



QUANTIFYING RISK, ENABLING OPPORTUNITY

# CATASTROPHE RISK IN AN AGE OF UNCERTAINTY

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# Enabling opportunity through catastrophe risk insurance



*‘When in doubt,  
do the courageous thing.’*

General Jan Smuts

Christ's College  
Cambridge, 1891-1894

# Doubt and courage in catastrophe risk underwriting

- Sparse amount of historical experience data
- Lack of information about the exposure
- Uncertainty over extreme events
- Model risk ambiguity



# The stampede by lightning



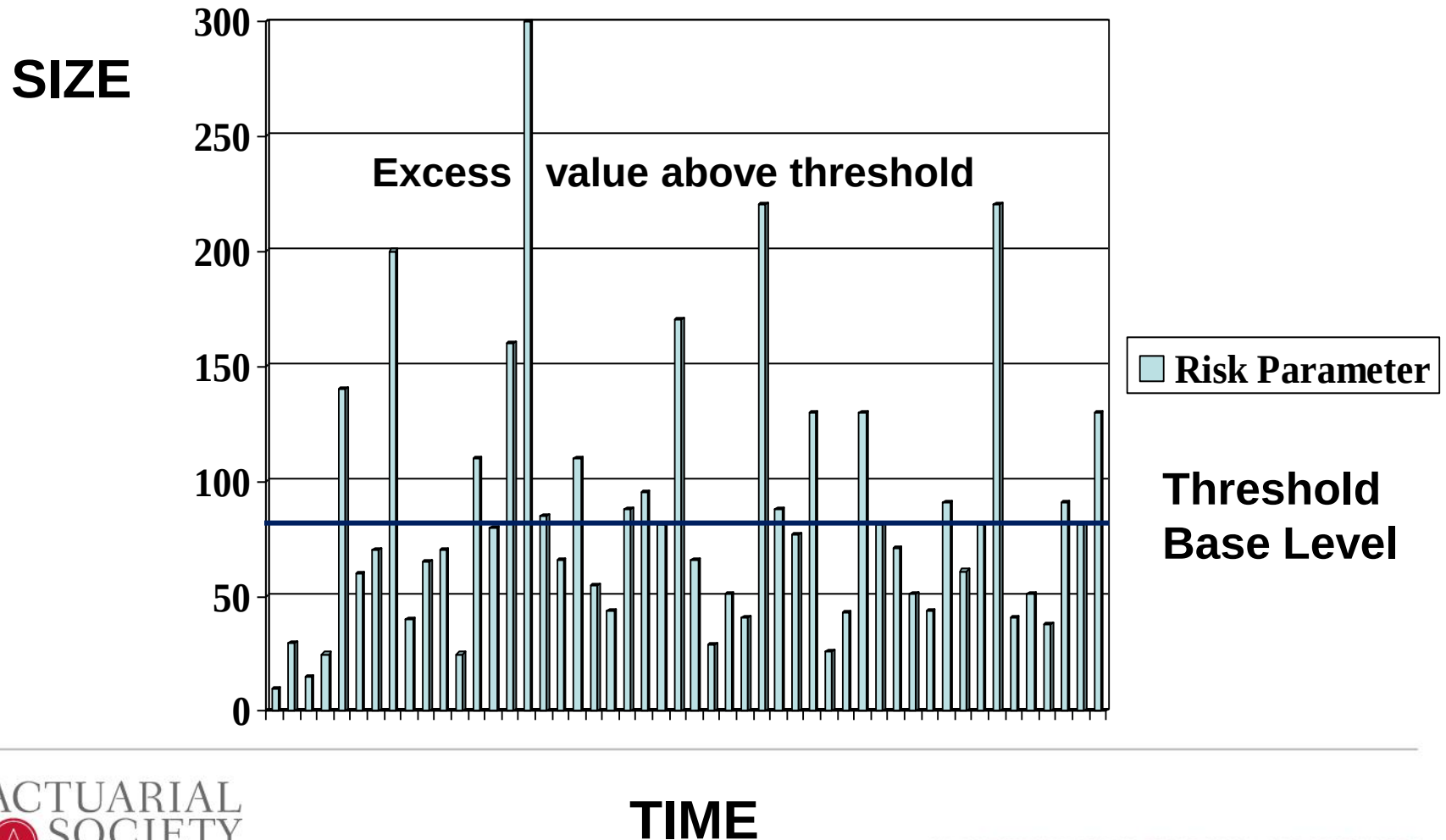
Frederick Rimington 1908

*'We must be comfortable with this environment of uncertainty, challenge, risk, danger, and competing agendas.'*

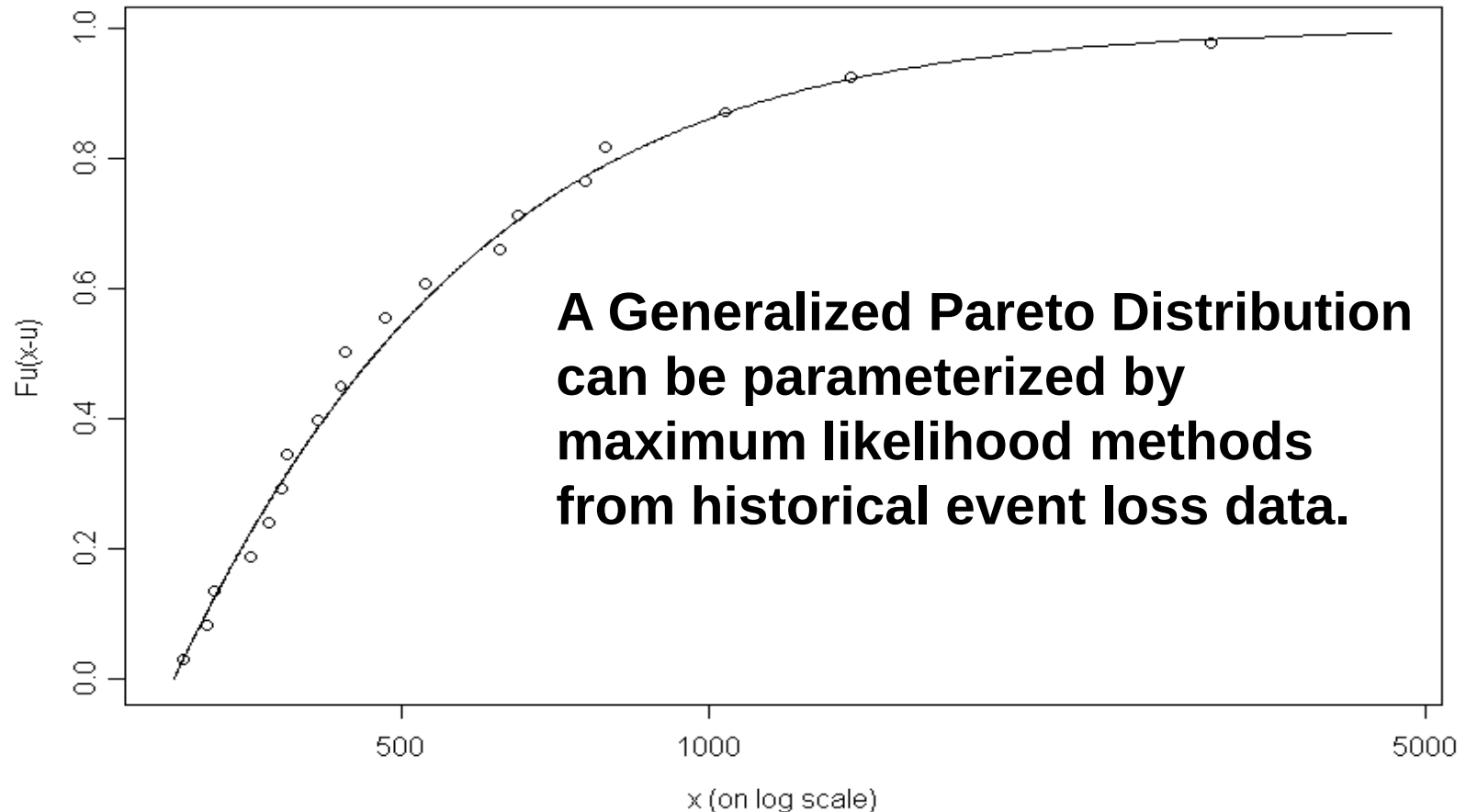
*'I use this image to tell you: I am comfortable with semi-chaotic situations.'*

General David Petraeus

# Peaks-over-threshold statistical model of extremes



# Statistical extrapolation of loss data



# The problem of inductive knowledge

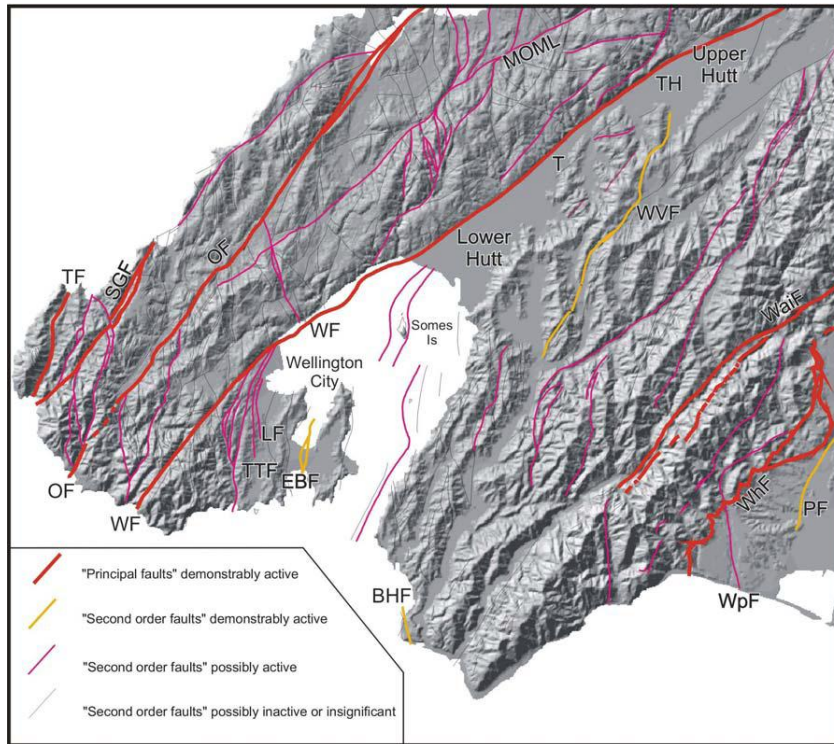
*“How do we know what we know?”*

*How do we know that what we have observed from given objects and events suffices to enable us to figure out other properties?”*



Nicholas Taleb,  
**The Black Swan**

# Historical disaster data mining



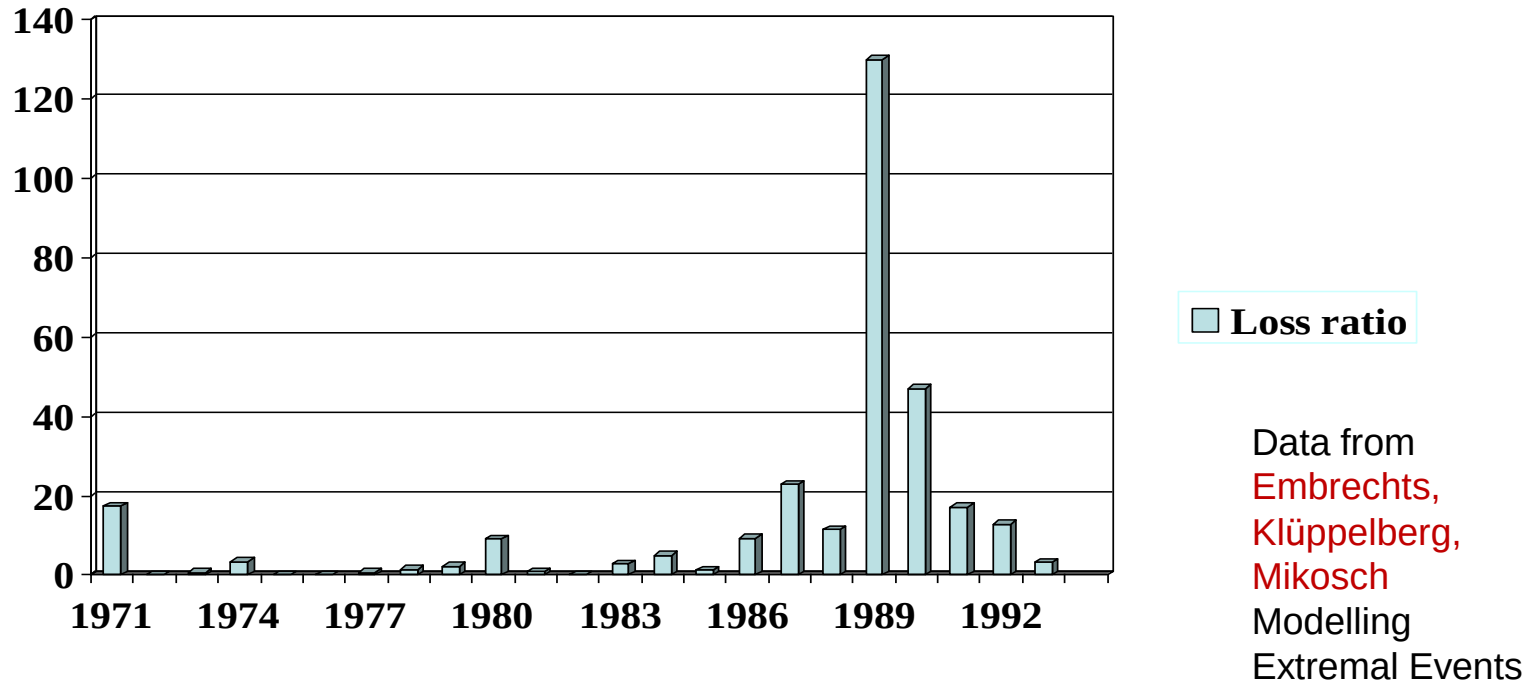
*‘For the promoter of colonisation, the New Zealand Company, these destructive earthquakes in 1855 were not good news.*

*The label of New Zealand as a land of earthquakes had to be downplayed if the flow of immigration were to continue.’*

**Magnitude Eight Plus,  
Rodney Grapes, 2000**

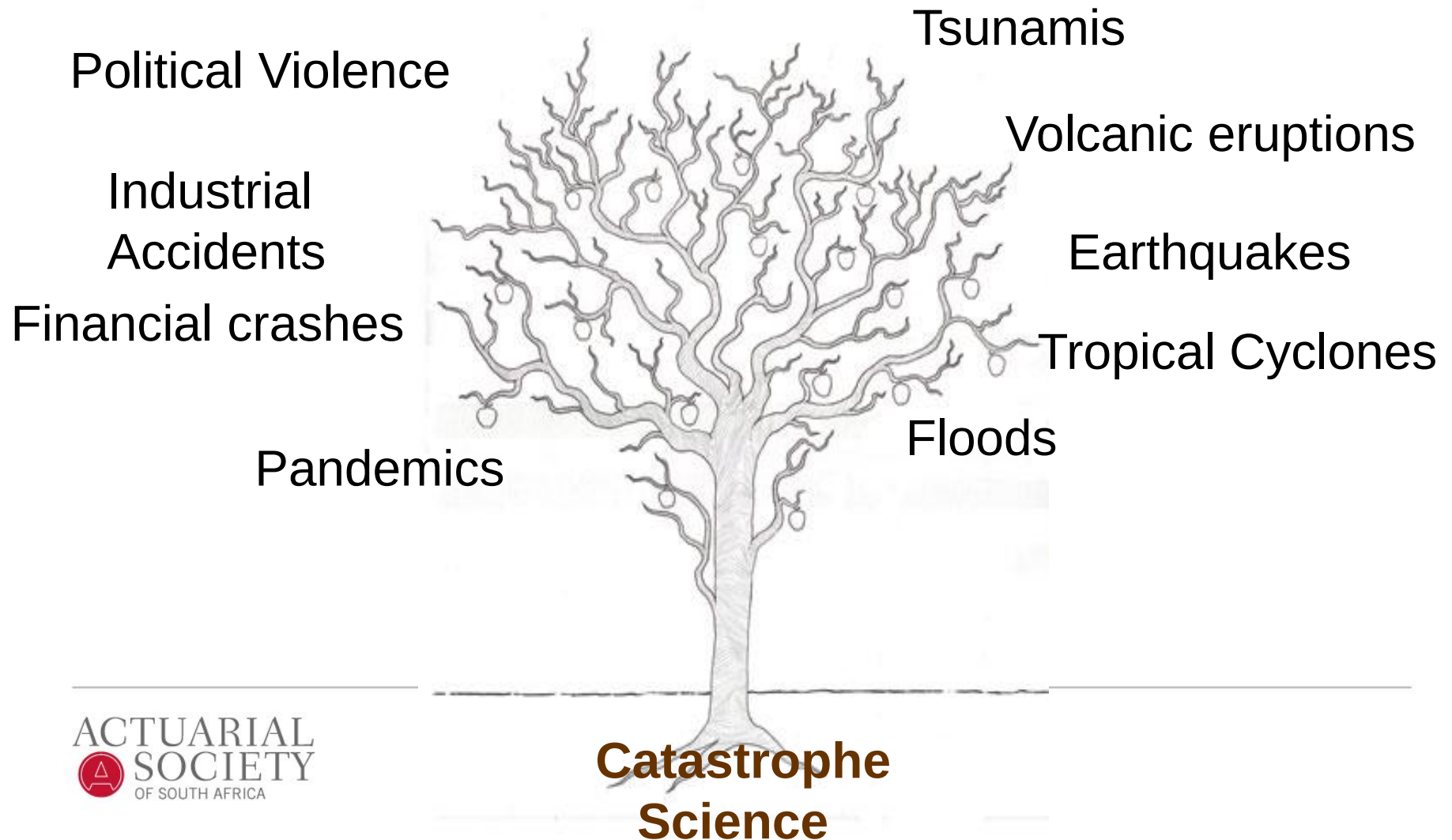
TF = Terawhiti Fault; SGF = Shepherds Gully Fault; OF = Ohariu Fault; MOML = Moonshine/Otaki/Mangaroa lineation; WF = Wellington Fault; TTF = The Terrace Fault; LF = Lambton Fault; EBF = Evans Bay Fault; BHF = Baring Head Fault; WVF = Whitemans Valley Fault; WaIF = Wairarapa Fault; WhF = Wharekauhau Fault; WpF = Wharepapa Fault; PF = Papatahi Fault; T = Taita; TH = Trentham-Heretaunga area.

