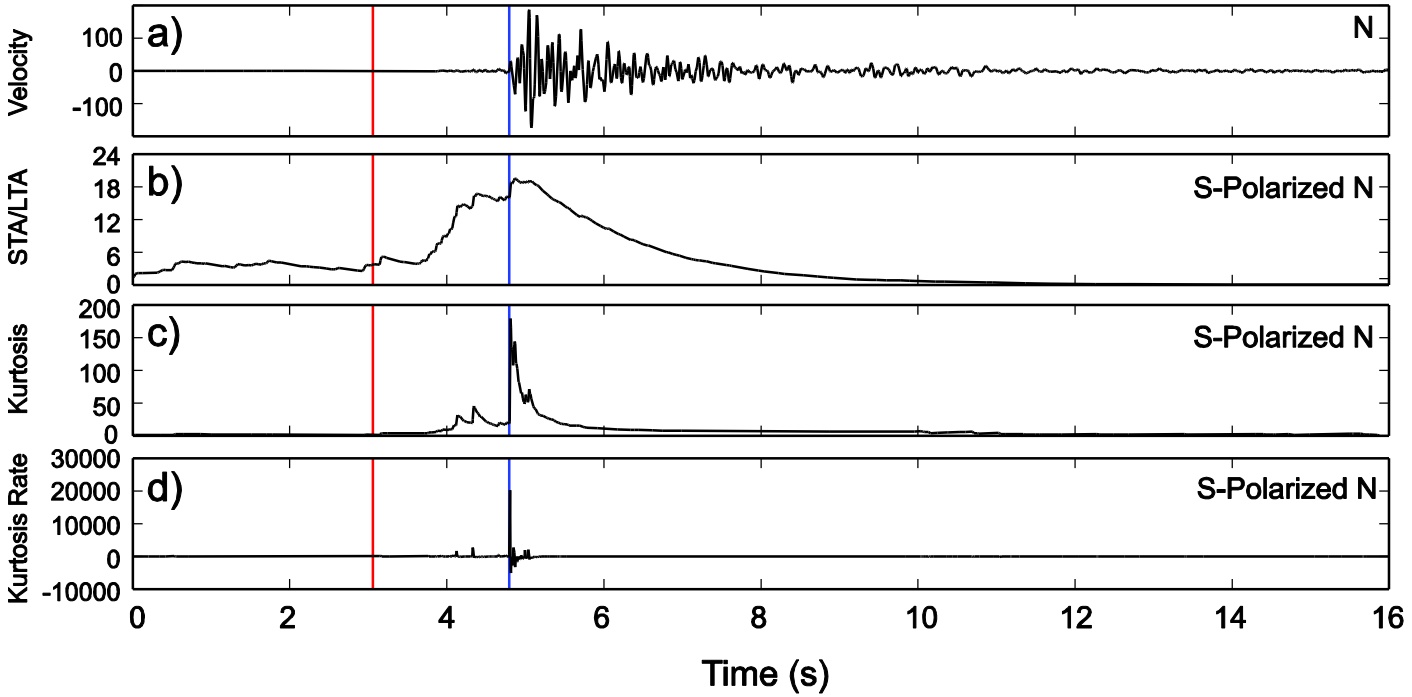
-Find all maxima above 0.6*peak_value (an algorithm parameter)

-Take latest maximum in time as trial S-pick

- Finds S-wave when polarization filter can’t remove P-wave

Stage 3

- Run kurtosis detector to localize arrival



-Cut data around trial S (based on S-P time)

-Avoids picking P wave when polarization filter fails to remove P energy

-Refine S pick to where derivative is largest

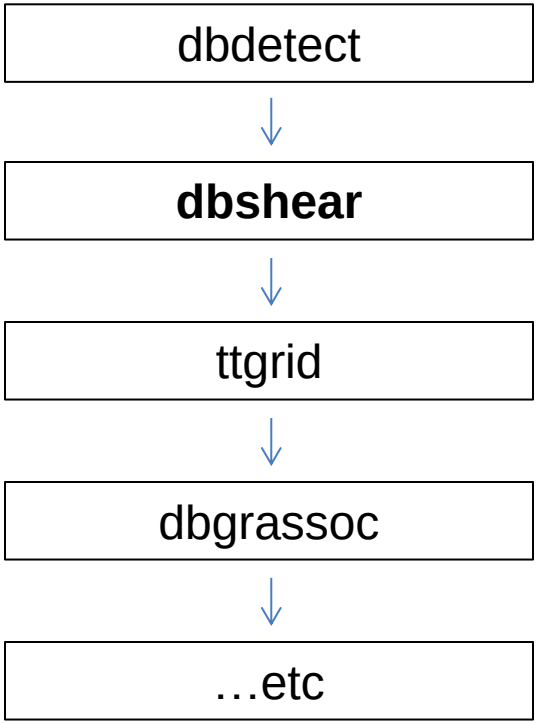
Additional details

- Designed for local networks with 3-c instruments
- Pick accuracy < 0.3 sec ~80% of the time for stations less than 70 km (details coming)
- Defaults to no pick made if S is too close to P in time

Software Implementation

- Core of algorithm (cov, STA/LTA, kurtosis) written in Fortran 90
- Python wrapper (F2Py) around F90 code in module form
- dbshear - Python script using antelope API & pick mod
  - Mimics usage style of existing software
  - Slots directly into Antelope workflow w/ no changes needed
  - Parallelized w/ multiprocessing module
  - One buffered output stream for writing

dbshear slots in after dbdetect and before dbgrassoc



Program sequence:

1) Read **local** vertical “P” detection from db.detection
2) Cuts data around “P” detection to minimize computation time
3) Makes an “S” detection on trace if possible
4) Writes “S” detection to db.detection

