Three-component seismic array location of volcanic explosions

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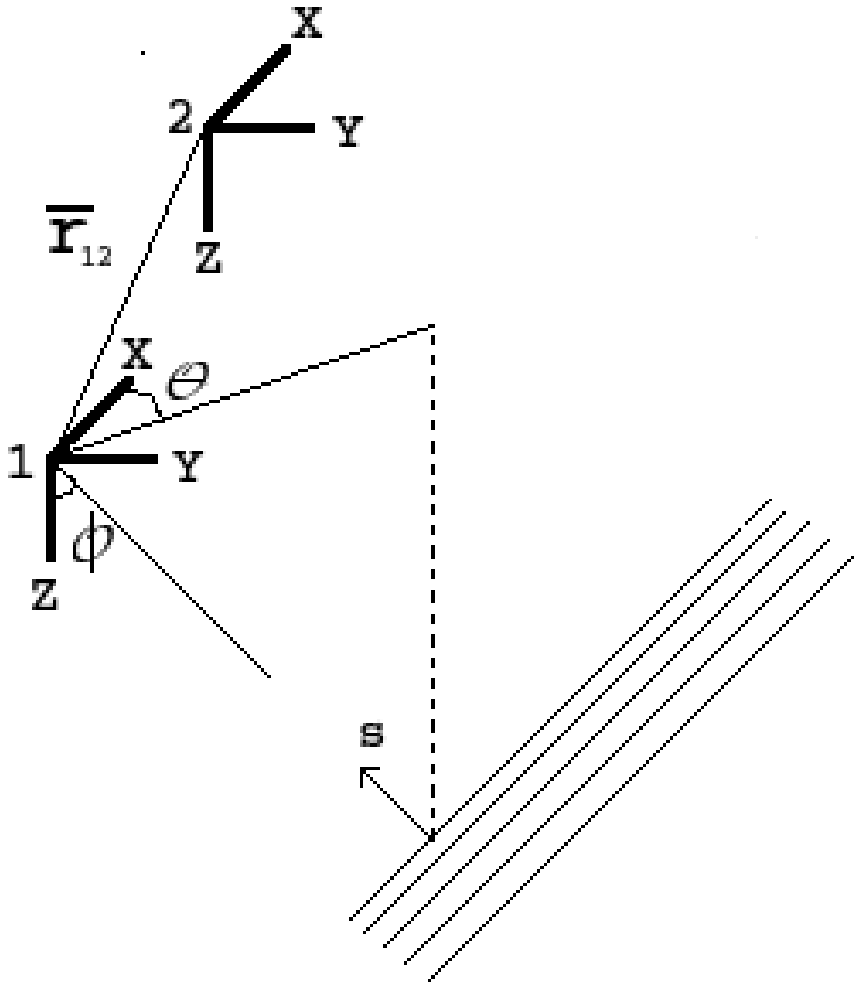
Antenna Design



- A plane wave field aproximation
- Array of three component seismometers
- X,Y,Z to N,E,V (north, east, vertical)

Processing Approach

One wavefield arrives at an antenna

The source S recorded on 1 component is:
$W(f_o) = S(f_o)exp(-2\pi j(\mathbf{r_n} \cdot \mathbf{k})) + B_n(f_o)$ where $\mathbf{k}\,(\theta, \phi)$ is the wavenumber, θ, ϕ azimuth and incidence angles of the wavefield

Three component data

$$\mathbf{W}_m(f) = \begin{bmatrix} X1 & Y1 & Z1 \\ . & . & . \\ XN & YN & ZN \end{bmatrix} \quad m = 1, 2, ..., M$$

3C MUSIC (Multiple Signal Classification)

Cross correlation

$$\mathbf{\Gamma}(f) = \mathbf{A}(f)\,\mathbf{\Gamma}_s(f)\,\mathbf{A}^H(f) + \sigma_B^2\mathbf{I} \quad \textit{where } \mathbf{\Gamma} = \sum_{i=1}^{M}(\mathbf{E}\left\{\mathbf{W}_i\,\mathbf{W}_i^{\mathbf{H}}\right\})$$

