Volcanology applied to emergencies

Steve Sparks, University of Bristol, UK

Cambridge Society for the Application of Research, 29 April 2013

Outline of talk

- Volcanic hazards and their assessment (Montserrat)
- Risk and uncertainty assessment methods
- False Alarms, Communication and Relocation
- Global volcanic hazards

Hazard

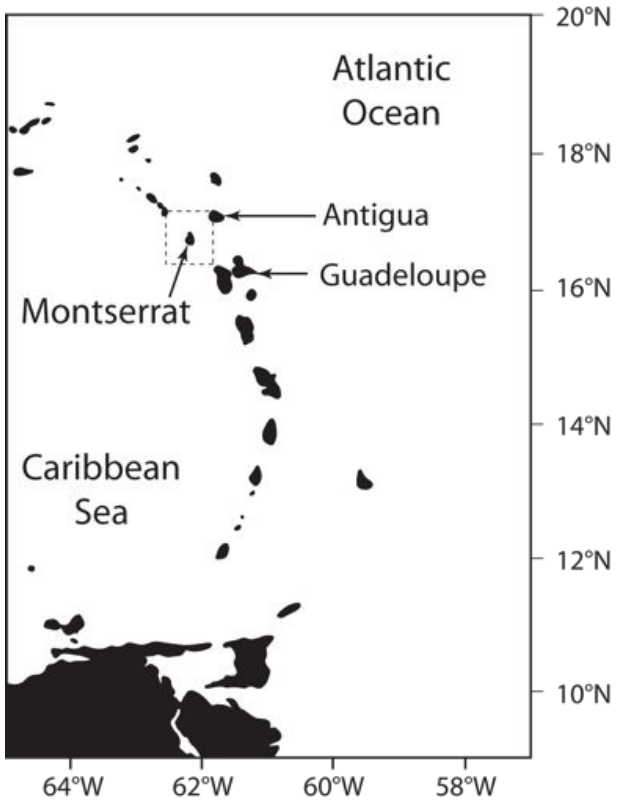
A volcanic hazard is any volcano-related phenomenon that threatens communities around a volcano

Pyroclastic flow

Lahar

Volcanic hazards are described by the physical characteristics of the phenomenon, by the areas that they are expected to effect, by their magnitude and return period

Location


Atlantic
Ocean
Antigua
Guadeloupe
Montserrat
Caribbean
Sea
20°N
18°N
16°N
14°N
12°N
10°N
64°W
62°W
60°W
58°W

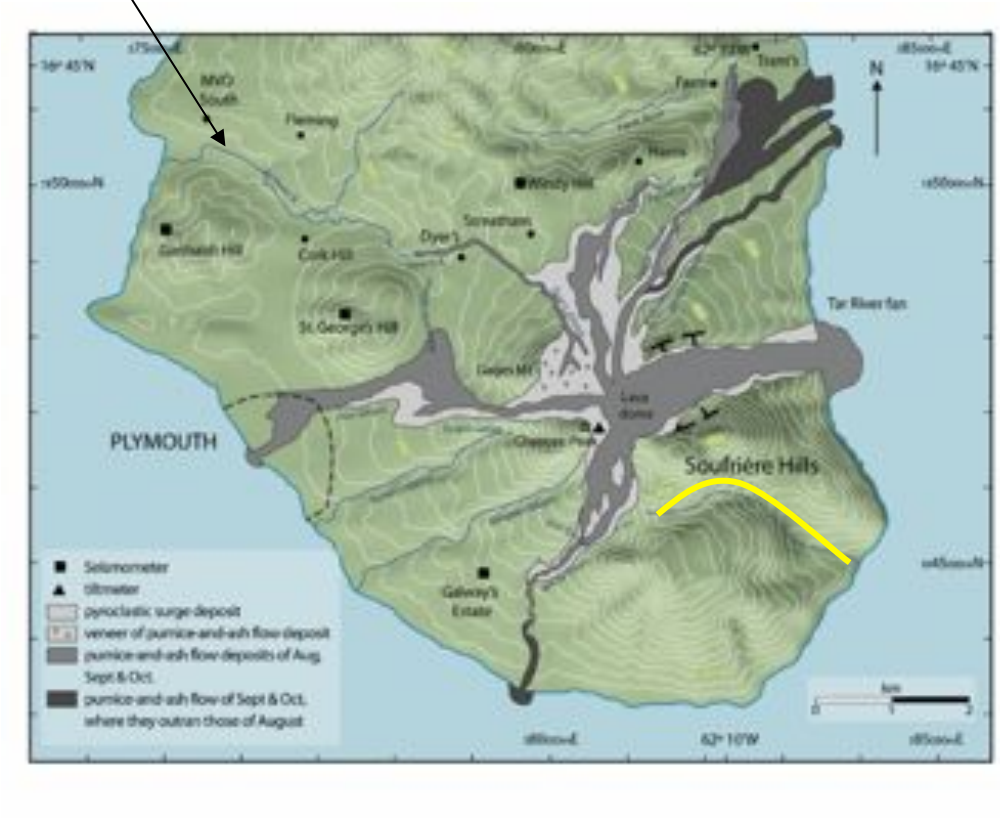

MAR DES CARAIBES
St John's
Codrington
Blackburne Airport
Harris
Cork Hill
PLYMOUTH
Morris
Old Fort Point
Mule Rock

Destruction of Plymouth

Hazards maps are determined by mapping of past volcanic events and by modelling of the natural processes

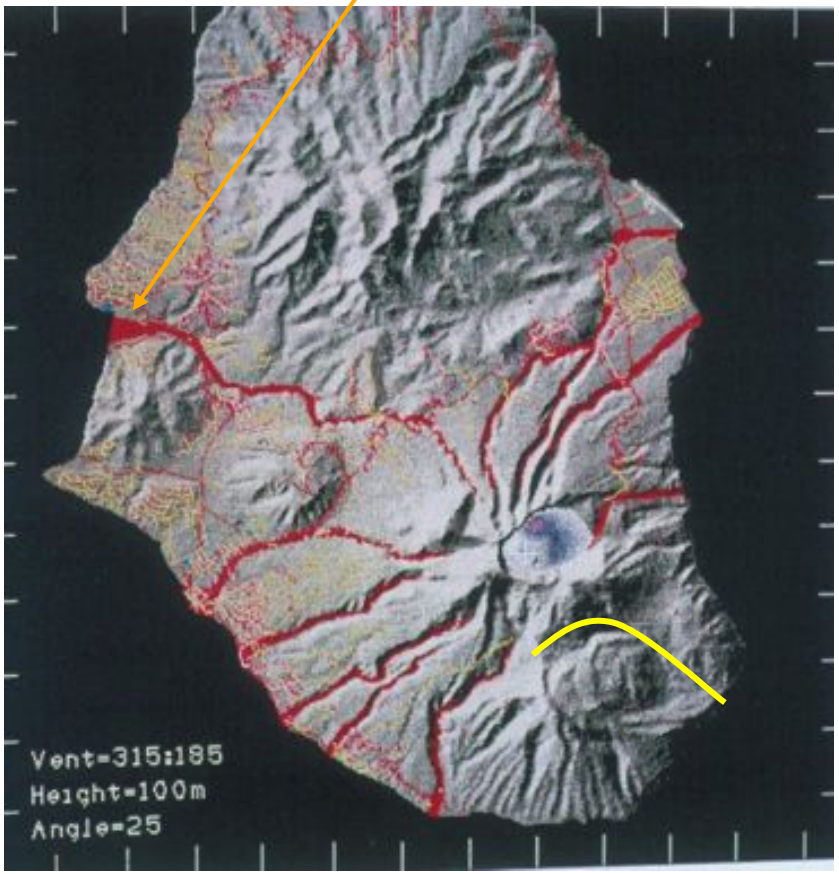
No flows

Yellow is unexpected flow



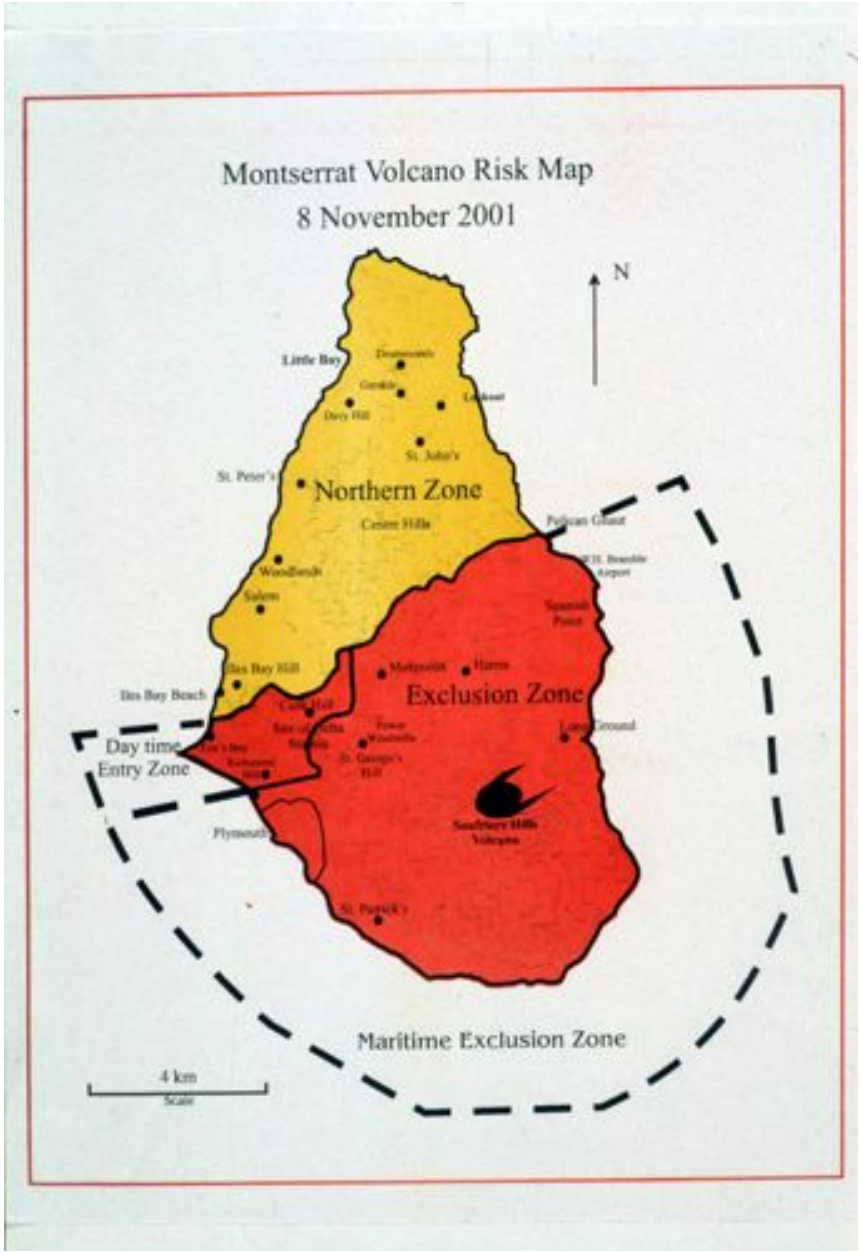
Pyroclastic flow deposits Montserrat (1996-1997)

Predicted Flows



Pyroclastic flow models

A hazards map depicts areas likely to be affected by future volcanic activity and related phenomena (e.g. pyroclastic flows)



Administrative zone maps are developed from hazards map but may take account of other factors (e.g. roads, infrastructure, etc)

These maps used for planning and crisis management

HAZARD FOOTPRINT

Living with an erupting volcano: hazard zones for crisis micro-management

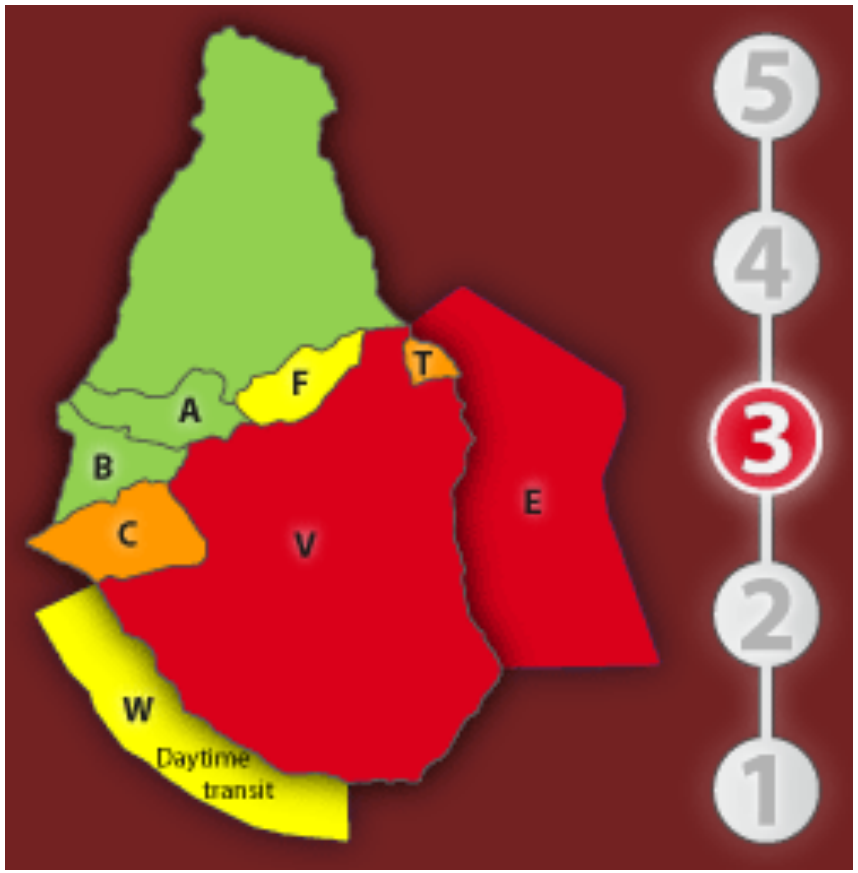
"…this island is exactly the wrong size for an eruption…"

