Modelling Mount Etna

Neil Slatcher and **Dr Mike James** have developed new data collection software and time-lapse imaging techniques to study volcanic activity on Mount Etna, Sicily. Here, they explain how their work is unveiling the complex processes that govern lava flows

Could you briefly describe your latest project, 'Quantifying lava flow dynamics with a very-long-range terrestrial laser scanner'?

NS: The key goals are to better understand the complex processes occurring in lava flows that affect parameters such as their maximum length. Capturing measurements of active flows in hazardous and inaccessible terrain can be highly challenging. To overcome these issues, we are using surveying and image-processing techniques that allow us to remotely capture measurements of active flows at distances of more than 3 km.

MJ: Our data provide the potential not only to enhance lava flow models for Mount Etna, but for generic models applicable to lava flows worldwide. We also have a direct working link with the Istituto Nazionale di Geofisica e Vulcanologia (INGV), which is responsible for monitoring geological hazards in Italy.

Are challenges presented by modelling complex processes controlling lava flow?

NS: We have a reasonable understanding of how single lava flows advance and how far they can travel. The difficulties lie in accurately measuring the critical parameters – such as effusion rate – and in determining how a flow field will evolve if the eruption continues once the flow front has cooled sufficiently to stop advancing. In this case, flow lengths can be controlled by complex processes such as the formation of breakouts from channels, flow inflation and the development of lava tubes.

Which questions related to lava flow dynamics does your research intend to address?

NS: We are trying to measure some of the key parameters that control how far an advancing lava will flow – its bulk rheology and effusion rate. Once the initial advancing lava front has cooled sufficiently to stop, what happens next? If channel levées are breached near the vent region then a new flow can be produced, often parallel and of similar length to the first. However, if breaching does not occur, the original flow can start to inflate and eventually a new flow can break out from the stalled flow front, substantially lengthening the original flow. We intend to better parameterise how lava rheology changes downflow, why flows eventually stop advancing, when and where breakouts occur and when inflation of the lava flow is likely.

Could you describe your use of very-long-range terrestrial laser scanners (TLS)?

MJ: Using a very-long-range TLS enables us to remotely capture detailed surface measurements of active flows in hazardous and inaccessible areas. We have also combined TLS topographic data with time-lapse imagery to enable flow velocities, and hence rheology, to be estimated. By combining these different techniques, we are able to overcome the specific limitations of each method and gain a deeper understanding of flow processes.

NS: The 3D measurements captured using the TLS provide an instantaneous snapshot of topography which can be used to identify areas of change since a previous survey. However, instantaneous TLS data do not distinguish between currently active and non-active flow regions. Ground-based thermal imagery clearly identifies the hot areas in the terrain, such as active channels, and thus enhances the interpretation of the TLS data to provide a fuller picture of recent and ongoing activity.

How have you combined time-lapse imagery and topographic data to track short-term changes in lava flow field configurations?

NS: In July 2012, repeat TLS measurements and time-lapse imagery of a small lava flow in the Bocca Nuova, one of the active craters on the summit of Mount Etna, were acquired. Combining time-lapse imagery with the TLS data allowed 2D flow velocity measurements in the images to be re-projected onto the 3D lava surface. This provided us with all of the information required – the depth of the flow, the width of the flow, flow surface velocity and the slope angle – and enabled us to determine the rheological properties of the lava and the lava effusion rate.

Moving forward, what future areas of research do you envisage?

