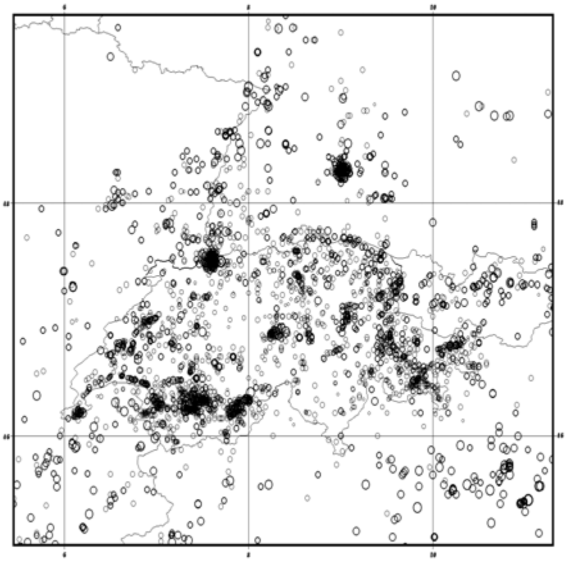
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Schweizerischer Erdbebendienst
Swiss Seismological Service

ECOS-09
Earthquake Catalogue of Switzerland
Release 2011

Swiss Seismological Service
ETH Zürich



ECOS-09 Catalogue

Public version

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Report

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Table of contents ECOS-09 Report

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Appendices (provided in electronic form)

Appendix A: ECOS – Earthquake Catalogue of Switzerland ECOS. Report to PEGASOS, Version 31.03.2002; ECOS Catalogue Version 31.03.2002. Swiss Seismological Service, ETH Zürich, 2002, 95.p.

Appendix B: Grundlagen des Makroseismischen Erdbebenkatalogs der Schweiz, Band 1, 1000–1680. Gabriela Schwarz-Zanetti and Donat Fäh. Herausgegeben vom Schweizerischen Erdbebendienst, Zürich. VDF, 2011.

Appendix C: Grundlagen des Makroseismischen Erdbebenkatalogs der Schweiz, Band 2, 1681–1878. Monika Gisler and Donat Fäh. Herausgegeben vom Schweizerischen Erdbebendienst, Zürich. VDF, 2011.

Appendix D: Calibration of historical earthquakes for the earthquake catalogue of Switzerland ECOS-09. Sonia Álvarez-Rubio, Philipp Kästli, Donat Fäh, Souad Sellami. Internal report of the Swiss Seismological Service, March 2010.

Appendix E: The BOXER method applied to the determination of earthquake parameters from macroseismic data – Verification of the calibration of historical earthquakes in the Earthquake Catalogue of Switzerland (ECOS2009). Sonia Álvarez-Rubio and Donat Fäh. Internal report of the Swiss Seismological Service, December 2009.

Appendix F: Catalogue for the period 1964 to 1974. Souad Sellami. Internal report of the Swiss Seismological Service, March 2010.

Appendix G: Documentation of the Swiss instrumental earthquake catalog, 1975-2008. Nicholas Deichmann and Souad Sellami. Internal report of the Swiss Seismological Service, December 2009.

Appendix H: Swiss instrumental local magnitudes. Nicholas Deichmann. Internal report of the Swiss Seismological Service, December 2009.

Appendix I: Determination of M_W and calibration of M_L (SED) – M_W regression. Bettina Allmann, Benjamin Edwards, Falko Bethmann, and Nicholas Deichmann. Internal report of the Swiss Seismological Service, March 2010.

Appendix J: Merging catalogues with focus on the period 1975-2008. Jochen Woessner, David Eberhard, Philipp Kästli. Internal report of the Swiss Seismological Service, March, 2010.

Appendix K: Conversion of local magnitude from foreign catalogs to SED local magnitude Nicholas Deichmann. Internal report of the Swiss Seismological Service, December 2009.

Appendix L: ECOS-09 Catalogue Format. Philipp Kästli. Internal report of the Swiss Seismological Service, March 2010.

1. Acknowledgements

ECOS-09, the Earthquake Catalogue of Switzerland, is a project of the Swiss Seismological Service (SED) and is a key step in the upgrade of the databases for earthquake hazard assessment for Switzerland and neighboring regions. ECOS was first published in 2002 and included a complete revision of the Macroseismic Earthquake Catalogue of Switzerland (MECOS-02). The 2009 update of the catalogue now includes the instrumental catalogue from the last seven years that relies on high quality broadband data, along with new findings and results from research in historical and instrumental seismology, focusing upon improved methods to derive homogenous magnitudes.

Support for ECOS-09 comes from internal ETHZ and SED budgets, and through a contract with swissnuclear for the compilation of the catalogue and database. We thank all agencies for their support.

ECOS-09 is generated by the fusion of different catalogues covering Switzerland and parts of France, Germany, Austria and Italy. Responsible agencies and experts from these countries have helped to prepare catalogues and data. We thank the following national agencies, research institutes and colleagues for this contribution: W. Brüstle, LED Baden-Württemberg; M. Henger and K. Klinge, BGR; G. Grünthal, GFZ; M. Stucchi and A. Gomez, INGV Milano; W. Lenhardt, ZAMG; M. Cara, N. Granet and C. Nicoli, BCSF; J. Lambert, BGRM; O. Scotti and J. Repussard, IRSN; F. Mele and S. Mazza, INGV Roma.

The revision of ECOS and MECOS was carried out by a dedicated group at SED during the years 2008–2011. The group listed below includes historians, seismologists and database experts (some of the people listed were involved only part time or for part of the project).

Prof. Dr. D. Giardini, Director SED
Dr. D. Fäh, ECOS-09 Project Manager

Team members in alphabetic order

- Dr. B. Allmann, magnitude calibration
- Dr. S. Alvarez-Rubio, calibration of historical events
- F. Bethmann, magnitude calibration
- Dr. N. Deichmann, instrumental catalogues, magnitude determination
- D. Eberhard, catalogue fusion
- Dr. B. Edwards, magnitude calibration
- Dr. S. Fritsche, instrumental and historical catalogues
- G. Gassner-Stamm, historical catalogue
- Dr. M. Gisler, historical and macroseismic investigations
- P. Kästli, database, calibration of historical events
- Dr. G. Schwarz-Zanetti, historical investigations
- Dr. S. Sellami, instrumental and historical catalogues
- Dr. J. Wössner, catalogue fusion and statistical analysis

2. Summary

In the last years, the Swiss Seismological Service (SED) has updated the Earthquake Catalogue of Switzerland and prepared an electronic version for publication. The version presented here (ECOS-09) is an excerpt of the SED-database and includes all earthquakes for which macroseismic or instrumental data exists. The catalogue is the result of the revision of recent earthquake catalogues for Switzerland. It encompasses – in differing degrees of completeness – the period between AD 250 and the end of 2008.

Depending on size and location of the events, the study of earthquakes before 1975 was undertaken in three steps: historical, macroseismic and seismological. Firstly, historical records were used to analyze known earthquakes. All available studies, catalogues of earthquakes and macroseismic databases from Switzerland and neighbouring countries were evaluated, matched, and stored in a database. Secondly, all earthquakes where significant effects were observed in Switzerland and its surroundings were re-evaluated and the associated intensity fields were determined. Intensity points for foreign locations were imported from available compilations. Earthquakes without significant damage (if known) were systematically reviewed for the years following 1878, while those from the period preceding 1878 were processed according to the availability of historical documents. Thirdly, all earthquakes with sufficient seismologically determined intensity observations were evaluated: their strength was determined using a regression procedure to derive source parameters (epicenter, depth, epicentral intensity, maximum intensity, magnitude). At the same time Swiss earthquake seismograms from the main European earthquake observatories since the beginning of the 20th Century were analyzed to derive a relationship between magnitude and intensity.

For the earthquakes after 1975, earthquake locations from the instrumental network of SED were reviewed. Due to the continual upgrade of the instrumental network over the years, the accuracy of locations has also become more reliable. In order to complete the catalogue, particularly in the border regions of Switzerland, it was supplemented with the available earthquake catalogues from neighbouring countries and international agencies. Existing since the mid-1980s, digital waveforms were used to calibrate different magnitude scales of other seismological observatories with the Richter magnitude (ML scale) of the SED. In addition, for all earthquakes a homogeneous magnitude estimate, based on the moment magnitude (Mw), was derived.

The earthquake catalogue ECOS-09 and the associated macroseismic database is available online on the website of the Swiss Seismological Service (http://www.seismo.ethz.ch). The data that are made public covers a region that includes the area of the Swiss national map at a scale of 1:500 000 plus a buffer zone of 30 kilometers (Swiss coordinates (km): 460-882 / 20-350; Geographical coordinates approx.: 5.6-11.1E / 45.4 -48.3N). The expected completeness of ECOS is regional and temporal and varies for different earthquake intensities. The ECOS09 catalogue corresponds to the level of knowledge about earthquakes in Switzerland in 2009.

2.1. Status of the Earthquake catalogue of Switzerland in 2002

In 2002, the Swiss Seismological Service (SED) prepared the earthquake catalogue of Switzerland (ECOS-02), including its publication on the internet. ECOS-02 is an extract of the database of the SED and contains all known events of Switzerland and the adjacent areas, for which either macroseismic observations or instrumental recordings are available. It covers the time period between 250 AD to the end of 2001, at different levels of completeness. The revision was concluded in 2002; the report can be downloaded from the SED website (Appendix A of this report, Swiss Seismological Service, 2002). We conducted three levels of investigation, dependent on the size and location of each event: historical, macroseismic and seismological levels of investigation.

At the historical level, available historical information was analyzed and, furthermore, all relevant earthquake studies, historical and instrumental catalogues and available macroseismic databases previously assembled in Switzerland and neighboring regions were merged into a database.

At the macroseismic level, all earthquakes located inside Switzerland or adjacent areas, which produced significant effects (i.e., intensity>V/VI) in Switzerland, were reassessed, and intensity fields were established. Intensity data points for localities outside Switzerland were imported from available compilations. Earthquakes with epicentral intensity smaller than VI inside Switzerland were reviewed for the period since 1878, or when information was found in historical sources. Earthquakes that occurred after 1975 are largely parameterized from instrumental recordings. The database holds macroseismic information for larger events (usually maximum intensity >III) for events after 1975.

Data from historical and macroseismic investigation is stored in a database called MECOS-02, the Macroseismic Earthquake Catalogue of Switzerland 2002. It was built by collecting and analyzing historical records, as well as by merging all available macroseismic information and earthquake studies. It provides macroseismic parameters and bibliographical references for each event. It also lists an inventory of fake earthquakes. A homogeneous quality level for the whole database and catalogue was compulsory.

At the seismological level, all earthquakes with a sufficient number and distribution of intensity points were uniformly regressed in order to derive source parameters (epicenter location, hypocentral depth class, epicentral intensity, maximum intensity, macroseismic magnitude) and their respective uncertainties. In order to perform magnitude/intensity calibration, a homogeneous set of instrumental magnitudes for significant Swiss earthquakes since the beginning of the 20th century was required. The evaluation of the events is based on the analysis of seismograms from European observatories. Moreover, digital waveforms, collected since the late seventies to compute digital magnitudes, were collected in order to re-calibrate the M_L scale used by SED, and to compute homogeneous regressions between different magnitude scales. Finally, foreign catalogues were merged with the Swiss catalogue, including the conversion to a common magnitude scale. The catalogue therefore provided a uniform estimate of the magnitudes for all events.

The completeness of ECOS-02 varies through time and region for different levels of magnitude. The earthquake catalogue covers the time from 250 AD to December 2001. Later earthquakes do not belong to the published ECOS-02 catalogue and were adapted to the results of current research without previous notification.

2.2. Update of the Earthquake Catalogue of Switzerland

The 2009 update of the catalogue is justified by several reasons. It allows a) for the inclusion of the revised instrumental catalogue for the time period prior to 2002, and for the recent time-period using high quality broadband data; b) for new findings and results from research in historical and instrumental seismology to be taken into account; and c) the application of improved methods to derive homogenous magnitudes for events in the historical and instrumental period.

Several historical events are now studied thoroughly, namely the well-known and large events. Over the course of a PhD thesis (Fritsche, 2008), the events of 1855, 1946 and 1964 were reassessed, including large sequences of aftershocks, each forming a specific event and thus enlarging the database. Major attention was given to the 1356 Basel event in a special project (Fäh et al., 2009). Its study included historical and archaeological investigation as well as the interpretation and parameterization of the event. Other events were re-analyzed over the course of several publications. All major events having occurred in the Kanton Graubünden were re-checked before publishing a book on the topic (Gisler et al., 2005). Additionally, all larger Swiss events were reassessed during the publication of a book covering all major earthquakes in Switzerland (Gisler et al., 2008).

The magnitudes of some of the calibration events used to calibrate historical earthquakes for ECOS-02 changed, due to reassessments by Braunmiller *et al.* (2005) and Bernardi *et al.* (2005), using available digital and analog recordings of events that occurred in the 20th century. This requires a new calibration of the historical events in the catalogue.

The Swiss instrumental catalogue has been revised, and updates of national catalogues from neighboring countries are implemented in ECOS-09. In an effort to obtain an earthquake catalogue of Switzerland and surrounding countries with homogenous moment magnitudes we have adopted a two-step procedure: first we convert local magnitudes of foreign catalogues to an equivalent Swiss local magnitude and then we convert these homogeneous local magnitudes into a common moment magnitude.

The new catalogue spans a period of more than 1000 years, with the first known Swiss event dated to 849 AD, with a more uncertain one in 250 AD in Augusta Raurica (Augst/CH). Instrumental information is included until the end of 2008. However some of the national catalogues from neighboring countries include events only until the end of 2007, the Italian catalogue ISIDE includes events until 9.9.2007. All information is stored in the database and, for historical documents, in the library of the Swiss Seismological Service, ETH Zürich. The main parts of the database structure from ECOS-02 were retained for the update of the catalogue. The description of the database structure can be found in the report published in 2002 (Appendix A).

An extended version of the catalogue, covering a wider area than this public version, is used in the Pegasos Refinement Project (PRP), and was reviewed in 2010 by an international group of experts.

3. Revision of the MECOS database

The core of the earthquake catalogue is MECOS: the Macroseismic Earthquake Catalogue of Switzerland. It includes a comprehensive and homogeneous database of historical and macroseismic information built upon the collection and analysis of historical data. It merges all available macroseismic inputs for significant events within Switzerland. After the first version of the Macroseismic Earthquake Catalogue of Switzerland in 2002 (MECOS-02), a complete revision has been undertaken in order to create a refined version of the catalogue (MECOS-09). Between 2003 and 2009 numerous additional information was collected and stored in the database, covering both recent earthquakes (2003 through to 2009) as well as historical ones (i.e., earthquakes before 1975). Research in archives and libraries generated new contemporary and copied historical material. In the majority of cases this included additional information for previously documented earthquakes, thus adding to the understanding of their macroseismic field. However, some newly detected earthquakes were also parameterized.

The database now consists of more then 32000 reports. More than 1500 historical earthquakes are thought to have occurred, many of them are certain, others unlikely, or even very uncertain. Each site consists of at least one report. Many sites consist of several reports. The same is true for the events: some are composed of only one site with an intensity data point, whereas others are well established by several hundred sites.

Over the course of the re-evaluation of MECOS, all historic and macroseismic data has been reassessed, including the bulk of data that was stored and analyzed over the years 2000 through to 2002, i.e., all information, new or already stored, has been re-checked and re-analyzed in terms of macroseismic intensity assessment using a more precise estimate of type, size and distribution. Several events have required major attention, particularly the very well known and large events.

As mentioned above, over the course of a PhD thesis (Fritsche, 2008), the events of 1855, 1946 and 1964, were reassessed and their results integrated into the database. Major attention was given to the large sequences of aftershocks. The 1855 earthquake in Visp was reconstructed by studying the site-effects and structural damage and thus generating a rather precise picture of the damage field. It remains the strongest earthquake of the last 300 years in Switzerland, causing severe damage in the Canton Valais. Key factors in such a study are the availability and accessibility of sufficient historical data. Given the existence of a complete contemporary damage assessment and the availability of early statistics, this investigation generated an excellent pool of data.

In the case of the 1946 earthquake, the goal of the study was to reconstruct the damage field and to investigate it with respect to possible site-effects. Historical research was combined with geophysical investigation, including a large number of experiments concerning the measurement of the fundamental frequency of resonance and the shear-wave velocities of the sedimentary layers. The results showed that damage in Valaisan districts with high percentage of settlement area on the lacustrine and fluviatile deposits of the Rhone Valley generally showed considerably higher losses than other districts.

Furthermore, the reconstruction of the damage field of the 1964 event was at stake. Given the existence of a contemporary damage assessment and other historical sources, the damage field can now be plotted in detail.

