IMPACTS OF THE EYJAFJALLAJöKULL VOLCANIC ERUPTION

Overview

- Introduction to the Icelandic volcano
- Volcanic Ash
  - Description of volcanic ash
  - Dangers to aircraft operations
- Description of the Eyjafjallajökull incident
  - Closure of European airspace
  - Impacts to airlines
  - Impacts to the economy
  - The Civil Aviation Authority's (CAA) response
- Discussion of the issues
  - The NAME dispersion model
  - Ash detection technology
    - Light Detection and Ranging – LIDAR
    - Satellite Imagery
    - Aerosonal detectors on UAVs, radiosondes, and dropsondes.
  - Ash concentration levels
- Conclusion

Eyjafjallajökull Volcano Eruption

- The volcano is located in Southern Iceland
- Eruption started on April 14, 2010.
- Eruption continued until May 23, 2010.
- Largest explosive eruption in Iceland since 1947.
  - Initial eruption was phreatomagmatic
    - Due to interactions between magma and water.
  - April 18th, eruption shifted to magmatic in nature
    - Due to decompression related to gas release.
  - Initial ash plume reached 12 km into the atmosphere
    - On April 18th, plumes started fluctuating between 2 & 5 km
    - On May 3rd, intensity increase cause plume to reach 9 km.
- Accord to Zehner, ash released had small grain size.

Properties of Volcanic Ash

- Looks like soft harmless powder
- Actually comprised of volcanic rocks and glass
- Irregular shape
- Sharp jagged edges
- Particles less than 2 mm in size
- Low density
- Extremely abrasive
- Capable of reaching temperatures in the near 700 Fahrenheit
- Capable of conducting electrical current