MUSIC Estimator

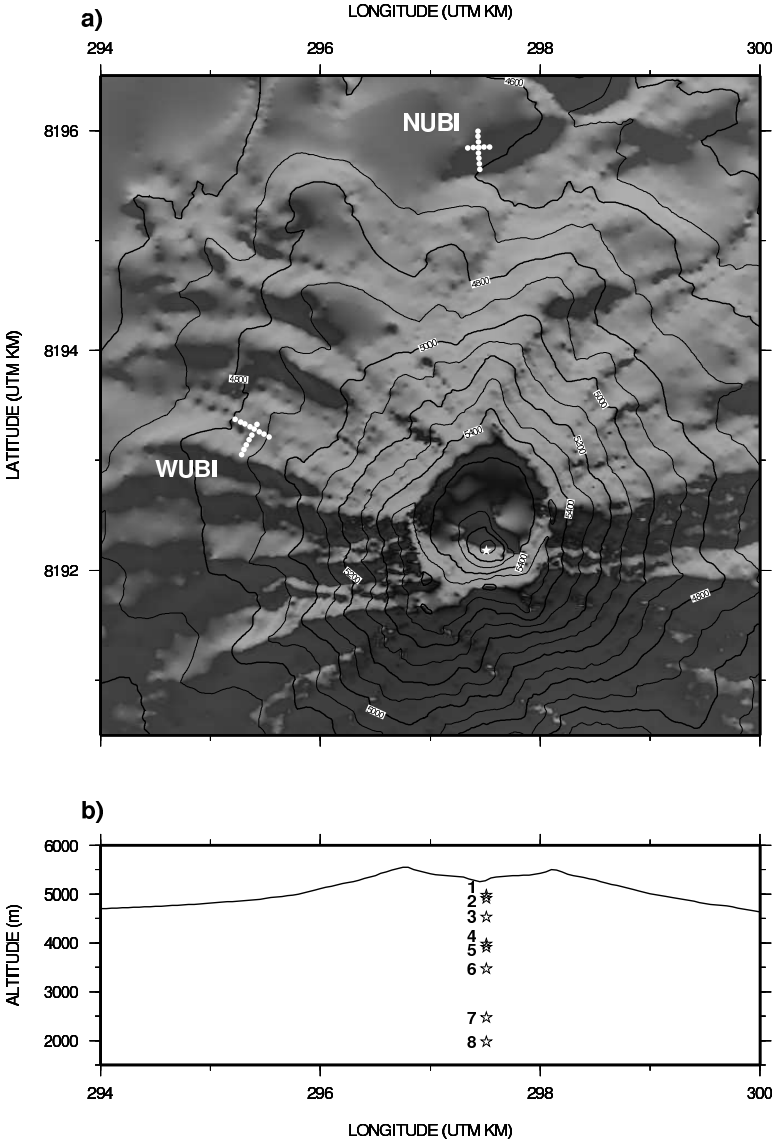
Using eigen analysis [a]

$$\mathbf{3C-MUSIC}(\theta,\phi) = \frac{1}{\mathbf{A}^H\mathbf{V}_N\mathbf{V}_N^H\mathbf{A}}$$

where, $\mathbf{A}(\theta,\phi) = [1\ , exp(-2\pi j(\mathbf{r}_2\cdot\mathbf{k})), ..., exp(-2\pi j(\mathbf{r}_n\cdot\mathbf{k}))]^T$ is the steering vector and $\mathbf{V}_N$ is the eigenvector for the noise sub-space

[a] Schmidt, R. O., 1986. Multiple emitter location and signal parameter estimation, IEEE