Major attention was also given to the 1356 Basel event (Fäh et. al, 2009), one of the most damaging earthquakes in intra-plate Europe. Its study included historical and archaeological investigation as well as its interpretation and parameterization. The effort integrated techniques from several different scholarly fields: history, seismology, archaeology, paleoseismology and engineering. The main goal was to create a more robust database than was already known. New and reinterpreted historical data from Basel and its surrounding areas, as well as archaeological findings of buildings that survived the event and still exist today, facilitated the macroseismic assessment. Palaeoseismological studies combined with historical evidence provided additional data. For the surrounding areas, archaeology offered sparse information on some castles and churches, sometimes supported by historical records. A contemporary source allowed the reconstruction of some of the stronger fore- and aftershocks. All information was integrated into the database.

Initially, all major events having occurred in the Kanton Graubünden have been re-checked when publishing a book on the topic (Gisler et al., 2005). The same holds true for all larger events, not mentioned above. They were resumed in the course of specific publications, especially for the publication of a book (Gisler et al., 2008) covering all large (i.e., damaging) events within the Swiss borders. This reassessment included all known events before the year 1000, the events mentioned above and those of 250, 1021, 1584, 1601, 1720, 1755, 1774, in addition to a number of smaller earthquakes.

All data ever entered into the database has undergone a re-assessment regarding intensities. In due course many smaller events which where, until now, based upon unchecked files with only macroseismic intensity data points (of which we do not have knowledge of how they were generated), were re-assessed, now based upon our own estimation.

Since the database is for internal use only, it was our ambition to publish as much of our knowledge as possible, in order to provide it to interested parties. In particular, the data is now outlined in two volumes (draft versions are presented in Appendix B and C), covering the time period between 1000 and 1878. The first part (Schwarz-Zanetti and Fäh, 2009; see Appendix B) summarizes our knowledge of events roughly between 1000 and 1680, in other words from the first traces in the Middle Ages to the early Enlightenment. The second part (Gisler and Fäh, 2009; see Appendix C) summarizes our notion of events between 1680 and 1878, covering the enlightenment era and the 19th century, and ending with the year when the Swiss Seismological Commission was established. For the period after 1880, all known events are summarized in the annual bulletins of the Swiss Seismological Service (Schweizerische Erdbebenkommission / Schweizerischer Erdbebendienst, 1881–1962; 1972–1974).

In Appendix B and C of this report, all known events reaching a threshold of a maximum intensity of six (VI) and above are discussed. Furthermore, the appendices include a number of smaller events, plus all supposedly fake or uncertain events.

For all earthquakes the following parameters and information are provided respectively: date, time (in UTC), location (if possible); rating of the event (true event; doubtful event; very doubtful event; fake event due to a timing error; fake event due to a location error; fake event); correction of time, date or location (if required); macroseismic parameters; historical tradition; discussion of the event; remarks.

To conclude, the following publication list displays our intention to publish the bulk of knowledge gained over the last ten years:

- Cara, M., W. Brüstle, M. Gisler, P. Kästli, C. Sira, C. Weihermüller, J. Lambert (2005): Transfrontier macroseismic observations of the Ml=5.4 earthquake of February 22, 2003 at Rambervillers, France. *Journal of Seismology* 9/3, p. 317–328.
- Fäh, D., M. Gisler, D. Giardini (2004): Historische Erdbeben in der Schweiz. Bundesamt für Bevölkerungsschutz (ed.): *KGS/PBC/PCP Forum*, Bern, p. 18–28.
- Fäh, D., Steimen, S., Oprsal, I., Ripperger, J., Wössner, J., Schatzmann, R., Kästli, P., Spottke, I. and P. Huggenberger, 2006. The earthquake of 250 A.D. in Augusta Raurica, a real event with a 3D site-effect? Journal of Seismology. DOI: 10.1007/s10950-006-9031-1, Vol. 10, No. 4, p. 459–477.
- Fäh, D., M. Gisler, Bernard Jaggi, P. Kästli, Thomas Lutz, Virgilio Masciadri, Christoph Matt, Dieter Mayer-Rosa, Dorothee Rippmann, G. Schwarz-Zanetti, Jürg Tauber, Thomas Wenk (2009): An interdisciplinary revision of the 1356 Basel Earthquake. *Geophys. J. Int.* (2009) 178, p. 351–374
- Fritsche, S., Fäh D., und D. Giardini (2005): Damage Fields and Site-Effects. Investigations on the 1855 Earthquake in Switzerland. *Proceedings of the international conference of the 250th Anniversary of the 1755 Lisbon Earthquake,* Lisbon, p. 340–346.
- Fritsche, S., Fäh D., Gisler M., and D. Giardini (2006): Reconstructing the damage field of the 1855 earthquake in Switzerland: historical investigations on a well-documented event. *Geophysical Journal International* 166, p. 719–731.
- Fritsche, S. (2008): Large Historical Earthquakes in Switzerland. Multidisciplinary Studies on Damage Fields and Site Effects, *Diss. ETH Zürich,* No. 17710, Zürich.
- Fritsche, S., Fäh D., Steiner B. and D. Giardini. (2009): Damage Field and Site Effect: Multidisciplinary Studies of the 1964 Earthquake Series in Central Switzerland. *Nat Hazards,* 48, p. 203–227.
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- Gisler, M. (2005): Optimism and Theodicy. Perception of the Lisbon Earthquake in Protestant Switzerland. *Studies on Voltaire and the Eighteenth Century* (SVEC), p. 247–264.
- Gisler, M. (2006): Die Anfänge der systematischen Erdbebenforschung in der Schweiz und der Beitrag der Innerschweiz. *Der Geschichtsfreund*,159, Altdorf, p. 29–38.

- Gisler, M., (2007): Erdbeben in der Schweiz im ersten Jahrtausend – Evidenzen und Grenzen. In: G.H. Waldherr, A. Smolka (ed.): *Antike Erdbeben im alpinen und zirkumalpinen Raum. Befunde und Probleme in archäologischer, historischer und seismologischer Sicht/ Earthquakes in Antiquity in the Alpine and Circum-alpine Region. Findings and Problems from an Archaeological, Historical and Seismological Viewpoint*, Stuttgart (= Geographica Historica 24), p. 133–153.
- Gisler, M., D. Fäh, D. Giardini (ed.) (2008): *Nachbeben. Eine Geschichte der Erdbeben in der Schweiz*, Bern: Haupt Verlag, 192 p. (compiles chapters by M. Gisler, G. Schwarz-Zanetti, S. Fritsche, D. Fäh, P. Kästli).
- Gisler, M., D. Fäh, N. Deichmann (2004): The Valais Earthquake of December 9, 1755. *Eclogae Geol. Helv*. *Swiss Journal of Geosciences* 97, p. 411–422.
- Gisler, M., D. Fäh, P. Kästli (2004): Historical Seismicity in Central Switzerland. *Eclogae Geol. Helv*. *Swiss Journal of Geosciences* 97, p. 221–236.
- Gisler, M., D. Fäh, R. Schibler (2003): Two serious earthquakes in the Rhine Valley at the end of the 18th century: The events of December 6, 1795 and April 20, 1796. *Eclogae Geol. Helv*. *Swiss Journal of Geosciences* 96, p. 357–366.
- Gisler, M., D. Fäh, R. Schibler (2004): Revising macroseismic data in Switzerland: The December 20, 1720 earthquake in the region of Lake Constance. *Journal of Seismology* 8/2, p. 179–192.
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- Gisler, M., D. Giardini (2007): Erdbeben in Europa – eine kleine Kulturgeschichte. *Vierteljahresschrift der Naturforschenden Gesellschaft in Zürich,*152/4, p. 101–110.
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- Gisler, M., M. Weidmann, D. Fäh (2005): *Erdbeben in Graubünden. Vergangenheit, Gegenwart, Zukunft*, Chur: Desertina, 135 p.
- Gisler, M., V. Masciadri (2008): Erdbeben in der Schweiz in der Spätantike und im Frühmittelalter. In: Gisler, et al. (ed.), *Nachbeben*, p. 11–19.
- Schwarz Zanetti, G., Deichmann, N., Fäh, D., Masciadri, V., Kästli, P., Schnellmann, M., Jimenez, M. (2006): Das Unterwaldner Erdbeben vom 18. September 1601. *Naturkatastrophen in der Zentralschweiz. Der Geschichtsfreund*, 159, p. 11–28.
- Schwarz-Zanetti G., Deichmann N., Fäh D., Masciadri V., Goll J. (2004): The Earthquake in Churwalden (CH) of September 3, 1295. *Eclogae Geol. Helv. – Swiss J. Geosciences* 97, p. 255–264.
- Schwarz-Zanetti G., Fäh D., Schibler R., Masciadri V., Kästli P., Giardini D. (2003): The earthquake in Unterwalden and the rockslide from the Bürgenstock into Lake Lucerne on September 18, 1601. *Eclogae geol. Helv. – Swiss J. Geosciences*, 96.
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- Schwarz-Zanetti, G., Masciadri, V., Fäh, D., Kästli, P. (2008): The false Basel earthquake of May 12, 1021. *Journal of Seismology* 12/1, p. 125–129.

Forthcoming:

- Gisler, M., D. Fäh (2010): Grundlagen des Makroseismischen Erdbebenkatalogs der Schweiz, Band 2 1681–1878. Herausgegeben vom Schweizerischen Erdbebendienst, Zürich. VDF 2011.
- Schwarz-Zanetti, G., D. Fäh (2010): Grundlagen des Makroseismischen Erdbebenkatalogs der Schweiz, Band 2 1000–1680. Herausgegeben vom Schweizerischen Erdbebendienst, Zürich. VDF, 2011.
- Schwarz-Zanetti, G. et al. (2011): Two earthquakes in the 16th century –Ardon 1524 and Aigle 1584. In preparation.

3.1. Macroseismic level

A homogeneous quality level for the whole database and catalogue is kept the same as in the 2002 version, using the European macroseismic scale (EMS-98). This allows us to establish a uniform macroseismic field for each event. We assigned a most probable intensity and a range of intensity by giving both minimum and maximum possible values. This range illuminated information gaps and uncertainties regarding historical interpretation. For legal reasons, we provide intensity data points (IDPs) only if analyzed by us, thus no foreign IDPs are provided. Foreign IDPs however, were used when calibrating border events. Intensity data points affecting localities outside Switzerland were imported into the database from all available compilations.

The macroseismic assessment draws upon the following:

- A large quantity of information and a complete documentation of every report: a copy of the manuscript or the critical edition, a transcription and, if necessary, a translation and a reference.
- The historical analysis, considering reliable documents, making the use of compilations redundant.
- The assessment of damage for events with contemporary damage assessment, which allowed a cross-check of the former assessment in ECOS-02.
- A discussion of the quality of historical documents is available in most cases.
- Inaccuracies and fake events are now reduced and documented (Appendix B and C).

Only one catalogue, the Italian historical catalogue, was replaced by a newer version (CPTI04), in which all events have a magnitude estimate (see chapter 7). Therefore no conversion of intensities between different scales was required in ECOS-09.

3.2. Completeness

The investigated time period 250–2009 AC is not homogenously covered by documents, with a high variability in time and space. An overview of the completeness of observed intensities in time and space, as assessed in 2002, is provided in Table 3.1 and Figure 3.1. The completeness is not improved in the new version of the catalogue, because it depends on the overall quantity and quality of available historical sources. The completeness of events over the century is not linear and varies with time and space. We refer to chapter 4.2.3 in the 2002 ECOS report (Appendix A) for further information on the different time periods.

3.3. Period 1964–1974

The period 1964 to 1974 is a transition period for Switzerland, between a period covered by historical investigations and the actual instrumental period in which seismicity is analyzed with seismic recordings from a dense regional network. We can distinguish two sub-periods in the transition, a first period, from 1964 to 1971 and a second, from 1972 to 1974. The first period is referred to as the ‘dark-ages’ because annual reports ceased to be issued. During the second period a network of analog seismic stations covering most of Switzerland was being installed.

Completeness	**Swiss regions**							
Time span	1 (InnerCH)	2 (ZH/SG)	3 (BE/WestCH)	4 (Basel)	5 (Wallis)	6 (Tessin)	7 (GR)	8 (GL)
563–799	n	n	n	n	u	n	n	n
800–899	u	u	n	n	n	n	n	n
900–999	n	u	n	n	n	n	n	n
1000–1099	n	u	n	n	n	n	n	n
1100–1199	n	VII	n	n	n	n	n	n
1200–1299	n	n	n	u	n	n	VIII	n
1300–1399	n	n	u	VIII	n	n	n	n
1400–1499	n	VII	n	VII	n	n	n	n
1500–1599	n	VII	VII	n	VIII	VIII	n	n
1600–1679	VIII	VII	n	VIII	n	VIII	n	n
1680–1730	VII	V	VII	VI	VIII	VIII	VII	VI
1730–1750	VII	VI	VII	VI	VIII	VIII	VII	V
1751–1800	VI	VI	VI	VI	VII	VII	VI	V
1801–1850	VI	V	VI	VI	VII	VI	VI	VI
1851–1878	VI	V	VI	VI	VI	VI	VI	VI
1878–1963	V	V	V	V	V	V	V	V
1964–1974	IV	IV	IV	IV	IV	IV	IV	IV

Table 3.1. *Completeness of observed intensities for different regions in Switzerland over given time periods. n: no primary sources found; u: completeness unknown. The Swiss regions are illustrated in Figure 3.1. The table is taken from the ECOS-02 report (see Appendix A).*

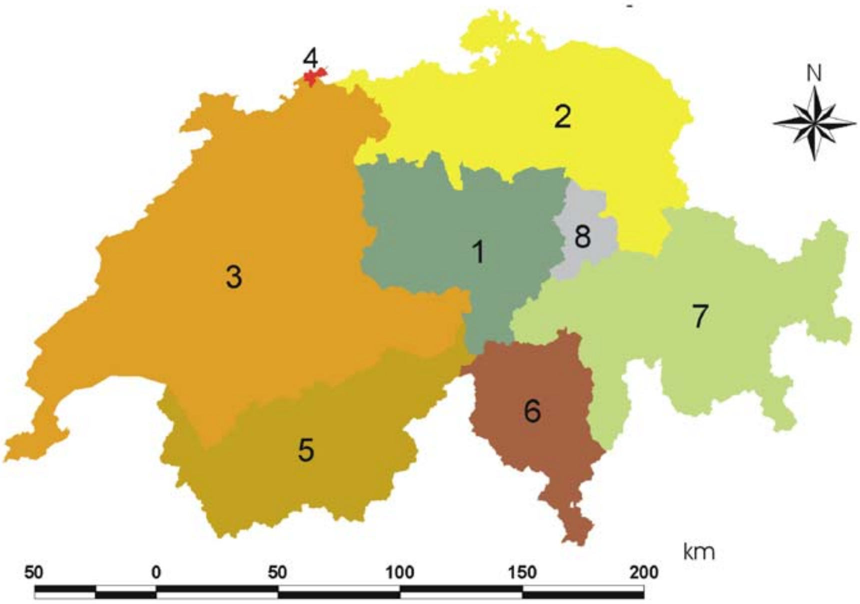


Figure 3.1*. Geographical distribution of catalogue completeness, according to Table 3.1. The figure is taken from the ECOS-02 report (see Appendix A).*

A detailed report on the situation of the Swiss Seismological Service and the seismicity in Switzerland and surrounding areas over the years 1964-1974 is provided in Appendix F, together with a detailed review of all events during this period. The catalogue ECOS-02 has been checked according to the original printed information available. Duplicates and fake events have been removed. The fake events were either mislocated strong foreign events that were felt in Switzerland or events originating from mines in France or dams in France and in Italy. In two other cases events with maximum intensities of about V in Wallis were discarded because there was no indication of their occurrence in existing sources. A few events may have been attributed to the construction of dams in Switzerland, Verzasca (TI), Linth-Limmern (GL) and Lac Hongrin (VD) but in doubtful cases they were kept in the catalogue as earthquakes.

