Volcanology and Geoinformatics

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1. Introduction

Geoinformatics (sometimes referred to as geographic information science) is a term which has a variety of descriptions, but generally it refers to data which has been collected through techniques such as remote sensing which is analysed, processed, and visualised on a computer (University of Twente, 2011). Remote sensing involves the use of electromagnetic radiation (Figure 1 shows the electromagnetic spectrum) to collect data about an object via an instrument which is separate from the object itself. There are two types of remote sensing systems, the first is 'active' and involves the production of pulses such as radar to look at topography whilst the second is 'passive' and relies on pre-existing incident electromagnetic radiation to image an object (Lillesand et al. 2008). Within this review, the influence of geoinformatics on volcanology will be discussed. At first glance it may seem that geoinformatics doesn't play a large role within volcanology, however when one delves deeper, there is a huge amount of research and literature utilising geoinformatics practices to solve and present volcanological problems. In the past, volcanology was purely based on written observations (Sigurdsson, 2000), however with the advancement of technology the need for processing and more sophisticated analytical techniques has led to the incorporation of geoinformatics within volcanology. A selection of these instances will be discussed in more detail in section 2. It is important to note that geoinformatics is not solely used in conjunction with terrestrial projects but extra-terrestrial ones as well, this will also be discussed.

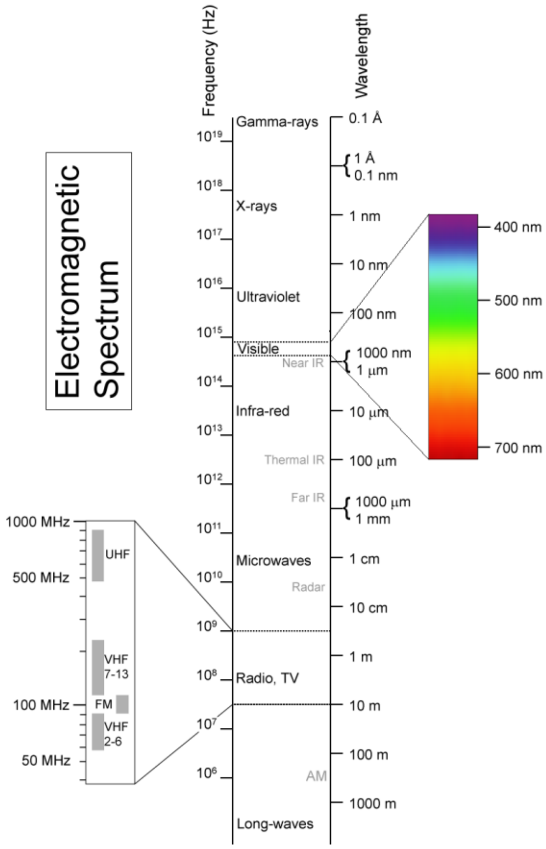

Figure 1: This graphic shows the Electromagnetic Spectrum. Graphic was taken from Wikipedia (2010)

2. Review

2.1. Monitoring

The monitoring of volcanoes is an important part of volcanology. Certain aspects of monitoring could not be done without the input of geoinformatics, one geoinformatics technique used is InSAR. InSAR (Interferometric Synthetic Aperture

Radar) is a technique which involves comparing two or more radar images of an area to facilitate in the creation of digital elevation models (DEMs) or to model deformation of a surface over a period of time (Smith, 2002), its main benefit is accuracy; up to a centimetre over a wide spatial area (USGS, 2008a). Figure 2 shows an example of an InSAR deformation image. One of

