Counterfactual Disaster Risk Analysis

Gordon Woo, RMS

Caesar's Palace, Las Vegas
November 14, 2018

Top tier of
Artificial Intelligence

October 19, 2017

Counterfactual Disaster Risk Analysis
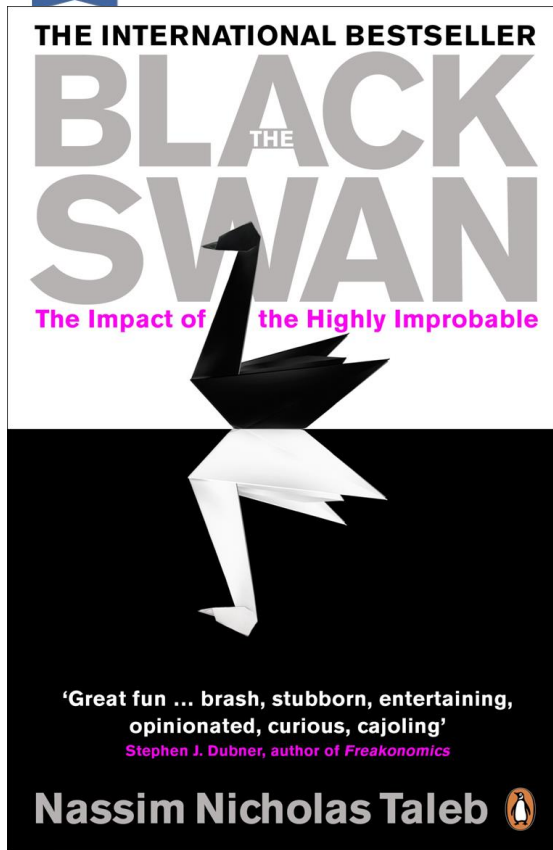
by Gordon Woo

ABSTRACT

The statistical foundation of disaster risk analysis is actual loss experience. The past cannot be changed and is treated by actuaries as fixed. But from a scientific perspective, history is just one realization of what might have happened, given the randomness and chaotic dynamics of nature. Stochastic analysis of the past is an exploratory exercise in counterfactual history, considering alternative possible scenarios. In particular, the dynamic perturbations that might transition a system to a disaster state are considered. The value of counterfactual disaster risk analysis is illustrated with examples from a diverse range of natural and man-made perils.

## KEYWORDS

Counterfactual, disaster, risk, analysis

LLOYD'S

Emerging Risk Report 2017
Understanding risk

Reimagining history
Counterfactual risk analysis

RMS

'Intelligence without imagination: a deadly combination'

Counterfactual thinking
to counter a failure of imagination

'*Think of the terrorist attack of September 11, 2001: had the risk been **reasonably conceivable** on September 10, it would not have happened.*'
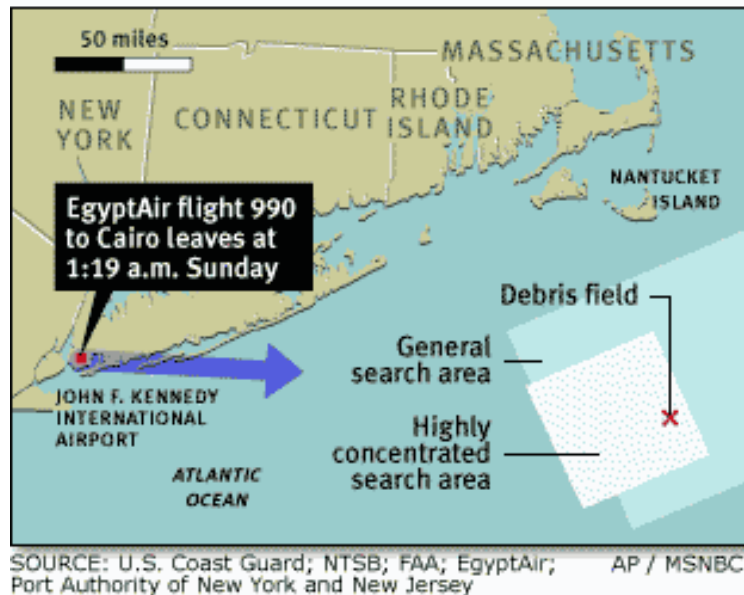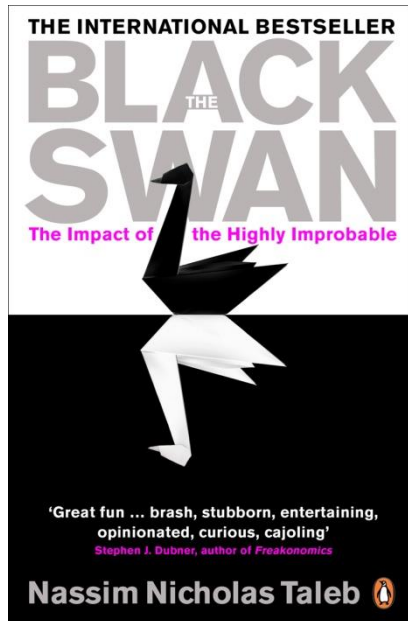
On October 31, 1999, Gameel Al Batouti, crashed EgyptAir Flight 990 en route from JFK to Cairo.

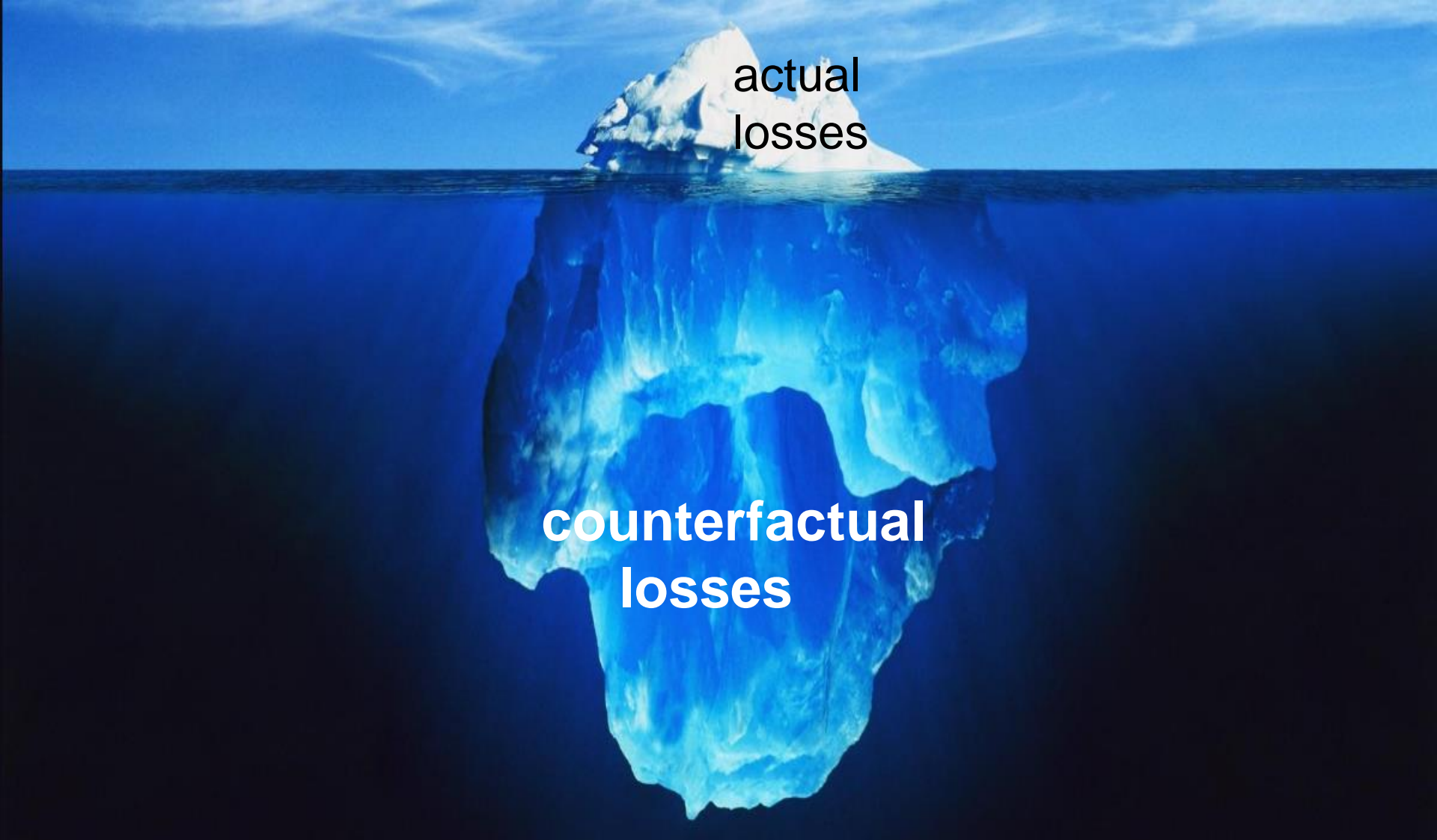His last words were: '*I trust in Allah*'.

Seattle plane hijack: 10 August 2018

Richard Russell hijacked a Bombardier passenger jet and took off from Seattle Airport just after a concert by Pearl Jam began at Safeco stadium.

actual
losses

**counterfactual
losses**

The bulk of information about potential losses is hidden below the surface of actual historical claims.

2017: The safest year in aviation history

- The last fatal airliner accident on U.S. soil was the Asiana Airlines crash landing in San Francisco in July 2013. Three teenage girls were killed in that incident, one of whom was struck by a rescue vehicle.

- The last fatal accident involving a U.S. carrier of any kind was the Colgan Air crash outside Buffalo, in February 2009, in which fifty people were killed.

- The last fatality involving a U.S. major carrier was a Southwest Airlines accident in Chicago in December 2005, in which a 737 slid from a snowy runway and collided with a car, killing a young boy.

Counterfactual air disaster scenario July 7, 2017 at SFO
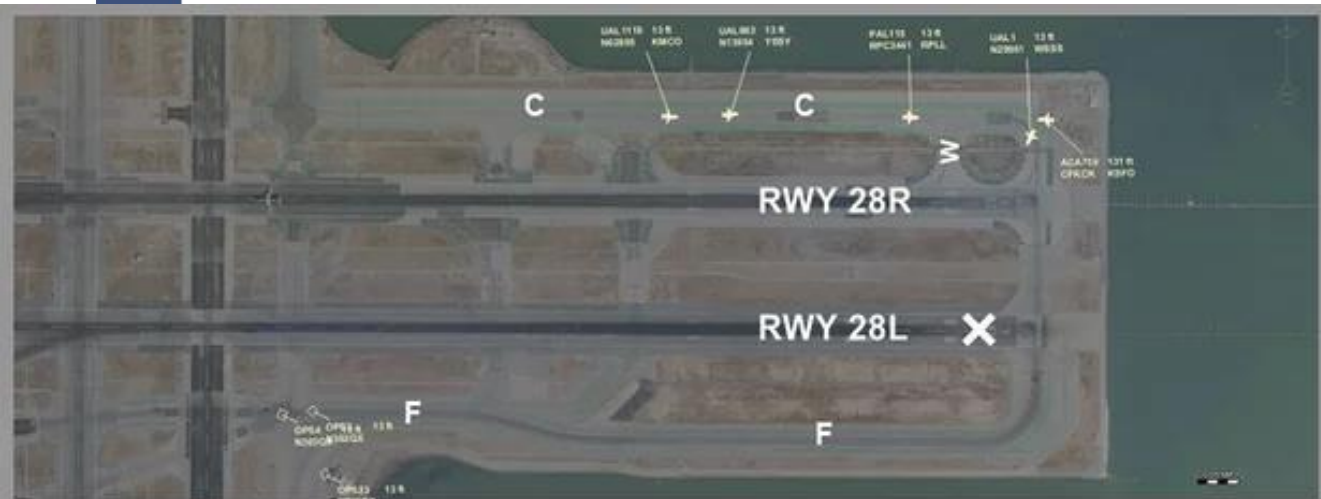
UAL1 (23:56:04): he's on the taxiway.
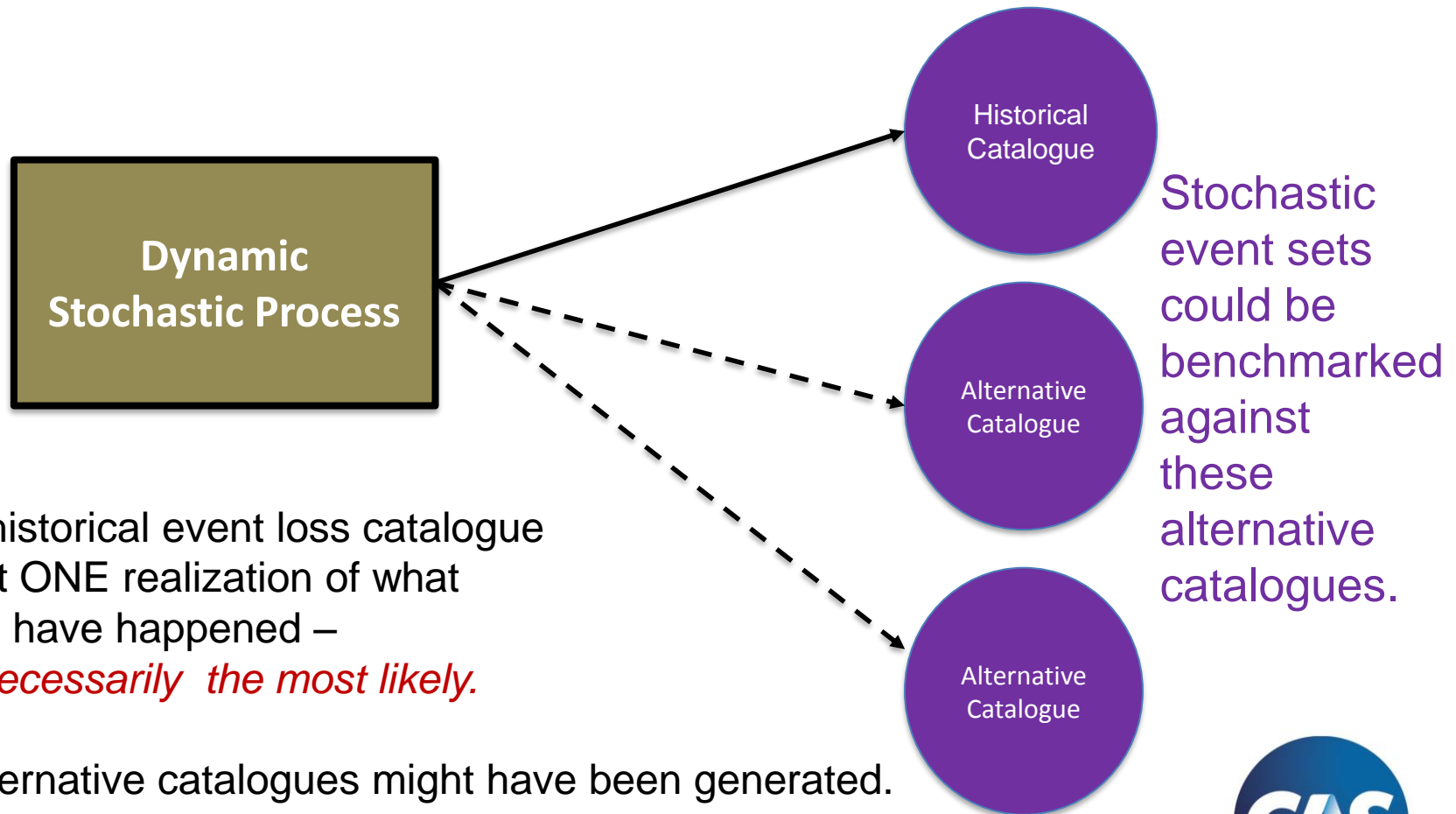

ACA 759

The Air Canada pilots mistook the taxiway for the runway next to it, and flew the AC759 jet to just 18m above ground, before pulling up 5 seconds from crashing.

