Monopole source applied to volcanic eruptions

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Volcano Acoustics Workshop
IAVCEI Kagoshima 2013

Simple acoustic monopole source* applied to volcanic eruptions:

Simplifications often invoked:

- Source is simple acoustic (i.e., point source or compact)
  - -> characteristic wavelength is >> vent region (ka<<1)
- Propagation is simple acoustic (i.e., omnidirectional)
  - -> raypaths spread radially
- Sound recorded is purely far-field term (kr>>1)
  - -> pressure falls off as 1/r
- Propagation is linear
  - -> linear relation between stress and strain (no shock)

Assumptions lead to:

- Recorded pressure is proportional to volumetric acceleration of the atmosphere

*Lighthill (1978), Waves in Fluids, 504 pp, Cambridge University Press

Acoustic monopole source (sinusoid):

$$\delta p(r,t) = i\omega\rho_0 \frac{Q(t-r/c)}{\Omega r} e^{i\omega(t-r/c)}$$

$\delta p(r,t)$ is the excess pressure (in Pa)

r is the distance (m)

c is the sound speed (m/s)

ρ_0 = density of air (kg/m^3)

Q is the source strength (volumetric flux in m^3/s)

Ω is solid angle (4π for whole space)

In terms of volume Flux:

$$\delta p(r,t) = \rho_0 \frac{\dot{Q}(t-r/c)}{\Omega r} \text{ where } \dot{Q} = \ddot{V} \text{ (volume acceleration)}$$

ρ_0 = density of air (kg/m^3)

$\dot{Q}$ is 'alternative' source strength (volumetric acceleration in m^3/s^2)

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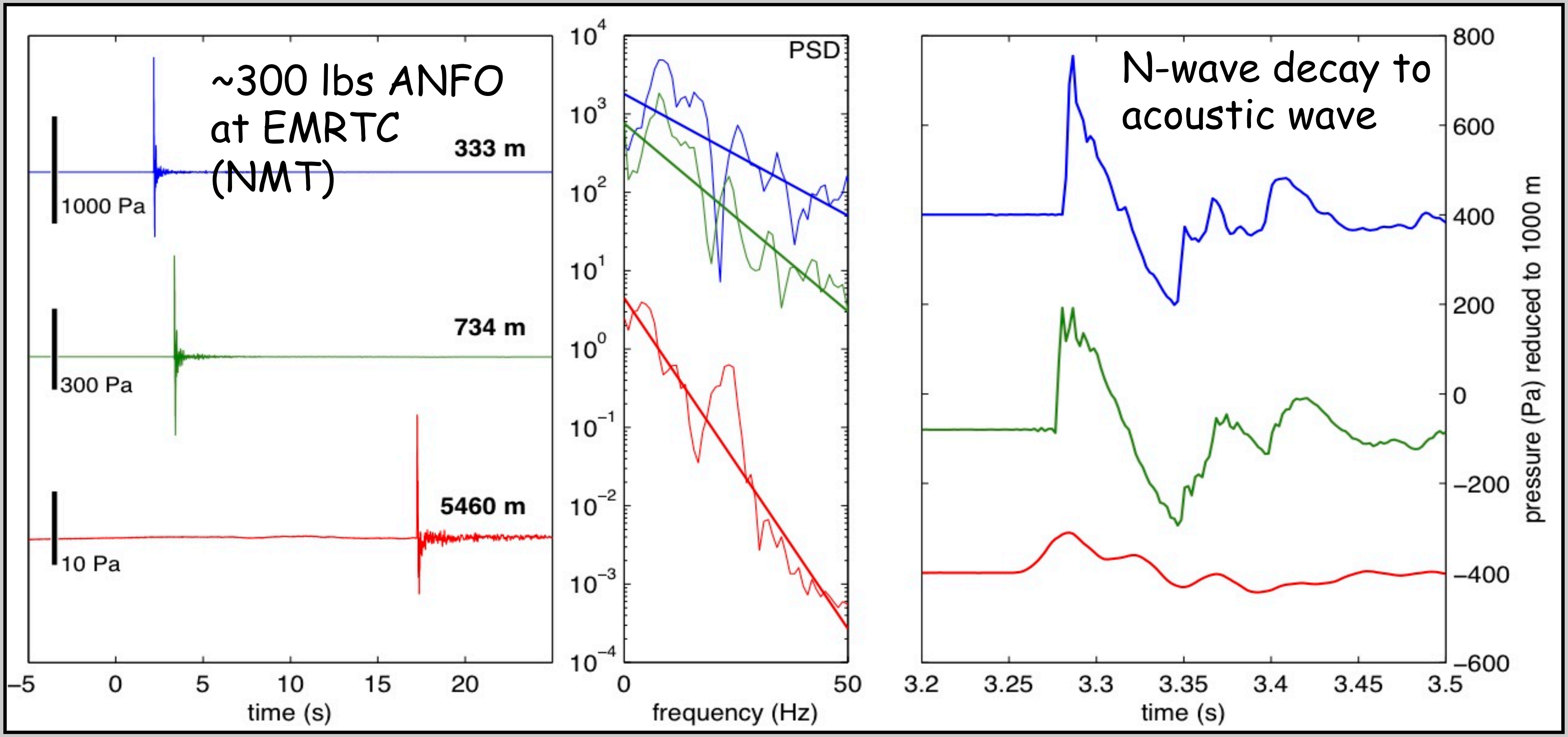
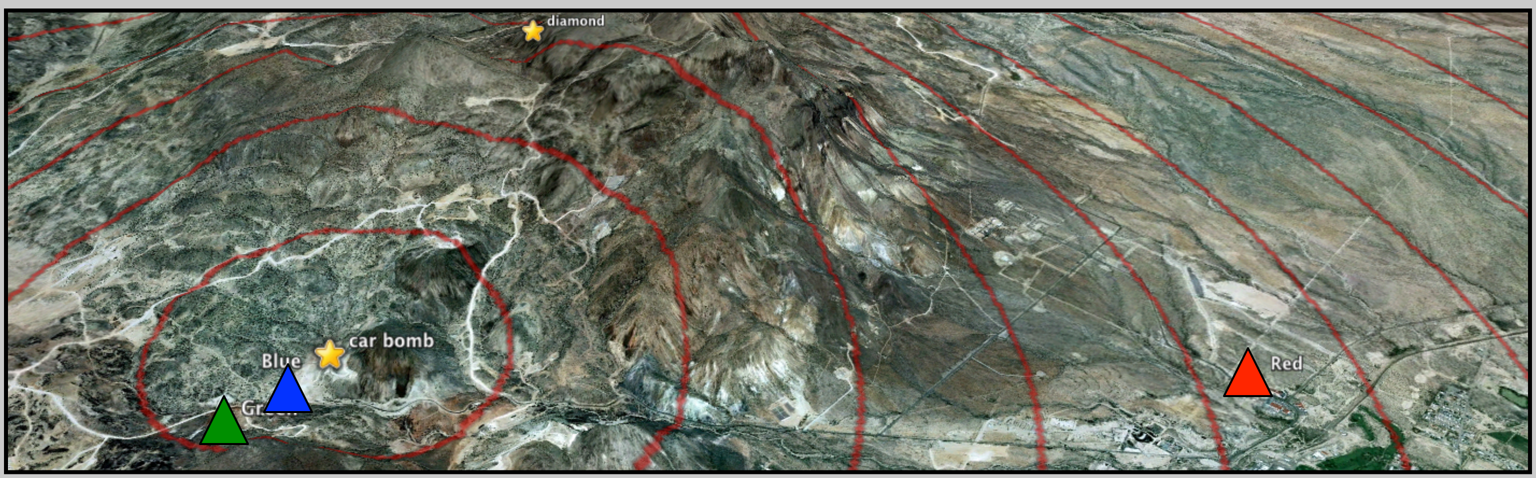
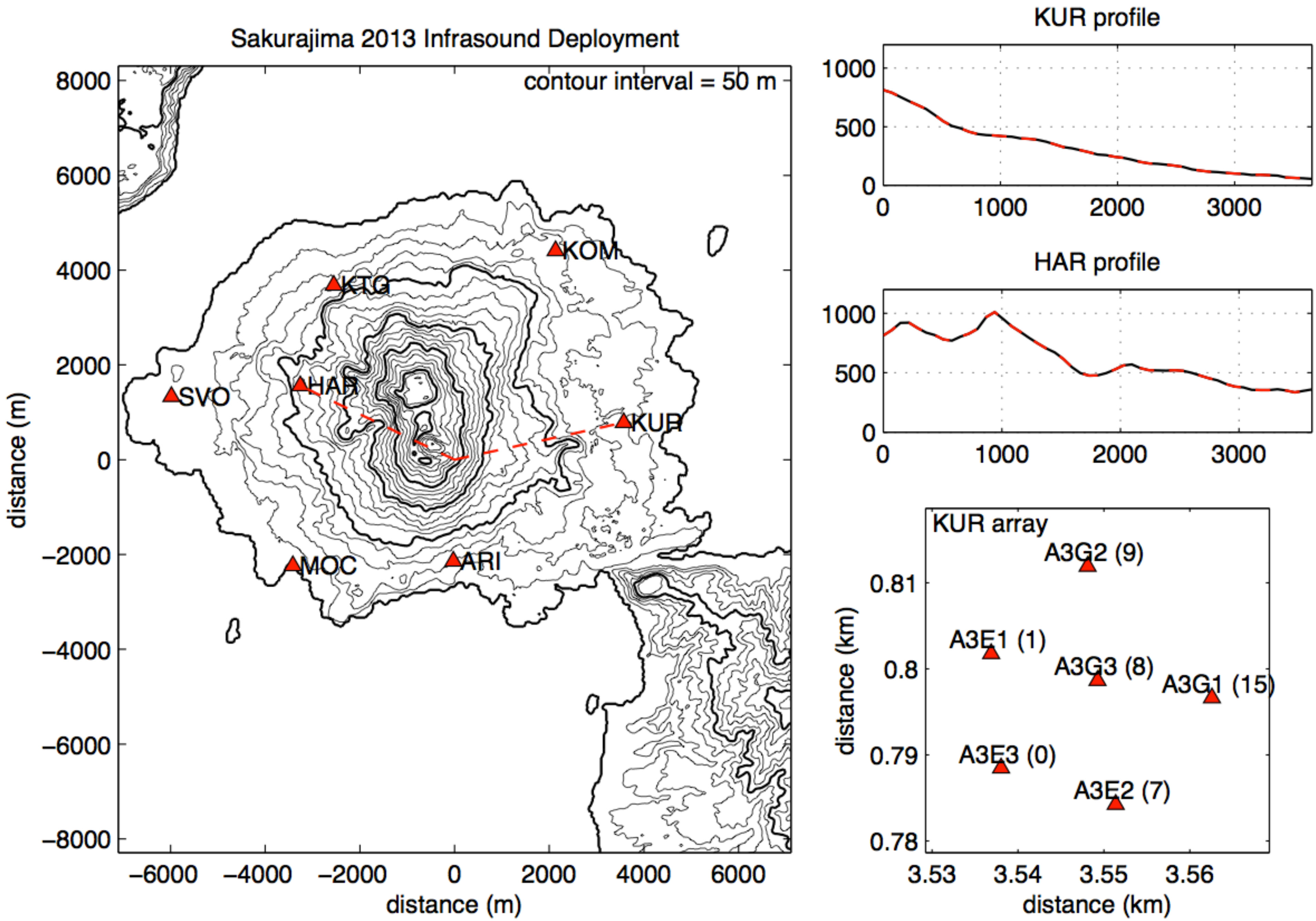
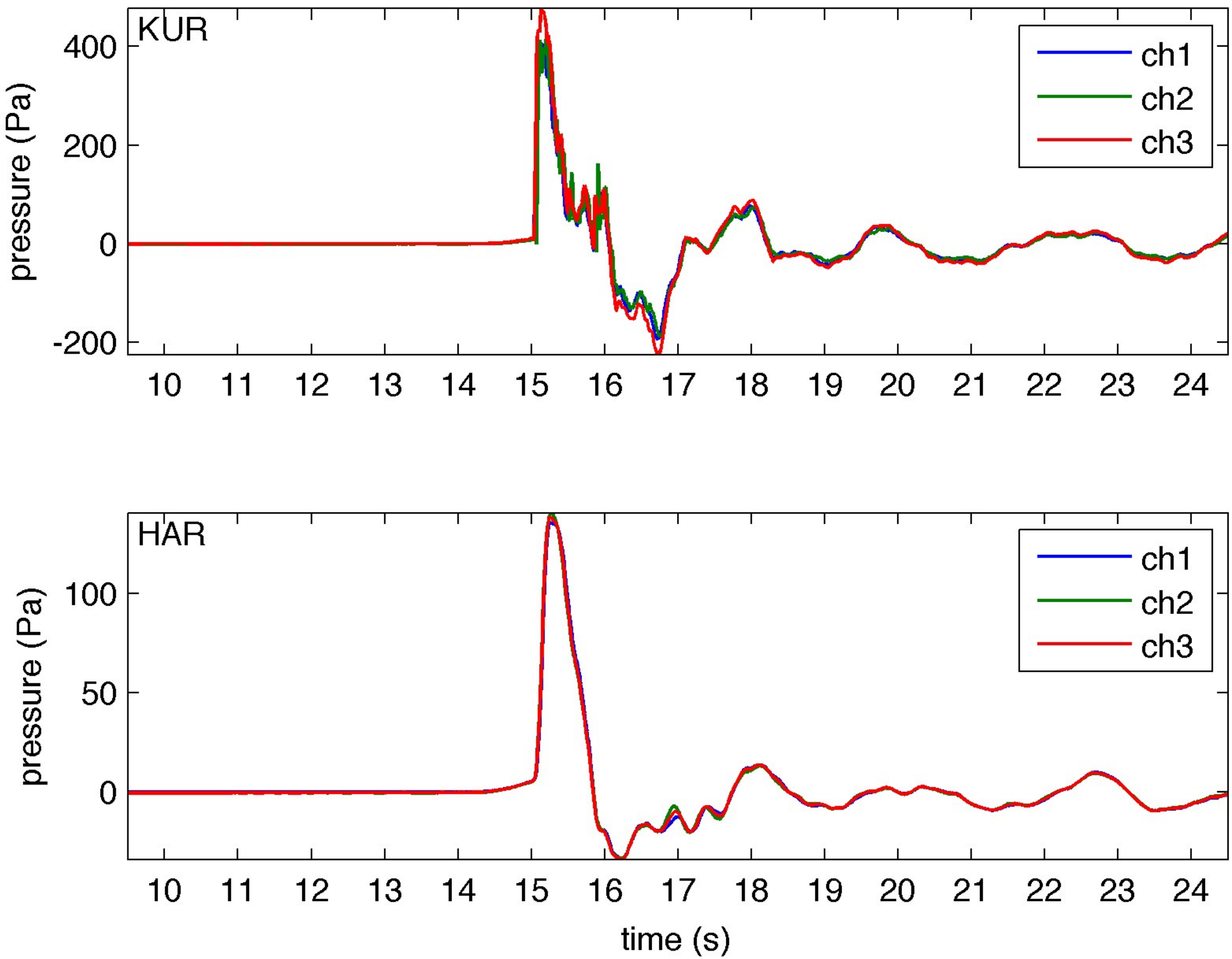

