Imperial College London
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MSc in Applied Computational Science and Engineering

Independent Research Project
Project Plan

Creating a Semi-automated tool to generate change in lava flow features of Magellan SAR images of Venus

by

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Abstract

Exploration of Venus' surface is solely possible by radar data due to Venus' thick atmosphere. To be able to understand its morphology and the way Venus' surface has changed through time, however there is no radar data at the moment that covers a big enough time period is see change. This research project aims to create a semi-automatic tool in python code that can take a radar image of Venus and generate synthetic expansion or formation of lava flows in the image.

Introduction

Venus is an important planet to understand as it is very similar to Earth in size and Earth's nearest planetary neighbour (Venus - NASA Science), but very different in the thick atmosphere with a high CO_2 content and temperature. Therefore it is important to understand Venus' surface evolution.

One of the main sources of information about Venus's surface came via the Magellan Satellite. This produced radar images from 1990 to 1993, giving us a good understanding of the variations of landforms and geology for 85% of Venus's surface (Ivanov and Head 2011), (Basilevsky and McGill 2007). Due to the short period which Magellan data covers, there is no way of viewing significant change in the landscapes, thus it is difficult to detect change and morphological processes.

However, the upcoming VERITAS mission from NASA (in 2028) and the Envision mission from the European Space Agency (in 2034) will improve the data regarding Venus's surface. Due to the 40 years between the data provided by Magellan and new data from the upcoming missions we will be able to answer one of the biggest questions regarding the planet: how has Venus changed? This answer will help us understand the processes that have formed the planet's landscape. The potential challenge in monitoring any change is that the radar images produced by Magellan and VERITAS are going to have very different back-scatter patterns even if there is change in the landscape due to the difference in orbit and angle of detection. To be able to detect the change in the images it is useful to know what these changes could look like on Magellan images, and thus help differentiate what could be changes in the landscape and changes may be due to the satellites.

The goal of my research project is to produce radar images from the Magellan dataset that depict morphological change that could have occurred in the 40 year time span since the original radar images were taken. Therefore, when the VERITAS and Envision data is collected there will be Magellan data to compare it with. Specifically, my project aims to create a semi-automatic tool to generate plausible and natural-looking change in lava flows in a Magellan radar images of Venus's landscape. The tool should take in a set of parameters and a radar image that will then produce an image with a lava flow in it, or the expansion of a previous lava flow.

Lava flows are greatly significant in shaping Venus's surface as there are no fluvial processes taking place and only minimal aeolian processes. Therefore, the main processes of change in the landscape is from tectonic activity (Ivanov and Head 2011), (Basilevsky and McGill 2007). Furthermore, the goal is to be creating change that would be possible between the Magellan data and the future VERATIS and Envision data thus it has to be processes that would have taken place to a significant extent in forty years. It has been confirmed that volcanism is widespread across the whole planet, and is "fundamentally important in the formation and evolution of the crust of Venus." (Head et.al. 1991). The most abundant lava flows are basaltic in composition (Head et.al. 1991), so will be the type I am planning on replicating.

There has been lots of research that uses radar data to map and analyse lava flows, mostly based on volcanism on Earth. For example, the paper on analysing lava flows on Hawaii (Dietterich et.al. 2012), (Zebker et.al. 1996) rely on looking at the coherency of radar images, which only works if you can get images of the same region, close to the same time by using inSAR. Overall, unlike observing lava flows on Earth, the limiting factor for Venus observation is the available data. So this project differs to prior research, as it relies on one set of Magellan SAR data from the 1990s that has a relatively low resolution, and there is a lack of radar contrast (Head et.al. 1991).

Methodology

To successfully complete this project there are two main objectives I need to fulfil.

1) Create and model the formation and expansion of a lava flow.

2) Generate this change in a radar image, and have this modelled change translated into the form of radar images (as backscatter intensity).

a) How would this kind of change effect the backscatter values?

b) How would it affect the texture and spatial fluctuations?

Objective 1

Firstly I need to model a lava flow. I will start by creating a pixel grid model of a flat surface and find the average estimated values for Venus for the parameters.

There have been lots of papers that discuss and have implemented code for fluid simulations, for example the paper ‘Stable Fluids’ (Stam 2023). This paper states that the best way to model fluid flows is to use the Navier-Stokes equation (Stam 2023). Which is defined as fluid changing over time by:

$$\nabla \cdot \boldsymbol{u} = 0$$

$$\frac{\partial \boldsymbol{u}}{\partial t} = -(\boldsymbol{u} \cdot \nabla)\boldsymbol{u} - \frac{1}{\rho}\nabla p + v\nabla^2\boldsymbol{u} + f$$

Where v is the viscosity of the fluid ρ is the density and f is the external forces. This equation represents how the fluid changes in space and time.

The “Stable Fluids” paper models fluid more similar to a water simulation on earth, therefore certain parameters will be different for my application, such as f will take gravity of Venus instead of earth. In addition, v will be this viscosity of basaltic lava, I may have viscosity as a parameter that can be changed by the user of the code so that the tool can be applied to different lava types. Furthermore, the solidifying lava also has to be taken into account.

