EPSRC Vacation Bursaries

Testing the structural uncertainties in volcanic ash cloud predictions and their impact on aviation

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Impact of volcanic ash on aviation

Physical effects on aeroplanes flying through ash:

- Temporary engine failure due to melted ash solidifying on the engine cooling systems.
- Damage to the compressor fan blades and fuel nozzles.
- Abrasion on the windows and the metal fuselage.

Economic effects on the aviation industry:

- Expenses lost as customers use other modes of transport to reach their destination.
- During the 2010 Eyjafjallajokull eruption, the aviation industry experienced a loss of € 3.3 billion between 15th April and 20th May (Mazzocchi et al. 2010).

Since the **2010 Eyjafjallajokull eruption**, guidelines for safe volcanic ash concentrations have been issued by the UK Civil Aviation Authority (CAA).

What is NAME?

The **Numerical Atmospheric-Dispersion Modelling Environment (NAME)** is a **Lagrangian particle-trajectory** model developed by the UK Met Office after the 1986 Chernobyl disaster. NAME tracks particles as they are advected by a 3D wind field provided by the UK Met Office's numerical weather prediction data.

NAME is one of many **Volcanic Ash Transportation and Dispersion (VATD)** models used by the **Volcanic Ash Advisory Centres (VAACs)** to forecast the dispersion of volcanic ash clouds. Forecast hazard charts outline areas of ash concentrations too hazardous for aircraft to fly through at specified flight layers as shown in Figure 1:

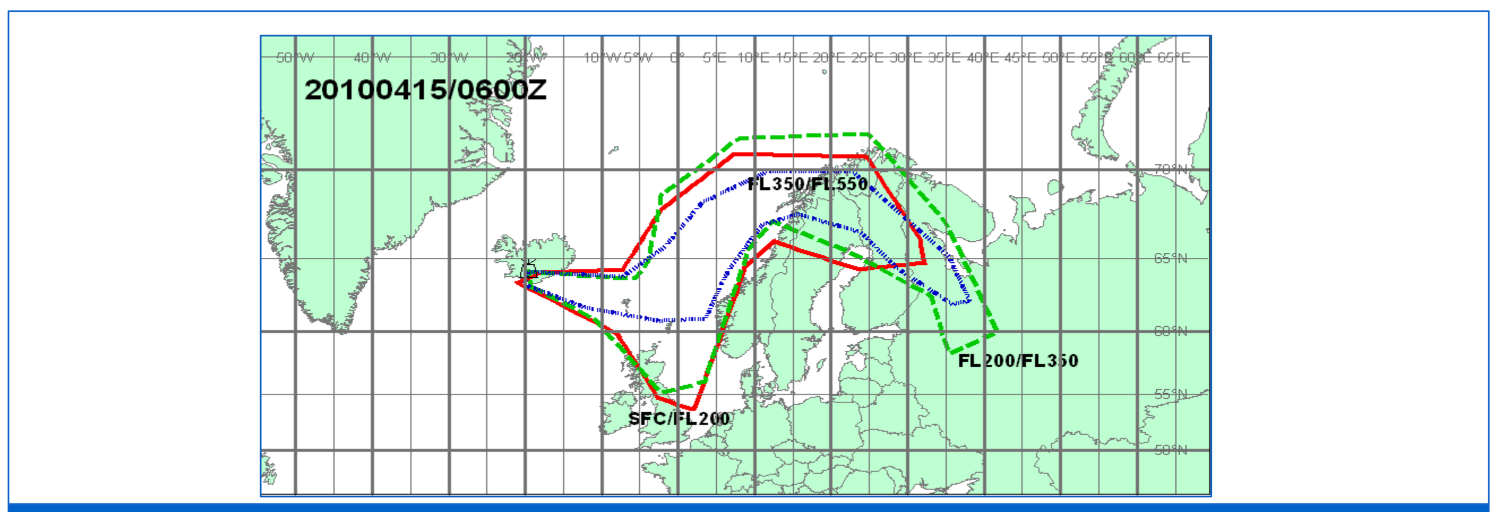

Figure 1: A forecast hazard chart issued by the London VAAC at 0600 UTC on 15/04/2010, outlining the furthest extent of ash particles at a flight level of 20,000ft (FL200), FL200-350, FL350-550.

Structural uncertainty in NAME

The **structural uncertainty** can be defined as how well NAME replicates the reality of dispersion given our best estimate of the eruption. Missing processes and choices in the model setup impact the modelled ash cloud.

This study focused on **two parameters** that were varied to observe how they impact ash cloud dispersion and its spatial extent. Table 1 shows the simulation specifications.

