Volcanic hazard assessment – Day 1: Lava flows

Volcanic risk module / CERG–C / ELSTE

Sébastien Biasse - sebastien.biasse@unige.ch

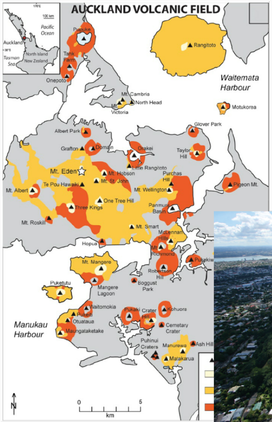
Costanza Bonadonna, Lucia Dominguez, Corine Frischknecht, Eduardo Rossi, Maria-Paz Reyes

10 May 2022

If a tree falls in a forest...?

If a tree falls in a forest...?

Auckland volcanic field vs. Jan Mayen



Course's objectives & schedule

DEPOSIT ▸ ESP ▸ SCENARIO ▸ HAZARD ▸ EXPOSURE

Course's objectives & schedule

Day 1: **Lava flow**

1. Lava flow modeling using several approaches
2. Introduction to probabilistic hazard assessment
3. Hazard assessment of lava flows

Day 2: **Tephra fallout**

1. Introduction to tephra fallouts and ESP
2. Deeper into probabilistic hazard assessment
3. Probabilistic hazard assessment for tephra fallout

Some admin

Vent 1	**Vent 2**	**Vent 3**	**Vent 4**	**Vent 5**
Fernanda Naranjo Hidalgo	Camille Pastore	Monique Johnson	Million Mengesha	Anabella Fantozzi
Mattias Coullie	John Gallego Montoya	Angie Ramirez Huerta	Ana Maria Perez Hincapie	Jonas Schranz
Florent Keller	Karen Nicollet	Elise Cerutti	Génio Lay Da Silva	Nicolas Serrano
Salome Gogoladze	Douglas Stumpp	David Gutierrez Rivera	Sylvain Köhli	Amin Abutaleb
Elias Garcia Urquia	Mario Cifuentes Jacobs	Delair Ndibi Etoundi	Giorgi Merebashvili	

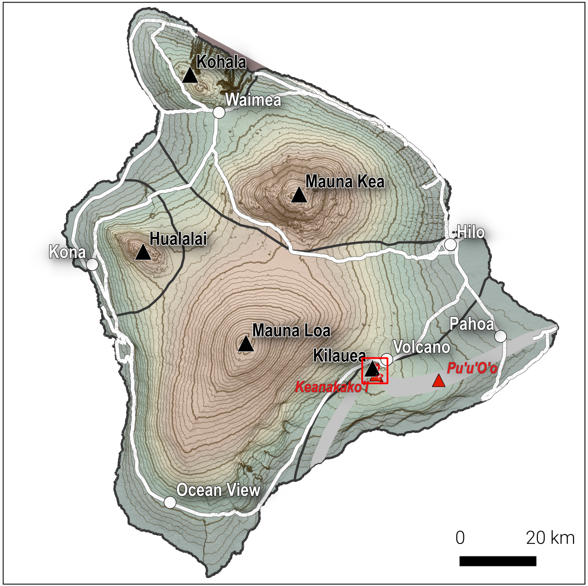
Theory + lab → Part of the grade! → See question sheet on Moodle

Today: Lava flows

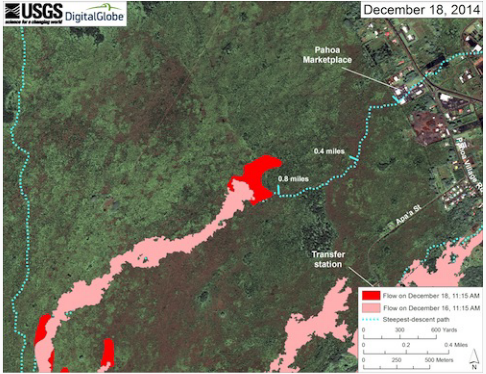
Lava flows

Lava channel → A’a → Pahoehe

Pahoa crisis, Hawaii, 2014



Pahoa crisis, Hawaii, 2014



Lava flow part I

Path of steepest descent

Path of steepest descent

DEM: Digital Elevation Models

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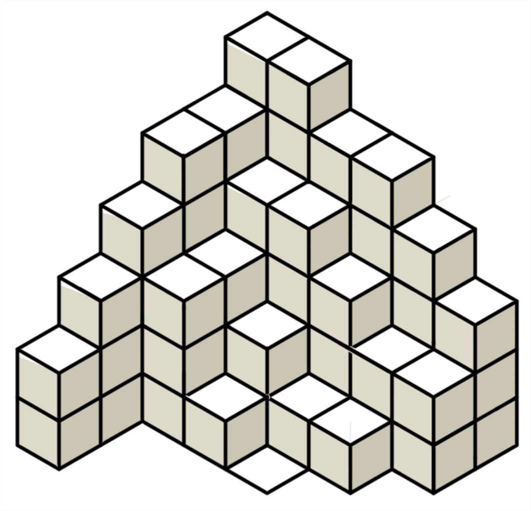
Hydrological models

