VESUVIUS 2000

Project objectives

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Urban Habitat Constructions Under Catastrophic Events
Trieste, 17 January 2008

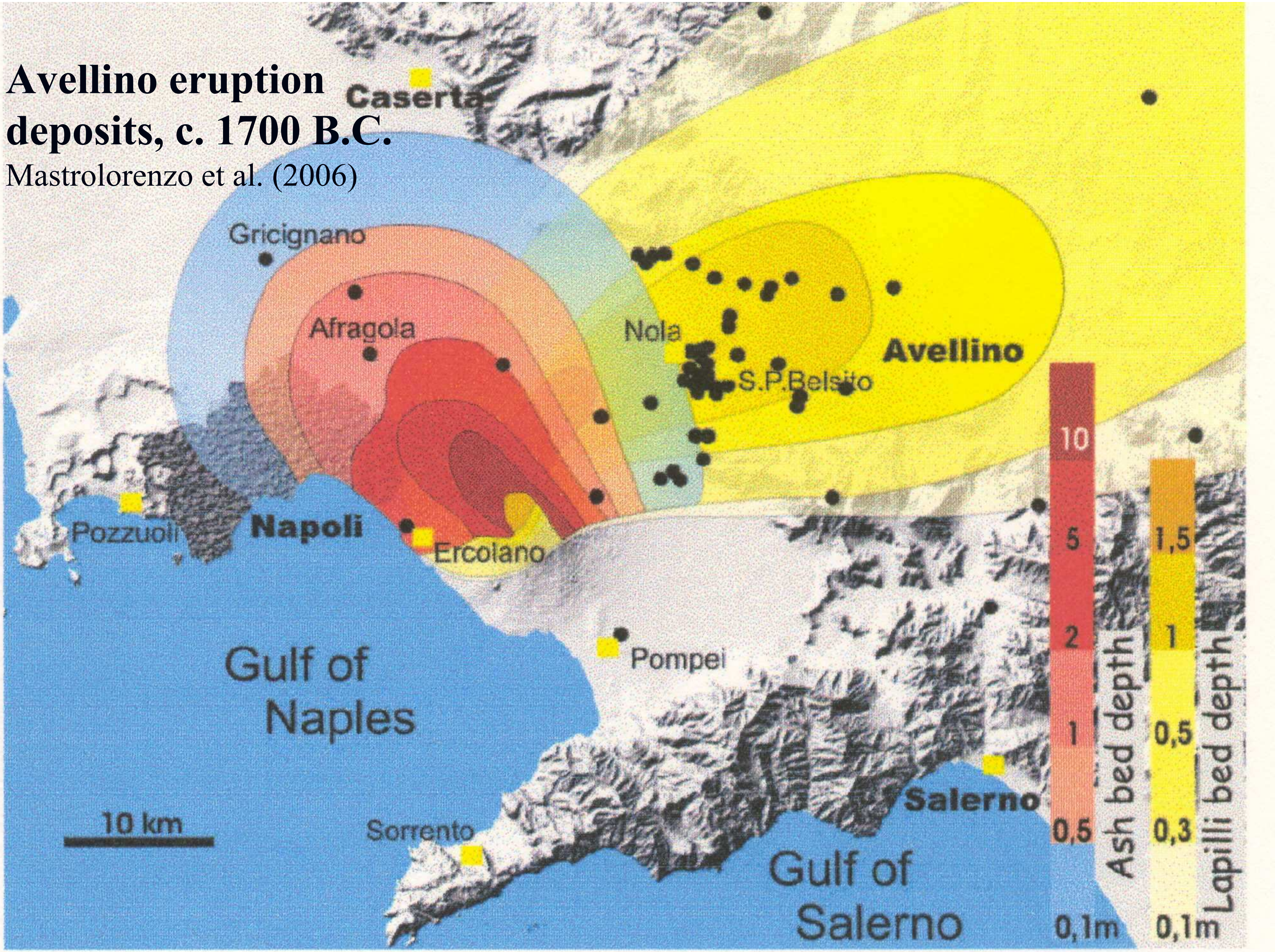
20,000 years of plinian and sublinian eruptions

300 km^3 of eruption deposits

Eruption	Fall deposits			Pyroclastic surges and flows		
	Thickness	Distance	Direction	Thickness	Distance	Direction
	m	km		m	km	
Basal 17,000 y.B.P. plinian	2 0.2	4.5 22	N NE	3.5	4	N
Greenish 15,000 y.B.P. plinian	1 0.4	4.5 9	N N	15 2	4.5 9	N N
Lagno Amendolare 11,000 y.B.P. plinian	2 1	4 20	NW E–NE	Absent		
Ottaviano 8000 y.B.P. plinian 22 km, 3 km^3	4 3 1.5 0.5	5 10 20 30	N–NE N–NE N–NE N-NE	10 3.5 0.5 0.1	4.5 7 3.5 20	N NE NE NE
Avellino 3750 y.B.P. plinian 36 km, 4 km^3	0.8 1 0.6 0.1 1	6 15 30 40 3.5	E–NE E–NE E–NE E–NE NE	6 2 1 0.5 0.2	8 12 15 6 20	NW NW NW NE NW
Pompeii 79 A.D. plinian, 30 km, 3 km^3	14 4 2 1	5 8 20 40	W S–SE S–SE S–SE	15 10 2 3	5 8 8 10	W W–SW N–NE SE
Pollena 472 A.D. subplinian 20 km, ~ 1 km^3	1.3 1.2 0.9 0.3 0.7	5 8 20 30 10	NE NE NE NE NE	10–14 2 0.5	5 8 10	NW NW N–NE
1631 A.D. subplinian 20 km ~ 1 km^3	0.7 0.5 0.3 0.2 0.1	8 10 15 20 25	E–NE E–NE E–NE E–NE E–NE	0.3 0.2 0.1 4	5 10 15 7	E–NE E–NE E–NE S

Avellino eruption deposits, c. 1700 B.C.

Mastrolorenzo et al. (2006)



Pompeii eruption deposits, 79 A.D.

(Sigurdsson et al., 1985)

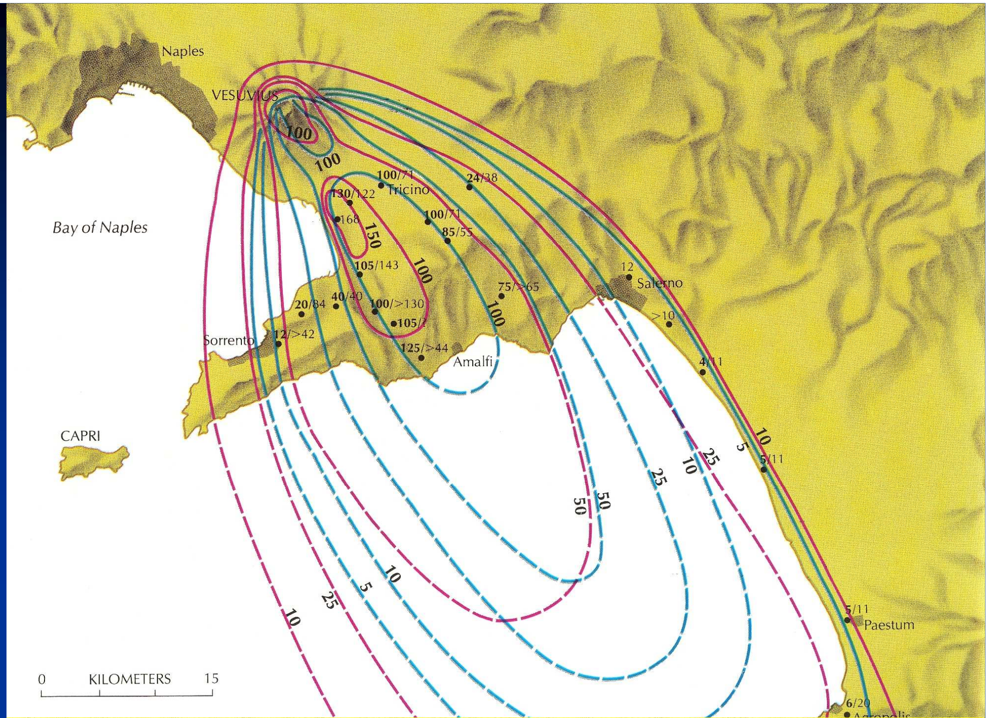
Pumice-fall deposits (cm)

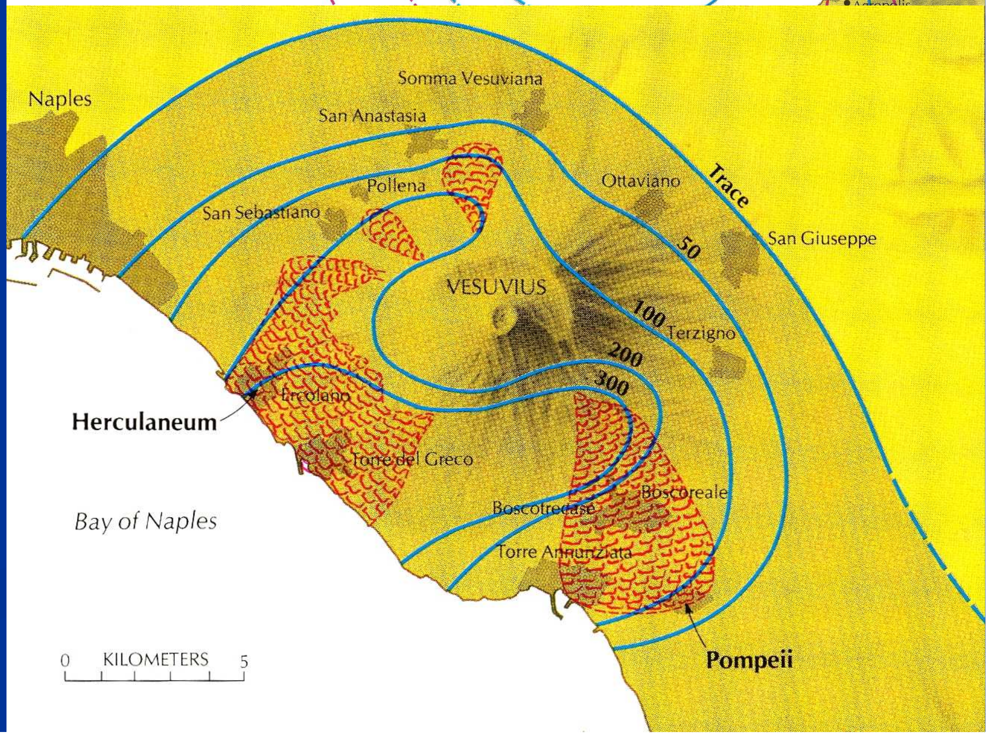
Red - gray pumice

Blue - white pumice

Surge and flow deposits (cm)