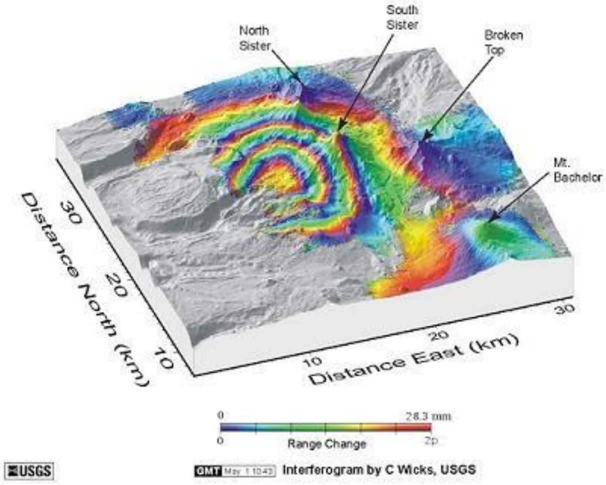

Figure 2: Taken from USGS (2008a) this image is an example interferogram created using the InSAR technique. This interferogram shows uplift occurring approximately 3 miles east of South Sister. Differences between images are indicated by the colour scale at the base.

the first to look at the uses of InSAR was Graham (1974) who investigated its potential in projecting topography. The use of InSAR is now more widely used on volcanoes, for example recently it has been applied to the Soufriere Hills Volcano (Wadge et al. 2011), Popocatepetl, and Colima (Pinel et al. 2011). InSAR is particularly useful for monitoring large volcanic areas such as the complex geologic setting at Yellowstone however due to the lack of time available on existing satellites, the continuity of any data is limited and therefore other techniques such as GPS deformation have been applied and preferred (USGS, 2011). The InSAR technique is often used in combination with others, such as GPS, tiltmeters and laser ranging (USGS, 2008a). Other focuses of InSAR include earthquakes, glacial studies and the subsidence of land (Smith, 2002).

A more common volcanological technique is thermal imaging of volcanoes, which can be implemented with ground based instruments, fixed wing aircraft and satellites to detect the heat/temperature of a variety of features. Examples of satellites with thermal imaging capabilities include ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) and Landsat TM (Thematic Mapper). ASTER has been used by (Ganas et al. 2010) to look at heat flux around the Nisyros volcano in the Aegean Sea, whilst an example of Landsat TM data use is the investigation of fumaroles at Mt. Unzen, Japan (Kaneko and Wooster, 1999).

Ground based monitoring using thermal imaging of lava lakes is commonplace, due to its increased accuracy and the expense of respective satellite methods. Examples of use include at Mt. Erebus, Antarctica (Calkins et al. 2008) and Erta Ale, Ethiopia (Spampinato et al.2008). Ground based monitoring of lava flows, eruption columns and hydrothermal features can also be completed in this way. Sawyer and Burton (2006) used an FTIR (Fourier Transform Infrared Spectroscopy) spectrometer to determine the effects of volcanic plumes on thermal radiation measurements at Stromboli, Italy. Fixed wing thermal imaging is conducted in Yellowstone National Park on hydrothermal systems around geysers such as Old Faithful. Changes in temperature can be useful in determining heat flux from the interior of the earth (USGS, 2011).

Satellite imagery can be used in a multitude of ways to support volcanological interests and monitoring. Satellite data can be used to assess the aftermath of an eruption, including the assessment of damage to buildings, the extent of area affected and others. An example is shown in Figure 3. Assessments such as these can be included in hazard maps

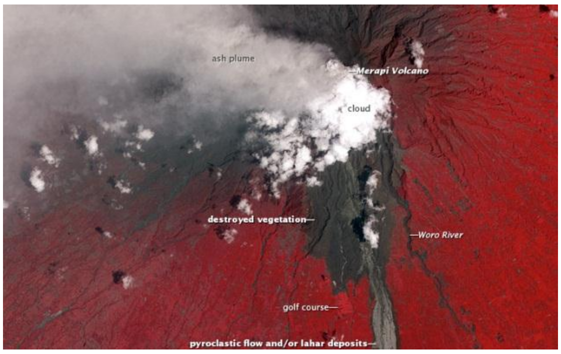

Figure 3: Example of a false colour composite image from the Earth Observatory (2010). The red indicates vegetation, whilst the grey indicates areas which have been devastated by PDCs and lahars. Also shown is the eruption plume.

(discussed in section 2.2). Analysis of satellite imagery can also be used to advise authorities on appropriate action, a good example is Mt. Nyiragongo, DR of the Congo, its active lava lake and devastating lava flows (Oppenheimer, 1998). This is also useful on volcanoes such as Mt. Etna.