↓

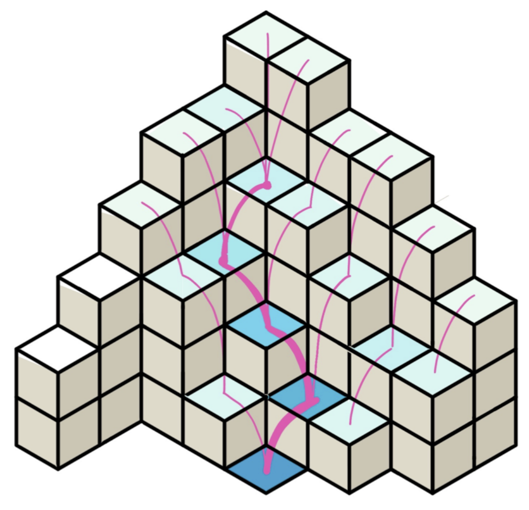
Flow accumulation → Stream network → Drainage basins



Path of steepest descent

Flow accumulation

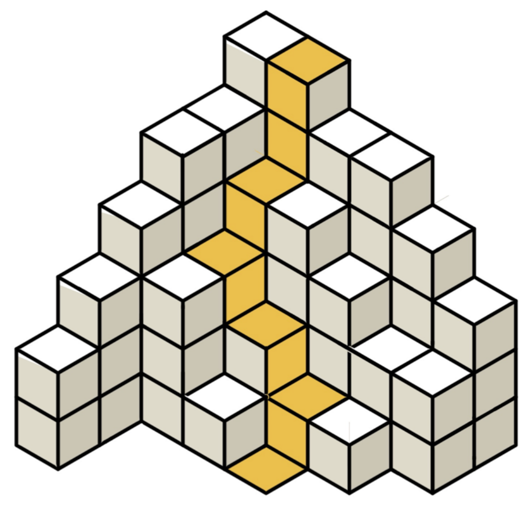
- Cumulative number of upstream pixels that contribute to surface water drainage to any given downstream pixel
- From any pixel, flow goes in the direction of the largest $-\Delta Z$
- Once flow direction is estimated, the algorithm counts how many upstream pixels contribute to any given downstream pixel



Path of steepest descent

Stream network

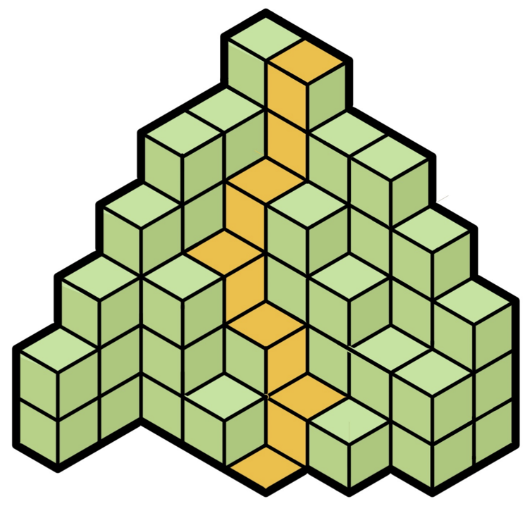
- Applies a threshold of count values c to the Flow Accumulation raster to delineate a **stream**
- If a given pixel has a number of contributing pixels C such as $C \geqslant c$, then the pixel is assumed to be part of the stream
- Stream network is a synonym of path of steepest descent



Path of steepest descent

Drainage basins

- Classifies which stream each pixel contributes to.
- Think of it as a watershed, where ridges act as limits between zone contributing to different streams and valleys accumulate most of the surface flow.



Exercise 1: Path of steepest descent for La Palma

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Aims:

- Analyse hydrological properties of la Palma based on a 25-m DEM
- Revisit historical lava flows based on the geological map
- Get a critical perspective on the path of steepest descent approach

Exercise 1: Path of steepest descent for La Palma

Aims:

- Analyse hydrological properties of la Palma based on a 25-m DEM
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Workflow:

- Go to http://cerg-c.github.io
- Go through the following exercises:
  - Teaching / Setting up QGIS
  - Teaching / Lava hazard / Introduction
  - Teaching / Lava hazard / Getting started
  - Teaching / Lava hazard / Steepest descent

Exercise 1: Path of steepest descent for La Palma

Let's get started together

1. Start QGIS, change language
2. Install Q-LavHA
3. Download and load QIS data

Exercise 1: Path of steepest descent for La Palma

Don't forget to fill up the questions sheet!

Let's get started together

1. Start QGIS, change language
2. Install Q-LavHA
3. Download and load QIS data

How likely are you to recommend the path of steepest descent to a friend?

★ ★ ★ ★ ★

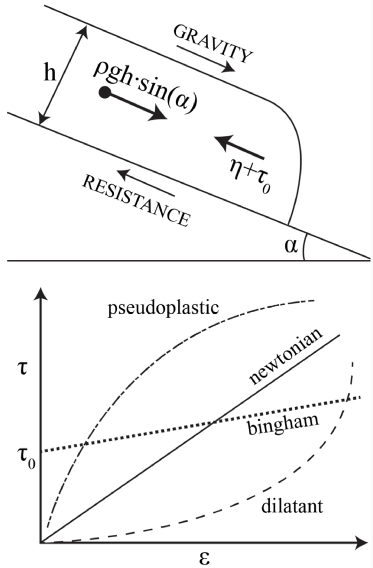
Lava flow part II

Modeling lava flows

Shear stress

The shear stress τ is the load stress applied to a fluid $\rightarrow$ i.e., the force per unit area acting in the direction and parallel to the flow surface:

$$\tau = \rho gh \times sin(\alpha)\ [Pa = Nm^{-2}]$$



When and why do lava flows?

