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Effusive Eruption Modelling project: Assessing UK impacts of trace species and sulphur deposition

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See also NH2.1/AS3.19, 15:30–15:45 EGU2015-14100 UK hazard assessment for a Laki-type volcanic eruption: modelling results for sulphur dioxide and sulphate aerosol, Claire Witham

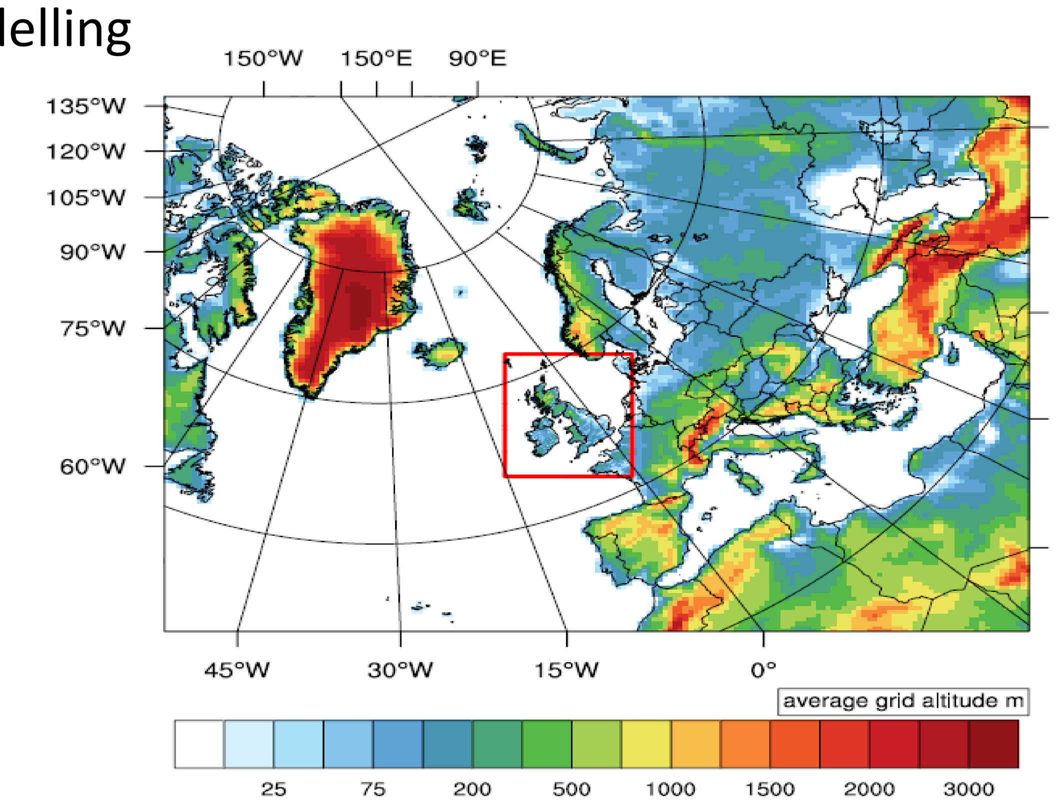
Background to modelling

- the potential UK impacts of a future eruption were assessed by characterising the source of a Laki-type eruption scenario and subsequently modelling the eruption with two CTM models over the European domain
- EMEP4UK (CEH) and NAME (Met Office) models were run with 10 years meteorology and a repeating 5 week eruption scenario (resulting in 80 eruption scenarios under the 2003-2012 meteorology
- Witham et al. (EGU2015-14100) present the results from the flight level and surface level modelling results for SO_2 and SO_4^{2-} concentrations
- This poster presents EMEP4UK model results for:
  1) Proxies for surface concentrations of halogen acid and H_2S
  2) EMEP4UK model surface sulphur concentrations and deposition used to assess ecosystem impacts

Emission source

- Each daily emission has a different vertical profile composed of five layers
- different masses of SO_2 are emitted into each layer.
- Over the whole eruption ~24% SO_2 is emitted into the stratosphere,~76% the troposphere.
- eighty, non-overlapping, 6-week eruption periods in 2003-2012 were defined.

