ID: 50

Near real-time ash cloud height estimation based on GOES-16 satellite imagery: a case study at Cotopaxi volcano, Ecuador

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The timely acquisition of accurate ash cloud heights is crucial for aviation safety and forecasting volcanic ash dispersion and fallout. As visual observation is not always possible, here we assess the suitability of retrieving ash cloud heights from GOES-16 satellite imagery during the 2022-2023 Cotopaxi eruption. We used the Volcanic Cloud Monitoring web interface to derive ash cloud heights from 97 VOLCAT solutions, 136 images using brightness temperature and 126 images using plume direction, combining the last two with global meteorological models. Additionally, 186 ash cloud heights were compiled from Washington-VAAC advisories. Comparing these results with 270 ash emission heights captured with visual cameras, we found a consistent underestimation in most satellite-derived estimates. While W-VAAC advisories and the plume direction method produce the closest approximations, they also exhibit significant deviations. Remarkably, the brightness temperature method, despite underestimating ash plume height the most, displays the best linear regression with visual observations, indicating a reliable correlation that is particularly useful for larger emissions. In operational terms, VOLCAT provides the fastest results in 20 to 30 minutes, while the brightness temperature and plume direction methods require an additional 5 to 7 minutes. W-VAAC advisories are generally issued within 30 minutes but not always immediately after the start of an emission. In conclusion, near-real-time retrieval of ash cloud height from GOES-16 imagery is a promising alternative to direct visual observation, particularly at night, in adverse weather, or for remote volcanoes. Improvements, such as incorporating high-resolution local meteorological models, are essential for accurate height estimation.

ID: 51

Portable and low cost TIR ground based system for volcanic emission monitoring. Measurements strategy and error assessment.

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Among satellites, ground-based systems are indispensable tools for the monitoring volcanic activity, capable of producing reliable results in real time. The meaningful advantage of the ground-based instruments is that they can provide quasi-continuous coverage in space and time with a generally high sensitivity, while the main drawback is their generally insufficient density and limited spatial coverage.

In the past two years, a novel portable and low cost TIR ground based system have been developed for the detection of volcanic emission and the retrievals of Volcanic Cloud Top Height and SO_2 columnar abundance. It consist of three broadband cameras, two Thermal InfraRed (TIR) and one Visible (VIS), able to acquire data simultaneously at high frequency during both day and night. In order to make quantitative estimation of the volcanic SO_2 columnar abundance, an 8.7 µm filter is installed in front of one of the TIR cameras.

In this work, the characteristics of the system are detailed, together with the procedure developed for the retrievals of VCTH, SO_2 columnar abundance and flux. A particular emphasis is dedicated to the analysis of the retrieval errors by considering geometric, atmospheric, and plume characteristics uncertainties.

As test case, the measurements carried out on Etna and Stromboli (Italy) during different field campaigns carried out in 2021 and 2023 and Sabancaya volcano (Perù) in 2022 are considered. The results obtained have been also cross-compared with those obtained by satellite systems and UV ground based cameras.

ID: 72

The VULCAIN CubeSat mission for studying volcanoes and active thermal areas

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This work aims to present the VULCAIN mission study to design and characterize new CubeSat satellites for Earth Observation dedicated to volcanoes. The project, funded by the Italian Space Agency (ASI) and supervised by the European Space Agency (ESA), includes six Italian partners (research institutes and industry). The project involves the construction of two 12U nanosatellites flying in formation in order to obtain stereoscopic images. Each satellite embarks two instruments on-board: a Commercial Off-The-Shelf (COTS) visible camera and a multispectral thermal camera with four channels in the 8-12 µm spectral range. The expected spatial resolution is less than 40 m and less than 100 m for visible and thermal camera, respectively. The combining of VIS-TIR data allows to improve the observation on volcanic areas, reducing the geolocation error and enhancing the spatial resolution of thermal measurements. The main scientific objectives are to measure the Land Surface Temperature (LST), as well as the SO2 content in degassing plumes and to detect ash emissions from active volcanoes. Moreover, the using of two nanosatellites in formation allows to obtain 3D images of volcanoes to support the morphological analysis. A total of 34 volcanic sites, located in Europe, Central and South America and Indonesia, have been selected as primary targets for the VULCAIN space mission.

