ID: 33

Observations of volcanic plume chemistry and exposure in Hawaii using a distributed low-cost sensor network

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Volcanic eruptions pose a potential air quality hazard for hundreds of millions of people worldwide from de-gassing, tephra, and secondary formation of particulate matter (PM). Recent improvements in low-cost air quality sensor technology have made it possible to rapidly deploy dense air quality monitoring networks in a wide range of environments. Such networks offer several advantages: i) small, stand-alone sensors for rapid deployment and network flexibility during urgent situations, ii) increased spatial resolution and continuous, real-time in situ monitoring, and iii) new ways to engage and interact with local communities.

This presentation highlights ongoing observations from a surface-based low-cost sensor network (18 stations) deployed on the Big Island of Hawai`i from 2021-2023. During active eruptive phases, ~1,000-3,000 tons per day of sulfur dioxide (SO_2) gas is continuously released from the Kīlauea summit. As the plume is transported downwind towards populated areas, the SO_2 gas photochemically transforms into fine PM, with potential negative health impacts for Island residents.

The low-cost sensor network measures SO_2 gas concentrations with electrochemical sensors and PM size distributions using a combination of optical particle counters and nephelometers. Network sensors are calibrated in the field against government regulatory-grade monitors. Long-term, high spatial resolution data from the sensor network allows characterization of the plume's chemical transition in terms of gas-particle conversion rate and particle size distribution during a range of atmospheric conditions. Additionally, the network enables fine-grained population exposure estimates to both SO_2 and PM as the plume chemically evolves.

ID: 87

Numerical modelling of the volcanic plume dispersion from the hydrothermal system of La Soufrière de Guadeloupe - Implication for the health of the population

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Passive volcanic degassing results in the emission of toxic gases such as H_2S at quasi-steady rates over long periods of time that pose a significant hazard to human health even in low gas concentrations. Currently, La Soufrière de Guadeloupe has one of the highest gas emission rates in the Lesser Antilles arc, with gas emitted mainly from low-temperature fumaroles. In this study, gas dispersion from the volcano between 2016–2021 was modelled using a numerical code that takes into account wind and atmospheric data, topography and gas flux measurements. We ran c.100 individual simulations of the most frequently observed wind and gas flux conditions using a Monte-Carlo scheme. Our results, validated using air-quality measurements and citizen science surveys, show that the most exposed zones are the hamlet of Matouba and the upper St. Claude. These areas have 20% and 5% probability, respectively, of exceeding H_2S guidelines for long-term gas exposure (70 ppb).

ID: 104

'All four engines have failed!': The psychological and behavioural impacts to passengers and crew on flight BA009 which flew through the 1982 Gallungung ash cloud

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Flight BA009, which was en route from London to Auckland, unknowingly flew through an ash plume from Mt Galunggung, Indonesia on 24 June 1982. As 'smoke' filled the cabin, one by one each of the four engines failed. Over 13 minutes of gliding descent, in which the flight deck crew tried, initially unsuccessfully, to restart the engines, many passengers believed they would crash into the ocean. The flight crew managed to restart 3 engines, as the plane descended out of the plume, allowing a safe emergency landing at Jakarta airport.

Twenty semi-structured interviews were conducted with passengers and crew of flight BA009, to investigate how they responded (thought, felt, behaved) to the sensory signs of the incident (e.g., 'smoke' in the aircraft, sounds and movements related to engines failing and restarting attempts and the descent, light phenomena on the windows, wings and engines), whether they experienced any acute or chronic psychological or physiological health impacts and whether crew announcements and behaviour influenced passenger behaviour. The interviews also explored whether the experience impacted their lives since the event.

The interview data, together with secondary data from documentaries and a book written by a passenger, are being analysed using reflexive thematic analysis. The findings will be used to inform civil aviation training, risk assessments and scenario planning in relation to pilot reticence, route planning, and consumer confidence, and will provide valuable evidence on behaviour of passengers in aviation crises.

ID: 162

Respiratory health impacts of volcanic and other natural hazard events in Aotearoa New Zealand

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Understanding the public health impacts of natural hazard events informs risk modelling and allows mitigation actions to be investigated. International literature shows new respiratory illness and exacerbation of existing respiratory disease is associated with hazards including volcanic gas and ash, earthquakes, tsunami, bushfire, convective storms, tropical cyclones, and floods. These respiratory health impacts have been attributed to confined conditions in emergency shelters, aspiration of contaminated water, reduced access to medical assistance and medication, damage to housing and infrastructure, stress and increased levels of smoking, mobilised pollen and dust, and air pollution from debris, smoke, and volcanic ash.

