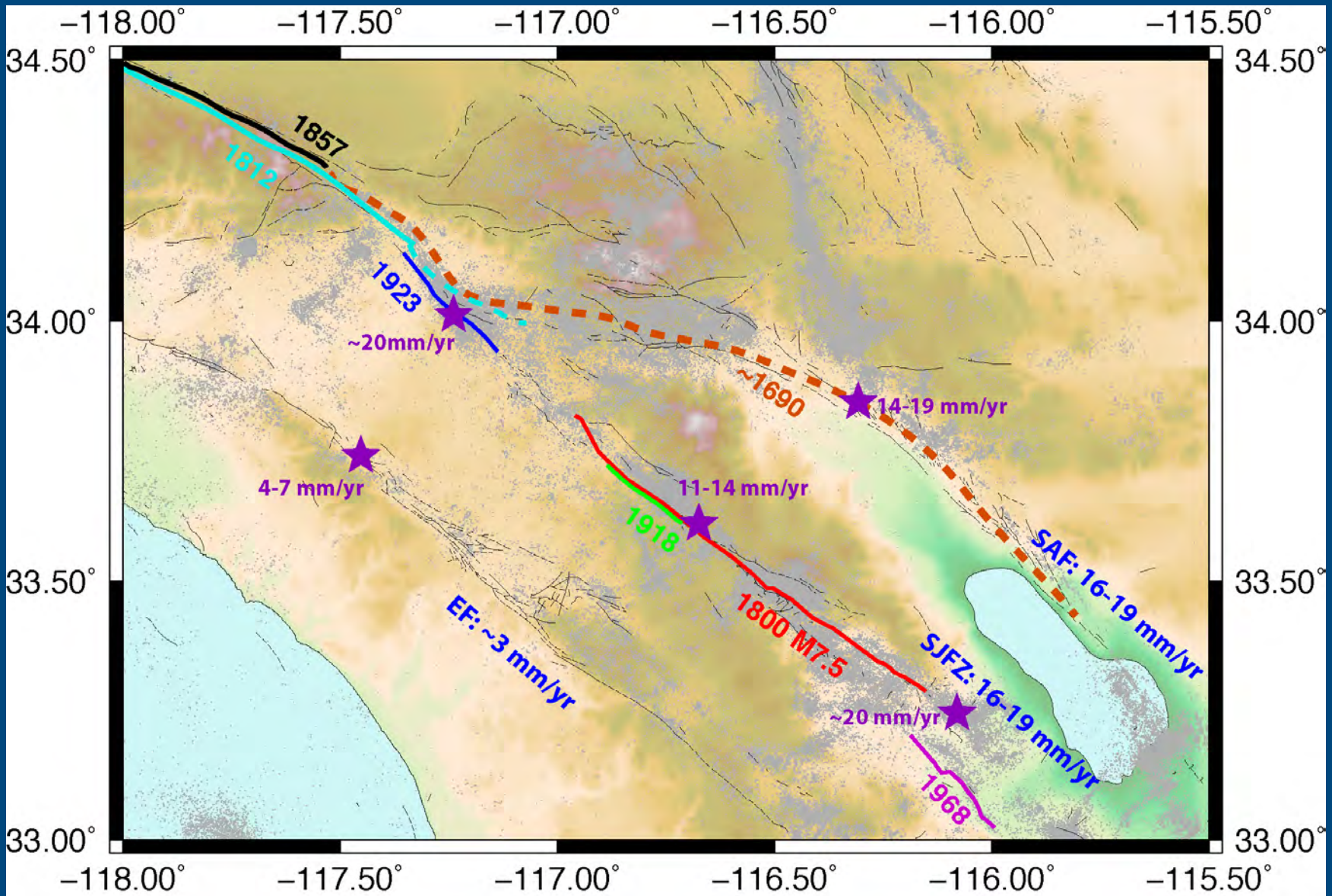
San Jacinto Fault Zone and Sage Brush Flat High Frequency Experiments

Frank Vernon

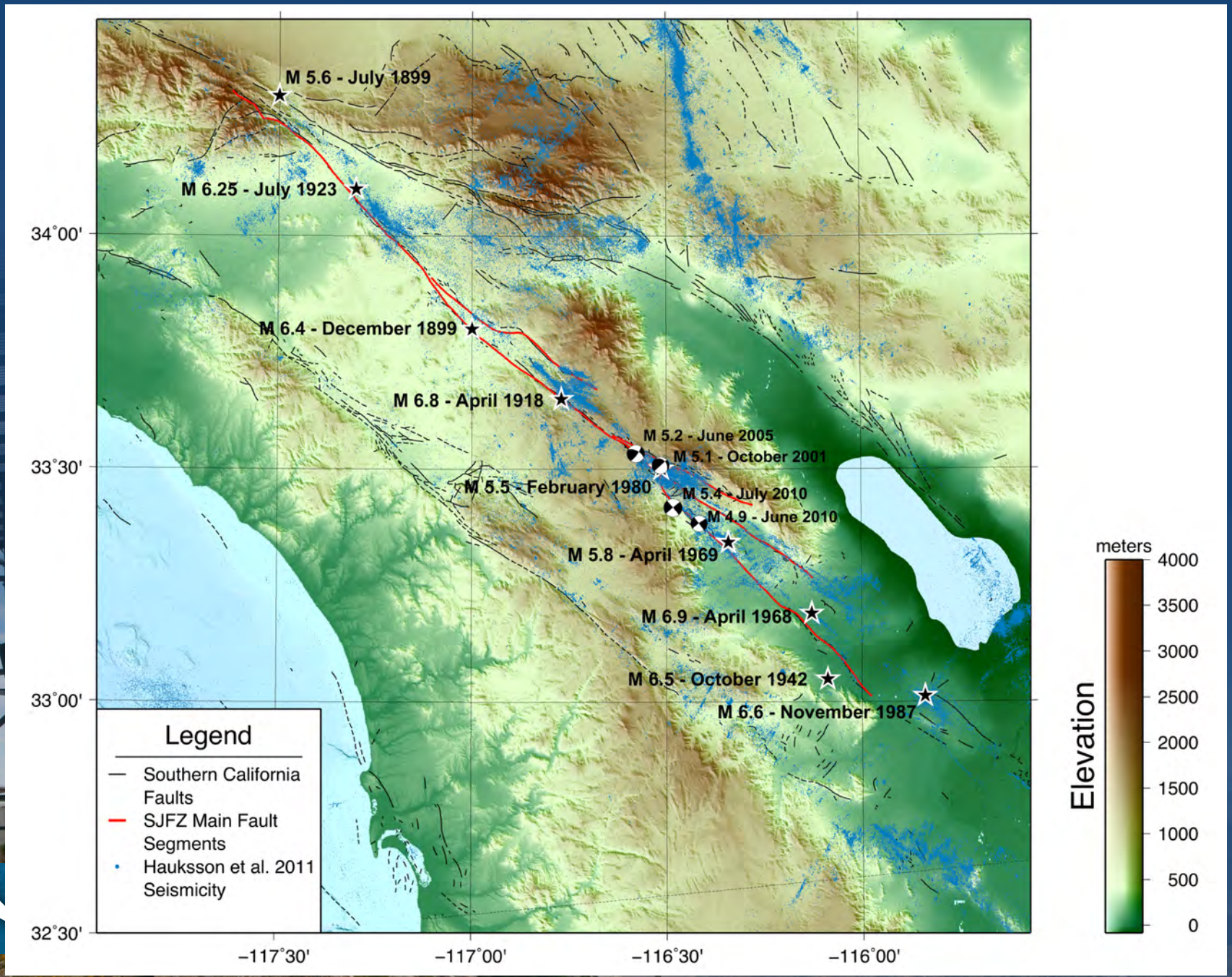
Scripps Institution of Oceanography
University of California, San Diego

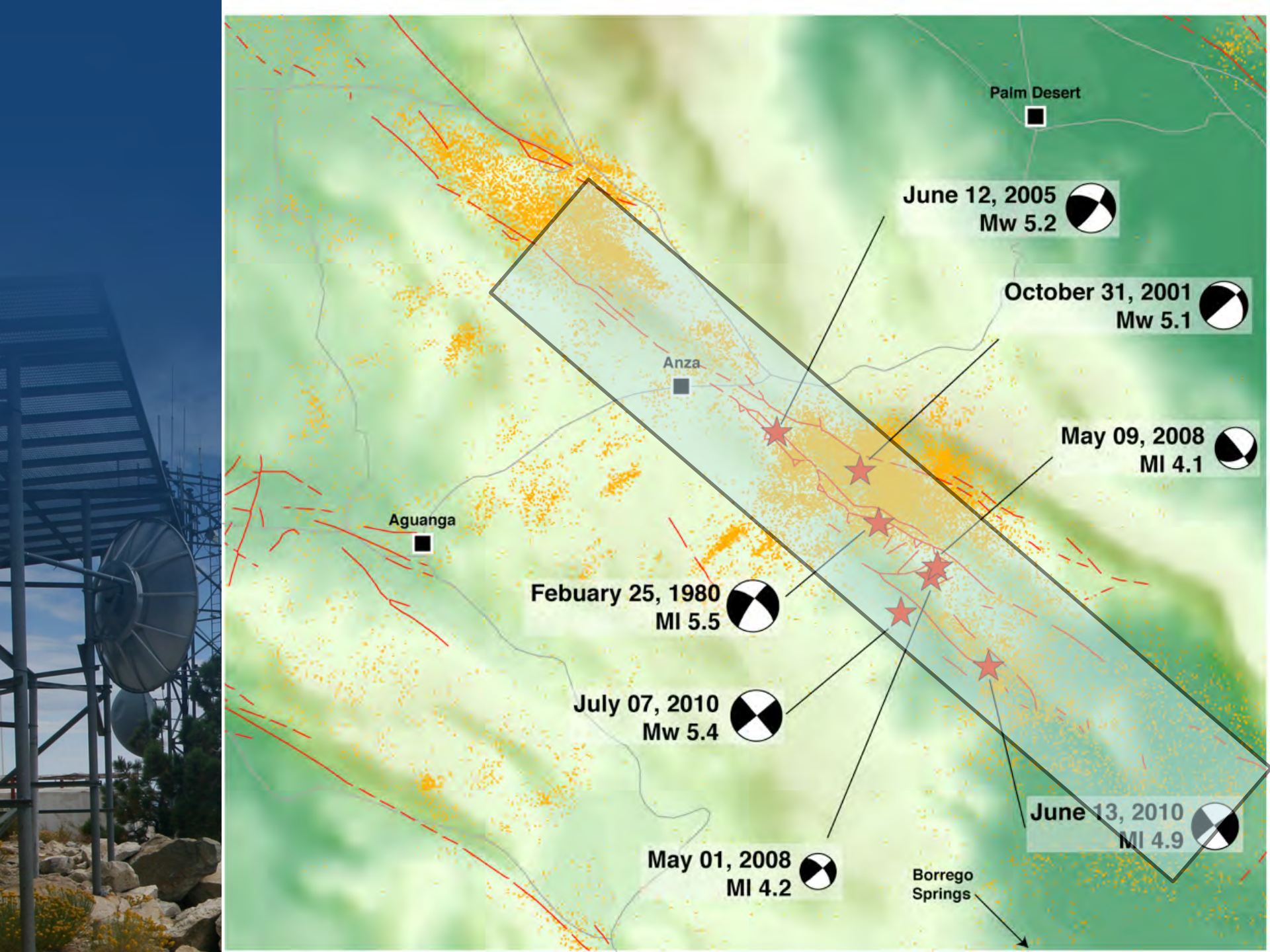
2015 Udine AUG
13 March 2015

Southern California Major Ruptures



San Jacinto Fault Zone

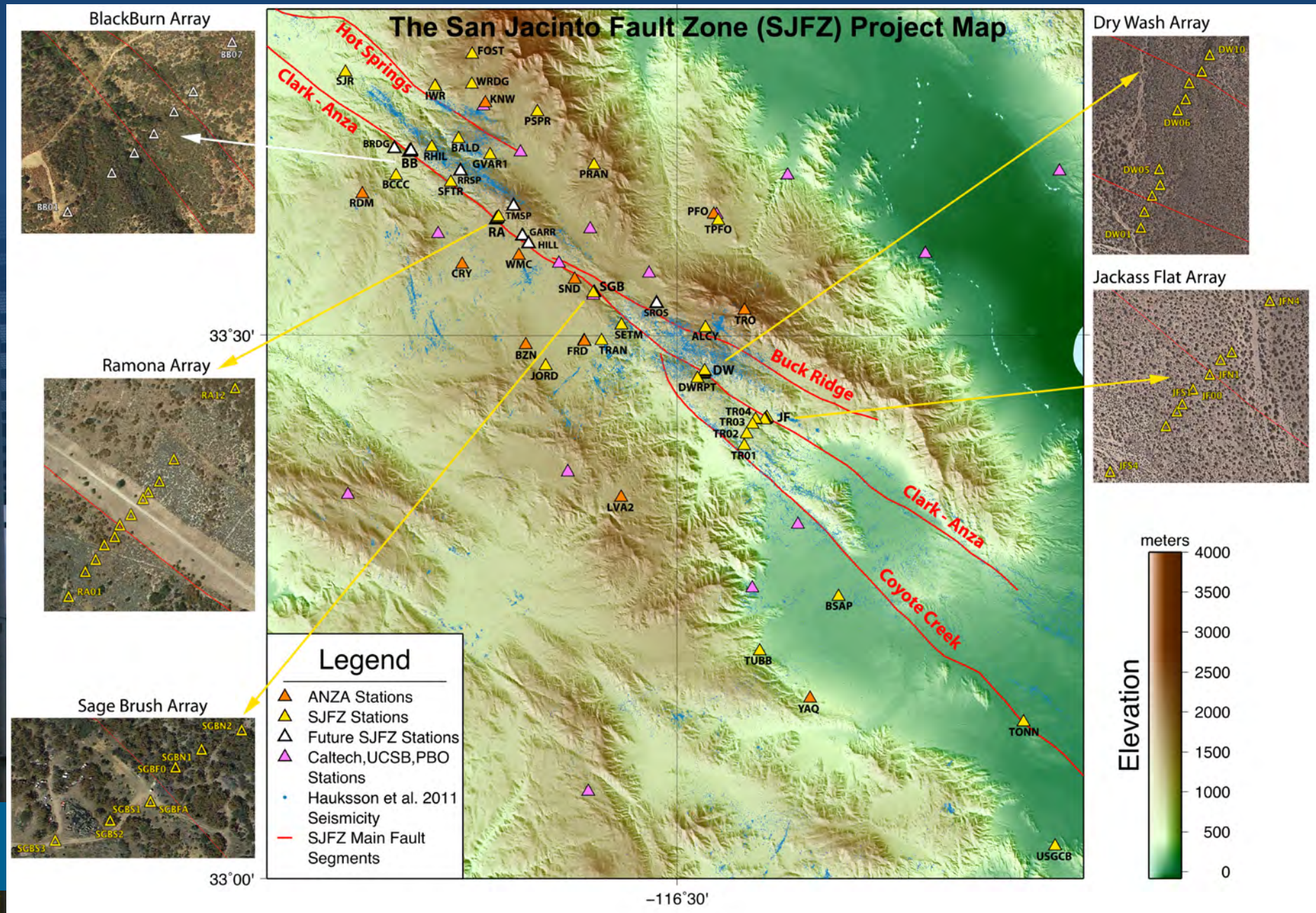



Palm Desert
June 12, 2005
Mw 5.2
October 31, 2001
Mw 5.1
Anza
May 09, 2008
Ml 4.1
Aguanga
Febuary 25, 1980
Ml 5.5
July 07, 2010
Mw 5.4
June 13, 2010
Ml 4.9
May 01, 2008
Ml 4.2
Borrego
Springs

San Jacinto Fault Zone
Realtime Virtual Observing Network

- ANZA Seismic Network (24)
- Plate Boundary Observatory (8)
- Southern California Seismic Network (~30)
- UC Santa Barbara (3)
- PASSCAL
  - 5 Linear Fault Crossing Arrays
    - *45 total elements*
  - 20 stand alone stations
- 8 Borehole Strainmeters
- 12 Permanent GPS

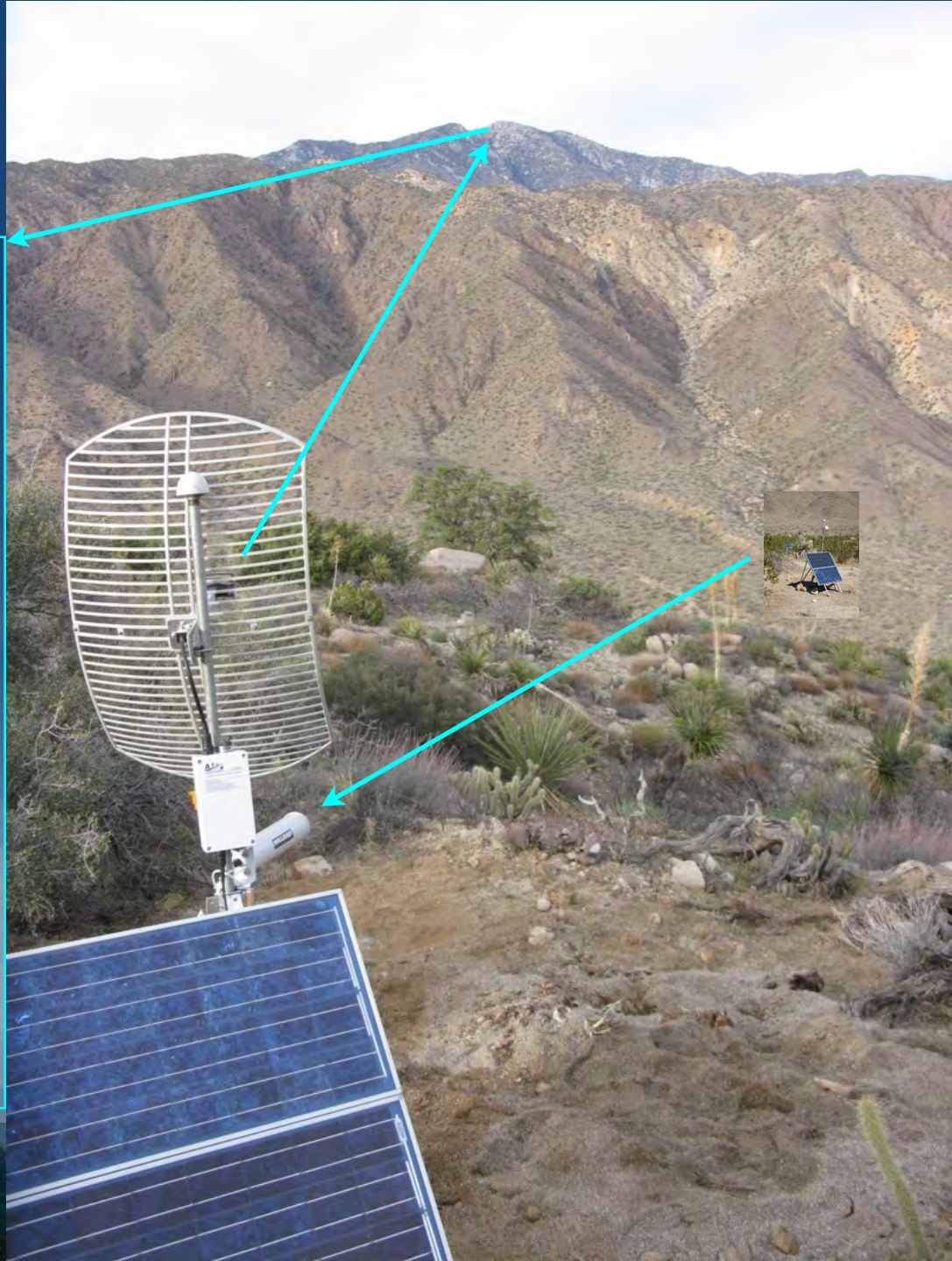
The SJFZ Project Deployment Map



PASSCAL Ad Hoc Telemetry

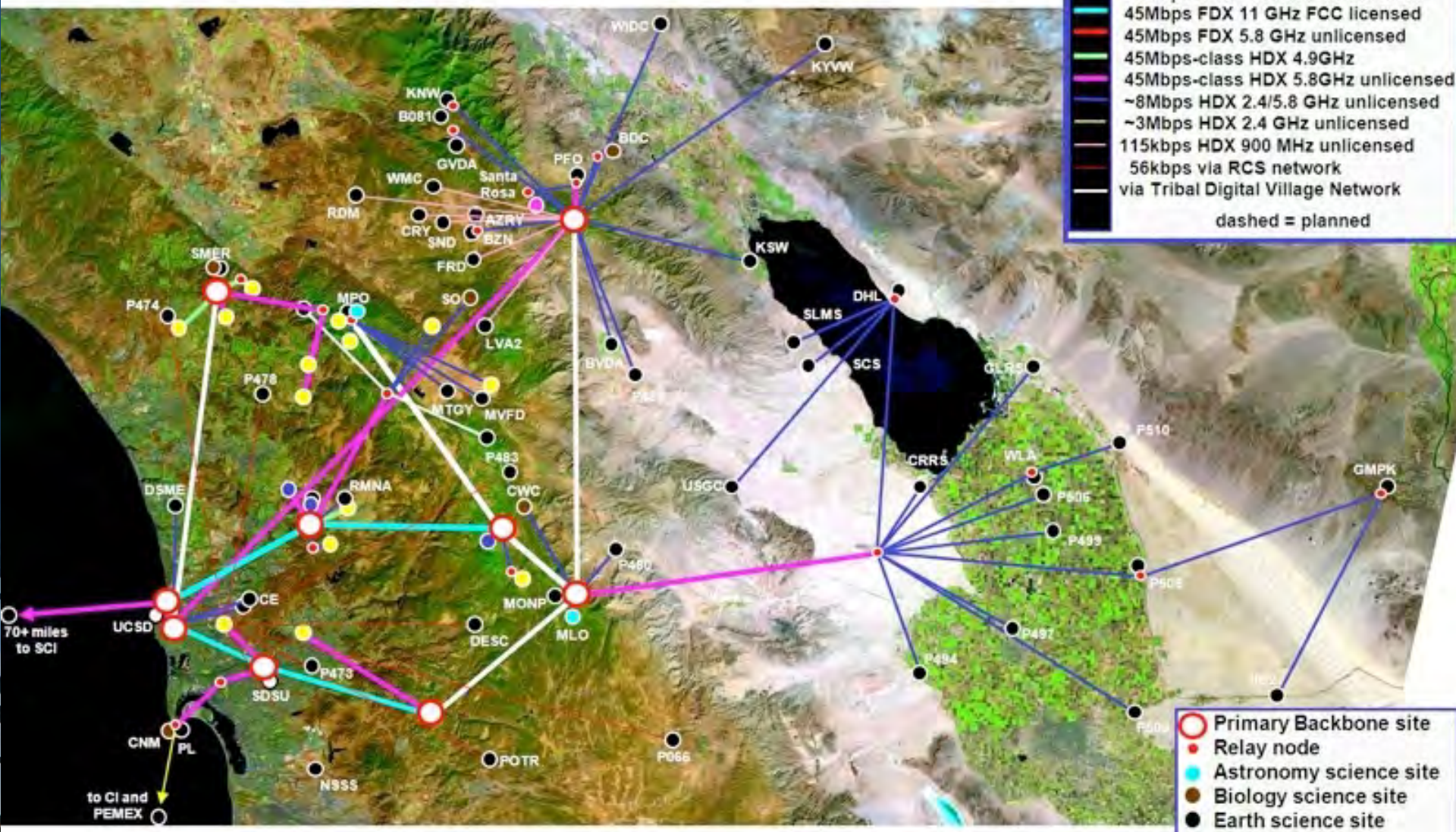
SCRIPPS INSTITUTION OF OCEANOGRAPHY
UC San Diego

