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Short communication

# Two large historical earthquakes in Fennoscandia still large

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**Abstract**

Recent studies have claimed that two of the largest earthquakes in Fennoscandia, in 1759 and 1819, should have their magnitudes reduced by 0.5 and approximately 1 $M_S$ units, respectively. It is shown that there is no cause for these downgradings in the macroseismic data and the implications of reduced seismic hazard and risk for Fennoscandia are unwarranted.

*Keywords:* Fennoscandia; Large earthquakes; Macroseismic data; Magnitudes

## 1. Introduction

Although Fennoscandia is a typical intraplate region with generally low seismicity, occasional larger earthquakes ($M_S > 5$) occur, especially in the relatively more active western part. The past approximately 250 years is the period of relatively good and consistent observations of significant seismic events throughout the area. Two of the largest earthquakes occurred in northern Kattegat on 22 December 1759 and near the coast of Nordland, Norway, on 31 August 1819. These events have recently had their size reduced, by a magnitude of 0.5-1 $M_S$ units, in studies by *Kebeasy and Husebye* (2003) and *Husebye and Kebeasy* (2004), respectively. In the present study, it is claimed that the reductions are unjustified and the results of erroneous, biased and negligent interpretation of the existing macroseismic data. These two earthquakes together with the ones off the coast of Møre-Trøndelag, Norway, on 9 March 1866 and in the Oslo Fiord on 23 October 1904 no doubt still constitute a four-leaf clover of the most significant Fennoscandian events in the past quarter of a millennium.

An extensive contemporary and later literature describes the strong meizoseismal effects and the large size of the felt areas of the 1759 and 1819 earth-quakes. Some of the most recent studies dedicated to the quakes are *Ambraseys* (1985), *Muir Wood and Woo* (1987) and *Muir Wood* (1989) treating both events, *Kebeasy and Husebye* (2003) the 1759 event, and *Husebye and Kebeasy* (2004) and *Kebeasy et al.* (2003) the 1819 event. The Muir Wood and Woo (1987) study, where $M_S$ was regressed on the felt area, represents a significant downgrading of earlier magnitude values. The *Muir Wood and Woo* (1987) and *Muir Wood* (1989) values agree with recent instrumental magnitudes for some historical events in the North Sea (*Bungum et al.*, 2003). The *Kebeasy and Husebye* (2003), *Husebye and Kebeasy* (2004) and *Kebeasy et al.* (2003) studies stand out in the way that many observations are drastically re-evaluated or even discredited, with fragile arguments, suggesting a further significant reduction of the size of each event. It will be shown that and why these results are unreliable.

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## 2. The 22 December 1759 earthquake

*Kebeasy and Husebye* (2003) list different sets of intensities of the 1759 event: "original" as assigned by *Ambraseys* (1985), *Muir Wood and Woo* (1987) or *Muir Wood* (1989), reassessed according to the European Macroseismic Scale EMS-98 (*Grünthal*, 1998) and reduced based on results from 3D finite difference modelling. Table 1 compares the data listed by *Kebeasy and Husebye* (2003) with the corresponding original ones. As seen in the table, there are not many intensities which actually agree with those of the claimed references and many values given by these references are also missing in the table. Even more alarming is that the differences show an obvious trend in decreased or even, for large distances, discarded

*Table 1*
Intensities for the 1759 earthquake listed by *Kebeasy and Husebye* (2003) and corresponding values from the original references (*Ambraseys*, 1985; *Muir Wood and Woo*, 1987; *Muir Wood*, 1989). Only localities at distances above 150 km are listed

| Country | Place (increasing distance for each country) | Ambraseys (1985) | Muir Wood and Woo (1987), Muir Wood (1989) | Kebeasy and Husebye (2003) | | |
|---|---|---|---|---|---|---|
| | | | | a | b | c |
| Sweden | Lidköping[d] | III | V | IV | III | |
| | Jönköping | - | V | IV | | |
| | Laholm | - | V | IV | | |
| | Kristinehamn | - | V | III | | |
| | Karlstad | - | V | III | | |
| | Örebro | - | IV | | | |
| | Arboga | - | IV | | | Ii[e] |
| | Stockholm | II | II-IV | III? | II? | |
| Norway | Trønsberg | - | V | IV | | |
| | Skien | - | IV | | | |
| | Birkeland | - | V | IV | III | |
| | Kristiansand | - | IV | | III | |
| | Kongsberg | - | IV | III | | |
| | Odalen | - | IV | III | | |
| | Fåberg | III | IV | III? | | |
| | Fron | - | IV | III? | II? | |
| | Bergen | - | IV | III? | ? | |
| Denmark | Helsingør | - | V | VI | V | III |
| | Vejle | - | V | | IV | |
| | Copenhagen | V | IV | | III | I |
| | Sorø | - | V | | | III |
| | Odense | III | IV | V | | III |
| | Fyn | | IV | | III | |
| Germany | Holstein | - | IV | III | | I |
| | Flensburg | - | IV | III | | I |
| | Schleswig | III | IV | III | | I |
| | Kiel | - | IV | III | | I |
| | Hamburg | II | IV | III | | I |