We will describe findings of an exploratory epidemiological study carried out to establish if statistical relationships can be observed between respiratory hospitalisation and non-accident emergency department visits, and natural hazard events in Aotearoa. We will show results from a cluster analysis that utilised a catalogue of natural hazard events occurring in Aotearoa New Zealand since 1993 and Ministry of Health data for the same period, and describe where effects are modified by age, gender, ethnicity and indicators of deprivation.

We will present findings by Region and hazard type, allowing us to identify the impacts of sustained geothermal activity on communities. We will also present a detailed descriptive analysis for health impacts during the 1995-1996 Ruapehu eruption.

ID: 245

Natural radioactivity and volcanic areas: the Lazio region (Italy) case study among air quality, risk assessment and health hazard

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In the framework of the EU-funded LIFE-Respire project, a large amount of data (radionuclide content, soil gas and water samples, terrestrial gamma, indoor radon) was collected from different volcanic districts of the Lazio region (central Italy) that are characterized by low to high Geogenic Radon Potential (GRP). Considering that the GRP is often linked to indoor radon risk levels, we have conducted multidisciplinary research to: (i) define local GRPs and investigate their relationship with associated indoor Rn levels; (ii) evaluate inhaled radiation dosages and the associated risk to the inhabitants; and (iii) define radon priority areas (RPAs) as required by the Directive 2013/59/Euratom.

At the scale of the municipality, there is a good correspondence between the highest GRP areas and the highest indoor radon concentrations and gamma dose values, thus confirming that geology affects at least the lowest levels (e.g., ground and basements) of a building.

In several cases, the radiation dose received by people due to indoor radon is higher than the level for which some mitigation actions are required or recommended. A preliminary assessment of radiological risk displays a good correspondence with the distribution of lung cancer cases in the Lazio GRP map, as shown by the incidence rate map (out of 100,000) of the cases found in the Lazio region. These areas can be considered as Radon Priority Areas, where municipal administrations can carry out monitoring activities at a detailed scale and adopt ad hoc remediation systems.

ID: 252

Cytotoxicity of nonsilicate volcanic aerosol

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More than 800 million people are thought to be exposed to volcanic emissions as a result of eruptions and persistent degassing. The adverse health effects of volcanic ash and long-term exposure to volcanic gases have been associated with various respiratory symptoms and cardiovascular endpoints. While there is existing knowledge on the health effects of volcanic ash and gases, a significant gap in evidence remains concerning the potential cytotoxic effects of non-silicate volcanic aerosols associated with persistent and intermittent degassing. Size distributions and the size-resolved chemistry of such aerosol is known to be complex and to reflect a range of factors, including magma chemistry, manner of degassing, and meteorological conditions. To address this gap, we undertook a sampling campaign in the summer of 2023 at Mt Etna and Vulcano. The samples were collected from both the plume and downwind in populated area. We report here on preliminary analyses of the chemistry and cytotoxicity of the samples that we collected and consider the wider implications of our findings for understanding the human health risk of exposure to volcanic plumes.

ID: 352

Assessing the air quality hazards of chronic exposures to volcanic gases and particulate matter on Montserrat, Eastern Caribbean

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The Soufrière Hills volcano has not erupted ash since 2011 yet emits roughly 440 tonnes per day of sulphur dioxide (SO_2) with recent spikes reaching up to 1000 tonnes per day. Depending on meteorological conditions, local communities on Montserrat may be exposed to variable and potentially poor air quality (AQ) through high concentrations of SO_2 and other key species such as inhalable (<2.5 μm diameter) particulate matter ($PM_{2.5}$). SO_2 is known to cause health problems even in low concentrations, and PM is classified as a carcinogen. Monitoring of AQ pollutants is needed to facilitate assessment of the chronic health risks of volcanic emissions.

The aim of this project is to conduct the first calibrated, high temporal resolution assessment of the concentrations and dispersion of volcanic SO_2 and PM on Montserrat to advise local agencies on ambient AQ levels and allow for human health risk assessment, with the case for long term AQ monitoring to be reviewed. Discussions with government officials and local scientists at the Montserrat Volcano Observatory (MVO) were used to co-develop this research.

During a 2023 field campaign, a 13 site SO_2 and PM sensor network was installed to collect data over 2 years. Here, we present results from the network's first fully calibrated dataset. Filter-pack samples were also collected for particle size and compositional analyses, and various community engagement activities were conducted. These data will be taken with MVO's long-term passive measurements of SO_2 and volcanic emission flux data to understand the spatiotemporal impacts of the volcano.

