COMET

CENTRE FOR THE OBSERVATION AND MODELLING
OF EARTHQUAKES, VOLCANOES AND TECTONICS

ANNUAL REPORT
2018 / 2019

NERC
SCIENCE OF THE ENVIRONMENT

BGS
1835

Incan ruins backed by an active normal fault in the Peruvian Andes
Credit: Dr Alex Copley, Bullard Laboratories, University of Cambridge

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Cover image: Bagana volcano shot from Wakovi village, Bougainville, in September 2019
Credit: Dr Brendan T. McCormick Kilbride, University of Manchester

DIRECTOR'S WELCOME

COMET's fifth annual report comes as we enter an exciting new phase.

Thanks to hard work from everyone in COMET, we submitted a proposal to continue COMET activities until 2021 and we are delighted that this was successful. The review panel "noted the excellent science that COMET produces, and that the Centre is highly regarded within the community." The panel also "commended the impact COMET and its science has, both within [our] community and wider, which is far higher than could be reasonably expected for a Centre of [our] size."

Over the next few years our strong partnership with the British Geological Survey (BGS) will continue and deepen. We are now working closely with the BGS to develop a joint programme of activities beyond 2021 focused on making fundamental advances in exploiting satellite EO data to improve understanding of seismic and volcanic hazards and to reduce risk.

COMET scientists have been successful in obtaining external funding to continue co-funding COMET research activities. COMET scientists at Leeds and the BGS are partners in the new Global Challenges Research Fund (GCRF) Multi-Hazard Urban Disaster Risk Transitions Hub, which aims to reduce disaster risk for the inhabitants of some of the world's most vulnerable yet fastest-growing cities. COMET and BGS are contributing expertise in seismology, remote sensing, volcanic hazards and multi-hazard approaches to disaster risk reduction, giving us an exciting new opportunity to build resilience to environmental shocks and disasters in some of the world's poorest urban areas. COMET scientists at Bristol and Leeds were also successful in winning GCRF funds to "make satellite deformation analysis accessible" to scientists in volcano observatories in low- and middle-income countries. And COMET scientists at Manchester, Oxford, Cambridge and Leeds have been successful in winning several major projects to further develop the use of satellite EO for monitoring volcanic emissions.

We have also continued to make progress against our core scientific objectives. LiCSAR, our processing system designed to handle the vast amounts of data from the Sentinel-1 satellite mission, is now providing high-resolution deformation data for the entire Alpine-Himalayan seismic belt and we are continuing to expand its coverage. We are also sharing the results through external platforms for maximum reach, as well as developing a system to allow partners to rapidly access information on events and hazards.
Our system using the Sentinel-1 satellite mission to monitor volcano deformation, LiCSAR-volcano, is also now operational, allowing us to monitor ground deformation at more than 900 volcanoes worldwide, including Africa and Central and South America - regions with large explosive volcanoes currently only covered by limited ground surveys. We have doubled our volcanic dataset to include over 68,000 interferograms, with automated processing now running routinely on active volcanoes.

COMET's capacity to monitor volcanic ash as well as SO2 emissions in near-real time using the Infrared Atmospheric Sounding Interferometer (IASI) continues to improve, and in particular we have made progress on using IASI to monitor smaller and lower altitude emissions as well as ongoing activity. We are also making exciting progress in applying new techniques to investigating hazards, with colleagues at Bristol and Leeds using machine learning and artificial intelligence alongside satellite imagery from Sentinel-1 to identify ground deformation around volcanoes.

The COMET community, and our students and early career researchers in particular, continue to go from strength to strength, making huge contributions to our progress as a group. I particularly commend COMET students Simone Mancini - for his 2018 American Geophysical Union Outstanding Student Presentation Award - and Chen Yu – for making it onto the Web of Science Highly Cited Papers list. I would also like to send congratulations, on behalf of all at COMET, to Philip England, Juliet Biggs, Marek Ziebart, Tamsin Mather and Marie Edmonds for their recent high profile awards. Their achievements are described later in this document, alongside the full range of COMET activities over the past year.

Finally, I would like to express thanks, from all COMET members past and present, to our founding director Professor Barry Parsons. Barry has been a driving force within COMET since its inception whilst his observations, physical models, and insights have been used by researchers all over the world. Despite celebrating his 70th birthday, marked in September 2018 by a career celebration in Oxford, we trust that Barry will continue to be an active member of the COMET family for many years to come.

Professor Tim Wright,
COMET Director

CHAIR’S FOREWORD

Over the past year, COMET has continued to produce exciting science whilst meeting its obligations to the wider scientific community.

July 2018 saw the COMET family come together in London’s Lea Valley, where in the brilliant sunshine we saw how COMET is continuing to advance understanding of the earthquake cycle and volcanic activity. The Advisory Board was once again impressed by the productivity and achievements of the last year, the quality of the science presented, and the collaborative spirit of COMET across all career levels.

Work by COMET’s students and early career researchers continued to excite, with updates on topics as diverse as volcanic eruptions in Ethiopia, the tectonics of the High Andes, and detecting landslides triggered by the 2015 Nepal earthquake. We can see that many students and early career scientists now “grow up” in COMET to become leaders in their chosen field, whether in academia, government or industry. In addition, COMET’s provision of data and services including LiCSAR, image matching for topography and deformation, and retrievals of gas and ash from spectrometers represent an admirable effort driven by a talented and enthusiastic group.

We now look forward, in this new phase, to helping COMET set new research aspirations and practical goals, and to seeing further progress on areas such as magma-tectonic interactions and multi-hazards. These will doubtless be delivered alongside other benefits that are borne from a closer relationship between COMET and the BGS.

On behalf of the COMET Advisory Board,

Professor Ramon Arrowsmith, Chair, COMET Advisory Board

The interior of an ancient mountain range: the Lewisian of NW Scotland
Credit: Dr Alex Copley, Bullard Laboratories, University of Cambridge

INTRODUCTION

The Centre for Observation and Modelling of Earthquakes, Volcanoes and Tectonics (COMET) provides national capability in the observation and modelling of tectonic and volcanic hazards.

We deliver services, facilities, data and long-term research to produce world-leading science that can help the UK and others to prepare for, and respond rapidly to, earthquakes and eruptions.

Based at the Universities of Bristol, Cambridge, Durham, Leeds, Liverpool, Manchester, Newcastle, Oxford, Reading, and University College London (UCL), we use satellite Earth Observation (EO) techniques such as Synthetic Aperture Radar Interferometry (InSAR) alongside ground-based observations and geophysical models to study earthquakes and volcanoes, and understand the hazard they pose. As well as providing scientific leadership in EO, we have a vibrant young community of postgraduate students and early career researchers.

We work in partnership with the British Geological Survey (BGS), with our sponsors the Natural Environment Research Council (NERC), with the European Space Agency (ESA), and with many other national and international partners.
In addition, we are working with business, Government and the space agencies to ensure that the UK continues to invest in and benefit from satellite missions.

For the next phase of COMET (2019-2021), we are building on past achievements to further understand seismic and volcanic hazard and their behaviour over space and time. We are also developing a closer relationship with the BGS, ensuring that our activities align with and contribute to their science strategy, Gateway to the Earth.[1]

This report gives an overview of COMET's activities during 2018-19, highlighting major scientific achievements as well as progress against our key objectives. It covers the period 1 January – 31 December 2018 for publications, and 1 April 2018 – 31 March 2019 for all other outputs.

1 www.bgs.ac.uk/about/strategy.html

Upper slopes of Bagana with highly channelised lava flows, photographed from drone.
Credit: Dr Kieran Wood, University of Bristol

A LOOK BACK AT 2018/19

Scientific Developments

Earthquake research reveals seismic forecast

Research led by COMET's Richard Walters (Durham), published in Earth and Planetary Science Letters[2], described how the timing and size of three deadly earthquakes that struck Italy in 2016 may have been pre-determined. Importantly, this discovery could improve future earthquake forecasts.

The joint British-Italian team of geologists and seismologists, which also included Leeds's Dr Laura Gregory, showed that the clustering of the three quakes might have been caused by a cross-cutting network of underground faults. All three earthquakes occurred on the same major fault, with several smaller faults preventing a single massive earthquake and also acting as pathways for naturally occurring fluids that triggered later earthquakes.

The cluster of three earthquakes, termed a "seismic sequence", each had magnitudes greater than six and killed more than 300 people in Italy's Apennine Mountains between 24 August and 30 October 2016.

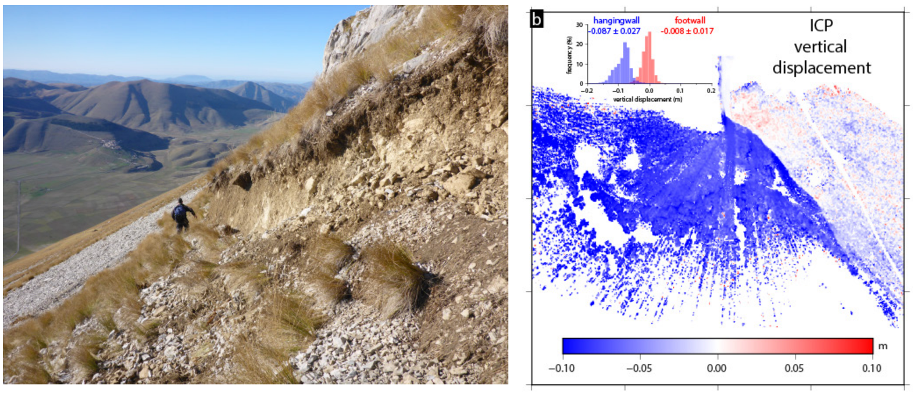
Dr Walters and the team used satellite data to estimate which part of the fault failed in each earthquake, and compared this pattern with the location and timing of thousands of tiny aftershocks throughout the seismic sequence, with the results addressing a long-standing mystery in earthquake science – why a major fault system sometimes fails in a single large earthquake that ruptures its entire length, versus failing in multiple smaller earthquakes drawn-out over months or years.

They found that intersections of small faults with the main fault system separated each of the three largest earthquakes, strongly suggesting these intersections stop the growth of each earthquake and prevent the faults failing in a single large event.

In addition, the scientists found that after the first earthquake, thousands of aftershocks crept northwards along these same fault intersections at a rate of around 100 metres per day, in a manner consistent with naturally occurring water and gas being pumped along the faults by the first earthquake on 24 August, 2016.

The second earthquake, on 26 October, occurred exactly when these fluids reached its location, therefore controlling the relative timing of failure.

The findings could have wider implications for the study of seismic hazards, enabling scientists to better understand potential earthquake sequences following a quake.



Left: Rupture of the M 6.6 Norcia earthquake on the side of Mt Vettore. Right: Vertical displacement across the fault measured using differential Terrestrial Laser Scanning. The rupture occurred during the third earthquake in the seismic sequence and gives researchers a record of the deformation. Credit: L.Gregory/L Wedmore

2 Walters, R. et al. (2018) Dual control of fault intersections on stop-start rupture in the 2016 Central Italy seismic sequence, Earth and Planetary Science Letters doi:10.1016/j.epsl.2018.07.043

Complex deformation pattern in central Italian earthquake

Sometimes exciting science comes from being in the right place at the right time (with the right high-resolution monitoring equipment in tow). The field-based team working on the 2016 Central Italian earthquake sequence arrived in the region the same day (26th October) that the second large earthquake in the sequence struck. Using a terrestrial laser scanner, they captured a high-resolution lidar point-cloud of the surface rupture caused by the 26th Oct earthquake. The third, and largest, earthquake struck a few days later (a magnitude 6.6 at 7:40 AM on the 30th Oct), rupturing the same fault that had slipped previously. The first dataset became a 'pre-earthquake' dataset, and they re-imaged the same area following the 30th October.

The pattern and size of discrete offset at the surface can help to understand what happened in an earthquake, and over multiple earthquake cycles, cumulative offset leaves a record of each event in the landscape. This record is used to infer past earthquake activity and in turn forecast how likely earthquakes may be in the future. In this second paper on the 2016 Italian sequence published in GRL3, COMET scientists led by Dr Luke Wedmore (now at Bristol) analysed the precise pattern of ground motion around the fault during the 2016 magnitude 6.6. Norcia earthquake. With their pre- and post-EQ datasets, they calculated exactly how the ground moved during the event to millimetric precision, in order to better understand how earthquake motion is partitioned on and off the discrete fault. This uniquely precise map of surface deformation had never been captured before.

The team found that the vertical motion of the fault is mainly focused on the fault itself, and the measurements agree with measurements of fault displacement using traditional field surveying techniques. In contrast, the horizontal motion is distributed over an 8m wide zone, with approximately 50% of the movement occurring away from the fault – this is known as off-fault deformation. Their results have important implications for how evidence of past earthquakes preserved in the landscape are interpreted in light of future seismic hazard.

A LOOK BACK AT 2018/19

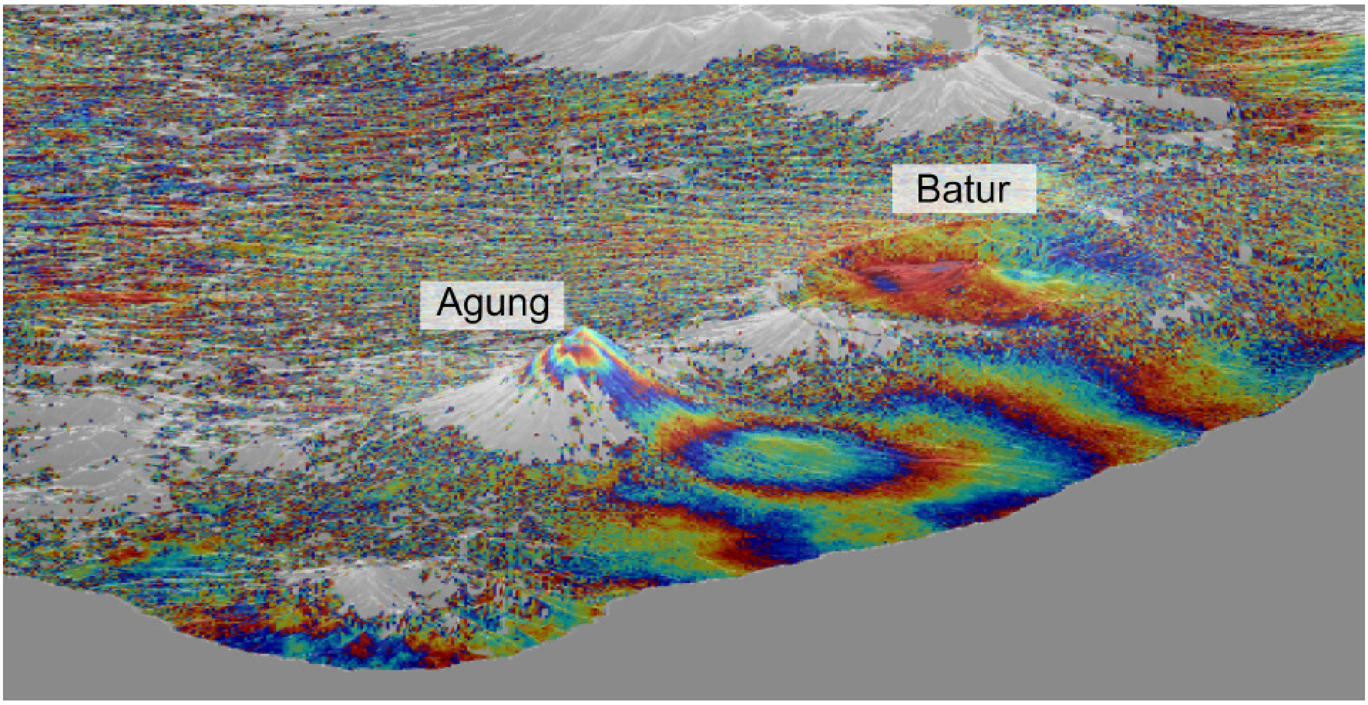
Satellite images reveal interconnected plumbing system that caused Bali volcano to erupt

Work by COMET's Juliet Biggs and Fabien Albino (Bristol) used Sentinel-1 data to uncover why the Agung volcano in Bali erupted in November 2017 after 50 years of dormancy. Their findings, published in Nature Communications[3], could have important implications for forecasting future eruptions in the area.

Two months prior to the eruption, there was a sudden increase in the number of small earthquakes occurring around the volcano, triggering the evacuation of 100,000 people. The previous eruption of Agung in 1963 killed nearly 2,000 people and was followed by a small eruption at its neighbouring volcano, Batur. Because this past event was among the deadliest volcanic eruptions of the 20th century, a great effort was made to monitor and understand the re-awakening of Agung.

Satellite data from the Sentinel-1 mission was used to map ground motion, which may be an indicator that fresh magma is moving beneath the volcano and the study, carried out in collaboration with the Center for Volcanology and Geological Hazard Mitigation in Indonesia (CVGHM), detected uplift of about 8-10 cm on the northern flank of the volcano during the period of intense earthquake activity. Both the earthquake activity and the ground deformation signal were located five kilometres away from the summit, which means that magma must have been moving sideways as well as vertically upwards.

This provides the first geophysical evidence that Agung and Batur volcanoes may have a connected plumbing system, with important implications for eruption forecasting and potential to explain the occurrence of simultaneous eruptions such as those seen in 1963.



Sentinel-1 InSAR data showing ground uplift on the flank of Agung volcano. Credit: Fabien Albino, COMET, University of Bristol

3 Albino et al. (2019) Dyke intrusion between neighbouring arc volcanoes responsible for 2017 pre-eruptive seismic swarm, Nature Communications doi:10.1038/s41467-019-08564-9

Can AI and satellites help predict volcanic eruptions?

Work led by COMET scientists Juliet Biggs (Bristol) and Andy Hooper (Leeds) is developing new methods for using artificial intelligence and satellite data to monitor and potentially help predict volcanic eruptions.

An article published in Nature in March 2019[4] outlines how Juliet's team at Bristol is using machine learning alongside satellite imagery from ESA's Sentinel-1 mission to spot ground distortion around volcanoes. Their new neural network examined over 30,000 Sentinel-1 images of more than 900 volcanoes, flagging around 100 images for closer examination. Of these, at least 39 were accurate detections of ground distortion. By using an algorithm to initially sort through the vast amounts of data, researchers can better focus on key volcanoes and areas of interest. The team is also now using simulations of eruptions to improve the precision of the algorithm[5].

Meanwhile at Leeds, Andy's team is using a technique that searches for changes in the satellite data. Where the ground around a volcano is deforming, their method can flag if the distortion speeds up, slows down, or changes in some other way, allowing researchers to detect even small ground alterations over long periods[6].

Next steps for both groups include testing their approaches on COMET's Volcano Deformation Database[7], with the ultimate goal of processing data for all volcanoes, all of the time.

4 www.nature.com/articles/d41586-019-00752-3
5 Biggs, J. et al. (2018) Application of Machine Learning to Classification of Volcanic Deformation in Routinely Generated InSAR Data, JGR: Solid Earth doi:10.1029/2018JB015911
6 Gaddes, M. et al. (2018) Blind Signal Separation Methods for InSAR: The Potential to Automatically Detect and Monitor Signals of Volcanic Deformation, JGR Solid Earth doi:10.1029/2018JB016210
7 www.comet.nerc.ac.uk/volcanoes/

A LOOK BACK AT 2018/19

Impact and influence

COMET works closely with governments, Non-Governmental Organisations (NGOs) and other partners to deliver real-world impact, shape policy decisions and improve how we manage natural hazards.

Through our partnership with BGS, we provide emergency advice for the Scientific Advisory Group in Emergencies (SAGE) and Cabinet Office Briefing Room (COBR), for example for the June 2018 eruption of Volcán de Fuego (Guatemala). COMET also feeds into the weekly advice on volcanic hazards and impacts that BGS provides to the Department for International Development (DfID) and other UK Government departments, and to the European Emergency Response and Coordination Centre.

Much of our work continues to be focused in countries eligible for Overseas Development Assistance (ODA), with new initiatives including the Global Challenges Research Fund (GCRF) Multi-Hazard Urban Disaster Risk Transitions Hub. This £20m initiative is using satellite data to assess seismic and volcanic hazard and vulnerability in cities at high risk.

We are also continuing to develop closer links with the Global Earthquake Model (GEM) and Global Volcano Model (GVM) as well as the US Geological Survey (USGS) and their Powell Centre Working Group. We sit on the Committee on Earth Observation Satellites (CEOS) Working Group on Disasters (leading the Pilot and Demonstrator projects) and Deep Carbon Observatory, and make our data available via the European Plate Observing System (EPOS).

Finally, we work with the space agencies, advising ESA on Sentinel-1's acquisition strategy and helping to develop new EO missions, including two of the three missions chosen to compete as ESA's 10th Earth Explorer: Stereoid and G-Class.

Sentinel 1 in orbit
Credit: ESA

Training and education

Our flagship training event is our annual InSAR course, held in Leeds over three days each autumn. The course aims to improve InSAR processing and analysis skills for students and early career researchers as well as those working in industry and the public sector, focusing on topics such as accessing and processing data, time series analysis and data modelling. We are currently planning our next workshop for autumn 2019. We also contribute to a wide range of external training courses, nationally and internationally. Last year, these included the GEORAMP and HERCULES summer school on geohazards, monitoring and modelling in Vienna.

Exchange visits provide further opportunities. COMET Bristol researchers were part of a team travelling to Guatemala to teach local scientists how to use drones to map the Fuego volcano after it erupted violently in June 2018, resulting in several hundred deaths[8]. The four-day workshop provided training in safe flight protocols, data acquisition and image processing using quadcopters and 3D modelling software.

The summit of Volcán de Fuego showing active vents. Credit: Universities of Bristol, Birmingham and INSIVUMEH

8 www.bristol.ac.uk/news/2018/november/drone-expertise-volcanic-eruptions.html

A LOOK BACK AT 2018/19

Last year we also provided training for researchers from the Chinese Academy of Science and Technology (CAST) demonstrating how to best collect observations from radar satellites such as Sentinel-1 and TanDEM-X, alongside the Chinese Gaofen-3 satellite mission. We also hosted visiting researchers from Kazakhstan and China amongst other countries, providing training on EO and strengthening links between our universities.

Our membership of the Copernicus Academy also means that we are connected to European research institutions and other organisations to jointly develop lectures, training courses, internships and educational material. The aim is to empower the next generation with suitable skill sets to use Copernicus data and information services to their full potential.

Our efforts even extend to career advice, with an article on the Futurum website[9] outlining how we can use earthquake studies to save lives, and the various routes to being an earthquake scientist see page 17.

For the future, and building on our webinar series, we are investigating online options that will extend our reach and make our training and education provision more accessible.

9 www.futurumcareers.com/studying-earthquakes-to-save-lives

EARTHQUAKES WITH DR ALEX COPLEY

TALKING POINTS

1) **What impacts can earthquakes have on communities?** *(See Introduction, p1 of article)*

2) **Why is it important to consider potential earthquakes when building towns and cities?** *(See Introduction, p1 of article)*

3) **What is an earthquake?** *(See 'What is an earthquake and what causes them?' – p1)*

4) **In your own words, describe why earthquakes commonly occur along plate boundaries.** *(See 'What is an earthquake and what causes them?' – p1)*

5) **Why would studying earthquakes help town planners and construction companies?** *(See 'Why do scientists monitor earthquakes?' – p1*

6) **What techniques and methods do scientists like Alex use to study previous earthquakes, and help prepare for future events?** *(See 'How do scientists monitor earthquakes?' – p 2)*

ACTIVITIES YOU CAN DO AT SCHOOL, COLLEGE OR AT HOME

CAN YOUR HANDMADE STRUCTURES WITHSTAND AN EARTHQUAKE?

Use toothpicks and marshmallows, or straws and plasticine, or ice-block sticks and a hot glue gun to construct a model of a building. Your goal is to make the building model as earthquake-proof as possible. To test it, you'll need a large amount of set jelly in a tray. Place your model on top of it and shake the tray from side to side to simulate an earthquake. Observe how your structure performs, and most importantly, what could be done to make it more earthquake resistant.