Ground based (radar) and satellite monitoring of ash clouds can be useful and was important during the eruption of Eyjafjallajökull in 2010. Figure 4 shows an example of eruption column monitoring; this image is of Etna in 2002.

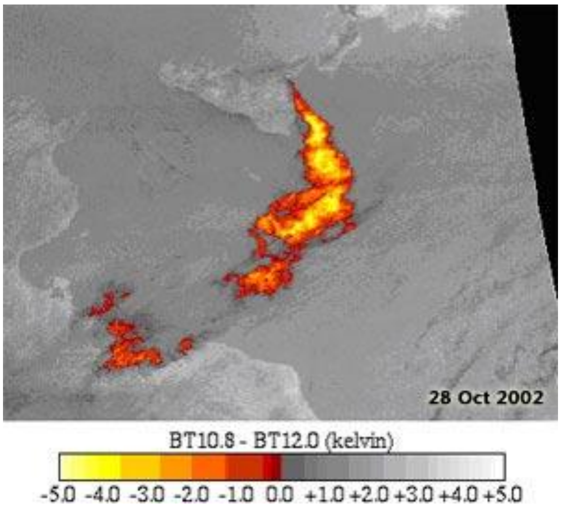

Figure 4: An AVHRR (Advanced Very High Resolution Radiometer) image of the eruption column from Mt. Etna (Met Office, 2002).

After the furore surrounding the eruption of Eyjafjallajökull and the disruption it caused to air traffic in 2010 (Schumann et al. 2010), the science of modelling the spread of ash from an eruption column received renewed attention in the literature. Due to the hazard that even small amounts of ash can cause to aviation (Peterson and Dean, 2008), many models have been created to compute the most likely position of ash in the atmosphere based on a variety of model parameters as discussed by Pering (2010). As an example, the Washington DC VAAC (Volcanic Ash Advisory Centre) uses the versatile HYSPLIT (HYbrid Single-Particle Lagrangian Integrated Trajectory) model (NOAA Air Resources Laboratory, 2011). The model used by the UK Meteorological Office (MET Office) is NAME (Numerical Atmospheric-dispersion Modelling Environment), which was originally used to calculate dispersal of nuclear radioactivity (Ryall and Mayron, 1998). An example of an ash dispersion model projection using HYSPLIT is shown in Figure 5. These models use simulations which are then overlain onto satellite imagery or raster/vector based maps.

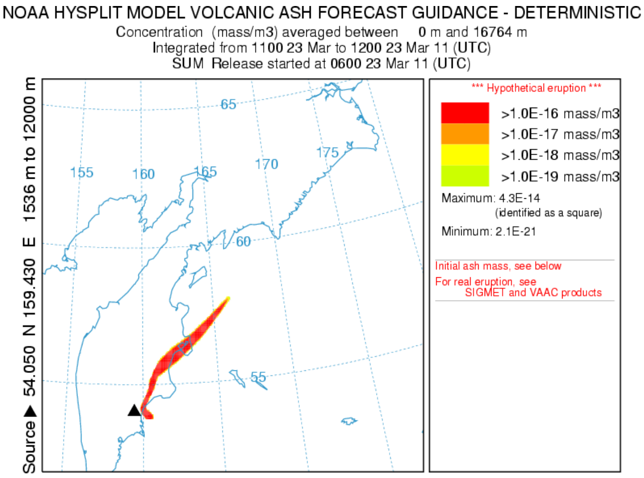

Figure 5: An example of a projection for Karymsky, Russia created using the NOAA Air Resources Laboratory (2011) online simulation tool.

2.2. Mapping

Mapping is an important part of understanding the history of a volcano and is currently being extensively undertaken in previously unmapped areas such as Chile and Iceland where more detailed/renewed study is needed. Examples of previous study in Iceland include Klausen (2004, 2006), and in Chile, González et al. (2008). The results of these mapping expeditions can be combined with GIS applications resulting in one concise image such as Figure 6. One such example of mapping volcanic rocks within the UK is Glencoe, Scotland, where there is scattered evidence of a violent volcanic history (Kokelaar and Moore, 2006).