Ubinas volcano experiment

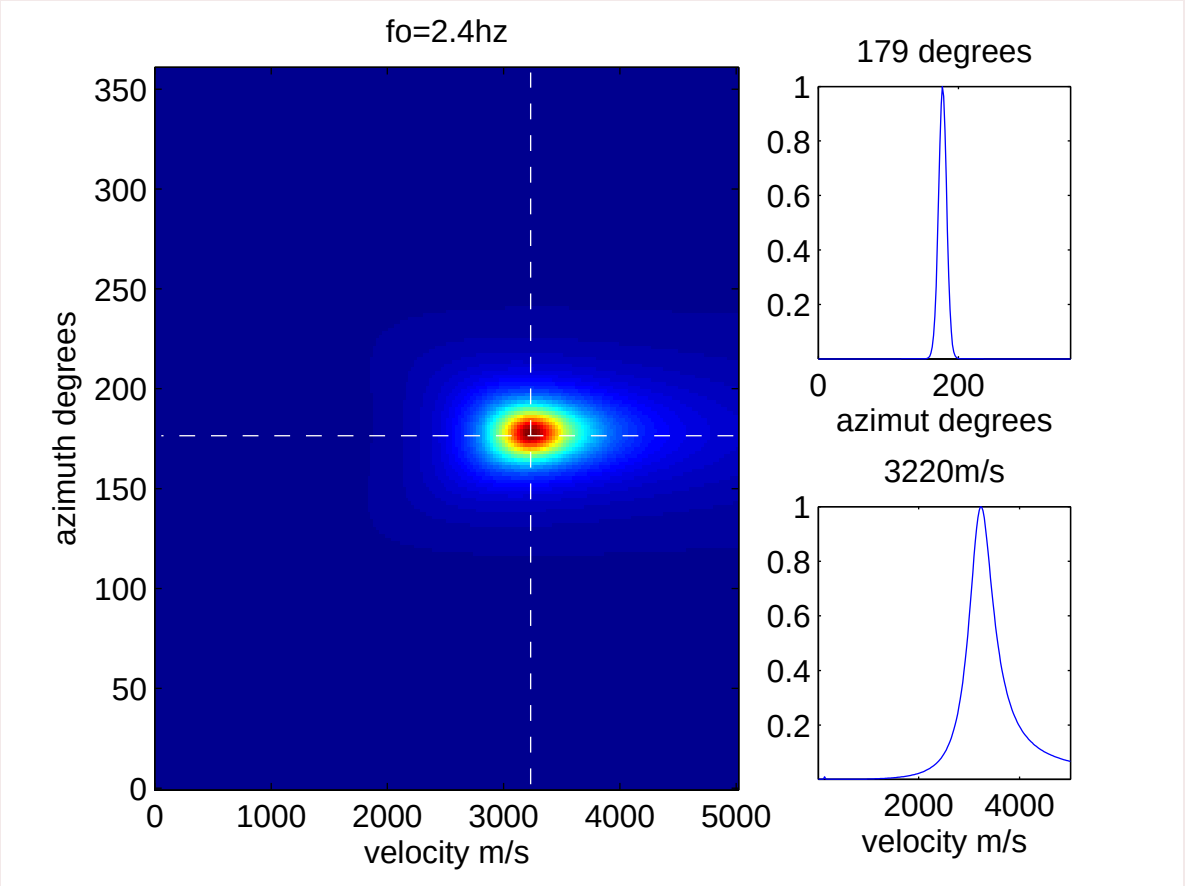


- The most active volcano in Peru
- Experiment in 2009: 454 LP, 18 explosions and 12 VT recorded
- Last crisis was in 2006
- Synthetic data[a] for 8 sources

[a] OBrien,G.S. Bean,C.J., 2004. A 3d discrete numerical elastic lattice method for seismic wave propagation in heterogeneous media with topography, Geophysical Research Letters

