Bayesian Event Tree for Long-Term Volcanic Hazard Assessment (LTVH): A New Plugin for QGIS

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7th Cities on volcanoes 19 - 23 Noviembre 2012 Colima, Mexico
Problem?
A potentially active volcano

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Surrounded by touristic areas
That could erupt again in the near future
...we need to quantify volcanic hazard and its uncertainty

Random events $\theta$

$\theta_1 = \text{unrest}$

Space of possibilities $\Omega$

$\Omega_1 = \{\text{yes, no}\}$
...we need to quantify volcanic hazard and its uncertainty

Random events $\Theta$

$\theta_1 = \text{unrest}$

$\theta_2 = \text{origin}$

Space of possibilities $\Omega$

$\Omega_1 = \{\text{yes, no}\}$

$\Omega_2 = \{\text{magmatic, geothermal, seismic, other}\}$

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Colima, Mexico
...we need to quantify volcanic hazard and its uncertainty

<table>
<thead>
<tr>
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<td>$\Omega_4 = {\text{central, north, south, east, west}}$</td>
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<td>$\Omega_4 = {\text{central, north, south, east, west}}$</td>
</tr>
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<td>$\theta_5 = \text{composition}$</td>
<td>$\Omega_5 = {\text{mafic, felsic}}$</td>
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Colima, Mexico
...we need to quantify volcanic hazard and its uncertainty

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</tr>
<tr>
<td>$\theta_6 = \text{size}$</td>
<td>$\Omega_6 = {\text{VEI} \geq 5, \text{VEI} 4, \text{VEI} 3, \text{VEI} \leq 2}$</td>
</tr>
</tbody>
</table>
Event Tree of Possibilities

- UNREST:
  - Yes
  - No

- ORIGIN:
  - Magmatic
  - Geothermal
  - Seismic
  - Other
  - Stop

- OUTCOME:
  - No Eruption
  - Magmatic Er.
  - Sector Failure
  - Phreatic Er.
  - Clone
  - Stop

- LOCATION:
  - Zone 1
  - Zone 2
  - Zone 3
  - Zone 4
  - Zone 5

- COMPOSITION:
  - Clone
  - Clone
  - Clone
  - Clone
  - Mafic
  - Felsic

- SIZE:
  - Clone
  - VEI >= ?
  - VEI = ?
  - VEI = ?
  - VEI <= ?
How do we estimate the volcanic hazard?
Bayesian Inference

Uncertainty before observing the data

\[ P(\theta) \]

Probabilities PRIOR to observing the data

Dirichlet \((D\theta)\)

\[ \theta_k \sim D\theta(\alpha_{ki}) \]

nodes \( k = 1, \ldots, 6 \)

branches \( i = 1, \ldots, J_k \)

\( J_k \) # branches node \( k \)
How do we estimate the volcanic hazard? Bayesian Inference

Uncertainty before observing the data

\[ P(\theta) \]

Probabilities PRIOR to observing the data

Dirichlet \((Di)\)

OBSERVED DATA

\[ P(y|\theta) \]

LIKELIHOOD Probabilities

Multinomial \((Mu)\)

\[ \theta_k \sim Di(\alpha_{ki}) \]

nodes \( k = 1, \ldots, 6 \)
branches \( i = 1, \ldots, J_k \)
\( J_k \) # branches node \( k \)

\[ [y_k | \theta_k] \sim Mu(y_{ki}, \theta_k) \]

nodes \( k = 1, \ldots, 6 \)
branches \( i = 1, \ldots, J_k \)
\( J_k \) # branches node \( k \)
What data do we have?

<table>
<thead>
<tr>
<th>Eruption</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chahorra</td>
<td>1798 B.P.</td>
</tr>
<tr>
<td>Mta Reventada</td>
<td>895 B.P.</td>
</tr>
<tr>
<td>Lavas Negras</td>
<td>1150 B.P.</td>
</tr>
<tr>
<td>Roques Blancos</td>
<td>1714 B.P.</td>
</tr>
<tr>
<td>Mta Blanca</td>
<td>2000 B.P.</td>
</tr>
<tr>
<td>PV surges</td>
<td>(2528–2000) B.P.</td>
</tr>
<tr>
<td>Hoya del Cedro</td>
<td>(2528–2000) B.P.</td>
</tr>
<tr>
<td>Mta Majua</td>
<td>(2528–2000) B.P.</td>
</tr>
<tr>
<td>Mta de la Cruz</td>
<td>(2528–2000) B.P.</td>
</tr>
<tr>
<td>Arenas Blancas</td>
<td>(2528–2000) B.P.</td>
</tr>
<tr>
<td>Mta Los Conejos</td>
<td>(2528–2000) B.P.</td>
</tr>
<tr>
<td>Bocas de Maria</td>
<td>(2528–2000) B.P.</td>
</tr>
<tr>
<td>Mta Las Lajas</td>
<td>(2528–2000) B.P.</td>
</tr>
<tr>
<td>El Boqueron</td>
<td>2528 B.P.</td>
</tr>
<tr>
<td>Cañada Blanca</td>
<td>(5911–2528) B.P.</td>
</tr>
<tr>
<td>Abejera Baja</td>
<td>5911 B.P.</td>
</tr>
<tr>
<td>Abejera Alta</td>
<td>5486 B.P.</td>
</tr>
<tr>
<td>Pico Cabras</td>
<td>(7900–5486) B.P.</td>
</tr>
</tbody>
</table>

18 magmatic eruptions last 8000 years
3 C, 7 N, 1 S, 6 E, 1 W
3 Basaltic, 15 Phonolitic
6 VEI 4, 3 VEI 3, 9 VEI ≤ 2
How do we estimate the volcanic hazard? Bayesian Inference

