# Extreme Geohazards
# Reducing the Disasters Risk Associated With Low-Probability, High-Impact Events

Hans-Peter Plag, Mitigation and Adaptation Research Institute, Old Dominion University, Norfolk, VA, USA

*Supported by*:
Geohazards Community of Practice of the Group on Earth Observations (GEO)
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GEO GROUP ON EARTH OBSERVATIONS

GHCP GEOHAZARD COMMUNITY of PRACTICE

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# INTRODUCTION: Terminology

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**Extreme Events:**

- **Extinction Level Events:** more than a quarter of all life on Earth is killed and major species extinction takes place.
- **Global Catastrophes:** more than a quarter of the world human population dies and that place civilization in serious risk.
- **Global Disasters:** global-scale events in which a few percent of the population die.
- **Major Disasters:** disasters exceeding $100 Billion in damage and/or causing more than 10,000 fatalities.

*Modified from Hempsell (2004)*

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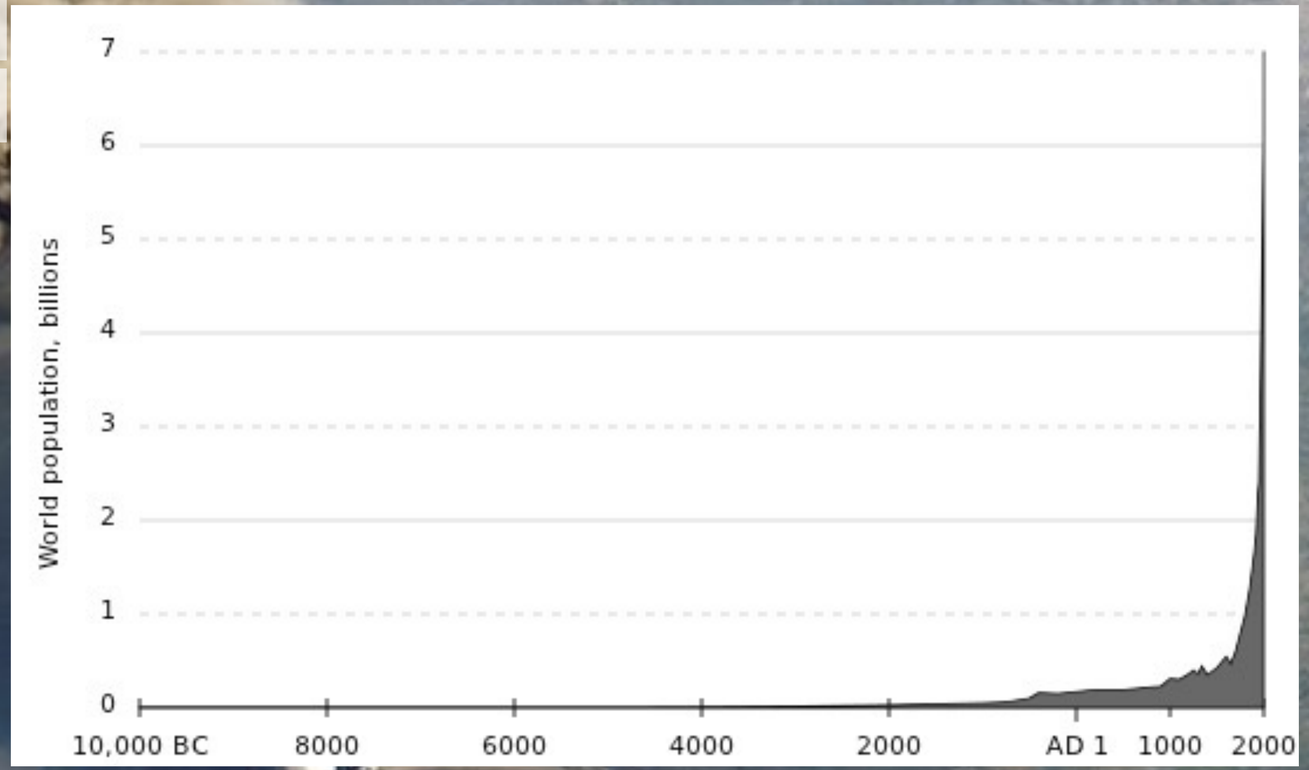

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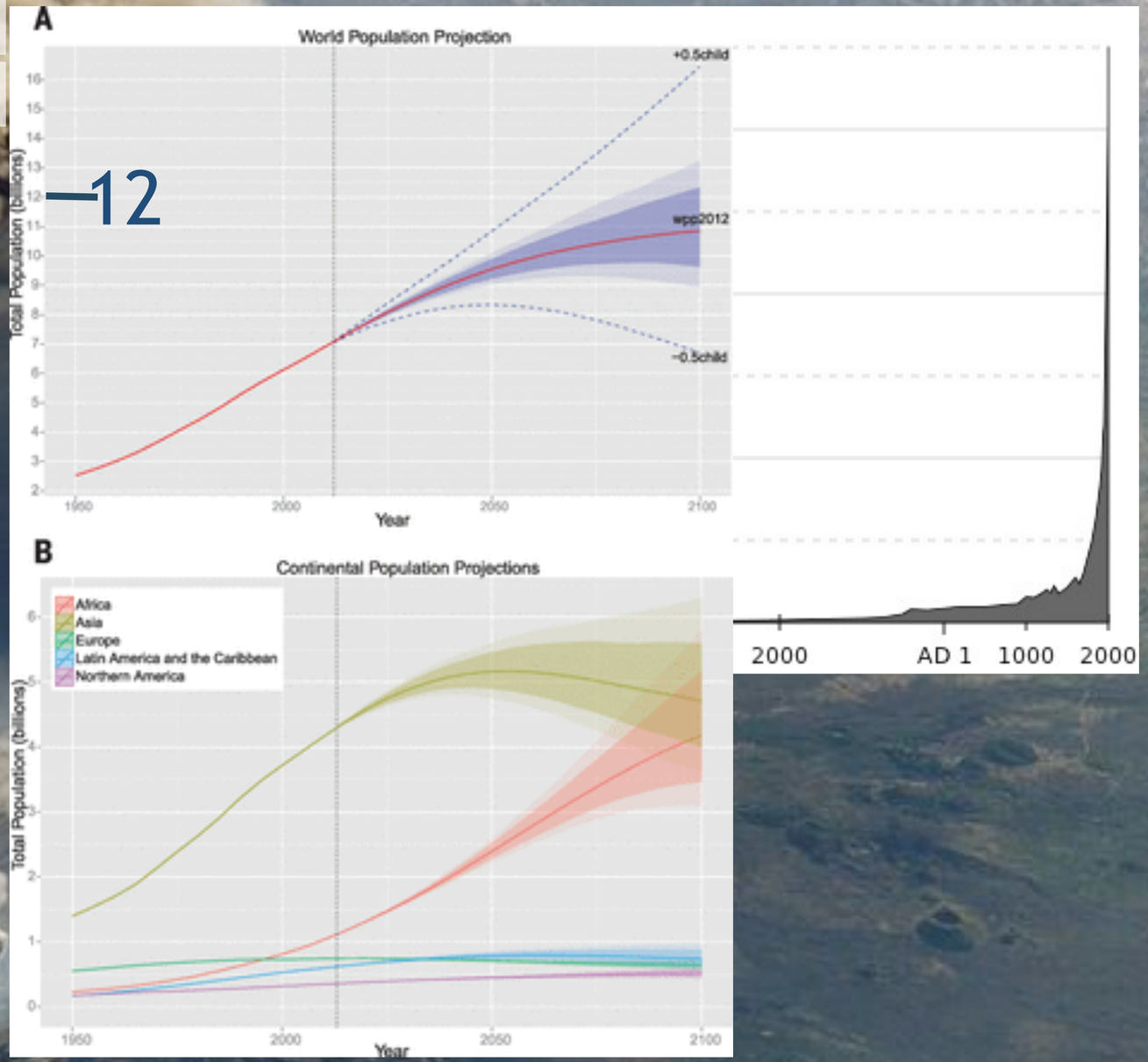


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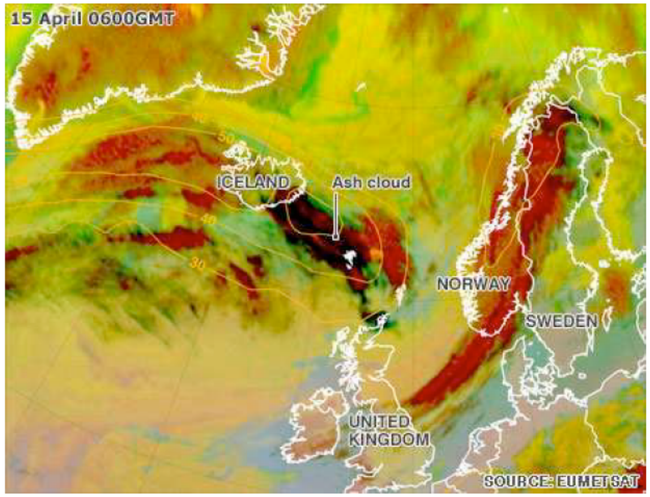

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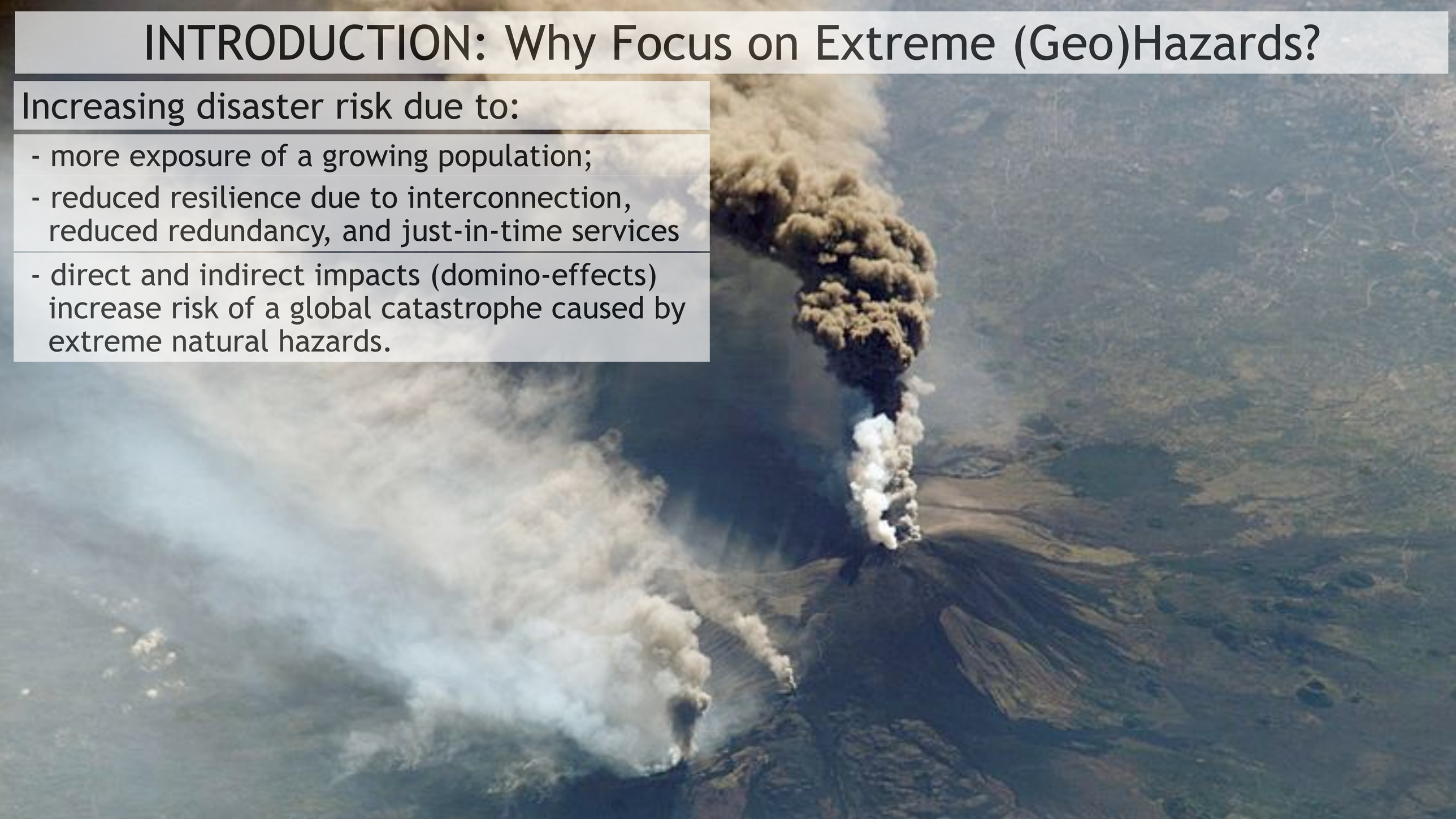

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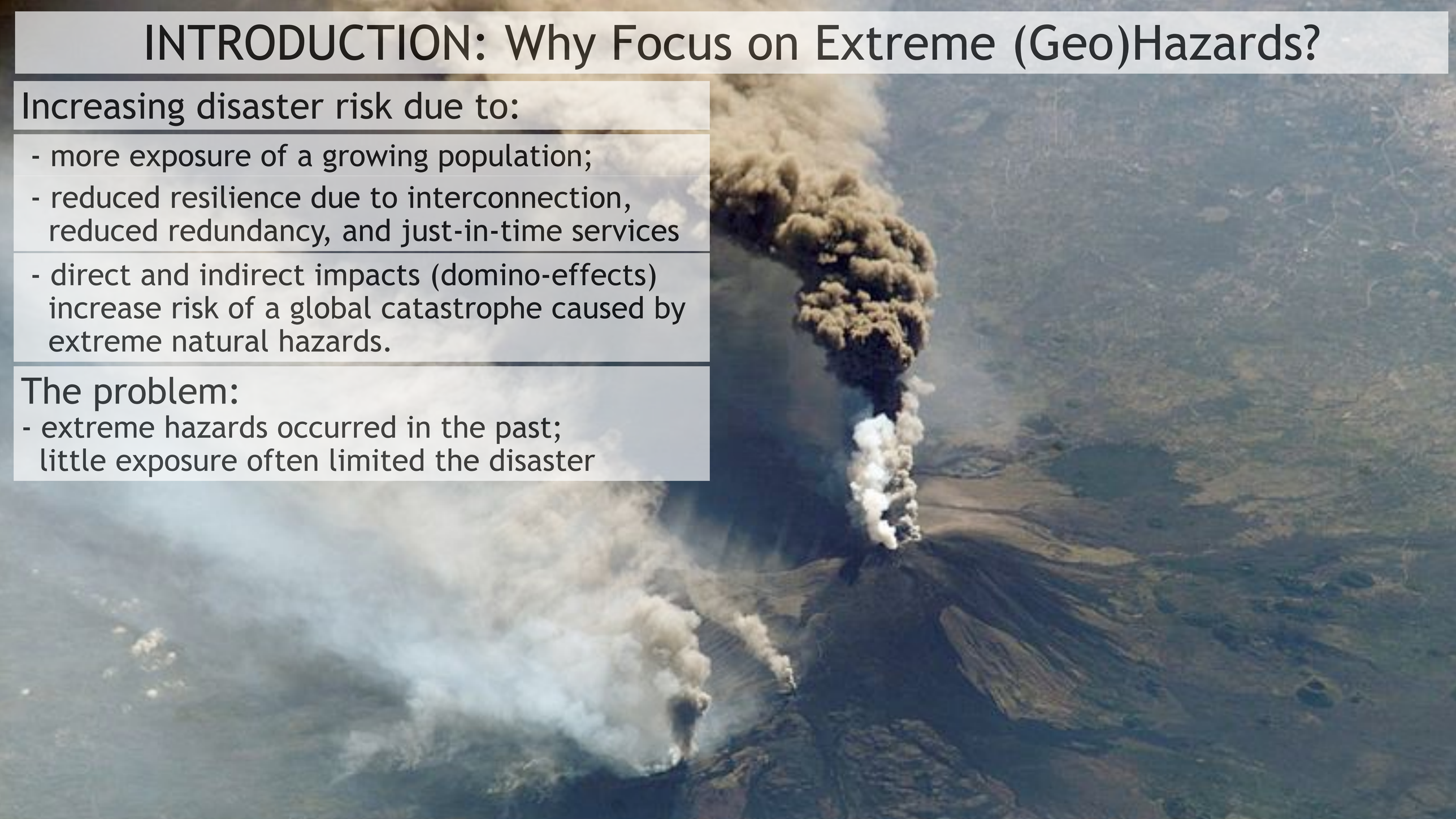

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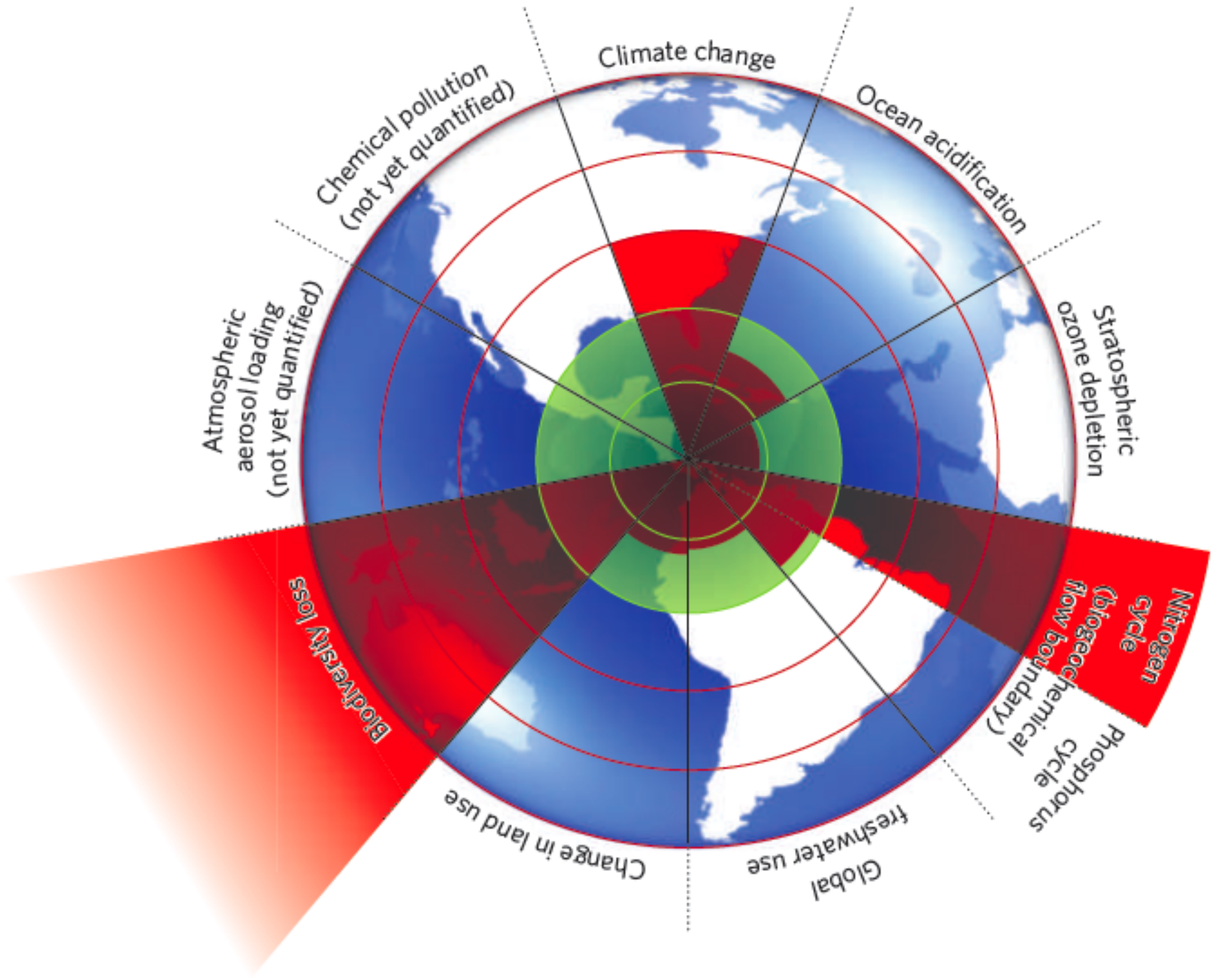


The Global Boundaries of the "safe operating space for humanity" (Rockström et al., 2009)

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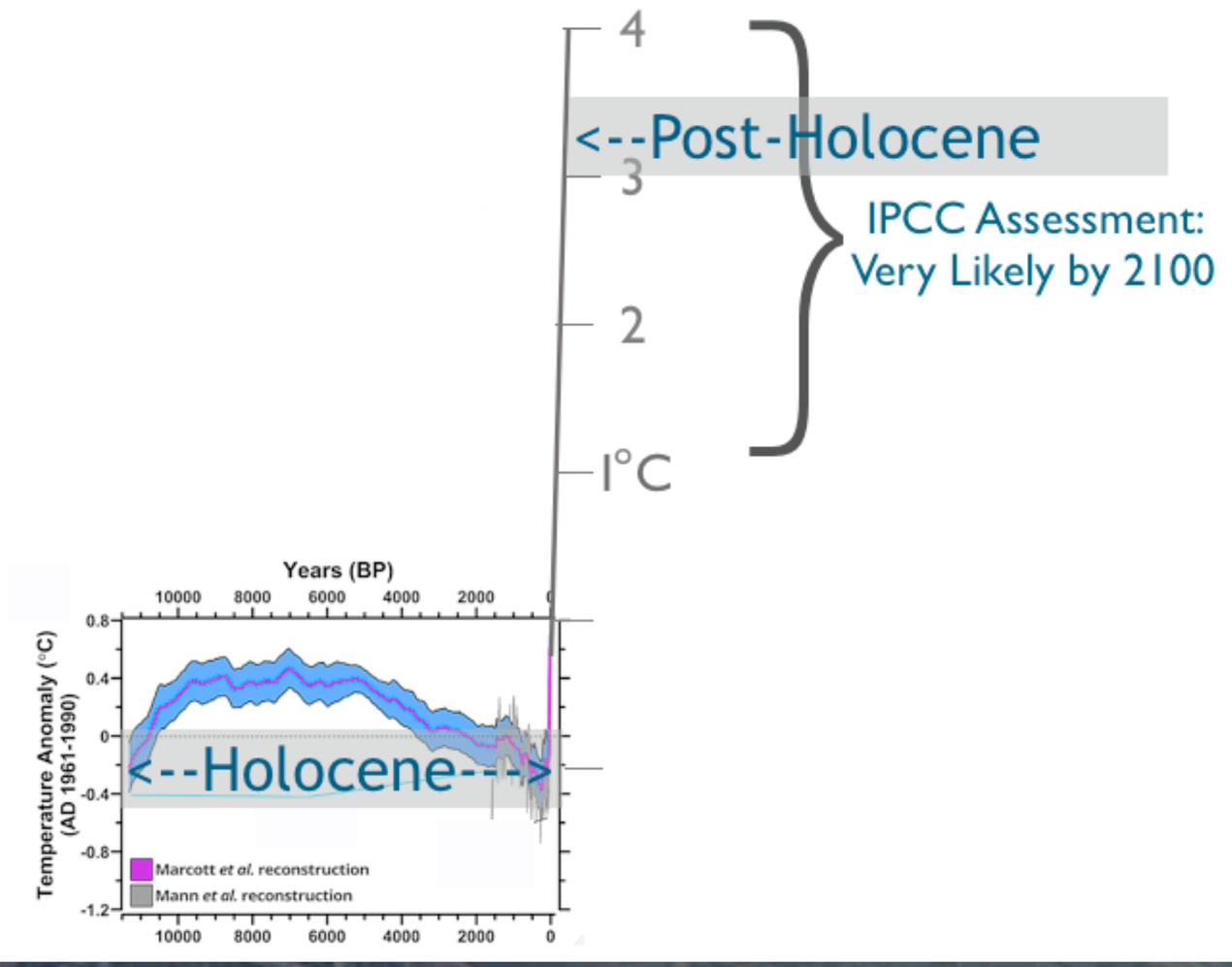

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risk = probability x vulnerability x exposure

$$r_h^T(I,x,t) = p_h^T(I,t) \cdot S_h^{a(x,t)}(I,t) \cdot a(x,t)$$

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Poisson distribution; Chance that one or more
“1 in *N* years” events occur in a century:

| $N$ | $C$ in % |
|---|---|
| 10 | 99.99 |
| 100 | 63.21 |
| 500 | 18.13 |
| 1,000 | 9.516 |
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| 100,000 | 0.100 |

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In the 20th century we have been lucky ...

