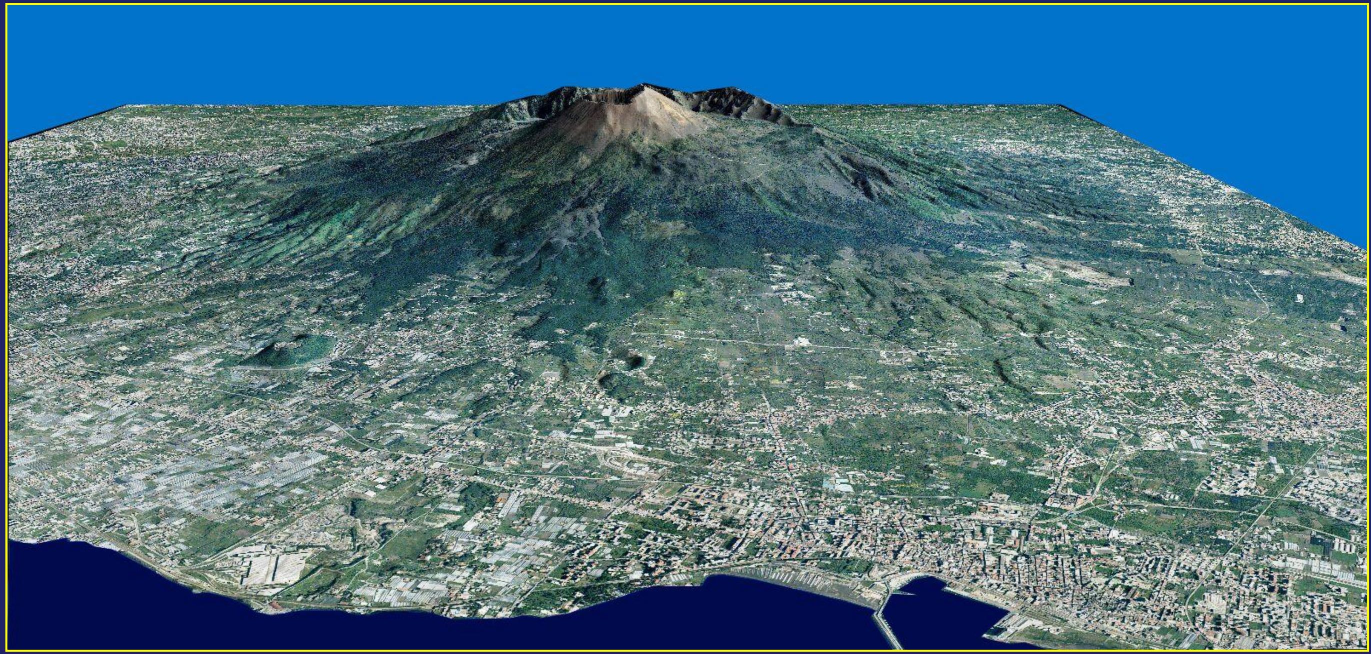
European Geosciences Union - General Assembly 2013 - Vienna, Austria - 09 Apr. 2013
GIFT Workshop

Risk assessment of Vesuvius volcano



Franco Barberi *Univ Roma Tre, Italy*

Eruptive history

79 A.D. - 1944:

Growth of the present cone

-open conduit persistent activity (i.e.1631–1944) interrupted by repose periods closed by subplinian eruptions such as in

1631

472

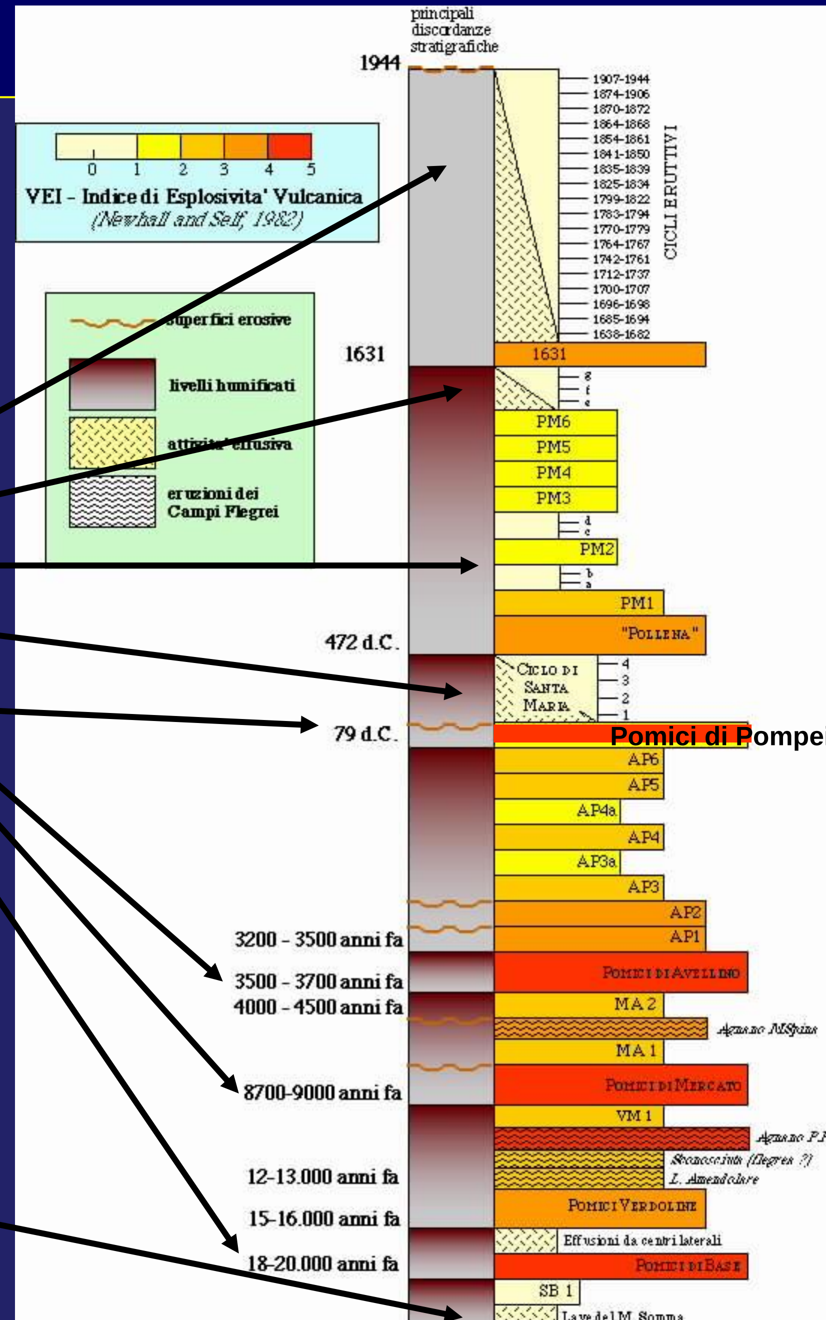
18.000 ka - 79 A.D.:

4 major plinian eruptions

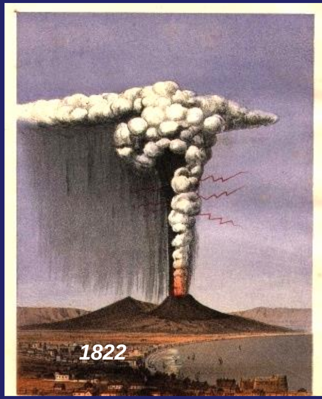
Alternated by a dozen of medium to small explosive eruptions

30.000 - 20.000 ka:

Formation of Mt. Somma



The reference eruption for the Vesuvius emergency plan



In 1944, after nearly 3 centuries of almost continuous activity, Vesuvius entered a new quiescence stage whose duration cannot be assessed.

The choice of the next eruption (type, energy, related hazards) is of fundamental importance for the preparation of an adequate plan for the protection of the exposed people.

This is not an easy task because of the difference recorded in the Vesuvius eruptions along time. Recent studies addressed the evaluation of the probability of occurrence at short or mid-term for the three main types of Vesuvius explosive eruptions.

Probability of occurrence (repose time 60 to 200 years)		
Violent Strombolian	Sub-Plinian I	Plinian
(VEI = 3)	(VEI = 4)	(VEI = 5)
72%	27%	1%
Modified after Marzocchi et al., 2004		

A Sub-Plinian eruption, similar to that occurred in 1631, though less probable than a "violent Strombolian", was selected as the reference event for the Vesuvius emergency preparedness plan

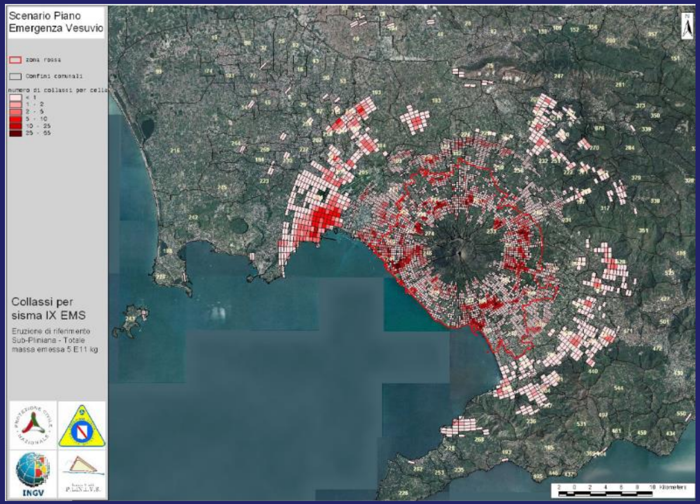
Main hazards related to a Sub-Plinian eruption

