New methods of probabilistic hazard assessment of tephra dispersal: application to the Neapolitan area

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The intrinsic uncertainty and variability associated to the size of next eruption strongly affects short to long term tephra hazard assessment. Often, emergency plans are established accounting for the effects of one or a few selected reference scenarios. Probabilistic hazard assessments for tephra dispersal need the definition of eruptive scenarios with associated probabilities, a meteorological dataset covering a representative time period and a tephra dispersal model. Probabilistic assessment results from weighting a statistical number of simulations considering different volcanological and meteorological conditions. Volcanological inputs such as erupted mass, eruption column height, eruption duration, bulk granulometry, fraction of aggregates typically encompass a wide range of values. Because such a variability, it is clear that the eruptive scenario cannot be adequately defined using single values for the volcanological inputs. Here we account for this variability using a range for each eruptive parameter and assuming a uniform or beta Probability Density Function between the extreme values of the range. Once a PDF is defined, meteorological and volcanological inputs are chosen by using a stratified sampling method that consists of dividing the population into mutually exclusive, exhaustive and homogeneous sub–groups before sampling. The ECMWF reanalysis dataset are used for exploring different possible meteorological conditions. This procedure allows avoiding the bias introduced by selecting a single reference setting and thus neglecting most of the intrinsic sources of eruptive variability. Results from one or more dispersal models are then integrated through a Bayesian tool to quantify epistemic uncertainties. Finally, this Bayesian tephra dispersal hazard assessment allows us to produce probabilistic hazard curves for strategic structures and of standard hazard maps in analogy with the seismic case, representing the information primarily used in risk mitigation actions. As examples, here we explore this issue by analyzing long term volcanic hazard for tephra fall at Vesuvius and Campi Flegrei, Italy. We integrate the simulations by two tephra dispersal models, the analytical HAZMAP and the numerical FALL3D models respectively, into BET_VH.

The results obtained clearly show that volcanic hazard based on all possible eruptive settings is significantly different from the analysis based on a single reference setting, as used in volcanic hazard common practice. We highlight the differences with a previously published study in which three different scenarios were again considered, but each scenario had fixed volcanological inputs. As examples, we also show the resulting probabilistic hazard curves for a few strategic points in Naples, and a standard hazard map displaying, at every point, the maximum tephra load with a probability equal to 10% expected to be exceeded in 50 years.

Short-term probabilistic hazard assessment of tephra dispersal: application to the Neapolitan area

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During volcanic unrest episodes, as well as during eruptions, it is of primary importance to produce short term tephra fallout forecast, and frequently update it to account for the rapidly evolving situation. This information is crucial for crisis management, since tephra may heavily affect building stability, public health, transportations and evacuation routes (airports, trains, road traffic) and lifelines (electric power supply). Theoretically, this assessment should be based on sound modeling procedures stemming from frequently updated meteorological forecast and information about the crisis evolution. In addition, the relevance of epistemic uncertainties arising from the forecast of the future eruption dynamics and wind conditions, and from the tephra dispersal model, should be estimated.

Here, we present a new methodology for short term hazard assessment of tephra fallout. This methodology is based on the model BET_EF, in which measures from the monitoring system are used to routinely update the forecast of some parameters related to the eruption dynamics, that is, the probabilities of eruption, of every possible vent position and every possible eruption size. Then, considering all possible vent positions and eruptive sizes, tephra dispersal models are coupled with frequently updated meteorological forecasts. Finally, these results are merged through a Bayesian procedure, accounting for epistemic uncertainties at all the considered steps.

As case study, we report the application of this procedure to Mt. Vesuvius. Tephra dispersal is simulated using two models (the analytical HAZMAP and the numerical FALL3D models respectively). We consider three possible eruptive sizes (a low, a medium and a high eruption scenario respectively) and five possible vent positions (the central crater vent location, and four radial sectors on the volcano slopes). The analysis is performed using the evolving volcano dynamics as simulated during the Civil Protection exercise MESIMEX (2006). The probabilities related to eruption dynamics, and estimated by BET_EF, are based on monitoring parameters, and relative thresholds, that were set and published before the beginning of the exercise.

Modelling thickness variability in tephra deposition

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Analysis of tephra deposits is important for hazard and risk assessment of explosive eruptions due to its widespread impacts. Most studies describe tephra attenuation using numerical models based on advection-diffusion equations. We start from the Gonzalez-Mellado and De la Cruz-Reyna (2010) semi-empirical attenuation model. Here, the mean expected tephra thickness is estimated for a specific location as

$$T(r,\xi) = \gamma \exp(-\beta U r\, [1-\cos(\xi-\phi)\,])\, r^{-\alpha}$$

where T is the tephra thickness (cm) at distance from the vent r (km) in direction ξ. The effective volume γ, degree of wind dispersal βU, mean wind direction ϕ and attenuation rate α are parameters to be estimated.

Normally, isopachs are drawn to estimate the attenuation model, but this involves varying degrees of subjectivity. In a significant difference from common practice, our estimation uses actual individual tephra thickness measurements, rather than the derived isopachs. These thicknesses differ from an ideal (model) thickness due to randomness in the particle movements and to a lesser extent, landscape variability (which should be accounted for in the physical sampling process). This difference is termed the *sampling error* and can be explicitly incorporated in the estimation procedure. Since the thickness is strictly non-negative, and we expect a larger error for larger measurements, a multiplicative error structure is assumed. This suggests distributions such as the lognormal, Weibull and gamma to express this variability. The attenuation model is treated as a link function giving the expected thickness at a given location. The parameters in the model and the variance in the error distribution are estimated using maximum likelihood.

The 1973 Heimaey eruption was a typical small scale basaltic explosive eruption ideal for illustrating this method. While the Weibull and gamma fit the data well, the lognormal did not because of its tendency to require a number of greatly over-thickened measurements. Thus linear regression of the logarithm of thickness on distance is not an accurate means of predicting the expected tephra thickness. The estimated parameters from the other two error models were consistent with the observations made at the time of the eruption.

For multiple source eruptions, the model is implemented in a mixture framework to account for multiple lobes and/or vents. The source and direction of tephra deposits can then be identified from only the observed tephra thickness measurements. The Weibull distribution was used for the 1977 Ukinrek Maars eruption, which lasted for two weeks, producing two maars. The mixture attenuation model was able to identify lobes in the correct directions from each maar, matching the observed eruptive stages.

Estimation of Airborne Ash Density using a Real-time Volcanic Ash Dispersion Model PUFF

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A real-time volcanic ash tracking model Puff is applied to Sakurajima Volcano in Japan in order to estimate the airborne ash density. The ash fallout by the Puff model is compared with the in-situ observation around Sakurajima Volcano for one year in 1985, and the particle mass in the model is calibrated to match with the fallout record. The eruption mass flux and the plume height for the Puff model input were estimated from the real-time seismic record with ten minute's interval for one year. Based on the calibration for the ash fallout in Puff model, we have estimated the airborne ash density and its dispersion. According to the result, the airborne ash density is estimated quantitatively for all time and 3D space as a rough first guess. Ash density less than 2 mg/m3 is one criterion for aviation safety. It is shown by the analysis that the ash density above 2 mg/m3 is restricted in a narrow area near the volcano, and the density decreases rapidly to the safe level for the aviation by dispersion of ash particles. The information of the airborne ash density is useful for the real-time aviation safelty.

