Use of event trees in volcanic crises

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Probabilistic volcanic event trees are used to help scientists assess the likelihood of hazardous events during many volcanic crises around the world. Event trees present a logical framework for the display of multiple possible outcomes of volcanic unrest (e.g., Newhall and Hoblitt 2002). As presented in Fig. 1, scenarios are mutually exclusive on the left-hand side of the tree, but can be simultaneous on the right-hand side of the tree, because multiple hazards can be produced during any single eruption (labeled 'parallel' on Figure 1). Two types of probability values are displayed on the tree. Conditional probabilities describe the probability of a single event given that the previous event has occurred. Additionally, we list the total or nodal probability, which is the conditional probability of that event multiplied by the nodal probability of the previous event.

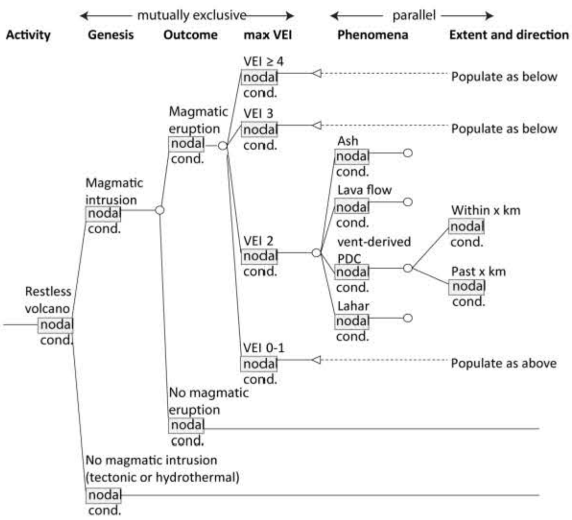

Fig. 1 – A generic format for event trees during volcanic unrest. Two probabilities are listed at each node/fork in this tree. Conditional probabilities indicate likelihood for events given the condition that the previous event has occurred (labeled 'cond.' above). In contrast, 'nodal' probabilities are the product of the conditional probability of that event and the nodal probability of the previous event (to the left in the tree).

The Activity and Genesis columns of the event tree are based on monitoring data and on comparison to monitoring data from past eruptions; whereas, the Outcome, max VEI, and Phenomena columns are based on a combination of monitoring and geologic data, and the Extent and Direction column is based on geologic data (e.g., extent and distribution of past deposits) and modeling.

Here, we discuss past Volcano Disaster Assistance Program (VDAP) successes and challenges in application of event trees to crises, recent improvements in event tree utilization, and recommendations for future event tree use.

In several ways, VDAP has found success in our use of event trees to assess hazards during volcanic crises. First, event trees provide a platform for discussion of diverse data streams, including local monitoring data, information about eruptive history, and results of hazard dispersal models, which are supplemented by comparisons and statistical queries of global data. In VDAP's application of event trees, scientists discuss these data streams and decide upon a consensus interpretation of the likely implications (Newhall and Pallister 2015). This process provides an opportunity to understand different points of view, whereby we document data as well as opinions informed by expert experience and interpretation of these data. In some cases, past eruptive behavior, global analogs, and current monitoring data all point toward the same interpretation and thus the event tree provides a well-justified forecast based on multiple lines of evidence (e.g., dome extrusion at Sinabung volcano, Indonesia, in 2013, see event tree documentation in Wright et al. 2018). In other examples, however, past eruptive behavior is poorly known or widely variable, global analogs are difficult to determine, and/or monitoring data are sparse. These cases are more difficult to interpret, resulting in greater uncertainty to probability estimates. The event tree thus helps document and communicate this uncertainty and direct the course of further study, instrumentation, or data collection.

In general, a complete event tree is data-rich and the multitude of probability values on the tree makes interpretation by the non-expert difficult. Therefore, in general only two scenarios are communicated and presented. These scenarios include (1) the most likely path through the event tree and (2) the low probability but high consequence scenario. By presenting this condensed summary of event tree likelihood, the group assessing the volcanic hazards can highlight key areas of concern and more effectively communicate results to emergency managers who may not be familiar with probabilistic analysis. As noted by Newhall and Hoblitt (2002), where appropriate data (and expertise) are available to evaluate mitigation, infrastructure and value, additional "Vulnerability" and "Risk" columns can be added to the event tree. Currently, however, this is not possible in most crisis situations due to lack of data availability.

As used by VDAP, event trees are stored as spreadsheet files that contain many sheets, recording all event tree supporting data files (Fig. 2). They thereby provide a digital location to collate information pertinent to the evaluation of volcanic hazards.

In the past several years, VDAP's use of event trees has changed in several ways, including the format of the tree structure, the content within event-tree files, and the process of expert elicitation and consensus derivation. Below, we summarize and provide examples for several ways in which these changes have improved the quality of event trees.