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Assessing impacts: X-ness (Casti, 2012):

$$X = \frac{\delta E}{E}\left(1 - \frac{U}{U + I}\right)$$

*X*: X-ness
*δE*: Impacted ensemble (population, GDP, ...)
*U*: Unfolding time
*I*: Impact time

# INTRODUCTION: Measuring Impacts

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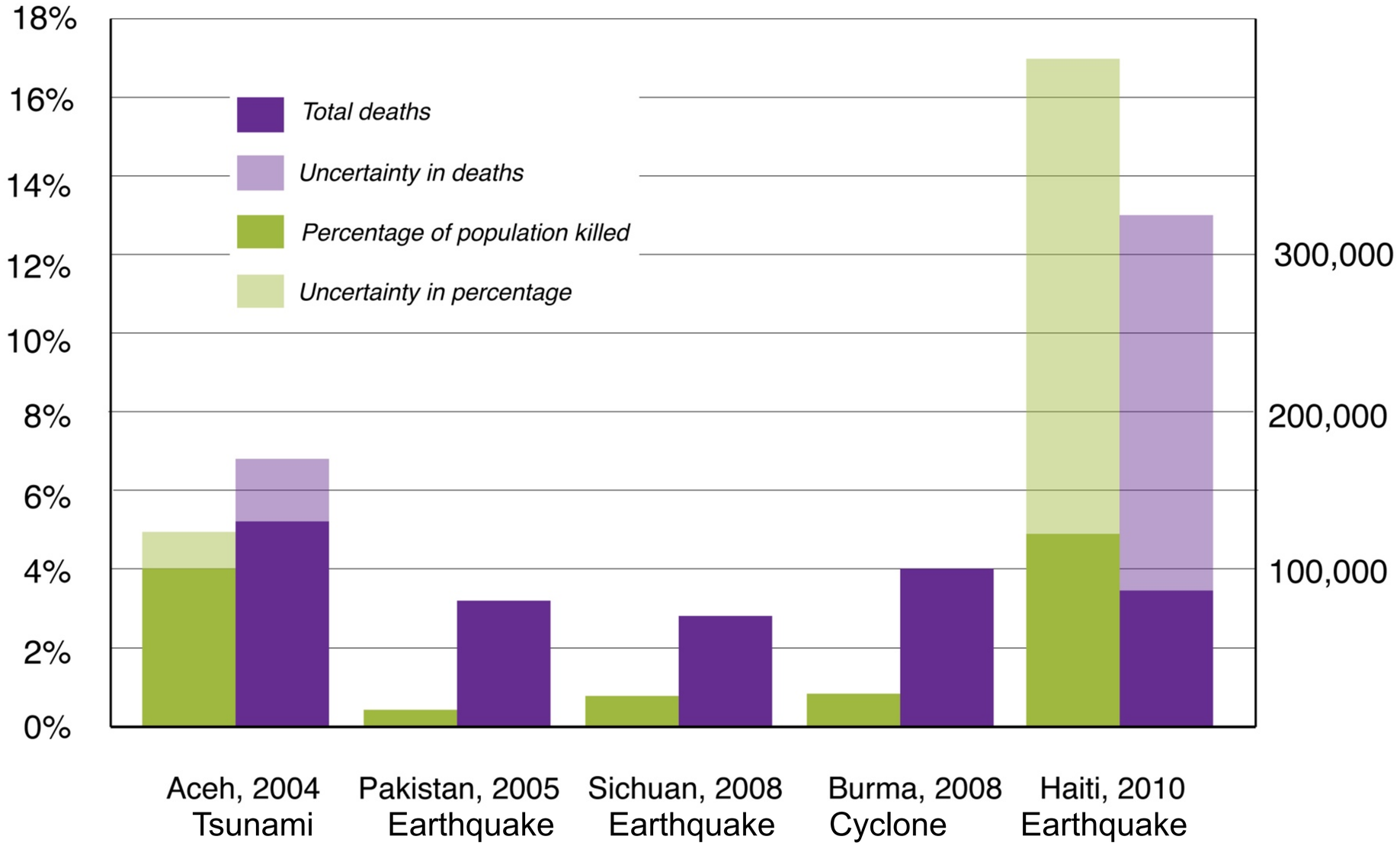

# White Paper

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www.geohazcop.org/workshops/Sant_Feliu_2011/

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**Understanding Extreme Geohazards: The Science of the Disaster Risk Management Cycle**

***European Science Foundation Conference***
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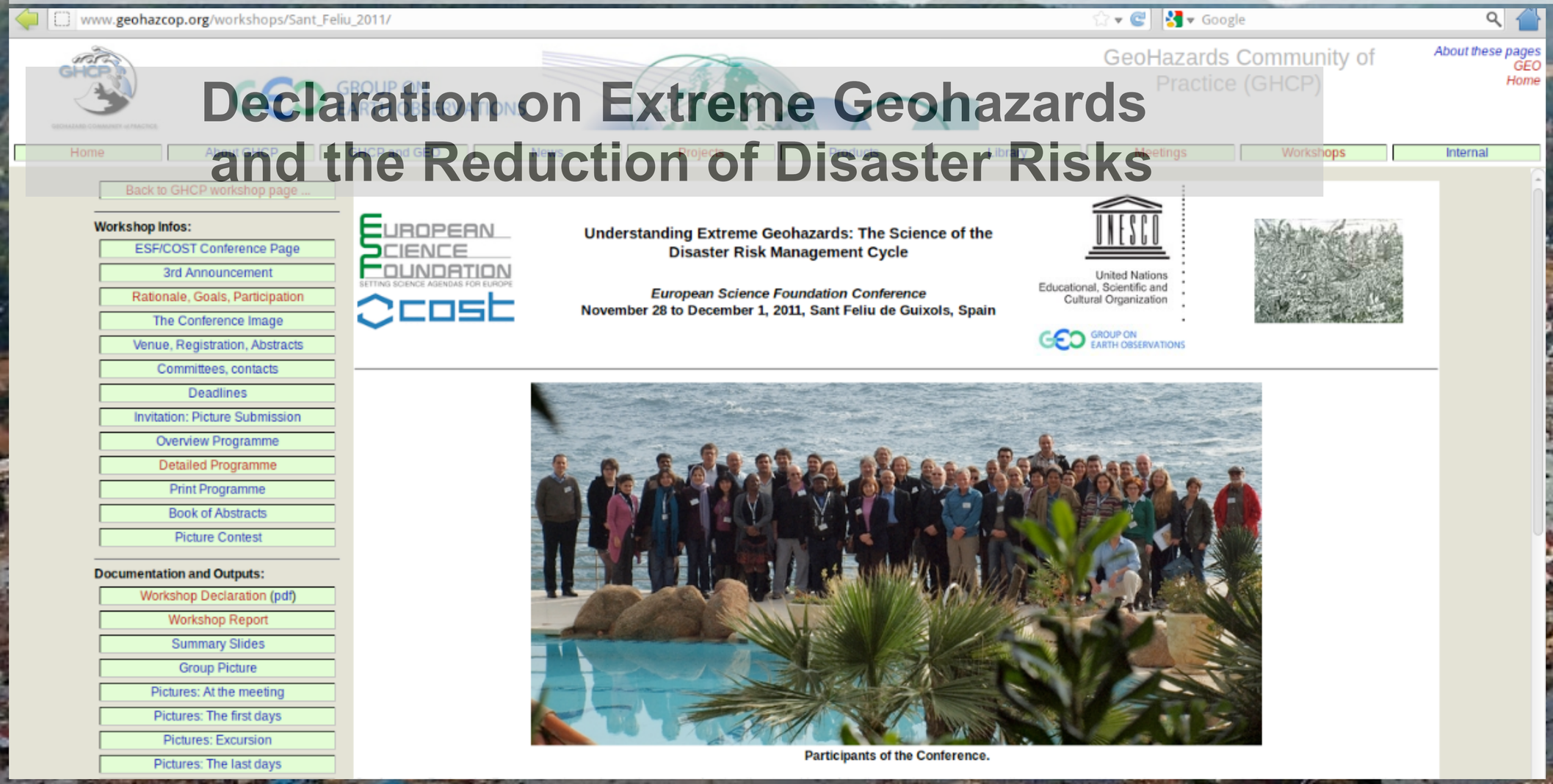


## Declaration on Extreme Geohazards and the Reduction of Disaster Risks

Resulted in two main activities:

- Global Geohazards Information System for Disaster Risk Reduction (GGIS-DRR)
- White Paper on Extreme Geohazards

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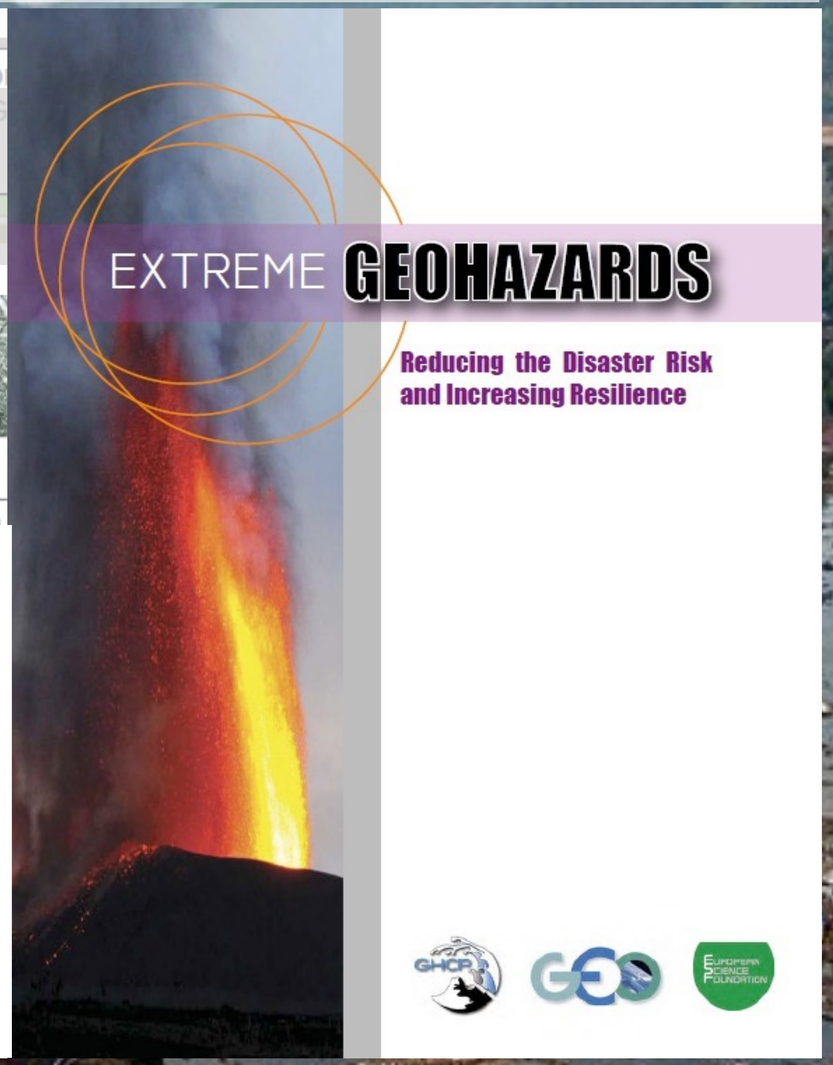


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# GEOHAZARDS

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## Extreme Geohazards:

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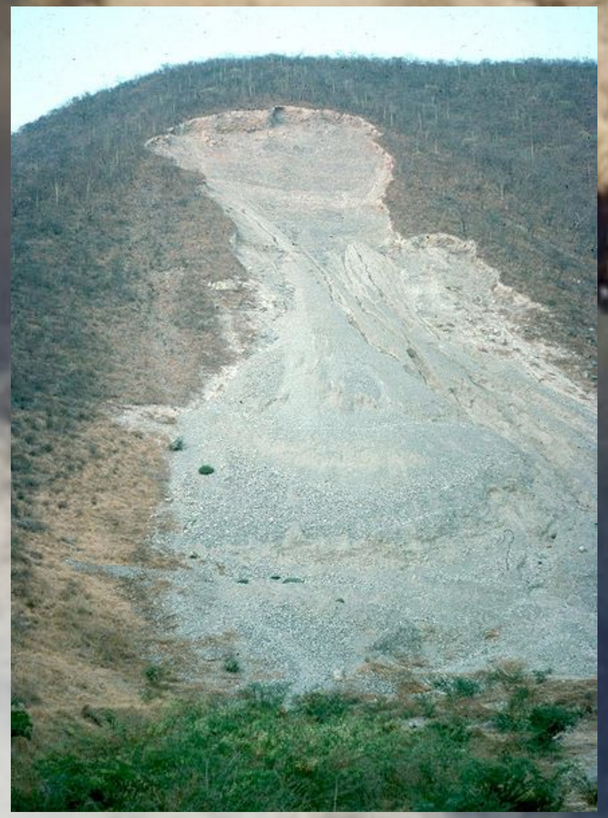
Extreme Geohazards:

- landslides



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Extreme Geohazards:

- landslides
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- landslides
- tsunamis
- earthquakes
- volcanic eruptions

# GEOHAZARDS

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## 1980 - 2008

| Hazard | Events | Fatalities | Per year | Affected | Per year | Damage | Per Year | R |
|---|---|---|---|---|---|---|---|---|
| Drought | 410 | 558,565 | 19,261 | 1,551,455,122 | 53,498,452 | 76,949 | 2,653 | 0.036 |
| Cylone | 1,211 | 402,911 | 13,893 | 496,560,639 | 17,122,781 | 533,371 | 18,392 | 0.081 |
| Earthquake | 706 | 385,630 | 13,298 | 136,333,515 | 4,701,156 | 351,079 | 12,106 | 0.283 |
| Tsunami | 18 | 229,551 | 7,916 | 2,481,879 | 85,582 | 10,046 | 0.346 | 9.249 |
| Flood | 2,887 | 195,843 | 6,753 | 2,809,481,489 | 96,878,672 | 397,334 | 13,701 | 0.007 |
| Heat Wave | 126 | 89,889 | 3,100 | 4,614,411 | 159,118 | 21,990 | 758 | 1.948 |
| Volcano | 140 | 25,197 | 869 | 4,080,791 | 140,717 | 2,871 | 99 | 0.617 |
| Land Slide | 366 | 20,008 | 690 | 7,031,523 | 242,466 | 6,060 | 209 | 0.285 |
| Cold Wave | 156 | 11,595 | 400 | 6,875,103 | 237,073 | 5,902 | 204 | 0.169 |
| Tornado | 182 | 4,780 | 165 | 12,710,204 | 438,283 | 31,511 | 1,087 | 0.038 |
| Avalanche | 73 | 3,532 | 122 | 69,637 | 2,401 | 807 | 28 | 5.072 |
| Wild Fire | 294 | 1,666 | 57 | 5,766,092 | 198,831 | 42,807 | 1,476 | 0.029 |

http://www.preventionweb.net/english/professional/statistics/

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## 1980 - 2013

| Hazard | Events | Fatalities | Affected | Damage | R |
|---|---|---|---|---|---|
| Earthquakes and tsunamis | 865 | 866,882 | 158,794,738 | 737,379 | 0.546 |
| Droughts | 499 | 561,540 | 1,766,356,773 | 117,612 | 0.032 |
| Floods | 3,741 | 229,080 | 3,277,580,121 | 619,190 | 0.007 |
| Extreme Temperatures | 461 | 166,921 | 97,822,633 | 54,327 | 0.171 |
| Volcanoes | 160 | 25,539 | 4,476,906 | 2,870 | 0.570 |

http://www.emdat.be/advanced search/.

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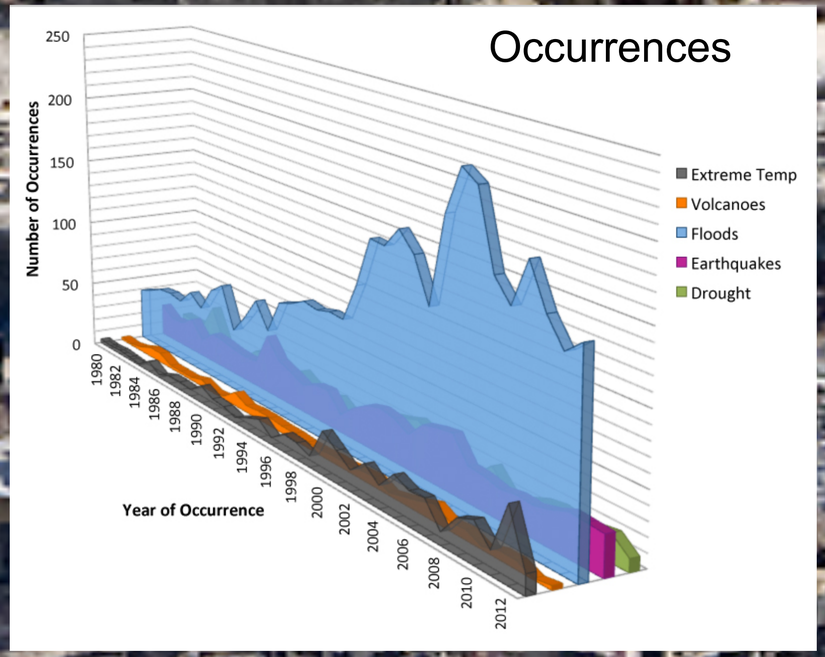
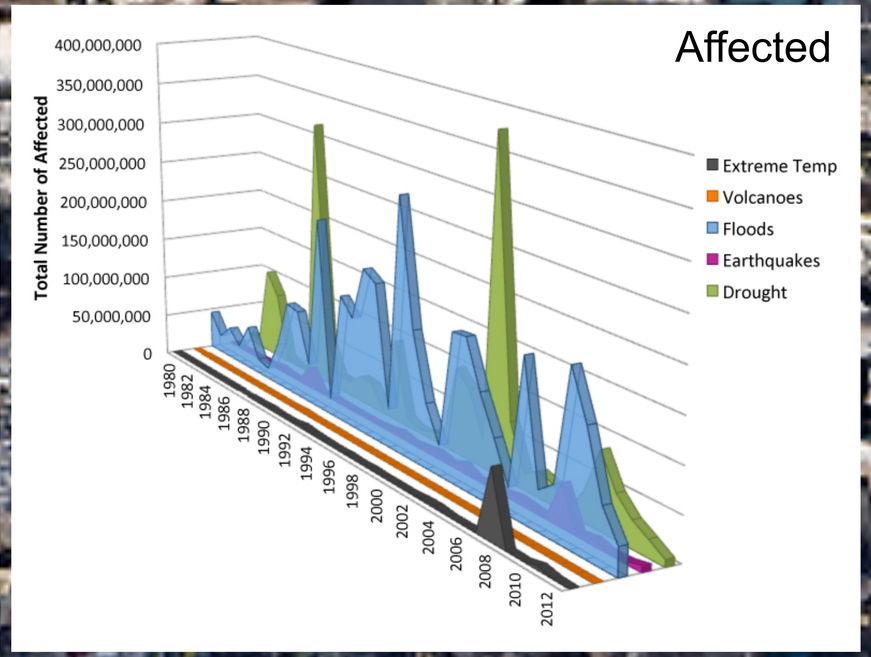
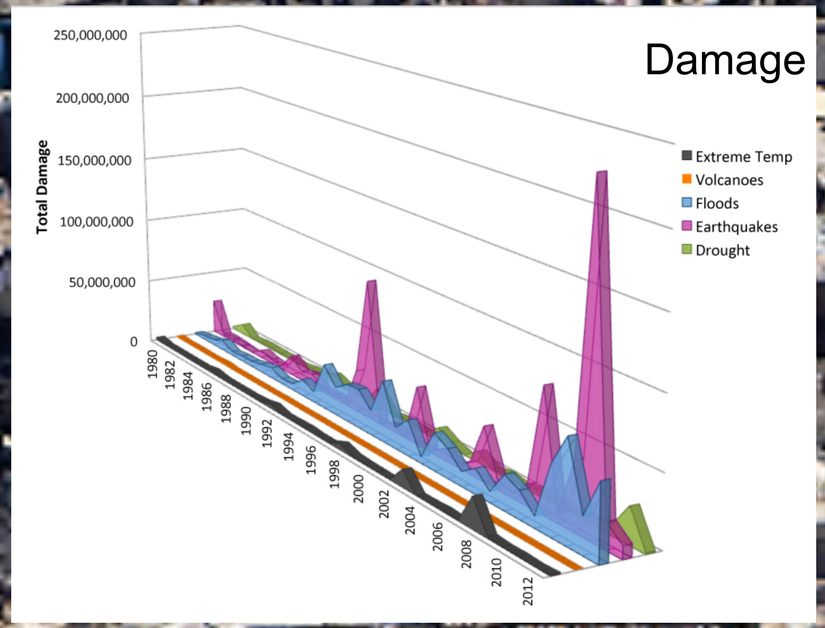
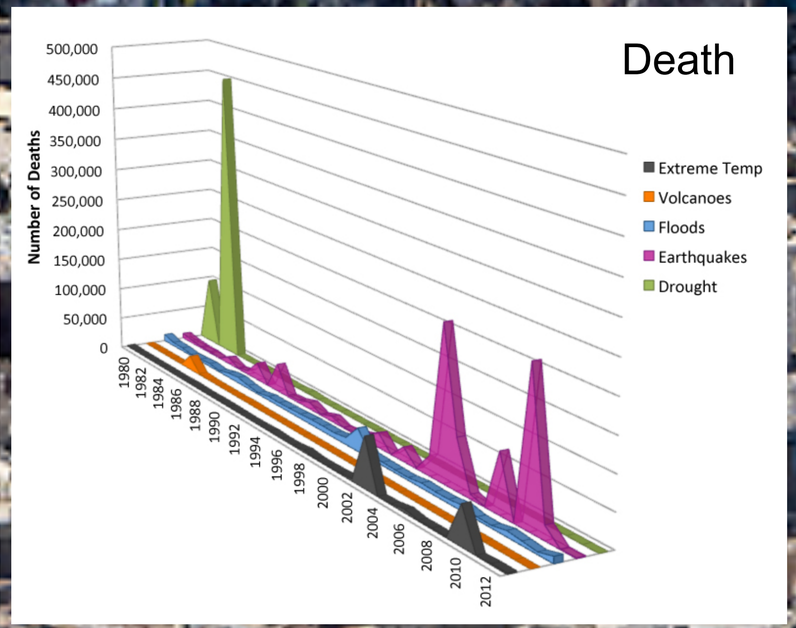
## International Disaster Database



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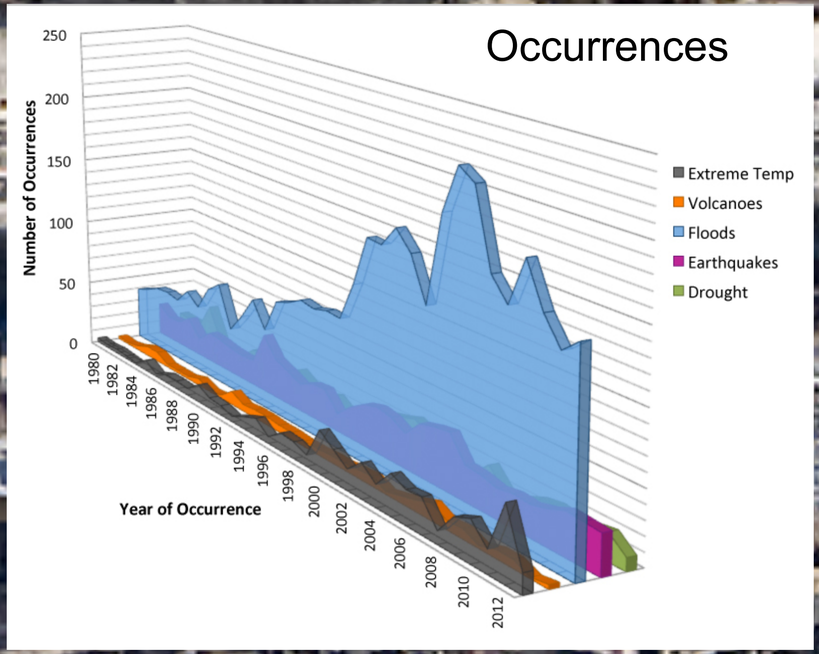


