GIFT Workshop
EGU 2017, Wien

LIVING IN A CALDERA

The case of Campi Flegrei, Italy

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STRATOVOLCANOES


Kanaga, Alaska


Fujii, Japan


Colima, Mexico


Cotopaxi, Ecuador


Aso, Japan

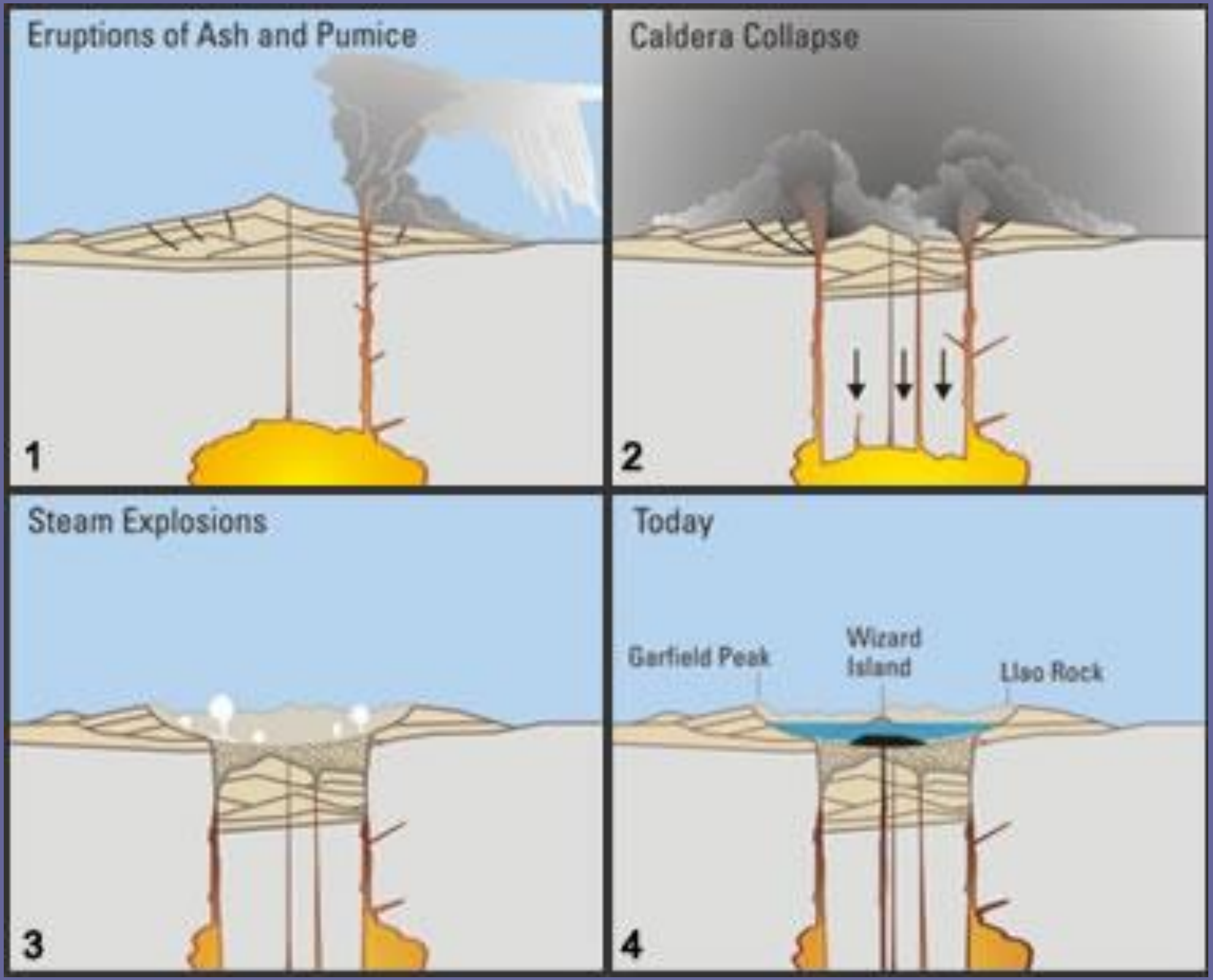

Crater Lake, Oregon

CALDERAS


Kaguyak, Alaska


Santorini, Greece

Caldera formation mechanisms

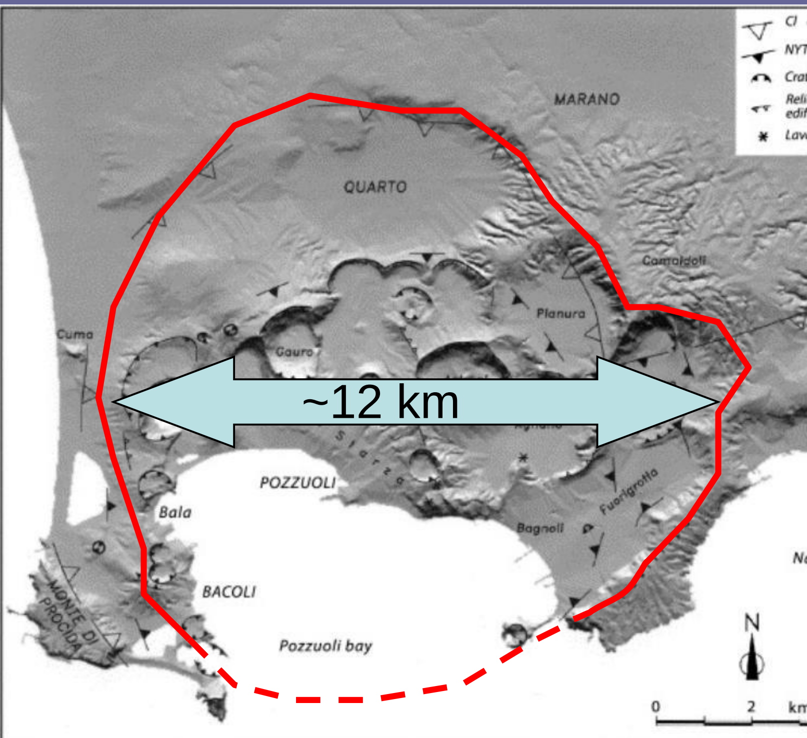


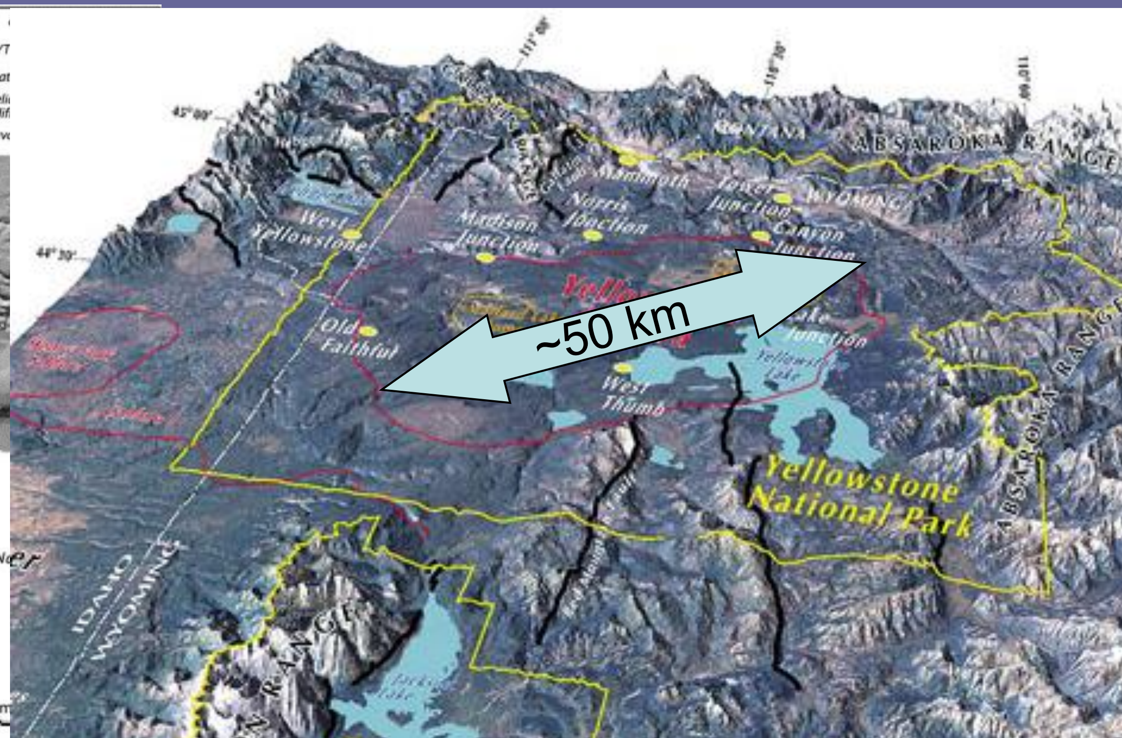
Example from Crater Lake caldera, OR, US

source: USGS

Campi Flegrei, Italy

Yellowstone, Wyoming






Campi Flegrei, Italy


La Solfatara, Campi Flegrei

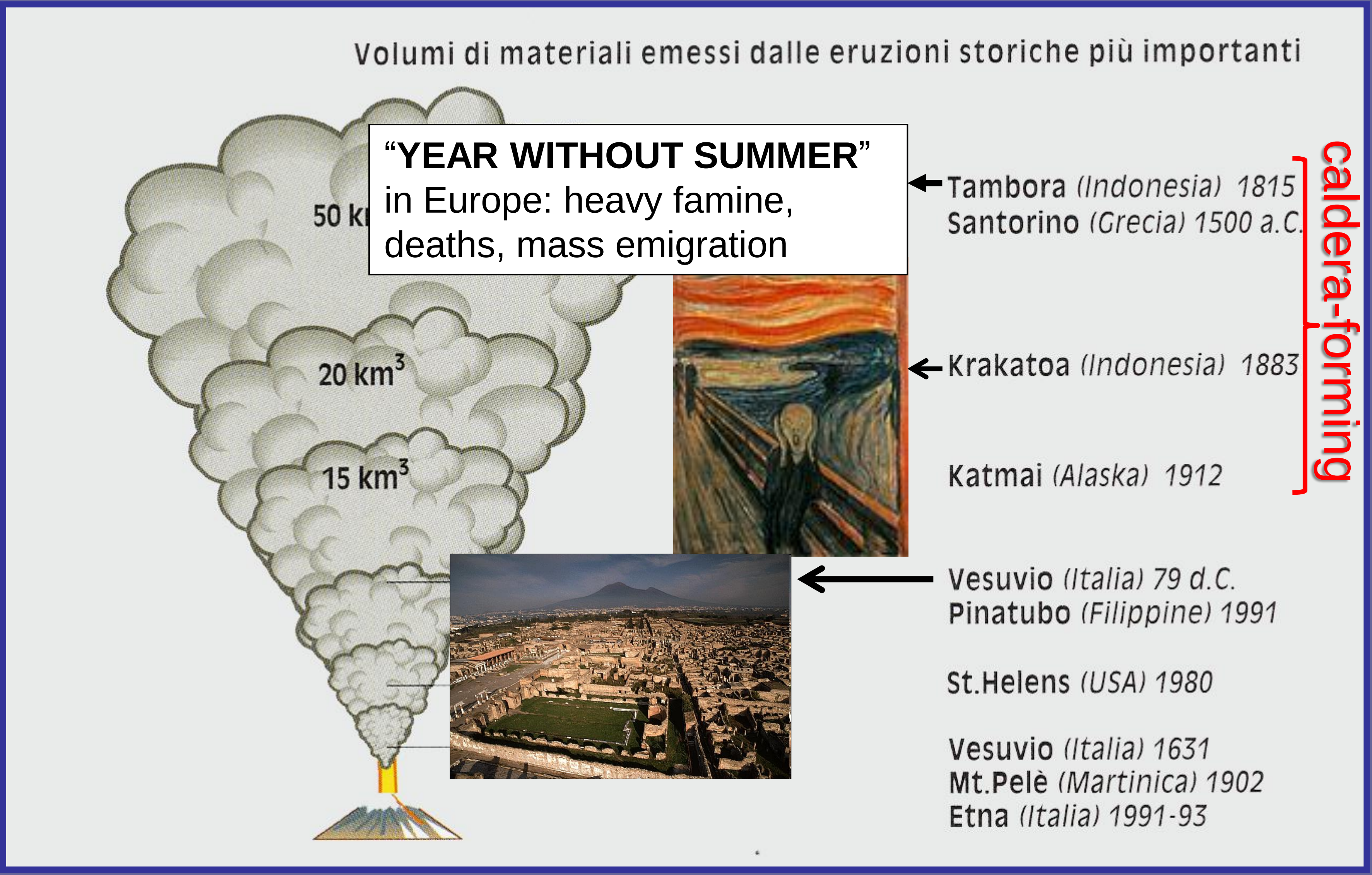

Yellowstone, WY (US)

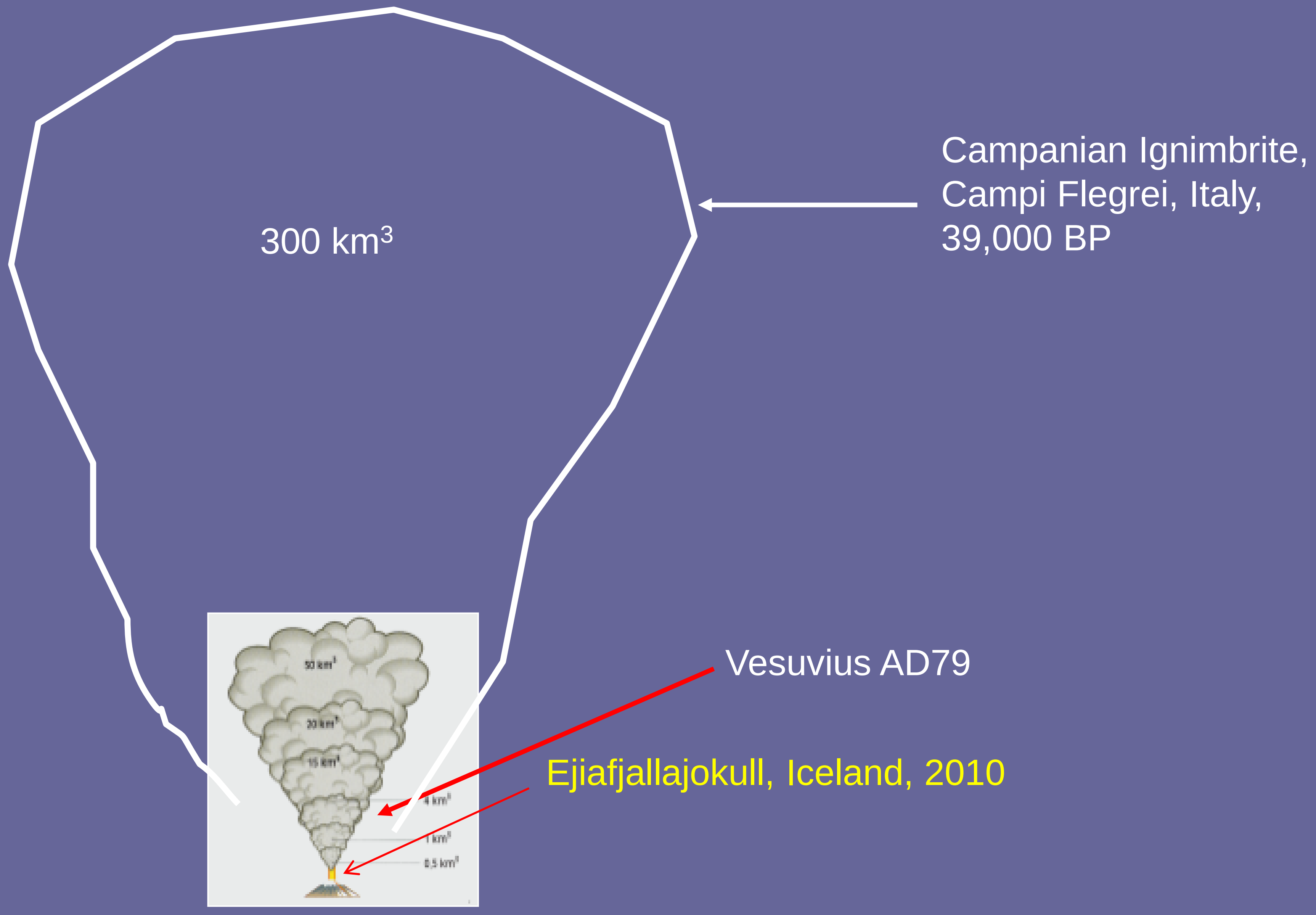

Old Faithful Geyser, Yellowstone

Comparison between energies from volcanic eruptions, other natural events, and that of the Hiroshima atomic bomb