- **Pre-eruption earthquakes**

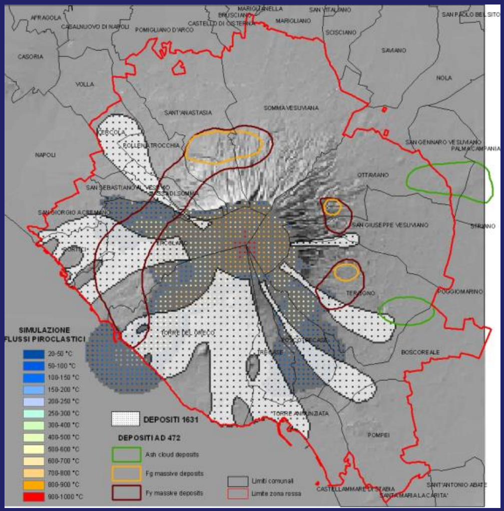
- **Eruption ongoing:**
  - **ash fallout from wind dispersed tephra of sustained column (yellow zone)**
  - **pyroclastic flows from column collapse (red zone)**

- **Sin-and-post eruption: lahar by rain mobilization of loose tephra on the volcanic edifice and downwind steep reliefs (blu zone)**

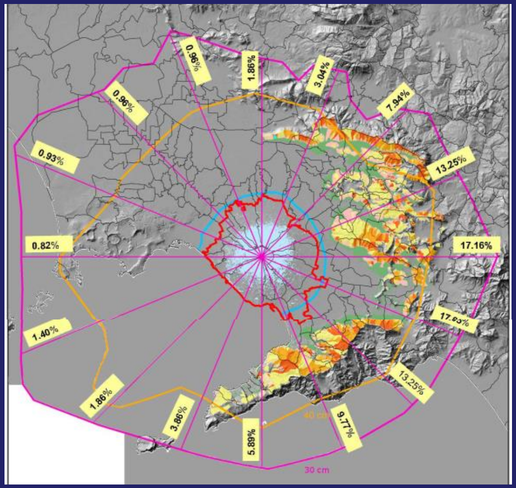
Earthquakes



Pyroclastic Flows



Lahar

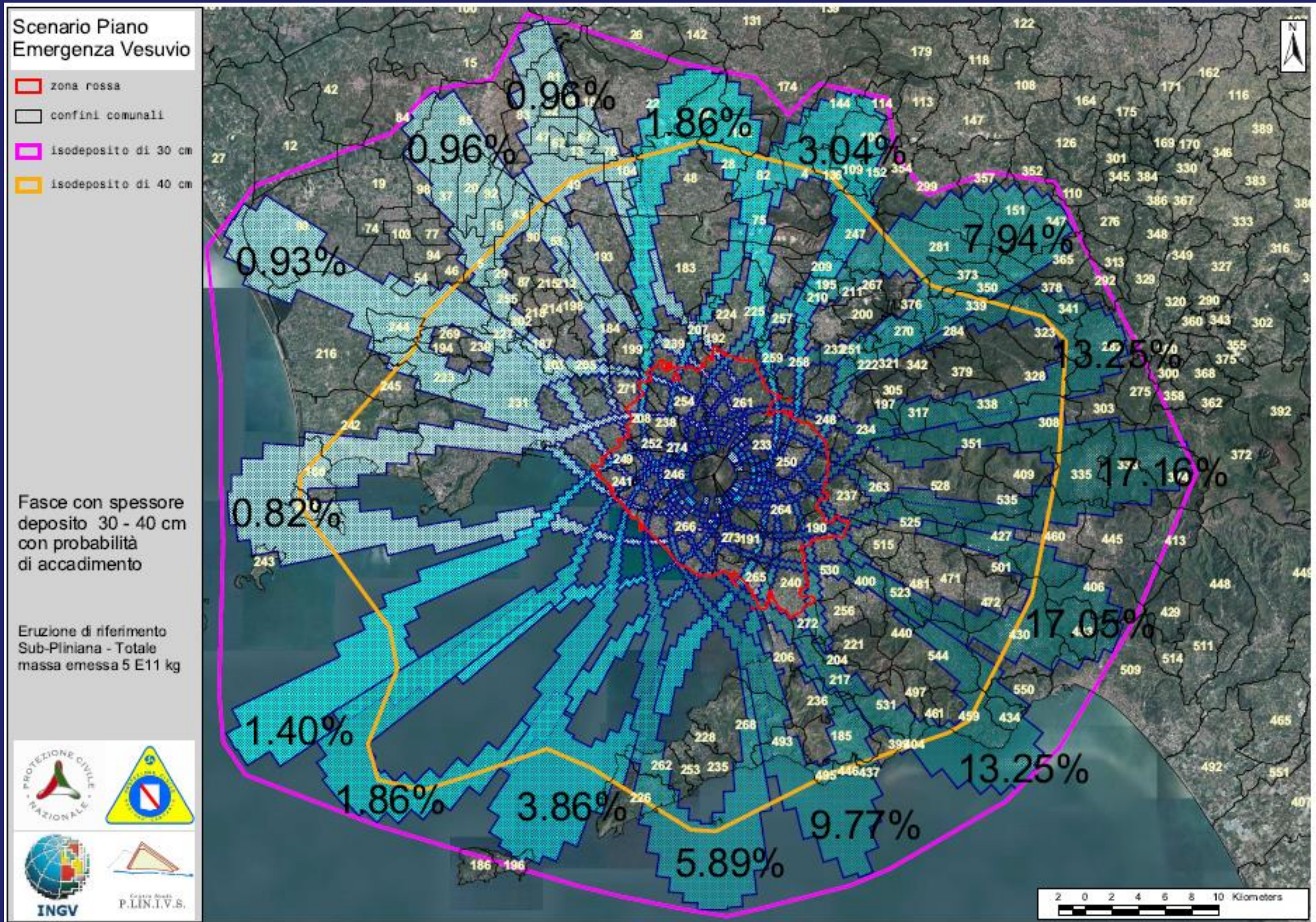


Risk = hazard x vulnerability x exposure

Hazard assessment for pyroclastic fallout
(yellow zone)

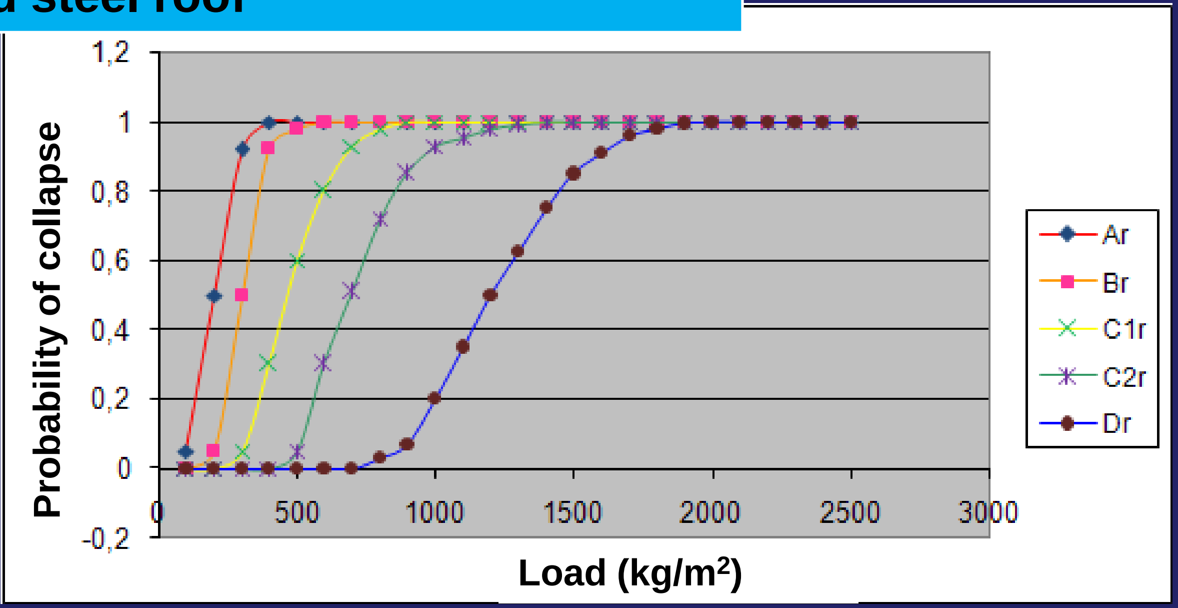
Reference eruption: Sub-Plinian (VEI=4) **Column height**: 18 km

Total discharged mass: $5x10^{11}$ kg **Wind data**: 1991-2010 (from NOAA)



