Understanding magmatic processes and seismo-volcanic source localization with multicomponent seismic arrays

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Thesis Defense

May 30th, 2013

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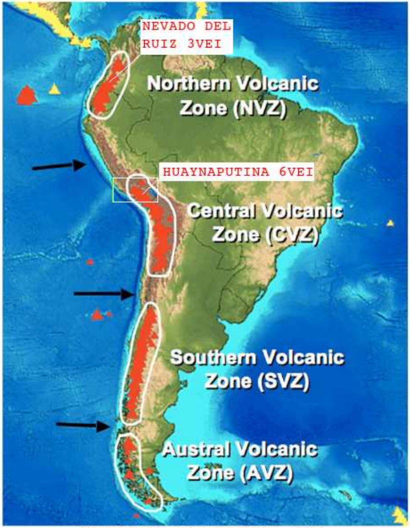
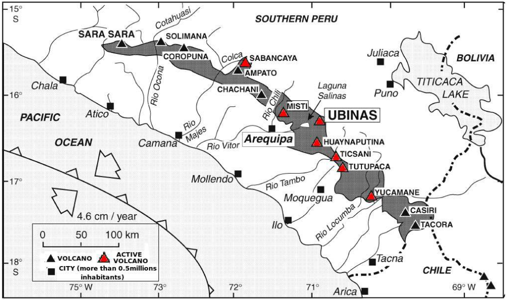
Volcanoes



VOLCANIC ARC IN THE ANDES (Tilling 2009)
▲ VOLCANO



Volcanism in Peru CVZ (Thouret et al 2005)

- Millions of people are at risk from volcano hazards along the Andes (*Tilling 2009*)
- 2 major volcanic events: Nevado del Ruiz VEI 3 (1985) and Huaynaputina VEI 6 (1600) (VEI = volcanic explosivity index from 0 to 7)
- Seven active volcanoes in southern Peru

Misti volcano - 5822 m (Altitude)

EL MISTI the most dangerous volcano

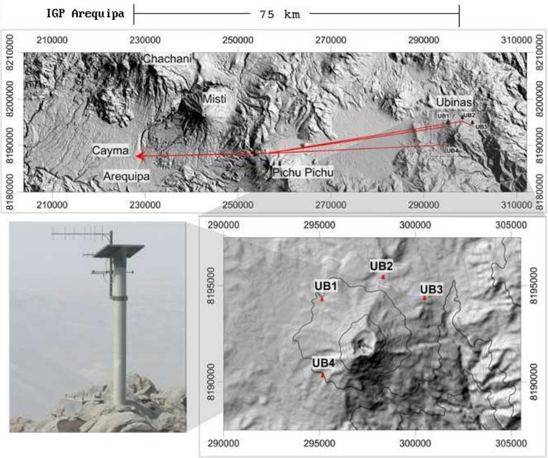
- Misti volcano: Lat -16.3 Lon: -71.4 Alt: 5822 m
- Arequipa city, the 2nd most important of Peru, 17 km away south-west of Misti crater
- Arequipa: more than 1 million inhabitants
- A telemetry seismic network of 5 stations around Misti volcano

Ubinas volcano - 5672 m (Altitude)

UBINAS the most active volcano

- Ubinas crater: Lat:-16.3 Lon:-70.9 Alt:5672 m
- An andesitic stratovolcano, more than 5000 people living within 12 km from the crater
- 23 eruptions between 1550 - 1899
- 10 eruptions between 1906 - 1999
- Eruption rate: 7 per century (*Thouret et al 2005*
- Last eruption: 2006 - 2009

Classical seismic network in Ubinas



- Seismic network is a group of seismometer to monitoring the volcano
- Ubinas: 4 seismometers, short-band response (1Hz), single component (vertical) since 2006, Old technology

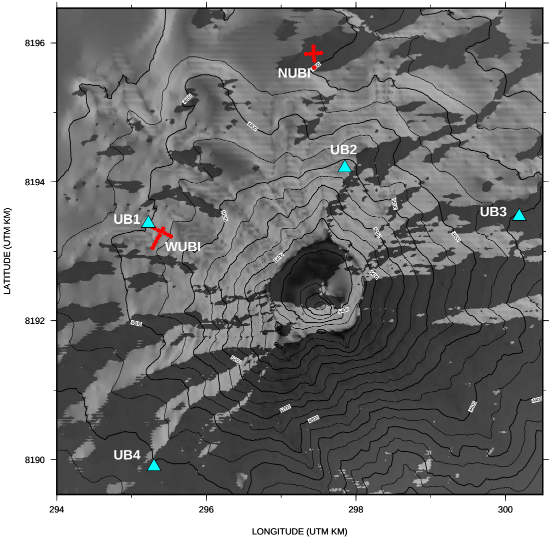
- Seismic activity dominated by volcanic earthquakes (explosive, LP, tremors events)
- This type of signals are different of normal earthquakes (Waveforms with emergent onset, unclear P and S seismic phases)
- Traditional means do not work his type of signals, they cannot be localized
- New methods needs to be developed
- Ubinas eruption is characterized by vulcanian style (short-duration highly explosive and destructive).
- Last eruption produced ash columns of 3 km, and ashfall was reached 20 km away the volcano.

Outline

Plan

1. Introduction
   - How to study Ubinas volcano?
   - New instrumentation
   - Experiment Ubinas 2009
2. Source Localization
3. Application and Interpretation
4. Conclusions and perspectives

How to study Ubinas volcano?



- Two seismic antennas (NUBI and WUBI).
- **Using three component (3C) seismometers**.
- Goal: Extract information of wave fields to understand magma mechanisms
- Seismic array can measure an important vector consist of **slowness, back-azimuth and incidence angle**

State of the art 1C/3C

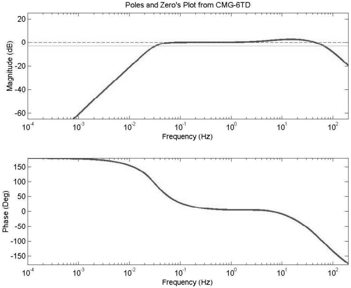
Author	Method	Volcano
Saccorotti & Del Pozzo (2000)	1C-antennas	Stromboli (Italy)
Metaxian et al (2002)	1C-antennas	Arenal (Costa Rica)
Almendros et al (2001b)	1C-antennas	Kilauea (USA)
La Rocca et al (2004)	1C-antennas	Stromboli (Italy)
Di Laito et al (2007)	1C-antennas	Etna (Italy)

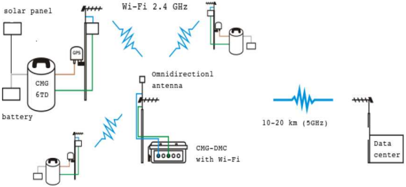
- Earthquake depths related to magma transport were not clearly estimated from array data.
- Locating the magma depth is crucial to understand eruptive mechanisms.
- *Chouet et al 2003 and 2013* highlight the evolution of broadband 3C-seismometers

New instrumentation

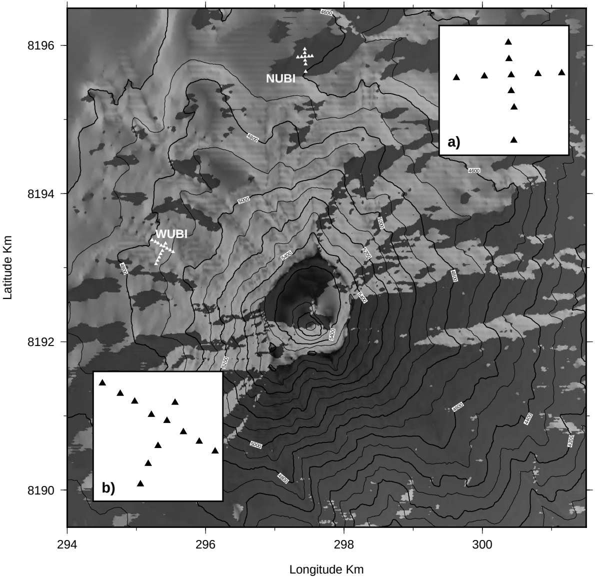
- Three component with broadband sensors.
- High dynamic range with 24-bit digitizer.
- Wireless communication capabilities (WiFi)
- Compact with very low power consumption

Band width: 0.03 - 50 Hz





Experiment Ubinas: May - July 2009



Experiment supported by: IRD, UCD, IGP

- NUBI: 10 instruments (Guralp 6TD and 3EPS)
- WUBI: 12 instruments (Guralp 6TD and Titan-Neomax)
- Sensor distance: around 50m, aperture seismic array: 300m
- Altitude: NUBI at 4632 m high and WUBI 4732 m
- Distance: NUBI 3750 and WUBI 2567 m away the crater
- Extreme environment range between, -10 Celsius, high altitude.