ID: 355

Lateral variation in the aerosol composition of degassing lava flows, with implications for particulate matter and trace metal exposure.

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Along with emissions from the main volcanic vent, lava flows can contribute an additional source of gases (such as SO_2, HCl and HF) and particulate matter (PM) to the atmosphere. This can significantly increase the spatial extent of air pollution during a volcanic eruption, particularly when activity is effusive and extensive lava flows are generated, such as at the Fagradalsfjall eruptions in Iceland or La Palma in Tenerife. Even when the main crater is distal to populations centers, if lava flows extend proximally to urban or inhabited areas, they may increase population exposure to harmful gases and PM, where the composition and size distribution of this PM is a key factor in determining the severity of potential health impacts.

Using drone-based sampling platforms filter pack measurements have been collected above degassing lava flows at the Fagradalsfjall 2021, 2022, and 2023 eruptions in Iceland. Sampling occurred over laterally extensive lava flows ranging from 200m to 1.5km from the main vent, where effusion rates can be used to estimate lava flow ages. Preliminary results show chalcophile elements (Cd, Se, As, Pb) are depleted more rapidly in degassing emissions, as the lava flow becomes more evolved, relative to Cl- (Cu, Cs, Zn) or oxide- (Al, Mg, Mn, Fe) complexed elements. FTIR measurements suggest this may reflect variable degassing behavior, controlled by element speciation and volatility. This has implications for understanding how exposure to potentially toxic elements may vary as lava flows become increasingly evolved and extend towards populated areas.

ID: 481

Silicate volcanic ash at the PM10 level: integrating compositional and 3D particle characteristics to assess long-term effects of a short-term hazard

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Adverse health effects from volcanic eruptions are associated primarily with gas and ash clouds. Risk mitigation strategies for naturally hazardous minerals in the environment (e.g. silicate volcanic ash) need to integrate mineral chemical composition with three-dimensional particle characteristics (shape and surface features) to fully assess potential mechanisms of toxicity. In this contribution we show how combining confocal laser microscopy, a non-destructive technique capable of resolving 3D geometry of PM_{10} and $PM_{2.5}$ particles, with spectroscopic analysis, provides a novel and rapid way to assess the minero-chemical properties of volcanic ash (Wertheim et al. 2023).

Silicate ash samples from the Tajogaite eruption (La Palma, 2021) show angular forms with variable sharp surface features in confocal imaging. Volcanic particles were added to cell plates containing A549 epithelial lung cells, then a strain of pneumococcal bacteria was introduced and incubated. When colony forming units were counted (a measure of viable bacteria), those lung cells that had been exposed to ash showed a clear increase in pnuemococcal bacterial adhesion over control cells. Therefore, exposure to the smallest ash particles, which are also remobilised long after the eruption, can increase the likelihood of contracting respiratory illness.

Applying such a multidisciplinary approach can help to define mechanisms for respiratory illness in populations such as the Canary Islands, where residents are at risk of multiple sources of exposure to both volcanic ash and inorganic dust.

ID: 502

Bioreactivity of sub-10 µm geogenic particles: comparison of volcanic ash and desert dust

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Exposure to ambient particulate matter (PM) with an aerodynamic diameter of < 10 µm (PM_{10}) is a well-established health hazard. There is increasing evidence that geogenic (earth-derived) particles can induce adverse biological effects upon inhalation, though there is high variability in particle bioreactivity that is associated with particle source and physicochemical properties.

In this study, we investigated physicochemical properties and biological reactivity of volcanic ash from the April 2021 eruption of La Soufrière volcano, St. Vincent, and two desert dust samples: a standardized test dust from Arizona and an environmentally sampled Gobi Desert dust. We determined particle size, morphology, mineralogy, surface texture and chemistry in sub-10 µm material to establish if there is an association in observed bioreactivity with differences in particle physicochemical properties. We assessed cellular responses (cytotoxic and pro-inflammatory effects) to acute particle exposures (24 h) using two types of cells of the human airways (BEAS-2B bronchial epithelial cells and A549 alveolar type II epithelial cells). We also assessed particle oxidative potential, which is generally implicated in inflammatory responses to particles, and the presence of adhered microorganisms, which can generate an immune response.

The results showed that volcanic ash and desert dust exhibit intrinsically different particle surface textures and chemistry, and variable mineralogical content. We found that dust from the Gobi Desert dust is more bioreactive than freshly erupted volcanic ash and Arizona test dust, which is possibly linked to the presence of microorganisms (bacteria) and/or nanoscale fibre-like silicate minerals on particle surfaces.