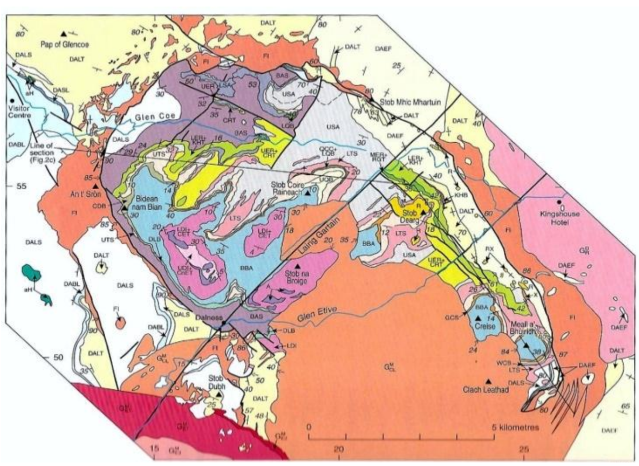
Figure 6: Taken from Kokelaar and Moore (2006), this image gives an overview of the geology in and around the Glencoe caldera volcano.

Figure 7: The operation of a terrestrial very long range laser scanner on an active volcano. The camera is set up 1km from the summit (BGS, 2011).

One of the newest forms of geoinformatics involves the use of very-long-range scanners (Figure 7) to produce detailed 3D images of volcanic edifices from a safe distance, similar to the cameras used at Erta Ale (section 2.2). This was first attempted by Hunter et al. (2003) who used a set of cameras to scan the summit of Mt. Etna, Sicily. This technique has now progressed further and has involved modelling the crater at Mt. Vesuvius, Italy (Pesci et al. 2007) and the imaging of lava flows (James et al. 2009). In 2009 a study of Erta Ale by a team from Durham University successfully mapped in 3D the interior of the crater of the volcano (BBC, 2009). It is innovative studies such as this which are the future for geoinformatics and volcanology.

2.2.1. Hazard Mapping

The use of geoinformatics within modern hazard mapping is now the standard way of producing this type of map. Hazard maps are produced for a large selection of volcanoes which are deemed the most hazardous to human life. The main hazards to be considered by volcanological hazard maps are Pyroclastic Density Currents (PDCs), ashfall and lahars, because these are the main threats to life from an eruption event. GIS software is often used in combination with multiple studies (geological and computational) to produce a map with multiple sources of data. ‘Buffering’ operations can be performed to indicate hazards around a certain object (such as a river and the threat of lahars), these are often done in tandem with hazard programs such as LAHARZ (Schilling, 1998). An example of this is Muñoz-Salinas et al. (2009) who used LAHARZ to simulate a varying array of lahars from Popocatepetl, Mexico. Other data needed for producing hazard maps include knowledge of the 3D topography (provided by radar or field surveys) and satellite/Ordnance Survey style maps to overlay hazard information on. An example of a hazard map of the area surrounding Mt. Rainier, USA is shown in Figure 8.

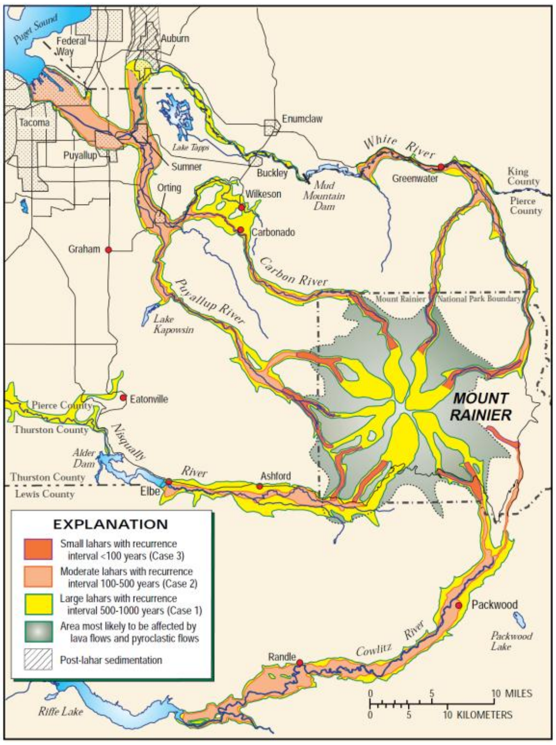

Figure 8: An example of a hazard map for the Mt. Rainier area. Shown are the possible hazards from lahars, lava flows and PDCs. Taken from the USGS (2008b).