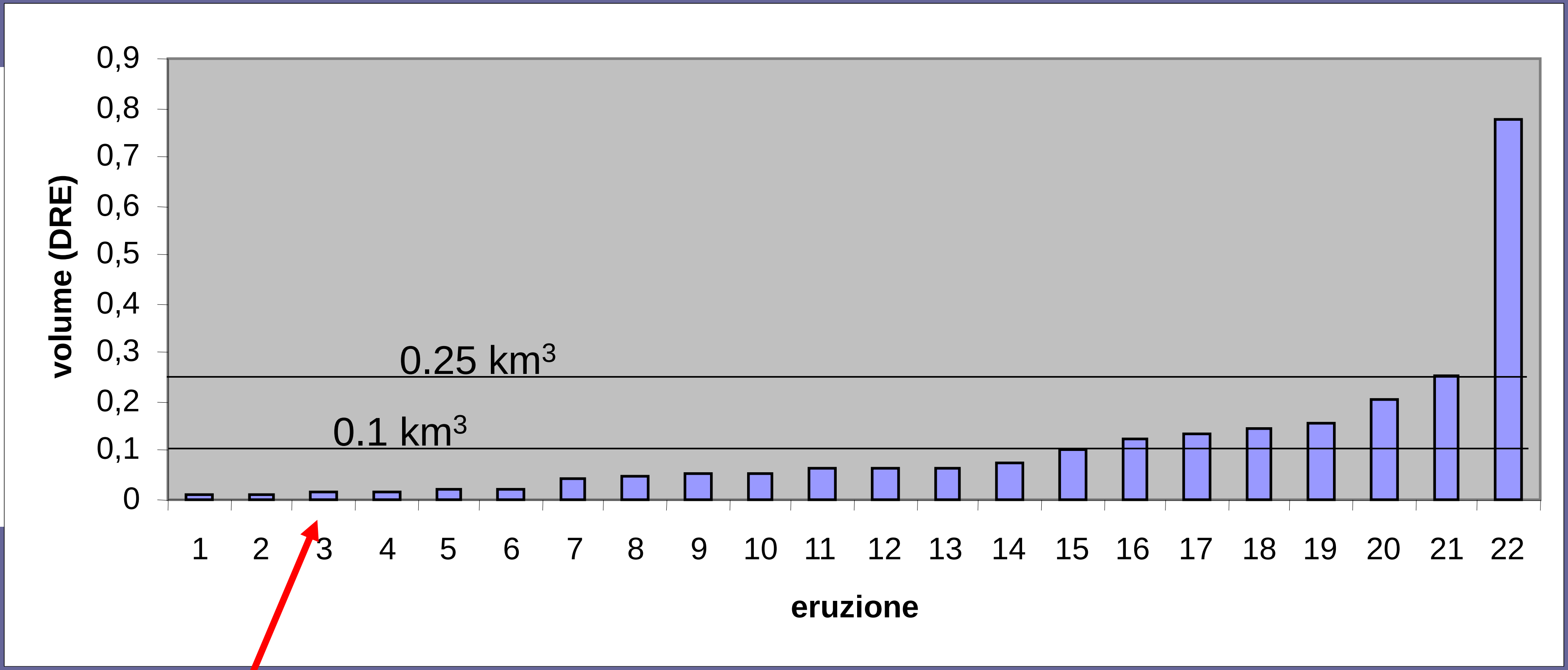
Event	*Energy (Tons TNT)* *Minimum*	*Maximum*
Landslide (Stromboli 2002)	100	1000
Tornado	1000	10000
Hiroshima bomb	10000	100000
Eruption of Mt. St Helens, 1980, or of Vesuvio, 1631	**One thousand** times larger than the Hiroshima bomb	
Campanian Ignimbrite eruption, Campi Flegrei, 39 ka BP: **caldera formation**	**One million** times larger than the Hiroshima bomb	
Impact with asteroid (recurrence 100,000 years)		

Volume of products from historical eruptions




300 km³
Campanian Ignimbrite, Campi Flegrei, Italy, 39,000 BP
Vesuvius AD79
Ejiafjallajokull, Iceland, 2010

Magnitude of eruptions during last 5,000 years of activity at Campi Flegrei



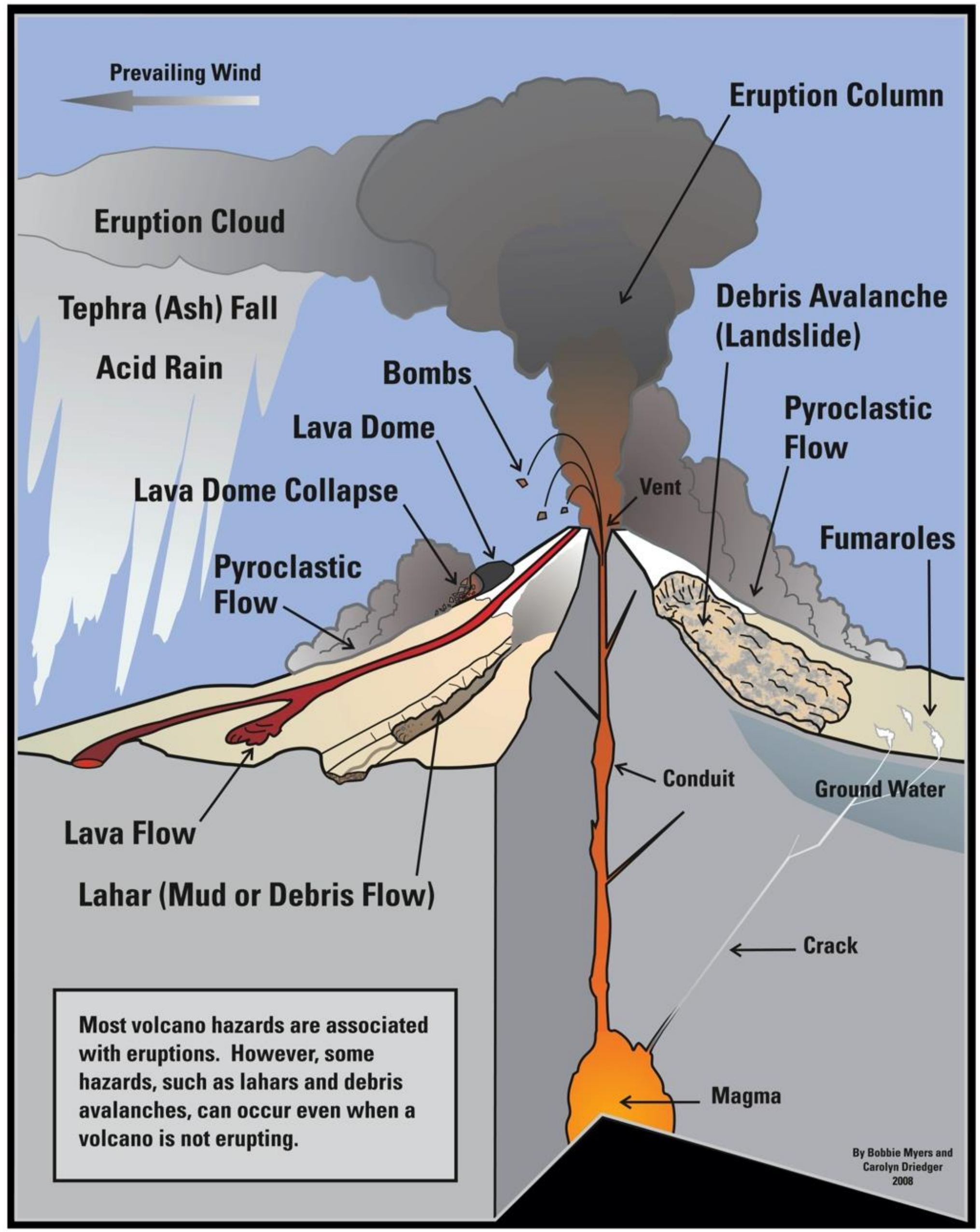
AD 1538 Monte Nuovo

500 thousands people living inside the Campi Flegrei caldera

Monte Nuovo
(1538 AD)

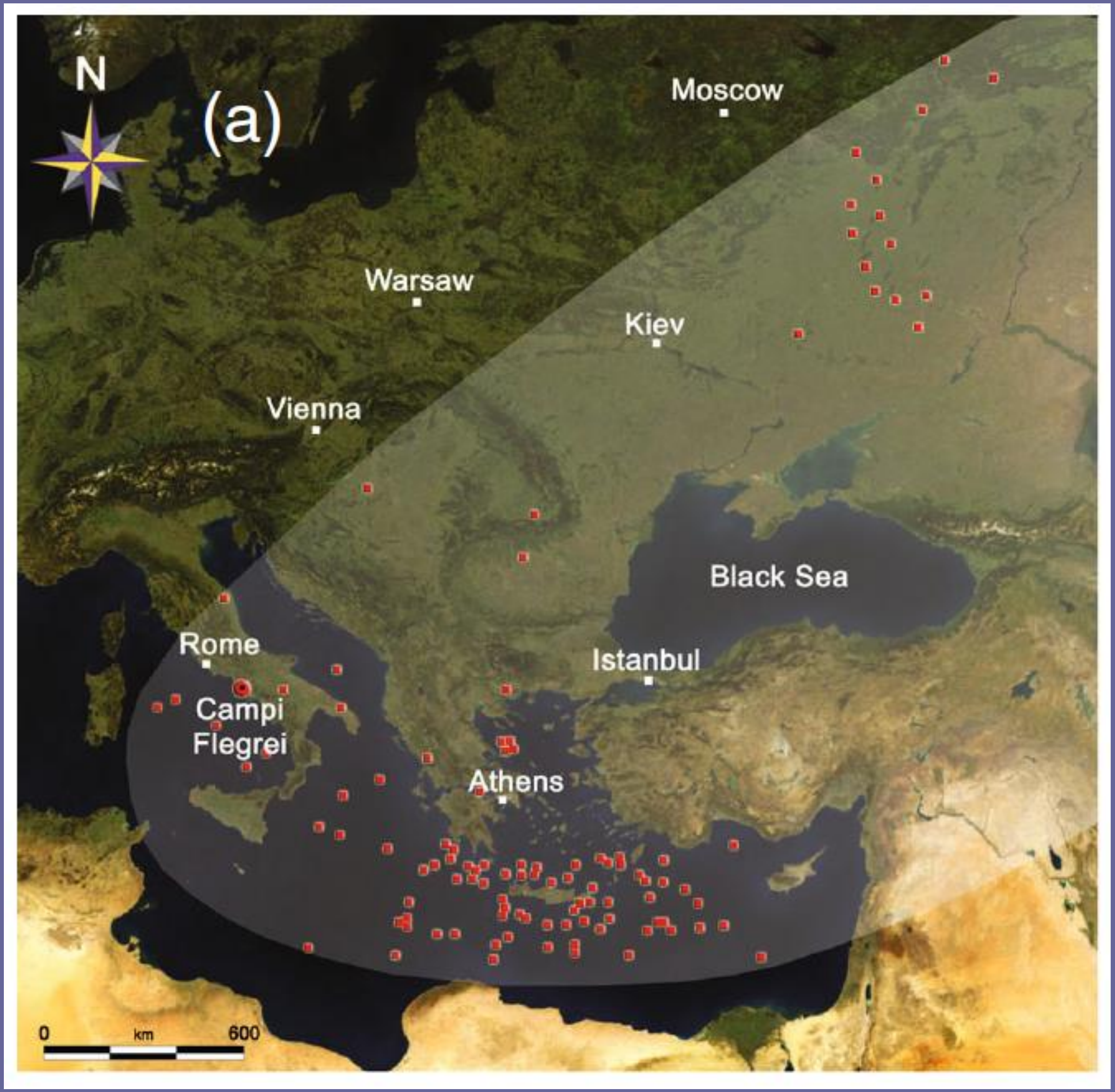

Campi Flegrei
Naples
Ischia
Vesuvius
About 3 million people exposed to volcanic hazard


Etna (Italy), 1983
Pinatubo (Philippines), 1991
Calbuco (Chile), 2015
Sinabung (Indonesia), 2016
Montserrat, Antilles, nineties
Mount Pelee, Martinique, 1902
Pompei and Vesuvius, AD79

