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The volcanic ash and its impact on European air transport industry. A case study on the detection and impact of the the Eyjafjallajökull volcanic ash plume over North-Western Europe between 14th and 21st April 2010

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Abstract. Volcanic activity has caused significant hazards to numerous airports worldwide, with local to far-ranging effects on travelers and commerce. The AERONET network provides data regarding aerosol optical thickness, and many other inversion products for sites all over the world, and represents an efficient tool in the detection of aerosol intrusions, including volcanic ash. This paper also presents the evolution of air traffic during the eruption of the Eyjafjallajökull volcano between 14th and 21st April. Over 94.866 flights were canceled with more than 10 million passengers forced to remain grounded. Economic effects of the volcanic crisis were disastrous with more than 1.7 billion dollars in losses, over 200 million daily loss caused by the necessity of staying grounded, electricity costs, rerouting of aircrafts and the accommodation of passengers left on ground.

Key Words: volcanic ash, plume, AERONET, detection, impact, transport industry, loss in crisis.

Rezumat. Activitatea vulcanică reprezintă un hazard semnificativ pentru aeroporturile din întreaga lume, cu efecte severe asupra pasagerilor dar şi asupra economiei. Reţeaua AERONET furnizează date despre adâncimea optică a aerosolului, dar şi alţi produşi de inversie pentru sute de locaţii de pe glob. Astfel reţeaua AERONET este un instrument extrem de performant şi eficient de detecţie a intruziunilor de aerosoli, inclusiv a cenuşii vulcanice. Această lucrare prezintă şi evoluţia traficului aerian în timpul erupţei vulcanului Eyjafjallajökull între 14 şi 21 aprilie. Peste 94.866 de zboruri au fost anulate şi peste 10 milioane de pasageri au fost nevoiti sa ramână la sol. Efectele economice ale acestei erupţii au fost dezastruoase, cu pierderi de peste 1.7 miliarde de dolari, peste 200 de milioane pe zi, rezultate din anularea unor curse de pasageri, costuri cu electricitatea, redirecţionarea unor zboruri, şi cazarea pasagerilor a căror curse au fost anulate.

Cuvinte cheie: cenuşă vulcanică, nor, AERONET, detecţie, impact, transporturi, pierderi, criză.

Introduction. Volcanism is a very dynamic geological process that has spectacular manifestations which can be at the same time risk factors and often prove fatal for human life. The best known volcanic events are represented by: lava flows, mud flows, gas emissions, pyroclastics and pyroclastic flows and also secondary effects such as tsunami and other phenomena which influence climate and the chemistry of the atmosphere (Hamaker 1982; Petrescu 2002; Petrescu-Mag 2009).

Pyroclastics, are solid fragments originated from deep beneath the Earth that form after explosive eruptions, the materials generated being spread much faster and on a much bigger surface than the lava. They are represented by volcanic bombs, lapilli (rocks with some millimeters or centimeters in dimension, thrown by the volcano during eruption), volcanic ash with very small particle dimensions (2 mm – 1/16 mm) and dust particles (<1/16 mm). They can be very fine fragments of glassy lava, volcanic rock particles in an amorphous or crystalline structure. Generally the ash contains over 75%

pyroclastic fragments and is referred to as tuff. The ash that contains fewer than 75% pyroclastic particles is called tufit (Guffanti et al 2008).

Although volcanic ash is composed of materials with very small dimensions, the damages it may be cause can be significant because, after expelled in the atmosphere to a very high altitude (kilometers), it is scattered and usually falls on large surfaces. The volcanic ash originated from the eruption of St. Helens volcano (S.U.A.) in 1980 acted like a screen that bloked sun light on a distance of 150 km from the center of the eruption. Over 100 km away from the eruption, in Yakima, the quantity of fallen volcanic ash was about 600,000 tonnes (Baciu 2008). Ash deposits can destroy crops, can lead to clogging of the water surfaces or it can also lead to collapse of poorly constructed buildings.

Perhaps the most important risk concerns aircrafts, due to the strong corrosive effect of the ash expelled to great altitudes in the atmosphere, on the engines of the aircrafts. This leads to a high risk of malfunctions which can result in accidents. Among the best known events of this kind were those of 1982 when, after the 15 eruptions of Indonesia's volcano, Galunggung, between April and June 1982, pyroclastic materials were thrown up to 9000-12000 m, causing serious problems to aircrafts flying in that area. Most affected was a Boeing 747-200 belonging to the British-Airways Company and a jumbo jet belonging to Singapore Airways, obliged to execute a forced landing in Jakarta. In 1989, a KLM flight over Alaska had the same fate.

Volcanic ash expelled to great heights in the atmosphere may cause problems to aircraft engines. These materials have a highly corrosive effect primarily on turbines as they get temporarly or definitevly blocked after aspiring the dust which melts at the high temperatures inside the reactor and then cools down and solidifies on the cooler parts of the engine. Ash can also damage the propellers, can cause sudden engine failiure, all added to difficult flying conditions, in poor visibility, due to the scratches on the windshield caused by friction with the ash (see Figure 1).

