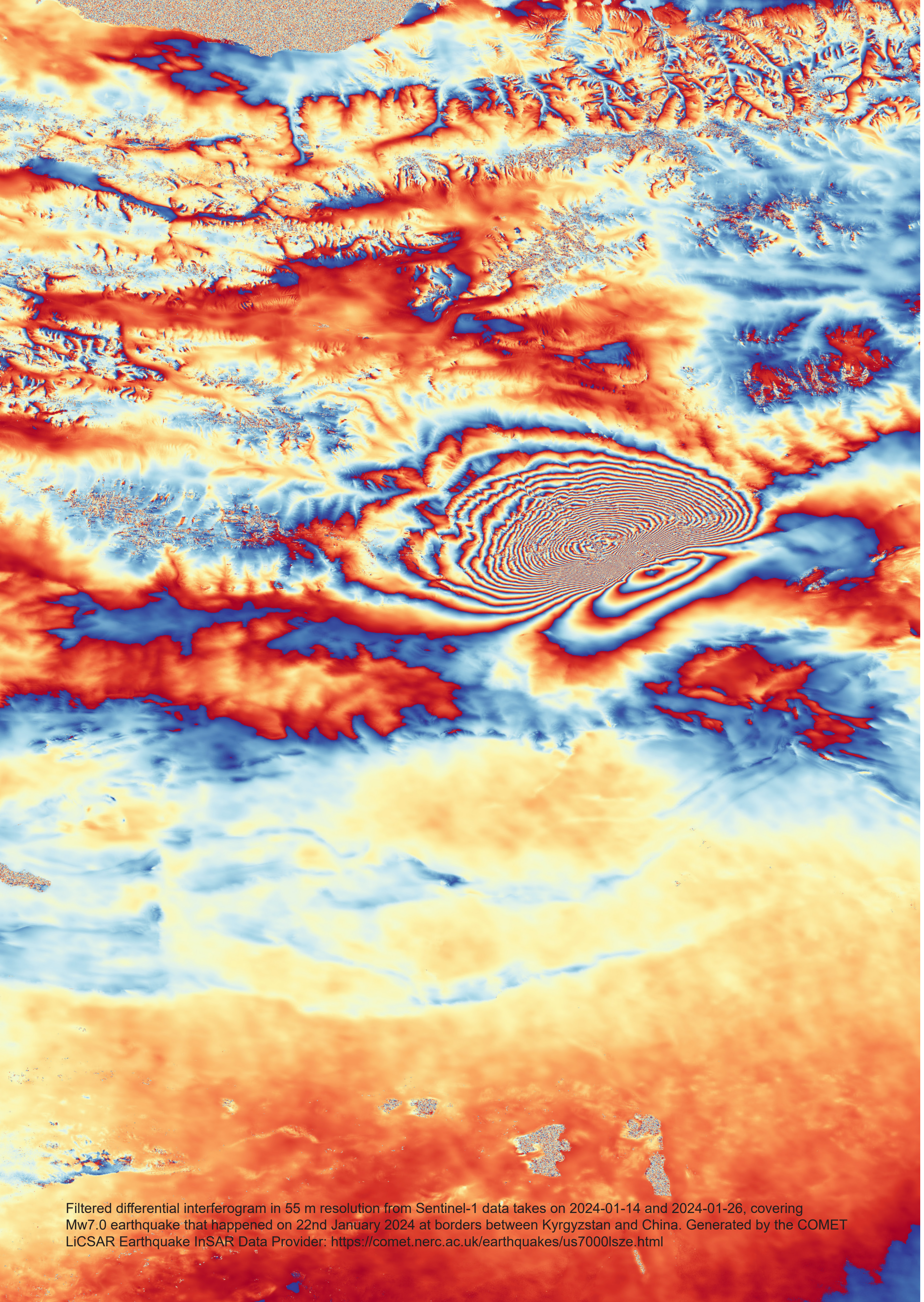
COMET

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

ANNUAL REPORT
2023/2024

British Geological Survey

UKRI Natural Environment Research Council



Filtered differential interferogram in 55 m resolution from Sentinel-1 data takes on 2024-01-14 and 2024-01-26, covering Mw7.0 earthquake that happened on 22nd January 2024 at borders between Kyrgyzstan and China. Generated by the COMET LiCSAR Earthquake InSAR Data Provider: https://comet.nerc.ac.uk/earthquakes/us7000lsze.html

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Cover photo: Winning image of the COMET 2024 Photography/Image competition.
'Your Friendly Neighbourhood Volcano'
Credit: Dan Manns, University of Exeter

INTRODUCTION

The Centre for Observation and Modelling of Earthquakes, Volcanoes and Tectonics (COMET) delivers cutting-edge science in Earth Observation, Tectonics and Volcanism. Through the integrated application and development of EO data, ground-based measurements, and geophysical models, COMET studies earthquakes and volcanoes, and the hazards they pose. 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.

A national-scale community with considerable size and impact, COMET brings together leading scientists across the British Geological Survey (BGS) and 6 UK partner universities: Bristol, Cambridge, Leeds, Manchester, Oxford, and University College London (UCL). In addition to this, we have associate members across a number of other UK institutions, including: Cardiff University, University of Edinburgh, University of Exeter, Imperial College London, Newcastle University, University of Plymouth, University of Portsmouth, University of Sheffield, the University of East Anglia, and the WTW Research Network. We provide scientific leadership in EO, while also bringing together a vibrant community of postgraduate students and early career researchers.

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), National Centre for Earth Observation (NCEO) and European Space Agency (ESA), 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 report gives an overview of COMET's activities during the third year of our current 5-year programme of work. Following a 2-year transition, COMET is now delivered in partnership with BGS. The report highlights major scientific achievements, as well as progress against our key objectives covering the period 1st April 2023 – 31st March 2024.

DIRECTOR'S WELCOME

Welcome to COMET's tenth annual report! This year, we submitted the COMET 2024-2029 Science Programme to the British Geological Survey (BGS) for review and we are pleased to confirm that it has been accepted to continue until March 2029. Scientists across COMET and the BGS work collaboratively to plan COMET's core National Capability science programme, which ensures that our members have a meaningful input into the strategic direction of the Centre, and that they stay active, engaged and directly involved in the work that we do. From April 2024, the current 2021-2026 objectives will be superseded by the 2024-2029 science programme.

In Year 3 of the current 2021-2026 programme (April 2023-March 2024), COMET has continued to work on scientific objectives that were jointly developed with BGS and are aligned with BGS's strategic priority of "Multihazards and Risk" to deliver national-level science in the observation and modelling of geohazards.

Our Earth Observation Data and Services work has included the continued growth of the COMET-LiCSAR Sentinel-1 InSAR processing facility, with approximately 1,593,000 interferograms processed by March 2024. An incredible 466,000 interferograms have been processed over this reporting year. Our machine learning work has focussed on improving the quality of the data used by our algorithms, through collaboration with both scientists working on the COMET Volcanic and Magmatic Deformation Portal and The Centre for Environmental Modelling and Computation (CEMAC, University of Leeds).

In our earthquakes and tectonics theme, we have focused on creating regional maps of the Tien Shan of central Asia (co-funding from NATO SPS, Leverhulme Trust) and the South Caucasus (co-funding from EPSRC, industry). We also produced the first 500 m-resolution east and vertical velocity fields over the entire Tianshan mountain range derived from 8 years of Sentinel-1 data as part of our partnership with the Global Earthquake Model (GEM).

In our volcanology and magmatism theme, we have continued to update our global dataset on volcanic emissions and daily SO2 website hosted at the University of Manchester, specifically focusing on Etna (Italy), Villarrica (Chile) and on the Reykjanes Peninsula during this reporting year. In preparation for ESA's Harmony satellite mission, we have also been demonstrating the potential use of the satellite's expected capabilities and simulating data at the proposed resolution of Harmony's equipment.

We have made adaptations and improvements to all COMET codes and products across all themes, and we are working on organising, cataloguing and, where necessary, archiving data. In addition to the programme of National Capability work addressed in this report, our scientists continue to lead and contribute to a wide range of aligned projects and programmes.

The strength of COMET and the amazing work that we are able to do is reliant on the scientific excellence of its 160+ members and students. This year we welcomed a number of exceptional new members into the COMET community, with a wide range of research expertise, and a number of existing COMET members took up new roles within the Centre. Please see the "New Starters" pages (pp. 8 – 10) for more information.

The awards listed in this report every year further highlight the exceptional talent within our membership. I would like to congratulate all of the recipients of these honours this year on their successes both nationally and internationally. Please see the "Awards and Recognition" page (p. 46) for more information.

This year, COMET has developed lines of communication with the UK Foreign, Commonwealth and Development Office (FCDO), including providing information for the 2023 Morocco earthquake. We have provided advice and expertise to volcano observatories, governments, and international organisations and groups. In addition to this, COMET (led by Sam Wimpenny) has produced a resource aimed ay improving Equity, Diversity and Inclusion in fieldwork: COMET Guidelines for Safe, Inclusive and Equitable Research Fieldwork. For more information, see the "Impact, Innovation, and Influence" section. (pp. 36-37)

In other news, I will be joined as COMET co-Director by Professor Juliet Biggs from 1 April 2024. Juliet has extensive experience across all of COMET's remit and I'm looking forward to working with her as COMET continues to go from strength to strength.

Professor Tim Wright
COMET Director (April 2024)

ADVISORY BOARD COMMENTS 2023

COMET Objectives and Scientific Programme

COMET still sits very much at the cutting edge of developments of techniques in InSAR, such as unwrapping and north-south oriented deformation, sub-pixel offset tracking, and artificial intelligence methods. Also in the addressing of fundamental questions of science. COMET has important roles as a service and dataset provider, but also in asking the big fundamental science and we think it is doing this very well.

COMET does amazing work with limited funds, but with some additional funds, there is great potential to do so much more, such as analysing all the data produced in LICSAR, and hiring a dedicated outreach officer. In terms of connections to the world via BGS – BGS could enable and arm COMET to communicate and disseminate their work more widely. The presence of the UK's Foreign, Commonwealth and Development Office (FCDO) civil servants at the COMET Annual Meeting is a great step forward. Clearly there is a huge need and opportunity to connect what COMET (in its widest sense) does, to those who need the information, in a language and format they can understand, and BGS could help with this.

We would like to see more input from scientists working on physics based models (for both earthquakes and volcanoes) and we suspect that the forthcoming COMET Modelling Workshop (27th June 2024) will assist with this. The need for bringing data and models together is now very pressing.

We would like to see some presentation or perspective on the international framework for this science: what other agencies/organisations are doing in these fields across Europe (especially in the aftermath of Brexit), and how they compare to or how COMET is linked to them.

We expect and would like to see that COMET retains its energy and positivity going forward.

Annual Science Meeting

The structure and content of this year's COMET annual meeting (26th-28th June 2023) were excellent and entirely positive. The feeling was open, inclusive and very engaging. The community clearly feels very comfortable, collaborative and open amongst themselves and this is clearly a great advantage, since COMET's scientific outputs speak for themselves. It was very well organised to expose the scientific outputs. The break-out sessions and bottom-up responses were great. The short sessions are good – to break up the flow of the meeting and encourage discussion.

We think that an overview talk (of the type that Ekbal Hussain, BGS Scientist, presented about Turkey) about the great complexity of and devastation caused by a big event/disaster of this kind presented at each COMET meeting would be a great addition. Such human level talks are an excellent reminder of why and how COMET needs to do what it does.

Advisory Board Members 2023

In-person attendees:

Philippa Mason (Imperial College London, UK)

Nicola D'Agostino (INGV, Roma, Italy)

Elisa Carboni (RAL Space, UK)

Eleonora Rivalta (GeoForschungsZentrum (GFZ), Potsdam, Germany; University of Bologna, Italy)

Valerie Cayol (University Clermont Auvergne, France)

Online attendee:

Romain Jolivet (École Normale Supérieure, France)

Sheared and partially molten rocks from NW Scotland. These rocks became hot enough in the deep crust of a mountain belt to produce melt (pale bands) that became aligned by deformation. This process has a large impact on the strength of the crust.
Credit: Alex Copley, University of Cambridge

NEW STARTERS

Rami Alshembari, Postdoctoral Researcher, University of Exeter

Rami completed his PhD in 2023 at the University of Exeter, where he focused on applying physics-based models to interpret volcano deformation and improve eruption forecasting. He is now a Postdoctoral Research Fellow at the University of Exeter, working on the NERC-funded project Deforming Volcanoes with Dynamic Magma-Mush Models (DV3M). His research involves developing dynamic magma mush (DMM) models to analyze volcano deformation during episodes of unrest, integrating numerical modeling with geological and geophysical datasets. Rami's work aims to advance understanding of transcrustal magmatic systems and improve eruption forecasting, with a focus on high-risk volcanoes such as Soufrière Hills in Montserrat and Sakurajima in Japan.

James Dalziel, Earth Risk Research Lead, WTW Research Network

James is Earth Risk Research Lead for insurance broker and risk advisory firm WTW's Research Network, working with academic and industrial research partners in the fields of volcanology, seismology, geology and geophysics. His research collaborations centre around geohazards such as volcanic eruption, earthquake, landslide and tsunami; including modelling and remote sensing, risk mitigation, exposure, vulnerability, and the interaction between compounding and cascading hazards. He previously completed a Masters by Research in Geology at the University of Bristol, studying the relationship between seismic moment and magmatic volume change during precursory volcanic unrest.

Amy Donovan, Professor of Environmental Geography, University of Cambridge

Amy is Professor of Environmental Geography at the University of Cambridge and co-chair of the UK Alliance for Disaster Research. She works on the use of scientific knowledge in decision making in disaster contexts, particularly active volcanoes, and has also conducted research on volcanic gas monitoring and petrology. She has collaborated globally with volcano observatories and other scientific organisations both in volcano monitoring and in the communication of scientific advice. Amy's current research involves working with communities, observatories and outreach organisations in Latin America. She currently supervises PhD students who have projects in Iceland, the Caribbean, Latin America and Central Asia.

Adriano Gualandi, Assistant Professor, University of Cambridge

Adriano is an Assistant Professor in Geophysics at the Department of Earth Sciences, University of Cambridge. He is also a visiting researcher at the Italian National Earthquake Observatory section of the National Institute of Geophysics and Vulcanology (INGV). Prior to his current role in Cambridge, he was a researcher at the INGV in Rome (Italy), a visiting researcher at the École Polytechnique in Paris (France), a NASA Postdoctoral Fellow at the Jet Propulsion Laboratory in Pasadena (CA, USA), and a postdoctoral researcher at the California Institute of Technology in Pasadena (CA, USA). He studied at the University of Bologna, where he received his PhD in Geophysics with a fellowship from INGV, and where he received his B.S. and M.S. degrees in Physics, with a specialisation in Earth Physics. His research mainly focuses on the study of nonlinear dynamical systems, friction, earthquakes and geodesy. He uses satellite and remote sensing data as well as local networks data to better understand geophysical extreme events.

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Holly Hourston, Earth Observation Scientist, BGS

Holly started her scientific career studying for an MSci with joint honours in Astronomy and Physics at the University of Glasgow. After discovering an interest in planetary science through her undergraduate, she undertook an MSc by Research in Geology, studying organic molecules in carbonaceous chondrite meteorites. She has turned her focus back towards the Earth and now works for the British Geological Survey as an Earth Observation scientist in the Geodesy & Remote Sensing team. She spends most of her time analysing InSAR data to study deformations due to various geological, climatic and anthropogenic influences, and is developing machine learning algorithms and statistical approaches to automate interpretations of InSAR data.

Sacha Lapins, Leverhulme Early Career Fellow, University of Bristol

Sacha completed his PhD in 2021 at the University of Bristol, which was focused on detecting and characterising seismicity at East African volcanoes through deep learning. Following a postdoctoral position aimed at advancing the use of Distributed Acoustic Sensing (DAS) for passive microseismic monitoring, including detecting icequakes in Antarctica and monitoring carbon capture and storage (CCS) sites, he was awarded a Leverhulme Early Career Fellowship to continue research in developing deep learning methods for analysing volcanic seismicity. He also holds a Royal Society International Exchange grant with scientists at the University of Costa Rica (UCR), aimed at enhancing our understanding of subsurface fluid processes along the Costa Rican volcanic arc, and is involved with an EPSRC-funded project ("DarkSeis") aimed at imaging the urban subsurface with DAS and dark fibre (unused telecommunications cables).

Lorenzo Mantiloni, Postdoctoral Researcher, University of Exeter

Lorenzo completed his PhD in 2023 at the University of Potsdam, Germany. His research was carried out at the German Research Centre for Geosciences GFZ within the MagmaPropagator project, and focused on numerical and analogue modelling of magmatic dyke pathways and stress in the Earth's crust. The goal was to develop a physics-based forecast of future locations of eruptive vents across calderas and other volcanic systems. He is now a postdoctoral researcher at the Camborne School of Mines, University of Exeter, as part of the DV3M project. His current research includes poro-visco-elastic models of dynamic magma-mush reservoirs. He investigates the strain, state of stress and stability of such systems under different regimes of magma supply, to assess when and where magma chambers are more likely to fail and possibly trigger an eruption.

Emma McAllister, Remote Sensing Geoscientist, BGS

As a remote sensing geoscientist within the Geodesy and Remote Sensing Team, I specialise in the application of optical remote sensing and machine learning techniques to address coastal erosion. My primary focus involves the development of automated methodologies for the identification and extraction of shoreline features. This is achieved through image processing, machine learning algorithms, and multispectral satellite imagery. Additionally, I am responsible for the monitoring and archival of GNSS data obtained from 160 sites across the UK as part of my role within the British Isles continuous GNSS Facility (BIGF).

NEW STARTERS

Erin Mills, Remote Sensing & Multi-Hazard Geoscientist, BGS

Erin works within the Geodesy and Remote Sensing team at BGS. While completing a Masters in Cartography, Erin was able to partner with BGS on the thesis ‘utilising remotely sensed radar data to identify rafting volcanic pumice & potential relationships across backscatter coefficients’ in the context of impacts on fragile coastal communities. Now, her work focuses on multi-hazard cascades and compound interrelationships, with the integration of EO data and products to quantify and monitor local, regional and national hazards in the context of DRR. Interests of societal/cognitive perception of hazards and the how use of cartography can enable effective mitigational response.

Maximillian Van Wyk de Vries, Assistant Professor in Natural Hazards, University of Cambridge

Max holds a joint appointment between the departments of Geography and Earth Sciences and leads the Cambridge Complex and Multihazard research group (CoMHaz). He is also a Visiting Research Associate (Multi-hazards and Resilience) at the British Geological Survey. His research focuses on multihazard processes, particularly landslides, volcanoes, and cryospheric hazards, with a strong emphasis on their interactions. His current work includes hazard evaluation at ice-clad volcanoes, large-scale landslide detection using satellite imagery, and exploring the two-way interactions between glacial retreat and landsliding.

