Seismic and Tsunami Early Warning Activities in Iceland

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SIXTH FRAMEWORK PROGRAMME

2 Near-real-time fault mapping

A near-real-time relative relocation (double-difference) procedure is in development for the SAFER region of SW-Iceland (see main map). The method relies on pre-existing high-precision event locations, from which a library of waveforms is built. Each new event is then compared to the library via cross-correlation to obtain a high-precision location in near-real-time. Over 50,000 earthquakes have been relatively located in the SAFER region, some of which have enabled the mapping of ~100 faults. Using this approach, earthquakes can be associated with already mapped faults in near-real-time; additionally, new faults can be illuminated. If the new events are foreshocks, they may reveal the fault-plane of the on-comming larger earthquake.

Test results from three areas are shown below. At sites H and K extensive fault mapping has been performed, and at site (Á) an earthquake swarm is in progress due to magma movements. In all three areas, the relocation procedure significantly improves the original locations.

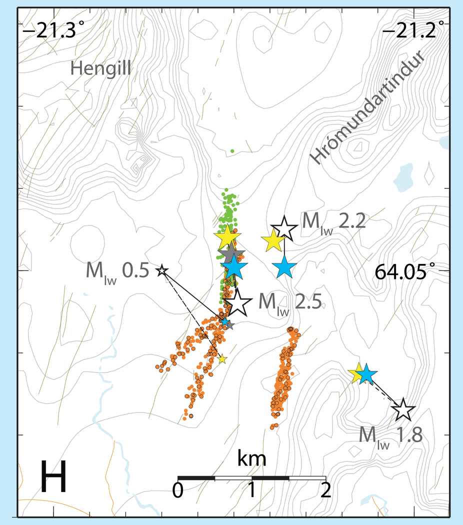


Figure 2.1. Hengill region showing mapped sub-surface faults (orange, green) and 4 test locations (stars), scaled by magnitude. The original, automatic location is shown in white, the relative location in blue, and the interactive location in yellow. Of the 160 library events (black circles), relative times from the 40 highest correlating events are inverted for the best location. Previously, two test events, shown in grey, were relatively located.

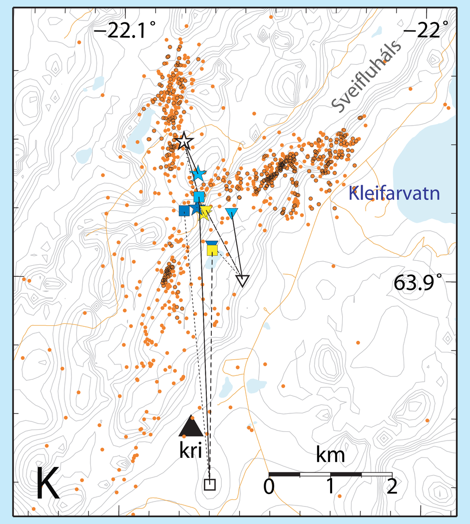


Figure 2.2. Kleifarvatn area, based on the colour scheme in Fig. 2.1. Three M 1.6 events are relocated using waveforms from 4 (light blue) and 8 (dark blue) closest stations, respectively. The 320 library events (black circles) have absolute location accuracy < 100 m. The procedure takes 4 minutes using 4 stations and twice as long using 8 stations. Further optimization will significantly decrease run-time.

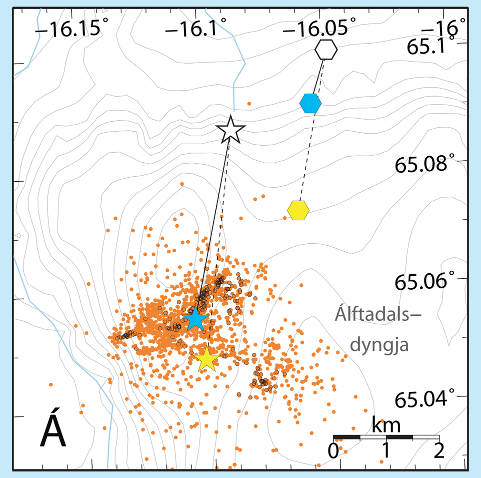


Figure 2.3. Álftadalsdyngja region, based on the colour scheme in Fig. 2.1. Waveforms from 4 closest stations are used to locate two M ~0 events. The library contains 200 events (black circles) at depths between 11 and 17 km. One event is originally at 1 km depth (star) but relocates to 15 km depth. The other event, originally at 5 km depth (hexagon), is drawn 1 km towards the library group and stays shallow.

3 Earthquake shake maps

For further details, see session: SM16-1WE5O-005

To provide data for near-real-time generation of shake maps, an algorithm has been installed on seismic stations. It reports values for peak ground velocity (PGV) and acceleration (PGA), when these significantly exceed the background level in any of four separate frequency bands. As soon as the first such report arrives at the processing centre, alert maps can be generated displaying the ground motion values as well as time information (Fig. 3.2 and 3.3).

Once the location and magnitude have been determined for the event, a shake map can be generated. In order to estimate the site effects on observed intensity, available information on near-surface lithology has been collected (Fig. 3.1).

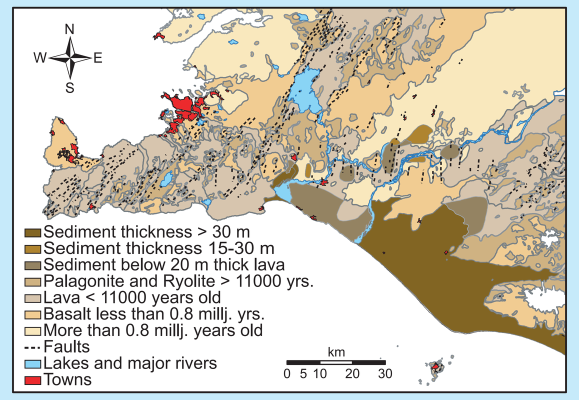


Figure 3.1. Surface geology of SW-Iceland, based on data from the Icelandic Institute of Natural History and Kristján Sæmundsson.

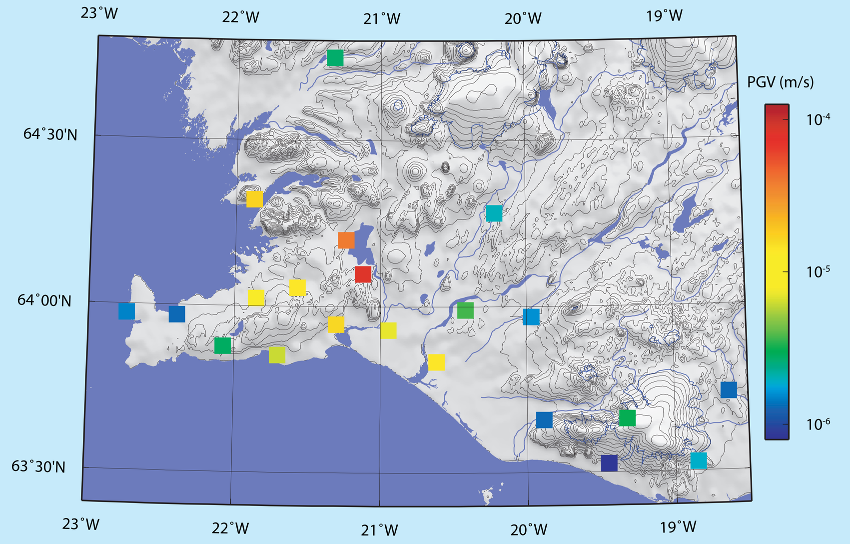


Figure 3.2. Map showing observed Peak Ground Velocity (m/s) for a M 1.9 event on April 1 2008.

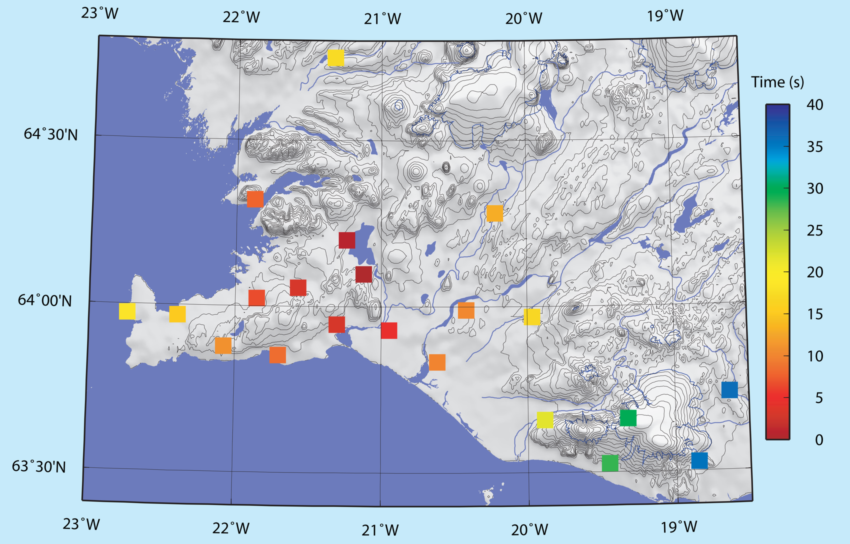


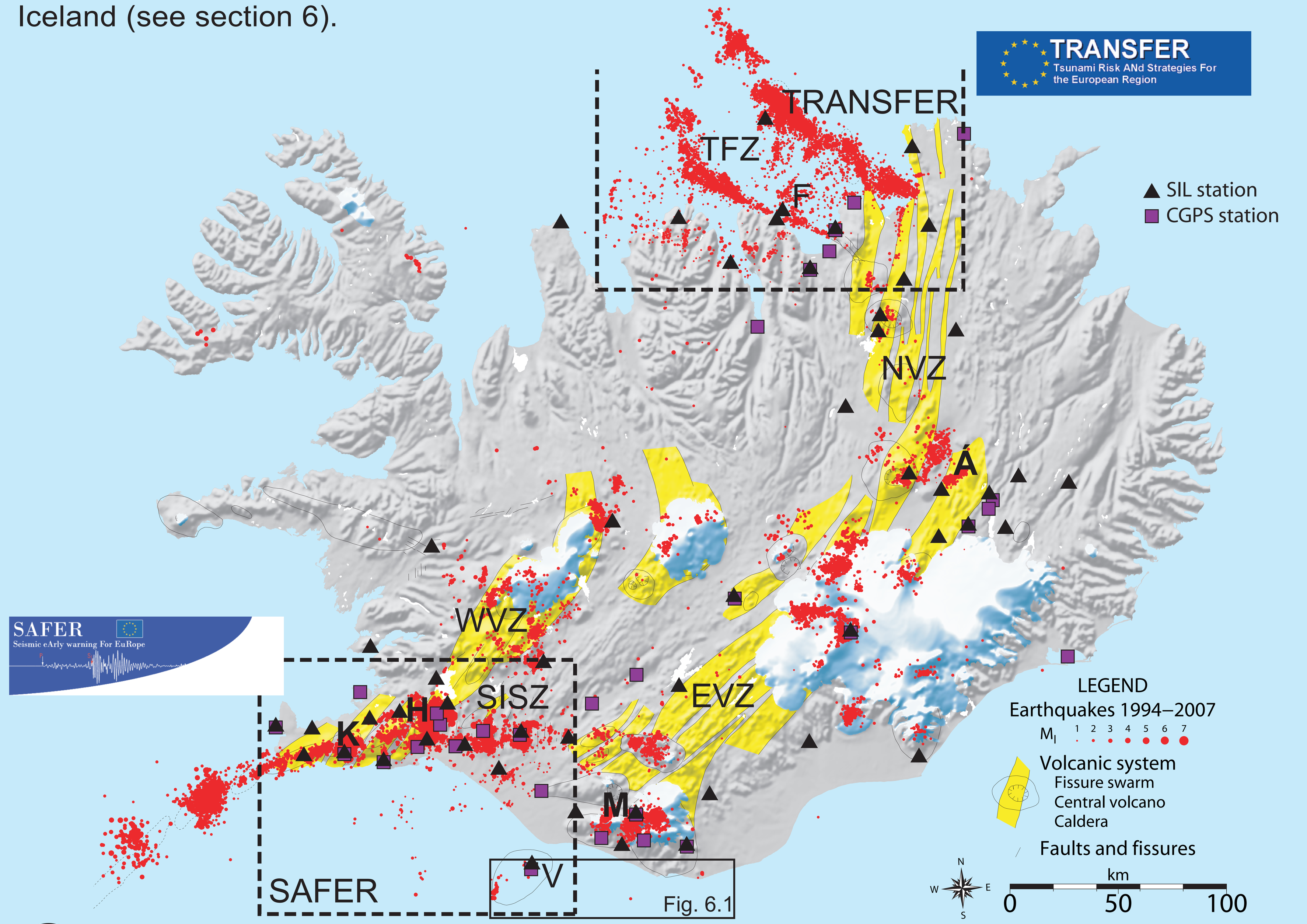
Figure 3.3. Map showing real-time of PGV, for M 1.9 event on April 1 2008.

1 Introduction

In Iceland, the Mid-Atlantic ridge is offset by two transform zones: the South Iceland Seismic Zone (SISZ) and the Tjörnes Fracture Zone (TFZ), as shown below. Historically, these zones have produced damaging earthquakes. In June 2000, two Mw 6.5 earthquakes struck the SISZ three days apart. Rifting takes place in the volcanic zones (WVZ, EVZ and NVZ).

To monitor seismic and volcanic activity, the Icelandic Meteorological Office (IMO) operates a 52-station digital seismic network (SIL), and a 30-station continuous GPS network.

Southwest Iceland is the focus of IMO's research in the SAFER project (see sections 2 - 5). In the TRANSFER project, IMO's research is centred on tsunami-related studies in northern Iceland (see section 6).



4 Crustal stresses and earthquake prediction

A common observation following a large earthquake is that areas experiencing a positive change in Coulomb failure stress (ΔCFS) exhibit increased seismicity. The predictive value of such an observation is limited by the lack of information of CFS values before the earthquake causing the change. However, if absolute CFS values are known, the predictive value of the method is increased. In the SISZ, stress-tensor and water-pressure fields can be estimated using micro-earthquakes. The resulting stress estimates turn the ΔCFS method into a full CFS method. This approach has been applied to the June 2000 earthquakes (Fig. 4.1 and 4.2).

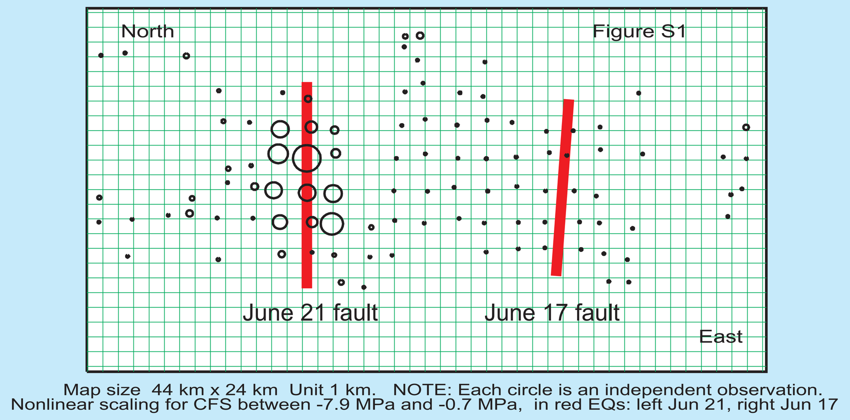


Figure 4.1. Median, absolute CFS values for Jan 1992 to June 17 2000. Circle size is proportional to absolute CFS on N-S, right-lateral strike-slip faults. The CFS ranges from -8 MPa to -0.7 MPa. The elastic increase in CFS at the epicentre of the J21 earthquake, caused by the J17 earthquake, is about 0.3 MPa. The 3-day delay of the J21 earthquake is most likely explained by water-flow effects due to the stress field change. Note the accurately anticipated location of the triggered J21 earthquake.

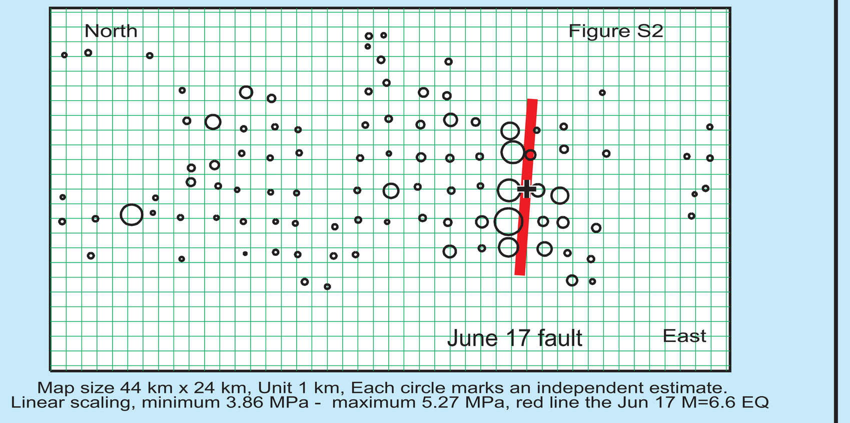


Figure 4.2. Median values of shear stress between Jan. 1992 and June 16 2000 in the same region as Fig. 4.1. The figure shows that the J17 event was an *asperity* earthquake. Note that the area of the large deviatoric stresses coincides with the position of the actual earthquake to within 1-2 km. Use of absolute crustal stresses in this manner will improve earthquake warnings.