BUILD A SEISMOGRAPH

A seismograph is a piece of equipment used to measure to movement caused by earthquakes. Why not make one from regular household items? There are several websites with instructions to help you do that. Search 'make your own seismograph' with your preferred search engine. For example, here's one from Science World:
www.scienceworld.ca/resources/activities/make-your-own-seismograph

RESEARCH AN EARTHQUAKE

Select a significant earthquake from the past 50 years. Create a 2-minute video presentation, or 'news report', outlining the details of the earthquake (i.e. what, where, when, why and how). Include interviews with friends or family who can pretend to be eye witnesses or experts in seismology (you may have to help them understand a thing or two about earthquakes!).

A LOOK BACK AT 2018/19

Communication, outreach and engagement

We want people from all backgrounds to understand our science and its relevance to lives across the planet.

Our latest webinars[10] have explored controls on earthquakes and tectonics and how the material properties of the lithosphere vary over space and time; investigated what drives volcanic unrest; and explained our work on radar interferometry to our Spanish-speaking audience. Each time we have been joined by a live audience of up to 100 with more than 450 additional views on YouTube to date.

Our work is also widely accessible online and in print. One recent news article in Nature[11] explained how COMET teams at Leeds and Bristol are using artificial intelligence and satellite data to monitor and potentially help predict volcanic eruptions. Another investigated the timing and size of three deadly earthquakes that struck Italy in 2016, and the relationships between them[12]. Others have described fieldwork on Bagana Volcano in Papua New Guinea, explained the science behind stunning images of the Kilauea eruption on Hawaii, and outlined how satellites can be used to monitor earthquakes.

Blog posts are another great way to communicate our ideas and concepts more informally, for example what it's like to live in the shadow of a volcano[13], and how to encourage diversity in science[14].

Interactive websites bring a new dimension to our outreach activity. Explore[15], the University of Oxford's digital outreach platform, tested user knowledge on natural disasters, including earthquakes and eruptions, highlighting the work of COMET researcher Austin Elliott along the way.

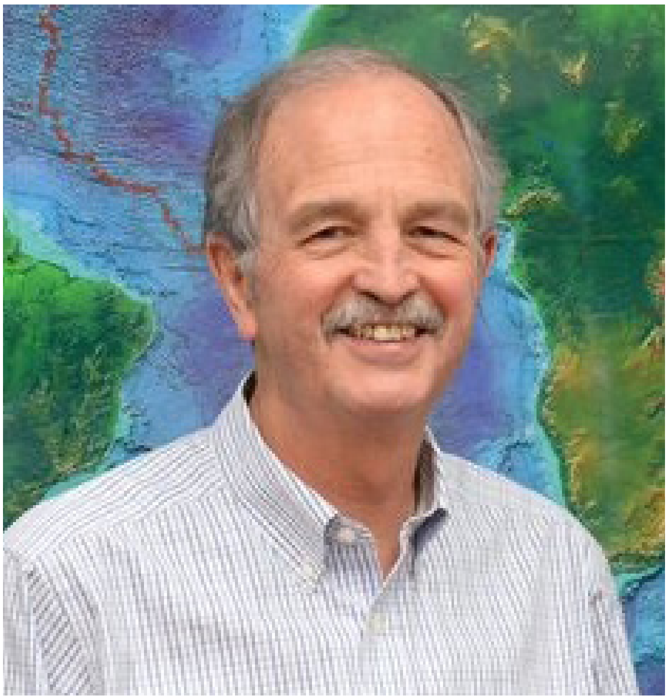
And in the mainstream media, we have commented on events ranging from the 2018 Indonesian tsunami and the Kilauea eruption on Hawaii, Chinese satellite re-entry, and even using InSAR and geomechanical modelling to assess the effects of North Korean nuclear explosions.

COMET's own website views have meanwhile increased from 20,000 in 2015, when the new website was launched, to over 120,000 at the time of writing (June 2019). The website provides not only our latest news but also access to our webinars, datasets and services, including the relaunched volcano deformation database[16]. We also now have almost 2,000 followers on Twitter[17].

10 www.comet.nerc.ac.uk/comet-webinar-series/
11 www.nature.com/articles/d41586-019-00752-3
12 www.phys.org/news/2018-08-deadly-italian-earth quakes-future-seismic.html
13 www.ox.ac.uk/news/science-blog/living-volcanic-gases-0
14 www.ox.ac.uk/news/science-blog/women-science-series-volcanology-sexism-and-lego
15 www.oxplore.org/question-detail/could-you-survive-a-natural-disaster#2306
16 www.comet.nerc.ac.uk/volcanoes/
17 @nerc_comet

In person, we attended events such as the Northern Ireland Science Festival and London's New Scientist Live, explaining the causes of volcanism on planet Earth, types of eruption, and what it is like to work on an active volcano. We also went to the pub with Pint of Science, where researchers share what they do and why they do it with the public in a convivial setting, to talk about volcanic violence and magnetic madness!

Deserving of special mention, in September 2018, as part of a Royal Astronomical Society (RAS) event to mark his retirement, Professor Barry Parsons gave a public lecture, Earthquakes from Space, at Oxford University's Museum of Natural History. This talk kicked off a celebration of Barry's achievements throughout his career, including as founding Director of COMET.



Professor Barry Parsons, University of Oxford

PROGRESS AGAINST OUR 2017/18 OBJECTIVES

Continue the development of the COMET/LiCS InSAR processing system to include unwrapped interferograms and average Line Of Sight (LOS) velocities. Share results via the ESA GTEP and EPOS portals

Milan Lazecky, Scientific programmer, Leeds

We have further improved the automated routines for producing unwrapped Sentinel-1 interferograms over tectonically and volcanically active world regions. Interferograms are served through the LiCSAR portal and will soon all be available via both CEDA and the ESA GTEP/EPOS portals. Routines for providing time series and map outputs of average LOS velocities are under development as well as integration of the GACOS system for correction of atmospheric disturbances. The whole system is running within CEDA's JASMIN computing facility.

Unwrapped data are available for all frames and LOS velocities have been produced for selected regions, including Anatolia. The pyroko/kite tool box for seismic source modelling has added new functionality to import LiCSAR outputs and associated metadata automatically[18].

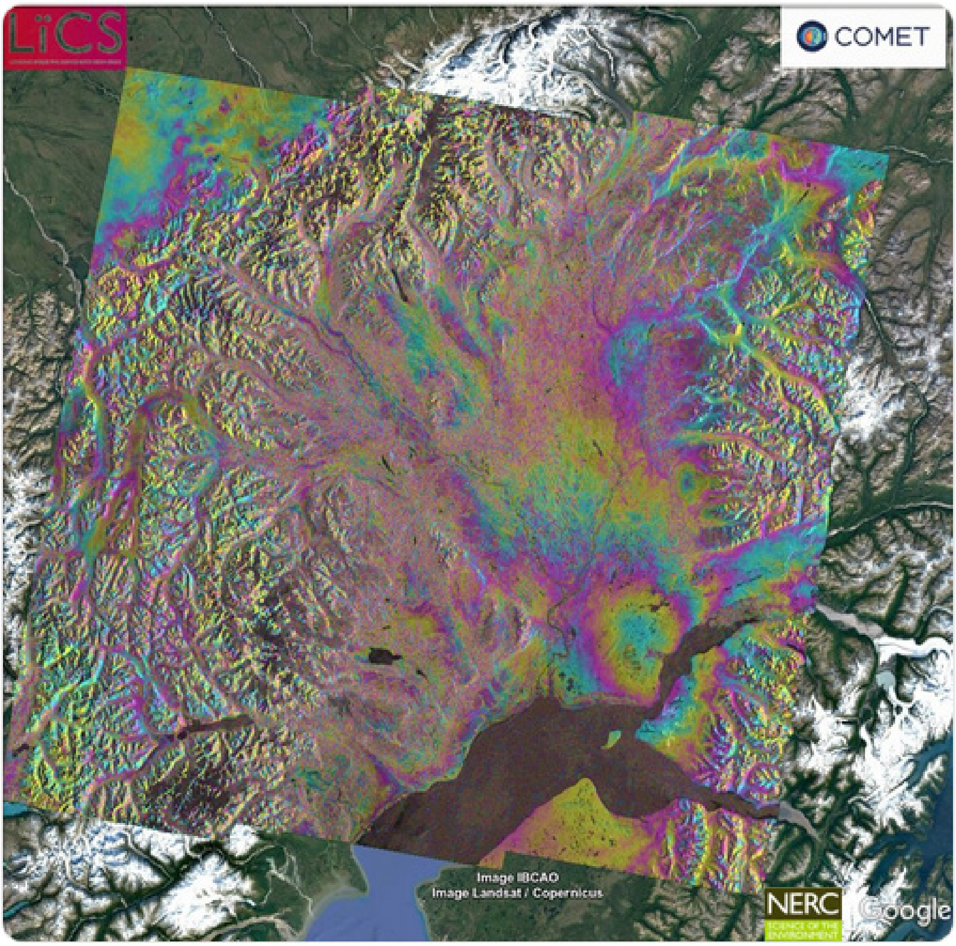
COMET LiCSAR website offering basic interferograms of tectonic or volcanic areas to the public

18 www.pyrocko.org/kite/docs/current/quickstart.html#download-and-import-data-from-comet-licsar

Establish an automatic fast response system within LiCSAR that prioritises rapid data processing of earthquakes and eruptions. Provide support for assessing the Alpine-Himalayan belt

Milan Lazecky, Scientific programmer, Leeds

We have arranged a semi-automatic system supporting other researchers by allowing on-demand interferometric processing. These processing results are collected with the aim of providing an overall assessment of displacements over the Alpine-Himalayan belt. In parallel with this, we are continuing to develop a fast response system which will generate early interferograms after a significant seismic or volcanic event and share them with key stakeholders.



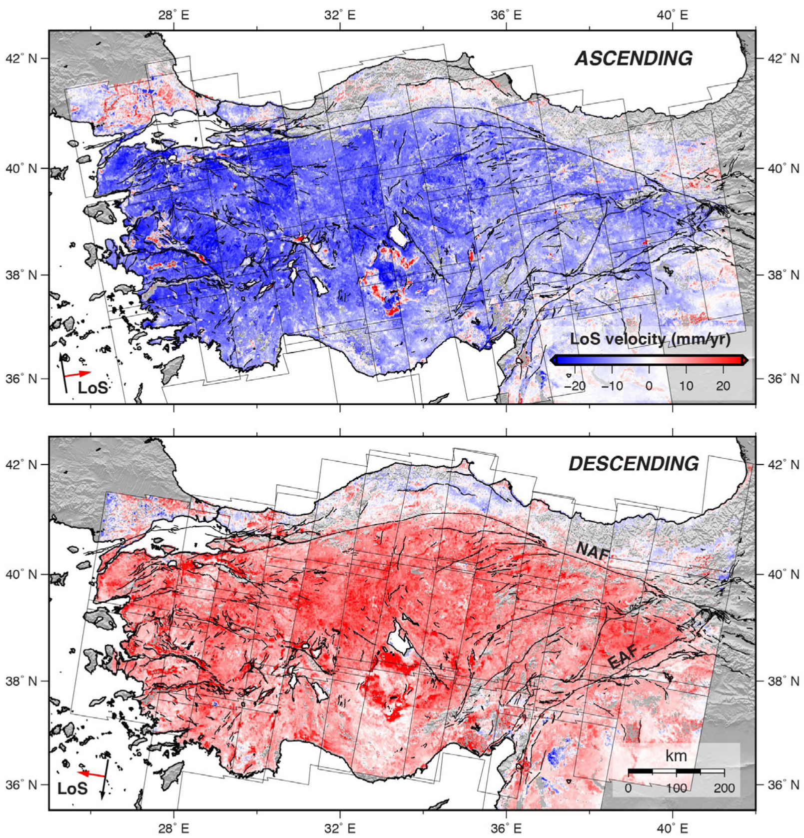
Example interferogram from LiCS showing deformation caused by the M7.0 earthquake at Anchorage, Alaska on 30th Nov 2018

PROGRESS AGAINST OUR 2017/18 OBJECTIVES

Make time series and velocity fields available for the Alpine Himalayan Belt and East African Rift. Share results via the ESA GTEP and EPOS portal

Jonathan Weiss, COMET researcher, Leeds[19]

We have made significant progress towards this goal. One highlight is that we now have complete line of sight velocity fields and time series for Anatolia in ascending and descending geometries (Figure below). These have required significant new processing and bug fixes to enable reliable interferometric data to be available for the tracks. Time series and velocities have been produced with a new NSBAS-style routine developed by visiting researcher Yu Morishita (GSI Japan). We have also incorporated atmospheric corrections made using the GACOS system.



Line of sight velocities from Sentinel-1 for Anatolia in ascending and descending geometries with LiCSAR frame outlines. NAF=Northern Anatolian Fault; EAF=Eastern Anatolian Fault

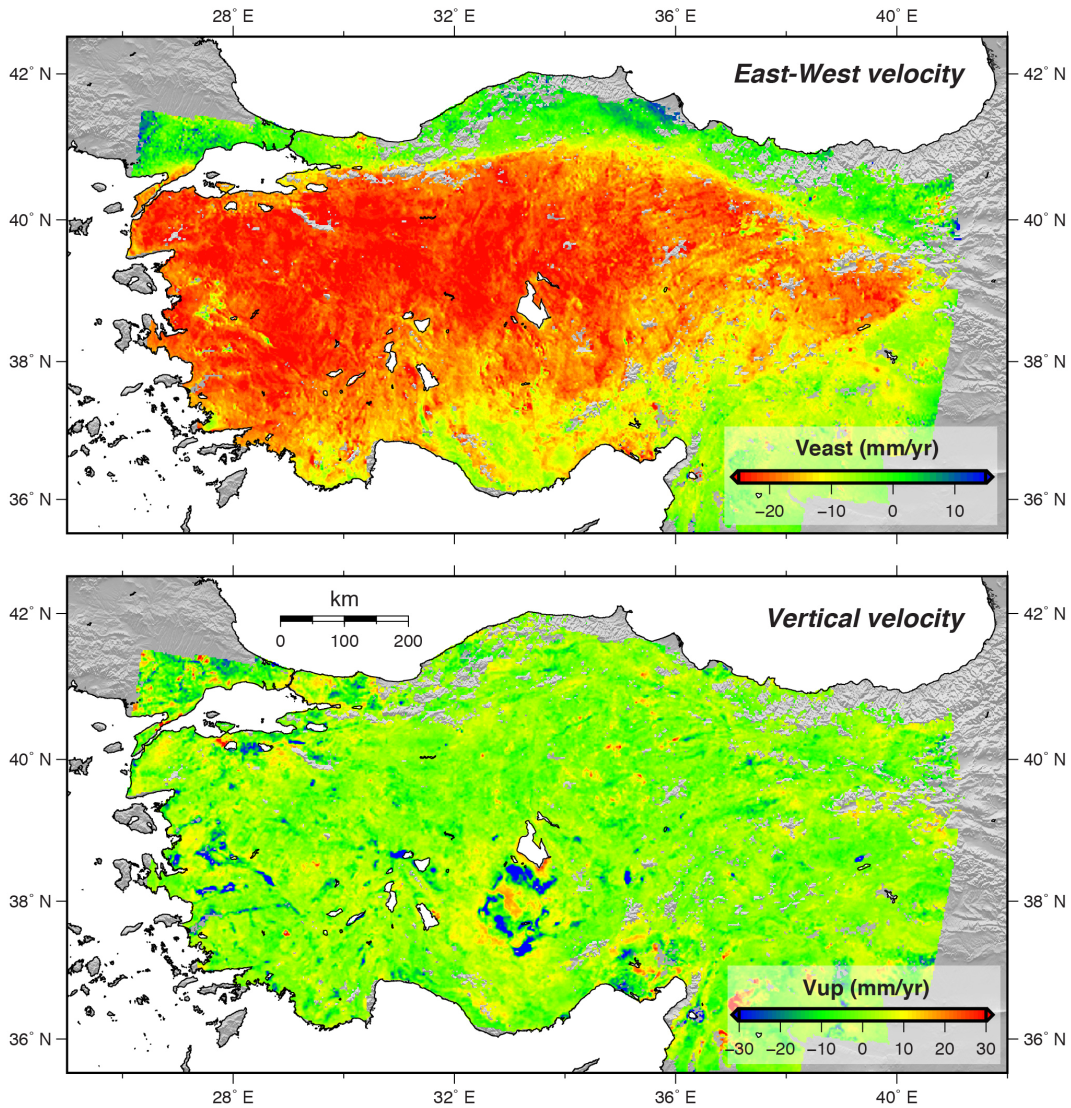
A large number of COMET students and scientists are now working on expanding the coverage for the Alpine-Himalayan Belt and East African Rift. We expect to complete this task in the next 12 months.

19 Now at Institute of Geosciences, University of Potsdam

Produce the first strain map for the Alpine Himalayan Belt from GNSS and InSAR, and deliver a country-scale deformation map for Ethiopia. Continue to evaluate methods for deriving continuous velocity and strain rate fields

Jonathan Weiss, COMET researcher, Leeds

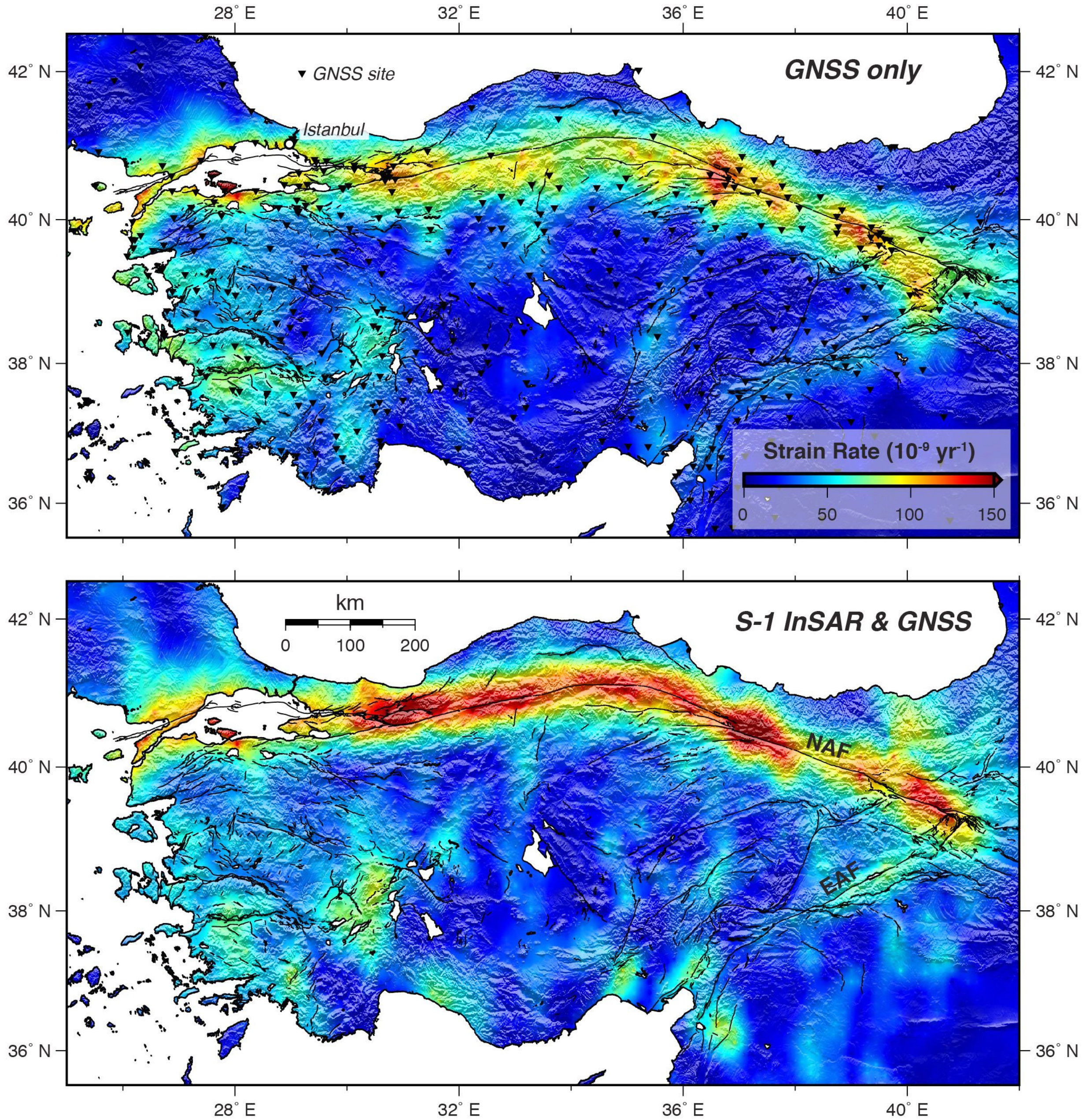
We continue to use Anatolia as a test area for the production of velocity and strain fields. We take two approaches. In the first, we combine InSAR and GNSS data to invert for high-resolution vertical and east-west velocity fields (Figure below). These detailed velocity fields show largely tectonic motions in the east-west field and non-tectonic deformation in the vertical fields. We expect to have similar results for the entire AHB and for Ethiopia in 2020.



East-west and vertical velocity fields for Anatolia

PROGRESS AGAINST OUR 2017/18 OBJECTIVES

As a second step, we jointly invert the LOS velocities and GNSS data to estimate tectonic strain using methodology developed by Wang and Wright (2012). An example of preliminary results for Anatolia is shown below. Although the results are still noisy, inclusion of the Sentinel-1 data better localises the tectonic strain associated with the major faults in the region and in particular the North Anatolian Fault (NAF). Further work will refine the methodology and extend the analysis to larger regions.



Tectonic strain (second invariant of the strain rate tensor) for Anatolia

The surface ruptures of the 2016 Parina earthquake in the Andes mountains
Credit: Dr Alex Copley, Bullard Laboratories, University of Cambridge

PROGRESS AGAINST OUR 2017/18 OBJECTIVES

Refine and further populate the database of active faults in Central Asia using collective expertise and up-to-date scientific results about each studied fault, and make it publically available

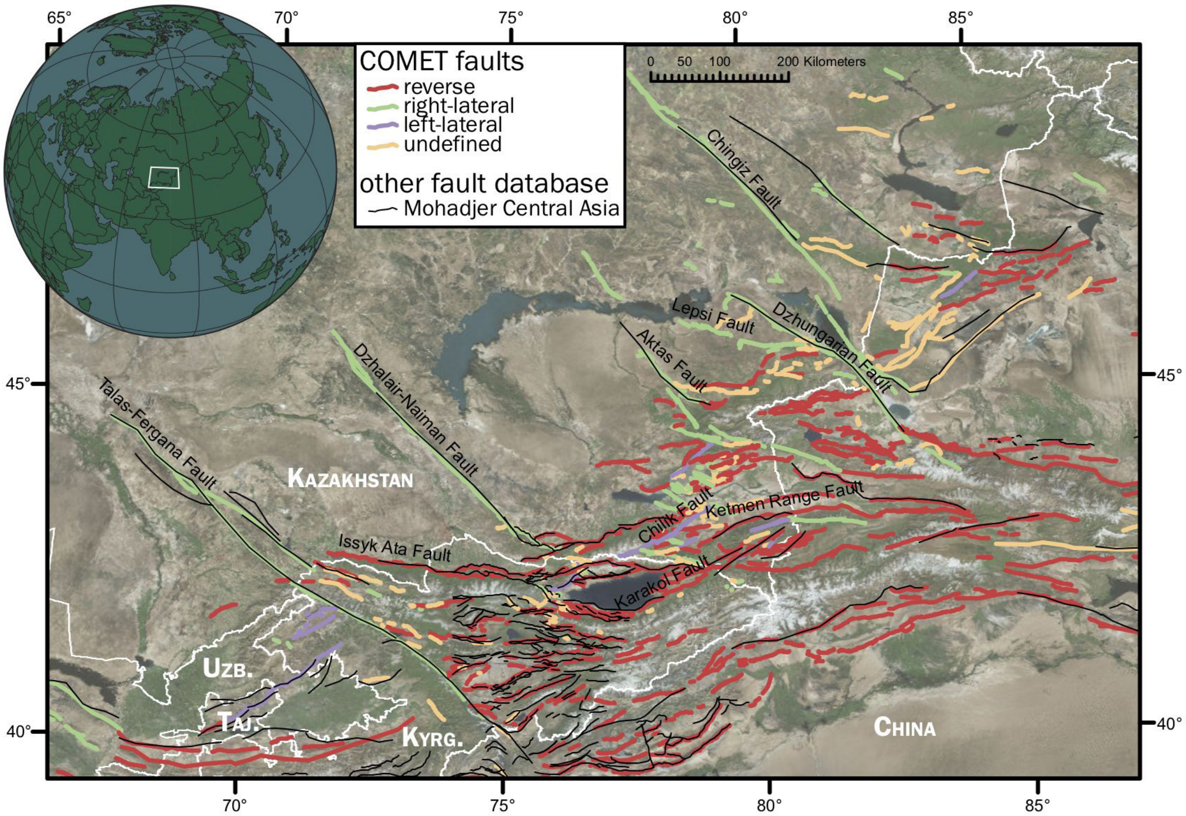
Austin Elliott, COMET researcher, Oxford

Over the past year we have advanced our database of active faults in the Tien Shan and Kazakh steppe into a definitive and flexible source of information on active tectonic structures of this region which is central to COMET research. The faults represented in detail in this geographic database reflect an important contribution to seismic hazard studies of this region based on neotectonic observations and earthquake histories rather than seismicity studies alone.

