PROBABILITY ASSESSMENT OF POSSIBLE VOLCANIC ASH CONTAMINATION FOR THE BULGARIAN AIRSPACE BY DEVELOPING OF EVENT TREE AND RISK MATRIX FOR HYPOTHETICAL VOLCANIC ERUPTION

Maria PETKOVA

BULATSA, Sofia, Bulgaria (maria.petkova@bulatsa.com)

DOI: 10.19062/2247-3173.2017.19.2.20

Abstract: *The objective of this study is to explore the risk assessment of potential volcanic ash contamination of Bulgarian airspace using a multi-complex analysis of potential volcanic sources, combined with suitable weather conditions and a detailed analysis of the final outcomes connected with the impact of volcanic ash on airspace management relating to departures, arrivals and en-route flights over Bulgarian airspace. This paper present research of probability assessment of volcanic sources in Italy, which may spread volcanic ash in short time (up to 12hours) to Bulgarian airspace.*

Keywords: *volcanic ash, risk analysis, risk assessment, event tree analysis*

1. INTRODUCTION

The objective of this study is to explore the risk assessment of potential volcanic ash contamination of Bulgarian airspace using a multi-complex analysis of potential volcanic sources, combined with suitable weather conditions and a detailed analysis of the final outcomes connected with the impact of volcanic ash on airspace management relating to departures, arrivals and en-route flights over Bulgarian air space.

The risk assessment of volcanic sources is based on the estimation of probability characteristics relating to the activity of volcanic sources in Europe. The lesson learned from the crisis in 2010 related to volcanic eruption has shown that particular weather conditions have a significant impact on airspace management for many countries in Europe. The prevailing winds during the eruption of Eyjafjallajökull, that advected the volcanic ash to the south and southeast of Iceland, were unusually persistent and unusually common. Indeed, for eruptions in recent decades this eruption is the only one where the ash dispersal is to the south and southeast from Iceland. Although the specific atmospheric circulation in the first and second decade of April 2010 presented only 6% of all weather patterns for atmospheric circulation over Iceland and W Europe this event caused the largest disruption in aviation since Second World War, as airspace over large areas was closed for several days with delays and flights cancelations [1].

That is why, being able to recognize and define the atmospheric circulation in close connection with its statistic distribution based on the monthly and seasonal proportion over Europe and the Balkans has an important value for the assessment concerning the region of interest. The next step for the evaluation is connected with a compilation of risk matrix for each particular source as a component of a complex matrix related to medium and high potential risk of contamination for volcanic ash sources close to the Bulgarian airspace. The sources are grouped based on countries of occurrence.

The method used for the multi-risk assessment is based on an event tree analysis off potential volcanic eruption and provides good opportunities for presenting all the events that should be assessed, the interaction between them and the final probability for their occurrence. . The initial parameters of potential volcanic eruption used are those with the highest conditional probability –VEI and some specific details such as height of eruptive column, volume of volcanic ash, and duration of eruption. So, the complex analysis should be based on a multi-risk assessment of the behavior of volcanic eruption, throw away and spreading of volcanic ash in the atmosphere by prevailing winds and all the aspects of impact to a specific airspace. The special focus is both on spatial and temporal scales and their significant roles for the mitigation measures that should be taken in order to update airspace management for controlled airspace in case of lack of time.

Event tree analysis (ETA) is an analysis technique for identifying and evaluating the sequence of potential accident scenario following the occurrence of an initial event. ETA is represented by graphical logical structure known as an event tree (ET). The ETA may result in many different outcomes from a single initiating event and it provides the capability to obtain a probability for each outcome. The main scope of ET is to determine how an initial event will develop into different scenarios in order to create rulemaking measures for control and successful procedures for the mitigation of final negative outcomes.

This approach is very adequate and easily applicable for risk analysis and assessment of volcanic ash contamination of Bulgarian airspace by spreading ash from volcanoes located close to, and much faraway from, the borders of Bulgarian FIR.

2. DEVELOPING OF AN EVENT TREE FOR A HYPOTHETICAL VOLCANIC ERUPTION

The scope of this study is focused on the research of a domain with ranges within 35°– 55° N latitude and 10°–35° E longitude (Fig. 1) referred to for shortness East Mediterranean and Balkans, (EM&B) for the purpose of this study. This domain contains volcano sources that originate in Italy and which could affect Bulgarian airspace in case of eruption and spreading of volcanic ash.

