COMET

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

ANNUAL REPORT 2024/2025

British Geological Survey

Natural Environment Research Council

Cover image: “Which Way?”
Ben Johnson, University of Oxford

Photo credit: Ourzazate Basin, Morocco, reverse fault
Zakeria Shnizai, University of Oxford

CONTENTS

INTRODUCTION

The UK Centre for Observation and Modelling of Earthquakes, Volcanoes and Tectonics (COMET) provides world-leading science, data, and advice on volcanic and seismic hazards. COMET uses satellite measurements alongside ground-based observations and geophysical models to study earthquakes and volcanoes and help understand, prepare for, and respond to the hazards they pose.

COMET brings together leading scientists across the British Geological Survey (BGS) and 7 UK partner universities: Bristol, Cambridge, Edinburgh, Leeds, Manchester, Oxford and Sheffield. In addition to this, we have associate members across a number of other UK institutions, including: Cardiff, East Anglia, Exeter, Imperial College London, Newcastle, Plymouth, UCL and the WTW Research Network. We provide scientific leadership in Earth Observation (EO), while also bringing together a vibrant community of postgraduate students and early career researchers.

The services, facilities, data and long-term underpinning research in EO science and geohazards that we produce benefit the wider community of environmental scientists, while helping the UK and other countries to prepare for, and respond rapidly to, earthquakes and eruptions.

COMET was founded in 2002, rapidly establishing itself as a leading centre for the integrated exploitation of EO, ground-based data, and geophysical models for research into geohazards. In 2018, COMET was awarded the Royal Astronomical Society's group achievement award in recognition of its unique and long-term contributions. Since 2014, recognising shared strategic agendas, science drivers, and the benefits of increased collaboration, COMET has been progressively building a strategic partnership with the BGS. We also work closely with the Natural Environment Research Council (NERC), European Space Agency (ESA), UK Foreign, Commonwealth and Development Office (FCDO), as well as many other national and international partners. Our work with business, Government and space agencies helps to ensure that the UK continues to invest in and benefit from satellite missions.

This annual highlight report covers the period 1st April 2024 – 31st March 2025, the first year of our current 5-year science programme.

CO-DIRECTOR'S WELCOME

Welcome to COMET's eleventh annual report!

This year's report marks a departure from previous "phases" of COMET in a number of ways. Firstly, we have started our 2024-2029 Science Programme, which will run until March 2029. Secondly, this is my first year as COMET Co-Director, serving alongside Professor Tim Wright, COMET Co-Director (Leeds). And, finally, we have changed the format of our annual report. We have split the report into two parts: one to showcase highlights over the reporting year (this report), and another to track progress against our objectives.

Report icon key:

- Magmatism and Volcanic Hazard
- Earth Observation
- Tectonics and Seismic Hazard
- Impact

Over the past year, COMET has continued to deliver long-term science and services that are aligned with the British Geological Survey's "Multihazards and Risk" priorities. Our Earth Observation Data and Services work has seen remarkable growth, with the COMET-LiCSAR Sentinel-1 InSAR processing service now exceeding 2 million interferograms. For more information about progress and developments of COMET services over the last year, see p. 9-10. We have also completed a ten-year-long project to map continental strain over the Alpine-Himalayan Belt (p. 11-13), improved modelling of volcanic magma system evolution (pp. 26-28) and made crucial steps towards forecasting eruption using SO2 emissions (pp. 14-16).

Our high-impact activities this year included our work with Ethiopian collaborators in response to the Fentale volcanic eruption (pp. 14-16)., and our work in central Asia to inform resilient hydropower plant design (pp. 17-21). We also provided data in response to the Myanmar Earthquakes in March 2025 (pp. 17-21), tracked a volcanic crisis in the Aegean Sea in near-real-time (pp. 17-21), and funded outreach work to support disaster preparedness efforts in Nepal (pp. 17-21).

COMET's strength lies in the scientific excellence of our 160+ members and students. This year we welcomed exceptional new members with diverse research expertise, and several existing members took on new roles within the Centre. See "New Starters" (pp. 5-7) for details. The awards listed in this report highlight the talent within our membership. Congratulations to all recipients on their national and international successes. See "Awards and Recognition" (p. 46) for more information. We also hosted our first industry and stakeholder engagement event, "Research and Innovation Forum: Volcanic and Tectonic Multihazards" (p. 41), in November 2024, and shared COMET work with 98 attendees at the COMET annual meeting 2024 (Huddersfield) and with ~40 members at the COMET student meeting 2025 (Bristol).

I'm delighted to work alongside Tim as COMET Co-Director as COMET continues to grow, expand the support we provide to the scientific community, and further develop collaborations with BGS and our international partners.

Professor Juliet Biggs
University of Bristol

Photo credit: Lenticular cloud forming near Mount Etna, as seen from Rifugio Sapienza
Jack Campbell, University of Cambridge

NEW STARTERS

Rhys Charles (University of Bristol)
Rhys Charles is a public engagement specialist based at the University of Bristol. He has been with COMET since August 2024, aiding in running engagement projects, organising events, and curating online and physical engagement resources.

Jin Fang (University of Leeds)
Jin Fang is a COMET Research Fellow at the University of Leeds, collaborating with Professor Tim Wright on investigating ductile tectonic deformation through satellite geodesy.

Brandon VanderBeek (University of Leeds)
Brandon VanderBeek is a Research Fellow at the University of Leeds exploring probabilistic seismic imaging of geothermal systems. After spending several years developing imaging methods aimed at constraining mantle anisotropy, he is now applying these approaches to infer properties of crustal fracture networks beneath Etna volcano (Italy) and the Hengill geothermal field (Iceland).

Shailza Sharma (University of Leeds)
Shailza Sharma is a Research Fellow working on the DEEPVOLC project at the University of Leeds, where she develops deep learning models to forecast volcanic activity using spatio-temporal satellite data. Her expertise spans computer vision, generative modeling, deep learning, and generative AI.

NEW STARTERS

Siyuan Zhao (University of Leeds)
Siyuan Zhao is a Research Fellow in the Institute of Geophysics and Tectonics at the University of Leeds. His current research focuses on using satellite Earth observation data to investigate the interactions between seismic and volcanic activity.

Tim Davis (University of Bristol)
Tim Davis is a Postdoctoral Researcher based at the University of Bristol. His research aims to understand the physics underpinning volcanic systems using continuum mechanics.

Alexandra Morand (University of Bristol)
Alexandra Morand is a Research Associate at the University of Bristol. Her research focuses on the numerical and analogue modelling of magmatic storage. She is particularly interested in the effect of magma buoyancy, along with deformation and fractures produce by magma emplacement in the crust.

Zakeria Shnizai (University of Oxford)
Zakeria Shnizai is a Postdoctoral Researcher at the University of Oxford, specializing in active tectonics and geology through the integration of satellite imagery and field data.

Zachary Sudholz (University of Cambridge)
Zachary Sudholz is a Postdoctoral Research Associate at the the University of Cambridge. Zachary's research focuses on high-temperature geochemistry and petrology of Earth's lithosphere.

Alice Turner (University of Cambridge)
Alice Turner is an Earthquake Seismologist. Her research focuses on understanding what causes earthquakes by analysing data from the seismic waves that are created during an earthquake.

NEW STARTERS

Joaquin Julve (Cardiff University)
Joaquin Julve Lillo is a Research Associate at Cardiff University. His research integrates numerical modelling with geological and geophysical data to investigate earthquake dynamics at natural faults. In 2024, he became a COMET Postdoctoral Researcher, joining the ASPERITY project led by Dr. Ake Fagereng.

Sophie Butcher (BGS)
Sophie Butcher is a Volcanologist at the British Geological Survey (BGS). Butcher uses seismic monitoring data from volcanoes to understand patterns of unrest in space and time, and ultimately better understand eruption processes. Butcher has been an Associate Member of COMET since joining BGS in 2023.

Clive Oppenheimer (University of Cambridge)
Clive Oppenheimer is a Professor of Volcanology and geoscientist based in the Department of Geography at the University of Cambridge. His interests include magmatic and volcanic processes, the climatic and societal impacts of eruptions, remote sensing, paleoclimatology and geoarchaeology.

Sandra Piazolo (University of Leeds)
Sandra Piazolo uses field observations, microstructural analysis combined with numerical modelling and physical experiments to understand the deformation behaviour of rocks through time and space. Sandra is particularly interested in the dynamic interplay between brittle – ductile deformation and fluid -rock interaction.

Rachel Holley (Viridien)
Rachel Holley is InSAR technical Lead in the Satellite Mapping team at geoscience company Viridien (formerly NPA and CGG). She works on a wide variety of commercial and R&D projects across many market sectors, including mining, infrastructure, oil and gas, and natural hazards.

Weiyu Zheng (University of Bristol)
Weiyu Zheng is a Senior Research Associate at the University of Bristol, where she processes InSAR data to monitor and analyze volcanic deformation globally.

Photo credit: Remnants of an eruption fissure at Laki in Iceland
Ben Esse, University of Manchester

COMET OBJECTIVES 2024-2029

Our science activities have been jointly developed with the BGS and are aligned with BGS priorities in "Multihazards and Risk" as set out in their 2023-2028 science strategy. 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.

OUR SCIENCE OBJECTIVES FOR 2024-2029:

Earth Observation Data and Services

1. Deformation, Topography and Surface Change from satellite geodesy and data:

- Maintain and Improve the COMET-LiCSAR Sentinel-1 service.
- Extend the COMET-LiCSAR system to other satellites.
- Derivation and use of high-resolution topographic data for surface change and hazard assessment.

2. Retrievals of volcanic emissions from satellite spectrometers:

- Retrieval of volcanic gases and particles from IASI, IASI-NG, CrIS and IRS.
- Volcanic flux time series.

3. Geoinformatics and Machine Learning:

- Improve the sharing and use of COMET datasets through the development of integrated and interactive COMET data portals that are responsive to end-user needs.
- Develop machine learning approaches and tools that can be applied to COMET satellite data sets.

Tectonics and Volcanism

1. Tectonics and Seismic Hazard:

- Develop and deploy a geodetically-based earthquake hazard model.
- Establish the processes that control fault rheology and dynamics, with particular emphasis on the distribution and characteristics of earthquakes and fault creep.
- The rheology and dynamics of the ductile crust and upper mantle, and the large-scale migration of tectonic strain.

2. Magmatism and Volcanic Hazard:

- Analyse long-term (decadal) patterns of volcanic activity globally.
- Integrate multiparameter datasets into physically-realistic models of volcanic and magmatic systems.
- Assess the effects of volcanic emissions.
- Develop and test the models needed for interpreting satellite data during volcanic crises.

DATASETS AND SERVICES

Data and services remain a central pillar of COMET to support the geoscience community and enhance the ability of the user community to prepare for and to respond effectively to earthquakes and volcanic eruptions. This section provides an overview of COMET's data and services, highlighting key activities and progress made over the past year (from April 2024 to March 2025).

COMET-LiCS Sentinel-1 InSAR portal

The LiCSAR service provides continuous, ready-to-use InSAR time series to support the monitoring of tectonic and volcanic deformation. It automatically processes Sentinel-1 data to produce interferograms and coherence maps, generally within two to four weeks of data acquisition. The service focuses on the Alpine-Himalayan tectonic belt and active volcanic regions. It also incorporates atmospheric corrections through the GACOS system, developed by the COMET team to generate high spatial resolution zenith total delay maps.

In the past year, LiCSAR processed approximately 400,000 full-frame Sentinel-1 interferograms, all made available via the COMET-LiCSAR online portal.

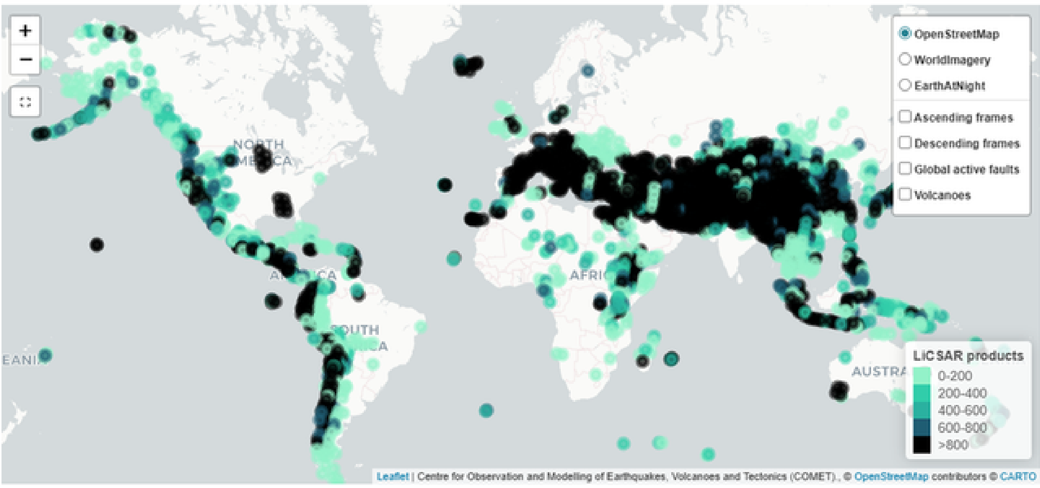
Between November 2024 and early 2025, the LiCSAR service experienced delays in data updates due to scheduled infrastructure maintenance. While the system continued to operate during this period, the disruptions affected the regular updating of the data archive.

Service functionality has now been progressively restored, and LiCSAR is returning to full capacity, with timely updates being re-established across all frames.

Furthermore, following the launch of the Sentinel-1C satellite in December 2024, the LiCSAR system has been upgraded and is now ready to process data from this new mission.

Also, two new versions of the LiCSBAS software—the main toolbox supporting LiCSAR time series processing—were released over the past year. The latest updates include improved features for phase inversion, reference point handling, phase bias estimation, timeseries offsets from earthquakes, and removal of plate motion effects. A key enhancement is the new capability to process burst overlap data.

Looking ahead, we remain committed to maintaining and improving processing performance, expanding geographic coverage, and adapting the service to support data from future satellite missions.

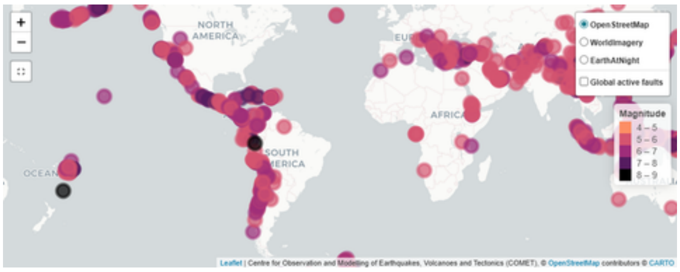


DATASETS AND SERVICES

COMET Earthquake Responder

The Earthquake Responder service supports rapid response efforts following significant seismic events by providing ready-to-use co-seismic InSAR data. In the last year, the service responded to approximately 110 global earthquakes (magnitude >5.1), generating pre- and co-seismic interferograms for each event. These products were made publicly available through the COMET-LiCSAR Earthquake Portal.

While the system currently operates in a semi-automated mode, requiring some manual oversight, development is underway to achieve full automation. This will ensure even faster response times and enhanced support for post-earthquake scientific assessments and emergency decision-making.



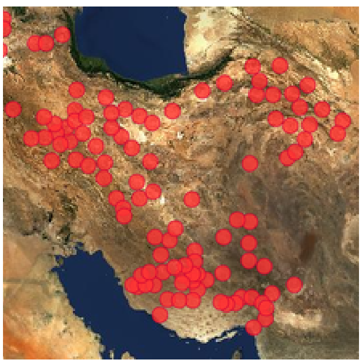
COMET Volcano Portal

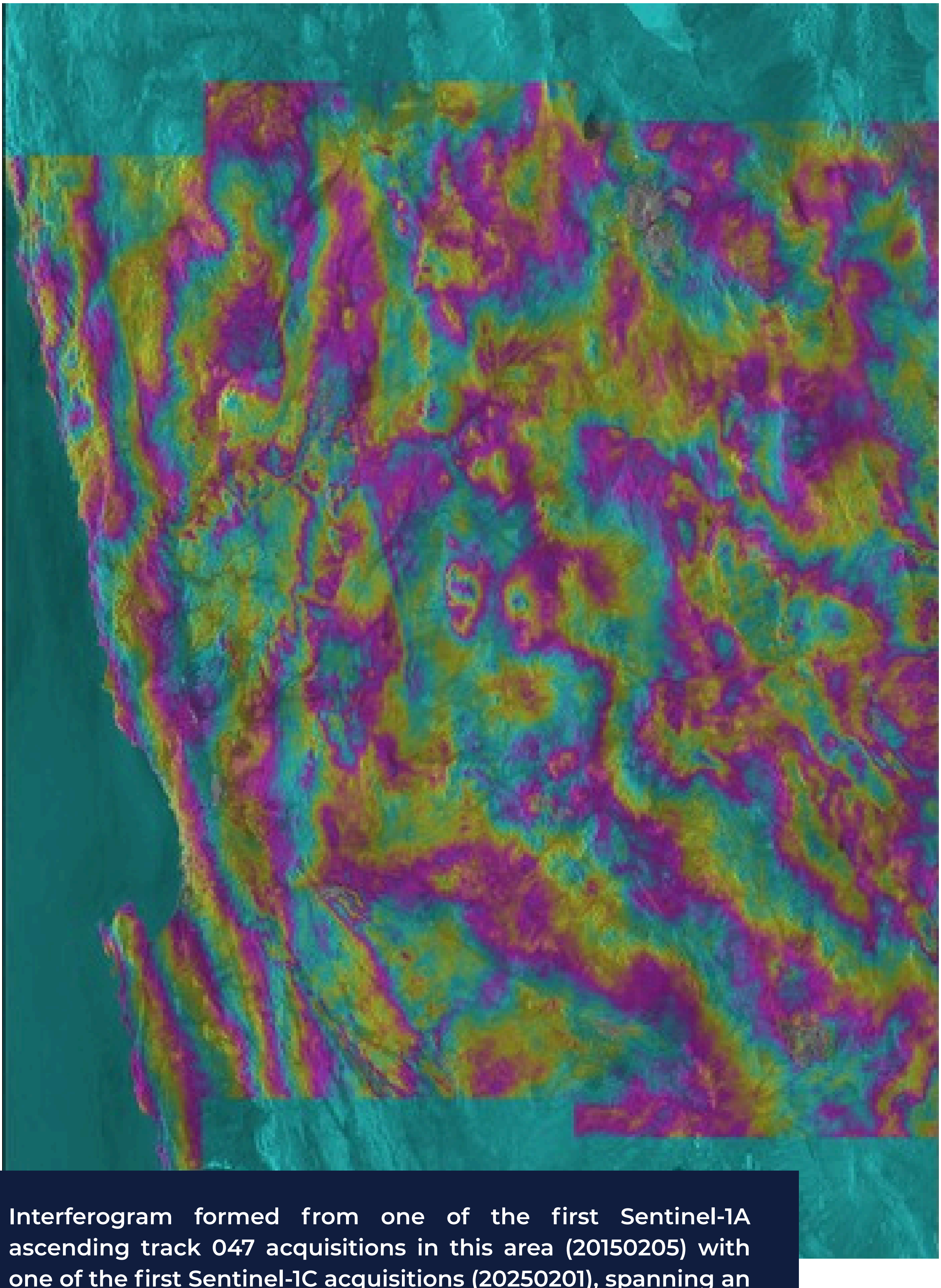
The COMET Volcano Portal enables online analysis of automatically processed LiCSAR Sentinel-1 interferograms over active volcanoes. The platform provides tools for users to detect and assess volcanic deformation signals, including displacement time series, profile plotting, and probability maps generated using machine learning techniques.
Over the past year, the system automatically detected and processed data for approximately 45 volcanic events, which are now accessible through the portal. Ongoing efforts aim to enhance these tools and expand coverage to include more volcanoes worldwide.