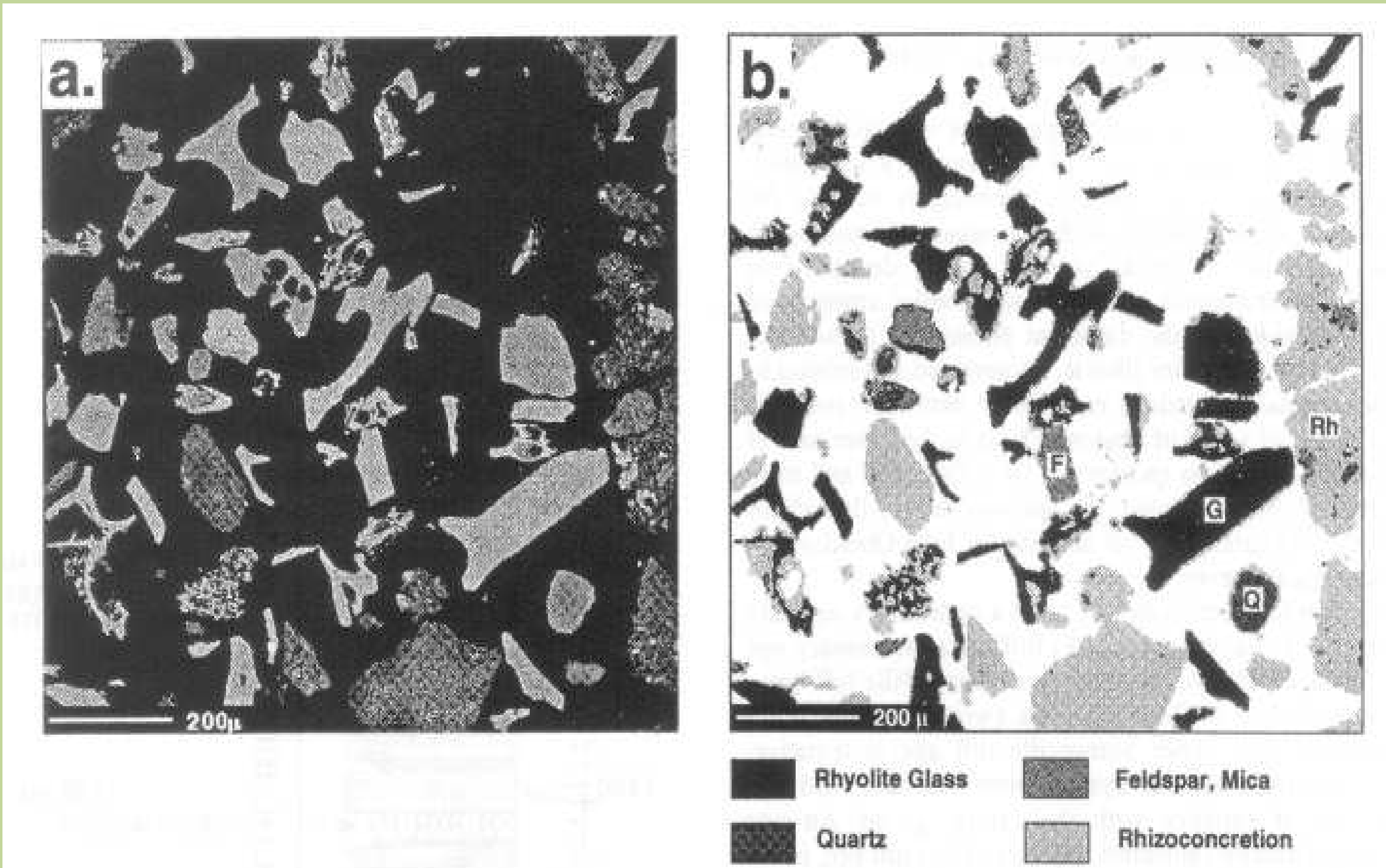

Figure 1. Volcanic ash composition.

Dangers of Volcanic Ash

- Ash Abrades External Components of Airplanes
  - Windshields
  - Navigation Light Lenses
  - Dented wings and stabilizers
- Ash Reduces Engine Performance and May Cause Engine Failure
  - Coats Fuel Nozzles
  - Plugs Cooling Holes
  - Erodes Moving Parts
  - Clogs sensors
  - Ash can turn to glass with in engine causing blockage
- Ash Contaminates the Interior of Airplanes
  - Interior Environment uses Outside Air
  - The Fine Nature of the Ash Can Pass Through Most Filters
  - Damaging Electronic Equipment

Closure of European Airspace

- April 14 – London VAAC issued advisory stating ash was moving towards Europe.
  - Closures started in Scotland and Norway
- April 15 – Closures included all of UK airspace
  - Closured in France lead to closing of 24 French airports
- April 16 – German Airspace was affected
- Eventually No Fly Zones extended as far east as the city of Minsk, Belarus.

