Deterministic Ballistic Hazard Assessment of Mount Ruapehu, New Zealand

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Abstract:

Ballistic blocks ejected during volcanic eruptions pose serious threat to human safety and infrastructure, traveling at dangerous speeds over wide trajectories. Mount Ruapehu, Tongariro National Park, New Zealand has experienced numerous phreatomagmatic eruptions over the past century, including two moderate eruptions in the past two decades. The ballistics ejected during the September 25th, 1995 and the September 25th, 2007 eruptions were mapped in order to establish a data supported hazard map for the mountain. The spatial distribution of ballistics from each eruption were mapped to provide a closer look into directionality and density of craters post-eruption. The current hazard map is derived from estimated ballistic trajectory, lahar hazards, and ash fall impact. This study aims to provide a hazard map that looks specifically at ballistic hazards to aid GNS Science and the Department of Conservation to improve safety measures on the mountain. The newly proposed ballistic hazard map includes two 1500 meter zones which are defined by risk of human injury or death. The extreme (inner) hazard zone can experience up to 4 ballistic blocks per square meter, which translates to a nearly 100% fatality rate. Improving hazard risk protocol on the mountain is crucial to keeping Ruapehu visitors and infrastructure safe.

Introduction:

Mount Ruapehu, located on New Zealand’s North Island (Figure 1), is an increasingly popular destination for trampers, skiers, and outdoor enthusiasts. This active stratovolcano has had two major eruptive events in the past two decades, in 1995 and 2007 (Scott et al., 1998; Kilgour et al., 2010). The Department of Conservation (DOC), GNS Science, and the commercial ski fields (Whakapapa, Turoa and Tukino) have worked together to establish safety guidelines and protocols in the event of a future eruption. There have been comprehensive hazard studies done on lahars and ash fall, however, there is a lack of information on the ballistic hazards from Ruapehu (Christenson et al., 2010; Kilgour et al. 2010; Pardo et al., 2012).
Ballistic projectiles pose a serious threat to human safety and infrastructure during volcanic eruptions (Figure 2). During the 2007 Ruapehu eruption, ballistics struck the crater shelter, damaging the building and seriously injuring one of two sleeping trampers. Ballistic blocks are greater than a few centimeters in diameter and are ejected from the eruptive column with near parabolic trajectories (Wilson, 1972). Ballistics can be ejected up to 2km from the crater, and therefore threaten visitors and infrastructure within the vicinity (Blong, 1984; Fitzgerald et al., 2014).
The aim of this deterministic hazard assessment is to provide GNS Science, the Department of Conservation, and local commercial ski fields with further information so that they may update their ballistic hazard and risk information for visitors. Aerial photos taken following the September 25th, 1995 and September 25th, 2007 eruptions of Ruapehu are used to provide insight to the severity of the ballistic hazard (Scott et al., 1998; Christenson et al., 2010; Kilgour et al., 2010). Snow and ash provide clear impact craters in the photos, allowing for post-eruption mapping to occur. The spatial distribution of these impact craters is used to develop distribution map and later a hazard map of the volcano. This map aims to provide the relevant authorities with further information regarding the eruptive behaviors of Mt. Ruapehu, and help inform of further safety measures that can be taken in the event of future eruptions.

Methods:

Ballistic Distribution

This research focuses on the area directly surrounding the Crater Lake. Aerial photographs taken from the 1995 and 2007 phreatomagmatic eruptions of Ruapehu provide insight to the distribution of ballistics during such eruptions. These two eruptions have the strongest photographic data of the Ruapehu eruptions with regards to ballistics, and are also representative of the average size of the Ruapehu eruptions. It is assumed that the impact craters identified in the photos were the result of ballistic impact during eruption, and therefore provide a distinct distribution when mapped. Crater impacts in the snow and ash are easily identifiable in these photos, given their spherical shadows contrasted against the flat layer produced by the fall. Each crater was given an individual point. Using the ArcMap program, images provided by GNS Science were georeferenced onto a digital elevation model (NZ 8m DEM, LINZ Data Service) of Mt. Ruapehu. The DEM and images were projected using New Zealand Transverse Mercator 2000 (NZTM2000).

A point shapefile was created for each georeferenced photo. Once all points were plotted, the shapefiles of each individual eruption were combined using the Merge tool into one dataset. The merged shapefiles from each eruption were later combined to produce the hazard map.

