Appendix A

ECOS – Earthquake Catalogue of Switzerland
ECOS

Report to PEGASOS
Version 31.03.2002

ECOS Catalogue Version 31.03.2002.

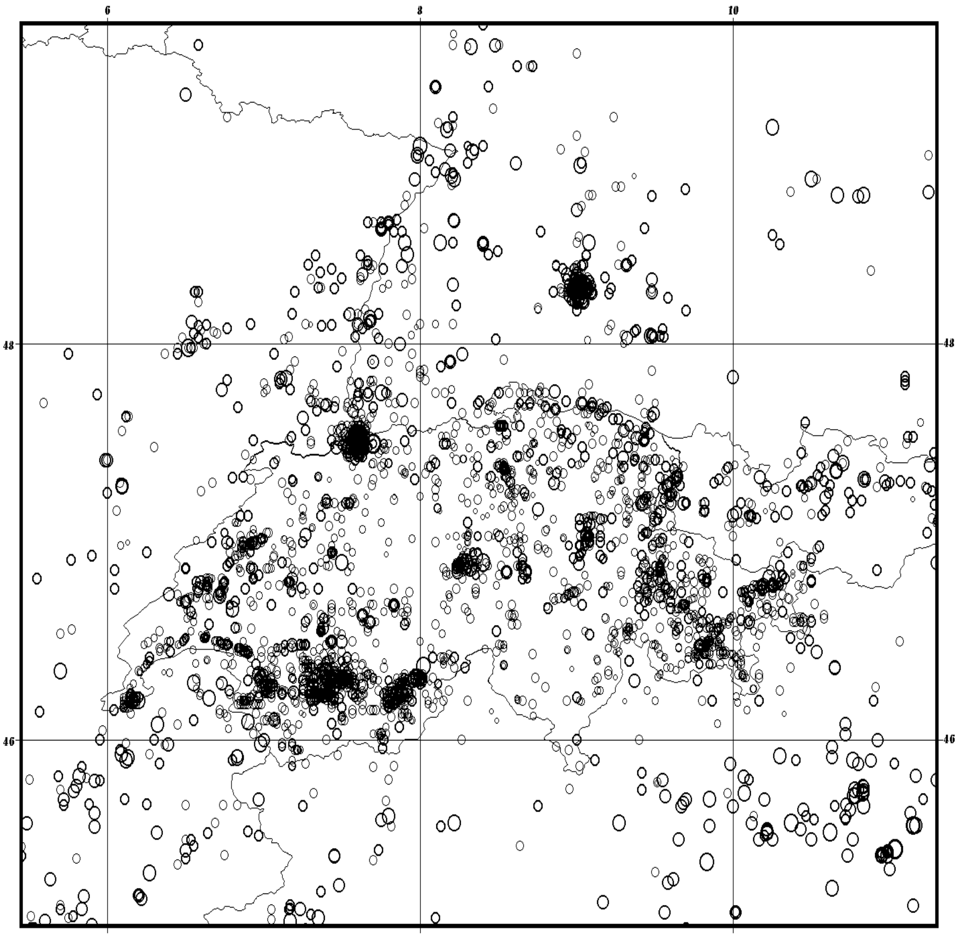
Swiss Seismological Service,
ETH Zürich

ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Swiss Seismological Service

ECOS

Earthquake Catalogue of Switzerland



ECOS Report to PEGASOS, Version 31.03.2002

ECOS Catalogue, Version 31.03.2002

Table of contents ECOS Report

1 Acknowledgements

ECOS – 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 includes the revision of the Macroseismic Earthquake Catalogue of Switzerland (MECOS-02).

Support for ECOS comes from internal ETHZ budget, from grants of the Swiss Nationalfonds, from Swiss Federal Nuclear Safety Inspectorate (HSK) and through an Agreement of Cooperation with NAGRA for the compilation of the catalogue and database. We thank all agencies for their support.

ECOS is generated by the fusion of 15 catalogues covering Switzerland and partly France, Germany, Austria and Italy. Responsible agencies and experts from these countries have helped by supplying catalogues and data. We thank national agencies, research institutes and colleagues for contributing data and catalogues: W. Brüstle, LED Baden-Württemberg; M. Henger and G. Leydecker, BGR; K. Bonjer, IFG Karlsruhe; G. Grünthal, GFZ; F. Scherbaum, Potsdam; M. Stucchi and P. Albini, IRRS/INGV; W. Lenhardt, ZAMG; M. Nicolas and Y. Menechal, LDG; A. Levret, IPSN, J. Lambert, BGRM; M. Di Bona and A. Amato, INGV.

We thank all the colleagues that assisted with historical data and interpretations: G. Grünthal, GFZ, G. Leydecker, BGR, G. Schneider, Stuttgart, P. Alexandre, Bruxelles, P. Albini and M. Stucchi, IRRS/INGV, J. Vogt, Strasbourg, A. Levret, IPSN.

The compilation of ECOS and of MECOS-02 was carried out by a dedicated group at SED during 1999-2001; the work will continue in 2002 for the completion of the ECOS database. The group includes historians, seismologists and database experts, with the composition and duties listed below (some of the people listed were involved only part time or for part of the project).

ECOS	Prof. Dr. D. Giardini, Director SED, Responsible for ECOS
	Dr. D. Fäh, ECOS Project Manager
MECOS-02	Dr. G. Schwarz-Zanetti, scientific direction of MECOS-02, historical investigations
	M. Gisler, manager of MECOS-02 project, historical and macroseismic investigations
	L. Gantner, historical investigations
	C. Scheidegger, historical investigations
	Dr. V. Masciadri, expert for palaeographical problems, classics and medieval latin
	Dr. M.J. Jimenez, parameterization of historical earthquakes
	R. Schibler, macroseismic investigations
	R. Koglin, ECOS database
	D. Isenegger, ECOS database
	P. Kästli, ECOS database
ECOS	Dr. S. Sellami, instrumental catalogues
	Dr. J. Braunmiller, determination of magnitudes and seismic moments
	Dr. N. Deichmann, magnitude determination, catalogue fusion
	J. Wössner, ECOS catalogue fusion
	F. Bernardi, magnitude determination for historical earthquakes
	F. Bay, strong-motion attenuation and magnitudes
	Dr. S. Wiemer, magnitude statistics and regressions
	D. Schorlemmer, magnitude statistics
	M. Furrer, magnitude calibration
	S. Steimen, magnitude calibration

In addition, M. Baer, U. Kradolfer and D. Mayer-Rosa have extensively advised on magnitude calibration and catalogue completeness.

2 Foreword

Switzerland is characterized by moderate seismic activity, with uneven distribution in time and over the Swiss territory; 29 events in MECOS with Io ≥ VIII (MSK64) occurred over the last 1000 years, mostly concentrated in the Wallis, the Basel area and central Switzerland. The existing Swiss earthquake catalogue is spanning the time period 250 to 2000; however, reliable instrumental information is available only since 1975 and the bulk of the catalogue is derived from macroseismic input.

The assessment of seismic hazard for Switzerland relies chiefly on the historical record of earthquakes, independently from the chosen method of computation (i.e. deductive, historical, site specific). This is because the catalogue provides information over the last 1000 years, while the paleoseismological evidence is still very preliminary and the seismotectonic constraints on probabilistic hazard assessment are not stringent. The existing seismic hazard map of Switzerland (Sägesser & Mayer-Rosa, 1978) was derived using a deductive approach and was based on the compilation of the Swiss earthquake catalogue and macroseismic database (Basler-Hoffman & SED, 1975).

A subsequent study by Rüttener (1995) focused on the treatment of uncertainties and produced site specific hazard for 12 locations in Switzerland. The study analyzed the uncertainties in the macroseismic data with respect to intensity assessment, hypocentral parameters, intensity attenuation laws and catalogue completeness. It can be concluded that (i) efforts should be made to extend the earthquake history through paleoseismic investigations, (ii) hazard should be computed in ground motion parameters with appropriate attenuation laws, and (iii) local site effects should be taken into consideration by careful modeling. These three points are the focus of the SCENARIO project (Giardini et al., 1997; Fäh et al., 2000).

The Swiss earthquake catalogue and macroseismic database have not been significantly improved since 1975. To proceed further with the evaluation of seismic hazard for Switzerland, a substantial revision of the macroseismic database and of the Swiss earthquake catalogue is required. This report documents the compilation of ECOS, the Earthquake Catalogue of Switzerland.

2.1 Status of the Earthquake catalogue of Switzerland

The Swiss earthquake catalogue in use today at the SED is largely derived from the earthquake catalogue compiled by Sägesser & Mayer-Rosa (1978), with some modifications by Rüttener (1995), and from the integration of the instrumental catalogue since 1974. Before 1974, earthquake parameters were based essentially on macroseismic data, with few additions from international bulletins (ISC); in the last 20 years, hypocentral parameters and magnitudes are derived from instrumental data for all events with $M_L \geq 2$ and the macroseismic field is mapped for each event with I ≥ IV. The main catalogues and databases for Switzerland are as following.

2.1.1 MECOS − the Macroseismic Earthquake Catalogue of Switzerland, 1000-2000

MECOS derives largely from the compilation of Sägesser & Mayer-Rosa (1978), which was based on the critical reading of the main compilers and of several primary sources for Swiss earthquakes (Basler-Hoffman & SED, 1975). In addition to the catalogue, the complete file contains the lists of localities reported by the main compilers and the epicentral intensity assigned for each compiler; site intensities are only rarely reported and a database of intensity points is not compiled. Earthquake parameters were assigned ad-hoc by comparing different authors; parameter uncertainties were also roughly estimated.

2.1.2 Isoseismal maps, 1878-1962

The Swiss Earthquake Commission was founded in 1878 and published yearly bulletins until 1963, containing isoseismal maps for significant events. This database of maps does not however include the individual site intensities. Isoseismal lines are mostly expressed in Rossi Forel 1883 intensity scale.

2.1.3 Macroseismic database, 1917-2000

For earthquakes since 1917, the SED had transferred the macroseismic reporting cards into files, which can be used to map the macroseismic field. Neither isoseismal maps nor hypocentral parameters have been computed from these event files. Unfortunately, for some events the original macroseismic information has been lost, most notably for the 1946 Wallis earthquake, the largest event in Switzerland of this century.

2.1.4 IECOS − the Instrumental Earthquake Catalogue of Switzerland, 1975-2000

Instrumental recording started in Zurich in 1911. Up to 1975, instrumental locations were based on a limited number of stations (up to 5) and were supplemented for larger events from data from the Bureau Central International de Sismologie (BCIS) and later by the International Seismological Centre (ISC). Since 1975, seismicity is recorded with high precision by the Swiss seismographic network, complete for magnitude 2 and higher; magnitudes M_L and M_d are used. Mapping of macroseismic fields complements the numerical solutions for events with Io ≥ IV.

2.2 Upgrade of the Earthquake Catalogue of Switzerland

The next generation of seismic hazard for Switzerland (Giardini et al., 1997) will be expressed in terms of spectral ground motion parameters and provide site specific hazard. The catalogue and macroseismic database available at SED has limitations which will hinder its application in modern hazard assessment:

The limitations can be summarized as follows: (a) the database of site intensity-points exists only for some events after 1917, (b) different intensity scales (Rossi Forel, MS, MSK64, EMS98) are used in the database, (c) there is no complete central archive of compilers and of primary sources for Swiss events, (d) little documentation exists on how the historical earthquake parameters in the catalogue were obtained, on their homogeneity and on their uncertainties, (e) some significant earthquakes (Io ≥ VIII) were never studied in detail, and (f) magnitude scales for the historical and instrumental periods have not been equalized.

To improve the evaluation of seismic hazard for Switzerland, the SED completed a substantial revision of the macroseismic database and of the Swiss earthquake catalogue in the 1999-2002 period. The resulting catalogue and database ECOS achieves the following main goals:

- ECOS is the new unified earthquake catalogue for Switzerland and neighboring regions, covering all seismogenic areas which produce significant seismic hazard for Switzerland.
- The ECOS core is MECOS-02, the revised Macroseismic Earthquake Catalogue of Switzerland, which includes a comprehensive and homogeneous database of historical and macroseismic information built by collecting and analyzing primary sources and compilers of historical information and by merging all available macroseismic information and earthquake studies.
- ECOS is built by the fusion of 15 macroseismic and instrumental earthquake catalogues and can serve as a basis for homogeneous hazard assessment in the Central European area.
- ECOS is characterized by homogeneous assessment of earthquake parameters, by a common magnitude M_W for all the events and by the assessment of errors or bounds for all source parameters.

2.3 Structure of this report

This report is structured in four main chapters. In Chapter 3 we describe the main requirements, design principles and format of the ECOS catalogue and database, in Chapter 4 and 5 the compilation of MECOS-02 and ECOS, Chapter 6 deals with all issues in uniform magnitude assessment. We also include specific references and a number of Appendices.

3 ECOS: requirements, design, format

The project ECOS intended to: compile a complete inventory of intensity points for earthquakes with intensities equal or larger than VI in Switzerland and neighboring regions; incorporate in a database all relevant information compiled in existing national databases and/or earthquake studies in Switzerland, France, Germany, Italy and Austria; derive a unified earthquake catalogue with uniform source parameters.

3.1 Selection of events to be investigated

ECOS includes all known events required for the characterization of the seismicity for all the seismic source zones significant for hazard assessment for Switzerland. It includes events within a distance of 200-300 km from the Swiss borders. Three classes of events are defined, for which different levels of investigations have been carried out.

Class 1: All earthquakes located within or outside Switzerland, which produced significant effects (I>V/VI) in Switzerland. MECOS lists 135 events with intensity VII or higher and 220 events with intensity VI and VI-VII in the larger Western-Central Alpine region; this list has been checked against the BEECD and national catalogues in neighboring countries for inconsistencies, duplications and false events (Albini et. al., 2000). Macroseismic intensities within Switzerland have then been assessed by collecting and analyzing original historical sources and compilers; macroseismic intensities for points outside Switzerland have been imported from existing available macroseismic databases or from previous detailed event studies. Source parameters (location, epicentral intensity) for all class-1 earthquakes located in Switzerland have been systematically re-assessed. The revision of MECOS for all Class 1 events produces the MECOS-02 catalogue.

Class 2: Earthquakes located outside Switzerland, which produced no significant intensity effects in Switzerland. These events are needed for the definition of the seismic potential of source zones which could produce earthquakes with significant effects for Switzerland; their source parameters have been imported directly from existing national databases in neighboring countries.

Class 3: Earthquakes with epicentral intensity smaller than VI inside Switzerland. Earthquake parameters have been taken directly from MECOS, from the existing yearly reports of the SED since 1878, or when information was found in historical sources.

3.2 Investigation levels

Three levels of investigations are conducted, depending on the size and location of the events: historical, macroseismic and seismological investigations. This three-layer structure is maintained also in the ECOS Database.

Historical level. Existing seismological literature has been analyzed and all relevant earthquake studies, catalogues and available macroseismic databases previously assembled in Switzerland and in neighboring countries have been merged in the database. A homogeneous quality level for the whole database and catalogue has been maintained, using European standards developed during the BEECD project to define the quality of the macroseismic information and the uncertainties of the derived parameters. All original sources have been compiled and the root classification has been investigated according to BEECD standards (Stucchi et al., 1998).

Macroseismic level. For all Class 1 events we assess intensities for all locations in Switzerland and map the intensity field. Intensity points for localities outside Switzerland are imported from available compilations. All intensity points assessed in MECOS-02 are in EMS98; all intensity points imported from other databases have been transformed in EMS98, and the MECOS-02 database includes both the original intensity and the EMS98 values.

Seismological level. For all earthquakes with a sufficient number and distribution of intensity points, uniform regressions have been applied to derive source parameters (epicenter, hypocentral depth class, epicentral intensity, maximum intensity, macroseismic magnitude) and the respective uncertainties, using regression schemes accounting for regionalized intensity attenuation and hypocentral depth. In order to produce a catalogue with a uniform earthquake size assessment and rescale all magnitudes for the Swiss earthquake catalogue, the magnitude/intensity calibrations and the instrumental magnitudes computed in recent times has been reassessed through a range of investigations: the analysis of seismograms from key European observatories to derive homogeneous instrumental magnitudes for significant Swiss earthquakes since the beginning of the 20^{th} century; the analysis of digital waveforms collected since the late Seventies to compute digital magnitudes and re-calibrate the M_L scale used by SED; rescaling magnitudes computed since 1975 by the SED and in this study to a uniform scale; computing homogeneous regressions between different magnitude scales.

3.3 ECOS Database

The ECOS database (Figure 3.1) includes all historical, macroseismic and seismological data and is structured in three layers, corresponding to the type of information to be collected according to the Event Classes specified above. The ECOS database includes also all graphical and GIS interfaces for the analysis and display of the macroseismic data. The Historical Layer archives original historical information in form of original and translated text, photo-reproductions, prints, pictures. The Macroseismic Layer stores the macroseismic intensity points in the original scale (EMS98 for MECOS-02, other scales for points imported from other catalogues) and converted to EMS98 for use in uniform seismological interpretations. The Seismological Layer is the ECOS catalogue. The ECOS Database is presented in Appendix A.

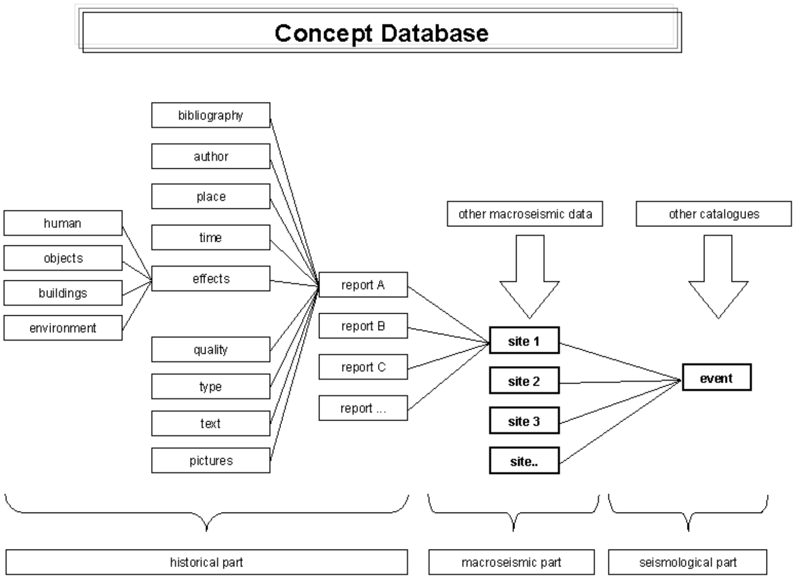


Figure 3.1 . Structure of the Database.

3.4 External Data

Switzerland is a small country with many borders. As a consequence, much of the Swiss seismicity takes place close to the borders, significant Swiss earthquakes produce important effects in bordering countries, most Swiss earthquakes are also contained in the national catalogues of neighboring countries.

Therefore, we need to include in ECOS earthquakes located outside Switzerland which produced significant effects in Switzerland (Class 1 events, with intensity VI or higher in Switzerland). For all such events, we import in MECOS-02 the already compiled macroseismic data from other databases and their source parameters from other catalogues.

We also need to include events which produced no significant intensity effects in Switzerland, but which are needed for the definition of the seismic potential of seismic sources in neighboring regions. Their source parameters have been imported directly from existing national databases in neighboring countries. An overview of the imported catalogues and the area covered by them is given in Figure 3.2 and Figure 3.3.

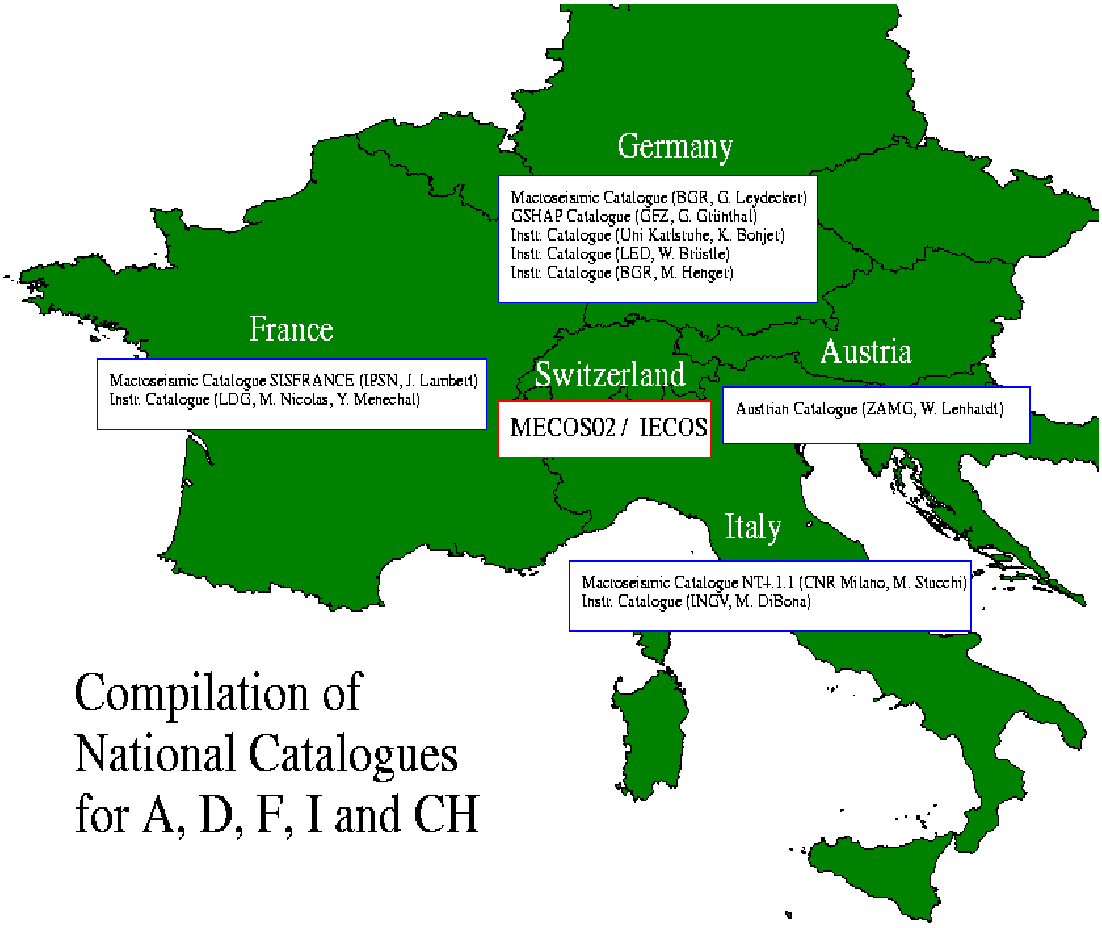


Figure 3.2. Distribution of the national catalogues included in the compilation of the ECOS catalogue. Information from the International Seismological Centre (ISC) is also included.

The catalogue has been compiled by fusion of 15 different instrumental and macroseismic catalogues. Figure 3.3 illustrates the coverage of the foreign catalogues. All these catalogues and the catalogue fusion are described in Chapter 5. The conversion of data and parameter formats for inclusion in ECOS are described in Appendix D.

The catalogue gives a reference moment magnitude M_W for all earthquakes and all original magnitudes are preserved and listed. Details on how the magnitude was derived are given in Chapter 6. Magnitude uncertainties are also listed.

It should be remarked that we do not attempt to build a consensus catalogue for the larger Swiss region. This is a worthy but complex task, involving five countries and over 15 catalogues, and is deferred to a later stage.

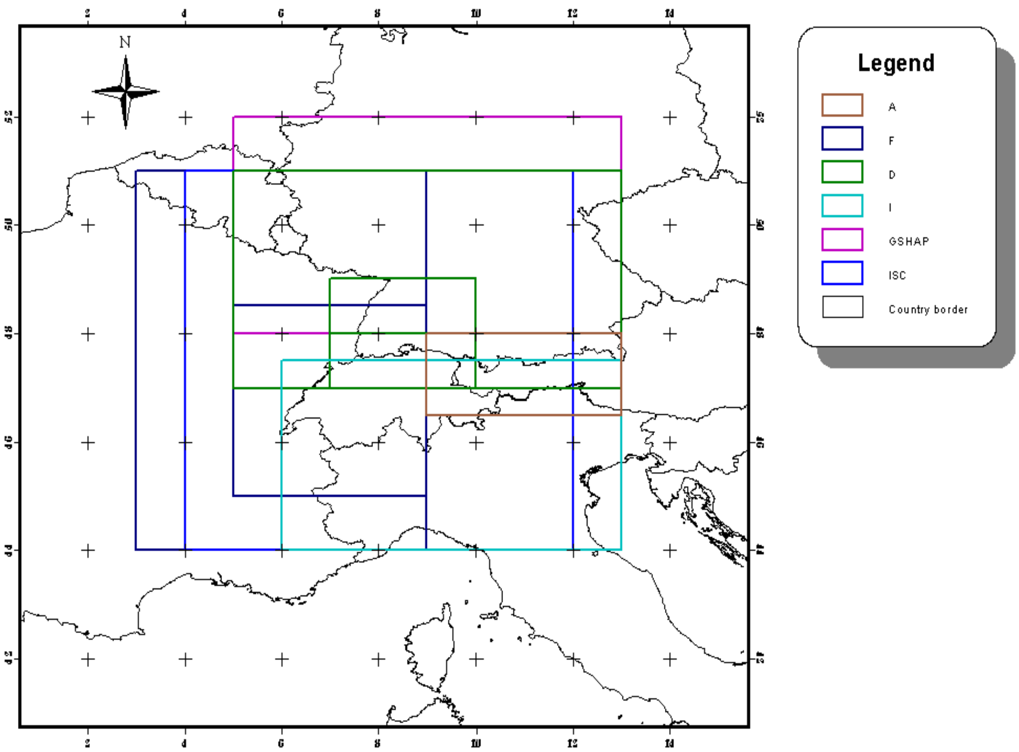


Figure 3.3. Geographical coverage of the macroseismic and instrumental catalogues which have been included to compile ECOS. Details on all catalogues are given in Chapter 5. Catalogue conversions are detailed in Appendix D.

3.5 ECOS Catalogue Format

3.5.1 Parameters and formats of event records

Parameter	Description	Format
Datanr	unique identifier for the dataset	Double
cc	certainty code	Integer
Type	type of event code	Integer
Year	Year	Integer
Month	Month	Integer
Day	Day	Integer
Hour	Hour	Integer
Minute	Minute	Integer
Second	Second	Double
Lat	latitude N in degrees	Double
Lon	longitude E in degrees	Double
ceN	code for epicentral location uncertainty in NS-direction	Integer
ceE	code for epicentral location uncertainty in EW-direction	Integer
h	focal depth in km	Double
ch	code for focal depth uncertainty	Integer
M_W	moment-magnitude	Double
cM_W	code for moment-magnitude uncertainty	Integer
M_W _ag	agency code for moment-magnitude	Integer
Io	epicentral intensity	Integer
cIo	code for epicentral-intensity uncertainty	Integer
Io_sc	code for macroseismic scale of Io	Integer
Io_ag	agency code for intensity assignment of Io	Integer
Ix	maximum observed intensity	Integer
cIx	code for maximum-intensity uncertainty	Integer
Ix_sc	code for macroseismic scale of Ix	Integer
Ix_ag	agency code for intensity assignment Ix	Integer
Isp	number of intensity site-points in Swiss database	Integer
catalogue_id	original catalogue code	Integer
ax	area of largest effects	Text
Comment	comment to the database entry	Text

3.5.2 Magnitude parameters

In addition to the parameters listed above, in each event record there are up to 24 possibilities to enter different magnitude estimates for the same event from different catalogues.

Parameter	Description	Format
mag1	magnitude value 1	double
mag1_sc	type code for mag1	integer
mag1_c	code for magnitude uncertainty of mag1	integer
mag1_ag	agency_code for mag1	integer
mag2	magnitude value 2	double
mag2_sc	type code for mag2	integer
mag2_c	code for magnitude uncertainty of mag2	integer
mag2_ag	agency_code for mag2	integer
……..		
mag24	magnitude value 24	double
mag24_sc	type code for mag24	integer
mag24_c	code for magnitude uncertainty of mag24	integer
mag24_ag	agency code for mag24	integer

3.5.3 Tables of codes in the ECOS database

The following tables describe the codes for the parametric earthquake catalogue.

Certainty code (cc)

cc	certainty code
1	event certain
2	event questionable
3	event fake
4	event fake: no earthquake
5	event fake: historical tradition error
6	event fake: dating problems (calendar & night)

Type of event code (type)

type	description
0	unknown
1	Induced
2	Explosion
3	Earthquake
4	Earthquake main and single event
5	EQ aftershock
6	EQ foreshock
7	EQ swarm event

Code for uncertainty of horizontal epicenter location (ceN,ceE)

ceN, ceE	EXY [km]
0	unknown
1	5
2	≤ 10
3	≤ 20
4	≤ 50
5	≤ 100
6	> 100

Code for uncertainty of focal depth (ch)

ch	EZ [km]
0	unknown
1	≤ 5
2	≤ 10
3	> 10
4	according to macroseismic determination

Code for magnitude uncertainty (cM_W, mag1_c, mag2_c, …)

Code	units
0	unknown
1	≤ 0.2
2	≤ 0.5
3	≤ 1.0
4	> 1.0

Code for intensity uncertainty (clo, clx)

clo, clx	units
0	unknown
1	< 0.5
2	= 0.5
3	= 1.0
4	= 2.0

Code for macroseismic scale (Io_sc, Ix_sc)

Io_sc, Ix_sc	macroseismic_scale_type	shortcut
0	unknown	
1	European macroseismic scale 1992	EMS92
2	European macroseismic scale 1998	EMS98
3	Medvedev scale 1953	M53
4	Mercalli-Cancani-Sieberg scale 1932	MCS
5	Modified Mercalli scale 1931	MM
6	Modified Mercalli scale 1956	MMS
7	Medvedev-Sponheuer-Kárník scale 1964	MSK64
8	Medvedev-Sponheuer-Kárník scale 1981	MSK
9	Rossi Forel scale 1883	RF
10	Mercalli-Sieberg scale	MS
11	Montandon	Mon

Code for reference and authors (M_W_ag, Io_ag, Ix_ag, catalogue_id, mag1_ag,.., mag10_ag)

Code	country	catalogue	Agency_id	Description of Agency
1	Switzerland	Mecos	SED	Swiss Seismological Service
2	Switzerland	Mecos02	SED	Swiss Seismological Service
3	Switzerland	Iecos	SED	Swiss Seismological Service
4	Germany	Instr_BRD_Cat	BGR	Bundesamt für Geowissenschaften und Rohstoffe
5	Germany	Macr_BRD_Cat	BGR	Bundesamt für Geowissenschaften und Rohstoffe (Leydecker Catalogue)
6	Germany	Instr_LED_Cat	LED	Landeserdbebendienst Geolog. Landesamt Baden-Württemberg
7	Germany	Instr_Karls_Cat	Karlsruhe	Universität Karlsruhe
8	Italy	NT4.1.1	CNR/GNDT	Consiglio Nazionale delle Ricerche, Milano
9	Italy	Instr_Italy_Cat	INGV	Istituto Nationale di Geofisica e Vulcanologia
10	France	Sisfrance	BRGM	Bureau de Recherche Geophysique et Miniere
11	France	LDG_Cat	LDG	Laboratoire de Detection Geophysique
12	Austria	Austria_Cat	Austria	ZAMG Zentralanstalt für Meteorologie und Geodynamik
13	Germany	GSHAP	GFZ	GeoForschungsZentrum Potsdam
14	France	IPSN_Catalogue	IPSN	Recherche des characteristique de séismes historique en France (Book)
15	GB	ISC_Catalogue	ISC	International Seismological Center

Code for magnitudes (mag1_sc,.., mag10_sc)

Code	type of magnitudes	shortcut
1	local magnitude	M_L
2	Surface wave magnitude	M_S
3	body wave magnitude	m_b
4	macroseismic magnitude	M_m
5	duration magnitude	M_d
6	moment magnitude	M_W

4 MECOS-02

MECOS-02 is the new macroseismic earthquake catalogue and database of significant earthquakes for Switzerland, and includes all identified events which produced intensity VI or higher in Switzerland. We present here the existing MECOS catalogue and the revision to MECOS-02.

4.1 MECOS (Macroseismic earthquake catalogue of Switzerland)

The compilation of Sägesser & Mayer-Rosa (1978) was based on the critical reading of the main compilers and of several primary sources for Swiss earthquakes (Basler-Hoffman & SED, 1975). The macroseismic database contains the list of all main localities reported by the main compilers and the epicentral intensity assigned for each compiler; site intensities are only rarely reported. Earthquake parameters were assigned by comparing different authors [http://seismo.ethz.ch/products/catalogs/mecos/]. Parameter uncertainty classes are also given. MECOS integrates yearly bulletins for the period 1879 to 1963 published by the Swiss Earthquake Commission and the Swiss Seismological Service. These bulletins contain isoseismal maps for significant events. This database does not include individual site intensities; isoseismal lines are mostly expressed in Rossi-Forel intensity scale. For some earthquakes since 1917, the SED had transferred the macroseismic cards into files, which can be used to map the macroseismic field.

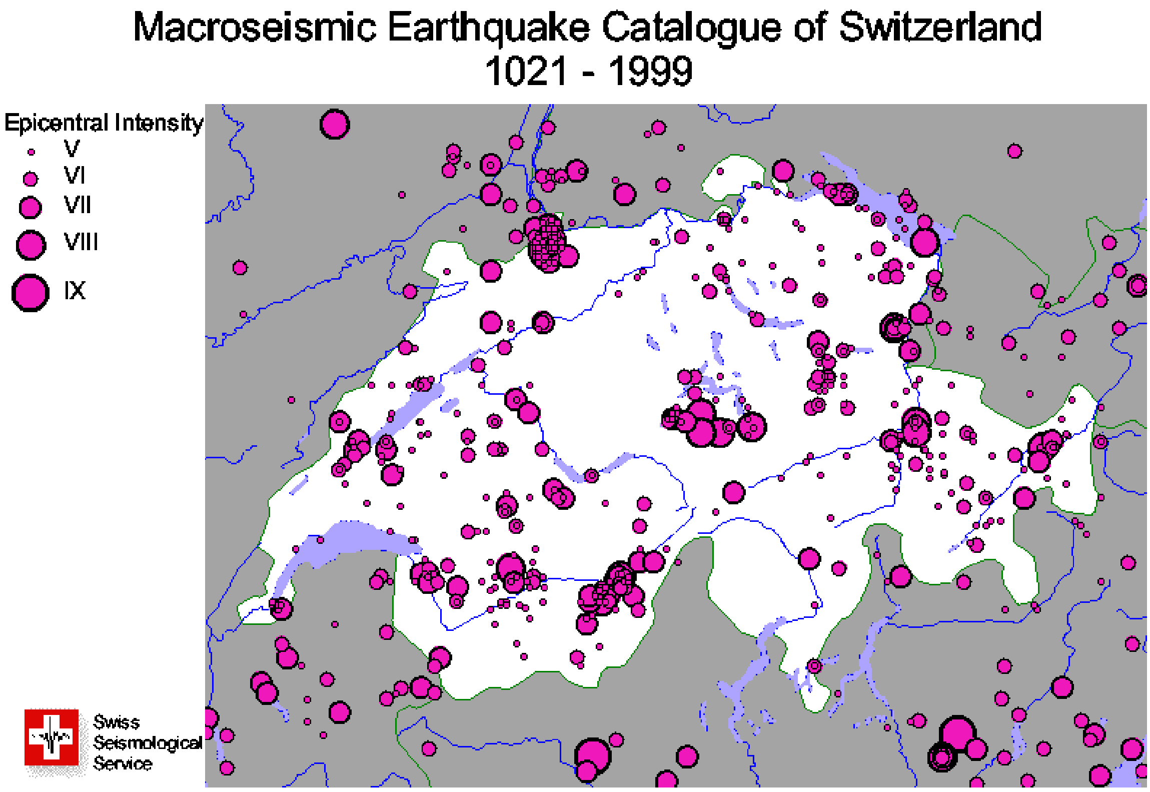


Figure 4.1. Map of earthquakes from MECOS.

