CASE-STUDY FOR A HYPOTHETICAL ERUPTION OF ETNA AND THE APPROPRIATE WEATHER CONDITIONS FOR DISPERSION OF VOLCANIC ASH TO BULGARIAN AIRSPACE

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Abstract: *The objective of this study is the consequences of a hypothetical eruption of Etna in Italy and the appropriate conditions for dispersion of volcanic ash to Bulgarian air space in a particular situation. The risk assessment of potential volcanic ash contamination in Bulgarian airspace is based on a multi-complex risk analysis of potential volcanic sources, combined with suitable weather conditions and detailed analysis of the final outcomes connected to the impact of volcanic ash on airspace management over Bulgarian airspace.*

Keywords: *volcanic ash, atmospheric circulation, risk analysis, risk assessment*

1. INTRODUCTION

The objective of this study is the consequences of a hypothetical eruption of Etna in Italy and the appropriate conditions for dispersion of volcanic ash to Bulgarian airspace in a particular situation.

In fact, Etna is the most active volcano in Europe. Over the last seventeen years there have been eleven eruptions of Etna, four of them stronger more than VEI 3. Fortunate is the fact that more of eruptions are feeble up to VEI 1. This is the reason why there is no significant dispersion of volcanic ash into the atmosphere, despite the locally contaminated area close to the volcano source.

The risk assessment of potential volcanic ash contamination in Bulgarian airspace is based on a multi-complex risk analysis of potential volcanic sources, combined with suitable weather conditions and detailed analysis of the final outcomes connected to the impact of volcanic ash on airspace management over Bulgarian airspace.

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, 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. In the light of the above mentioned, 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.

2. DATA AND METHODOLOGY

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.

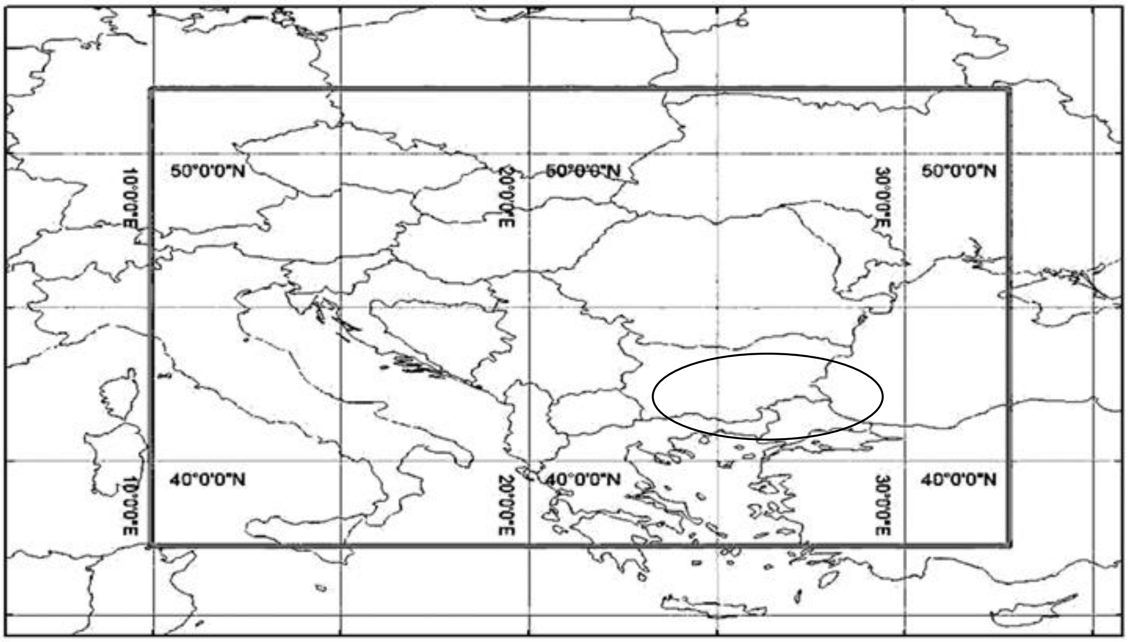

FIG 1. Domain for the research

The methodology presented in this article is based on Atmospheric Physics, risk analysis and risk management regarding event tree analysis and risk matrix and finally the possible impact on the real air traffic.

