Atmospheric Research 160 (2015) 39–49

Contents lists available at ScienceDirect

Atmospheric Research

journal homepage: www.elsevier.com/locate/atmos

Impact evaluation of potential volcanic plumes over Spain

J.A. Adame [a,*], M.D. Valentí – Pía [a], M. Gil-Ojeda [b]

[a] Atmospheric Sounding Station-El Arenosillo, Atmospheric Research and Instrumentation Branch, National Institute for Aerospace Technology (INTA), Crta. Huelva Matalascañas, km 34, 21130 Mazagón, Huelva, Spain

[b] Department of Earth Observation, Remote Sensing and Atmosphere, National Institute for Aerospace Technology (INTA), 28850 Torrejón de Ardoz, Spain

ARTICLE INFO

Article history:
Received 27 November 2014
Received in revised form 4 March 2015
Accepted 6 March 2015
Available online 12 March 2015

Keywords:
Volcanic eruption
Volcanic ash
Dispersion modelling
HYSPLIT

ABSTRACT

The volcanic ash transport to Spain has been investigated as a part of a broader scale forecast system. Based on a double criterion, distance and eruptive history, four volcanic areas potentially affecting Spain have been investigated: Azores Islands (Portugal), Canary Islands (Spain), Iceland, and southern Italy. The paths of simulated plumes have been computed from daily forward trajectories for the period 2005–2012 using the volcanoes' locations as departure points. The frequency of impact of the hypothetical plumes has been calculated for eight regions in Spain. The probability in all cases is low. Portuguese and Spanish volcanoes present the highest probability in the warm season (~3.5%); the volcanic ash from Iceland would be expected to arrive mainly in the cold season (<1.5%). Italian volcanoes show the lowest probability (<0.5%). The weather patterns associated to the arrival of volcanic plumes from the four volcanic areas have been identified. The mean times required for the ash plumes to reach Spain from the Canary Islands, Azores Islands, Iceland, and Italy are 40, 42, 57, and 61 h, respectively. The HYSPLIT model has been used to study the volcanic plumes' dispersion and concentration fields in three aviation reference atmospheric layers. Values with high hazard for aviation have been obtained over Spain following the hypothetical eruption of a Canary Islands volcano. Fields of medium hazard would be found over Spain after a Portuguese volcano eruption. The volcanic ash from Icelandic volcanoes shows low hazard, while Italian volcanoes indicate a null hazard in most cases.

1. Introduction

Volcanoes play a fundamental role on the Earth. They have direct effects on human health, animals, and vegetation and can disrupt the global radiation budget. Volcanic plumes represent significant hazards to aircraft because ash damages the engines, reduces the visibility, and sulphuric acid aerosols from SO_2 hydration might cause fuel contamination and have corrosive effects on windows and jet engines (Tupper et al., 2006; ICAO, 2007).

Seventy-five percent of the world's active volcanoes are located along the Pacific Ocean ridge, whereas only 6.8% of them are in the European area (Siebert and Simkin, 2002). On occasion, the flow of a volcanic plume may cause traffic disruptions, with the highest incidence observed in aviation traffic. The most recent case was the eruption of the Eyjafjallajökull volcano in Iceland in April–May 2010, which caused unprecedented flight cancellations throughout Europe (Langmann et al., 2011) and the 2011 Cordón Caulle eruption in Chile, which caused disruptions across the Southern hemisphere.

Encounters between aircraft and volcanic plumes are reported in the aviation literature. In ICAO (2007), 83 encounters between 1935 and 1993 were reported and classified based on Severity of Encounter. The most serious incidents occurred in the first 24 h after the eruption and at distances less than 1000 km from the source (Guffanti et al., 2010).

Large uncertainties in the load of the material ejected and its variability with time, and also in the height of the top of the plume, make an accurate forecast unfeasible, and only rough estimations of large areas where high concentrations of ash

* Corresponding author at: Atmospheric Sounding Station-El Arenosillo (INTA), Crta. Huelva Matalascañas, km 34, 21130 Huelva, Spain.
E-mail address: adamecj@inta.es (J.A. Adame).

http://dx.doi.org/10.1016/j.atmosres.2015.03.002
0169-8095/

might be present are distributed by the official Volcanic Ash Advisory Centres (VAAC). As a consequence, additional instrumentation not originally developed for volcanic ash tracking has been used for this purpose, such as remote sensing from satellites images, Lidar, and in-situ measurements among others (Ansmann et al., 2011; Thomas and Prata, 2011; Newman et al., 2012; Revuelta et al., 2012). In addition, a number of studies have been performed to compare dispersion models' output and observations (Colette et al., 2010; Stohl et al., 2011; Devenish et al., 2012; Webley et al., 2012).

While the tracking of a plume a few days after the eruption is a challenging task, the estimation of the impact probability of given volcanoes in certain areas can be performed by using the analysis of the meteorological fields, which may provide useful statistical information for the civil protection authorities, not only on the probability but also on the time required for the plume to arrive at the area of interest.

