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ORIGINAL PAPER

Usage of an early warning and information system Web-site for real-time seismicity in Iceland

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Abstract Iceland has been subjected to destructive earthquakes and volcanic eruptions throughout history. Such events are often preceded by changes in earthquake activity over varying timescales. Although most seismicity is confined to micro-earthquakes, large earthquakes have occurred within populated regions. Following the most recent hazardous earthquakes in 2000, the Icelandic Meteorological Office (IMO) developed an early warning and information system (EWIS) Web-site for viewing near-real-time seismicity in Iceland. Here we assess Web-site usage data in relation to earthquake activity, as recorded by the South Iceland Lowland (SIL) seismic network. Between March 2005 and May 2006 the SIL seismic network recorded 12,583 earthquakes. During this period, the EWIS Web-site logged a daily median of 91 visits. The largest onshore event (M_L 4.2) struck 20 km from Reykjavík on 06 March 2006 and was followed by an immediate, upsurge in usage resulting in a total of 1,173 unique visits to the Web-site. The greatest cluster of large ($\geq M_L$ 3) events occurred 300 km offshore from Reykjavík in May 2005. Within this swarm, 9 earthquakes $\geq M_L$ 3 were detected on 11 May 2005, resulting in the release of a media bulletin by IMO. During the swarm, and following the media bulletin, the EWIS Web-site logged 1,234 unique visits gradually throughout the day. In summary, the data reveal a spatial and temporal relationship between Web-site usage and earthquake activity. The EWIS Web-site is accessed immediately after the occurrence of a local earthquake, whereas distant, unfelt earthquakes generate gradual interest prompted by media bulletins

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and, possibly, other contributing factors. We conclude that the Internet is a useful tool for displaying seismic information in near-real-time, which has the capacity to help increase public awareness of natural hazards.

Keywords Early warning · Web-site usage · Seismicity · Iceland

1 Introduction and aims

The Internet is a powerful tool for broadcasting near- and real-time hazard information to, potentially, an almost global audience (Anderson 2003). Hazard information Web-sites are accepted as an essential and increasingly indispensable tool for scientists, emergency managers and residents (Rohrmann 2007). Across the World Wide Web there are many sites that act as research and communication platforms by providing up-to-date information on earthquake activity (e.g. http://earthquake.usgs.gov/; http://www.emsc-csem.org/; http://www.iris.edu/). These Web-sites carry a range of earthquake information such as near-real-time seismic data, seismic catalogues, seismic hazard maps, shake maps and earthquake preparedness and response strategies. However, publishing hazard information does not necessarily mean that the information has been communicated effectively to interested stakeholders and users (Krishnan 2005; Hampel 2006). Usage statistics are a revealing measure of Web-site utilisation, particularly in relation to national levels of seismicity. Such statistics are relatively straightforward to acquire and provide insight into the performance of the site and the public's interaction with it (Bauer 2000; Guenther 2003; van der Heijden 2003; Steyaert 2004; Welch 2005). Therefore, in order to determine if access to hazard information is taking place, the first step for Web-site managers is to assess when and how often the site is accessed.

Historically, geologic hazards are common in Iceland, with one hazardous earthquake and two volcanic eruptions occurring per decade, on average (Sigmundsson 2006). Following damaging earthquakes that struck southwest Iceland in June 2000 (Stefánsson et al. 2000), the Icelandic Meteorological Office (IMO) began work on a Web-site for viewing near-real-time earthquake activity using results from the South Iceland Lowland (SIL) national seismic network (Bödvarsson et al. 1996). The Web-site was developed under the acronym EWIS: Early Warning and Information System, and the goal was to provide a portal from which users and interested stakeholders may access the latest seismic information. The EWIS Web-site uses GIS technology to display earthquake epicentres recorded by the SIL seismic network. Such online resources help users to recognise earthquake hazards, thereby potentially improving public awareness (Dunbar 2007).

Here we present usage statistics for the EWIS Web-site which became operational in February 2005 to May 2006. The aim of this research is to assess when and how often the site is being accessed, and to determine if there is a spatial or temporal relationship between Web-site usage and earthquake activity. To achieve this, we compare increase in Web-site activity in relation to seismicity. Our article begins with a summary of the geology and tectonics of Iceland, followed by an outline of population statistics and Internet penetration in Iceland. We outline the structure and function of the EWIS Web-site, before presenting and evaluating earthquake and Web-site usage data.

2 Geology and tectonics of Iceland

Straddling the Mid-Atlantic Ridge (MAR), Iceland owes its presence to anomalously high levels of volcanism due to the interaction of the MAR with a mantle plume, which is centred beneath Iceland (Sigmundsson 2006). Since the MAR represents a divergent plate boundary, the Icelandic crust is subject to tensional stresses imposed by plate-spreading and rifting episodes (Geirsson et al. 2006). Consequently, earthquakes and volcanic eruptions within the rift-zone are common and have resulted in the formation of approximately 35 volcanic systems (Thordarson and Larsen 2007).

Offshore, the MAR is manifested by the Kolbeinsey Ridge (KR) to the north of Iceland and by the Reykjanes Ridge (RR) to the southwest (Einarsson 1991) (Fig. 1). Onshore, the MAR comprises a series of interacting seismic and volcanic zones. The seismic zones begin with the Reykjanes Peninsula (RP) located in the southwest, pass through the Hengill Triple Junction (HTJ) and the South Iceland Seismic Zone (SISZ) and continue into the Tjörnes Fracture Zone (TFZ) in the north (Einarsson 1991). The southern and northern segments of these zones interact with the RR and the KR, respectively.

Present-day seismicity in Iceland is confined mostly to micro-earthquakes (i.e. $\leq M_L$ 3; Jakobsdóttir et al. 2002). However within the SISZ alone, 37 destructive earthquakes have taken place since 1164 AD (Clifton and Einarsson 2005). During the first operational decade—1991 to 2000—of the SIL seismic network, over 160,000 earthquakes were detected within Iceland and the surrounding offshore zones (Jakobsdóttir et al. 2002).

Earthquakes occur frequently in the HTJ, the SISZ and the TFZ. Typically, earthquake swarms coincide with the accumulation of magma at shallow depths, sometimes leading to

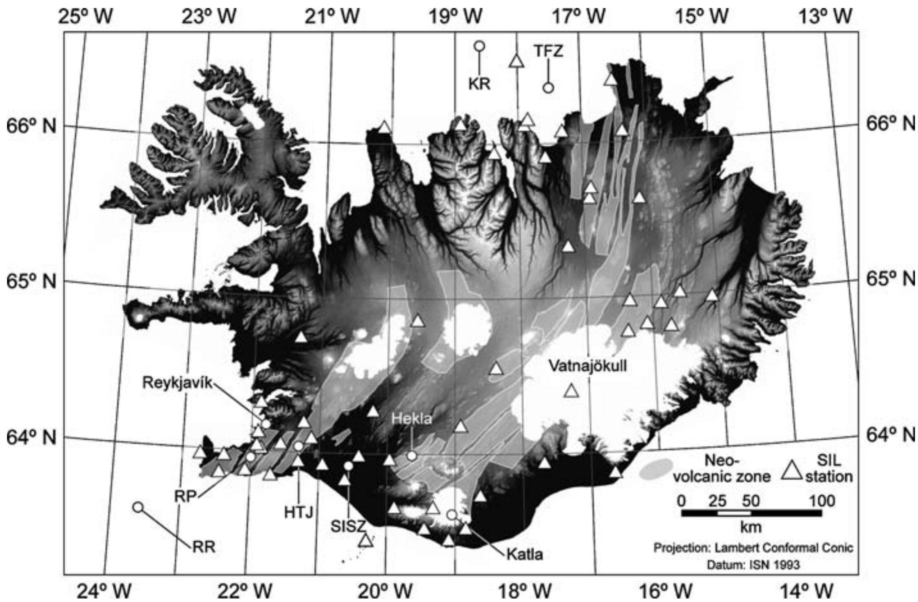


Fig. 1 Tectonic setting of Iceland, depicting the neo-volcanic and seismic zones, the volcanoes Hekla and Katla and the Vatnajökull ice-cap. The labelled seismic zones comprise the Reykjanes Ridge (RR), the Reykjanes Peninsula (RP), the Hengill Triple Junction (HTJ), the South Iceland Seismic Zone (SISZ) and the Tjörnes Fracture Zone (TFZ). Note that the abbreviated labels denote the location of each seismic zone but not its extent; for further information, see Einarsson (1991)

volcanic eruptions (Sigmundsson et al. 1997; Sturkell et al. 2006). Additionally, Hekla and Katla—two volcanoes renowned for frequent, destructive eruptions—parallel the SISZ (Fig. 1).