# Yearly loss ratios for earthquake insurance in California

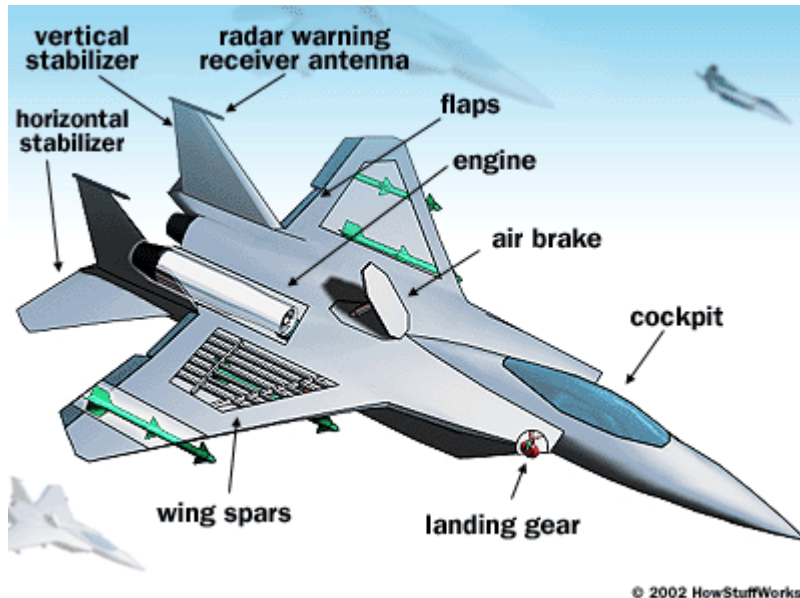


**The loss ratio for 1994 was: 2272.7**

# Lateral thinking on catastrophes



# Lateral thinking on catastrophes



Flight systems for F-15 jets have damage-adaptive technology relevant for making electric power grids more resilient.

Nature, 499, July 2013

# Self-similarity of landscape



*'Things have a scale.  
The small may be a  
model of the large, and  
the large of the small.'*

*A stone, when it is  
examined, will be found  
to be a mountain in  
miniature.'*

*John Ruskin,  
19th century art historian*

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# Power laws from scale invariance

Suppose that physical parameters  $k$  and  $\lambda$  are related in a scale invariant way. Under a scale change:

$$k_1 / k_2 = f(\lambda_1 / \lambda_2)$$

$$f(\lambda_1 / \lambda_3) = k_1 / k_3 = \{k_1 / k_2\} \{k_2 / k_3\} = f(\lambda_1 / \lambda_2) f(\lambda_2 / \lambda_3)$$

**The only non-trivial  
continuous solution is:**  $f(\lambda) = \lambda^q$



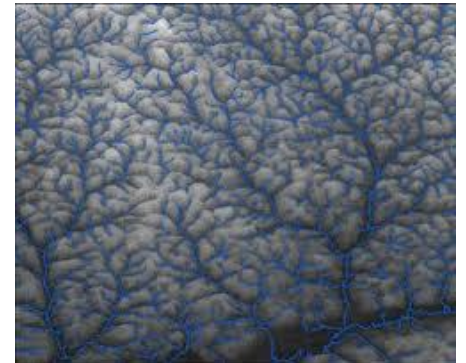
# Power law scaling in river basins

The sinuosity of individual river channels, and branching characteristics of the drainage tree were seen with a new perspective post-Mandelbrot.

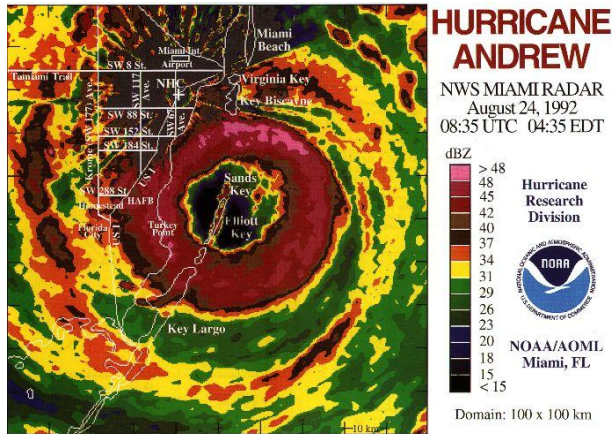
e.g. Hack's Law: The length  $L$  of the longest stream in a drainage region is proportional to some power of its area  $A$ :

$$L \propto A^{0.6}$$

The number of streams  $N(L)$  with length above a given length  $L$  is proportional to  $L^{-D}$ .



# Record catastrophe insurance losses



Northridge earthquake 1994



Tohoku tsunami 2011



New York terrorism 2001

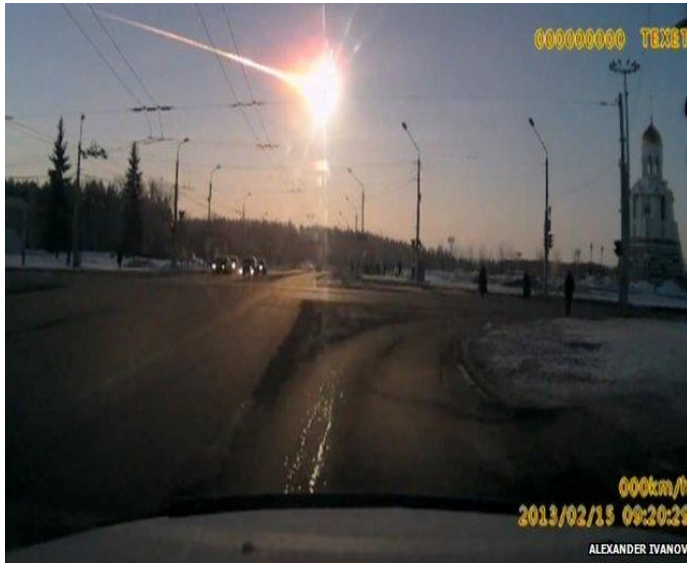
# Disaster: an unfavourable aspect of a star

- What actually happened historically was **NOT** pre-determined; it is just one specific realization of what might have happened in a stochastic process.
- Where events are frequent, most of what can happen has already happened a number of times.
- However, for rare extreme events, the actual historical dataset is sparse.
- Consideration of counterfactual ‘near-miss’ scenarios augments a meagre dataset.

*‘The terror of the unforeseen is what the science of history hides.’*

Philip Roth

# Meteorite strike on Chelyabinsk, Russia, 15 February 2013



The explosive energy of the impact was equivalent to 460 kilotonnes of TNT. This makes it the most energetic event reported since the June 1908 Tunguska meteorite in Siberia. **Had this struck about 5 hours later, St. Petersburg would have been obliterated.**

# The human learning curve

The rate of reduction of errors  $A$   
is proportional to the number of errors:  $A' \propto -A$

In January 2013, a potentially catastrophic battery fire aboard a Boeing 787 in Boston forced the grounding of Dreamliners around the world for 4 months.



# Prevailing deterministic view of history

Historical hazard experience is regarded as binary – a disaster either happened or it did not.

- But what if the environmental circumstances had been somewhat different?
- What was the chance of a disaster?



# Counterfactual disasters: resampling history

- Disasters are complex functions of variables defining the state of the world at a given time. Changes in the input environmental values perturb the output disaster consequences.
- Each historical scenario corresponds to a specific realization of the input environmental values. Perturbations to these values leads to alternative disaster scenarios.

$$D = f(E_1, E_2, E_3 \dots E_n)$$

# Recurrent catastrophic river flooding

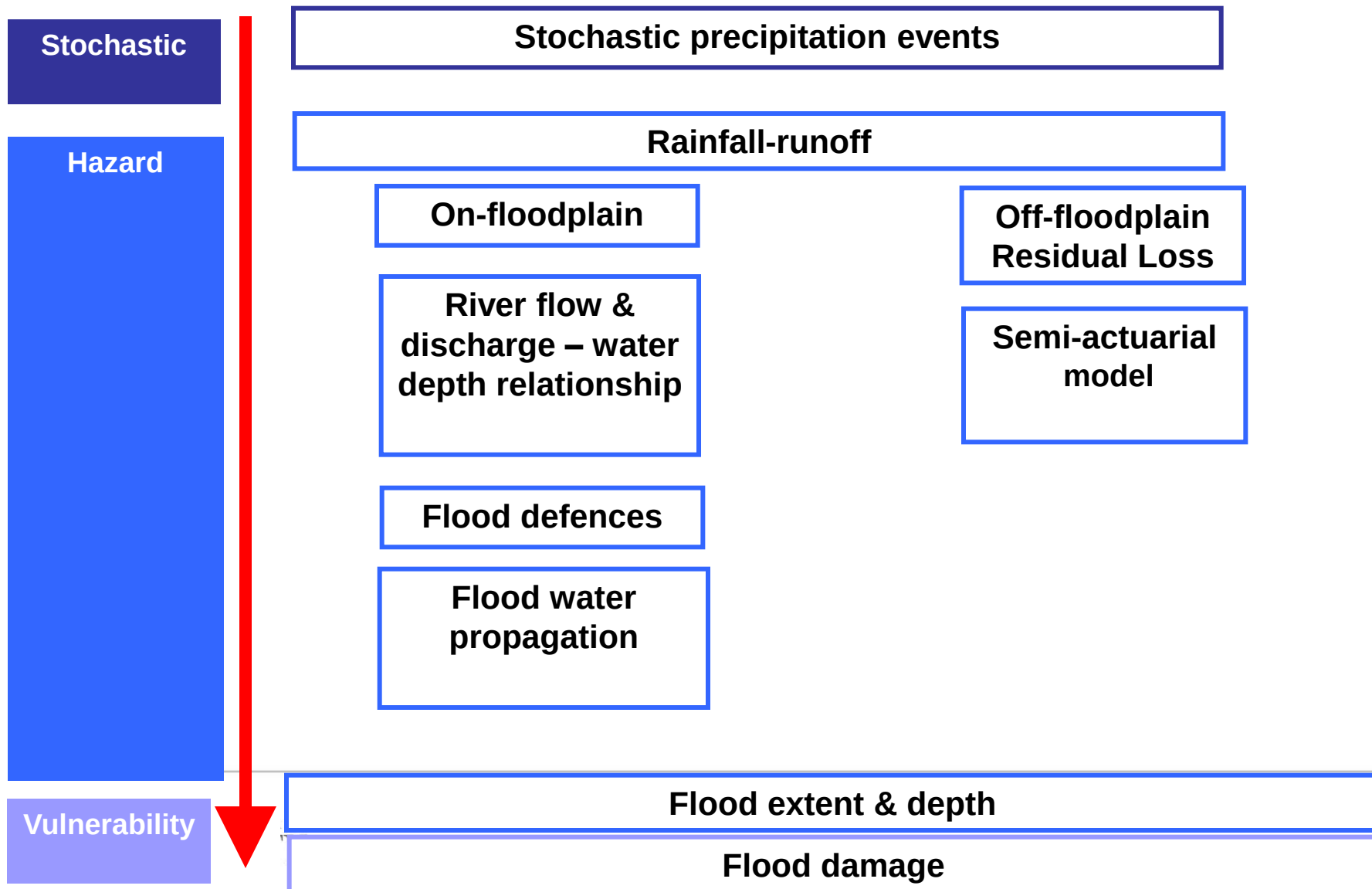


Central Europe flooding  
August 2002

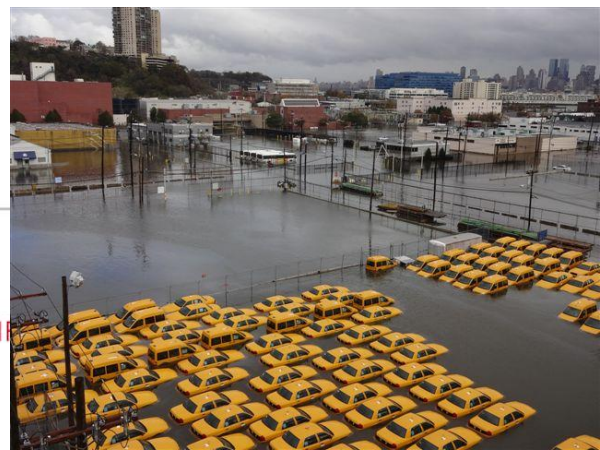
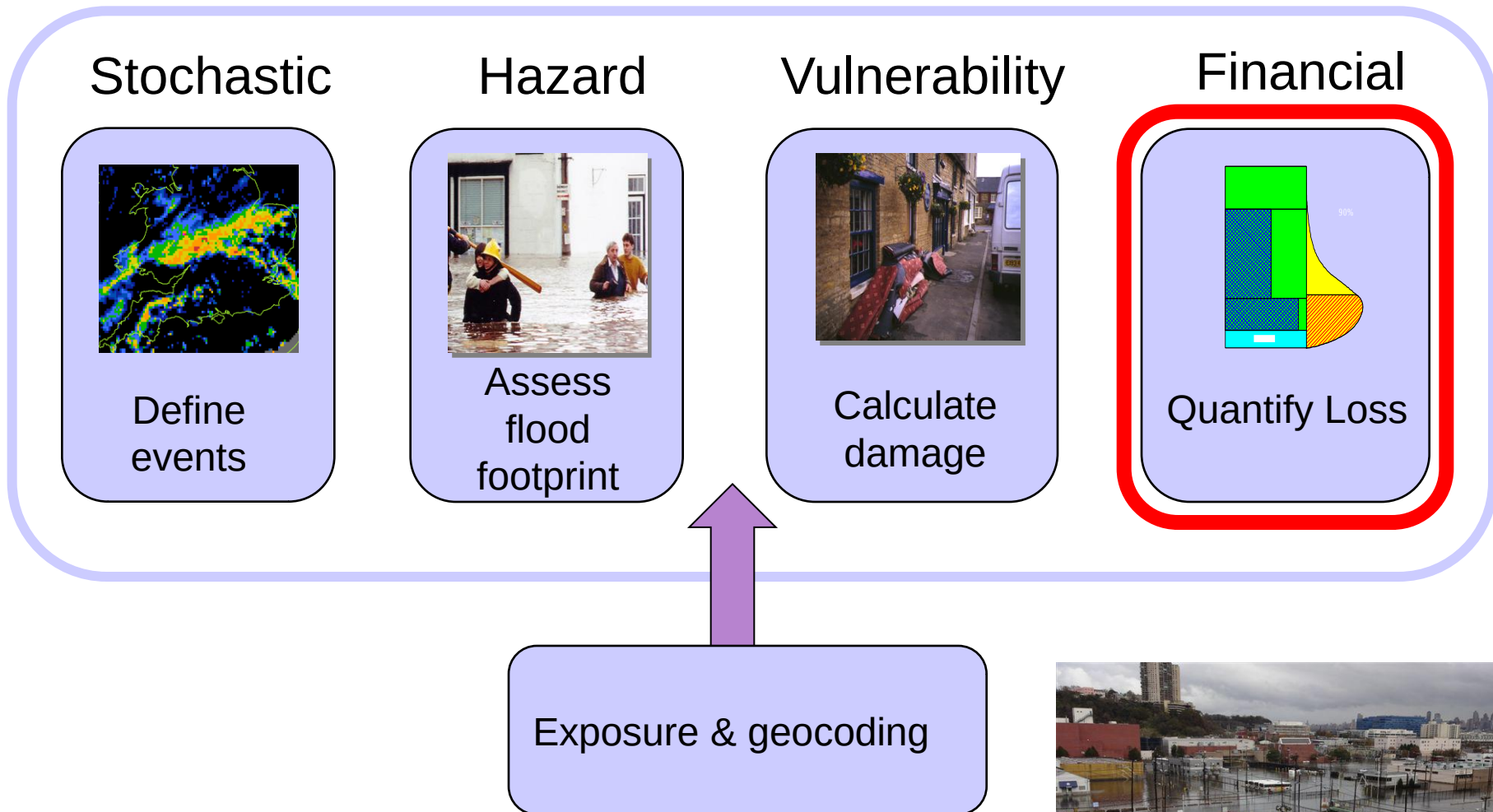