The paper “Numerical simulations of flood basalt lava flows: Roles of parameters of lava flow morphologies” provides an in-depth description on how to numerically model basaltic lava flow, which takes into consideration viscosity, lava’s yielding strength, eruption rate, cooling and topographic features (Miyamoto and Sasaki 1998). In the paper “Stable Fluids" it is modelling a Newtonian fluid, as it aims to simulate water-like fluids, but it is clear from (Miyamoto and Sasaki 1998) and (Asimow and Wood 1992) that it is better to define lava as a Bingham fluid, characterised by a yield strength and plastic viscosity (Miyamoto and Sasaki 1998) and (Asimow and Wood 1992). Therefor I will be using the adapted fluid equations from (Miyamoto and Sasaki 1998) and (Asimow and Wood 1992) to create my lava model.

Objective 2

For objective two, this will be the case of sticking the modelled lava flow into the radar image. To do this I am planning on analysing radar images and working out what the backscatter signature is common for basaltic lava flows and using this to convert the modelled pixel array into the radar image. First I will filter a sample radar image to separate out the lava flows from the rest of the Image.

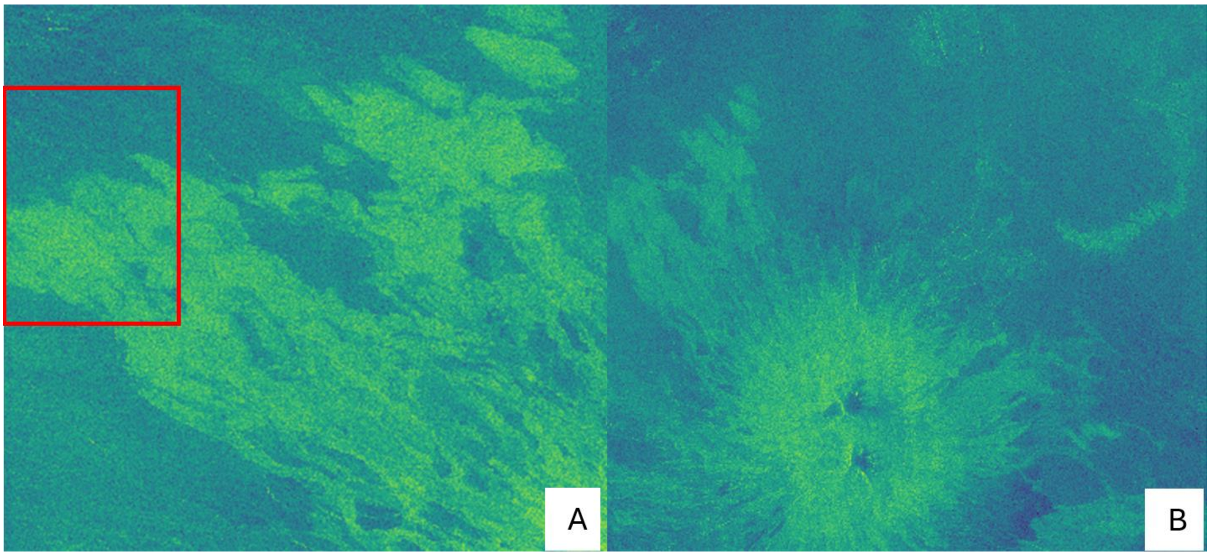


Figure 1 A shows the dB corrected lava flow that is used as a sample lava flow. B the original plot of the dB corrected, of the Sapas Mons Volcano.

To begin to understand how the backscatter pattern of the lava flow, I started by creating a histogram of the pixel values, shown on figure 2. It seems that there are two peaks in the data, which could suggest the average pixel values of the lava flow. So the pixel values were split by the value -10, as an attempt to split that data between the peaks.

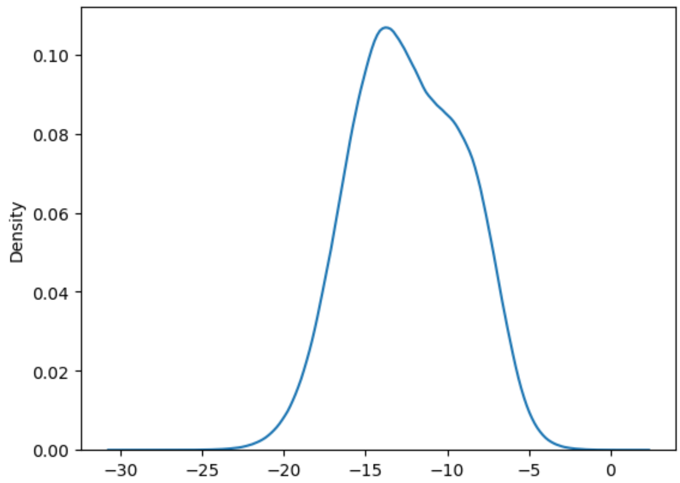


Figure 2 This is the pixel value histogram for figure 1A

Figure 3a shows that by splitting the data by -10 value, it has made the lava flows a lot clearer and they are the areas that are more densely populated by pixels with the values greater than -10. To get rid of the single pixels that are making the dotted effect I tried using a convolutional filter, where that kernel chooses the modal value in the kernel, shown in figure 3b. This did not improve the image much apart from simplifying it. Instead of using a modal filter, I used a gaussian filter and with a sigma value of 3, shown in figure 3c, the image was much improved as the lava flow looks completely separate to the rest of the image.

