PyBetVH, a software tool to model Probabilistic Volcanic Hazard Assessment

Laura Sandri
Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Bologna

laura.sandri@ingv.it

Roberto Tonini
Istituto Nazionale di Geofisica e Vulcanologia, Osservatorio Nazionale Terremoti

roberto.tonini@ingv.it

The tool is presently available for download at https://gitlab.rm.ingv.it/roberto.tonini/pybetvh
More documentation available as Electronic Supplementary Material of Tonini et al (2015) CaGeo

Outline

What is probabilistic (volcanic) hazard? (*15 min*)

- definition & hazard curves
- aleatory and epistemic uncertainty
- long- and short-term
- Bayesian approach

BET model (*5 min*)
- event trees
- BET model

Explanation of the input and output files of PyBetVH (*30 min*)

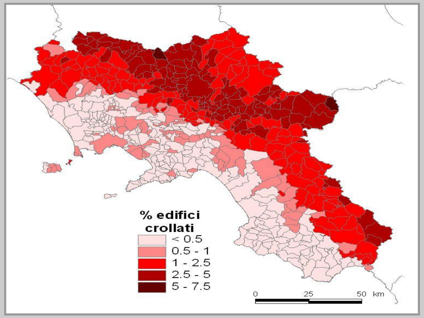
5-min break

Installation of PyBetVH on your devices (*20 min*)

An example (*45 min*)

main scientific input

Risk = Hazard * Exposure * Vulnerability



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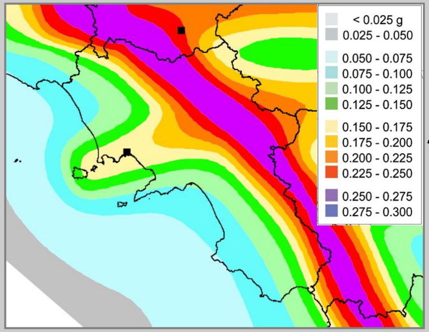

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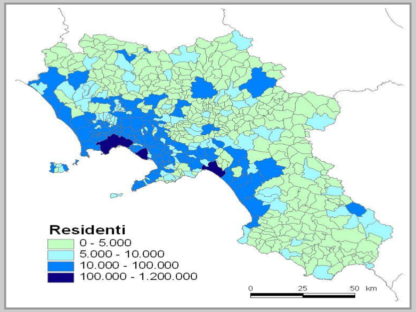
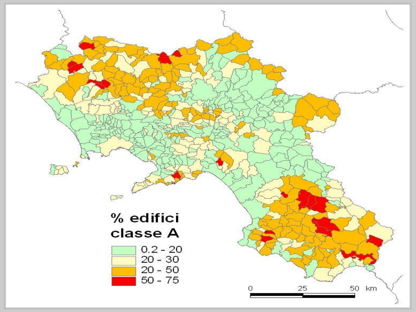


*



main scientific input

Risk = Hazard * Exposure * Vulnerability

Hazard:

probability of a given *hazardous phenomenon* to impact a given *point* above a given *intensity threshold* in a given *time window*

main scientific input

Risk = Hazard * Exposure * Vulnerability

Hazard:
probability of a given *hazardous phenomenon* to impact a given *point* above a given *intensity threshold* in a given *time window*

For example: probability of experiencing a tephra load larger than 300kg/m^2 in Napoli from an eruption in 100 years

main scientific input

Risk = Hazard * Exposure * Vulnerability

Hazard:

intensity of a given *hazardous phenomenon* impacting a given *point* with a given *exceedance probability* in a given *time window*

main scientific input

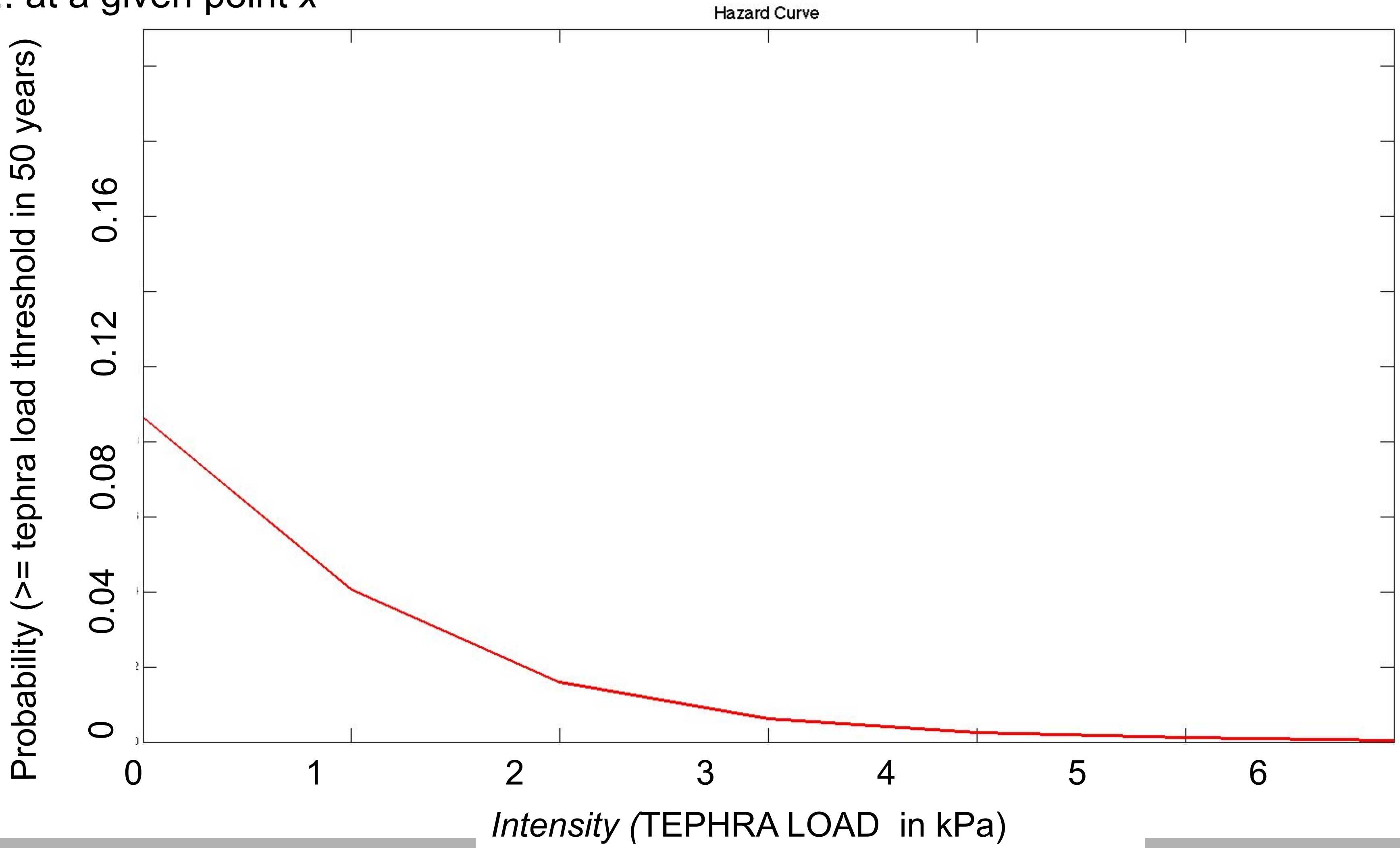
Risk = Hazard * Exposure * Vulnerability

Hazard:
intensity of a given *hazardous phenomenon* impacting a given *point* with a given *exceedance probability* in a given *time window*

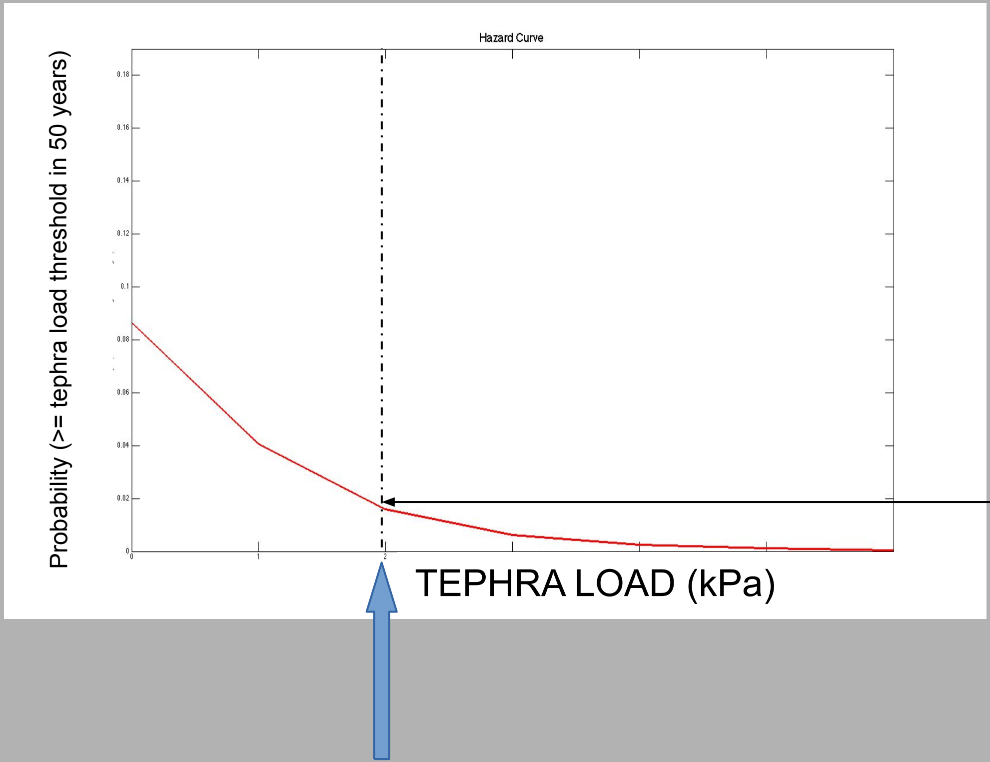
For example: intensity (in kg/m^2) of tephra ground load with an exceedance probability of 5% expected in Napoli from an eruption in 100 years

How to express hazard? The hazard curve

... at a given point $\vec{x}$



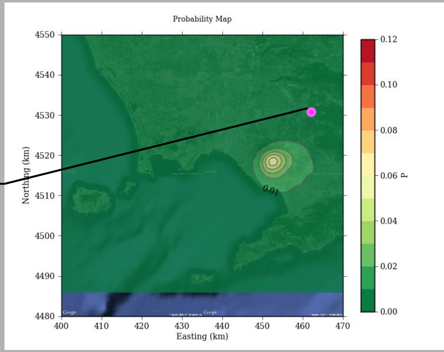
Hazard Curves include all the information on aleatory uncertainties. From Hazard Curves, one can derive Hazard Maps and Probability Maps



Intensity threshold

Probability map

probability **of a given *hazardous phenomenon* to impact a given *point* above a given *intensity threshold* in a given *time window***



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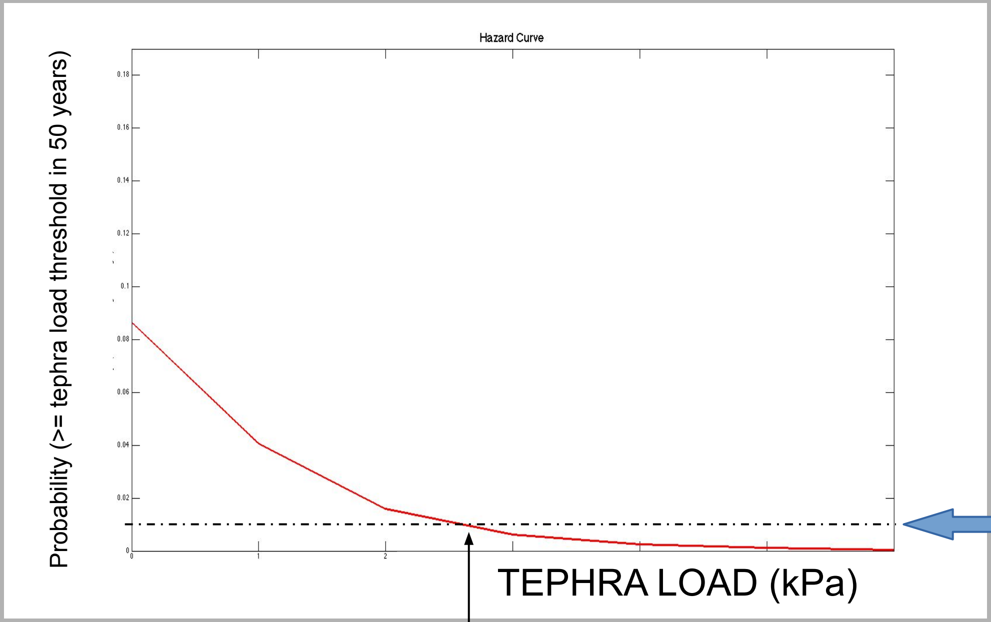
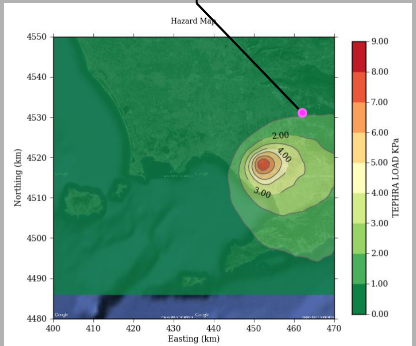


Exceedance probability threshold

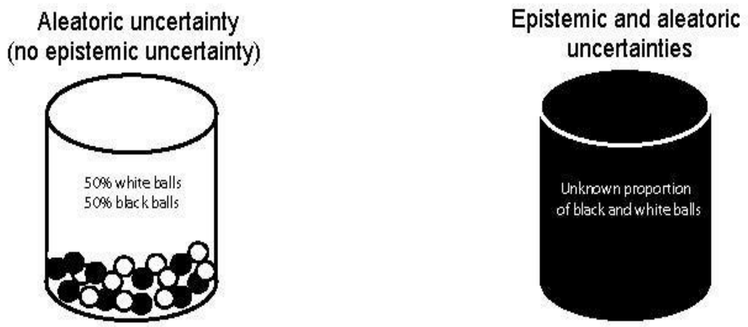
Hazard map:

intensity **of a given** ***hazardous phenomenon*** **impacting a given** ***point*** **with a given** ***exceedance probability*** **in a given** ***time window***



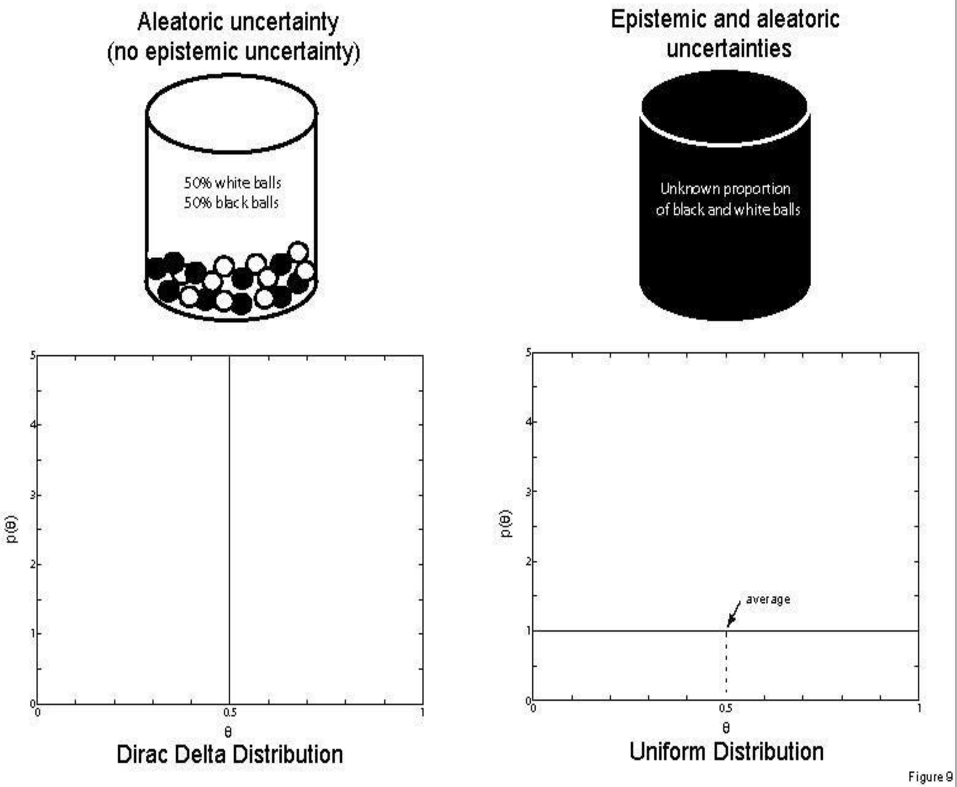
Bayesian inference – the importance of epistemic uncertainty

… about the ELLSBERG PARADOX

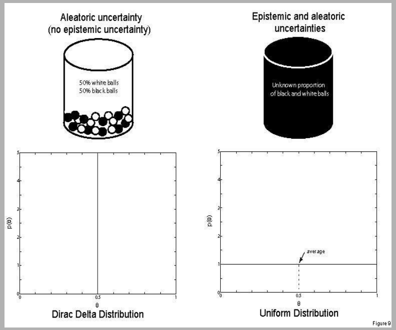


Bayesian inference – the importance of epistemic uncertainty

… about the ELLSBERG PARADOX

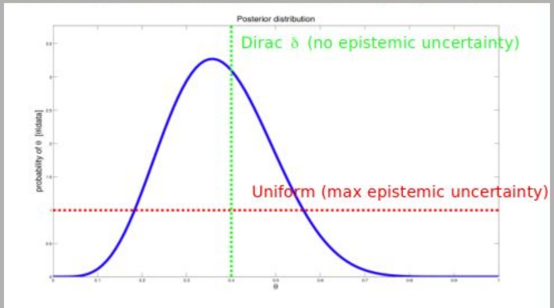


Bayesian approach



There is no “true” value

→ we define a probability density function (pdf) to describe every quantity



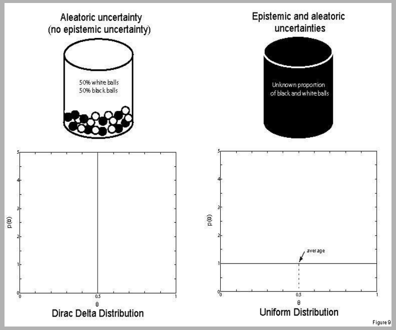
Bayesian approach

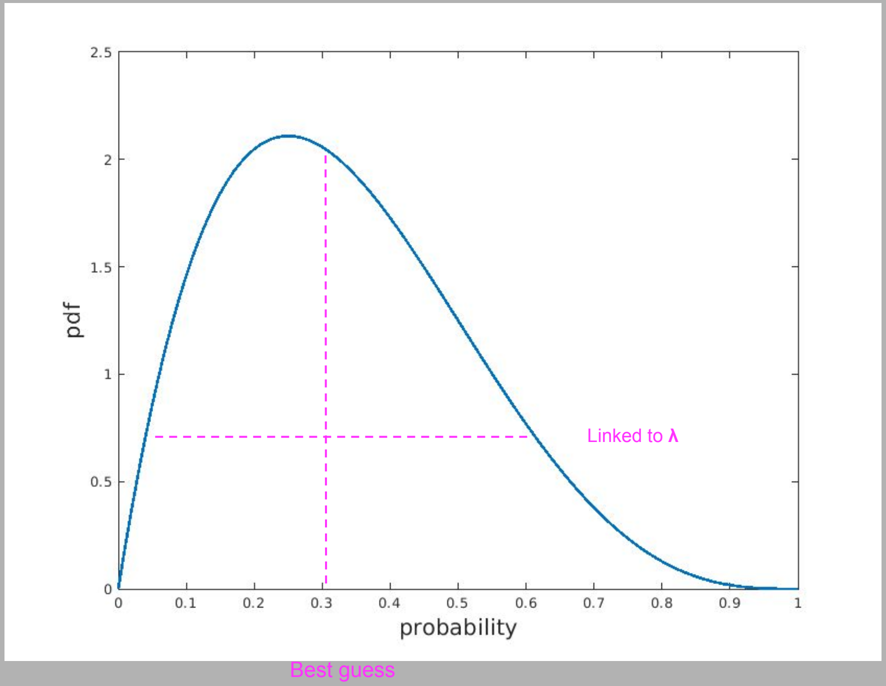
There is no “true” value

→ we define a probability density function (pdf) to describe every quantity

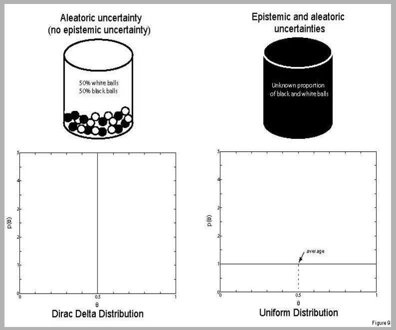
For the ***pdf of a probability***→ Beta distribution:

1) Parameterized by a **best guess *θ*** value and an equivalent number of data ***λ***
2) Suitable for a probability → defined on [0,1]
3) Conjugate of the Binomial function (Bernoulli trial scheme) describing the likelihood to observe *k* successes out of *n* trials





Bayesian approach



There is no “true” probability value

→ we define a probability density function (pdf) to describe every quantity

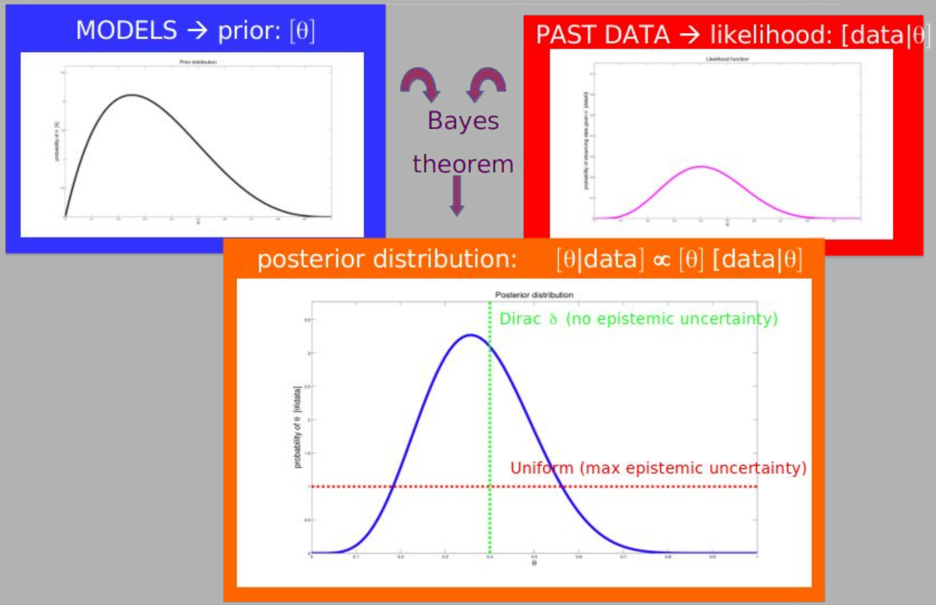
The pdf is estimated by considering heterogeneous pieces of information

$$[\theta \mid \mathtt{data}] = [\theta]\,[\mathtt{data} \mid \theta]$$

posterior pdf

prior pdf (based on theory or models)

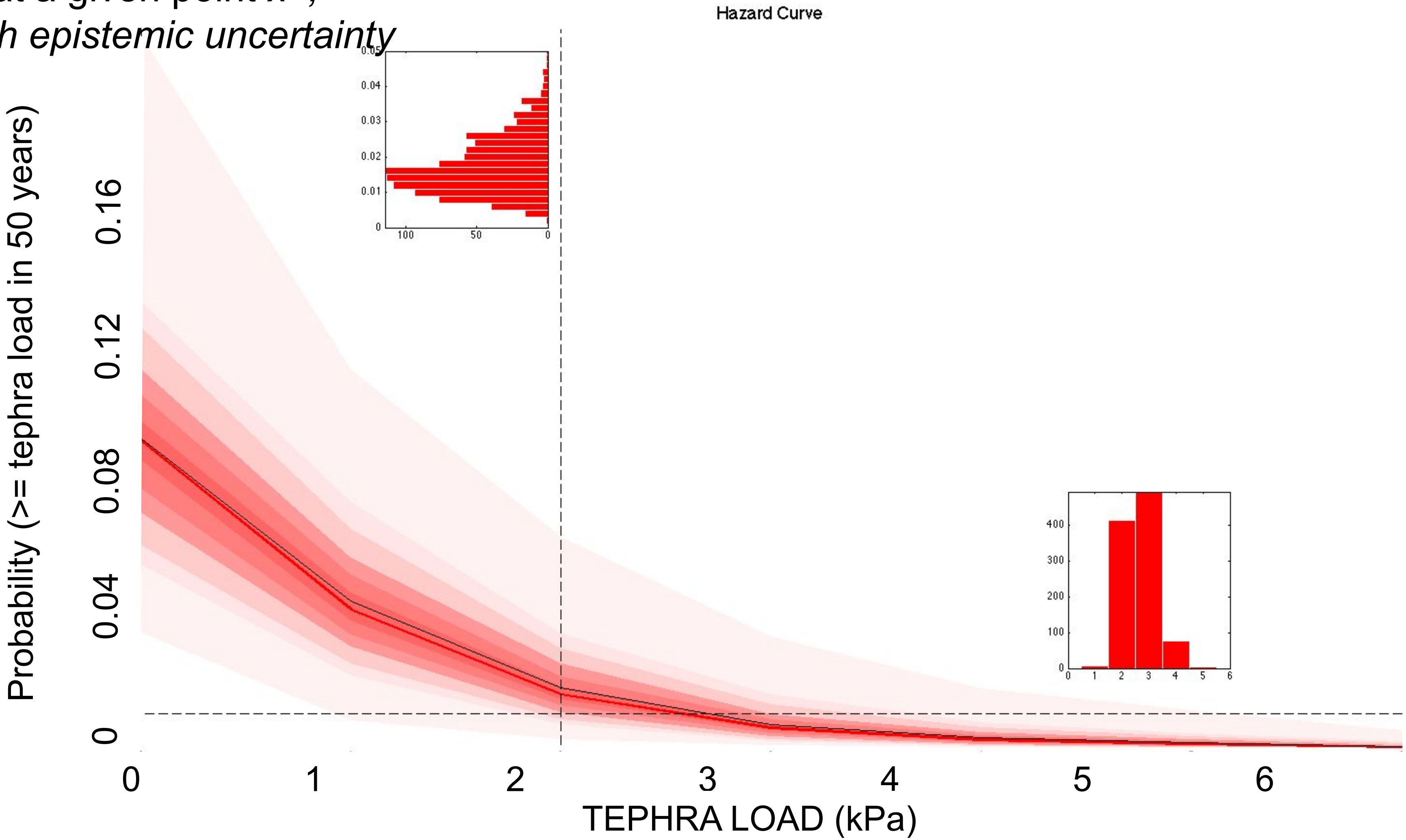
likelihood (based on past data)



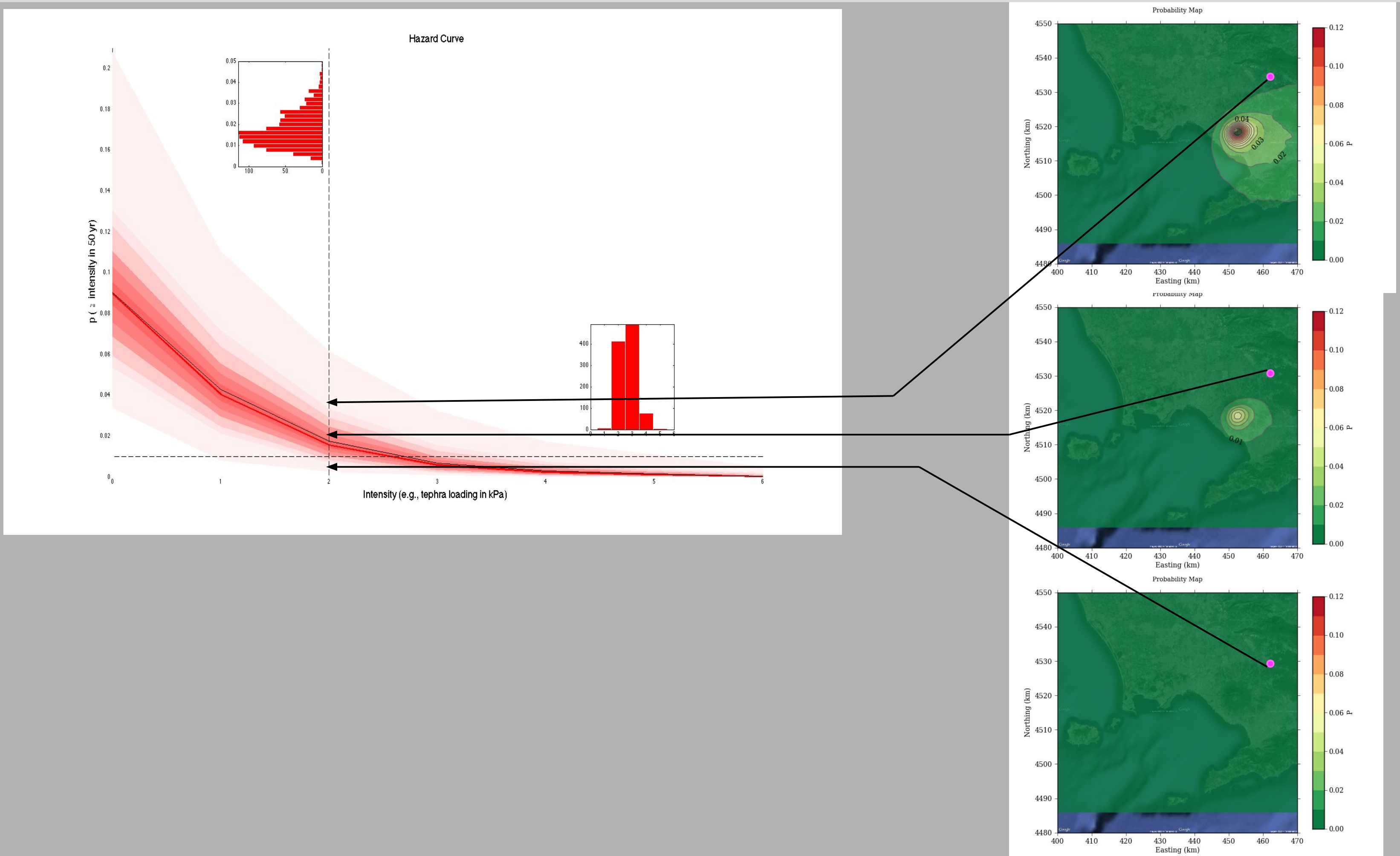
The conjugacy of the Beta with the Binomial simplifies the application of the Bayes theorem (update of $\boldsymbol{\theta}$ and $\boldsymbol{\lambda}$ by k and n)

... at a given point $\vec{x}$,

with epistemic uncertainty

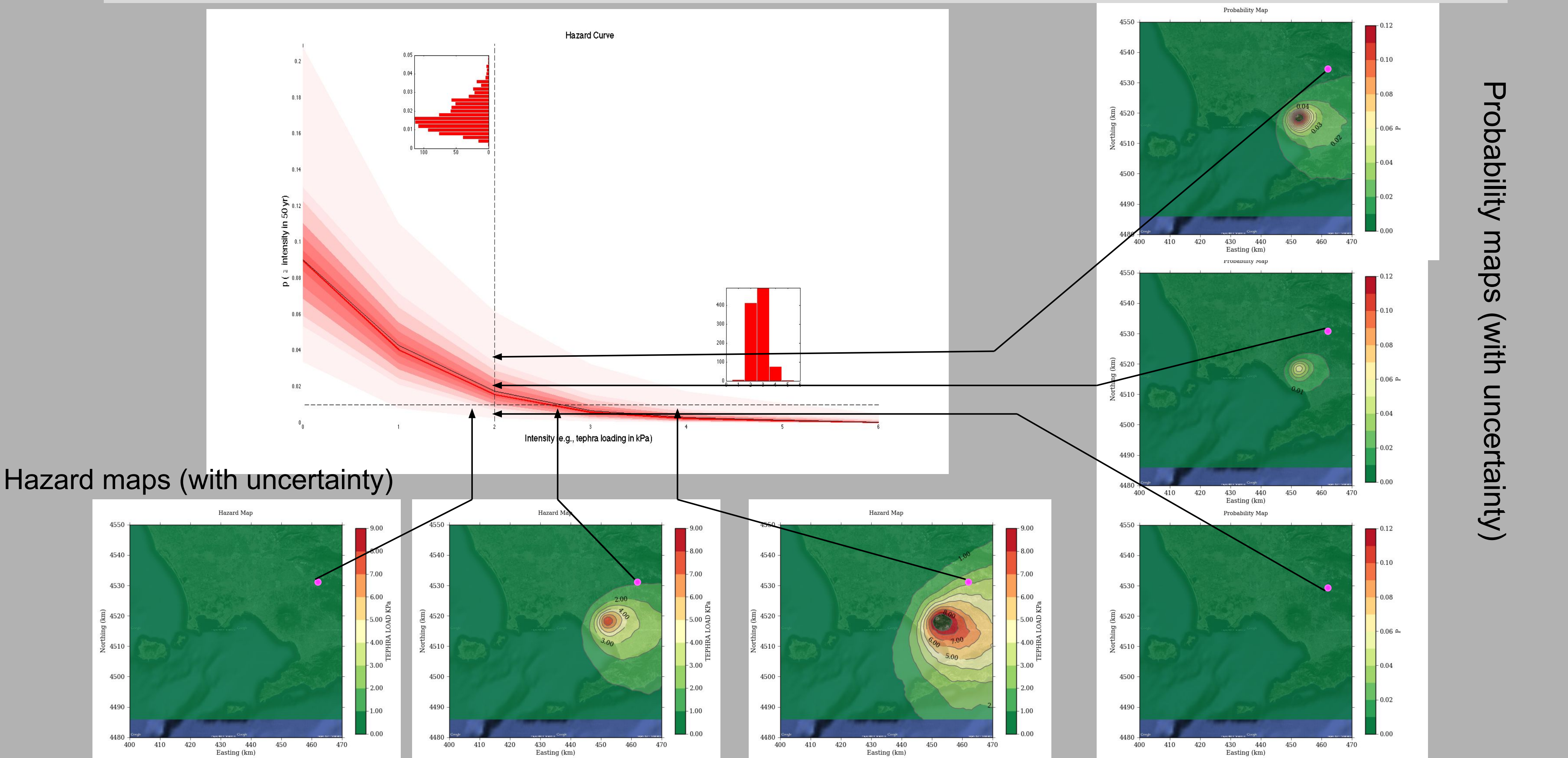


Bayesian Hazard Curves represent the most complete output from hazard analysis as they include all the information on aleatory and epistemic uncertainties. From Bayesian Hazard Curves, one can derive Bayesian Hazard Maps and Probability Maps:



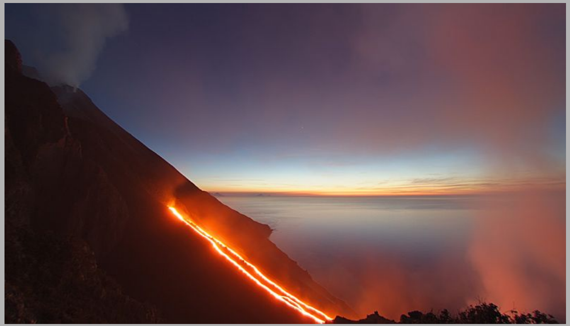
Probability maps (with uncertainty)

Bayesian Hazard Curves represent the most complete output from hazard analysis as they include all the information on aleatory and epistemic uncertainties. From Bayesian Hazard Curves, one can derive Bayesian Hazard Maps and Probability Maps:

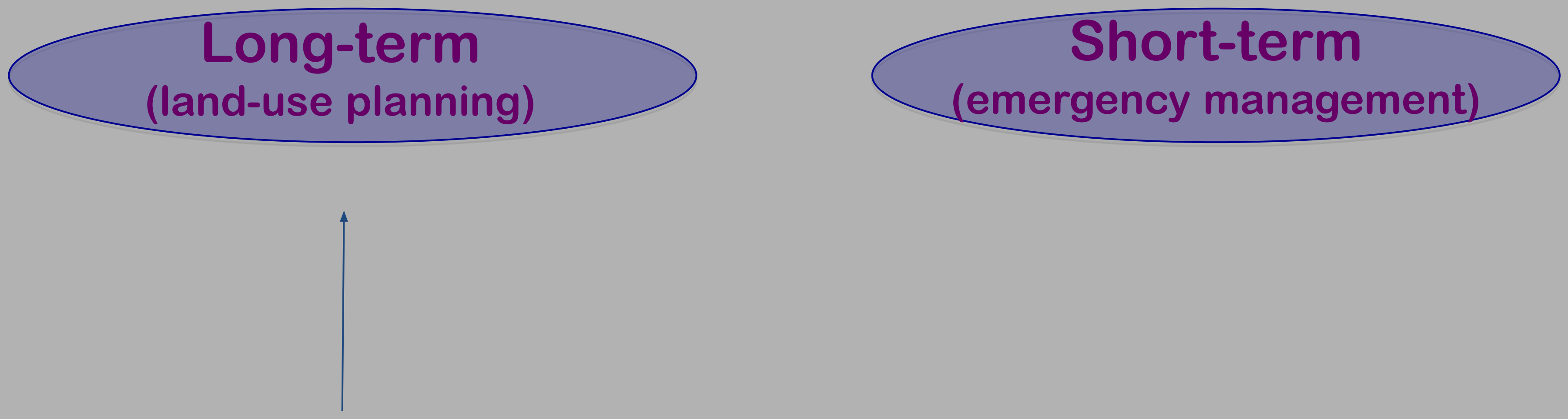


Volcanic Hazard Assessment

Multiple hazards

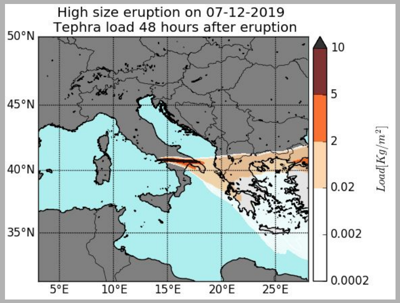


Volcanic Hazard Assessment

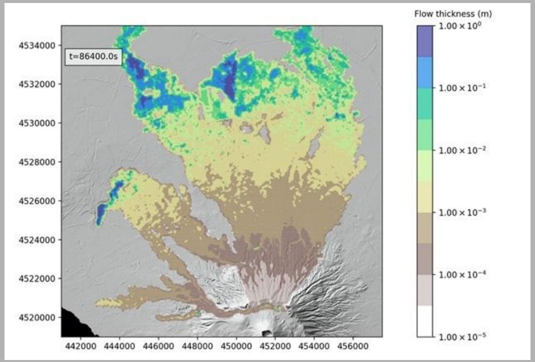


Volcanic Hazard Assessment

Long-term
(land-use planning)