Uncertainty

- Volcanic hazards maps are depictions of the LIKELIHOOD of future volcanic phenomena affecting places and people
- Volcanic phenomena are naturally variable, often complex and not fully understood
- There are many sources of uncertainty in forecasting the areas that volcanic activity will effect and the severity of the effects
- Uncertainties arise from: natural variability, inadequate data, biased data, incomplete data, lack of understanding of the processes, limitations to predictive models, ambiguity, unknown unknowns

THE DESCRIPTION OF VOLCANIC HAZARDS IS THUS NECESSARILY PROBABILISTIC AND REQUIRES ASSESSMENT OF UNCERTAINTIES

Issues that arise from the probabilistic nature of volcanic hazards and the intrinsic uncertainties



- zonation maps require well-defined boundaries for pragmatism
- boundaries cannot divide areas that are completely safe from those that are unsafe
- levels of danger or safety need to be defined to decide on and justify boundaries through concepts of vulnerability and risk
- more data, better observations, improved models may reduce uncertainties, BUT can increase uncertainties
- probabilities inferred by statistical techniques are hard to communicate

Changing Zonation Maps

Hazards are only of concern when they pose risks to communities

Risk = Vulnerability x Hazard

Vulnerability and Risk defined in terms of humans and society

Different usage by social scientists

Hazard is a human construction

Hazard = level of danger

Vulnerability

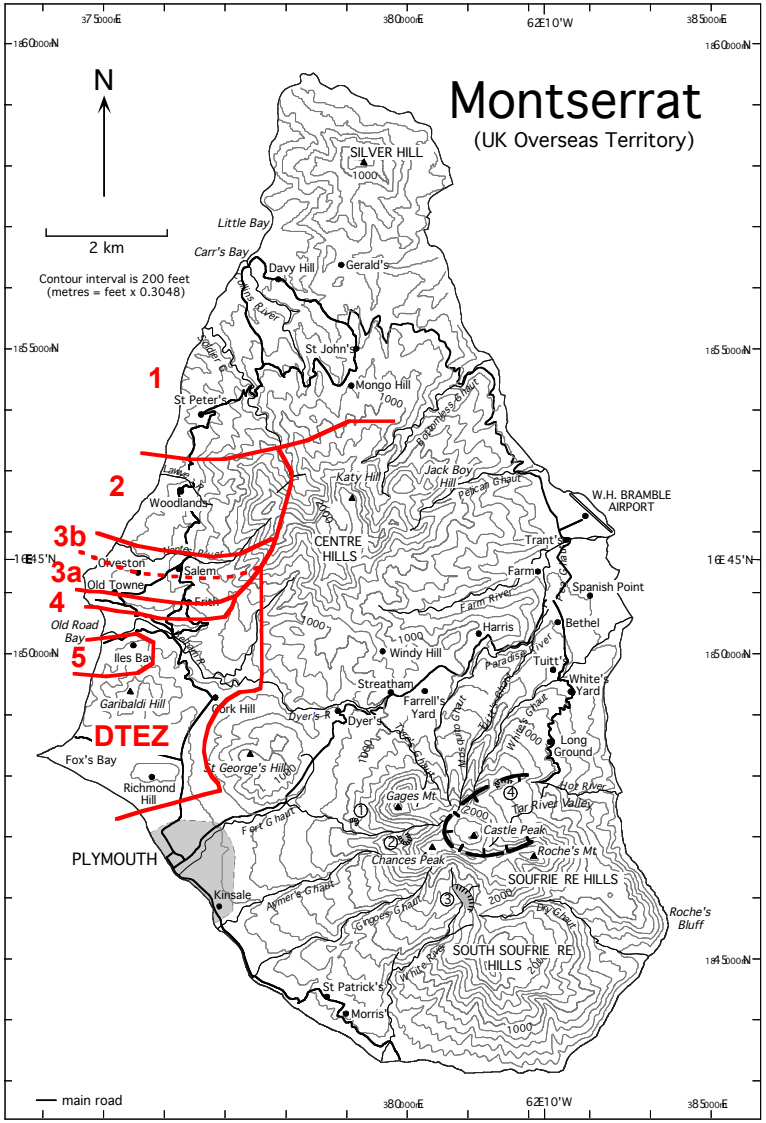


Fig. 4 Montserrat: population zones used for risk assessment modelling

St Pierre, Martinique (1902)
29,000 people died
from a pyroclastic flow

Typically volcanic vulnerability is defined in terms of people living in area under threat from volcanism

Risk

Typically risk in volcanic crises is defined in terms of loss of life

Individual risk: the chances of an individual being killed

Societal risk: the chances of a society experiencing a certain number of deaths

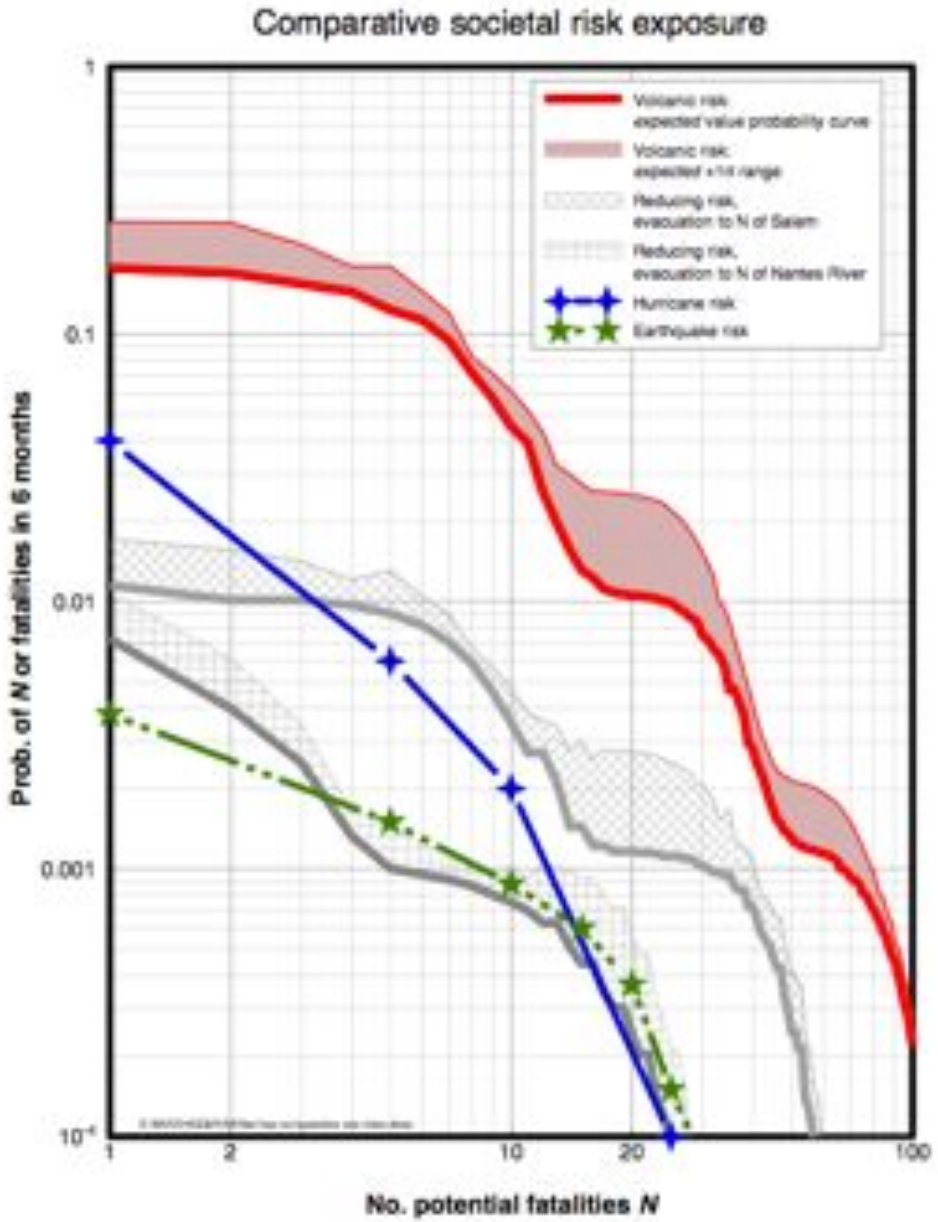
Normally expressed as annualised probabilities (chances of being killed in a year)

These risks are not just determined by the hazard but are also influenced by human behaviour (e.g risk perceptions, denial, exaggeration of threat) and societal responses (e.g. land-use planning, evacuation, development strategies)

UK Individual Risk Scale

HIGH	**>1 in 100**
MODERATE	**1 in 100 to 1 in 1000**
LOW	**1 in 1000 to 1 in 10000**
VERY LOW	**1 in 10000 to 1 in 100000**
MINIMAL	**1 in 100000 to 1 in a million**

Chief Medical Officer

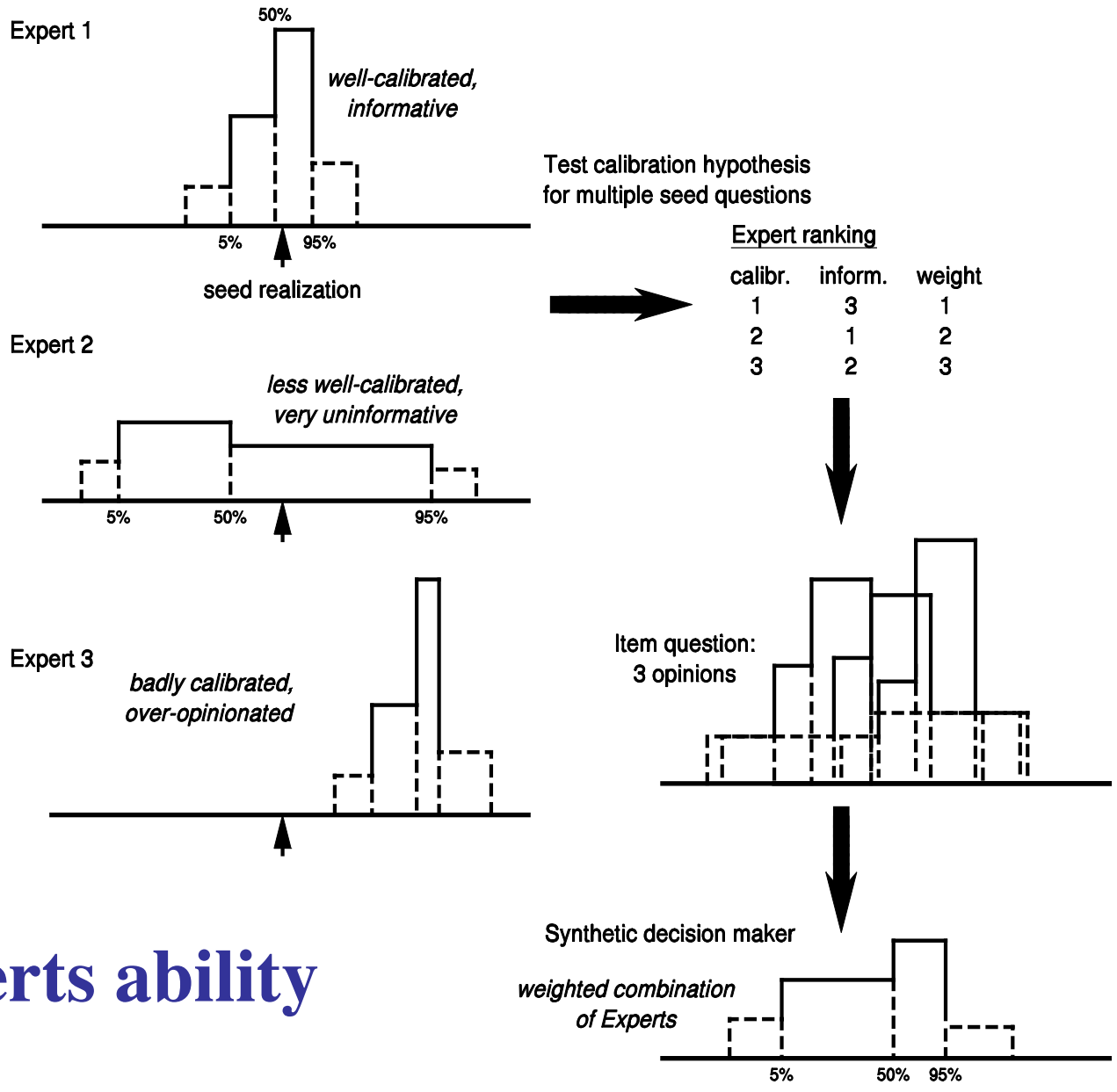

Comparative societal risk exposure
Volcanic risk
expected value probability curve
Volcanic risk
expected +1σ range
Reducing risk,
evacuation to N of Salem
Reducing risk,
evacuation to N of Nantes River
Hurricane risk
Earthquake risk
1
0.1
0.01
0.001
10⁻⁴
1
2
10
20
100
Prob. of N or fatalities in 6 months
No. potential fatalities N