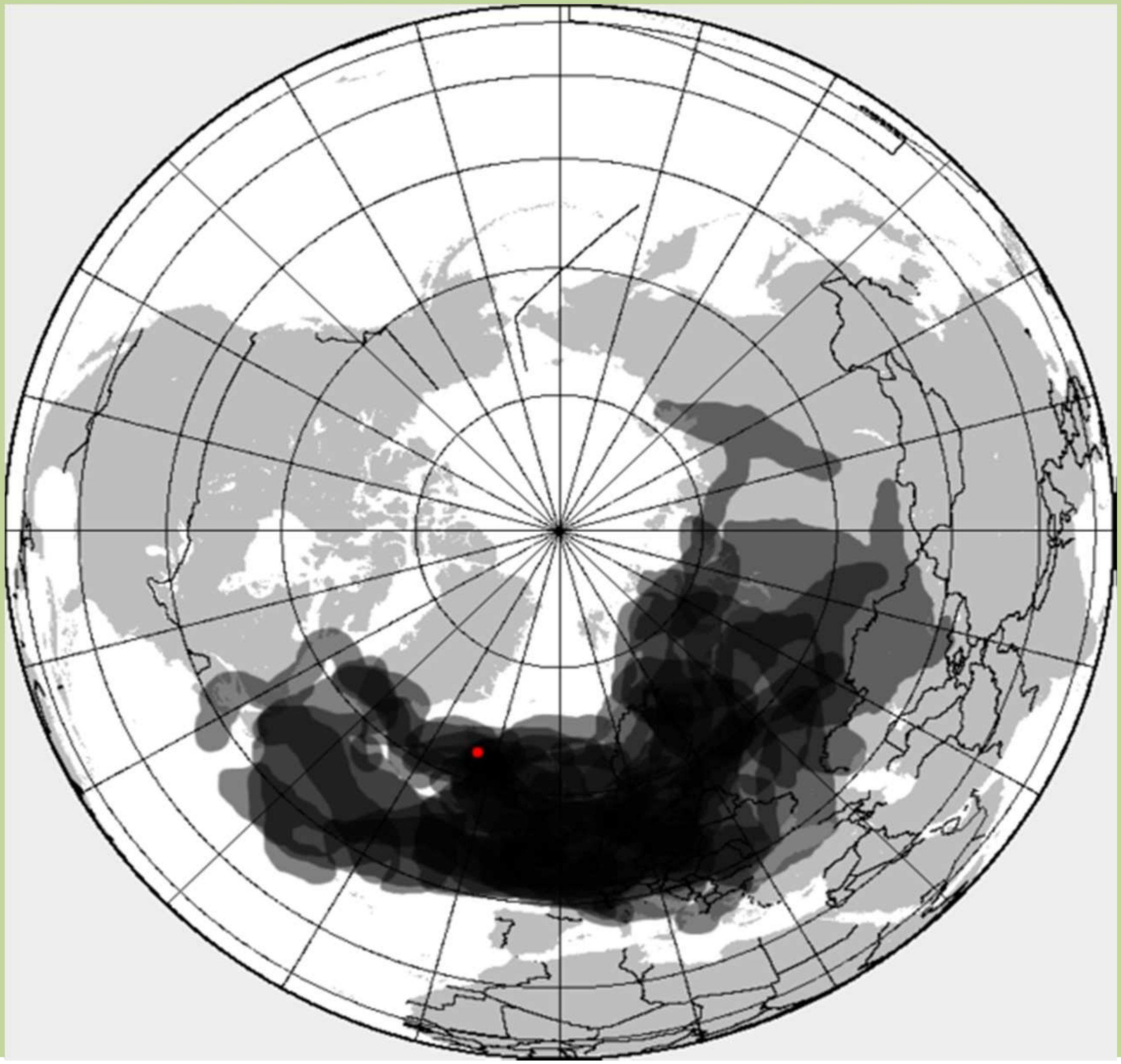

Figure 2. Composite image of area affected by the Eyjafjallajökull ash cloud.

Impacts to Airlines

- April 16 – all UK flights in England and Wales were grounded.
  - British Airways forced to divert incoming US flights to Scotland.
- April 17 – British Airways all flights to and from London airports.
  - Lufthansa cancelled all European flights.
  - Ryanair cancelled all Northern European flights
  - Aerofloat cancelled 40 flights to European
- Estimated total of 11,000 flights cancelled due to the eruption.
- International Air Transport Association (IATA) estimated 148 million Euros a day loss to airline industry.
  - 2.5 billion Euros total.
  - KPMG corporation estimated the loss to be closer to 200 million Euros a day.

Impacts to Airlines and Travel Companies

- European Airline Stock prices dropped with in the first two days of the incident.
  - British Airways fell 3.3.%
  - Air France fell 3.4%
  - Luthansa fell 4.1%
- British Airways and Air France pursued compensation from the European Union and other governmental agencies for loss of revenue.
- TUI, a European travel company, also requested compensation for the $6 million Euro loss per day it experienced.