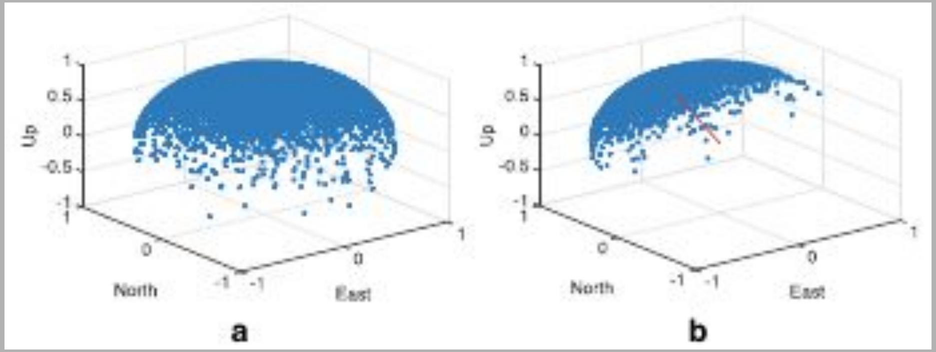
Martinez et al, 2022



De' Michieli-Vitturi et al, 2024

Data used for long-term hazard assessment:

- Model output (many different runs with different initial and boundary conditions, and eruption size/type and vent location) → computing capacity



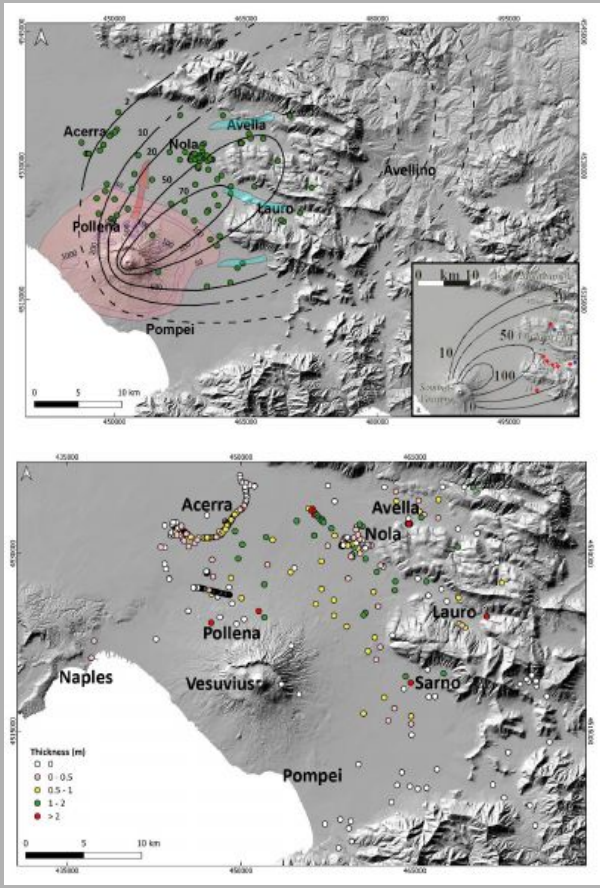
Strehlow et al, 2015

Volcanic Hazard Assessment

Long-term
(land-use planning)

Data used for long-term hazard assessment:

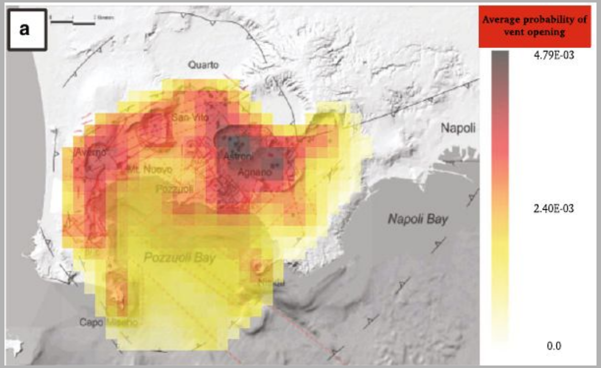
- Model output (many different runs with different initial and boundary conditions, and eruption size/type and vent location) → computing capacity
- “Past data”



Di Vito et al, 2024

Volcanic Hazard Assessment

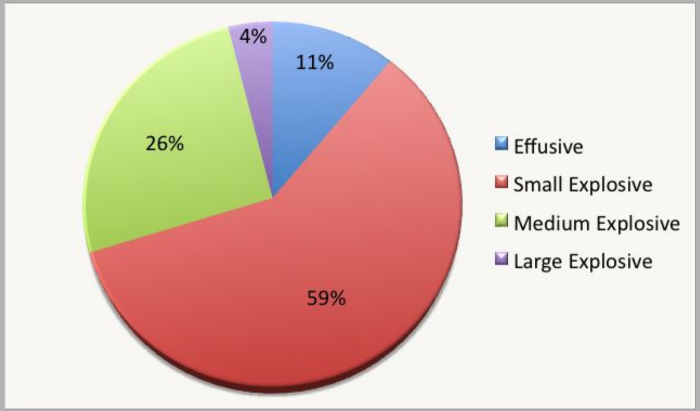
Long-term
(land-use planning)



Selva et al, 2010

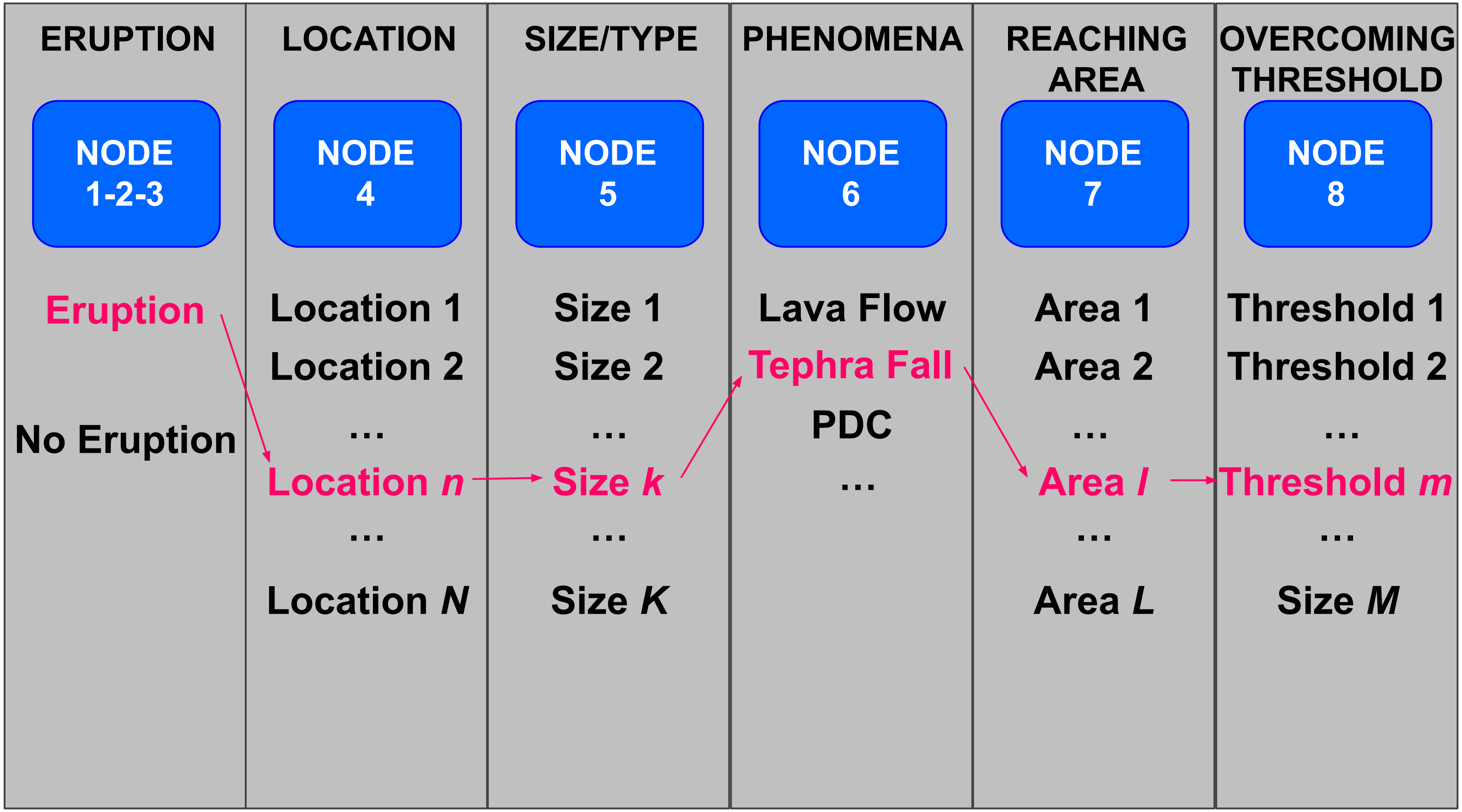
Data used for long-term hazard assessment:

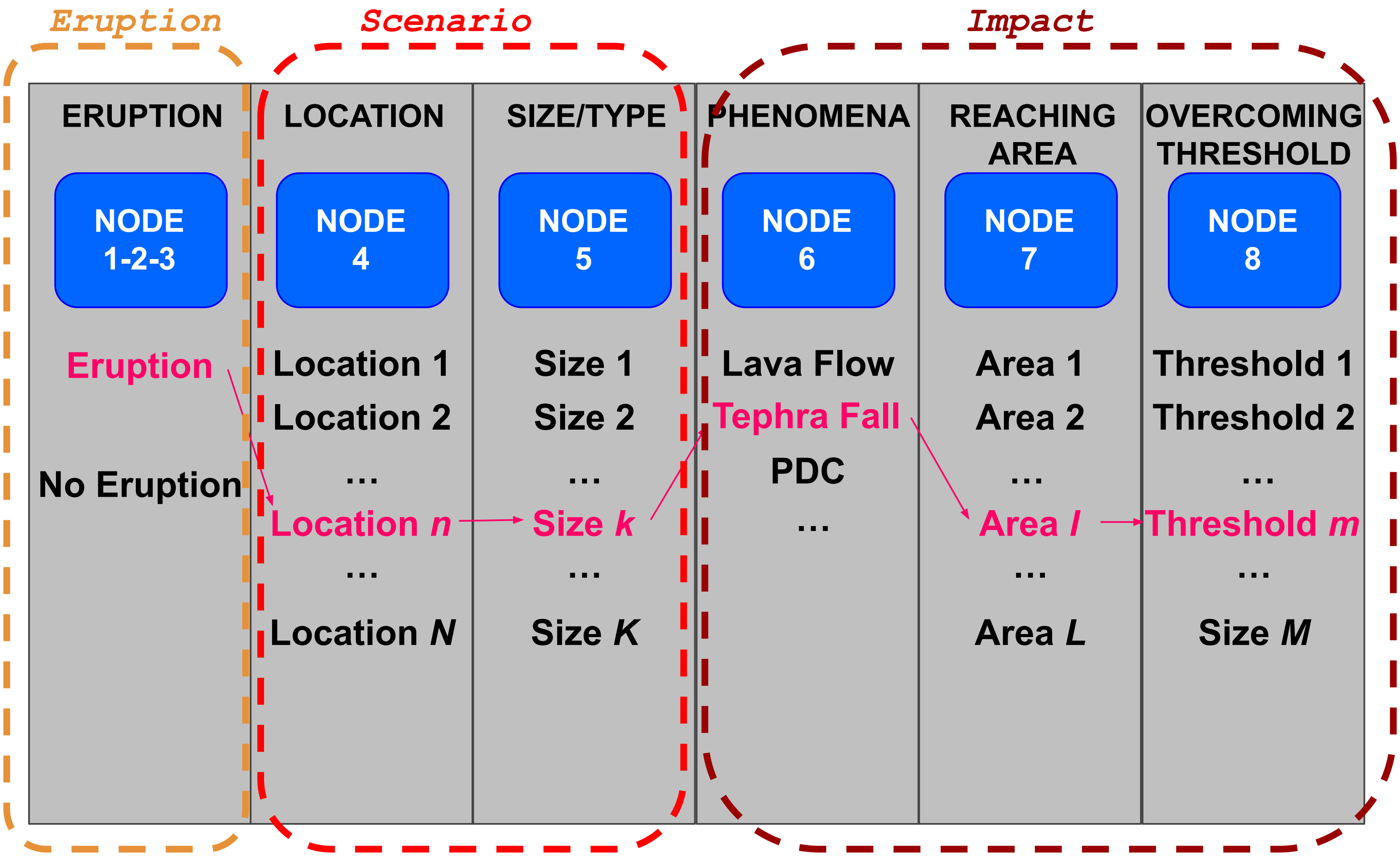
- Model output (many different runs with different initial and boundary conditions, and eruption size/type and vent location) → computing capacity
- "Past data"
- we must account for the whole natural variability of the phenomenon, and properly combine ALL POSSIBLE ERUPTIVE SCENARIOS



Selva et al, 2012

Event Tree


ERUPTION
NODE 1-2-3
Eruption
No Eruption
LOCATION
NODE 4
Location 1
Location 2
…
Location n
…
Location N
SIZE/TYPE
NODE 5
Size 1
Size 2
…
Size k
…
Size K
PHENOMENA
NODE 6
Lava Flow
Tephra Fall
PDC
…
REACHING AREA
NODE 7
Area 1
Area 2
…
Area l
…
Area L
OVERCOMING THRESHOLD
NODE 8
Threshold 1
Threshold 2
…
Threshold m
…
Size M


Eruption
Scenario
Impact
ERUPTION
NODE 1-2-3
Eruption
No Eruption
LOCATION
NODE 4
Location 1
Location 2
…
Location n
…
Location N
SIZE/TYPE
NODE 5
Size 1
Size 2
…
Size k
…
Size K
PHENOMENA
NODE 6
Lava Flow
Tephra Fall
PDC
…
REACHING AREA
NODE 7
Area 1
Area 2
…
Area l
…
Area L
OVERCOMING THRESHOLD
NODE 8
Threshold 1
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…
Threshold m
…
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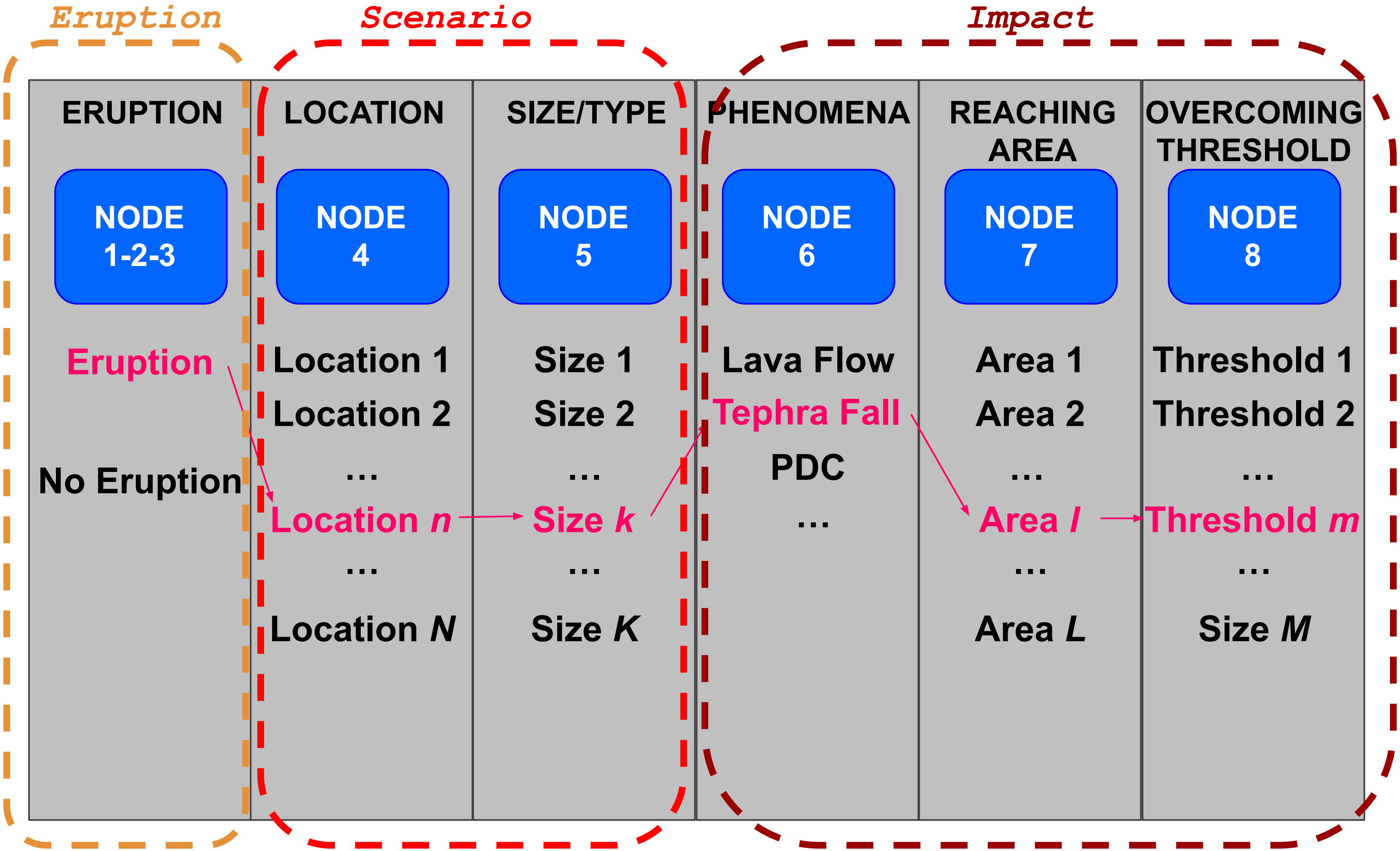
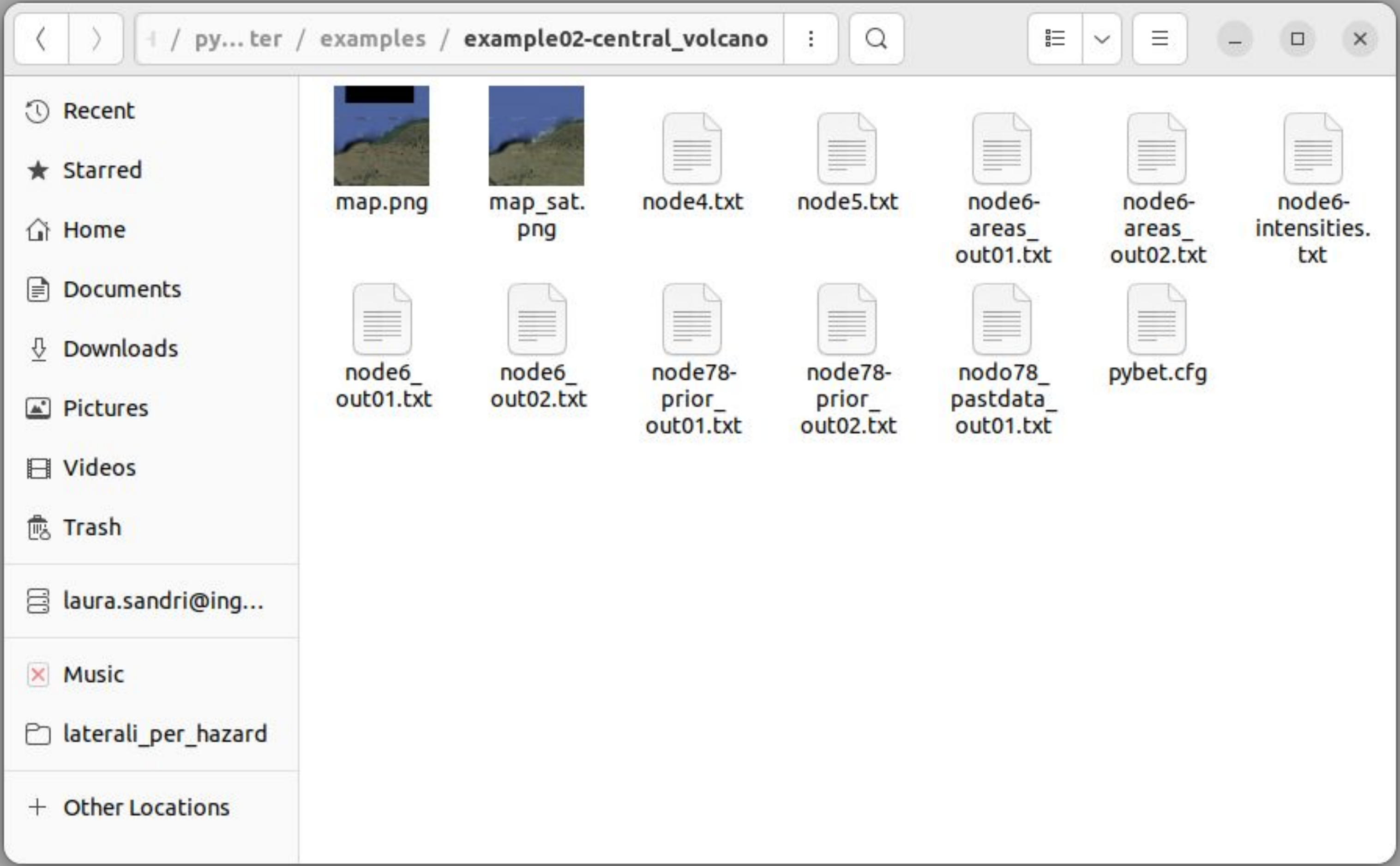