Impact of varying the Meteorological Temporal Resolution

NAME **linearly interpolates** the wind field data between each time the wind field changes. The temporal resolution was varied between **3 - 21 hours** as shown in Table 1. The **column integrated mass loading (CIML)** is defined as the ash concentration integrated over the depth of the atmosphere (measured in μg/m²).

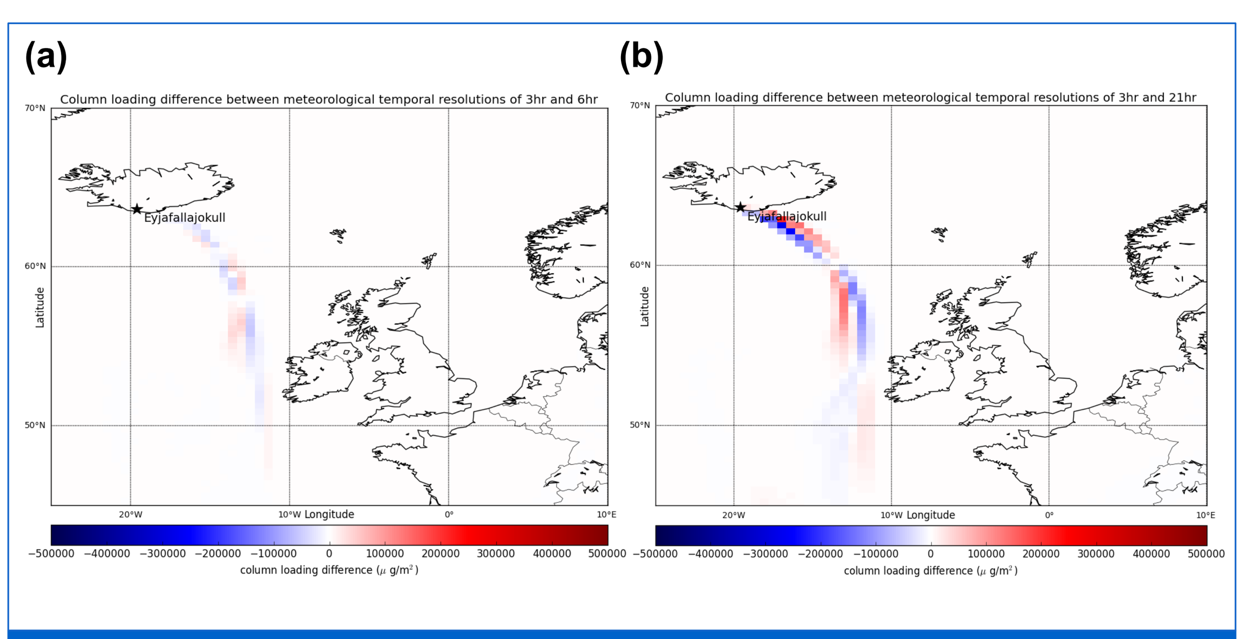

Figure 2: (a) CIML difference between the 3 hour and 6 hour temporal resolutions; (b) CIML difference between the 3 hour and 21 hour temporal resolutions. Both at 0600 on 3rd May 2010.

- Figures 2a and 2b show the change of the position of the ash plumes – Indicated by the dipole of negative and positive values of CIML.
- **Coarser resolutions** result in the **ash cloud becoming more displaced**, as shown by the stronger dipoles and less intertwining of the CIML differences.

- Figure 3 shows the number of grid cells below CIML of -5000 μg/m² when varying the temporal resolution.
- As the time resolution became coarser, the number of cells below this threshold increased.
- The lines level off indicating that as the plumes become more displaced and overlap less, CIML differences saturate.

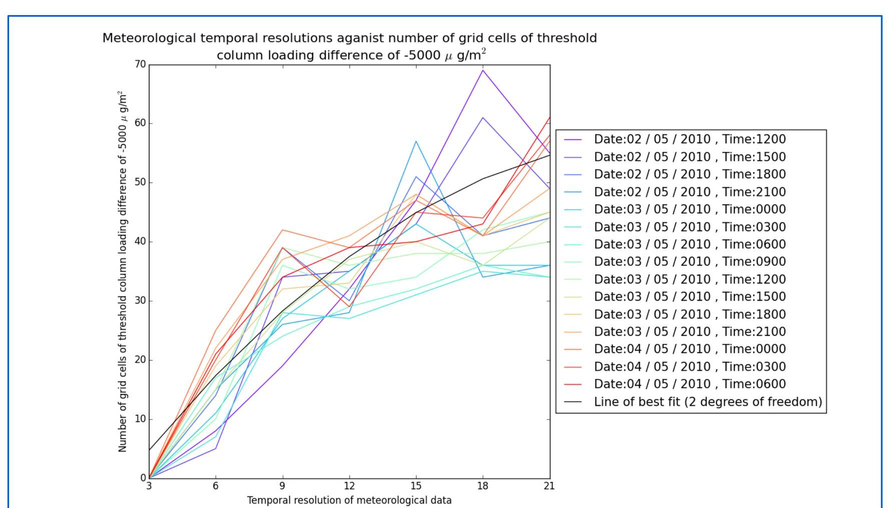

Figure 3: Temporal resolution plotted against the number of grid cells below ash concentrations of -5000 μg/m². The legend shows multiple lines plotted every three hours during a period starting at 1200 2nd May 2010.