For further details, see sessions: SM1-1MO3O-001 and NH5.1-1TH2O-004.

5 Real-time aftershock forecasting

Preparations for implementing aftershock hazard forecasting (STEP) are under-way. When completed time-dependent maps, published on the Web in near-real-time, will forecast in probabilistic terms the risk of site intensities reaching a given level.

In this initial stage we have derived new relations for attenuation of peak ground velocity (PGV) and acceleration (PGA) with distance, based on data from 46 earthquakes in SW-Iceland (Fig. 5.1). The attenuation relationships take into account near-field effects, which can be seen in Fig. 5.2 and 5.3 as the non-linear part of the curves representing the larger earthquakes.

Before curve-fitting, magnitudes were corrected for bias, by relying on events with well-determined magnitudes. The resulting PGV-distance relation can be used to correct underestimated event magnitudes.

The attenuation relations and new estimates of modified Mercally intensity (MMI) vs PGV and PGA (Fig. 5.4) will also be used for the shake-map application.

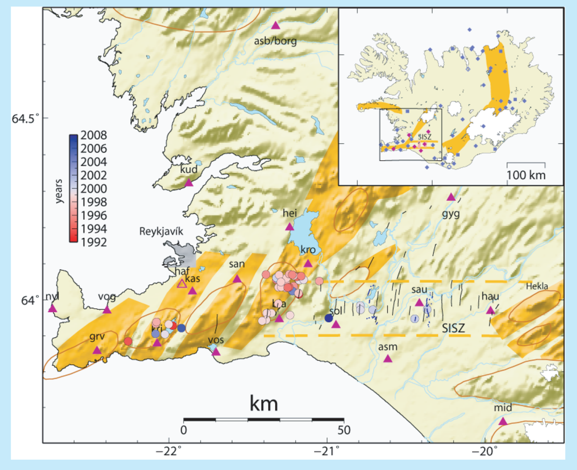


Figure 5.1. SW-Iceland, showing epicentres used for the attenuation relationships. Triangles denote the location of SIL stations.

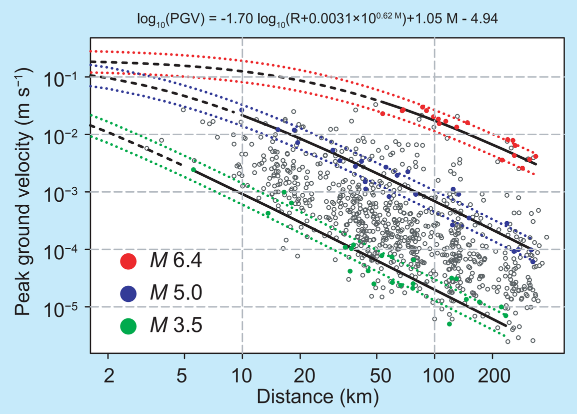


Figure 5.2. PGV observations (grey circles) from data in Fig. 5.1 as a function of distance. Three selected magnitudes are shown. The solid curves represent the fitted model to the three events. The dotted curves denote the 20% and 80% quantiles of the model residuals.

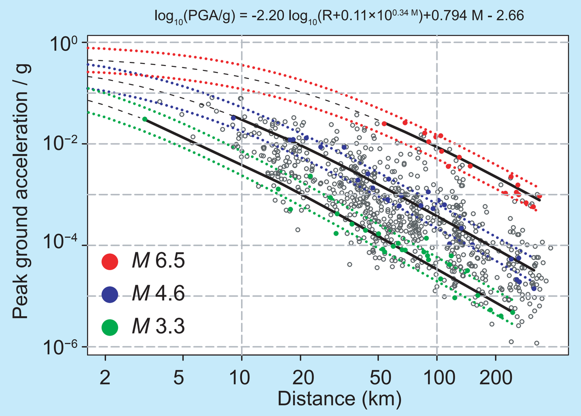


Figure 5.3. PGA values derived from velocity observations. Data from three events (different from those in Fig. 5.2) are highlighted. The solid curves represent the fitted model to the data. In the acceleration plot, the extrapolated curve of the 6.5 event is seen to go near 0.5g at its highest. Despite the lack of near-field observations from the largest earthquake, no weighting was needed to obtain this realistic value.

