Volcanic hazard assessment – Day 2: Tephra fallout

Volcanic risk module / CERG–C / ELSTE

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Good morning!

→ Download and save Day 2 material onto your H: drive

→ Extract content (i.e., right click, *"Extraire tout..."*)

→ Extract the content of TephraProb.zip (yes — still on the H: drive)

→ Try and open Matlab 2022a

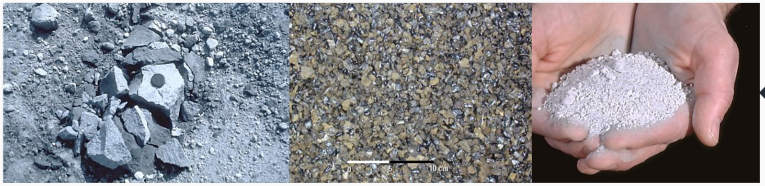
What is tephra?

Fragmented material regardless of size or composition

Blocks > 64 mm

Lapilli 64-2 mm

Ash < 2 mm

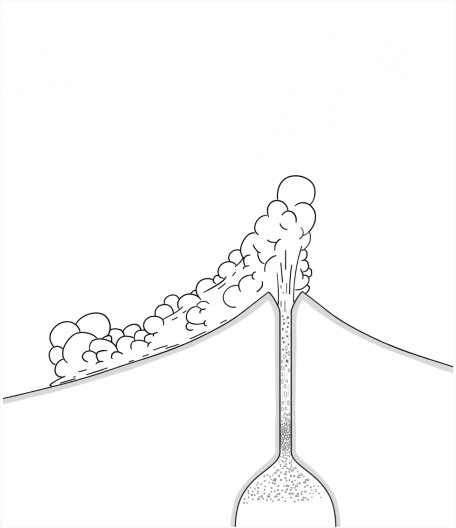


Coarse ash
2-0.063 mm

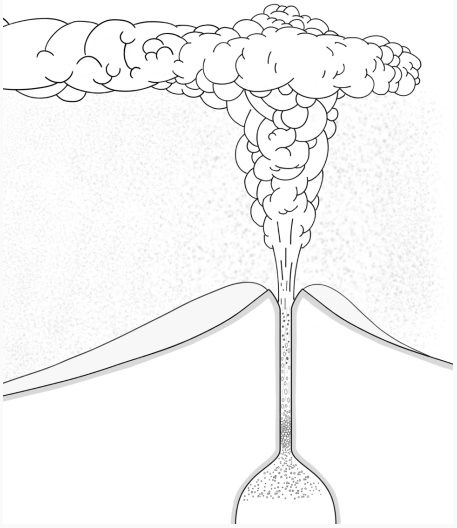
Fine ash
< 0.063 mm

What is tephra?

Pyroclastic density currents (PDC)



Tephra fall



Why are tephra deposits important?

→ They record eruption dynamics

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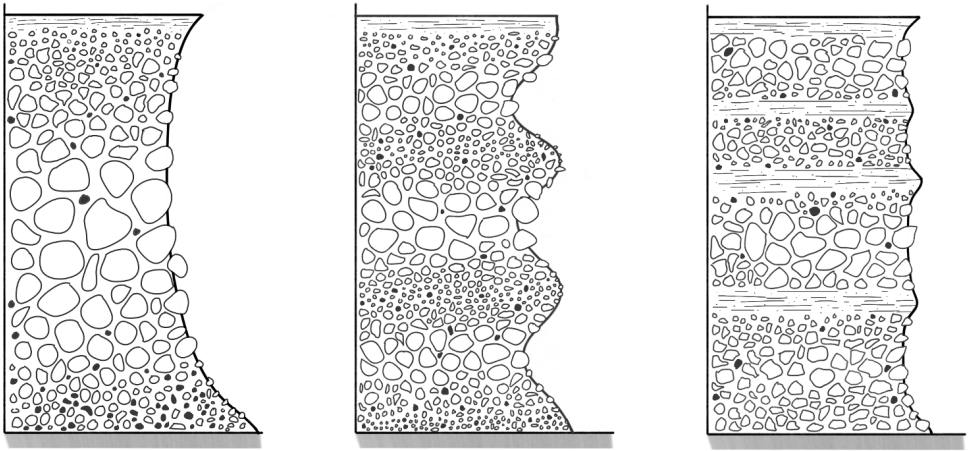
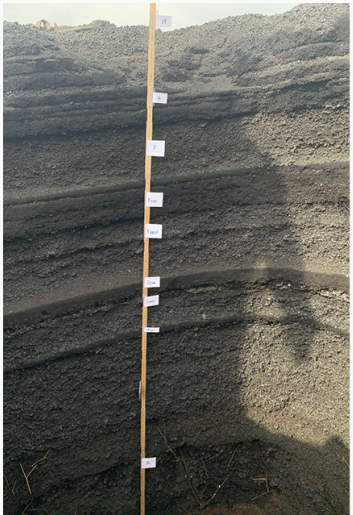


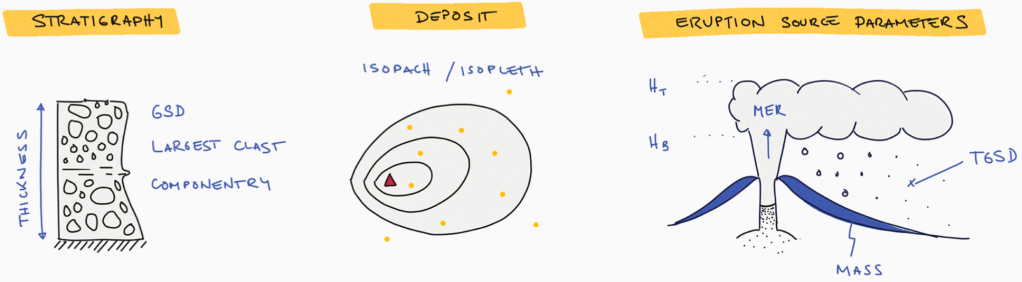
Why are tephra deposits important?

→ They are a time machine to past eruptions



Why are tephra deposits important?