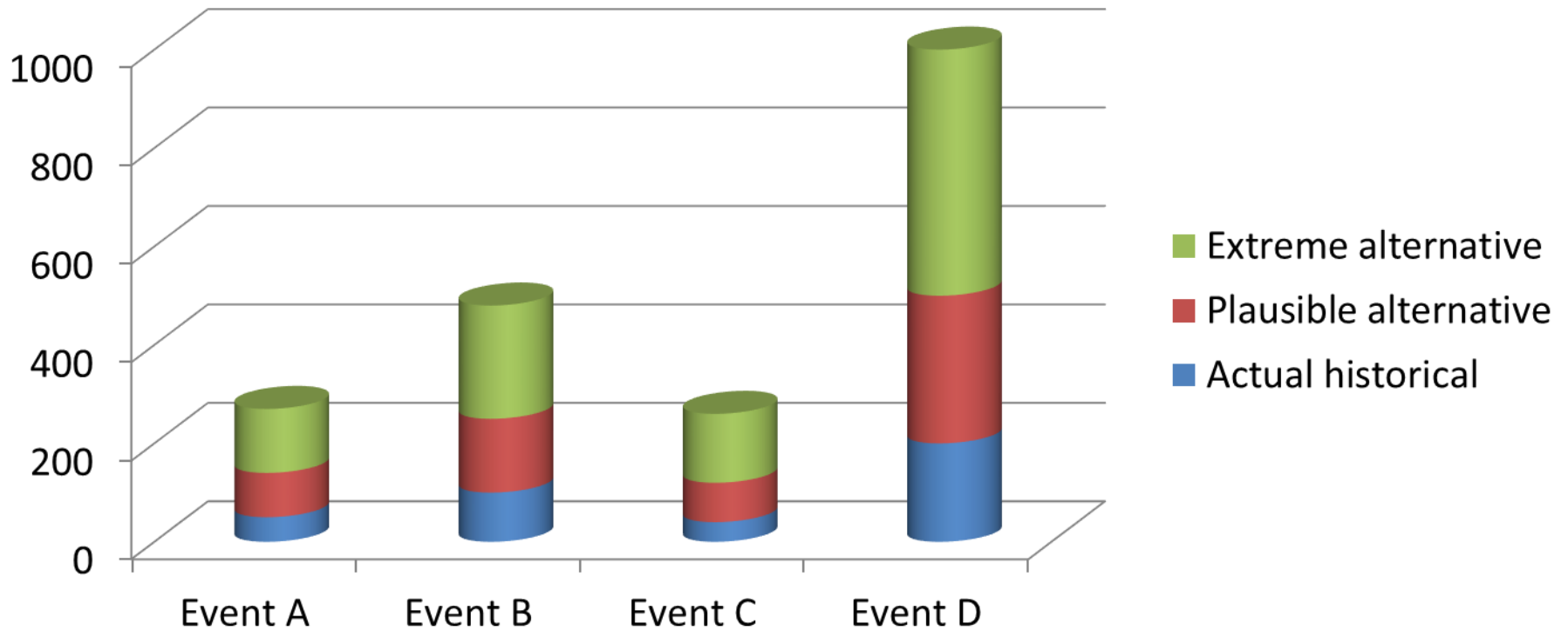This was almost the worst ever civil aviation disaster.

How large would the insurance loss have been?

Focusing more on the process than the events

Dynamic Stochastic Process

Historical Catalogue

Alternative Catalogue

Alternative Catalogue

Stochastic event sets could be benchmarked against these alternative catalogues.

The historical event loss catalogue is just ONE realization of what could have happened –
not necessarily the most likely.

....Alternative catalogues might have been generated.

CAS

Gauging the volatility of historical losses

Virtual table of losses

Counterfactual analysis of the j'th historical event would generate a table of counterfactual losses $C_1(j), C_2(j), C_3(j)...$

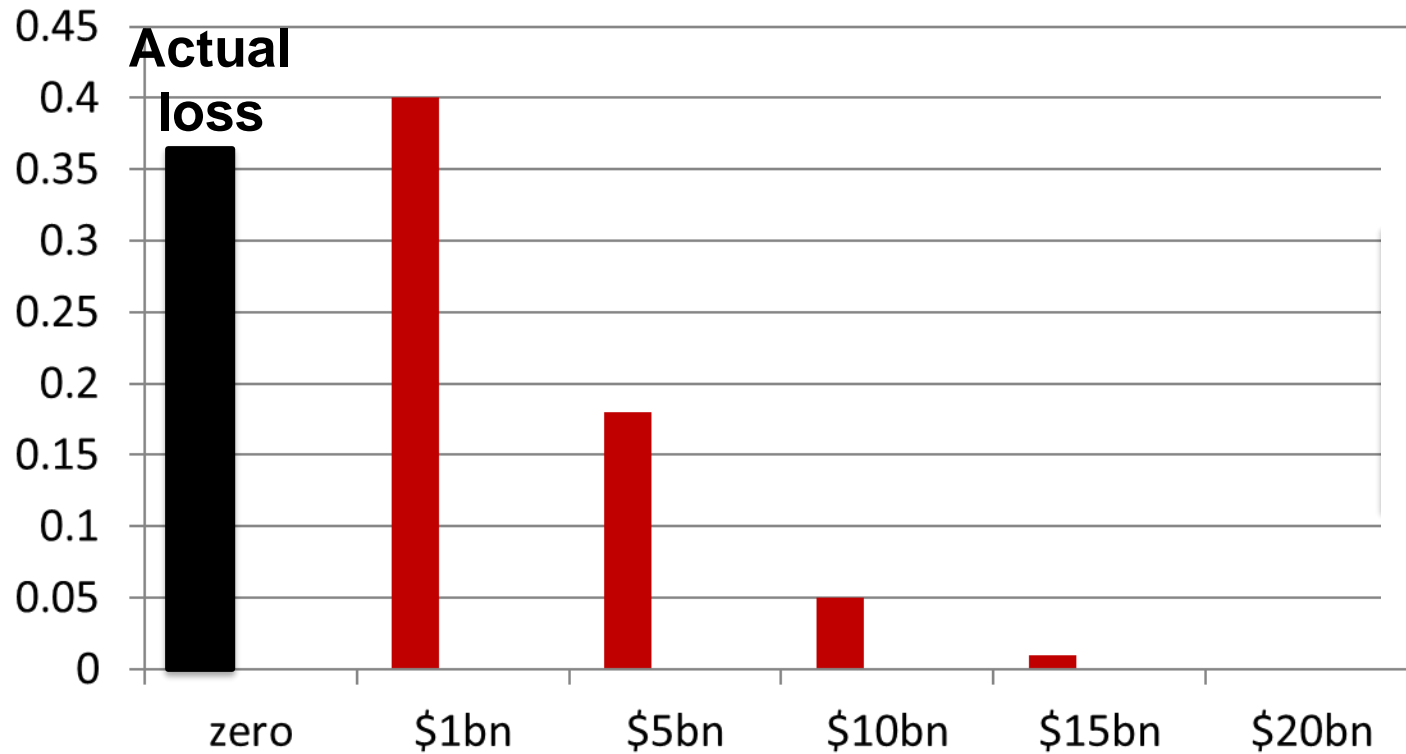with associated probability estimates: $p_1(j), p_2(j), p_3(j)...$

Virtual loss table for a historical event

Virtual Losses ($billion)	Probability
Zero	**0.36**
One	**0.40**
Five	**0.18**
Ten	**0.05**
Fifteen	**0.01**
Twenty	**0.00**

Virtual loss distribution

Probability

Actual loss

0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0

zero $1bn $5bn $10bn $15bn $20bn

Loss

Downward counterfactuals

If Things
Had
Gone
Wrong

Fritz

Leiber

If Things
Had
Turned
for the
Worse

Fritz

Leiber
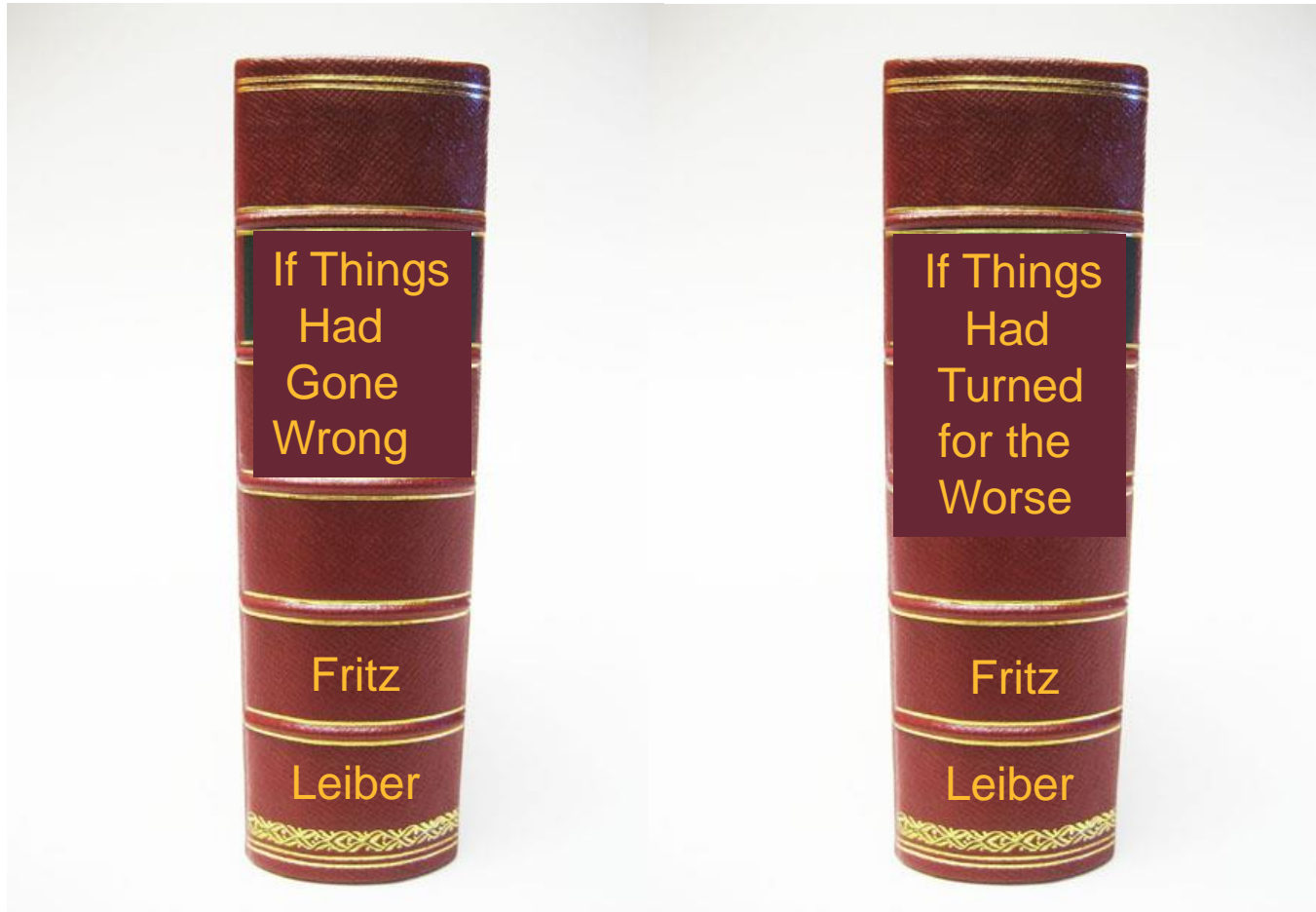
Downward counterfactual thought experiment
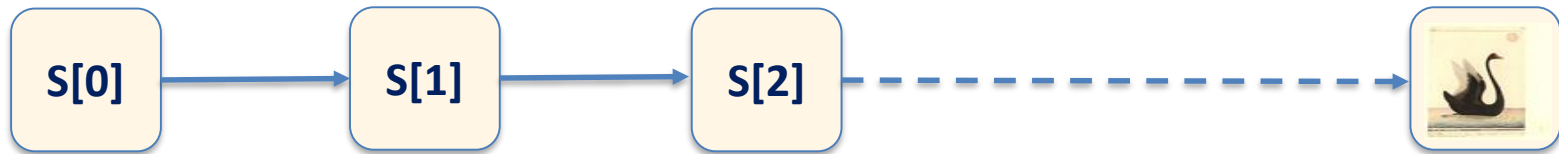
Consider a historical hazard system state **S[0]** that led to a major economic loss of **L**.

Construct an alternative hazard system state **S[k]** that would have led to a major economic loss of **L + k* Δ*L**, where **Δ = 5%** , and **k = 1.**

Repeat for ever increasing integer values of **k = 0, 1, 2,….n**

State transition path to a Black Swan


The Counterfactual Class of Black Swans:
The set of extreme events that can be explicitly constructed by progressive downward counterfactual simulation of a historical event.

