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Modelling Volcanic Ash and Lahars for Hazard Risk Assessment

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Outline

1. Volcanic Eruption Hazards
2. Improved Forecasting of Airborne Volcanic Ash Dispersion
3. Tephra Deposition from Wind-affected Volcanic Plumes
4. Characterising Long-term Exposure to Volcanic Gas Emissions
5. Towards Predictive Lahar Models
6. Challenges and Opportunities

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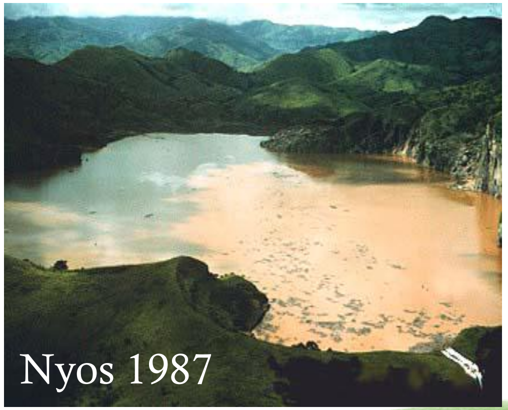
Volcanic Eruption Hazards



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Volcanic Eruption Hazards

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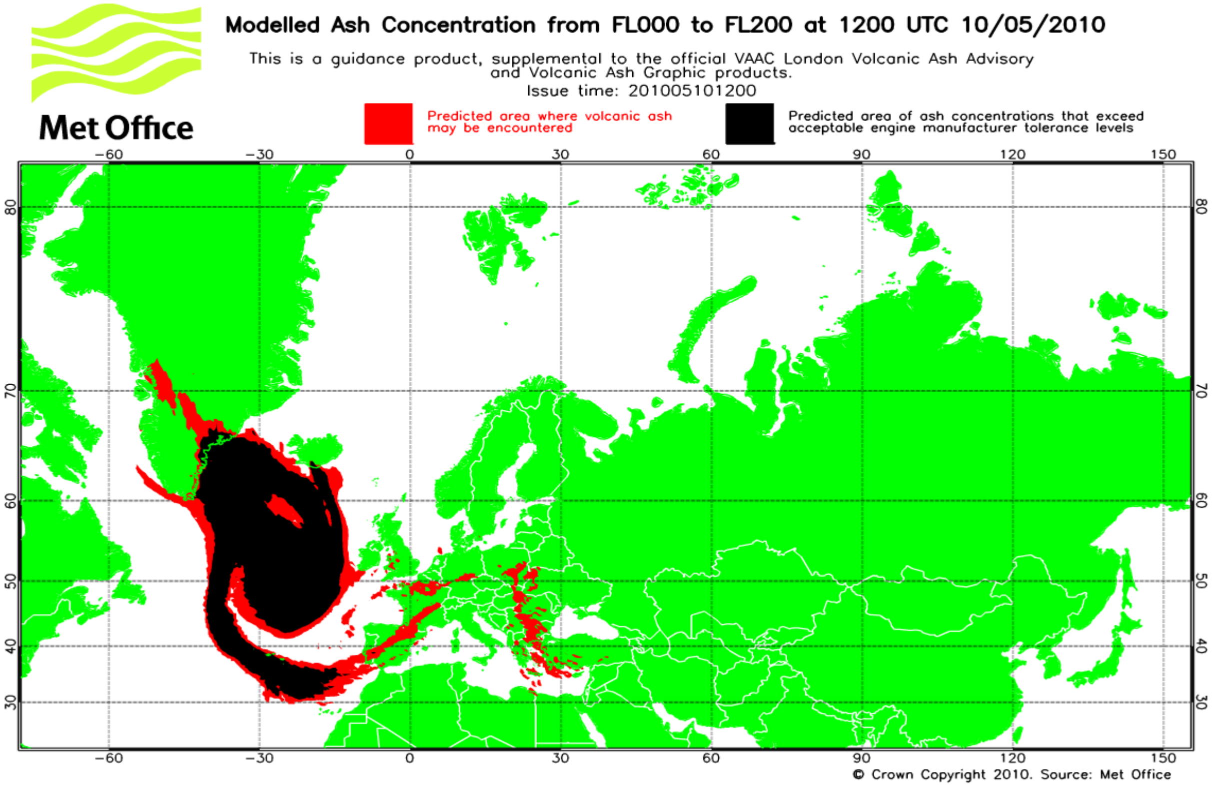
Prediction of Airborne Volcanic Ash Concentration



2010 eruption of Eyjafjallajokull (Iceland) produced widespread disruption to aviation over European airspace