Experiment Ubinas: May - July 2009

Hard work

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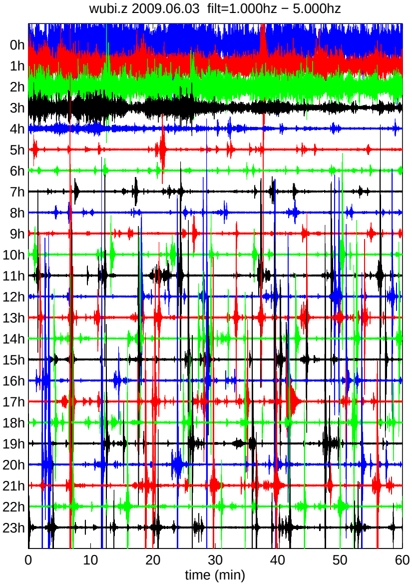
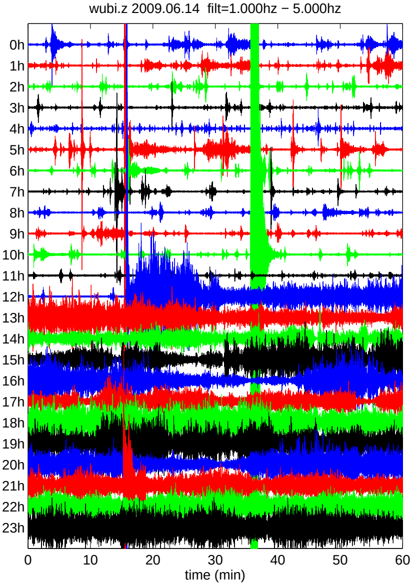
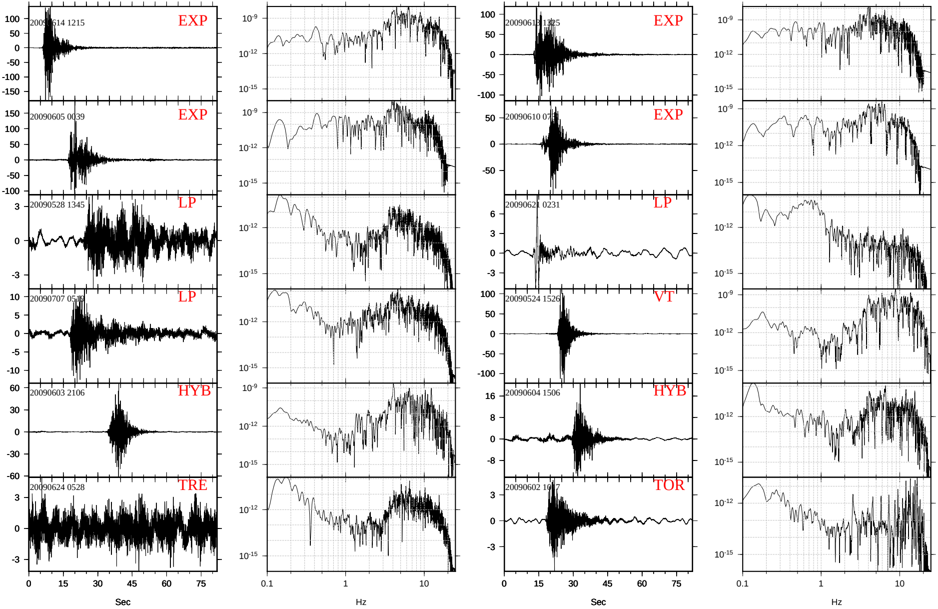
Ubinas seismic activity

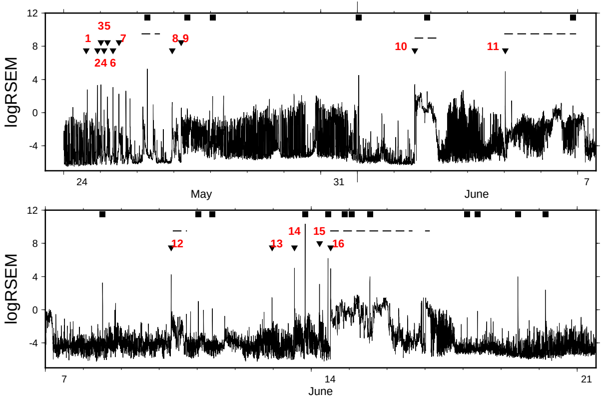




Seismic waveforms on Ubinas



Global activity on Ubinas - RSEM



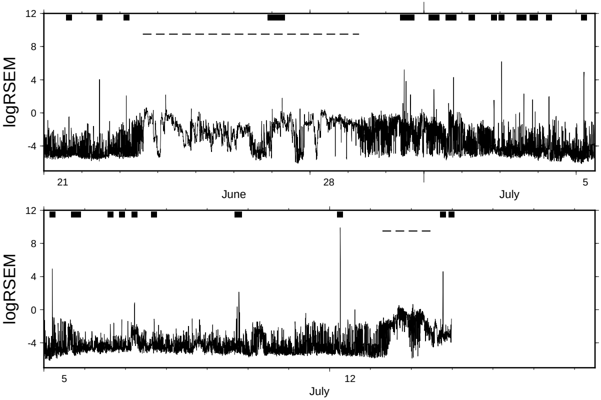
Antenna: WUBI 24-May-2009 to 20-Jun-2009

$$RSEM(iT) = log\left[\left(\frac{1}{T}\sum_{t=iT-\frac{T}{2}}^{t=iT+\frac{T}{2}} y^2(t)\right)^{\frac{1}{2}}\right]$$

Realtime Seismic Energy Measurement

- Based on RSEM method (*De la Cruz Reyna and Reyes Davila et al 2001*) on 1C vertical component.
- More than 400 LP, 16 explosions, several hours of tremors events manually selected and compared with IGP catalog
- Inverted triangles represent vulcanian explosions
- Dashed lines represent tremor events
- Black squares represent subduction earthquakes

Global activity on Ubinas - RSEM



Antenna: WUBI 21-Jun-2009 to 14-Jul-2009

$$RSEM(iT) = log\left[\left(\frac{1}{T}\sum_{t=iT-\frac{T}{2}}^{t=iT+\frac{T}{2}} y^2(t)\right)^{\frac{1}{2}}\right]$$

Realtime Seismic Energy Measurement

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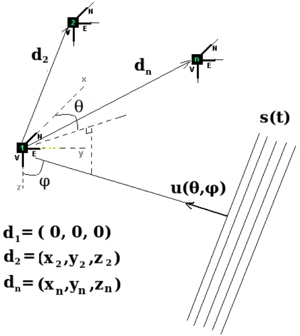
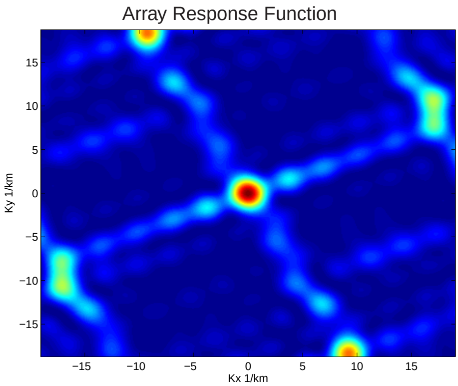
Plan

Small aperture seismic array





- Slowness vector:

$$\mathbf{u}(\theta,\phi) = \frac{1}{v_a}\begin{bmatrix} -\cos(\theta)\sin(\phi) \\ -\sin(\theta)\sin(\phi) \\ -\cos(\phi) \end{bmatrix}$$

  v_a is the apparent velocity

- Delay: $\tau_n = \mathbf{d_n} \cdot \mathbf{u}(\theta,\phi)$

- Multicomponent sensor: 3C seismometers sense full seismic waves
- Irregularly sensor spacing array due to the volcano topography ($d_n < \lambda_{min}/2$)