PASSCAL Ad Hoc Telemetry



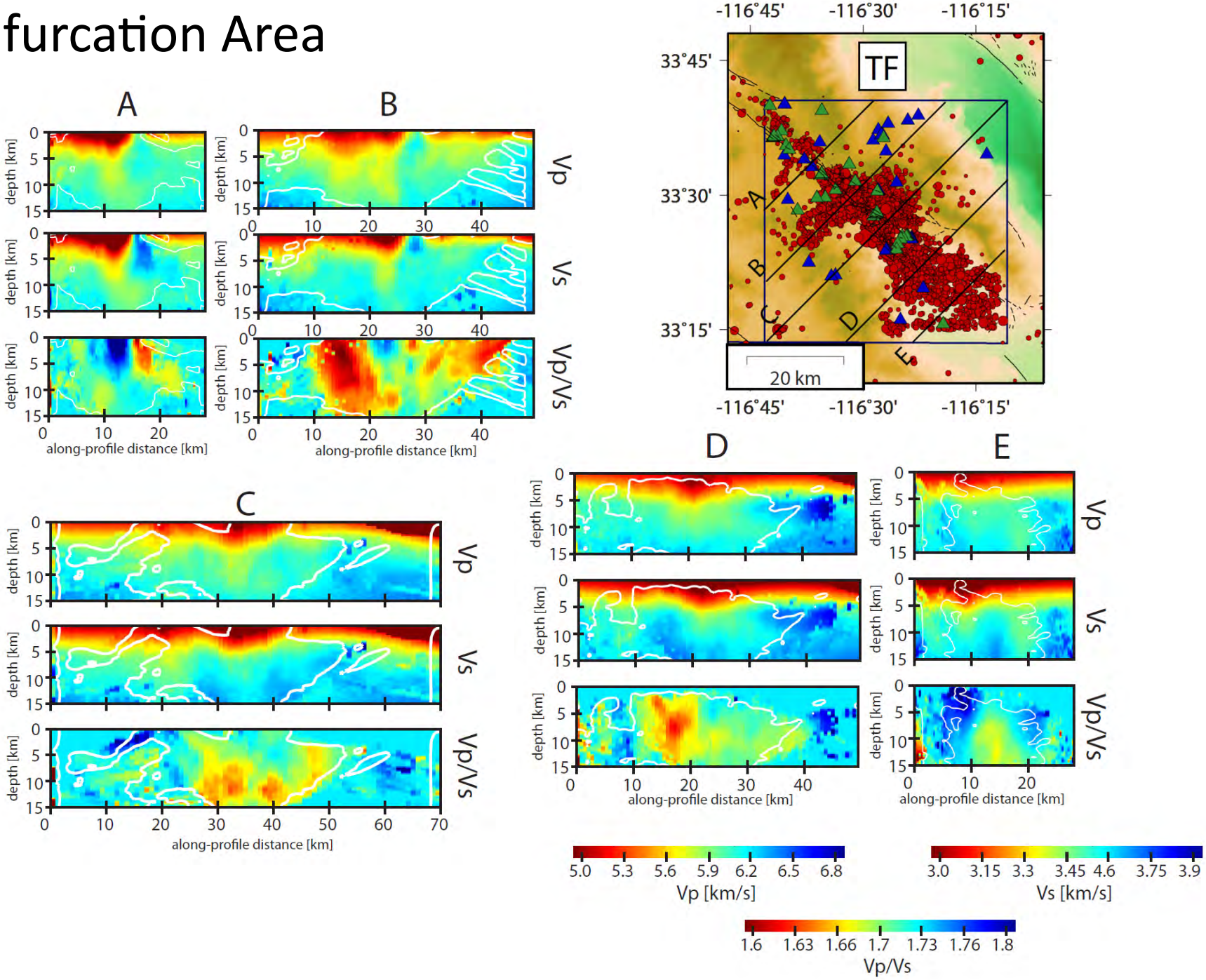
SCRIPPS INSTITUTION OF OCEANOGRAPHY
UC San Diego

HPWREN topology – January 2012



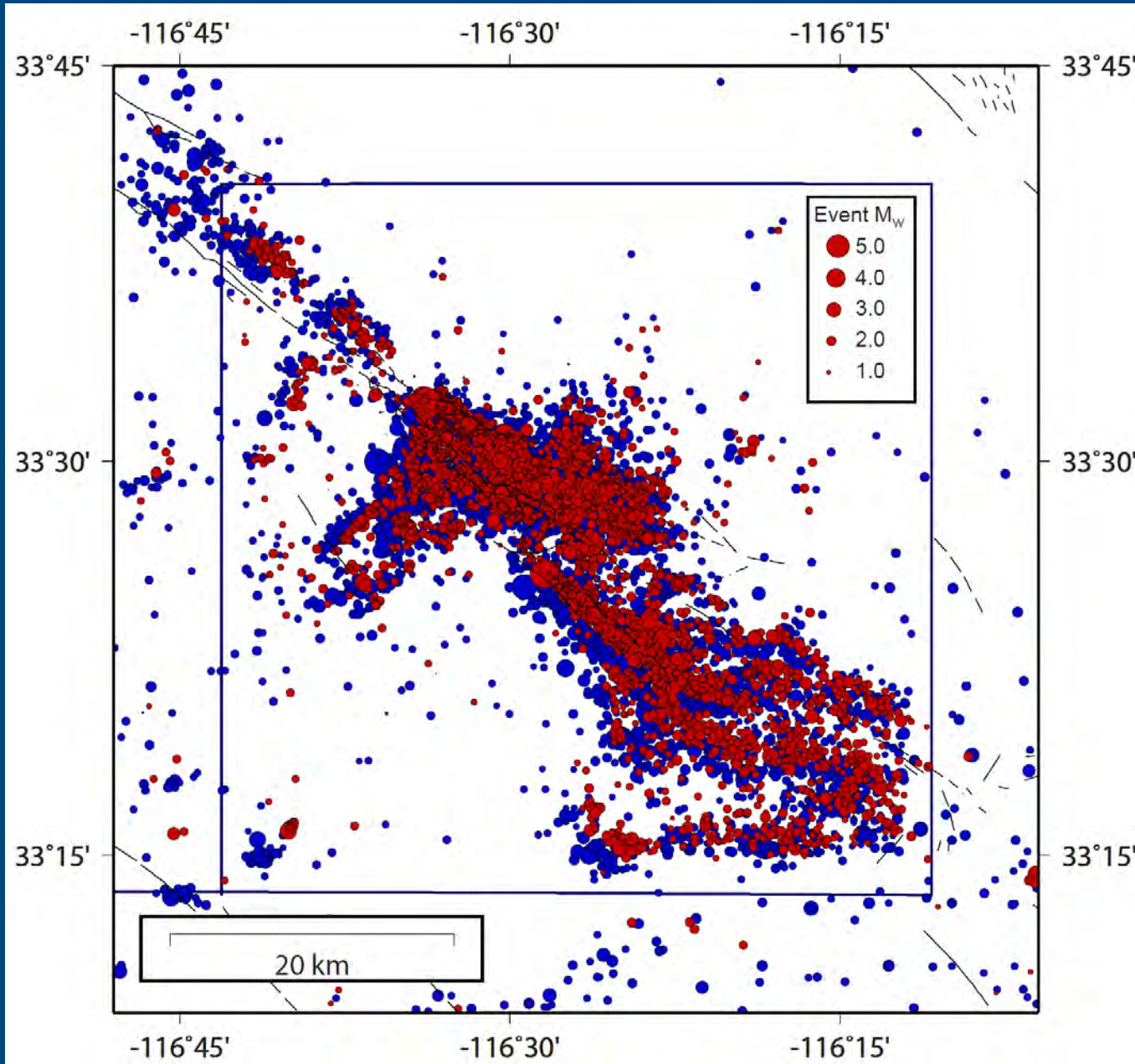
Applied Network Research http://anr.ucsd.edu

Trifurcation Area



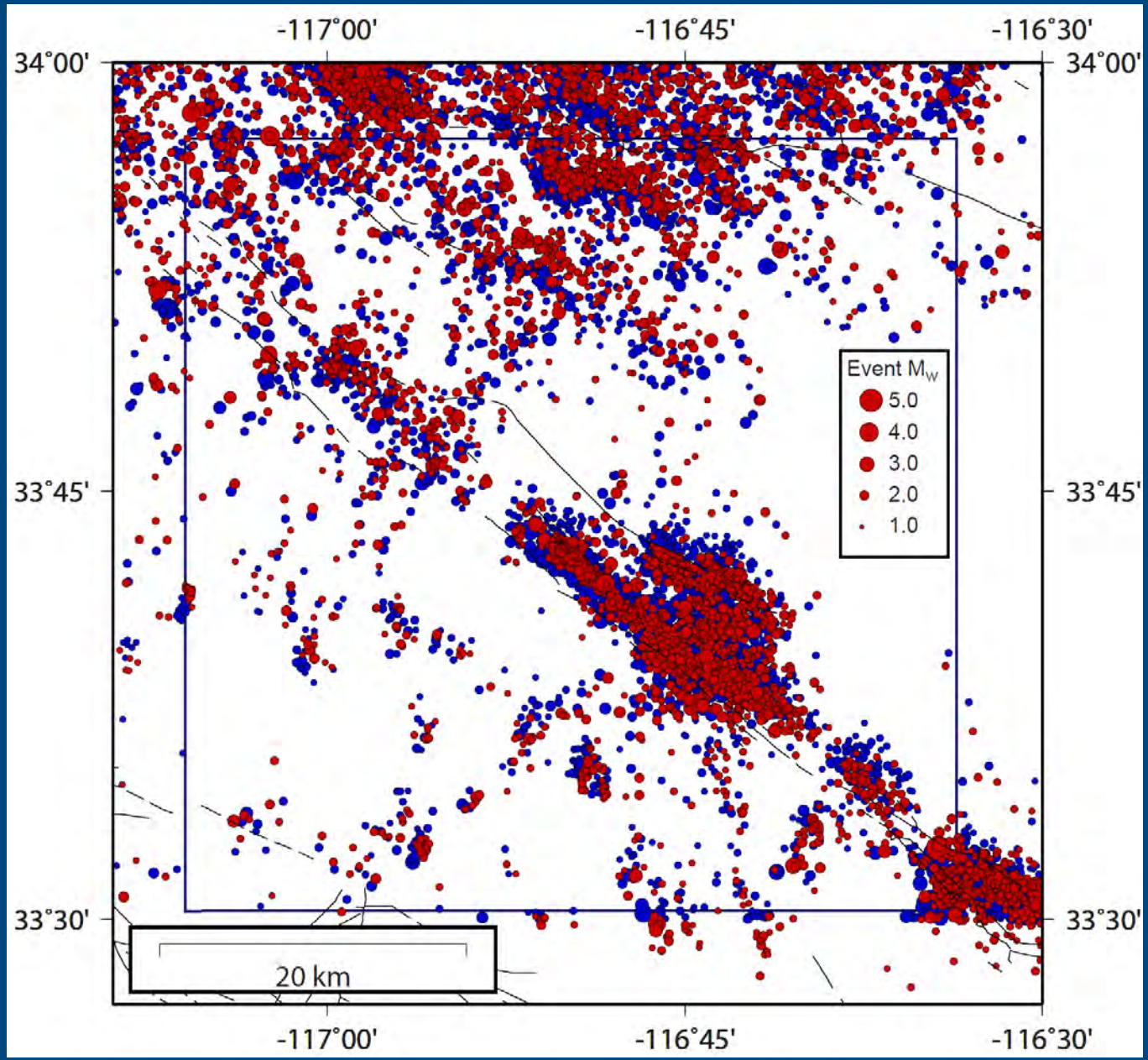
Trifurcation Area 1 km Resolution Tomography

- Original locations in blue
- Relocations in red



Hot Springs 1 km Resolution Tomography

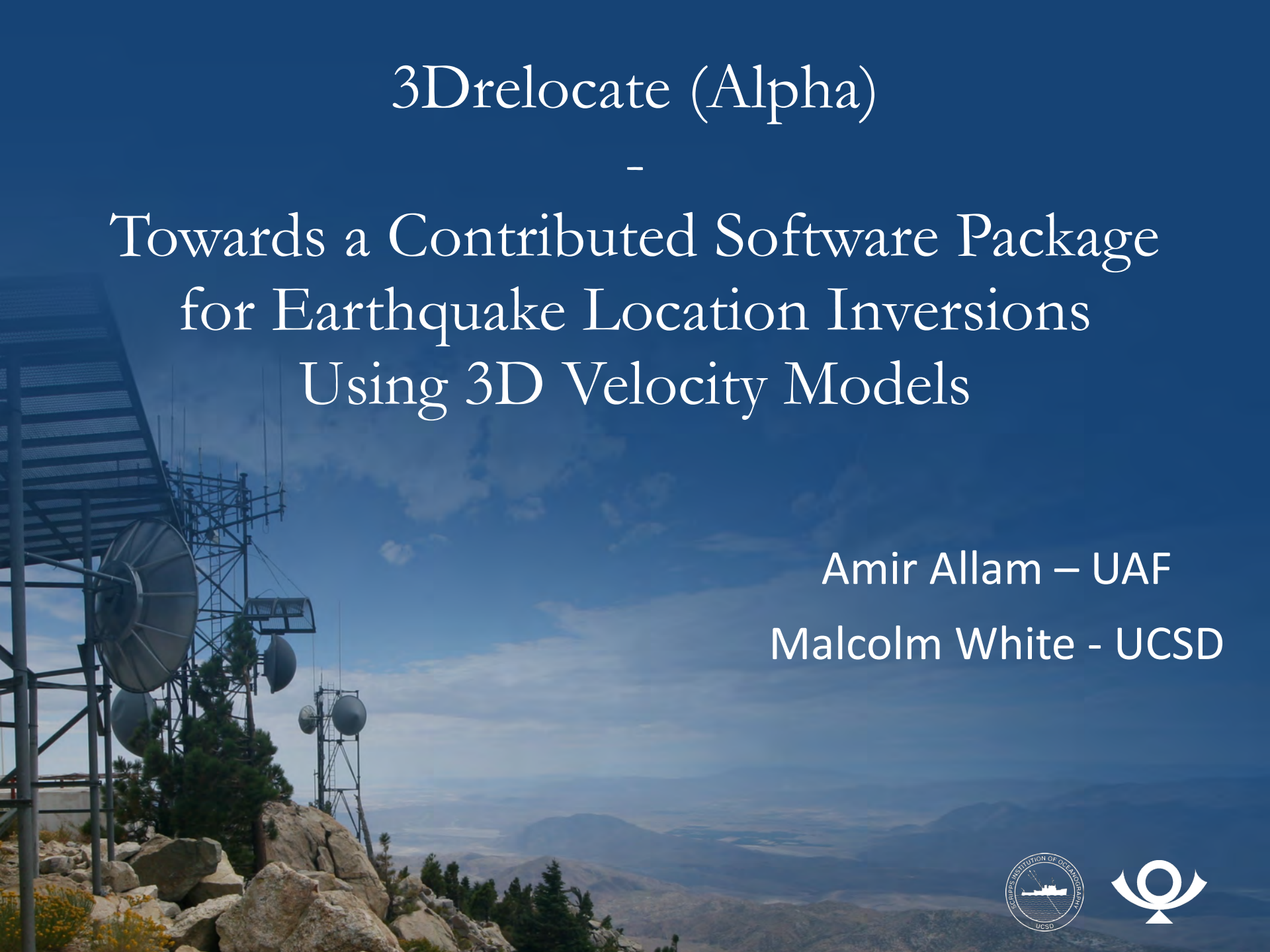
- Original locations in blue
- Relocations in red



3Drelocate (Alpha)

-

Towards a Contributed Software Package for Earthquake Location Inversions Using 3D Velocity Models



Amir Allam – UAF

Malcolm White - UCSD

Basic Components

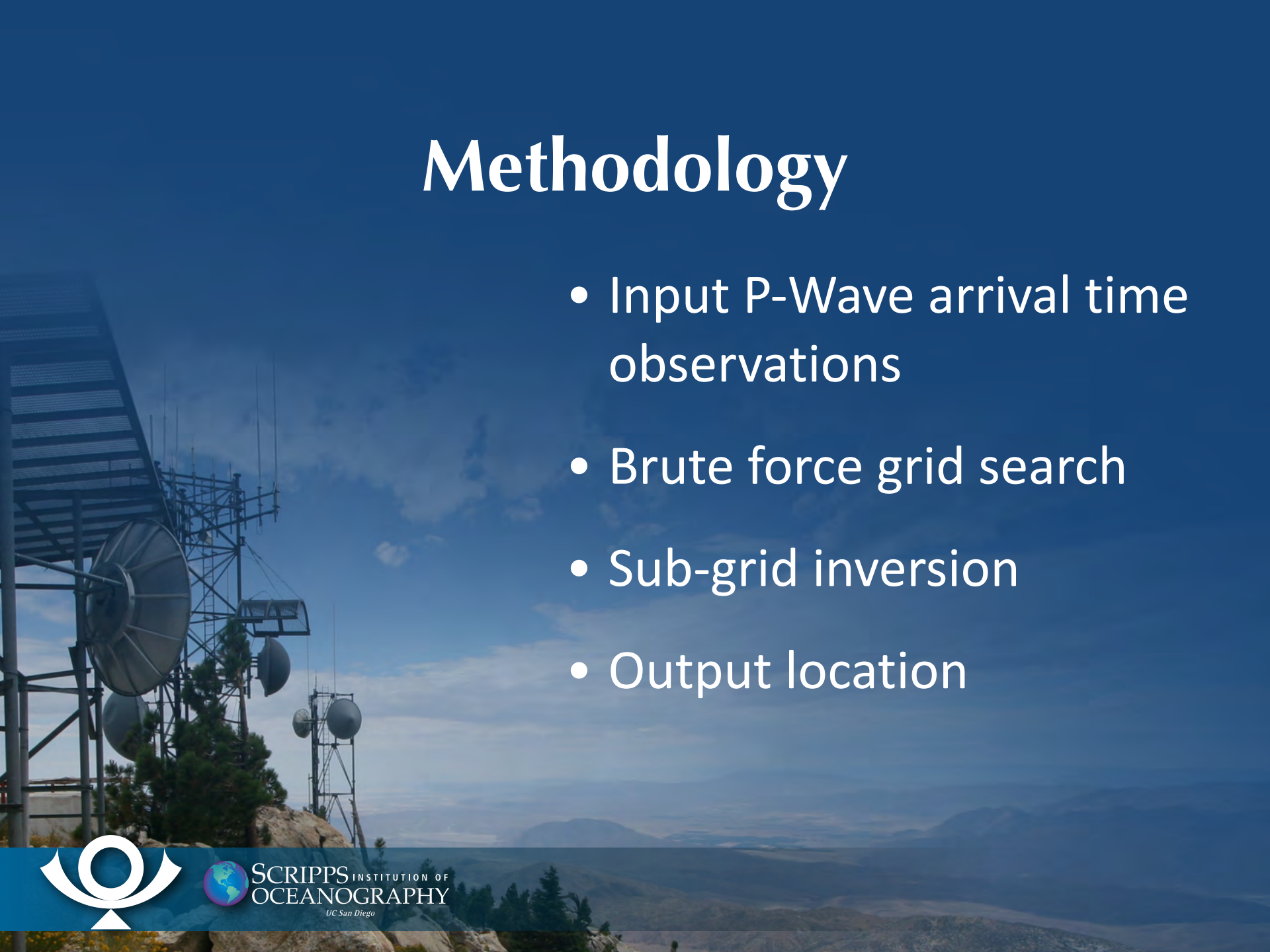
- generate_ttimes_fm3d
  - Command line tool
  - An I/O wrapper around fm3d
  - Builds source-to-station travel-time lookup files, accounting for 3D seismic velocity structure
- 3Drelocate
  - Command line tool
  - Interfaces Antelope database with inversion algorithm in loctools3d.core_tools
  - Can be replaced with interface to any data format

Basic Components

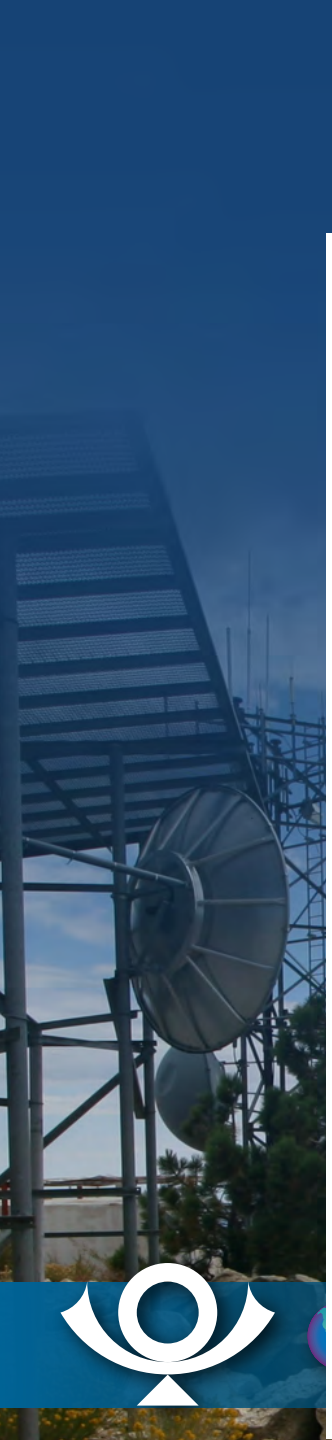
- loctools3d.core_tools
  - Python module
  - Implements location inversion algorithm
  - Implements internal data structures to allow for interface layer to be written for any data format
- fm3d (N. Rawlinson)
  - 3D wave-front tracking software
  - Accounts for 3D seismic velocity structure
  - Essential third-party component