Red - pyroclastic flows





Choices for the future

- Wait for eruption and pray that 1 million people can be evacuated in 1-2 days
  Vesuvius Evacuation Plan:
  - scientific, social and technological failure
- Force socio-economic decline around Vesuvius
  - empowers organized crime and involuntary exodus
- Construct sustainable habitats for Vesuvians
  VESUVIUS 2000
  - overcome incommensurable barriers

Vesuvius Evacuation Plan

1. Promoted within the Italian government in 1995 by the geologists (fearing the development of VESUVIUS 2000 objectives)

2. Eruption can be predicted at least 3 weeks in advance (based on unspecified precursors)

3. 600,000 people within 7 km of Vesuvius can be safely and orderly evacuated under frequent earthquakes (transportation systems and escape routes will remain operable)

4. Relocated people will be dispersed all over Italy (hosting regions will not be affected socially and politically)

5. The abandoned Vesuvius area will be protected from looters and inflow of new people (what will be protected and how remains unspecified)

6. People at distances greater than 7 km (includes Naples) will not be affected by the eruption and massive deportation of Vesuvians

- Vesuvius Evacuation Plan is promoting scientific, social, and technological ignorance within the Italian institutions and people exposed to the risk

- The top-down hierarchical control of emergency management is flawed

  (recall hurricane Katrina, Sumatran tsunami, 1998 Sarno landslides and current waste disposal in Campania)

- People around Vesuvius can today only pray for the help from San Gennaro

- Actions should be focused on the goal of protecting lives, property, maintaining continuity of operations. This is maintained through the shared knowledge.
- Proper risk management requires:
    - Detection of risk
    - Recognition and interpretation of risk
    - Communication of risk to multiple organizations
    - Self-organization and mobilization of a community to reduce the risk and respond to the danger
- Without a well-defined, functioning information infrastructure supported by appropriate technology, the collective response of a community exposed to serious threat will fail

VESUVIUS 2000 objectives

- Combine danger with opportunities to manage volcanic risk. Consider the **Risk Matrix**:

		OPPORTUNITY	
		YES	NO
DANGER	YES	FUNGIBILITY **1**	BETTER SAFE THAN SORRY **2**
	NO	WASTE NOT, WANT NOT **3**	INDIFFERENCE **4**

- Build new habitats for Vesuvians
  - exclusion zone (< 5 km radius)
  - limited protection (5-10 km radius)
  - sustainable habitat (> 10 km radius)
  - engineers need to understand:
    - design parameters for building residential, commercial, industrial, infrastructure systems
    - patterns of supply and use of materials, energy, information, services, products
    - protection measures against earthquakes, tephra fall, fyroclastic flows, ballistic blocks

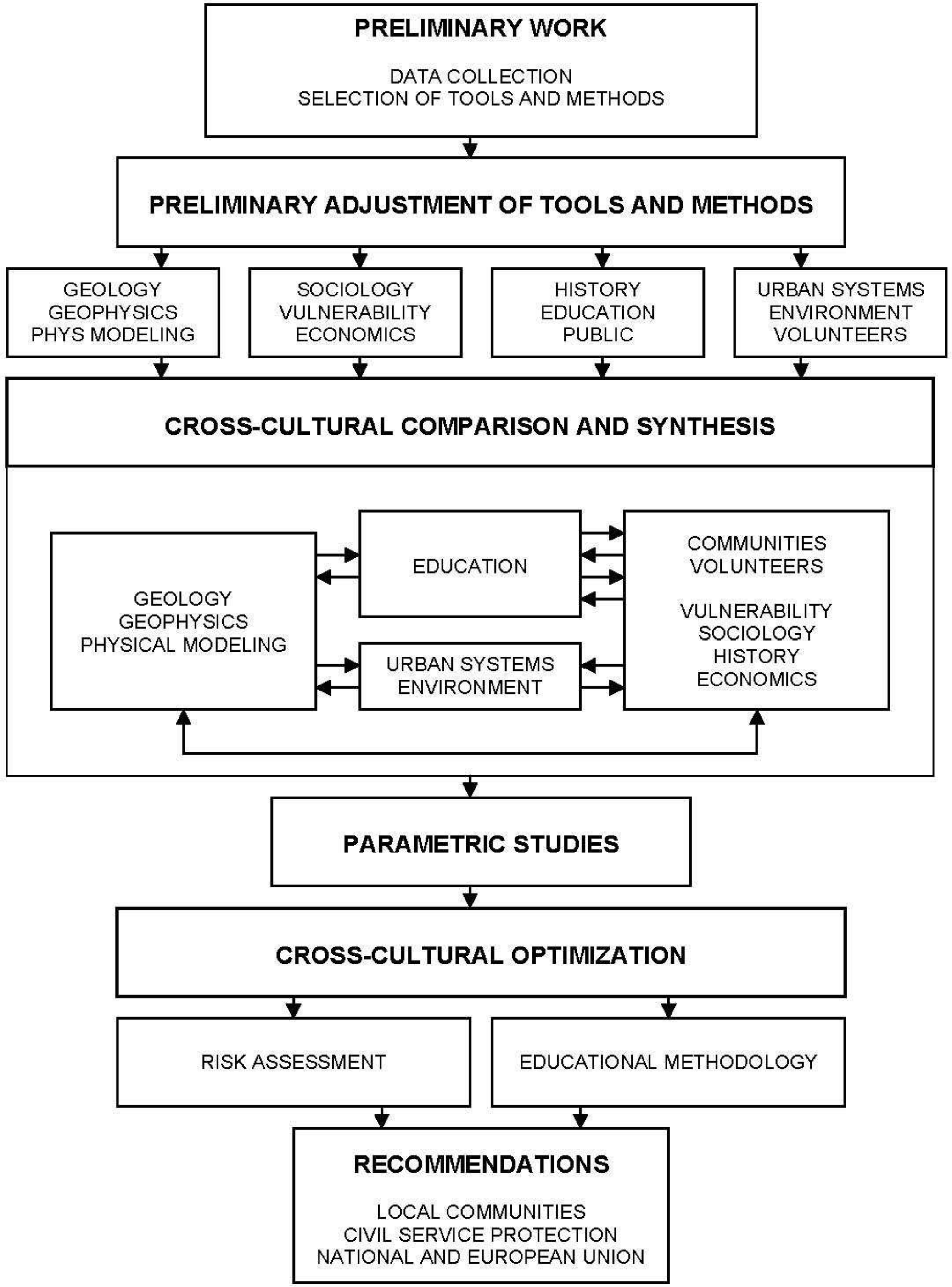
- Employ urban center design paradigms
  - Sustainability
    - basic human needs (food, water, space)
    - socio-political rights
    - health care
    - education
    - equitable distribution of resources
    - jobs
    - housing
    - sense of belonging
    - limited geographical & resources footprints
    - autoregulation of territory
    - manageability

- System of systems approach
  - balance localized and centralized activities
  - spread transportation, utilities, recreation, business, residential neighborhoods across interconnected clusters
  - decide levels of interaction between
    - ❑ <u>biological component</u> (human activities, vegetation, microorganisms)
    - ❑ <u>social component</u> (ideas, collective, activities, organizations of inhabitants)
    - ❑ <u>machine component</u> (life support artifacts)

- Utilize systems design tools:
  - Probabilistic risk analysis
  - Global Volcanic Simulator
  - Seismic Zonation
  - Geographical Information System
  - Econometrics
  - Urban planning
    - structural mechanics
    - sustainable habitat design paradigms
- Involve people at risk as co-authors in planning
- Promote education that fosters security culture
- Provide economic incentives to develop safe areas into prosperous communities

VESUVIUS 2000

interdisciplinary feasibility study for the Vesuvius area



SYSTEMS DESIGN TOOLS

Probabilistic Risk analysis

- Risk analysis tries to answer the questions:
  - What can happen?
  - How likely is it to happen?
  - If it happens, what are the consequences?
- Risk analysis includes
  - All possible scenarios S_i
  - Likelihood of each scenario L_i
  - Consequences of *i*th scenario X_i