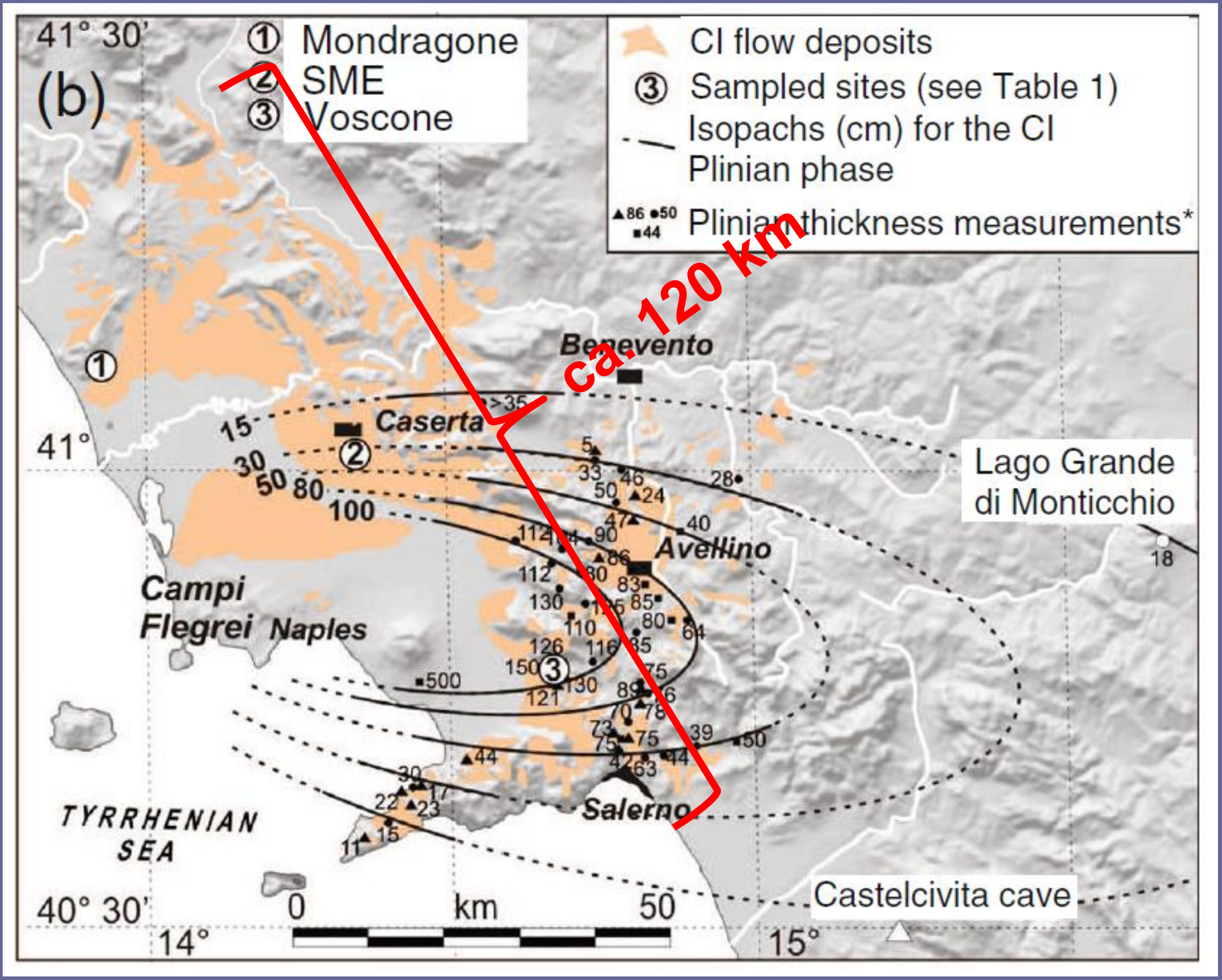

Prevailing Wind
Eruption Column
Eruption Cloud
Tephra (Ash) Fall
Acid Rain
Debris Avalanche (Landslide)
Bombs
Lava Dome
Pyroclastic Flow
Lava Dome Collapse
Vent
Fumaroles
Pyroclastic Flow
Conduit
Ground Water
Lava Flow
Lahar (Mud or Debris Flow)
Crack
Most volcano hazards are associated with eruptions. However, some hazards, such as lahars and debris avalanches, can occur even when a volcano is not erupting.
Magma
By Bobbie Myers and Carolyn Driedger 2008

Naples and Vesuvius, today

The area of dispersal of volcanic ash during the Campanian Ignimbrite eruption at Campi Flegrei, ca. 39,000 years ago



In yellow: flow deposits of the Campanian Ignimbrite eruption

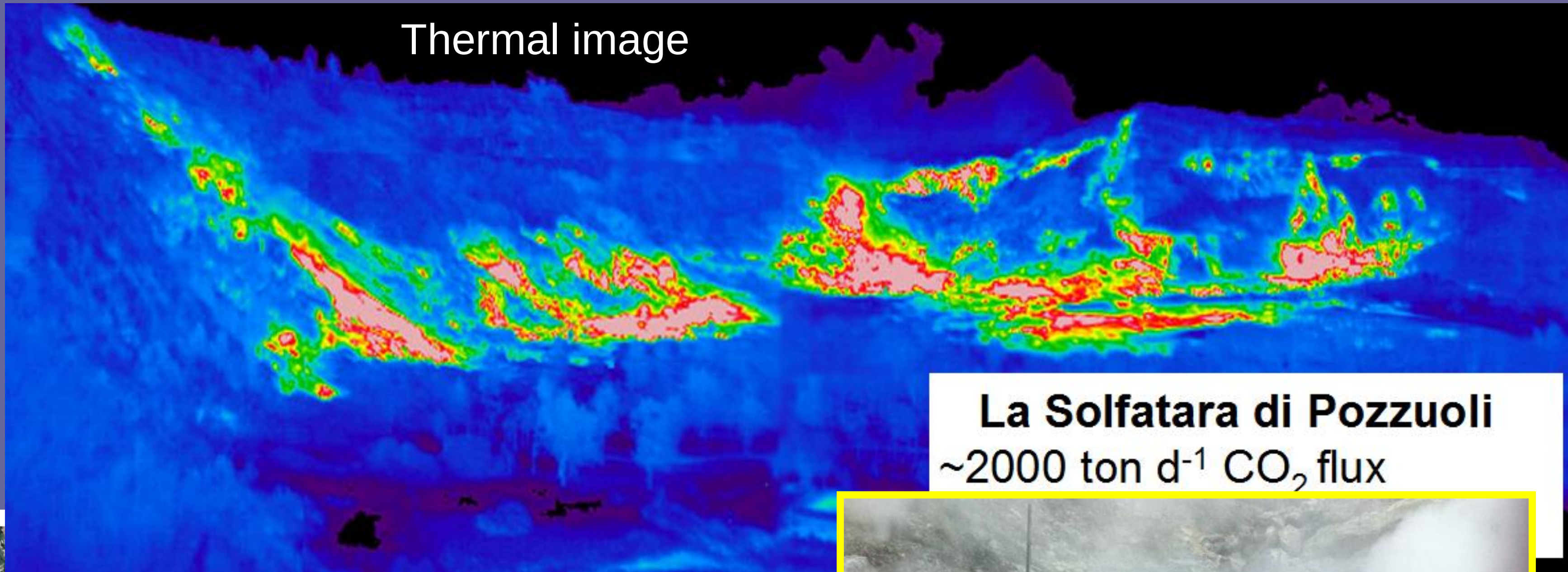


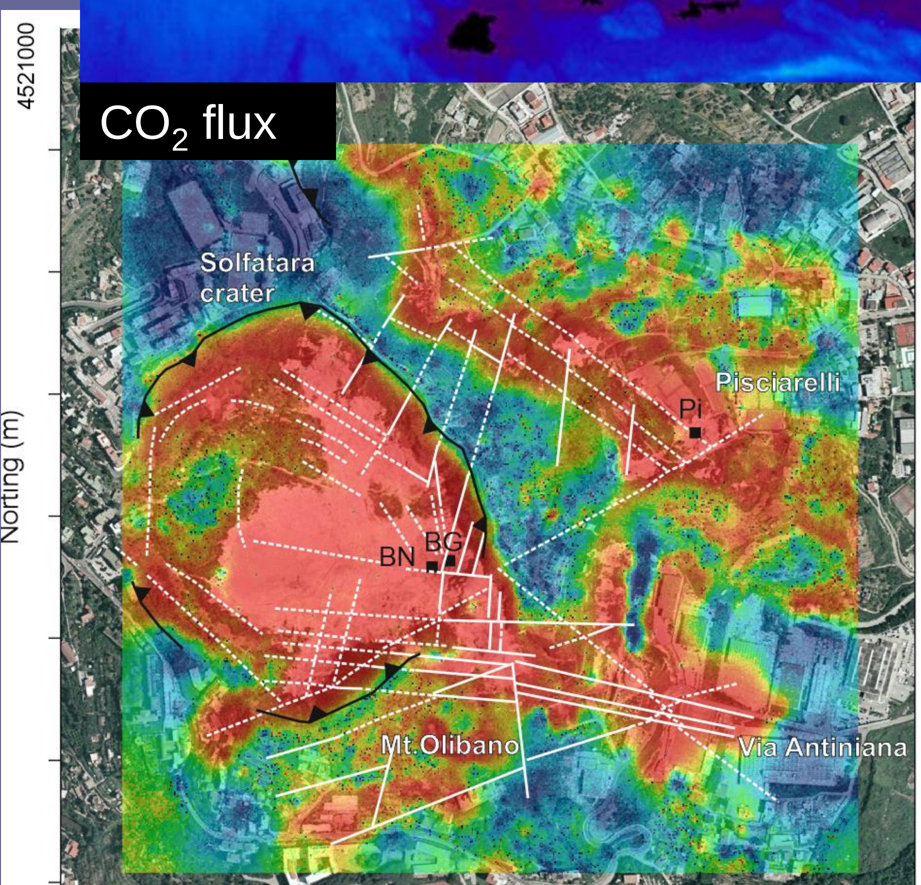
Deposits of the Neapolitan Yellow Tuff eruption of Campi Flegrei, ca. 15,000 years ago, in the city of Naples

Phreatic explosions may occur as a consequence of pressure accumulation close to the surface

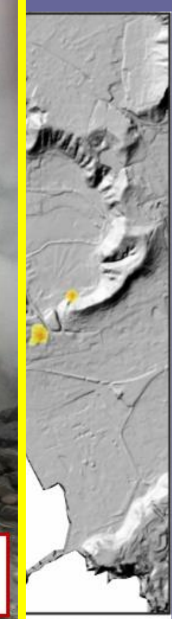
They are extremely difficult to anticipate

La Solfatara, Campi Flegrei

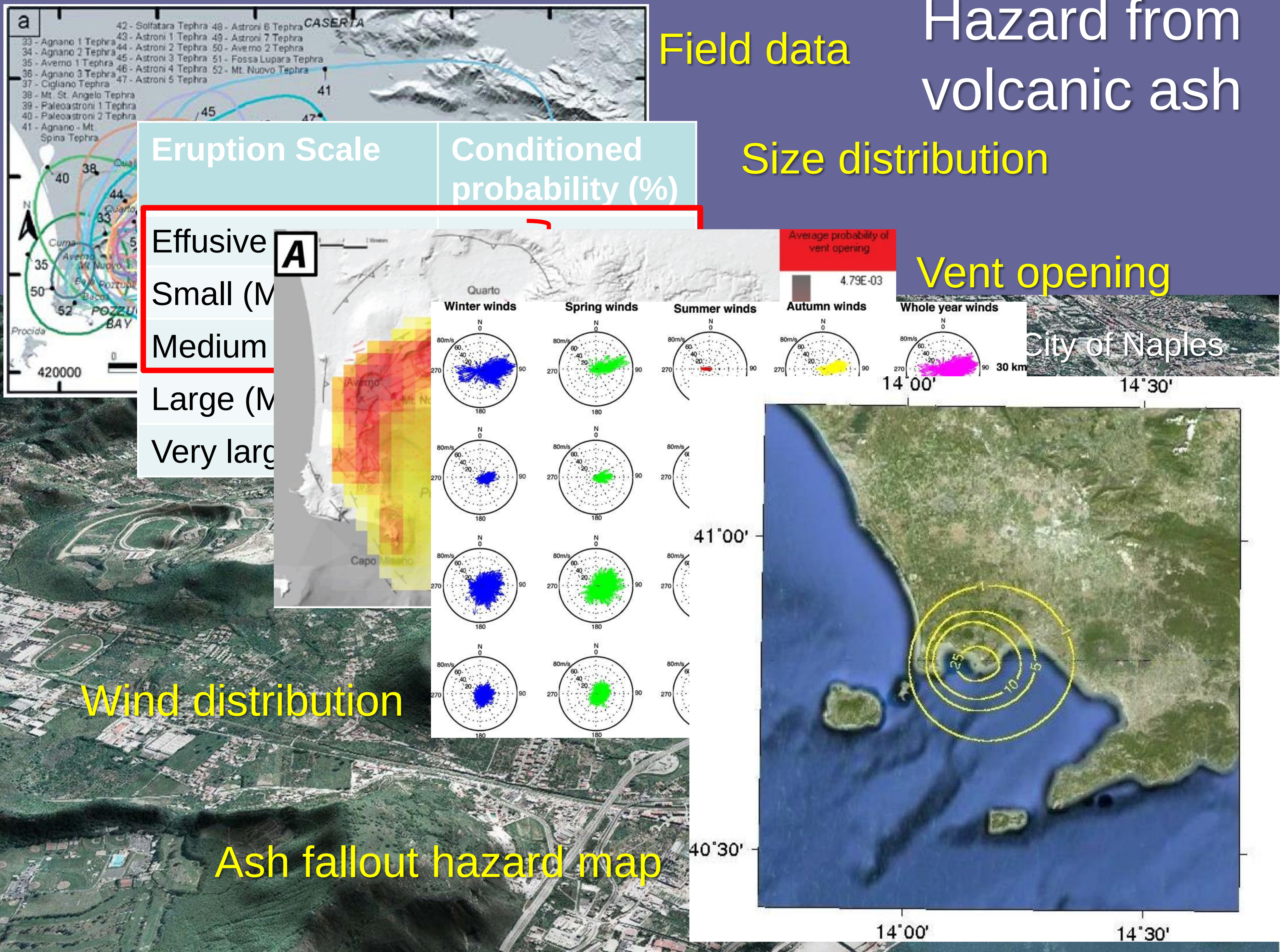

Thermal image
La Solfatara di Pozzuoli
~2000 ton d^{-1} CO_2 flux


CO_2 flux
4521000
Norting (m)
Solfatara crater
Pisciarelli
Pi
BN
BG
Mt.Olibano
Via Antiniana