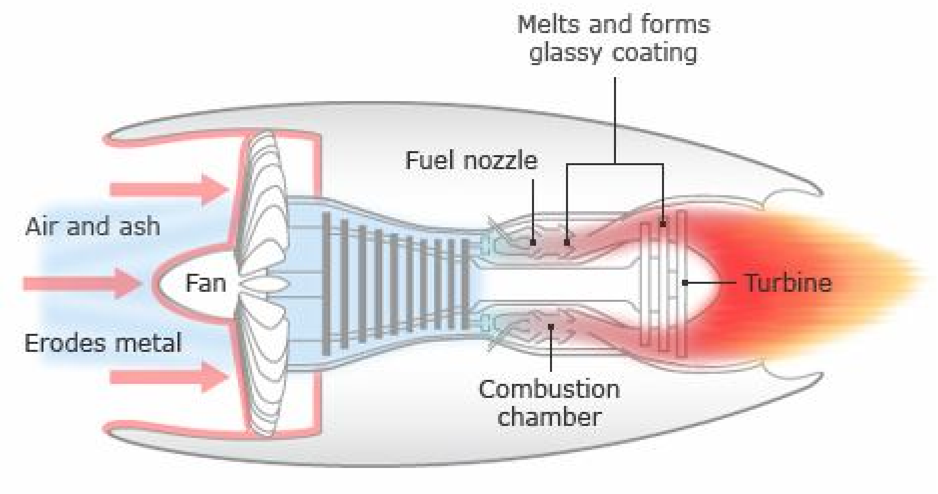


Figure 1. Volcanic ash affecting the turbine system.

The detection of the volcanic ash plume by AERONET stations in Europe

Material and Method. The AERONET (AErosol RObotic NETwork) is a network of ground-based sun photometers established by NASA and PHOTONS (University Lille1, CNRS-INSU, CNES) which measure atmospheric aerosol properties. The measurement system is a solar-powered CIMEL Electronique 318A spectral radiometer that measures Sun and sky radiances at a number of fixed wavelengths within the visible and near-infra red spectrum.

AERONET provides continuous cloud-screened observations of spectral aerosol optical Thickness (AOD). The Aerosol Optical Thickness is a measure of the proportion of radiation absorbed or scattered along a path through a partially transparent medium (Dubovik et al 2002). AERONET also provides information about wavelength dependency of the aerosol optical thickness (Angstrom exponent). Inversion products are also available, such as aerosol volume size distribution, and many others (Dubovik & King 2000).

A volcanic ash intrusion will induce a specific variation of these parameters, as follows: an increase in AOD, a decrease of the Angstrom exponent, the decrease of the fine Mode Fraction due to the fact that volcanic ash particles are relatively large (>1µm).

The source of the intrusion detected is estimated by using the HYSPLIT back-trajectory model (Draxler & Rolph 2010) developed by NOAA, which uses archived GDAS meteorological data in order to compute back-trajectory.

Results and Discussion. Data from 3 AERONET stations across Europe were analyzed: Chilbolton - United Kingdom, Hamburg - Germany and Lille - France.

a) Chilbolton, United Kingdom (N 51°88'38", W 01°26'13")

The volcanic ash intrusion was detected on the 16th of April at around 12:00 UTC, with the specific markers of the presence of volcanic ash shown below.

The increase of the Aerosol Optical Thickness (AOD) at different wavelengths (AOT_340 - AOT_1020) can be seen at this time, with values exceeding 0.5 around 14:00 UTC, values showing an increase of particles along the optical path (see Figure 2).

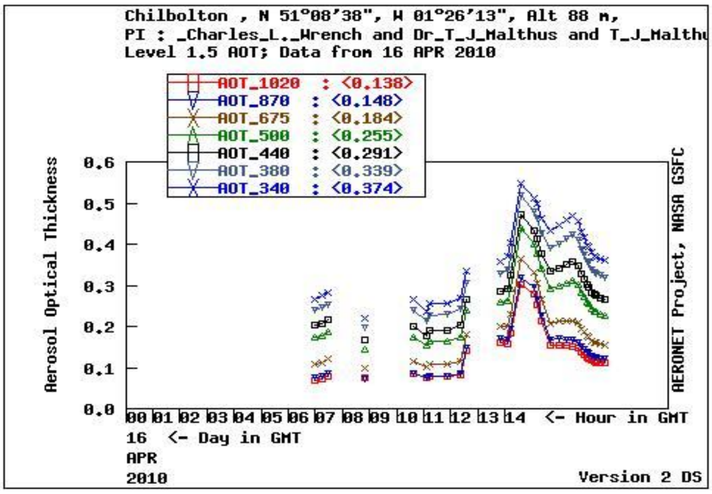


Figure 2. AOD Level 1.5 data from APR 16th of 2010.

A decrease of the Angstrom exponent (see Figure 3) shows the predominance of volcanic ash particles contributing to the measured AOT.

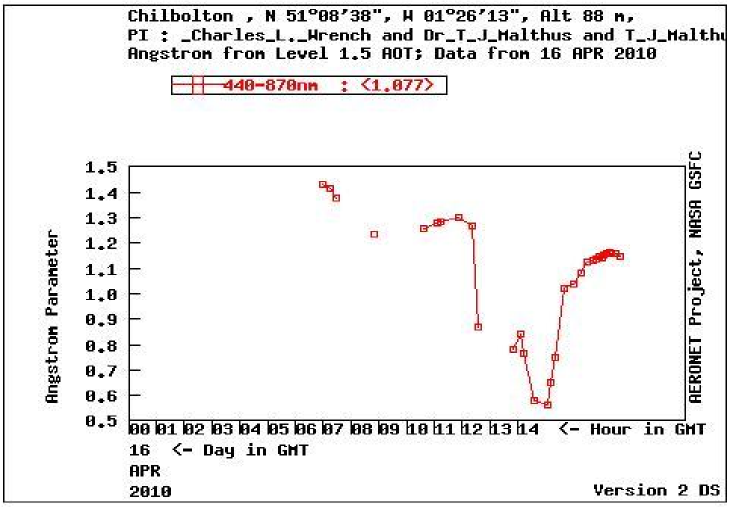


Figure 3. Angstrom Parameter data from APR 16th of 2010.