2.3. Extra-terrestrial Geoinformatics

The NASA satellites Voyager I and II were among the first to capture images of the distant moons and planets of our solar system (NASA, 2011), whilst instruments such as the Hubble Telescope; which went into orbit on the 25th April 1990, (NASA, 2010) and Galileo (Geissler and McMillan, 2008), have been invaluable to the exploration and understanding of space. Mapping of planetary bodies has been an important part in developing theories of solar system creation; this has been completed in detail by many satellite missions, giving us high quality products for Mars and the Moon. Many studies of volcanological features have been completed, with a large amount of work focusing on Mars and the Moon due to the quality of data. However studies have also been undertaken on more distant moons such as Io (Jupiter) where Geissler and McMillan (2008) studied images collected by Galileo to decipher information on volcanic plumes. Enceladus (Saturn) is also studied because of its interesting cryovolcanism (Collins and Goodman, 2007). With the limited data quality (spatial resolution is usually low due to data transmission limitations) geo-processing techniques involve more skill and analysis.

Authors such as Lionel Wilson of Lancaster University and James Head of Brown University, even with huge amounts of research on the planets under their belts, could not have completed many of their studies without the use of geoinformatics. Wilson and Head (2004) is an example of the use of Martian images to investigate a possible phreatomagmatic eruption. Campbell (1984) and Glaze (1999) have benefitted from the remote sensing of Venus, with the latter using remote sensing data to look at the potential sources of volcanic input into the atmosphere.

Data is now becoming more accessible with the entirety of the Moon and Mars able for 'Google Earth' viewing (views of both are shown in Figure 9). Tools such as these are more accessible to everyone and demonstrate the value of geoinformatics.

2.4. Recent Developments

The most recent development within remote sensing and geoinformatics is the launch of the ESA (European Space Agency) satellite GOCE (Gravity field and steady-state Ocean Circulation Explorer), which detects the sometimes minute differences in gravitational fields of certain areas. This has many applications in several aspects of Earth Sceince, however this satellite has not been used (to the authors knowledge at time of writing) in any volcanological areas (ESA, 2011). However research into gravity changes at volcanoes isn't new, with many studies completed, such as Rymer et al. (1998) on Krafla, Hautmann et al. (2009) on Soufriere Hills and Bonaccorso et al. (2011) on Mt. Etna.