COMET Subsidence Portal

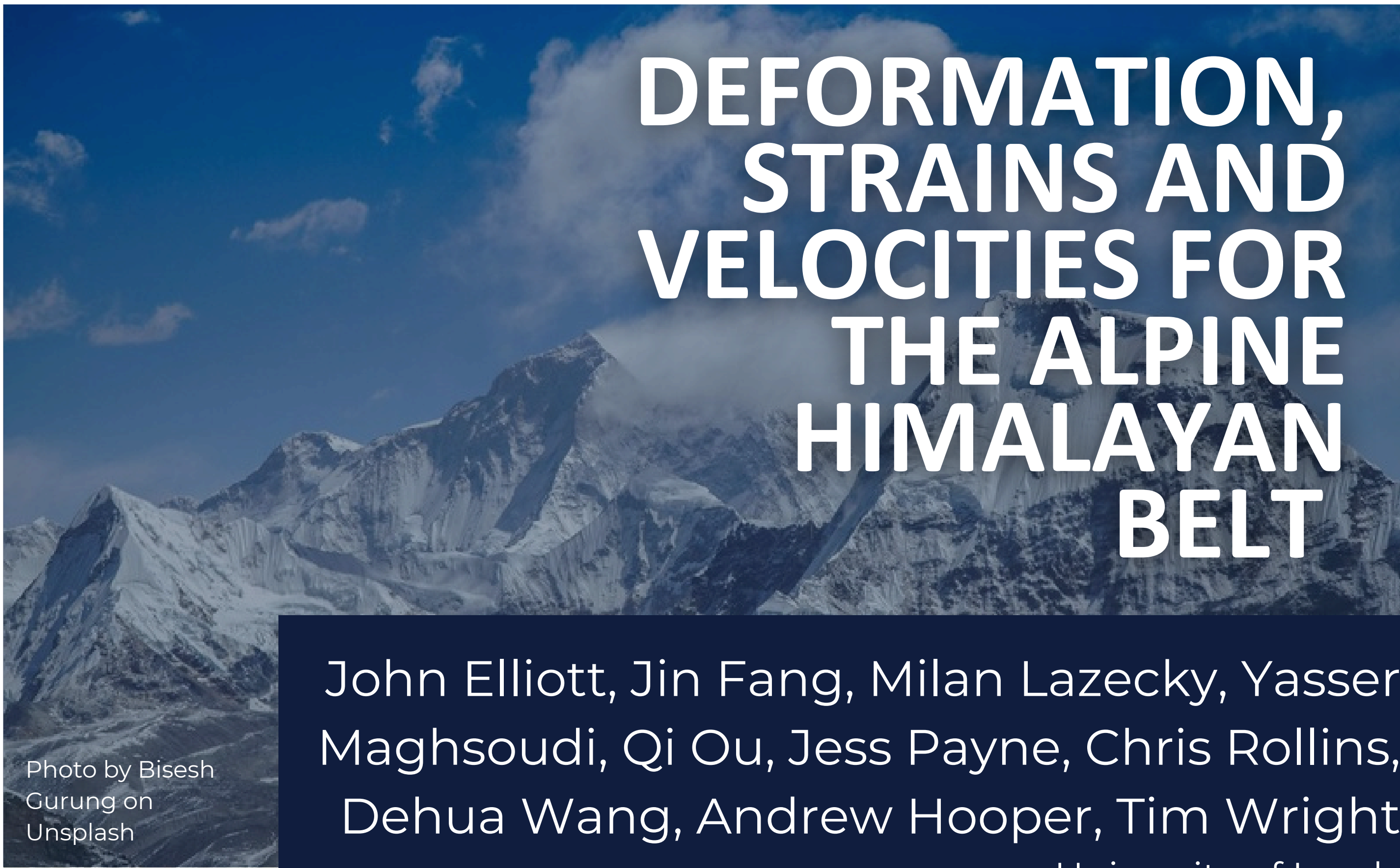
While COMET's primary focus is on tectonic and volcanic processes, its InSAR data processing also produces valuable by-products that support a broader range of geoscientific research. One such by-product is land subsidence deformation maps, which are particularly relevant for studies on environmental change, groundwater extraction, and urban infrastructure stability.

Currently, the portal includes 106 rapidly subsiding regions across Iran, within the Alpine-Himalayan belt. Over the past year, deformation time series for these regions have been regularly updated and made available online, providing an up-to-date resource for researchers and stakeholders. Although the portal currently focuses on Iran, future development aims to expand both its analytical capabilities and geographic coverage to include additional subsiding areas across the broader Alpine-Himalayan belt.





Interferogram formed from one of the first Sentinel-1A ascending track 047 acquisitions in this area (20150205) with one of the first Sentinel-1C acquisitions (20250201), spanning an interval of 10 years. The region is between the Chilean Coast at Antofogasta and the Atacama Desert on the Tropic of Capricorn. As one of the driest places on earth, the coherence is maintained very well over 10 years.



DEFORMATION, STRAINS AND VELOCITIES FOR THE ALPINE HIMALAYAN BELT

Photo by Bisesh Gurung on Unsplash

John Elliott, Jin Fang, Milan Lazecky, Yasser Maghsoudi, Qi Ou, Jess Payne, Chris Rollins, Dehua Wang, Andrew Hooper, Tim Wright

University of Leeds

This work was led by COMET Scientists, supported by COMET staff, and uses COMET data.

It has been 10 years in the making but the culmination of the joint LiCS COMET effort to process Sentinel-1 data across the entire Alpine Himalayan Belt with the aim of capturing the distribution of continental strain is now complete.

This is the first trans-continental scale three-component velocity field of the Alpine-Himalayan Belt derived from the archive of Sentinel-1 satellite radar observations. We image both zones of strain accumulation associated with major faulting and extensive diffuse deformation elsewhere across the continents. The horizontal deformation is dominated by tectonics, whilst the vertical by other surface processes such as fast and persistent subsidence due to water extraction from aquifers.

Surface velocities and strain rates from satellite geodesy have become essential tools for understanding the distribution of tectonic deformation, faulting and seismic hazard. However, across large regions of distributed continental deformation, such as the Alpine-Himalayan Belt, data are only sparsely available.

While previous studies have mainly used spatially sparse GNSS to measure deformation at such large scales, these approaches cannot characterize shorter wavelength features of deformation in many places. We use Sentinel-1 radar images acquired during 2016-2024 to provide trans-national average surface velocities and time series at 1 km spatial resolution stretching a distance of over 11,000 km from southern Europe to eastern China, covering an area more than 20 million square kilometres.

COMET HIGHLIGHT EO: Deformation & Surface Change

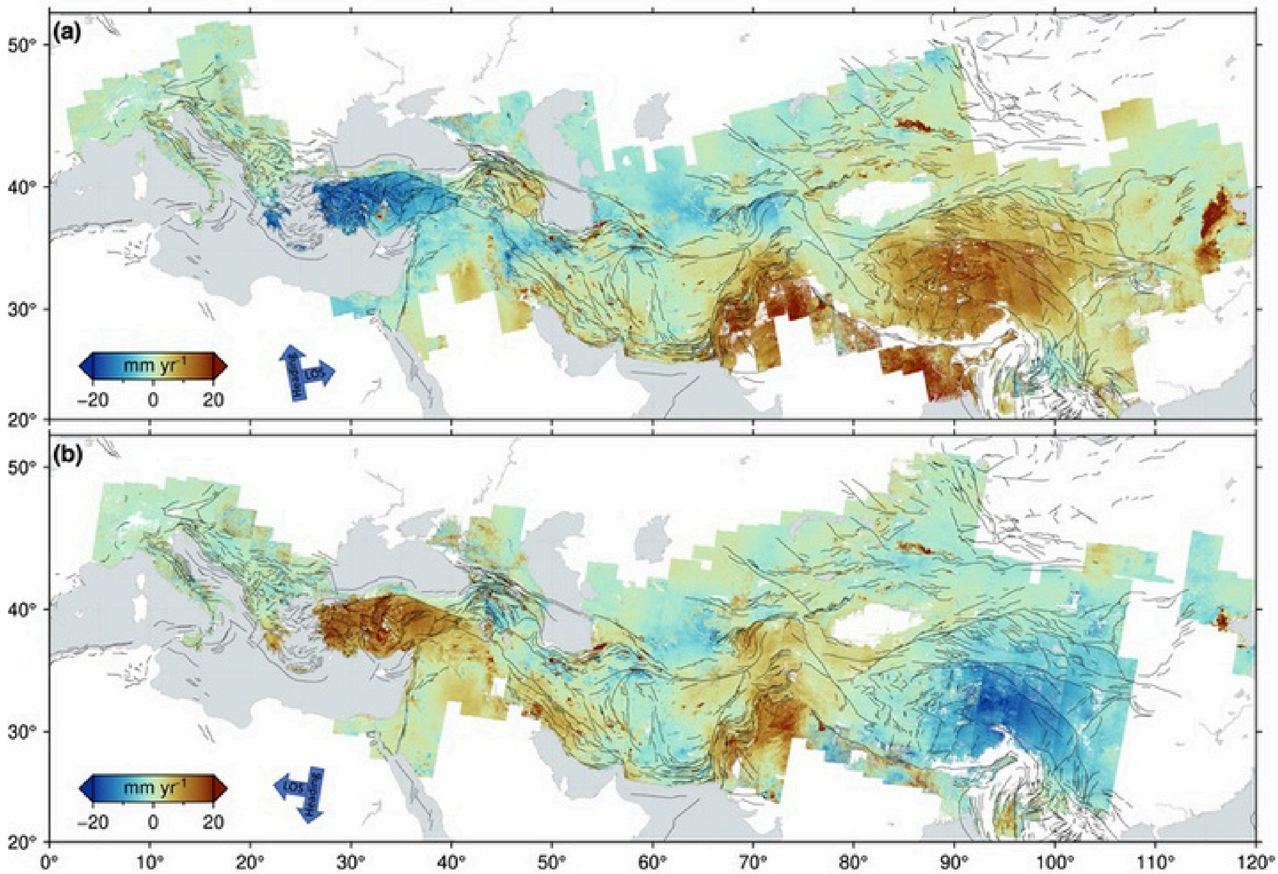


Figure 1: Average mosaic of referenced line of sight velocities for the Alpine Himalayan Belt on (a) ascending and (b) descending orbital heading directions, with positive values indicating motion away from the satellite. Active fault traces (black lines) are from Styron & Pagani (2020).

We produce the velocity field by combining data from over 220,000 Sentinel-1 SAR images with a new belt-wide compilation of over 49,000 GNSS velocities from 150 previously published studies, all combined in a consistent Eurasian reference frame (Figure 1). We achieve levels of uncertainty in the horizontal ~2–3 mm/yr and we are able to measure strain rates down to ~ 10 nstr/yr, or better in some very coherent regions (Figure 2). Horizontal strain rates are derived from gradients of the velocity field, yielding near-continuous spatial deformation information over the entirety of the largest deforming region on the planet (Figure 2).

The horizontal velocities and strains are dominated by tectonic deformation, which has a bimodal behaviour – focused on major faults but distributed elsewhere. Strain rates over 50 nstr/yr are concentrated on major strike-slip faults of Anatolia and the Tibetan Plateau and major convergence zones of the Himalayas and Pamirs, the bulk of the Alpine Himalayan orogeny is undergoing diffuse deformation at relatively low strain rates.

Significant regions of distributed deformation are found across Western Anatolia, Iran, the Makran, the whole of the Tian Shan and all of the Tibetan Plateau. We observe large-scale anti-clockwise rotations of northern Arabia and Anatolia, as well as along the Chaman Fault zone from the Makran through to the Hindu Kush and Eastern Syntaxis. We observe major broad clockwise rotations around the Western Syntaxis of the Himalayas. Regions of elevated strain are also found to be associated with creeping faults and postseismic deformation from recent major earthquakes. The results agree well with previously derived strain rate fields with GNSS only, but the InSAR provides greater detail on short wavelengths for regions that lack very high densities of GNSS.

Shorter-wavelength vertical velocities are dominated by non-tectonic processes, in particular the widespread over-exploitation of groundwater. The vertical rates are due to near-surface processes such as water extraction from aquifers, and permafrost changes at high elevations, except in regions of rapid convergence such as the Pamirs and the Himalayas where we observe tectonic uplift due to deeper convergence processes. Rates of subsidence much greater than 10 mm/yr are observed in several regions of Western and Central Turkiye, most of Iran, Pakistan and in the Junggar Basin and Beijing regions of China.

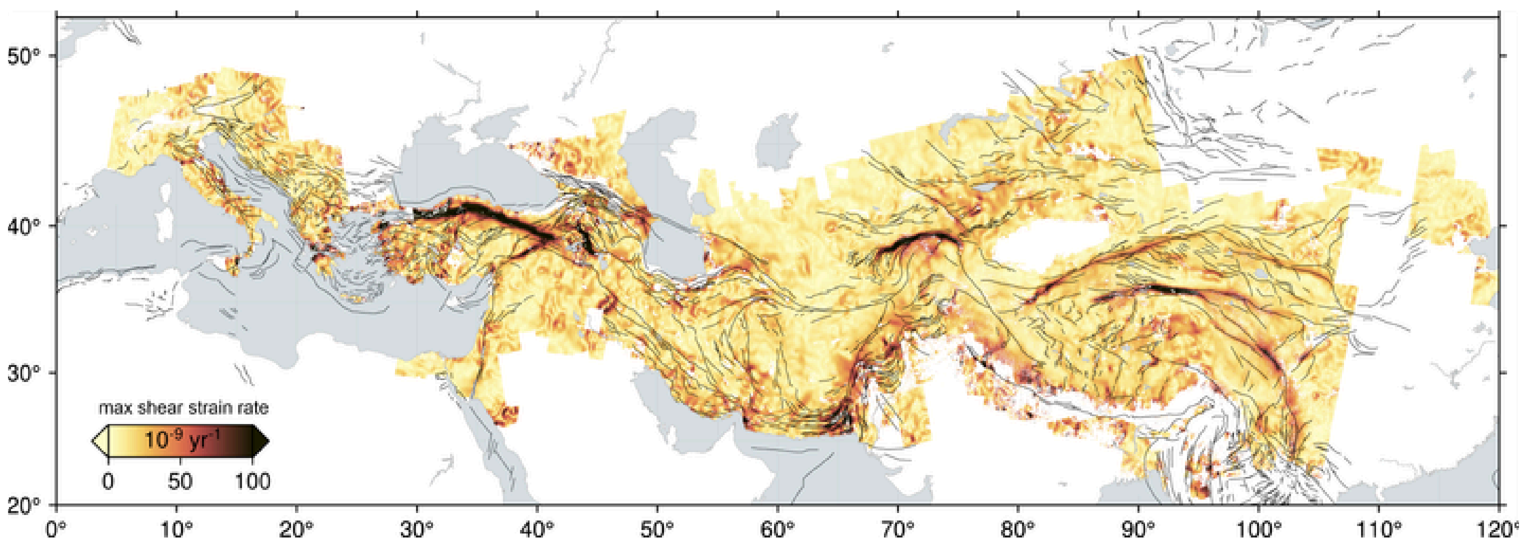
The data are openly available from the LiCS portal and the results will be made available in a repository so that these data can become of significant importance to the community in moving on the field of active tectonics, continental deformation and seismic hazard.