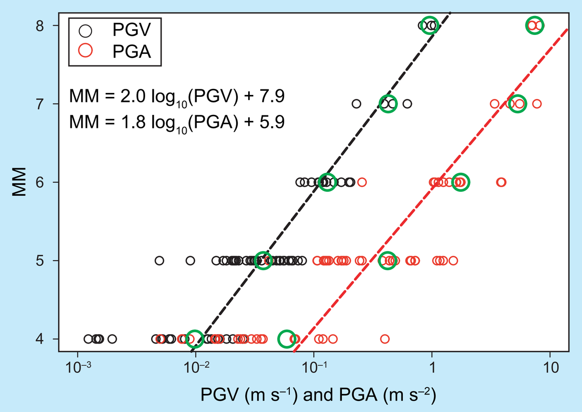


Figure 5.4. Mercally intensity as a function of PGV and PGA. The lines were fitted to the mean amplitude values (green) of the intensity classes.

6 Tsunami early warning research

Historically, localised tsunami hazards in Iceland have resulted from: (i) large, offshore earthquakes; (ii) glacial floods into coastal waters (Fig. 6.1); (iii) rockfalls into either coastal or inland water bodies; and (iv) snow and ice avalanches into coastal fjords. Additionally, coastal deposits show that ocean-crossing tsunami, such as that caused by the early Holocene Storegga submarine slide, have impacted Iceland. In 1755, an M ~7 earthquake triggered a small tsunami in the Tjörnes region (Table 6.1 and location 'F' on main map). Selected sources of tsunami are highlighted in Table 6.1.

Year	Source location Longitude (°)	Latitude (°)	Trigger	Affected region
1721	-19.1	63.6	Volcanic eruption	V
1755	-17.6	66.1	Earthquake	F
1896	-20.99 – -20.04	63.98	Earthquake	SISZ
1967	-19.6	63.7	Rockfall	M

Table 6.1. Selected, historic tsunami in Iceland. Abbreviated regions are shown in the main map.

Our aim is to estimate the source parameters of large, offshore earthquakes in near-real-time; this work will involve adapting the SAFER early-warning algorithms to the TFZ region. Using the relocation method (section 2), we aim to identify faults capable of generating hazardous earthquakes. To further constrain source estimates we will expand the SIL network using real-time data from other seismic networks; additionally, we will also increase the resolution of the continuous GPS network (see main map) via high-rate sampling of crustal deformation.

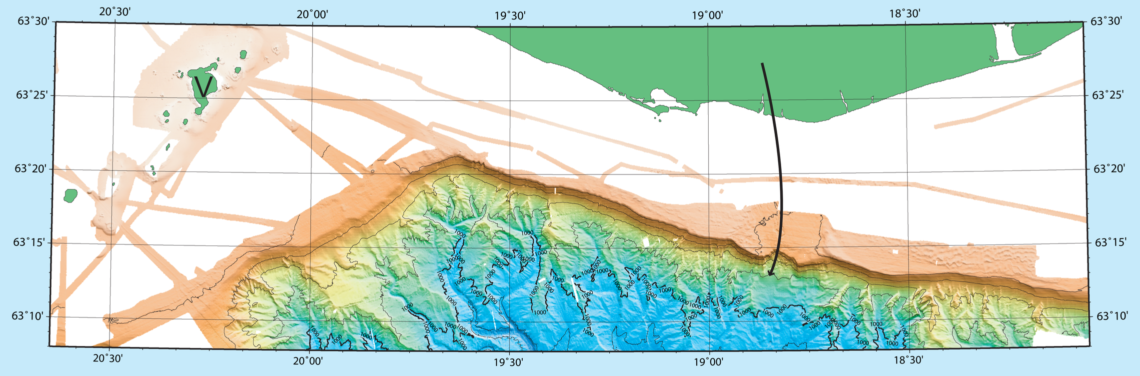


Figure 6.1. Near-shore bathymetry south of Mýrdalsjökull (see main map). The arrow outlines the route of glacial floods entering the near-shore environment. In 1721, a glacial flood caused a small tsunami that reached the Vestmannaeyjar islands (V).