Detailed fault mapping is maintained in an ArcGIS geodatabase, where each fault is defined by up to 20 attributes ranging from names (primary, alternate, and segments) through structural detail (sense of motion, dip, rake) and paleoseismic information (slip rate, slip age, most recent event date, seismic recurrence interval) to reference information (including the contributor, any references, and any metadata or notes on certainty).

The database consists of at least 55 named structures and hundreds more newly mapped faults based on both remote and field-based observations by COMET researchers over the past 5+ years. Mapping principally from five individual COMET researchers has been winnowed from 4,250 individual overlapping, redundant, or conflicting line segments to a simpler more unified representation of just over 2,000 segments, and further refinement of representative geometric accuracy continues. Editorial decisions have to be made about the representation of faults for various purposes, and through discussion and partnership with the managers of other regional fault databases we are developing methods and guidelines to best present the data we have.

We have established a partnership with researchers at the Global Earthquake Model (GEM) Foundation to unify and streamline the production of this database. It will be made available online to other COMET researchers later this year, and after a suitable vetting process, made more broadly accessible. This database will serve as the foundation for further cooperation between COMET and GEM developing methods to analyse fault systems and derive meaningful seismic hazard models from sparse and non-uniform observations.



Faults of the COMET Central Asia Fault Database, showing documented sense of motion and some of the 55+ identified fault names. For comparison, faults in the existing regional database of Mohadjer et al., 2016 are shown as thin black lines. COMET researchers have vastly supplemented existing fault maps particularly in southern Kazakhstan, and several COMET publications document a large set of new observations of fault geometry, slip rate, and event history (Campbell et al., 2015; Gruetzner et al., 2016; Mackenzie et al., 2019)

References

Campbell, G.E., Walker, R.T., Abdrakhmatov, K.Y., Jackson, J., Elliott, J.R., MacKenzie, D., Middleton, T., et al. (2015) Great earthquakes in low strain rate continental interiors: An example from SE Kazakhstan, J. Geophys. Res. B Solid Earth doi:10.1002/2015JB011925

Grützner, C., Carson, E., Walker, R.T., Rhodes, E.J., Mukambayev, A., Mackenzie, D., Elliott, J.R., et al. (2016) Assessing the activity of faults in continental interiors: palaeoseismic insights from SE Kazakhstan, Earth Planet. Sci. Lett. doi:10.1016/j.epsl.2016.11.025

Mackenzie, D., Walker, R., Abdrakhmatov, K., Campbell, G., Carr, A., Gruetzner, C., Mukambayev, A., et al. (2019) A creeping intracontinental thrust fault : past and present slip-rates on the Northern edge of the Tien Shan , Kazakhstan, Geophys. J. Int. doi:10.1093/gji/ggy339

Mohadjer, S., Alan Ehlers, T., Bendick, R., Stübner, K. & Strube, T. (2016) A Quaternary fault database for central Asia, Nat. Hazards Earth Syst. Sci. doi:10.5194/nhess-16-529-2016

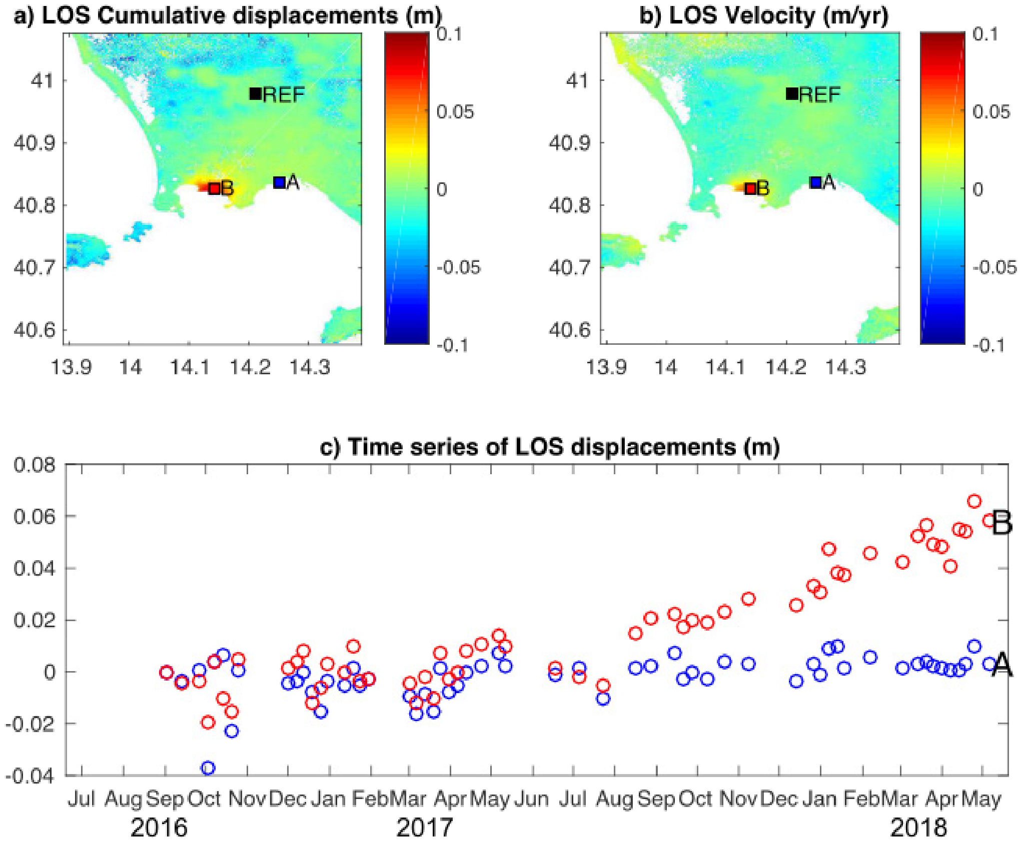
PROGRESS AGAINST OUR 2017/18 OBJECTIVES

Develop automatic monitoring of ground deformation signals on Holocene active volcanoes (LiCSAR-Volcano)

Fabien Albino, COMET researcher, Bristol
Milan Lazecky, Scientific programmer, Leeds
Juliet Biggs, COMET scientist, Bristol
Nantheera Anantrasirichai, Bristol

In 2018, we pursued our efforts to develop systematic processing of Sentinel-1 SAR data on all active volcanoes using the LiCSAR automated system. One year ago, we had 32,681 interferograms, but at the time of writing (May 2019) we had doubled our dataset to 68,349 interferograms of more than 900 volcanoes.

LiCSAR automated processing[20] is now running routinely on active volcanoes. We are now able to generate time series of deformation from several years on several volcanic centres, mostly in Africa and in Europe.



InSAR Sentinel-1 data detecting new episode of unrest at the Campi Flegrei volcano (Italy). a) Line Of Sight (LOS) cumulative displacements from September 2016 to May 2018. The point REF corresponds to the reference pixel where we assume no deformation, A is a coastline point showed for comparison and B the centre of the caldera; b) LOS velocity for the same period; c) Time series of LOS displacements for the two points A and point B, showing a linear uplift at the Campi Flegrei caldera at a rate of 7 cm/yr starting on August 2018

The COMET Volcano Deformation Database[21] has meanwhile been successfully transferred to the COMET website where it provides the three most recent wrapped interferograms and coherence maps. The next development will be to provide as routine other outputs such as the time series of deformation or statistics analysis on coherence maps.

We also continue to work on the automatic detection of ground deformation signals using machine learning techniques (see Research Highlight: Deep learning-based methods for detecting volcanic deformation InSAR data).

21 www.comet.nerc.ac.uk/volcanoes/

PROGRESS AGAINST OUR 2017/18 OBJECTIVES

Further refine IASI SO2 and ash retrieval techniques for monitoring low level volcanic emissions as well as specific eruptions

Elisa Carboni, COMET researcher, Oxford[22]

The science focus of our work is on the evolution of volcanic plume properties such as SO2 concentration and ash particle size. In the absence of a new event we intend to study the plumes from the 2008 Chaitén, 2008 Kasatochi, 2010 Eyjafjallajökull and 2015 Calbuco eruptions. This work is supported by several technical advances. For ash plumes this includes using CO2 slicing to provide a height constraint (described by Isabelle Taylor later in this issue), and using the refractive index parameterisation of ash derived in the last phase of COMET. We anticipate refining SO2 estimates using additional data from TROPOMI. Considerable interaction is expected with other scientists in the NERC R4Ash and V-PLUS projects.

Continue the development of the COMET Bayesian deformation modelling software, GBIS, including routines to account for the topographic effect on surface displacements and new analytical and numerical forward models

Daniel Juncu, COMET researcher, Leeds

Marco Bagnardi left his post this year and has been replaced by Daniel Juncu. Marco continues to develop and maintain GBIS, which was downloaded by 313 users from 41 countries in the 18 months since release. The software is already being widely used by the community - at least 14 publications using GBIS are found by Google Scholar, of which only 4 are authored by COMET members
.

In the next year, we plan to implement an inversion routine for modelling arbitrary geometry deformation sources to add to the existing models in GBIS. This would be suitable for modelling deformation in volcanic and hydrothermal areas. We also aim to introduce the capability to account for topography, so that the software will give better results in regions with strong relief.

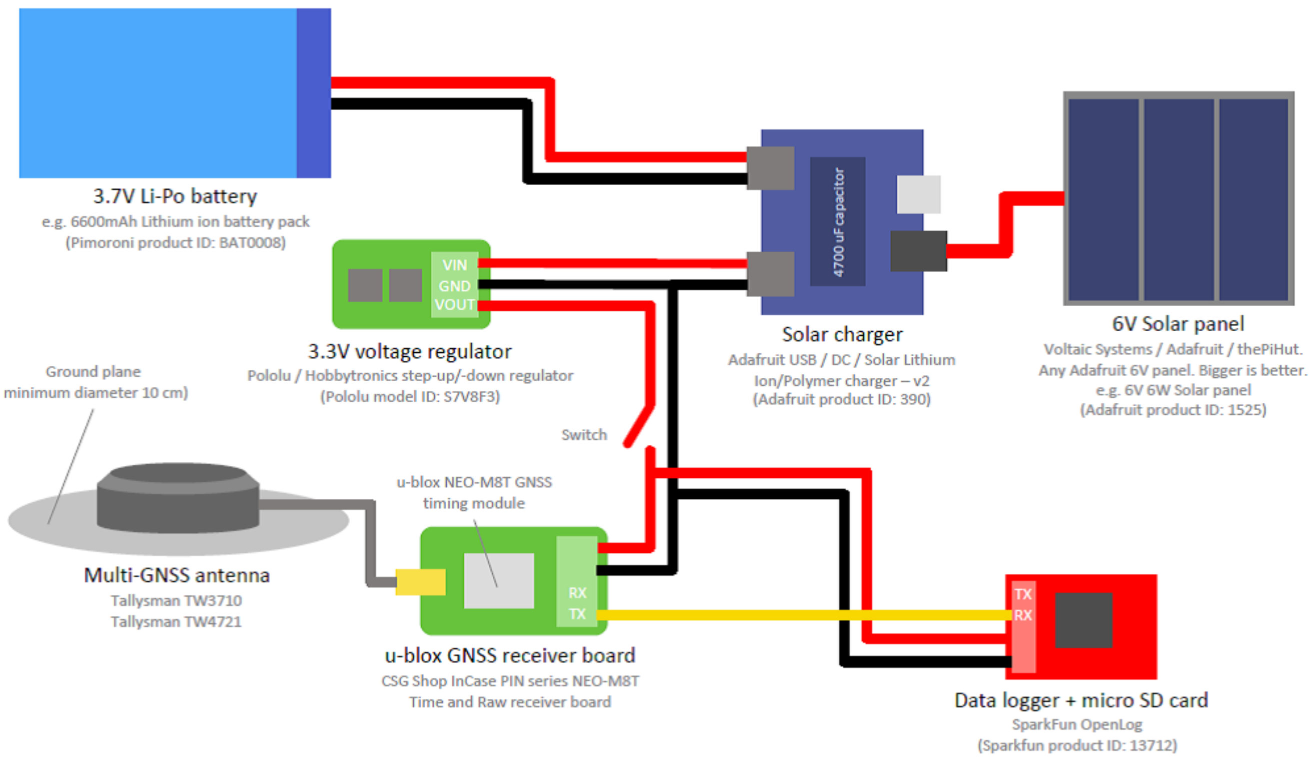
22 Now at Rutherton Appleford Laboratory

PROGRESS AGAINST OUR 2017/18 OBJECTIVES

Further develop a low-cost GNSS sensor network for autonomous real-time deformation monitoring, focusing on assessing the performance of two prototype sensors in terms of precision over different baseline lengths and power consumption

Chris Atkins, COMET researcher, UCL[23]

A full prototype low cost low power single frequency GPS instrument has now been developed, and full instructions are available for its design, build and use. In the current version, raw GNSS data is piped straight onto an SD card, with power consumption minimised to around 0.2W, making it much more feasible to use with a solar panel. The instrument should also be able to operate for months unaided, with total costs amounting to £200-300 depending on the exact parts used.



Wiring diagram for the sensor network

The instrument was demonstrated to BGS in March 2019, and they are now working on building and testing multiple units, providing a good platform from which to add more functionality including upgrading the instrument to multiple frequency.

A paper is also in development, describing a data processing strategy to reduce the effect of multipath error and apply it to the data collected by the instrument.

23 Now at Leica, Switzerland

Instrument mounted on top of a metal pole with a 6V 6W solar panel attached
Credit: Chris Atkins, UCL

PROGRESS AGAINST OUR 2017/18 OBJECTIVES

Strengthen links between COMET and relevant national and international research organisations such as GEM and VMSG, facilitating collaboration and discussion

As above, COMET's database of active faults in Central Asia will serve as the foundation for further cooperation between COMET and the Global Earthquake Model (GEM) in developing methods to analyse fault systems and derive meaningful seismic hazard models from sparse and non-uniform observations. This will generate new seismic hazard models from our global high-resolution strain-rate maps of the Alpine-Himalayan Belt and East African Rift, derived from InSAR and GNSS. We will also be producing maps of active faults in Central Asia and their rates of activity using high resolution imagery and topography, combined with fieldwork and Quaternary dating, which will be used by our partners at GEM to further understanding of hazard and risk. We plan a workshop with GEM in September 2019 at which we will build on our collaboration. We are also developing further links to the USGS for geodetic earthquake response.

Working with colleagues across COMET and BGS, identify strategic goals and new opportunities for 2019 onwards

In the last year we successfully bid for funding for the period 2019-2021. In this new phase of COMET we will be further integrating our knowledge, expertise and resources in a way that helps to deliver the BGS strategy, Gateway to the Earth, and, in particular, its aim of increasing resilience to environmental hazards. Discussions at our annual meeting between COMET, our Advisory Board and the BGS will begin the development of a long-term plan beyond 2021 that sets out how COMET will operate in full partnership BGS.

Dr Laura Gregory scouting for normal fault scarps, overlooking the Gulf of Gokova, western Turkey
Credit: Huw Goodall, University of Leeds

REVIEW

COMET and the Earthquakes without Frontiers project

James Jackson, COMET scientist, Cambridge
Philip England, COMET scientist, Oxford
Alex Copley, COMET scientist, Cambridge
Richard Walker, COMET scientist, Oxford

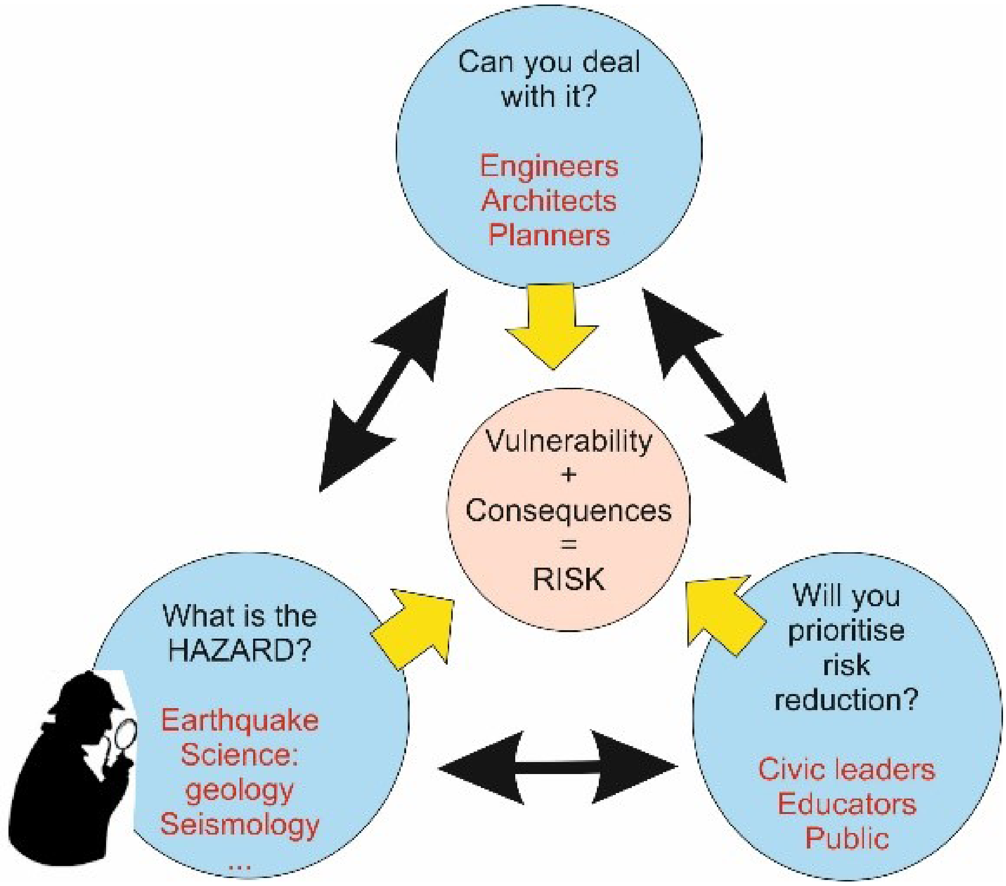
The **Earthquakes without Frontiers (EwF)** project was funded by NERC and the Economic and Social Research Council (ESRC). Co-led by James Jackson and Philip England from Cambridge and Oxford, the project also brought together natural and social scientists from Durham, Hull, Leeds and Northumbria Universities and from the Overseas Development Institute and British Geological Survey, as well as collaborators in Albania, China, Greece, India, Iran, Italy, Kazakhstan, Kyrgyzstan, Nepal, Turkey and Turkmenistan.

The project's aim was to try and start a process that used our knowledge of earthquake science to increase public safety in those regions. It involved many scientists from the COMET group, and formally ran from 2012-2018, but its activities and impact continue.

The problem: most earthquake-related deaths happen in Asia. Many more people die in moderate-sized earthquakes in continental interiors than in the largest earthquakes that occur in oceanic subduction zones. Continental earthquakes occur on many faults distributed over vast regions and repeat infrequently compared to those on subduction interfaces, which mostly accommodate plate motion on single faults. Populations in Asia are concentrated in megacities in vulnerable locations that have been destroyed in the past, but that previous earthquake may have occurred beyond living or recorded memory, and earthquake risk is rarely prioritized over other pressing concerns of everyday life.
The principal aims of EwF were to collaborate within the international partnership to:

1. ***Provide transformational knowledge*** of the earthquake hazards in places where it is rudimentary or poorly known.
2. ***Find effective pathways*** for using earthquake science to increase public safety.
3. ***Enhance local capability*** in earthquake science and public communication.

In all participating countries, vulnerable populations were more aware, and concerned with, daily issues such as congestion, pollution, traffic, water and food supplies, air quality, health and poverty than with earthquake hazard. The challenge was to find creative ways of prioritising natural hazards through three-way conversations between scientists, the public and those responsible for public safety policy. Input from all three is needed to increase resilience.



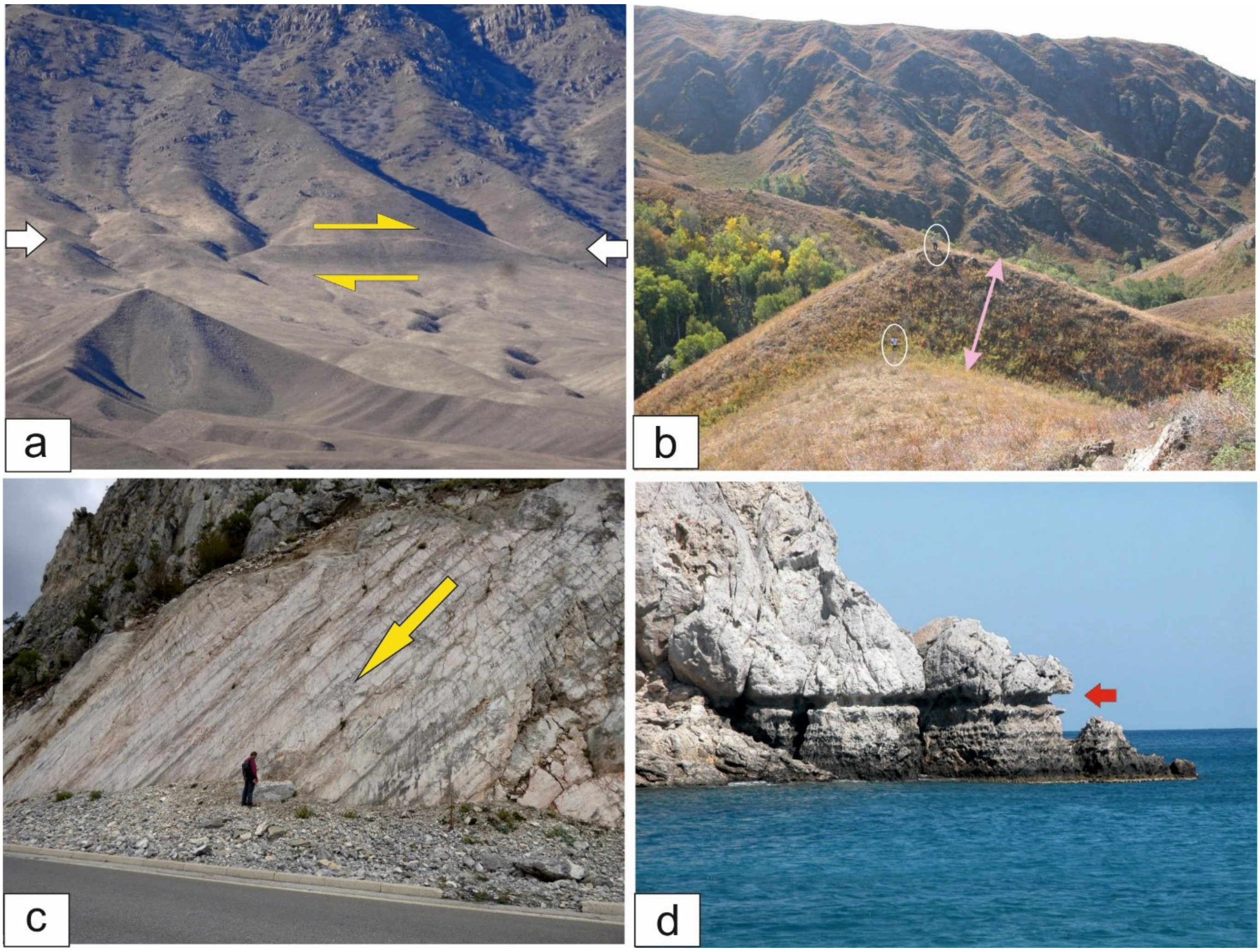
Elements and exchanges necessary to reduce earthquake risk through the use of earthquake science

Our strategy and approach was informed by the realization that (a) the international partnership in EwF revealed much common ground between countries, and that some novel solutions and approaches were transferable between them; and (b) that, at the same time, simply participating in high-quality research as part of an international team enhanced the standing and local effect of our partners.