Expert elicitation for assessing uncertainty and risk

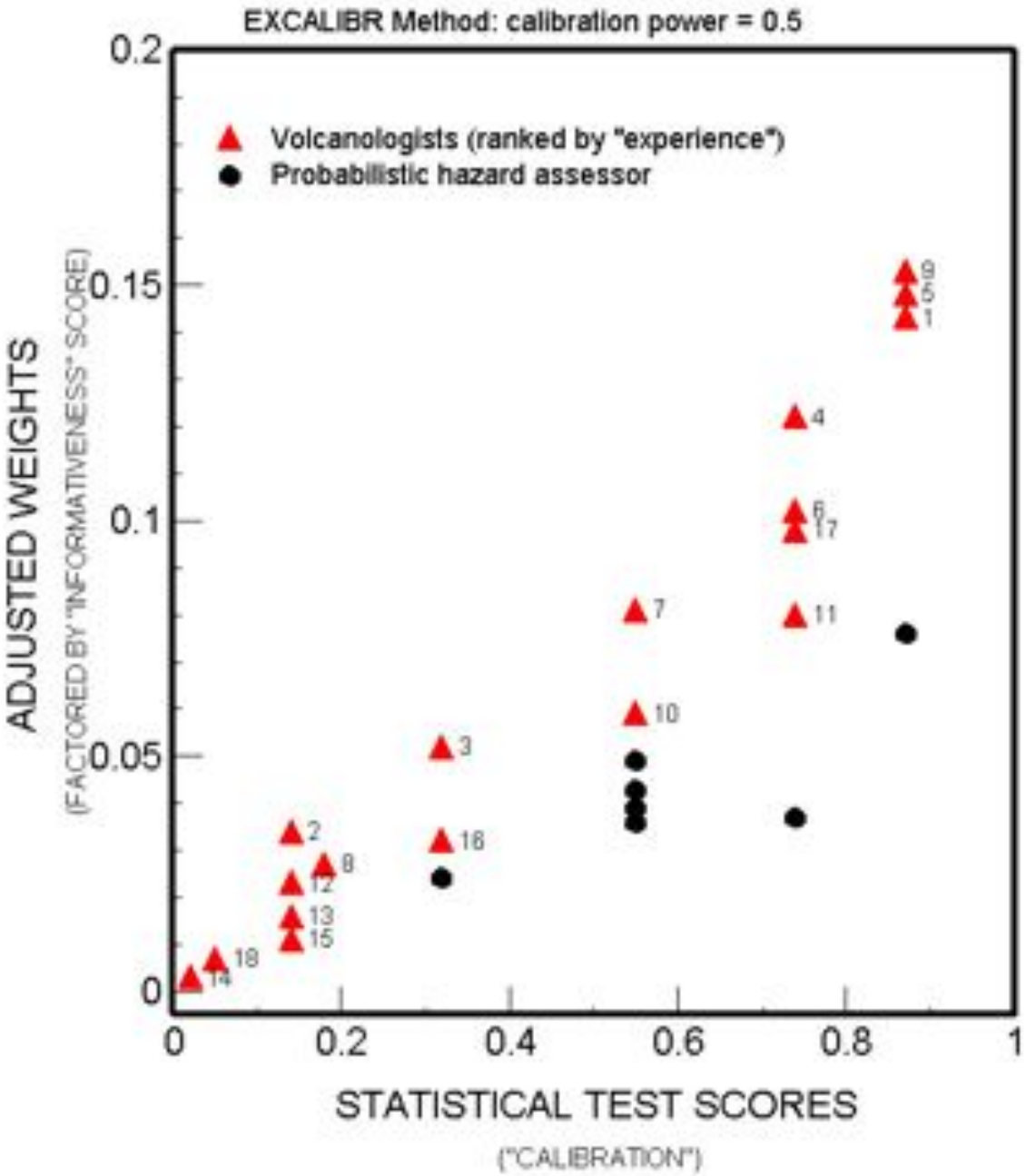
Pooled estimates and opinions:

What is the chance that a village 6 km NW of the volcano will be inundated by a pyroclastic flow?

Experts ability



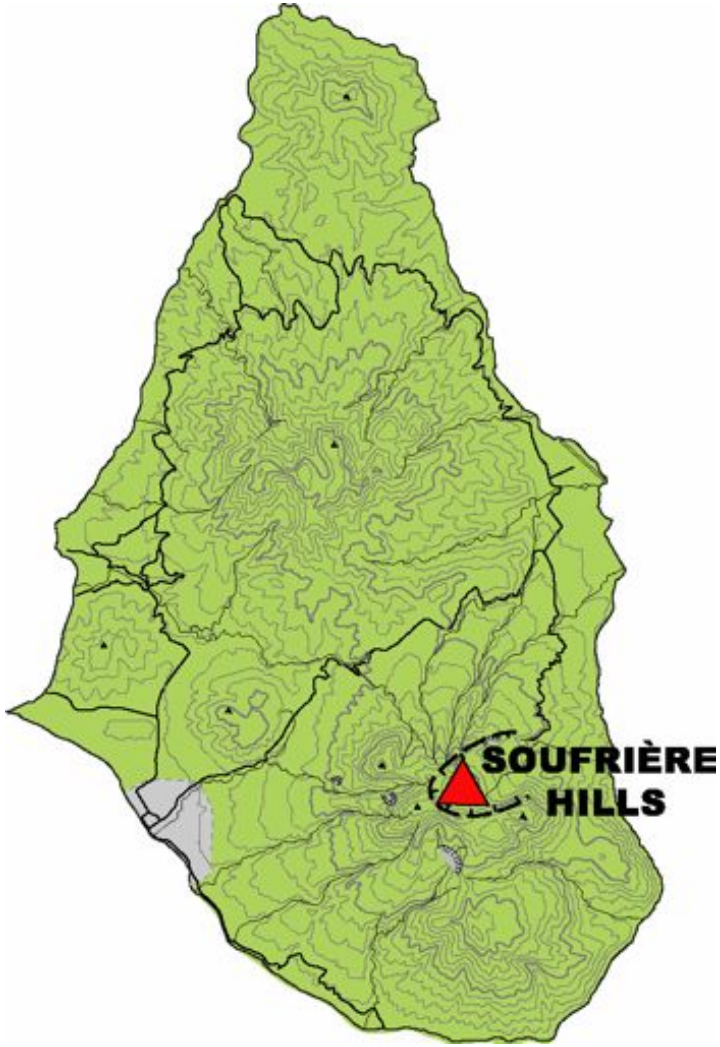
ELICITATION WEIGHTS FOR INDIVIDUAL SCIENTISTS



Quantitative risk assessment

Pyroclastic flow hazards on Montserrat

Lower Belham valley, Montserrat
Evacuated 8 October 2002



Ingredients of model I

- Probability of collapse to the northwest
- Probability of pyroclastic flow reaching area (>3 million cubic metres)
- Surge cloud behaviour
- Number of people in area (casualties)
- 6 month time period

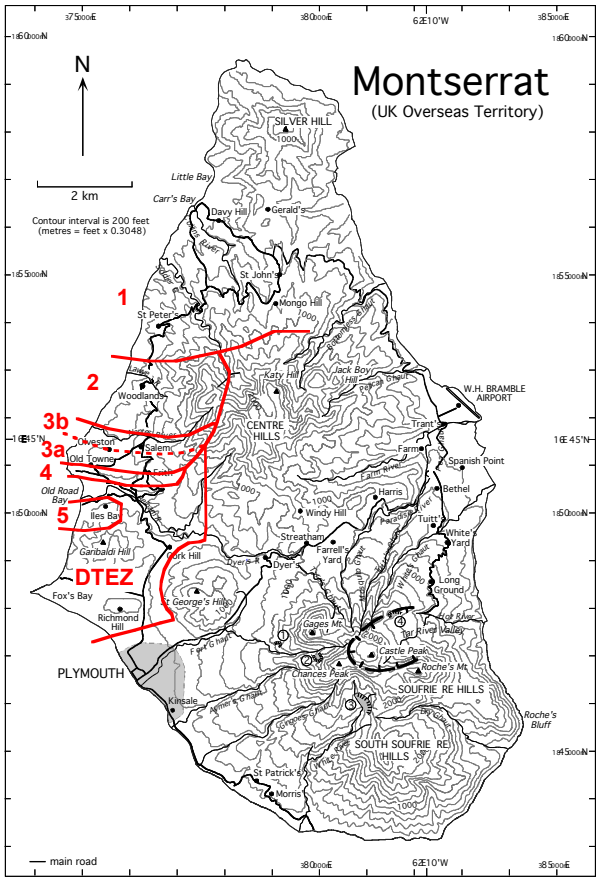


Fig. 4 Montserrat: population zones used for risk assessment modelling

Ingredients of model II

Evaluation of probabilities and their uncertainties by:

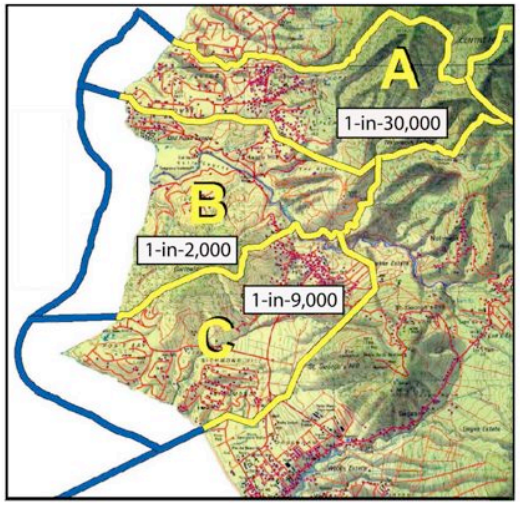
- **Models**
- **Empirical evidence**
- **Expert elicitation methods**
- **Monte Carlo sampling of uncertainties**

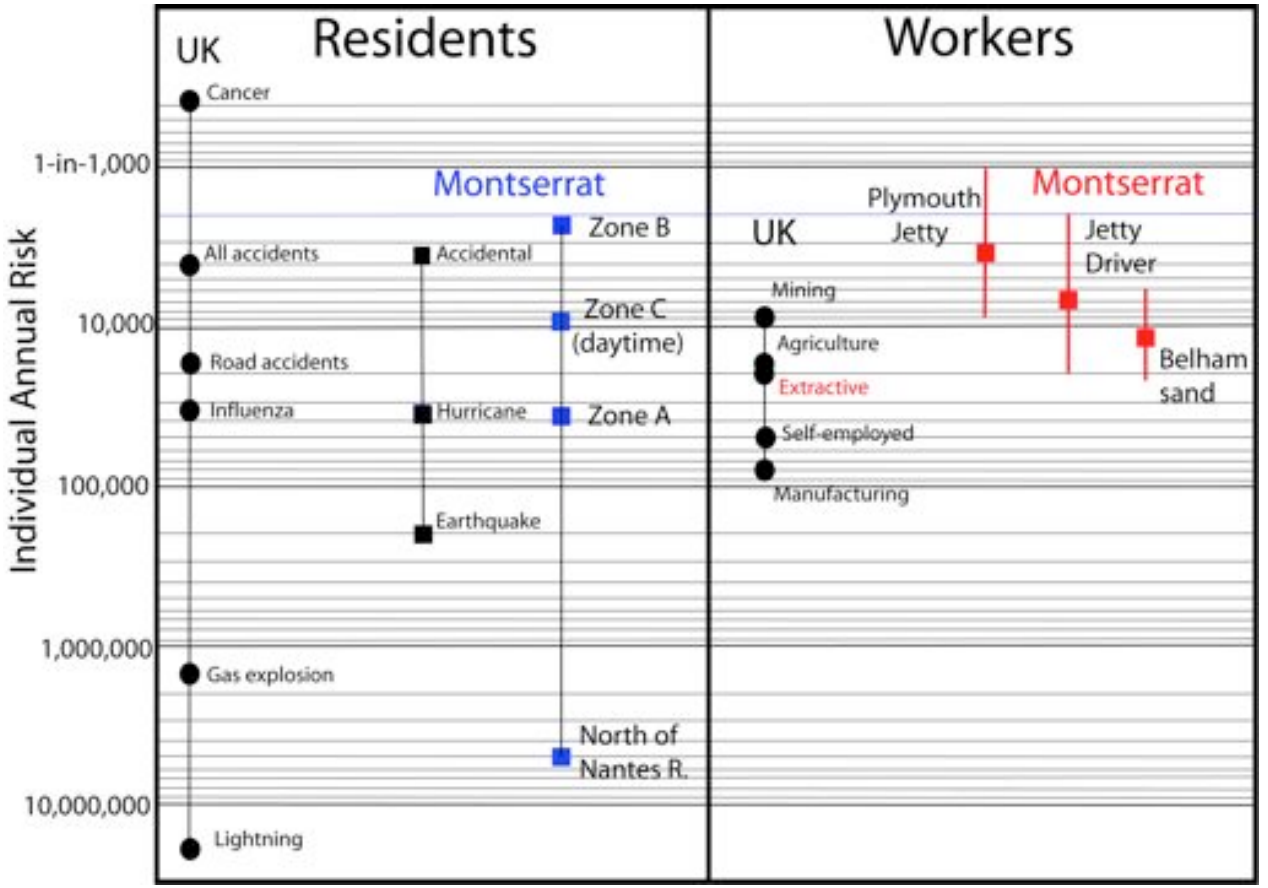
15% chance of pfs getting to Belham Valley
70% chance of collapse to the east

Willy Aspinall: facilitator


12 July 2003
What happened?


Largest historic dome collapse
(210 million cubic metres)
on 12th July 2003
13th July 2003
Risk reduced!
People moved back



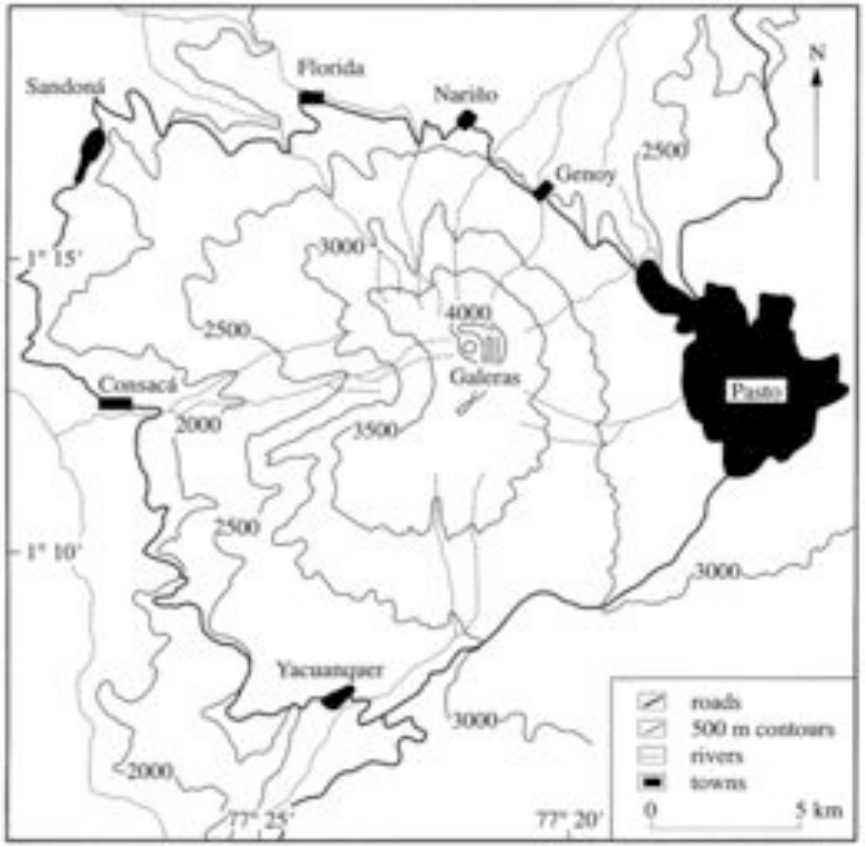


Risk to sand miners November 2011

Guadeloupe, 1976

False Alarms and communication

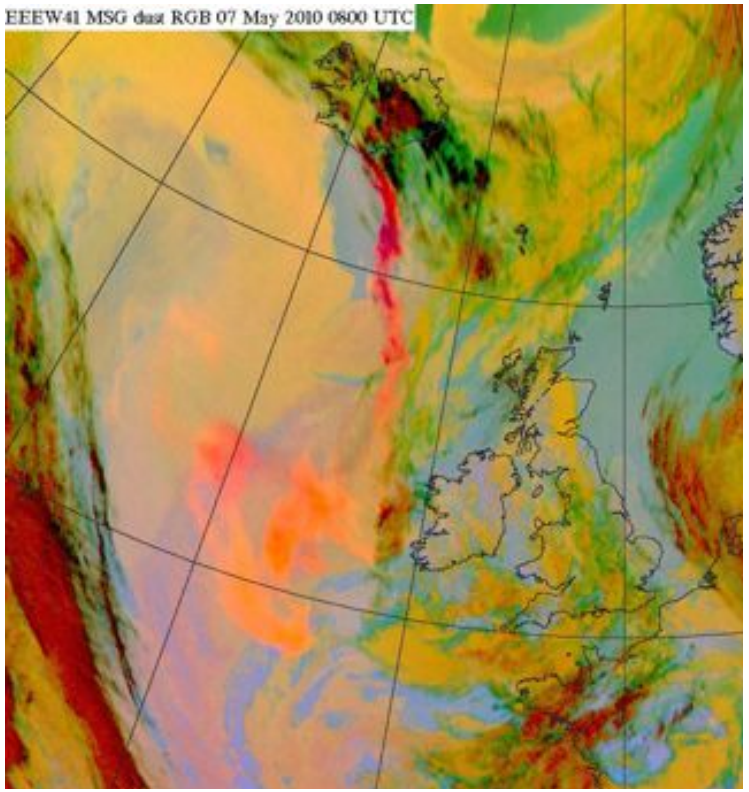
….a volcanic crisis leads to a major evacuation, but the eruption is stillborn; scientists are embroiled in public controversy, severe criticism and recriminations

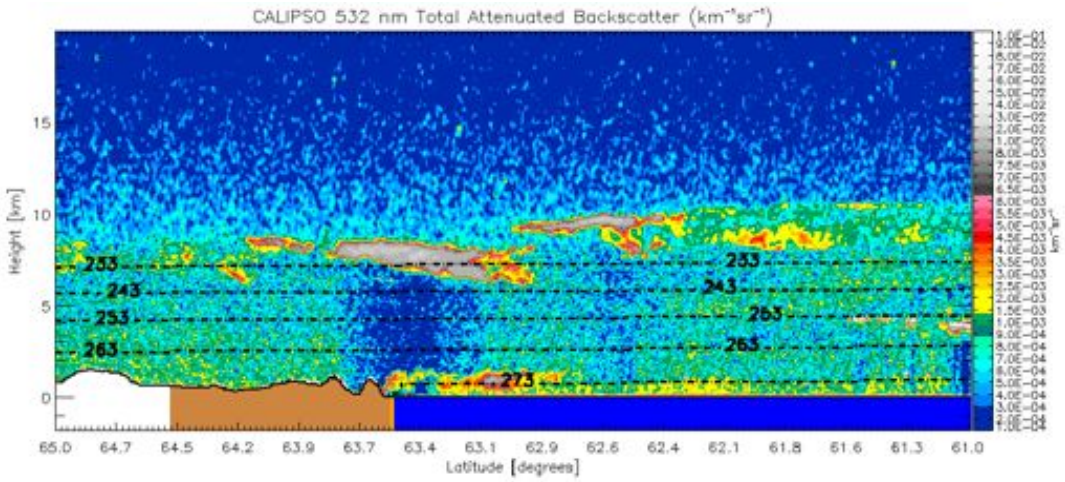


Galeras, Colombia
Relocation controversy


Eyjafjallajökull, Iceland 2010

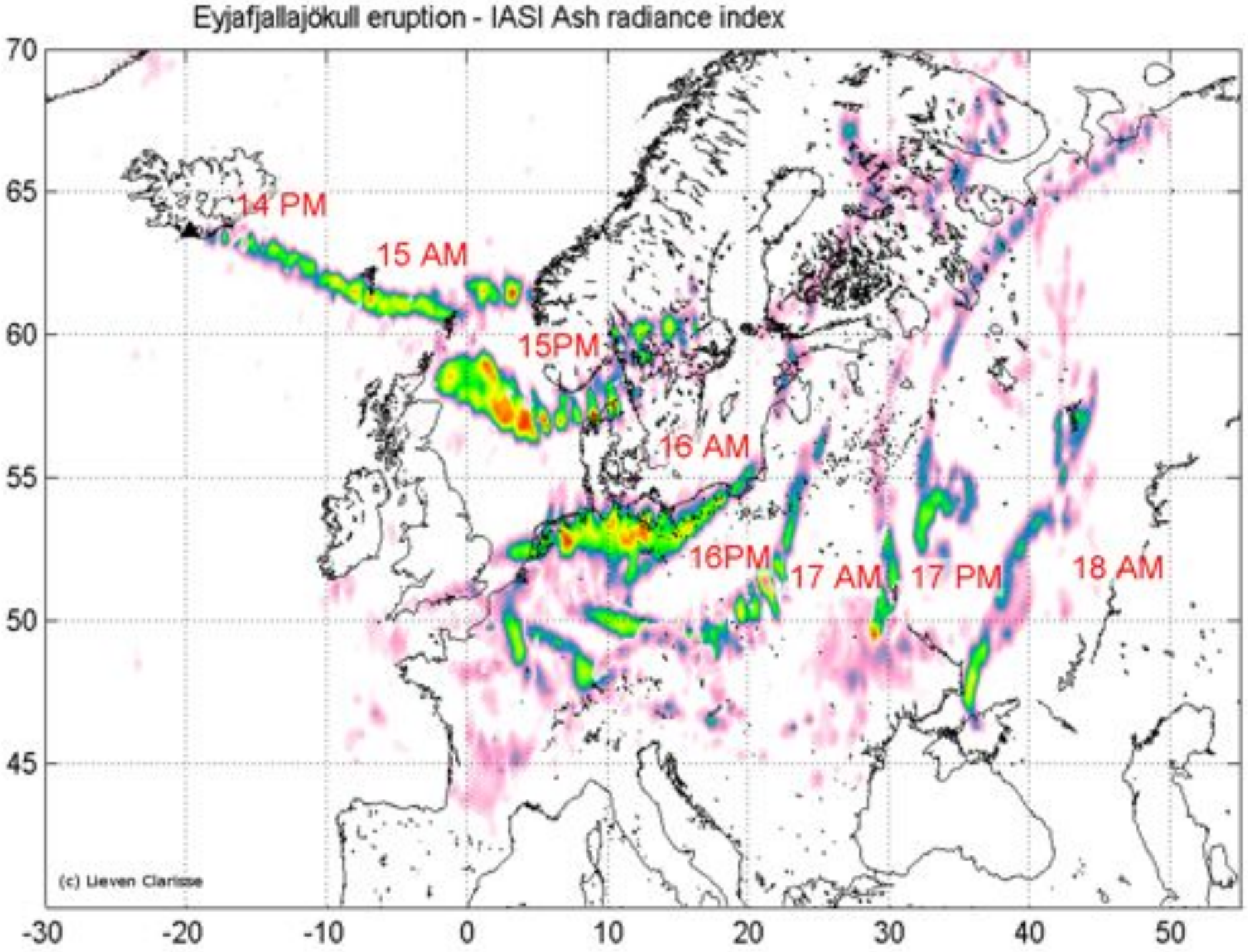
Iceland ash emergency



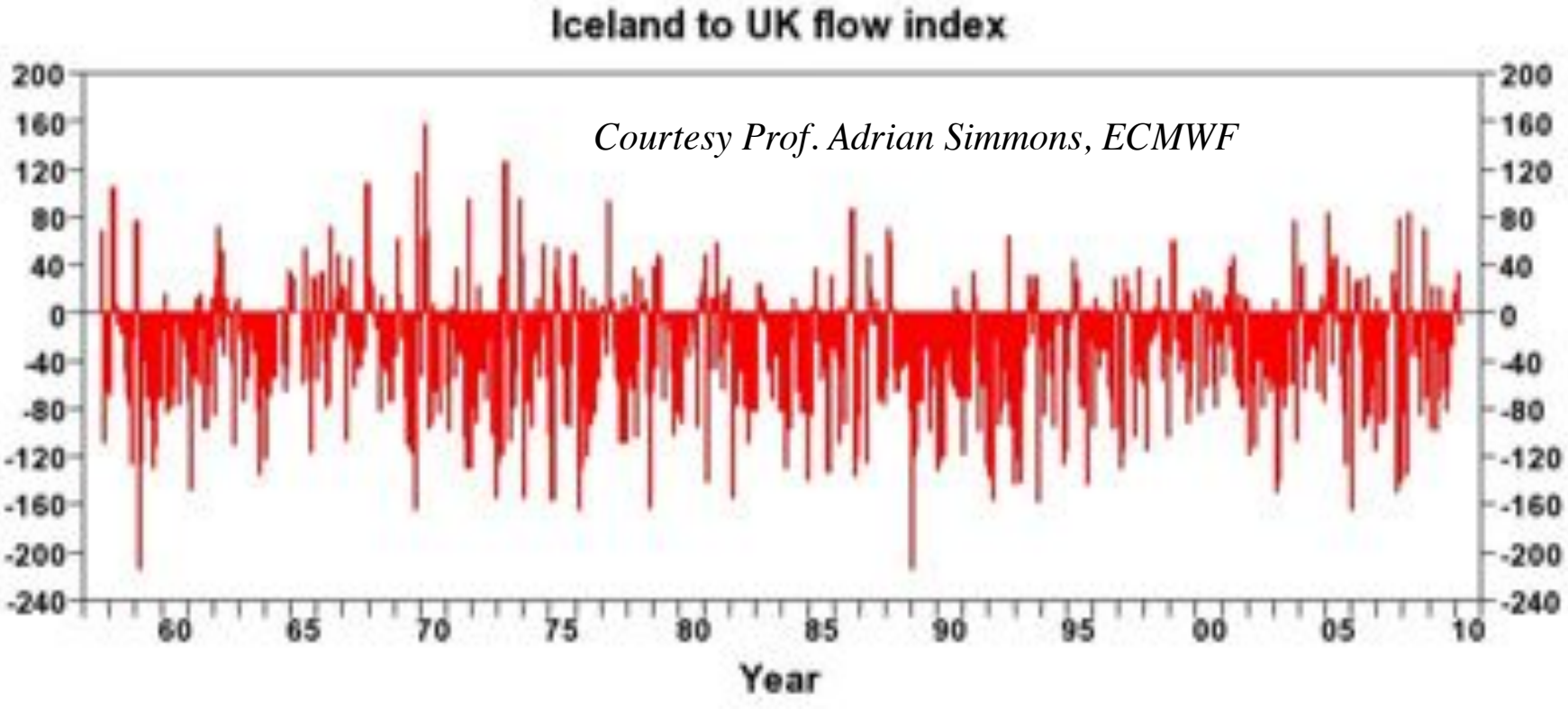


Grounded aircraft flying into and out of Europe for 6 days

Cost '$200M' a day (> 1 bn €)