Formulation for single component (1C)

Signal received by one-component sensor

$$W_n(f) = S(f)exp(-j2\pi f_s \tau_n) + B_n(f)$$

Antenna output in matrix form

$$\mathbf{W(f)} = \mathbf{A}(\theta,\phi)S(f) + \mathbf{B(f)}$$

Steering vector

$$\mathbf{A}(\theta,\phi) = \begin{bmatrix} 1 \\ exp(-j2\pi f_s(\mathbf{d}_2 \cdot \mathbf{u})) \\ \cdots \\ exp(-j2\pi f_s(\mathbf{d}_n \cdot \mathbf{u})) \end{bmatrix}$$

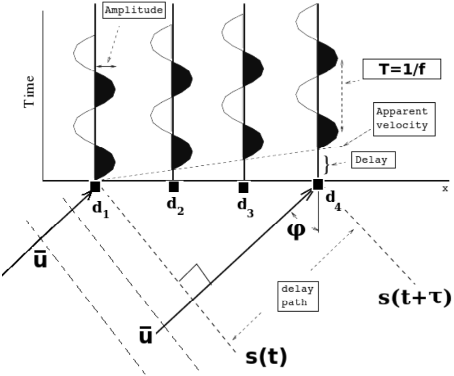
Cross-spectral matrix

$$\Gamma_W = \xi\left[\mathbf{W(f)}\mathbf{W}^H(f)\right]$$

ξ. is the expectation operator, $(.)^H$ is the conjugate transpose operator

$$\Gamma_W = \mathbf{A}(\theta,\phi)\xi\left[S_1(f)S_1^H(f)\right]\mathbf{A}^H(\theta,\phi) + \sigma_b^2\mathbf{I}$$

Noise is spatially white with variance σ_b^2, **I**=Identity matrix

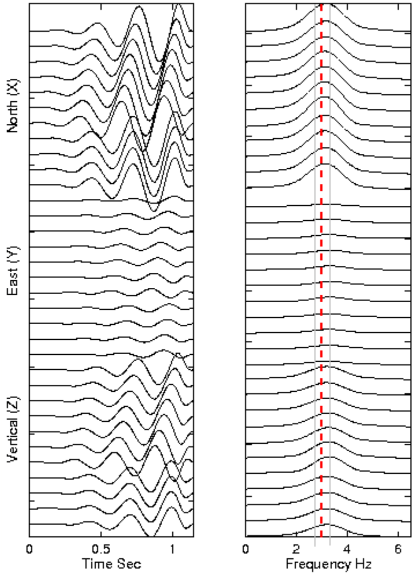


Direction of arrival algorithms

- Conventional methods (Beamforming Capon), Subspace-based methods (ESPRIT, MUSIC)
- Maximum-likelihood Methods (Deterministic, Stochastic)

Extension to three components (3C)

Given a time series window



3C Data of the one-snapshot, N=number of sensors

$$\mathbf{W3C}_m(f) = \left(\begin{bmatrix} X_{1,m} \\ \cdots \\ X_{N,m} \end{bmatrix}, \begin{bmatrix} Y_{1,m} \\ \cdots \\ Y_{N,m} \end{bmatrix}, \begin{bmatrix} Z_{1,m} \\ \cdots \\ Z_{N,m} \end{bmatrix} \right)$$

$$\mathbf{W3C}_m(f) = [X_m(f), Y_m(f), Z_m(f)]$$

Cross-spectral matrix for M-snapshots

$$\widehat{\Gamma}_{W3C} = \sum_{m=1}^{M} \xi \{ \mathbf{W3C}_m \, \mathbf{W3C}_m^{\mathbf{H}} \}$$

$$\boxed{\widehat{\Gamma}_{W3C} = \frac{1}{M} \sum_{m=1}^{M} (\mathbf{X}_m \mathbf{X}_m^H + \mathbf{Y}_m \mathbf{Y}_m^H + \mathbf{Z}_m \mathbf{Z}_m^H)}$$

MUSIC-3C algorithm

Based on Multiple Signal Classification (*Schmidt 1986, Bienvenu and Kopp 1983*)

.

Signal and noise sub-space

$$\Gamma_{W3C} = \mathbf{A}(\theta,\phi)\Gamma_S \mathbf{A}^H(\theta,\phi) + \sigma_b^2 \mathbf{I}$$

Eigen-analysis (Orthogonal decomposition)

$$\widehat{\Gamma}_{W3C} = \sum_{n=1}^{N} \lambda_n \mathbf{v_n} \mathbf{v_n^H}$$

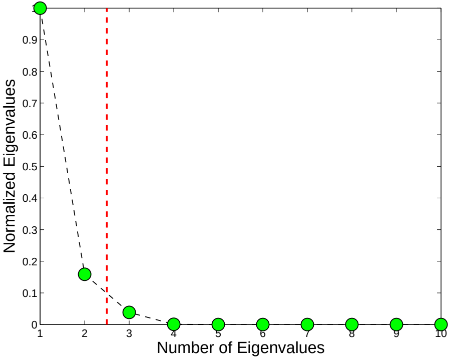
λ_n = eigen-value, $\mathbf{v_n}$ = eigen-vector

Orthogonal projector

$$\Pi^{\perp}_{W3C} = \sum_{n=p+1}^{N} \mathbf{v}_n \mathbf{v}_n^H$$

MUSIC estimator

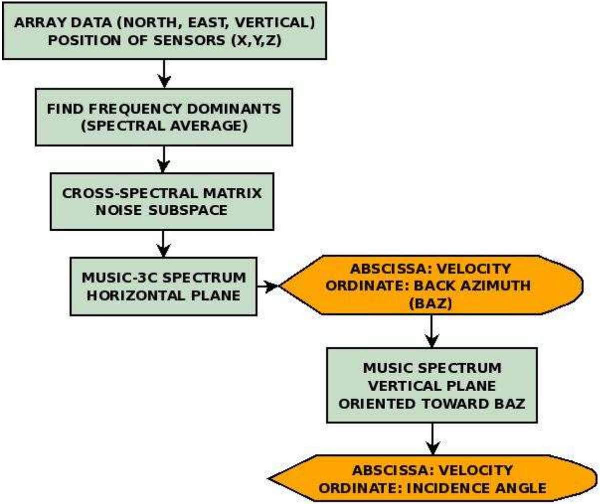
$$\mathbf{M}_{3C}(\theta,\phi) = \frac{1}{\mathbf{A}^H(\theta,\phi)\,\Pi^{\perp}_{W3C}\,\mathbf{A}(\theta,\phi)}$$



Noise subspace projector assuming *2* sources

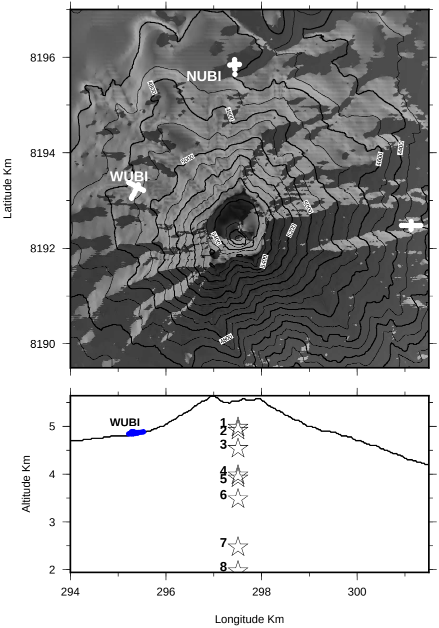
$$\lambda_1 \geq \lambda_2 \geq \lambda_3 > \dots > \lambda_{10} \approx \sigma_b^2$$

MUSIC 3C algorithm flowchart



- Input parameters: 3C Array data, position of the seismometers (X,Y,Z).
- Back-Azimuth (BAZ) is related to the horizontal plane (XY).
- Incidence angle (INC) or elevation angle is related to the vertical plane oriented to the BAZ.
- MUSIC-3C provides TWO SPECTRA.
- Three parameters are defined: Back-azimuth, Incidence angle, slowness.