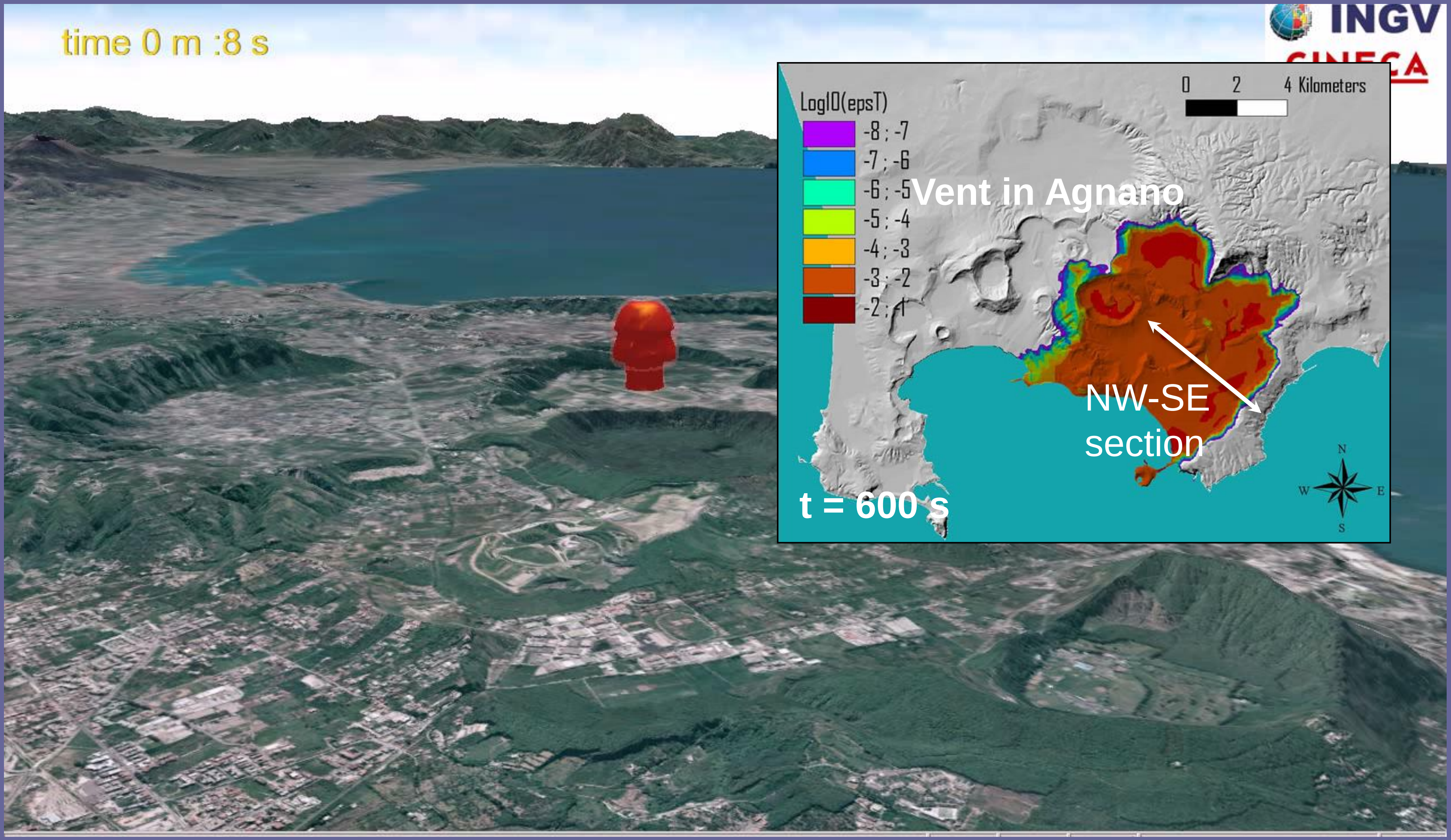

Pisciarelli 2013, Tmax 120°C



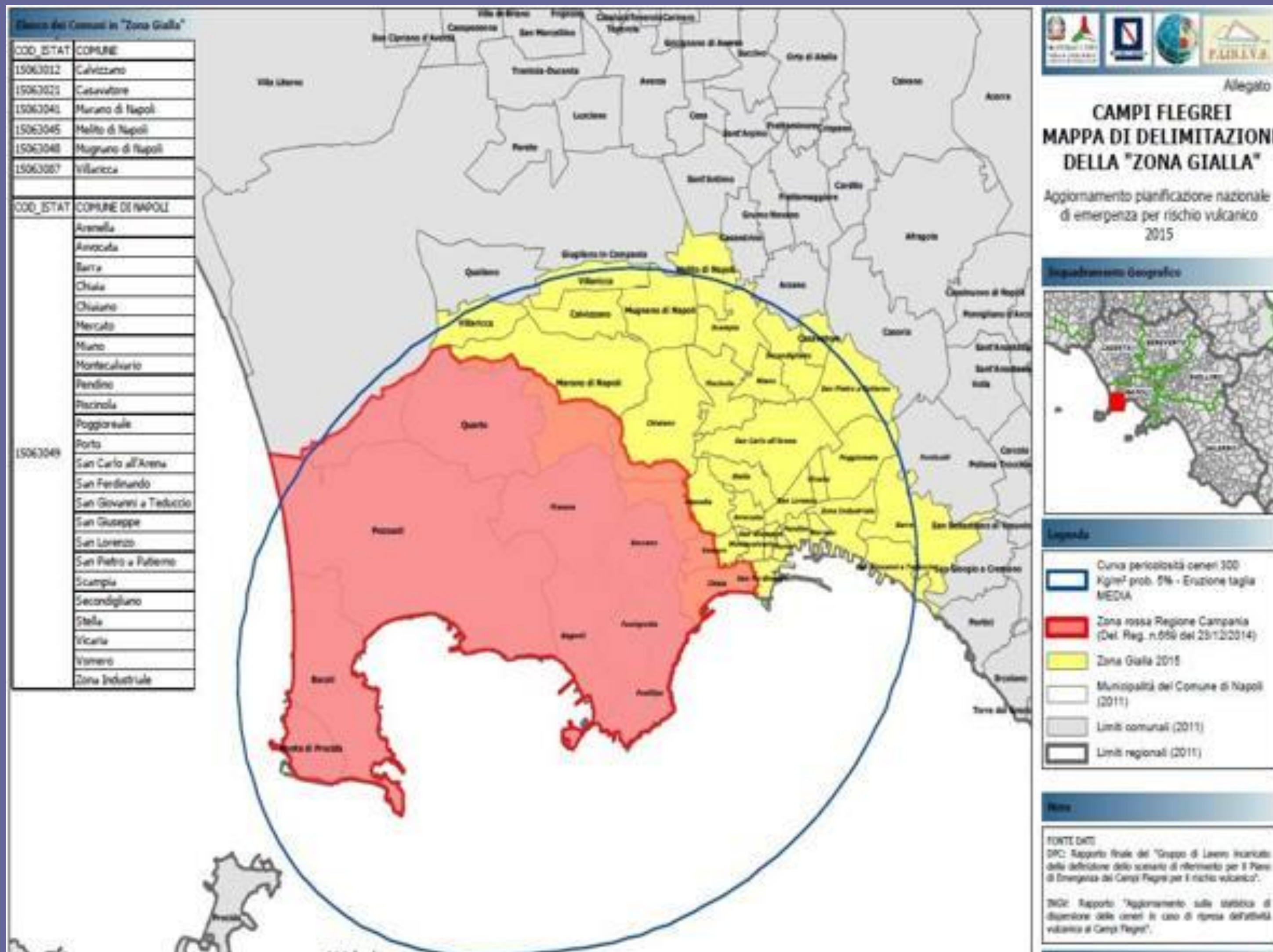
Hazard from volcanic ash



Numerical simulations of pyroclastic flows from a medium scale eruption originating in the Agnano Plain, Campi Flegrei



Red zone: potential invasion by pyroclastic flows
Yellow zone: potential severe damage from volcanic ash accumulation

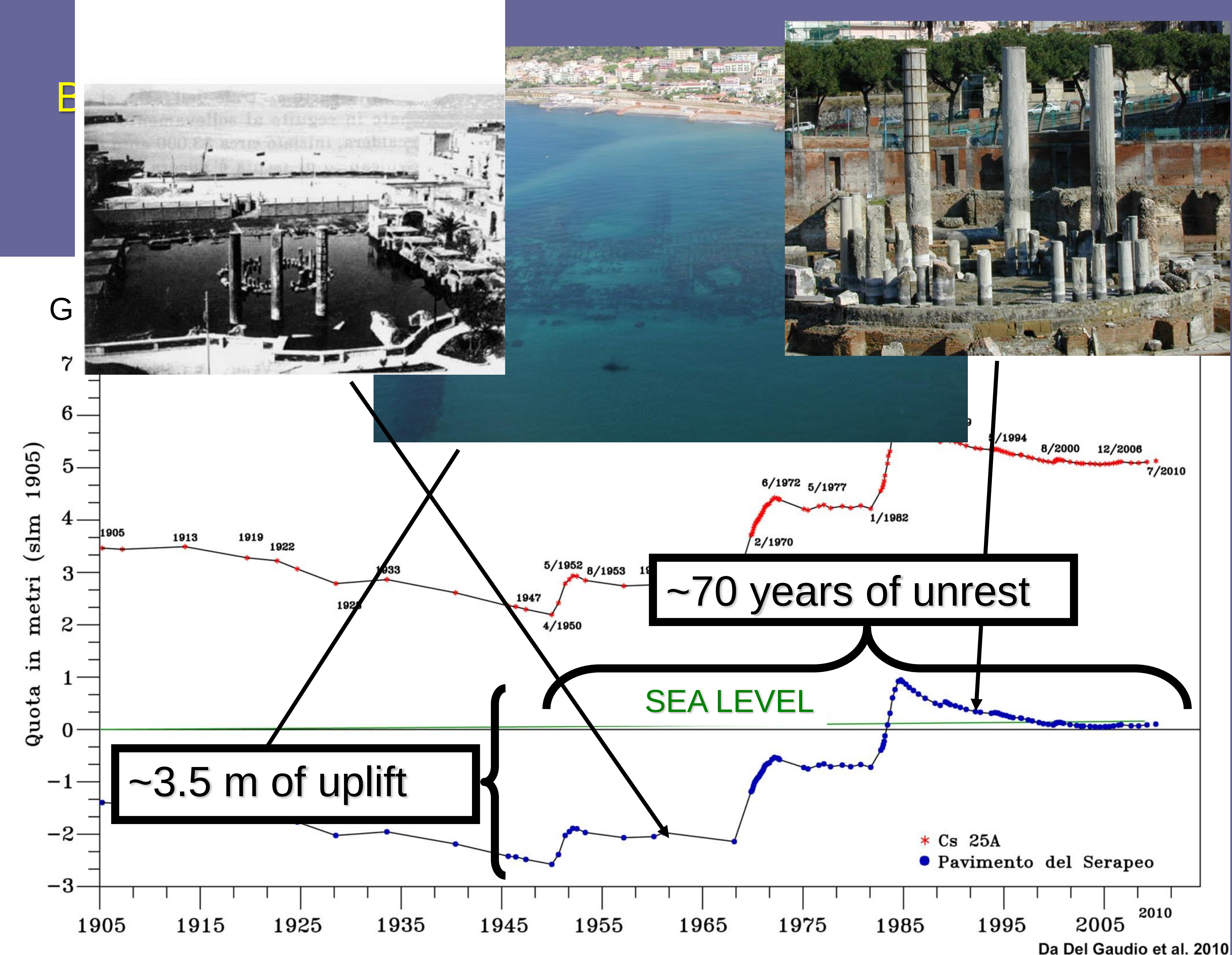


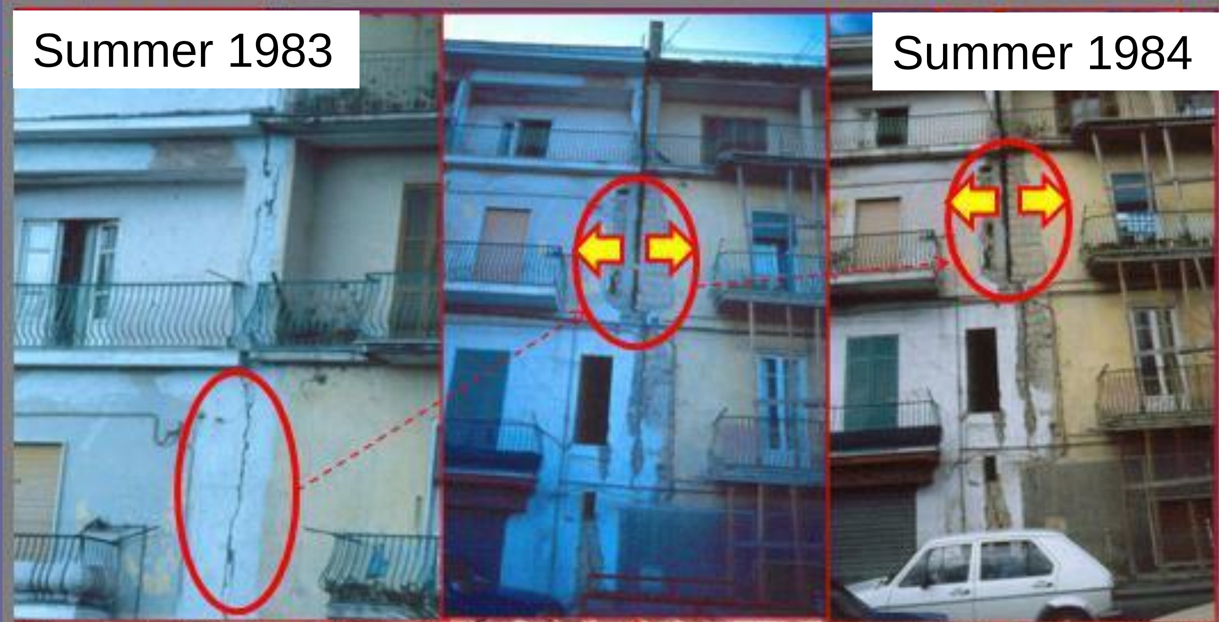
PREPAREDNESS:

How to anticipate the occurrence of an eruption?

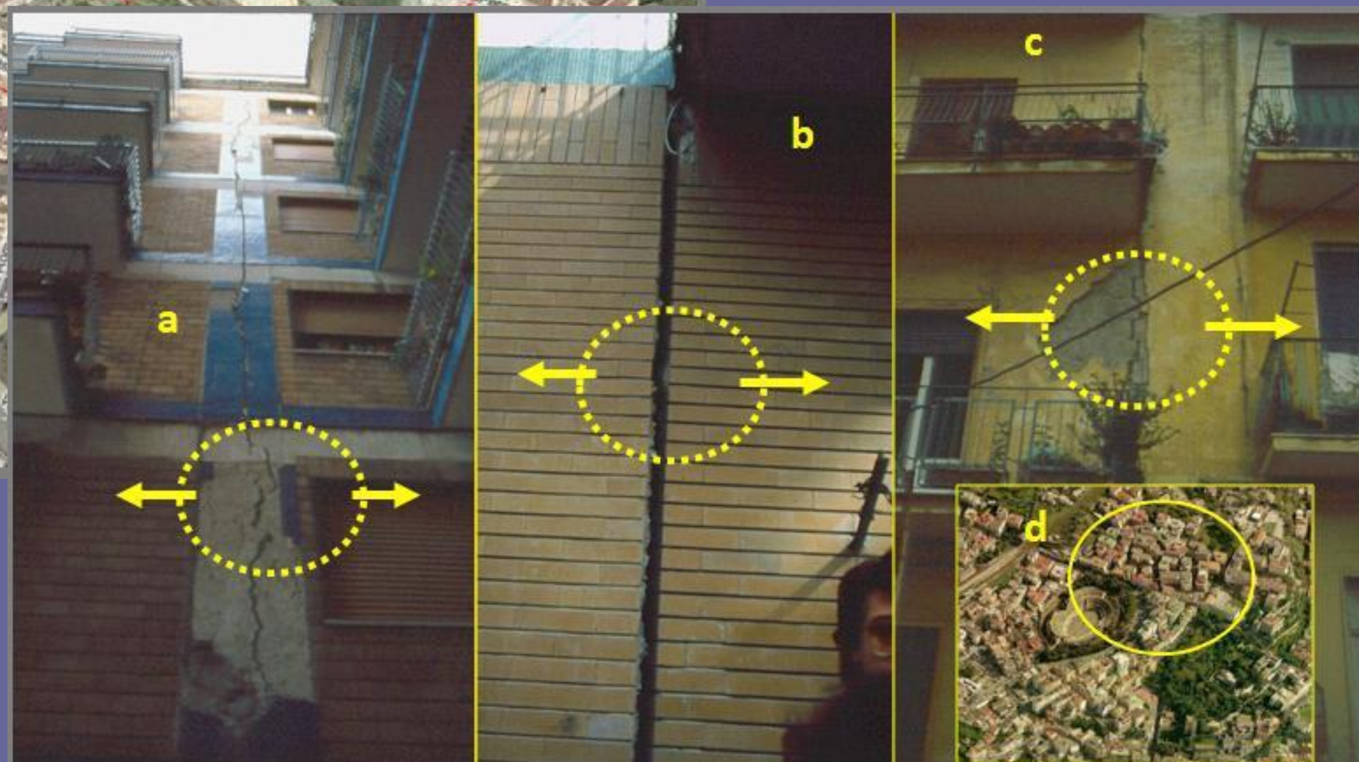
Calderas often display unrest dynamics that if observed at stratovolcanoes, they would almost certainly culminate into an eruption