3C MUSIC Algorithm

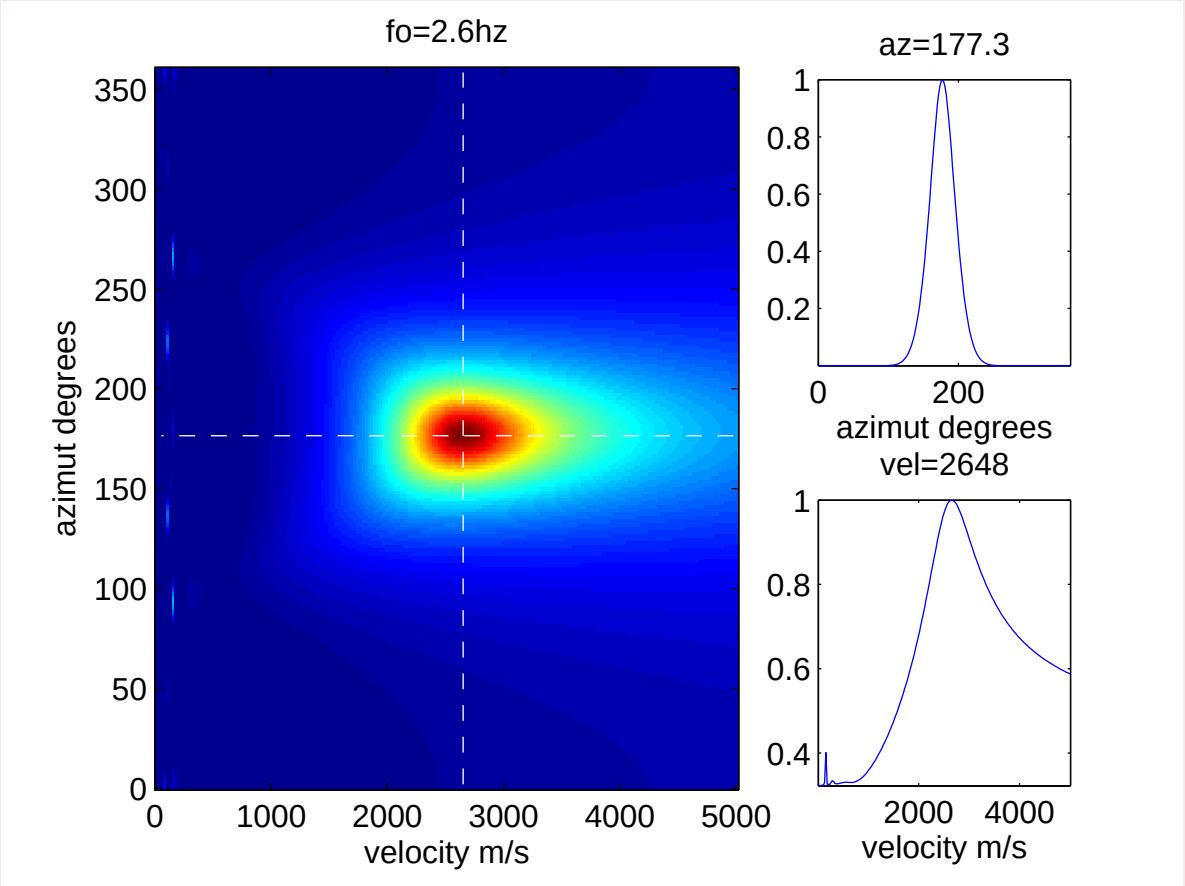
3C-MUSIC spectrum



- 3C MUSIC for the synthetic data, source 3 antenna NUBI
- Azimuth error is 1%

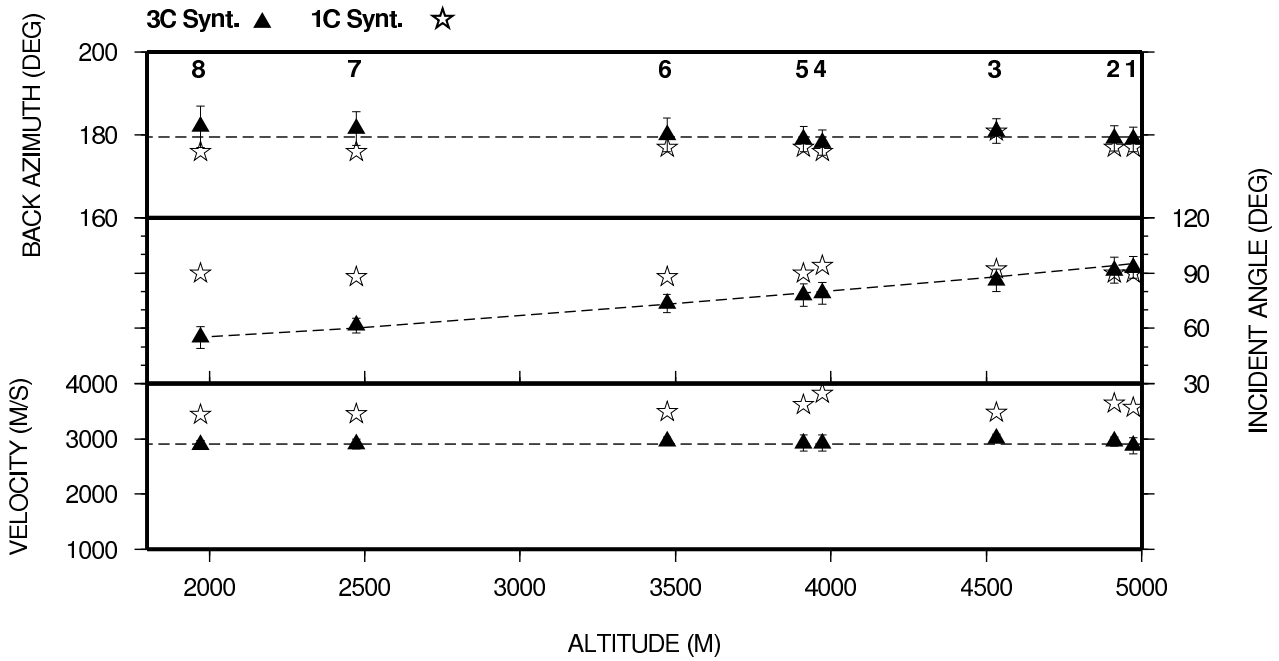
1C MUSIC Algorithm (vertical component)