Modeling volcanic ash resuspension. Application to the 15-16 October 2011 outbreak episode in Central Patagonia, Argentina

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Resuspension of volcanic ash by wind can cause strong impacts at scales from local to regional, including deterioration of air quality and disruption of airports if the concentration of resuspended ash at low atmospheric levels exceeds critical values. For example, following the eruption of Cordon del Caulle in Chile, several Argentinean airports in central and northern Patagonia were continuously disrupted during strong wind episodes, causing considerable economic impact on the region. A major outbreak episode occurred during 15-16 October 2011, with resuspension forming a large ash cloud that reached as far as Buenos Aires city and Uruguay. The ash cloud forced the Ezeiza International airport to shut down and raised the air quality indicators above the maximum limits allowed. Resuspension of ash from fallout deposits depends on a complex combination of meteorological conditions (wind intensity, friction velocity, soil moisture) and physical properties of particles. When the intensity of wind blowing across a granular soil exceeds a certain threshold, mid-size particles (larger than about 50 um) begin to saltate and, when falling back to ground, break the cohesive forces of smaller particles on the surface favouring its suspension. The emission rate (vertical flux of particles), which strongly depends on the saltation flux of larger particles, determinate the formation and subsequent transport of ash clouds. Unfortunately, emission schemes specific for volcanic ash are inexistent. Here we implement several emission schemes originally developed for emission of mineral dust in the WRF-FALL3D modelling system and investigate its use for volcanic ash using the 15-16 October 2011 outbreak episode as a test case.

NWP ensembles for volcanic ash plume forecasting

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Numerical Weather Prediction (NWP) models solve a system of equations to provide a forecast of wind velocity, temperature, pressure and precipitation for a future time. NWP models do not capture the smallest scales, therefore there will always be a degree of error in the model forecast for any NWP system. Small differences in initial conditions may lead to large differences in the forecasts.

In this contribution, we extend previous work on addressing the problem of propagation of uncertainties in the volcanic input (source) parameters by additionally propagating uncertainties in the windfields in an ash transport and dispersal model. Windfields as well as source parameters represent major sources of uncertainty in ash transport and dispersion simulations. We thus expect ash transport forecasts to be deeply affected by perturbations in forecast wind speed as well as source conditions.

We hindcast the motion of the ash cloud for the eruption of Eyjafjallajokull, Iceland, which had a peak ash emission in the period 14-18 April 2010. We couple three numerical tools to analyze this issue. The first is the Weather Research and Forecasting (WRF) model used to forecast wind speed. The second tool is a volcanic eruption column trajectory model, *puffin*, employed to incorporate volcano observations and then provide initial conditions for a volcanic ash cloud transport and dispersal (VATD) model. The third tool is thus a VATD model, *puff*, used to propagate ash parcels in the wind field.

Based on our lack of knowledge of the exact conditions of the source, probability distributions are assigned to the parameters which are later sampled in a weighted, Monte Carlo-like fashion using either polynomial chaos quadrature or cut point techniques. For windfields, ensemble methods are sometimes considered to be an effective way to estimate the probability density function of future states of the atmosphere by addressing uncertainties present in initial conditions and in model approximations. We are using the Global Ensemble Forecast System (GEFS) generated by the National Center for Environmental Prediction (NCEP), which is a weather forecast model made up of 21 separate ensemble members. The forecasts are produced four times daily, at 0000, 0600, 1200, and 1800 UTC, starting 0000 UTC April 14 to 0000 UTC April 18 on a 1° latitude by 1° longitude grid. A continuous WRF run/integration with a single GEFS member initialization is done resulting in outputs at every 3 h at each of 74 pressure levels. Output moments and probabilities are then computed by properly summing the weighted values of the output parameters of interest. The results are presented as a forecast envelope and show how volcanic source term uncertainty and windfield stochastic variability can affect the forecast. Thus, we produce a nominally complete probabilistic forecast of ash cloud position.

On-line coupling of volcanic ash with global and regional meteorological models

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Large explosive volcanic eruptions can inject significant amounts of tephra and gaseous materials into the atmosphere inducing an multi-scale array of physical, chemical and biological feedbacks within the environment. The assessment of the tephra dispersion hazards is critical when determining local and regional environmental and socio-economic disruptions. Additionally, stratospheric sulfate aerosols generated from volcanic sulfur gases and fine ash particles might result in disturbance of the energy balance and chemistry of the atmosphere at a global scale. Effective models for forecasting the spatial and temporal distribution of volcanic ash and sulfate aerosols are necessary to assess the magnitude of these feedback effects, and they have become critical tools in addressing the scientific, economic and political issues associated with large volcanic eruptions. However, the magnitude of these feedback effects within the climate system still remains poorly documented.

In the frame of the NEMOH network, a training network under the European Community FP7 for the numerical, experimental and stochastic modelling of volcanic processes and hazards, we aim at validating the off-line hypothesis currently assumed by most tephra transport models, by analyzing the extent to which the near-source and regional meteorology is affected by dense ash clouds altering the radiative budget and the climate system in general. The first step of this 3-year project, is to compare the spatial and temporal distribution-sedimentation of volcanic ash outputs from the off-line FALL3D-TTDM with those on-line from the new non-hydrostatic Multiscale Meteorological model on a B grid (NMMB). For this purpose, the transport and sedimentation module for volcanic ash existing in the FALL3D model is coupled to a new version of the NMMB model. This presentation summarizes the capabilities, limitations, and sources of uncertainty from modelling ash dispersal for large volcanic eruptions, both off and on-line with meteorological models.

The NMMB model is the evolution of the WRF-NMME meteorological model. The BSC is also implementing an on-line gas-aerosol chemical module to model sulfate aerosols generated during large explosive volcanic eruptions and evaluate their impact within the climate system.

Assessing and visualising risk from multi-phase volcanic events: a new web-based modelling platform applied to Greater Tokyo, Japan

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Volcanic eruptions differ from other natural perils in that they may occur over extended periods of time and involve a number of hazards with different spatial and temporal scales. We present Multi-Peril Online, a new research tool that provides a consistent framework for modelling and visualising probabilistic volcanic risk. Unique to this platform is the ability to store hazard data temporally as well as spatially. Vulnerability functions relate risk to the duration and timing of the hazard as well as magnitude. This will allow for analysis of transport, utility and business network disruptions.

The platform incorporates advanced natural hazard risk analytics common in insurance loss modelling and provides a means to store and analyse large hazard and exposure datasets. Hazard and exposure information may be stored at various resolutions so that the risk from intense local hazards, such as lahars, may be analysed alongside widespread hazards such as tephra fall. Outputs are measures of risk (for example, economic loss or casualties) with corresponding average recurrence intervals and annual exceedance probabilities. Results may be plotted for a given location or mapped for a particular threshold.

The framework may be applied to any area at risk from volcanic hazards. A defined data format means that probabilistic hazard simulation results may be uploaded to the platform independent of the software or techniques utilised in their creation. Vulnerability functions may be viewed and edited online and additional functions corresponding to a user's exposure may also be added.

To demonstrate the features of this framework, probabilistic multi-phase tephra hazard simulations for Fuji, Asama, Hakone, Haruna, Kusatsu-Shirane and Kita-Yatsugatake volcanic centres have been uploaded to the platform. Exposure information for the Greater Tokyo region was also added including population, building, and land-use data. We will present improved probabilistic loss results for building damage, clean-up operations and agricultural production and discuss ways in which event duration and timing can be further incorporated into risk modelling strategies.

BET _VR: a probabilistic tool for long–term volcanic risk assessment

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We present a new methodology that extends the concept of Bayesian Event Tree to the quantitative assessment of Volcanic Risk (BET_VR). New nodes (levels) of analysis are added to the BET_VH structure (Bayesian Event Tree for Volcanic Hazard), accounting for the vulnerability and exposure levels. In particular, the goal of this approach is to provide the assessment of risk curves (the exceedance probabilities for different levels of losses) accounting for the uncertainties (both aleatory and epistemic) in hazard and fragility assessments, loss evaluation and exposure.

Here, we present a preliminary application to the direct monetary risk related to tephra fall in Naples. In particular, we selected several areas of Naples for which fragility models and census databases are available. In these areas, the hazard assessment for tephra fall from Mt. Vesuvius and Campi Flegrei is considered, and coupled to vulnerability and exposure assessments. As a result, both risk curves and expected values are evaluated, propagating epistemic uncertainties from the very beginning (eruption probability) to the very end (losses due to damages) of the assessment.

The analysis described here is carried out in the framework of the project "Quantificazione del Multi–Rischio con approccio Bayesiano: un caso studio per i rischi naturali della città di Napoli", funded by the Italian Ministry of Education, Universities and Research (Ministero dell'Istruzione, dell'Università e della Ricerca), and the FP7 European project "MATRIX" (New multi–hazard and multi–risk assessment methods for Europe).