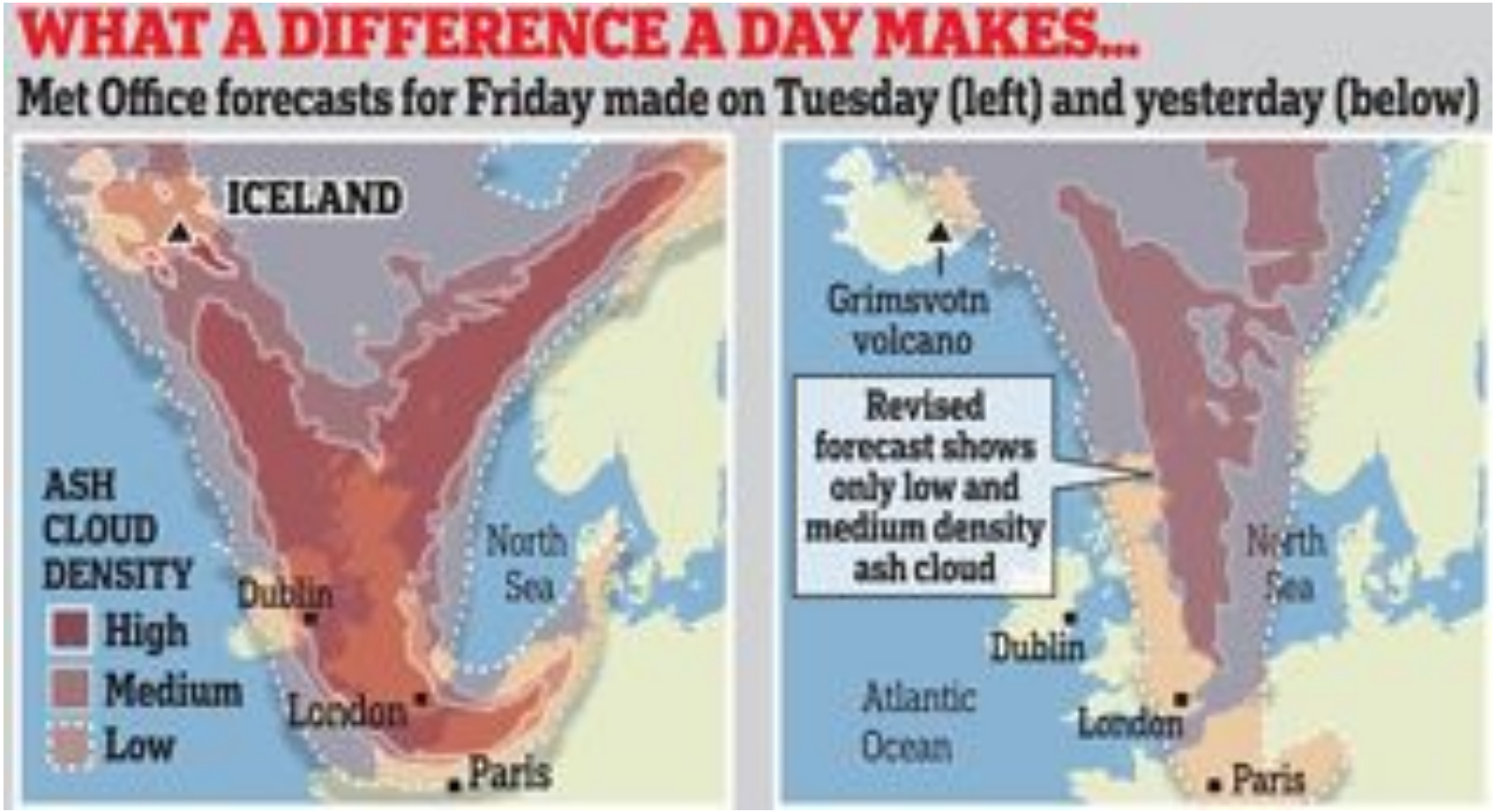

Eyjafjallajökull eruption - IASI Ash radiance index
14 PM
15 AM
15PM
16 AM
16PM
17 AM
17 PM
18 AM
(c) Lieven Clarisse
70
65
60
55
50
45
-30
-20
-10
0
10
20
30
40
50

Unfavourable winds

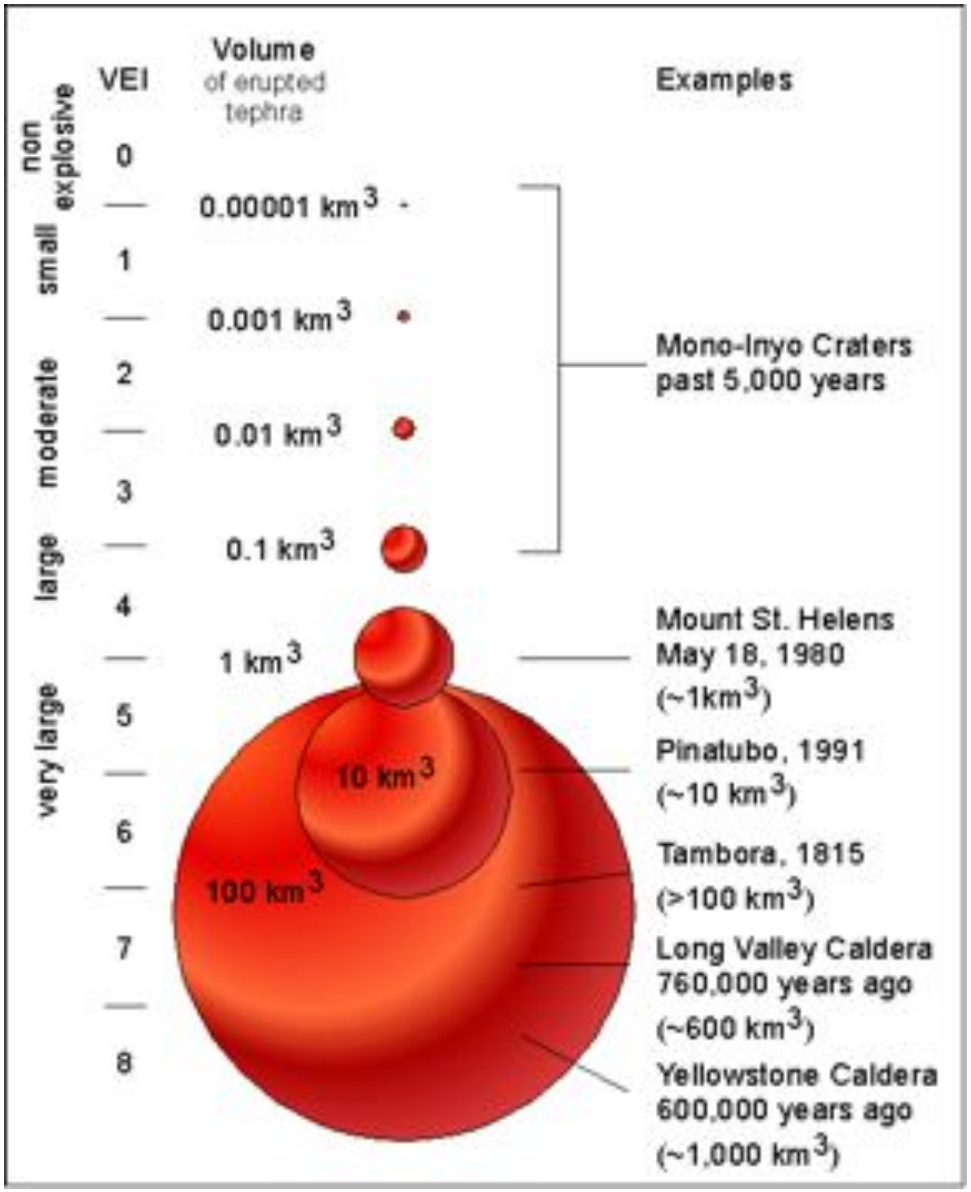


About 25% of months have positive values of index (i.e. from Iceland to UK) **~1 in 60 year event**

- Grounded aircraft flying into and out of Europe for 6 days
- Cost ‘$200M’ a day (> 1 bn €)
- Significant political fallout
- Travel disruption and insurance claims



Grimsvotn June 2011
Environmental models



Magnitudes of volcanic eruptions

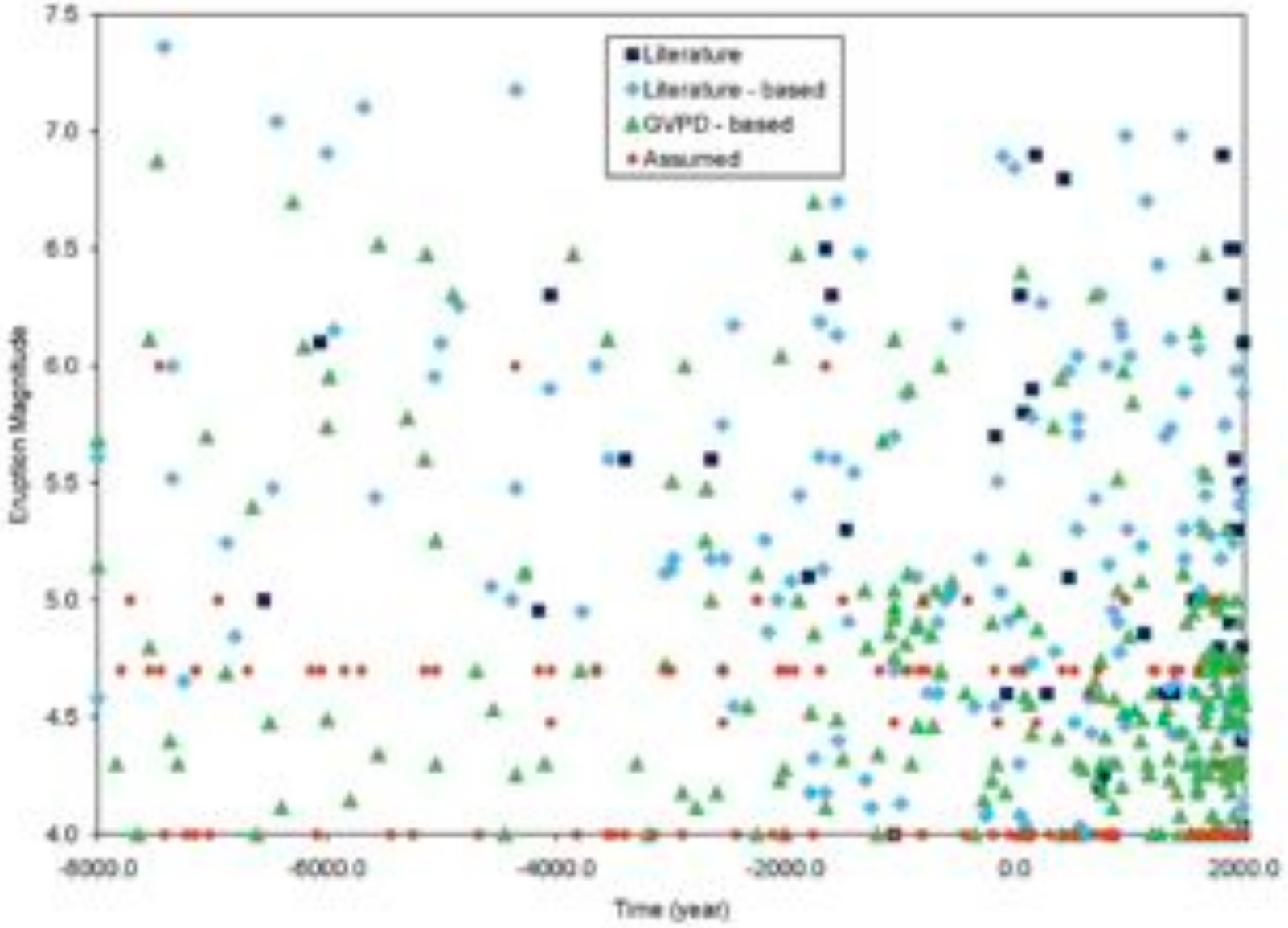
$M = \mathrm{Log}_{10} m - 7$

m is mass erupted in kg

Intensity is mass erupted per unit time

Eyjafallajokull 2010	10^6 **kg/s**
Mt St Helens 1980	10^7 **kg/s**
Pinatubo 1991	10^8 **kg/s**
Taupo AD 180	10^{11} **kg/s**

Holocene record of explosive volcanism



Deligne, Sparks and Cole (JGR in press)

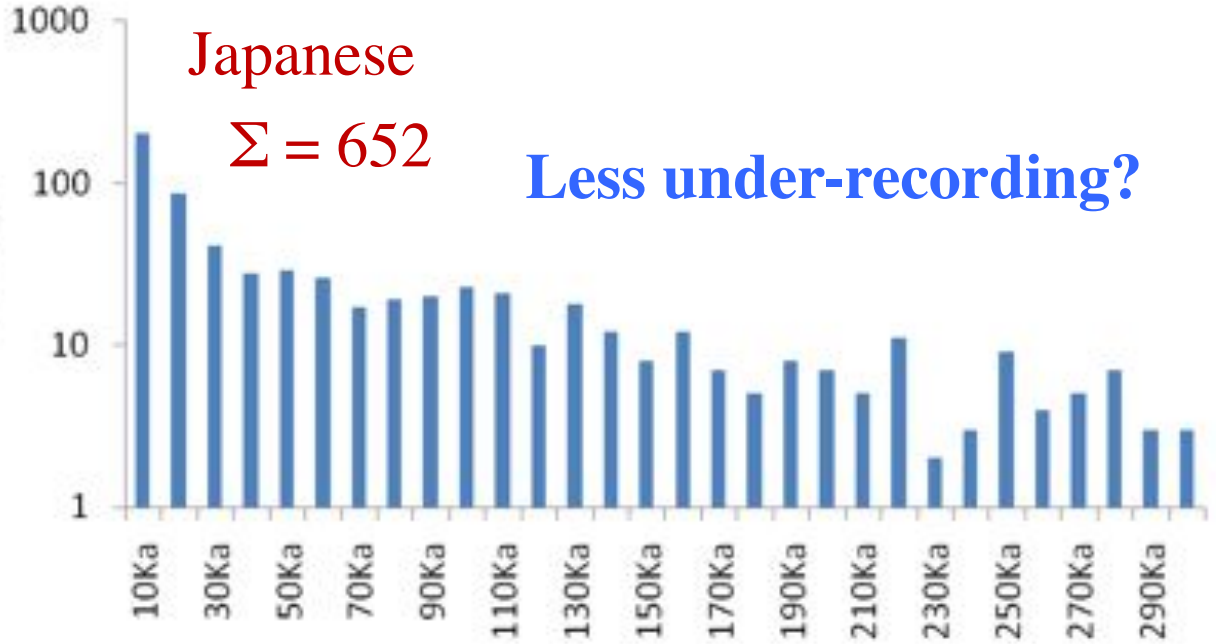
Initial results I : No. of eruptions

Non-Japanese

Σ = 930

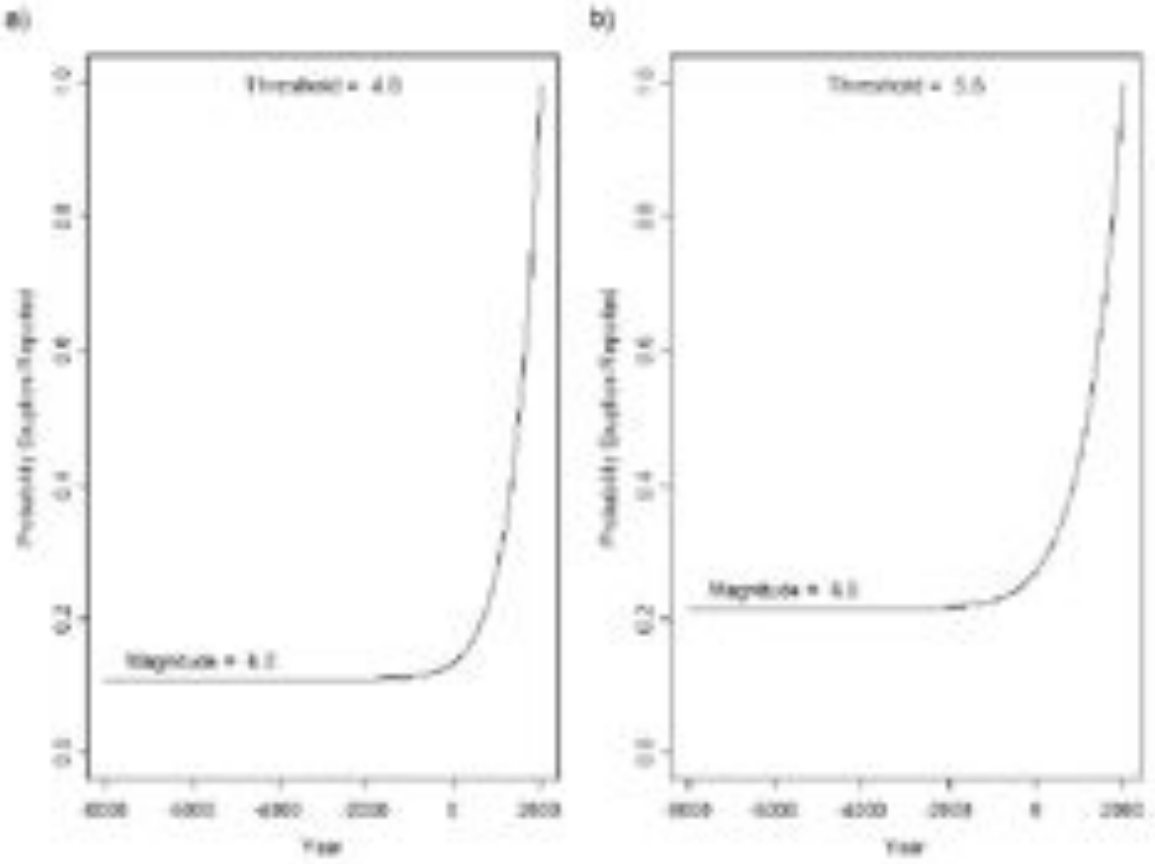
Japanese

Σ = 652

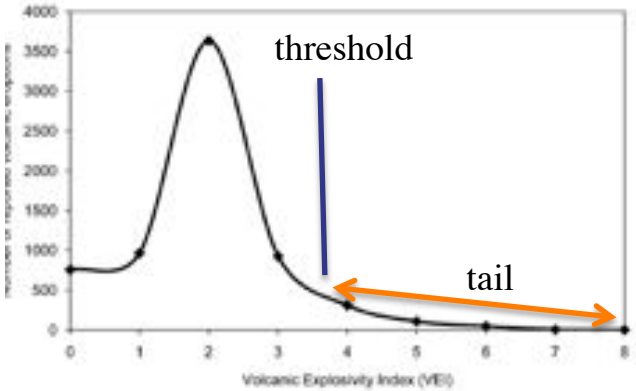


Less under-recording?

Global magnitude-frequency relationship

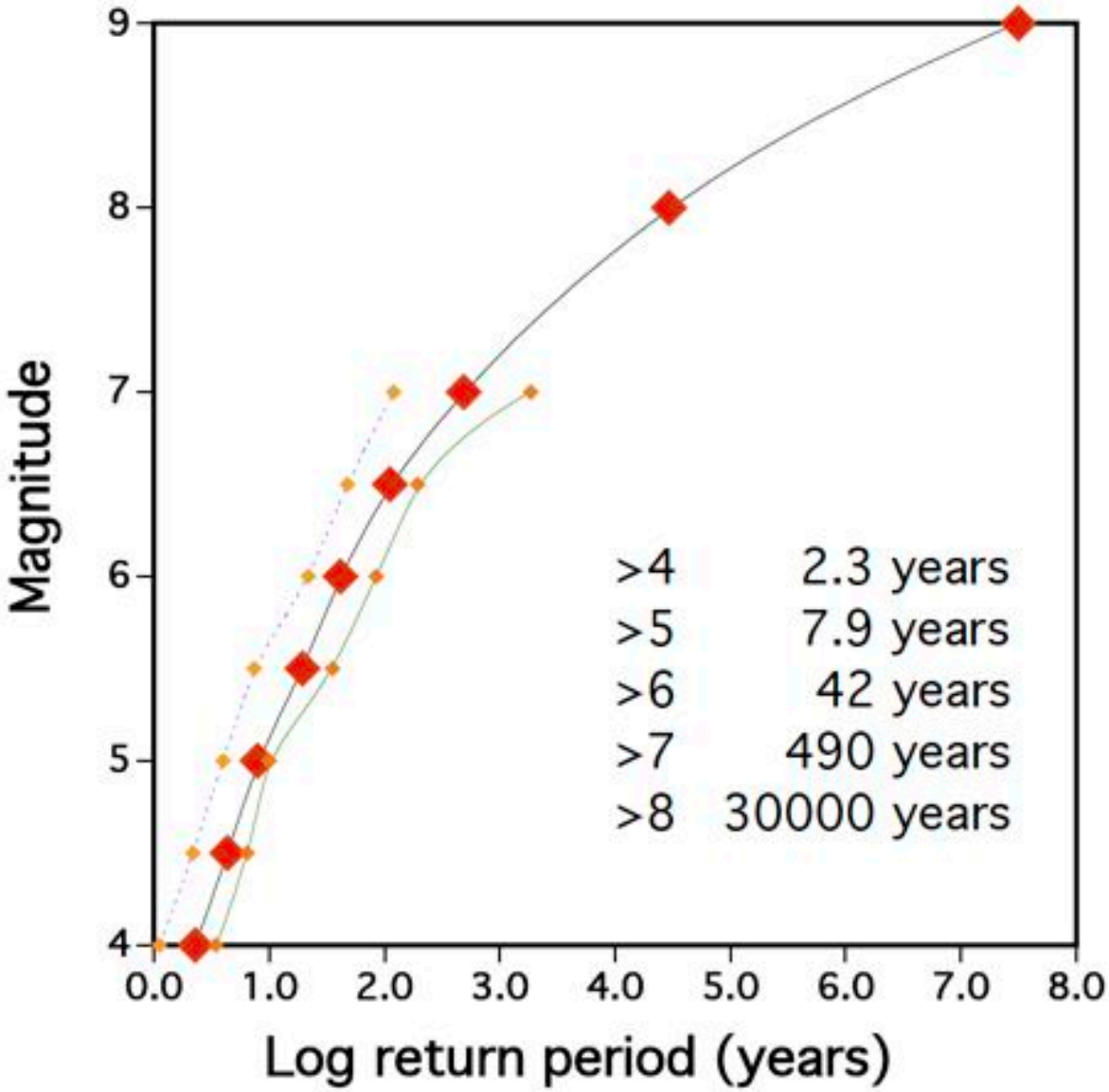


Under-recording

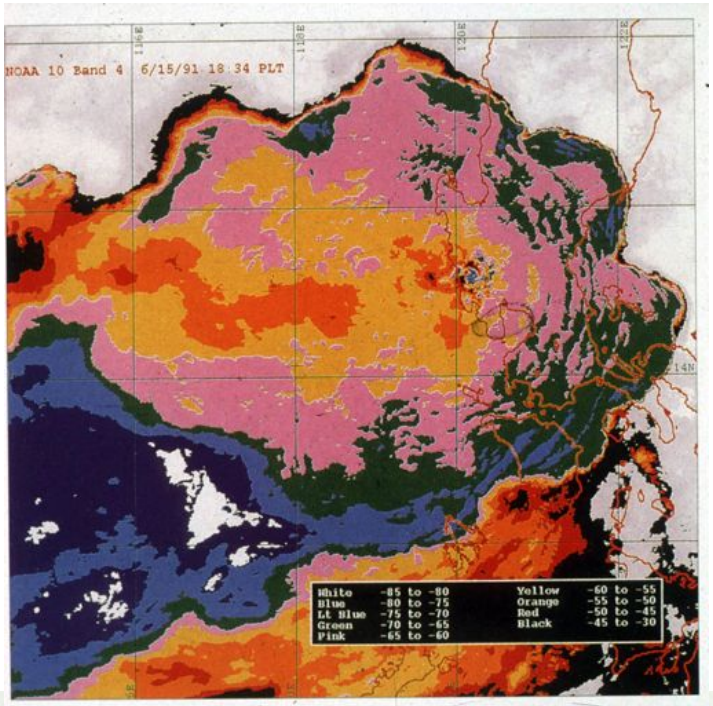


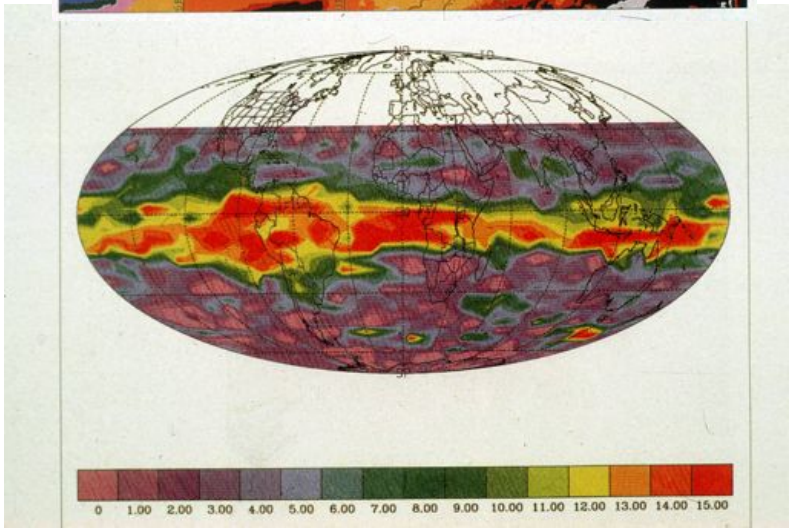
Threshold dependence

Deligne, Sparks and Cole (JGR 2010)