Decrease of the Fine Mode Fraction is also an indicator of the presence of volcanic ash particles, due to the fact that the average size of volcanic ash particles is larger than 1 μm and are therefore classified as coarse particles. The graph below shows the decrease of the Fine Mode Fraction starting at around 12:00 UTC form above 0.7 and reaching under 0.4 in just two hours (15:00 UTC) (see Figure 4).

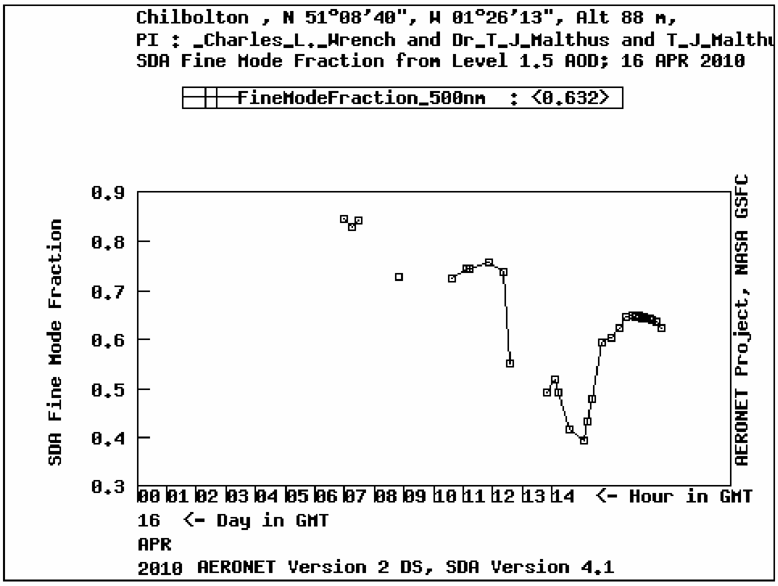


Figure 4. SDA Fine Mode Fraction retrievals from APR 16th of 2010.

The NOAA HYSPLIT back-trajectory model shows that the air mass reaching Chilbolton on April 16th at 13:00 UTC passed over the eruption area on April 15th at 06:00 UTC (see Figure 5).

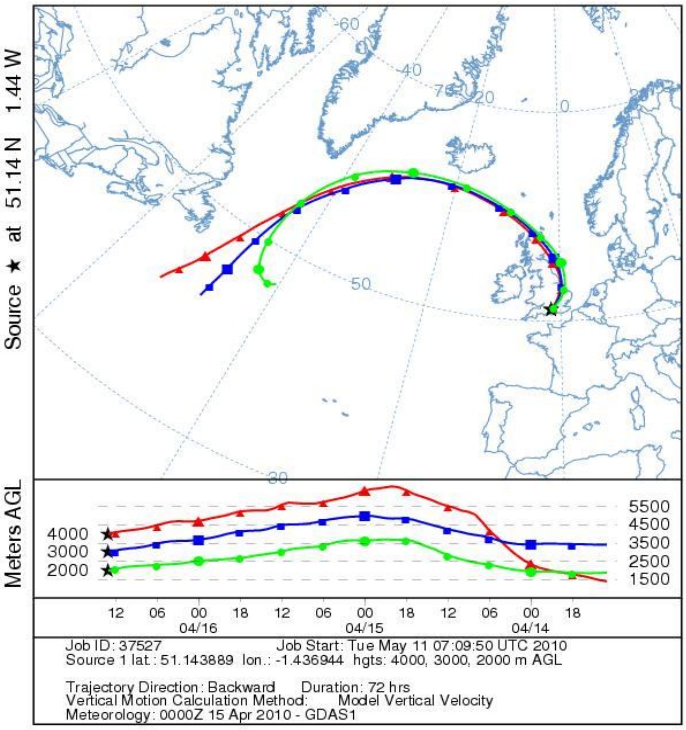


Figure 5. NOAA HYSPLIT backward-trajectories ending at 13:00 UTC 16th Apr 2010 – GDAS Meteorological Data.

Similar variations of these parameters were detected in Lille, France and Hamburg, Germany, as shown below:

b) Lille, France (N 50°36'43", E 03°08'31")

The volcanic ash intrusion was detected on the 17th of April at around 14:00 UTC, with the specific markers of the presence of volcanic ash shown below. The increase of the Aerosol Optical Thickness (AOD) can be observed in Figure 6. A decrease of the Angstrom exponent is shown in Figure 7.