3 Population statistics and Internet penetration in Iceland

In December 2005, Iceland's population was 2,99,891, of which 62.5% live in the capital region of Reykjavík and 7.5% (22,413 citizens) live in the region encompassing the SISZ (Statistics Iceland 2006a). Since 2000, when the last damaging earthquakes occurred in this region, the population has increased by 6.1% (Statistics Iceland 2006a). Furthermore, this region has become a popular tourist destination.

Computer and Internet usage in Iceland is exceptionally high. Eighty-three percent of households are connected to the Internet, of which 85% have high-speed connections (Statistics Iceland 2006b). Statistics Iceland (2006b) reports that almost 90% of Icelandic citizens between the ages of 16 and 74 are Internet users and, of these, 80% use the Internet daily. Moreover, 79% of users interact with public authorities via the Internet, whilst a further 8% are interested in doing so.

4 EWIS Web-site: structure and function

The EWIS project uses a time-dependent GIS to unite seismic data with other relevant spatial information on the project's Web-site (Figs. 2 and 3). The goal of the EWIS project is to provide a publicly accessible display of nationwide seismicity, based on up-to-date results from the SIL seismic network (Roberts et al. 2005). Typically, instrumentally detected earthquakes are displayed automatically on the EWIS Web-site within 10 min of their occurrence. The initial map on the EWIS Web-site contains 48 h worth of observations that span the entire detection range of the SIL seismic network: that is, $M_L - 1$ and greater, where M_L denotes the local magnitude for earthquakes in Iceland. Aside from the default, small-scale map (Fig. 2), users can obtain further geographic information by changing the scale of the map. Additionally, seismic data can be visualised in time-series graphs and portions of data can be downloaded in ASCII format from the Web-site for separate analysis.

The public version of the EWIS Web-site was released in Iceland on 11 February 2005 and the site has remained on line since. Known in Icelandic as *Skjálftavefsjá*, the public version of the Web-site is restricted to an Icelandic version available via the home-page of the IMO Physics Department (http://hraun.vedur.is/ja). Alternatively, the site can be accessed directly from http://drifandi.vedur.is/skjalftavefsja/index.html.

5 Methods

Our analysis included three separate datasets: (1) usage data from the EWIS Web-site; (2) seismic data from the SIL seismic network and (3) details of media bulletins issued by IMO. All datasets were obtained for the study period from 01 February 2005 to 31 May 2006. We will discuss each dataset separately before describing the methods used to analyse the combined data.

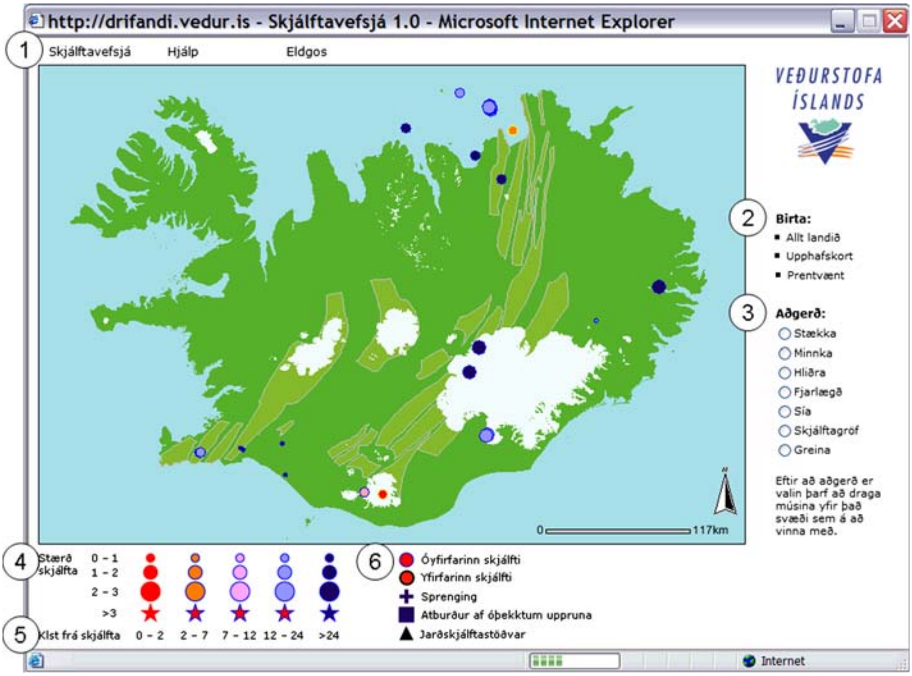


Fig. 2 Home page of the EWIS Web-site. The circled numbers refer to the following features: (1) Drop-down menus and map displaying recent earthquakes registered by the SIL seismic network. Note that the filled circles signify epicentres, sized in relation to their magnitude. (2) Display options. (3) Map tools and graphing options, including functions for changing the scale of the map and for measuring distances. (4) Legend for earthquake epicentres; events greater than M_L 3 are denoted by a star, otherwise a circle. (5) Legend to explain the age of the earthquake in hours; events older than 24 h are identified by blue circles. (6) Legend representing type of seismic event (e.g. automatically or manually located earthquake, man-made explosion and unknown event) and seismic station

The Web-server hosting the public version of the EWIS Web-site was equipped with the freely available *AWStats* program, designed to monitor Web traffic (see: http://awstats.org). For each unique visit, the software logs the time, date, duration, number of pages visited and the user's Internet protocol (IP) address. In our analysis, we retrieved information on the number of unique visits and the time and date of all logged IP addresses. A unique visit is recorded as at least one hit to the Web-site from a host during a 24-h period. Therefore, repeated visits from the same host during this period are not included in the daily total.

The logged IP address will indicate the host's geographic location. In order to determine this information, a custom-made 'bespoke' program was written to identify the country pertaining to each IP address. However, counting unique IP addresses can be problematic. For example, Internet service providers (ISP) and companies implement a range of methods, such as dynamic ISP addressing, to skew the analysis (Jana and Chatterjee 2004). Furthermore, not all unique, daily visits to the EWIS Web-site logged an IP address. A variety of privacy protection and anonymity services will allow the user to block personal information and numerous computers can be masked behind one IP address. See Oppliger (2000) for a description of privacy protection and anonymity services for the Internet. Aside from these shortcomings, IP addresses can be used as a guide to the location of Web-site visitors.