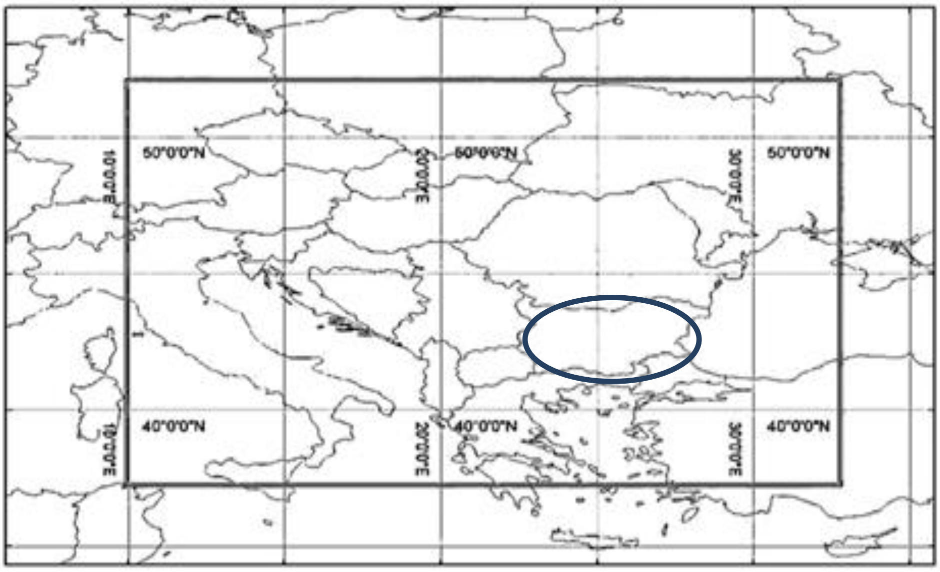


FIG 1. Domain for the research

The risk assessment of volcanic ash contamination of Bulgarian airspace is a fundamental research based on a probabilistic risk assessment of natural hazards such as volcanic eruption, together with an examination of dispersion of volcanic ash in the atmosphere by prevailing winds. Based on the aviation flow management, the impact on the air traffic for the specified region has been assessed.

The attempt of risk assessment of volcanic ash sources is based on statistical methods. The application is an approach borrowed from the assessment of the risk of earthquakes and their consequences [2].

The framework of this is methodology is established on four fundamental tasks associated with:

- Identification of volcanic sources.
- Determining the probabilistic characteristics for each of the volcanic ash sources based on the following dependency: **Volcanic Explosivity Index (VEI)- Volcanic Eruption Frequency**
- The process of modeling stochastic events by using numerical models for volcanic ash dispersion.
- Detailed probabilistic assessment of volcanic ash contamination with respect to the distance and azimuth for the studied area

The most effective method for evaluating the sequence of potential accident scenario is the graphical, tree-like presentation of events in which branches are logical steps from a general prior event through increasingly specific subsequent events (intermediate outcomes) to final outcomes. Constructing event trees for volcanic crises shows the progressive development of different scenarios and possible outcomes from volcanic unrest. An estimation of the rate at which volcanic ash load decays with distance from the source, as a function of magnitude, eruptive column height, duration, dispersal model and wind speed is required for the stochastic set of events under consideration. The dispersal of volcanic ash through the atmosphere and deposition at ground level that diminish gradually in load (kg/m2) with distance from the source but in directions controlled by the wind. Therefore, ash load attenuation and the impact on the region of interest is a complex function of distance and azimuth from the source. And finally, the estimation of probabilities for each event through the tree is a good opportunity for statistical assessment of each outcome.

The conceptual model presents the general steps describing the movement of the system from current conditions through increasingly specific conditions to final outcomes.

The simplified models of a generic tree with progressively specific levels or branches present different possible scenarios for developing an initial event and is presented in Fig.2.

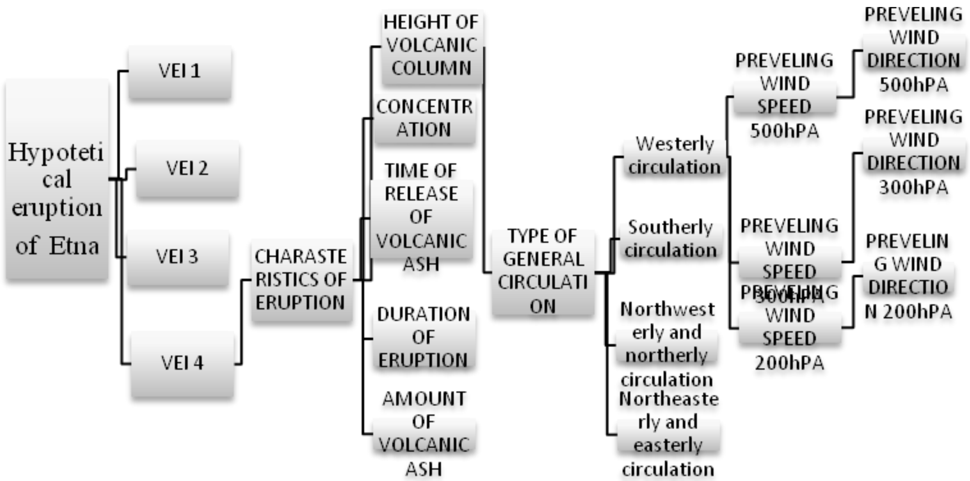


FIG 2. Generic event tree describing possible scenarios for hypothetical eruption of Etna

