Mathematical Modelling and Self-Learning Systems

Masters Thesis

Volcanoes as dynamical systems

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The Goal

Analysis the physical states of volcanoes using LSTM

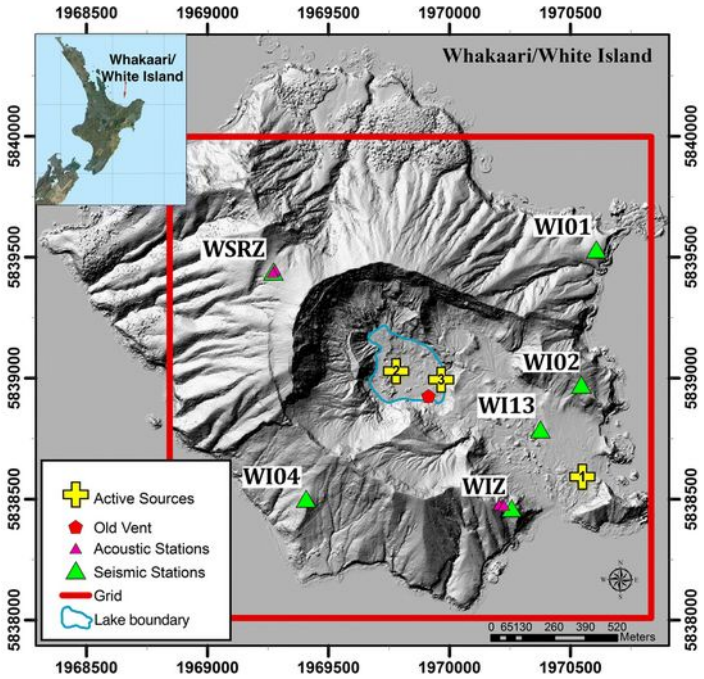
What are we going to be talking about?

1. A Background on Volcanoes
2. A Dynamical Systems Perspective
3. A Neural Network approach to Eruption Detection
4. What is an LSTM
5. Data Acquisition, Processing and Modelling Approach
6. Results
7. Summary

A Background on Volcanoes

- A volcanic eruption:
  - Hot magma rises
  - Increased pressure
  - Explosive eruption
- White Island(Whakarri) 2019 event
  - Phreatic eruption
- > 1,500 volcanoes across the world

A map of Whakaari Island, New Zealand

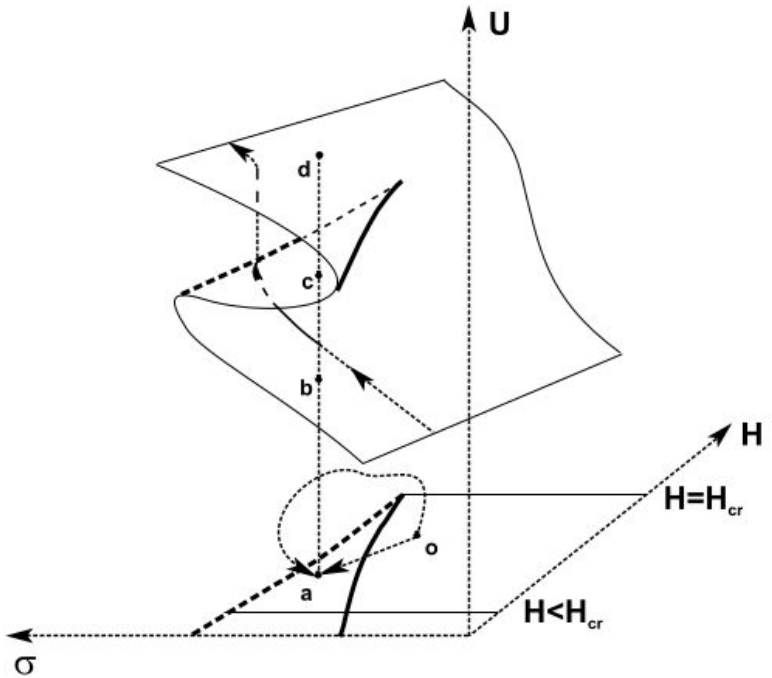


Source: Braden Walsh et al. “Geophysical examination of the 27 April 2016 Whakaari/White Island, New Zealand, eruption and its implications for vent physiog-nomies and eruptive dynamics”. In: Earth, Planets and Space 71.1 (2019), pp. 1–18.