$$R = (S_i, L_i, X_i)_{\text{complete}}$$

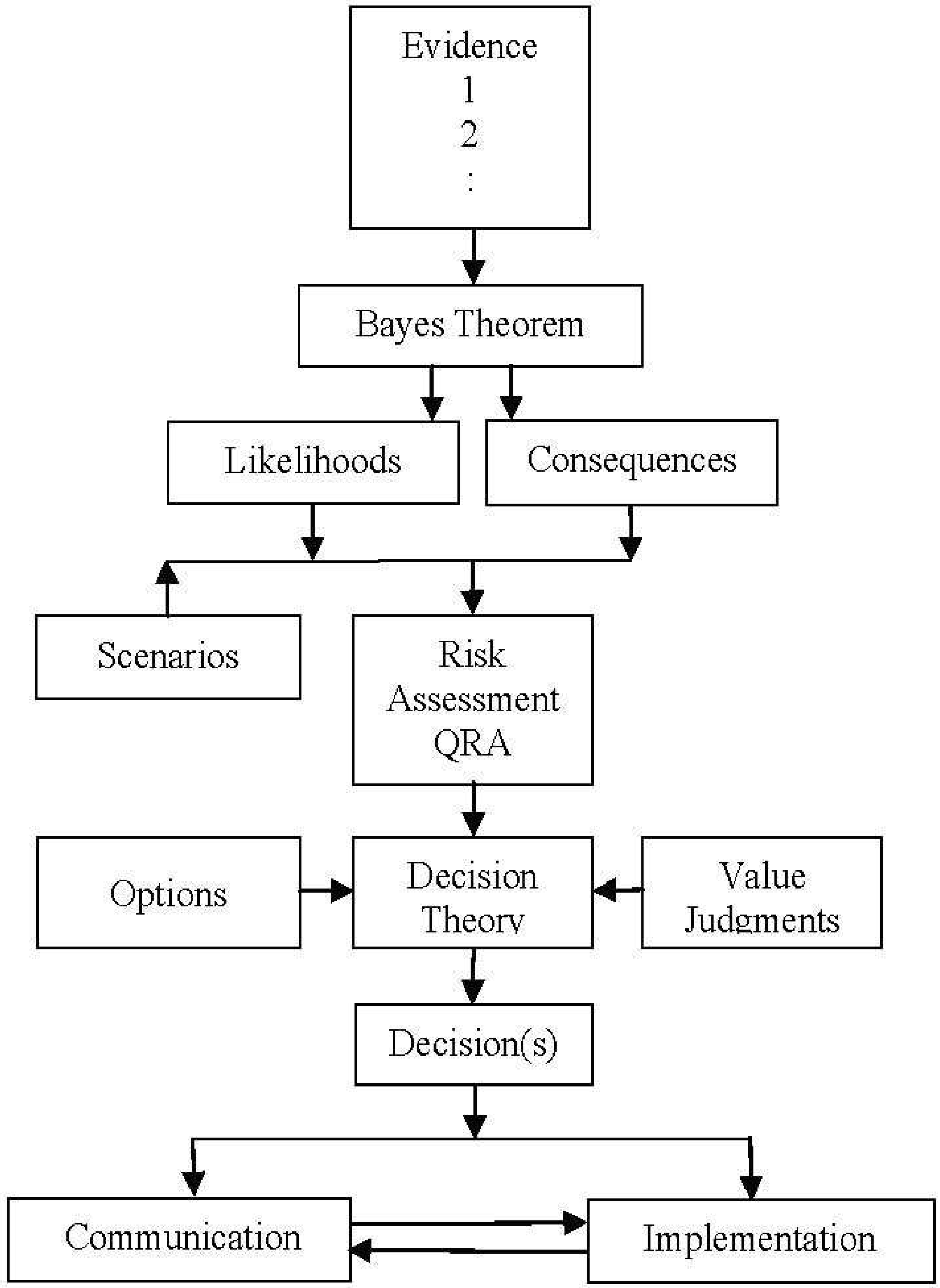
- Quantitative Risk Analysis (QRA)
- Specification of preferences
- Maximization of utilities of decisions d_i

$$u(d_i) = P(X / d_i) = \sum_{j=1}^{m} P(X / d_i @ A_j) P(A_j / d_i)$$

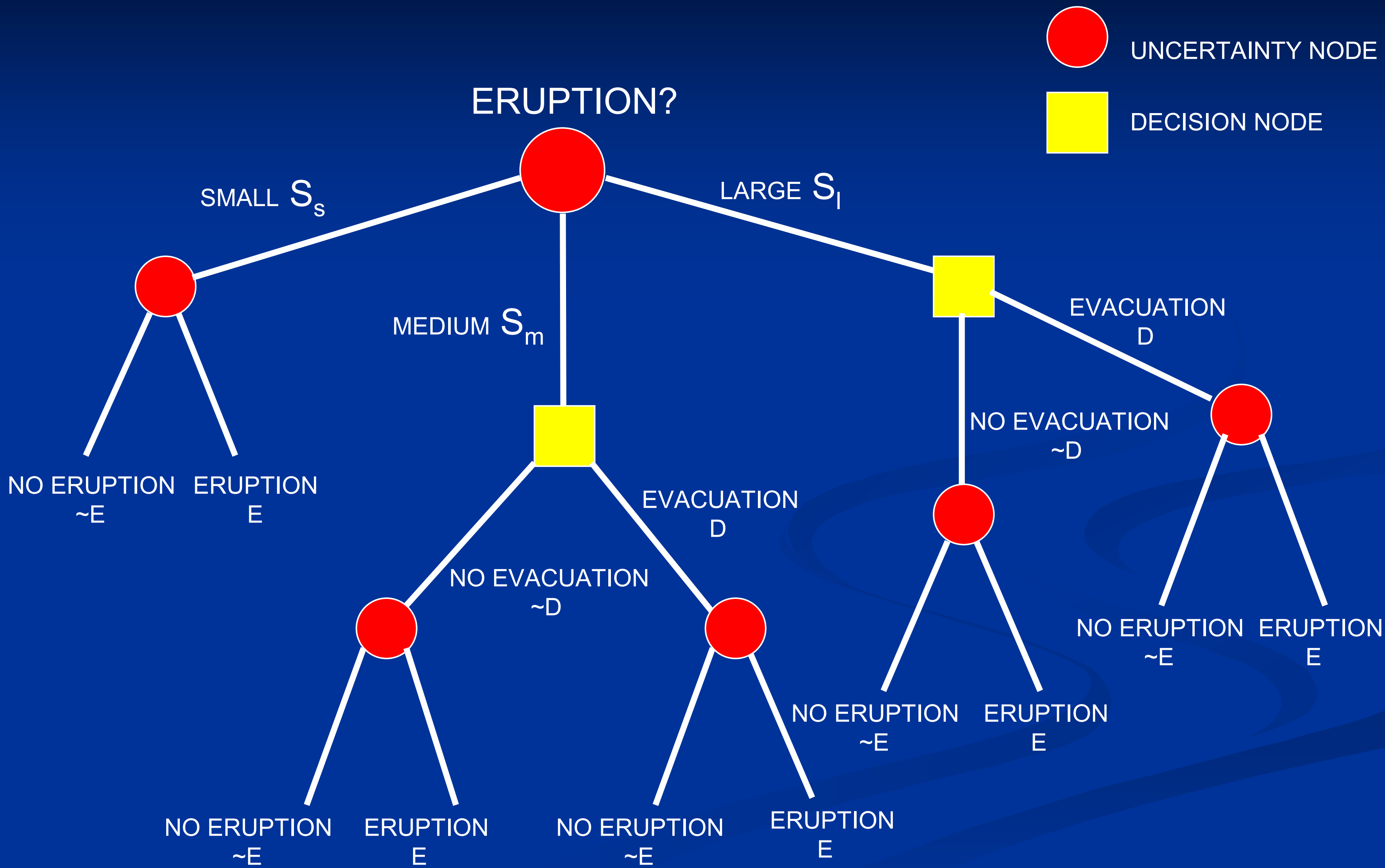
Rational decision theory

- Quantification of seismic, volcanic, socio-economic, urban planning scenario probabilities
- Specification of preferences (options & value judgments)
- Development of multi-attribute utility theory (decision making under uncertainty)

"the *value* of an item must not be based on its *price*, but rather on the *utility* that it yields" (Daniel Bernoulli, 1731)



Example: Evacuation from Vesuvius area



(a) Events E and ~E form a partition: $E \cap \sim E = 0$, $E \cup \sim E ‹ \Omega$

$P(S_l) = P(S_l/E)P(E) + P(S_l/\sim E)P(\sim E)$

$P(S_m) = P(S_m/E)P(E) + P(S_m/\sim E)P(\sim E)$

(b) Conditional probabilities:

$P(E/S_l) = P(S_l/E)P(E) / P(S_l)$, $P(\sim E/S_l) = P(S_l/\sim E)P(\sim E) / P(S_l)$

$P(E/S_m) =P(S_m/E)P(E) / P(S_m)$, $P(\sim E/S_m) = P(S_m/\sim E)P(\sim E) / P(S_m)$

(a) + (b) = Bayes' Theorem

(c) Independence of events

$P(E\&D) = P(E)\, P(D)$

(d) Utility cost (consequence) of decision to evacuate

$u(C) = P(C/E\&D)P(E\&D)+P(C/\sim E\&\sim D)P(\sim E\&\sim D)+$
$P(C/\sim E\&D)P(\sim E\&D)+P(C/E\&\sim D)P(E\&\sim D)$

$P(E\&D) = P(E\&D/S_l)P(S_l) + P(E\&D/S_m)P(S_m) + P(E\&D/S_s)P(S_s)$

$P(E\&D/S_l) = P(E/D\&S_l)P(D/S_l)$, $P(E/S_l)P(S_l)=P(S_l/E)P(E)$, …

$P(D/S_l) = 1$, $P(D/S_m) = 1$, $P(D/S_s) = 0$ (put fate in decisions)

$P(D/S_l) = 0$, $P(S/S_m) = 0$, $P(D/S_s) = 0$ (ignore decisions)

$k \equiv [P(C/E\&\sim D)-P(C/E\&D)]/[P(C/\sim E\&D)-P(C/\sim E\&\sim D)] > 0$ (O(1))

$u(C)_{\text{put fate in decisions}} < u(C)_{\text{ignore decisions}}$

LIKELIHOOD RATIO $= \dfrac{P(S_l/E)+P(S_m/E)}{P/S_l/\sim E)+P(S_m/\sim E)} > \dfrac{P(\sim E)}{k\,P(E)}$

odds = P(E)/P(~E)

(ratio of favorable to unfavorable outcomes)

$P(E) = 1 – \exp[-6.534\tau \exp(-1.18\ \text{VEI})]$

τ = 1/52 yr, VEI = 4 (subplinian)

LR > 10^3 (evacuation 1 week)

τ = 1 yr, VEI = 4 (subplinian)

LR > 10 (allarm1 month)

τ = 100 yr, VEI = 4 (subplinian)

LR > 10^{-1} (prevention 100 yr)

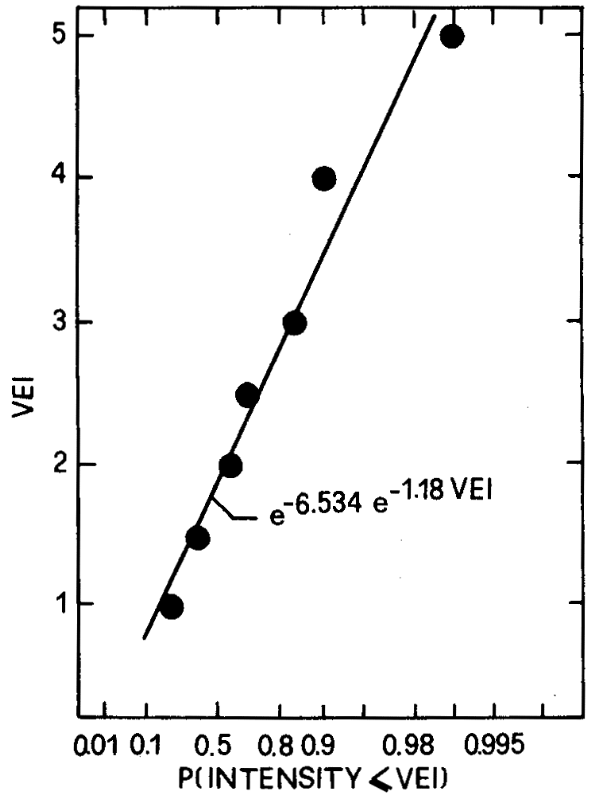
$LR_{PRACTICAL}$ < 5 (1 DAY RAIN PREDICTION)

- Cannot evacuate on short notice without incuring great cost, unless have reliable eruption precursors.