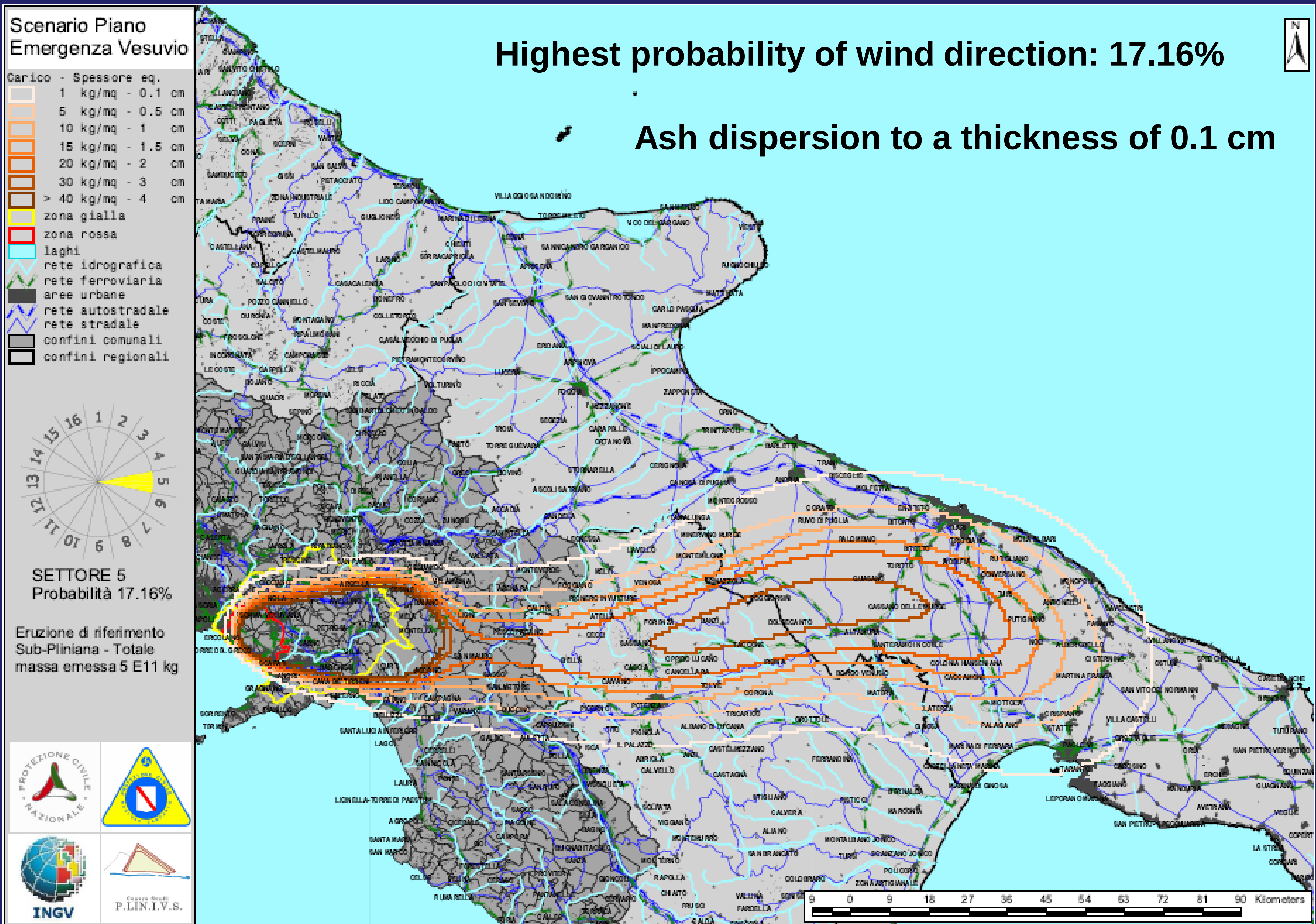
Roof vulnerability to ash load

Type	Description
Ar	Weak pitched wooden roof
Br	Flat standard wooden roof Reinforced concrete flat roof – SAP type Weak steel and little vaults flat roof
C1r	Flat r.c. roof older than 20 years
C2r	Flat r.c. roof younger than 20 years
Dr	Recent pitched r.c. roof Recent pitched steel roof



After Zuccaro et al., 2008

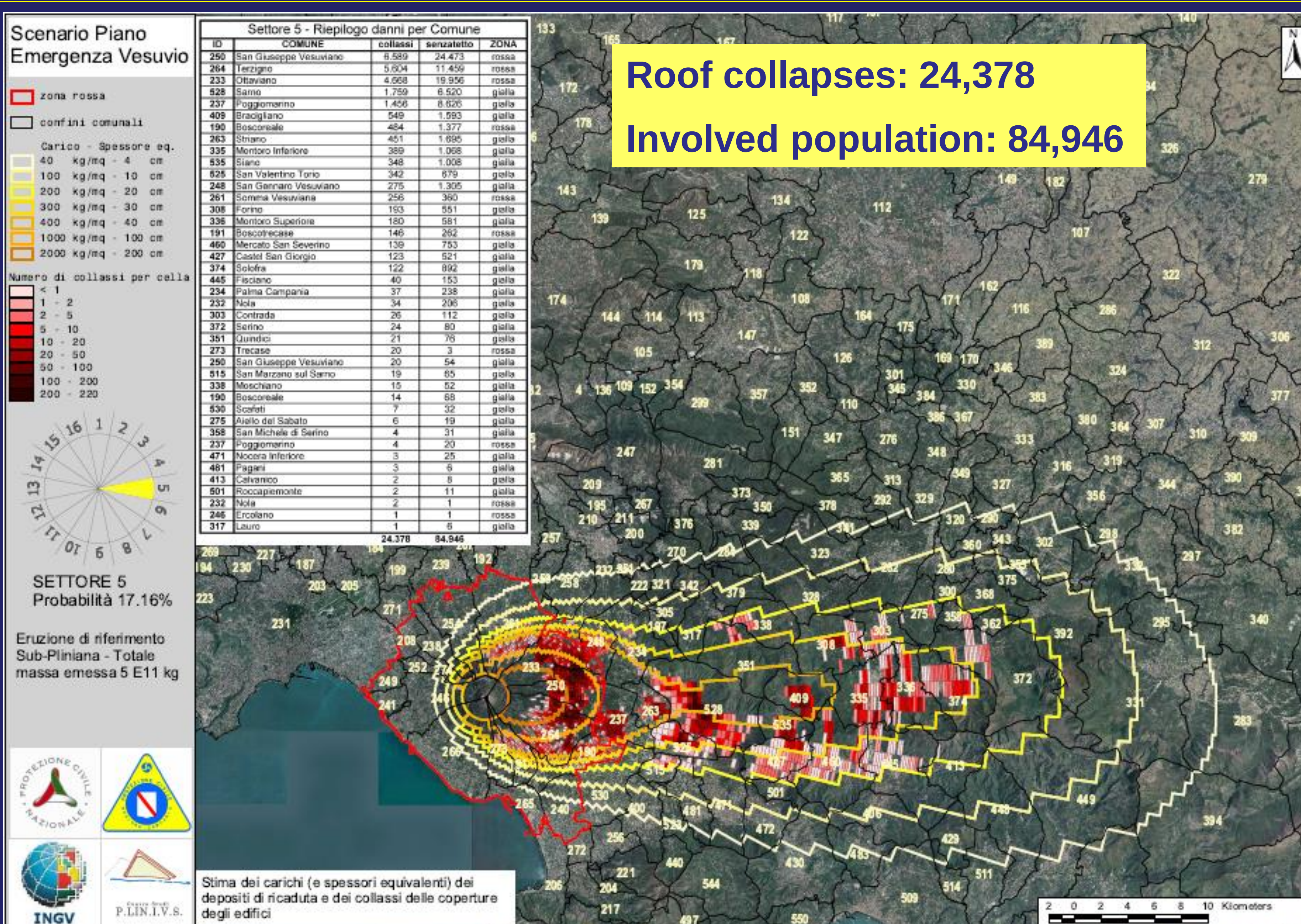
Hazard assessment for pyroclastic fallout