Dubious values according to *Kebeasy and Husebye* (2003) are marked (?) and not used in their final isoseismal map. Although each value in column (a) should be identical to one of the values in the columns to the left, there is a clear trend of decreased values for shield located sites (Sweden and Norway). Many data in the original references are also omitted by *Kebeasy and Husebye* (2003). Where the value does not change from one column to the one next to the right, the latter is left blank.

[a] "Original" as assigned by *Ambraseys* (1985) or *Muir Wood and Woo* (1987), *Muir Wood* (1989).
[b] Reassessed according to the European Macroseismic Scale EMS-98 (*Grünthal*, 1998).
[c] Reduced based on results from 3D finite difference modelling.
[d] "Lindköping" by *Kebeasy and Husebye* (2003); a non-existing name erroneously interpreted as Linköping by them.
[e] Arboga is located in the shield and should have no basin correction.

values for localities in the shield, i.e., in southern Norway to the north and southern and central Sweden to the NE-SE (Table 1). There is also a general trend to decrease many EMS-98 intensities by one unit or more. This is unexpected, since this scale agrees with previous intensity scales for the range of intensities considered here (V and smaller). As examples of localities with discredited data can be mentioned Bergen, although the observations clearly motivate a similar intensity assignment as in Hamburg at a similar epicentral distance but on the southern, basin side (*Muir Wood and Woo*, 1987), and Stockholm, where “the shaking in some houses was so noticeable that there could be no mistake about the real cause” and “the wind was quite mild” (*Kjellén*, 1903; translated) contrast to the dismissal by Kebeasy and Husebye (2003) as a gust of wind phenomenon.

The strong effects for buildings and other structures in the near areas of Denmark and Sweden are summed up by, e.g., *Muir Wood and Woo* (1987). According to *Kjellén* (1903), the earthquake was felt up to Ångermanland in central Sweden, although not along the coast of the Gulf of Bothnia.

The first part of the *Kebeasy and Husebye* (2003) study contains 3D finite difference modelling along a profile basically south of the assumed 1759 epicentre (some displacement to the east). It shows a wave amplification in the Danish and North German basins of up to 10 times compared to rock, the maximum at 6 Hz at the centre of the Danish basin. The authors relate this order of amplification, corresponding to one order of magnitude, to two orders of intensity, a dubious statement. Although according to the text the basin intensities thus should be reduced by 1-2 units, 2 units are subtracted for all basin localities to get the final (right column) values of Table 1. This is a both stereotype and inadequate adjustment of the observed values and is in conflict with the recommendation of *Grünthal* (1998): “absolutely no attempt should be made to discard or reduce intensity assignments on the grounds that they were influenced by soil conditions” (p. 29). This statement is important, since it would otherwise to some extent be arbitrary to decrease observed intensity values in soil areas or to increase them for hard rock. Besides, there is no investigation by *Kebeasy and Husebye* (2003) what frequencies best represent the macroseismic observations (cf., e.g., *Sokolov and Chernov*, 1998) - such a correlation might have reduced the applied factor 2 also for the highest amplification localities at the centre of the Danish basin.

Macroseismic maps based on the original data are roughly symmetrical around the epicentre (*Ambraseys*, 1985; *Muir Wood and Woo*, 1987; *Muir Wood*, 1989: see Fig. 1). The EMS-98 adjusted values produce an asymmetrical map, smaller in the shield areas than in the basins (upper map of Fig. 7 in *Kebeasy and Husebye*, 2003). Reducing the intensity for basin localities, an approximately symmetrical area is again obtained, much smaller than that based on the original data (Fig. 1) and implying a decrease in the magnitude of the earthquake from $M_S$ = 5.6 to 5.1. An $M_L$ = 4.6 earthquake in northern Kattegat in 1985 showed a similar symmetrical (but of course more limited) distribution of isoseismals based on original data (*Arvidsson et al.*, 1991), indicating insignificant influence of the Danish basin on the felt observations. It is thus obvious that the downgrading by *Kebeasy and Husebye* (2003) is not trustworthy.