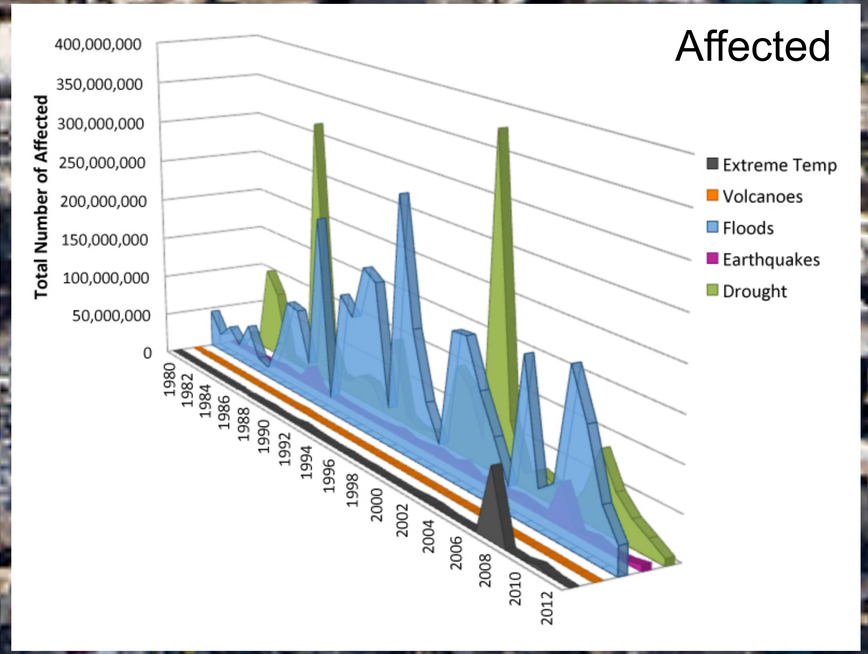


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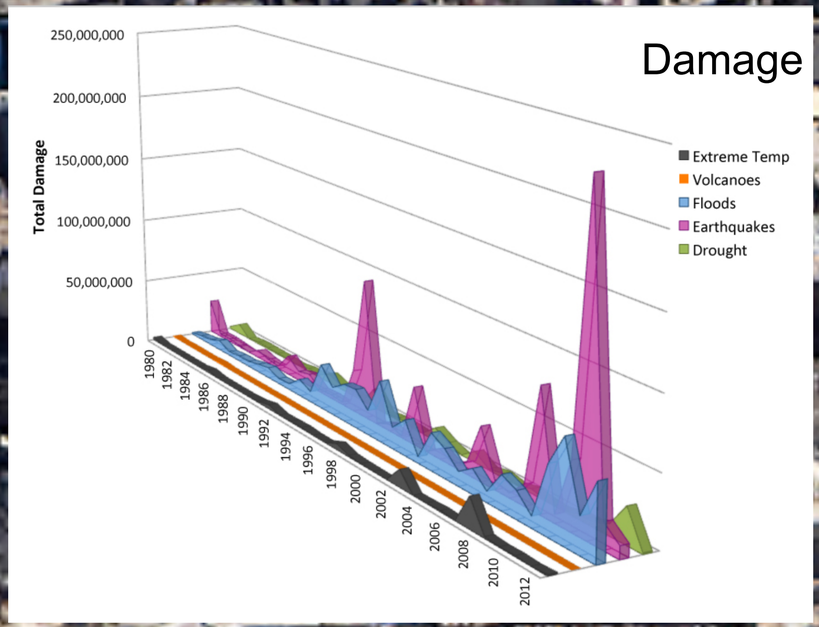


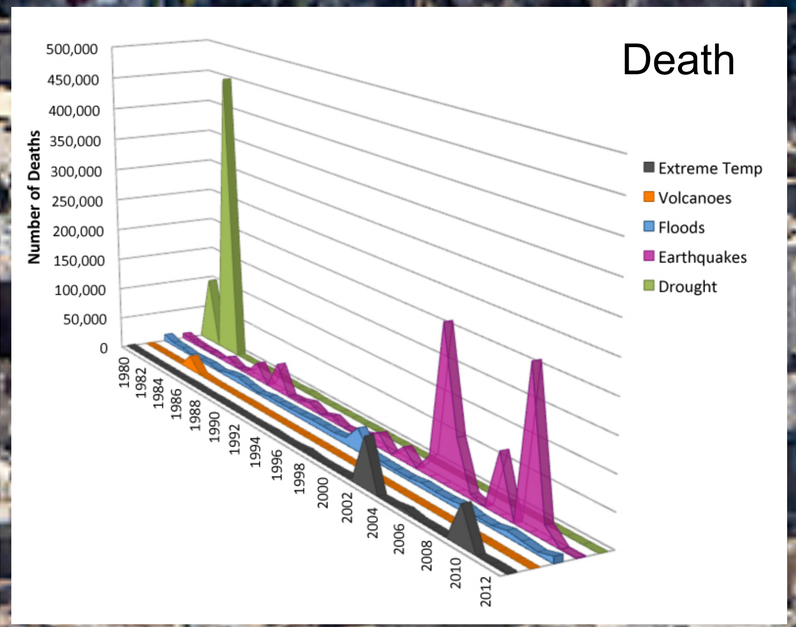


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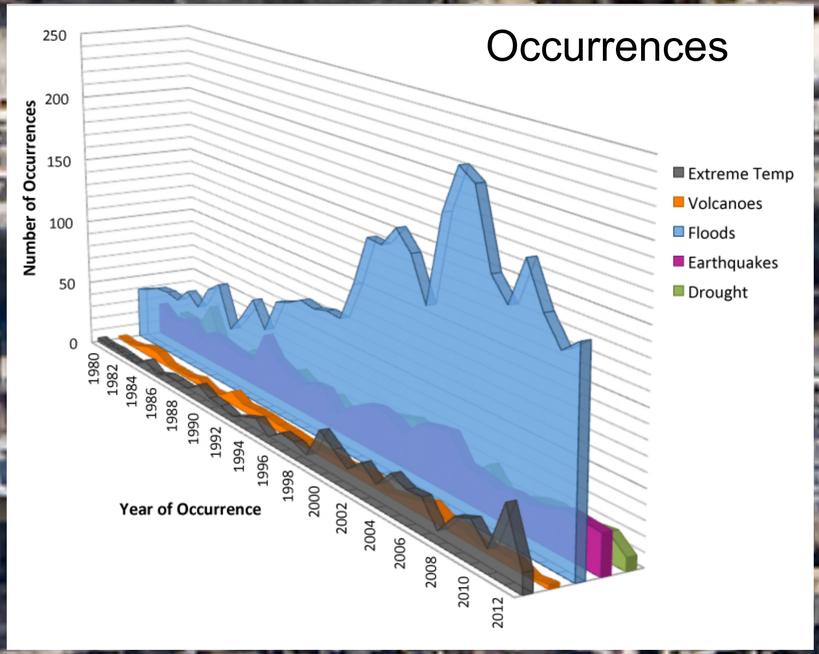


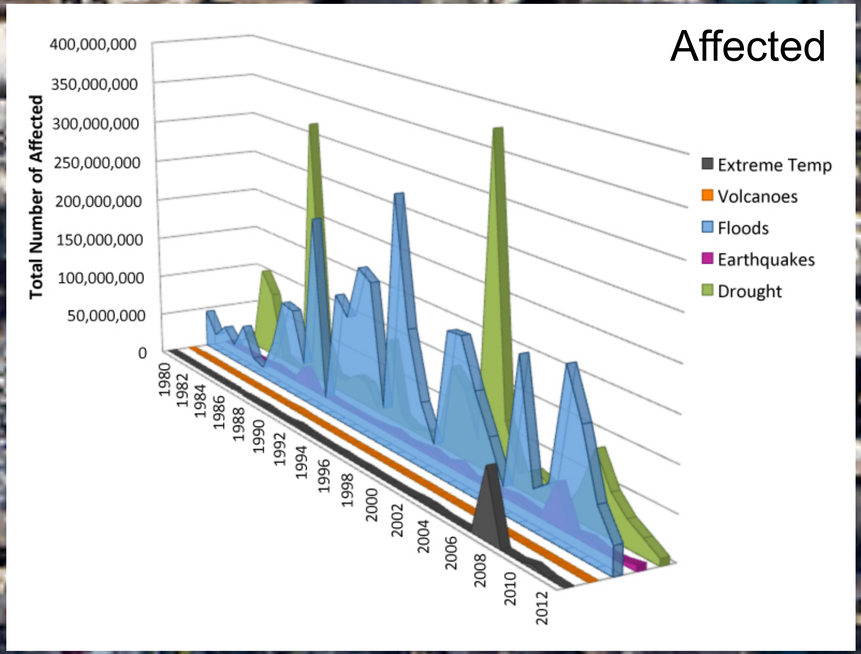


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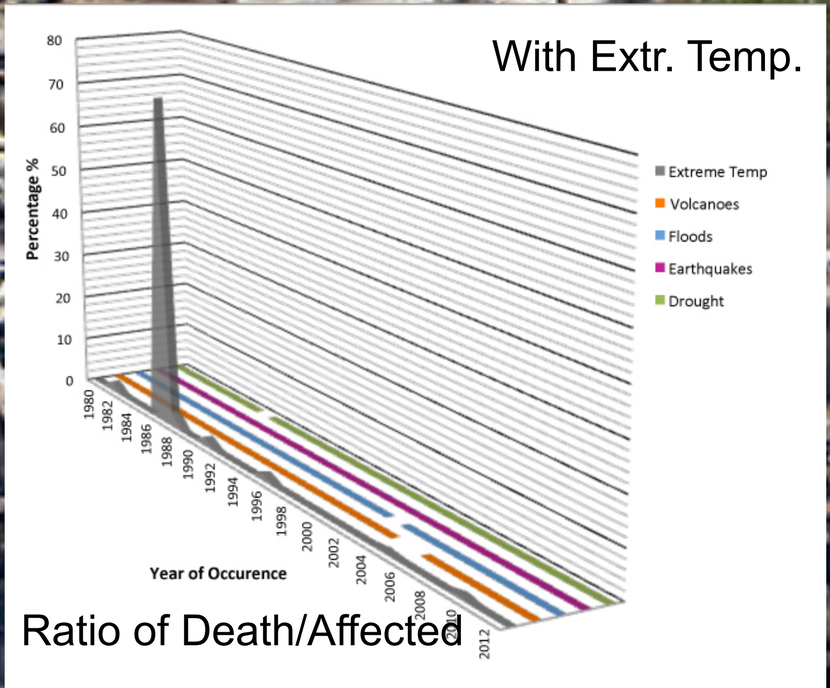
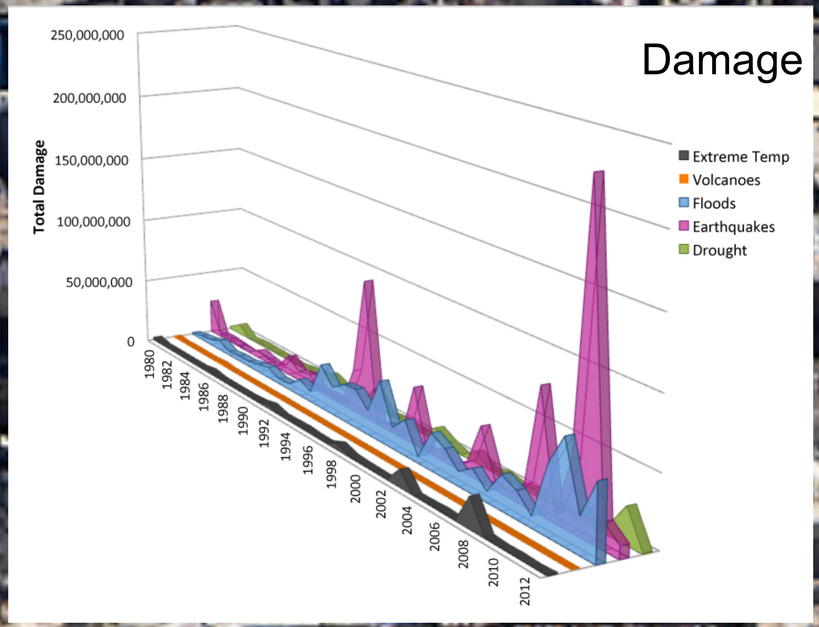
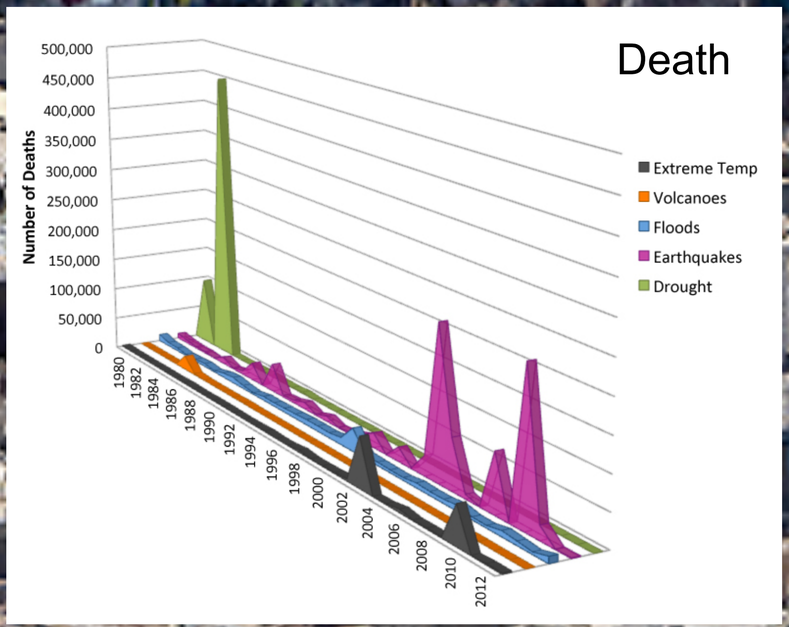



Ratio of Death/Affected

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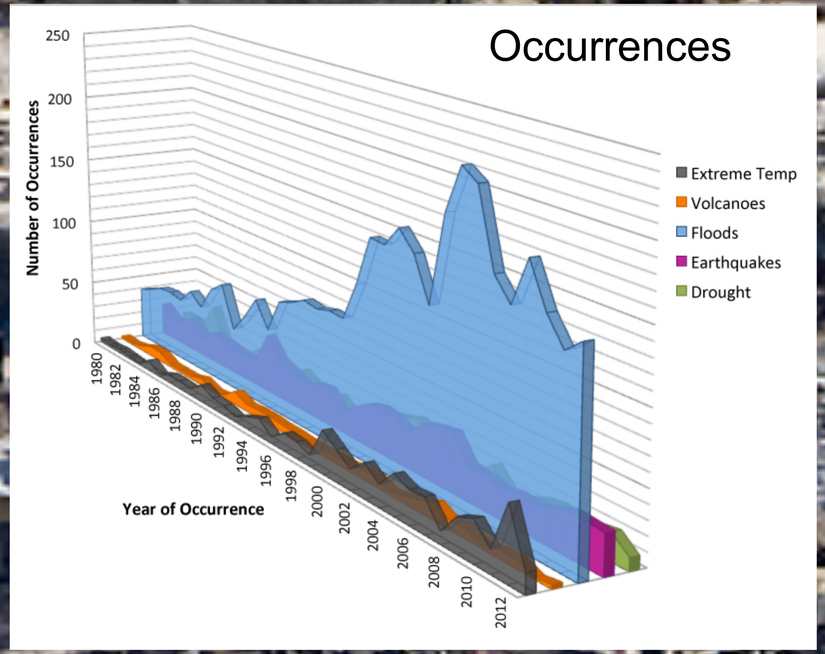
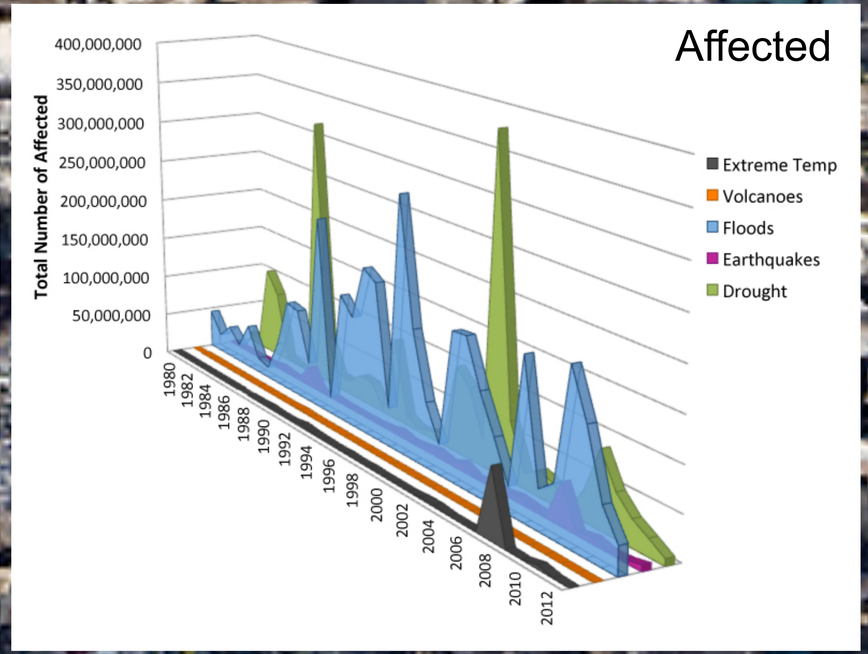
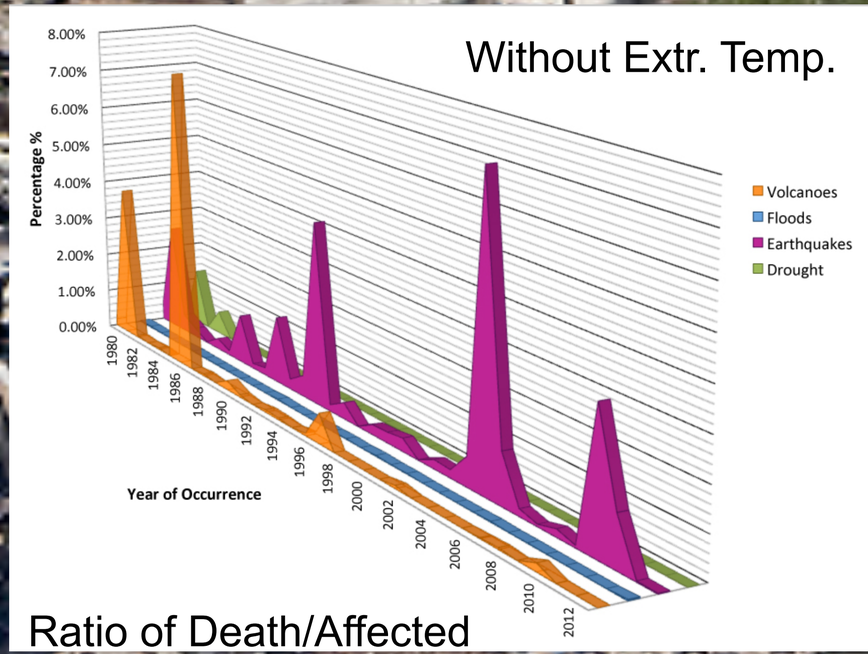
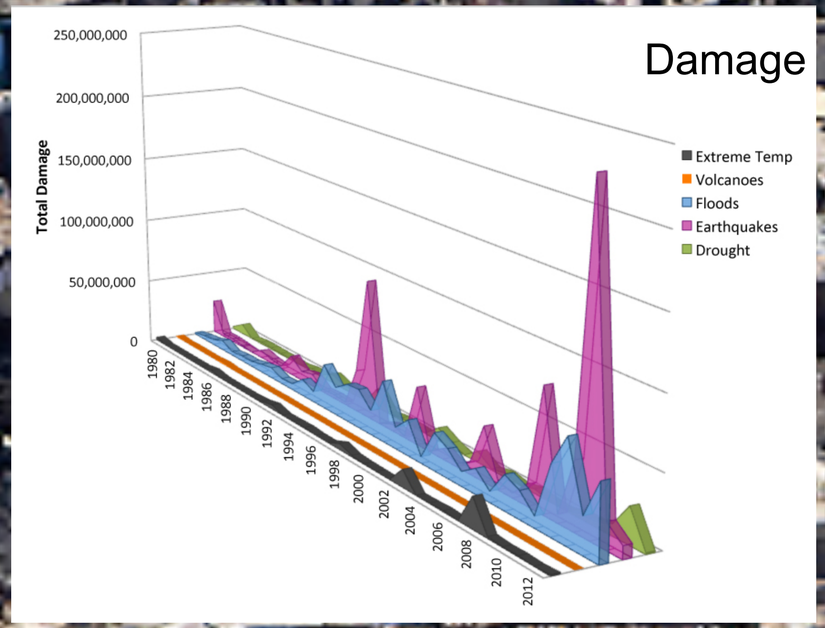
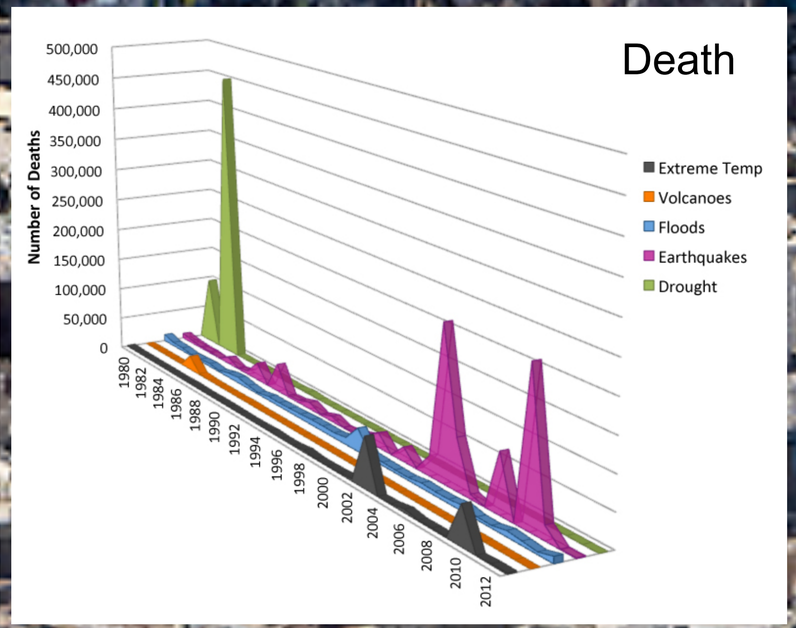


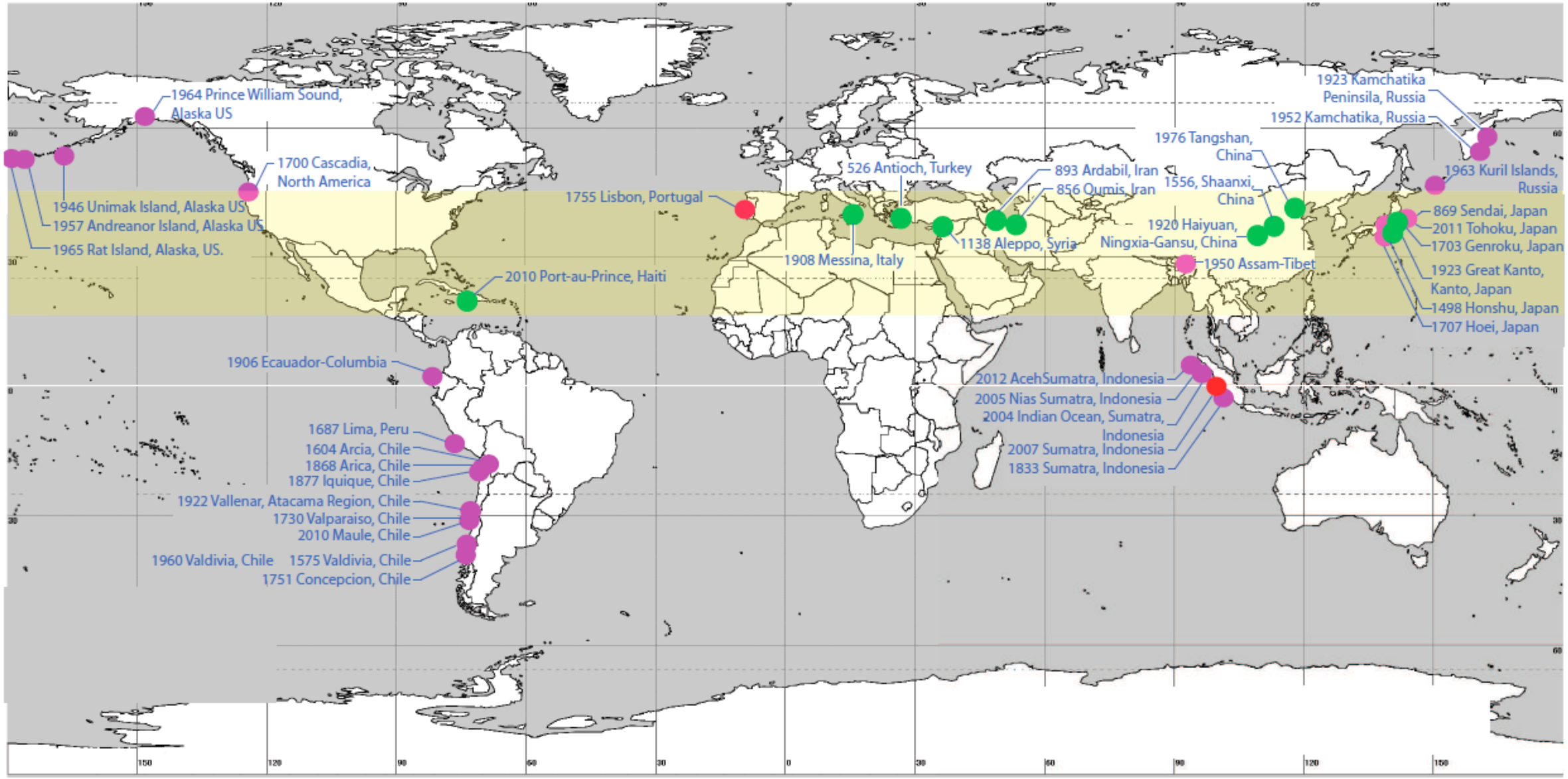




Ratio of Death/Affected

http://www.emdat.be/advanced search/.