3. DEFINITION OF GENERAL ATMOSPHERIC CIRCULATION IMPACTED DISPERSION OF VOLCANIC ASH INTO THE UPPER AND LOWER ATMOSPHERE

For the identification of the synoptic weather conditions, a classification is used based on the Objective Grosswetterlagen (GWL) Catalogue adapted from the Hess-Brezowsky (HB) classification of circulation patterns. Based on the mean air pressure distribution (sea level and 500 hPa level) over the North Atlantic Ocean and Europe, the classification initially identifies three groups of circulation types (zonal, mixed and meridional), which are divided into 5 major types (westerly circulation types, southerly circulation types, northwesterly and northerly circulation types, northeasterly and easterly circulation types, main high/low pressure area over Central Europe). The Objective-GWL system is an objective computational version of the 29-type Hess and Brezowsky Grosswetterlagen system of classifying European synoptic regimes developed within the framework of the COST-733 international program. The last years, studies concerning the circulation type classifications were developed within COST Action 733 "Harmonisation and Applications of Weather Types Classifications for European Regions" whose main objective is to: "achieve a general numerical method for assessing, comparing and classifying weather situations in Europe, scalable to any European (sub) region with time scales between 12 h and 3 days and spatial scales from 200 to 2,000 km, applicable for a number of situations".

By applying the same approach and using Bulgaria as a main reference point, the local circulation over the East Mediterranean and Balkans (EM&B) region is classified in sixth anti-cyclonic types and eight cyclonic types described in Appendix 1.

Frequencies for weather circulation have been calculated over the 2014–2016 period. Table 1 simultaneously presents the main types of cyclonic atmospheric circulation with their seasonal relative frequency distribution. Even though this is a very short period from the standpoint of climatology, it has a good representation for the purpose of the current research.

The classification of different types of synopsis situations is focused on the relationship between spreading volcanic ash and synoptic circulation patterns. That is why, circulation types are derived for a specific time and region of interest using different predictor variables (e.g. sea level pressure, upper wind (direction and speed) for standard pressure levels, 500 hPa geopotential heights).

In fact, for the discussed volcano sources in Italy, the main appropriate general weather circulation for dispersion to the EM&B is the cyclonic circulation. All cyclonic sub-types for the EM&B region of interest are classified and presented in Table 1.

The methodology applied for the calculation of cyclone frequency is based on a daily subjective analysis and expertise of GFS numerical model data for the sea level pressure and 500 hPa geopotential heights. All isobars with mean sea level pressure (MSLP) equal to or lower than 1,015 hPa were counted on a daily basis for the present statistics. The 1,015 hPa threshold value was chosen following author expertise in the synoptic meteorology field. The results and conclusions have been made for all seasons. The monthly occurrence frequency was computed by dividing the number of cyclones counted during one month of a certain year by the total number of cyclones from the analyzed interval. Thus, 389 cyclones have been analyzed, the majority of them being of the mesoscale type with lifecycle from 3 to 5 days.

Table 1. Cyclonic circulation types at 500 hPa level over the Balkans, along with a brief description of their synoptic characteristics and the relative frequency of appearance on a seasonal basis during the period 2013-2016

Cyclonic types	Description	Relative frequency (%) number			
Type		Winter (Dec/Jan/ Feb)	Spring (March/Apr/ May)	Summer (June/July/ August)	Autumn (Sept/Oct/Nov)
C	A cyclonic center is located over Bulgaria	11.0	13.0	13.1	13.0
Cs	A cyclonic center is located south of Bulgaria	9.1	9.7	3.9	5.2
Csw	A cyclonic center is located west or southwest of Bulgaria	19.0	14.7	7.0	11.5
Cnw	A cyclonic center is located northwest of Bulgaria	4.2	5.8	3.6	4.0
Cne	A cyclonic center is located northeast of Bulgaria	13.5	10.1	7.9	8.6
Cse	A cyclonic center is located southeast of Bulgaria	1.7	2.6	0.5	0.9
Cn	A cyclonic center is located north of Bulgaria, usually much further north than 50 °N	0.7	0.9	0.2	0.3
Cw	A cyclonic center is located far west (at about 50 °E) or far northeast (at about 50 °N) of Bulgaria	5.5	3.6	1.0	2.9

It should be mentioned that the appropriate weather condition for contamination of Bulgarian airspace by volcanic ash from the volcano Etna is the cyclonic weather type with its center of low pressure to the south-west of Bulgaria (Csw). This type of weather patterns is characterized by significant values of south-west prevailing wind for the upper levels.

