# Deliverable 8.3: Report on case studies for the socio-economic impact of ACTRIS

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# Contents

# 1. Introduction

The intensification of environmental problems in recent years, and in particular those related to air quality and climate change, requires upgrading the methodologies and tools used to analyse these phenomena and support decision-makers. To this end, of particular importance is the availability of reliable climatic and other atmospheric data, which can be used either as input data to various models to improve the simulation of physical processes they include or directly for policy making and supporting decision-makers.

ACTRIS Research Infrastructure (RI) is a pan-European initiative that unites the observations and related research on aerosols, clouds, and trace gases with final aim to provide high-quality research infrastructure services to a wider user community. Integrating European ground-based stations equipped with advanced atmospheric probing instrumentation, ACTRIS will have the essential role to support building of new knowledge as well as policy issues on climate change, air quality, and long-range transport of pollutants.

The main objectives of ACTRIS are:

- To provide long-term observational data and to substantially increase the number of high-quality data relevant to climate and air quality research on the regional scale produced with standardized or comparable procedures throughout the network.
- To provide a coordinated framework to support transnational access to European advanced infrastructures for atmospheric research strengthening high-quality collaboration in and outside the EU and access to high-quality information and services for the user communities (research, Environmental protection agencies, etc.).
- To develop new integration tools to fully exploit the use of multiple atmospheric techniques at ground-based stations, in particular for the calibration/validation/integration of satellite sensors and for the improvement of the parameterizations used in global and regional scale climate and air quality models. ACTRIS aims at providing time series of climate and air quality related variables not directly measured which are presently not available through existing data centers.
- To enhance training of new scientists and new users in particular students, young scientists, and scientists from eastern European and non-EU developing countries in the field of atmospheric observation.
- To promote the development of new technologies for atmospheric observation of aerosols, clouds and trace gases through close partnership with EU companies. In this context, ACTRIS2 aims at contributing to more than 4 new operating standards for atmospheric monitoring by the end of the project.

From the above it is obvious that the development and operation of ACTRIS RI may improve substantially the environmental information available on the quality of the atmospheric environment and the climate, generating wider benefits for the society.

In general, investing in research infrastructures contributes to improved research in various scientific areas, the development of innovative methods, the improvement of methodological approaches and computational tools, etc., which in the long run can lead to concrete innovative products, and services that are taken up and diffused in society, contributing to improving the quality of life (Florio et al., 2014;

Griniece et al. 2015; Soutukorva and Hasselström, 2015). Also, research infrastructures can play an important role in scientific communication and scientific education (Florio et al., 2014). For example, large scale research infrastructures may organize open days for the general public or for schools, leading to increased public awareness of science. In addition, research infrastructures are used to train and develop the skills of young scientists, and an increasing number of students undertake their master's or doctoral theses at these research facilities (Florio et al., 2014; Griniece et al. 2015; Soutukorva and Hasselström, 2015). There can also be concrete benefits that result from improving local infrastructure, urban planning and community services as the investment on research infrastructures may revitalise certain areas with important indirect societal benefits (Florio et al., 2014). While such impacts on society are broad, indirect and very difficult to attribute and quantify, in the context of this project an attempt was made to systematically analyse this type of societal impacts attributed to ACTRIS RI, providing, to the extent possible, quantitative estimates of their magnitude (see Deliverables 8.1 and 8.2) (Mirasgedis et al., 2018 and 2019).

In addition to the above-mentioned impacts on society through the development of research, education and the economy, the ACTRIS RI creates societal benefits from the direct provision of services to users outside the scientific community (Florio et al., 2014). For example, real-time monitoring of particulate and dust concentrations in the atmospheric environment provides decision-makers with the information they need to systematically monitor the evolution of a pollution or dust transfer episode and adapt appropriate management policies. Specifically, ACTRIS will leverage far-reaching benefits, by providing support to local, regional, national and international authorities and organizations for: (i) monitoring air quality both at background level and in areas affected by high levels of air pollutants due to human activities, unfavourable meteorological conditions and natural phenomena (e.g., heat waves, volcanic eruptions, desert dust transport); (ii) increasing public awareness, knowledge and debate regarding air quality and the potential impacts on public health, environment and climate; and (iii) contributing to the strategic design of appropriate policies and measures in the short- and long-term for tackling the negative impacts of air pollution on society, with a view to maximizing social welfare.

This deliverable aims to analyse this type of societal impact associated with the ACTRIS research infrastructure. Specifically, it seeks to formulate the methodological framework for analysing the benefits to the society associated with the provision of ACTRIS outcomes and products to users outside the scientific community.

The present report is structured as follows:

*Chapter 2* presents some illustrative examples of how the ACTRIS RI was or could be used to provide direct services to users outside the scientific community, generating benefits for society.

*Chapter 3* provides a description of the methodological approaches that can be implemented for analysing the wider effects to the society attributed to ACTRIS infrastructure. A distinction is made between bottom-up and top-down approaches, highlighting their advantages and limitations.

*Chapter 4* focuses on a case study and describes how the bottom-up approach described in Chapter 2 can be used to estimate the societal benefits arising from the utilization of ACTRIS products and services. Specifically, the Eyjafjallajökull volcanic eruption in spring 2010 is examined, and the impact, in both physical and economic terms, of the potential use of the research infrastructure in question on air traffic management is assessed.

Finally, in *Chapter 4* the main findings of the study are summarized, and conclusions are drawn.

# 2. Overview of the societal benefits attributed to ACTRIS RI

ACTRIS RI produces high-quality observations of short-lived climate pollutants (SLCPs) having a residence time in the atmosphere from hours to a few weeks. These short lifetimes make their concentrations highly variable in time and space and involve processes that are not well understood. Consequently, ACTRIS data increases the capacity for understanding the processes driving their life cycle and their impacts on climate and air quality.

ACTRIS supports research and knowledge enrichment in research areas ranging from short-term hazardous weather, heatwaves, and health issues, to long-term evaluation of climate change and policy effectiveness in mitigation. This ability to provide data that could predict the future behaviour of the atmosphere over multiple time scales, from hours to decades, benefits society in many sectors including energy, heath, security, economy and policy. Note that all atmospheric predictions use complex models that are underpinned by observations. Consequently, high quality observations are necessary to constrain the processes that these predictive models are attempting to describe; since without these, forecasting the interaction and feedback between the multitude of processes in the atmosphere becomes highly unreliable at longer timescales. Without a clear understanding of the mechanisms determining climate change or pollution episodes, prediction of these atmospheric processes will not be improved.

As ACTRIS provides unique data and helps to improve understanding of atmospheric processes related to air pollution, aerosol-cloud interactions, and climate change, it could benefit European society in several ways. Indeed, the acquired data and knowledge allows society to better identify atmospheric hazards, climate change and health issues supporting society in its response and mitigation policies. Examples are numerous on both country and European level. On country level (Greece for instance) successful example of ACTRIS results was the information of the local population during dust or smog events related to biomass burning which resulted in increasingly high particulate matter (PM) levels.

Indeed, mineral dust particles that are emitted from the desert areas in Sahara and the Middle East travel long distances in the atmosphere and affect air quality, weather, climate and local ecosystems at the Mediterranean basin. Dust affects the radiative transfer in the area, cloud processes due to the activation of dust particles as cloud condensation nuclei (CCN) and ice nuclei (IN). In terms of health impacts, increased $PM_{10}$ concentrations of fine dust aerosols may cause respiratory diseases and other related health issues. Greece and Eastern Mediterranean generally is very often affected by windblown dust originating from Sahara, due to its proximity to the Africa coastline. In terms of health effects, the severity of the dust events is mainly dictated by the amounts of dust aerosol near the surface. Such conditions with increased surface $PM_{10}$ of Saharan origin are more often found in Crete when the air masses originate from the nearby dust sources of Libya.

On March 2018, Crete was affected by a series of important dust intrusions of desert dust transported from northern Africa with the highest one occurred on March 22$^{nd}$. This event was clearly seen in the daily composites of MODIS visible channel and also in the geostationary Dust RGB images of MSG-SEVIRI. The presence of dust was initially detected in the western parts of the island (Chania), where the phenomenon peaked at noon, with maximum recorded $PM_{10}$ of 500 μg/m$^3$. Meanwhile, in the central and eastern areas (Heraklion and Finokalia) the dust concentrations also begun to increase during the morning hours of 22 March 2018 and in contrast to Chania the dust concentration rather than declining, suddenly began to increase rapidly so that at 15:00 UTC in the afternoon it reached a record value of 4730 μg/m$^3$ in Heraklion. The concentration of dust at the easternmost station (Finokalia), increased sharply in the afternoon, and at 17:20 UTC a new record value for Greece was again recorded at 6340 μg/m$^3$, exceeding the 5000 μg/m$^3$ upper limit of the tested range reported by the instrument's manufacturer (Figure 2.1). The average daily values recorded at Chania, Heraklion and Finokalia were 206, 1125 and 850 μg/m$^3$ respectively. The intense dust presence over Finokalia was also monitored and characterized with ACTRIS aerosol remote sensing measurements performed with the portable, polarization, Raman lidar of the National Observatory of Athens (NOA). Using polarization measurement capability, these lidar observations indicated that in Finokalia pick dust concentrations of the order of 1450 μg/m$^3$ are observed at about 3.5 km on 22 March at 03:00-04:00 UTC (Solomos et al., 2018).

The dust intrusion was detected by synergistic observational and modelling approach, using the resources of the Greek National Research Infrastructure (RI) PANACEA (PANACEA- PANhellenic infrastructure for Atmospheric Composition and climatE change), operating the national facilities of the ACTRIS RI Greece and population was immediately alerted. This event after Crete consequently covered almost all Greece and population of Athens and other big cities of Greece were immediately alerted.

Regarding data impact of ACTRIS RI on European activities, the Eyjafjallajökull volcanic eruption in 2010 is another very good example. This case, described in detail below, demonstrated the unique capability of the ACTRIS community to rapidly provide relevant information on the state of the atmosphere for civil aviation authorities.

It should be noted that the above are only some examples of ACTRIS utilization in monitoring environmental aspects; several other cases have been addressed by ACTRIS, but are not described here.