Risk assessment for pyroclastic fallout

Roof collapses: 24,378

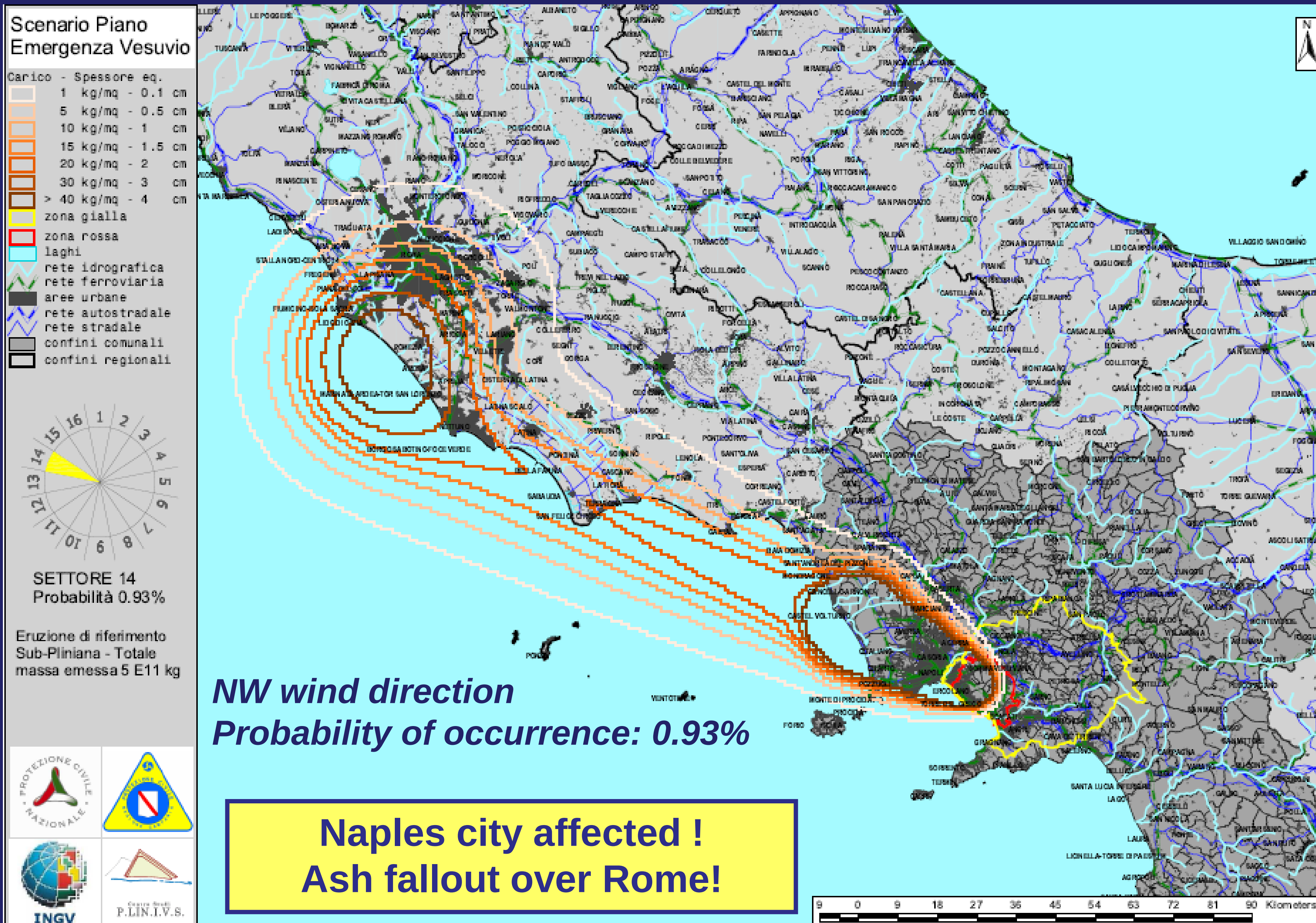
Involved population: 84,946



Settore 5 - Riepilogo danni per Comune

ID	COMUNE	collassi	senzatetto	ZONA
250	San Giuseppe Vesuviano	6.589	24.473	rossa
264	Terzigno	5.604	11.459	rossa
233	Ottaviano	4.668	19.956	rossa
528	Sarno	1.759	6.520	gialla
237	Poggiomarino	1.456	8.626	gialla
409	Bracigliano	549	1.593	gialla
190	Boscoreale	484	1.377	rossa
263	Striano	451	1.695	gialla
335	Montoro Inferiore	389	1.068	gialla
535	Siano	348	1.008	gialla
525	San Valentino Torio	342	679	gialla
248	San Gennaro Vesuviano	275	1.305	gialla
261	Somma Vesuviana	256	360	rossa
308	Forino	193	551	gialla
336	Montoro Superiore	180	581	gialla
191	Boscotrecase	146	262	rossa
460	Mercato San Severino	139	753	gialla
427	Castel San Giorgio	123	521	gialla
374	Solofra	122	892	gialla
445	Fisciano	40	153	gialla
234	Palma Campania	37	238	gialla
232	Nola	34	206	gialla
303	Contrada	26	112	gialla
372	Serino	24	80	gialla
351	Quindici	21	76	gialla
273	Trecase	20	3	rossa
250	San Giuseppe Vesuviano	20	54	gialla
515	San Marzano sul Sarno	19	65	gialla
338	Moschiano	15	52	gialla
190	Boscoreale	14	68	gialla
530	Scafati	7	32	gialla
275	Aiello del Sabato	6	19	gialla
358	San Michele di Serino	4	31	gialla
237	Poggiomarino	4	20	rossa
471	Nocera Inferiore	3	25	gialla
481	Pagani	3	6	gialla
413	Calvanico	2	8	gialla
501	Roccapiemonte	2	11	gialla
232	Nola	2	1	rossa
246	Ercolano	1	1	rossa
317	Lauro	1	6	gialla
		24.378	84.946	

Hazard assessment for pyroclastic fallout



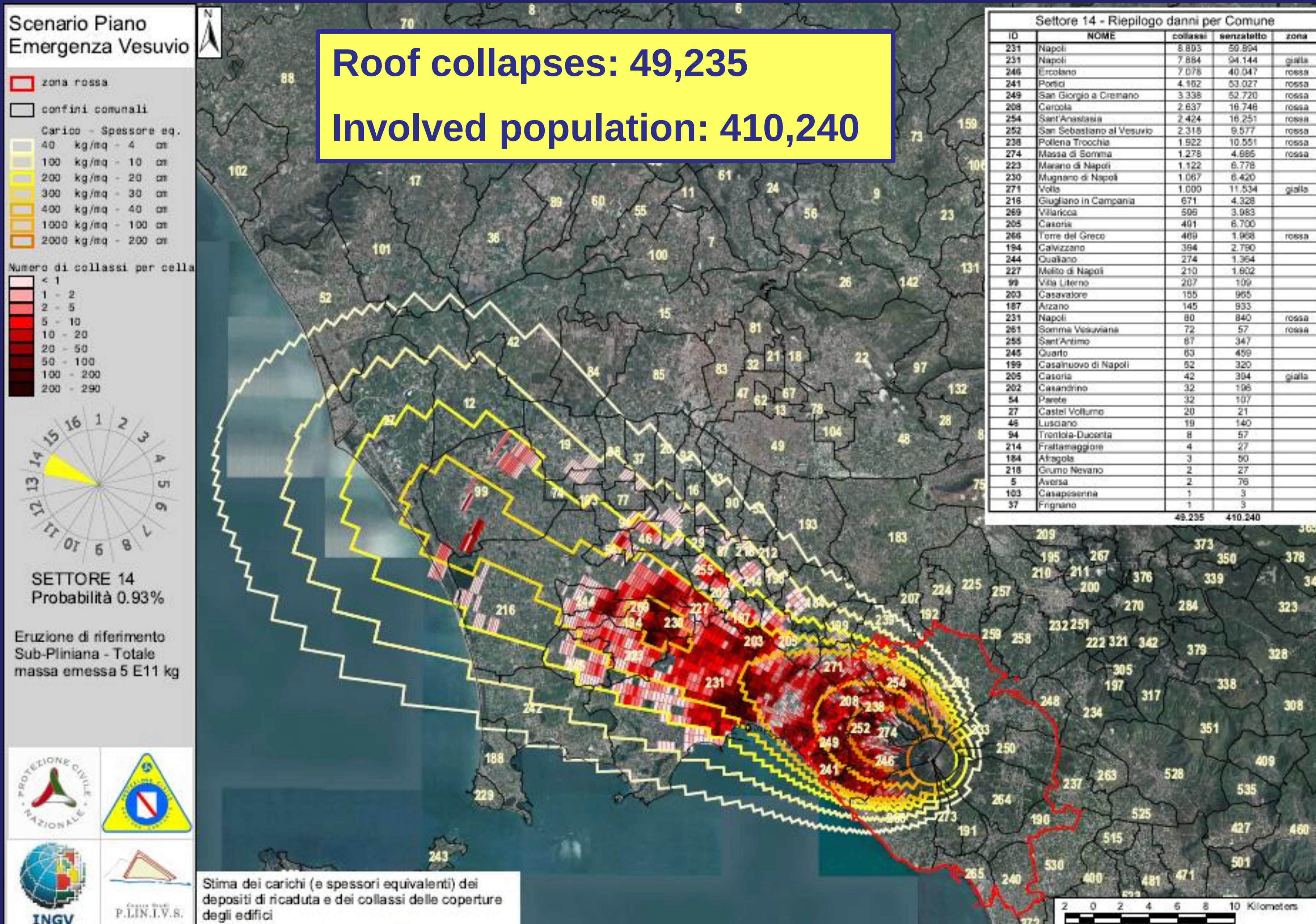
NW wind direction
Probability of occurrence: 0.93%

Naples city affected !
Ash fallout over Rome!

Risk assessment for pyroclastic fallout

Roof collapses: 49,235

Involved population: 410,240



Settore 14 - Riepilogo danni per Comune

ID	NOME	collassi	senzatetto	zona
231	Napoli	8.893	59.894	
231	Napoli	7.884	94.144	gialla
246	Ercolano	7.078	40.047	rossa
241	Portici	4.162	53.027	rossa
249	San Giorgio a Cremano	3.338	52.720	rossa
208	Cercola	2.637	16.746	rossa
254	Sant'Anastasia	2.424	16.251	rossa
252	San Sebastiano al Vesuvio	2.318	9.577	rossa
238	Pollena Trocchia	1.922	10.551	rossa
274	Massa di Somma	1.278	4.685	rossa
223	Marano di Napoli	1.122	6.778	
230	Mugnano di Napoli	1.067	6.420	
271	Volla	1.000	11.534	gialla
216	Giugliano in Campania	671	4.328	
269	Villaricca	596	3.983	
205	Casoria	491	6.700	
266	Torre del Greco	469	1.968	rossa
194	Calvizzano	384	2.790	
244	Qualiano	274	1.364	
227	Melito di Napoli	210	1.602	
99	Villa Literno	207	109	
203	Casavatore	155	965	
187	Arzano	145	933	
231	Napoli	80	840	rossa
261	Somma Vesuviana	72	57	rossa
255	Sant'Antimo	87	347	
245	Quarto	63	459	
199	Casalnuovo di Napoli	52	320	
205	Casoria	42	394	gialla
202	Casandrino	32	196	
54	Parete	32	107	
27	Castel Volturno	20	21	
46	Lusciano	19	140	
94	Trentola-Ducenta	8	57	
214	Frattamaggiore	4	27	
184	Afragola	3	50	
218	Grumo Nevano	2	27	
5	Aversa	2	76	
103	Casapesenna	1	3	
37	Frignano	1	3	
		49.235	410.240	

Criticalities from pyroclastic fallout

Many persons live in zones that could be severely affected by tephra fallout in the first phase of the eruption. The highest damages would be produced by a WNW wind, toward the city of Naples, which fortunately has a very low occurrence probability (<1%).