$$P^{(\Delta T)}(\geq \mathtt{impact}) = P^{(\Delta T)}(\mathtt{eruption}) * \sum_{i,j}[P(\mathtt{scenario}_{i,j} | \mathtt{eruption}) * P^{(\mathtt{area}\ l)}(\mathtt{impact} | \mathtt{scenario}_{i,j})]$$

Input files to PyBetVH

This is a folder you have in the examples provided with the code (EXAMPLE 2)



Input files to PyBetVH

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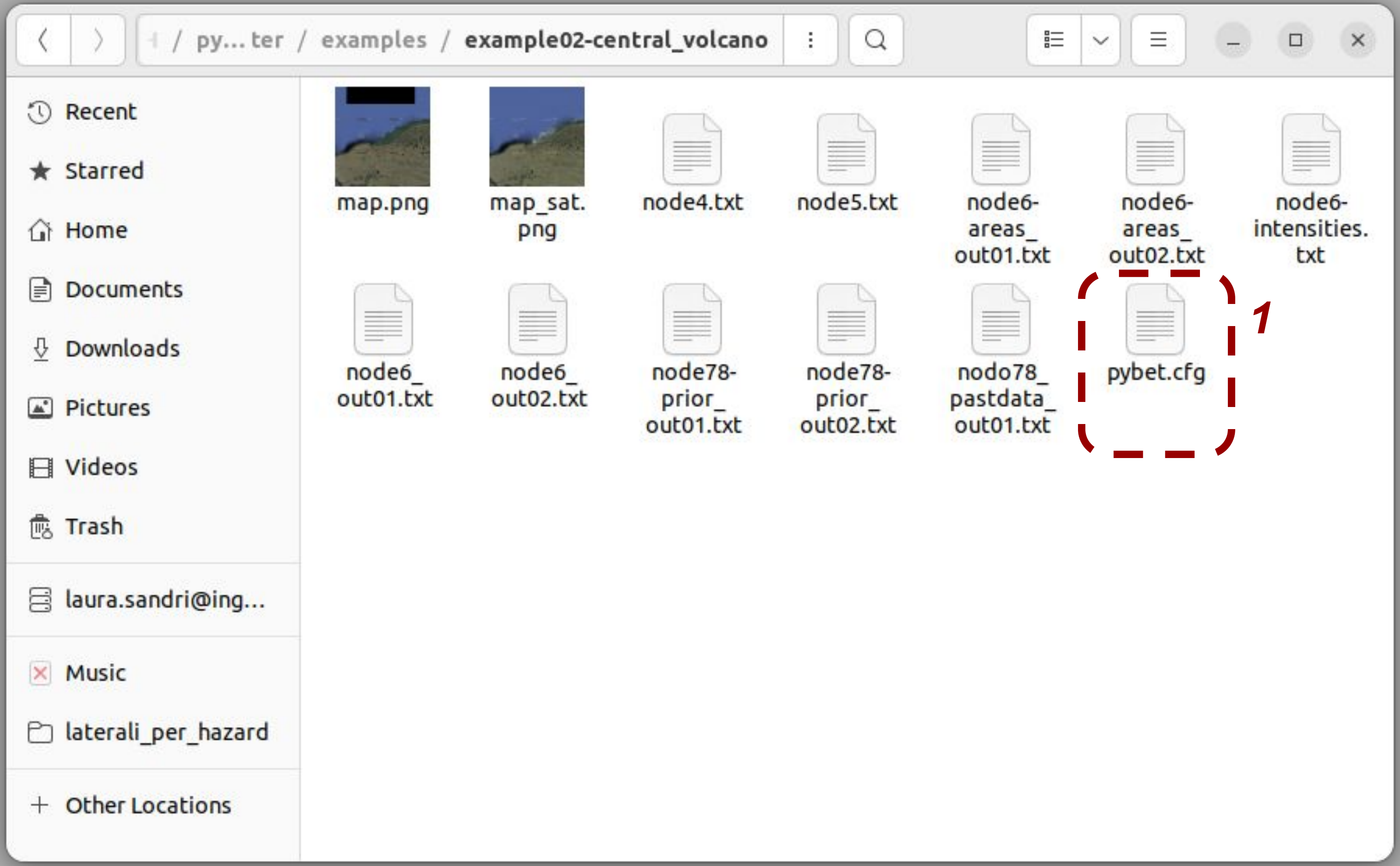


Input files to PyBetVH

FILE pybet.cfg

It has:

- FIXED name (do not change it)

```
[Main Settings]
volcano name = Example 2 Central Volcano
volcano center = 242856, 8196254
shape = Cone
utm zone = 51N
geometry = 500, 2100, 22
time window = 1
sampling = 500
background map = map_sat.png
map limits (m UTM) = 202714.3, 272714.3, 8162857.1, 8217857.1

[Node 1]
prior probability = 1.0
equivalent n. data (lambda) = 1
past data (successes) = 0
past data (total) = 0

[Node 2]
prior probability = 1.0
equivalent n. data (lambda) = 1
past data (successes) = 0
past data (total) = 0

[Node 3]
prior probability = 0.015
equivalent n. data (lambda) = 1
past data (successes) = 14
past data (total) = 110

[Node 4]
file name = node4.txt
equivalent n. data (lambda) = 1

[Node 5]
node 4-5 dependence = False
n. sizes = 3
file name = node5.txt

[Node 6]
n. outcomes = 2
outcomes = Tephra Dispersal, Ballistic Impact
units = kg/m2, no-unit
n. areas = 180, 960
file name = node6
file intensities = node6-intensities.txt
file points-areas = node6-areas

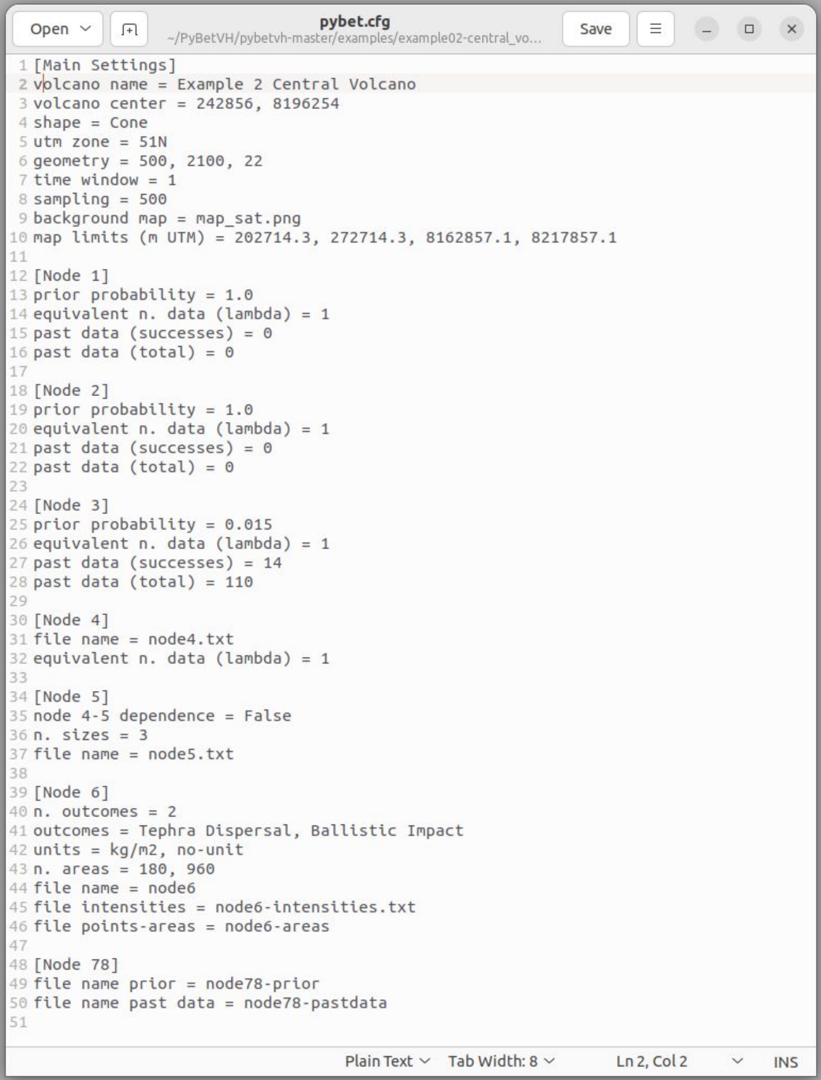
[Node 78]
file name prior = node78-prior
file name past data = node78-pastdata
```

Input files to PyBetVH

FILE pybet.cfg

It has:

- FIXED name (do not change it)
- FIXED structure in BLOCKS delimited by [...]

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[Main Settings]
volcano name = Example 2 Central Volcano
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shape = Cone
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[Node 78]
file name prior = node78-prior
file name past data = node78-pastdata
```

Input files to PyBetVH

FILE pybet.cfg

It has:

- FIXED name (do not change it)
- FIXED structure in BLOCKS delimited by [...]
- Each block refers to a node in the event tree

pybet.cfg
~/PyBetVH/pybetvh-master/examples/example02-central_vo...

```
[Main Settings]
volcano name = Example 2 Central Volcano
volcano center = 242856, 8196254
shape = Cone
utm zone = 51N
geometry = 500, 2100, 22
time window = 1
sampling = 500
background map = map_sat.png
map limits (m UTM) = 202714.3, 272714.3, 8162857.1, 8217857.1

[Node 1]
prior probability = 1.0
equivalent n. data (lambda) = 1
past data (successes) = 0
past data (total) = 0

[Node 2]
prior probability = 1.0
equivalent n. data (lambda) = 1
past data (successes) = 0
past data (total) = 0

[Node 3]
prior probability = 0.015
equivalent n. data (lambda) = 1
past data (successes) = 14
past data (total) = 110

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outcomes = Tephra Dispersal, Ballistic Impact
units = kg/m2, no-unit
n. areas = 180, 960
file name = node6
file intensities = node6-intensities.txt
file points-areas = node6-areas

[Node 78]
file name prior = node78-prior
file name past data = node78-pastdata
```

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Input files to PyBetVH

FILE pybet.cfg

```
[Main Settings]
volcano name = Example 2 Central Volcano
volcano center = 242856, 8196254
shape = Cone
utm zone = 51N
geometry = 500, 2100, 22
time window = 1
sampling = 500
background map = map_sat.png
map limits (m UTM) = 202714.3, 272714.3, 8162857.1, 8217857.1
```

1st Block: [Main settings]
It defines the volcano (name, coordinates, geometry), the background map and its limits

ALL COORDINATES MUST BE IN THE SAME UNITS (UTM meters (m))

Input files to PyBetVH

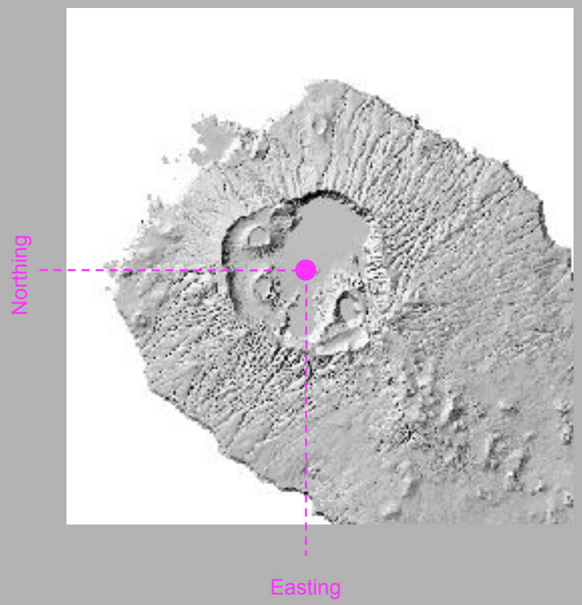
FILE pybet.cfg

```
[Main Settings]
volcano name = Example 2 Central Volcano
volcano center = 242856, 8196254
shape = cone
utm zone = 51N
geometry = 500, 2100, 22
time window = 1
sampling = 500
background map = map_sat.png
map limits (m UTM) = 202714.3, 272714.3, 8162857.1, 8217857.1
```

1st Block: [Main settings]
It defines the volcano (name, coordinates, geometry), the background map and its limits

ALL COORDINATES MUST BE IN THE SAME UNITS (here it is meters (m))

`volcano name =` …
`volcano center` = **Easting, Northing** (same units)



Input files to PyBetVH

FILE pybet.cfg

```
[Main Settings]
volcano name = Example 2 Central Volcano
volcano center = 242856, 8196254
shape = Cone
utm zone = 51N
geometry = 500, 2100, 22
time window = 1
sampling = 500
background map = map_sat.png
map limits (m UTM) = 202714.3, 272714.3, 8162857.1, 8217857.1
```

```
[Main Settings]
volcano name = Example 1 Volcanic Field
volcano center = 455906, 5774512
shape = Field
geometry = 48000, 44000, 5, 5, 20
utm zone = 21S
time window = 1
sampling = 500
background map = map_sat.png
map limits (m UTM) = 394906.0, 594906.0, 5694512.0, 5894512.0
```

1st Block: [Main settings]
It defines the volcano (name, coordinates, geometry), the background map and its limits

ALL COORDINATES MUST BE IN THE SAME UNITS (here it is meters (m))

`volcano name` = …
`volcano center` = **Easting, Northing** (same units)
`shape` = Cone or Field

Input files to PyBetVH

FILE pybet.cfg

```
[Main Settings]
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volcano center = 242856, 8196254
shape = Cone
utm zone = 51N
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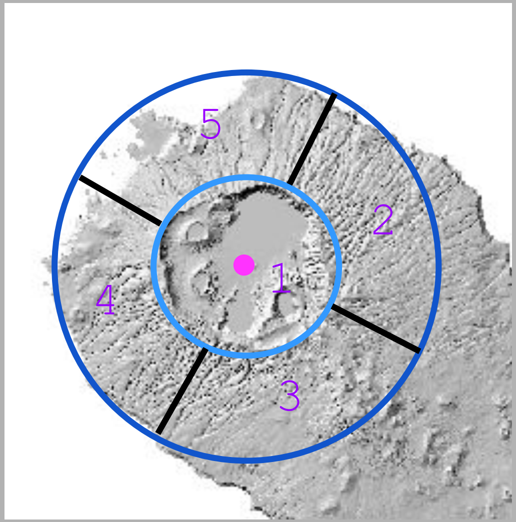
```

1st Block: [Main settings]
It defines the volcano (name, coordinates, geometry), the background map and its limits

ALL COORDINATES MUST BE IN THE SAME UNITS (here it is meters (m))

`volcano name` = …
`volcano center` = **Easting, Northing** (same units)
`shape` = Cone or Field
`geometry` = If Cone 3 numbers



Input files to PyBetVH

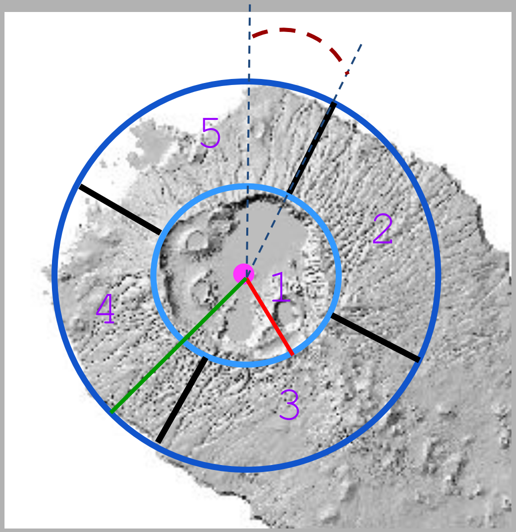
FILE pybet.cfg