Instrumental recording started in Zurich in 1911. Until 1975 the instrumental locations were based on a limited number of stations (up to 5) and were supplemented for larger events from data from the Bureau Central International de Sismologie (BCIS) and later by the International Seismological Centre (ISC).

Some important earthquakes of Switzerland have been analyzed in detail by special studies: among these the 1356 Basel (Mayer-Rosa and Cadiot, 1979) and the 1946 Wallis earthquakes (Schibler et al., 2000).

4.1.1 MECOS parameters

The historical data was implemented in eight data files, a MECOS file and seven CHIST files. These CHIST files are essentially working files used inside SED. MECOS and the CHIST files were checked against each other and a MECOS working file was defined and implemented in the ECOS Access database. The parameters are listed in Table 4.1.

Parameter	Description	Scale or data range
DATANR	Number: Unique Key for the dataset (entity set)	1 – 5000
GROUP	Number: Key for the group of datasets. All members of a group are the information for one event. Result from the import from the filemaker file Chist over the group attribute.	1 – 5000
No	Number: Secondary Key from the list_italy_comment entity set (Created new for appending list_italy)	
MARKER	Boolean: This marker identifies the valid dataset out of a group.	
P	Number: Priority	1 = earthquake, 2 = source questionable, 3 = fake
YE	year	1021 – 31.12.2001
MO	month	
DA	day	
HO	hour	
MI	minute	
SE	second	
CT	Comment to time	
LAT	Latitude °N	37 – 49
LON	Longitude°E	4.9 – 21.4
Ce	Uncertainty of epicenter location in classes (Comment to epicenter location)	0 - 5
EXY	Uncertainty of epicenter location in km	0 - 100
I	Maximum observed intensity according to MECOS	10 - 89
Ix	Maximum observed intensity according to BEECD	4 -90
CI	Uncertainty of IX or IO (Comment to IX or IO)	0 - 6
SC	Intensity scale of IX and IO	1 = MSK64, 2 = RF, 3 = MCS, 4 = MM, 5 = Mon, 6 = unknown
ORTSANGABE	Locations of observed earthquake effects	
ANZ	Number of macroseismic observations	
REF1	Reference	
PRESHOCK	Marker to identify that it was a foreshock	
AFTERSHOCK	Marker to identify that it was a aftershock	
H	Hypocentral depth in km	0 - 41
EZ	Uncertainty of hypocentral depth in km	0 – 99.9
CH	Uncertainty of hypocentral depth in classes (Comment to hypocentral depth)	0 -5
IO	Epicentral intensity according to MECOS	2 – 89
IO_BEECD	Epicentral intensity according to BEECD	20 - 110
RS	area/radius of perceptibility in km	1 - 1550
IR	Intensity in the distance of the radius of perceptibility	1 - 45
SC_IR	Intensity scale of IR according to the macroseismic_scale table (No relationship defined. Has to be done in the query)	
CI_IR	Uncertainty of IR according to the ci table (No relationship defined. Has to be done in the query)	0 - 9
M	Existence of a macroseismic map	
AX	Area of largest effects	
REF2	Reference 2	

Parameter	Description	Scale or data range
P2		
LT	Number of the map of the Federal Office of Topography Switzerland (Swiss National Map 1:100'000)	
AZ	Azimut	
T	Recorded time series in seconds related to the epicentre	
MAGNITUDE	Magnitude, either equal to MM or to ML	1.3 – 6.1
ML	Local magnitude (since the year of 1930)	0.7 – 6.1
MM	Macroseismic magnitude (before the year of 1930)	2.4 – 6.3
NOM	Number of macroseismic observations from MECOS-Web	
SCH	Damage to humans, buildings and environment; code with 3 digits describing the effect on humans, landscape, and buildings. Humans :1= low death toll, 2 = high death toll; buildings: 3 = cracks, 4 = chimney, 5 = destruction; landscape: 6 = landslide, 7 = rockfall, 8 = avalanche	
V	Number of foreshocks: 1 = one, 2 = several, 3 = huge number	1 – 3 (Not defined: *, ?;)
N	Number of aftershocks: 1 = one, 2 = several, 3 = huge number	1 - 3 (Not defined: *, ?;)
HAUPTSTOSS	Date of mainshock	
KORR	Corrections that have been made by former compiler	
F	Second macroseismic map	
DS	Dataset source (source file)	
NR	Number of references (M = multiple references)	
R	Root (According to BEECD)	
RC	Root class (According to BEECD)	
Sen	Source entry number	
Set	Source entry type	
Ar	Amount of References	
Co	Comment to number of macroseismic observations	No values
Cm	Comment to Mm	
Ben	BEECD entry number	

Table 4.1. Parameters defined in the MECOS catalogue.

4.1.2 Completeness

Important dates regarding the completeness of the MECOS catalogue and completeness estimation of previous studies are given in Table 4.2 and Figure 4.2. These studies mainly focused on the distribution of intensities during the last 1000 years. Although small intensities appear in the early centuries, the catalogue was interpreted to be complete only for the largest intensity grades.

Date		NAGRA Report (1982 Homogeneous periods	Rüttener (1995) completeness	Grünthal (1998) completeness
169	1st chronical	1300-1754	1300 I>=9 1600 I=8	1300 I>=8 1575 I=7 1650 I=6
1755	Lisbon earthquake	1755-1878	1750 I=6,7	
1856	1st Catalogue in Switzerland			
1878	1st SED 'Jahresbericht'	1879-1941	1878 I=4,5	1875 I=5
1880	Earthquake commission			
1913	Installation of seismic stations			
1941	Additional station in Brig	1942-1974		
1963	Suspension of the 'Jahresbericht' until 1971			
1975	Installation of the seismic network			

Table 4.2. Estimation of catalogue completeness in MECOS .

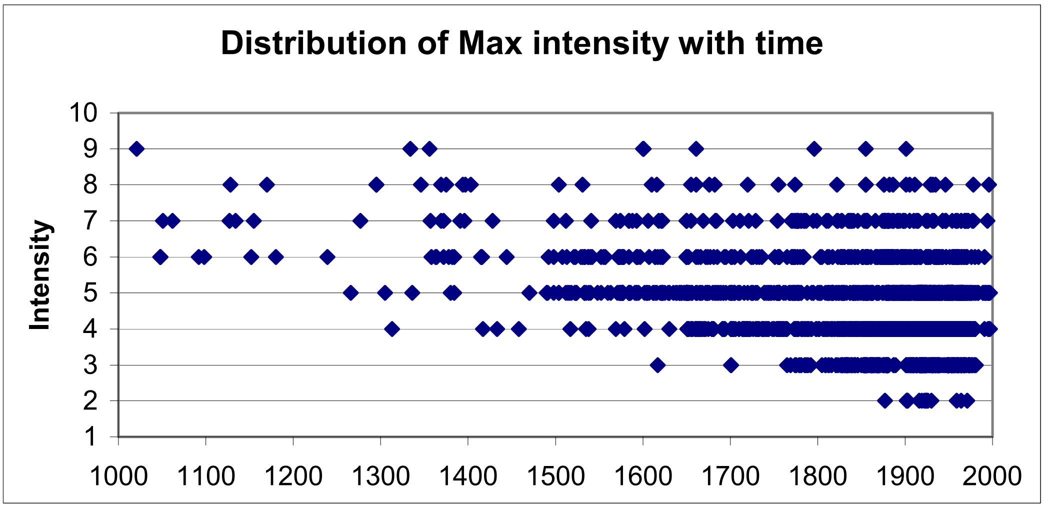


Figure 4.2. Distribution of the maximum intensity of the events in MECOS.

4.1.3 Error estimation and quality

Information about the error in MECOS and its quality are very limited and can be summarized as follows: (a) the database of site intensity-points exists only for some events after 1917, (b) different intensity scales (Forel, MS, MSK, EMS98) are used in the database, (c) there is no complete central archive of compilers and of primary sources for Swiss events, (d) little documentation exists on how the historical earthquake parameters in the catalogue were obtained, on their homogeneity and on their uncertainties, (e) some significant earthquakes (Io ≥ VIII) were never studied in detail. For the historical earthquakes before 1878, mostly earthquake compilations were used. This led to duplications of events, and for some events to misleading information concerning the size of the earthquake.

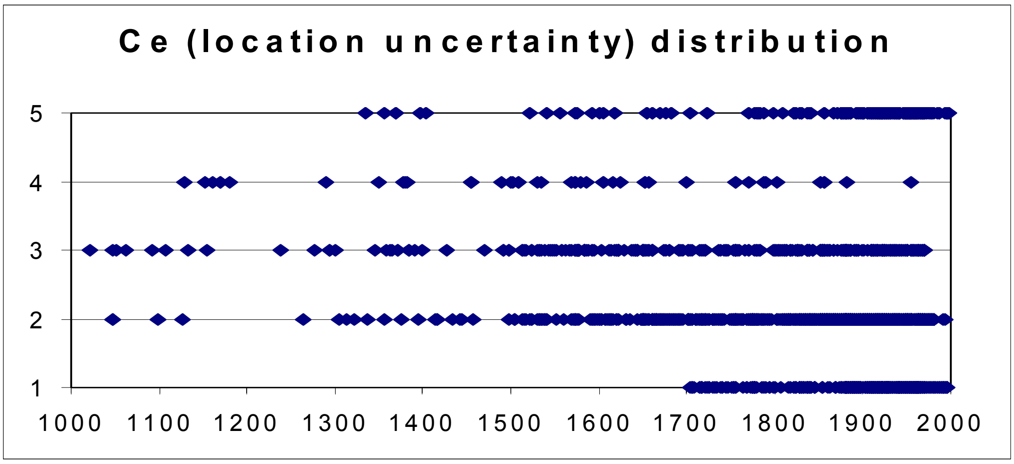


Figure 4.3. Distribution of the location uncertainty of the events in MECOS. Parameter Ce is explained in Table 4.1.

The location uncertainty with time is given in Figure 4.3. The location uncertainty in MECOS has often been underestimated. A reevaluation of the uncertainty has been made during the revision of MECOS.

4.2 MECOS-02: historical level

4.2.1 Approach

For all Class 1 earthquakes we conducted a historical investigation, covering over 600 events and a time span of 14 centuries. The historical catalogues and the so-called compilations have been analyzed. Compilations have a long tradition; even in the annals and chronicles of the Middle Ages we find copies of older manuscripts. Earthquake compilations - among others - were published since the 16th century, as for example the works of Lycosthenes (1557), Rasch (1591), Scheuchzer (1706ff.) and Bertrand (1766). One of the most famous examples is the compilation of Volger (1857). Copies and interpretations always contain the possibility of errors and simulate often a broad base of data. Nevertheless, these compilations served as a thread to start looking in libraries and archives for documents such as annals, chronicles written by clergy and laymen, private and official documents, newspapers, journals and so forth. Many of them needed paleographical and philological preparatory work, because they have been hand-written and composed in languages such as Middle High German, Latin, Romance, French and Italian. They had to be transcribed and translated into German. All information from these sources has been introduced into the MECOS-02 database.

A reliable base of statements on earthquakes asks for independent and corresponding eyewitness reports or primary sources. Reliable copies of lost sources can complete these documents. The primary sources have been interpreted by the historical-critical method (developed in the 19th century, e.g. J. G. Droysen (1857)). The external criticism tries to define the author and his surrounding, the place of observation, the date of the event and the context of the writing, which gives an assessment of the source quality (A: eyewitness; B: very close to the event; C: compilation; F: fake event; U: unknown event). The internal criticism is focused on the description. Aspects of mentalities and writing skills have also been considered. The ideal case of several primary sources allows a cross checking. But all above in earlier time it was not always possible to find enough primary sources to do so.

Goal of this method is a provable historical minimal-statement. Otherwise, the contemporary use of a language, religious or scientific intentions can lead to misinterpretations. Only described damage allows to define a damaging earthquake, that means that short descriptions of events as is often found for the Middle Ages can only be interpreted with a very high uncertainty.

A list of all investigated archives and sources is given in Appendix B; the full historical bibliography is given in Appendix C.

4.2.2 Investigated periods

Early and High Middle Ages

Generally, the historical information on earthquakes is very rare. The first known event is in 849; besides, a more uncertain event in 250AD in Augusta Raurica (Augst) and a rockslide in the Wallis in 563 are found. The events in the annals of the Early und High Middle Ages are characterized through very short descriptions as “an earthquake happened on the day of …”, but an indication of an intensity is often missing. In 1117 the first description of damages appear. And just at the end of the 13th century certain annals pass over to longer descriptions, as for example in the Annales Colmarienses for the event 1295.

Late Middle Ages

In the 14th century the first chronicles of towns arise in Switzerland and the authors recorded descriptions of natural phenomena, sensitized through a series of natural disasters in the middle of this century as for example the earthquake of Villach 1348. Therefore, the famous event of October 1356 is described in several chronicles, letters and other documents. In 1399 in the region of Basel the oldest known diary with nature observations started. It contains beside of weather and astronomy two earthquakes. In the middle of the 15th century a gap in the information exists, probably because of the wars during this time.

16th and 17th centuries

The density of the information grows in different kinds of documents as chronicles, diaries, official registers and in scientific and religious analyses. But even the most interesting events as 1584 and 1601 show gaps in the reported places. A destructing earthquake around Sion, discovered during this project, is reported by only one witness.

18th century

In the first half of the 18th century science in Switzerland increased. We find a number of hand-written documents on several topics of natural phenomenon such as earthquakes. The 1755 earthquake in the Valais was of very high interest because of the Lisbon earthquake a month before. In the second half of the century, scientists were not that much interested in earthquakes anymore. For this time, we had to focus on private documents such as journals, letters and so forth. In this century the production of newspapers already started. We found a newspaper, which appeared monthly in Zurich and provides information on earthquake for the German part of Switzerland with certain reliability.

19th century

In the 19th, century the production of newspapers increased enormously. Therefore, most of the information on earthquakes has been taken out of these kinds of documents, in conjunction with scientific papers for example produced by the “Naturforschende Gesellschaft” (established in 1746). For the 1855 earthquake in the Valais the investigation of Volger has been analyzed among many other documents.

20th century

For the 20th century three different types of documents has been consulted: newspapers, the annuals of the Swiss earthquake commission (established in 1879) and the “Meldekarten” of the SED. A new investigation and a crosschecking with the existing Macroseismic data files have controlled already existing site intensities for a series of earthquakes.

4.2.3 Completeness

The investigated time period 250-2000 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 is provided in Table 4.3 and Figure 4.4. Over the centuries, the practice with written records changed quite often, depending on many factors. Nevertheless, the growth of written documents is obvious and the results of the investigation are very much influenced by this fact. Therefore, the catalogue might be created out of 3 (or sometimes even less) or several hundreds intensity data points.

From a historical point of view, completeness just does not exist because history can always be revised under new perspectives and new documents may be found. However, the most important archives and libraries have been visited. Historians, archaeologists and other people have been contacted, and the most important chronicles, diaries and journals have been checked (see Appendices B and C).

The completeness of events over the century is not linear. The political situation, for example, may have been much more important for a chronicler than an earthquake (i. e. the French and Swiss revolution at the end of the 18th century). On the other hand, there were time periods, when science bloomed, e.g. 1510-1525 or 1650-1750, and scientists have been very much interested in natural phenomenon such as earthquakes. For such periods, they left behind a bundle of scientific papers. Per contra, in the second half of the 18th century earthquakes were not in the focus of many people and therefore have been recorded rarely. However, it can be assumed that extreme events are recorded in the last millennium (e.g. the large earthquake in 1117).

In the course of the Early and High Middle Ages earthquakes reported by eyewitnesses are found only in the few annals of monasteries in the northeast of Switzerland. Therefore, the complete-ness for events with intensity VII and higher has to be estimated between 5%-20%. In the 12th and

13th century, the knowledge and interest in science increased in general, and the first two earthquakes with damage descriptions appear. For this time span, all the printed sources have been evaluated. In the 14th and 15th century the 1356-event terrified the population and increased sensitivity of the observers in the towns, mainly in Basel. In this time the education improved, paper mills and printing were invented, which then increased the number of reported damaging events. It can be estimated that the completeness of events with intensity VII and higher is around 50 %, though a gap in the chronicles in the middle of the 15th century exists. During the 16th and the 17th century the amount of information grew, and 75% of the stronger events are assumed to be known. A lack of information can be found in the mountain areas (Graubünden, Central Switzerland, Tessin and Wallis) where reliable sources appear slowly just around 1500.

For the Middle Ages until 1259 the work of Alexandre (1990), who investigated the printed primary sources of Central Europe, is also introduced into MECOS-02. Therefore, we can assume to have recognized the most prominent events of this time period.

Finally, not all archives in Switzerland have the same level of handling documents. In some archives the access to and the investigation of new documents is very difficult for many reasons. There are some regions, where one would expect a high number of events, as for example in the Valais. Due to difficulties to access the archives and the investigated documents, only few events could be found for the early period of the catalogue. Other archives such as the Staatsarchiv Zug have around 40'000 of the "Ratsprotokolle 1552-1798" that are accessible in a database in form of a summary.

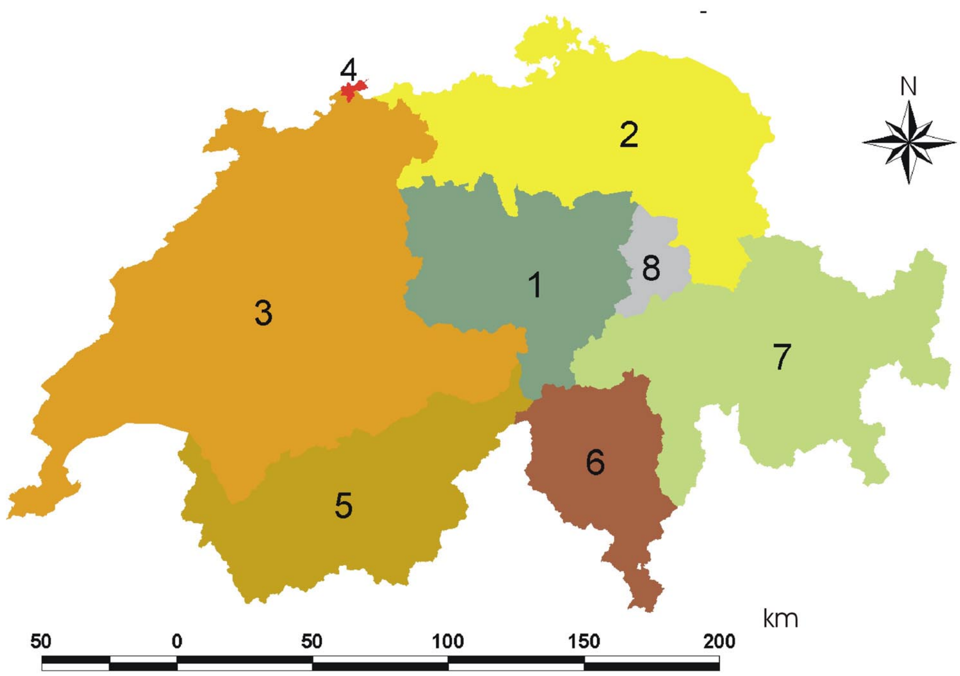


Figure 4.4. Geographical distribution of catalogue completeness, according to Table 4.3.

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 4.3. Completeness of observed intensities for different regions in Switzerland for given time periods. n: no primary sources found; u: completeness unknown. The Swiss regions are illustrated in Figure 4.4.

4.2.4 Calendar

During the Middle Ages and the early modern times, several calendars existed in parallel. This produces problems that have to be taken into account properly. During the Middle Ages three systems existed: the roman dating with “calendae”, “nones” and “ides”, the dating with the name days and the counting of every day in a month. Between the 4th and the 15th of October 1582 Pope Gregor corrected the difference between the tropical year and the Julian calendar. This new style is named Gregorian Style or calendar. Officially, the first catholic cantons in Switzerland changed to the Gregorian calendar in January 1584. Canton Unterwalden followed in 1587 and the Wallis in 1655. Several protestant cantons changed in January 1701, others in 1724 and canton Graubünden followed between 1760 and 1812. However, the private use of the calendar style can be different from the official one. Thus, the calendar is the reason for many event duplications in this period. Therefore, the weekday or at least the region of the observation had to be known to decide the style. The last Julian dated event in the catalogue is in 1796. In MECOS-02, all dates after 1584 have been converted into Gregorian style. The heterogeneity in calendar style can be observed until the 19th century.

During the Middle Ages, the time followed the schedule in monasteries, so that the time could be estimated for many events. But also sundials were known.

Other errors in MECOS go back to expressions like “around St. …”, or to the different use of the word “vigilia” for the evening or for the evening of the day before. In general, events during the night can be interpreted differently even through witnesses. And misprints of dates in compilations created many new events.

4.2.5 Localities

Old names of localities were re-identified and translated through encyclopedias such as *Orbis Latinus* by Graesse (1972). Wrong translations were recognized, as for example the expression

"Welschland" for Romandie or Neuenburg, which had to be corrected to Italy, the correct translation at that time. A fake event in Styria (Steiermark) could be backtracked to Syria.

The location uncertainty in MECOS has often been underestimated. A reevaluation of the uncertainty has been made for the events which were not revised, mainly historical events with intensity smaller than 5. The uncertainty has been changed according to the time (Table 4.4). Events with intensity larger than five have been reassessed from the macroseismic fields.

MECOS : ce	**Mecos-02 : ceN/ceE**	**Application**
ce=4 (>50 km)	ce=5 (50-100 km)	
ce=3 (10-50 km)	ce=4 (20-50 km)	Before 1650
ce=2 (5-10 km)	ce=3 (10-20 km)	Before 1750
ce=1 (0-5 km)	ce=2 (5-10 km)	Before 1879

Table 4.4. Reassessment of the location uncertainty.

4.2.6 Results

The new MECOS-02 :

- Major improvements are a higher quantity of information, the quantification and the complete documentation of every report: a copy of the manuscript or the critical edition, a transcription and if needed a translation and a bibliography.
- The historical analysis is based whenever possible on primary sources and the reliance on compilations could be reduced.
- A root and archive classification of historical sources for earthquakes in Switzerland is now established.
- The increased information allowed a cross checking of events and the definition of quality of this information. Many mistakes could be corrected, such as misprints, which appeared in chronicles and have been transferred over the years.
- The use of many primary sources allows a more reliable understanding of earthquake damage as a basis to map macroseismic fields.

4.3 MECOS-02: Macroseismic level

We establish macroseismic site intensities from the historical information. The European macroseismic scale EMS98 (Grünthal, 1998) has been adopted and is used for the whole database; all intensity points assessed in MECOS-02 are in EMS98.

The problem in the assessment of site intensities was the fact that we had to interpret historical information within a time span of 1000 years on an equal level, though the meaning of the information was not the same over these centuries. "Terraemotus magnus" in the 12th century for example does not mean the same as "ein grosser Erdbidem" in the 18^{th} century, but it still has to be interpreted as "strong event". The same problem arises for the descriptions of human reactions, effects on buildings, environment etc.

In addition to estimating intensities for all Swiss localities, we imported intensity values for all Class 1 earthquakes from all available databases and compilations: for Italy from the NT4 database, for France from the SisFrance database, for Germany from working files of F. Scherbaum (University of Potsdam, Germany), G. Leydecker (Bundesanstalt für Geologie und Rohstoffe, Hannover, Germany) and G. Grünthal (GeoForschungsZentrum, Potsdam, Germany). All intensity points are preserved in the original intensity scale in the database, and we convert them all to EMS98 for compatibility with the new Swiss intensity points. The intensity values were not changed significantly by upgrade to EMS98, since the values mainly describe the same damage pattern. We defined the uncertainty of the intensity as ΔI=±1 to account for translation inaccuracy. Table 4.5 gives the correspondence used between different earthquake intensity scales for intensities smaller than VI; for intensities higher than VI, the intensities were re-evaluated from the data.

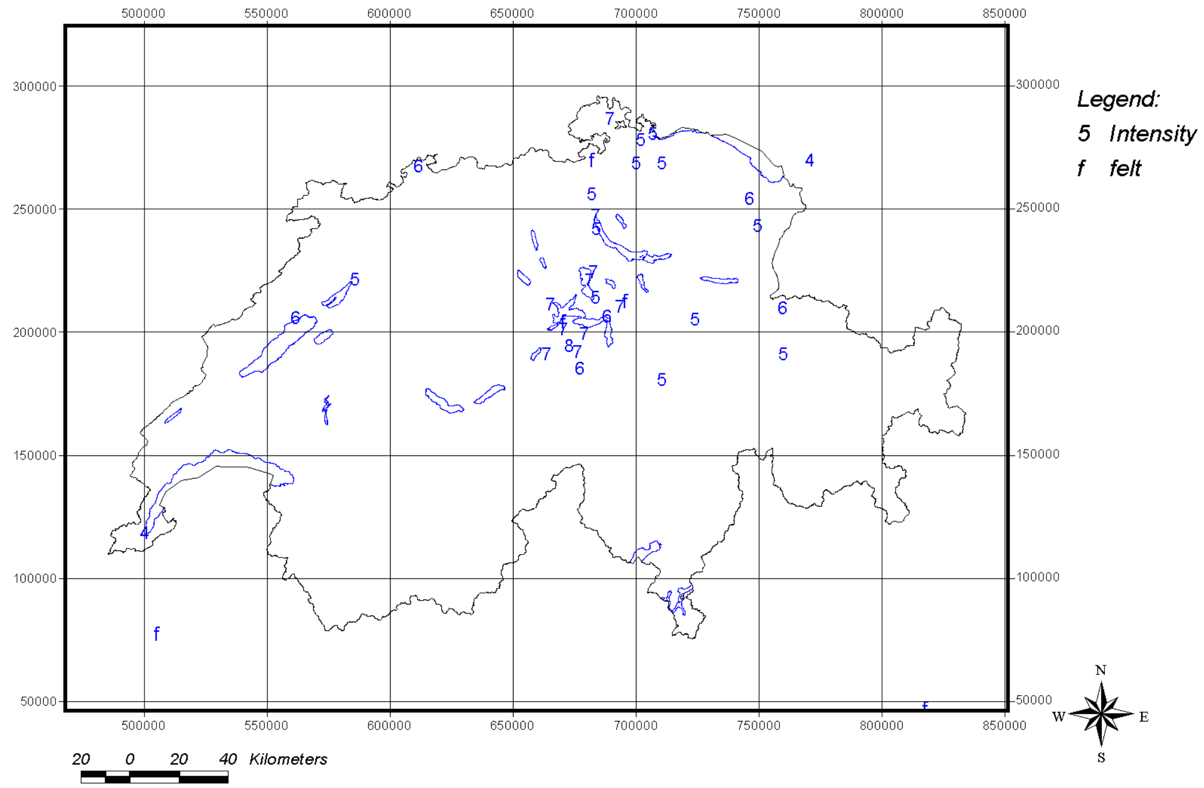
Scale	Intensity value					
EMS98	I	II	III	IV	V	
EMS92	I	II	III	IV	V	
M53	I	II	III	IV	V	
MCS	II	III	IV	V	VI	
MM	I	II	III	IV	V	
MMS	I	II	III	IV	V	
MSK64	I	II	III	IV	V	
MSK81	I	II	III	IV	V	
RF	I	II	III	IV	V	VI
MS	I	II	III	IV	V	

Table 4.5. Conversion of intensities to EMS98 for MECOS events with epicentral intensity Io ≤ 5.

When uncertainty in the assignment of the intensity exists, we list in the database a most probable intensity value, and the minimum and maximum possible values.

Finally, for each Class 1 event we obtain a macroseismic field. Two examples for large events in 1601 and 1946 are shown in Figures 4.5.

Event N°31: 1601.09.18



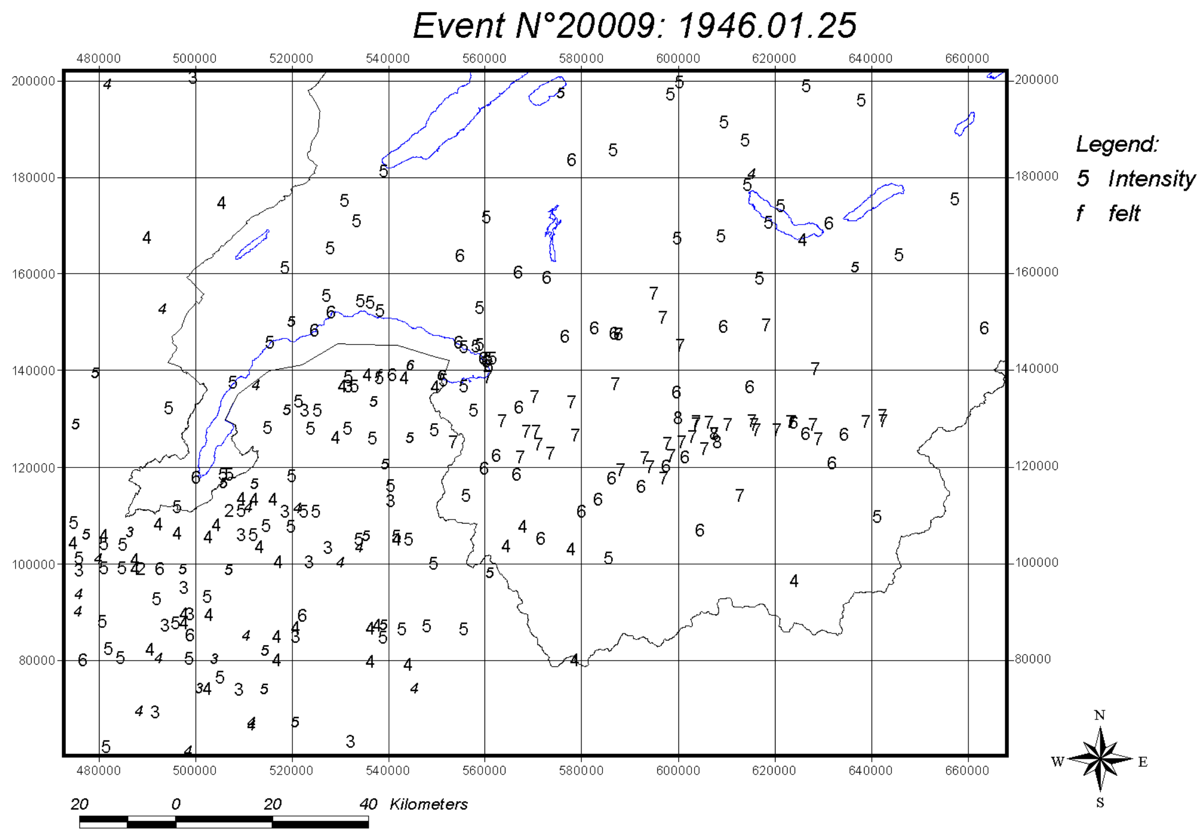


Figure 4.5. Macroseismic fields of the 1601 and 1946 earthquakes.

4.4 MECOS-02: Seismological level

For each event in the MECOS-02 catalogue we derive seismic parameters (epicentral location, depth class (if possible), macroseismic magnitude M_m, epicentral intensity Io) and their uncertainty. We first determine appropriate attenuation and magnitude calibration relations for Swiss intensity data. Then, for all earthquakes in Class 1, we derive these parameters from the macroseismic field. Finally, we analyze and include all parameters from bulletins and reports since 1879.

4.4.1 Parameterization of historical earthquakes

The strategy for the parameterization of historical earthquakes was established to:

- derive homogeneous source parameters for all historical events in Switzerland;
- equalize macroseismic with instrumental parameters to build a uniform catalogue for the period 1000-2000;
- provide homogeneous assessment of uncertainty through the whole historical and instrumental period.

We performed a comprehensive testing phase using a number of well calibrated and well distributed earthquakes of the 20th century for which we have good macroseismic control and robust instrumental parameters. The tests aimed at establishing the principles and algorithms to be adopted for the parameterization of historical earthquakes. The tests and the final procedure are described below. A more complete review of the possible approaches is given in two internal SED report (Steimen, 2000a,2000b; Jimenez, 2001).

Our analysis is based on four main steps:

1. establish a set of calibration events;
2. the attenuation of intensity with distance for the Swiss region;
3. the calibration of a macroseismic magnitude scale;
4. the systematic processing of all historical earthquakes.

Parts 1-3 are described here below, Part 4 in section 4.5.

4.4.1.1 Calibration events

We obtain a set of well controlled calibration events by selecting earthquakes of the 20th century with a well distributed macroseismic field derived in our MECOS-02 investigations and with instrumental magnitudes homogeneously computed by us (see Chapter 6). From an initial set of 31 events, we select a final list of 15 events spanning the whole Swiss region, a wide magnitude range, and large well distributed macroseismic fields .

Events are grouped in two depth classes, according to the characteristics of the macroseismic field and the instrumental information: shallow (S) events are characterized by high attenuation of intensity with distance in the near epicentral area while deep events show a lower attenuation (see Figure 4.7). Magnitudes M_W are derived from instrumental M_L or M_S magnitudes (see Chapter 6). Table 4.6 lists the event parameters: date, location, number of used intensity observations, moment magnitude, intercept intensity, epicentral intensity, and depth (see text below). Figure 4.6 displays the geographical distribution of the events.

4.4.1.2 Attenuation of intensity for the Swiss region

The intensity field of an earthquake depends on the source characteristics (depth, source extension, magnitude), propagation path which includes local effects and also on the sensitivity of people and man-made structures to ground motions and thus on the intensity attenuation with distance and azimuth.

Year	Month	Day	Lat / [°]	Lon / [°]	N	M_W	I_{int}	Io	Depth
1910	5	26	47.4	7.3	212	4.8	5.3	60	D
1911	11	16	48.22	9	683	5.8		(80)	D
1935	6	27	48.04	9.47	473	5.7		(75)	D
1946	1	25	46.35	7.4	638	6.1	7.2	80	D
1946	5	30	46.3	7.42	408	6	6.9	70	D
1954	5	19	46.36	7.07	194	5.4	5.9	60	D
1960	3	23	46.37	8.15	601	5.3	6.8	80	S
1964	3	14	46.87	8.32	422	5.7	6.4	70	S
1971	9	29	47.15	9.02	298	5.1	5.3	60	D
1976	3	26	47.58	9.44	127	3.5	4.5	50	S
1978	9	3	48.28	9.03	657	5.2		(75)	D
1980	7	15	47.63	7.52	531	4.9	5.3	(65)	D
1994	12	14	45.96	6.42	537	4.3	5.5	60	S
1996	7	15	45.94	6.09	717	4.6	6.1	70	S
1999	2	14	46.78	7.21	96	4	4.2	50	D

Table 4.6. Parameters of the calibration events: date, location, number of used observations N, magnitude, intercept intensity, and epicentral intensity in MECOS-02. Io in brackets describes events for which no reassessment of epicentral intensity was performed by the SED group. The bracketed values are taken from the original national catalogue. No intercept values for those events (1911, 1935, 1978) for which only observations at distances above 70km were considered in the magnitude calibration.