# GEOHAZARDS: Earthquakes



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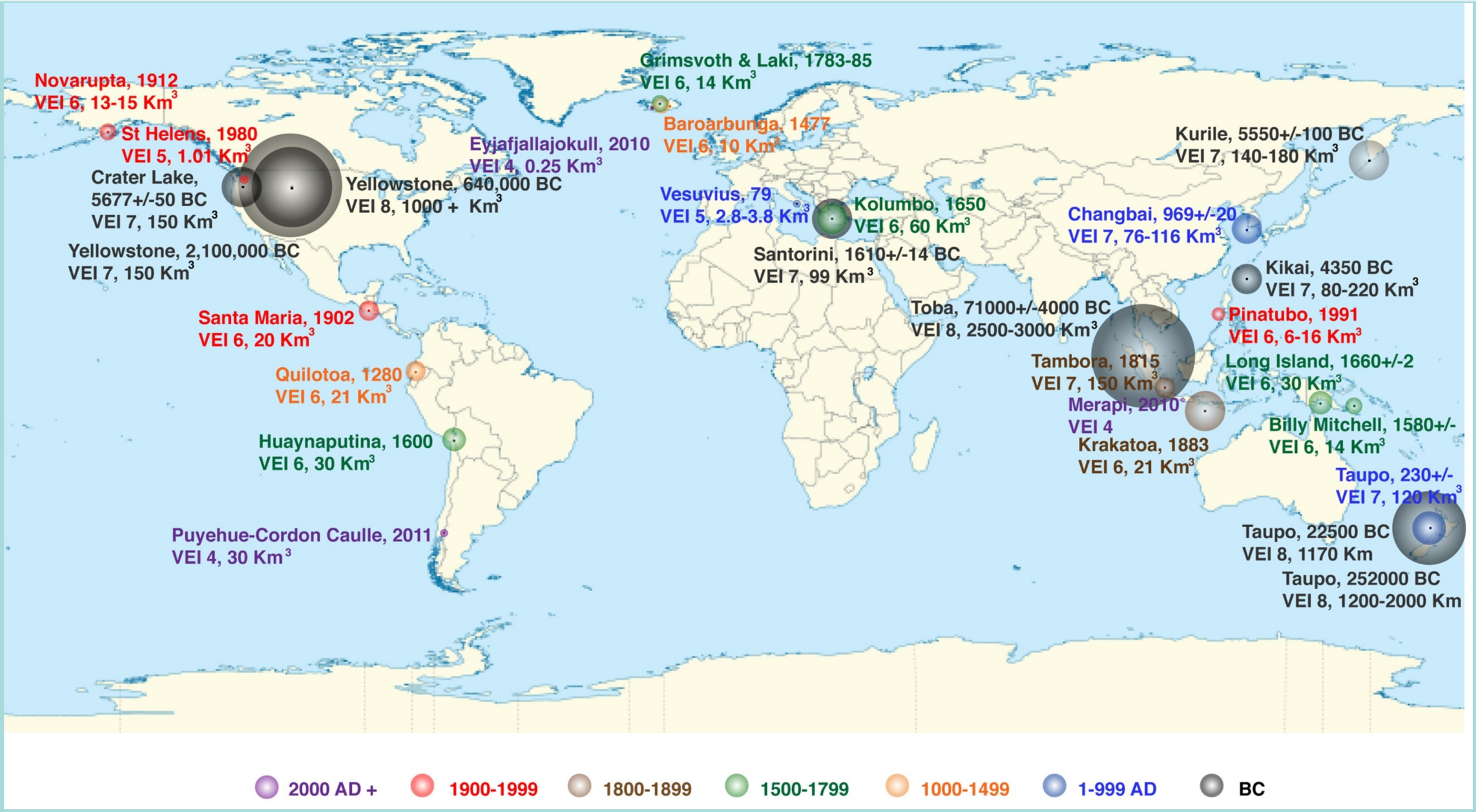

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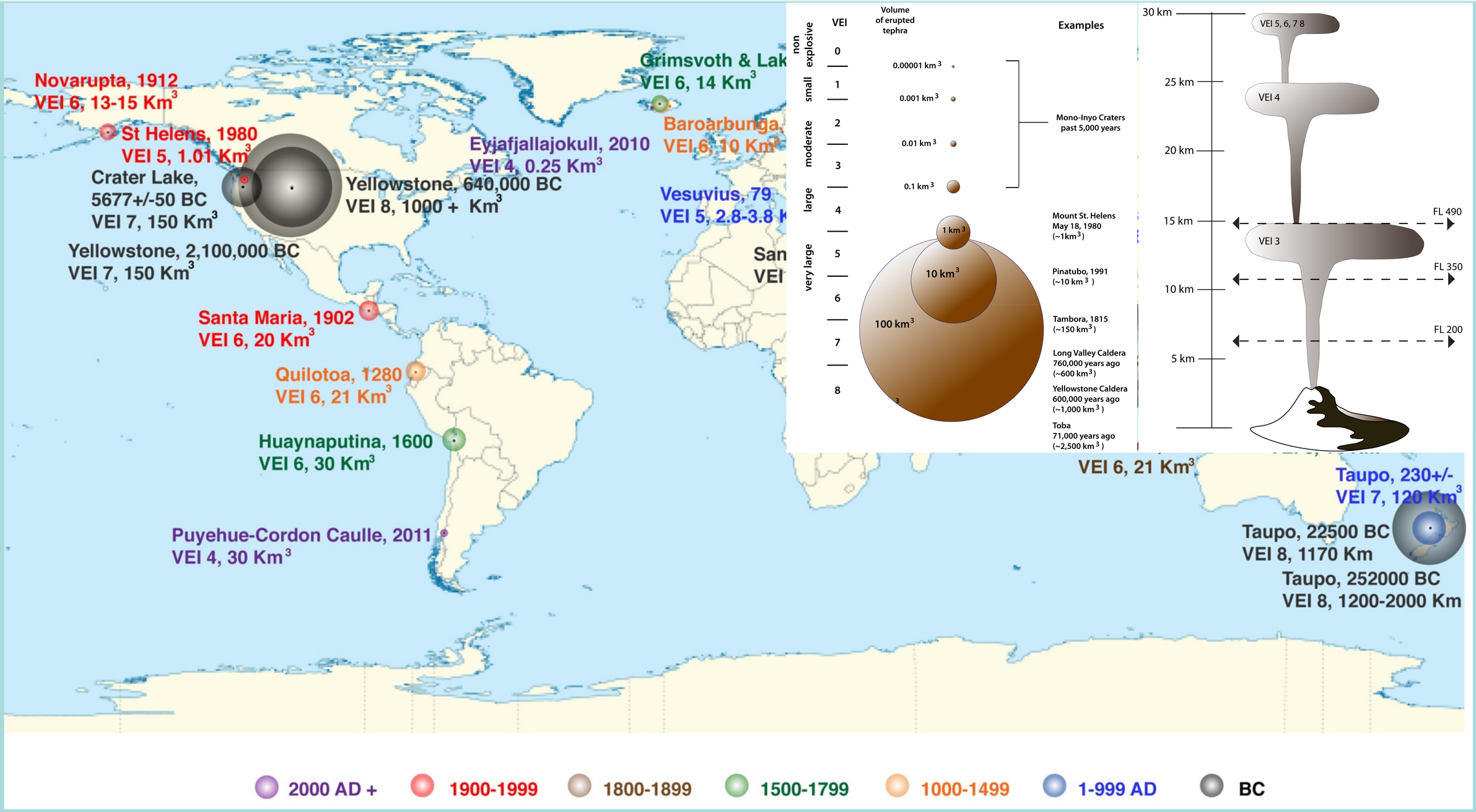

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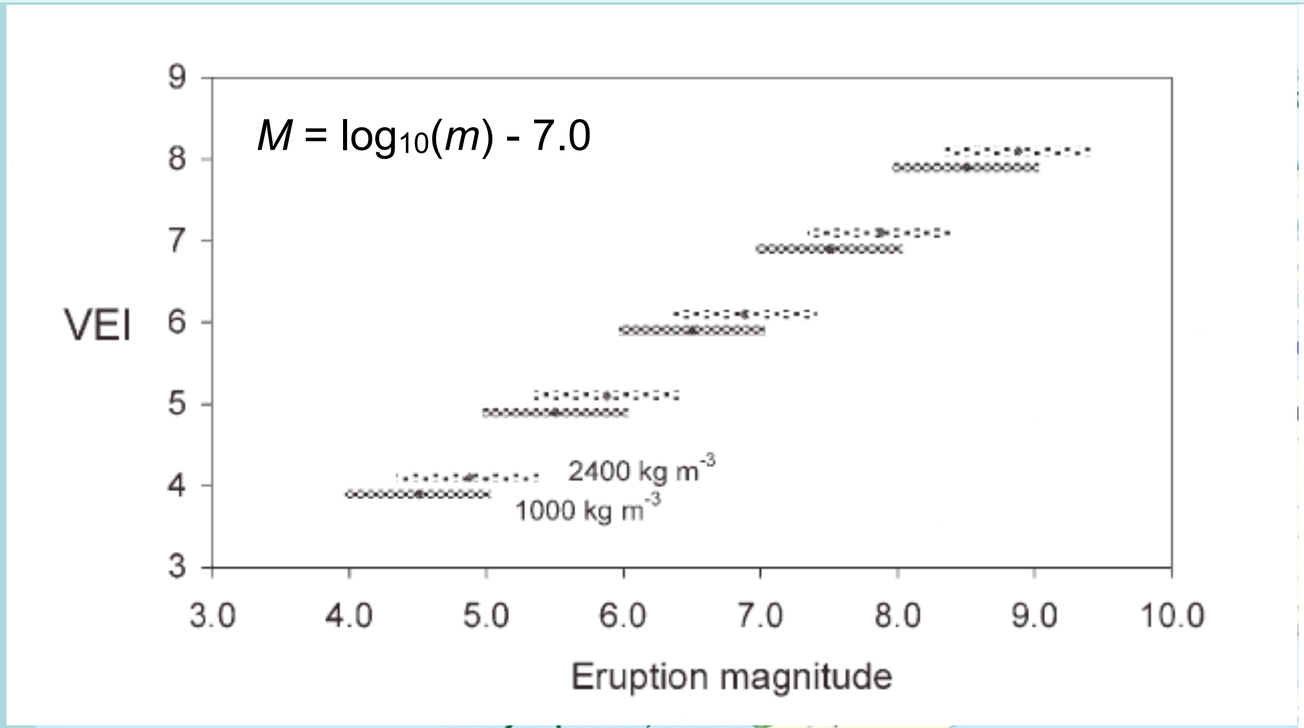


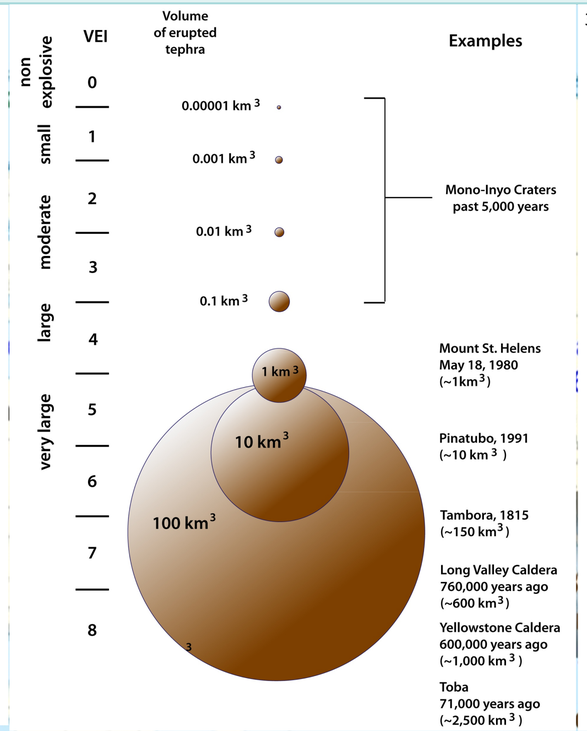


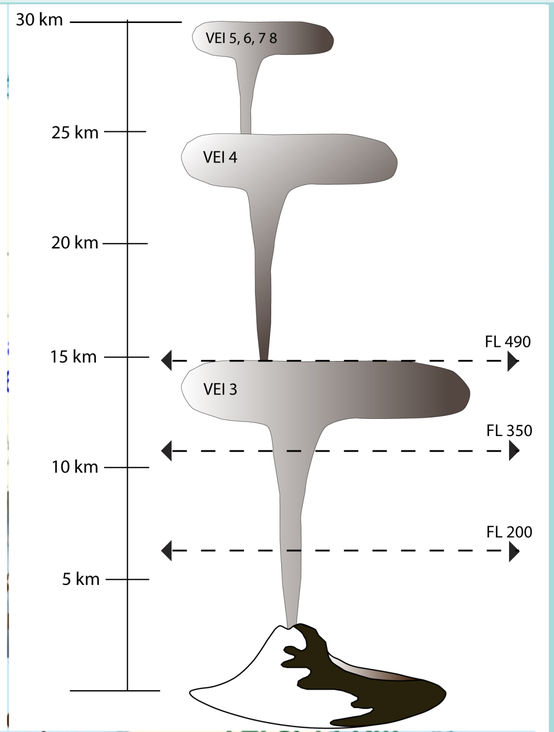


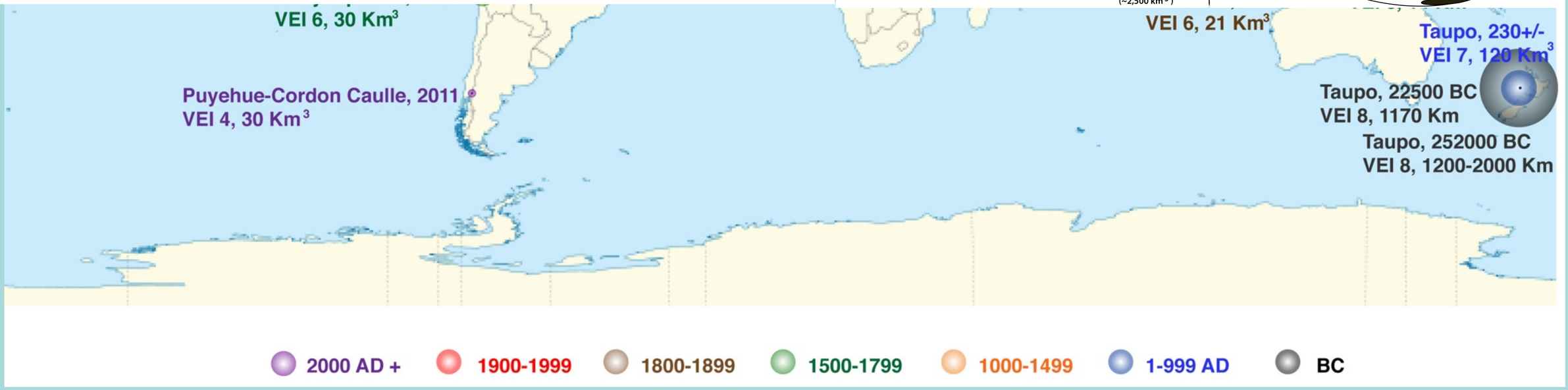

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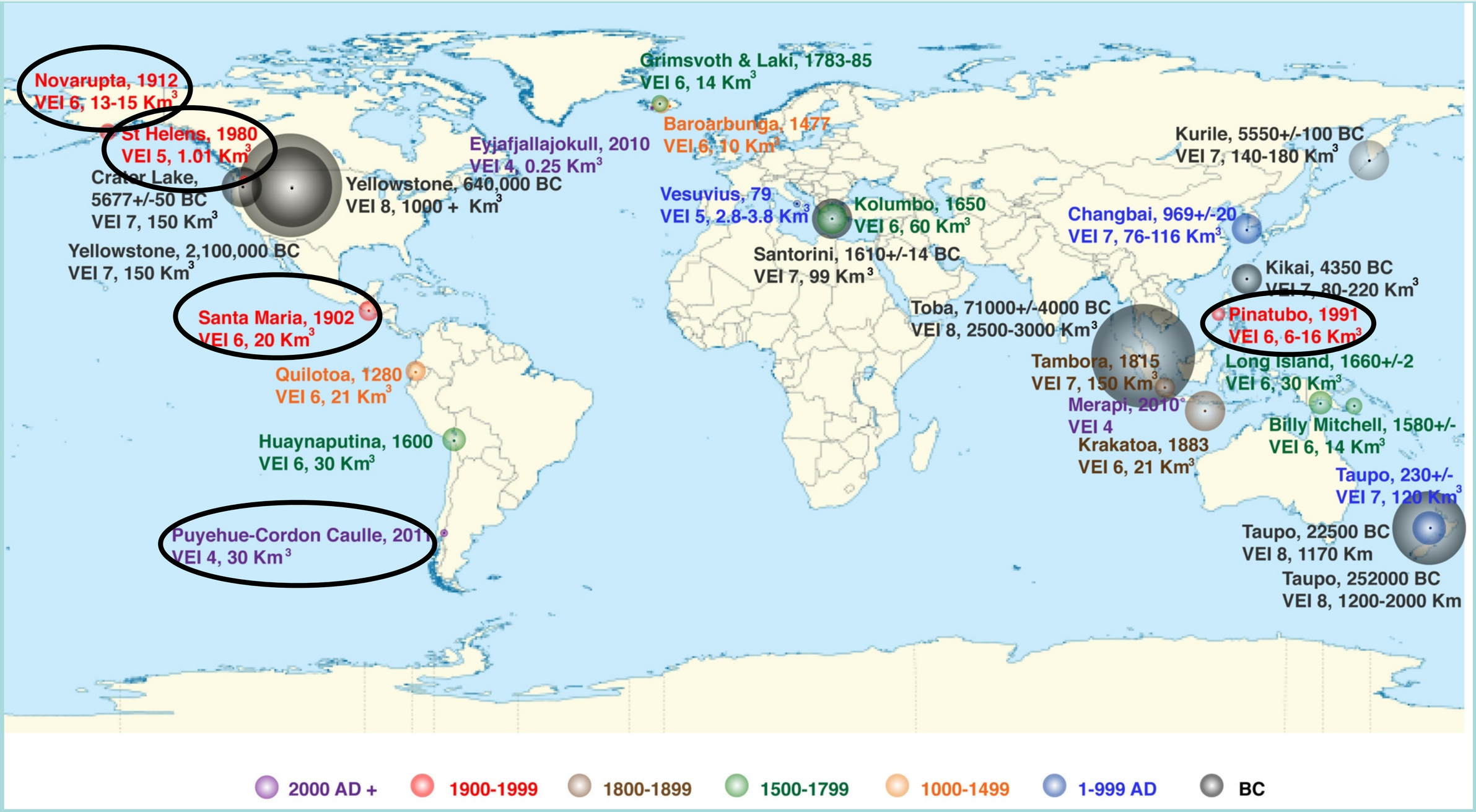

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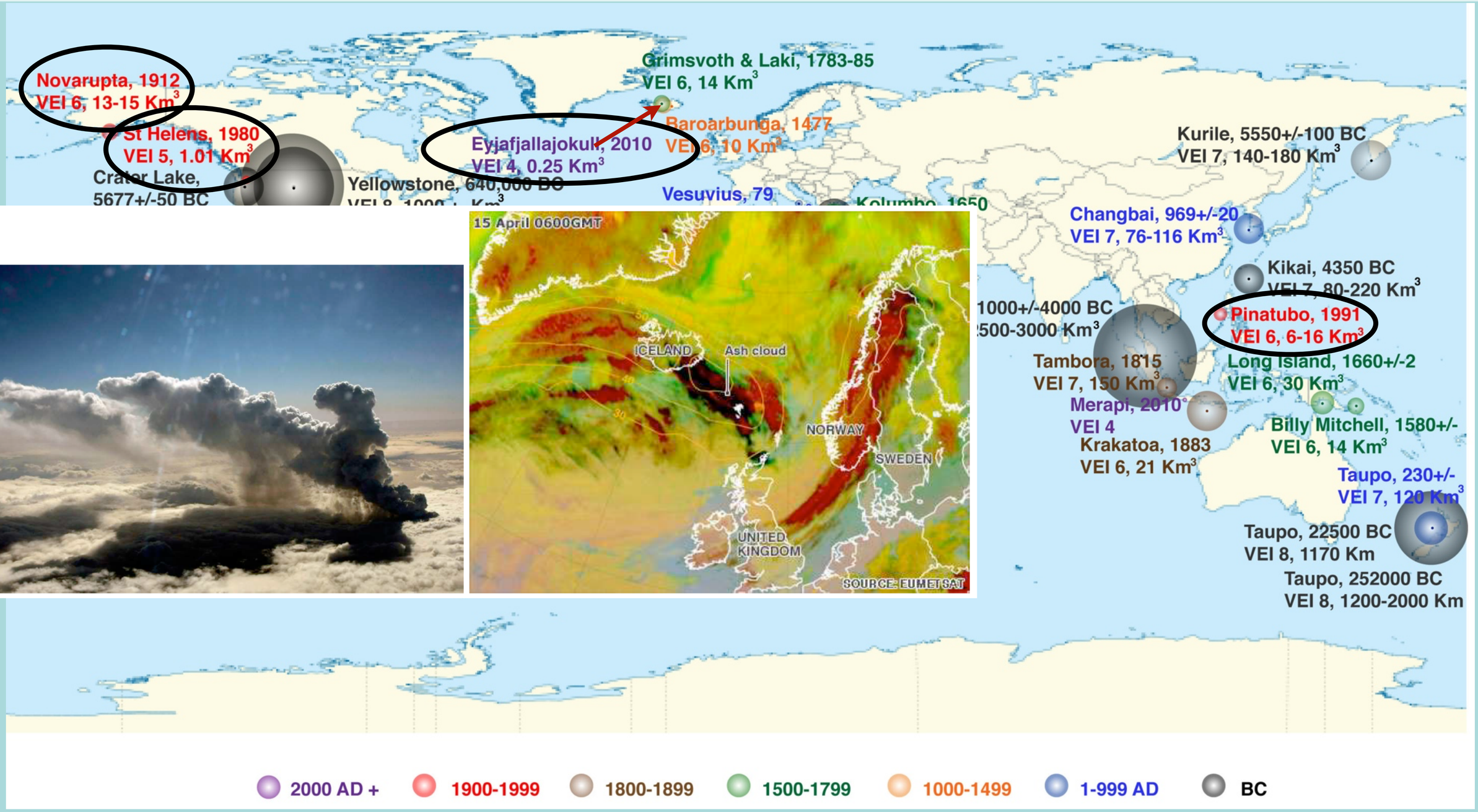