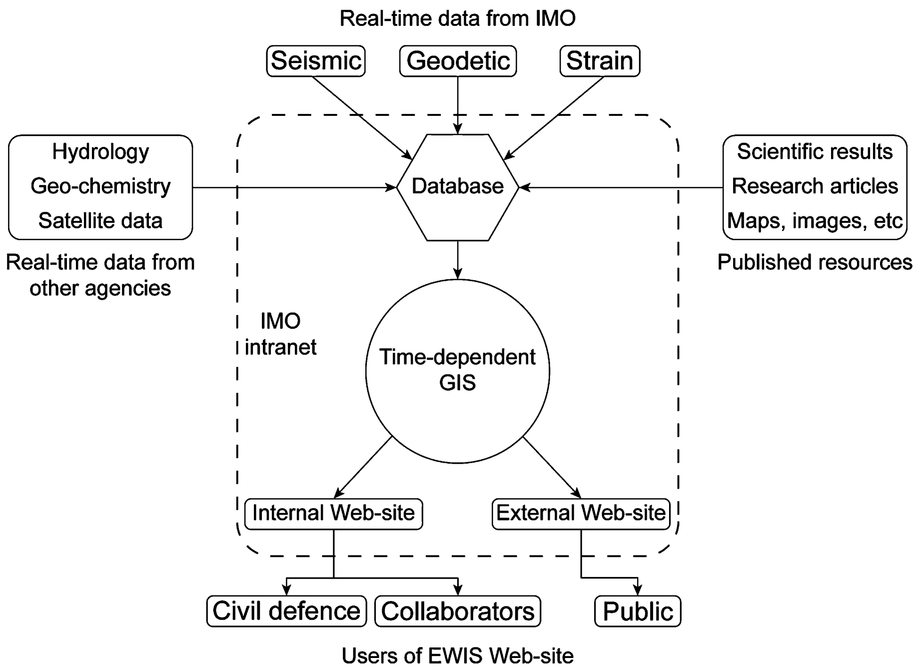


Fig. 3 Flow diagram explaining the flow of data into and out of the EWIS system, and the dual role of the EWIS Web-site as a platform for scientific and public communication of seismic hazards

Earthquake data, recorded by the SIL seismic network, were extracted from the SIL database via structured query-language statements over time-spans for which Web-site statistics existed. These data included the time, date, latitude, longitude and local magnitude of all instrumentally detected earthquakes. The data were subsequently analysed using *ESRI ArcGIS*™ software.

Media bulletins are issued in response to either single earthquakes in excess of M_L 3 or to seismicity that might lead to an imminent volcanic eruption (see Vogfjörd et al. 2005). In the former case, statements are confined to earthquakes sourced on land or within about 100 km of the coast. Consequently, some larger earthquakes within the study period go unreported due to their remote locations. Bulletins are sent to the news desks of Iceland's media agencies as concise email messages, detailing the time, location and size of the earthquake. The same information is posted as public news on the IMO Web-site, usually within an hour of the bulletin being issued. The lag-time between registering seismic data and releasing a bulletin to media agencies is about 45 min for earthquakes that may have been felt by the public. There is a longer delay for earthquakes that are unlikely to have been felt by the public.

A preliminary analysis of the EWIS usage data and the SIL seismic data included the creation of an epicentral map of all earthquakes during the study period and time-series graphs of seismicity and Web-site usage. Additionally, regression tests were performed to assess the dependence of earthquake activity on Web-site usage.

Additional analysis was undertaken on the three days with the greatest increase in daily Web-site usage. First, we produced epicentral maps for each selected date. On these maps, a buffer zone with an arbitrary 50-km radius was defined around epicentres $\geq M_L$ 3. On the modified Mercalli scale of earthquake intensities, the minimum intensity at which humans can detect seismicity is MM II (Wood and Neumann 1931). In Iceland, for distances $\leq$50 km from the source of an earthquake, the minimum magnitude necessary for MM II intensity is likely to be M_L 3 (Halldórsson 1992). However, this threshold often varies in response to earthquake location, focal mechanism, site effects and varying levels of perception (Wood and Neumann 1931). Second, cumulative plots of earthquake activity and Web-site usage were compiled to explore the relationship between seismicity and site usage.

6 Results

First, we present the distribution of earthquakes during the study period, followed by the EWIS usage data. Next, we assess the dependence of Web-site usage on earthquake activity and compare this to the release of media bulletins. We then present Web-site usage and earthquake data for the three days that recorded the greatest daily total of Web-site visits during the study period.

6.1 Spatial and temporal distribution of earthquakes during the study period

From 01 March 2005 to 31 May 2006, the SIL seismic network recorded 12,583 earthquakes. The spatial distribution and magnitude classes of these events are shown in Fig. 4. Nearly all earthquakes were concentrated in Iceland's seismic and volcanic zones highlighted in Fig. 1. Over 99% of earthquakes were $<M_L$ 3; only 0.94% were $\geq M_L$ 3. The largest event, which occurred on 12 November 2005, registered M_L 4.4 and was located offshore approximately 550 km NNE from Reykjavík on the Kolbeinsey Ridge. Two other earthquakes registering M_L 4.4 and 4.3 occurred on 19 October 2005 more than 900 km from Reykjavík. The largest onshore event, located on the Reykjanes Peninsula, registered M_L 4.2 and it occurred on 06 March 2006.

In Fig. 5a, we plot the total number of daily earthquakes of M_L −1 to 4.4 from 01 March 2005 to 31 May 2006. This activity yielded a total seismic moment of 2.82×10^{16} Nm. Included in the total of 12,583 were 118 earthquakes $\geq M_L$ 3. Their temporal distribution is shown in Fig. 5b. The greatest total, daily, earthquake rate occurred on 04 November 2005. The greatest cluster of large events ($\geq M_L$ 3) recorded by the SIL seismic network occurred on 11 May 2005 when nine earthquakes took place on the Reykjanes Ridge. The location of this activity is illustrated in Fig. 4.

6.2 Site usage and geographic provenance of users

Between 01 February 2005 and 31 May 2005, the EWIS Web-site received 54,676 unique visits. Figure 6 presents summed, daily visits to the EWIS Web-site and the cumulative number of visits during the study period. Web-site visits during February 2005 are included in Fig. 6 to show the increase in usage following media coverage of the site's public release. Excluding usage during the first week of public availability, which was influenced strongly by media coverage, the site reached maximum levels of daily usage on 11 May 2005, 22 June 2005 and 06 March 2006 (Fig. 6). On these days, unique visits numbered

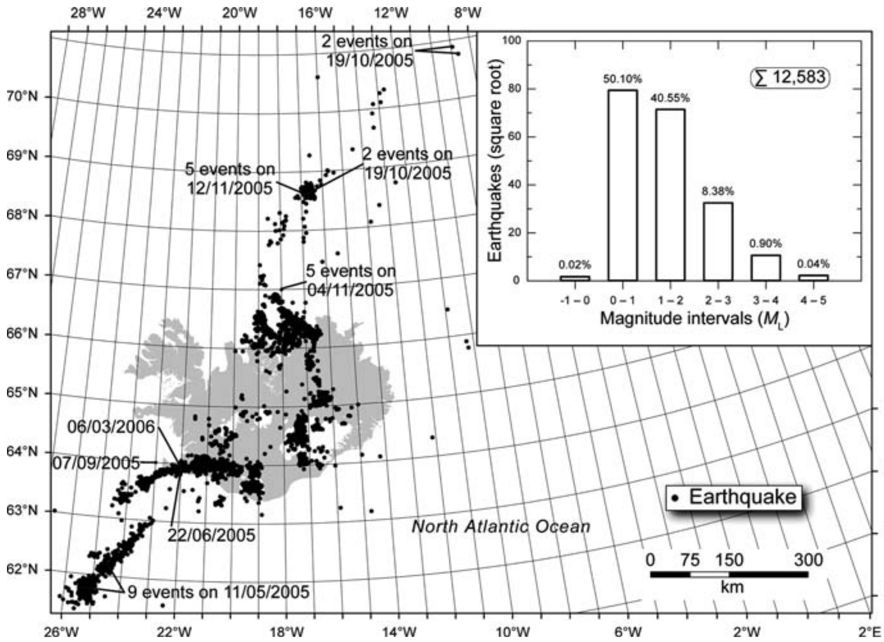


Fig. 4 From 01 March 2005 to 31 May 2006 12,583 earthquakes occurred in Iceland, mostly within the neo-volcanic and seismic zones depicted in Fig. 1. Labelled earthquakes are described in subsequent figures. Note that the lineation depicted by epicentres south of 63° N is offset to the east slightly due to inaccuracies in the location of earthquakes sourced from outside the SIL network. The inset histogram shows the frequency of earthquake magnitudes recorded during the study period. Labelled events are described further in Table 1

1,234, 551 and 1,173, respectively. During the monitoring period, the median number of daily visits was 91.