If there are M historical events, how complete is $\bigcup\limits_{j=1}^{M} B_j$?

1981 Atlantic Hurricane season

Stochastic simulation of the 1981 season (including Dennis) would generate a virtual loss histogram
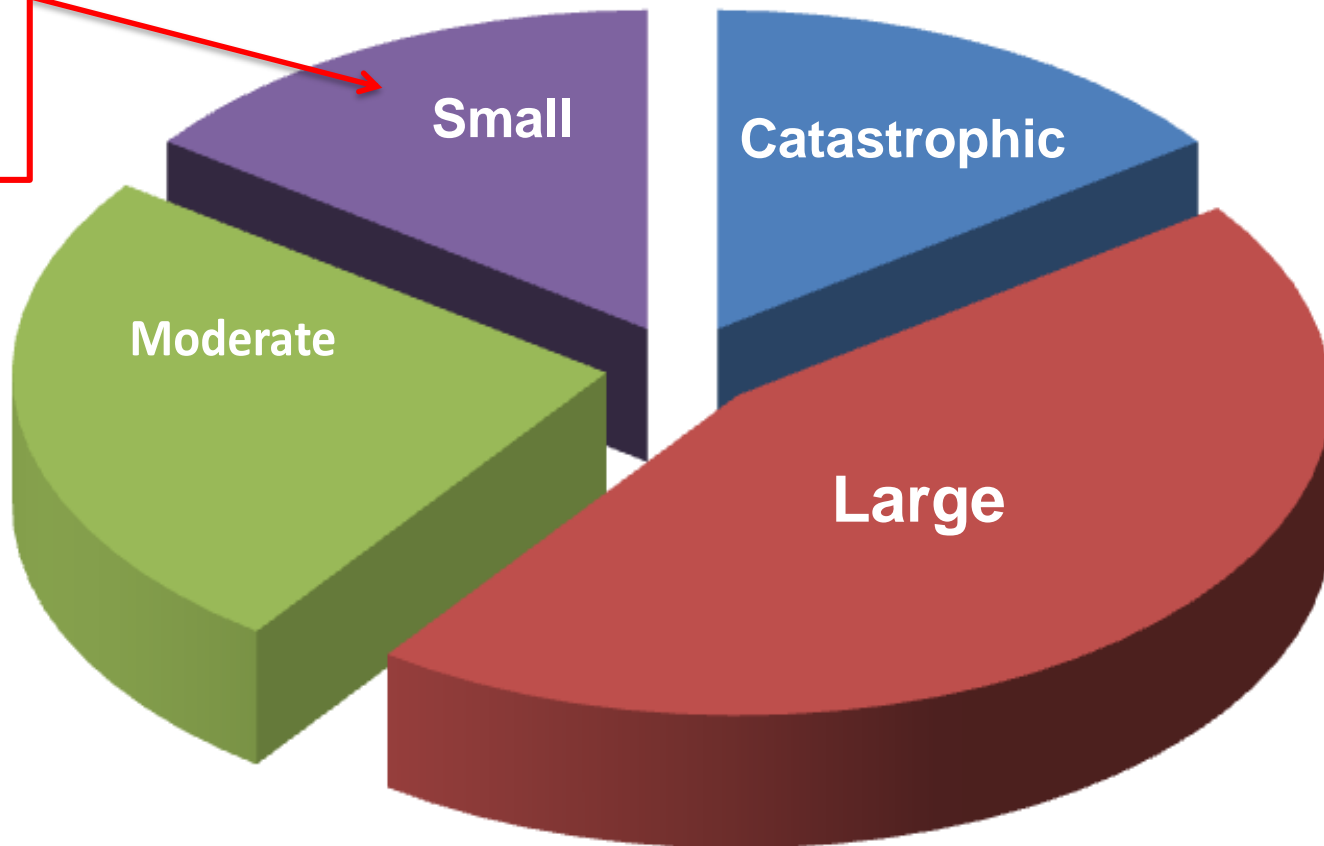
Dennis
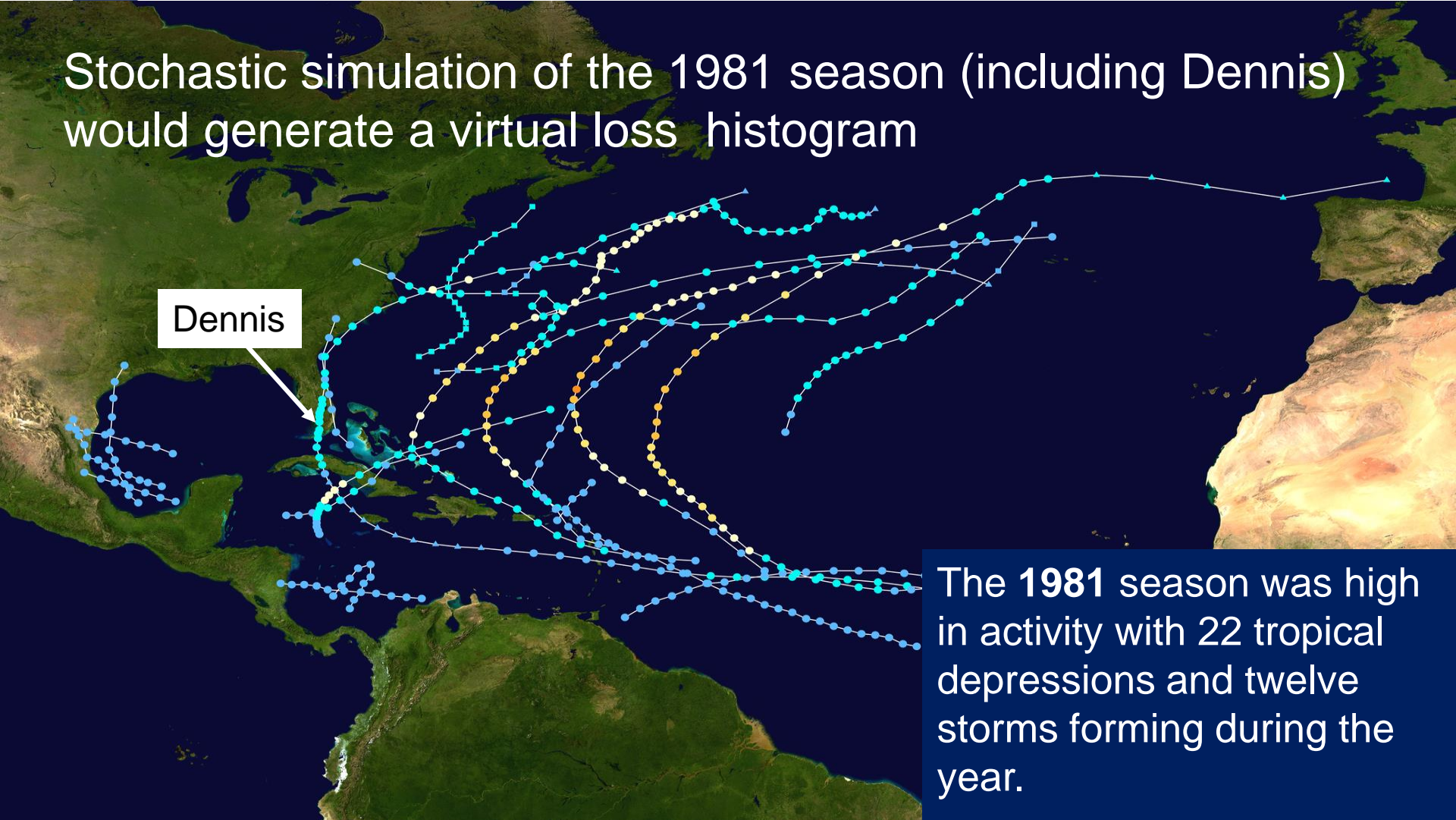
The **1981** season was high in activity with 22 tropical depressions and twelve storms forming during the year.

Nine of these systems made landfall.

Potential for outcome bias

Fortunate historical hazard and loss outcome

Small

Catastrophic

Moderate

Large

The psychology of near misses

When playing lotteries or gambling, nearly missing
a winning jackpot encourages continued interest
in playing on.

However, when a major loss is narrowly averted,
the behavioral tendency is to want to move on.

HURRICANE ALICIA
CATEGORY 3

Hurricane Alicia in August 1983 was the first hurricane to hit the United States mainland since Hurricane Allen in August 1980.

The time between these two storms totalled three years and eight days – the longest streak since 1932.

This soft inter-event soft period was a period of expansion within Lloyd's of London, which welcomed new members, lured by the false promise of extremely high returns in a short period.

Pass-the-parcel spiral in catastrophe reinsurance

Following Hurricane Alicia in 1983, the market began to notice an anomalous effect called the London market spiral. Although the direct insured loss from Alicia settled down to its ultimate value fairly quickly, the gross reinsured amount of loss continued to grow year after year.

This happened because market participants kept receiving additional claims and in turn submitting additional claims to their own cat covers, thereby generating more reinsurance claims (which generated more recoveries etc.).

James Stanard and Michael Wacek

Misinterpretation of loss record

May 4, 2015

Just two years before the end of the 'drought'

LIVESCIENCE

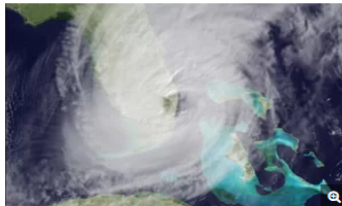NEWS TECH HEALTH PLANET EARTH STRANGE NEWS ANIMALS HISTORY CULTURE SPACE

Live Science > Planet Earth

US in Longest 'Hurricane Drought' in Recorded History

By Laura Geggel, Senior Writer | May 4, 2015 07:13am ET

Hurricane Wilma seen by satellite as it crossed Florida in October 2005. Wilma was a Category 3 storm when it made landfall in the state and is the last major hurricane to hit the U.S. since that time.
Credit: NOAA/NASA

In a stroke of luck, no major hurricanes rated Category 3 or higher have struck U.S. soil during the past nine years, a new study finds.

This is the country's longest "hurricane drought" in recorded history, or since 1851, the researchers said. The previous record lull lasted eight years, from 1861 to 1868, they said.

Hurricane Wilma, a hurricane that hit Florida in 2005, was the last Category 3 storm to make landfall in the United States. Other storms — including Hurricane Ike (Category 2, 2008), Hurricane Irene (Category 1, 2011) and Hurricane Sandy (Category 1, 2012) — caused significant damage, but their winds weren't as strong. [A History of Destruction: 8

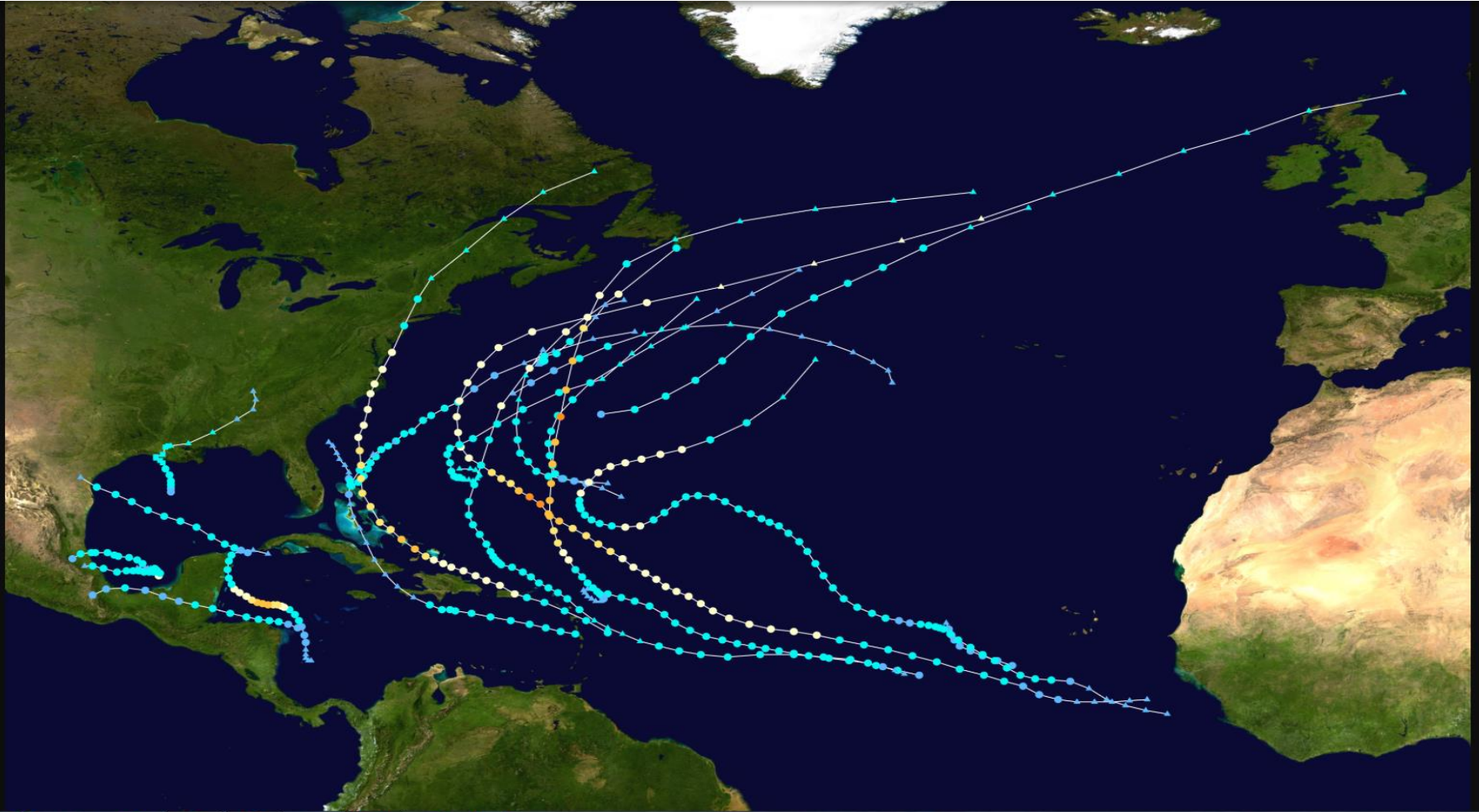Years of minimal or low losses can lead to market underwriting complacency.