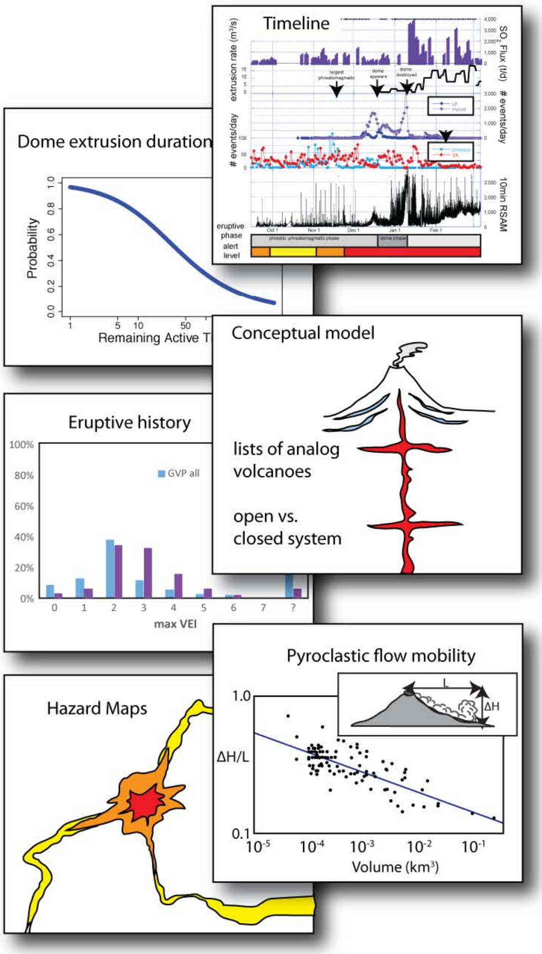

Fig. 2 – Event tree documentation includes: a timeline of monitoring parameters during the current crisis, eruptive history information, flow mobility approximations, dome-forming eruption explosion timing, maps, conceptual models, citations of pertinent references and more).

For example, VDAP increasingly utilizes global databases to supplement local data. This includes existing databases (e.g., WOVOdat and GVP; Newhall et al. 2017 and GVP 2013), as well as new databases and data analysis tools that VDAP is currently developing.

Global data also informs use of energy cones (based on the H/L, or height change/runout length mobility ratio) to estimate pyroclastic density current (PDC) runout distances (e.g., Wadge and Isaacs, 1988), where PDC volume vs. H/L relationships are sourced from the FlowDat database (cf. Ogburn et al. 2016). In cases where adequately detailed topographic data are available, we also use statistical and physical flow models to better inform nodes of the tree dealing with the potential distribution of flowage hazards. We are also beginning to use results of thousands of runs of physical models of ash dispersal and deposition (Schwaiger, et al., 2012) based on long-term records of wind-field data and appropriate ranges of VEI to inform nodes of the tree dealing with tephra fall hazards.

In addition, we now use the DomeHaz (Ogburn et al. 2012, 2015) database to explore questions related to the timing of explosions, the significance of extrusion rates, and the duration of dome-forming eruptions. For example, the statistical method of Wolpert et al. (2016) proved useful in estimating the likely remaining duration of the ongoing Sinabung eruption.

Current VDAP projects include the development of databases of detailed eruption chronologies, metrics for searching for analog volcanoes, and new data-analysis techniques. For example, VDAP seismologists have developed tools for detecting seismic rate anomalies both before the starts of eruptions and during eruptive sequences and have statistically quantified the circumstances under which these anomalies might be useful for forecasting.

We recommend six practices to make use of event-tree analysis as effective, robust, and informative as possible. (1) Create draft event trees in advance of an unrest crisis using background data and global analogs. Creation of event trees in advance of a crisis makes updating the trees with current monitoring information much faster and easier than creation of a tree during a crisis. As previously noted, nodes on the left-hand side of the tree in Figure 1 rely more heavily on real-time monitoring data, whereas those on the right rely more heavily on past eruptive behavior and model results. As such, much of the documentation for nodes on the right hand side of the tree can be input during quiescent periods. (2) Document or reference all known information that informs event-tree results AND document all outstanding questions that would help inform results if they were known. Documentation should be digitally linked to the draft tree(s). (3) Aim to make changes in the format of event trees that reflect the relevant hazards. For example, if sector collapse and lateral blast hazards are of concern, they should not be omitted from the tree. Format changes can also be made based upon risk considerations. For example, if planned evacuation zones extend to 20 km from the volcano's summit and people live only at distances farther away, it may not be necessary to list ballistics and their travel distances on the event tree. Further, reference PDC runout distances (in the Extent column of Fig. 1) can be selected based on risk considerations: e.g., what is the likelihood that PDC runout will surpass an evacuation radius? (4) Use a modified version of the original tree after an eruption has fully started, so that eruption scenarios are framed in terms of changes to the current activity level (e.g., Fig. 3). (5) Document the duration over which the forecast is valid and make a plan to update the tree when specified criteria are reached. (6) Document uncertainty in forecast likelihoods, either by listing the range of probabilities of individual experts or an uncertainty estimate around the consensus value.

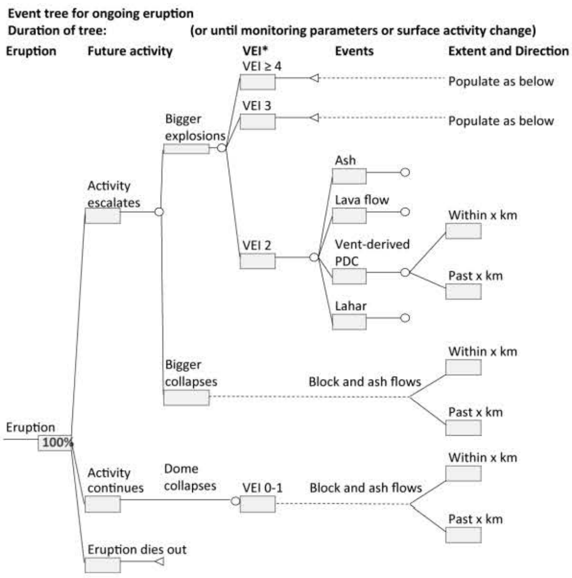

Fig. 3 – One possible format for the event tree structure during an ongoing eruption sequence.

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