A Dynamical Systems Perspective

- ‘An eruption is an event, separated from other similar events by a rest (or dormant) interval’ - Slezin
- *U* denotes the magma discharge rate.
- Basic governing parameters:
  - magma chamber depth, *H*
  - conduit conductivity, *σ*
- Theory applied to well documented eruptions [Tolbachik(1975-76) & Mount St.Helen’s (1980)]

magma ascent velocity, U, as a function of governing parameters H and σ



Source: Yu.B Slezin. “The mechanism of volcanic eruptions (a steady state approach)”. In: Journal of Volcanology and Geothermal Research 122.1 (2003), pp. 7–50. ISSN: 0377-0273.

A Neural Network approach to Eruption Detection

- Carbiel et al (1996)
- Raw data from recordings at Stromboli Volcano, Italy.
- Substitutes the original state space of the volcano dynamical system with a pseudo state space.
- Used a feedforward neural network - Input includes a delay component.

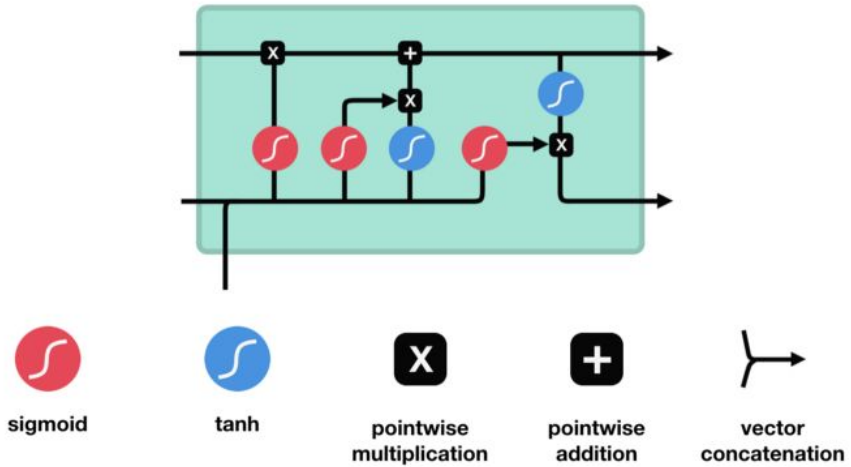
Volcanic Eruption at Stromboli, 2014

Source:

- Carniel. “Neural networks and dynamical system techniques for volcanic tremor analysis”. In: 39.2 (1996).
- https://earth.esa.int/web/earth-watching/historical-views/content/-/article/stromboli-volcano/

What is an LSTM?

- A type of recurrent neural network
- An LSTM cell
- Implemented through Tensorflow with Keras



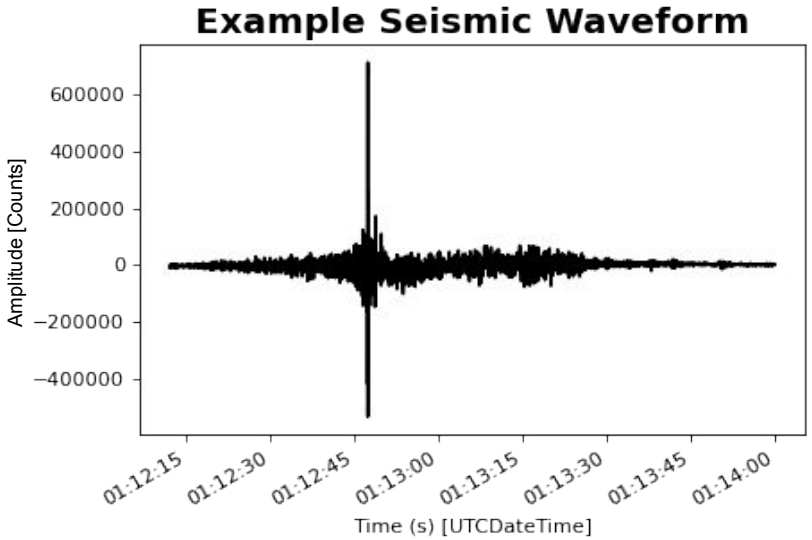
Source: https://towardsdatascience.com/illustrated-guide-to-lstms-and-gru-s-a-step-by-step-explanation-44e9eb85bf21

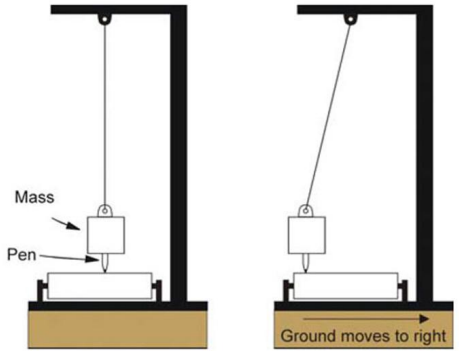
Data

- White Island (Whakarri) from the WIZ station [GeoNet] on the 9/12/2019

- Seismometer creates seismogram

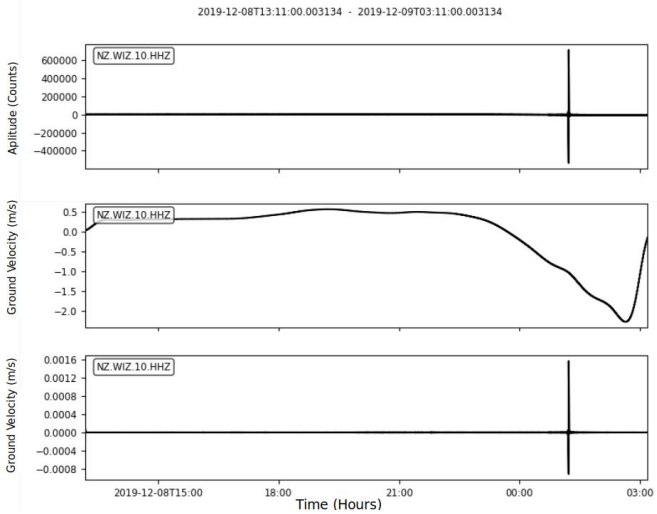
- 5,040,001 data points in the raw data.

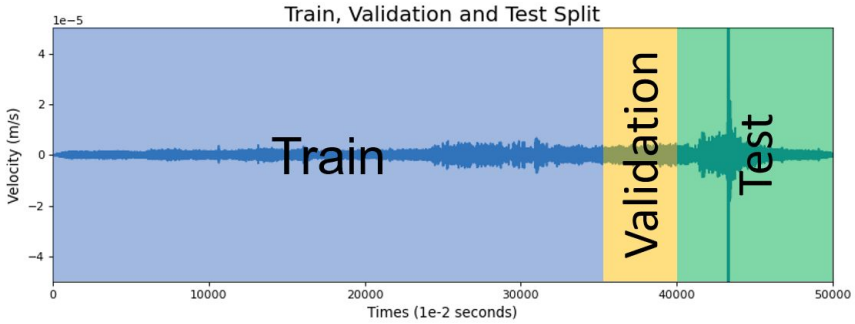




Source: https://www.bgs.ac.uk/discovering-geology/earth-hazards/earthquakes/how-are-earthquakes-detected/

Picture of the time series data at each stage of processing: Raw Data, Data with response removed & filtered data