Stanley Yip, Postdoctoral Researcher, University of Leeds

Stanley completed his PhD in 2023 at the University of Bristol. His research was on integrating ground deformation and SO_2 observations to quantify magma compressibility to better understand the detectability of observations of volcano deformation. He now works as a postdoctoral researcher at the University of Leeds as part of the Natural Environment Research Council’s Pushing The Frontiers Project, Magma Accommodation and Ground Movement Analysis (MAGMA). His current research focuses on reconciling analogue, analytical and numerical volcano deformation models to understand the role of crustal heterogeneity on observations of volcano deformation and working towards developing realistic numerical volcano deformation model.

Other Membership Changes:

COMET Associate to COMET Scientist:

- Margarita Segou, BGS
- Annie Winson, BGS
- Pui Anantrasirichai, University of Bristol
- Sam Wimpenny, University of Bristol

COMET OBJECTIVES

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 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 2021-2026 are:

Our science objectives for 2021-2026 are:

EO data and services

1. Deformation from Satellite Geodesy:
- Improve COMET-LiCSAR Sentinel-1 service
- Improve atmospheric correction services
- Extend the COMET-LiCSAR system to other satellites

2. Topography, Deformation, and Surface Change Analysis from High-Resolution imagery:
- Semi-automation of satellite-derived displacement maps of large ground deformation signals, and of topography and topographic change
- Utilize digital topographic data at global, regional, and local scales to aid the fieldwork activities of COMET members and the mapping of hazards at regional scale
- Derivation and analysis of high-resolution topographic datasets for seismic hazard in and around cities

3. Retrievals of Volcanic Emissions from Satellite Spectrometers:
- Adapt fast linear retrieval of ash and SO_2 to process data from IASI-NG and IRS
- Extend existing SO_2 and ash time series and investigate retrievals for other volcanic species
- Automation of SO_2 flux time series retrievals

4. Geoinformatics and Machine Learning:
- Improve the sharing of satellite data and time series through the development of an integrated and interactive COMET data portal
- 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 in partnership with the Global Earthquake Model (GEM)
- Produce and deliver maps of active faults, incorporating new results regarding their rates of activity and past earthquakes
- Assess temporal variations in strain across distributed fault networks
- Build dynamic models that can explain lithosphere deformation across timescales

2. Magmatism and Volcanic Hazard
- Analyse long-term (decadal) patterns of volcanic activity globally
- Assess the contribution of volcanic SO_2 to global climate and aviation
- Develop and test the models needed for interpreting satellite data during volcanic crises

Our annual progress against these objectives is recorded in the ‘Science Update’ sections of the Annual Report.

RESEARCH HIGHLIGHTS: EO DATA AND SERVICES

Research Highlight: A Universally Applicable InSAR Phase Bias Correction Strategy — Recent Developments

Yasser Maghsoudi, COMET Staff Scientist, University of Leeds
Andrew Hooper, COMET Scientist, University of Leeds
Tim Wright, COMET Director, University of Leeds
Milan Lazecký, COMET Staff Scientist, University of Leeds

The Sentinel-1 satellite's short revisit time is advantageous for maintaining better coherence in interferograms over short intervals, resulting in more accurate assessments of rapid deformation. However, the use of shorter-interval, multilooked interferograms may introduce a bias, known as a "fading signal", in the interferometric phase, leading to unreliable velocity estimates (Ansari et al. 2021)[1].

In the first part of the project, funded by the European Space Agency (ESA), we explored characterizing phase bias, focusing on one of its primary indicators—the closure phase. We explored loop closure time-series, considering different look directions (ascending and descending), evaluating the impact of filtering and multilooking on closure phases, investigating loop closures across diverse landcovers, examining the polarization dependency of closure phases and investigating the correlations between the time series of phase closures and various environmental proxies. For instance, we plotted the phase closure time-series obtained from both filtered and unfiltered interferograms in Campi-Flegrei, Italy in figure 1 (left) where blue line represents the closure loops time series using unfiltered data, and the orange line represents the filtered interferograms. We also demonstrated the effect of applying additional box car filtering with window sizes 10 and 20 in green and red lines respectively. Figure 1 (right) shows how the loop closure time-series correlate with Leaf Area Index (LAI) time series.

In the second part of the project, we are developing a universally applicable phase bias correction. We previously developed an empirical mitigation strategy that corrects the phase bias based on the assumption that the change in strength of the bias in interferograms of different length has a constant ratio (Maghsoudi et al. 2022). Now, we are investigating the applicability of the proposed method across various scenarios and compare it with alternative approaches. The preliminary results show the effectiveness of the proposed strategy. Figure 2 illustrates the InSAR Velocities derived from 6, 12, and 18-Day Interferograms in Campi-Flegrei, Italy before (left) and after (right) correction. As can be seen, the velocities corresponding to the phase bias are significantly diminished after correction around the Campi-Flegrei volcanoes.

Correcting for the phase bias is particularly important for InSAR processing systems, such as the COMET LiCSAR system (Lazecký et al. 2020)[3], which aims to study geohazards over large areas.

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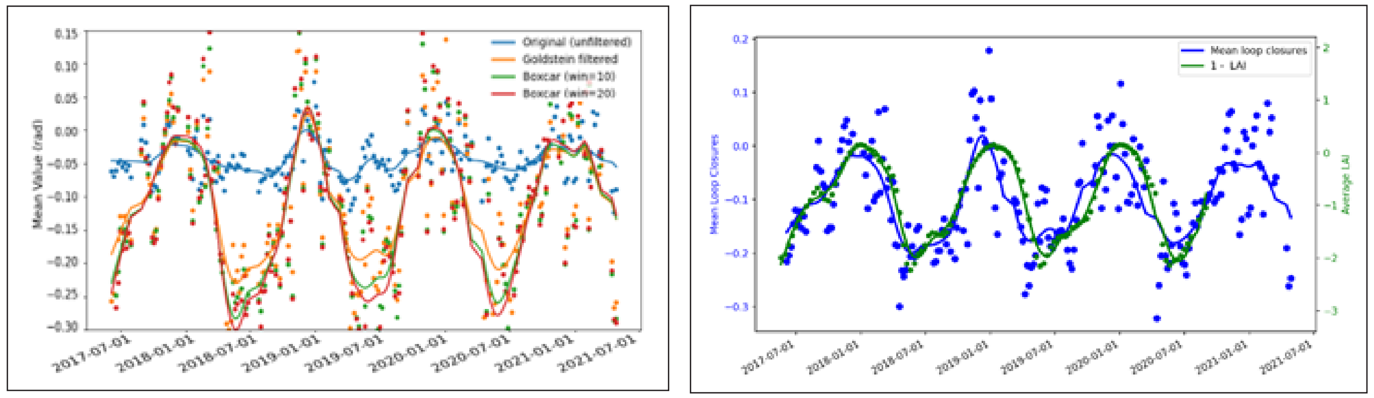

Figure 1. Comparison of Loop Closure Time-Series from Filtered (Goldstein and boxcar) and Unfiltered Interferograms (left), and comparison of Loop Closure Time-Series with LAI (right) in Campi-Flegrei, Italy.

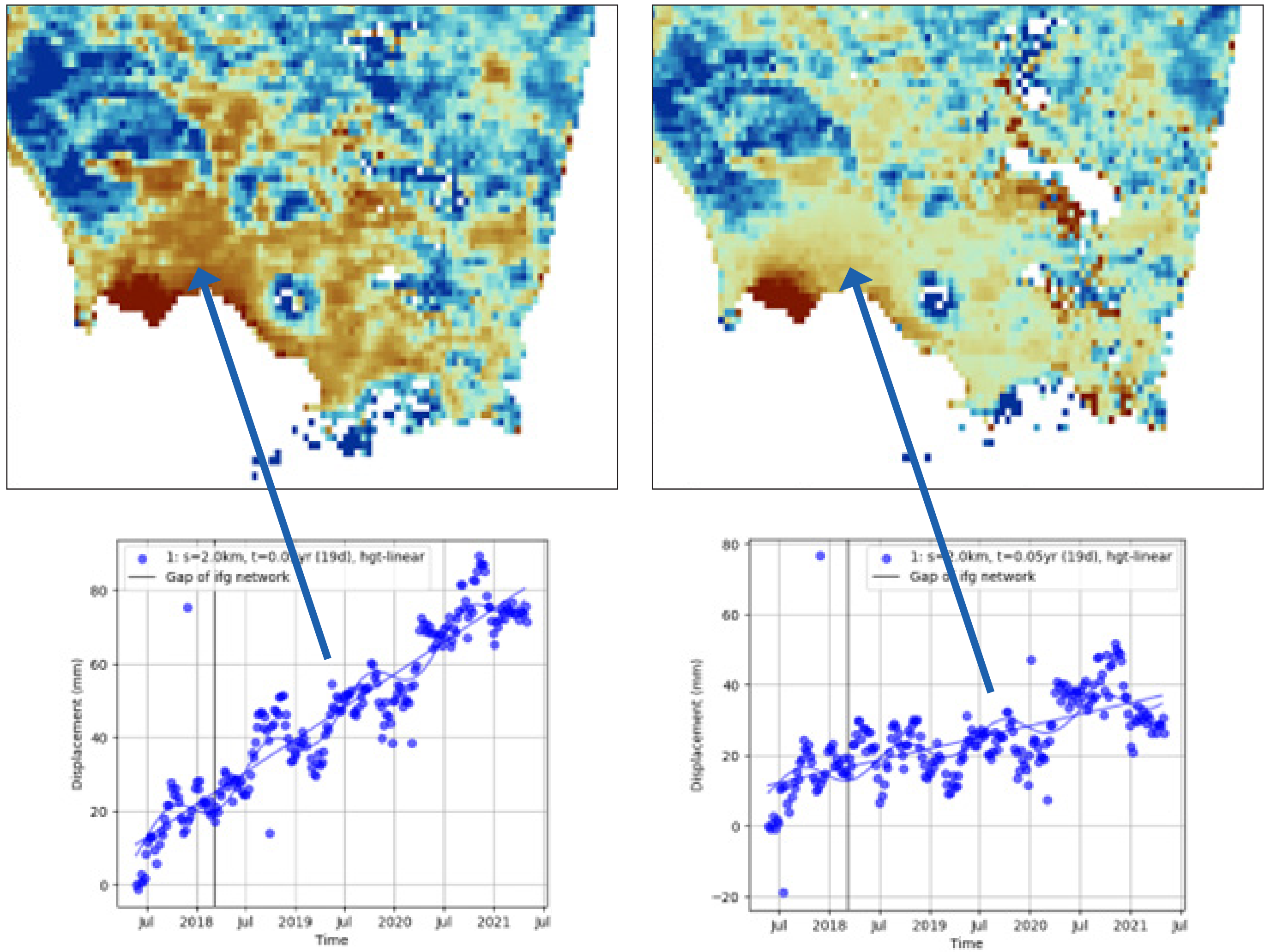

Figure 2. InSAR Velocities derived from 6, 12, and 18-Day Interferograms in Campi-Flegrei, Italy, before (left), and after (right) correction. The time-series displacements for an example point is shown before and after correction in the bottom plots.

RESEARCH HIGHLIGHTS: EO DATA AND SERVICES

Research Highlight: Measuring Topopgraphic Change after Volcanic Eruptions Via Satellite Radar: Simulations in Preparation for ESA's Harmony Mission

Odysseas Pappas, COMET Postdoctoral Researcher, University of Bristol
Juliet Biggs, COMET Deputy Director, University of Bristol

Volcanoes are dynamic systems whose surfaces constantly evolve. During volcanic eruptions, which can pose great threat to local communities, significant changes to the local topography occur as edifices build up and/or collapse, and lava, tephra and other eruptive products are deposited. Monitoring such changes in topography is crucial to risk assessment and the prediction of further eruptive behaviour.

Bistatic InSAR is particularly suited to this task as it allows for the creation of digital elevation models that can accurately map out three-dimensional changes in the topography, regardless of weather conditions. However, very few such missions are currently operational.

Harmony is an upcoming ESA Earth Explorer mission that will be providing bistatic InSAR capabilities for the measurement of stress and deformation across the cryosphere, the oceans and the solid Earth. This includes regular measurements of the topographic change caused by volcanic eruptions. It will consist of two satellites carrying passive SAR instruments operating in tandem with Sentinel-1 in two different formations; in across-track interferometry (XTI) mode the Harmony satellites will be able to produce digital surface models for the evaluation of topographic change at a spatial resolution of 20m and with a 12 day revisit period (Figure 1).

In preparation for the Harmony mission, we demonstrated the use of high resolution TanDEM-X InSAR data for the measurement of topographic change after recent eruptions in El Reventador[4,5,6], Ecuador and La Soufrière[7], St. Vincent and the Grenadines. Additionally, we simulated SAR data at the lower resolution of 20m expected of Harmony and repeated our InSAR processing at this lower resolution, so as to gain insights into Harmony's capability to quantify topographic change.

In El Reventador, the subsampled Harmony data were able to provide measurements of emplaced lava flow volume and area closely in agreement with those obtained from the full resolution TanDEM-X data shown in Figure 2. Values obtained from both methods are also in agreement with 3rd party measurements found in the relevant literature. This demonstrates that Harmony's 20m resolution can resolve and accurately measure topographic change, such as the emplacement of lava flows. However, in the case of La Soufrière[7], St. Vincent, the steep terrain in combination with the significant topographic change around the crater after the 2021 eruption led to a particularly challenging case for InSAR; while TanDEM-X data were capable of measuring the produced topographic change with relative accuracy, the resolution of Harmony was not sufficient to delineate and successfully unwrap the closely packed interferogram fringes. This led to unwrapping errors that significantly compromised measurement accuracy, with the topographic change features corresponding to the new crater and tephra deposits appearing misaligned and of lower magnitude than expected (Figure 3).

The experimental results highlight the potential benefits of InSAR monitoring of topographic change related to volcanic eruptions, especially when available with the spatial and temporal resolution envisaged by Harmony. Additionally, attention is brought to the effect of acquisition pass direction with respect to local topography, the challenges arising in areas of steep topography and the importance of qualitative masking of measured topographic change based on estimates of DEM height precision and spatial resolution.

This research has been conducted with support from an EPSRC IAA Award via the University of Bristol and COMET, and a manuscript is currently in review with *Remote Sensing of Environment*[8].

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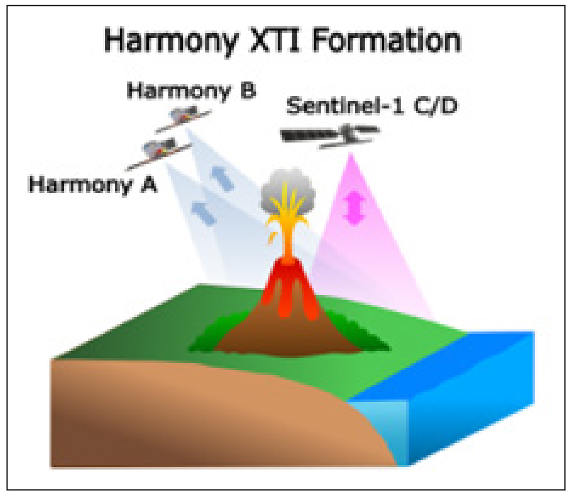


Figure 1. In Harmony's XTI formation the two satellites will be both trailing Sentinel-1, with an orbit-varying baseline between them and will produce 3D surface elevation models for the measurement of topographic change at a dense 12-day interval.

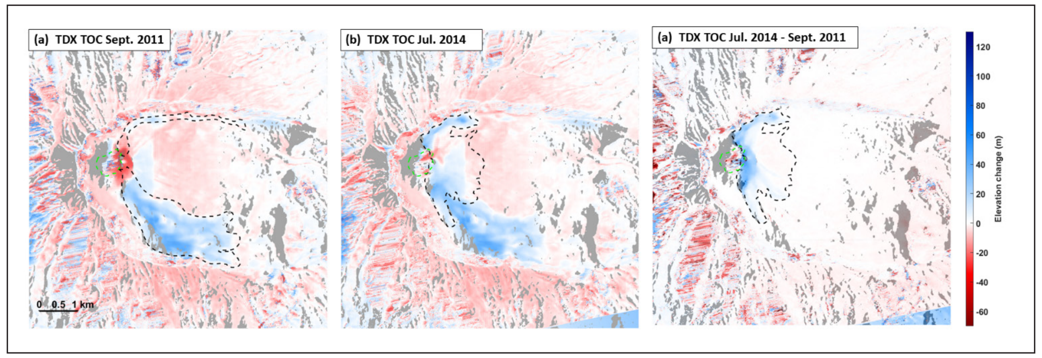


Figure 2. TanDEM-X topographic maps of the lava flow field at El Reventador, Ecuador (a) Topographic change map using September 2011 TDX data relative to Shuttle Radar Topography Mission (SRTM) topography. Lava flow field from 2002-2009 in dashed black line. (b) Topographic change map using June 2014 TDX data relative to SRTM topography. Lava flow field from 2011-2016 dashed black line. (c) Topographic change map using June 2014 TDX data (relative to SRTM + September 2011 topography). Summit area outlined in dashed green line. Grey pixels are masked at 9m resolution and 12m precision.

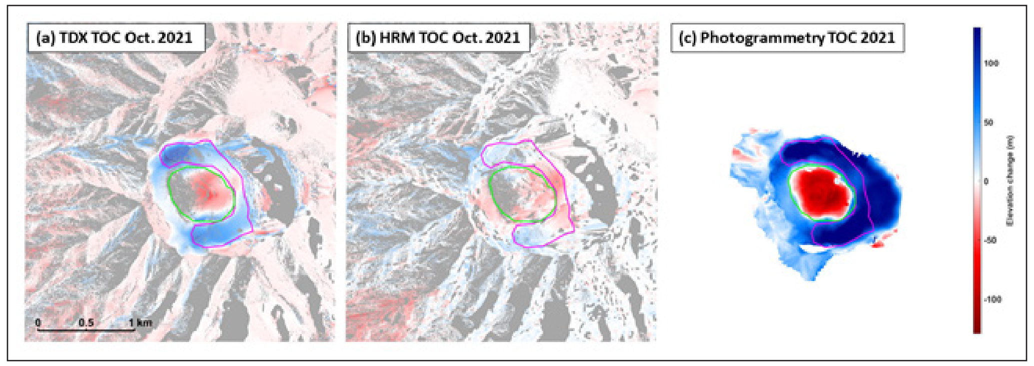


Figure 3. Topographic change after the eruption of St Vincent La Soufrière. Topographic change maps generated from (a) TDX data and (b) HRM data. Masking via resolution and precision maps with resolution thresholds at 4m and 40m for TDX and HRM respectively, precision threshold at 10m. (c) Topographic change as measured by A. Stinton, MVO via photogrammetry. New crater area and tephra field deposits demarcated in green and magenta respectively. The underestimation of topographic change in the TDX data is believed to be due to changes in the tephra deposits due to rain and other weather effects, occurring in the interval between the acquisition of the photogrammetry data and the later TDX acquisition.