The geographic provenance of 26,197 unique visits to the EWIS Web-site was determined: 81.4% of visits originated in Iceland; 4.2% originated in the United States and 2.3% of visits originated in Germany. The remaining 12.1% are attributable to 64 other countries.

6.3 Earthquake activity, Web-site usage and media bulletins

In this section, we assess the dependence of usage of the EWIS Web-site on earthquake activity over the study period and compare this to the release of media bulletins. Figure 7 illustrates summed, daily Web-site visits measured against daily earthquake rate. The scattergram shows dense clustering of points about a centroid ($x = 30$; $y = 107$), and many outlying pairs that do not scale uniformly. Given that each value is consistently precise, the outlying data cannot be disregarded. The slope of the least squares regression line ($R^2 = 0.19$) in Fig. 7 explains 19% of the variance in Web-site visits. For the size of the dataset ($n = 457$), this association, although weak, is significant at the 95% confidence level, despite non-uniform scattering. Likewise, a weaker, albeit still significant correlation at the 95% confidence level ($R^2 = 0.13$) exists between increasing earthquake size and increasing Web-site usage (Fig. 8).

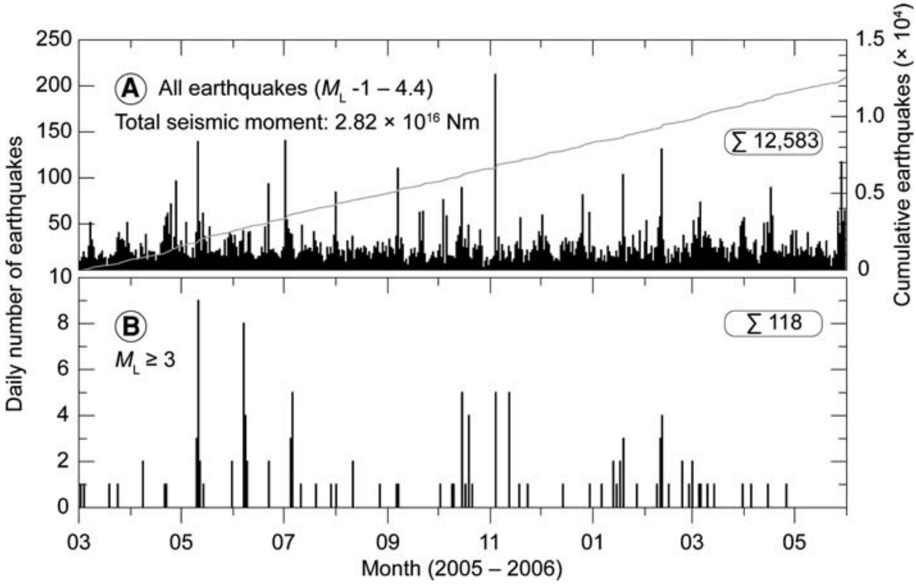


Fig. 5 (**a**) Temporal distribution of all earthquakes. A total of 12,583 earthquakes with a M_L of −1 to 4.4 occurred between 01 March 2005 and 31 May 2006 creating a total seismic moment of 2.82 × 10^{16} Nm. The grey line denotes the cumulative number of earthquakes. (**b**) Temporal distribution of earthquakes $\geq M_L$ 3 between 01 March 2005 and 31 May 2006. During this period 118 earthquakes $\geq M_L$ 3 were recorded

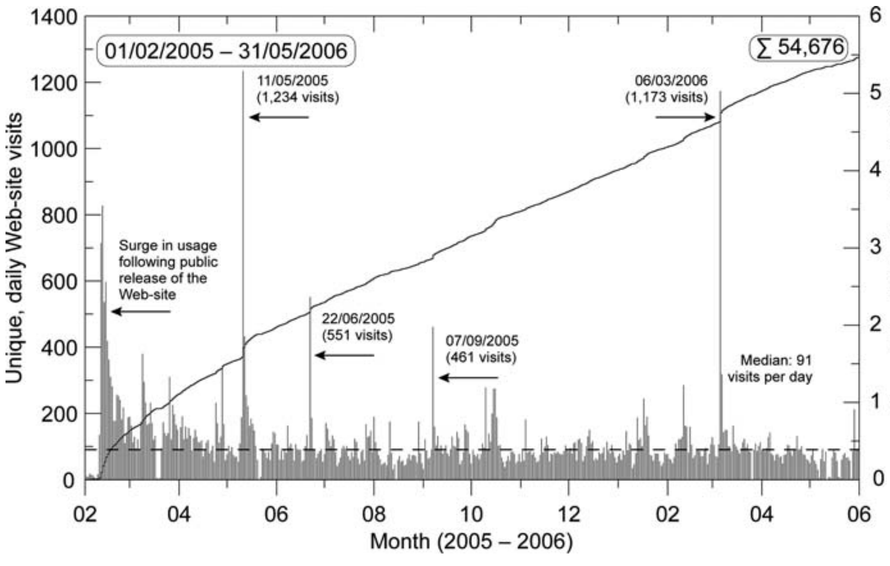


Fig. 6 The total number of daily hits to the EWIS Web-site from 01 February 2005 to 31 May 2006. The dotted line represents the median number of daily Web-site visits during this period which is 91. The solid line indicates the cumulative Web-site visits

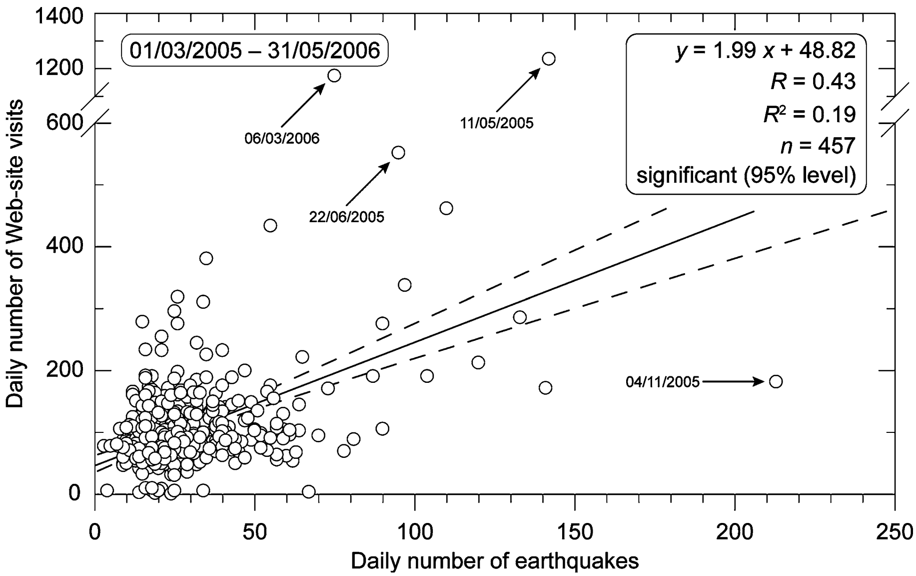


Fig. 7 Relationship between the total number of daily earthquakes and total number of unique daily visits to the EWIS Web-site from 01 March 2005 and 31 May 2006. Labelled points are described in Table 1