ID: 191

Rapid mapping by multi-sensor UAV surveying for monitoring 2021-2023 volcanic unrest at Vulcano Island

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In September 2021, the geophysical and geochemical parameters measured on the Island of Vulcano by the surveillance network and periodic surveys recorded significant changes. Among the additional measures setup by the scientific community and INGV, several thermal and ALS surveys were carried out between October 2021 and October 2023 using a DJI Matrice 300 UAV systems. The collected data allowed to extract data and maps directly georeferenced using POS/NAV RTK approach. The Laser Scanner sensors used to extract a Digital Terrain Models are a Genius R-Fans-16 and DJI Zenmuse both coupled with an RGB camera to obtain the orthophoto. The aerial thermal surveys, performed using a Zenmuse XT2 – Ht20 thermal camera, were integrated by ground-based data collected from fixed points of interest to map the fumarole field. The focus of the surveying activity was on the detection and mapping of the fumarole temperatures and of potential instability on the flanks of the volcano edifice. The surveys were carried out in the northern area of Vulcano, the summit area, namely 0.357 km2, of the Gran Cratere La Fossa. Furthermore, a 3D reconstruction of the top of the cone, the area of Forgia Vecchia and the area of the 1988 landslide, was aimed at identifying morphological variations in the most unstable areas. In this period events of anomalous degassing occurred in the Eastern Bay, with an increase in the emission of gases and hydrothermal fluids, which produced a phenomenon of whitening of the waters in front of the Baia di Levante of Vulcano. For this event, optical-thermal monitoring was carried out both on land near the port and the Faraglione area and in the sea where different streams of hydrothermal gases were detected. The collected data permitted to detect and monitor the magnitude and the areal extension of fumarolic fields contributing to set-up a safe, cost-effecting, and detailed monitoring approach useful to the understanding of the un-rest evolution.

ID: 209

The role of gas monitoring at Volcán de Colima, Mexico

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Gas monitoring at Volcán de Colima, Mexico started in the 90s with COSPEC measurements and occasional visits to the summit fumaroles. Geochemical precursors were detected prior to the eruption in 1998: increases in SO_2 flux, anomalous concentrations of boron in spring waters and a more magmatic signature of the water isotopes detected in fumarole condensates. More recently significant variations in SO_2 flux have been detected using UV spectrometers in scanning mode; these have been related to movement of magma in the system. Activity of Volcán de Colima can be characterized by frequent transitions between eruptive styles; periods of effusion with dome growth often coincide with Vulcanian explosions, with SO_2 flux measurements allowing visualization of the rapid sealing of the system during the explosive cycles. A clear relationship between effusion rate and the magnitude and frequency of Vulcanian explosions has provided an insight into the generation mechanism and outgassing processes. The gas output does not always correlate with the magma effusion rate, reflecting different magma sources in the complex plumbing system, a characteristic supported by petrological and geophysical measurements.

Recent advances in gas monitoring at Colima have included the direct analysis of gas composition in the plume using a UAV and the installation of a new SO_2 camera. Satellite observations are being integrated into the monitoring network, for both thermal and gas emission. First results will be presented, along with protocols designed to facilitate effective communication of the volcano status to the government authorities.

ID: 220

Improved global monitoring of volcanic plumes combining LEO and GEO retrievals in support of volcanic observatories and aviation stakeholders

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Volcanic eruptions can have transboundary impacts and pose a direct threat to aviation and local populations. Increasing the knowledge on volcanic processes is critical. In this context, satellite datasets are playing a crucial role.

Here we present our activities, as part of the Belgian Natural hAzards Monitoring from SATellites (NAMSAT) project, aiming at developing a web-based data service and portal dedicated to airborne hazards, providing near-real time access to satellites volcanic plume observations and added-value products.

Our starting point is the SACS early warning system (https://sacs.aeronomie.be) which is based on low earth orbit (LEO) satellite aerosols and SO_2 observation/detection (e.g., from IASI and TROPOMI). While a LEO instrument offers selective detection, its revisiting time is very limited. The scope of NAMSAT is to extend SACS to geostationary earth orbit (GEO) satellite data with a delivery few minutes after sensing time, by applying linear discrimination techniques to detect aerosols and SO_2 from SEVIRI, GOES and HIMAWARI sensors (forming the so-called global GEO-ring).

This presentation will also highlight the planned added-value products of NAMSAT, such as time-series of relevant observations (SO_2 mass, height, aerosols/ash detection) over fixed or user-defined volcanic regions. These products are developed to tackle the needs of volcanological users (i.e., data available before/during eruptions). Aviation stakeholders are also interested by improved situational awareness using advanced GEO-based detection. We will illustrate the intended NAMSAT services for recent eruptions.

ID: 224

Gas dispersal model validation and related hazard assessment at La Solfatara crater, Campi Flegrei, Italy

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It is well known that uncertainties in quantifying gas volcanic hazard derive from the approximations associated with the physics and formulation used to reproduce the natural phenomena, as well as the limited amount of available data that can be used to calibrate the models.

Here, we show an ongoing study aimed at producing quantitative long-term probabilistic hazard maps at La Solfatara, posed by CO_2 dispersal at proximal distances from the emission area, trying to explore the full range of uncertainty in the input parameters and boundary conditions.

We selected La Solfatara crater (Campi Flegrei, Italy) as best-case study since it hosts one of the largest persistent fumarolic sites of the world in a highly urbanized area, which may represent a threat to human health if concentrations and exposure times will exceed certain thresholds.