SCIENCE UPDATE: EO DATA AND SERVICES

1. Deformation from satellite geodesy

Progress report: improve COMET-LiCSAR Sentinel-1 service.

Objective coordinators: Tim Wright (Leeds), Luke Bateson (BGS), Juliet Biggs (Bristol)
COMET Research Staff: Yasser Maghsoudi (Leeds), Milan Lazecky (Leeds)

Throughout the reporting year, our focus remained on the long-term development of our COMET-LiCSAR Sentinel-1 InSAR processing facility. We further optimised the LiCSAR processing chain, for example by a modified coregistration step that drops its processing time by tens of percent or by updating phase unwrapping method and functionality of the LiCSBAS tool, both leading to more reliable time series outputs. We interacted with major platforms, such as the Copernicus Data Space Ecosystem as the primary data source, CEDA Archive for long-term accessible storage of LiCSAR products and the European Plate Observation System for their dissemination.

As of March 2024, we have processed 328,000 Sentinel-1 acquisitions in 2262 LiCSAR frames, resulting in the generation of approximately 1,593,000 interferograms. This represents a significant increase from March 2023, during this reporting year we processed approximately 466,000 interferograms. The figure below illustrates the number of generated interferograms over time.

	frames	Sentinel-1 epochs	Interferograms
March 2023	2022	270,907	1,126,753
March 2024	2162	328,460	1,593,420
Annual increment	140	57,553	466,667

Table 1: Comparison of the LiCSAR system in March 2023 with March 2024

Our primary focus for processing zones has been on the tectonic and volcanic frames. Within the Alpine-Himalayan Belt (AHB) region, we have successfully processed the frames located in Tibet, Turkey and Caucuses and Iran and they have been added to our monthly list of updates. As for the volcanic frames, we have given priority to those on the A1 list of volcanoes. Table 2 and 3 shows the number of LiCSAR products in AHB and A1 as of March 2024 respectively.

AHB frames	Epochs	IFGs	Ave. Tmaxlen	GACOS Average	Total epochs	Percentage processed
645	153,489	732,469	7.84 yr	80%	169,685	91%

Table 2: The number of various LiCSAR products in AHB as of March 2024.

A1 frames	Epochs	IFGs	Ave. Tmaxlen	GACOS Average	Total epochs	Percentage processed
277	57,076	264,533	6.56 yr	89%	64,488	83%

Table 3: The number of various LiCSAR products in A1 volcanic priority zone as of March 2024.

Since mid-2023, we additionally clip and keep original resolution Sentinel-1 data processed over volcanoes. We keep this dataset up to date in line with the routine updates of LiCSAR frames. This strategy allows us to better optimise multi-temporal interferometric network and resolution towards reliable time series in challenging volcanic areas. Currently over 820 such frame subsets contain over 100 temporal epochs allowing for such analysis. We implemented those strategies in new tools that are being applied and further developed.

Progress report: improve atmospheric correction services.

Objective coordinators: Tim Wright (Leeds), Luke Bateson (BGS), Juliet Biggs (Bristol)
COMET Research Staff: Yasser Maghsoudi (Leeds), Milan Lazecky (Leeds)
Contributors: Fei Liu, COMET Research Student (Leeds)

The tropospheric correction service developed by COMET, known as GACOS, continues to support the LiCSAR system. As of March 2023, we have stored these crucial interferometric phase corrections for 80% of the 328,460 temporal epochs processed, and we routinely apply them in our time-series inversion procedures.

Additionally, we further explored possibilities on correcting ionosphere using Global Ionosphere Maps (GIM) and implemented a mechanism within LiCSAR processing chain to generate the ionospheric correction phase screens using solutions calculated by the Center for Orbit Determination in Europe (CODE). We improved LiCSAR coregistration routine and implemented corrections utilizing models IRI2016, CODE, and their experimental combination, of ionospheric disturbances inducing along-track offsets and line-of-sight phase delay (figure below) within daz toolbox and with ongoing implementation into LiCSBAS time series inversion tool.

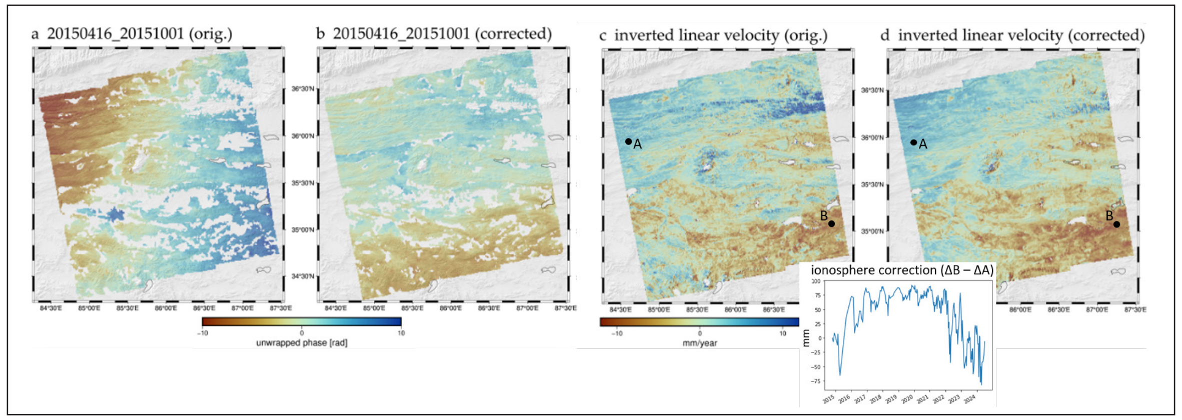


Figure 1: Selected unwrapped interferogram using phase before (a) and after (b) ionospheric phase screen correction based on CODE GIM, and effect of this correction on inverted time series velocity (c, d)

Progress report: extend the COMET-LiCSAR system to other satellites.

Objective coordinators: Andy Hooper (Leeds), Alessandro Novellino (BGS), Juliet Biggs (Bristol)
COMET Research Staff: Yasser Maghsoudi (Leeds), Milan Lazecky (Leeds)
Contributors: Lin Shen, COMET Postdoctoral Researcher (Leeds), Mark Bemelmans, COMET Research Student (Bristol), Eva Zand, COMET Research Student (Leeds)

We have reached an agreement with the Italian Space Agency for the addition of Cosmo-SkyMed products over the CEOS supersites to the COMET portfolio.

We will be using the NASA JPL-released software tool ISCE for the coregistration of the X-band data.

We will be able to produce and distribute interferograms for this constellation too, for example during volcanic crises.

In the long term, we plan to incorporate NISAR interferograms in the LiCSAR Earthquake InSAR Data Provider and Volcanic and Magmatic Deformation Portal. In this case, we are investigating the frames and orbit passes of the satellite and how we can use its acquisitions to cover Sentinel-1 areas with poor coherence/coverage.

SCIENCE UPDATE: EO DATA AND SERVICES

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

Progress report: semi-automation of satellite-derived displacement maps of large ground deformation signals, and of topography and topographic change.

Objective coordinators: Richard Walker (Oxford), Ekbal Hussain (BGS), John Elliott (Leeds)
COMET Research Staff: Tamarah King (Oxford), Scott Watson (Leeds), Milan Lazecky (Leeds)

One ongoing activity that contributes to this objective is a survey of active fault, landslide, and hydrological hazards along the South Caucasus infrastructure corridor (Leeds, Oxford). We are combining visual mapping with InSAR and optical image matching to identify faults and regions susceptible to landsliding. Working with the Global Earthquake Model (GEM) as a partner, we hope to build this information into improved risk assessment for infrastructure projects. A new CASE PhD studentship at Oxford (supervisor team in Oxford, BGS, Cambridge, CASE partner WTW Research Network) aims to develop strategies for monitoring multi-hazards for major infrastructure in the transport corridors of central Asia.

Progress report: utilize digital topographic data at global, regional, and local scales to aid the fieldwork activities of comet members and the mapping of hazards at regional scale.

Objective coordinators: Richard Walker (Oxford), Luke Bateson (BGS), Laura Gregory (Leeds)
COMET Research Staff: Tamarah King (Oxford)

This theme underpins a wide array of COMET-related research. Regional mapping efforts are ongoing in a number of places globally, including the Tien Shan of central Asia (co-funding from NATO SPS, Leverhulme Trust) and the South Caucasus (co-funding from EPSRC, industry). Imagery and digital topography is underpinning a number of studies recently published or ongoing, including studies of individual destructive earthquakes such as the 1948 Asgabat and 1935 Quetta earthquakes. A focus of effort over the past 12 months has been to organise, catalogue, and archive digital elevation models derived from high-resolution stereo optical data and field-based drone survey. These are now available on opentopography, and we aim for a short article (EOS or equivalent) to describe the importance of these kind of efforts in data sparse regions.

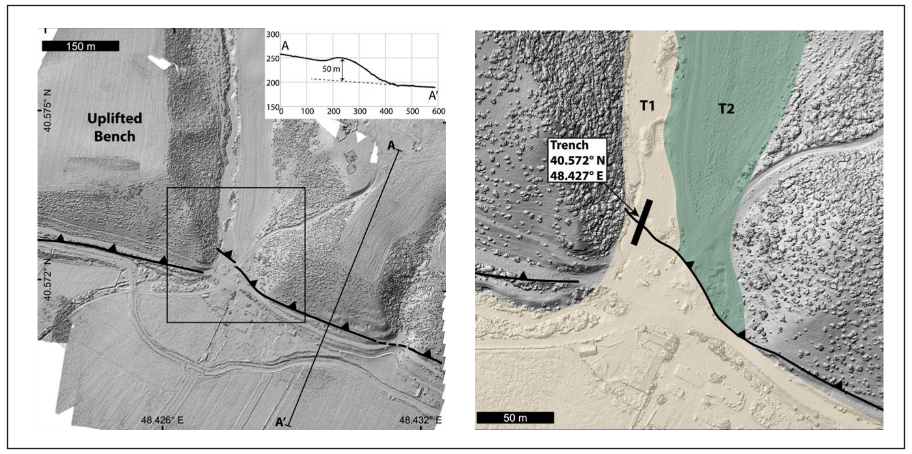
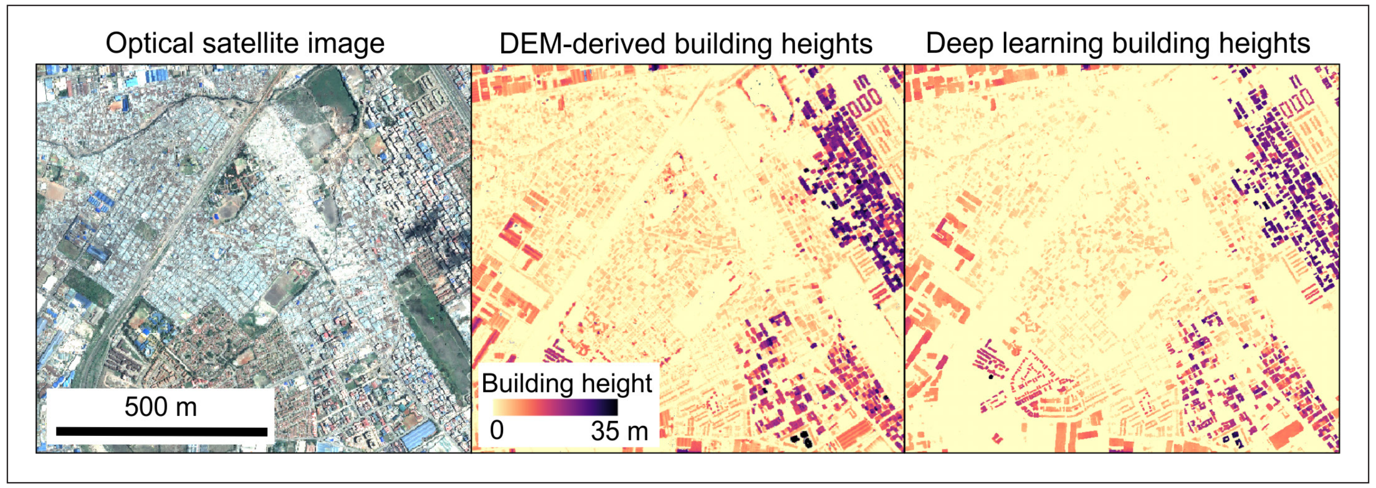


Figure 1: Figure is of a drone-based topographic survey of active faults in Azerbaijan, shown to be likely responsible for destructive earthquakes in 1668 and 1902 (Pierce et al., 2024).

Progress report: derivation and analysis of high-resolution topographic datasets for seismic hazard in and around cities.

Objective coordinators: John Elliott (Leeds), Ekbal Hussain (BGS), Richard Walker (Oxford)
COMET Research Staff: Tamarah King (Oxford), Scott Watson (Leeds), Milan Lazecky (Leeds)

Building on our work deriving high-resolution digital elevation models (DEMs) using satellite imagery, we have started to explore the use of these city DEMs to train generative adversarial network deep learning models to estimate building heights. Once trained, the model can estimate building heights using a single (non-stereo) optical satellite image. This information can then be used to update exposure datasets for use in seismic risk assessments, and would support ongoing collaborations with BGS aiming to quantify the material consumption of built environments. Our initial results for the city of Nairobi show this could be a promising approach to generate building height datasets without requiring costly high-resolution DEMs. We plan to expand our training and validation approach to other cities.



SCIENCE UPDATE: EO DATA AND SERVICES

3. Retrievals of volcanic emissions from satellite spectrometers

Progress report: adapt fast linear retrieval of ash and SO_2 to process data from IASI-NG and IRS.

Objective coordinators: Don Grainger (Oxford), Tamsin Mather (Oxford), Samantha Engwell (BGS)
COMET Research Staff: Ben Esse (Manchester), Isabelle Taylor (Oxford)

The IASI-NG and IRS instruments are due for launch in 2025 and the spectra are not expected to be available for some time after this. The existing linear SO_2 retrieval for IASI has been translated from IDL to Python to boost usability and accessibility, and to make it easier to adapt for future instruments. In addition, a student has worked on a new IASI linear retrieval for SO_2 which uses the v1 SO_2 absorption feature (rather than the v3) in preparation for MTG-IRS. This newer version of the linear retrieval has less sensitivity to SO_2 compared to using the v3 absorption band but nevertheless shows potential. It also shows some promise for lower altitude sources which were not captured with the original retrieval.

Near real-time data from the IASI SO_2 linear retrieval is available through the COMET volcano portal for recent acquisitions.

Progress report: extend existing SO_2 and ash time series and investigate retrievals for other volcanic species.

Objective coordinators: Don Grainger (Oxford), Tamsin Mather (Oxford), Samantha Engwell (BGS)
COMET Research Staff: Ben Esse (Manchester), Isabelle Taylor (Oxford)

Work has continued in maintaining the IASI long-term SO_2 datasets and preparing these for publication/archiving. Work has also begun on translating the existing linear retrievals into python. We were successful in obtaining Leverhulme and NERC grants allowing us to begin the development of new satellite retrievals for volcanic clouds. We plan for these to include SO_2, volcanic ash, H_2SO_4 and water vapour.

Additional work has focused on recent eruptions of note using both IR and UV instruments, including Tajogaite (La Palma, Spain, 2021), Hunga Tonga – Hunga Ha'apai (Tonga Islands, 2022) and the ongoing activity on the Reykjanes Peninsula, Iceland.

Progress report: automation of SO_2 flux time series retrievals.

Objective coordinators: Mike Burton (Manchester), Samantha Engwell (BGS), Marie Edmonds (Cambridge)
COMET Research Staff: Ben Esse (Manchester)

We have continued to monitor ongoing volcanic activity at specific volcanoes of interest using the daily SO_2 website hosted by the University of Manchester, specifically Etna (Italy), Villarrica (Chile) and on the Reykjanes Peninsula during this reporting year. This website is updated daily with emissions calculated with the PlumeTraj back-trajectory toolkit and the data have been used by the respective volcano observatories in the above areas for handling eruption response. We have also continued to work on global emission monitoring for all volcanoes worldwide (again using TROPOMI and PlumeTraj). This work is completed for 2024 and a publication is in preparation. Finally, we are preparing to set this up as an automated service hosted on JASMIN alongside the COMET Volcano Deformation Portal to run in near real-time and be freely available for all.

4. Geoinformatics and machine learning

Progress report: improve the sharing data and time series through the development of an integrated COMET data portal.

Objective coordinators: Susanna Ebmeier (Leeds), Luke Bateson (BGS), John Elliott (Leeds)
COMET Research Staff: Scott Watson (Leeds), Yasser Maghsoudi (Leeds), Milan Lazecky (Leeds), Isabelle Taylor (Oxford), Matt Gaddes (Leeds)

The COMET data portal now provides Synthetic Aperture Radar data through the LiCSAR Portal with additional tools available through the Earthquake InSAR Data Provider, Subsidence Portal and the Volcanic and Magmatic Deformation Portal. The LiCSAR portal now contains over 1,500,000 interferograms and was accessed over 1,000 times each month in the last year. This year a new bulk download capability was added to allow users to easily download their choice of data products for each frame. About 300 users from around the world (including Europe, America, South America and SE Asia) engage with the Volcanic and Magmatic Deformation Portal per month, with most interest generated by deformation from current eruptions. The Subsidence Portal is visited by > 60 engaged users per month, about half of whom are from Iran, with the most visited region page being the Western Tehran Plain.

Improvements to the Volcanic and Magmatic Deformation Portal in the last year included the addition of a range of resolutions for time series tools to suit different computational capacities of the user and the automated exclusion of defunct frames. We are currently working on adding new machine learning based tools to the volcano portal including LiCSAlert results and on automated quality control using daily updated statistics that will allow data to appear on portal automatically when the quality is good enough, without requiring human intervention. In response to the Turkyie-Syria earthquake in February 2023, we improved the LiCSAR Earthquake InSAR Data Provider to incorporate pixel offset tracking for large earthquakes. Automatically generated interferograms capturing the M6.8 earthquake in Morocco in September 2023 were used by BBC news. We also published an article (https://doi.org/10.5194/gc-6-75-2023) discussing strategies for improving the communication of satellite-derived InSAR through COMET's online InSAR portals.

The COMET Infrared Atmospheric Sounding Interferometer (IASI) Data Viewer was created to plot the latest sulphur dioxide retrieval on an interactive map (April 2023), which currently updates every ~10 minutes. The COMET IASI portal also links to a data archive. Future work will make the data archive more user friendly by providing a calendar search function and quick-look images.