## 3. The 31 August 1819 earthquake

The main arguments for *Husebye and Kebeasy* (2004) and *Kebeasy et al.* (2003) to downgrade the 1819 Nordland, Norway, earthquake are threefold: (1) irreliability of reported macroseismic data at large distances; (2) absence of reports of macroseismic data at coastal locations at intermediate distances (“negative evidence”); and (3) explanation of strong meizoseismal observations as secondary effects and due to heavily increased wave amplification.

(1) The event was reported felt down to Stockholm and possibly Oslo, in western Finland and up to the Kola peninsula. The radius of perceptibility proposed by *Husebye and Kebeasy* (2004) is just over 300 km (Fig. 2). They discard data at larger distances as unreliable or mixed with local earthquakes, without giving any supporting indications of this. Reports from Kola are less trustworthy, still the effects are distinct for many of the other long distance observations (see, e.g., *Ambraseys*,

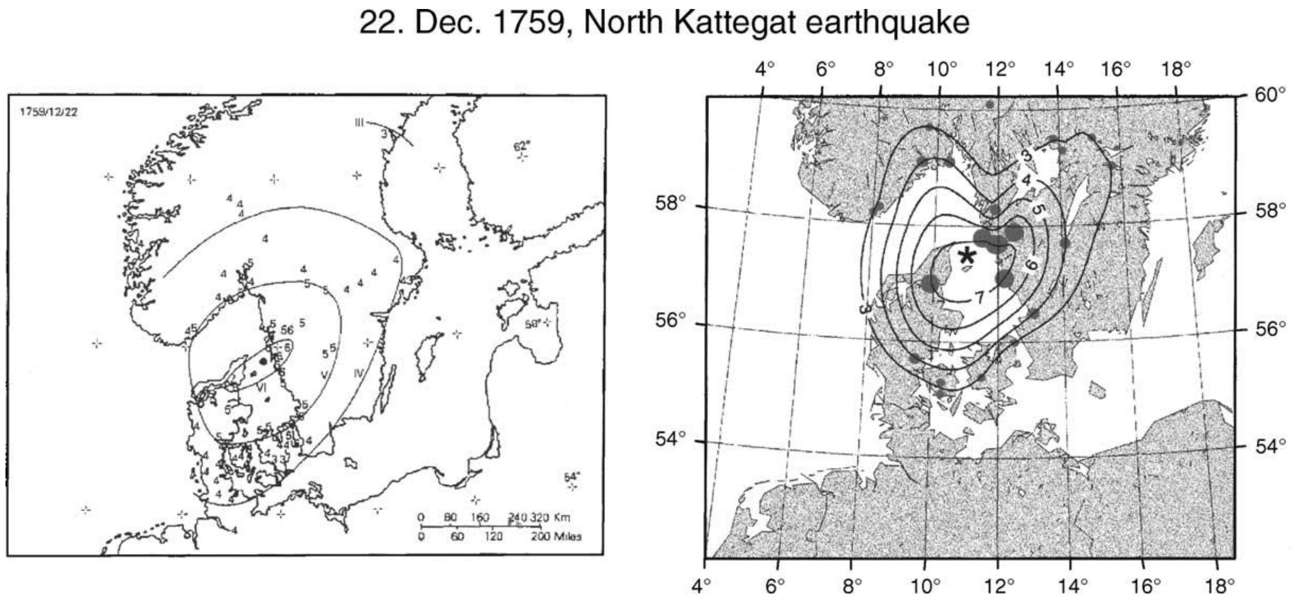


*Fig. 1.* Isoseismal maps with intensity data points for the earthquake in northern Kattegat on 22 December 1759. Left: map from *Muir Wood* (1989), average radius of perceptibility about 500 km. Right: map from *Kebeasy and Husebye* (2003), average radius of perceptibility about 330 km.

1985). Not least for Stockholm, at a distance of some 800 km, there is convincing documentation of the felt effects as quoted, e.g., by *Ambraseys* (1985) and *Muir Wood and Woo* (1987). The interpretation by the latter of evidence of typical long-period observations at the margin of the felt area for this size of an event is plausible. Fig. 2 includes the macroseismic area pictured by *Muir Wood* (1989).

