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Modelling the impact of a hypothetical sub-Plinian eruption at La Soufrière of Guadeloupe (Lesser Antilles)

R. Spence [a,*], J.-C. Komorowski [b], K. Saito [a], A. Brown [d], A. Pomonis [d], G. Toyos [a], P. Baxter [c]

[a] Department of Architecture, Cambridge University, Cambridge CB2 1PX, UK
[b] Equipe de Géologie des Systèmes Volcaniques, Institut de Physique du Globe de Paris, CNRS UMR 7154, France
[c] Institute of Public Health, Cambridge University, Forvie Way, Cambridge, UK
[d] Cambridge Architectural Research Ltd, Unit 6, 25, Gwydir St, Cambridge CB1 2LG, UK

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ABSTRACT

This paper describes the development and application of an impact model for a future hypothetical sub-Plinian eruption of La Soufrière of Guadeloupe. The model was designed to assess the impact from either a single or multiple eruption scenarios, each defined in terms of a map of the intensity of three volcanic hazards; volcanogenic earthquake, tephra fallout and pyroclastic density currents. The impact from the three hazards can be assessed independently or alternatively the joint impact of the three hazards can be assessed. The outputs that are produced from the model are; the number of buildings with collapsed roofs, and the number of fatal and non-fatal casualties.

Two versions of the impact model were developed, one that uses a spreadsheet and another that is implemented using a Geographical Information System (GIS). Both versions use the same types of hazard inputs and vulnerability functions to derive the number of building collapses and casualties, but have different spatial resolution of the final outputs. The spreadsheet version aggregates the results at a zone level defined specifically for this project whereas the GIS was designed to produce results using 250 m grid-squares. The outputs from the two versions, when using the same eruption scenario, produced somewhat different results, highlighting the importance of defining the appropriate spatial resolution.

The vulnerability functions were developed using data on the building stock that was collected by a local survey, in which data on the form of construction, condition, location and types of openings and the variation of these parameters across the affected area were collected. The vulnerability functions incorporated new assessments of fire risks induced by pyroclastic density currents.

The model was applied to La Soufrière using a range of input hazard scenarios based on reconstruction of the most recent sub-Plinian magmatic eruption which occurred in 1530 AD. A sensitivity analysis of the model was carried out choosing the inputs from a range of defined input values. The effect on losses and casualties of a range of possible mitigation measures was assessed by running the original model and the modified model using the same input eruption scenario. A separate casualty treatment model was also developed and tested.

1. Introduction

One of the aims of the EXPLORIS Project was to develop tools to assess and quantify the impact of plausible eruption scenarios from explosive volcanoes on the surrounding human settlements. Eruption modelling tools have been developed which are able to assess the probable spatial and temporal distribution and intensity of the eruption products, whether in the form of tephra fall (Macedonio et al., 2005; Pfeiffer et al., 2005) or pyroclastic density currents (PDCs), (Neri et al., 2007, 2008-this issue). The probable distribution of the eruption products in past eruptions can also be estimated by means of field investigations (Komorowski et al., 2008-this issue; Boudon et al., 2008-this issue). To convert this information into data useful for Civil Protection authorities in planning future protection strategies, a tool is needed to assess the exposure of the population and human settlements to particular eruptions, and to estimate its vulnerability to the associated volcanic hazards and the probable physical damage and human casualty consequence of particular eruption scenarios. The tool developed under EXPLORIS was designed to fit the following requirements:

- applicable to the diverse conditions of the 4 EXPLORIS volcanoes (i.e. Vesuvius, Cete Cidades, Teide, Soufrière of Guadeloupe), with a range of possible eruption styles, and potentially applicable also to volcanic eruptions elsewhere
- able to deal with a range of possible types of buildings and settlements found in the European area

* Corresponding author.
E-mail address: robin@carltd.com (R. Spence).

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- considers the range of major volcanic hazards associated with explosive volcanoes, namely tephra fall, pyroclastic flows of various types, and volcanogenic earthquakes
- designed to utilise input data in the form of GIS maps, both for the volcanic hazards and for the exposure data, and to produce maps of the output
- able to be used to investigate the effect of uncertainty in any of the model inputs on the calculated impact
- able to be used to investigate the effects of a range of possible mitigation actions

This paper describes the tool and its application to a particular range of eruption scenarios for a hypothetical future eruption of La Soufrière of Guadeloupe, similar to the recently reconstructed 1530 AD Soufrière sub-Plinian eruption (Komorowski et al., 2008-this issue; Boudon et al., 2008-this issue). A previous paper (Spence et al., 2005b), described an earlier version of the model, and its application using a set of highly simplified hypothetical hazard maps. Some changes in the model, notably its transformation from a spreadsheet to a GIS format, make it essential for some aspects of the current version to be described in this paper (Section 2). The vulnerability data used are described in Section 3. Section 4 then describes the way in which the current understanding of the 1530 AD eruption was used to develop a set of GIS maps for each of the principal hazards.