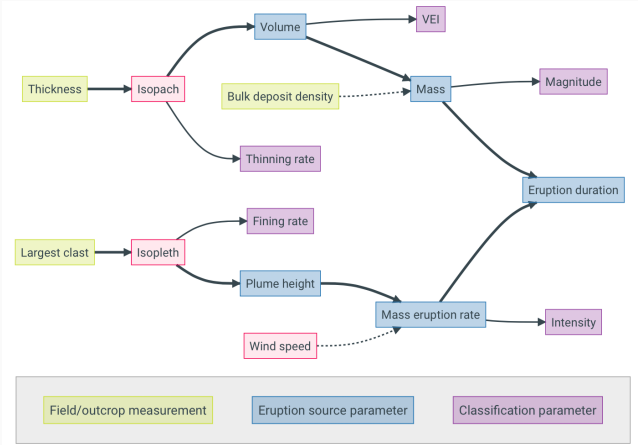
→ They allow quantifying eruption source parameters



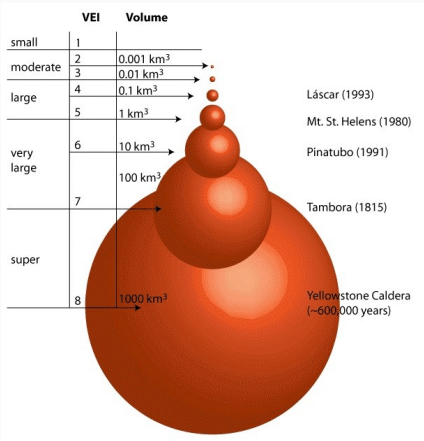
→ Plume height, erupted mass, total grain-size distribution

Why are tephra deposits important?

Mapping toolbox

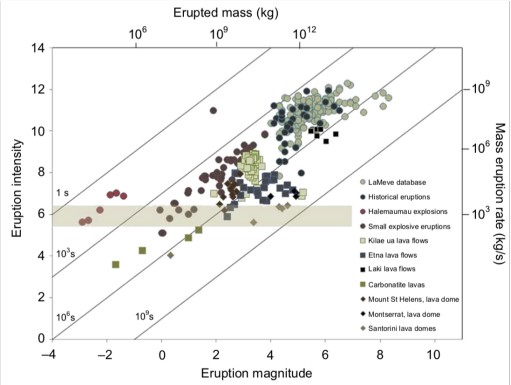


Volcanic Explosivity Index (VEI)



Why are tephra deposits important?

Magnitude vs. intensity



Intensity: $log_{10}(MER\ [kg/m^2]) + 3$

Magnitude: $log_{10}(Mass\ [kg]) + -7$

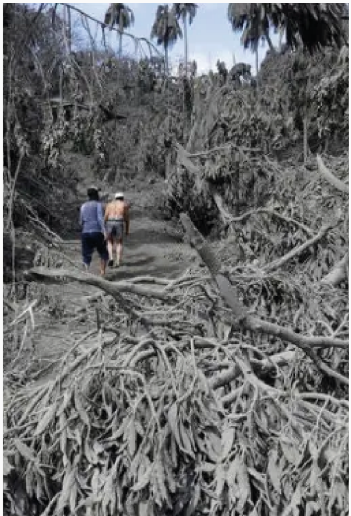
Calbuco 2015: VEI 4
Hours-days, height = 15 km asl

Eyjafjallajökull 2010: VEI 4
Weeks-months, max height = 6-9 km asl

”The past is the key to the future”

Why are tephra deposits hazardous?

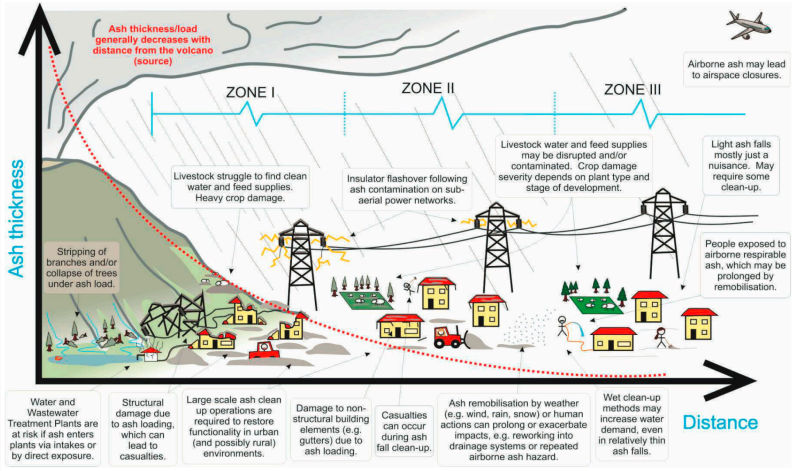
Cited as a cause of death in 21% of volcanic eruptions → roof collapse



Why are tephra deposits hazardous?

Complex spatio-temporal impact patterns

Destruction → Damage → Disruption



”There is no such thing as a natural disaster ”

— UNDRR

The interface between hazard and impact

$$I = f(H, V)$$

- **I:** Impact from ground tephra accumulation
- **H:** Spatio(-temporal) distribution of hazard intensity metrics
- **V:** Vulnerability → how exposed element will be negatively impacted by hazard

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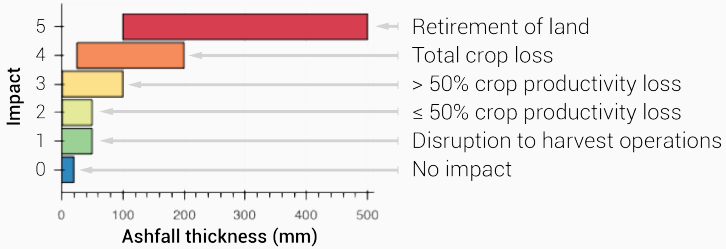
Damage/disruption states (DDS): Stepwise categorisation of impact as a function of hazard intensity



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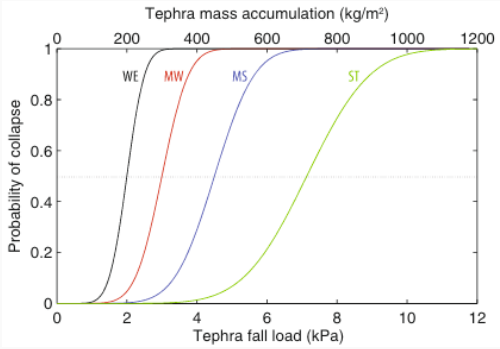
Fragility/Vulnerability functions: Mathematical function expressing a probability of impact/relative cost for a given hazard intensity



