‘SOME MODELS ARE USEFUL’ -

LEARNINGS AND REFLECTIONS ON REDUCING RISK FROM VOLCANOES

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(and many others)

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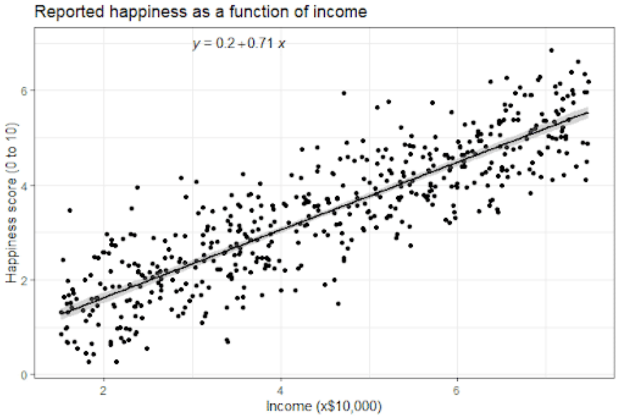
Outline

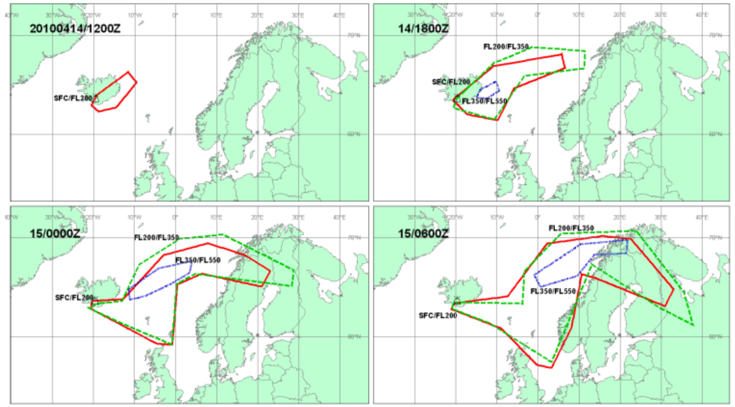
- About models…
- Typical scientific uses of models to characterise and predict volcanic hazard events
- Other ways that models can help reduce disaster risk

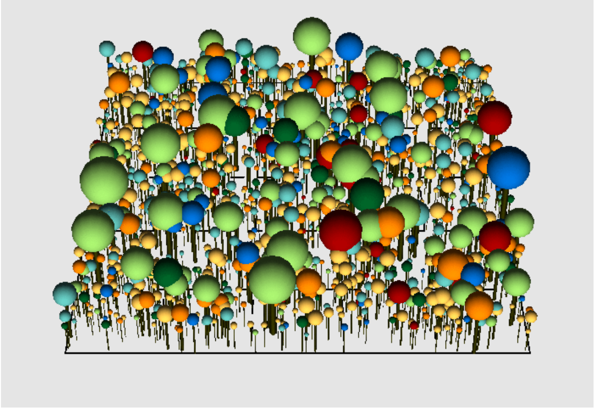
What is a model?

- Not these


- But these



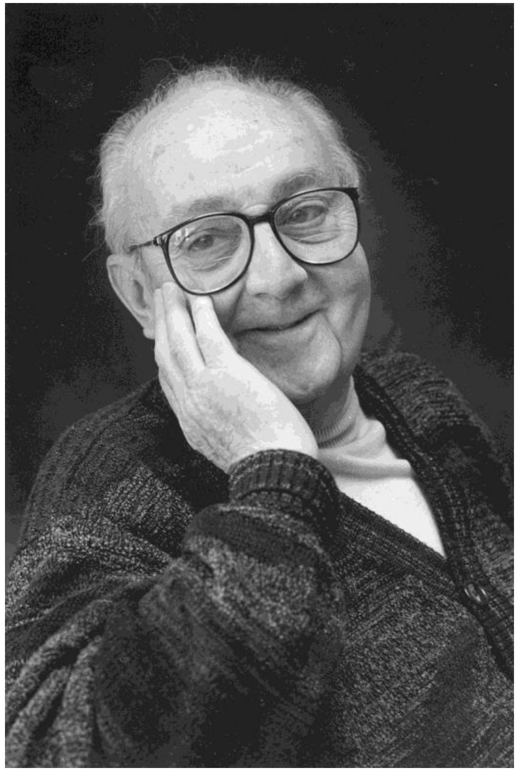




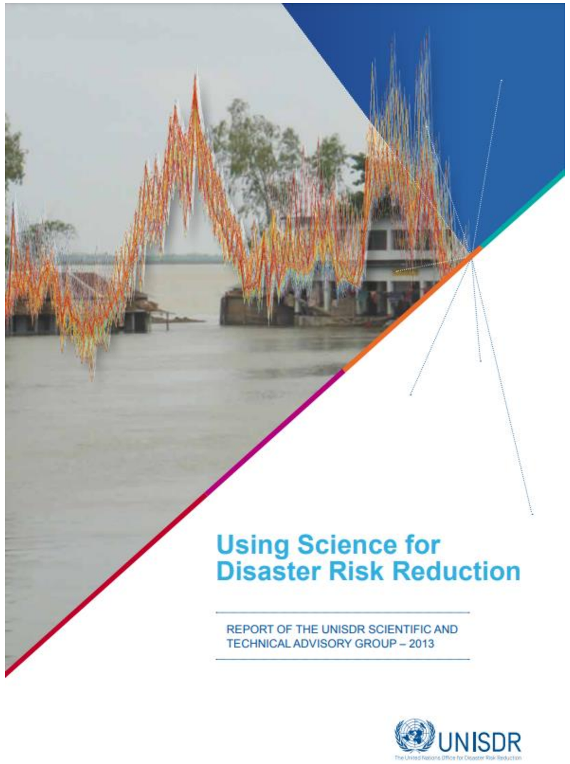
- A model is a simplified representation of a physical process
- Models help us to understand and interpret observations and to predict future events

All models are wrong…

… but some are useful



George Box FRS
(1919-2013)



integration of science into disaster risk reduction policy making

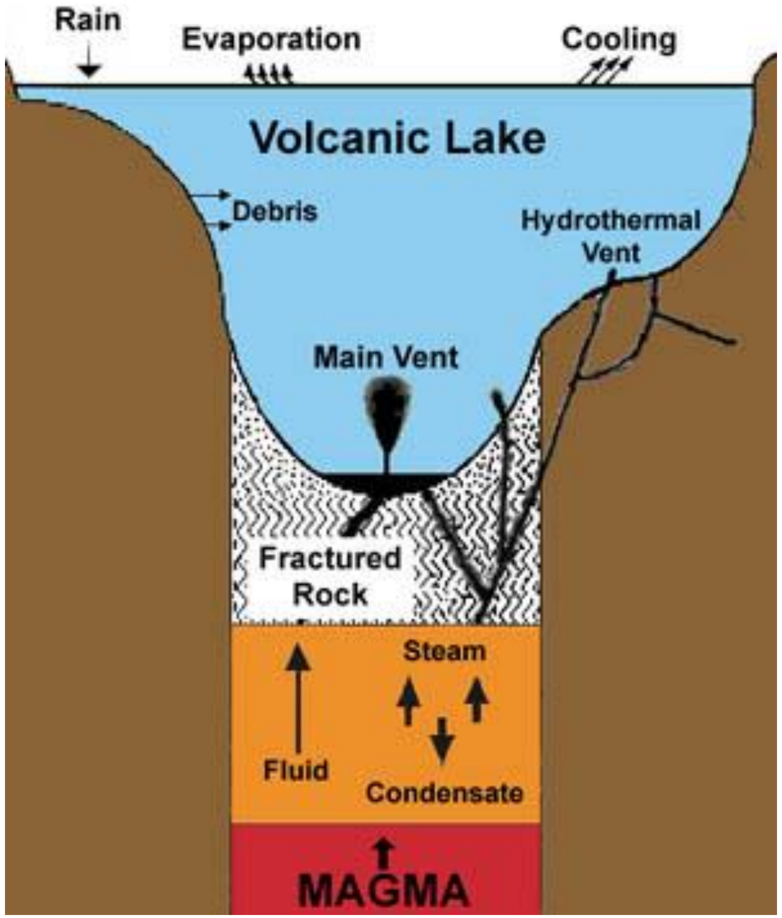
will depend on science being ‘useful, useable and used’

Dangerous Volcanic Lakes

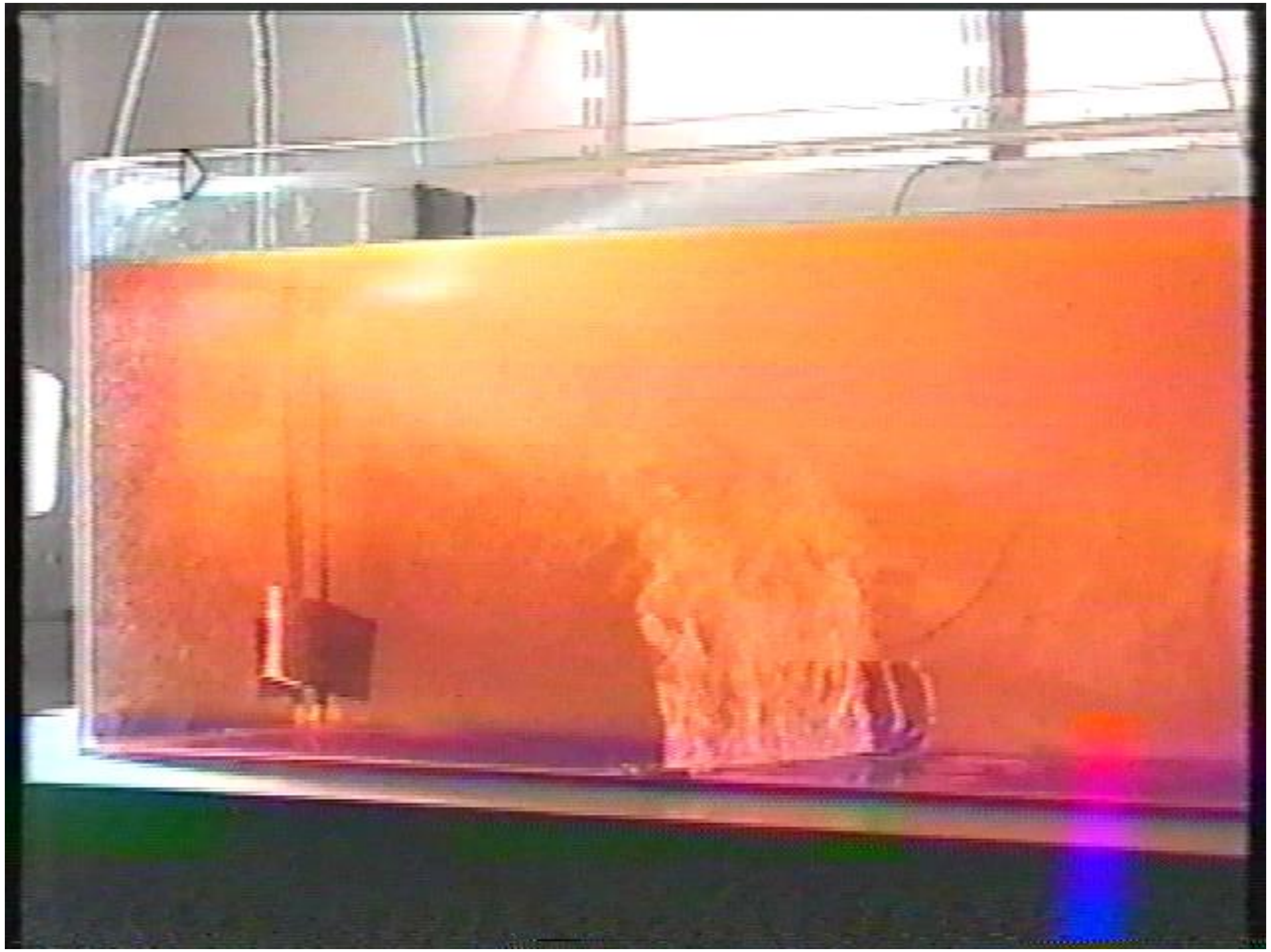
Lake Nyos, Cameroon

- Volcanically-derived CO_2 is highly soluble in water and was gradually stored at depth in the lake
- Landslide triggered lake overturn in 1986 and subsequent gas release killed 1750 people and 3500 livestock