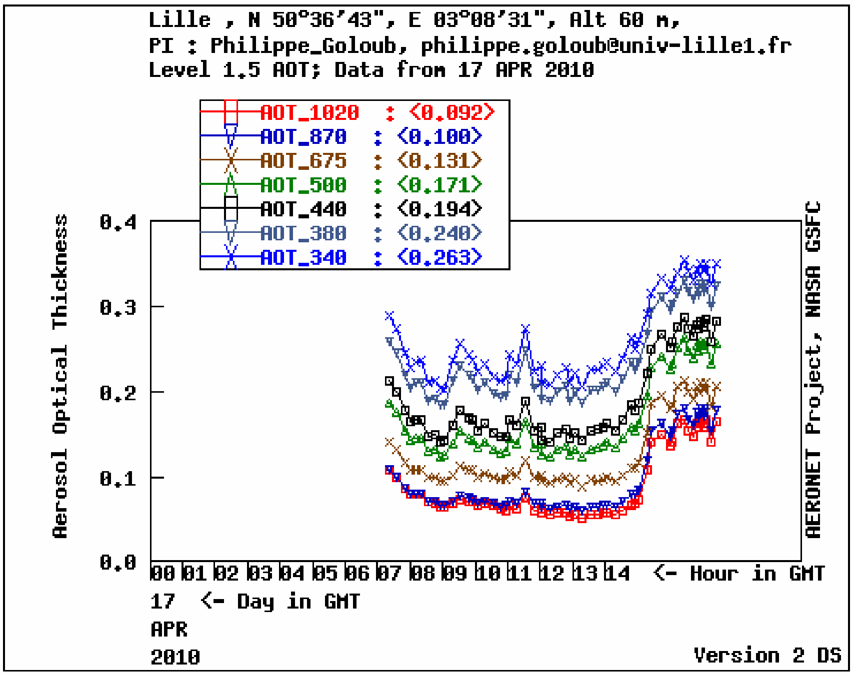


Figure 6. AOD Level 1.5 data from APR 17th of 2010.

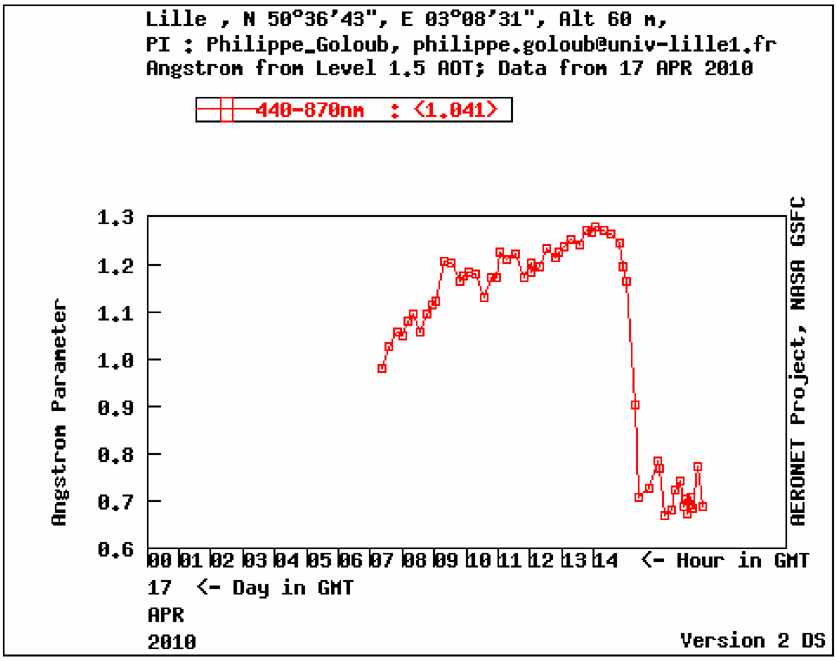


Figure 7. Angstrom Parameter data from APR 17th of 2010.

Decrease of the Fine Mode Fraction can be observed in Figure 8.

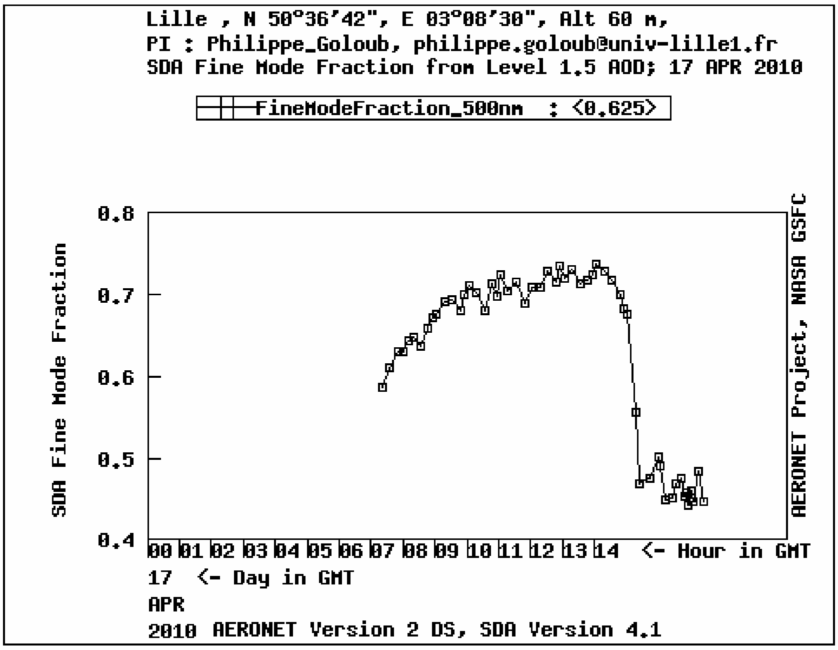


Figure 8. SDA Fine Mode Fraction retrievals from APR 17th of 2010.

The NOAA HYSPLIT back-trajectory model shows that the air mass reaching Lille on April 17th at 14:00 UTC passed over the eruption area on April 15th at 15:00 UTC (see Figure 9).