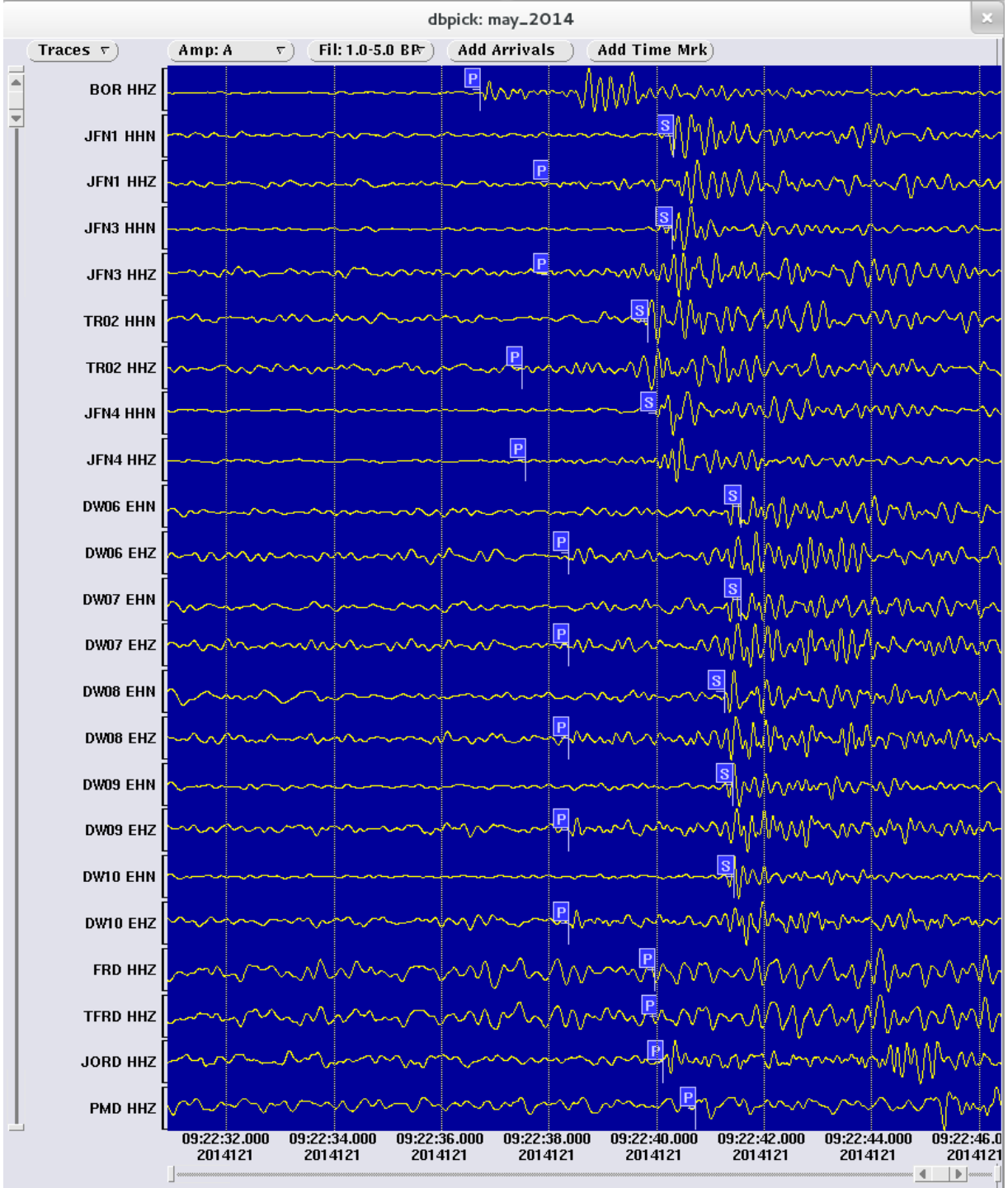
Why before association?

- Better constraints on first locations
- More events detected with S+P vs P only
- P and S picks able to be reviewed at same time
- More information for downstream users

