NUMERICAL HAZARD ZONATION FOR PYROCLASTIC DENSITY CURRENT SCENARIOS, AT FAIAL AND TERCEIRA ISLANDS (AZORES)

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This poster participates in YSOPP

Young Scientists' Outstanding Poster Paper Contest

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ABSTRACT

Pyroclastic density currents (PDCs) are hot mixtures of volcanic particles and gas that flow at high speed along the topography. This most hazardous and destructive volcanic phenomenon has been responsible for tens of thousands of fatalities over the last centuries. Therefore, it is essential to assess areas susceptible to being affected by PDCs and the potential impact on people and infrastructures. The potentially affected areas can be estimated using the energy cone model, a simple and easy method to evaluate potential hazardous areas and produce hazard maps with low-level computer resources. The model correlates the height of the drop (H) and the run-out distance (L), using a friction parameter - the Heim coefficient (μ). The angle (α) of inclination of the energy cone is defined by arctan (H/L). Here we have used a GIS-integrated energy cone model to estimate the potential extent of PDCs on Faial and Terceira islands (Azores) for different eruptive scenarios. The simulations were performed using H/L range between 0.2 and 0.4, and assuming column collapse heights of 500, 750 and 1000 m above the centre of the caldera (~ 600 m a.s.l. in both cases). A DEM of the islands with a 10 m grid spacing was used in the simulations. The hazard maps produced show the dispersal areas of the PDCs for each eruptive scenario, and combining the maps allows us to plot hazard zones for each volcano, reflecting the different conditions under which PDCs can develop. In Faial the most susceptible area is the northwest flank of the central volcano. However, most of the island could also be affected by PDCs during large eruptive events. On Terceira, the north part of the island is the more susceptible area in all scenarios analysed. Nevertheless, it should be considered that the extent of the PDCs calculated represents minimum dispersal areas, due to the conservative nature of this model. The areas affected by PDCs in the simulations were also compared with the mapped distribution of the ignimbrites produced during the last caldera-forming events in Faial and Terceira: the C11 eruption (~ 1000 years ago) and the Lajes-Angra Ignimbrite (~ 23 000 years ago), respectively. The calculated areas revealed similarities in the pattern of dispersal, although the run-out distance was smaller than the mapped deposits. Field data shows that the PDCs produced during these eruptions were able to concentrate and flow along topographic depressions (e.g. river-valleys), reaching the sea at 10 to 14 km from the vent in Faial and Terceira, respectively.

1. INTRODUCTION

Pyroclastic density currents (PDCs) are fast moving mixtures of hot gas and volcanic particles that flow along the topography under the influence of gravity. These currents are the most hazardous phenomena produced during explosive volcanic eruptions and are responsible for great destructions and thousands of deaths in the last centuries.

In the Azores archipelago, large ignimbrites, the deposits of PDCs, occur on at least three islands (Faial, Terceira and São Miguel), while smaller PDCs deposits are found also in Graciosa Island (Gertisser et al., in press). In historical times, during the 1630 eruption of Furnas Volcano (São Miguel Island), 80 people were killed by PDCs (Cole et al., 1995).

Thus, it is extremely important to understand PDC eruptive dynamics and physical characteristics in order to provide an accurate assessment of the hazardous areas and the impact on human populations and critical infrastructures. The assessment of PDCs hazard involves the identification of areas susceptible to being invaded by these volcanic products. In this work we used a GIS-integrated energy cone model to estimate the areas potentially affected by the PDCs. The main goal is an evaluation of the hazard associated with the propagation of PDCs on the islands of Faial and Terceira.

2. GEOLOGICAL BACKGROUND

The Azores archipelago consists of nine volcanic islands located in the North Atlantic Ocean (Fig. 1). The islands of Faial and Terceira are two active volcanic islands located in the central group of the Azores archipelago. They are, respectively, the third and second most populated islands of the archipelago, with a population of ~ 60 000 and ~ 15 000 inhabitants (Fig. 2).

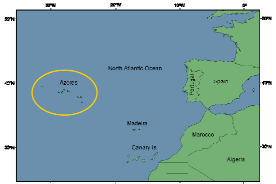

Fig. 1. Geographical location of Azores archipelago.

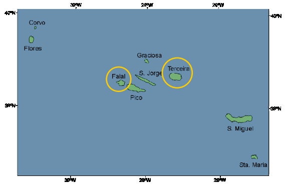

Fig. 2. Location of Faial and Terceira islands in the Azores archipelago.