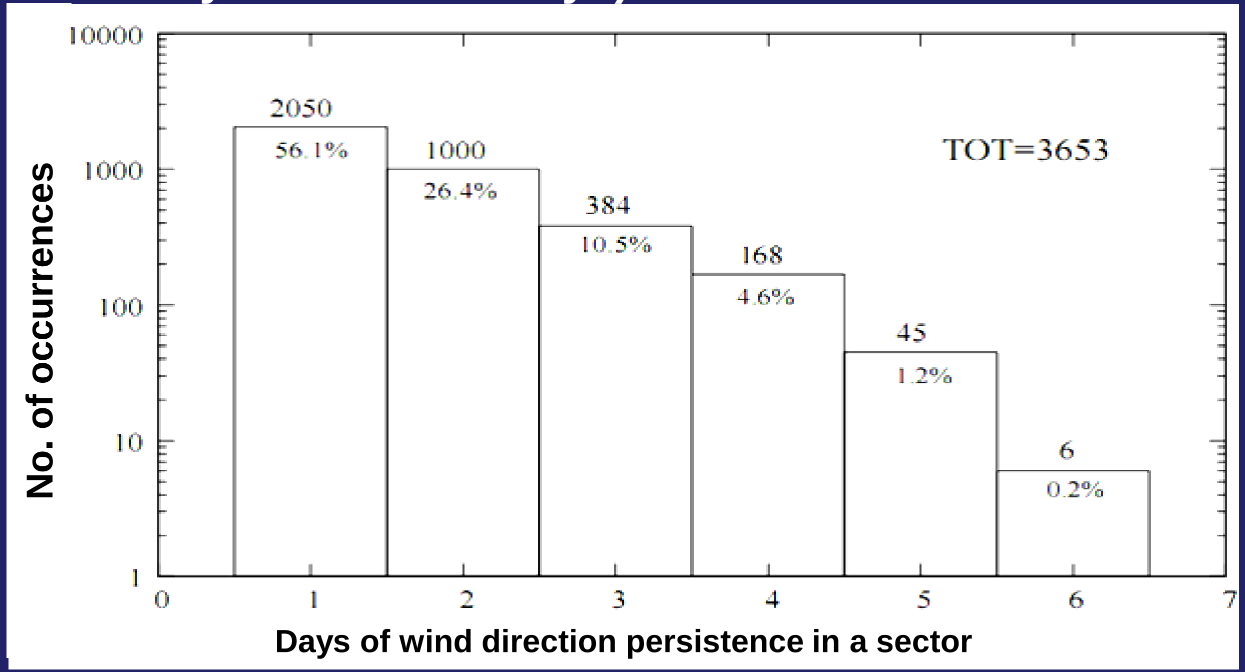
The zones to the East of Vesuvius are the most exposed to pyroclastic fallout, as there is a probability of about 60 % that wind will blow toward ENE to SE. Depending on the specific wind direction and the dimensions of invested villages 22,960 to 32,415 roof collapses involving from 84,946 to 158,842 people are expected.

Most of these collapses would obviously occur within the red zone exposed to pyroclastic flow hazard which should be evacuated before the eruption onset.

However, also villages outside that zone will be severely affected. As they are not exposed to pyroclastic flow hazard, their pre-eruption evacuation is not foreseen in the plan.

Criticalities from pyroclastic fallout

It is almost impossible to identify in advance the sector that will be effectively affected by pyroclastic fallout, as wind direction changes too rapidly (probability of persistence only 10% after 3 days).

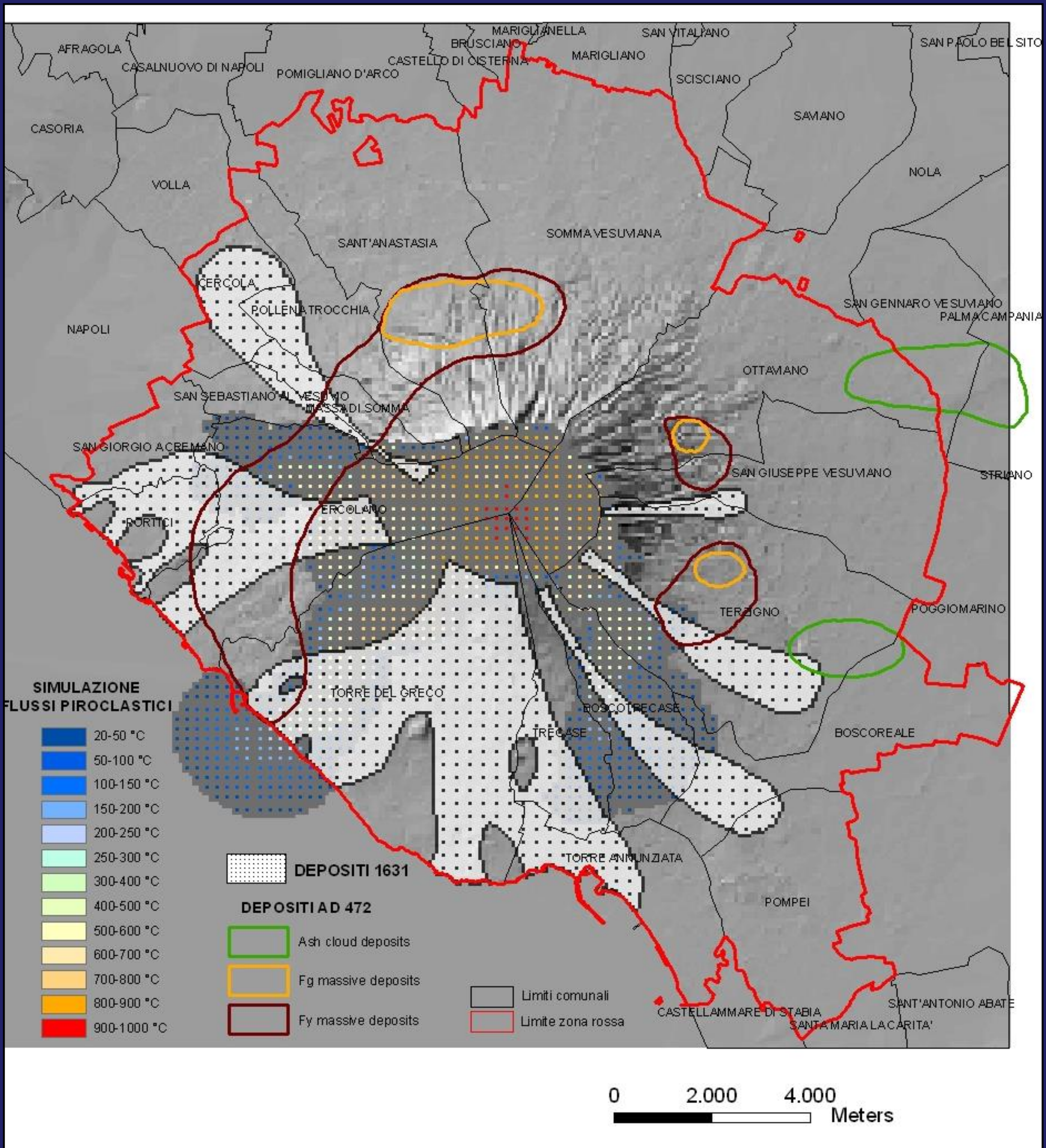


Two prevention actions can be envisaged to mitigate the roof collapses risk:

1) at the moment of the eruption onset, when the exposed sectors will be known, people should be moved from the buildings more vulnerable to ash load, to pre-identified safe near structures

2) a long-term program of interventions to reduce roof vulnerability in the Vesuvian yellow zone has to be undertaken.

Area exposed to Pyroclastic Flows: Red Zone



Red zone limit defined by:

- **run out boundaries of pyroclastic flows of the 1631 and 472 subplinian I eruptions;**
- **3D simulations of pyroclastic flows from a subplinian I eruption.**

Important:

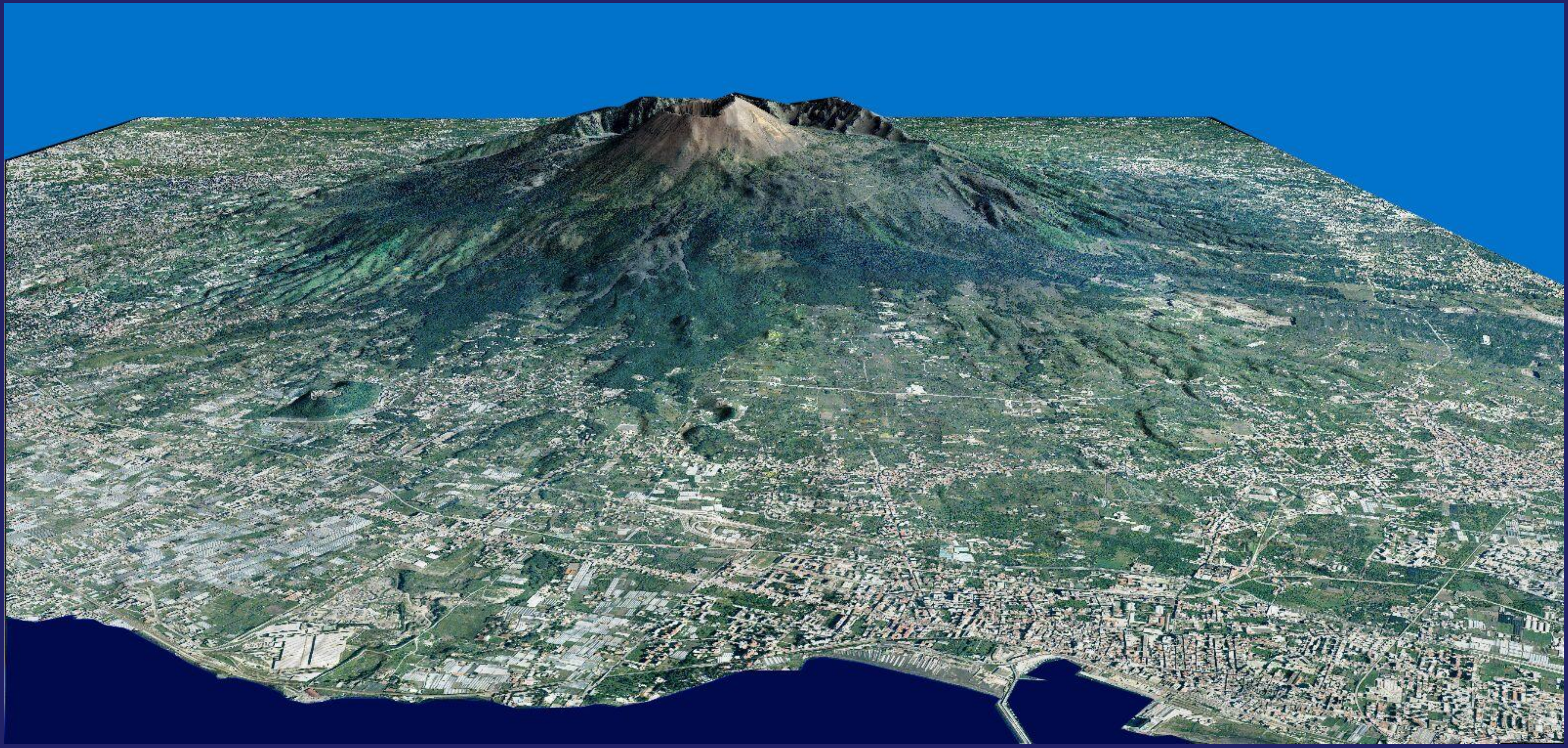
propagation time of the pyroclastic flows from the crater to the urbanized areas is of only few minutes.

Buildings cannot resist dynamic pressure of PF.

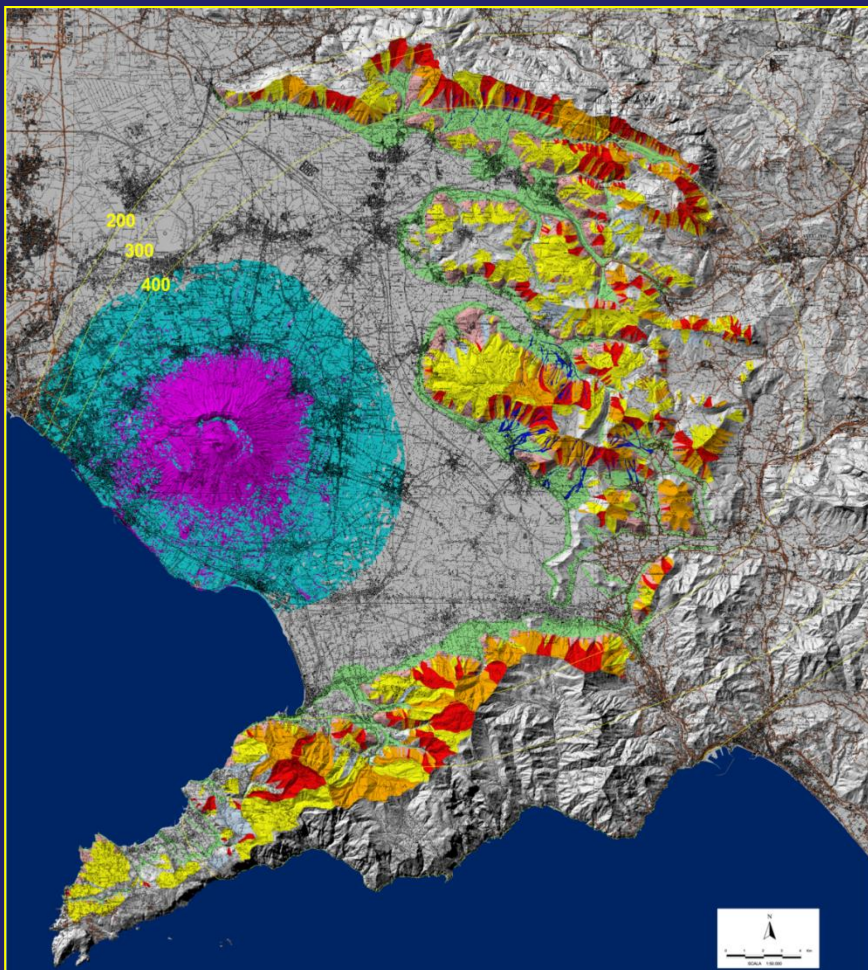
The red zone has to be evacuated before the eruption onset

Red zone exposed to pyroclastic flow risk:

18 municipalities with 550,000 residents



Hazard assessment for lahars (mud flows)



Zones exposed to lahar hazard (rain mobilization of loose tephra on steep slopes) are:

- the volcanic edifice (same zone exposed to p.f.)

- all downwind steep slopes interested by tephra fallout (mostly to the E of the crater)

Exposed population in downwind zones: 181,000

The Vesuvius emergency plan

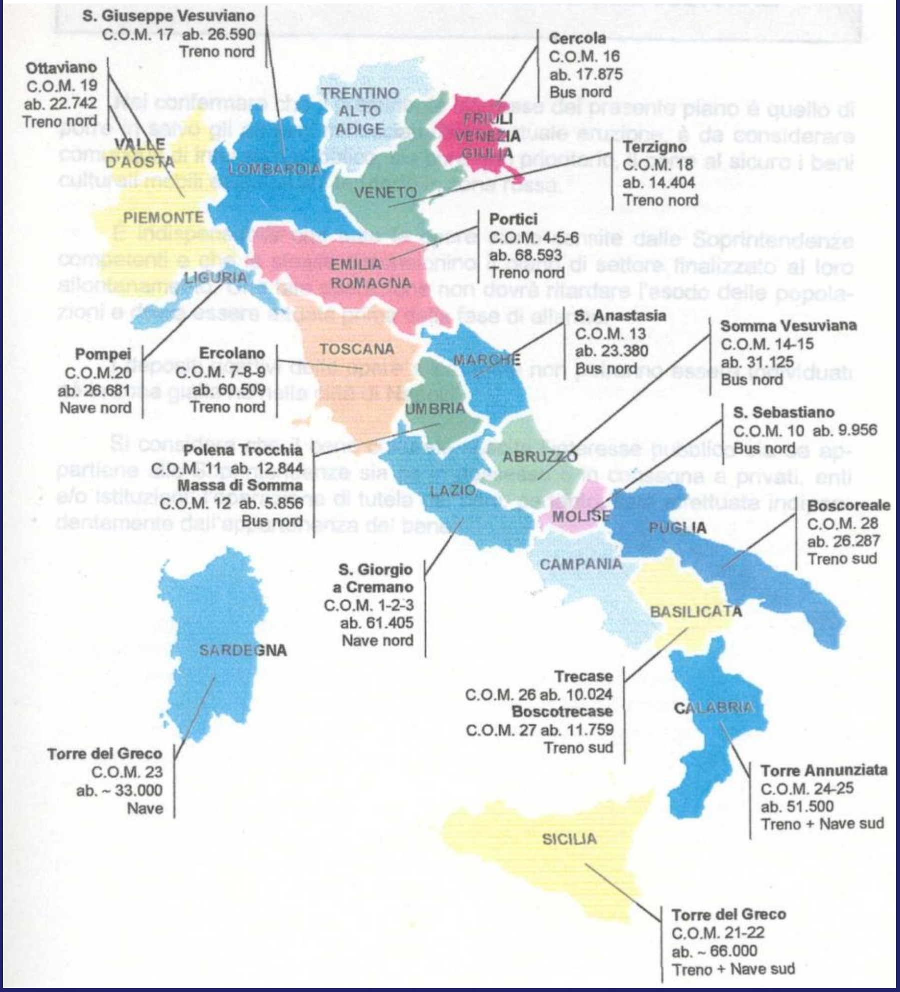
Residents of each municipality of the Red Zone will be transferred in one Italian Region and hosted so to maintain as far as possible their links (administration, school, health care).

A twinning agreement has been signed by all Regions and the National Government.

Drilling exercises are regularly carried out involving 1000-2000 students and their families in order to improve links with the hosting communities.

People evacuated from the Yellow and Blue Zones will be hosted in Campania Region.