Volcanic eruption durations: Forecasts and controls.

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During volcanic eruptions a question commonly asked is "How long will the eruption last?" To help answer this, we develop means of forecasting the eventual end of a volcanic eruption using statistical and physical approaches.

Ideally we would consider a period of continuous magma effusion as the basic building block of an eruption. Due to the nature of volcanic eruptions and the quality of historical records the start and/or end date of an eruption can be ambiguous, so some eruption durations carry an uncertainty of up to several days or weeks whereas others are known to a precision of less than one day. Short breaks in activity were dealt with by treating eruptive phases separated by periods of inactivity of less than 10 days as belonging to the same eruption.

Using this method we have critically assessed the literature and compiled datasets of historic eruption durations for Piton de la Fournaise (Indian Ocean), the flank eruptions of Mt Etna (Italy) and for 7 Icelandic volcanic systems. We present a statistical forecasting tool, which models the distribution of historic eruption durations within a dataset, and uses survival analysis to give the probability of a future eruption exceeding a specified duration. Such forecasts could be useful for emergency response planning prior to an eruption, providing insight into the likely time scale of the scenario being considered. The method also allows the probability of exceeding a specified duration to be calculated in cases where an eruption has already been occurring for a known amount of time. To assess the effect of duration uncertainty on the forecasted results the model has been run using maximum and minimum possible eruption durations with results showing an insignificant difference.

We also present a comparative study of the distribution of eruption durations for the datasets compiled. Results indicate a predominance of shorter eruptions at Piton de la Fournaise, and longer eruptions at Hekla (Iceland). For an individual eruption, the final duration can be considered to be a function of the volume of material available and the physical parameters controlling the rate at which this material is erupted i.e. magma viscosity, conduit radius, conduit height etc. The unique distribution of eruption durations at each volcano can then be interpreted to be a result of the range and distribution of the possible volumes and values for these parameters, which are specific to the volcano itself. Recognition of these leading controls on eruption duration could underpin the development of a physical model to forecast future eruption durations. Such a model could be refined throughout the early stages of an eruption, accounting for the physical properties that the eruption demonstrates, thus providing a forecasting tool that includes more information than the previously mentioned statistical model. Both approaches show great promise for their application in real life situations.

Eruption scenario of Usu volcano, Japan

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The national research group on volcanic eruption forecasting is preparing the eruption scenarios (event trees with probabilities) for representative active volcanoes, such as Izu-Oshima, Miyakejima, Sakurajima, Shinmoedake (Kirishima), and Usu. During recent eruptions at Sakurajima and Shinmoedake, the eruption scenarios were prepared and used to try to evaluate the development of on-going eruptions.

At Usu volcano, after a sector collapse about 7 to 8 ka, the eruptive activity resumed in 1663 with the plinian and pyroclastic surge events. Since then, five summit eruptions with the plinian columns had occurred in the end of 17th Century, 1769, 1822, 1853, 1880-1889, and 1977-78, and three flank eruptions with phreatic to phreatomagmatic events had occurred in 1910, 1943-45 and 2000. These eruptions were recorded in old documents or observed geophysically from the beginning of 20th Century. These eruptions occurred statistically every 30+/-4 years. Except small flank eruptions, there is a good negative correlation between the erupted volume and frequency in log unit. Seismic precursory started generally a few days before the eruption in respective of eruption locations. The summit eruption started after acceleration of seismic activity, while the flank eruption did after passing the peak of seismic activity. In respective of the eruption locations, eruptions ended with the formation of lava domes or cryptdomes, except for the 1663 eruption. The larger the erupted volume, the shorter the eruption duration. As a whole, the volume of eruption decreased with time and the magma became less evolved from 75 % SiO2 in 1663 to 69 % SiO2 in 2000. Temporal development of three cycles of magma plumbing system, in each of which mafic magma injected into chemically zoned, shallow magma chamber, is proposed.

The probability of flank failure in future can be calculated about 0.01, and those of the summit and flank eruptions are about 0.3 and 0.5, respectively. The summit eruption starts with the plinian event column in about 0.75 probability, while the flank eruption starts in about 0.7 probability without magmatic eruption. However, this may be a rough indicator because these data are based mainly on the eruption records during these 300 years. For example, summit-subsidence eruption occurred at Miyakejima for the first time in about 2500 years, and pyroclastic flow eruption at Unzen in about 4000 years. Movement of the fault system suggesting a future sector collapse in the northern flank of the volcano was observed during the last two eruptions. New eruption scenario not based only on the past eruption records should be prepared.

Quantifying the volcanic ash hazard to aviation in Southeast Asia

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Southeast Asia (SEA) hosts a densely populated airspace and some of the most active volcanic arcs on the planet. This combination has resulted in dozens of aircraft-volcanic ash encounters in the past 50 years. Only ~80 of 346 potential ash-producing volcanoes in SEA have been mapped in detail. We approximate the hazard at the remaining 266 by comparing their morphologies to the well-documented 80, and use simplified profiles of the 80 as proxy histories for the 266. We assume that volcanoes with similar morphologies have similar eruptive behavior.

We define 5 classes of volcanoes, based on morphology but also considering degassing behavior. These are: (1) Laguna class volcanoes, fields of maars, cinder cones, spatter cones, and shields. The type example is the Laguna Volcanic Field, Philippines (13.204, 123.525). There are 35 Laguna class volcanoes in SEA (N_{Laguna}=35). (2) Mayon class volcanoes, open-vent, frequently active, steep sided stratocones. Most have small summit craters, spatter ramparts, small pyroclastic fans (typically <3 km but up to 5 km in radial length) and lava flows. The type example is Mayon Volcano, Philippines (13.257, 123.685). N_{Mayon}=41. (3) Kelut class are semi-plugged composite cones with dome complexes, pyroclastic fans, and commonly with debris avalanche deposits or collapse scars. The type example is Kelut Volcano, Indonesia (-7.933, 112.308). N_{Kelut}=176. (4) Pinatubo class are large plugged stratovolcanoes with extensive (tens of km) pyroclastic fans and large summit craters or calderas up to 5 km in diameter. The type example is Pinatubo Volcano, Philippines (15.133, 120.350). $N_{Pinatubo}$=22. (5) Tambora-Toba class are calderas with long axes >5 km and surrounded by extensive ignimbrite sheets. The type examples are Tambora Volcano, Indonesia (-08.25, 118.00) and Toba Caldera, Indonesia: (02.583, 098.833). Silicic domes that might produce large caldera-forming eruptions are also classified as Tambora-Toba class. $N_{T\text{-}T}$=19.

We estimate the probabilities of each VEI eruption from each morphologic class in the next decade, based on (Poisson) the eruptive history of the class. The probability is 1 (Pr =1) that ≥1 volcano in every class will produce ≥1 small (VEI 1-2) eruption, that a Mayon class volcano will produce a VEI 3 eruption, and that a Kelut class volcano will produce a VEI 4 eruption. A VEI 5 eruption has a Pr = 0.2 of occurring from a Kelut class and a 0.1 from a Pinatubo class volcano. The probability of a VEI ≥6 eruption is <0.01 from all classes combined. Ongoing work will address ash dispersion from these eruptions into heavily traversed air traffic corridors in SEA.