2.1. FAIAL ISLAND

Subaerial activity of Faial Island started more than 800 000 years ago. About 16 000 years ago the Caldeira Volcano changed its eruptive style to mainly explosive activity of trachytic nature. During the last 16 000 years, this central volcano produced at least 14 explosive eruptions, all of them associated with a caldera-forming event, about 1000 years ago, generating extensive PDCs (Pacheco, 2001).

The C11 Ignimbrite produced during this eruption is the largest on Faial's eruptive history and covers an important portion of the island (Fig. 3).

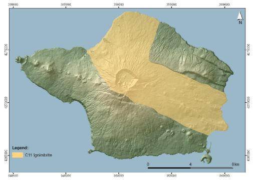

Fig. 3. Distribution of the C11 Ignimbrite in Faial Island.

2.2. TERCEIRA ISLAND

The volcanic history of Terceira is divided in two major groups separated by the Lajes-Angra Ignimbrite. The Lower Terceira Group (> 23 000 years) consists of all the deposits pre-dating the Lajes-Angra Ignimbrite. The Upper Terceira Group (< 23 000 years) includes the deposits of 116 recognized eruptions from Pico Alto and Santa Bárbara volcanoes and the fissure zone (Self, 1974).

The Lajes-Angra Ignimbrite covers about two thirds of Terceira (although in many areas it is buried by younger volcanics) and is the latest in a history of PDC forming eruptions from Pico Alto volcano (Fig. 4). Including the Lajes-Angra Ignimbrite, seven ignimbrites and two other PDCs deposits have been identified (Gertisser et al., in press).

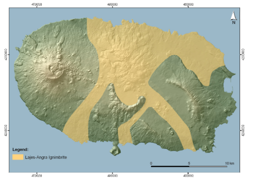

Fig. 4. Distribution of the Lajes-Angra Ignimbrite in Terceira Island.

ACKNOWLEDGMENT

Work supported by PhD grant (M3.1.2/F/022/2007 - Transport and depositional processes of pyroclastic density currents in the Azores: Implications for the assessment of the associated volcanic hazards) to A. Pimentel by the Science and Technology Regional Fund (FRCT) of the Azores Regional Government.

3. ENERGY CONE MODEL

The model used for the computation of the areas potentially affected by PDCs is based on the energy cone concept proposed by Malin and Sheridan (1982). This method provides a simple and conservative approach to evaluate potential hazardous areas and produce hazard maps with modest computer resources.

The energy cone model correlates the height of the eruptive column collapse (H) and the run-out distance of the PDCs (L), as a type of friction parameter - the Heim coefficient (μ). The inclination of the energy cone is an angle (α) defined by arctan (H/L) (Fig. 5). In this work we choose a GIS-integrated energy cone model (Felpeto et al., 2007) to estimate the potential extent of PDCs in Faial and Terceira islands and produce hazard maps for different eruptive scenarios.

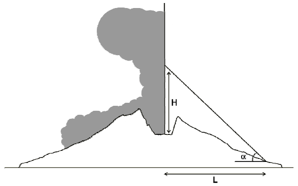

Fig. 5. Energy cone sketch.

As the propagation of PDCs can be related to the magnitude of an eruption, we performed three sets of simulations for each island, assuming column collapse heights of 500, 750 and 1000 m above the centre of the calderas (~ 600 m a.s.l.), representing eruptions of increasing magnitude. In the simulations we used ratios H/L between 0.2 and 0.4 (α = 11° - 22°) corresponding to PDCs ranging from large voluminous currents (0.2 - 0.29) to small volume currents (0.33 - 0.39) (Sheridan and Macias, 1995; Nakada, 2000). Digital elevation models (DEMs) of the islands with a grid spacing of 10 m, derived from 1:25 000 topographic maps, were used in the simulations.

4. SIMULATION RESULTS

Maps (Fig. 6) show the minimum dispersal areas of PDCs for each eruptive scenario simulated for Faial and Terceira. The maps clearly demonstrate the strong effect of the underlying topography on the extent of PDCs, which are also controlled by the column collapse height. In Faial, the northwest flank of the Caldeira Volcano is the area most susceptible to PDCs. However, almost all the island may be also affected in the case of high magnitude eruptive events. On Terceira, the north part of the island is the more susceptible area in all the eruptive scenarios analysed. The lateral dispersal of PDCs increases with magnitude of the eruption simulated.