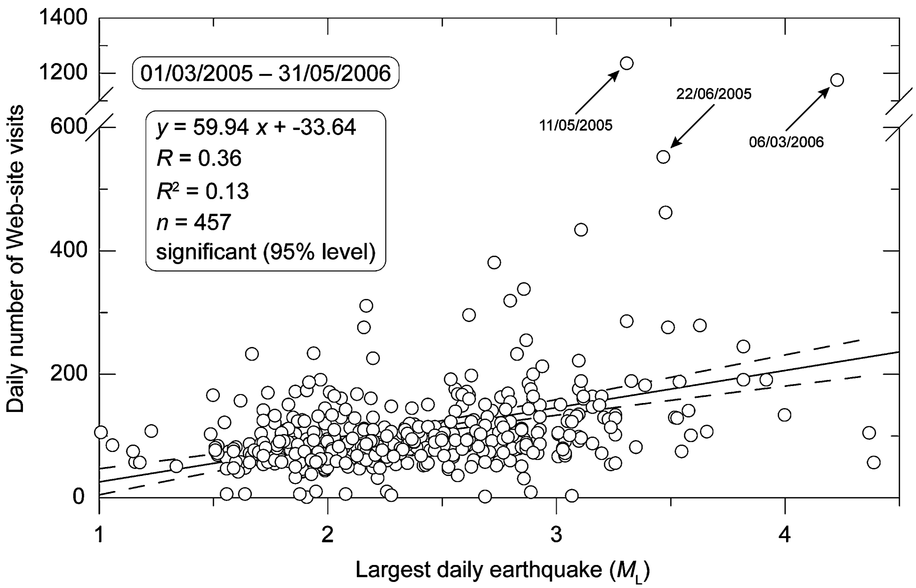


Fig. 8 Relationship between the largest daily earthquake and total number of unique daily visits to the EWIS Web-site from 01 March 2005 to 31 May 2006. Labelled points are described in Table 1

Note that there is no sharp increase in usage levels when earthquakes exceed M_L 3 (Fig. 8). Nevertheless, the data show a strong similarity between felt earthquakes (i.e. 22 June 2005 and 06 March 2006) and heightened Web-site usage. In both scattergrams (Figs. 7 and 8), the outermost data relate to an offshore swarm of earthquakes on 11 May 2005 (see Fig. 9). In summary, a positive, weak, linear correlation is apparent—on a daily scale—between earthquake intensity and size and the number of Web-site visits at the 95% level of certainty. However, because only part of the variance within Figs. 7 and 8 is described by linear regression, additional factors must contribute to the pronounced variations in Web-site usage.

Details about the outlying data in Figs. 7 and 8 are provided in Table 1. Despite recording the highest magnitude earthquakes no media bulletins were released on 19 October 2005 and 12 November 2005, primarily because these earthquakes were not felt. Occurring well offshore (see Fig. 4), these earthquakes did not prompt an increase in Web-site usage (logged daily, unique visits were 104 and 56, respectively). Five large earthquakes occurred on 04 November 2005 all sourced far from populated areas. The media bulletin announcing this activity was released mid-afternoon on 04 November 2005. Daily Web-site activity doubled the recorded median rate for the study period. Fifteen percent of unique visits with IP addresses were logged prior to the media bulletin release. Eighty-five percent were logged after its release at 15:57 GMT. The one event on 07 September 2005, located more than 50 km from communities on the Reykjanes Peninsula, occurred at 03:27 GMT. In response to this event, IMO released a media bulletin at 09:32 GMT. Daily Web-site usage registered five times the median, with 84% of unique visits with IP addresses logged after the media bulletin was issued.

6.4 EWIS usage and earthquake data for dates with the greatest daily total of Web-site visits

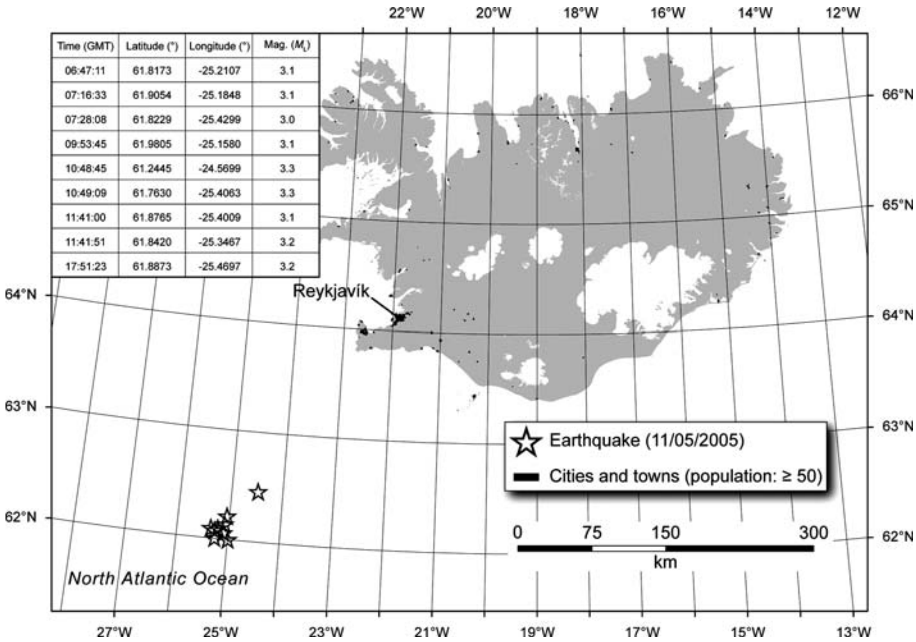
We present earthquake and daily usage data for 11 May 2005, 22 June 2005 and 06 March 2006. On these days, the three highest peaks in Web-site activity were recorded. Daily Web-site hits from 11 to 14 February 2005 (the week of the Web-site's public release) were between 536 and 827, whereas no earthquakes $\geq M_L$ 3 occurred during February 2005. Consequently, our analysis begins on 01 March 2005.

6.4.1 Usage and earthquake data for 11 May 2005

A swarm of earthquakes located approximately 300 km offshore from Reykjavík on the Reykjanes Ridge began on 10 May 2005. Nine earthquakes $\geq M_L$ 3 occurred on 11 May

Table 1 Details of outlying data including the release of media bulletins, visits to the EWIS Web-site, total number of earthquakes, number earthquakes $\geq M_L$ 3 and if the events occurred within the 'felt' distance of local towns and cities

Date	Media bulletin release (GMT)	Web-site visits	Total earthquakes	Earthquakes $\geq M_L$ 3	"Felt"
11/05/2005	10:16	1,234	142	9	No
06/03/2006	16:13	1,173	75	1	Yes
22/06/2005	9:01	551	95	1	Yes
07/09/2005	9:32	461	110	1	No
04/11/2005	15:57	181	213	5	No
19/10/2005	–	104	50	4	No
12/11/2005	–	56	25	5	No



Time (GMT)	Latitude (°)	Longitude (°)	Mag. (M_L)
06:47:11	61.8173	-25.2107	3.1
07:16:33	61.9054	-25.1848	3.1
07:28:08	61.8229	-25.4299	3.0
09:53:45	61.9805	-25.1580	3.1
10:48:45	61.2445	-24.5699	3.3
10:49:09	61.7630	-25.4063	3.3
11:41:00	61.8765	-25.4009	3.1
11:41:51	61.8420	-25.3467	3.2
17:51:23	61.8873	-25.4697	3.2

Fig. 9 Nine earthquakes $\geq M_L$ 3 occurred about 300 km off the coast of Iceland on 11 May 2005. The time of occurrence, the epicentral location and the magnitude (M_L) of each earthquake is given in the inset table. The depicted epicentres are subject to positional errors due to inaccuracies in the location of earthquakes outside the area of the SIL network