We performed a model validation considering the present-day CO_2 diffusive flux and concentration measurements taken during May 2023, considering local weather conditions.

Successively, we run two gas dispersion scenarios based on the twenty-year dataset of diffusive and fumarolic gas flux measurements. Probabilistic hazard results consider the meteorological variability over the last thirty years taken from the Copernicus ERA5 reanalysis dataset, providing relevant implications in case of a potential future worse-scenario unrest. To do this, we used VIGIL-1.3.5 (VolcanIc Gas dispersIon modeLling), an open-source Python tool designed for automating the process to get probabilistic applications of passive gas dispersion modelling.

ID: 231

Assessing tephra fall hazard from Etna paroxysms: modelling their temporal occurrence and ash dispersion based on an integrated catalogue from literature data and radar- and satellite-derived data

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Between 1986 and 2022, Etna's summit events, aka paroxysms, have been observed by several ground- and satellite-based remote sensors. Each paroxysm is described by its eruptive source parameters (ESPs). Most of Etna paroxysms since 1986 are listed in literature and known in terms of date, top of the column height (H) and duration.

In this work we enriched the list by adding new information to forty events detected by the X-band Radar in Fontanarossa airport, allowing the retrieval of Mass Eruption Rate (MER), column height, onset and end times, and erupted mass. For other events with no ESPs derivable by radar observables, the analysis of thermal and visible cameras and Seviri images allowed to estimate the onset and end times and H, which could then be converted into MER by empirical relationships.
The updated catalogue of paroxysms was then used to:
- statistically model the temporal occurrence of Etna paroxysms, which typically occur in clusters. The statistical description of the time between successive clusters' onsets and of the inter-paroxysms time within clusters, allowed generating a set of synthetic catalogues of paroxysms onset times;
- define suitable probability density functions for paroxysms' ESPs;
- run two tephra dispersal models (TEPHRA2 and FALL3D) for each synthetic onset time, with ESPs sampled from their distribution.
The result of this study is a probabilistic hazard assessment at Etna for the tephra accumulated at the ground during a paroxysm, a cluster of paroxysms, and within a given exposure time window.

This study received support by "PANACEA-PIANETA DINAMICO" project.

ID: 273

Processing software of SO2 emissions measured by UV cameras/ Software de procesamiento de emisiones de SO2 medidas con cámaras UV

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With its high temporal and spatial resolution, SO_2-UV cameras have proven to be a very attractive tool for monitoring emission and estimating fluxes (volcanic or anthropogenic sources). With these properties, they are also well suited to contribute to warning systems (e.g., in the mitigation of volcanic crisis and its impact on aviation).
We present a recently developed python-based software specifically developed for quick analysis of SO_2-UV camera data during, e.g., field campaigns, featuring an easy-to-use graphical user interface. It has been successfully used during two editions of the "Convective and Volcanic Clouds training school" to analyze data from the field campaigns. Functionalities included are: (1) automatic or manual (single shift or accounting for distortion effects) x-y shift to spatially align on- and off-band images, (2) correction of the vignetting effect by either processing dark- and clear-sky reference images, or by applying a manual or automatic background fitting, (3) translation of apparent absorbance into line-of-sight columns by either using a fixed pre-calculated convergence factor (from lab measurements) or by calculating a convergence factor after automatic detection of the field of view from an aligned spectrometer for which column densities have been pre-processed (e.g., by using QDOAS software retrievals); (4) estimating the plume speed using an optical flow algorithm. (5) Retrievals of SO_2 emission rates.

The functionality will be demonstrated using data measured with an Envicam3 in the harbor of Antwerp, at Etna and Nyiragongo volcanoes.

ID: 302

Inverting volcanic gas compositions for subsurface magma storage and launching depths

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An exciting development in volcanology has been the discovery of precursory shifts in the CO_2/S of gas emissions months to hours before eruption [1]. Equally interesting are the near steady-state ratios that occur during inter-eruptive periods. What are the source depths of these different gases, and how can they be used to inform forecast models? Here we report data on experimentally rehomogenized melt inclusions (MIs), to illuminate the initial CO_2 and S content of feeder magmas and, with the Sulfur_X model [2], describe melt and vapor composition during magma ascent. We focus on Turrialba volcano (Costa Rica), presenting data on MIs in basalt from the 1865 eruption, with comparison to pre-, syn-, and inter-eruptive MultiGas data from 2014-2018 [3]. MI rehomogenization doubles the previous estimates of CO_2 concentration to ~ 4000 ppm CO_2. Sulfur_X predicts that ascent of magma with 4000 ppm CO_2 and 3500 ppm S will reach vapor saturation at ~20 km depth, with a vapor CO_2/S ratio >8, similar to the gas observed weeks prior to eruption. The steady-state syn- and inter-eruptive gas (CO_2/S ~ 2-3) could derive from magma at 4-8 km depth, consistent with geophysically-determined depths of magma storage and the depth of H_2O saturation. Thus, eruptions may be triggered by deep magma that ascends rapidly after reaching saturation with a CO_2-rich vapor, and fed from magma storage regions at the depths of H_2O saturation.