```
[Main Settings]
volcano name = Example 2 Central Volcano
volcano center = 242856, 8196254
shape = Cone
utm zone = 51N
geometry = 500, 2100, 22
time window = 1
sampling = 500
background map = map_sat.png
map limits (m UTM) = 202714.3, 272714.3, 8162857.1, 8217857.1
```

1st Block: [Main settings]
It defines the volcano (name, coordinates, geometry), the background map and its limits

ALL COORDINATES MUST BE IN THE SAME UNITS (here it is meters (m))

`volcano name = …`
`volcano center` = **Easting, Northing** (same units)
`shape` = Cone or Field
`geometry` = If Cone 3 numbers: radius for the crater area, radius for the volcano edifice, degrees from North for the first lateral sector



Input files to PyBetVH

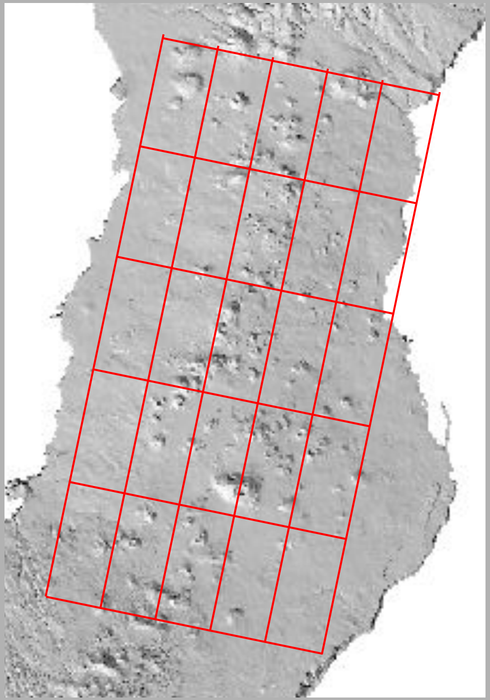
FILE pybet.cfg

```
[Main Settings]
volcano name = Example 1 Volcanic Field
volcano center = 455906, 5774512
shape = Field
geometry = 48000, 44000, 5, 5, 20
utm zone = 21S
time window = 1
sampling = 500
background map = map_sat.png
map limits (m UTM) = 394906.0, 594906.0, 5694512.0, 5894512.0
```

1st Block: [Main settings]
It defines the volcano (name, coordinates, geometry), the background map and its limits

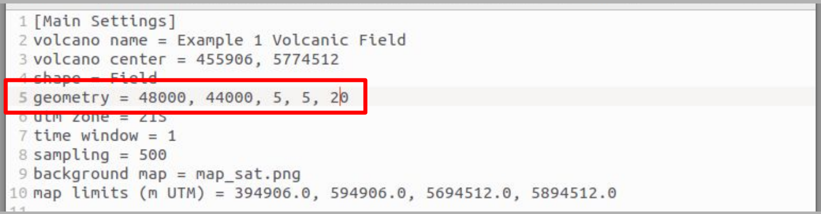
ALL COORDINATES MUST BE IN THE SAME UNITS (here it is meters (m))

`volcano name` = …
`volcano center` = **Easting, Northing** (same units)
`shape` = Cone or Field:
`geometry` = If Field 5 numbers:



Input files to PyBetVH

FILE pybet.cfg

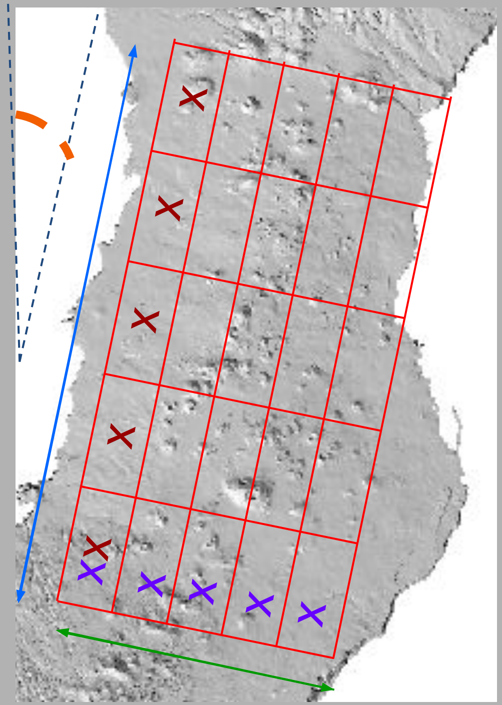


```
[Main Settings]
volcano name = Example 1 Volcanic Field
volcano center = 455906, 5774512
shape = Field
geometry = 48000, 44000, 5, 5, 20
utm zone = 21S
time window = 1
sampling = 500
background map = map_sat.png
map limits (m UTM) = 394906.0, 594906.0, 5694512.0, 5894512.0
```

1st Block: [Main settings]
It defines the volcano (name, coordinates, geometry), the background map and its limits

ALL COORDINATES MUST BE IN THE SAME UNITS (here it is meters (m))

`volcano name` = …
`volcano center` = **Easting, Northing** (same units)
`shape` = Cone or Field:
`geometry` = If Field 5 numbers: distance along Easting, distance along Northing, number of cells along Easting, number of cells along Northing, degrees from North for direction



Input files to PyBetVH

FILE pybet.cfg

```
[Main Settings]
volcano name = Example 1 Volcanic Field
volcano center = 455906, 5774512
shape = Field
geometry = 48000, 44000, 5, 5, 20
utm zone = 21S
time window = 1
sampling = 500
background map = map_sat.png
map limits (m UTM) = 394906.0, 594906.0, 5694512.0, 5894512.0
```

1st Block: [Main settings]
It defines the volcano (name, coordinates, geometry), the background map and its limits

ALL COORDINATES MUST BE IN THE SAME UNITS (here it is meters (m))

`volcano name = …`
`volcano center` = **Easting, Northing** (same units)
`shape` = Cone or Field
`utmzone` = *self explaining*

Input files to PyBetVH

FILE pybet.cfg

```
[Main Settings]
volcano name = Example 1 Volcanic Field
volcano center = 455906, 5774512
shape = Field
geometry = 48000, 44000, 5, 5, 20
utm zone = 21S
time window = 1
sampling = 500
background map = map_sat.png
map limits (m UTM) = 394906.0, 594906.0, 5694512.0, 5894512.0
```

1st Block: [Main settings]
It defines the volcano (name, coordinates, geometry), the background map and its limits

ALL COORDINATES MUST BE IN THE SAME UNITS (here it is meters (m))

`volcano name` = …
`volcano center` = **Easting, Northing** (same units)
`shape` = Cone or Field
`utmzone` = *self explaining*
`time window` = number in the unit that will be used also in Node 1 to define the probability of unrest IN THIS TIME WINDOW (e.g., 1 month, 30 days, 10 years)

Input files to PyBetVH

FILE pybet.cfg

```
[Main Settings]
volcano name = Example 1 Volcanic Field
volcano center = 455906, 5774512
shape = Field
geometry = 48000, 44000, 5, 5, 20
utm zone = 21S
time window = 1
sampling = 500
background map = Map_sat.png
map limits (m UTM) = 394906.0, 594906.0, 5694512.0, 5894512.0
```

1st Block: [Main settings]
It defines the volcano (name, coordinates, geometry), the background map and its limits

ALL COORDINATES MUST BE IN THE SAME UNITS (here it is meters (m))

`volcano name` = …
`volcano center` = **Easting, Northing** (same units)
`shape` = Cone or Field
`utmzone` = *self explaining*
`time window` = number
`sampling` = number of samples to describe the pdf at each node (the larger the more defined the pdf, but also the slower the code)

Input files to PyBetVH

FILE pybet.cfg

```
[Main Settings]
volcano name = Example 1 Volcanic Field
volcano center = 455906, 5774512
shape = Field
geometry = 48000, 44000, 5, 5, 20
utm zone = 21S
time window = 1
sampling = 500
background map = map_sat.png
Map limits (m UTM) = 394906.0, 594906.0, 5694512.0, 5894512.0
```

1st Block: [Main settings]
It defines the volcano (name, coordinates, geometry), the background map and its limits

ALL COORDINATES MUST BE IN THE SAME UNITS (here it is meters (m))

`volcano name` = …
`volcano center` = **Easting, Northing** (same units)
`shape` = Cone or Field
`utmzone` = *self explaining*
`time window` = number
`sampling` = number of samples
`background map` = name on map file (png, jpg)

Input files to PyBetVH

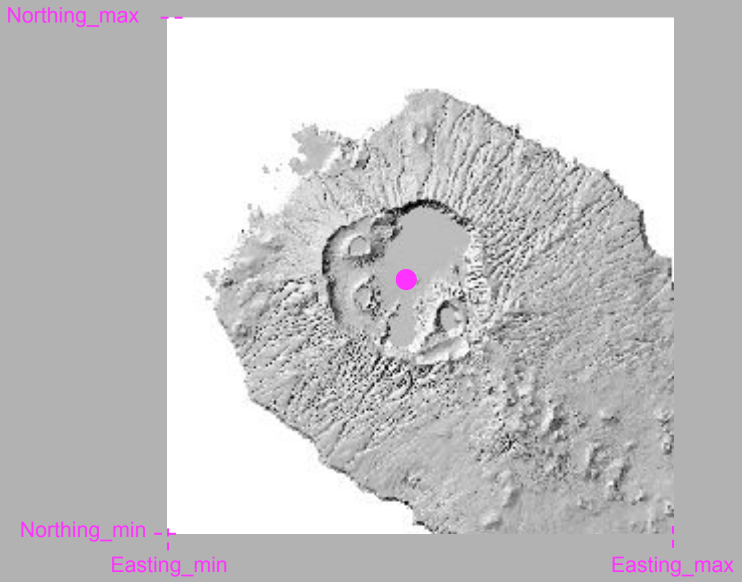
FILE pybet.cfg

```
[Main Settings]
volcano name = Example 1 Volcanic Field
volcano center = 455906, 5774512
shape = Field
geometry = 48000, 44000, 5, 5, 20
utm zone = 21S
time window = 1
sampling = 500
background map = map_sat.png
map limits (m UTM) = 394906.0, 594906.0, 5694512.0, 5894512.0
```

1st Block: [Main settings]
It defines the volcano (name, coordinates, geometry), the background map and its limits

ALL COORDINATES MUST BE IN THE SAME UNITS (here it is meters (m))

`volcano name =` …
`volcano center` = **Easting, Northing** (same units)
`shape` = Cone or Field
`utmzone` = *self explaining*
`time window` = number
`sampling` = number of samples
`background map` = name on map file (png, jpg)
`map limits (m UTM)` = Easting_min, Easting_max, Northing_min, Northing_max in m UTM



Input files to PyBetVH

FILE pybet.cfg

2nd, 3rd and 4th Blocks: [Node 1], [Node 2], [Node 3]

Overall, they define the probability of eruption in the time windowhey are 3 separate nodes but for long term we suggest to leave the first 2 as they are and only act on Node 3

```
[Node 1]
prior probability = 1.0
equivalent n. data (lambda) = 1
past data (successes) = 0
past data (total) = 0

[Node 2]
prior probability = 1.0
equivalent n. data (lambda) = 1
past data (successes) = 0
past data (total) = 0

[Node 3]
prior probability = 0.015
equivalent n. data (lambda) = 1
past data (successes) = 14
past data (total) = 110
```

Input files to PyBetVH

FILE pybet.cfg

2nd, 3rd and 4th Blocks: [Node 1], [Node 2], [Node 3]

Overall, they define the probability of eruption in the time windowhey are 3 separate nodes but for long term we suggest to leave the first 2 as they are and only act on Node 3

```
[Node 1]
prior probability = 1.0
equivalent n. data (lambda) = 1
past data (successes) = 0
past data (total) = 0

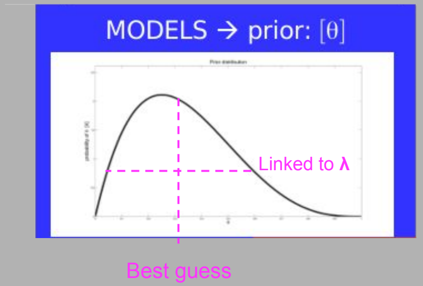
[Node 2]
prior probability = 1.0
equivalent n. data (lambda) = 1
past data (successes) = 0
past data (total) = 0

[Node 3]
prior probability = 0.015
equivalent n. data (lambda) = 1
past data (successes) = 14
past data (total) = 110
```

Common structure:

`prior probability =` **best guess of prior**

`equivalent n. data (lambda)` **= λ**



Input files to PyBetVH

FILE pybet.cfg

2nd, 3rd and 4th Blocks: [Node 1], [Node 2], [Node 3]

Overall, they define the probability of eruption in the time windowhey are 3 separate nodes but for long term we suggest to leave the first 2 as they are and only act on Node 3

```
[Node 1]
prior probability = 1.0
equivalent n. data (lambda) = 1
past data (successes) = 0
past data (total) = 0

[Node 2]
prior probability = 1.0
equivalent n. data (lambda) = 1
past data (successes) = 0
past data (total) = 0

[Node 3]
prior probability = 0.015
equivalent n. data (lambda) = 1
past data (successes) = 14
past data (total) = 110
```

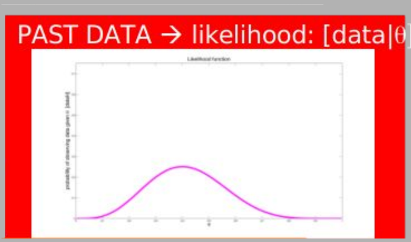
Common structure:

`prior probability =` **best guess of prior**

`equivalent n. data (lambda)` **= λ**

`past data (successes) =` number of successes (e.g., 4 magmatic unrest)

`past data (total) =` number of trials (e.g., 10 unrest)



Input files to PyBetVH

```
[Node 4]
file name = node4.txt
equivalent n. data (lambda) = 1
```

FILE pybet.cfg

5th Blocks: [Node 4]
It defines the spatial probability of vent opening, conditional to an eruption.

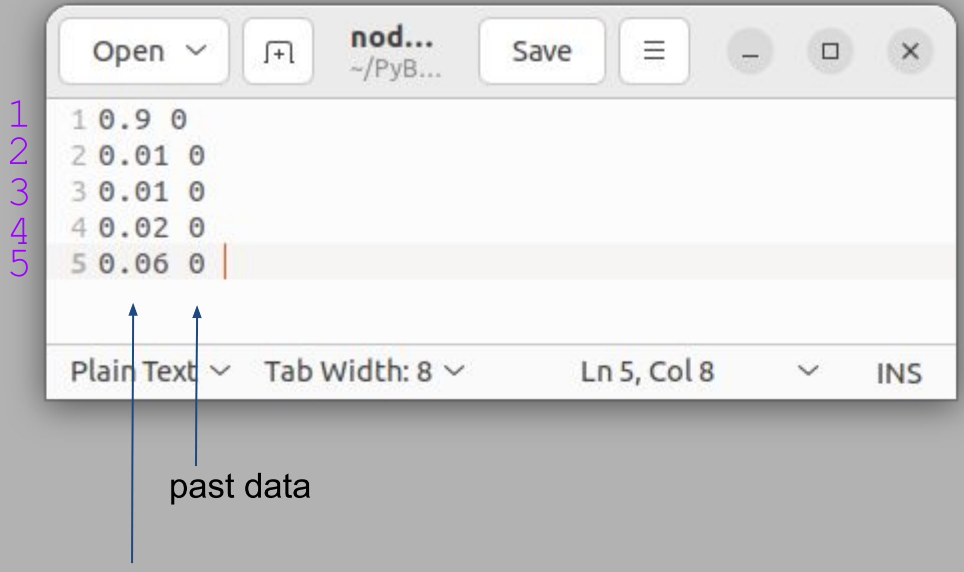
This is done through a **file**

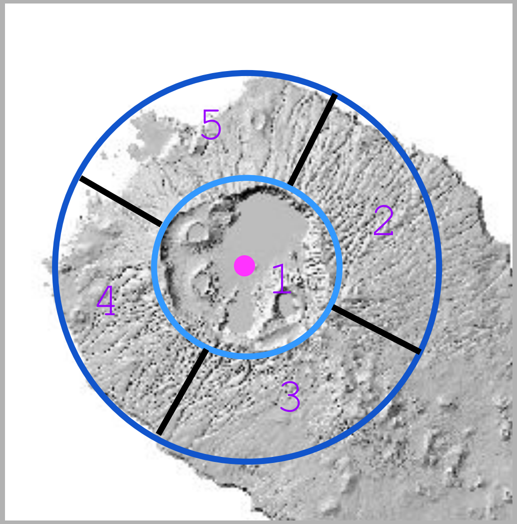
`file name =` **a file name**
`equivalent n. data (lambda)` **= λ**

Input files to PyBetVH

FILE for node 4 (here node4.txt)

node4.txt structure if Geometry is CONE





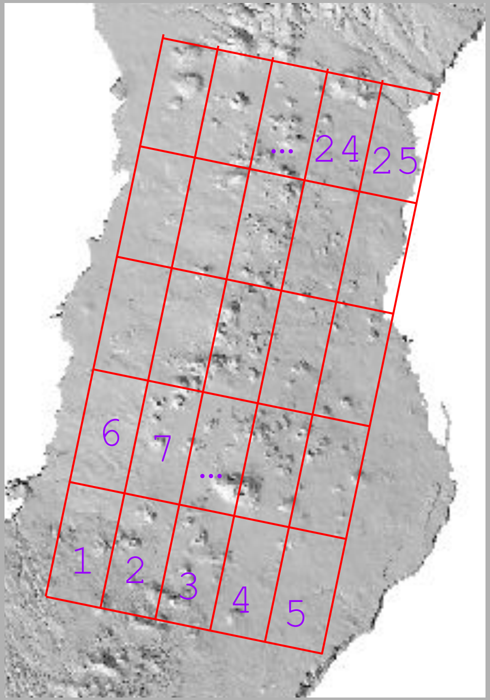
FILE for node 4 (here node4.txt)

node4.txt structure if Geometry is FIELD

```
0.000835 0.0
0.00835 0.0
0.03314 3.0
0.002505 0.0
0.0 0.0
0.040315 0.0
0.10675 3.0
0.09321 5.0
0.03648 0.0
0.00668 5.0
0.002505 0.0
0.184575 14.0
0.076025 2.0
0.117165 15.0
0.01336 0.0
0.0 0.0
0.055045 1.0
0.060055 3.0
0.035645 0.0
0.117165 5.0
0.0 0.0
0.0 0.0
0.005845 0.0
0.00501 0.0
0.0 0.0
```

past data

prior probability



Input files to PyBetVH

```
[Node 5]
node 4-5 dependence = False
n. sizes = 3
file name = node5.txt
```

FILE pybet.cfg

6th Blocks: [Node 5]
It defines the probability distribution of the eruptive sizes (aka Frequency-Magnitude distribution), conditional to an eruption.

This is done through a **file** (here named node5.txt)

Input files to PyBetVH


```
[Node 5]
node 4-5 dependence = False
n. sizes = 3
file name = node5.txt
```

FILE pybet.cfg

6th Blocks: [Node 5]
It defines the probability distribution of the eruptive sizes (aka Frequency-Magnitude distribution), conditional to an eruption.

This is done through a **file**

`Node 4-5 dependence =` **False**[1]

1 - For reasons of time, we do not manage the case of F-M distribution that is spatially varying

Input files to PyBetVH

FILE pybet.cfg

```
34 [Node 5]
35 node 4-5 dependence = False
36 n. sizes = 3
37 file name = node5.txt
38
```

6th Blocks: [Node 5]
It defines the probability distribution of the eruptive sizes (aka Frequency-Magnitude distribution), conditional to an eruption.

This is done through a **file**

`Node 4-5 dependence =` **False**
`n. sizes =` **an integer number** for the number of size classes (e.g., VEI)

Input files to PyBetVH

FILE pybet.cfg