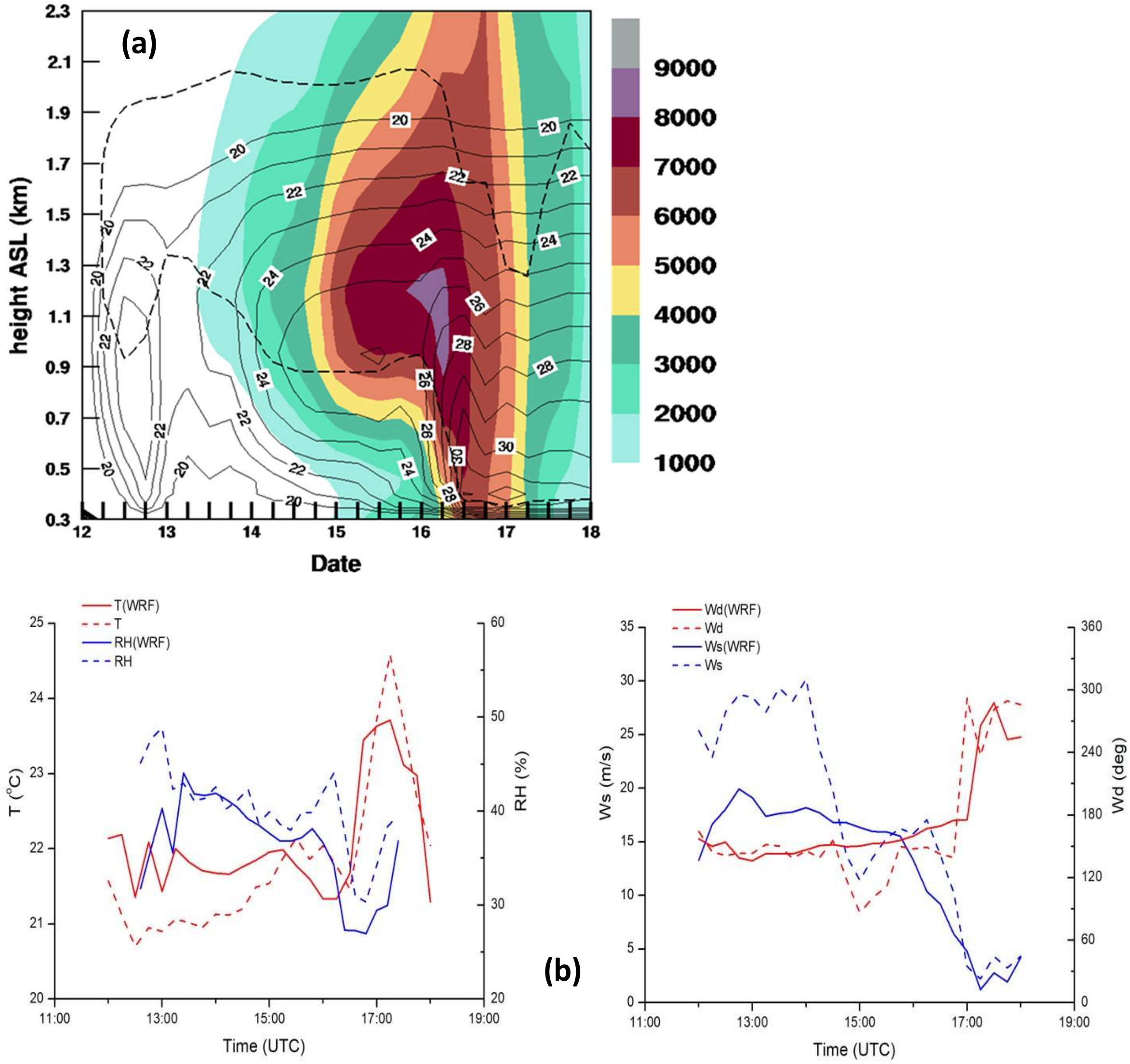



**Figure 2.1**. a) Time-height cross section over Finokalia every 15 minutes from the 1×1 km domain, during 12:00-18:00 UTC, 22 March 2018. The color scale represents dust concentration (μg m$^{-3}$), black line contours is the ambient temperature (°C) and the dashed line represents 10% relative humidity. b) Measured and modeled temperature (°C), wind speed (m s$^{-1}$), wind direction (degrees) and relative humidity (%) at the station of Finokalia, 12:00-18:00 UTC, 22 March 2018. (source: Solomos et al., 2018).

# 3. Methodological framework for analysing the societal benefits of ACTRIS RI

## 3.1 Top-down vs. bottom-up approaches to value the direct benefits to the society

Quantifying, in physical or economic terms, the wider benefits to society of developing and operating the ACTRIS research infrastructure presents significant methodological difficulties, mainly due to the nature of these benefits that are related to environmental information improvements, monitoring air quality, creation of technology and other innovations, etc., which can then be used in decision making, environmental planning, the development of innovative products and services, etc. Usually, these benefits are not integrated in existing market mechanisms, have no observable price in the market and therefore it is difficult to compare them with the development, operation and maintenance costs of the research infrastructure under consideration.

An overall (or aggregated or top-down) assessment of these benefits could be made using techniques of environmental economics. These techniques aim at deriving the Willingness to Pay (WTP) of individuals for a given environmental good/service or for avoiding a deterioration of this environmental good/service, or correspondingly their Willingness to Accept (WTA) compensation for a given nuisance level or for accepting deterioration of the environmental good/service in question. Value estimates resulting from these approaches are site-specific in the sense that they depend upon socioeconomic variables, education, age, traditions and other parameters changing with location and times, and therefore are associated with considerable uncertainties. On the other hand, attributing monetary values to non-market goods seems to form a powerful tool for incorporating them in decision-making processes.

The techniques used for the economic valuation of non-market goods can be categorized in two main categories (Hanley et al., 1997):

- Direct or stated preference techniques seek to infer individuals' preferences for the environmental goods/services in question directly by asking them to state their preferences for the environment. They rely on the use of surveys from which estimates are derived of the non-market goods/services in question. The two main stated preference techniques are contingent valuation and choice modelling. The basic idea of contingent valuation is that respondents are presented with a description of a change (e.g., undertaking measures to improve air quality monitoring in an area), and a question is asked to identify their willingness to pay for this change to occur. The basic idea is relatively straightforward, but in practice there are many critical features in the design of a contingent valuation survey. Choice modelling presents significant similarities with contingent valuation and relies also on surveys. The main differences between contingent valuation and choice modelling relate to how goods are described, and in the way valuation questions are asked. Specifically, in choice modelling the environmental goods/services in questions are decomposed into their constituent attributes, and respondents evaluate multiple scenarios that have different features or attributes.
- Indirect or revealed preference techniques seek to recover estimates of individuals' WTP for the non-marketed goods by observing their behavior in related markets. The most commonly used

revealed preference techniques are the hedonic price and travel cost methods. Market-based approaches are also classified under this category. In the hedonic pricing method, for example, a related market often used for environmental quality is the housing market, and economists seek to infer individuals' valuation of environmental improvements by considering their behavior in this market. In the travel cost method, the analysts try to infer the values people place on a recreational site through their expenditure on travel to the site. The market-based approaches are used to estimate the economic values of environmental goods / services that are an input into the production of a good or service that can be bought and sold in a market at an observable price. For example, when ecological changes lead to a small change in timber or commercial fishing harvests, the market price of timber or fish can be used as a measure of willingness to pay for that marginal change.

In the case of the ACTRIS research infrastructure, where the resulting societal benefits are difficult to relate directly to a specific marketable product, stated preference techniques are considered more appropriate to value these benefits. Application of these methods requires extensive surveys where the individuals are asked to fulfill appropriately designed questionnaires and answer questions about how they value the products and services provided by ACTRIS research infrastructure. Indicatively, the basic questions asked in these market surveys could be:

"*Would you be willing to pay €xxx to improve air quality monitoring by expanding the ACTRIS RI?*", or

"*How much money are you willing to pay for ACTRIS RI to continue providing the environmental information and other services it supports?*", or

"*What amount of money would you require as compensation for the interruption of environmental information and other services provided by ACTRIS RI?*"

However, the implementation of such an approach was not implemented in the context of the present analysis due to:

- Limitations on the availability of economic and human resources. The ACTRIS research infrastructure covers almost all the European continent and therefore a survey aimed at evaluating the resulting societal benefits should be carried out at a pan-European level.
- ACTRIS research infrastructure is still in the development phase and consequently the resulting societal benefits have not been fully realized by society. Implementation of such research is therefore likely to underestimate these benefits.

Therefore, the implementation of a stated preference approach to value the societal benefits of ACTRIS RI is premature and could be planned and implemented at a later stage (already foreseen in the ACTRIS-IMP program).

In contrast to the previously presented top-down approaches, which attempt an overall evaluation of the societal benefits associated with ACTRIS research infrastructure, in the context of this study, a bottom-up approach has been developed to roughly assess these benefits. Specifically, a number of case studies is analyzed, where environmental information or other services provided by the research infrastructure in question are used for decision making, environmental planning, etc., and the resulting benefits are estimated in relation to a reference scenario where the information / services provided by ACTRIS would not be available. Then, the overall societal benefits can be calculated from individual case studies based on the frequency of occurrence of such episodes and the use of ACTRIS products and services. A more detailed presentation of this methodological approach is given in the next section.

## 3.2 Quantifying the societal benefits of ACTRIS RI through the analysis of specific case studies

This section outlines the methodological framework that can be used to quantify the societal benefits of ACTRIS research infrastructure through the analysis of specific case studies. It is noteworthy that the development and operation of ACTRIS, as any other research infrastructure, results in the accumulation of new knowledge, improves existing methodological approaches and tools, and enhances fundamental science and technological developments. In the long run, these effects result in societal benefits through the development of innovative products and services, the provision of more reliable information, etc. This type of benefits associated with the development and operation of ACTRIS research infrastructure were analyzed in the context of Deliverable 8.1. This study focuses on the analysis of the direct impact of the examined research infrastructure on society, mainly through the provision of more reliable environmental information in the short run to policy makers, local authorities, government, etc. This analysis is done by investigating specific case studies, based on the following steps.

*Drafting a list of case studies where the data and services provided by ACTRIS research infrastructure have been utilized.* At this first stage it is important to record as thoroughly as possible the case studies, in which ACTRIS data have been utilized to facilitate decision-making, elaborate environmental plans, improve information provided to authorities and the public, etc. This list should include only case studies where the research infrastructure in question can provide additional information in relation to other existing infrastructures, metering networks, etc. In those case studies the environmental information or other ACTRIS services can be provided either occasionally due to an emergency (e.g., a volcano eruption, a major dust event, an environmental accident with air pollution release, etc.) or on an ongoing basis.

*Contribution analysis of the ACTRIS research infrastructure per case study*. For each case study identified in the preceding step, it is important to highlight the contribution of ACTRIS in either quantitative (preferably) or qualitative terms. Specifically, in each case two scenarios should be developed and comparatively evaluated:

- An ACTRIS scenario, which will present all environmental protection measures / policies / initiatives adopted, utilizing information derived by ACTRIS to deal with the specific case study under examination. To the extent possible, the interventions finally implemented as well as the environmental benefits / damages associated with their implementation should be presented in quantitative terms.
- A no-ACTRIS scenario, which will describe what would had happened in the absence (or non-exploitation) of ACTRIS infrastructure. Again, the interventions implemented, and the resulting environmental improvements or losses should be presented quantitatively.

*Economic evaluation of the two scenarios developed.* Having developed the two alternative scenarios of the case study under consideration, their comparative economic evaluation is then carried out. Specifically, the cost/benefit of environmental protection measures adopted, utilizing information derived by ACTRIS, will be compared with the costs and benefits of measures that would have been adopted if the detailed data of ACTRIS were not available to decision makers. In other words, the net benefits of an ACTRIS scenario will be compared with the net benefits of the no-ACTRIS scenario, where the environmental problem in question is treated without taking into account the information provided by ACTRIS. Such analyses will include, to the extent possible, market and non-market goods. Some of the techniques of environmental economics presented in the previous section may be used for the economic valuation of non-market goods. Alternatively, the analysis can be based on the application of benefits transfer approaches, relying on the results of other similar studies tailored to the case study under consideration.

*Integrated assessment of the societal benefits attributed to ACTRIS research infrastructure*. At this final stage of the proposed methodological framework, the individual societal benefits calculated for each case study due to ACTRIS utilization are aggregated in order to calculate the overall societal benefits attributed to the research infrastructure under consideration. This calculation is based on the following formula (adopted from European Commission (1995) and European Commission (2005) and originally used for estimating the environmental externalities associated with severe accidents):

$$SB = \sum_{i=1}^{n} \left( \frac{1}{p_i} \times \left( NB_{AS_i} - NB_{nAS_i} \right) \right)$$

Where:

SB: the total economic value of the benefits to the society resulting from the utilization of ACTRIS data and services per year.

$p_i$: frequency of occurrence of the episode covered by the case study i (in years).