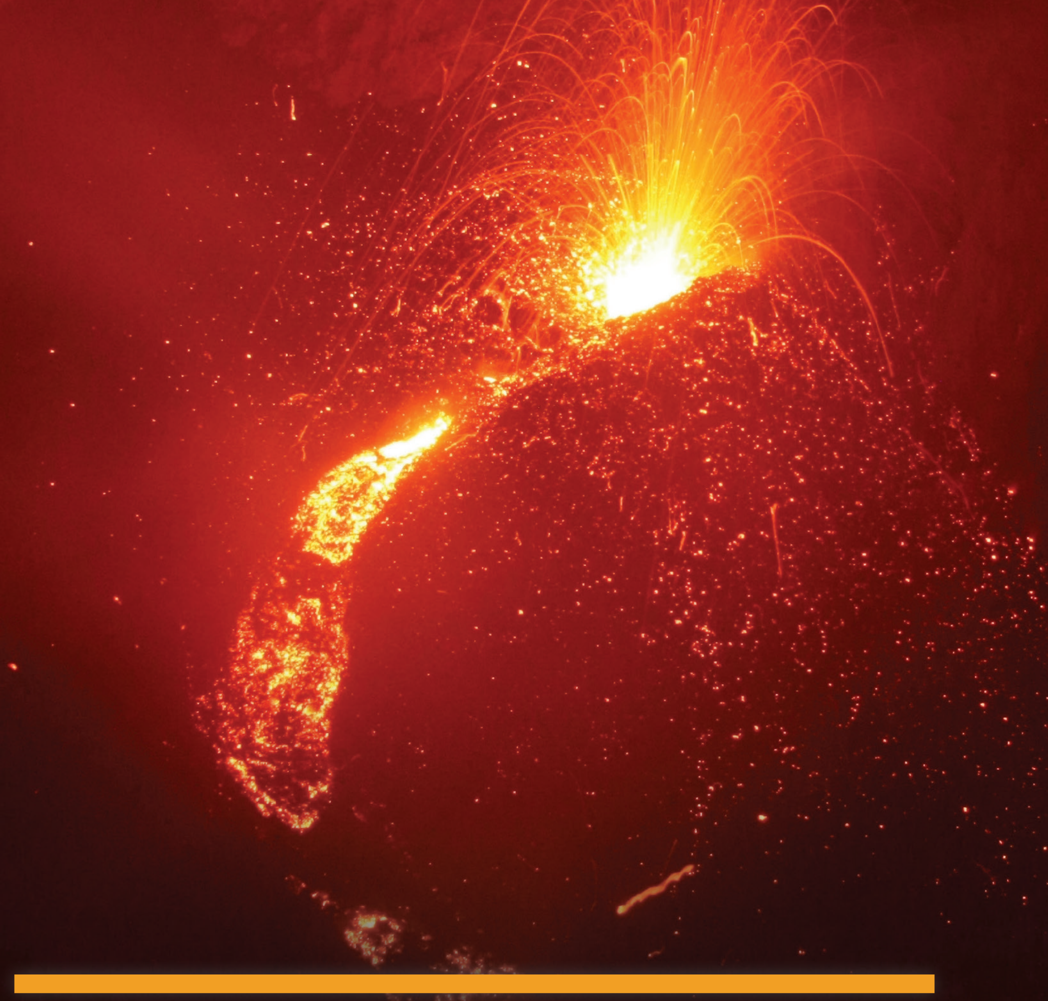
NS: One of our major long-term goals is to record the emplacement of a larger-scale, longer-duration lava flow. By employing the techniques we are developing to the study of larger-scale eruptive activity, there is significant potential for improving our understanding of the complex processes that control the maximum flow lengths associated with longer eruptions.

The SE crater region of Mount Etna, Sicily.

NEIL SLATCHER AND DR MIKE JAMES

Stratovolcano **study**

Researchers at **Lancaster University**, UK have embarked on the 'Quantifying lava flow dynamics with a very-long-range terrestrial laser scanner' project, which combines topographical data, thermal imaging and time-lapse photography to quantify the complex processes that control lava flow dynamics



Strombolian activity and lava flow in the Bocca Nuova crater, caught by a remote time-lapse camera.

STRATOVOLCANOES ARE CAPABLE of both violent explosive eruptions and the quieter effusion of lava flows. Consequently, their stereotypical conical shapes are built from explosive products, such as pumice and volcanic ash, and multiple layers of interleaved lavas. Although the dispersal of ash can result in widespread hazard, lava often forms channels to flow in, and can descend the volcano's flanks presenting a hazard to local communities and infrastructure. During long-lived eruptions, the channels can 'roof over' to form insulating lava tubes that allow the lava to flow even further from the eruptive vent.