Application on synthetic data

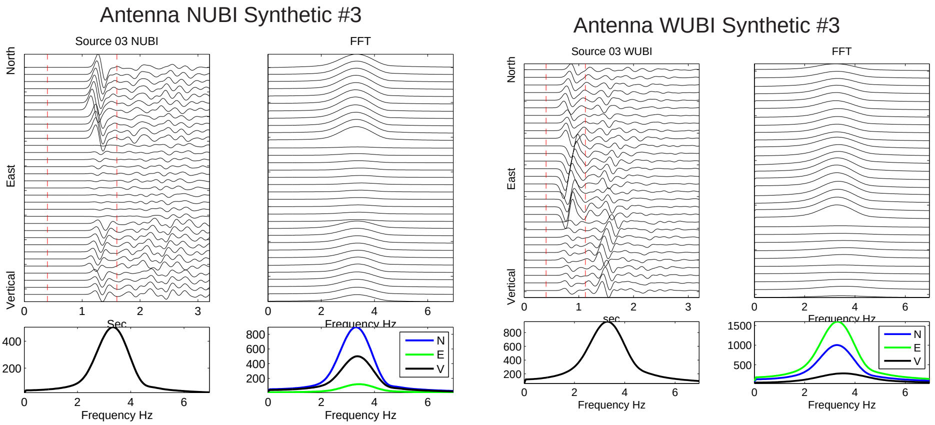


- 8 sources simulated with “3D discrete numerical elastic lattice method for seismic waves” (O’Brien et al. 2004)
- Homogeneous media, Vp=3000, Vp/Vs=$\sqrt{3}$, rock density=2300 kg/m^3
- Three component synthetic data (N, E and V).

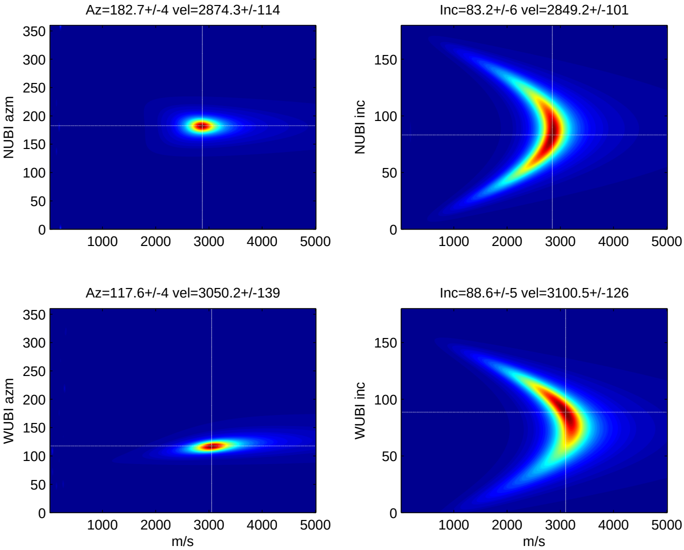
Source	Altitude (m)
1	4972
2	4912
3	4532
4	3972
5	3912
6	3472
7	2472
8	1972

- Thanks Dr. Gareth O’Brain for these simulations (UCD Geophysics Group).

Synthetic source # 3

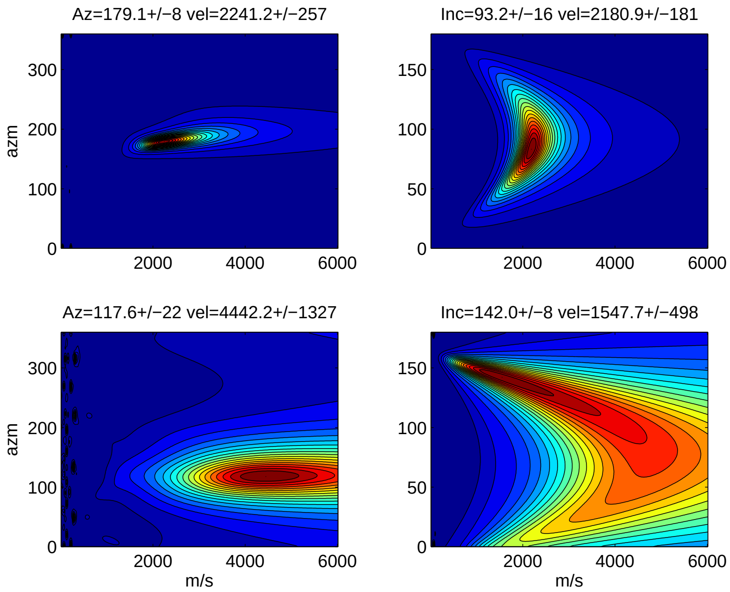


MUSIC-3C on source #3

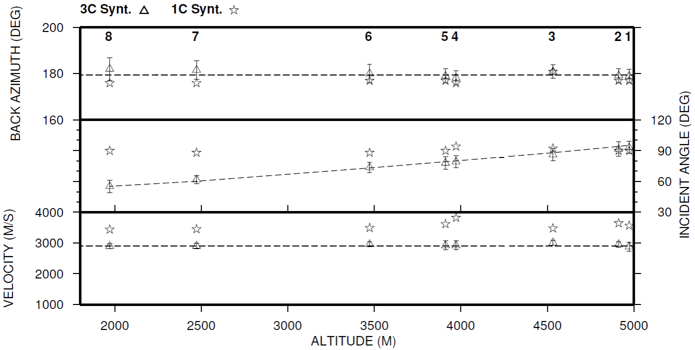


- Error calculations are based on the width of 90% below the maximum peak

MUSIC-1C on source #3



Comparison between 3C and 1C

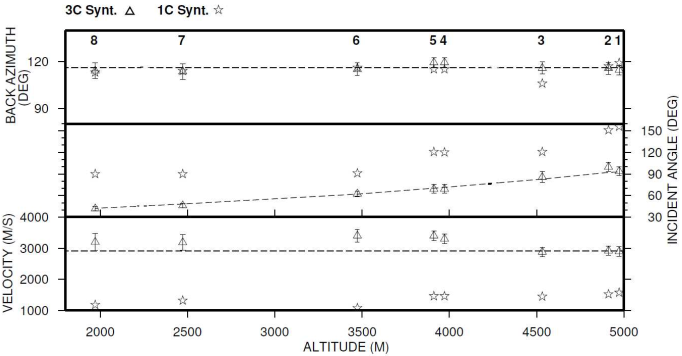


Solution for 8 synthetic sources for NUBI antenna

L. A. Inza, J.I. Mars, J. P. Métaxian, G. S. OBrien, O. Macedo. ***Seismo-volcano source localization with triaxial broad-band seismic array, 2011****, Geophysical journal international*

- Synthetic source localization on NUBI, triangles = 3C, stars = 1C.

Comparison between 3C and 1C

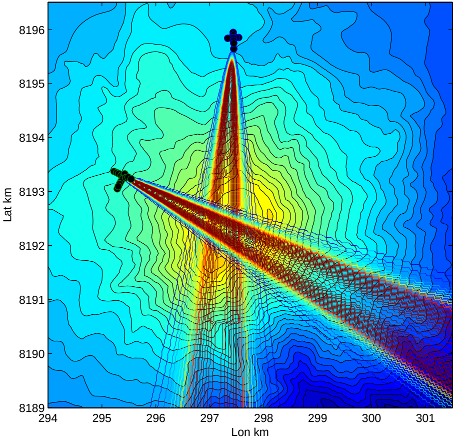


Solution for 8 synthetic sources for WUBI antenna

L. A. Inza, J.I. Mars, J. P. Métaxian, G. S. OBrien, O. Macedo. ***Seismo-volcano source localization with triaxial broad-band seismic array, 2011****, Geophysical journal international*

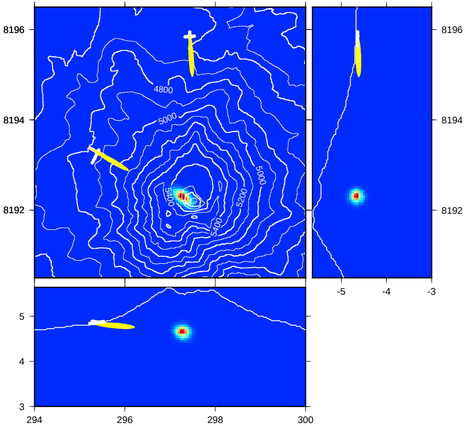
- Synthetic source localization on WUBI, triangles = 3C, stars = 1C.