Estimated cost of the disruption was $2 billion over 4 days

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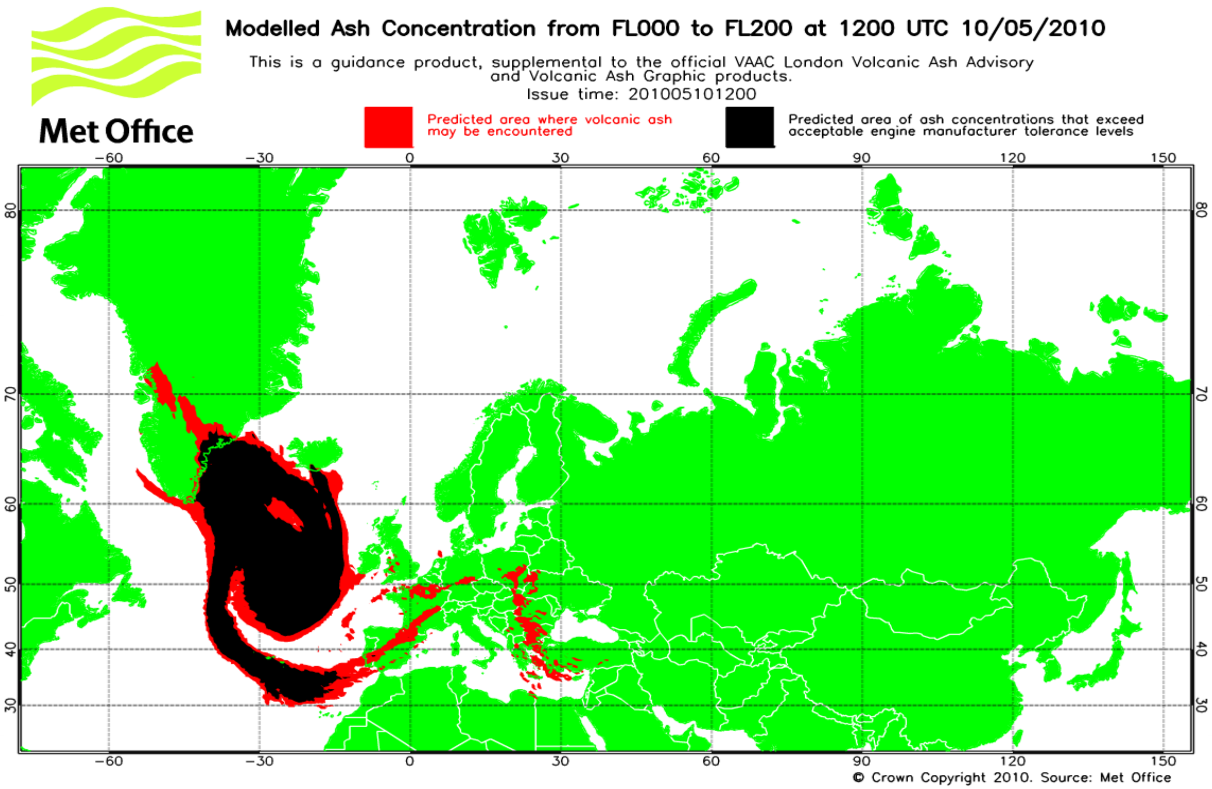

Lagrangian-NWP models of far-field suspended ash concentration need estimates of plume height and ash mass flux as input

Eyjafjallajokull produced small plumes that were strongly affected by the wind

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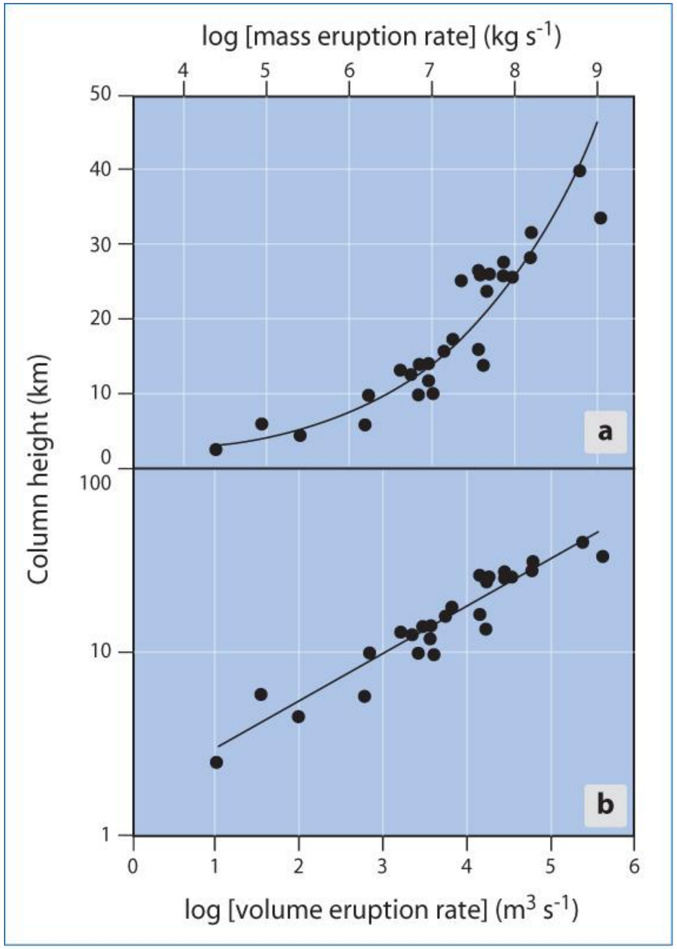
Prediction of Airborne Volcanic Ash Concentration



Volcanic ash flux is usually estimated from plume height via buoyant plume theory

Relationship is calibrated on larger (better preserved) deposits without consideration of wind