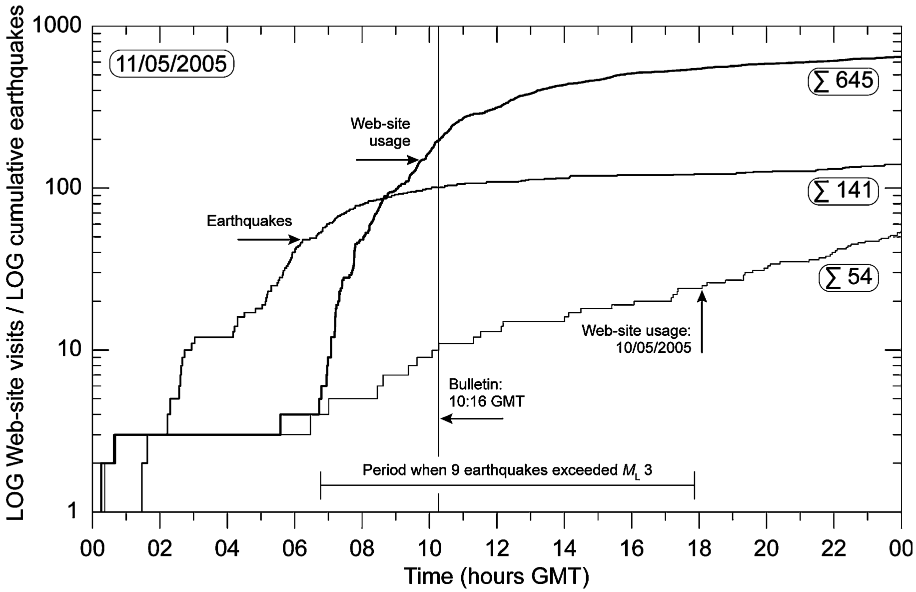


Fig. 10 LOG cumulative Web-site visits with unique IP addresses on 10 and 11 May 2005 and LOG cumulative earthquakes on 11 May 2005. Nine earthquakes $\geq M_L$ 3 occurred during the period from 06:47 until 17:51 GMT. A media bulletin was issued by IMO at 10:16 GMT

2005. The locations of these events are shown in Fig. 9. The time, location and magnitude of each of these events are given in the inset table in Fig. 9. In response to this seismicity, IMO released a media bulletin at 10:16 GMT on 11 May 2005.

We catalogued more than 1,200 unique visits to the EWIS Web-site on 11 May 2005. Web-site activity increased substantially after the first large earthquake on this day (Fig. 10). This pattern of increase was unlike the daily usage pattern on 10 May 2005. The geographic location of 645 unique visits was determined from IP addresses—a significant increase from the 54 visits of the previous day. Thirty percent of the total daily Web-site visits occurred in the period between the first earthquake at 06:47 GMT and the release of the media bulletin at 10:16 GMT. In total, 85.7% of the daily Web-site visits originated in Iceland, 2.9% originated in Denmark and 2.6% originated in Sweden. Sixteen other countries accounted for the remaining 8.7%.

6.4.2 Usage and earthquake data for 22 June 2005

An earthquake occurred 23 km from Reykjavík on 22 June 2005 at 07:43 GMT. This event registered M_L 3.5. Figure 11 shows the epicentral location within 50 km of Reykjavík and its surrounding communities. A media bulletin announcing the earthquake was issued at 09:01 GMT.

Our analysis for 22 June 2005 included 551 visits to the EWIS Web-site. A significant increase in Web-site visits occurred directly following the local earthquake at 07:43 GMT, as shown in Fig. 12. This pattern of increase was considerably different from the daily usage on 21 June 2005. The geographic location of 313 Web-site users was determined for 22 June 2005 as compared to 41 on the previous day. Twenty-one percent of the daily visits

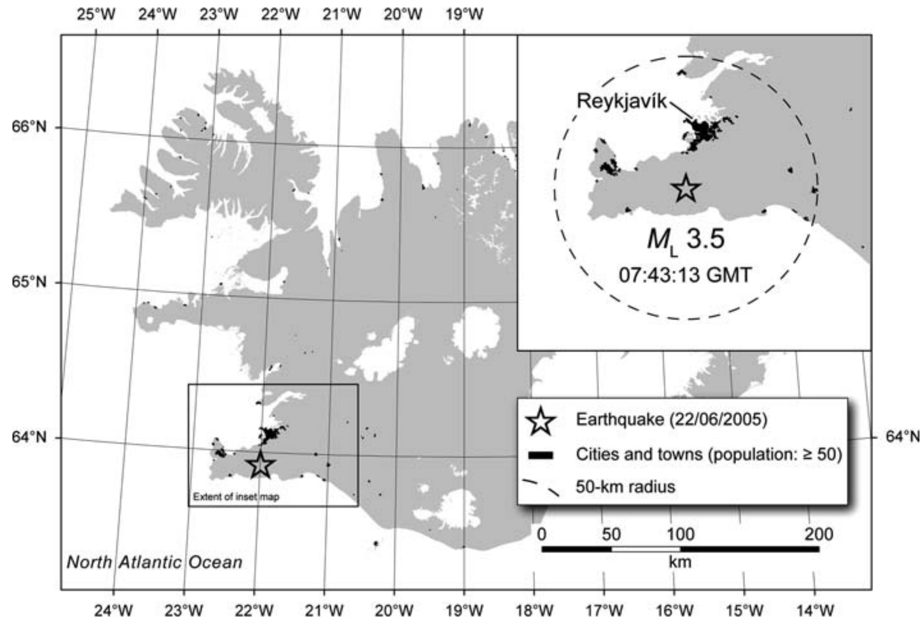


Fig. 11 An earthquake of magnitude M_L 3.5 occurred 23 km from Reykjavík on 22 June 2005. The inset map shows the earthquake's proximity to Reykjavík

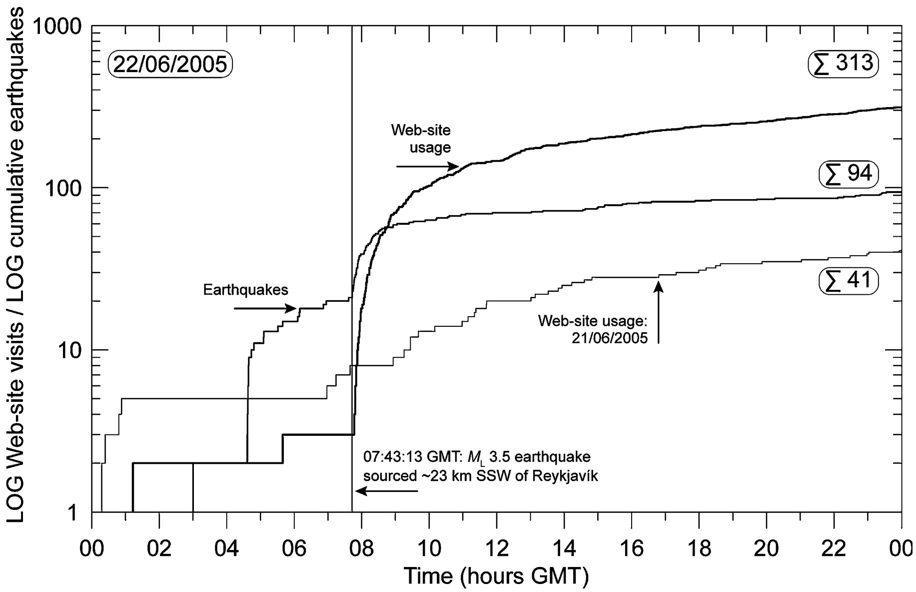


Fig. 12 LOG cumulative Web-site visits with IP addresses on 21 and 22 June 2005 and LOG cumulative earthquakes on 22 June 2005. An earthquake registering M_L 3.5 occurred at 07:43 GMT. An IMO media bulletin was posted at 09:01 GMT

took place during the period between the earthquake at 07:43 GMT and IMO's media bulletin release at 09:01 GMT. Seventy-eight percent of the daily visits occurred after 09:01 GMT. Nearly all unique visits originated from Iceland (97.1%). Denmark, Norway and the United States were each responsible for 0.6% of visits with the remaining 1.1% originating from three other countries.