Localization - Probability approach



- $p_{BAZ}(\theta) = \frac{1}{\sqrt{2\pi\Delta\theta}} exp\left(-\frac{1}{2}\frac{(\theta-\theta_{BAZ})^2}{\Delta\theta}\right)$, $(0 \leq \theta \leq 360^\circ)$
- $p_{INC}(\phi) = \frac{1}{\sqrt{2\pi\Delta\phi}} exp\left(-\frac{1}{2}\frac{(\phi-\phi_{INC})^2}{\Delta\phi}\right)$, $(0 \leq \phi \leq 120^\circ)$
- Probability density function of the grid topography $\rho(x, y, z)$

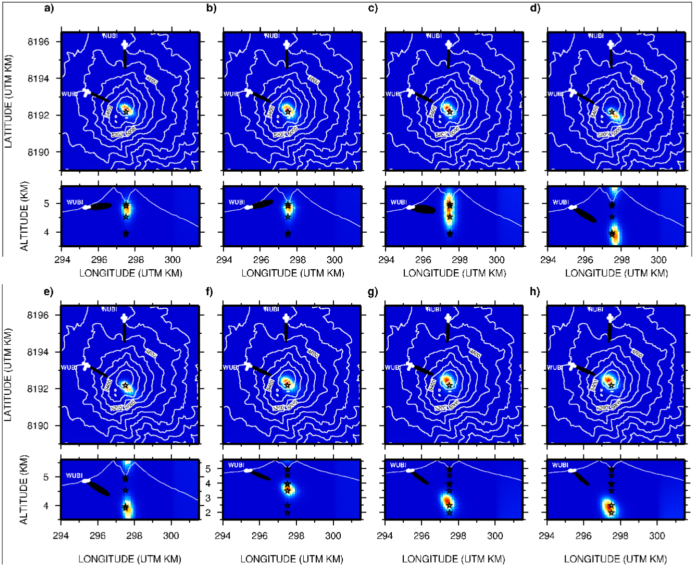
Localization - Probability approach



- $$\rho(x,y,z) = \prod_{i}^{2} (\rho^{i}_{BAZ}(x,y,z)\rho^{i}_{INC}(x,y,z))$$
- Mean quadratic radius (error) $R = \sqrt{\sigma_1^2 + \sigma_2^2 + \sigma_2^3}$
- Most likely source region

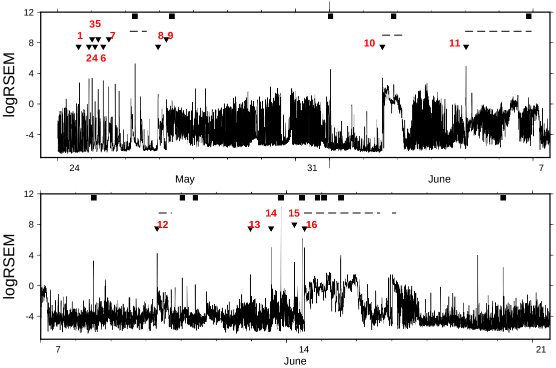
Source localization

MUSIC-3C results (2 antennas): NUBI and WUBI for 8 synthetic sources



Plan

Vulcanian activity



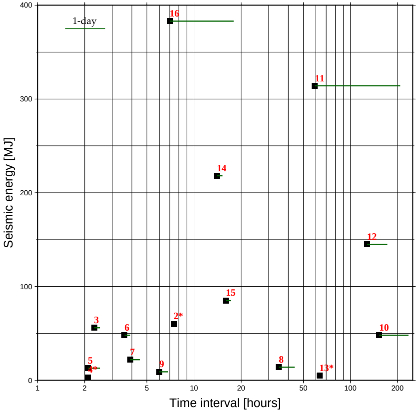
- Black triangles are 16 explosions
- Dashed lines are tremor
- Black square are subduction earthquakes

Explosion chronology

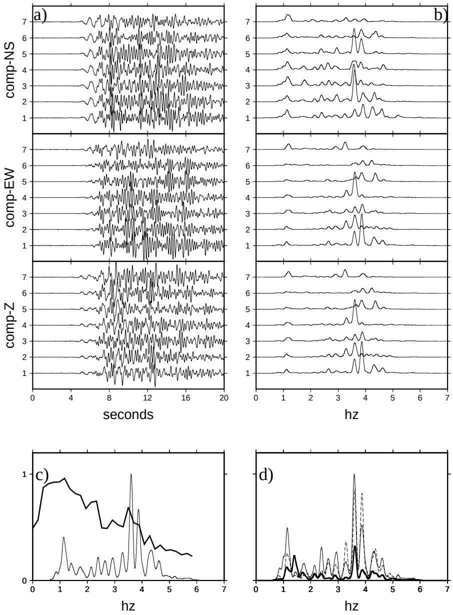
Item	Date Time
1	2009/05/24 14:43:33
2	2009/05/24 22:05:23
3	2009/05/25 00:21:56
4	2009/05/25 02:26:47
5	2009/05/25 04:35:05
6	2009/05/25 08:14:40
7	2009/05/25 12:06:59
8	2009/05/26 22:54:33
9	2009/05/27 04:52:53
10	2009/06/02 13:27:42
11	2009/06/05 00:39:37
12	2009/06/10 07:31:35
13	2009/06/12 23:16:03
14	2009/06/13 13:26:02
15	2009/06/14 05:15:24
16	2009/06/14 12:15:42

Vulcanian activity statistics

Explosion	E (MJ)	Intervals	Tremor
1	3	0	0
2	60	7.4 h	0
3	56	2.3 h	0.5 h
4	3	2.1 h	0
5	13	2.1 h	1.6 h
6	48	3.6 h	0.5 h
7	22	3.9 h	1.5 h
8	14	1 d 10.8 h	4 h
9	9	6 h	1.1 h
10	48	6 d 8.6 h	16 h
11	314	2 d 11.2 h	2 d 3 h
12	145	5 d 7.8 h	9 h
13	5	2 d 15.3 h	0
14	218	14 h	20 min
15	85	16 h	0.5 h
16	383	7 h	1 d 13 h

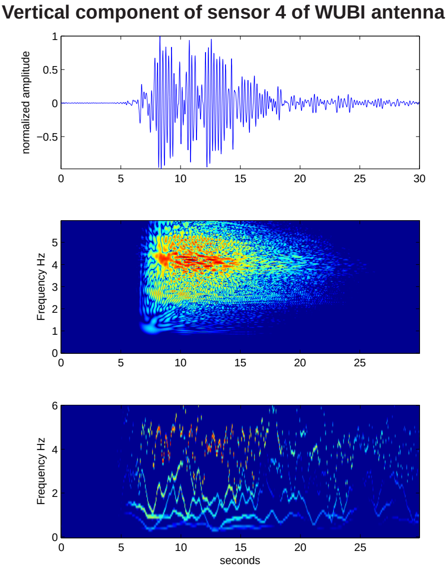


Signal of Explosion #7



- Explosion event (WUBI array on 25 May 2009 12h07m)
- a) Time series signals
- b) Frequency signals
- d) Average per component of frequency signals
- c) Global average of frequency signals (thin curve).
- c) Coherence Average (thick curve) shows good coherency at 0.5 and 2.2 Hz, low coherency between 2.2 and 6 Hz.