Impacts to the Economy

- Automotive industry was impacted as Nissan and BMW plants were forced to stop production due to disruption of supply routes.
- In China, factories had delays in shipping jewelry and clothing.
- In South Korea, Samsung and LG were unable to ship more than 20% of their daily electronic exports.
- Hong Kong tourist industry was impacted as hotels and restaurants were unable to receive shipments of imported cheese, chocolates, and flowers.

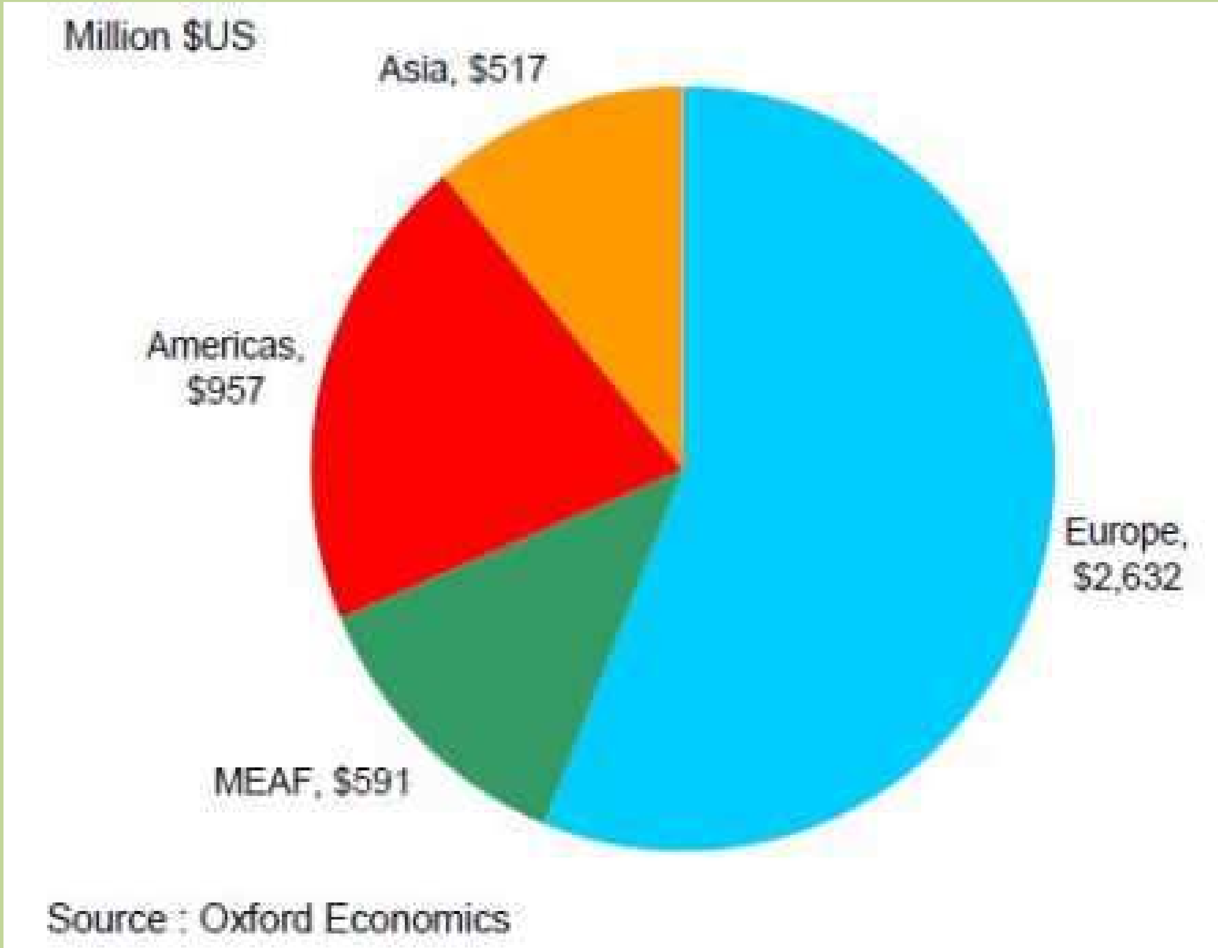

Figure 3. Impact of Eyjafjallajökull eruption on global economy.