COMET scientists were particularly involved in the first of our major aims: that of increasing knowledge of the earthquake hazards, in particular the identification and characterisation of active faults, using the whole range of land- and space-based observational techniques available within the COMET group. This includes identifying, mapping and clarifying the earthquake history and potential of faults, using Quaternary geology and geomorphology, paleoseismology and historical records.

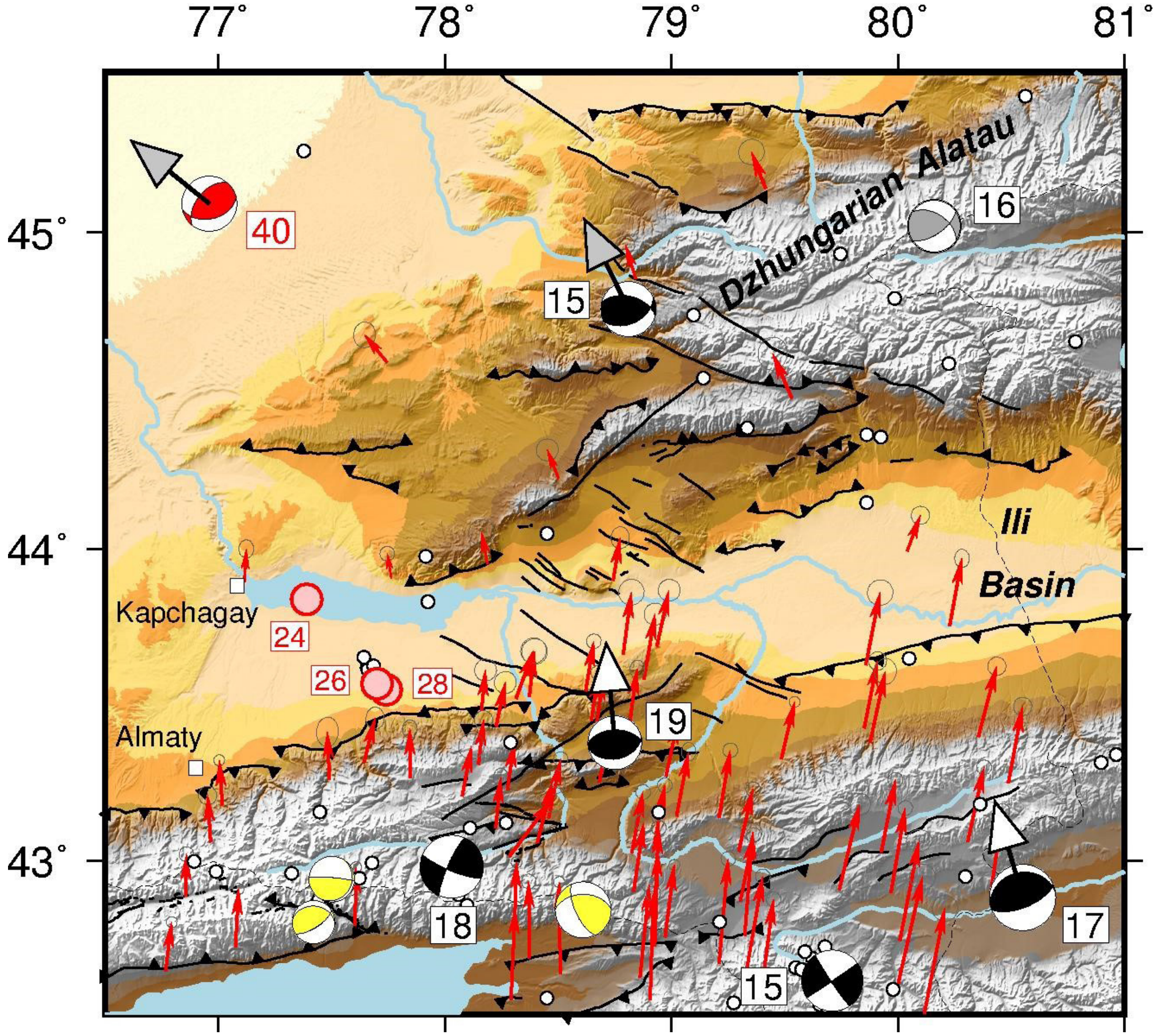
In much of central Asia active faulting has not been studied with the modern insights and methods that are now available, and the hazard and its context are almost unknown. As well as finding the faults responsible for past destructive earthquakes, much has been done to synthesize the relationship between active faulting, geomorphology, earthquake mechanisms and strain-rate fields from GPS. In the Mediterranean, our work has included finding the sources of large tsunamis that have devastated the coast in the past.

REVIEW



(a) The principal Kopet Dag strike-slip fault, NW of Ashgabat, the capital of Turkmenistan, which was destroyed in an earthquake in 1948, probably on this fault system. Streams are offset in a right-lateral sense between the white arrows. (b) The Lepsy fault in Kazakhstan, with a 10m offset (pink arrow; the white circles indicate people for scale) traceable for 100 km along strike. Paleoseismology indicates the offset probably occurred in a single earthquake in the last 400 years. (c) An active normal fault at Kukës in Albania, whose slip vector (yellow arrow) can be compared with earthquake focal mechanisms and GPS measurements. (d) Uplift of the eastern coast of Rhodes, SE Greece, in a single tsunami-generating event about 2000-4000 years ago

A great deal of original and innovative research came out of this engagement in basic scientific work across the entire Mediterranean-Middle East-central Asian earthquake belt, from Albania to China (E-W) and India to Mongolia (N-S), with about 100 papers published in leading Earth sciences journals over the course of the project. Most of these were co-authored by our international EwF partners, greatly increasing their own recognition, both within their own countries and internationally.



An example of a synthesis of GPS velocities (red arrows, relative to Asia), earthquake mechanisms (with slip vectors and accurate depths in boxes, in km) and active faulting in the region around Almaty in Kazakhstan, which was damaged by major earthquakes in 1887, 1889 and 1911. One achievement during the EwF project was to clarify the causative faulting of the 1889 and 1911 earthquakes. A great deal of effort goes into producing such maps, and in many parts of central Asia they are simply unavailable

REVIEW

Impact: Pathways to increased resilience. A significant challenge has been to encourage those responsible for public safety to prioritise earthquake resilience over other concerns. A particular problem in many countries is the willingness of the public and civic leaders to believe that scientists will one day produce a short-term earthquake prediction: this absolves leaders from any responsibility and removes any incentive to take preparatory action. An effective approach has been to use our Chinese and Italian colleagues to explain where this strategy leads: in the case of Italy and the 2009 L'Aquila earthquake, to the law courts; and in China after the 2008 Wenchuan earthquake, to the declaration that 'reliance on short-term prediction killed 80,000 people'.

Our goal is to influence public-safety policy away from a misguided hope in short-term earthquake prediction and towards effective education, mitigation and preparation. The main emphasis of our impact and science-into-policy agenda has been to help our local partners in their engagement with their own public, politicians and civic leaders. This has often involved accompanying them as a visible, but silent, presence, allowing our partners to demonstrate that they are connected to the international earthquake-science community, which not only enhances their own reputation and credibility, but also reassures those they are trying to convince. This has been a particularly effective benefit of the international partnership. We have participated in such meetings in Iran, Kazakhstan, Kyrgyzstan, Nepal, India and China.

The Partnership: engagement and capacity building. A major activity of the project was to encourage international partners to meet, to share and exchange ideas, experience and expertise. This led to many creative interactions and new opportunities for joint initiatives and engagement with policy makers. In addition to international partnership meetings in Tabriz, Almaty, Bishkek, Kathmandu and X'ian, we ran training workshops in earthquake science for young researchers in Trieste, Tehran and Jammu. We also helped our local partners to produce well-informed and accurate publicly-accessible material to increase public awareness and help prioritize earthquake hazard.

Some examples of engagement and outreach. (a) partners from Nepal and Kyrgyzstan meet in the Aksu Valley, Kyrgystan, to look at the fault responsible for the earthquake that damaged Almaty in Kazakhstan in 1911. (b) Richard Walker leads a group of international partners and Kazakh students, introducing them to active fault-related geomorphology at the Tien Shan range front near Almaty. (c-f) Examples of literature produced by EwF. (c) Earthquakes: A to Z (in Kazakh). A public education document produced with the Yessenov Foundation in Kazakhstan. (d) Earthquake Science and Hazard in Central Asia. (in Russian). An accessible report produced with the Yessenov Foundation in Kazakhstan and Overseas Development Institute (London). (e) Homecoming (in Chinese). A scenario report, based on a similar idea in Nepal, which describes an assessment of the effects of a modern repetition of an historical earthquake, in this case in 1558 near X'ian. The assessment is based on thorough modern earthquake science, and is recounted both in accessible language for policy makers and as a cartoon story (f) for the public

Conclusions. The EwF project was a bold experiment: an attempt to use scientific knowledge and partnership to increase public safety in a region that badly needs it. Like all genuine experiments, it was an evolving process, revealing some things that worked unexpectedly well and others that were less successful. Among the important lessons we learnt was the great positive, innovative and constructive potential of a partnership of active committed scientists across the region, who interacted and shared experience and ideas in an effective and creative way. We are actively pursuing ways to continue to work together in this way.

Further information. There are many references to scientific and outreach work of the EwF project on its website: http://ewf.nerc.ac.uk/

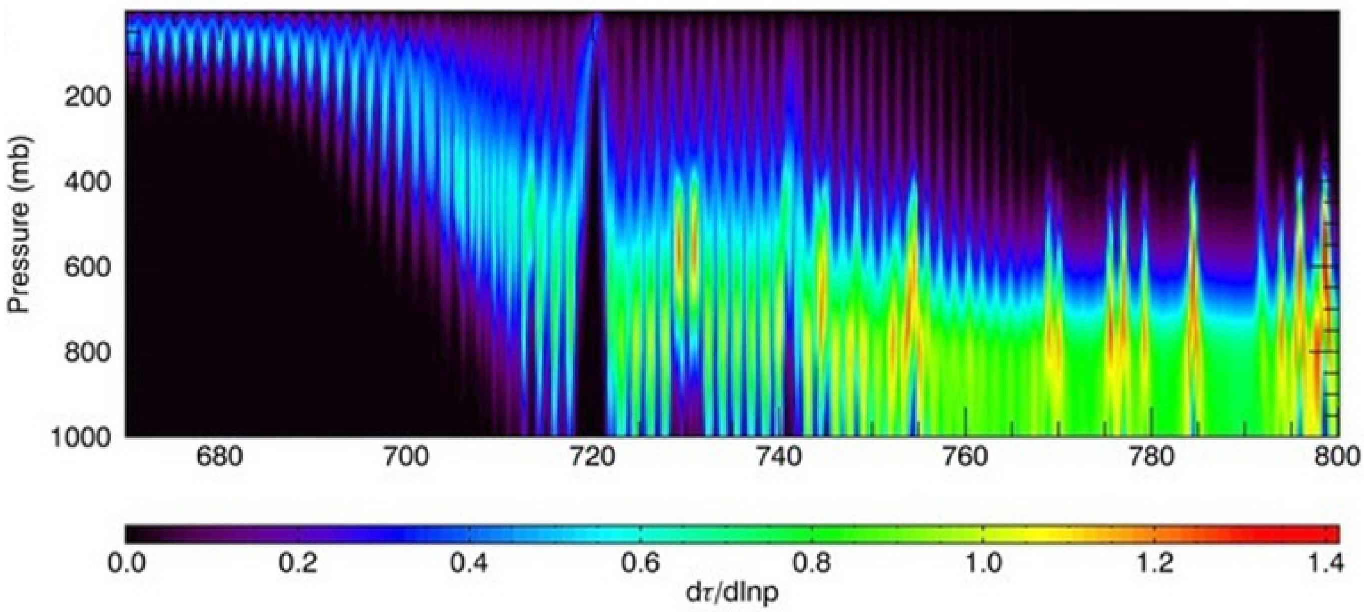
RESEARCH HIGHLIGHT

Ash cloud altitudes from the Infrared Atmospheric Sounding Interferometer (IASI)

Isabelle Taylor, PhD student, Oxford

In order to minimise the hazard presented by volcanic ash clouds it is important to know their position in three dimensions, which includes knowing the altitude. The CO_2 slicing technique has been widely applied to obtain the altitude of meteorological cloud but there is also potential for using the technique to find the altitude of volcanic ash.

The CO_2 slicing technique utilises an absorption feature (665-750 cm-1; 13.3-15 μm) within the thermal infrared where there is information on the altitude of different cloud layers. For channels at lower wavenumbers within this spectral range the atmosphere appears opaque and so only high clouds are visible. Whereas at higher wavenumbers the atmosphere is more transparent and it is possible to identify clouds lower down in the atmosphere. This changing sensitivity to different heights in the atmosphere can be exploited to obtain the height of clouds.

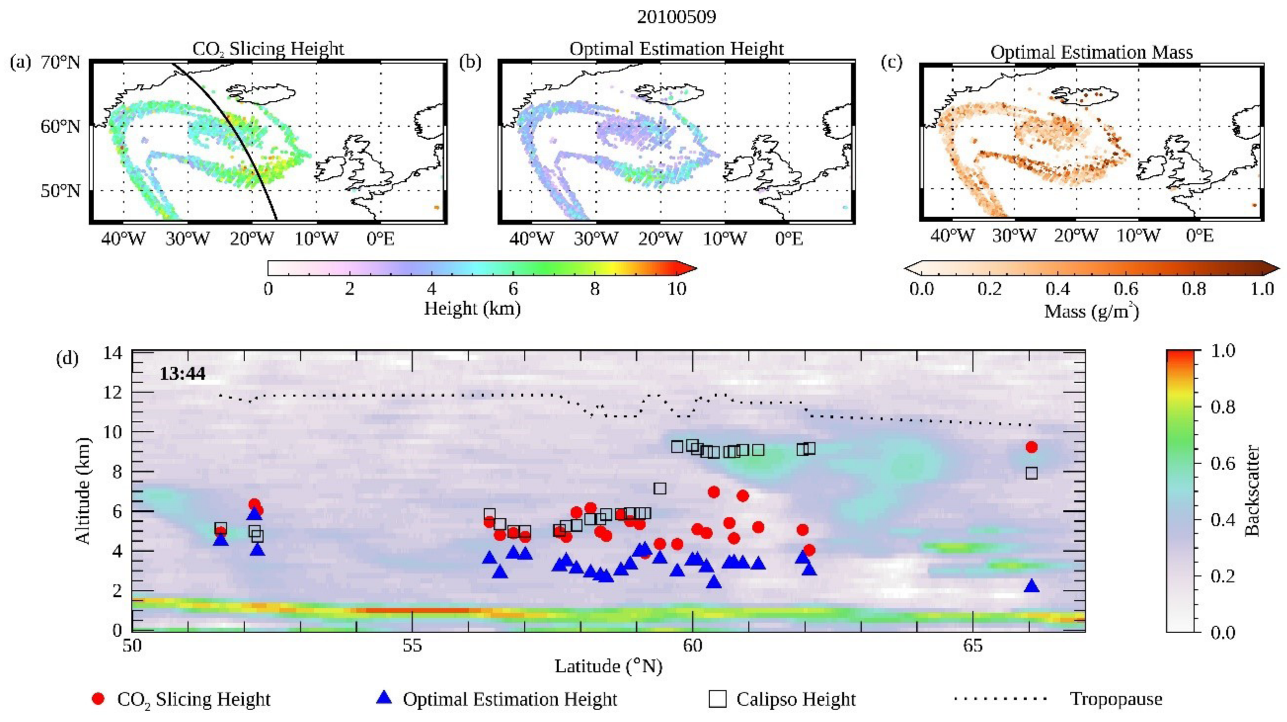


The change in atmospheric transmittance (τ) with pressure (p). This gives us some indication of which part of the atmosphere each channel is sensitive to

Our aim was to apply this method to volcanic ash using the Infrared Atmospheric Sounding Interferometer (IASI). This instrument has over 300 channels within the CO2 absorption feature. The first challenge we had trying to adapt this technique for IASI and for ash, was to select a subset of these channels to use. To do this we applied the technique to modelled data for all of IASI's channels within the CO2 absorption band.

Modelled data was then used to check how the retrieval performed when these channels were used together. These results were encouraging and so we then applied the technique to scenes from the Eyjafjallajökull (2010) and Grímsvötn (2011) eruptions.

A satellite borne LiDAR was used for validation and the results were also compared against an optimal estimation scheme developed for IASI (Ventress et al., 2016). An example from the Eyjafjallajökull eruption is shown below. Overall, the CO2 slicing showed improved results compared to the optimal estimation scheme. One suggestion from this study is that we can use the output of this technique in the future as an a priori in the optimal estimation scheme in order to improve its results.



(a) CO2 slicing heights for 9th May 2010 during the Eyjafjallajökull eruption. (b) Optimal estimation heights. (c) Optimal estimation mass. (d) A CALIOP backscatter profile from the 9th May 2010. Overplotted on this are the heights obtained with the optimal estimation and CO2 slicing techniques

References

Taylor, I.A., Carboni, E., Ventress, L.J., Mather, T.A., Grainger, R.G. (in review) An adaptation of the CO2 slicing technique for the Infrared Atmospheric Sounding Interferometer to obtain the height of tropospheric volcanic ash clouds, Atmos. Meas. Tech. Discuss. doi: 10.5194/amt-2018-447

Ventress, L.J., McGarragh, G., Carboni, E., Smith, A.J., Grainger, R.G. (2016) Retrieval of ash properties from IASI measurements, Atmos. Meas. Tech. doi: 10.5194/amt-9-5407-2016

RESEARCH HIGHLIGHT

Rapid detection of landslides with satellite radar

Katy Burrows, PhD student, Durham

At Durham, we have developed an automated method of using satellite radar imagery to identify triggered landslides following an earthquake. Our new method is more accurate than existing radar methods and can generate information on landslides more quickly than conventional methods which use optical imagery.

Earthquake-triggered landslides present a significant hazard and may damage transport and communication infrastructure, disrupting relief efforts. Information on where landslides have occurred is therefore invaluable but generating this information quickly enough to be useful in the emergency response effort is challenging.

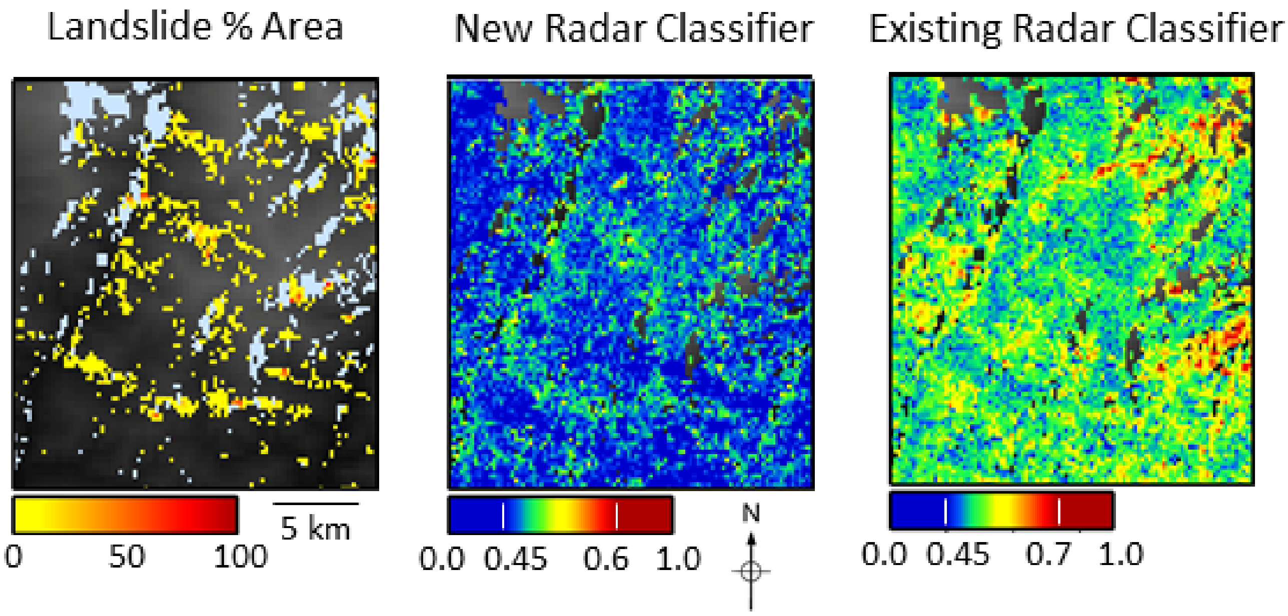
As triggered landslides may affect an area on the scale of tens of thousands of kilometres, they are commonly mapped using optical satellite imagery. This is a time-consuming process and requires cloud-free daylight imagery, which is often unavailable for days or weeks following an earthquake. As we show in our research, published this year in Remote Sensing[24], satellite radar is a potential solution to this problem. Data can be acquired day and night in all weather conditions and in recent years the number of satellite radar constellations has increased so that imagery is now available within a few weeks of a trigger event anywhere on Earth.

From two radar images acquired at different times, we can calculate a map of 'coherence', a measure of the noise level in the images, indicative of how consistent the scattering properties of the ground are through time. For example, the scattering properties of bare rock change little, resulting in high coherence. Surfaces such as vegetation or water whose scattering properties vary through time have a lower coherence. As landslides significantly modify the Earth's surface by moving material and stripping away vegetation, areas where landslides have occurred are expected to have low coherence. We have developed a new method which uses coherence for large-scale landslide classification.

In a conventional 'boxcar' estimate, coherence is estimated for a pixel from the similarity in the signal change of a small group of pixels surrounding it. For a pixel lying within a landslide, most of this group will also lie within the landslide. The signal change of these pixels will be random, resulting in a low coherence estimate. As well as this, we calculated a 'sibling' coherence. In this method, a small group of pixels which exhibit similar behaviour in a long time-series of pre-seismic imagery are selected from within a larger window (Spaans and Hooper, 2016). The coherence of a landslide pixel is thus dependent on the similarity in signal change of pixels which are dispersed over a wider area and therefore less likely to also lie within landslides. The sibling coherence map is therefore relatively insensitive to landslides. In our new method, we produce a landslide classification surface by differencing these two coherence maps. This method outperforms existing radar coherence methods, which were developed for urban damage mapping and do not perform well for landslide mapping in rural areas (e.g. Yun et al. 2015).