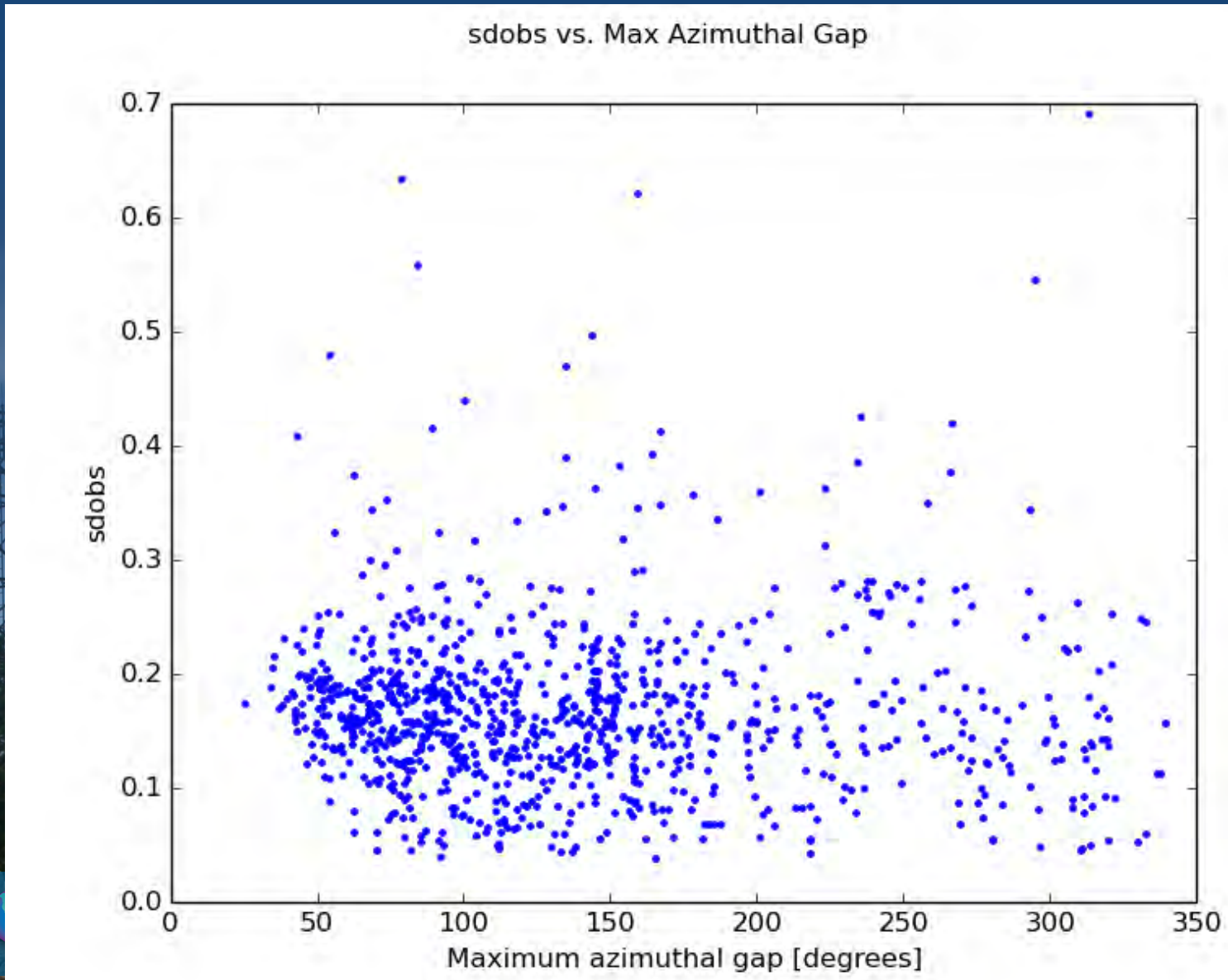
Methodology

- Input P-Wave arrival time observations
- Brute force grid search
- Sub-grid inversion
- Output location