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The complexity of volcanic risk

- **Multi–hazard** → interaction & variability in space and time

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- **Multi–hazard** → interaction & variability in space and time
- Wide range of **eruptive styles** → no magnitude/intensity relationship

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The complexity of volcanic risk

- **Multi–hazard** → interaction & variability in space and time
- Wide range of **eruptive styles** → no magnitude/intensity relationship
- Multiple **hazard metrics** → Tephra: load, thickness, grain-size, soluble salts

Pre–event exposure/impact/risk studies require:

→ Ability to *predict* the hazard

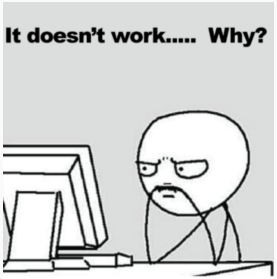
Tephra fallout part I

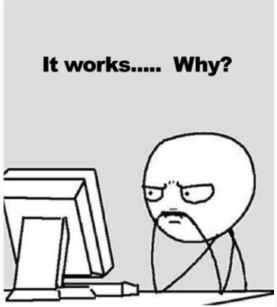
Physical modeling

What is a model?

Models are approximation of reality!

- For natural hazards:
  - Initial conditions → MODEL → Hazard intensity





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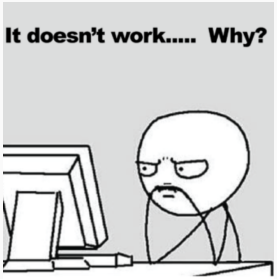
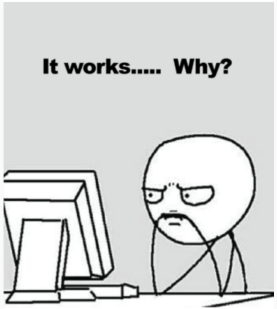
Type of models:

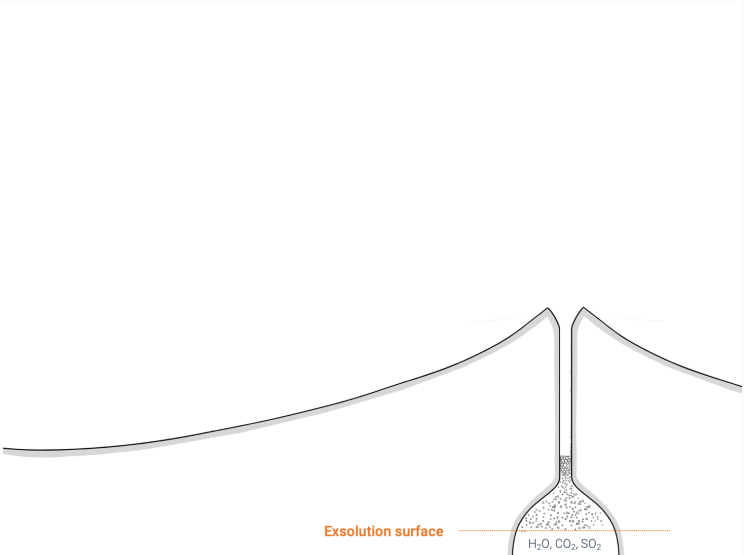
- **Mathematical**: Data-driven, include statistical or machine learning-powered models
- **Physical**: rely on a simplified formulation of physical laws