Association with s

Test dataset: Jan. 2013 with all ANZA, SJFZ stations, 9 sta. minimum

- dbdetect alone -- 518 events detected
- dbdetect + dbshear -- 596 events detected
  - with dbgrassoc in ‘reprocess S’ mode
  - ~2:1 P picks vs S picks after association
- ~15% more events were found by including S
- If S picking was done after association, these events would be unknown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Fil: 1.0-5.0 BP
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Add Time Mrk
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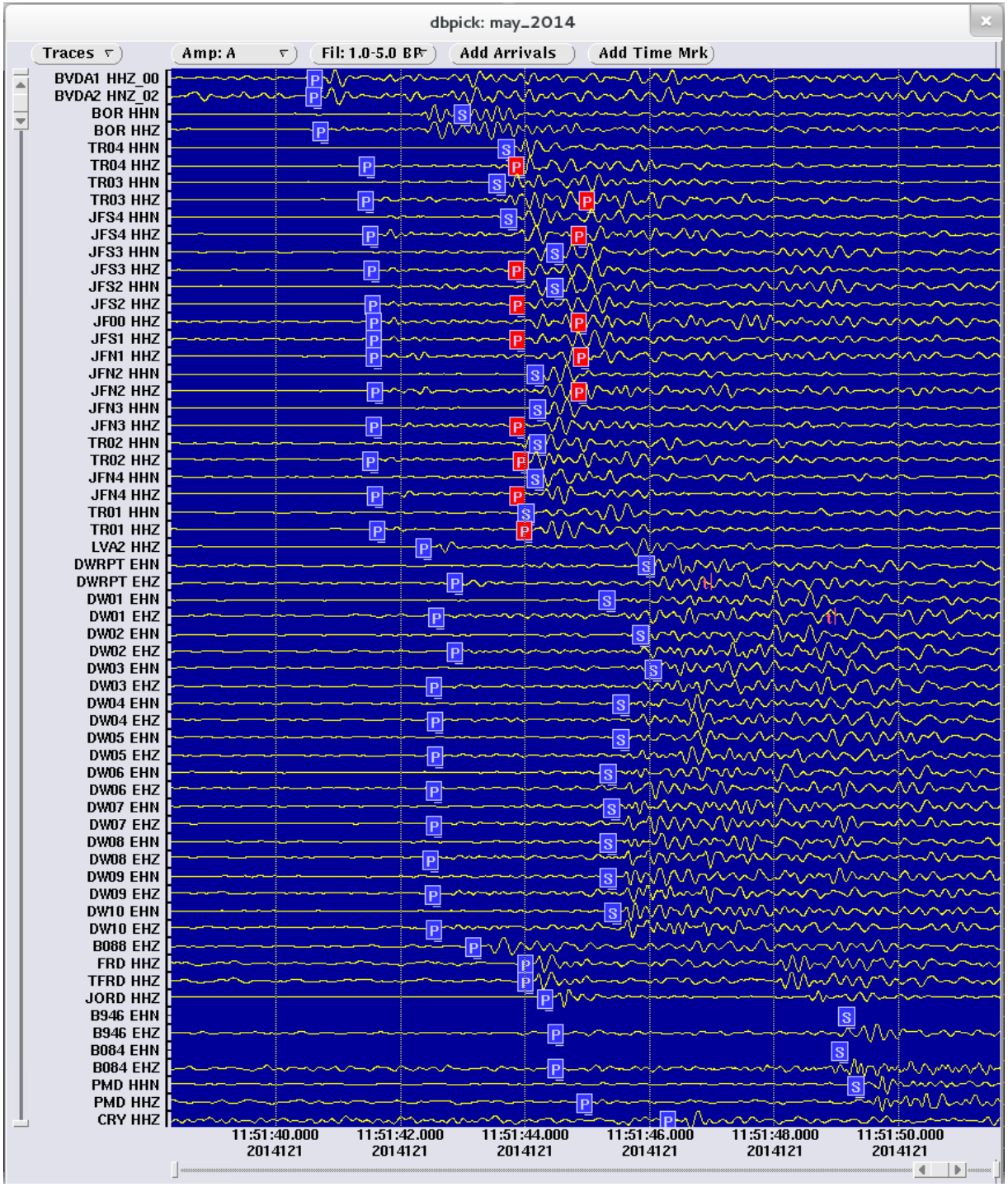
JFN1 HHN
JFN1 HHZ
JFN3 HHN
JFN3 HHZ
TR02 HHN
TR02 HHZ
JFN4 HHN
JFN4 HHZ
DW06 EHN
DW06 EHZ
DW07 EHN
DW07 EHZ
DW08 EHN
DW08 EHZ
DW09 EHN
DW09 EHZ
DW10 EHN
DW10 EHZ
FRD HHZ
TFRD HHZ
JORD HHZ
PMD HHZ
09:22:32.000 2014121
09:22:34.000 2014121
09:22:36.000 2014121
09:22:38.000 2014121
09:22:40.000 2014121