The situation is absolutely different in the case of Santorini eruption. The more suitable weather situation is the presence of a cyclone situated south or south-east of Bulgaria (Cs or Cse). Cyclonic circulation favors dispersion of volcanic ash to the region of interest. If Santorini erupts, the contamination for Bulgarian air space will be possible not only for dispersion of volcanic ash into the upper atmosphere but also for deposition of volcanic ash to the surface [1].

The relative frequency values for the weather type Cs are 9% more significant than Cse with 1.7% for both winter and spring time of the year. The frequencies for the summer and autumn are considerably lower.

4. SUMMARY OF SOME RESULTS CONCERNING THE HYPOTHETICAL ERUPTION OF ETNA AND THE SIGNIFICANT VOLCANIC ASH CONTAMINATION OF THE ENTIRE BULGARIAN AND NEIGHBORING AIRSPACE

4.1 INITIAL PARAMETERS FOR SIMULATION

Hypothetical volcanic eruption of Etna was simulated for 15 January 2017 at 00UTC. The HYSPLIT numerical model for dispersion of volcanic ash was started for this eruption. The Hybrid Single-Particle Lagrangian Integrated Trajectory model (HYSPLIT), developed by NOAA’s Air Resources Laboratory was used for the assessment and analysis of dispersion of volcanic ash. The investigation of the current situation is based on the following initial parameters:

- Start of eruption on 15 January 2017 00UTC
- Summit elevation 10991FT
- Height of volcanic eruptive column 9000m(FL300)
- Vertical dispersion of ash up to 18000m
- Volcanic explosivity index (VEI) - 3
- Duration of eruption is 48h
- There is wet deposition of volcanic ash

The run of the model produces deterministic dispersion output using a mass eruption rate estimated from the eruption height including an estimate of the mass fraction of fine ash. Assuming a magma density, and a fraction of fine ash that generally remains aloft, we can calculate the mass eruption rate, for input to HYSPLIT, given the eruption height. The best-fit line contains a large amount of scatter due to many factors including uncertainty in estimated ash column height, estimated volumetric eruption rate, temporal variations in eruption height and/or volume, water vapor entrainment, and effect of wind.

Output from the deterministic run is also shown as particle plots, color-coded by height, including a vertical cross section of the plume as viewed perpendicular to the dashed line, time scale for ash dispersion.

There is always uncertainty in forecasting volcanic ash dispersion in real-time. Basic model inputs such as ash column top height and eruption duration (start and stop time) may or may not be known well. The mass of ash in the eruption is uncertain.

The uncertainties of three-dimensional meteorological data (winds, etc.) depend on the meteorological observations used to initialize the model and the numerical analysis and forecast. [2]

4.2 DESCRIPTION OF WEATHER PATTERNS ON 15 JANUARY 2017

The current weather situation is assessed as a general cyclonic circulation (Csw) using HB classification. Regarding the upper level analysis, there is upper trough at 500 Hpa that will move to the east, spreading warm and moist air over the Balkans. At the surface, there is a cyclone centered in the south-eastern part of Italy (Csw type from Table 1), which would be moving to Greece for the next few hours. There are significant southwest winds at 500Hpa, 300Hpa and 200Hpa, which appeared as a major cause for spreading the volcanic ash from the hypothetical eruption of Etna to the region of interest. (fig. 2a, b). In fact, the current weather situation is the most common for the EM&B region with a frequency value of 23.7% for the period from January to May and 13.5% from June to November.