Forecasting the occurrence of an eruption at calderas is much more difficult than for stratovolcanoes


~70 years of unrest
~3.5 m of uplift
SEA LEVEL
Quota in metri (slm 1905)
1905
1913
1919
1922
1933
1947
4/1950
5/1952
8/1953
2/1970
6/1972
5/1977
1/1982
5/1994
8/2000
12/2006
7/2010
Cs 25A
Pavimento del Serapeo
1905 1915 1925 1935 1945 1955 1965 1975 1985 1995 2005 2010
Da Del Gaudio et al. 2010



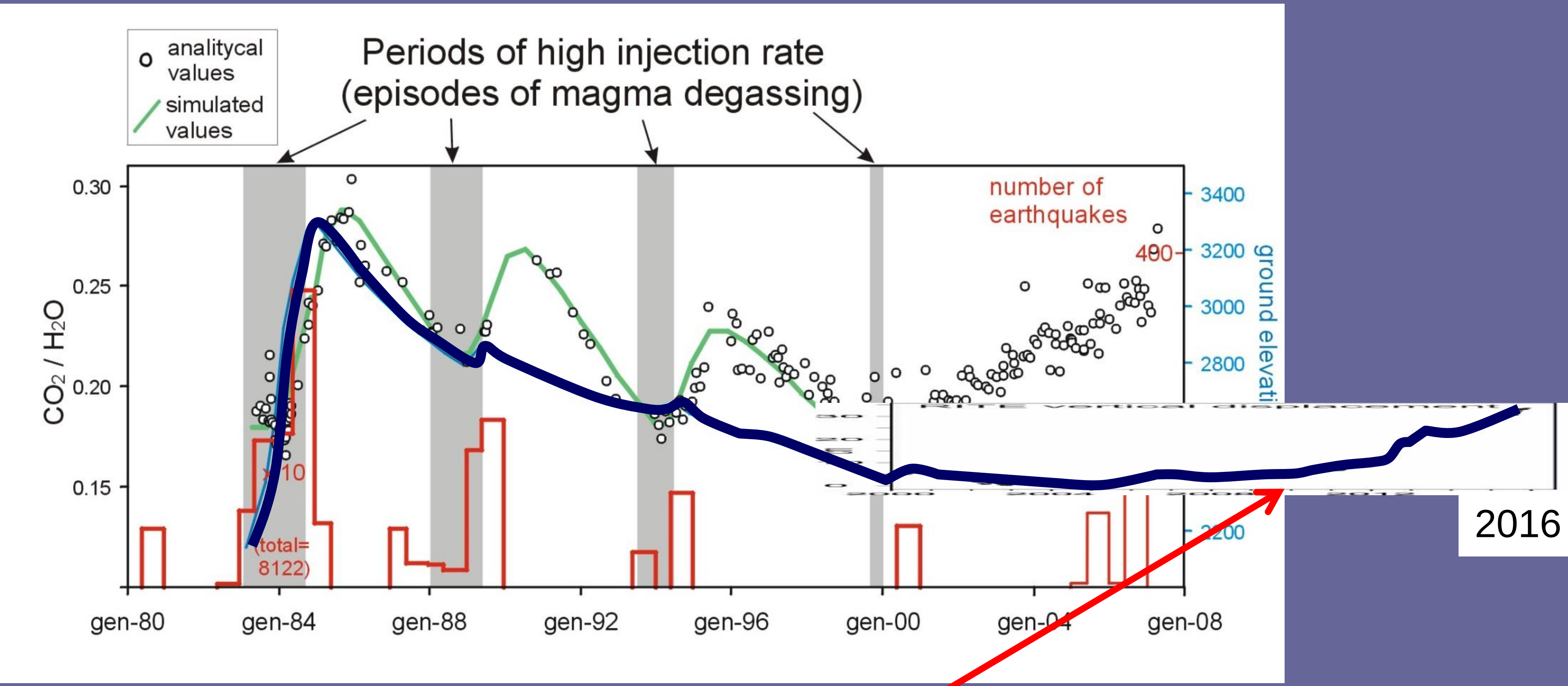
Severe damages to edifices in Pozzuoli during the 1982-84 bradiseismic crisis



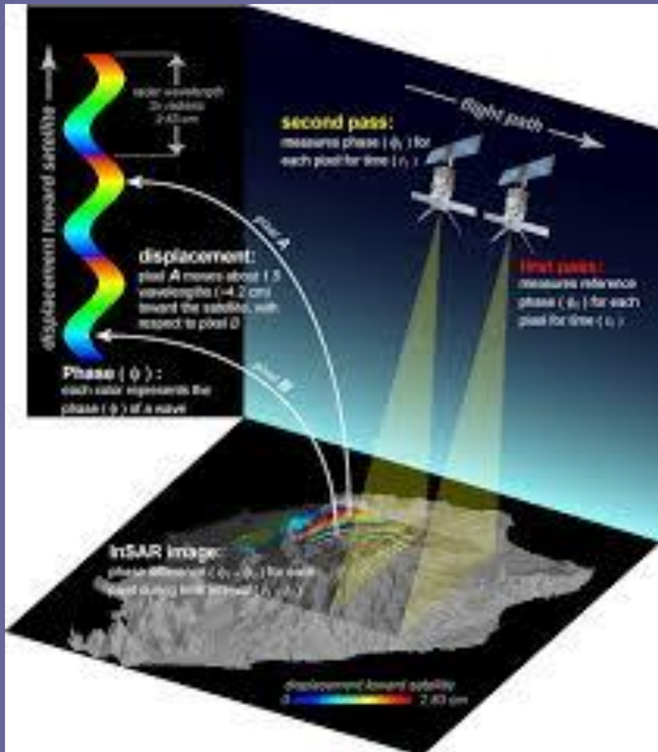
40,000 people relocated


Dominant subsidence
since Roman times

Campi Flegrei caldera, Italy

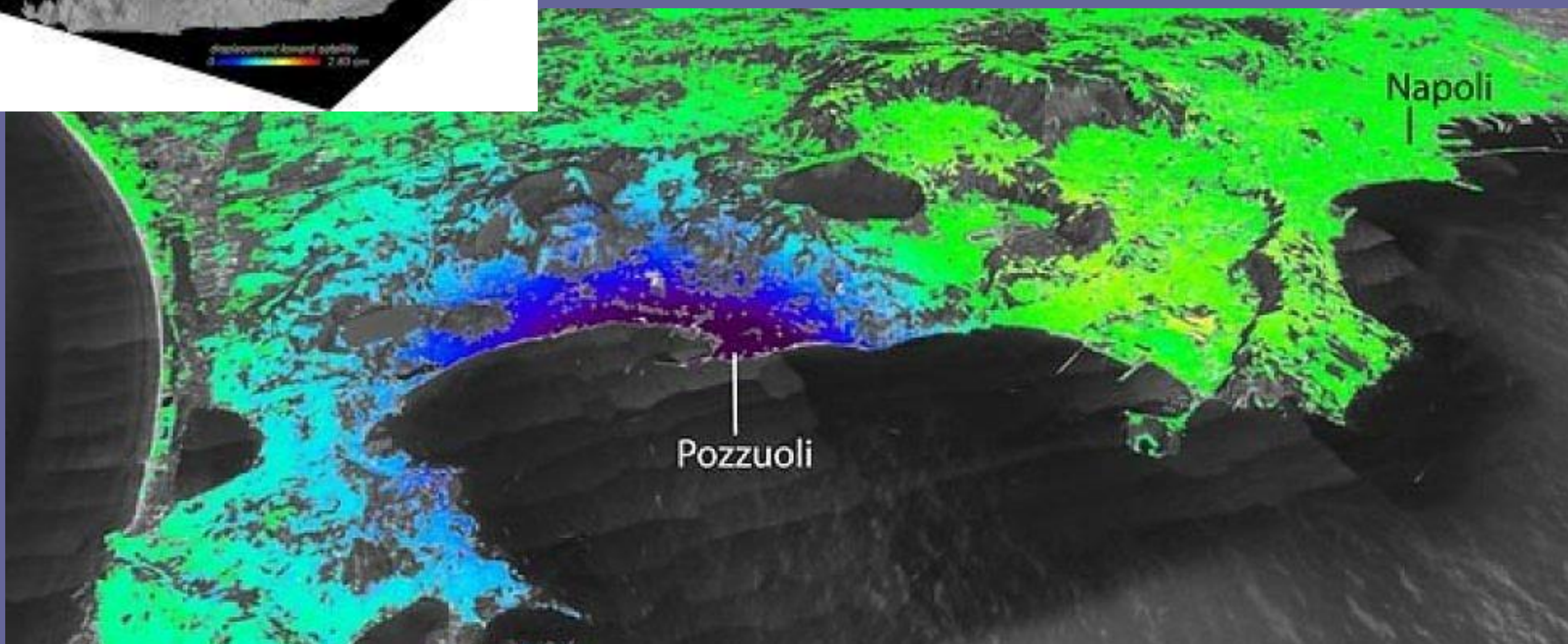


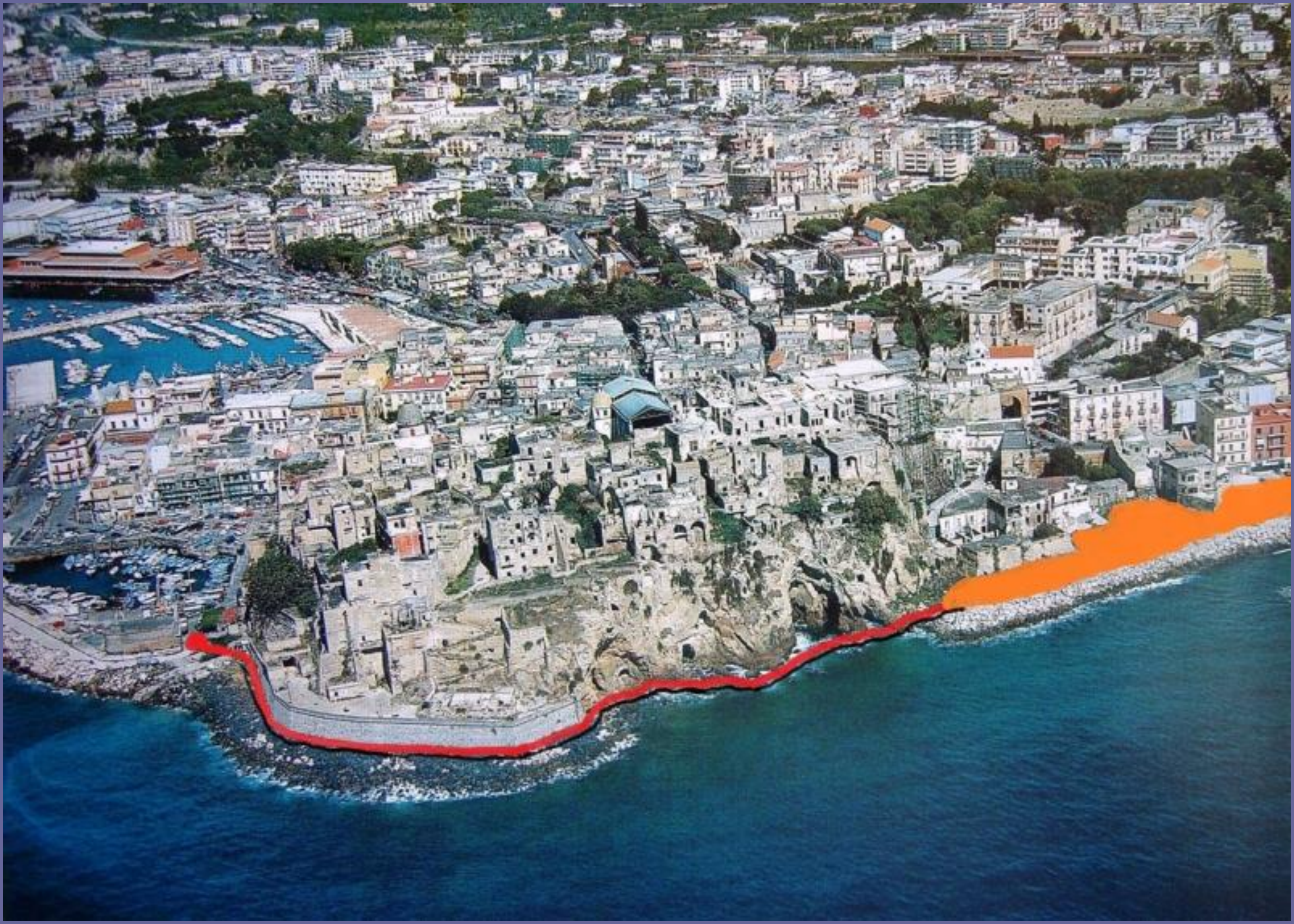
Change in the trend of deformation with the new millennium