In a competitive soft market, insurance rates may be lowered during a 'hurricane drought', and increasing risk accumulations may not be compatible with risk appetite.
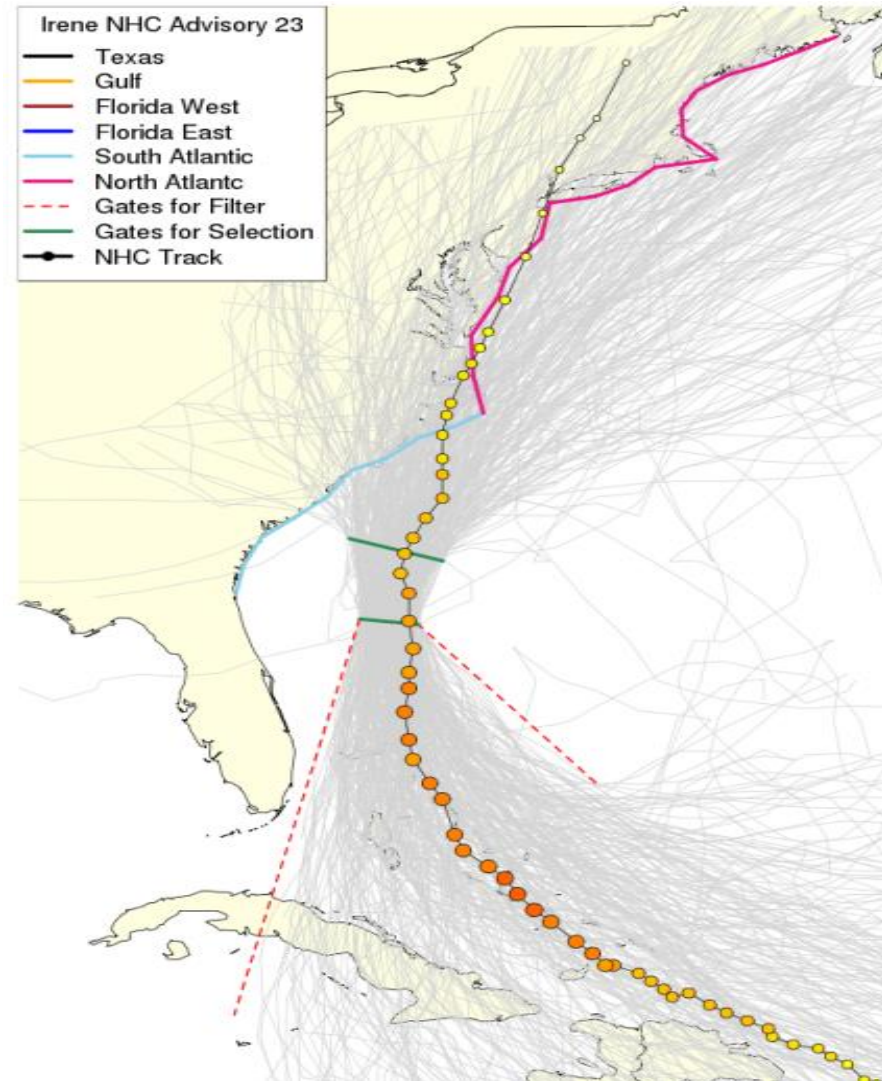
2011 Atlantic hurricane season

Hurricane Irene: August 2011

As of August 25th, 2011,
a counterfactual analysis can be
undertaken to assess the likelihood
that the insured loss from Hurricane
Irene might have been in excess of
$50 billion.

**This is estimated from an RMS
study of the possible track
evolution of the hurricane as it
funnelled through the track
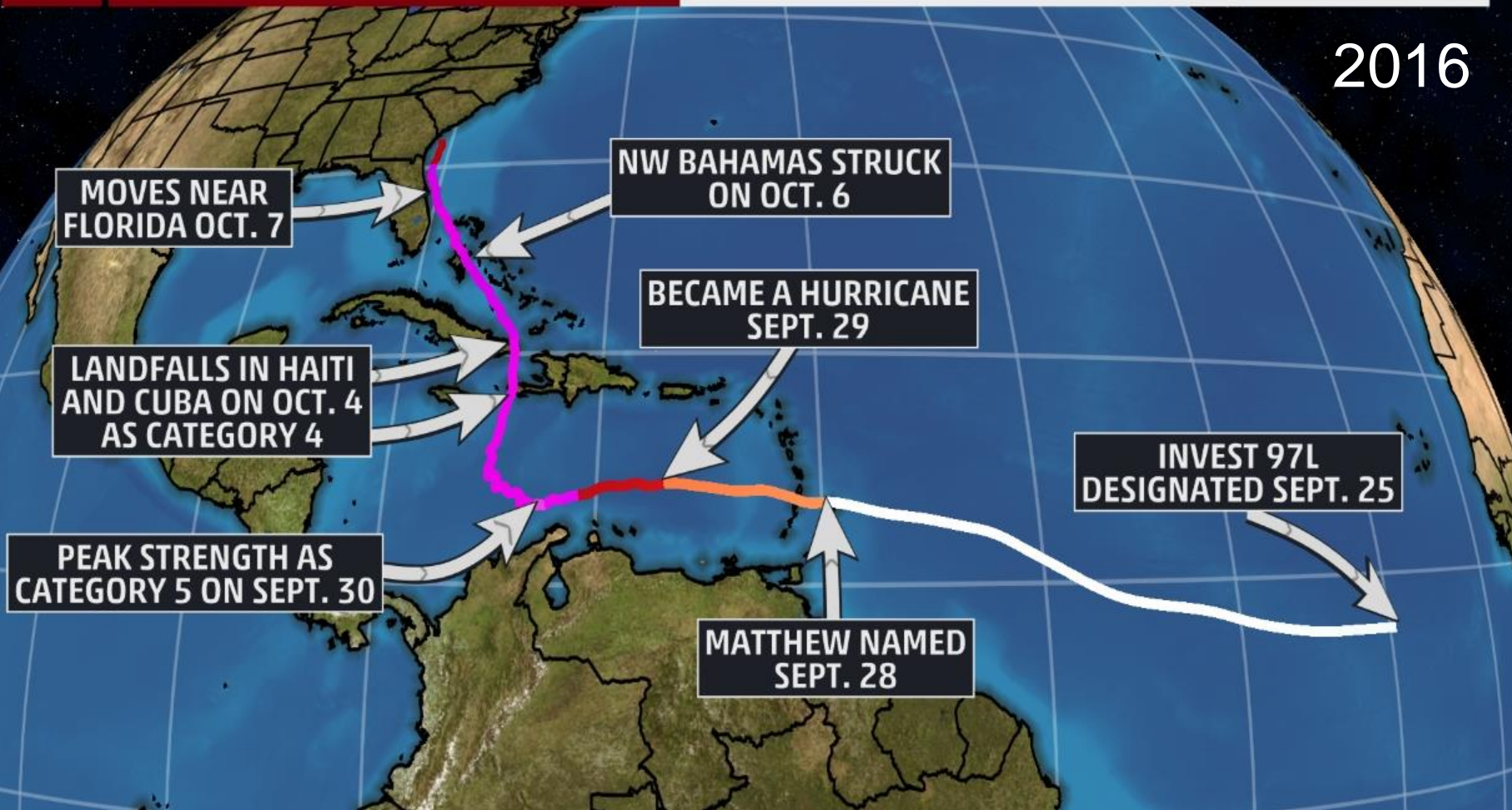selection gates marked in green.**

This likelihood is estimated to have
been in excess of 1%.

Irene NHC Advisory 23
— Texas
— Gulf
— Florida West
— Florida East
— South Atlantic
— North Atlantc
--- Gates for Filter
— Gates for Selection
—●— NHC Track

MATTHEW'S HISTORY | LATE SEPTEMBER-EARLY OCTOBER

2016

MOVES NEAR FLORIDA OCT. 7

NW BAHAMAS STRUCK ON OCT. 6

BECAME A HURRICANE SEPT. 29

LANDFALLS IN HAITI AND CUBA ON OCT. 4 AS CATEGORY 4

INVEST 97L DESIGNATED SEPT. 25

PEAK STRENGTH AS CATEGORY 5 ON SEPT. 30

MATTHEW NAMED SEPT. 28

IRMA STEERING   SAT   9/9

IRMA TURN TO NORTH
THIS WEEKEND? UNCERTAINTY
WHERE THAT OCCURS

Hurricane Irma

Potential track area

The ratio of counterfactual to actual
US insurance loss might have been > 5

Date
Sept 07

Time (AST)
2:00pm

Max. wind
175mph

SOURCE: NOAA

UNITED STATES

MEXICO

Florida

CUBA

Atlantic Ocean

Caribbean Sea

DOMINICAN REP.

PUERTO RICO

5am AST, Sep 07

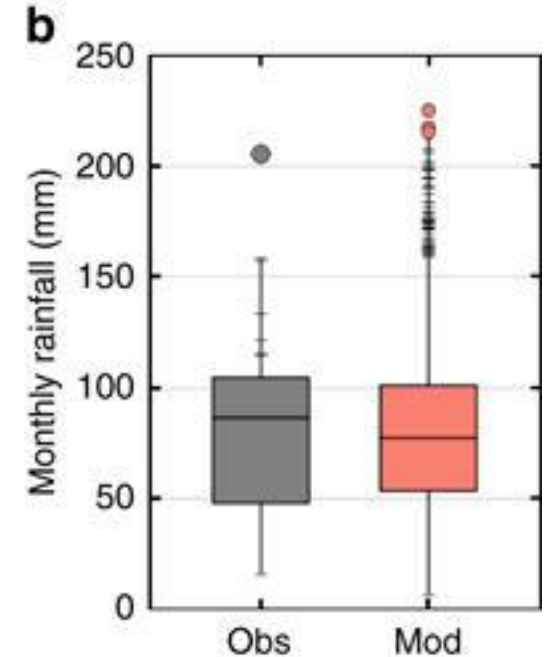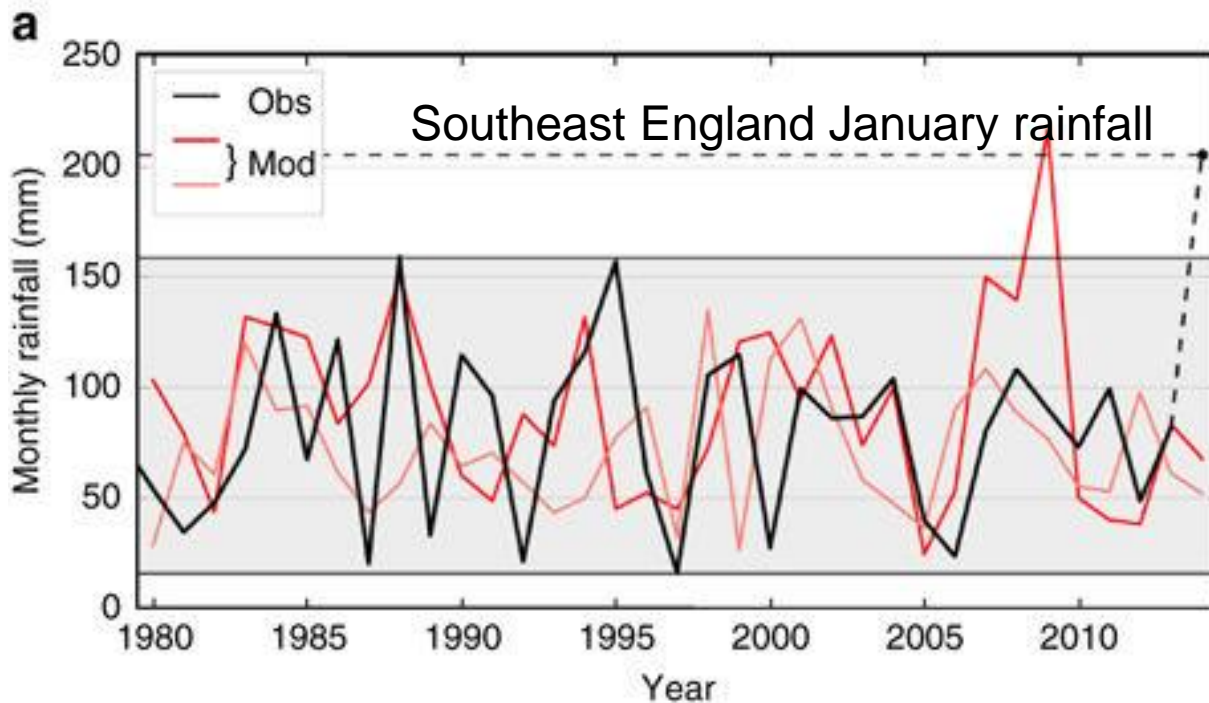# Hurricane Florence September 2018

CUMBRIA FLOODING IN 2009

Large volumes of water equal to 4,500 times the average flow of the River Thames were carried over the Atlantic before some of it was dumped over the **Lake District**, producing **record rainfall** and **widespread flooding** in November 2009.

Area of Flooding in 2009

Different concentrations of water vapour in the air
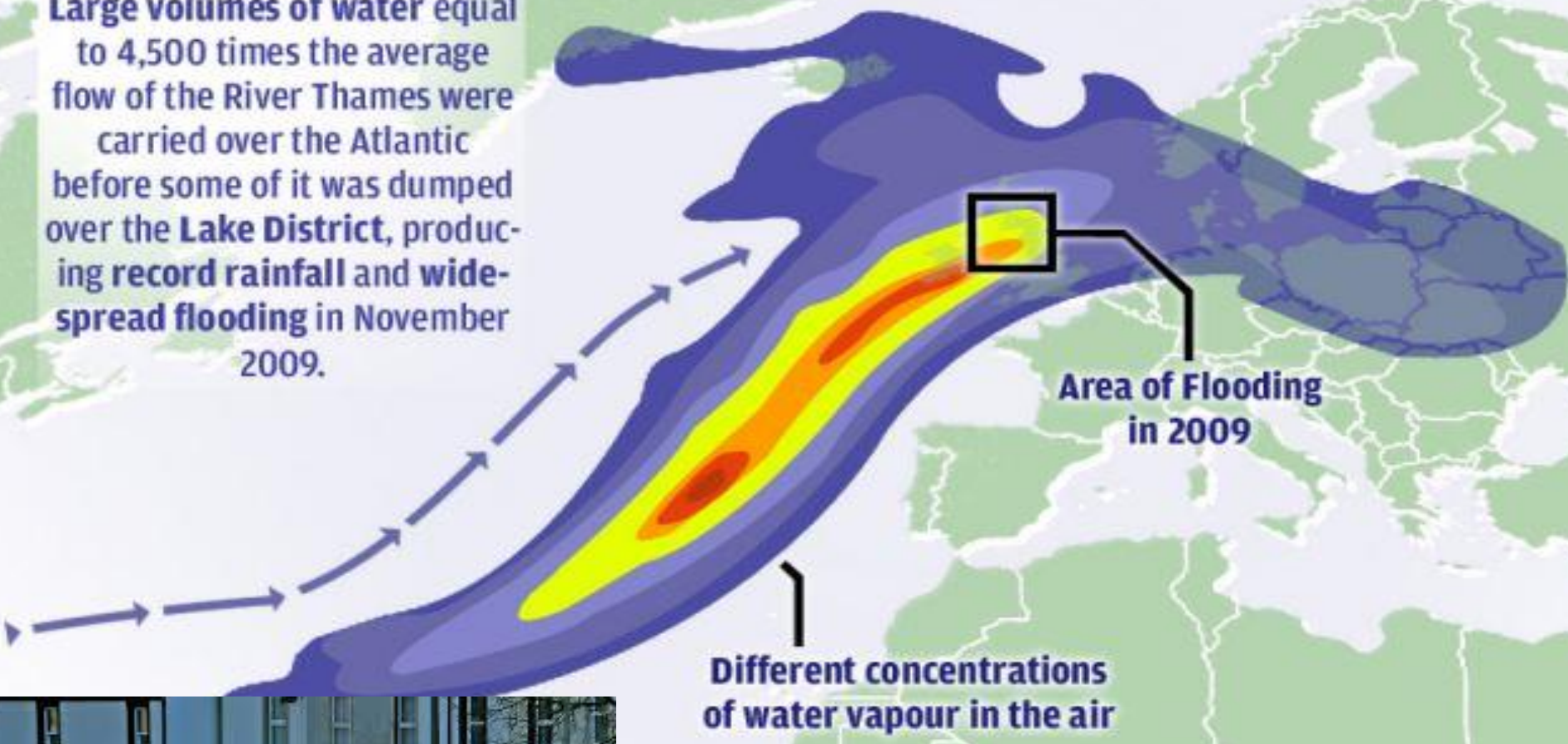
UK flooding from extreme rainfall

Unprecedented Simulated Extremes using Ensembles

Southeast England January rainfall

Thompson V. et al. , Nature Communications, July 2017: High risk of unprecedented UK rainfall in the current climate.   [Met Office Unified Model simulating 100x more winters than in 1981-2015.]

Probabilistic definitions of causation

PN is the probability of necessary causation.
It is defined as the probability that the event **Y**
would not have occurred in the absence of the event **X,**
given that both events **Y** and **X** did in fact occur.

PS is the probability of sufficient causation.
It is defined to be the probability that **Y** would have occurred in the
presence of **X**, given that **Y** and **X** did not occur.

**PNS** is the probability of necessary and sufficient causation.
It is defined as the probability that **Y** would have occurred in the
presence of **X,** and that **Y** would not have occurred in the absence of **X**.

2003 European heat wave attribution

Oppressive heat across Europe

Officials throughout Europe warned people to stay out of the sun as many countries face temperatures approaching 100 degrees.
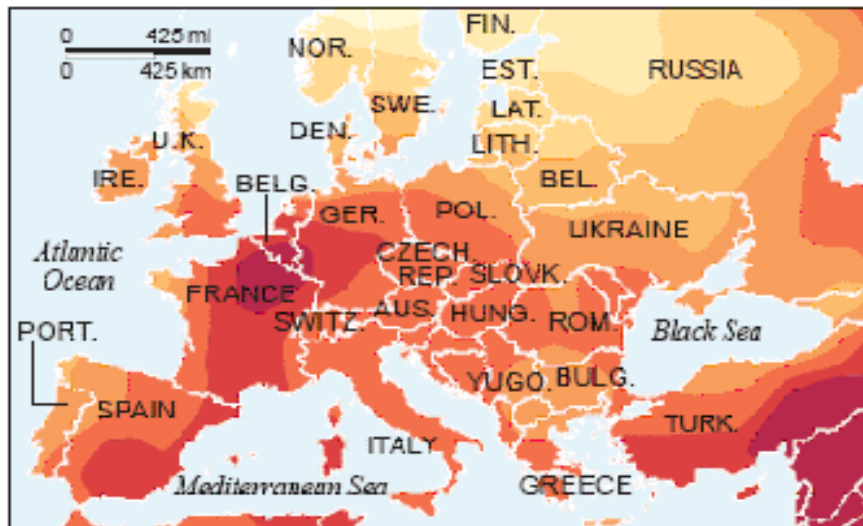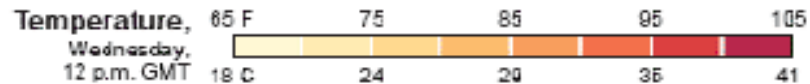
SOURCE: Weather Underground   AP

More than 20,000 people died after the record-breaking heatwave in August 2003.

For the 2003 European heat wave, PN = 0.9 whereas PS =0.0072

(Hannart, Pearl et al. 2016)

Climate change as a **necessary cause** of catastrophic societal losses

External Weather Hazard → Critical Infrastructure Failure → Catastrophic Societal Losses

Climate Change

Human Error
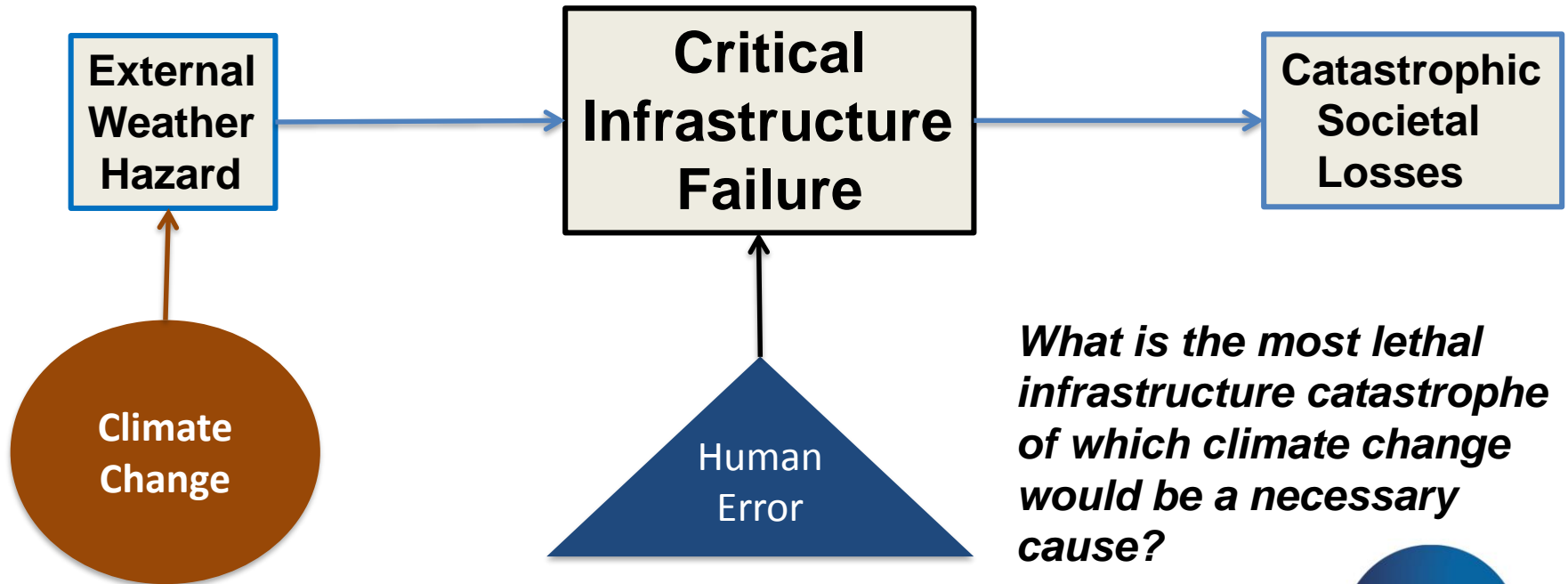
What is the most lethal infrastructure catastrophe of which climate change would be a necessary cause?

Oroville dam, Northern California

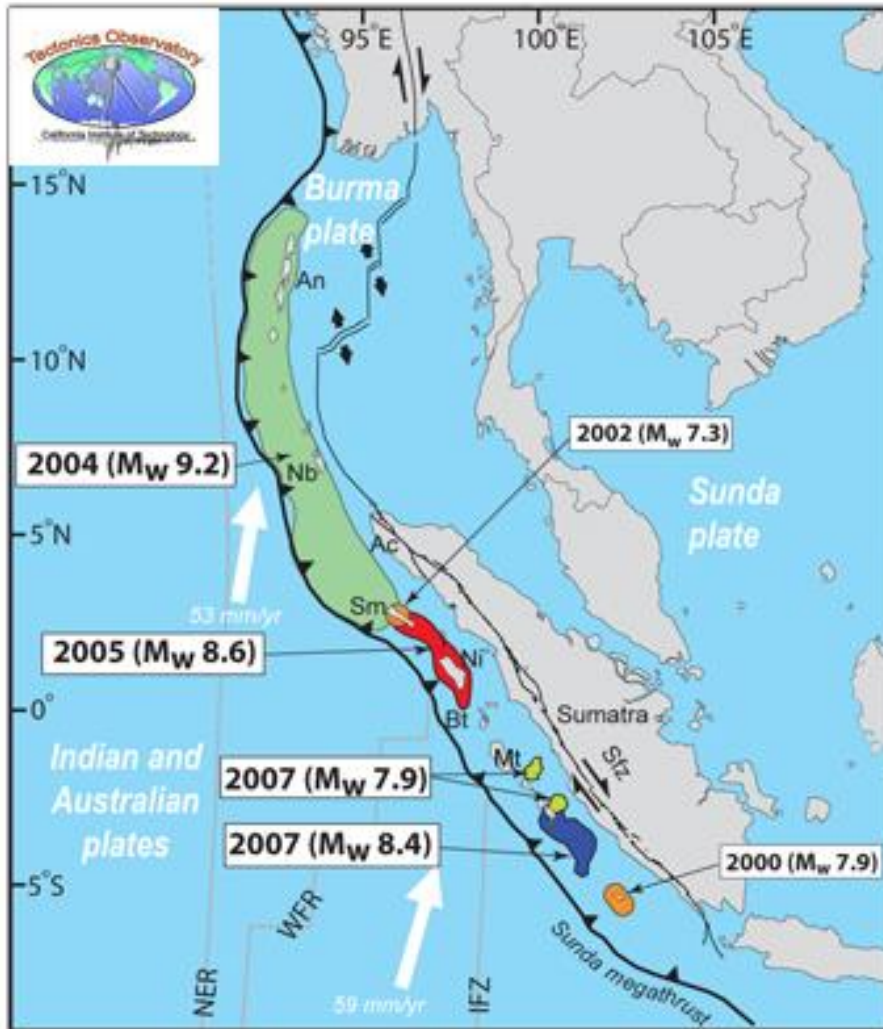On 7 February 2017, water from powerful winter storms rushed under the spillway, which forced up giant slabs and ripped a huge hole in the structure.

The spillway was built in the late 1960s. The designer was just two years out of college with no prior professional experience designing spillways.

Runaway great earthquake

The giant December 26, 2004, Sumatra earthquake ruptured the greatest fault length of any recorded earthquake, spanning a distance of 1500 km – *and could have been bigger still.*

Map of Sumatra region showing the extent of the ruptured fault segments for three recent giant earthquakes.

Green shows 2004, red shows 2005, and blue and yellow show 2007.

Caltech Tectonics Obervatory

Counterfactual Analysis of Runaway Earthquakes

## by Gordon Woo and Arnaud Mignan

ABSTRACT

The historical record of earthquakes is a crucial data resource for seismic hazard analysis. In every region, the largest events are rare and difficult to parameterize. Where such events are associated with the ruptures of mapped faults, defining the extent of possible fault ruptures is an important challenge that is often guided by historical precedent in which geologic, particularly paleoseismic, studies are limited. Counterfactual risk analysis recognizes that a historical event is just one realization of many possible alternatives: a fault rupture that happened in

intrinsic variability, if a catalog is sparse, the Gutenberg–Richter model can be statistically overfitted.

From the perspective of an earthquake physicist, the complexity of fault-rupture dynamics and the heterogeneity of fault-slip surfaces rule out the possibility of predicting the outcome of an incipient rupture. Each historical earthquake is one particular realization of a stochastic seismogenic process. In this earthquake lottery, the actual historical realization is just one sample from a probability distribution of possible outcomes

'Traces of tsunami damage were found from Miyagi Prefecture (4) to Fukushima Prefecture (7). However, researchers found evidence of damage in Iwate Prefecture (3), leading them to believe the earthquake might have measured around magnitude 9.'

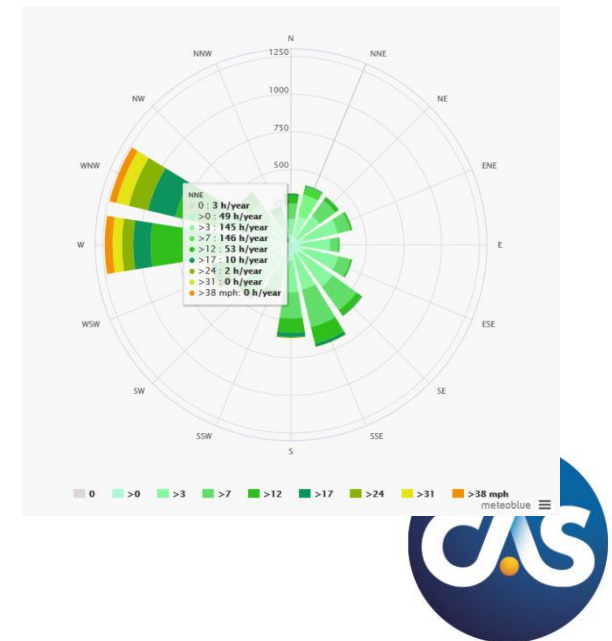Japan Society of Engineering Geology meeting,

Osaka, 12 October 2007

Sanriku 869 → Tohoku 2011
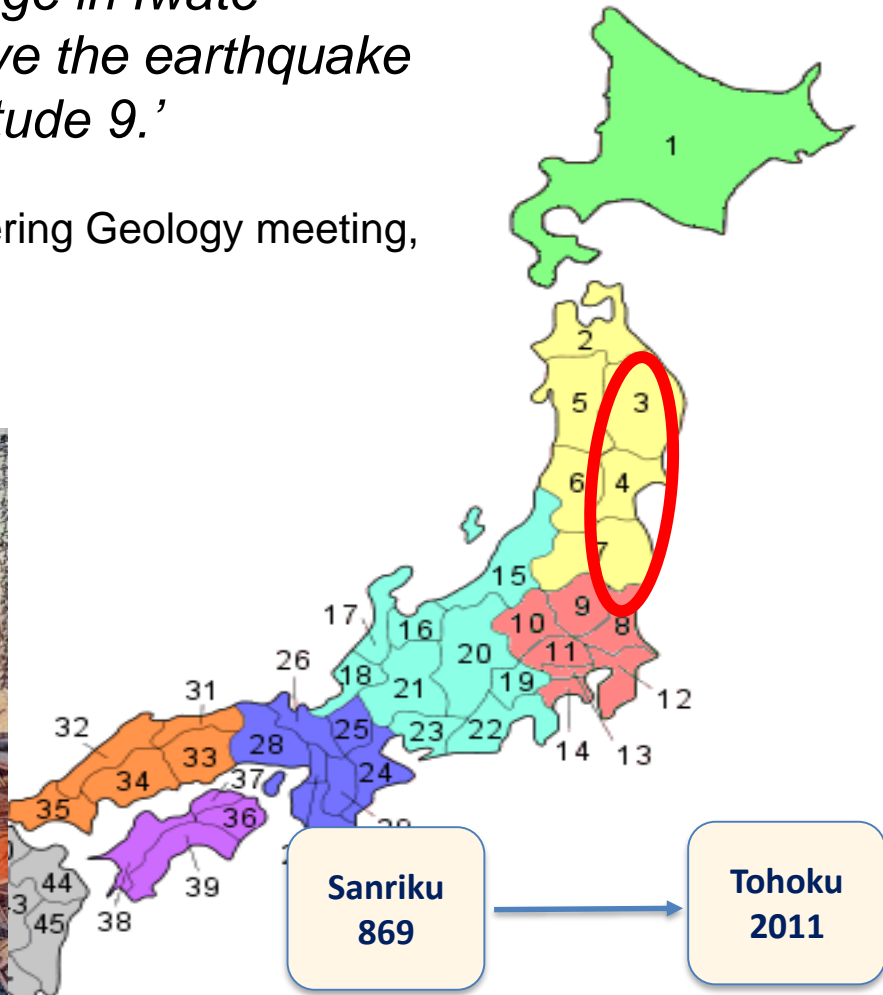
Fukushima nuclear accident March 2011

Had the winds been less favourable, the exclusion Zone around the site would have been larger.

Based on wind rose data for Fukushima, there was about an even chance of the wind blowing the radioactivity inland.

Lower San Fernando Dam

February 9, 1971

M6.7

Counterfactually, had the reservoir been at its maximum height, (or a strong aftershock occurred), water would have overtopped and eroded the dam, and flooded the valley with millions of tons of water.
100,000 might have been killed.

The 1857 Fort Tejon Earthquake
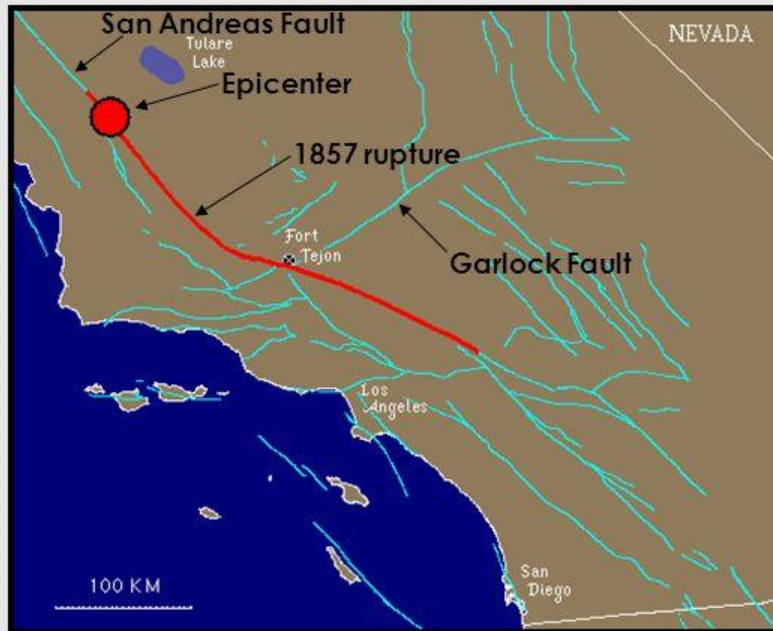
Rupture area (in red) of 1857 Ft. Tejon earthquake

- January 9, 1857, an ~M 7.8 earthquake ruptured the San Andreas Fault from Parkfield through the Big Bend segment and southeast at least to Wrightwood, a total of at least 360 kilometers.

- Fort Tejon, a military outpost at the southernmost end of the Carrizo Plain was one of few population centers near the epicenter.

- The ground shook for 1 to 3 minutes.

- The earthquake produced as much as 8 meters of offset in the Carrizo Plain and 3 to 4 meters in the Mojave Desert.

How unlikely was it for the rupture to progress past the Big Bend of the San Andreas Fault?

3D dynamic rupture modelling suggests that this may not be so likely.

Julian Lozos (2017)
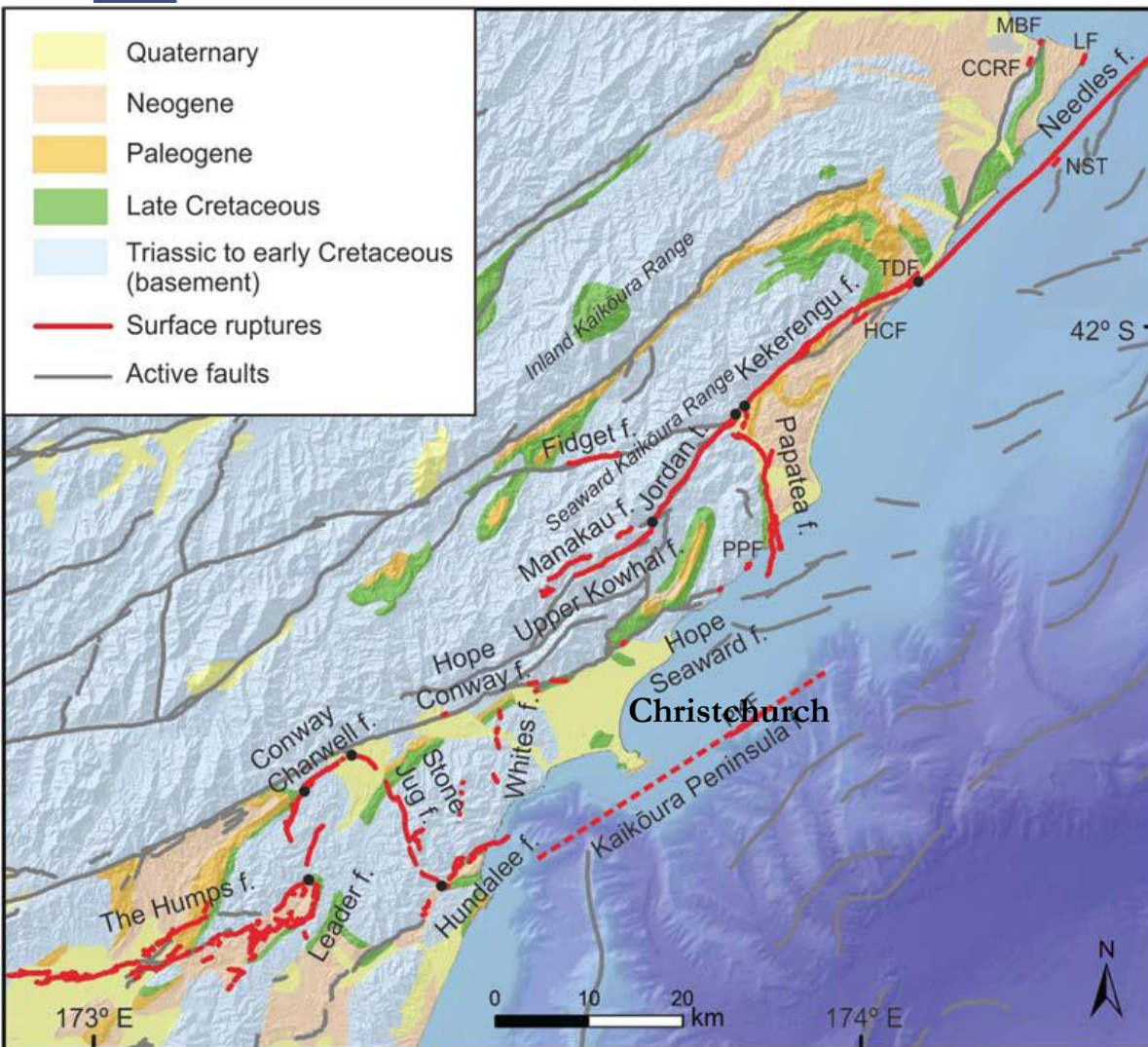
The Kaikoura earthquake
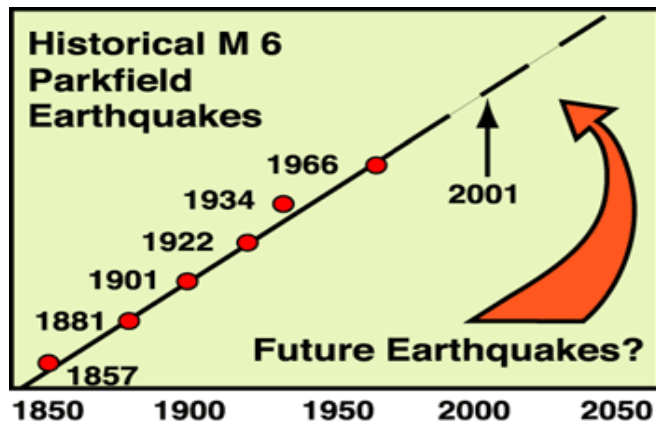# New Zealand
14 November 2016
M7.8

22 faults ruptured in this highly complex earthquake, which may not have been a likely outcome.

Rupture of the Hope Fault would have been more likely and would have increased the regional shaking damage.
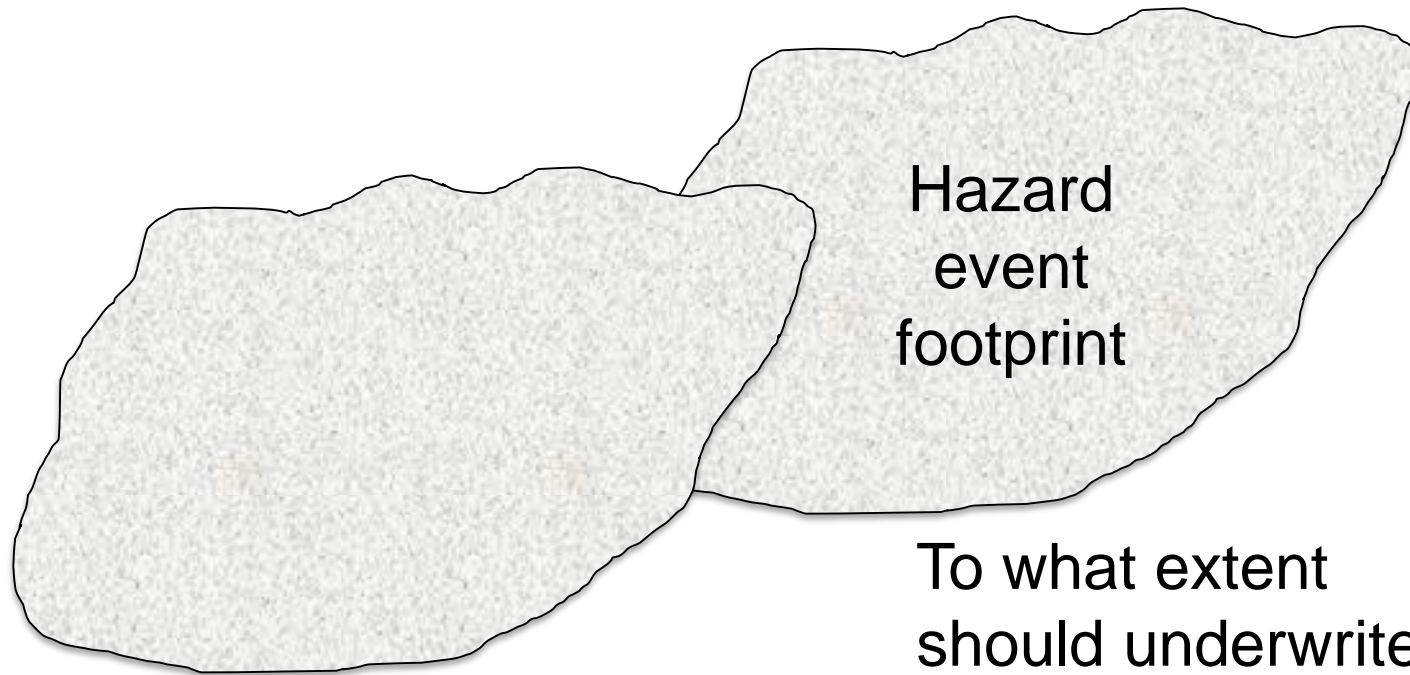
A new perspective on historical catalogues

- An event catalogue is just one realization of what may have happened in the past.
- Catalogues should not be over-interpreted and over-fitted.
- An event that occurs may actually be an unlikely thing to happen.
- Underwriters need to treat historical catalogues with due circumspection.

Historical M 6 Parkfield Earthquakes

1966
1934
1922
1901
1881
1857

2001

Future Earthquakes?