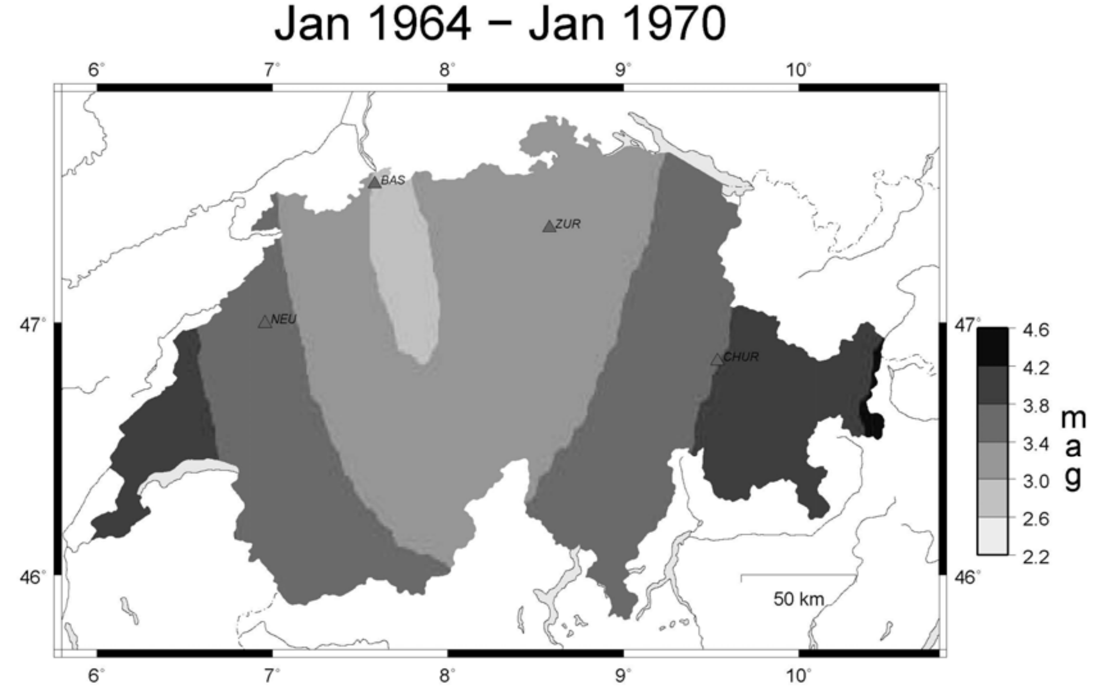
The seismic activity is dominated by the 1964 earthquake swarm in the Sarnen region. The two largest events reached an intensity of VII. This high activity in the Sarnen region eclipsed another swarm activity at the same time in the region of Trun, in the upper Rhine Valley. However, for this one the strongest event did not exceed an intensity of V. A larger event occurred in the Glarus region in September 1971 and reached intensity VI. Other events that were widely felt in north-eastern and south-western Switzerland, occurred near the borders of Germany (Swabian Jura area) and France (the Chablais Region) respectively.

During 1971 to 1974, the seismic network was developed considerably. Figures 3.2 show the influence of the station distribution on the detection threshold of events of a certain magnitude. Even in 1974 macroseismic information was important to characterize felt earthquakes in Switzerland. In the late sixties, the increase in seismicity can be associated to the large amount of data coming from the increasing number of stations in other networks. These data, mainly from French stations, compensate the lack of sensitivity of the Swiss network mainly in the western part of Switzerland. However the accuracy of the earthquake parameters is unknown.

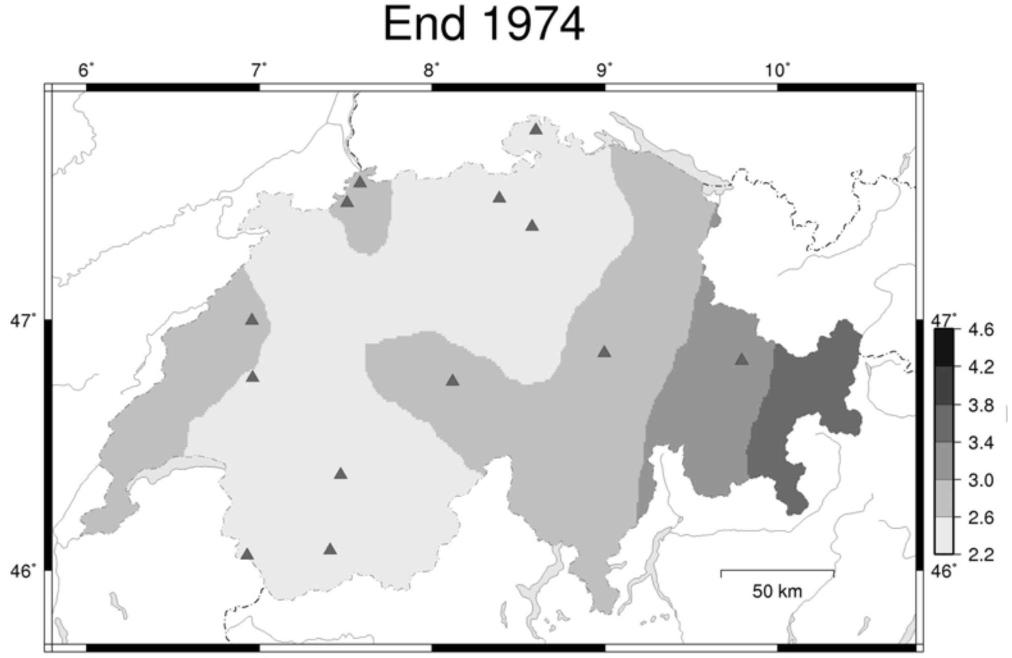
The evolution of the seismicity in time is also seen in Figure 3.3, where the event's intensity and magnitude distributions are plotted with time. One can observe the transition from a period prior to 1964, where events were systematically characterized by their intensities, and the period where the magnitude detection threshold improved with time after 1970.

If we look at the entire period, the data are rather inhomogeneous. Not only do the data come from different networks but also from very different types of seismic stations (the oldest were operating since 1911). In the sixties the intensity scale used changed from the Rossi-Forel scale (RF) to the MSK64 scale, which was systematically applied since 1972 until the mid-nineties.

Although events with magnitude of the order of two were recorded, this magnitude level is far from being complete. This is due to the lack of recording capacity on paper and the reduced space coverage of seismic stations. For the period until 1971 we consider the events with a magnitude of 3.5 to be complete. They have been compiled in Table 3 in Appendix F. New information for these events has been added. This information consists of original macroseismic fields, international studies or phase readings. The magnitude and location uncertainties have been reviewed for ECOS-09. The necessary corrections have been applied to the database and appear in the new catalogue version.

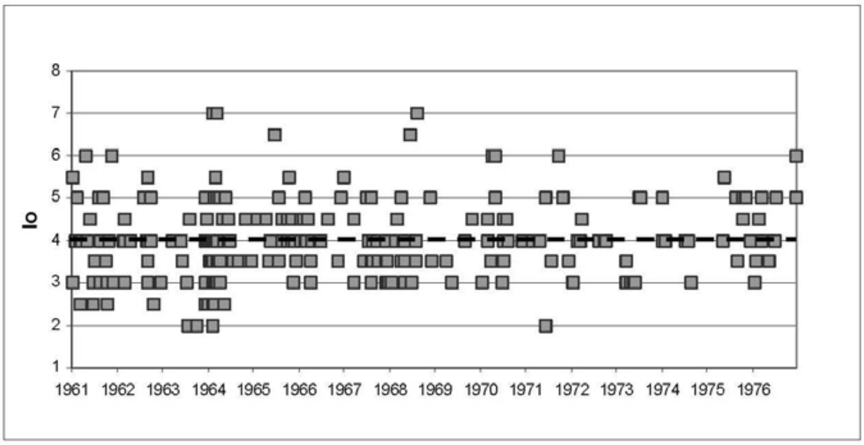


Jan 1964 − Jan 1970



End 1974

***Figure 3.2**. Operational seismograph stations and evolution of the instrumental magnitude threshold during this time period. The grey scale is the magnitude threshold of the detectable events.*



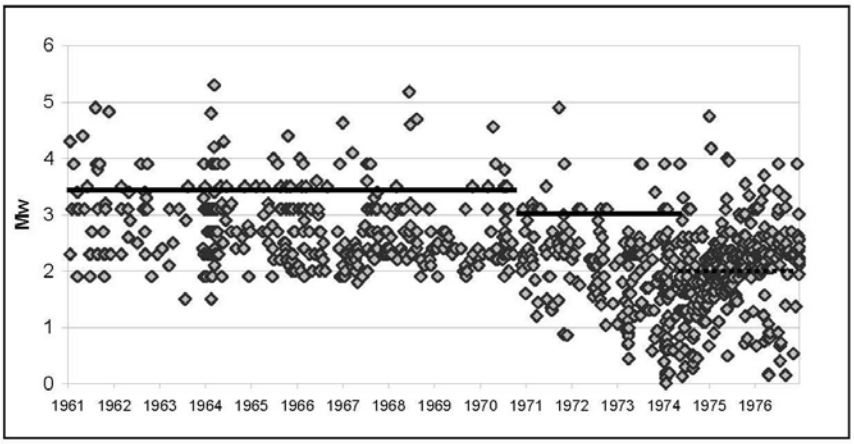


Figure 3.3. *Distribution of events in time from 1960 to 1976. The events are given in epicentral EMS98-intensity (above) and Mw-magnitude (below). The dark lines give an estimation of the completeness.*

4. Parameterization of historical earthquakes

The Swiss Seismological Service contributed to the work package *NA4 distributed archive of historical earthquake data* in the framework of the NERIES project. Part of this work was a calibration initiative for improving the determination of earthquake parameters from macroseismic data (Gomez Capera et al., 2009). The main objective of this exercise was to test methods for assessing earthquake parameters from macroseismic data. The procedures included various published and unpublished methods, using repeatable and homogenous procedures, and homogeneous input data.

The methods selected for the calibration were: Bakun and Wentworth (1997), Boxer (Gasperini, 2004) and Meep (Musson et al., 2008). They have been applied in five Europeans areas: Aegea, Iberia, Italy, Great Britain and Switzerland. The team from the Swiss Seismological Service focused on Swiss events. The assessment included the computation of location and magnitude; depth was only addressed in the Meep method. The study focused on the dependency of the magnitude on regional attenuation, the impact of the incompleteness of macroseismic datasets, and the reliability of the derived magnitudes.

The research carried out by the SED is the preparatory work for the revision of the ECOS-09. From the experiences during this project the Bakun and Wentworth (BW) method was selected as the main method for the reassessment of the historical events in ECOS-09. This was due to its flexibility and the possibility of including a-priori historical information for the epicenter location. BW was also applied during ECOS-02. The Boxer method is used to validate results from BW, specifically for earthquakes larger than the events in the Swiss calibration dataset.

4.1. Calibration method for historical events

The historical earthquakes are parameterized (epicentral location, magnitude, and depth if possible) following a similar strategy as applied in ECOS-02 (Swiss Seismological Service, 2002; Fäh et al 2003). We use the *Bakun and Wentworth* method, hereafter referred to as *BW* (Bakun and Wentworth, 1997; Hinzen and Oemisch, 2001; Bakun and Scotti, 2006). In what follows we summarize the main steps and procedures used. More details can be found in Appendix D.

The calibration in ECOS-09 follows a two-stage procedure, which decouples the estimation of the distance dependence of the macroseismic data (intensity attenuation model) from the magnitude estimation (magnitude to standardized intensity calibration). For developing the macroseismic attenuation model we tested different functional forms that relate intensity decay to distance (seen in the spatial distribution of the intensity data points (*IDPs)*), including in some cases also focal depth:

$$I_{obs} - I_{sc} = f\left(d, h\right) \tag{4.1}$$

where I_{obs} are the observed intensities, I_{sc} is the event-individual scaling intensity, which is derived in an iterative regression process (see Appendix D), *d* stands for epicentral distance D or hypocentral distance R, and *h* is the focal depth.

For each attenuation model we define a standardized intensity at a specific standard distance. The standard distance is generally 30 km hypocentral distance (I_{30}). The influence of the focal depth on the estimation of the magnitude is then significantly reduced. Macroseismic magnitude, *M*, is defined as follows:

$$M = \alpha I_{30} + \beta \tag{4.2}$$

In the following, the steps of the calibration are schematically described, and the main results of the ECOS-09 calibration and parameterization of historical earthquakes are given.

4.1.1. Calibration procedure

We have investigated different models with different variables and functional forms. The models are given in Table 4.1.

Three different calibration datasets have been used. Calibration *dataset 2* is the largest. This dataset is consecutively reduced, by removing events with a small number of IDPs. These are *dataset 3* and *dataset 4*. This reduction allows an improvement of the fit of the attenuation curve to the IDPs according to equation (4.1). For these two last sets a regionalization of alpine and foreland events was also established.

Functional form	Intensity attenuation models
Logarithmic and linear	$I - I_{sc} = aLn\left(d^{*}/h\right) + b\left(d^{*} - h\right)$
Logarithmic	$I - I_{sc} = aLn(R) + b$
Linear	$I - I_{sc} = aD + b$
Cubic	$I - I_{sc} = a\sqrt[3]{R} + b$

Table 4.1. *The different intensity attenuation models investigated in ECOS-09, D: epicentral distance; R: hypocentral distance; a,b: calibrated coefficients.* (*) *This functional form has been investigated for both distances D and R.*

From the datasets, we defined a subset of events, which have instrumentally derived moment magnitudes (M_W) to perform the magnitude calibration defined in equation 4.2. Their moment magnitudes are hereafter referred to as *Mw(bestmag).* In order to reduce the bias in the macroseismic field due to heterogeneous distributions of IDPs, incompleteness of the smaller intensity classes, and variable quality of the macroseismic data, we have processed the calibration datasets with different strategies. We apply a distance weighting to the IDPs (proportional to squared distance). IDPs smaller than intensity 3 have not been used. The intensity representation used is 'no-binning' due to consistency reasons when applying the *BW* method. Finally outliers were identified and removed during the regression process.

In terms of the focal depth, the calibration of the intensity attenuation model has been performed following the following three strategies:

- *Fixed depth strategy*: Focal depth is set to 10km for all events.
- *Variable depth strategy*: We allowed depth h to vary between 3 and 25 km.
- *Mixed strategy* (only used as a performance test): We fixed the depth for those calibration events where depth is known from instrumental data and by taking into account the known seismicity characteristics, specifically no events are located below 15km in depth in the Alps. For events with unknown depth, we used depth as a free parameter during the fitting to the functional form in equation 4.1.

Fixed and variable depth strategies have a different impact on the standardized intensity calibration.

The magnitude calibration (equation 4.2) is performed with the subsets of events with instrumental moment magnitude, *Mw(bestmag)*. This is done for each calibration dataset and strategy. The regression was performed using three weighting schemes:

- No weighting of the IDPs.
- Weighting by the number of IDPs.
- Weighting by the quality of the IDPs.

4.1.2. Results of the calibration

The main steps of the calibration procedure are:

- Processing of the data and selection of the most adequate intensity attenuation model
- Assess calibration coefficients in equation 4.1 according to the intensity attenuation model (Table 4.1) using a) all IDPs available (intensity three and above) for each event, b) only the three highest intensity classes, and c) using the intermediate intensity classes (Intensity 4 to 6).
- The three strategies described were applied using fixed depth, variable depth, and mixed depth strategies.
- Derive the coefficients of the magnitude calibration in equation 4.2. This is done for the three IDP weighting schemes listed above.

Figure 4.1 schematically describes the different steps in the calibration procedure.

The model using a logarithmic and linear term had the best fit to observed macroseismic data:

$$I_{obs} - I_{sc} = aLn\left(R/h\right) + b\left(R - h\right) \qquad (4.3)$$

It consistently resulted in good results over all strategies shown in Figure 4.1. This attenuation model was therefore selected as the *ECOS-09* intensity attenuation model.

Based on the performance of the calibration of ECOS-09 model over the different calibration datasets and depth strategies, we have selected five strategies that performed best. For *dataset 4*, there were insufficient data points to perform a reliable regression of equation 4.2. The same is true for a regional assessment of foreland events using *dataset 2* or *dataset 3*.

The magnitude estimates obtained with the five strategies for the same event are variable in the sense that firstly there is considerable scatter, and secondly there is no single calibration strategy that performs the best for all events. Four of the selected strategies are based on calibration *dataset 2,* which is the largest one, and gives good results in the magnitude calibration. All the attenuation models are very similar with the exception of the Alpine attenuation model developed with *dataset 3* (for more details see Appendix D). That's why this model is selected as the fifth strategy.

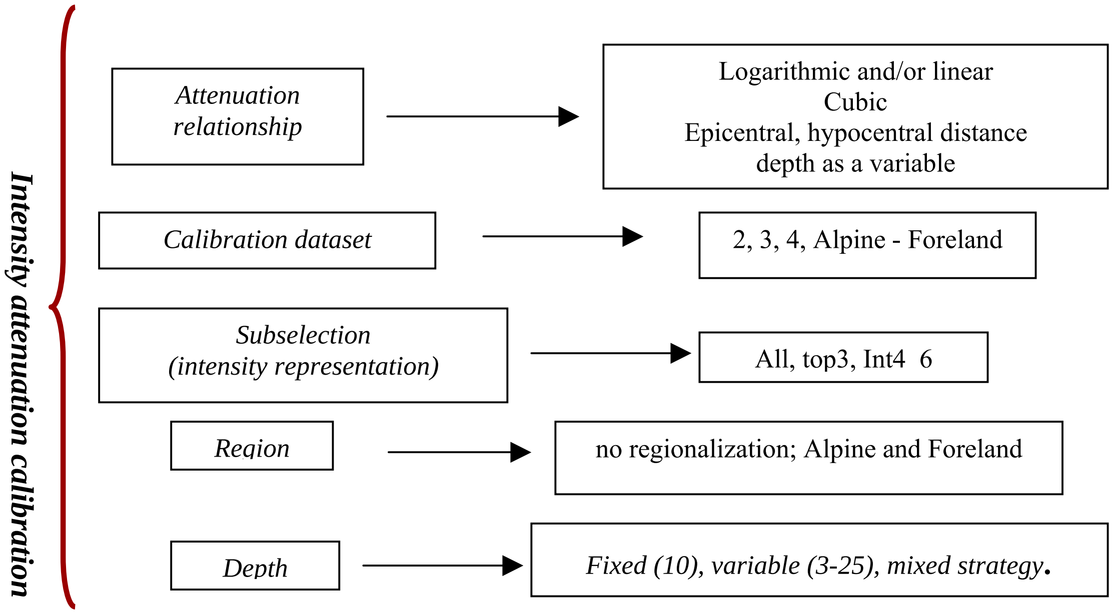


Figure 4.1. *Overview of the different calibration strategies.*

Three attenuation models have *variable depth* as parameter. In the iteration process of the regression we search for each event the best fitting depth. The depth was plotted geographically and a trend was recognized (shallow events in the Alpine area, deep events in the foreland), that corresponds to our understanding of the depth distribution from the instrumental period. However, for most of the events in the calibration dataset the inverted depths cannot be tested because depth is unknown.