~300 lbs ANFO
at EMRTC
(NMT)
333 m
734 m
5460 m
1000 Pa
300 Pa
10 Pa
time (s)
PSD
frequency (Hz)
N-wave decay to
acoustic wave
pressure (Pa) reduced to 1000 m
time (s)


diamond
car bomb
Blue
Red

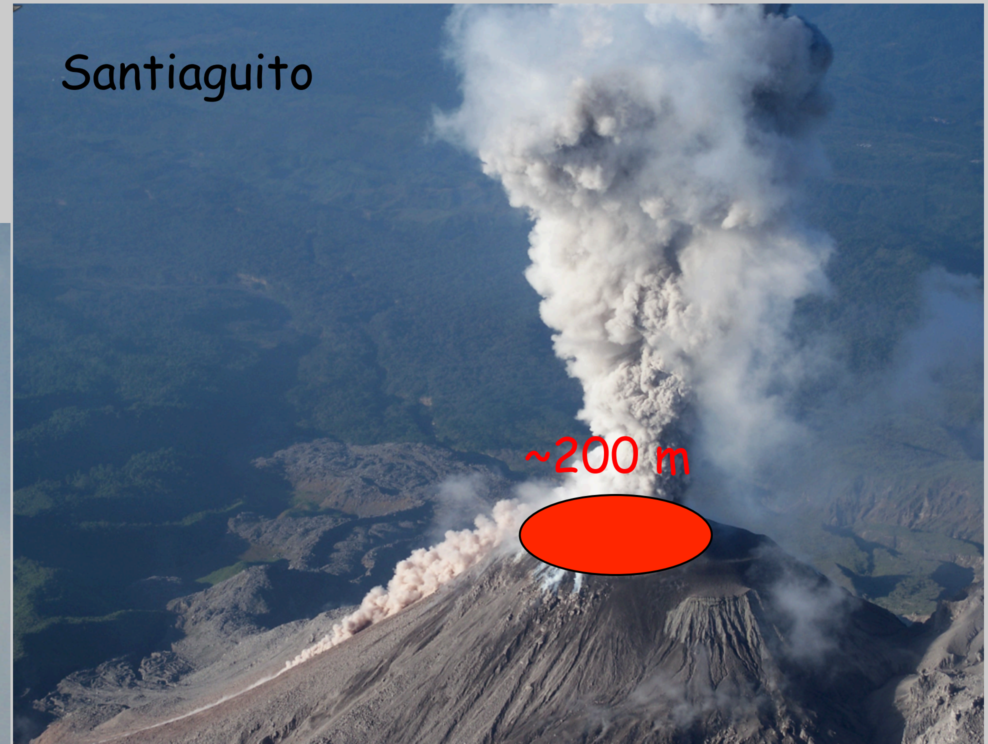


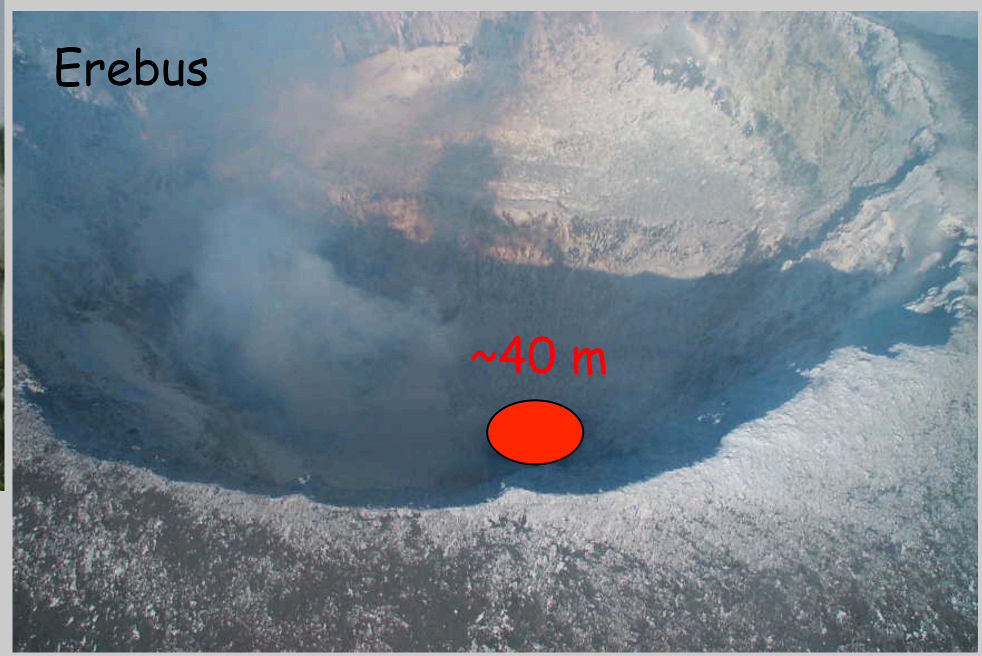
Sakurajima 2013 Infrasound Deployment
contour interval = 50 m
KOM
KTG
SVO
HAR
KUR
MOC
ARI
distance (m)
KUR profile
HAR profile
KUR array
A3G2 (9)
A3E1 (1)
A3G3 (8)
A3G1 (15)
A3E3 (0)
A3E2 (7)
distance (km)


KUR
ch1
ch2
ch3
400
200
0
-200
pressure (Pa)
10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
HAR
ch1
ch2
ch3
100
50
0
pressure (Pa)
10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
time (s)

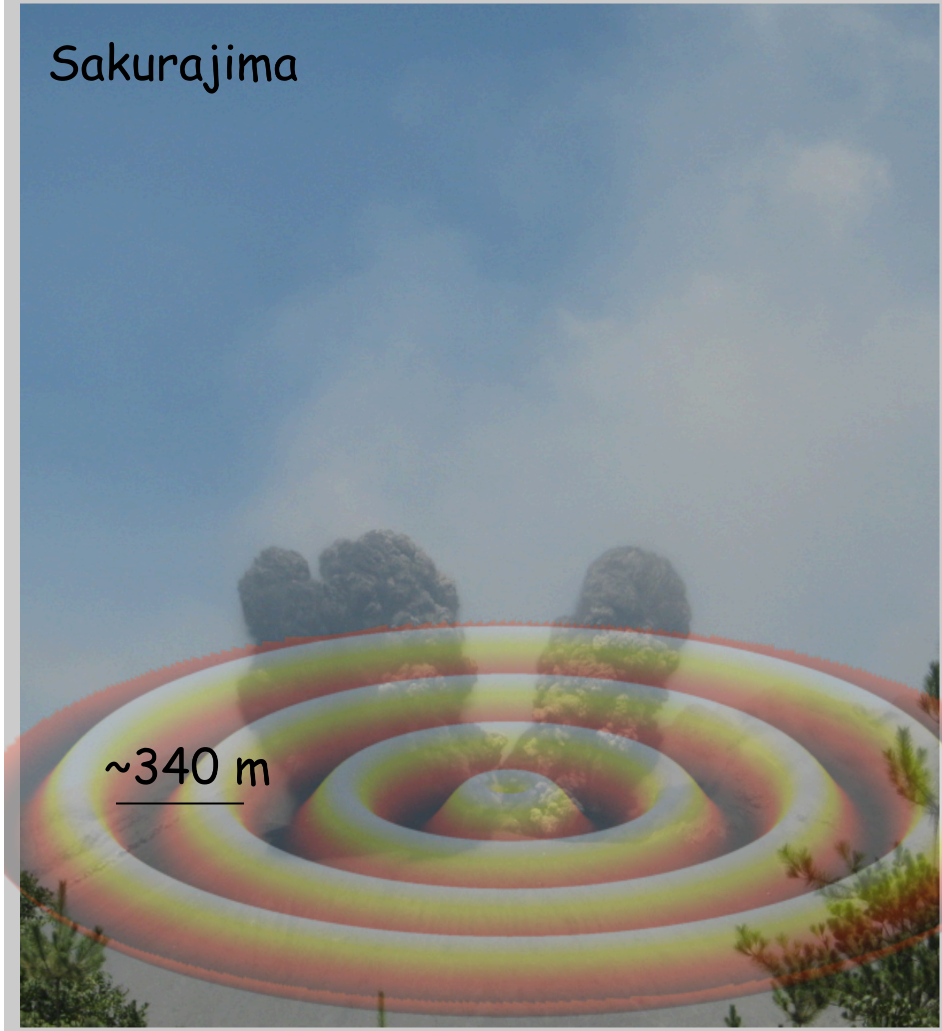
Possible Volcanic Monopoles

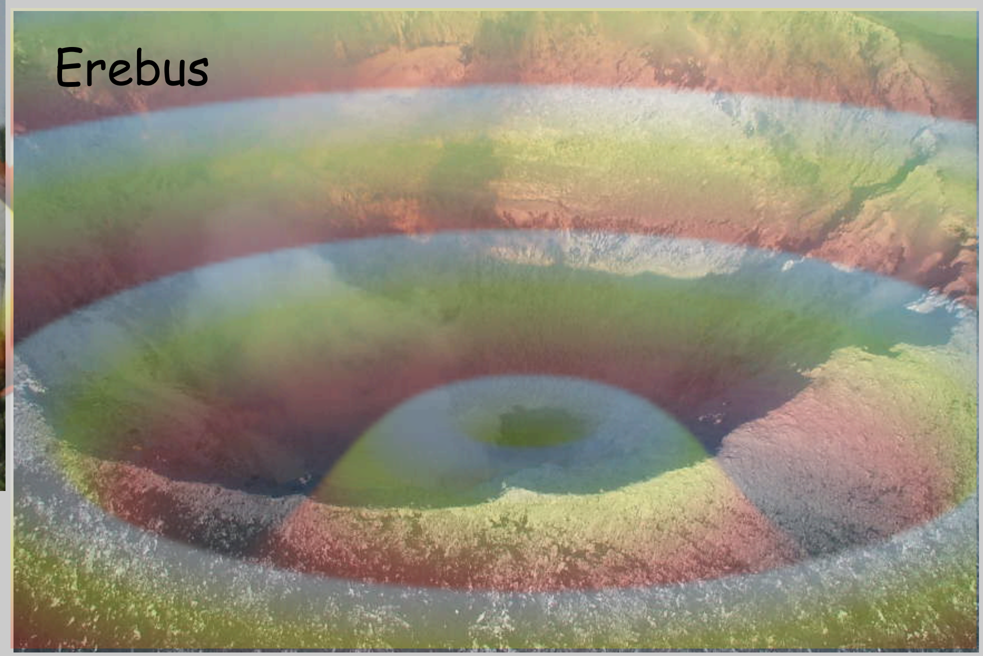
Vent Dimensions

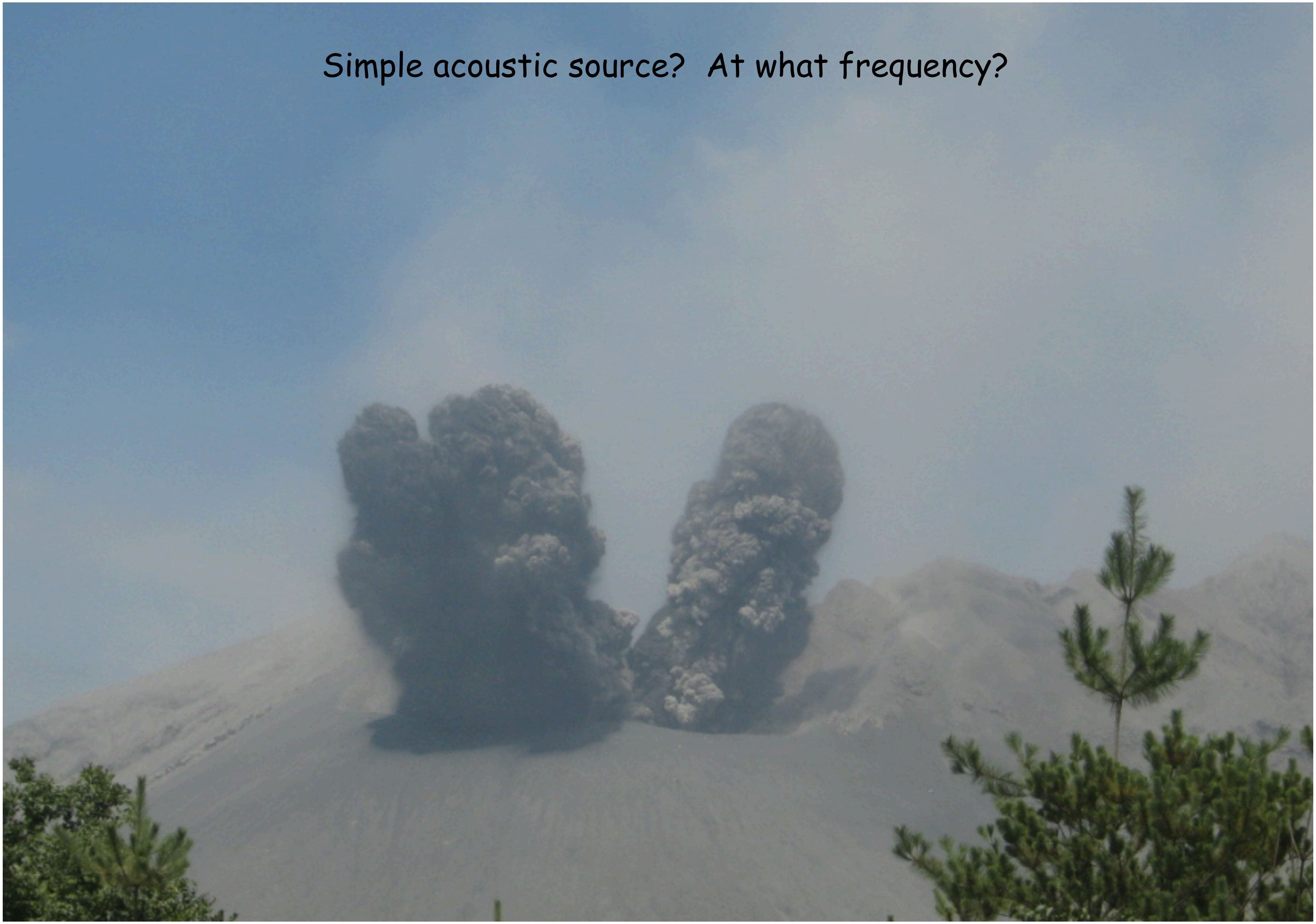




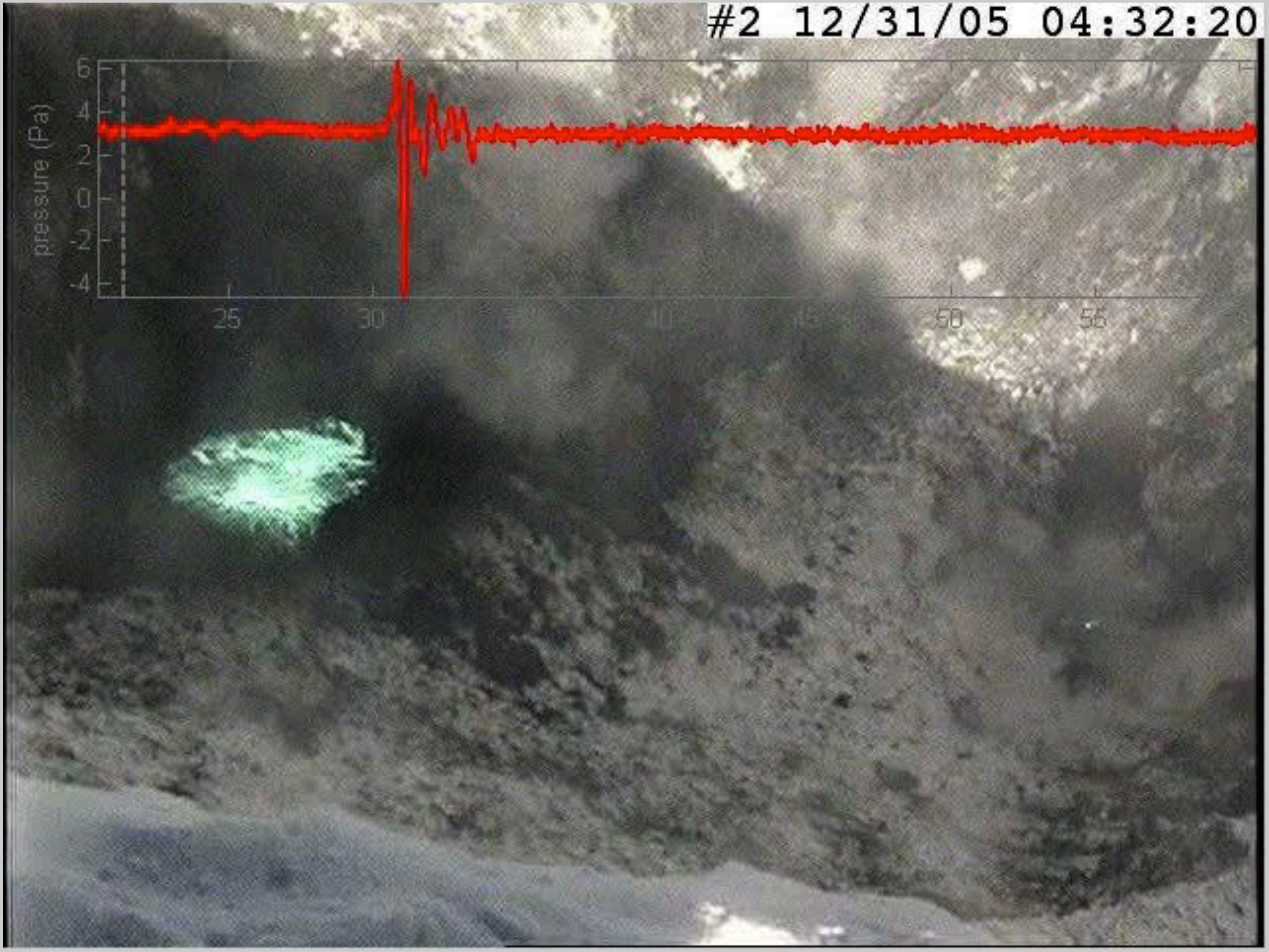
~1 Hz infrasound





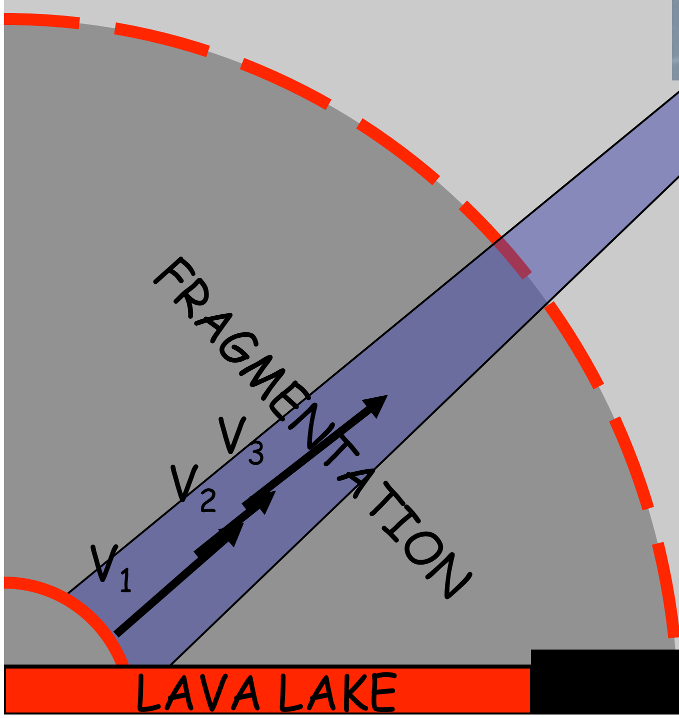

Simple acoustic source? At what frequency?