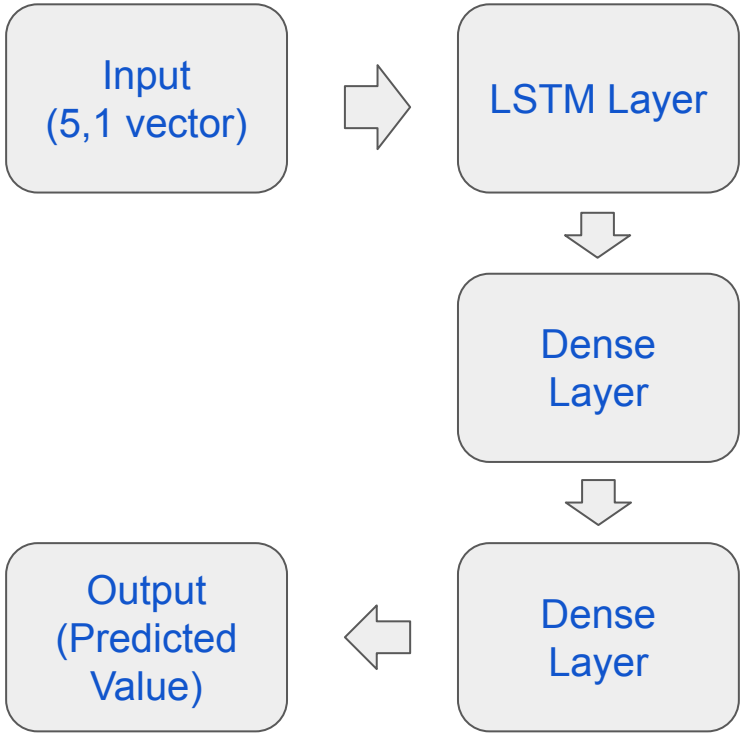




Data Processing

- Obspy: A python toolbox for seismology
- The data was processed as follows:
  - removing instrument response
  - detrending
  - filtering (removing frequencies < 3Hz)
  - changing the sampling rate - 0.0125 (80 Hz)
  - Writing the Data to a file
- The data was normalized and split into training, validation and test sets
- The data is passed the data through a sliding window class