Magnitude
9
8
7
6
5
4
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
Log return period (years)
>4 2.3 years
>5 7.9 years
>6 42 years
>7 490 years
>8 30000 years

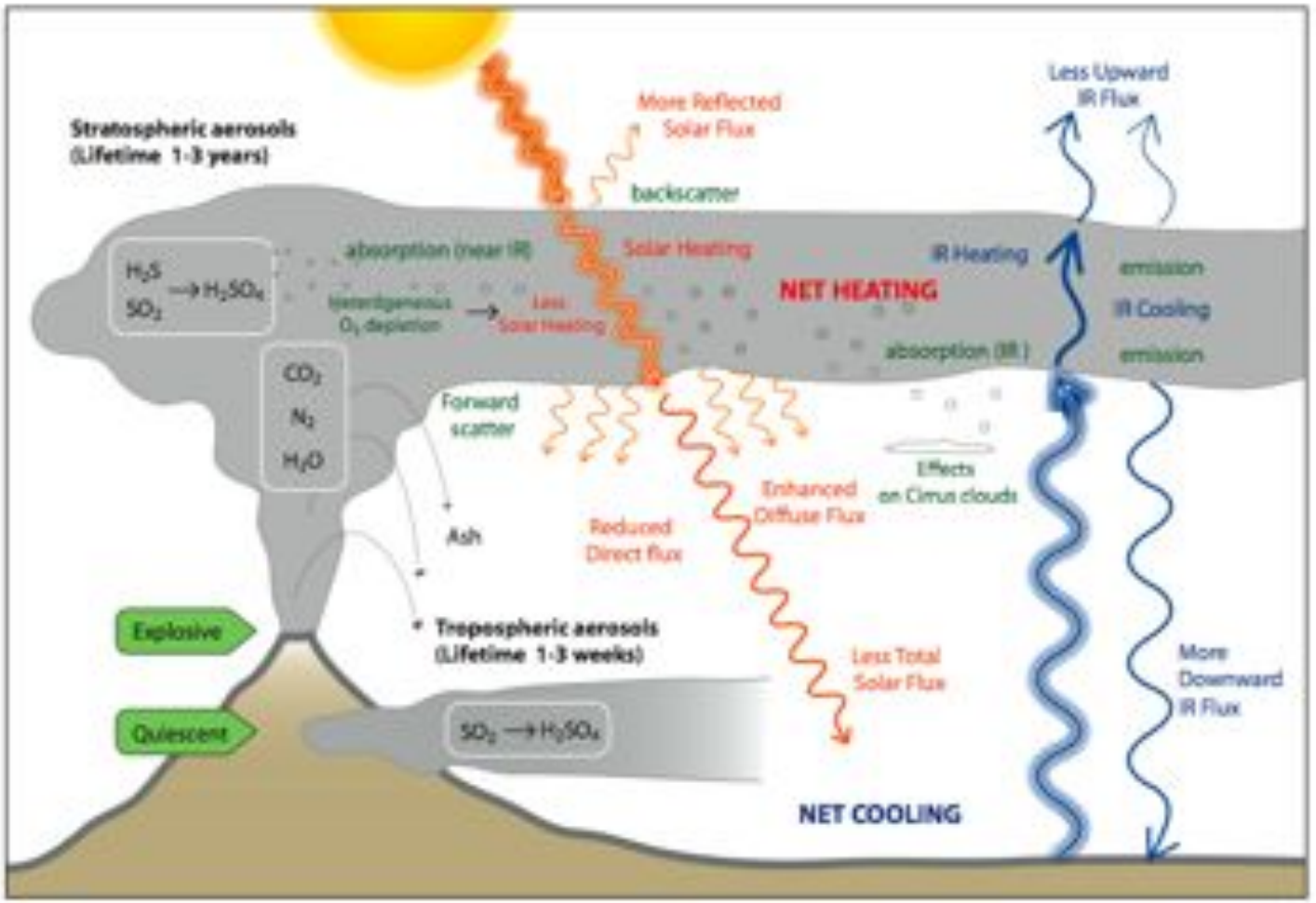
But the volcanic hazards are not just local…..



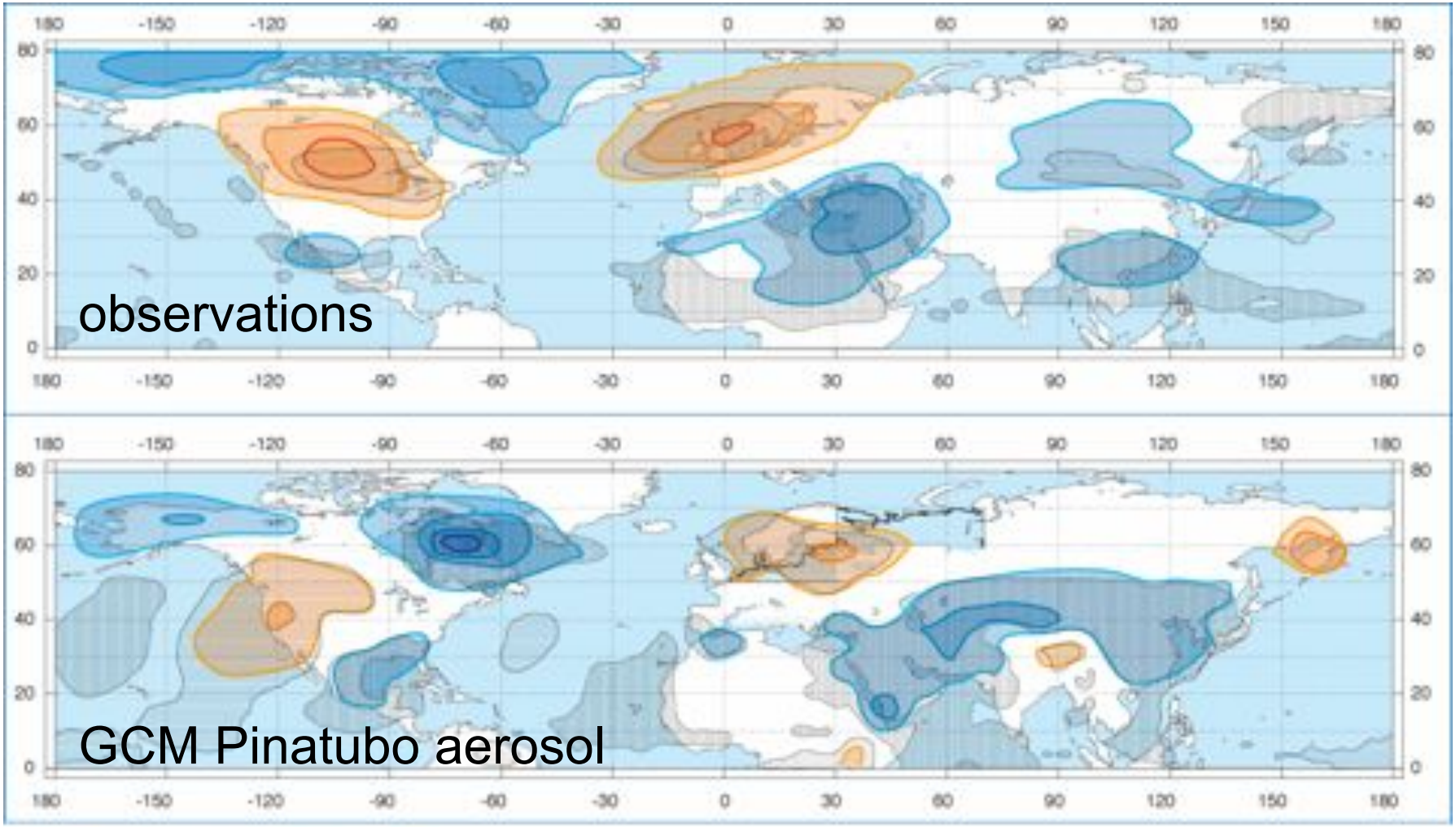


Global effects of Pinatubo 1991

Volcanism and Climate Change



Courtesy Alan Robock

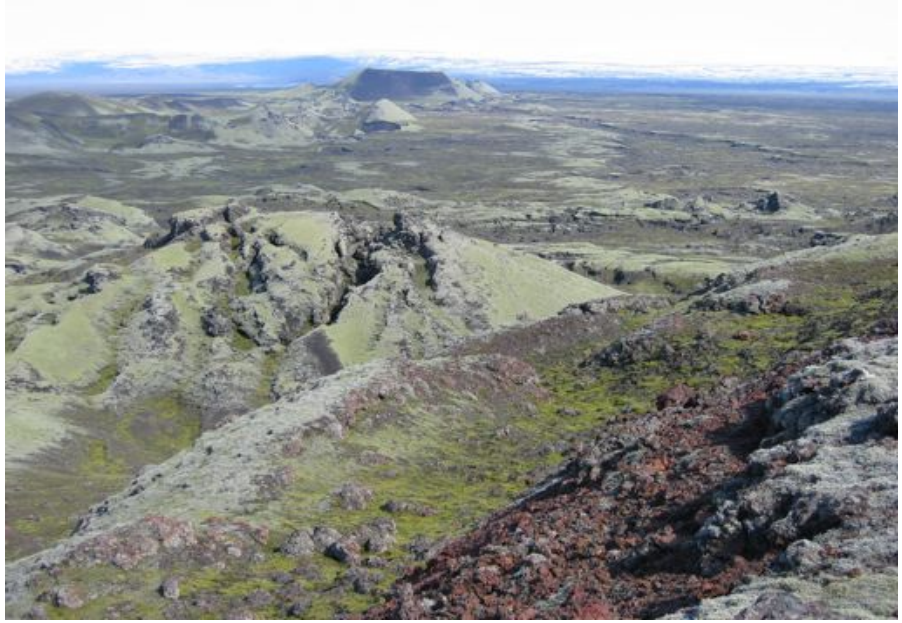


Temperature anomalies in the northern-hemisphere winter of 1991-1992 after the Pinatubo eruption.

Another Tambora 1815 or Laki 1783 in 21st century?

Return period ~ 250 year about a 1 in 3 chance

1815 eruption of Tambora, Indonesia ~ 30 km^3



1783 eruption of Laki, Iceland ~ 12 km^3

Great Famine of 1816

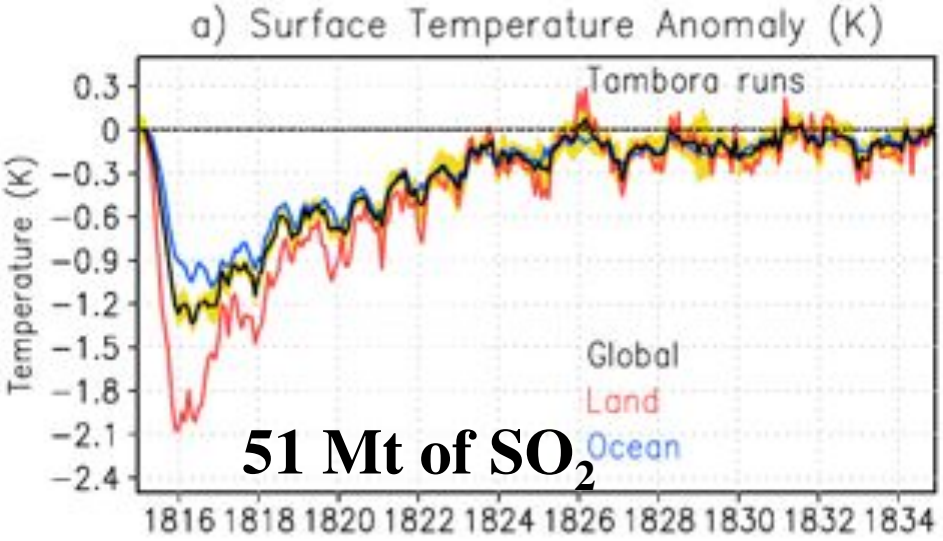
'*Coldest July in a 192 years record.*' (Lancashire Plain, UK)

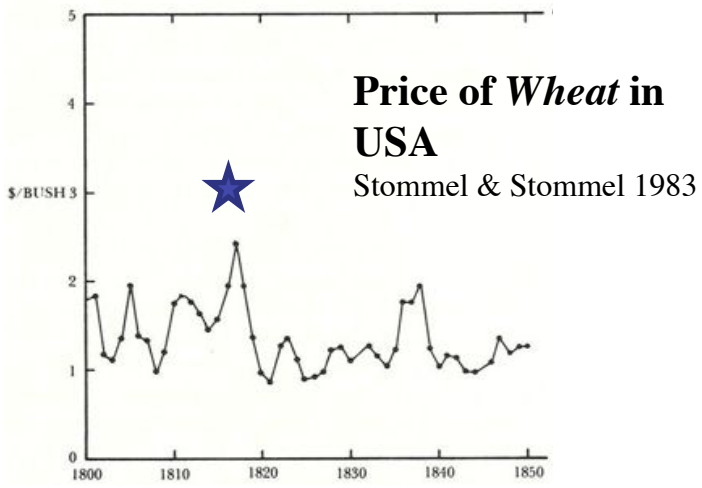
'*Coldest summer in 1753-1960.*' (Geneva, Switzerland)

'*Great frost* [in June] – *we must learn to be humble.*' (Branford, USA)

'*In July ice froze as 'thick as window glass"*. (Maine, USA)

'*..for the harvest entirely failed from the badness of the weather.*' (Ireland)

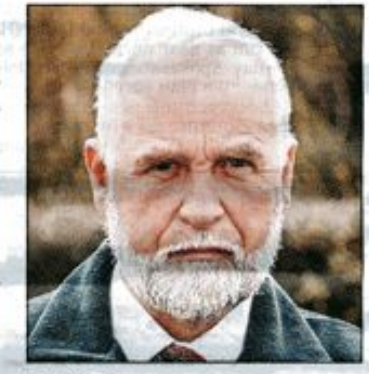




Price of *Wheat* in USA
Stommel & Stommel 1983

'We could be sitting on a Mendip volcano'

By Oliver Hulme
wells@midsomnews.co.uk
01749 832335



Nigel Taylor

A volcano erupts in Ecuador

Does a great and terrible fate await us if drilling starts below the Mendip hills to extract gas?