Erebus

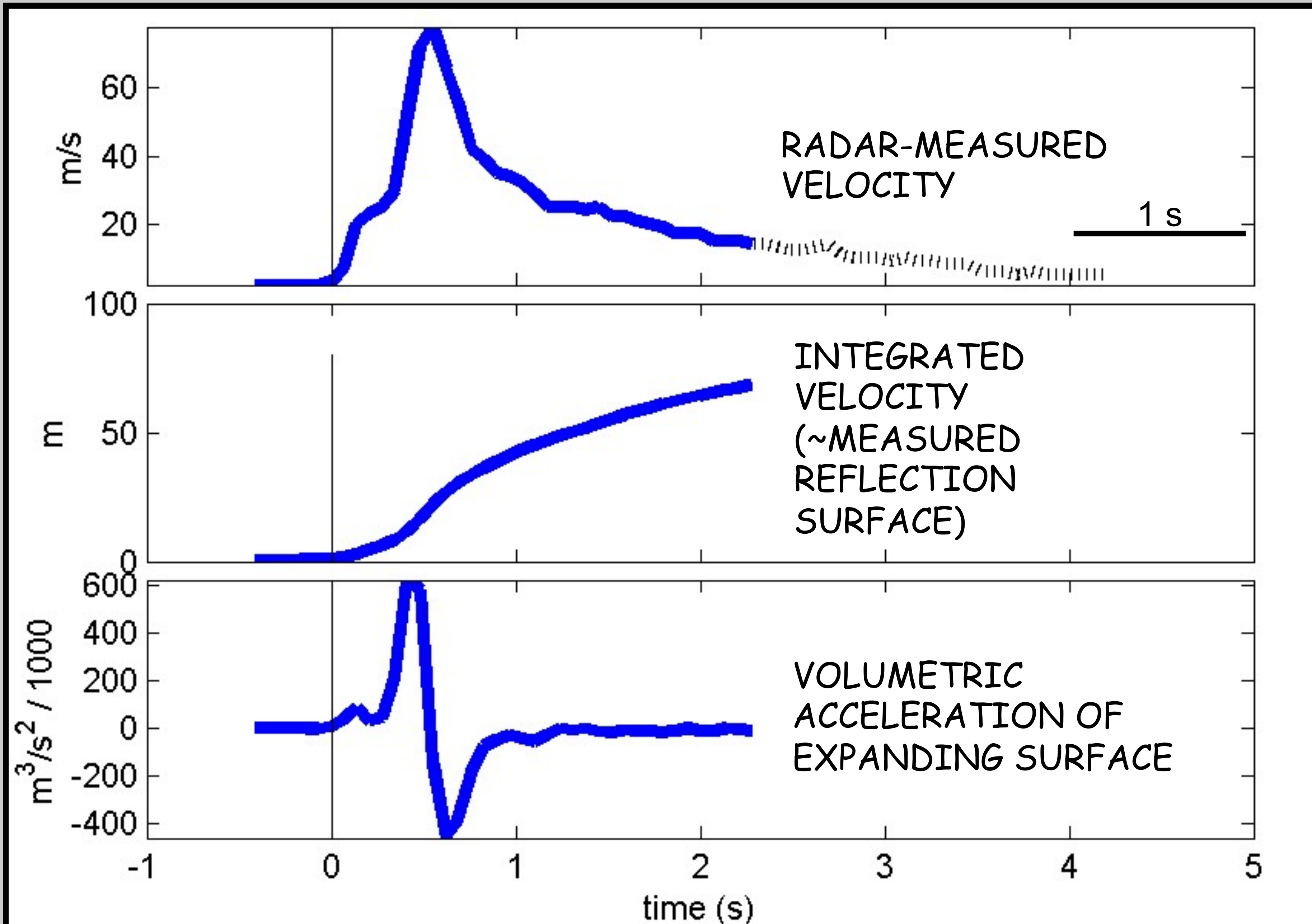

#2 12/31/05 04:32:20
pressure (Pa)
6
4
2
0
-2
-4
25
30
50
55


#2 12/31/05 10:53:37
40
45
50
55
60
65
70
75


#2 12/31/05 11:44:29
pressure (Pa)
20
0
-20
-40
-60
-80
30
35
40
45
50
55
60
65



More on this @: Gerst et al. (2013) The first second of volcanic eruptions from the Erebus Volcano lava lake, Antarctica – Energies, pressures, seismology, and infrasound, Journal of Geophysical Research, V. 118, 1-23



RADAR-MEASURED VELOCITY
1 s
m/s
60
40
20
INTEGRATED VELOCITY (~MEASURED REFLECTION SURFACE)
m
100
50
0
VOLUMETRIC ACCELERATION OF EXPANDING SURFACE
m^3/s^2 / 1000
600
400
200
0
-200
-400
-1
0
1
2
3
4
5
time (s)

Acoustic Monopole Source

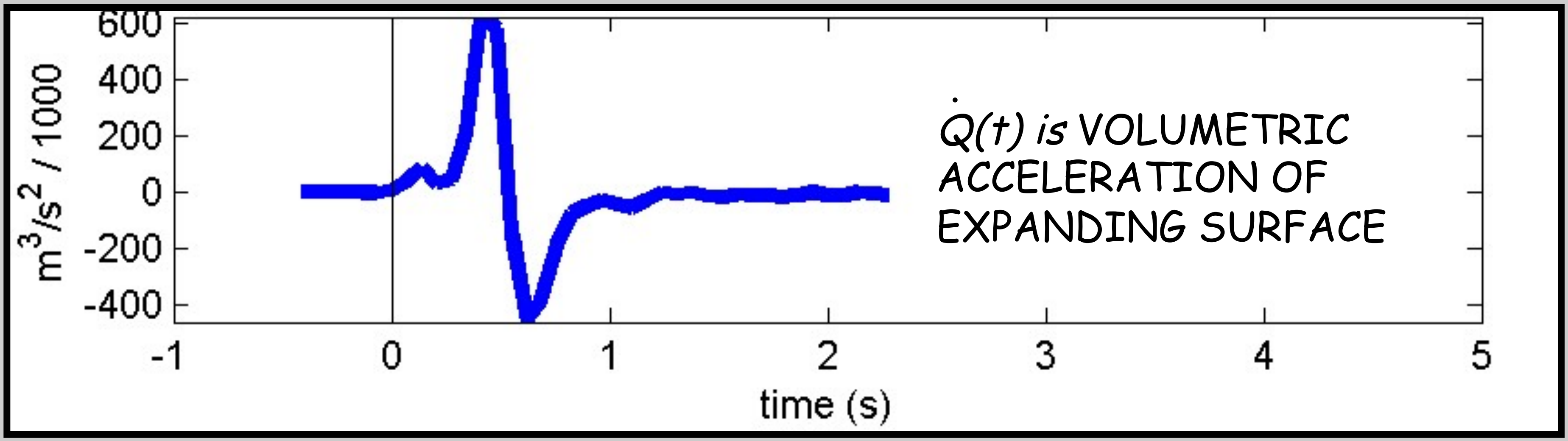
$$\delta p(r, t) = \rho_0 \frac{\dot{Q}(t - r/c)}{2\pi r}$$

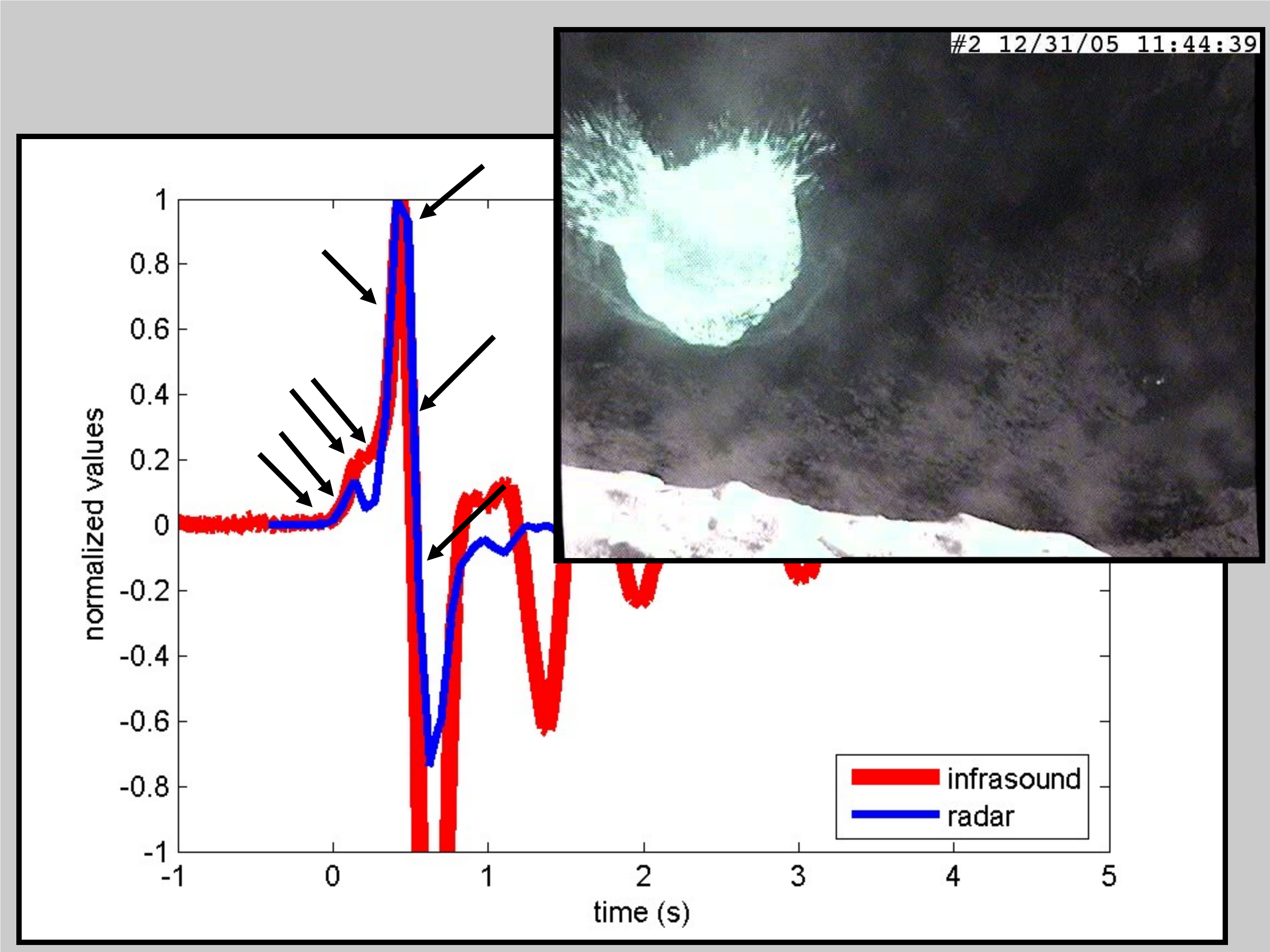
$\delta p(r,t)$ is the excess pressure (in Pa)

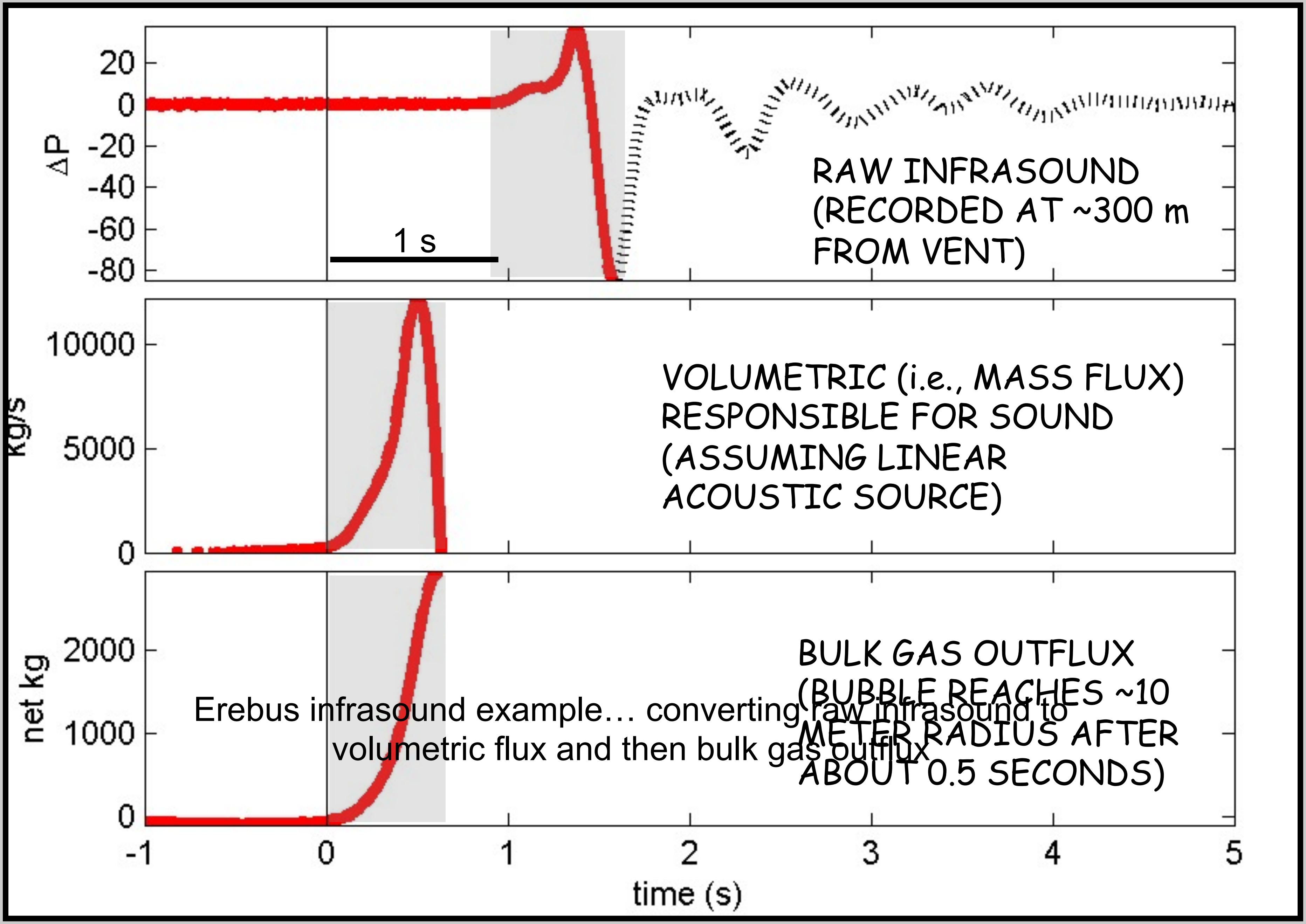
r is the distance and c is the sound speed

$\dot{Q}$ is the source strength (volumetric acceleration in m^3/s^2)