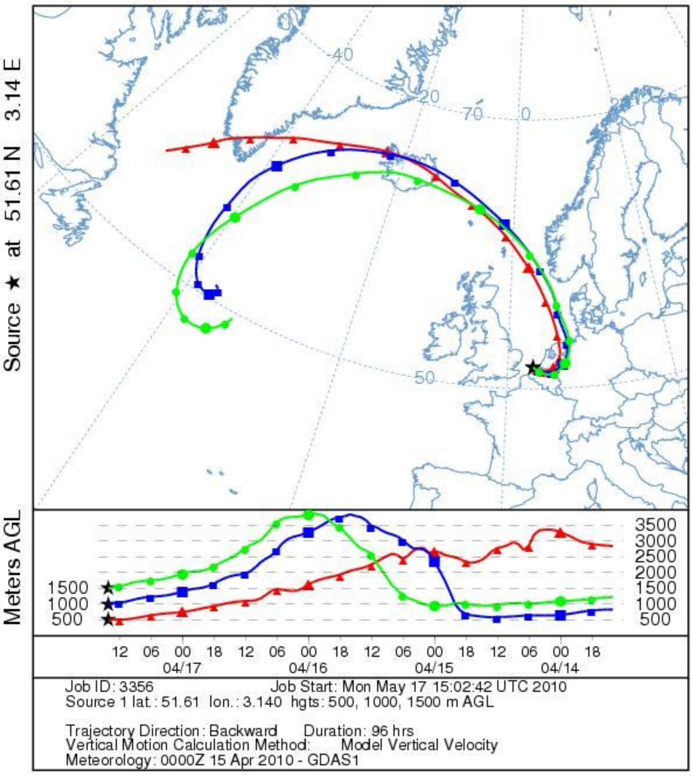


Figure 9. NOAA HYSPLIT Model - Backward-trajectories ending at 14:00 UTC 17th Apr 2010 – GDAS Meteorological Data.

c) Hamburg, Germany (N 53°34’04”, E 09°58’22”)
The volcanic ash intrusion was detected on the 18th of April at around 14:00 UTC, with the specific markers of the presence of volcanic ash shown below.
The increase of the Aerosol Optical Thickness (AOD) is shown in Figure 10.

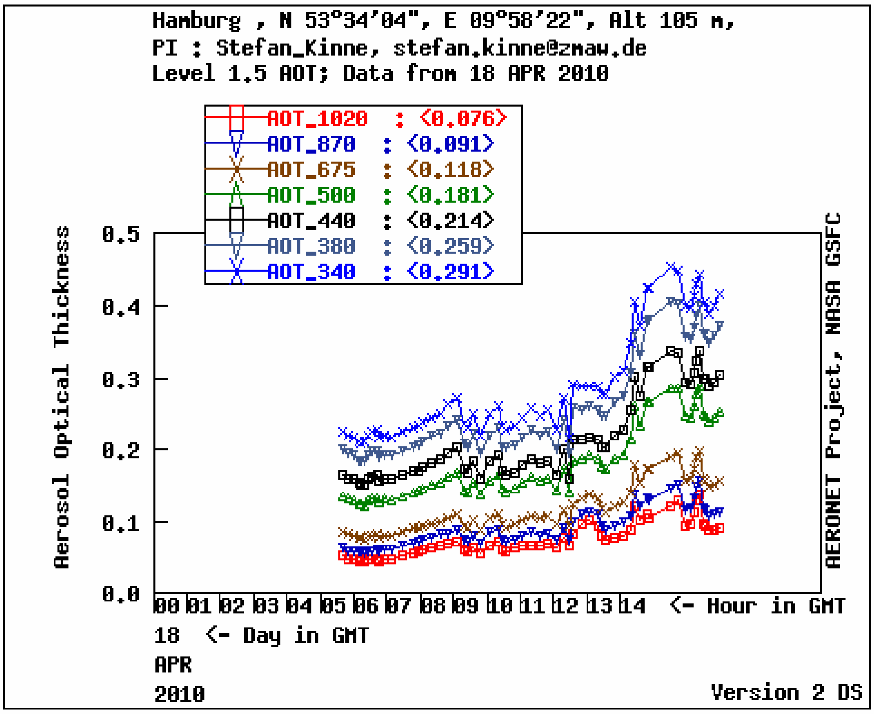


Figure 10. AOD Level 1.5 data from APR 18th of 2010.

A decrease of the Angstrom exponent can be observed in Figure 11.

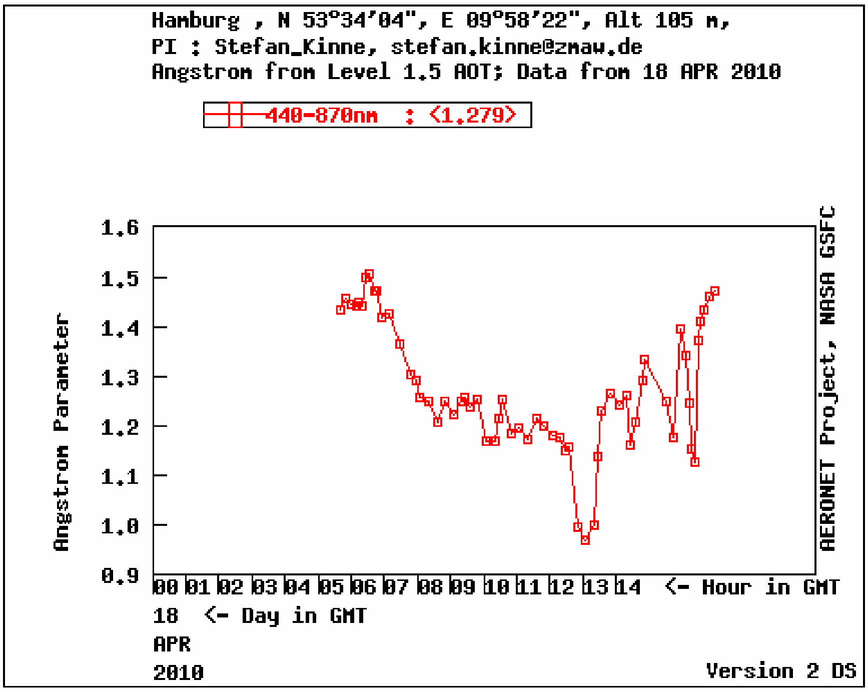


Figure 11. Angstrom Parameter data from APR 18th of 2010.