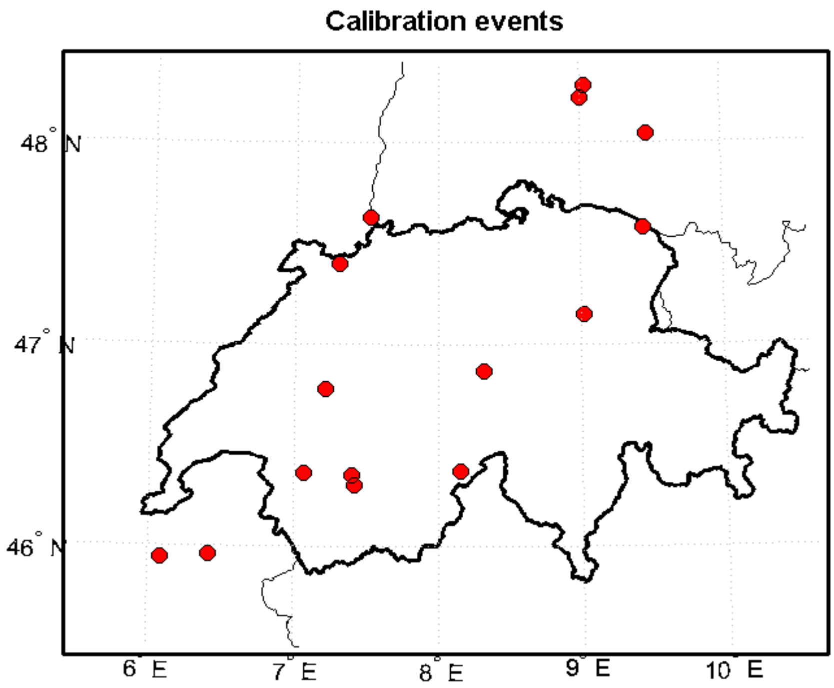


Figure 4.6. Geographical distribution of the calibration events.

We make the following choices:

- After testing with an extended source representation, we adopt a point representation of the earthquake for the attenuation field. This is justified because Swiss earthquakes never reach a very large magnitude, the macroseismic field for old earthquakes is often sparse and the distribution of intensity points is strongly biased by the topography, with most observations aligned along the valleys.
- For the same reason we ignore possible azimuthal dependence of the intensity attenuation.
- We test with codes with an explicit depth formulation, but the scatter of the data and our ignorance of precise hypocentral depths do not allow a full depth formulation; in the end we separate the set of calibration events in two broad classes, as listed in Table 4.6.

In the end, we adopt an empirical approach through a simple general formulation with a minimum of free parameters:

$$I(M, d) = a + b M + c f(d)$$

where the intensity field depends only on the size of the event and on a functional of distance.

We decouple the attenuation and magnitude and we obtain a separate intensity-distance relation and an intensity-magnitude regression:

$$I(d) - I(d{=}0) = c f(d),$$

and

$$I(d{=}0) = a + b M.$$

This implies that the earthquake is quantified in terms of its intensity field (distance attenuation and intercept intensity, defined below), which is then correlated to a magnitude measure. We have also experimented with joint attenuation and magnitude parameterization, but the separation allows a more practical handling of the catalogue, since a change of the intensity-magnitude regression does not affect the parameterization of the intensity field.

To obtain the intensity attenuation with distance, as a first step for each calibration event we fit the distance attenuation of the intensity field, I(d), to a functional relation, and derive a measure of epicentral intensity which we term intercept intensity I(d=0).

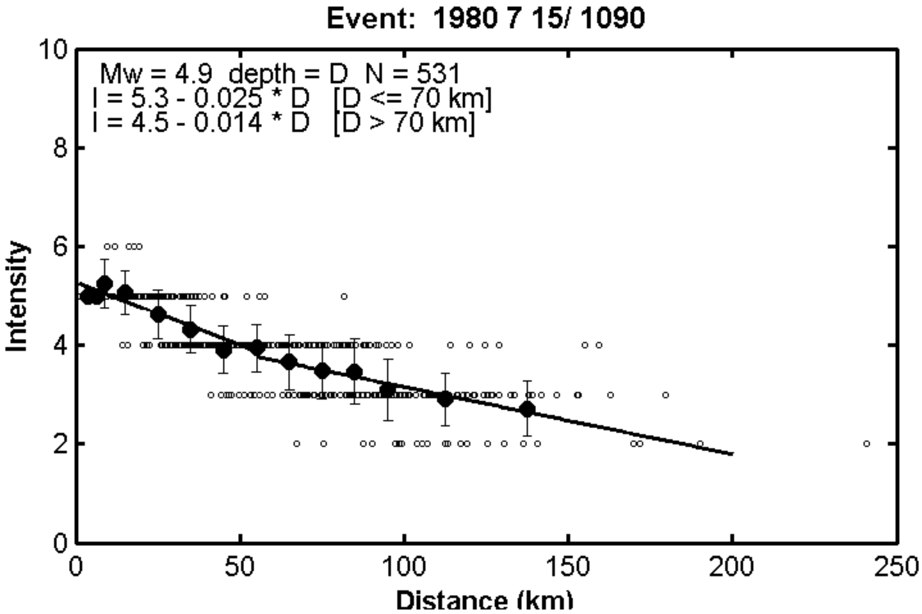
For the regressions, we experiment with several intensity functions, since intensities have large spatial dispersion and variation; we test single intensity points, median distance for each intensity class, logarithm of the median distance for each intensity class, mean intensity for binned distance ranges and the logarithm of the mean intensity for binned distance ranges. In the end, we obtain the most robust results using mean intensity for defined distance ranges. We try different combinations of distance bins and we adopt smaller bins at close distances, with bins of 2.5 km (0-10 km), 10 km (10-100 km) and 25 km (100-200 km). Poor quality intensity observations are not considered in the computation of mean intensities.

We experiment with different distance functions. In the end, the form which provides the best fit to the mean intensities is a bi-linear function, with the hinge at 70 km distance. Attenuation is high in the first 70 km, but once the macroseismic field reaches 70 km, intensity decays very smoothly with distance, larger events having large macroseismic fields. This effect is very well seen also in the attenuation of instrumental weak and strong motions (Bay et al., 2001) and it is explained by the energy contributed by the reflected phases at the Moho.

We invert for the best linear fitting in the 0-70 km distance range, to determine the attenuation slope and the intercept intensity (I_{int}) for all calibration events. Two regression examples for the 1980 and 1996 events are shown in Figure 4.7. The resulting attenuation slopes are displayed in Figure 4.8; slope values span from -.02 to -.05; lower absolute values correspond to deeper events, while very steep slopes are obtained for shallow events, as confirmed by instrumental depths; a slope of -.04 separates shallow from deep events. The different slopes of shallow and deep events are well seen in Figure 4.7.

By adopting a linear attenuation with distance, we miss the epicentral intensity peak typical of shallow events (Ambraseys, 1985; Levret et al., 1994). This implies that the intercept intensity is generally lower than the epicentral intensity (see. the 1996 event in Figure 4.7). This is not a limitation, however, since we do not use this approach to compute epicentral intensity, but to achieve a robust parameterization of the intensity field, which here is given by a single intercept and slope. We will discuss below the relation between intercept and epicentral intensities.

In the bi-linear regression we obtain slopes and intercepts also for the distance range 70-200 km. Examples for the 1980 and 1996 events are shown in Figure 4.7; the slopes are displayed in Figure 4.9 (in this distance range we loose the smaller events). We observe a very low attenuation with distance, with typical slopes ranging around -.01. Slopes in the second branch do not show significant variations with epicentral depths; they do show a regional variation, with the lowest attenuation for events in the Alpine province as compared to the Alpine Foreland.



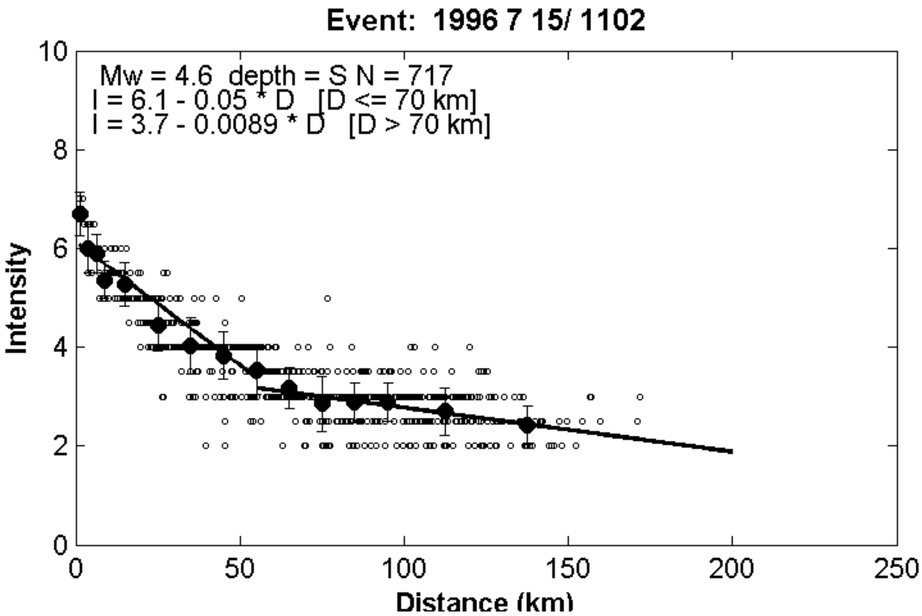


Figure 4.7. Attenuation of intensity versus epicentral distance for two events, the 1980 Sierentz event and the 1996 shallow event in the Alps. Circles represent individual intensity values. Mean intensities with distance (in 2.5, 10 and 25 km bins) are shown as solid circles. Errors bars are ± 1 standard deviation of the data. Intensity-distance attenuations are fitted with a bi-linear function (solid line) in the 0-200 km range with the hinge at about 70 km.

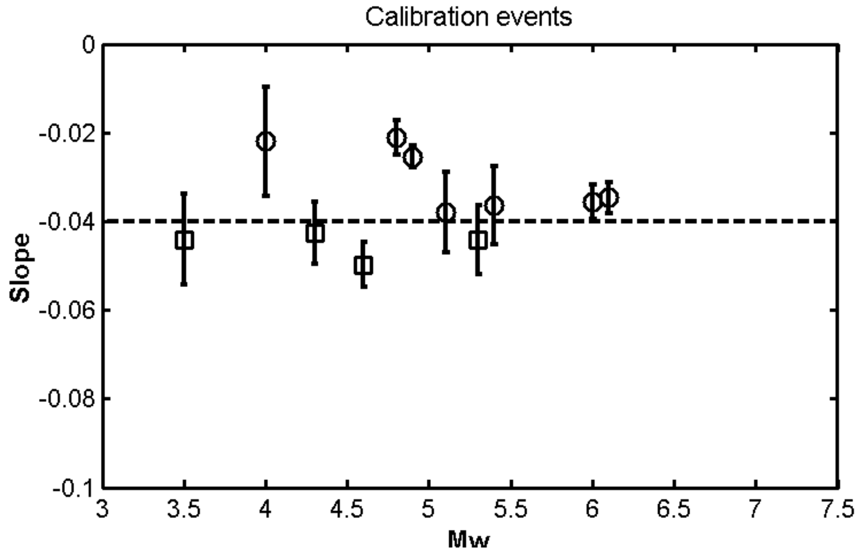


Figure 4.8. Attenuation slopes of calibration events at close distances, obtained by least squares linear fitting of mean intensities in the 0-70 km range. Shallow and deep events shown as squares and circles, respectively. Error bars are 1 standard error.

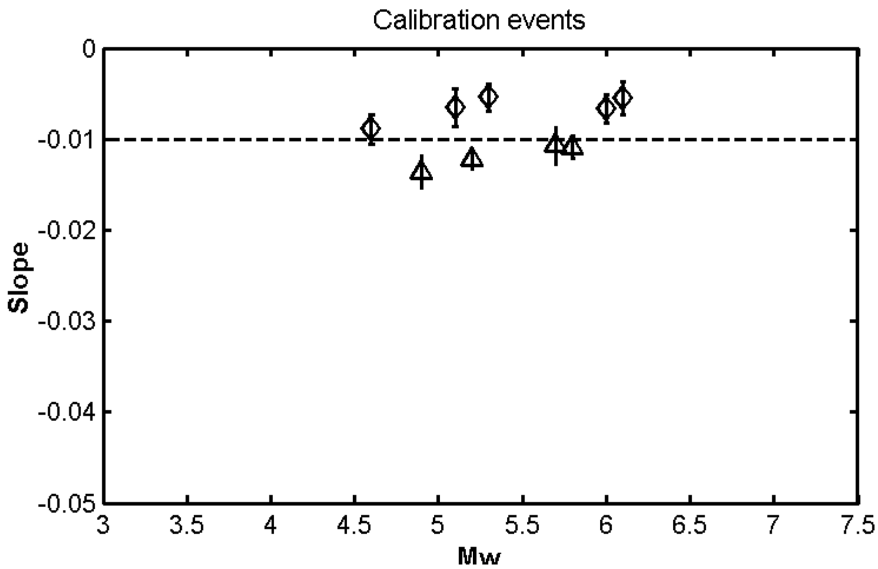


Figure 4.9. Attenuation slopes of calibration events at large distances, obtained by least squares linear fitting of mean intensities in the 70-200 km distance range. Foreland and alpine events shown as triangles and diamonds, respectively. Error bars are 1 standard error.

As a second step, we derive intensity attenuation relations for the whole dataset of calibration events. On the basis of the results in Figure 4.8 and 4.9, we group calibration events in shallow and deep events for the 0-70 km range, and in Foreland and Alpine events for the 70-200 km range. Fitting the mean intensity values normalized by the intercept intensities we derive the following attenuation relations for shallow and deep events, and for the Foreland and Alpine provinces:

Shallow: $I(d) - Iint = -0.043\ D$
Deep: $I(d) - Iint = -0.030\ D$
Foreland: $I(d) - Iint2 = -0.0115\ D$
Alps: $I(d) - Iint2 = -0.0064\ D$

In Figure 4.10 we show the four best fitting lines for the four groups, all normalized to intercept intensity. As noted above, for very shallow events epicentral intensities sometimes exceed intercept intensities, by about 0.5 intensity degree.

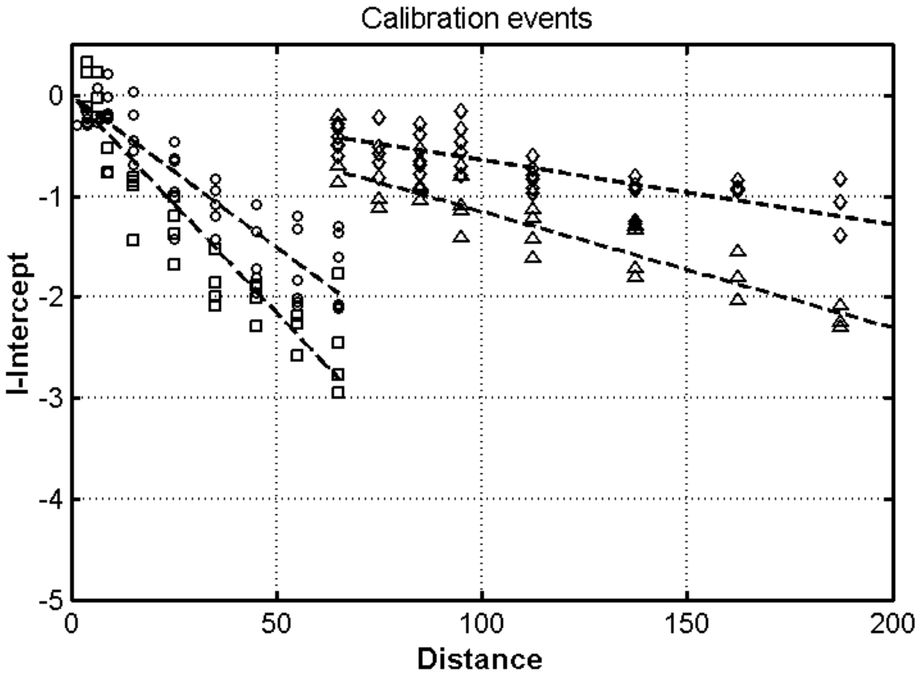


Figure 4.10. Best fitting lines for mean intensities with distance, normalized to intercept intensities, computed in the 0-70 and 70-200 km distance range. Circles, squares, triangles and diamonds represent deep, shallow, foreland and alpine events.

4.4.1.3 Calibration of a macroseismic magnitude scale

We calibrate the size of historical earthquakes by correlating the intercept intensity to magnitude M_W. Intercept values are computed above, by linear fitting of mean intensity values in the 0-70 km distance range. The M_W values for the calibration set are derived from instrumental M_S and M_L values, computed in Chapter 6. We obtain two separate linear regressions for shallow and deep events:

Shallow: $I_{int} = 0.096 + 1.27\ M_W$

Deep: $I_{int} = -1.73 + 1.44\ M_W$

In the regressions I_{int} (M_W) above, we can see M_W as independent variable. We have also derived the regressions M_W (I_{int}), but these are very similar to the regressions given above (see Figure 4.10). Combining the intensity-distance and magnitude-intensity relations, we derive the regressions M_m(Iobs) which will be used for the systematic assessment of macroseismic magnitudes for the ECOS compilation.

For points in the 0-70 km distance range we obtain:

Shallow : $M_m = [Iobs - 0.096 + 0.043\ D] / 1.27$

Deep : $M_m = [Iobs + 1.73 + 0.030\ D] / 1.44$

For points in the 70-200 km distance range we obtain:

Shallow-Foreland : $M_m = [Iobs + 1.65 + 0.0115\ D] / 1.27$

Shallow-Alpine : $M_m = [Iobs + 1.93 + 0.0064\ D] / 1.27$

Deep-Foreland : $M_m = [Iobs + 2.76 + 0.0115\ D] / 1.44$

Deep-Alpine : $M_m = [Iobs + 3.04 + 0.0064\ D] / 1.44$

The linear regressions are shown in Figure 4.11. While the number of points is not very high, the correspondence of intercept intensities and M_W is robust. Shallow events produce clearly a higher local intensity than deeper events, as expected. We do not control the high magnitude range of the distribution, and we assume here that the distribution is linear and does not saturate at high magnitudes.

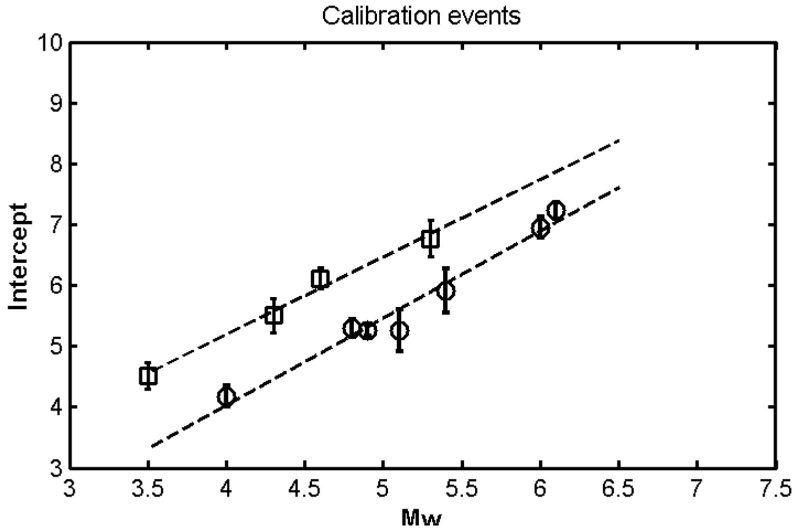


Figure 4.11. Regression of intercept intensities versus magnitude M_w. Shallow and deep events shown as squares and circles, respectively. Error bars are 1 standard error.

Our intensity-magnitude calibration is notably low compared with existing macroseismic magnitude calibrations. In Figure 4.12 we compare the expected intensity attenuation for a magnitude 6 event derived in this study with those from Ambraseys (1985) and Levret et al. (1994). Our relation is lower, implying that we need higher magnitudes to produce the same intensity levels. There are two reasons for this behaviour:

- Non-linear source effects in the near-field and site effects, inherent also to Io estimates, have another effect when defining attenuation based on average radii of isoseismals than defining attenuation based on average intensity within a distance range. Also incompleteness of lower intensity observations can cause differences between the two methods.
- Our use of intercept intensity, which is lower than the epicentral intensity used in other intensity-magnitude relations, again by half degree on average.

These effects can be clearly seen when reviewing the 1356 Basel earthquake, the largest known historical earthquake in Central-Northern Europe. This event had been assigned epicentral intensity IX-X in past investigations, and magnitudes in the range of 6.2-6.5. The MECOS-02 macroseismic field for the Basel earthquake is shown in Figure 4.13; in the epicentral region we see points with intensity IX as well as VIII; epicentral intensity would be certainly a IX, and the intercept intensity is VIII-IX. Nonetheless, the magnitude required to produce an event with this intercept intensity and such a large area of strong intensity (VII and higher) is 7.1 in our relation, well in line with the damage levels produced by well controlled earthquakes in recent times. However, since we are not confident that we can extend the linear relation to much higher magnitudes and since we believe that the upper bound of 7.6 for the 1356 Basle earthquake is unrealistic, we make an exception for the Basle event and set the magnitude down to M_W=6.9 according to Table 4.7. For example, the 1995 Kobe event (M_W 6.9) and the 1999 Izmit event (M_W 7.6) did not produce an intercept intensity higher than IX, and probably as low as VIII-IX, using the EMS98 scale and our intercept intensity definition. We do not expect to reach an intercept intensity VIII-IX from a magnitude 6 event.

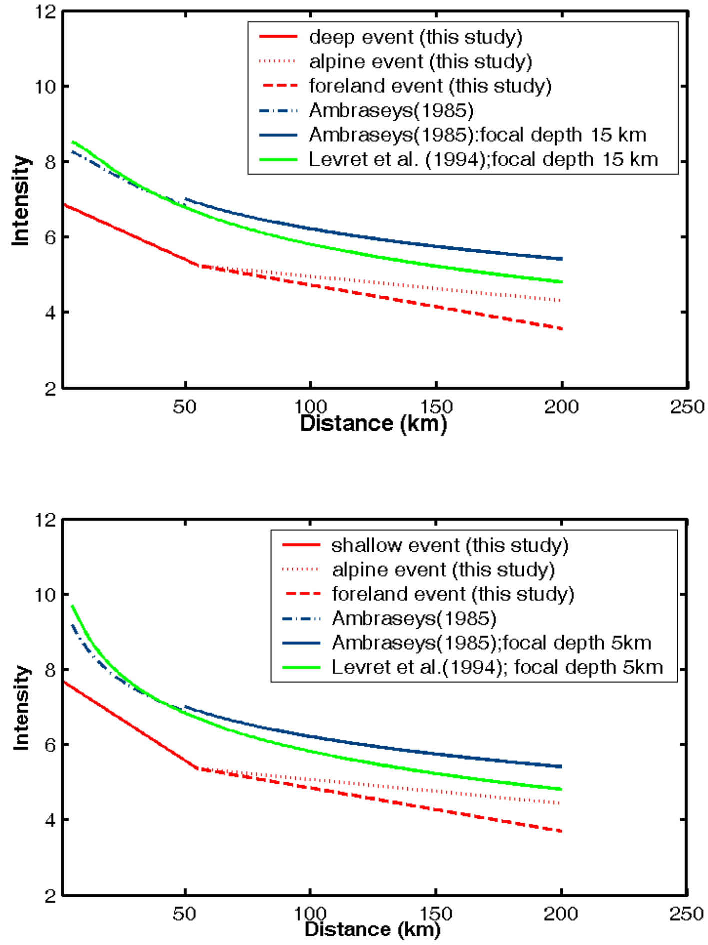


Figure 4.12. Comparison between Magnitude-Intensity relationships in this study with relations in Ambraseys (1985) and Levret et al. (1994) for a magnitude 6.0 event. Top, deep event; bottom, shallow event.

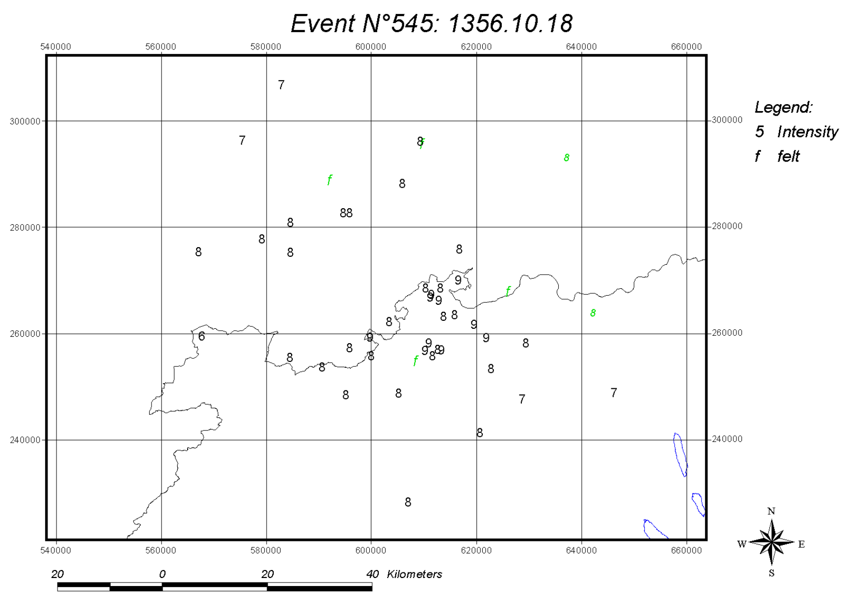


Figure 4.13. Macroseismic field of the 1356 Basel earthquake, extracted from the MECOS-02 database; only the area close to the epicenter is shown. EMS98 scale is used.

4.4.2 Period 1000-2000: macroseismic parameters

We estimate earthquake source parameters for all Class 1 events from seismic intensity data.

4.4.2.1 Epicentral Location & Magnitude

We use a systematic parameter-space search to estimate epicentral location and magnitude for all events with macroseismic data. We modified the Bakun & Wentworth (1997) approach introducing our attenuation calibrations to estimate M_m (calibrated to M_W), source location and uncertainties. Earthquake parameters are determined by a grid search scheme, fitting the macroseismic field with a three step procedure:

1. calculate M_m and rms [M_m] for each trial source location
2. draw contours of rms [M_m] in the grid of trial epicenters to bound the epicentral region and estimate the epicentral uncertainty
3. draw contours of M_m over the grid of trial epicenters to establish the event magnitude and its confidence level

For each trial epicenter, M_m is derived as the mean of the M_i values from single intensity observations:

$$M_m = \text{mean}\,(M_i) = \text{mean}\,((I_i + c_0 + c_1 Di)/c_2)$$

where I_i is the intensity value (EMS98) at site i and D_i the epicentral distance of observation I_i. Constants c_0, c_1, c_2 were derived from the calibration events and are given above in section 4.4.1.

The epicentral region is bounded by contours of:

$$\text{rms}\,[M_m] = \{\sum_i [w_i\,(Mm - Mi)]^2 \,/\, \sum_i w_i^2\}^{1/2}$$

w_i is a distance weighting function (cosine) so that observations at near distances are preferentially weighted to resolve epicentral region.

We apply the method twice for shallow and deep conditions to determine the depth class of the event. For the majority of the events we only use the intensity points within 70km distance, but when only few intensity points are available for an event, all available historical information is used to decide for the depth class and to compute the macroseismic magnitude M_m.

An example of the epicentral and magnitude determination for the 1946 event is shown in Figure 4.14. Both rms [M_m] and magnitude contours are shown; magnitude contours show the best fitting magnitude at each point, while the rms [M_m] contours show for the same point the misfit to the macroseismic field. For this event, a well distributed macroseismic field is available (see Figure 4.5), and the best location (black star) is well constrained, and within a few kilometers distance from the MECOS epicenter (white star). The M_W magnitude at the epicentral location is 6.1. The best fit is obtained using the attenuation calibration for a normal crustal earthquake depth.

4.4.2.2 Epicentral Intensity

We follow Gasperini et al. (1999) and define epicentral Intensity, Io, to be equal to the observed maximum intensity if at least two data points with that intensity value are present; otherwise, Io is set to the second highest observed value (lower bound represented by I_{max} minus one degree). We compute Io for all events of Class 1 and 3 in ECOS, with assigned intensity points in Switzerland, and we list them in ECOS. When only few intensity points are available for an event, historical information is used to determine Io. We also list epicentral intensity Io whenever reported in other catalogues or sources (Class 2 events), but all too often we do not have sufficient information on how they were assessed and we do not attempt to regress them uniformly.

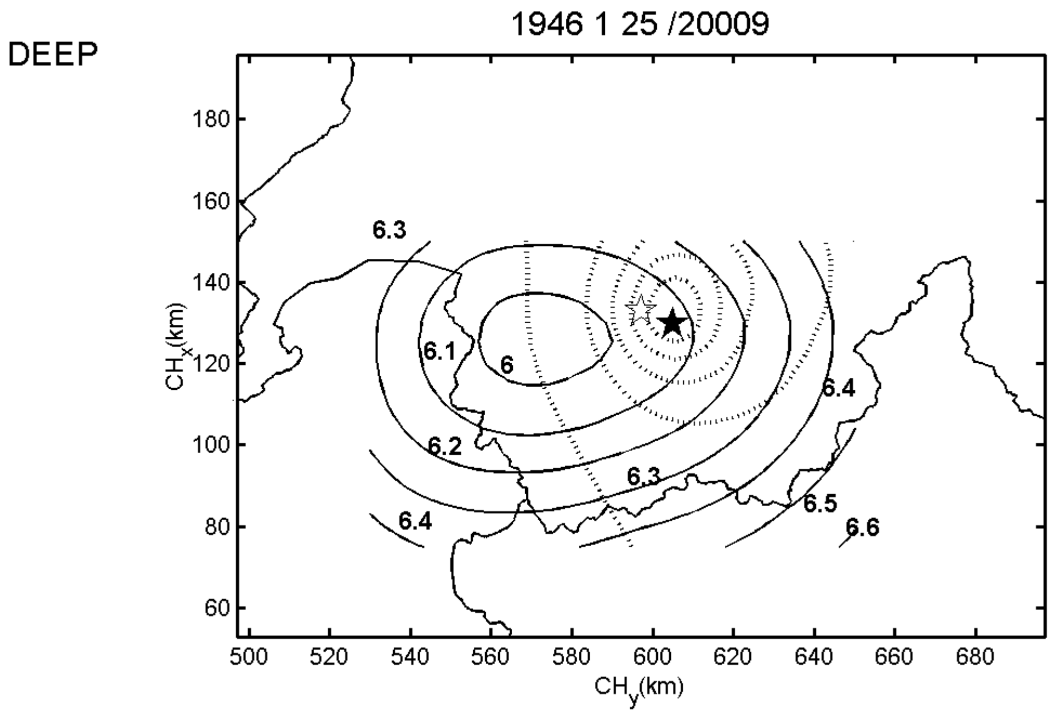


Figure 4.14. Application of the modified Bakun and Wentworth (1997) approach for the 1946 Wallis earthquake. rms [M_m] (dotted lines) and magnitude contours (solid lines) are shown. The macroseismic and MECOS epicenters are shown by black and white stars. The best fit is obtained for a normal crustal depth (here marked deep).

4.4.2.3 Converting Io to M_W

When not enough intensity points are available to apply our procedure (Section 4.4.2.1), we need to develop a method to convert Io to M_W. Using the expressions given in section 4.4.1.3, we obtain the conversion Table 4.7 which can be applied to convert Io to M_W for shallow and deep events. For events that are neither clearly shallow nor deep, we also tabulate average expected M_W values with intermediate or unknown crustal 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
						8	6.2	≤1
						9	6.9	≤1

Table 4.7. Conversion values for Io into M_w.

This conversion scheme is applied as follows:

Shallow conversion:
The shallow conversion formula was used to calculate M_W for entries in ECOS originating from MECOS 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 investigation by an historian the depth class was 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. The intermediate value was determined reducing the intensity value by 0.5 and taking the average value of both regression formulas as M_W. The reasoning is that the epicentral intensity is usually higher than the intercept intensity used in our regressions. For example, for an event with Io=3 we consider a I_{int}=2.5 and we average the M_W (shallow)=1.85 and M_W (deep)=2.95 to obtain M_W =2.4.

4.4.3 Period 1879-1974: seismic parameters

4.4.3.1 Period 1879 - 1963

In addition to the evaluation of macroseismic source parameters for all Class 1 events, the revision of MECOS for this time period is based on the information given in the original data files, the yearly reports (Jahresberichte Schweizerische Erdbebenkommission, 1879-1912, Jahresberichte Schweizerischer Erdbebendienst, 1913-1963) of the Swiss Seismological Service and earthquake record cards that have been compiled by Basler-Hoffman & SED (1975) and by Sägesser & Mayer-Rosa (1978). Since the information quality changes with time, a set of general guidelines and additional guidelines for certain time periods have been developed in order to be as consistent and objective as possible in judging the given information. These guidelines are described in detail in an internal report of the Swiss Seismological Service (Wössner, 2001).

For the input data, we evaluated several SED files with slightly different, and often duplicated or conflicting information. The computer files are the MECOS database and seven “CHIST” data files (SED internal working files, Mayer-Rosa and Baer, 1993). Printed information includes the yearly reports of the Swiss Seismological Service (Schweizerische Erdbebenkommission, 1879-1912, Schweizerischer Erdbebendienst 1913-1963) and the earthquake record cards from the archive of the Swiss Seismological Service.

Basically, all information given in the data files, in the yearly reports and in the record cards has been introduced into the ECOS database. The transfer of the original information into the database includes a unification of this information, which raised the question to which extent the original heterogeneous information can be processed uniformly and consistently. We followed some basic principles:

- Earthquakes of intensities smaller than VI (Class 3 events) are now included in the database and judged according to the developed guidelines.
- The original information was introduced without changing its content, e.g. intensities were assigned in the original scale according to the scale published in the Jahresbericht, mostly the Rossi-Forel 1883 intensity scale.

- Uncertainties for the location and intensity have been assigned according to the information given, depending on the observed intensities and the time period.
- Certainty codes (cc) have been defined in order to differentiate reliable sources from questionable sources and fakes.
  - cc = 1: earthquake, reliable source
  - cc = 2: source questionable, not necessarily related to an earthquake
  - cc = 3: fake

Table 4.8. summarizes the parameters taken from the original sources. The uncertainties are introduced according to the catalogue specifications tables given in Chapter 3.

Shortcut	Description	Shortcut	Description
YE	Year	ANZ	Quantity of macroseismic observations
MO	Month	LAT	Latitude [° N]
DA	Day	LON	Longitude [° E]
HO	Hour	CE	Uncertainty of the epicenter location
MI	Minute	EXY	Error of epicenter location in km, corresponding to CE
SE	Second	ORTSANGABE	Locations of macroseismic reports
REF1	Reference	AX	Area of largest effect (epicentral area)
RS	Maximum radius of perceptibility [km]	I	Maximum observed intensity
cc	Certainty code	CI	Uncertainty of I
Aftershock	Assumed aftershock	SC	Macroseismic scale of I
Foreshock	Assumed foreshock		

Table 4.8. Parameters derived from original sources for the MECOS-02 catalogue.

Interpretation of the original source parameters.

Time: (Parameters YE, MO, DA, HO, MI, SE)
The time given in MECOS is UTC (Universal time coordinated). For the time period 1879 to 1955, the time of the original sources had to be converted from local time to UTC. The time assignments given in the sources are reliable for year, month, day and hour for the whole time period, in the later part minute indications are also reliable.