$NB_{ASi}$ : the net benefits of managing case study i, utilizing environmental information from the ACTRIS research infrastructure. In the case of environmental damage then this parameter has a negative sign.

$NB_{nASi}$ : the net benefits of managing case study i, without utilizing environmental information from the ACTRIS research infrastructure. As previously, in case of environmental damages then this parameter has a negative sign.

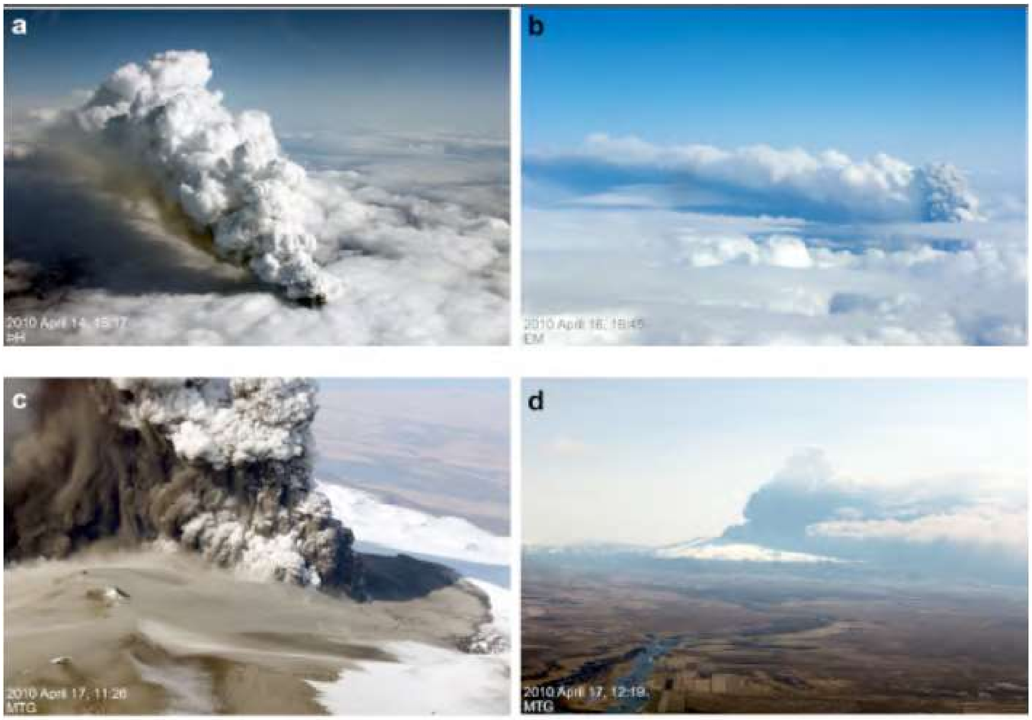
# 4. Case study: the Eyjafjallajökull volcanic eruption

## 4.1 Short description

The Eyjafjallajökull central volcano in Iceland has a relief of about 1.5 km, located at the eastern margin of the southern lowlands. It is 27 km long (east to west) with a maximum width of 14 km (north to south) and it encompasses an area of about 300 km$^2$. It is covered by a small glacier, about 80 km$^2$ in area and 14–15 km long in the east-west direction (above 800–900 m). The maximum thickness of the ice cover before the 2010 eruption was 200–250 m. The small, ice-filled summit caldera is about 2.5 km across with a 1.4 km wide breach towards north (IMO, 2012).

Only three eruptions have been documented in Eyjafjallajökull before 2010, in 920, 1612 and 1821–1823. Prior to 1991, the volcano was seismically quiet for at least 20 years. Enhanced seismic activity beneath Eyjafjallajökull, detected in 1991, was followed by persistent micro earthquake activity during the following decade with intense seismic swarms beneath the north-eastern and south-eastern flanks in 1994 and 1999 and a smaller swarm beneath the summit crater in 1996. Following this decade of unrest, the volcano was relatively quiet until March 2009 when a few earthquakes were recorded beneath the north-eastern flank. Seismic activity increased gradually throughout the year, escalating in an intense swarm in February–March 2010 (Langmann et al., 2012). Simultaneous inflation observed by GPS and interferometric satellite radar (InSAR) data confirmed magmatic accumulation within the volcano and heralded the subsequent eruptions. On the 20$^{th}$ of March 2010, a short effusive fissure on the volcano's flank opened, while a second fissure opened on the 31$^{st}$ of March. Activities at the fissures terminated at 6$^{th}$ and 12$^{th}$ April respectively (IMO, 2012). Lacking deflation during the flank eruption is supposed to be caused by continuous feeding of magma from greater depths. This further inflow of magma, together with previously intruded material (supposedly intrusion events of 1994 and 1999), inevitably led to the main summit eruption on 14th of April, after the eruptive fissure on the flank closed on 12th of April and the volcanic system quickly reached a level of overpressure again (Langmann et al., 2012; Sigmundsson et al., 2010). The main summit eruption occurred on the 14$^{th}$ of April and can be divided in three phases:

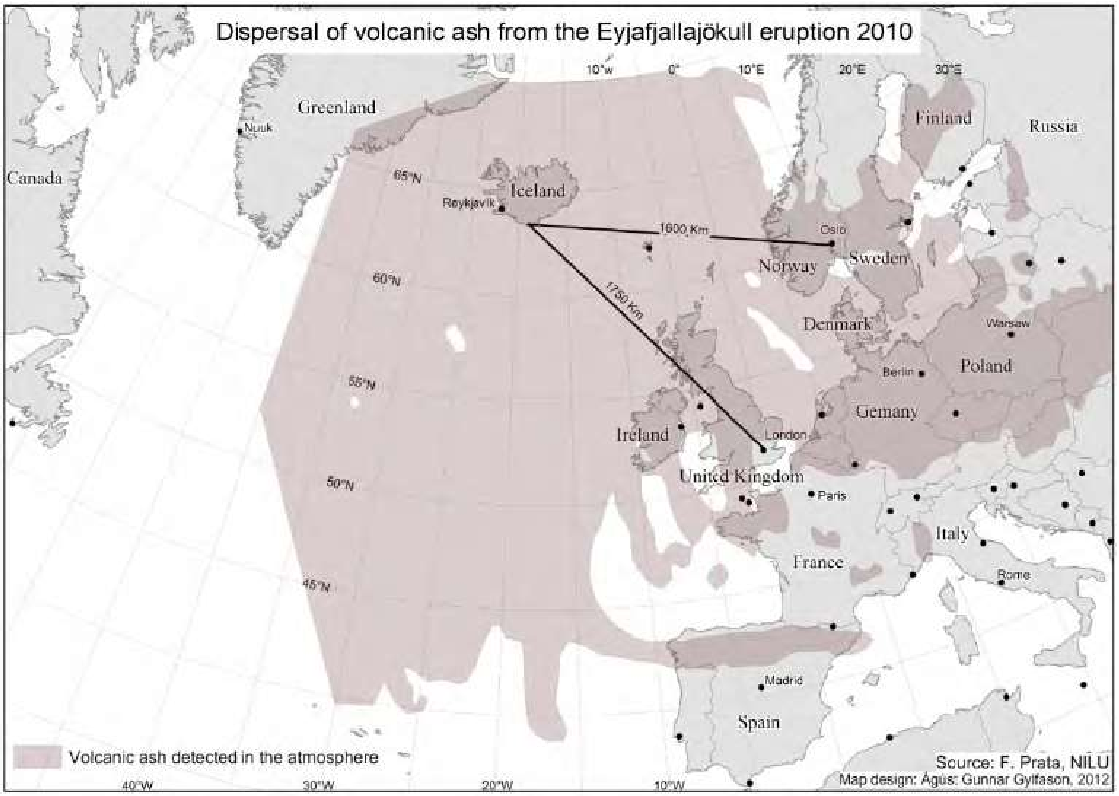
- An explosive phreatomagmatic phase started at the onset of the eruption on 14$^{th}$ of April and lasted for 5 to 7 days (**Figure 4.1**). Together with the melt water of the glacier, magma fragmented explosively into large volumes of very fine ash, ejected up to 11 km into the atmosphere
- From 18$^{th}$ of April, explosive activity decreased continuously to a more effusive eruption and as a result the ash particles got coarser and the ash plume only reached heights of 3-5 km.
- Around 5$^{th}$ of May, explosive activity increased again. There was a change to a rather small, but sustained magmatic explosive eruption, producing significant amounts of ash and pumice. The ash plume rose up to 10 km and fine ash was widely dispersed. The continuous eruption ended around the 23$^{rd}$ of May.




Source: IMO 2012

**Figure 4.1**. Photos taken from aircraft during April, phase 1.

In summary, the combination of the phreatomagmatic explosive activity due to melt water and above average evolved magma due to resting magma pockets of previous intrusions is supposed to have caused this exceptional amount of fine ash dispersed up to 11 km high into the atmosphere. In addition, prevailing weather patterns had a significant effect on the distribution of ash (**Figure 4.2**). It is noted that only about 3% of Iceland land area experienced excessive ash fall (Jónsdóttir, 2011).




Source: IMO 2012

**Figure 4.2**. Dispersal of volcanic ash from the Eyjafjallajökull volcano eruption in 2010. The shaded area shows where the satellites detected ash in the atmosphere during the eruption.

The aviation sector is double vulnerable to volcanic hazards as both airports and planes are affected. There were at least 171 incidents of volcanic ash on the tarmac of airports in 28 countries during the period 1944 - 2006. Since 1980, an average of five airports were affected each year, indicating that such incidents are not uncommon on a global scale. Out of the 129 reported incidents, 94 incidents are confirmed ash encounters, with 79 of those resulting in various degrees of airframe or engine damage (Lechner et al., 2018; Picquout et al., 2013). The texture of volcanic dust is very light and easily remobilized by wind. It is invasive and penetrates the smallest openings such as ventilation systems. This ash is conductive and can carry an electrical charge up to two days after its issue, which threatens to short circuit any loosely protected electrical system.

From 1953 to 2014, eruptions from 40 volcanoes located in 16 countries have caused damaging encounters of aircraft with ash clouds. While the most damaging encounters have occurred within 24 h of eruption onset and/or within 1,000 km of the source, less safety-significant but still economically damaging encounters have occurred at greater distances and extended times (Lechner et al., 2018). This ash is finely pulverized rock, ranging from 0.1 mm (a few hours' buoyancy in the atmosphere) to 5 µm (a few weeks). These particles are quite hard which leads to an abrasive effect on devices and they also contain sulfuric acid (resulting from the eruption), which is trapped in the roughness of the particles, and can cause chemical corrosion of the equipment. Another danger of the ash is related to its melting temperature (about 1,000°C). Modern jet-turbine engines run (at cruising speed) at temperatures higher than the above-mentioned melting point (about 1,400°C). The accretion of volcanic ash silicates on turbine engine blades can, and has, resulted in engine stalling and inability to restart. The accretion or incidence of volcanic ash silicates on and in the airframe can lead to critical interruption of electrical and hydraulic aircraft systems (Lechner et al. 2018; Picquout et al. 2013).

The eruption of Iceland's Eyjafjallajökull volcano in 2010 clearly demonstrated the vulnerability of the aviation sector to volcanic eruptions that occur in or near to high density airspace and highlighted that most issues related to aviation safety and volcanic ash have wide, global implications. At the same time, the need to improve policy responses and crisis management procedures became evident as more than 100,000 commercial flights were cancelled during the volcano's eruptive phase and over $5 billion in global GDP were lost, while the International Air Transport Association (IATA) estimated that its airlines alone lost $1.7 billion.