[1] Werner et al., 2019. Deep Carbon. [2] Ding et al., 2022, G3. [3] deMoor et al, 2016, JGR

ID: 338

TROPOMI SO2 flux and Multigas measurements at Popocatépetl: insight into volcano dynamics and importance for crisis management.

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After two years of relatively low activity, Popocatépetl volcano produced, in May and June 2023, powerful ash emissions that strongly affected economic, agricultural, and aerial activities. In this work we present a data set of daily SO_2 fluxes, measured with the images of TROPOMI, and occasional gas composition, measured with a portable field analyzer, carried out before, during and after the May-June eruptive crisis. These data allow us to achieve a better understanding of the causes of this reactivation of the volcano and issue a forecast on the activity of the coming months. They also took also an important part in the crisis management and in the decisions to raise and later lower the alert level of the volcano.

The SO_2 flux began to increase slowly from January and, at the beginning of May, before the start of the crisis, had increased fivefold. The SO_2 flux on May 21st 2023 was the highest ever measured by satellite at Popocatépetl.. The CO_2/SO_2 ratio suffered a modest increase (from ~1.5 in 2022 to ~3 in May) before the crisis, but measurements after it reached the highest values since the strong activity of February-March 2019. This dataset suggest that the activity of May-June 2023 was the result of a gradual process of recharge in juvenile magma of the volcano's feeding system, started at least 5 months earlier. This magma has not yet lost all of its eruptive potential, suggesting that more episodes of activity can be expected in the coming months.

ID: 358

Satellite measurements of plumes from the April 2021 eruption of La Soufrière, St Vincent

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La Soufrière, on St Vincent, erupted explosively from 9th to 22nd April 2021, emitting multiple large plumes of ash and gas into the atmosphere. This study looked at these plumes with two satellite instruments.

The first instrument used was the Advanced Baseline Imager (ABI) on the Geostationary Operational Environmental Satellite (GOES). Using the instrument's high temporal resolution (1-10 minutes) a minimum of 35 explosive events were identified. These events were grouped into four phases: (1) an initial explosive event; (2) a sustained explosive eruption; (3) a pulsatory phase and (4) a waning phase.

The second instrument used is the Infrared Atmospheric Sounding Interferometer (IASI) on the MetOp satellites. This instrument is sensitive to sulfur dioxide (SO_2). An SO_2 retrieval scheme has been applied to the plumes from La Soufrière, revealing structure to the plume which reflects the multiple explosive events that occurred during the eruption. These retrievals are used to show the plume's transport across the globe. In total it is estimated that the eruption emitted 0.63±0.5 Tg, with much of this being emitted into the upper troposphere, around the height of the tropopause and lower stratosphere.

The study identified a number of similarities between the 1979 and 2021 eruptions of La Soufrière. These include that both eruptions consisted of a series of explosive events and produced plumes with similar heights. These similarities may be helpful for being better prepared for future eruptive activity and the study highlights the role that satellite data can play in characterising eruptive events.

ID: 396

Coupling multispectral ground and space TIR systems for monitoring volcanic emissions

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A major challenge in the remote sensing of volcanoes is the acquisition of timely data over the course of an eruption. Larger eruptions can last for hours to days, but many small, low energy events lasting seconds to minutes are missed. Therefore, acquisition at temporal scales of < 1 hour are crucial, but no such system to acquire such data from Earth orbit exists. In countries such as Guatemala, timely measurement of these second to minute processes is important, given the hazardous activity of its volcanoes. Until an orbital volcano mission is selected, a solution is to combine current satellite data with those from ground-based systems. Cameras that collect broadband thermal infrared (TIR) data provide high temporal, image-based, temperature of eruptive activity. There also exists the ability to collect compositional and particle size information of volcanic plumes using bandpass filters with TIR cameras, retrieving emissivity comparable to satellite data. Here, we present data collected by two such systems, a multispectral adaptation of a FLIR S40 and the MMT-Cam, a miniaturized multispectral camera using a FLIR A65 camera that were deployed in Guatemala. Data from these systems, combined with satellite data of ash plumes and deposits, allow us to assess any compositional and hazard potential of the volcano. Preliminary results from Fuego, Guatemala, show a close spectral match to laboratory spectra of glass-rich basaltic-andesite ash samples. The combination of both camera and satellite technologies allows higher resolution temporal acquisitions so changes in this material can be assessed over various timescales.