$\Omega = 2\pi$ for hemispherical spreading

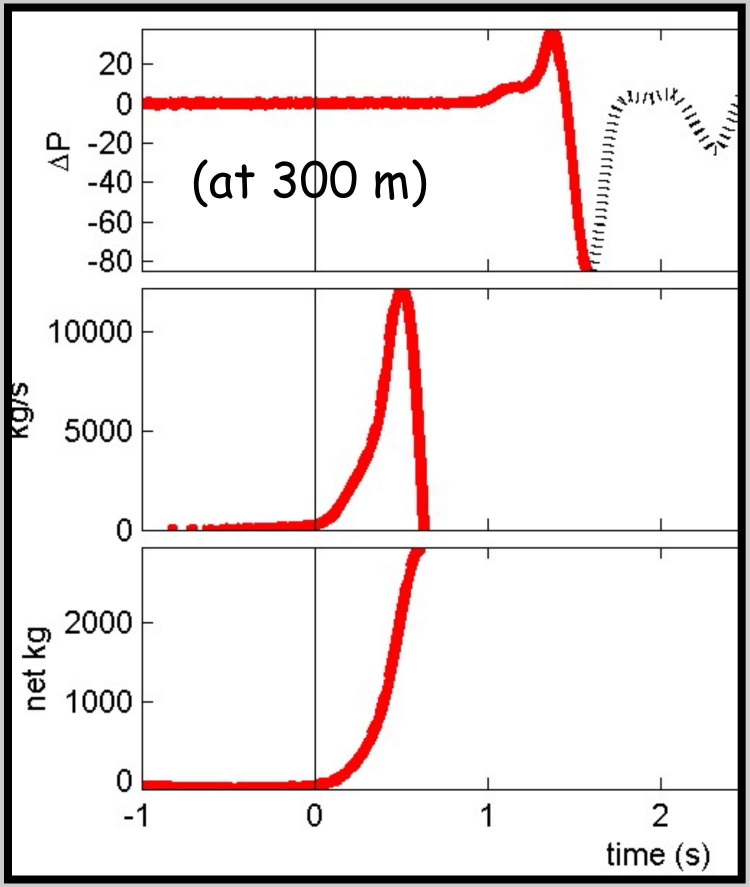



#2 12/31/05 11:44:39
normalized values
time (s)
infrasound
radar
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1
0
1
2
3
4
5

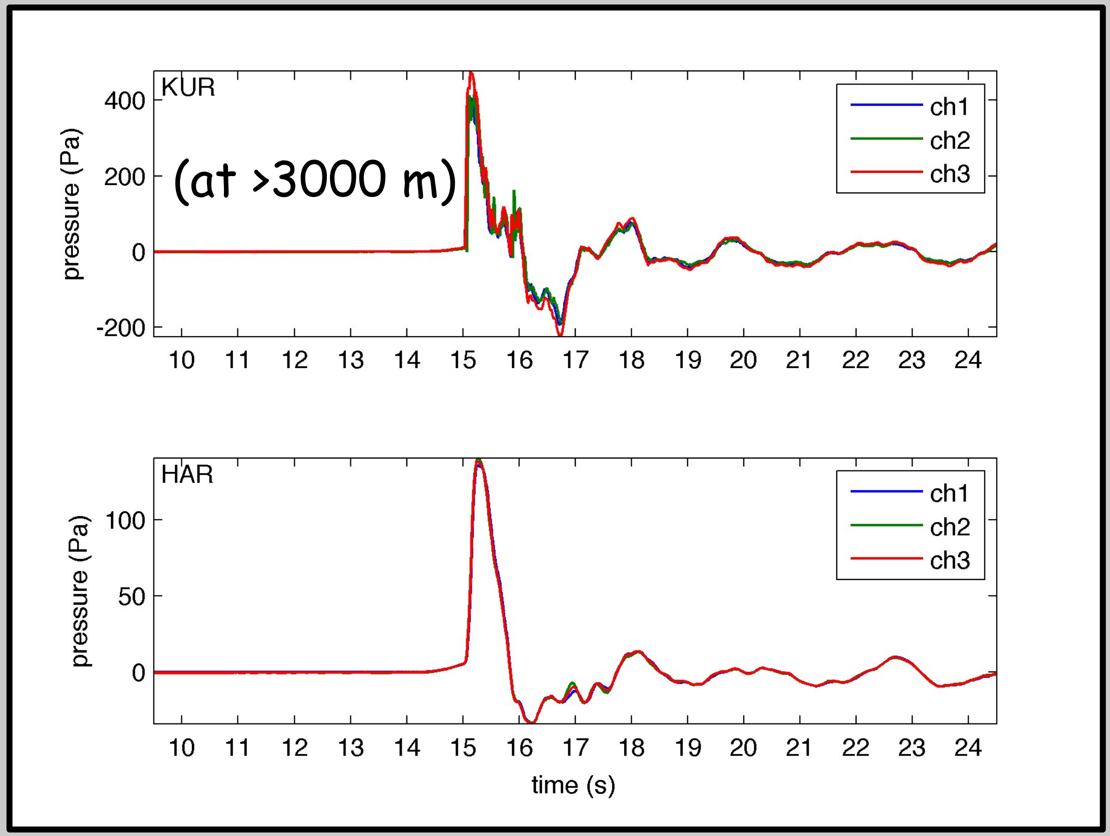


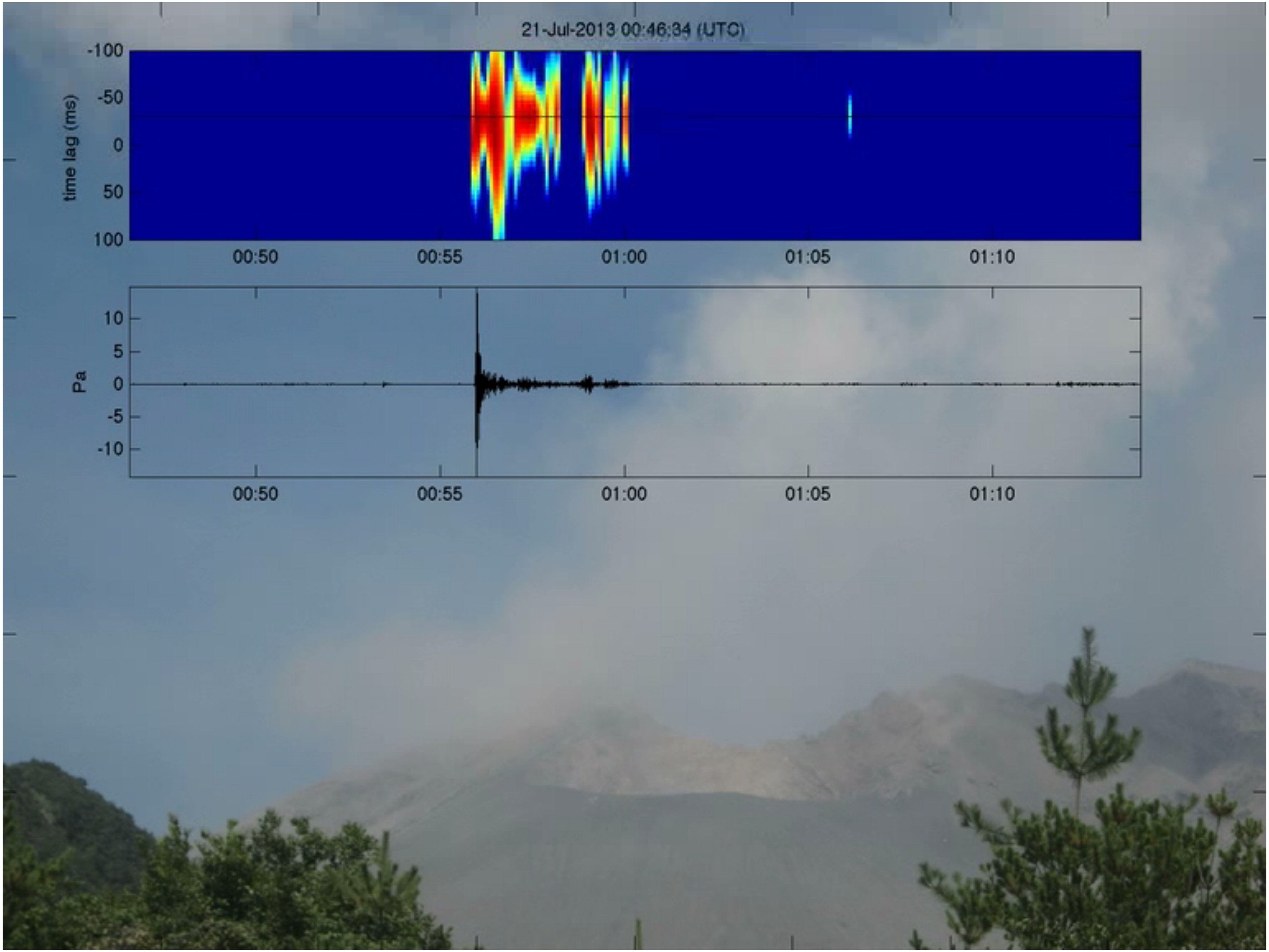
Erebus infrasound example… converting raw infrasound to volumetric flux and then bulk gas outflux

