Cellular Automata Models Of Volcanism

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1. Introduction

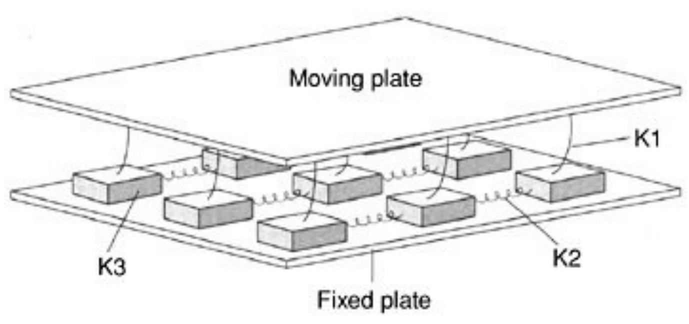
Natural phenomena, such as volcanoes, earthquakes and tsunamis, can have devastating effects on people. Observatories across the globe monitor the seismic activity in the vicinity of volcanoes in an attempt to gain advance warning of potential volcanic activity. Seismic activity can be chaotic and yet maintain some underlying order, something which is demonstrated by a 'self-organised criticality' model. My summer research project initially considered the cellular automata models of earthquakes introduced by Olami, Feder and Christensen (OFC), which exhibit self-organised criticality. I then considered the models by Piegari *et al.*, who extended the OFC model to consider volcanic activity.

2. Aims/Objectives

To develop an understanding of cellular automata models: reproducing the work of Piegari *et al* for statistical outcomes of interest; analysing the effectiveness of this model at recreating observed statistics for volcanoes.

3. Initial Earthquake model

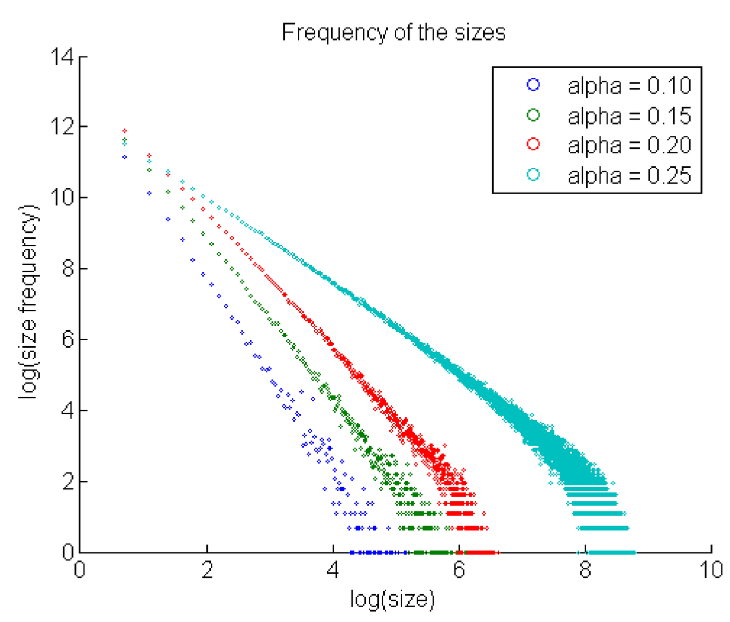
The OFC model is based on the idea of a 'slider-block' as shown in the figure[4] below. Each of the blocks are sandwiched between 2 plates, one stationary and one that moves at a constant rate. As the plate moves, the force acting against the friction between the fixed plate and each block rises, until a threshold value is met and one of the blocks moves. Each block interacts with its neighbours via some simplified rules. E.g. the stress from the moving block is then distributed to its neighbouring blocks, which can cause a knock-on effect, resulting in an earthquake event.



In the chamber of a volcano, fractures in the rock provide openings through which magma can rise up towards the surface. These fractures can open up in response to different triggering mechanisms such as regional stress or earthquakes.

4. Key Earthquake Model Results

In 1956, Gutenburg and Richter proved that there is a relationship between the magnitude of an earthquake and its rate of occurrence. I was able to show events in my earthquake model followed a similar relationship, therefore increasing its credibility.



5. Volcano model methodology

With a credible code for dealing with the stress within the rocks of a volcano chamber, I incorporated the addition of magma to the system, initially through a simple system which considered a cell to either be full or empty, as shown in the 2008 paper by Piegari *et al.*. I then developed my code by adding the additional effect of certain properties of magma such as exsolved water content.

6. Results

The figures below model the inside of the volcano chamber at the time of a volcanic eruption. The bottom of each grid is connected to the magma reservoir through which magma rises into the chamber. The top of the grid represents the Earth's surface through which magma during an eruption escapes.