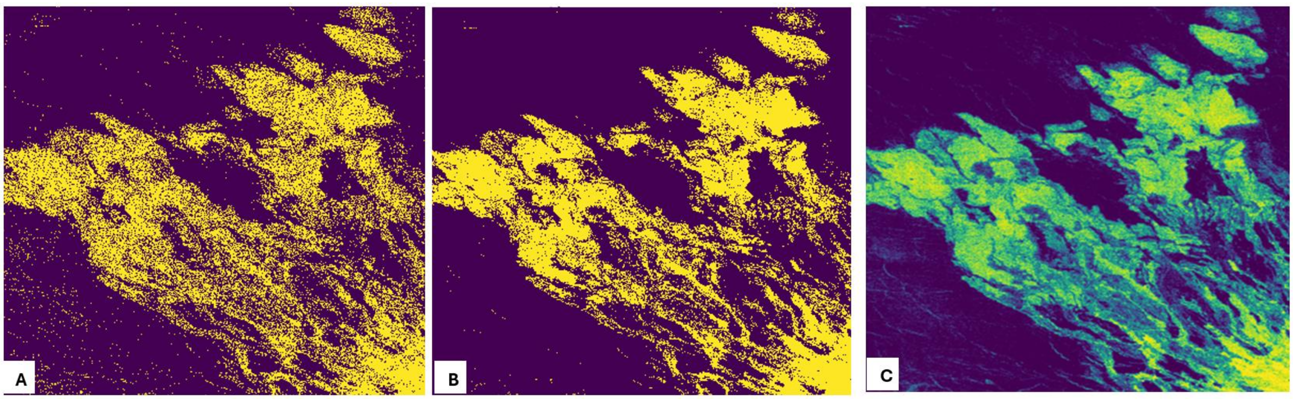
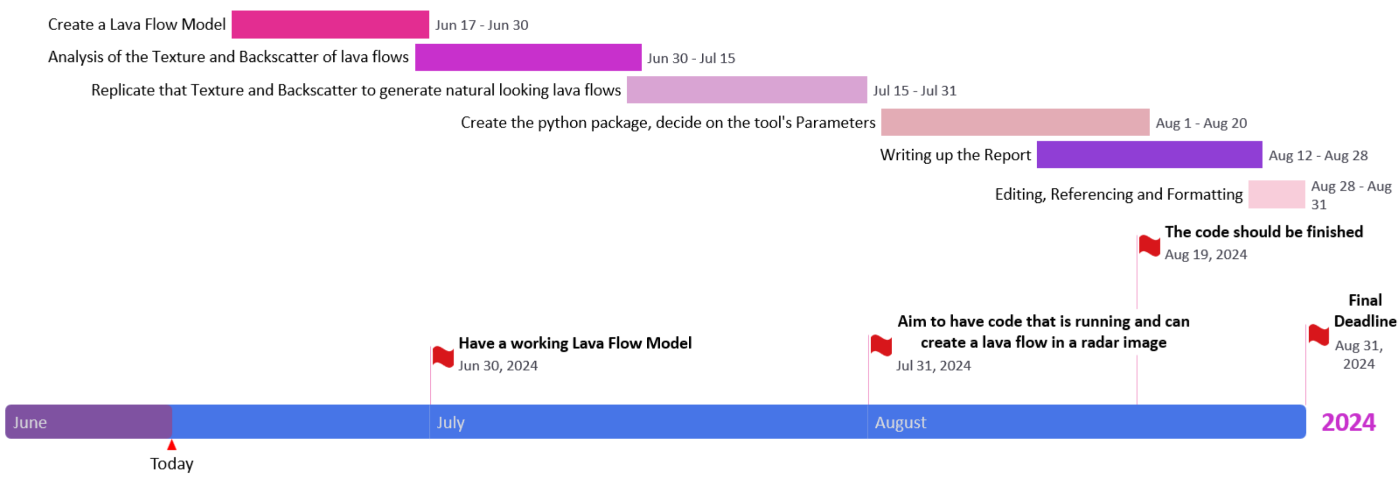


Figure 3, A shows the Binary image, B shows the image with modal pixel value filter and C shows a gaussian filtered image.

Project Timeline

My current plan for completing this project is to dedicate the next month creating code for a working lava flow simulation as well as code that can produce synthetic radar images of lava flows. My aim is by mid-July to have initial code that can produce a lava flow in a radar image. Then I will spend the following month improving on the code, so improving the quality of the images as well as designing the code to be user friendly and well packaged. Finally, I will dedicate August to writing up the report.



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