Probabilistic invasion maps of long-term pyroclastic density current hazard at Campi Flegrei caldera (Italy)

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Campi Flegrei is an example of active and densely urbanized caldera with a very high risk associated with the occurrence of pyroclastic density currents (PDCs) produced by explosive events of variable scale and vent location. The mapping of PDC hazard in such a caldera setting is particularly challenging not only due to the complex dynamics of the flow but also due to the large uncertainty on future vent location and the complex topography affecting the flow propagation. Nevertheless, probabilistic mapping of PDC invasion, able to account for the intrinsic uncertainties affecting the system, is needed for hazard assessment. In this study we present a variety of probabilistic PDC hazard maps of the Campi Flegrei area based on different invasion models and accounting for the uncertainty in vent opening and event size. Invasion models were based on simple empirical correlations derived by field reconstruction of past events, simplified one-dimensional models based on a linear decay of the flow energy (e.g. energy line), and correlations derived from 2D and transient numerical simulations of the flow dynamics. Field data referred mostly to the third epoch of activity of the volcano (i.e. last 5 kyr) although the analysis was extended to the last 15 kyr. In addition to the uncertainty affecting the vent location the probability invasion maps illustrate some of the uncertainties and features affecting the invasion models adopted. Results show that, consistently with field evidences, the central-eastern part of the caldera (i.e. Agnano-Astroni) is the area most exposed to flow invasion whereas values up to about 5-10

Probabilistic Hazard Mapping: A flexible Approach for Crisis Management

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We present a fully probabilistic analysis of the impact by pyroclastic density currents from the Soufriere Hills Volcano, Montserrat as simulated by TITAN2D. The methodology presented is new and specifically devised to address the complications associated with continuous assessment and reassessment of the status of an eruption as well as the use, and testing of, variable probability models as the understanding of the physical system is improved. For the Belham River Valley, a strategically crucial drainage system in Montserrat, we undertake a high spatial-density of site-specific probability calculations for inundation by pyroclastic flows, and thereby construct contour maps of probabilistic hazard. We present a methodology that uses flow simulations to characterize the probability of inundation from pyroclastic density currents, but requires a relatively small number of simulations and importantly, divorces those simulations from any probabilistic models of initial conditions. The key to this methodology is the realization that a particular set of initial conditions will result in flow inundation (or not) at a given map point regardless of how likely that set of initial conditions is. Our strategy therefore separates initial condition space into regions that lead to inundation and regions that do not. With that knowledge in hand, we effectively turn the probability calculation into a post-processing step to be computed without the need to undertake additional flow simulations. Furthermore, this allows for accommodation of changing eruption scenarios, or our understanding of the eruption, without coupling those to a new set of initial condition simulations. We demonstrate this by testing the method for several probability models which are constructed based on different activity levels of the volcano as well as over short (1-month) to long (10-year) periods. Utilized in this manner, the methodology provides a level of flexibility and computational efficiency, which is uniquely placed to respond and improve real-world hazard assessments.

Constraints on eruption precursors from crustal structure and pore-fluid pressure

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Accelerating rates of occurrence of volcano-tectonic (VT) events show a remarkably restricted range of behaviour before eruptions, independent of magma composition and tectonic setting. The VT events are controlled by fault movement. Restricted patterns of VT behaviour may thus reflect the operation of a common distribution of faults in the crust around a magma reservoir.

The range of precursory VT behaviour has been encapsulated by the empirical Voight criterion (Ref. 1), the limits of which have since been supported by theoretical analyses (Refs 2 and 3). Comparable behaviour has been observed in the laboratory among increasing rates of acoustic emissions (AE) before the bulk failure of rock samples. In detail, however, previous studies have implicitly assumed different loading conditions on the breaking rock. Thus laboratory data typically refer to failure in compression under constant stress or constant strain rate, whereas field data at volcanoes refer to local failure in extension under constant or variable strain rate. The apparent universality of fracturing trends, independent of loading condition, is consistent with precursors being controlled under natural conditions by a structural feature that can develop at length scales from laboratory samples to the crust. This feature must involve discontinuities that (1) are present before a precursory sequence begins and (2) can control rates of precursory fracturing independent of the prevailing stress field. A second, contemporaneous field constraint is that deformation must allow faults to move apart, so that magma can ascend to the surface. Local stress fields must thus satisfy conditions for deformation with a tensile component.

The structural characteristics are satisfied by a Hill-type distribution of discontinuities (Ref. 4), for which a network of fractures, some of which in the field may be filled with magma, are connected to each other by obliquely-oriented faults. Activation of faults in such a network has the potential to induce AE or VT events under stress fields suitable for extension or compression. For crust to fail with a tensile stress component, the applied differential stress cannot exceed about four times its tensile strength (Ref. 5). As a result, pore-fluid pressures greater than hydrostatic must prevail in the vicinity of magma bodies if these are to feed magma to the surface from depths greater than about 2.0-2.5 km.

(1) Voight B (1988) Nature. 332: 125-130; (2) Kilburn, CRJ (2003) J Volcanol Geotherm Res, 125: 271-289; (3) Kilburn CRJ (2012) J Geophys Res, doi: 10.1029/2011JB008703; (4) Hill DP (1977) J Geophys Res, 82: 1,347-1,352; (5) Shaw HR (1980) In Hargeaves RB (Ed.) Chap. 6, Physics of Magmatic Processes, Princeton University Press.

Evaluating the performance of models for rates of pre-eruptive seismicity

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Volcanic eruptions are commonly preceded by elevated rates of seismicity. Various models have been proposed to explain apparently systematic trends in pre-eruptive earthquake rate and potentially promise quantitative forecasts of the timing of future eruptions. However, these models, and their forecasting power, remain largely untested. Here we evaluate the performance of models based on the exponential and power-law forms of Voight's relation. Drawing on examples of pre-eruptive seismicity from volcanoes including Mount St Helens, Mt Etna, and Pinatubo, we use statistical techniques for model preference, estimating parameter uncertainty, and constraining forecast convergence rates. A comparison between the observed behaviour and that for idealized synthetic data finds reasonably good agreement. However, unsurprisingly, there is evidence for pre-eruptive processes not captured in these simple models, including episodes of relative quiescence immediately prior to the onset of eruption that may be indicative of magma migration. These results suggest that the uncertainty in eruption forecasts based on such models is even larger than the inherent model-based uncertainty, and highlight the necessity for improved understanding and quantitative models for pre-eruptive processes.

The material failure forecast method as a potential eruption forecasting tool: application to the 2012 unrest episode at White Island volcano, New Zealand

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White Island volcano is one of the most active volcanoes in New Zealand, expressed historically as small-to-medium scale eruptive sequences and quiescent periods with continuous degassing, seismic activity and crater floor deformation. The presence of spectacular active geothermal features (hot springs, fumaroles, crater lake) also makes it one of the most attractive tourist destinations in the country.

After more than 10 years of relatively minor hydrothermal activity, some sustained periods of volcanic tremor started in June 2012 and marked the beginning of a new volcanic unrest episode, including ash eruptions, small scale geysering and a micro dome building episode. This volcanic tremor has been recorded by a continuously operating seismic station situated on the crater rim. The evolution of tremor intensity is monitored using the Real-time Seismic Amplitude Measurement (RSAM) which is often coupled to the surface changes such as the 5 August 2012 eruption and the January 2013 geysering events.

We present results from a test of the material Failure Forecast Method (FFM) in hindsight on the different volcanic tremor episodes using RSAM data and assess how the predicted failure times fit with observations made at the volcano. We then discuss how these results can allow a better understanding of the volcano unrest episode and the relevance of the FFM for future volcano monitoring at White Island.

The potential role of a database in building an event probability tree: Case of Mt. Merapi eruptions

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Mt. Merapi has frequent eruptions with a repose period of less than 7-years, a long history of monitoring, and a well-known geological history. These three aspects together make the volcano a good case study for simulation in building event probability trees.

The Merapi eruptions were preceded by various anomalies in monitoring data including geochemical, seismic and deformation. Although each unrest episode has its own specific pattern, it still shares common behaviour with other episodes. This common behaviour may be characteristic of Mt. Merapi. For building a retrospective event tree for the case of Merapi unrest, we use multiple historical events such as those of 1986, 1994, 1997, 1998, and 2001. A complete database of historical unrest from those years would be a key for having an accurate event tree of 2006. For the simulation, we use information in WOVOdat about historical unrest of Merapi to aid in quantitative estimates of probability.

For volcanoes with less frequent eruptions or longer repose periods, and for those without monitoring data, we can consider some analogous volcanoes for reference. One of the advantages of having a worldwide database of volcanic unrest, especially for volcanoes with limited monitoring data, is that it provides a way to build event trees quickly without waiting for new research on the restless volcano itself.