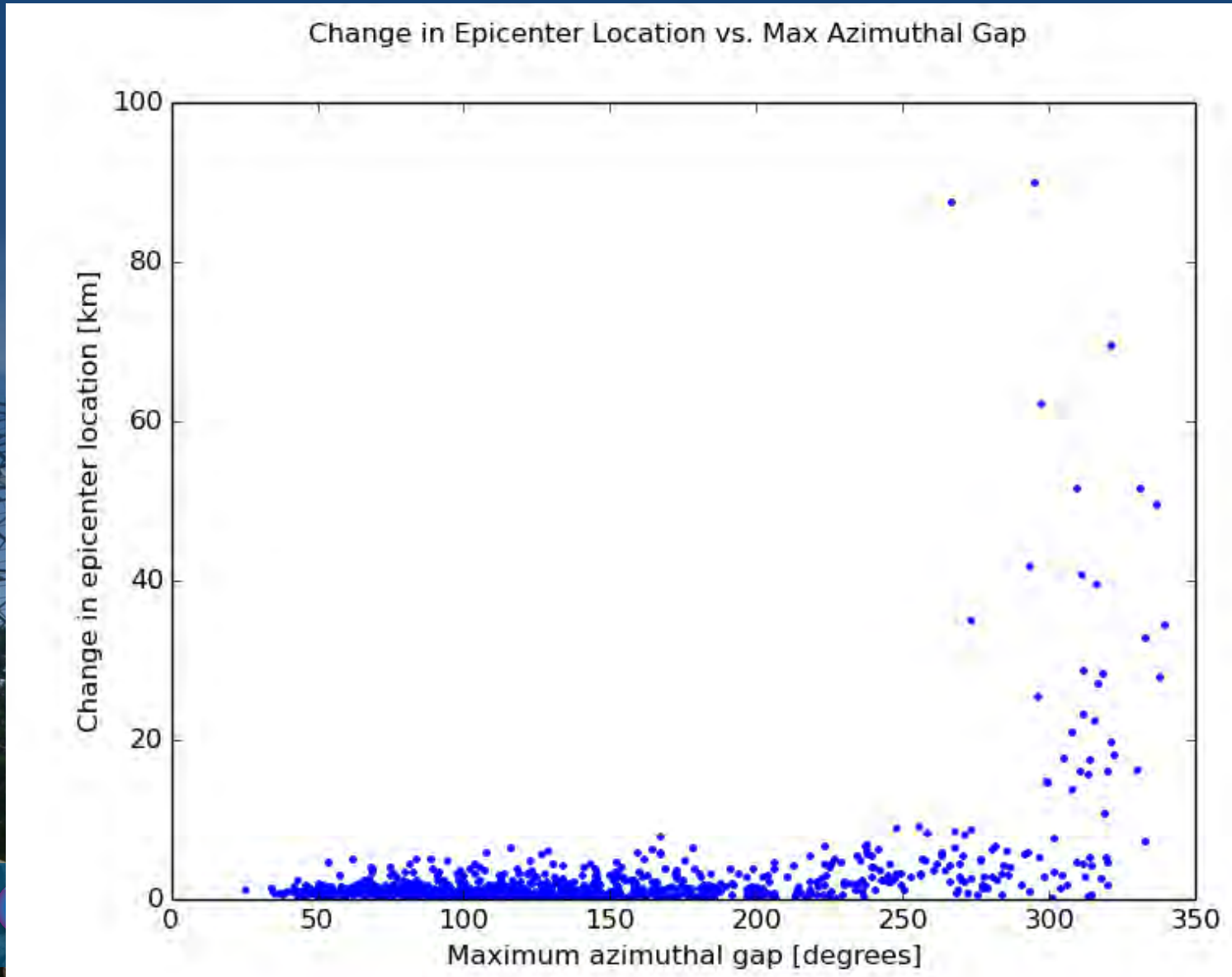


3D sdobs vs Max Az Gap

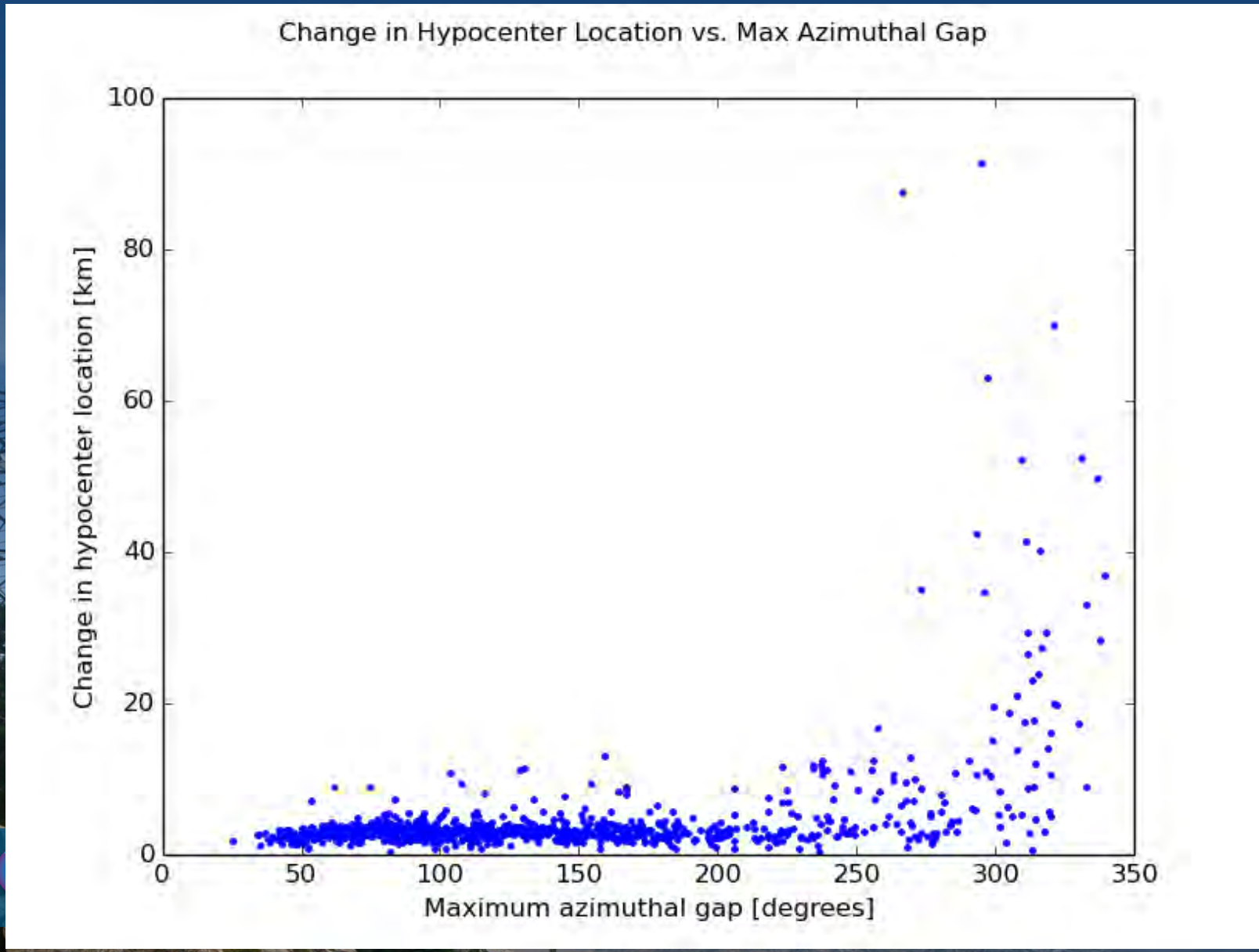




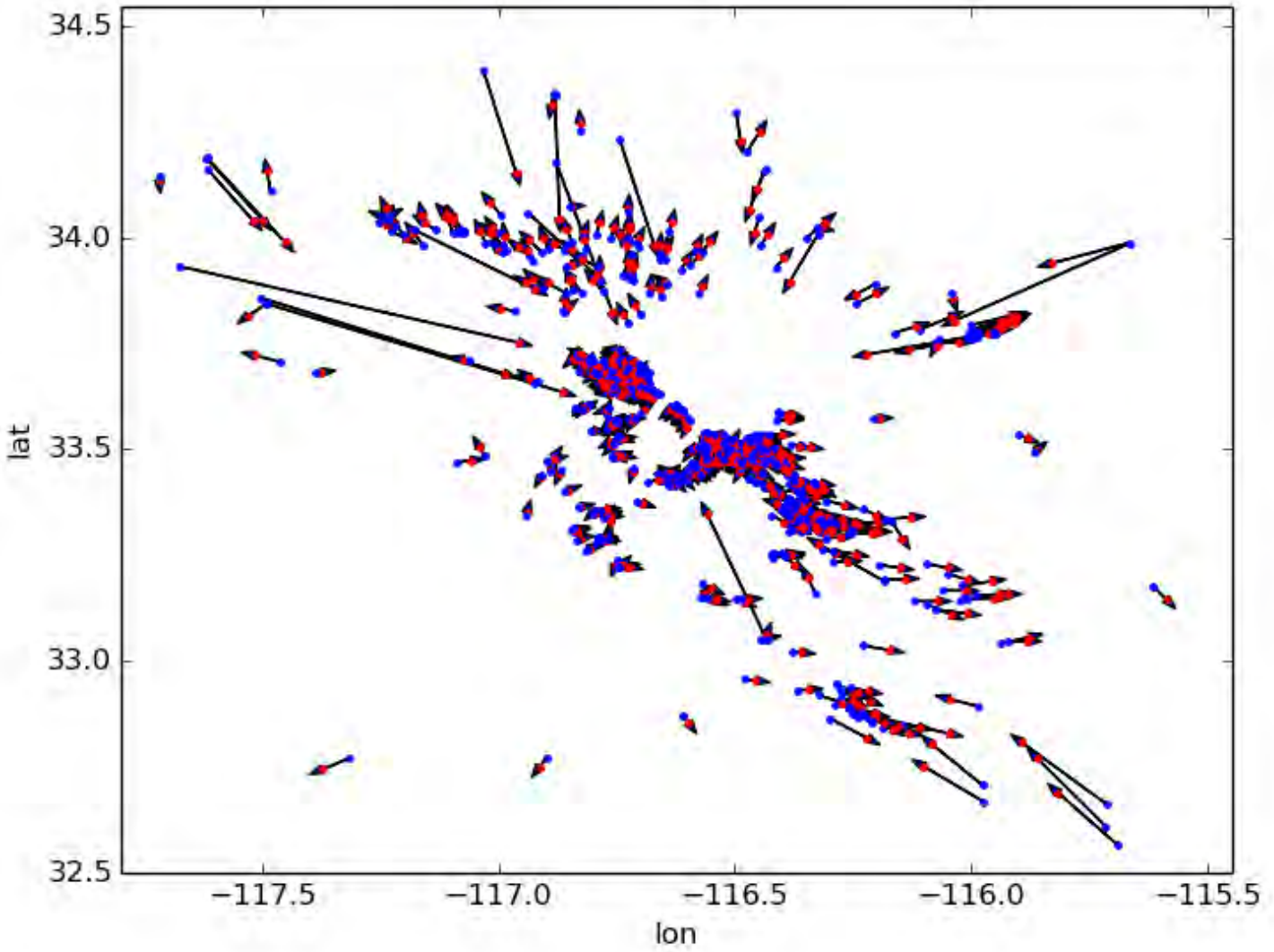
3D epicentral distance vs Max Az Gap



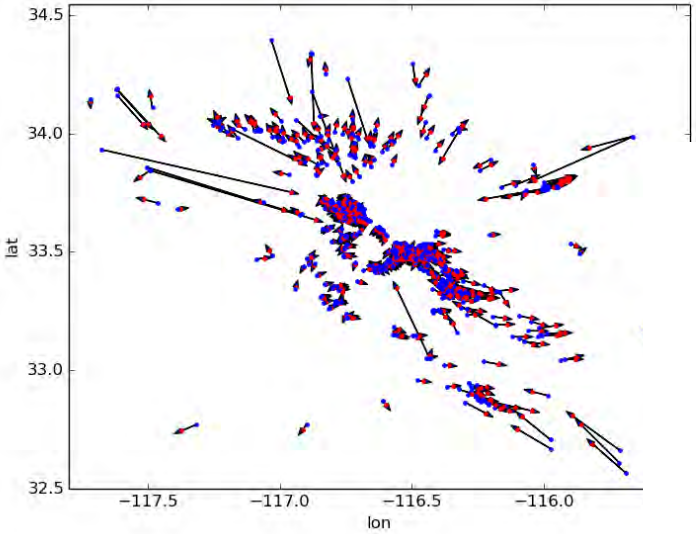
3D hypocentral distance vs Max Az Gap

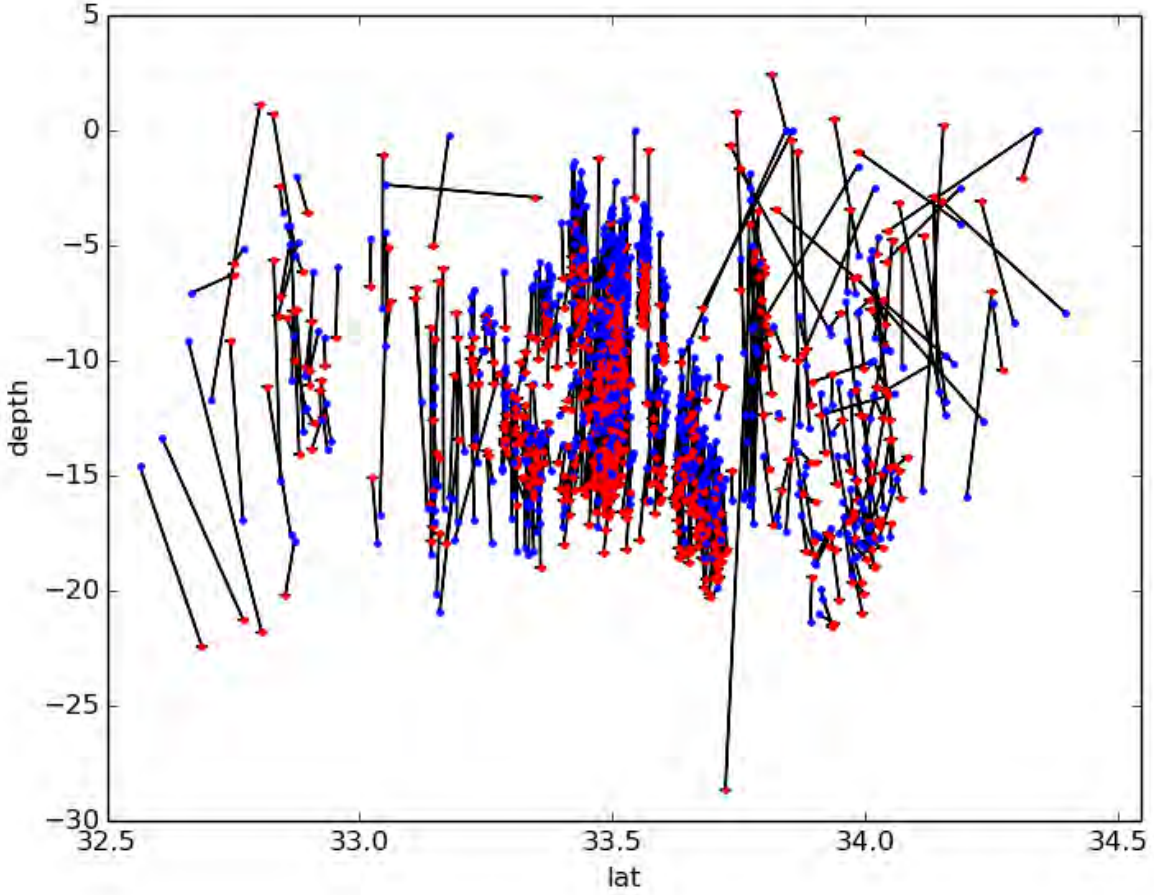


3d vs 1D all data

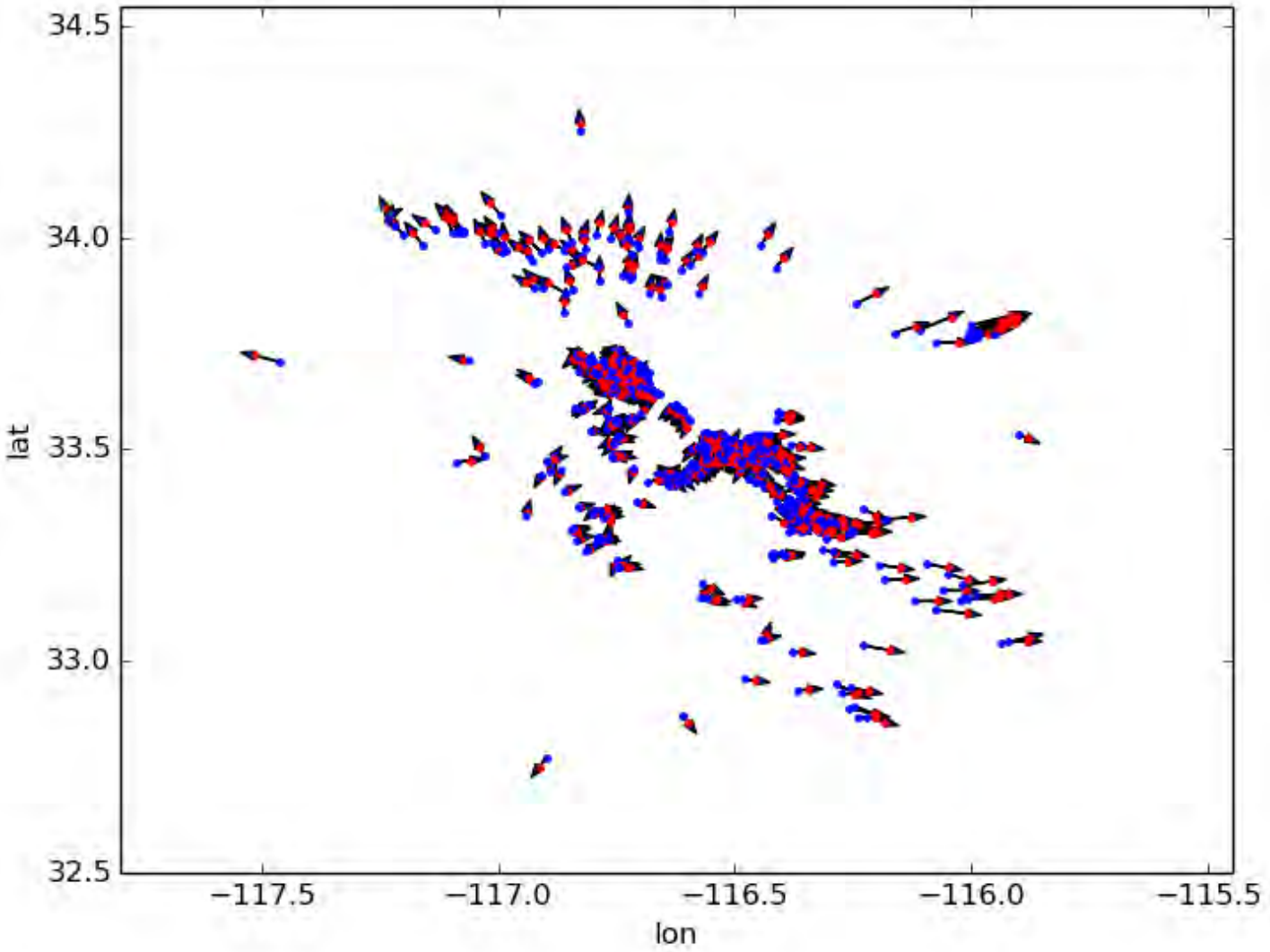


3d vs 1D all data

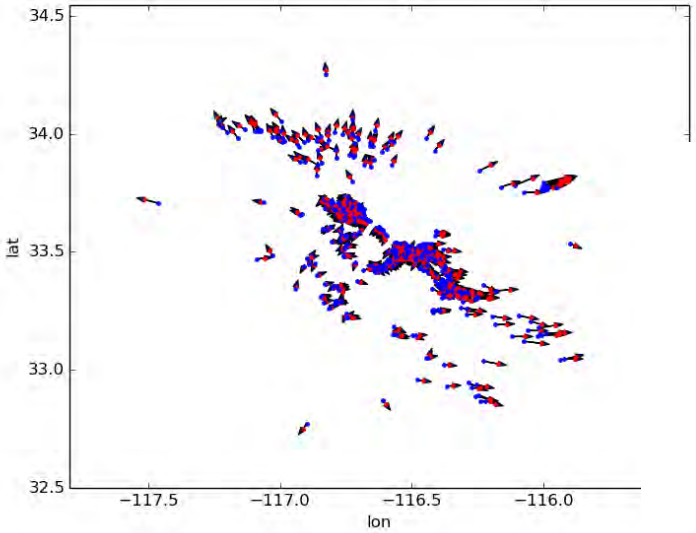


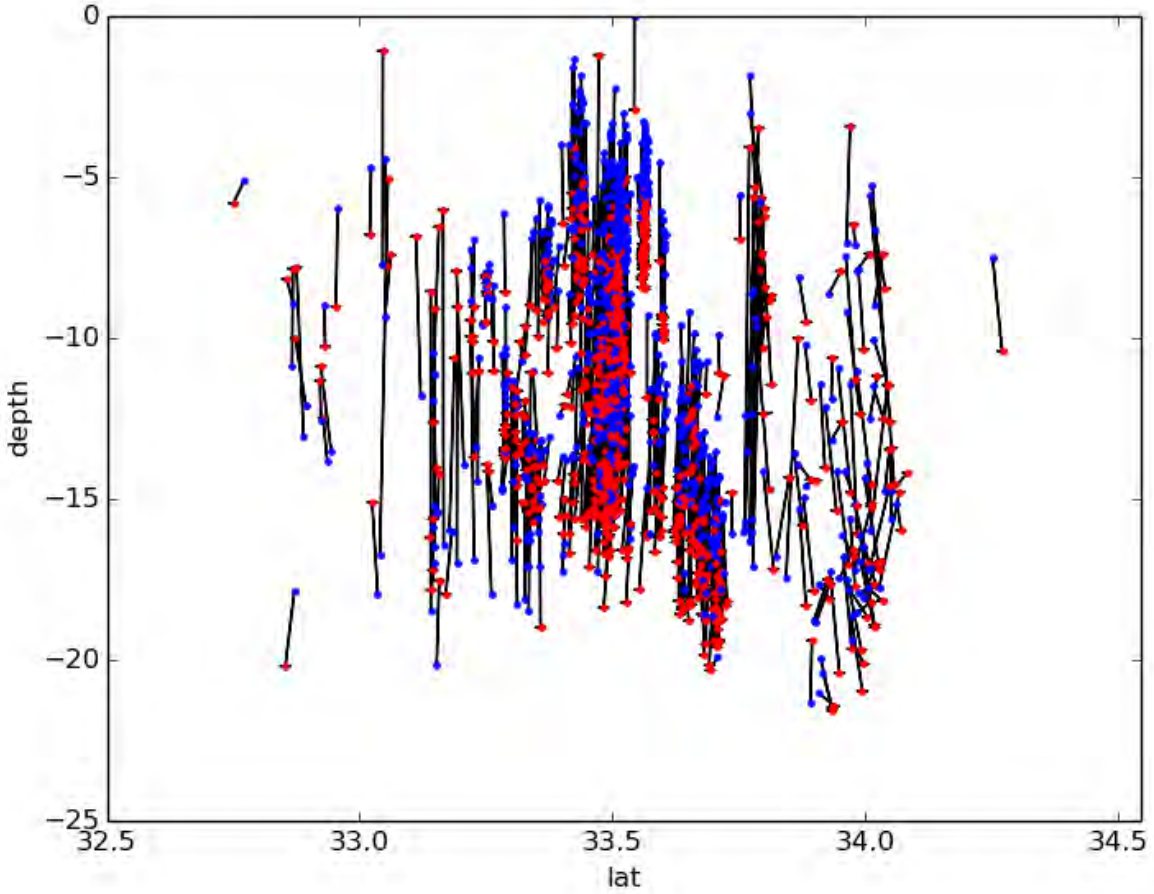


3d vs 1D Max Az Gap < 200°

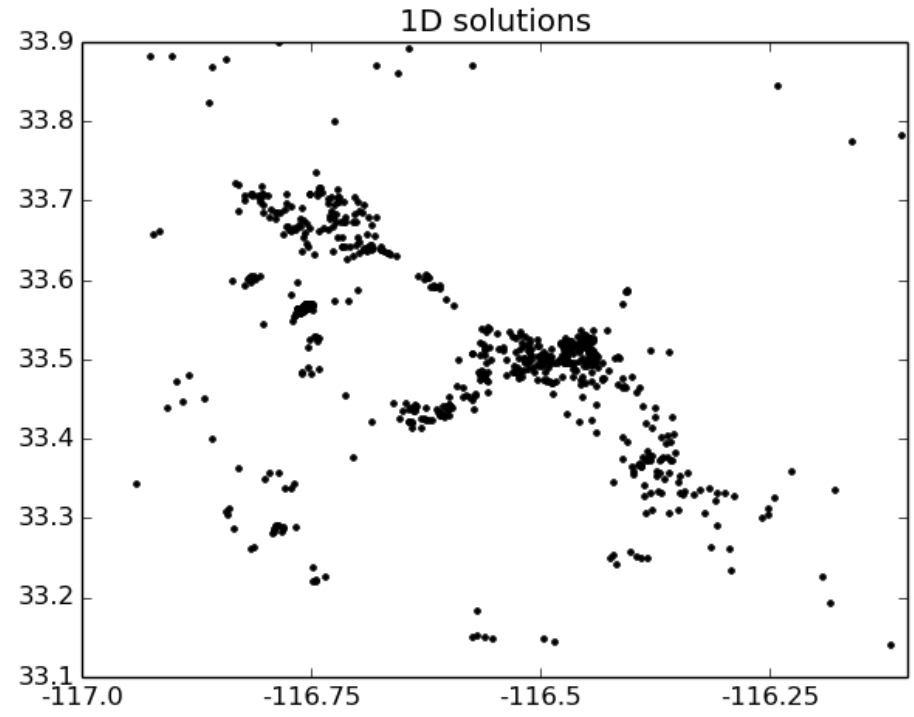


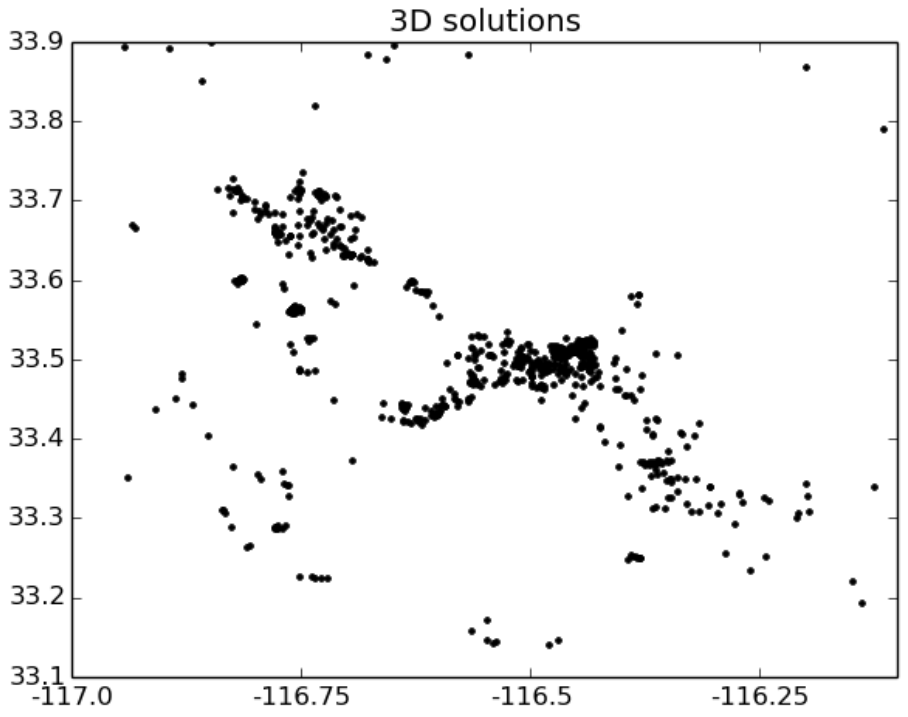
3d vs 1D Max Az Gap < 200°

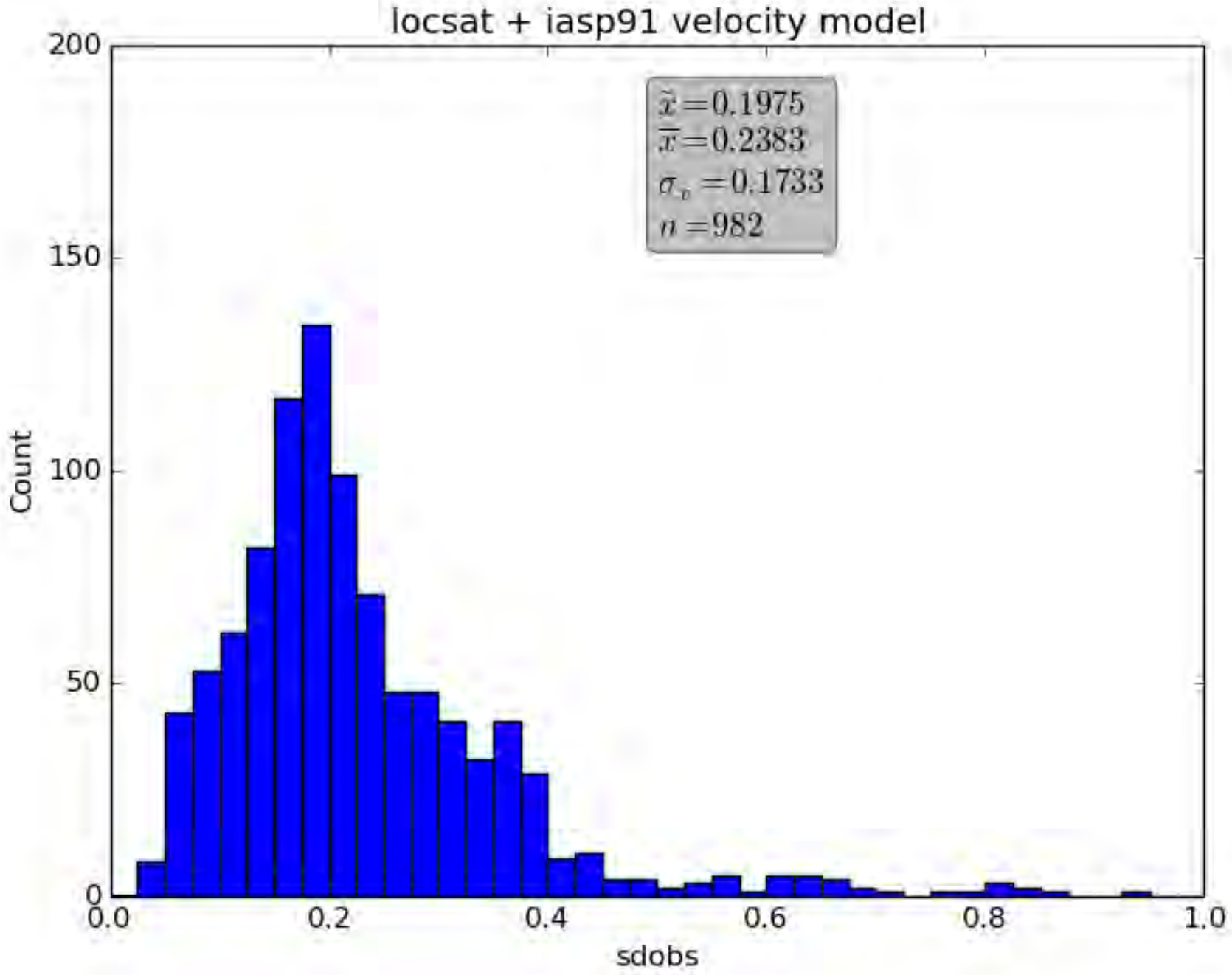


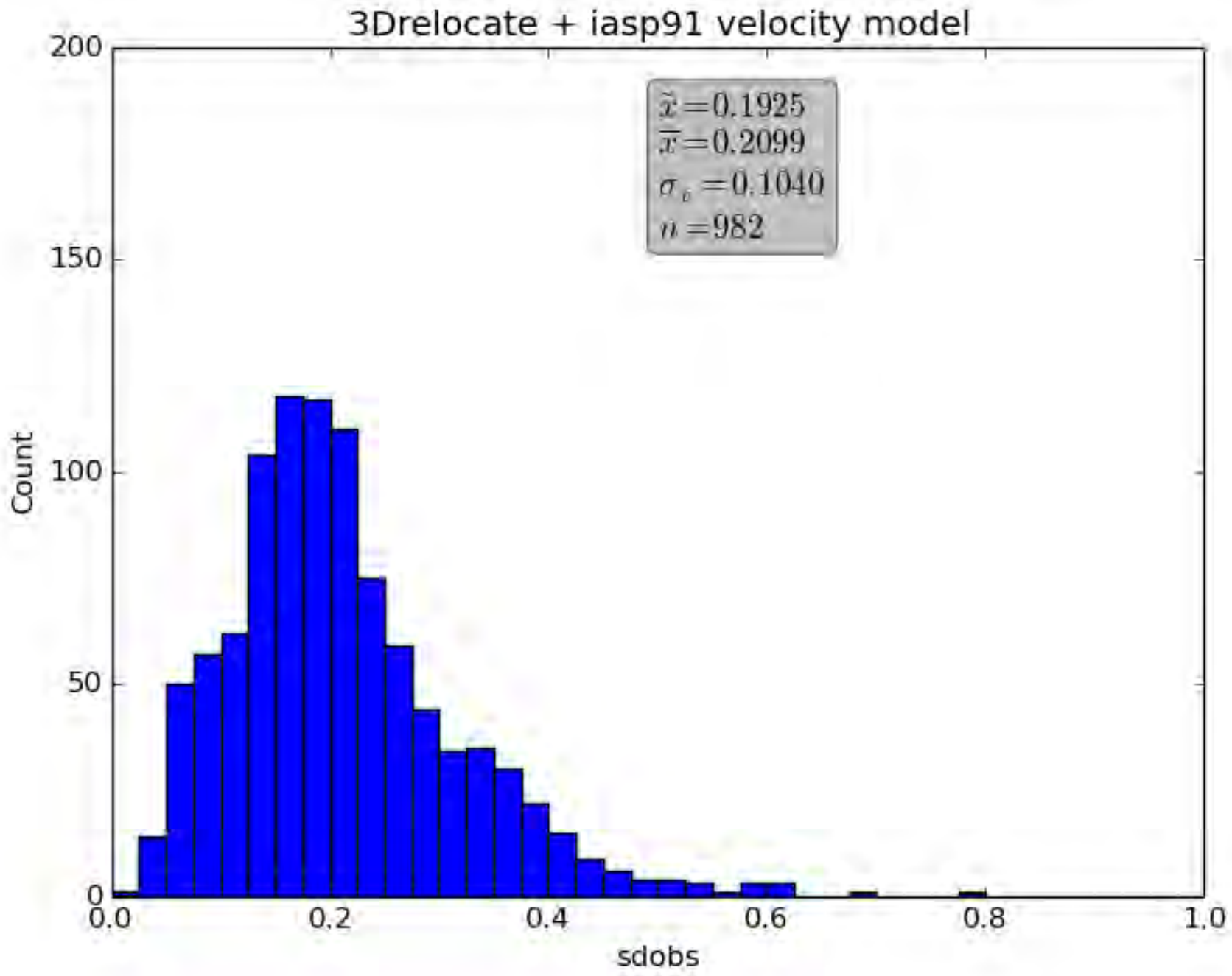


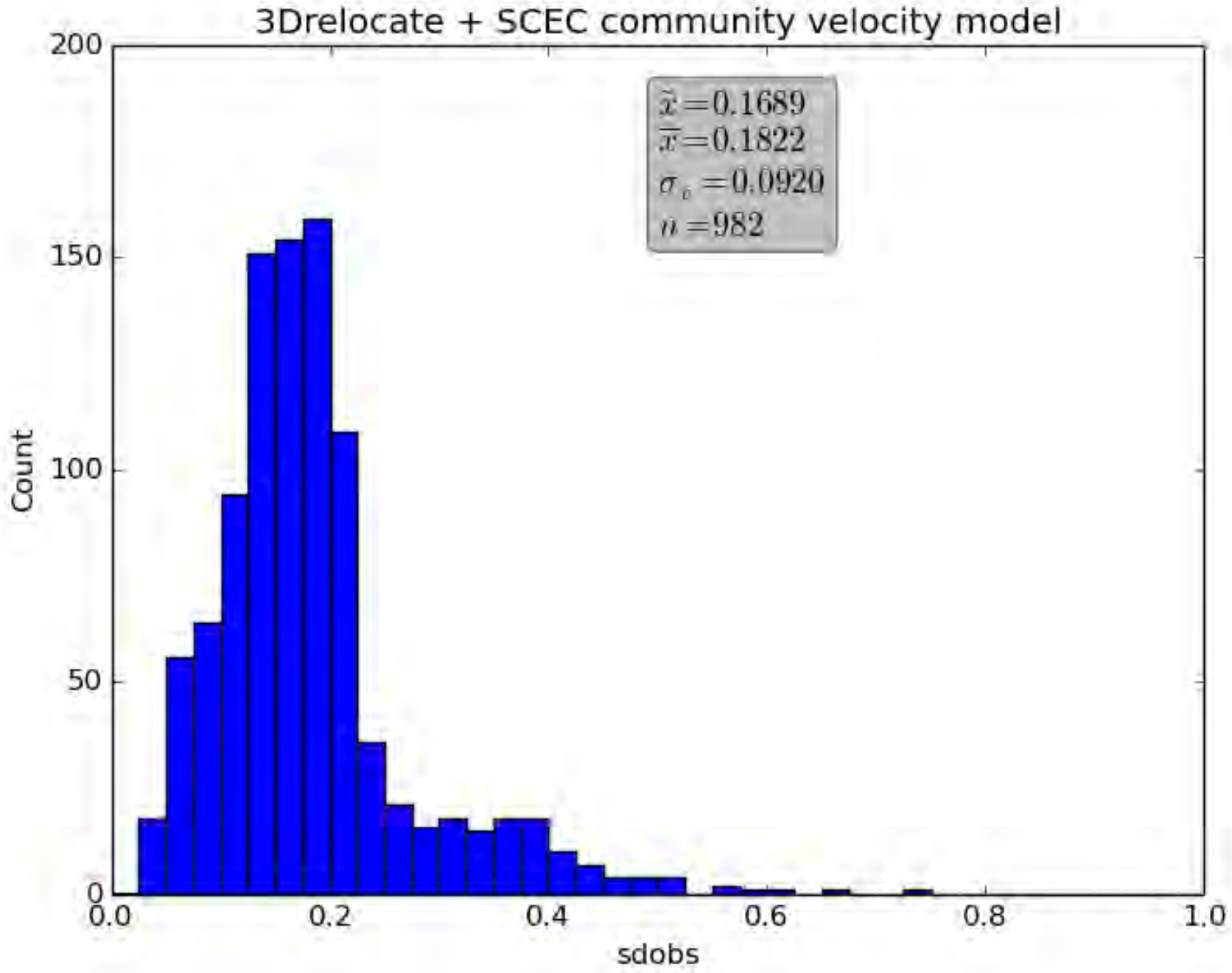
3d vs 1D

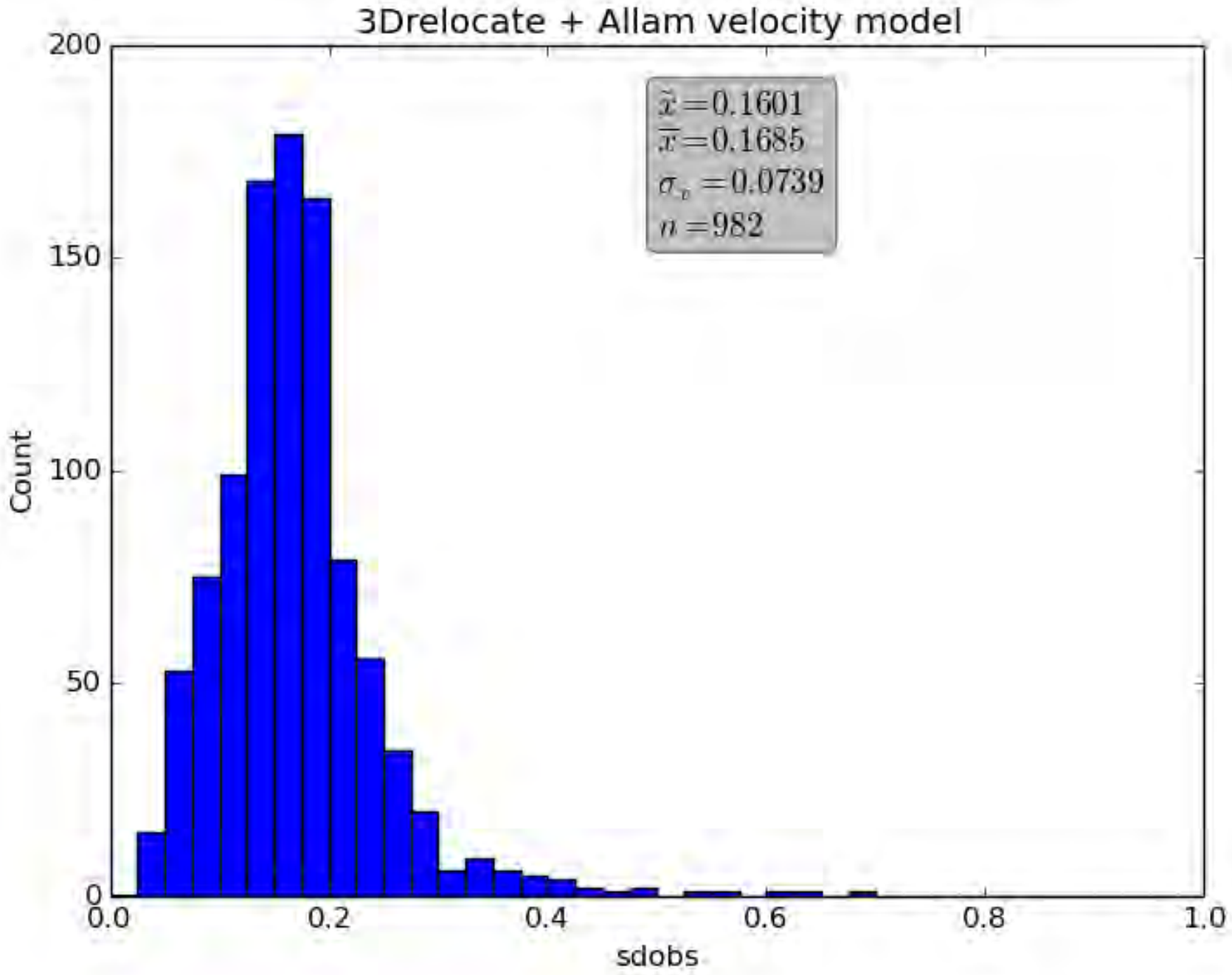

1D solutions
33.9
33.8
33.7
33.6
33.5
33.4
33.3
33.2
33.1
-117.0
-116.75
-116.5
-116.25