Type of Experiment	Vertical Distribution of Emission	Plume Height	Start Time	End Time	No. Particles emitted	Temporal Resolution
Varying the particle emission rate	Top-hat 1km depth	10km	1st May 0600 UTC	3rd May 0600 UTC	100 - 100,000 per hour	3 hours
Varying the temporal resolution	Top-hat 1km depth	10km	1st May 0600 UTC	4th May 0600 UTC	10,000 per hour	3 – 21 hours

Table 1: Summary of the simulation specifications for the two experiments.

Impact of varying the particle emission rate

Each model particle in NAME represents a **fraction of the actual mass of ash emitted**. Particles are then stochastically moved by unresolved turbulence in the wind field. Table 1 shows the particle emission rate was varied between **100-100,000 particles per hour** in various simulations.

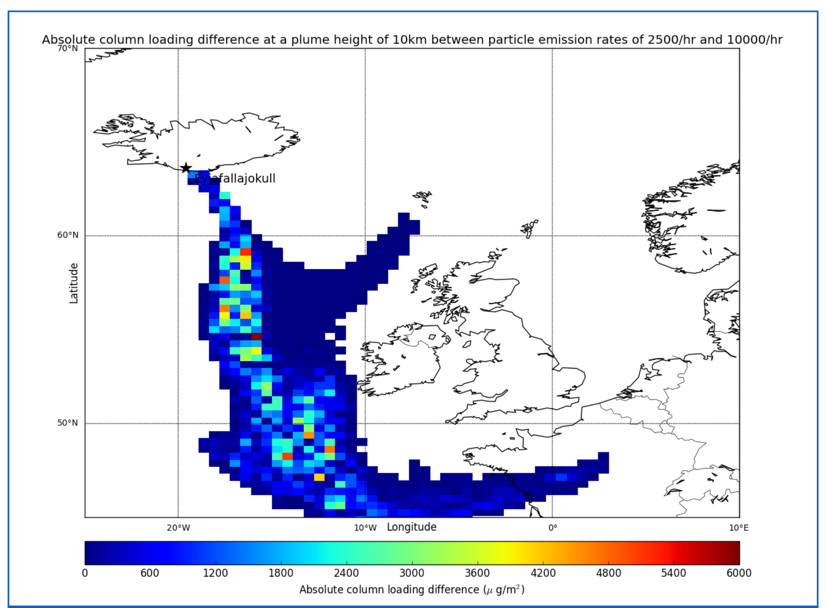

Figure 4: CIML absolute difference between particle emission rates of 2500 and 10,000 per hour at 0600 UTC on the 2nd May 2010. ($|CIML_{2500} - CIML_{10000}|$)

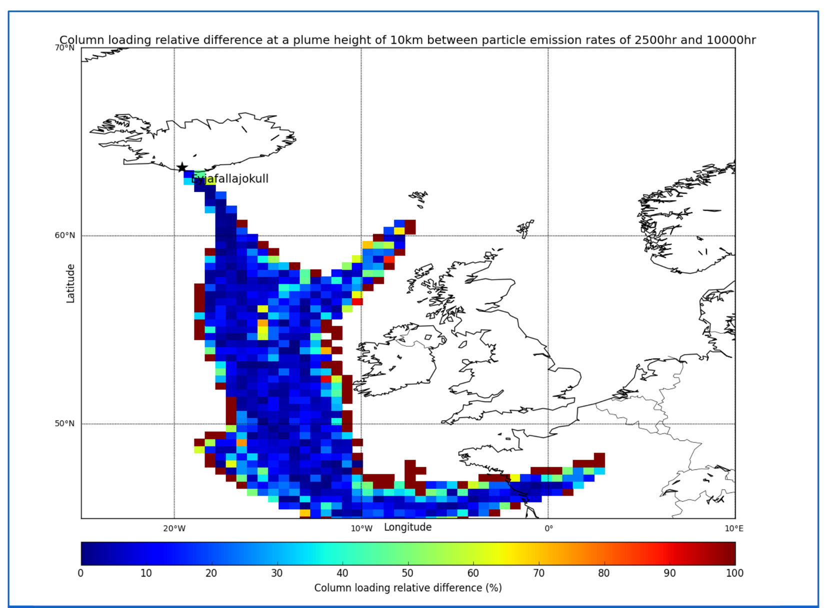

Figure 5: CIML relative difference between particle emission rates of 2500 and 10,000 per hour at 0600 UTC on the 2nd May 2010.