Location: (Parameters LAT, LON, CE, EXY, ANZ, ORTSANGABE, AX)
For earthquakes with intensities smaller than V, the location has been assigned using the coordinates of the location where the earthquake was reported by extracting the coordinates from the SwissMap50 (2000). In case of several locations, the barycentre of these towns was calculated using Swiss coordinates before being converted into geographic coordinates. The uncertainty of the location has been assigned depending on the intensity, according to the catalogue parameters CE and EXY:

- Earthquakes with intensity $I \leq 3$: the uncertainty is set to ce=3.
- Earthquakes with intensity $3 < I < 5$: the uncertainty is set to ce=2, if less than six macroseismic reports are documented ($ANZ \leq 5$).
- For earthquakes with intensity $3 < I < 5$ and more than six reports ($ANZ \geq 6$) which have an uncertainty given already in the MECOS file, we maintain the existing uncertainty. Without a given uncertainty, it is set to ce=2.
- Earthquakes with intensity $I \geq 5$: ce=2 if not already existing in the database MECOS.

Each town from which a macroseismic observation is being reported, the number of ANZ increases by one. Even if several observations in one town are documented, this counts as one report. The parameter ax is not given for all entries. ANZ is found in a complementary database to ECOS at the Swiss Seismological Service.

Intensities: (Parameters I, CI, SC, RS)

The intensities were directly taken from the original sources, and introduced in the field of maximum observed intensity. It is assumed that they are reliable. The original intensity scale is the Rossi-Forel 1883 scale, except for the yearly reports of the time period 1879-1883. For this time period, another scale is published in the Jahresberichte and is actually a suggestion by F. A. Forel, thus being roughly the same as the RF 1883 scale. In case of no intensity value given, the intensity value was assigned according to the original scale. Uncertainties have been assigned depending on the intensity.

- For intensities I < 4:
  - The uncertainty is generally set to cI=3.
  - Intensities marked with a question mark in the yearly reports are assigned cI=4. The certainty code is set to cc=2.
- For intensities I ≥ 4:
  - The uncertainty is set to cI=2 if not already existing in the database.

The radius of perceptibility (RS) has been taken from the original MECOS database. In case of differences between this information and the original reference in the yearly reports, the value of RS from the yearly reports was introduced in the comment line. Radii of perceptibility have been investigated in more detail by Basler-Hofmann & SED (1977).

Foreshock / Aftershock:

Earthquakes are marked as foreshock and aftershock if there are indications in the original source or by subjective judgment in case of spatial and temporal coincidence of earthquakes. This has to be understood as assumed to be a fore- or aftershock. An investigation concerning the spatial and temporal distribution for a specific region and event has not been conducted for Class 3 events.

Results

MECOS-02 now contains about 2300 events for the time period 1878-1963.

Completeness

The catalogue is complete for the historical records given in the yearly reports of the Swiss Seismological service in the time period 1879-1963 for intensities of I ≥ V for earthquakes located on Swiss territory. The completeness for smaller intensities (I<V) cannot be evaluated.

4.4.3.2 Period 1964 - 1974

Between1963 to 1974 many changes occurred at the Swiss Seismological Service. Table 4.9, at the end of this section summarizes important changes during this period. The 'Jahresberichte' ceased to be issued in 1963. From 1972 on, yearly seismological bulletins were published again and the new seismological network started to be developed and was operational in 1975. The MECOS catalogue for this time period has been checked and completed. The following sources were available from the archive of SED.

Printed information:

- Earthquake record cards for the period 1964-1974 (Schweizerischer Erdbebendienst, Erdbebenkatalog auf Karteikarten, 1878-1974)
- Partial information from NAGRA bulletin NTB 83-08. The NAGRA printed catalogue covers only the north east of Switzerland, the region 47-48N and 7.5-9.0E (NTB83-08 – Nagra-Technischer Bericht (Mayer-Rosa el al., 1983)).
- A printout of a electronic seismological bulletin for the period 1964-1970 (Schweizerischer Erdbebendienst, Jahresberichte 1964-1971, Printout of a computer file)
- Yearly bulletin of the SED 1972, 1973, 1974 (Jahresberichte des Schweizer Erdbebendienstes, 1972-74)

Several computer files exist from previous projects but they could not be used because information on archived data of these files was lacking or insufficient.

The record cards were described in the previous section, they were compiled for the study of Basler-Hoffmann & SED (1975). The raw data found in the printout of the electronic seismological bulletin (64-71) consisted on phase readings and amplitudes from the station ZUR, NEU, and BAS (Zurich, Neuchatel, Basel), location, magnitude (M_d or M_L) and some macroseismic information: localities and intensities (MSK). The location of the event was reported by different agencies SEDZ or ISC or BCIS (Strasbourg). For some events, the epicentre was indicated as uncertain. For events located by SEDZ an indication of error is given (erz, erh and rms), but is not reliable. From September 1969, no more amplitudes were available from SED, which implies that there were no more magnitude determinations. For the latest period (1972 to 1974), the information found in the bulletin is more reliable, the number of stations and the quality of the data increased.

The catalogue for this period has been modified extensively. The number of entries increased from 248 to about 478. More than half of the existing entries were modified, mainly the magnitudes changes, and additional information was introduced. The additional events correspond either to events in the border area of Switzerland or, in most cases, small events with low magnitude or intensity. The threshold magnitude is about 2.

The magnitudes added for the period 1963-1969 were duration magnitudes M_d. Although the magnitude threshold seems to be low (2.5), we assigned an uncertainty of cM_d = 4 (it corresponds to ± 1unit) because methods used to determine the magnitude remain unclear (Mayer-Rosa personal communication). For the later period from 1972 on, the data is more reliable and the uncertainty cM_L is set to 2 when no other special indication was found. Duplicate events have been checked and removed, fore- and after-shocks marked when recognized. In February and March 1964, two earthquakes, which reached an intensity of VII, stroke Sarnen. They were preceded and followed by numerous small events. About 40 events of this sequence were felt (intensity 3 and higher).

The completeness in the period (until 1971) is probably not better than magnitude 3.5 due to the magnitude uncertainty. For the second period (1972-1974) the magnitude completeness is about 2.5 to 3, the error location is less than 10 km. For the entire period, the intensity is considered complete from about III to IV, as a first estimation.

Date	Number of stations available for earthquake location	Availability of the bulletins	Additional information
1963	BAS (Basel), CHU (Chur) NEU (Neuchatel), ZUR (Zurich)	Interruption of the publication of the'Jahresberichte'	
1964	maximum 3 BAS (Basel), NEU (Neuchatel), ZUR (Zurich)	Information in a' print out' of a computer file	M_L and M_d threshold 2.5 Error on M_d large cM_d = 4 ce = 3
1969	Phase readings but no amplitude readings		No more magnitude readings from SED
1972	Up to 6 BUB, DIX, LIN	New issue of the seismic yearly bulletin 'Jahresberichte'	M_L threshold 2 cM_L =2 ce =2
1974	Up to 13		Magnitude threshold 1.8

Table.4.9. Summary of the main information for the period 1964-1974

5 ECOS

ECOS is the earthquake catalogue for Switzerland and includes all seismicity of relevance for the assessment of seismic hazard for Switzerland. It thus originated from the fusion of all historical and instrumental catalogues (15) relevant for the larger Swiss region. Here we describe the different catalogues which have been merged in ECOS and the procedures used for the fusion. We discuss event identification, duplicates, event locations and their errors. Magnitudes are discussed in Chapter 6.

For all catalogues, we have transformed and ported the original parameters in the ECOS format. All catalogue conversions are listed in Appendix D.

All entries in ECOS are summarized in the following Tables 5.1 and 5.2.

	ID	Catalogue	Agency_ID	M_L	M_S	m_b	M_m	M_d	M_W	Io	Ix
CH	1	Mecos	SED	564			86	123		3214	952
CH	2	MECOS-02	SED				266			197	213
CH	3	Iecos	SED	6077	25				46	65	23
D	4	Instr_BGR	BGR	1307						175 (MSK64)	
D	5	Macr_BGR	BGR	2744	152		473			5206	76 (MS, MSK64)
D	6	LED	LED	556							5 (EMS98)
D	7	Karlsruhe	Karlsruhe	1463							
D	13	GSHAP	GFZ						81	81 (EMS92)	
I	8	NT4.1.1	CNR/GNDT		2458		2358			2091 (MSK64)	937 (MSK64)
I	9	Instr_Italy	INGV	410				250			
F	14	IPSN_Cat	IPSN				58				
F	10	Sisfrance	BRGM							362(MSK64)	
F	11	Instr_France	LDG	2372				810			
A	12	Austria	ZAMG	428						419 (MSK64, EMS92, EMS98)	
UK	15	ISC_Cat	ISC		18	118					

Table 5.1. The original agencies, the magnitudes, and intensities provided for events with certainty code 1 or 2 in ECOS. The listed numbers of magnitudes and intensities may be higher than the amount of records in ECOS since all magnitudes were imported and kept in the event records even when the event was identified as duplicate.

Country	Catalogue	Agency (Person), WEB site	Time period	Intensity / Magnitude range	Intensity	Magnitude
CH	IECOS	SED	1975 to 2001	$M_L \geq 0.4$	None	M_L
CH	MECOS	SED	1021 to 1997	all	Io	M_L, M_m
D	Instr_BGR	BGR (M. Henger)	1968 to 2001	$M_L \geq 2.5$ Io ≥ 2	Few	M_L
D	Macr_BGR	BGR (G. Leydecker)	813 to 1995	Io > 1 $M_L \geq 1.0$	Io, Ix	M_L, M_s, M_m
D	LED	LED (W.Brüstle)	1995 to 2000	Io ≥ 2 M_L 0	Few	M_L
D	Karlsruhe	IFG Karlsruhe (K.Bonjer)	1975 to 1994	$M_L \geq 0$		M_L
D	GSHAP	http://www.gfz-potsdam.de/pb5/pb53/index.htm	1728 to 1992	Io ≥ 5 $M_w \geq 4.0$	Io	M_W
I	NT4_1_1	http://emidius.itim.mi.cnr.it	1005 to 1992	Ix ≥ 3.5 $M_m \geq 3.1$ $M_s \geq 2.7$	Ix and Io	M_m, M_s
I	Inst_Italy	INGV received from di Bona	1.1.1975 to 31.3 .2001	$M_L \geq 2$ $M_d \geq 2.5$		M_L, M_d
F	IPSN					M_m
F	SISFRANCE	BGRM (J.Lambert)	858 to 1999	I ≥ 5, I ≥ 4 from 1900	Io	none
F	Instr_france	LDG (M.Nicolas, Y.Menechal)	1962 to 1999	$M_L \geq 2.5$ $M_d > 1.8$	None	M_L M_d
A	Austria	ZAMG (W.Lenhardt)	1201 to 2001	5 < I <9 $1.4 < M_L < 6.1$	Io	M_L
UK	ISC	http://www.isc.ac.uk/Bulletin	1911 to 2001	$m_b \geq 3$		M_s, m_b

Table 5.2. List of sources, contacts, period covered, minimum parameter range and types of given magnitude for the seismic catalogues merged into ECOS.

5.1 Switzerland

5.1.1 MECOS

MECOS is described in Chapter 4. Catalogue conversions are given in Appendix D.

5.1.2 MECOS-02

MECOS-2 is described in Chapter 4. Catalogue conversions are given in Appendix D.

5.1.3 IECOS - Instrumental earthquake catalogue of Switzerland

Although instrumental records of earthquakes in Switzerland and surrounding regions exist since the beginning of the 20th century, a modern nationwide seismograph network was put into operation by the Swiss Seismological Service in the early Seventies. Therefore, in view of completeness and uniformity of the data, this instrumental earthquake catalogue begins with the year 1975 and includes events with magnitude $M_L \geq 3$ for the entire Swiss territory.

This catalogue covers the region included in the Swiss national map at the scale of 1:500'000:

Swiss km-coordinates: 480-865 / 262-302
Geographic coordinates: 5.9-10.9E / 45.7-47.9N

Unless noted otherwise, the information corresponds to the information on file at the Swiss Seismological Service and is based mainly on the locations calculated using data from stations in Switzerland.

For more information on the station network and data analysis procedures, see the 1998 earthquake activity report by Baer et al. (1999) available on the home page of the Swiss Seismological Service (http://seismo.ethz.ch/products/catalogs/iecos/) or the literature given in the reference list of this report.

For events for which more reliable locations are available in the literature (events outside Switzerland and events which were studied in more detail), locations have been corrected accordingly. However, all magnitude values are those calculated by the Swiss Seismological Service.

In addition to the IECOS data file published on the website of the Swiss Seismological Service, a second data file with earthquakes including events in the magnitude range of $0 < M_L \leq 2.9$ is included in the database ECOS.

The original parameters contained in the IECOS catalogue are:

Parameter	**Description**	**Scale or data range**
Year	Year	1975 - 2000
Month	Month	
Day	Day	
Hour	Hour	
Minute	Minute	
Second	Second	
Lat	Latitude / [°N]	45.7 - 47.9
Lon	Longitude / [°E]	5.9 - 10.9
CH_x	Swiss coordinate / [km]	480-865
CH_y	Swiss coordinate / [km]	262-302
H	focal depth / [km]	0 - 40
Mag	local magnitude	0 – 5.7
Quality	Quality	A - D
Cant_count	Swiss canton or country	
Locality	Area of largest effects	
RMS	root mean square of travel time residuals	
GAP	largest angle between epicentre and two adjacent stations	
ErrH	horizontal uncertainty of location / [km]	
ErrZ	vertical uncertainty of hypocentral depth / [km]	
DM	minimum epicentral distance	
No	number of recording used for location	

Table 5.3: Original parameters of the IECOS catalogue.

Figure 5.1 shows the magnitudes (M_L SED) of all events for the period 1975-2000 included in IECOS. Clearly visible is the continuously decreasing magnitude threshold with time as the station density of the national network increases. The anomalously large number of small events during the period 1987-1992 is due to a local six-station temporary network operated around the hydro-

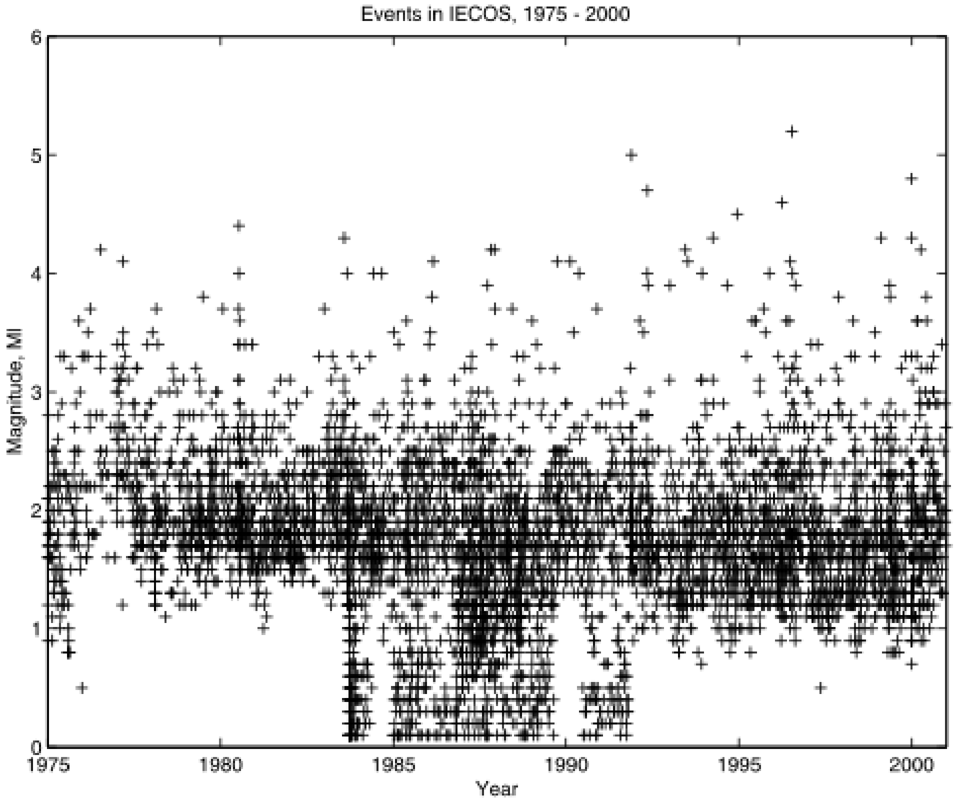


Figure 5.1: Local magnitude distribution of IECOS for the time period 1975 –2000. Note the decrease of magnitude threshold with time.

electric reservoir of Tseusier in the Valais as well as due to two sets of portable seismographs deployed east of Basel and in eastern Switzerland, which temporarily decreased the magnitude threshold.

IECOS contributes a total number of about 5750 events to the database. Catalogue conversions are given in Appendix D. A detailed description of the seismicity in Switzerland is given in Deichmann et al. (2000).

Error estimation and quality factors are available only for earthquakes of local magnitude $M_L \geq 3.0$. The criteria are outlined in Table 5.4 and the translation to the uncertainty levels in ECOS format is displayed.

ECOS parameters		**Original parameters of IECOS**					
ceN / ceE	**EXY / [km]**	**Quality**	**GAP / [°]**	**DM / [km]**	**RMS / [s]**	**errH / [km]**	**errZ / [km]**
1	≤ 5	A	≤ 180	≤ 1.5*H	≤ 0.4	≤ 2	≤ 3
1	≤ 5	B	≤ 200	≤ 25	≤ 0.6	≤ 5	≤ 10
2	≤ 10	C	≤ 270	≤ 60		≤ 10	
3	≤ 20	D	> 270	> 60		> 10	

Table 5.4. Criteria and location uncertainty corresponding to the quality rating of the hypocentral parameters.

5.2 *France*

5.2.1 Instrumental catalogue LDG

We have received the catalogue from Laboratoire de Detection Géophysique (LDG, Yves Ménéchal) on July, 6th 2001. The catalogue contains events that have been checked and relocated with additional readings from other agencies. A version of this catalogue is available on the net but without relocation at the following web site http://renass.u-strasbg.fr. The areas requested ordered by magnitudes are:

$M_L \geq 2.5$: 5°E / 45°N – 9°E / 48.5°N

$M_L \geq 3.5$: 3°E / 44°N – 9°E / 51°N

The instrumental catalogue exists since 1962. On the web it is possible to select the yearly catalogues since 1980. The data can be downloaded by autodrm. The locations are from LDG.

The original parameters included in the LDG instrumental catalogue are given in Table 5.5.

Original: french instrumental catalogue		
Parameter	**Description**	**Scale or data range**
Date (Jour, mois, année)	year, month, day	1.1.1962– 31.12.1999
Heure origine TU (heure, minute, seconde)	hour, minute, second	
latitude	latitude (decimal degrees)	44°N – 50°N
Incertitude sur la latitude	quality of localization of the latitude	0 – 62.8 km
Longitude	longitude (decimal degrees)	3°E – 9°E
Incertitude sur la longitude	quality of localization of the longitude	0 – 130.8 km
Profondeur	Depth; -2 means not determined	2 –34 km;
Magnitude locale M_L	M_L	≥ 2.5
Incertitude sur la magnitude ML C_ M_L	uncertainty of the Ml; ; 9.9 means not determined	0 – 0.6
Magnitude de durée	Md	≥ 2.5
Incertitude sur la magnitude M_d C_M_d	uncertainty of the Md; ; 9.9 means not determined	0 – 0.3
Résidu quadratique moyen (RMS) de la localisation	root mean square	0 – 15.5
Nombre de phases utilisées lors de la localisation	Number of phases	Up to 110
Numéro de région sismique	number of the seismic region	
Azimut	Azimut	
Demi grand axe	major axis of the ellipse	
Demi petit axe	minor axis of the ellipse	

Table 5.5. Original parameters of the French instrumental catalogue.

In the end, a total number of about 2400 events were adopted to ECOS. Catalogue conversions are given in Appendix D. Note the remarks concerning essentially the uncertainty codes. The events remaining in ECOS are displayed in Figure 5.2.

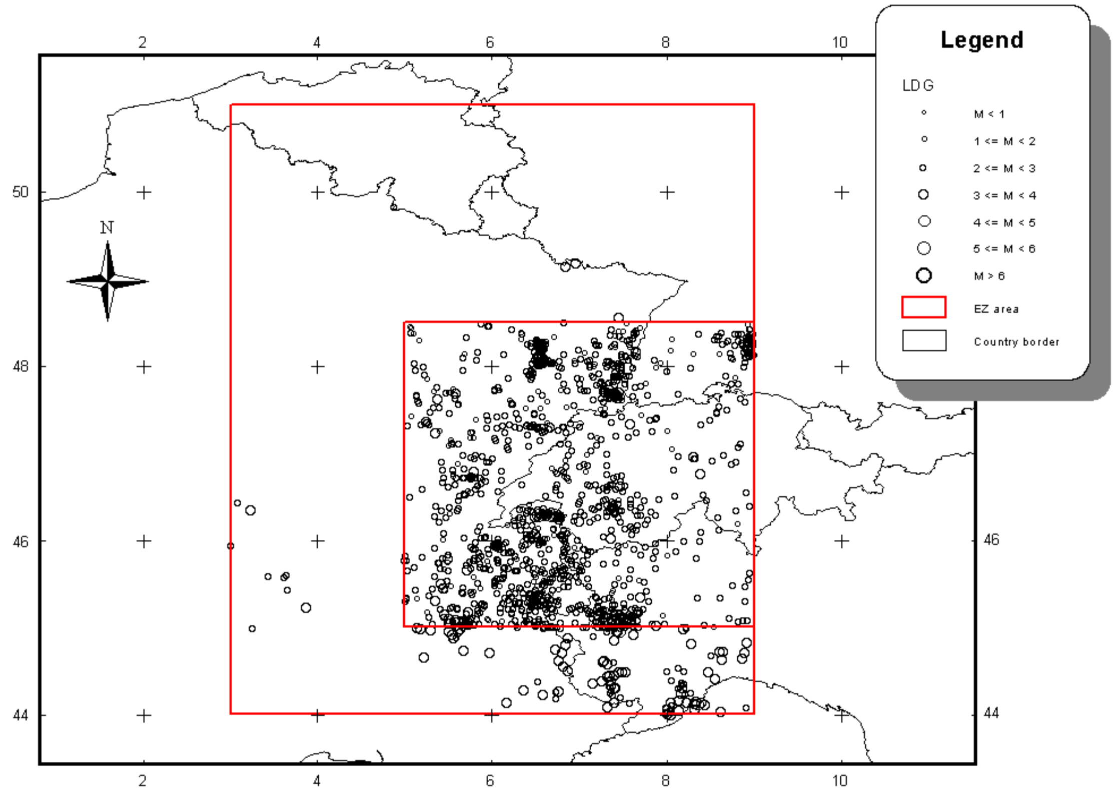


Figure 5.2. Earthquakes adopted to ECOS from the instrumental catalogue of France (LDG). The red rectangulars show the areas data was requested from.

5.2.2 Earthquake catalogue SisFrance

The catalogue was obtained on the 22nd of June, 2001, from J. Lambert of the Bureau de Recherche Geophysique et Minière (BRGM). This catalogue is also available on the WEB www.sisfrance.net. The historical macroseismic catalogue only includes intensities, no magnitudes. The first entry with intensity is the year 858.

Two files were received with different time period, magnitude threshold and geographical extend:

a) A first selection includes large events (Intensity >= 5) and a large area (3°-9°E and 44°-50°N) from around year 1000 (858).

b) A second selection includes events in the border (5°-9°E and 45°-48.5°N) with intensities between 4 and 5 from year 1900.

The original parameters of the SisFrance catalogue are given in Table 5.7.

Parameter	Description	Scale or data range
Annee	Year	Zone A: 858 – 31.02.1999 for Io >=5 Zone B: 01.01.1900 – 31.12.1999 for 4.0 <= Io
Mois	Month	
Jour	Day	
HH	Hour	
Mn	Minute	
Q	quality of localization	A: some km B: around 10 km C: between 10 and 20 km

		D: minor than 50 km
latitude	Latitude	Zone A: 44°N – 50°N Zone B: 45°N – 48.5°N
longitude	Longitude	Zone A: 3°E – 9°E Zone B: 5°E – 9 °E
xLamb	French coordinate	
yLamb	French coordinate	
Q	quality of the Io	A: sure B: between A and C C: uncertain K: like B (Sponheuer)
Io	epicentral intensità	Zone A : >= 5 Zone B: between 4 and 5
appellation	Epicenter	
Region	country or region	

Table 5.7. Original parameters of the historical French catalogue SiSFrance.

A total number of about 400 events were adopted to ECOS. A detailed list of changes due to the cut off is outlined in Appendix D. The events remaining in ECOS are displayed in Figure 5.3.

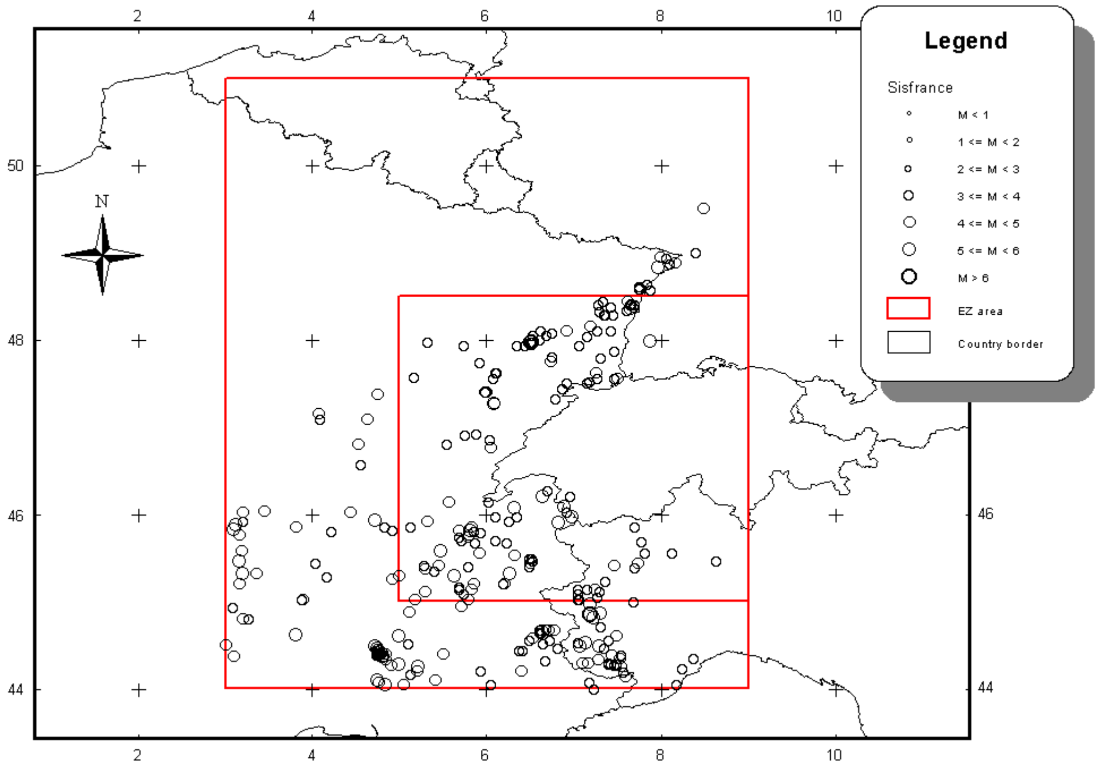


Figure 5.3. Earthquakes adopted to ECOS from the historical catalogue of France (Sisfrance). The red rectangulars show the areas data was requested from.

5.2.3 Earthquake catalogue IPSN

The catalogue of the Institute de Protection et de Sûrete Nucléaire (IPSN) covers 140 earthquakes felt in France in the time period 1356-1990 with an MSK64 intensity V and above. The information was generally adopted from the IPSN catalogue was the macroseismic magnitude value and the existing uncertainty value. The catalogue consists of a book that describes the parameters and lists the events as well as the corresponding macroseismic field. Additionally, an atlas with 140 macroseismic maps accompanies the book. A few events have been added from the IPSN catalogue to ECOS. We found macroseismic magnitude information for about 60 events listed in ECOS.

The uncertainty of the macroseismic magnitude is given in a quality code translated to ECOS uncertainty code as follows:

IPSN uncertainty	ECOS parameter cMag20
A	2
B	3
C	4

5.3 *Italy*

5.3.1 Instrumental catalogue INGV

The instrumental catalogue of Italy was obtained from M. di Bona from the Istituto Nazionale di Geofisica e Vulcanologia (INGV). The file was generated on September 7th, 2001. The request was placed to obtain the catalogue until 2000 including all events in the area 6°-13°E and 44°-48°N.

The parameters of the catalogue are given in Table 5.8.

Original: italy instrumental catalogue		
Parameter	**Description**	**Scale or data range**
Lat	latitude (N)	44 – 47.5
Lon	longitude (E)	6.0 - 13
Dep	depth (km)	Up to 143
Md	mean duration magnitude	2.5– 4.8
M_L	mean local magnitude	2 – 5.4
RMS	root mean square of residuals	
Ndf	number of data used in the location	Up to 8
Q1	quality factor based on errors (range from A to D with decrease of quality)	A – D
Q2	quality factor based on the network geometry (range from A to D with decrease of quality)	A – D
Or. Time	Origin Time (UTC)	1.1.1975 – 31.03.2001

Table 5.8. Original parameters of the Italian instrumental catalogue of INGV.

A total number of about 360 events were adopted to ECOS and are displayed in figure 5.4. Catalogue conversions and a detailed list of changes due to the cut off are given in Appendix D.

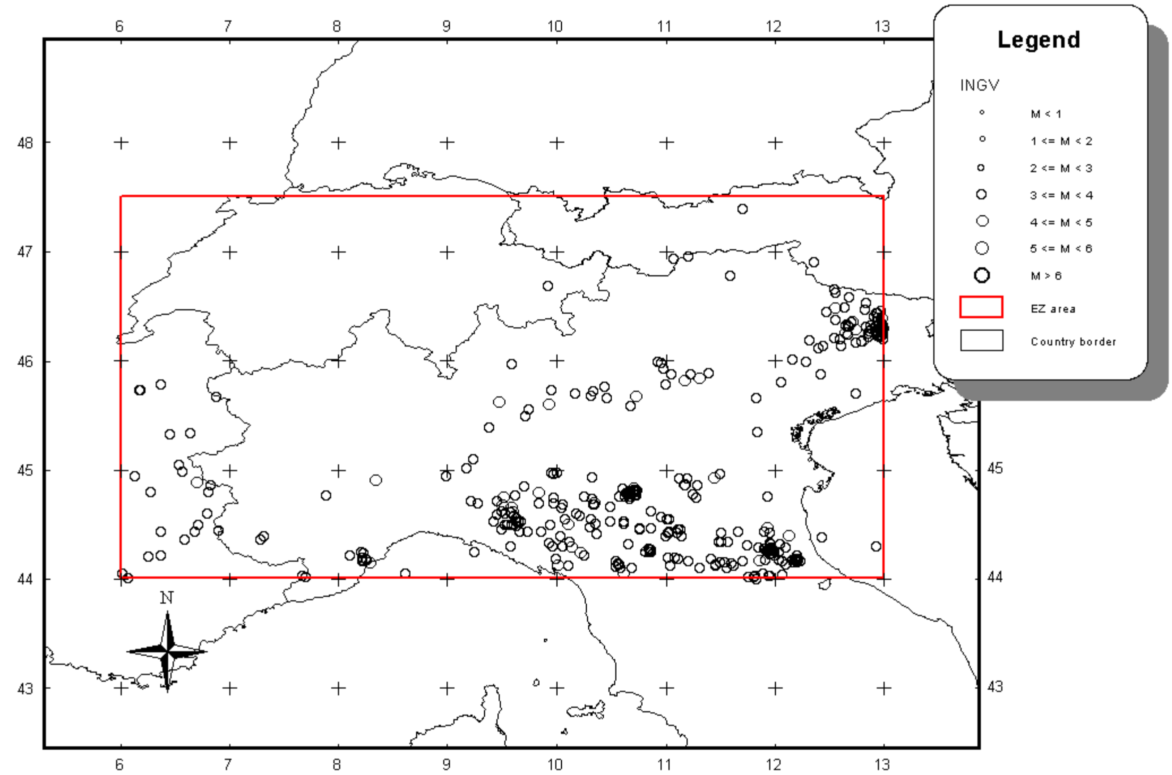


Figure 5.4: Earthquakes adopted to ECOS from the instrumental Italian catalogue. The red rectangular shows the area data was requested from.

5.3.2 NT4_1_1

The historical catalogue of Italy is available on the following internet site: [http://emidius.itim.mi.cnr.it/NT/home.html]. The catalogue was retrieved on July, 3, 2001.

The parameters of the catalogue are given below in Table 5.9.

Original: italian macroseismic catalogue: nt4_1_1_92		
Parameter	**Description**	**Scale or data range**
N	Number	
Tr	type of record (database, Catalogue)	DB, CP
Ye	Year	1005 – 1992
Mo	Month	
Da	Day	
Ho	Hour	
Mi	Minute	
Se	Second	
Ax	Epicenter	
Rt	root of the parameter (catalogue)	
Os	origin of datasets (catalogue)	
Nmo	Number of macroseismic Obs	Up tp 1516
Nip	Number of intensity site Points	Up to 1367
Ix	maximum observed intensity	Up to 110
Io	epicentral intensity	≥ 35 -110
Lat	Latitude	36°N – 47°N (Estimation)
Lon	Longitude	5.5°E – 15°E (Estimation)

Original: italian macroseismic catalogue: nt4_1_1_92		
Parameter	**Description**	**Scale or data range**
Pa	type of determination of the parameters (Io, Lat, Lon)	Blank normal cases Or special cases: PM , PO , PG
Sz	seismogenic zone	1-98
Ta	type of the determination of the seismogenic zone	G geographical A attributed
Agm	Agency of determination of the magnitude	
Ms	Ms	27 - 75
Td	type of determination of the magnitude	O observed (Mlh); C and F(Etna region) calculated from Mb or Ml; M and E(Etna region) macroseismic, G geologic (1 event)
Nio	Number of obs. for the determination of Ms	Up to 9
Sd	stddev. of Ms	0 – 67
Mm	Macroseismic magnitude	31 - 73
H	Depth	Null -60

Table 5.9. Original parameters of the historical Italian catalogue NT4.1.1.

About 2450 events were adopted to ECOS. Catalogue conversions and a detailed list of changes due to the cut off are given in Appendix D. The events of NT4.1.1 that remain in ECOS are illustrated in Figure 5.5.