```
34 [Node 5]
35 node 4-5 dependence = False
36 n. sizes = 3
37 file name = node5.txt
```

6th Blocks: [Node 5]
It defines the probability distribution of the eruptive sizes (aka Frequency-Magnitude distribution), conditional to an eruption.

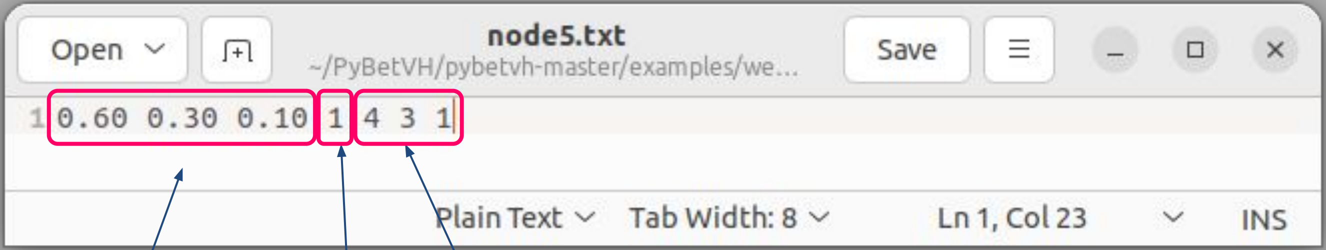
This is done through a **file**

`Node 4-5 dependence =` **False**
`n. sizes =` **an integer number** for the number of size classes (e.g., VEI)
`file name =` **a file name**

Input files to PyBetVH

FILE for node 5 (here node5.txt)

node5.txt structure



prior probabilities for all sizes

equivalent n. data (lambda) on the prior

past data for all sizes

Input files to PyBetVH

FILE pybet.cfg

7th Blocks: [Node 6]
It defines several information on the hazard: the number of hazardous phenomena considered, the hazard measure for each of them, the target grids.

This is done through some **files**

```
[Node 6]
n. outcomes = 1
outcomes = Tephra Load
units = kg/m2
n. areas = 135
file name = node6
file intensities = node6-intensities.txt
file points-areas = node6-areas
```

Input files to PyBetVH

FILE pybet.cfg

7th Blocks: [Node 6]
It defines several information on the hazard: the number of hazardous phenomena considered, the hazard measure for each of them, the target grids.

This is done through some **files**

`n. outcomes =` **an integer number** for the number of hazardous events considered

```
[Node 6]
n. outcomes = 1
outcomes = Tephra Load
units = kg/m2
n. areas = 135
file name = node6
file intensities = node6-intensities.txt
file points-areas = node6-areas
```

Input files to PyBetVH

FILE pybet.cfg

7th Blocks: [Node 6]

It defines several information on the hazard: the number of hazardous phenomena considered, the hazard measure for each of them, the target grids.

This is done through some **files**

`n. outcomes =` **an integer number** for the number of hazardous events considered

`outcomes =` **names** for the hazardous events (comma separated if >1)

```
[Node 6]
n. outcomes = 1
outcomes = Tephra Load
units = kg/m2
n. areas = 135
file name = node6
file intensities = node6-intensities.txt
file points-areas = node6-areas
```

Input files to PyBetVH

FILE pybet.cfg

7th Blocks: [Node 6]
It defines several information on the hazard: the number of hazardous phenomena considered, the hazard measure for each of them, the target grids.

This is done through some **files**

`n. outcomes =` **an integer number** for the number of hazardous events considered

`outcomes =` **names** for the hazardous events (comma separated if >1)

`units =` **units of hazard measure** for each hazardous event (comma separated if >1)

```
[Node 6]
n. outcomes = 1
outcomes = Tephra Load
units = kg/m2
n. areas = 135
file name = node6
file intensities = node6-intensities.txt
file points-areas = node6-areas
```

Input files to PyBetVH

FILE pybet.cfg

7th Blocks: [Node 6]
It defines several information on the hazard: the number of hazardous phenomena considered, the hazard measure for each of them, the target grids.

This is done through some **files**

`n. outcomes =` **an integer number** for the number of hazardous events considered
`outcomes =` **names** for the hazardous events (comma separated if >1)
`units =` **units of hazard measure** for each hazardous event (comma separated if >1)
`n. areas =` **integer numbers** of target grid points for each hazardous event (comma separated if >1)

```
[Node 6]
n. outcomes = 1
outcomes = Tephra Load
units = kg/m2
n. areas = 135
file name = node6
file intensities = node6-intensities.txt
file points-areas = node6-areas
```

Input files to PyBetVH

```
[Node 6]
n. outcomes = 1
outcomes = Tephra Load
units = kg/m2
n. areas = 135
file name = node6
file intensities = node6-intensities.txt
file points-areas = node6-areas
```

FILE pybet.cfg

7th Blocks: [Node 6]

It defines several information on the hazard: the number of hazardous phenomena considered, the hazard measure for each of them, the target grids.

This is done through some **files**

`n. outcomes =` **an integer number** for the number of hazardous events considered

`outcomes =` **names** for the hazardous events (comma separated if >1)

`units =` **units of hazard measure** for each hazardous event (comma separated if >1)

`n. areas =` **integer numbers** of target grid points for each hazardous event (comma separated if >1)

`file name =` **a PART OF file name** with the probability distribution of each hazardous event for each eruptive size

Input files to PyBetVH

```
39 [Node 6]
40 n. outcomes = 1
41 outcomes = Tephra Load
42 units = kg/m2
43 n. areas = 135
44 file name = node6
45 file intensities = node6-intensities.txt
46 file points-areas = node6-areas
```

FILE pybet.cfg

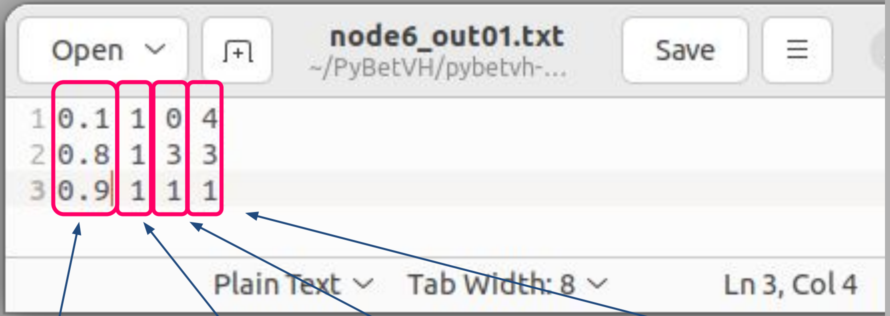
7th Blocks: [Node 6]
It defines several information on the hazard: the number of hazardous phenomena considered, the hazard measure for each of them, the target grids.

This is done through some **files**

`n. outcomes =` **an integer number** for the number of hazardous events considered
`outcomes =` **names** for the hazardous events (comma separated if >1)
`units =` **units of hazard measure** for each hazardous event (comma separated if >1)
`n. areas =` **integer numbers** of target grid points for each hazardous event (comma separated if >1)
`file name =` **a PART OF file name** with the probability distribution of each hazardous event for each eruptive size

You have to create a file for each hazardous event:
*node6*_out01.txt
*node6*_out02.txt …

each with structure:



prior probabilities for all sizes

equivalent n. data (lambda) on the prior for all sizes

past events generating the outcome for each sizes

past events of each size

Input files to PyBetVH

FILE pybet.cfg

```
[Node 6]
n. outcomes = 1
outcomes = Tephra Load
units = kg/m2
n. areas = 135
file name = node6
file intensities = node6-intensities.txt
file points-areas = node6-areas
```

7th Blocks: [Node 6]
It defines several information on the hazard: the number of hazardous phenomena considered, the hazard measure for each of them, the target grids.

This is done through some **files**

`n. outcomes =` **an integer number** for the number of hazardous events considered
`outcomes =` **names** for the hazardous events (comma separated if >1)
`units =` **units of hazard measure** for each hazardous event (comma separated if >1)
`n. areas =` **integer numbers** of target grid points for each hazardous event (comma separated if >1)
`file name =` **a PART OF file name** with the probability distribution of each hazardous event for each eruptive size
`file intensities =` **a file name** containing the intensity thresholds for the hazard curve

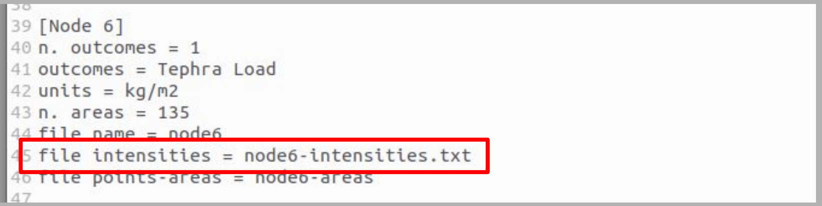
Input files to PyBetVH

FILE pybet.cfg

7th Blocks: [Node 6]
It defines several information on the hazard: the number of hazardous phenomena considered, the hazard measure for each of them, the target grids.

This is done through some **files**

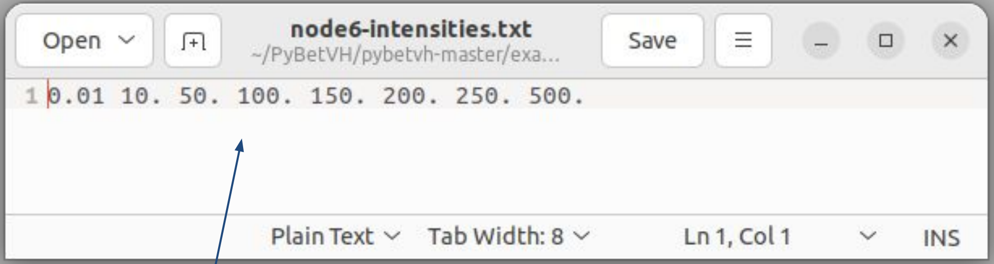
`n. outcomes =` **an integer number** for the number of hazardous events considered
`outcomes =` **names** for the hazardous events (comma separated if >1)
`units =` **units of hazard measure** for each hazardous event (comma separated if >1)
`n. areas =` **integer numbers** of target grid points for each hazardous event (comma separated if >1)
`file name =` **a PART OF file name** with the probability distribution of each hazardous event for each eruptive size
`file intensities =` **a file name** containing the intensity thresholds for the hazard curve



```
[Node 6]
n. outcomes = 1
outcomes = Tephra Load
units = kg/m2
n. areas = 135
file name = node6
file intensities = node6-intensities.txt
file points-areas = node6-areas
```

You have to create a file (here *node6-intensities.txt*)

with structure:



thresholds values on the x-axis of hazard curves

Input files to PyBetVH

FILE pybet.cfg

```
[Node 6]
n. outcomes = 1
outcomes = Tephra Load
units = kg/m2
n. areas = 135
file name = node6
file intensities = node6-intensities.txt
file points-areas = node6-areas
```

7th Blocks: [Node 6]

It defines several information on the hazard: the number of hazardous phenomena considered, the hazard measure for each of them, the target grids.

This is done through some **files**

`n. outcomes =` **an integer number** for the number of hazardous events considered

`outcomes =` **names** for the hazardous events (comma separated if >1)

`units =` **units of hazard measure** for each hazardous event (comma separated if >1)

`n. areas =` **integer numbers** of target grid points for each hazardous event (comma separated if >1)

`file name =` **a PART OF file name** with the probability distribution of each hazardous event for each eruptive size

`file intensities =` **a file name** containing the intensity thresholds for the hazard curves

`file points-areas =` **a PART OF file name** containing the coordinate of each target grid point

Input files to PyBetVH

FILE pybet.cfg

7th Blocks: [Node 6]

It defines several information on the hazard: the number of hazardous phenomena considered, the hazard measure for each of them, the target grids.

This is done through some **files**

`n. outcomes =` **an integer number** for the number of hazardous events considered

`outcomes =` **names** for the hazardous events (comma separated if >1)

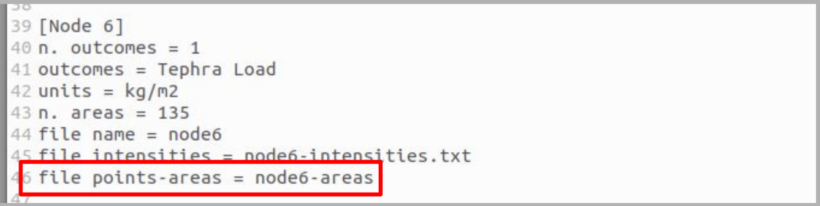
`units =` **units of hazard measure** for each hazardous event (comma separated if >1)

`n. areas =` **integer numbers** of target grid points for each hazardous event (comma separated if >1)

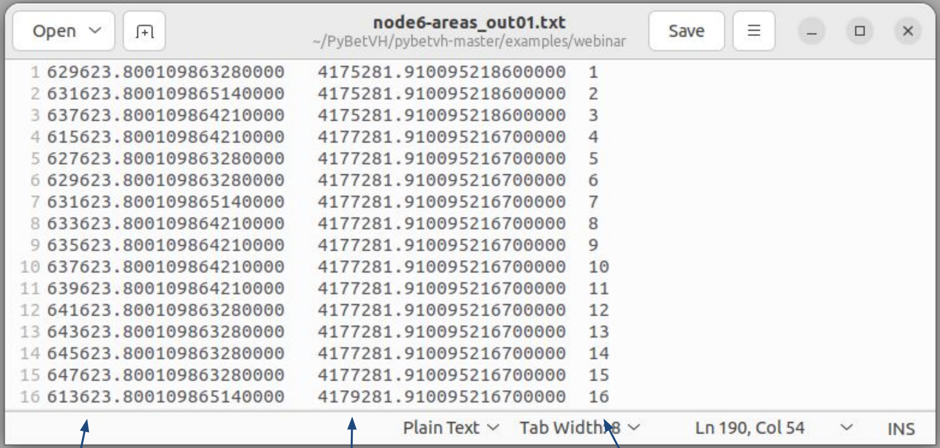
`file name =` **a PART OF file name** with the probability distribution of each hazardous event for each eruptive size

`file intensities =` **a file name** containing the intensity thresholds for the hazard curves

`file points-areas =` **a PART OF file name** containing the coordinate of each target grid point



```
[Node 6]
n. outcomes = 1
outcomes = Tephra Load
units = kg/m2
n. areas = 135
file name = node6
file intensities = node6-intensities.txt
file points-areas = node6-areas
```




```
629623.800109863280000    4175281.910095218600000    1
631623.800109865140000    4175281.910095218600000    2
637623.800109864210000    4175281.910095218600000    3
615623.800109864210000    4177281.910095216700000    4
627623.800109863280000    4177281.910095216700000    5
629623.800109863280000    4177281.910095216700000    6
631623.800109865140000    4177281.910095216700000    7
633623.800109864210000    4177281.910095216700000    8
635623.800109864210000    4177281.910095216700000    9
637623.800109864210000    4177281.910095216700000    10
639623.800109864210000    4177281.910095216700000    11
641623.800109863280000    4177281.910095216700000    12
643623.800109863280000    4177281.910095216700000    13
645623.800109863280000    4177281.910095216700000    14
647623.800109863280000    4177281.910095216700000    15
613623.800109865140000    4179281.910095216700000    16
```

longitude

latitude

number of the grid cell

Input files to PyBetVH

FILE pybet.cfg

7th Blocks: [Node 6]

It defines several information on the hazard: the number of hazardous phenomena considered, the hazard measure for each of them, the target grids.

This is done through some **files**

`n. outcomes =` **an integer number** for the number of hazardous events considered

`outcomes =` **names** for the hazardous events (comma separated if >1)

`units =` **units of hazard measure** for each hazardous event (comma separated if >1)

`n. areas =` **integer numbers** of target grid points for each hazardous event (comma separated if >1)

`file name =` **a PART OF file name** with the probability distribution of each hazardous event for each eruptive size

`file intensities =` **a file name** containing the intensity thresholds for the hazard curves

`file points-areas =` **a PART OF file name** containing the coordinate of each target grid point

```
[Node 6]
n. outcomes = 1
outcomes = Tephra Load
units = kg/m2
n. areas = 135
file name = node6
file intensities = node6-intensities.txt
file points-areas = node6-areas
```

node6-areas_out01.txt
~/PyBetVH/pybetvh-master/examples/webinar

```
629623.800109863280000    4175281.910095218600000    1
631623.800109865140000    4175281.910095218600000    2
637623.800109864210000    4175281.910095218600000    3
615623.800109864210000    4177281.910095216700000    4
627623.800109863280000    4177281.910095216700000    5
629623.800109863280000    4177281.910095216700000    6
631623.800109865140000    4177281.910095216700000    7
633623.800109864210000    4177281.910095216700000    8
635623.800109864210000    4177281.910095216700000    9
637623.800109864210000    4177281.910095216700000    10
639623.800109864210000    4177281.910095216700000    11
641623.800109863280000    4177281.910095216700000    12
643623.800109863280000    4177281.910095216700000    13
645623.800109863280000    4177281.910095216700000    14
647623.800109863280000    4177281.910095216700000    15
613623.800109865140000    4179281.910095216700000    16
```

Input files to PyBetVH

FILE pybet.cfg

8th Block: [Node78]
It defines the impact of the hazardous events considered on the target grid

Information is based on simulations from a numerical or empirical model and/o from past data

```
[Node 78]
file name prior = node78-prior
file name past data = node78-pastdata
```

Input files to PyBetVH

FILE pybet.cfg

```
[Node 78]
file name prior = node78-prior
file name past data = node78-pastdata
```

8th Block: [Node78]
It defines the impact of the hazardous events considered on the target grid

Information is based on simulations from a numerical or empirical model and/o from past data

`File name prior =` **a PART OF file name** containing the prior probability of each target grid point experiencing the hazardous event above each threshold, given eruption size and vent position

Input files to PyBetVH

FILE pybet.cfg

```
[Node 78]
file name prior = node78-prior
file name past data = node78-pastdata
```

8th Block: [Node78]
It defines the impact of the hazardous events considered on the target grid

Information is based on simulations from a numerical or empirical model and/o from past data

`File name prior =` **a PART OF file name** containing the prior probability of each target grid point experiencing the hazardous event above each threshold, given eruption size and vent position

node78-prior_out01.txt
~/PyBetVH/pybetvh-master/examples/webinar