09:22:42.000 2014121
09:22:44.000 2014121
09:22:46.0 2014121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Add Time Mrk
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BVDA2 HNZ_02
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BOR HHZ
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TR04 HHZ
TR03 HHN
TR03 HHZ
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JFS4 HHZ
JFS3 HHN
JFS3 HHZ
JFS2 HHN
JFS2 HHZ
JF00 HHZ
JFS1 HHZ
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JFN2 HHZ
JFN3 HHN
JFN3 HHZ
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TR01 HHZ
LVA2 HHZ
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DW08 EHN
DW08 EHZ
DW09 EHN
DW09 EHZ
DW10 EHN
DW10 EHZ
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TFRD HHZ
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PMD HHZ
CRY HHZ
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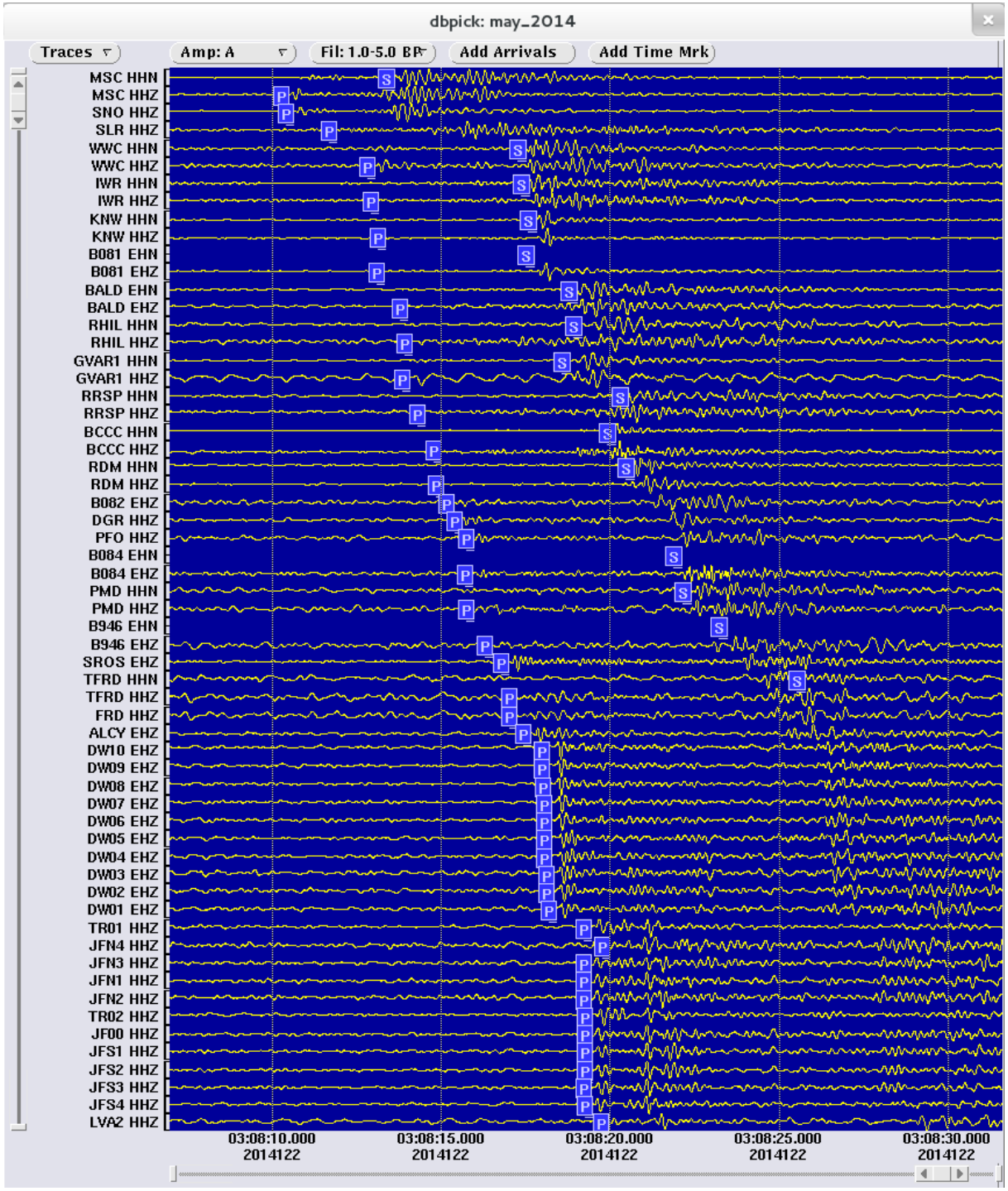