Civil Aviation Authority's Response

- The CAA came under criticism due to the impacts.
- Richard Branson, founder of Virgin Atlantic stated,
  - "The restrictions were unforgivable and the authorities dealing with the crisis had made crass, stupid decisions"
- CAA responded by stating they would work to improve the dispersion model by working in close cooperation with
  - operators,
  - service providers
  - the London VAAC and other neighboring VAACs
- CAA also responded by entering discussions with aircraft manufacturers to consider what mitigations could be put in place to safety conduct aircraft operations in areas affected by ash.

The NAME dispersion model

- The Numerical Atmospheric Dispersion Modeling Environment (NAME)
  - Model used by London VAAC to predict spread of ash
  - Originally developed after the Chernobyl accident of 1986.
  - Established history modeling a wide range of atmospheric dispersion events.
- Model uses wind speed and direction as primary parameters
  - Also includes vertical temperature profiles and boundary layer height.
- Model can account for fallout due to gravity, impaction with the surface, and precipitation effects.
- Verification results have proven the NAME is good at spatial forecast of ash dispersion and its ability in forecasting location and amounts of peak ash concentration.

The NAME dispersion model - Faults

- Largest uncertainty in the NAME is the ability to accurately reflect the status of eruption at the time of model initialization.

- The ability to accurately model ash dispersion is dependent on knowing:
  - Height, diameter, and time variance of the eruptive column.
  - The initial concentration and particle size of the ash.
  - The amount of ash deposition near the volcano.

- Originally designed to predict aerosols other than volcanic ash.
  - More specific algorithms for volcano ash should be included in the model.

Figure 4. Estimation of Eyjafjallajökull ash cloud as of April 17th, 2010 @ 18:00 UTC.

Ash Detection Technology
LIDAR

- Light Detection and Ranging (LIDAR)
  - Uses a pulsed laser to image objects.
  - Can be mounted on aircraft, satellites, or ground.
  - Targets can be any size – ideal for small sized ash particles.
  - Only instrument capable of providing vertical distribution of aerosols.
  - Capable of providing density profiles.
  - During the Eyjafjalljokull event, the Earlinet network of LIDAR provided critical meteorological information.
  - Unfortunately, there was a lack of LIDAR near the eruption site, and initial eruption data was unable to be obtained

Ash Detection Technology
Satellite Imagery

- Geostationary satellites have monitored volcanic eruptions since the 1970s.
  - In 1970s – limited to single band infrared and visible images.
    - Difficulty distinguishing ash from cirrus clouds.
  - In 1980s – images formed by using temperature difference between 2 infrared bands.
    - Difficulty distinguishing low-level ash in moist tropical atmospheres or from ice embedded in ash clouds
  - In 1990s – multi-spectral techniques were developed that used multiple infrared bands or channels that were sensitive to ash and other components of ash clouds
  - Current technology uses brightness temperature differences (BTD) between three infrared channels centered on 3.9, 10.7, and 12.0 micrometer wavelengths.
    - The BTDs are generated by the differences in the radiative properties of volcanic ash, clouds, and underlying surfaces.

