Comments on the Lurøy 1819 earthquake controversy

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The Lurøy earthquake of 31st August1819 has, for a long time, been rated the largest known earthquake in Norway and in the whole of NW Europe. Recently, Husebye and Kebeasy (2004) published a reassessment of the size or magnitude of this earthquake and claimed that its MS-magnitude should be MS = 5.1 instead of the commonly accepted value of MS = 5.8. However, Wahlstrøm (2004) and Bungum & Olesen (ibid) subsequently concluded that the MS = 5.8 value still remains a reasonable, justifiable and defendable estimate. Bungum & Olesen argue, in accordance with the present hazard model for the region, that a M6+ earthquake can occur today in the most seismically active areas including Western Norway. In the present comment I argue that the Bungum & Olesen complaints regarding the original Husebye & Kebeasy Lurøy study are not justified and the mentioned disaster scenario is not entirely convincing since the documented earthquake damage in the region is very moderate. Another argument here is that re-analysis of presumed large historical earthquakes has resulted in significantly lower magnitudes – down from 5.8 – 6.4 to the 5.0 – 5.4 range.

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Introduction

In a short note in this NGJ issue, Bungum and Olesen (ibid; B&O) question a recent analysis of the Lurøy earthquake of 31 August 1819 by Husebye and Kebeasy (2004, H&K). Wahlstrøm (2004) has also disputed the revised Lurøy magnitudes and also a similar downgrading of the Kattegat earthquake of 1759 (Kebeasy & Husebye 2003; Husebye & Kebeasy 2005). The problem at hand is to decide how large in magnitude historic earthquakes taking place prior to ca 1900 in Norway and adjacent areas actually were. This issue has been subject to much research and in general pre-1980 magnitude estimates have been reduced as demonstrated for Scandinavia and adjacent seas (see Table 1 - where the Oslofjord 1904, Doggerbank 1931 and Roermond (NL) 1992 earthquakes are included for completeness). Before addressing specific statements in the paper by Bungum and Olesen (2005, ibid)) it is necessary to clarify the main problem at hand, namely estimating earthquake size from macroseismic data based on observations from people having felt the earthquake in question and also the extent to which man-made structures have been damaged.

From mm-intensities to MS/ML-magnitudes: Problems and pitfalls

How people have felt an earthquake and the damage caused to man-made structures and the landscape are usually quantified by means of a seismological intensity scale like the 12-step Modified Mercalli scale or the recent, detailed European Macroseismic Scale (EMS; Grünthal 1998). However, for I = 5 or less the differences between the MM- and EMS-scales are small except for one important feature, namely, corrections for damage due to poorly constructed houses, observations stemming from upper floors in tall buildings and finally isolated reports from distant areas. Such factors, unless corrected for, may cause a positive bias in the final magnitude estimate. An example of this is the isolated Overhalla (220 km away) report of a collapsed chimney. Likewise, observations from Statsbygd (ca. 345 km away) and far away Stockholm (ca 800 km) stem from people residing on the 2nd and 3rd floors of buildings. In the case of the Kattegat earthquake of 1759 Kebeasy and Husebye (2003) showed that sedimentary strata typical of the Danish and North German basins probably caused prominent wave field amplifications thus explaining the relative strong shakings reported from parts of Denmark and northern Germany.

When converting Intensity to Magnitude corrections for such effects are a necessary evil since magnitude relates to the size of the source at the focus. A practical problem in many circumstances is what statistical weight should be given to intensity observations of say I = 5 and I = 2 (hardly felt) at sites separated by just a few hundred meters. Another stems from flimsy macroseismic reports; for example, Kjellen (1910) stated that the Kattegat earthquake was felt in Ångermanland – a county in NE Sweden – nothing more. In the case of Lurøy, Ambreseys (1985) gave I = 4 for a Kola village (more than 1000 km away) based on a

French report claiming that this earthquake was felt by a Lappish tribe. The magnitudes in H&K's Lurøy-paper and in those by Muir Wood (1989) and Muir Wood and Woo (1987; MW&W) are related to the felt area for I = 3 in a log-linear relation uncorrected and together with 'flimsy' observations have the effect of increasing the size or magnitude of the earthquake in question.