Uncertainty before observing the data

\[ P(\theta) \]

Probabilities PRIOR to observing the data

Dirichlet (\textit{Di})

\[ \theta_k \sim \text{Di}(\alpha_{ki}) \]

nodes \( k = 1, \ldots, 6 \)
branches \( i = 1, \ldots, J_k \)
\( J_k \) # branches node \( k \)

OBSERVED DATA

\[ P(y|\theta) \]

LIKENLIHOOD Probabilities

Multinomial (\textit{Mu})

\[ [y_k|\theta_k] \sim \text{Mu}(y_{ki}, \theta_k) \]

nodes \( k = 1, \ldots, 6 \)
branches \( i = 1, \ldots, J_k \)
\( J_k \) # branches node \( k \)

Uncertainty after observing the data

\[ P(\theta|y) \]

Probabilities POST observing the data

Dirichlet (\textit{Di})

\[ [\theta_k|y_k] \sim \text{Di}(\alpha_{ki} + y_{ki}) \]

nodes \( k = 1, \ldots, 6 \)
branches \( i = 1, \ldots, J_k \)
\( J_k \) # branches node \( k \)

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How do we estimate the volcanic hazard?
Bayesian Inference

Posterior probability $\rightarrow$ Expected value of a r.v. that follows a Dirichlet distrib. of parameters $\alpha + y$

$$E[\theta_{kn}] = \frac{\alpha_{kn} + y_{kn}}{\sum_{i=1}^{J}(\alpha_{ki} + y_{ki})}$$

where,

$y$ is the observed data

$$\alpha_{ki} = E[\theta_{ki}] (\lambda_{ki} + J_{k} - 1)$$

written in terms of the data weight and prior weights (inputs to the model) to account for the epistemisc and aleatoric uncertainty.

Uncertainty after observing the data
$$P(\theta|y)$$

Probabilities POST observing the data

Dirichlet ($Di$)

$$[\theta_{k}|y_{k}] \sim Di(\alpha_{ki} + y_{ki})$$

nodes $k = 1, ..., 6$
branches $i = 1, ..., J_{k}$
$J_{k}$ # branches node $k$
Event Tree of Probabilities
Bayesian Event Tree

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Is there a tool to compute these probabilities?

There is a free plugin for the open source QGIS called “volcano” which contains the bayesian event tree under LTVH.

For now just Mac and Linux.
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Colima, Mexico
<table>
<thead>
<tr>
<th>NODE NAME</th>
<th>EVENT</th>
<th>PAST DATA</th>
<th>PRIORI WEIGHT</th>
<th>DATA WEIGHT</th>
</tr>
</thead>
<tbody>
<tr>
<td>unrest</td>
<td>yes</td>
<td>18</td>
<td>0.5</td>
<td>1</td>
</tr>
<tr>
<td>unrest</td>
<td>no</td>
<td>62</td>
<td>0.5</td>
<td>1</td>
</tr>
<tr>
<td>origin</td>
<td>magmatic</td>
<td>18</td>
<td>0.25</td>
<td>1</td>
</tr>
<tr>
<td>origin</td>
<td>geothermal</td>
<td>0</td>
<td>0.25</td>
<td>1</td>
</tr>
<tr>
<td>origin</td>
<td>seismic</td>
<td>0</td>
<td>0.25</td>
<td>1</td>
</tr>
<tr>
<td>origin</td>
<td>other</td>
<td>0</td>
<td>0.25</td>
<td>1</td>
</tr>
<tr>
<td>outcome</td>
<td>magmatic eruption</td>
<td>18</td>
<td>0.25</td>
<td>1</td>
</tr>
<tr>
<td>outcome</td>
<td>sector failure</td>
<td>0</td>
<td>0.25</td>
<td>1</td>
</tr>
<tr>
<td>outcome</td>
<td>phreatic eruption</td>
<td>0</td>
<td>0.25</td>
<td>1</td>
</tr>
<tr>
<td>outcome</td>
<td>no eruption</td>
<td>0</td>
<td>0.25</td>
<td>1</td>
</tr>
<tr>
<td>location</td>
<td>Central</td>
<td>3</td>
<td>0.2</td>
<td>1</td>
</tr>
</tbody>
</table>

or add PAST DATA - PRIORI WEIGHT - DATA WEIGHT values at each Branch of the Event Tree
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Colima, Mexico
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19 - 23 Noviembre 2012 Colima, Mexico
### 7th Cities on volcanoes

#### 19 - 23 Noviembre 2012
Colima, Mexico

#### ZONE

<table>
<thead>
<tr>
<th>ZONE</th>
<th>Past Data</th>
<th>Priori Weight</th>
<th>Data weight</th>
<th>PROBABILITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Central</td>
<td>3</td>
<td>0.2</td>
<td>0.1739</td>
</tr>
<tr>
<td>2</td>
<td>North</td>
<td>7</td>
<td>0.2</td>
<td>0.3478</td>
</tr>
<tr>
<td>3</td>
<td>South</td>
<td>1</td>
<td>0.2</td>
<td>0.0870</td>
</tr>
<tr>
<td>4</td>
<td>East</td>
<td>6</td>
<td>0.2</td>
<td>0.3043</td>
</tr>
<tr>
<td>5</td>
<td>West</td>
<td>1</td>
<td>0.2</td>
<td>0.0870</td>
</tr>
</tbody>
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#### INFO LOCATION

#### BAYESIAN EVENT TREE - LOCATION

![Bayesian Event Tree Diagram]

1: Central
2: North
3: South
4: East
5: West
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Colima, Mexico
0.85% ???!#!
Dammit! Its higher than I thought!
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