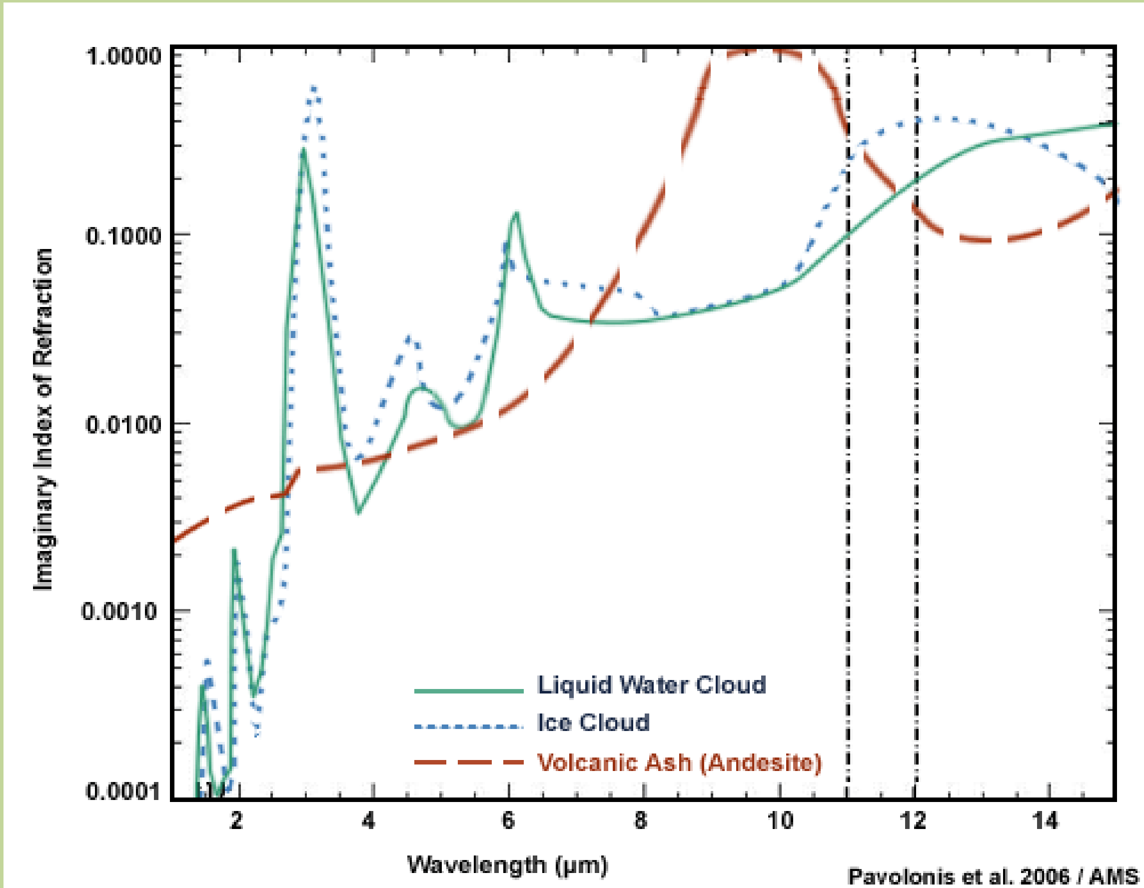

Figure 5. Wavelengths used for ash detection.

Ash Detection Technology

Satellite Imagery

- Satellites used in ash detection include:
  - Geostationary Operational Environmental Satellite (GOES)
    - Used by the United States
    - Currently has 5 infrared channels
    - Next Generation of GOES to have 16 channels
  - Meteosat Second Generation (MSG)
    - Used by Europe
    - Has 12 infrared channels.
- Use of more infrared channels in calculating BTDs will could lead to more accurate satellite imagery.
- During the Eyjafjallajokull incident many areas of airspace were closed even though ash was not visible on satellite imagery.
  - The discrepancy between the satellite imagery and the dispersion models was a contributing factor in the criticism the CAA received.

Ash Detection Technology
Aerosol Detectors

- Aerosol Detectors can be mounted to
  - Unmanned aircraft (UAVs)
  - Radiosondes & Dropsondes
- Aerosol Detectors can provide
  - Size distribution data
  - Vertical profile of ash concentrations
- During the Eyjafjallajokull incident, low cost aerosol detectors were mounted to balloon-borne radiosondes, and released over Stranraer, Scotland.
  - Provided critical data for ash concentration levels
  - Limited to only Stranraer, Scotland
- Data of this type would have been effective in
  - Determining dangers of due to ash concentration in critical flight area, therefore allowing aircraft to operate if ash concentrations were below danger levels.
  - Determining conditions near eruption site for input into the dispersion model.