Note, it is not clear whether Muir Wood also used a Magnitude-Intensity relation for I = 4 area of perception and/or non-linear formulas as detailed in Table 1 in B&O. Regrettably, Bungum and Olesen do not discuss possible corrections to the Lurøy intensity observations, but accept without reservation all the values of Muir Wood and Woo (1987, Fig. A7.2) reproducing them in their Fig. 1.

Comments on Bungum and Olesen´s objections to the Lurøy study of H&K (2004).

B&O start with 'Magnitude scale and assessments' and in this regard reproduce the MW&W formulas for magnitude-intensity relations. A small third term is valid only for large events (Mag> 5.5) and then only for 0.2 - 0.3 magnitude units. B&O use the square root of this term in their Table 1 formula discussion. Anyway, inserting values for logA3 and logA4-areas as listed by MW&W (their Table 3.4) we get a MS = 5.2 and adding the 'third' term we get MS = 5.4. However, using the NORSAR formula, also given here by MW&W, we get MS = 5.7 which is close to the 'official' MS = 5.8 for this earthquake. Like B&O I am slightly confused as to how MW&W obtained the MS = 5.8 value listed in their Table 3.4.

In their chapter on 'Intensity observations ' B&O again consider various magnitude-intensity scales and also elaborate on mistakes made by Swedish scientists in interpreting Lurøy shakings reported from Sweden's Bothnian Bay area. They quote Wahlstrøm (2004) who argued that Kjellen's (1910) publication was the more convincing for not downgrading the magnitude of this event. Kjellen published an impressive account on Swedish earthquakes but apparently, by mistake, refers to the 1819 Lurøy event as a Swedish earthquake.

Specific comments on the MW&W intensity observations reproduced in B&O's Fig. 1 are as follows. The most vivid Stockholm descriptions stem from a 3rd floor residence and according to EMS recommendations should be lowered by one intensity unit thus becoming I = 2. Some observations in the Umeå-Lycksele area (NE Sweden) stem from residents on the 2nd floor; in other cases they are reported as having been felt on one side of the river but not on the other. Again, intensities were reduced by 1 or 2 units by H&K as compared to those of MW&W. On the Norwegian side the small farming community of Brekken is given I = 4 (one observation), but there are no reports from the nearby mining town of Røros. In Stadsbygd the report stems from a 2nd floor residence (vicar´s house), while the Overhalla I = 4 is due to a reported chimney falling down. The Overhalla community population was about 3000 people in 1801 and since just one extreme type of observation was reported H&K reduced its intensity to 3. This observation does not make sense unless the said chimney was in a poor condition or the site response was strong since close to the presumed epicenter near Lurøy damage to chimneys was mostly reported.

To the far north, the Senja and Vesterålen observations stem from a notice in a local newspaper in 1842 (Kolderup 1913) so its I = 5 intensity of MW&W was a questionable I = 3 in the H&K tabulation. In general, there were few reports from S. Helgeland, Lofoten and Vesterålen although several villages in these areas are within 100 kms of Lurøy. There are many vivid descriptions of mast-high waves in Ranafjorden, boulders tumbling down mountain sides and even a potato field 'sliding' into the sea but surprisingly reappearing hours later (e.g. see Heltzen 1834, Sommerfelt 1927, Keilhau 1836, Kolderup 1913). Since such observations do not relate directly to macroseismic magnitude estimation per se (see Table 1 of B&O) I will refrain from further elaboration here. However, there is only moderate damage to housing like some with heavy roofs of stone falling down and some walls collapsing but nothing about furniture sliding around inside houses and/or broken pottery. Such effects were reported from Stockholm and the Bothnian Bay area. It is not easy to reconcile small damages to man-made housing with triggering of rock avalanches, even in the vicinity of Bodø - a small village in 1819. Besides, Ambreseys (1985) does not find evidence of such disturbances near Bodø but originated from a British adventurer travelling through this area and looking for sea serpents (now whaling safaris) in Vestfjorden and off-shore Andøya). Another puzzling feature is the scarcity of observations from S. Helgeland, Lofoten and Vesterålen. MW&W explained this in terms of few people living in these areas (wrong) while Wahlstrøm (2004) states that people did not bother to report. Keilhau (1836) lists just one previous earthquake (1815) in this area causing strong shaking in Saltdalen. To me the obvious explanation is that perhaps there was not much to report. Furthermore, the priests Heltzen (at Hemnes) and Sommerfelt (in Saltdalen) are considered unlikely to be the only naturalist interested priests in the region as they were all University of Copenhagen graduates in those days.