To test our new method, we used an inventory of landslides triggered by the 2015 Gorkha, Nepal earthquake (Roback et al. 2018). Using data acquired by Sentinel-1, we were able to recreate large scale patterns in landslides, allowing identification of regions that had experienced significant numbers of landslides. This information has been shown to be useful to emergency response coordinators, providing an overview of which areas have been worst hit by landslides following an earthquake.

24 Burrows, K. et al. (2019) A New Method for Large-Scale Landslide Classification from Satellite Radar, Remote Sensing doi:10.3390/rs11030237



Left: Map showing the percentage area of 200 x 200 m pixels covered by landslides following the 2015 Gorkha earthquake. From the inventory of Roback et al. (2018). Middle: landslide classification surface generated by differencing two coherence estimates (Burrows et al. 2019). Right: an existing coherence-based classification method designed for urban damage mapping (Yun et al. 2015). Both radar surfaces were generated from Sentinel-1 satellite radar imagery and have been normalised to obtain a number between 0 and 1, with 1 most likely to be a landslide

References

Burrows, K., Walters, R.J., Milledge, D., Spaans, K., Densmore, A.L. (2019) A New Method for Large-Scale Landslide Classification from Satellite Radar, Remote Sensing doi:10.3390/rs11030237

Roback, K., Clark, M.K., West, A.J., Zekkos, D., Li, G., Gallen, S.F., Chamlagain, D., Godt, J.W. (2018) The size, distribution, and mobility of landslides caused by the 2015 Mw7. 8 Gorkha earthquake, Nepal, Geomorphology doi:10.1016/j.geomorph.2017.01.030

Spaans, K. and Hooper, A. (2016) InSAR processing for volcano monitoring and other near real time applications, Journal of Geophysical Research: Solid Earth doi:10.1002/2015JB012752

Yun, S.H., Hudnut, K., Owen, S., Webb, F., Simons, M., Sacco, P., Gurrola, E., Manipon, G., Liang, C., Fielding, E., Milillo, P. (2015) Rapid Damage Mapping for the 2015 Mw 7.8 Gorkha Earthquake Using Synthetic Aperture Radar Data from COSMO–SkyMed and ALOS-2 Satellites, Seismological Research Letters doi:10.1785/0220150152

RESEARCH HIGHLIGHT

How do lateral rheology contrasts affect the growth of mountain ranges?

Camilla Penney, PhD student, Cambridge

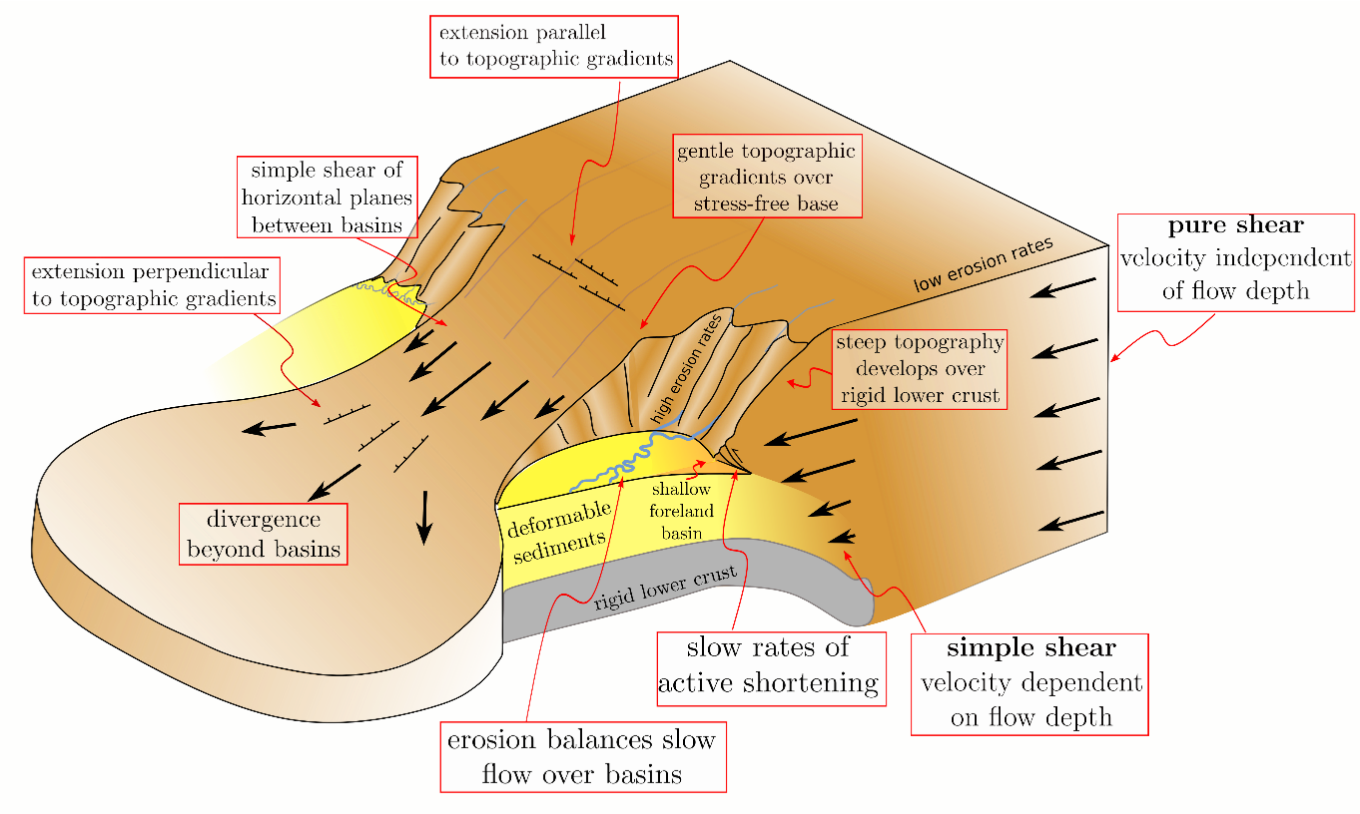
The rheology of the continental lithosphere controls how the lithosphere deforms in response to tectonic forces. From earthquake-source studies, seismic tomography and gravity data, amongst others, we can see lateral contrasts in this rheology, with stronger, less deforming cratons, and more easily deformed, younger rocks around them. At the University of Cambridge we (Camilla Penney and Alex Copley) have been combining numerical modelling with geological and geophysical data to understand the effects of these lateral rheology contrasts on the shape and temporal evolution of mountain ranges.

Previous numerical models of continental deformation either make simplifying assumptions which don't allow for the movement of weaker, rapidly-deforming rocks over strong lower crust, or use unrealistic geometries and rheologies. We have developed a new model which can account properly for the effects of lateral rheology contrasts. By improving on previous methods of time-stepping, we have been able to investigate the evolution of mountain ranges over tens of millions of years.

A wealth of geophysical and geological data suggesting that the lower crust of the Sichuan Basin and Central Lowlands of Myanmar is much stronger than that of the rapidly-deforming, high topography between them makes the south-eastern margin of the Tibetan Plateau an ideal place in which to study the effects of lateral rheology contrasts. Our initial modelling therefore focussed on understanding the evolution of mountain ranges in this region.

Our modelling shows that having strong, undeforming lithosphere in the Sichuan Basin and the Central Lowlands of Myanmar can lead to first-order features of the topography, earthquake distribution and GPS-velocity field. We also compared the rates of uplift from our model to recent geological data which use the oxygen isotope composition of carbonates to infer past elevations of mountains. We find that the uplift rates from using a simple rheology for the mountain ranges fit well with these geological data. Our results suggest that the geophysical and geological observations in South-East Tibet can be explained by lateral rheology contrasts without the need for the complex rheologies, such as a low-viscosity, lower-crustal channel, which have previously been proposed.

Our results show that the geology at the edges of mountain ranges controls the topographic slopes, style of faulting and lateral extent of the ranges which develop. Where mountain ranges grow adjacent to old, anhydrous cratons, the rigid lower crust leads to the formation of steep topographic gradients, as seen in the Longmen Shan, in South-East Tibet, and the western Kunlun ranges, at the southern margin of the Tarim Basin. Such ranges tend not to propagate far over the rigid lower crust, and we have shown that they can even stop moving forward if erosion rates are high. In contrast, mountain ranges growing adjacent to younger, hydrous lithosphere tend to form gentle topographic gradients. These results have to potential to explain many features of the shape and evolution of mountain ranges globally, from the embayments of the Zagros Mountains to varying widths and gradients of the Andes. Understanding the effects of lateral rheology contrasts on the shape and evolution of mountain ranges will also allow us to use measurements of surface strain rates and topography to probe the rheology of the lower crust.



How do rigid regions affect the growth of topography? Steep topographic gradients develop above the region of rigid lower crust because of the dependence of velocity on flow depth. Regions without strong lower crust deform by pure shear of vertical planes, which results in gentle topographic gradients. Between two rigid regions flow is similar to flow in a pipe. Beyond the basins the flow can spread out, leading to extension. These features are similar to the strain rates and topography in South East Tibet, suggesting that lateral rheology contrasts play a first-order role in deformation in this region

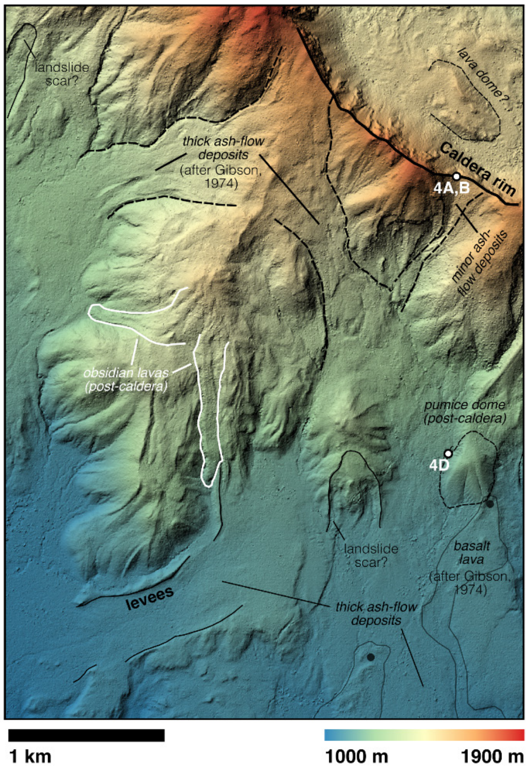
RESEARCH HIGHLIGHT

Topography of Ethiopian volcanoes: locations, magnitudes and styles of past activity

Jonathan Hunt, PhD student, Oxford

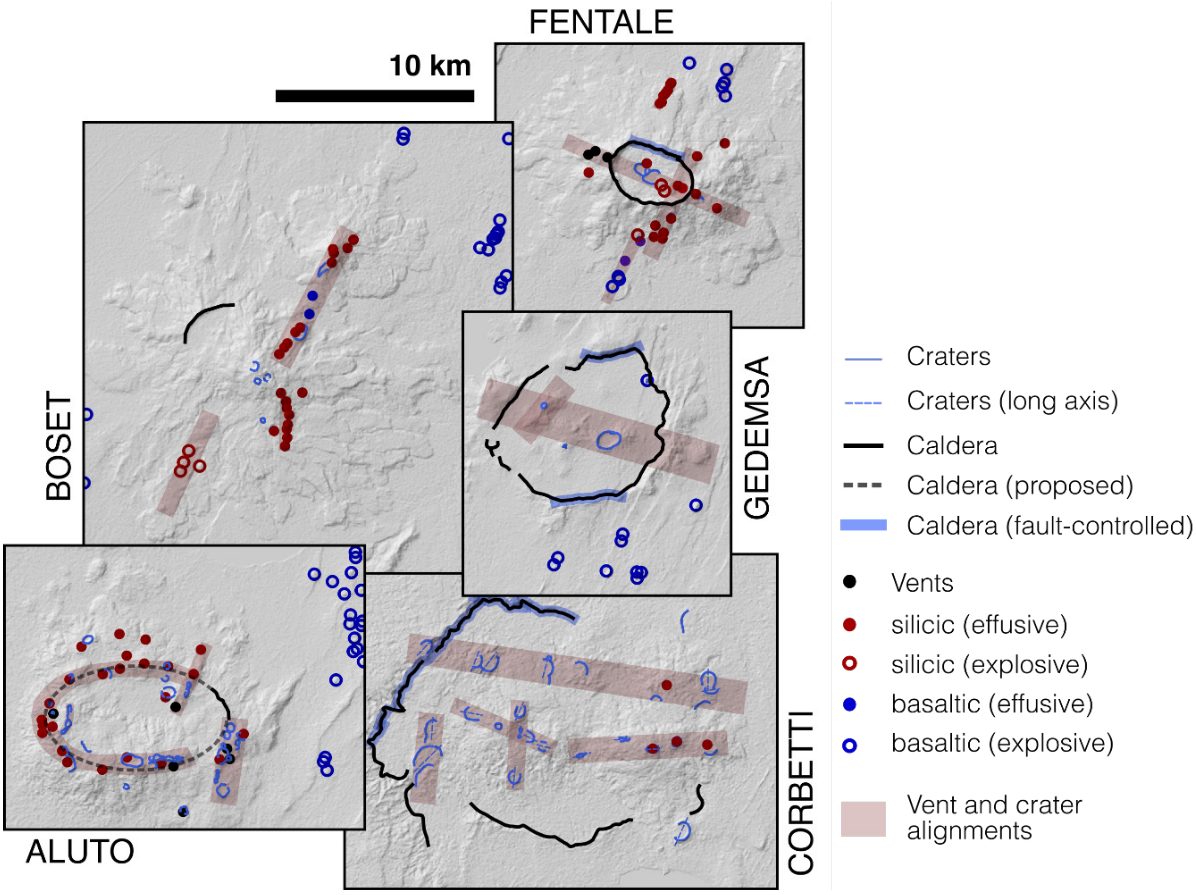
Volcanoes in Ethiopia have been the focus of little research historically, leaving many fundamental questions unanswered. These questions have been the focus of the RiftVolc project over the last 5 years. Mapping of vents, craters and volcanic deposits provides valuable information on eruption locations. Estimating the volumes of these eruptions and investigating the behaviour of lava and other products provides further constraints for hazard assessment.

Ethiopian volcanoes are large and mostly inaccessible, presenting great challenges for mapping. We created high-resolution digital elevation models (DEMs) using satellite images captured from the Pleiades constellation. We used these DEMs, in addition to previously generated models from lidar, to identify and estimate the locations, magnitudes and styles of past activity at four volcanoes in the Main Ethiopian Rift and Afar.



Digital elevation model (combined elevation and hillshade) of a portion of Fentale volcano, with flow deposits and features mapped

We mapped previously unidentified deposits, particularly at Fentale volcano which has been more active in its post-caldera stage than researchers had thought until now. The locations of vents and craters align along faults and fractures – many of these alignments are sub-parallel to the rift and approximately orthogonal to extension.

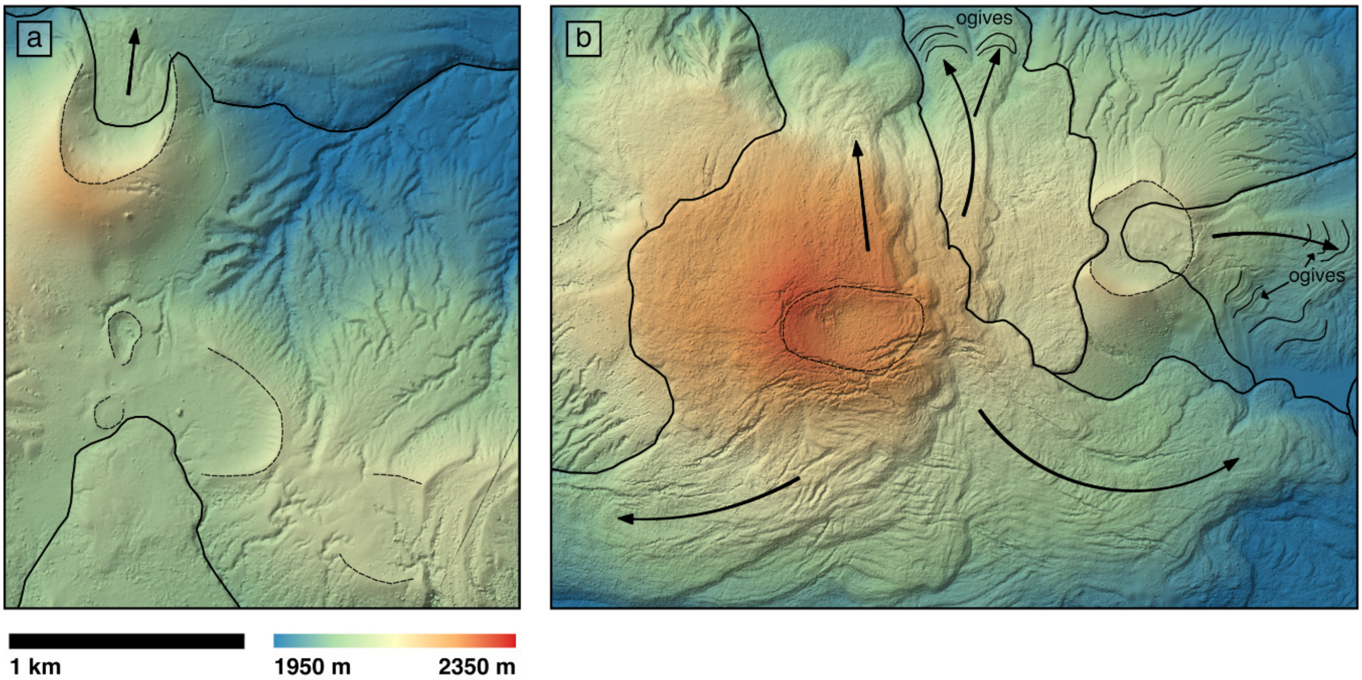


Summary figure of structures at the three study volcanoes in the Main Ethiopian Rift (Fentale, Gedemsa and Corbetti) along with two previously studied volcanoes (Boset and Aluto). A range of alignments and structural features are observed at each centre

Some of the alignments cross-cut the rift and are associated with older, buried structures. The shapes of large craters have also been controlled by faults.

Volumes of lava flow deposits at Fentale are much lower than at Corbetti, where large coulees are emplaced. The DEMs reveal large craters near the source of these large coulees, implying a preceding explosive phase to the eruptions.

RESEARCH HIGHLIGHT



Digital elevation model (combined elevation and hillshade) of the two edficies at Corbetti volcano (a: Urji; b: Chabbi). Large coulees at Chabbi originate from large crater structures

We have provided some constraints on flow rheology using morphometric parameters, including the geometry of levees and the spacing of wrinkles on the surface of the flows. Laboratory experiments on peralkaline lavas like those found at rift volcanoes in Ethiopia have suggested lower viscosities compared to their calc-alkaline counterparts. Viscosities estimated from morphometry are similar to or lower than common calc-alkaline viscosities, consistent with experiments.

DEMs can be used to great effect in comparing and investigating large and inaccessible volcanoes. The observations that we have made will support ongoing hazard assessment in an area of rapid population growth and vulnerable infrastructure, and develop our understanding and appreciation of Ethiopian rift volcanism.

References

Hunt, J. A., Pyle, D. M., & Mather, T. A. (2019) The geomorphology, structure, and lava flow dynamics of peralkaline rift volcanoes from high-resolution digital elevation models, Geochemistry, Geophysics, Geosystems doi:10.1029/2018GC008085

RESEARCH HIGHLIGHT

Multi-year satellite observations of sulphur dioxide gas emissions and lava extrusion at Bagana Volcano, Papua New Guinea

Brendan T. McCormick Kilbride, COMET associate, Manchester

Bagana volcano, Papua New Guinea, is among the youngest and most active volcanoes on Earth. The prevailing activity at Bagana comprises long-lived effusive eruptions of blocky basaltic andesite lava, rare explosive events, and continuous emissions of sulphur dioxide (SO2)-rich gases.

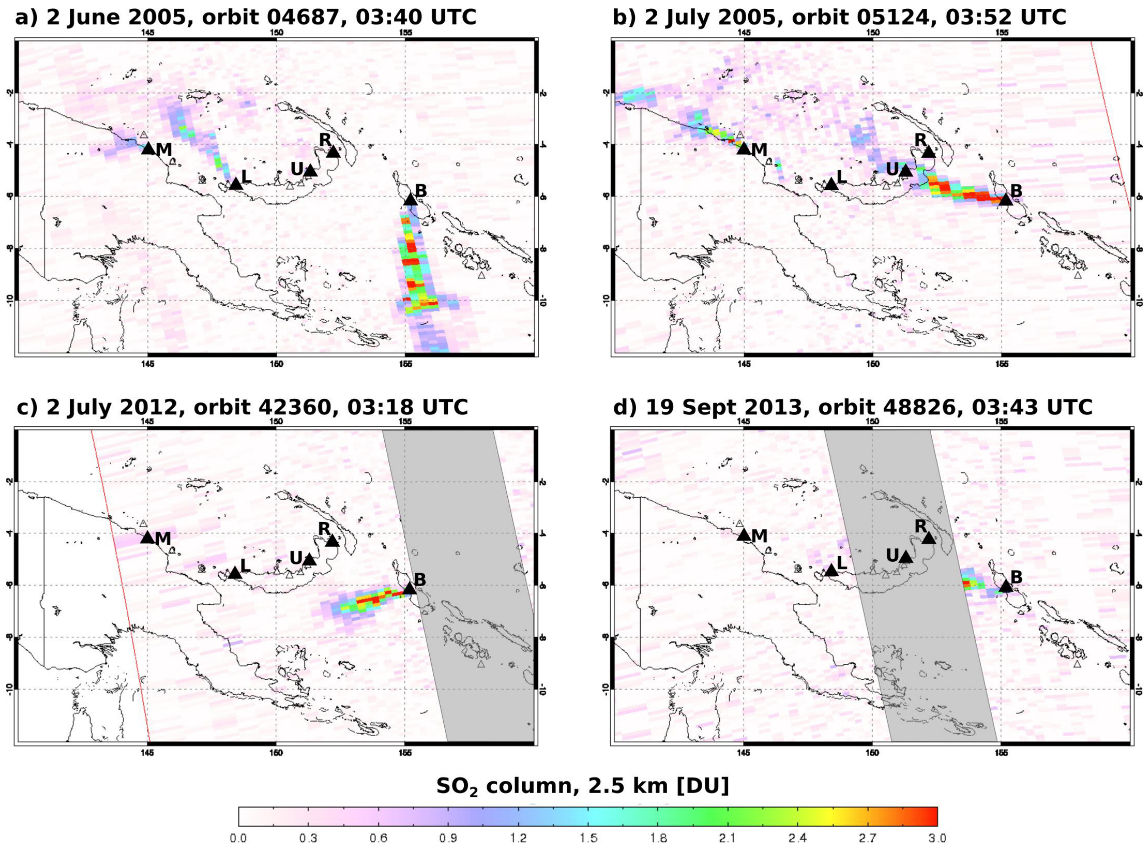
Bagana viewed from the village of Patsikopa, on the flanks of the volcano

Bagana occupies a remote location in the interior of Bougainville Island and the majority of our work on this volcano has thus far[25] relied on satellite observations. In this study (1), we used ultraviolet (OMI) and infrared (MODIS) spectroscopy to explore multi-year trends in gas emissions and lava extrusion from Bagana.

25 We have just been awarded funding from Deep Carbon Observatory (PI McCormick Kilbride, $25k) to conduct drone-based measurements of plume gas.

Our previous work (2) has shown that Bagana is a young volcano, apparently growing at a remarkable pace. Comparing digital elevation models from aerial or satellite observations compiled over different time intervals, we found that Bagana maintains a long-term mean extrusion rate of 1 cubic metre of lava per second (m3 s-1). With an estimated edifice volume of 5-9 cubic kilometres, the volcano may have been built in as little as 300 years. Intriguingly, the neighbouring pyroclastic shield volcano of Billy Mitchell experienced a caldera-forming eruption dated to ~440 years before present (B.P.). Exploring a genetic link between the cessation of activity at Billy Mitchell and the onset of eruptions and edifice construction at Bagana is a goal of our future petrological work.