A Mendip hills expert says it might. Nigel Taylor, caver, wildlife and nature campaigner, explosives expert and Mendip district councillor, has carried out a study of the Mendip Hills and has discovered that there is a volcanic plug that could be holding back a river of lava ready to erupt if disturbed.

"It may sound ridiculous," said Mr Taylor, "but it is no more ridiculous than drilling deep into the earth's crust and setting off explosions to release trapped gas without knowing all of the potential consequences.

"We could be sitting on a Mendip volcano."

Mr Taylor says that Moons Hill Quarry, which is situated at the heart of the Mendip Plateau near Stoke St Michael, is a massive Silurian Volcanic plug of Basalt rock.

He said: "The rain falling onto the Mendips soaks down, and are superheated on their journey to the Roman Baths at Bath by volcanic activity deep in the earth's surface under that volcanic plug, long thought extinct."

"But what could happen if the exploration company is allowed to carry out 'Fracking activities' on the Mendips?"

Fracking is the process of pumping water underground until the gas bearing shale fractures and releases the pressurised gas it contains.

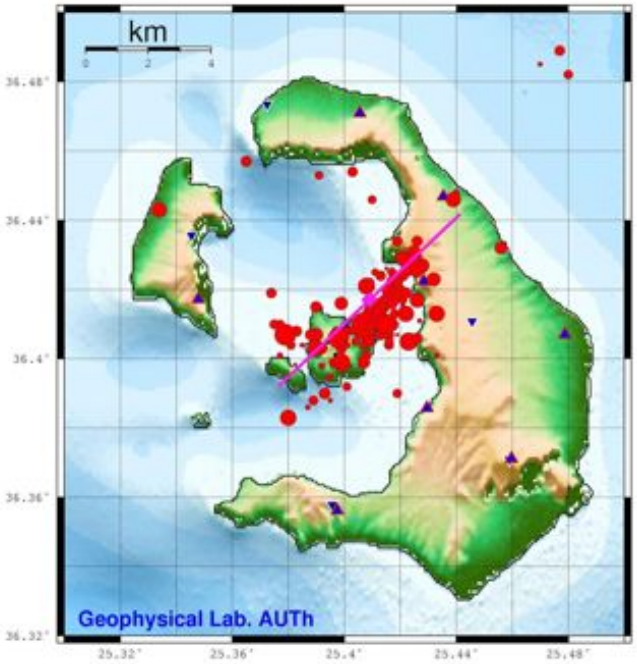
In the United States fracking has been blamed for widespread pollution – with its release in the water supply causing tap water to catch fire.

The energy industry says the process is safe and an essential source of energy for the future.

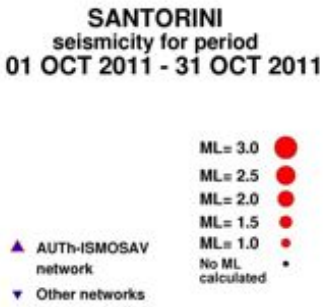
Mr Taylor said: "I am keeping an open mind about all of this, but have more than a pressing concern about a risk that nobody appears to have either realised or considered.

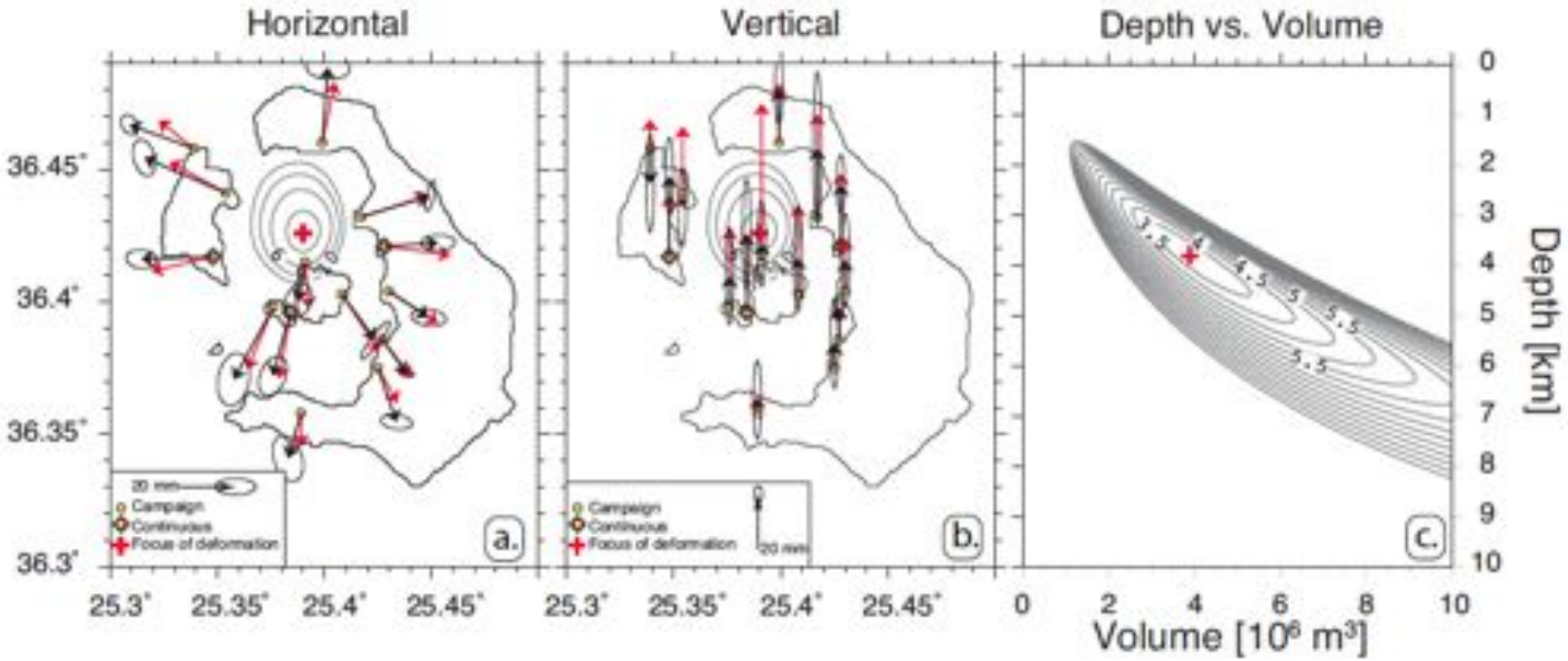
"We could either end up diverting the hot waters from Bath into ruptured rocks deep below us, pollute them with shale oils and gases, or the doomsday nightmare scenario – destabilise our geology and awake a sleeping giant."

Science information and Misinformation in the media age



Uplift 0.8 cm/month in 2011
Seismicity and deformation now low

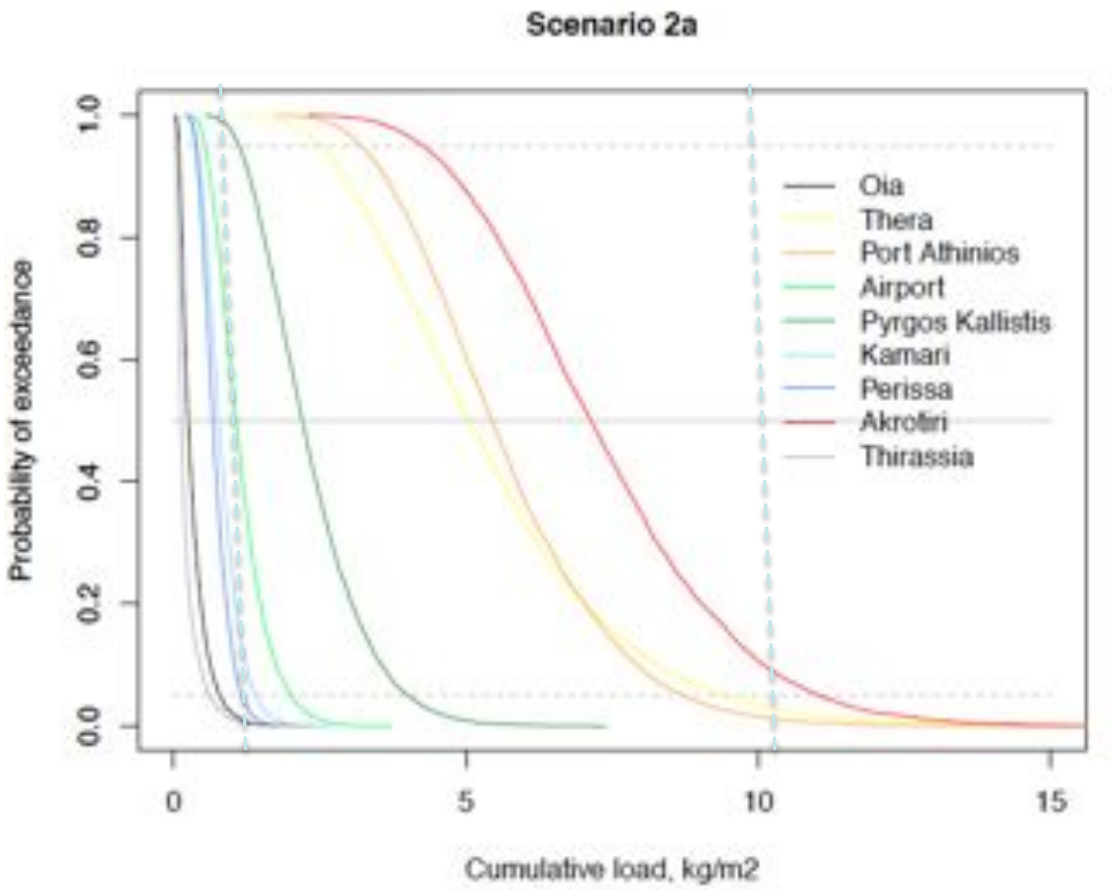




Newman et al (GRL, 2012)

Each category is independent Poisson process

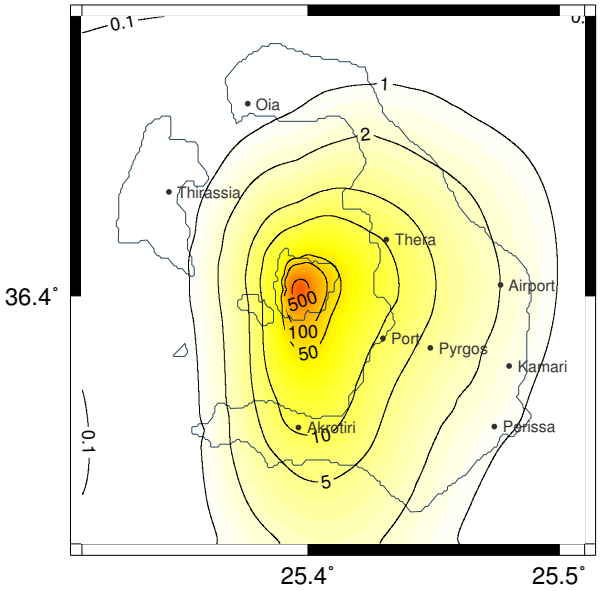
Cumulative load 2 years



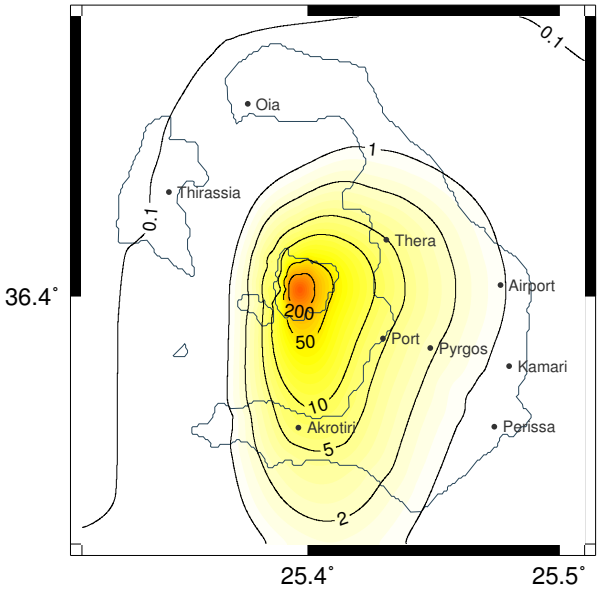
10 kg/m^2 = 1 cm ash

1 kg/m^2 = 1 mm ash

Scenario 2a 5%ile cumulative deposit (kg/m2)



Scenario 2a 50%ile cumulative deposit (kg/m2)



Thanks for your attention