Erebus

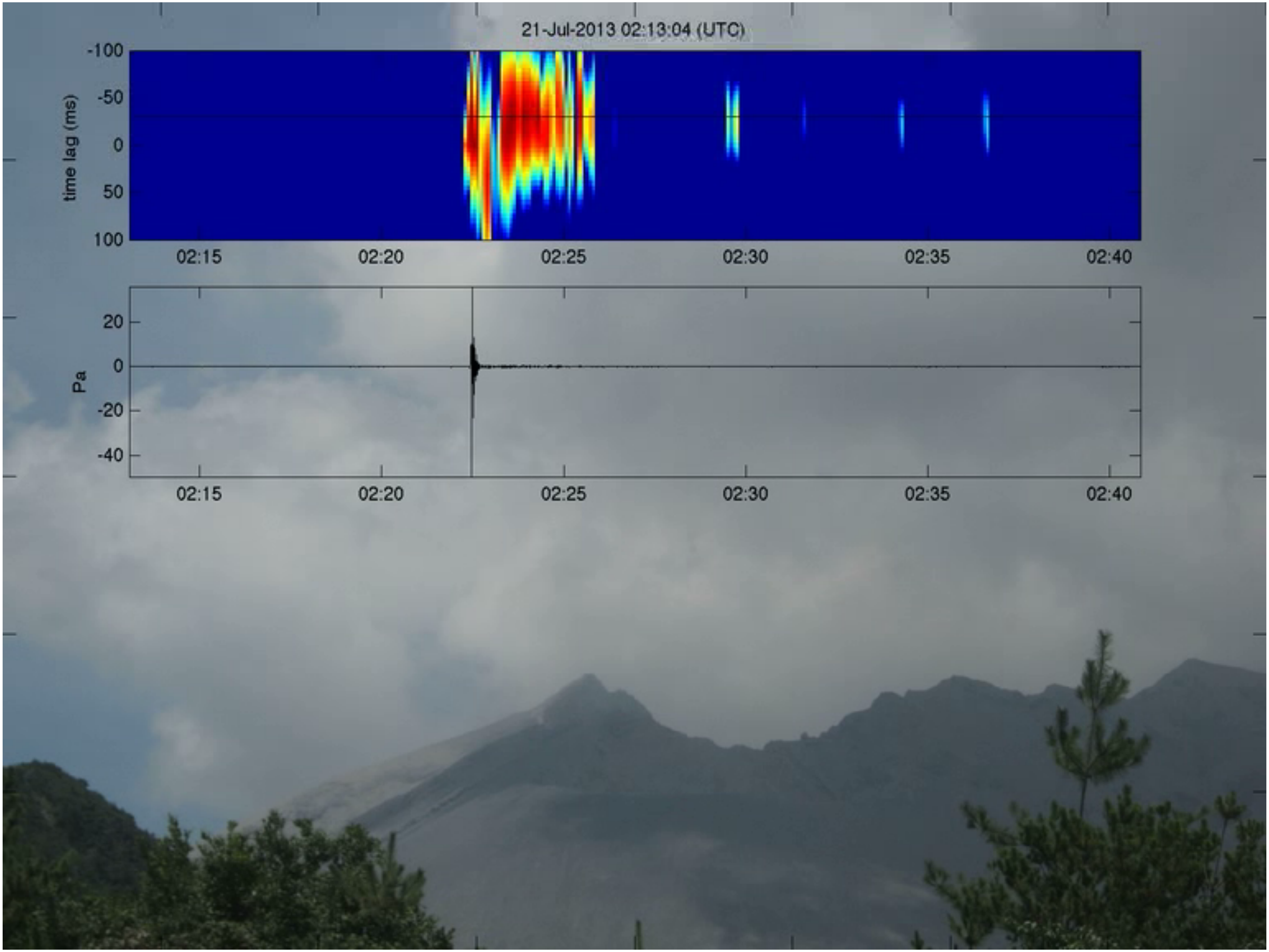


Sakurajima

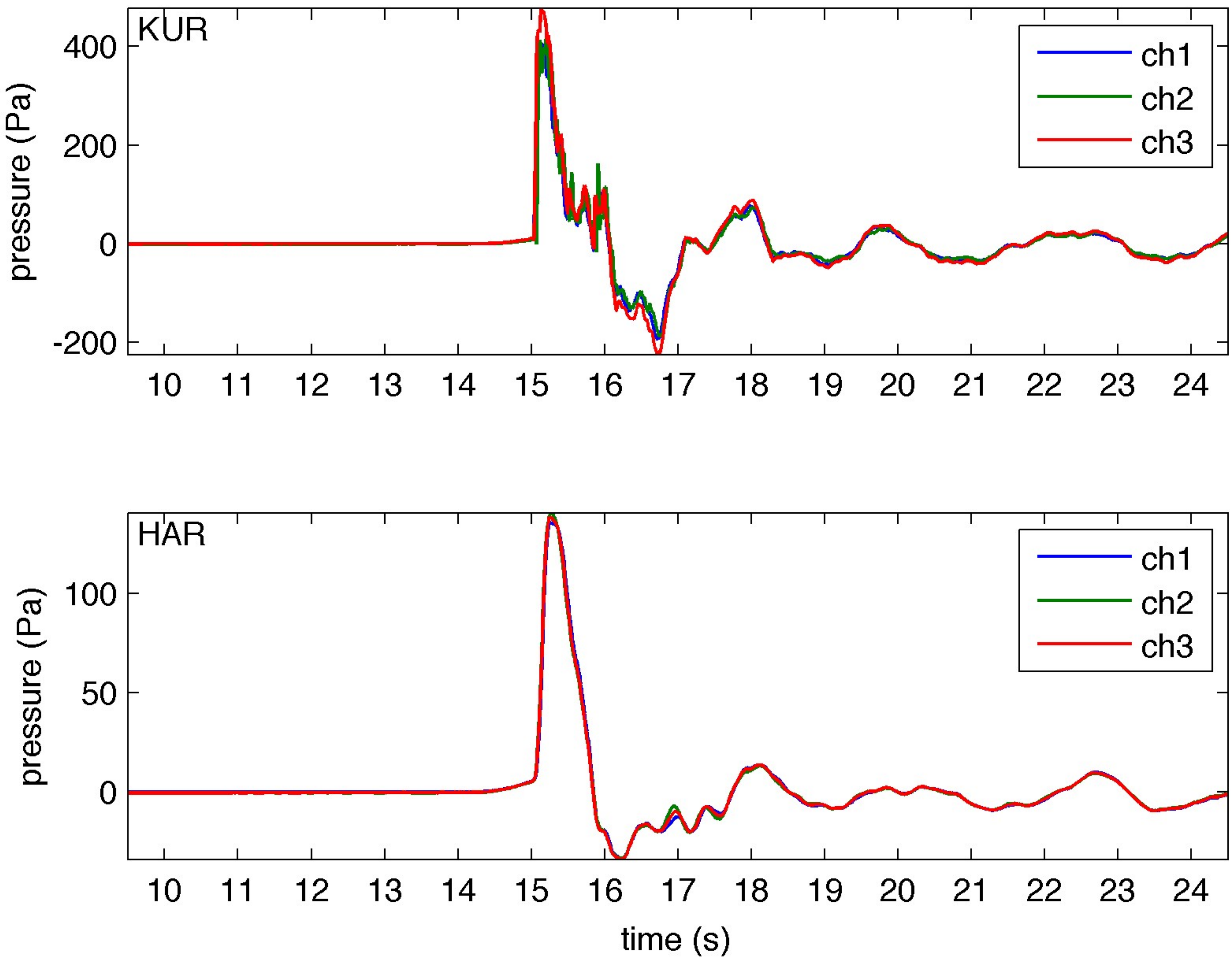


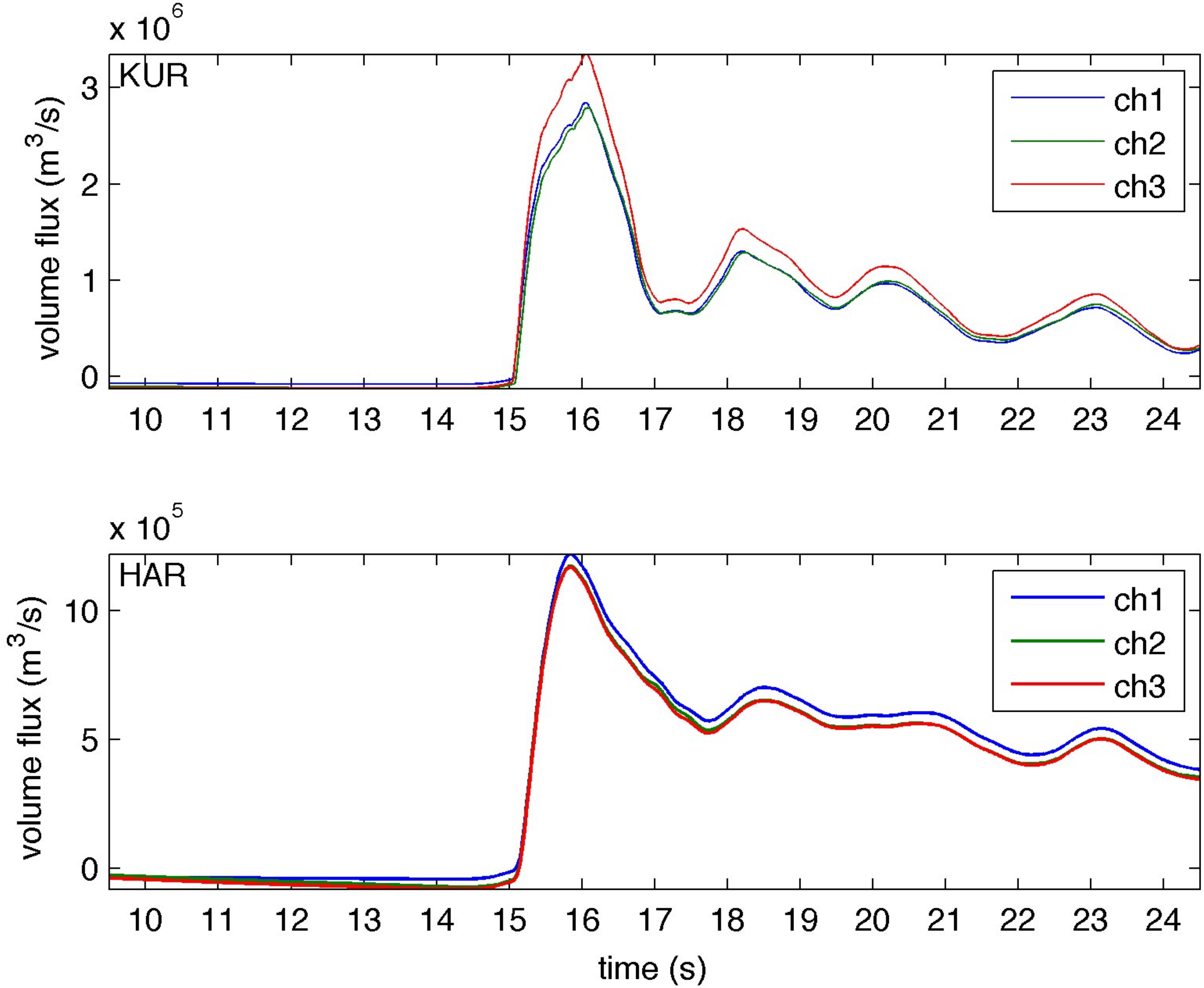


21-Jul-2013 00:46:34 (UTC)
time lag (ms)
-100
-50
0
50
100
00:50
00:55
01:00
01:05
01:10
Pa
10
5
0
-5
-10
00:50
00:55
01:00
01:05
01:10

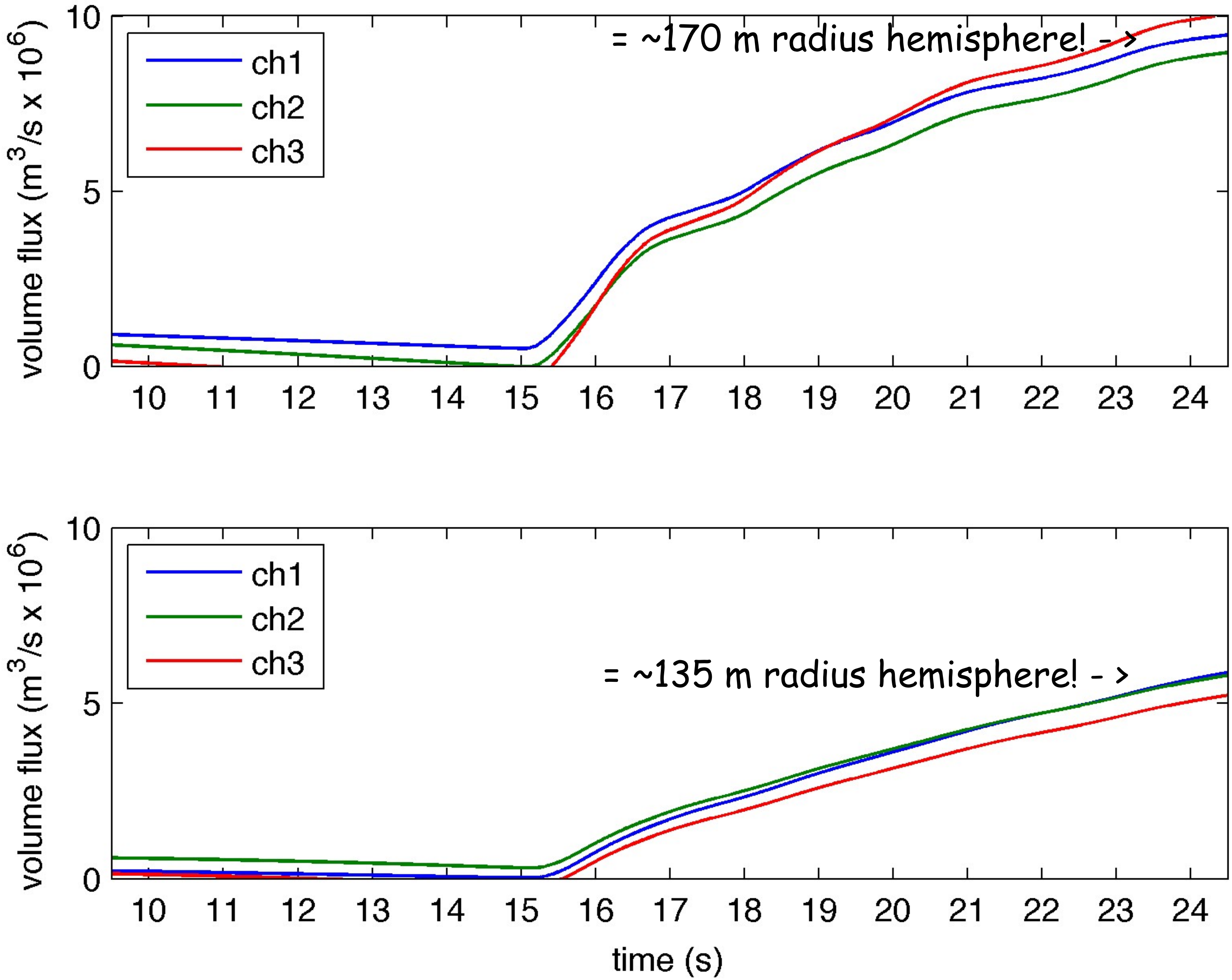


21-Jul-2013 02:13:04 (UTC)
time lag (ms)
-100
-50
0
50
100
02:15
02:20
02:25
02:30
02:35
02:40
Pa
20
0
-20
-40
02:15
02:20
02:25
02:30
02:35
02:40


KUR
ch1
ch2
ch3
400
200
0
-200
pressure (Pa)
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
HAR
ch1
ch2
ch3
100
50
0
pressure (Pa)
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
time (s)



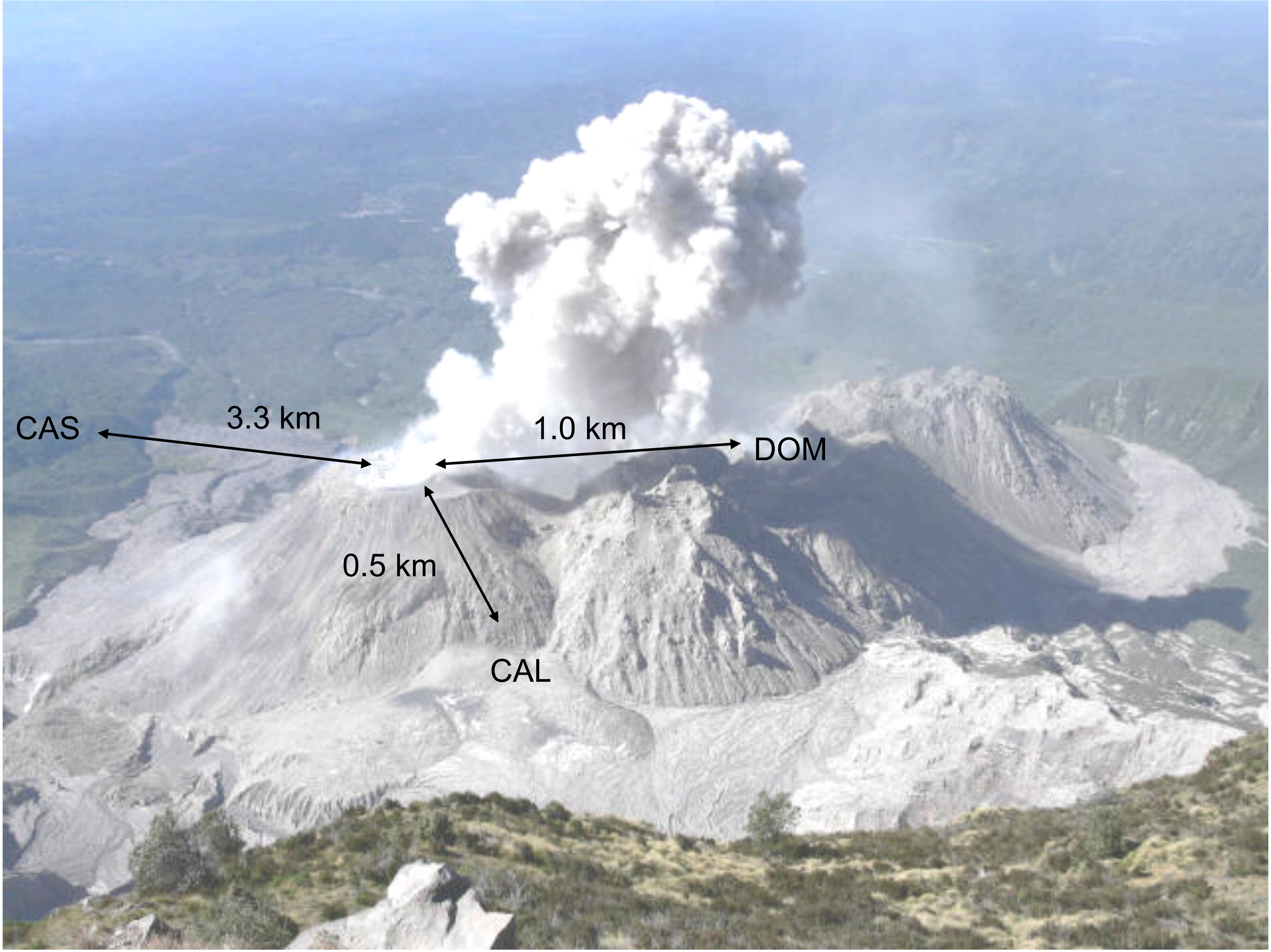
x 10^6
KUR
volume flux (m^3/s)
ch1
ch2
ch3
0
1
2
3
10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
x 10^5
HAR
volume flux (m^3/s)
ch1
ch2
ch3
0
5
10
10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
time (s)

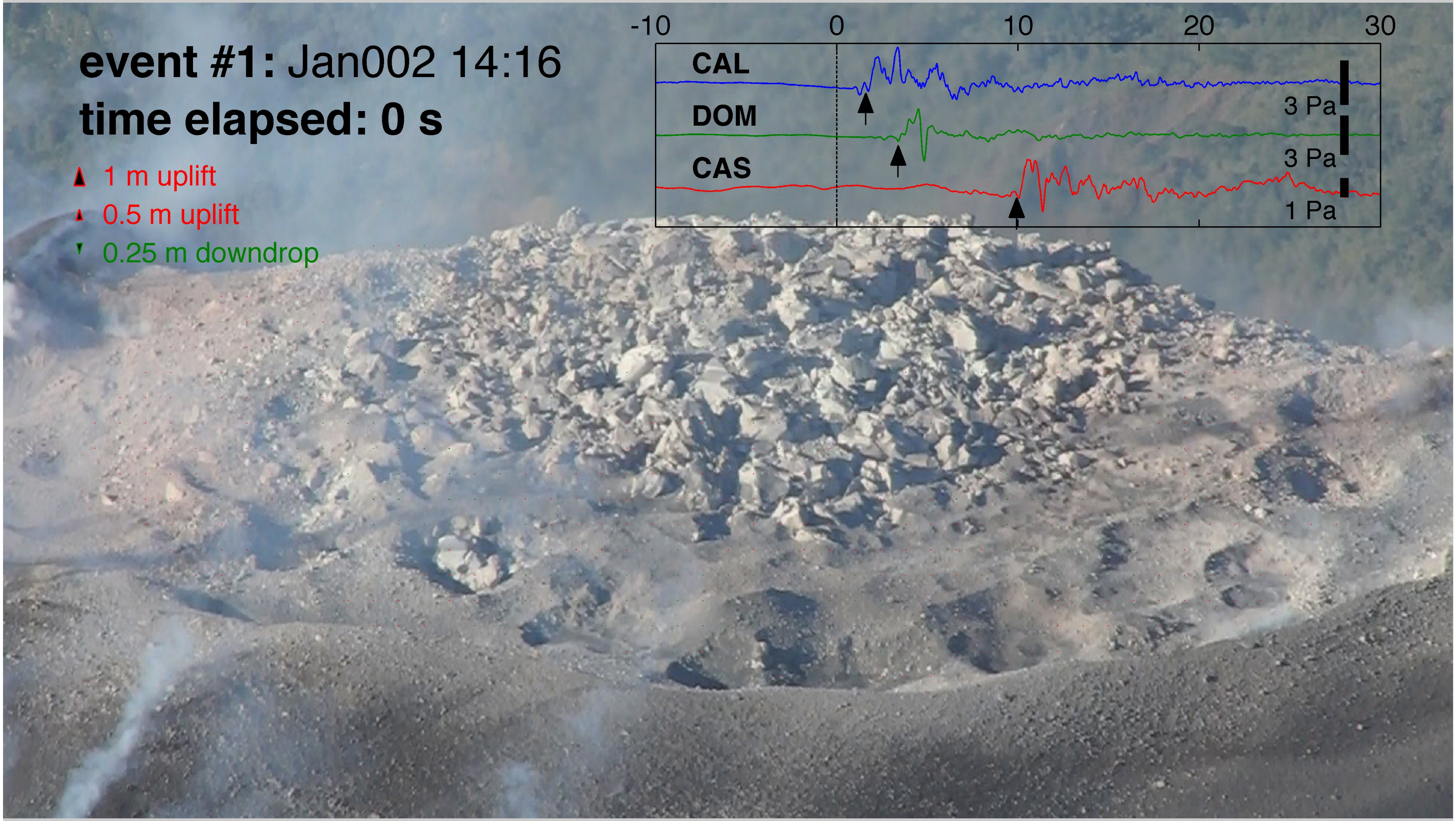


= ~170 m radius hemisphere! - >
ch1
ch2
ch3
volume flux ($m^3/s \times 10^6$)
= ~135 m radius hemisphere! - >
time (s)