SCIENCE UPDATE: EO DATA AND SERVICES

Progress report: develop machine learning approaches and tools that can be applied to COMET satellite data sets.

Objective coordinators: Andy Hooper (Leeds), Ekbal Hussain (BGS), Juliet Biggs (Bristol)
COMET Research Staff: Matt Gaddes (Leeds)
Additional contributors: Michelle Rygus (University of Pavia, Italy), Alessandro Novellino (BGS), Ekbal Hussain (BGS)

This work was funded primarily in this reporting period by the COMET co-funding projects ERC Consolidator Grants DEEPVOLC (Grant ID: 866085, PI: A. Hooper) and MAST (Grant ID: 101003173, PI: J. Biggs).

Many of the COMET machine learning approaches are applied to Sentinel-1 images that feature subaerial volcanoes with the goal of developing routine global monitoring. Work has therefore focussed on improving the quality of the data used by these algorithms, through collaboration with both scientists working on the COMET Volcanic and Magmatic Deformation Portal and The Centre for Environmental Modelling and Computation (CEMAC), Leeds. This initially required the rationalisation of various approaches, and has resulted in a single time series being calculated using LiCSBAS for each COMET volcano frame. The "Time series Analysis" and "LiCSAlert" (volcano monitoring algorithm) tabs on the Volcanic and Magmatic Deformation portal then use this single data source, allowing for any improvements that are made to the processing for a volcano to feed through to both products.

The LiCSAlert volcano monitoring algorithm was previously deployed on the JASMIN computing system to work towards providing routine global monitoring. To allow end users (such as volcano observatories) to view and explore the data easily, a web-based interface was developed, which is now hosted on the Volcanic and Magmatic Deformation Portal. Due to the complexities of interpreting the monitoring results for ~1500 volcanoes that are usually imaged by both ascending and descending satellite passes, a LiCSAlert dashboard has also been developed to allow a user to quickly determine if there are any volcanoes that the algorithm has detected as entering a period of unrest.

We have explored the use of unsupervised deep learning approaches for detecting volcanic deformation signals. Unliked supervised learning methods which require a balanced training dataset, which is often not representative, unsupervised learning methods train the model only on baseline data, when no volcanic deformation is occurring, and identify anomalous patterns which may correspond to deformation events. We tested three different state-of-the-art architectures, one convolutional neural network (PaDiM-Patch Distribution Modeling) and two generative models (GANomaly and DDPM), and develop a preprocessing approach to deal with noisy and incomplete data points. Our final anomaly detection outperforms the supervised learning, particularly where the characteristics of deformation are unknown (Popescu et al, in prep).

We have also retrained the convolutional neural network (CNN) that uses unwrapped data to classify different volcanic deformation types, and to determine the deformation's spatial extent. This involved replacing the now outdated encoder module (VGG16) with a more recent one (EfficientNetB0), and resulted in a clear improvement in model performance. This work has resulted in a publication (Gaddes et al, accepted).

We have continued work investigating machine learning approaches to extract meaningful insights from InSAR-derived displacement time series, including dimensionality reduction methods to improve time series clustering. We tested and applied this method in Bandung Indonesia, which resulted in a publication (Rygus et al, 2023).

We also explored the use of Interferometric Synthetic Aperture Radar (InSAR) techniques in monitoring ground groundwater-induced subsidence in the Bandung Basin, Indonesia. The first study proposed a framework involving dimensionality reduction, clustering, and change detection to interpret large InSAR datasets and investigate physical ground behavior (https://doi.org/10.3390/rs15153776). The second work, which is soon to be submitted, developed a hydro-geomechanical model for the basin to address the lack of historical pumping data and forecast future land subsidence and aquifer storage changes.

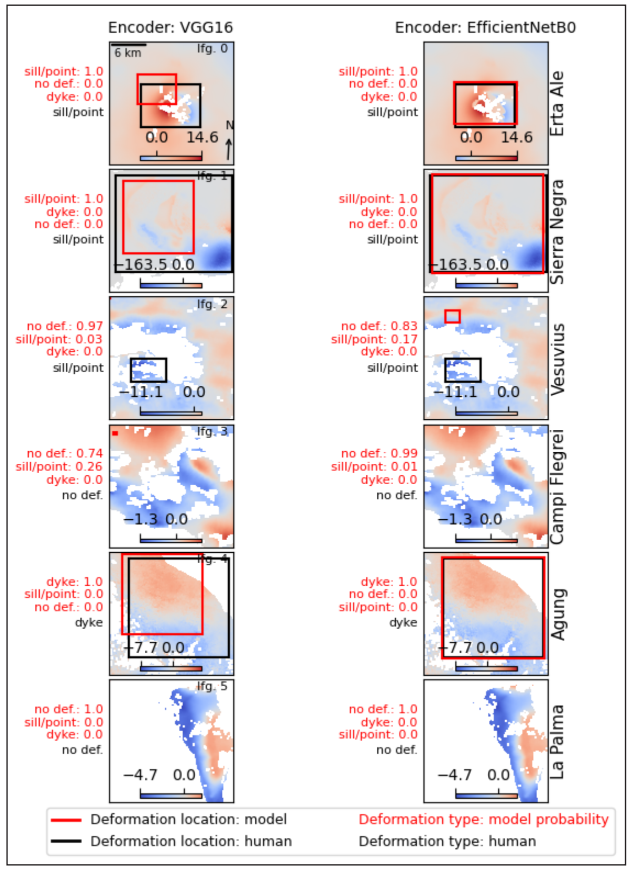


Figure 1: Results of applying our classification and localisation deep learning model to six Sentinel-1 interferograms (units: cm of LOS displacement). Text to the left of each interferogram shows the probabilistic model prediction of the deformation type (red), and human-generated label (black). Bounding boxes show the size and location of deformation predicted by the model (red), and from a human-generated label (black). Column one shows the results from a model trained with the VGG16 encoder, and column two with the newer EfficientNetB0 encoder which is better able to accurately locate deformation. At La Palma (row six), our model correctly identifies the signal as atmospheric ("no def.")".

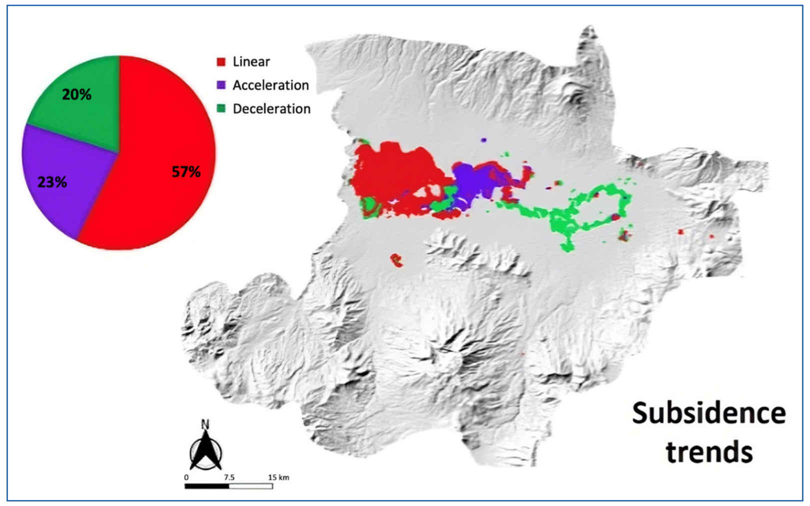


Figure 2: Map of the spatial distribution of the subsidence trend clusters extracted from the vertical displacement dataset. Figure reproduced from: Rygus, M.; Novellino, A.; Hussain, E.; Syafiudin, F.; Andreas, H.; Meisina, C. A Clustering Approach for the Analysis of InSAR Time Series: Application to the Bandung Basin (Indonesia). *Remote Sensing*. 2023, 15, 3776. https://doi.org/10.3390/rs15153776

RESEARCH HIGHLIGHTS: TECTONICS AND VOLCANISM

Research Highlight: Distinctive Magmatic Systems Share Common Response to Deep Magma Flux

Eoin Reddin, Postdoctoral Researcher, University of Galway

The western Galápagos islands of Isabela and Fernandina are amongst the most volcanically active regions on Earth. They are home to 6 major volcanoes: Wolf, Darwin, Fernandina, Alcedo, Sierra Negra, and Cerro Azul (Figure 1), all of which experience frequent eruptions, high-magnitude deformation, or periodic magmatic intrusions. The close proximity of these volcanoes, combined with frequent deformation and good year-round coherence, facilitates InSAR time series analysis and allows for their behaviour to be directly compared to one another. We identify characteristic differences in deformation style between each volcano, related to the maturity of the volcano and the sub-volcanic structure, as well as clear correlations in deformation time series. We show that correlated displacements consistently occur at these volcanoes during periods of increased magma supply to the shallow crust.

Using Sentinel-1 interferograms produced by the LiCSAR automatic interferometric processor (Lazecký et al., 2020), we construct time series of displacement for each of these volcanoes between 2017–2022. We address errors introduced by tropospheric phase delay using GACOS corrections (Yu et al., 2018), and construct displacement time series using LiCSBAS (Morishita et al., 2020). We perform subsequent analysis to constrain volumes of intruded magma using GBIS (Bagnardi and Hooper, 2018), and identify correlated displacements between volcanoes using correlation analysis, and independent component analysis (ICA).

By comparing this dataset with previous observations of deformation in the western Galápagos and with a synthesis of published literature, we show in Reddin et al. (2024) that magma storage conditions and the dynamics of volcanic unrest have been consistent for at least 30 years. At Wolf, we show that most magma influx occurs during eruptions, rapidly flushing through the volcanic system. We identify magmatic intrusion into the sub-volcanic system at Darwin, consistent with the resurgent-like behaviour seen at other volcanoes. We see frequent changes in deformation at Fernandina, and hypothesise that the 2020 eruption there may have had a sub-marine component. Alcedo has at least two distinct areas that are subsiding – one via a magmatic source and another from a hydrothermal source. Sierra Negra has some of the highest magnitude deformation of any volcano in the world, while unrest at Cerro Azul has been concentrated on the Eastern Flank for at least 30 years.

Despite the distinctive displacement patterns exhibited by each volcano, in Reddin et al. (2023), we show that there are frequent episodes of correlated deformation between volcanoes. By analysing our dataset using correlation analysis and ICA, we show that multiple volcanoes respond to fluxes in magma supply from the Galápagos plume, through interconnected magmatic systems (Figure 2). Magmas at each volcano are geochemically distinct (Kurz and Geist, 1999), sampling a different part of the plume. As such, we hypothesise that these correlations are driven by stress interactions at the base of the crust, influencing volume change in shallow magma reservoirs, while maintaining geochemical heterogeneity.

With these studies, we show the utility of leveraging dense InSAR datasets when applied to active volcanic settings. By first considering deformation local to each volcano, we identify characteristic unrest behaviour unique to each volcano. Then, by expanding the scope of our study to consider broader trends in deformation we show how bottom-up magma flux may influence multiple volcanoes simultaneously. These studies underscore the potential of the western Galápagos for future studies, given the abundant geodetic data, close cluster of volcanoes, and high degree of volcanic activity.

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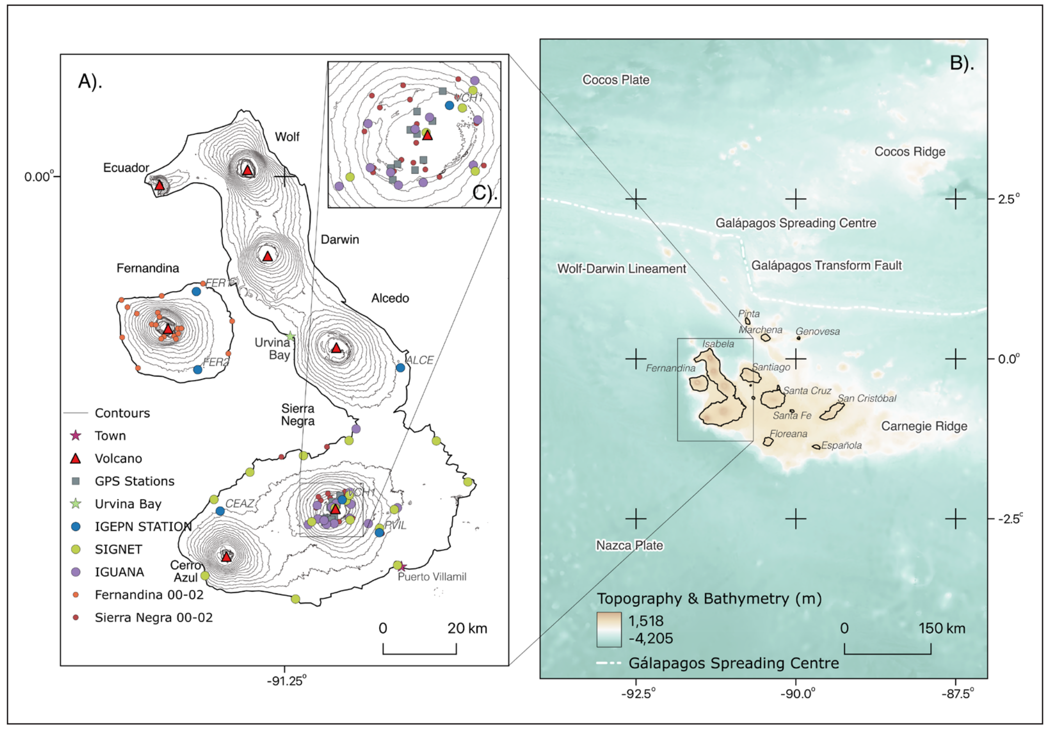

Figure 1: View of the broader setting of the Galápagos (from Reddin et al., (2024)). A). The western Galápagos islands of Isabela and Fernandina, showing the locations of major volcanoes (red triangles). Annotated is Puerto Villamil (the population centre on Isabela), Urvina Bay (location of a major unrest episode In 1954), and the locations of continuous and campaign ground-based monitoring. B). A regional view of the tectonic setting of the Galápagos. Tectonic faults, and plates are labelled, as are other Galápagos islands, while bathymetry and topography is indicated by the colorscale. C). Locations of monitoring equipment within the caldera at Sierra Negra, the most densely monitored Galápagos volcano.

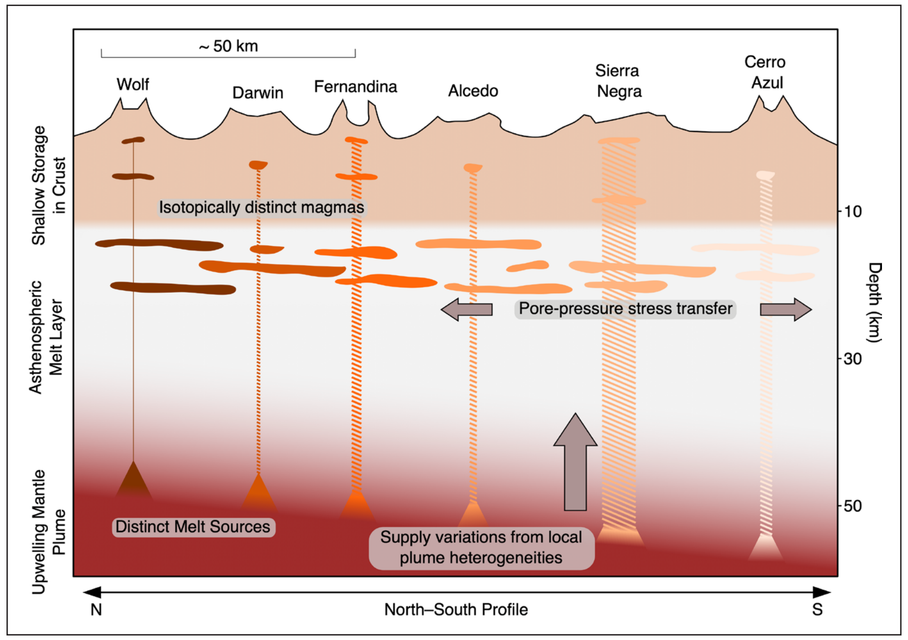

Figure 2: Illustration of the hypothesised bottom-up mechanism for correlated deformation in the western Galápagos volcanoes (from Reddin et al., (2023)). Recent magma supply to each volcano is given by the width of hatched areas, with Sierra Negra accounting for approximately 55% of the total supply since 2000. The volcanoes sample geochemically distinct plume sections. These distinct supplies are connected at the base of the crust through pore-pressure stress transfer between sills. The flux of magma to the shallow crust, causing measurable deformation, varies in magnitude and partitioning according to a combination of plume supply variations and eruption.

RESEARCH HIGHLIGHTS: TECTONICS AND VOLCANISM

Research Highlight: Monitoring Air Quality Impacts At The Litli-Hrútur 2023 Eruption, Iceland

Laura Wainman, COMET Research Student, University of Leeds
Evgenia Ilyinskaya, COMET Associate, University of Leeds
Josefa Sepulveda Araya, COMET Research Student, University of Leeds

The Litli-Hrútur eruption began on the 10th of July 2023, on the Reykjanes Peninsula in Iceland. The eruption was the third in three years, with two previous eruptions occurring in 2021 (Geldingadalir) and 2022 (Meradalir) within the Fagradalsfjall volcanic system (see Figure 1). The Litli-Hrútur eruption began with multiple fissures stretching for over 1 km, with an effusion rate of up to 50 m3/s during the first day of the eruption (Global Volcanism Program, 2023). Over the following days the fissures then reduced to form a single active cone (with a lower average effusion rate of 13 – 9 m3/s) which continued to spew lava to the south-west for several weeks.

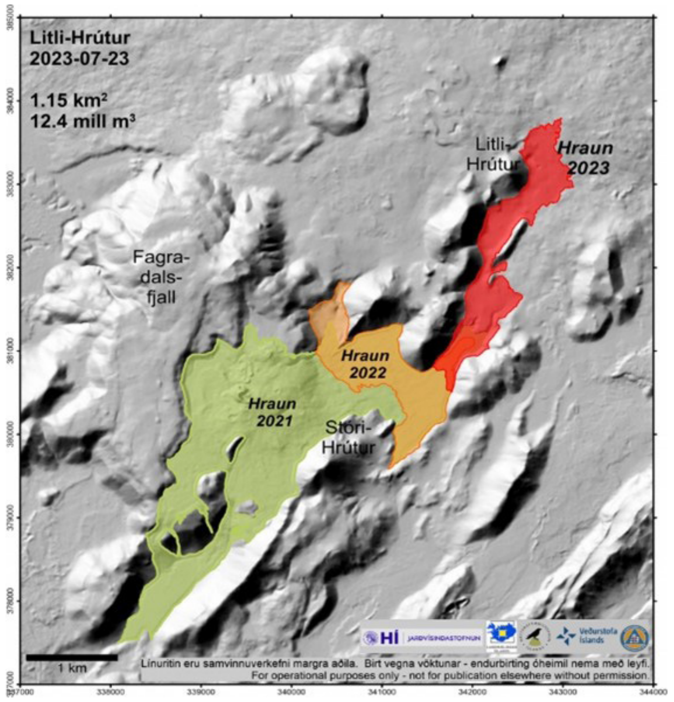

Figure 1: Map of lava flows from the 2021-23 agradalsfjall eruptions. Hraun = Year.