Studies to investigate the ash cloud probability of reaching European air space has been performed recently (Sulpizio et al., 2012; Scaini et al., 2014), for example, a short explosive eruption of Hekla volcano was performed by Leadbetter and Hort (2011). The transport of simulated daily plumes from the volcano was studied over the period 2003–2008, using meteorological data from the global archives of the Met Office's Unified Model and the NAME dispersion model. The results show a high probability of ash concentrations to the east of Iceland and probabilities exceeding 20% in latitudes north of 50° N. Highest probabilities of encounters within the European continent were indicated for wintertime. The paper also explores the hazard in major European airports by analysing the probability of volcanic ash deposition and air concentration from ground surface to 3048 m (which represents the flight level FL100, see Section 2.3). The results for Madrid (Barajas Airport) show a 16% probability of ash deposition in at least one of the four days following an eruption.

The difficulties in accurately estimating the position and loading of the ash plume were noted from the experience gained after the Eyjafjallajökull (Iceland) eruption in May 2010. In particular, scientific aircraft had significant problems in identifying the position of the plume in research flights during the crisis.

Spain can suffer the influence of Atlantic volcanoes (Iceland, Azores Islands, and Canary Islands) and Mediterranean volcanoes (Italy). The knowledge of the probability of impact of the ash cloud and the arrival time at a particular location from an erupting volcano is relevant to civil aviation authorities and crisis committees, and it is the main motivation of the present work. The paper is organised as follows: Section 2 describes the selection of the volcanic areas, the model and setup used, and the trajectory classification. Section 3 presents the estimated probabilities (Section 3.1), associated pathway and weather conditions (Section 3.2), and ash dispersion in specific events (Section 3.3). Finally, conclusions are provided in Section 4.

2. Area description and methodology

2.1. Volcanoes typology and selection

Mastin et al. (2009b) have developed Eruption Source Parameters (ESP) for the world's volcanoes. They have collected data from well documented eruptions. Volcanoes are classified in 11 types of eruptions based on their magma type. Recent mafic (rich in magnesium and iron) magmas are designated as M, and silicic magmas (rich in silica) are designated as S. Each eruption is subclassified as standard (0), small (1), medium (2), and large (3), according to the eruption intensity. From the 1520 volcanoes analysed, 43.26% are typified as S0 and a 31.12% as M0. The ESP defined in Mastin et al. (2009b) have been used in this work, other ESP would produce different results.

To establish the potential arrival of volcanic plumes in Spain, a number of volcanoes have been selected. The selection is based on the following criteria: a) distance, only volcanoes located at less than 3000 km from centre of the Iberian Peninsula; and b) eruptive history, all volcanoes with at least one explosive eruption in the last 70 years. Table 1 lists those 11 volcanoes fulfilling the imposed conditions, and summarises the main data. For the sake of simplicity, volcanoes of similar height, location, and eruption type have been grouped together, and one from each group is selected for analysis. These volcanoes are representatives of four volcanic areas: Italy (Southern region), Iceland, Azores Islands (Portugal) and Canary Islands (Spain) (Fig. 1a).

Two volcanoes have been selected in Portugal (Fayal and Terceira) and Spain (Hierro and La Palma). There are four groups for Icelandic volcanoes represented by 1) Grímsvötn as the most active one (approximately 70 eruptions over the last 1100 years) (Tesche et al., 2012), 2) Eyjafjallajökull, because of the previously demonstrated capability to spread ash along southern Europe (Ansmann et al., 2010), 3) Katla as the highest volume of magma erupted (Óladóttir et al., 2008), and the third most active volcano according to the historical records (1100 years), with at least 21 eruptions since the late 9th century (Thordarson and Larsen, 2007), and 4) Krafna, located further north, far from the rest and with a lower plume top. For the Italy area, the Etna, Stromboli, and Vesuvius volcanoes have been selected.

2.2. Model description and trajectory classification

The HYSPLIT (Hybrid Single Particle Lagrangian Integrated Trajectory) model has been used in this study (Draxler and Hess, 1998). HYSPLIT is widely used in atmospheric studies in two configurations: for trajectory calculations and as a dispersion model (Yerramilli et al., 2009; Escudero et al., 2011; Hernández-Ceballos et al., 2012; Kvietkus et al., 2013). Forward trajectories initiated at the locations of the volcanoes were tracked to establish the arrival probability. Daily trajectories have been computed at 12:00 UTC, run time of 120 h, and the height has been defined according to the criterion established in Mastin et al. (2009a). Kinematic three-dimensional trajectories were calculated using the vertical wind component information provided by the meteorological files.

The GDAS-NCEP model maintained by the NOAA/ARL (Air Resources Laboratory), with a temporal resolution of three hours, spatial resolution of $1° \times 1°$ (in latitude and longitude) and 23 vertical levels (from 1000 to 20 hPa) has been used to determine the meteorological fields. The selected period covers 8 years, from 2005 to 2012. Therefore, a total of 2920 trajectories have been used in this analysis for each volcano.

From the set of trajectories, those impacting Spain have been selected. For this purpose, Spain has been divided into seven regions, two insular (Balearic and Canary islands) and five peninsular (Fig. 1c). The airports with the largest number