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MSC HHZ
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SLR HHZ
WWC HHN
WWC HHZ
IWR HHN
IWR HHZ
KNW HHN
KNW HHZ
B081 EHN
B081 EHZ
BALD EHN
BALD EHZ
RHIL HHN
RHIL HHZ
GVAR1 HHN
GVAR1 HHZ
RRSP HHN
RRSP HHZ
BCCC HHN
BCCC HHZ
RDM HHN
RDM HHZ
B082 EHZ
DGR HHZ
PFO HHZ
B084 EHN
B084 EHZ
PMD HHN
PMD HHZ
B946 EHN
B946 EHZ
SROS EHZ
TFRD HHN
TFRD HHZ
FRD HHZ
ALCY EHZ
DW10 EHZ
DW09 EHZ
DW08 EHZ
DW07 EHZ
DW06 EHZ
DW05 EHZ
DW04 EHZ
DW03 EHZ
DW02 EHZ
DW01 EHZ
TR01 HHZ
JFN4 HHZ
JFN3 HHZ
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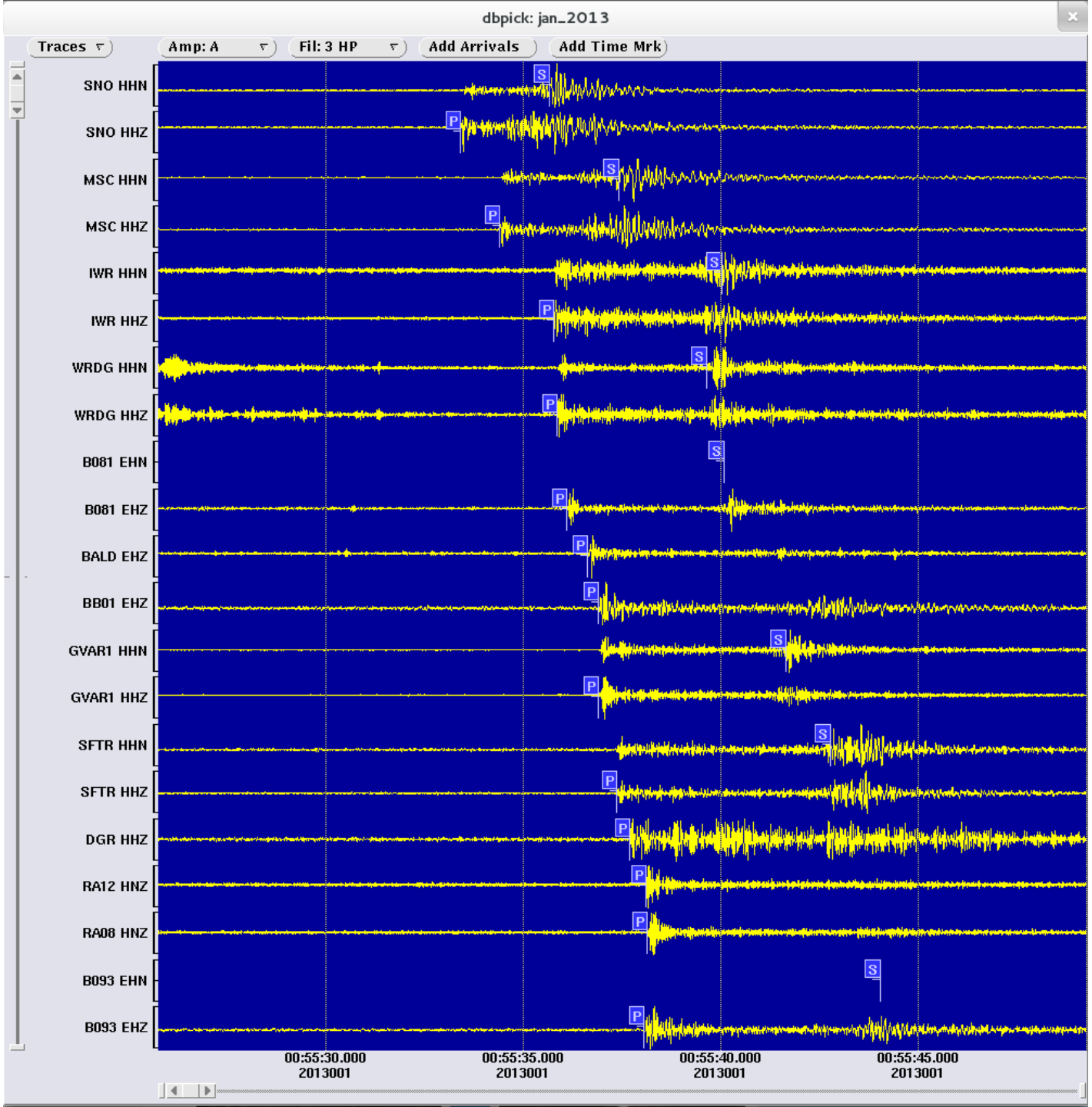
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Add Time Mrk
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SNO HHZ
MSC HHN
MSC HHZ
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IWR HHZ
WRDG HHN
WRDG HHZ
B081 EHN
B081 EHZ
BALD EHZ