Using the merged point dataset, a spatial density map was created using the Kernel Density tool in ArcMap (following the methodology of Breard et al. (2014) and Fitzgerald et al. (2014)). This provides a general view of the ballistic distribution by area around Crater Lake. Based on the kernel density, three transects for each eruption were drawn extending from the center of the crater (Figure 3). The direction of each transect was determined by the general distribution identified in the kernel. The transects were clipped to the ballistics that fall within them, then collated in order to provide a more definitive distribution pattern over a given distance (Figure 4). The transects were also used to determine possible directionality of ballistic trajectory for Ruapehu eruptions with the intent of seeing how distribution varied with azimuth from the crater. This map provides crater density for the 3 km² around Crater Lake, making it the primary tool for determining a ballistic hazard zone for the area around the crater.
In order to understand the hazard over multiple eruptions and over a longer timescale, the 1995 and 2007 spatial density maps were compiled to create a composite distribution. This map can be used as the basis for the hazard zones. The subsequent final hazard map aims to reflect the ballistic distribution of the 1995 and 2007 phreatic Ruapehu eruptions (Figure 5). Ruapehu has historically experienced phreatic eruptions and the two events studied provided the ideal data to conduct this research. Two 1500 meter zones were used to define the hazard zones. The zones are defined by crater density per square meter. Any area with a density of greater than or equal to one crater per square meter was defined as extreme risk of injury or death (Fitzgerald et al., 2014).

Results:

After plotting the impact craters for both eruptions, the direction of ballistic distribution was found to be relatively variable (Figure 3). The cumulative distribution data indicates that directionality is variable in each eruption, and therefore the hazard zones should be circular. The 1995 eruption had a wide ballistic distribution, spreading from the west to the southeast. The wider distribution resulted in higher concentration of ballistics closer to the crater. Ballistics ejected in the 2007 eruption were more concentrated towards the northeast. These ballistics traveled somewhat farther compared to the 1995 ballistics, ranging up to 1500 meters from the vent (Figure 4). The patches of dense points are areas where georeferenced photos were used to plot craters. The remaining craters were plotted from estimated locations based on other photos as well as considering the distributions derived from the transects. The plotted craters in this study are limited to those documented in available photographs. Some ballistics are capable of traveling beyond the hazard zone by rolling and they can pose a threat farther down the mountain.

Figure 3. Map which shows the craters distribution from both eruptions. The transects used to determine density per area are defined by the colored rectangles.
Figure 4. Ballistic distribution by area based on the transects used for both eruptions. The transects were collated in order to produce a more accurate distribution.

The hazard zone ranges are defined by the distribution per area of the ballistic craters, but the hazard of each zone is based on risk of injury or death (Figure 4). The extreme risk zone is based on a ballistic block concentration of up to 4 blocks per square meter. The surrounding buffer zone of moderate to high risk considers a few blocks that are ejected farther from the crater, as well as rolling blocks downslope.

Figure 5. Ballistic hazard map of Ruapehu. Hazard zones based on crater density along with ballistic distribution by area. Zones are defined by risk of injury or death.
Discussion:

The purpose of this deterministic hazard assessment was to provide GNS Science and DOC with a ballistic hazard map that was supported by ballistic distribution data from past eruptions. The current hazard map covers an area defined by multiple hazards, including ballistics, lahars, and ash. By conducting a ballistic hazard assessment, we have a better understanding of the eruptive behaviors of Ruapehu with respect to ballistic distribution.

The trajectories of the ballistic particles can be tracked using photos and videos of active eruptions, determining ejection angle and subsequently how directed the ballistic distribution is. Crater size, distribution, topography and apparent ballistic trajectory can be used as parameters in a ballistic trajectory model (Tsunematsu et al., 2013). Multiple hazard maps would then be produced with respect to size of eruption and appropriate hazard area. The density data collected during this study can be used as a parameter in the ballistic trajectory model (Tsunematsu et al., 2013) to model future eruption scenarios. Crater density and ballistic trajectory defined by the photos of the 1995 eruption may be input into the model in order to produce a trajectory model that can be manipulated. Manipulating the parameters of this model yields different possible eruptive scenarios of the volcano (Fitzgerald et al., 2014). It could also provide information on directionality, which could not be determined solely based on crater density.

Another discrepancy that could be rectified by the ballistic trajectory model is crater density. Craters plotted on georeferenced photos resulted in patches of concentrated craters as there were areas where no photos could be used for mapping purposes. This skewed the overall density per area, which was corrected by the use of transects. The transects were then patched together by areas of concentration to provide a well-defined distribution. However, the ballistic trajectory model would provide a clearer ballistic density. This study only looked at two moderately sized eruptions, and so in the event of a larger eruption the hazard zone would significantly expand.

Conclusions:

Given the ballistic crater distribution derived from the photographic data of the 1995 and 2007 eruptions of Mt Ruapehu a deterministic hazard assessment of the mountain can be established. Using plotted craters, spatial density tools, and distribution statistics, the produced hazard map is based solely on ballistic data. As indicated on the hazard map (Figure 5), visitors within three kilometers of Crater Lake during an eruption are at a high risk of injury from ballistics. Ballistics can also roll further downhill after the initial impact, and therefore may be a hazard outside of the three square kilometer proposed radius. Further ballistic trajectory modeling could improve this hazard zone and provide insight to the eruptive behavior of Ruapehu and the possibility of larger future eruptions. The data supported hazard map aims to aid GNS Science and the Department of Conservation to improve upon the current hazard zones on Mount Ruapehu.
References:


