Emulation of Volcanic Ash Dispersion

Natalie Harvey[1] | Nathan Huntley[2] | Helen Dacre[1] | Andy Hart[3] | David Thomson[4] | Helen Webster[4]

[1] University of Reading, [2] University of Durham, [3] Food and Environment Research Agency, [4] UK Met Office

What happens in the event of a Volcanic eruption?

In the event of an eruption the Volcanic Ash Advisory Centres (VAACs) issue **hazard maps**, based on forecasts of meteorological conditions, of **instantaneous horizontal ash coverage** in three vertically integrated layers of the atmosphere at **6 hourly-intervals**. The boundaries of the ash show the **maximum expected extent** of the plume. Figure 1 shows the hazard map issued at 1800 on 14/04/2010 during the Eyjafjallajökull eruption.

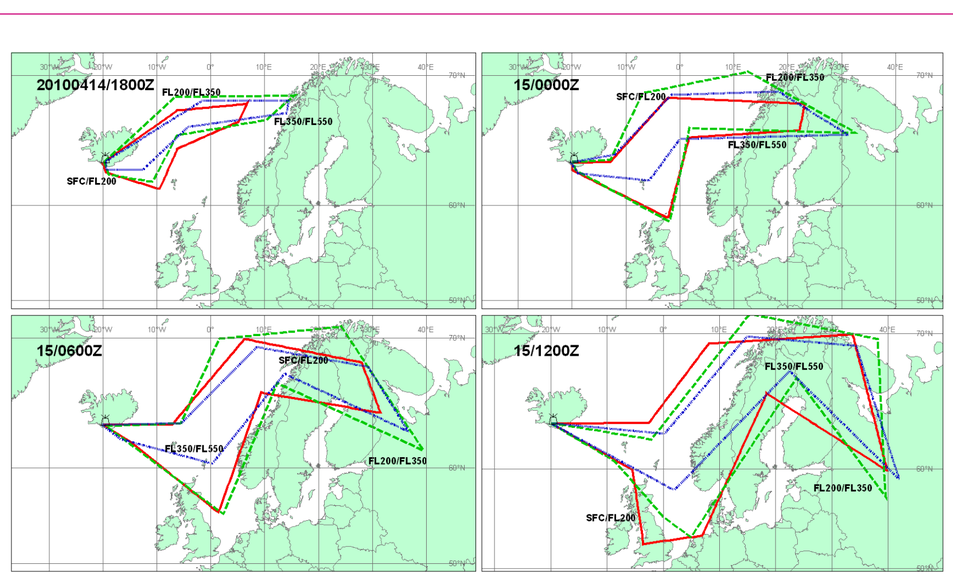

Figure 1:The forecast hazard map issued by the London VAAC at 1800 on 14/04/2010 during the Eyjafjallajökull eruption in 2011. Contours shows the outermost extent of the volcanic ash cloud in 3 layers of the atmosphere (surface - flight level(FL) 200, FL200-FL350 and FL350-FL550).

Hazard maps are created by running **Volcanic Ash Transport and Dispersion (VATD)** models. In the case of the London VAAC the VATD model used is the **Numerical Atmospheric –Dispersion Modelling Environment (NAME)** which is run at the UK Met Office.

After the 2010 Eyjafjallajökull eruption the UK Civil Aviation Authority brought in new guidelines that not only require predictions of ash location but also **ash concentration**.

VATD models can predict ash concentrations, however, currently there is **no formal framework** for determining the uncertainties on these forecasts.

The **Robust Assessment and Communication of Environmental Risk (RACER)** project aims to **quantify these uncertainties** with a view to producing a generic framework to provide information about volcanic ash risk which is both **robust** and **easy to communicate** and **transferable to other hazards**.

Emulation

The NAME model runs **too slowly** to evaluate at very many parameter choices. We can however use an **emulator** to **predict** the model's output at any parameter choices given a collection of runs at other parameter choices.

An emulator is a **simple approximation** of the complicated model that can be evaluated almost instantly. Rather than trying to approximate the entire output, we intend to concentrate on **interesting summaries** of the output, for instance maxima, minima, or averages in particular areas at particular times.

Our emulators for a given quantity, y, will consist of **two parts**: a linear combination of simple functions $g_i(x)$ of the parameters x, corresponding to the **mean trend**, and a **variance term** u(x) chosen so that the covariance between two parameter choices depends on the **distance** between them.

$$y(x) = \sum_i \beta_i g_i(x) + u(x)$$

This leads to an emulator that estimates the **expected value** and the **variance** for the summary y should we run NAME at parameter choice x, such that:

- For any x that we actually ran NAME for, the expected value of y(x) is the **value we observed** from the model run, and the variance is **zero**.
- When x is **near** a choice at which we ran NAME, the expected value will be **close** to this observed value and the variance will be **low**.
- When x is **far** from any model run, the expected value will be close to the **mean trend** and the variance will be **high**.

With this emulator, we can explore the parameter space much faster, and furthermore identify plausible and implausible regions (for instance through **history matching**). Early investigations suggest that the average concentration over a particular region and time can be used to build useful emulators.

The NAME model

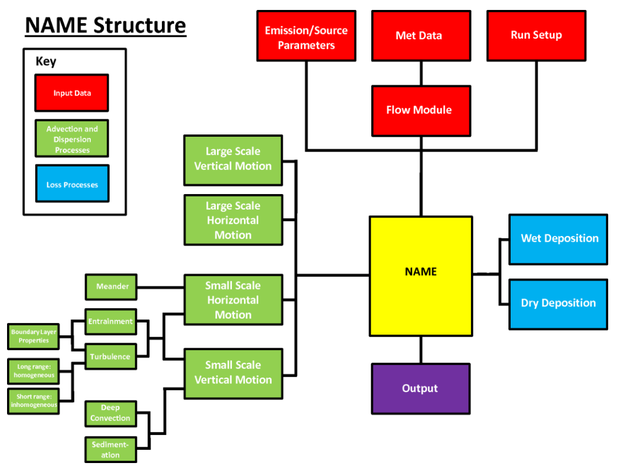

Figure 2: A schematic of NAME showing its structure and processes that are represented within it.

- Lagrangian particle model
- Particles move with the resolved wind described by the meteorology plus a random component to represent the effects of atmospheric turbulence
- Also includes loss processes
- Used to model a wide variety of atmospheric dispersion events
  - Nuclear accidents
  - Airborne animal diseases
  - Routine air quality forecasts

Sources of uncertainty in NAME

Input parameters - Are the inputs used to drive the model accurate?

The accuracy of the NAME predicted ash location and concentration are extremely dependent on the accuracy of the eruption source parameters (ESPs) and the driving meteorology. Table 1 details these parameters. In an emergency response situation not all of these parameters are known so the simulations are run with pre-determined default parameters.

Parameter uncertainty - are the parameters used in the model correct?

In NAME both advection, dispersion and loss processes are parameterised. Each parameterisation includes parameters based on empirical evidence or observation (see Table 1) that determine the motion of the particles and thus the final forecast. Each of these parameters have an associated uncertainty.

Parameter	Description and default value
Plume height	This is defined as the maximum height above mean sea level that the ash plume reaches in the vicinity of the volcano vent. This can be time varying but kept constant unless a significant and sustained change.
Vertical distribution of ash	This can vary throughout the eruption and is not always uniform. Default: constant emission at heights from volcano vent to plume top.
Mass eruption rate	Empirical relationship based on plume height. This can be time varying.
Size distribution of ash	The default distribution used in NAME is based on average measurements made in the plumes of 3 historic explosive eruptions and ignores ash larger than 100 μm
Duration of eruption	Eruption lasts until local Met service informs VAAC it has stopped.
Particle shape	Default: spherical
Size/Area of eruption	Default: line.
Distal fine ash fraction	The fraction of the ash mass which survives the near source fall out processes. Default: 5%.
Particle density	Assumed to be 2300 kgm^{-3}
Meteorological fields	Updated every X hours, linearly interpolated. Fields include wind speed, temperature, humidity, cloud and rainfall.
Turbulent mixing	Standard deviation of horizontal /vertical velocity and Lagrangian timescale for free tropospheric turbulence and horizontal meander
Vertical mixing by convection	Scheme is based on presence and depth of convective cloud.
Dry Deposition	Deposition velocity determined using a resistance analogy
Wet Deposition	Scavenging coefficients based on rain rate and empirical constants
Sedimentation	Sedimentation velocity determined using a drag co-efficient

Table 1: Descriptions and default parameters used to initialise and drive NAME (red). Parameters associated with advection/dispersion processes (green) and loss processes (blue).

The uncertainty ranges for the parameters in Table 1 have been determined through a process of expert elicitation.

Structural uncertainty – the model is an approximation to reality

As with any model, there are some processes that are not represented in NAME. These include aggregation of particles, gravity current spreading and particle diffusive convection (could rapidly remove ash near source).
The uncertainty introduced by this will also be assessed using expert elicitation.

Future Work

- Fully develop a **statistical emulator** of NAME to investigate more easily the **whole of parameter space** and thus co-dependencies between the uncertain parameters.
- Create a **transferable framework** for assessing uncertainty in modelling natural hazards.
- Develop **novel methods** to **communicate the uncertainty** clearly for the end-users of the volcanic ash forecasts. One possibility is a probabilistic volcanic ash forecast.