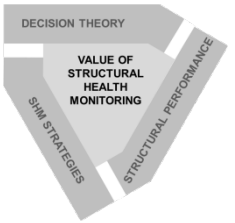

The Societal Value of Monitoring Seismic Hazard

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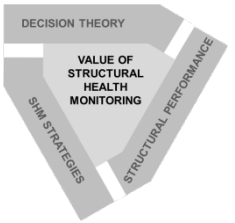
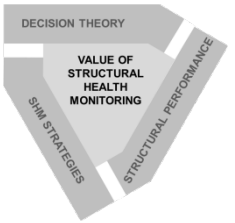


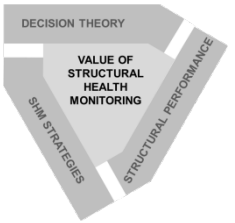
Contents

- Monitoring of Seismic hazard
- Stakeholders
- Seismic hazard in Iceland
- Seismic monitoring networks in Iceland
- Recent seismic events in Iceland
  - M6.5 in 2000 and 2008
- Application of information and knowledge
- Value for stakeholders
  - Importance of realistic hazard assessment
- Summary and final remarks



Seismic monitoring networks

- Current seismic networks in Iceland will be introduced and their significance for society and industry discussed
- Seismic networks differ from traditional SHM networks
- They are aimed at mapping geo hazard and earthquake action
- They have either:
  - a wide focus on a national / regional level
  - a narrow focus on a town, a specific site or single structure
    - Arrays, structural monitoring
- Seismic networks serve a multitude of stakeholders
- The information they provide is essential for to build a safe and resilient society.

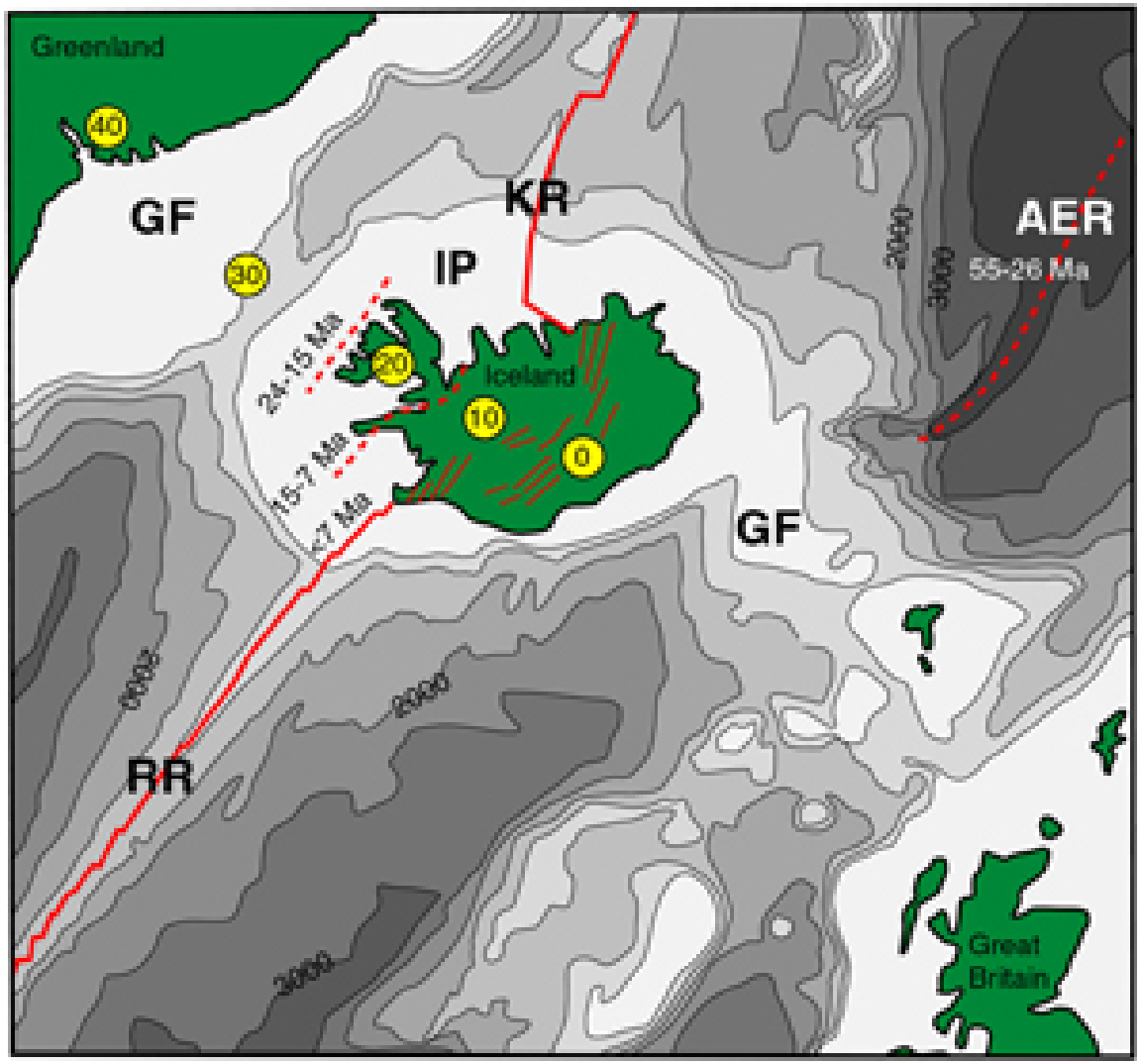


Stakeholders of SMN´s

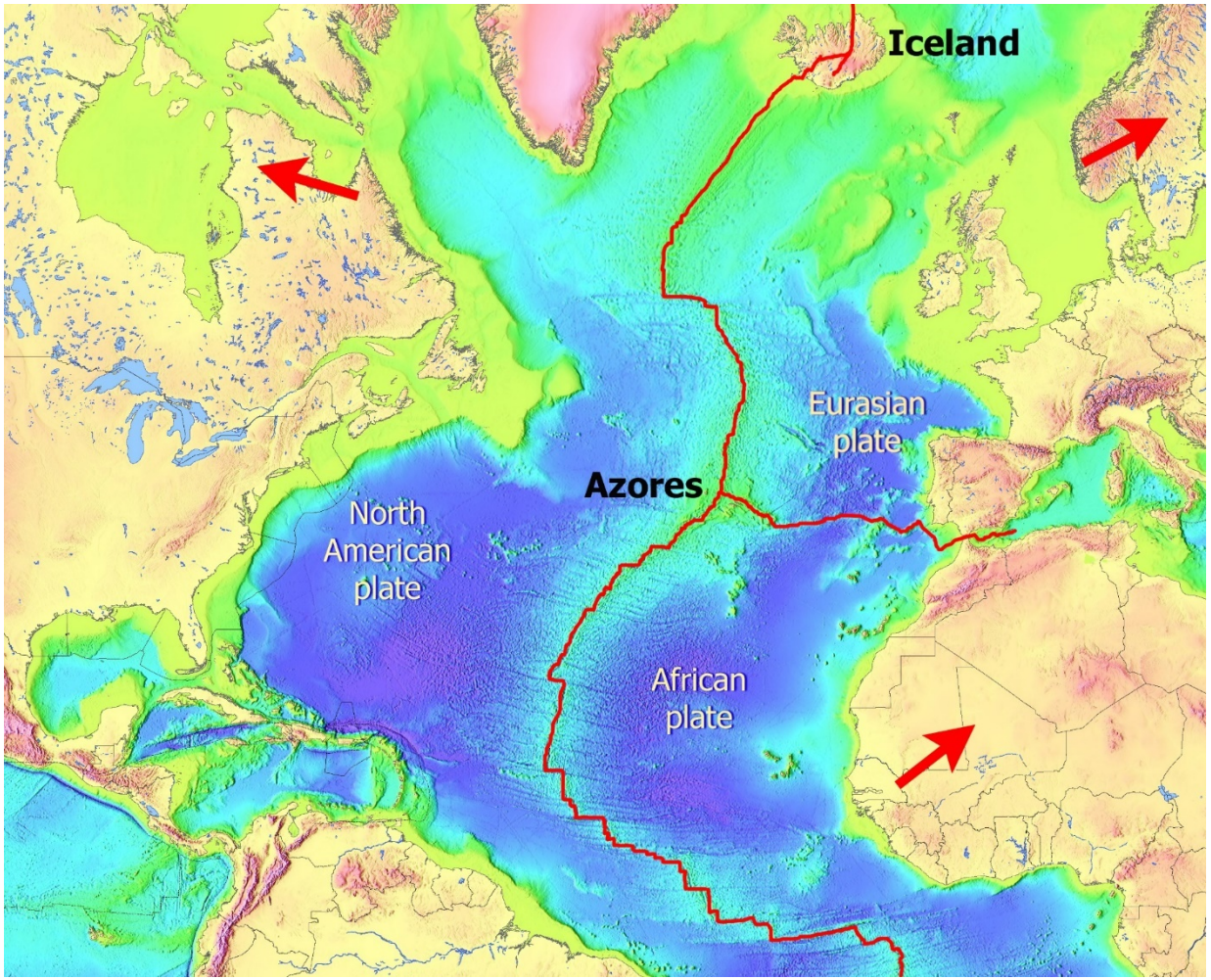
- General population and house owners
  - Safety and resilience of buildings and infrastructure
  - Disaster preparedness
- The Municipalities
  - Planning
  - Building regulations
- The State
  - Planning
  - Building regulations and design requirements
  - Insurance/Reinsurance of public and private real estates
- Major Industry
  - Site selection and design specifications
  - Insurance/Reinsurance of real estates and other assets

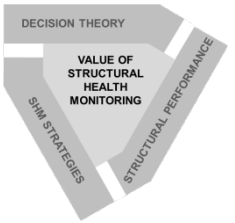
Tectonics of Iceland:
Combination of plate and plume tectonics

- Mid-Atlantic Ridge of tectonic extension between the North American and Eurasian Plates.
  - RR=Reykjanes Ridge
  - KR=Kolbeinsey Ridge
- In Iceland the interplay between the tectonic extension and mantle plume define the geodynamics
  - Including volcanic and earthquake occurrence



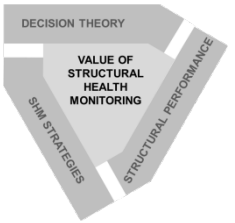
(Maclennam, 2001; Kaban et al., 2002)


Iceland
Eurasian plate
Azores
North American plate
African plate



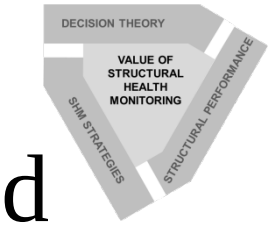
History of earthquake recordings in Iceland

- Icelandic earthquakes have been recorded since around 1900
  - From 1886 to 1927, there are sporadic recordings
  - Since 1927, seismological observations are almost continuous
- Earthquake-monitoring systems permanently installed and operated in Iceland:
  - The seismological network of the Science Institute of the University of Iceland consists of 29 seismometers (start-up ~1960's)
  - The SIL-system (South Iceland Lowland), operated by the Icelandic Meteorological Office, 43 digital seismic stations (startup~1990)
  - The strong motion accelerometer network in Iceland (startup ~1985)
    - Operated by the EERC of The Univ. of Iceland
    - Wide spread ground motion stations in South and North Iceland
    - Strong motion arrays in Hveragerdi in the South and Husavik in the North
      - Icearray I and Icearray II