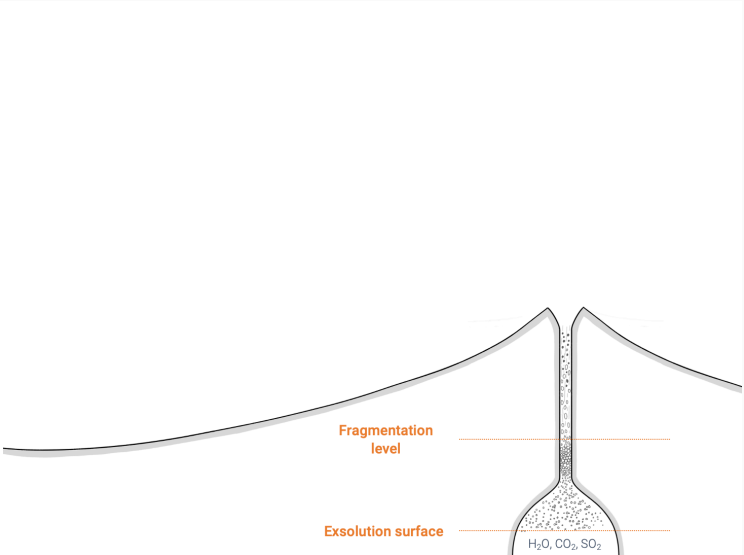


Model parametrisation for tephra fallout

1. The rise of magma to the surface

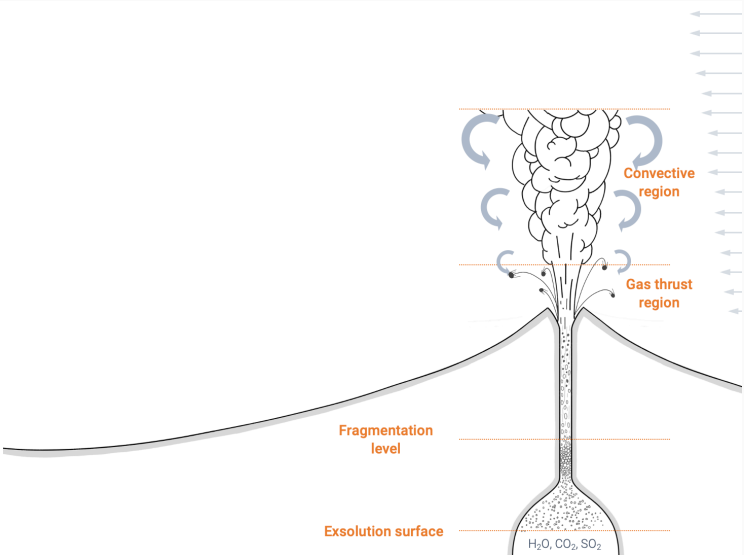


2. The generation of tephra

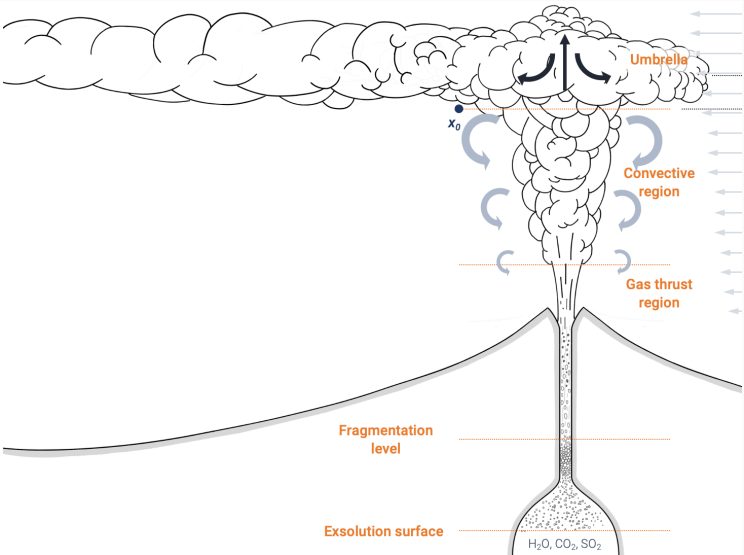


Model parametrisation for tephra fallout

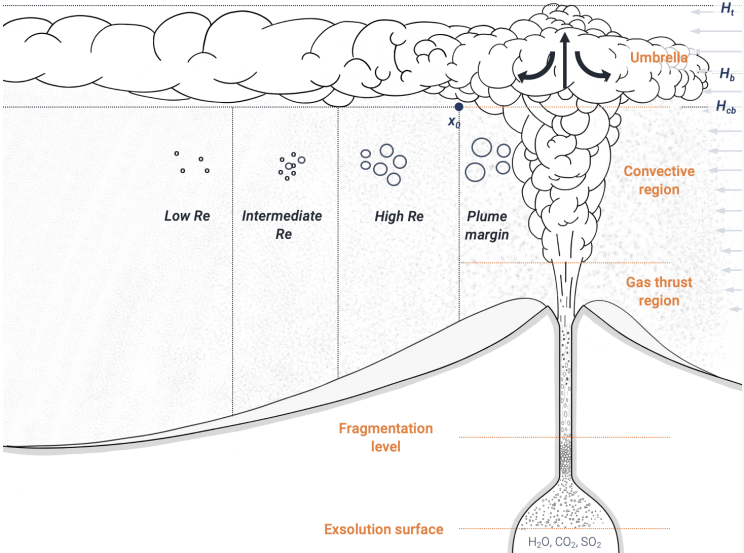
3. The rise tephra in the atmosphere → the vertical column



4. The dispersal by the wind → the "mushroom" cloud



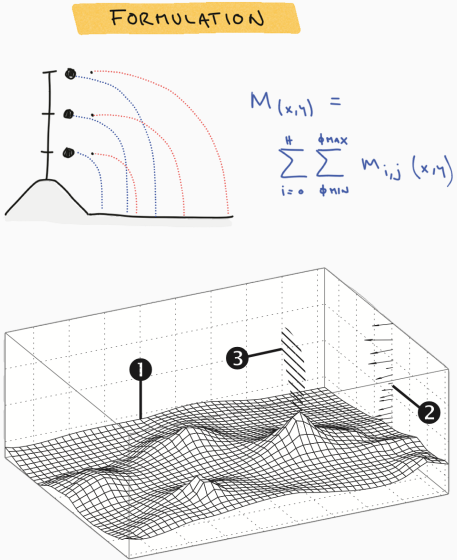
5. The sedimentation of particles onto the ground → the tephra deposit



Forecasting tephra fallout

Tephra2

- Analytical solution of the advection-diffusion equation
- 2D, Eulerian, time-independent
- Assumptions → fast



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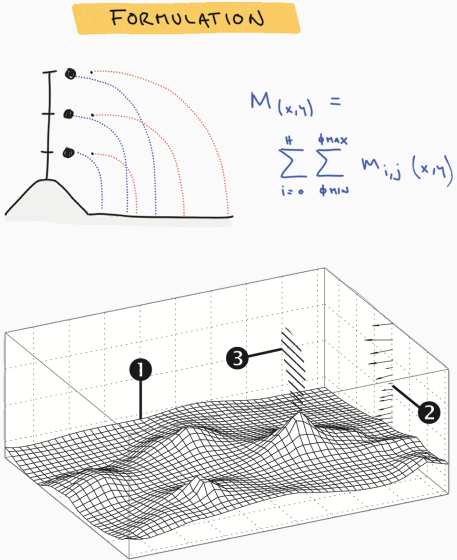
Eruption source parameters

1. Calculation grid
2. Wind profiles
3. Eruption source parameters
    - Plume height
    - Eruption mass
    - Total grain-size distribution
    - Plume mass distribution



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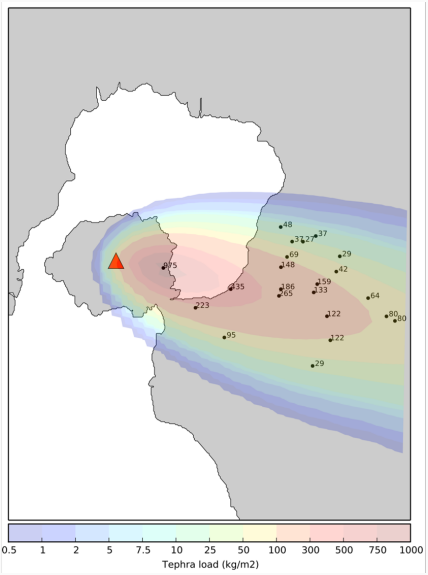
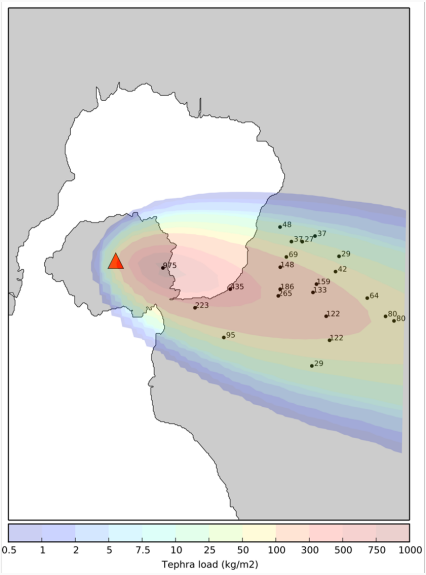