Central Europe flooding June 2013

# River flood modelling flowchart

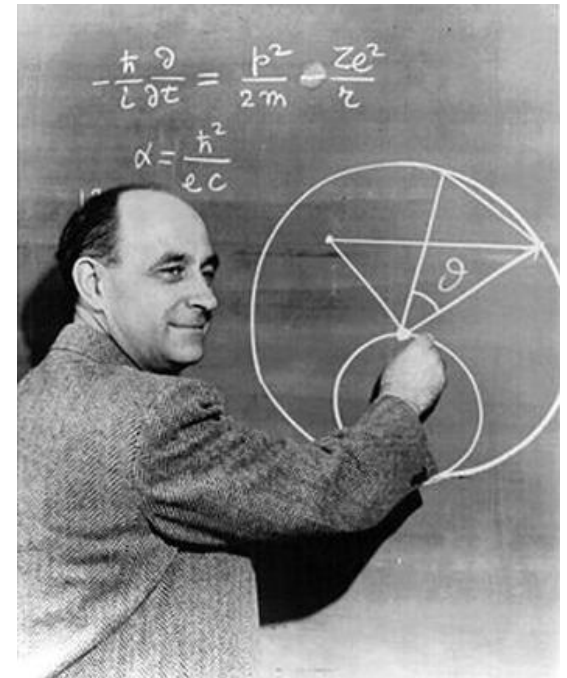


# Building blocks of a flood model



# Making sound approximations: Fermi Problems

- The art of approximation is an invaluable skill for a catastrophe risk modeller.
- Sound approximations are essential for reliable practical risk management.



Enrico Fermi

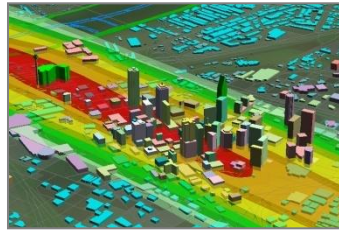


# Tornado risk modelling

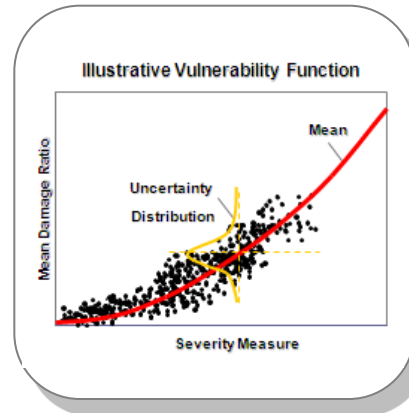
Define Tornado  
Event Set



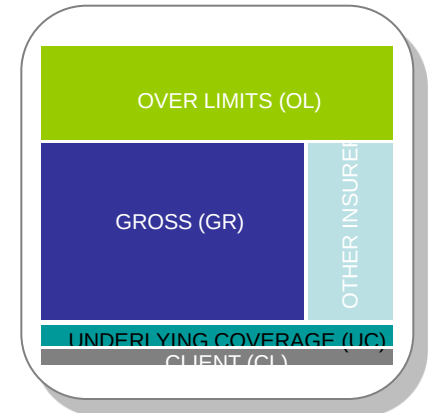
Assess Wind Speed  
Hazard



Calculate Damage  
Vulnerability

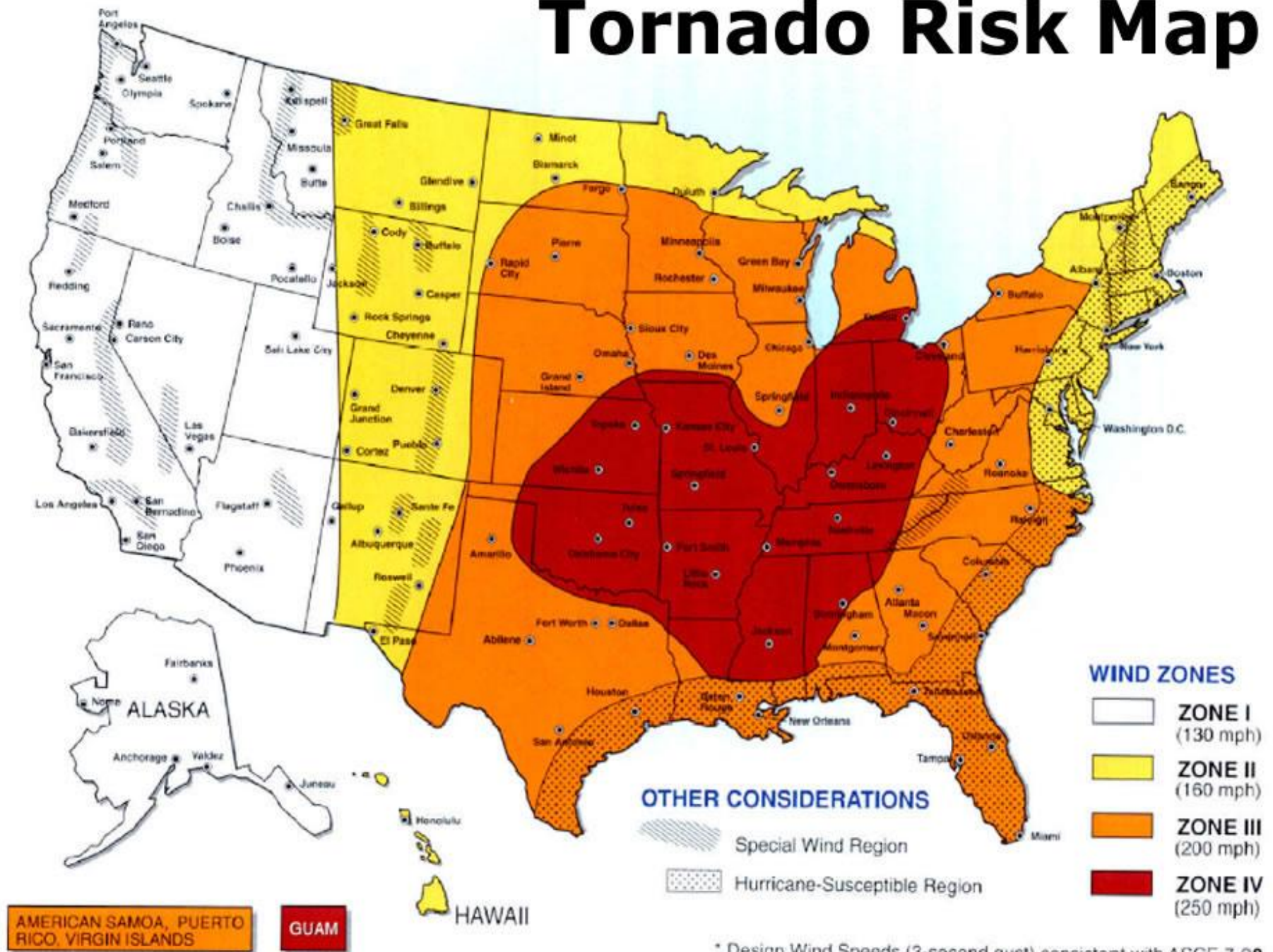


Quantify Financial  
Loss  
**Financial**



- A stochastic event model which simulates the meteorological range of potential tornadoes.
- A hazard model determines the peak windspeed for each simulated storm and site location.
- A vulnerability model linking hazard and damage.