EMEP4UK modelling



The model horizontal resolution scales down from 50 km x 50 km in the main EMEP 'Greater European' domain (which includes Iceland) to 5 km x 5 km for the domain covering the British Isles

- Model run with the EmChem09 chemical mechanism 72 species & 137 reactions.
- Anthropogenic emissions of NO_x, NH_3, SO_2, primary $PM_{2.5}$, primary PM_{coarse}, CO, & NMVOC
- UK emissions from the National Atmospheric Emission Inventory (NAEI, http://naei.defra.gov.uk) at 1 km² resolution, aggregated to 5 km x 5 km
- For the outer domain emission estimates use the EMEP 50 km x 50 km resolution provided by CEIP (http://www.ceip.at/), including emissions for Etna.
- The volcanic emissions are injected in the appropriate level at (horizontal resolution 50 km²) emissions above the model vertical domain are injected in the highest level.
- The land-based gridded emissions are distributed vertically according to a default distribution based upon the SNAP codes (Simpson et al., 2012).
- Hourly temporal resolution was used to derive air quality and other detailed information

➢ HCl and HF were modelled as a soluble tracer, ***X_{sol}*** using HNO_3 solubility, dry & wet deposition

➢ Two non-reactive tracer concentrations, ***$X_{insol,\ low}$*** **&** ***$X_{insol,high}$*** were put into the model runs. With $X_{insol,low}$ assessed as a proxy for H_2S

Trace species

- HF and HCl are emitted in variable amounts from volcanic eruptions, perturbing both the atmospheric composition and adding to effects from sulphur species. H_2S is also emitted.
- Within a single eruption sequence the volatile ratios, HCl:SO_2 and HF:SO_2 are likely to be highly variable. However to initialise the model runs an estimate was made using literature appropriate for an Icelandic Laki-type eruption were assessed (11 studies, subset of a wider literature survey).
- There are very few Icelandic H_2S studies. The range of ratios covers 0.01 – 2.86, with the only Icelandic measurement from Surtsey, Iceland with alkali-basalt reporting a H_2S:SO_2 ratio of 0.04, Halmer et al. (2002).
- X_{sol}:SO_2 was set to 1:1 $X_{insol,\ low}$:SO_2 = 0.04 $X_{insol,high}$ =0.3
- It is emphasised that ratios selected were conservative to allow for a reasonable worst case scenario type assessment.

Summary statistics of literature values

	HCl:SO_2	HF:SO_2	H_2S:SO_2
Range	0.03-1.69	0.03-0.34	
arithmetic mean	0.47	0.09	
geometric mean	0.31	0.05	
Selected value	1	0.3	0.04

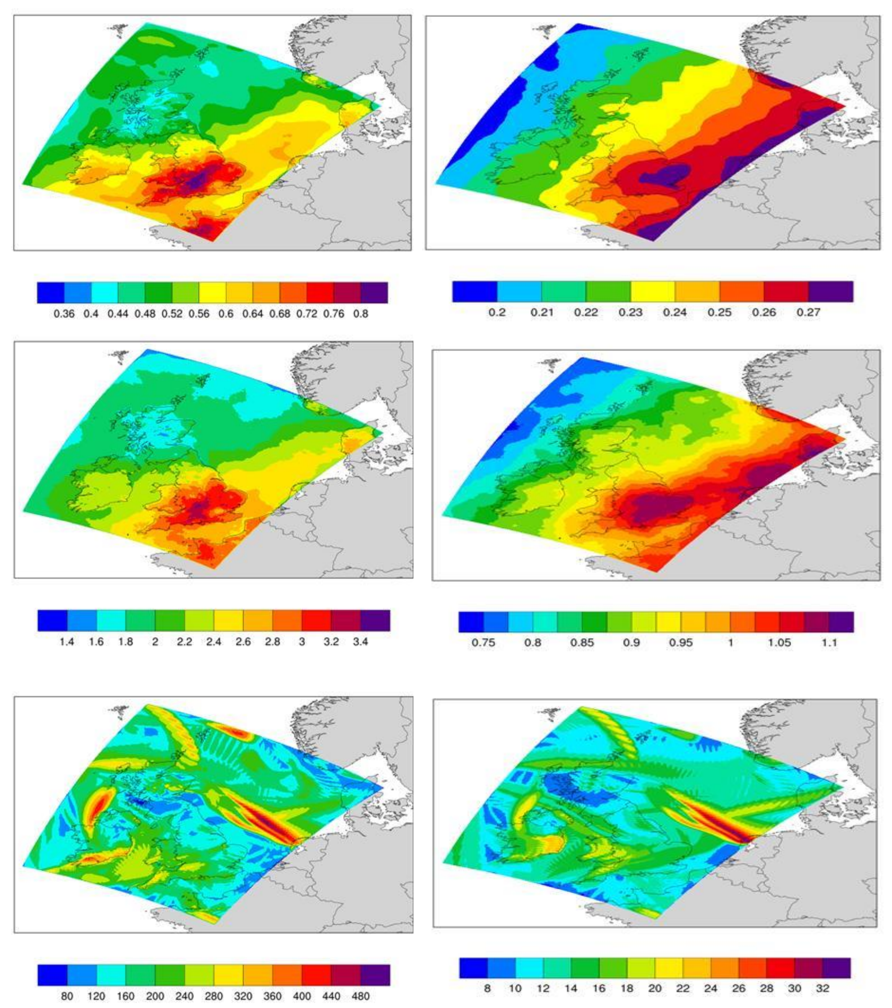
Air quality metrics used for halogen acids and HBr in the UK

	Averaging period	Level
HF	1 hour	0.2ppm/ 0.16mg/m³ (1)
HCl	1 hour	0.5ppm/0.75mg/m³ (1)
HBr	1 hour	0.2ppm/ 0.7mg/m³ (1)
H_2S	24 hour	150µg/m³ (2)

(1) http://www.ivhhn.org/index.php?option=com_content&view=article&id=83
(2) ; (2) http://archive.defra.gov.uk/environment/quality/air/airquality/publications/halogens/fullreport.pdf

Results

Concentration statistics for the 10 year dataset



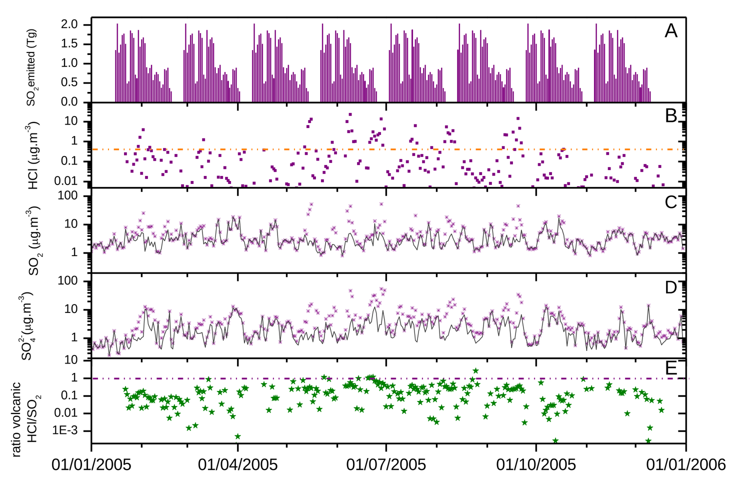
Hourly average (units: µg.m⁻³.)
X_{sol}: X_{sol}:SO_2=1
Mean (upper panel);
95th percentile (middle panel)
maximum (lower panel)

Hourly average
X_{insol} Xinsol:SO_2 = 0.04
Mean (upper panel);
95th percentile (middle panel)
maximum (lower panel

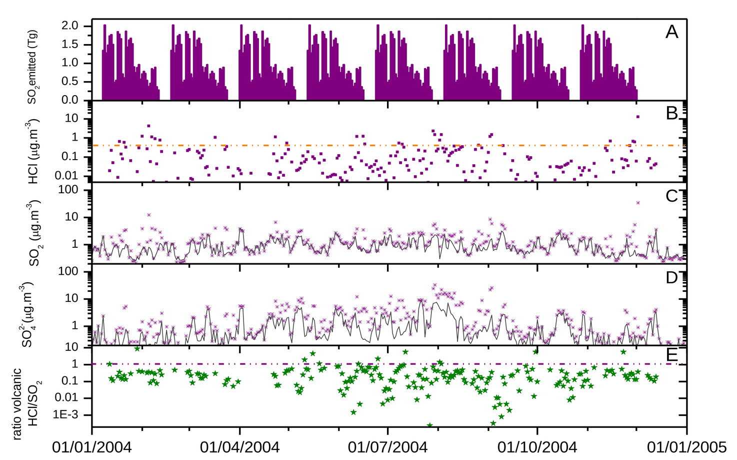
Example site specific analysis

- For 30 sites where Defra long term monthly average HCl, SO_2 & PM composition are measured (http://pollutantdeposition.defra.gov.uk/networks)
- the daily average data from the model run was extracted.
- 2 examples are shown below

Shetland, Scotland, 2004



Cromwell Road, London, 2005



A: Volcano emissions (Tg);
B: Modelled (purple squares) and measured average ambient (orange line) HCl
C: Modelled SO_2: Baseline (continuous), eruption scenario (crosses)
D: Modelled SO_4: Baseline (continuous), eruption scenario (crosses)
E: Ratio of HCl to SO_2: eruption scenario emission ratio (purple line); eruption scenario-baseline (green crosses).

Summary

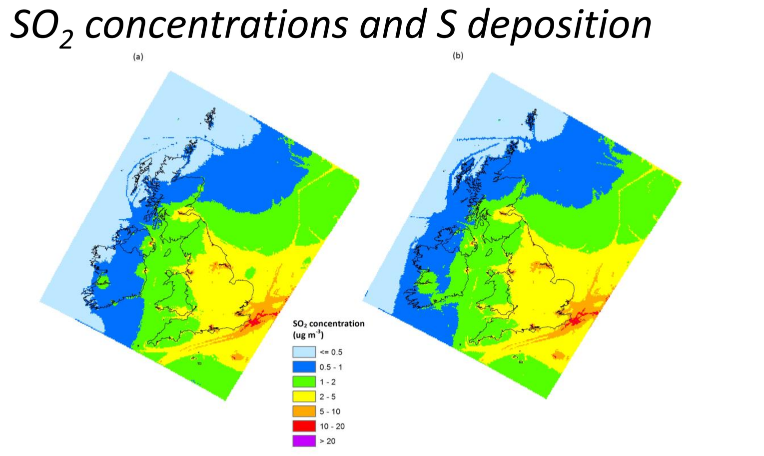
- HCl and HF emissions of the same magnitude as SO_2, modelled as a soluble species, result in average concentrations at the UK surface mostly <1 µg m^{-3} with a 95th percentile <5 µg m^{-3}.
- Average modelled HCl concentrations are similar to normal UK coastal HCl concentrations
- Even with conservatively high emission ratios the hourly human health limits for HF and HCl are not exceeded in any of the simulations
- H_2S modelled as an insoluble species emitted in the ratio range of 0.04 - 0.3 µg m^{-3} does not exceed the relevant human health 24-hour limit of 150 µg m^{-3}

Ecosystem impacts

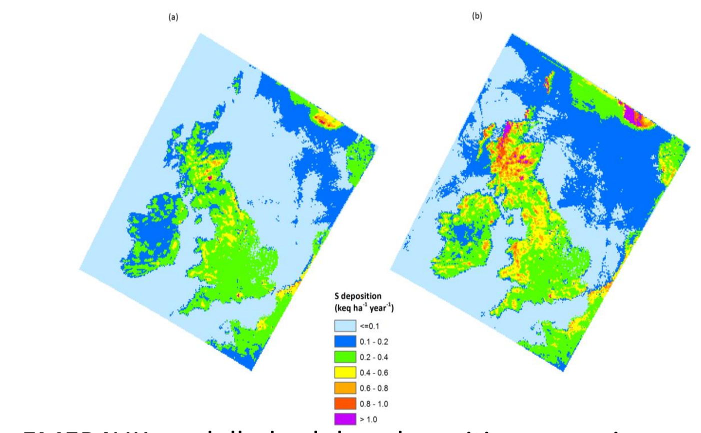
- SO_2, nitrogen oxides (NO_x=NO+NO_2) and ammonia (NH_3) can contribute to acidification and adversely affect natural and semi-natural habitats.
- sensitivity of habitats to acidification is assessed using "**critical loads**" *a quantitative estimate of the exposure to one or more pollutants below which significant harmful effects on specified elements of the environment do not occur according to present knowledge" (Nilsson & Grennfelt,1988)*
- The amount of acid deposition that exceeds the critical load is called the "**critical load exceedance**" and indicates an ecosystem is at risk from potential harmful effects in the long term but is **not** a quantitative estimate of "damage" to the environment.
- A "**critical level**" is the gaseous concentration of a pollutant (e.g., SO_2) above which damage has been observed. The excess pollutant concentration above the critical level is referred to as the "**critical level exceedance**"

Results

SO_2 concentrations and S deposition

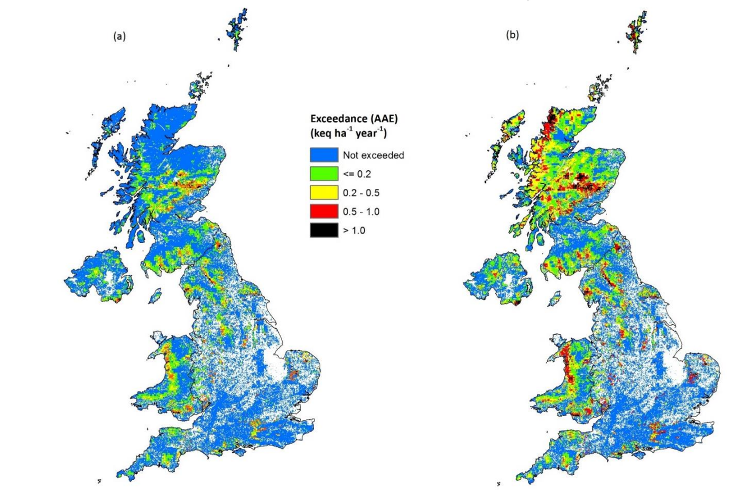


EMEP4UK modelled SO2 concentrations for (a) baseline scenario; (b) average Laki-type scenario

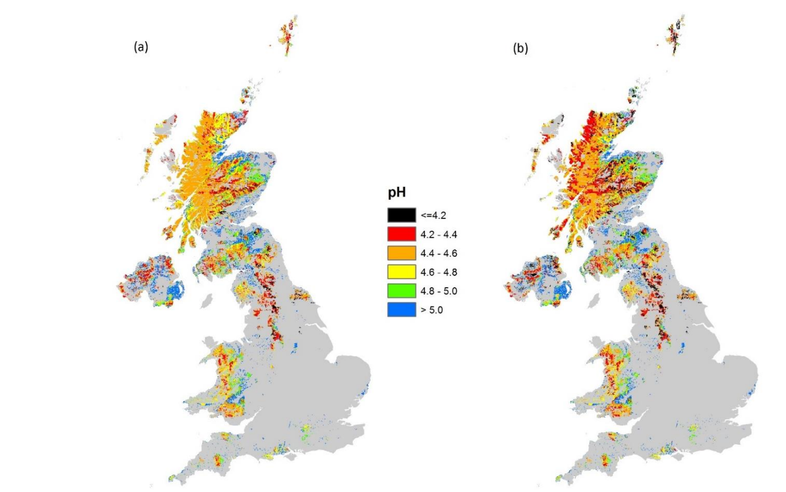


EMEP4UK modelled sulphur deposition assuming moorland vegetation everywhere for (a) baseline scenario; (b) average Laki-type scenario

Critical load exceedance and dynamic modelling



Acidity critical loads exceedance (as Average Accumulated Exceedance keq ha⁻¹ year⁻¹) for all habitats combined for (a) baseline; (b) average Laki-type scenario.



Modelled pH in 2005 for areas of UK dwarf shrub heath for (a) the baseline scenario; (b) the average Laki-type scenario.

Summary

Concentrations and critical levels exceedance

- The annual mean SO_2 concentrations are 2.02 µg m^{-3} (range 0.26- 38.2 µg m^{-3}) for the baseline, and 2.23 µg m^{-3} (range 0.35- 38.5 µg m^{-3}) for the average Laki-type scenario.
- Exceedance of critical levels does not increase significantly.

Sulphur deposition and critical loads exceedance

- Annual S deposition increases ~50%, similar to peak industrial S pollution in the 1970s.
- Sensitive ecosystem area exceeding their critical load doubles *for that year*: 22%-51%.
- Scotland has the greatest proportional increase in exceedance, with areas of dwarf shrub heath at most risk.

Dynamic modelling

- Average soil pH drops only slightly but returns to near normal within 5 years. However, even a small drop in pH can result in damage when pH is already low, particularly to downstream freshwater natural systems and aquaculture. Impacts are likely be localised.
- Effects of concentrated, short-term peaks of S-deposition were not fully evaluated.

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The results show that although an Icelandic plume will reach the UK and affect the atmospheric composition, in the scenario done trace species HCl and HF X_{sol} (modelled as HNO_3) do not exceed air quality levels.
The emission scenarios considered do not capture the entire range of variability in the numerous aspects of such a Laki-type eruption and in-particular only one set of ratios has been simulated so the values given should be taken as guidance only

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