Owing to an unusually long summer dry spell the surrounding vegetation, which is predominantly moss and grasses in this part of Iceland, was readily combustible and easily ignited by the extending lava flows. This resulted in the most extensive wildfires on modern record in Iceland, covering over 2.5km², and being visible from space (NASA Earth Observatory, 2023).

The wildfires resulted in a dense and acrid smoke which covered much the area surrounding the eruption site and along with volcanic emissions, which consist of gases (such as SO_2, CO_2, H_2S, HCl) and particulate matter (PM) emitted from the main crater as well as extending lava flows, this severely impacted local air quality. With tourists and members of the public continuing to hike to the eruption, many without respiratory protection, concerns were raised over the potential for exposure to harmful levels of air pollution.

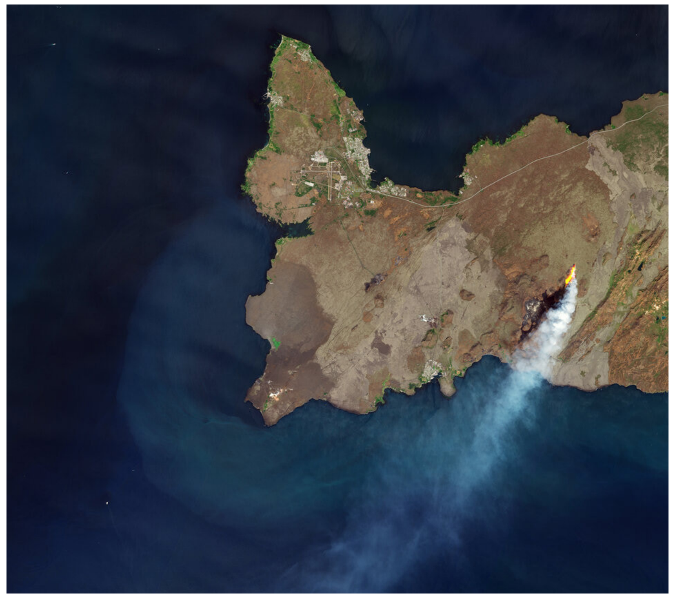

Figure 2: The Lilti-hrutur eruption captured by Sentinel-2. Image from ESA (2023).

In response, on the 17th of July 2023, a team from the University of Leeds joined an emergency 18-hr air quality monitoring campaign alongside researchers from the University of New Mexico and coordinated by the Icelandic Meteorological Office. A range of monitoring equipment was deployed using ground and drone-based platforms at different locations around the eruption site. This included optical particle counters (OPCs) to constrain the size distribution of particulate matter, as well as filter packs, and MultiGas instruments to characterise PM and gas compositions. We found elevated levels of PM10 and PM2.5 along the major hiking path used by tourists visiting the eruption site, with levels exceeding the safe limit for exposure as defined by the Environment Agency of Iceland and World Health Organisation (Figure 2). Consequently, the Icelandic Civil Defence advised all visitors to the eruption site to wear suitable respiratory protection.

Ongoing analysis of PM collected by filter pack sampling shows clear differences in the trace element compositions from different emission sources. For example, main vent emissions are dominated by chalcophile elements such as As, Te, Se, and Sn, whilst down-flow lava emissions are characterised by a higher proportion of Cl-complexing metals such as Cu, Zn, Rb, and Cs. The effects of mixing between volcanic and wildfire emissions are also being investigated, where preliminary SEM analysis shows fibrous organic material coating volcanically derived silicate particulates (Figure 3). The effects of mixing between volcanic and wildfire emissions are still poorly understood, but it may lead to a hybrid composition and altered air pollution characteristics.

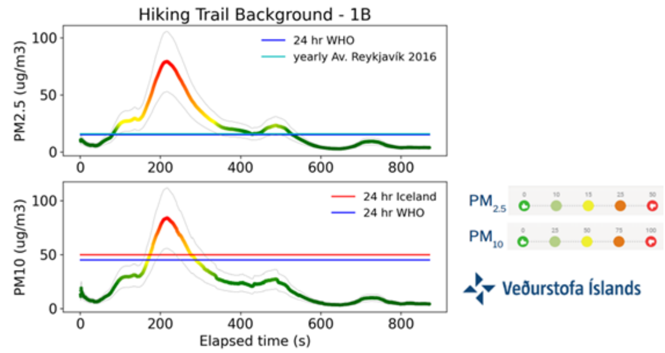

Figure 3: PM10 and PM2.5 concentrations measured using a ground-based OPC along the tourist hiking path at the Litli-Hrútur eruption site for 15 minutes. Within this time both exceeded safe exposure levels (defined by Environmental Agency of Iceland and WHO).

Since the end of the Litli-Hrútur eruption on 5th August 2023 there have been five further eruptions and two intrusions within the Svartsengi volcanic system, which lies to the west of the Fagradalsfjall system on the Reykjanes Peninsula. On the 14th of January 2024 lava flows reached the outskirts of the town of Grindavik, igniting and destroying three homes. The lava-urban interface (LUI) emissions, generated as lava flows burn houses or other infrastructure such as roads, are likely to have a distinct composition compared to end member volcanic or urban emission sources. Alongside volcanic air pollution, LUI are likely to contain additional halogens, NO_x and volatile organic compounds (VOCS) derived from burning human-made materials such as plastics. Subsequent field campaigns have been carried out by the University of Leeds team at eruptions throughout the past few months, although capturing the LUI emissions has proven difficult given the precise conditions needed and short timeframes of the recent eruptions (some lasting only 24-48 hrs). The team, led by Dr Ilyinskaya, were recently awarded a NERC Urgency grant to sample LUI emissions using drone-based platforms and are waiting for the next opportunity!

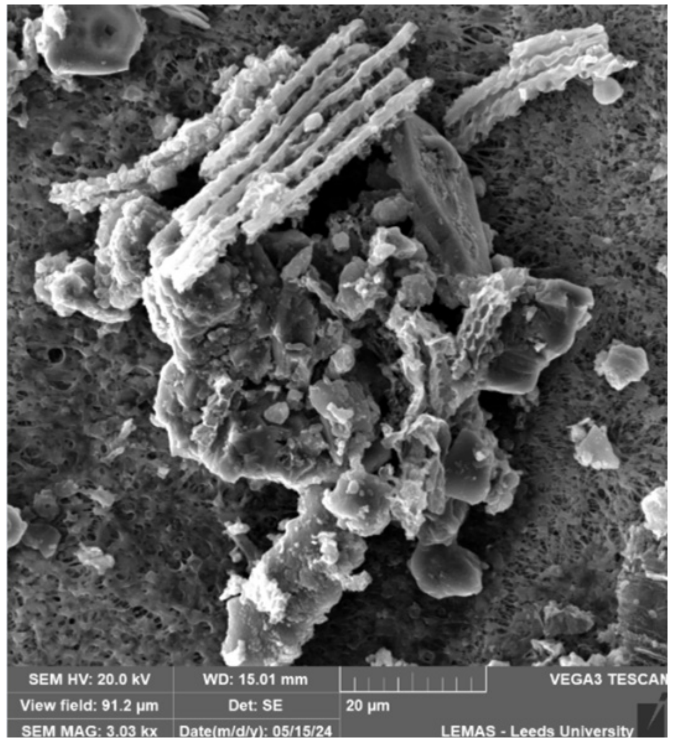

Figure 4: SEM image showing volcanically derived silicate particulate coated with fibrous burned organic matter. Sample collected in mixed volcanic-wildfire pollution along hiking path.

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RESEARCH HIGHLIGHTS: TECTONICS AND VOLCANISM

Research Highlight: Comparative Analysis of Deep Learning Seismic Phase Pickers in Detecting Hydraulic-Fracturing Induced Microseismicity from a Borehole Array

Cindy Lim Shin Yee, COMET Research Student, University of Bristol

Deep learning (DL) phase pickers have emerged as efficient and effective solutions to processing big data. These DL pickers have successfully detected earthquakes missed by other standard detection methods[18,19,20]. However, the applicability of these models to detect induced microseismicity in high-frequency borehole data is currently unclear.

We compare four established models (GPD, U-GPD, PhaseNet and EQTransformer) trained on regional earthquakes recorded at surface stations (100 Hz) in terms of their picking performance on high-frequency borehole data (2000 Hz) from the Preston New Road (PNR) unconventional shale gas site in the UK. Our benchmark dataset, the PNR-1z dataset[21] (Clarke et al., 2018), consists of continuously recorded waveforms containing over 38,000 seismic events previously catalogued, ranging in magnitudes from -2.8 to 1.1. This benchmark catalogue was generated by proprietary beamforming-based code modelled after the Coalescence Microseismic Mapping (CMM) method[22]. We analyse the picking performances and compare the number of events recalled from the CMM catalogue as well as the new events from the resulting DL catalogues. We also validate new model detections with an event moveout filter to ensure that the new events originate from the hydraulic fracturing stimulation zone.

Overall, PhaseNet and U-GPD yield the best arrival time precision, GPD recalls 60% of the existing catalogue but produces imprecise picks, and EQT, while capable of precise picks, frequently misses phase arrivals and only recalls 45.8% of the catalogue (Figure 1). Catalogue comparison results show that PhaseNet and U-GPD demonstrate exceptional recall rates of 95% and 76.6%, respectively, and additionally detect over 15,800 and 8,300 new events, respectively (Figure 2). These high recall rates are a testament to the generalisability of these models, including to the much higher frequencies and the borehole environment of the PNR-1z dataset.

PhaseNet's success could be attributed to its exposure to more diverse instrument data during training, along with its relatively small model size, which might mitigate overfitting to the training data. Figure 2b shows that U-GPD outperforms PhaseNet during high seismic activity due to its smaller window size (400-samples compared to PhaseNet's 3000-sample window). All models start missing events below Mw -0.5, indicating that additional training with microseismic datasets could be beneficial. Nonetheless, PhaseNet may already satisfy the monitoring requirements of some users without further modification, as it detected over 52,000 events at PNR.

These findings suggest that DL models can offer effective solutions to the big data challenge. They can be applied in an array of diverse settings, including the detection high-frequency, low magnitude seismicity in high sampling rates and can enhance risk mitigation strategies at unconventional exploration sites for both induced and natural seismicity. By leveraging these advanced models, we can achieve more efficient and accurate monitoring, leading to more informed decision-making during real-time microseismic monitoring.

This study was conducted in collaboration with Sacha Lapins, Margarita Segou and Maximilian Werner. The paper is in review in Geophysical Journal International[23].

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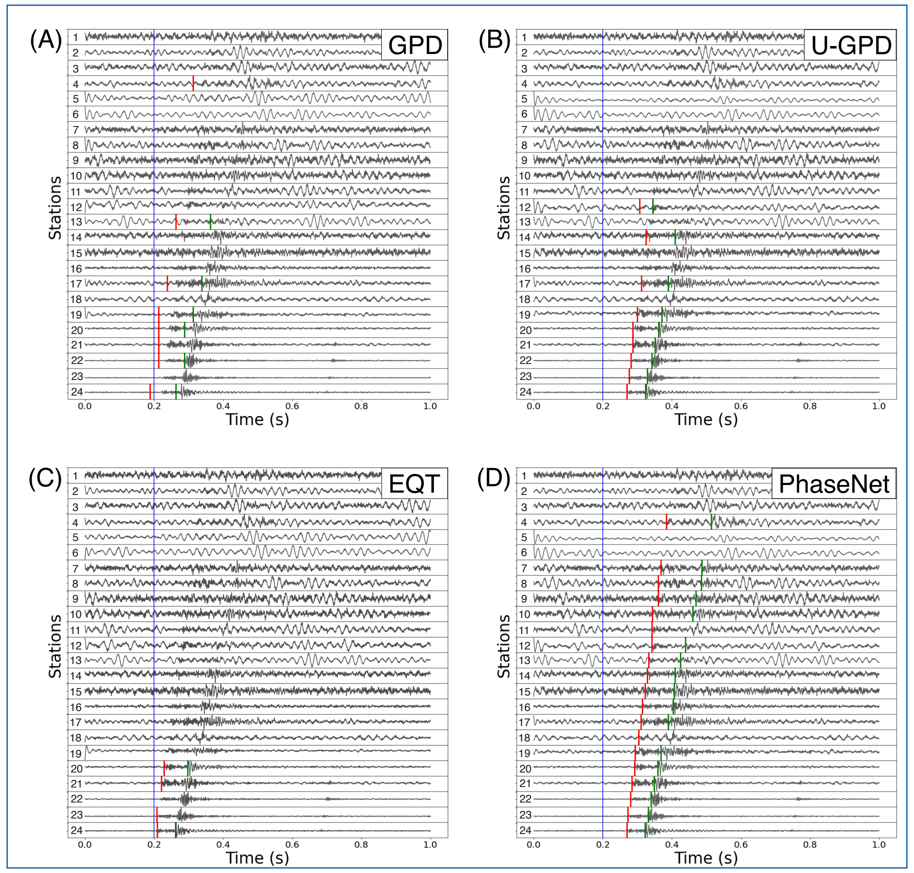

Figure 1: Seismograms (Z component) of the same event across the PNR-1z borehole array from Stations 1 to 24 (shallow to deep) showing the P-wave (red vertical lines) and S-wave (green vertical lines) phase picks from (A) GPD, (B) U-GPD, (C) EQTransformer and (D) PhaseNet. The blue vertical line across all stations is the inferred event origin time.

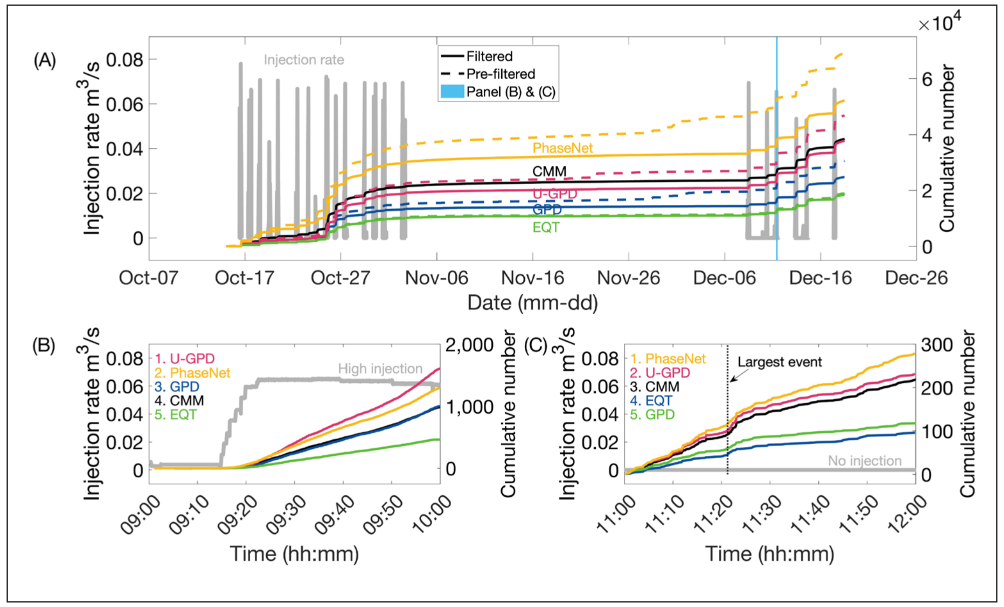

Figure 2: Temporal plots of the cumulative model detections (right y-axis) (A) across the PNR- 1z continuous dataset with injection rates (in grey, left y-axis) for PhaseNet (yellow), U-GPD (red), CMM (black), GPD (blue) and EQT (green). Solid lines represent the event-moveout filtered catalogue, while dashed lines represent the pre-filtered catalogue. One-hour windows during (B) high injection rate and high event rate, and (C) no injection but when the largest PNR-1z event occurred. Insets in (B) and (C) lists the performance ranking of the DL models and CMM method.

RESEARCH HIGHLIGHTS: TECTONICS AND VOLCANISM

Research Highlight: COMET in Deep Time: When and how did Continental Tectonics end up like it is now?

Alex Copley, COMET Scientist, University of Cambridge

It's fair to say that the Archean (the period of time from 4.0 to 2.5 billion years ago) does not feature very highly in the list of COMET topics of interest. So why is it worth you reading this text? Well, partly because it's always worthwhile hearing about things you don't already know, and partly because what was happening way back then established many of the first-order geological contrasts that govern how the continents deform at the present day. The most spectacular example is probably the stark contrast between the ancient rigid cores of the continents, and the younger regions that generally pervasively deform like piles of honey. This contrast controls a number of features of the present-day Earth that we want to understand, such as the locations, magnitudes, and depths of earthquakes, and the geometry and evolution of mountain belts and extensional basins.

The Archean was an unusual place by our standards: there was no complex life, the continents were barren, and there were no chips. There was much more radioactive heating in the crust than at the present day, because of the presence of isotopes formed in the supernova that created the interstellar cloud from which the Earth formed, and which have since decayed away. This was a time when many of the ancient cores of the continents, which are now rigid, were assembled and stabilised. So what are these continental cores, how did they form, and why are their properties so notable at the present day?

The dominant rock type in the Archean shields is something the petrologists call 'TTG', which is a family of igneous rocks closely related to granite, but with less potassium than is common in modern granites. To create such a chemical composition requires large amounts of melting of hydrated basalt, at high temperatures (e.g. over 900 °C). In crustal-scale seismological images, these regions of TTG are often seen to be made up of multiple stacked thrust sheets. Various exotic tectonic mechanisms have previously been suggested to explain these characteristics, but based upon current thinking about modern mountain belts, a new view has presented itself. All of the characteristics of TTG crust can be produced in a modern-style mountain belt, where deformable material is spreading out over a rigid base (e.g. like Tibet over India), but in the presence of hotter temperatures due to the higher amounts of radioactive isotopes present in the crust in the Archean. Such a viewpoint explains the composition and geometry of the rocks, and implies that as far back as we have an accessible rock record, the continents were behaving in the same manner as at the present day.

So why is it extremely rare to find a modern TTG? The decay in the rate of radiogenic heating over the Earth's history means that whilst previously many mountain belts could get hot enough to form TTGs, it is now only the very largest that would have a chance. Coupled to the gradual chemical evolution of the crust over Earth's history, the prevalence of TTGs therefore naturally decreases through time.