Non–magmatic branches in the Bayesian Event Tree for eruption forecasting (BET_EF), and their implications for unrest tracking

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In the previous set up of the Bayesian Event Tree for eruption forecasting (BET_EF), only magmatic eruptions are considered. However, non–magmatic events, such as increased hydrothermal, seismic or phreatic activity, are often obvious signals of volcanic unrest that may cause damages. Here we propose an implementation of the BET_EF that may account for these kind of non–magmatic risks related to volcanic areas. This implementation requires a modification at the second node of the Event Tree where the nature of the unrest is introduced. In order to assign the probability to the new branches of Node 2, suitable monitoring parameters, and thresholds should be established; ultimately, this requires a more profound understanding of the delicate transition from volcanic quiescence to unrest, and of the differences in the processes generating different kinds of volcanic unrest (e.g., what could be a precursor for a phreatic eruption?). We think that this further ramification of the BET_EF code will bring several advantages: it permits to (1) better describe the cause of unrest of any volcano, also including the numerous volcanoes in a state of non–magmatic unrest, not considered earlier, (2) forecast the evolution of non–magmatic unrest into non–magmatic eruptions (Node 3) that pose direct volcanic hazard without magma involvement (e.g., phreatic eruptions, mechanic failure of volcanic edifices, gas hazard), and (3) quantify the probability of non–magmatic unrest being precursory signals themselves when building up towards magmatic unrest or magmatic eruptions (e.g., tectonic earthquakes triggering an eruption, transition from phreatic to phreatomagmatic eruptions). The latter point implies strong modifications in the numerical calculations of the BET_EF probabilities. This research is part of the VUELCO project; the proposed modifications are useful to better describe volcanic unrest, especially for the closed–conduit target volcanic systems of Campi Flegrei (Italy), Morne Aux Diables (Dominica), Teide (Tenerife, Spain), Cotopaxi (Ecuador) and Soufrière Hills (Montserrat).

Effective decision making during volcanic crises using operations research and bayesian decision theory

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Understanding the potential evolution of a volcanic crisis is crucial to improving the design of effective mitigation strategies. This is especially the case for volcanoes close to densely-populated regions, where inappropriate decisions may trigger widespread loss of life, economic disruption and public distress. An outstanding goal for improving the management of volcanic crises, therefore, is to develop objective, real-time methodologies for evaluating how an emergency will develop. Here we use operations research to show how evaluations can be improved during the different stages of an emergency by applying a Decision Model Architecture for volcanic crisis management.

Operations Research (OR) is a field of mathematics that uses advanced analytical methods to help make better decisions, and to arrive at optimal solutions to complex decision-making problems. We use a Bayesian Decision Theory approach from OR to design a model framework that incorporates decision making at all the stages of a volcanic crisis. The model combines the multiple hazard and risk factors that decision makers need for a holistic analysis of a volcanic crisis. These factors include all possible eruptive scenarios and their probabilities of occurrence, the evolution of the monitoring parameters, the evaluation of the population at risk, the evacuation time associated with each eruptive scenario, the cost of a false alarm, and the cost of a failed forecast. The combined results identify the most likely scenarios and provide the basis for establishing a range of recommended actions as an emergency evolves.

What to do when there is neither time nor a group of experts for expert elicitation?

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Two increasingly popular approaches to probabilistic eruption forecasting rely on carefully structured expert elicitation. The Bayesian Event Tree for Eruption Forecasting (BET-EF; Marzocchi et al., 2008) conducts elicitations well in advance of a crisis to identify parameters and thresholds that can then be applied objectively during real volcanic crises. The method of Cooke (1991), adapted by Aspinall (2006), elicits expert opinion during simulated or real volcanic crises. In the latter method, experts are pre-tested to weight their credibility and then asked to evaluate probabilities of various outcomes for unfolding unrest. Both methods are based on monitoring data, eruptive history, volcanologic theory and models and both involve some subjectivity. The main difference is whether subjective analysis is done before or during a crisis.

In some volcanic crises, there is neither a prior elicitation or time and a group to do a new elicitation. An alternative is for one or a few scientists to use all available data sets to estimate probabilities at each node of an event tree such as the generic one proposed by Newhall and Hoblitt (2002). Some of these data sets are small, e.g., limited data on VEIs of the volcano in question. But even at poorly-known volcanoes, the data set may be expanded by considering unrest and eruptions at analogous volcanoes. Several databases can help, e.g., WOVOdat for statistics on origin of unrest, likelihood and magnitude of eruption; Smithsonian GVP database and VOGRIPA for eruption magnitude, phenomena, sectors, and distance); research on the effects of eruptions to judge vulnerability; VPI (Ewert and Harpel, 2000), LandScan, or census data to know populations at risk; and research on human responses to judge whether those at risk can be moved. It is not necessary to favor one data set over another; we consider all and use high and low estimates as measures of uncertainty at each node. The data and logic are explained for each node of the event tree in an accompanying document. Our method risks excessive reliance on the expertise of just a few individuals, but it has an advantage of easy-to-follow tracing of the data and logic for each estimate of probability at each node.

Will such a simple approach stand in a court of law? If each data set for each node is clearly presented and justified, and no attempt is made to choose between them, the facts can stand by themselves. No pertinent data set is ignored, or subsumed into a more amorphous product of many data sets and interpretations. BET-EF and the Cooke-Aspinall method have the advantage of many viewpoints and they may protect individual scientists from legal challenges. However, these procedures may be impractical during a rapidly evolving crisis at a poorly-known volcano. We see great value in all of these probabilistic approaches to forecasting and we recommend that all of them be used and compared whenever practical.

Space-time Analysis of Volcanic Eruptions and Disasters in Japan for the Past 2,000 Years

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Historic records of volcanic activities and disasters provide very useful lessons for disaster mitigation planning. Every historic document ever recorded in Japan dealing with volcanic disaster events has presently been re-surveyed and verified. Records have been obtained for a total of 1,162 eruptions over the past 2000 year for 110 active volcanoes. The 47 active volcanoes newly designated for constant monitoring by the Japan Meteorological Agency (JMA, 2011) account for 87% of all the eruptions. By reviewing documentation and referring to published data, values of the Volcanic Explosivity Index (VEI) for approximately 90% of the eruptions recorded could be evaluated. VEI 1 and 0 eruptions were recorded only during the most recent 100 and 50 years, respectively. The numbers of VEI 2 and 3 are mostly distributed over the past 500 years, with VEI 3 numbering the highest. Present results for the past 2000 years in Japan are generally similar in tendency to the world data for the past 10,000 years reported by the Smithsonian Institution (2010). However, there have been no VEI 6 and 7 eruptions recorded in Japan.

Using the frequency-distribution analyses for eruptions as a function of VEI value, we have obtained the average frequency for each level of VEI. VEI 5 eruptions occur approximately once every 180 years, and VEI 4 eruptions occur once every 50 years with some fluctuations. VEI 3 and VEI 2 eruptions occur approximately once every18 years and 4 years, respectively, but with somewhat larger fluctuations. After the space analysis, we obtained a regional view of volcanism in Japan. Kyushu is the most volcanic active area and after Kyushu, Kanto-Chubu, Izu-Mariana, Hokkaido, and Tohoku, in that order. However, larger VEI 4 and 5 eruptions tend to occur in Hokkaido. After the results were summed up by numbers of casualties, human and physical damages due to volcanic disasters, excluding deaths not directly related to the eruptions, e.g. starvations or epidemics, there were approximately 20,000 victims over the past 2,000 years. Over 80% of the deaths were due to volcanic tsunami, followed by deaths from lahars, including mudflows or debris flows, pyroclastic falls, debris avalanches, and pyroclastic flows. The highest number of victims per an eruption was due to volcanic tsunami and debris avalanche, although these are very infrequent.

After performing present space-time analyses for eruptions and volcanic disasters over the past 2000 years in Japan, specific and available data could be obtained and useful information-resources for volcanic disaster mitigation could be provided. We expect local decision-makers, administrative officials of disaster mitigation organizations and academic researchers to use these present results effectively to propose robust counter-measure strategies to implement when future volcanic events occur.