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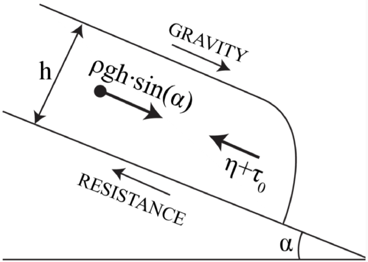
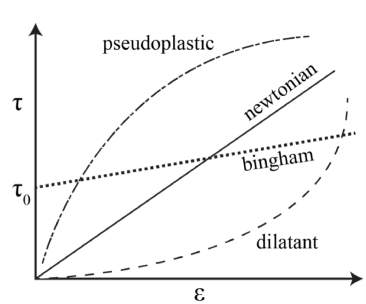
Strain rate

The strain rate ϵ is the rate of deformation when a shear stress is applied $\rightarrow$ i.e., velocity gradient:

$$\epsilon = \frac{dV}{dZ}\ [s^{-1}]$$



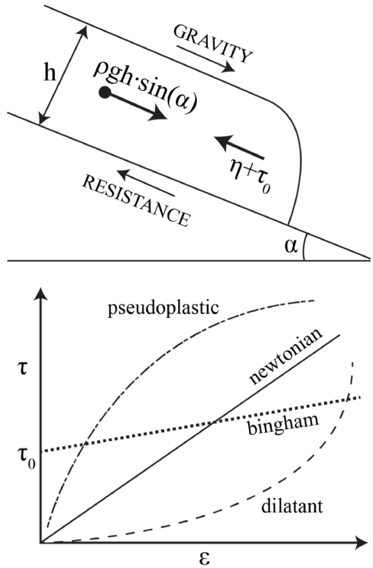


When and why do lava flows?

Yield strength

The yield strength τ_0 is the shear stress above which deformation begins**:

$$\tau_0 = \rho g h_0 \times sin(\alpha) \; [Pa = Nm^{-2}]$$



Yield strength

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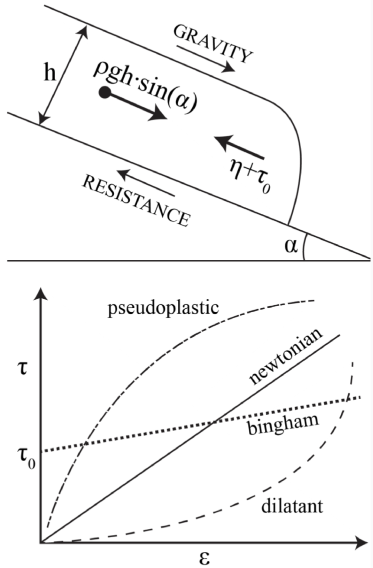
Viscosity

The viscosity η is the resistance of fluid to flow when shear stress is applied:

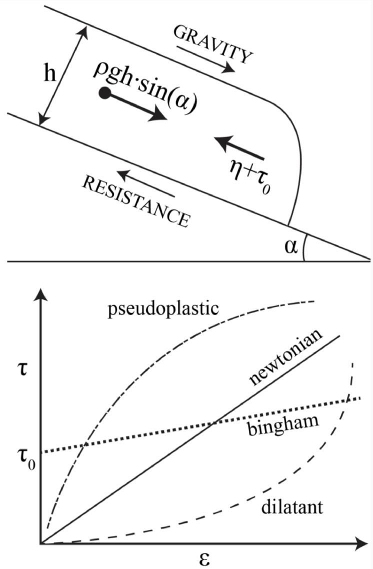
$$\eta = \frac{d\tau}{d\epsilon} \; [Pa\ s = Nm^{-2}s]$$



When and why do lava flows?

Summary:

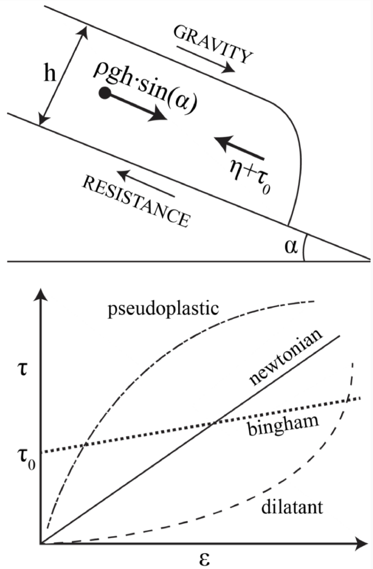
- Flow occurs when **driving forces** exceed **resistive forces**
- Response/behaviour of the fluid depends on its **rheology**



Flow types

Newtonian fluids

- Newtonian fluids start to flow/deform when an infinitesimally low shear stress is applied
- The relationship between the applied force (→shear stress) and rate of deformation (→strain rate) is linear