BB01 EHZ
GVAR1 HHN
GVAR1 HHZ
SFTR HHN
SFTR HHZ
DGR HHZ
RA12 HNZ
RA08 HNZ
B093 EHN
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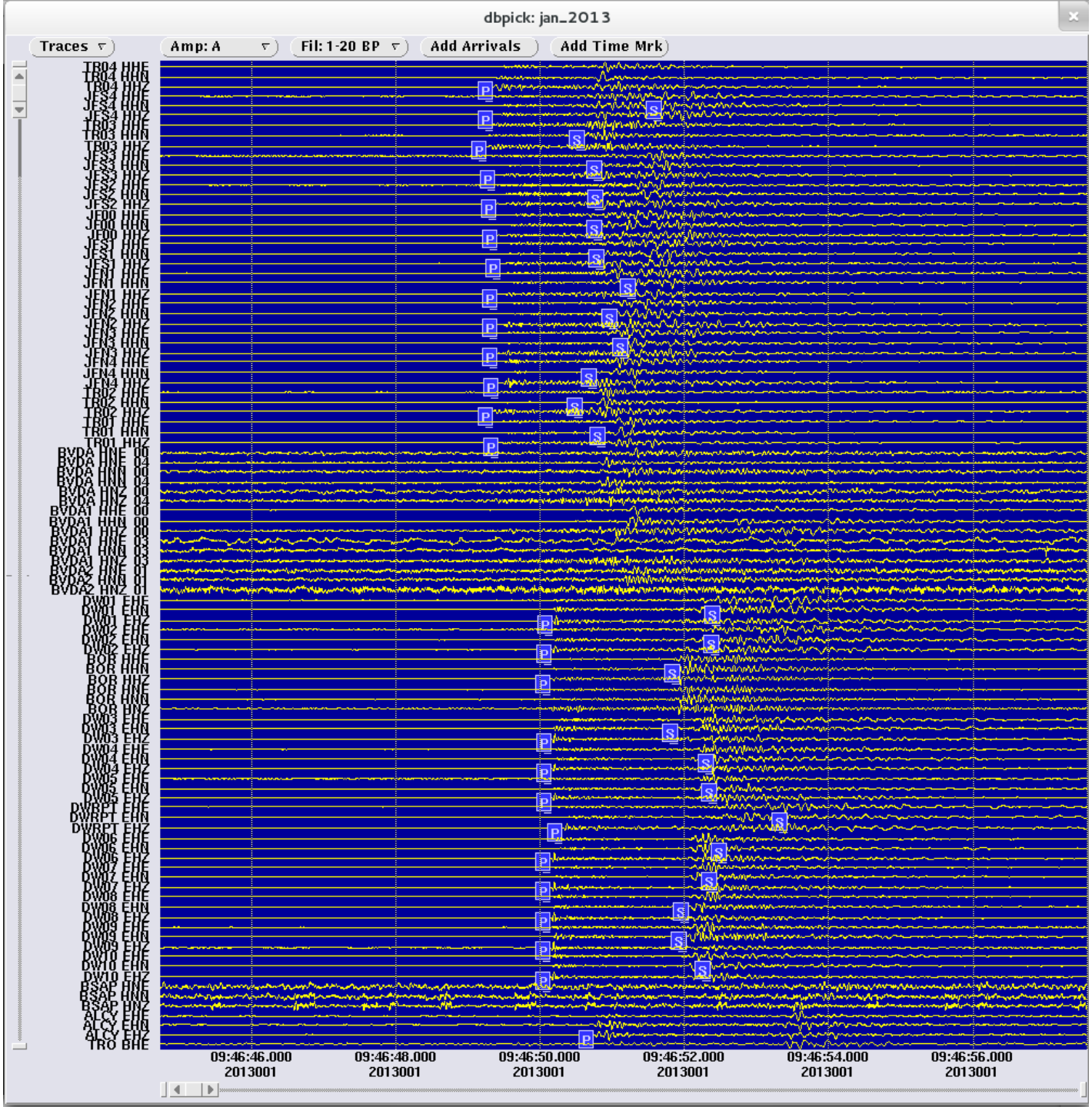
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Traces
Amp: A
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TR04 HHZ
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JFS3 HHN
JFS3 HHZ
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BOR HNN
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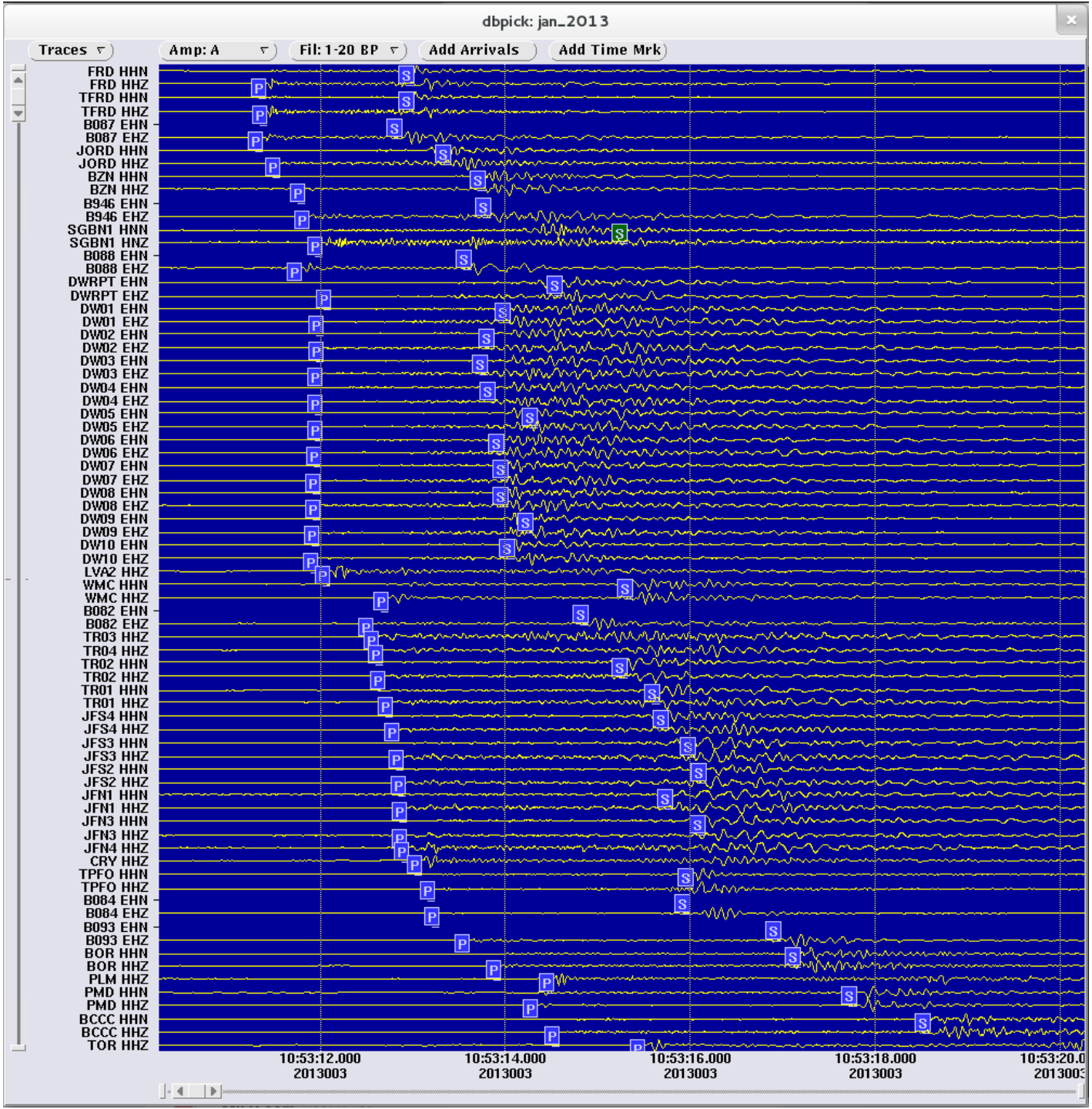
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Fil: 1-20 BP
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JFN3 HHZ
JFN4 HHZ
CRY HHZ
TPFO HHN
TPFO HHZ
B084 EHN
B084 EHZ
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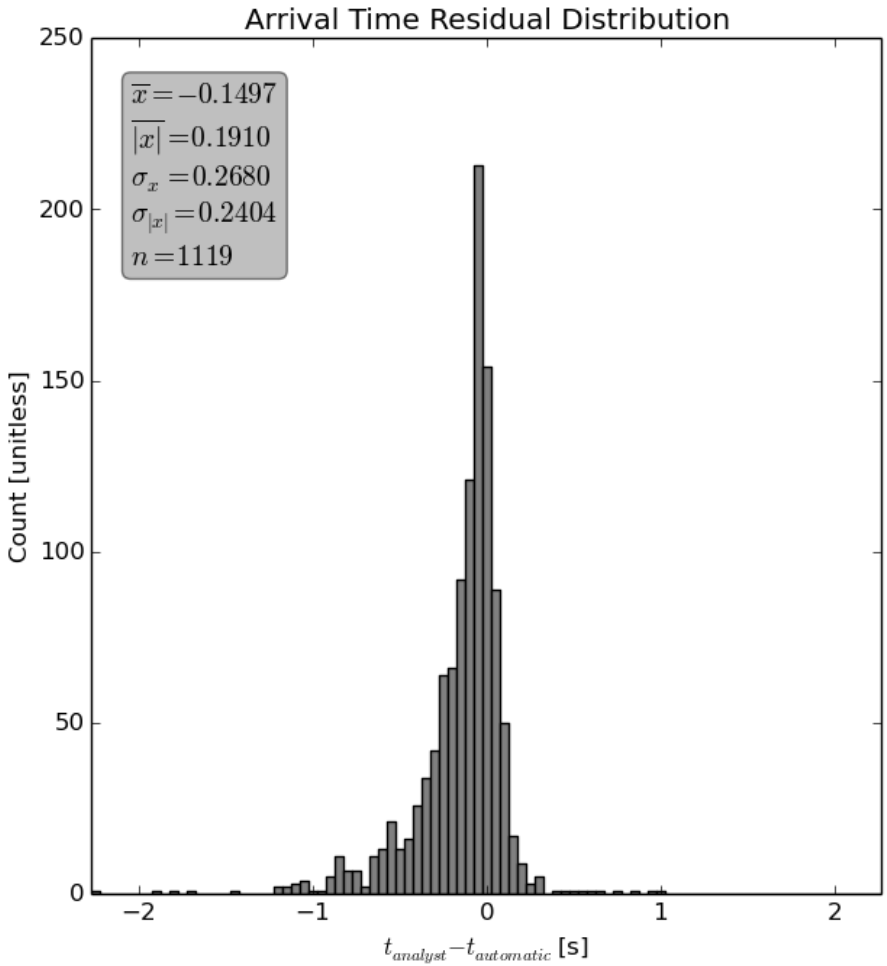
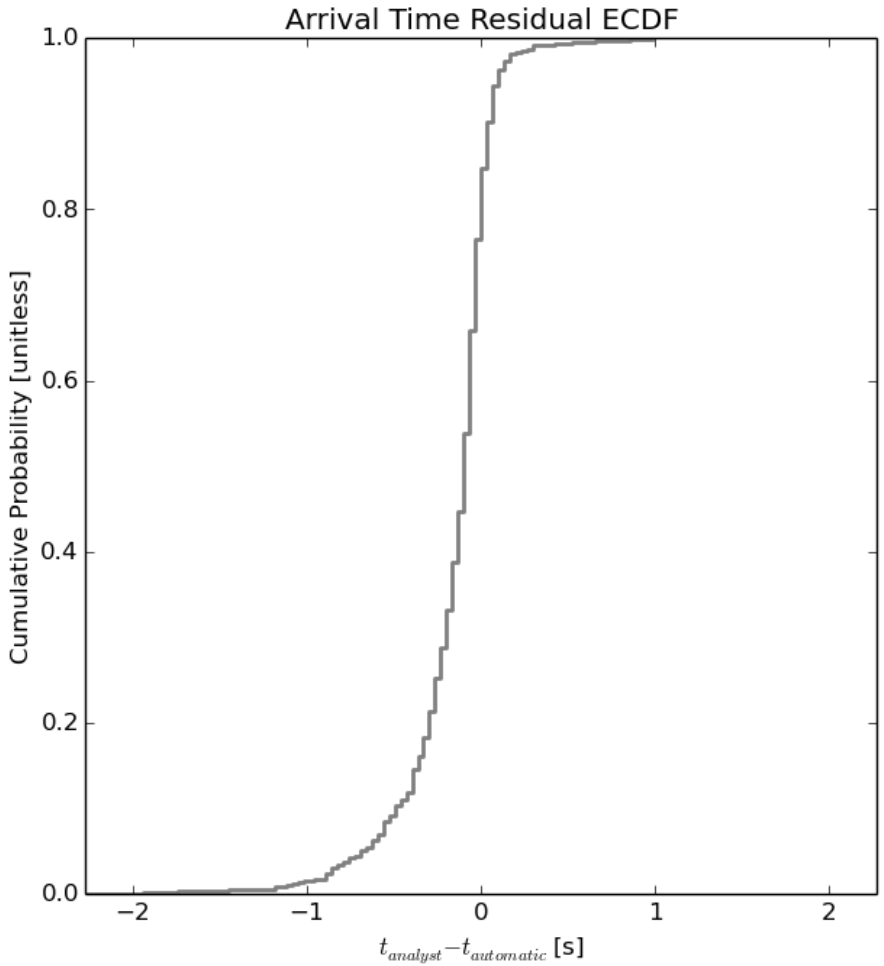
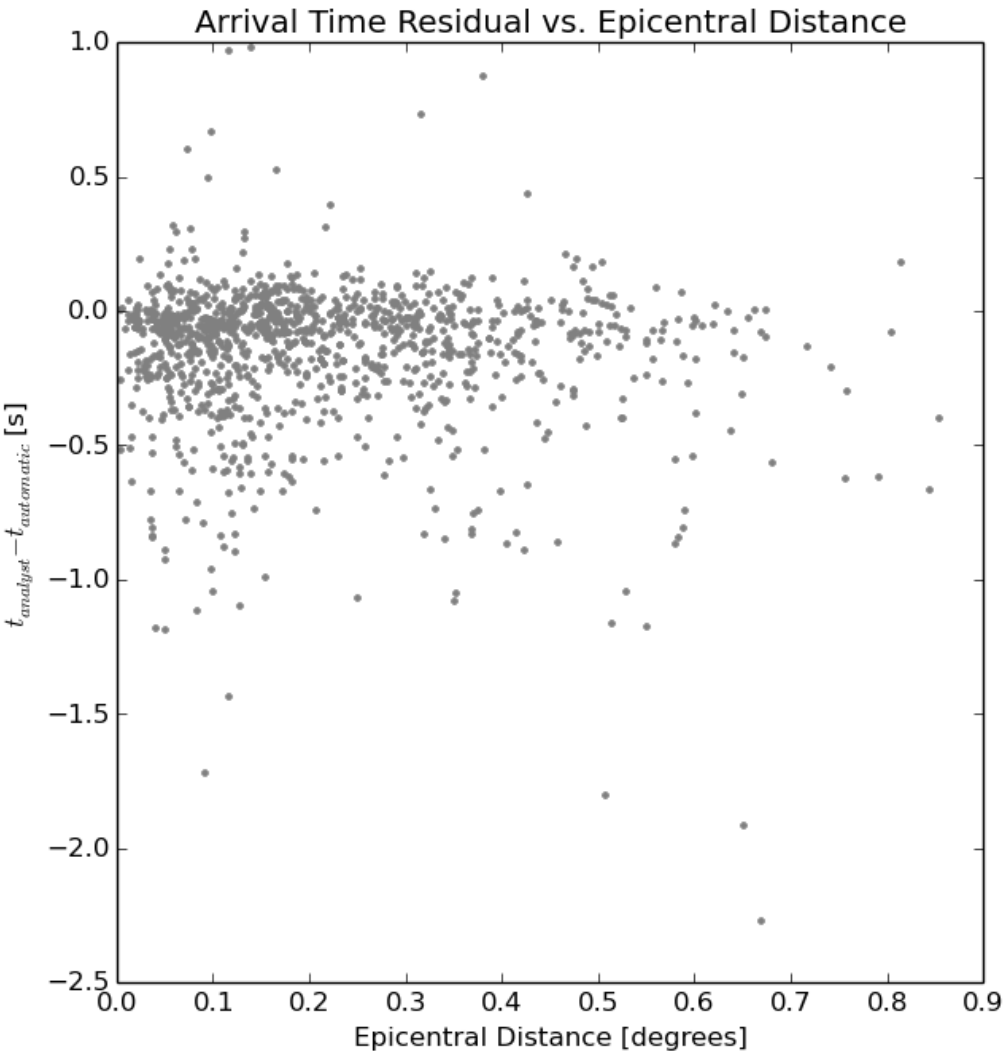
Pick accuracy