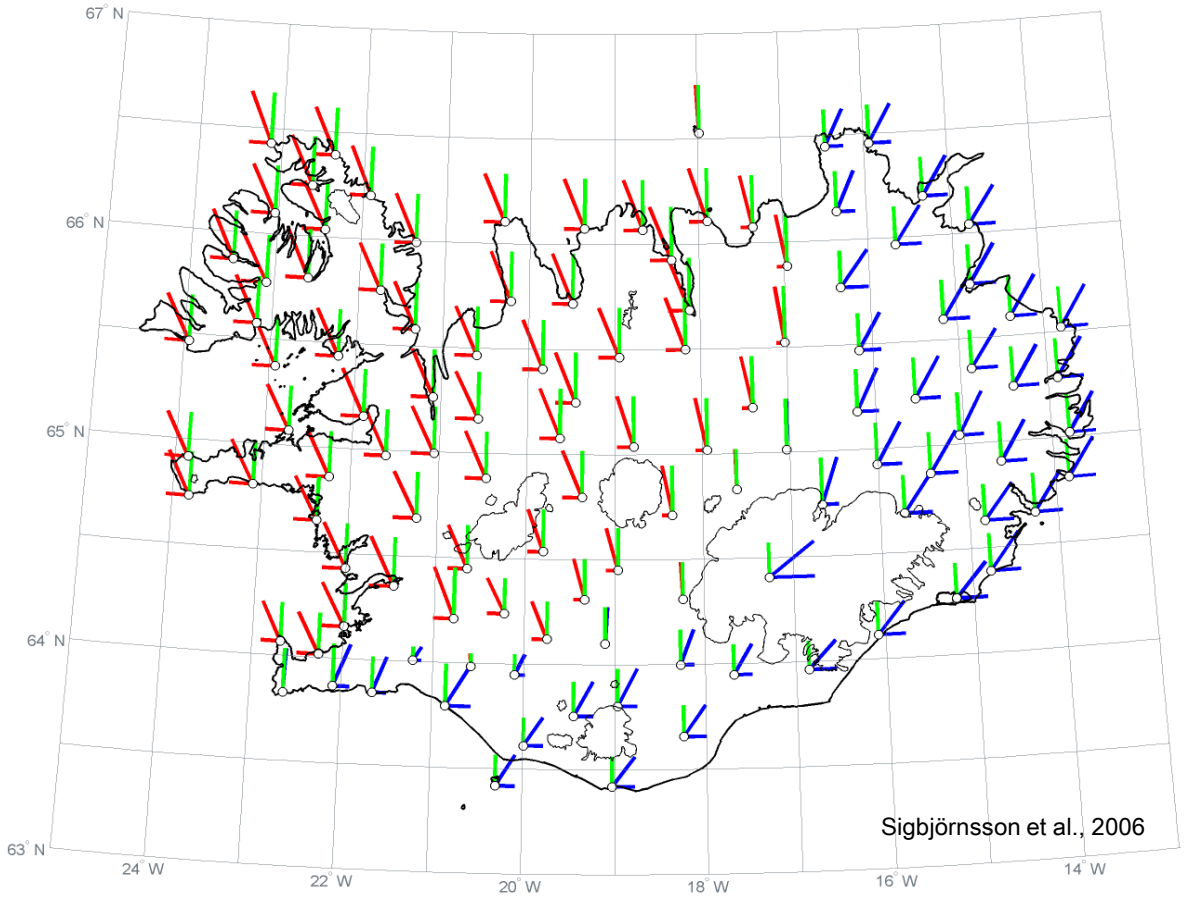


Systems monitoring seismicity and seismic action

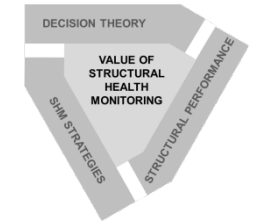
- Seismological network
  - Monitoring seismicity of all magnitudes, from < zero and up
  - Aimed at mapping seismicity for geological purposes
  - Traditionally uses velocity sensors tuned to monitor specific frequency bands (2-3, 3-4, 5-6 Hz)
  - Sensors close to the epicentre of a large events exceed their measurement range
- Strong motion network
  - Monitoring acceleration above a specified threshold limit
  - Using acceleration sensors with a measurement range of 1 g (g=9.8 m/s^2) or more
  - Aimed at mapping seismic effects for engineering purposes
  - Ground motion and Structural response
- GNSS / Continuous GPS monitoring networks
  - Fixed stations
  - Mobile stations placed on fixed points during regular campaigns



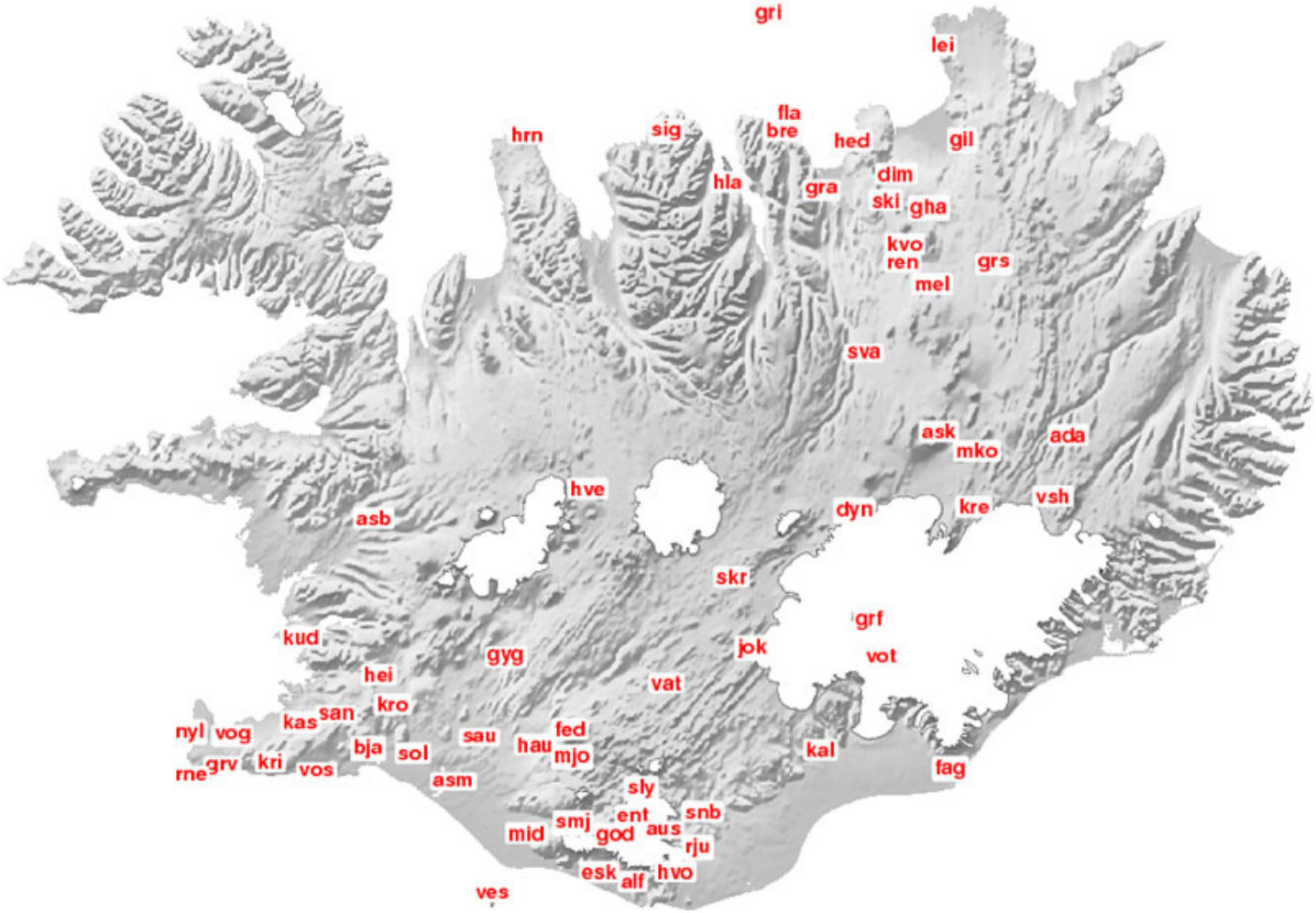
Present-Day Geodynamics of Iceland

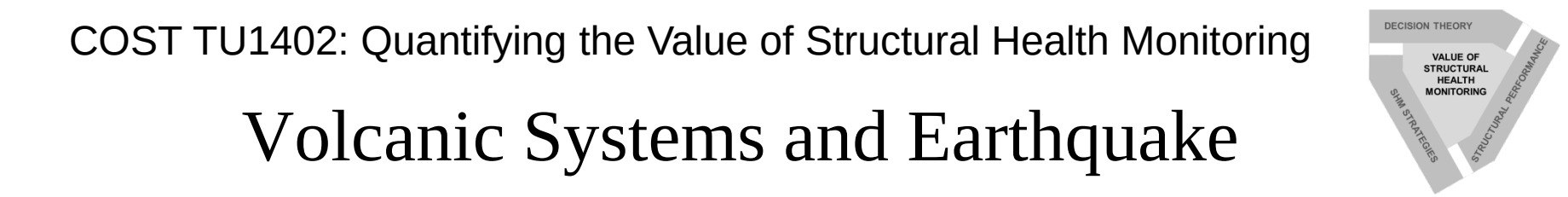


- Average horizontal velocities from GPS measurements
  - Green=NS-comp.
  - Red = West comp.
  - Blue= East comp.
- Evaluated based on data from campaigns in 1994 and 2004
- Defines the Present-Day Rift Axis of the Mid-Atlantic Ridge in Iceland