Twinning map



The success of the emergency plan depends on the reliability of volcanic forecast

- Eruption onset is heralded by geophysical and geochemical precursors:

- anomalous seismicity
- ground uplift
- gravimetric, magnetic, electric anomalies
- new fumaroles and increasing heat flow and gas output
- chemical and isotopic variations in the composition of gas and thermal waters

- Successes: Rabaul, 1995; Pinatubo, 1991; Izu-Ohshima, 1986
- False alarm: Soufriere, 1976
- Failed alarm: Nevado del Ruiz, 1985

Precursory phenomena are used to define the state of the volcano in a process with increasing probability of eruption (alert level)

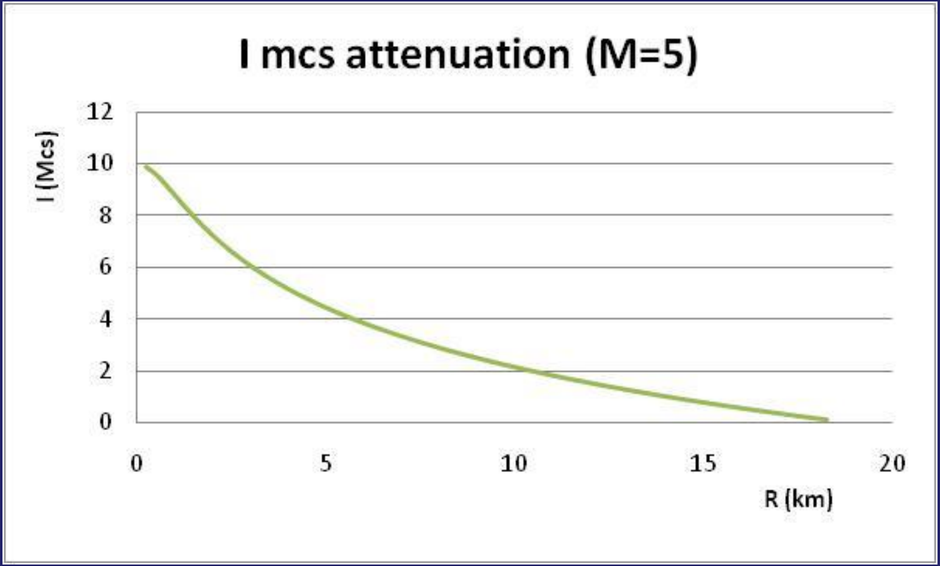
Level	Main actions
Attention	Monitoring increase
Pre-alarm	Civil Protection preparation to the emergency
Alarm	Evacuation of the red zone (550,000 people)

A recently discovered dramatic problem: risk from pre-eruption earthquakes (before alarm is declared and red zone evacuated)

- Epicenters in the crater area
- Focal depth 3-4 km
- Magnitude: 4.5 - 5.5 max
- Intensity at epicenter VIII-IX

$$I_{MCS} = (1.33 – \log_{10}(PGA))*5$$

(Intensity in the settlements nearest to crater: VII-VIII)



Seismic vulnerability of Vesuvius buildings

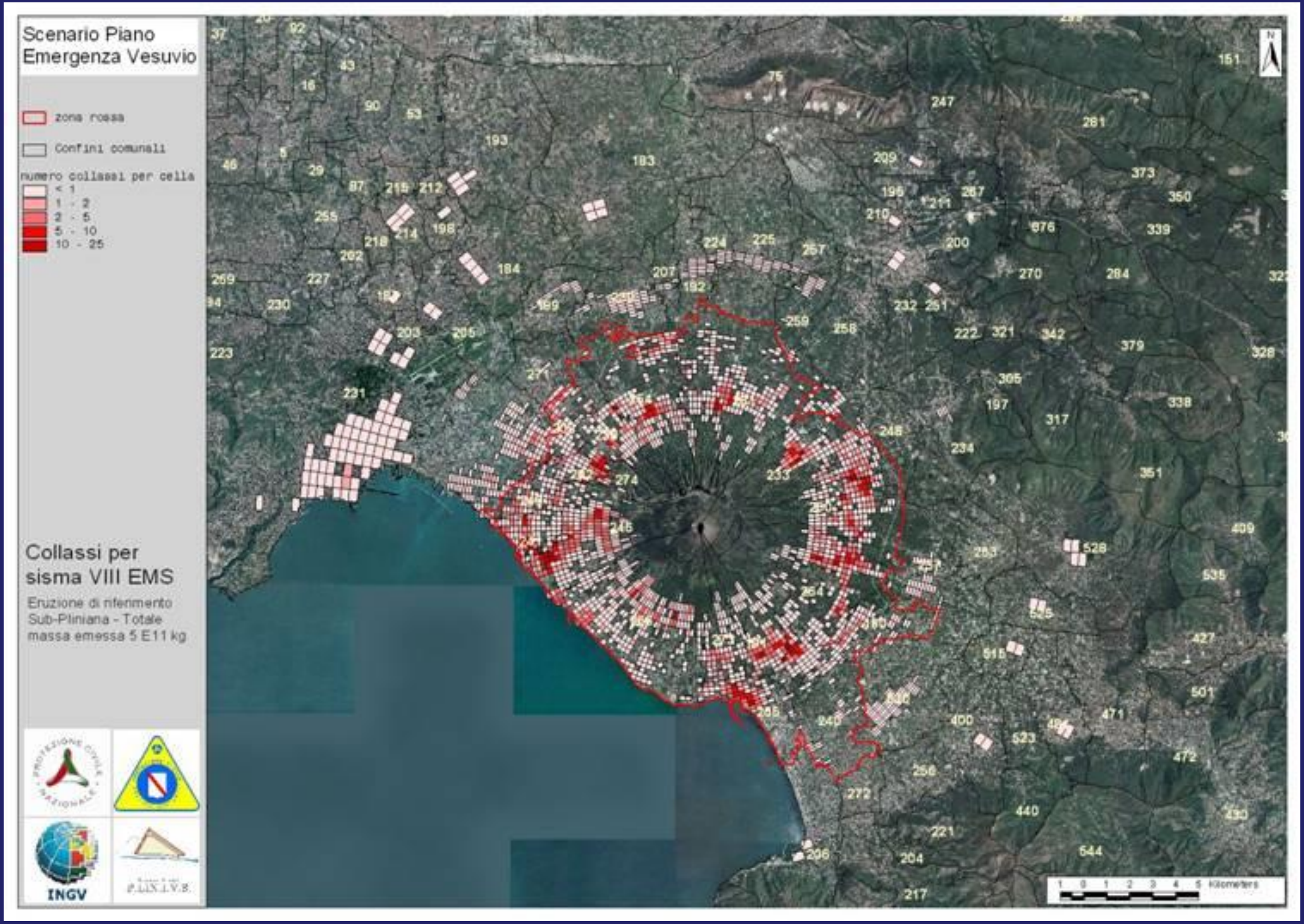
The seismic vulnerability has been directly evaluated on about the 50 % of the all buildings of the red zone; the residual 50% has been evaluated by aerial photogrammetry and statistic calibration of the census data ISTAT 2001.

Seismic Building Structures Classification

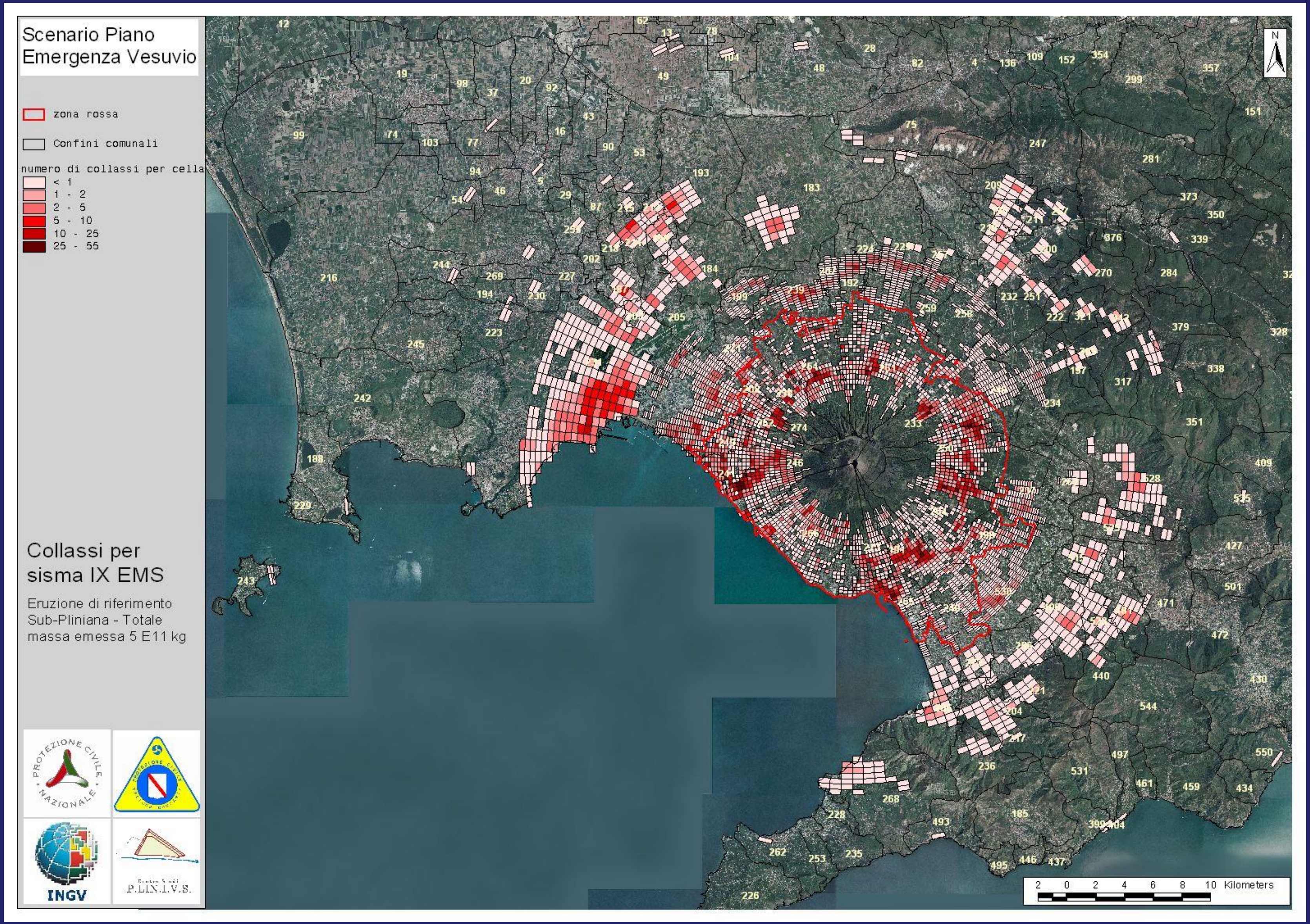
Vertical Structures \ Horizontal Structures	POOR RIGIDITY Vaults and/or wooden floor (without ties)	POOR TECHNO-LOGY "SAP" Floor	MEDIUM RIGIDITY Vaults and/or wooden floor (with ties)	MEDIUM HIGH RIGIDITY Iron beam floor	HIGH RIGIDITY Reinforced Concrete floor.
WEAK MASONRY Rubble masonry neglected (lavic stone, not squared tuff, etc.)	A	A	A	A	A
MEDIUM QUALITY Rubble masonry maintained (lavic stone, not squared tuff, etc.)	A	A	B	B	B
GOOD MASONRY Squared masonry (Lavic stone, tuff etc.)	A	A	B	B	C
FRAMED STRUCTURES (R.C. or steel)	-	B	-	-	C