The colour code on the right describes the exsolved water content of the magma as it rises, and the beige coloured cells represent fractured cells, generated by the earthquake model and through which the magma can percolate.

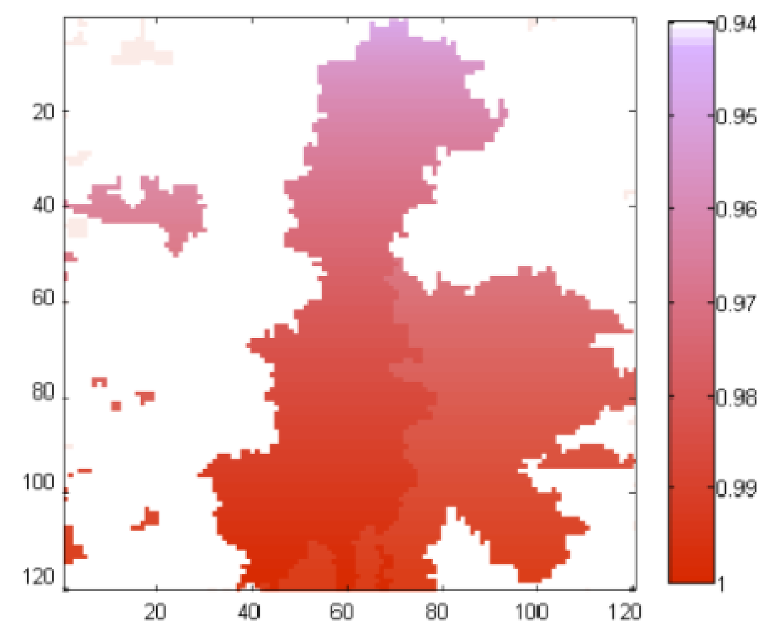


Figure 1

In Figure 1 we can see that at the time of eruption , a large volume of magma with a low water content is connected to the surface, whereas in Figure 2 a smaller volume of magma with a higher water content is involved in the eruption.

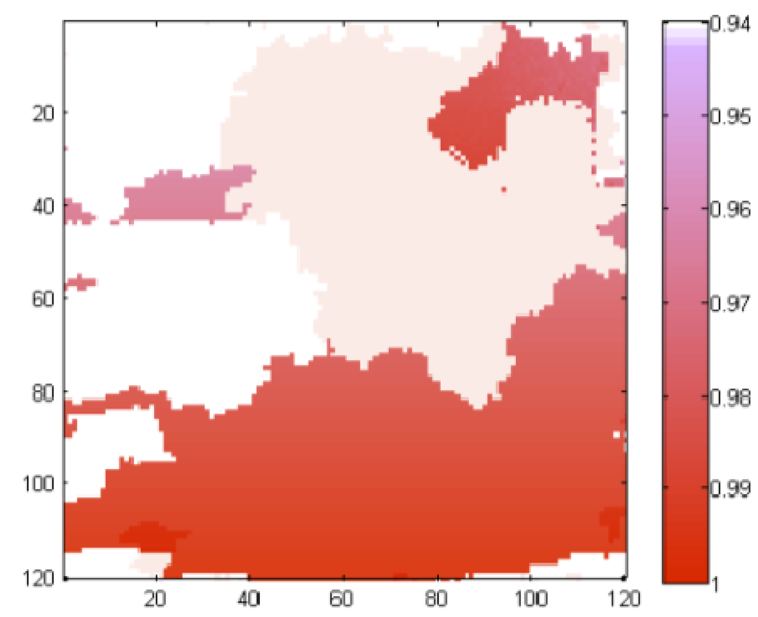


Figure 2

The most common eruptions are those which have lost the majority of their water content by the time the magma is ejected from the system as shown in Figure 1. Events where the ejected magma contains a higher water content as in Figure 2, are rarer. As I continue this research I hope to show that my model recreates these statistics quantitatively.

7. Conclusion

I have obtained an understanding of cellular automata models, replicated earlier models applied to earthquakes, and started to develop these models for application to volcanic activity.

Whilst a general agreement was achieved there were some discrepancies with the detailed results of the Piegari *et al.* papers and these need to be resolved prior to any future research.

My figures and plots show sensible behaviour for the rise of magma. And the statistics obtained are broadly correct. However, to further enhance my research I would:

1. Confirm the precise methods used by Piegari *et al*. to improve the agreement of the results.
2. Investigate other variables that have a major impact on volcanic eruptions, and incorporate these to develop a more comprehensive model.

References:

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