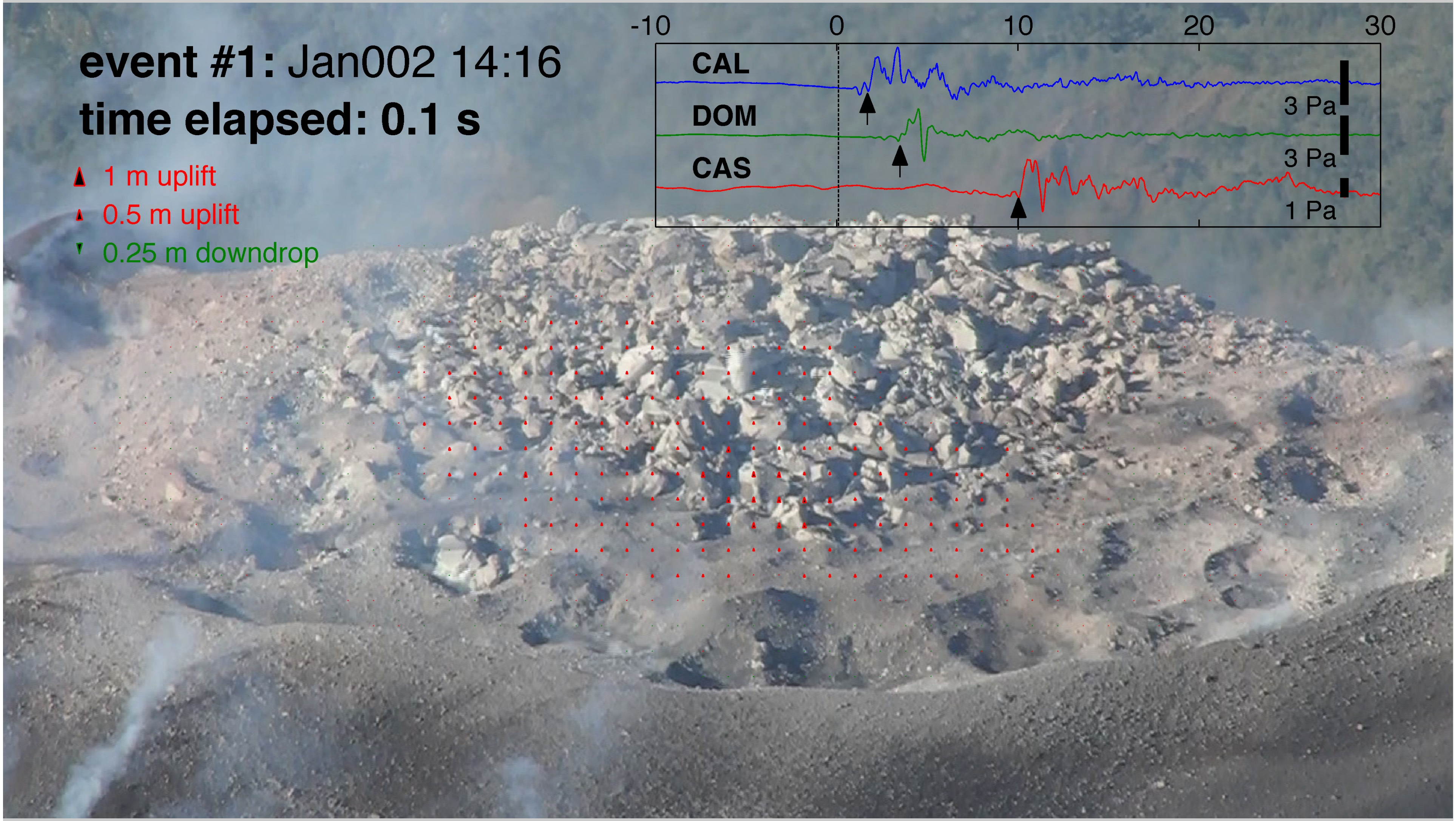

Santiaguito

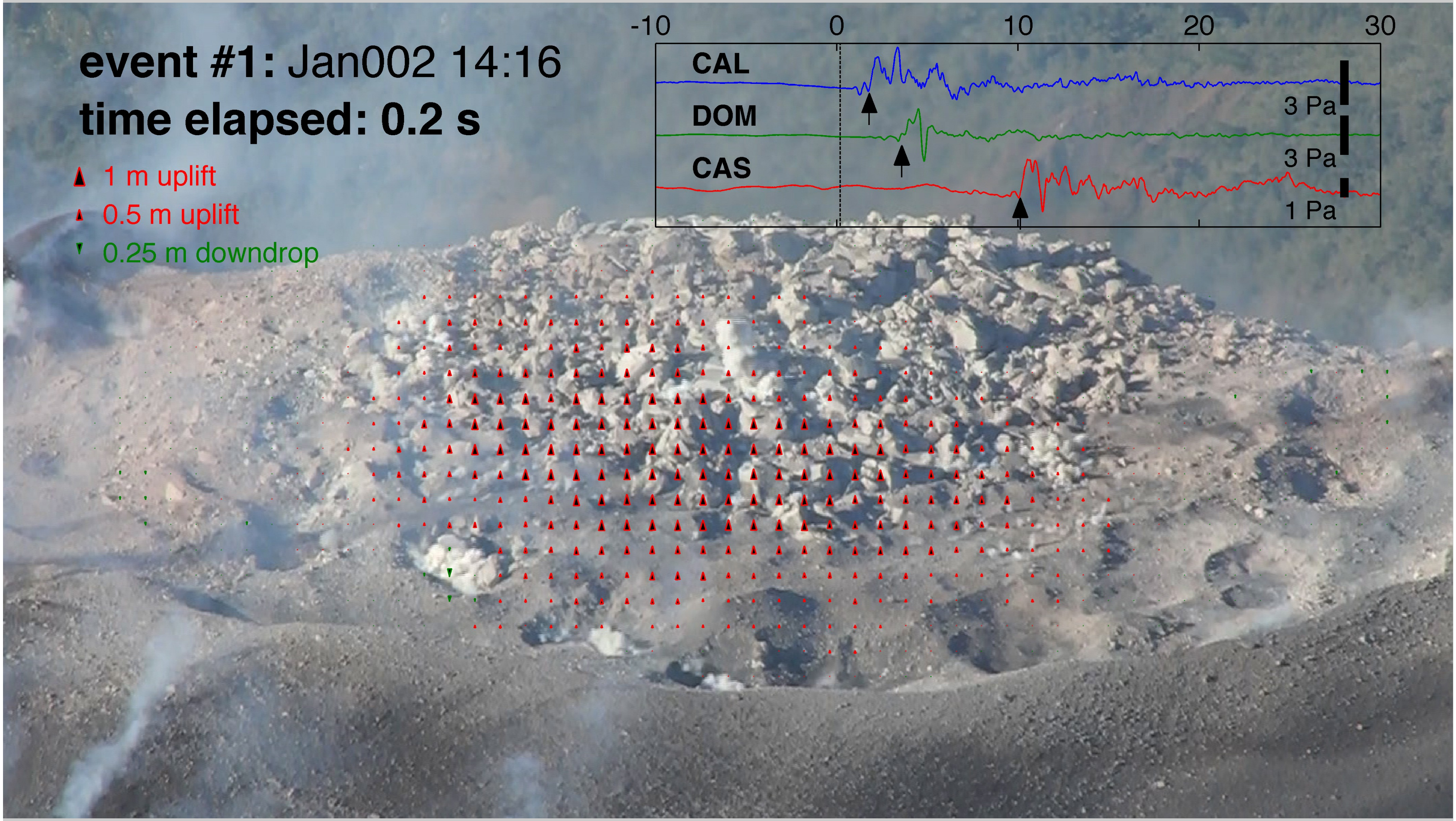
Event #1: occurring Jan 002 at 14:16:46


CAS
3.3 km
1.0 km
DOM
0.5 km
CAL

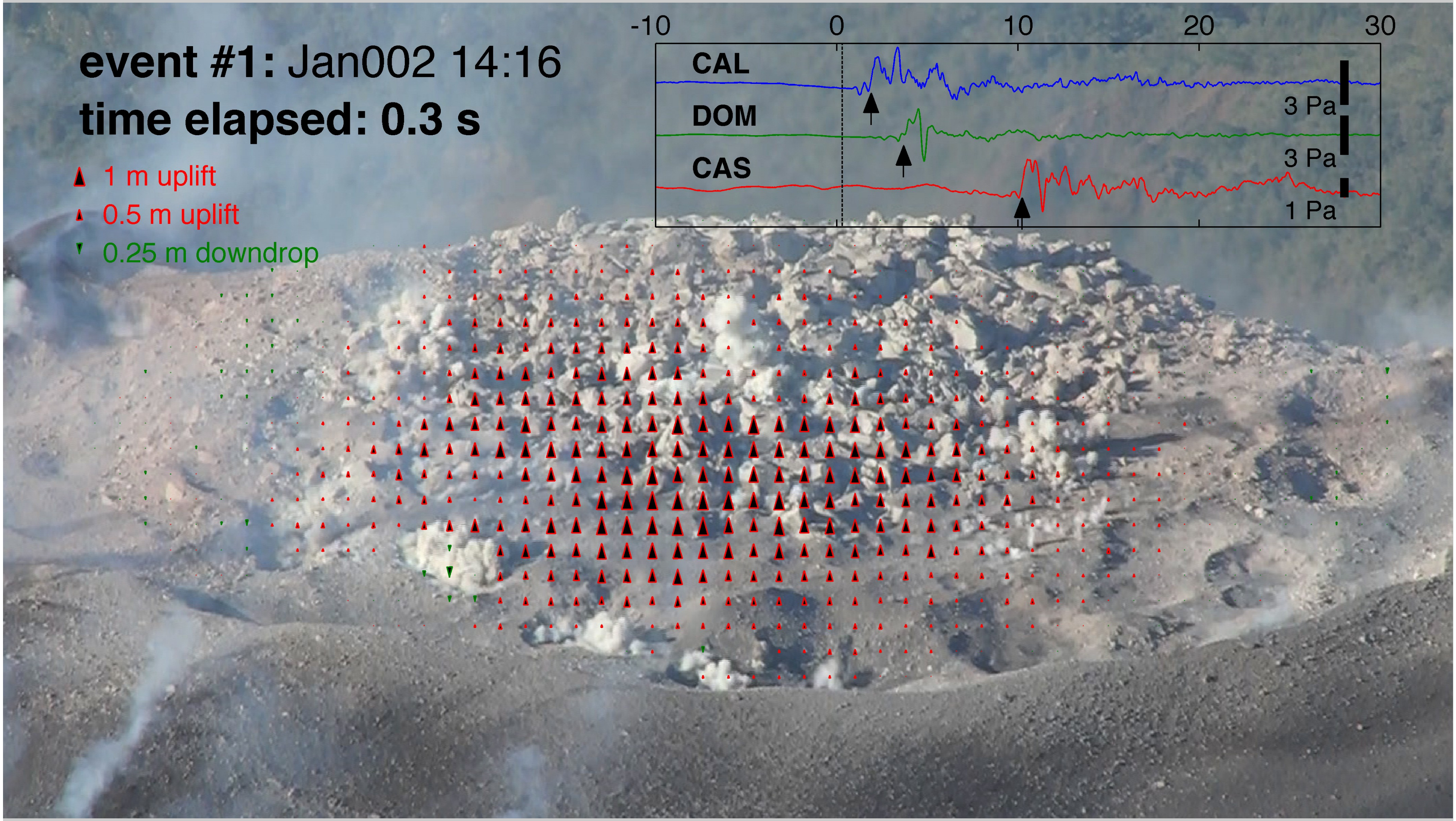


event #1: Jan002 14:16
time elapsed: 0 s
1 m uplift
0.5 m uplift
0.25 m downdrop
-10
0
10
20
30
CAL
DOM
CAS
3 Pa
3 Pa
1 Pa

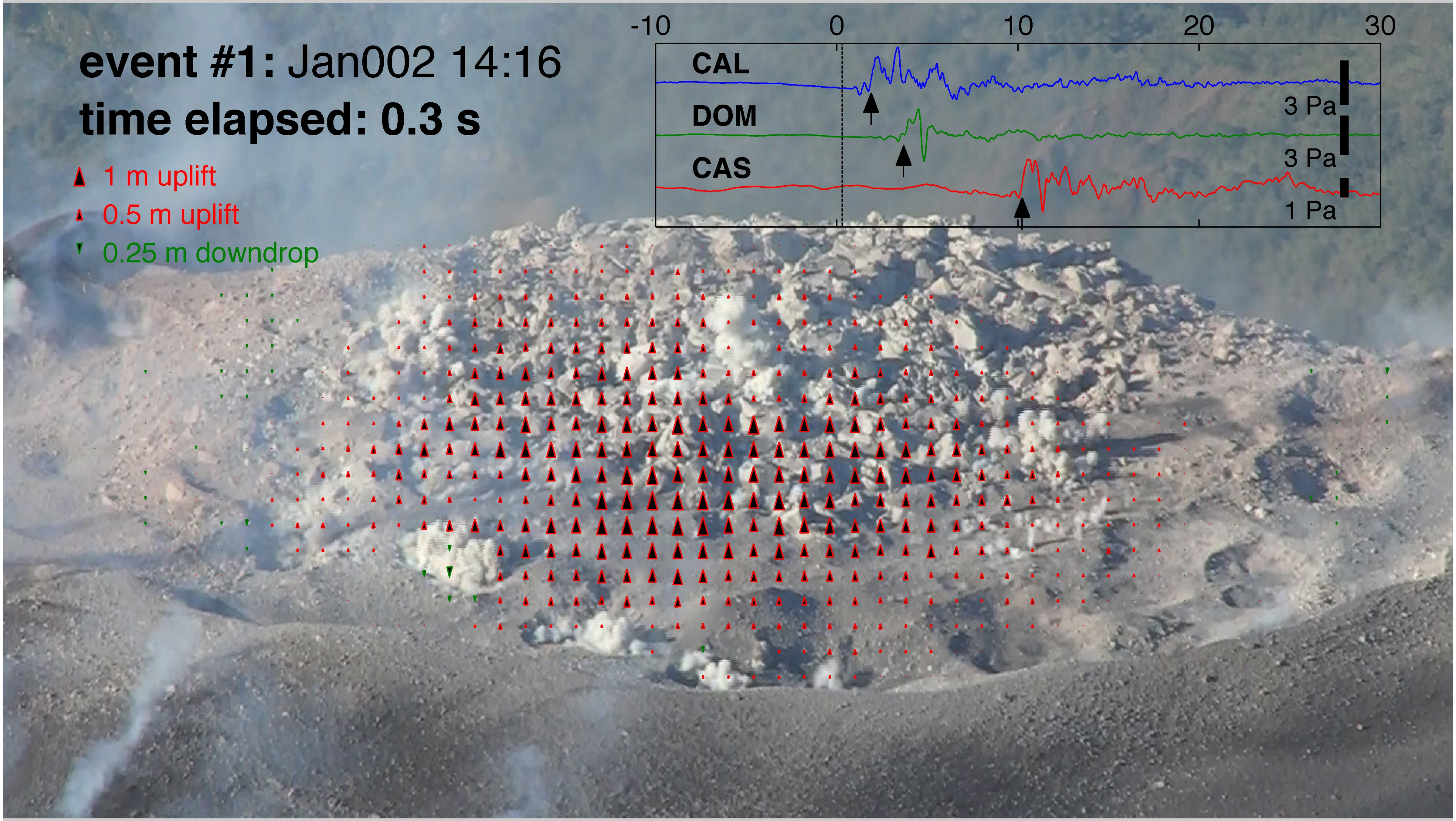

event #1: Jan002 14:16
time elapsed: 0.1 s
1 m uplift
0.5 m uplift
0.25 m downdrop
-10
0
10
20
30
CAL
DOM
CAS
3 Pa
3 Pa
1 Pa



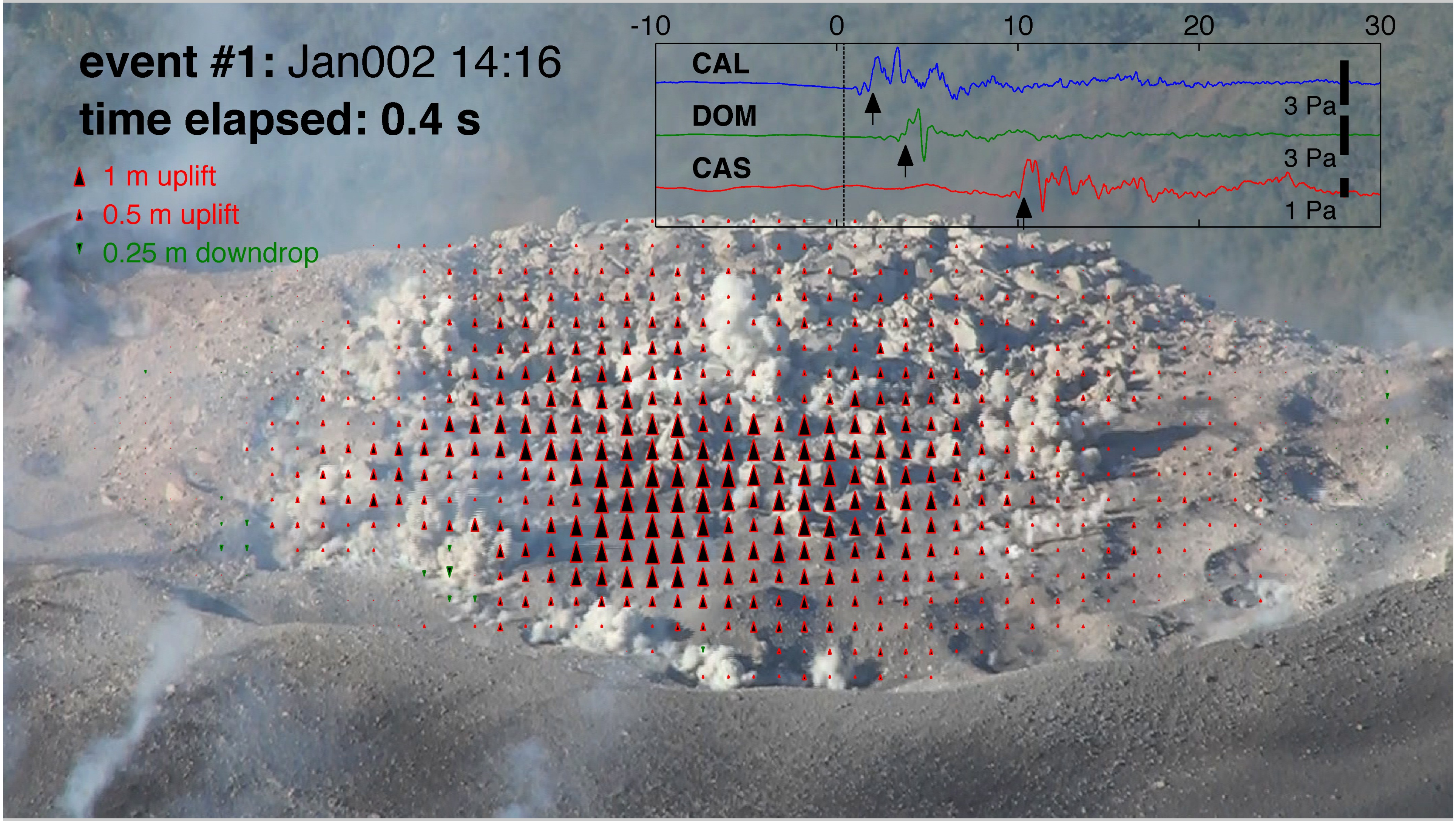
event #1: Jan002 14:16
time elapsed: 0.2 s
1 m uplift
0.5 m uplift
0.25 m downdrop
-10
0
10
20
30
CAL
DOM
CAS
3 Pa
3 Pa
1 Pa