Pre–event exposure/impact/risk studies require:

✓ Ability to *predict* the hazard

The missing part

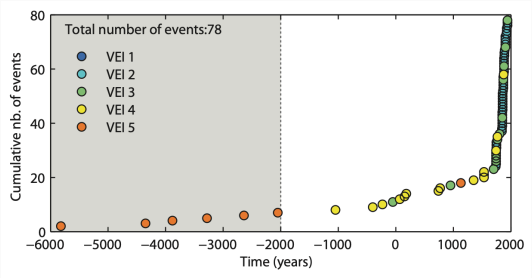
What is missing?

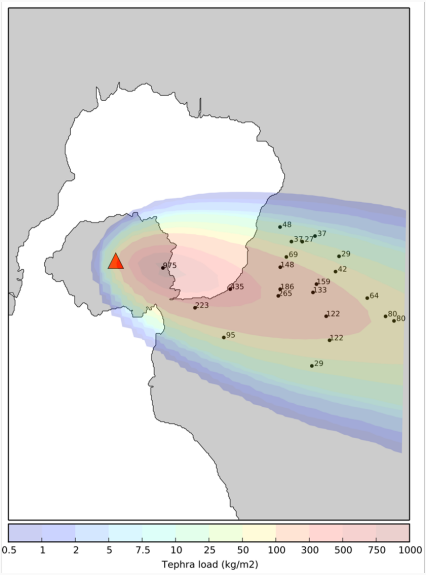


The missing part

What is missing?

1. The eruptive history...

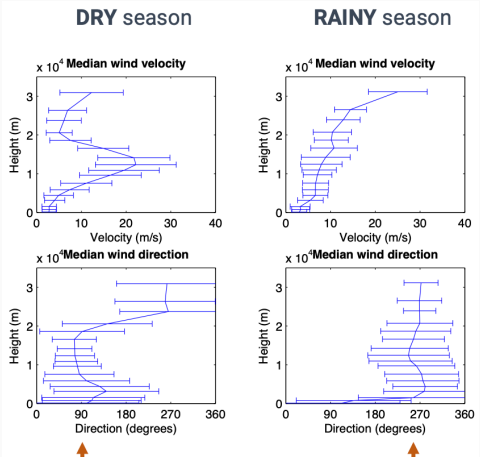


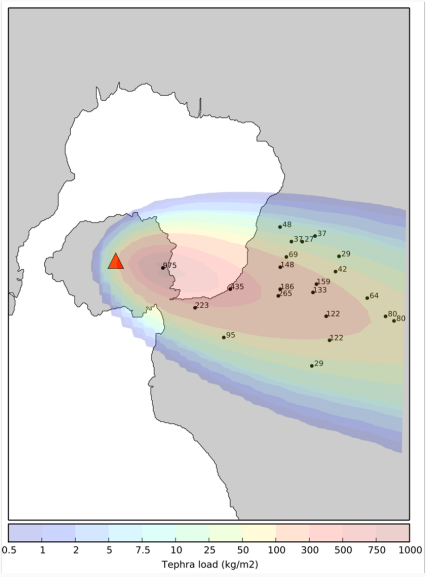


The missing part

What is missing?

2. The atmpospheric variability...





Pre–event exposure/impact/risk studies require:

✓ Ability to *predict* the hazard

→ Ability to describe the *variability* of eruptive conditions

Tephra fallout part II

Probabilistic hazard modeling

Deterministic to probabilistic modeling

Lava flows:

- **Input**: Uncertainty on DEM + vent location
- **Hazard metrics**: Boolean yes/no inundation
- **Output**: Probability of flow inundation

Deterministic to probabilistic modeling

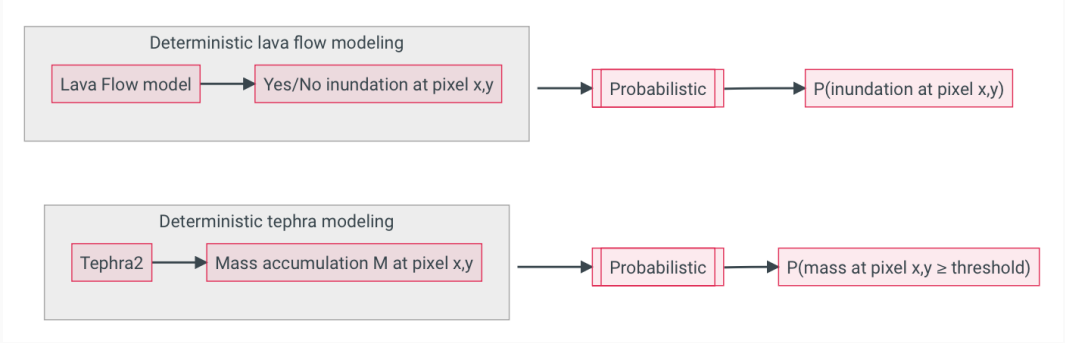
Lava flows:

- **Input**: Uncertainty on DEM + vent location
- **Hazard metrics**: Boolean yes/no inundation
- **Output**: Probability of flow inundation

Tephra fallout:

- **Input**: Uncertainty on ESP + wind
- **Hazard metrics**: Tephra load (kg/m^2)
- **Output**: Probability to exceed tephra load

Deterministic to probabilistic modeling

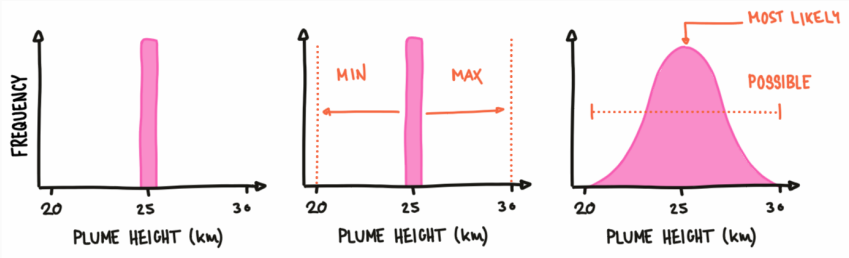


Probabilistic eruption scenarios

ESP for Tephra2: Plume height, erupted mass/volume, grain-size distribution

Workflow:

- Identify the relevant **Eruption Source Parameters** (ESP) for model/problem
- For each ESP, define:
  - Range
  - Distribution



Probabilistic eruption scenarios

ESP for Tephra2: Plume height, erupted mass/volume, grain-size distribution

Definition: Eruption scenarios can be developed around:

- Reference eruption
- VEI
- Intensity
- Eruptive style
- ...