With respect to relevant International Civil Aviation Organization (ICAO) provisions in place at the time, upon receiving notification from the Icelandic Meteorological Office and armed with a necessary set of eruption source parameters, the London Volcanic Ash Advisory Centre (VAAC) activated its atmospheric transport and dispersion model and, supported by an observational analysis, began issuing volcanic ash advisories on the extent and movement of the volcanic ash cloud. London VAAC correctly forecasted that volcano ash could be carried over long distances and aircraft operators responded (in accordance with procedures and guidelines in place) by cancelling flights in contaminated and potentially contaminated airspace. Scottish and Norwegian airspace was the first to close down on the evening of the eruption. By the 18th of April, the airspace from Norway to the Canary Islands, and Ireland to Ukraine were virtually closed. This extensive shutdown lasted until the 21st of April, with air traffic resuming close to normal levels on the 22nd of April (Ellertsdottir, 2014). As mentioned in ICAO Journal (2013) "this was the only option that would adequately ensure flight safety". However, IATA noted (ICAO Journal 2013) "Although safety was guaranteed, it turned out that the model, actions and procedures at the time, implied unnecessary closure of immense portions of airspace leading to unacceptable financial losses". Similarly, Alexander (2013) describes the decision-making process as a "managerial improvisation" as detailed information on ash concentration levels became available only after the 20th of April; safe levels of suspended volcanic ash particulates were not defined; and relevant decision-making procedures were not in place.

In this context, the effects (by means of flights cancelled, passengers and aviation market segments affected, costs, etc.) of the policy responses to the Eyjafjallajökull volcano eruption in 2010 could describe a no ACTRIS scenario. This is because even if ACTRIS performed intensive measurements during the event, the RI was at that time not ready for a fast response to the emergency and also because it was not clearly defined which information could be of real interest for managing this hazard and how information should be distributed. Since then, many advancements have been achieved because the maturity of RI increased but also because activities performed in the EUNADICS-AV H2020 project (http://www.eunadics.eu) for improving the resilience and management of aviation hazards (including volcanic eruptions, dust transfers, forest fires and nuclear hazards) by improved data provision. However, ACTRIS stations performed intensive measurements during the Eyjafjallajökull eruption in 2010 and this allowed the characterization of the volcanic aerosol plume around Europe in terms of spatio-temporal distribution and optical properties (Pappalardo et al., 2013). Given that available measurements from ACTRIS infrastructure cover mainly the April 2010 period, the scenario developed refer only to that period.

## 4.2 The no-ACTRIS scenario

The main summit eruption of the Eyjafjallajökull volcano in Iceland occurred on the 14th of April 2010. The main period of crisis with European airspace closures, was from the 15th to 22nd of April, though the effects started earlier and ended later, especially in Iceland.

According to EUROCONTROL (2010) data, during this period of April, about 104,000 flights were cancelled and 10 million passengers were unable to board, while there were 112,000 flights (**Table 4.1**). More than 85% of the cancelled flights concern flights within Europe (as defined in the context of EUROCONTROL Statistical Reference Area, ESRA08[1]). The peak of flight cancellations was on the 18th of April when only 19% of the total number of planned flights finally occurred. Since 19th of April, there were some additional flights scheduled (5,285) to reposition aircrafts, crew and to accelerate the repatriation of stranded passengers.

In line with the profile of flights cancelled and according to IATA (2010) data, European airlines represented 70% of grounded passenger capacity (**Figure 4.3**), followed by airlines from Asia – Pacific (11%) and North America (10%). In terms of operations affected (**Figure 4.4**), European airlines had 75% of its operations closed at the peak of the ash plume (i.e. close to grounded passenger capacity), followed by African airlines (30%), though their share of grounded passenger capacity was only 3%. A similar profile was recorded for airlines from Middle East (25% of operations vs. 5% of grounded passenger capacity).

[1] For more information, see https://www.eurocontrol.int/sites/default/files/2019-03/eurocontrol-7-year-forecast-february-2019-annex1.pdf

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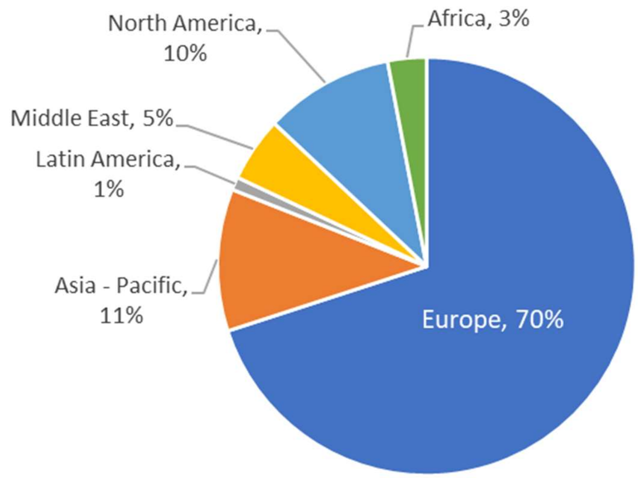


Source: IATA 2010

**Figure 4.3**. Airlines share of grounded passenger capacity

**Table 4.1**. Overview of the impacts of Eyjafjallajökull eruption to Europe (EUROCONTROL Statistical Reference Area) during April 2010 (source: https://www.eurocontrol.int/sites/default/files/article/attachments/201004-ash-impact-on-traffic.pdf)

| | | 15-Apr | 16-Apr | 17-Apr | 18-Apr | 19-Apr | 20-Apr | 21-Apr | 22-Apr | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|
| 1. Within Europe | Actual Flights | 16,016 | 8,979 | 3,341 | 3,031 | 6,503 | 9,178 | 16,653 | 21,320 | **85,021** |
| | Estimated Cancelled Flights | 7,376 | 14,339 | 13,602 | 15,648 | 16,363 | 13,357 | 6,520 | 2,072 | **89,276** |
| | Estimated Passengers Unable to Board (Thousands) | 568 | 1,162 | 1,210 | 1,353 | 1,296 | 1,024 | 517 | 98 | **7,229** |
| 2. To/From Russia, Asia | Actual Flights | 1,317 | 708 | 324 | 450 | 677 | 956 | 1,469 | 1,639 | **7,540** |
| | Estimated Cancelled Flights | 352 | 1,082 | 1,169 | 1,174 | 922 | 596 | 185 | 30 | **5,510** |
| | Estimated Passengers Unable to Board (Thousands) | 47 | 166 | 200 | 208 | 157 | 101 | 40 | -8 | **910** |
| 3. To/From North Africa | Actual Flights | 924 | 502 | 464 | 475 | 706 | 975 | 1,069 | 1,207 | **6,322** |
| | Estimated Cancelled Flights | 76 | 425 | 807 | 935 | 199 | -125 | -318 | -207 | **1,793** |
| | Estimated Passengers Unable to Board (Thousands) | 11 | 57 | 108 | 126 | 32 | -16 | -43 | -30 | **246** |
| 4. North Atlantic | Actual Flights | 788 | 284 | 193 | 156 | 233 | 499 | 750 | 998 | **3,901** |
| | Estimated Cancelled Flights | 190 | 712 | 772 | 822 | 755 | 438 | 202 | -20 | **3,872** |
| | Estimated Passengers Unable to Board (Thousands) | 35 | 156 | 177 | 183 | 168 | 105 | 52 | -1 | **876** |
| 5. To/From Middle East | Actual Flights | 776 | 399 | 254 | 337 | 388 | 516 | 811 | 909 | **4,390** |
| | Estimated Cancelled Flights | 106 | 362 | 509 | 588 | 398 | 279 | -7 | -27 | **2,208** |
| | Estimated Passengers Unable to Board (Thousands) | 23 | 76 | 103 | 116 | 86 | 55 | 3 | -8 | **454** |
| 6. Mid/South Atlantic | Actual Flights | 242 | 143 | 133 | 131 | 141 | 204 | 251 | 270 | **1,515** |
| | Estimated Cancelled Flights | 1 | 105 | 157 | 173 | 130 | 46 | -11 | -27 | **575** |
| | Estimated Passengers Unable to Board (Thousands) | 2 | 27 | 38 | 42 | 33 | 11 | -2 | -5 | **146** |

| | | 15-Apr | 16-Apr | 17-Apr | 18-Apr | 19-Apr | 20-Apr | 21-Apr | 22-Apr | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|
| 7. To/From Southern Africa | Actual Flights | 184 | 94 | 84 | 59 | 79 | 148 | 229 | 228 | **1,105** |
| | Estimated Cancelled Flights | 27 | 147 | 154 | 194 | 154 | 55 | -7 | -17 | **706** |
| | Estimated Passengers Unable to Board (Thousands) | 9 | 36 | 37 | 43 | 36 | 15 | 1 | -3 | **174** |
| 8. Overflying Europe | Actual Flights | 308 | 286 | 306 | 336 | 311 | 336 | 328 | 346 | **2,557** |
| | Estimated Cancelled Flights | 22 | 36 | 42 | 28 | -6 | -6 | 3 | -16 | **103** |
| | Estimated Passengers Unable to Board (Thousands) | 1 | 4 | 6 | 5 | -2 | -2 | -3 | -5 | **5** |
| TOTAL | Actual Flights (Thousands) | 20.6 | 11.4 | 5.1 | 5 | 9 | 12.8 | 21.6 | 26.9 | **112.4** |
| | Estimated Cancelled Flights (Thousands) | 8.2 | 17.2 | 17.2 | 19.6 | 18.9 | 14.6 | 6.6 | 1.8 | **104** |
| | Estimated Passengers Unable to Board (Millions) | 0.7 | 2 | 2 | 2 | 2 | 1 | 0.6 | 0 | **10** |

**Note**: Negative values mean that more flights took place (or larger aircraft were in use) than in the reference days before and after the crisis

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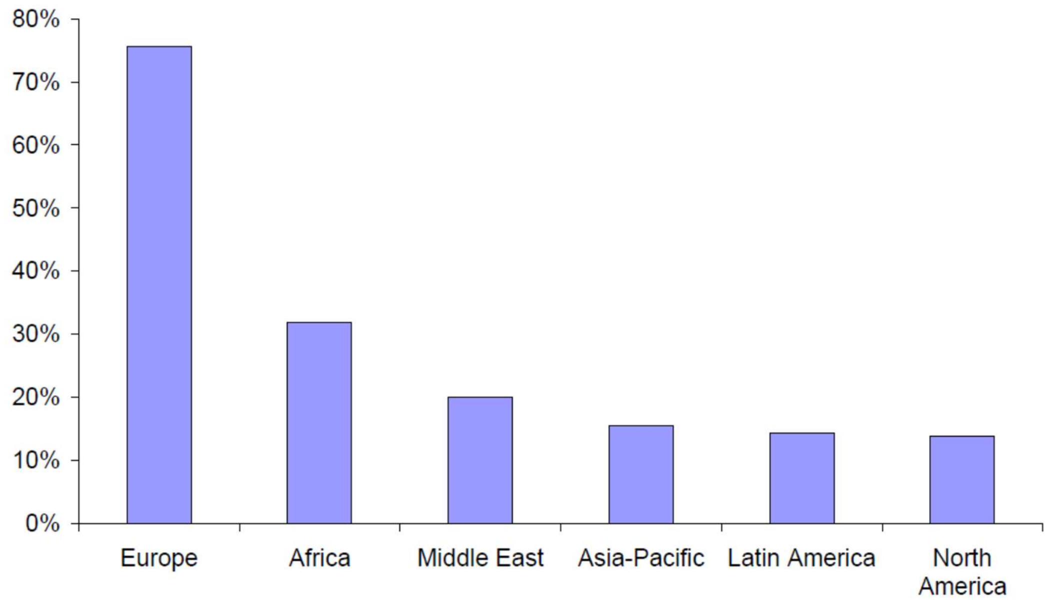


Source: IATA 2010

**Figure 4.4**. Proportion of airlines operations affected by the eruption of Eyjafjallajökull volcano during April 2010

A 90% reduction of traffic for five consecutive days in April was recorded for Finland, the UK and Ireland (**Table 4.2 and Table 4.3**), while Icelandic traffic was affected for 13 days rather than 8 days seen elsewhere. Finland was the worst affected country (81% loss of flights), even compared with Iceland, as Iceland maintained some flights to north America. With respect to Finland, it should be noted that the closures continued there up to the 22nd of April. The overall loss of flights for UK and Ireland was 74% as they recovered more quickly from the 21st of April. Malta and Greece saw the lowest flights reduction (16% and 19% respectively).