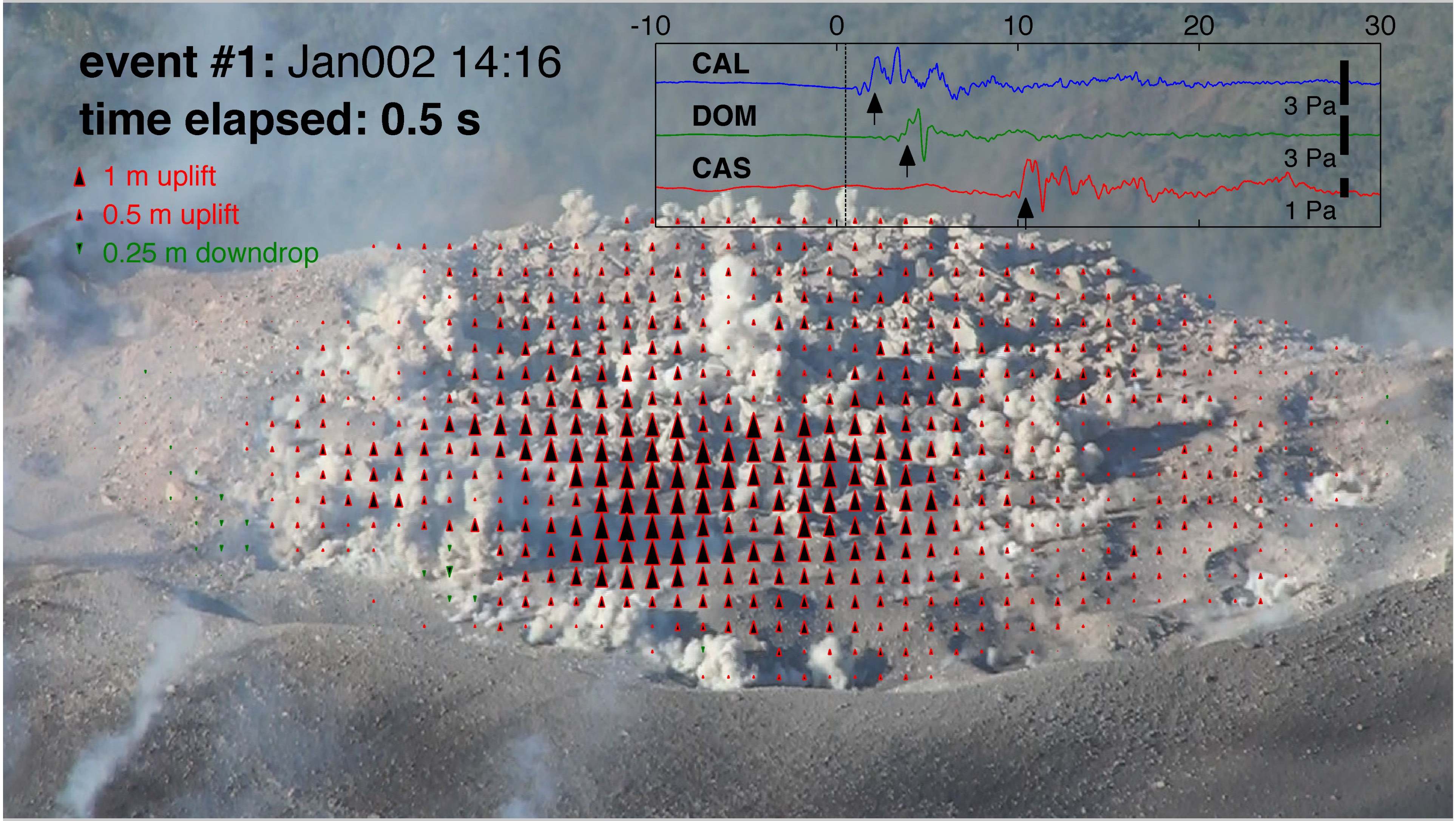


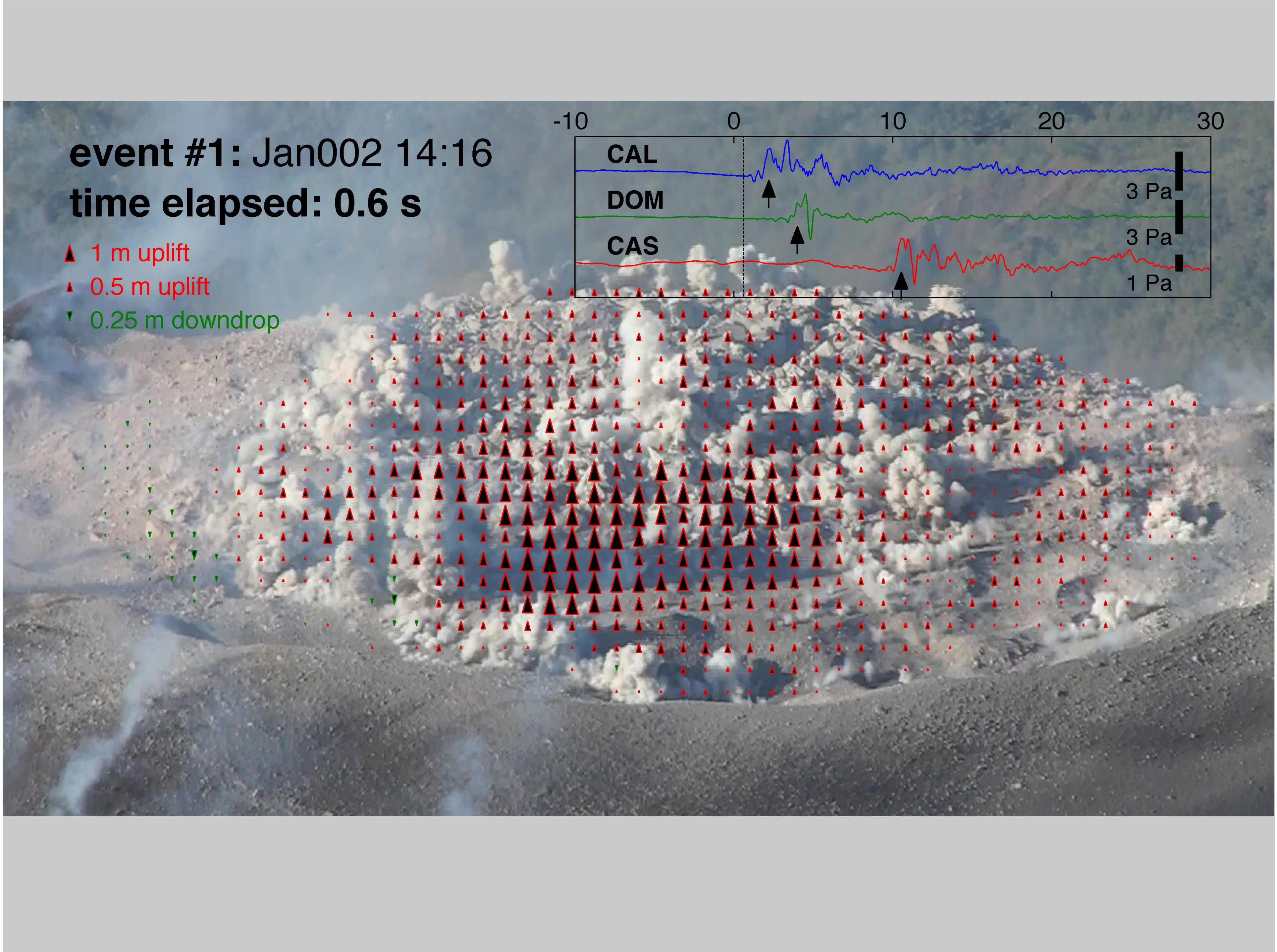
event #1: Jan002 14:16
time elapsed: 0.3 s
1 m uplift
0.5 m uplift
0.25 m downdrop
-10
0
10
20
30
CAL
DOM
CAS
3 Pa
3 Pa
1 Pa



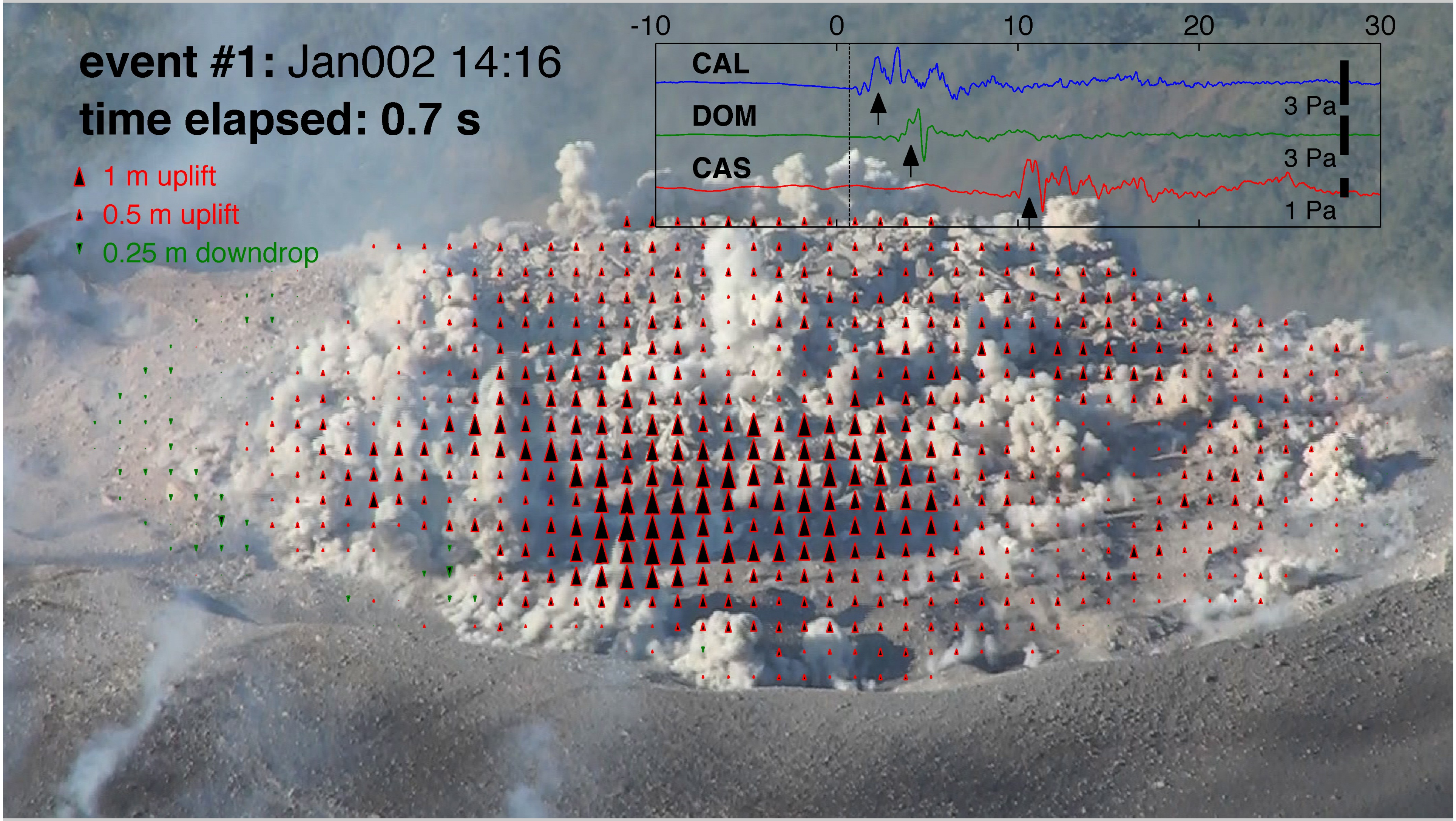
event #1: Jan002 14:16
time elapsed: 0.3 s
1 m uplift
0.5 m uplift
0.25 m downdrop
-10
0
10
20
30
CAL
DOM
CAS
3 Pa
3 Pa
1 Pa


event #1: Jan002 14:16
time elapsed: 0.4 s
1 m uplift
0.5 m uplift
0.25 m downdrop
-10
0
10
20
30
CAL
DOM
CAS
3 Pa
3 Pa
1 Pa

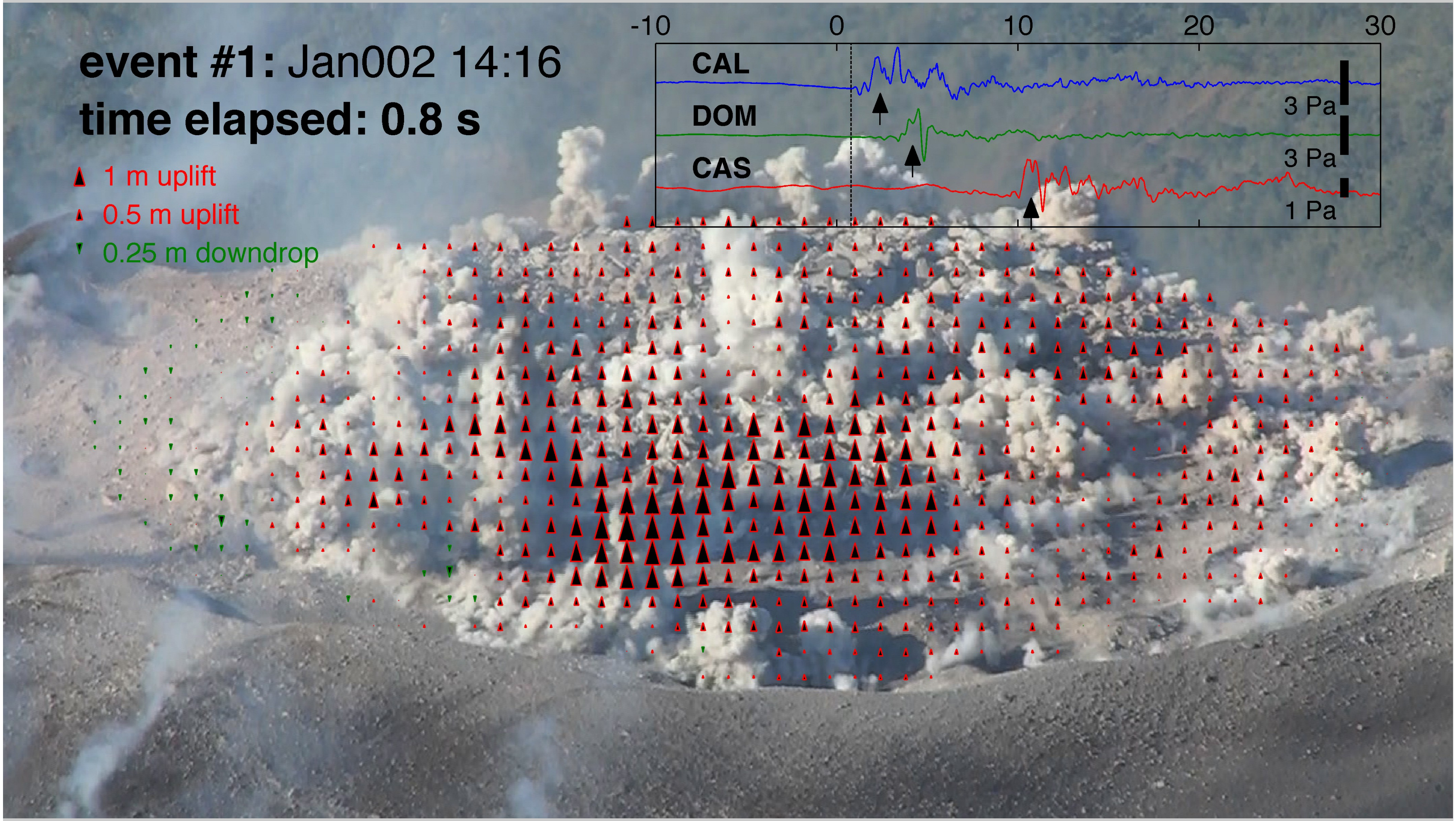

event #1: Jan002 14:16
time elapsed: 0.5 s
1 m uplift
0.5 m uplift
0.25 m downdrop
-10
0
10
20
30
CAL
DOM
CAS
3 Pa
3 Pa
1 Pa