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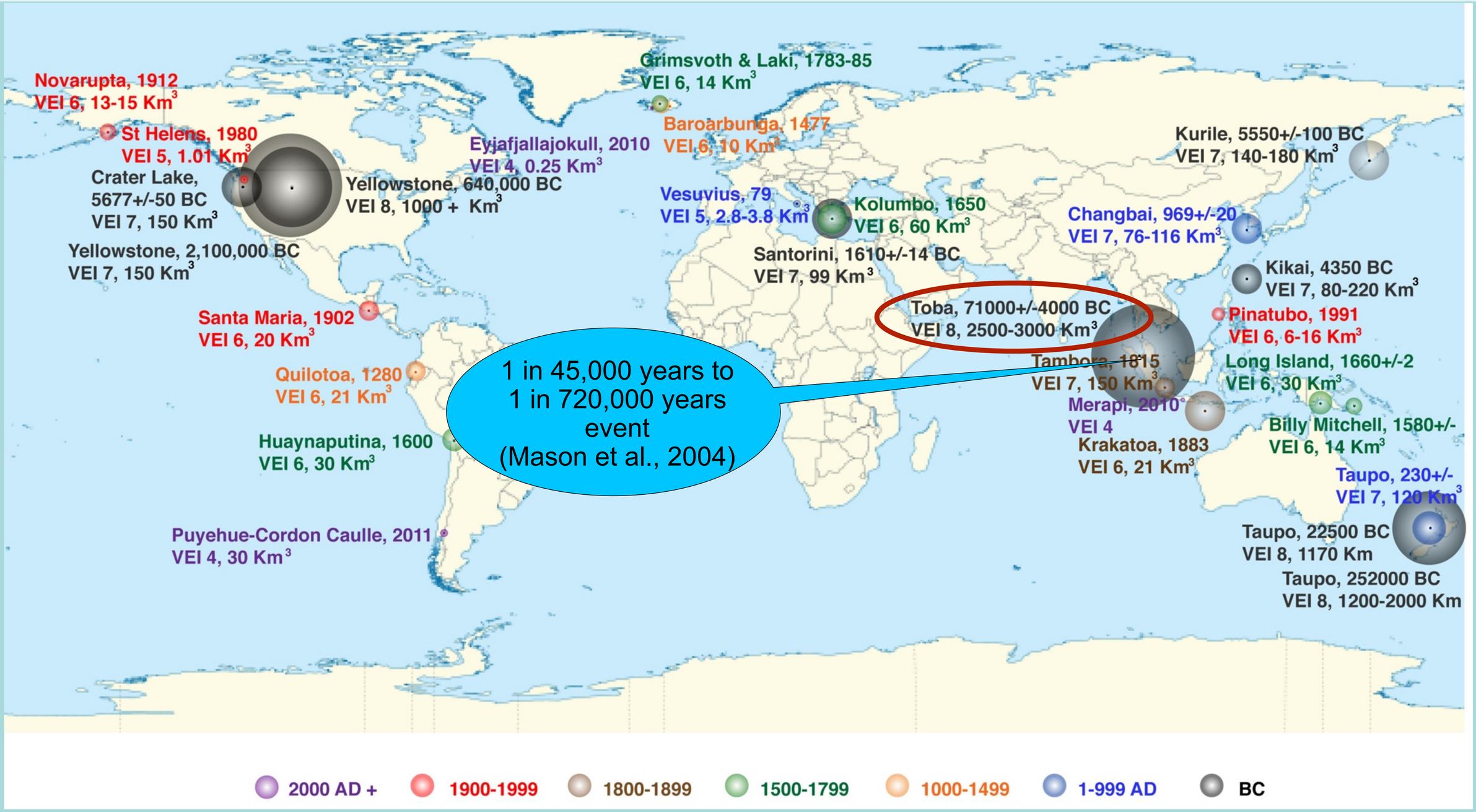

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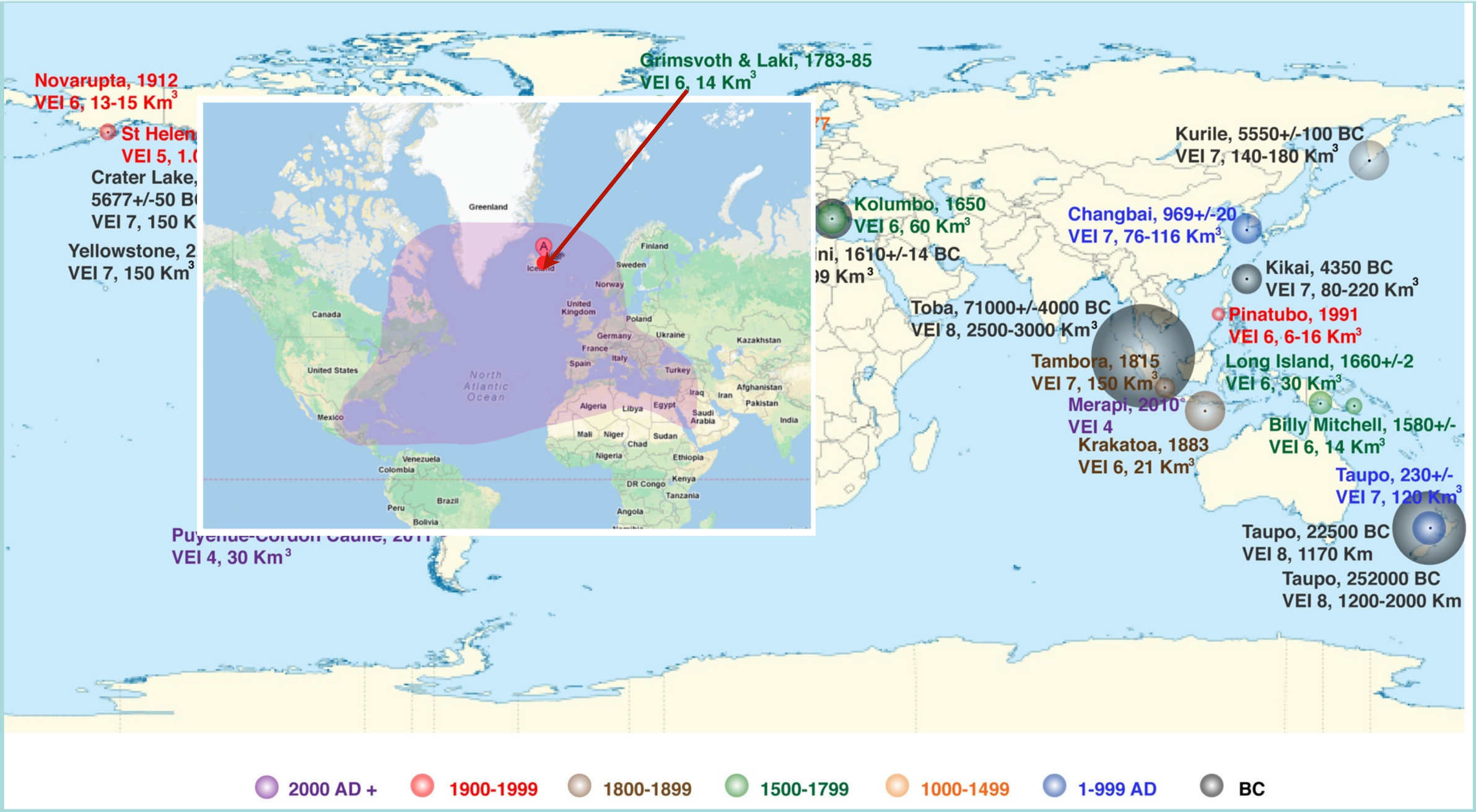

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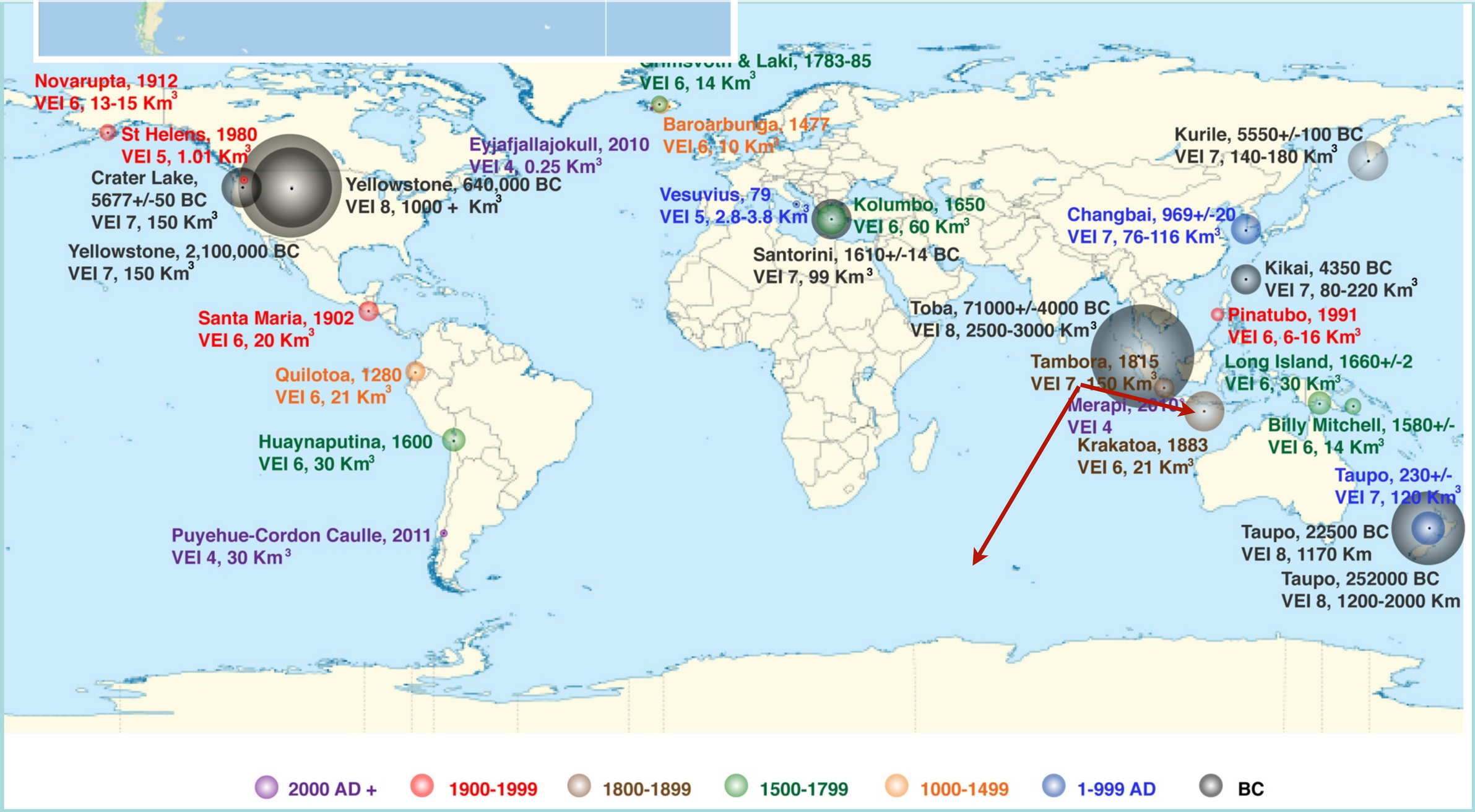

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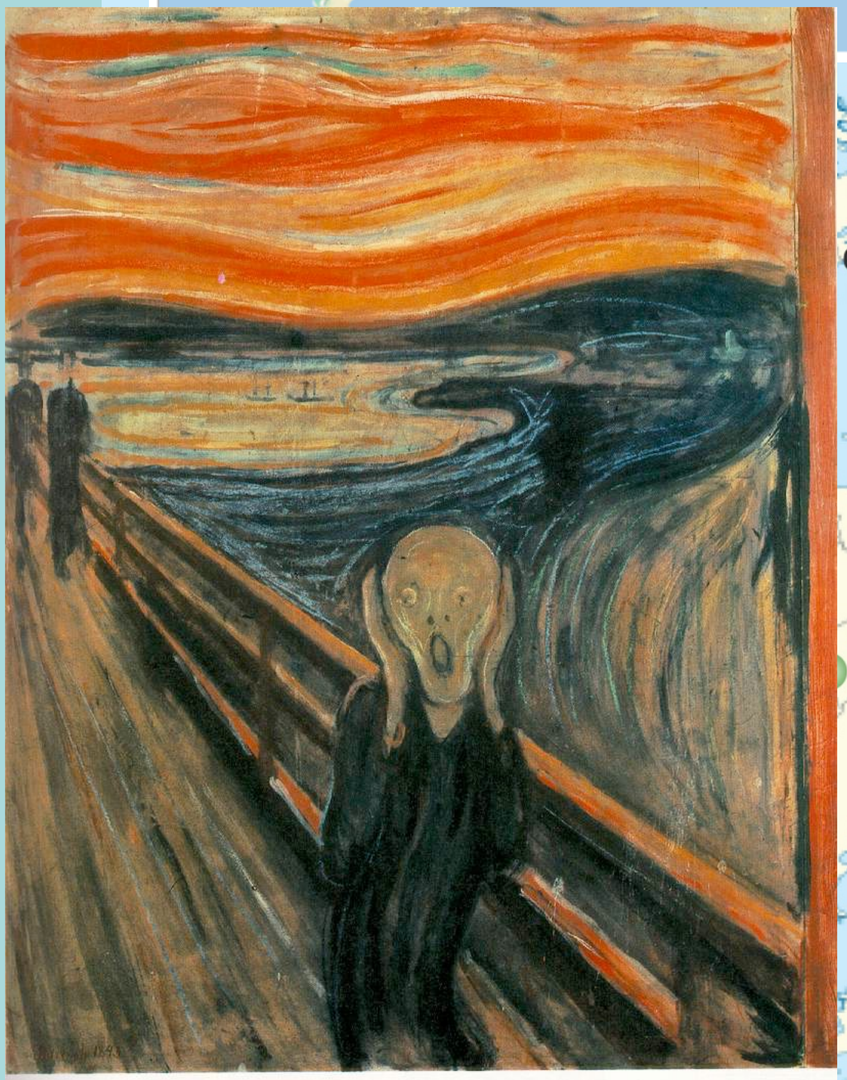

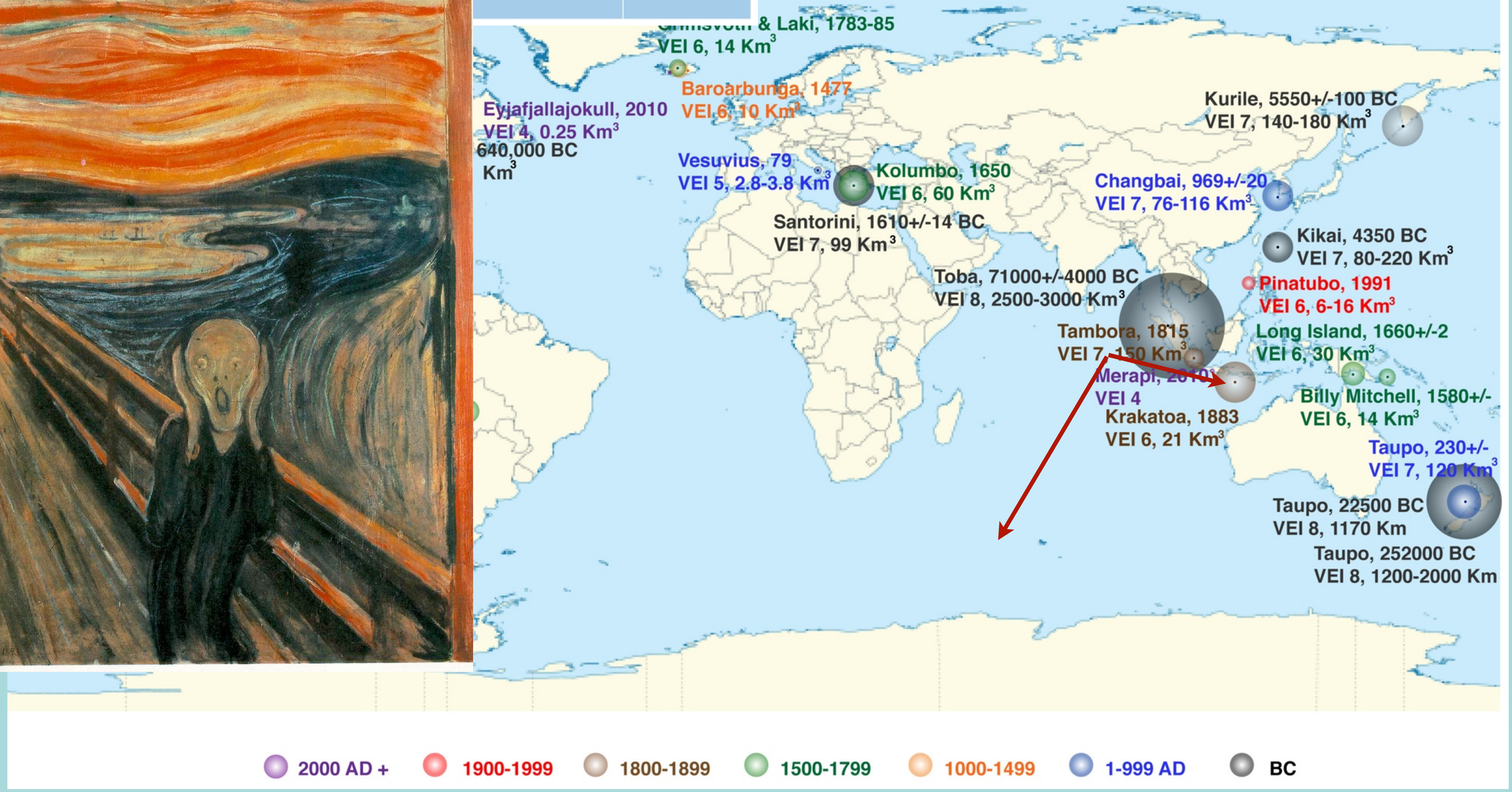

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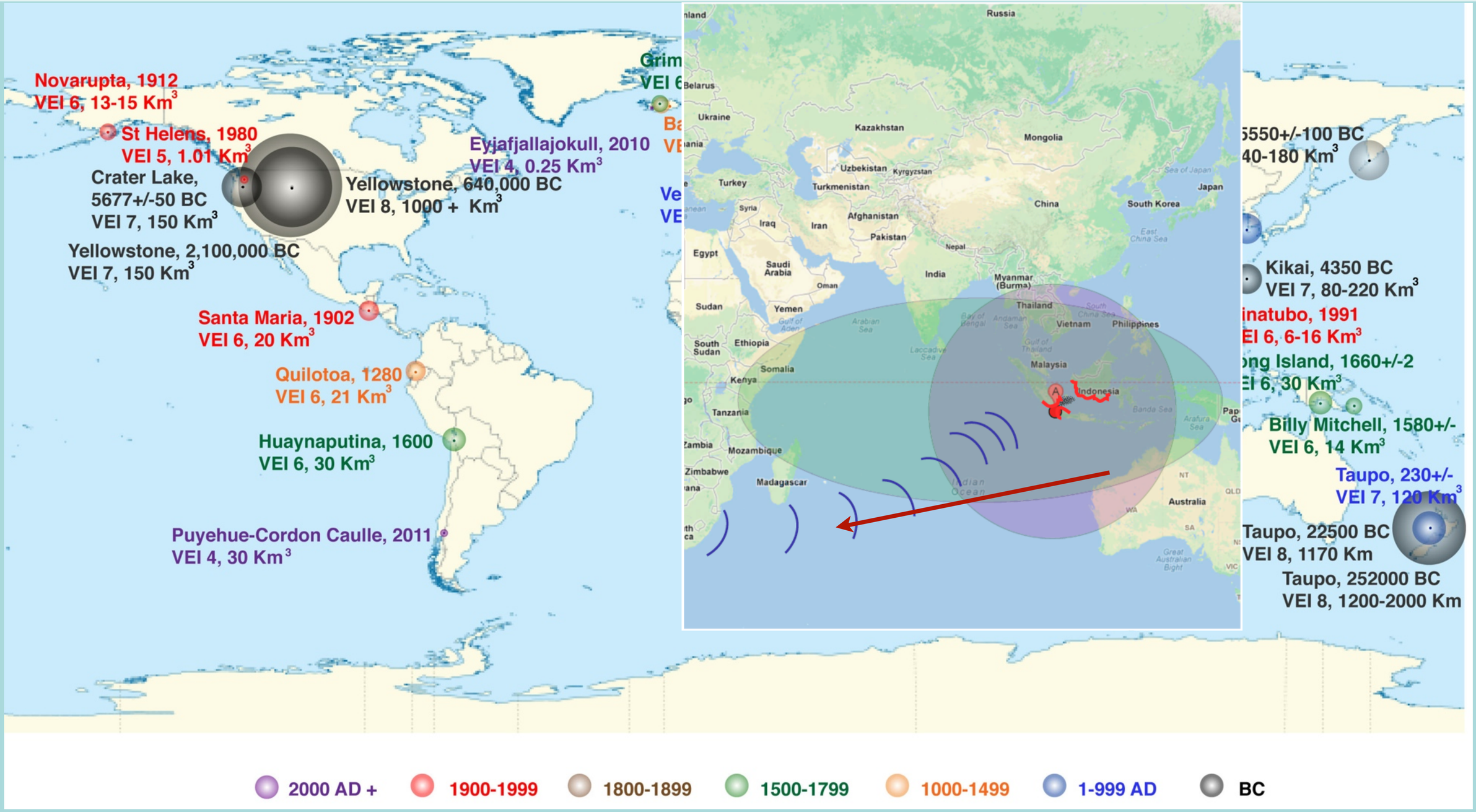