Table 7.2. Classification of Eruptions of Vesuvius in Terms of Volcanic Eruption Index (VEI) or Intensity.[a]

VEI	Eruption type	Number	Probability *P*
1	Lava effusion	21	0.228
1.5	Strombolian crisis	15	0.391
2	Strong strombolian activity	17	0.576
2.5	Strong strombolian activity and lava fountains	10	0.685
3	Small eruption column (similar to 1944)	15	0.848
4	Subplinian eruption (similar to 1631)	5	0.902
5	Plinian eruption (similar to 79)	8	0.989
6	Ultraplinian eruption (Monte Somma)	1	1.000

[a] *P* is the cumulative frequency that the intensity is less than or equal to VEI. For example, $P(\text{VEI} \le 2) = (21 + 15 + 17)/92 = 0.576$.



Vulnerability of structures

Wind (regional, induced by eruption)
Earthquakes (regional and volcanic)
Ash fall (diameter < 1 cm)
Pyroclastic, mud and lava flows
Ballistic impacts (d = 10 cm – 1 m)
Fire and hazardous materials

Loadings on structures

Structural (dynamic) response

Influence of deformation on loading

Uncertainty analysis

Safety and serviceability at 5, 10, 20, 50 km

Produce design procedures for building residential, commercial and industrial structures around Vesuvius

Required contributions:

- geological, geotechnical, and seismic characterization of sites around Vesuvius (scenarios and likelihoods)
  (this group can contribute)
- physical modeling of eruptions (scenarios and likelihoods)
  (this group can contribute)
- building architects (shape and functionality of structures)
  (future contributions)
- urban planners (distribution of structures)
  (future contributions)
- buildings design procedures - force and energy dynamical analysis
  (this group can contribute)

Seismic Hazard Analysis

- Probabilistic approach (traditional method)
  - large number of poorly constrained parameters (Gutenberg-Richter type models)
  - results have large uncertainties for regions with prolonged quiescence
  - approach unsuitable for designing structures around Vesuvius

Seismic Zonation

- Scenario-based deterministic approach
  (Klügel Mualchin & Panza, 2006; Panza, Romanelli & Vaccari, 2001)
  - determine scenario earthquakes for considered locations
    - identify seismogenic zones, faults
    - identify largest earthquakes from each source
    - identify gelological, geotechnical, geophysical site conditions
    - establish attenuation relations for propagation of seismic signals
    - determine likelihoods of scenarios
    - establish uncertainty of modeling parameters
  - determine design parameters for structural analysis
    - ground displacement spectrum at location(s) of interest
    - ground velocity spectrum at location(s) of interest
    - ground acceleration spectrum at location(s) of interest

Seismic Zonation

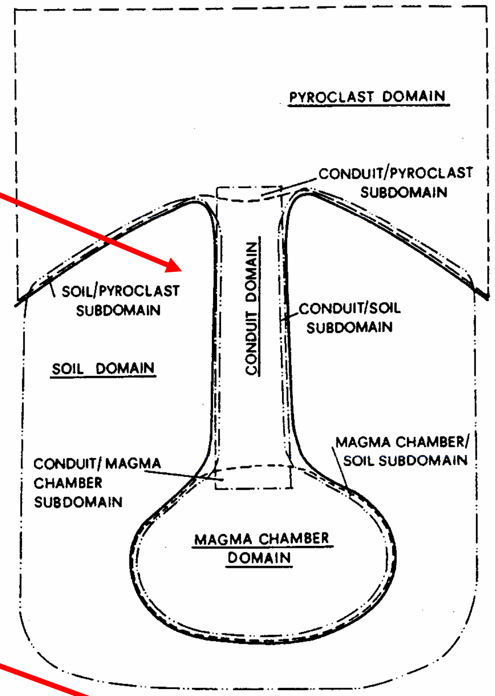
- Scenario-based neo-deterministic approach
  (Peresan, Zuccolo, Vaccari & Panza, 2007)
  - determine scenario earthquakes for considered locations
    - identify seismogenic zones, faults
    - identify largest earthquakes from each source
    - identify gelological, geotechnical, geophysical site conditions
    - construct synthetic seismograms for different earthquake classes
    - determine likelihoods of scenarios
    - establish uncertainty of modeling parameters
  - determine design parameters for structural analysis
    - displacement spectrum at location(s) of interest
    - velocity spectrum at location(s) of interest
    - acceleration spectrum at location(s) of interest

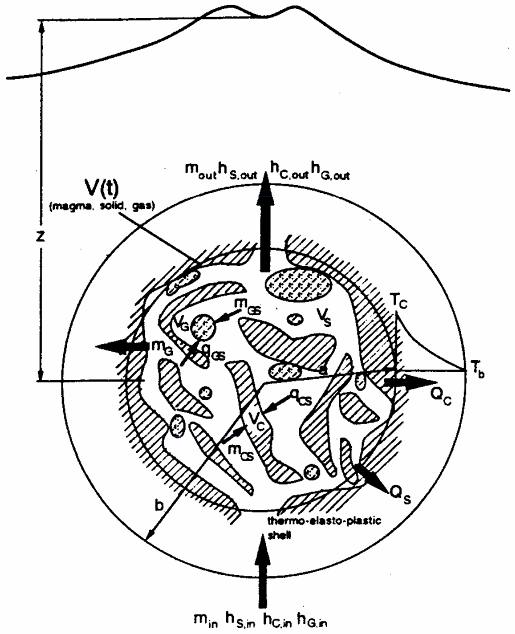
Global Volcanic Simulator

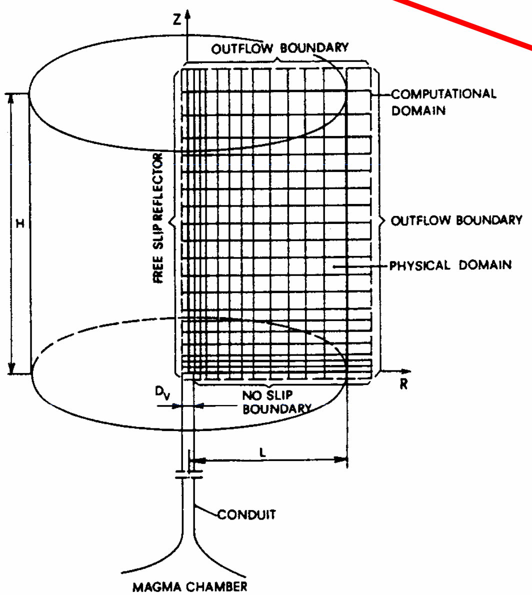
Dobran (1993, 1994, 2001, 2006)

- Physico-mathematical-computer model of volcanic system
- Determine scenarios and their likelihoods
    - Magma chamber dynamics
    - Opening of volcanic conduits
    - Conduit flow dynamics
    - Dispersion of pyroclasts in the atmosphere
    - Ash fall from eruption column
    - Propagation of pyroclastic, lava and mud flows
    - Dispersion of ballistic blocks

- Domain decomposition
  - ➢ magma chamber
  - ➢ conduit
  - ➢ soil and rock
  - ➢ atmosphere
- 3-dimensional
  - ➢ transient
  - ➢ multiphase
  - ➢ nonequlibrium
  - ➢ eulerian
  - ➢ lagrangean (ballistics)
- Numerical implementation
  - ➢ implicit
  - ➢ parallel computer architectures







Law	Mass	Linear Momentum	Angular Momentum	Energy	Entropy
$\mathbf{\Psi}^{(\alpha\delta)}$	1	$\mathbf{v}^{(\alpha\delta)}$	$\mathbf{r}\times\mathbf{v}^{(\alpha\delta)}$	$\epsilon^{(\alpha\delta)}+\frac{1}{2}\mathbf{v}^{(\alpha\delta)}\cdot\mathbf{v}^{(\alpha\delta)}$	$s^{(\alpha\delta)}$
$\mathbf{J}^{(\alpha\delta)}$	0	$-\mathbf{T}^{(\alpha\delta)}$	$-\mathbf{r}\times\mathbf{T}^{(\alpha\delta)}$	$\mathbf{q}^{(\alpha\delta)}-\mathbf{T}^{(\alpha\delta)T}\mathbf{v}^{(\alpha\delta)}$	$\mathbf{h}^{(\alpha\delta)}$
$\mathbf{\Phi}^{(\alpha\delta)}$	0	$\mathbf{b}^{(\alpha\delta)}$	$\mathbf{r}\times\mathbf{b}^{(\alpha\delta)}$	$\mathbf{b}^{(\alpha\delta)}\cdot\mathbf{v}^{(\alpha\delta)}$	$R^{(\alpha\delta)}$
$\mathbf{B}^{(\alpha\delta)}$	0	$\mathbf{0}$	$\mathbf{0}$	$r^{(\alpha\delta)}$	$\zeta^{(\alpha\delta)}$
$\mathbf{\Delta}^{(\alpha\delta)}$	0	$\mathbf{\Delta}_m^{(\alpha\delta)}$	$\mathbf{r}\times\mathbf{\Delta}_m^{(\alpha\delta)}$	$\Delta_\epsilon^{(\alpha\delta)}$	$\Delta_s^{(\alpha\delta)}$

$\mathbf{\Delta}_m^{(\alpha\delta)}=(2H\nu\mathbf{n}+\nabla_s\nu)^{(\alpha\delta)}$, $R^{(\alpha\delta)}=r^{(\alpha\delta)}/\theta^{(\alpha\delta)}$, $\zeta^{(\alpha\delta)}\geq$