6.4.3 Usage and earthquake data for 06 March 2006

On 06 March 2006 at 14:31 GMT, an M_L 4.2 earthquake struck the Reykjanes Peninsula. The location of the epicentre, 23 km from Reykjavík, was well within the buffer of a 'felt' earthquake for many populated areas (Fig. 13). In response, IMO released a media bulletin at 16:13 GMT.

On 06 March 2006 the EWIS Web-site recorded 1,173 unique visits. Of these, 799 visits registered an IP address. Until the earthquake at 14:31 GMT, the EWIS Web-site had received a daily total of just 13 visits (with IP addresses—the same daily total as the previous day). However, within an hour of the earthquake occurring, 414 additional visits to the site were logged (Fig. 14). Ninety-six percent of daily Web-site visits on 06 March 2005 occurred after the earthquake and 64% occurred in the 1-h and 42 min between the event and the release of the media bulletin. This increase in Web-site usage is obvious when compared to Web-site usage on 05 March 2006 (Fig. 14). On 05 March 2006, the Web-site received a daily total of just 33 visits with IP addresses. The majority (93.9%) of Web-site visits on 06 March 2006 originated in Iceland; 1.9% originated in the United States and 1.0% originated in Sweden. The origin of the remaining 3.2% is attributable to 12 other countries.

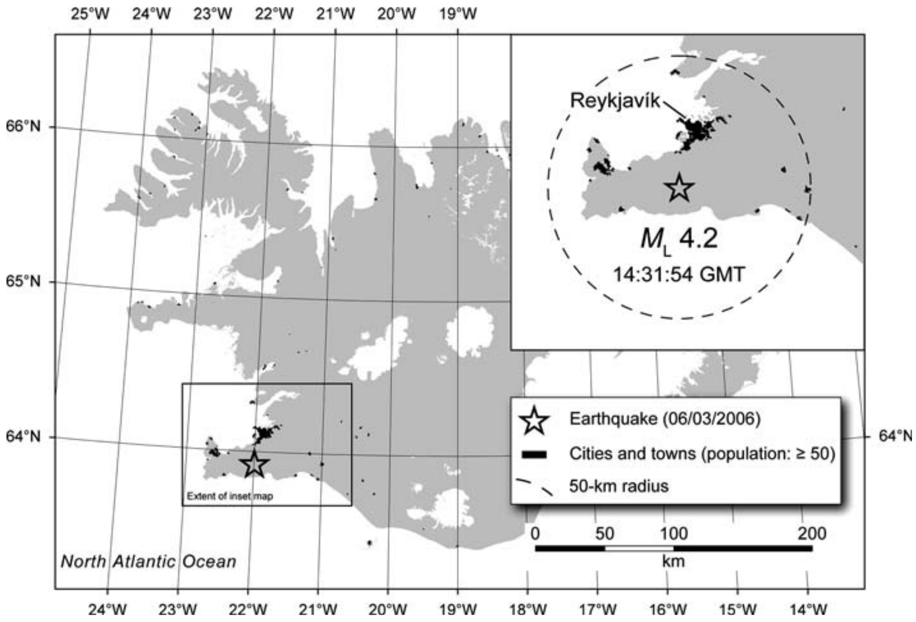


Fig. 13 One earthquake occurred on 06 March 2006, sourced 23 km from Reykjavík. The inset map shows the earthquake's proximity to Reykjavík

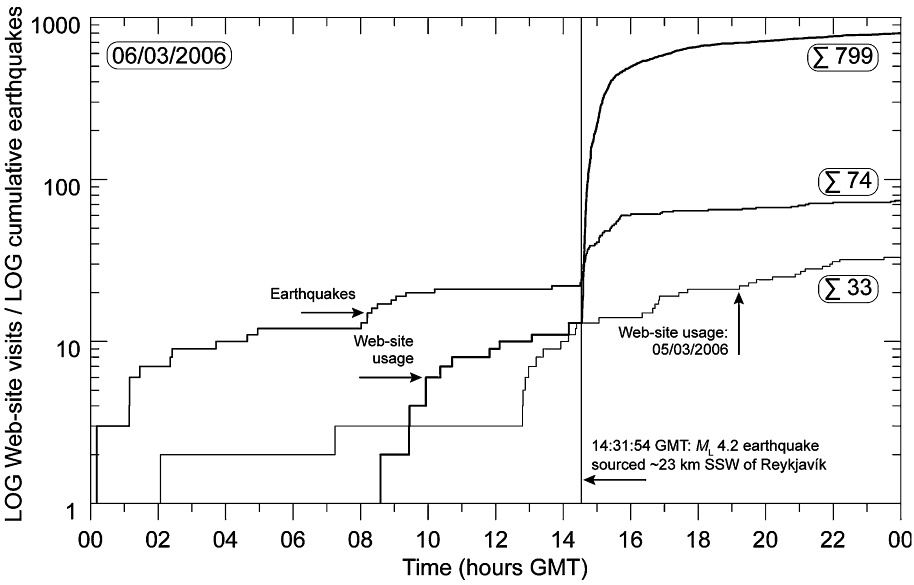


Fig. 14 LOG cumulative Web-site visits with IP addresses on 05 and 06 March 2006 and LOG cumulative earthquakes on 06 March 2006. An earthquake registering M_L 4.2 occurred at 14:31 GMT. A media bulletin announcing this event was issued at 16:13 GMT by IMO

7 Discussion, limitations and recommendations

The total number of earthquakes and their distribution was consistent with past trends during the period from 01 March 2005 to 31 May 2006 (see Einarsson 1991; Jakobsdóttir et al. 2002). Nearly all earthquakes had a magnitude $<M_L$ 3 and were located within Iceland's seismic zones. The largest events occurred offshore more than 500 km from populated regions. However, some large events ($\geq M_L$ 3) were located within 50 km of local communities.

The EWIS Web-site was accessed regularly throughout the study period. The highest number of unique, daily Web-site visits coincided with days of high-magnitude ($\geq M_L$ 3) earthquakes (except for usage during the week of the Web-site's public release). The greatest cluster of large earthquakes and the highest number of unique, daily Web-site visits were recorded on the 11 May 2005. The largest onshore event, which was close to Reykjavík, occurred on the 06 March 2006. This day also recorded the second highest number of unique, daily visits to the Web-site. The event on 22 June 2005 was also located close to Reykjavík. The third highest number of daily Web-site visits was logged on this day.

For each of these days Web-site usage was significantly higher than the previous day. Web-site usage on 11 May 2005 steadily increased at the commencement of the period of large earthquakes and prior to the release of IMO's media bulletin. Similarly, Web-site usage on 22 June 2005 and 06 March 2006 increased immediately after the earthquakes occurred and prior to the media bulletin release, although at a much faster rate than that recorded on 11 May 2005. The event on 22 June 2005 did not generate as much Web-site interest as the event on 06 March 2006, despite its close proximity to Reykjavík. This earthquake occurred at 07:43 GMT prior to business hours and was of a lower magnitude than 06 March 2006 event. It is highly likely that many local residents were travelling to work at this time and simply did not feel the earthquake. However, other factors such as depth or focal mechanism of the earthquake, may have affected the public's ability detect this activity and therefore resulted in less Web-site visits.

An increase in Web-site usage was not logged on the two days that recorded the three largest events during the study period. These events, all located well offshore, did not warrant a media bulletin release from IMO. Earthquake activity on 04 November 2005 recorded the highest daily total of earthquakes as well as the second highest number of large earthquakes in one day. Despite a media bulletin announcing this activity Web-site usage only doubled the median for the study period. This media bulletin was not issued until 15:57 GMT. Regardless of the bulletin's timing, the EWIS Web-site recorded the majority (85%) of its daily visits after its release. Likewise, the Web-site usage was not significant prior to the media bulletin describing the early morning event on 07 September 2005. Following the release of IMO's media bulletin at 09:32 GMT, the EWIS Web-site experienced a significant increase in usage, equivalent to the upsurge in visits recorded after the media bulletin on 04 November 2005. The EWIS Web-site logged the fourth highest number of daily visits on 07 September 2005. It is apparent that the timing of such media bulletins is a primary influence on the usage of the EWIS Web-site; however, other forms of media coverage about earthquake activity are likely to affect site usage.