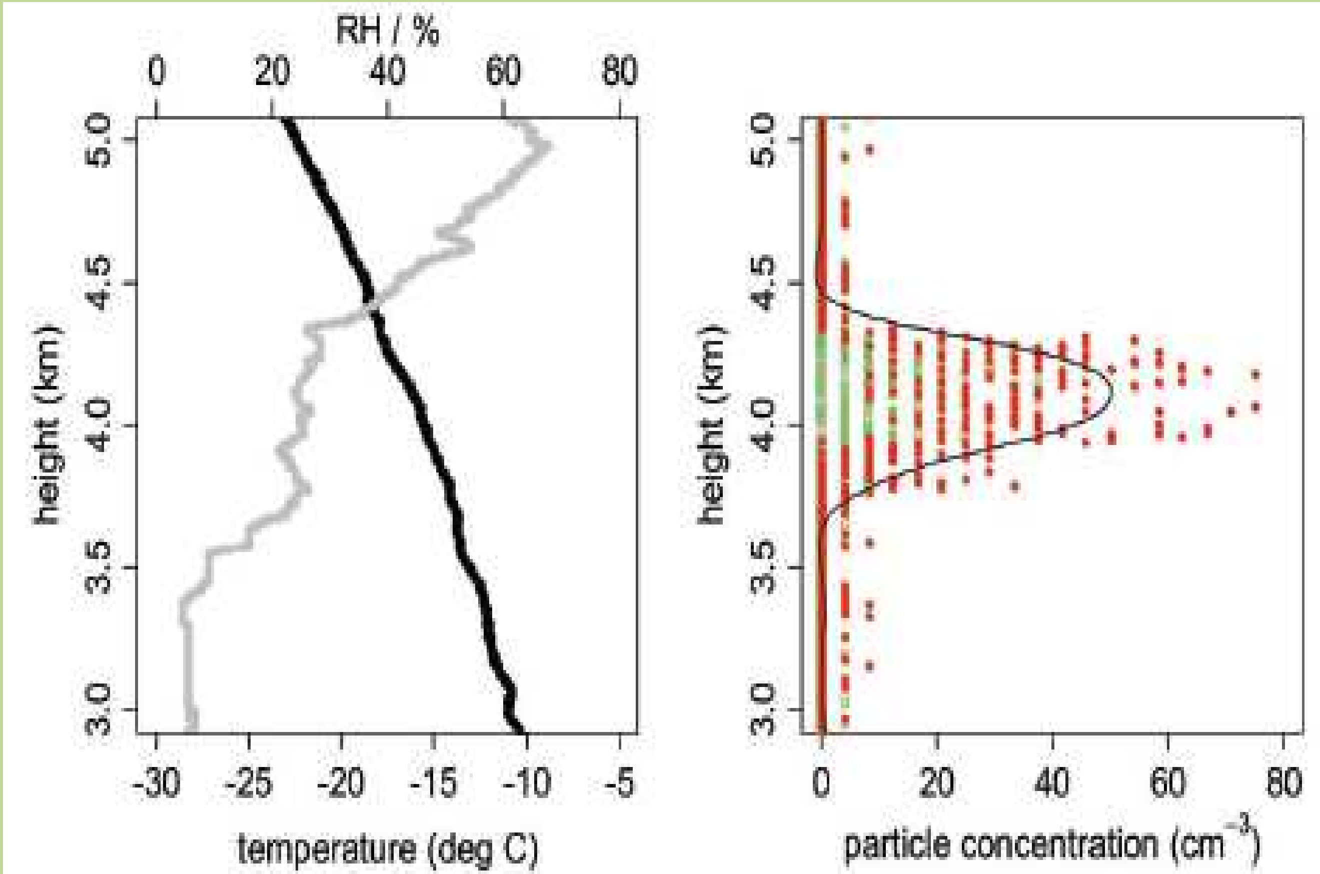

Figure 6. Vertical profiles of ash cloud from radiosonde over Stranraer, Scotland.