$\Delta_\epsilon^{(\alpha\delta)}=(2H\nu\mathbf{n}\cdot\mathbf{S}+\nabla_s\nu\mathbf{S}+\nu\nabla_s\cdot\mathbf{S})^{(\alpha\delta)}$, $\Delta_s^{(\alpha\delta)}\geq 0$

$$\frac{\partial}{\partial t}(\rho^{(\alpha\delta)}\mathbf{\Psi}^{(\alpha\delta)})+\nabla^o\cdot(\rho^{(\alpha\delta)}\mathbf{\Psi}^{(\alpha\delta)}\mathbf{v}^{(\alpha\delta)})+\nabla^o\cdot\mathbf{J}^{(\alpha\delta)}$$
$$-\rho^{(\alpha\delta)}\mathbf{\Phi}^{(\alpha\delta)}=\rho^{(\alpha\delta)}\mathbf{B}^{(\alpha\delta)}$$

$$(m^{(\alpha\delta)}\mathbf{\Psi}^{(\alpha\delta)}+\mathbf{J}^{(\alpha\delta)}\mathbf{n}^{(\alpha\delta)})+(m^{(\beta\eta)}\mathbf{\Psi}^{(\beta\eta)}+\mathbf{J}^{(\beta\eta)}\mathbf{n}^{(\beta\eta)})=\mathbf{\Delta}^{(\alpha\delta)}$$

$$m^{(\alpha\delta)}=\rho^{(\alpha\delta)}(\mathbf{v}^{(\alpha\delta)}-\mathbf{S}^{(\Lambda\delta)})\cdot\mathbf{n}^{(\alpha\delta)}$$

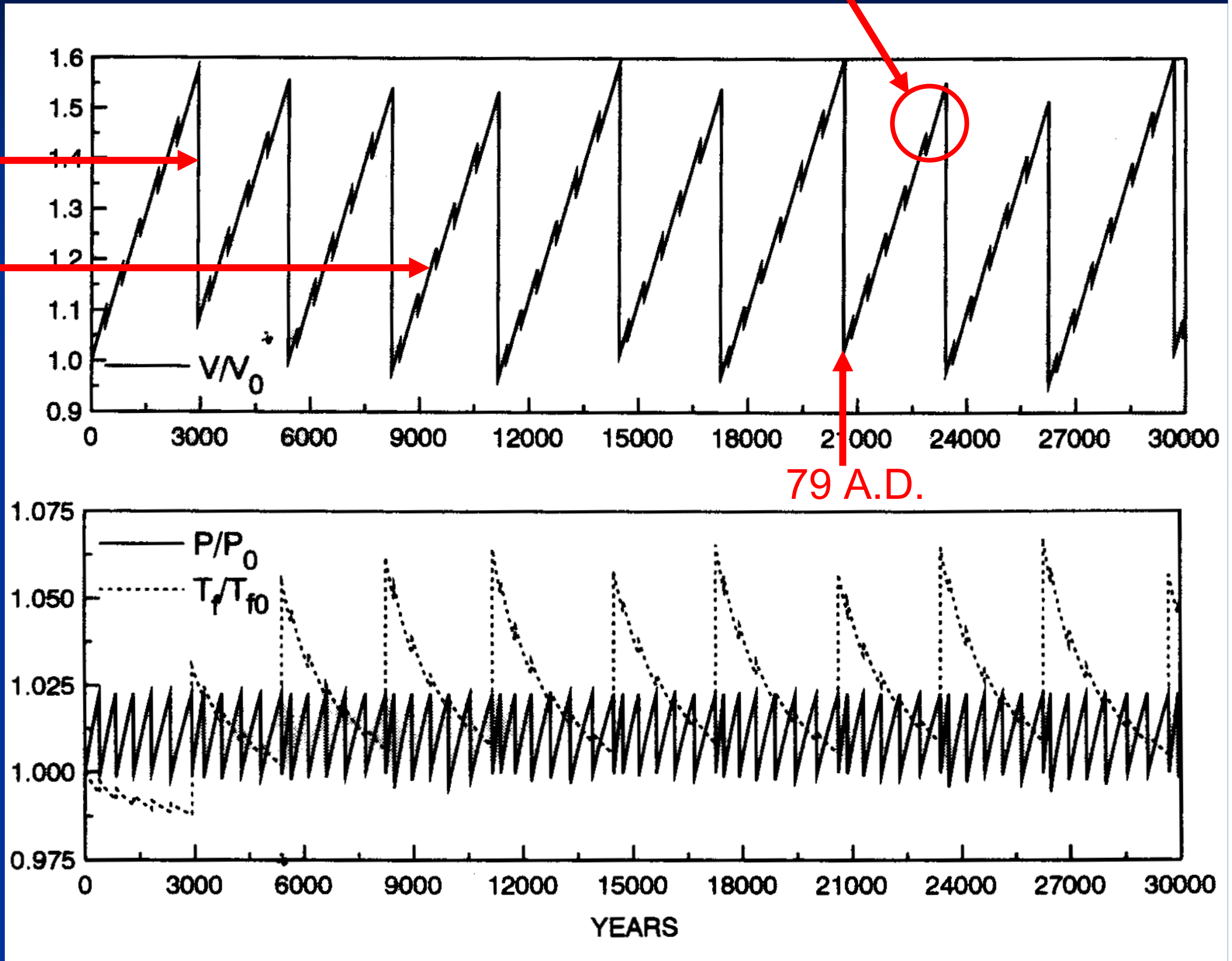
Magma chamber dynamics

- Pressure buildup and relief
  - magma supply
  - melting and crystallization of magma
  - differentiation (compositional change)
- Visco-plastic deformation of magma reservoir
- Thermo-visco-elastic deformation of surrounding rocks
- Simulation of 20,000 years of volcanic activity

Vesuvius is here now

Plinian Eruption

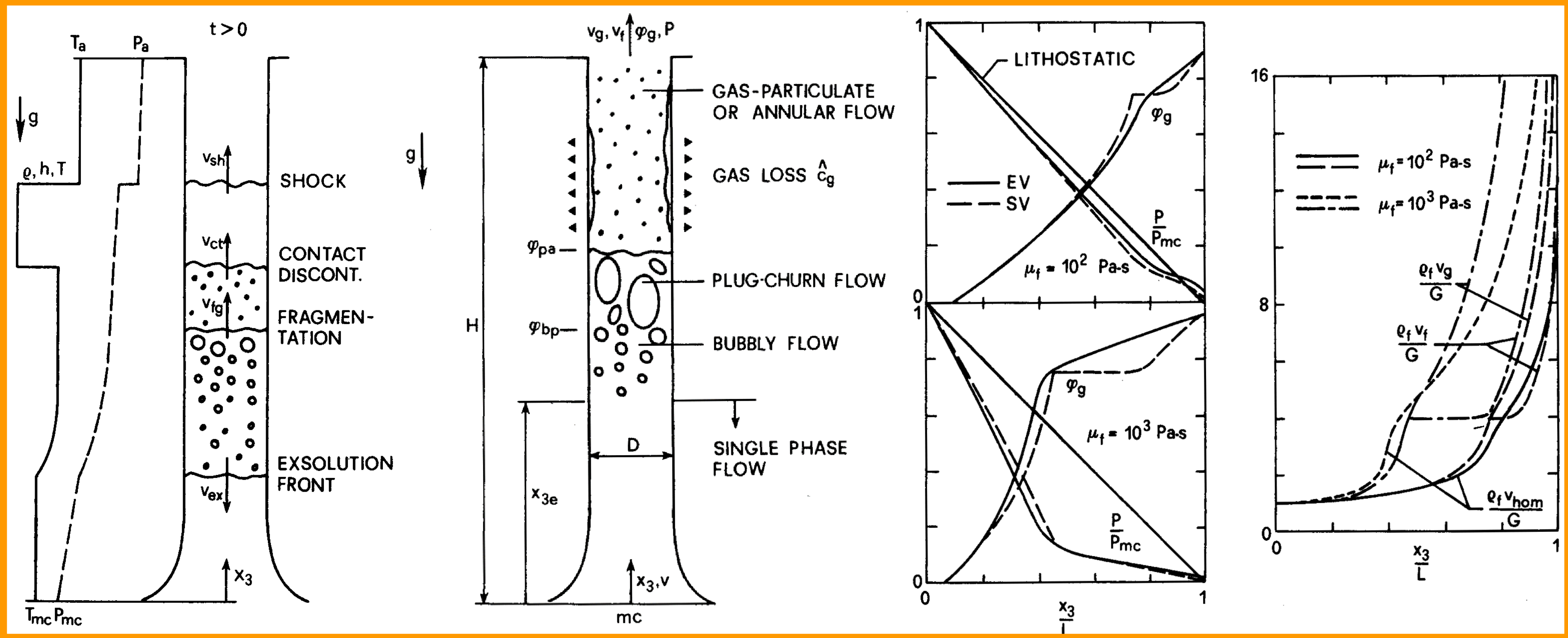
Subplinian eruption



Next eruption:

This or next century, plinian or subplinian

➢ Conduit flow dynamics



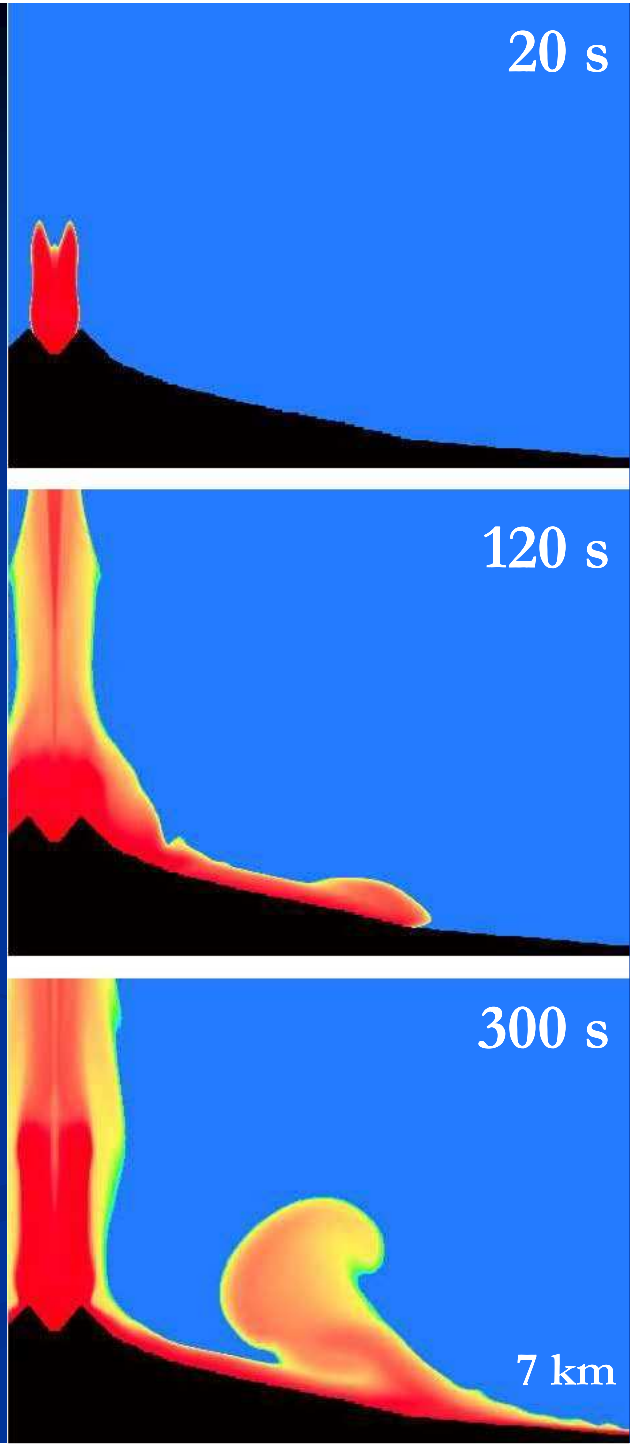
Conduit opening

quasi-steady state flow

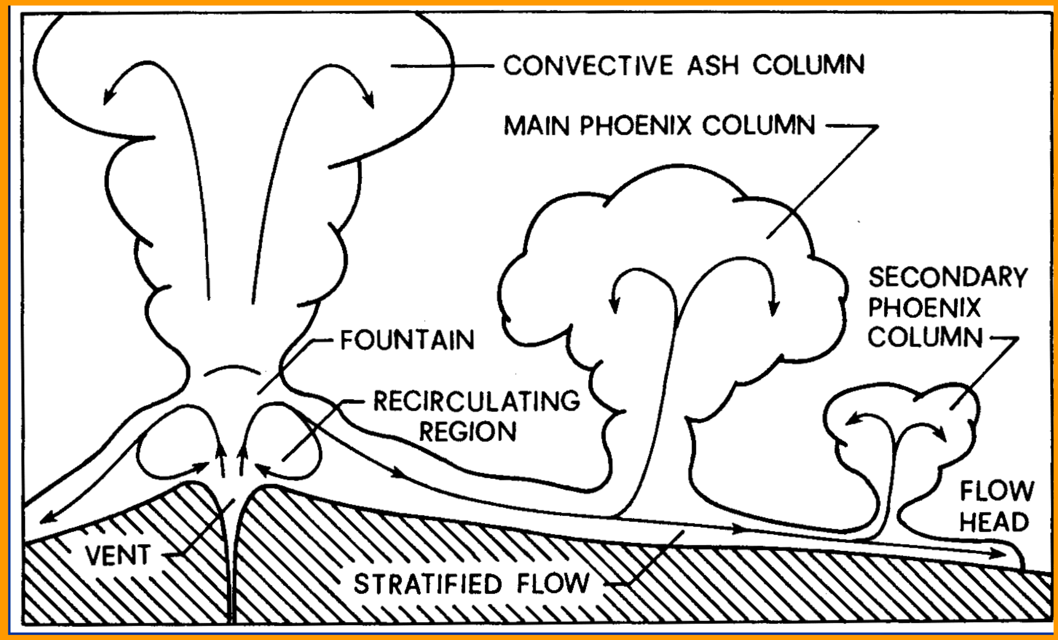
➢ Pyroclastic dispersion

(2-phase nonequilibrium model)

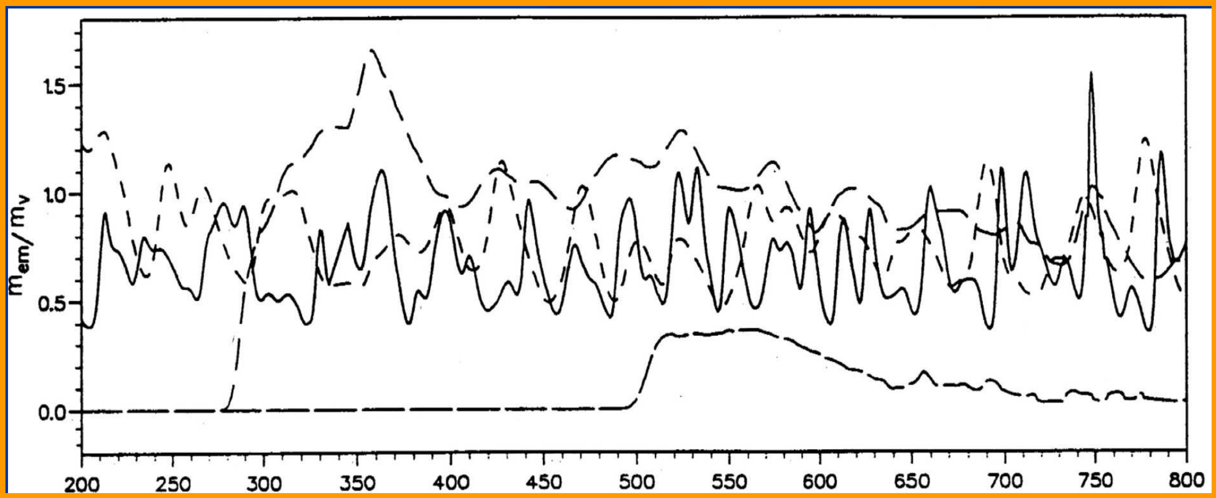
- Vent conditions from magma chamber and magma ascent models
- Plinian eruption rate: 10^8 kg/s
- Pyroclastic flows reach 7 km in 5 minutes
- 3-7 km^3 of material erupts in 20 h
- people within 10 km will perish
- people within 50 km will be impacted
- Naples, the next Pompeii?