Example: Seismic vulnerability of Torre Annunziata

Expected damage scenario for a single earthquake of intensity VIII



Expected damage scenario for a single earthquake of intensity IX

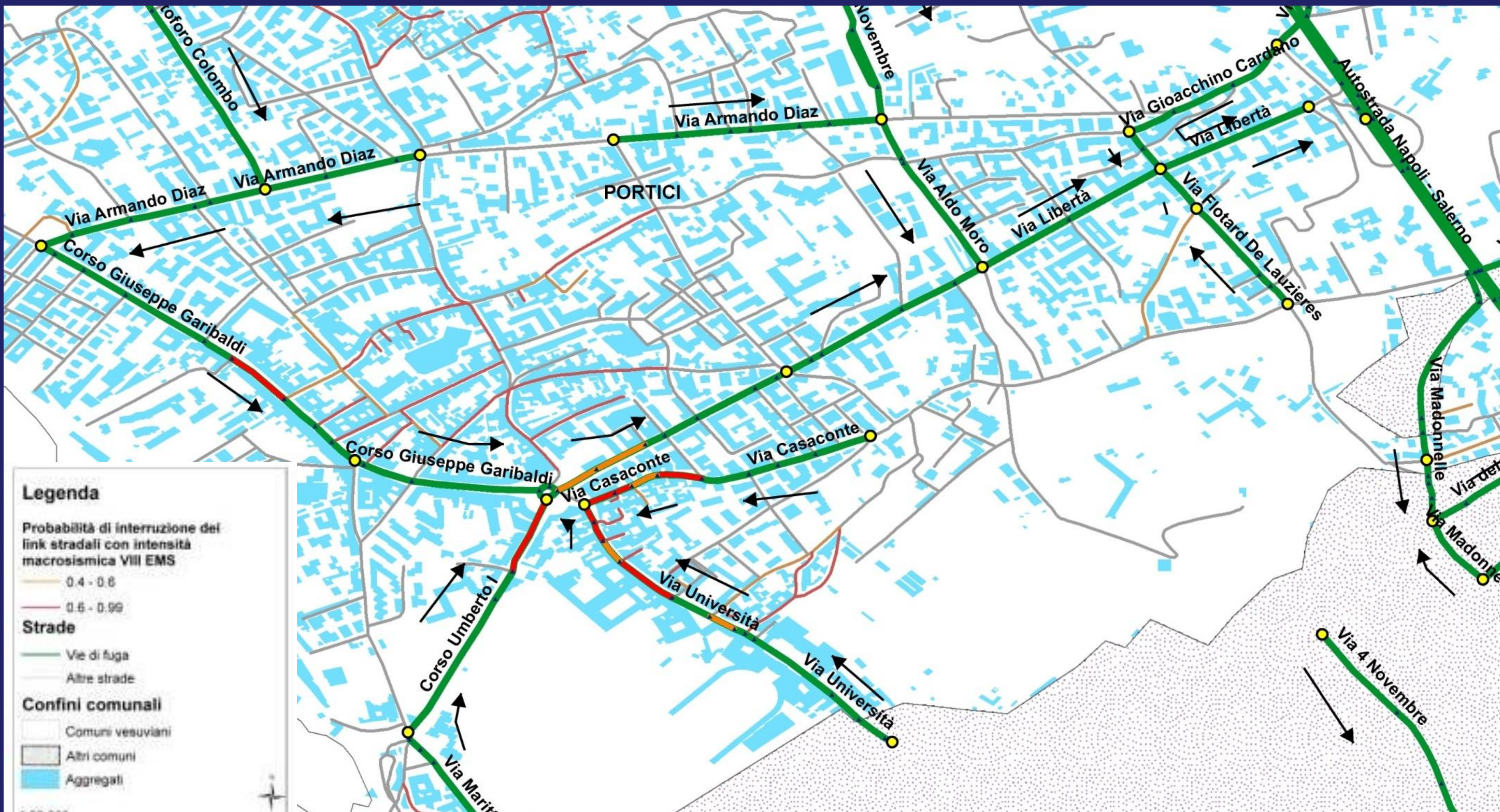


Total damages from earthquakes

	Event of Intensity VIII at the epicentre				
Zone	**tot. Collapse**	**Blds. Unusable**	**Deaths**	**Injuried**	**Homeless**
red	301	1418	31	107	9631
other	2406	5700	184	662	25430
Total	**2707**	**7118**	**215**	**769**	**35061**

	Event of Intensity IX at the epicentre				
Zone	**tot. Collapse**	**Blds. Unusable**	**Deaths**	**Injuried**	**Homeless**
red	2012	6316	237	842	44334
other	5261	9754	463	1697	42996
Total	**7273**	**16070**	**700**	**2539**	**87330**

Red zone: impact of the earthquakes of the unrest phase on the evacuation road practicability (Portici)



Red zone: impact of the earthquakes of the unrest phase on the evacuation road practicability

PROB. Pi OF INTERRUPTION FOR INTENSITY VIII (NUMBER OF ROAD LINK INTERRUPTED)			
municipality	Pi ≥60%	40%≤Pi≤60%	Pi< 40%
Boscoreale	20	41	275
Boscotrecase	16	42	217
Cercola	2	8	78
Ercolano	22	36	184
Massa di Somma	2	10	59
Ottaviano	21	43	196
Pollena Trocchia	2	6	50
Pompei	0	3	52
Portici	25	23	103
San Giorgio a Cremano	1	10	51
San Giuseppe Vesuviano	12	38	158
San sebastiano al Vesuvio	1	14	77
Sant'Anastasia	16	34	139
Somma Vesuviana	17	35	220
Terzigno	22	39	164
Torre Annunziata	9	42	364
Torre del Greco	4	19	240
Trecase	0	12	130
TOTALI	**192**	**443**	**2757**

PROB. Pi OF INTERRUPTION FOR INTENSITY IX (NUMBER OF ROAD LINK INTERRUPTED)			
municipality	Pi ≥60%	40%≤Pi≤60%	Pi< 40%
Boscoreale	92	60	184
Boscotrecase	73	50	152
Cercola	15	20	53
Ercolano	80	49	113
Massa di Somma	20	18	33
Ottaviano	90	39	131
Pollena Trocchia	12	5	41
Pompei	4	9	42
Portici	55	33	63
San Giorgio a Cremano	15	15	32
San Giuseppe Vesuviano	64	54	90
San sebastiano al Vesuvio	23	16	53
Sant'Anastasia	60	27	102
Somma Vesuviana	69	52	151
Terzigno	74	44	107
Torre Annunziata	89	72	254
Torre del Greco	33	50	180
Trecase	25	23	94
TOTALI	**893**	**636**	**1875**

Criticalities from precursory earthquakes

The evaluation of expected damage due to earthquakes occurring during the unrest phase of a possible eruption at Vesuvius is very relevant to assess the criticality of the evacuation plan for the red zone.

Many buildings in the red zone have an high level of seismic vulnerability, therefore vast damages caused by pre-eruption earthquakes have to be expected.

This could lead to:

- face up a severe seismic emergency, before the official warning of impending eruption;
- the ruins of the buildings deriving from total or partial collapses could compromise the practicability of some crucial escape paths and hamper the rescue activities of the trapped victims.

A Mitigation Plan to reduce the vulnerability of the buildings along the evacuation paths is urgently needed.

CONCLUSIONS

Nearly 550,000 persons live in the "Red Zone" exposed to pyroclastic flows, and they will have to be evacuated before the eruption onset. However, evacuation could be severely hampered by damages from pre-eruption earthquakes.

Many other persons live in zones that could be severely affected by tephra fallout in the first phase of the eruption. The highest damages would be produced by a WNW wind, toward the city of Naples, which fortunately has a very low occurrence probability (<1%).

CONCLUSIONS

The zones to the East of the Vesuvius are the most exposed to pyroclastic fallout, as there is a probability of about 60 % that wind will blow toward ENE to SE. Depending on the specific wind direction and the dimensions of invested villages 22,960 to 32,415 roof collapses involving from 84,946 to 158,842 people are expected.

Abour 181,000 people are exposed to lahar hazard in the same eastern zones.

Last but not least: the risk perception of Vesuvian inhabitants is totally inadequate.