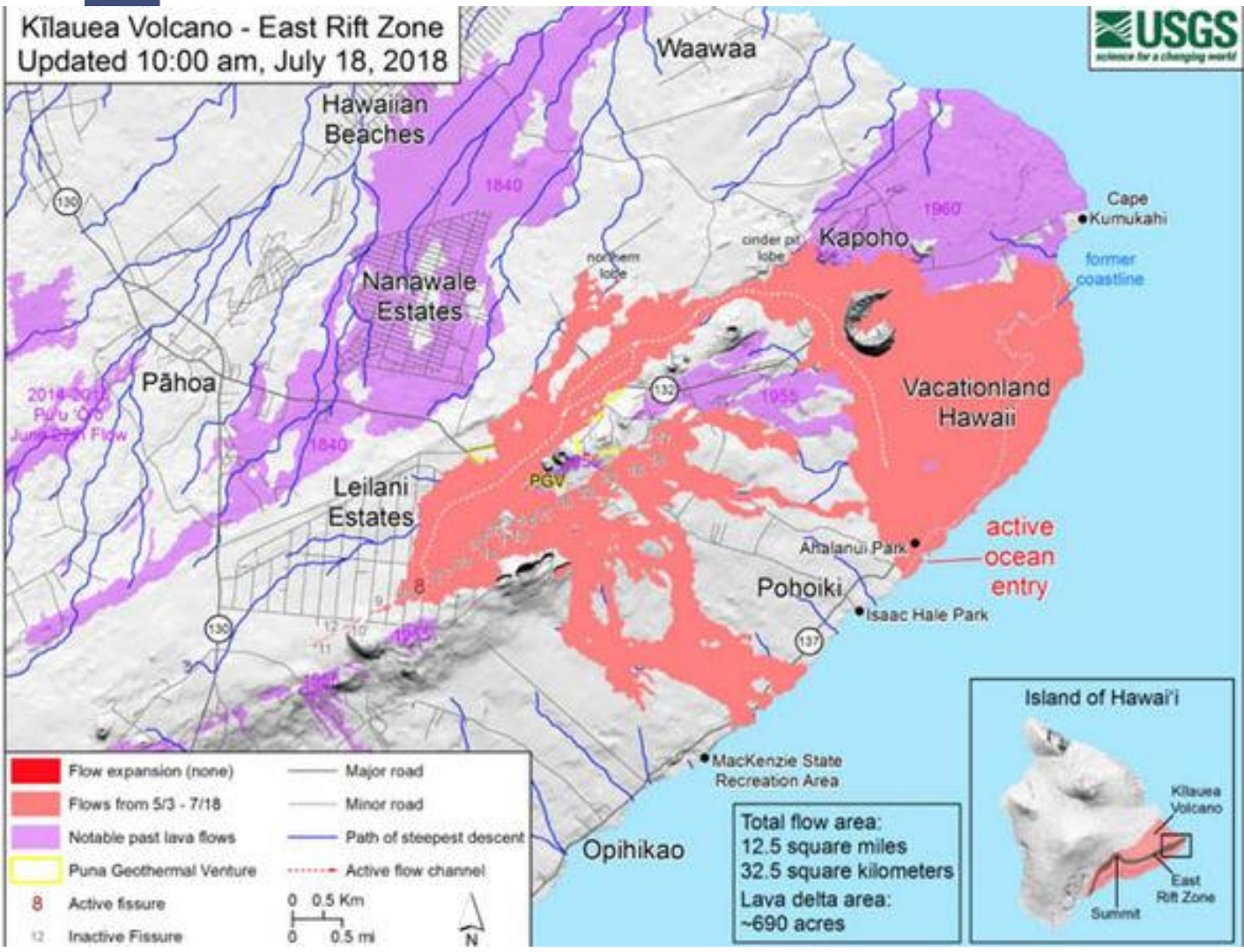1850   1900   1950   2000   2050

Yes - in 2004

Virtual site claims experience for underwriting

Hazard event footprint

To what extent should underwriters allow for near misses?

Hawaii realtors sell property providing information on historical lava flows,
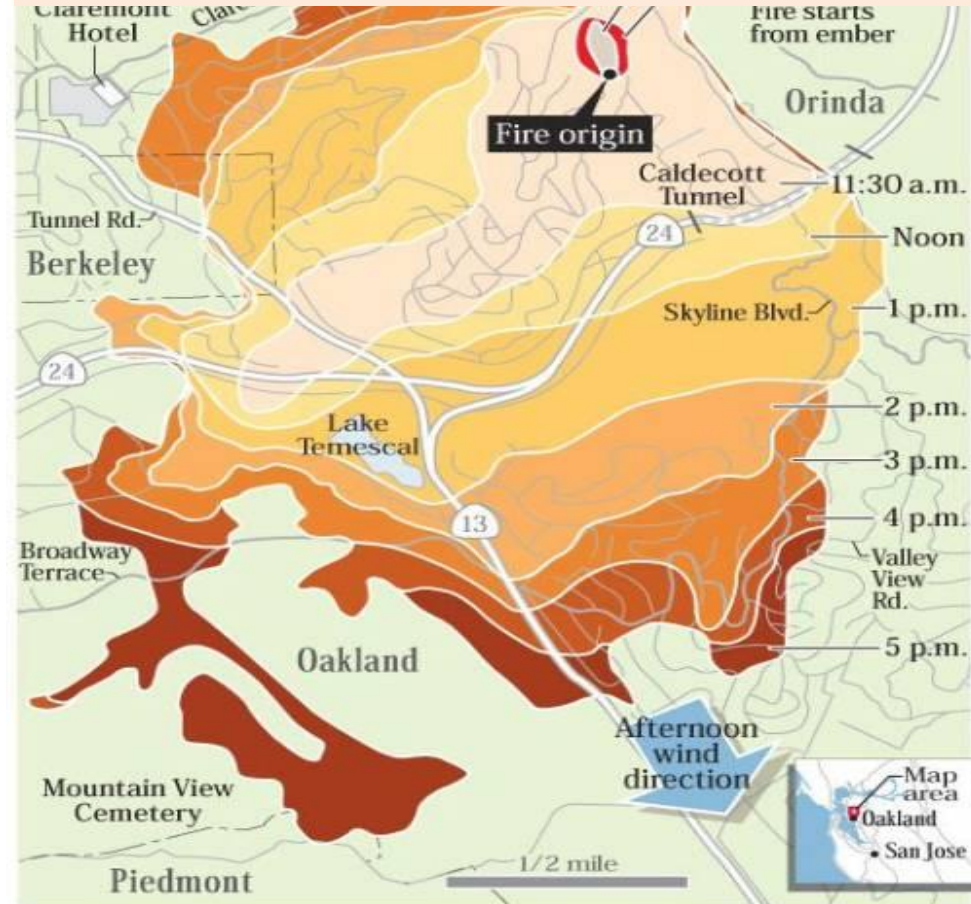
as if they defined the risk.

East Bay Hills wildfire
October 1991

"It's hard to get organized and run for your life at the same time!"

The Oakland Hills fire, killed 25 people, injured 150, and destroyed more than 3,800 homes.

Eleven died in traffic jams while evacuating. Eight others died on narrow streets in the same area.

The economic loss has been estimated at $1.5 billion.

Claremont Hotel · Clar·
Fire starts from ember
Fire origin
Orinda
Caldecott Tunnel — 11:30 a.m.
Tunnel Rd.
Berkeley
24
Noon
Skyline Blvd. — 1 p.m.
24
Lake Temescal
2 p.m.
3 p.m.
13
4 p.m.
Broadway Terrace
Valley View Rd.
Oakland
5 p.m.
Afternoon wind direction
Map area
Oakland
Mountain View Cemetery
San Jose
Piedmont
1/2 mile

Source: Oakland Fire Department   DAVE JOHNSON/BAY AREA NEWS GROUP

According to the National Weather Service, rainfall that began Thursday amounted to 0.4 inches in Santa Rosa, 0.45 inches in Geyserville and 0.2 inches in Napa.

'The precipitation helped firefighters quite a bit.'

Tubbs Fire

Adobe Fire

Nuns

The October 2017 Tubbs fire destroyed at least 5,200 homes and structures, making it the most destructive wildfire in California state history, as well as one of the deadliest.

The fire was pushed downhill at unusually high speeds by winds that sometimes exceeded 50 mph.
Burning embers were blown ahead of the main front, leaping ahead and igniting new fires.

In about three hours, the fire reached Santa Rosa.
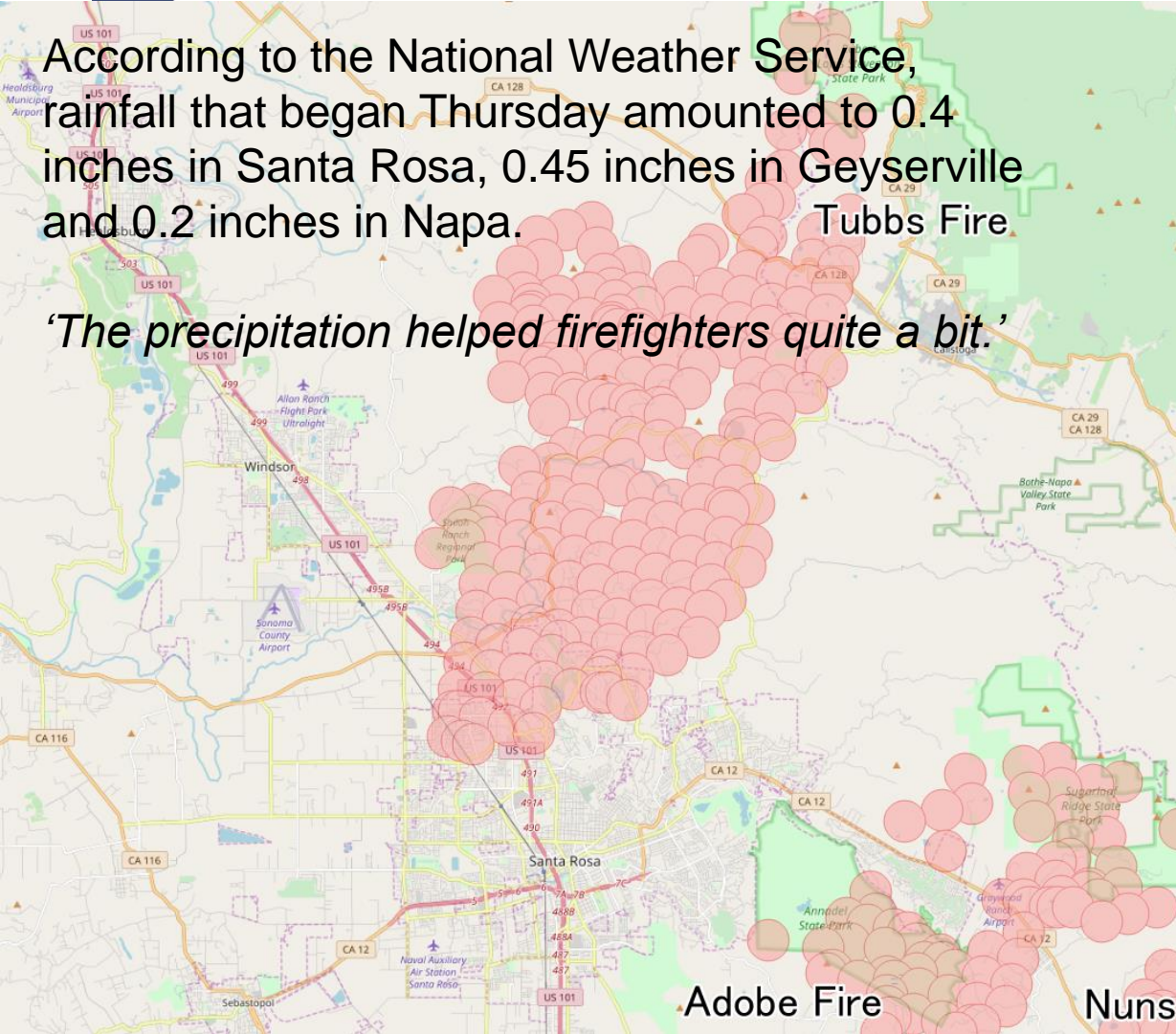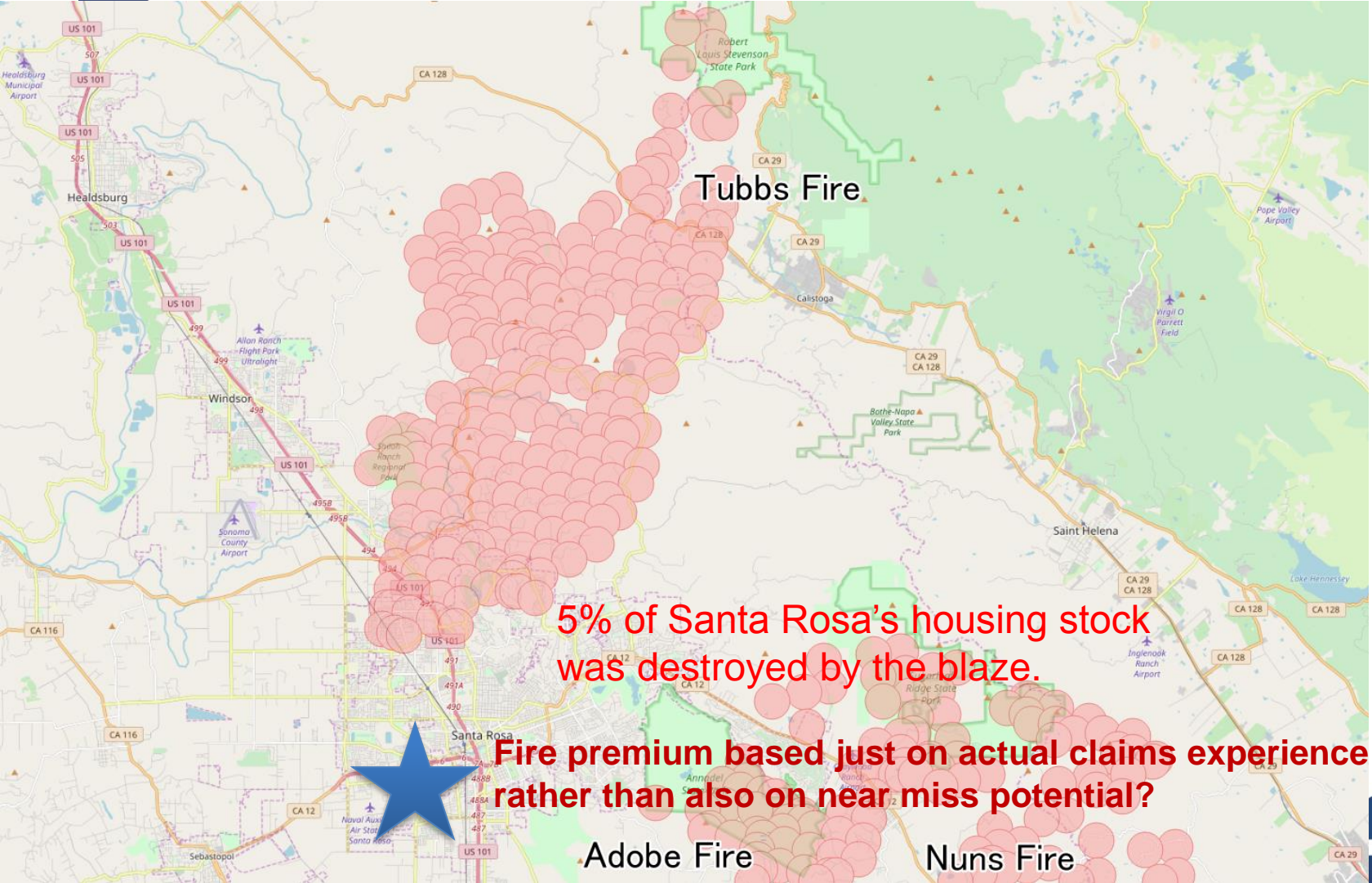
Tubbs Fire

5% of Santa Rosa's housing stock
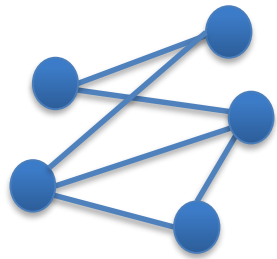was destroyed by the blaze.