# Tornado Risk Map



\* Design Wind Speeds (3-second gust) consistent with ASCE 7-98



**The insured loss from the Moore, Oklahoma, EF 5 tornado of May 20, 2013 is likely to exceed the previous record of \$2.8 billion.**

# Beyond the historical record

- Although not in the prime tornado hazard zone, properties in Atlanta do need tornado insurance.
- On March 14, 2008, for the first time since records began in 1800, an EF2 tornado struck downtown Atlanta.
- Although conditions were not optimal, an isolated supercell developed just northwest of the city of Atlanta on that evening.
- The storm intensified as it moved into the city and produced a tornado that caused damage along a path six miles long.



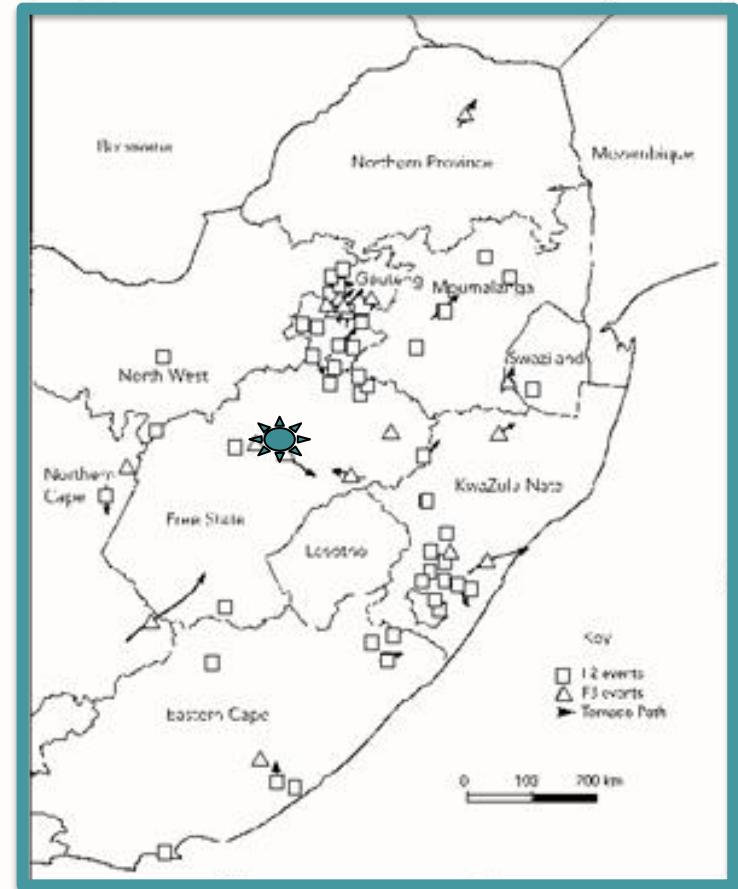
# Clustered spatial distribution of tornadoes

*‘Tornadoes can occur basically anywhere where a thunderstorm is possible.*

*Most of them have been observed in Gauteng, the Free State, KwaZulu-Natal (along a line from Pietermaritzburg to Ladysmith) and the northern region of the former Transkei.’*



South African  
Weather Service



# Welkom tornado    March 20, 1990

## Moore, Oklahoma, tornado

- 1,150 homes were destroyed in the EF5 tornado, which extended over an area of approximately 50 sq.km.
- Town population is about 55,000.

Adjusting for population  
and tornado area:

$$(400,000/55,000) * (20/50) * 1,150 = 3,345$$

## Welkom, Free State, tornado

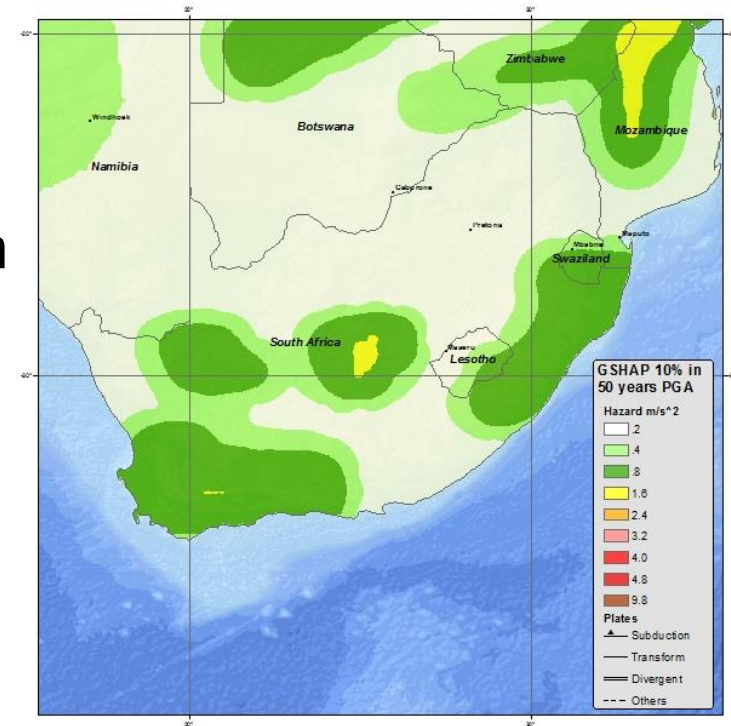
- 4,000 homes were destroyed in the tornado, which extended over an area of approximately 20 sq.km.
- Current town population is about 400,000.
- Structural damage loss ~ R230 million

# Earthquake hazard in South Africa

M6.3 earthquakes on 29 September 1969, Ceres, 100km northeast of Cape Town, and earlier on 4 September 1809, on the Milnerton fault, about 8 km from the Koeberg nuclear plant.



Maximum magnitude is estimated at about M7.0.



# Loss exceedance computation

The mean annual number of exceedances of loss  $L$  is given by the following sum over all event scenarios  $S$ , with frequency  $f(S)$  :

$$\nu(L) = \sum_S f(S) \cdot P(\text{Loss} \geq L | S)$$

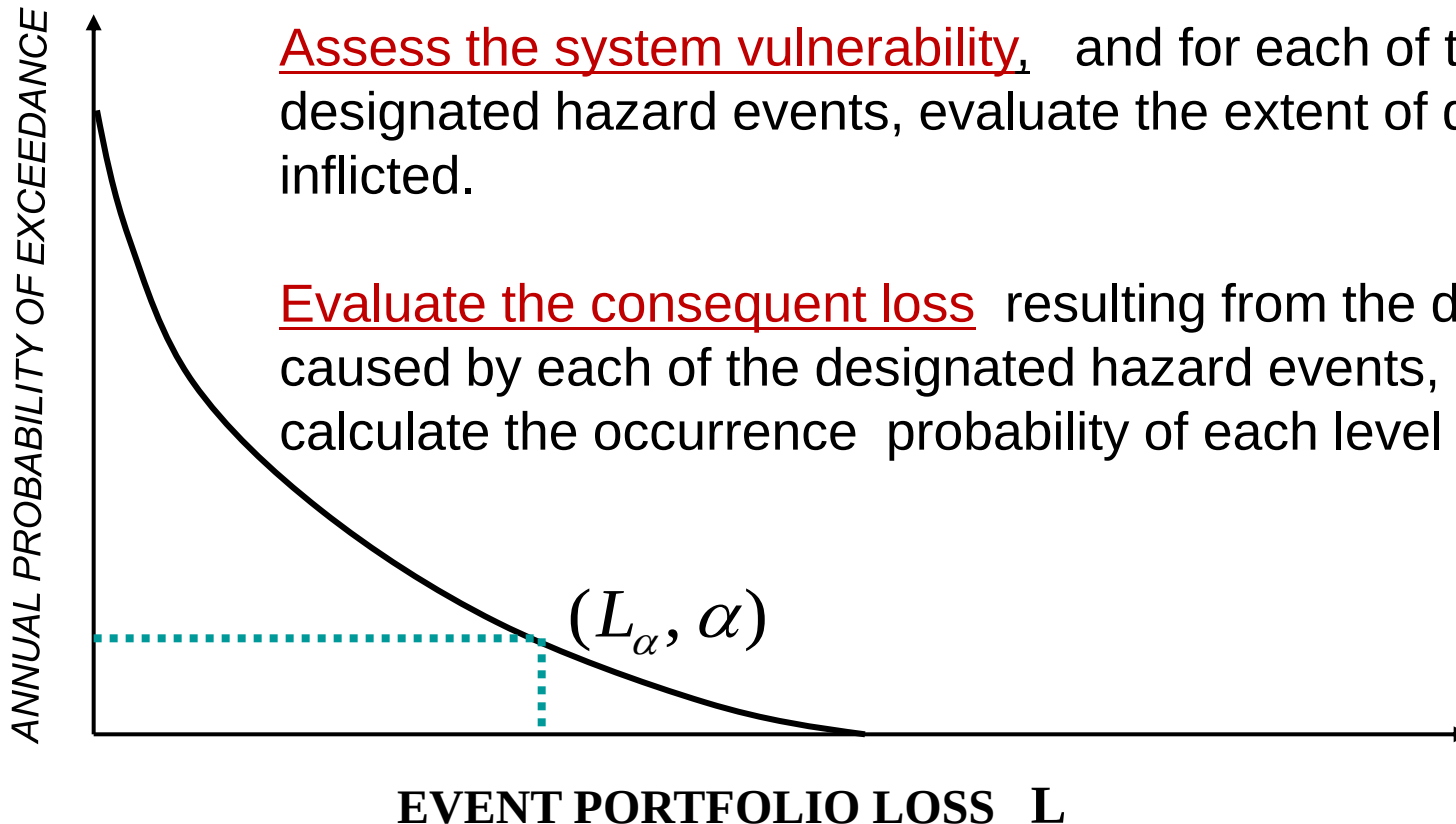


# Probabilistic Risk Assessment thought process

Identify the hazard events which might cause a loss, and estimate their probability of occurrence.

Assess the system vulnerability, and for each of the designated hazard events, evaluate the extent of damage inflicted.

Evaluate the consequent loss resulting from the damage caused by each of the designated hazard events, and calculate the occurrence probability of each level of loss.



# Knowing the design basis and code compliance



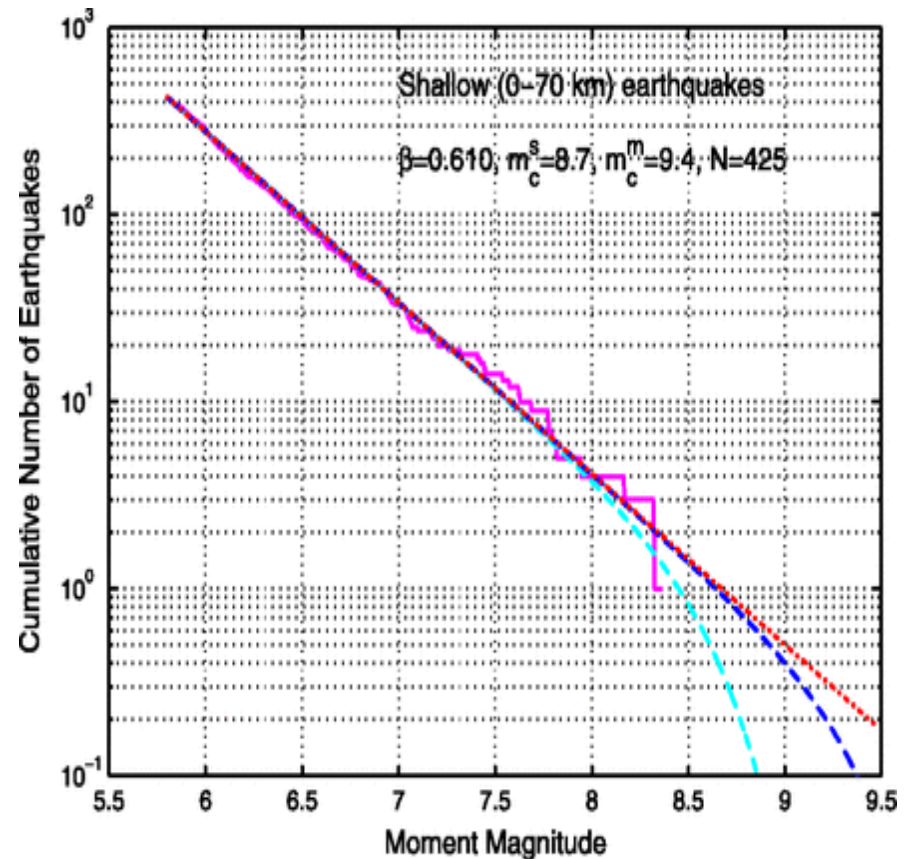
Rana Plaza, Dhaka, Bangladesh  
24 April 2013

Jamuna Bridge,  
Bangladesh



# The seismological learning curve

- Acts of God
- Earthquake weather, KNMI
- Electric field precursors
- Subduction zone  
Maximum Magnitude < 9
- Seismic gaps?



(Kagan & Jackson, 2013)

# Manmade catastrophe risk

| Subd. Zone | Mw  | Age     |
|------------|-----|---------|
| N.E. Japan | 8.2 | 130 Myr |
| Tonga      | 8.3 | 120 Myr |
| Kuriles    | 8.5 | 100 Myr |
| Kamchatka  | 9.0 | 80 Myr  |
| Aleutians  | 9.1 | 60 Myr  |
| Alaska     | 9.2 | 40 Myr  |
| Chile      | 9.5 | 20 Myr  |

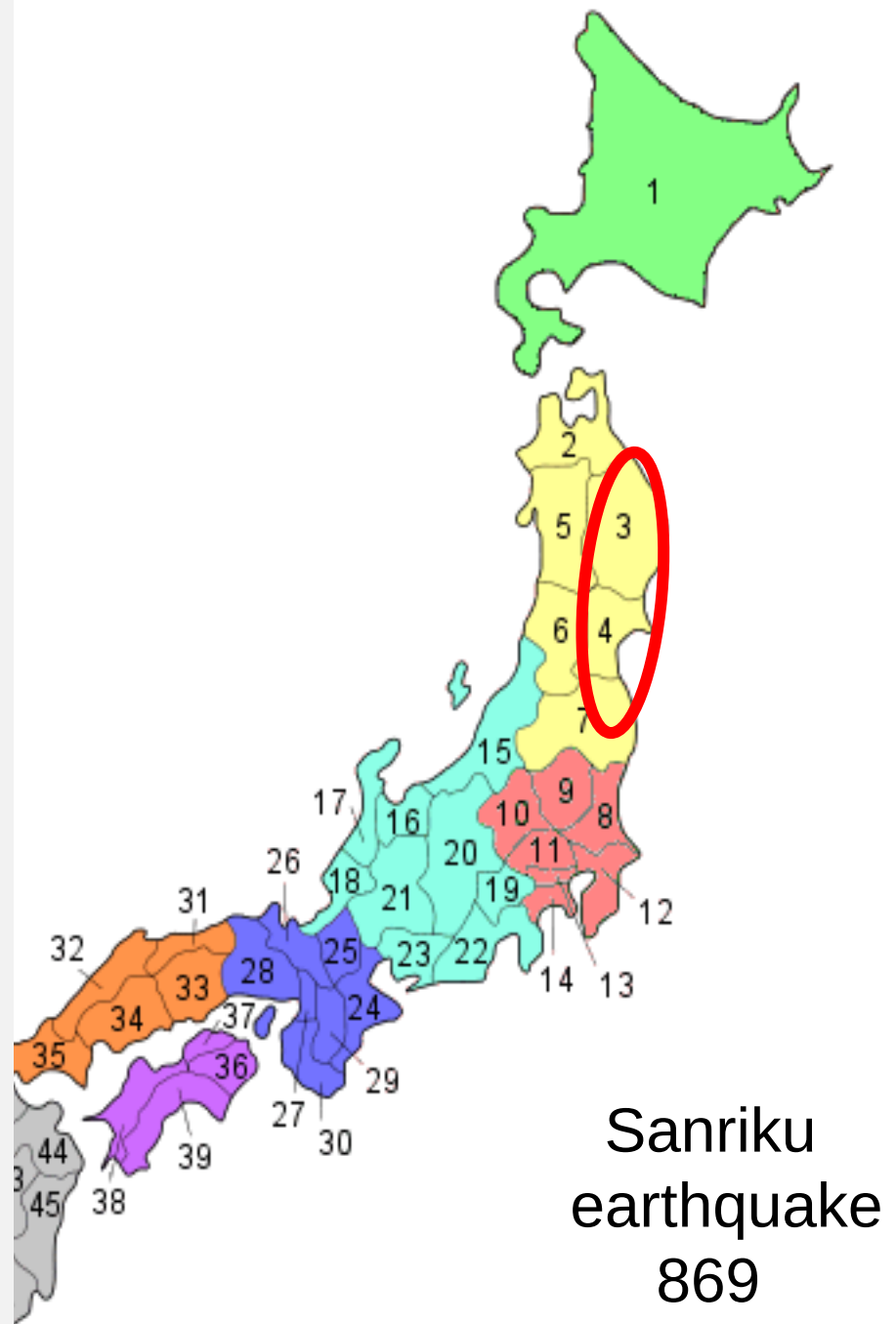
(Ruff and Kanamori, 1980)