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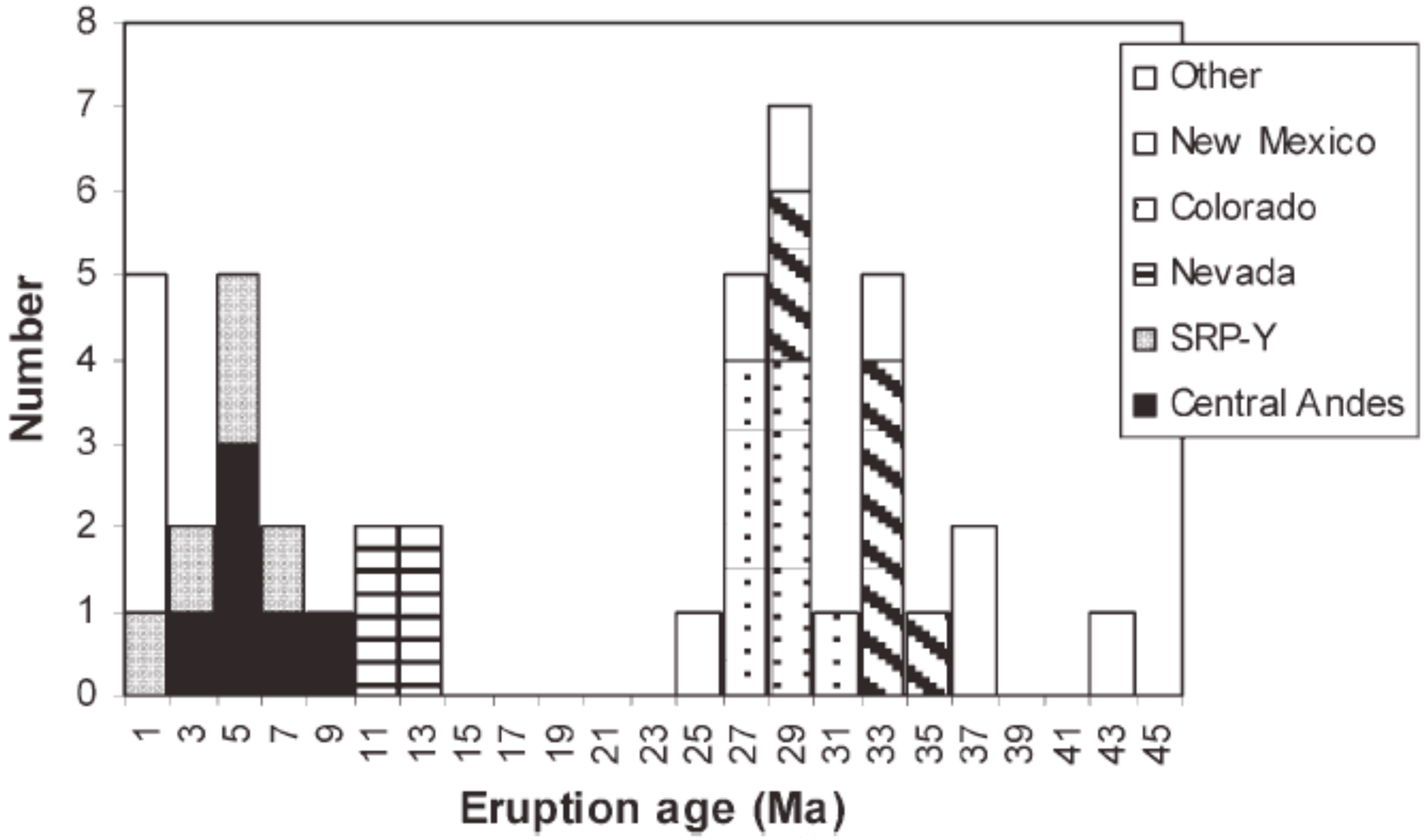
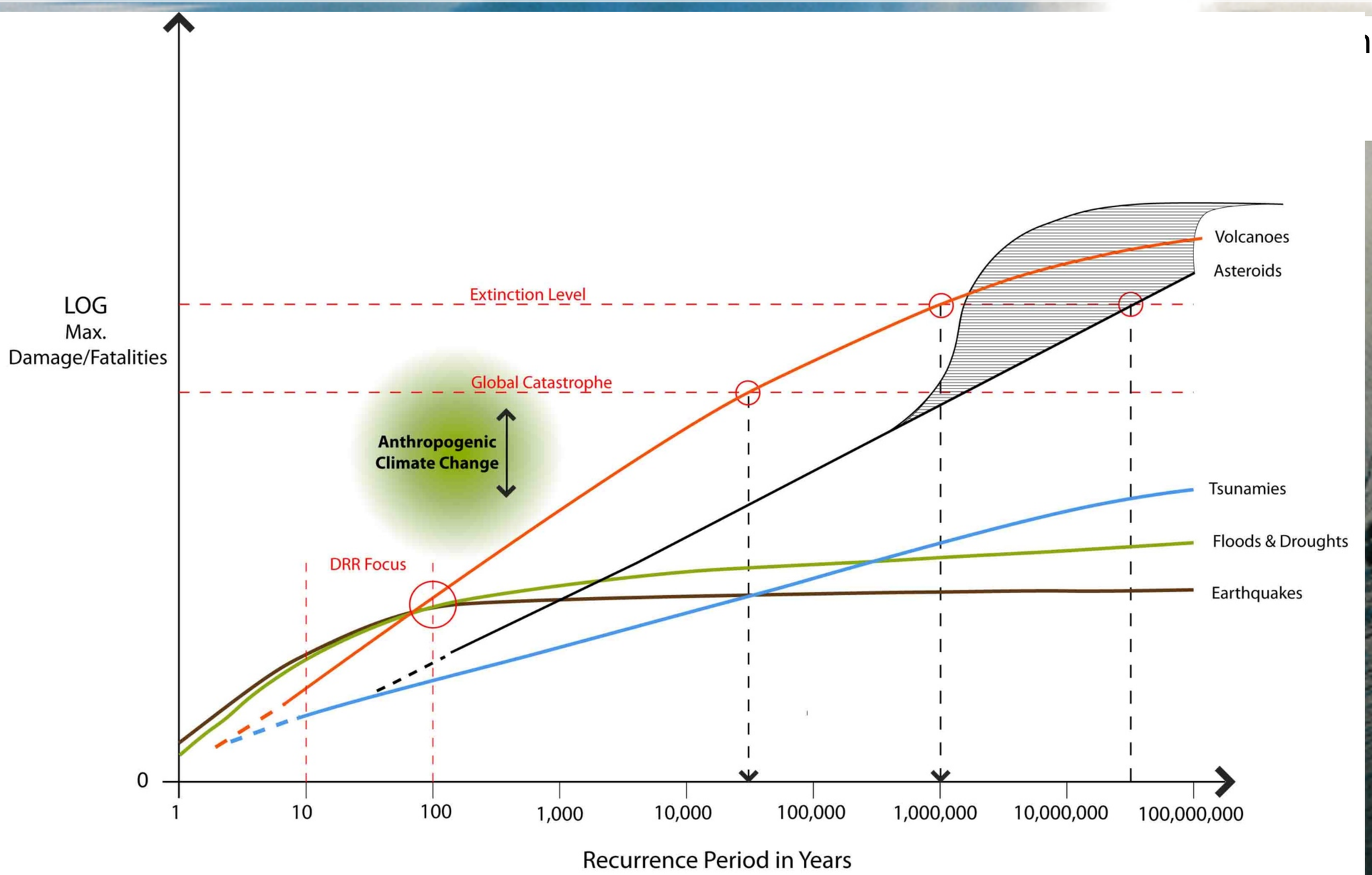


# GEOHAZARDS: The Big Picture

VEI 8 / M … time
- 1.4 eve
- largest



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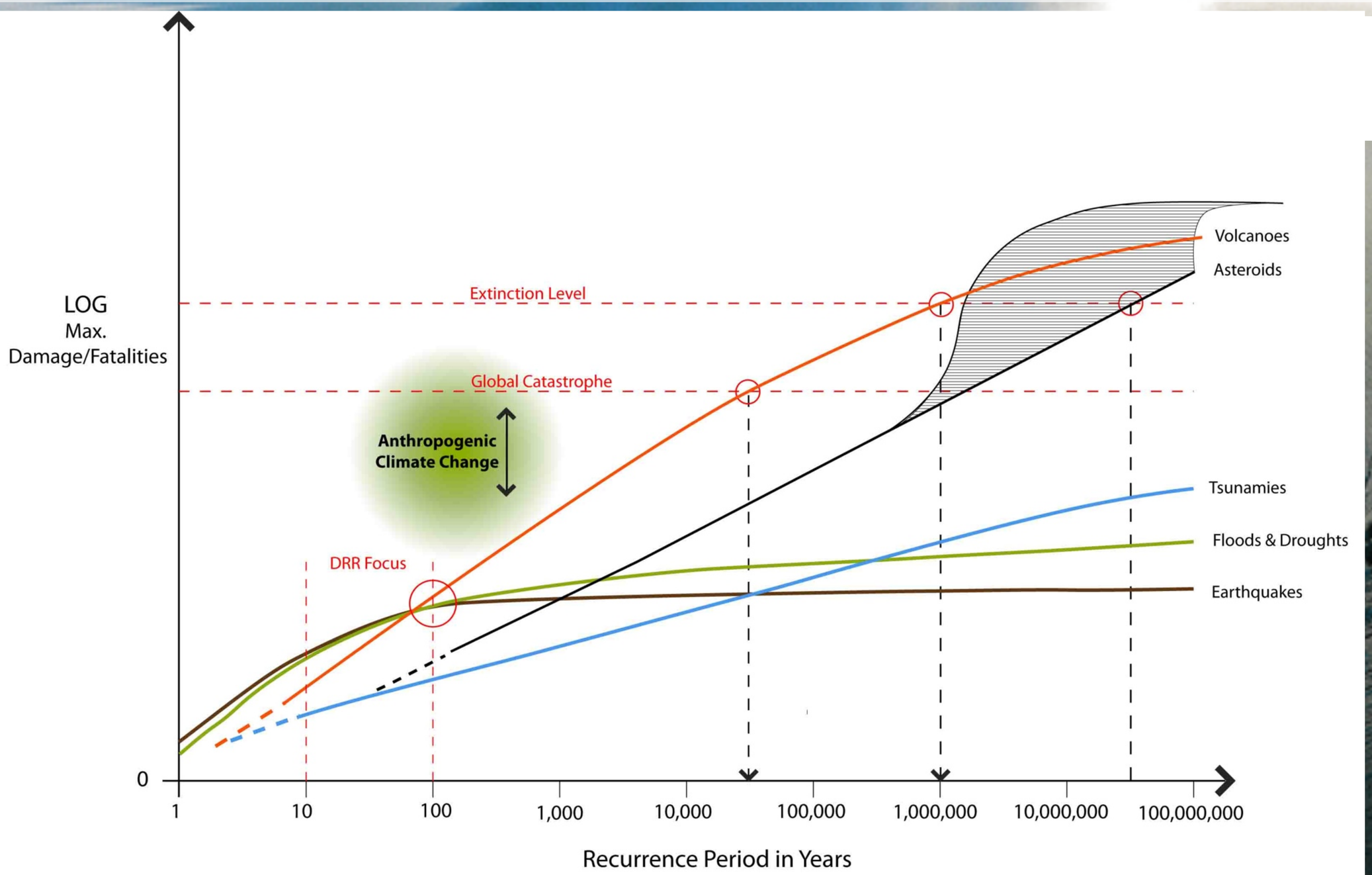

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VEI 8 / M 8:
- 1.4 events/Ma to 22 events/Ma
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VEI 7 / M 7:
- on timescales of ~100 ka, M7-M8 eruptions greater energy release than the largest expected impactors
- M7 are relatively frequent ...

# GEOHAZARDS: Volcanic Eruptions

| Year | Location | VEI | $km^3$ | Deaths | Comment |
|---|---|---|---|---|---|
| 2011 | Puyehue-Cordon Caulle, Chile | 4 | 30 | | |
| 2010 | Merapi, Indonesia | 4 | | 353 | MCD: pyroclastic flows |
| 2010 | Eyjafjallajökull, Iceland | 4 | 0.25 | 0 | Caused severe traffic distortions |
| 1991 | Pinatubo | 6 | 6-16 | 847 | MCD: failing roofs |
| 1985 | Nevado de la Ruiz, Colombia | 3 | 0.03 | 25,000 | MCD: Lahar |
| 1980 | St Helens | 5 | 1 | 57 | |
| 1919 | Kelut, Indonesia | | | 5,100 | MCD: mudflows |
| 1912 | Novarupta, Alaska | 6 | 15-30 | unknown | |
| 1902 | Mount Pelee, Martinique | 4 | >0.1 | 29,000 | MCD: pyroclastic flow |
| 1902 | Santa Maria, Guatemala | 6 | 20 | >5,000 | |
| 1883 | Krakatau, Indonesia | 6 | 21 | 36,000 | MCD: tsunami |
| 1882 | Galunggung, Indonesia | 5 | | 4,000 | MCD: mudflows |
| 1815 | Tambora, Indonesia | 7 | 150 | 92,000 | MCD: starvation |
| 1783-85 | Laki and Grimsvoth, Iceland | 6 | 14 | 9,400 | MCD: famine and fluorine poisoning; deaths are for Iceland only |
| 1660 | Long Island | 6 | 30 | | |
| 1650 | Kolombo | 6 | 60 | | |
| 1631 | Vesuvius, Italy | | | 3,500 | MCD: mud and lava flows |
| 1600 | Huaynaputina | 6 | 30 | | |
| 1580 | Billy Mitchell | 6 | 14 | | |
| 1477 | Baroarbunga, Iceland | 6 | 10 | | |
| 1280 | Quilotoa | 6 | 21 | | |
| 969 ± 20 | Changbai, China | 7 | 76-116 | | |
| 230 | Taupo | 7 | 120 | | |
| 79 | Vesuvius, Italy | 5 | 2.8-3.8 | 3,400 | MCD: Ash flows |
| 1610 ± 14 BC | Santorini | 7 | 99 | | |
| 4350 BP | Kikai | 7 | 80-220 | | |
| 5550 ± 100 BC | Kurile | 7 | 140-150 | | |
| 5677 ± 50 BC | Crater Lake | 7 | 150 | | |
| 26500 BC | Oruanui, New Zealand | 8 | | | |
| 73000 ± 4000 BP | Toba, Indonesia | 8 | 2500-3000 | | Killed up to 60% of the global population; MCD: starvation |
| 640000 BP | Yellowstone | 8 | 1000 | | |

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n the largest expected impactors

VEI 7 / M 7:
- at least seven events in the Holocene
- ~5% - 10% chance that this will happen in the 21st century
- Will have very different impact than previously

# GEOHAZARDS: Volcanic Eruptions and Modern Society

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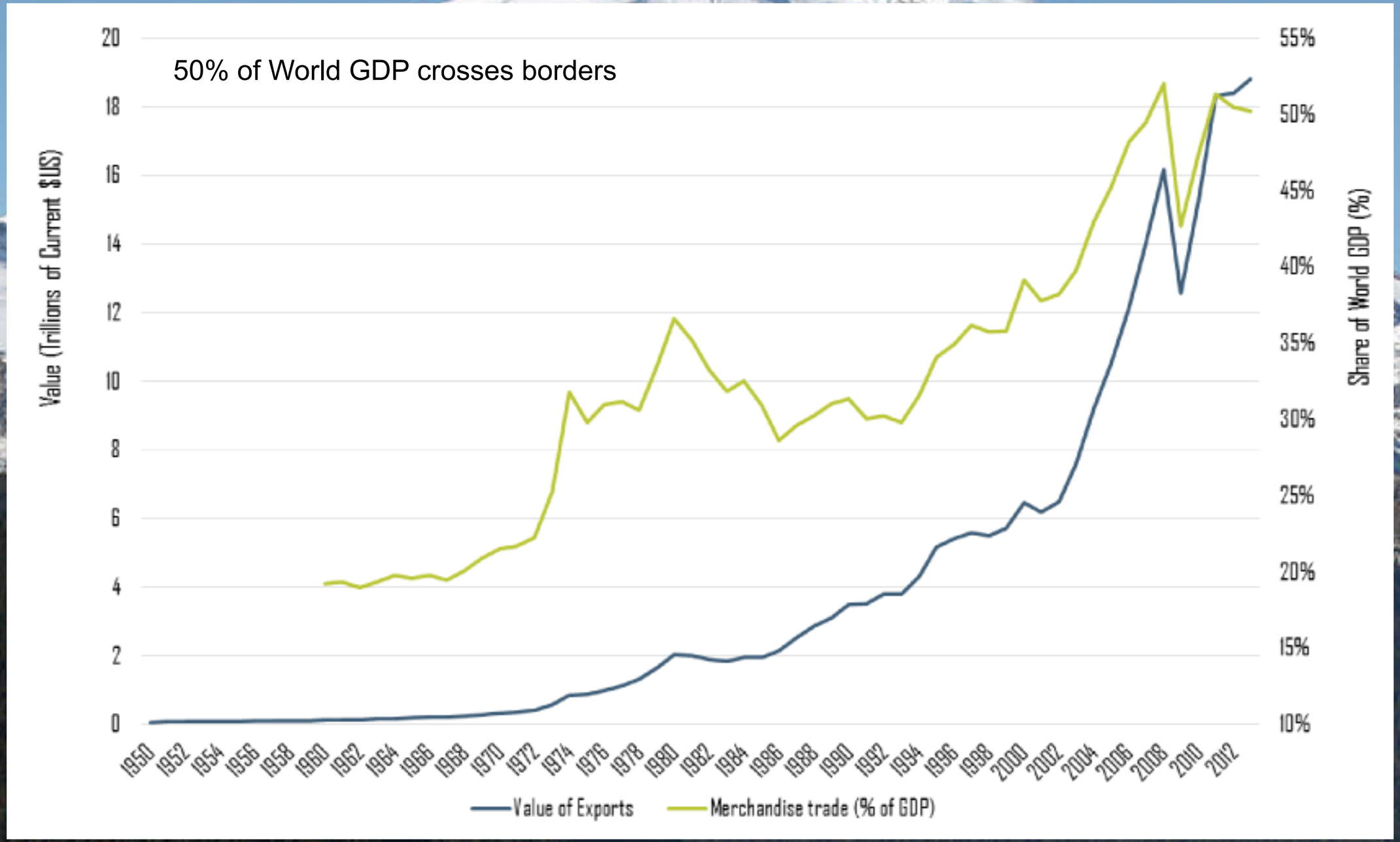
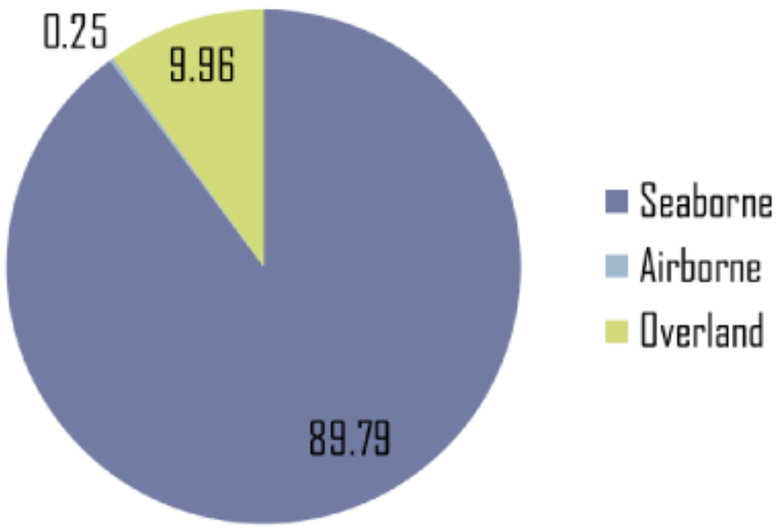
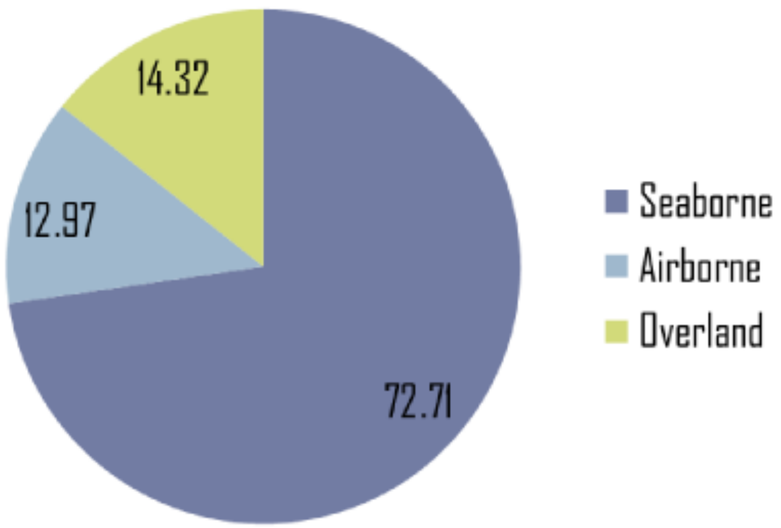
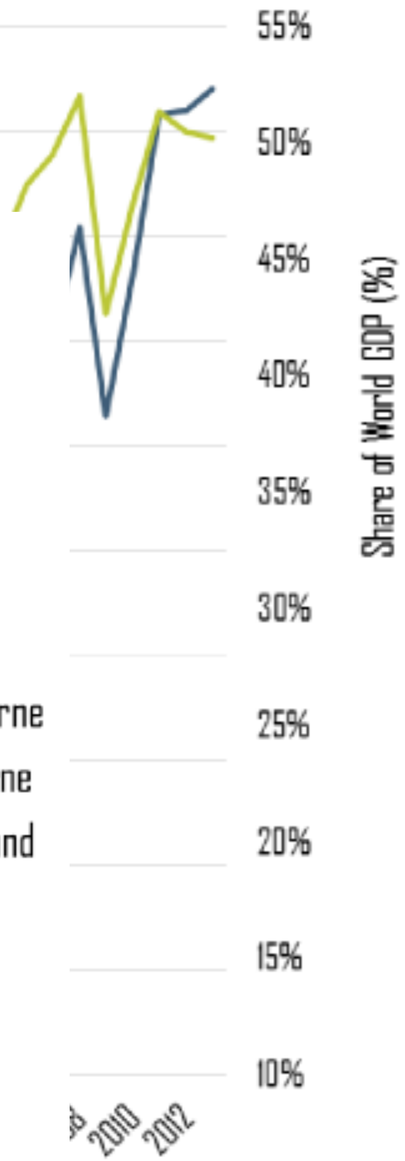


# GEOHAZARDS: Volcanic Eruptions and Modern Society

50% of World GDP crosses borders



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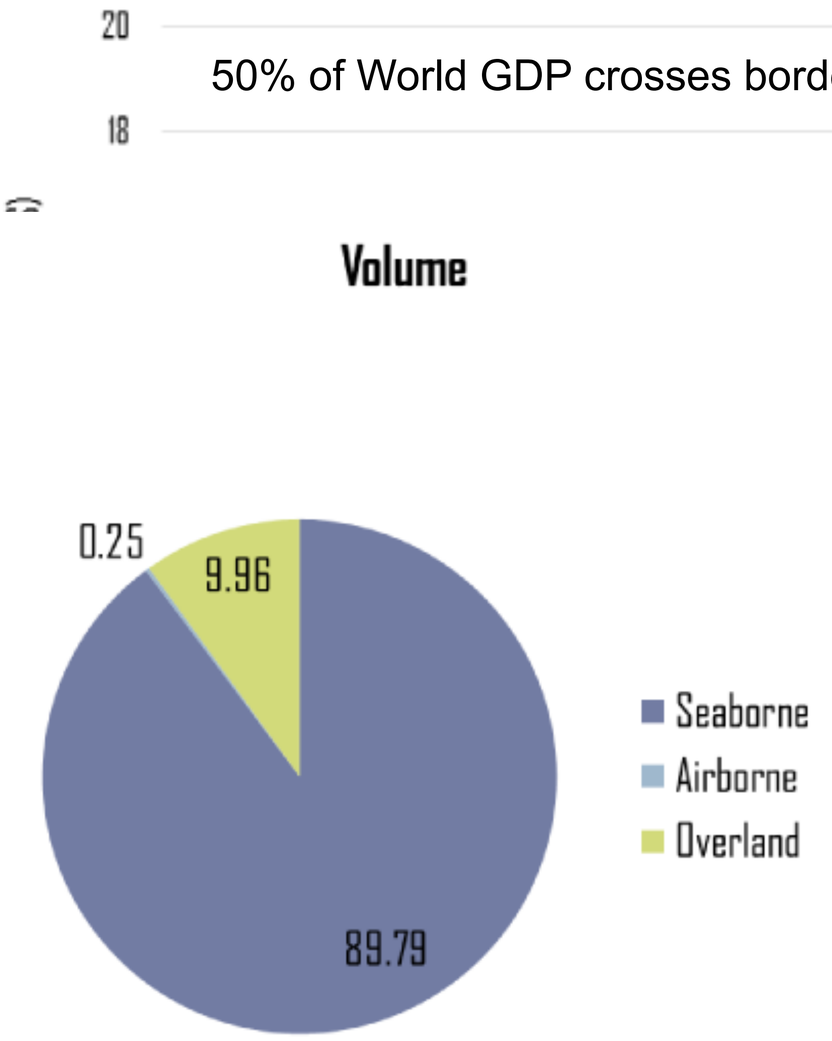