Flow types

Newtonian fluids

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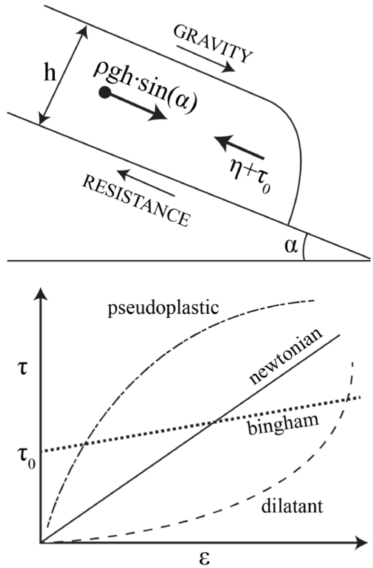
- The relationship between the applied force (→shear stress) and rate of deformation (→strain rate) is linear

Non-newtonian fluid

A fluid is non-newtonian when one of these conditions is met:

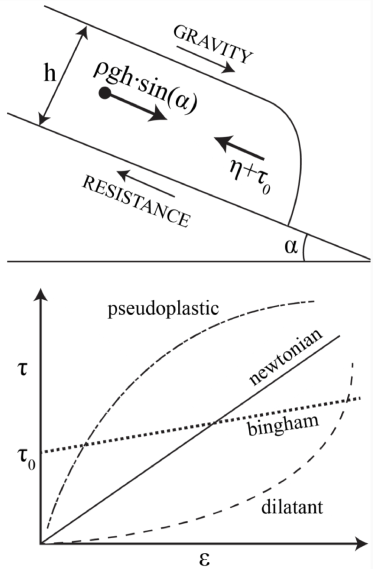
- The relationship between shear stress and strain rate is non-linear
- A yield strength must be exceeded before flowing occurs, after which the shear stress/strain rate relationship can be linear or not



Non-newtonian fluid

Amongst non-newtonian fluids, fluids with variable shear stress/strain rate include:

- **Dilatant fluids**: apparent viscosity increases with increasing shear rate → shear thickening fluids
- **Pseudoplastic fluids**: apparent viscosity decreases with increasing shear rate → shear thinning fluids



Flow types

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Amongst non-newtonian fluids, fluids with variable shear stress/strain rate include:

- **Dilatant fluids**: apparent viscosity increases with increasing shear rate → shear thickening fluids
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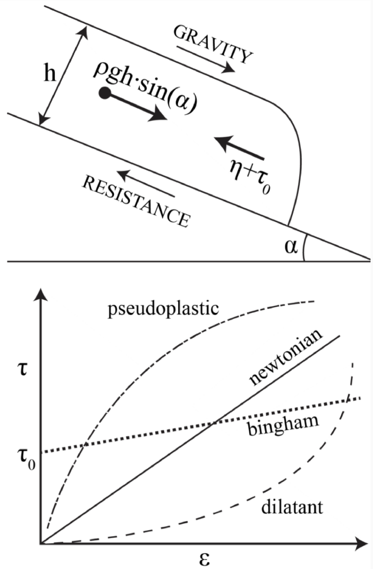
Bingham fluids are a special type of non-newtonian fluids characterized by a yield strength and a linear shear stress/strain rate relationship



Experiment time!

Movie time!

Lava flow videos

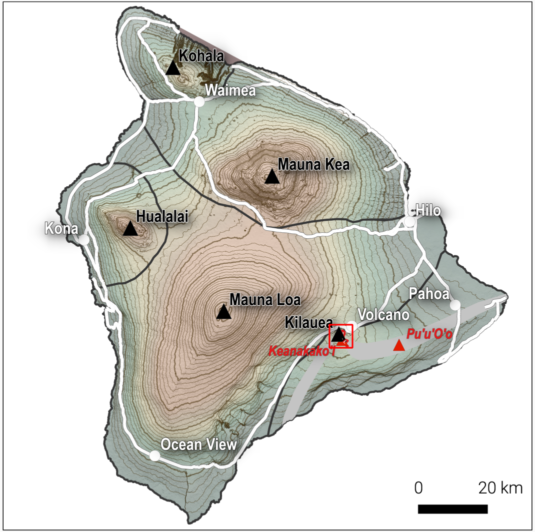
Put these physical concepts in the perspective of actual lava flows!
Look at these videos, and describe them in terms of:

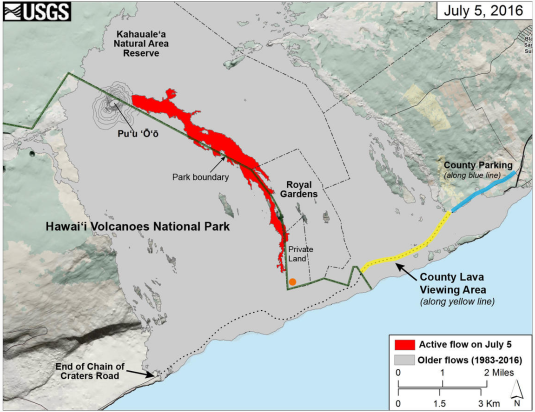
- Flow shape, geometry, morphology, texture
- Colour (as an indicator to which physical parameter)
- Velocity and flow rate
- Driving and resisting forces

What type of fluid are lava flows?