Figure 2 (below): Maximum shear strain rate (nstr/yr) for the Alpine Himalayan Belt determined from the Sentinel-1 and GNSS velocity field.

This has been made possible by the systematic acquisitions of the Sentinel-1A and 1B satellites and the openness of the data archive by ESA. The launch of Sentinel-1C in at the end of 2024 will allow the continuity of such measurements in future.

Our new velocity and strain rates are foundational data sets that reveal the details of how the continents deform for the first time at trans-continental scale. One hundred years after Argand (1922)'s observations and tectonic map of the deformation of Eurasia, we look forward to the community developing, testing and applying new/different algorithms to our open access data, and to the resulting improved understanding of continental tectonics and seismic hazard.

AHB Team: Elliott, J. R., J. Fang, M. Lazecky, Y. Maghsoudi, Q. Ou, J. Payne, C. Rollins, D. Wang, A. Hooper, T. J. Wright (submitted), Deformation, Strains and Velocities for the Alpine Himalayan Belt from trans-continental Sentinel-1 InSAR & GNSS, Remote Sensing of the Environment.



FORECASTING ERUPTION EVOLUTION WITH SO_2 EMISSIONS DURING THE 2021 TAJOGAITE ERUPTION IN LA PALMA, SPAIN

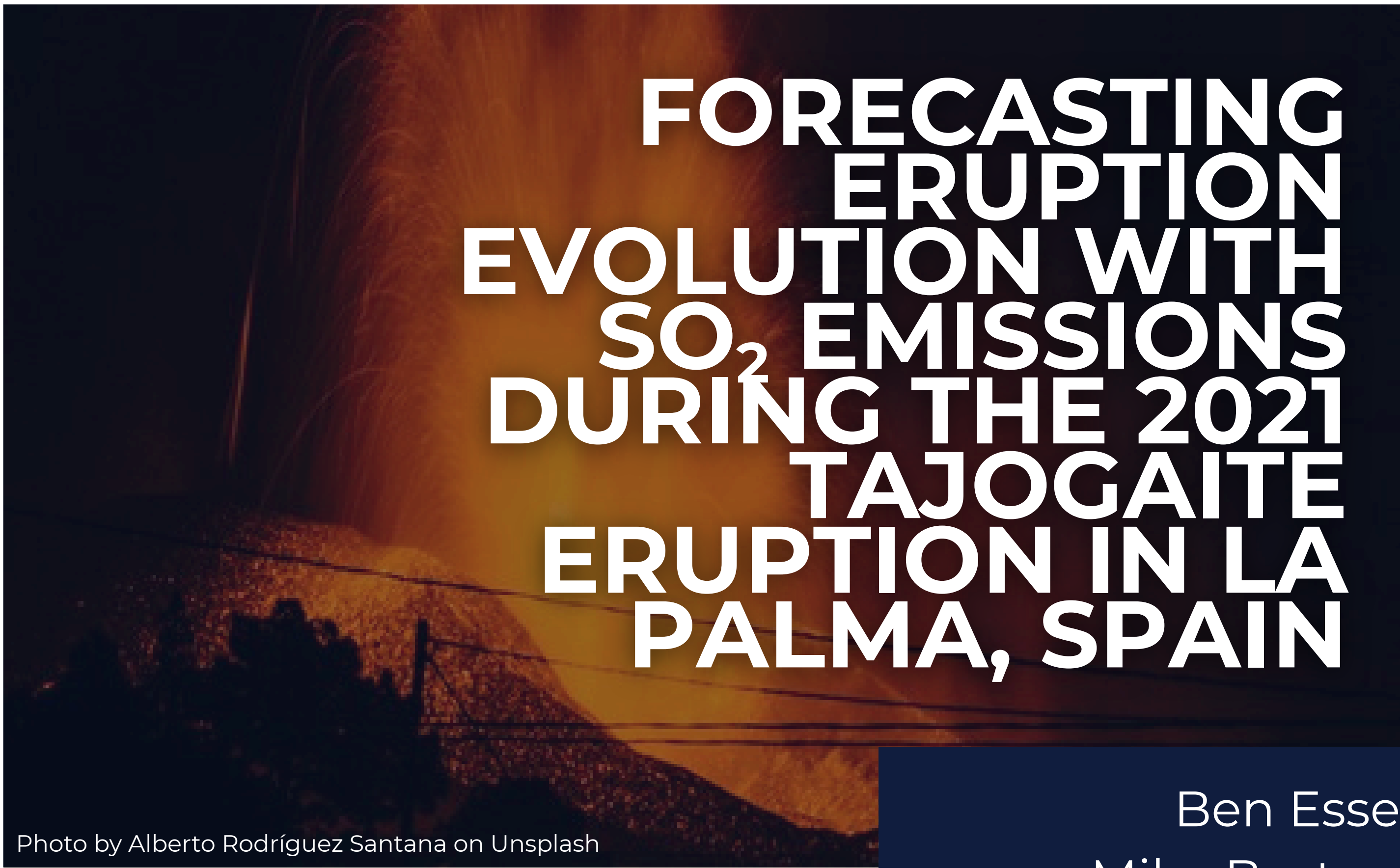


Photo by Alberto Rodríguez Santana on Unsplash

Ben Esse
Mike Burton
University of Manchester

La Palma is the most volcanically active island in the Canaries, with over half of the historical eruptions form the archipelago taking place here. The most recent eruption took place from 19th September – 13th December, generating lava flows that buried close to 3000 buildings and led to the evacuation of almost 8000 people.

Managing the response to such an eruption relies on an understanding of how it is likely to evolve and how long it will last, however this information is difficult to ascertain in real time. Several methods have been developed to address this, using decaying lava effusion rates derived from satellite-derived thermal emissions [1] or from the decay in deformation measured by GPS stations [2].

Throughout the eruption we reported the daily SO_2 emissions calculated from satellite imagery using the TROPOspheric Monitoring Instrument (TROPOMI).

This work was led by a COMET Science Staff member and COMET Scientist.

These daily images were analysed using PlumeTraj, a trajectory analysis toolkit designed to calculate sub-daily height and time resolved SO_2 emissions from daily satellite SO_2 imagery (see Fig.1 for an example of TROPOMI imagery and PlumeTraj results). These results were communicated to the Instituto Volcanológico de Canarias (INVOLCAN) and the Instituto Tecnológico y de Energías Renovables (ITER) who were responsible for monitoring the eruption.

It became apparent that the SO_2 emissions were decaying exponentially with time, which led to an estimated eruption end in December or January, which was communicated to INVOLCAN during the eruption.

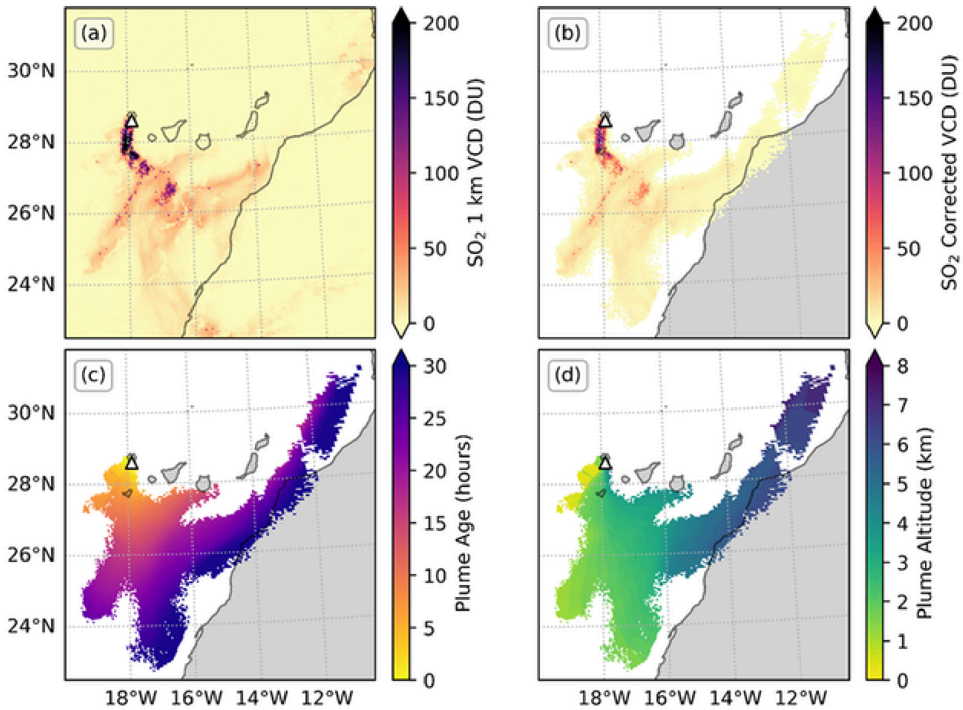


Figure 1: Example of PlumeTraj results. (a) The original 1 km VCD given in the operational TROPOMI product, (b) the altitude corrected VCD value, (c) the plume age at the time of measurement and (d) the plume altitude at the time of measurement. The location of the vent is given by the white triangle. The overpass time was approximately 14:35 (UTC) on 10 October 2021 (orbit number 20688)

Once the activity had ended, we decided to investigate how well we could have forecasted the evolution of the eruption at different times throughout the activity, and how consistent the results would have been. The full eruption results are shown in Fig. 2, showing good agreement in plume altitudes with measurements from calibrated visible cameras.

Fitting an exponentially decaying model to the cumulative emissions produced consistent decay rates from late October onwards, allowing a consistent hindcast of the eruption activity to be made.

This suggests that the eruption end is defined by the point at which the magma flow through the conduit can no longer sustain the eruption, which here was when the SO_2 emission rate dropped to 6% of the initial SO_2 emission.

Looking forward, we can apply the lessons learned here to future eruptions, with the possibility of forecasting the likely evolution, as well as the possible end date, in near real-time. This will assist eruption crisis managers and inform response plans, helping to mitigate the impacts of similar eruptions in the future. These results were published in the Bulletin of Volcanology in February 2025[3].

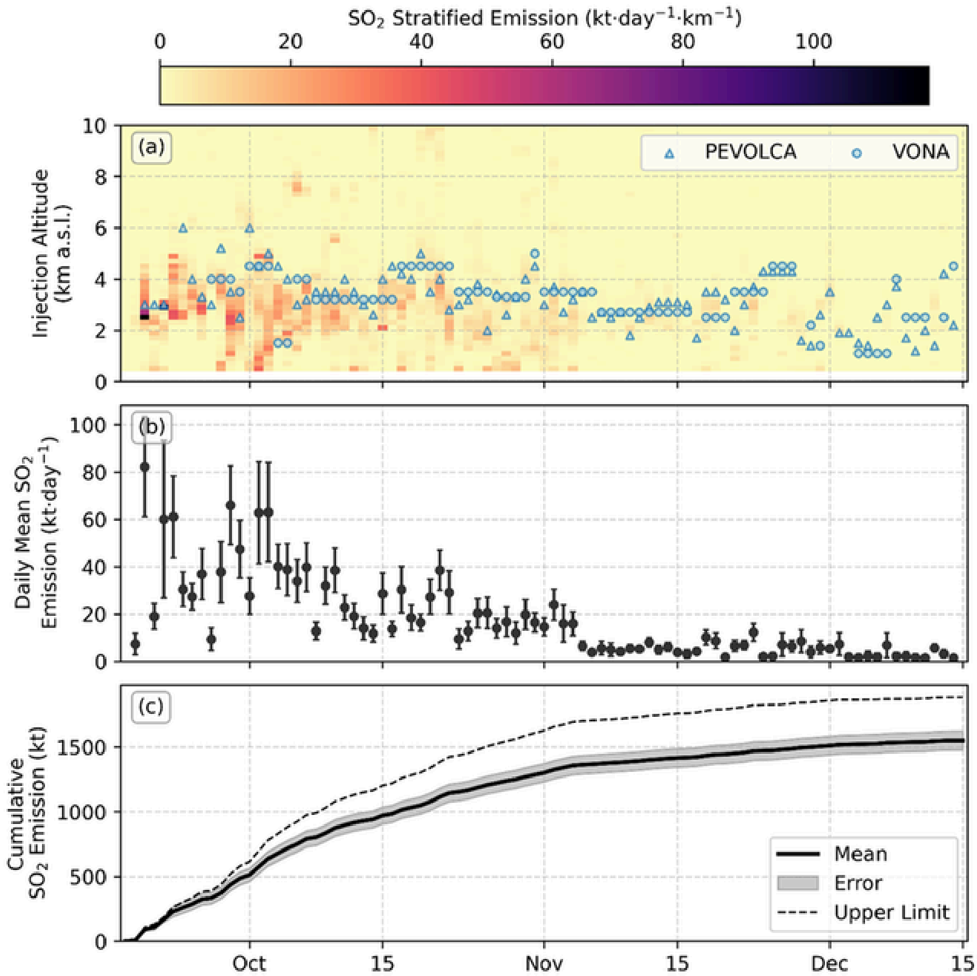


Figure 2: SO_2 emissions from the Tajogaite eruption. (a) The total daily stratified emissions as a function of altitude (colormap) with plume altitudes from the PEVOLCA and VONA (blue triangles and circles, respectively) reports for comparison (data from Bonadonna et al. (2022)), (b) the daily mean SO2 emission rates calculated by PlumeTraj and (c) the cumulative emitted SO_2 for the mean (solid line, uncertainty given by shaded region) and upper limit of daily measurements (dashed line).

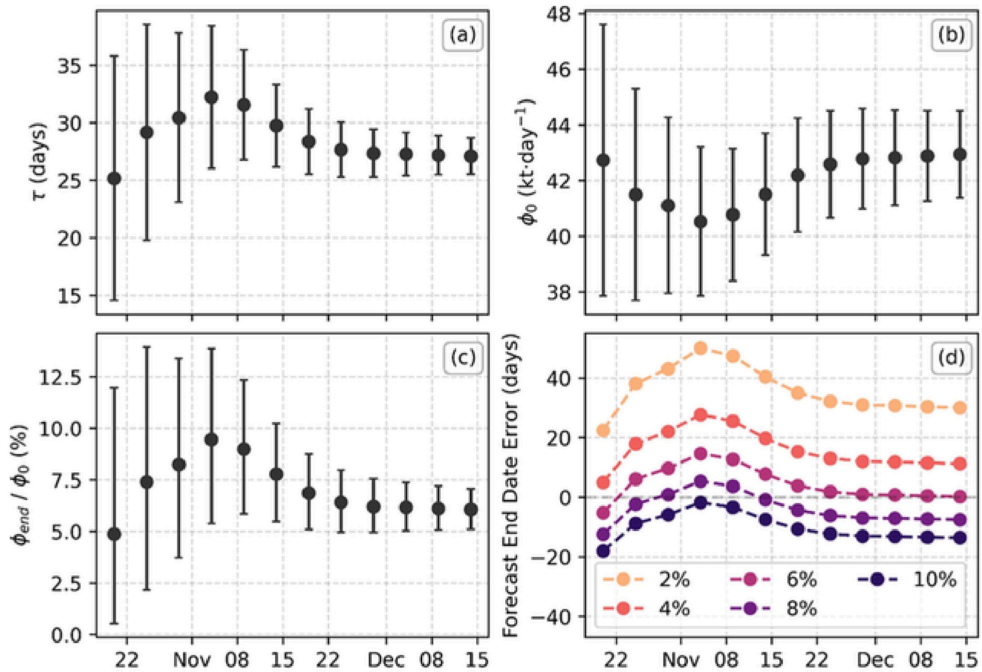
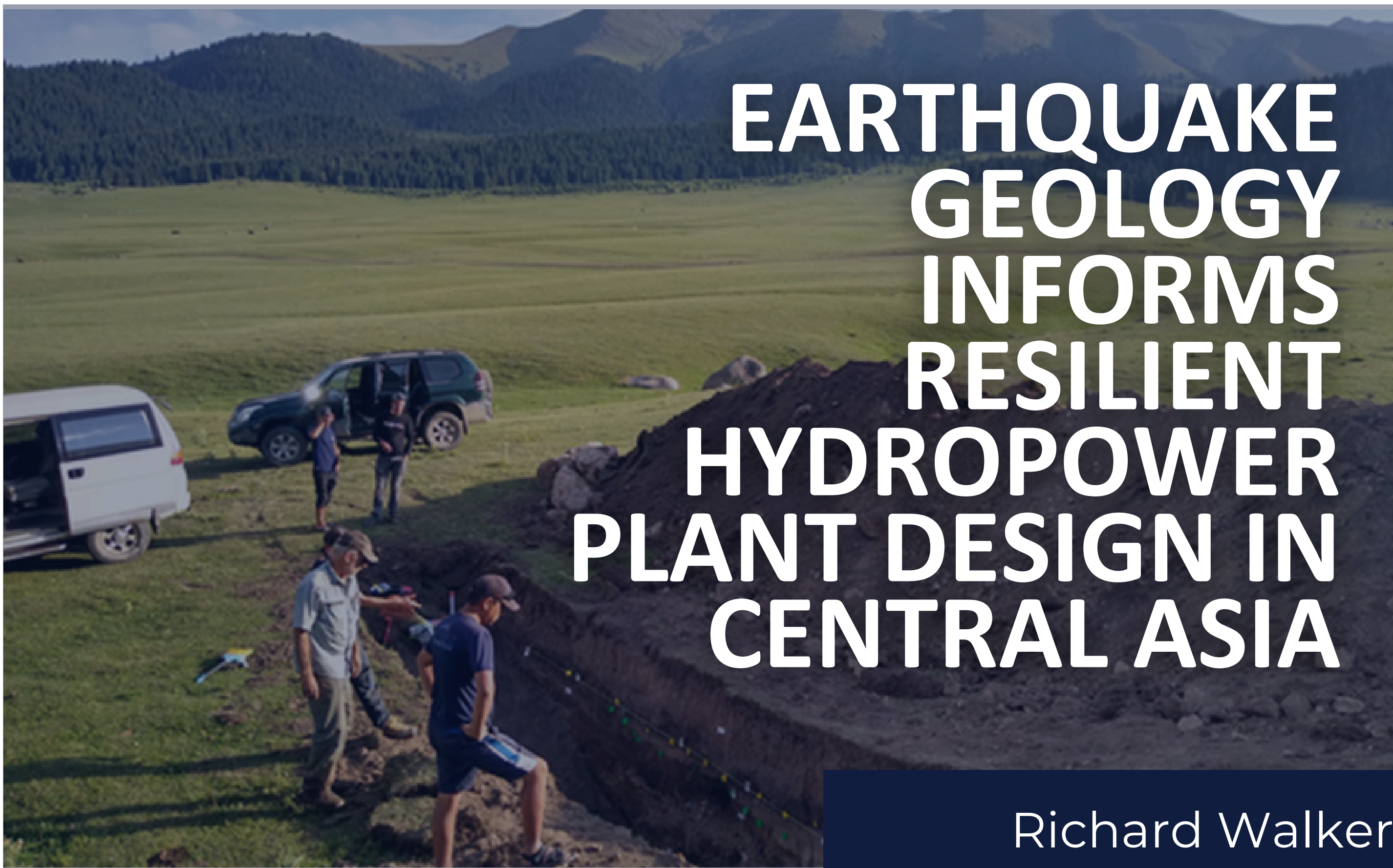


Figure 3: SO_2 emission forecast results from 20th October. (a) Fitted decay constant, τ; (b) fitted initial emission rate, φ_0; (c) the final SO_2 emission rate as a percentage of the initial emission rate, φ_0; and (d) difference in forecasted and actual eruption end dates assuming different cut-off emission thresholds.