Present technology enables scientists to measure effusion rates during short volcanic eruptions and to forecast the length of the lava flow. For longer eruptions, however, forecasting the length of the lava flow is more complex because factors such as channel breakout, flow inflation, and the development of lava tubes need to be taken into account. Scientists believe effusion rate variations over relatively short periods of time could have a significant impact on lava flow length, either by reinforcing channel levées and thereby increasing the potential for the formation of lava tubes, or by leading to lava breakouts and channel switching.

Lava effusion rate is one of the main factors controlling the maximum length of lava flows. An understanding of short-term variations in effusion rates is essential if we are to construct an accurate understanding of the evolution of lava channels and hence a proper assessment of lava length, or the extent to which any given lava front will travel. At present, however, modelling lava flow processes during sustained eruptions is difficult because scientists have insufficient data to pinpoint when and where events such as channel switching will take place.

MAGMATIC ACTIVITY

At the Lancaster Environment Centre (LEC) within Lancaster University in the UK, researchers have embarked upon the 'Quantifying lava flow dynamics with a very-long-range terrestrial laser scanner' project. The study – run by PhD student Neil Slatcher under the supervision of Dr Mike James – is developing new techniques to improve measurements of active lava flows. Slatcher's work is funded by a Collaborative Awards in Science and Engineering (CASE) studentship grant from the UK's Natural Environment Research Council (NERC), while the CASE partner, 3D Laser Mapping, also provides funding.

> Slatcher's work aims to develop new techniques that enable high-resolution, 3D datasets of active lava flows to be acquired

The scientists chose Mount Etna as their study area because of its relatively frequent eruptions. With the aim of building a better understanding of the mechanisms that occur in lava flow that affect important parameters such as maximum length, the project responds to the inability of current models to represent complex processes such as channel switching and flow inflation. "Observations of active flows have shown that the effusion rate changes over relatively short timescales – in the order of hours – and could also influence maximum flow lengths by either enhancing the levées that bound channels or by forming breakouts and driving channel switching," Slatcher elaborates.

One of the major challenges impeding scientists' understanding of lava flow processes is capturing field measurements at adequate spatial and temporal scales. Slatcher's work aims to develop new techniques that enable high-resolution, 3D datasets of active lava flows to be acquired.

TERRESTRIAL LASER SCANNERS

In their study of Mount Etna, Slatcher and his colleagues used a RIEGL LPM-321 very-long-range terrestrial laser scanner (TLS). This portable, tripod-mounted instrument uses laser pulses to capture 3D measurements of the surrounding surface area. The TLS, which can be used for imaging volcanic terrain over distances of up to 3.5 km, allowed Slatcher to build up detailed models of the surface topography.

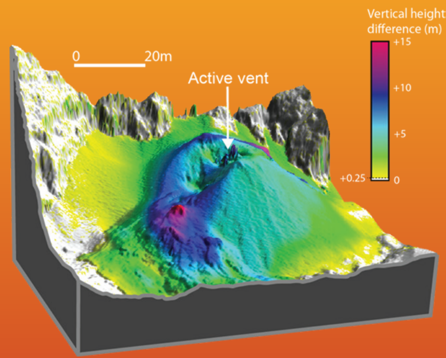
Working on volcanoes is often hazardous and inhospitable, which means it can be difficult to identify locations that are accessible but also

CRUCIAL COLLABORATION

3D Laser Mapping has supplied a long range laser scanner to monitor volcanic lava flows on Mount Etna in Sicily.

The project's aim is to increase understanding of volcanic activity by combining highly precise terrain measurements with ground based thermal imagery, to provide unprecedented data and a better understanding of active lava flows.

"Partnerships, such as that with 3D Laser Mapping, are very important because they facilitate collaboration and knowledge transfer between academic researchers and UK businesses," James explains.



3D laser scan data from inside one of the active summit craters at Mount Etna. The data are coloured by the height changes that were detected over four days during July 2012.

enable high-quality TLS measurements to be captured. Detailed TLS surveys can be slow, which prevents data from being taken at a sufficient frequency to accurately determine flow dynamics. To combat these issues and optimise data acquisition, Slatcher developed custom TLS survey planning software. "To simplify the use of the TLS instrument in challenging environments, we developed a suite of software tools that enabled us to identify optimal locations to deploy the TLS and enhance data capture once in the field," he elucidates.

In addition to the hostile landscape, Slatcher and his colleagues also had to contend with the transient nature of volcanic activity. Volcanic eruptions can be relatively short-lived, and it was often difficult to ensure the researchers and their equipment were in the right place at the right time to capture measurements of an active lava flow. Despite these difficulties, the researchers were able to collect data from several active lava flows.

THERMAL IMAGING

After mapping the area using TLS, the topographical data were combined with ground-based thermal imaging. While the TLS data provided an instantaneous snapshot of surface topography, it was difficult to distinguish between active lava flows and static, inactive areas. To overcome this, thermal imaging enabled clear identification of hot areas in the terrain.

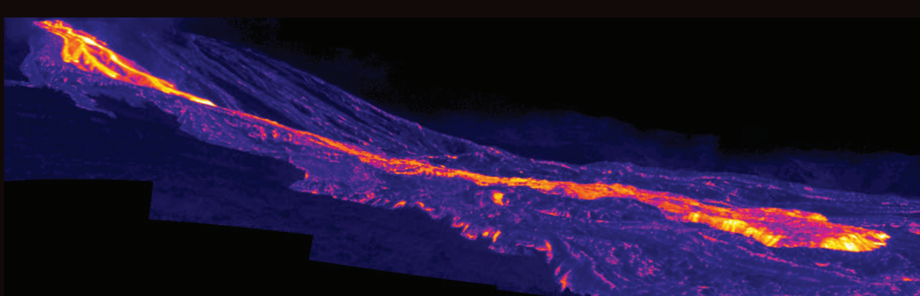
The researchers also combined the topographical and thermal imaging data with time-lapse photography. "Through combining these data types, critical parameters including effusion rates, lava flow surface velocities and the physical properties of the lava can be estimated and used to improve our understanding of flow dynamics," Slatcher reveals.

Pulling the data together allowed the researchers to identify instability in lava flows and assess the likelihood of breakout events, as well as the direction and extent of lava fronts on Mount Etna. It was also possible to analyse the data for signs of flow inflation – a potential precursor to the formation of a lava tube, and levée instability – which can signal levée collapse and lava breakout.

FROM LAVA TO GLACIERS

The implications of the team's work range far beyond Mount Etna, presenting the opportunity to generate data that may enhance models applicable to lava flows worldwide. In addition, the techniques developed by the Lancaster volcanologists can be applied to other geophysical flows such as glaciers.

Looking ahead, Slatcher and James expect the results of this latest study to be applied to assessing and predicting longer lava flows, which are able to travel many kilometres from their volcanic source and therefore pose a significant danger to local communities and infrastructure.



A typical lava flow on Mount Etna, as detected by thermal imagery. The active flow (~1 km long) is indicated by the warm colours and is fed from the main channel shown by the narrow yellow feature in the top left.

INTELLIGENCE

QUANTIFYING LAVA FLOW DYNAMICS WITH A VERY-LONG-RANGE TERRESTRIAL LASER SCANNER

OBJECTIVES

To better understand the complex processes occurring in lava flows that affect parameters such as their maximum length.

KEY COLLABORATORS

Dr Ciro del Negro; **Dr Gaetana Ganci**; **Dr Sonia Calvari**, INGV, Catania, Italy

Professor Harry Pinkerton, Lancaster Environment Centre, Lancaster University

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3D Laser Mapping

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DR MIKE JAMES is a lecturer in the Lancaster Environment Centre, Lancaster University with research interests spanning volcanology to soil erosion. His expertise focuses on using ground-based remote sensing to understand environmental processes.

NEIL SLATCHER is a final year PhD student at Lancaster University. His current research is focused on optimising the use of Terrestrial LiDAR for geohazard assessment. Additional research focuses on the development of low-cost sensors for monitoring active volcanoes.