→ The **purpose** of the study influences **how** a scenario is developed!

A note about uncertainties

Uncertainties:

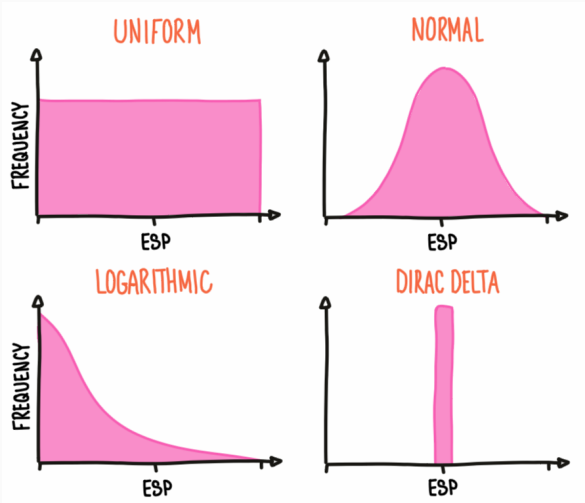
→ Epistemic uncertainties: derives from the lack of knowledge regarding a phenomena. In theory, we could reduce it with more knowledge.

→ Aleatoric uncertainties: associated with the inherent randomness of natural processes. Nothing much we can do about it, really!

A note about uncertainties

ESP distributions:

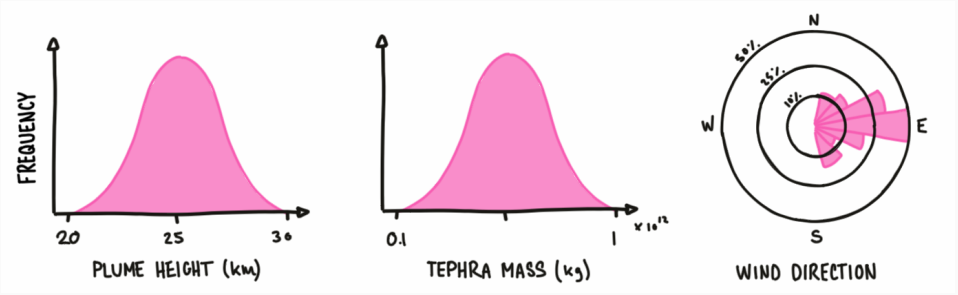
- Account for both epistemic and aleatory uncertainties
- Reflect our knowledge of the system
- Based on:
  - → Ideally, field studies
  - → Literature reviews
  - → Analogue volcanoes/eruptions
  - → Eruption databases



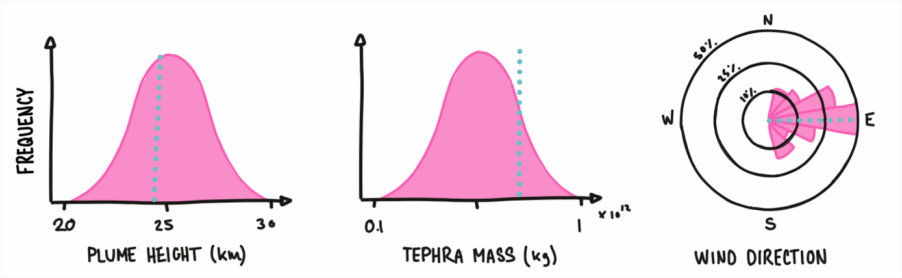
Probabilistic modeling

We are studying the famous **Mt. Bonadonna** volcano — a majestic but at time deadly volcano. Based on our knowledge (and fear) of it, we defined the following eruption scenario:

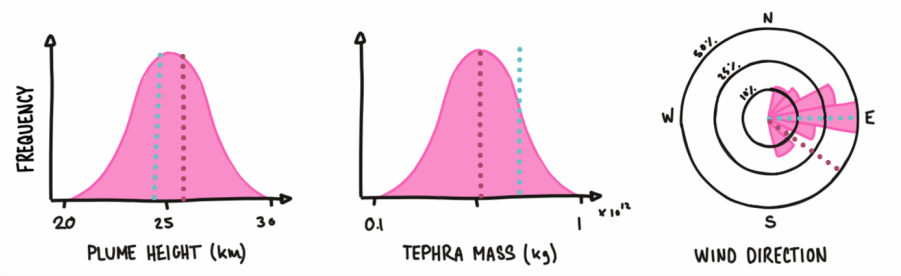
- **VEI 4** → 10^{11} – 10^{12} kg of tephra, Gaussian distribution
- **Plume height:** 20–30 km asl, Gaussian distribution
- **Wind conditions:** 20 years from Reanalysis databases



Probabilistic modeling

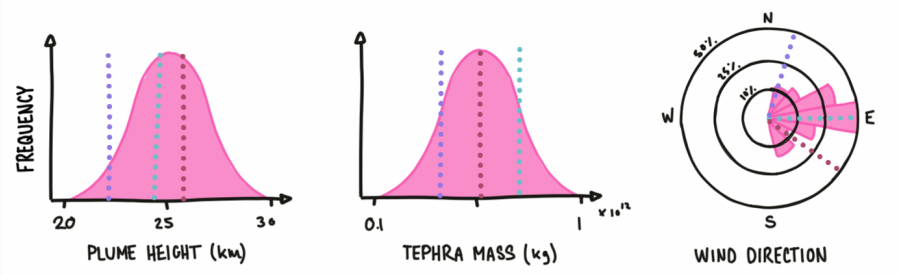


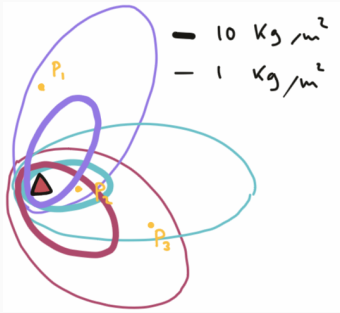
Probabilistic modeling



	P_1	P_2	P_3
M_{x_1,y_1}	0	15	7
M_{x_2,y_2}	0	12	5

Probabilistic modeling





	P_1	P_2	P_3
M_{x_1,y_1}	0	15	7
M_{x_2,y_2}	0	12	5
M_{x_3,y_3}	5	2	0
$P[M \geq 1\ kg/m^2]$	1/3	3/3	2/3
$P[M \geq 10\ kg/m^2]$	0/3	2/3	0/3

Pre–event exposure/impact/risk studies require:

✓ Ability to *predict* the hazard

✓ Ability to describe the *variability* of eruptive conditions

How to display hazard outputs?