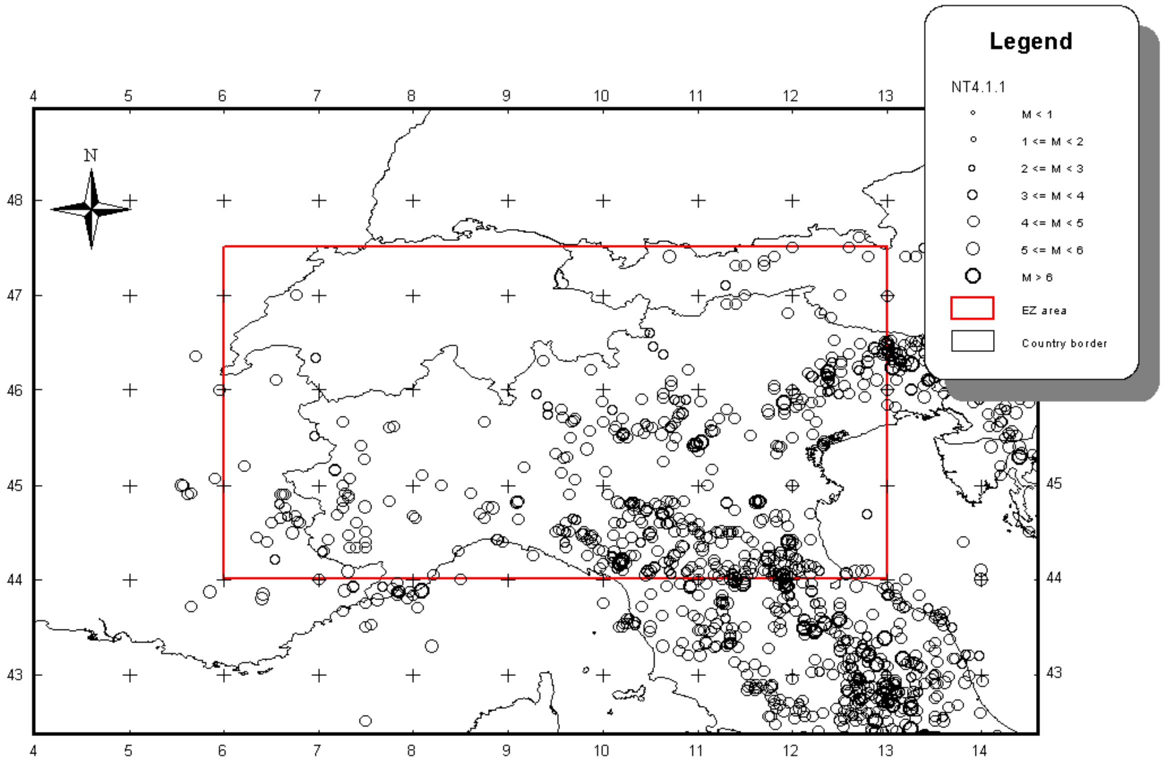


Figure 5.5: Earthquakes adopted to ECOS from the historical Italian catalogue (NT4.1.1). The red rectangular shows the area data was requested from.

5.4 Germany

5.4.1 Historical earthquake catalogue of Germany, BGR

The historical earthquake catalogue of Germany was obtained from G. Leydecker of BGR (Federal Institute for Geosciences and Natural Resources) on July, 2nd, 2001. The catalogue is not available online but information can be found on the BGR website at http://www.bgr.de/quakecat/. The request was placed to obtain the catalogue until 2000 including all events in the area 5°-13°E and 46°-51°N.

The historical catalogue was compiled by G. Leydecker and the ideas are shortly summarized by the description obtained together with the computer file:

1. To include all earthquakes with intensity or magnitude higher than the later defined limits inside the FRG and outside of such seismic regions which exceed the political borders.
2. To include all strong earthquakes outside the FRG which had been felt at least with intensity V in the FRG.

The lower limits of intensity or magnitude of interest with respect to the time period are:

time period	lower limit of	
	Intensity	magnitude
< 1700	Io = IV	
1700 – 1899	Io = III	
1900 – 1959	Io = III	M_L = 3.0
1960 – 1973	Io = III	M_L = 2.5
1974 -	Io = III	M_L = 2.0

Table 5.10. Intensity and magnitude thresholds for the historical German earthquake catalogue of BGR.

The area of interest was defined in general to be 47°-56°N and 5°-15°E. These restrictions were not been strongly followed in each case. For example: If there had been a smaller earthquake than above defined in an area with low seismicity, it was included. Or: If there had been a smaller earthquake inside the area of interest but too far from the borders of the FRG, it was excluded. On the other side, strong earthquakes outside the defined area that had been felt in the FRG with less than intensity V were included. The original catalogue contains about 9400 events.

The parameters of the catalogue are given Table 5.11.

Parameter	Description	Scale or data range
Ye	year	813 – 25 .12.1995
Mo	month	
Da	day	
ho	hour	
mi	minute	
se	second (rounded)	
shocks		1 = a non-classified foreshock is reported 2 = a non-classified aftershock is reported 3 = several shocks 4 = many shocks or part of an earthquake series
lat_deg	latitude N in degree	46°N – 56°N
lat_min	latitude N in minutes	
lat_10_min	latitude N in tenth of minutes	
lon_deg	longitude E in degree	6°E – 15°E
lon_min	longitude E in minutes	
lon_10_min	longitude E in tenth of minutes	
e_or_w	east or west	0 or blank indicates longitude E 1 indicates longitude W
		blank

Parameter	Description	Scale or data range
ce	quality of epicentre	1 = ± 1 km 2 = ± 5 km 3 = ± 10 km 4 = ± 30 km 5 > ± 30 km
reg1	seismogeographical region	see Leydecker 2000
reg2	political region	see Leydecker 2000
H	depth in km	
ch	quality of depth	blank = unknown G = fixed by geophysicist 1 or 4 = ± 2 km 2 or 5 = ± 5 km 3 or 6 = ± 10 km 4, 5, 6 are based on macroseismic depth estimation
ml	local magnitude Ml	decimal point between first and second digit
ms	surface wave magnitude Ms	decimal point between first and second digit
mk	macroseismic magnitude Mm	decimal point between first and second digit
sc	code for the used macroseismic scale	MS = Mercalli-Sieberg MK = Medvedev-Sponheur-Karnik (MSK 1964) EM = European Macroseismic Scale 1992 (update MSK-scale)
Io	epicentral intensity Io or maximum observed intensity	In case of max. observed intensity there is a "M" in field ci
ci	quality of epicentral intensity	normally blank M = indicates that the value in Io is not the epicentral intensity but the maximum felt intensity outside the epicentre 1 = epicentral intensity derived from doubtful sources 2 = estimated error ± 0.5 - ± 1.0 3 = estimated error equal or greater ± 1.0
i_radius	intensity belonging to the radius of perceptibility	Normally blank means intensity 3.0, else decimal point between first and second digit
radius	radius of perceptibility in km	
rad_5	radius of isoseimal in km of intensity 5	
rad_6	radius of isoseismal in km of intensity 6	
rad_7	radius of isoseismal in km of intensity 7	
rad_8	radius of isoseismal in km of intensity 8	
azi	azimuth of isoseismals elongation against north	multiplied by 10 gives the value in degree
axis	axis relation of elliptic isoseismals	
nom	number of macroseismic observations in powers to 10	
damages	damages	1 = injured person (s) 2 = killed person (s) 3 = fissures in ground surface 4 = change in flow of spring (s) 5 = landslide 6 = landslide of greater dimension
type	type of earthquake	blank = tectonic 1 = collapse 2 = rockburst B = event in a mining area, including oil and gas production fields C = rockburst in a coal mine P = presumably explosion

Parameter	Description	Scale or data range
		S = reservoir induced D = doubtful event
ref	reference abbreviation	
aftershock		normally blank 1 = an (after)shock related to this event with an own card follows; see remarks in shocks
ax	location	describes the epicentre, maximum 27 characters

Table 5.11. Original parameters of the historical German catalogue of BGR.

The catalogue was cut to the corner values defined by the original request. Finally, about 6150 events from the macroseismic catalogue of Germany were adopted to ECOS which are displayed in figure 5.6. Catalogue conversions and a detailed list of changes due to the cut off are given in Appendix D.

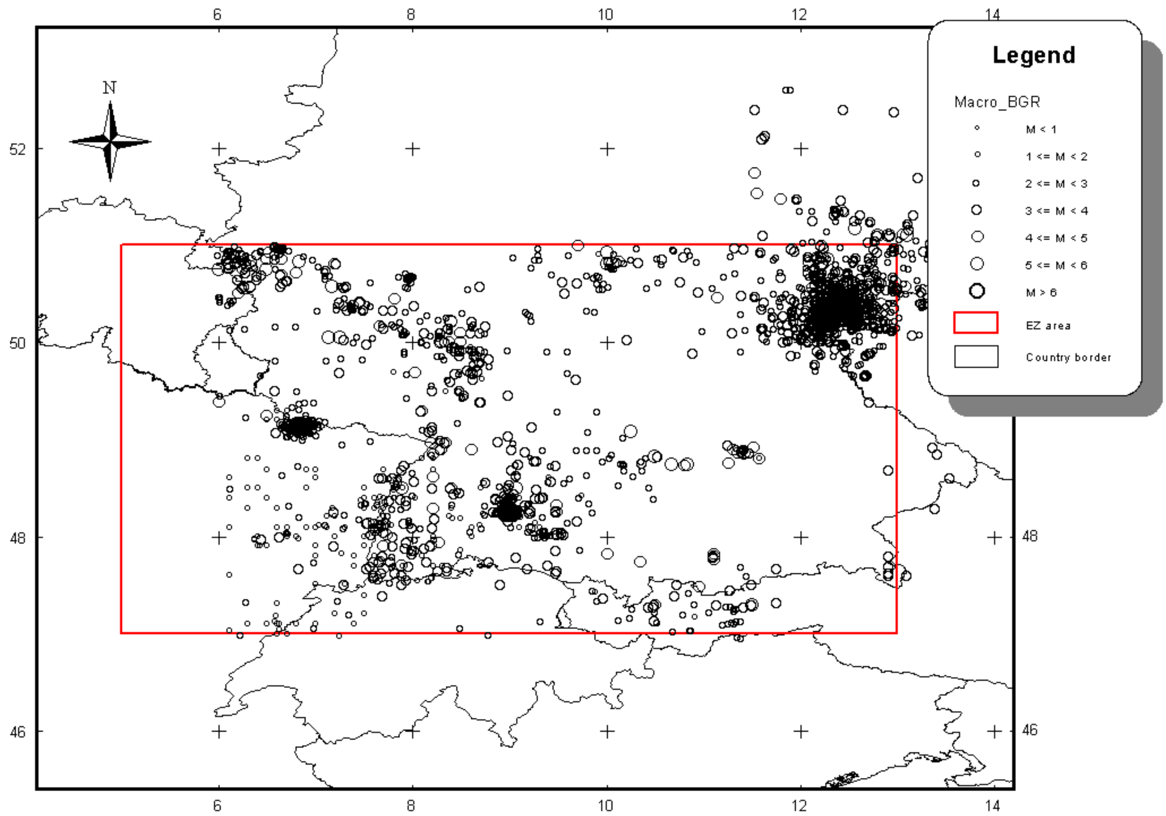


Figure 5.6 . Geographical distribution of the historical German catalogue of BGR. The red rectangular shows the area data was requested from.

5.4.2 Instrumental catalogue for Germany, BGR

The instrumental catalogue for Germany was obtained by a request to the Bundesanstalt für Geowissenschaften und Rohstoffe (BGR, Federal Institute for Geosciences and Natural Resources) on July 20th, 2001. The catalogue is available online at http://www-seismo.hannover.bgr.de/. The request was placed by email with the following specifications: M ≥ 2.5 in the region 47°-51°N and 5°E-13°E in a time span from 1968-2000. The original catalogue contains 1344 events.

The parameters of the catalogue are given below.

Parameter	Description	Scale or data range
Date	Year	29.9.1968 – 23.06.2001
Date	Month	
Date	Day	
Time	Hour	
Time	minute	
Time	second (rounded)	
Lat	latitude in decimal degree	47° - 51°N
Lon	longitude in decimal degree	5° - 13°E
Dep	Focal depth in km	0 –40
nobs	number of stations	
Agency	Agency	
Typ	Type	
Magn	Magnitude incl. magnitude type (only M_L)	2.5 – 5.7
Ref	Reference	
Int	Intensity	2 –7.5
Region	Region	

Table 5.12. Original parameters of the instrumental German catalogue from BGR.

The catalogue was cut on December, 31st, 2000. This change gave a reduction to about 900 events that were adopted to ECOS. Catalogue conversions and a detailed list of changes due to the cut off are given in appendix D. The events remaining in ECOS are displayed in Figure 5.7.

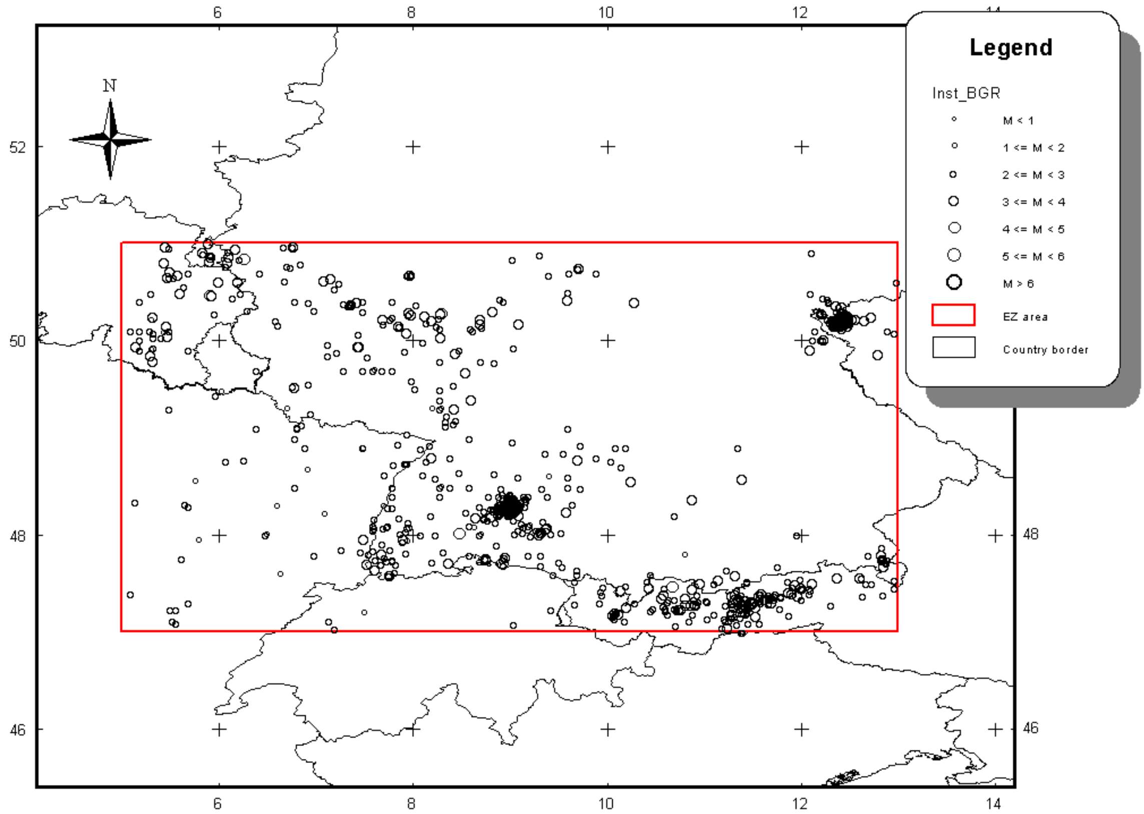


Figure 5.7. Geographical distribution of the BGR instrumental German catalogue. The red rectangular shows the area data was requested from.

5.4.3 Instrumental catalogue for Germany, Karlsruhe

This catalogue was obtained from K. Bonjer from the Geophysical Institute Karlsruhe, University of Karlsruhe (*http://www-gpi.physik.uni-karlsruhe.de/*) in September 2001. The dataset is not available online. The request was placed to obtain the catalogue in the time span of 1975-1994 including all events below latitude 48°N. The original Karlsruhe catalogue we received contains about 2200 events with the specifications given in the catalogue parameters in the time span from 1971-1997. We have no information of magnitude completeness.

The parameters of the catalogue are given in Table 5.13.

Parameter	**Description**	**Scale or data range**
Laufende Nummer	Number	10 - 22220
Agency-Code	agency code	see appendix D
Datum	date information	1.1.1975 – 31.12.1994
Zeit	time information	
Latitude	latitude in degrees and minutes	46.5°N - 48°N
Longitude	longitude in degrees and minutes	5°E – 13°E
Tiefe	Focal depth in km	0 – 30 km
Lokalmagnitude	local magnitude	If M_L = 1.11, the magnitude has not been determined but is smaller than M_L =1.5.

Table 5.13. Original parameters the instrumental catalogue of Karlsruhe.

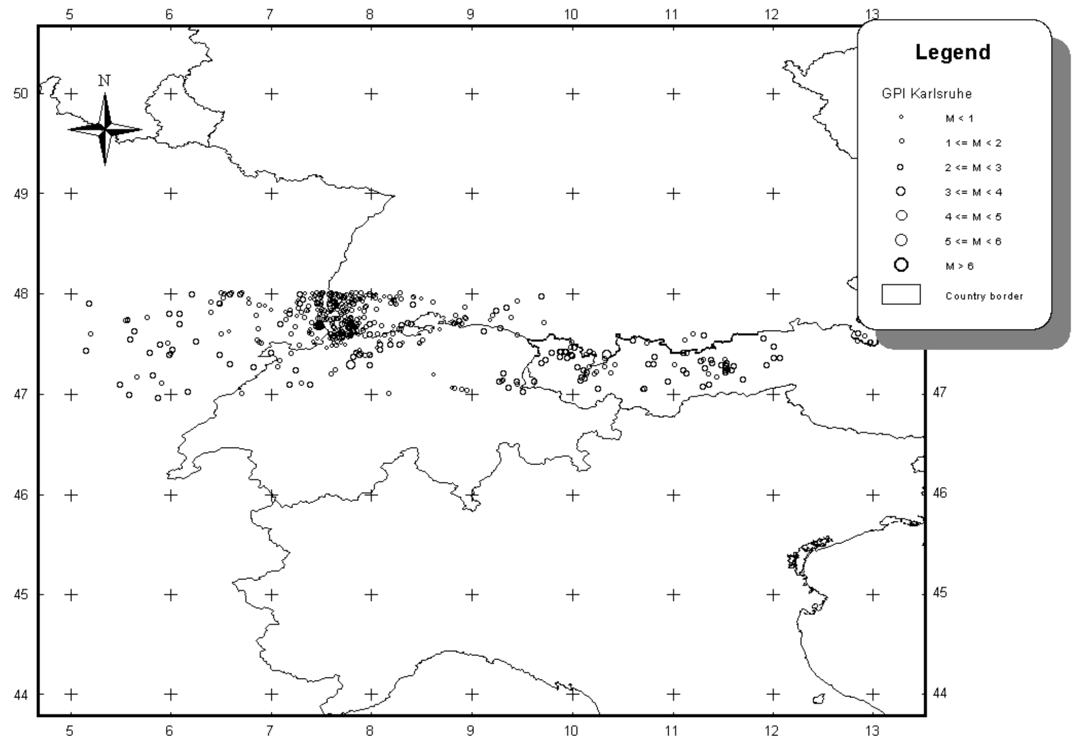


Figure 5.8. Geographical distribution of the Karlsruhe instrumental catalogue Events of all magnitudes were requested below 48°N.

The Karlsruhe catalogue was cut between the dates 1.1.1975-31.12.1994 since the Landeserbebendienst of Baden-Württemberg became the responsible surveying institution in 1995. Due to cuts, ECOS imports about 1400 events from the Karlsruhe catalogue. Catalogue conversions and a detailed list of changes due to the cut off are given in Appendix D. The events remaining in ECOS are illustrated in Figure 5.8. Some events are located in Switzerland, but do not exist in the instrumental catalogue of Switzerland. The reasons for this are multifold, e.g. small magnitude events might turn out as quarry blast since these have been removed from IECOS and are difficult to identify. Moreover, the Swiss Seismological Service might not have recorded some events due to network problems.

5.4.4 Instrumental catalogue for Germany, LED

The catalogue was obtained from W. Brüstle of the Landeserdbebendienst Baden-Württemberg (LED), a department of the Landesamt für Geologie und Rohstoffe (LGBR), in August 2001. The request was placed to obtain the catalogue in the time span of 1995 – 2000 including all events below the latitude 48°N. The catalogue obtained is published on the website of the LGBR at http://www.lgrb.uni-freiburg.de/d/fr_fach.htm. The catalogue obtained also included data from 1994.

The LED catalogue is complete for earthquakes of local magnitudes $M_L \geq 2.0$ in the borders of the state of Baden-Württemberg. Additional earthquakes from outside the state of Baden-Württemberg were added if located at close distances or if the earthquake is of general importance. The catalogue in its original form contains about 700 events.

The parameters of the catalogue are given Table 5.14.

Parameter	Description	column	Scale or data range
Nummer	LED internal number	1-4	723
Jahr	year	6	1.8.1994 – 28.12.2000
Monat	month	to	
Tag	day	13	
Stunde	hour	15	UTC
Minute	minute	to	
Sekunde	second	24	
Breite	Latitude	26	41.1 °N – 51.57°N
Länge	Longitude	38	2.95°E – 30.7°E
Herdtiefe	depth in km	40-43	0 – 28
Bestimmung	type of determination of the depth	44	* or G means not calculated but assumed
Lokalmagnitude	local magnitude	46-51	0.4 – 6.1
Maximalintensität	intensity Io	53-56	MSK 1964 2.0-5.0
Schuetterradius	radius of perceptibility	58-64	
Lokalisierungsart	type of localisation	66	M = manually A = automatic
Lokalisierungsgenauigke it	Uncertainty code of epicentral location	67	A <= 2 km B < = 5 km C <= 10 km D >= 10 km
Seismologische Institutionen	agency	69-71	
Lokalität	locality	73-85	
Region	seismological or political region	86-89	
Kommentar	comment to the event		

Table 5.14. Original parameters of the instrumental catalogue of Germany of LED.

The original data exceeds the requirements of the request in space and time. About 550 events from the original catalogue remain in ECOS. Catalogue conversions and a detailed list of changes due to the cut off are given in Appendix D. The events remaining in ECOS are displayed in Figure 5.9. Some events are located in Switzerland, but do not exist in the instrumental catalogue of Switzerland. The reasons for this are multifold, e.g. small magnitude events might turn out as quarry blast since these have been removed from IECOS and are difficult to identify. Moreover, the Swiss Seismological Service might not have recorded these events due to network problems.

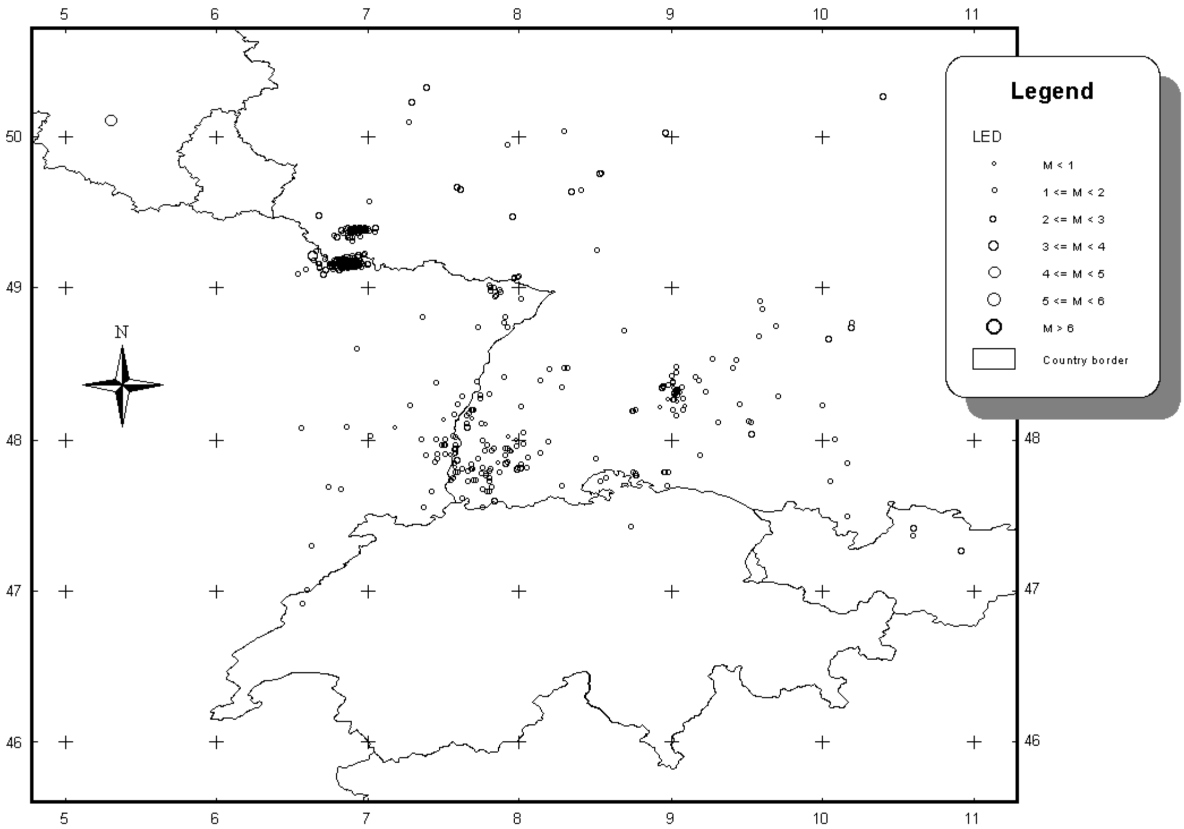


Figure 5.9. Geographical distribution of the LED instrumental catalogue remaining in ECOS. Events of all magnitudes were requested for 48°N and below.

5.4.5 GSHAP catalogue for Germany

The GSHAP-Region 3 Catalogue was obtained from G. Grünthal from the GeoForschungsZentrum (GFZ) Potsdam on June, 29th, 2001. The catalogue and the description can be found on the websites of the Global Seismic Hazard Program (GSHAP) at http://www.gfz-potsdam.de/pb5/pb53/project/gshap/gshap.html. The request was placed to obtain data including events in the area 5°-13°E and 47°-51°N. The catalogue was compiled by G. Grünthal and the GSHAP Region 3 team. The following description of the catalogue summarizes the original received description.

The seismicity file for the GSHAP REGION 3 is a byproduct of this project prepared at the GSHAP Regional Centre at the GFZ in Potsdam in forma of an earthquake catalogue. The catalogued area is identical with the GSHAP Region 3. Generally, there was agreed within the GSHAP to produce data files for events with moment magnitudes $M_W \geq 5$. The relatively low seismic activity in the GSHAP Region 3 required to lower the threshold magnitude. A value of $M_W \geq 4$ was agreed among the partners of Region 3. Contributors to the seismicity data file are listed in the final report on GSHAP Region 3. The compilation of the catalogue from individual files and earthquake lists implied that many events were introduced from more than one source. The specification of the preferred solution was made over national polygons, with priority to the domestic catalogue. The original parameters have been used to greatest possible extent. Revised parameters from published special studies have been introduced so far specific information reached the Centre. Only what can be considered a tectonic earthquake is included in the catalogue. Rockbursts and events of obscure origin (like storms, fake events, etc.) are excluded. Earthquakes classified as fore- and aftershocks are part of the catalogue, although not fulfilling the criteria of time independence. Local time and Universal (Greenwich) times are mixed and appear as given by the respective local sources.

The moment magnitude M_W is calculated, with decreasing priority, from seismic moment, magnitude (M_L, M_S, etc.) or intensity, given by a local source. Hanks and Kanamori's (1979) relation is used for the calculation from seismic moment. When no seismic moment is given, locally published formulae for the transformation from another magnitude concept or intensity are used when available, for the other cases formulae resulting from regressions at the GSHAP regional centre are used.

The parameters of the catalogue are given in Table 5.15.

Parameter	Description	Scale or data range
Jahr	year	1700 - 1993
Monat	month	
Tag	day	
Stunde	hour	
Minute	minute	
Sekunde	second	
Breite	latitude / [°]	48 - 52
Länge	longitude / [°]	5 - 13
Io	observed maximum intensity (EMS92)	40 - 80
M_W	moment magnitude	4 - 6
Referenz	reference	

Table 5.15. Original parameters of the GSHAP Region 3 catalogue.

No changes were performed adopting the GSHAP catalogue and a total number of about 81 events were adopted to ECOS, illustrated in Figure 5.10. Catalogue conversions are given in Appendix D.

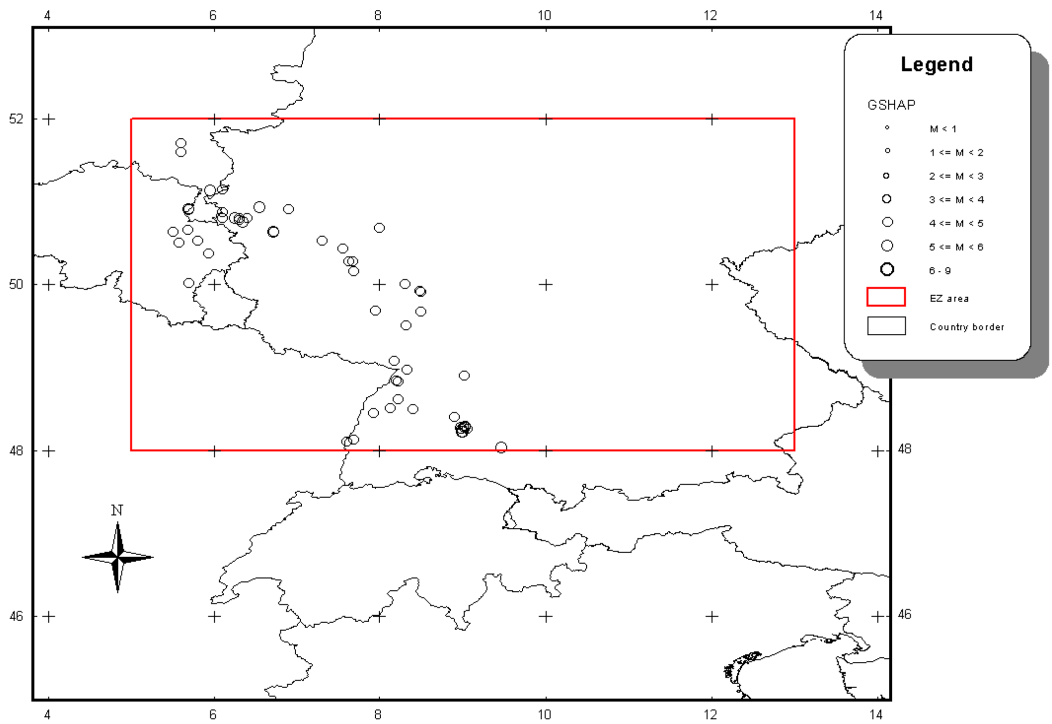


Figure 5.10. Geographical distribution of the German portion of the GSHAP catalogue. The red rectangular shows the area data was requested from.

5.4.6 Fusion of the German earthquake catalogues

We combined five German earthquake catalogues in order to obtain a unified German catalogue. In this process, we faced the problem of duplicates, i.e. earthquakes that are listed in two or several catalogues. In order to obtain a catalogue without duplicates, priority rules were defined and duplicate entries were deleted. Nevertheless, additional information from the catalogue entry that is not kept is adopted to a proper data field, e.g. the magnitude or intensity values.

Duplicate entries were found in the German catalogues starting at 1968 between the four catalogues. There are no duplicates between the Karlsruhe and the LED catalogue since these two comprise successive time periods. The rules we used to identify duplicates are a summarized in Table 5.16.

Date	difference in time / [s]	difference in epicenter / [°]
1968 – 1974	≤ 30	≤ 0.5
1975 - 2000	≤ 5	≤ 0.1

Table 5.16. Identification rules of duplicates in the German catalogues.

We identified 96 duplicate earthquakes. The earthquake entries were analyzed by a seismologist and judged according to the following rules:

- Locations and magnitudes from Karlsruhe and LED catalogue have priority against BGR catalogue with references to ISC / USGS/ EMSC.
- Karlsruhe catalogue has priority for location and time values in case of a Sierentz-earthquake.
- BGR events with reference to LDG for earthquakes in France have priority to Karlsruhe and LED catalogue except for Sierentz earthquakes.
- BGR entries have priority to Karlsruhe catalogue if Karlsruhe gives magnitude 1.11 (this means that the magnitude is below M_L=1.5, but not determined).
- BGR events that are referenced to SED have priority for events in Switzerland to other catalogues.
- GSHAP events have priority to earthquakes entries of the BGR historical catalogue of Germany.

Note that from now on, in this report this catalogue is referenced as German catalogue.

5.5 Austria

5.5.1 Earthquake catalogue for Austria

The Austrian catalogue was obtained from W. Lenhardt of the Zentralanstalt für Meteorologie und Geodynamik, Hauptabteilung Geophysik (http://www.zamg.ac.at/) on July, 17th, 2001. The request was placed to obtain the historical catalogue including all events of epicentral intensity Io ≥ 5 and the instrumental catalogue including all events of magnitude M ≥ 3. The catalogue obtained lists in its original form about 430 events in the time period 01.01.1201 – 10.07.2001 for the entire Austrian territory.

The parameters of the catalogue are given Table 5.17.

Parameter	Description	Scale or data range
Nr	Number	1 - 431
Jahr	Year	01.01.1201 – 10.07.2001
Mo	Month	given time: UTC
Tg	Day	
HH	Hour	
MM	Minute	
Sek	Second	
Br	Latitude in decimal degrees	Polygon borders of Austria (see Appendix)
Lg	Longitude in decimal degrees	
Z	Depth (km)	0-40
M_L	Local Magnitude	3.0- 7.0
Io	Epicentral Intensity	5.0-10.0
Epizentrum	Epicentre	
Region	Bundesland / state of Austria	

Table 5.17. Original parameters of the Austrian catalogue.

The earthquake catalogue lists events that are located in the borders of the polygon that can be seen in the figure below. The earthquake data remaining in ECOS is shown in Figure 5.11. Catalogue conversions are given in Appendix D.

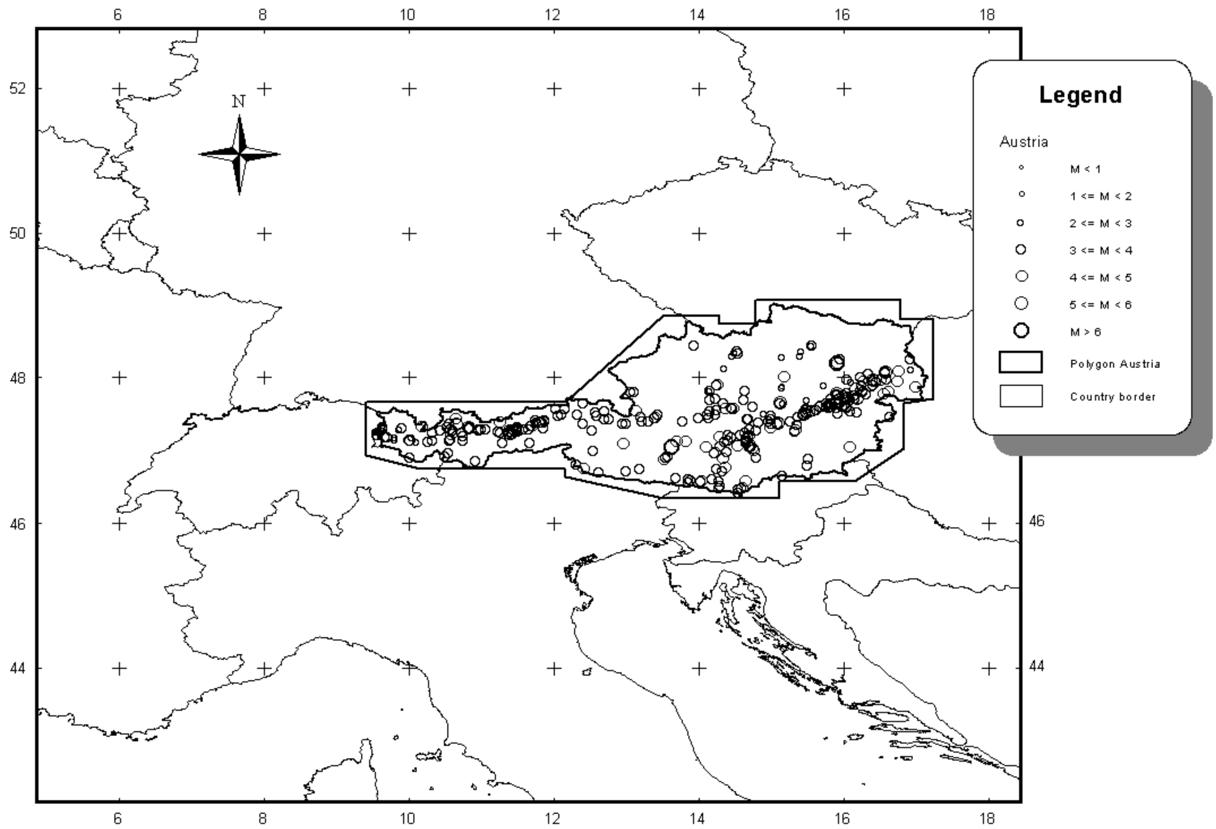


Figure 5.11. Geographical distribution of the Austrian catalogue. The black polygon shows the area data exists in the Austrian catalogue.