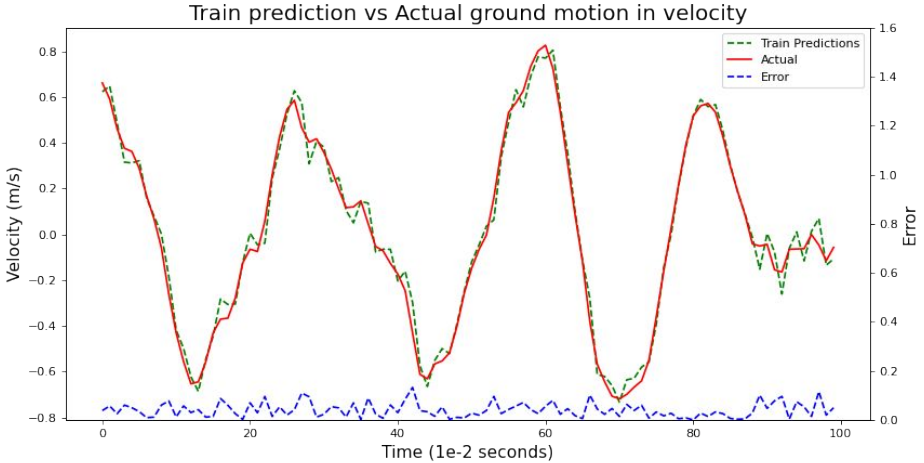
Modelling Approach: LSTM

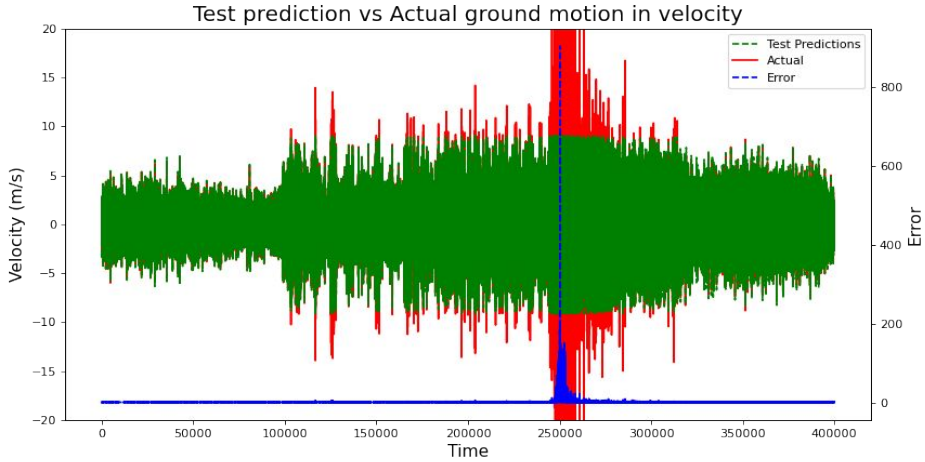


- Model trained/validated and tested on Seismic waveform (time series data)
- The optimizer is Adam
- The loss function is MSE
- Trained for 10 epochs

Results

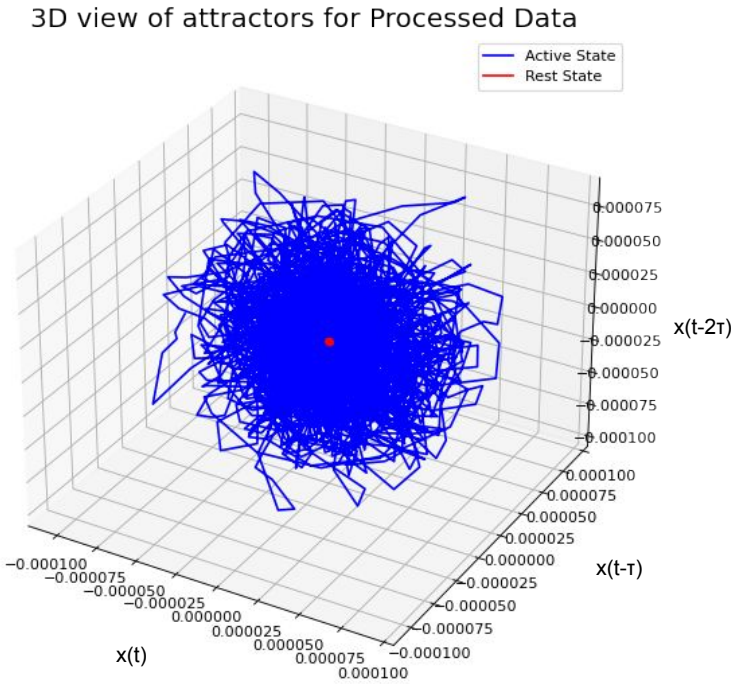
- Visually, Good Accuracy when predicting on the ‘steady’ (rest) state.
- The loss is low and is not decreasing much after first epoch.
- The model interprets that two different attractors exists





Results (Continued)

- Visualisation of the two attractors
- A resting attractor surrounded by an erupting chaotic attractor.



Source: Discussions with Andrew Keane

Summary

- A volcano can be described a dynamic system with two attractors, a resting attractor where the volcano is said to be dormant and an eruptive chaotic attractor.
- LSTM was selected as the model for this thesis based on its ability to retain information.
- The White Island Data was acquired through the seismic dataset, GeoNet. A number of preprocessing operations were carried out in order to get the input in the correct format before it could be passed into a model
- An LSTM model was complied
- The model interprets the existence of two different attractors

Thank you for your attention - Questions?