References

1. Bonny, E. & Wright, R. Predicting the end of lava flow-forming eruptions from space. Bull Volcanol 79, 52 (2017).
2. Charco, M. et al. The 2021 La Palma (Canary Islands) Eruption Ending Forecast Through Magma Pressure Drop. Geophysical Research Letters 51, e2023GL106885 (2024).
3. Esse, B. et al. Forecasting the evolution of the 2021 Tajogaite eruption, La Palma, with TROPOMI/PlumeTraj-derived SO_2 emission rates. Bull Volcanol 87, 20 (2025).



EARTHQUAKE GEOLOGY INFORMS RESILIENT HYDROPOWER PLANT DESIGN IN CENTRAL ASIA

Richard Walker
University of Oxford

Richard Walker reports on a new project involving COMET National Capability support to aid the design of major hydropower plants in Kyrgyzstan...

This work was led by a COMET Scientist and supported by COMET staff.

EARTHQUAKE GEOLOGY AND EARTHQUAKE HAZARD

High-quality fault maps, and regular updates to them, underpin environmental impact assessment, construction policy and risk mitigation for critical infrastructure, and are required within construction policy in many parts of the world. High-quality maps require high-resolution satellite imagery and topographic data as primary basemap data, followed by detailed field-based investigation at key sites to verify observations and assess potential magnitudes of past earthquakes, and subsequent laboratory analysis of samples to determine the age of past earthquakes (giving both average intervals between events, and the time elapsed since the most recent).

As the availability of very-high-resolution elevation data has revolutionised the ability to identify and characterise active faults (e.g. Johnson et al., 2014; Zhou et al., 2015; Ren et al., 2025), the collection and dissemination of very high-resolution digital elevation datasets has become increasingly important as a basis of hazard mapping. These include national or regional coverage in areas such as New Zealand and the Western USA enabled through expensive and long-running airborne LIDAR survey (e.g. Morgenstern et. al., 2024; Prentice et al., 2009).

However, the commissioning of regional or national-scale airborne LIDAR survey remains out of reach in many earthquake-prone regions, including the central Asia region.

The lack of high-resolution digital topographic datasets leads to knowledge gaps of potential environmental and societal impacts, increasing hazard exposure and vulnerability, and provides a potential barrier to resilience and assessment of long-term sustainability.

IMPORTANCE OF UK NATIONAL CAPABILITY

Long-term National Capability support has an important role in COMET efforts to develop high-resolution digital datasets in regions where such data are not typically available, using stereo optical satellite images to extract high quality digital elevation datasets at regional scale, using UAV-derived low altitude aerial survey to produce centimetre-scale elevation products at local scale, and in building ultra-fine 3D models of trench exposures to aid paleoseismic interpretations. The range of datasets have uses both in pure scientific research and in applications towards earthquake hazard assessment. Our team at the Oxford University Department of Earth Sciences, in collaboration with colleagues from the appropriate national institutes, regularly use elevation products derived from stereo imagery to generate detailed fault maps and earthquake rupture maps in central Asia. These studies have enabled detailed mapping and site characterisation including sources of earthquakes in the instrumental, historical and prehistorical past, and provided constraint on earthquake scaling in the central Asia region, maximum magnitudes, and the potential for complex multi-fault rupture.

The National Capability aspects of this work are in the technical skills related to the production of the digital datasets, and in the expert-level interpretation of active faulting interpreted from them. These skills are combined with a commitment to the dissemination of skills within the UK, and globally within national institutes that deal with earthquake hazard.

THE KAMBARATA HYDROPOWER CASCADE

An application that is of importance to us is in the earthquake resilience of dams and reservoirs. The development of hydropower (HPP) infrastructure in central Asia is critical in achieving regional climate and economic development goals. An important series of dams along the Naryn river of Kyrgyzstan (Fig. 1) are an integral part of this wider programme. Though some, including the major Toktogul dam and reservoir, were built in the late 20th century, the programme has accelerated in recent years with new construction and planning.

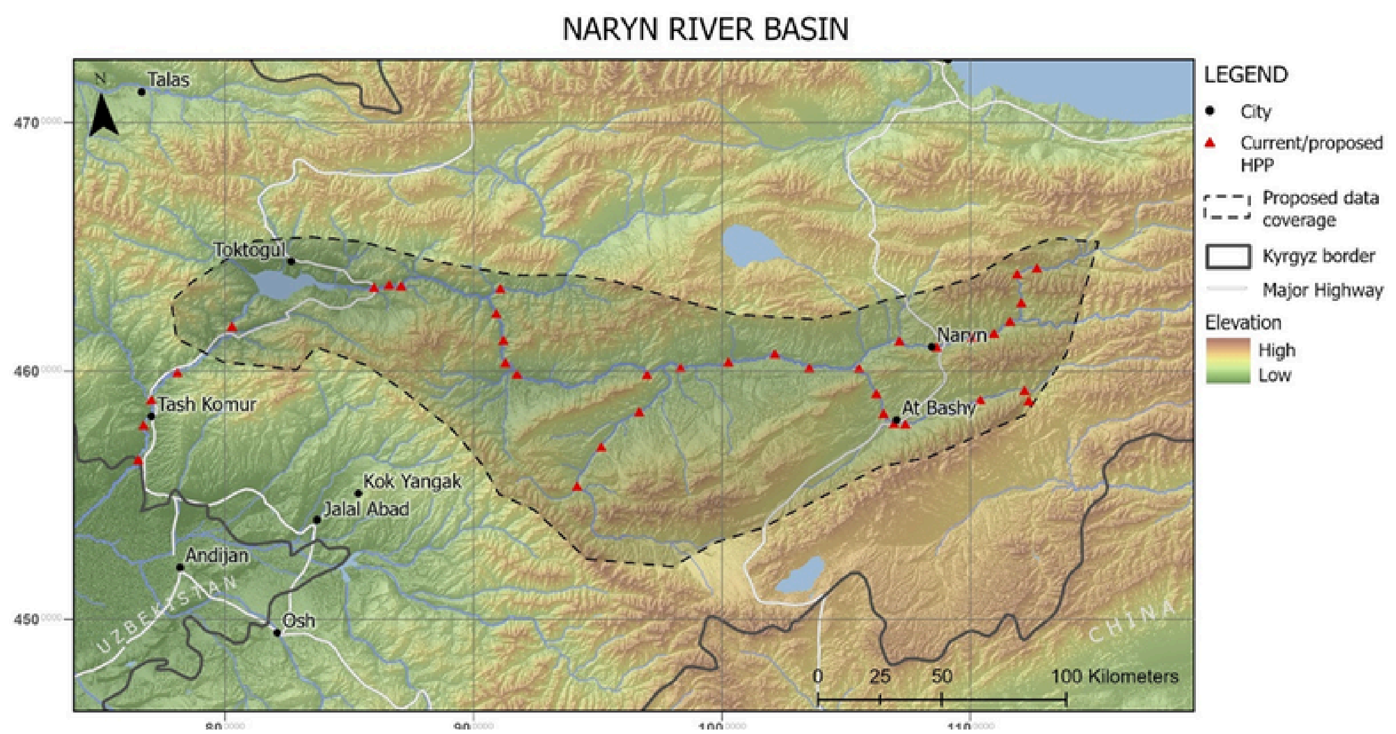
Much of the development, however, is in regions where there is uneven or incomplete knowledge of earthquake hazards. These hazards can have catastrophic effects on dam function and stability, with breaching and downstream flooding posing significant risks to provision of service, financial investment, and life safety.

Earthquakes happen on active geological faults, and dam failure can be caused by ground rupture, earthquake shaking, or through the triggering of landslides. Critically, the probabilities and intensities of these processes are controlled by proximity to the active fault on which the earthquake occurred. Maps of active faults, and knowledge of the potential size and regularity of earthquakes upon them, enable us to position and design infrastructure safely.

Through a 2024 pilot study with the Institute of Seismology, Kyrgyz National Academy of Sciences, we demonstrated the risks from a lack of underpinning active fault data. We identified a major active fault (Kambarata fault) running through the turbine hall of Kambarata-2, and within 100 m of the dam (Figs. 2 and 3).

This is a particularly striking example of both the lack of existing data to aid planning, and also the urgency in developing and disseminating such data regionally such that hazards like this one can be avoided or mitigated within the design process for future developments.

Through that pilot work, and interactions with personnel from the UK's FCDO (Foreign, Commonwealth, and Development Office) and the World Bank CAWEP (Central Asia Water and Energy Program), we fed our improved knowledge of the Kambarata active fault directly into feasibility study of the Kambarata-1 HPP, which is due to be one of the biggest dams in the world when constructed. Our work thus leads to a better informed and resilient design.



The Naryn river catchment, with existing and proposed HPP sites shown as red triangles (source: https://energy.carecprogram.org/wp-content/uploads/2023/11/Project-Construction-of-the-Upper-Naryn-HPP-Cascade.pdf) and the approximate limit of high-resolution satellite data obtained within Phase-1 (area within dashed line). Figure produced by Emma Greenough.

Prof. Kanatbek Abdrakhmatov (Director of the Institute of Seismology in Bishkek), pointing out a near-surface reverse fault at the trench site, Kambarata-2.

THE NEED FOR REGIONAL MAPPING AND CAPACITY STRENGTHENING

Following from that initial pilot study, and the demonstration of the need for improved and updated active fault maps, we have gained support through the FCDO for undertaking detailed active fault mapping and paleoseismology studies throughout the Naryn river catchment where there are either existing or planned hydropower power plants. The project will result in direct impacts in terms of reduced exposure and vulnerability, both financial and in life-safety terms, to dam failure.

A first stage in this new and ongoing project is in the acquisition of stereo satellite images across the region, from which we will produce high-quality digital elevation products. The dataset offers an exceptional opportunity to develop detailed underpinning active fault and related geohazard maps with uniform coverage across the entire region.

Together with our partners in the Institute of Seismology in Bishkek we will produce an improved map, combined with site specific information on earthquake potential of individual faults in proximity to the plants.

We will combine the mapping with efforts towards the strengthening with improved capacity within the partner institutes to regularly make/ update the maps, and to provide information on earthquake potential through field investigation. We are using the Naryn project as a demonstrator of wider need of these kind of approaches in the assessment of hazards to infrastructure sites, towns and cities regionally. We are also continuing our efforts in offering workshops and training activities, which are an important part of our activities within COMET, and which also formed a major component of a recent NATO Science for Peace and Security Programme grant (Fig. 4). Through these training efforts we contribute to the widening of access to skills within national institutes, and the development of region-wide networks of practitioners.

The assessment of earthquake hazard from geological information is a crucial part of the design and environmental impact assessment of any major development.

It also underpins detailed scenarios of earthquake shaking for cities (e.g. Amey et al., 2021 and 2023). There is a widespread need for such approaches in many parts of the world, and through National Capability support we are able to contribute to efforts that build more resilient societies. Even in the UK we are able to contribute towards resilience, with critical energy infrastructure such as nuclear power, and water management in the form of reservoirs, both requiring detailed active fault assessment.

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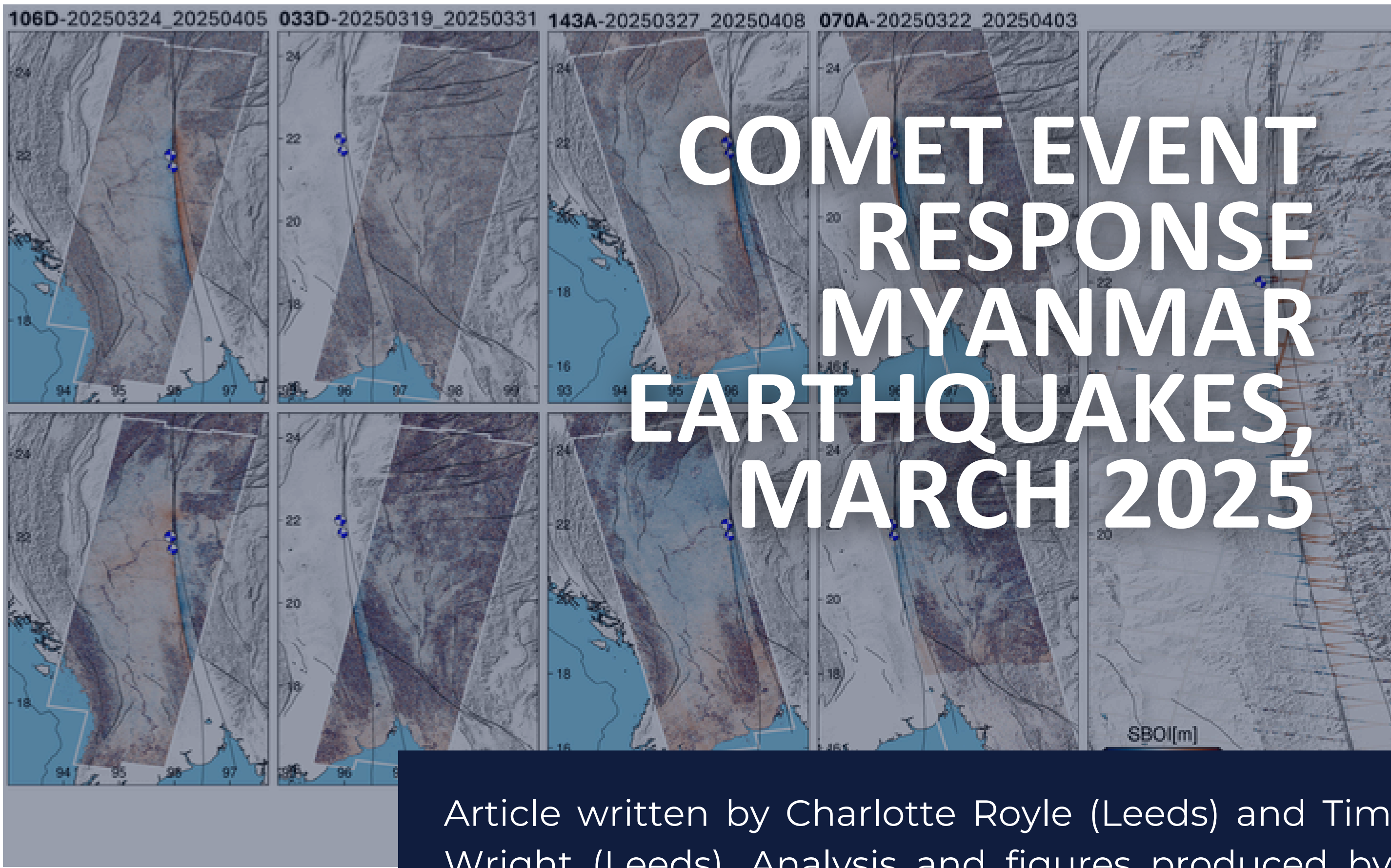
Teaching discussions at the trench. Part of our 2022 field workshop in paleoseismology, organised within the NATO SPS programme on environmental security from earthquakes in the Tien Shan.

Acknowledgements

The work described here has been supported through COMET, together with the Leverhulme Trust, the NATO SPS Programme, and UKRI through NERC and EPSRC. The current project is funded through the FCDO and COMET. We thank all those involved in the 2024 fieldwork and later follow-up, including Neill Marshall (COMET staff scientist until January 2025, now employed at the Royal Observatory of Belgium), Emma Greenough (D.Phil student in Oxford, part funded through WTW), Kanatbek Abdrakhmatov (Director, Institute of Seismology), Erkin Rahmedinov (researcher, Institute of Seismology), Aidyn Mukambayev (Acting Deputy Director, KNDC, Kazakhstan), Charles Morris (Economic Develpment Councillor, UK Embassy, Bishkek). We also thank the FCDO staff and World Bank CAWEP team for their interaction and support.