5.6 International Seismological Centre (ISC)

The ISC Centre maintains a continually growing file of past earthquakes, which is available for research studies and to help with the assessment of seismic hazard. The file contains estimates of origins of earthquakes dating from 1904 but naturally only major earthquakes are present for the earlier years. The file becomes more complete with time and now contains more than 1,000,000 events world-wide. About 150,000 more events are added each year.

The main sources of data for the Historical Earthquake File are the International Seismological Summary for the period 1913-63 and the ISC thereafter. Additional sources for the earlier periods include the Bureau Central International de Séismologie, Strasbourg, the US Coast and Geodetic Survey and standard catalogues such as "Seismicity of the Earth" by Gutenberg and Richter. For the period more recent than that for which ISC information is available, information from the Preliminary Determination of Epicenters, and Quick Epicenter Determination Services of the US National Earthquake Information Center is added to the file, and preliminary telexed information about major events is included within a few weeks of occurrence. The file contains details of earthquakes from the instrumental period only, with no events before 1904.

Events can be selected from the file online at http://www.isc.ac.uk/ by any combination of criteria, relating to time, location, depth, magnitude, intensity or locating agency. Composite estimates can also be provided which combine origin parameters with magnitude determinations from other agencies.

From the online database of the ISC, earthquakes were retrieved for the whole time period from 1904 on in a region of 4°-12° E and 44°-51°N.

Note that from the ISC catalogue, only the body wave magnitude m_b and the surface wave magnitude Ms were adopted to the final catalogue. The magnitudes of about 150 events were included in ECOS.

The ISC parameters are listed in Table 5.18 and the catalogue conversions in Appendix D.

Parameter	Description	Scale or data range
Year	Year	1904 - 2000
Month	Month	
Day	Day	
Hour	Hour	
Minute	Minute	
seconds	Seconds	
time_error	origin time error (seconds; blank if fixed origin time)	
time_rms	root mean square of time residuals (seconds)	
Lat	latitude / [°] (negative for S)	44 - 51
Lon	longitude / [°] (negative for W)	4 - 12
Smaj	semi-major axis of 90%ellipse or it's estimate (km; blank if fixed epicentre)	
Smin	semi-minor axis of 90%ellipse or it's estimate (km; blank if fixed epicentre)	
Az	strike of error ellipse clock-wise from North (degrees)	0 <= x <= 360
Depth	focal depth (km)	0 - 84
fixed flag	fixed flag	f = fixed depth station d = depth phases blank if not a fixed depth
Ch	depth error 90% (km; blank if fixed depth)	
Ndef	number of defining phases	
Nsta	number of defining stations	
Gap	gap in azimuth coverage (degrees)	
Mdist	distance to closest station (degrees)	
maxdist	distance to furthest station (degrees)	
analysis_type	analysis type	a = automatic, m = manual, g = guess
loc_method	location method	i = inversion, p = pattern recognition, g = ground truth, o = other

Parameter	Description	Scale or data range
event_type	event type	c = meteoritic event, e = earthquake, h = chemical explosion, I = induced event, l = landslide, m = mining explosion, n = nuclear explosion, r = rock burst, x = experimental explosion, uk = unknown, s= suspected, k = know, f = felt, d = damaging
Author	author of the origin	
OrigID	origin identification	
Magnitude_Art	Magnitude type	
Mb	body wave magnitude	3.2 – 5.4
Err	magnitude error	
Ms	surface wave magnitude	4.1 – 6.2
Author_mag	author of the origin	
OrigID_mag	origin identification	

Table 5.18. Original parameters of the ISC catalogue.

5.7 Fusion of the different catalogues in ECOS

After reformatting the national earthquake catalogues in order to produce a uniform catalogue format, the different national catalogues are integrated into a unique database. As described in Appendix D, the catalogue information was modified to match the parameter requirements of the ECOS database and catalogue.

To achieve a uniform catalogue, we now face two main problems:

- sort out all events that are so called duplicates, i.e. events that are listed in two or several national catalogues;
- implement a uniform magnitude scale for the whole combined catalogue (Chapter 6).

In order to discard duplicates, a strategy was developed taking into account the accuracy and reliability of the given information for different time spans. Problems arose due to the heterogeneity of the national catalogues, e.g. the different magnitude thresholds of completeness, which required visual inspection and the analysis of several events in a cooperation of a historian and a seismologist.

An earthquake entry of a national catalogue with the earthquake located in the same country has priority to entries in other national catalogues. As, especially for events before 1975, the uncertainty of specific parameters in an earthquake entry is rather high (location, origin time, magnitude, etc.), country borders cannot be judged as sharp differentiation limits. Therefore, buffer zones in the border areas where defined with lateral extension on each side of the country border. Duplicates were treated differently if they are located inside or outside a buffer zone.

A second reason for adopting a buffer zone is that we can assume that duplicate events in the buffer zone are reasonably well controlled by networks after 1975. We used the magnitudes of the duplicate events in the buffer zones to calibrate magnitude regression toward the implementation of a uniform magnitude for the whole ECOS (Chapter 6).

Table 5.19 shows the restrictions used to define earthquake entries in different catalogues to be considered as duplicates. Figure 5.12 illustrates the 20 km buffer zones for Switzerland, France and Germany. Inside the defined buffer zones, duplicates are evaluated and judged according to the priority rules defined in Table 5.20. The earthquake entries in the national catalogues that locate earthquakes in a buffer zone were identified using a Geographic Information System (GIS) tool.

Date	difference in time / [s]	difference in epicenter / [degrees]	lateral extension of buffer zones [km]
≤1899	no limit	≤ 0.5	no limit
1900 - 1974	≤ 30	≤ 0.5	50
1975 – 2000	≤ 5	≤ 0.1	20

Table 5.19. Selection parameters to define earthquake entries of different national catalogues as duplicates, and definition of buffer zones.

The following cases can be distinguished:

Case 1: Duplicates located outside a buffer zone

Duplicates were searched for according to the rules in Table 5.18. In contrast to events located in the buffer zone, the earthquake entry of the national catalogue in which the earthquake is located was used. For the time period of 1975-2000, this is justified due to the existing network configurations. And for all time periods, it is ultimately the responsibility of national agencies to locate national seismicity.

Case 2: Duplicates located in a buffer zone, with both locations in the same country

An earthquake entry of a national catalogue with the earthquake located in the same country has priority to the entry in the other national catalogue. The magnitude information from both catalogues is kept. For example, for an earthquake located in the 20 km buffer zone inside Switzerland and listed in both the SED and LDG catalogue, we keep only the SED location but all magnitudes.

Case 3: Duplicates located in a buffer zone, with cross location of duplicates

In some cases, both national agencies locate an earthquake inside the buffer zone of the other country. In this case, we analyzed the entries in the different catalogues by hand and displayed the events in the GIS. For decision making, we used the country priority given in Table 5.20.

Date	Catalogue priority
≤1899	CH > I > F > D > A
1900 – 1974	CH > I > F > D > A
1975 – 2000	CH > D > F > I > A

Table 5.20. Priority rules for earthquake entries from different national catalogues in case of cross location of duplicates in the buffer zone. The column “catalogue priority” explains from which national catalogue the final entry is taken.

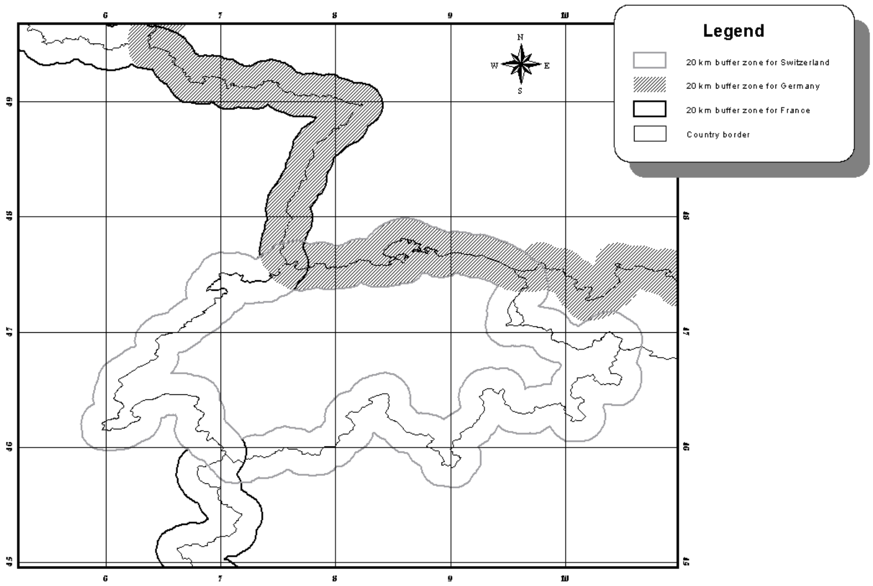


Figure 5.12. 20 km buffer zones for the identification of duplicates.

Case 4: Events not listed in the national catalogue

An earthquake is located in a country, never mind if outside or inside the buffer zone, but the national catalogue does not list the event. Nevertheless, the earthquake is listed in two other national catalogues. In this case, the earthquake entry of the Swiss catalogue was used and the duplicate information from other catalogues was discarded after gathering the additional information. This case occurred for example for events in the time period from 1975-2000 in France, since the French catalogue obtained has a magnitude threshold of $M_L \geq 2.5$. The Swiss and German catalogues have lower magnitude thresholds, thus these events have to be judged in a different way.

Case 5: Cross location of duplicates outside the buffer zone

In a very small amount of cases, the different national agencies located an earthquake vice versa outside the buffer zone in the other country. In this case, we analyzed the entries in the different catalogues by hand and displayed the events in the GIS. For the decision, we either used the country priority (see Table 5.20) or the information given in the national catalogues.

Case 6: Border area Austria – Switzerland in the time period 1975-2000

As the network configuration of the Swiss Seismological Service has a better azimuthal distribution compared to the Austrian network for events that are located west of 10.5° E, the earthquake entries are taken from the Swiss catalogue. Events located east of 10.5° E, the earthquake entry of the Austrian catalogue is adopted.

Case 7: Border area Switzerland – Italy in the time period 1975 – 2000

For duplicates that are located north of 46°N on the Italian territory and contained in the Swiss and the Italian catalogue, the earthquake entries of the Swiss catalogue were kept for the sake of consistency in the final catalogue. Nevertheless, it has to be mentioned that in this region, both seismic networks have a rather low density and both locations might have bigger uncertainties as in other regions.

The fusion process results in a unified catalogue incorporating earthquakes from the national catalogues of Austria, Germany, France, Italy and Switzerland as well as magnitudes of the ISC and the IPSN catalogue (Levret, 1996).

The catalogue was checked by eye since the duplication rules were very strict especially for events with a time difference of one hour eliminating duplicates due to the usage of local time or Greenwich Mean Time (GMT). The criteria in this second check were only a time limit of 10 seconds or one hour and 10 seconds for the time after 1968, but no distance limit. About 600 more duplicates were found and removed in this quality check. This leads especially to the identification of duplicates that are located deep in one of the countries. The bigger differences in epicentral locations are explained with the lower ability of national networks to locate earthquakes correctly for events almost in regional distances.

The historical catalogue was also extensively checked by eye for duplicates and fake events taking into account the various calendars existing at certain times. Fake events and duplicates are listed in the fake list of the database and are removed from the catalogue.

6 Calibration of a homogeneous M_w magnitude

To compile a uniform catalogue for seismic hazard analysis, we adopt M_W as the size estimator for all events in ECOS, because M_W is a parameter directly related to source physics, unlike the other magnitude scales that are based on seismogram amplitude measurements (like the body wave, surface wave, and local magnitude scales).

The ECOS Catalogue reports a M_W assigned by the SED for each earthquake if possible. All original magnitudes or size estimates reported by other sources are saved in the event records (see ECOS format in chapter 3). This chapter explains how we derived the regression laws between the different magnitude scales used by different catalogues in different periods, how we estimate magnitude uncertainties and what selection rules we adopt in regressing a uniform M_W.

Here, we first present how moment magnitude (M_W) is directly determined, then present surface wave magnitude (M_S) estimates for larger instrumentally recorded historic events in and near Switzerland from the 20th century and relate the M_S estimates with M_W. Next, we outline local magnitude determination (M_L) at the SED and obtain a calibration of M_L versus M_W. Outside Switzerland, other networks provide location and size estimates, and in the next step, we relate our SED magnitudes with the magnitudes determined by other groups. In the end, we obtain an earthquake catalogue, that contains directly comparable earthquake size estimates for each earthquake in terms of M_W, our unified magnitude.

We also discuss the effects of neglecting station corrections in the M_L determination and of adopting fixed shifts rather than linear or more complicate regressions when converting different magnitude scales to M_W.

In the course of this project, we visited archives and collected data to obtain a comprehensive overview of historic and instrumentally recorded earthquakes that occurred in or near Switzerland. The quality of the information and the accuracy of the earthquake size parameters varies dramatically even for the instrumentally recorded events, leading to surprisingly large corrections in the determination of M_W for some datasets and periods.

6.1 Determination of M_W (SED)

To establish a set of consistent calibration relations for a M_W scale, we first need to calibrate a correct M_W for Swiss events. The new networks of broadband stations in Switzerland and other European countries allow routine moment tensor determination with regional waveforms for all stronger earthquakes in the entire European-Mediterranean region, and thus a robust M_W calibration.

In Switzerland, we started analyzing $M_L \geq 3$ earthquakes in 1999 with the installation of the Swiss Digital Seismograph Network (SDSNet). SDSNet three-component, complete broadband seismograms are inverted for the earthquake source parameters (moment tensor) by minimizing the least squares misfit between observed and synthetic seismograms. Strike, dip, rake, and seismic moment follow directly from the moment tensor formulation; and the earthquake depth is found by repeating the inversion for several trial depths. The inversion is performed at relatively low frequencies; thus a simple one-dimensional velocity-depth model is sufficient to calculate synthetic seismograms. The method is described in Nabelek and Xia (1995); results for Swiss earthquakes are listed in Deichmann et al. (1999) and Baer et al. (2000). To date we have obtained 24 moment tensor solutions for earthquakes that occurred in or near Switzerland since 1999 ranging in size from M_W = 2.4 to 4.9 (circles Figure 6.1 top).

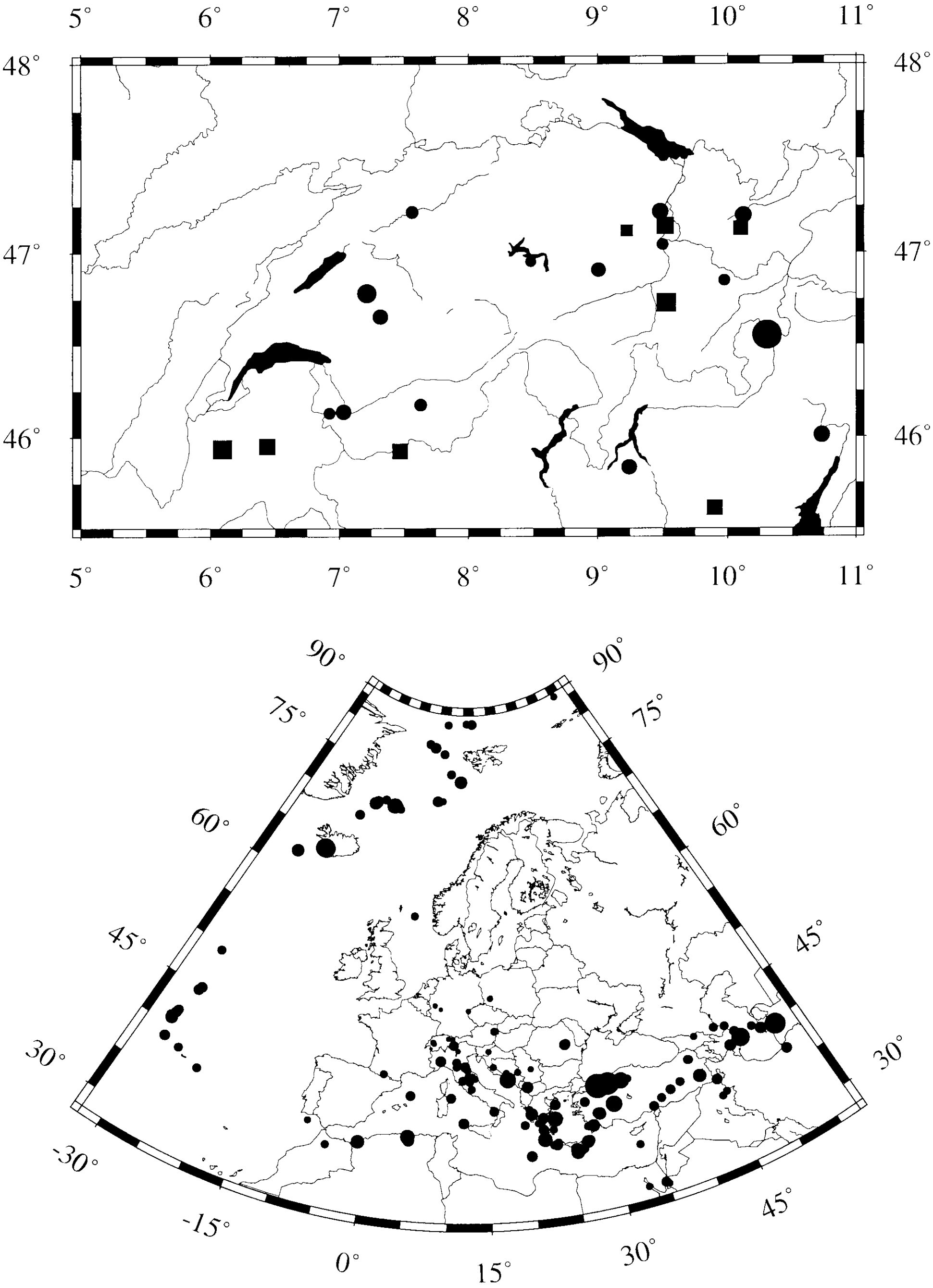


Figure 6.1. 24 earthquakes that occurred in or near Switzerland since 1999 ranging in size from Mw = 2.4 to 4.9 for which we computed a moment tensor solution using data from the Swiss Digital Seismic network (circles) and 10 larger events in and near Switzerland (3.6 < Mw < 5.2) that occurred between 1978 and 1997 for which we obtain a moment tensor solution from broadband stations in neighboring countries (squares). One recent and two older events occurred slightly outside the map region. Bottom: Distribution At of earthquakes in the larger European-Mediterranean region for which we computed a moment tensor solution since 1999. At some locations - Martigny, Lech, Bormio – several events are basically collected, thus not each individual event is shown.

Several broadband stations in neighboring countries have been operating since the 1970's. Using these data, we determined moment tensor solutions for an additional 10 larger events in and near Switzerland (3.6 ≤ M_W ≤ 5.2) that occurred between 1978 and 1997 (squares Figure 6.1 top).

The combined data set of 34 moment tensor solutions provides the only direct estimates for seismic moment (and thus moment magnitude) for earthquakes in and near Switzerland. For these events, we use these direct M_W estimates as our "unified magnitude" estimate. These 34 events also provide a link for earthquakes that have no directly determined moment magnitude (through linear regression, see paragraphs below).

Before proceeding with regressions, we need to ascertain whether our magnitude determinations are biased. For the 34 Swiss moment tensor solutions, we cannot directly estimate the quality of the M_W estimates. For larger events that occurred during the last 3 years in the entire European-Mediterranean region, we have determined almost 300 moment tensor solutions (Figure 6.1 bottom) (Braunmiller et al., 2001; Braunmiller, 2001). For 63 of these, a Harvard CMT solution also exists. We compared our M_W estimates with the Harvard estimates (Figure 6.2) and found that the average difference M_W (SED) - M_W (HRV) is only 0.02 (+- 0.12) magnitude units. The scatter is relatively symmetric around 0 (bottom Figure 6.2) and we detected no systematic variation of the differences with size (top Figure 6.2). We also performed two linear regressions. First, M_W (HRV) was considered independent and we obtained M_W (SED) = 0.07 + 0.99 M_W (HRV). Second, M_W (SED) was considered independent and we obtained M_W (HRV) = 0.17 + 0.97 M_W (SED). The "double regression" results also show that M_W (SED) and M_W (HRV) are basically identical in the M_W = 5.0 to 7.5 range where our data sets overlap. The deviation and scatter between our M_W estimates and M_W (HRV) are no worse than what is observed when comparing other data sets to Harvard. For example, the average difference between M_W determined for 628 events by "quick" USGS and Harvard moment tensor solutions is 0.01 (+- 0.12) magnitude units.

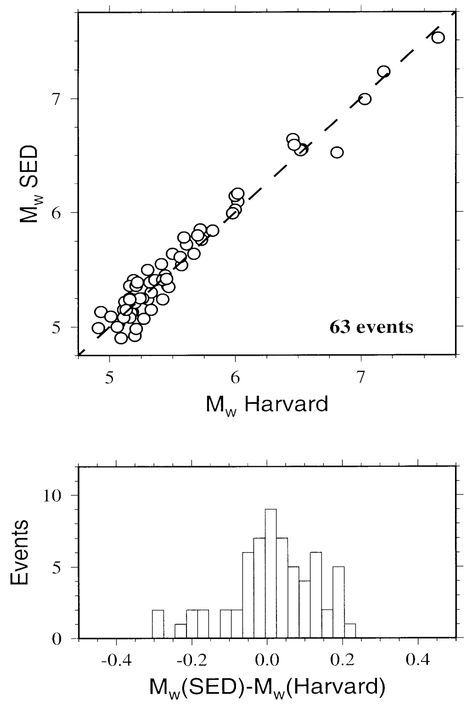


Figure 6.2. Comparison of Mw from Harvard CMT solutions and Mw(SED) for 63 events in the European-Mediterranean region. Top: Mw(SED) versus Mw(HRV). Bottom: Mw(SED) - Mw(HRV). Details in text.

Inadequacies of the crustal model, incorrect estimates of source depth, the signal-to-noise ratio of the data, and the frequency content considered all affect the quality of the waveform fit and influence the seismic moment estimate. However, from our experience modeling the waveforms, we estimate that the uncertainties in seismic moment translate to a small uncertainty in M_W of about 0.1 magnitude units.

For 77 earthquakes in the European-Mediterranean region, we have a surface wave magnitude estimate from the USGS (monthly PDE catalogue) besides our M_W estimate. Figure 6.3 shows our M_W estimates versus M_S(PDE); at the bottom the individual data points are shown whereas the top shows the events binned in 0.1 unit M_S-bins. Binning was performed to down-weight the more numerous smaller events in the regression analysis. The long dashed line represents a one-to-one relation. Obviously most events fall above the one-to-one relation and M_W (SED) is larger than M_S(PDE). Linear regression results in M_W (SED) = 2.18 + 0.64 M_S(PDE) (binned data set). Our data (and the linear regression) basically coincide with a global M_W -Ms relationship determined by Ekström and Dziewonski (1988) (short dashed line).

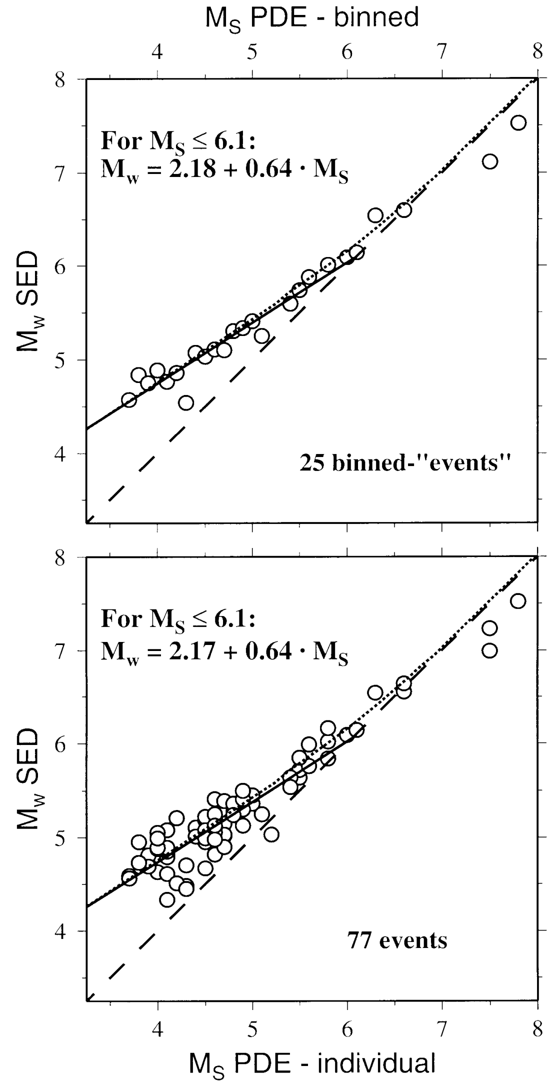


Figure 6.3. Comparison of Ms from USGS PDE and Mw(SED) for 77 events in the European-Mediterranean region. Bottom: all events. Top: events binned in 0.1 magnitude bins. The global relation of Ekstroem and Dziewonski (1988) is shown. Details in text.

For 174 earthquakes in the European-Mediterranean region, we have a body wave magnitude estimate from the USGS (monthly PDE catalogue) besides our M_W. Figure 6.4 shows M_W (SED) versus m_b(PDE). The individual events (bottom) show a large scatter particularly for smaller events (near m_b= 4.5). The binned data set (0.1 unit m_b-bins) is less affected by scatter and we prefer the regression results from this data set. Starting at about magnitude 4.5, M_W is significantly above m_b. The slope of the regression analysis, 0.77 (M_W independent) and 1.21 (m_b independent), deviates from 1 and m_b increasingly underestimates M_W with increasing event size. This behavior is expected from the saturation of the body wave magnitude scale.

For 34 earthquakes in and near Switzerland we have a direct measure of the moment magnitude M_W. The M_W values determined at the SED compare well with the Harvard estimates (for larger events). Our M_W estimates also agree with a global M_W - M_S relation. We estimate that the uncertainties in the M_W (SED) estimates are on the order of 0.1 magnitude units.

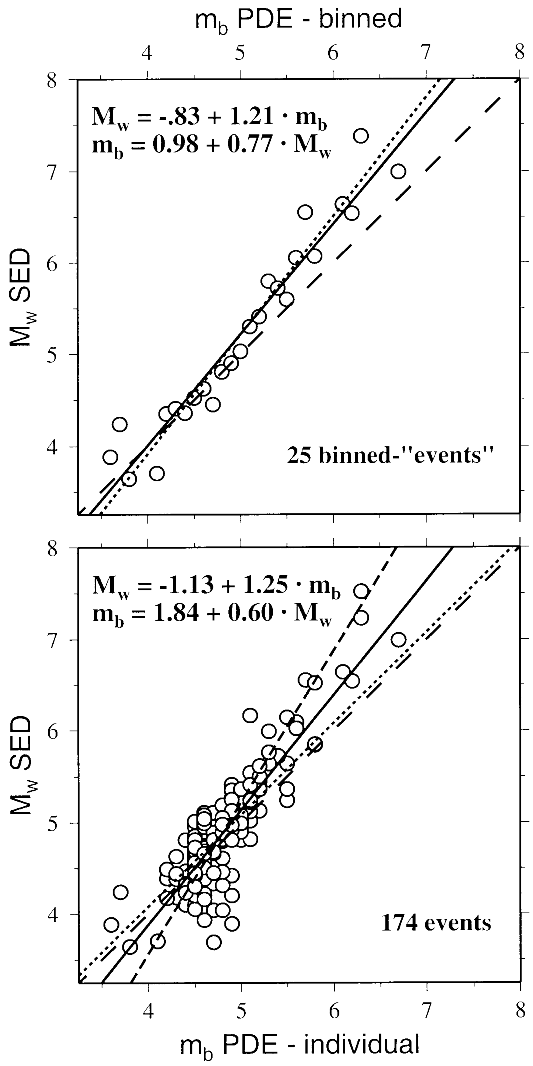


Figure 6.4. Comparison of m_b from USGS PDE and Mw(SED) for 174 events in the European-Mediterranean region. Details in text.

6.2 Determination of M_S for larger historic events in Switzerland

Having calibrated a M_S/ M_W relation, we can compute a homogeneous magnitude scale valid for the whole instrumental period (since the beginning of the 20th century). A homogeneous magnitude scale is needed because the instrumental earthquake catalogue in Switzerland covers only the last 25 years and most larger earthquakes, happened before that time. To obtain an absolute M_W calibration for historical earthquakes we need a set of earthquakes with both a macroseismic field and an instrumental magnitude, and this cannot be done for Switzerland with a dataset that covers only the last 25 years. In the 20th century seismological observatories were installed in many European countries and instrumental data start to exist (mainly for larger events). In this section, we describe how we collected historical seismograms and how we determined surface wave magnitude estimates.

We collected and scanned paper records from several institutions in Europe for 29 selected larger earthquakes that occurred in or near Switzerland during the 20th century. We visited, the observatories in Fürstenfeldbruck, Jena and Göttingen in Germany, Vienna (Austria), Zagreb (Croatia) and Brussels (Belgium), and obtained paper copies from several other observatories (e.g., De Bilt, the Netherlands; Ebre, Spain). We read the maximum amplitude and the corresponding wave period from the seismograms and then converted the amplitudes to ground motion using the instrument gain at the measurement period. Surface wave magnitudes (M_S(his)) are then calculated with the Prague-formula (Vanek et al. 1962) for the amplitude and period measured and the given station-event distance. The M_S (his) values are solely based on readings from long-period Wiechert instruments because the instruments are stable and their responses are fairly well known. Individual M_S(his) estimate are determined for each component, and the median value is assigned as the event M_S(his).

For 25 out of the 29 events we were able to read amplitudes from Wiechert instruments from several components and/or stations. The parameters for 25 events are given below (date, Io, M_S(his), number of components and stations, name of stations):

Year	Month	Day	Io	Ms	C	S	Station
1905	12	25	7	4.4	2	1	Munich
1910	5	26	7	4.3	1	1	Göttingen
1911	11	16	8	5.8	5	4	Uccle, Vienna, Zagreb, Göttingen
1915	8	25	7	4.5	4	2	Uccle, Vienna
1924	4	15	7	5.4	7	3	Uccle, Vienna, Munich
1925	1	8	7	4.7	5	2	Uccle, Vienna
1929	3	1	7.5	5.1	4	2	Vienna, Munich
1933	8	12	7	4.6	6	3	Uccle, Vienna, Munich
1935	6	27	7.5	5.6	10	4	Uccle, Vienna, Zagreb, Göttingen
1943	5	28	7	5.5	7	3	Uccle, Zagreb, Göttingen
1946	1	25	8	6.2	6	3	Uccle, Zagreb, Göttingen
1946	1	26	6.5	5	2	1	Zagreb
1946	5	30	7	6	5	2	Uccle, Zagreb
1954	5	19	6.5	5.3	9	4	Uccle, Vienna, Zagreb, Göttingen
1960	3	23	7	5.1	8	3	Uccle, Vienna, Göttingen
1961	8	9	6	4.7	3	1	Zagreb
1964	2	17	7	4.7	4	2	Zagreb, Göttingen
1964	3	14	7	5.6	9	3	Vienna, Zagreb, Göttingen
1968	6	27	6.5	4.8	2	1	Vienna
1968	8	19	6.5	5	5	2	Vienna, Zagreb
1971	9	29	7	4.8	6	3	Vienna, Zagreb, Göttingen
1978	9	3	7.5	5.6	5	2	Zagreb, Göttingen
1980	7	15	6	4.5	3	1	Göttingen
1991	11	20	6	4.7	3	1	Göttingen
1996	7	15	7.5	4.5	3	1	Göttingen

Table 6.1. List of earthquakes for M_S calibrations. Details in text.

6.2.1 Converting M_S(his) to M_W

We have to convert the 25 M_S(his) estimates to a unified magnitude (M_W). We showed in Figure 6.3 that the M_S values determined by PDE and SED's direct M_W determinations are well connected by the Ekström and Dziewonski (1988) relation. However, we need to prove whether M_S(his) equals M_S(PDE), and thus, if we can convert to M_W using the Ekström and Dziewonski (1988) relation.

For four larger events (1911, 1935, 01/25/1946, 05/30/1946) M_S estimates from Pasadena (Gutenberg) agree with our estimates [differences in the estimates are -0.4, 0.0, 0.2, 0.2; positive for M_S(his)> M_S(Pasadena)]. Independent recent M_S estimates from the USGS, ISC or Moscow exist only for two events (1978, 1996); the M_S(his) estimates are between 0.0-0.3 units higher than the independent estimates. Both checks support the general validity of our measurements. On the other hand, we have three events (1978, 1991, 1996) where we have a direct M_W estimate from regional moment tensor inversion that we consider high-quality size estimates. Plotting the M_S(his)- M_W pairs on top of the M_S(PDE)- M_W pairs suggests that the M_S(his) values are on the high end of possible M_S-values. If the M_S (his) estimates are too high (for their true M_W), we would obtain values of M_W that are much too high when converting straight from M_S(his) to M_W.

As an additional, more robust test, we compare our regional M_W estimates with MSh values determined automatically at the SED using broadband data recorded by SDSNet network. (MSh is determined by vectorially adding the horizontal components). We have obtained regional M_W (SED) and MSh(SED) for 89 earthquakes in the European-Mediterranean region. When plotting (Figure 6.5) the MSh values determined at periods of about 20 s (the period for which M_S was originally derived and is in use at the USGS), we observe that the MSh values are systematically too low (we already showed in Figure 6.3 that our M_W estimates are "good") and the linear regression M_W -MSh is above the relation suggested by Ekström and Dziewonski (1988). The bottom of Figure 6.5 shows for the same events M_W -vs-MShF, where MShF are computed by variable filtering of the seismogram according to distance (following the suggestions in the Manual of Seismological Observatory Practice, Willmore (1979); the center periods for events at regional distances vary from 6 to 12 s). Filtering the data at periods shorter than 20 s results in slightly higher MShF-estimates (compared to the MSh values) and the M_W -MShF data points follow the Ekström and Dziewonski (1988) curve. This suggests that filter period has an effect on the M_S value determined. In the case of the historic events, we read the amplitudes from analog records and most periods that were associated with the largest seismogram amplitude were around 4 s. These periods are even shorter than the periods used for MShF. We then determined MSh4 (the center period was fixed to 4 s) values for 18 events that occurred within a few hundred kilometers from the SDSN network; in this way we reverse the set-up compared to the historic events that occurred in Switzerland and were recorded at stations a few hundred kilometers from Switzerland. Figure 6.5 shows a comparison of M_W with MShF and MSh4 for these 18 events. The bottom part of Figure 6.5 shows the MShF-vs- M_W data points fit the M_W -Ms relation given by Ekstroem and Dziewonski (1988) (dashed line). For the top part of Figure 6.5, we shifted the M_W -Ms curve by 0.2 units (of M_W) down to obtain a good match between M_W and MSh4. The results of this test suggest that measuring the surface wave amplitudes at periods shorter than the ones suggested in Willmore (1979) results in a slight overestimation of M_S (and thus M_W).