3D solutions
33.9
33.8
33.7
33.6
33.5
33.4
33.3
33.2
33.1
-117.0
-116.75
-116.5
-116.25

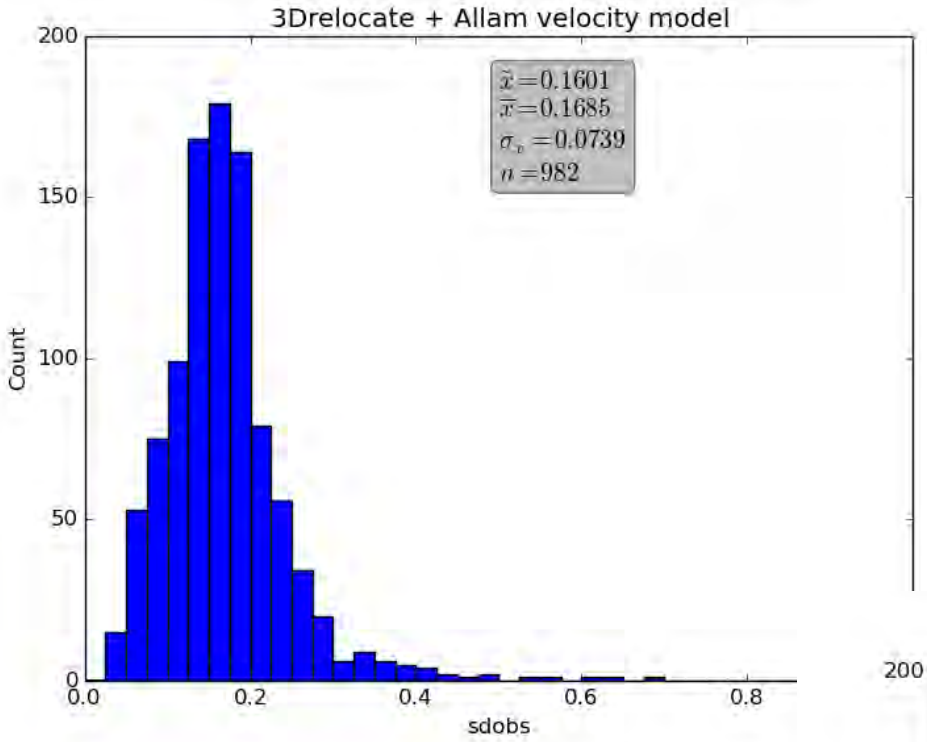

locsat + iasp91 velocity model
$\tilde{x}=0.1975$
$\overline{x}=0.2383$
$\sigma_x=0.1733$
$n=982$
Count
sdobs
0
50
100
150
200
0.0
0.2
0.4
0.6
0.8
1.0

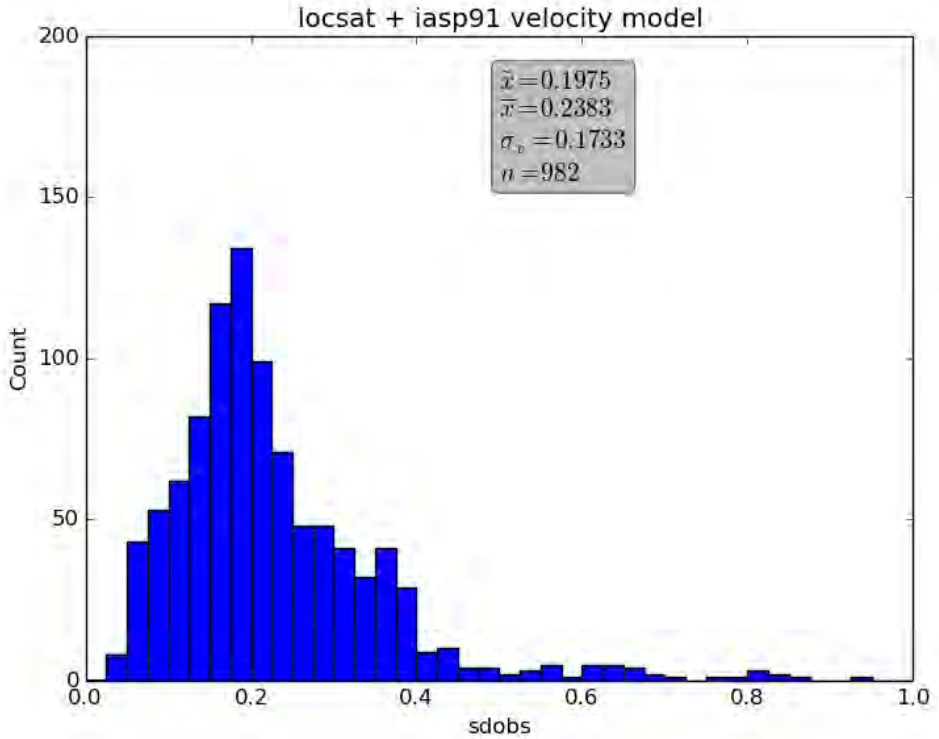

3Drelocate + iasp91 velocity model
$\tilde{x}=0.1925$
$\overline{x}=0.2099$
$\sigma_s=0.1040$
$n=982$
Count
sdobs
0
50
100
150
200
0.0
0.2
0.4
0.6
0.8
1.0


3Drelocate + SCEC community velocity model
$\tilde{x}=0.1689$
$\overline{x}=0.1822$
$\sigma_x=0.0920$
$n=982$
Count
sdobs
0
50
100
150
200
0.0
0.2
0.4
0.6
0.8
1.0


3Drelocate + Allam velocity model
$\tilde{x}=0.1601$
$\overline{x}=0.1685$
$\sigma_x=0.0739$
$n=982$
Count
sdobs
0
50
100
150
200
0.0
0.2
0.4
0.6
0.8
1.0

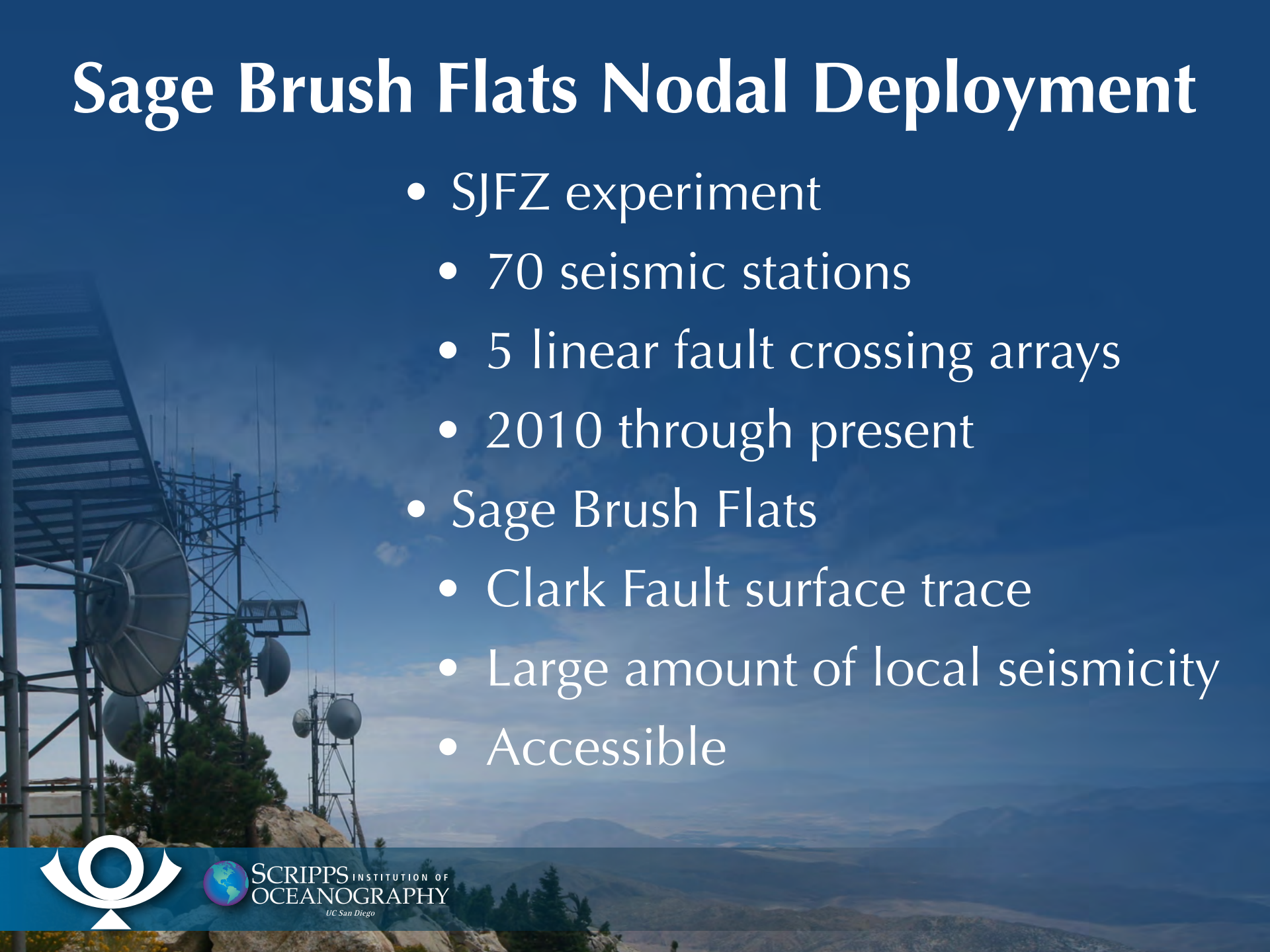
D


3Drelocate + Allam velocity model
$\tilde{x}=0.1601$
$\bar{x}=0.1685$
$\sigma_x=0.0739$
$n=982$
Count
sdobs
0
50
100
150
200
0.0
0.2
0.4
0.6
0.8

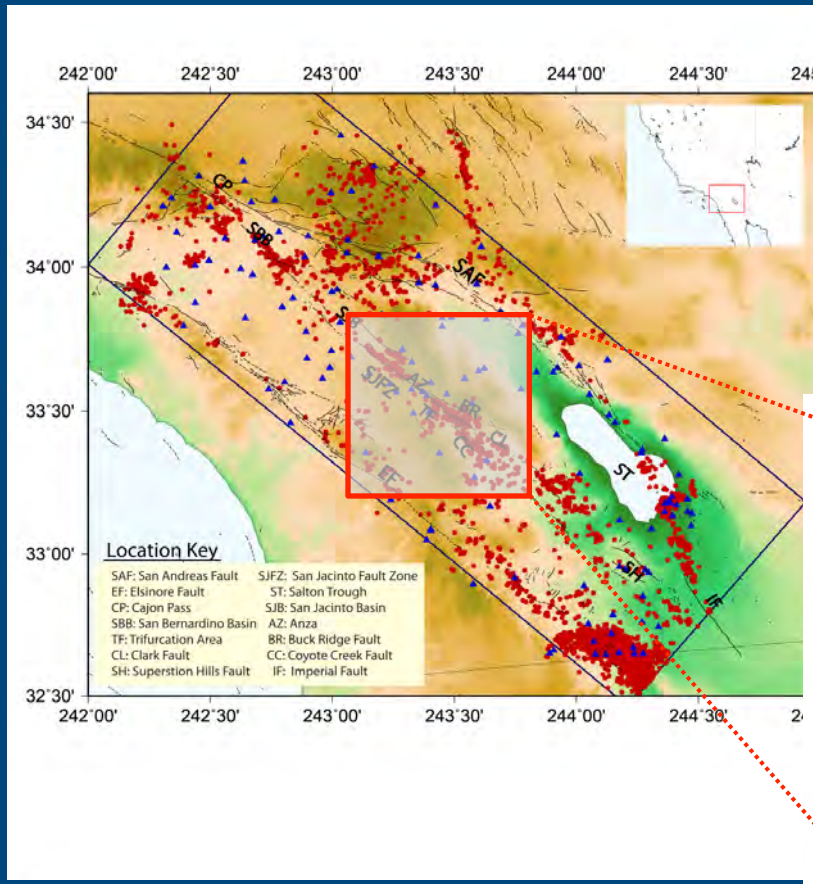

locsat + iasp91 velocity model
$\tilde{x}=0.1975$
$\bar{x}=0.2383$
$\sigma_x=0.1733$
$n=982$
Count
sdobs
0
50
100
150
200
0.0
0.2
0.4
0.6
0.8
1.0

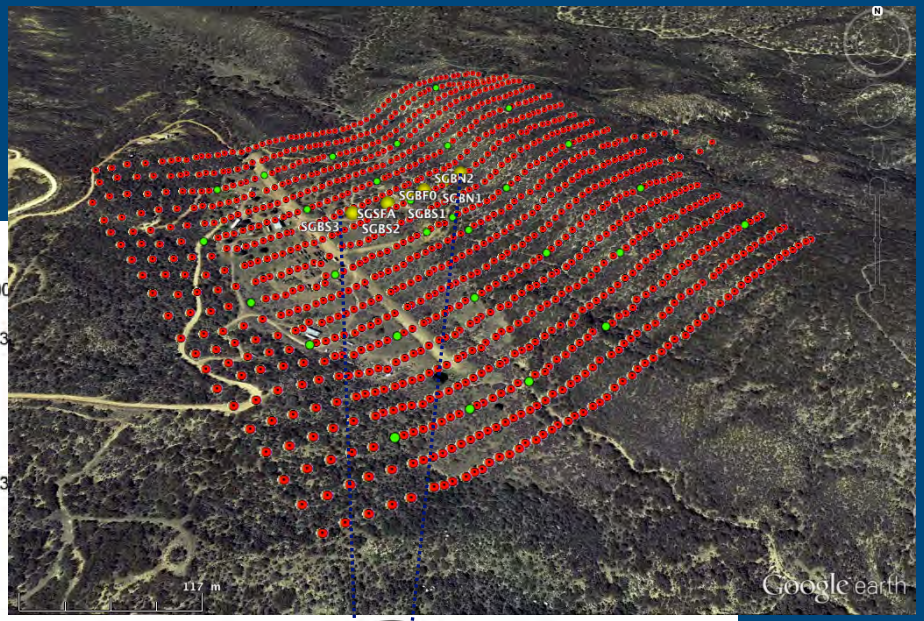
Sage Brush Flats Nodal Deployment

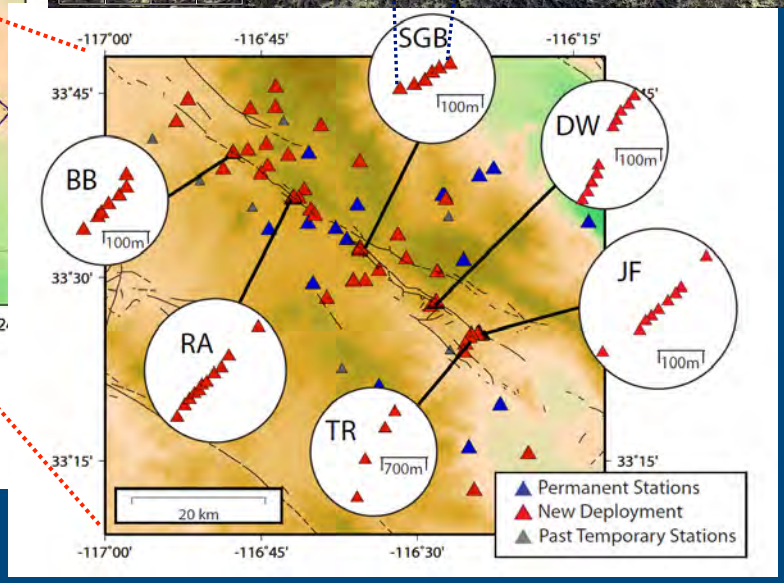
- SJFZ experiment
  - 70 seismic stations
  - 5 linear fault crossing arrays
  - 2010 through present
- Sage Brush Flats
  - Clark Fault surface trace
  - Large amount of local seismicity
  - Accessible