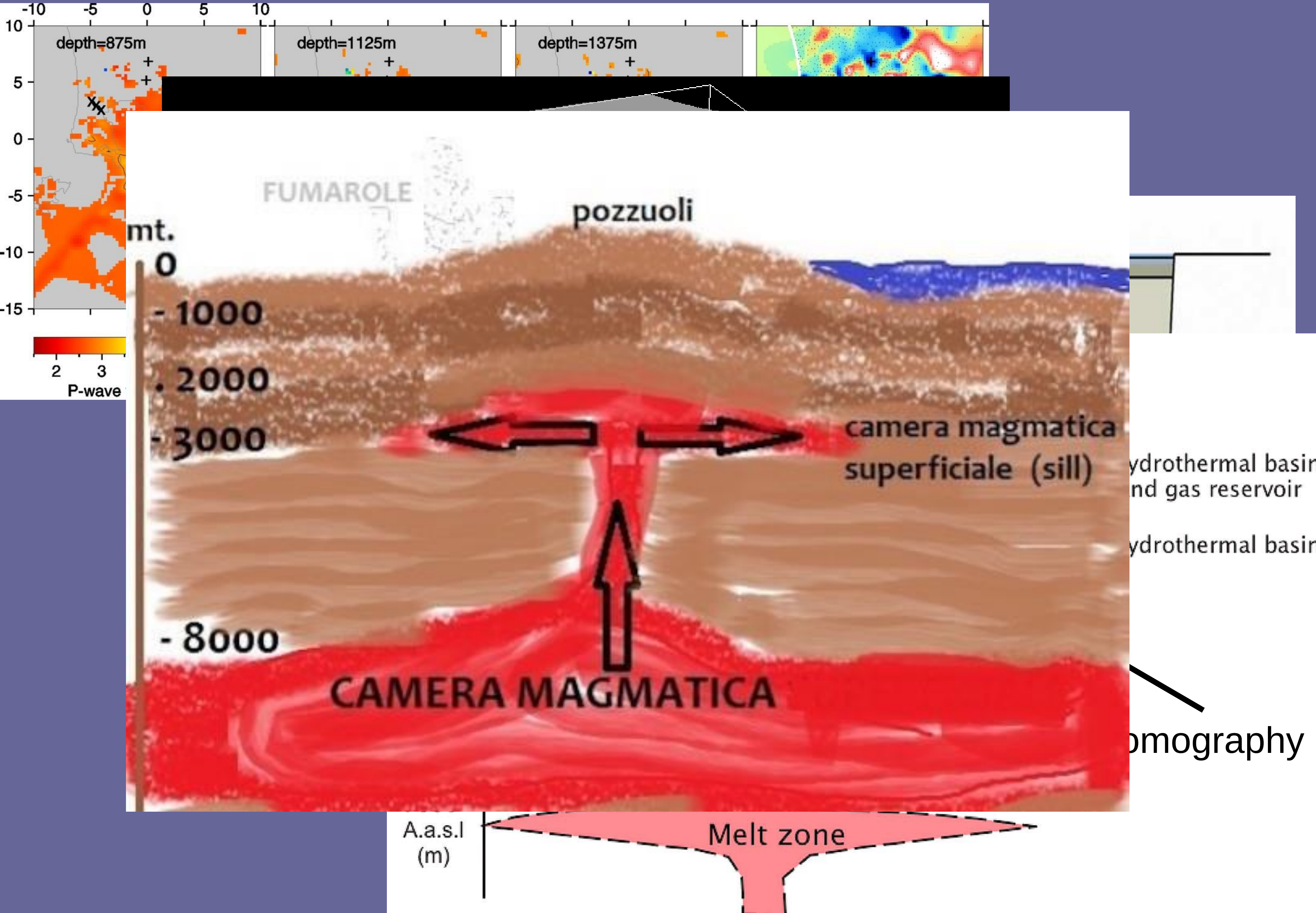
InSAR image of recent deformation at Campi Flegrei

showing uplift of the central caldera portion

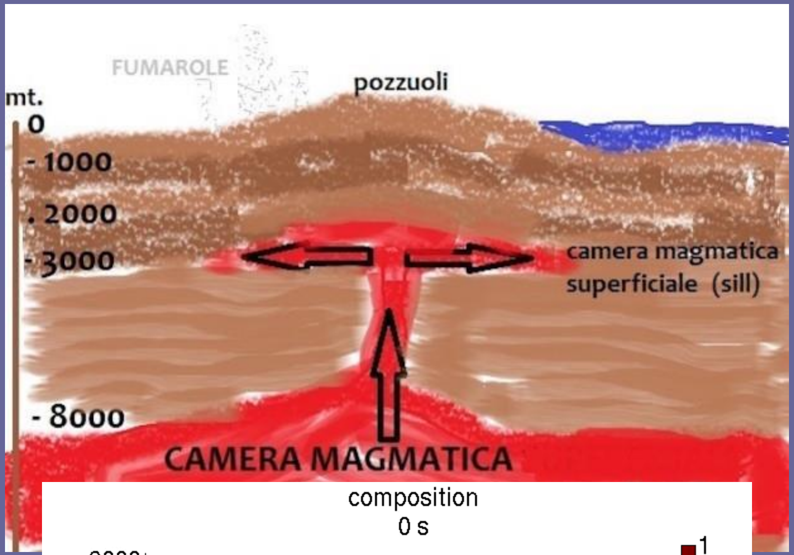




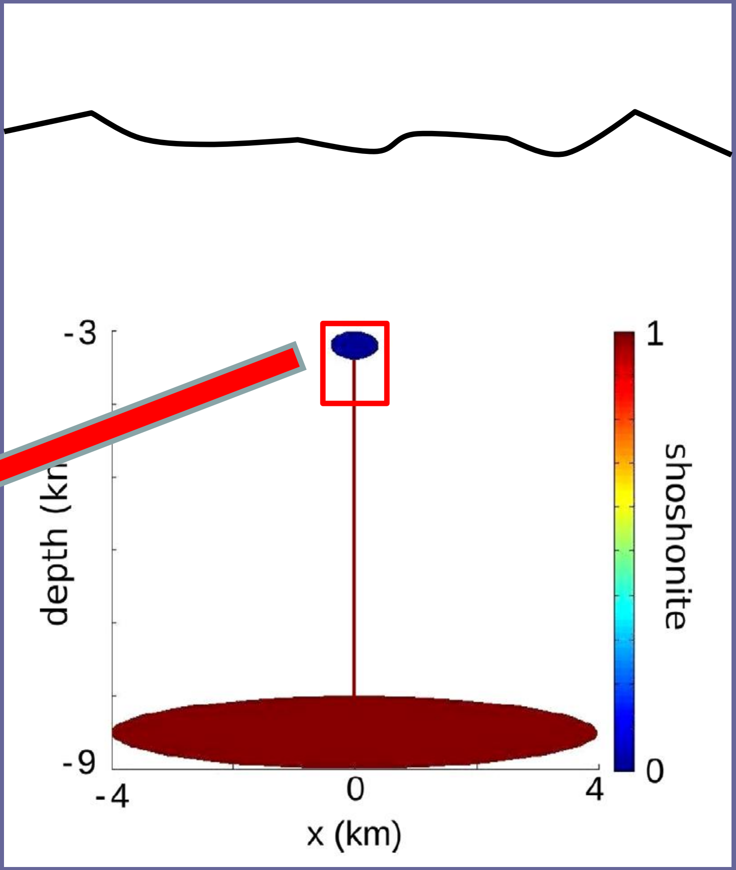
Coastal line (red) and beach (orange) in Pozzuoli, until the fifties of last century



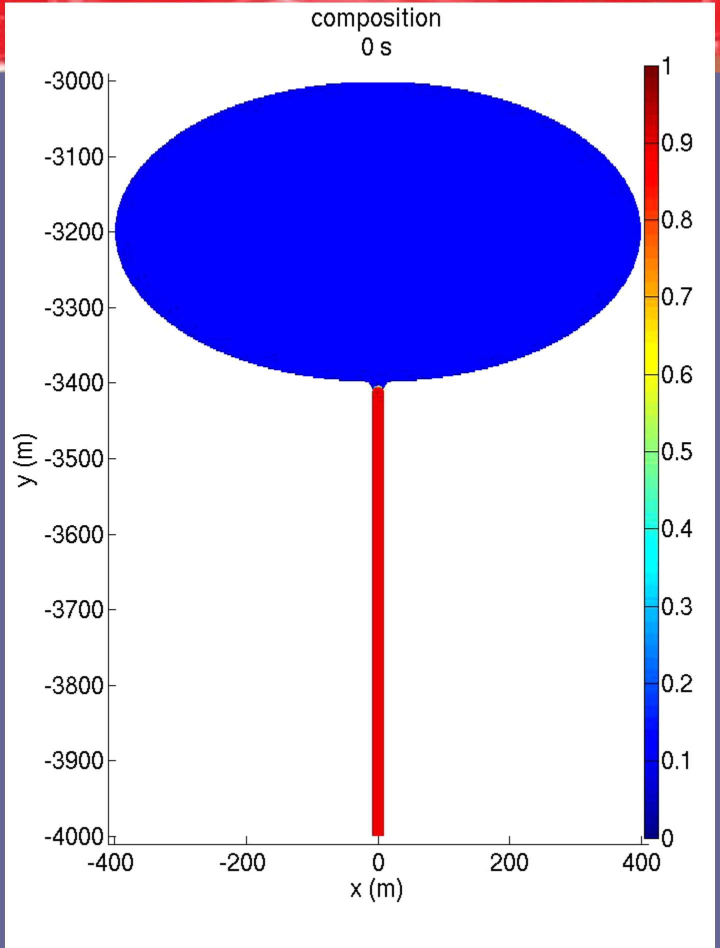
depth=875m
depth=1125m
depth=1375m
-10 -5 0 5 10
10
5
0
-5
-10
-15
2 3
P-wave
FUMAROLE
pozzuoli
mt.
0
- 1000
. 2000
- 3000
- 8000
camera magmatica
superficiale (sill)
CAMERA MAGMATICA
ydrothermal basin
nd gas reservoir
ydrothermal basin
omography
A.a.s.l
(m)
Melt zone



FUMAROLE
pozzuoli
mt.
0
- 1000
. 2000
- 3000
camera magmatica
superficiale (sill)
- 8000
CAMERA MAGMATICA

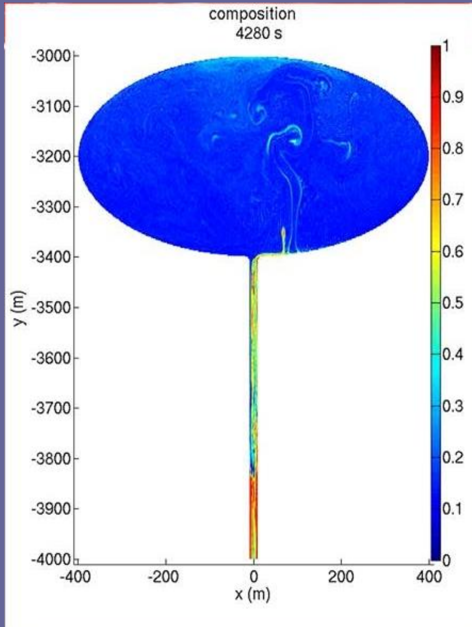


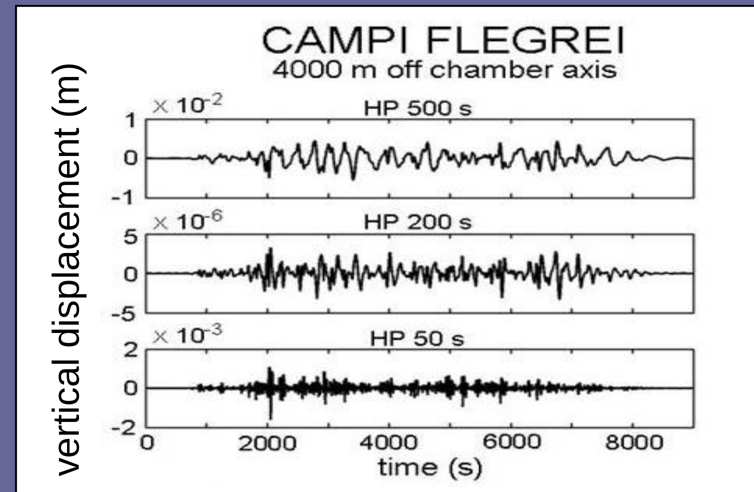
-3
-9
-4
0
4
x (km)
depth (km)
1
0
shoshonite



composition
0 s
-3000
-3100
-3200
-3300
-3400
-3500
-3600
-3700
-3800
-3900
-4000
y (m)
-400
-200
0
200
400
x (m)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0

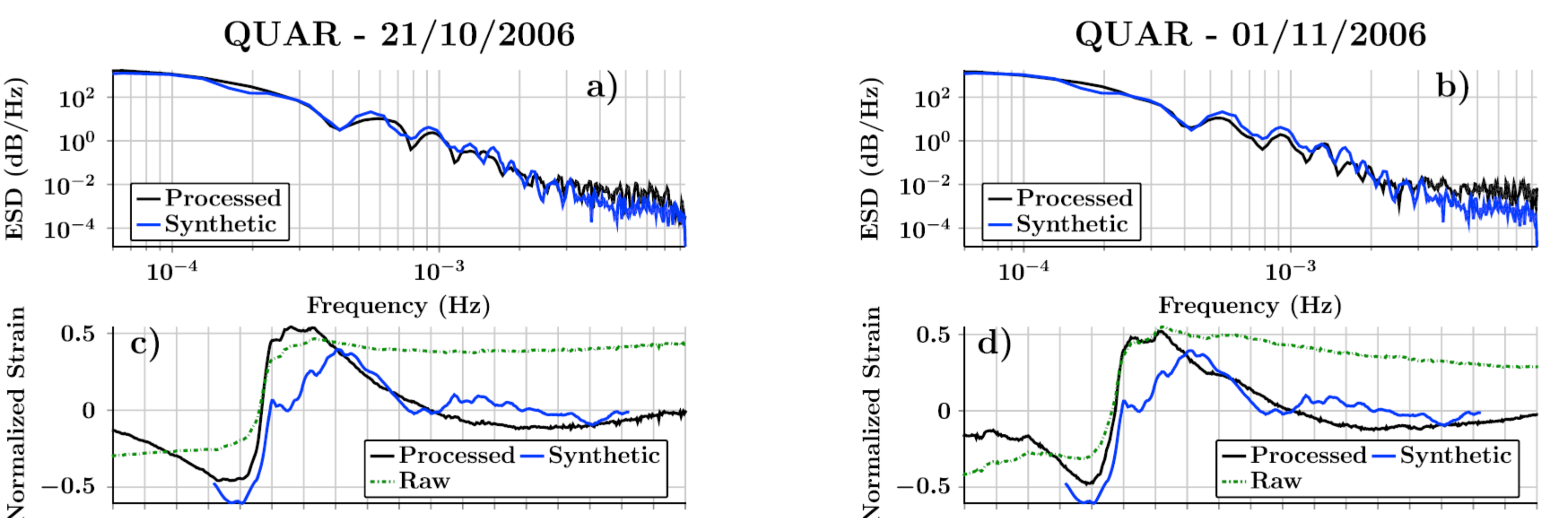
From magma dynamics… …to ground movements…