Dangerous Volcanic Lakes

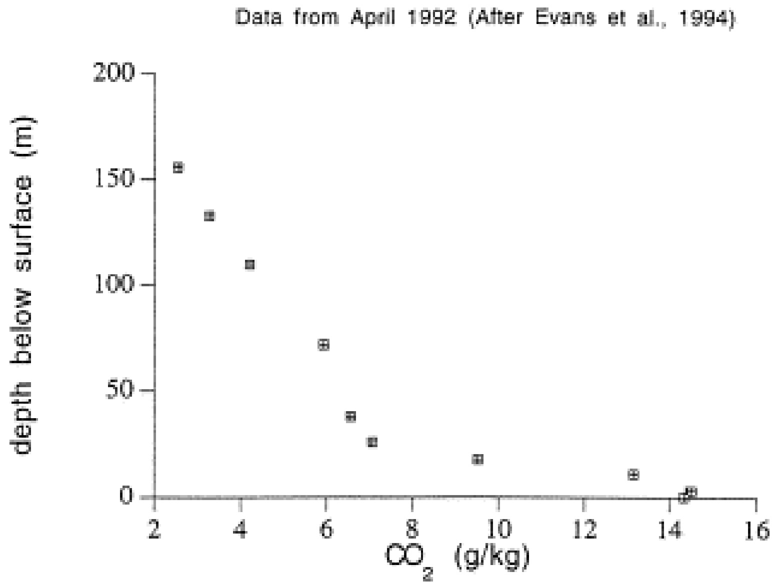


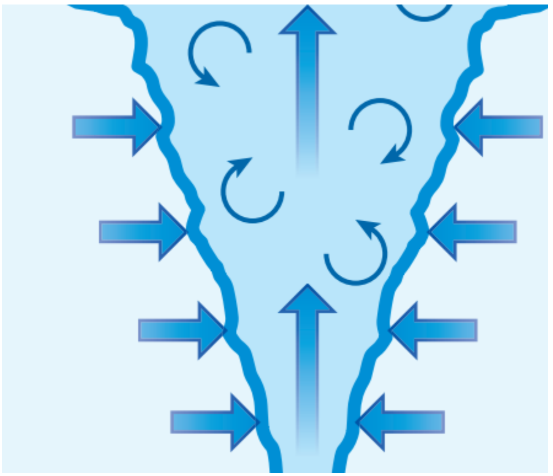
Schematic view of gas release into a volcanic crater lake

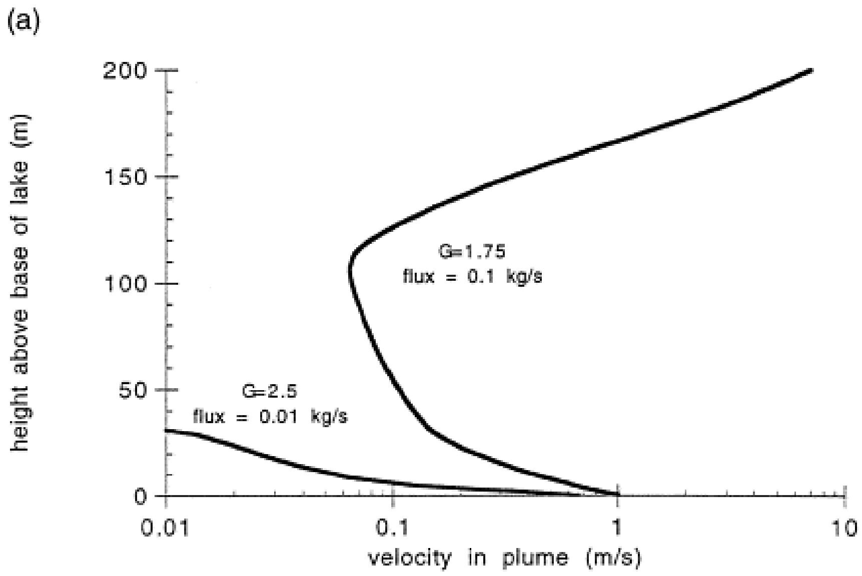


Laboratory experiment showing how plumes of exsolved gas bubbles drive circulation in a tank of salt water

Dangerous Volcanic Lakes

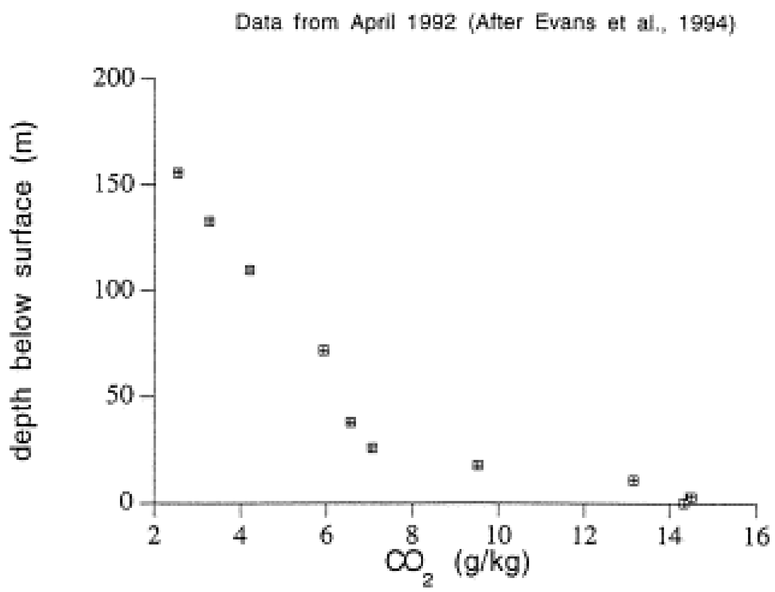


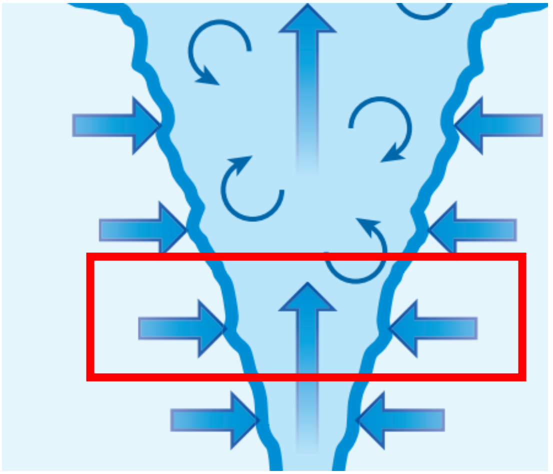


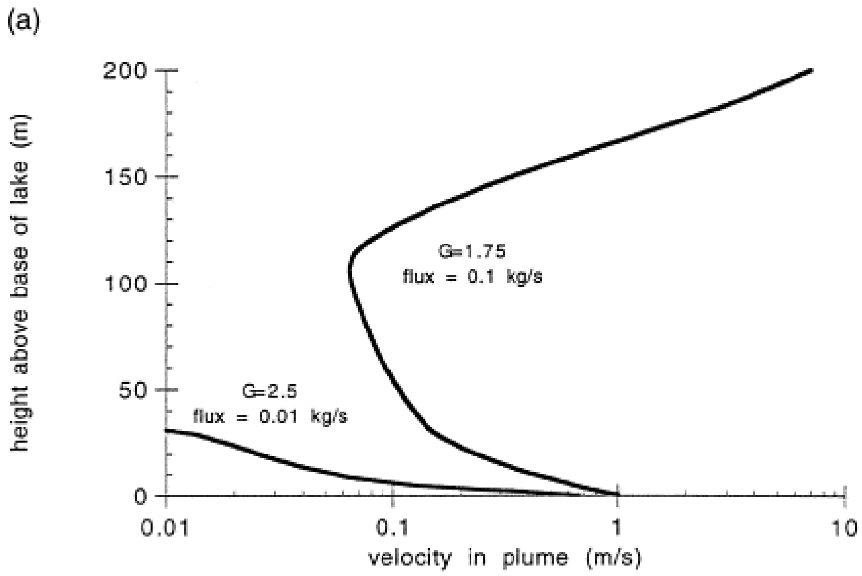


A model of CO_2 exsolution in a volcanic crater lake can be formulated, based on the gradient of CO_2 concentration and the dynamics of bubble plume mixing with lake water, to predict the height to which the bubble plume will rise in the lake