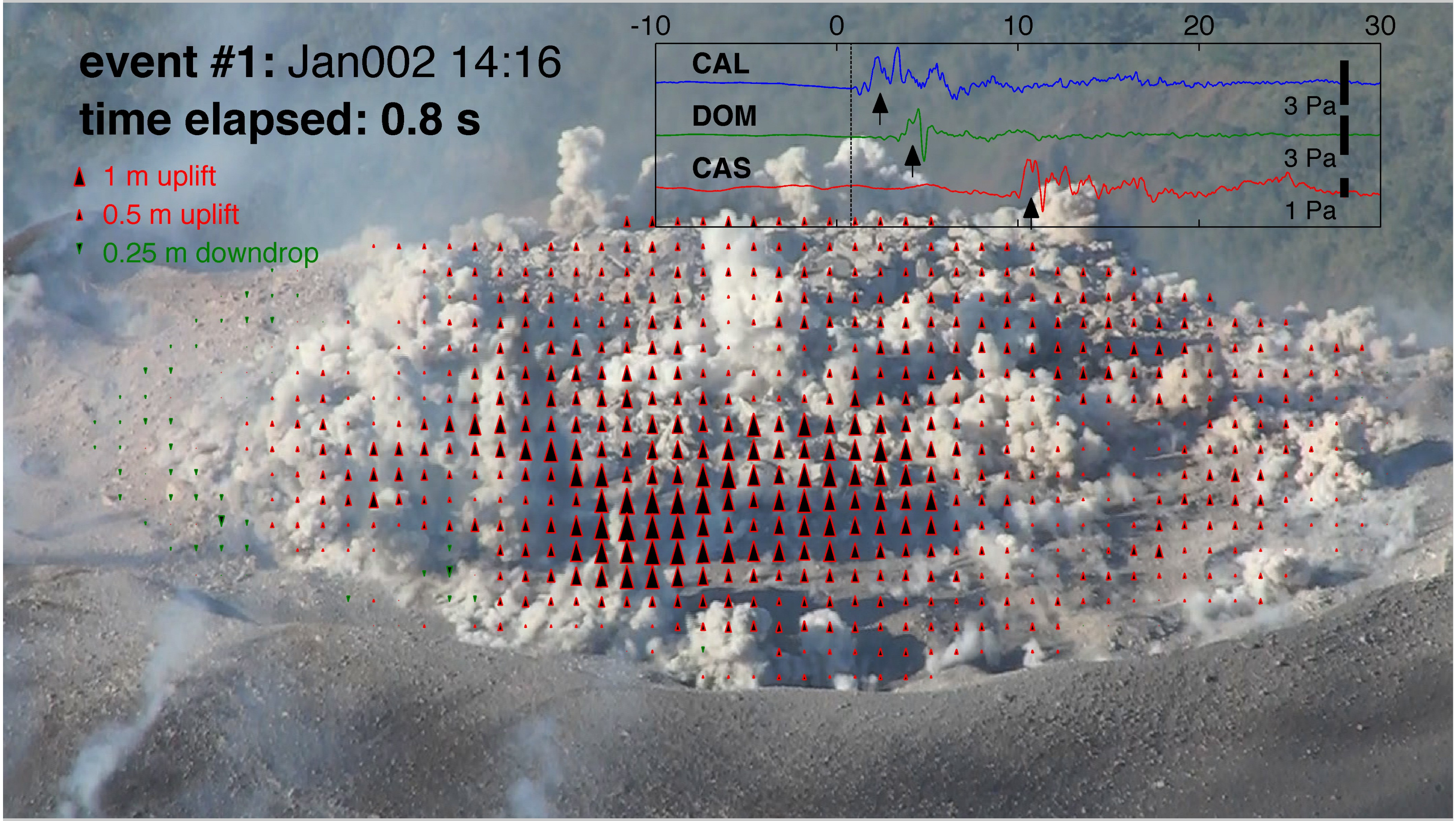


event #1: Jan002 14:16
time elapsed: 0.6 s
1 m uplift
0.5 m uplift
0.25 m downdrop
-10
0
10
20
30
CAL
DOM
CAS
3 Pa
3 Pa
1 Pa

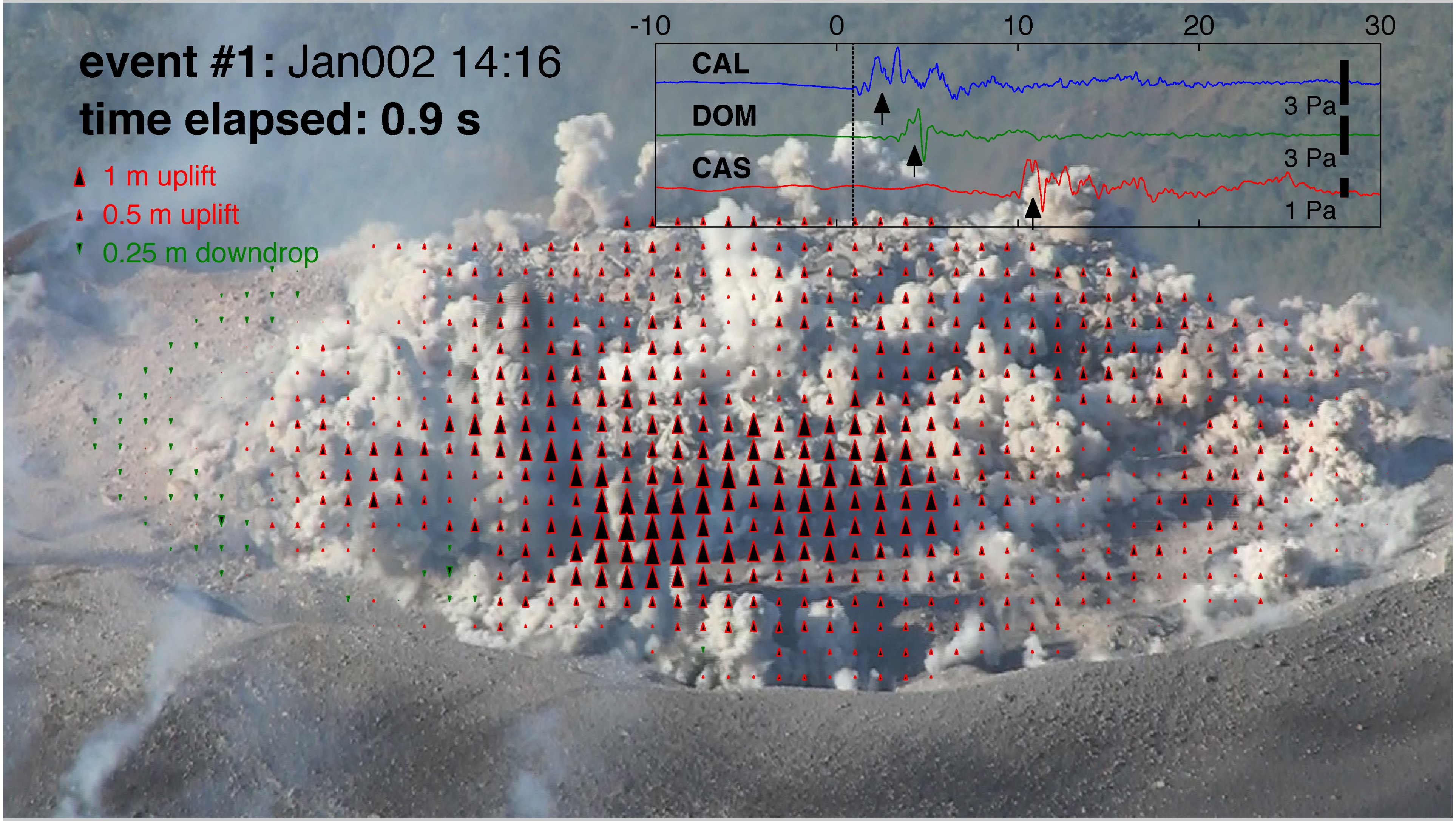


event #1: Jan002 14:16
time elapsed: 0.7 s
1 m uplift
0.5 m uplift
0.25 m downdrop
-10
0
10
20
30
CAL
DOM
CAS
3 Pa
3 Pa
1 Pa

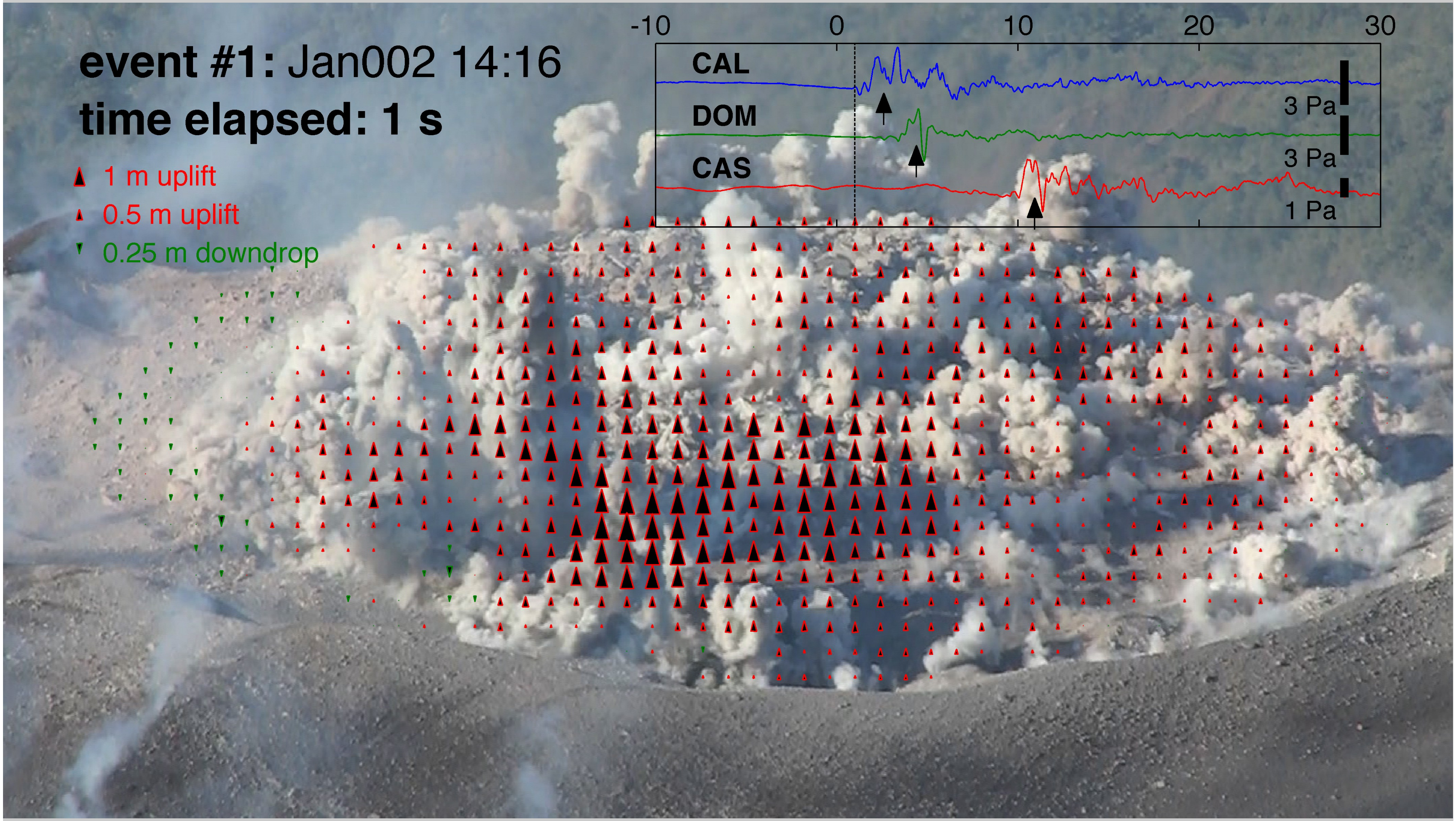

event #1: Jan002 14:16
time elapsed: 0.8 s
1 m uplift
0.5 m uplift
0.25 m downdrop
-10
0
10
20
30
CAL
DOM
CAS
3 Pa
3 Pa
1 Pa



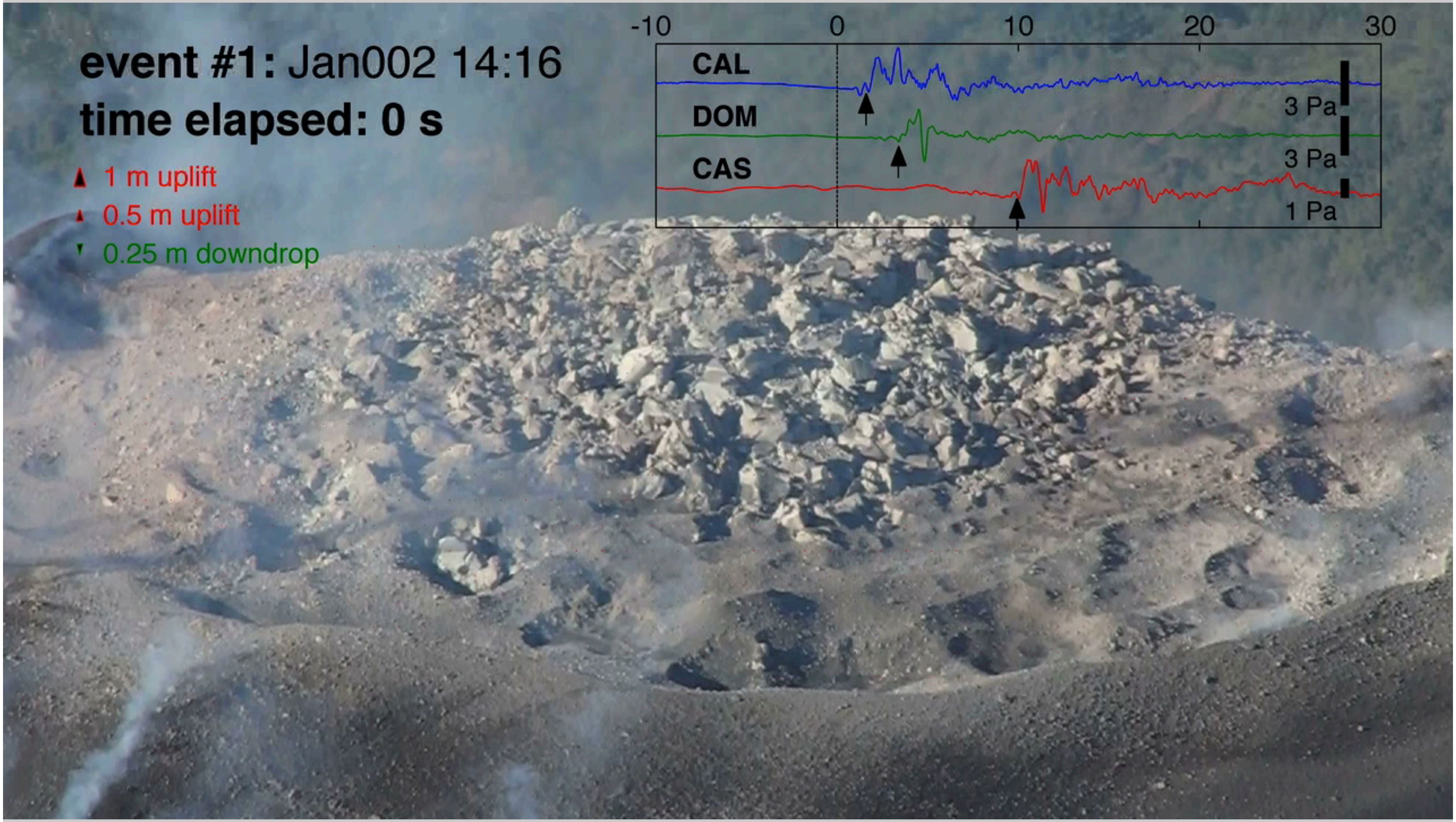
event #1: Jan002 14:16
time elapsed: 0.8 s
1 m uplift
0.5 m uplift
0.25 m downdrop
-10
0
10
20
30
CAL
DOM
CAS
3 Pa
3 Pa
1 Pa



event #1: Jan002 14:16
time elapsed: 0.9 s
1 m uplift
0.5 m uplift
0.25 m downdrop
-10
0
10
20
30
CAL
DOM
CAS
3 Pa
3 Pa
1 Pa



event #1: Jan002 14:16
time elapsed: 1 s
1 m uplift
0.5 m uplift
0.25 m downdrop
-10
0
10
20
30
CAL
DOM
CAS
3 Pa
3 Pa
1 Pa


event #1: Jan002 14:16
time elapsed: 0 s
1 m uplift
0.5 m uplift
0.25 m downdrop
-10
0
10
20
30
CAL
DOM
CAS
3 Pa
3 Pa
1 Pa