Sparks 1986, Mastin et al 2009

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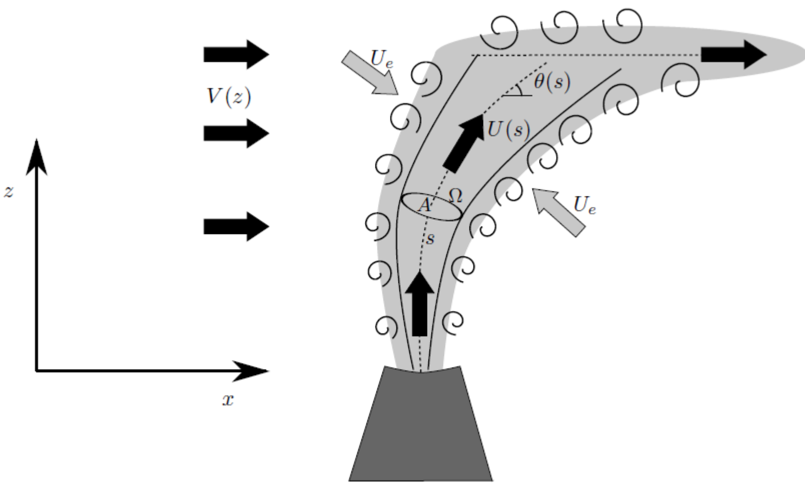
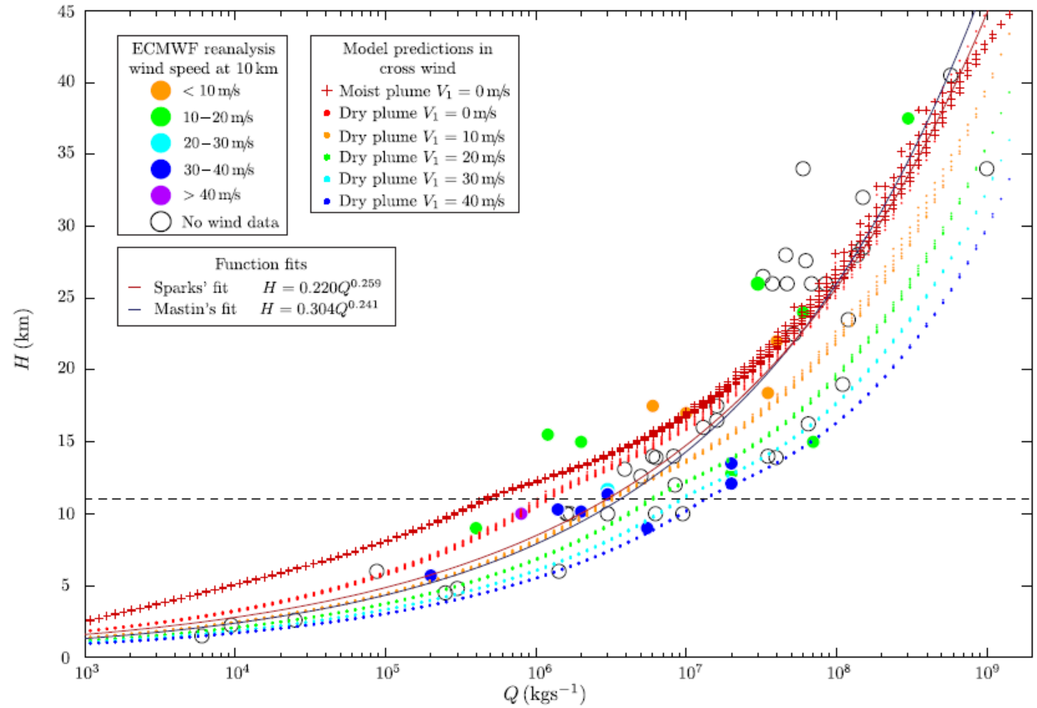
Prediction of Airborne Volcanic Ash Concentration





Reanalysis of historical data using ECMWF wind data shows a systematic trend of plume height decreasing as wind speed increases

Analysis using integral plume models with additional mixing due to wind can predict plume height and mass flux for plumes strongly affected by wind

Woodhouse et al., sub. Nature Geoscience

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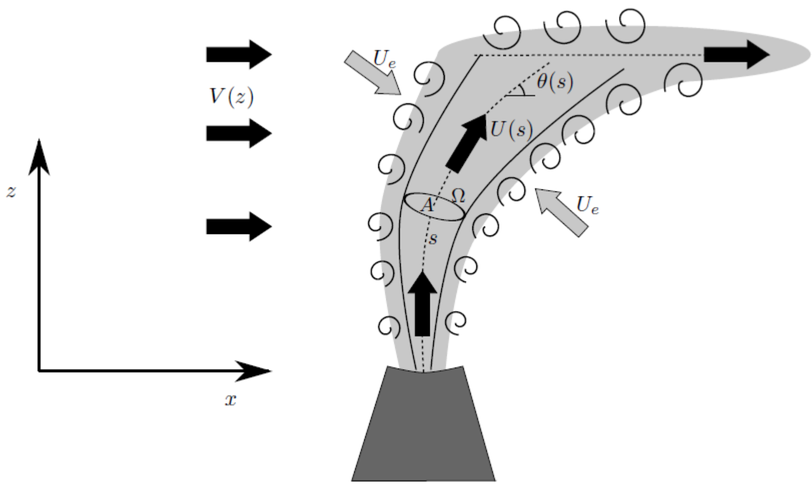

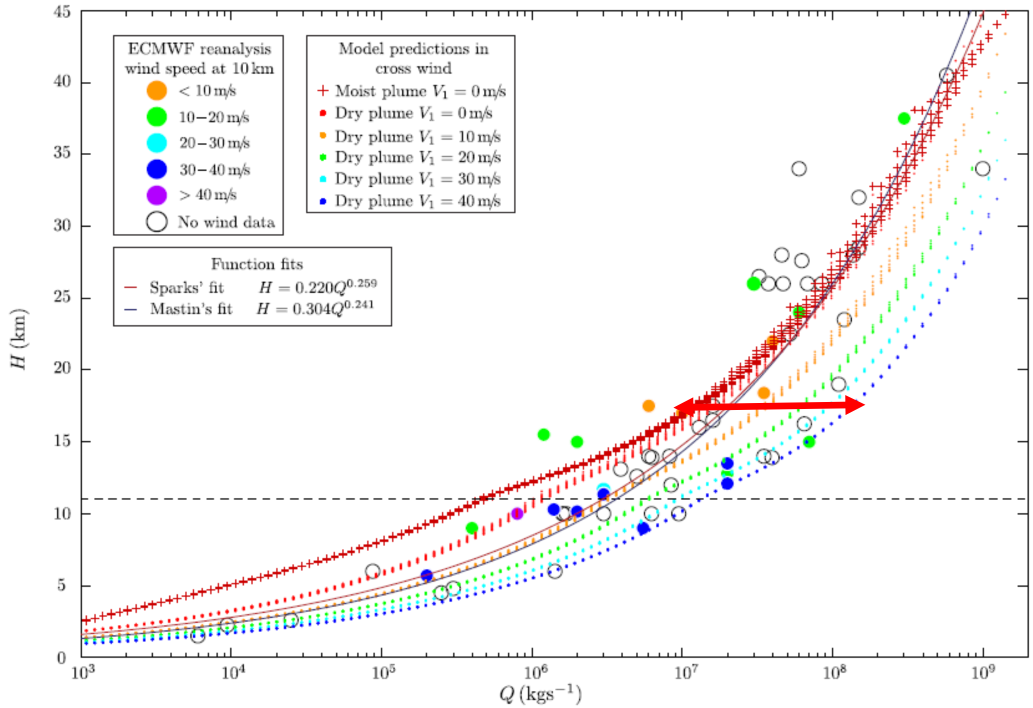

Model results adequately reproduce observations (particularly below the tropopause)

Source mass flux can be more than 10 times larger than no-wind model

Woodhouse et al., sub. Nature Geoscience

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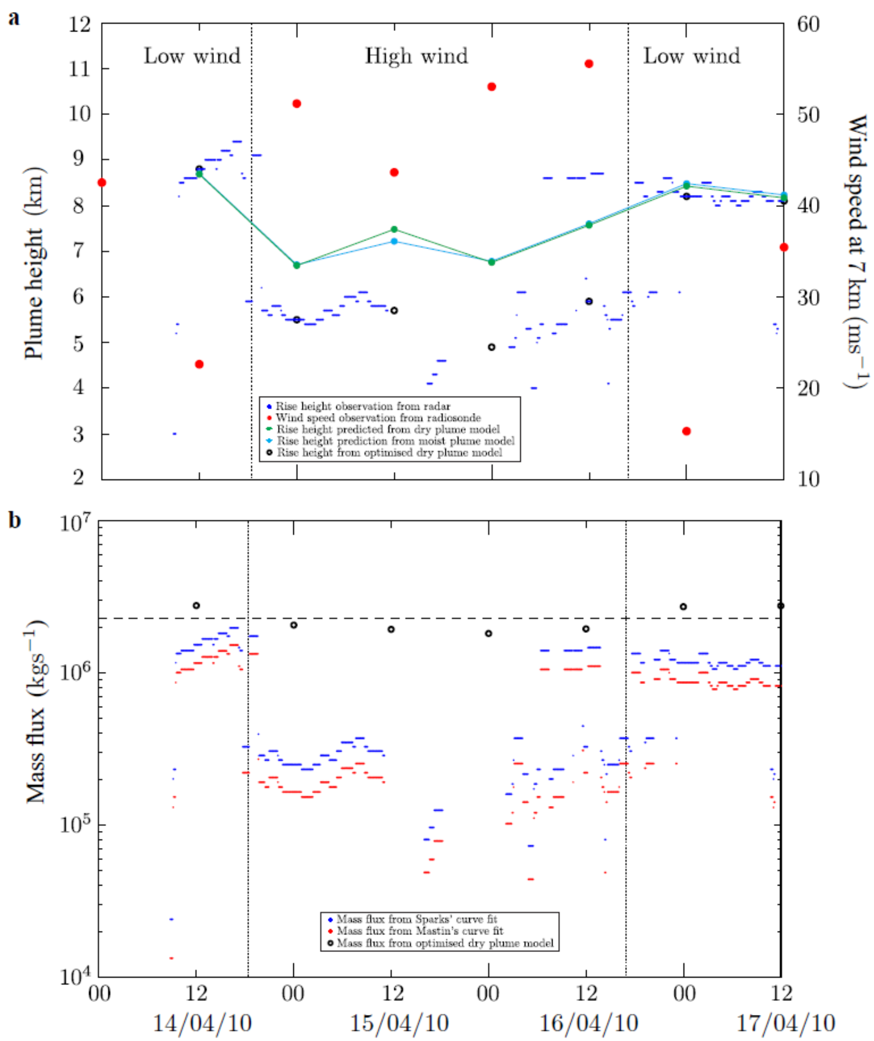
Prediction of Airborne Volcanic Ash Concentration



Model predictions compared with observations during Eyjafjallajokull eruption

Radar data obtained from Keflavik airport (150 km from volcano)

Blues lines are model predictions, red dots are wind speed at 7 km height

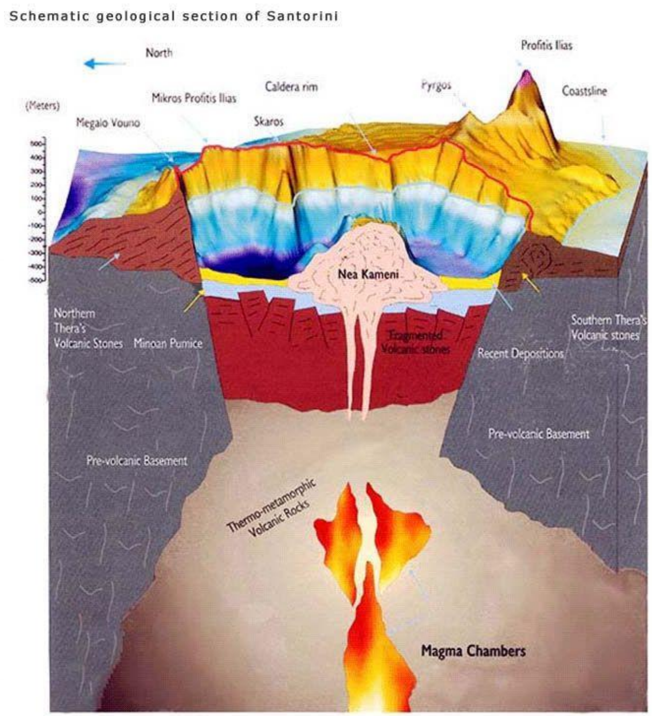
Model predicts anti-correlation between wind speed and plume height, but cannot capture all details without some tuning

Sudden changes in plume height are more likely to result from changes in wind than large changes in source mass flux

New inputs for far-field models

Woodhouse et al, sub. Nature Geoscience

Tephra Deposition from Wind-affected Ash Plumes



We have applied our model of wind-affected volcanic plumes to predictions of tephra deposition for the current unrest at Santorini, Greece

Current high rates of uplift suggest shallow magma emplacement under Kameni islands

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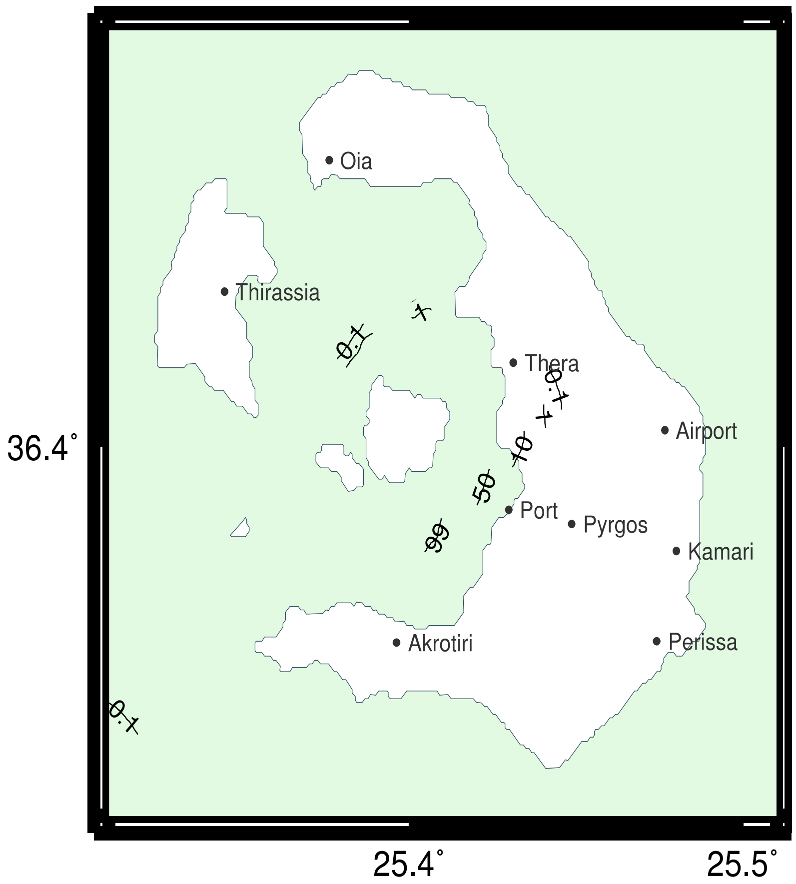
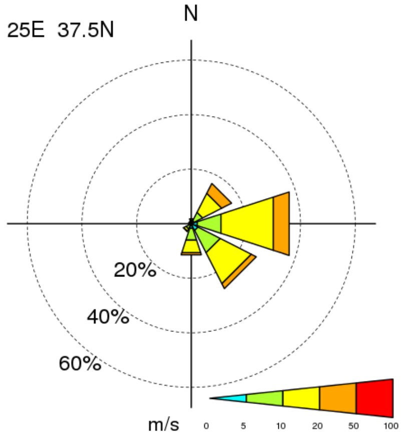
Tephra Deposition from Wind-affected Ash Plumes

Scenario 2a P(cumulative deposit >=10 kg/m2)





Wind speed and direction at 1 to 10 km

Wind-affected plume model has been used to set input conditions for tephra advection-diffusion model TEPHRA2

Stochastic forecasting of threshold deposition (~ 1 cm ash thickness) to be exceeded over two years of eruption based on 20 years of daily wind data

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Report to Greek Commission on Santorini 2012

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Tephra Deposition from Wind-affected Ash Plumes

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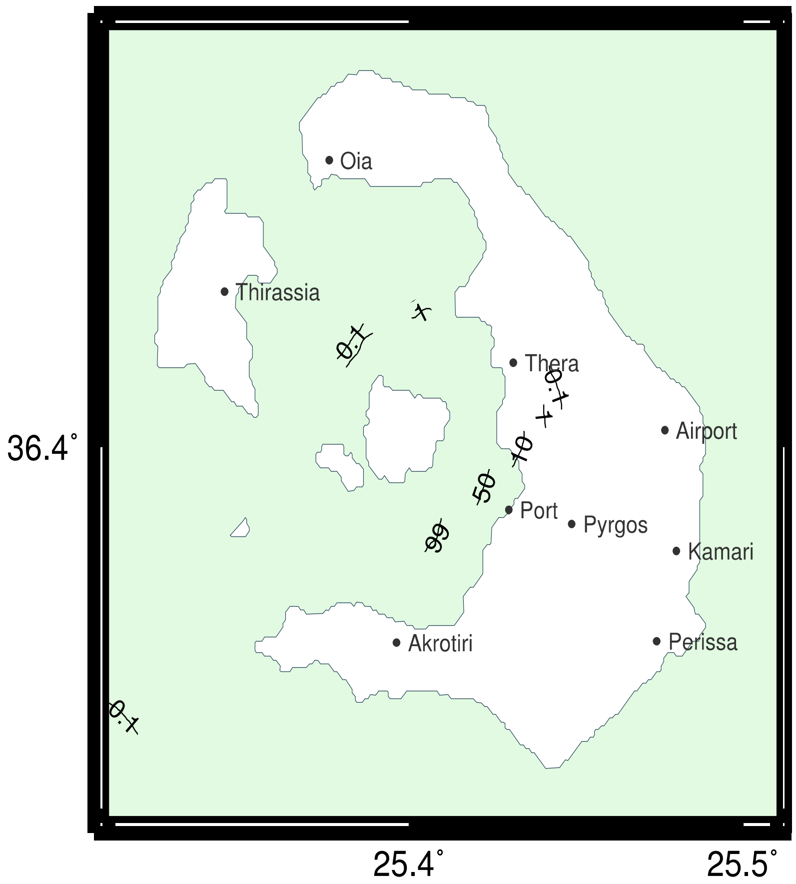

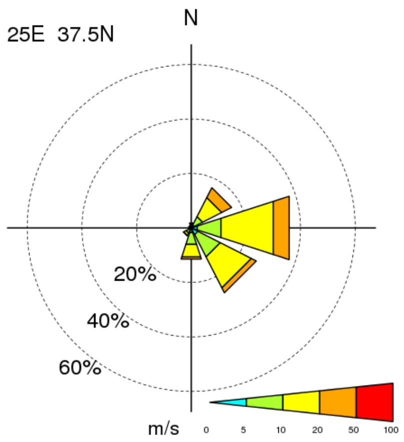

Wind speed and direction at 1 to 10 km

Eruption scenarios include ash venting (most likely) and sub-Plinian (largest considered or "worst case")

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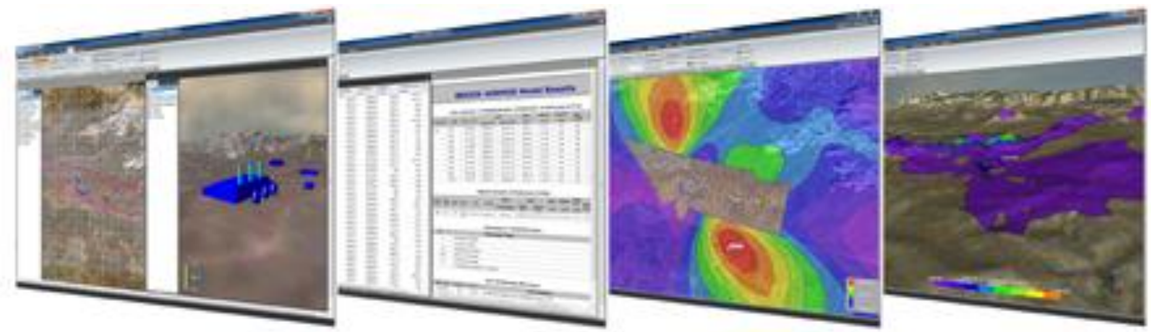
Modeling Exposure to Volcanic Gas Emissions



US EPA pollutant dispersal model AERMOD has also been applied to future Santorini eruptions to assess short and long term hazard to SO_2 and respirable particle exposure

Sulphur Dioxide	$PM_{2.5}$ Particles	PM_{10} Particles
15 minute mean	24 hour mean	24 hour mean
μgm^{-3}	μgm^{-3}	μgm^{-3}
0-88	0-11	0-16
89-176	12-23	17-33
177-265	24-34	34-49
266-354	35-41	50-58
355-442	42-46	59-66
443-531	47-52	67-74
532-708	53-58	75-83
709-886	59-64	84-91
887-1063	65-69	92-99
1064 or more	70 or more	100 or more

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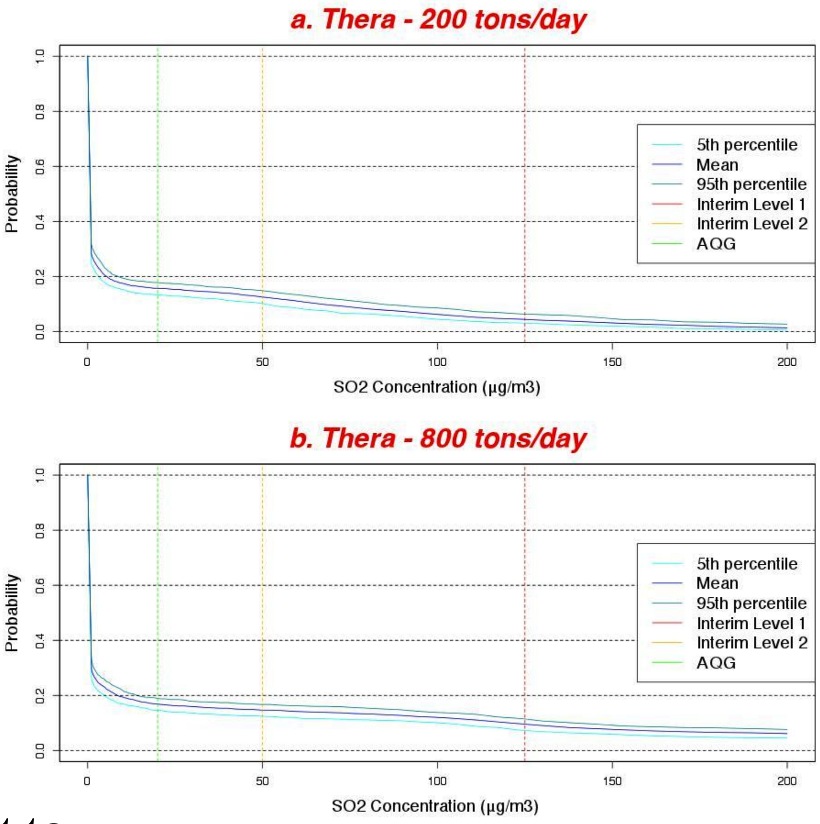


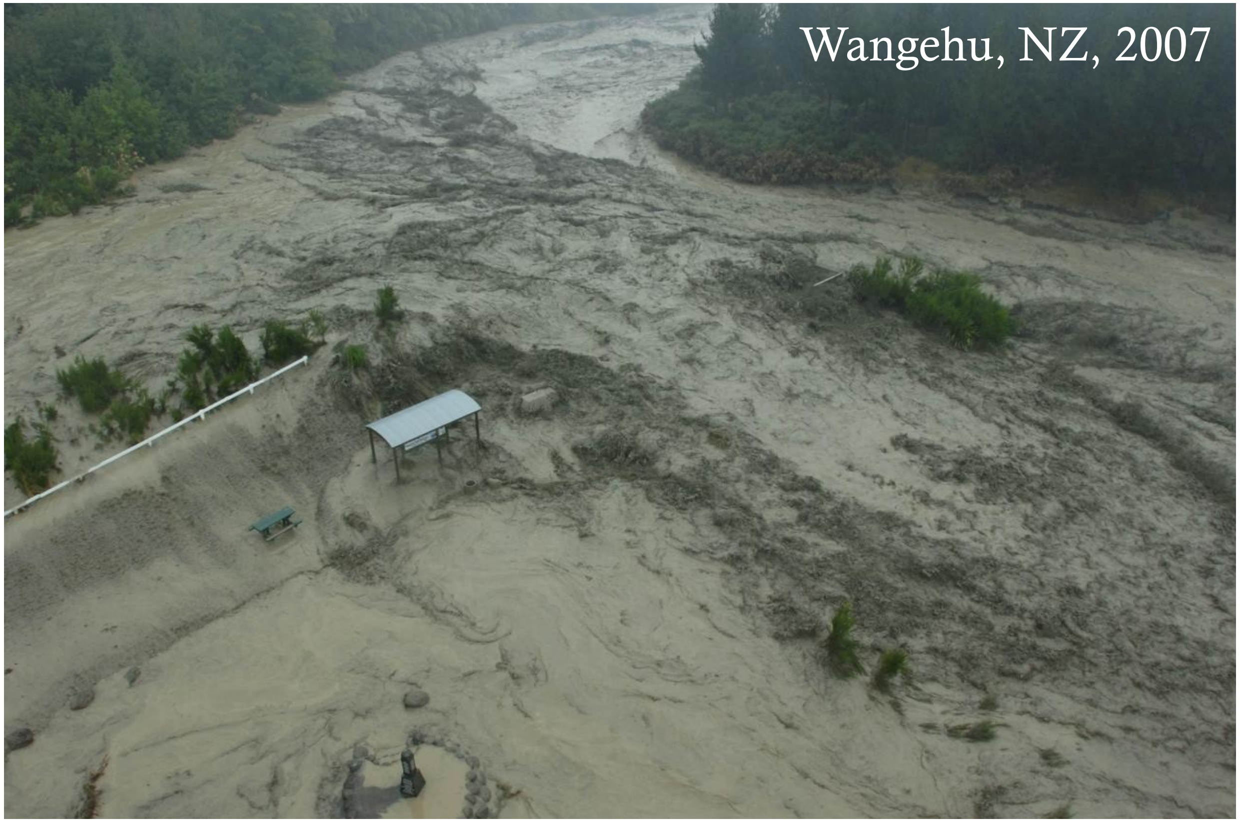
The probability of exposure from two SO_2 emission scenarios has been explored: typical for arc magma degassing rates; worst case