ID: 474

Understanding and monitoring volcanic emissions with infrasound

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During eruptions pulverised rock fragments – commonly referred to as volcanic ash – are blasted from volcanoes into the atmosphere driven by hot gases. The direct threat to aircrafts from volcanic emissions is a major concern. Not surprisingly, eruptions generate acoustic waves when vigorous jets of volcanic material are injected into the atmosphere; these signals represent an excellent candidate for understanding eruption dynamics and monitoring volcanic activity in real-time. Here, we show results from a multi-disciplinary study of paroxysmal activity at Mt. Etna during 2021, integrating analysis of eruption infrasound with thermal IR and ground-based X-band radar observations of volcanic activity. We analyse acoustic array data to identify the onset of eruptive activity and to evaluate the time evolution of flow velocity at the vent (50-125 m/s). Infrasound waveforms are corrected for topographic scattering and the effect of vent geometry using pre-calculated attenuation maps obtained from finite difference numerical modelling of the acoustic wavefield propagation. We also obtain independent flow velocity estimates from ground-based thermal infrared and X-band radar data, in excellent agreement with the values derived from acoustic measurements. We demonstrate how flow velocity measurements could be used to rapidly estimate the height of the eruptive column via near real-time numerical modelling of plume rise, or validation of pre-computed ash plume scenarios. Finally, we discuss the increasing potential of infrasound methods as a real-time eruption monitoring tool and their impact on decision making during volcanic crises.

ID: 494

Observing volcanic aerosol optical properties with portable MicroTops-II sun-photometers

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Through their varied and diverse activity, volcanoes emit both gaseous and particulate species that can affect the downwind atmospheric composition, aerosol layer and radiative balance at different spatiotemporal scales and in both the troposphere and the stratosphere. Therefore, the characterisation of aerosol emissions from volcanoes is a crucial step towards the assessment of eruptive activity together with their importance for regional air quality and regional-to-global climate. Remote-sensing techniques, is a powerful easy tool for characterising aerosol emissions from volcanoes and their atmospheric dispersion and aging processes, getting insights into eruptive activity and estimates their downwind impacts on the air quality and the radiative balance. The optical properties of volcanic aerosols can be measured in the near-field, i.e., in proximity and/or in the surrounding area or emitting vents, using portable Sun-photometers such as the Microtops-II (MII). In the last few years, we have developed new multispectral methodologies to observe volcanic aerosols with MII and applied to different volcanoes: Mt. Etna and Stromboli (Sicily), Pacaya (Guatemala) and Mt Rittmann (Antartide) volcanoes. Itinerant techniques were also developed to map the aerosol optical properties and their evolution in extended areas. Data showed the flexibility and the different possibilities of this technique.

ID: 506

Ensemble atmospheric dispersion modelling of volcanic species: interpreting ensemble data and applications

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Customarily, operational forecast systems rely on volcanic ash transport and dispersal (VATD) models to produce deterministic forecasts. VATD models are powerful tools to generate realistic representations of the spatio-temporal distribution of airborne volcanic species (i.e. ash and gases) and tephra deposits using a physics-based approach. However, these models include multiple physical parameterisations which are highly sensitive to errors in model input parameters (e.g. eruption source parameters) and also depend on uncertain external data (e.g. meteorological fields from numerical weather prediction models). The use of ensemble modelling strategies makes it possible to take into account uncertainties in model inputs, physical parameterisations and meteorological data, and has become increasingly more popular over the past decade. This study explores different approaches for dealing with ensemble data using statistical techniques, reduction of data complexity, and clustering analysis. The advantages and disadvantages of potential products generated by an operational volcanic ash dispersion forecast system are discussed in detail. Finally, we show examples of some possible applications of the use of ensemble atmospheric dispersion modelling, including ensemble-based data assimilation techniques, volcanic deposit reconstruction, and source term inversion methods (DT-GEO: A Digital Twin for GEOphysical extremes, project under grant agreement No. 101058129; ChEESE-2P: Centre of Excellence for Exascale in Solid Earth, project under grant agreement No. 101093038).

ID: 514

Ensemble Dispersion Modelling of Volcanic Ash Resuspension

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Volcanic ash deposited during volcanic eruptions can be resuspended under favourable conditions and cause several negative effects on human health. In addition, ash in the atmosphere may pose hazards to aircraft operation and, consequently, dispersion forecasts of resuspended ash are essential to support civil aviation management after volcanic crises. In recent years, significant advances have been made in the numerical modelling. Atmospheric dispersion models are typically used to predict volcanic ash transport and produce deterministic forecasts. However, no previous study has explored the use of ensemble simulations in the context of volcanic ash resuspension. The goal of this research work is to carry out a probabilistic study based on an ensemble modelling approach using the FALL3D dispersal model. To this purpose, critical input parameters have been perturbed to take into account different sources of uncertainty. The dispersal model was driven by meteorological data from the Global Ensemble Forecast System (GEFS) to include the variability in the meteorological conditions. In order to build the ensemble efficiently, a sensitivity study was performed to identify the most relevant parameters using a clustering technique to organise the ensemble data in groups of similar datasets. This study is the first effort aimed at establishing an ensemble forecast system for volcanic ash resuspension. The findings reported here shed new light on the most sensitive parameters affecting the numerical simulations and the advantages and disadvantages of the different products which can be generated from the ensemble data (DT-GEO, project under grant agreement No. 101058129).