Ash Concentration Levels
How much ash is to much Ash?

- Numerous test flights were flown to investigate aircraft tolerance to volcanic ash
  - The Natural Environmental Research Council (NERC) Dornier 228
    - Flew 6 flights from April 15 to April 21.
  - Falcon Flight 19
    - Flew on April 19
    - Engines disassembled and no damage found that would prohibit safe aviation operations.
  - Facility for Airborne Atmospheric Measurements (FAAM) Bae 146
    - Flew 11 flights from April 20 to May 18.
  - British Airways' Boeing 747 and Air Berlin's Airbus A330
    - Both Airlines requested permission to conduct their own test flights
    - Neither flight reported problems or showed evidence of damage to engines.

Ash Concentration Levels
How much ash is to much Ash?

- Discussions were entered with the aircraft equipment manufactures (OEMs)
  - Prior to the incident the OEMs were reluctant to set a level of ash tolerance their equipment could withstand.
  - The key factor addressed in the discussions was airworthiness of an aircraft after an ash encounter.
  - The major airframe and engine manufactures eventually authorized operations into areas with ash densities of $2x10^3$ g/m^3.
    - They also stated they were content for operators to make decisions to operate in areas of higher concentrations as long as visible ash was avoided.
- In response to the feedback, the CAA issued 4 new flight zones. In addition to the normal flight zone, the other three include:
  - Enhanced Procedure Zones
  - Time Limited Zones
  - No Fly Zones

Ash Concentration Levels

- The International Civil Aviation Organization (ICAO) recognized the new approach but renamed the zones by ash contamination level. Below is the list from the CAA guidelines.

Area of Low Contamination: An airspace of defined dimensions where volcanic ash may be encountered at concentrations equal to or less than $2x10^{-3}$ g/m^3, but greater than $2x10^{-4}$ g/m^3.

Area of Medium Contamination: An airspace of defined dimensions where volcanic ash may be encountered at concentrations greater than $2x10^{-3}$ g/m^3, but less than $4x10^{-3}$ g/m^3.

Area of High Contamination: An airspace of defined dimensions where volcanic ash may be encountered at concentrations equal to or greater than $4x10^{-3}$ g/m^3, or areas of contaminated airspace where no ash concentration guidance is available.

Notes:

1) Other names have previously been used to describe areas containing various concentrations of volcanic ash, including Enhanced Procedure Zone (EPZ), Time Limited Zone (TLZ) and No-Fly Zone (NFZ). However, these are now withdrawn.
2) Some Volcanic Ash Advisories (VAAs) in other parts of the world may not differentiate between different levels of contamination.

Conclusions

- The Eyajafjallajokull caused major disruptions to both aviation and the global economy.
- More accurate ash forecasting is need
  - Requires knowledge of the initial conditions for input in the numerical dispersion models.
  - Better use of existing technologies
    - LIDAR
    - Aerosol Detectors
  - Improved satellite technology that includes more infrared channels would allow for better distinction of ash on satellite imagery.
- Research into tolerable ash concentrations led to creation of new flight zones which will allow operations in areas of limited ash.
  - Research should continue to evaluate the long term effects of operation in the new flight zones.
- The CAA came under criticism for the European Closure
  - With improvements to detecting the initial eruptive event and monitoring of ash concentration levels a crisis of this nature can be avoided in the future.
  - That said, safety is the primary concern of the CAA, and given the situation appropriate measure were taken to ensure the safety of the public.

Summary

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Questions

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