The airports most affected in April naturally correspond to the most affected States: Helsinki, Dublin, Manchester and Edinburgh all had less than 25% of the expected number of flights over the 8-day period (15.04 – 22.04).

**Table 4.2**. Estimated cancellations per state (defined using airspace structure) and day during April 2010 (source: https://www.eurocontrol.int/sites/default/files/article/attachments/201004-ash-impact-on-traffic.pdf)

| | 15-Apr | 16-Apr | 17-Apr | 18-Apr | 19-Apr | 20-Apr | 21-Apr | 22-Apr | TOTAL |
|---|---|---|---|---|---|---|---|---|---|
| Albania | 17% | 43% | 68% | 77% | 31% | 14% | 0% | 0% | **34%** |
| Austria | 15% | 61% | 98% | 99% | 76% | 53% | 21% | 0% | **52%** |
| Belarus | 0% | 63% | 86% | 83% | 61% | 23% | 14% | 0% | **42%** |

| | 15-Apr | 16-Apr | 17-Apr | 18-Apr | 19-Apr | 20-Apr | 21-Apr | 22-Apr | TOTAL |
|---|---|---|---|---|---|---|---|---|---|
| Belgium / Luxemburg | 39% | 96% | 98% | 98% | 97% | 72% | 25% | 0% | **65%** |
| Bosnia - Herzegovina | 18% | 33% | 91% | 97% | 67% | 31% | 0% | 0% | **43%** |
| Bulgaria | 21% | 61% | 88% | 96% | 68% | 38% | 0% | 0% | **47%** |
| Canary Islands | 25% | 34% | 55% | 45% | 23% | 1% | 0% | 0% | **25%** |
| Croatia | 20% | 40% | 92% | 95% | 68% | 39% | 0% | 0% | **45%** |
| Cyprus | 9% | 29% | 46% | 44% | 28% | 11% | 0% | 0% | **21%** |
| Czech Republic | 12% | 87% | 98% | 98% | 89% | 66% | 28% | 6% | **60%** |
| Denmark | 60% | 87% | 99% | 99% | 97% | 91% | 40% | 16% | **72%** |
| Estonia | 24% | 95% | 97% | 99% | 96% | 83% | 46% | 19% | **68%** |
| FYROM | 16% | 49% | 86% | 91% | 69% | 30% | 6% | 0% | **45%** |
| Finland | 39% | 90% | 98% | 100% | 93% | 96% | 82% | 64% | **81%** |
| France | 20% | 67% | 87% | 92% | 77% | 54% | 16% | 0% | **51%** |
| Germany | 20% | 84% | 98% | 99% | 96% | 81% | 40% | 2% | **64%** |
| Greece | 11% | 32% | 47% | 42% | 12% | 0% | 0% | 0% | **19%** |
| Hungary | 15% | 66% | 98% | 98% | 79% | 54% | 16% | 3% | **53%** |
| Ireland | 54% | 94% | 98% | 100% | 100% | 90% | 48% | 8% | **74%** |
| Italy | 9% | 30% | 74% | 77% | 59% | 26% | 6% | 0% | **35%** |
| Latvia | 23% | 95% | 97% | 98% | 93% | 75% | 36% | 7% | **65%** |
| Lisbon FIR | 25% | 40% | 56% | 46% | 32% | 0% | 0% | 0% | **26%** |
| Lithuania | 8% | 87% | 90% | 91% | 81% | 61% | 25% | 0% | **55%** |
| Malta | 11% | 32% | 39% | 28% | 13% | 0% | 0% | 0% | **16%** |
| Moldova | 17% | 50% | 95% | 92% | 80% | 43% | 17% | 14% | **51%** |
| Netherlands | 53% | 96% | 98% | 99% | 98% | 75% | 33% | 1% | **68%** |
| Norway | 92% | 73% | 92% | 77% | 44% | 50% | 15% | 34% | **57%** |
| Poland | 10% | 88% | 97% | 95% | 89% | 76% | 31% | 2% | **60%** |
| Romania | 12% | 52% | 94% | 97% | 81% | 42% | 12% | 1% | **48%** |
| Santa Maria FIR | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | **0%** |
| Serbia & Montenegro | 18% | 48% | 92% | 97% | 68% | 39% | 0% | 0% | **47%** |
| Slovakia | 17% | 77% | 98% | 97% | 78% | 48% | 13% | 0% | **53%** |
| Slovenia | 20% | 55% | 97% | 99% | 70% | 51% | 9% | 0% | **50%** |
| Spain | 18% | 39% | 59% | 66% | 37% | 16% | 0% | 0% | **30%** |
| Sweden | 54% | 84% | 99% | 99% | 83% | 80% | 57% | 32% | **71%** |
| Switzerland | 13% | 64% | 98% | 98% | 94% | 61% | 23% | 2% | **56%** |
| Turkey | 13% | 39% | 51% | 50% | 31% | 23% | 0% | 0% | **26%** |
| Ukraine | 7% | 38% | 80% | 81% | 48% | 25% | 13% | 4% | **38%** |
| UK | 74% | 95% | 99% | 99% | 99% | 93% | 38% | 6% | **74%** |
| EU27 | 27% | 62% | 80% | 83% | 72% | 56% | 25% | 5% | **50%** |
| ESRA08 | 28% | 60% | 77% | 80% | 68% | 53% | 23% | 6% | **48%** |

**Table 4.3**. Actual flights and estimated cancelled flights per state (defined using airspace structure) and day during April 2010, excluding overflights that pass through the airspace but do not depart or arrive a local airport (source: https://www.eurocontrol.int/sites/default/files/article/attachments/201004-ash-impact-on-traffic.pdf)

| | | 15-Apr | 16-Apr | 17-Apr | 18-Apr | 19-Apr | 20-Apr | 21-Apr | 22-Apr | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|
| Albania | Actual Flights | 46 | 54 | 13 | 6 | 25 | 30 | 54 | 49 | **277** |
| | Estimated Cancelled Flights | 4 | 6 | 40 | 52 | 35 | 15 | 10 | 1 | **163** |
| Austria | Actual Flights | 939 | 496 | 15 | 11 | 530 | 714 | 897 | 1,016 | **4,618** |
| | Estimated Cancelled Flights | 122 | 582 | 795 | 884 | 455 | 232 | 133 | 45 | **3,248** |
| Belarus | Actual Flights | 44 | 26 | 11 | 16 | 22 | 33 | 39 | 43 | **234** |
| | Estimated Cancelled Flights | 1 | 20 | 31 | 22 | 16 | 13 | 7 | 2 | **112** |
| Belgium/Luxemburg | Actual Flights | 667 | 42 | 19 | 29 | 42 | 406 | 897 | 1,211 | **3,313** |
| | Estimated Cancelled Flights | 463 | 1,063 | 797 | 909 | 1,063 | 712 | 229 | -81 | **5,154** |
| Bosnia-Herzegovina | Actual Flights | 35 | 30 | 4 | 1 | 19 | 21 | 39 | 47 | **196** |
| | Estimated Cancelled Flights | 6 | 9 | 22 | 27 | 20 | 21 | 2 | -6 | **101** |
| Bulgaria | Actual Flights | 137 | 108 | 42 | 24 | 78 | 108 | 152 | 143 | **792** |
| | Estimated Cancelled Flights | 19 | 68 | 70 | 115 | 79 | 32 | 10 | 13 | **405** |
| Canary Islands | Actual Flights | 396 | 463 | 361 | 387 | 503 | 579 | 817 | 703 | **4,209** |
| | Estimated Cancelled Flights | 160 | 269 | 516 | 326 | 132 | -23 | -221 | -147 | **1,012** |
| Croatia | Actual Flights | 163 | 132 | 21 | 33 | 74 | 99 | 119 | 182 | **823** |
| | Estimated Cancelled Flights | 38 | 59 | 175 | 139 | 95 | 68 | 51 | 19 | **645** |
| Cyprus | Actual Flights | 141 | 108 | 78 | 92 | 110 | 105 | 180 | 183 | **997** |
| | Estimated Cancelled Flights | 17 | 61 | 103 | 90 | 78 | 44 | 28 | -25 | **397** |
| Czech Republic | Actual Flights | 480 | 124 | 10 | 7 | 109 | 223 | 380 | 512 | **1,845** |
| | Estimated Cancelled Flights | 46 | 371 | 351 | 433 | 392 | 233 | 97 | 14 | **1,937** |
| Denmark | Actual Flights | 465 | 138 | 2 | 1 | 4 | 14 | 636 | 794 | **2,054** |
| | Estimated Cancelled Flights | 540 | 757 | 604 | 748 | 957 | 922 | 327 | 211 | **5,065** |
| Estonia | Actual Flights | 87 | 11 | 0 | 0 | 4 | 18 | 75 | 111 | **306** |

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| | | 15-Apr | 16-Apr | 17-Apr | 18-Apr | 19-Apr | 20-Apr | 21-Apr | 22-Apr | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|
| | Estimated Cancelled Flights | 25 | 99 | 59 | 82 | 89 | 70 | 14 | 1 | **438** |
| FYROM | Actual Flights | 32 | 29 | 5 | 12 | 16 | 24 | 30 | 35 | **183** |
| | Estimated Cancelled Flights | 2 | 3 | 20 | 18 | 13 | 3 | 2 | -1 | **59** |
| Finland | Actual Flights | 460 | 57 | 4 | 2 | 31 | 3 | 77 | 182 | **816** |
| | Estimated Cancelled Flights | 211 | 566 | 398 | 492 | 628 | 653 | 612 | 489 | **4,047** |
| France | Actual Flights | 4,039 | 1,554 | 559 | 286 | 1,020 | 1,854 | 3,388 | 4,585 | **17,285** |
| | Estimated Cancelled Flights | 606 | 3,108 | 3,147 | 3,777 | 3,352 | 2,408 | 992 | 60 | **17,450** |
| Germany | Actual Flights | 5,095 | 1,043 | 68 | 69 | 214 | 1,011 | 3,168 | 5,590 | **16,258** |
| | Estimated Cancelled Flights | 706 | 4,867 | 4,431 | 4,793 | 5,525 | 4,792 | 2,772 | 211 | **28,098** |
| Greece | Actual Flights | 733 | 632 | 517 | 546 | 653 | 721 | 789 | 817 | **5,408** |
| | Estimated Cancelled Flights | 66 | 217 | 281 | 251 | 142 | 17 | -25 | -18 | **930** |
| Hungary | Actual Flights | 306 | 124 | 11 | 20 | 72 | 141 | 248 | 324 | **1,246** |
| | Estimated Cancelled Flights | 30 | 213 | 237 | 264 | 254 | 181 | 104 | 12 | **1,293** |
| Ireland | Actual Flights | 161 | 75 | 19 | 2 | 2 | 21 | 228 | 536 | **1,044** |
| | Estimated Cancelled Flights | 491 | 601 | 552 | 631 | 634 | 557 | 400 | 116 | **3,983** |
| Italy | Actual Flights | 3,173 | 2,600 | 761 | 738 | 1,114 | 1,936 | 2,733 | 3,277 | **16,332** |
| | Estimated Cancelled Flights | 260 | 915 | 2,188 | 2,403 | 2,415 | 1,357 | 687 | 156 | **10,380** |
| Latvia | Actual Flights | 149 | 7 | 1 | 0 | 2 | 49 | 122 | 174 | **504** |
| | Estimated Cancelled Flights | 34 | 196 | 146 | 172 | 186 | 125 | 46 | 9 | **914** |
| Lisbon FIR | Actual Flights | 524 | 433 | 304 | 321 | 430 | 465 | 723 | 757 | **3,957** |
| | Estimated Cancelled Flights | 190 | 286 | 411 | 398 | 292 | 175 | -62 | -43 | **1,647** |
| Lithuania | Actual Flights | 106 | 16 | 5 | 7 | 30 | 45 | 92 | 123 | **424** |
| | Estimated Cancelled Flights | 14 | 103 | 80 | 89 | 80 | 71 | 26 | -3 | **459** |
| Malta | Actual Flights | 82 | 60 | 40 | 46 | 63 | 67 | 79 | 112 | **549** |
| | Estimated Cancelled Flights | 15 | 26 | 60 | 53 | 15 | 25 | -2 | -15 | **178** |