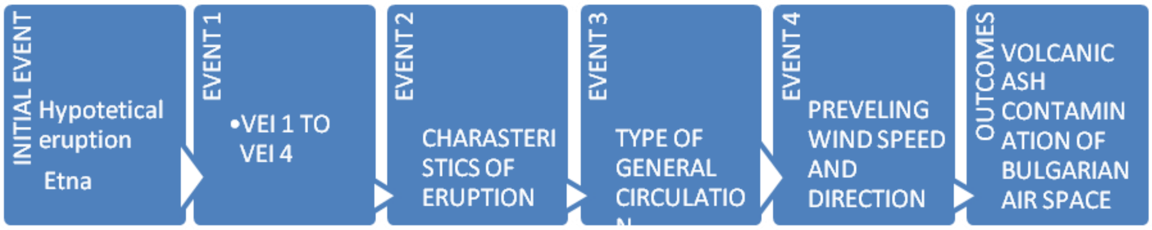


FIG 3. Conceptual model for a hypothetical eruption of Etna and generic event tree describing possible scenarios

3. SOME THEORETICAL BACKGROUND OF STATISTICAL CALCULATION

For environmental and natural issues, risk factors can be conveniently defined as a function of the probability that a certain event will occur and of the extent of the damage caused to man, environment and objects. In many cases risk is considered as

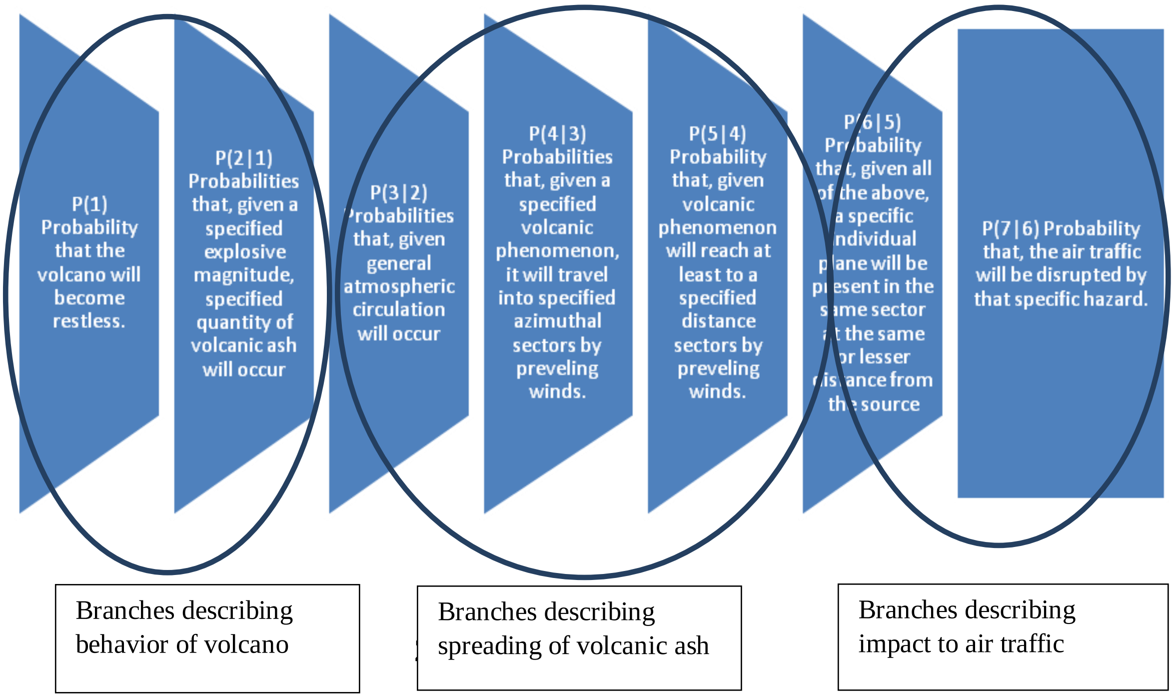
R = **H x L x V** (1)

where **H** is the probabilistic hazard, **L** the value at risk, and **V** the vulnerability,

This definition basically coincides with the one provided by the European Community (EN 1050, 1996) which indicates risk related to a specific source (or hazard) as a function of the magnitude of the potential damage (defined as **D** = **L x V**) that may result from the considered hazard and from the probability that it will occur (also a function of the frequency and duration of the exposure, of the probability it will occur and of the possibility to avoid or limit the damage).