COMET EVENT RESPONSE MYANMAR EARTHQUAKES, MARCH 2025



Article written by Charlotte Royle (Leeds) and Tim Wright (Leeds). Analysis and figures produced by COMET Science Staff Member Milan Lazecky and PhD student Muhammet Nergizci.

On 28th March 2025, a 7.7-magnitude earthquake struck Myanmar, affecting large areas of the country and causing widespread destruction.

A powerful 6.4-magnitude aftershock followed 12 minutes later, approximately 31 kilometres south of the initial shaking. The country, and surrounding areas, were also subjected to hundreds of smaller aftershocks for weeks after the initial event. Myanmar's military government have estimated that the death toll has surpassed 3,000 people and an additional 4,500 have suffered injuries. The shallow depth of the earthquake (~10km) caused violent ground shaking and extensive damage to local buildings and infrastructure.

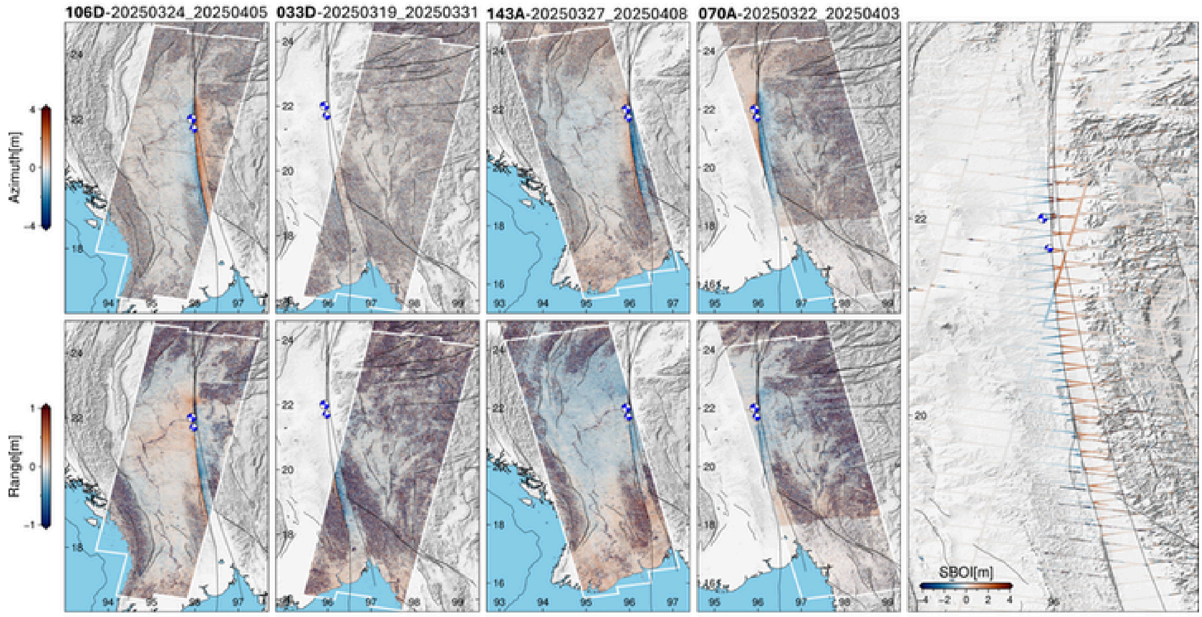
This work was led by COMET Scientists, supported by COMET staff, and uses COMET data.

Data from ESA's Sentinel-1 satellite first captured on 29th March clearly show the physical effects of the earthquake on the region. The earthquake ruptured a remarkably long and simple fault, around 500 km in total length, with a relative motion across the fault of up to around 6 m (west side to the north, east side to the south). Although most of the motion is horizontal, there is also a vertical offset of around 1 m across the fault (east side down).

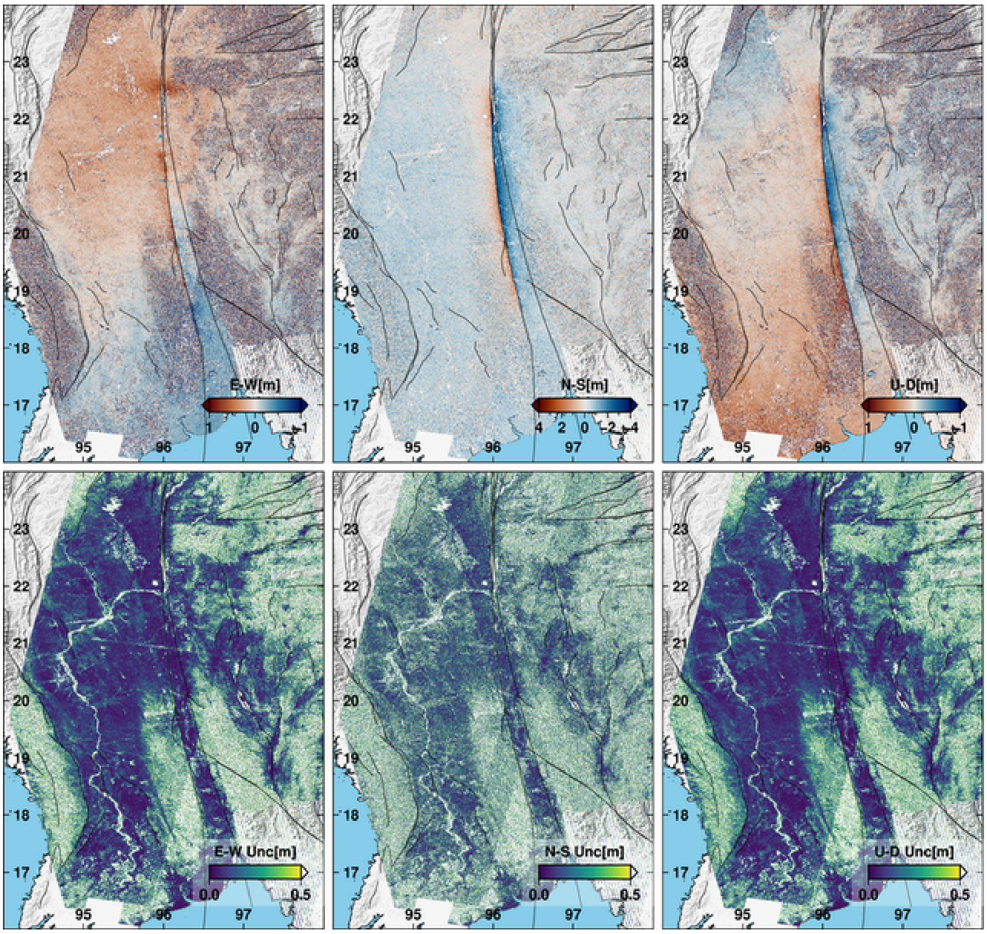
One of Myanmar's largest cities, Mandalay, sits close to this extensive ground movement (at around 22°N), explaining the significant human and structural impact of the event.

COMET HIGHLIGHT

By combining Sentinel-1 imagery from before and after the earthquake, COMET scientists have been able to measure surface deformation that is clearly visible in the data sets shown below:



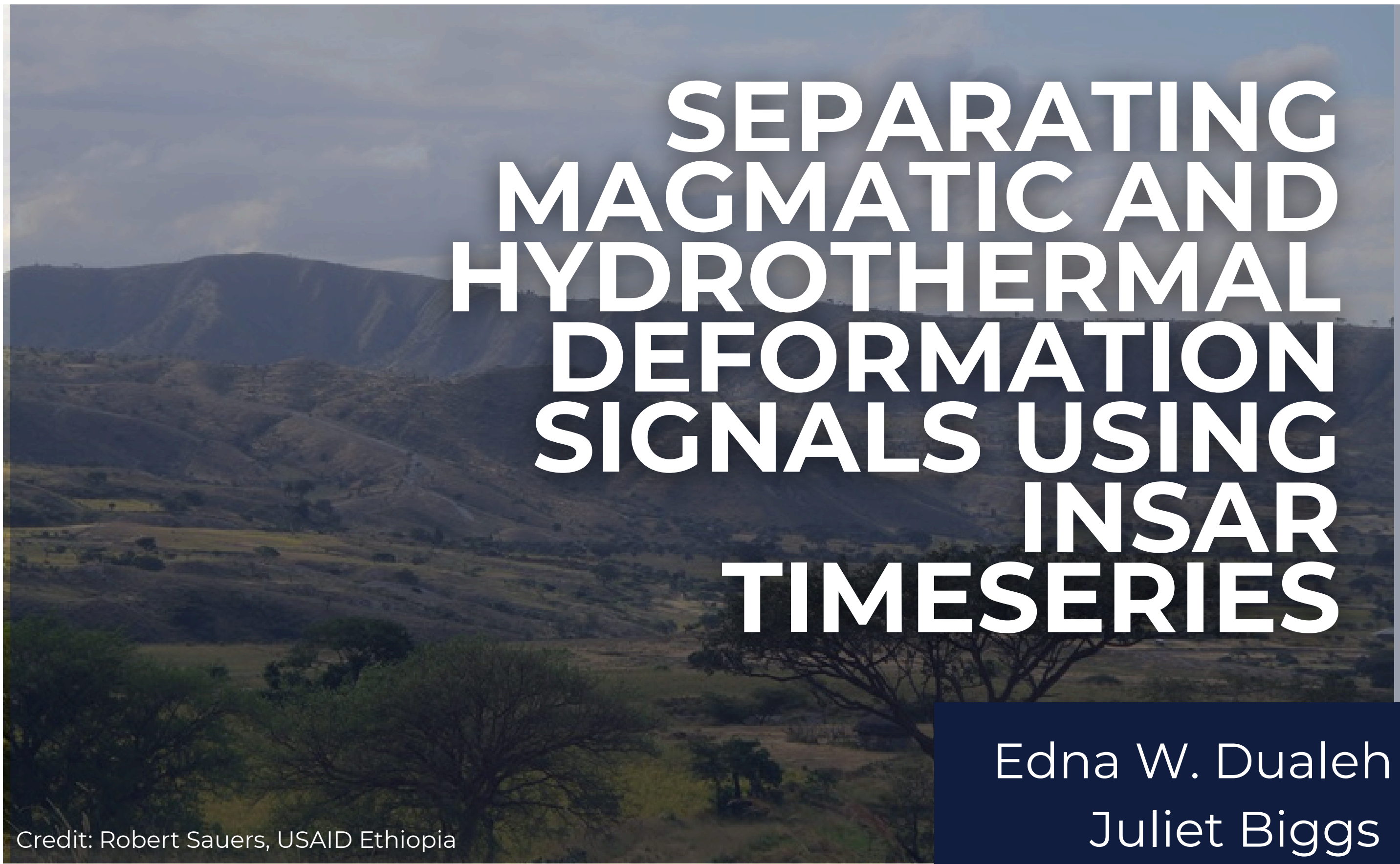
Data from four Sentinel-1 tracks (2 ascending and 2 descending), each consisting of three standard LiCSAR frames (~13 bursts per subswath), were used to cover the deformation zone. Azimuth offsets (top panels) capture along-track (north–south) deformation. Range offsets (bottom panels) represent Line-of-Sight (LoS) deformation. Burst Overlap Interferometry (right) provide high-resolution along-track deformation. Red indicates southward, and blue indicates northward motion.



3D co-seismic displacement fields and associated uncertainties were estimated using a Weighted Least Squares approach applied to the offset tracking datasets. Red colors represent east, north, and up directions, respectively. Only pixels with sufficient multi-geometry observations were used

The images above contain modified Copernicus Sentinel-1 data analysed by COMET. Data processing uses JASMIN, the UK's collaborative data analysis environment (http://jasmin.ac.uk).

SEPARATING MAGMATIC AND HYDROTHERMAL DEFORMATION SIGNALS USING INSAR TIMESERIES



Credit: Robert Sauers, USAID Ethiopia

Edna W. Dualeh
Juliet Biggs
University of Bristol

Led by a COMET Science Staff member, supported by a COMET Scientist, and uses COMET services.

Distinguishing whether volcanic unrest is driven by magmatic sources, hydrothermal processes or a combination of both is critical for hazard assessment and remains debated at many calderas worldwide (e.g., Campi Flegrei, Yellowstone, Long Valley).

Deformation signals observed at volcanoes often reflect a mix of sources: magmatic (e.g. magma moving), non-magmatic (e.g., hydrothermal or structural processes) and non-volcanic (e.g., instrument noise or atmospheric delay). Recent advances in machine learning and satellite data, particularly from ESA's Sentinel-1 mission, has enabled more detailed analysis of the spatial and temporal patterns in the deformation signals.

We applied spatial Independent Component Analysis (sICA) using COMET's LiCSAlert package to separate magmatic and hydrothermal contributions based on their spatial characteristics.

We focused our analysis on Corbetti Caldera, Ethiopia, an actively deforming caldera in the central Main Ethiopian Rift that has been steadily uplifting (~4.5-5.5 cm yr-1) since 2009. Corbetti Caldera has a known laterally bound hydrothermal system cross cutting the caldera with previously observed deformation signals.

The Sentinel-1 timeseries over Corbetti Caldera shows a relatively steady uplift signal from 2014-2022 consistent with previous studies (e.g., Albino et al., 2021; Lloyd et al., 2018). Using the ICASAR algorithm within LiCSAlert, we identified two spatially distinct components (Fig 1): one that correlates with a shallow magmatic source (IC1) and another with the laterally bound hydrothermal system (IC2). Although the overall InSAR signal can be fitted with a single point source, we found that the extracted ICs can be modelled equally well using two separate models.

We demonstrate how without ICA it would be unlikely that this second source would be considered when modelling the deformation data.

The approach demonstrated assumes that the processes have distinct spatial patterns. We applied it at three continuously deforming calderas: Campi Flegrei (Italy), Aluto (Ethiopia) and Laguna del Maule (Chile), where the unrest has previously been attributed to either the magmatic system or hydrothermal system, or a combination of both.

While sICA was not successful in discriminating between potentially overlapping processes at Campi Flegrei or Laguna del Maule, it did separate a localised subsidence signal near geothermal wells at Aluto from a broader deformation signal potentially linked to the hydrothermal or magmatic system.

Our results show that while blind signal separation methods, such as ICA, can help to identify overlapping deformation sources, the individual contributions are not always possible to completely separate spatially or temporally.

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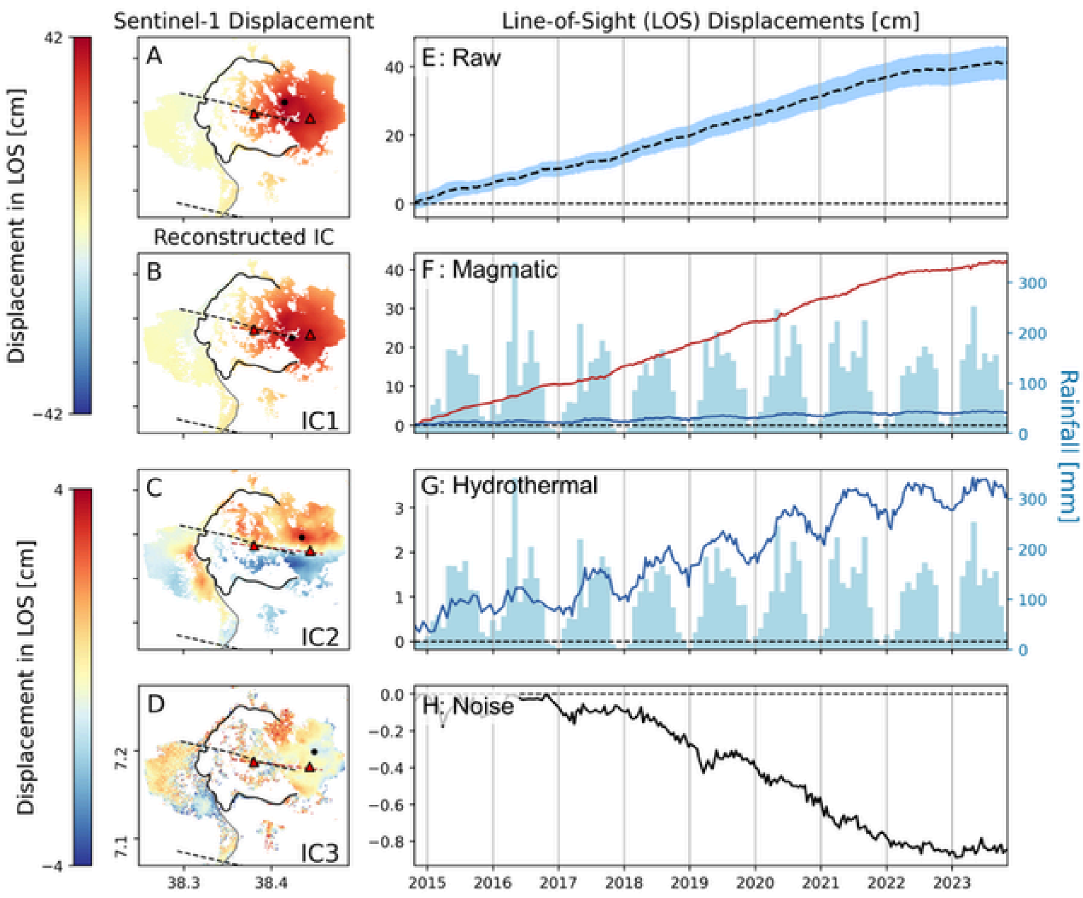
Top row shows the Sentinel-1 era (2014–2023) spatial (a) and maximum line-of-sight timeseries (e) of ground displacement for Corbetti Caldera. Errors (blue area) is one standard deviation for all possible reference points for pixel shown in (a). Subsequent rows show the individual reconstructed Independent Components (ICs) (b–d) spatial patterns and (f–h) maximum LOS displacement with respect to the local rainfall data (Harris et al., 2020). Black circles indicate location of timeseries.