Decrease of the Fine Mode Fraction can be observed in Figure 12.

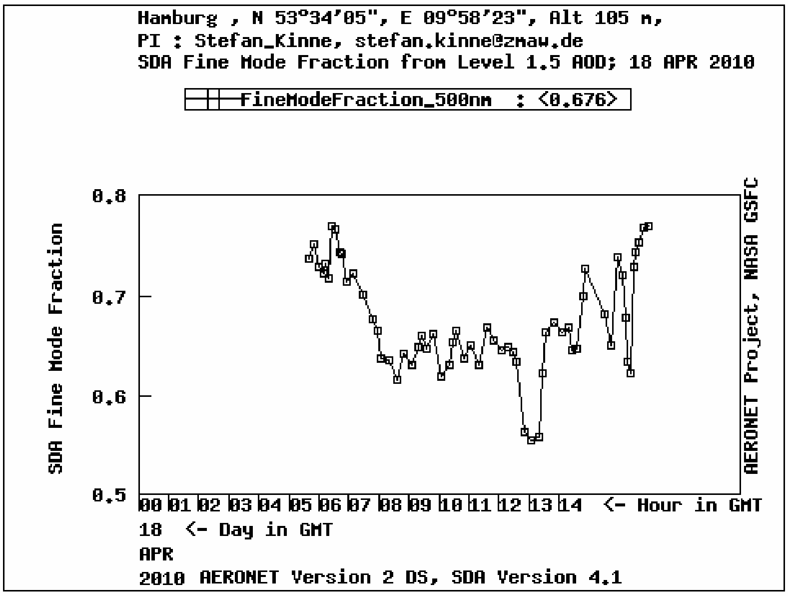


Figure 12. SDA Fine Mode Fraction retrievals from APR 18th of 2010.

The NOAA HYSPLIT back-trajectory model shows that the air mass reaching Hamburg at 14:00 UTC passed over the eruption area on April 15th at 18:00 UTC (see Figure 13).

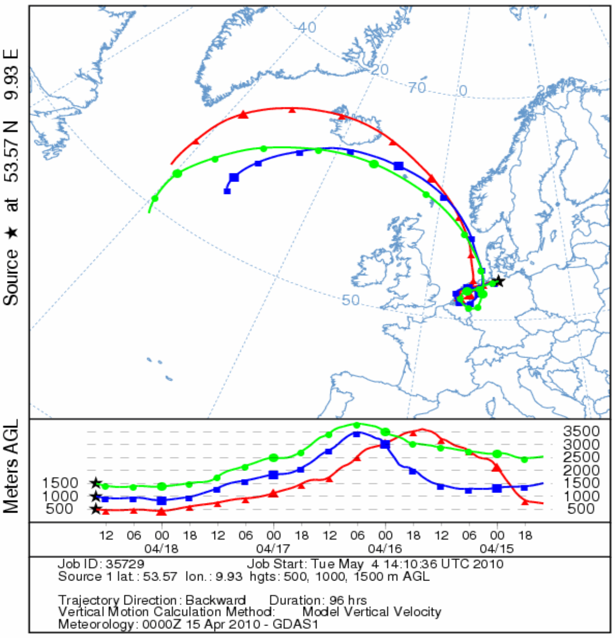


Figure 13. NOAA HYSPLIT Model - Backward-trajectories ending at 14:00 UTC 18th Apr 2010 – GDAS Meteorological Data.

Air traffic evolution during the eruption of Eyjafjallajökull volcano and the effects of the volcanic eruption

Eyjafjallajökull volcano is one of the smallest glaciers of Iceland. After starting its seismic activity during December 2009, it erupted for the first time on March 20th, 2010. But this was a small eruption. After a few days, on April 14th, it started to erupt again, but this time from under the ice and with much more power.

Traffic evolution during the eruption of Eyjafjallajökull volcano

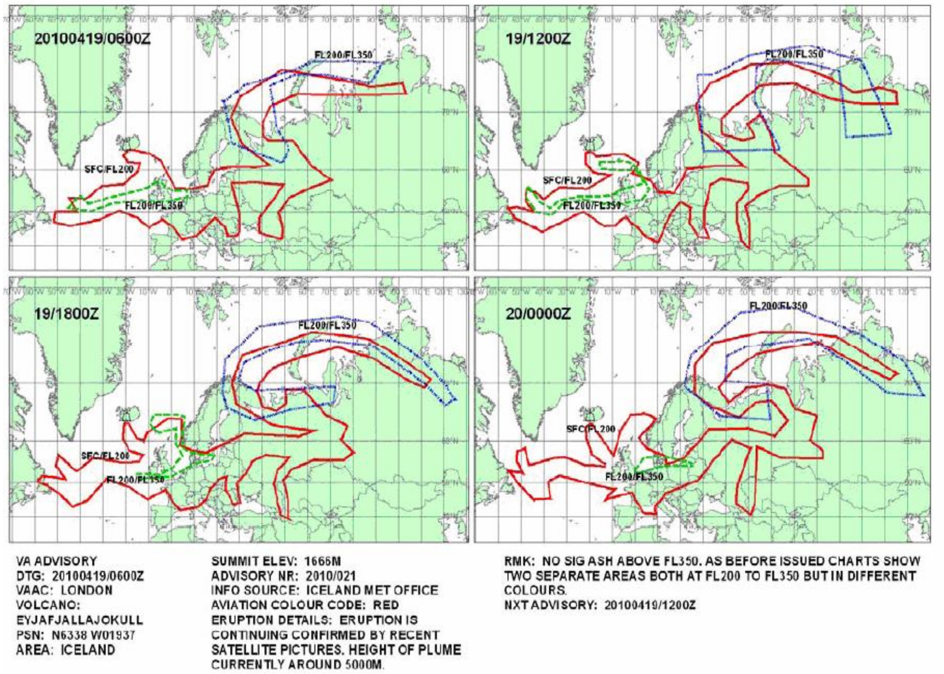
Following the April 14th eruption, Eurocontrol - European Organisation for the Safety of Air Navigation through the Central Flow Management Unit (known as the CFMU) was warned that air traffic could be disrupted because the volcanic ash cloud was moving south-east, fact shown by the radars in Sweden and Netherlands. As there were 28,087 scheduled flights that day, there was a great risk for at least one of them to have problems because of this cloud. After consulting the London Volcanic Ash Advisory Centre, two teleconferences were held between 14.30 and 18.30, moderated by London, during which the most important scenarios for closing the air space in Europe were prepared.