- Figure 4 shows the centre of the plume contains the greatest difference in ash concentration as this contains the greatest amount of particles.
- The edges contain fewer particles thus the difference is minimal.

- Figure 5 shows the edges of the plume highlight areas of **relative percentage difference greater than 100%.**
- Varying the particle emission rate shows small differences in the ash concentration along the edges of the plume, but relative to the default particle emission rate, differences are considerably larger.
- The percentage relative difference was calculated from Equation 1.

Equation 1

$$\text{Relative Percentage Difference} = \frac{|CIML_{2500} - CIML_{10000}|}{CIML_{10000}} \times 100$$

- Figure 6 shows that as the particle emission rate decreases exponentially, the sum of the absolute difference increases.
- Decreasing the particle emission rate from 100,000 to 100 per hour, led to an **order of magnitude of change in the sum of the absolute difference**.
- If concentrations were to boarder unsafe levels, then changing the particle emission rate could mean the difference between open airspace and closed airspace.
- As time increases the sum of the absolute difference increases due to continued emission and increasing in spatial extent of dispersing ash.

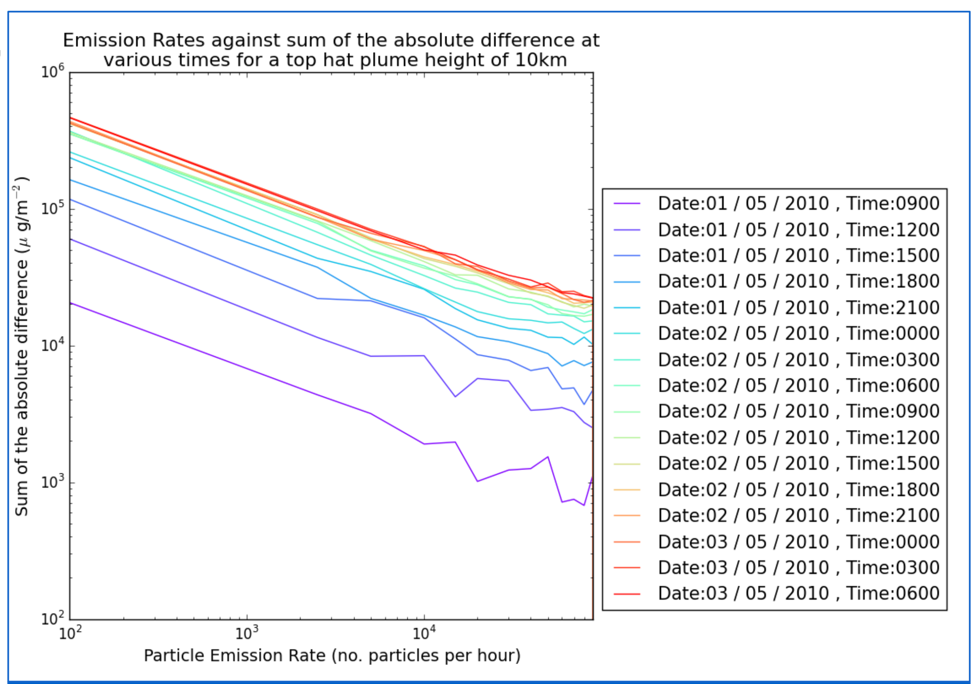

Figure 6: Particle emission rates against the sum of the absolute CIML differences.
The legend shows multiple lines plotted every three hours during a period starting on 1st May at 0900 UTC to the 3rd May at 0600 UTC.

Summary

Varying the meteorological temporal resolution

- The small temporal wind field variations were eliminated as the temporal resolution decreased.
- As the temporal resolution became coarser:
  - The ash plumes were substantially more displaced.
  - CIML concentration differences increased.
- At a resolution of 21 hours, CIML differences saturate as the plumes becomes more displaced and overlap less.
- **Decreasing the temporal resolution increased the uncertainty** of the ash plumes **positioning and spatial extent**.

Varying the particle emission rate

- The difference in CIML was greatest in the plume centre. The relative percentage difference was greatest at the plume edges.
- Varying the particle emission rate from 100,000 – 100 per hour, increased the sum of the CIML absolute difference by **one order of magnitude**.
  - Could potentially change ash concentrations within the plume.
  - If concentrations boarder unsafe levels, varying the particle emission rate could result in CAA guidelines for safe ash density to be exceeded.

References: Mazzocchi, M., F. Hansstein, M.Ragona, 2010: The 2010 volcanic ash cloud and its financial impact on the European airline industry. *CESifo Forum*, **11**, 92-100.