Alongside its apparent youth and vigour, Bagana is an unusually large emitter of volcanic gases to the atmosphere, a fact evidenced by an earlier satellite-based study (3) carried out during McCormick Kilbride's COMET-funded PhD research. In our new work, we used new OMI data (reprocessed using the latest retrieval algorithm) alongside MODIS measurements of thermal energy release (a proxy of active lava extrusion) and compared multi-year gas emission budgets to extruded lava volumes. We found that the mass flux of sulphur dioxide into the atmosphere over the past decade is far too high to be sustained by erupted lavas alone, requiring unfeasibly sulphur-rich magmas.



Example maps of volcanic sulphur dioxide emissions in Papua New Guinea, based on OMI observations. Volcanoes identified are Manam (M), Langila (L), Ulawun (U), Rabaul (R) and Bagana (B). Grey shading illustrates data gaps resulting from the OMI row anomaly (ORA), a phenomenon attributed to a partial blocking of the sensor's viewing port. In certain cases the ORA can fully or partly obscure a volcanic SO2 plume, leading to underestimates in mass flux of gas to the atmosphere

RESEARCH HIGHLIGHT

Our favoured interpretation is that Bagana's prodigious gas emissions are sustained in part by a volatile-rich magma, likely of basaltic composition, which resides deeper in the volcano's plumbing system than the crystal-rich basaltic andesites that are erupted. Emerging petrological evidence (4) suggests that interactions between multiple magma batches are recorded in the complex crystal cargo of erupted lavas. For the time being, what seems clear is that the ability of volatile phases to separate from their host magmas and ascend through the plumbing system (c.f. becoming trapped and over-pressurising the reservoir) is critical for maintaining Bagana's dominantly effusive mode of activity. Any collapse in this permeability (whether in the magma column or conduit wallrocks) is likely to result in a shift to explosive activity and a concomitant increase in risk faced by the surrounding villages, which are largely isolated from available monitoring and warning infrastructure.

Bagana viewed from offshore to the southwest, approximately 20 km from the summit. Note the strong gas plume

References

1. McCormick Kilbride, B.T., Mulina, K., Wadge, G., Johnson, R.W., Itikarai, I., Edmonds, M. (2019) Multi-year satellite observations of sulphur dioxide gas emissions and lava extrusion at Bagana Volcano, Papua New Guinea, Frontiers in Earth Science doi:10.3389/feart.2019.00009

2. Wadge, G., McCormick Kilbride, B.T., Edmonds, M., Johnson, R.W. (2018) Persistent growth of a young andesite lava cone: Bagana volcano, Papua New Guinea, Journal of Volcanology and Geothermal Research doi:10.1016/j.jvolgeores.2018.03.012

3. McCormick, B.T., Edmonds, M., Mather, T.A., Carn, S.A. (2012) First synoptic analysis of volcanic degassing in Papua New Guinea, Geochemistry, Geophysics, Geosystems doi:10.1029/2011GC003945

4. McCormick Kilbride, B.T., Ellis, B.S., Vukmanovic, Z., Buisman, I., Salem, L.C., Edmonds, M. (in prep.). Petrolographic and geochemical analyses of recent lavas from Bagana volcano, Papua New Guinea.

This is a close view of Bagana volcano summit, taken from drone.
Credit: Dr Kieran Wood, University of Bristol

RESEARCH HIGHLIGHT

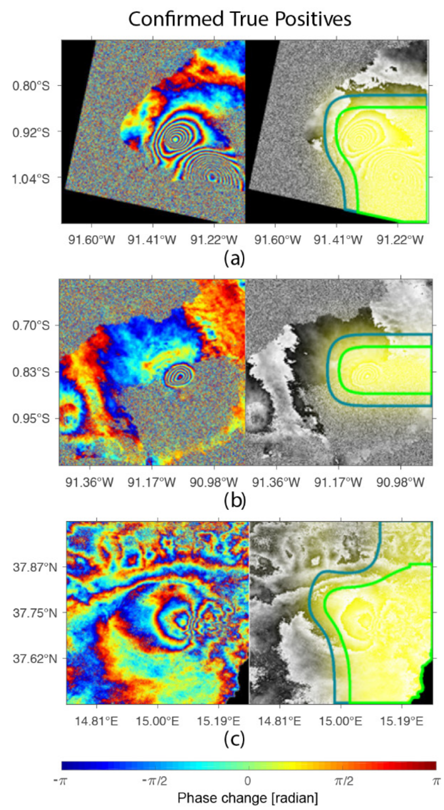
Deep learning-based methods for detecting volcanic deformation InSAR data

Nantheera Anantrasirichai, Bristol

The majority of volcanoes worldwide have little or no groundbased monitoring, but InSAR techniques have the potential to measure surface deformation at volcanoes globally. The launch of Sentinel-1 is providing unprecedented data access but poses new challenges, as more data are available than can be analysed by manual inspection. Our work demonstrates that machine learning using deep convolutional neural networks (CNNs) has the capability to identify deformation signals from a large data set of interferograms.

In collaboration with the Bristol Vision Institute (BVI), COMET scientists have developed a deep learning-based framework for detecting deformation in satellite images. COMET's automated processing system, LiCSAR[26], produced a trial dataset of 30,000 Sentinel-1 interferograms at 900 active volcanoes which was used to develop and test the prototype methods. Our proof-of-concept study shows that interferometric fringes provide strong visual features for image classification using a convolutional neutral network (CNN). However, the dataset available for training deep-learning systems is inherently imbalanced because only a small proportion of volcanoes are deforming, and these do not fully represent the diversity of possible signals. To produce a more representative training dataset, our follow-up study constructed synthetic interferograms composed of a combination of model deformation patterns and atmospheric effects extracted from weather models using the COMET GACOS system[27].

After training the CNN with a combined dataset consisting of synthetic models and selected real examples, the system achieved a positive predictive value (PPV) of 82% (82% of the positive results were true positives). Although applying atmospheric corrections to the entire dataset is computationally expensive, it is relatively simple to apply them to the small subset of positive results. This further improves the detection performance without a significant increase in computational burden (PPV of 100%). This figure shows the detected volcanic deformation signals on Cerro Azul and Sierra Negra, Galapagos in May 2017, and Etna, Italy in October 2016.



Original image (left) and overlaid with probability of being volcanic deformation (right). Confirmed true positive results from (a) Cerro Azul (20170320-20170401), (b) Sierra Negra, (20170519-20170718), (c) Etna (20161003-20161015). The brighter yellow means higher probability. Areas inside dark and bright green contours are where P>0.5 and P>0.8, respectively. Each colour cycle (fringe) represents 2.8 cm of displacement in the satellite line-of-sight

Our study shows that machine learning can efficiently detect large, rapid deformation signals in wrapped interferograms. Further development will be required to detect slow or small deformation patterns, which can be done using other inputs such as unwrapped stacked interferograms. Our work is the first to use machine learning approaches for detecting volcanic deformation in large datasets and demonstrates the potential of such techniques for developing volcanic unrest alert systems based on satellite imagery.

26 www.comet.nerc.ac.uk/COMET-LiCS-portal/
27 www.ceg-research.ncl.ac.uk/v2/gacos/

Huw Goodall trenching a fault near Mugla in western Turkey for cosmogenic
isotope sampling, being supervised by Dr Laura Gregory
Credit: Bora Uzel , Dokuz Eylul University, Turkey

PUBLICATIONS

COMET has a strong publication record: since January 2014, our researchers have published 682 articles in peer-reviewed scientific journals covering both the Earth and atmospheric sciences, attracting almost 7,000 citations. 154 (22.6%) of these are in the top 10% most cited publications worldwide, with three quarters the result of international collaborations.

140 were published between 1 January and 31 December 2018 (Annex 1), and, of these, 20 had student first authors:

Yasir Al-Husseinawi *et al*. (2018) Evaluation of the Stability of the Darbandikhan Dam after the 12 November 2017 Mw 7.3 Sarpol-e Zahab (Iran–Iraq Border) Earthquake, Remote Sensing doi:10.3390/rs10091426

Ruth Amey *et al*. (2018) A Bayesian Method for Incorporating Self Similarity Into Earthquake Slip Inversions, Journal of Geophysical Research: Solid Earth https://doi.org/10.1029/2017JB015316

David Arnold *et al.* (2018) Using satellite radar amplitude imaging for monitoring syn-eruptive changes in surface morphology at an ice-capped stratovolcano, Remote Sensing of Environment doi:10.1016/j.rse.2018.02.040

Matthew Gaddes *et al.* (2018) Blind Signal Separation Methods for InSAR: The Potential to Automatically Detect and Monitor Signals of Volcanic Deformation, JGR Solid Earth doi:10.1029/2018JB016210

Michael Hodge *et al.* (2018) The role of coseismic Coulomb stress changes in shaping the hard link between normal fault segments, Journal of Geophysical Research: Solid Earth doi:10.1002/2017JB014927

Michael Hodge *et al.* (2018) Controls on early-rift geometry: new perspectives from the Bilila-Mtakataka fault, Malawi, Geophysical Research Letters doi:10.1029/2018GL077343

Jonathan Hunt *et al.* (2018) The geomorphology, structure and lava flow dynamics of peralkaline rift volcanoes from high-resolution digital elevation models, Geochemistry Geophysics Geosystems doi:10.1029/2018GC008085

Ryan Lloyd *et al.* (2018) Evidence for cross rift structural controls on deformation and seismicity at a continental rift caldera, Earth and Planetary Science Letters doi:10.1016/j.epsl.2018.01.037

Ryan Lloyd *et al.* (2018) Sustained uplift at a continental rift caldera, Journal of Geophysical Research: Solid Earth doi:10.1029/2018JB015711

Cyril Muller *et al.* (2018) Temporal evolution of the magmatic system at Tungurahua Volcano, Ecuador, detected by geodetic observations, Journal of Volcanology and Geothermal Research doi:10.1016/j.jvolgeores.2018.11.004

Gemma Prata *et al.* (2018) A new parameterization of volcanic ash complex refractive index based on NBO/T and SiO2 content, Journal of Geophysical Research – Atmospheres doi:10.1029/2018JD028679

Jacqueline Ratner *et al*. (2018) Crowd-sourcing structure-from-motion data for terrain modelling in a real-world disaster scenario: a proof of concept, Progress in Physical Geography doi:10.1177/0309133318823622

Isabelle Taylor *et al.* (2018) Exploring the utility of IASI for monitoring volcanic SO2 emissions, Journal of Geophysical Research: Atmospheres doi:10.1002/2017JD027109

Tesfaye Temtime *et al*. (2018) Spatial and temporal patterns of deformation at the Tendaho geothermal prospect, Ethiopia, Journal of Volcanology and Geothermal Research

Sam Wimpenny *et al.* (2018) Extension and dynamics of the Andes inferred from the 2016 Parina (Huarichancara) earthquake, Journal of Geophysical Research doi:10.1029/2018JB015588

Chen Yu *et al*. (2018) Generic atmospheric correction model for Interferometric Synthetic Aperture Radar observations, Journal of Geophysical Research: Solid Earth doi:10.1029/2017JB015305.

Chen Yu *et al*. (2018) Interferometric synthetic aperture radar atmospheric correction using a GPS-based iterative tropospheric decomposition model, Remote Sensing of Environment doi:10.1016/j.rse.2017.10.038[28]

Chen Yu *et al.* (2018) Small Magnitude Co-Seismic Deformation of the 2017 Mw 6.4 Nyingchi Earthquake Revealed by InSAR Measurements with Atmospheric Correction, Remote Sensing doi:10.3390/rs10050684

Zheng Wang *et al*. (2018) A New Nonlocal Method for Ground-Based Synthetic Aperture Radar Deformation Monitoring, IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing doi:10.1109/JSTARS.2018.2864740

Zheng Wang *et al.* (2018) A new approach to selecting coherent pixels for ground-based SAR deformation monitoring, ISPRS Journal of Photogrammetry and Remote Sensing doi:10.1016/j.isprsjprs.2018.08.008.

28 Web of Science Highly Cited Paper 2018

Dr Sam Wimpenny analysing a recent normal fault scarp in the Peruvian Andes
Credit: Dr Alex Copley, Bullard Laboratories, University of Cambridge

COLLABORATIONS AND PARTNERSHIPS

COMET continues to strengthen its scientific collaborations, both within the UK and overseas. Our partnership with BGS is delivering cutting-edge research on earthquakes and volcanoes as well as hazard monitoring services, whilst we are a key partner in several major international initiatives:

EUROVOLC[29] is an EC Horizon2020 Infrastructure project established to support interconnection and collaboration within the European volcanological community and enable access to the community's research infrastructure and data. The project builds upon experiences of FUTUREVOLC, with partners from 9 European countries representing volcano research and monitoring institutions, civil protection agencies, a volcanic ash advisory centre and companies from R&D, IT and geothermal industries.

The **European Plate Observing System**[30] (EPOS) is a long-term plan to facilitate integrated use of data, data products, and facilities from distributed research infrastructures for solid Earth science in Europe. EPOS brings together Earth scientists, IT experts, decision makers, and public to develop new concepts and tools that will help us to better manage geohazards.

The NERC **V-Plus** (Volcanic plume understanding and forecasting: Integrating remote-sensing, in-situ observations and models) project is seeking to transform our understanding of volcanic plumes and deliver methods and tools that enhance monitoring and forecasting capabilities in the UK and beyond. It will exploit data from the new TROPOMI satellite mission to characterise and track volcanic plumes, and combine this with other observations and atmospheric modelling to study plumes with unprecedented fidelity, and translate the tools for direct use by VAACs and volcano observatories.

Also funded by NERC, **R4Ash** (Radar-supported next-generation forecasting of volcanic ash hazard) is developing new approaches to forecasting the extent and evolution of ash-rich volcanic plumes, alongside techniques for understanding uncertainty and state-of-the-art satellite observations of volcanic plumes. This will provide critical insights into how plumes evolve as they are dispersed, and obtain real-time data that will be transformational for volcanic plume forecasting and hazard assessment.

The UKRI **GCRF Urban Disaster Risk Hub** is a £20 million international collaboration aiming to provide new understanding of multi-hazard for four target cities (Istanbul, Kathmandu, Nairobi and Quito), and inform policy development on risk reduction as a result. The project includes using EO techniques, primarily satellite data, to produce data sets and information on hazard that can be used by Hub partners in achieving the wider project aims.

The NERC-funded **Digital Environments: Dynamic Ground Motion Map of the UK** is exploring whether Sentinel-1 data can be integrated with sensors on the ground and embedded in the built environment to contribute to the UK Digital Environment. It will implement cutting edge approaches to data handling, analysis and decision making, combining expertise in InSAR with image processing, machine learning, landslides, subsidence and onshore energy production.

29 www.eurovolc.eu
30 www.epos-ip.org/

The NERC-funded **Looking inside the Continents from Space** (LiCS) project is using Sentinel-1 data to revolutionise our knowledge of how continents deform, how strain accumulates during the earthquake cycle, and how seismic hazard is distributed. LiCS is combining satellite data with ground-based observations to map tectonic strain throughout the Alpine-Himalayan Belt and East African Rift, using the results to inform new models of seismic hazard.

The LiCSAR service is now providing Sentinel-1 InSAR products for download, with interferograms and coherence maps produced automatically using the LiCSAR processor, and new interferograms available within two weeks of data acquisition. The initial focus on the Alpine-Himalayan tectonic belt is also being expanded with the aim of producing a complete archive for tectonic and volcanic areas globally, as well as development of a rapid event response facility.

RiftVolc[31], led by the Universities of Edinburgh and Bristol, focuses on volcanoes and volcanic plumbing systems in the East African Rift Valley. It is investigating what drives eruptions over geological timescales; what controls the active magmatic system and volcanic unrest; and what the potential threats from future volcanic activity are.

RiftVolc has led to a step change in our understanding of many Ethiopian volcanoes, with recently published research addressing topics such as post-caldera volcanism along the Main Ethiopian Rift, and seasonal patterns of seismicity and deformation at the Alutu geothermal reservoir.

The NERC Innovation **Project Making Volcano Deformation Data Accessible,** involving Juliet Biggs, Fabien Albino and Nantheera Anantrasirichai (Bristol) and Susi Ebmeier (Leeds) will 1) develop web-based products and services to allow volcano observatories to use automatically processed satellite data; 2) build capacity in ODA countries to access and interpret satellite data; and 3) implement and refine algorithms to flag volcanic unrest and develop an alert system. Following exchange visits with our partners from the Instituto Geofisico, Ecuador and IGSSA, Ethiopia, we plan to run a project workshop alongside the 2020 Cities on Volcanoes conference in Crete.

31 www.riftvolc.wordpress.com/

AWARDS AND RECOGNITION

Philip England (Oxford) was awarded the 2018 AGU Walter H. Bucher Medal[32] in recognition for his original contributions to the basic knowledge of crust and lithosphere. This includes, particularly through the Earthquakes without Frontiers project, study of both the science and the societal impacts of earthquakes in continental regions where they have taken their greatest toll but are least well understood.

Tamsin Mather (Oxford) received the Royal Society Rosalind Franklin Award and Lecture, made to an individual for an outstanding contribution to any area of Science, Technology, Engineering and Mathematics (STEM) and to support the promotion of women in STEM. Her award lecture, given in October 2018, Volcanoes: from fuming vents to extinction events, has received more than 900 views on YouTube[33].

Marie Edmonds (Cambridge) won the VMSG Thermo-Fisher Scientific Award, giving the keynote lecture at the 2019 VMSG meeting. This award is given annually to an individual who has made a significant contribution to current understanding of volcanic and magmatic processes.

Marek Ziebart (UCL) received the Tycho Brahe Award from the US Institute of Navigation for his outstanding contributions to the science of space navigation, guidance and control, citing his outstanding innovation and leadership in the area of high precision, physics-based radiation force modelling for spacecraft orbit dynamics.

Juliet Biggs (Bristol) was announced as a 2018 Philip Leverhulme Prize Winner, recognising her outstanding research in volcanology to date and future potential. Juliet is using the prize to investigate the mechanisms that drive volcano deformation globally by exploiting the new wealth of satellite data available.

Tim Craig (Leeds) won the 2019 Winton Prize in Geophysics from the Royal Astronomical Society. The award is made to a Post Doctoral Fellow in a UK institution whose career in geophysics has shown the most promising development.

COMET student **Simone Mancini** (Bristol) received an Outstanding Student Paper Award at the 2018 AGU Fall Meeting for his presentation “Improving Physics-based Earthquake Forecasting During the 2016-2017 Central Italy Earthquake Sequence”.

Also a COMET student, **Chen Yu’s** (Newcastle) 2018 paper on interferometric synthetic aperture radar atmospheric correction[34], published in Remote Sensing of Environment, became a Web of Science Highly Cited Paper.

Alongside these awards, over the past year COMET members have also given numerous invited talks and keynote lectures across the globe, recognising their standing on the international stage.

32 www.honors.agu.org/winners/philip-england/
33 www.youtu.be/4GS7MVOx1Vc
34 Yu et al. (2018), Interferometric synthetic aperture radar atmospheric correction using a GPS-based iterative tropospheric decomposition model, Remote Sensing of Environment doi:10.1016/j.rse.2017.10.038

FUTURE PLANS

Our specific science objectives for 2019-2021 are:

EO data and services

Deformation from satellite geodesy:

- Continue the long-term development of our Sentinel-1 InSAR processing facility at Jasmin/CEDA, focusing on producing consistent, reliable, and accessible long-term rates of deformation and time series globally for the tectonic belts and subaerial volcanoes.
- Work towards producing 3D velocities by exploiting burst overlaps in Sentinel-1.
- Automate the production of time series, improving our atmospheric correction service, to enable rapid response following volcanic or seismic events using data from multiple satellites.

Topography, deformation, and surface change analysis from high-resolution imagery:

- Automate the production of displacement measurements from Sentinel-2 data.
- Develop methodologies to exploit the ongoing expansion in high-resolution optical satellite images (e.g. from CubeSats and satellite video).
- Produce datasets as required by the hazard teams.

Retrievals of volcanic emissions from satellite spectrometers:

- Develop methods to derive SO2 fluxes at quiescent degassing volcanoes (back to 2007 for IASI; 2017 for Tropomi).
- Incorporate laboratory measurements of ash optical properties of volcanic ash into IASI retrievals so we can estimate SiO2 composition.

Geoinformatics and machine learning:

- Consult with end users and build a unified, integrated portal to simplify COMET data access.
- Develop Machine Learning algorithms to identify anomalous behaviour at volcanoes.
- Trial Machine Learning algorithms with stakeholders towards real-time operation at volcanoes.

Tectonics and seismic hazard

- Construct the first global high-resolution strain-rate map, from InSAR and GNSS, of the Alpine-Himalayan Belt and East African Rift.
- Produce and deliver (to GEM), maps of active faults and their rates of activity, initially in Central Asia.
- Assess temporal variations in strain across distributed fault networks, in Central Asia, Turkey and Italy.
- Begin development of next-generation of geodynamic models of continental deformation linking short and long timescales.

Magmatism and volcanic hazard

- Produce deformation time series for all subaerial volcanoes, beginning to build a long term (decadal) view of processes occurring at volcanoes in different stages of the eruptive cycle.
- Construct the first global assessment of current volcanic SO2 flux from IR and UV data.
- Build models of magmatic systems that can explain gas and deformation observations, initially in Iceland.
- Develop near real-time tools for monitoring volcanic unrest, using machine learning approaches for analysing large volumes of satellite data.

At the same time, we will continue to deliver national capability in the observation and modelling of geohazards, working with the wider scientific community and practitioners to maximise uptake of and impact from the results, as well as delivering national public good.

We will also look forward to working more closely with BGS to deliver against our mutual aims of better understanding both hazard and risk.