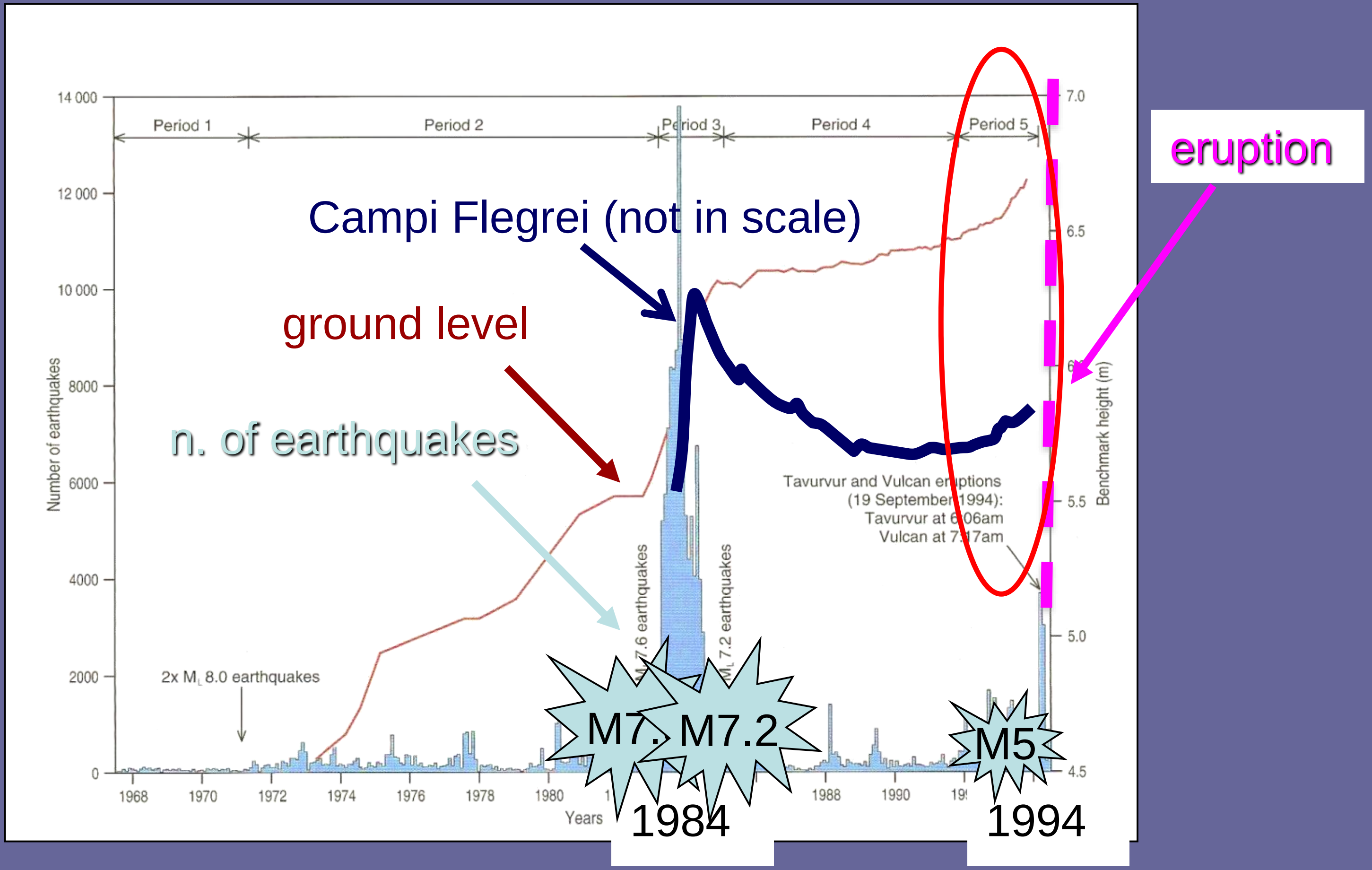


… then to comparison

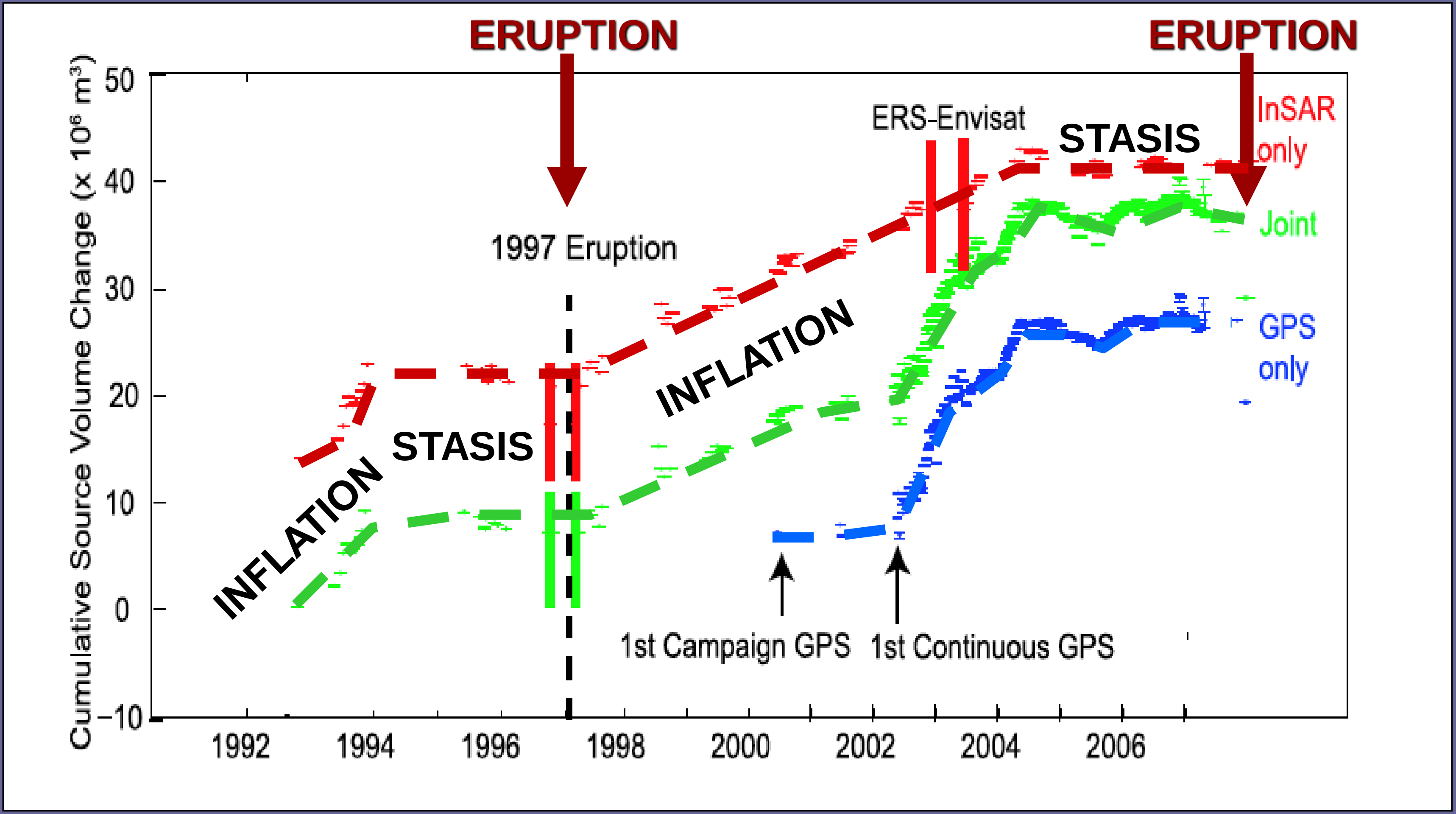
Blue lines: computed Black lines: observed



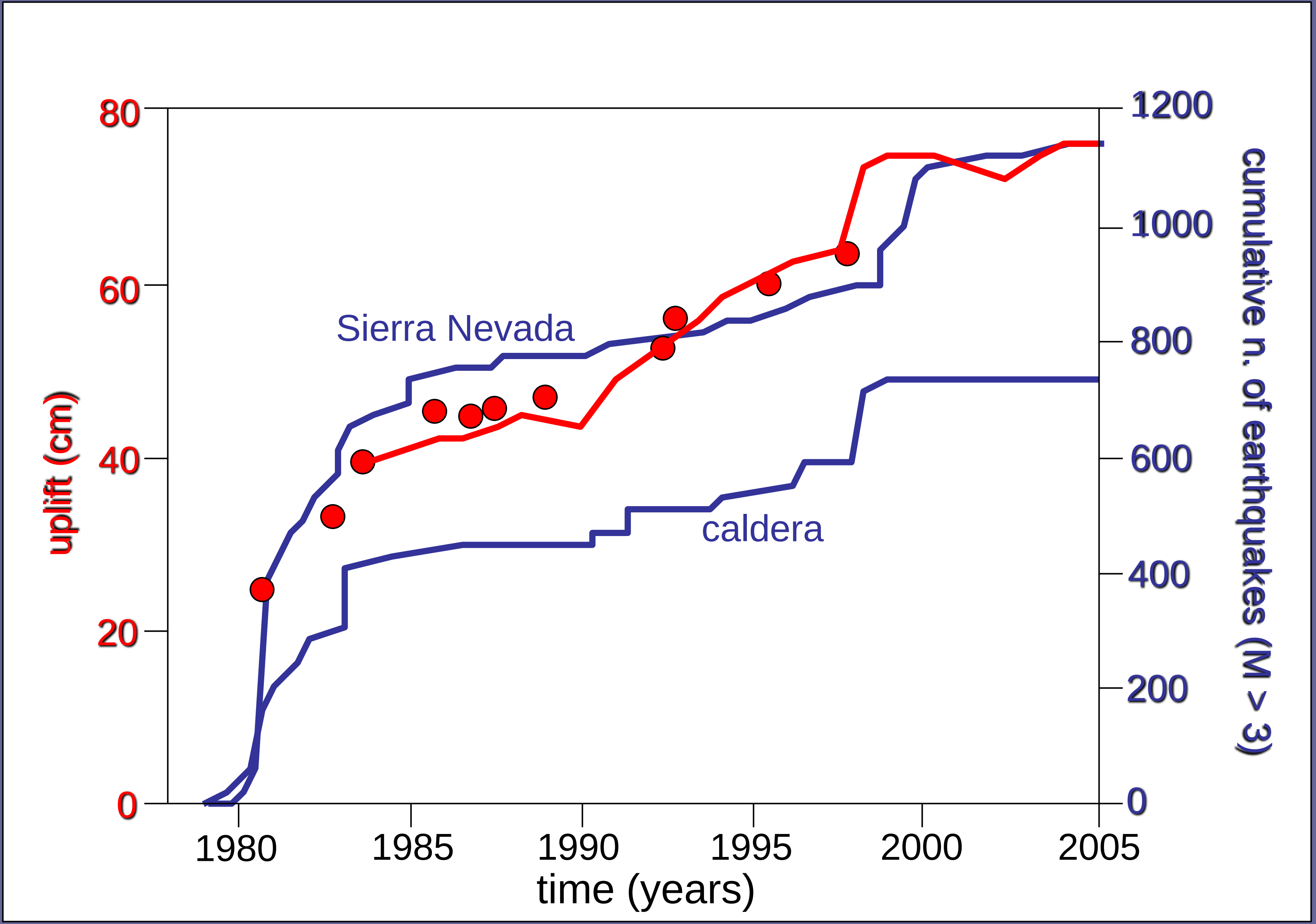
RABAUL caldera, Papua New Guinea



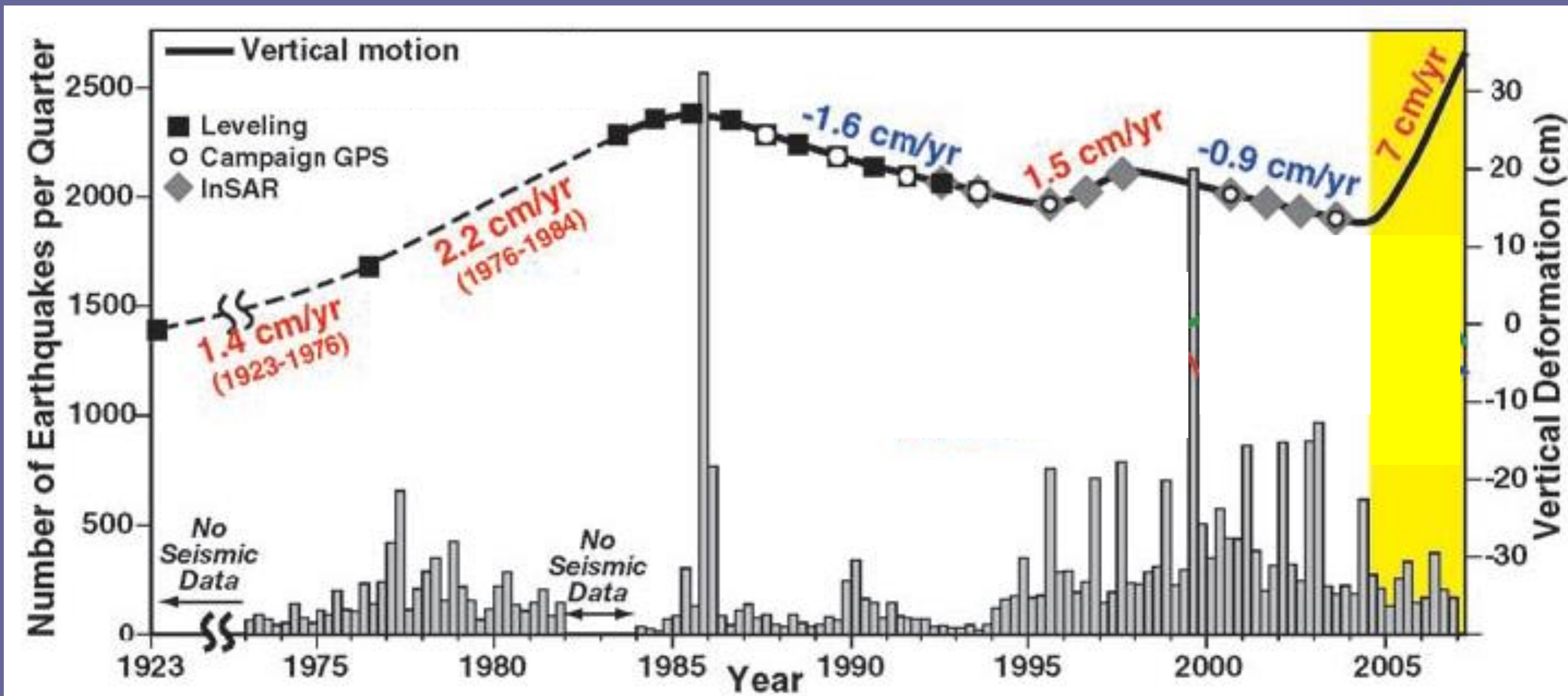
Okmok caldera, Aleutian Arc, US



Long Valley caldera, California, US



Yellowstone caldera, Wyoming, US

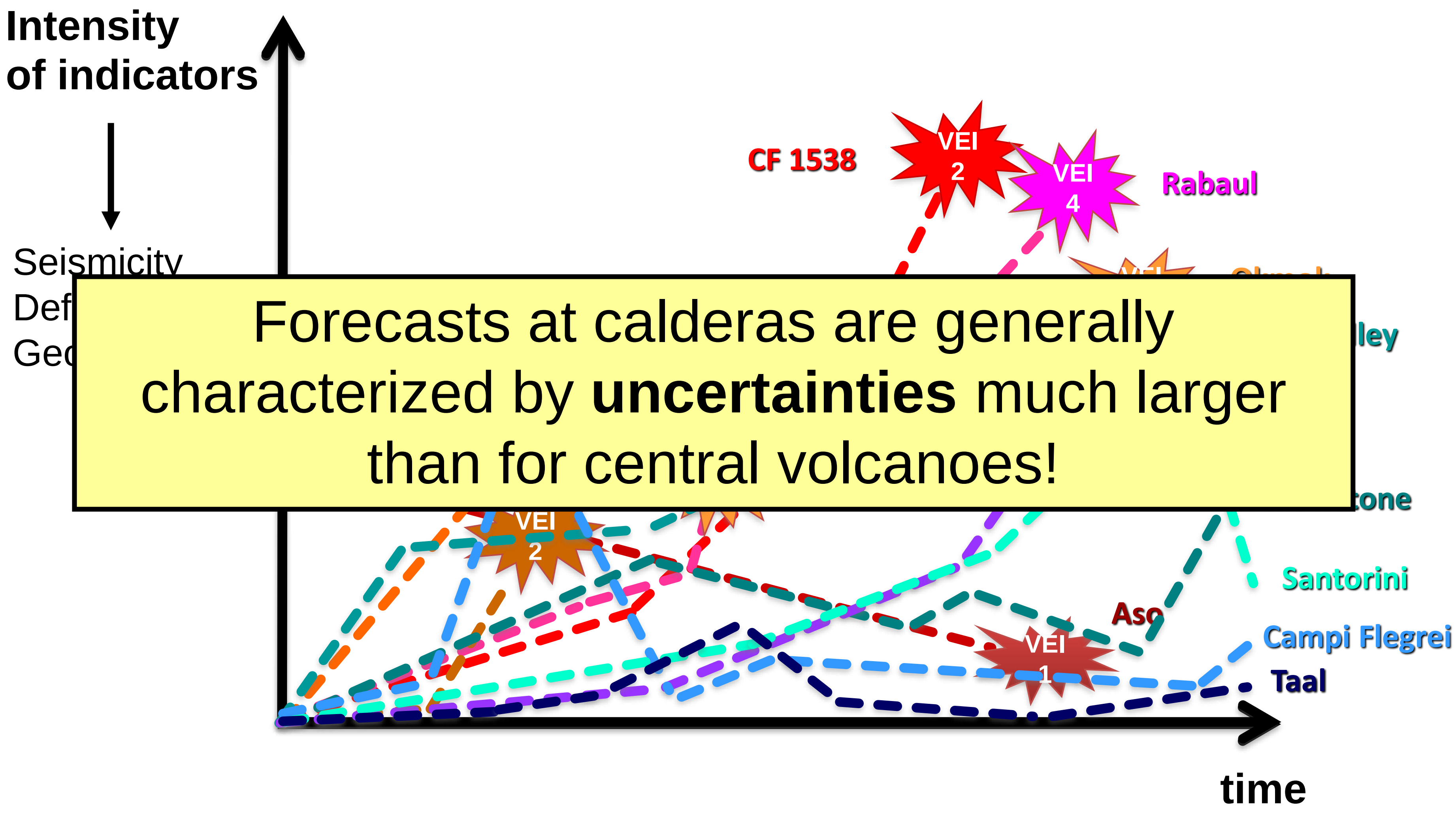


CALDERAS: the "hot" questions

- what's the relative roles of magma and hydrothermal circulation in determining unrest dynamics at calderas?