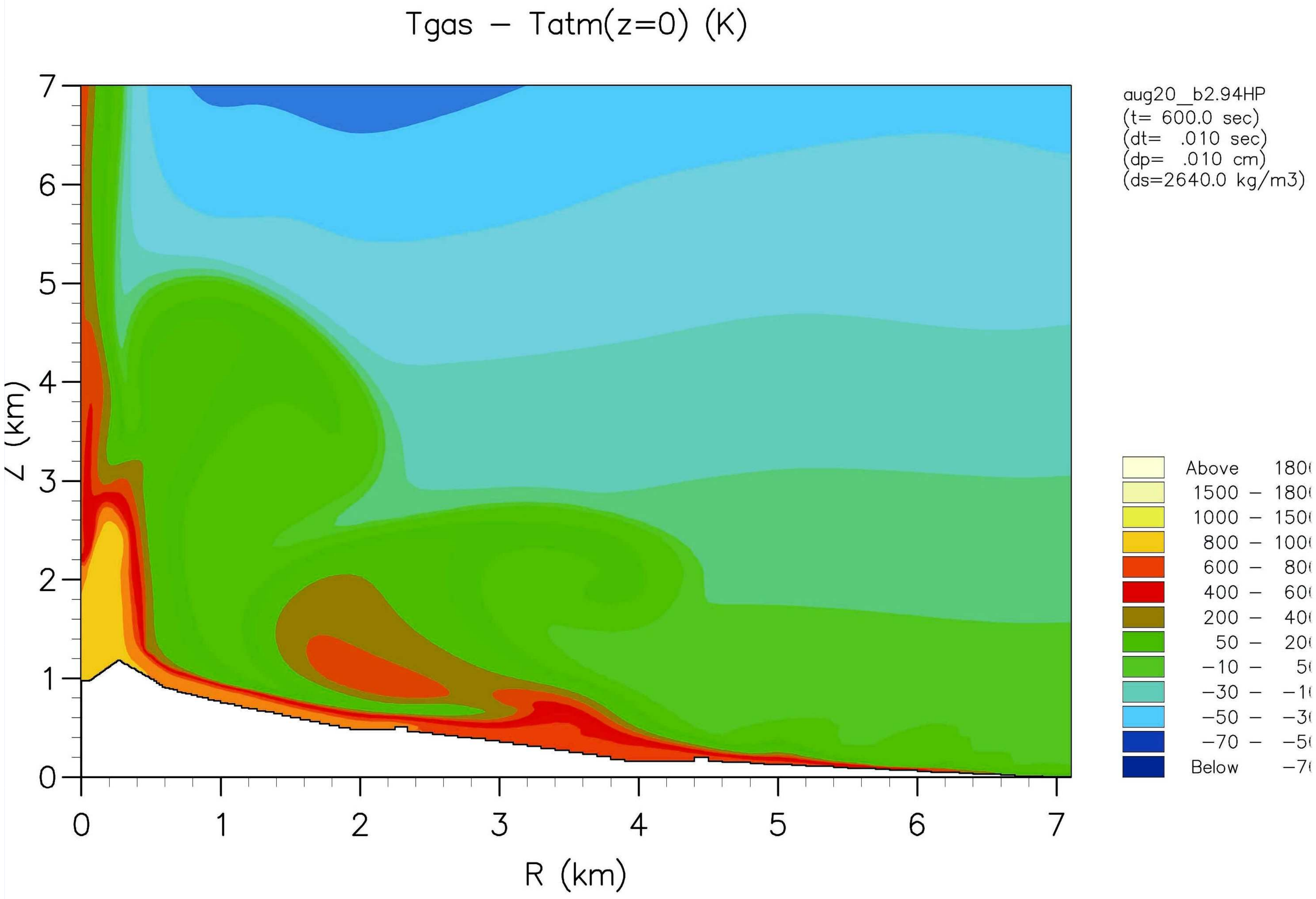


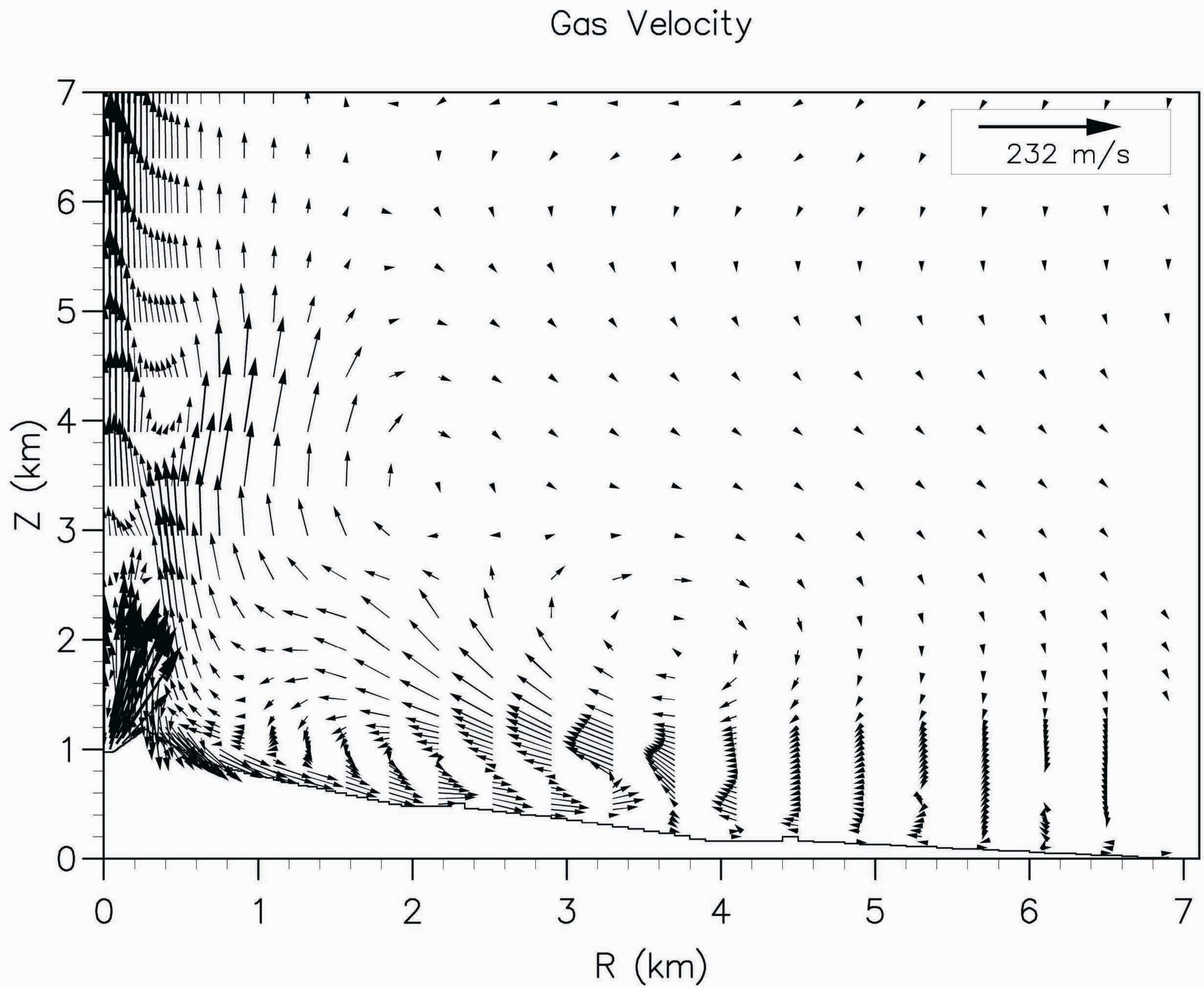
Flow regions close to the vent and in the pyroclastic flow

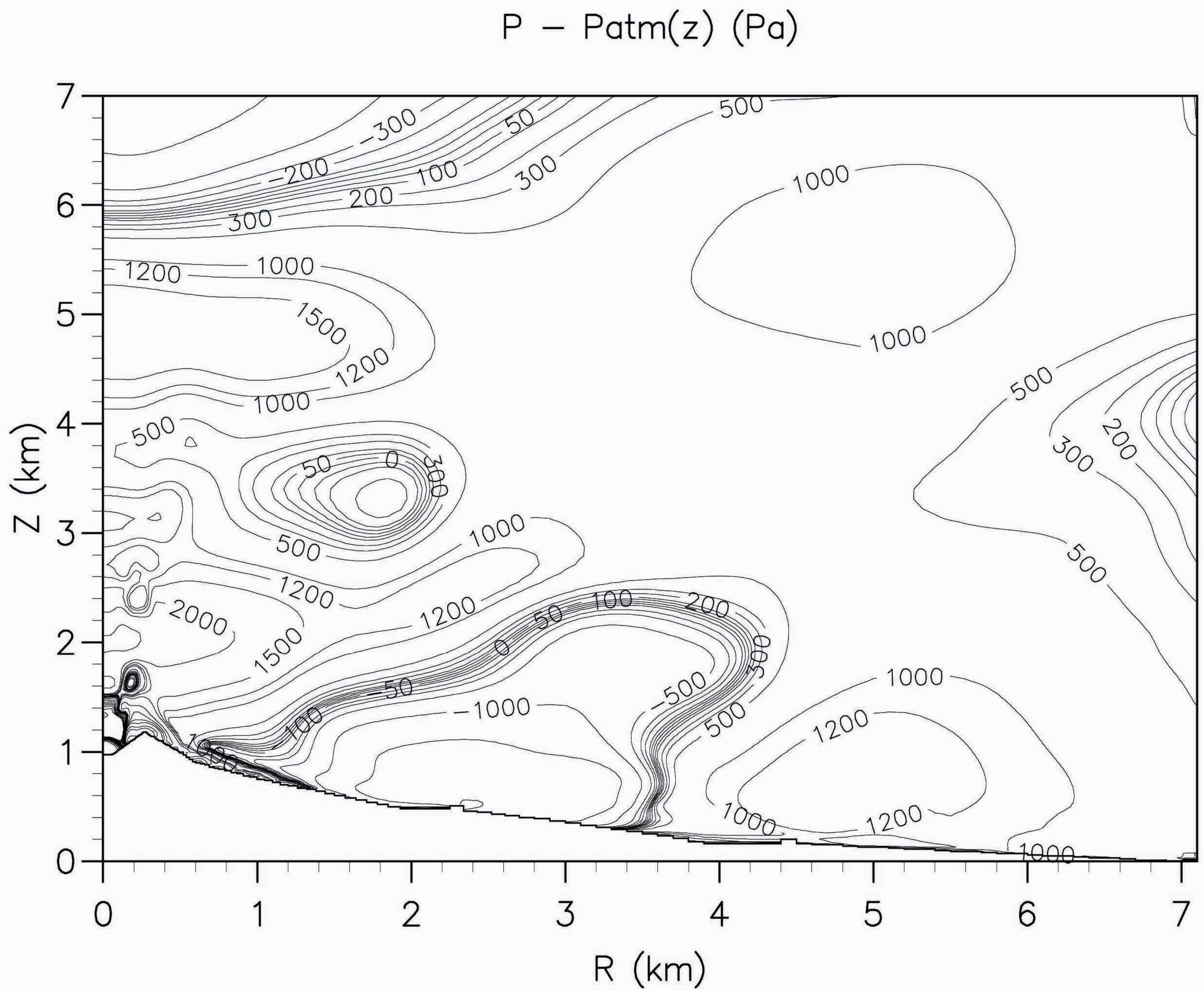


Pyroclastic mass flow rate fluctuations at different distances from the vent

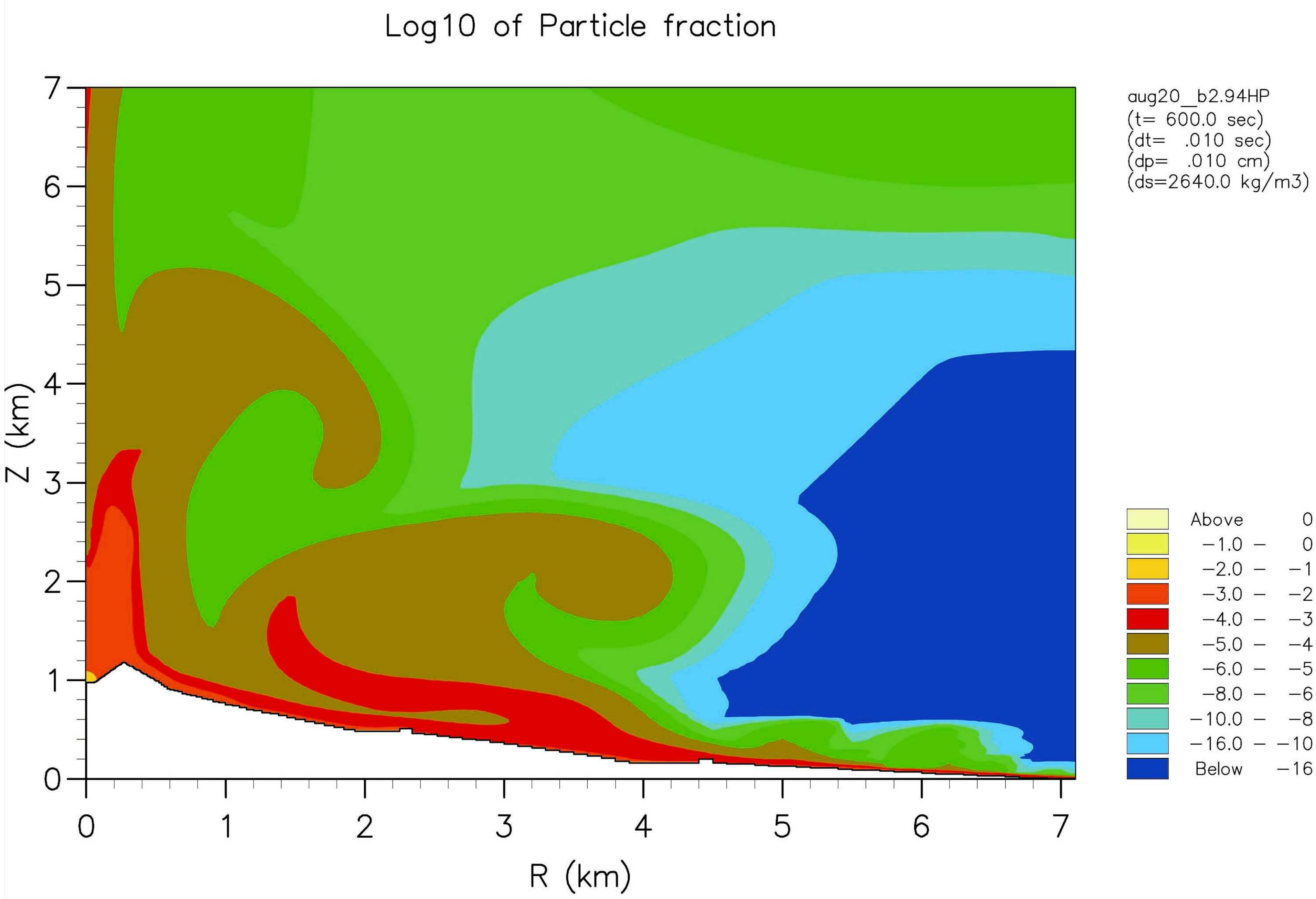



Tgas – Tatm(z=0) (K)
aug20_b2.94HP
(t= 600.0 sec)
(dt= .010 sec)
(dp= .010 cm)
(ds=2640.0 kg/m3)
Z (km)
R (km)
0
1
2
3
4
5
6
7
Above 180
1500 – 180
1000 – 150
800 – 100
600 – 80
400 – 60
200 – 40
50 – 20
–10 – 5
–30 – –1
–50 – –3
–70 – –5
Below –7