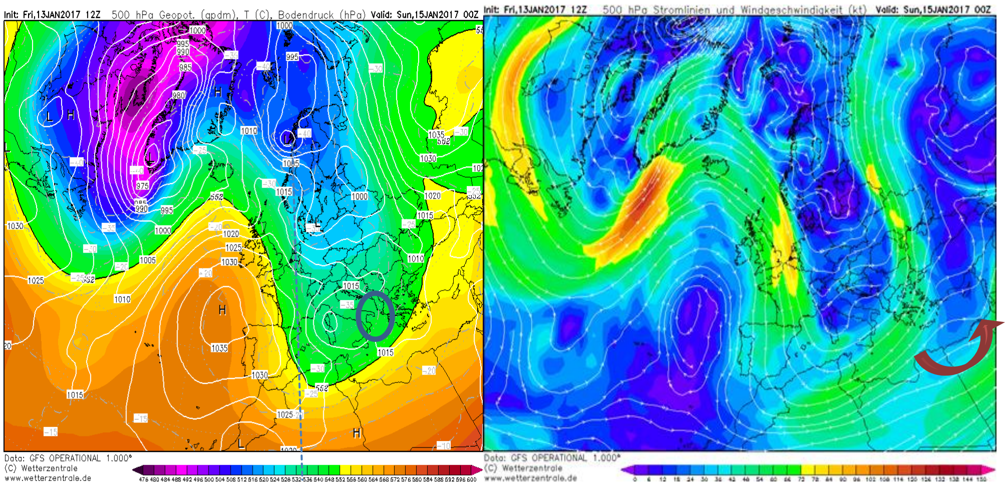

FIG.2.a) Mean sea level pressure and 500 hPa geopotential height chart b) Isotach of upper winds on 500Hpa pressure level

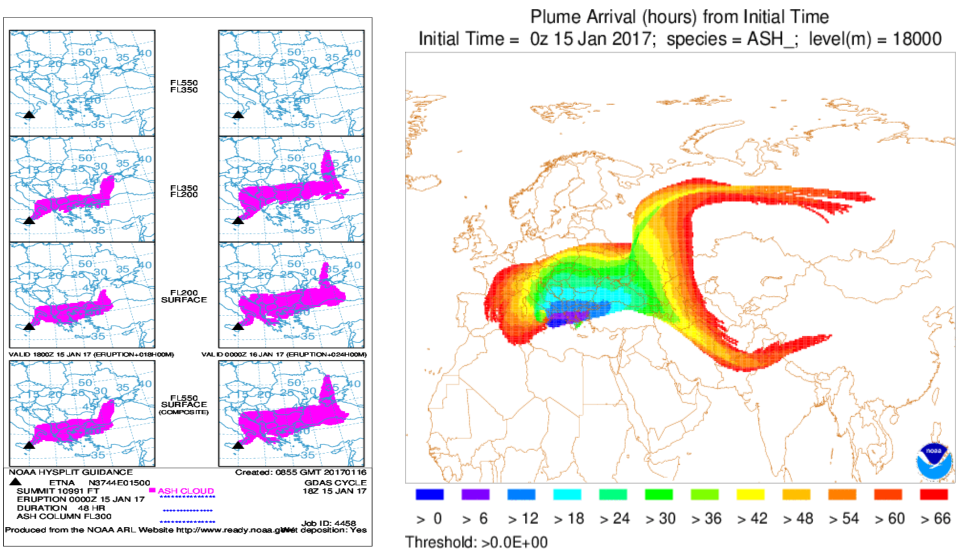

FIG.3.a) Dispersion of volcanic ash for hypothetical eruption of Etna for different flight levels b) Time-scale for plume arrival of dispersion of volcanic ash

The graphic results from fig.3 a, b show that volcanic ash is spreading to the Bulgarian airspace from 12 to 18 hours after eruption. As one can see, spreading by the significant values of upper winds (fig.3 b), the volcanic ash reached the southern part of Bulgarian airspace up to 12 hours after eruption, later on the volcanic ash is spreading to entire FIR for up to 6 hours. Generally, as a result of contamination, the southern parts of LBSF west, LBSF east, as well as LBWN sector would be impacted. There is a significant ash spreading from the surface to the higher layers up to FL350.

5. CONCLUSIONS

The actual distribution of air traffic provided by BULATSA for the period of 15 January 12UTC to 16 January 00UTC is presented in the Fig.3.

Table 2. Actuals flights for Bulgarian airspace on 15 January 2017 provided by BULATSA

	FL	LBSF WEST	LBSF EAST	LBWN
00:00-06:00	<250	10	1	2
	250-350	14	11	55
	350-660	30	27	123
06:00-12:00	<250	21	16	21
	250-350	58	69	75
	350-660	120	98	140
12:00-18:00	<250	20	11	24
	250-350	77	107	133
	350-660	144	115	170
18:00-24:00	<250	14	6	9
	250-350	34	63	75
	350-660	58	51	100