**Fire premium based just on actual claims experience
rather than also on near miss potential?**

Adobe Fire

Nuns Fire

Alternative terrorism loss catalogues

Terrorist cell

A planned attack against the US Bank (Library Tower in L.A.), the tallest building in western USA, was interdicted in early 2002 with the arrest of a key Al Qaeda operative in Asia.

Weighing the fog of war: Illustrating the power of Bayesian methods for historical analysis through the Battle of the Dogger Bank

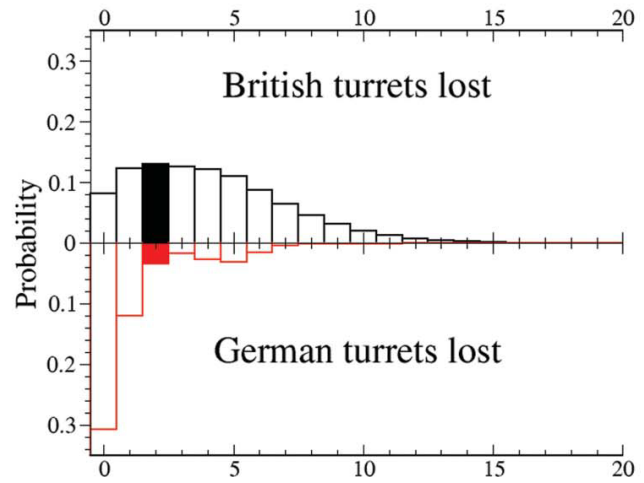Niall MacKay, Christopher Price & A. Jamie Wood

Results from Approximate Bayesian Computation
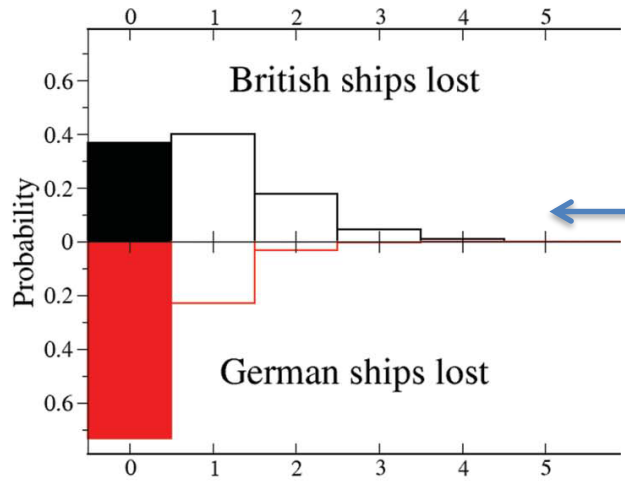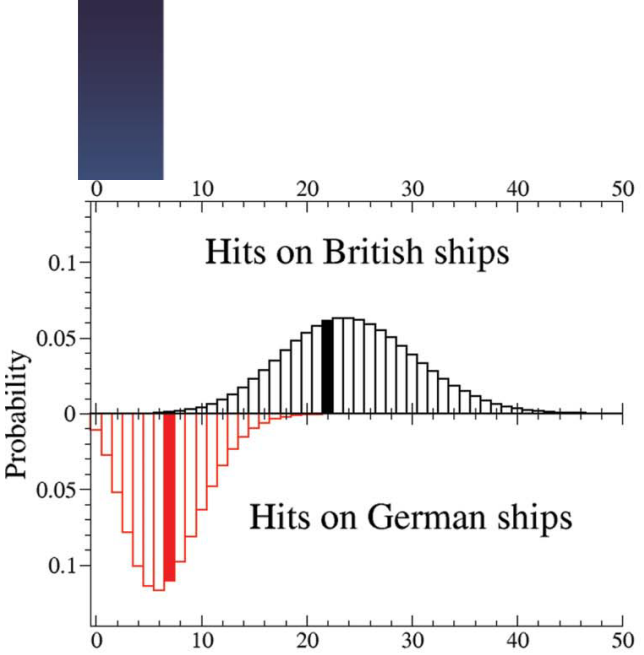
The British navy was fortunate: the expected result would have been the destruction of at least one ship, and possibly as many as three.

The belief of military historians that this was a squandered British victory on January 24, 1915 - IS FALSE.
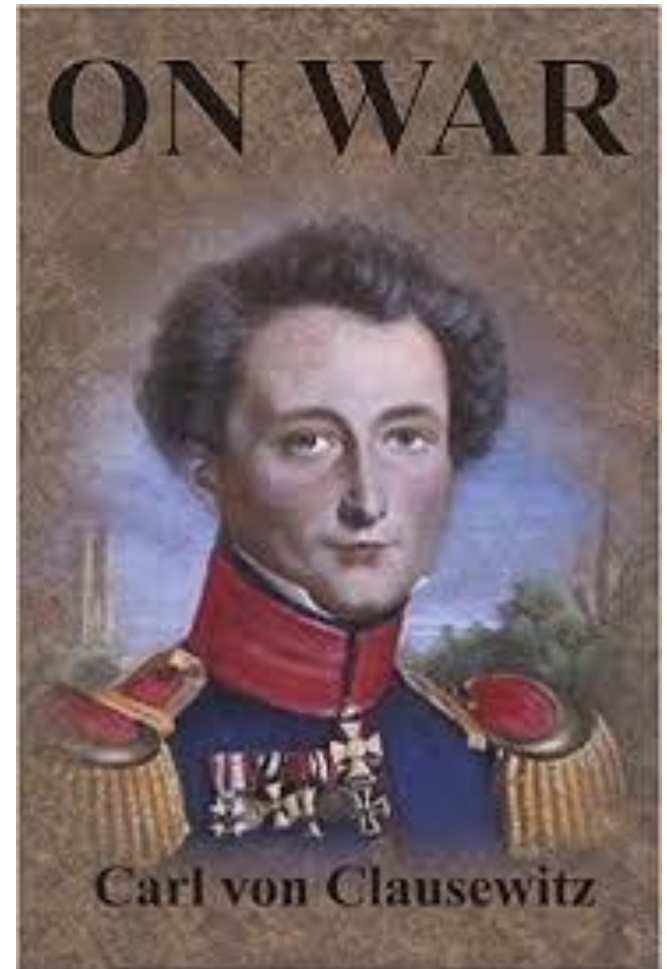
'*Perfecting the art of warfare entails knowing not only what has occurred in previous wars,*

....but also everything that could have occurred.'

'*Perfecting the art of cyber risk underwriting entails knowing not only what has occurred in previous cyber attacks,*

....but also everything that could have occurred.'

ON WAR

Carl von Clausewitz

Ransomware on a Cherokee Jeep

'The Jeep vulnerability was discovered by ethical researchers.

But imagine if that exploit was done by a cybercriminal where all those Jeeps were impacted with ransomware.'

Steve Grobman
Intel Security CTO

Human dimension to the SWIFT heist

Malware was planted on the computer systems of the Bangladesh Bank. The North Korean Lazarus Group has been linked with this heist.

On February 4, 2016, **$81m** was stolen from the Bangladesh Bank and was laundered in the Philippines casino industry. Another $20 million was recovered due to a Sri Lanka bank query: '*Foundation*' being misspelt as '*Fundation*'.

Counterfactually, another $850m might have been lost, but for a fluke coincidence of the name 'Jupiter', that resulted in orders being blocked by the New York Fed.

Counterfactual event tree for zero days
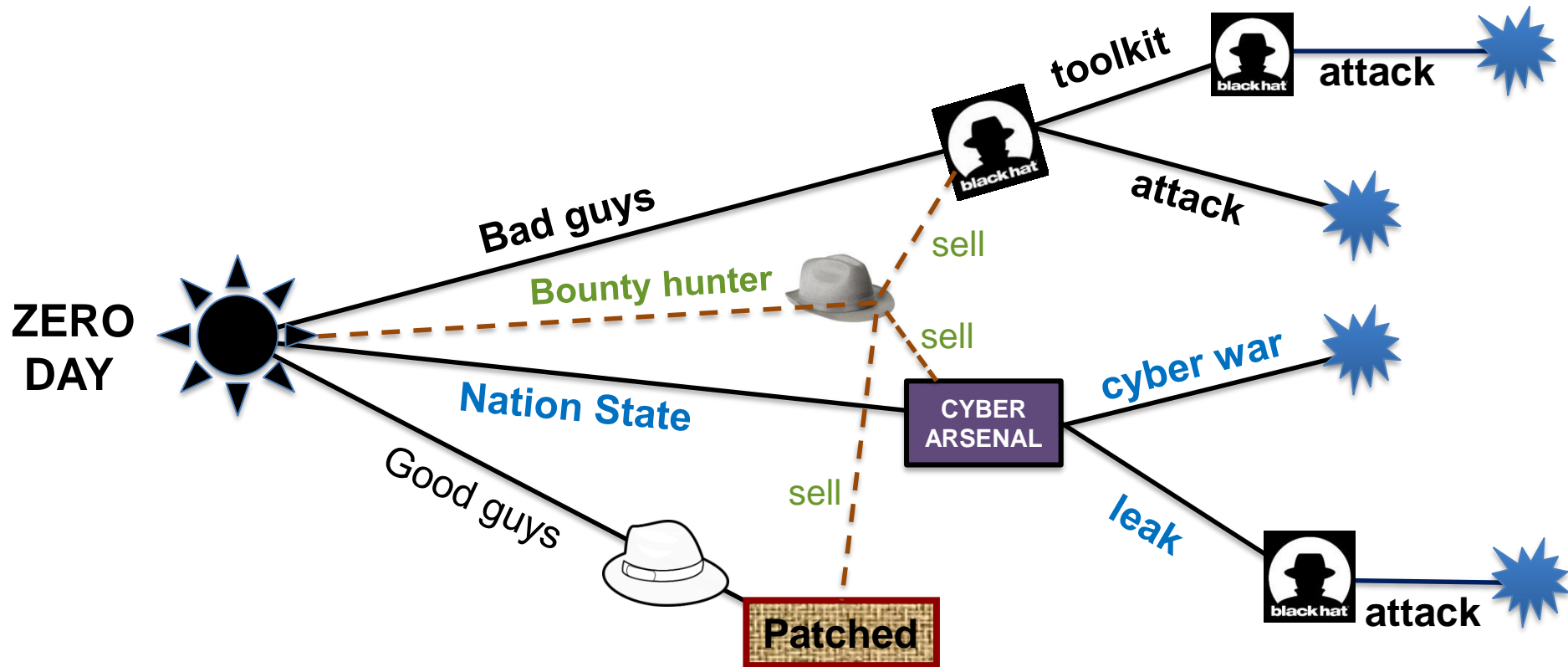
Timeline to May 12, 2017, WannaCry attack

These two events could have happened three months earlier.

January 7

Shadow Brokers posted screenshots taken from Equation Group's 2013 Windows Ops disk.

February 14

Microsoft cancels Patch Tuesday for the first time

March 14

Microsoft Patch of Eternal Blue

April 8

Contents of the 2013 Window Ops disk released the day after U.S. cruise missile attack on Syria
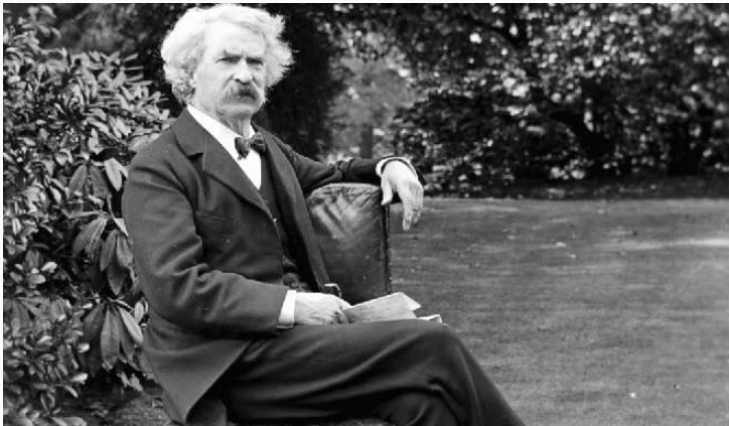
May 12

WannaCry Ransomware attack

Counterfactual Disaster Scenarios

'History doesn't repeat itself, but it does rhyme.'

Mark Twain

Counterfactual scenarios are rooted in actual occurrences, and are intrinsically realistic.

Compared with future events, the highest resolution for a catastrophe risk scenario is achievable for recent historical events.

Questions and Discussion