ID: 577

Forecasting small SO2 rich plumes during the Fagradalsfjall eruptions 2021-2023: challenges for reliable concentrations

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During the Fagradalsfjall eruptions, the CALPUFF dispersion model was used operationally to forecast ground-level exposure to SO_2. The initial graphical presentation of the forecast used the color code system used by the Environmental Agency of Iceland to refer to critical SO_2 thresholds of concern for human health. The model however was found to predict peaks that were not observed. In reaction to the recognition of this overprediction, two additional maps that showed the most likely areas to be impacted by elevated SO_2 concentrations within 6- and 24-hours were also released after the first month of the first eruption. People were encouraged to check the real-time measurements available on the EAI webpage for gas concentrations at the station closest to them in addition to utilizing the forecasts. The small-sized plumes (most common heights between 1 – 2 km asl) are challenging to model as the boundary layer has a dominating impact on them. Additionally, the domain of interest is a small peninsula where very local atmospheric dynamics are not well captured by the meteorological models driving the dispersion code. Various approaches are being tested to improve the model forecast including updating plume height and SO_2 flux source terms using different data sources and producing probabilistic maps as well as developing an AI-based algorithm for quantifying the eruption source parameters in near-real time. Our results highlight the challenge in achieving accurate simulations of volcanic plume dispersion. The performance remains to be improved with respect to forecasting reliable ground-level concentrations of volcanic SO_2.

ID: 607

CO2 hazard monitoring in the inhabited areas of Puerto Naos and La Bombilla (La Palma, Canary Islands)

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The Tajogaite eruption at Cumbre Vieja volcano (La Palma, Canary Islands), is considered the most important urban eruption of the last 75 years in Europe. After the eruption onset, the main post-eruptive volcanic hazard present is the anomalous CO_2 emissions affecting inhabited coastal areas of Puerto Naos and La Bombilla, which are located 6 km distance from the eruptive vents. The first records of high CO_2 concentration levels outdoor in these areas were made by INVOLCAN approximately three weeks before the onset of the Tajogaite eruption (December 13, 2021; Hernández et al. 2022). To investigate the degassing phenomenon, diffuse CO_2 and H_2S emission surveys have been performed at La Bombilla, and outdoor and indoor air CO_2 concentration surveys have been regularly conducted at La Bombilla and Puerto Naos since December, 2021. Diffuse CO_2 emission at La Bombilla showed values from 4.4 to 170t·d^{-1} (average=16t·d^{-1}) and δ^{13}C-CO_2 values ranged between -8.63 to -4.28‰ vs. VPDB (average=-5.6‰). Temporal evolution of the diffuse CO_2 emission rates showed the maximum value during the first survey (170t·d^{-1}), with the rest ranging between 2 and 20t·d^{-1}. The outdoor air CO_2 concentration measured at 15 cm high in La Bombilla and Puerto Naos showed values from air (ppm) up to 87% (average=0.67%) and up to 30% (average=0.23%), respectively, the highest ever measured during the post-eruptive period. Both inhabited areas should be continuously monitored to reduce the risk associated to gas emissions, and at present, innovative decisions are being considered to mitigate the hazard associated to the CO_2.

ID: 236

Behavioural, psychological and physiological impacts to occupants of civil aviation encounters with volcanic emissions

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Volcanic eruptions produce plumes of ash, gas and aerosols that present a risk to aviation. Research has previously focussed on the risks to aircraft structure from ash encounters. However, the acute and chronic impacts to mental and physical health of passengers and crew are under-studied, as is the behaviour of aircraft occupants during the exposures.

Volcanic plumes vary in composition but include toxic components and can extend over all standard aviation flight levels. In this study, we have reviewed the evidence for health and behavioural impacts as a result of volcanic emissions entering aircraft. Serious health risks are low for healthy people, but respiratory irritation is likely for high exposures. Asthmatics are particularly vulnerable, and relatively low and short exposures can potentially result in severe respiratory impacts.

Other risks include anxiety and uncertainty about the physical health effects of exposures, potentially resulting in crew reticence to fly if a volcanic encounter is expected. Such risks could be mitigated through communication of the likely impacts.

Overall, the risks to health are low, but the lack of encounters with extremely large gas-rich eruptions as well as the lack of research on the topic make definitive conclusions impossible. New research should include working with flight crews and air traffic control representatives to establish the likelihood of emergency protocols being triggered, and the scale of consequent disruption.