1C-Music spectrum



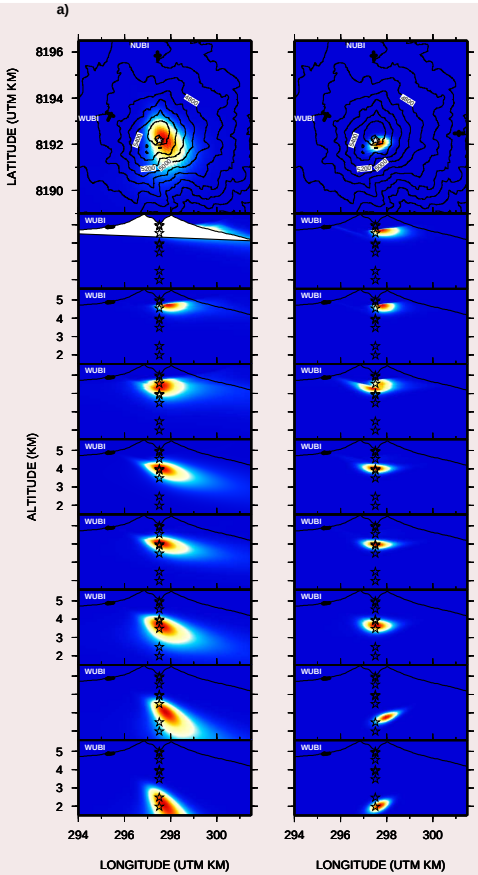
- 1C MUSIC for the synthetic data, source 3 antenna NUBI
- Azimuth error is 6%

Results



- Results for all synthetic data sets for NUBI array
- 3C-MUSIC works well, error 1% in azimuth and incidence
- 1C-MUSIC has larger errors 6%