There is much confusing and contradicting macroseismic

Table 1. List of the 6 largest known earthquakes in Norway and adjacent seas.

DATE Y/M/D	H/M/SEC	Location	Io	MAG.1	MAG.2	REF.1	REF.2
1759/12/22	00/30/00	57.7N 11.1E	7	5.7	5.2	MW&W, AMB	K&H
1819/09/31	14/30/00	66.4N 14.4E	7	5.8	5.1	MW&W, AMB	H&K
1866/03/09	01/20/00	65.2N 06.0E	7	5.7	?	MW&W, G&W	-
1904/11/23	10/26/00	59.2N 10.5E	7	6.4/5.4	5.4	R&AL/ MW&W	B&AL
1931/06/07	00/25/00	54.1N 01.5E	-	6.3/6.1	5.3	R&AL/ M&AL	B&AL
1992/04/13	01/20/00	51.1N 05.1E	8	5.6	5.4	ISC	B&AL

Table 1. List of the 6 largest known earthquakes in Norway and adjacent seas. Two non-historic earthquakes are included as well. The 1931 Doggerbank event is rated the largest in the UK though its epicentre was clearly off-shore. The columns are date, origin time, epicentre coordinates and max intensity Io. Mag.1 is the presumed original MS-magnitude while Mag.2 is the revised MA-magnitude. Also, magnitudes are sometimes complicated because relations between ML = Lg- or local mag., Mw = Moment mag. and MS = Surface or Rayleigh wave mag. vary considerably between studies and also between regions. REF.1 pertains to the original magnitude estimate while REF.2 pertains to works corresponding to MAG.2 estimates. Note, the Møre event in 1866 has not yet been reanalyzed. The references are; AMB = Ambraseys (1985), B&AL = Bungum et al. (2003); G&W = Grünthal & Wahlstrøm (2003), H&K = Husebye & Kebeasy (2004), ISC = International Seismological Commission Bulletin, K&H = Kebeasy& Husebye (2003), M&AL = Main et al. (1999), MW&W = Muir Wood & Woo (1987) and R&AL = Ringdal et al. (1982). Kolderup (1913) gives detailed descriptions of all tabulated earthquakes except the recent one at Roermond in the Netherlands in 1992.

reporting and both MW&W and Ambreseys (1985) are quite critical on this issue but not so B&O nor Wahlstrøm (2004). Keilhau (1836) offers an instructive example. The Lisbon earthquake of 1st November 1755 was reportedly felt early in the morning both in Kristiansand and by ships at anchor about 7 hours before it was felt in Lisbon! Perhaps there is here a mix-up with a local earthquake in the nearby offshore Skagerrak graben, if indeed it was an earthquake at all. A puzzle is why the Lurøy earthquake triggered avalanches in Lurøy, Nesna, Utskarpen, Træna and Bodø (disputed) but did not cause severe damage to man-made constructions and housing. B&O elaborate on earthquake triggering of avalanches and mention that a M6 earthquake may have such effects 50 - 100 km away. H&K and Kebeasy et al. (2003) argue that a shallow focus in combination with exceptional topographic (3D synthetics) wave field amplifications offers a plausible explanation. Also, Ambreseys (1985) does not find an obvious correlation between avalanches of various kinds in Norway and earthquake occurrences. There is definitely no simple one-to-one relationship here.