Figure and caption from Dualeh et al., 2025.



FROM DEEP TIME TO REAL-TIME: DECODING VOLCANO DEFORMATION STYLES THROUGH NUMERICAL MODELLING OF MAGMA SYSTEM EVOLUTION

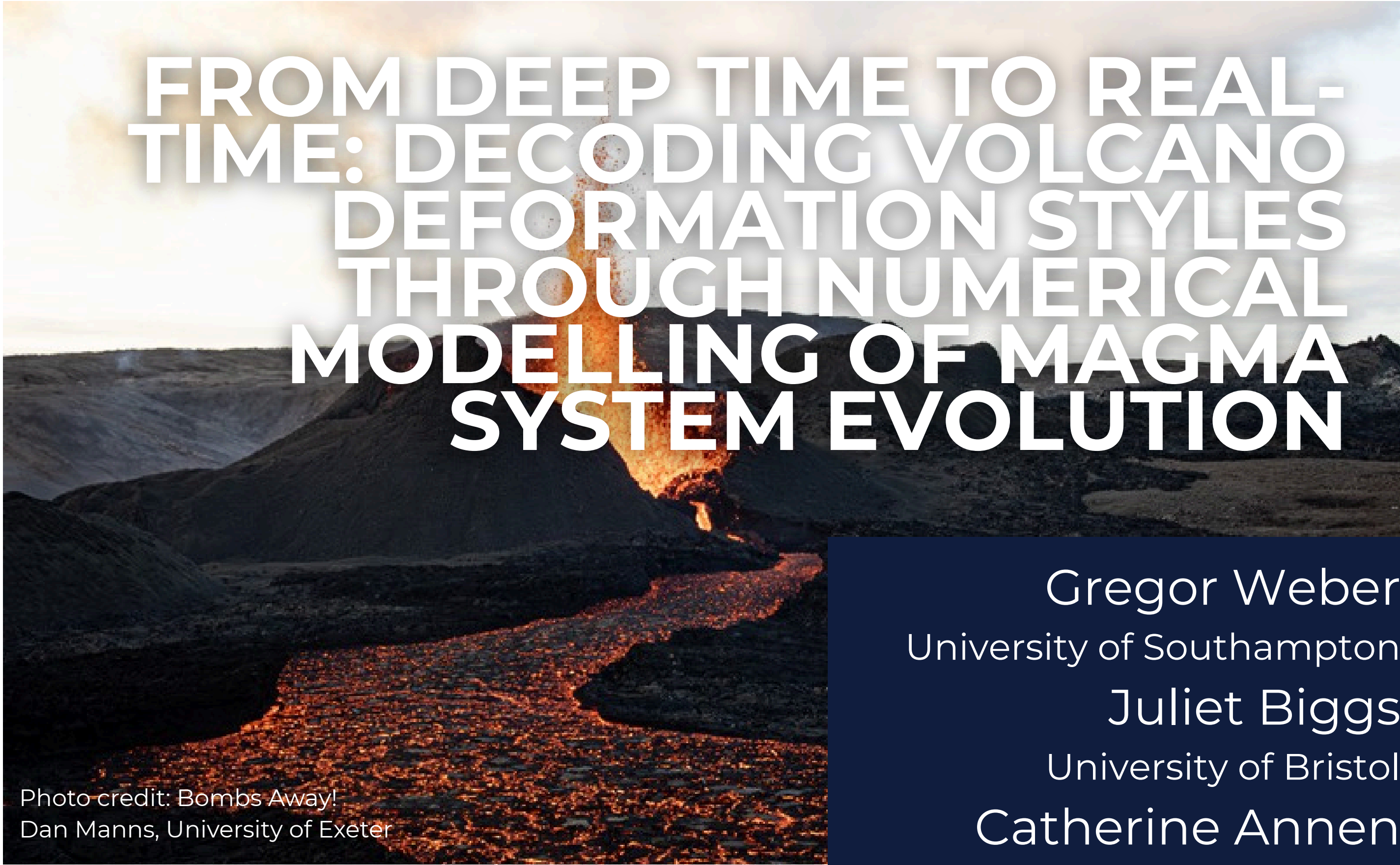


Photo credit: Bombs Away!
Dan Manns, University of Exeter

Gregor Weber
University of Southampton
Juliet Biggs
University of Bristol
Catherine Annen
Czech Academy of Sciences

This work was led by a COMET Postdoctoral Researcher and supported and contributed to by a COMET Scientist.

Volcanic ground deformation can provide critical insight into the subsurface dynamics of magmatic systems and aid eruption forecasting. While commonly attributed to short-term magma movement on the order of days to decades[1], deformation signals are also shaped by the long-term rheological evolution of the crust over geological timescales (10^5–10^6 years)[2,3]. This coupling has received limited attention in the past. Our recent study bridges this timescale gap, integrating models of the long-term thermal evolution with short-term viscoelastic deformation to explore how sustained magma flux and system longevity control surface responses relevant for volcano monitoring[4].

Using a numerical approach, we simulated the progressive thermal evolution of the crust over a million years, driven by repeated sill and dike intrusions at various long-term magma flux rates.

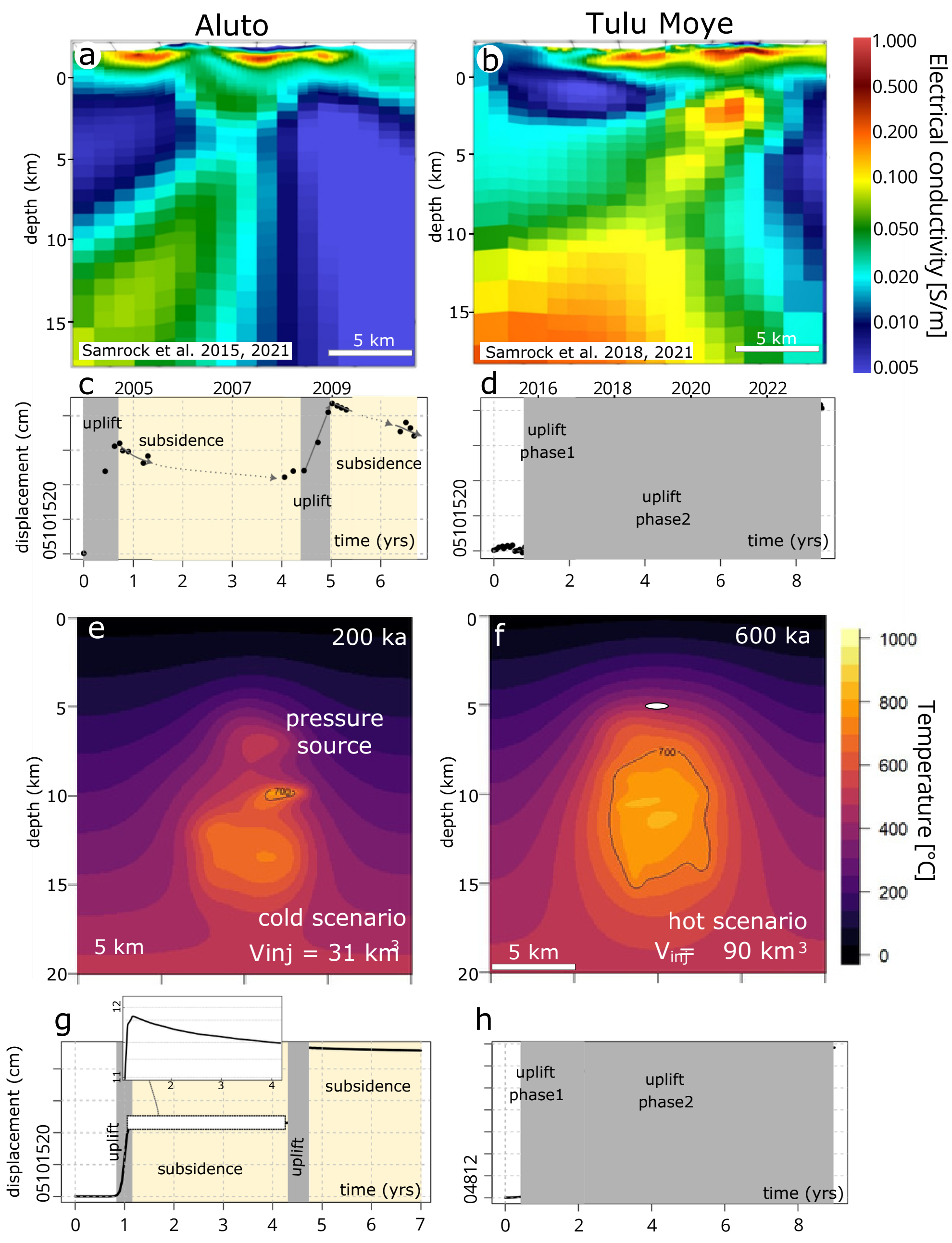
The thermal results at different evolutionary stages of magmatic systems were then implemented in time-dependent viscoelastic deformation simulations over a 10-year observational window. This allowed us to track surface deformation patterns as a function of magmatic system lifespan and long-term magma input rate.

The results show a clear distinction in ground deformation behaviour between hot and cold magmatic systems.

Cold systems - those built with low long-term magma flux or in earlier evolutionary stages - tend to display subsidence following magma input. In contrast, hot systems that have experienced higher long-term magma flux or longer-lived magmatic activity consistently produce monotonic uplift. These patterns arise from differences in the vertical thermal gradient around the pressure source.

COMET HIGHLIGHT

a, b Magnetotelluric imaging of Aluto[7,8] and Tulu Moye volcano[7,9], highlighting higher electrical conductivity (S/m) in warmer colours. Higher electrical conductivities have been modelled as indicative of increased temperature and melt fraction[7]. Reprinted from Samrock, F. et al. (2021). EPSL, 559, 116765. Copyright © 2024, with permission from Elsevier. c, d Surface displacement observations, revealing uplift (dark shading) and subsidence (bright shading) cycles at Aluto[5,6], and monotonous but variable slope uplift at Tulu Moye (COMET Volcano Deformation Web Portal: (b) Sentinel-1 descending LiCSBAS timeseries from 2014-2024, showing deformation associated with the 2015 dyke and an increase in uplift rate from ~2019 at Fentale (modified from COMET Event Response Report 1.2, 22 Oct 2024).)



e, f Temperature fields post 200 ka and 800 ka of magma injection, respectively, displaying peak temperatures consistent with temperature reconstructions based on magnetotelluric data. White ellipsoid denotes the 5 km depth overpressure source. g Surface deformation simulation for 'cold' scenario e modelled with two consecutive pulses of overpressure, resulting uplift-subsidence cycles. The inset provides a close-up view of a subsidence episode. h Displacement time-series for 'hot' scenario f, modelled as a single overpressure pulse, showing an initially steep phases of uplift, followed by uplift with gentler slope.

In colder systems, where temperatures are higher beneath the source, viscoelastic creep is directed downward, causing surface subsidence. In hotter systems, elevated temperatures both above and below the source result in balanced viscoelastic relaxation and net uplift. Crucially, it is the contrast in crustal relaxation timescales across the source, not the absolute temperature, that dictates whether subsidence or uplift will occur.

These predictions align closely with real-world observations from the Aluto and Tulu Moye caldera systems in the East African Rift. Despite their proximity and geological similarities, the two volcanoes exhibit markedly different deformation behaviour. Aluto, underlain by cooler crustal conditions, has shown cycles of uplift followed by subsidence. Tulu Moye, with higher ambient temperatures in the crust, has exhibited persistent uplift. These contrasting patterns match the modelled thermal states and deformation outcomes (Fig. 1), illustrating how surface deformation time series can reflect deeper thermo-mechanical structures.

Importantly, the study highlights an important role of non-static crustal rheology in volcano deformation modelling.

Even shallow reservoirs (~5 km depth), often modelled as purely elastic, can display significant viscoelastic behaviour depending on the evolving thermal structure. Misinterpreting these effects could lead to errors in estimating magma movements, source depth, or volumes - parameters that are critical for hazard assessments.

Beyond improving modelling capabilities, the study shows that deformation patterns themselves can serve as diagnostic tools for subsurface conditions. Persistent uplift may signal a hot, mature system, while alternating uplift and subsidence could indicate a younger, colder reservoir. When combined with independent constraints from geochronology, petrology, and geophysical imaging, these signals can offer first-order estimates of magma flux and system architecture.

This work sets the stage for a more integrated approach to interpreting volcanic unrest. By linking deep-time magmatic evolution with modern geodetic observations, the study provides a framework for understanding how the growth and transformation of volcanic systems influence short-term deformation signals. This perspective enhances our fundamental understanding of magmatic systems as evolving, thermally dynamic features of the Earth's crust.

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Photo by Tânia Mousinho on Unsplash

TRACKING IN (NEAR) REAL-TIME A VOLCANIC CRISIS IN THE AEGEAN SEA

Margarita Segou
Brian Baptie, Rajat Choudhary,
Wayne Shelley, Foteini Dervisi
British Geological Survey

This work was led by COMET Scientists at BGS.

The revolution of Machine-Learning (ML) is now poised to help seismologists accumulate high-resolution datasets and explore hidden connections between earthquakes faster and more efficiently than ever before. The latter is especially critical during evolving seismic disasters since it can deliver excellent scientific outcomes in emergency response time frames transforming decision-making and mitigation efforts.

BGS scientists led by Dr. Margarita Segou and including seismologists, Brian Baptie and PhD student Foteini Dervisi, and data scientists, Rajat Choudhary and Wayne Shelley, tracked seismicity from the evolving crisis around Santorini in the Aegean volcanic chain in February 2025, in near-real time using deep-learning algorithms and cloud environment computational capabilities. Here, we summarize our efforts focusing on the accelerating pace of high-resolution, high-accuracy science that ML now supports.

We analysed continuous data recorded by stations within 100 km from Santorini using the ML-based workflow, QuakeFlow (Zhu et al., 2023) to develop a near real-time high-resolution earthquake catalogue. Data from the regional node of the European Integrated Data Archive hosted by the National Observatory of Athens (NOA) were downloaded and processed daily, providing updated catalogues of activity.

We benchmarked the results against the NOA catalogue, which was updated in near real-time. For the period between February, 1st and March, 3rd, we obtained 1,630,883 P and S-wave phases from 24 seismic stations, that led to the detection of 48,056 earthquakes ranging between local magnitudes -1 to 5.3. For comparison, the standard catalogue contains 4623 events.

The results clearly show the spatial evolution of seismicity between Santorini and Amorgos islands around the islet of Anydros with the majority of focal depths between 5-12 km. This is a known extensional province within the Aegean volcanic arc.

The ML catalogue also allowed us to estimate hourly seismicity rates that allow us to track the level of activity in near real-time. The strong temporal variation of hourly seismicity rates from February 2nd onwards shows that the seismicity occurs in intense swarms that is typical of the magma migration, or circulation of hydrothermal fluids.

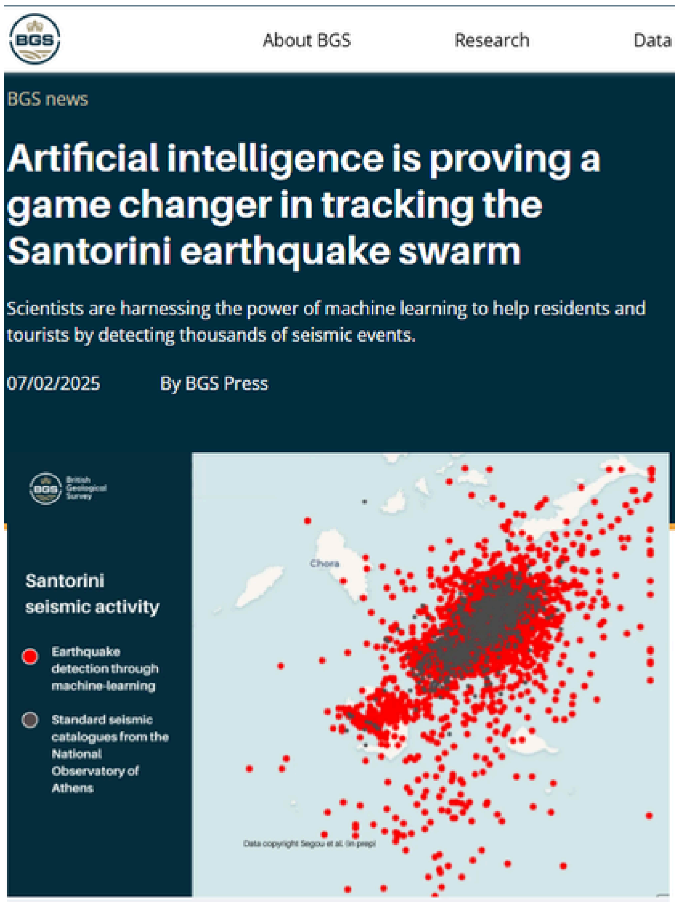
The seismicity begins to decay from February 10th with the exception of an intense swarm on late February 14th between 18:00-21:00 UTC. The intense nature of this swarm and reports of volcanic tremor caused concern among scientists and in social media. However, our ML-based detection clarified that the phenomenon was in fact a prolonged microseismic swarm of very small to small magnitude events highly clustered in time and in space, located at the southwest tip of the lateral seismicity propagation path within the Anydros tectonic horst.