Daily probabilities for different exposure Limits

This is preliminary work that needs further input to explore uncertainty and probabilistic framework

Report to Greek Commission on Santorini 2012

Towards Predictive Models of Volcanic Lahars



Lahars are destructive volcanic mudflows with complex material properties

Cabot Institute involved in two major UK initiatives to develop models for lahar dynamics (STREVA) and model uncertainty (CREDIBLE)

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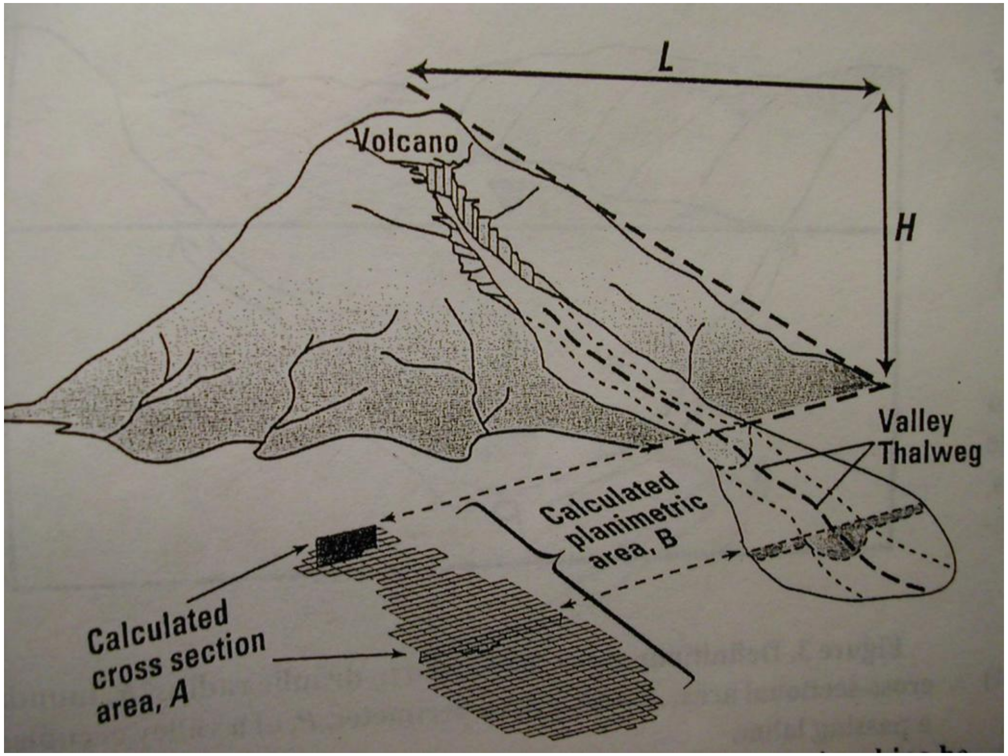
Towards Predictive Models of Volcanic Lahars



Widely-used hazard models e.g. LAHARZ (USGS) based on empirical fits to previous observations (27 individual events) of lahar inundation

$$A = 0.05V^{2/3}$$

$$B = 200V^{2/3}$$

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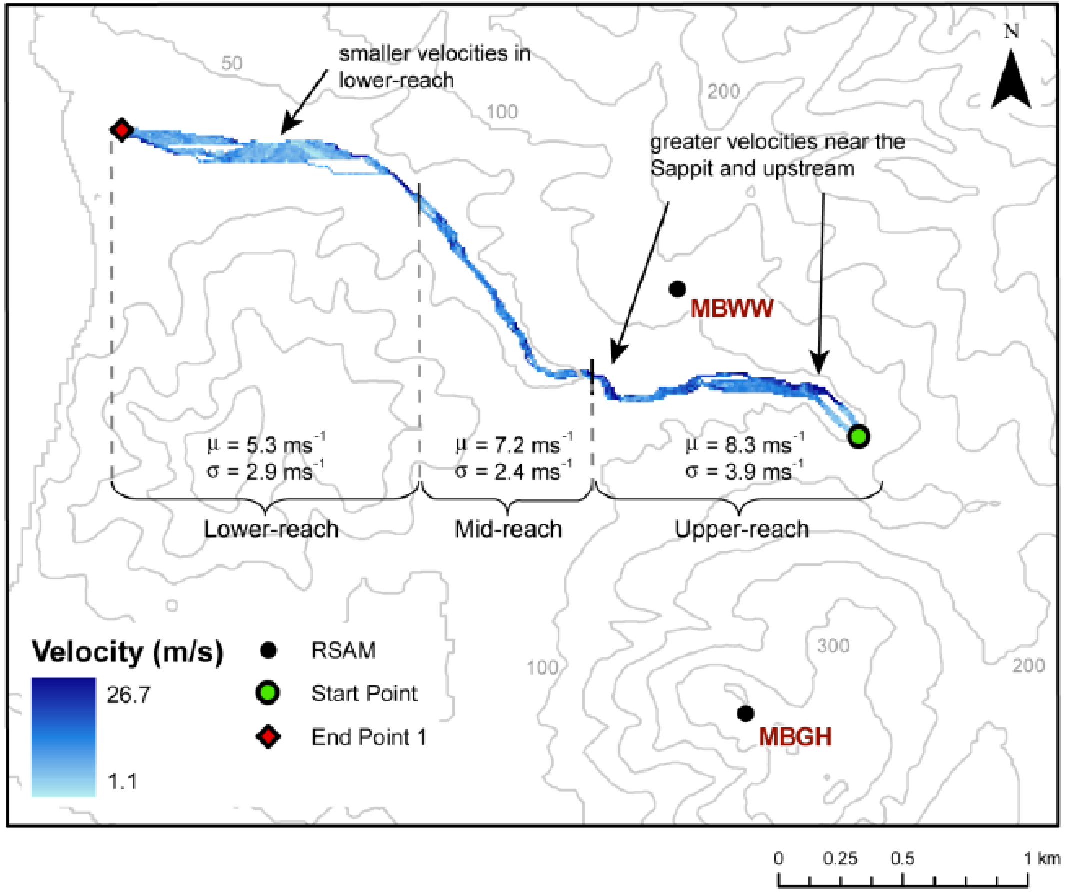
Towards Predictive Models of Volcanic Lahars