This was the moment when the first decisions to close the airspace were taken. Scotland and Norway were the first countries to take measures in restricting the air space, followed until midnight by Sweden and Findland. During the night of April 14th to 15th, the UK air space is closed, excepting the Birmingham area. Also Denmark and Ireland take measures to partially close the air space.

No less than 28.578 flights were scheduled For April 15th, of which only 20.842 have flown and many were already in the air when, at 12 o'clock Belgium, Netherlands and southern Sweden closed their air space completely and Eurocontrol officially announced the press about the dangers of the volcano and announced the redirecting of all transatalntic flights to the south of Europe where the traffic was not yet affected. Panic was installed among the passengers whose flights were canceled, and also among those who had to fly that night. Because it was impossible to give an exact prediction of the duration and the evolution of the cloud, many of them chose to spend the night there rebooking for the next day. Around the evening, the first restrictions for the French air space were taken by the closure of the Lille - Reimes area, rising the number of canceled flight to 7.736 after the first day.

On April 16th no less than 16.938 flights were canceled due to the movement of the cloud towards the center of Europe which led to further restrictions on the airspaces of Germany and the countries in Central and Eastern Europe.

During the day, Volcanic Ash Advisory London presents the first predictions for the next days. Figure 14 showes the prediction for April 19th and 20th describing the cloud height and its location in Europe. The red line marks the limit below 6000 m and the green line marks the limit below 10,000 m in altitude.



VA ADVISORY
DTG: 20100419/0600Z
VAAC: LONDON
VOLCANO:
EYJAFJALLAJOKULL
PSN: N6338 W01937
AREA: ICELAND

SUMMIT ELEV: 1666M
ADVISORY NR: 2010/021
INFO SOURCE: ICELAND MET OFFICE
AVIATION COLOUR CODE: RED
ERUPTION DETAILS: ERUPTION IS CONTINUING CONFIRMED BY RECENT SATELLITE PICTURES. HEIGHT OF PLUME CURRENTLY AROUND 5000M.

RMK: NO SIG ASH ABOVE FL350. AS BEFORE ISSUED CHARTS SHOW TWO SEPARATE AREAS BOTH AT FL200 TO FL350 BUT IN DIFFERENT COLOURS.
NXT ADVISORY: 20100419/1200Z

Figure 14. Predictions of Volcanic Ash Advisory for next days. Source: VA Advisory.

On April 17th, 17.228 flights were canceled and several countries extended their restrictions, France closed Paris, Reimes and Brest areas, followed by Germany who closed its air space in Langen (Dusseldorf and Frankfurt), Karlsruhe and Bremen area and in the evening, also Munich area. Also, the first airports were closed in Switzerland (Geneva and Zurich) and Italy (Milan, Padua, Bergamo), also, in the evening, Austria, Czech Republic, Slovakia, Estonia, Poland and Hungary have completely blocked their air space while Romania and Ukraine have imposed restrictions for some airports.

April 18th was the hardest day for the European airlines, over 19.761 flights beeing canceled, also because of the total closure of the airspace of France and Spain as well as of countries like Romania, Ukraine, Croatia, Slovenia, Bulgary, Luxembourg, Latvia, Bosnia-Herzegovina so that Europe's sky remained almost "empty" with only a little activity in the south (see Figure 15).

After 4 PM some countries decide to partially open their air space (Maastricht Rhein, Bremen, Milan, Padua areas) while others decide to totally open the air space during the evening and the night (Spain, France, Austria, Poland, Switzerland) but only under 6000 m.

On April 19th only 18.796 flights were canceled because some sectors have become operational for some heights.

Meanwhile, numerous flight verification for different altitudes and with different aircrafts are made by major airlines. Positive results of these tests led to an assembling of the EU transport ministers who had decided to continue testing with empty planes and to partially open the air space if no imminent danger is found.

Thus, on April 20th, only 14.407 of a total of 27.508 flights schedueled to fly were canceled. The main countries supplying flights have started to reopen their airspaces.

On April 21st, the last day of the European airlines crisis, only 6.171 flights were canceled and the restrictions were maintained only in the north of Scotland, Sweden and in the area of Helsinki and the northwest of Brest. The transport ministers' meeting was suspended and things seemed to be back to normal.