| | | 15-Apr | 16-Apr | 17-Apr | 18-Apr | 19-Apr | 20-Apr | 21-Apr | 22-Apr | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|
| Moldova | Actual Flights | 37 | 33 | 0 | 2 | 1 | 27 | 29 | 34 | **163** |
| | Estimated Cancelled Flights | -6 | 6 | 32 | 28 | 36 | 10 | 6 | -3 | **109** |
| Netherlands | Actual Flights | 791 | 38 | 31 | 18 | 26 | 531 | 1,125 | 1,460 | **4,020** |
| | Estimated Cancelled Flights | 687 | 1,432 | 1,134 | 1,235 | 1,400 | 912 | 387 | 18 | **7,205** |
| Norway | Actual Flights | 136 | 461 | 64 | 283 | 936 | 838 | 1,401 | 1,097 | **5,216** |
| | Estimated Cancelled Flights | 1,527 | 1,180 | 737 | 885 | 693 | 815 | 229 | 566 | **6,632** |
| Poland | Actual Flights | 661 | 88 | 8 | 28 | 24 | 26 | 494 | 766 | **2,095** |
| | Estimated Cancelled Flights | 131 | 713 | 556 | 584 | 758 | 727 | 326 | 26 | **3,820** |
| Romania | Actual Flights | 462 | 354 | 26 | 6 | 93 | 278 | 404 | 458 | **2,081** |
| | Estimated Cancelled Flights | 6 | 107 | 299 | 314 | 369 | 163 | 80 | 10 | **1,347** |
| Santa Maria FIR | Actual Flights | 72 | 97 | 90 | 86 | 116 | 149 | 151 | 99 | **860** |
| | Estimated Cancelled Flights | 5 | -17 | -19 | -18 | -45 | -85 | -80 | -22 | **-281** |
| Serbia & Montenegro | Actual Flights | 202 | 168 | 32 | 15 | 95 | 117 | 162 | 188 | **979** |
| | Estimated Cancelled Flights | -25 | 24 | 148 | 166 | 82 | 59 | 36 | -11 | **479** |
| Slovakia | Actual Flights | 93 | 41 | 1 | 1 | 36 | 72 | 69 | 109 | **422** |
| | Estimated Cancelled Flights | 8 | 43 | 46 | 57 | 53 | 20 | 18 | -8 | **236** |
| Slovenia | Actual Flights | 49 | 45 | 0 | 1 | 27 | 20 | 60 | 113 | **315** |
| | Estimated Cancelled Flights | 30 | 39 | 56 | 60 | 48 | 47 | 16 | -34 | **263** |
| Spain | Actual Flights | 3,017 | 2,367 | 1,570 | 1,247 | 2,338 | 2,743 | 3,324 | 3,684 | **20,290** |
| | Estimated Cancelled Flights | 582 | 1,276 | 1,683 | 2,130 | 1,188 | 700 | 154 | -85 | **7,627** |
| Sweden | Actual Flights | 656 | 228 | 6 | 8 | 297 | 295 | 460 | 806 | **2,756** |
| | Estimated Cancelled Flights | 725 | 916 | 536 | 853 | 1,035 | 1,022 | 900 | 575 | **6,562** |
| Switzerland | Actual Flights | 1,142 | 673 | 24 | 22 | 28 | 500 | 1,010 | 1,269 | **4,668** |
| | Estimated Cancelled Flights | 159 | 638 | 1,177 | 1,224 | 1,244 | 721 | 276 | 32 | **5,472** |
| Turkey | Actual Flights | 1,442 | 1,165 | 907 | 990 | 1,214 | 1,236 | 1,578 | 1,660 | **10,192** |

| | | 15-Apr | 16-Apr | 17-Apr | 18-Apr | 19-Apr | 20-Apr | 21-Apr | 22-Apr | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|
| | Estimated Cancelled Flights | 162 | 512 | 617 | 663 | 277 | 252 | -97 | -56 | **2,330** |
| Ukraine | Actual Flights | 415 | 326 | 78 | 109 | 264 | 341 | 401 | 420 | **2,354** |
| | Estimated Cancelled Flights | -1 | 124 | 295 | 273 | 120 | 27 | 8 | -6 | **840** |
| UK | Actual Flights | 1,292 | 283 | 69 | 56 | 46 | 282 | 3,418 | 5,356 | **10,802** |
| | Estimated Cancelled Flights | 4,300 | 5,323 | 4,408 | 4,862 | 5,449 | 5,103 | 2,041 | 236 | **31,724** |
| EU27 | Actual Flights | 18,695 | 9,285 | 3,874 | 3,399 | 6,698 | 10,512 | 18,718 | 24,353 | **95,534** |
| | Estimated Cancelled Flights | 7,014 | 16,409 | 16,311 | 18,640 | 18,441 | 14,091 | 6,548 | 1,356 | **98,809** |
| ESRA08 | Actual Flights | 20,247 | 11,109 | 4,793 | 4,639 | 8,727 | 12,476 | 21,232 | 26,571 | **109,794** |
| | Estimated Cancelled Flights | 8,128 | 17,171 | 17,170 | 19,534 | 18,921 | 14,647 | 6,564 | 1,804 | **103,940** |
| Total based on | Actual Flights | 28,927 | 14,729 | 5,776 | 5,528 | 10,708 | 16,142 | 30,048 | 39,025 | **150,883** |
| national data | Estimated Cancelled Flights | 12,356 | 26,781 | 27,219 | 30,484 | 29,654 | 23,196 | 10,539 | 2,258 | **162,480** |

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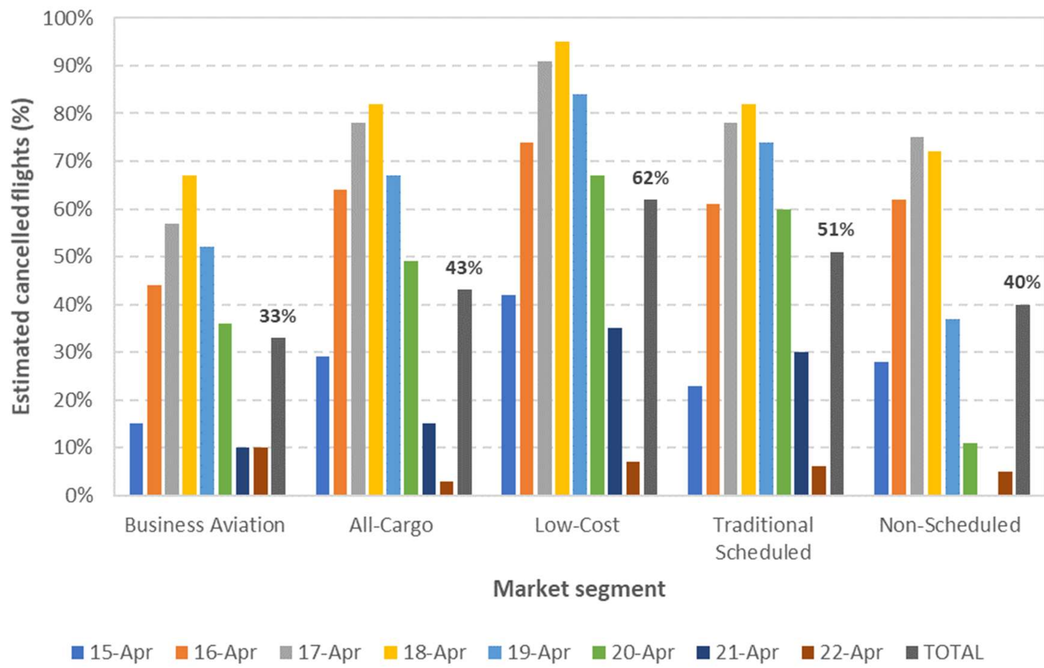
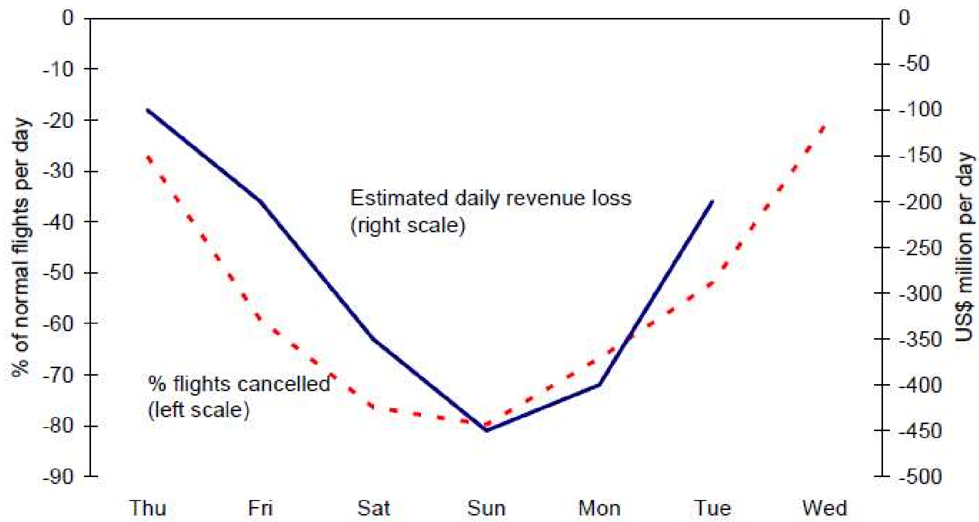
The impacts of the volcano eruption varied among the different aviation market segments: business aviation; all cargo; low cost; traditional scheduled; non – scheduled (charter flights). Traditional scheduled flights accounted for about 58% of the cancelled flights, but it is the low-cost market segment that was the worst affected market as cancelled flights accounted for 62% of total low-cost flights scheduled (**Figure 4.5**). According to EUROCONTROL (2010) this could be attributed to geographical exposure (as there were many low - cost flights in Ireland and the UK), traffic covered (mainly short-haul that recovered less-quickly compared to long-haul) and a less flexible business model. On the contrary, the least reductions happened to business aviation (34%) as it was easier to adapt in the changing circumstances and make use of the available open airspace.