The final formulation of the calibration of *ECOS-09* model is as follows:

1. The intensity attenuation model is defined, in terms of the event-individual scaling intensity I_{sc} as follows:

$$I_{obs} - I_{sc} = aLn\left(R/h\right) + b\left(R-h\right) \tag{4.4}$$

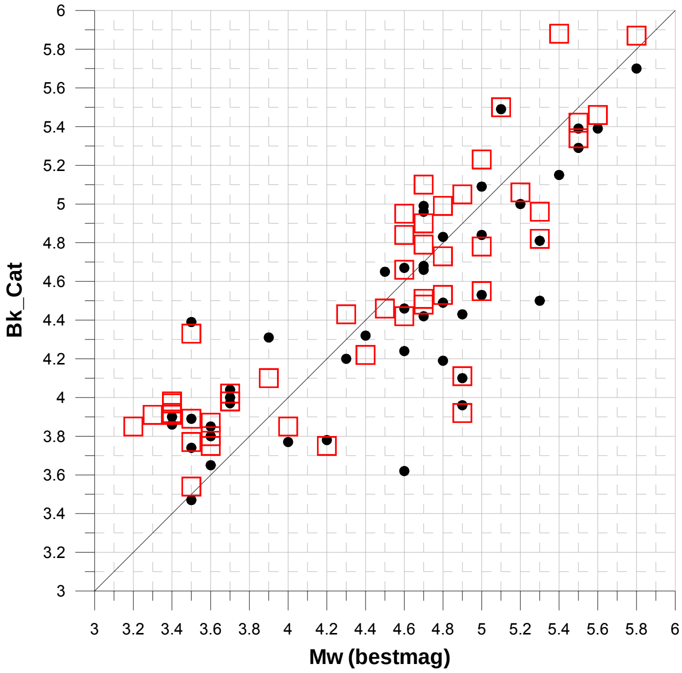
2. The magnitude to intensity relation is defined for the standardized intensity or intercept intensity at 30km hypocentral distance I_{30}:

$$M = \alpha I_{30} + \beta$$
$$I_{30} = aLn\left(30/h\right) + b\left(30-h\right) + I_{sc} \tag{4.5}$$

3. From equations 4.4 and 4.5, magnitude can be related to observed intensity. This relation is implemented in the BW method and was used to assess the epicentral location and magnitude:

$$M = c_1 I_{obs} + c_2 Ln\left(R/h\right) + c_3\left(R-h\right) + c_0 \tag{4.6}$$

where the calibration coefficients $c_0, c_1, c_2 c_3$ are calculated from a, b, α, β (see Table 4.2 and 4.3). Finally five different strategies were implemented in the BW method and tested for the events in the calibration dataset. The outcome of this test is shown in Figure 4.2. For intermediate steps and results refer to Appendix D.


Bk_Cat
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5.8
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5
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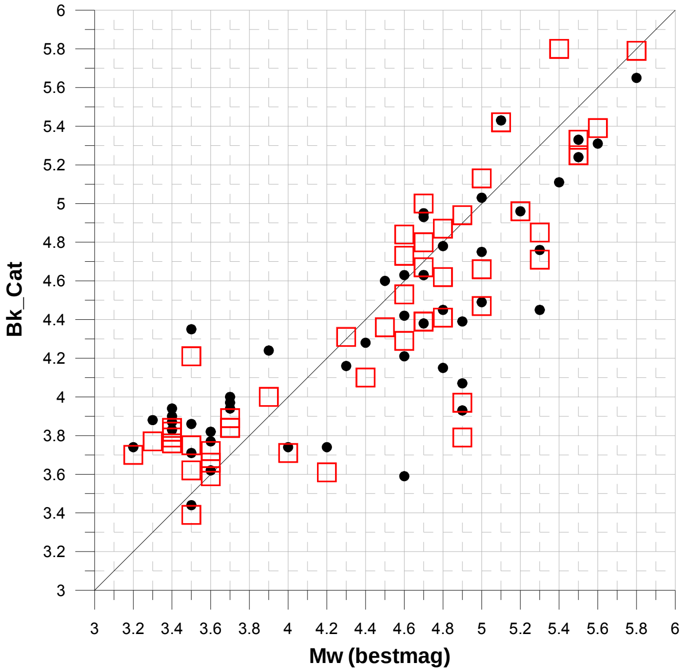
Mw (bestmag)

(a)


Bk_Cat
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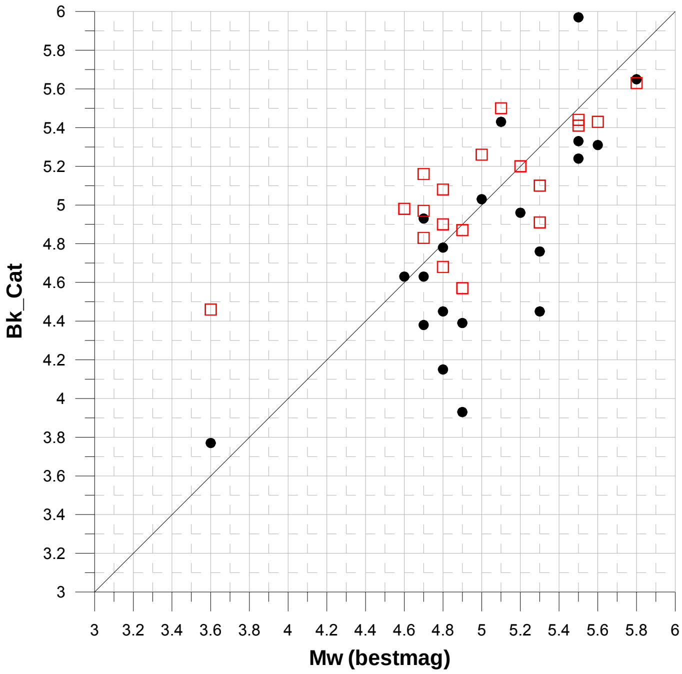
3 3.2 3.4 3.6 3.8 4 4.2 4.4 4.6 4.8 5 5.2 5.4 5.6 5.8 6
Mw (bestmag)

(b)



(c)

Figure 4.2. *Mw(bestmag) compared to the estimated magnitudes at the epicenter locations (Bk_Cat) for the subset of events of calibration datasets with Mw(bestmag). In the magnitude calibration, IDPs are weighted by their quality.*

(a): (●) all intensities, fixed depth strategy; (□) top3 intensities, fixed depth strategy.

(b): (●) all intensities, variable depth strategy (here h=10km); (□) top3 intensities,variable depth strategy (here h=10km).

(c): (●) all intensities, variable depth strategy (here h=10km); (□) all intensities, Alpine events, variable depth strategy (here h=10km).

ECOS-09 intensity attenuation model Strategy				Calibrated coefficients		
Calibration Dataset	Intensity representation	Regionalization	depth	Logarithmic coefficient (a)	Linear coefficient (b)	StDev
2	All intensity levels$^{(*)}$	-	Fixed depth (h=10Km)	-0.67755	-0.00174	0.4073
2	Three highest intensity levels	-	Fixed depth (h=10Km)	-0.4834	-0.00179	0.3647
2	All intensity levels$^{(*)}$	-	Variable depth (h=3-25Km)	-0.69182	-0.00084	0.3897
2	Three highest intensity levels	-	Variable depth (h=3-25Km)	-0.50945	-0.00192	0.3556
3	All intensity levels$^{(*)}$	Alpine	Variable depth (h=3-25Km)	-1.07853	0.00414	0.4226

Table 4.2. *Calibrated coefficients of ECOS-09 intensity attenuation models for the five different strategies selected for the parameterization. StDev: standard deviation of the regression. (*) Only IDPs with intensity 3 and larger were used.*

ECOS-09 intensity attenuation model Strategy				Magnitude to intensity at 30km hypocentral distance Different weighting schemes								
				No weighting			Weighting by IDP number			Weighting by IDP quality		
Calibration dataset	Intensity representation	Regiona -lization	depth	(α)	(β)	StDev	(α)	(β)	StDev	(α)	(β)	StDev
2	All intensity levels$^{(*)}$	-	Fixed depth (h=10km)	0.7725	1.0363	0.325	0.7482	1.178	0.332	0.734	1.28	0.342
2	Three highest intensity levels	-	Fixed depth (h=10km)	0.732	1.132	0.309	0.698	1.329	0.319	0.6753	1.4617	0.327
2	All intensity levels$^{(*)}$	-	Variable depth (h=3-25km)	0.7364	1.1568	0.394	0.7561	1.0934	0.395	0.7317	1.2567	0.407
2	Three highest intensity levels	-	Variable depth (h=3-25km)	0.7124	1.1288	0.332	0.7194	1.1075	0.331	0.6944	1.258	0.333
3	All intensity levels$^{(*)}$	Alpine	Variable depth (h=3-25km)	0.4623	2.7547	0.332	0.4817	2.758	0.333	0.4506	2.9314	0.332

Table 4.3. *Calibrated coefficients of magnitude to intercept intensity at 30km hypocentral distance for the five different strategies that were finally used. StDev: standard deviation of the regression. (*) Only IDPs with intensity 3 and larger were used.*

4.1.3. Strategy of the assessment of macroseismic earthquake parameters

The following strategy has been applied for the assessment of earthquake parameters of historical events in ECOS-09 using the *BW* method:

1) We have applied four calibrated non-regional attenuation models and one Alpine model (see equation 4.6). Two models are for depths fixed at 10km, whilst three strategies are with variable depth. The four non-regional relations are derived from the largest calibration dataset (*dataset 2*) and the Alpine relation is derived from a smaller one (*dataset 3*) (the coefficients are given in Table 4.2 and Table 4.3).
2) With the *BW* method, we have assessed the macroseismic magnitude at the original catalogue location, at the location of the minimum magnitude and the minimum magnitude root mean square (RMS). The epicenter location presently in the catalogue was defined taking into account the available historical information. As long as there is no historical evidence that the epicenter is incorrect, we have not changed the location. We have then derived RMS as function of depth at the epicenter location, and if the RMS curve shows a relevant minimum, we have estimated the depth and corresponding magnitude (see an example in Figure 4.3. and Figure 4.4). For events that have new historical evidence or new sets of IDPs, we have performed a full re-assessment of the epicenter location using all information.
3) In order to better control the depth selection, we have plotted the IDPs as a function of epicentral distance (Figure 4.5) overlaying the theoretical curves by assuming different depth levels, using the derived magnitudes at the corresponding depth. The final decision on the magnitude and depth is made including information from the RMS plots horizontally as well as vertically, and taking into account the possibility of poor performance of one of the calibration strategies. If no clear decision of depth was possible we have taken the magnitude for a depth of 10km. In this case depth is not assigned to the event. The magnitude is defined by the median of magnitudes from the strategies that perform well and are valid for this case (Alpine only for alpine events, only depth strategies in case a depth is assigned to the events). Finally each event is compared to the events of similar magnitude, and magnitudes are adjusted for those cases in which the event has obviously too high or too low magnitude. Such cases are mostly for events with irregular and sparse macroseismic fields.

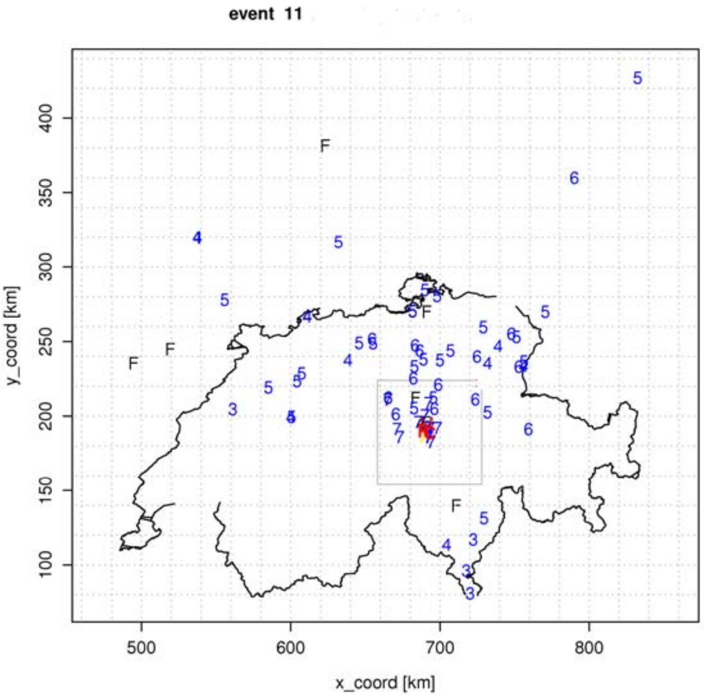
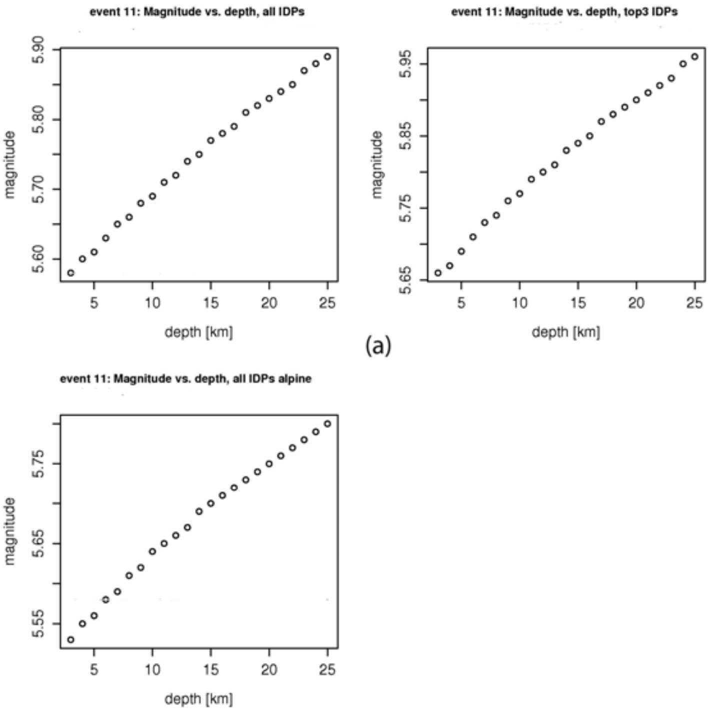
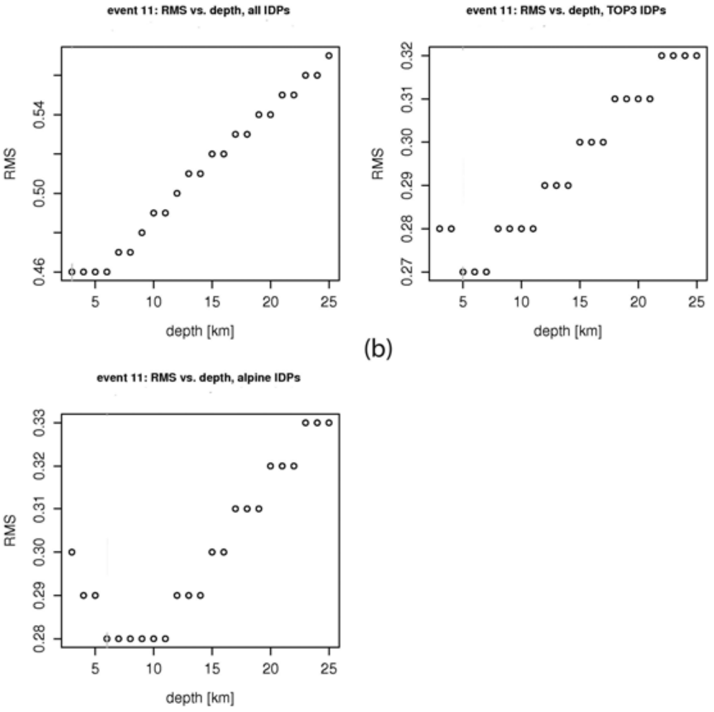


Figure 4.3. *Intensity field of event 11 (1774.09.10). In red the catalogue location is shown. In this example the catalogue location corresponds well to the minimum RMS location assuming shallow depth.*