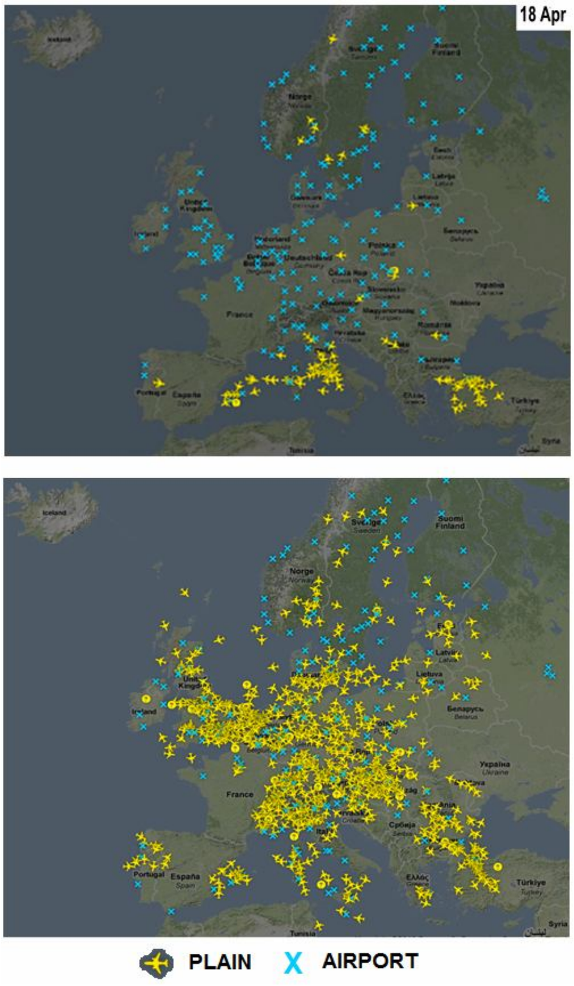


Figure 15. European airspace in 18th April compared with a normal day. Source: flightradar24.com

Economic effects of the volcano crisis

The summing-up after the largest aviation crisis that reached Europe after World War II reveals that over 94.866 flights were canceled with more than 10 million passengers forced to remain grounded. Economic effects of the volcanic crisis were disastrous with more than 1.7 billion dollars in losses, over 200 million daily loss caused by the necessity of staying grounded, electricity costs, rerouting of aircrafts and the accommodation of passengers left on ground.

Data reported by IATA (see Figure 16) show that over 29% of the aviation sector was affected and among the most affected companies were Lufthansa, with a decrease of shares' value by 4.1%; KLM-Airfrance, with a decrease of shares' value by 3.4%; British Airways with a decrease of approx. 3.3%. Also low-cost companies had losses, for example EasyJet lost approx. 7 million dollars for every day in which the flights were canceled.

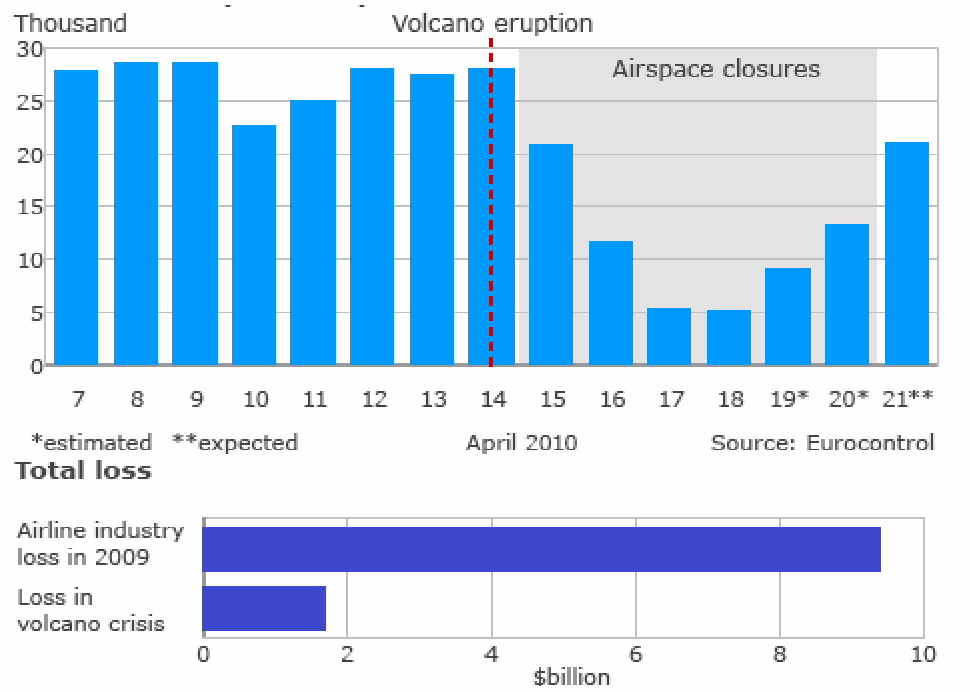


Figure 16. Flights in European airspace and loss of airlines. *Source*: IATA

Conclusions. Nature shows that it can surprise us in any moment and an event like this can cause the worst crisis. To prevent these situations, airlines and authorities need to invest much more in detection and prevention systems for natural disasters. Authorities need to find fast and economical alternatives to substitute the possible paralyzed air traffic. Airlines are now undergoing one of their most difficult periods since the losses caused by the volcano crisis add up to those caused by the economic crisis (Oprea, 2010).

Volcanic activity has resulted in significant hazards to numerous airports worldwide, with a recent (since 1980) frequency of approximately five airports affected per year on average. The hazards and risks are geographically dispersed, involving many source volcanoes and affecting airports in more than two dozen countries. Volcanic activity will continue to threaten airports, but, with foresight and diligence, some of the adverse effects can be reduced to the benefit of travelers and commerce.

The AERONET network provides a solid platform for aerosol related studies and is an indispensable tool for the study of events such as the Eyjafyallajokull eruption.

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