- why so often large unrest dynamics do not culminate in an eruption, whereas instead variations much smaller in duration and amplitude may do?

- how to anticipate the occurrence of eruptions at calderas?



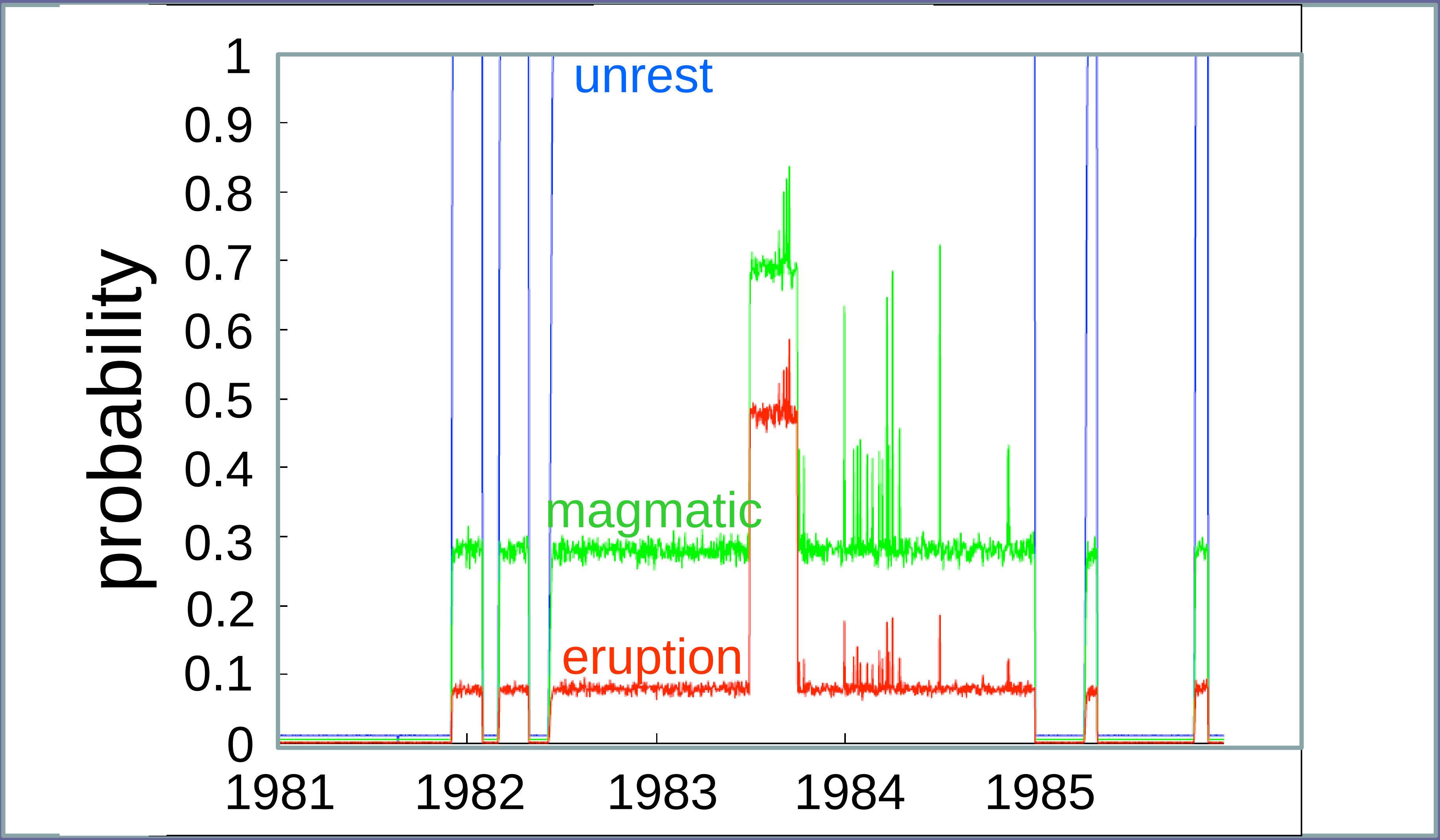
Forecasts at calderas are generally characterized by **uncertainties** much larger than for central volcanoes!

Di Lorenzo, Acocella, Scandone, 2013 (redrawn)

(project INGV-DPC 2012-13 – report)

Probabilistic approach to eruption forecast

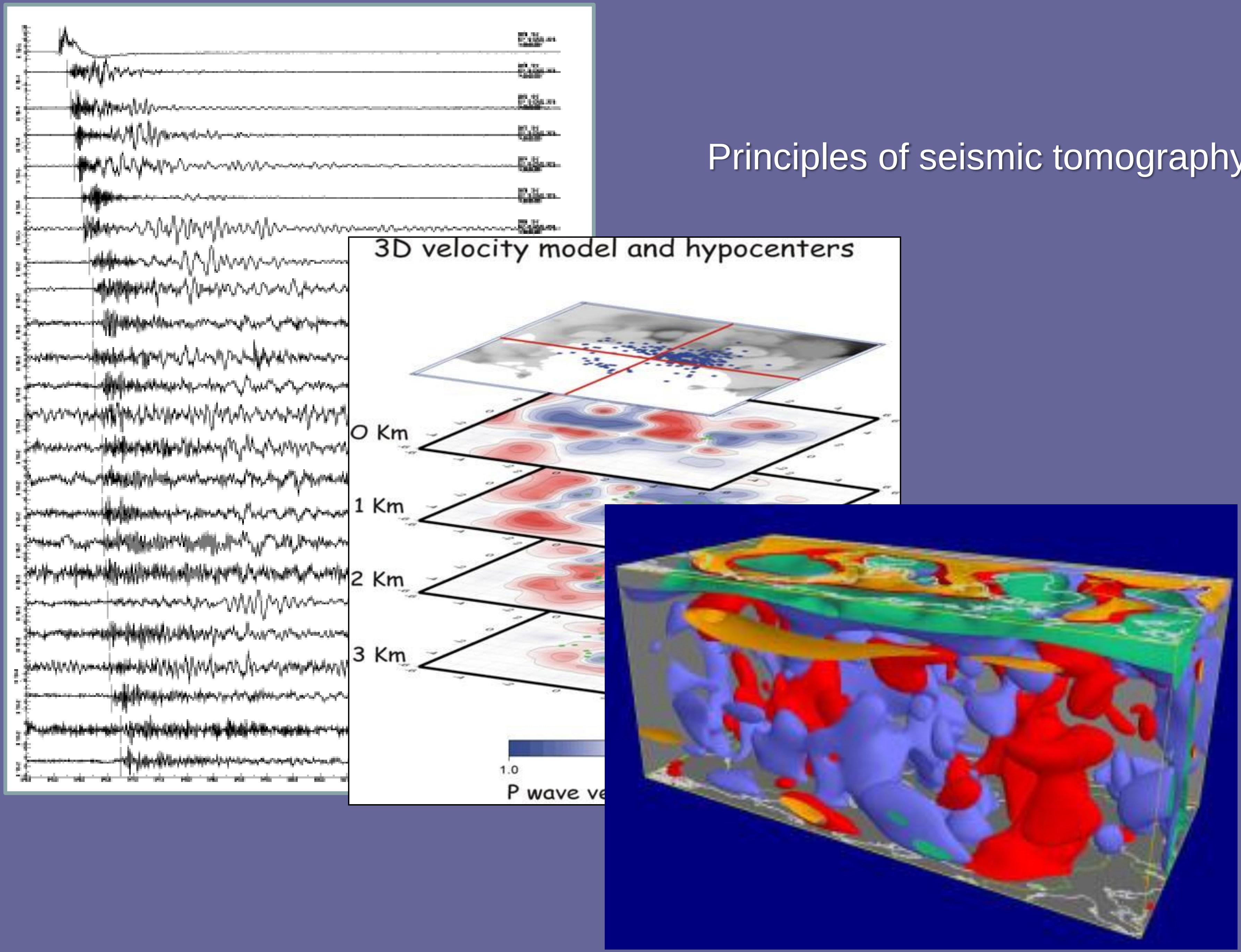
Application to Campi Flegrei crisis 1982-1984



Campi Flegrei tomorrow?

MANY THANKS

Principles of seismic tomography



Campi Flegrei – Pre-eruptive Event Tree

ELICITATION V		BACKGROUND	Gray area	UNREST	Gray area	MAGM. UNREST	Gray area	ERUPTION
VT (M > 0.8)	[ev/day]		5	15				
LP/VLP/ULP	[ev/month]		2	10				
Rate uplift	[cm/month]		0.7	1.3				
Uplift	[cm]		2	6	6	15		
T Pisciarelli			100	110				
VLP/ULP					1	5		
Deep VT (M > 0.8)	[ev/day]				2	20		
Deep LP (> 2 Km)	[ev/day]				3	20		
Disp. Hypocenters	[km]						1	3
Tremor								YES
Deep Tremor (>3.5 Km)						YES		
Acc. seismic events								YES
Acc. RSAM								YES
New fractures								YES
Macr. (dm) variation in def.								YES
Migr. max uplift								YES
Ext degassing				YES				
Magm. comp. gases						YES		
HF - HCl - SO2						YES		YES
Phreatic activity								YES

DELPHI METHOD

Red parameters: Seismicity

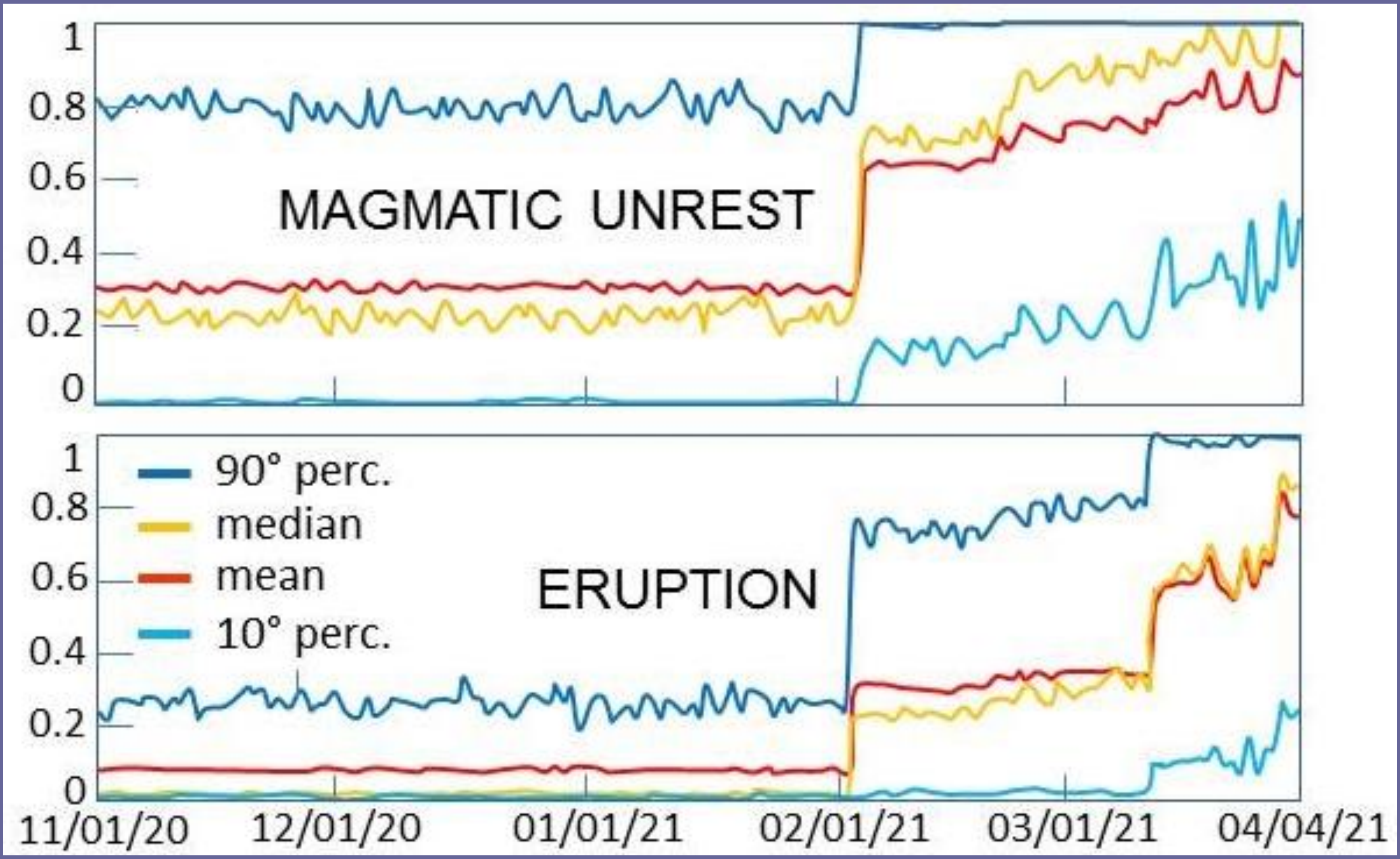
Green parameters: Deformation

Blue parameters: Geochemistry

Boolean parameters are represented by "YES"

"Gray areas" correspond to variable probability of being in the adjacent states, depending on the measured values

after Selva et al., 2011


MAGMATIC UNREST
ERUPTION
90° perc.
median
mean
10° perc.
1
0.8
0.6
0.4
0.2
0
11/01/20
12/01/20
01/01/21
02/01/21
03/01/21
04/04/21

CALDERAS: why are they different?

- The structure of calderas is profoundly different from that of stratovolcanoes

- “negative” as opposed to “positive” edifice
- boarder faults
- chaotic rock assemblage
- development of large geothermal circulation
- resurgency
- compressional/extensional portions
- several distinct post-collapse vents
- …