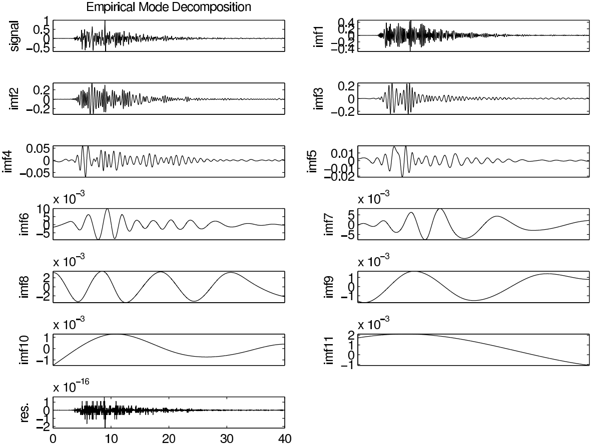
Time-Frequency for explosion # 7



- Instantaneous frequency of IMFs provide instantaneous frequencies
- EMD is more suitable for seismic than Wigner-Ville
- Hilbert-Huang Transform (HHT) is more suitable for stationary signals as the seismic
- Frequency bands: Band A: 0.5-2.2 Hz and Band B: 2.2-6 Hz
- HHT is based on instantaneous frequency of EMD signals.

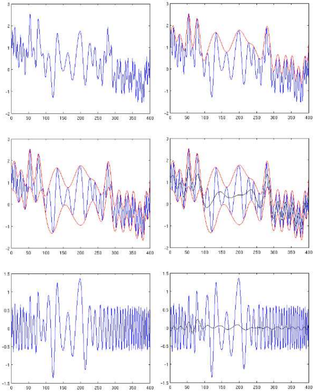
Empirical mode decomposition (EMD)

$$s(t) = \sum_{i=1}^{n} IMF_i(t) + r_n(t)$$



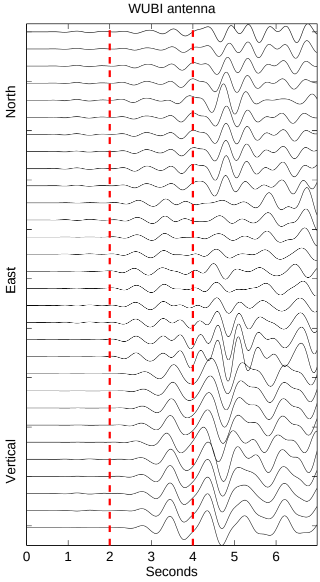
EMD acts essentially as a filter bank

Sifting process for 1 IMF (*Huang et al 1998*)

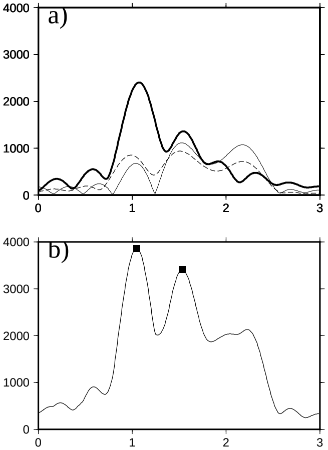


Band A (0.5-2.2 Hz)

Signals of explosion #7 filtered on band A



Average of frequency signals per component, East (thin curve), North (dashed curve) and Vertical (thick



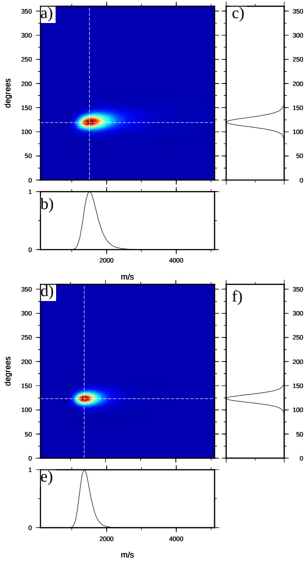
curve)

hz

Global average of frequency signals, peaks found in F1=1.1 and F2=1.5 Hz (black squares)

MUSIC-3C spectra for both peaks F1 and F2

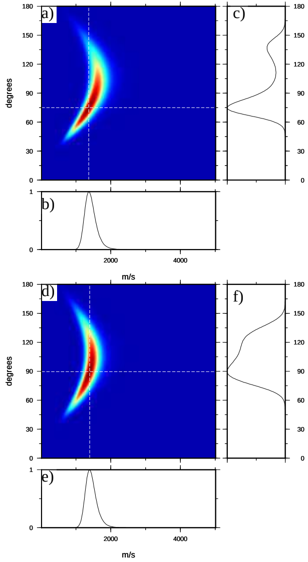
122+/-4 deg 1356+/-188 m/s



120+/-5 deg 1507+/-250 m/s

Back-azimuth same target

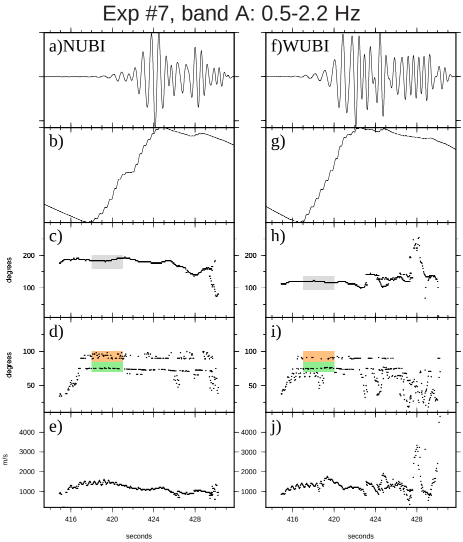
75+/-10 deg 1367+/-140 m/s



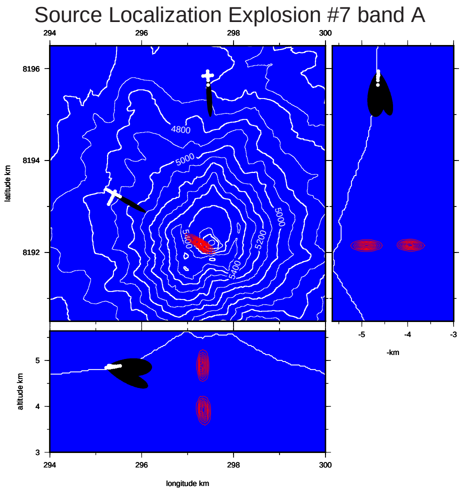
89.0+/-15 deg e) 1391+/-150 m/s

Incidence angle different 2 targets 2-SOURCES

MUSIC-3C on sliding window for explosion #7, band A

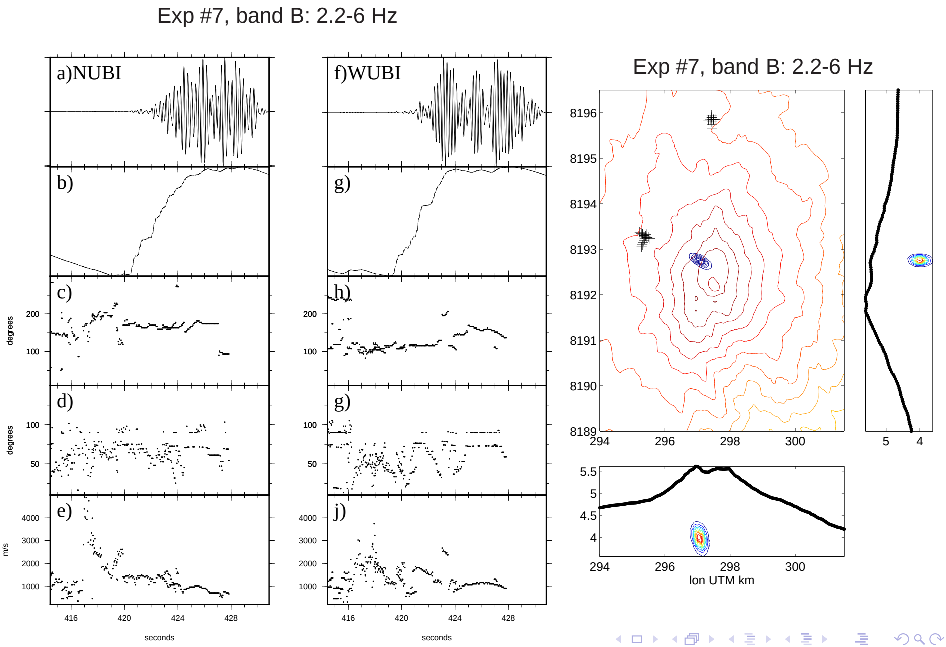


BAZ: NUBI 181.5+/-4 WUBI 117.8+/-3. Incidence: NUBI 74.2+/-7 (green) 93+/-8 (orange). WUBI 75+/-8 (green) 90+/-8 (orange)