The importance of seismicity rates from data-rich ML catalogues in monitoring the evolving seismic crises is evident since the above observations were made within hours and can be produced in real-time, if waveform data are only available. It is important to state that ML offers a seamless workflow to develop earthquake catalogues, estimate fault characteristics in the form of moment tensors, relocated epicenters of seismic activity to image active faults and, enhanced offline products that otherwise would take months to accumulate.

While the daily tracking of the evolving crisis gained the interest of the international community, we also processed data from the months before the crisis started. he results showed clearly that elevated levels of activity started at least two months before. Our ML workflow found 1530 previously undetected events whereas routine processing found only 164 events.

In terms of disaster mitigation and scientific response preparation, the advance notice gained by the advanced processing scheme could have been an important one.

The technological trajectory of ML algorithms in Seismology has not only improved our observational capabilities but has fundamentally altered the timeframes within which scientific insights can be derived and communicated. Where once the scientific community operated on timescales of weeks or months to process, analyse, and publish findings on complex earthquake sequences or volcanic unrests, today's infrastructure enables analysis within hours or even minutes. Certainly, new challenges arise (Beroza et al., 2021), such as data availability and the digital divide in global scale for advanced monitoring capabilities, but solid earth scientists are poised to explore at least these questions.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Artificial intelligence is proving a game changer in tracking the Santorini earthquake swarm

Scientists are harnessing the power of machine learning to help residents and tourists by detecting thousands of seismic events.

07/02/2025 By BGS Press

COMET EVENT RESPONSE FENTALE, ETHIOPIA MAGMA INTRUSIONS 2024-2025

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IPGP

This work was led by COMET Scientists, supported by COMET staff, and uses COMET data and services.

Seismic activity near Fentale volcano in the Main Ethiopian Rift started in late September 2024 and a M4.9 earthquake on 27 September was felt as far away as Addis Ababa (120 km).

As ongoing civil unrest meant limited ground access to the region, COMET was contacted by colleagues from Addis Ababa University to assist in analysing satellite data to help with the response. COMET responded by providing satellite observations of ground deformation and surface changes, preliminary interpretations and models.

Over the next 7 months (September 2024 to March 2025), a sequence of magmatic dike intrusions occurred within the Fentale-Dofen magmatic segment, accompanied by subsidence at Fentale and activity within the caldera of Fentale Volcano. The largest of these intrusions was ~40 km in length that opened by up to ~10 m with a total volume of ~1 km3 and lasted 60 days (17 Dec 2024 – 15 Feb 2025). The proximity of nearby towns, villages and the Ethiopia-Djibouti road and railway connections to the site of magma intrusion generated concern in the face of increasing activity. Due to damage to infrastructure, opening of surface fissures and the possibility of an eruption, ~75,000 people were evacuated as of 23 January (OCHA, 2025).

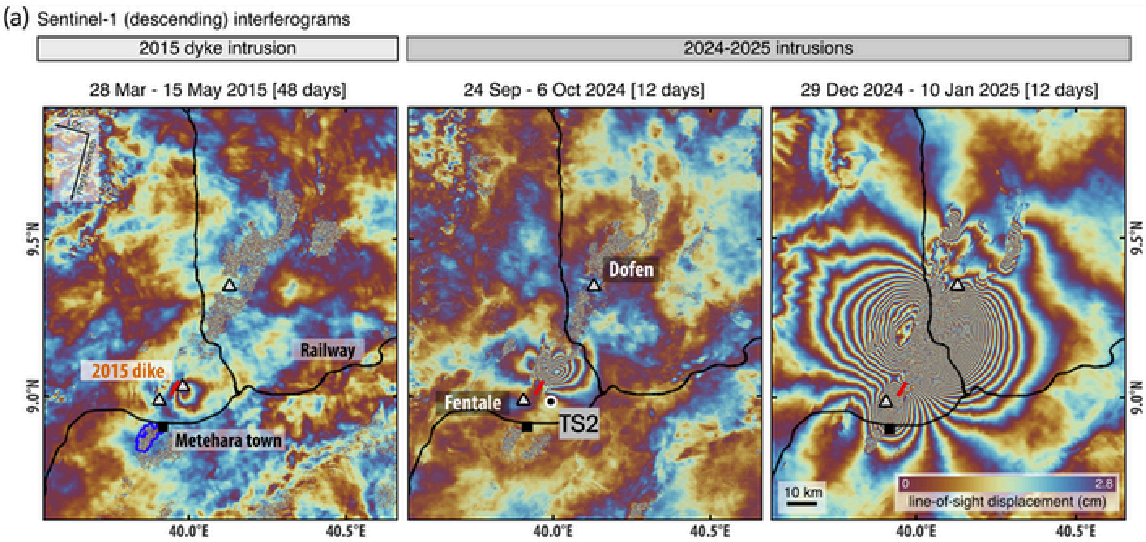
IMPORTANCE OF UK NATIONAL CAPABILITY

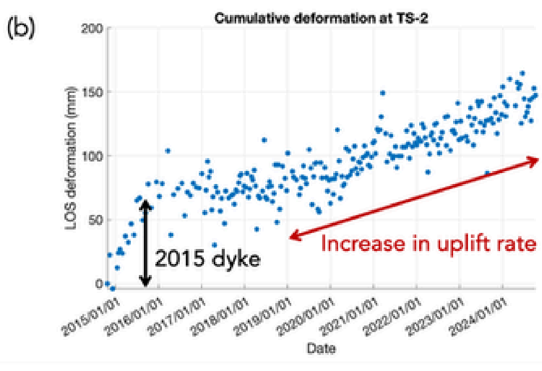
COMET's response was underpinned by our national capability datasets and services, and long-term partnerships. The LiCSAR automated processing system provided near real-time access to Sentinel-1 descending interferograms (Lazecký et al., 2020) which showed the seismicity was associated with magma propagation along a dike. Analysis of archive Sentinel-1 data using LiCSBAS time-series (Morishita et al., 2020) on the COMET Volcanic and Magmatic Deformation Portal (Watson et al., 2023) revealed that there was gradual uplift at Fentale since ~2017-2019 before the ongoing crisis. Through COMET's partnership with the CEOS GVEWERS programme, we were also able to task COSMO-SkyMed (CSK) satellites, providing observations to stakeholders at high temporal and spatial resolutions and we worked with ESA to restart ascending pass acquisitions with Sentinel-1A.

A high-resolution Pleiades DEM obtained through our partners at IPGP through the CIEST2 initiative (CNES-FormaTerre) enabled us to image deformation within the caldera, including a 30 m collapse.

The National Capability aspects of this work are in the technical skills related to the production of the digital datasets, and in the expert-level interpretation of active faulting interpreted from them. These skills are combined with a commitment to the dissemination of skills within the UK, and globally within national institutes that deal with earthquake hazard.

(a) Sentinel-1 descending LiCSAR interferograms showing the spatial extent and displacement for the 2015, September-October 2024 and December 2025-March 2025 dike intrusions. Surface trace of the modelled 2015 dike is indicated by the red line (Tessema et al., 2020).





(b) Sentinel-1 descending LiCSBAS timeseries from 2014-2024, showing deformation associated with the 2015 dyke and an increase in uplift rate from ~2019 at Fentale (modified from COMET Event Response Report 1.2, 22 Oct 2024).

Throughout the crisis, COMET's real-time analysis of the satellite data was shared with our partners at Addis Ababa University and used by a scientific committee comprising scientists from Addis Ababa University (IGSSA and School of Earth Science), the Geological Institute of Ethiopia and other relevant institutions in monitoring the events and keeping the Ethiopian Disaster Risk Management Commission (EDRMC) and the public continuously informed. COMET also published a series of Event Response Reports through the COMET website to support situational awareness and decision making by relevant stakeholders. These reports supported BGS' International Natural Hazards Forward Look (INHFL) reports and volcano advisory assessments for the UK's FCDO. This is an example of where satellite observations played a critical role in informing and supporting crisis response efforts.


Mount Fentale, Ethiopia Credit: Ninara31 https://www.flickr.com/photos/150102727@N06/

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DISASTER READY! SERIOUS GAMES FOR DRR EDUCATION IN NEPAL

Laura Wainman
University of Leeds

This work was co-funded by COMET.

Can a boardgame reduce disaster risk? COMET PhD Researcher, Laura Wainman is trying to find out...

“Bhūkampa! Bhūkampa!” “Earthquake!” the shouts echo around the classroom. “I would have won!” a boy exclaims, begrudgingly sliding his counter back by 5. Students gather around the game board in collective frustration, determined to quickly make up for their lost points. The surrounding valley, however, remains peaceful; we’re sat outside the classroom, basking in the first warm days of the dry season. There is no hint of the earthquake that’s just happened, or the one that may be yet to come.

We’re playing the Disaster Ready! boardgame as part of an earthquake preparedness workshop in a local school. Upon meeting the principal that morning, she explained that they haven’t been able to teach much on earthquakes this year - they can’t afford the textbooks.

This is one of many such workshops, delivered in schools as well as to community groups, during my 6 weeks in Nepal. This trip is Phase I of the project, and it’s about asking questions:

“Can a boardgame really be an effective teaching tool for disaster preparedness?”, “How can we contextualise the game within Nepal, for Nepali students?”, “Do the teachers see it as a valuable tool to use in the future?”.

The game itself developed collaboratively, inspired by other so-called “Serious games” used in academic outreach, as well as by larger organisations such as the Red Cross. The underlying principle is to replicate, in some way, a physical or social reality. Through play, the participants learn more about this reality and develop strategies for dealing with the challenges it presents.

Nirmala explaining the rules of the game in Nepali.

The Disaster Ready! game aims to encapsulate this as a disaster risk reduction (DRR) education tool – being set within a rural Nepali community, players must move around the village, performing individual and collective actions, as well as acquiring response and recovery cards for when disaster strikes. Actions gain players points and include things such as packing an emergency bag, practicing "drop, cover, hold", or making a collective emergency plan for their village. Disasters are triggered randomly by landing on red tiles, forcing players to draw a card from the hazard deck containing earthquakes ranging in magnitude from M1-M7.

Across all the sessions I delivered during my time in Nepal, the overwhelming response to the Disaster Ready! game was one of curiosity and enthusiasm. Equivalent lecture style presentations on earthquake risk and preparedness, although similar in content, were often met with reserved interest, or polite disinterest.

These presentations, me at the front, the audience facing, often felt othering – I was an outsider coming to lecture, not to listen. Playing the game went some way to dissolving these boundaries. The focus switched from my theoretical knowledge, well-intentioned but often naïve in the face of the everyday challenges communities are facing to the experiences of those who live with earthquake risk every day. Shared stories of worry and anxiety, of soup split by ground shaking, of laughter over how many nappies could fit in an emergency bag, replaced what could have been cold and distant knowledge. The game served to humanise the experience of living with earthquake risk and in doing so connected people over their shared realities, generating conversations around what it means to be prepared, both on an individual and community level.

The enthusiasm of the children was especially contagious, and the highlight of most sessions was watching their eyes light up as they unpacked the game to begin playing. The Nepali education system, particularly in the most rural areas, is severely underfunded and poorly resourced. Some teachers, for example. lack any formal training and most rely on rote learning methods to instil information in their students.

Nirmala and I delivering a session on hazards and preparedness in Nepal. Trialling a lecture-style format for comparison with uptake for the game.

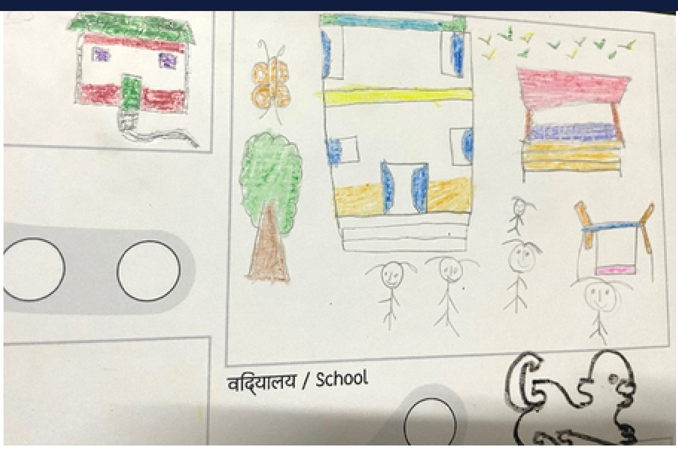
COMET HIGHLIGHT

Noisy, dilapidated classrooms offer a poor learning environment, and many students struggle to concentrate as a result. This makes learning through a game, like Disaster Ready!, novel and exciting. It is an entirely new approach for many students, encouraging active participation, role play, decision making, and a chance for critical discussion in a system where children's voices are rarely heard.

The game was so captivating in part due to its illustrations. These were done by artist Micheal Heap, who's based at the Leeds Arts University. The initial illustrations were our "best guess" of how to represent a Nepali village. With neither of us having actually been to Nepal before, we based our drawings of houses and schools on those we could find on the internet. Of course, we also knew that this approach would fall short of capturing the vibrancy and life of Nepal, or the cultural cues known only to a native Nepali person.

Because of this, we were keen to use Phase I of the trip to understand, artistically, how we could improve the game and embed it within a Nepali context. To do this, I ran a series of workshops with the children whilst in Nepal, encouraging them to draw their houses, villages, and surrounding environment on blank versions of the game boards.

Some of the children's drawings. Houses, their school, a butterfly, and a Nepali dog.



What we got back was a wealth of beautiful illustrations – dogs in characteristic Nepali style, flowers, butterflies, adorned temples, rice fields and tractors. These are the images that will bring the game to life.

Having returned from Nepal, the Disaster Ready! project is now in Phase II – re-development. This includes revising the illustrations on the board and cards based on the student's drawings. We hope this will more fully capture the context of Nepal and give the students a sense of ownership over the game when it is sent back to them.

Connecting with Nepali educators and teachers has also led to invaluable input into the game. This includes revising my attempts at Nepali translations – currently "passable" but overly formal for younger children and, I'm told, with an alarming lack of grammar. Phase II will also see the expansion of the game into other hazards such as wildfires, floods, and landslides. These hazards are felt more frequently than earthquakes by many communities in Nepal but can be just as devasting.

The effects of climate change are anticipated to worsen the frequency and severity of these events in Nepal over the next few decades and the country is considered highly vulnerable to climate disasters by the UN.

Building these additional hazards into the Disaster Ready! game is therefore critical to a more holistic approach to community preparedness and risk education. Whilst the challenges of living with the threat of multiple hazards can be many, so too can the opportunities to increase preparedness and resilience to multiple events simultaneously.

For example, an emergency bag is useful following an earthquake, but also after a flood, or whilst evacuating due to a wildfire. A community evacuation procedure can be adapted to multiple eventualities and even in its formation may strengthen the sense of collective preparedness and decision-making capacity within the community. This line of thinking can be extended well beyond the traditional disaster risk and preparedness remit. Many communities expressed that their primary vulnerability to disasters such as earthquakes, was in fact their everyday food precarity, lack of access to clean water, and the struggle to survive on incomes well below the poverty line. Asking people to pack non-perishable food in an emergency bag is hardly reasonable when they have insufficient food to eat that evening. In this sense, for many communities, installing a water tank, educating women, or providing agricultural training would do as much for disaster resilience as any DRR-specific actions, whilst simultaneously improving the day-to-day quality of life for many.

The future of the Disaster Ready! game remains somewhat uncertain, caught between ambitions for greater impact and a lack of funding to support our vision.

Whilst in Nepal, many students and teachers asked to keep copies of the game, expressing their support for its continued use within their DRR curriculums. The five copies of the game that I took out with me were left for teachers and educators to continue to use, although ultimately, these will have only a very small impact in filling the large void of DRR resources in Nepal.

This is where the vision for Phase III of the project comes in – expansion. What if we could print 150 copies of the game, to be distributed to 50 schools in Nepal? What impact could that have?

Playing the Disaster Ready! game as part of a community outreach session.

Over 5 years this would translate to 15,000 students having played the Disaster Ready! game. By 2050 - the year that Nepal aims to be “disaster resilient” - over 75,000. These numbers have the potential to make a significant impact, locally, regionally, and maybe even nationally. Crucial to the success of any future phases of this project is of course partnering with and transferring autonomy over the game to local stakeholders. Phase III would therefore be carried out with an in-country partner such as an NGO or academic institution in Nepal, key to monitoring the use of the game over the next few years and evaluating its impact.

One of my final experiences in Nepal was to visit the village of Langtang, situated to the north of Kathmandu and accessible only by helicopter or 3 days of trekking through the jungle. For me, this experience came to represent many of the challenges that persist around delivering DRR education, both in Nepal and globally. But it also inspired me - this work is meaningful, necessary, and should be something that I strive to do throughout my career. The village of Langtang was one of the worst affected by the 2015 Gorkha earthquake, with over 300 casualties due to a landslide which all but wiped out the village.

Walking along the hiking path through the valley you pass by what remains, now buried under 20 metres of rubble. My guide, Ram, explained that the landslide happened 30 minutes after the initial earthquake and that ultimately, the actions that people took in those intervening minutes proved critical. Those who were younger, and had generally had more access to education, knew that following the earthquake they should move into open space because of the increased risk of a landslide.

These few people survived. But most people in the community, many of whom had never had the chance to engage with any DRR outreach or education, stayed behind. Sheltering in their homes, despite surviving the earthquake, they were left directly in the path of the landslide. The knowledge that saved lives, and that could have saved more if it had only been taught and shared more widely, can fundamentally be reduced down to only two sentences:

"Landslide risk is higher following an earthquake. Move to open space and away from steep slopes".