San Jacinto Fault Zone Dense Array



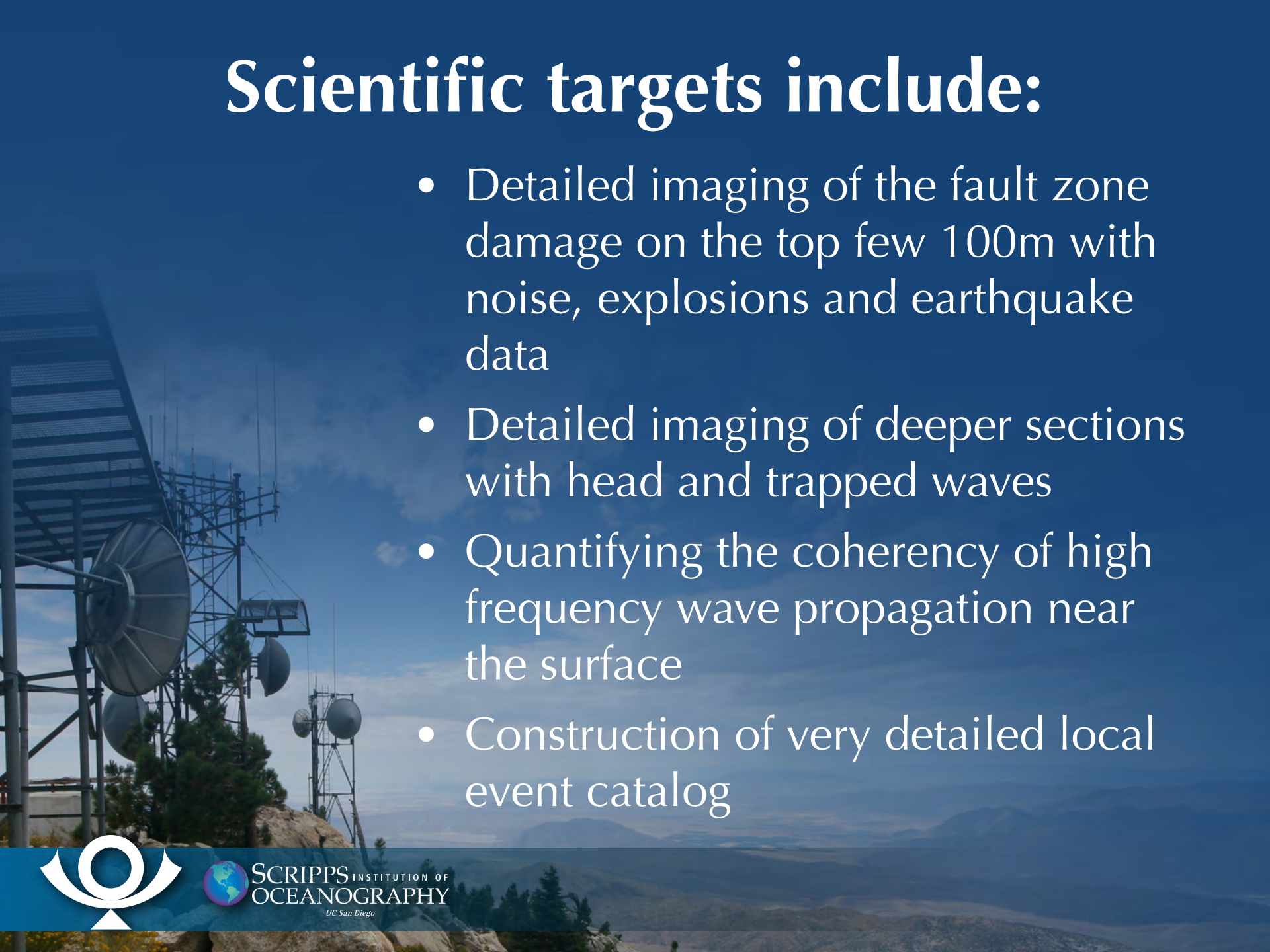




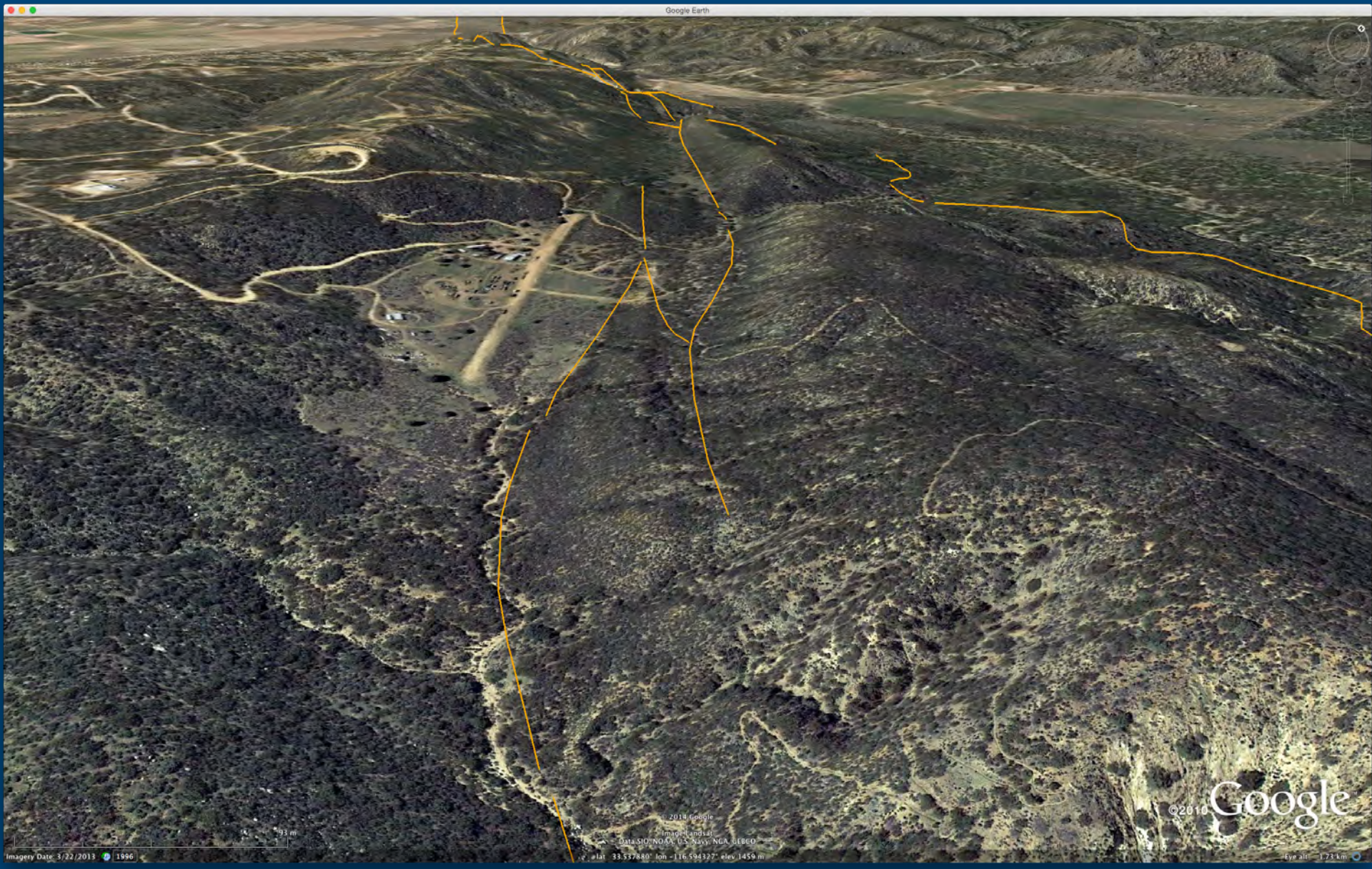
(Left) Regional seismic stations (blue triangles) and seismicity (red circles) of plate-boundary region in southern California. (Bottom right) Over 70 additional (red triangles) instruments and dense linear arrays across and around the SJFZ. (Top right) Highly-dense rectangular array with 1108 vertical-component nodes. The green dots are locations of "Betsy" gun shots.

Scientific targets include:

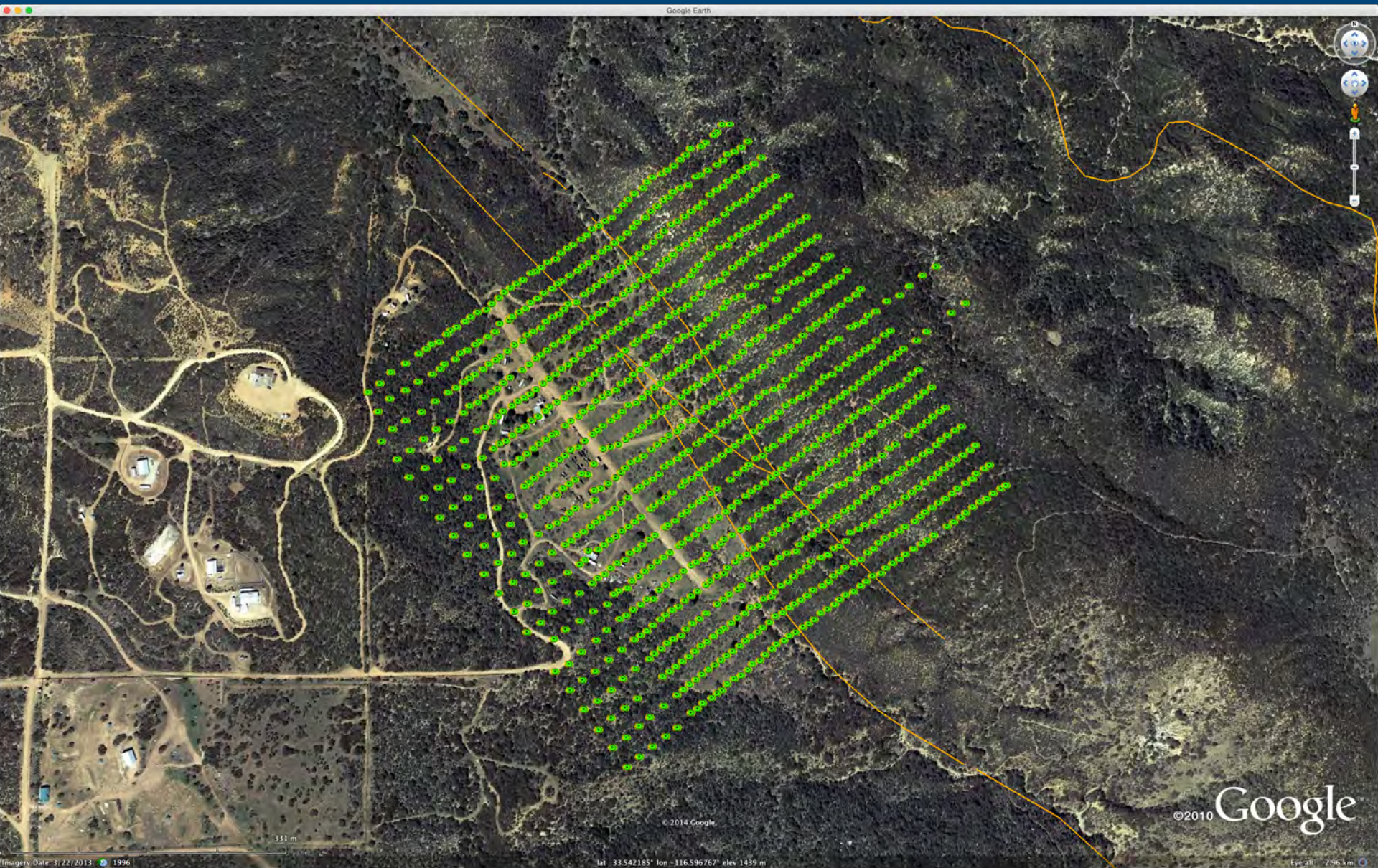
- Detailed imaging of the fault zone damage on the top few 100m with noise, explosions and earthquake data
- Detailed imaging of deeper sections with head and trapped waves
- Quantifying the coherency of high frequency wave propagation near the surface
- Construction of very detailed local event catalog