Based on the last test, we converted the M_S(his) values using Ekström and Dziewonski's (1988) relation and subtracted 0.2 units to obtain our unified size estimate for the 25 historic events that have a M_S(his).

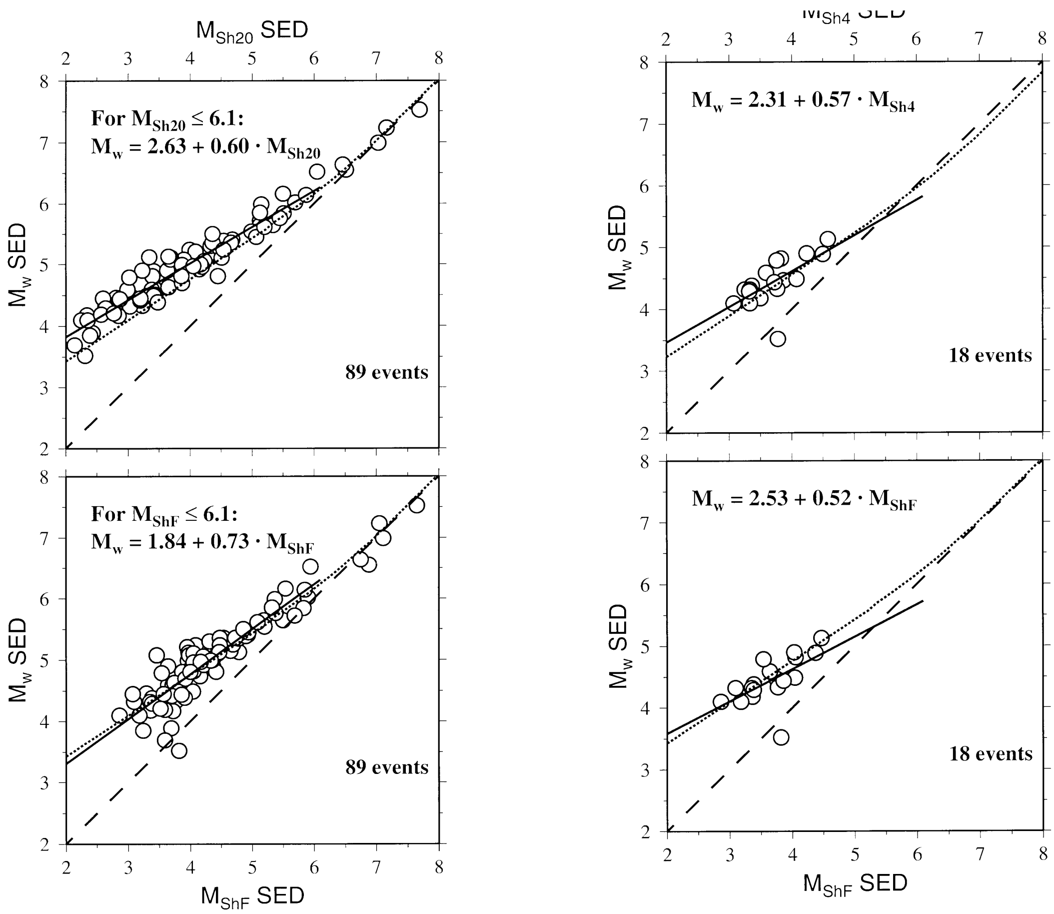


Figure 6.5. Comparison of M_S computed at SED with M_W(SED). Top left: M_W (SED) versus Msh20(SED), Ms magnitude computed with horizontal records at a fixed period of 20 seconds by SED, for 89 events in the European-Mediterranean region. Bottom left: M_W (SED) versus MshF(SED), Mw magnitude computed by variable filtering according to distance (periods 6-12 seconds), for the same events. Top right: M_W (SED) versus Msh4(SED), Ms magnitude computed with horizontal records at a fixed period of 4 seconds by SED, for 18 events in the larger Swiss region. Bottom right: same as bottom left, for the 18 events shown in panel top right. All details in text.

6.3 Determination of M_L(SED) and calibration of M_L (SED)- M_W regression

The majority of the earthquakes in the ECOS catalogue are small events in the recent instrumental period (since 1975), which are generally quantified with a M_L magnitude in the different catalogues. We need to calibrate the M_L given since 1975 by SED and other agencies.

6.3.1 Determination of M_L (SED) magnitude

The determination of local magnitude M_L at the SED has to be divided in three time periods. The bulk of the observations falls in the first time period that began with the installation of the short-period seismic network in Switzerland 1975 and continued until the end of 1998. In 1999, the first high-dynamic range broadband stations became operational and until the end of 2001, the magnitude estimates are based on a mix of short-period and broadband stations. Starting in 2001, only broadband data will be available.

Although the first seismographs in Switzerland were already operational in the beginning of the 20th century, a modern nationwide seismograph network came into operation only in the early 1970's. At first, all data were continuously recorded on microfilm. As of 1984, the analog data are digitized in real-time and stored as digital event files. Starting in late 1998, this station network consisting of analog short-period instruments with a limited dynamic range is gradually being replaced by a new digital broad-band network. The transition from the old to the new network will be completed in January 2002.

Routinely determined instrumental magnitudes for all recorded events are thus available as of 1975. During the transition period from the short-period (SP) to the broad-band (BB) network, the SED determined magnitudes using both station networks.

For both instrument types, local magnitudes (M_L) are calculated according to

$$M_L = \log A(W\text{-}A) - \log Ao(D),$$

where A(W-A) is the equivalent amplitude in mm of a Wood-Anderson seismograph and Ao accounts for distance attenuation. The empirically determined distance correction used for Switzerland is (Kradolfer 1984):

$$-\log Ao = 0.0180\, D + 1.77 \quad \text{for } D \leq 60 \text{ km}$$

$$-\log Ao = 0.0038\, D + 2.62 \quad \text{for } D \leq 60 \text{ km}$$

A comparison of this attenuation relationship with the one introduced by Richter for California as well as with an attenuation proportional to the reciprocal of the epicentral distance is shown in Figure 6.6.

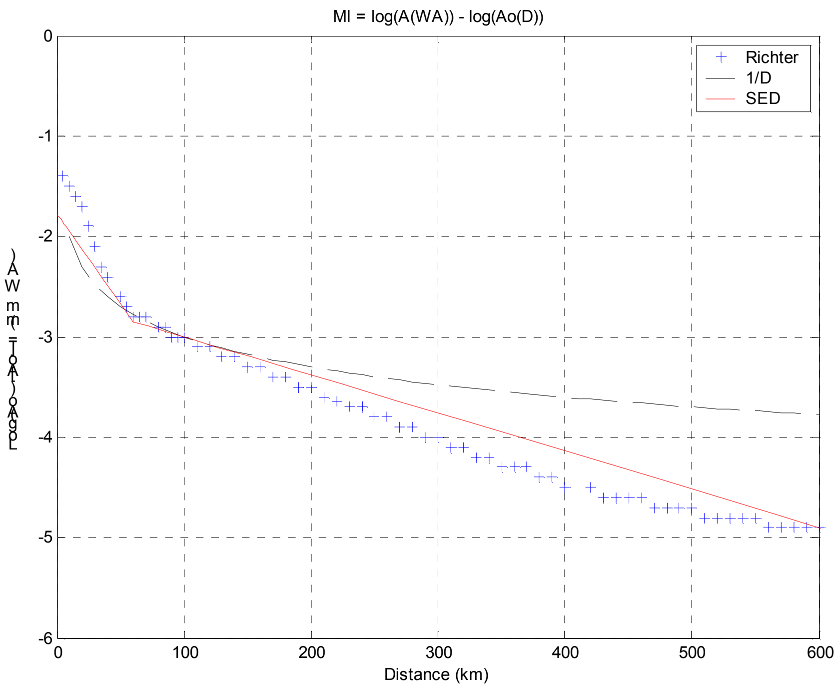


Figure 6.6. Amplitude-distance relation used for computing local SED magnitudes compared to the one introduced by Richter for California and to an attenuation proportional to the reciprocal distance (1/D).

SP magnitudes are based on the maximum amplitude of vertical component records proportional to ground velocity. The frequency range of the recording system is limited by the eigenfrequency of the seismometers (0.5 - 1 Hz) and by a 12 Hz, 6 pole Bessel low-pass filter. For events with magnitudes greater than about 3, many high-gain traces are clipped, so that their magnitudes rely heavily on the 6-8 stations with an additional low-gain channel (APL, BAL, BRI, CHE, DAV, SIERE, ROM, WIL). The equivalent Wood-Anderson amplitude to the maximum of the vertical component velocity traces is calculated from the value of the instrument transfer function at the dominant period of the signal (determined roughly from the period of the phase from which the amplitude is read). For events that occurred before 1984, this period is assumed constant and equal to 0.3 s. The final magnitude value is adjusted by adding 0.4, to account for the empirically determined average amplitude ratio of horizontal to vertical components (Kradolfer 1984).

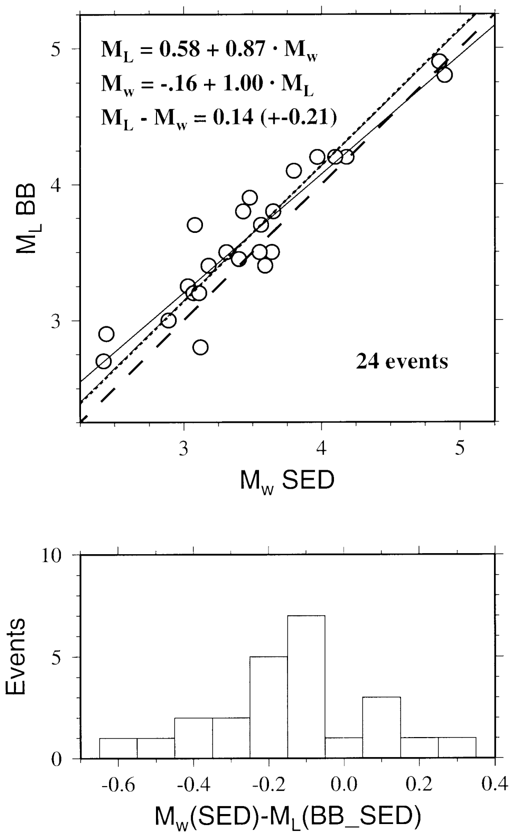


Figure 6.7. Comparison of M_L(BB-SED), M_L computed with broadband records by SED, versus M_w (SED) for 24 events in the Swiss region in the 1999-2001 period. Top: M_L (BB-SED) versus M_w(SED). Bottom M_w (SED) – MwM_L(BB-SED). Details in text.

To determine BB magnitudes, the broad-band signals are filtered with a recursive, time domain, impulse invariant Wood-Anderson filter. The maximum amplitude of the two filtered horizontal traces corresponding to ground displacement is converted to the equivalent signal on a Wood-Anderson seismograph (W-A) assuming an amplification of 2800. Based on a preliminary assessment, an additional 0.1 is added to the computed W-A magnitudes of the BB stations to be consistent with the SP magnitudes.

For events since 1999, M_L estimates from the broadband data, the short-period data and the combined data set can be compared. Considering the uncertainties in the original data, we suggest that all M_L estimates from SED can be considered equivalent.

The effects of station distribution on the M_L estimates was also checked. And our preliminary results (see discussion below) indicate that introduction of station corrections to the magnitude estimates will not change the M_L estimates systematically or significantly. We thus decided not to introduce such station corrections.

For a test set of 24 earthquakes that occurred 1999-2001 (Figure 6.1 top), we can directly compare waveform modeling derived M_W with M_L estimated only from broadband stations. Figure 6.7, shows the comparison (top regression analysis, bottom histogram of the M_W - M_L -differences) between the two. We find that M_L on average is 0.14 (+-0.21) units larger than M_W (short dashes); the scatter is surprisingly large. Linear regression with M_W as independent variable results in M_L = 0.58 + 0.87 M_W, and with M_L as independent variable in M_W = -0.16 + 1.00 M_L (thin solid lines). Regression analysis and average difference do not deviate much from each other.

Based on the above discussion, we subtract 0.2 magnitude units from M_L(SED) to convert the M_L(SED) values to unified magnitude M_W.

We conducted other tests to verify whether our M_L procedures could be influenced by the use of short-period sensors with a nominal Wood-Anderson calibration. We retrieved all available data from digital stations for the last 2 decades within a 600 km distance (for example from station GFRO in Grafenberg) and computed M_L for significant Swiss events for which we had already a good M_L from the Swiss network. We do not observe any systematic deviation between the two magnitude scales (Furrer, 1999).

6.3.2 Using fixed shifts rather than linear regressions in M_L- M_W regressions

Our strategy for converting from M_L to M_W was to keep the conversion simple and as accurate as the data allow. Applying the linear regression results appears first as the best solution. However, considering that the average difference and the regression results deviate only slightly combined with the uncertainties involved in the magnitude determination suggest to apply an average shift rather than linear regression. We also encounter another problem when using a linear regression. The M_L values currently are given with one decimal accuracy and adding (or subtracting) conversion terms based on the linear regression results would artificially change the frequency magnitude distribution. This is illustrated schematically in Figure 6.8. A uniform magnitude (Mold) distribution (top) with one decimal accuracy is converted to a new magnitude Mnew using a linear relation between Mold and Mnew (straight line in middle part), however, magnitude accuracy is at the one decimal level and the correction that is applied is "discretized" (stair steps) resulting in a altered distribution (bottom). Any slope different than 1 in the relation connecting "old" and "new" will cause stair-step corrections and thus a change in the distribution. We do not want to do that. One solution would be to recalculate all M_L values with two digit accuracy and then to apply the conversion (or to build in the linear regression based conversion when determining the individual station magnitudes). We are considering doing this in the future, but have not done so yet.

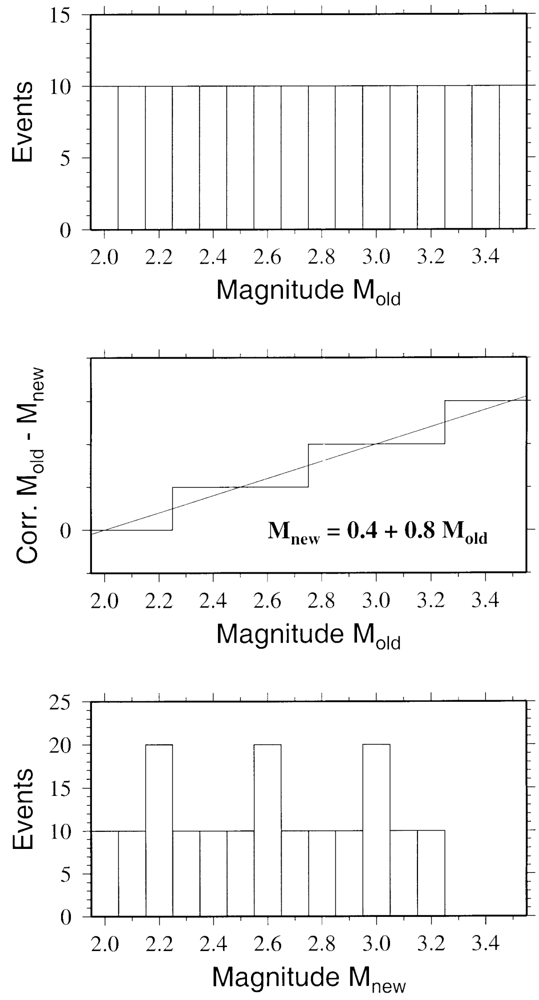


Fig. 6.8. Schematic illustration of the effects of adopting a linear regression in magnitude conversion. Top: uniform frequency-magnitude (M_{old}) distribution with one decimal accuracy. Middle: the straight line is the linear conversion to be applied to M_{old} toward the new magnitude M_{new}; however, magnitude accuracy is at the one decimal level and the correction is "discretized" (stair steps). Bottom: the resulting M_{new} frequency-distribution shows artificial steps in correspondence to the jumps in the discretized linear corrections. Details in text.

6.3.3 Comparison between short-period and broad-band M_L magnitudes

Having calibrated a M_L / M_W regression for the recent Swiss M_L, we need to check if this regression holds also for the 1975/1999 period. The transition from the SP- to the BB-network provides a unique opportunity for a comparison between two independent data sets to assess the consistency and reliability of the instrumental magnitudes. The data base for this comparison consists of all earthquakes with $M_L \geq 1.0$ recorded between January 1999 and June 2001 in Switzerland and surroundings. To expand the data set to higher magnitudes and larger epicentral distances, the M 5.0 Merano event of 2001/07/17 and the M 4.1 Bormio event of 2001/10/01 are also included.

The event magnitude, which is equal to the median value of all single station magnitudes, is hereafter called the SED magnitude. In addition to the SED magnitude, for each event we also calculated the median value of all short-period and broad-band station magnitudes separately, referred to as SP and BB magnitudes, provided that the event was recorded by at least five stations of both types. This condition is met by 137 events out of a total of 647. Figure 6.9 shows a plot of the corresponding SP- vs. BB-magnitudes as well as a histogram of the magnitude differences. The results show that on average the BB- and SP- magnitudes of the SED are consistent with each other, but that they scatter with a standard deviation of almost 0.2 magnitude units. The regression of the SP- on the BB-magnitudes supports this conclusion as well, whereas the regression of the BB- on the SP- magnitudes suggests that for magnitudes greater than about 3, the SP-magnitude values are somewhat larger than the BB magnitudes. As shown in Figure 6.10, the same analysis restricted to the 26 events with magnitude greater than 3 also suggests that for the larger events the SP magnitudes are on average about 0.1 units higher than the BB Magnitudes. However, considering the small number of data points and their large scatter, this could just as well be a fortuitous feature of the particular data set and of the fact that at higher magnitudes the signals at most short-period stations are clipped.

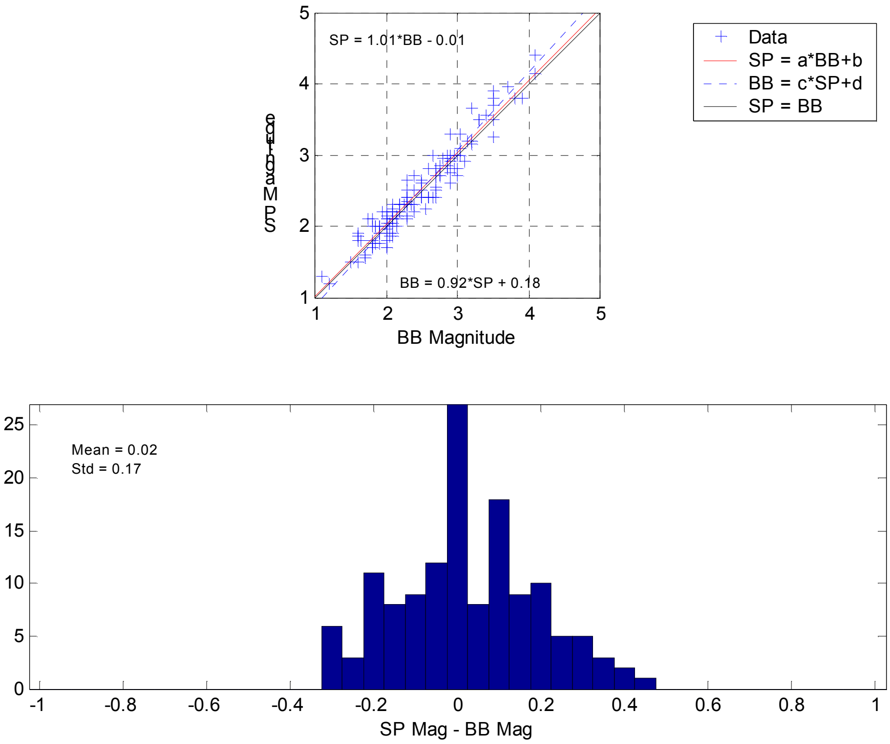


Figure 6.9. Differences between median short-period (SP) and median broad-band (BB) magnitudes for all events with at least 5 SP and 5 BB records. The data set comprises all events with M≥1.0 after 1999.

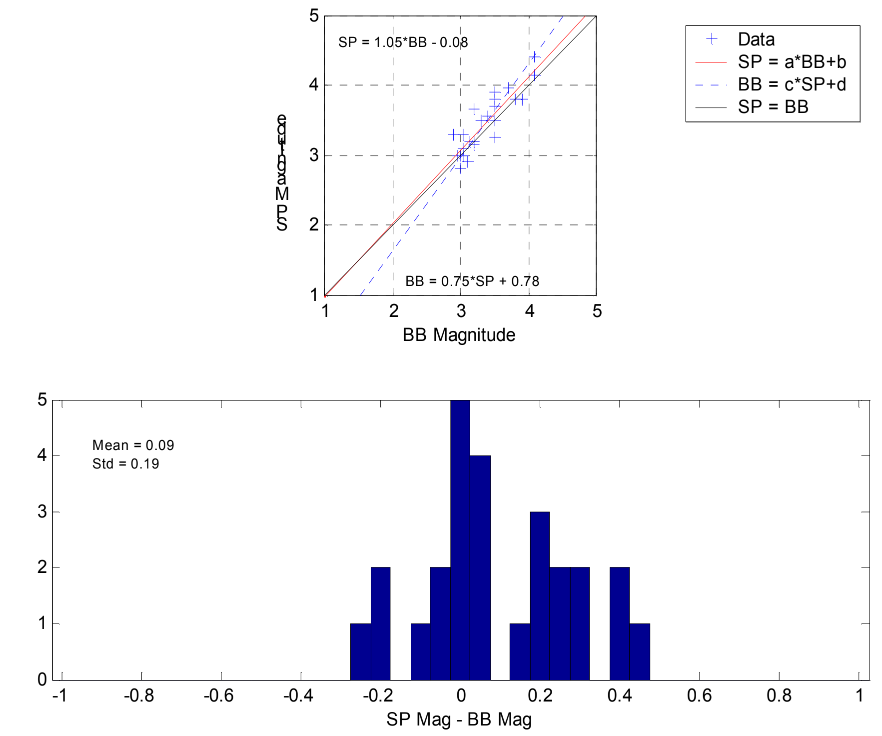


Figure 6.10. Same as Figure 6.9, for all events with M ≥ 3.

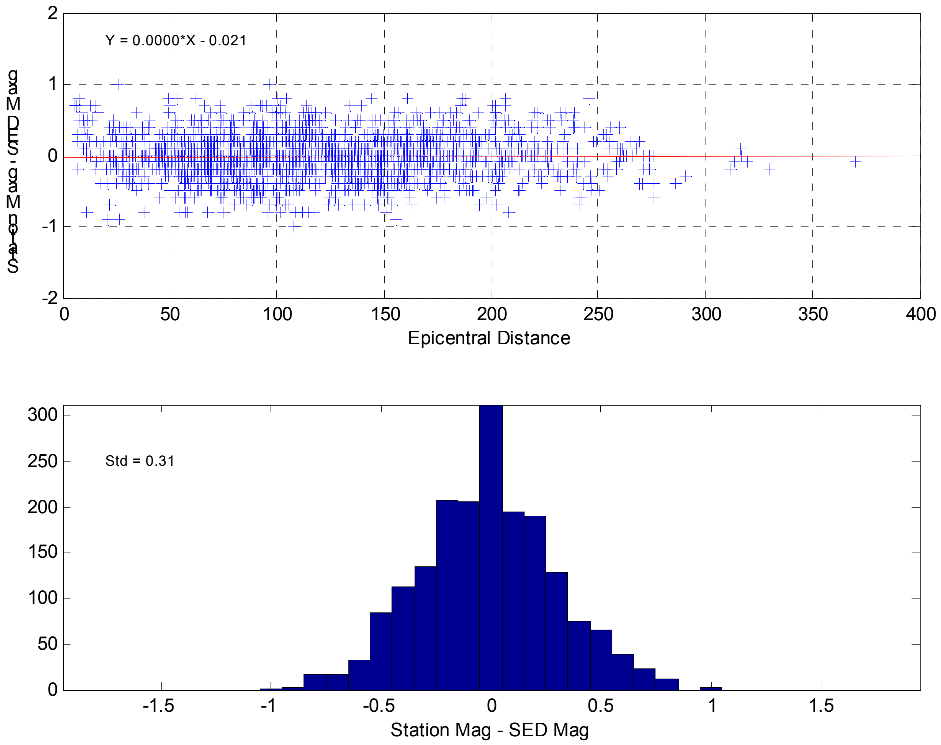


Figure 6.11. Deviations of single-station magnitudes from the median magnitude (SED) of each event. The data set comprises all relocated events with M≥2.4 after 1999.

Figure 6.11 shows a histogram of differences between individual station magnitudes and the median magnitude of each event as well as these differences as a function of epicentral distance. The data comprise 1854 single station magnitudes taken from a subset of the original data that includes only events with SED magnitudes greater than 2.3. These events have been reevaluated by a single analyst in order to ensure that analysis procedures were uniform and that large deviations of individual stations from the corresponding event magnitude are not due to errors in amplitude measurements. The results do not provide any evidence for a systematic dependence of individual station magnitudes on epicentral distance. This conclusion is supported also by similar analyses restricted to events with magnitudes greater than 3 or to epicentral distances greater than 30 km. Thus for magnitude determinations, the attenuation relationships of Kradolfer (1984) are in agreement with the available data.

Deviations of individual station magnitudes from the median value for a particular event scatter with a standard deviation of 0.3 but can also reach a whole magnitude unit. In the reevaluated data set, deviations larger than 1 magnitude unit were found to be due to errors in the amplitude readings.

In conclusion, within the uncertainty of the available data, the newer BB magnitudes, as determined by the routine procedures of the SED, are consistent with earlier SP magnitudes. From the comparison of SP and BB median magnitudes of the 137 events, the lower estimate of the random error at the level of 1 standard deviation of any given SED event magnitude is ± 0.2. From the larger scatter of individual station magnitudes relative to the corresponding median event magnitude, the uncertainty of event magnitudes determined from only a few stations is considerably larger.

Given that 0.1 is added routinely to the BB magnitudes to achieve conformity with the SP magnitudes and that the original Wood-Anderson gain of 2800 is used instead of the correct gain of 2080, as derived by Urhammer et al. (1990), the SED magnitudes are systematically higher by about 0.2 relative to the original Ml as defined by Richter.

6.3.4 M_L magnitude residuals of SED stations and their influence on b-values

Switzerland is a country with a strong geological contrast between the Alps and the Alpine Foreland. A recent study of site attenuation by Bay et al. (2002) found a statistically significant difference of a factor of about two in amplification between SED network sites in the foreland and Alps, respectively. Therefore, we decided to investigate the influence of these site amplifications on SED magnitudes and resulting b-values. Understanding the influence of magnitude residual is complicated by the fact that SED analog stations clip for larger events at closer distances, except for a few low gain stations.

We computed station magnitude residuals by subtracting the individual magnitudes at a station from the overall median magnitude for a particular event (SED magnitudes are the median of all contributing stations). These station residuals are, in general, constant with time, and can reach up to a difference of 0.2, on average. For three selected sites (BAL, OSS, and LLS), we plot the magnitude residual as a function of time in Figure 6.12. A map of the mean of all residuals is show in Figure 6.13, showing clearly the regional difference between Alpine Foreland and Alps; however, a few exceptions exit with stations in the Alps being a positive residual and foreland stations being a negative residual.

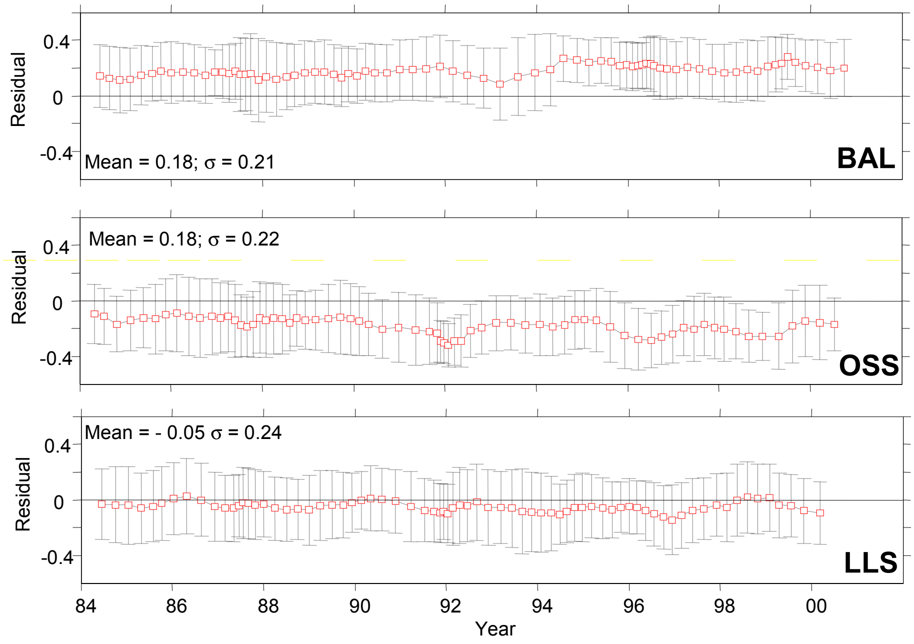


Figure 6.12. Top: Magnitude residual at station BAL, OSS, and LLS as a function of time. Using a moving average, the mean of the difference between the magnitudes at each station and the median SED magnitude is plotted.

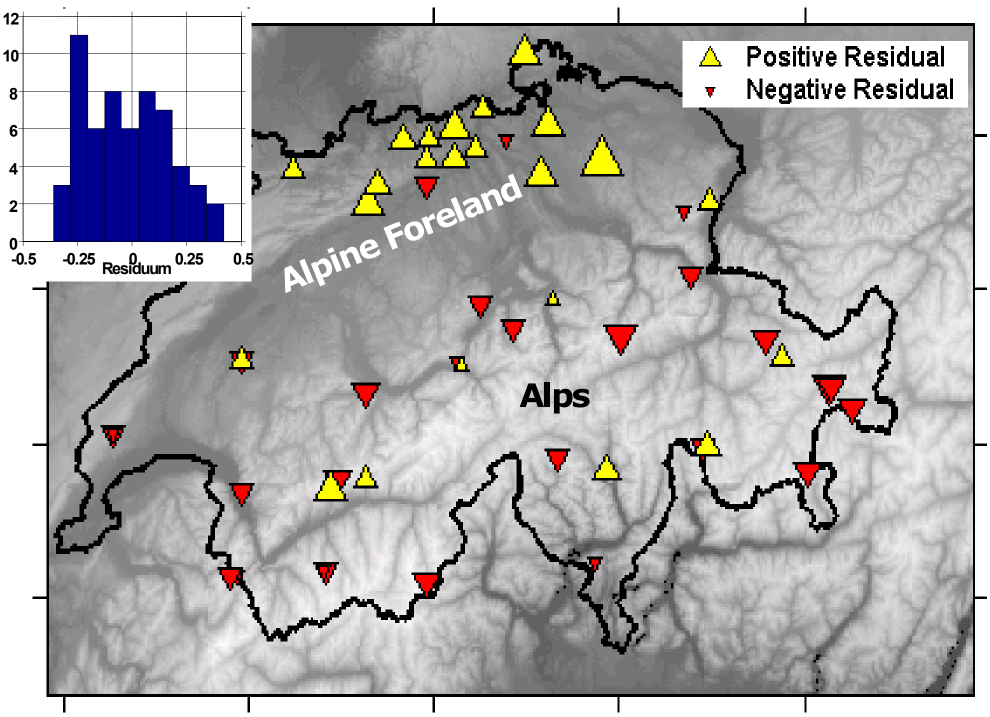


Figure 6.13. Map of the magnitude stations residual computed for the period 1992 – 2001. Yellow triangles indicate this site has a larger magnitude, averaged over all events, than the median SED magnitude. Smaller than average residuals are shown as inverted triangles. Symbol size according to residual size. The inset in the upper left shows the distribution of all residuals.

To estimate the influence of these site residuals on the SED catalogs and resulting b-values, we computed a corrected catalogue in the following manner: 1) Compute the mean site residual at each station, separate for the period 1984-1992 (location algorithm: hypo) and 1992-2001 (location algorithm: grid-search). 2) Compute the corrected median event magnitude, M_{corr}, for each event in the catalogue. 3) Compute the residual $\Delta m = M_{old} - M_{corr}$ for each event.

The mean correction in magnitudes (Figure 6.14) is with 0.015 very close to zero, but there is considerable scatter. Next, we address the question of a potential regional bias of the event magnitude correction, which would have an influence on regional b-values. We plot a map of residuals in Figure 6.15. Symbol colors differentiate positive and negative residuals; the symbol size is proportional to the correction (in 0.1 magnitude steps). Squares mark events whose magnitude did not change. The map contains all events with 2 <= M <= 5. We computed such maps for a number of magnitude ranges and periods. From Figure 6.15 we conclude that the individual event magnitude corrections are spatially quite scattered. There is, however, a predominance of large yellow triangles, particularly in the Basel and Wallis regions. This suggests that an over proportionally number of the magnitudes of larger events in the SED catalogue have been reduced by more than 0.1 magnitude units. This bias is likely caused by the predominance of low gain stations in the Alpine Foreland. No evidence was found for a possible bias of the smaller magnitude events.

To assess the influence of this potential magnitude bias on regional b-values, we compute b-value based on the maximum likelihood method (Aki, 1965; Bender, 1983) for the entire catalogue and selected sub-regions (Figure 6.16). For the overall catalogue, the increase in the b-value is less than 0.02 and well within the uncertainty. For sub regions such as the Basel and Wallis region, the change is generally smaller than 0.05. The maximum influence can be found when analyzing the combined seismicity in the Alpine Foreland (Figure 6.16). Here, the reduction of magnitudes of a number of larger events leads to an increase in the b-value of 0.08 (from 0.89 to 0.97). This difference, however, is not significant at the 90% confidence limit, when tested using Utsu (1992) test.

In conclusion, SED seismic stations show a regional magnitude bias due to local site conditions. This bias is in general stationary with time (Figure 6.12), and follows the Foreland-Alps tectonic boundary (Figure 6.13). The bias can be removed by introducing site-specific magnitude corrections; however, the corrected catalogue remains statistically indistinguishable from the original SED catalogue. Therefore, the instrumental SED catalogue does not correct for site-specific magnitude residuals.