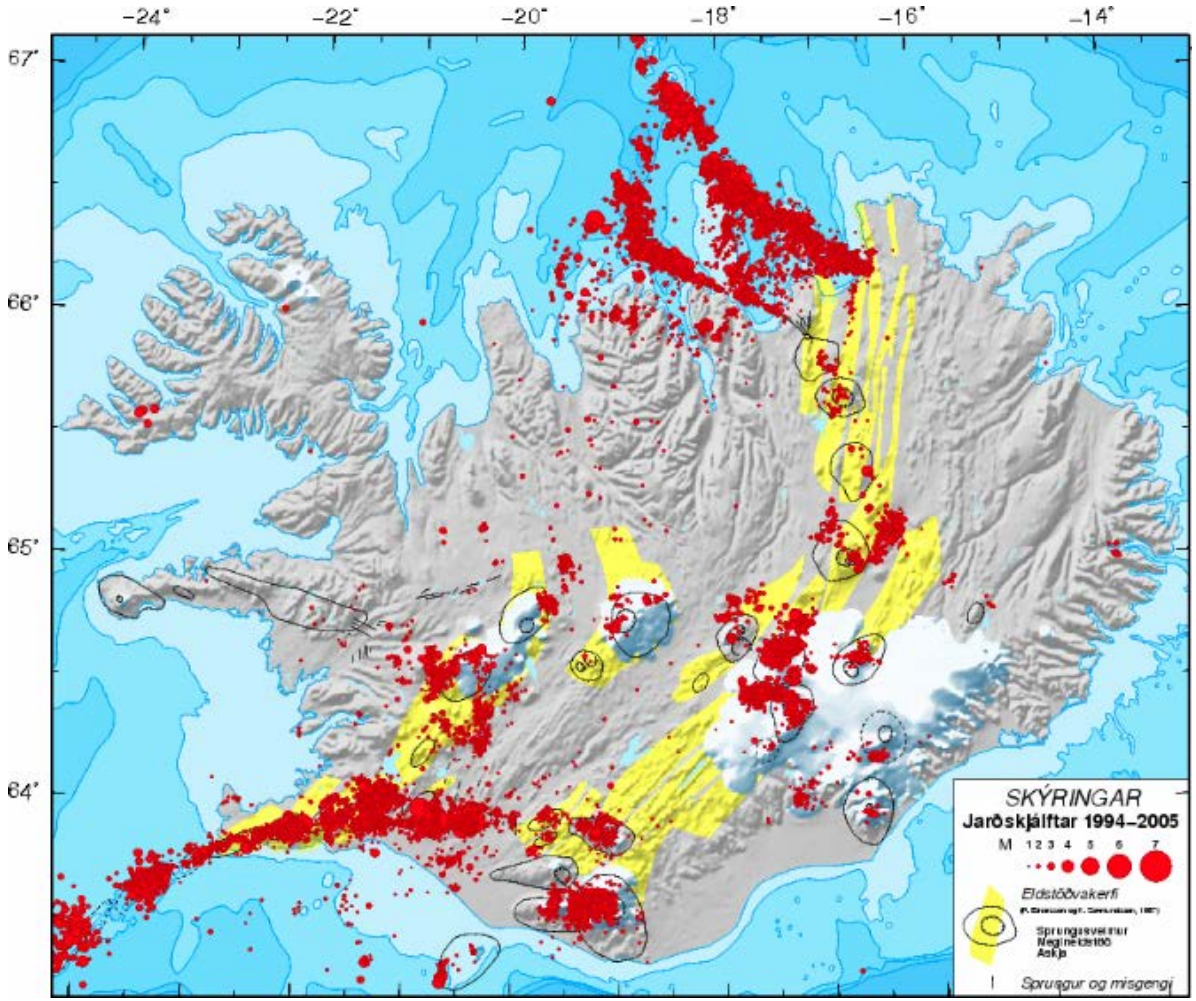


The SIL seismometer system

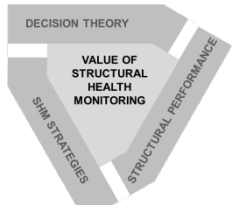




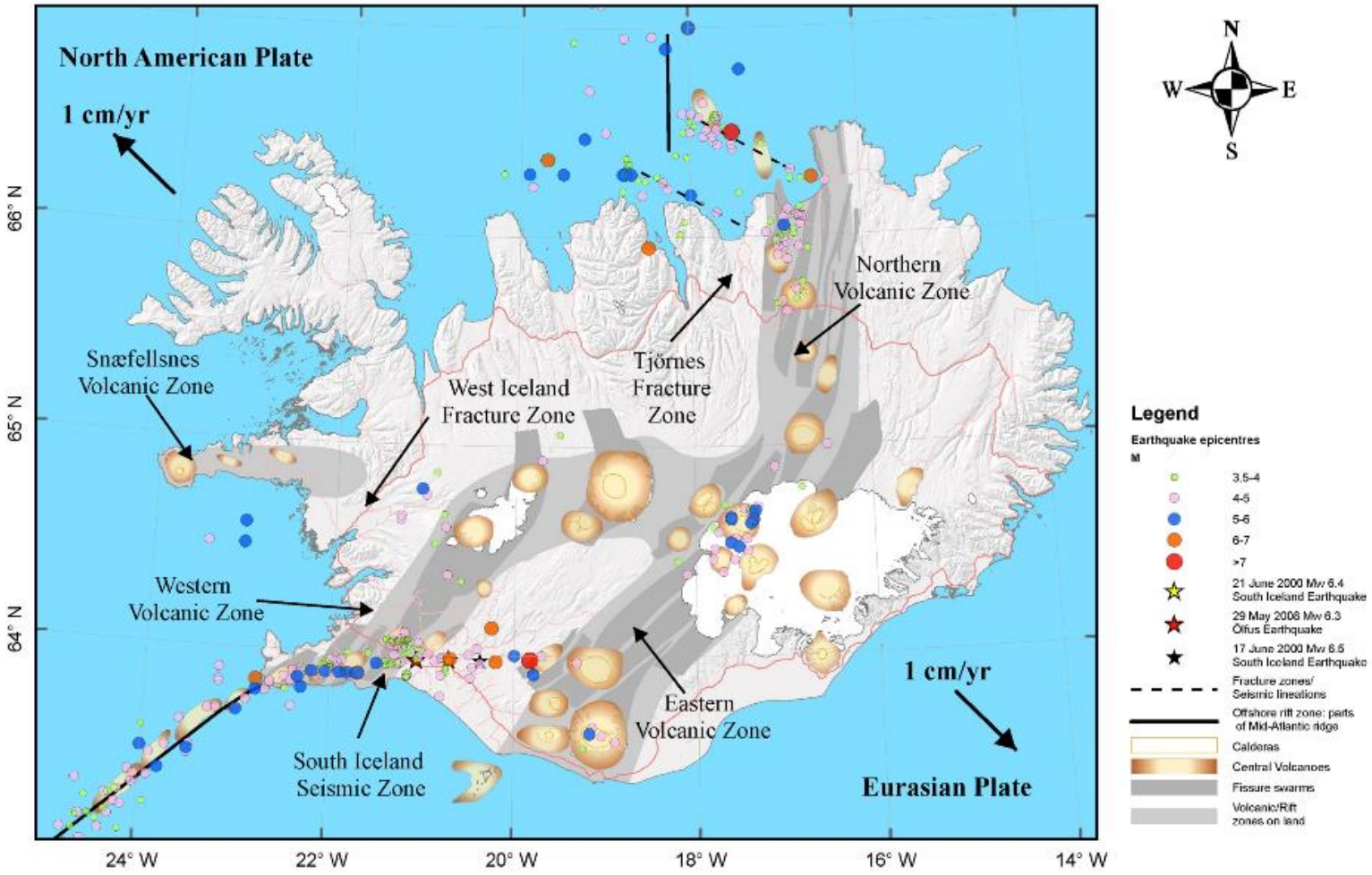
Volcanic Systems and Earthquake Epicentres in Iceland

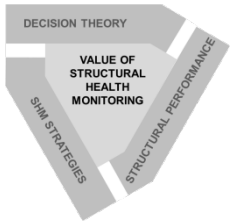


- Red dots: earthquake epicentres between 1994 and 2005
- Black circles: central volcanoes
- Yellow regions: fissure swarms
- White regions: Glaciers



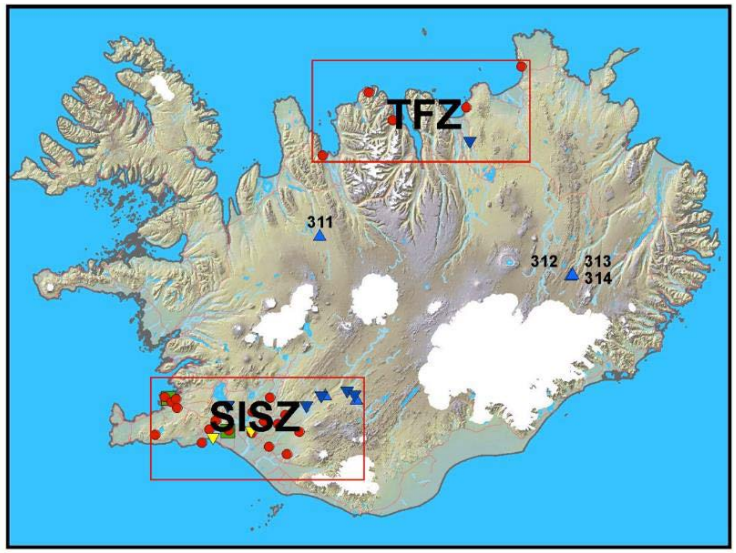
Main tectonic structures and earthquake epicentres

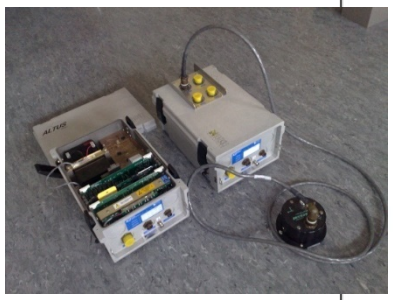




The Icelandic Strong-motion Network

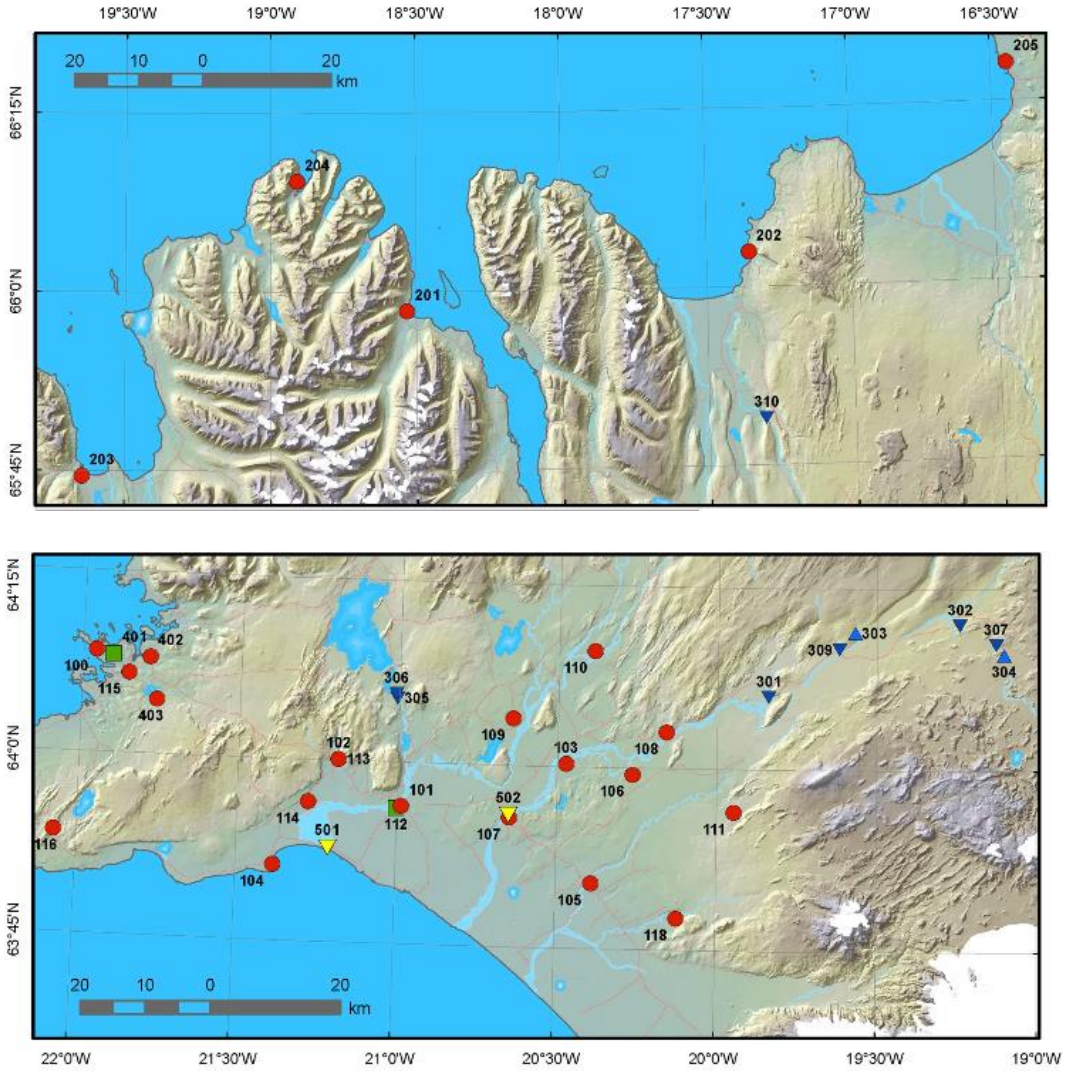
39 ground motion stations



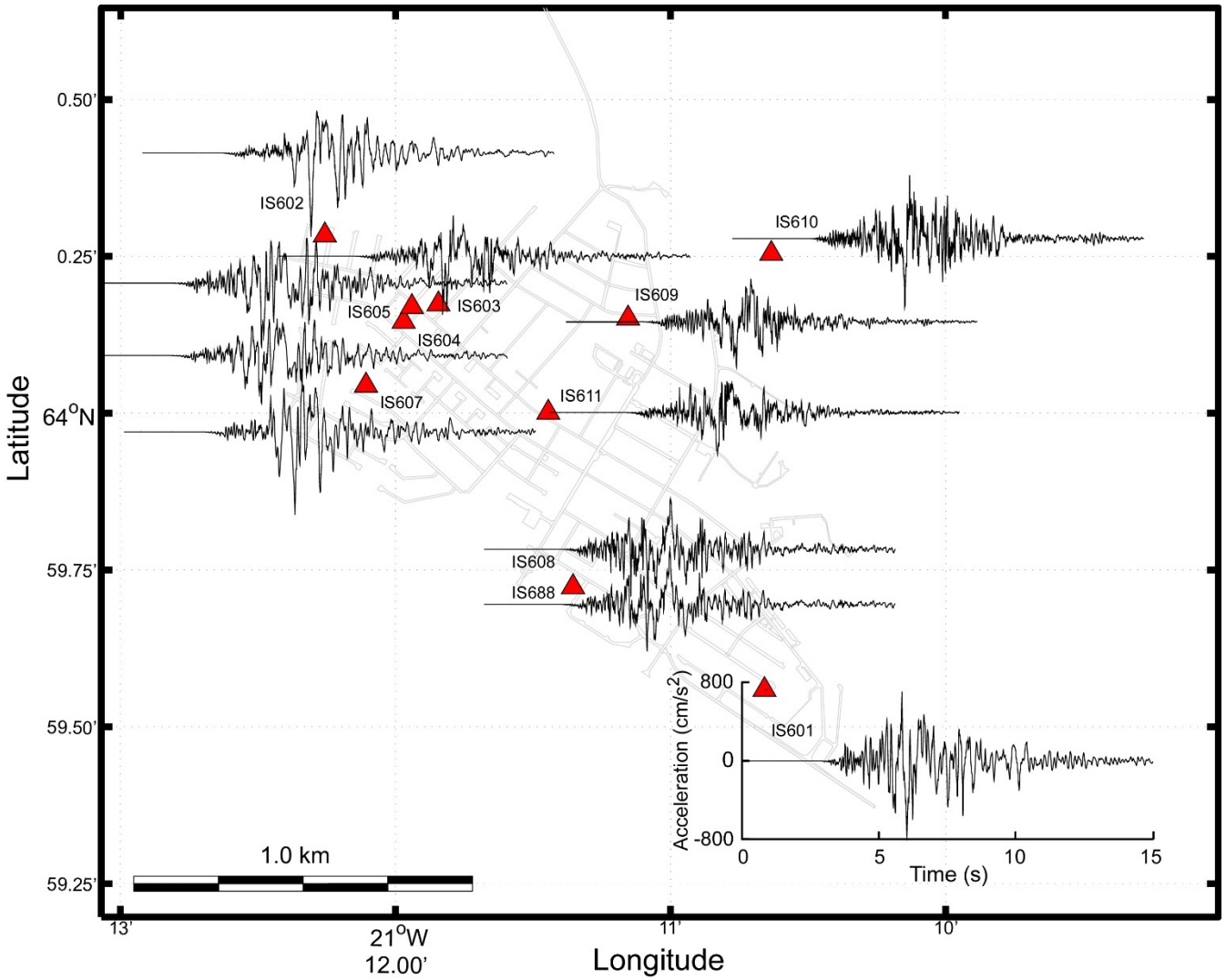


Accelerometric stations on

- Bridge
- Ground Response
- Office Building
- Power Station
- Dam



IceArray I, data from M6.3 on 29.05.2008

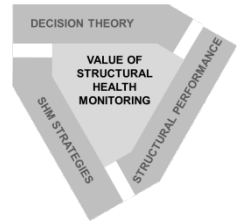


Location:

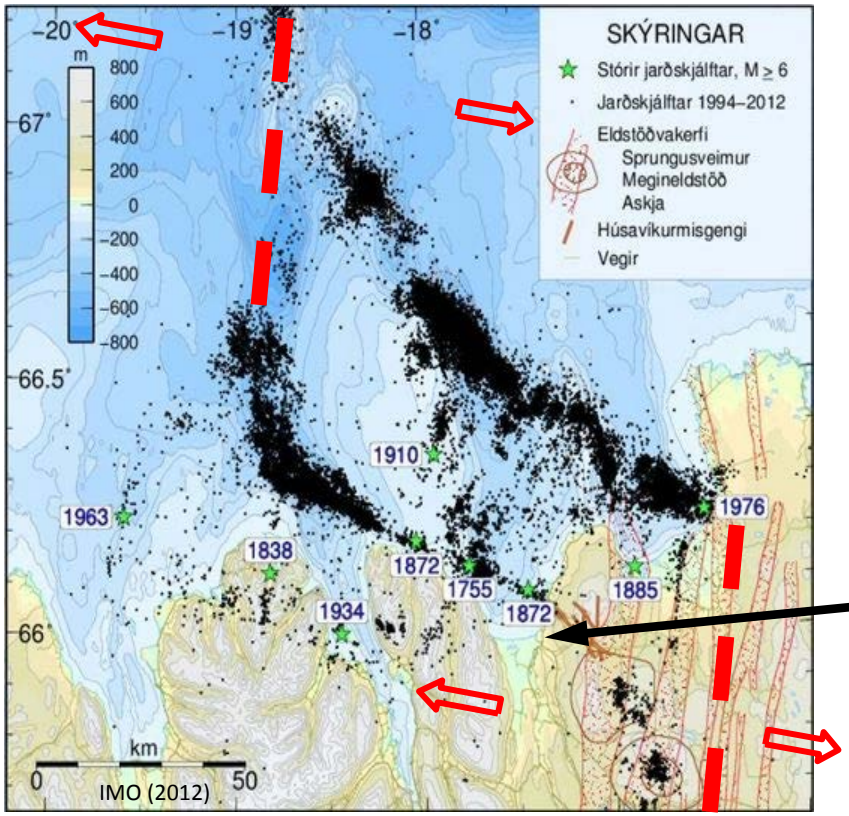
- Hveragerði in South Iceland

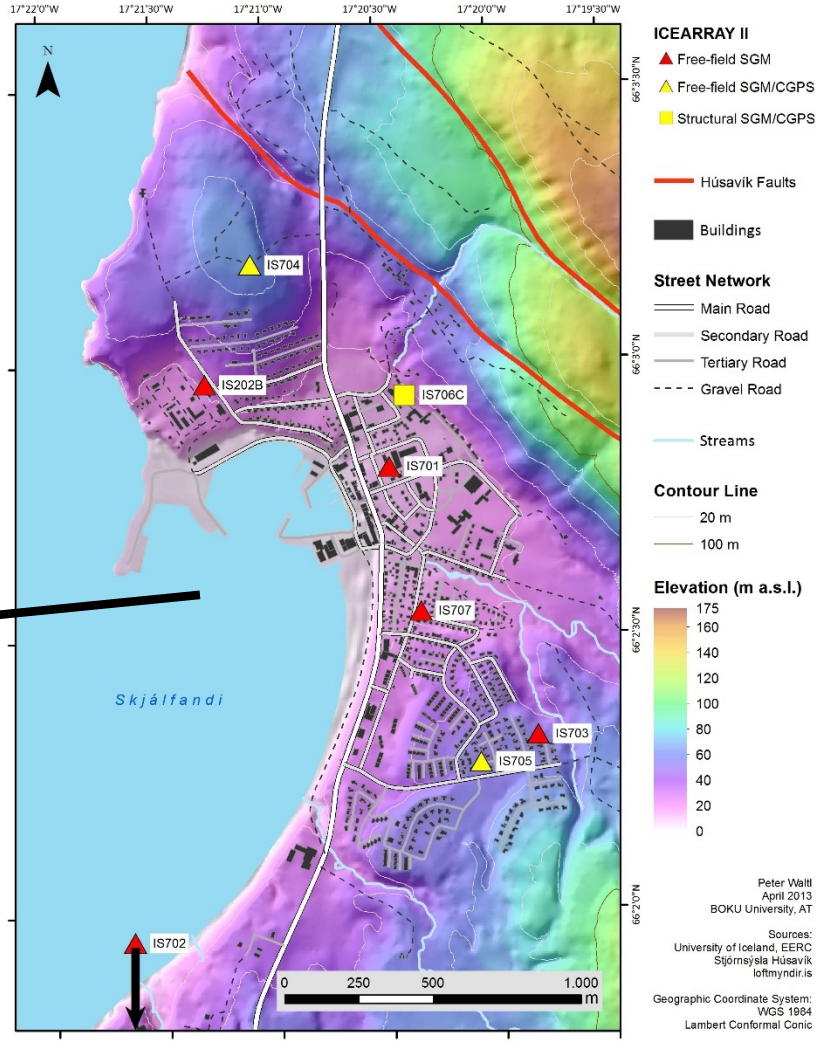
Purpose:

- Spatial variabilty of ground motion
- Earthquake source process

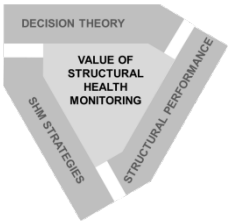


IceArray II – Húsavík, North Iceland





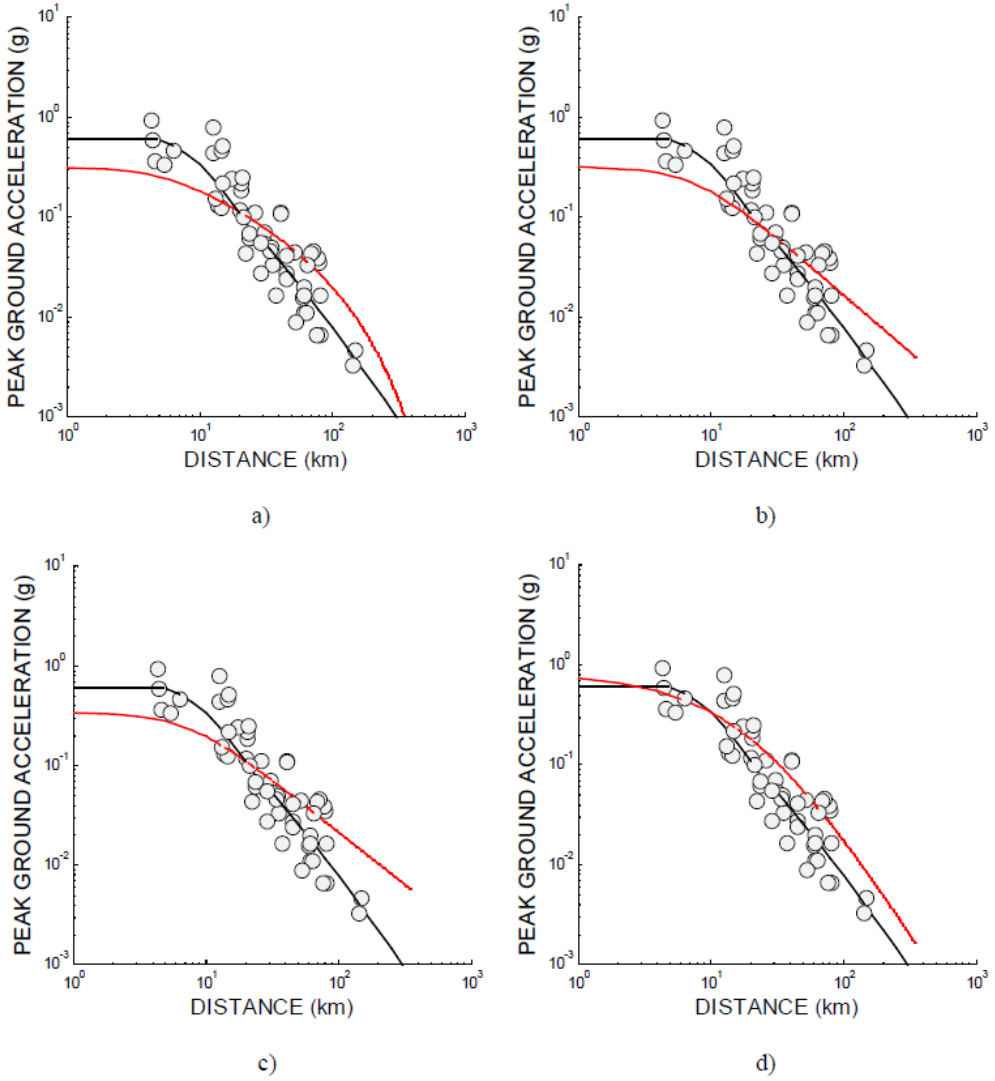
- Recent strong historical earthquakes (Green stars)
- Micro earthquake epicentres 1994-2012 (Black dots)
- Rift axis (red dashed lines) and direction of rifting



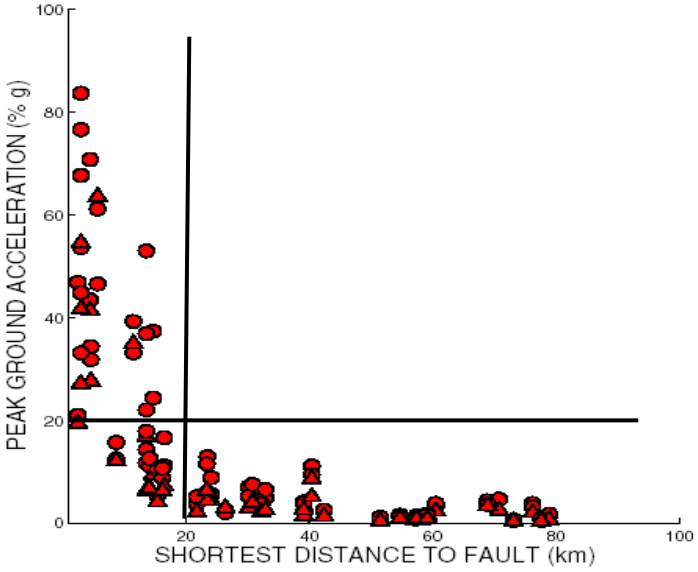
Application of the Data

- Engineering strong ground motion modelling
- Seismic hazard assessment
- Vulnerability profiles – damage in historic earthquakes
- Risk assessment and loss estimation
- System identification
- Soil dynamics, site effects
- Earthquake mitigation
- Earthquake resistant design and earthquake scenarios
- Base isolation systems
- Engineering education

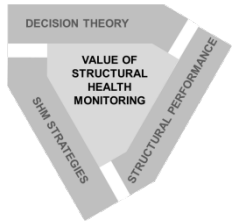
Attenuation relations compared to recorded PGA from two Icelandic earthquakes (Mw 6.5)



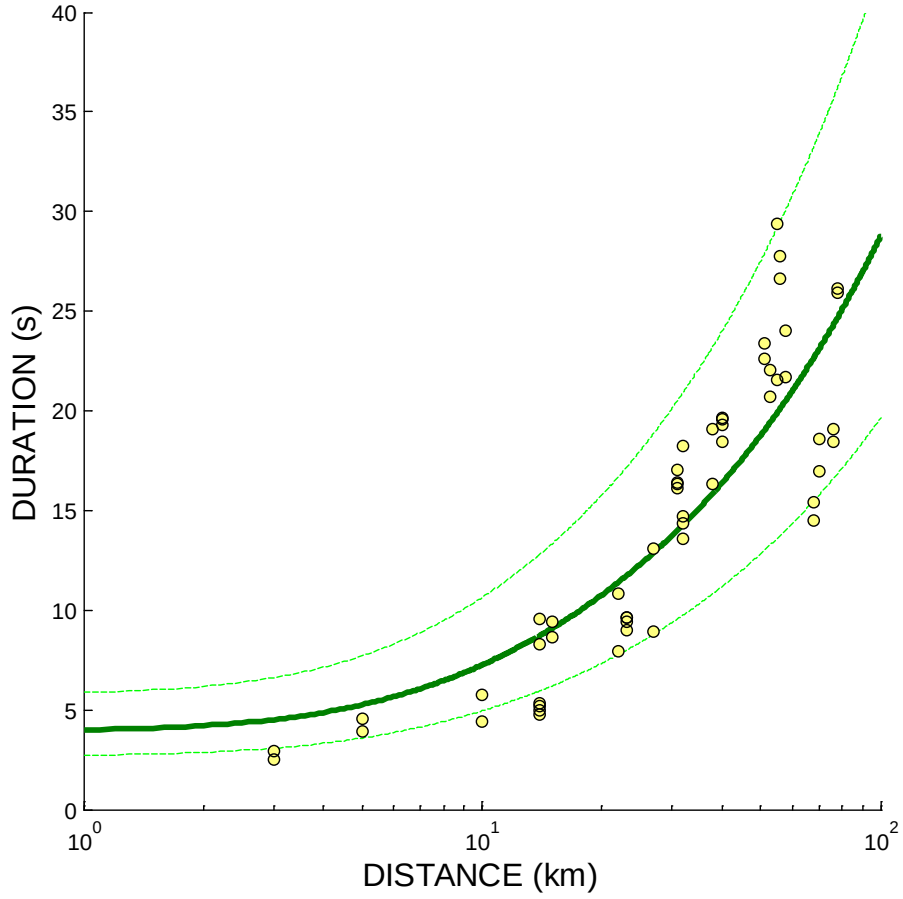
Attenuation relations,
red curves, based on data from
a) New-Zealand
b) Europe and Middle East
c) Extensional regimes (SEA99).
d) Californian data.



(*Sigbjörnsson and Ólafsson, 2004*)



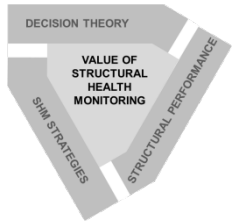
Duration values obtained for the June 2000 South Iceland Earthquakes compared to suggested duration model (solid line).



The data fits within the error bounds of ±1 standard deviation and the model seems to display the general trend of the data fairly well.

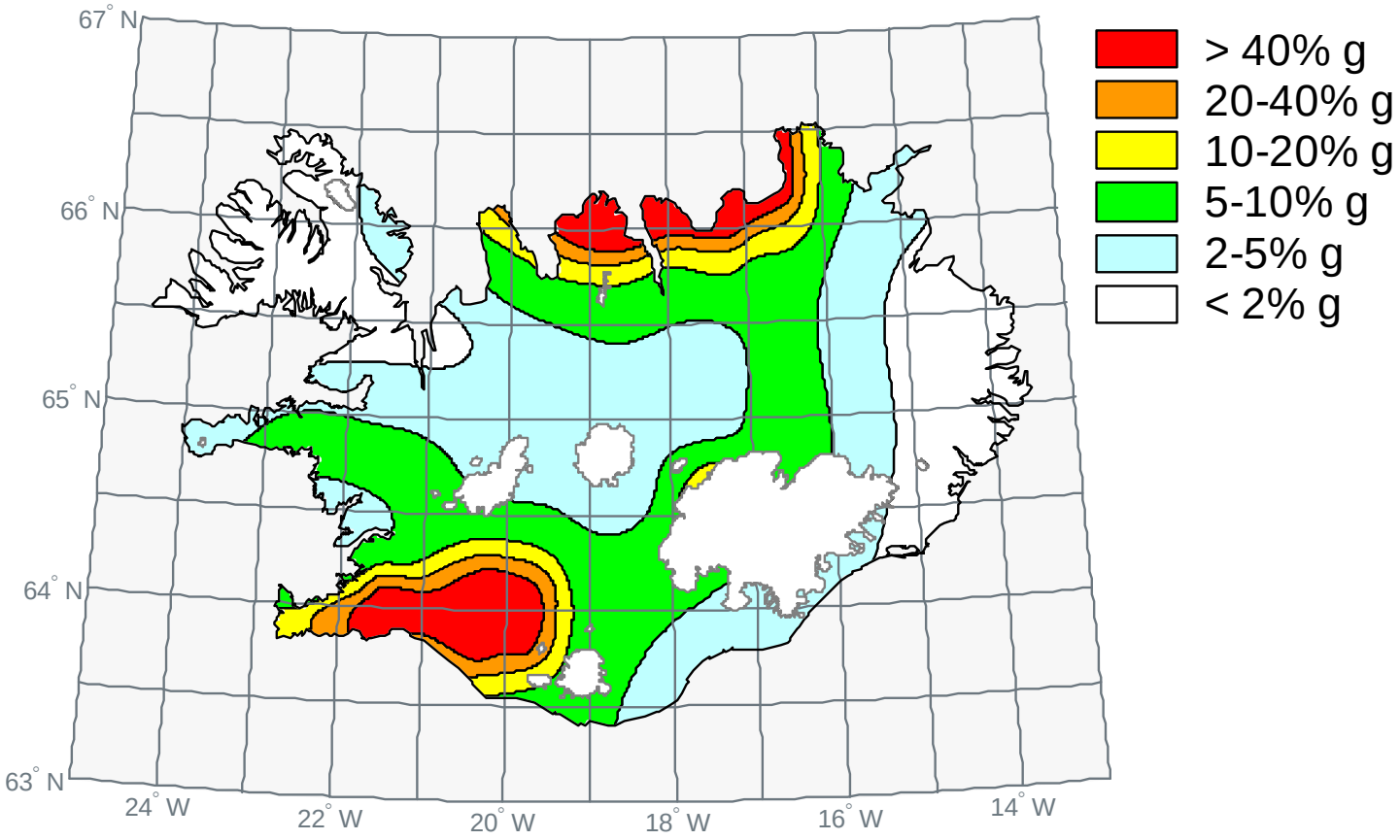
The observed scatter is linked to factors such as the source, path and local site effects, which all affect the ground motions.

(*Snæbjörnsson & Sigbjörnsson, 2008*)



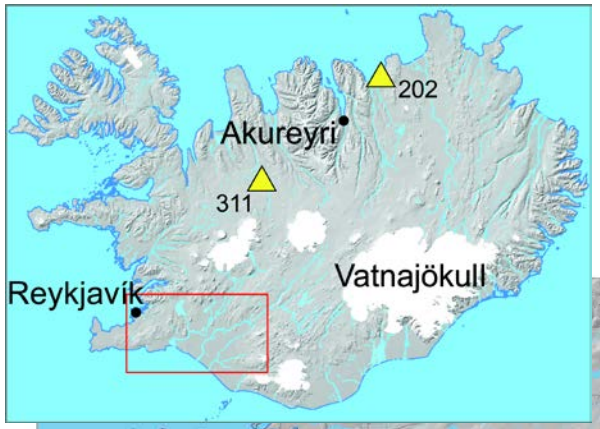
Earthquake hazard map for Iceland

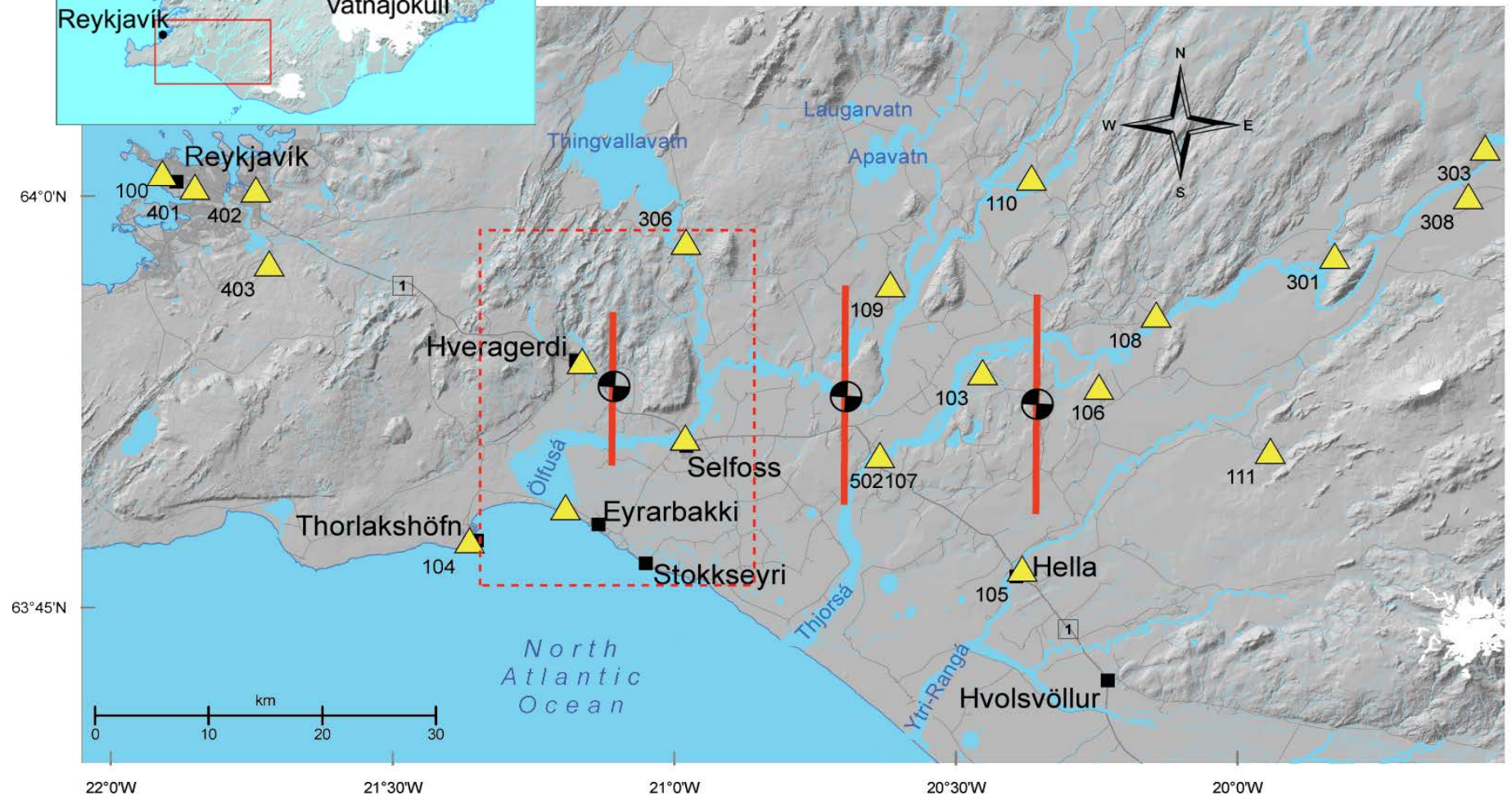
showing peak ground acceleration with mean return period 475 year

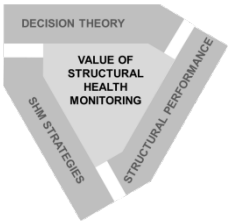


(*Sólnes, Sigbjörnsson, Elíasson, 2004*)

SISZ
The South Iceland Seismic Zone

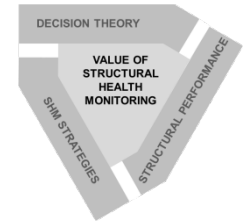




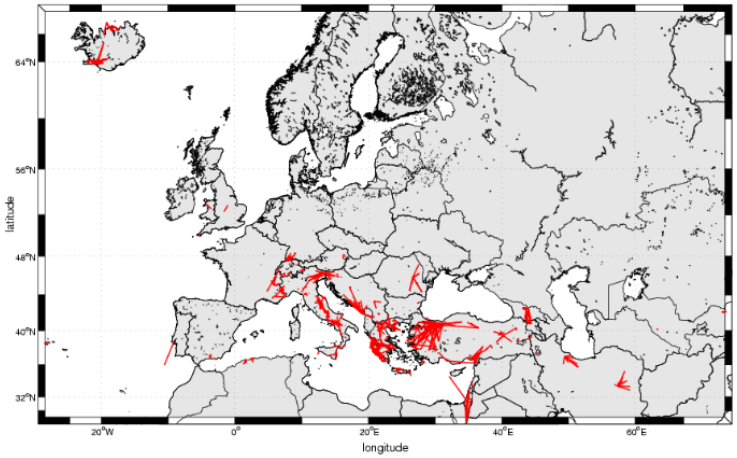


South Iceland earthquakes 2000 and 2008

***Date*:**	**17 June 2000**	**21 June 2000**	**29 May 2008**
***Origin time*:**	**15:41**	**00:52**	**15:45**
***Surface fractures*:**	**~ 20 km**	**~ 20 km**	**(small)**
***Max. recorded PGA*:**	**64% g**	**84% g**	**88% g**
***Damage area*:**	**~ 438 km^2**	**~ 358 km^2**	**~ 320 km^2**
***Magnitude* (M_w):**	**6.5**	**6.4**	**6.3**
***Epicentre*:**	63.97° N 20.36° W	63.97° N 20.71° W	63.98° N 21.13° W



ISESD
Internet site for European strong motion data

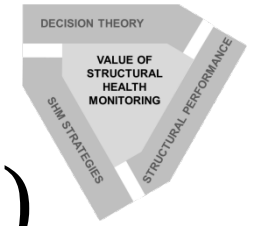


Partners:
Imperial College of Science, Technology and Medicine, London, UK
University of Iceland, Reykjavik, Iceland
University of Trieste, Italy
Institute of Seismology and Earthquake Eng., Thessaloniki, Greece

http://www.isesd.hi.is

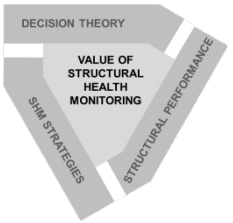
The Internet site provides an interactive, fully relational database and databank with more than 3,000 uniformly processed strong-motion records and associated earthquake-, station and waveform-parameters.

The user can search the database and databank interactively and download selected strong-motion records and associated parameters.