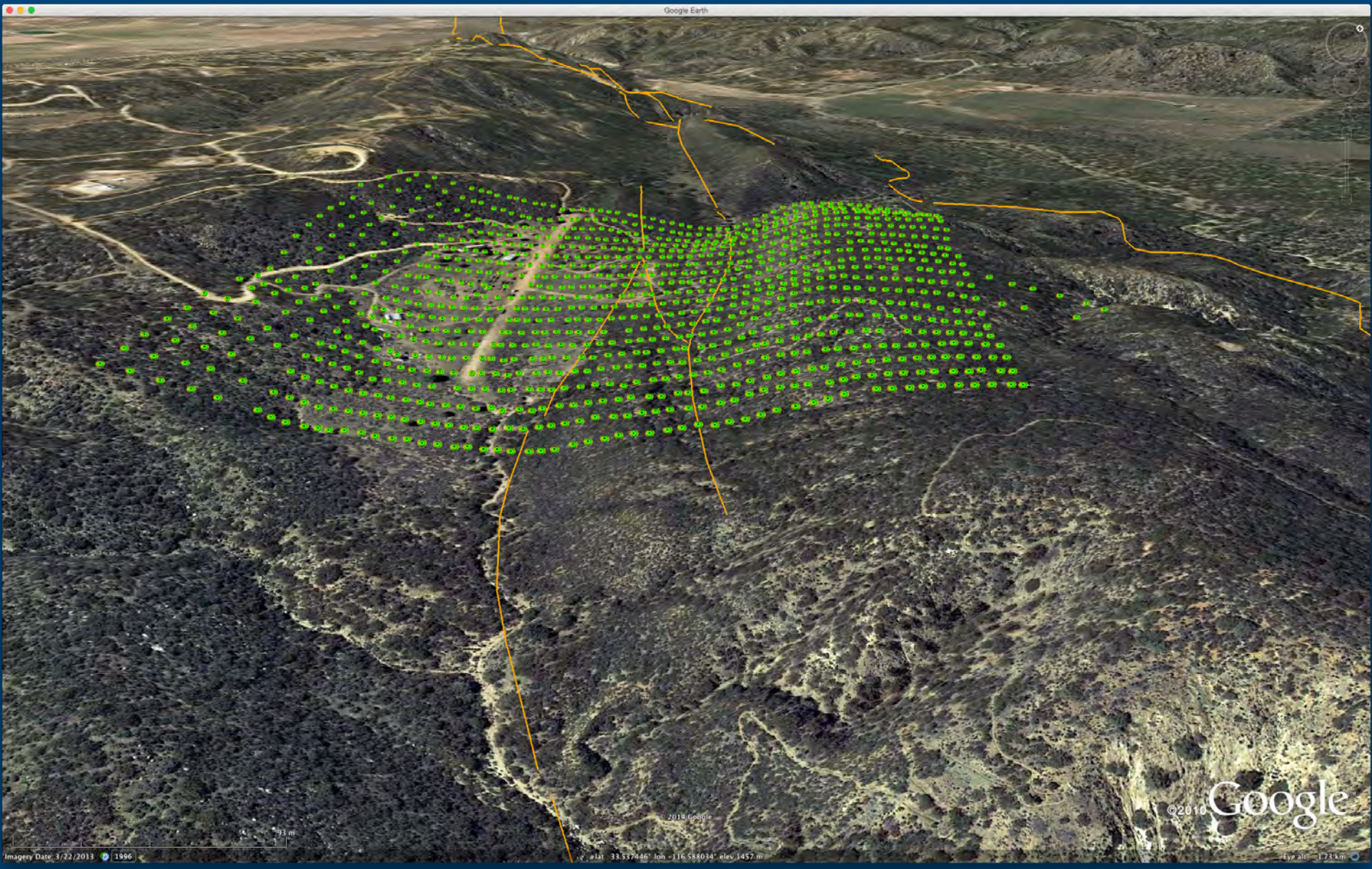
Sage Brush Flats - Clark Fault

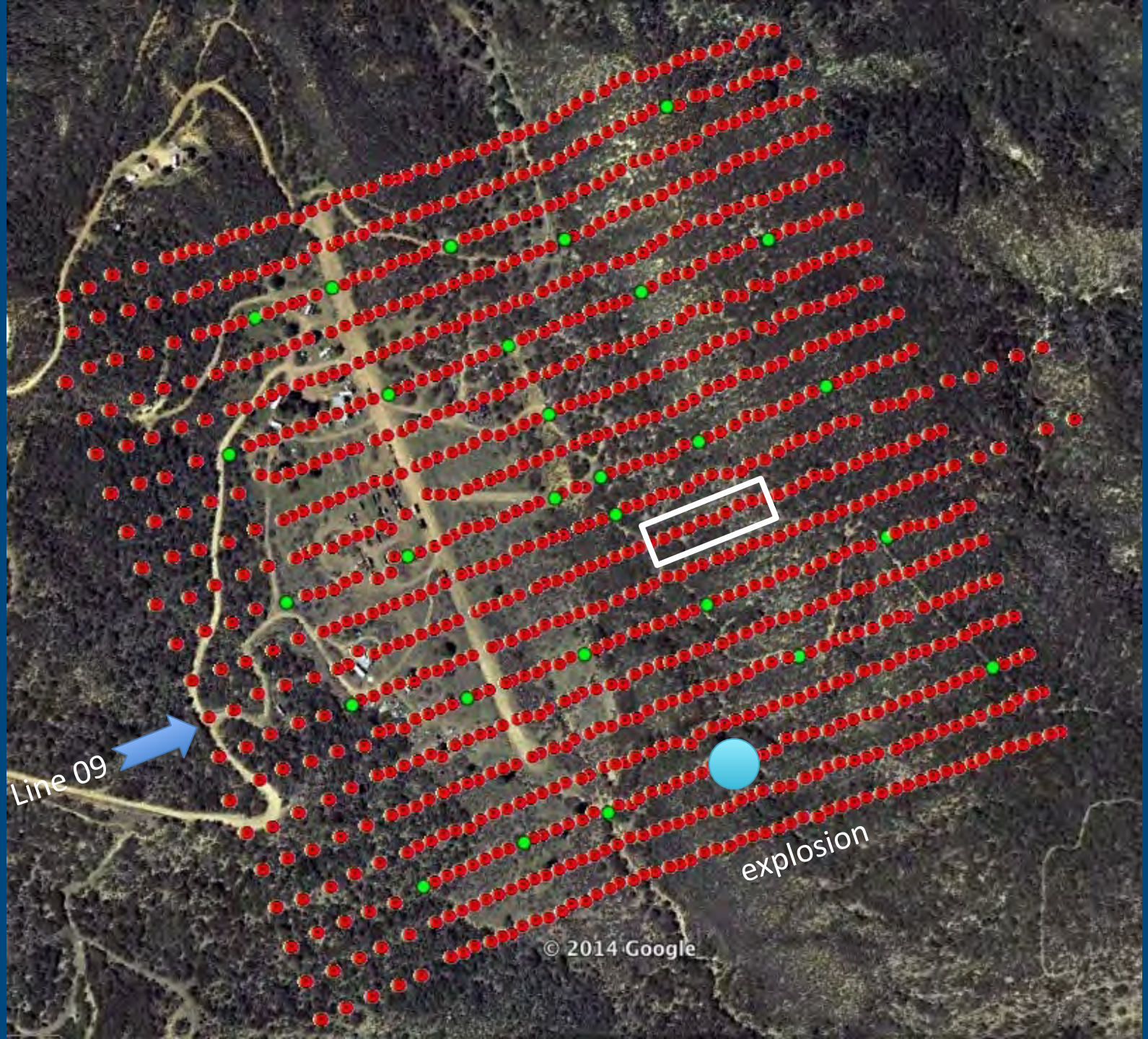


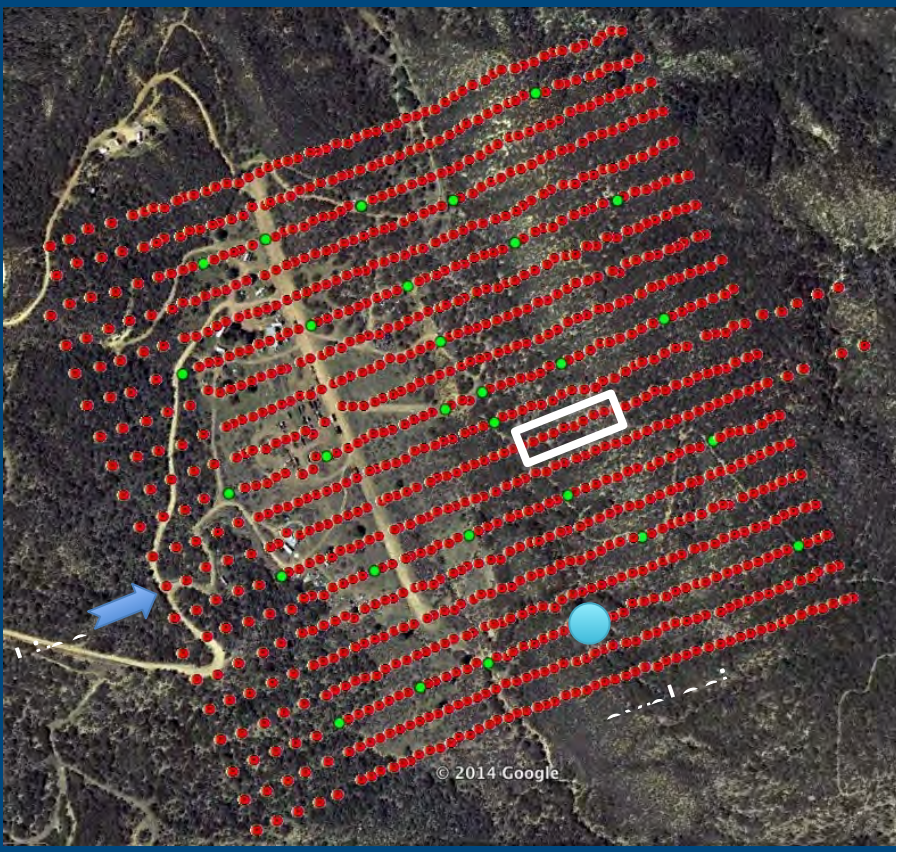
Sage Brush Flats - Nodal Array



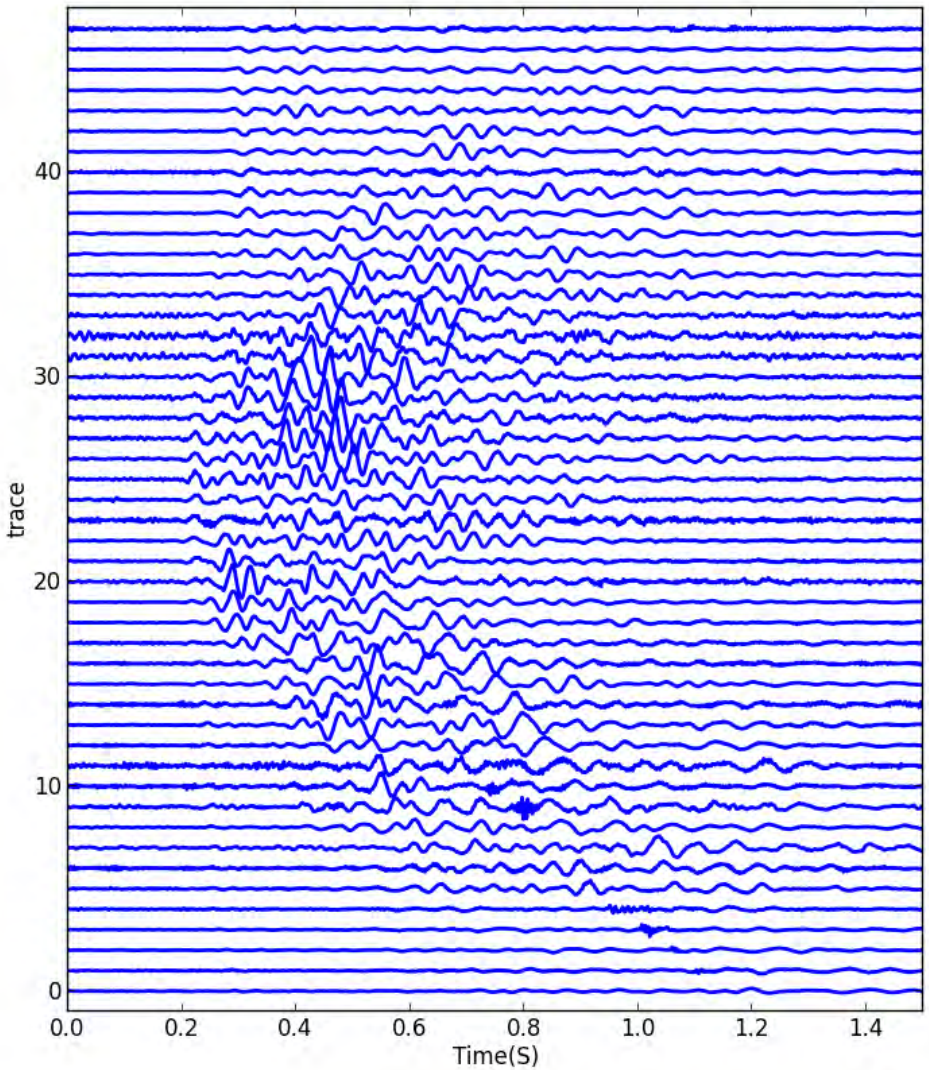
Sage Brush Flats - Oblique View

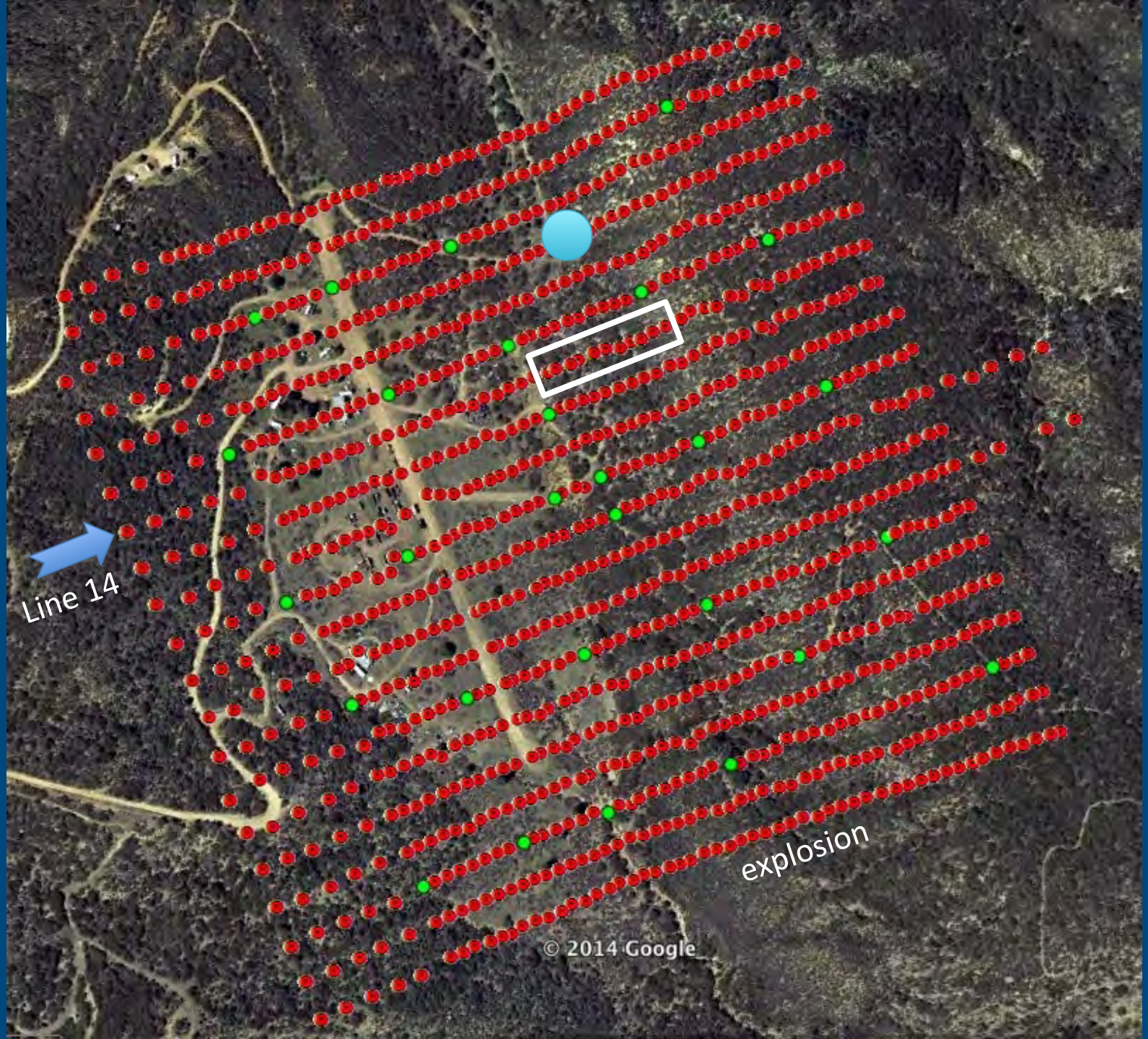


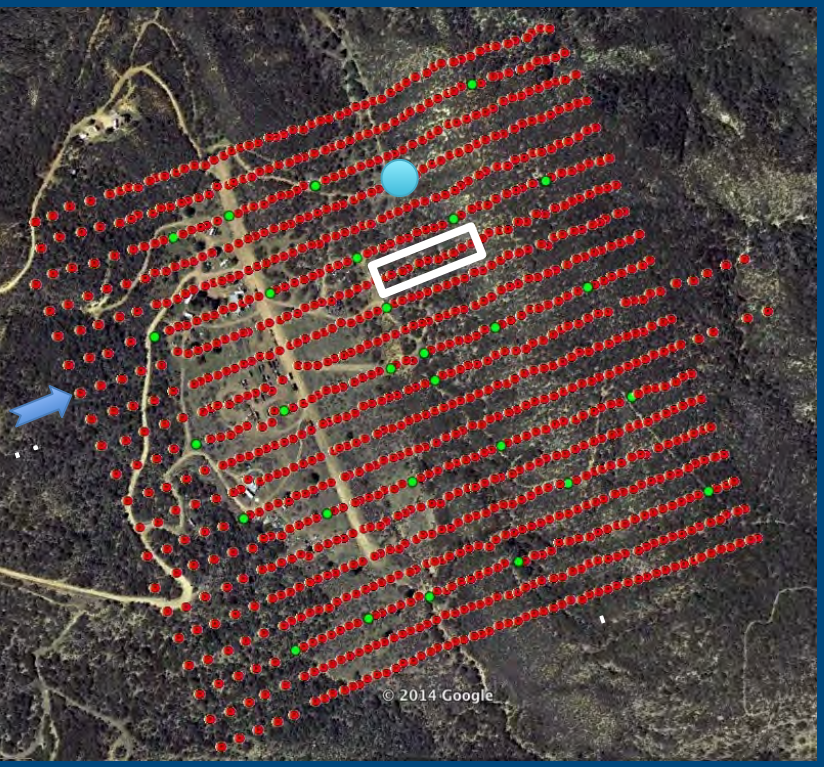

Line 09
explosion
© 2014 Google



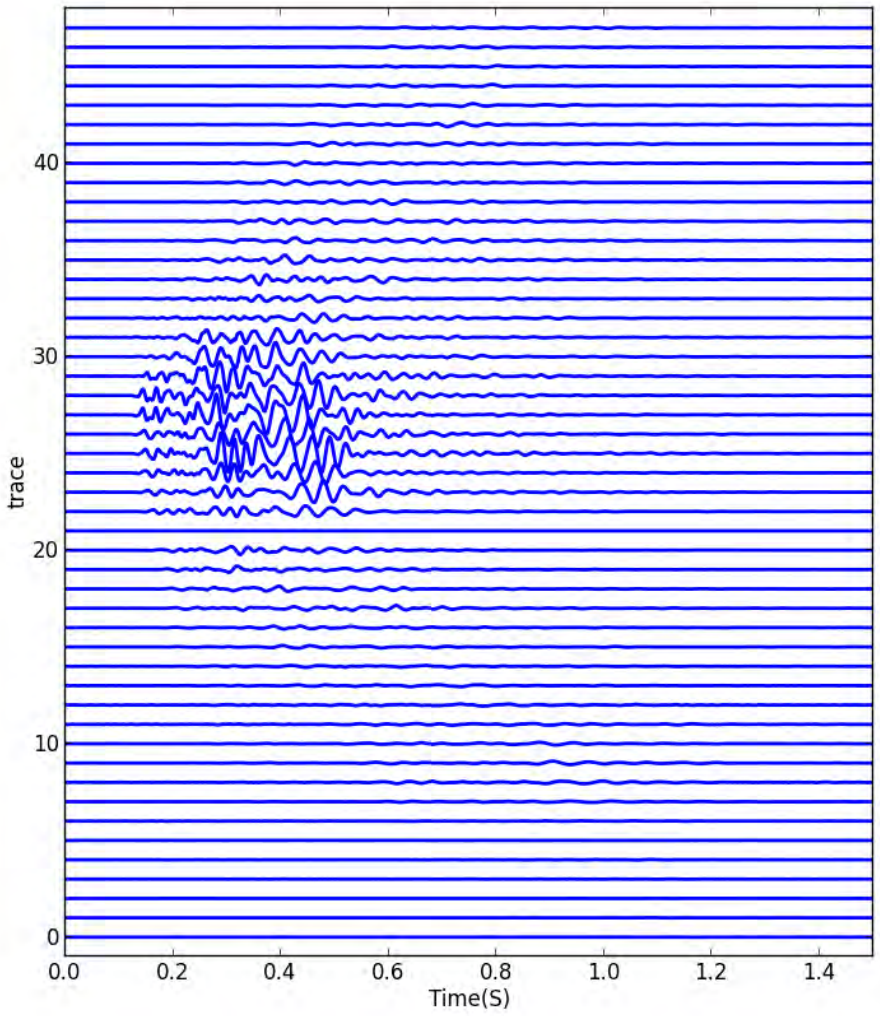
Potential trapped waves

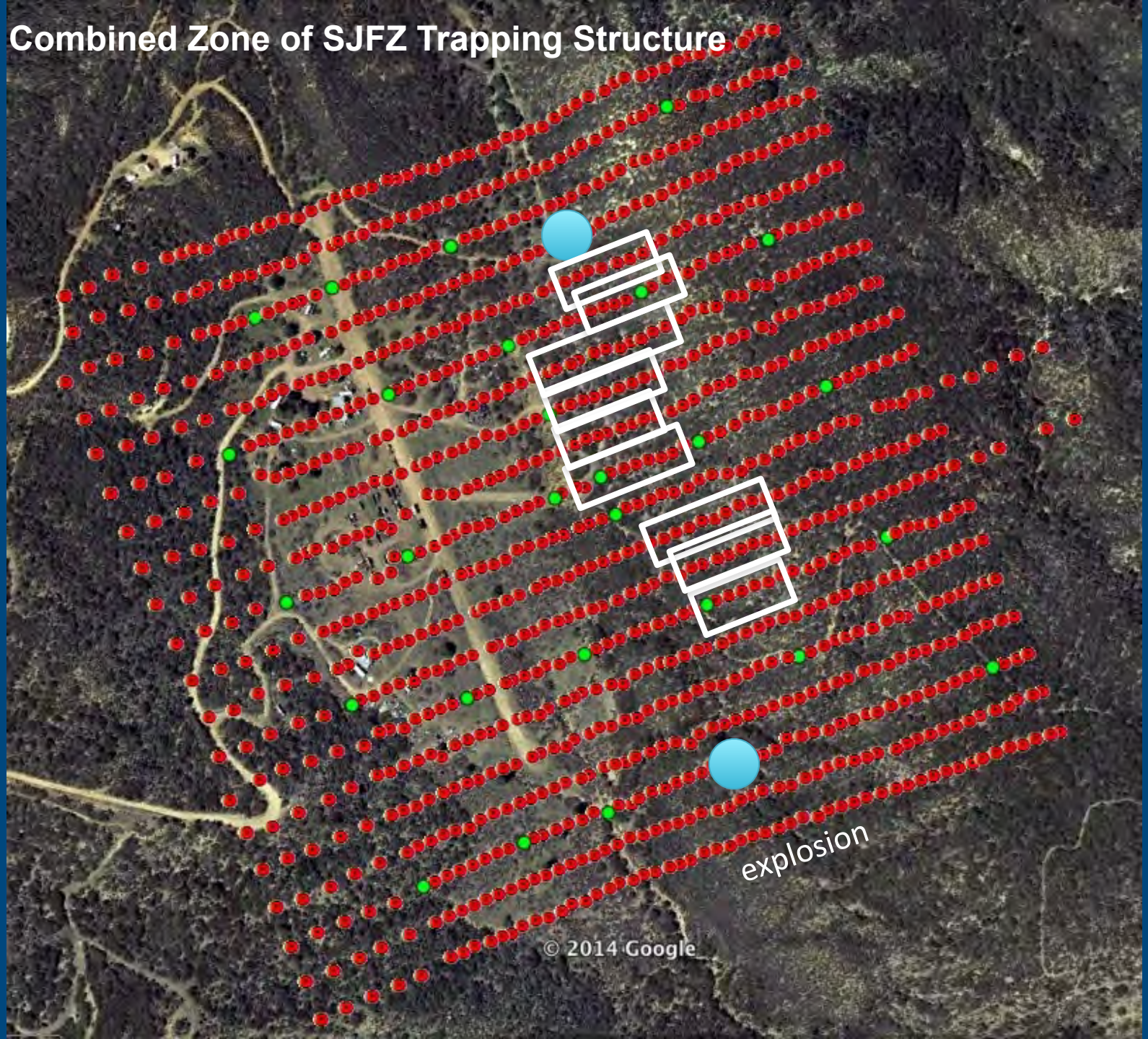



Line 14
explosion
© 2014 Google

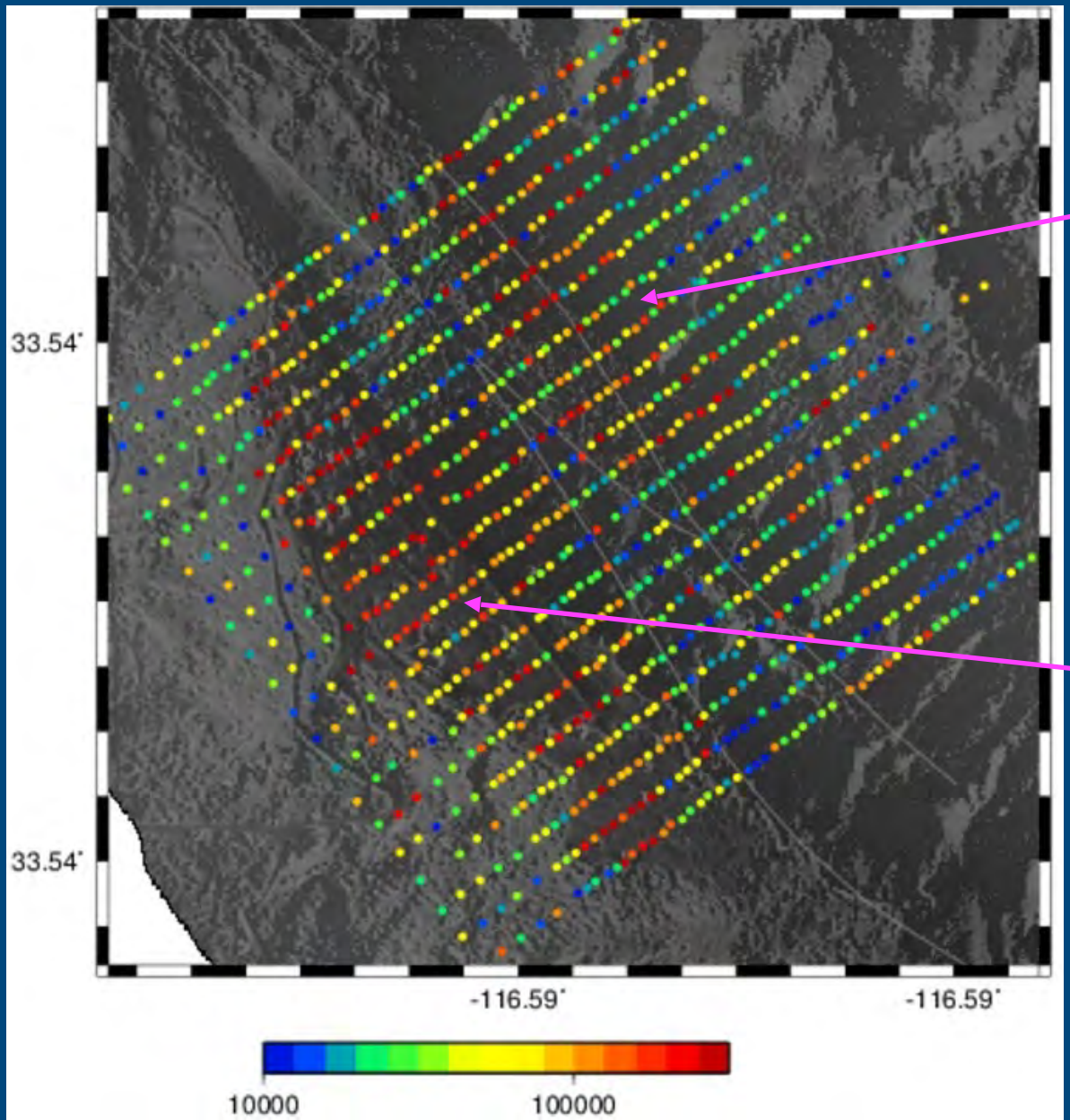


Potential trapped waves




Combined Zone of SJFZ Trapping Structure
explosion
© 2014 Google

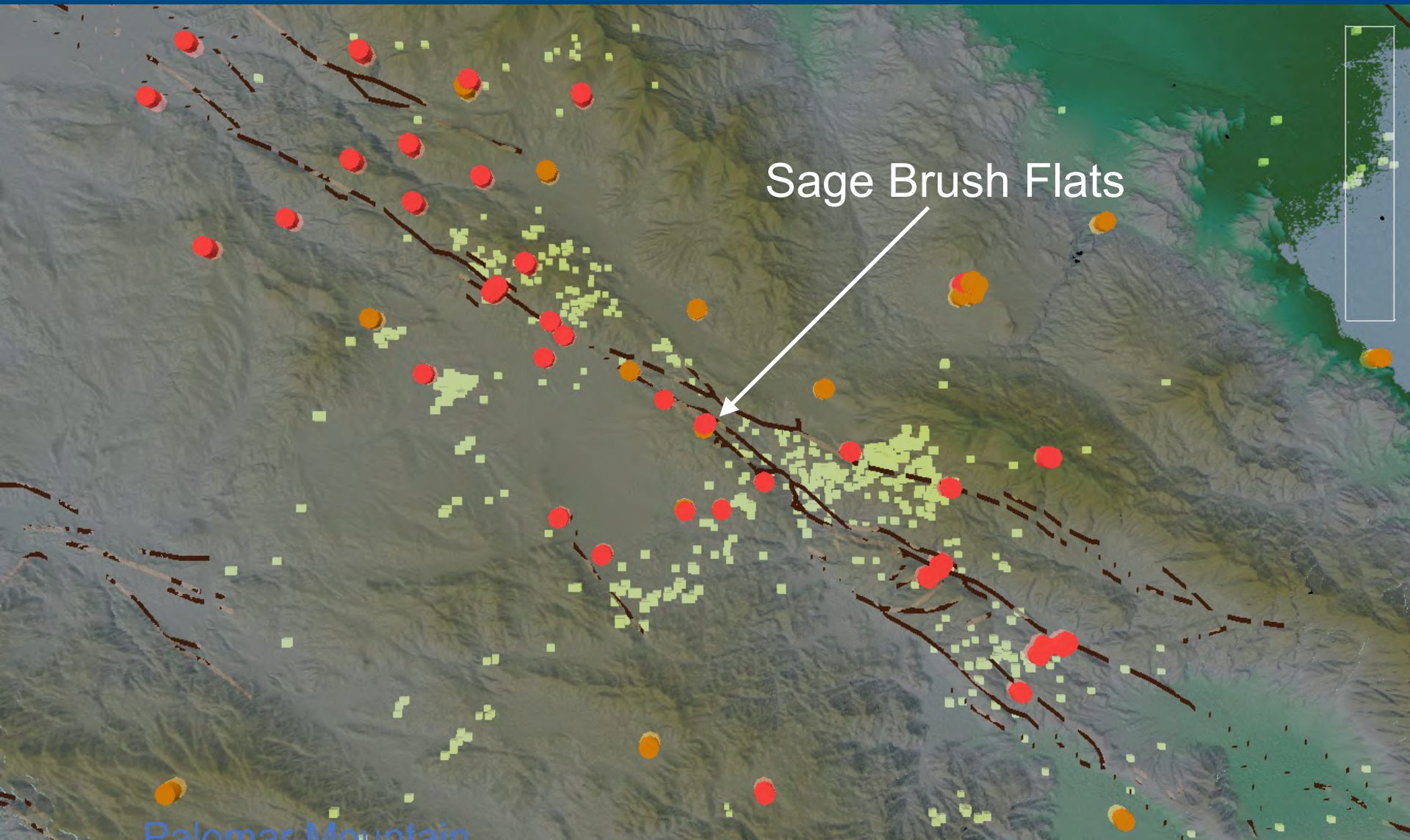
Median power (amplitude squared) recorded for duration of experiment



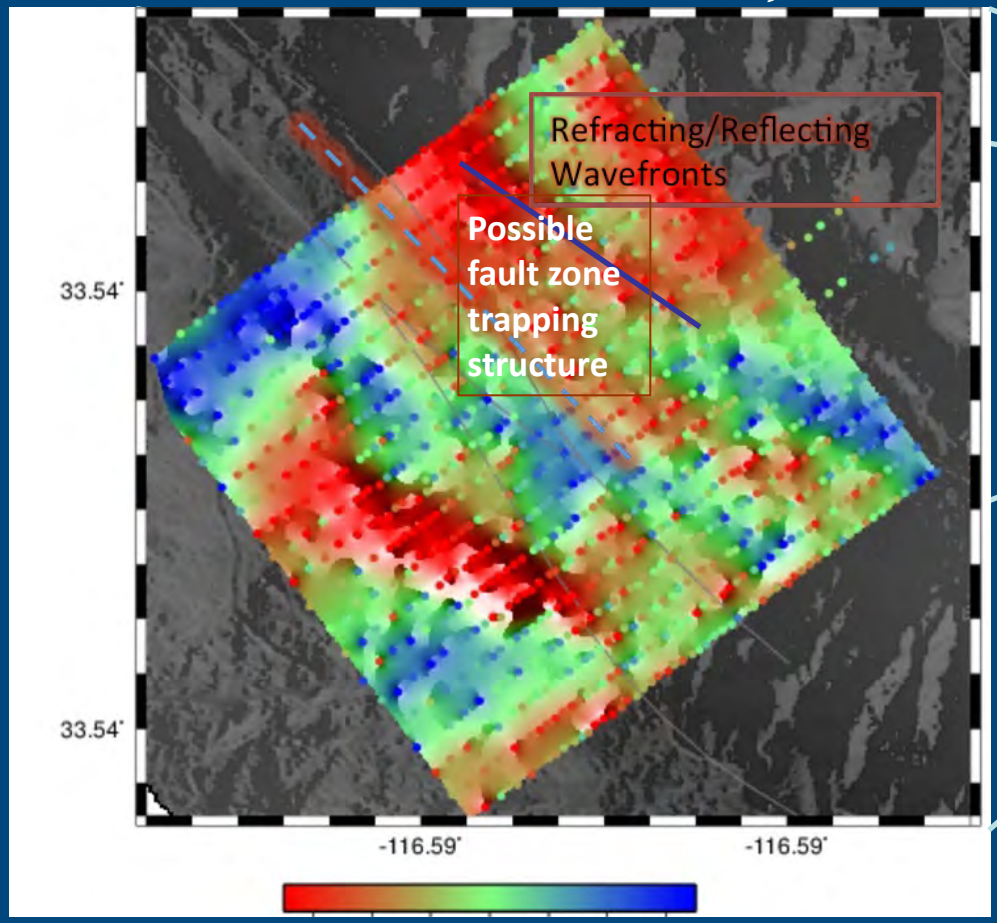
This zone of amplified motion is associated with possible trapping structure (see next slides)

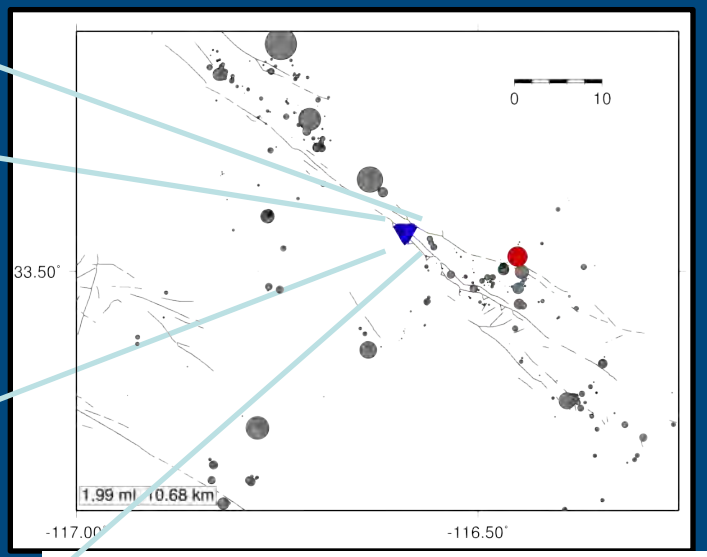
This zone is associated with landowners home and machines (cultural noise), plus possible small sedimentary basin