```
0.08 0.07 0.06 0.05 0.04 0.03 0.02 0.01 10
0.18027 0.00017665 0 0 0 0 0 0 10
0.34923 0.2496 0.12613 0.076223 0.016252 0.0018548 0 0 10
0.08 0.07 0.06 0.05 0.04 0.03 0.02 0.01 10
0.20217 0.0023847 0 0 0 0 0 0 10
0.36893 0.26956 0.14944 0.096714 0.031532 0.0076842 8.8324e-05 0 10
0.08 0.07 0.06 0.05 0.04 0.03 0.02 0.01 10
0.22637 0.011129 0 0 0 0 0 0 10
0.39154 0.29217 0.17797 0.11968 0.053789 0.021374 0.0054761 0 10
0.08 0.07 0.06 0.05 0.04 0.03 0.02 0.01 10
0.25499 0.029323 0 0 0 0 0 0 10
0.41397 0.3154 0.20924 0.14944 0.080904 0.04266 0.018725 0.0036213 10
0.08 0.07 0.06 0.05 0.04 0.03 0.02 0.01 10
0.28484 0.05741 0 0 0 0 0 0 10
0.43923 0.34199 0.23936 0.17833 0.1112 0.067568 0.039039 0.0174 10
0.08 0.07 0.06 0.05 0.04 0.03 0.02 0.01 10
0.17356 0 0 0 0 0 0 0 10
0.33881 0.23618 0.11703 0.066154 0.013514 0.0013249 0 0 10
```

1st line:	$p_1, p_2, \dots p_{Ni}, \Lambda_{7\&8}$ for grid point 1, vent position 1, size class 1
2nd line:	$p_1, p_2, \dots p_{Ni}, \Lambda_{7\&8}$ for grid point 1, vent position 1, size class 2
...	...
Ns^{th} *line*:	$p_1, p_2, \dots p_{Ni}, \Lambda_{7\&8}$ for grid point 1, vent position 1, size class Ns
$(Ns+1)^{th}$ *line*:	$p_1, p_2, \dots p_{Ni}, \Lambda_{7\&8}$ for grid point 1, vent position 2, size class 1
...	...
$(Nv*Ns)^{th}$ *line*:	$p_1, p_2, \dots p_{Ni}, \Lambda_{7\&8}$ for grid point 1, vent position Nv, size class Ns
$(Nv*Ns+1)^{th}$ *line*:	$p_1, p_2, \dots p_{Ni}, \Lambda_{7\&8}$ for grid point 2, vent position 1, size class 1
...	...
$(Np*Nv*Ns)^{th}$ *line*:	$p_1, p_2, \dots p_{Ni}, \Lambda_{7\&8}$ for grid point Np, vent position Nv, size class Ns

Input files to PyBetVH

FILE pybet.cfg