Source: https://www.eurocontrol.int/sites/default/files/article/attachments/201004-ash-impact-on-traffic.pdf

**Figure 4.5**. Cancelled flights per aviation market segment and day during the 8-day period of April 2010

A total of 104,000 flights cancelled in ESRA08 area during the 8-day period 15.04 – 22.04 of April 2010 following the main summit eruption of the of the Eyjafjallajökull volcano in Iceland. According to IATA (2010) its members saw revenues losses of about $1.7 billion. Revenues losses vary from day to day (**Figure 4.6**), in line with airspace closure and reached a maximum value of $418 million on the 19$^{th}$ of April. **Table 4.4** presents more details on revenue losses per country-pair routes for the traditional scheduled market segment (passenger transport) on the 19$^{th}$ of April 2010. The route UK – US was the most affected, accounting for 8% of revenue losses and 3% of passengers affected at that day.




Source: https://www.eurocontrol.int/sites/default/files/article/attachments/201004-ash-impact-on-traffic.pdf

**Figure 4.6**. Cancelled flights per aviation market segment and day during the 8-day period of April 2010

**Table 4.4**. Revenues losses for IATA members and passengers affected on the 19th of April 2010 (source: IATA 2010)

| April 19, 2010 | Passengers | | Revenue | |
|---|---|---|---|---|
| **Country pairs** | **Number** | **% total** | **$US million** | **% total** |
| United Kingdom - United States | 37,018 | 3.0% | 24.9 | 8.0% |
| France - France | 47,200 | 3.8% | 8.7 | 2.8% |
| Germany - United States | 20,681 | 1.7% | 7.7 | 2.5% |
| France - United States | 13,474 | 1.1% | 7.4 | 2.4% |
| United Kingdom - United Kingdom | 63,054 | 5.0% | 6.3 | 2.0% |
| Germany - Germany | 55,589 | 4.5% | 5.5 | 1.8% |
| United Kingdom - Australia | 4,802 | 0.4% | 4.6 | 1.5% |
| France - Japan | 3,084 | 0.2% | 4.3 | 1.4% |
| Switzerland - United States | 4,652 | 0.4% | 3.6 | 1.2% |
| Netherlands - United States | 7,000 | 0.6% | 3.4 | 1.1% |
| Germany - Japan | 2,284 | 0.2% | 3.3 | 1.1% |
| Ireland - United States | 5,501 | 0.4% | 2.9 | 0.9% |
| United Kingdom - Canada | 5,024 | 0.4% | 2.8 | 0.9% |
| United Kingdom - Japan | 1,902 | 0.2% | 2.7 | 0.9% |
| United Kingdom - South Africa | 3,840 | 0.3% | 2.6 | 0.9% |
| United Kingdom - United Arab Emirates | 4,796 | 0.4% | 2.6 | 0.8% |
| United Kingdom - Hong Kong | 3,256 | 0.3% | 2.6 | 0.8% |
| United Kingdom - India | 7,508 | 0.6% | 2.5 | 0.8% |
| United Kingdom - Singapore | 2,102 | 0.2% | 2.0 | 0.7% |
| France - Morocco | 10,236 | 0.8% | 1.9 | 0.6% |
| Other affected routes | 946,078 | 75.7% | 208 | 67.1% |
| Total | 1,249,083 | 100.0% | 310 | 100.0% |
| Ancillary revenues | | | 31 | |
| Cargo revenues | | | 47 | |
| Expected 2010 growth | | | 30 | |
| **TOTAL** | | | **418** | |

On the basis of the information presented above for the 19th of April, revenues losses per flight (as estimated by national data) are estimated at $14,100, while on average (i.e. for the 8-day period), revenues losses per flight are estimated at $10,500.

## 4.3 The ACTRIS scenario

In the context of this study, the NO ACTRIS scenario presented in the previous section is comparatively evaluated to the so-called ACTRIS scenario, which examines differences in the management of the Eyjafjallajökull volcano crisis if decision-makers could utilize the information provided by ACTRIS research infrastructure with the knowledge and the methodologies nowadays available. Specifically, the ACTRIS scenario is based on specific assumptions and simplifications, which are presented below, and outlines indicatively how the situation as regards air transport could would have been evolved if the environmental information that could be provided by the research infrastructure in question had been exploited. It is noteworthy that this analysis is indicative and aims to show a practical implementation of the methodological framework presented in Chapter 3, as well as to give a rough approximation of the magnitude of benefits that could be attributed to ACTRIS RI from its exploitation in the specific case study.

In this context, it is considered that the competent authorities across Europe were experienced in dealing with such a crisis and that the thresholds as regards ash concentrations in the atmosphere to impose air traffic restrictions (officially adopted in 2016) were already in place. Specifically, for the quantitative analysis of this case study it is assumed that no-fly zones are established in areas where Volcanic Ash Mass Concentration is greater than 2,000 μg/$m^3$ following the ICAO regulation for European and North Atlantic regions[2].

The analysis makes use of the volcanic aerosol measurements from the ACTRIS research infrastructure that are available for the reference period (i.e., April – May 2010) (Pappalardo et al., 2013). The ACTRIS lidar component provided the aerosol mask for the April-May 2010 period using an integrated observations/models approach (Mona et al., 2012) and the aerosol optical properties for the volcanic layers in a specific relational database available at www.earlinet.org. In particular, the volcanic aerosol backscatter value was recorded with 1-hour resolution whenever possible. From this quantity, volcanic ash concentration is estimated through an assumption on the extinction to backscatter ratio and on the mass specific extinction coefficient (Ansmann et al., 2012).

However, it should be noted that these measurements did not cover all regions of Europe, and there were no data available yet for some northern European countries (e.g., the United Kingdom, Sweden, Belgium, Finland) that were significantly affected during the crisis due to their proximity to the Eyjafjallajökull volcano. Specifically, lidar measurements of the ash concentrations from the ACTRIS research infrastructure in the period April - May 2010 were available for 13 European countries, namely Norway, Greece, Spain, Poland, Romania, Netherlands, Ireland, Portugal, Germany, Italy, Belarus, France, and Switzerland. Even for these countries, the weather conditions were characterized by the presence of low clouds around Europe, so that even if measurements were planned as continuous at all the lidar stations, the result was that the available measurements were not continuous, did not cover all days, and in some cases within the day data could only be available for some hours. Especially in May 2010, available measurements for the dates that the phenomenon intensified were extremely limited, and so the ACTRIS scenario was developed only for the period April 15-22, 2010.

Based on the data presented by EUROCONTROL (2010) as regards the number of flights cancelled in each country due to the management measures implemented to deal with the Eyjafjallajökull crisis in 2010, the European countries can be distinguished in:

[2] https://www.icao.int/EURNAT/EUR%20and%20NAT%20Documents/EUR+NAT%20VACP.pdf

- Countries directly affected if more than 80% of scheduled flights were cancelled, even for one day during the reference period. In those countries it is considered that the airspace was closed at least for some time during 15-22 April 2010.
- Countries indirectly affected, where the number of flight cancellations did not exceed 80% of the total number of scheduled flights, any day during the crisis. For these countries it is assumed that their airspace was open, and any flight cancellations can be attributed to the inability to land in the country of destination.

In total 9 out of the 13 European countries for which measurements from the ACTRIS research infrastructure were available in the reference period, were found to be directly affected by Eyjafjallajökull volcanic eruption, namely Norway, Poland, Romania, the Netherlands, Ireland, Germany, Belarus, Switzerland, and France. On the contrary, Greece, Spain, Portugal, and Italy are considered to be only indirectly affected. Among the countries directly affected, a sufficient number of measurements in the period 15-22 April 2010 were available only for Poland, the Netherlands, Germany, Belarus, Switzerland, and France (**Table 4.5**), so the ACTRIS scenario was initially developed only for those countries and for the days that measurements from the ACTRIS research infrastructure were available.

**Table 4.5.** Availability of ash concentration measurements from ACTRIS RI in directly affected countries during the Eyjafjallajökull volcano eruption in April 2010.

| | | Dates of measurements | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Country** | **Station** | 15APR | 16APR | 17APR | 18APR | 19APR | 20APR | 21APR | 22APR |
| Norway | Andenes | | | | | | | | |
| Poland | Belsk | | | | | | | | |
| Romania | Bucharest | | | | | | | | |
| Netherlands | Cabauw | | | | | | | | |
| Ireland | Cork | | | | | | | | |
| Germany | Hamburg | | | | | | | | |
| | Leipzig | | | | | | | | |
| | Munich | | | | | | | | |
| Belarus | Minsk | | | | | | | | |
| Switzerland | Neuchatel | | | | | | | | |
| | Payerne | | | | | | | | |
| France | Palaiseau | | | | | | | | |

For each of the countries directly affected by the volcanic eruption and for each day of the reference period for which measurements from ACTRIS RI were available, the maximum ash concentrations recorded per day were identified (**Table 4.6**). As none of those countries had an extensive lidar network installed in the reference period (the maximum number of available lidar systems was three in Germany) and in many cases the measurements were not continuous during the day, the aforementioned maximum ash concentrations were increased by 50% in order to have a conservative estimate of the potential maximum concentration that could be recorded on the corresponding day in the country under consideration. As clearly depicted in Table 4.6, the modified maximum concentrations of ash exceed the threshold of 2,000 μg/m$^3$, one day in Switzerland (April 18, 2010) and three days in Germany (16-18 April 2010).

**Table 4.6.** Maximum concentrations of ash measured by ACTRIS RI each day of the period 15-22 April 2010 in the European countries directly affected by Eyjafjallajökull volcanic eruption (in μg/m$^3$).

| Country | Ash concentrations | Dates of measurements | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 15APR | 16APR | 17APR | 18APR | 19APR | 20APR | 21APR | 22APR |
| Poland | Daily max | | 108.0 | 30.5 | 15.5 | | 9.2 | 14.5 | |
| | Modified max | | 161.9 | 45.7 | 23.3 | | 13.8 | 21.7 | |
| Netherlands | Daily max | | 936.2 | 336.5 | 744.2 | 251.3 | 252.9 | 130.7 | 245.3 |
| | Modified max | | 1404.3 | 504.8 | 1116.3 | 376.9 | 379.3 | 196.0 | 368.0 |
| Germany | Daily max | | 2442.5 | 1433.6 | 1354.0 | 1219.4 | 690.8 | 999.2 | 861.1 |
| | Modified max | | 3663.7 | 2150.4 | 2031.0 | 1829.0 | 1036.2 | 1498.8 | 1291.6 |
| Belarus | Daily max | | 18.1 | 124.1 | | 24.1 | 31.7 | 42.1 | |
| | Modified max | | 27.2 | 186.2 | | 36.2 | 47.5 | 63.2 | |
| Switzerland | Daily max | 17.3 | 78.8 | 261.3 | 1574.0 | 103.6 | | | |
| | Modified max | 26.0 | 118.1 | 391.9 | 2361.0 | 155.4 | | | |
| France | Daily max | | 218.6 | 460.9 | 405.8 | 85.4 | 113.3 | 79.6 | 74.0 |
| | Modified max | | 327.8 | 691.3 | 608.7 | 128.2 | 170.0 | 119.3 | 111.0 |

In the context of the ACTRIS scenario, for the countries directly affected by the volcanic eruption the number of cancelled flights was re-estimated for the period 15-22 April 2010, based on the following assumptions:

- For days where measurements were not available from the ACTRIS research infrastructure, the number of cancelled flights in the respective countries was assumed to be identical to the NO ACTRIS scenario.
- For a day where the modified maximum concentration of ash in a country exceeds the threshold of 2,000 μg/m$^3$, it is considered that the airspace of that country should remain closed and therefore the number of cancelled flights is identical to the NO ACTRIS scenario.
- For a day where the modified maximum concentration of ash in a country does not exceed the threshold of 2,000 μg/m$^3$, it is considered that the airspace of that country remains open, although some flights might have been cancelled. Specifically, it is considered that all flights to destinations outside Europe can be realized, even if a partial modification of the route followed is required. For flights within Europe (including domestic flights) it is assumed that approximately 40-80% of the number of scheduled flights could be realized. Specifically, if one day the modified maximum concentrations of ash did not exceed the predefined threshold in any of the countries directly affected by the volcanic eruption, then it is assumed that in that particular day the 80% of the flights within Europe could have been operated properly. On the contrary, if at least in one

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of the directly affected countries, the modified maximum concentration of ash had exceeded the predefined threshold one day, then it is considered that in all other directly affected countries in which concentrations do not exceed the threshold, only the 40% of the flights within Europe could have been implemented in this particular day.