Gas Velocity
232 m/s
Z (km)
R (km)
0
1
2
3
4
5
6
7



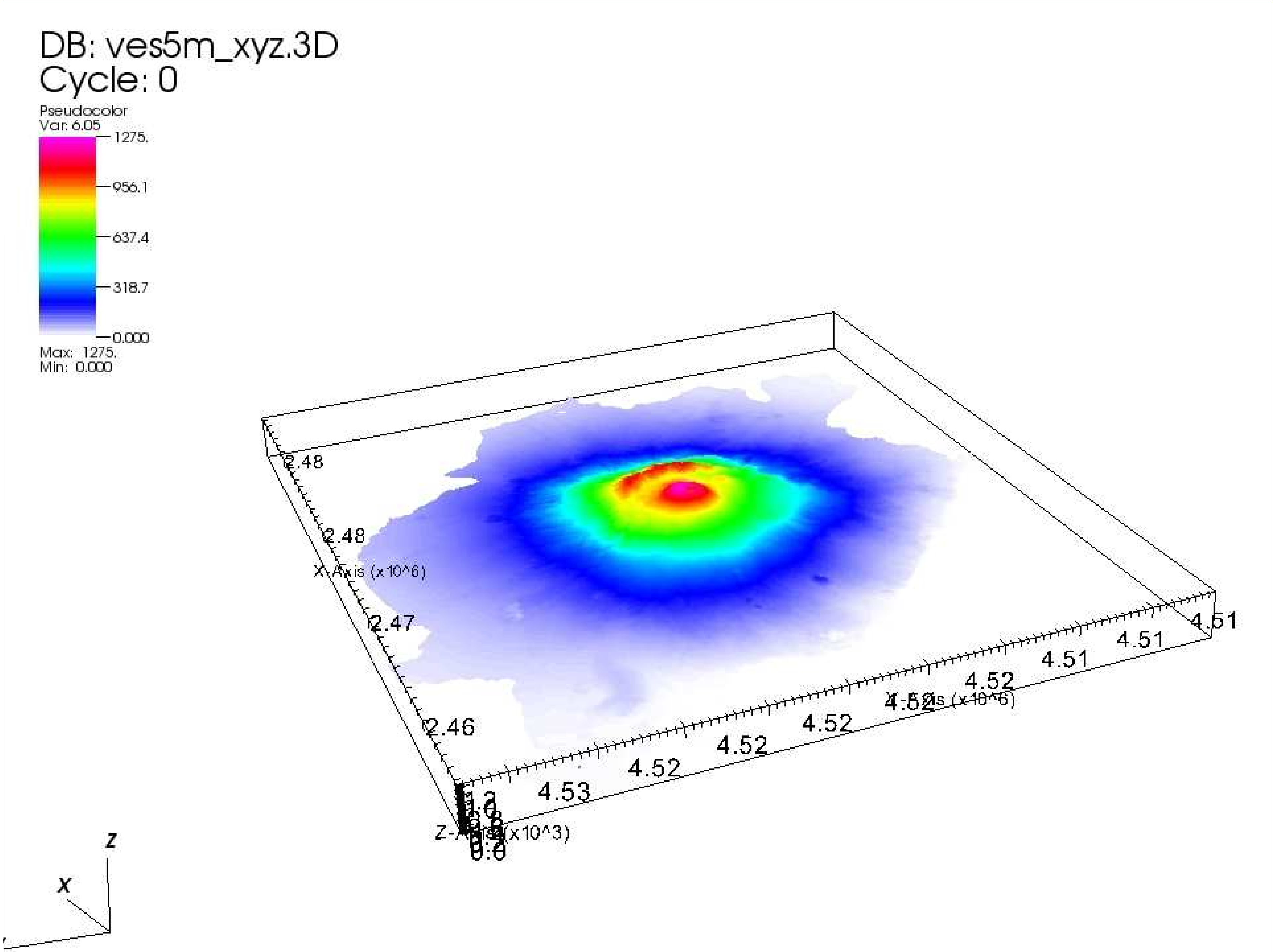
P − Patm(z) (Pa)
Z (km)
R (km)
0
1
2
3
4
5
6
7
-300
-200
50
100
200
300
500
1000
1200
1500
2000
0
-50
-500
-1000

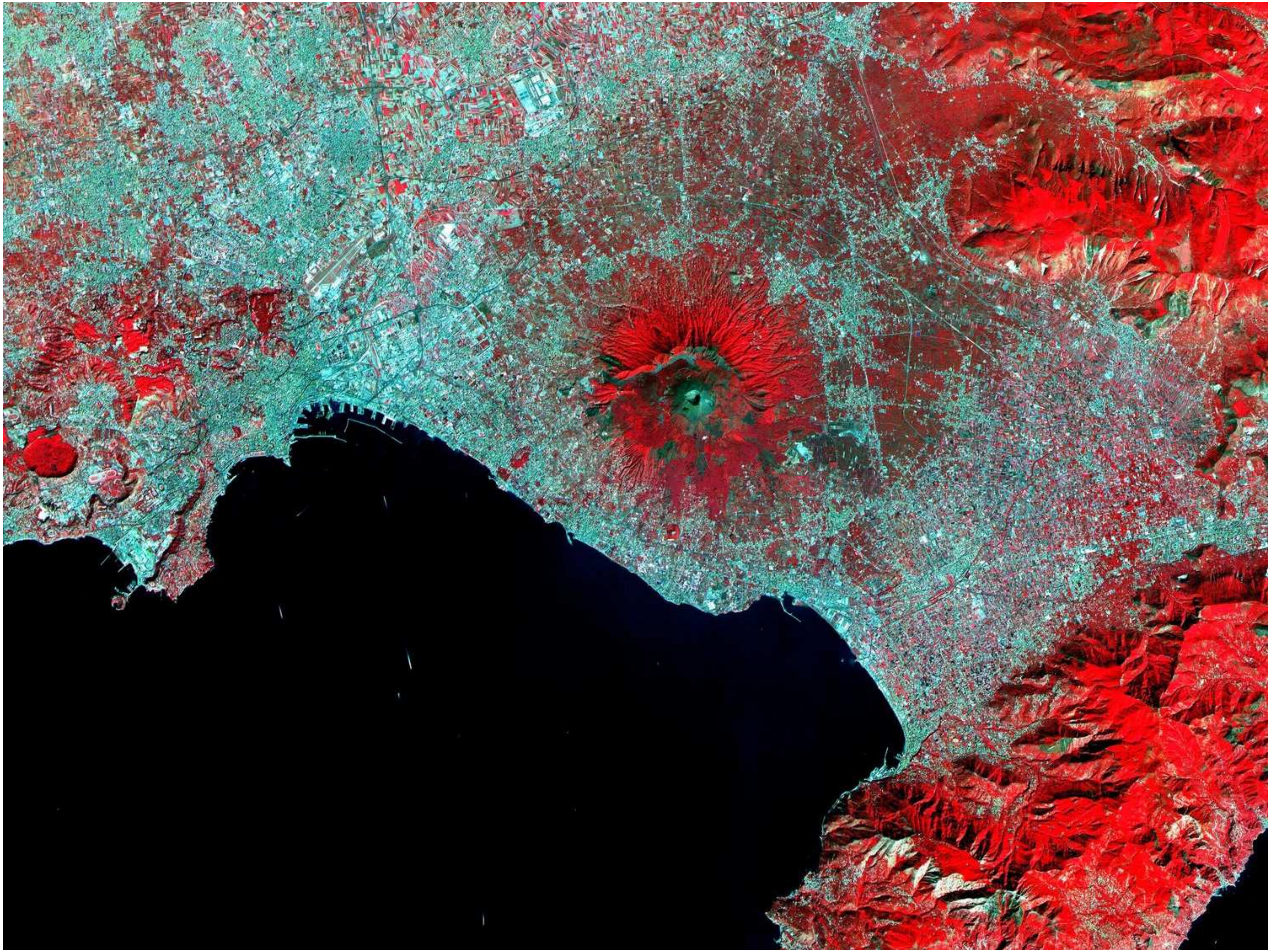


Log10 of Particle fraction
Z (km)
R (km)
0
1
2
3
4
5
6
7
aug20_b2.94HP
(t= 600.0 sec)
(dt= .010 sec)
(dp= .010 cm)
(ds=2640.0 kg/m3)
Above 0
-1.0 – 0
-2.0 – -1
-3.0 – -2
-4.0 – -3
-5.0 – -4
-6.0 – -5
-8.0 – -6
-10.0 – -8
-16.0 – -10
Below -16

Geographical Information System

- Analyze the Campanian Plain for
  - population dynamics
  - real estate property (residential, commericial, industrial)
  - service facilities (energy, water, cultivation)
  - infrastructures
  - environment (recreation, waste processing & disposal)
  - identify areas for future habitats
- Produce topographic maps for simulations
  - with key existing structures superimposed
  - with future structures superimposed


DB: ves5m_xyz.3D
Cycle: 0
Pseudocolor
Var: 6.05
1275.
956.1
637.4
318.7
0.000
Max: 1275.
Min: 0.000
X-Axis (x10^6)
2.48
2.48
2.47
2.46
Y-Axis (x10^6)
4.53
4.52
4.52
4.52
4.52
4.52
4.51
4.51
4.51
Z-Axis (x10^3)
Z
X



Grand challenge problems

- What are the sustainability design paradigms?
- How will safety requirements limit options in other sectors?
- Does the defense from the volcano require new paradigms for urban infrastructure?
- Is homeland defensible against all conceivable scenarios?
- What methods of energy supplies and waste disposal and recycling are required?

- What kind of habitat (centralized vs. clustered?
- How will the habitats interact with Naples and surroundings?
- What cultural patrimonies can be protected and how to protect them?
- What can remain within the exclusion zone?
- How to effectively cooperate with politicians, professionals, people?

Toward security and prosperity

<u>VESUVIUS 2000</u>

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