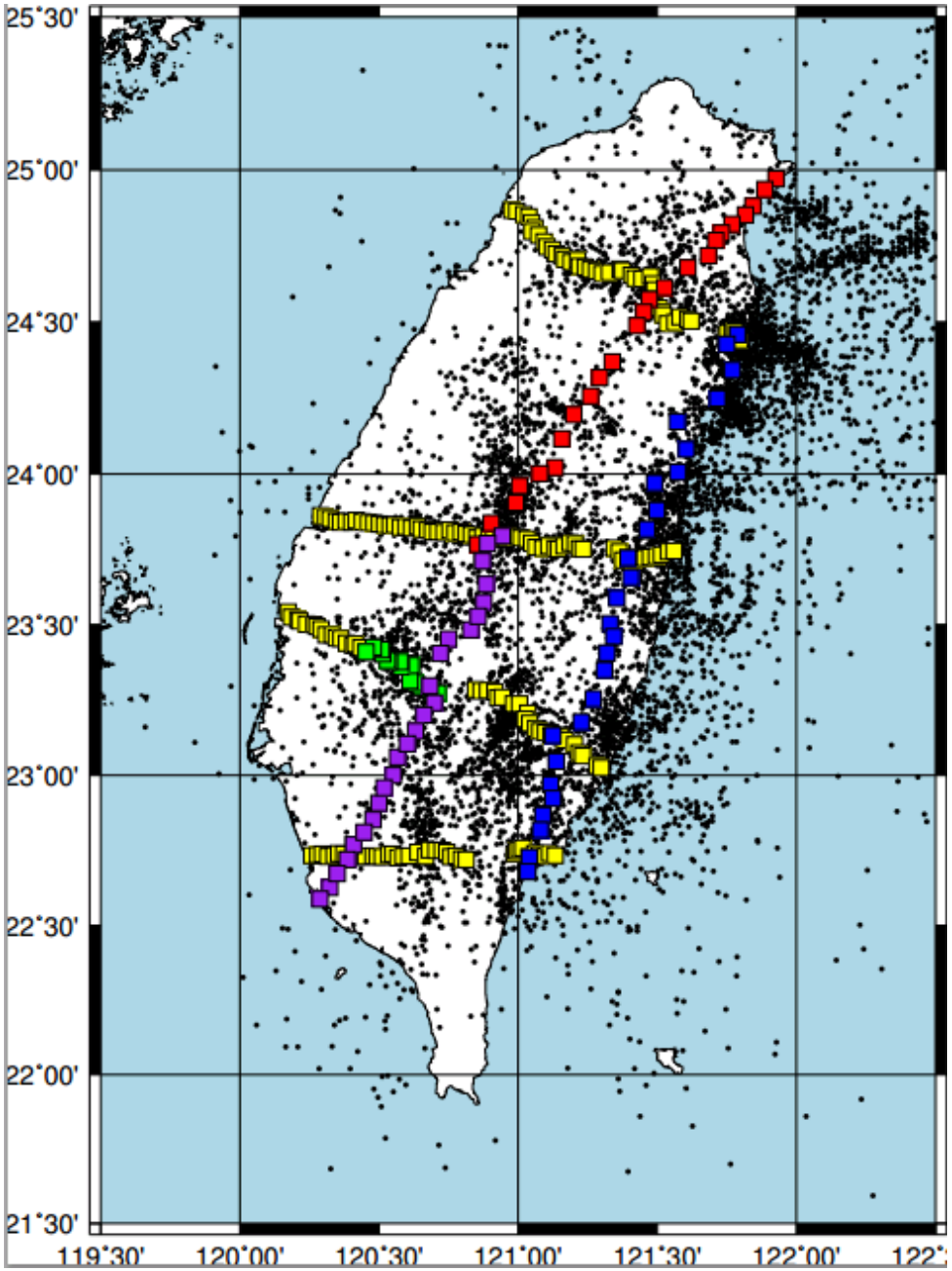


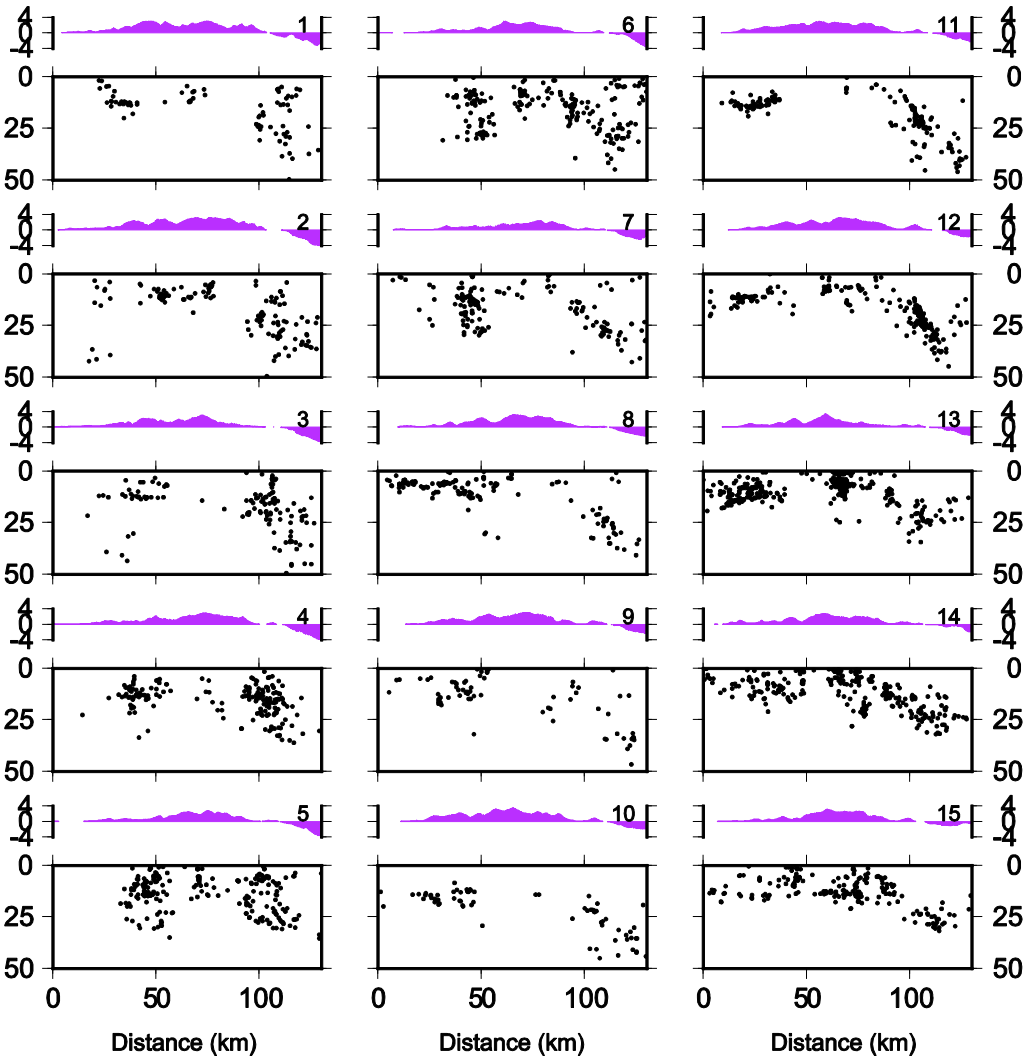
Pick accuracy

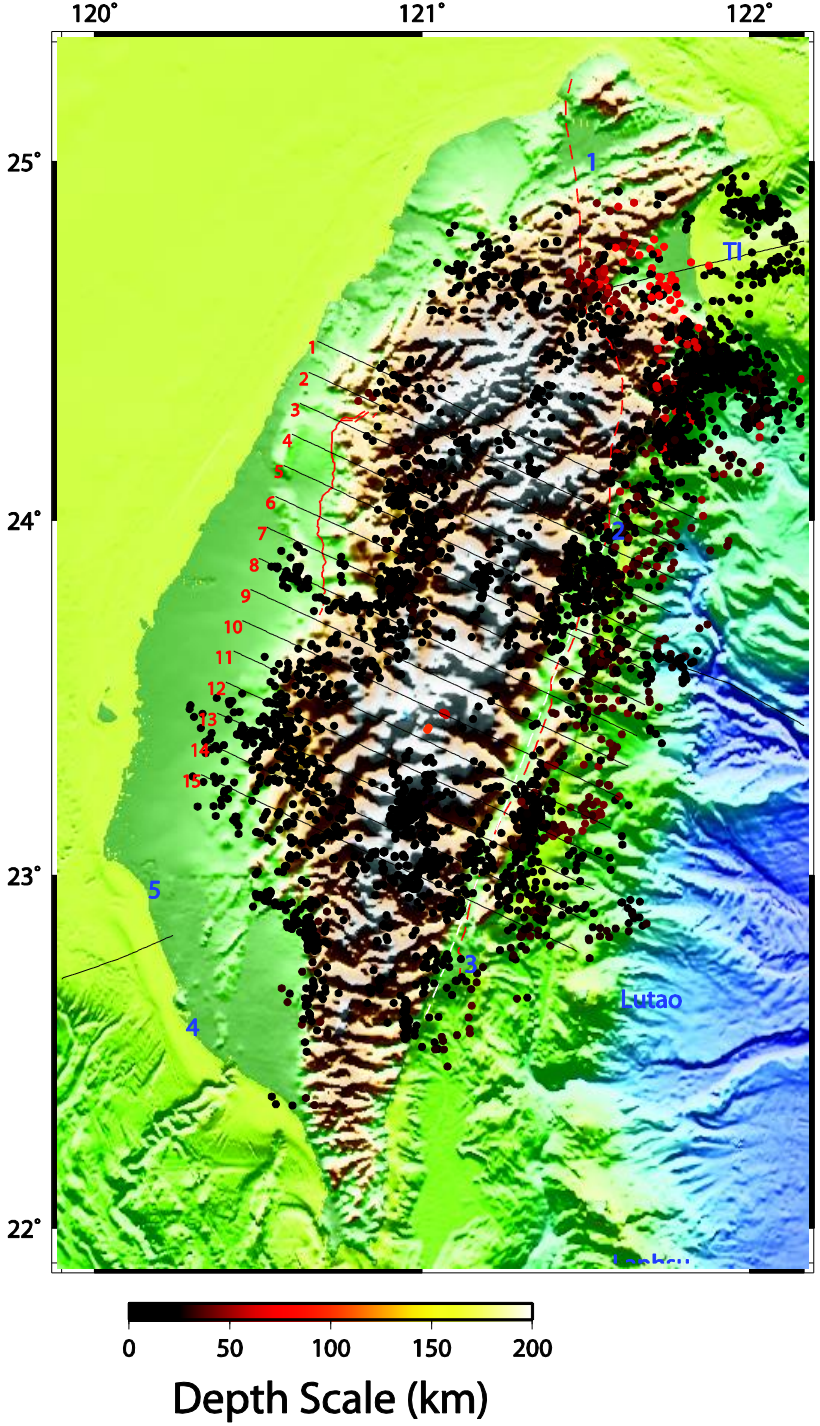


TAIGER dataset

- 297 EH, HH stations deployed from 01-06-2009 to 06-26-2009
  - ~200 operational for only 3 months
- Stations deployed as 7 linear arrays across island
- Permanent national network (CWB): ~3300 events
- Automatic detection: ~8400 events




1
6
11
2
7
12
3
8
13
4
9
14
5
10
15
4
0
-4
0
25
50
0
50
100
Distance (km)


120°
121°
122°
25°
24°
23°
22°
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
TI
Lutao
0
50
100
150
200
Depth Scale (km)

Conclusions

- We developed a robust, auto. S picking algorithm for continuous data
- Algorithm is implemented with Antelope API and integrated with current working environment
- It has been successfully applied to a number of different regions around the world