*‘Traces of the tsunami damage were found from Miyagi Prefecture (4) to Fukushima Prefecture (7).*

*However, in the most recent study, the researchers found evidence of damage in Iwate Prefecture (3), leading them to believe the earthquake that caused the tsunami might have measured around a magnitude of 9.’*

Japan Society of Engineering Geology  
meeting, Osaka, 12 October 2007

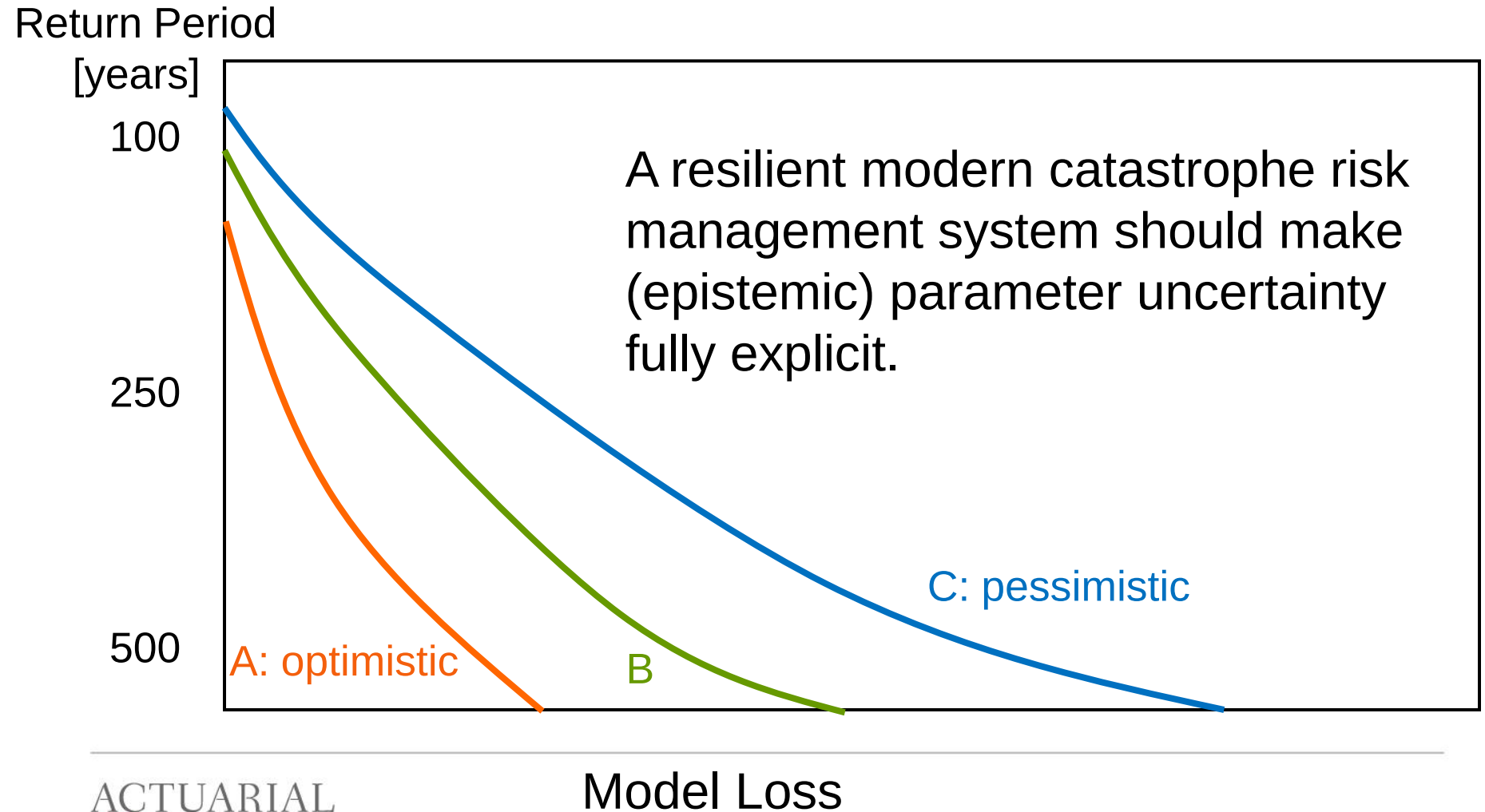


# Deep uncertainty about the future

Analysts do not know, or the parties to a decision cannot agree on, or understand:

- The appropriate conceptual models that describe the complex relationships among the key forces that drive the future;
- The probability distributions used to represent uncertainty about key variables and parameters in the mathematical representations of these conceptual models;
- How to value the desirability of alternative outcomes.

# Model dependence of Exceedance Probability curves



# Bayesian analysis of model uncertainty

Consider a class of  $N$  models  $M = \{M_1, M_2, \dots, M_N\}$   
with model parameters  $\theta_i$

$$\Pr(L|Data) = \sum_i \Pr(L|Data, M_i) * \Pr(M_i|Data)$$

where

$$\Pr(L|Data, M_i) = \int d\theta_i \Pr(L|Data, M_i, \theta_i) * \Pr(\theta_i|M_i, Data)$$

$$\text{and } \Pr(M_i|Data) \propto \Pr(M_i) * \Pr(Data|M_i)$$

A.J.G. Cairns (2000)  
A Discussion of Parameter and  
Model Uncertainty in Insurance

# Strategies for minimizing regret

Regret is defined as the difference between the performance of a future strategy, given some value measure, and that of what would have been the best performing strategy in that same future scenario.

Regret of strategy  $j$  in future  $f$  is expressed as:

$$\text{Regret}(j,f) = \underset{\text{All strategies } j'}{\text{Max}} \{ \text{Performance}(j',f) \} - \text{Performance}(j,f)$$

Computer searches can help identify robust strategies — that is, those with consistently small regret across many futures using many different value measures.

# Open model environment

- Advanced simulation framework
- Complex contract modelling
- Multiple risk models

EXTENSIBLE DATA WAREHOUSE

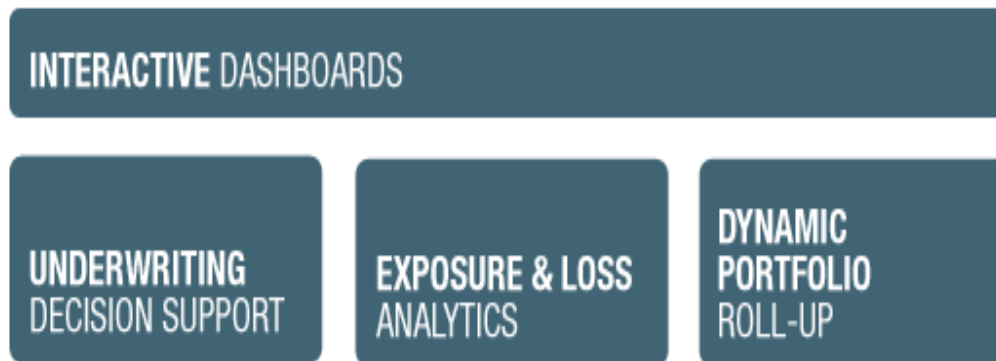
ENTERPRISE  
INTEGRATION

SUPERCOMPUTING INFRASTRUCTURE

# The future of catastrophe modelling

## Needed for holistic risk management:

A modern real-time exposure and risk management environment should enable insurance carriers to manage all of their risk models, exposures and analytics on a single, open platform.



# Catastrophe simulator training

The catastrophe risk modelling platform environment will be new and unfamiliar to underwriters.

To probe the behavioural aspects of this challenge, simulator training for underwriters may be developed to equip them with some experience in dealing with extreme situations.



# Transparency in risk management

**Three daily questions for US intelligence officers:**

What do you know?

What don't you know?

What do you think?



General Colin Powell

*..... and tell me the difference.*