GLOSSARY

AGU	American Geophysical Union
BGS	British Geological Survey
CAST	China Academy of Space Technology
CEOS	Committee on Earth Observation Satellites
COMET	Centre for the Observation and Modelling of Earthquakes, Volcanoes and Tectonics
DEM	Digital Elevation Model
EO	Earth Observation
EPOS	European Plate Observing System
ESA	European Space Agency
EwF	Earthquakes without Frontiers
GACOS	Generic Atmospheric Correction Online Service for InSAR
GCRF	Global Challenges Research Fund
GEM	Global Earthquake Model
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GSRM	Global Strain Rate Model
GTEP	Geohazards Thematic Exploration Platform
GVM	Global Volcano Model
IASI	Infrared Atmospheric Sounding Interferometer
IGEPN	Instituto Geofísico de la Escuela Politécnica Nacional
InSAR	Synthetic Aperture Radar Interferometry
LiCS	Looking inside the Continents from Space

LOS	Line of Sight
NASA	US Space Agency (National Aeronautics and Space Administration)
NCEO	National Centre for Earth Observation
NERC	Natural Environment Research Council
NGO	Non-Governmental Organisation
OMI	Ozone Monitoring Instrument
RAS	Royal Astronomical Society
SAR	Synthetic Aperture Radar
UCL	University College London
USGS	US Geological Survey
VMSG	Volcanic and Magmatic Studies Group

COMET PUBLICATIONS JANUARY-DECEMBER 2018

Albino, F., Amelung, F., Gregg, P. (2018) The Role of Pore Fluid Pressure on the Failure of Magma Reservoirs: Insights From Indonesian and Aleutian Arc Volcanoes, Journal of Geophysical Research: Solid Earth, 10.1002/2017JB014523

Al-Husseinawi, Y., Li, Z., Clarke, P., Edwards, S. (2018) Evaluation of the stability of the Darbandikhan dam after the 12 November 2017 Mw 7.3 Sarpol-e Zahab (Iran-Iraq Border) earthquake, Remote Sensing, 10.3390/rs10091426

Amey, R.M.J., Hooper, A., Walters, R.J. (2018) A Bayesian Method for Incorporating Self-Similarity Into Earthquake Slip Inversions, Journal of Geophysical Research: Solid Earth, 10.1029/2017JB015316

Anantrasirichai, N., Biggs, J., Albino, F., Hill, P., Bull, D. (2018) Application of Machine Learning to Classification of Volcanic Deformation in Routinely Generated InSAR Data, Journal of Geophysical Research: Solid Earth, 10.1029/2018JB015911

Arnold, D.W.D., Biggs, J., Wadge, G., Mothes, P. (2018) Using satellite radar amplitude imaging for monitoring syn-eruptive changes in surface morphology at an ice-capped stratovolcano, Remote Sensing of Environment, 10.1016/j.rse.2018.02.040

Arzilli, F., Fabbrizio, A., Schmidt, M.W., Petrelli, M., Maimaiti, M., Dingwell, D.B., Paris, E., Burton, M., Carroll, M.R. (2018) The effect of diffusive re-equilibration time on trace element partitioning between alkali feldspar and trachytic melts, Chemical Geology, 10.1016/j.chemgeo.2018.07.035

Bagnardi, M., Hooper, A. (2018) Inversion of Surface Deformation Data for Rapid Estimates of Source Parameters and Uncertainties: A Bayesian Approach, Geochemistry, Geophysics, Geosystems, 10.1029/2018GC007585

Bie, L., Hicks, S., Garth, T., Gonzalez, P., Rietbrock, A. (2018) ‘Two go together’: Near-simultaneous moment release of two asperities during the 2016 Mw 6.6 Muji, China earthquake, Earth and Planetary Science Letters, 10.1016/j.epsl.2018.03.033

Birhanu, Y., Wilks, M., Biggs, J., Kendall, J.-M., Ayele, A., Lewi, E. (2018) Seasonal patterns of seismicity and deformation at the Alutu geothermal reservoir, Ethiopia, induced by hydrological loading, Journal of Volcanology and Geothermal Research, 10.1016/j.jvolgeores.2018.03.008

Blachowski, J., Jiránková, E., Lazecký, M., Kadlečík, P., Milczarek, W. (2018) Application of satellite radar interferometry (PSInSAR) in analysis of secondary surface deformations in mining areas. Case studies from Czech Republic and Poland, Acta Geodynamica et Geomaterialia, 10.13168/AGG.2018.0013

Cadoux, A., Iacono-Marziano, G., Scaillet, B., Aiuppa, A., Mather, T.A., Pyle, D.M., Deloule, E., Gennaro, E., Paonita, A., (2018) The role of melt composition on aqueous fluid vs. silicate melt partitioning of bromine in magmas, Earth and Planetary Science Letters, 10.1016/j.epsl.2018.06.038

Cattania, C., Werner, M.J., Marzocchi, W., Hainzl, S., Rhoades, D., Gerstenberger, M., Liukis, M., Savran, W., Christophersen, A., Helmstetter, A., Jimenez, A., Steacy, S., Jordan, T.H. (2018) The forecasting skill of physics-based seismicity models during the 2010-2012 canterbury, New Zealand, earthquake sequence, Seismological Research Letters, 10.1785/0220180033

Caudron, C., Taisne, B., Neuberg, J., Jolly, A.D., Christenson, B., Lecocq, T., Suparjan, Syahbana, D., Suantika, G. (2018) Anatomy of phreatic eruptions, Earth, Planets and Space, 10.1186/s40623-018-0938-x

Chiarugi, A., Viciani, S., D'Amato, F., Burton, M. (2018) Diode laser-based gas analyser for the simultaneous measurement of CO_2 and HF in volcanic plumes, Atmospheric Measurement Techniques, 10.5194/amt-11-329-2018

Civico, R., Pucci, S., Villani, F., Pizzimenti, L., De Martini, P.M., Nappi, R., Agosta, F., Alessio, G., Alfonsi, L., Amanti, M., Amoroso, S., Aringoli, D., Auciello, E., Azzaro, R., Baize, S., Bello, S., Benedetti, L., Bertagnini, A., Binda, G., Bisson, M., Blumetti, A.M., Bonadeo, L., Boncio, P., Bornemann, P., Branca, S., Braun, T., Brozzetti, F., Bru-Nori, C.A., Burrato, P., Caciagli, M., Campobasso, C., Carafa, M., Cinti, F.R., Cirillo, D., Comerci, V., Cucci, L., De Ritis, R., Deiana, G., Del Carlo, P., Del Rio, L., Delorme, A., Di Manna, P., Di Naccio, D., Falconi, L., Falcucci, E., Farabollini, P., Faure Walker, J.P., Ferrarini, F., Ferrario, M.F., Ferry, M., Feuillet, N., Fleury, J., Fracassi, U., Frigerio, C., Galluzzo, F., Gambillara, R., Gaudiosi, G., Goodall, H., Gori, S., Gregory, L.C., Guerrieri, L., Hailemikael, S., Iezzi, F., Invernizzi, C., Jablonská, D., Jacques, E., Jomard, H., Kastelic, V., Klinger, Y., Lavecchia, G., Leclerc, F., Liberi, F., Lisi, A., Livio, F., Lo Sardo, L., Malet, J.P., Mariucci, M.T., Materazzi, M., Mazzarini, F., McCaffrey, K.J.W., Michetti, A.M., Mildon, Z.K., Montone, P., Moro, M., Nave, R., Odin, M., Pace, B., Paggi, S., Pagliuca, N., Pambianchi, G., Pantosti, D., Patera, A., Pérouse, E., Pezzo, G., Piccardi, L., Pierantoni, P.P., Pignone, M., Pinzi, S., Pistolesi, E., Point, J., Pozzi, A., Proposito, M., Puglisi, C., Puliti, I., Ricci, T., Ripamonti, L., Rizza, M., Roberts, G.P., Roncoroni, M., Sapia, V., Saroli, M., Sciarra, A., Scotti, O., Skupinski, G., Smedile, A., Tarabusi, G., Tarquini, S., Terrana, S., Tesson, J., Tondi, E., Valentini, A., Vallone, R., Van Der Woerd, J., Vannoli, P., Venuti, A., Vittori, E., Volatili, T., Wedmore, L.N.J., Wilkinson, M., Zambrano, M., (2018) Surface ruptures following the 30 October 2016 M w 6.5 Norcia earthquake, central Italy, Journal of Maps, 10.1080/17445647.2018.1441756

Clark, B., Jones, G.D., Kendall, H., Taylor, J., Cao, Y., Li, W., Zhao, C., Chen, J., Yang, G., Chen, L., Li, Z., Gaulton, R., Frewer, L.J. (2018) A proposed framework for accelerating technology trajectories in agriculture: A case study in China, Frontiers of Agricultural Science and Engineering, 10.15302/J-FASE-2018244

Clark, C.D., Ely, J.C., Greenwood, S.L., Hughes, A.L.C., Meehan, R., Barr, I.D., Bateman, M.D., Bradwell, T., Doole, J., Evans, D.J.A., Jordan, C.J., Monteys, X., Pellicer, X.M., Sheehy, M. (2018) BRITICE Glacial Map, version 2: a map and GIS database of glacial landforms of the last British–Irish Ice Sheet, Boreas, 10.1111/bor.12273

Copley, A., Grützner, C., Howell, A., Jackson, J., Penney, C., Wimpenny, S. (2018) Unexpected earthquake hazard revealed by Holocene rupture on the Kenchreai Fault (central Greece): Implications for weak sub-fault shear zones, Earth and Planetary Science Letters, 10.1016/j.epsl.2018.01.014

Craig, T.J., Copley, A. (2018) Forearc collapse, plate flexure, and seismicity within the downgoing plate along the Sunda Arc west of Sumatra, Earth and Planetary Science Letters, 10.1016/j.epsl.2017.12.004

Craig, T.J., Parnell-Turner, R. (2018) Corrigendum to “Depth-varying seismogenesis on an oceanic detachment fault at 13°20′N on the Mid-Atlantic Ridge” [Earth Planet. Sci. Lett. 479 (2017) 60–70] (S0012821X17305162)(10.1016/j.epsl.2017.09.020), Earth and Planetary Science Letters, 10.1016/j.epsl.2018.03.053

Dai, K., Chen, G., Xu, Q., Li, Z., Qu, T., Hu, L., Lu, H. (2018) Monitoring highway stability in permafrost regions with X-band temporary scatterers stacking InSAR, Sensors (Switzerland), 10.3390/s18061876

Ebmeier, S.K., Andrews, B.J., Araya, M.C., Arnold, D.W.D., Biggs, J., Cooper, C., Cottrell, E., Furtney, M., Hickey, J., Jay, J., Lloyd, R., Parker, A.L., Pritchard, M.E., Robertson, E., Venzke, E., Williamson, J.L. (2018) Synthesis of global satellite observations of magmatic and volcanic deformation: implications for volcano monitoring & the lateral extent of magmatic domains, Journal of Applied Volcanology, 10.1186/s13617-018-0071-3

Edmonds, M., Grattan, J., Michnowicz, S. (2018) Volcanic Gases: Silent Killers, Advances in Volcanology, 10.1007/11157_2015_14

Edmonds, M., Mather, T.A., Liu, E.J. (2018) A distinct metal fingerprint in arc volcanic emissions, Nature Geoscience, 10.1038/s41561-018-0214-5

Edmonds, M., Woods, A.W. (2018) Exsolved volatiles in magma reservoirs, Tectonophysics, 10.1016/j.tecto.2018.01.004

Elliott, A.J., Oskin, M.E., Liu-zeng, J., Shao, Y.-X. (2018) Persistent rupture terminations at a restraining bend from slip rates on the eastern Altyn Tagh fault, Tectonophysics, 10.1016/j.tecto.2018.01.004

England, P. (2018) On Shear Stresses, Temperatures, and the Maximum Magnitudes of Earthquakes at Convergent Plate Boundaries, Journal of Geophysical Research: Solid Earth, 10.1029/2018JB015907

Esse, B., Burton, M., Varnam, M., Kazahaya, R., Wallace, P.A., Von-Aulock, F., Lavallée, Y., Salerno, G., Scollo, S., Coe, H.(2018) Quantification of ash sedimentation dynamics through depolarisation imaging with AshCam, Scientific Reports, 10.1038/s41598-018-34110-6

Fagereng, Å., Biggs, J. (2018) New perspectives on ‘geological strain rates’ calculated from both naturally deformed and actively deforming rocks, Journal of Structural Geology, 10.1016/j.jsg.2018.10.004

Feng, M., Bie, L., Rietbrock, A. (2018) Probing the rheology of continental faults: Decade of post-seismic InSAR time-series following the 1997 Manyi (Tibet) earthquake, Geophysical Journal International, 10.1093/gji/ggy300

Fontijn, K., McNamara, K., Zafu Tadesse, A., Pyle, D.M., Dessalegn, F., Hutchison, W., Mather, T.A., Yirgu, G. (2018) Contrasting styles of post-caldera volcanism along the Main Ethiopian Rift: Implications for contemporary volcanic hazards, Journal of Volcanology and Geothermal Research, 10.1016/j.jvolgeores.2018.02.001

Furtney, M.A., Pritchard, M.E., Biggs, J., Carn, S.A., Ebmeier, S.K., Jay, J.A., McCormick Kilbride, B.T., Reath, K.A. (2018) Synthesizing multi-sensor, multi-satellite, multi-decadal datasets for global volcano monitoring, Journal of Volcanology and Geothermal Research, 10.1016/j.jvolgeores.2018.10.002

Gaddes, M.E., Hooper, A., Bagnardi, M., Inman, H., Albino, F. (2018) Blind Signal Separation Methods for InSAR: The Potential to Automatically Detect and Monitor Signals of Volcanic Deformation, Journal of Geophysical Research: Solid Earth, 10.1029/2018JB016210

Geurts, A.H., Cowie, P.A., Duclaux, G., Gawthorpe, R.L., Huismans, R.S., Pedersen, V.K., Wedmore, L.N.J. (2018) Drainage integration and sediment dispersal in active continental rifts: A numerical modelling study of the central Italian Apennines, Basin Research, 10.1111/bre.12289

COMET PUBLICATIONS JANUARY-DECEMBER 2018

Govin, G., Najman, Y., Copley, A., Millar, I., van der Beek, P., Huyghe, P., Grujic, D., Davenport, J. (2018) Timing and mechanism of the rise of the Shillong Plateau in the Himalayan foreland, Geology, 10.1130/G39864.1

Gregory, L.C., Mac Niocaill, C., Walker, R.T., Bayasgalan, G., Craig, T.J. (2018) Vertical axis rotation (or lack thereof) of the eastern Mongolian Altay Mountains: Implications for far-field transpressional mountain building, Tectonophysics, 10.1016/j.tecto.2018.03.020

Guo, J., Li, X., Li, Z., Hu, L., Yang, G., Zhao, C., Fairbairn, D., Watson, D., Ge, M. (2018) Multi-GNSS precise point positioning for precision agriculture, Precision Agriculture, 10.1007/s11119-018-9563-8

Hamlyn, J., Wright, T., Walters, R., Pagli, C., Sansosti, E., Casu, F., Pepe, S., Edmonds, M., McCormick Kilbride, B., Keir, D., Neuberg, J., Oppenheimer, C. (2018) What causes subsidence following the 2011 eruption at Nabro (Eritrea)?, Progress in Earth and Planetary Science, 10.1186/s40645-018-0186-5

Harnett, C.E., Thomas, M.E., Purvance, M.D., Neuberg, J. (2018) Using a discrete element approach to model lava dome emplacement and collapse, Journal of Volcanology and Geothermal Research, 10.1016/j.jvolgeores.2018.06.017

Hawthorne, J.C., Bartlow, N.M. (2018) Observing and Modeling the Spectrum of a Slow Slip Event, Journal of Geophysical Research: Solid Earth, 10.1029/2017JB015124

Hodge, M., Fagereng, Å., Biggs, J. (2018) The Role of Coseismic Coulomb Stress Changes in Shaping the Hard Link Between Normal Fault Segments, Journal of Geophysical Research: Solid Earth, 10.1002/2017JB014927

Hodge, M., Fagereng, Å., Biggs, J., Mdala, H. (2018) Controls on Early-Rift Geometry: New Perspectives From the Bilila-Mtakataka Fault, Malawi, Geophysical Research Letters, 10.1029/2018GL077343

Hooper, A., Wright, T.J., Spaans, K., Walters, R.J., Elliott, J., Weiss, J.R., Bagnardi, M., Hatton, E.L., Gonzlez, P.J., Albino, F., Ebmeier, S.K., Biggs, J., Gaddes, M., Qiu, Q., McDougall, A. (2018) Global monitoring of fault zones and volcanoes with sentinel-1, International Geoscience and Remote Sensing Symposium (IGARSS), 10.1109/IGARSS.2018.8517519

Houseman, G.A. (2018) Why Earthquakes Threaten Two Major European Cities: Istanbul and Bucharest, European Review, 10.1017/S1062798717000448

Hu, L., Xing, C., Dai, K., Li, Y., Li, Z., Zhang, J., Yan, R., Xu, B., Fan, Z. (2018) Research on the crustal deformation characteristics in Beijing using INSAR and GNSS technology, International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives, 10.5194/isprs-archives-XLII-3-559-2018

Hussain, E., Wright, T.J., Walters, R.J., Bekaert, D.P.S., Lloyd, R., Hooper, A. (2018) Constant strain accumulation rate between major earthquakes on the North Anatolian Fault, Nature Communications, 10.1038/s41467-018-03739-2

Hutchison, W., Mather, T.A., Pyle, D.M., Boyce, A.J., Gleeson, M.L.M., Yirgu, G., Blundy, J.D., Ferguson, D.J., Vye-Brown, C., Millar, I.L., Sims, K.W.W., Finch, A.A. (2018) The evolution of magma during continental rifting: New constraints from the isotopic and trace element signatures of silicic magmas from Ethiopian volcanoes, Earth and Planetary Science Letters, 10.1016/j.epsl.2018.02.027

Ilyinskaya, E., Mobbs, S., Burton, R., Burton, M., Pardini, F., Pfeffer, M.A., Purvis, R., Lee, J., Bauguitte, S., Brooks, B., Colfescu, I., Petersen, G.N., Wellpott, A., Bergsson, B. (2018) Globally Significant CO 2 Emissions From Katla, a Subglacial Volcano in Iceland, Geophysical Research Letters, 10.1029/2018GL079096

Juncu, D., Árnadóttir, T., Geirsson, H., Guðmundsson, G.B., Lund, B., Gunnarsson, G., Hooper, A., Hreinsdóttir, S., Michalczewska, K. (2018) Injection-induced surface deformation and seismicity at the Hellisheidi geothermal field, Iceland, Journal of Volcanology and Geothermal Research, 10.1016/j.jvolgeores.2018.03.019

Karlstrom, L., Richardson, P.W., O'Hara, D., Ebmeier, S.K. (2018) Magmatic Landscape Construction, Journal of Geophysical Research: Earth Surface, 10.1029/2017JF004369

Lazecky, M., Lhota, S., Penaz, T., Klushina, D. (2018) Application of Sentinel-1 satellite to identify oil palm plantations in Balikpapan Bay, IOP Conference Series: Earth and Environmental Science, 10.1088/1755-1315/169/1/012064

Lazecky, M., Lhota, S., Pohanková, Z., Wenglarzyová, P., Joshi, N. (2018) Evaluation of forest loss in Balikpapan Bay in the end of 2015 based on Sentinel-1A polarimetric analysis, IOP Conference Series: Earth and Environmental Science, 10.1088/1755-1315/169/1/012026

Lechner, P., Tupper, A., Guffanti, M., Loughlin, S., Casadevall, T. (2018) Volcanic Ash and Aviation—The Challenges of Real-Time, Global Communication of a Natural Hazard, Advances in Volcanology, 10.1007/11157_2016_49

Li, N., Xu, Z., Zhao, H., Huang, X., Li, Z., Drummond, J., Wang, D. (2018) ISBDD model for classification of hyperspectral remote sensing imagery, Sensors (Switzerland), 10.3390/s1803078

Li, T., Feng, A., Liu, Y., Li, Z., Guo, K., Jiang, W., Du, J., Tian, Z., Xu, W., Liu, Y., Wang, Y. (2018) Three-dimensional (3D) morphology of Sansha Yongle Blue Hole in the South China Sea revealed by underwater remotely operated vehicle, Scientific Reports, 10.1038/s41598-018-35220-x

Li, Z., He, J., Xu, X., Jin, X., Huang, W., Clark, B., Yang, G., Li, Z. (2018) Estimating genetic parameters of DSSAT-CERES model with the GLUE method for winter wheat (Triticum aestivum L.) production, Computers and Electronics in Agriculture, 10.1016/j.compag.2018.09.009

Li, Z., Jin, X., Yang, G., Drummond, J., Yang, H., Clark, B., Li, Z., Zhao, C., (2018) Remote sensing of leaf and canopy nitrogen status in winter wheat (Triticum aestivum L.) based on N-PROSAIL model, Remote Sensing, 10.3390/rs10091463

Li, Z., Li, P., Ding, D., Wang, H. (2018) Research Progress of Global High Resolution Digital Elevation Models, Wuhan Daxue Xuebao (Xinxi Kexue Ban)/Geomatics and Information Science of Wuhan University, 10.13203/j.whugis20180295

Li, Z., Wang, J., Liu, C., Song, X., Xu, X., Li, Z. (2018) Predicting grain protein content in winter wheat using hyperspectral and meteorological factor, 2018 7th International Conference on Agro-Geoinformatics, Agro-Geoinformatics 2018, 10.1109/Agro-Geoinformatics.2018.8476098

Li, Z., Ziebart, M., Bhattarai, S., Harrison, D., Grey, S. (2018) Fast solar radiation pressure modelling with ray tracing and multiple reflections, Advances in Space Research, 10.1016/j.asr.2018.02.019

Liu, E.J., Cashman, K.V., Rust, A.C., Edmonds, M. (2018) Insights into the dynamics of mafic magmatic-hydromagmatic eruptions from volatile degassing behaviour: The Hverfjall Fires, Iceland, Journal of Volcanology and Geothermal Research, 10.1016/j.jvolgeores.2018.05.016

Liu, P., Chen, X., Li, Z., Zhang, Z., Xu, J., Feng, W., Wang, C., Hu, Z., Tu, W., Li, H. (2018) Resolving surface displacements in Shenzhen of China from time series InSAR, Remote Sensing, 10.3390/rs10071162

Lloyd, R., Biggs, J., Birhanu, Y., Wilks, M., Gottsmann, J., Kendall, J.-M., Ayele, A., Lewi, E., Eysteinsson, H.(2018) Sustained Uplift at a Continental Rift Caldera, Journal of Geophysical Research: Solid Earth, 10.1029/2018JB015711

Lloyd, R., Biggs, J., Wilks, M., Nowacki, A., Kendall, J.-M., Ayele, A., Lewi, E., Eysteinsson, H. (2018) Evidence for cross rift structural controls on deformation and seismicity at a continental rift caldera, Earth and Planetary Science Letters, 10.1016/j.epsl.2018.01.037

Long, S., Tong, A., Yuan, Y., Li, Z., Wu, W., Zhu, C. (2018) New approaches to processing Ground-based SAR (GBSAR) data for deformation monitoring, Remote Sensing, 10.3390/rs10121936

Mackenzie, D., Walker, R., Abdrakhmatov, K., Campbell, G., Carr, A., Gruetzner, C., Mukambayev, A., Rizza, M. (2018) A creeping intracontinental thrust fault: Past and present slip-rates on the Northern edge of the Tien Shan, Kazakhstan, Geophysical Journal International, 10.1093/GJI/GGY339

Madjid, M.Y.A., Vandeginste, V., Hampson, G., Jordan, C.J., Booth, A.D. (2018) Drones in carbonate geology: Opportunities and challenges, and application in diagenetic dolomite geobody mapping, Marine and Petroleum Geology, 10.1016/j.marpetgeo.2018.02.002

Magee, C., Stevenson, C.T.E., Ebmeier, S.K., Keir, D., Hammond, J.O.S., Gottsmann, J.H., Whaler, K.A., Schofield, N., Jackson, C.A.-L., Petronis, M.S., O'Driscoll, B., Morgan, J., Cruden, A., Vollgger, S.A., Dering, G., Micklethwaite, S., Jackson, M.D. (2018) Magma plumbing systems: A geophysical perspective, Journal of Petrology, 10.1093/petrology/egy064

Marra, G., Clivati, C., Luckett, R., Tampellini, A., Kronjäger, J., Wright, L., Mura, A., Levi, F., Robinson, S., Xuereb, A., Baptie, B., Calonico, D. (2018) Ultrastable laser interferometry for earthquake detection with terrestrial and submarine cables, Science, 10.1126/science.aat4458

Mcgarragh, G.R., Poulsen, C.A., Thomas, G.E., Povey, A.C., Sus, O., Stapelberg, S., Schlundt, C., Proud, S., Christensen, M.W., Stengel, M., Hollmann, R., Grainger, R.G. (2018) The Community Cloud retrieval for CLimate (CC4CL)-Part 2: The optimal estimation approach, Atmospheric Measurement Techniques, 10.5194/amt-11-3397-2018

Mestre-Quereda, A., Lopez-Sanchez, J.M., Ballester-Berman, J.D., Gonzalez, P.J., Hooper, A., Wright, T.J. (2018) Evaluation of the Multilook Size in Polarimetric Optimization of Differential SAR Interferograms, IEEE Geoscience and Remote Sensing Letters, 10.1109/LGRS.2018.2839179

COMET PUBLICATIONS JANUARY-DECEMBER 2018

A.J, Michael., M.J. Werner (2018) Preface to the focus section on the collaboratory for the study of earthquake predictability (CSEP): New results and future directions, Seismological Research Letters, 10.1785/0220180161

Middleton, T.A., Parsons, B., Walker, R.T. (2018) Comparison of seismic and geodetic strain rates at the margins of the Ordos Plateau, northern China, Geophysical Journal International, 10.1093/gji/ggx446