Seismic hazard implications

An interesting piece of information given by B&O is that national (Norway) hazard analyses are not tied directly to the observed seismicity but to seismotectonic considerations of intraplate areas. In particular failed rift structures may 'cause' M7 (magnitude 7) earthquakes and an example is the 3 M7+ New Madrid, Missouri events in 1811/12 (Hough 2004). It appears that the County Governor of Hordaland (2004) does not know this since in a recent geohazard study, the Lurøy earthquake is used as a yardstick for the claim that a M6+ earthquake may occur in the county of Hordaland within a 500 year time span. If so, and if the earthquake strikes in the Bergen area, more than a thousand people may be injured but somewhat fewer will be killed according to his report. A M4.5 event may occur in a 10 – 50 years time interval in Hordaland and may cause some damage to man-made structures. These predictions would mean that some documentation should exist for such disasters since Bergen has been a major Norwegian city since the year 1200. Moreover, there is no elaboration in the County Governor's report (2004) on felt and damage by earthquakes in historic time, nor on the frequency of earthquake activity with time.

One argument by B&O to retain a M6+ earthquake rests on mobile seismograph network deployment in the Lurøy-Sjona (Rana) area during 1997/99 (Fig. 3 in B&O). The deployment area is optimised from a project point of view (many earthquake recordings likely), but is not particularly representative for the average seismicity of Norway and adjacent seas. However, from this study by Hicks et al. (2000) it is concluded that the return periods for ML6 events are 2300 years, but for all Norway and adjacent seas the return periods would be about 100 years for MS = 6 earthquakes (Bungum et al. 2000). Regrettably, B&O do not attempt to validate this statement. The question is simply, where are their 'predicted' ML6 earthquakes located? – (from Table 1 the expected 2-4 events are non-existent). There is one possible exception here, namely, the Møre earthquake on 9 March, 1866. MW&W give MS = 5.7 but this earthquake has not been subjected to a critical re-analysis.

Concluding remarks

I appreciate B&O's critical comments on H&K's Lurøy paper but on the other hand it is somewhat disappointing that these scientists do not address the basic problem connected with the analysis of incomplete and possibly faulty macroseismic observations dating back nearly 200 years. Statements claiming that on average a magnitude 6+ earthquake may occur every 100 years should have been substantiated as in my opinion no M6 earthquake has taken place in Fennoscandia at all during the last 500 years. Of note is the recent Kaliningrad earthquake of 21 September 2004 and ML = 5.0 instrumental magnitude. It was felt in cities like Ålborg (DK), Oslo (N), Pori and Helsinki (SF), St. Petersburg (RU) 800-1000 km away. The I=3 radius of perception corresponding to a ML = 5.0 earthquake is only ca. 400 km (Husebye & Mäentyniemi 2005). The lessons to be learned from macroseismic observations of this event are that the Lurøy observations like those from Kola, western Finland and Stockholm should be deleted. We simply cannot have large earthquakes and hardly any damage to man-made structures. Statements like 'robust one-storey wood dwellings are too sturdy etc' are not considered strictly valid. Overturning of furniture, crushing of pottery etc should have been reported frequently for some of the largest earthquakes claimed but few such reports exist. Also, large resources are used for operating seismograph networks in the region but the results are not so useful since focal parameter estimates are not particularly accurate for an event population completely dominated by chemical explosions (Huseby et al. 2002).

Finally, Muir Wood & Woo (1987) and Muir Wood (1989) give the largest intensity values both for the Kattegat 1759 and the Lurøy earthquakes, but since no intensity corrections are considered the corresponding magnitude estimates will be upwardly biased. The revised magnitude estimates for primarily the Lurøy earthquake (Husebye & Kebeasy 2004) and the Kattegat earthquake of 1759 (Kebeasy & Husebye 2003) may not be accepted by Bungum & Olesen (2005) and Wahlstrøm (2004), but they represent an attempt to understand complex phenomena from limited information.

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