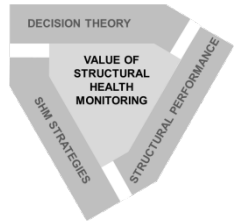
The Iceland Catastrophe Insurance (ICI)

- The ICI was founded in 1975 after a volcanic eruption in the Vestmann Islands as a public undertaking by a special Act of the Parliament of Iceland.
- The ICI functions as an insurance company.
- The purchase of catastrophe insurance for earthquakes, volcanic eruptions, avalanches, rock slides and floods is compulsory for all real estate; as well as for contents insured against fire.
- Buildings are insured according to their valuation for fire as assessed by the Registers in Iceland (fee 0.02% of insured value).
- Since fire insurance of buildings is compulsory in Iceland, all buildings are likewise insured against natural perils covered by the program.
- Infrastructure and lifelines, not normally insured against fire, are separately insured by the Iceland Catastrophe Insurance.
- Major industry is generally separately insured or self insured
- In September 2014, the ICI covered assets of ~60 billion Euro
- The existance of the ICI increases the resilience of the society

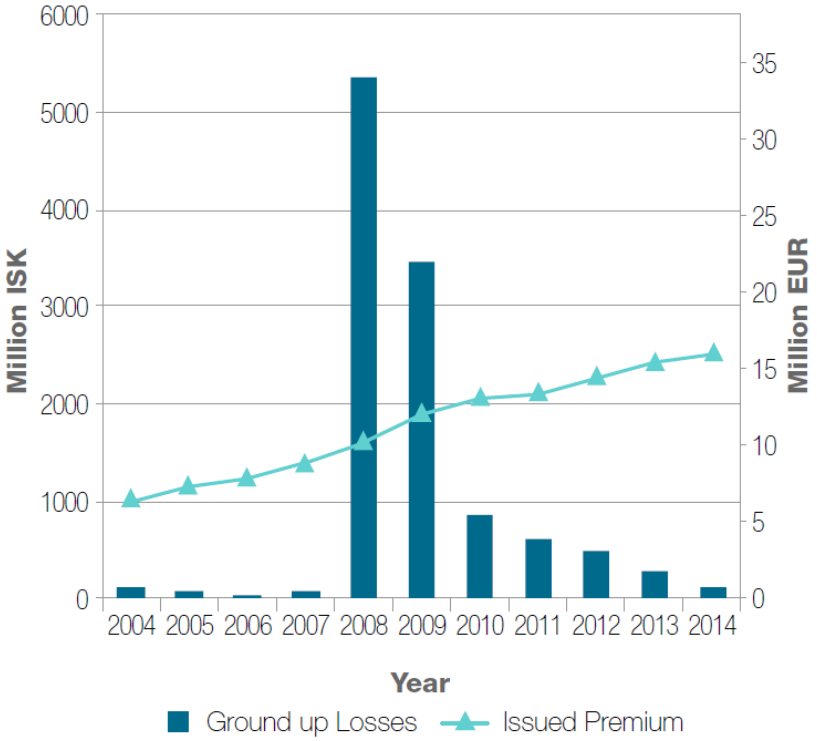


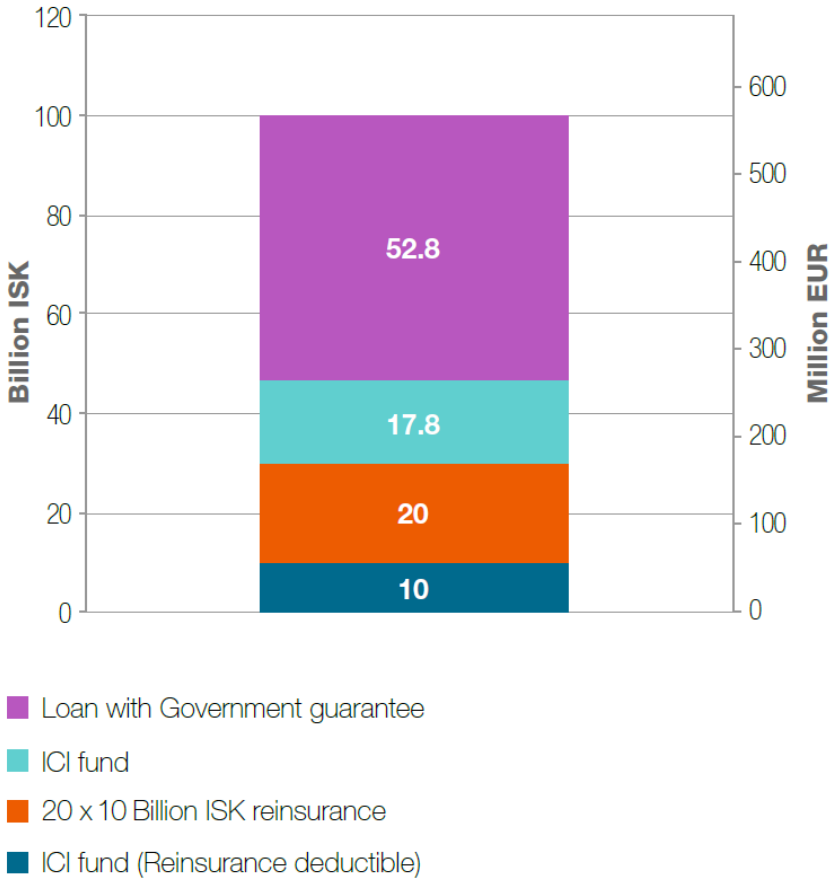
Damaging environmental events in Iceland 1973 - 2014

Year	Event	Place	Loss in mill. Euro	% of GDP
1973	Volcanic eruption	Vestmann Islands	136.8	13.10%
1974	Avalanche	Neskaupstadur	8.4	0.61%
1976	Earthquake, M 6.5	Kopasker, NE Iceland	-	-
1983	Mud and iceflow		-	-
1984	Wind driven ocean flooding	Akranes, vest coast	-	-
1990	Wind driven ocean flooding	South and west coast	1.9	0.03%
1991	Storm	South and west coast	11.8	0.19%
1995	Avalanches	Sudavik & Flateyri	13.8	0.21%
1996	Glacial outburst flooding due to Volcanic eruption	Skeiðararsandur, Grímsvötn, Vatnajökull glacier	8.6	0.20%
2000	Two Earthquakes M 6.5	South Iceland	34.2	0.43%
2008	Earthquake M 6.3	Ölfus, south Iceland	79.8	0.51%
2010	Volcanic eruption	Eyjafjallajökull	2.3	0.02%
2011	Volcanic eruption	Grímsvötn, Vatnajökull glacier	1.2	0.01%



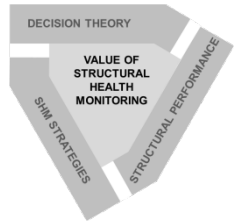
Damage, Premiums and Payment liability for single event



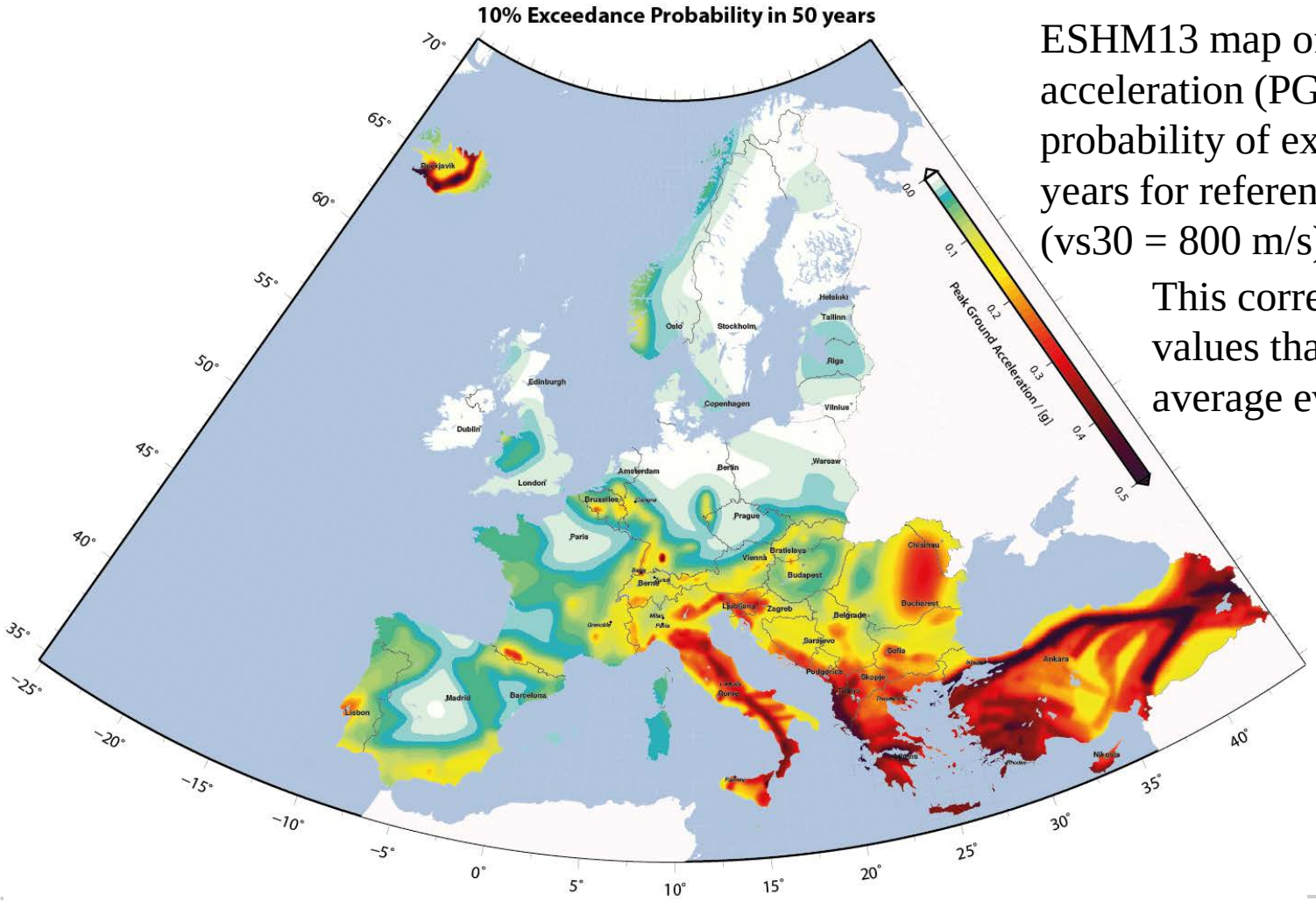


Profit and loss to reinsurers between 2000-2011

- Premium EURO **25,536,000**
- Claim EURO **23,415,600**
- Overall reinsurer profit EURO **2,120,400**

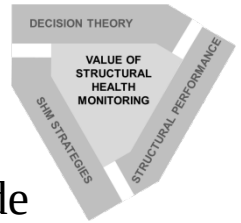


The 2013 European Seismic Hazard Model "Seismic Hazard Harmonization in Europe (SHARE)"