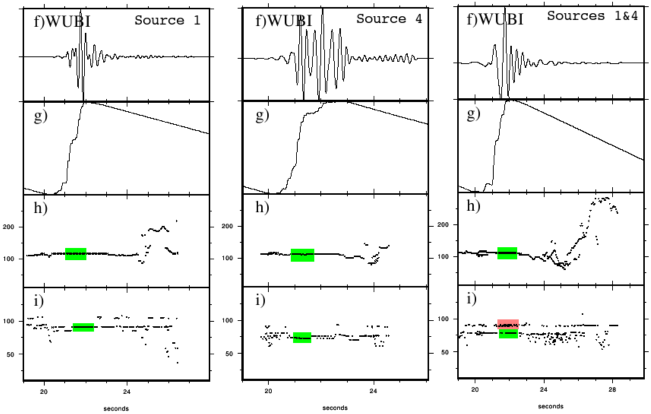


Location (km): Lat 297.37 Lon 8192.34 Alt1 3.95 Alt2 4.85 Error: +/-250 m (2 SOURCES)

MUSIC-3C analysis on band B 2.2-6 Hz

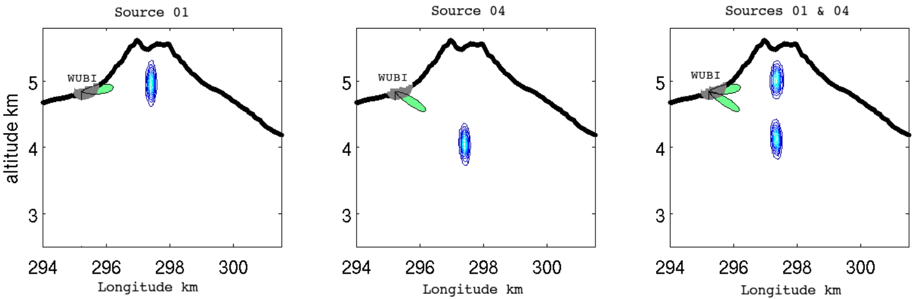


MUSIC-3C analysis on synthetic data 1 and 4



- **Source 01** Back-azimuth: NUBI 180.2+/-3 and WUBI 117.6+/-2. Incidence: NUBI 95.3+/-5 and WUBI 92.8+/-6
- **Source 04** Back-azimuth: NUBI 181.8+/-4 and WUBI 114.6+/-2. Incidence: NUBI 79.4+/-7 and WUBI 73.5+/-6
- **Source 01 & 04** Back-azimuth: NUBI 182+/-3 and WUBI 116.7+/-4. Incidence: NUBI 94.6+/-8 78.7+/-9 and WUBI 93.2+/-7 74.6+/-8

Source localization of synthetic 1 and 4



Locating 16 explosions

Explosion location average: X=297.3981 km, Y=8192.3 km, Z1=3981.3 m, Z2=4813.8 m Error=291 m.

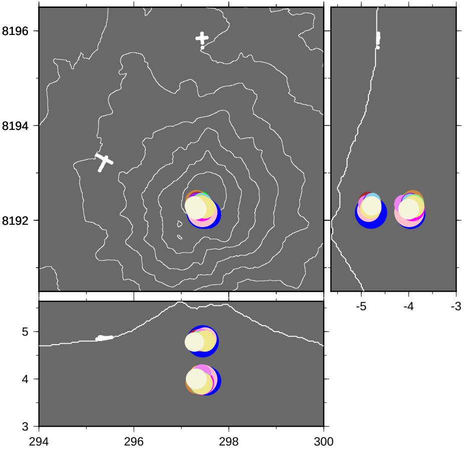
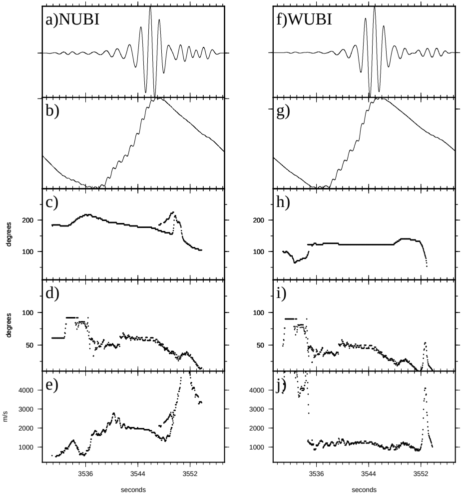
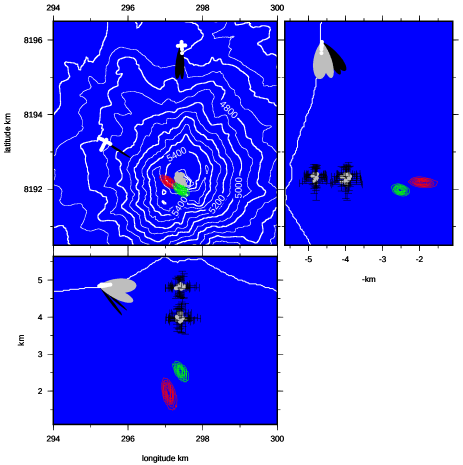


Table: Source Localization given by MUSIC-3C analysis on the 16 explosion events.

Item	Xlon-Ylat	Alt1	Alt2	Error
1	297.53 8192.12	3.96	4.79	0.42
2	297.43 8192.34	4.06	4.85	0.24
3	297.41 8192.41	3.97	4.81	0.27
4	297.30 8192.41	4.01	4.81	0.20
5	297.32 8192.41	3.92	4.78	0.31
6	297.37 8192.34	3.95	4.85	0.28
7	297.37 8192.20	4.10	4.85	0.25
8	297.36 8192.28	3.98	4.82	0.27
9	297.44 8192.17	3.99	4.85	0.42
10	297.43 8192.24	3.92	4.77	0.35
11	297.43 8192.34	4.11	4.89	0.26
12	297.37 8192.38	3.97	4.79	0.27
13	297.47 8192.39	3.97	4.77	0.22
14	297.39 8192.35	3.88	4.81	0.28
15	297.43 8192.28	3.91	4.80	0.32
16	297.32 8192.23	4.00	4.78	0.29

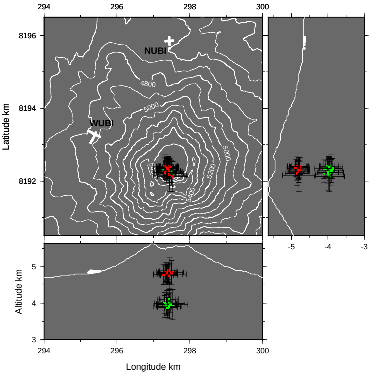
MUSIC-3C analysis on LP events





- BAZ: NUBI 187+/-8 WUBI 119+/-4. Incidence: NUBI 49.9+/-6 WUBI 37.8+/-4
- BAZ: NUBI 181+/-6 WUBI 119+/-4. Incidence: NUBI 60+/-9 WUBI 49+/-3
- Location (km): Lat 297.2 Lon 8192.2 Alt1 1.8 Error 490m (red)
- Location (km): Lat 297.5 Lon 8192 Alt1 2.5 Error 339m (green)

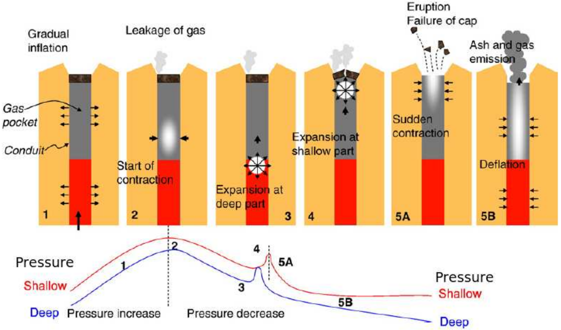
Mechanism of vulcanian explosion - 2 sources



- *Lokmer et al 2007* studied the distortion of the seismic propagation in heterogeneous media (Etna volcano), it is minimized when distances between sources and receivers (sensors) are close.
- Two sources located at two different depths separated by about 800 m, the first at the shallow crater and other at the deeper.
- *Thomas and Neuberg (2012)* have referred multiple seismic sources for low frequency activity at Montserrat volcano.
- *Ruiz et al 2005* analyzed recordings of infra-sound and seismic, earthquakes travel-times for vulcanian activity at Tuguragua volcano presented two sources.
- *Iguchi et al 2008* referred to two sources for vulcanian activity, the first caused by the abrupt decompression of the conduit and subsequently, the second source by the abrupt increase of the internal pressure.