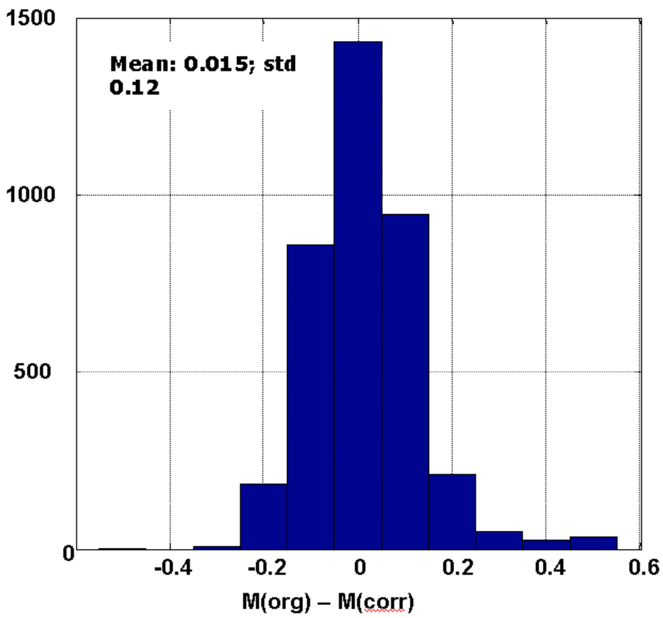


Figure 6.14. Histogram of the difference in magnitudes between the original and corrected catalogue.

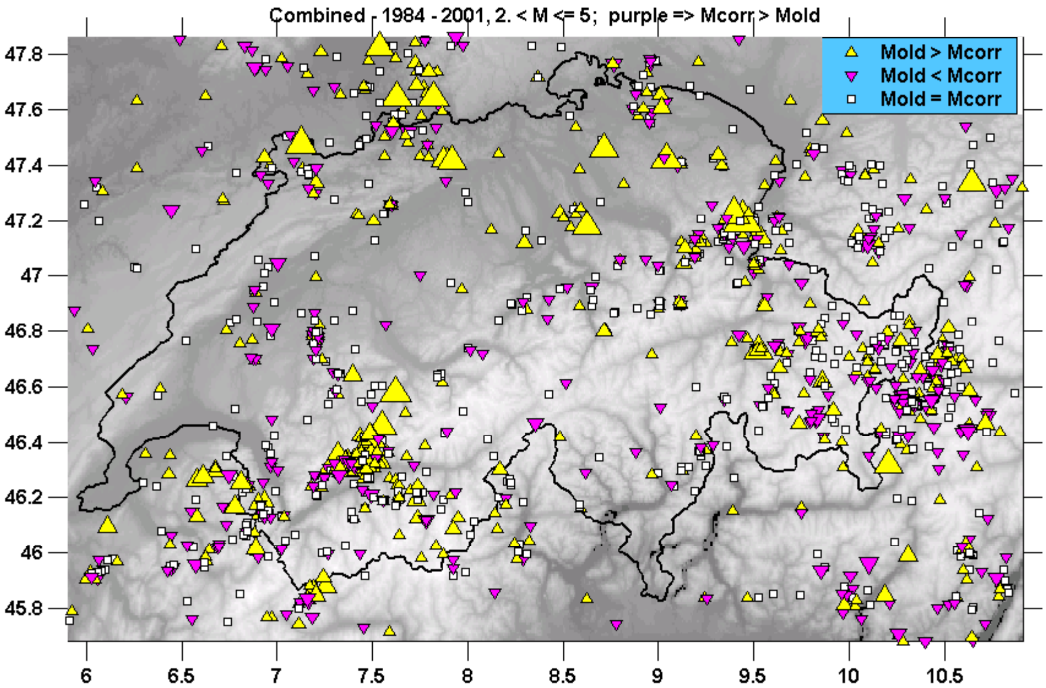


Figure 6.15. Map of the magnitude residuals for all events in the SED catalogue between 1992 and 2001 with a Magnitude of M>=2.0. The marker size is proportional to the residual (in 0.1 magnitude unit steps). Yellow (up) triangles show events for which the corrected magnitude is smaller then the original one, magenta (down) triangles mark the opposite. White squares mark events with no change in magnitude.

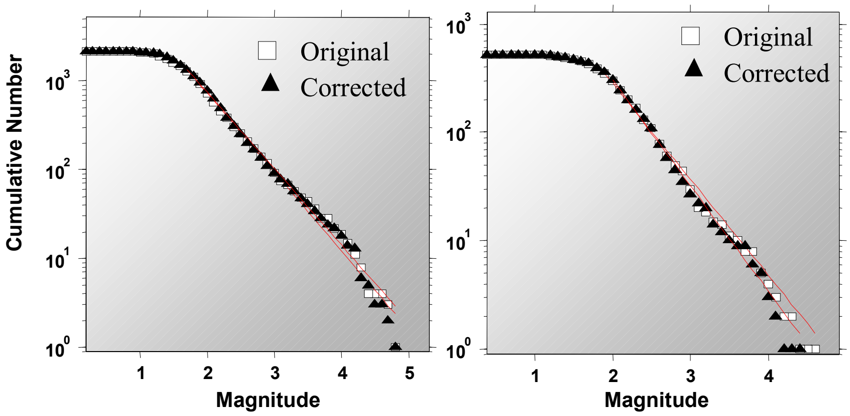


Figure 6.16. (Left) Comparison of the frequency-magnitude distribution of the original SED catalogue for the period 1992 – 2001(open squares) with the corrected catalogue (solid triangles). The difference in b-value of < 0.02 between the two catalogs is not statistically significant. (Right) Comparison of the frequency-magnitude distribution of the original SED catalogue for the Alpine Foreland for the period 1984 – 2001(open squares) with the corrected catalogue for the same regions (solid triangles). The corrected catalogs has a maximum likelihood b-value 0.08 higher than the original one; however, this difference is not statistically significant.

6.3.5 Calibration of M_L magnitudes from strong-motion data

The calibration of spectral strong-ground motion attenuation laws hinges on accurate magnitude calibrations. The magnitude calibration has been tested during a comprehensive analysis of attenuation for Switzerland. In Figure 6.17 we display the normalized excitation of ground motion at 40 km hypocentral distance for peak filtered amplitudes at 2Hz (column 1) and 10Hz (column 2). D1 (black dots) are excitation terms obtained from the inversion of short period data recorded before Jan. 2000 (Bay et al., 2001); as there are almost no M_w available for these events the relationship by Braunmiller, et al. (2001) is applied: $M_w = M_L - 0.2$ to transform M_L into M_w (A). D2 (gray dots) are inversion for independent broadband data from 15 events recorded after Nov. 1999 for which independent M_w exist. These higher quality data are independently processed from the D1 short period data and normalized to 40km distance with the attenuation functional developed by Bay et al. 2001; the average amplitude is computed for each event. LSQR D2 (gray solid line) is the corresponding linear least square fit, LSQR D1 (black solid line) is the least square fit of the short period data. The good agreement between the two lines in (A) suggest that the magnitude conversion is valid also for data that were not included in Braunmiller´s M_w - M_L regression. To further emphasize this, we also show that the fit is worse if we apply no correction (B) or if we adopt $M_w = M_L - 0.4$ (C).

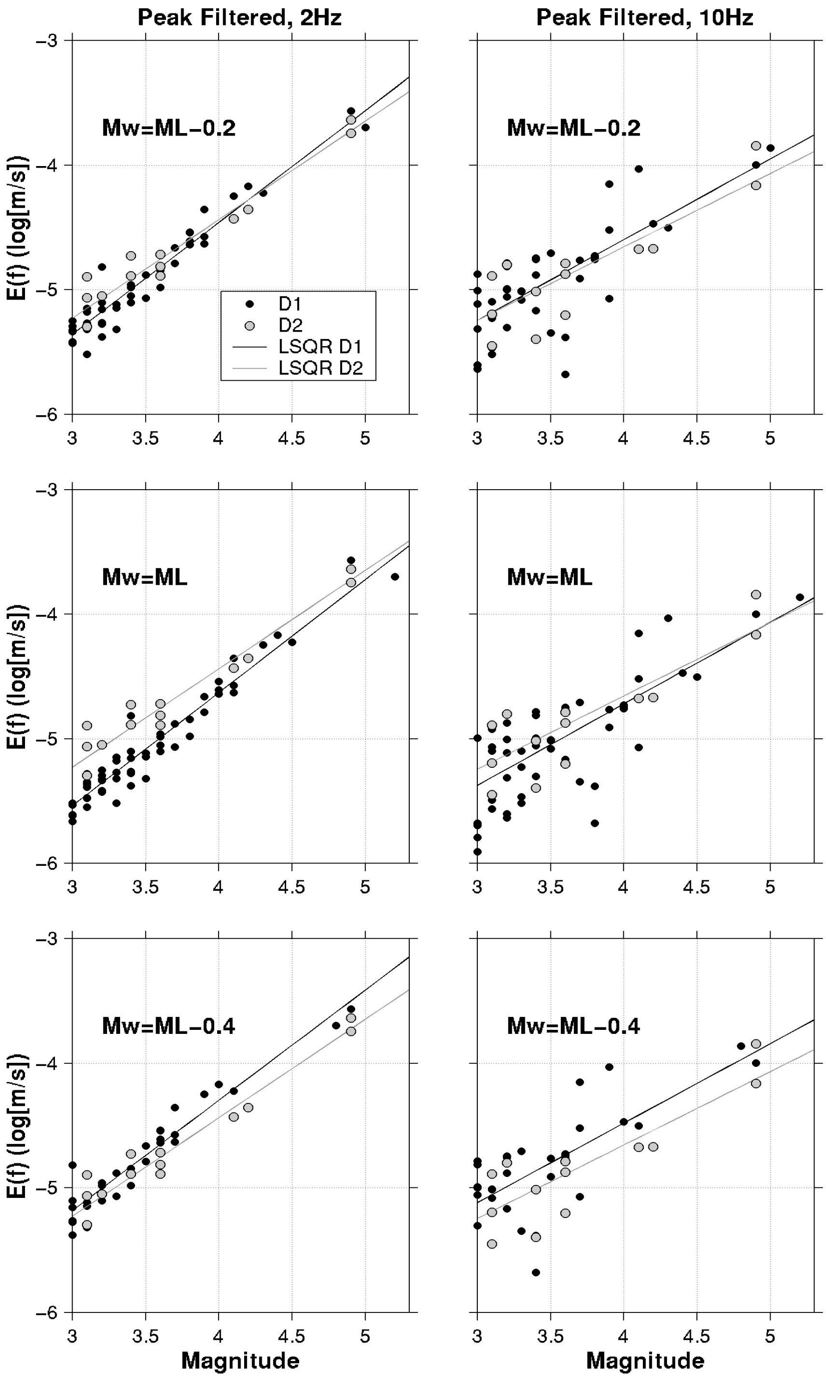


Figure 6.17. Magnitude calibration. All details in text.

6.4 Calibration of Mm for historical earthquakes in Switzerland

Using the Ms values computed for the early instrumental events (Chapter 6.2.1) and M_L for a few well controlled events, we define a calibration set of events used in Chapter 4 to estimate a macroseismic magnitude Mm calibrated with M_W.

6.5 Calibrating instrumental magnitudes of other agencies against M_W

Several observatories record seismic events in the Swiss border region, determine event locations and magnitudes. For events near the border, we expect that the location accuracy of the neighboring networks is probably similar to ours (and thus their magnitudes). For sets of border-events magnitudes of either network should not be substantially biased by large possibly ill-determined distance-attenuation terms and they are ideal for calibrating the magnitudes against each other.

For the border regions with Germany and France but less so for Italy, we have a sufficient number of earthquakes in our SED catalogue that also appear in catalogs of the respective country. We selected events within 20 km of the border that are listed in two catalogs (one of them SED), with location differences no larger than 10 km and time differences no bigger than 5s. We then calibrate the magnitude estimates provided by the other networks against our M_W estimates.

The results presented below show surprising systematic differences and scatter in the magnitude distributions, as indicated also in a previous study (Giardini et al., 1997). In our case, we restricted the analysis to events that were (presumably) relatively well recorded by the national networks since all events occurred inside the network coverage; for these events we expect consistent magnitude values (similar magnitudes for one event across the networks). We find a good agreement between the magnitudes determined by SED, LED, and Karlsruhe. For the other border areas, we observe that the LDG catalogue is internally consistent but systematically shifted (by more than 0.5 magnitude unit in both M_L and M_d), and that magnitudes at INGV are determined with too high scatter.

6.5.1 Border Germany-Switzerland

In the German-Swiss border region, two main instrumental catalogs exist besides the SED catalogue. From the mid-1970's until 1994, Karlsruhe University operated a seismic network in the Southern Rhinegraben. The network was then modified and became part of the "Landeserdbebendienst Baden-Württemberg" (LED).

For the Karlsruhe catalogue, we have a 150 event subset within 20 km of the Swiss border (on either side) that has been analyzed by Karlsruhe and the SED. Figure 6.18 shows the event distribution (top) and the magnitude difference-histogram (bottom). From the Karlsruhe catalogue we only used events bigger than M_L =1.5, thus we also excluded thus all SED M_L < 1.5 events from further consideration (and one event where the magnitude difference was larger than one unit). Events excluded are shown as black dots, events used for determining average differences and linear regression are large open circles. The scatter (or magnitude difference) is large. The average deviation and the largest number of events is close to -0.20 (+- 0.20), or in other words M_L(KHE) on average equals M_L(SED), M_L(KHE) is on average 0.2 units larger than M_W (SED). The data set cover only a limited range of magnitudes, and for example, no M > 3 event is in the combined data set. Linear regression results (with M_W (SED) and M_L(KHE) as independent variables, respectively) do not seem to fit the cloud of data points any better than the average difference. We thus decided to convert M_L(KHE) to unified magnitude M_W by subtracting 0.2 magnitude units.

The LED began operation in 1995 and since then an event data of set of 34 earthquakes has been located by the LED and the SED in the border region (M_L above 1.6). The distribution of magnitude differences and the average difference (-0.27 +- 0.15) is shown in Figure 6.18. The data set is small for linear regression analysis and the range of magnitudes is small (causing large uncertainties in the estimated slope of the regressed data). We thus convert M_L(LED) to unified magnitude M_W by subtracting 0.3 magnitude units.

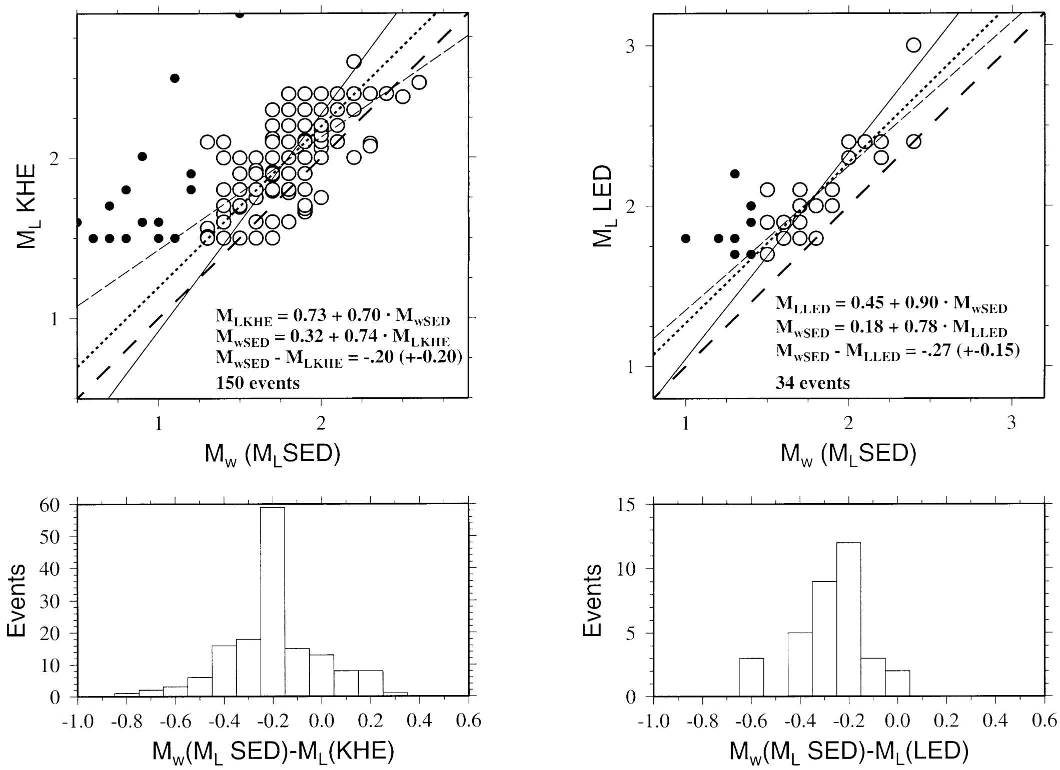


Figure 6.18. Left column. Comparison between M_L(KHE) from Karlsruhe and M_W(M_L-SED) magnitudes for 150 duplicate events in the Germany-Switzerland buffer zone. M_W(M_L -SED) are M_W magnitudes derived from M_L (SED) magnitudes. Top: M_L(KHE) versus M_W (M_L-SED); we display both independent regressions and the best constant shift; for completeness reasons, events indicated with black dots are not used in the regressions. Bottom: M_W (M_L-SED) – M_L(KHE). Right column. Same comparison between M_L (LED) and M_W (M_L-SED) magnitudes for 34 duplicate events. All details in text.

6.5.2 Border France-Switzerland

For the French-Swiss border, magnitude estimates from the SED and the LDG exist. LDG determines local magnitude M_L and duration magnitude M_d. For M_L(LDG), the common data set contains 61 events with M >= 2.5 (the lower limit in the LDG catalogue). The distribution is shown in Figure 6.19. The average difference between M_W and M_L(LDG) is -0.59 (+- 0.18) magnitude units. The scatter is not worse than for the Karlsruhe or LED data sets (relative to SED) but the average difference is significantly larger. Linear regression results give very similar differences in the magnitude range where data pairs exist. We convert M_L(LDG) to unified magnitude M_W by subtracting 0.6 magnitude units. For M_d (LDG), 71 common events from the border region are in the LDG and the SED catalogs. The average difference between M_W and M_d (LDG) is -0.81 (+- 0.26) magnitude units (Figure 6.19). The scatter is bigger than for the M_L(LDG), Karlsruhe or LED data sets. At large M_W, the M_d (LDG) magnitude scale seems to saturate and our average difference may actually (slightly) underestimate the true magnitude bias in the M_d(LDG) data. We convert M_d(LDG) to unified magnitude by subtracting 0.8 magnitude units. For larger events, M_d(LDG) starts to saturate. For earthquakes in France that are in our final catalogue and where the final unified magnitude is based on French magnitude estimates, we use for larger events M_L(LDG) to convert to M_W whenever possible to avoid this saturation problem.

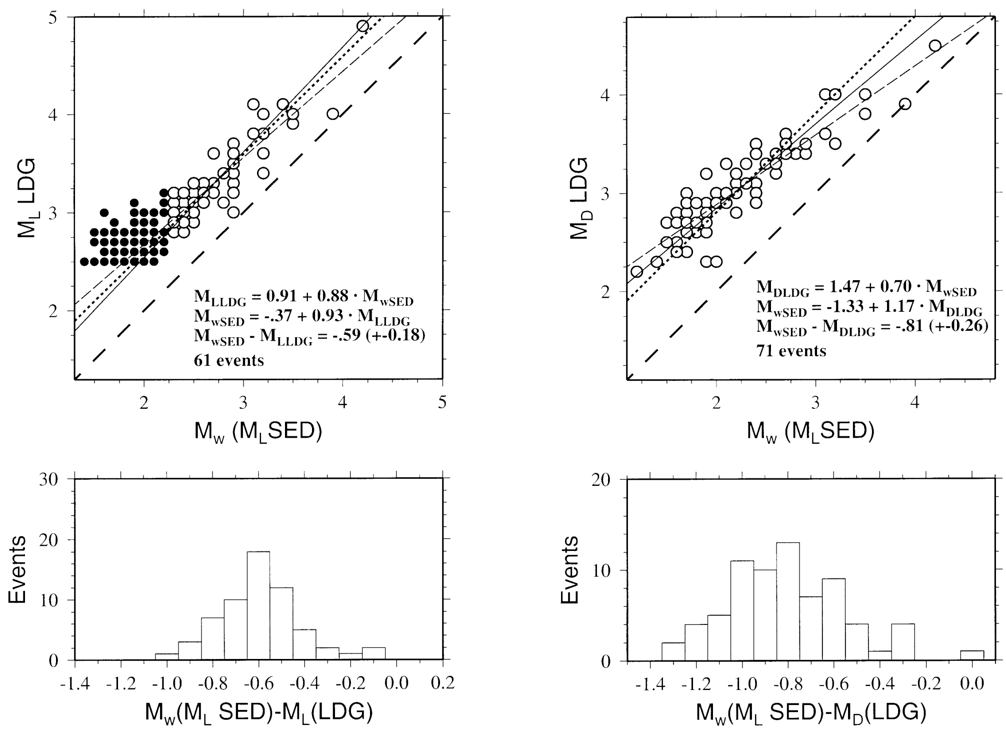


Figure 6.19. Left column. Comparison between M_L(LDG) and M_W(M_L -SED) magnitudes for 61 duplicate events in the France-Switzerland buffer zone. M_W (M_L -SED) are MW magnitudes derived from M_L(SED) magnitudes. Top: M_L(LDG) versus M_W (M_L -SED); we display both independent regressions and the best constant shift; for completeness reasons, events indicated with black dots are not used in the regressions. Bottom: M_W (M_L-SED) – M_L(LDG). Right column. Same comparison between M_d(LDG) and M_W (M_L-SED) magnitudes for 71 duplicated events. All details in text.

6.5.3 Border Italy-Switzerland

We have only few events that are listed in the SED and the Istituto Nazionale di Geofisica (ING) catalogs. ING determines M_L and M_d. For M_L(ING), the common data set consists of only 15 M >= 3.5 events (Figure 6.20). The scatter M_L(ING) versus M_W is large, differences of 1-1.5 magnitude units are not uncommon. The scatter is also reflected in the linear regression lines that cut through the data cloud in an apparent random fashion. Even the average difference (M_W - M_L(ING) = -0.30 +- 0.48) does not describe the individual differences adequately. We subtract 0.3 magnitude units from M_L(ING) to get unified magnitude M_W simply because we lack better information about the nature of the M_L(ING) data set. For M_d(ING), the situation is similar (Figure 6.20). Only 12 events in the border region are in both catalogs. Although the data set is small, we applied a correction of +0.1 units when converting M_d(ING) to unified magnitude M_W.

6.5.4 Border Austria-Switzerland

We do not have duplicate events in the buffer zone with Austria, and therefore we can not calibrate a magnitude conversion relation. We take location and magnitude for Austrian events located west of 10.5°E from the Swiss catalogues, and Austrian ZAMG locations and magnitudes for events to the East. For events from the Austrian catalogue, the Austrian local magnitude M_L is used directly as M_W.

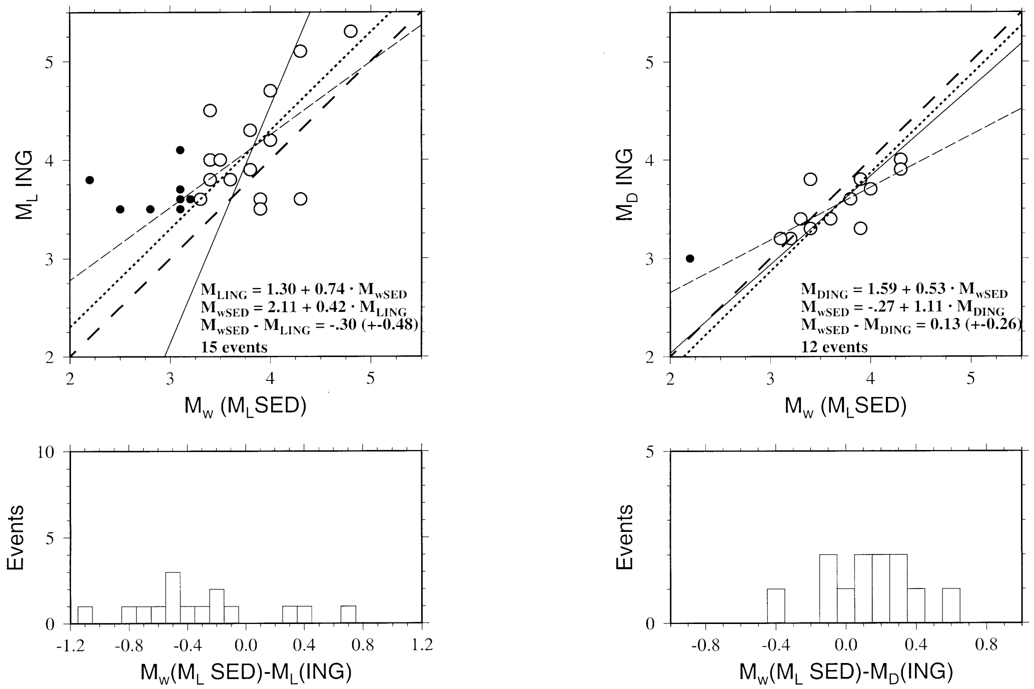


Figure 6.20. Left column. Comparison between M_L (ING) and M_W (M_L-SED) magnitudes for 15 duplicate events in the Italy-Switzerland buffer zone. M_W (M_L-SED) are M_W magnitudes derived from M_L(SED) magnitudes. Top: M_L(ING) versus M_W (M_L - SED); we display both independent regressions and the best constant shift; for completeness reasons, events indicated with black dots are not used in the regressions. Bottom: M_W (M_L-SED) – M_L(ING). Right column. Same comparison between M_d(ING) and M_W (M_L-SED) magnitudes for 11 duplicated events. All details in text.

6.6 Determination of M_W for Swiss events prior to 1975

For events prior to 1975 we have an internally consistent determination of intensities and a conversion relation to obtain a value for M_W. The uncertainty (2 standard dev.) of this M_W is in general 1 unit when derived from Io (see Section 4.4.2.3) and 0.5 units when derived from the whole macroseismic field (see Section 4.4.2.1). For close to 500 of these events an M_L value also exist. How and by whom this M_L value was determined is not clear at this time. In the annual reports of the SED prior to 1964 there is no mention of magnitudes but only information on amplitudes read from the few seismograms available at that time. Presumably the available Ml values were calculated from these amplitudes, but we do not know by what method and on the basis of what attenuation relation.

For a small number of events from this period we have M_S values. For these events, M_W is determined from M_S.

Finally we need to adopt a procedure to determine M_W for those events, for which we have both M_W from intensities and M_L. From the analysis of post 1975 instrumental magnitudes we see that individual station magnitudes scatter about the median value with a single standard deviation of 0.3 units and with possible outliers of more than 1 unit. Given a "sufficient" number of readings, the median magnitude value for a post-1975 event is estimated to have an uncertainty of +/- 0.2 units (1 stand. dev.). However, for events with only one or two usable amplitude readings (such as for events with M>4) the uncertainty is at least +/- 0.3 (1 stand. dev.) or +/- 0.6 (2 std's). Drawing an analogy from this analysis to the pre-1975 instrumental magnitudes, it is clear that the associated uncertainties are in the same range as the uncertainties of M_W derived from the intensities. Since the instrumental M_L values of pre-1975 events are not significantly more reliable than the intensity derived M_W values, we adopt the latter values as the "unified magnitude values" for this period. This has the advantage of ensuring an internally consistent catalogue rather than mixing apples and oranges.

6.7 Magnitude uncertainties and magnitude bounds

All ECOS events have a M_W and related uncertainty, as summarized also in the section 6.8 below. We have defined the procedures for the determination of magnitude uncertainties in the different sections. In some cases uncertainty is derived probabilistically from a standard deviation in a regression, in other cases it corresponds to limiting bounds, in others the given uncertainty is really just a guess. In general, our approach to assign uncertainties was conservative and uncertainty classes in ECOS should be treated as high confidence intervals which are exceeded by only few outliers.

6.8 Summary of magnitude conversions in the ECOS catalogue

Conversion scheme from different magnitudes to a unified moment magnitude M_W in ECOS.

Time period: 1975-2000:

Magnitude	Conversion formula	St. dev.	cM_w	Magnitude no.	Remark
M_L(SED)	M_L -0.2	±0.2	1	1	
M_S(SED)	M_S-0.2	±0.1	1	3	
M_w (SED)	M_w	±0.1	1	24	
M_L(LED)	M_L-0.3	±0.4	2	11	
M_L(KA)	M_L-0.2	±0.4	2	12	
M_L(BGR)	M_L	unknown	0	7	no calibration possible
M_L(BGR) referenced to SED	M_L-0.2	±0.2	1	7	for entries with M_L
M_L(BGR) referenced to LED	M_L-0.3	±0.4	2	7	for entries with M_L
M_L(BGR) referenced to KA	M_L-0.2	±0.4	2	7	for entries with M_L
M_L(BGR) referenced to LDG	M_L-0.6	±0.4	2	7	for entries with M_L
M_L(BGR) referenced to ISC	M_L	unknown	0	7	for entries with M_L
M_L(BGR_macro) referenced to SED	M_L-0.2	±0.2	1	8	for entries with M_L
M_L(BGR_macro) referenced to KA	M_L-0.2	±0.4	2	8	for entries with M_L
M_L(BGR_macro) referenced to LDG	M_L-0.6	±0.4	2	8	for entries with M_L
M_L(BGR_macro) referenced to LED	M_L-0.3	±0.4	2	8	for entries with M_L
M_L(BGR_macro)	M_L	unknown	0	8	for entries with M_L
M_S(BGR_macro)	M_S	unknown	0	10	for entries with M_S and no M_L

Table 6.2.: Conversion formulae to the unified moment magnitude M_W for the time period 1975-2000.

Magnitude	Conversion formula	St. dev.	cM_w	Magnitude no.	Remark
M_w (GSHAP)	M_w	unknown	0	13	
M_L (A)	M_L	unknown	0	21	
M_L(INGV)	M_L-0.3	±0.7	3	16	for entries with only a M_L
M_d(INGV)	M_d+0.1	±0.5	2	17	for entries with only an M_d
M_d(INGV), M_L(INGV)	[(M_L-0.3)+ M_d+0.1)]/2	±0.5	2	16, 17	for entries with M_d and M_L
M_L(LDG)	M_L-0.6	±0.4	2	11	for entries with only a M_L for time period 1962-1999
M_d(LDG)	M_d-0.8	±0.5	2	11	for entries with only an M_d for time period 1962-1999
M_L(LDG) M_d (LDG)	M_L-0.6	±0.4	2	11	for entries with M_d and M_L for time period 1962-1999

Table 6.2.: Conversion formulae to the unified moment magnitude M_W for the time period 1975-2000 continued.

Time period before 1975

Catalogue	Intensity Io Magnitude	Conversion formula	Standard deviation	cMw	Remark
Sisfrance	Io	Intermediate Io-M_w formula	unknown	3	if no IPSN magnitude given
IPSN	M_m(IPSN)	M_m	unknown	0	magnitude no 20
MECOS	Io	Intermediate Io-M_w formula	±1	2 or 3	Io<5: shallow event formula Io≥5: decision case by case Io≥6: regression
MECOS	M_L	M_L -0.2	±1	3	in case of no Io, standard deviation set by advise from D. Mayer-Rosa
MECOS	M_d	M_d	±1	3	in case of no M_W(SED), M_S(SED), M_L and Io
Macroseismic Germany		Intermediate Io-M_w formula		3	for entries with no magnitude
ISC	m_b(ISC)	m_b	unknown	0	magnitude no 22
	M_S(ISC)	M_S	unknown	0	magnitude no 23
NT4.1.1	M_S	M_S-0.2	unknown	0	
NT4.1.1	M_m	M_m	unknown	0	not used since always M_S available

Table 6.3.: Conversion formulae to the unified moment magnitude M_W before 1975.

Some events remain without a unified moment magnitude. These are either very old events that are only mentioned and regarded as earthquake but without any closer quantification or events for which we only obtained a maximum observed intensity Ix, but nothing else (e.g. some events from the macroseismic German catalogue).

7 Conclusions

The ECOS catalogue is the new standard for the assessment of seismic hazard in Switzerland and bordering regions. It contains over 20'300 events from the year 250 until present in the geographical limits 3°E / 44°N to 13°E / 51°N. A map of all events with magnitude $M_W \geq 3.0$ is shown below.

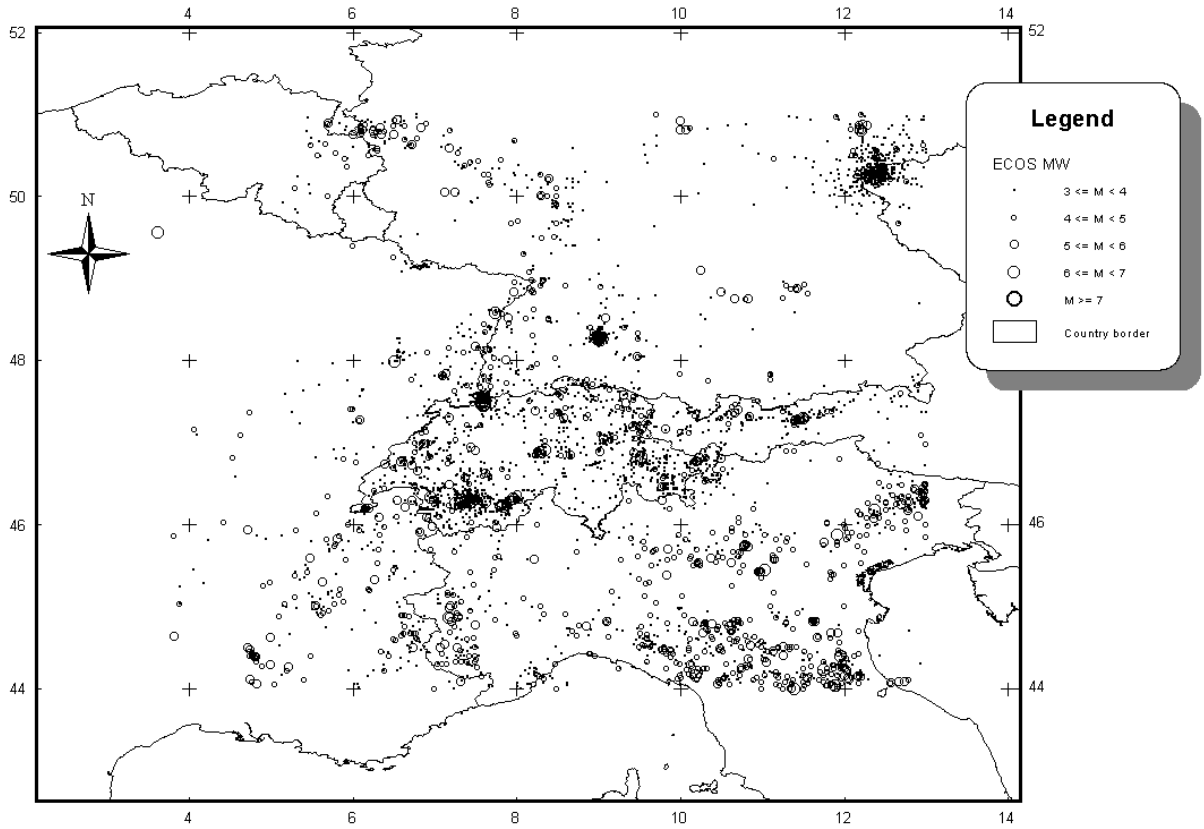


Figure 7.1. A map of events with $M_W \geq 3.0$ included in ECOS.

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9 Appendices

9.1 Appendix A: ECOS Database

9.2 Appendix B: Historical archives and sources

9.3 Appendix C: Historical bibliography

9.4 Appendix D: Catalogue conversion to ECOS format