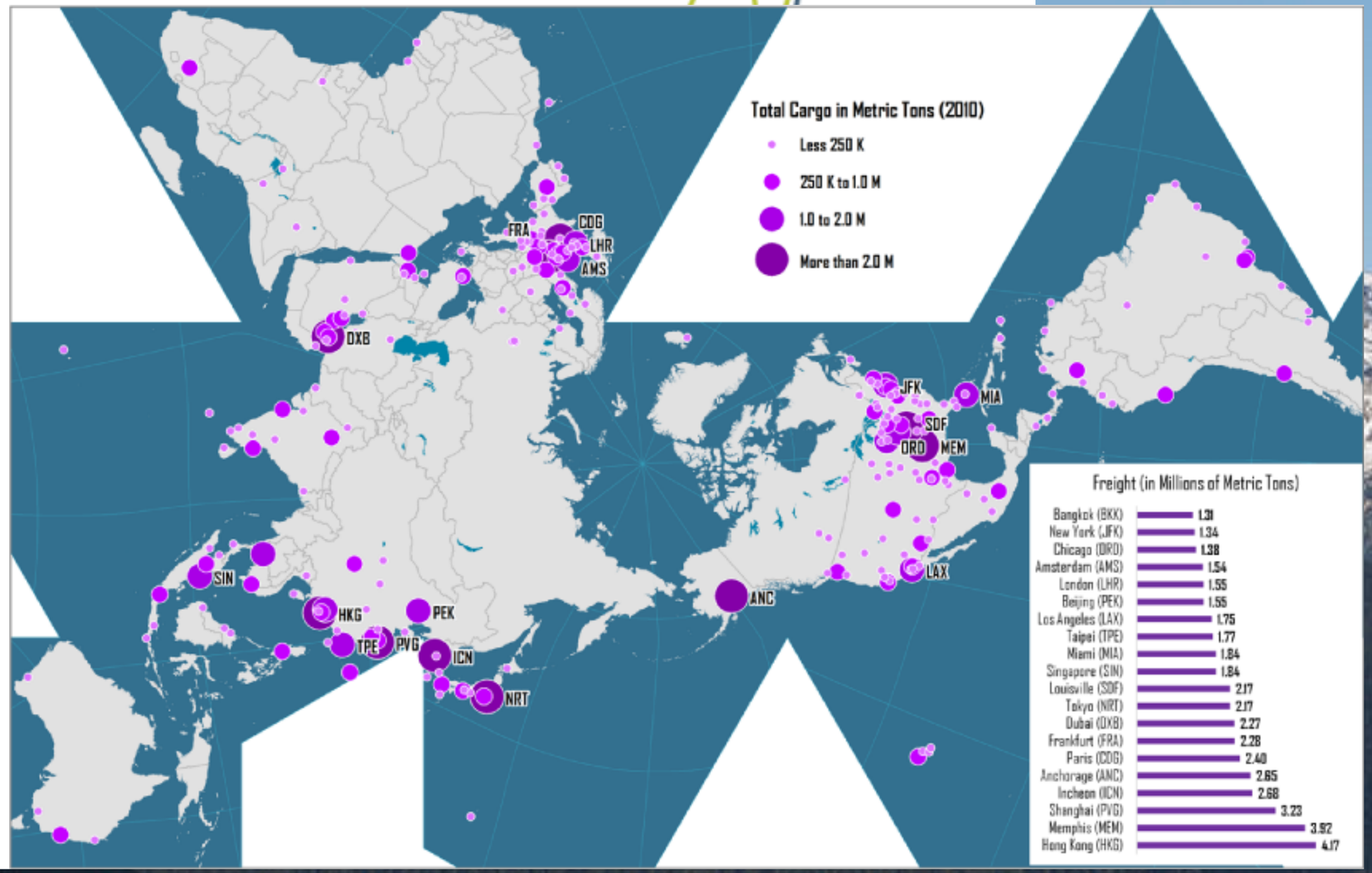

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Agricultural Water Stress

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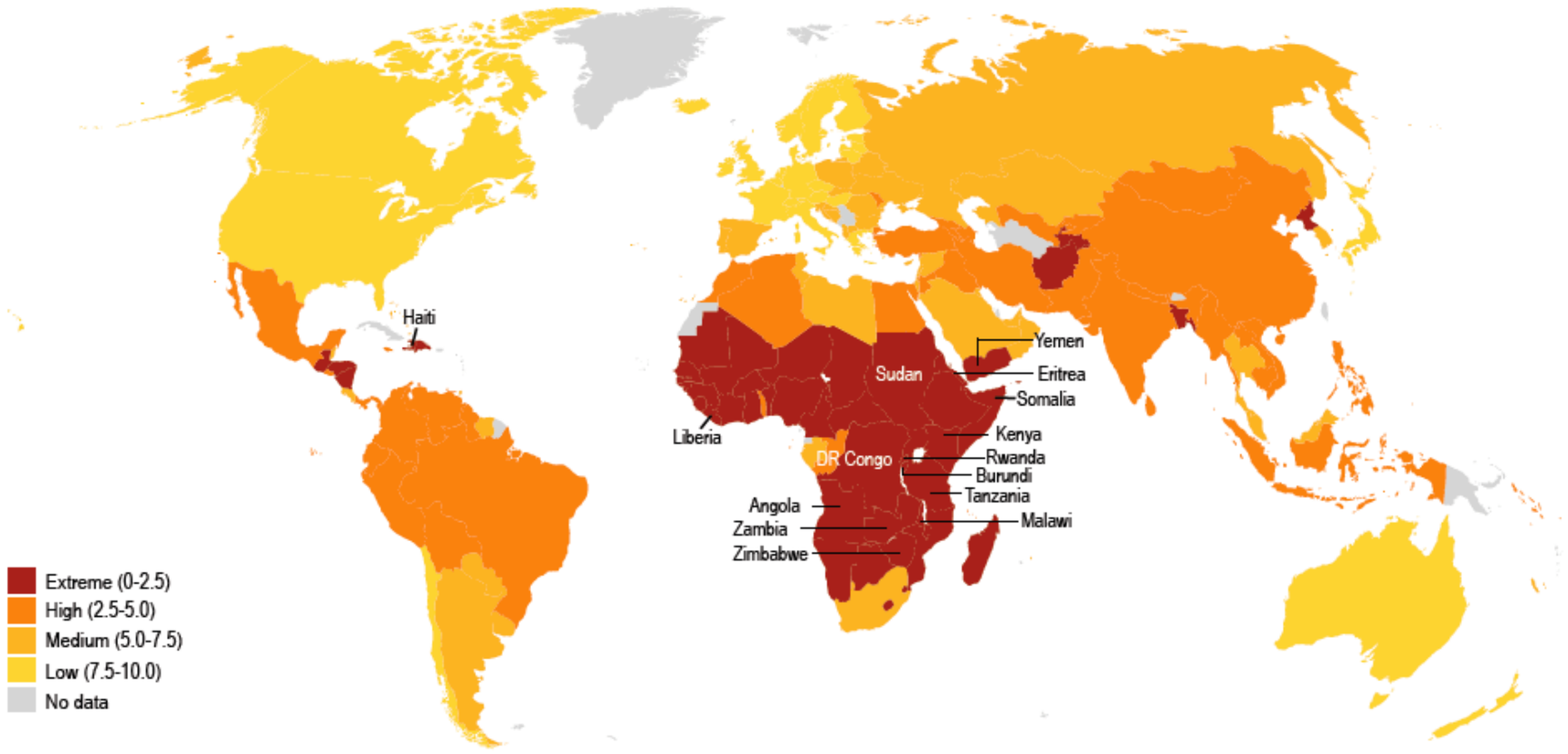
## Maplecroft's global map of food security




**Food Security Index:** This map is the visual representation of the Maplecroft Food Security Index (FSI). The FSI evaluates the risk of food insecurity in 163 countries across the globe. It provides a quantitative assessment of the availability, stability and access to food supplies, as well as the nutritional outcomes that result from food insecurity. Each country is assigned an index score based on its performance across 18 key indicators, classified into four sub-indices. Four categories of risk have been identified based on the FSI value for each country – extreme risk (0.0-2.5), high risk (2.5-5.0), medium risk (5.0-7.5) and low risk (7.5-10.0).

Agricultural Water Stress

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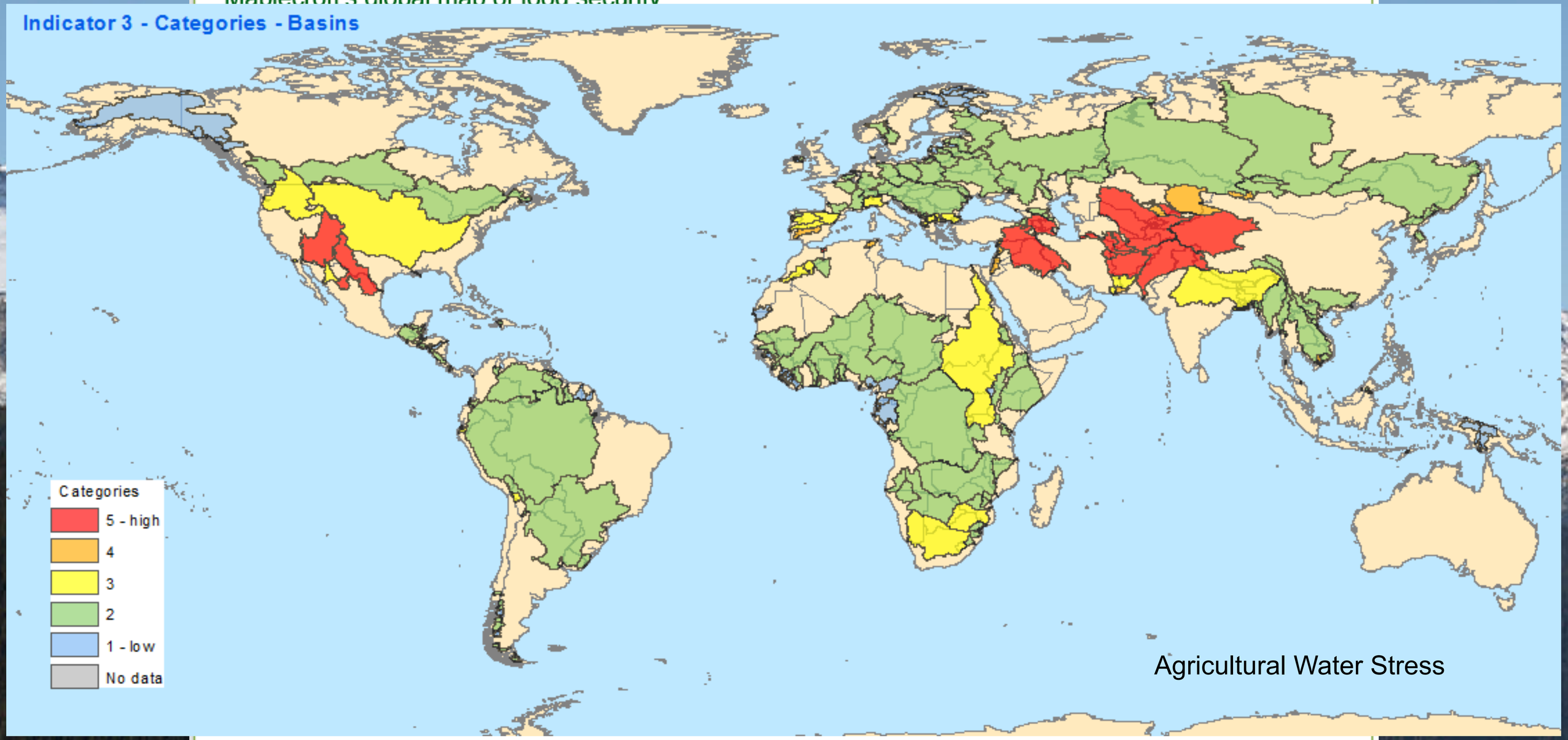

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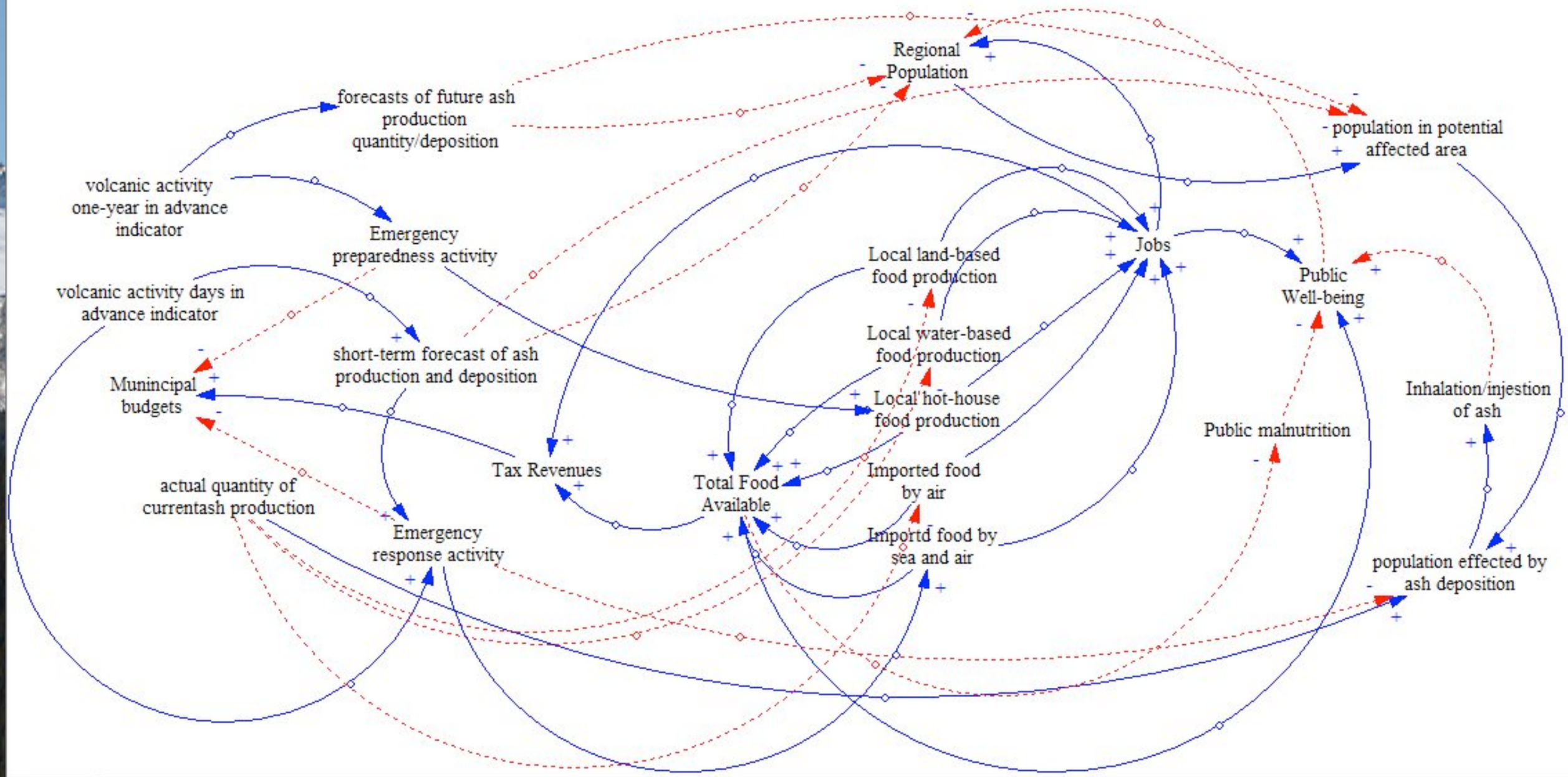
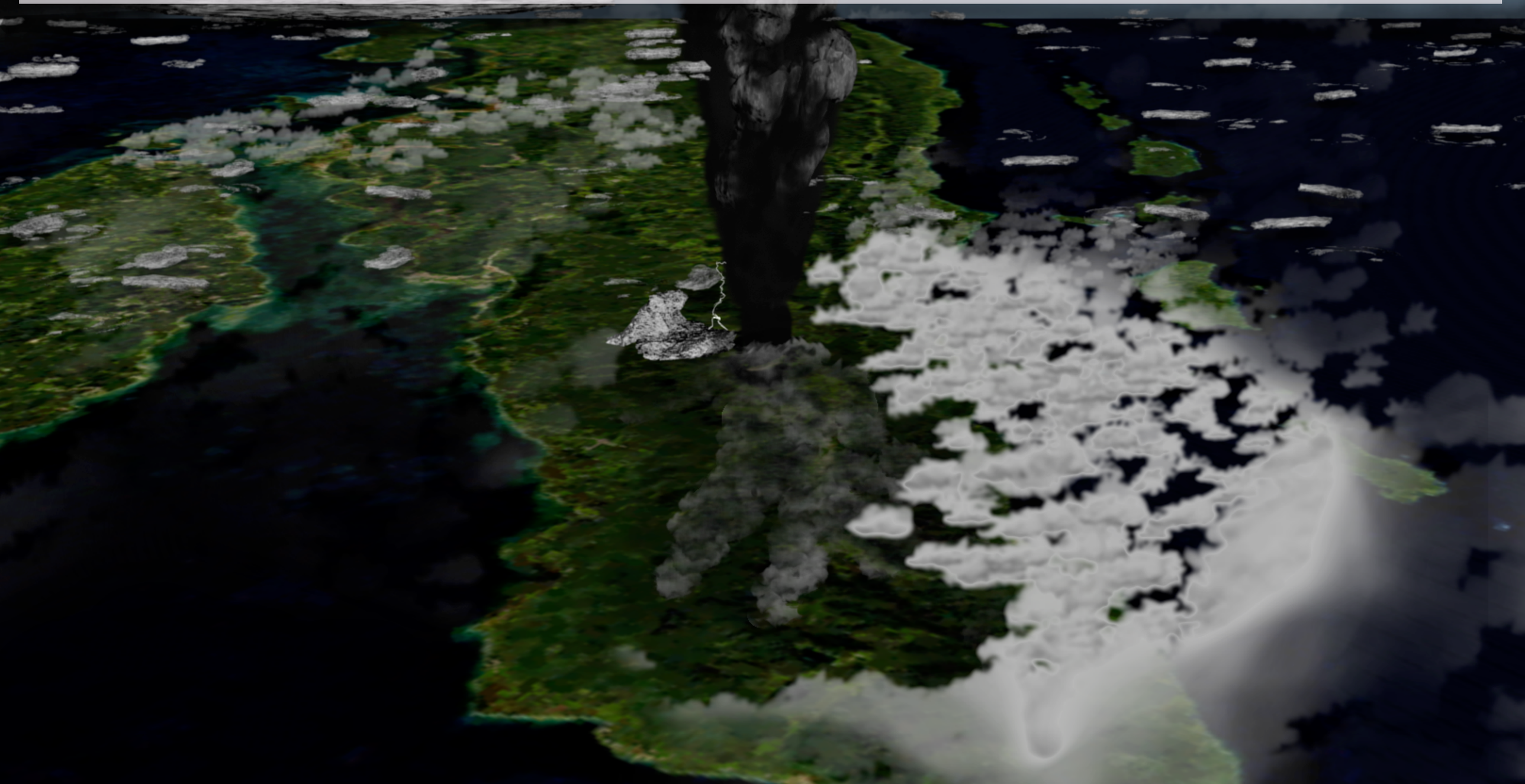


# Cost-Benefit Analysis



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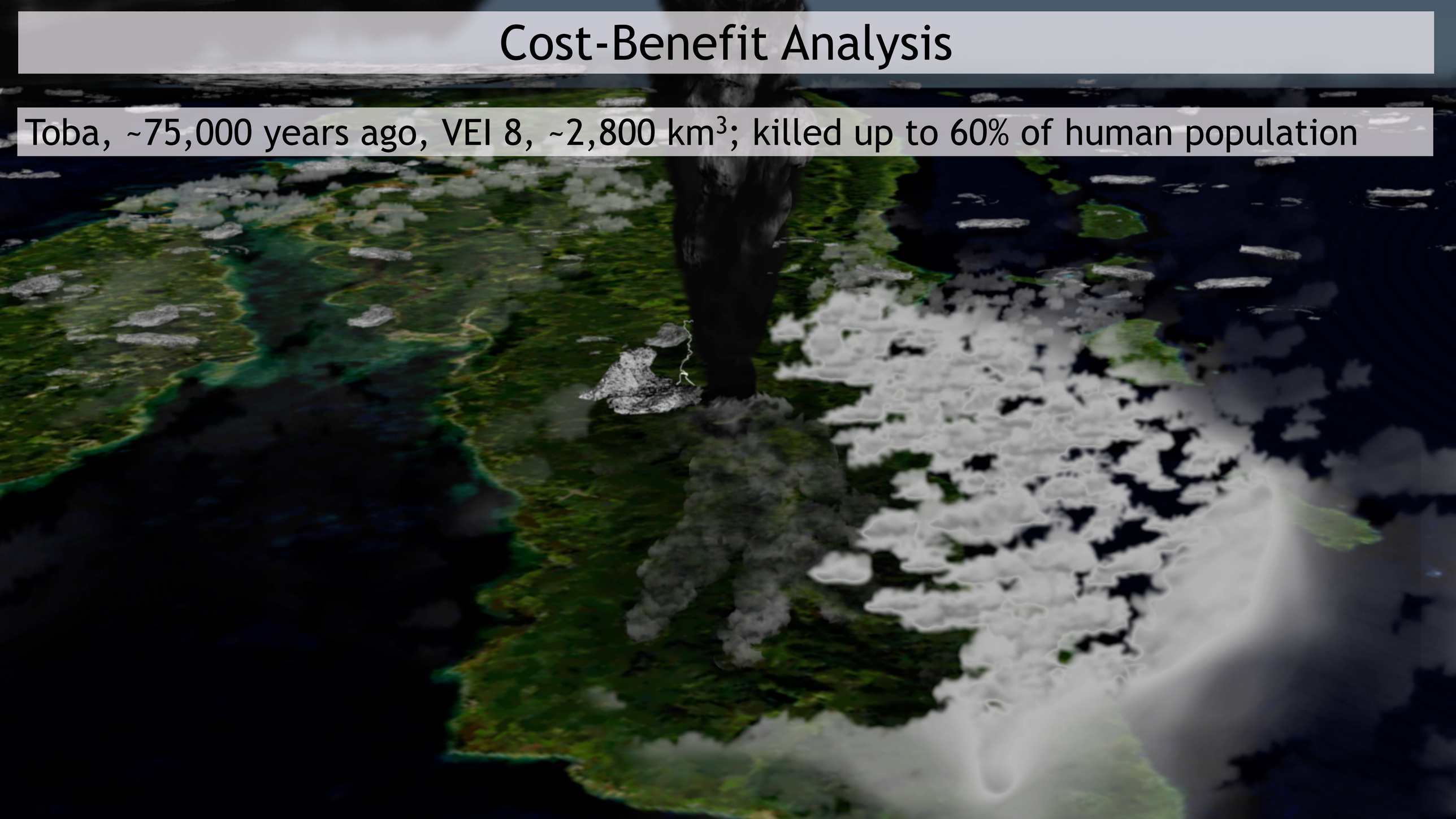

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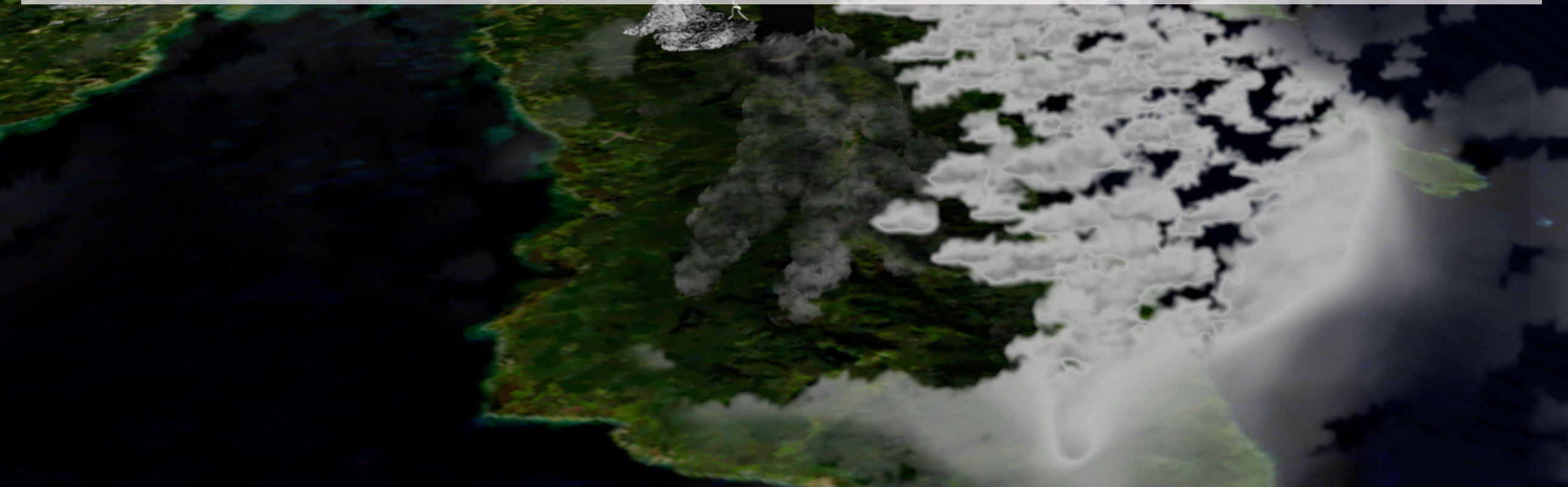