Dangerous Volcanic Lakes



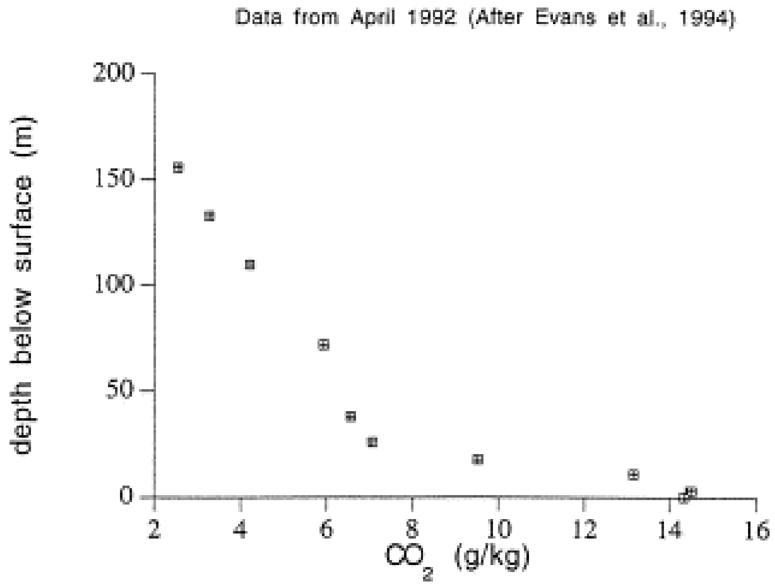


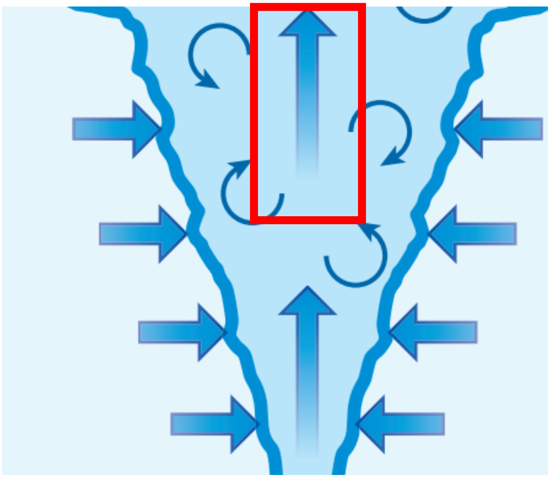


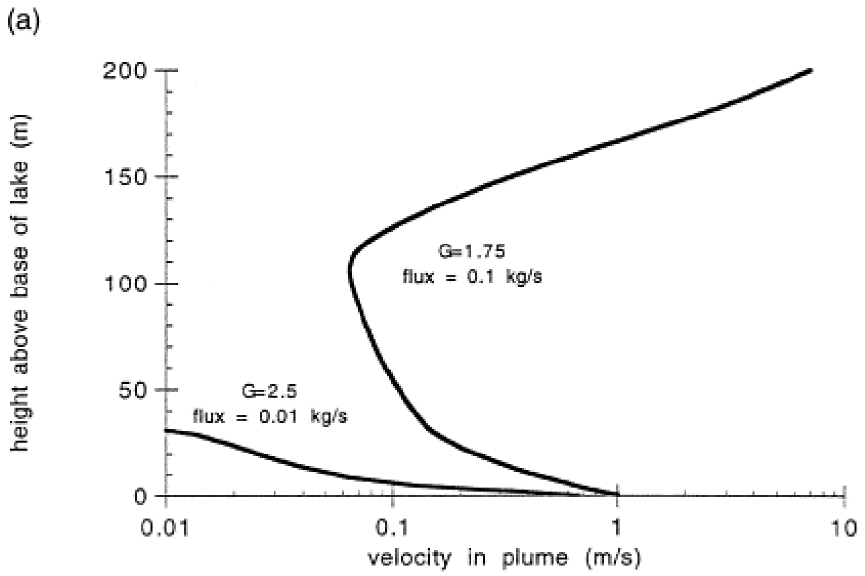
$$\boxed{\frac{\mathrm{d}Q}{\mathrm{d}z} = 2\epsilon\rho_e^{1/2}M^{1/2}}$$

This equation describes how the bubble plume mixes in surrounding lake water, which contains dissolved CO_2

Dangerous Volcanic Lakes





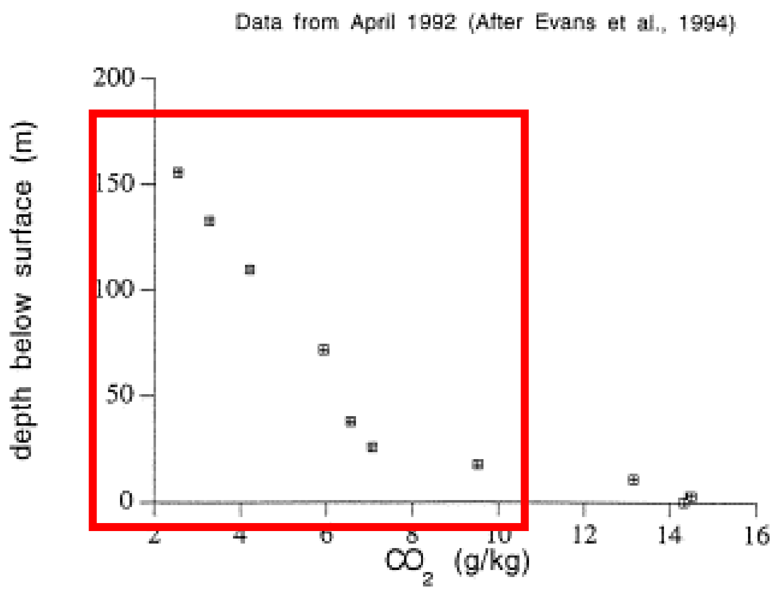


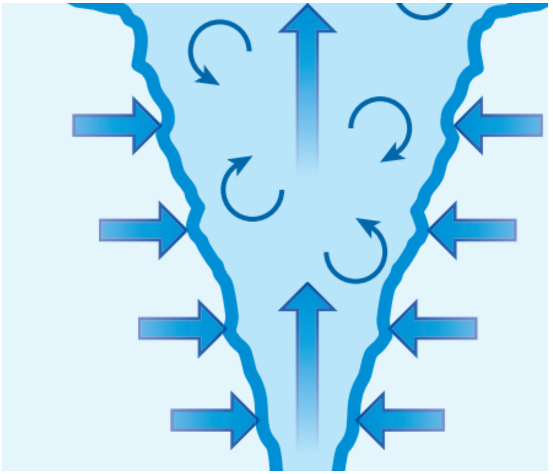
$$\frac{dQ}{dz} = 2\epsilon\rho_e^{1/2}M^{1/2}$$

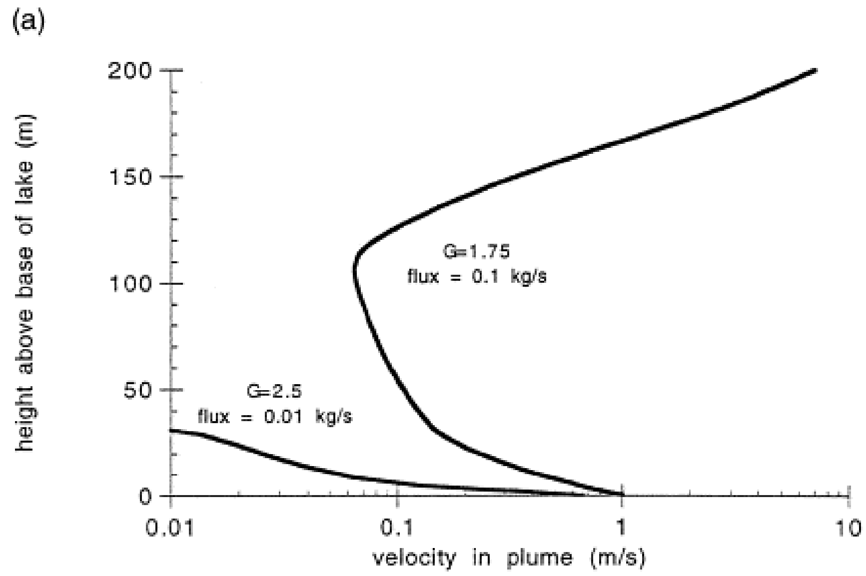
$$\boxed{\frac{dM}{dz} = \frac{(\rho_e - \rho)gQ^2}{\rho_o M}}$$

This equation describes how the bubble plume rises by buoyancy

Dangerous Volcanic Lakes







$$\frac{dQ}{dz} = 2\epsilon\rho_e^{1/2}M^{1/2}$$

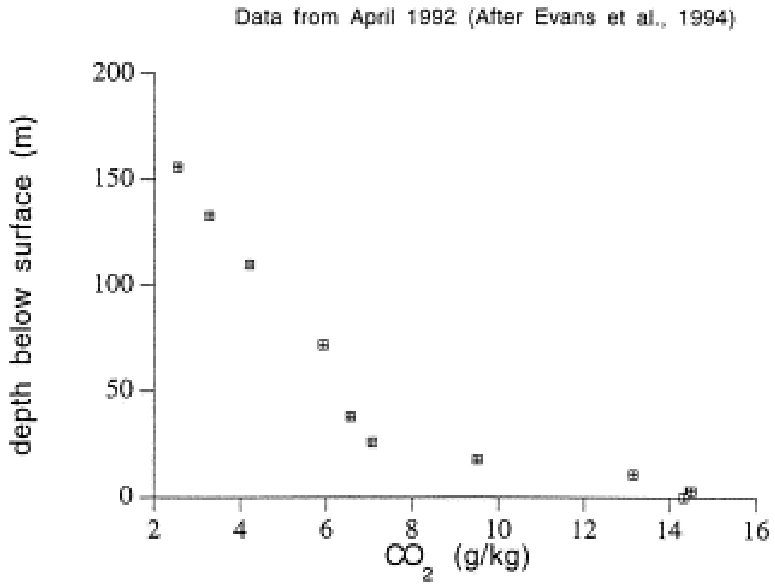
$$\frac{dM}{dz} = \frac{(\rho_e - \rho)gQ^2}{\rho_o M}$$

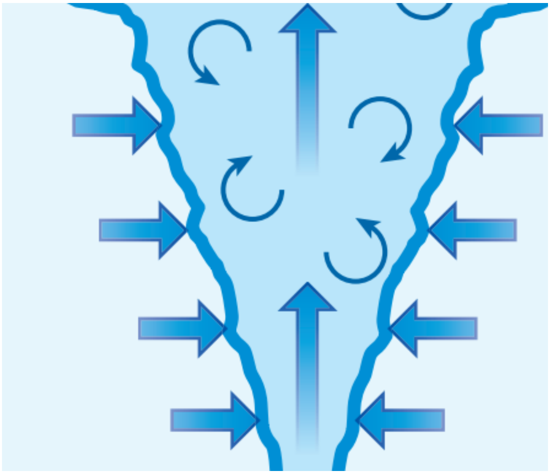
$$n_e(z) = n_s(0) - 0.03\,Gz/H$$

$$\text{for} \quad z < z_1 = n_s(0)\,H/0.03G$$

This equation describes how the dissolved CO_2 varies with depth in the lake, and this gradient controls whether the plume will rise to the top of the lake or stop at some lower level

Dangerous Volcanic Lakes





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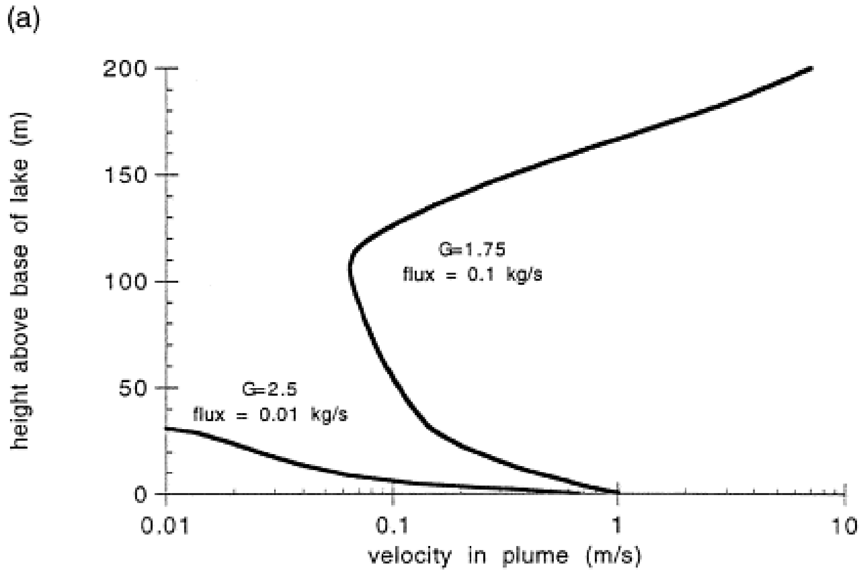


Model solutions identify CO_2 concentration profiles that result in gas eruptions

(Woods and Phillips 1999)

Dangerous Volcanic Lakes

The solution – degas the lake using a long siphon!

Dangerous Volcanic Lakes

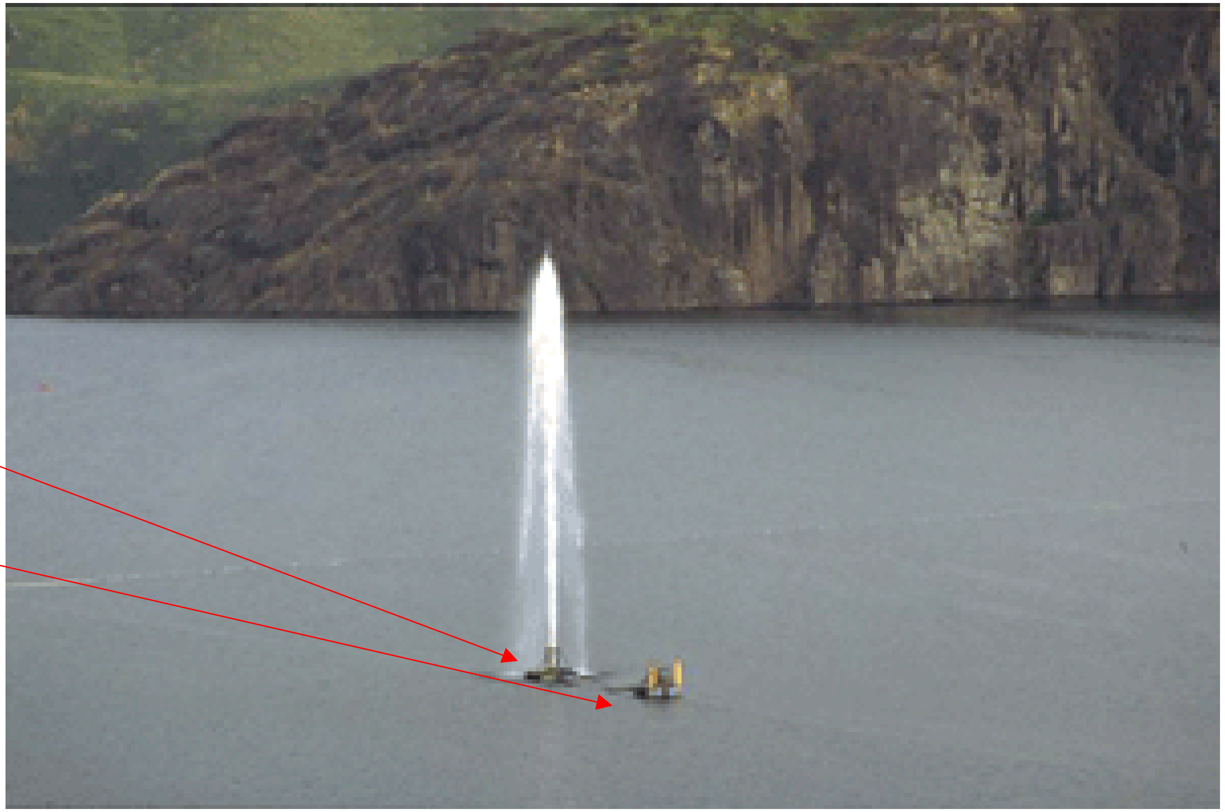
Don't
drop this

The solution – degas the lake using a long siphon!

The model showed that dropping the pipe during construction could be sufficient to trigger a gas eruption

Dangerous Volcanic Lakes

These might sink



The solution – degas the lake using a long siphon!

The model showed that the gas eruption might cause the pontoon and boats to sink

Dangerous Volcanic Lakes

The solution – low density plastic pipe used for the siphon

Volcanic Ash!

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The big debate: Analysis, opinion and full reports
SEE PAGES 4,5,6&7

BRITAIN IS SHUT TO THE WORLD

Volcano could cause air chaos for weeks

MILLIONS of passengers were stranded at home and abroad today as a cloud of volcanic ash grounded flights to and from all UK airports for the first time. As insurers and airlines began to calculate the cost, experts warned the chaos could continue for weeks.

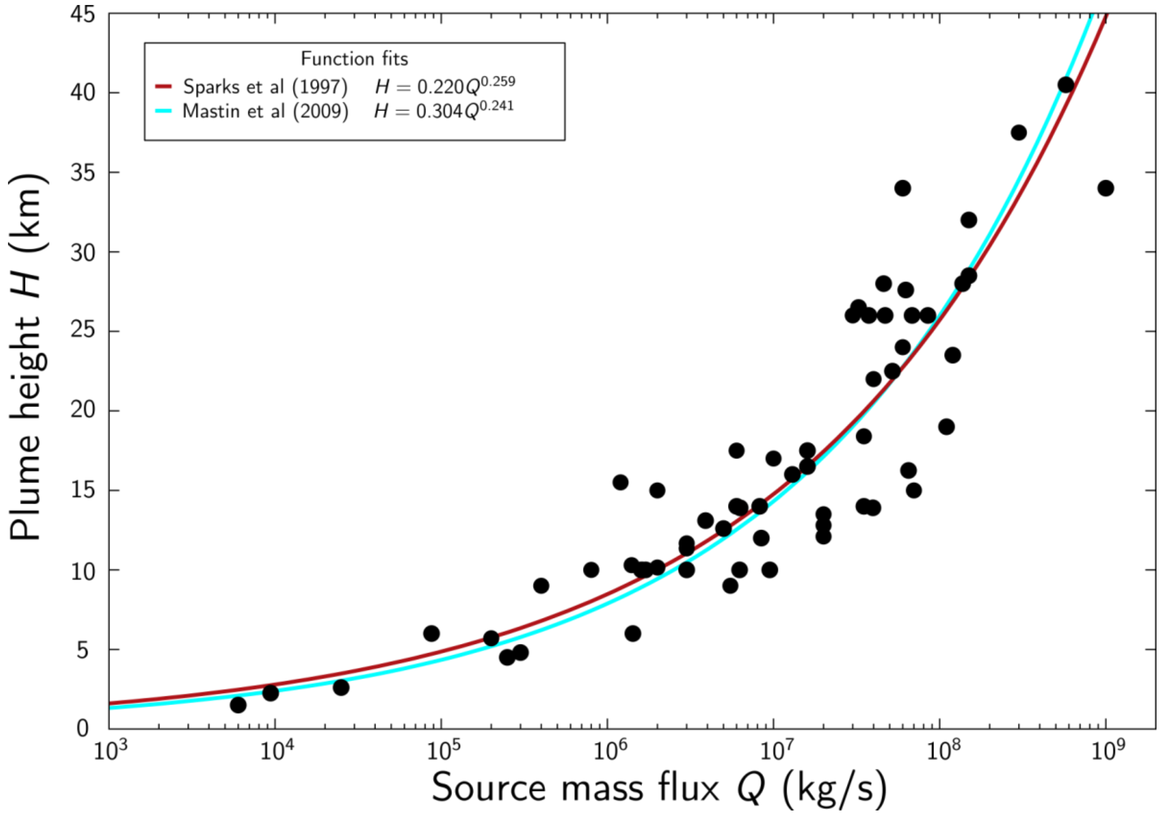
MILLIONS OF HOLIDAYS RUINED – PAGES 2&3

GATWICK: A scene repeated at every airport in Britain yesterday

The eruption of Eyjafjallajokull in 2010 sent volcanic ash into the atmosphere over Europe, disrupting air travel

Explosive Volcanic Eruptions

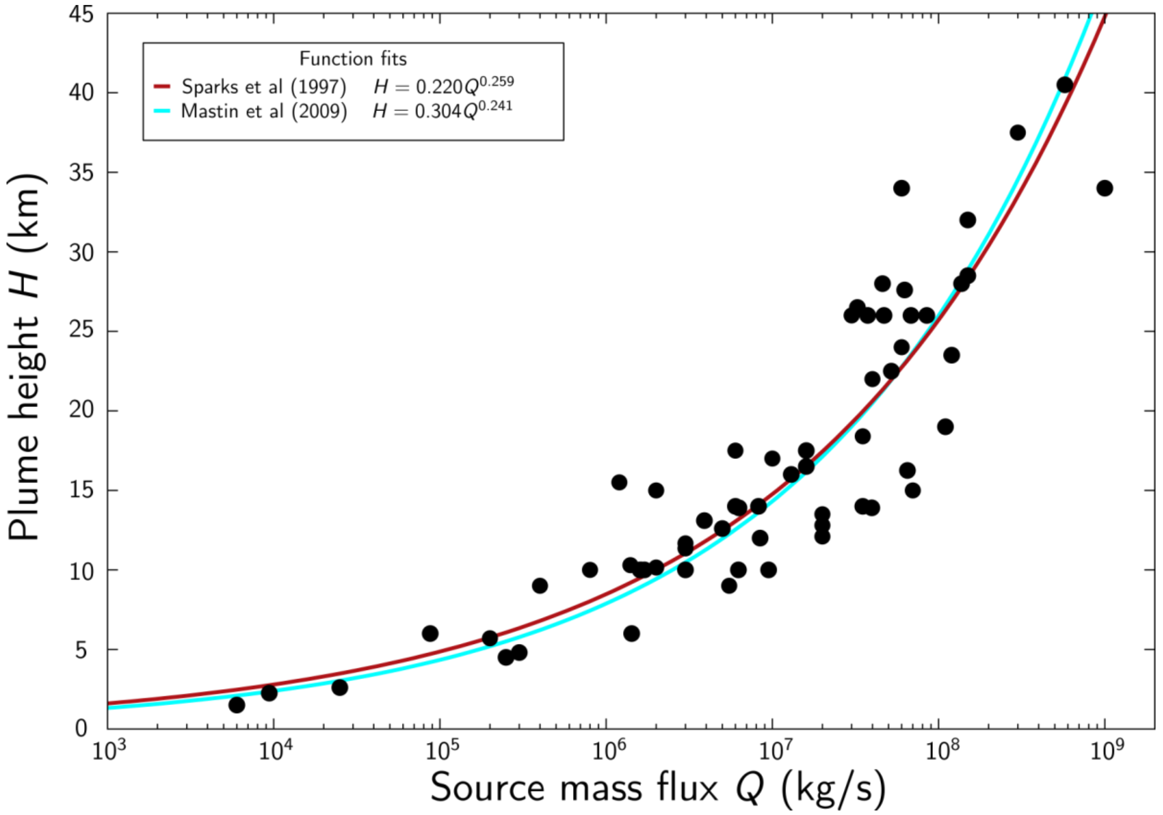
Puyehue 2011



In a large explosive eruption, a plume of volcanic ash rises to some maximum height in the atmosphere

This height can be used to estimate the source mass flux, which tells us how far ash might be dispersed

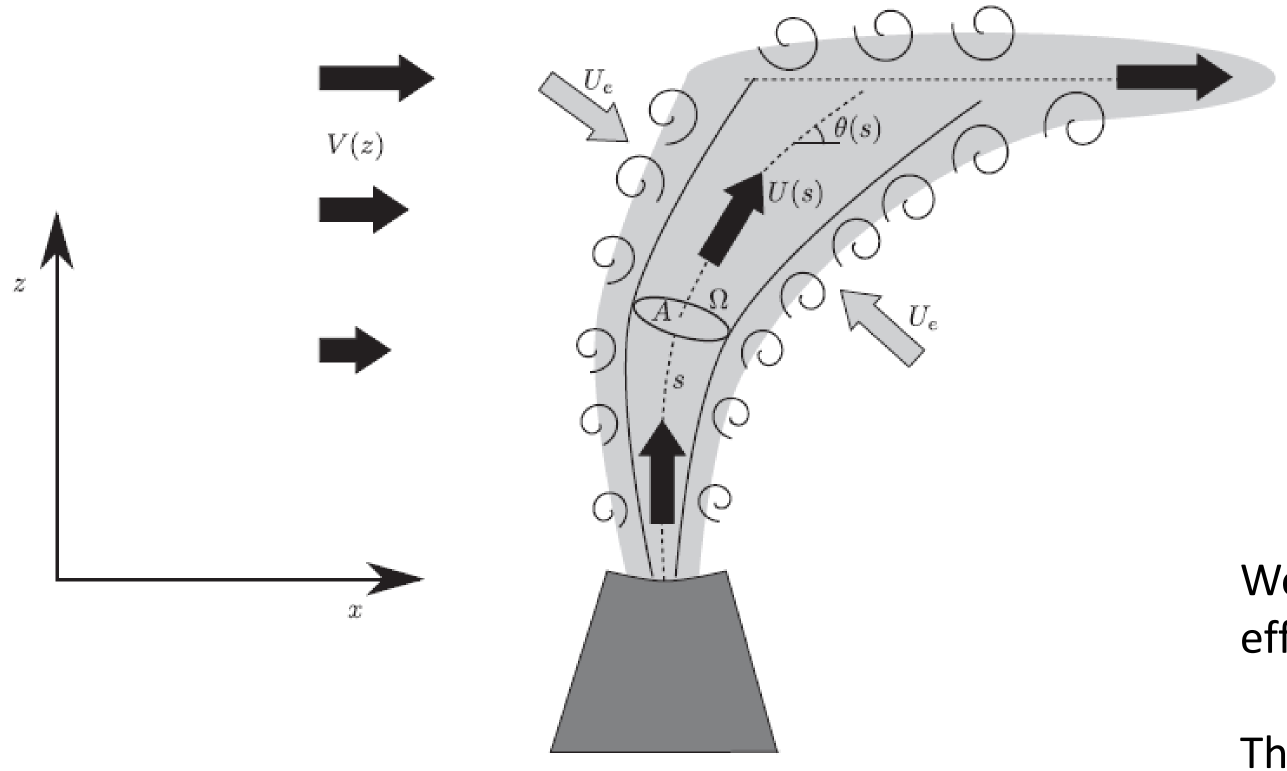
Eyjafjallajokull 2010



When the atmospheric wind is strong, the plume cannot rise as high for a given source mass flux

Not accounting for the wind means the source mass flux will be underestimated, and this could be by orders of magnitude

Wind-affected Volcanic Plume Model

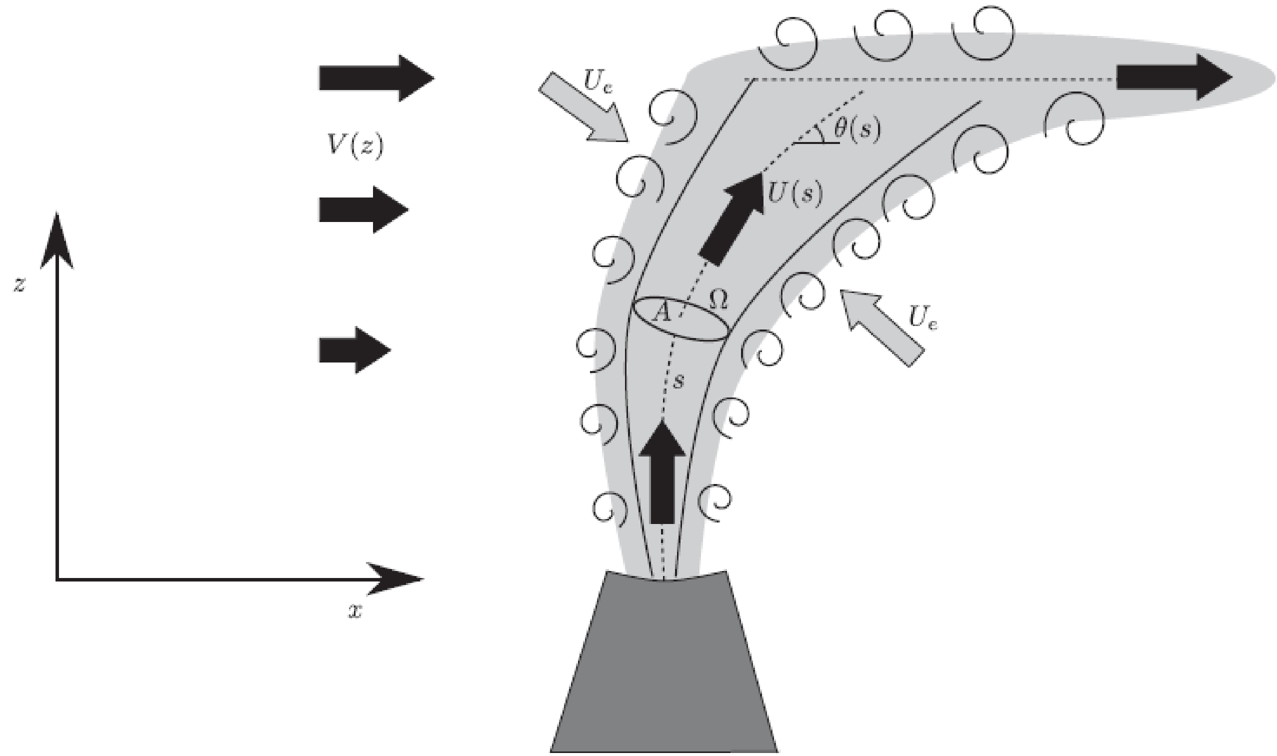


Plume entrains ambient fluid and momentum from cross-wind

We can write down a mathematical model describing the effect of the wind bending the volcanic ash plume

This model uses similar physics as the bubble plume rising in a volcanic crater lake

Wind-affected Volcanic Plume Model



$$\frac{\mathrm{d}}{\mathrm{d}s}\left(\rho U R^2\right) = 2\rho_a U_e R,$$

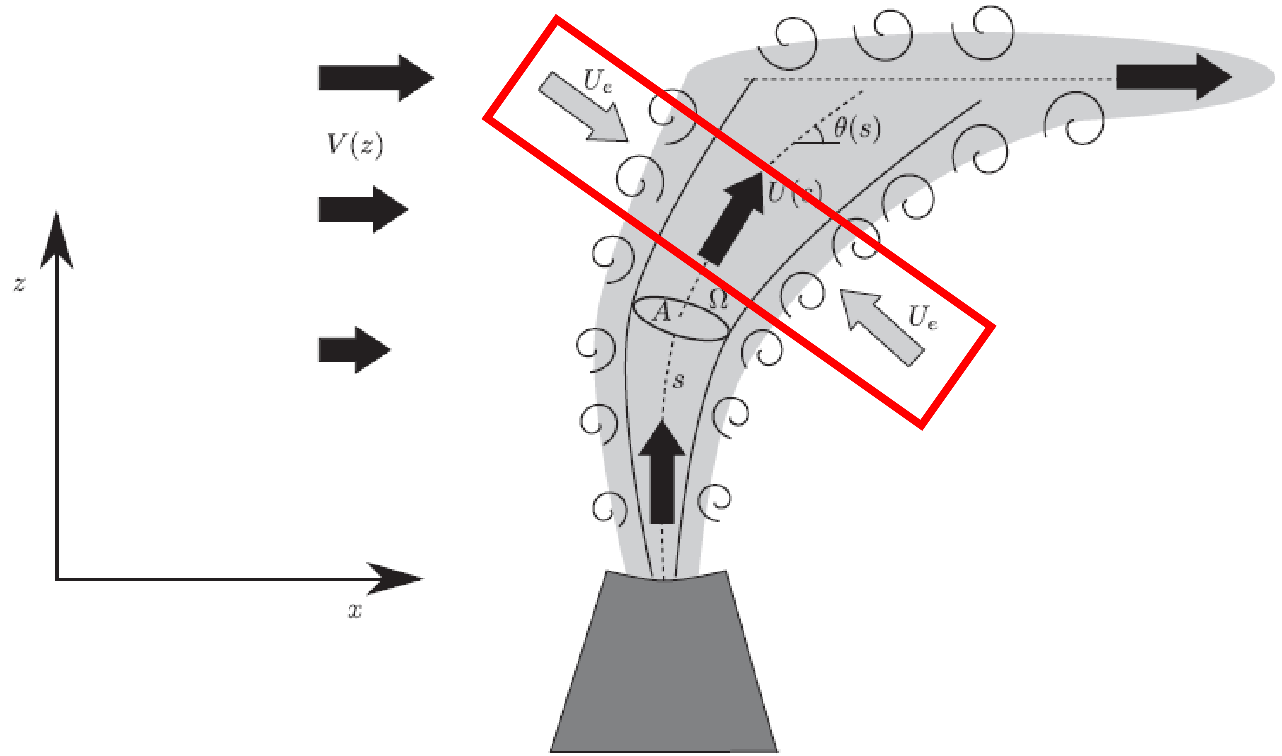
$$\frac{\mathrm{d}}{\mathrm{d}s}\left(\rho U^2 R^2 \sin\theta\right) = (\rho_a - \rho) g R^2,$$

$$\frac{\mathrm{d}}{\mathrm{d}s}\left(\rho U^2 R^2 \cos\theta\right) = 2\rho_a U_e R V,$$

$$\frac{\mathrm{d}}{\mathrm{d}s}\left(\rho U R^2 \left(C_p T + \frac{U^2}{2} + gz\right)\right) = 2\rho_a R U_e \left(C_a T_a + \frac{U_e^2}{2} + gz\right).$$

$$U_e = k_s \left|\frac{M}{Q} - V\cos\theta\right| + k_w |V \sin\theta|.$$

Wind-affected Volcanic Plume Model



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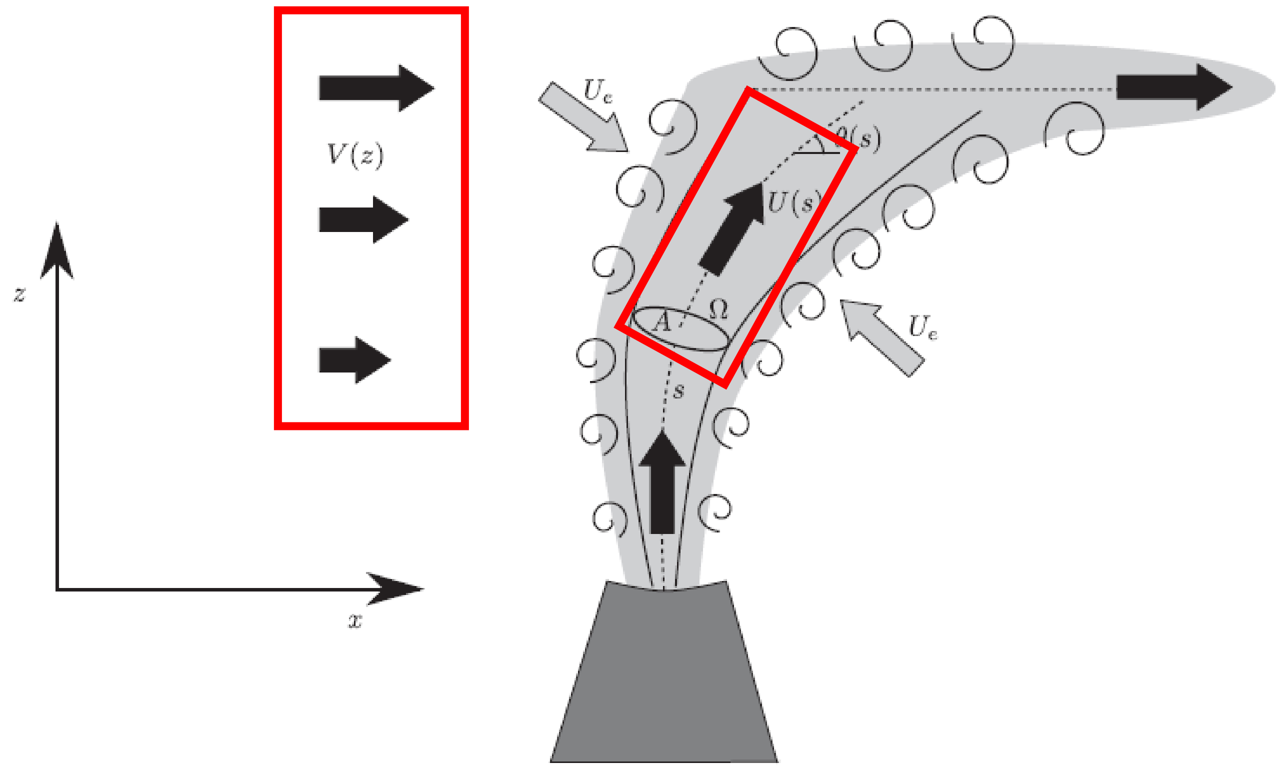
$$\boxed{U_e = k_s \left|\frac{M}{Q} - V\cos\theta\right| + k_w |V \sin\theta|.}$$

These equations describe how the surrounding air and wind is mixed into the plume

Wind-affected Volcanic Plume Model



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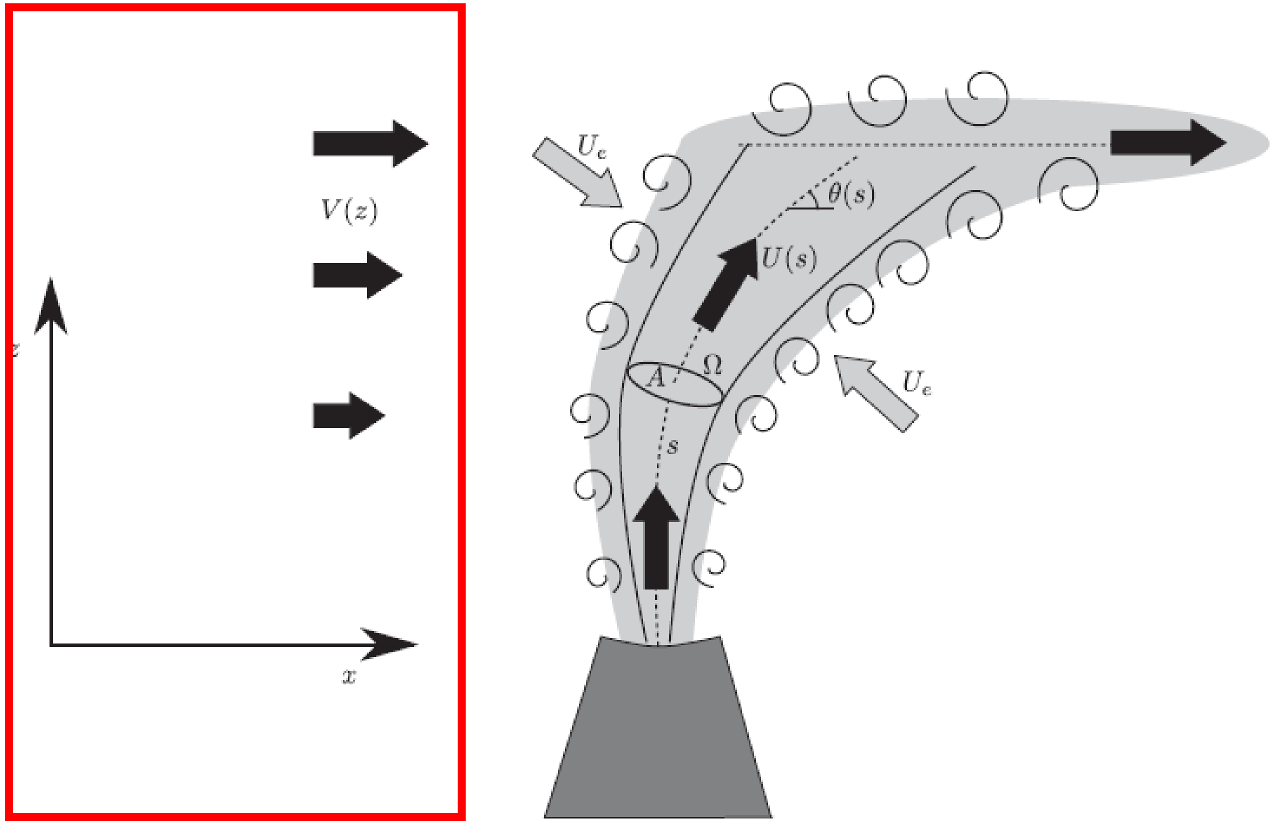
$$\frac{\mathrm{d}}{\mathrm{d}s}\left(\rho U R^2 \left(C_p T + \frac{U^2}{2} + gz\right)\right) = 2\rho_a R U_e \left(C_a T_a + \frac{U_e^2}{2} + gz\right).$$

$$U_e = k_s \left|\frac{M}{Q} - V\cos\theta\right| + k_w |V\sin\theta|.$$

These equations describe how the plume rises by buoyancy in the atmosphere

Wind-affected Volcanic Plume Model



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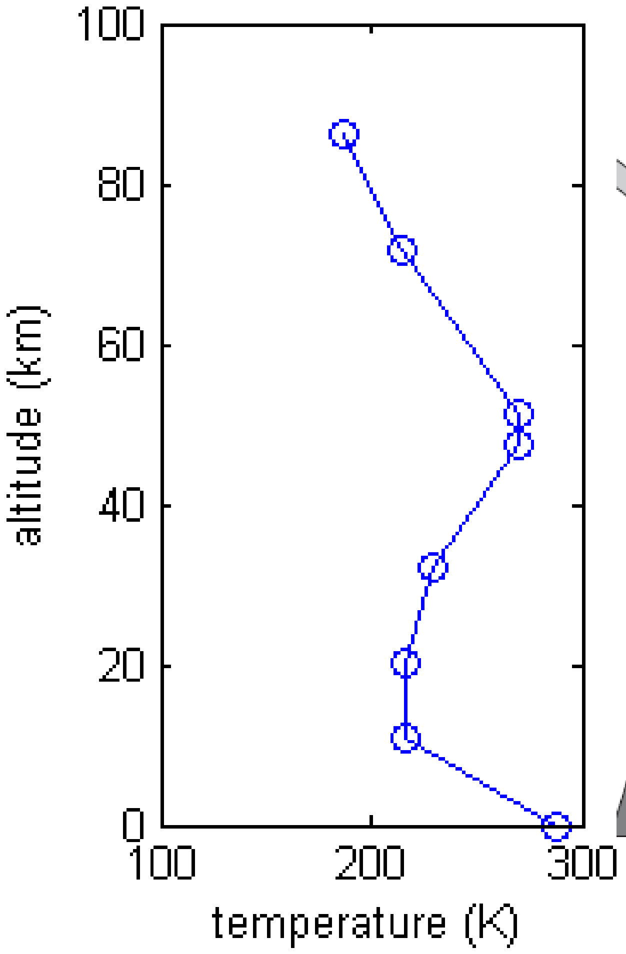
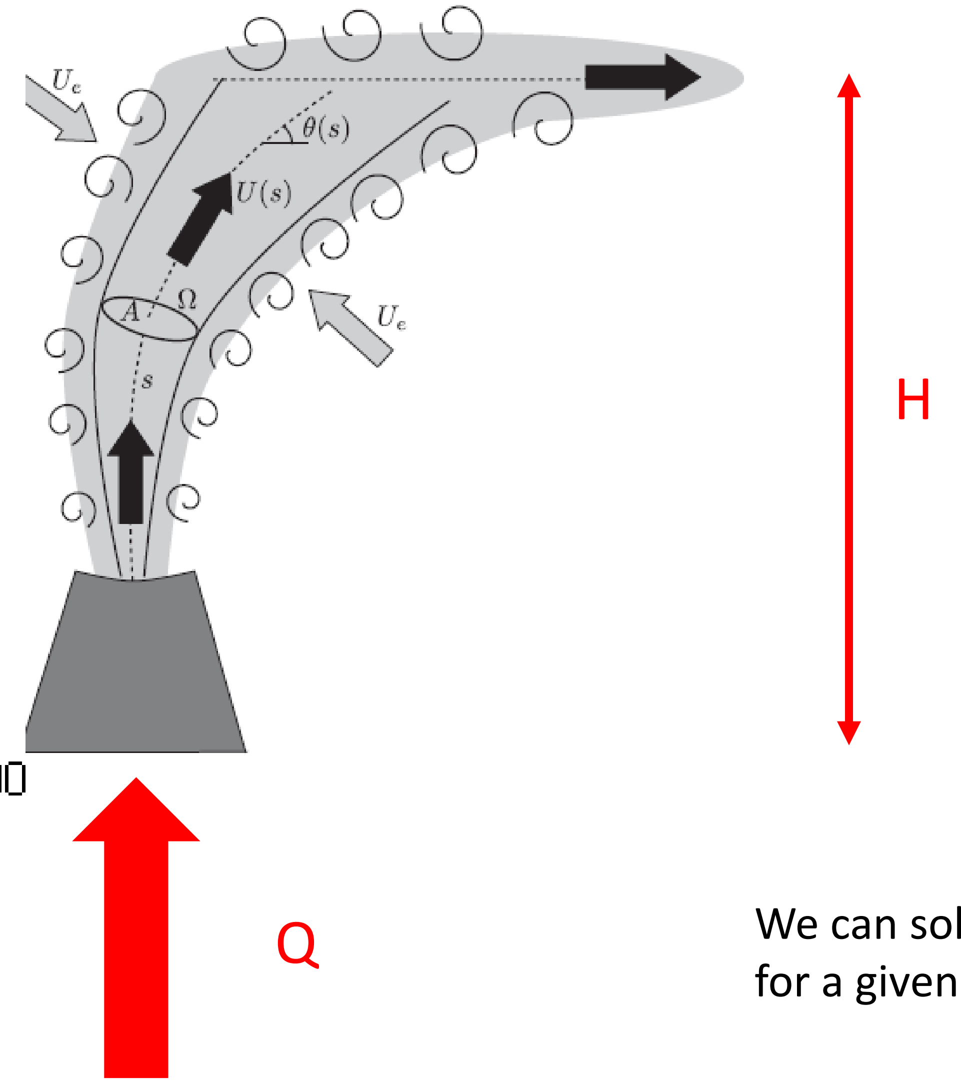
$$U_e = k_s \left| \frac{M}{Q} - V\cos\theta \right| + k_w |V \sin\theta|.$$

These equations describe how properties change with height in the atmosphere, which affects the rise of the plume

Wind-affected Volcanic Plume Model





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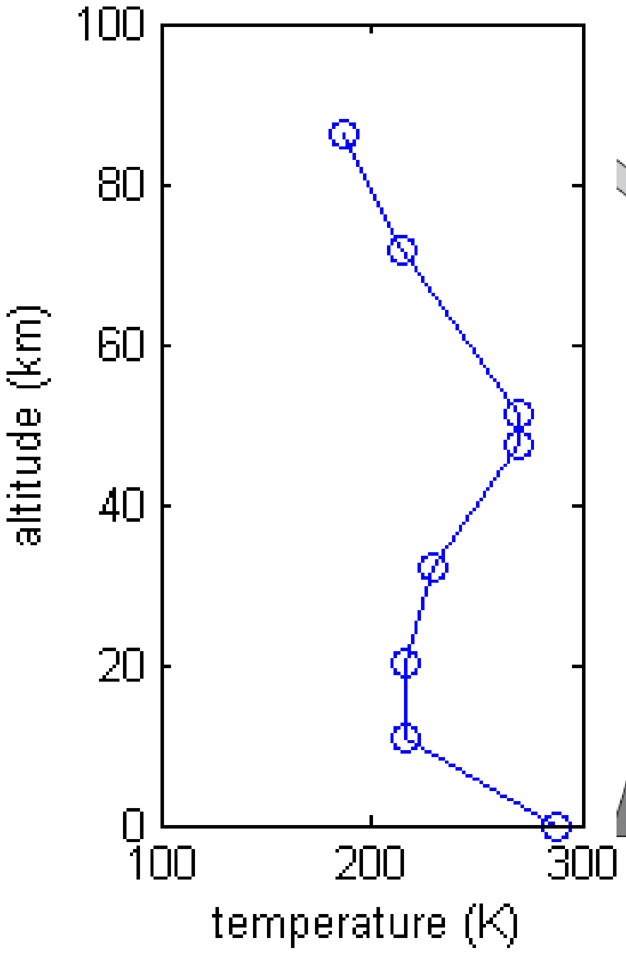
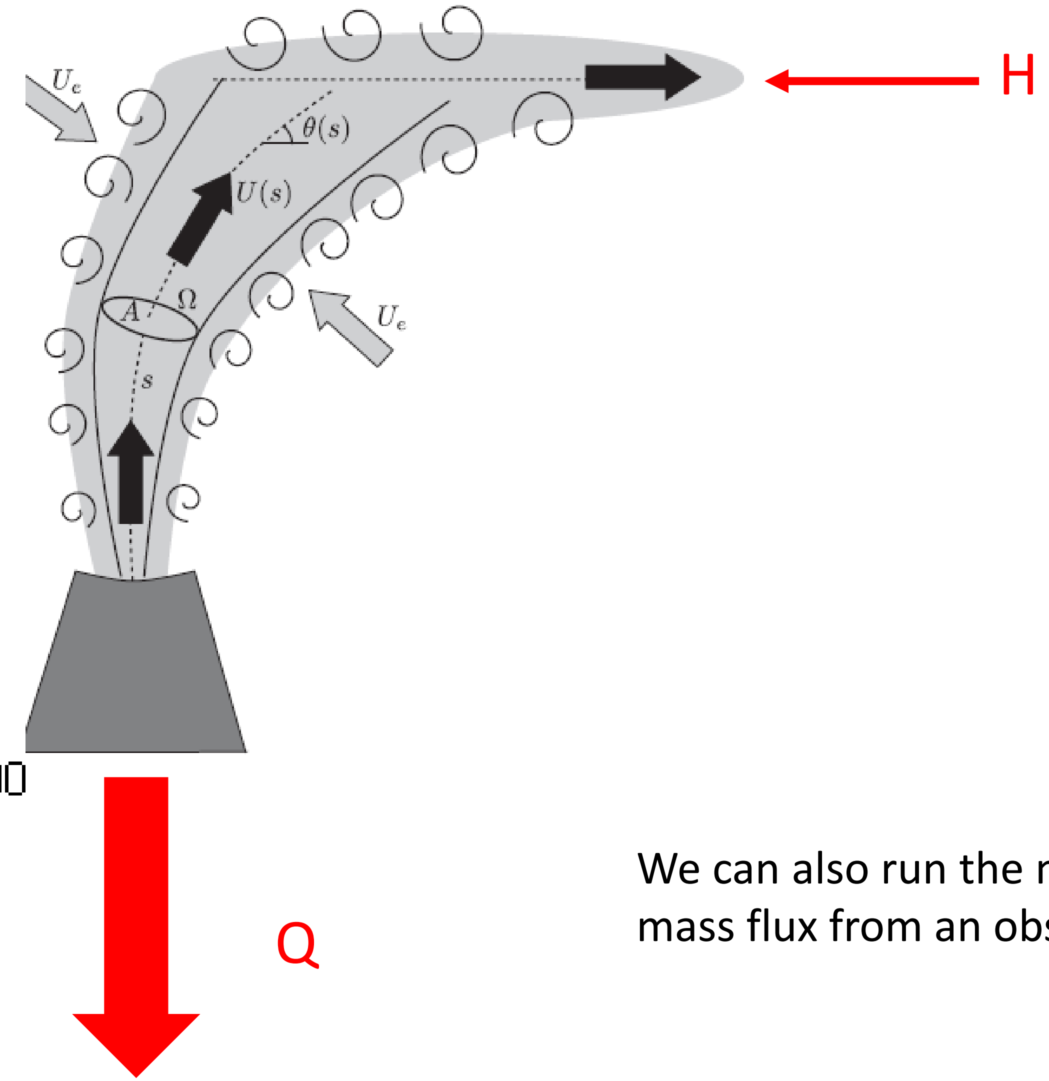
$$U_e = k_s \left|\frac{M}{Q} - V\cos\theta\right| + k_w |V\sin\theta|.$$

We can solve these equations to predict plume height for a given source mass flux

Wind-affected Volcanic Plume Model





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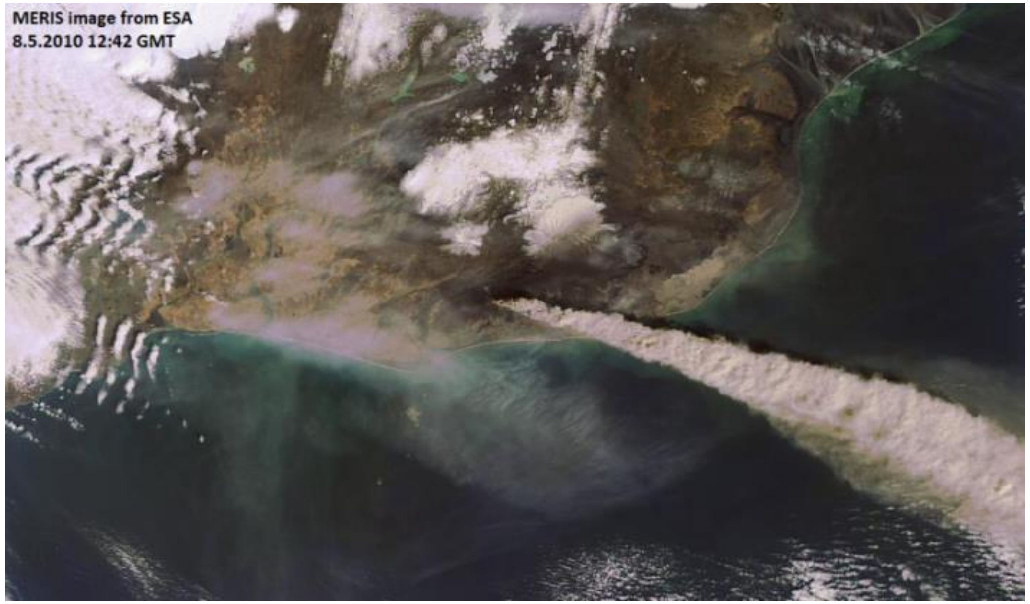
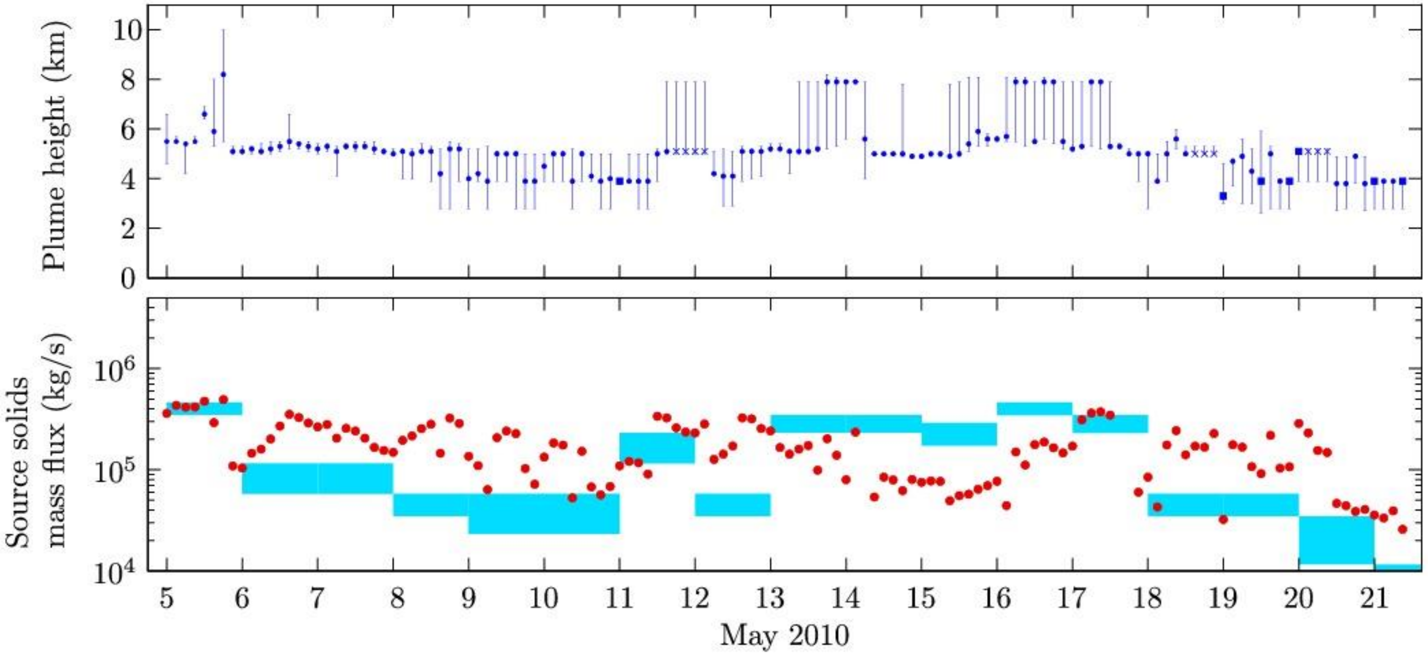
$$U_e = k_s\left|\frac{M}{Q} - V\cos\theta\right| + k_w|V\sin\theta|.$$