Conclusion: It is slightly more complicated...

Case study: the 2016 61G flow





Case study: the 2016 61G flow

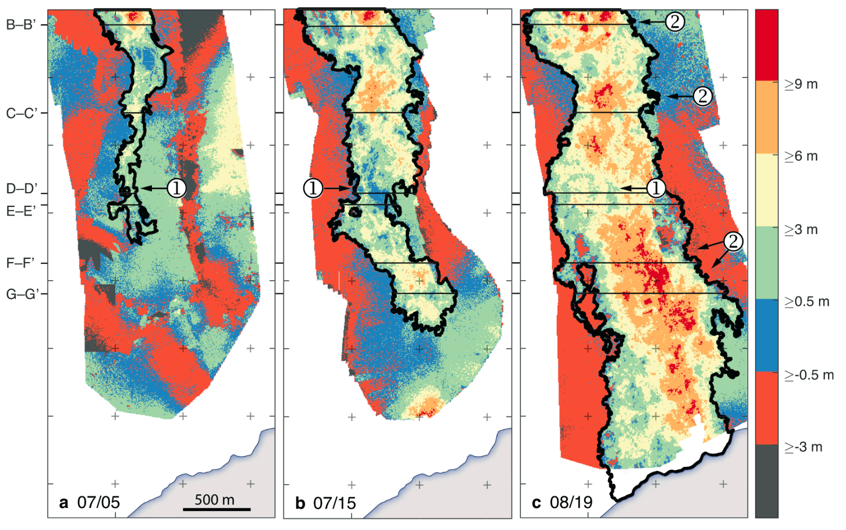
Pahoehoe toes → Thermal insulation → Lava tube

Case study: the 2016 61G flow

Morphology transition → Topography

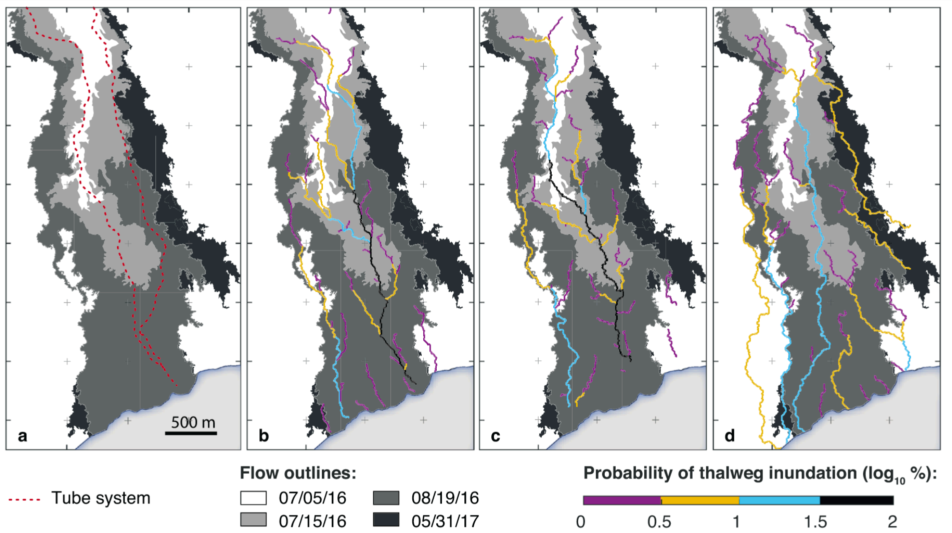
Case study: the 2016 61G flow

Structure-from-motion → DEM evolution



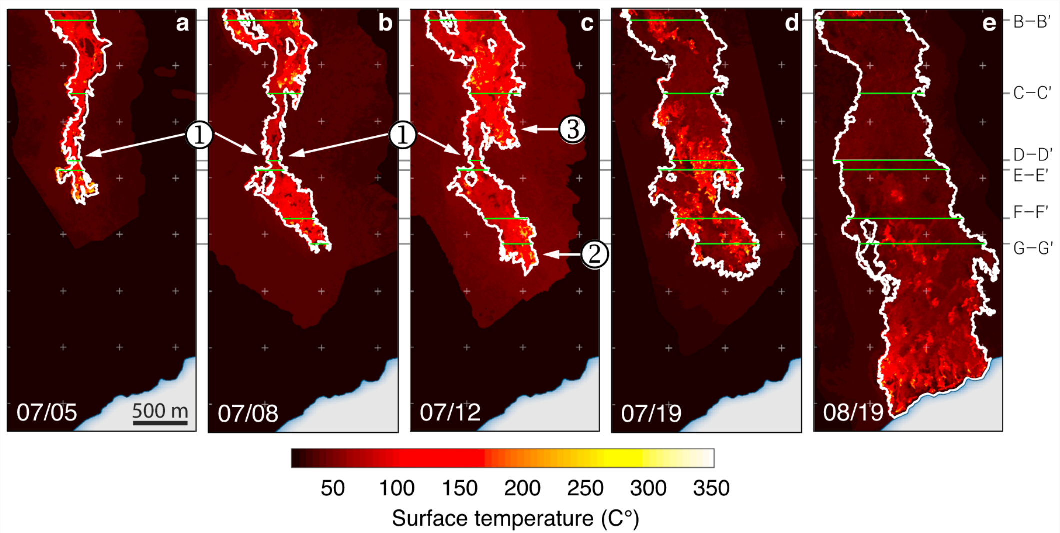
Case study: the 2016 61G flow

DEM evolution → Validation of steepest descent



Case study: the 2016 61G flow

Thermal imagery → Heat budget



Perspective

Lava flows often result in long–lasting crises characterised by large uncertainties. This is partly the case because:

- Lava flows are too complex to (currently) be fully described by physical models
  - → Spatio-temporal evolution of parameters affecting rheology,
  - → Interaction with environment, stochastic processes
- Need a framework to account for, quantify and communicate **uncertainties**
  - → Epistemic vs aleatory

Perspective

"A simple, imperfect model is better than no model"

"All models are wrong, but some are useful"

→ A lot of models are available (see Resources page) **but**

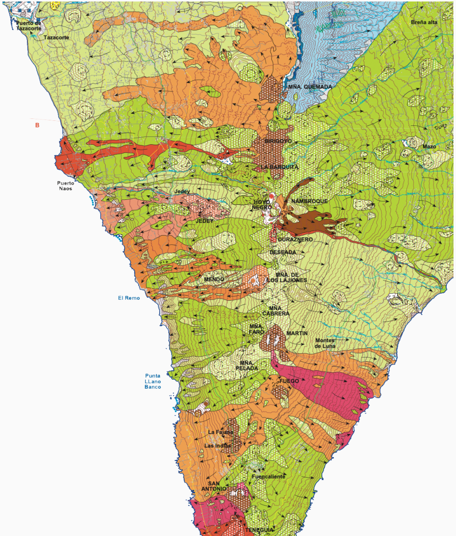
→ They require understanding limitations and sources of uncertainties

Lava flow part III

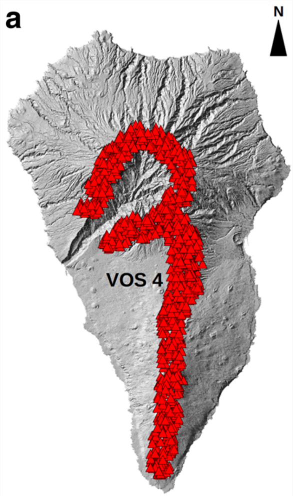
Probabilistic modeling

Vent location

Monogenetic vents

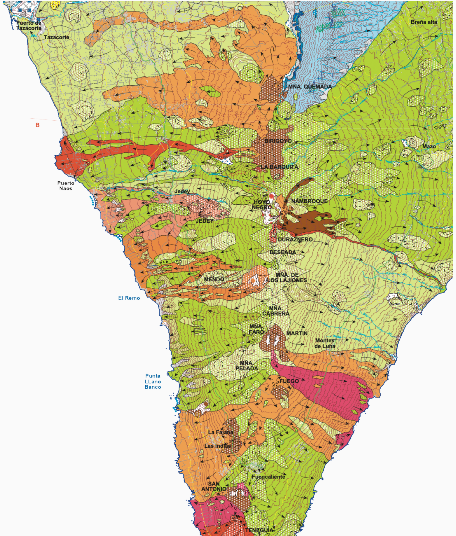


Future eruptions

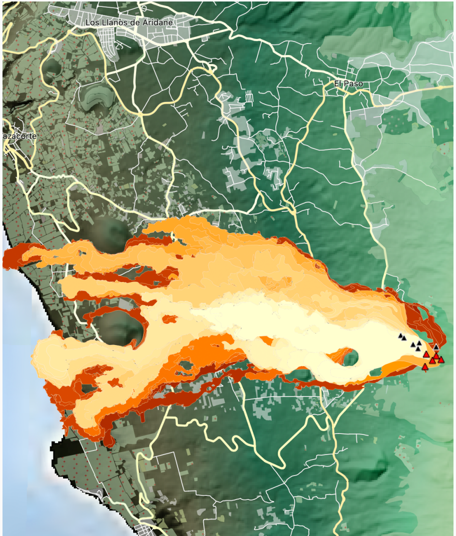


Vent location

Monogenetic vents



Multiple vents for one eruptions

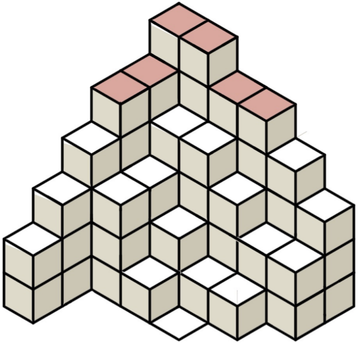


How do we account for the uncertainty on vent location in our hazard assessment for lava flow inundation?

Exploring vent location...

...using a frequentist approach:

1. Assumption that a new vent can open from all these vents
   → For now, assume *equal probability*



Exploring vent location...