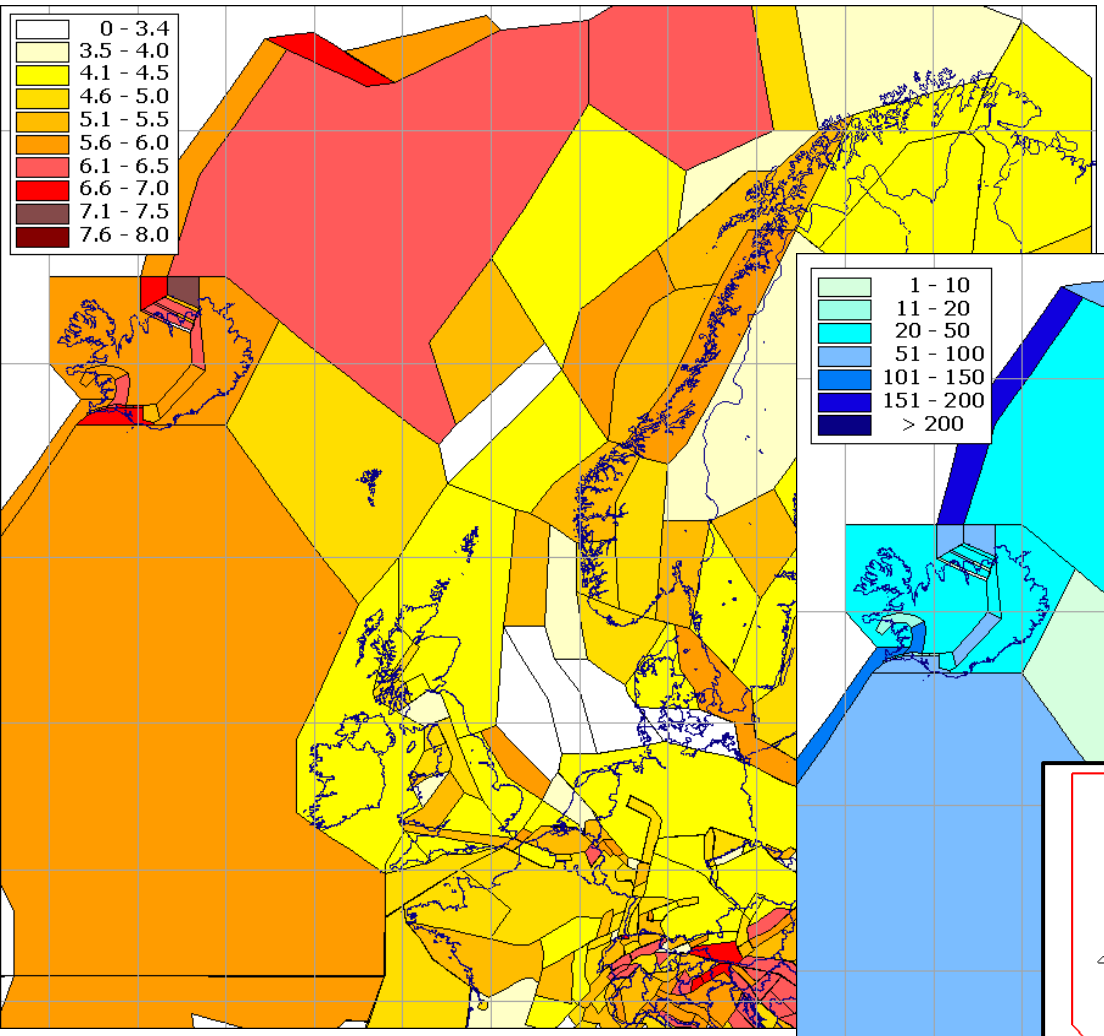


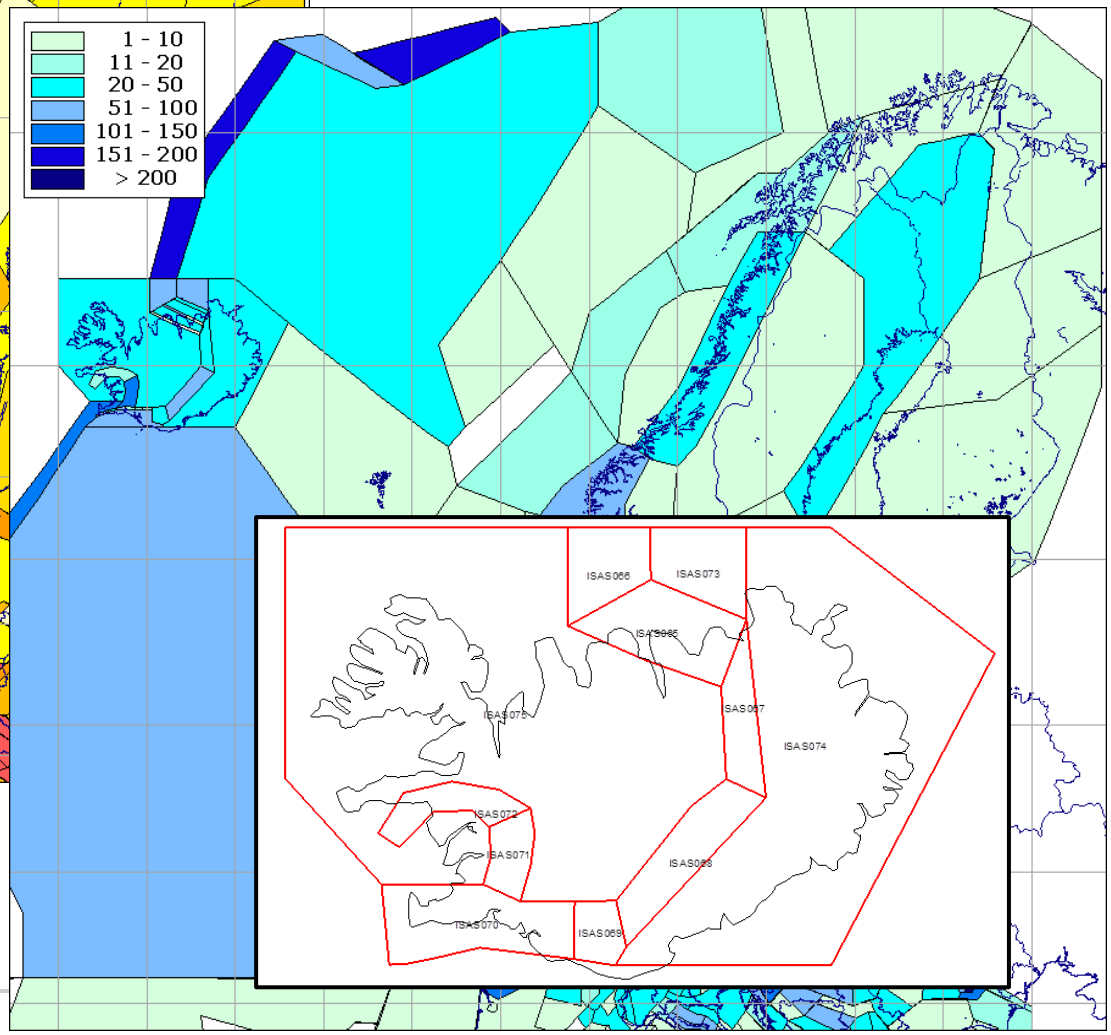
ESHM13 map of peak ground acceleration (PGA) for 10 % probability of exceedance in 50 years for reference rock soil (vs30 = 800 m/s).

This corresponds to PGA-values that return on average every 475 years.

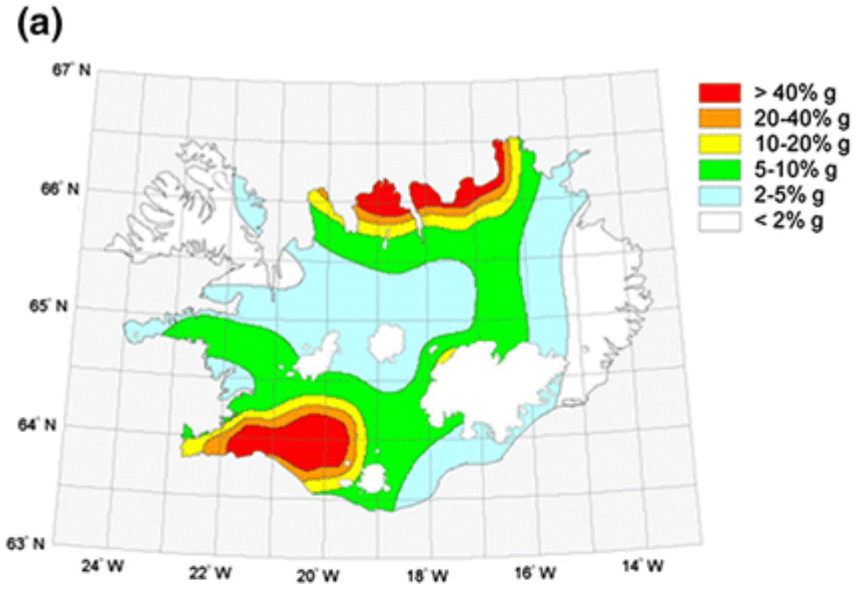


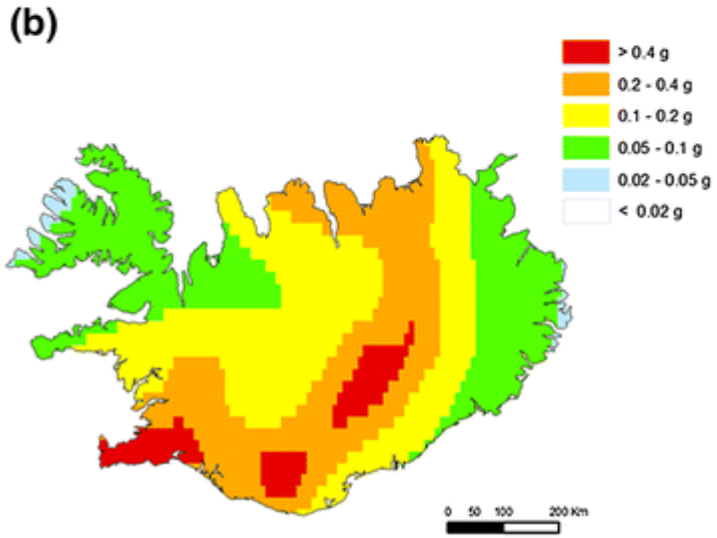
Largest observed magnitude in SSZs by adopting the CENEC catalog (Grünthal et al., 2009).





Number of earthquakes in each SSZ by adopting CENEC catalog (Grünthal et al., 2009).





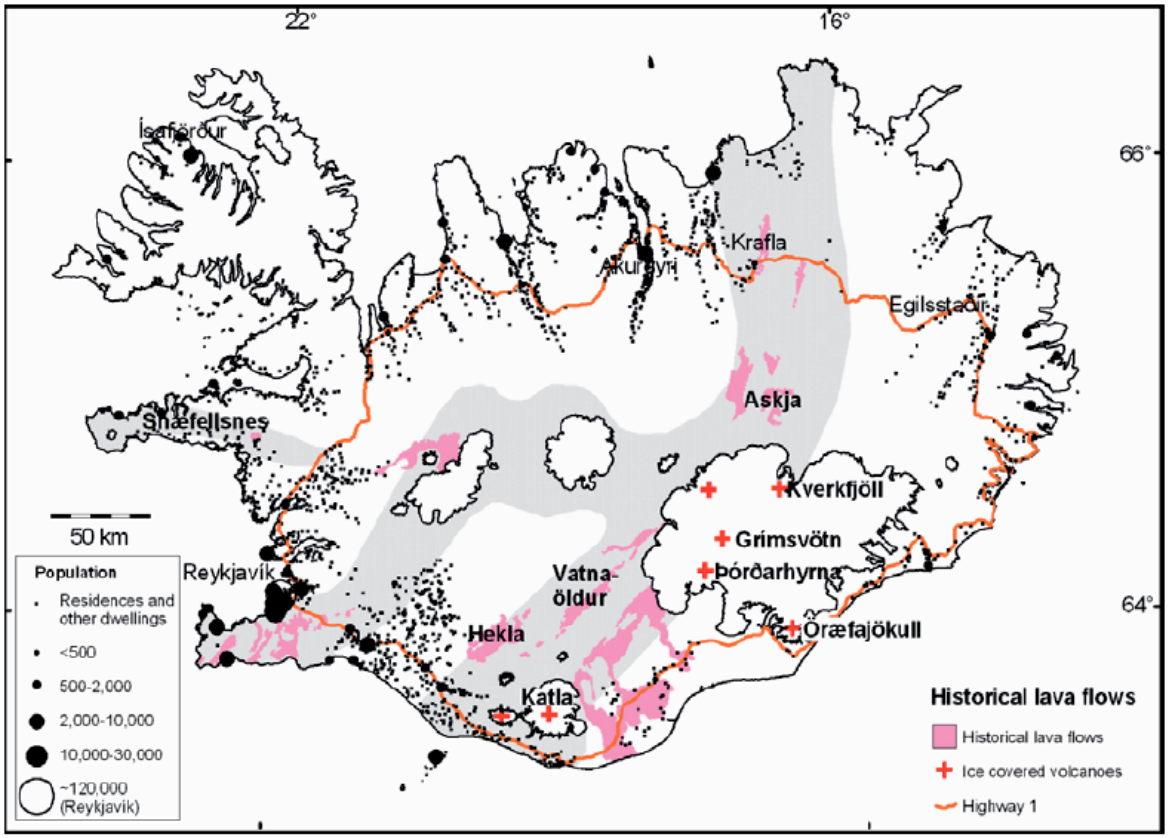
Hazard maps for Iceland in terms of PGA with exceedance probability of 10 % in 50 years provided by:

(a) Solnes et al. (2004), and

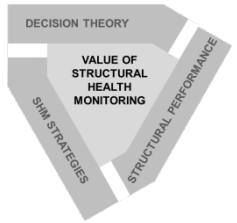
(b) SHARE project (Giardini et al. 2013).

Please note that in the original figure by Solnes et al. (here reproduced) the glaciers were plotted above the PGA colour layer by masking in some cases the actual hazard value.
For the sake of comparison, the colour scale of that figure was adopted also for the SHARE map

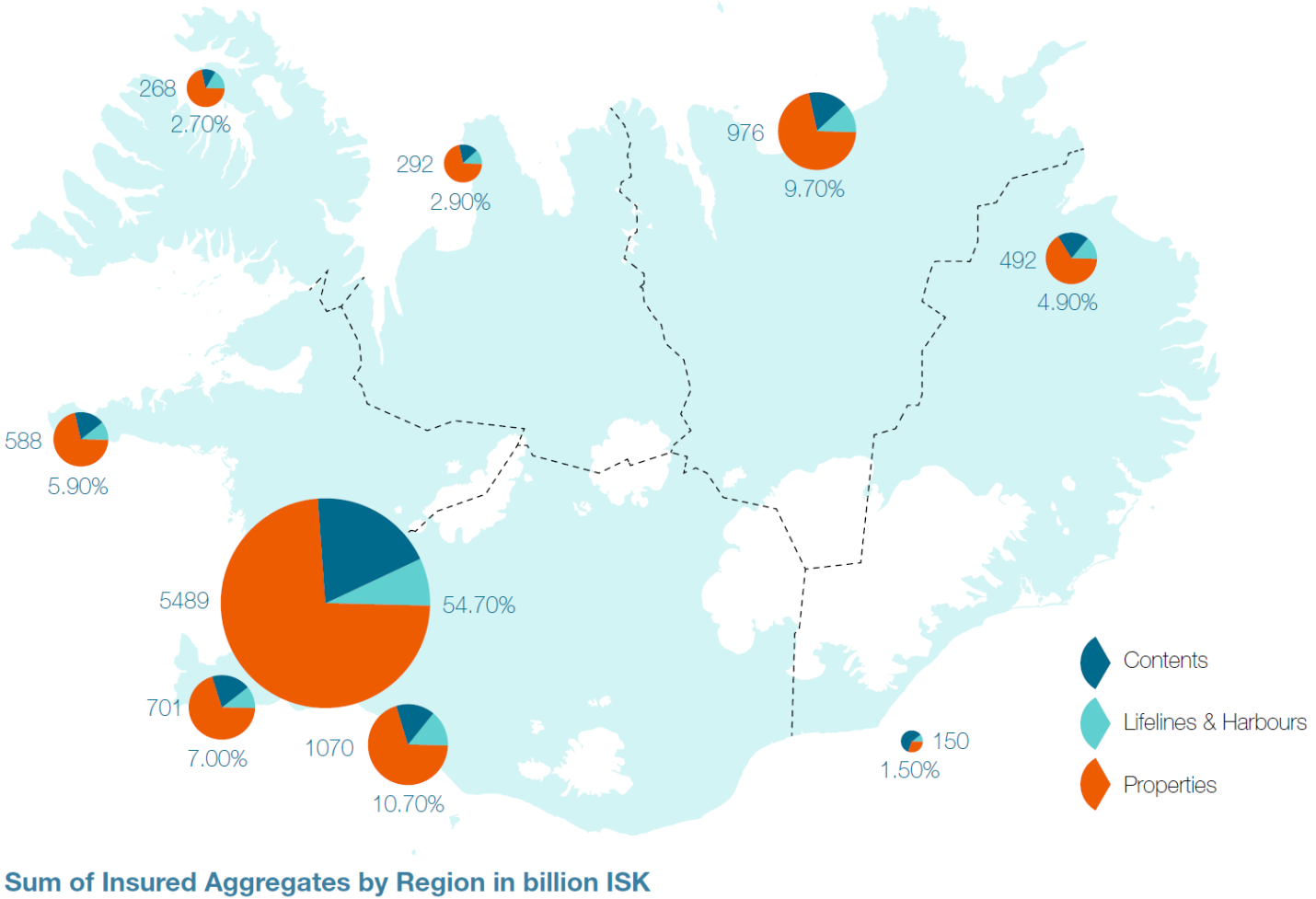
Population Density in Iceland

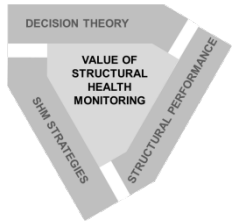


Guðmundsson et al (2008)