ID: 626

Forecasting volcanic activity over the next decade: The plans for rapid-revisit orbital thermal infrared (TIR) data

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The fundamental ability to forecast a new eruption using orbital data remains aspirational despite decades of spaceborne data acquisition, modeling, and analysis. In contrast, thermal change detection is routine and used to rapidly identify a new eruption already in progress. Sensors with lower spatial (≥ 1 km) and higher temporal (≤ 24 h) resolutions are best suited for this detection and provide near-real time information. However, our recent work examines both higher spatial, lower temporal resolution low-Earth orbit (LEO) as well as low spatial, higher temporal resolution geostationary orbit (GEO) data to identify precursory thermal eruption signals. Foundational to this is the ability to retrieve subtle (1-2 K) temperatures, which are easily overlooked using current change detection approaches. Decades of orbital TIR data enable a unique opportunity to quantify these low-level anomalies and small plumes over long periods. Most significant is the finding that the smaller, subtle detections served as precursory signals in ~81% of eruptions. Over the next decade, several high spatial (~ 60 m) resolution sensors are planned that provide daily (or better) TIR data at every volcano, vastly improving thermal baselines and detection of precursors. One of these, the Surface Biology and Geology (SBG) IR instrument, has planned volcano-specific data products crucial for accurate daily monitoring. However, the next step-change in orbital volcanology comes with a proposed hypertemporal mission to acquire sub-minute scale TIR data to determine mass and thermal flux rates of gas emissions, eruptive ash plumes, and lava flows from space for the first time.

ID: 737

Trends in SO2 emissions during eruption cycles at persistently degassing volcanoes

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Effective use of gas measurements for eruption forecasting requires an understanding of long-term degassing behavior as context. Progress has been made in quantifying volcanic emissions of sulfur dioxide (SO_2) at over 120 degassing volcanoes using ground-based sensor networks and analysis of decadal-scale satellite datasets. Being less constrained by the style or location of volcanic activity, satellite measurements provide greater insight into trends in degassing during eruption cycles. Here, we present an analysis of over 15 years of SO_2 measurements by the Ozone Monitoring Instrument (OMI) aboard NASA's Aura satellite, focused on observed trends in SO_2 emissions spanning eruptions of varying magnitude. The OMI measurements provide estimates of annual mean SO_2 emissions at ~100 volcanoes active between 2005 and 2020, around 80 of which erupted during the period. Superposed epoch analysis (SEA) of SO_2 emission trends for the erupting volcanoes (with eruption magnitudes ranging from Volcanic Explosivity Index [VEI] 2 to 4) provides evidence that higher SO_2 emissions in the years preceding eruption yield lower magnitude eruptions, and vice versa. Post-eruptive SO_2 degassing exceeds pre-eruptive emissions for several years after VEI 3-4 eruptions and may scale with eruption size; consistent with larger eruptions being supplied by larger magma intrusions which continue to degas in subsequent years. The SEA is most robust for VEI 3 eruptions, which are the most common events in the recent global eruption record. Limited observations of larger eruptions (VEI 5+) suggest significant differences in degassing trends during these events.

ID: 122

Discrete Ash clouds from Sangay Volcano – Ecuador 2015-2020 eruption period, ash volume estimations using VAAC data base

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During the last twenty years of the 21th century, Ecuador experienced four volcanic eruptions that were observed through ground base – satellite techniques. The ash clouds from long term discrete eruptions impacted communities and agriculture land, likely Sangay volcano. Thus, we present an indirect method to estimate the emitted ash volume to contribute to Civil Defense crisis management. We compiled an ash catalog using 1011 Washington VAAC reports, and documented ash fall data of the main eruptions of Sangay volcano 2015-2020 period to compute ash fall volumes following Pyle (1989) and Legros (2000). The results were used to calibrate the thermal plumes equations given by Sparks et al. (1997) and then to compute the emitted ash from each discrete event as function of the ash cloud height. Our results indicated that at least 2.65×10^6 m^3 of ash was emitted during 2015-2018 eruptive episode, and at least 9.85×10^6 m^3 for 2019-2020 period. The ash emission volumes were cross correlated with seismicity and thermal alarms from Terra and Aqua satellite platforms, and we observed an intermittent and effusive style during 2015-2018 to a continuous open conduit activity during the 2019-2020. The HYSPLIT online app was used to model the 9/6/2020, and 20/9/2020 eruptions. The results suggested a concordant ash dispersion pattern and arrival times to the populated areas; however, for 12/6/2020 minor event the spatial and temporal results did not allowed model the ash cloud dispersion. Thus, our results could be useful to the volcanic risk management and crisis response.