The most convincing argument against the downgrading of the 1819 earthquake is the macroseismic map by *Kjellén* (1910). His map of an earthquake on 31 August 1819 in the afternoon does not include Norway and obviously he was not aware of the strong Norwegian observations at the same time, documented by *Keilhau* (1836), when he compiled and analyzed the Swedish and Finnish data almost a hundred years after the occurrence of the quake. Even without the Norwegian data, the erroneously cut depicted felt area by *Kjellén* (1910) implies one of the greatest Fennoscandian earthquakes in historical time. There are thus simultaneous observations over a large area which are totally independent of the meizoseismal data to confirm this as a large earthquake.

(2) The distinction between an earthquake not being reported felt and one being reported not felt - only the latter is true negative evidence - is essential in the interpretation of macroseismic data. The coast of Nordland is one of the highest seismically active areas in Fennoscandia. The fact that a strong earthquake 200 years ago had not been reported at various sites some hundred km away from the epicentre is no clear indication that such an earthquake has not occurred, since it would have been observed in a similar way as common smaller more local quakes, to which no special attention was paid in these old times, at least not in written documentary form. That the earthquake was felt beyond doubt at many more distant locations rather makes it highly probable that it was felt also at the “missing” sites. Thus the lack of observations at intermediate distances - not reports that the event was not felt - is not a convincing argument for downgrading the event.

(3) The meizoseismal effects of the 1819 earthquake include phenomena of landslides, rock avalanches, liquefaction and high water waves. For Fennoscandia, some instances of these events are unique consequences of earthquakes. Furthermore, chimneys and other parts of houses collapsed, and people and horses had problems to stand (see further descriptions in, e.g., *Ambraseys*, 1985 and *Muir Wood and Woo*, 1987). Such observations are rare in the Fennoscandian earthquake record. 3D finite difference modelling of the area close to the strongest geological events con-