Albeit a small sample size from extremely large datasets, we consider that these results suggest both a spatial and temporal relationship between Web-site usage and seismic activity. A spatial relationship is evident from activity and Web-site usage on 22 June 2005 and 06 March 2006. These events located close to Reykjavík generated immediate increases in Web-site usage which was independent of IMO's media bulletins. In contrast, large events located well offshore, such as those on 19 October 2005 and 12 November

2005, did not warrant a media bulletin and therefore did not generate any Web-site interest. Temporal analysis of daily Web-site usage suggests that the public utilises the EWIS Web-site immediately after sensing an earthquake, whereas distant, ‘unfelt’ earthquakes generate gradual interest, prior to and following a media bulletin.

The increased use of the EWIS Web-site following an earthquake or a media broadcast announcing one indicates that the Icelandic community trusts the scientific information provided on the site. Wu and Bechtel (2002) reported that increased Internet usage in relation to hazard information is dependant upon the user’s perception of the strength and reliability of a site. For example, scientific information based Web-sites proved reliable during the Cyclone Larry disaster in Australia in March 2006 when some residents complained that the television and radio broadcasts were outdated and conflicted with the up-to-date scientific information provided on the Bureau of Meteorology Web-site http://www.bom.gov.au (King et al. 2006). In a survey on trusted sources of volcanic hazard information Haynes et al. (2007) identified scientists as the second most publicly trusted group. With respect to infrequent hazards such as earthquakes, the public’s trust in the social institutions providing hazard information will determine whether or not risk communication has been effective (Paton 2007). Trust in IMO and the information they provide through their Web-site should positively affect hazard awareness and risk communication in Iceland.

During the study period the majority of Web-site visits originated in Iceland. This pattern was also evident on 11 May 2005 during the offshore earthquake swarm. However, following the onshore earthquakes on 22 June 2005 and 06 March 2006, nearly all Web-site visits originated in Iceland. Although the data shows that the EWIS Web-site is reaching an international audience, the pattern from these 3 days suggests that locally ‘felt’ earthquakes generate greater domestic interest.

It is beyond the scope of this analysis to determine what factors influence the use of the EWIS Web-site. However, based on our data we speculate that many factors effect Web-site usage (e.g. earthquake proximity to populated regions, magnitude of the earthquake, timing of the earthquake, the release and timing of media bulletins). Interestingly, Web-site usage increased on 11 May 2005 prior to IMO’s media bulletin announcing this offshore activity. This increase in Web-site usage could be attributable to several factors. For example, IMO’s homepage is viewed regularly by various media agencies in Iceland (I. Helgason, personal communication, 2006). Consequently some earthquakes are reported on national radio prior to IMO releasing a bulletin. International Web-site visits on this day, and during the entire study period, may be attributable to scientific research or public curiosity (possibly from Icelandic expatriates). Additionally, various seismological Web-sites alert subscribers via e-mail when a large earthquake is detected. For example, the European-Mediterranean Seismological Centre (EMSC) alerts its subscribers to earthquake activity in the European region.

Although significant, our analysis of the EWIS usage data with seismicity in Iceland is limited. For example, public and scientific IP addresses were not separated for the analysis and therefore our result may be biased. Researchers based in Iceland regularly access the site thus increasing daily Web-site usage. Additionally, some Icelandic seismologists are positioned in other Nordic research institutions and therefore may have increased the number of foreign visitors to the Web-site during our study period. Furthermore, it is likely that the EWIS Web server was saturated with site requests during periods of heightened seismicity (e.g. following the earthquake on 06 March 2006). Potentially, the number of unique, daily visits may have been higher on these days. This first analysis of Web-site usage data in relation to seismicity in Iceland provides valuable information for IMO about when and how often earthquake information is being accessed. However, from these results, we cannot gauge the effectiveness of the EWIS Web-site as a tool for communicating earthquake information nor can we adequately determine to what extent the media has influence over Web-site usage. This is an important recognition because as Chatman (1986) showed in an analysis and test of diffusion theory, many factors interplay to determine how 'participants' interact with, view and take up information presented to them. This has clear implications for organisations tasked with the responsibility of communicating hazard information to members of the public and other interested stakeholders.

Based on these limitations we recommend that future development and research into the EWIS Web-site incorporate:

- An assessment of public usage of the EWIS Web-site by eliminating scientific IP addresses from the dataset.
- A simple questionnaire attached to the Web-site for visitors to complete. This questionnaire could contain questions such as 'why did you access the EWIS Web-site', 'did you feel an earthquake' and 'if so, where and when did you feel this earthquake'. The option to leave a return email address should be included in the questionnaire in order for Web-site managers to gain clarification of responses if necessary. Furthermore, this will provide Web-site managers with the opportunity to direct additional questions about the Web-site which ask the user to rate the effectiveness of the Web-site as a communication tool for hazard information. Such data would then allow a detailed examination of the effectiveness or otherwise of this tool for delivering information about hazards—something beyond the scope of our study.
- An increase in Web-server capacity to allow more simultaneous 'hits' to the EWIS Web-site during periods of heightened use.
- Assessment of usage statistics and earthquake activity, once every 12 months, in order to determine site performance and the public's interaction with it.

Additionally, it is important to publicise the EWIS Web-site through the media to increase people's awareness of seismic and volcanic hazards. Over 1,200 people accessed the Web-site on 11 May 2005, despite earthquake activity occurring offshore, approximately 300 km from Reykjavík. This is interesting to note because if people hear about damaging earthquakes in the SISZ or volcanogenic earthquakes associated with Katla or Hekla they may use the EWIS Web-site to monitor their own personal risk or risk posed to family members living in vulnerable areas. This is highly likely considering that 87% of Icelander's interact with, or would be interested in interacting with, public authorities via the Internet. Therefore, continued development of the EWIS Web-site could further increase public awareness of earthquake hazards. Furthermore, with the increase in tourism in Iceland, especially in the SISZ, an English version of the Web-site, promoted through tourism Web-sites such as http://www.icetourist.is and http://www.visitreykjavik.is, could help to increase hazard awareness amongst foreign visitors.

8 Conclusions

Launched in February 2005, the EWIS Web-site displays near-real-time earthquake activity using results from the SIL national seismic network. Our analysis of Web-site usage data compared with earthquake activity suggests that there is a spatial and temporal relationship between earthquake activity and Web-site usage. Earthquakes occurring close to local communities on 22 June 2005 and 06 March 2006 triggered an immediate upsurge in Web-site usage, whilst the distant earthquakes on 11 May 2005, 07 September 2005 and 04 November 2005 generated a gradual increase prior to and following a media bulletin. Furthermore, the release and timing of media bulletins announcing earthquake activity affected daily Web-site usage. IMO did not issue any media bulletins for the larger off-shore events on 19 October and 12 November 2005 and consequently, usage of the EWIS Web-site was not outstanding. However, earthquakes occurring on 07 September and 04 November 2005 were publicised by IMO, instigating a significant increase in daily usage. We speculate that the unexpected increase in Web-site visits, which began before IMO released a media bulletin announcing the large offshore events on 11 May 2005, is due to other media broadcasts from Icelandic agencies or international seismological Web-sites. Given the insight that the EWIS usage statistics have afforded, we recommend that other agencies responsible for disseminating information on natural hazards undertake similar assessments of how and when their public Web-sites are being accessed.

The usage data show that although the EWIS Web-site is attracting an international audience, the majority of users originated in Iceland. Considering that the site is only available in Iceland this comes of no surprise. Therefore, an English translation of the EWIS Web-site publicised through Icelandic and international media and travel agencies are recommended to help increase local and international awareness of seismic and volcanic hazards.

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