So what has all this got to do with earthquakes? Once formed, the TTGs then experienced subsequent mountain-building events within the still-hot Archean crust, which heated them up again, partially melted them, and removed all of the volatiles (including water). The resulting inert residue becomes extremely strong, and is insulated from the upper mantle by the thick lithospheric root that forms during the mountain-building. Once formed, these regions of dehydrated TTG then comprise the strong cores of the continents that characterise the present day. They are generally old because of the special conditions needed to create them (thick and very hot mountain belts), and there is therefore a limit at the present day to the rate at which strong crust can develop.

Taken together, the above results show that: (1) continental tectonics has operated in a similar manner to the present day since very early in the Earth's history, the only difference being the details of the compositions of the igneous rocks formed due to the temperatures experienced; (2) the mosaic of strong continental cores that dominate the geometry of present-day tectonic deformation have undergone a continual shifting of location, and sense of strain along their edges, but the volume of rigid crust is likely to have been set in the first half of Earth's history; and (3) the active deformation of the continents, including the locations and characteristics of earthquakes, is inextricably linked to the geological history of the rocks involved.

For more details, and for various other aspects of applying modern-day tectonic principles to the geological record, see: Alex Copley and Owen Weller, Modern-style continental tectonics since the early Archean, Precambrian Research, doi:10.1016/j.precamres.2024.107324, 2024. To see our local example of rigid, TTG, Archean crust, head to the Lewisian gneiss in NW Scotland.

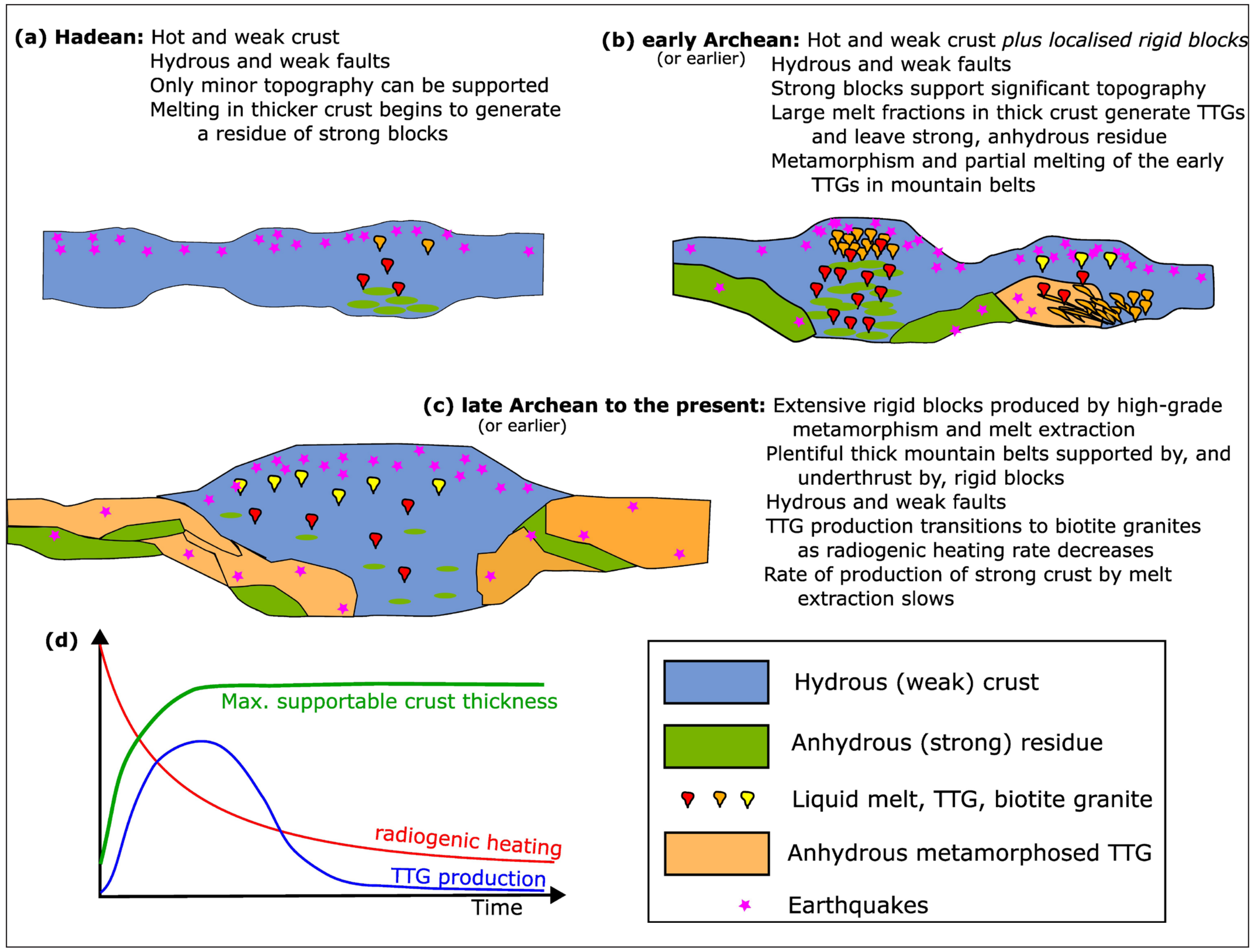

Figure 1: Schematic diagram of the evolution of continental deformation through Earth history.

SCIENCE UPDATES: TECTONICS AND VOLCANISM

1. Tectonics and Seismic Hazard

Progress report: develop and deploy a geodetically-based earthquake hazard model in partnership with the Global Earthquake Model.

Objective coordinators: Tim Wright (Leeds), Ekbal Hussain (BGS), Richard Walker (Oxford)
COMET Research Staff: Tamarah King (Oxford), Yasser Maghsoudi (Leeds), Milan Lazecky (Leeds), Qi Ou (Leeds)
Contributors: John Elliott (Leeds)

COMET and GEM have been formally collaborating since 2021 with the overarching aim of improving seismic hazard modelling in Central Asia, and exploring methods for closer integration of the latest scientific developments in areas such as satellite geodesy and palaeoseismology.

One of the aims of the partnership is to compare the observations of continental deformation across the region of Central Asia (as measured by the geodetic techniques of InSAR and GNSS), with the known active faulting of the region established through many previous geomorphological and geological studies. To this end, in work led by John Elliott and Qi Ou, we produced the first 500 m-resolution east and vertical velocity fields over the entire 2500 km-long 1000 km-wide Tianshan mountain range derived from 8 years of Sentinel-1 data (Figure 1). Using the LiCSAR system and the LiCSBAS software developed by COMET, we processed ~100,000 interferograms and analysed them using our newly improved unwrapping, error detection and correction, and time series analysis algorithms. This yielded 90 LiCS frames of line-of-sight velocities. To tie these frames together and reference the velocities to an absolute rather than relative frame, we compiled 4,321 regional GNSS velocities from 25 publications, rotated them into a common fixed-Eurasia reference frame, culled them based on several criteria, and finally combined them into a field of 882 velocities (568 2D and 314 3D) for the Tian Shan region, available at https://github.com/earjcr1/AHB_GPS/tree/main/tianshan).

Our velocity fields (Figure 1) show that the Tianshan is undergoing 5-6 mm/yr of east-west extension, with complex vertical motions. Shortening appears localised on range-frontal thrusts and basin-bounding faults, whereas extension is distributed across the range. Measurable strike-slip motion is observed on the sinistral Madan fault (2-3 mm/yr), and the dextral Talas Ferghana Fault (1-2 mm/yr).

Having compiled the geodetic and fault data sets (see below for updates on faulting) for the construction of the earthquake occurrence model. We created a working version of a homogenised instrumental as well as historical (i.e. macroseismic) earthquake catalogue and we worked at the construction of the fault-based component of the occurrence model using the active fault database compiled within the COMET-GEM collaboration.

This is feeding into updates of the Central Asia hazard model (CEA), which also includes sub-fault to multi-fault earthquake modelling, made possible by the development of GEM's software tool for the creation of these earthquake sources, FERMI. Both the development of FERMI and the CEA model are a work in progress, and the CEA model is serving as the test-case for modelling a very large (sub-continental scale) fault system. The current model shows progress; for example, it matches ~80% of the slip rates on the fault segments involved, but clearly needs additional improvements to the rupture rate inversion component of the model building process. These improvements are underway, and a high-quality time-independent hazard model of the region is expected to be completed in 2024.

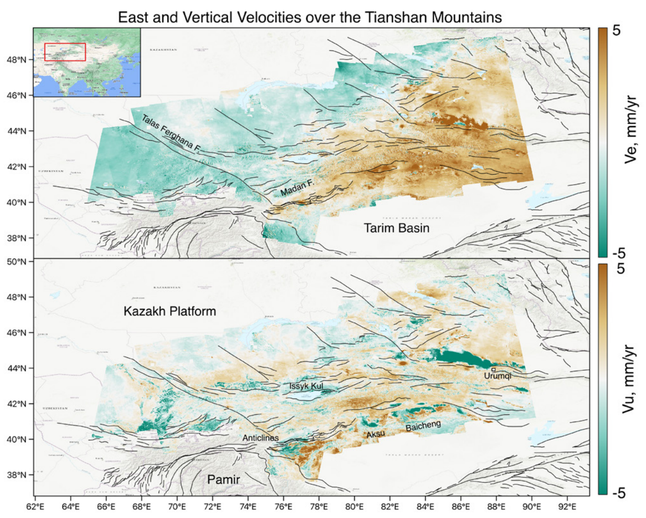

Figure 1: East and vertical velocities over the Tianshan derived from 8.5 years of Sentinel-1 InSAR data. Black lines show active faults from the GEM Active Fault Database.

Progress report: produce and deliver maps of active faults, incorporating new results regarding their rates of activity and past earthquakes.

Objective coordinators: Richard Walker (Oxford), Ilaria Mosca (BGS), Alex Copley (Cambridge)
COMET Research Staff: Tamarah King (Oxford), Neil Marshall (Oxford)

In the last year, Tamarah King left her post as the COMET Research Staff member assigned to this task, and we have recently appointed Neill Marshall to the role. Tamarah's digital compilation of active faults across central Asia is now in review, and available through the COMET web portal. Neill Marhsall is now leading a project aimed at assessed active fault distribution across the South Caucasus, including mapping and the development of paleoearthquake archives from trenching. Research Fellow Zakeria Shnizai (Oxford) is undertaking a region-wide survey and mapping of historical earthquakes in the western India-Eurasia plate boundary zone, including sources of significant hazard in Kabul (1505 earthquake) and Quetta (1935), and also the recent Herat quadruplet. All of these studies are aided by optical imagery and digital topography.

Progress report: assess temporal variations in strain across distributed fault networks.

Objective coordinators: Laura Gregory (Leeds), Brian Baptie (BGS), Richard Walker (Oxford)

One aspect of this theme is to combine geodetic constraints on strain accumulation with the long-term accommodation of that strain as slip on faults. The ability to assess long-term temporal changes in earthquake behaviour requires earthquake records spanning in excess of 1000 years in many places. COMET activities in this theme thus combine paleoseismic investigation, aided through satellite and low-altitude aerial survey, and integrating with geodetic and seismological techniques. Our main activities over the last year include 1) working with GEM (COMET-GEM collaboration, including a number of COMET partners) to assess temporal variation in earthquake behaviour in central Asia, 2) The development of paired InSAR velocity fields and tectonic geomorphology studies to assess the paucity of major historical earthquakes in the South Caucasus region (Oxford), 3) Assessment of completeness, reliability, and temporal variability in seismicity from historical catalogues in China. This was a masters student project, supervised by Qi Ou (Edinburgh) and Richard Walker (Oxford) along with industrial partners at Gallagher Re., 4) Publication of country-wide insar velocity field for Iran (Leeds), and submission of a paper directly comparing consistency between geodetic (InSAR, GNSS) and geological slip-rates on the major strike-slip faults of Iran (Oxford, colleagues in Iran).

Progress report: build dynamic models that can explain lithosphere deformation across timescales.

Objective coordinators: Alex Copley (Cambridge), Brian Baptie (BGS), Tim Craig (Leeds)

The progress in this objective has involved: 1) the development and application of tectonic models of the early Earth, and the subsequent evolution of material properties, to explore how the continents obtained the material properties that govern their present-day tectonic behaviour (Copley & Weller 2024[24]; see research highlight on page 30-31); 2) as a first step toward establishing the importance of igneous heat transport in controlling the temperature, and so rheology and deformation, of mountain belts, we have established a method to estimate the timescale, temperature, and mechanism of intrusion of granitic bodies (Copley et al 2023)[25], which we are now applying to a global compilation of data and to our new observations; 3) an examination of the rheology of foreland lithosphere, synthesising observations from the margins of multiple mountain belts (Wimpenny et al 2023)[26]; 4) a PhD student at Leeds is producing new results regarding the controls on long-term postseismic transients in extensional settings.

References:

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26. Sam Wimpenny, Tim Craig, Alice Blackwell, Lower Crustal Normal Faulting and Lithosphere Rheology in the Atlas Foreland, Journal of Geophysical Research: Solid Earth, https://doi.org/10.1029/2023JB028090, 2023.

SCIENCE UPDATES: TECTONICS AND VOLCANISM

2. Magmatism and Volcanic Hazard

Progress report: analyse long-term (decadal) patterns of volcanic activity globally.

Objective coordinators: Susanna Ebmeier (Leeds), Melanie Duncan (BGS), Marie Edmonds (Cambridge)

As the time spanned by systematic satellite radar data measurements increases, we can begin to assess long term trends in volcanic processes. Several researchers within COMET have been working with long time series of volcanic deformation to advance our understanding of volcanic processes around the world. Eoin Reddin has analysed deformation time series from the Western Galápagos to show that the location and geometries of reservoirs has been persistent for the past three decades (Reddin et al., 2024) and that displacements over at least the past five years show episodes of correlation between volcanoes, especially during periods of high magma flux, indicative of a zone of deep magmatic connectivity (Reddin et al., 2023). Edna Dualeh has used spatial Independent Component Analysis to isolate magmatic deformation from structurally-bound hydrothermal signals at Corbetti Caldera in Ethiopia where the magmatic signal shows uplift of 5.1 cm/yr, and deformation from the structurally controlled hydrothermal field has a seasonal signal with a magnitude of ~1 cm (Dualeh et al, in review, GRL).

Other recent case studies of long-term volcanic deformation include Fei Liu's work describing the onset of uplift and Socompa, Northern Chile (Liu et al., 2023), Josefa Sepulveda's analysis of recent uplift at Askja, Iceland and Pedro Espín Bedón's work on persistent co-eruptive uplift at Sangay, Ecuador (Espín Bedón et al., submitted to JVGR).

Long term displacement time series also present new challenges and opportunities for modelling. Ben Ireland is working on a regional catalogue of volcano deformation patterns for the East African Rift, including developing methods for automatic deformation modelling. Gregor Weber is working on integrating thermal models of crustal-scale magma evolution (105-106 years) with thermo-mechanical simulations of ground deformation (days-decades). His results reveal a coupling between surface deformation and the protracted thermal evolution of magma systems, modulated by magma flux and system lifespan. Relatively cold magma systems (~750˚C after 1Ma) exhibit cycles of uplift and subsidence, while comparatively hot plumbing systems (~900˚C after 1Ma) experience solely uplift, albeit at decaying rates. (Weber et al, in review, NComms).

Work is also continuing on long term SO_2 datasets derived from IASI data and the automated analysis of emission rates globally with TROPOMI since 2018.

Progress Report: assess the contribution of volcanic SO_2 to global climate and aviation.

Objective coordinators: Don Grainger (Oxford), Samantha Engwell (BGS), Matt Watson (Bristol)
COMET Research Staff: Isabelle Taylor (Oxford), Ben Esse (Manchester)
Contributors: Juliette Delbrel (Manchester), Mike Burton (Manchester), Cat Hayer (Manchester)

Work in this area has focussed on improving the quantification of SO_2 from the IASI & CrIS instruments.

Throughout the reporting year, our focus has been on aspects around SO2 hazard to aviation. Through the COMET PhD project led by Juliette Delbrel, we have worked to quantify the exposure of aircraft to volcanic SO_2. In particular, we have focused on aircraft affected by the 3 month-long 2021 eruption of Tajogaite volcano in the Canary Islands. Flight routes of an aircraft were superimposed onto SO_2 concentration information derived from back-trajectory analysis of the Tropospheric Monitoring Instrument (TROPOMI) SO_2 satellite imagery. This enabled an assessment of the SO_2 dosage the aircraft was subjected to. Results showed that the dose varied significantly due to geographical variations in SO_2 concentration but that they were below that of the current SO_2 human health thresholds.

COMET ANNUAL REPORT 2024

Progress report: develop and test the models needed for interpreting satellite data during volcanic crises.

Objective coordinators: Juliet Biggs (Bristol), Sue Loughlin (BGS), Andy Hooper (Leeds)
COMET Research Staff: Matt Gaddes (Leeds), Edna Dualeh (Bristol)
Contributors: Mark Bemelmans (Bristol), Pui Anantrasirichai (Bristol), Robert Popescu (Bristol), Ben Esse (Manchester)

During this reporting year, a wide range of work has been done in testing different methods to interpret SAR, InSAR and SO_2 measurements. High resolution SAR data was used to observe large flank motions at Merapi Volcano, through the development of pixel offset tracking methods. The detailed analysis demonstrated the advantages of using high-resolution SAR data at volcanoes where otherwise overlooked due to sensor resolution and magnitude of the motion (M. Bemelmans).

Further development of the open-source Geodetic Bayesian Inversion Software (GBIS) was carried out in response to the ultra-rapid intrusive activity and subsequent eruptions on the Reykjanes Peninsula in Iceland (A. Hooper), Sigmundsson et al (2024).

There have been continued efforts to develop automatic methods to automatically detect changes in ground deformation in InSAR through machine learning and signal separation methods (M. Gaddes, P. Anantrasirichai, R. Popescu). The LiCSAlert algorithm has been accurately used at a wide range of volcanoes to monitor deformation changes. Currently, it is being integrated onto the LiCS Volcano Portal to apply this monitoring globally (M. Gaddes; more info in "Geoinformatics and Machine Learning" update). Additionally, these methods have been used to distinguish between deformation sources with different spatial patterns (e.g., magmatic, hydrothermal) at caldera systems (E. Dualeh).

SO_2 timeseries have been used to investigate eruption processes by monitoring precursory degassing, identify changes in eruption styles and even demonstrated potential use in forecasting the evolution of volcanic activity. This work aims to be automated and applied to volcanoes worldwide (B. Esse).

IMPACT, INNOVATION AND INFLUENCE

Impact

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.