ID: 411

Metal Toxicity in Human Populations Living Among Volcanoes

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There is a well-known health risk associated with chronic exposure to metals, such as arsenic, cadmium, lead and mercury, originating from anthropogenic sources like industry and agriculture. Those same metals are also emitted by volcanoes in emissions of gas. fluids and ash and have potential to cause toxicity. The global flux of anthropogenic metals surpasses that of those emitted by volcanoes, but during periods of activity, or locally, individual volcanoes have the potential to release metal fluxes comparable to those of industrialized areas.

Health consequences stemming from volcanic metals may manifest through various pathways. Firstly, individuals within proximity to volcanoes may inhale fine ash particles and gases, introducing these materials directly into the respiratory system. Secondly, volcanic emissions can contaminate essential resources like soil and water, subsequently affecting food sources and making indirect exposure a significant concern.

We reviewed existing literature tying population health to volcanic exposure and compared disease incidence affecting different organ systems, including the endocrine and respiratory systems, in volcanic and non-volcanic areas. Current literature suggests that chronic diseases, such as lung and thyroid cancers, as well as multiple sclerosis, occur with greater incidence in volcanic regions as compared to non-volcanic regions, with many of these same diseases attributed to excess metal exposure. Direct correlation studies of metal content in volcanic materials with disease incidence are still needed, thus by identifying and quantifying these risks, this research aims to determine a causal pathway and route of exposure between volcanogenic metals and the development of chronic health conditions.

ID: 758

Health research during volcanic eruptions: Lessons from multiagency responses in Hawai‘i

David Damby[1], on behalf of a wonderful team of scientists and practitioners

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The 2018 eruption of Kīlauea Volcano (Hawai‘i, USA) resulted in a multitude of health hazards, each with corresponding differences in mitigation and communication needs. This prompted a multiagency, geology-health response in support of community and first responder protection, and comprised efforts by local, state and federal organizations along with many academic partners. Throughout the 2018 eruption, these efforts included: ash and emissions measurement, sampling, and characterization; air quality sensor deployment and real-time air quality monitoring; water quality impacts modelling and direct testing; operational dispersion and fallout modelling; information production and dissemination; monitoring and evaluating community health outcomes; amongst others. As these efforts were established, response decisions were informed by research and experiences gained from the Halema‘uma‘u summit eruption, which commenced in 2008, and the 1983 – 2018 Pu‘u‘ō‘ō eruption, as well as insights from eruptions elsewhere in the world.

Knowledge generated through research during eruption crises is essential to achieving the goals of preparedness and timely response, but such efforts can be particularly challenging when data are transient or inaccessible in real-time. Here we present an overview of public health-focused actions and health research conducted before, during and after the 2018 Kīlauea eruption. We discuss how those outcomes have informed interagency work during subsequent eruptions of Kīlauea as well as response operations during the 2022 eruption of Mauna Loa. Integrating the lessons learned from each eruption with global experiences has helped us to improve our capacity to respond as well as identify critical research targets for future eruptions.

ID: 780

A physicochemical analysis of volcanic ash from Sinabung volcano, Indonesia, for respiratory health hazard assessment

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Volcanic eruptions can produce a range of hazards resulting in significant environmental, social and health impacts. The inhalation of volcanic ash has been found to cause acute respiratory issues such as coughing, wheezing, worsening asthma symptoms and bronchitis. There is also concern that ash from lava dome collapse, or explosions through a dome, can contain crystalline silica which has been found to cause silicosis and lung cancer in some industrial settings when inhaled. In August 2010, after around 1200 years of quiescence, Sinabung volcano, in Sumatra, Indonesia, began erupting with lava domes being formed. No analysis had been carried out on Sinabung ash for respiratory health hazard.

Twelve samples of volcanic ash, collected between 2014 and 2019, were analysed using International Volcanic Health Hazard Network protocols to assess physicochemical properties including bulk composition, particle size and crystalline silica content. The andesitic to basaltic andesitic ash contained a substantial amount of inhalable particles (up to 23.2 % <10µm). Crystalline silica in the form of cristobalite was found in all samples, ranging in quantity from 1.3-4.5 wt. %. Quartz varied between none detected to 2.8 wt.%. Ash particles were mainly angular and blocky with fibre-like particles found in all samples analysed although these were not high in number and did not appear to show compositions of concern. The data suggest that, whilst crystalline silica is present in samples, the primary concern is the quantity of inhalable ash present, and efforts should be made to reduce the exposure of communities.