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1. Assumption that a new vent can open from all these vents
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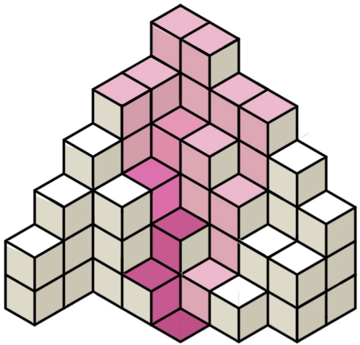
2. Run *path of steepest descent* from all vents
   → Some pixels are *more likely* to be inundated



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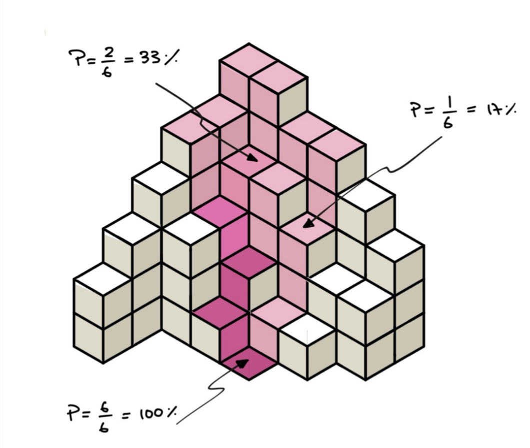
1. Assumption that a new vent can open from all these vents
   → For now, assume *equal probability*
2. Run *path of steepest descent* from all vents
   → Some pixels are *more likely* to be inundated
3. Count the **number of times** a given pixel is inundated and **normalise** by the number of vents



Deterministic vs probabilistic modeling

Deterministic scenario

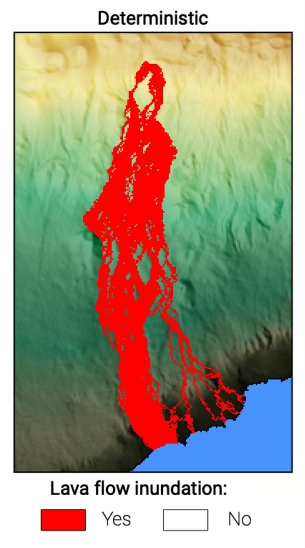
One user-defined value for each model input

↓

One model run

↓

One possible outcome



Deterministic vs probabilistic modeling

Probabilistic scenario

Range of values as model inputs

↓

Many model runs with input conditions sampled in input ranges

↓

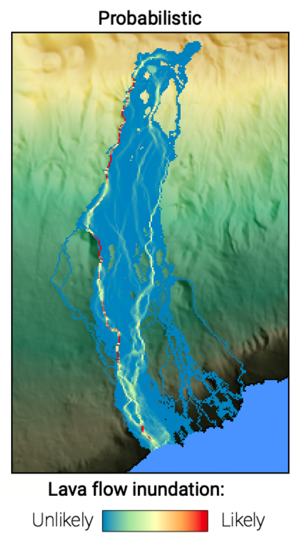
Aggregation of all possible outcomes into probabilities

↓

Allows exploring:

→ Uncertainties on input parameters

→ What could happen in the future



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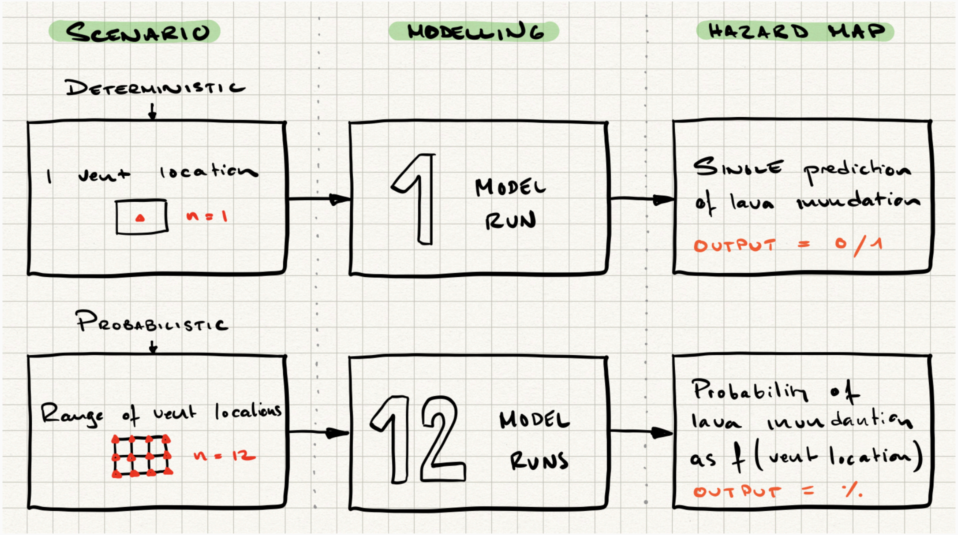
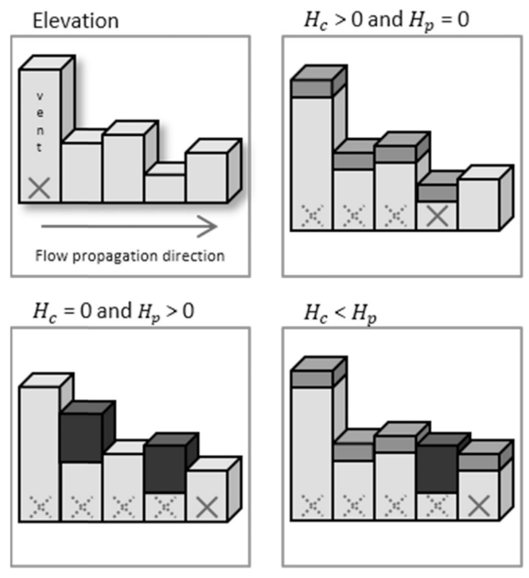