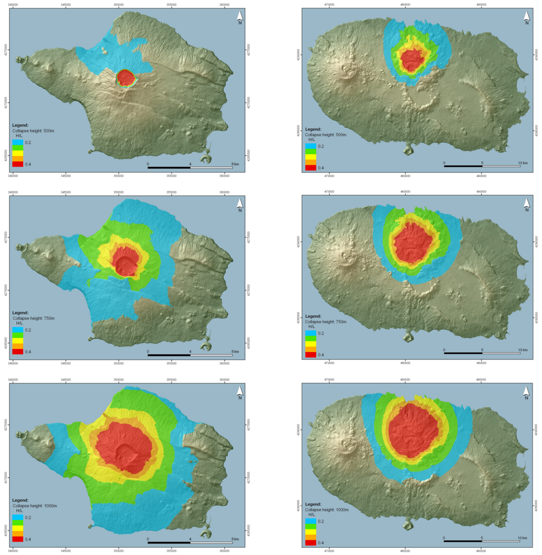

Fig. 6. Minimum dispersal areas of PDCs for different eruptive scenarios in Faial and Terceira islands.

5. HAZARD MAPS

Hazard maps for PDCs scenarios were produced for Faial and Terceira islands based on the simulations of the potential extent of PDCs performed previously. The grids of the maps in Fig. 6 were combined in order to provide a first order approximation of hazard zones for each volcano. A value of 1 or 0 was assigned to each grid cell depending on whether the cell is invaded by PDCs or not. Hazard maps were then made by adding the grids cumulatively and dividing the value on each cell by the number of simulations performed, and finally multiplying by 100. The result is a final grid with the relative probability of a given cell being affected by PDCs.

The maps produced were classified into three hazards classes/zones through the "natural break" method (Jenks and Caspall, 1971), allowing the definition of groups and patterns within the data set (Fig. 7a and 7b). Results for Faial show that the area around the caldera and the northwest part of the island are considered under high to moderate hazard from PDCs. In the case of Terceira, the high to moderate hazard areas are located in the central-north sector of the island.

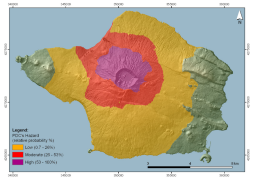

Fig. 7a. PDCs hazard map for Faial Island.

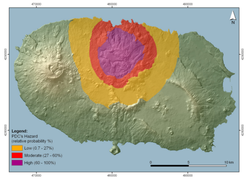

Fig. 7b. PDCs hazard map for Terceira Island.

The PDCs hazard zones were also compared with field data relative to the ignimbrites produced during the last caldera-forming eruptions in Faial (C11 eruption ~ 1000 years ago) and Terceira (Lajes-Angra Ignimbrite ~ 23 000 years ago). The potentially affected areas calculated show some similarities in the pattern of dispersal although the run-out distances are smaller. The mapped distribution of the ignimbrites demonstrate that the PDCs were able to concentrate and flow along topographic depressions (e.g. river-valleys) beyond the area defined by the energy cone, reaching the sea at 10 to 14 km from the vent in Faial and Terceira, respectively (Fig. 8a and 8b).

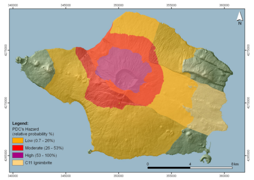

Fig. 8a. Comparison of PDCs hazard map and distribution of C11 Ignimbrite in Faial Island .

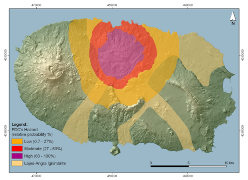

Fig. 8b. Comparison of PDCs hazard map and distribution of Lajes-Angra Ignimbrite in Terceira Island.

6. FINAL REMARKS

The energy cone model simulations preformed demonstrated the strong effect of the topography and height of the collapsing columns on the dispersal of the PDCs. Nevertheless, it should be kept in mind that the extent of PDCs calculated represents minimum dispersal areas, due to the conservative nature of this model that only takes into account the effect of gravity in the propagation of PDCs. The two hazard maps produced show that the surroundings of the calderas are the areas with higher PDCs hazard. However, the northwest flank of the Caldeira Volcano in Faial and the north sector of Pico Alto Volcano in Terceira are also high hazard areas.

The GIS-integrated energy cone model used in this work revealed to be a useful and simple tool to assessment hazardous areas during volcanic crises and may be also applied to manage the risk associated to the impact of PDCs on people and critical infrastructures. Future work will include (1) more simulations with different parameters (constrains on column collapse height and H/L), (2) the production of maximum velocity and dynamic pressure maps and (3) the introduction of vulnerability elements to estimate the volcanic risk associated to PDCs.

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