This year, COMET scientists were asked by the UK's Foreign, Commonwealth and Development Office (FCDO) to advise them on the Morocco earthquake. The response was led by BGS, but input was provided by the following COMET members: Brian Baptie, Ekbal Hussain, Alessandro Novellino and Tim Wright.

COMET has continued to develop lines of communication with the FCDO and has started work on useful resources for policymakers (in discussion with the FCDO) to ensure long-term, impactful engagement. Through our partnership with BGS, we also provide emergency advice for the Scientific Advisory Group in Emergencies (SAGE) and Cabinet Office Briefing Room (COBR) and further scientific expertise on volcanic hazards and impacts as requested to UK government departments and the European Emergency Response and Coordination Centre.

COMET Scientist Ekbal Hussain (BGS) was named on the new Seismic hazard model development programme for Indonesia. A paper on the Lembang Fault hazard (with Hussain as first author) that was published in 2023 led to media engagement and inclusion into the committtee preparing the new update to the seismic hazard map for Indonesia.

We have developed close 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. The COMET-GEM contract extension until December 2025 was finalised in this reporting period.

The FCDO supports the work of the Montserrat Volcano Observatory (MVO) and provides funding for the MVO Scientific Advisory Committee (SAC), who assess volcanic activity at Montserrat on an annual basis. COMET members sit on this committee and contribute to the UK's understanding of potential hazardous activity. In December 2023, the SAC produced a report that noted an increase in "unrest" at the volcano, but advised that: "the chance that explosions or pyroclastic flows will occur within the next year remains low. Continuous monitoring of the volcano is essential." The Secretary of State for Foreign, Commonwealth and Development Affairs was questioned about activity at the volcano in March 2023, and he drew upon the SAC's reports in his response.

COMET (led by Sam Wimpenny) also produced the COMET Guidelines for Safe, Inclusive and Equitable Research Fieldwork. The team hopes that these resources can promote open lines of communication when planning fieldwork activities and that they will be adapted as living documents with community input. Researchers are encouraged to acknowledge these guidelines in research publications if they use them to develop their fieldwork practices, such as adopting a code of conduct, to measure uptake and impact.

COMET Scientist, Tim Craig (University of Leeds), participated in a USGS Powell Centre workshop on Tsunami Hazards, aimed at informing the next iteration of the National Tsunami Hazard Map for the USA.

COMET (Jurgen Neuberg and Evgenia Ilyenskaya) contributed to a pilot study and position paper on air monitoring on Montserrat for the FCDO and the Government of Montserrat. The position paper will influence both the ongoing tender process of the Montserrat Observatory (MVO) and the future of air monitoring on Montserrat.

Members of COMET are working on an initiative with the Committee for Earth Observation Satellites (CEOS) Working Group on Disasters to support the uptake of satellite imagery by volcano observatories. G-VEWERS aims to be a permanent and sustainable effort to coordinate tasking, provision and in some cases analysis of satellite data to support volcano monitoring with biennial, renewable quotas for otherwise unavailable radar and optical imagery. We also sit on the Deep Carbon Observatory committee, 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, with COMET scientists selected for the Mission Advisory Group for Phase B2/C for Earth Explorer 10 mission Harmony, and Sentinel-1-NG.

Innovation

COMET actively contributes to codesigned and innovative research seeking to increase the use and benefits of data and development of tools and applications:

- COMET (Juliet Biggs) contributed to the Malawi Active Fault (MAFD)[27] and Seismogenic Source Model Databases (MSSM)[28]. The Malawi Seismogenic Source Model (MSSM)[28] is a geospatial database that documents the geometry, slip rate and seismogenic properties (i.e. earthquake magnitude and frequency) of active faults in Malawi. The MSSM is the first seismogenic source database in central and northern Malawi, and represents an update of the South Malawi Seismogenic Source Database[29] because it incorporates new active fault traces, new geodetic data (Wedmore et al., 2021)[30] and a statistical treatment of uncertainty, within a logic tree approach.

Influence

COMET members engage in activities of national and international importance in an advisory capacity:

Samantha Engwell (COMET Scientist, BGS) is 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.

Samantha Engwell (COMET Scientist, BGS) also holds a liason role between the International Union of Geodesy and Geophysics (IUGG) and International Civil Aviation Organization (ICAO) to aid communication of new research to operations, and operational needs to researchers.

Andy Hooper (COMET Scientist, University of Leeds) serves on the Mission Advisory Group for the Sentinel-1 NG mission, the follow on from the current Sentinel-1 satellite constellation.

Juliet Biggs (COMET Scientist, University of Bristol) and **Andy Hooper** (COMET Scientist, University of Leeds) both serve on the Harmony Mission Advisory Group for Earth Explorer 10.

Luke Bateson (COMET Scientist, BGS) and **Alessandro Novellino** (COMET Scientist, BGS) serve as members of the Advisory Board for the European Ground Motion Service (EGMS). The European Ground Motion Service (EGMS) provides consistent and reliable information regarding natural and anthropogenic ground motion over the Copernicus Participating States and across national borders, with millimetre accuracy. The EGMS represents a baseline for ground motion applications at continental, national and local level. For the first time, this service provides free and consistent information on ground motion for all of Europe. This quantative information is wide reaching and enables the public and government to be better informed on the hazards in their area.

Jurgen Neuberg (COMET Scientist, University of Leeds) Chairs the International Association of Seismology and Physics of the Earth's Interior (IASPE)/International Association of Volcanology and Chemistry of the Earth's Interior's (IAVCEI) Commission on Volcano Seismology & Acoustics and the European Seismological Commission's Seismic phenomena associated with volcanic activity Working Group.

Mike Burton (COMET Scientist, University of Manchester) and **Jurgen Neuberg** (COMET Scientist, University of Leeds) serve as members of the the Montserrat Scientific Advisory Committee (SAC).

References:

27. MAFD: Williams, J. N., Wedmore, L. N., Scholz, C. A., Kolawole, F., Wright, L. J., Shillington, D. J., ... & Werner, M. J. (2022). The Malawi active fault database: An onshore□offshore database for regional assessment of seismic hazard and tectonic evolution. Geochemistry, Geophysics, Geosystems, 23(5), e2022GC010425.
28. MSSM: Williams, J. N., Wedmore, L. N., Fagereng, Å., Werner, M. J., Mdala, H., Shillington, D. J., ... & Chindandali, P. (2021). Geologic and geodetic constraints on the seismic hazard of Malawi's active faults: The Malawi Seismogenic Source Database (MSSD). Natural Hazards and Earth System Sciences Discussions, 2021, 1-47.
29. Williams, J. N., Mdala, H., Fagereng, Å., Wedmore, L. N., Biggs, J., Dulanya, Z., ... & Mphepo, F. (2020). A systems-based approach to parameterise seismic hazard in regions with little historical or instrumental seismicity: The South Malawi Active Fault Database. Solid Earth Discussions, 2020, 1-101.
30. Wedmore, L. N., Biggs, J., Floyd, M., Fagereng, Å., Mdala, H., Chindandali, P., ... & Mphepo, F. (2021). Geodetic constraints on cratonic microplates and broad strain during rifting of thick Southern African lithosphere. Geophysical Research Letters, 48(17), e2021GL093785.

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. The COMET InSAR Training Workshop 2023 (7th-8th September 2023) was hosted both in-person and online with over 200 participants from 55 countries. Lectures and practical exercises included: InSAR backgrounds and basics, InSAR time series analysis, atmospheric effects and corrections, earthquake deformation and modelling, and InSAR volcanic applications and modelling. The practical sessions used Jupyter notebooks to allow participants to interactively analyse data. User feedback was overwhelmingly positive, with 100% of respondents (n=47) rating the workshop positively and stating they would recommend the workshop to colleagues.

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.

We also contribute to a wide range of external training courses, nationally and internationally.

Runner up in the COMET 2024 Photography/Image competition.
'Drone-eye view of the Litli-Hrutur eruption crater, Iceland July 2023'
Credit: Laura Wainman, University of Leeds

COMMUNICATION, OUTREACH AND ENGAGEMENT

Communication and public engagement are important aspects of COMET's mission as we want the science we produce 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.

Webinars

COMET webinars promote research from COMET scientists in 1 hr seminars (40 – 50 mins + questions), which are advertised to the wider scientific community, and uploaded to our YouTube channel, social media, and website.

The COMET and COMET+ webinars[31] have covered a number of topics, including: insights from the 2020 Mw6.0 Jiashi Earthquake in Tian Shan, aerosol formation in young volcanic plumes, a model of crustal deformation in the Mediterranean and Middle East, a nationwide assessment of subsidence induced hazard in Iran with InSAR, solid Earth deformation in the Antarctic Peninsula, and using GNSS observations for improving InSAR atmospheric corrections.

In total we have offered 5 COMET+ webinars and 2 COMET webinars within our normal programme of talks. The COMET+ webinar series showcases work across a diverse range of backgrounds and topics, and are usually presented by international colleagues or partners of COMET. We also created and uploaded 5 practical videos about our Research Fieldwork Guidelines for use by the scientific community.

Over the last year, we have had between 120-130 registrations per webinar, on average. The webinars and podcasts we uploaded to YouTube in this reporting period have reached a large audience, with approximately 1000 views and the fieldwork guidelines videos had an additional ~850 views.

Website and Social Media

The COMET website received 63,177 views and 26,659 visitors in the last year. The website highlights our research and latest news, but also provides access to our webinars, datasets and services, including the volcano deformation database.[32] We are currently updating the look and content of the website to ensure that it is user-friendly and up-to-date.

COMET continues to promote our research and the achievements of our members to a public audience through social media. We continued to grow our audience on social media platforms, gaining 338 Twitter followers over the last year – we now have 4077 followers.[33] Our Instagram followers have also risen by 40 people to 172.36 We also started a LinkedIn page, which now (June 2024) has 161 followers!

References:

31. comet.nerc.ac.uk/comet-webinar-series/
32. comet.nerc.ac.uk/volcanoes/
33. @nerc_comet
34. https://www.instagram.com/comet_nerc/

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Media

Our work is widely accessible online and in print and COMET experts are contacted by the media to provide expert information about a range of topics.[35] COMET members have commented on a wide range of topics and shared their research in the media over the last year, including on: the risks to aircraft from volcanic eruptions, Earth's newest "baby" volcano, the devastating 6.8 magnitude earthquake in Morocco on 8th September 2023, the series of earthquakes in Afghanistan that occured in 2023, PurpleAir and how it is helping researchers to study volcanic pollution, a defoming volcano in Naples, the historical context of the 2023 Türkiye earthquakes, an earthquake in Cornwall, a study that shed new light on ancient volcanoes' environmental impacts, earthquake evidence in Azerbaijan's Greater Caucasus mountains, and the volcanic unrest in Iceland.

Public Engagement and Outreach

COMET researchers attended public events and visited educational institutions to promote their research. The Royal Society's annual Summer Science Exhibition, for example, is a prestigious science public engagement event that has taken place in central London for more than 200 years. David Pyle, COMET Scientist based in Oxford's Department of Earth Sciences, was an exhibit lead at this event in 2023, presenting COMET-related volcanic research. He comments: *"We have created a multi-sensory and hands-on exhibit that will show how people have tried to sense or detect change at restless volcanoes both through observation and measurement; and how scientists use sensing data to understand what is happening underground."* COMET members have also given 7 talks to schools and undergraduate student groups in this reporting period.

Podcasts are an engaging and effective way of communicating research information to a public audience. The Infinite Monkey Cage presenters Brian Cox and Robin Ince were joined in July 2023 by COMET Scientist Professor Tamsin Mather (University of Oxford) alongside Professor Chris Jackson (Jacobs/Imperial College) to find out if supervolcanoes are something to worry about.

COMET Director Professor Tim Wright (Leeds) also shared the secrets of Earth's shifting tectonic plates with Emma Kennedy on Why? Podcast.

COMET members also regularly appear on the radio, such as COMET Scientist Dr Ekbal Hussain (BGS)'s interview for 'Hazard Science', Rangoli Radio, talking about his work and roles models, including COMET Director, Tim Wright.

Outreach Highlight: COMET at Girls in GeoScience
In July 2023, a group from the University of Bristol's volcanology group represented COMET at the Girls into Geoscience careers day at the University of Plymouth. The group, consisting of Volcanology PhD students Hannah Ellis and Ben Ireland, as well as MSc Volcanology students Alex Daniels and Anne-Marie Molina, delivered a workshop covering three different aspects of volcanological hazards.

References:

35. https://comet.nerc.ac.uk/in-the-news/

COMMUNICATION, OUTREACH AND ENGAGEMENT

Firstly, we showcased what volcanic rocks looked like under the microscope, and how this affects the types of eruptions they are likely to produce. Next, we put a volcanic twist on the classic Coke and Mentos experiment, thinking about how gas and overpressure impacts the energy of a volcanic eruption. Finally, and most relevant to COMET, we shared with the participants how we can monitor volcanoes remotely using drones, where the participants could explore vast 3D models of volcanic terrain created using drones.

All the material and instruction needed for these demos is available on the COMET outreach repository, available for use by any COMET-affiliated personnel.

Anne-Marie and Alex had the following to say about the experience: *"We were at Plymouth University representing COMET for an event called "Girls into Geoscience", where we talked about the different areas of volcanology to try and encourage these girls to pursue a career in geoscience! We wanted to pique their interest by showcasing volcanic rocks, drone imagery, and had a simulation of a volcanic eruption with a Coke and Mentos experiment.*

We loved seeing the girls get involved with the interactive activities which they may not have access to in a classroom and loved their questions for us. It was really rewarding to see the girls understand volcanic processes through our experiment and get a sense of the intricacies which take place prior to a volcanic eruption in different settings around the world. This was an amazing opportunity to speak to so many girls with different backgrounds that came together with an interest in geoscience. It felt great to be able to inspire some of them with our own stories and hopefully they'll pursue a career in geoscience!"

COMET EDI and Outreach Fund Highlight: The (S)AR-Sandbox
By Mark Bemelmans, University of Bristol

This past year I have started working on an Augmented-Reality (AR) sandbox to make some concepts of remote sensing and Earth Observation interactive and tangible. When thinking of Earth Science, many think of rocks, mountains, and minerals, with few thinking of earth observation satellites and what they can tell us about the shape of the earth and the geologic processes at play. This sandbox is a tool to bring those parts of earth science into the spotlight.

The sandbox is completely made from second-hand or repurposed materials (excluding the child-safe play sand). Thanks to Charles from the Earth Sciences workshop for converting the design ideas I had into reality. The sandbox uses an XBOX KinectTM to scan the surface of the sand to obtain its topography, and a projector to project the height map of the sand back onto itself. The effect is a colourful elevation map which you can change and interact with by moving the sand.

Figure 1: First successful test after several equipment failures.

I collected the materials for the project back in October 2023 together with Ben Blackledge from the School of Geographical Sciences at the University of Bristol, who had built a similar one a few years prior. He said that I would have the most trouble getting the code to work, but luckily for me, he was mostly wrong. It turned out the real problem was faulty equipment like a cable that destroyed several USB-ports on our laptops and a projector that failed upon arrival. Luckily, we were able to find replacements quickly and get the sandbox to work.

I showed the sandbox-off at the Volcanic and Magmatic Studies Group (VMSG) Annual meeting in January 2024 and it was a great success. Many people loved playing with the sand and making their own landscapes including a happy little volcano. It got interest from all sorts of attendees of the meeting and general members of the public who joined after a viewing of Into the Inferno at the event. Several were interested in how the technology worked to scan the surface of the sand and create the topographic map, which gave me the opportunity to talk about remote sensing and how we use satellites to do this for the entire globe!

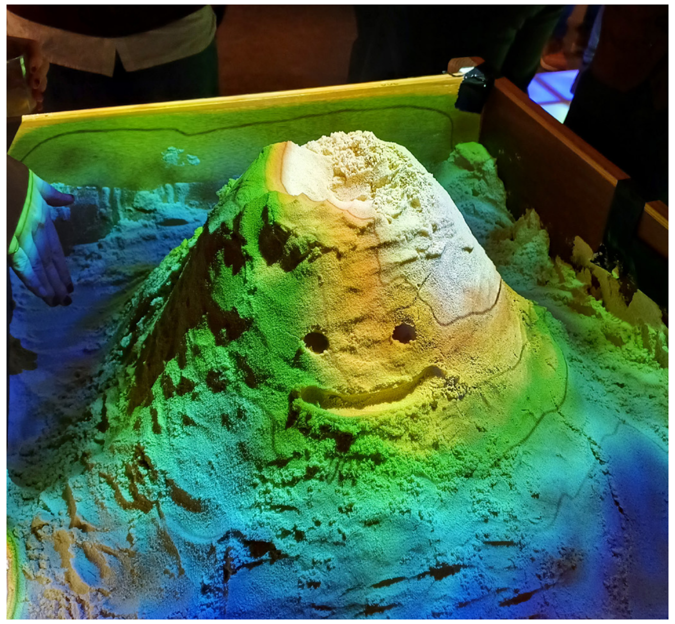


Figure 2: 'Happy Volcano' by Dan Manns
(source: https://x.com/DJCManns)

I plan to add more functionality to the sandbox soon, including an 'InSAR' mode that will be able to show changes to the elevation as surface displacement using fringes, just like you see in interferograms. I would also like to show lahar or landslide simulations with the sandbox to make those geologic hazards more tangible. Lastly, the sandbox can also be used in teaching. I am working to incorporate a geologic block model into the software that should help students understand 3D geological structures such as folds and faults and how they present themselves at the surface with varying topography. This project has been funded through the COMET Equality, Diversity, and Inclusion, and Outreach fund.

Be on the look-out for more sandbox related news and get in touch if you want the sandbox at your outreach event; it is semi-portable!

COLLABORATIONS AND PARTNERSHIPS

COMET has continued 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:

DEEPVOLC

DEEPVOLC is an ERC funded programme led by Andy Hooper at the University of Leeds that aims to forecast volcanic activity by applying artificial intelligence to new data. DEEPVOLC will apply deep learning algorithms to satellite data to combine knowledge from all volcanoes that have been active in the satellite-monitoring era. This will enable us to use knowledge of how volcanoes behave globally to identify deformation at volcanoes locally, and forecast how it will evolve. The aim is to create tools that can aid in forecasting of volcanic activity.

EPOS EUROPEAN PLATE OBSERVING SYSTEM

European Plate Observing System (EPOS)[36] ERIC Satellite Data TCS . 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.

EPOS ERIC is a continuation of the EPOS project aiming at creating a pan-European research infrastructure for solid Earth science to provide virtual access to data, products and services and physical access to facilities. Understanding how the Earth works as a system is critically important to modern society. Volcanic eruptions, earthquakes, floods, landslides and tsunamis are all Earth phenomena impacting on society. Solid Earth science is the place where to find answers on how to maintain the Earth a safe, prosperous, and habitable planet. Earth scientists use observational and experimental data to model how geo-hazards arise and evolve. EPOS, by providing open access to harmonized and quality-controlled data from diverse Earth science disciplines and by facilitating cross-disciplinary research, can contribute to this and other grand challenges.