We have applied flood models to dilute lahars on Montserrat to predict inundation and dynamics

Darnell et al Bulletin of Volcanology

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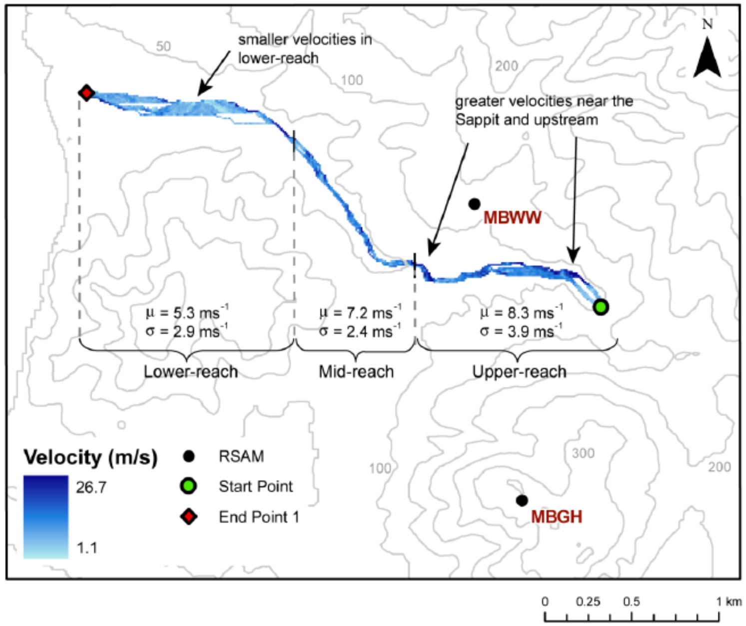
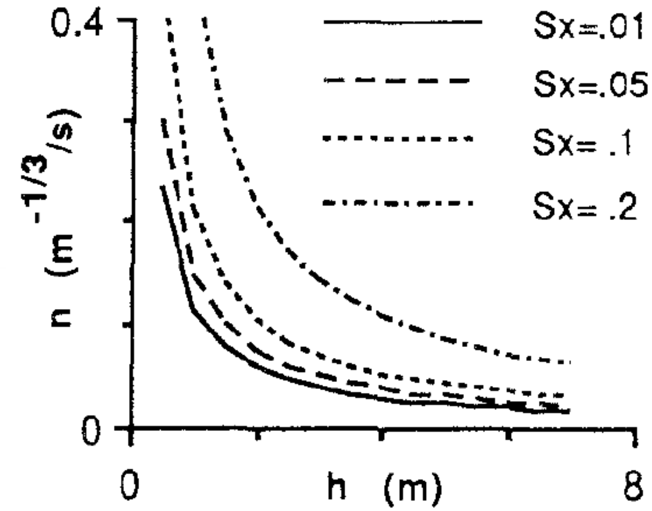
Towards Predictive Models of Volcanic Lahars





Model predictions are in reasonable agreement with observations

Approach needs to be further developed for higher concentration mudflows by calibration of hydraulic resistance coefficients using flume experiments

Initiation via rainfall and snow melting needs to be suitably parameterised (related research by Prof Fujita at Ujigawa Laboratory, DPRI)

 Darnell et al Bulletin of Volcanology

Challenges and Opportunities

New physical models are being developed for :

- Tephra deposition from smaller (and more common) explosive eruptions
- Airborne volcanic ash flux and intrusion height into the atmosphere
- Volcanic gas hazard
- Lahar initiation and dynamics

Opportunities exist for related :

- Model development
- Model testing with observational data
- Risk assessments for these hazard studies
- Population education for DRR
- ‘Citizen Science’ to obtain new measurement datasets

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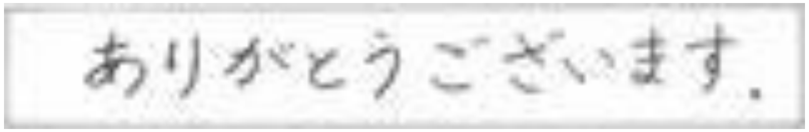

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Volcanic Eruption Hazards




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Challenges and Collaborations

Improved description of wind-affected plumes can improve hazard and risk estimation for smaller (more common) eruptions, but needs further testing against observations

Airborne ash concentration forecasting from future eruption scenarios is starting to become possible

Further scenarios need to be explored to assess application of gas dispersion modelling

Lahar models need experimental calibration data for a wide range of particle concentrations and flow conditions

Risk assessments for these hazard studies need to be explored and developed

Modeling Exposure to Volcanic Gas Emissions