How Many Explosive Eruptions are Missing from the Geologic Record? Analysis of the Quaternary Record of Large Magnitude Explosive Eruptions in Japan.

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Explosive eruptions of the Japanese islands, which are included in The Large Magnitude Explosive Eruptions database of Volcano Global Risk Identification and Analysis (VOGRIPA) project, are analyzed to understand the preservation potential of eruptions with time. The Large Magnitude Explosive Eruptions database is a part of the VOGRIPA project and contains information about the age of eruptions, pyroclastic ejecta volume, VEI (Volcanic Explosivity Index), magnitude and data source of volcanic records. The database attempts to include all known explosive eruptions to 1.8 Ma and VEI magnitude 4 or greater. The database contains 696 explosive eruptions. Half of the eruptions in the database occurred within the last 65 ka. 77% of the total eruptions occurred since 200 ka; the oldest eruption in the database is 2.25 Ma. In addition, percentages by eruption magnitude are: VEI 4 (40%), VEI 5 (42%), VEI 6 (13%) and VEI 7 (5%). Because it is reasonable to assume that smaller eruptions occur more frequently, fewer VEI 4 eruptions than VEI 5 eruptions indicates that small eruptions are missing in this database. Survivor functions of smaller VEI eruptions show steeper decreases and suggest smaller eruptions are more rarely preserved. Therefore the discrepancy in smaller eruptions is attributed to erosion of units. These preservation trends are modeled by functions and detrended. The result suggests 97% of VEI 4 events are missing from the record after 100 ka, whereas 40% for VEI 5 to 7 are missing after this time period. The change of preserved eruptions with time shows two major trends. The likelihood of an eruption preserved in the last 10 to 100 ka follows exponential trend, suggesting that many young deposits are rapidly eroded and go unidentified in the geologic record. Older deposits have a gentler trend, indicating that once the deposit is initially preserved it is more likely to be identified in the geologic record than suggested by simple exponential decay. The relationship between VEI and logarithmic scale recurrence rate shows recurrence rate decays by a factor of about 8.6 for each successive VEI category. These results indicate that eruption probabilities based on long term recurrence rate must account for the potential for even large eruptions to be missing from the geologic record.

An operational approach to generate and visualize Bayesian probabilistic volcanic hazard curves and maps by means of BET_VH tool

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The recent renewed software design of BET_VH code (available on the Vhub cyber-infrastructure at http://vhub.org/resources/betvh) has represented the opportunity for both improving dissemination and usability of this tool and, at the same time, introducing new important features as the calculation of volcanic hazard curves for a given point, or area, of interest and the corresponding hazard maps.

So far, the BET_VH tool was designed to plot maps for a selected target region showing the probability of overtaking a given threshold associated to a given phenomena (for example a given load of tephra fallout), either conditional to the occurrence of an eruption of a specific size from a specific vent, or absolute (i.e. considering every possible size and vent location). These maps can show either a best guess value (e.g. the mean or the median), or, being a Bayesian tool, can be provided in terms of a selected percentile, to have an idea of the dispersion around the best guess, i.e. of the epistemic uncertainty. Such maps are a good synthesis of the hazard evaluation, but much more information is available beyond these maps.

Hazard curves shows, for a given area of interest, the exceedance probability (y axis) as a function of the threshold intensity measure (x axis) of the considered phenomena (e.g. tephra load). The production of hazard curves within the renewed BET_VH tool represents a significant improvement since: (i) it allows to preserve more detailed hazard information, by providing the probability of overcoming different threshold values for each spatial point or area; (ii) hazard curves are the most common output from hazard investigations for quantitative risk assessment, as they can be successfully coupled to vulnerability analysis; (iii) they allow the production of statistical hazard maps, where the intensity providing a pre-defined value of the probability of exceedance is plotted (e.g. 10% in 50 years). Furthermore, as BET_VH is a Bayesian tool, the uncertainty associated to these curves is computed and visualized as well.

In the present work all the operational steps to provide hazard curves to BET_VH tool will be introduced and described, from the method of generating the curve to its implementation in the code and, finally, its visualization in the tool. The work is mutually supported by the ByMuR project, hosted at the Istituto Nazionale di Geofisica e Vulcanologia, Italy, and the Vhub team of the University at Buffalo, US.

HASSET: A probability event tree tool to evaluate future eruptive scenarios based on bayesian inference. Presented as a plugin for qgis

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Event tree structures constitute one of the most useful and necessary tools of modern volcanology to assess the volcanic hazard of future eruptive scenarios. They are particularly relevant to evaluate long- and short-term probabilities of occurrence of possible volcanic scenarios and their potential impacts on urbanized areas. In this contribution we present HASSET, a Hazard Assessment Event Tree probability tool, built on an extended version of the Bayesian event tree structure previously published for Teide-Pico Viejo stratovolcanoes, Tenerife, Canary Islands. This extended version of the event tree adds two additional nodes to the six existing ones to account for the type and extension of the hazard phenomena. Also, the new version introduces the Delta method to approximate the accuracy in the probability estimates, by constructing a one standard deviation variability interval around the expected value for each scenario. The method uses Bayesian Inference to assess volcanic hazard of future eruptive scenarios, by evaluating the most relevant sources of uncertainty when estimating the future probability of a specific volcanic event. HASSET is presented as a free software package in the form of a plugin for the open source geographic information system Quantum Gis (QGIS), providing a graphically supported computation of the event tree structure in an interactive and user-friendly way.

How to cope with volcano flank dynamics? a conceptual model behind possible scenarios for Mt. Etna

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Volcano flank dynamics poses a serious hazard, also involving the inhabited lower slopes. Mt. Etna is a well-studied unstable volcano, and a significant amount of data has been collected on the dynamics of its eastern and southern flanks. We first propose a conceptual model to describe and explain flank dynamics at Etna; we identify the preconditions, as due to the differential unbuttressing conditions at the volcano base, and the triggering factors, as shallow magmatic sources (dikes, reservoirs). Evidence and parameters and/or observations for flank dynamics are listed, summarizing the 1994-2010 period of activity. Based on this, we then propose a set of scenarios possibly occurring in case of unrest of the unstable flanks of Mt. Etna. Flank unrest is a variation in the steady state condition of the volcano flanks, possibly accompanied by significant ground deformation, seismicity and eruptions. The scenarios may provide a general reference and recommendation in case of five types of multi-hazard processes related (either as a cause or effect) to flank dynamics: 1) edifice inflation; 2) emplacement of dikes along the NE and/or S rifts; 3) seismicity along Pernicana Fault System; 4) seismicity on the S sector; 5) seismicity along Timpe Fault System. Each scenario is analyzed and recommendations are given. The scenarios may or may not be related to each other, in the sense that the probability of occurrence of one scenario may or may not be contingent or dependent upon the prior occurrence of another. These scenarios provide a qualitative analysis of the multi-hazard processes related to flank dynamics; a more quantitative (i.e. probabilistic) characterization is under consideration.

Analyzing hazard vulnerability in Mt. Baekdusan area using terrain factors

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Most steep slope failures take place in geographically unstable areas. The Mt. Baekdusan is known as a potentially active volcano in a typical mountainous terrain. This study prepared a digital elevation model of the Mt. Baekdusan area and created a hazard map based on topographical factors and structural lineament analysis. Factors used in vulnerability analysis include shaded relief image map, geographical data involving altitude, orientation, and gradient distribution, as well as contributory area of upslope, tangential gradient curvature, slope gradient curvature, and the distribution of wetness index among elements that comprise topography. In addition, the stability analysis was conducted based on the lineament intensity map. For structural lineament analysis of the terrain, 380 lineaments were decoded from investigation sections of the area, and the lineament rating was made according to the scale in consideration of their direction, frequency, and length. The study classified the following four main directions applying weighting on their frequency and extension: L-1 (N30o -40oE), L-2 (N20o-30oE), L-3 (N80oE), and L-4 (N80oW). As for frequency and the density of lineaments NNE-SSW direction is predominant. Concerning the disaster vulnerability of the Mt. Baekdusan region, the South east area of Mt. Baekdusan has a highest risk of disaster, while the level decreases in the eastern region.