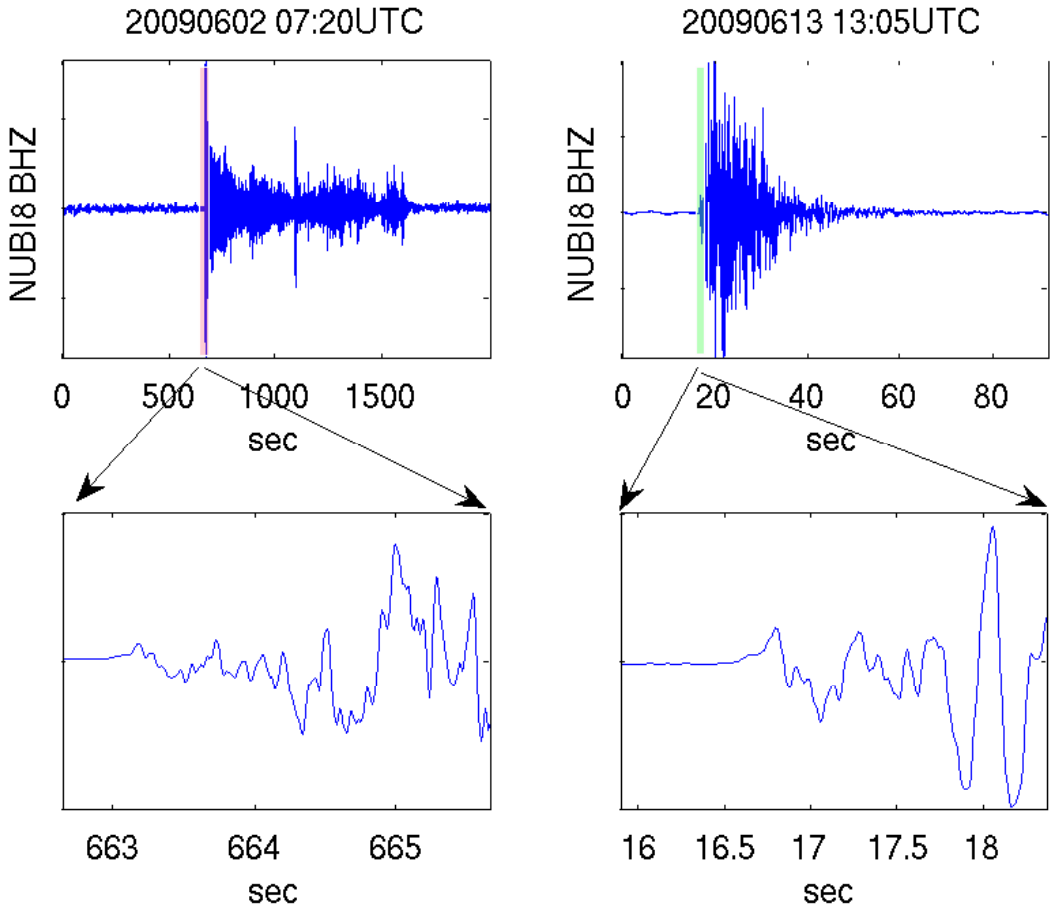
Location of synthetic data using both arrays



- Source location PDF of synthetic data [a]

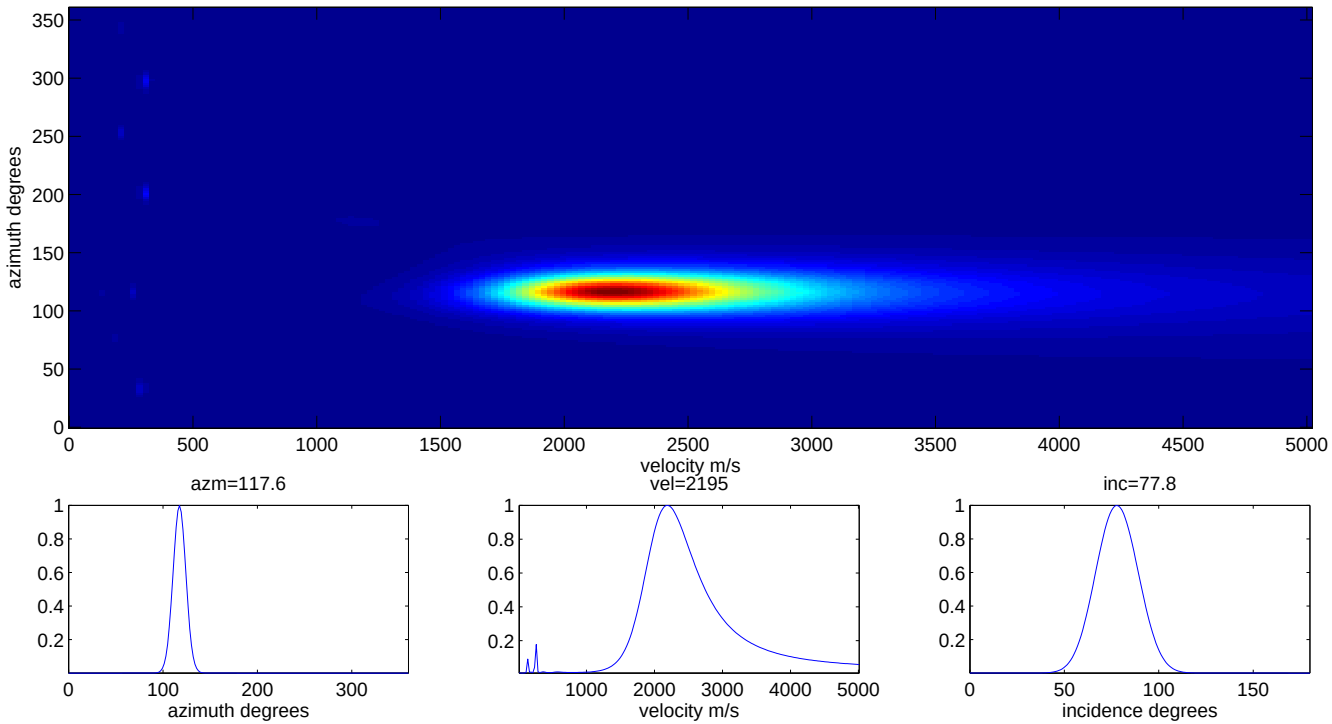
[a] Metaxian,J.P., Lesage,P.,Valette, B.,2002. Locating sources of volcanic tremor and emergent events by seismic triangulation, Geophys Researh Letters