The work described in this paper does not constitute a formal risk assessment for a future potential eruption of La Soufrière and should in no way be considered as such. Rather it discusses the methodology that could be used in a future formal risk assessment. In particular it discusses a new integrated multi-risk impact model that is based on realistic data that are combined to define a hypothetical simplified worst-case scenario. Such an approach is useful in establishing the necessary steps to ultimately communicate to the authorities, through a formal study, the potential magnitude of the integrated volcanic risks and the limits of potential volcanic devastation, based on reasonable worst-case assumptions.

The application of the casualty model to the eruptive scenario assumes no preventive evacuation has been implemented. It is discussed here because of the necessity to test and describe the model with realistic data. However the numerical results presented in this paper in terms of building collapses, injuries, and casualties are hypothethical and do not represent in any way a definitive forecast in case of a future eruption. They do however rely on realistic physical data and modelling and thus convey an order of magnitude estimate of the maximum magnitude of the impact given the specifics of the eruption and of the model and assuming in this case that no preventive measures (e.g. evacuation) were taken.

Several different applications of the impact modelling tool are described and discussed. In Section 5, the sensitivity of the resulting physical damage estimates to alternative possible input hazard parameters is presented. In Section 6, a comparison is made of the estimated casualties resulting from two different approaches to the zonation of the affected area. Section 7 examines the effects of a range of different mitigation actions on the estimated impacts. Section 8 summarises the development of a separate model to examine the process of rescue and treatment of casualties.

At the present time the model is concerned with impacts on buildings and primarily residential buildings, and does not include effects on infrastructure; it concentrates on those hazards which are most likely to accompany eruptions of the explosive type, and therefore does not consider lava flows; and it excludes consideration of secondary post-eruption hazards such as floods, lahars and mudslides. It also produces a single integrated estimate of damage and casualties as a result of the main phase of an eruption which could overall last from months to years.

2. Structure of the model

Fig. 1 shows the overall structure of the impact model. The impacted area is divided into a number of impact zones. The number of these zones selected will depend both on the level of definition of the input data (volcanic hazard data as well as building stock and population exposure data), and also on the output required. In this application, the area was divided into cells of 250 m×250 m for zonation of the population distribution and hazard impact. Section 5 looks at the impact of this choice of zonation on the estimated casualties.

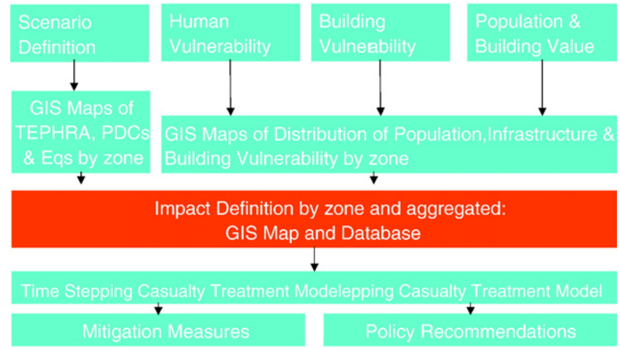

Fig. 1. The general structure of the impact model.

For each of the impact zones, three different types of input are required.

a) volcanic hazard scenario definitions
b) exposure data for buildings and population
c) vulnerability data for building damage and human casualties

The volcanic hazard scenario is defined in each zone by a single average intensity value for each of the three principal hazards affecting building damage, and further parameters which primarily govern casualty generation, but do not significantly affect property damage. The three main hazards affecting building damage are tephra fall static load pressure, PDC dynamic pressure, and earthquake ground shaking. Temperature and missile availability are additional parameters of importance in assessing the human casualty impact of a PDC.

For tephra fall, the parameter chosen is vertical gravitational load acting on the roofs in the area, measured in kPa, since it is the load which primarily determines the roof damage. Tephra fall eruption models do not always define load; sometimes only tephra fall depth is estimated. In this case an assumption needs to be made about the density of the fallen tephra, which may or may not be wet, or alternative assumptions made. In this model field and laboratory data on the deposits of the 1530 A.D. sub-Plinian eruption (Komorowski et al., 2008-this issue) determined a dry tephra fall deposit density of 1060 kg m^{-3}. The HAZMAP model determined isomass values expressed in kg m^{-2} from which static load pressures were derived to construct deterministic maps of dry static load pressure as well as probabilistic maps of exceeding a certain threshold load pressure related to specific risk levels (Komorowski et al., 2008-this issue).

For PDC pressure, the pressure level which needs to be defined is the lateral dynamic pressure at the level of ground floor windows (kPa), generally 1 to 2 m above ground floor level. This value is given as an average value for the whole of the impact zone. The effects of urban sheltering and flow turbulence ensure that there is wide variation in this value, even within a short distance, and the use of a single value is therefore controversial. Alternative models have examined the local effects of urban sheltering (Zuccaro and Ianello, 2004), but the model is not able to incorporate such detailed variation at present. The model does, however, incorporate an assumption about the vertical profile of PDC pressure, which is used to assess the impact on upper floor windows. For the estimation of the probability of window failure and also casualties indoors from infiltration, the temperature of the flow needs to be defined, or estimates made.