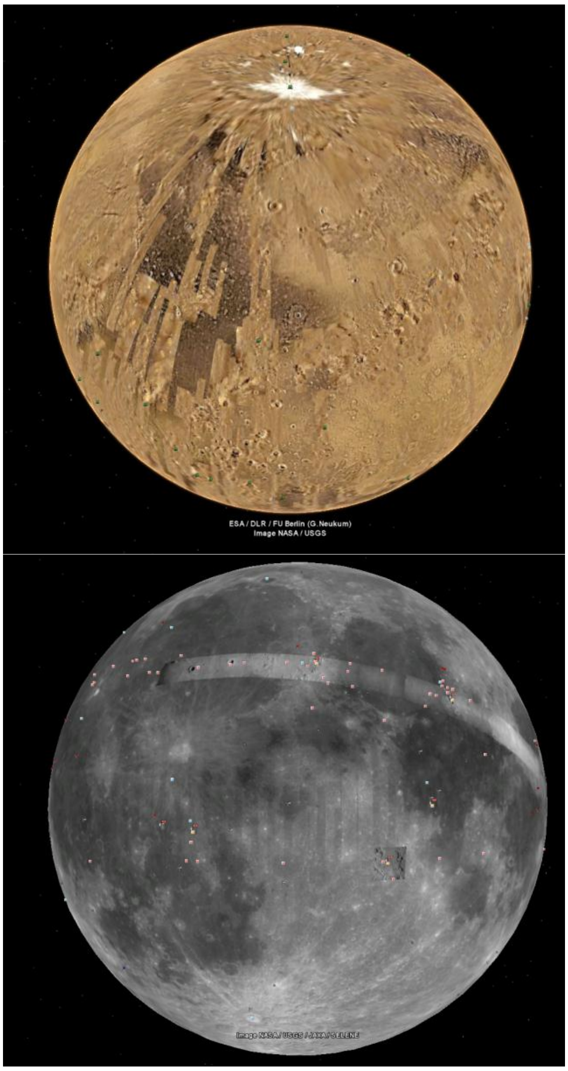

Figure 9: Google Earth (2011) images of Mars (Upper) and the Moon (Lower) taken from the application. These images demonstrate how far mapping and imaging has progressed and how easy it is to access.

Recent extra-terrestrial mapping developments have included high resolution images of the Moon (NASA, 2011) and the recent entry into orbit around Mercury of the Messenger probe (BBC, 2011). Prior to orbital entry, a flyby of Mercury by Messenger led to the discovery of the youngest signs of volcanism (yet detected) on the surface of Mercury (Prockter et al. 2010). In Prockter et al. (2010) is an excellent example of how GIS applications and techniques can be applied to characterise an area using the creation of polygons and lines, this is shown in Figure 10. This form of mapping is also seen on Earth in the form of geological maps. The geology of the UK has been well characterised by the British Geological Survey (BGS) and is available to download electronically to subscribers via Edina Digimap.

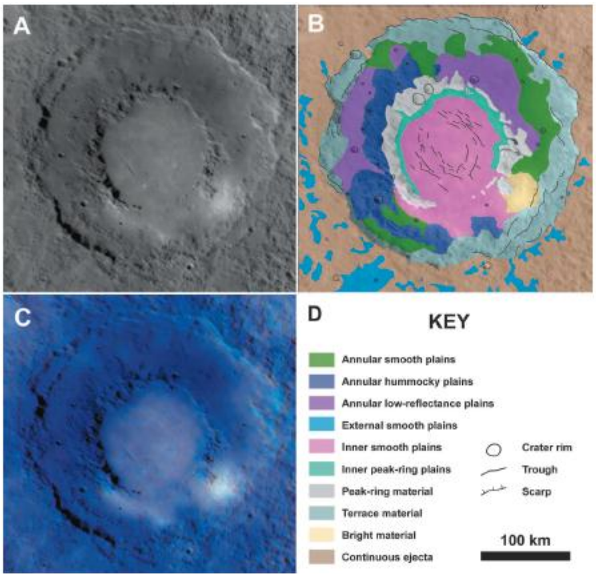

Figure 10: Taken from Prockter et al. (2010) this image shows a possible young volcanic area on Mercury using Messenger images. Image B is a characterisation of the type of surface seen, it is a good example of GIS use within volcanology.

2.5. Limitations of geoinformatics within volcanology

After discussing the uses of geoinformatics within volcanology it is useful to briefly think about the limitations involved. The major limitation affecting most volcanological geoinformatics studies is the availability of data, many areas where data is much needed suffer due to the variability of satellite passes. This issue is controlled by the availability of satellites for use and the type of orbit which a satellite may be on, be it geostationary (around the equator) or near-polar (almost perpendicular to the equator from pole to pole) (Lillesand et al. 2008). Another issue, highly relevant in the current climate, is cost. The more sophisticated and technologically advanced the equipment is, the more money it requires. Ground-based remote sensing projects are becoming more commonplace as they are discovered to be more cost beneficial. There are also many issues related to the instruments themselves, which will not be discussed here.

3. Conclusion

Whilst a number of volcanological areas related to geoinformatics were discussed separately, they should not be considered as individual entities. Many areas overlap and, in reality, are reliant on one another. Geoinformatics is a relatively new introduction to the scientific community which arrived in combination with improved technologies, whilst the early chapters of its involvement with volcanology have been written, the end is not in sight as it becomes more accessible to both researchers and the general public. Volcanological geoinformatics is not solely confined to the Earth and can be considered as active extra-terrestrially as well.

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