Lava flow part IV

Q-LavHA

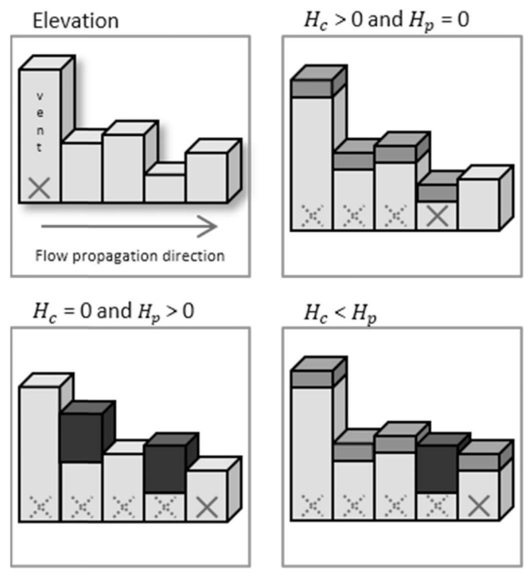
Q-LavHA

- **Q-LavHA** → QGIS plugin
- Starting point → path of steepest descent



Q-LavHA

- **Q-LavHA** → QGIS plugin
- Starting point → path of steepest descent
- Probabilistic approach to simulate:
  - Flow inflation → filling depressions → lateral spreading
  - Uncertainty on vent location



Q-LavHA

- **Q-LavHA** → QGIS plugin
- Starting point → path of steepest descent
- Probabilistic approach to simulate:
    - Flow inflation → filling depressions → lateral spreading
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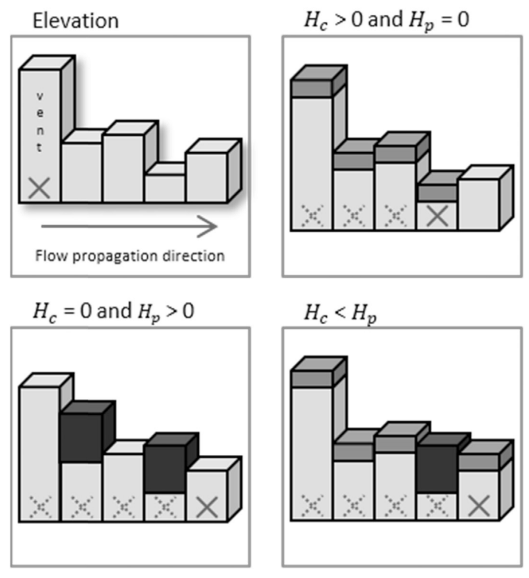
- Thousands of iteration of the path of steepest descent
    - Next inundated pixel not only based on $|\Delta Z|$, but on a probability function based on $|\Delta Z|$ of all adjacent pixels



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- Starting point → path of steepest descent
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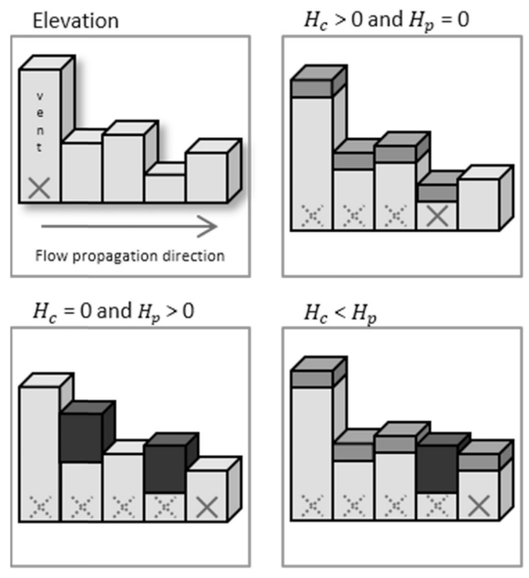
  - Flow inflation → filling depressions → lateral spreading
  - Uncertainty on vent location
- Thousands of iteration of the path of steepest descent
  - Next inundated pixel not only based on $|\Delta Z|$, but on a probability function based on $|\Delta Z|$ of all adjacent pixels
- **Output:** probability of flow inundation



Exercise 2: Probabilistic lava flow inundation hazard assessment for La Palma

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Aims:

- Perform a probabilistic hazard assessment for lava flow inundation for La Palma
- Contrast results when using point vs surface source

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Workflow:

- Make sure you have installed **Q-LavHA**
- Go through the Q-LavHA exercise on http://cerg-c.github.io

Exercise 2: Probabilistic lava flow inundation hazard assessment

Aims:

- Perform a probabilistic hazard assessment for lava flow inundation for La Palma
- Contrast results when using point vs surface source

Don't forget:

- To answer questions!

Questions?

sebastien.biasse@unige.ch
e5k / http://e5k.github.io