We can also run the model in reverse, to predict source mass flux from an observation of plume height

(Woodhouse et al 2013)

Wind-affected Volcanic Plume Model



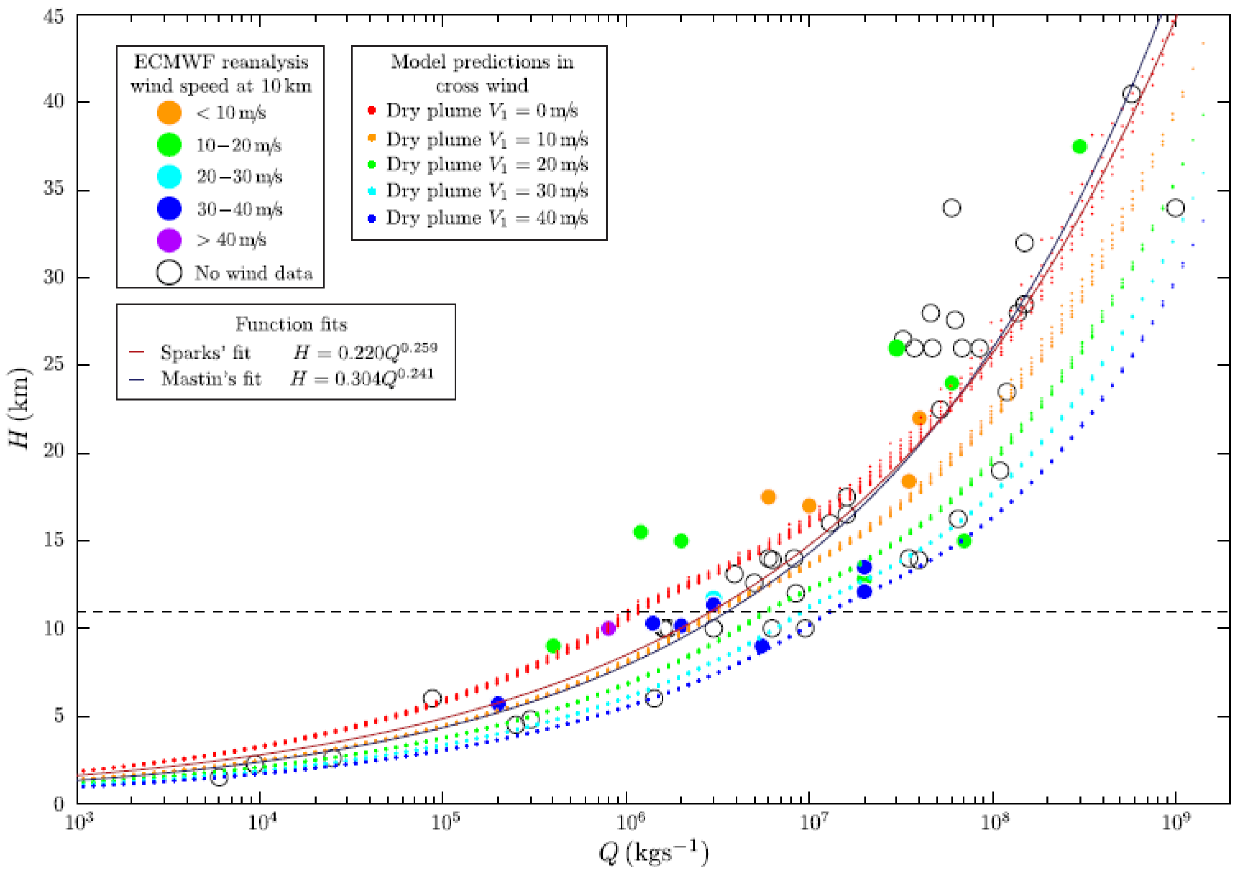


This is a comparison of the model against observations of plume height and wind speed during the Eyjafjallajokull eruption

The model shows that lower plume heights are associated with higher wind speeds, as expected

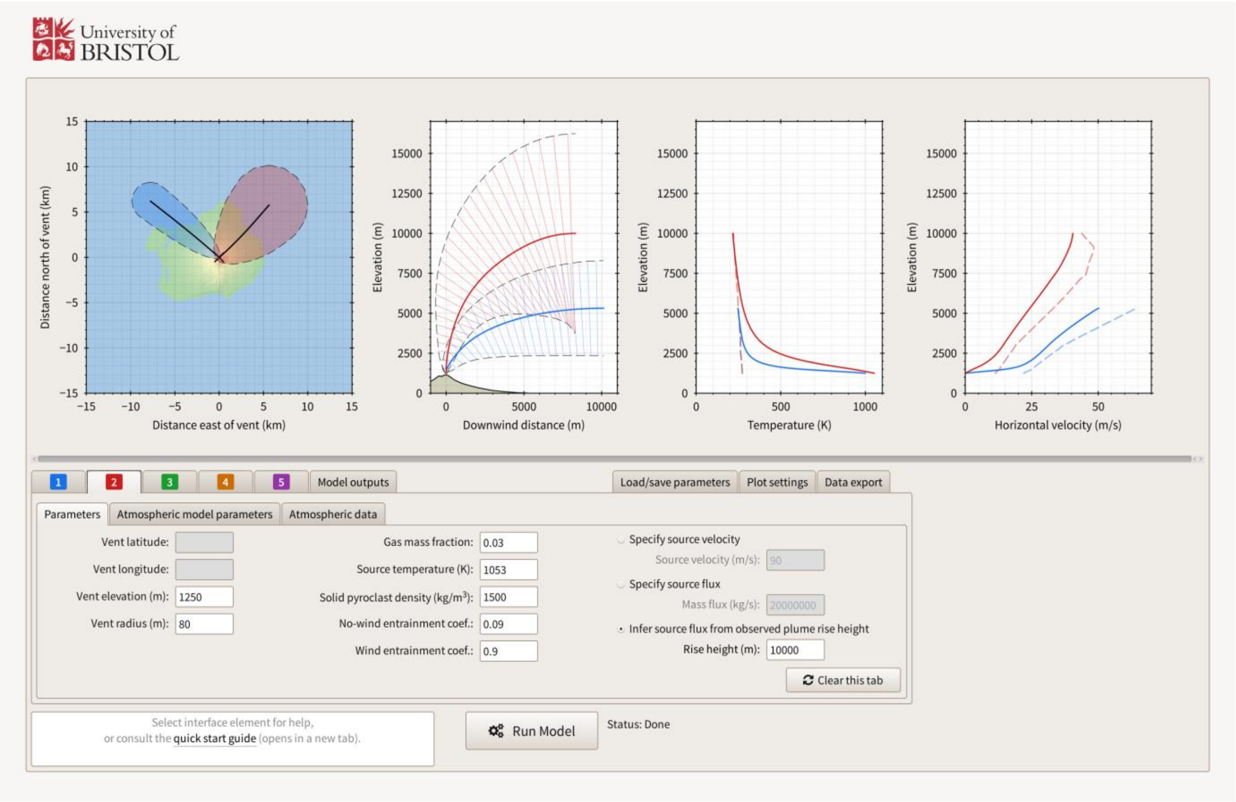
dark blue – Keflavik radar median & sd; Red – model predictions; light blue - deposit

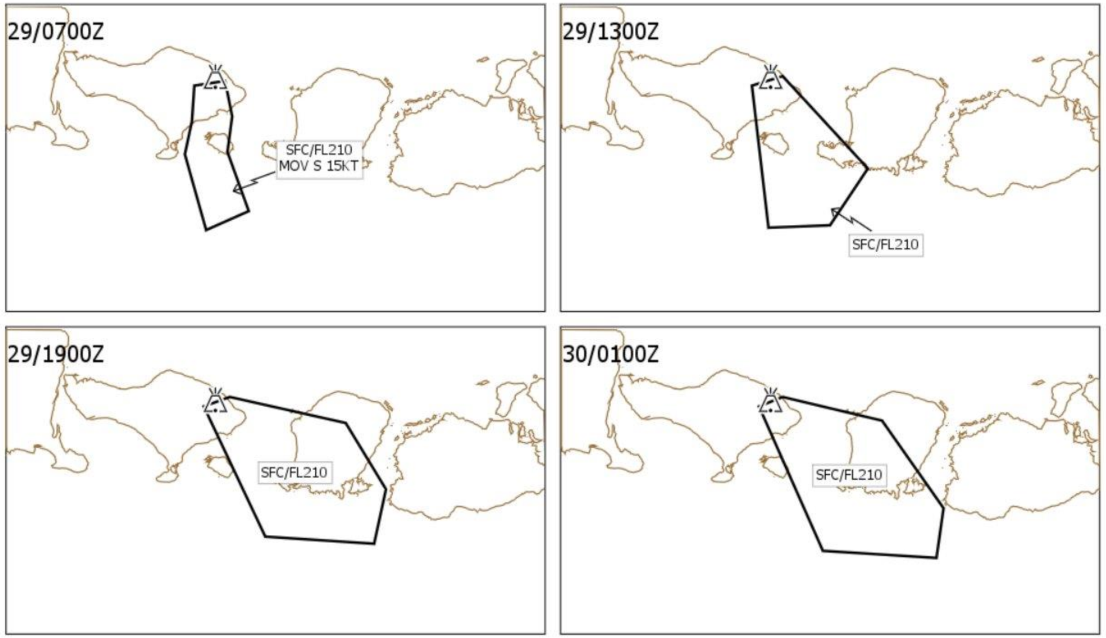
Wind-affected Volcanic Plume Model



The model also shows that some of the scatter in the relationship of plume height and source mass flux is due to the atmospheric wind, show in colour on this plot

The PlumeRise Model





VOLCANIC ASH ADVISORY

DTG:	20171129/0700Z	ADVISORY NR:	2017/41
VAAC:	DARWIN	INFO SOURCE:	HIMAWARI-8, WEBCAM, CVGHM, PIREP
VOLCANO:	AGUNG 264020	AVIATION COLOUR CODE:	RED
PSN:	S0821 E11530	ERUPTION DETAILS:	CONTINUOUS VA EMISSION TO FL210
AREA:	INDONESIA	RMK:	VA CLEARLY DISCERNIBLE ON SAT IMGERY WITHIN 30NM OF VOLCANO, BECOMING DIFFUSE FURTHER S. HEIGHT AND MOVEMENT BASED ON HIMAWARI-8 IMAGERY, MODEL GUIDANCE, WEBCAM, 29/0154Z PIREP, SURABAYA 29/0000Z SOUNDING AND 28/2245Z GROUND REPORT.
SUMMIT ELEV:	3142M	NXT ADVISORY:	NO LATER THAN 20171129/1000Z

Operational tool for inverting mass eruption rate from observations of plume height

(www.plumerise.bristol.ac.uk)

Useful Models

Scientific uses of models

- To provide fundamental understanding of processes and behaviour of natural systems
- To forecast impacts of hazard events
- To advise operational response

Tungurahua, Ecuador