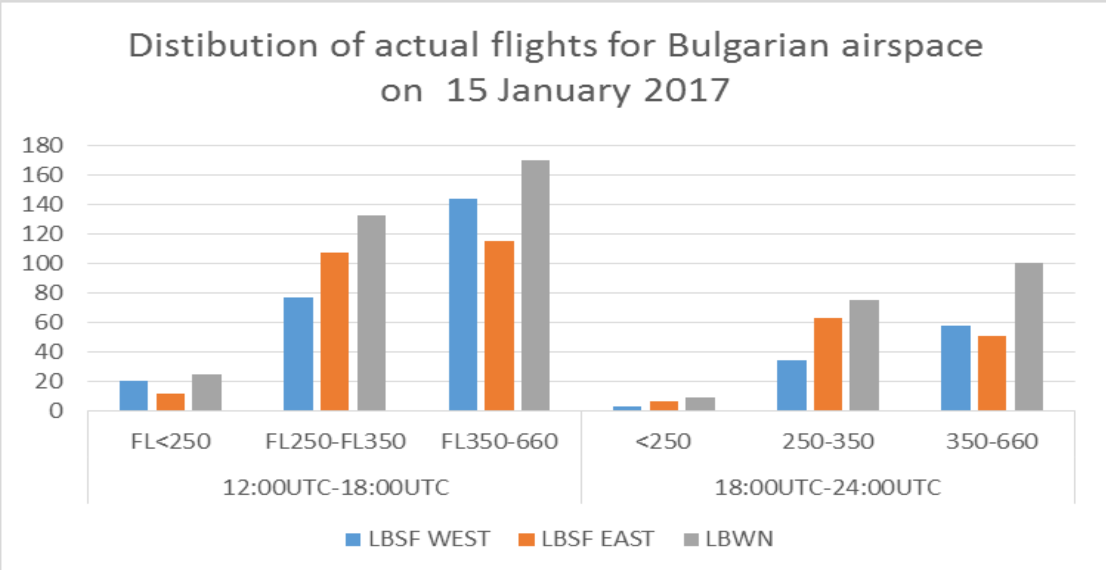

FIG 4. Distribution of actual flights depending of flights levels and time period on 15 January 2017 for the sectors in Bulgarian airspace provided by BULATSA

The analysis of the figures provided by BULATSA may be summarized as follows:

The affected flights for the period of maximum volcanic ash contamination will be 1043.

In general, the number for the lower flight levels (from the surface to the FL250), basically flights associated with landing and departures, is 84.

For the en-route air traffic the whole number is 959 including flights level from 350 to 550, which will also be impacted by a significant disruption in lower levels.

Another interesting fact when carefully looking at fir.3 a, b is that not only Bulgarian airspace may be impacted but also the neighboring airspaces. In this case, it is very important to take into account the appropriate measures for the air traffic and flow management regarding the possible ways of flights reorganization on a multinational level.

After the biggest crisis in aviation industry in 2010 connected with volcanic eruption and dispersion of volcanic ash to all over the Europe, EUROCONTROL has developed a tool for emergency situations in the presence of volcanic ash into the atmosphere. The main purpose of EVITA (European crisis Visualization Interactive Tool for ATFCM) is to provide collaborative online tool which allows users to visualize the impact of a crisis on air traffic and on the available air traffic network capacity in Europe. This visualization tool supports decision making in times of crisis and is the principal communications channel for airlines operating in Europe during major crisis situations.

In conclusion, - EVITA will be a suitable platform for solving the similar problems.

REFERENCES

[1] *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.*

[2] Mastin et al., 2009 *A multidisciplinary effort to assign realistic source parameters to models of volcanic ash-cloud transport and dispersion during eruptions, Journal of Volcanology and Geothermal Research, Vol. 186, 10-21*

APPENDIX 1

ANTI-CYCLONIC AND CYCLONIC TYPES CLASSIFICATION FOR THE EAST MEDITERRANEAN AND BALCANS (EM&B) REGION

Anticyclonic types	Description	Relative frequency (%) number			
Type		Winter (Dec/Jan/ Feb)	Spring (March/ Apr/ May)	Summer (June/July/ August)	Autumn (Sept/Oct /Nov)
A1	An anticyclonic centre is located to the west or northwest of the Bulgaria, usually over west, central or northern Europe	3.8	7.0	13.5	8.8
A2	An anticyclonic centre is located to the northeast of the Bulgaria	4.6	4.5	8.2	6.1
A3	An anticyclonic centre is located over the Bulgaria and the Balkans	5.8	6.7	12.0	12.0
A4	An anticyclonic centre is located to the west or southwest of the Bulgaria, over central or western Mediterranean or North Africa	11.2	8.7	11.7	13.9
A5	An anticyclonic centre is located to the south or southeast of the Bulgaria.	6.1	8.3	11.3	9.0
A6	An anticyclonic centre is located to the east or northeast of the Bulgaria	3.6	4.3	6.3	3.8

Cyclonic types	Description	Relative frequency (%) number			
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