Keywords: Mt. Baekdusan , Hazard map, Vulnerability, Geographical data, Lineament

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New empirical approach to estimate proximal volcanic hazard zones

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The conceptual model of the energy line is a simple but useful tool for the spatial analysis of volcanic processes. It is based in a basic frictional behavior, where the potential energy of a solid body sliding downward over a slope totally degrades by friction forces during the transport. This model parameterizes the maximum runout of the flow with the HL ratio where H is the vertical drop and L the lateral extent of each deposit. Because of the mobility is related to flow dynamics, there are typical values of HL for different flow types.

Cartographic application of this concept is straightforward and therefore useful to delineate hazard zones around stratovolcanoes. They are shaped from the intersection of surface topography with the theoretical cone produced by rotation of the energy line defined by the HL ratio, usually considering some additional elevation at the summit. However, most classical problems with this model are related to the large runouts of pyroclastic flows and large volume debris avalanches. In fact, the use of HL cones usually underestimates runouts in topographically depressed areas whereas it overestimates the hazard zone in the proximal area.

On the other hand, several studies based on morphometric analysis of regular shaped volcanoes depict highly non linear flank geometries. In fact, curved geometries as those traced from parabolic and logarithmic expressions seem to fit better the natural volcano shapes.

Here we propose a modified strategy to trace areas inundated by non-water saturated, high energy, gravitational-driven volcanic processes, now using parabolic-shaped energy cones. Because of the fast declining at the source and asymptotic behavior at the terminal zone, parabolic surfaces fit better the area inundated by high-mobility, channelized, pyroclastic density currents. Our initial test in the Central Andes shows promising results especially with high volume volcanic avalanches and some unusually large pyroclastic flows. This tool is intended as an empirical solution and understanding of the physical basis is beyond the scope of this contribution. However, we hypothesize that lateral momentum transfer, gas fluidization and interaction forces within the flow are playing a role in such a high mobility density currents, whose impact areas are better depicted with parabolic surfaces.

Sensitivity study of numerical weather-model parameters for quantitatively estimating ash concentration in the atmospheric surface layer with a computational ash dispersion model, FALL3D

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An estimation of ash concentration in the atmospheric surface layer, which is the lower part of the planetary boundary layer (PBL), is of practical interest in discussion on volcanic ash impacts on critical infrastructure. For estimating ash concentration in the atmosphere, numerical simulations with an ash transport- and deposition-model have become a powerful tool (e.g. Folch 2012). However, the performance of such simulations for the surface layer has not fully understood, while that for the atmosphere and the ground deposition have been actively examined. This might due to the complicated interaction between the ass dispersion- and meteorological-processes near the ground, suggesting that the accurate description of meteorological condition must be vital for such simulations.
Thus, we have carried out sensitivity study of numerical-weather model parameters for predicting the ash concentration in the atmospheric surface layer in the present study.

We consider a test case corresponding to the eruption at Mt. Shinmoe-dake on January 2011; the eruption column height is approximately 8000m and the total mass flow rate is about 5e9 kg during 2 hr.
We have used two models to examine the interaction between dispersion- and meteorological- processes: one is the CRIEPI weather forecasting and analysis system, NuWFAS, which consist of a numerical weather model, WRF, and some pre- and post-processing tools; the other is an ash transport- and deposition-model, Fall3D. In the numerical weather simulations with NuWFAS, the horizontal- and vertical-grid spacing is varied from 2.5 km to 10km and from 100 m to 500 m, respectively, to check the grid dependency. Two PBL scheme is used to discuss the implications for the turbulence diffusion coefficient in the planetary boundary layer.

After verifying the capability of this setup through the comparison with the observations of isomap of ash deposition, we discuss the predicted ash concentration in the atmospheric surface layer in detail; the time-series of ash concentration near the ground, especially near the vent, depict complex wave forms and there values fluctuates; this is due to the change in the advection and turbulence diffusion processes of volcanic ash. The numerical-weather prediction parameters decidedly affect wind speed and directions and also turbulence diffusion coefficients in the PBL, which have important roles in the advection and diffusion processes. Thus, such parameters have also effects on quantitative estimation of ash concentrations in the surface layer.

More details will be presented in a full paper, and we believe that our study must be helpful to develop computational ash transport- and deposition-models.

GIS-based tool for long-term risk management of civil aviation during explosive volcanic eruptions

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We present a software tool (yet under development) for the long-term management of risk from explosive volcanic eruptions on civil aviation. The tool covers the needs of stakeholders involved in the long-term civil aviation management and interested in taking long-term decisions based on a range of possible tephra dispersal scenarios. The main utility of the tool is the visualization of data from several sources. Geographic Information Systems (GIS) are the best instruments for the visualization of spatial phenomena and variables. The GIS-based tool performs three main actions: i) display of hazard and vulnerability information, ii) overlay of maps and, iii) estimation of expected impacts (airports disrupted, routes canceled, etc) on a probabilistic basis. We present the structure of the tool underlining the scientific background and technical aspects of each element.

First, hazard and vulnerability data are stored in a spatial database specifically designed to store probabilistic hazard data and vulnerability parameters efficiently. Hazard maps are stored in the database, which has a central role for the risk management process acting as a repository of maps that may be useful for different purposes and to a wide range of stakeholders. The relationship between the database and the GIS is explored showing the advantages for volcanic risk management. To our knowledge, this is the first *ad hoc* database proposed to store information about tephra dispersal hazard and vulnerability.

Second, and using spatially-based rules, the tool automatically estimates vulnerability and expected impacts for each map. Vulnerability and impact assessments are implemented by means of plugins embedded in the GIS main interface. GIS and plugins GUIs are friendly and enhance the accessibility for non-scientific users. The analysis has been automated for the European air traffic management during explosive eruptions. Results are relevant for the long-term risk assessment in the European area.

This tool improves the long-term risk management by automating the operations, making them faster and repeatable. The use of an open-source GIS enhances the capabilities of this tool as a data repository, due to the high interoperability with other software and formats. Although this is only a prototype and still needs further development, the up-to-date work can be a relevant contribution to the scientific community.

A thermal anomaly as a precursor for predictions of strong explosive volcanic eruptions

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Study of eruptions precursors in order to reduce a volcanic risk for the population is an urgent problem of Volcanology. Kamchatka is home to thirty active volcanoes. Five of them are producing paroxysmal explosive events: Klyuchevskoy, Molodoy Sheveluch, Bezymianny, Kizimen, Karymsky. In average one strong explosive eruption occur here every year. The papers on satellite monitoring of the 1997 and 1998 Bezymianny eruptions by Dehn and Schneider and the others, 2000, are one of the first works in which variations of temperature and size of a thermal anomaly in the volcano are considered to be operative precursor of explosive eruption. The experience of KVERT scientists on satellite monitoring of Kamchatka volcanoes proved this precursor to be effective also for volcanoes with different composition of erupted products. This precursor is based on the classical definition of the term volcanic eruption: an eruption is a process when a magma matter reaches the Earth surface. Both size and temperature of the anomaly are linearly associated with the amount of juvenile material which comes on the Earth surface at the moment of the anomaly detection in satellite image. Thermal anomaly which appears in a volcanic area evidences on warning signs of explosive eruption or that explosive event is likely in the nearest future. Hazard that poses such eruption to people and environment depends on composition of magma matter of the volcano. A thermal anomaly over Klyuchevskoy was for the first time revealed eight days in 2005 eruption, the crater was filled with cinder material, and two months in 2007 eruption, the crater was empty, prior to Strombolian eruption. There demonstrate that in any case a thermal anomaly over the volcano evidences that the volcano is likely to start explosive eruption soon. Since March 1956, the lava dome continuously growing in Bezymianny crater. Activity of the volcano between explosive eruptions is very weak, though slow extrusion of lava flows on the dome flank is observed, and a weak thermal anomaly is detected in satellite images. When a preparation of Bezymianny explosive eruption is starting, a size and temperature of anomaly over the dome began to increasing very quickly. Thanks to monitoring of variations of size and temperature of the anomaly, from 2001 till 2012 KVERT predicted 10 explosive eruptions of this volcano. Published in Internet VONA/KVERT Releases (http://www.kscnet.ru/ivs/kvert), containing warning of impending strong eruption before the eruptions realize forecasts in real time.