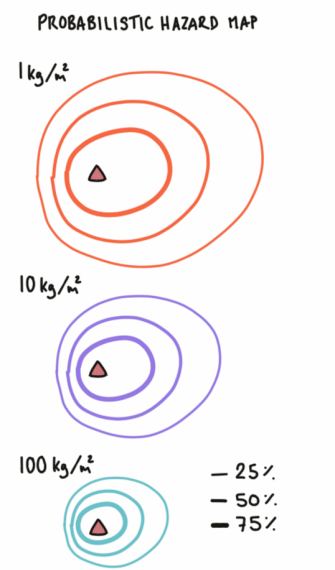
Probabilistic hazard visualisation

- For **lava flows**, there were 3 quantities to represent: easting (longitude), northing (latitude) and probability
- For **tephra fallout**, we have another quantity to represent: tephra accumulation
- There are **4** quantities → one too many to represent on a single map!

Method 1: Probability maps

Probabilistic hazard maps:

- Fixed threshold of tephra accumulation
- Other quantities are expressed continuously
- Display the spatial distribution of exceedence probabilities of a single threshold of tephra accumulation
- There are as many maps as accumulation thresholds



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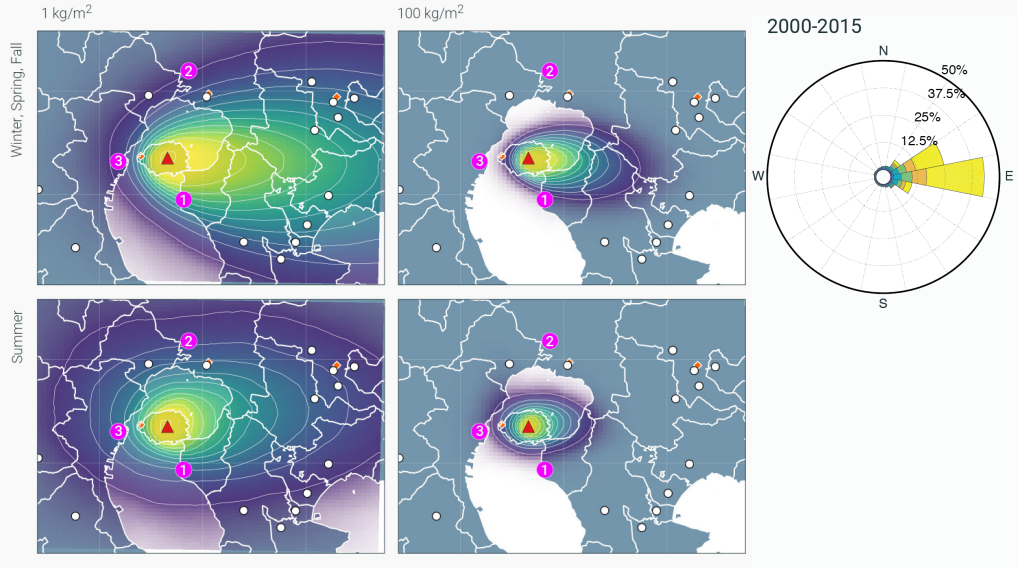
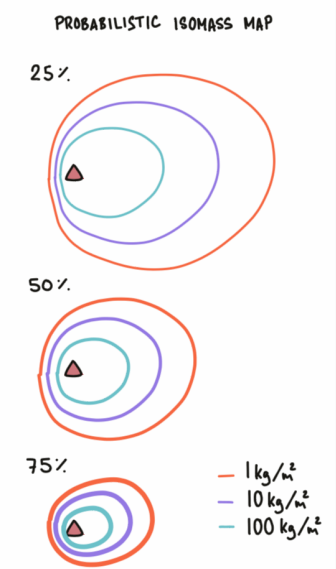


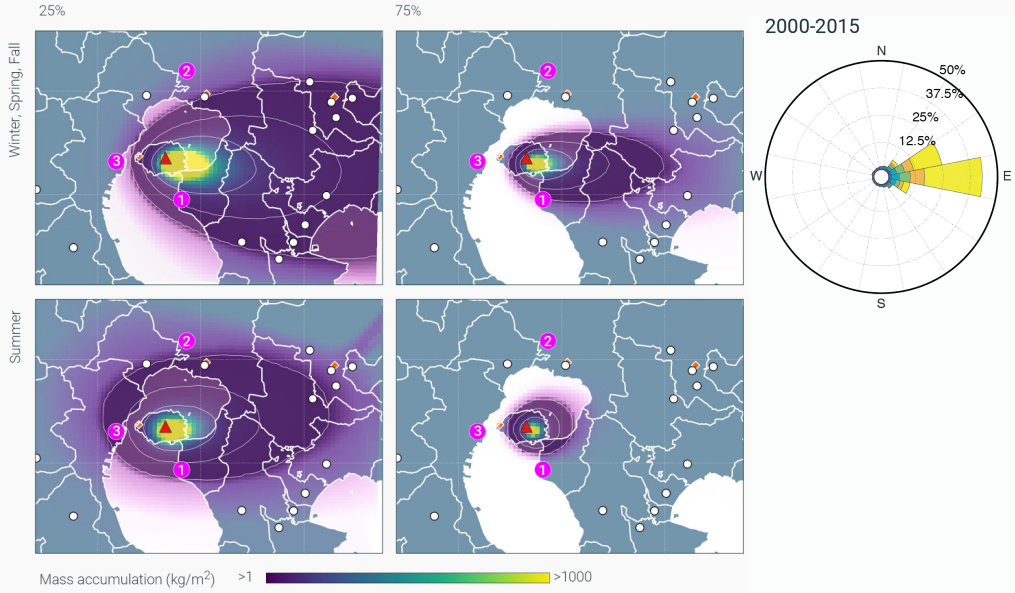
Method 2: Probabilistic isomass maps

Probabilistic isomass maps:

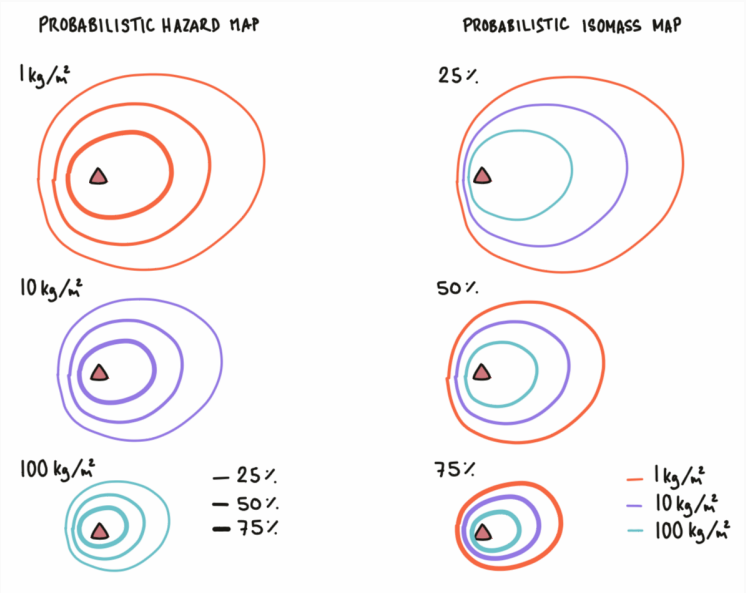
- Fixed threshold of exceedence probability
- Other quantities are expressed continuously
- Display the spatial distribution of exceedence probabilities for a single exceedence probability value
- There are as many maps as probability values



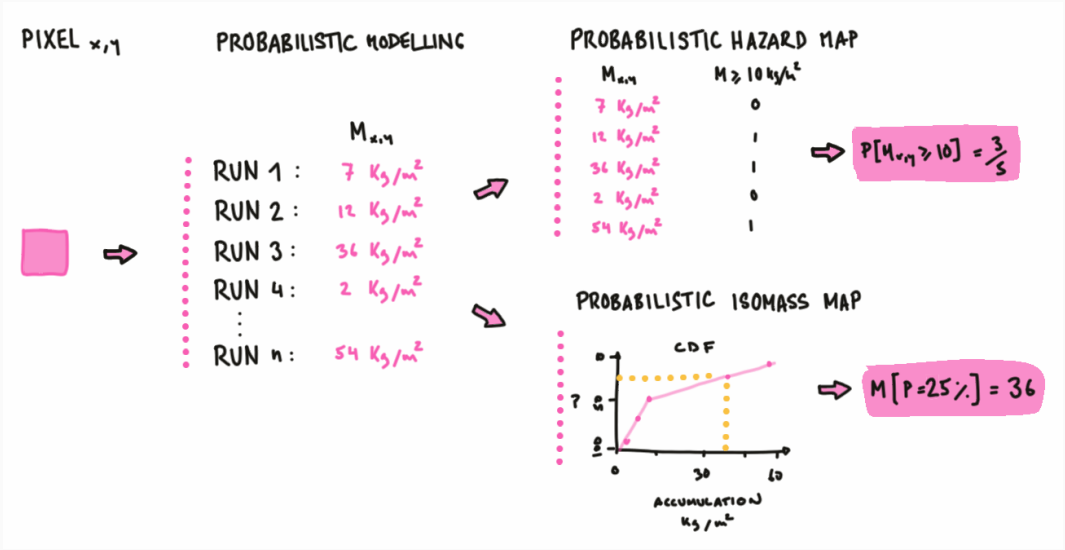
Method 2: Probabilistic isomass maps



Probability → isomass maps



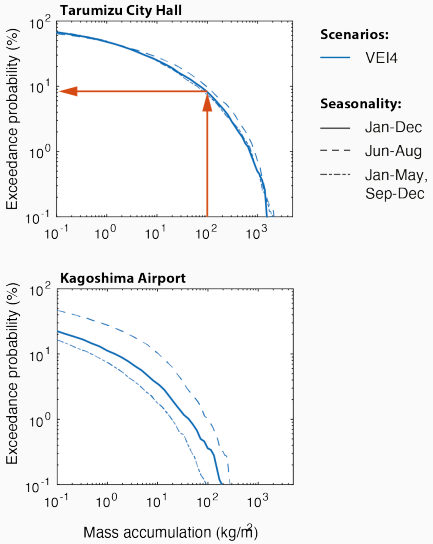
Probability → isomass maps



Method 3: Hazard curves

Hazard curves:

- Fixed latitude and longitude (→ one point)
- Other quantities are expressed continuously
- Display the probability of occurrence of a given tephra accumulation for a single location
- There are as many curves as points of interest



Exercise: Scenario–based probabilistic hazard assessment for tephra fallout for La Palma

Exercise

Objectives:

- Analyse the eruptive record
- Analyse wind patterns in a region
- Define an eruption scenario and ESPs
- Analyse hazard outputs

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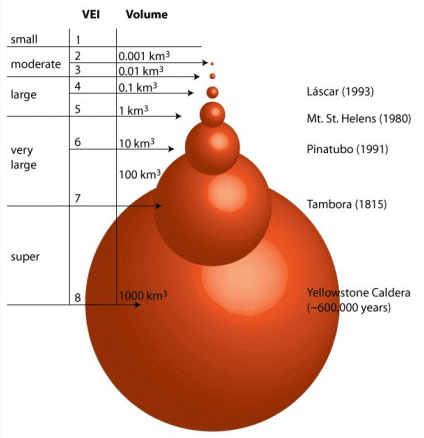
- Low-intensity VEI 3 eruption
- Similar volume, but long–lasting and less intense

Volcanic Explosivity Index (VEI)



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Admin:

- Produce hazard maps
- Answer question sheet