```
[Node 78]
file name prior = node78-prior
file name past data = node78-pastdata
```

8th Block: [Node78]
It defines the impact of the hazardous events considered on the target grid

Information is based on simulations from a numerical or empirical model and/o from past data

`File name prior =` **a PART OF file name** containing the prior probability of each target grid point experiencing the hazardous event above each threshold, given eruption size and vent position

`File name past data =` **a PART OF file name** containing the past data on the hazardous event

Input files to PyBetVH

FILE pybet.cfg

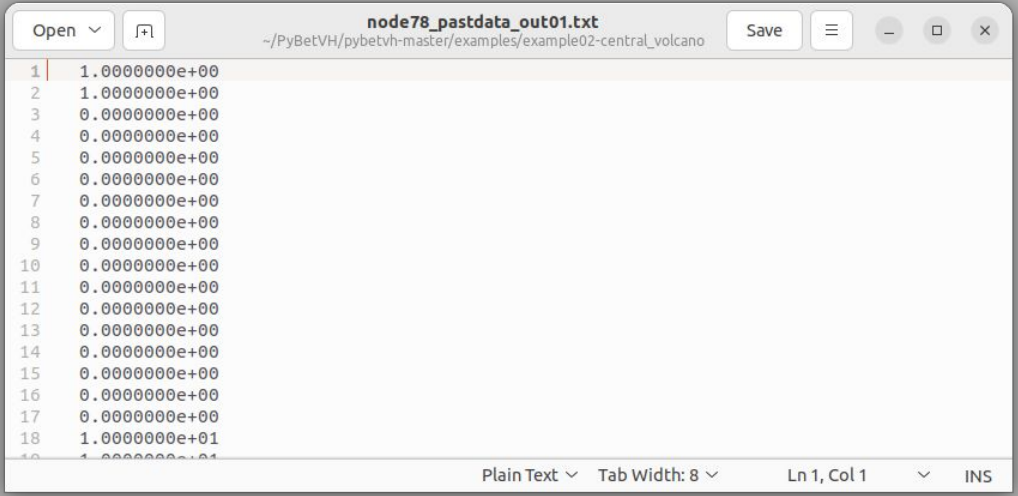
```
[Node 78]
file name prior = node78-prior
file name past data = node78-pastdata
```

8th Block: [Node78]
It defines the impact of the hazardous events considered on the target grid

Information is based on simulations from a numerical or empirical model and/o from past data

`File name prior =` **a PART OF file name** containing the prior probability of each target grid point experiencing the hazardous event above each threshold, given eruption size and vent position

`File name past data =` **a PART OF file name** containing the past data on the hazardous event



1[st] line:	index of the vent position of eruption 1
2[nd] line:	index of the size class of eruption 1
3[rd] line:	measured intensity value for grid point 1 in eruption 1
...	...
$(Np+2)^{th}$ line:	measured intensity value for grid point *Np* in eruption 1
$(Np+3)^{th}$ line:	index of the vent position of eruption 2
$(Np+4)^{th}$ line:	index of the size class of eruption 2
$(Np+5)^{th}$ line:	measured intensity value for grid point 1 in eruption 2
...	...
$Ne*(Np+2)^{th}$ line:	measured intensity value for grid point *Np* in eruption *Ne*

An example*

An island with a volcano. Historical catalogue of 8 eruptions in the last 1000 years:

4 effusive
3 small explosive
1 large explosive

No clue on the temporal model of occurrence of eruptions

* Download the folder with the files to run this examples from https://drive.google.com/file/d/1xFk0nGbHX_00qZoSIC_3wkz2AdX_71QJ/view?usp=sharing
Once downloaded, unzip it wherever you want and load it from the PyBetVH tool

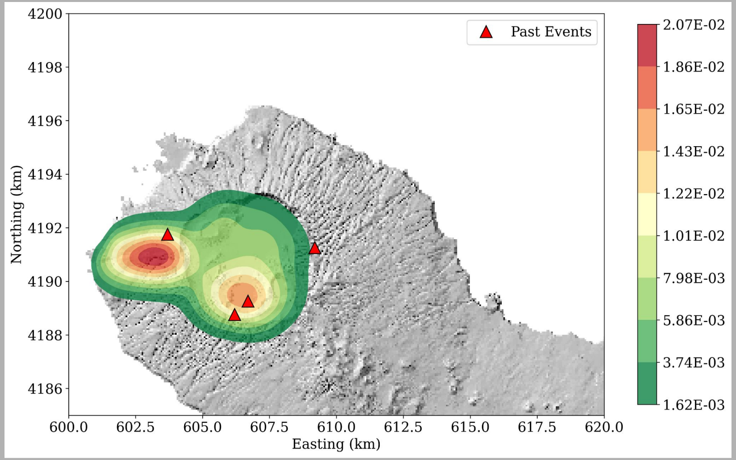
An example

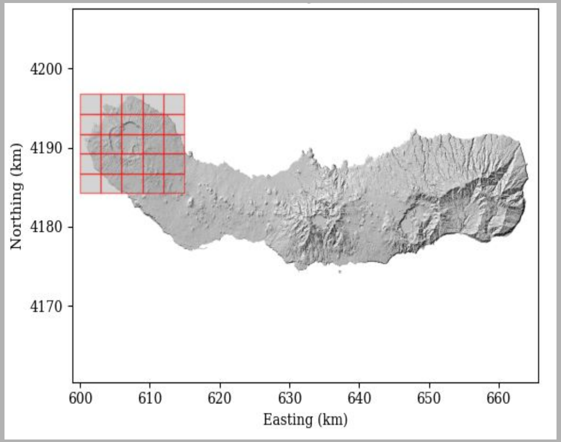
An island with a volcano. Historical catalogue of 8 eruptions in the last 1000 years:

4 effusive
3 small explosive
1 large explosive

No clue on the temporal model of occurrence of eruptions

A map for the spatial probability of vent opening based on geomorphological features





An example

An island with a volcano. Historical catalogue of 8 eruptions in the last 1000 years:

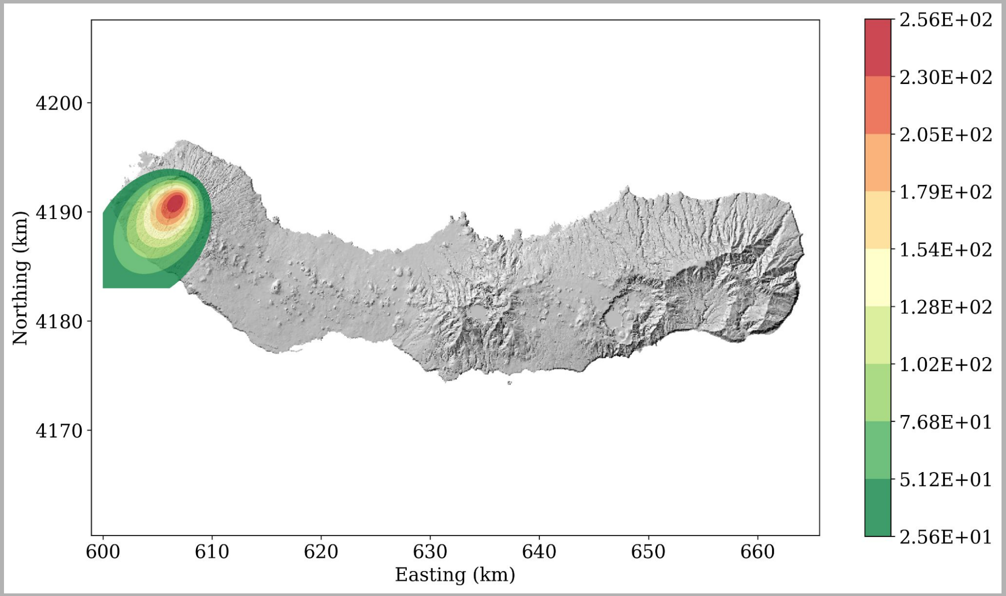
4 effusive
3 small explosive
1 large explosive

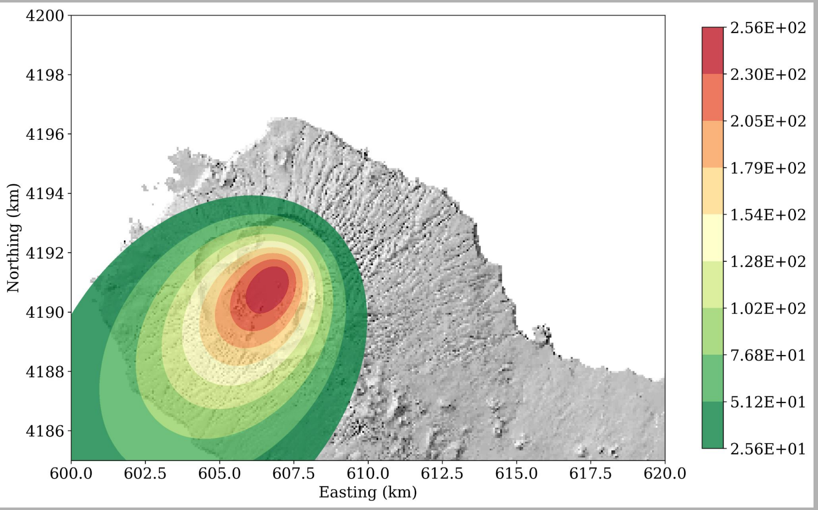
No clue on the temporal model of occurrence of eruptions

A map for the spatial probability of vent opening based on geomorphological features

Simulations from a numerical model of tephra dispersal for small and large explosive eruptions, sampling the statistics of wind profiles from specific Eruption Source Parameters defined for small and large explosive eruptions

PVHA for tephra fallout on the island?





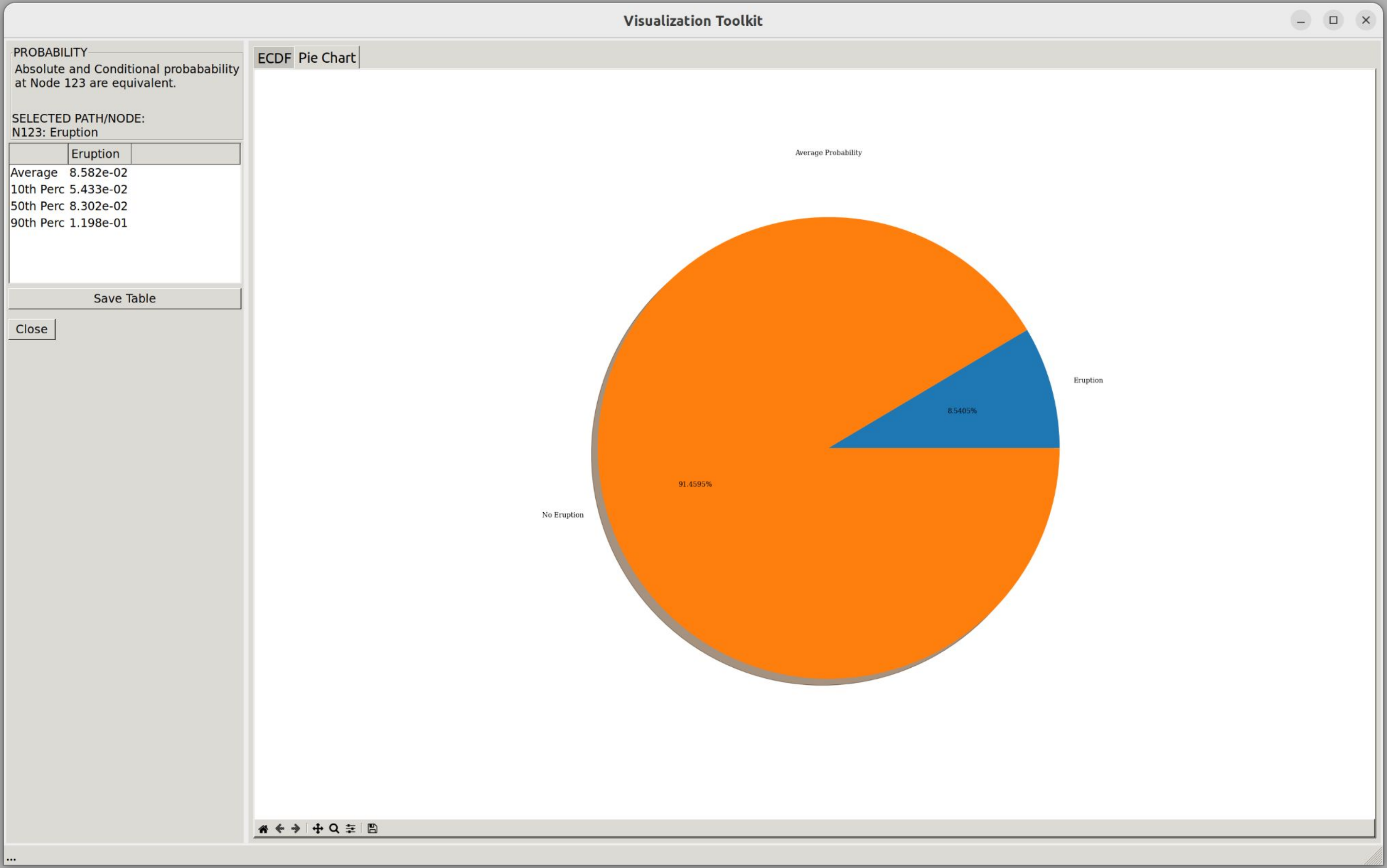
Let's try

1. Pie chart of the absolute probability of eruption / no eruption in 10 years
2. Absolute Probability of an eruption from vent 12 in 10 years
3. 90th percentile of the Conditional Probability of an eruption from vent 12
4. Distribution of the Absolute Probability of an eruption of EXPLOSIVE size from vent 13, in 10 years
5. Absolute hazard Curve for point 20 to overcome 300 kg/m^2 in 10 years from a LARGE explosive eruption
6. 90^{th} percentile of the conditional probability to overcome 300 kg/m^2 from an explosive eruption in point 20
7. 50^{th} percentile absolute HAZARD MAP for 3% exceedance probability in 10 years
8. 90^{th} percentile probability map for 100 kg/m^2 ground load in case of eruption

If you have not yet done so, download the zipped folder with the files to run this examples from
https://drive.google.com/file/d/1xFk0nGbHX_00qZoSIC_3wkz2AdX_71QJ/view?usp=sharing
Once downloaded, unzip it wherever you want and load it from the PyBetVH tool

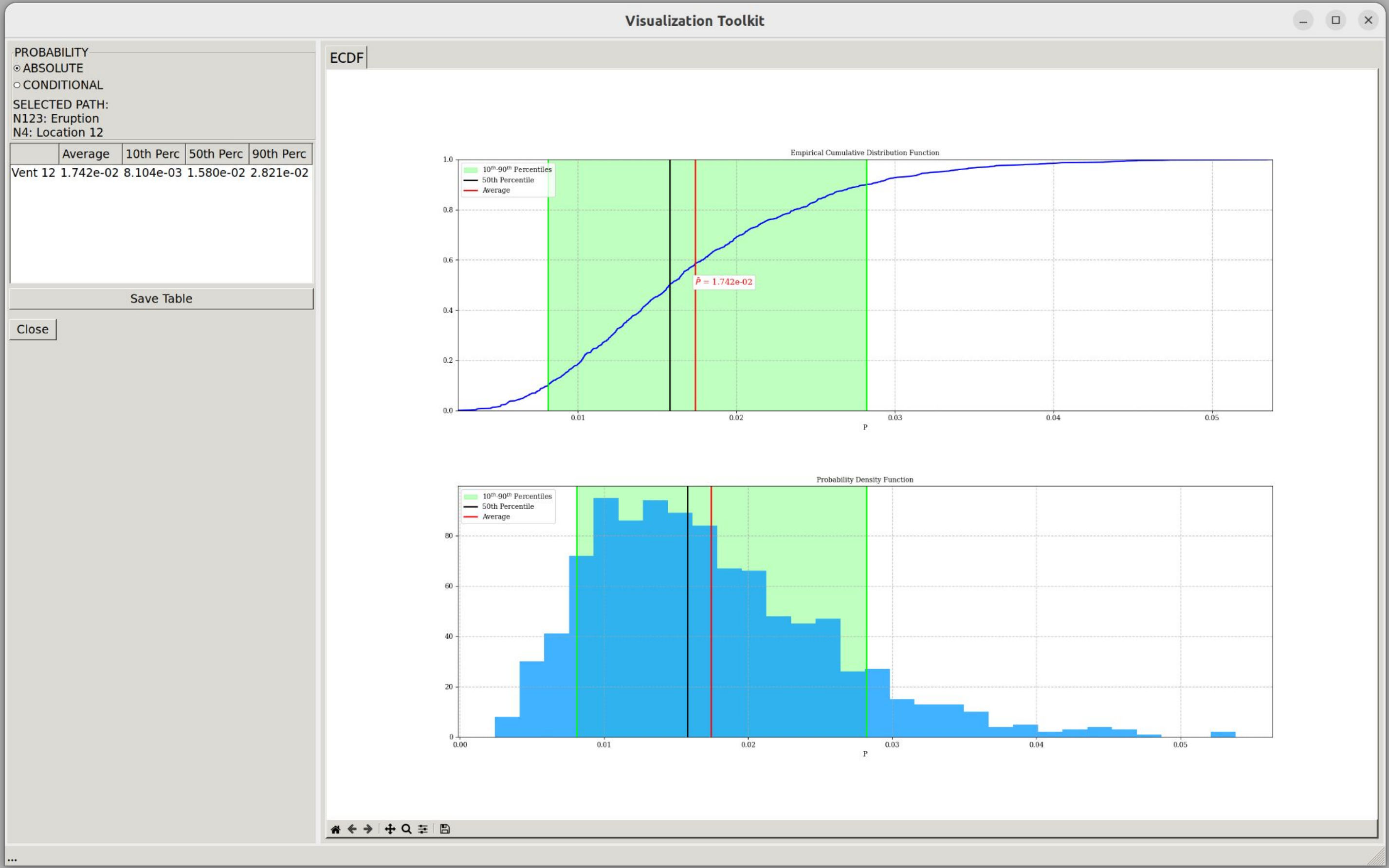
Let’s try

1 - Pie chart of the absolute probability of eruption / no eruption in 10 years



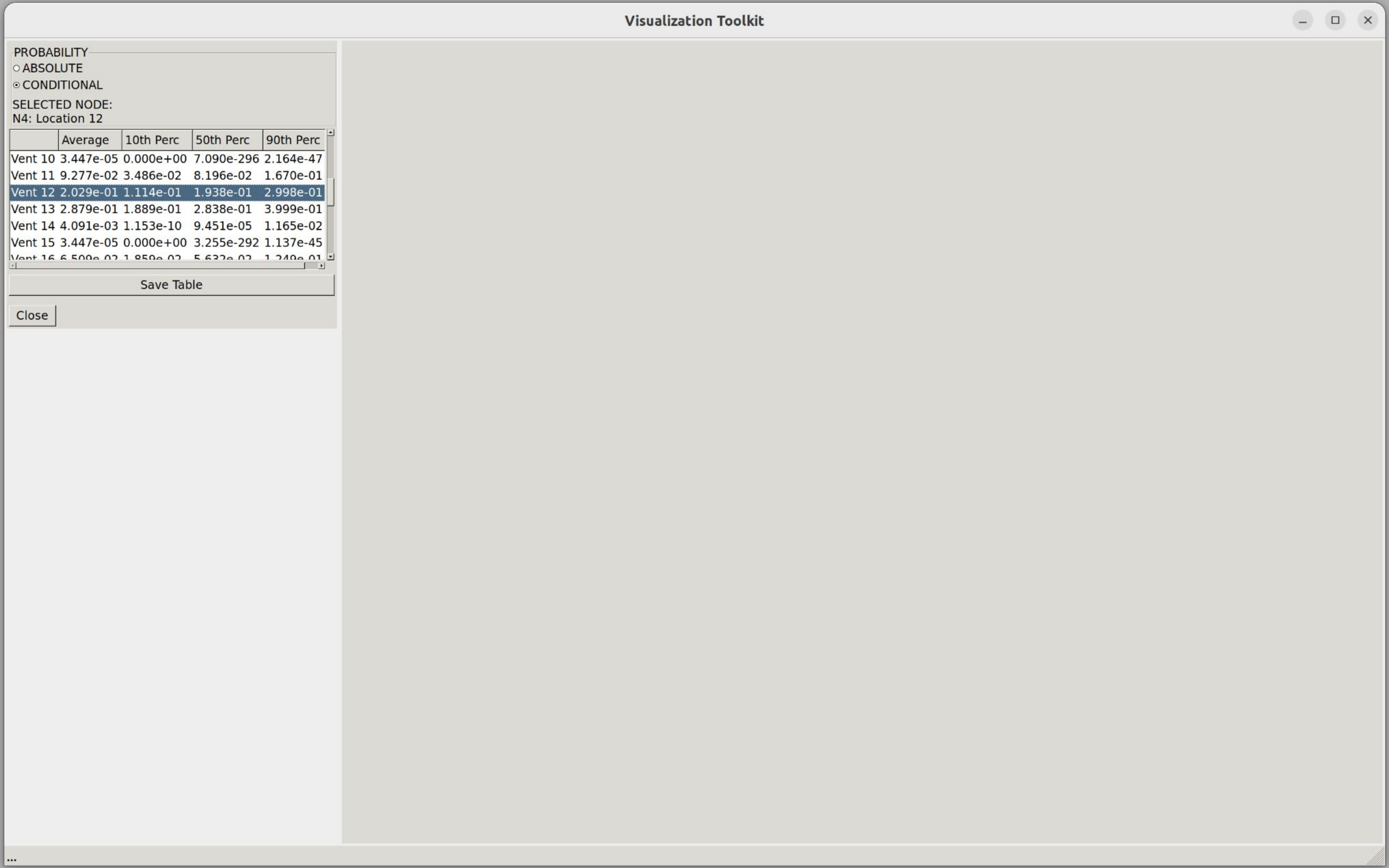
Let’s try

2 - Absolute Probability of an eruption from vent 12 in 10 years



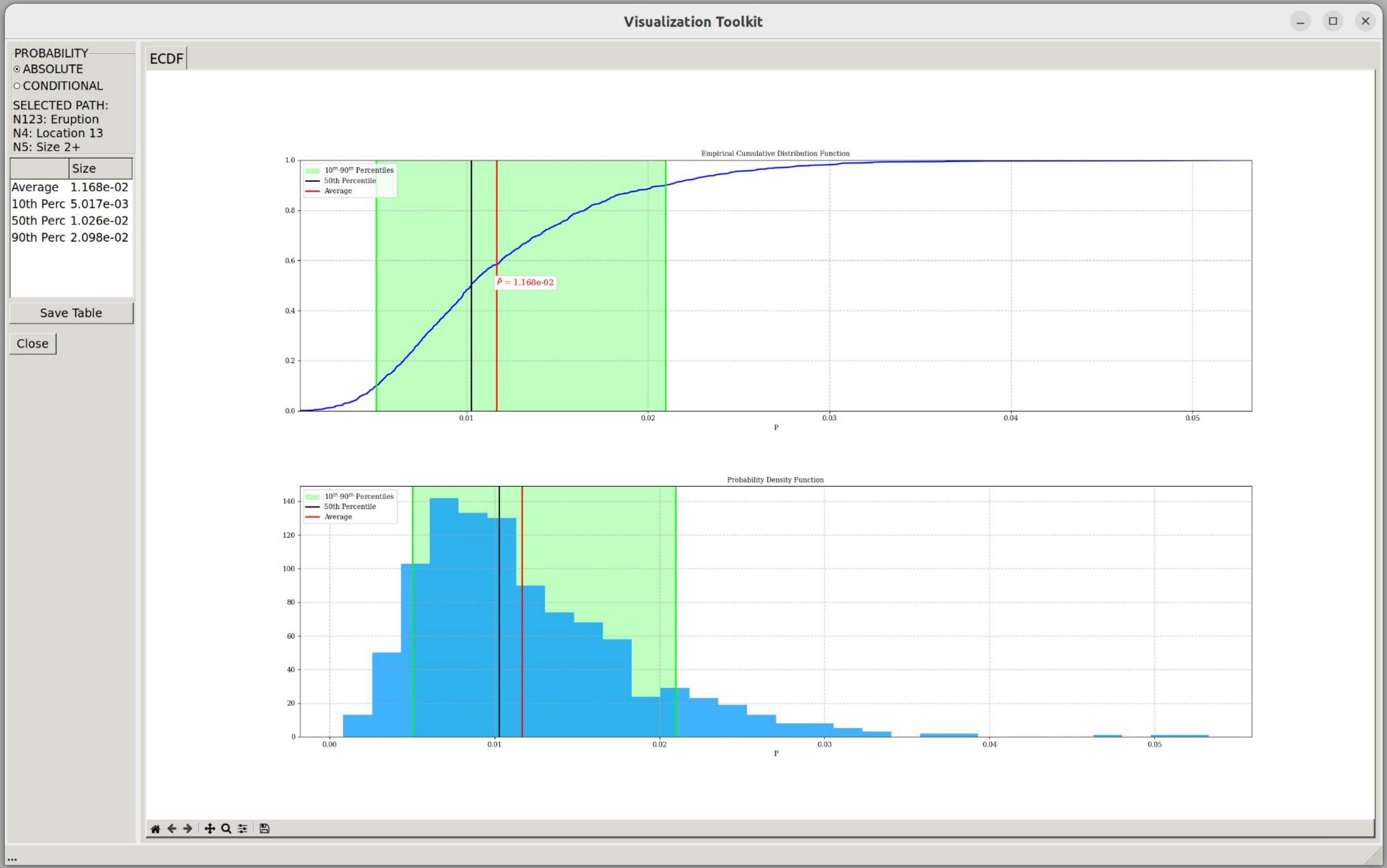
Let’s try

3 - 90th percentile of the Conditional Probability of an eruption from vent 12



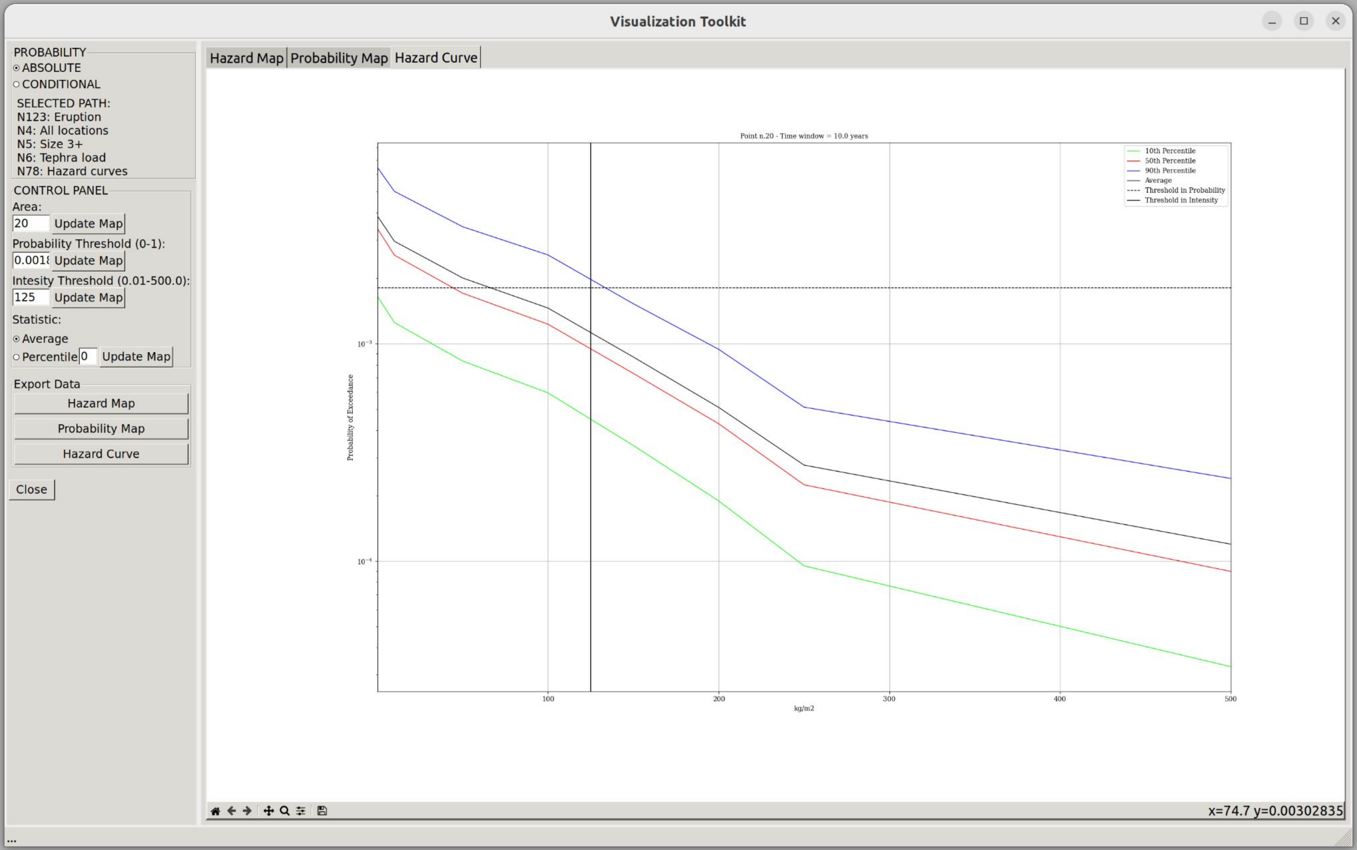
Let's try

4 - Distribution of the Absolute Probability of an eruption of EXPLOSIVE size from vent 13, in 10 years



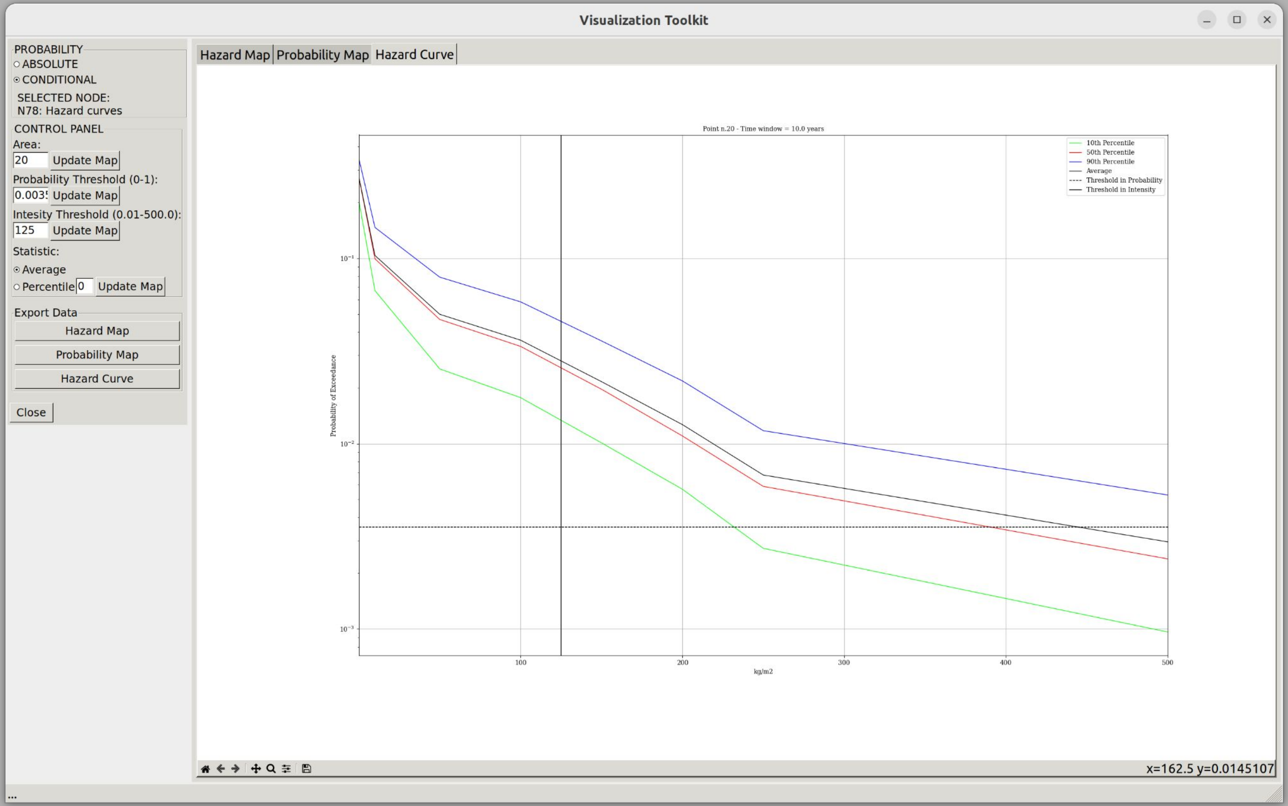
Let’s try

5 - Absolute hazard Curve for point 20 to overcome 300 kg/m^2 in 10 years from a LARGE explosive eruption



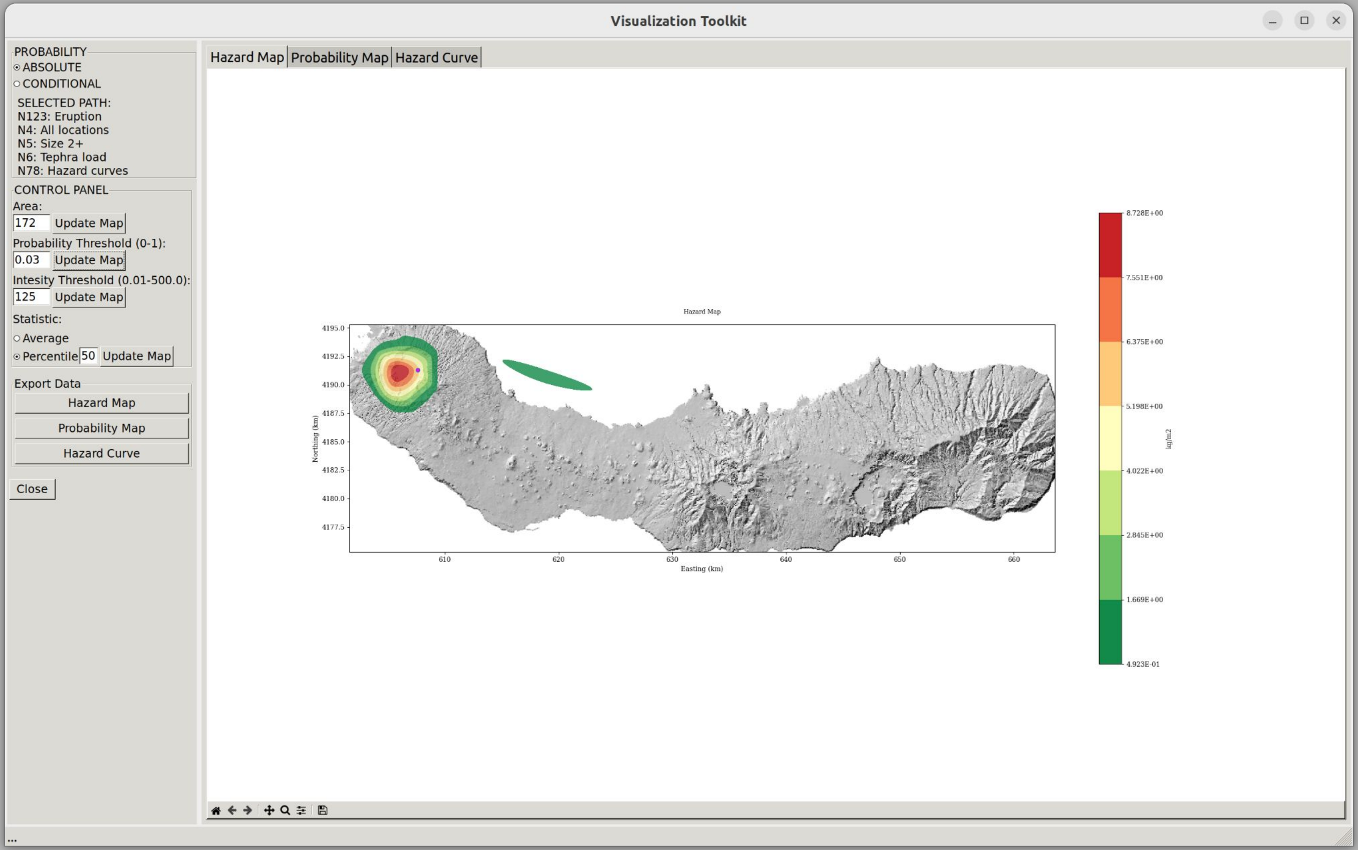
Let's try

6 - 90th percentile of the conditional probability to overcome 300 kg/m^2 from an explosive eruption in point 20



Let's try

7 - 50th percentile absolute HAZARD MAP for 3% exceedance probability in 10 years



Let's try

8 - 90th percentile probability map for 100 kg/m^2 ground load in case of eruption