ID: 132

Satellite Acquisition System for volcanoes monitoring at INGV Rome headquarter

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This presentation describes the MAST (Multimission Acquisition System) satellite acquisition system that has been operating at the INGV headquarters in Rome since 2019.

The EUMETSAT Consortium through the EUMETCast system distributes more than 120 Earth observation data and products (EO) in real time or in real time acquired from instruments on board satellites in geostationary and polar orbit operated by major international space agencies.

The MAST system receives and processes environmental satellite data and products transmitted by EUMETCast services. The system responds to the need to provide the INGV with information on major volcanic, environmental and seismic events. It also provides the necessary infrastructure to develop and implement new monitoring and research products generated by EO spatial data.

The MAST system has also been designed with the redundancy of its hardware and software components to increase the overall reliability of the system. Modular hardware components and open-source capture software based on Python were used in the GNU-Linux Os-based environment. These choices allow easier management of the MAST system completely controlled by INGV personnel without additional maintenance and licensing costs.

This presentation describes both the hardware and software structure related to the acquisition and organization of satellite data that are the basis of the generated products.

ID: 153

Late Pleistocene explosive volcanism at Kīlauea: Mapping, characterizing, and modelling the distribution of Pahala Ash

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Kīlauea volcano, on the Island of Hawaiʻi, is one of the best natural volcanic laboratories in the world. This volcano provides abundant opportunities to study magmatic and volcanic processes, in particular the emplacement mechanisms of lava flows, scoria cones, and airfall tephra deposits. Although Kīlauea is well known for its current effusive activity, explosive periods are evident throughout its history, as recorded by the Keanakākoʻi Tephra, Kulanaokuaiki Tephra, and Pahala Ash. Here, we focus on mapping the distribution of and characterizing the Pahala Ash, a >26-m-thick composite sequence of intercalated lavas and airfall tephra deposits that are exposed mostly along the Hilina Pali on Kīlauea's south flank, at ~12 km from the summit. Radiocarbon ages indicate a dominantly explosive period from at least 10 to 30 ka, but with older explosive periods inferred from stratigraphically lower tephras being observed in the field. Preliminary fieldwork indicates that these airfall tephra deposits have unusual thicknesses (individual layers >10 cm thick in places) and are coarser grained compared to more recent explosive eruptions from the summit of Kīlauea. Our observations, coupled with analyses of collected samples, provide essential data to reconstruct these airfall tephras using Ash3D models. This will improve our understanding of eruption parameters, such as eruption duration, plume height, erupted volume, and wind direction, that influenced emplacement of this unique airfall tephra deposit. These results will contribute to further understanding Kīlauea's past eruptive behavior and provide insights into the drivers of this volcano's explosive periods.

ID: 170

Quantifying primary sulphate aerosol formation with direct line-of-sight OP-FTIR measurements

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The emissions of gases and particulates which accompany volcanic eruptions may present significant health hazards and perturb atmospheric chemistry on local to global scales. Their composition also reflects initial volatile contents and magma ascent/storage processes, thus revealing the dynamics which control surface activity. A powerful tool to measure gas composition, Open Path Fourier Transform Infrared (OP-FTIR) spectroscopy, allows for remote quantification of gas abundances from safe distances. Recent studies have also enabled the quantification of particulate species via OP-FTIR using broader spectral features in the thermal infrared region of the spectrum (700-1300 cm^{-1} or 8-12 µm), in either emission geometry or by using a stable artificial source of radiation. However, this requires calibration sources or a specific geometry, which potentially limits applications. Here we present a quantitative algorithm capable of determining abundance and size of particulates from uncalibrated measurements with a highly dynamic radiation source, a more easily achievable geometry during eruptive crises. Using temperature-dependent absorption features for gases at longer wavenumbers, the complex thermal profile along the line-of-sight can be approximated, allowing us to focus the retrieval on particulate species. Temperature-dependent SO_2/SO_4^{2-} ratios suggest the rapid formation of primary aerosols in the very young plumes (< 1 min) at the point of emission. This method provides a way to quantify sulphur partitioning at the source and inform investigations of plume evolution downwind. As well, they represent a new tool for monitoring volcanic emissions in support of air quality determination and the study of plume dynamics.

ID: 196

Insights into magma dynamics at Etna (Sicily) from SO2 and HCl flux during the 2008-09 eruption

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Magma convection, where low viscosity gas-rich magma ascends, degasses and crystallises before sinking down the same conduit in either annular or side-by-side flows, has been proposed for active basaltic volcanoes, where excess gas fluxes relative to erupted lava volume can be observed. Experimental studies show that convection is produced by buoyant ascending gas-rich magma and descending degassed magmas following density difference contrast, while geophysical studies point to the endogenous growth of active volcanoes through magma accumulation in plutons. However, many aspects of the convection process remain unclear, in particular the depth to which magma ascends before overturning. Models have been proposed where overturn occurs at the near-surface and also at depths greater than 2 km from the top of the magma-filled conduit. The long-term monitoring of volcanic gas compositions may reveal new insights into the convection process, as each gas has a unique solubility-pressure profile. Here, we report measurements of SO_2 and HCl gas fluxes from Etna between October 2007 and May 2011, in which a ~90% collapse in halogen flux was observed together with an effusive eruption. This observation indicates supports that the halogen fluxes, during quiescent periods on Etna, require both magma supply to the shallowest levels and a period of residence. The lava effusion has the effect of reducing the shallow residence time, drastically reducing the halogen flux. These results provide a new interpretative framework for degassing process and gas composition monitoring to explain subtle variations in magma supply and residence times in basaltic volcanism.