How many thousands of papers and conference presentations have been produced on the tectonics of the Himalayas? How many field campaigns have drawn on local knowledge and relied on the resources of local communities? And yet, for so many living in this region they did not have the most fundamental, two sentences of knowledge that would have kept them safe. This is in part the result of decades of so-called "helicopter research", predominantly out of western universities and institutions. If colonial-era science was used to justify the exploitation of resources, then perhaps science under neocolonialism is marked by the extraction of knowledge without a commitment to reciprocity, dialogue, or delivering concrete benefit to communities in whose backyards we are working. This is one of my most lasting impressions - that sharing knowledge, in a way that truly empowers people and communities to understand their environment and to make their own decisions on preparedness and resilience, is fundamental to doing both DRR work and science well. The geoscience community has such a wealth of knowledge and resources, but currently this is struggling to reach the people that need it most. I sincerely hope that projects like Disaster Ready! will contribute to towards bridging this gap.

Want to support the project?

We are currently looking for funding to support Phase III of the project. If you know of suitable funding streams which could be worth applying to please reach out! Or if you have experience of DRR outreach, especially through "serious games" then we would love to collaborate and hear more

Acknowledgements
A warm thank you to all those who have and continue to support the Disaster Ready! Project: Soroptimist International Leeds, COMET, Volunteers Initiative Nepal (VIN), Dr Claire Quinn, Dr Laura Gregory, Dr Peter Sutoris, Micheal Heap, and Nirmala Karki.

AWARDS AND RECOGNITION

Tamsin Mather (COMET Scientist, University of Oxford) was amongst the distinguished group of scientists who were elected Fellows of the Royal Society in May 2024. This highly prestigious title is awarded to scientists who have made an exceptional and important contribution to science.

Samantha Engwell (COMET Scientist, BGS) has taken on the role of co-chair of the WMO advisory group for volcanic science applications for aviation (AG-VSA). The role of this group is to bring research into operations, with the ultimate aim of improving hazard information regarding volcanic emissions to civil aviation.

Ekbal Hussain (COMET Scientist, BGS) joined the NERC science committee from 2nd January 2025.

Sam Wimpenny (COMET Scientist, University of Bristol) received the Geological Society's William Smith Fund 2023, which is awarded to geoscientists within the first 10 years of their career. The fund recognises excellent contributions to geoscience research and its application, in the UK and internationally.

Annie Winson (COMET Scientist, BGS) started a new post as science advisor for the UK Foreign, Commonwealth and Development Office (FCDO) in the Research and Evidence Directorate.

Scott Watson (former COMET Staff Scientist current COMET Associate, University of Leeds) received the Remote Sensing and Photogrammetry Society's Len Curtis Award for for an outstanding technical publication published in the preceding year in the International Journal of Remote Sensing (IJRS).

COMMUNICATION AND ENGAGEMENT

Communication and public engagement are important aspects of COMET's mission, for the science produced by our members to be understood by a wide variety of people across the world. As part of this, we aim to improve access to and diversity in Environmental and Earth Sciences through effective outreach activities. Here are some highlights over the last year:

In October 2024, the Royal Society events and engagement team provided some funding to reprise the 'Sensing Volcanoes' exhibit at Manchester's Science and Industry Museum over five days as a part of the Manchester Science Festival.

Bridie Davies (Manchester) managed the event, supported by Jenni Barclay (Bristol) and David Pyle (Oxford), with volunteers from Manchester, Bristol, Oxford and the University of East Anglia.

https://www.tiktok.com/@newscientist/video/7425195201901104416

In February, Tamsin Mather delivered a presentation at the New Scientist Live event, speaking on the topic of "Volcanoes and Past Climate: Adventures with Deep Carbon".

COMET also attended as a UKRI representative at the Festival of Tomorrow, Swindon. Isabelle Taylor (Oxford), Tianyuan Zhu (Bristol), Rhys Charles (Bristol), and Charlotte Royle (Leeds) talked to hundreds of visiting families about the work being done by COMET researchers.

Guest feedback showed that they particularly enjoyed viewing the world through a thermal camera and understanding how similar methodology can be used in COMET research to monitor volcanic eruptions. Feedback was also positive for the hand specimens of volcanic rocks, which were combined with a labelling game for visitors to match the rock to its method of formation. 3D printed models of faults provided by the University of Leeds were used to better understand how earthquakes occur, allowing visitors to feel for themselves how the ground moves during seismic activity. **Over 90% of visitors surveyed responded that visiting the stall made them more interested in learning more about Earth Sciences.**

EVENTS

Research and Innovation Forum: Volcanic and Tectonic Mulithazards

COMET hosted its first Research and Innovation Forum at the University of Oxford on 28-29 November 2024 for ~45 attendees. This successful collaborative engagement event provided an opportunity for attendees to:

- Learn how COMET research can benefit a range of organisations,
- Network with world-renowned specialists in Earth Observation and modelling of natural hazards, and industry experts across a range of sectors,
- Discuss how to close key cross-sector skills gaps,
- Develop collaborative project ideas and plans.

The event included research showcase presentations, speed networking, and workshops to discuss ways of working together and explore what is missing to support research and drive innovation over the next 5-10 years.

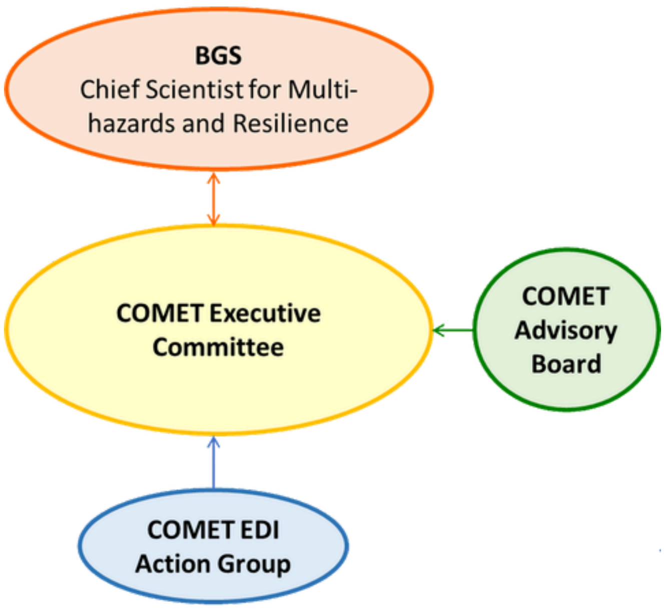
Some of COMET's key collaborators and a range of industry representatives were in attendance, including ARUP, British Geological Survey, CATALYST, European Space Agency, GEM Foundation, HR Wallingford, MS Amlin, Satellite Applications Catapult, SatSense, Space Hub Yorkshire, UK Centre for Ecology and Hydrology, Viridien and WTW.

We will continue to develop these discussions and follow up on actions from the meeting, including planning future engagement events. Watch this space for further developments!

GOVERNANCE AND COMMITTEES

COMET Executive Committee:

The COMET Executive Committee is the decision-making body for COMET, overseeing the management and delivery of the COMET science programme and developing proposals for future National Capability (NC) Science.



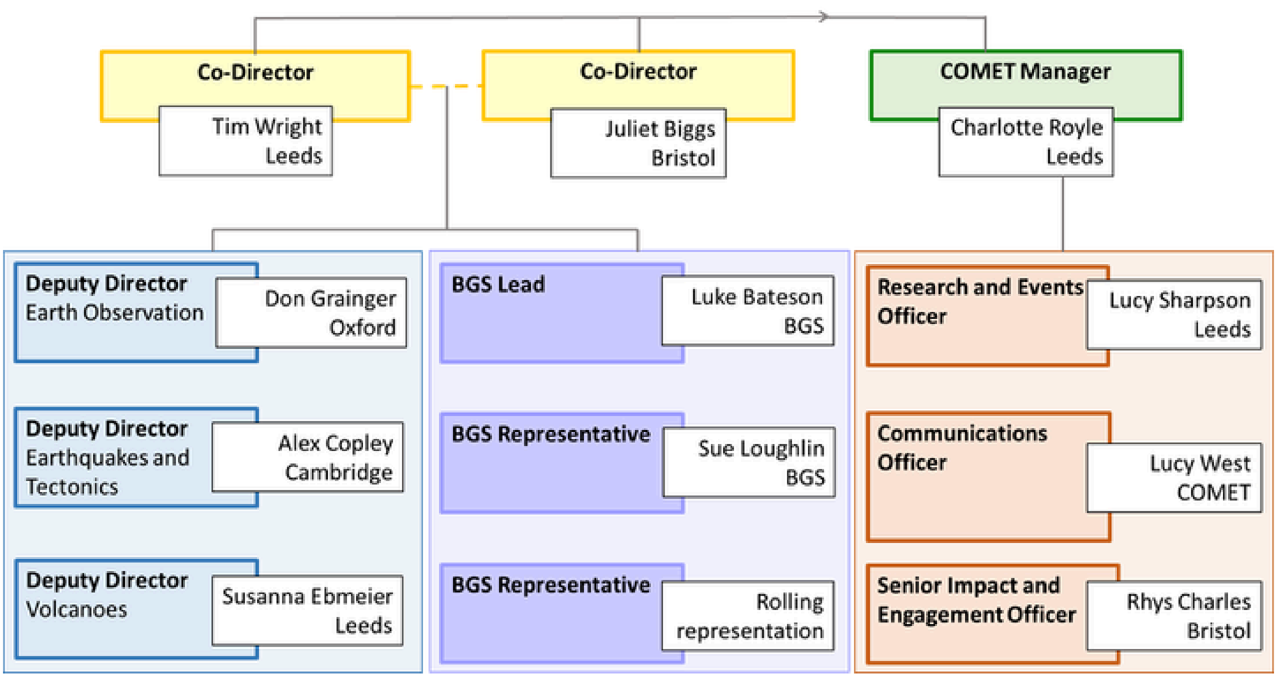
COMET Advisory Board:

The COMET Advisory Board meets once per year (at the COMET Annual Meeting) to provide strategic advice and feedback to the COMET Executive Committee, British Geological Survey (BGS), and the Natural Environment Research Council (NERC).

COMET Equity, Diversity & Inclusion Action Group:

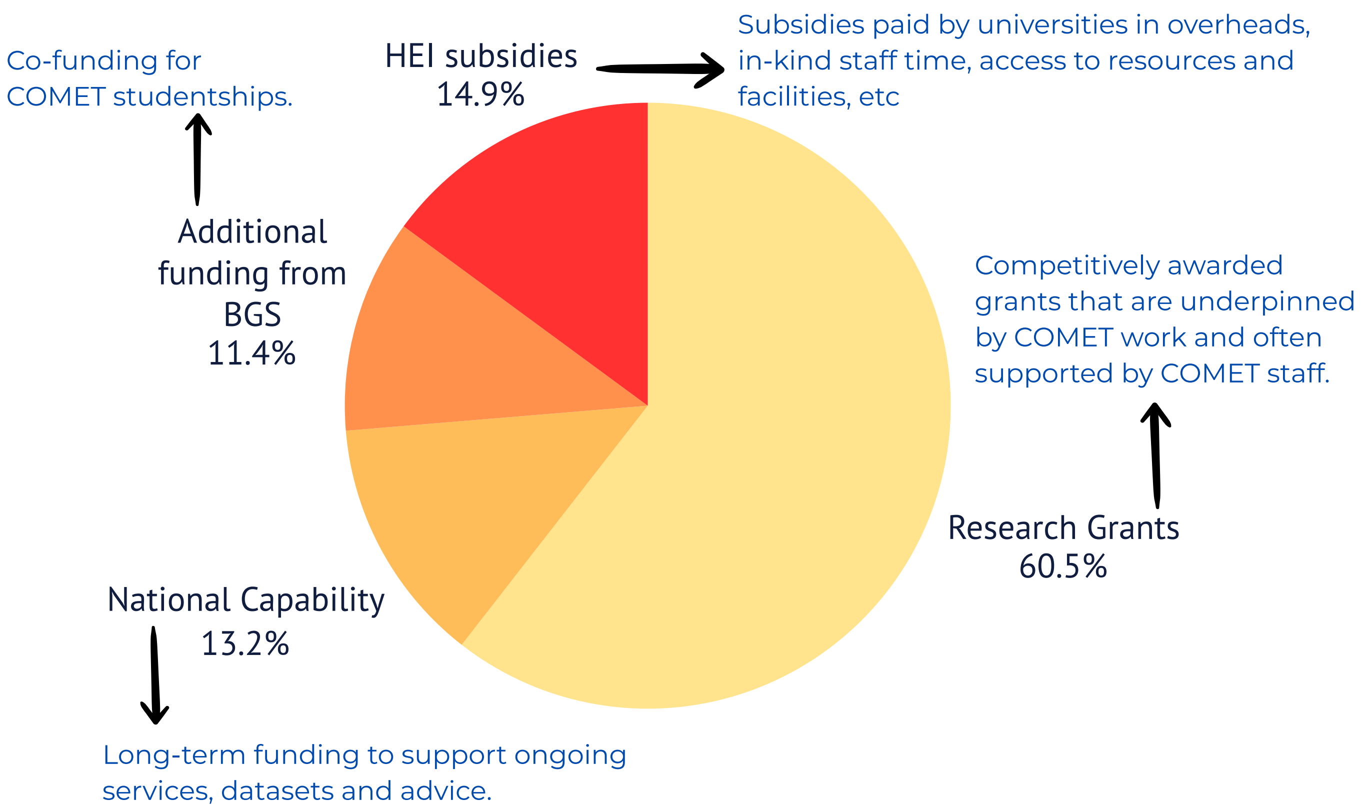
COMET is committed to delivering practical changes that help increase equity, diversity, and inclusion within our community. Building on existing suggestions for change from COMET members, the Equity, Diversity and Inclusion (EDI) Action Group will develop and oversee the EDI Action Plan and work alongside the COMET Directorate to ensure relevant actions are taken.

COMET DIRECTORATE

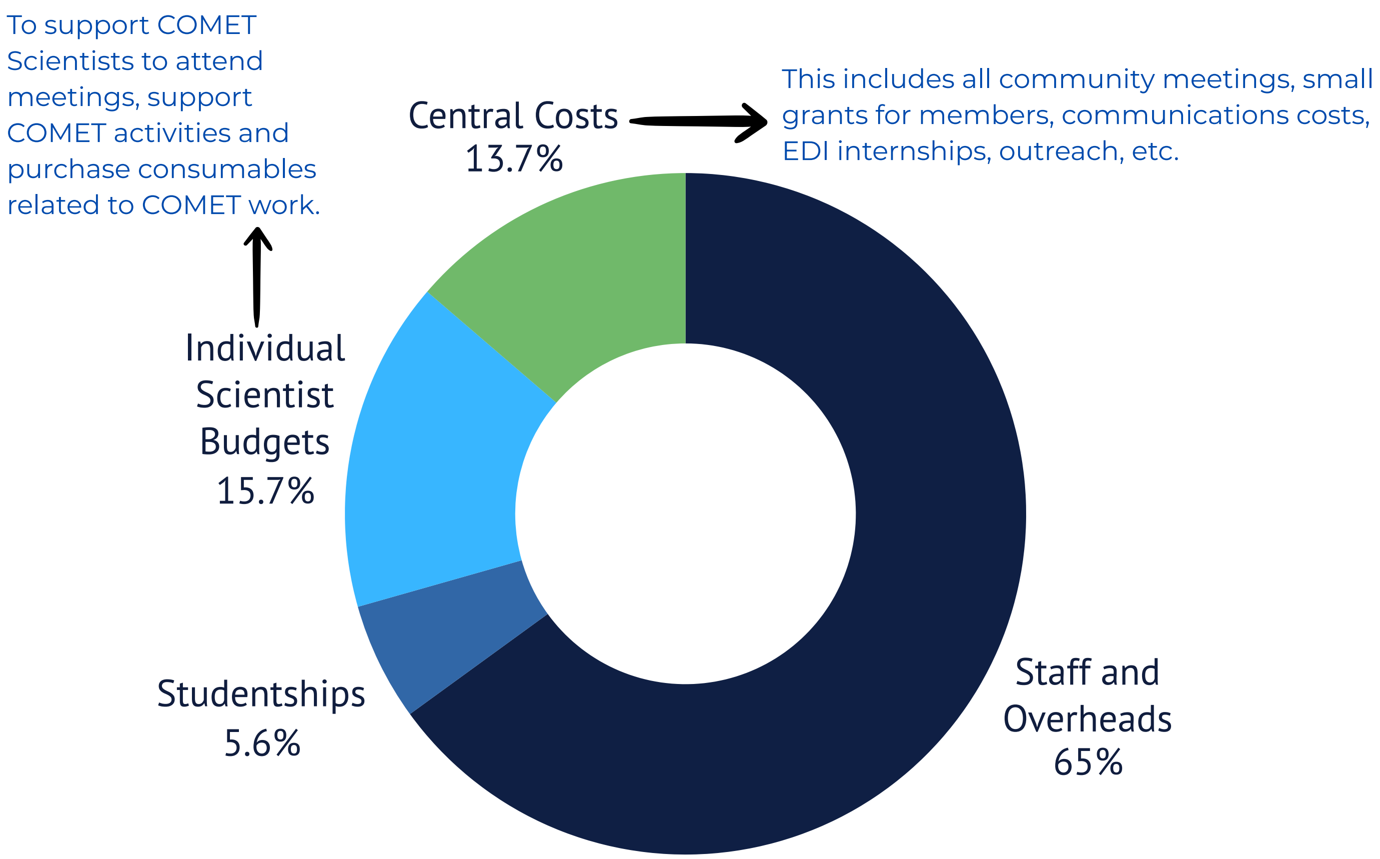


FINANCIAL OVERVIEW

HOW IS COMET FUNDED?



NATIONAL CAPABILITY BUDGET BREAKDOWN



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