Real data analysis - explosion



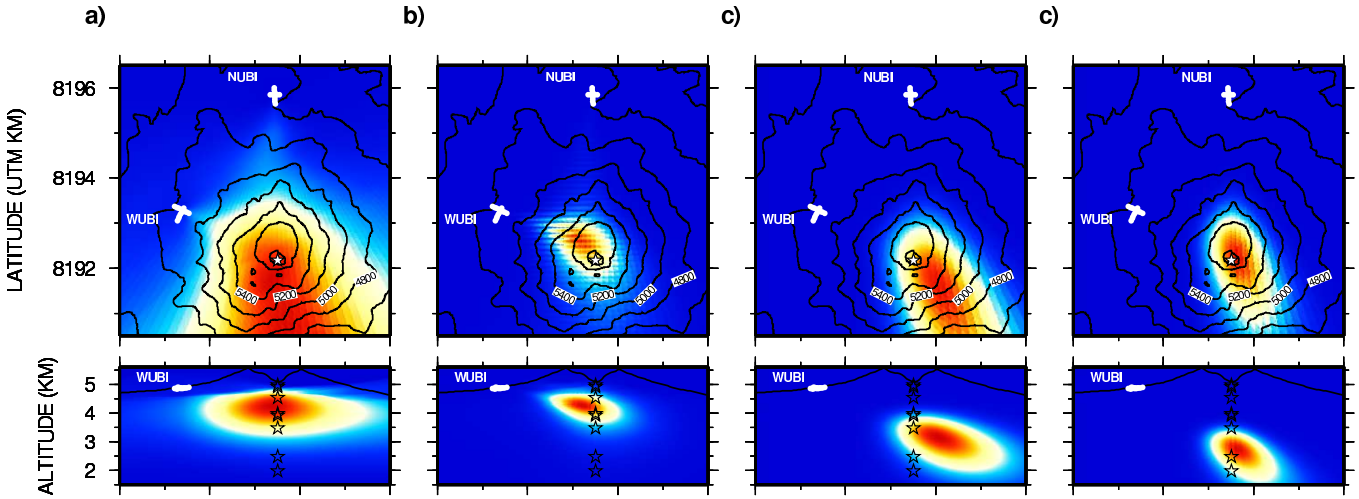
- Two explosions recorded on NUBI, sensor 8, vertical component

Real data analysis - explosion



- 3C MUSIC for one explosion event
- Azimuth is 117.6 incidence angle is 77.8 and apparent velocity is 2195m/s

Location of 4 explosions



- Explosions a and b similars waveforms
- Explosions c and d smaller amplitudes and durations

Conclusions

- Three component sensor array data used for the estimation of the azimuth and depth of LPs and explosions.
- Analysis of synthetic data with 1C-MUSIC estimates the azimuth with an error of +/-13%.
- Analysis of synthetic data with 1C-MUSIC cannot accurately estimate the depth
- Analysis of synthetic data with 3C-MUSIC estimates the azimuth with an error of +/-1%.
- Analysis of synthetic data with 3C-MUSIC estimates the depth with an error of +/-6%.
- 3C-MUSIC of four explosions recorded on Ubinas volcano gives the source beneath the crater with a depth of 1 km and 3 km.

Work in progress

- Analysis of all LP and explosions recorded in the experiment.
- Thanks you