ID: 470

Opening a skylight in steady open-vent outgassing at Mt. Etna

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Basaltic volcanoes can occur in almost all tectonic settings and are associated with diverse magma compositions and eruptive activity. The observation of the different degassing regimes and tracking of the transition from one to another are crucial for the understanding of physical and chemical triggering processes at depth. Mt. Etna is an open-vent basaltic volcano feeding a varying and quasi-persistent eruptive activity enveloped in an ordinary degassing regime of variable intensity from its four summit craters (North-east, South-East, Voragine and Bocca Nuova). The summit craters have evolved and grown in a timescale of almost a century, and recently since the middle of July 2023, a new degassing vent opened in the Bocca Nuova crater, showing a sustained high-temperature degassing of variable intensity. In the following months ground-based remote sensing field campaigns were carried out to characterise properly the chemical composition of the gas phase and fluxes, and the associated in-plume thermal release at the new vent. The composition of the volcanic gas emitted from this vent is consistent with that of a magma stored at very shallow depths. The geochemical and thermal characterisation of the degassing regime combined with the analysis of the seismic-volcanic signals allowed us to discriminate between degassing cycles likely related to periodic variations of the magma supply rate at shallow depths; thus enabling us to draw a conceptual picture of the mechanism behind the activity of the Bocca Nuova new vent.

ID: 546

Multiparametric monitoring of Cotopaxi volcano during the 2022–2023 eruption: the importance of SO2 degassing measurements

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On October 22, 2022, Cotopaxi started a mild eruptive episode with a 5-hour tremor and a small ash emission. Cotopaxi is monitored by the IG-EPN using a dense multi-parametric ground-based network complemented by freely available satellite data. Prior to the onset, only little SO_2 degassing was detected by the permanent and satellite monitoring networks. Thereafter, subaerial activity continued until July 2023, showing periodic patterns of seismicity, characterized by LP-events and tremor, SO_2 degassing above background levels and fluctuant SO_2/H_2S and CO_2/SO_2. The heights of the gas and ash columns varied between 100 and 3000m above the crater and some nights, a glow was observed at the crater.

A comparison of the SO_2 data provided by the permanent DOAS network and the TROPOMI sensor processed by MOUNTS shows interesting differences: 1) DOAS detected increased valid SO_2 measurements before the onset of eruptive activity, while TROPOMI detected SO_2 once the gas plumes were visible; 2) the permanent network yielded a higher SO_2 flux, except when ash was present in the plume; 3) TROPOMI showed higher SO_2 mass for higher plumes; and 4) the two degassing patterns are globally comparable.

Overall, data from ground-based and satellite instruments are complementary and equally useful for monitoring SO_2 degassing.

The correlation among the multiparametric data recorded at Cotopaxi indicates a limited magmatic recharge in an open vent system, contrasting with closed conditions observed during 2015. Multiparametric monitoring is crucial to forecast potential eruptive activity, especially to discriminate minor/major episodes, and to activate proper risk management protocols.

ID: 553

Tracking the activity of Etna summit craters area by multidisciplinary approach

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The summit area of an active volcano is constantly changing, following the growth and demolition phases resulting from eruptive activity. At Mt Etna, after the impressive summit eruptive activity occurred in 1964, the Central Crater modified its morpho-structural features with the only presence of two crater, the Voragine and the Bocca Nuova, the last featured by two sub-vents, BN1 and BN2. In the past decades other eruptions have alternated subsidence and collapse to filling episodes further modifying the summit craters. On 15 July 2023 we observed the reopening of BN2 that was filled during the 2015 Voragine activity. Before July 2023, the degassing activity of Mt Etna was confined on BN1 together with a sustained thermal anomaly at variable intensity detected by satellite data. The integration of remotely geochemical data (flux and chemical composition of bulk plume), seismic-volcanic signals and satellite data allow us to characterise the time-scale of the reactivation of BN2. In detail, from May we observed a progressive depletion of chlorine emission, followed from the second half of June, by thermal anomalies detected by satellite and successively by infrasonic signals located in the same area. These evidences suggest that this episode was preceded by a very shallow intrusion and storage of magma batch in the plumbing system of Etna at shallow level as indicated by the rich-Chlorine gas phase composition emitted by the new BN2.