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We assume:
- 10% of global population is killed if volcano eruption comes as a surprise

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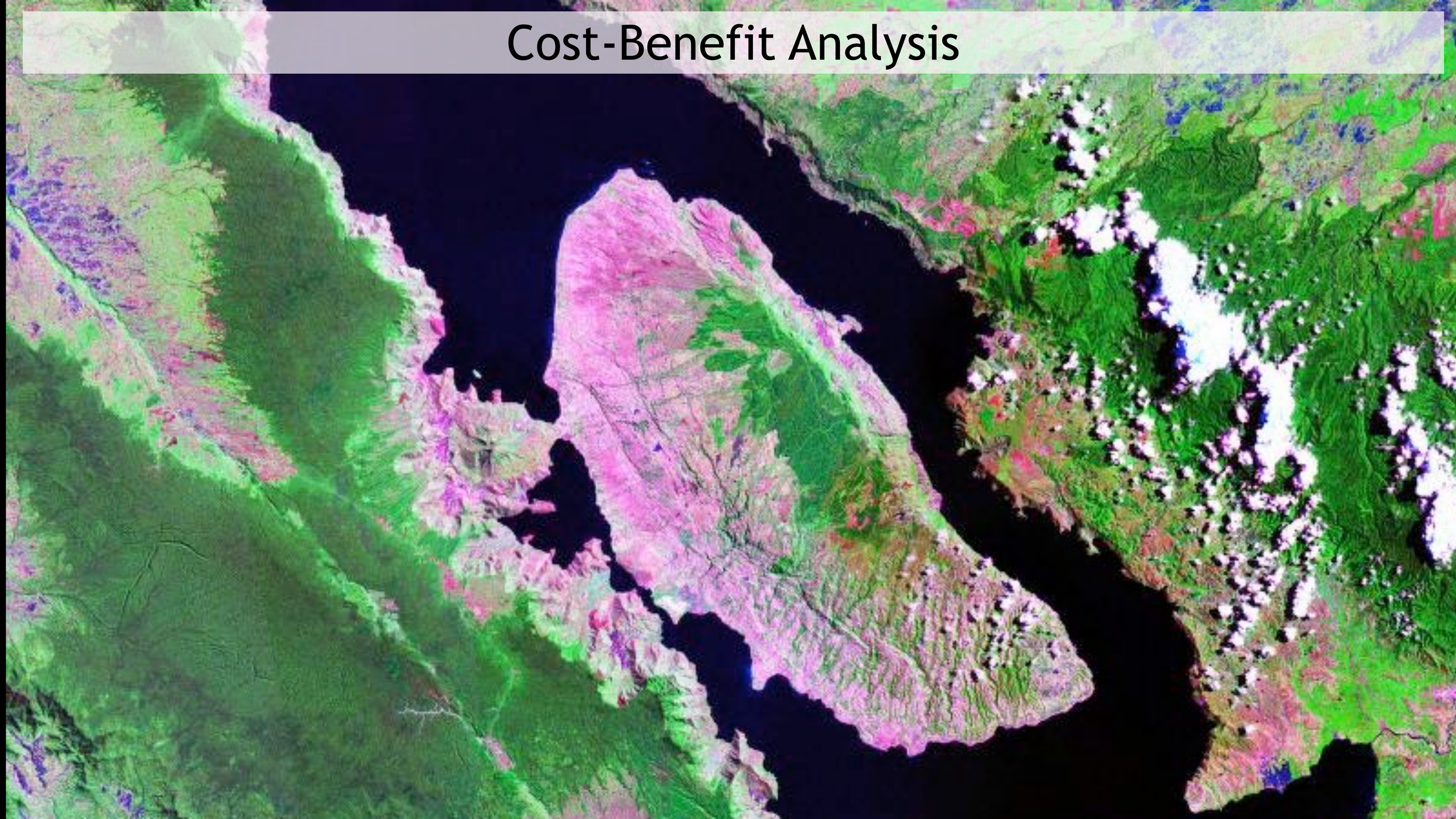

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Probability of M8 or larger in any given year: between $\mathbf{2.2 \cdot 10^{-5}}$ and $\mathbf{1.4 \cdot 10^{-6}}$ that a M8

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Global population over 7 billion: $1.1 to $7 billion/year.

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Probability of a random person dying in any particular year: $\mathbf{2.2 \cdot 10^{-6}}$ and $\mathbf{1.4 \cdot 10^{-7}}$.

- Value of statistical life (VSL): $9.1 million (U.S. Department of Transportation)
- U.S. citizen should be willing to spend $910 to eliminate a 1 in 10,000 risk of fatality

- Global VSL: $2.22 million
- Average person should be willing to pay $0.16 to $1.0 per year to eliminate the risk.

Global population over 7 billion: $1.1 to $7 billion/year.

Eliminating half of the risk is worth $0.5 to $3.5 billion/year.

# Cost-Benefit Analysis

Toba-type eruption: 1 in 45,000 to 714,000 years:
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2014 USGS Budget: $24.7 million for volcano monitoring
Same level globally: $370 million

Benefit to Cost ratio > 1.5 to 10!

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Same level globally: $37

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Details will not change the main conclusion:
- Spending on the order of $1 Billion/year on risk reduction for major volcanic eruptions makes economically sense based on standard cost-benefit analysis
- Would have many positive side effects not considered

# Conclusions and Recommendations

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**The largest volcano eruptions** of the Holocene (1 in 1000 years events):
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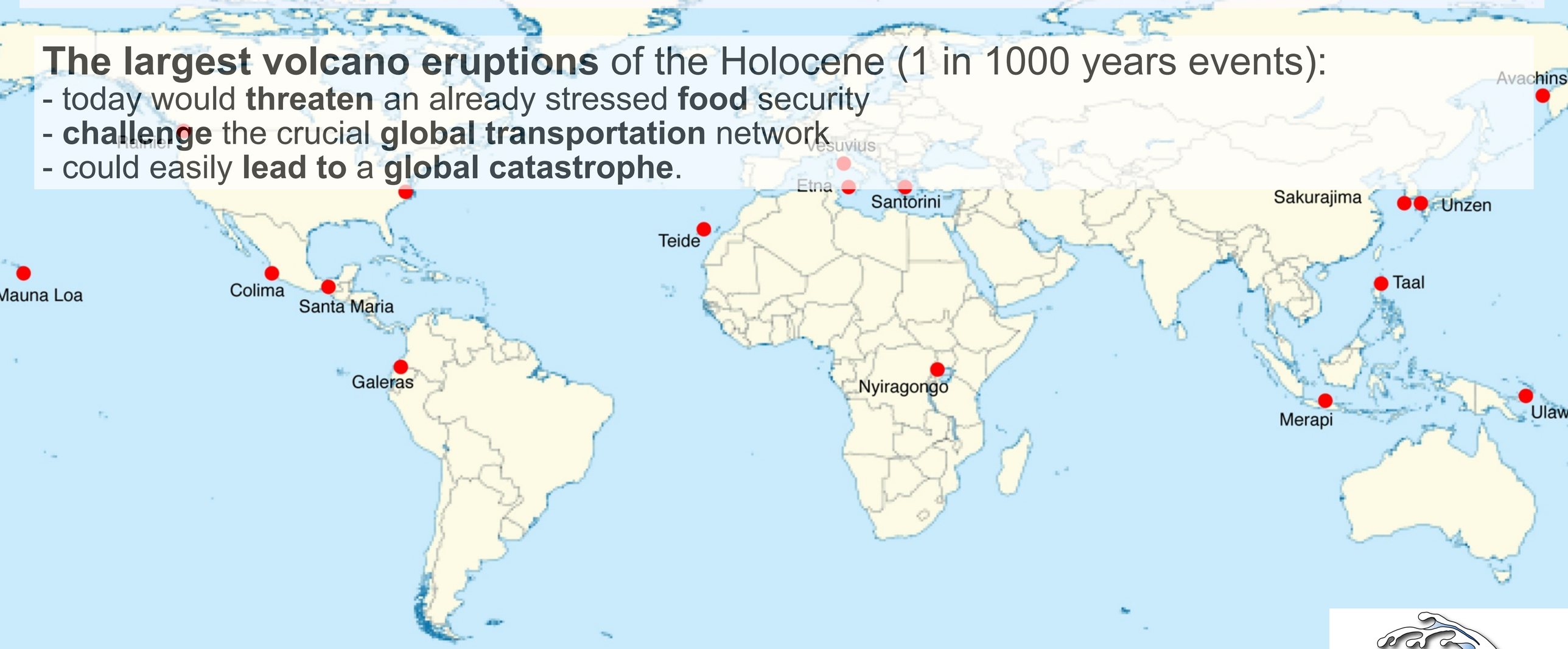


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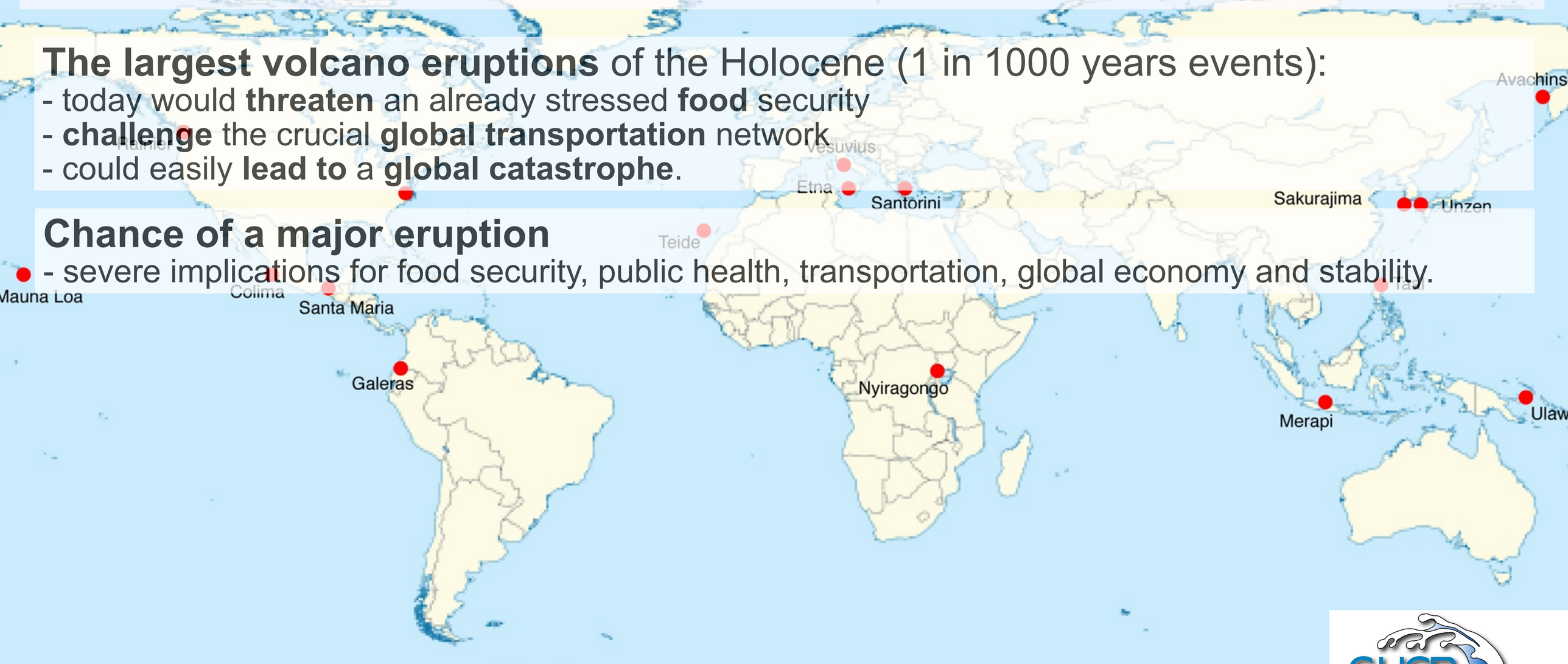


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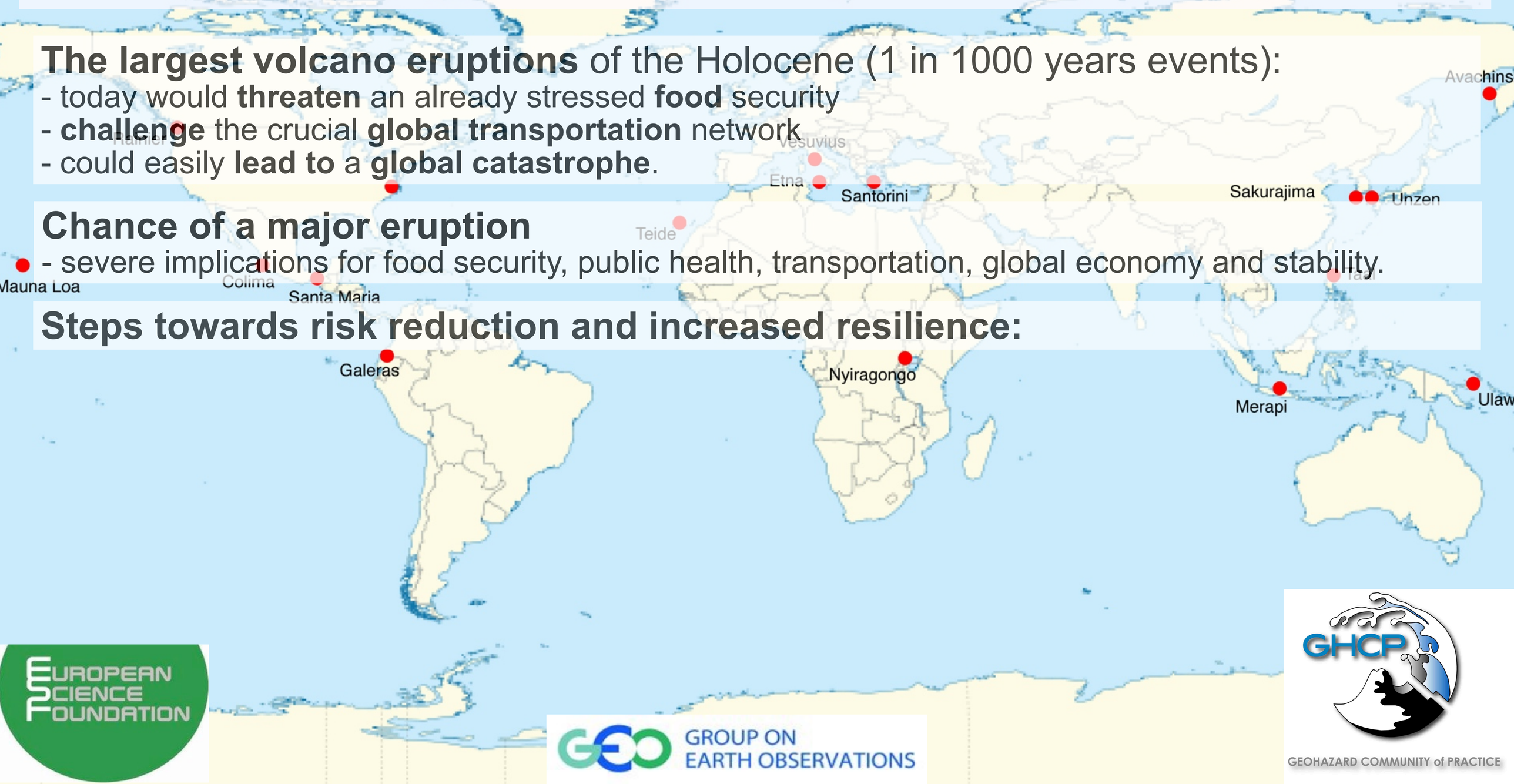


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Top 5 Global Risks in Terms of Likelihood

| | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 |
|---|---|---|---|---|---|---|---|---|
| 1st | Breakdown of critical information infrastructure | Asset price collapse | Asset price collapse | Asset price collapse | Storms and Cyclones | Severe income disparity | Severe income disparity | Income disparity |
| 2nd | Chronic disease in developed countries | Middle East instability | Slowing Chinese economy (< 6%) | Slowing Chinese economy (< 6%) | Flooding | Chronic fiscal imbalances | Chronic fiscal imbalances | Extreme weather events |
| 3rd | Oil price shock | Failed and failing States | Chronic disease | Chronic disease | Corruption | Rising Greenhouse Gas emissions | Rising Greenhouse Gas emissions | Unemployment and underemployment |
| 4th | China economic hard landing | Oil and Gas price spike | Global Governance Gaps | Fiscal crises | Biodiversity loss | Cyber attacks | Water supply crises | Climate Change |
| 5th | Asset price collapse | Chronic disease, Developed World | Retrenchment from Globalization (emerging) | Global Governance Gaps | Climate Change | Water supply crises | Mismanagement of population ageing | Cyber attacks |

Economic | Environmental | Geopolitical | Societal | Technological

**World Economic Forum**

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| 4th | Pandemics | Oil and Gas price spike | Chronic disease | Chronis disease | Asset price collapse | Chronic fiscal imbalances | Diffusion of weapons of mass destruction | Unemployment and underemployment |
| 5th | Oil price shock | Pandemics | Fiscal crises | Fiscal crises | Extreme energy price volatility | Extreme volatility in energy and agriculture prices | Failure of Climate Change adaptation | Critical information infrastructure breakdown |

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- core element: elaborate, comprehensive volcano observation system;
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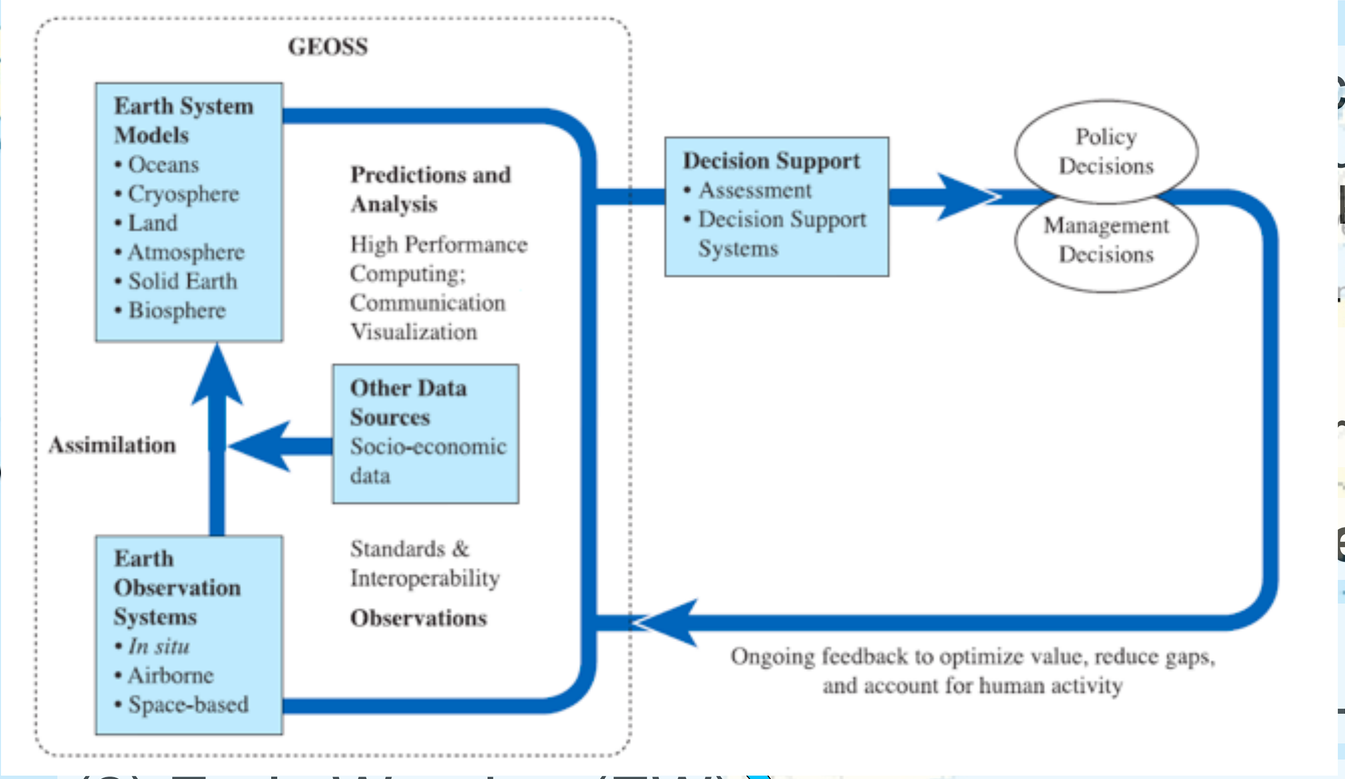


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# Conclusions and Recommendations

**Global Simulation Experiment for Tambora/Laki Type of Eruption to better understand interdependencies, cascading effects, and response**

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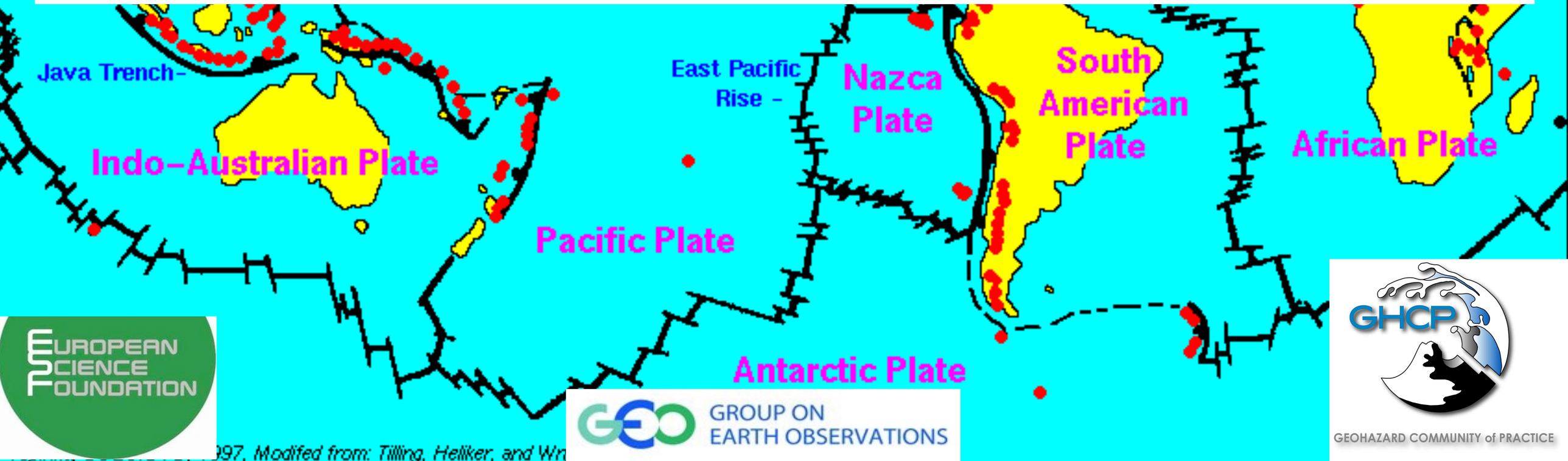
# Conclusions and Recommendations

## Post-Hyogo Framework of Action

Contribution:
- Understanding that we need to account for extreme risks at low-probability end
- Focus on improved global general resilience

It’s not the hazard, it’s the process that lead from hazard to disaster

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Post-2015
- Improve monitoring that could provide early warning for emerging global risks
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**Integrate (general) Resilience and Disaster Risk Reduction ==> RDRR**

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# Being out of scale: Human energy use makes each human equivalent to two elephants


14 Billion elephants: a heavy "load' for Earth