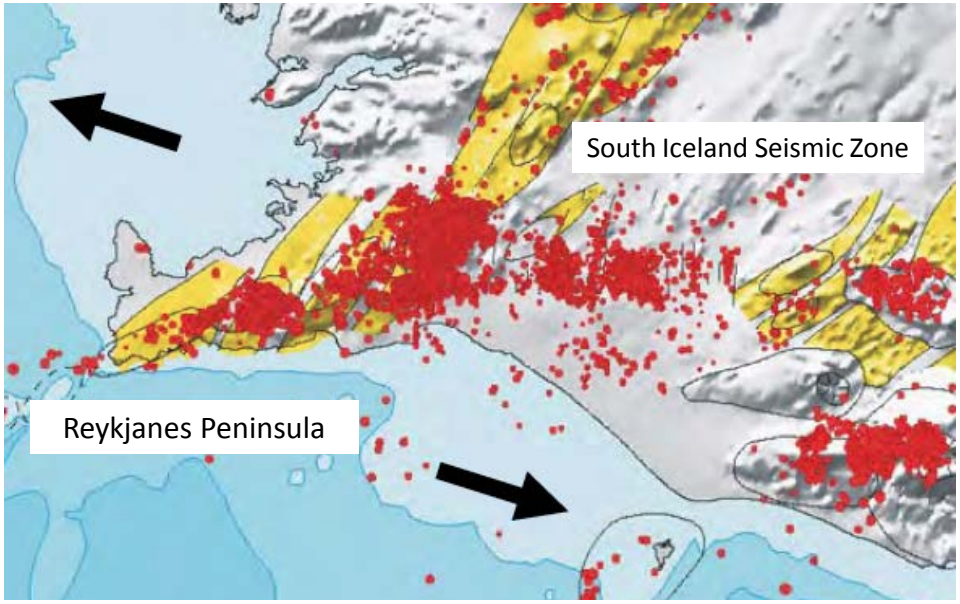


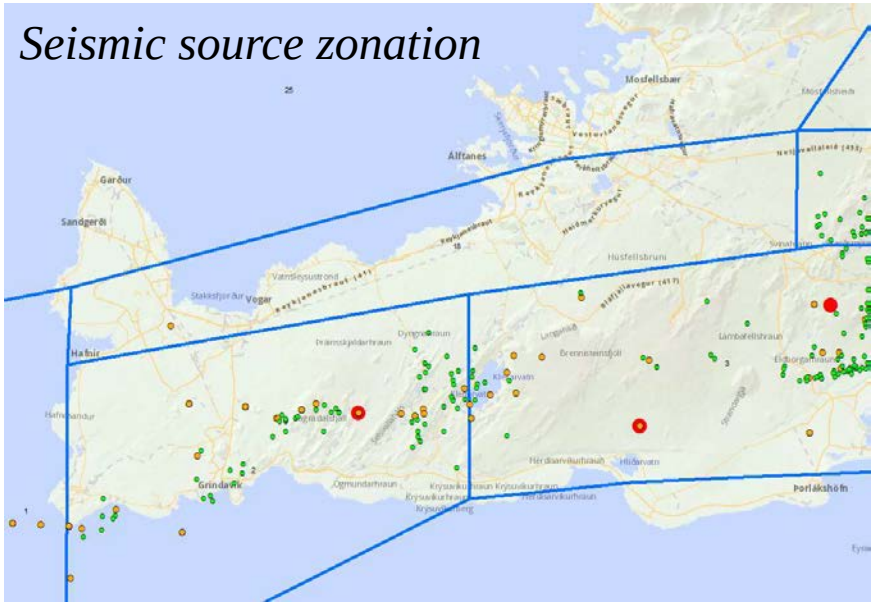
Value of Insured Aggregates by Region





Seismicity in the Reykjanes Peninsula and the Hengill Triple Junction

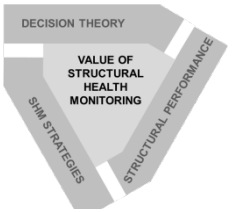




Reykjanes Peninsula

- Narrow seismic zone with shallow focus earthquakes
- Normal faulting
- Magnitude < 6

Hengill: A Triple junction between the Reykjanes Volcanic Zone, The Western Volcanic Zone, and the South Iceland Seismic Zone. Seismicity associated with the Hengill volcanic system and geothermal activity. (Magnitude < 5)



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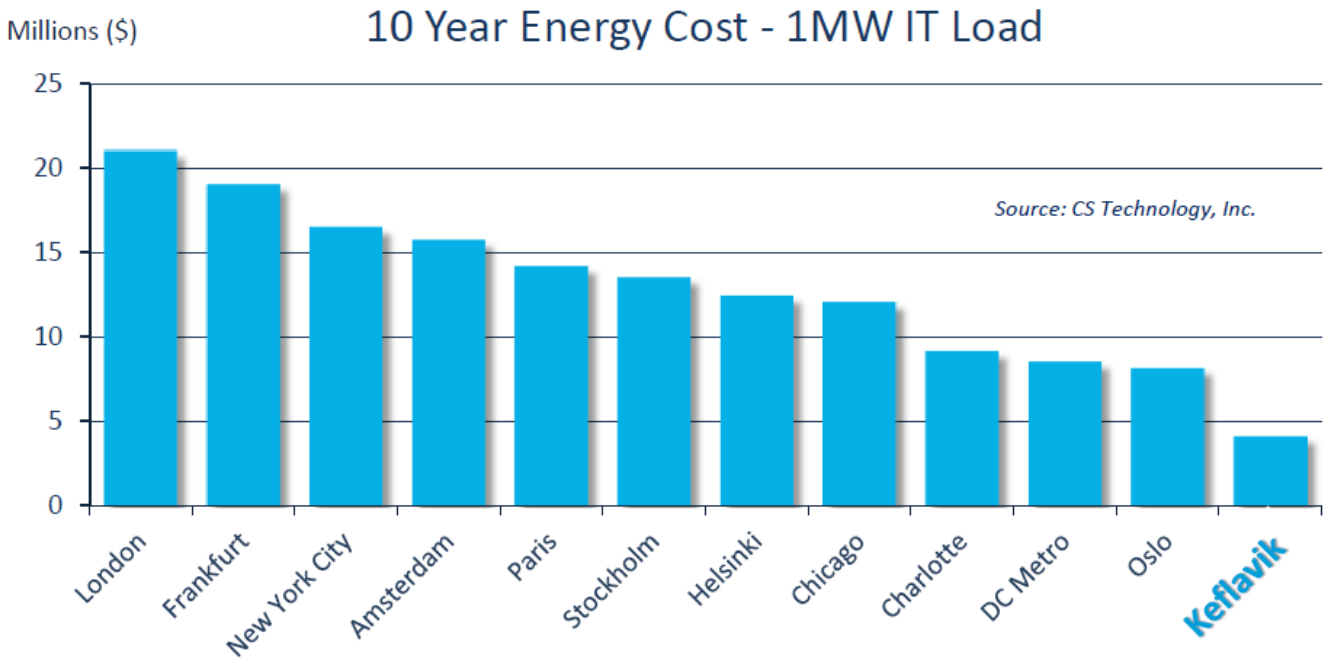
Energy Cost Comparison



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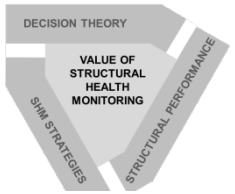
Is Iceland Poised to Become a Data Center Paradise?
IEEE Spectrum, Nov. 2014



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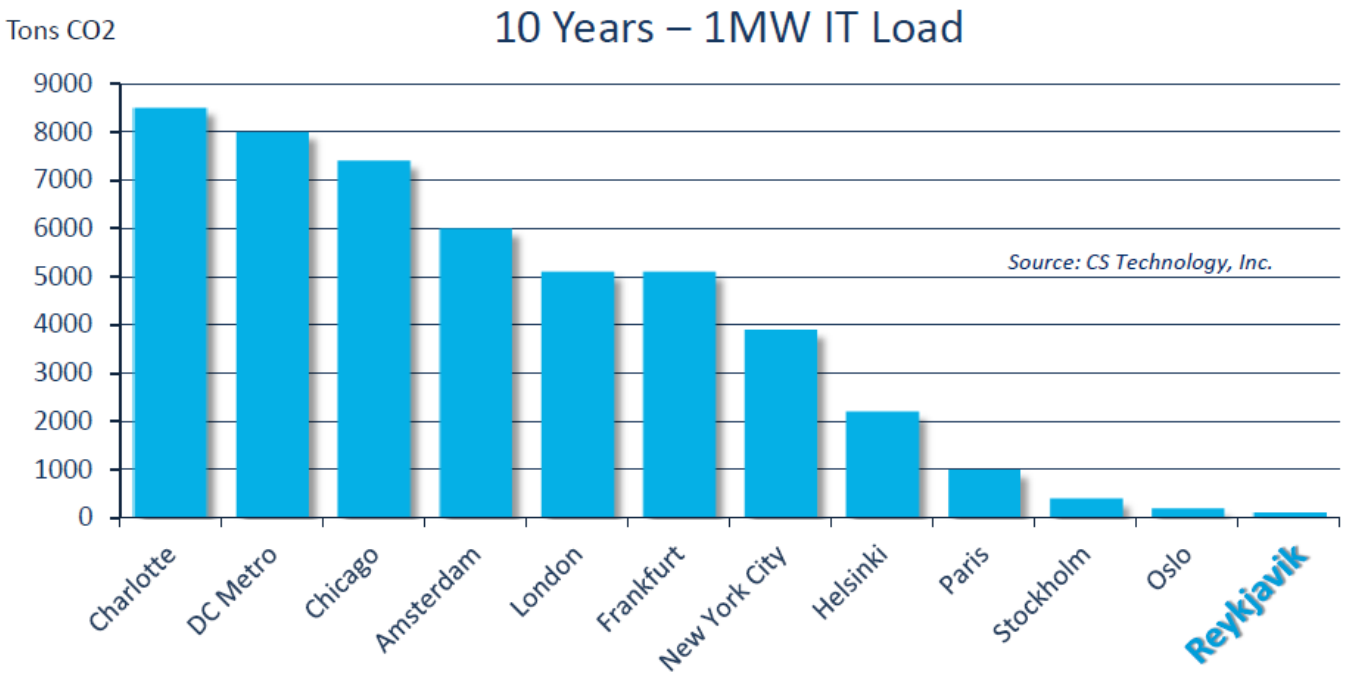
Carbon Footprint Comparison



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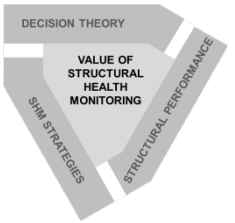
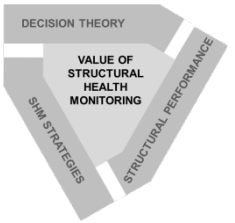
The world's silicon industry is aiming at rapidly increasing production in Iceland.
RJMM Multinational Holdings Inc, 2016.



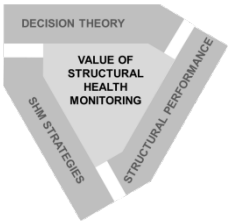
Information based on Strong Motion Monitoring

- The earthquake hazard in Iceland can be quantified as moderate on an international scale.
- It is fairly localized and primarily limited to the transfer zones in South and North Iceland and their immediate vicinity.
- The South Iceland earthquakes in 2000 and 2008 showed similar characteristics:
  - **Considerable spatial variation of ground motion peak parameters**
  - **High peak acceleration, partly due to local site conditions**
  - **Short duration of motion and**
  - **Rapid attenuation of motion with increasing distance to source.**
- In spite of considerable damage to buildings, their contents and utility systems, these recent events have demonstrated that buildings and installed equipment can reliable be designed to withstand the expected action.
- Electrical and telephone utilities operated uninterrupted during and after the earthquakes.



Final Remarks

- Valuable earthquake induced accelerometric data has been sampled in Iceland.
- The data has already been applied for various engineering purposes and will in future have further implications for the understanding of earthquakes and structural design.
- Strong motion recordings provide indispensable information for structural design and codification (*EUROCODE-8*)
- The data and the local expertise and experience developed through data monitoring, data analysis and related studies are important for the future development of infrastructure and industry through realistic assessment of the relevant Geohazard and the related risk.



Thank you for your attention!