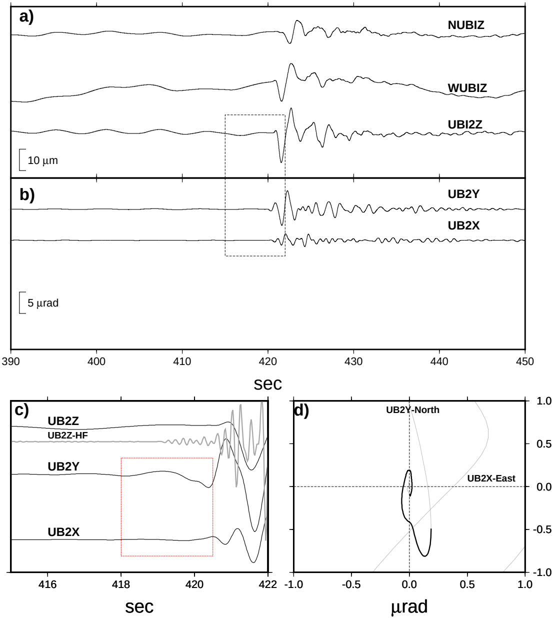
Vulcanian explosion mechanism

Iguchi et al. 2008: Tilt and infrasound observations from 3 stratovolcanoes **Sakurajima, Suwanosejima** (Japan) and **Semeru** (Indonesia)



1. Ascent of magma, pressure and volume increase (inflation) into the sealed conduit.
2. Pressure exceeds the strength of the cap, pressure decreased (deflation) due to gas is gradually released.
3. Gas bubbles increased disturbing the pressure in deep (increased), sudden outgassing, start the explosion.
4. Sudden expansion on the shallow part destroying the cap at the top of the conduit.
5. Failure of the cap at the top, sudden contraction due to failure of the cap, degassing from the conduit.

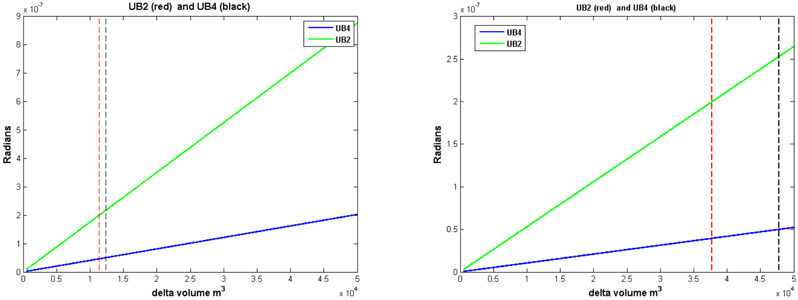
Mechanism of vulcanian explosion - Tilt observation



- a) Ground displacement waves of NUBI, WUBI and UBI2Z
- b) Tiltmeter waveforms
- c) Zoom of explosion onset waves
- d) Tilt X-Y diagram

MOGI Model

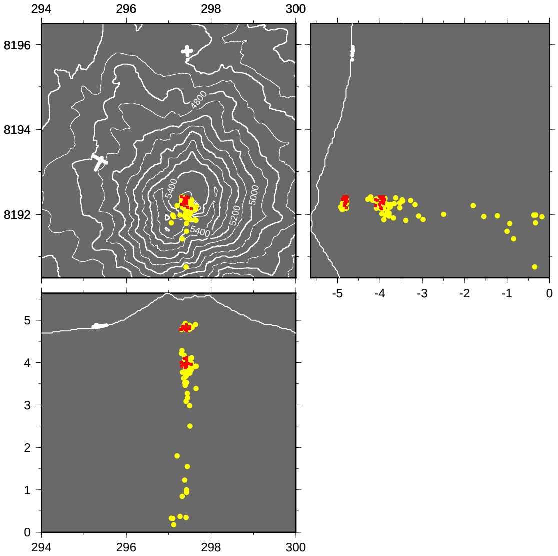
Relationship between tilt deformation and volume change in magma zone



- The relationship between surface tilt and volume change from *Mogi (1958)* $u = \frac{3\Delta V h^3}{4\pi h^2 (h^2+r^2)^{3/2}}$
- Mogi model fixed in an elastic, homogeneous and elastic half-space.
- Deeper source: Tilt UB2 $\Delta V = 11871.5m3 + / - 4\%$
- Shallow source: $\Delta V = 43374m3 + / - 13\%$
- Calculation of ground tilt performed using Mogi model matlab code, developed by François Beauducel

Plan

Conclusion - Magma pathway



- Red points are location of explosions, yellow points are LP events
- Source localization
- Vulcanian explosion

Conclusions

Contributions

- The new approach MUSIC-3C for locating seismo-volcanic source localization. MUSIC-3C was validated with synthetic datasets and compared with 1C-array data. The MUSIC-3C method properly estimated the back-azimuth, incidence angle and slowness, while 1C-array only the back-azimuth. MUSIC-3C method has retrieved 8 synthetic sources for Ubinas.
- A field experiment was carried out deploying 22 instrument at the flanks of Ubinas to collect array-data from 2 seismic antennas.
- Vulcanian activity recorded at Ubinas was analyzed by using the MUSIC-3C method. Two sources at different depths (800 m of separation) were found for explosion events by using the MUSIC-3C method. These two sources were interpretated using Iguchi model
- Fifty long period events have been located. Hypocenters were displayed on Ubinas map, as a magma pathway for Ubinas volcano.

Perspectives

- Data collection during the field experiment at Ubinas 2009 recorded hundreds of LP earthquakes and several hours of tremor events, which were not completely analyzed. These data need to be analyzed in order to understand the mechanism of magma movement.
- MUSIC-3C can be implemented for monitoring Ubinas and Misti volcanoes.
- The near surface velocity model image is necessary for Ubinas and Misti to evaluate the source localization.
- Implement MUSIC-3C with MUSIC wide-band approach.

Publications

1. **A. Inza**, J. P. Métaxian, J.I. Mars, C.J Bean, G. S. O'Brien, O. Macedo, D. Zandomeneghi. **2013**, Analysis of dynamics of Vulcanian activity of Ubinas volcano, using multicomponent seismic antennas. **Submitted to Journal of Volcanology and Geothermal Research in March 2013**. **Submitted**.
2. **L. A. Inza**, J.I. Mars, J. P. Métaxian, G. S. O'Brien, O. Macedo. Seismo-volcano source localization with triaxial broad-band seismic array, **2011**, Geophysical journal international, DOI: 10.1111/j.1365-246X.2011.05148.x. **Published**.
3. **Adolfo Inza**, Jérôme I. Mars, Jean-Philippe Métaxian, Gareth S. O'Brien, and Orlando Macedo. **2011**, Three-component array location of LP and explosions. EGU conference Vienna Austria. **Published**.
4. **L. A. Inza**, J.I. Mars, J. P. Mtaxian, G. S. O'Brien, O. Macedo. **2011**, Localization with multicomponent seismic array. 2011 4th IEEE International Workshop on Computational Advances in Multi-Sensor Adaptive Processing. San Jose Costa Rica. **Published**.
5. D. Zandomeneghi, **A. Inza**, J-P. Métaxian, and O. Macedo. **2012**, Long-Period seismic events at Ubinas Volcano (Peru): their implications and potentiality as monitoring tool. 2012 EGU conference Vienna Austria. **Published**
6. Traversa, P., O. Lengline, O. Macedo, JP. Métaxian, JR. Grasso, **A. Inza**, E. Taipe, **2011**, Short Term Forecasting of Explosions at Ubinas Volcano, Peru, Journal of Geophysical Research. Solid Earth, 116, p. B11301. p. B11301 ISSN 0148-0227. **Published**
7. Macedo, O., J. P. Métaxian, E. Taipe, D. Ramos and **A. Inza**. **2009**, Seismicity associated to Ubinas volcano eruption, 2006-2008, VOLUME book ISBN: 978-1-905254-39-2, 2009. **Published**.

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Thanks for your attention