Muller, C., Biggs, J., Ebmeier, S.K., Mothes, P., Palacios, P.B., Jarrín, P., Edmonds, M., Ruiz, M. (2018) Temporal evolution of the magmatic system at Tungurahua Volcano, Ecuador, detected by geodetic observations, Journal of Volcanology and Geothermal Research, 10.1016/j.jvolgeores.2018.11.004

Najman, Y., Burley, S.D., Copley, A., Kelly, M.J., Pander, K., Mishra, P. (2018) The Late Eocene-Early Miocene Unconformities of the NW Indian Intraplate Basins and Himalayan Foreland: A Record of Tectonics or Mantle Dynamics?, Tectonics, 10.1029/2018TC005286

Neuberg, J.W., Collinson, A.S.D., Mothes, P.A., C. Ruiz, M., Aguaiza, S. (2018) Understanding cyclic seismicity and ground deformation patterns at volcanoes: Intriguing lessons from Tungurahua volcano, Ecuador, Earth and Planetary Science Letters, 10.1016/j.epsl.2017.10.050

Nowacki, A., Wilks, M., Kendall, J.-M., Biggs, J., Ayele, A. (2018) Characterising hydrothermal fluid pathways beneath Aluto volcano, Main Ethiopian Rift, using shear wave splitting, Journal of Volcanology and Geothermal Research, 10.1016/j.jvolgeores.2018.03.023

Pankhurst, M.J., Morgan, D.J., Thordarson, T., Loughlin, S.C. (2018) Magmatic crystal records in time, space, and process, causatively linked with volcanic unrest, Earth and Planetary Science Letters, 10.1016/j.epsl.2018.04.025

Pardini, F., Burton, M., Arzilli, F., La Spina, G., Polacci, M. (2018) SO2 emissions, plume heights and magmatic processes inferred from satellite data: The 2015 Calbuco eruptions, Journal of Volcanology and Geothermal Research, 10.1016/j.jvolgeores.2018.08.001

Parks, M., Sigmundsson, F., Sigurðsson, Ó., Hooper, A., Hreinsdóttir, S., Ófeigsson, B., Michalczewska, K. (2018) Deformation due to geothermal exploitation at Reykjanes, Iceland, Journal of Volcanology and Geothermal Research, 10.1016/j.jvolgeores.2018.08.016

Percival, L.M.E., Jenkyns, H.C., Mather, T.A., Dickson, A.J., Batenburg, S.J., Ruhl, M., Hesselbo, S.P., Barclay, R., Jarvis, I., Robinson, S.A., Woelders, L. (2018) Does large igneous province volcanism always perturb the mercury cycle? Comparing the records of Oceanic Anoxic Event 2 and the end-cretaceous to other Mesozoic events, American Journal of Science, 10.2475/08.2018.01

Pfeffer, M.A., Bergsson, B., Barsotti, S., Stefánsdóttir, G., Galle, B., Arellano, S., Conde, V., Donovan, A., Ilyinskaya, E., Burton, M., Aiuppa, A., Whitty, R.C.W., Simmons, I.C., Arason, Þ., Jónasdóttir, E.B., Keller, N.S., Yeo, R.F., Arngrímsson, H., Jóhannsson, Þ., Butwin, M.K., Askew, R.A., Dumont, S., Von Löwis, S., Ingvarsson, Þ., La Spina, A., Thomas, H., Prata, F., Grassa, F., Giudice, G., Stefánsson, A., Marzano, F., Montopoli, M., Mereu, L. (2018) Ground-Based measurements of the 2014-2015 holuhraun volcanic cloud (Iceland), Geosciences (Switzerland), 10.3390/geosciences8010029

Plail, M., Edmonds, M., Woods, A.W., Barclay, J., Humphreys, M.C.S., Herd, R.A., Christopher, T. (2018) Mafic enclaves record syn-eruptive basalt intrusion and mixing, Earth and Planetary Science Letters, 10.1016/j.epsl.2017.11.033

Polacci, M., Arzilli, F., La Spina, G., Le Gall, N., Cai, B., Hartley, M.E., Di Genova, D., Vo, N.T., Nonni, S., Atwood, R.C., Llewellin, E.W., Lee, P.D., Burton, M.R. (2018) Crystallisation in basaltic magmas revealed via in situ 4D synchrotron X-ray microtomography, Scientific Reports, 10.1038/s41598-018-26644-6

Poulidis, A.P., Phillips, J.C., Renfrew, I.A., Barclay, J., Hogg, A., Jenkins, S.F., Robertson, R., Pyle, D.M. (2018) Meteorological Controls on Local and Regional Volcanic Ash Dispersal, Scientific Reports, 10.1038/s41598-018-24651-1

Pritchard, M.E., Biggs, J., Wauthier, C., Sansosti, E., Arnold, D.W.D., Delgado, F., Ebmeier, S.K., Henderson, S.T., Stephens, K., Cooper, C., Wnuk, K., Amelung, F., Aguilar, V., Mothes, P., Macedo, O., Lara, L.E., Poland, M.P., Zoffoli, S. (2018) Towards coordinated regional multi-satellite InSAR volcano observations: results from the Latin America pilot project, Journal of Applied Volcanology, 10.1186/s13617-018-0074-0

Pyle, D.M. (2018) What Can We Learn from Records of Past Eruptions to Better Prepare for the Future?, Advances in Volcanology, 10.1007/11157_2017_5

Pyle, D.M., Barclay, J., Armijos, M.T. (2018) The 1902–3 eruptions of the Soufrière, St Vincent: Impacts, relief and response, Journal of Volcanology and Geothermal Research, 10.1016/j.jvolgeores.2018.03.005

Queißer, M., Burton, M., Granieri, D. (2018) Large-area quantification of subaerial CO 2 anomalies with portable laser remote sensing and 2D tomography, Leading Edge, 10.1190/tle37030222a1.1

Queißer, M., Burton, M., Granieri, D., Varnam, M. (2018) Ground-based remote sensing of volcanic CO2 fluxes at Solfatara (Italy)-Direct versus inverse Bayesian retrieval, Remote Sensing, 10.3390/rs10010125

Reed, B.E., Peters, D.M., McPheat, R., Grainger, R.G. (2018) The Complex Refractive Index of Volcanic Ash Aerosol Retrieved From Spectral Mass Extinction, Journal of Geophysical Research: Atmospheres, 10.1002/2017JD027362

Reynolds, K., Copley, A. (2018) Seismological constraints on the down-dip shape of normal faults, Geophysical Journal International, 10.1093/GJI/GGX432

Rhoades, D.A., Christophersen, A., Gerstenberger, M.C., Liukis, M., Silva, F., Marzocchi, W., Werner, M.J., Jordan, T.H. (2018) Highlights from the first ten years of the New Zealand earthquake forecast testing center, Seismological Research Letters, 10.1785/0220180032

Romero, J.E., Vera, F., Polacci, M., Morgavi, D., Arzilli, F., Alam, M.A., Bustillos, J.E., Guevara, A., Johnson, J.B., Palma, J.L., Burton, M., Cuenca, E., Keller, W. (2018) Tephra From the 3 March 2015 Sustained Column Related to Explosive Lava Fountain Activity at Volcán Villarrica (Chile), Frontiers in Earth Science, 10.3389/feart.2018.00098

Ruiz-Armenteros, A.M., Lazecky, M., Hlaváčová, I., Bakoň, M., Manuel Delgado, J., Sousa, J.J., Lamas-Fernández, F., Marchamalo, M., Caro-Cuenca, M., Papco, J., Perissin, D. (2018) Deformation monitoring of dam infrastructures via spaceborne MT-InSAR. The case of La Viñuela (Málaga, southern Spain), Procedia Computer Science, 10.1016/j.procs.2018.10.049

Ruiz-Armenteros, A.M., Lazecky, M., Ruiz-Constán, A., Bakoň, M., Manuel Delgado, J., Sousa, J.J., Galindo-Zaldívar, J., De Galdeano, C.S., Caro-Cuenca, M., Martos-Rosillo, S., Jiménez-Gavilán, P., Perissin, D. (2018) Monitoring continuous subsidence in the Costa del Sol (Málaga province, southern Spanish coast) using ERS-1/2, Envisat, and Sentinel-1A/B SAR interferometry, Procedia Computer Science, 10.1016/j.procs.2018.10.050

Ruiz-Armenteros, A.M., Manuel Delgado, J., Ballesteros-Navarro, B.J., Lazecky, M., Bakon, M., Sousa, J.J. (2018) Deformation monitoring of the northern sector of the Valencia Basin (E Spain) using PS-InSAR (1993-2010), International Geoscience and Remote Sensing Symposium (IGARSS), 10.1109/IGARSS.2018.8519126

Ruiz-Armenteros, A.M., Manuel Delgado, J., Lamas-Fernández, F., Bravo-Pareja, R., Lazecky, M., Bakon, M., Sousa, J.J., Caro-Cuenca, M., Verstraeten, G., Hanssen, R.F. (2018) Multi-temporal InSAR monitoring of the Aswan high dam (Egypt), International Geoscience and Remote Sensing Symposium (IGARSS), 10.1109/IGARSS.2018.8517276

Ruiz-Constán, A., Ruiz-Armenteros, A.M., Martos-Rosillo, S., Galindo-Zaldívar, J., Lazecky, M., García, M., Sousa, J.J., Sanz de Galdeano, C., Delgado-Blasco, J.M., Jiménez-Gavilán, P., Caro-Cuenca, M., Luque-Espinar, J.A. (2018) SAR interferometry monitoring of subsidence in a detritic basin related to water depletion in the underlying confined carbonate aquifer (Torremolinos, southern Spain), Science of the Total Environment, 10.1016/j.scitotenv.2018.04.280

Sadeghi, Z., Valadan Zoej, M.J., Hooper, A., Lopez-Sanchez, J.M. (2018) A new polarimetric persistent scatterer interferometry method using temporal coherence optimization, IEEE Transactions on Geoscience and Remote Sensing, 10.1109/TGRS.2018.2840423

Salerno, G.G., Burton, M., Di Grazia, G., Caltabiano, T., Oppenheimer, C. (2018) Coupling between magmatic degassing and volcanic tremor in basaltic volcanism, Frontiers in Earth Science, 10.3389/feart.2018.00157

Schorlemmer, D., Werner, M.J., Marzocchi, W., Jordan, T.H., Ogata, Y., Jackson, D.D., Mak, S., Rhoades, D.A., Gerstenberger, M.C., Hirata, N., Liukis, M., Maechling, P.J., Strader, A., Taroni, M., Wiemer, S., Zechar, J.D., Zhuang, J. (2018) The collaboratory for the study of earthquake predictability: Achievements and priorities, Seismological Research Letters, 10.1785/0220180053

Shamshiri, R., Nahavandchi, H., Motagh, M., Hooper, A. (2018) Efficient ground surface displacement monitoring using Sentinel-1 data: Integrating distributed scatterers (DS) identified using two-sample t-test with persistent scatterers (PS), Remote Sensing, 10.3390/rs10050794

Shao, Y., Liu-Zeng, J., Oskin, M.E., Elliott, A.J., Wang, P., Zhang, J., Yuan, Z., Li, Z. (2018) Paleoseismic Investigation of the Aksay Restraining Double Bend, Altyn Tagh Fault, and Its Implication for Barrier-Breaching Ruptures, Journal of Geophysical Research: Solid Earth, 10.1029/2017JB015397

COMET PUBLICATIONS JANUARY-DECEMBER 2018

Silva, D., Piazolo, S., Daczko, N.R., Houseman, G., Raimondo, T., Evans, L. (2018) Intracontinental Orogeny Enhanced by Far-Field Extension and Local Weak Crust, Tectonics, 10.1029/2018TC005106

Spaans, K., Hooper, A. (2018) Insights Into the Stress Field Around Bár ðarbunga Volcano From the 2014/2015 Holuhraun Rifting Event, Journal of Geophysical Research: Solid Earth, 10.1002/2017JB015274

Sparrow, S., Millar, R.J., Yamazaki, K., Massey, N., Povey, A.C., Bowery, A., Grainger, R.G., Wallom, D., Allen, M. (2018) Finding ocean states that are consistent with observations from a perturbed physics parameter ensemble, Journal of Climate, 10.1175/JCLI-D-17-0514.1

Stock, M.J., Humphreys, M.C.S., Smith, V.C., Isaia, R., Brooker, R.A., Pyle, D.M. (2018) Tracking volatile behaviour in sub-volcanic plumbing systems using apatite and glass: Insights into pre-eruptive processes at Campi Flegrei, Italy, Journal of Petrology, 10.1093/petrology/egy020

Strader, A., Werner, M., Bayona, J., Maechling, P., Silva, F., Liukis, M., Schorlemmer, D. (2018) Prospective evaluation of global earthquake forecast models: 2 yrs of observations provide preliminary support for merging smoothed seismicity with geodetic strain rates, Seismological Research Letters, 10.1785/0220180051

Sus, O., Stengel, M., Stapelberg, S., Mcgarragh, G., Poulsen, C., Povey, A.C., Schlundt, C., Thomas, G., Christensen, M., Proud, S., Jerg, M., Grainger, R., Hollmann, R. (2018) The Community Cloud retrieval for CLimate (CC4CL)-Part 1: A framework applied to multiple satellite imaging sensors, Atmospheric Measurement Techniques, 10.5194/amt-11-3373-2018

Swindles, G.T., Watson, E.J., Savov, I.P., Lawson, I.T., Schmidt, A., Hooper, A., Cooper, C.L., Connor, C.B., Gloor, M., Carrivick, J.L. (2018) Climatic control on Icelandic volcanic activity during the mid-Holocene, Geology, 10.1130/G39633.1

Tape, C., Holtkamp, S., Silwal, V., Hawthorne, J., Kaneko, Y., Ampuero, J.P., Ji, C., Ruppert, N., Smith, K., West, M.E. (2018) Earthquake nucleation and fault slip complexity in the lower crust of central Alaska, Nature Geoscience, 10.1038/s41561-018-0144-2

Taroni, M., Marzocchi, W., Schorlemmer, D., Werner, M.J., Wiemer, S., Zechar, J.D., Heiniger, L., Euchner, F. (2018) Prospective CSEP evaluation of 1-Day, 3-month, and 5-Yr earthquake forecasts for Italy, Seismological Research Letters, 10.1785/0220180031

Taylor, I.A., Preston, J., Carboni, E., Mather, T.A., Grainger, R.G., Theys, N., Hidalgo, S., Kilbride, B.M. (2018) Exploring the Utility of IASI for Monitoring Volcanic SO 2 Emissions, Journal of Geophysical Research: Atmospheres, 10.1002/2017JD027109

Temtime, T., Biggs, J., Lewi, E., Hamling, I., Wright, T., Ayele, A. (2018) Spatial and temporal patterns of deformation at the Tendaho geothermal prospect, Ethiopia, Journal of Volcanology and Geothermal Research, 10.1016/j.jvolgeores.2018.04.004

Verdon, J.P., Kendall, J.-M., Butcher, A., Luckett, R., Baptie, B.J. (2018) Seismicity induced by longwall coal mining at the Thoresby Colliery, Nottinghamshire, U.K., Geophysical Journal International, 10.1093/gji/ggx465

Villani, F., Civico, R., Pucci, S., Pizzimenti, L., Nappi, R., De Martini, P.M., Agosta, F., Alessio, G., Alfonsi, L., Amanti, M., Amoroso, S., Aringoli, D., Auciello, E., Azzaro, R., Baize, S., Bello, S., Benedetti, L., Bertagnini, A., Binda, G., Bisson, M., Blumetti, A.M., Bonadeo, L., Boncio, P., Bornemann, P., Branca, S., Braun, T., Brozzetti, F., Brunori, C.A., Burrato, P., Caciagli, M., Campobasso, C., Carafa, M., Cinti, F.R., Cirillo, D., Comerci, V., Cucci, L., De Ritis, R., Deiana, G., Del Carlo, P., Del Rio, L., Delorme, A., Di Manna, P., Di Naccio, D., Falconi, L., Falcucci, E., Farabollini, P., Faure Walker, J.P., Ferrarini, F., Ferrario, M.F., Ferry, M., Feuillet, N., Fleury, J., Fracassi, U., Frigerio, C., Galluzzo, F., Gambillara, R., Gaudiosi, G., Goodall, H., Gori, S., Gregory, L.C., Guerrieri, L., Hailemikael, S., Hollingsworth, J., Iezzi, F., Invernizzi, C., Jablonská, D., Jacques, E., Jomard, H., Kastelic, V., Klinger, Y., Lavecchia, G., Leclerc, F., Liberi, F., Lisi, A., Livio, F., Sardo, L., Malet, J.P., Mariucci, M.T., Materazzi, M., Maubant, L., Mazzarini, F., McCaffrey, K.J.W., Michetti, A.M., Mildon, Z.K., Montone, P., Moro, M., Nave, R., Odin, M., Pace, B., Paggi, S., Pagliuca, N., Pambianchi, G., Pantosti, D., Patera, A., Pérouse, E., Pezzo, G., Piccardi, L., Pierantoni, P.P., Pignone, M., Pinzi, S., Pistolesi, E., Point, J., Pousse, L., Pozzi, A., Proposito, M., Puglisi, C., Puliti, I., Ricci, T., Ripamonti, L., Rizza, M., Roberts, G.P., Roncoroni, M., Sapia, V., Saroli, M., Sciarra, A., Scotti, O., Skupinski, G., Smedile, A., Soquet, A., Tarabusi, G., Tarquini, S., Terrana, S., Tesson, J., Tondi, E., Valentini, A., Vallone, R., Van Der Woerd, J., Vannoli, P., Venuti, A., Vittori, E., Volatili, T., Wedmore, L.N.J., Wilkinson, M., Zambrano, M. (2018) A database of the coseismic effects following the 30 October 2016 Norcia earthquake in Central Italy, Scientific Data, 10.1038/sdata.2018.49

Wacey, D., Noffke, N., Saunders, M., Guagliardo, P., Pyle, D.M. (2018) Volcanogenic Pseudo-Fossils from the 3.48 Ga Dresser Formation, Pilbara, Western Australia, Astrobiology, 10.1089/ast.2017.1734

Wadge, G., McCormick Kilbride, B.T., Edmonds, M., Johnson, R.W. (2018) Persistent growth of a young andesite lava cone: Bagana volcano, Papua New Guinea, Journal of Volcanology and Geothermal Research, 10.1016/j.jvolgeores.2018.03.012

Walters, R.J., Gregory, L.C., Wedmore, L.N.J., Craig, T.J., McCaffrey, K., Wilkinson, M., Chen, J., Li, Z., Elliott, J.R., Goodall, H., Iezzi, F., Livio, F., Michetti, A.M., Roberts, G., Vittori, E. (2018) Earth and Planetary Science Letters, 10.1016/j.epsl.2018.07.043

Wang, F., Wang, Z., Yang, H., Zhao, Y., Li, Z., Wu, J. (2018) Capability of remotely sensed drought indices for representing the spatio-temporal variations of the meteorological droughts in the Yellow River basin, Remote Sensing, 10.3390/rs10111834

Wang, Z., Li, Z., Mills, J. (2018) A new approach to selecting coherent pixels for ground-based SAR deformation monitoring, ISPRS Journal of Photogrammetry and Remote Sensing, 10.1016/j.isprsjprs.2018.08.008

Wang, Z., Li, Z., Mills, J.P. (2018) A New Nonlocal Method for Ground-Based Synthetic Aperture Radar Deformation Monitoring, IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 10.1109/JSTARS.2018.286474

Wauthier, C., Smets, B., Hooper, A., Kervyn, F., d'Oreye, N. (2018) Identification of subsiding areas undergoing significant magmatic carbon dioxide degassing, along the northern shore of Lake Kivu, East African Rift, Journal of Volcanology and Geothermal Research, 10.1016/j.jvolgeores.2018.08.018

Weiss, J.R., Ito, G., Olive, J.A., Brooks, B.A., Moore, G.F., Foster, J.H. (2018) Formation of the frontal thrust zone of accretionary wedges, Earth and Planetary Science Letters doi:10.1016/j.epsl.2018.05.010

Western, L.M., Rougier, J., Watson, I.M. (2018) Decision theory-based detection of atmospheric natural hazards from satellite imagery using the example of volcanic ash, Quarterly Journal of the Royal Meteorological Society, 10.1002/qj.3230
Wilkinson, P.B., Gunn, D.A., Holyoake, S., Dashwood, B.A.J., Brett, C.R., Rees, J.G. (2018) Low frequency acoustic and ultrasound waves to characterise layered media, NDT and E International, 10.1016/j.ndteint.2018.03.005

Williams, J.G., Rosser, N.J., Kincey, M.E., Benjamin, J., Oven, K.J., Densmore, A.L., Milledge, D.G., Robinson, T.R., Jordan, C.A., Dijkstra, T.A. (2018) Satellite-based emergency mapping using optical imagery: Experience and reflections from the 2015 Nepal earthquakes, Natural Hazards and Earth System Sciences, 10.5194/nhess-18-185-2018

Wimpenny, S., Copley, A., Benavente, C., Aguirre, E. (2018) Extension and Dynamics of the Andes Inferred From the 2016 Parina (Huarichancara) Earthquake, Journal of Geophysical Research: Solid Earth, 10.1029/2018JB015588

Yamasaki, T., Kobayashi, T., Wright, T.J., Fukahata, Y. (2018) Viscoelastic crustal deformation by magmatic intrusion: A case study in the Kutcharo caldera, eastern Hokkaido, Japan, Journal of Volcanology and Geothermal Research, 10.1016/j.jvolgeores.2017.10.011

Yang, H., Yang, G., Gaulton, R., Zhao, C., Li, Z., Taylor, J., Wicks, D., Minchella, A., Chen, E., Yang, X. (2018) In-season biomass estimation of oilseed rape (Brassica napus L.) using fully polarimetric SAR imagery, Precision Agriculture, 10.1007/s11119-018-9587-

Yu, C., Li, Z., Chen, J., Hu, J.-C. (2018) Small magnitude co-seismic deformation of the 2017 Mw 6.4 Nyingchi earthquake revealed by InSAR measurements with atmospheric correction, Remote Sensing, 10.3390/rs10050684

Yu, C., Li, Z., Penna, N.T. (2018) Interferometric synthetic aperture radar atmospheric correction using a GPS-based iterative tropospheric decomposition model, Remote Sensing of Environment, 10.1016/j.rse.2017.10.038

Yu, C., Li, Z., Penna, N.T., Crippa, P. (2018) Generic Atmospheric Correction Model for Interferometric Synthetic Aperture Radar Observations, Journal of Geophysical Research: Solid Earth, 10.1029/2017JB015305

Zhang, L., Werner, M.J., Goda, K. (2018) Spatiotemporal seismic Hazard and risk assessment of aftershocks of M 9 megathrust earthquakes, Bulletin of the Seismological Society of America, 10.1785/0120180126

Zhang, Y., Meng, X., Jordan, C., Novellino, A., Dijkstra, T., Chen, G. (2018) Investigating slow-moving landslides in the Zhouqu region of China using InSAR time series, Landslides, 10.1007/s10346-018-0954-8

Zhou, Y., Parsons, B.E., Walker, R.T. (2018) Characterizing Complex Surface Ruptures in the 2013 M w 7.7 Balochistan Earthquake Using Three-Dimensional Displacements, Journal of Geophysical Research: Solid Earth, 10.1029/2018JB016043

Zhou, Y., Thomas, M.Y., Parsons, B., Walker, R.T. (2018) Time-dependent postseismic slip following the 1978 M w 7.3 Tabas-e-Golshan, Iran earthquake revealed by over 20 years of ESA InSAR observations, Earth and Planetary Science Letters, 10.1016/j.epsl.2017.12.005

COMET PUBLICATIONS JANUARY-DECEMBER 2018

Zhuang, J., Peng, J., Xu, C., Li, Z., Densmore, A., Milledge, D., Iqbal, J., Cui, Y. (2018) Distribution and characteristics of loess landslides triggered by the 1920 Haiyuan Earthquake, Northwest of China, Geomorphology, 10.1016/j.geomorph.2018.04.012

Normal fault scarps near Cusco, Peru
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