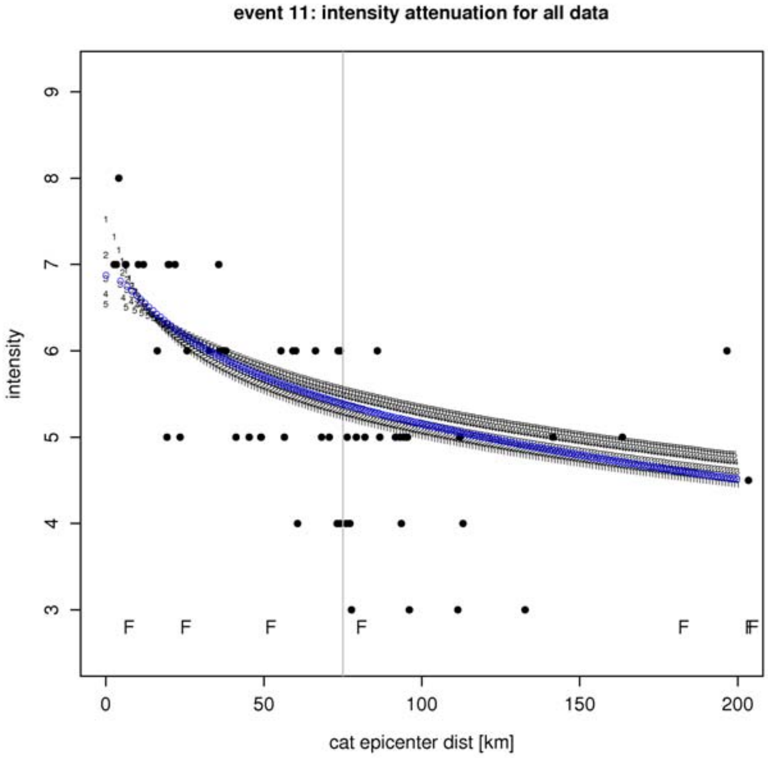


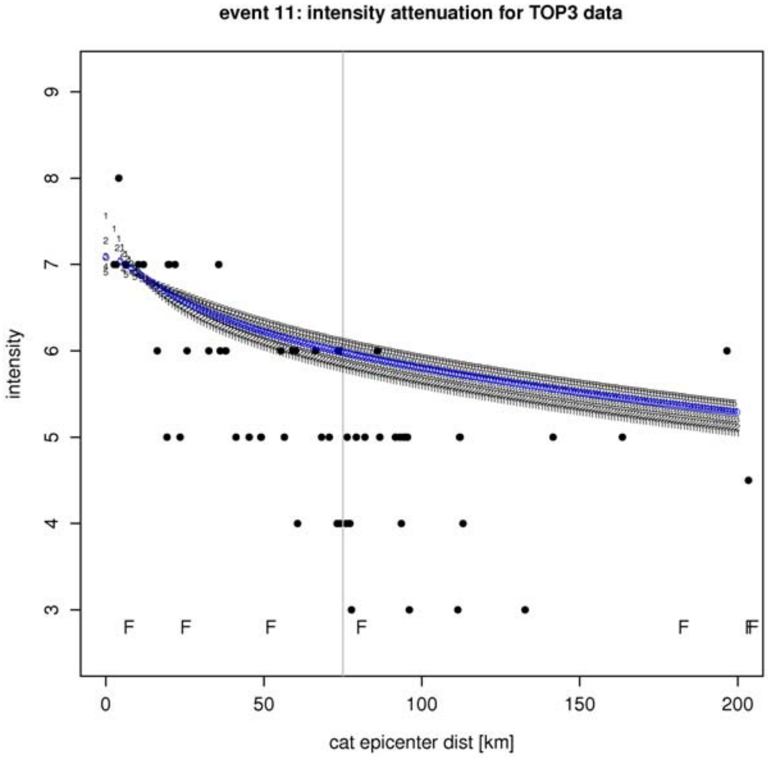
(a)



(b)

Figure 4.4. *After the epicenter is defined, a) the magnitude as function of depth and b) the RMS as a function of depth are computed. The figures refer to event 11 (1774.09.10) and the strategies: dataset 2, all intensities and the three highest intensity levels for variable depth; dataset 3, Alpine events, all intensities for variable depth. This is one part of the information used to validate the depth of the event. For this event the assigned depth is 8 Km and the corresponding magnitude is 5.7*


event 11: intensity attenuation for all data


event 11: intensity attenuation for TOP3 data

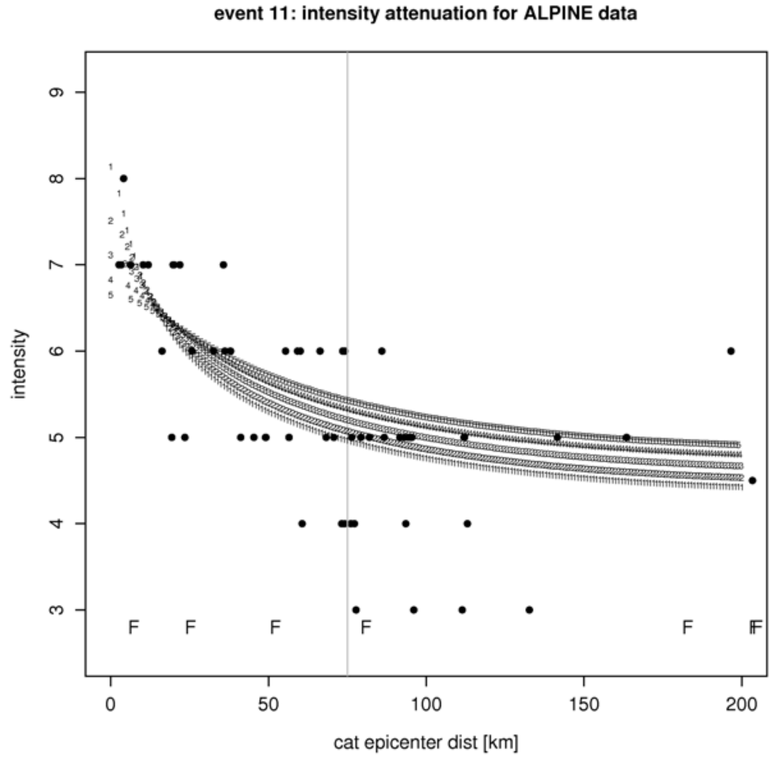


Figure 4.5. *After the epicenter is defined, the IDPs are plotted as a function of epicentral distance, overlaying the theoretical curves by assuming different depth levels (at 3km, 6km, 10km, 15km and 20km), and using the derived magnitudes at the corresponding depth. The figures refer to event 11 (1774.09.10) and the strategies: dataset 2, all intensities (top figure) and the three highest intensity levels (figure in the middle); dataset 3, Alpine events, all intensities (figure on the bottom). This is another part of the information used to validate the depth of the event. The assigned depth is 8 Km and the corresponding magnitude is 5.7. The blue curves correspond to the attenuation model assuming fixed depth.*

4.2. Converting Io to M_W

When insufficient intensity points were available to apply our calibration procedure described in section 4.1, we applied the same method to convert epicentral intensity Io to M_W as proposed in the 2002 version of the catalogue. The conversion is given in Table 4.4, which can be applied to convert Io to M_W for shallow and deep events. For most of the small events, depth cannot be assessed. We therefore applied the average expected M_W values related to intermediate or unknown depth.

Shallow events			Deep events			Intermediate		
Io	**M_W**	**ΔM_W**	**Io**	**M_W**	**ΔM_W**	**Io**	**M_W**	**ΔM_W**
2	1.5	≤1	2	2.6	≤1	2	1.7	≤1
3	2.3	≤1	3	3.3	≤1	3	2.4	≤1
4	3.1	≤1	4	4	≤1	4	3.2	≤1
5	3.9	≤1	5	4.7	≤1	5	3.9	≤1
6	4.7	≤1	6	5.4	≤1	6	4.7	≤1
						7	5.4	≤1

Table 4.4. *Conversion values for Io into M_w.*

The conversion scheme is applied as follows:

Shallow conversion: The shallow conversion formula was used to calculate M_W for events having an epicentral intensity Io<6 with only one or a few intensity points. For larger events with only one or two intensity points, available historical information is included to determine M_W.

Deep conversion: The deep conversion formula was used to calculate M_W for entries in the ECOS that have intensities Io<6 and for which, through the available IDPs, the depth class can be assigned as deep.

Intermediate conversion: The intermediate conversion formula is applied for events from foreign national catalogues for which only an epicentral intensity Io is given and no other magnitude is available, in addition to most of the small events for which depth cannot be assessed. Since only one new historical catalogue, the Italian catalogue (all events have a magnitude estimate) was included in the fusion of catalogues, no foreign event required the conversion of Io to M_W.

4.3. Validation of the calibration

The Boxer method (Gasperini et al., 1999) was also used to calibrate historical earthquakes that occurred in Switzerland (see Appendix E for a description of the method). This exercise serves as a cross-check of the calibration summarized in chapter 4.1, using the methodology introduced by Bakun and Wentworth (1997). The macroseismic earthquake parameters are epicenter location and magnitude. In a first step the Boxer method was calibrated with a selected dataset of Swiss events of the 20th century for which macroseimic data and moment magnitudes were available. This calibration was then tested. In a second step other existing calibration coefficients for the Boxer method were applied to the same Swiss dataset. One of these calibrations was derived from a selected dataset of Swiss events during the NERIES project (Gomez Capera et al., 2009), whilst other calibrations were derived from Italian data during the NERIES project and a national research project (see Appendix E).

Within the magnitude range of Swiss historical events, there is a need to assess parameters for earthquakes larger than the events in the Swiss calibration dataset. Basically, the Swiss calibration dataset does not provide reliable coefficients for the Boxer code above a moment magnitude of about 5.6-6.0, or for intensity 7 or larger. Furthermore, the extrapolation of the calibration method discussed in chapter 4.1 cannot be controlled for magnitudes larger than about 6.0. Therefore, independent coefficients that cover earthquakes with magnitudes above this limit were included in our study using the Boxer code. This has been achieved using coefficients for the Boxer code from the NERIES project and an Italian study. Finally all calibration coefficients have been tested, and different strategies were proposed including hybrid strategies that combine the Swiss calibration with Italian calibration coefficients (Appendix E).

From the suite of possible calibration coefficients for the Boxer method, a selection was applied to assess macroseismic location and magnitude of some historical events (see Table 4.5). The estimation of macroseismic location with the Boxer method is robust regardless of the calibration strategy used, as long as a sufficient number of intensity data points describe the area of maximum effects. The magnitude estimates obtained with the different strategies for the same event are variable in the sense that firstly there is considerable scatter, and secondly there is no single calibration strategy that performs the best for all events. Since all of the calibration procedures are reasonable, the variability in the magnitude provides a base to estimate epistemic uncertainty related to the Boxer method. Table 4.5 provides the range of magnitudes obtained with the Boxer method and the different procedures.

The magnitudes from the Boxer approach can now be used to validate the calibration procedure based on the BW method that was applied for the revision of the earthquake catalogue of Switzerland (ECOS-09). Finally we include in our comparison of magnitudes the same procedure as applied for ECOS-02, this time however, applying the magnitudes of the calibration events that changed after 2002 as consequence of the studies by Braunmiller et al. (2005) and Bernardi et al. (2005). The revised ECOS-02 calibration is discussed in Appendix E.

With the help of the Boxer method we can confirm our assessment of magnitudes based on the BW method within the limits of the calibration methods. The Boxer method has the disadvantage that it does not allow the epicentre location to be fixed in cases where historical information allows for this. For this reason the Boxer method was only applied for this comparison.

Year	Month	Day	Hour	Event Name in ECOS-02	Mw (bestmag) (1)	Mw ECOS-02 (2)	Revised Mw ECOS-02(3)	Range Mw (4) Boxer	Mw from BW method (5)	Mw ECOS-09 (6)
1295	09	03	00	Churwalden	-	6.5	6.2	6.0-6.5	6.2	6.2
1356	10	18	21	Basel	-	6.9	6.7	6.3-6.9	6.6	6.6
1584	3	11	11	Aigle	-	6.4	6.1	5.6-6.1	5.9	5.9
1601	9	18	1	Unterwalden	-	6.2	5.9	5.9-6.2	5.9	5.9
1685	3	8	19	Mittelwallis	-	6.1	5.9	5.4-5.8	5.3	5.3
1755	12	9	13	Brig-Naters	-	6.1	5.9	5.8-6.1	5.7	5.7
1770	3	20	15	Château-d'Oex	-	5.7	5.5	4.9-5.4	5.2	5.2
1855	7	25	11	Törbel	-	6.4	6.1	5.9-6.1	6.2	6.2
1905	12	25	17	Domat-Ems	4.7	4.8	4.7	4.5-5.1	4.8	4.7
1905	12	26	0	Tamins	-	5.1	5.0	4.6-5.2	4.7	4.7
1913	7	20	12	Ebingen	-	5.2	5.1	4.7-5.3	5.0	5.2*
1929	3	1	10	Bioley-Magnoux	5.0	5.3	5.0	4.3-5.1	4.7	5.0
1946	1	25	17	Ayent	5.8	6.1	5.8	5.8-6.0	5.7	5.8
1946	5	30	3	Ayent	5.5	6.0	5.5	5.2-5.6	5.4	5.5
1978	9	3	5	Ebingen	5.5	5.15	5.5	5.1-5.6	5.3	5.5
1991	11	20	1	Vaz/GR	4.7	4.6	4.7	4.7-5.3	4.6	4.7

Table 4.5. *Magnitude for a selection of events using different calibration procedures:*
(1) Mw (bestmag): Mw derived from instrumental recordings by Bernardi et al. (2005).
(2) Mw in the ECOS-02 catalogue.
(3) Revised Mw due to changes in magnitudes of the calibration events used for ECOS-02.
(4) Magnitude range obtained with the Boxer method using different strategies.
(5) Mw estimated with the BW method for ECOS-09.
(6) Mw in the ECOS-09 catalogue.
The event names refer to the names in the 2002 catalogue. They changed in ECOS-09.
** Magnitude from foreign catalogue.*

4.4. Uncertainties in the assessment of location and magnitude

The origin of uncertainties is manifold, and we believe that an exact evaluation is not possible in a strict statistical sense. In the first part of this section we outline the main sources of uncertainties. In the second we discuss the case for statistical uncertainties.

The single intensity data point is assigned a most probable intensity Iw and a range of intensity by giving both minimum (Imin) and maximum possible values (Imax). This range reflects our information gaps and uncertainties regarding historical interpretation. Since information quality and quantity varies throughout the centuries, a systematic error for a specific event or for a set of intensity points that rely on the same historical sources can never be excluded. We have tested the influence of the uncertainty of intensity by application of a Montecarlo simulation for the example of the 1356 Basel event (see Fäh et al., 2009 for more details). We simulated 10,000 datasets, using a discretized Gaussian probability model that assumes a probability of 0.5 for the most likely intensity at each point, and a total probability of 0.25 for the intensity between the most likely intensity and the maximum or minimum values, respectively. By applying the ECOS-02 procedure for different selections of IDPs, and also taking into account the change in the magnitudes of the calibration events after 2002 (see Appendix E), this procedure results in a median magnitude of Mw=6.48 (5-/95-percentile: 6.35…6.62) when using all IPDs regardless of their quality. If the uncorrected ECOS-02 calibration procedure is applied then the median is significantly higher at Mw=6.93 (5-/95-percentile: 6.78…7.1).

The second source of possible errors is the distribution of intensity data points. Possible problems might arise from irregular azimuth coverage due to national borders, gaps in historical information (e.g., in the Alpine areas before 1700), and strong variability of the density of data points due to population density or the lack of literacy in earlier centuries.

The bootstrap statistical method can be used to a certain degree to deal with the incompleteness problem and to account for epistemic uncertainties. The sampling with replacement can provide a set of different resampled IDP fields, such that the uncertainty of the magnitude and location is represented by the distribution of the parameters recovered from the resampled IDPs. Bakun and Scotti (2006) applied an extension of the Bakun and Wentworth (1997) method using bootstrap resampling techniques to the 1356 earthquake, by using their set of intensity data points. This procedure allowed them to quantify confidence levels for the epicenter location and the magnitude, without, however, using historical information to constrain the epicenter. They propose a moment magnitude between 5.9 and 7.2 at a 95 percent (±2σ) confidence level, and between 6.2 and 6.7 at 68 percent (±1σ) confidence level, with a preferred magnitude of 6.6. They point out that the properties of the attenuation model used are critical: they would obtain significantly larger magnitudes when using the ECOS-02 attenuation model for their estimates.

Bootstrap methods, however, cannot compensate for a lack of information especially when this is the case for the epicentral area of a particular event. Location problems with very irregular distributions of IDPs can be compensated through our historical knowledge. When assessing the magnitude, the lack of information from the area of the strongest effects or very irregular IDP distributions is difficult to compensate or correct for.

The third sources of uncertainties are the calibration methods themselves. Besides uncertainties introduced by the calibration methods, the calibration methods rely on a calibration dataset with more or less reliable moment magnitudes and intensity fields for the different events. In areas of low seismicity only a small number of earthquakes are available and, if possible, all stronger events of the 20th century have to be included in the calibration dataset. Bernardi et al. (2005) assessed the magnitude uncertainty for most of the events by providing a range for Mw, but not for all events. These values however do not cover the full uncertainty related to the methods applied. Moreover, some of the calibration events have an inhomogeneous geographical distribution of IDPs, depth is unknown for most of the calibration events, and epicenter location uncertainty cannot be assessed. These different uncertainties project into the calibration procedure and are partly reflected in the intercept–magnitude relation developed for the Bakun approach (see Appendix D) and in the comparison between derived macroseismic magnitude and original moment magnitude of the calibration events.

Uncertainties for magnitude and location were given in ECOS-02 through parameter uncertainty classes (see Appendix L). Despite retaining these parameter uncertainty classes in ECOS-09, we have studied some of the aspects of the uncertainty previously discussed, and accounted, to a certain degree, for a quantitative range of the total uncertainty. To assess the random component of the uncertainty, we computed location and magnitude distributions for the selected events in Table 4.5. In a first step, for each event 1000 intensity sets were drawn in a standard bootstrap with replacement process, providing each sample with the same number of intensity points as the original IDP field has. As a second step, we resampled the individual intensity assessment in order to reflect its uncertainty. We assigned one of the intensity values: expected intensity (Iw), minimum intensity (Imin), maximum intensity (Imax), assuming a probability model. Based on this probability model, the intensity of each data point in each sample IDP field was randomly assigned. We then applied the BW method to all the resamples, to assess location and magnitude for each of the ECOS-09 strategies. The results and analysis of the magnitude and location distributions computed are presented in Appendix D. We have assessed the magnitude and its uncertainty in terms of the mean and standard deviation of the magnitude distribution. This measure has been addressed as a lower bound of the uncertainty of the magnitudes. It however accounts for the uncertainty at the catalogue location and at the minimum RMS locations found with BW for each sample, and can be reduced if historical information is taken into consideration. From the distribution of the magnitude values for each event we propose to use a normal distribution.

We have partly addressed the uncertainty due to methodology (calibration models) in the test of the performance of the BW technique for the different ECOS-09 strategies (see Figure 4.2 and Appendix D). The residuals between the BW magnitude assessed for all strategies and the Mw(bestmag) of the calibration dataset are considered to be a measure of the epistemic uncertainty derived from modelling, if the Mw(bestmag) would be without error. We therefore consider the distribution of these residuals as an expected upper bound of overall uncertainty. In summary and taking into consideration the different estimations of uncertainty discussed here, an estimate of magnitude uncertainty in terms of two standard deviations (±2σ) would be in the range 0.2 to 0.9 magnitude units. For most of the events that were assessed with the BW method, the chosen uncertainty in the catalogue corresponds to 0.5 magnitude units (error class 2) or 1.0 magnitude unit (error class 3) (equal to 2 standard deviations).

The earthquake-locations were individually checked by taking into account historical knowledge that is not represented in the intensity field, the knowledge of seismogenic zones and sources, mainshock-aftershock locations, and the RMS-field resulting from the BW approach. This has an effect on the location error. The uncertainty in location can be approximated by the distribution of the locations of minimum RMS around the selected catalogue location using both BW results and historical knowledge. It has been found that, a high percentage of the RMS locations of the resamples, are within a distance less than 20 Km from the catalogue location. In many cases this percentage corresponds to two standard deviations (95%).

The uncertainty in location in the ECOS-09 catalogue is given as two standard deviations. For most of the events that were assessed with the BW method, this uncertainty corresponds to either 20km radius (error class 3) or 50 km (error class 4) (equal to 2 standard deviations) around the epicenter location, where the smaller error was assigned when the intensity field is considered to be sufficiently complete in terms of azimuth coverage, absence of gaps in historical information, and the number of IDPs with a large intensity range. For events that had an insufficient number of IDPs to apply the BW technique, the error class was chosen according to the available macroseismic and historical information.

5. Instrumental earthquake catalogue of Switzerland 1975-2008

Although the first seismographs in Switzerland were already operational at the beginning of the 20th century, a modern nationwide seismograph network came into operation only in the early 1970s. As of 1975 this network had achieved a sufficient density and the data analysis procedure had evolved to the extent that the catalogue can be regarded as a purely instrumental catalogue as of that year. With the advent of routine data processing by computer, the wealth of data acquired by the nationwide seismograph network has been regularly documented in monthly bulletins with detailed lists of all recorded events. Since 1996, annual reports summarizing the seismic activity in Switzerland and surrounding regions have been published in the second or third issue of the *Eclogae Geologicae Helvetiae - Swiss J. Geosciences* of the following year. In a slightly different form and in some instances with updated information that was not available at the time of publication, these annual reports are also accessible via the internet from http://www.seismo.ethz.ch/prod/j_reports. Included in the documentation found on this website is also an extensive bibliography of the seismicity of Switzerland since 1975.

Over the years, the network evolved in terms of number of stations, sensor types, signal transmission and data storage. As a consequence, data analysis and event location procedures changed as well. Many of these changes occurred gradually, often with an overlap between different periods. Nevertheless, for users of the catalogue it is useful to subdivide the Swiss instrumental catalogue into three distinct periods: the largely analog period until the end of 1983, the first digital period from 1984 to 2001 and the second digital period from 2002 to the present. It is essentially this last period that constitutes the largest difference between ECOS-02 and ECOS-09.

In what follows we summarize the main features of the catalogue in these three time periods and the procedures used at the SED to determine local magnitudes and their uncertainties. More details can be found in Appendix G and H.

5.1. Period 1975–1983

The stations comprising the national network during this period were equipped mainly with single-component short-period sensors. A few had three-component sensors with an additional vertical component low-gain channel, to provide unclipped recordings of stronger events. The signals were transmitted via analog (FM) telemetry to the central recording site at the SED and recorded continuously on microfilm (DEVELOCORDER). Signals of prominent events were also recorded on magnetic tape (PCM).

For data analysis the microfilm signals were displayed on a special projection table at a time scale of 2 mm/s. Arrival times and amplitudes were routinely measured on this table with a ruler and manually transferred to a computer file for further processing. A few events that occurred in the fall of 1983, for which digital signals are already available, were reprocessed later. For all other events, the information concerning locations and magnitudes for this time period in the present earthquake catalogue corresponds to the original routine data analysis.

In the course of the reassessment of the catalogue for ECOS-09, an attempt was made to identify possible quarry blasts that had not been noticed in the original analysis. In addition, we have attempted to assign a consistent quality rating to the event locations and magnitudes.

5.2. Period 1984–2001

This is a period of transition, first from analog to short-period digital and then to broad-band digital data acquisition. The network configuration was also evolving continuously during this period, due to both temporary installations and permanent changes. As a consequence, data archiving and processing also evolved continuously. The first digital records exist already as of September 1983. Nevertheless, the beginning of 1984 can be regarded as the start of the digital archiving and processing era at the SED. Even then, however, data continued to be recorded and analyzed in parallel on microfilm, and the digital waveform archive became complete only gradually over the following years. Subsequently, the events recorded on microfilm between November 1974 and December 1986 were scanned and archived as GIF-images.

The transition from a short-period network with analog telemetry to a fully digital broad-band network was also gradual. The first four broad-band stations went into operation at the end of September 1998. Installation of the new network was essentially completed by the end of 2001 and the last stations of the old network were decommissioned at the beginning of February 2002. In the meantime, the two networks were operated in parallel and the signals were routinely merged into the same data archive and processing software. A date of consequence for earthquake statistics based on the SED catalogue is the 27th of August 2001. On this day, the event detection was switched from the old short-period network to the new broad-band network. As a consequence of the higher upper limit of the frequency bandwidth and associated sensitivity increase at higher frequencies, the magnitude detection threshold of the network decreased significantly. This is already visible in the cumulative event plots published in the annual report for 2001.

At first, routine data analysis of the digital signals was performed on paper plots, normally with a time scale of 2 mm/s, mounted on a digitizing tablet. For significant events, arrivals were timed from plots with a higher resolution (typically 1 cm/s). During the course of 1992 the computer infrastructure and software had evolved sufficiently for it to become routine practice to analyze and time the signals interactively on the screen of a computer terminal. Over the years, some of the earlier events have meanwhile also been reanalyzed with the modern interactive software tools.

As of 1996 the seismicity in Switzerland and surrounding regions as well as the evolution of the station network and the data acquisition system have been documented in detail in the annual reports of the SED.

5.3. Period 2002–2008

Over the years, the initial high-gain broad-band network has been complemented by a few more stations with broad-band sensors. In 2003, four additional stations with 5 second-sensors were installed in north-eastern Switzerland and in the fall of 2005 a small array of eight short-period high-gain and one strong-motion sensor was installed in northern Ticino to monitor the induced seismicity in connection with the construction of the new Gotthard railway tunnel. Since December 2006, signals of the down-hole array installed to monitor the seismicity induced by a geothermal project in Basel are also included in the routinely processed data stream. In addition, signals of several strong-motion stations with high dynamic range are also used for the routine location of local earthquakes.

Some changes have also occurred during this period in the way the data has been analyzed. In the past, a group of about a dozen people with variable degrees of experience and motivation took turns to do the routine data analysis. As of October 2003 this task has been performed by only two and as of march 2007 by three experienced seismologists. Moreover, during the course of the year 2005, hypocentral locations began to be calculated routinely with a probabilistic earthquake location software based on a grid-search procedure in a 3D velocity model. Details can be found in the annual report for the year 2005 or in the introduction document on the website indicated above.

5.4. Swiss instrumental local magnitudes

From the short-period data local magnitudes were calculated based on maximum amplitudes measured from the vertical-component traces proportional to ground velocity, converted to an equivalent Wood-Anderson amplitude derived from an empirically determined relation. Magnitudes from the broad-band data are determined directly from the numerical Wood-Anderson simulations of the recorded broad-band signals. Details of the procedures are documented in Appendix H.
For the goals of ECOS-09 we have analyzed the instrumental local magnitude data of the SED to obtain an estimate of the uncertainty of the magnitude values and their internal consistency over time. Detailed output results of the interactively performed data analysis that is necessary for such an assessment is available only since 1999. Therefore, the adopted procedure consisted of two steps: first an analysis of the broad-band results from the period 2002-2008 and then a comparison of magnitudes calculated separately from the broad-band and the short-period signals recorded during the period 1999-2001.

The results can be summarized as follows:

1. From the analysis of the broad-band data collected over the period 2002-2008, individual station magnitudes scatter with a standard deviation of 0.33 about the median value for each event, and, except for distances less than about 10-20 km, for which the Swiss attenuation relation was not calibrated, there is no discernible distance bias.
2. Uncertainties of event magnitudes are larger for small magnitudes and smaller for larger magnitudes. For the purpose of assigning uncertainties to the local magnitudes of the entire instrumental catalogue, we therefore propose the following errors (one standard deviation): +/- 0.2 for M_L <=1.0, +/- 0.15 for 1.0 < M_L < 2.0 and +/- 0.1 for M_L >= 2.0
3. Within the uncertainty of the available data, the newer broad-band magnitudes, as determined by the routine procedures of the SED, are consistent with earlier short-period magnitudes.
4. Given that 0.1 is added routinely to the broad-band magnitudes to achieve conformity with the short-period magnitudes and that the original Wood-Anderson gain of 2800 is used instead of the corrected gain of 2080, the SED magnitudes are probably systematically higher by about 0.2 relative to the original M_L as defined by Richter.

6. Determination of M_W and calibration of M_L – M_W regression

We estimate moment magnitudes (M_W) for earthquakes in Switzerland recorded between 1998 and 2009. Compared to previous studies (e.g., Braunmiller, 2005) the M_W determination in Switzerland could be extended to lower magnitudes and scaling relations can be investigated from $M_L = 0$ to 5.4.
Three different spectral methods are applied to estimate M_W. The three processing methods follow different approaches of Edwards (2009), Allmann and Shearer (2007), and manually selected and processed uni-polar displacement pulses around the first arrival. All methods attempt to obtain the frequency-independent long-period spectral level below the corner frequency of a displacement spectrum (Brune, 1970, 1971).
Previously, M_W estimates were derived from moment tensor solutions based on broadband waveform fitting of local earthquakes with $M_L > 2.4$. In this magnitude range, a 1:1 scaling of $M_W = M_L - 0.2$ was found. Above $M_L = 4$, the newly obtained M_W estimates are consistent with the previously used scaling relation, with $M_W = M_L - 0.3$. Below $M_L = 4$, all three methods indicate that a 1:1-type relationship is inappropriate. Therefore, we propose a new empirical piecewise M_L to M_W scaling relation for earthquakes in Switzerland as shown in Figure 6.1. The scaling is linear below $M_L = 2$ and above $M_L = 4$, respectively. To obtain a smooth transition between the two linear scales we fit a quadratic relation in between ($2 \leq M_L < 4$) in accordance with observations made by Grünthal and Wahlström (2003), and Grünthal et al. (2009). The slope of the linear relation below $M_L = 2$ has been determined from the quadratic at $M_L = 2$. All datasets follow the proposed relation aside from the uncertainties discussed in appendix I.

- $M_L > 4$: $M_W = M_L - 0.3$
- $2 \leq M_L \leq 4$: $M_W = 1.327 + 0.253\, M_L + 0.085\, M_L^2$
- $M_L < 2$: $M_W = 0.594\, M_L + 0.985$

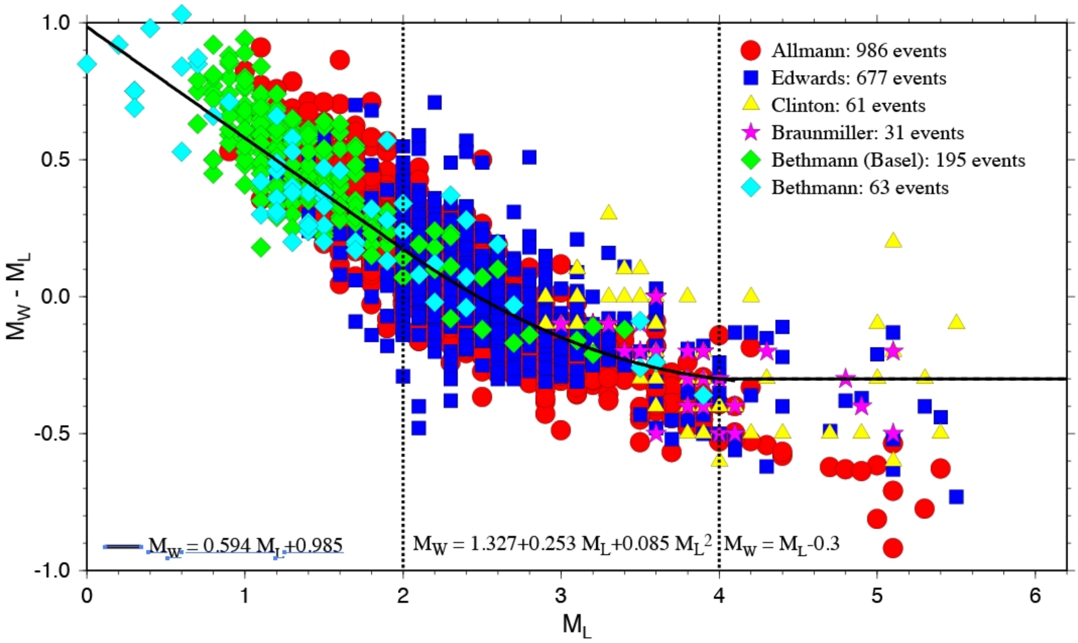


Figure 6.1. *Difference between M_L and M_W versus M_L of different datasets (different shaped and colored symbols). The black solid line shows the combined scaling relation from three different segments. The dataset of Bethmann has been shifted up by 0.28 for a better visual comparison.*

7. Merging catalogues for ECOS-09

We merged parametric earthquake catalogues from five countries including seven institutions to update data (see Table 7.1). Some of the national catalogues from neighbouring countries include events only until the end of 2007, the Italian catalogue ISIDE includes events until 9.9.2007. We requested updates and new releases including time, location, original and derived magnitudes, available intensity information, associated uncertainty parameters and available documentation. The data we obtained following the requests came in various quality levels and documentation detail. A detailed description of the input data and the procedures used to create the catalogue can be found in Appendix J (Merging catalogues with focus in the period 1975-2008). In the historical part of the ECOS-09 catalogues not all agencies provide the time in UTC.
Appendix J consists of three major sections:

1. Description of data received focussed mainly on the period 1975-2008
2. An analysis of the catalogues from the neighbouring countries and how these are merged to one catalogue for the instrumental period. In particular, the definition and search of multiple *entries* describing the same earthquake.
3. Procedures for quality assessment and assurance using visual and statistical methods.

Appendix J focuses on the period 1975-2008, however, includes two new catalogues that span larger time periods (CPTI04, CENEC). These two catalogues in particular provide information from specific studies of moderate to large magnitude events (Mw ≥ 4.5 and Mw ≥ 3.5). Therefore, some of the entries of these catalogues become primary in the ECOS-09 database. CPTI04 is the primary catalogue for the Italian territory in the historical time period.

Country	Short name	Institution	Period	Date of receipt	Contact
CH	SED09	SED	1975-2008	23/09/2009	N. Deichmann
D	BGR68-07	BGR	1968-2007	25/02/2009	W. Henger
D	LED09	LED	1996-2007	25/02/2009	W. Brüstle
D	CENEC	GFZ	1013-2004	08/04/2009	G. Grünthal
F	BCSF09	BCSF	1964-2009	03/03/2009	C. Nicoli
I	CSI1.0	INGV-Rome	1975-2002		F. Mele
I	CSI1.1	INGV-Rome	1981-2002		F. Mele
I	CSI09	INGV-Rome	2002-2003	23/02/2009	F. Mele
I	BOLLSI	INGV-Rome	2003-2005	23/02/2009	F. Mele
I	ISIDE	INGV-Rome	2005-2007	23/02/2009	F. Mele
I	CPTI04	INGV-Milan	217BC – 2002		M. Stucchi
A	ZAMG09	ZAMG	1980-2009	04/03/2009	W. Lenhardt

Table 7.1. *Overview of catalogues received covering mostly the instrumental period.*

7.1. Task definition

The basic task is to identify duplicate *entries* in the different catalogues covering the same regions. We define an *entry* in a catalogue to be a parametric description of an earthquake including time, location, magnitude, intensity and associated uncertainties. The search for duplicate entries focuses mainly on differences in location and origin time. Differences in the magnitude domain, for which different magnitude types need to be considered, are less important in the search if used at all (Details see Appendix K).
An automated identification process faces trade-offs in parameter selection: applying too large time and distance windows leads to define entries of different catalogues to describe the same earthquake which are not the same. Using windows that are too small implies not to find all duplicate entries. In addition, the windows are time-dependent. Without a doubt, location and timing of earthquakes have improved

over the last decades and event parameters become more and more similar in recent years; however, there are still many differences especially in the location and magnitude determination. Thus, a visual time-consuming check of the data is compulsory after the automatic procedure.

7.2. Merging procedure

The general strategy to merge the various catalogues follows principles applied to prepare the catalogue ECOS-02 (Fäh et al., 2003, SED, 2002). Alterations of the strategy origin in the limited personnel resources and time available to create catalogue ECOS-09. Our premise was to automate the process as much as possible which is, however, not entirely feasible.

Procedure to merge catalogues

- Compare the catalogues received for ECOS-02 and this project from the authoritative institutions of the different countries; decide on priority scheme for catalogues to be used based on the comparison.
- Generate a combined catalogue for each country, a national catalogue for Austria, France, Germany, and Italy (Appendix J, section 2). Here, we used different selection criteria to define duplicate entries for national catalogues.
- Combine catalogues from all countries and search for duplicate entries, select and tag entries as *primary* and *duplicate* (see Appendix J, section 3):
    - A *primary* entry defines the best possible information on one earthquake.
    - Keep all entries to one earthquake in the catalogue: *duplicate entries* are related to the *primary* entry through a unique identifier (*GroupID*). All entries remain in the database so all magnitudes can be provided.
    - The search for duplicates was done in an iterative procedure. We used two search criteria with different epicentral distance search radii (Δd = 10km and Δd = 20km), and a time difference of Δt = 0.25min (15 sec). Additionally we search with and without a magnitude difference criteria of ΔM = 1, regardless of magnitude type.
- Perform manual and automated quality checks to revise the automatic procedure the entries from the different catalogues. Adjust *primary* and *duplicate* information.
- Assign magnitudes according to magnitude conversion formulae (Appendix K)
- Assign uncertainties to the parameters (location, magnitude)
- Perform quality checks on the combined catalogue
  visual checks of the catalogue entries: All magnitudes above Mw=3.5, all magnitudes above M =2.5 in 200km radii around the locations of the Nuclear Power Plants (NPP) for the Pegasos Refinement Project (PRP), and in the 20km zone around the Swiss border. Entries for M ≥ 2.0 in the border region Swiss-France and Swiss-Germany.

Details on assigning magnitudes

For each entry in the catalogue, a unified moment magnitude Mw(SED) is assigned. The procedures to determine this magnitude are described in Appendix I and K. For instrumental magnitudes, the basic principle is to use regression formulae between local magnitude of the Swiss Seismological Service ML(SED) and the local magnitude of each other agency. Then this magnitude is converted using the Mw(SED)-ML(SED) relation. The least priority is given to an Mw computed from a macroseismic magnitude Mm.
In case an original Mw according to 1) Bernardi et al. (2005), 2) Baer et al. (2007) and Clinton et al. (2006), or 3) Braunmiller et al. (2002) is available, one of these is used. The priority sequence defined for ECOS-09, which can overrule the magnitudes of catalogue preference outside Switzerland is:

1.Mw published in Bernardi et al. (2005)
2. Mw derived by Clinton with quality A (>= 60% variance reduction, Baer et al. (2007), Clinton et al. (2006))
3.Mw derived by Braunmiller et al. (2005)
4.Mw derived from ML (Appendix K)

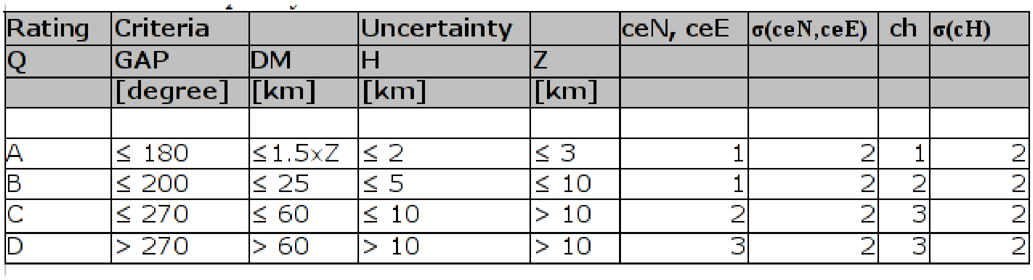
This implies that a computed Mw from the Swiss Seismological Service overrules all other computed or derived Mw determinations.

There are a few exceptions for instrumental magnitudes:

1) As the BGR catalogue is a compilation, the magnitude relations from the original catalogues are used to convert those that can be associated to the original source. Magnitudes that stem from other agencies are set equal to ML(SED)=M(BGR)+0.2. Then the conversion formula ML(SED) to Mw(SED) is used.
2) For the INGV case, there are around 285 events that only have a duration magnitude Md. For this, a relation ML(SED)-Md is used.

7.3. Defining location uncertainties for the period 1975-2008

The majority of the catalogues provided to the ECOS-09 team did not include information on location and/or magnitude uncertainty. In case estimates of uncertainty are provided, it is in general not straightforward to interpret the uncertainty. It is not obvious that the uncertainties describe 1σ or 2σ bounds, neither for location nor for magnitude uncertainty. Furthermore, the standard deviation describes an uncertainty related to a Gaussian distribution which is an additional assumption.
For location errors, it is important to understand the original computation of the uncertainties and it is essential to know which program was used. As we do not have all this information and in order to provide a consistent location uncertainty assessment, we decided to use a scheme by Deichmann et al., (2008) based on the GAP and the distance to the closest station. This, however, could not be applied to all data sets since we did not receive data or were not specific enough when we requested the data. The uncertainties determined based on the scheme by Deichmann et al. (2008) were converted to ECOS-09 quality classes (Appendix L). Datasets for which we do not have the information will not be associated with any quality class (Deichmann et al., 2008; Table 1) and obtain class 0 in the ECOS-09 classification (unknown). For data obtained from INGV, we used the location uncertainty given in the catalogue and converted those to the ECOS-09 quality classes. Table 1 summarizes the conversion scheme and the uncertainty bounds of the quality classes.



Rating	Criteria		Uncertainty		ceN, ceE	σ(ceN,ceE)	ch	σ(cH)
Q	GAP	DM	H	Z				
	[degree]	[km]	[km]	[km]				
A	≤ 180	≤1.5xZ	≤ 2	≤ 3	1	2	1	2
B	≤ 200	≤ 25	≤ 5	≤ 10	1	2	2	2
C	≤ 270	≤ 60	≤ 10	> 10	2	2	3	2
D	> 270	> 60	> 10	> 10	3	2	3	2

Table 7.2. *Definition of location uncertainty classes (Deichmann et al., 2008). ceN / ceE describe horizontal uncertainty class, ch the vertical uncertainty class (see Appendix L). The columns σ(ceN,ceE) and σ(cH) denote how the location uncertainty is understood in multiples of the standard deviation.*

7.4. Defining magnitude uncertainties for the period 1975-2008

Magnitude uncertainties are provided estimating the uncertainties for the Swiss local magnitude (ML(SED)) and combining the uncertainty with the uncertainty of the magnitude conversion (see Appendix K).

7.5. Summary of the merging procedure

In the period 01.01.1975-31.12.2008, more than 47000 listings were recorded between longitude 3.0°E-13.5°E and latitude 43.5°N-51.5°N.
Figure 7.1 displays the distribution of seismicity in the region covered by ECOS-09 with the unified moment magnitude Mw(ECOS-09). Figure 7.2 shows the cumulative number of events as a function of time for the entire region and period displayed in Figure 7.1. Figure 7.3 shows the frequency-magnitude distribution for the catalogue using the unified moment magnitude Mw(ECOS-09).

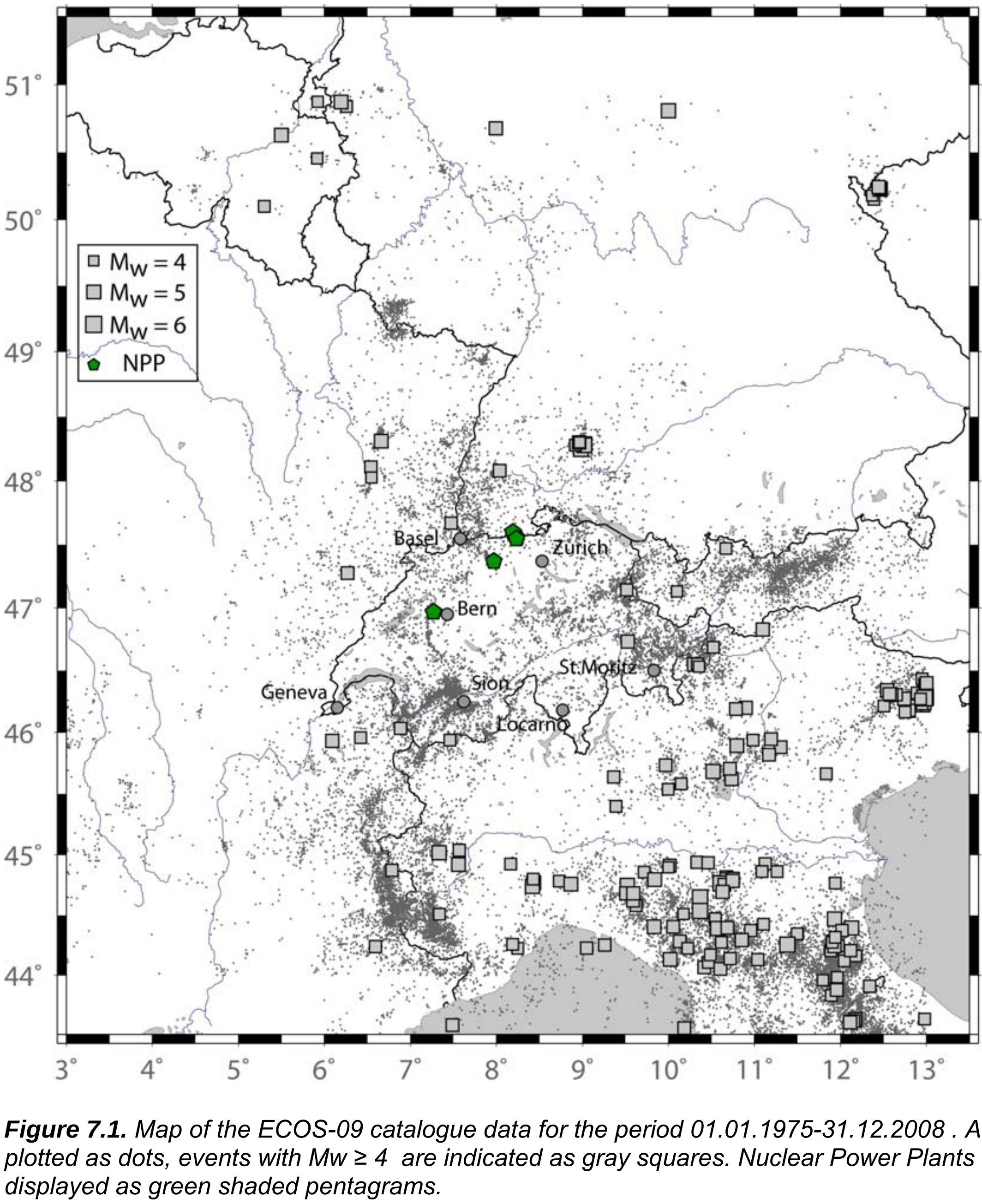


Figure 7.1. *Map of the ECOS-09 catalogue data for the period 01.01.1975-31.12.2008 . All events are plotted as dots, events with Mw ≥ 4 are indicated as gray squares. Nuclear Power Plants (NPP) are displayed as green shaded pentagrams.*

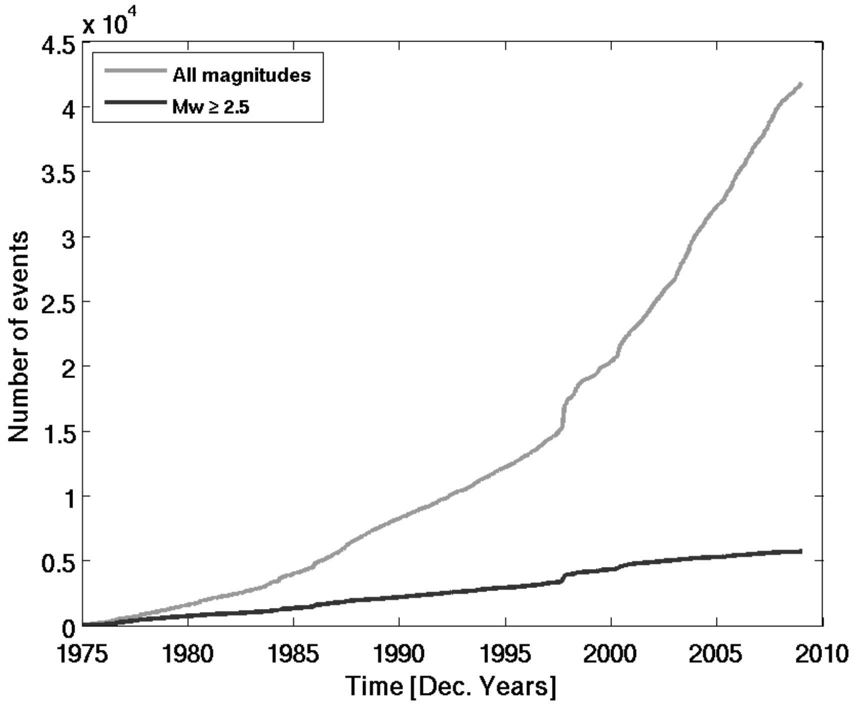


Figure 7.2. *Cumulative number of events in ECOS-09 from 1975-2008 as displayed in Figure 7.1 for all magnitudes (grey) and Mw ≥2.5.*

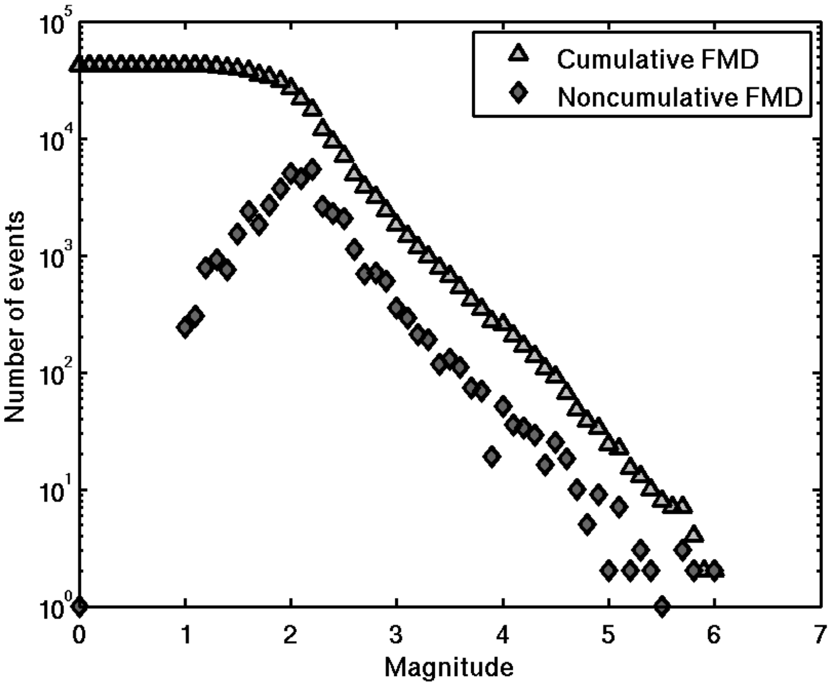


Figure 7.3. *Frequency-magnitude distribution for Mw(ECOS-09) in the period 01.01.1975-31.12.2008.*

8. Conversion of foreign M_L to equivalent Swiss M_L

In an effort to obtain an earthquake catalogue of Switzerland and surrounding countries with homogenous moment magnitudes, we have adopted a two-step procedure: first we convert local magnitudes of foreign catalogues to an equivalent Swiss local magnitude and then we convert these homogeneous local magnitudes into a common moment magnitude. In this chapter we present a brief summary of the procedures that we followed to evaluate the differences between the magnitudes of the events common to the Swiss catalogue and to the catalogues of Germany, Austria, France and Italy.