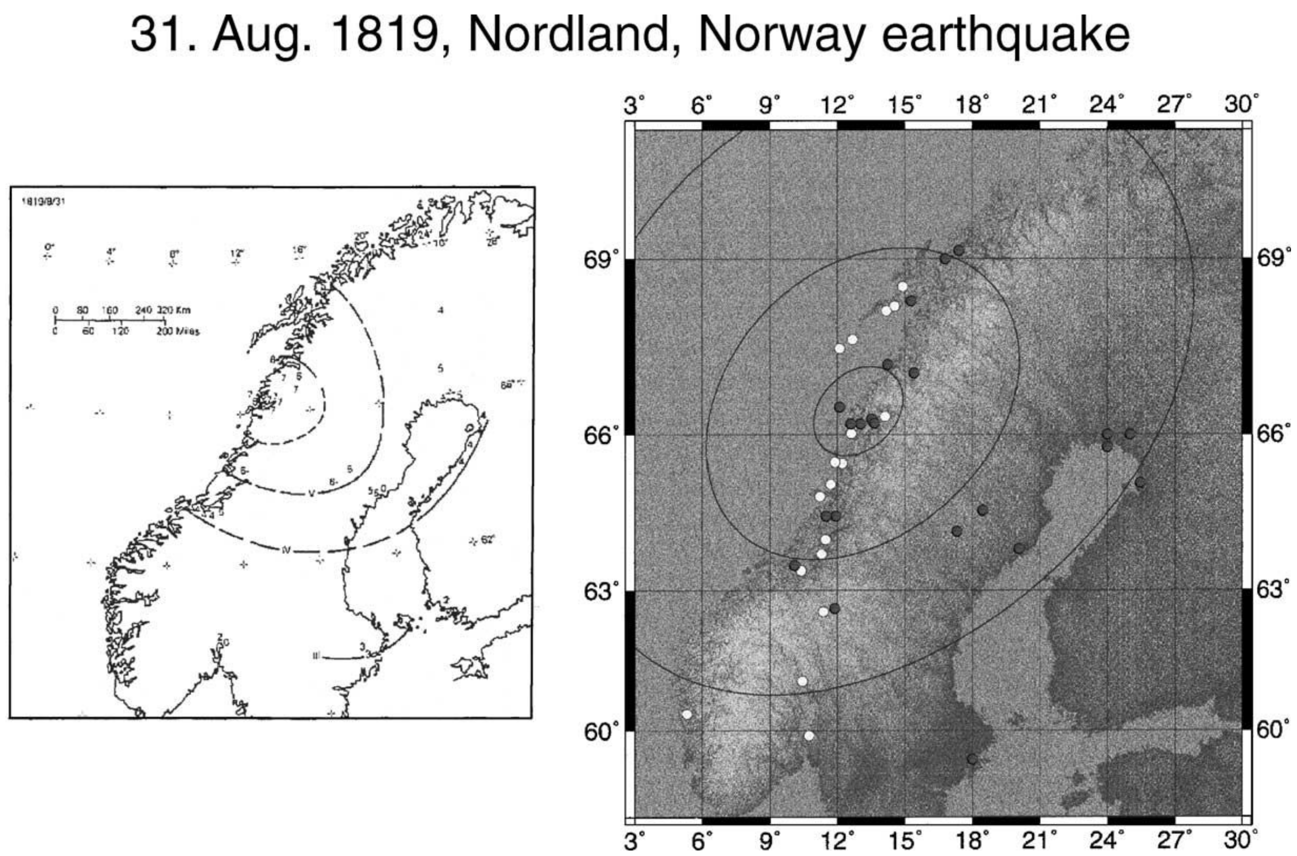


*Fig. 2.* Isoseismal maps with intensity data points for the earthquake near Lurøy, coast of Nordland, Norway, on 31 August 1819. Left: map from *Muir Wood* (1989), average radius of perceptibility about 800 km. Right: map from *Husebye and Kebeasy* (2004), where the central ellipse gives the proposed felt area corresponding to an average radius of perceptibility of just over 300 km (major axis 350 km, minor axis 262.5 km; reports existing for dark dots - with plus sign denoting suspicious information according to *Husebye and Kebeasy*, 2004 - and non-existing for bright dots).

nected to the earthquake show wave amplifications of up to about 20 times and more (*Kebeasy et al.*, 2003). Extensive rain is also attributed as an important factor for the occurrence of the events, with the earthquake acting just as a trigger (*Kebeasy et al.*, 2003). However, this was used more as a qualitative support for the downgrading of the size of the event, since the magnitude was calculated based only on the size of the macroseismic area, not the maximum intensity. The magnitude is now claimed to be $M_S$ = 5.1 to compare with previous values of 5.8-6.2. In conjunction with the observations at large distances, the meizoseismal effects fit into a pattern of one of the largest known earthquakes in Fennoscandia.

## 4. Discussion and conclusions

A high level of temporal consistency of the seismicity of Fennoscandia, notably the frequency-magnitude distribution, is well established in several studies (e.g., *Bungum et al.*, 1986; *Muir Wood et al.*, 1988; *Lindholm and Bungum*, 2000). Diminishing the largest magnitude events would distort this consistency. *Bungum et al.* (2000) demonstrate that magnitudes by *Muir Wood and Woo* (1987) imply a main recurrence period for Norway and adjacent offshore areas of the order of 100 years for $M_w$ or $M_S$ 6 earthquakes, consistent also with the observed occurrence frequency of several earthquakes larger than magnitude 5.

No critical scanning of most macroseismic data (especially the Swedish) was done in the *Kebeasy and Husebye* (2003) and Husebye and *Kebeasy* (2004) studies. Near and far distant effects show all signs of large earthquakes, as concluded in the earlier studies. The original macroseismic data for the 1759 event are adequate for the determination of the macroseismic parameters from which the magnitude is calculated, whereas tendentious intensity reassignments by *Kebeasy and Husebye* (2003) were made to conform to the modelling implications. The trend to reduce previous intensities by using the EMS-98 scale are unfounded. There is also no legacy to discard the far distant data from 1819 as unreliable, nor to use the absence of reports at some intermediate distance localities as full negative evidence. The strength and extent of the geological events accompanying this earthquake are in line with what can be expected for a magnitude $M_S$ of about 6. There are no references or discussion in *Kebeasy et al.* (2003) as to the correlation of earthquake triggered landslide effects in general and earthquake magnitude.

The modelled amplification of the soft basins does not, opposite to what is claimed by *Kebeasy and Husebye* (2003), seem to have any significant influence on the observed intensities from the 1759 earthquake. This is to a part likely related to what frequencies are correlated with the felt effects, which was not investigated by *Kebeasy and Husebye* (2003).

The downgrading of magnitudes imply lower seismic hazard and risk - *Husebye and Kebeasy* (2004) appreciate the reduction in risk to 25% for Helgeland (north Norway) and adjacent areas. However, the observed intensities in the meizoseismal areas (and elsewhere) remain first-hand data on which the maximum expected event size must be based. No modelling implied reductions or other manipulations should reduce the hazard. Therefore, the statement by *Kebeasy et al.* (2003) that the obtained downscaling of the 1819 event, by approximately one magnitude unit, is not entirely popular among many colleagues since it lowers the seismic risk is an insinuation without essence.

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