In the context of the ACTRIS scenario the number of cancelled flights for the six directly affected countries where measurements were available was re-calculated based on the above assumptions, and the results are presented in **Table 4.7**. Based on these assumptions, it seems that using ACTRIS measurements the number of cancelled flights in these countries could had been reduced by 48%. In other words, about 30,000 flights would not had been cancelled in six European countries during the period 15-22 April 2010 if the available measurements of ACTRIS RI could be utilized.

**Table 4.7.** Estimated number of cancelled flights in the directly affected countries by Eyjafjallajökull volcanic eruption the period 15-22 April 2010 according to the NO ACTRIS and ACTRIS scenarios.

| Country | Scenarios | Number of flights cancelled | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 15APR | 16APR | 17APR | 18APR | 19APR | 20APR | 21APR | 22APR | Total |
| Poland | NO ACTRIS | 131 | 713 | 556 | 584 | 758 | 727 | 326 | 26 | 3821 |
| | ACTRIS | 131 | 356 | 264 | 280 | 758 | 133 | 65 | 26 | 2013 |
| Netherlands | NO ACTRIS | 687 | 1432 | 1134 | 1235 | 1400 | 912 | 387 | 18 | 7205 |
| | ACTRIS | 687 | 716 | 538 | 593 | 242 | 166 | 77 | 4 | 3023 |
| Germany | NO ACTRIS | 706 | 4867 | 4431 | 4793 | 5525 | 4792 | 2772 | 211 | 28097 |
| | ACTRIS | 706 | 4867 | 4431 | 4793 | 956 | 874 | 550 | 49 | 17226 |
| Belarus | NO ACTRIS | 1 | 20 | 31 | 22 | 16 | 13 | 7 | 2 | 112 |
| | ACTRIS | 1 | 10 | 15 | 22 | 3 | 2 | 1 | 2 | 56 |
| Switzerland | NO ACTRIS | 159 | 638 | 1177 | 1224 | 1244 | 721 | 276 | 32 | 5471 |
| | ACTRIS | 29 | 319 | 558 | 1224 | 215 | 721 | 276 | 32 | 3374 |
| France | NO ACTRIS | 606 | 3108 | 3147 | 3777 | 3352 | 2408 | 992 | 60 | 17450 |
| | ACTRIS | 606 | 1554 | 1492 | 1813 | 580 | 439 | 197 | 14 | 6695 |
| Sub-total | NO ACTRIS | 2290 | 10778 | 10476 | 11635 | 12295 | 9573 | 4760 | 349 | 62156 |
| | ACTRIS | 2160 | 7822 | 7298 | 8725 | 2754 | 2335 | 1166 | 127 | 32387 |

The total number of flights cancelled in the period under consideration in all European countries directly affected by volcano eruption was estimated at 137,257 (EUROCONTROL, 2010). Consequently, the utilization of ACTRIS measurements in six countries could contribute in reducing the number of cancelled flights by 21.7%.

Reductions in the number of flights cancelled would also occur in the countries indirectly affected by the volcano eruption, as some of the airports in destination countries would be in operation in the reference period due to the utilization of the measurements provided by ACTRIS research infrastructure. A rough

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approximation of the number of cancelled flights in the countries affected indirectly, for the ACTRIS scenario, could be made assuming that the number of cancelled flights in these countries was reduced by the same percentage as calculated for all directly affected countries in the context of the ACTRIS scenario, regardless of the availability of ACTRIS measurements. EUROCONTROL (2010) estimates that in countries that were indirectly affected by the volcanic eruption from 15 to 22 April 2010, approximately 25,223 flights were cancelled (NO ACTRIS scenario). Based on these assumptions, it was estimated that approximately 5,473 flights could not be cancelled.

A total of 35,512 cancelled flights could had been realized from 15 to 22 April 2010, if the available measurements of the ACTRIS research infrastructure had been used in decision making. The financial benefit of avoiding these cancellations is estimated at about \$ 373 million taking into account only the airlines' revenue losses.

## 4.4 Limitations of the analysis

This chapter presents a pilot case study to quantify the potential benefits attributed to products and services generated by ACTRIS research infrastructure and can be used in managing episodes of high air pollution, transport of desert dust, high concentrations of ash due to the volcanic eruptions, etc. Specifically, the eruption of the Eyjafjallajökull volcano in spring 2010 was analyzed, which caused huge problems in air travel in Europe and financial losses of billions of dollars. According to the results of the analysis, utilizing ACTRIS data in the European countries that had relevant data from lidar measurements by the competent authorities could lead to avoiding losses of at least \$ 373 million.

However, it is noteworthy that the analysis carried out is characterized by significant uncertainties and the estimated benefits of utilizing the ACTRIS research infrastructure should be considered as a rough approximation of the magnitude of benefits that may arise in corresponding case studies. It should be seen as a pilot application of the bottom-up methodology developed in the context of this Work Package, for the quantitative assessment of the societal benefits of the research infrastructure in question.

As the NO ACTRIS scenario presents how the crisis was handled in April - May 2010, based on several relevant published studies, the major uncertainties of this analysis concern the development of the ACTRIS scenario, which estimates the decline in number of flights cancelled due to the utilization of the environmental information provided by ACTRIS with the current knowledge and developed methodologies.

A first major source of uncertainty is related to the estimated number of flights whose cancellation could have been avoided. In the context of this study, this estimation was based on several assumptions and simplifications. However, a more precise approach would require a detailed simulation of ash concentrations in European airspace during the crisis, detailed mapping of scheduled flights to and from each country, and based on this data, country-by-country identification of possible flights that might not have been cancelled. In this context, for each country with ACTRIS data available, identifying the type of flights that could eventually not be cancelled and the destination country / airport would be of particular interest.

The analysis undertaken was based on the number of flights cancelled during the days of the period under consideration. However, no data were available to estimate the percentage of affected passengers who permanently cancelled their journey or traveled by another flight in the following hours or days. The extraordinary flights that took place over the next hours or days in order to carry passengers whose flights had been cancelled were taken into account in the development of the scenarios. However, possible changes in the completeness of the flights undertaken in the periods following the days with flights' cancellations were not taken into account. A more integrated development of the two scenarios examined, should include not only the number of flights performed or cancelled, but also number of passengers who eventually traveled normally, or with a delay or failed to travel at all.

The valuation of the economic benefits associated with the avoided cancellations of flights was based on an average estimate of the revenues per flight. A more detailed mapping of non-cancelled flights would help to differentiate these revenues by type of flight (i.e., to North America, within Europe, etc.), and to more accurately calculate the resulting benefits. In addition to the airlines, financial losses were also caused to other stakeholders such as airports, ground transport companies, etc., which should also be considered in detailed analysis. More generally, from such an event, it is obvious that the whole economy is affected. For analyzing these impacts on the economy and GDP, general equilibrium or input output models could provide quantitative estimates, which should be included in the whole assessment.

# 5. Concluding Remarks

The development and operation of ACTRIS RI is expected to create significant positive socio-economic effects to the society through several pathways:

- Enhancing the scientific research in various fields and thus resulting in the development of innovative methods, the improvement of existing methodological approaches and computational tools, etc., which in the long run can lead to concrete innovative products, and services that could be taken up and diffused in society.
- Enhancing the scientific communication and scientific education.
- Improving local infrastructure, urban planning and community services as well as creating positive effects to the local economy.
- Providing products and services to users outside the scientific community.

This deliverable aims to formulate a framework for analyzing the societal benefits associated with the utilization of ACTRIS products and services by users outside the scientific community, and in particular by local, regional, national and international authorities and organizations. Products and services of ACTRIS RI can support these entities for: (i) monitoring air quality at background level but also in areas affected by high levels of air pollutants due to technological accidents, unfavorable meteorological conditions, natural phenomena (e.g., volcano eruptions, desert dust transfer), etc.; (ii) increasing public awareness, knowledge and debate as regards the air quality and the potential impacts on public health and the environment; and (iii) contributing in the strategic design of appropriate policies and measures in the short- and/or long-run for tackling the negative impacts of air pollution, with a view to maximize social welfare.

The quantification of these societal benefits can be done either by top-down approaches using techniques based on environmental economics, or by detailed bottom-up approaches examining individual case studies and comparing a scenario where environmental information or other services provided by the ACTRIS RI are used for decision making, environmental planning, etc., in relation to a reference (or no ACTRIS) scenario where the information / services provided by ACTRIS would not be available. In the context of this study, it was considered that the implementation of top-down approaches to value the societal benefits of ACTRIS RI is premature and could be planned and implemented at a later stage (already foreseen in the ACTRIS-IMP program). Instead, emphasis was put on presenting a coherent framework whereby analyzing specific case studies can derive quantitative estimates of the societal benefits of the RI under consideration (bottom-up approach).

This framework was piloted in the case of Eyjafjallajökull volcano eruption in spring 2010, by examining how the research infrastructure under consideration could contribute to a more efficient management of air transport over the period of the phenomenon.

Although the ACTRIS RI provided the relevant authorities with some information on the volcano ash transport, this information was not sufficiently used in crisis management, leading to the cancellation of more than 100,000 flights the period 15-22 April 2010. At that time the ACTRIS RI was not ready for the provision in near real time of the needed information for managing such kind of crisis. Nowadays on the contrary, this information could be available, as demonstrated during the EUNADICS-AV exercise (Hirtl et al., 2019), thanks to the methodological and technological improvements achieved within ACTRIS. In this context, the effects (by means of flights cancelled, passengers and aviation market segments affected, costs, etc.) of the policy responses to the Eyjafjallajökull volcano eruption in 2010 could describe a NO ACTRIS scenario.

This NO ACTRIS scenario is comparatively evaluated to the so-called ACTRIS scenario, which examines differences in the management of the Eyjafjallajökull volcano crisis if decision-makers could utilize the information provided by ACTRIS research infrastructure. Specifically, the ACTRIS scenario is based on specific assumptions and simplifications and outlines indicatively how the situation as regards air transport could have been evolved if the environmental information that could be provided by the research infrastructure in question had been exploited. It is noteworthy that this analysis is indicative and aims to show a practical implementation of the methodological framework formulated.

According to the results of the analysis, a total of 35,512 cancelled flights could had been realized from 15th to 22th April 2010, if the available measurements of the ACTRIS research infrastructure had been used in decision making. The financial benefit of avoiding these cancellations is estimated at about $ 373 million taking into account only the airlines' revenue losses. However, it is noteworthy that the analysis carried out is characterized by significant uncertainties and the estimated benefits of utilizing the ACTRIS RI should be considered as a rough approximation of the magnitude of benefits that may arise in corresponding case studies.

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