Precursory eruptions of the 2011 Shinmoedake eruptions, Kirishima volcanoes

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It is important for us to have knowledge of what takes place in the pre-eruption stage of plinian or sub-plinian eruptions on the surface. We also need such information for hazard maps and the forecasting of eruptions in which new vents are opened. We therefore consider the vent position and small precursory eruptions of the 2011 Shinmoedake eruption. Sub-plinian eruptions occurred without a prior distinct increase in earthquakes or land deformations from January 26 to 27, 2011 at Shinmoedake volcano. Therefore, we need to know how to quickly evaluate unusual preliminary phenomena and eruptions for the forecasting for sub-plinian eruptions.

We were able to take fresh ashfall samples generated by the January 19, 2011 eruption, which occurred just 7 days before the January 26 to 27 sub-plinian eruptions. The ashfall deposit was characterized by a low bulk depositional density, with an increase in absorbed water and very fine grains. It is important information of bulk density of deposit meaning fragmentation degree and absorbed water content meaning alterd fragments content for earlier signal of plinian and sub-plinian hazard information in addition. We must search carefully for likely signs of the January 19 ashfall, because we did not find an increase in earthquakes or preliminary signals of the sub-plinian eruption on January 26. For this reason, we need both summaries and detailed discussion of information regarding such precursory or unplugged ashfalls that follow plinian or sub-plinian eruptions, as provided by geological and paleographical surveys in the world. In addition, we need to develop tools or methods to help in the identification of deposit characteristics, e.g., thickness, bulk density, grain size, etc.

In addition, we need information indicating where new craters are being formed, not only for forecasting but also for developing hazard maps. The August 2008 eruption generated some fissured craters paralleled 1959 fissure craters. Then, seven small eruptions occurred in a continuous sequence from March to August 2010 along the August 2008 craters. In the Shinmoedake volcano, adjacent of time to the generations of craters or fumaroles, we consider one of the sources of important information for the next crater locations.

Seismic Precursors to Eruptions at Volcanoes in Extensional Stress Fields

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Volcano-tectonic (VT) seismicity is one of the most common precursors detected before volcanic eruptions. Previous studies have focused on quantitative analysis of precursory VT trends at volcanoes in compressional background stress fields, such as subduction zones. Using data from Mt Etna, in Sicily, we here extend analyses of VT behaviour to volcanoes in extensional background stress fields.

Before andesitic-dacitic eruptions at subduction-zone volcanoes, accelerations in VT event rate appear to evolve from early exponential trends, that may develop over several months, to a change that is faster than exponential (FTE) with time. The FTE trend tends to follow a hyperbolic increase (similar to an inverse-Omori trend) and can develop 10-14 days before eruption. In comparison, analysis of Etna´s flank eruptions of alkali basalt between 1977 and 2008 show that accelerations in precursory VT event rate preferentially change from initial exponential increases, over intervals of weeks, to FTE trends less than two days before eruption. FTE trends are thus strong indicators that an eruption may be imminent. However, although they may potentially provide warning times of days at subduction-zone volcanoes, analogous times are reduced to hours on Etna.

From their common occurrence, we propose that the exponential trends are related to an increase in the amount of damage around a volcano´s feeding system, caused by increases in magmatic pressure or by a local increase in tectonic extension. We further relate the abrupt nature of Etna´s FTE trend to the tensile propagation of a magma-filled fracture from a magma body to the surface. Propagation occurs when the damage accumulated around the magma body exceeds a critical value. The VT sequences, however, do not always culminate in an eruption. In such cases, fracture propagation must be halted underground by local stress barriers or by a decrease in the pressure gradient driving magma along the fracture. Even with a comprehensive model of precursory fracturing, therefore, eruption forecasts will be associated with an uncertainty due at least to a lack of knowledge of material heterogeneities and of local stress distributions in the crust along the path of a propagating fracture.

The base method for prediction of volcanic activity

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F. Omori had written in May 1911, after the first historical instrumental study of seismic and volcanic activity during the 1910 Usu (Hokkaido) eruption: "I believe the problem of forecasting of great volcanic eruption is, in some case, not very difficult". Great Japanese seismologist was right, although his modern followers are not so optimistical. Main feature of volcanic process – excess magmatic pressure. The pressure changes result in deformations of magmatic body and volcanic rocks. There are brittle (disjunctive) and plastic (plicative) deformations. Eruptions of the same volcano may have the clearly marked seismic preparation or not have it at all (for example: the 1975–1976 Tolbachik (Kamchatka) eruption was with good seismic preparation, but 2012 Tolbachik eruption started practically without it). The seismic monitoring may detect brittle deformations as volcanic earthquakes, but it cannot detect plastic deformation. Therefore seismic monitoring must be use together with methods of Earth surface monitoring for successful predictions.

I began own investigations from 1981–1987 Bezymianny (Kamchatka) eruptions with mostly plastic deformations. This eruptions had not significant seismic preparation: only rare weak seismic signals from rock avalanches before explosive eruption and volcanic tremor during it. During the study of 1980–1987 Bezymianny volcano eruptions I discovered the fact of hyperbolic increasing of volcanic activity before explosive-effusive eruptions. My attempts of using these regularities for the forecast were quite successful for several ordinary eruptions and 1985 Bezymianny directed blast (3 forecast levels: 8 months, 19 and 5 days before). Subsequently the studying of patterns for increasing-decreasing of volcanic activity and their comparison with empirical dependencies of the development of various natural processes allowed me to conclude that there is a wide class of self-developing natural processes, the dynamics of which is described by non-linear differential equation of the second order. Parameters of volcanoseismic activity and deformation volumes may be approximated and may be extrapolated by this equation. The correspondence between levels of volcanoseismic parameters and real volcanic phenomena must be found for successful prediction of volcanic eruptions' evolution of observed volcano. Retrospective estimations are executed on the examples of Bezymianny 1955–1970, 1981–1986, Sheveluch 1964, Kizimen 2010–2012 eruptions. They show possibility of the successful predicton of volcanic activity. Time prediction distances are very wide for this method: from 15–30 min for predictions on the base of volcanic tremor monitoring through 1–2 weak for ordinary eruptions up to 2 years (the 2010–c.t. Kizimen eruption). The "approximation–extrapolation" method seems as primitive, but it is the base (fundamental) primitiveness which must be used for predictions of volcanic activity first and foremost.

Seismic and volcanic risk assessment considering interactions in a multi-risk framework

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A multi-risk approach adopts a multi-hazard and a multi-vulnerability perspective in which the problems of risk harmonization and risk interactions become the fundamental scientific issue. Volcanic areas are generally located in geodynamic and geographic contexts in which multiple hazardous events such as earthquakes or landslides can affect independently or in cascades of events the same exposed elements. The multi-hazard is then a wide concept that, in general terms, can be split into two possible lines of applications:
(1) multi-hazard assessment may be seen as the process of assessing different (independent) hazards threatening a given (common) target area, and (2) it represents the process of assessing possible interactions or cascade effects among the different hazardous events.

In this work, we analyse different cases of cascading effects among hazards in Naples, Italy. We analyse in particular the seismic and specific volcanic hazards considering some interactions at the hazard level (i.e. cases in which the occurrence of one event/hazard affects the occurrence probability of another), and interactions at the vulnerability level, in which the effects on exposed elements caused by one hazard, will affect the element's vulnerability to the other one. The analysis described in this paper has been carried out in the framework of the FP7 European project 'MATRIX' (New multi–hazard and multi–risk assessment methods for Europe), and the project 'Quantificazione del Multi–Rischio con approccio Bayesiano: un caso studio per i rischi naturali della città di Napoli', funded by the Italian Ministry of Education, Universities and Research (Ministero dell'Istruzione, dell'Università e della Ricerca).