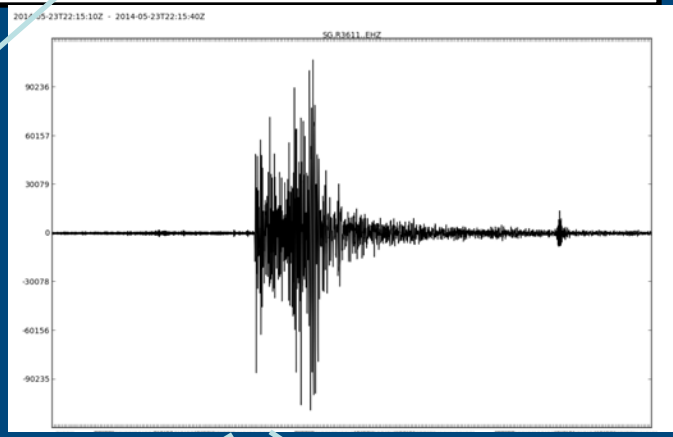
Seismicity during Nodal Experiment

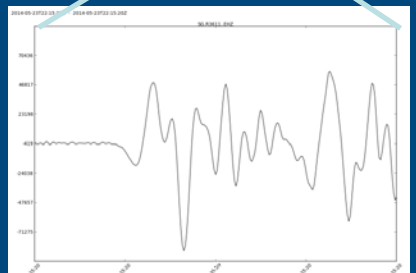


M2 Event, Distance:10.68 km

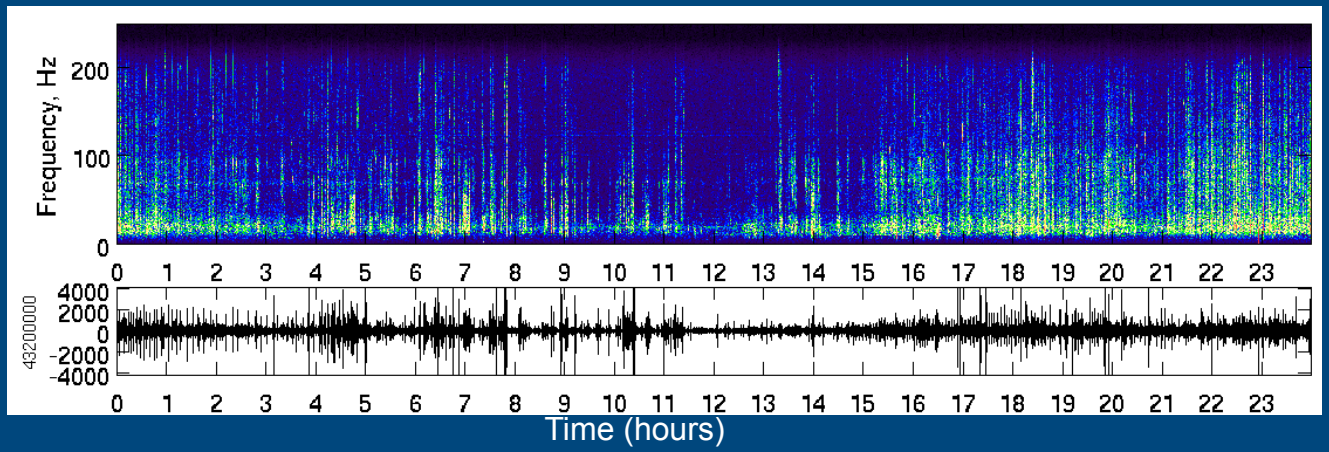








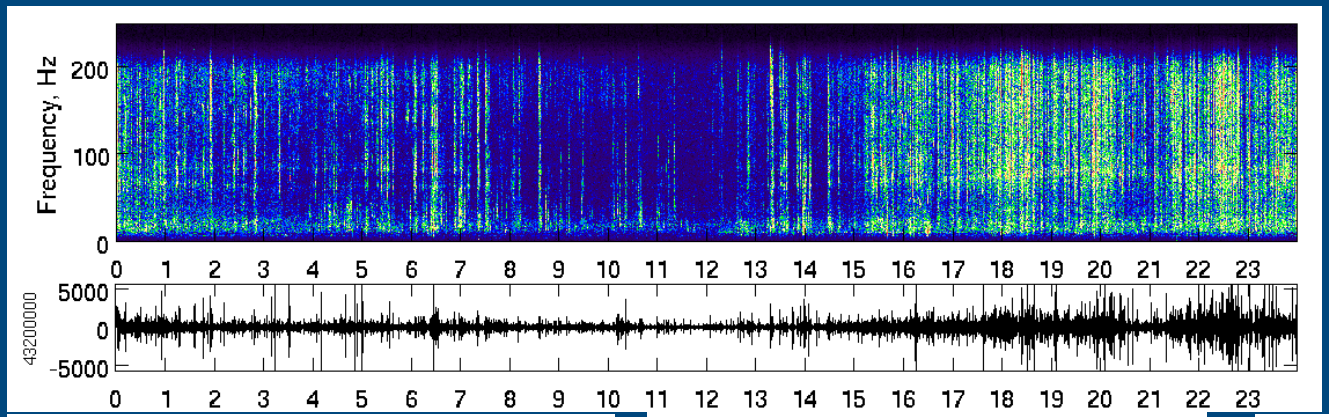
Example data and correlations from the dense deployment



Station R3413

Spectrogram for day 145

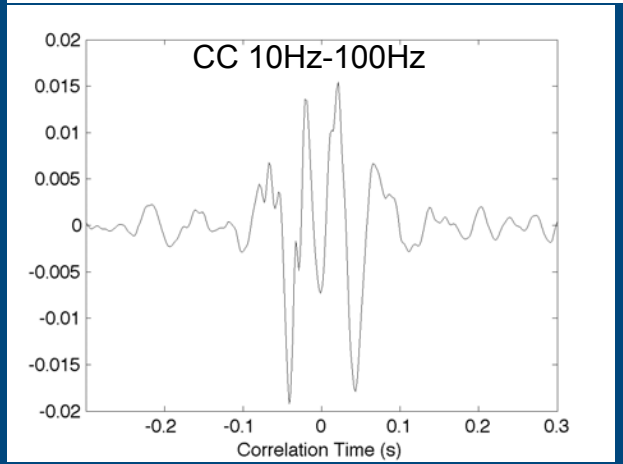
24h data for day 145

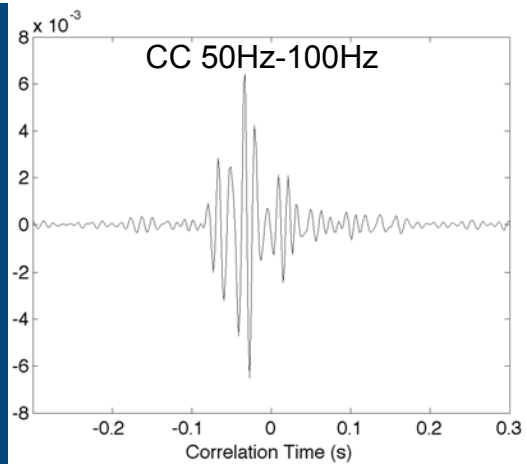


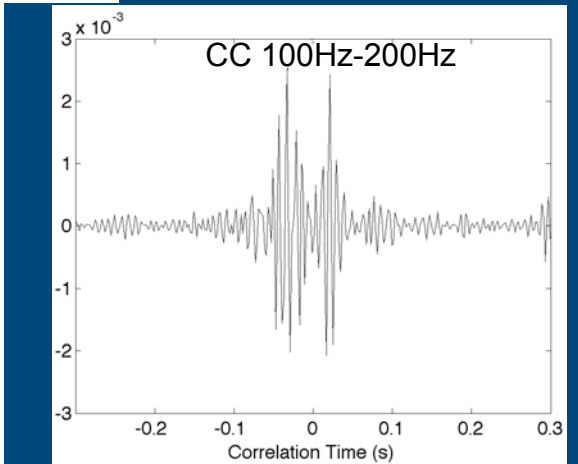
Station R3513

Spectrogram for day 145

24h data for day 145

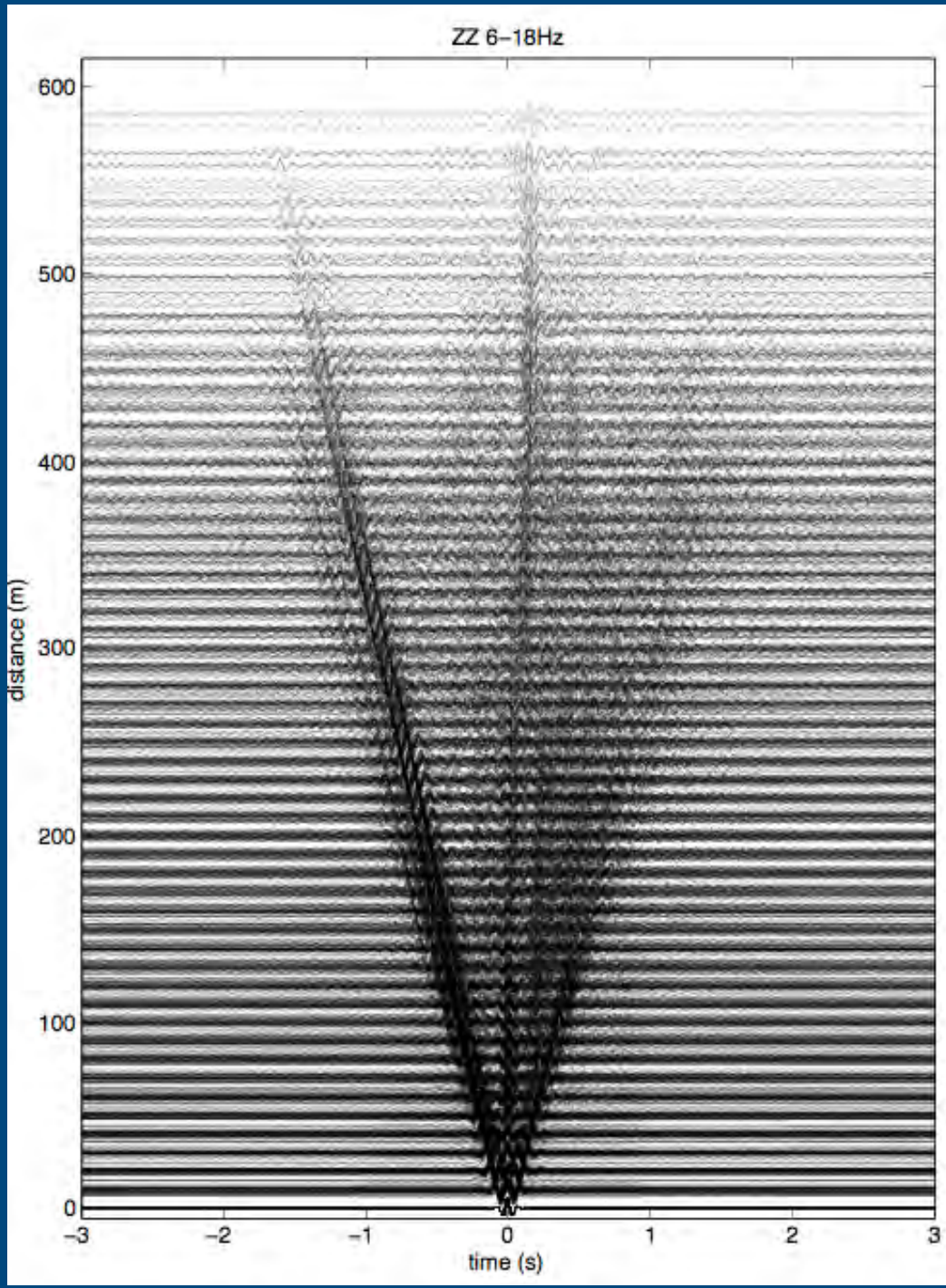




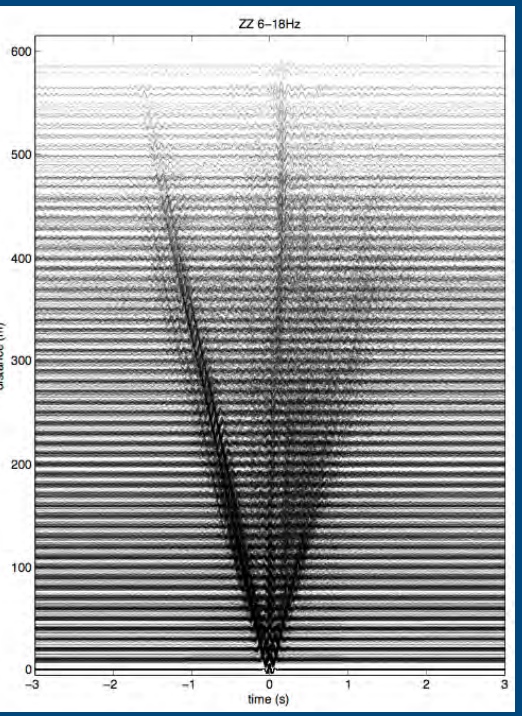


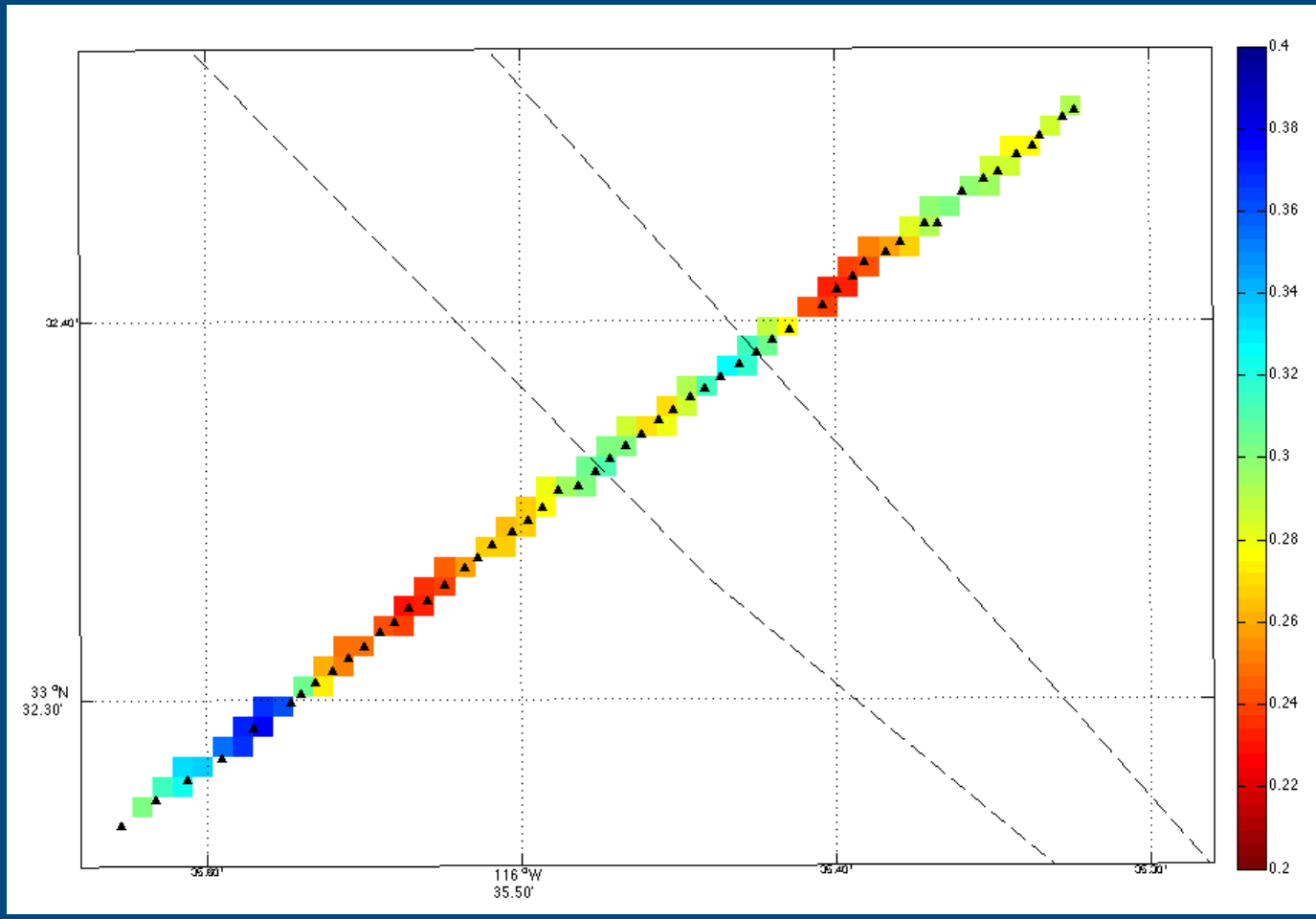
Ambient Noise Cross-correlation

- Preliminary Results
- Line 13
- 600 meters in length
- 55 elements
- 6-18 Hz



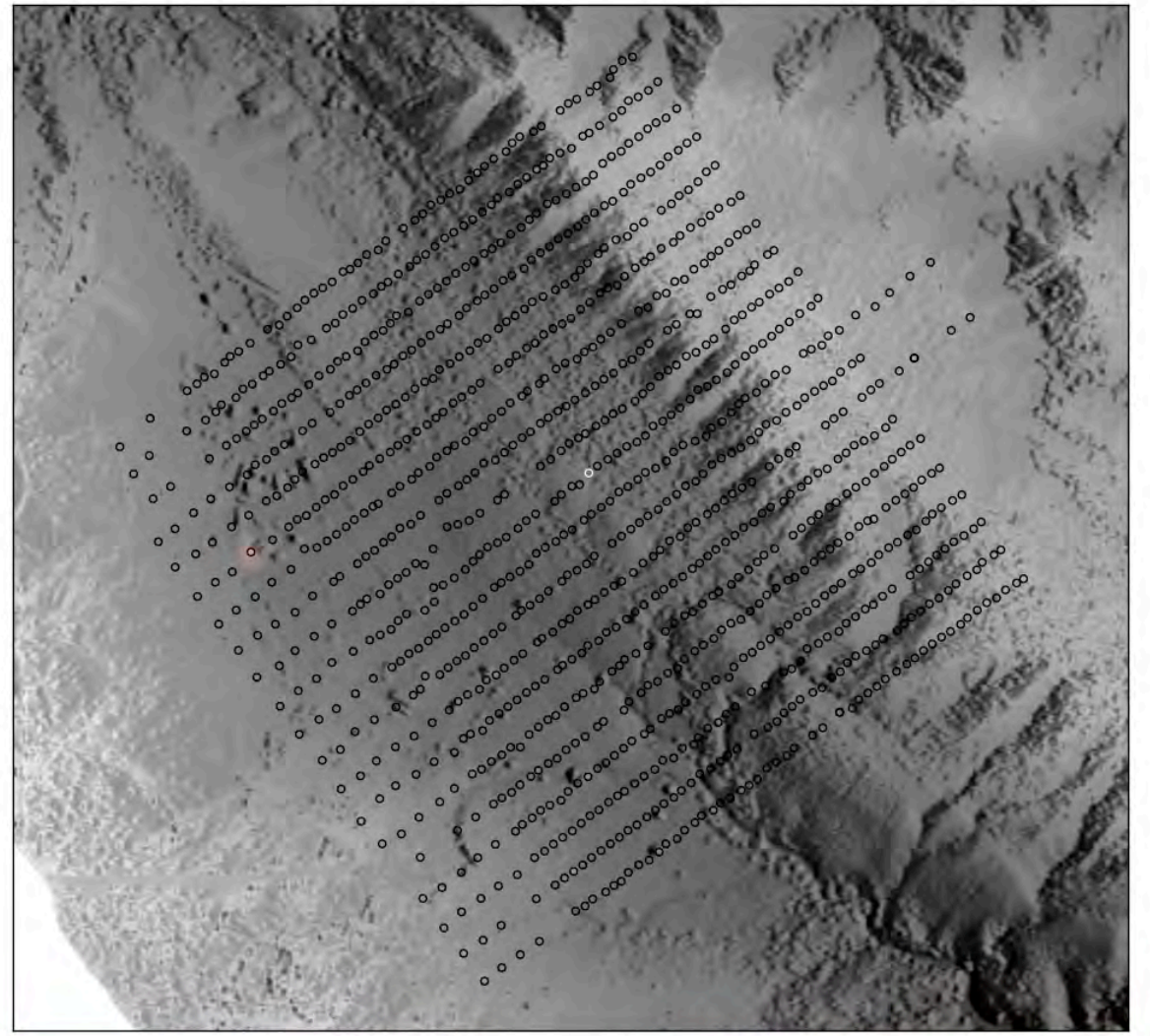
Ambient Noise Cross-correlation

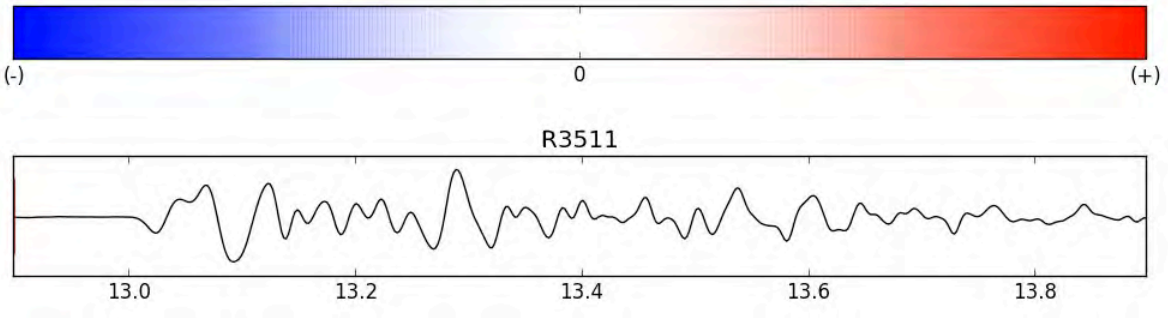




Surface wave velocity profile from tomographic inversion at 30 Hz

- P wave
- M_L 1.5
- Epicentral distance 11.3 km
- Azimuth 120°





- P wave
- M_L 2.3
- Epicentral distance 7 km
- Azimuth 329°