Based on statistical theory a conditional probability, written in the form P (n|n–1), is the probability of event n given that event (n–1) has occurred. The probability of any outcome, P (n), is the product of the probability of an initial event, P (1), and all further conditional probabilities, P(2|1)...P(n|n–1), leading to that outcome.

$$\mathbf{P\ (n)} = \boldsymbol{P(1).P(2|1).P(3|2)\ \dots\dots P(n|n-1)} \quad (2)$$



All probabilities are calculated based on the specific characteristics of any particular condition for each branch of the event tree.

The first two probabilities are connected with volcanic behavior; the following three are associated with the estimation of volcanic ash dispersion according to the general atmospheric circulation, and the final two represent the impact of volcanic ash to the air traffic ini the region of interest - FIR Sofia ant its sectors.

The conditional probabilities for eruption of volcanoes of a particular VEI are calculated based on the definition of probabilistic characteristics [3]. Volcanic ash sources located in Italy are assessed by means of probabilistic characteristics and the results concerning the conditional probability are summarized in table 2.

Table 2. Conditional probabilities for any VEI for active volcanoes in Italy

Active volcanoes that originate in Italy	Conditional probability VEI 1	Conditional probability VEI 2	Conditional probability VEI 3	Conditional probability VEI 4	Conditional probability VEI 5
Etna	0,89	0,92	0,454	0,25	0
Vesuvius	0,065	0,047	0,381	0,75	0,333
Stromboli	0	0,023	0,054	0	0
Vulcano	0	0	0,090	0	0
Pantelleria	0,021	0	0	0	0
Campi Flegrei Mar Sicilia	0,021	0	0	0	0

The Table 3, which represents a risk matrix of volcanic eruptions with VEI specifically for the volcanoes in Italy, is composed of such characteristics as volcano explosivity and distance to the region of interest.

Table 3. Risk matrix of volcanic eruptions with VEI specifically for the each of volcanoes in Italy

No risk	Low risk	Medium risk	Medium to High risk	High risk

Likelihood / Active volcanoes in Italy	Eruption style VEI 1	Eruption style VEI 2	Eruption style VEI 3	Eruption style VEI 4	Eruption style VEI 5
Etna					
Vesuvius					
Stromboli					
Vulcano					
Pantelleria					
Campi Flegrei Mar Sicilia					

4. METHOD FOR IDENTIFICATION OF CONTAMINATED AREAS

Contaminated zones should be precisely defined by using a numerical model such as the HYSPLIT model. The Hybrid Single-Particle Lagrangian Integrated Trajectory model (HYSPLIT), developed by NOAA's Air Resources Laboratory, is one of the most widely used models for atmospheric trajectory and dispersion calculations. It is a complete system for computing simple air parcel trajectories, as well as complex analysis transport, dispersion, chemical transformation, and deposition by simulations. The final results are revealed by means of graphical information about the zones contaminated by volcanic ash both for the different atmospheric layers and flight levels and for the process that has developed in the course of time, and in space.

5. CONCLUSION

When analyzing the presented results, it's possible to make a conclusion for each of the active volcanoes regarding severity of probability and risk for eruption with a specific VEI.

Taking into account the specific features of VEI and the fact that it is described by an exponential function, the presented risk matrix shows that eruption styles with a VEI of 3, VEI 4 and VEI 5 will be more violent and devastating than explosivity of VEI 1 and VEI 2. The volcano with the highest VEI is Vesuvius as it can be seen in table 3. Highly probable is its eruption in a variety of styles, some of them by higher VEI which would be much more devastating. In this case, the impact on the region of research will be more significant due to the concentration of volcanic ash reaching up to the critical limits.

Comparing the eruption mass amount of eruptive volcanic ash into the atmosphere, in such cases of extremely high explosivity, the significant increase of ash, in combination with the prevailing winds, would be dispersed on vast territories and would reach more distant regions from the volcanic ash sources.

Finally, as a result of the eruptions with a VEI of 4 of the Icelandic volcano Eyjafjallajökull, accompanied by the suitable conditions of the atmospheric circulation, the volcanic ash reached all over Europe and blocked the air traffic for a significant period of time. The losses for the aviation sector are calculated to amount to 4.2 billion euros.

REFERENCES

[1] *The 2010 Eyjafjallajökull eruption, Iceland,* Report to ICAO - June 2012, ISBN 978-9979-9975-4-2, p.91-p.93;

[2] *Global distribution of volcanism: Regional and country profile.* Report IV of the GVM/IAVCEM contribution to the UN-ISDR Global Assessment Report on Disaster Risk Reduction 2015;

[3] Petkova M., *Probabilistic characteristics of volcanic ash sources and the impact on Bulgarian airspace,* ISSN 1313-955X, BULTRANS 14-16 September 2016.