For Germany we have three different catalogues: BGR, LED 1975-1995 (which includes the catalogue of the University of Karlsruhe, KHE) and LED 1996-2008. The BGR and in part also the KHE catalogue are a compilation of data from different agencies. For events for which the provider of the magnitude is documented, we apply the conversion derived for that particular agency. For the others we use

$$M_L \text{ (converted)} = M_L \text{ (BGR)} + 0.2, \text{ and } M_L \text{ (converted)} = M_L \text{ (KHE)}.$$

This procedure is consistent with ECOS-02.

For the French data we had two catalogues at our disposal: the LDG catalogue for 1975-2000 used in ECOS-02 and the BCSF catalogue 1965-2008. Based on a comparison of the two catalogues and on the feedback obtained on a first version of the ECOS-09 report in October 2009, we decided to rely on the LDG catalogue until the year 2000 and on the BCSF catalogue as of 2001.

To explore the robustness of the conversion relation for each country, we computed mean and standard deviation of the magnitude differences as well as linear regression coefficients between SED local magnitude and foreign local magnitude for the following data selections:

1. The complete data set of common events;
2. A selection restricted to a common border region;
3. A common border region and deviation from mean magnitude difference < 2 sigma;
4. Common border region and location difference < 5km;
5. Common border region, location difference < 5km and deviation from mean magnitude difference < 2 sigma;
6. Selection same as 5, but only every second (odd) data point;
7. Selection same as 5, but only every second (even) data point;
8. Selection same as 3, but only first half of data;
9. Selection same as 3, but only second half of data.

In what follows, we summarize the main results of these comparisons; details of the complete analysis are documented in Appendix K to this report.

A comparison of the mean magnitude differences between the five foreign catalogues and the Swiss catalogue for all events in their respective common border region (case 2, above) as well as of their standard deviations gives a first impression of the large variability of these values and of the degree of consistency of the respective catalogues:

```
Germany (LED  1996-2007):     N =  391,  mean =  0.12,  std = 0.20
Austria (ZAMG 1975-2008):     N =  281,  mean = -0.17,  std = 0.26
France  (LDG  1975-2000):     N =  799,  mean =  0.54,  std = 0.26
France  (BCSF 1975-2008):     N = 1690,  mean =  0.39,  std = 0.28
Italy   (INGV 1975-2007):     N =  734,  mean = -0.18,  std = 0.37
```

After an evaluation of all the cases listed above, we propose the following conversion relations for the German and Austrian magnitudes, based on the regression results of case 5:

```
Germany (LED):    a = 0.964 +/-0.015,  b = -0.037 +/-0.037,  rms = 0.17
Austria (ZAMG):   a = 0.967 +/-0.021,  b = -0.269 +/-0.050,  rms = 0.23
```

with M_L(converted) = a * M_L(foreign) + b, and rms = root-mean-square of M_L(SED) – M_L(converted).

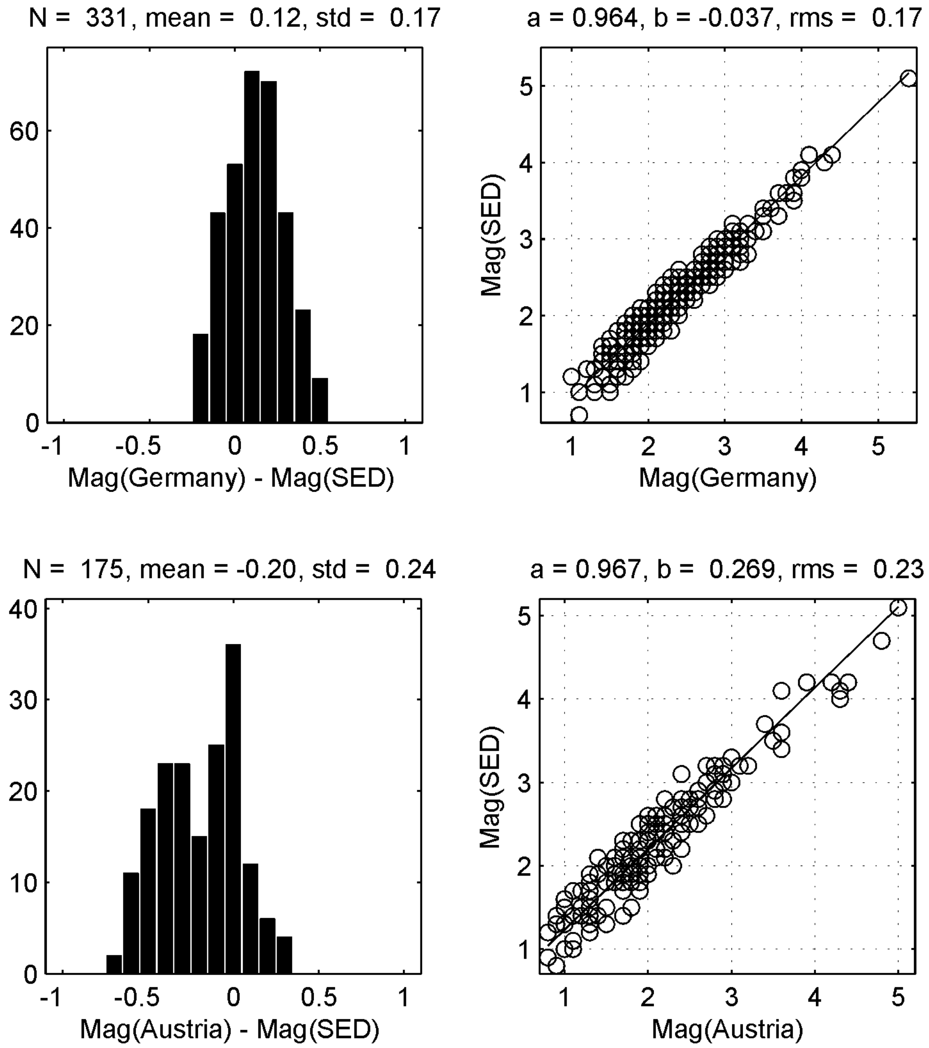


Figure 8.1. *Histograms of magnitude differences and regressions for Germany and Austria (case 5).*

For the French data we propose the following conversion relations:

France (LDG): a = 1.250 +/-0.026, b = -1.319 +/-0.079, rms = 0.23
France (BCSF): a = 1.136 +/-0.015, b = -0.692 +/-0.038, rms = 0.27

In the case of the LDG data, the relation was derived from a comparison of all available common events with locations within 1 degree from each other and with outliers beyond 2 standard deviations removed. For the BCSF catalogue, the regression is based on case 5 above, as for the LED and ZAMG catalogues.

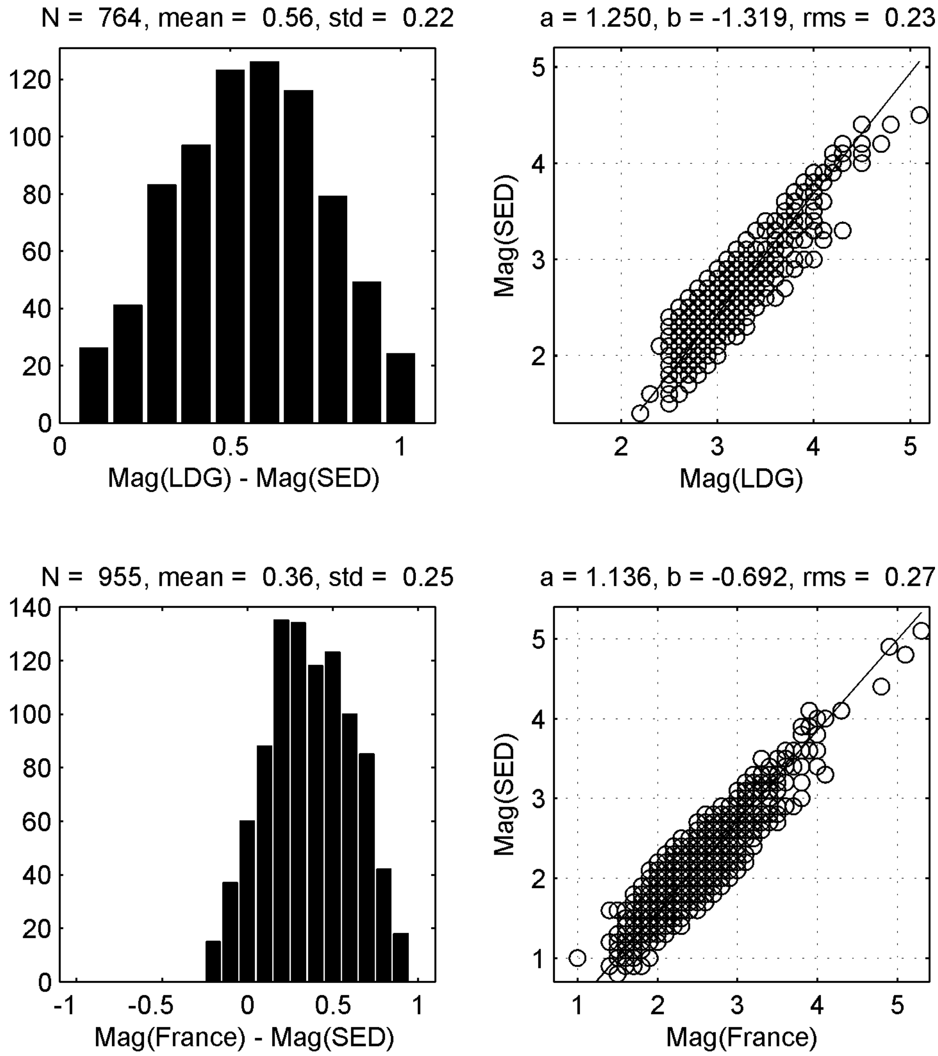


Figure 8.2. *Histograms of magnitude differences and regressions for France (LDG above, BCSF below).*

Until April 15th 2005, the sources of the Italian data are the CSI and the BOLLSI catalogues; after that date the information is based on the ISIDE catalogue. This change is clearly visible both in the completeness of the magnitudes and in their relation to the Swiss magnitudes. We therefore propose two different regressions for the Italian magnitudes, the first valid until April 15th 2005 and the second thereafter:

Italy (CSI, BOLLSI): a = 1.131 +/-0.041, b = -0.041 +/-0.096, rms = 0.33
Italy (ISIDE): a = 1.024 +/-0.047, b = 0.127 +/-0.094, rms = 0.23

For a series of events between 2003 and April 2005 only Md is available. As there is too little catalogue overlap for a direct conversion Md(INGV) to Ml(SED, we have converted these Md(INGV) to Ml(INGV) first, using a linear regression over 1308 italian events between 2003 and April 2005 for which INGV provides Md and Ml, with Md ranging from 1.4 to 5.0. The observed relationship is described by

a = 0.896 +/- 0.019, b = -0.312 +/- 0.048, rms = 0.24

where M_L ("INGV" converted) = a * M_D (INGV) + b and rms is the root-mean-square of the differences M_L (INGV) – M_L (converted).

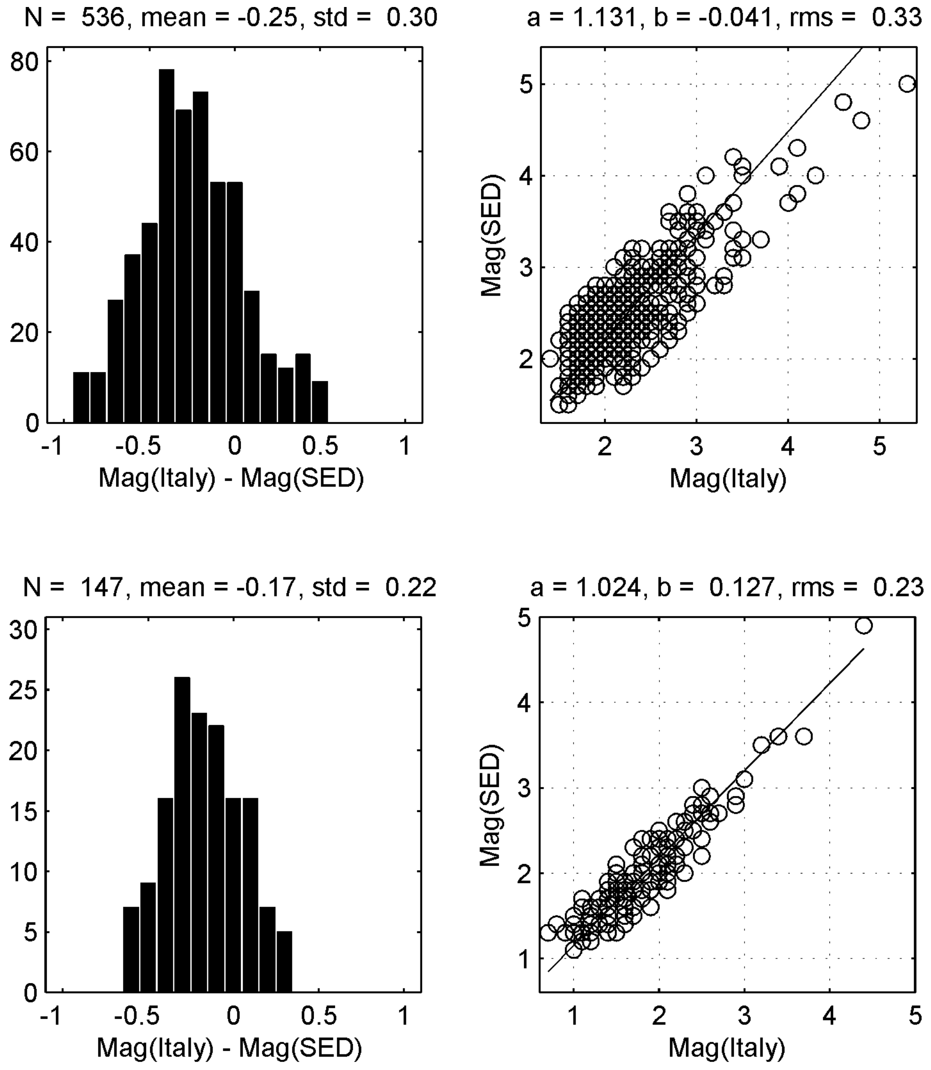


Figure 8.3. *Histograms of magnitude differences and regressions for Italy (CSI and BOLLSI above, ISIDE below).*

For assigning uncertainties to the converted magnitude values, we assume that, as in the Swiss catalogue, errors are larger for small events with fewer observations and smaller for larger events with more observations. Based on the analysis of the Swiss local magnitudes (see Chapter 5.4 and Appendix H) and the evaluation of the given foreign catalogues, we assign the following uncertainties to the original and converted magnitude values in ECOS-09 (one standard deviation):

Uncertainty estimates of original Magnitudes

	M_L <= 1.0	1.0 < M_L < 2.0	M_L >= 2.0
Germany:	0.20	0.15	0.10
Austria:	0.31	0.23	0.15
France (LDG):	0.34	0.25	0.17
France (BCSF):	0.34	0.25	0.17
Italy (CSI, BOLLSI):	0.40	0.30	0.20
Italy (ISIDE):	0.28	0.21	0.14

Uncertainty estimates of converted Magnitudes

	$M_L <= 1.0$	$1.0 < M_L < 2.0$	$M_L >= 2.0$
Germany:	0.20	0.15	0.12
Austria:	0.31	0.23	0.17
France (LDG):	0.43	0.33	0.25
France (BCSF):	0.39	0.29	0.20
Italy (CSI and BOLLSI):	0.46	0.36	0.22
Italy (BOLLSI Md-based):	0.50	0.41	0.39
Italy (ISIDE):	0.29	0.22	0.19

Note that the regression fits for the LDG and for the first period of the Italian data (CSI and BOLLSI) are quite poor for the higher magnitudes. Thus for magnitudes above 4, the error is more likely 0.3 than 0.25 or 0.22, so that 0.3 will be used as a basis for estimating the error of the converted Mw.

9. Public catalogue ECOS-09

From the catalogue version defined for the area between longitude 3.0°E-13.5°E and latitude 43.5°N-51.5°N, we have extracted the public catalogue ECOS-09 that covers a region that includes the area of the Swiss national map at a scale of 1:500 000 plus a buffer zone of 30 kilometers (Swiss coordinates (km): 460-882 / 20-350; Geographical coordinates approx.: 5.6-11.1E / 45.4 -48.3N). The earthquake catalogue ECOS-09 and the associated macroseismic database is available online on the website of the Swiss Seismological Service (http://www.seismo.ethz.ch).

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