GEM GLOBAL EARTHQUAKE MODEL working together to assess risk

GEM Global Earthquake Model (GEM)[37] - COMET has extended collaboration with GEM through a project aimed at improving probabilistic seismic hazard and risk assessment in Central Asia.

COMET and GEM have been formally collaborating since 2021 with the overarching aims of improving seismic hazard modelling in Central Asia and exploring methods for closer integration of the latest scientific developments in areas such as satellite geodesy and palaeoseismology.

Our initial three-year work programme was designed to begin in January 2021 and end at the end of 2023. However, NERC backdated the renewal meaning that the UK subscription expired in December 2022. In November 2022, we submitted a new proposal for the UK subscription, which included 3 years of continued collaboration starting in January 2023. The goals of this continued collaboration are described in the next section. The subscription was renewed in February 2023 for the period up to December 2025.

Under the terms of this collaboration, COMET receives annual funding equal to ¼ of the UK GEM subscription. This co-funds work on palaeoseismology and fault mapping (COMET post in Oxford) and InSAR work (COMET posts in Leeds). The funding is essentially to enable knowledge transfer of existing COMET activities in these areas into the GEM Central Asia seismic hazard model.

References:

36. https://www.epos-eu.org/epos-eric
37. https://www.globalquakemodel.org/gem

RISE Real-time earthquake risk reduction for a reSilient Europe

RISE (Real-Time Earthquake Risk Reduction for a Resilient Europe) - Earthquakes are the deadliest natural hazard. The aim of RISE is to develop tools and measures to reduce future human and economic losses. RISE is a three-year project financed by the Horizon 2020 programme of the European Commission and led by ETH Zurich.

Tomorrow's CITIES Urban Risk in Transition

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.[38]

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.

MAST

MAST: Imaging Magmatic Architecture using Strain Tomography Volcanologists watch for changes in magma that cause other phenomena. For instance, magma moving toward the surface usually causes swarms of earthquakes. With the aim of improving forecasting skills, the ERC-funded MAST project, led by Juliet Biggs (Bristol), will draw on the improved observations of magmatic systems. It will consider the geophysical and petrological evidence that a fluid-dominated 'magma chamber' is only one component of a much larger system with a heterogeneous distribution of melts, crystals and gases. The project will also use data collected by satellite images (dense time-series of high-resolution images), showing the complexity and diversity that was not apparent when only infrequent point measurements were available.

References:

38. https://tomorrowscities.org/

AWARDS AND RECOGNITION

Edna Dualeh (COMET Research Staff, University of Bristol) received the UK's Volcanic and Magmatic Studies Group's Willy Aspinall Prize for 2024. This is awarded to the lead author of an outstanding paper on applied volcanology or geoheritage published in English, who is within three years of their being awarded a PhD at a university in the UK.

Susanna Ebmeier (COMET Scientist, University of Leeds) won the individual ESA-EGU 2023 Earth Observation Excellence Award. Susanna's work focuses on using satellite images to further the scientific understanding of volcanic processes. This award honours individual scientists that have contributed to the innovative use of Earth observation data.

Samantha Engwell (COMET Scientist, BGS) 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.

David Pyle (COMET Scientist, University of Oxford) was awarded the 2024 Murchison Medal, awarded by the Geological Society of London for his considerable contributions to the field of volcanology. The Murchison Medal is awarded to geologists who have contributed significantly to 'hard' rock studies.

EQUITY, DIVERSITY AND INCLUSION

COMET is committed to delivering practical changes that help increase equity, diversity, and inclusion within our community.

During 2023-2024 the COMET EDI Action Group's activities have included:

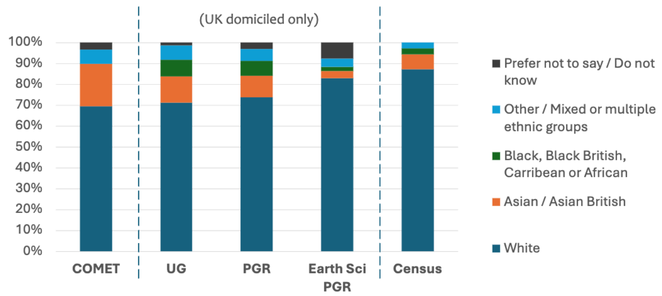
- Completing and publishing the COMET Fieldwork Guidelines project with 5 videos available on YouTube, and a Code of Conduct and Ethics and Inclusivity Assessment available on the COMET website. We also published a Comment in Nature Geoscience outlining the findings of the project and sharing the guidelines more widely.
- Acquired further £35k funding from Research England to support the PRIDE project looking specifically at the challenges facing LGBTQ+ researchers during fieldwork. Project is currently ongoing and includes Wimpenny and Watson as Co-I.
- Developed the COMET Remote Sensing of Disasters Working Group to bring together a community of researchers to reflect on how COMET science is and should be shared/used during disasters. First meeting scheduled for the Summer Meeting and will meet 4 times per year.
- Funded three projects through the EDI/Outreach Fund: Topography Sandbox [Bemelmens], outreach on seismic hazard in Nepal [Wainman], Schools Outreach in Leeds [Watson].
- Organised and funded two COMET Summer Internships with students now selected and preparing to undertake their projects. Received 60 applicants for 2 positions this year, highlighting their continued popularity.
- Continued to collect Diversity Monitoring data, which feeds forward into the working group's activities and strategies to increase the diversity of COMET's membership.
- Contributed to COMET's EDI statement which forms a component of our National Capability Funding and was included in the 2024/2029 science programme proposal.
- Developing a 1-page primer for international students on hidden costs associated with PhD funding and projects in the UK (ongoing).

COMET Diversity Monitoring Results 2024

Since 2020, COMET has conducted annual diversity monitoring with the intention of identifying focus communities for EDI and Outreach efforts.

Key Result 1: Ethnic Diversity in COMET

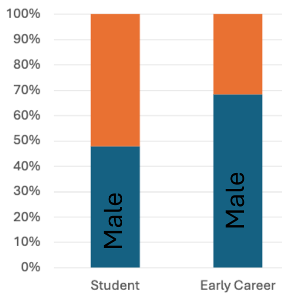
Although diverse, the COMET community underrepresents Black, Black British, Caribbean and African scientists. This trend is present in Earth Science PGRs everywhere and is persistent over 4 years.



Interventions: (1) Research internships support students from non-traditional backgrounds build their CV and we advertise these opportunities on targeted mailing lists (e.g. Black in Geoscience); (2) COMET+ webinars aim to increase the visibility of the excellent research of our diverse collaborative community.

Key Result 2: Who Does COMET Lose?

COMET loses 20% of young women scientists in the jump from PGR to post-doc/early career.



Interventions: (1) COMET Women's Network provides mentorship and support to young women scientists; (2) EDI committee forward workshops by other women's networks that support career development to our members; (3) current action by the EDI committee to develop fellowship/grant support network for early-career scientists.

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OUR MEMBERS, APRIL 2023 - MARCH 2024

COMET Directorate

Professor Tim Wright (Leeds) - COMET Director

Professor Juliet Biggs (Bristol) - Deputy Director (Volcanoes)

Professor Alex Copley (Cambridge) - Deputy Director (Earthquakes and Tectonics)

Professor Don Grainger (Oxford) - Deputy Director (Earth Observation)

Luke Bateson (BGS) - BGS Representative

Dr Susan Loughlin (BGS) – BGS Representative

Suzanne Banks (Leeds) - COMET Finance Administrator

Charlotte Royle (Leeds) - COMET Manager

Lucy Sharpson (Leeds) - COMET Research and Events Officer

COMET Scientists

As well as contributing to our objectives and partnerships through co-funded projects, COMET Scientists play a key role in internal review and forward planning for the COMET science programme.

Dr Pui Anantrasirichai (Bristol)

Dr Brian Baptie (BGS)

Professor Mike Burton (Manchester)

Dr Timothy Craig (Leeds)

Dr Melanie Jane Duncan (BGS)

Professor Marie Edmonds (Cambridge)

Dr John Elliott (Leeds)

Dr Samantha Engwell (BGS)

Dr Laura Gregory (Leeds)

Dr Jessica Hawthorne (Oxford)

Professor Andy Hooper (Leeds)

Dr Ekbal Hussain (BGS)

Professor Tamsin Mather (Oxford)

Dr Ilaria Mosca (BGS)

Professor Jurgen (Locko) Neuberg (Leeds)

Dr Alessandro Novellino (BGS)

Professor David Pyle (Oxford)

Dr Margarita Segou (BGS)

Professor Richard Walker (Oxford)

Professor Matthew Watson (Bristol)

Dr Max Werner (Bristol)

Dr Sam Wimpenny (Bristol)

Dr Annie Winson (BGS)

Professor Marek Ziebart (UCL)

COMET Emeritus

Professor Philip England (Oxford)

Professor Gregory Houseman (Leeds)

Professor James Jackson (Cambridge)

Dr David Kerridge (BGS)

Professor Barry Parsons (Oxford)

Professor Geoff Wadge (Reading)

COMET Research Staff

COMET Research Staff are all directly funded by core COMET National Capability funding.

Dr Edna Dualeh (Bristol)

Dr Matthew Gaddes (Leeds)

Dr Tamarah King (Oxford)

Dr Milan Lazecky (Leeds)

Dr Yasser Maghsoudi (Leeds)

Dr Qi Ou (Leeds)

Dr Isabelle Taylor (Oxford)

Dr C. Scott Watson (Leeds)

COMET Postdoctoral Researchers

COMET Postdoctoral Researchers usually work directly with or are supervised by a COMET Scientist or Associate.

Dr Rami Alshembari (Exeter)

Dr Jose Bayona (Bristol)

Dr Ben Esse (Manchester)

Dr Sacha Lapins (Bristol)

Dr Lorenzo Mantiloni (Exeter)

Dr Camila Novoa Lizama (Leeds)

Dr Odysseas Pappas (Bristol)

Dr Ian Pierce (Oxford)

Dr Lin Shen (Leeds)

Dr Gregor Weber (Bristol)

Dr Luke Wedmore (Bristol)

Dr Stanley Yip (Leeds)

OUR MEMBERS, APRIL 2023 - MARCH 2024

COMET Associates

COMET Associate Scientists are collaborators who are engaged with our science programme; this includes postdoctoral researchers with independent research fellowships who are based in COMET research teams. Associates are not funded by COMET, but are invited to annual science meetings (and other meetings as appropriate), included in internal communications, and encouraged to collaborate and engage with other COMET members for mutual benefit.

Dr Philip Benson (Portsmouth)
Dr Lidong Bie (UEA)
Dr Sarah Boulton (Plymouth)
Professor Peter Clarke (Newcastle)
Dr James Dalziel (WTW Research Network)
Professor Amy Donovan (Cambridge)
Professor Ake Fagereng (Cardiff)
Dr David Ferguson (Leeds)
Dr Matt Fox (UCL)
Dr Adriano Gualandi (Cambridge)
Dr Ping He (Leeds)
Dr James Hickey (Exeter)
Dr Anna Hicks (BGS)
Holly Hourston (BGS)
Dr Evgenia Ilyinskaya (Leeds)
Professor Mike Kendall (Oxford)
Professor Zhenhong Li (Newcastle)
Dr Emma McAllister (BGS)
Erin Mills (BGS)
Dr Brendan McCormick Kilbride (Manchester)
Dr Craig Magee (Leeds)
Dr Zoe Mildon (Plymouth)
Dr Andy Nowacki (Leeds)
Dr Tom Pering (Sheffield)
Dr Margherita Polacci (Manchester)
Professor Ed Rhodes (Sheffield)
Dr Chris Rollins (GNS Science/Leeds)
Dr Dylan Rood (Imperial)
Dr Peter Rowley (Bristol)
Dr Susanne Sargeant (BGS)
Dr Anja Schmidt (Cambridge/ DLR & LMU Munich)
Dr Margarita Segou (BGS)
Dr Victoria Smith (BGS)
Dr Maximillian Van Wyk de Vries (Cambridge)
Dr Charlotte Vye-Brown (BGS)
Dr Tom Wilkes (Sheffield)
Dr Gang Zheng (Leeds)

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COMET Students

All COMET students receive supervision from COMET members. While a few studentships are funded directly by COMET, most of the students within the COMET community are externally funded.

I Made Kris Adi Astra (Oxford)
Josefa Sepulveda Araya (Leeds)
Simon Orrego Astudillo (Bristol)
Pedro Espin Bedon (Leeds)
Mark Bemelmans (Bristol)
Rachel Bilsland (Leeds)
Alice Blackwell (Leeds)
Reza Bordbari (Leeds)
Felix Boschetty (Leeds)
Jack Campbell (Cambridge)
Manon Carpenter (Leeds)
Jennifer Castelino (Leeds)
Anna Pardo Cofrades (Manchester)
Rebecca Colquhoun (Oxford)
John Condon (Leeds)
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ALL COMET PUBLICATIONS APRIL 2023 - MARCH 2024

COMET has a strong publication record: since 2014, COMET has published 783 papers in international scientific journals, including 73 in Science or Nature Research journals, attracting 38239 citations to date.

77 were published between 1 April 2023 and 31 March 2024, and, of these, 14 had student first authors.

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Askja Caldera, Iceland, summer 2023
Credit: Josefa Sepulveda Araya, University of Leeds

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GLOSSARY

AG-VSA	Advisory group for volcanic science applications for aviation
AHB	Alpine-Himalayan Belt
AR	Augmented-Reality
BGS	British Geological Survey
CASE	Collaborative Awards in Science and Engineering
CCS	Carbon Capture and Storage
CEA	Central Asia Hazard Model
CEDA	The Centre for Environmental Data Analysis
CEMAC	The Centre for Environmental Modelling and Computation
CEOS	Committee on Earth Observation Satellites
CNN	Convolutional Neural Network
CMM	Coalescence Microseismic Mapping
COBR	Civil Contingencies Committee
CODE	Center for Orbit Determination in Europe
COMET	Centre for the Observation and Modelling of Earthquakes, Volcanoes and Tectonics
CoMHaz	The Cambridge Complex and Multihazard research group
COSMO-SkyMED	SAR Sensor
CrIS	Cross-track Infrared Sounder
DAS	Distributed Acoustic Sensing
DDPM	Denoising diffusion probabilistic models
DEEPVOLC	Forecasting Volcanic Activity Using Deep Learning
DEM	Digital Elevation Model
DL	Deep learning
DMM	Dynamic Magma Mush
DRR	Disaster Risk Reduction
DTM	Digital Terrain Model
DV3M	Dynamic Magma-Mush Models
EDI	Equity, Diversity and Inclusion
EGMS	European Ground Motion Service
EGMS	The European Ground Motion Service
EO	Earth Observation
EOS	Earth Observing System
EPOS	European Plate Observing System
EPOS ERIC	European Research Infrastructure Consortium
EPSRC	Engineering and Physical Sciences Research Council
EPSRC IAA	Impact Acceleration Account
ERC	European Research Council
ESA	European Space Agency
FCDO	Foreign, Commonwealth & Development Office
FERMI	GEM's new fault modelling tool
GACOS	Generic Atmospheric Correction Online Service for InSAR
GANomaly	Semi-Supervised Anomaly Detection via Adversarial Training
GBIS	Geodetic Bayesian Inversion Software
GCRF	Global Challenges Research Fund
GEM	Global Earthquake Model
GFZ	German Research Centre for Geosciences
GIM	Global Ionosphere Maps
GVM	Global Volcano Model
HRM	20 m sub-sampled versions of the TDX Single Look Complex data
IASI	Infrared Atmospheric Sounding Interferometer
IASI-NG	Infrared Atomospheric Sounding Interferometer-Next Generation
IASPE	International Association of Seismology and Physics of the Earth's Interior
IAVCEI	International Association of Volcanology and Chemistry of the Earth's Interior's
ICA	Independent Component Analysis
ICAO	International Civil Aviation Organization
IDL	Interactive Data Language
INGV	National Institute of Geophysics and Volcanology
InSAR	Synthetic Aperture Radar Interferometry
IR	Infrared
IRS	InfraRed Sounder
IUGG	International Union of Geodesy and Geophysics
ISCE	InSAR Scientific Computing Environment
JASMIN	Globally-Unique Data Analysis Facility
JVGR	Journal of Volcanology and Geothermal Research
LAI	Leaf Area Index
LGBTQ+	Lesbian, gay, bisexual, transgender and queer or questioning
LiCS	Looking inside the Continents from Space
LiCSAlert	An algorithm to detect changes in the signals at sub-aerial volcanoes that are imaged by the Sentinel-1 satellites
LICSAR	COMET-LICS InSAR processing suite, built on top of Gamma Remote Sensing InSAR software
LICSBAS	An open-source package in Python and bash to carry out InSAR time series analysis using LiCSAR products
LUI	Lava Urban Interface
MAGMA	Magma Accommodation and Ground Movement Analysis
MAST	Imaging Magmatic Architecture using Strain Tomography
MSSM	The Malawi Seismogenic Source Model
MTG-IRS	Meteosat third generation infrared sounder
MVO	Montserrat Volcano Observatory
NASA	US Space Agency (National Aeronautics and Space Administration)
NASA-JPL	National Aeronautics and Space Administration-Jet Propulsion Laboratory
NATO SPS	North Atlantic Treaty Organisation
NCEO	National Centre for Earth Observation
NERC	Natural Environment Research Council
NGO	Non-Governmental Organisation
NISAR	NASA-ISRO SAR Mission
PaDiM	Patch Distribution Modeling
PM	Particulate Matter
PNR	Preston New Road
RISE	Real-Time Earthquake Risk Reduction for a Resilient Europe
SAC	Scientific Advisory Committee
SAGE	Scientific Advisory Group in Emergencies
SEM	Scanning Electron Microscope
Sentinel-1	Constellation of Two Satellites
SMSSD	The South Malawi Seismogenic Source Database
SRTM	Shuttle Radar Topography Mission
TanDEM-X	TerraSAR-X add-on for Digital Elevation Measurement
TDX	TanDEM-X
TROPOMI	The TROPOspheric Monitoring Instrument
TTG	Family of igneous rocks closely related to granite
UCL	University College London
UCR	University of Costa Rica
UKRI	UK Research and Innovation
UV	Ultraviolet
VAAC	Volcanic Ash Advisory Centre
VMSG	The Volcanic and Magmatic Studies Group
VOCS	Volatile Organic Compounds
V-Plus	Volcanic Plume Understanding and Forecasting: Integrating Remote-Sensing, In-situ Observations and Models
WMO	Word Meteorological Organisation
WTW	Willis Towers Watson
XTI	Cross-track interferometry

COMET

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