Appendix H:

Swiss instrumental local magnitudes

Nicholas Deichmann, SED, 2009/12/17

Introduction

In the following we document procedures followed at the SED for calculating local magnitudes from instrumental records of Swiss earthquakes during the time period 1975-2008.

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 was continuously recorded on microfilm. As of 1984, the analog data is 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 was 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.

Changes in data acquisition systems:

1975- 1987: short-period, mostly single-component, analog telemetry (FM), recording on microfilm (Develocorder);
Sep.1983- Jan. 2002: as before, but centrally digitized at the SED, at first with a 10-bit digitizer (FHP) and later with a 12-bit digitizer (AHP); during this period digital data was also acquired from several local networks, but only the data of the Tseuzier and Nagra networks, recorded locally on Kinemetrics PDR-2 data loggers (PDR) and subsequently integrated into the event archive, were used routinely for magnitude calculations.
Sep.1998- present: broad-band three-component, 24 bit, digital telemetry.

Changes in routine analysis procedures:

Jan. 1975-Sep. 1983: vertical seismogram amplitudes (ground velocity) and periods measured with a ruler (in mm) on the microfilm projection table.

Oct. 1983 – Aug. 1995: mix of Develocorder amplitudes (in mm) and digital counts of the analog/digital converters; the Develocorder amplitudes and periods were measured either on the projected microfilm seismograms on the projection table or from paper plots of the digital signals, analyzed on a digitizing tablet; the digital counts and periods were determined interactively from the screen of a computer terminal; the latter became available only in 1992 and initially was used in parallel to the paper plots and digitizing tablet; older data could only be analyzed in this way retroactively for some chosen events.

Sep. 1995 – Aug. 1998: only digital counts of the analog/digital converters.

Sep. 1998 – Jan. 2002: mix of vertical-component short-period digital counts and Wood-Anderson filtered horizontal-component broad-band digital counts.

Feb. 2002 –present: Wood-Anderson filtered horizontal-component broad-band digital counts (with the exception of the short-period station LKBD2).

Consequently, for the purpose of magnitude analysis, it is expedient to subdivide the instrumental catalog in the following time intervals:

1975 – 1998: short-period analog and digital
1999 – 2001: transition from short-period digital to broad-band digital
2002 – present: broad-band digital

Distance attenuation

For both the short-period (SP) and the broad-band (BB) instruments, local magnitudes (Ml) are calculated according to

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

where A(W-A) is the equivalent amplitude in mm of a Wood-Anderson seismograph and Ao accounts for distance attenuation. The conversion from SP and BB amplitude measurements to equivalent W-A amplitudes is documented in the following sections.

The empirically determined distance correction used for Switzerland is (Kradolfer 1984):

$$-\log Ao = 0.0180 * D + 1.77 \quad \text{for } D <= 60 \text{ km}$$
and
$$-\log Ao = 0.0038 * D + 2.62 \quad \text{for } D >= 60 \text{ km}.$$

A comparison of this attenuation relationship with several other attenuation relations is shown in Figure 1. The SED relation is not calibrated for distances below about 20 km, and for distances below 10 km it leads to a severe overestimation of the magnitudes. Between about 20 and 300 km, the relationships used in Switzerland and south-western Germany (Stange, 2006) are very similar.

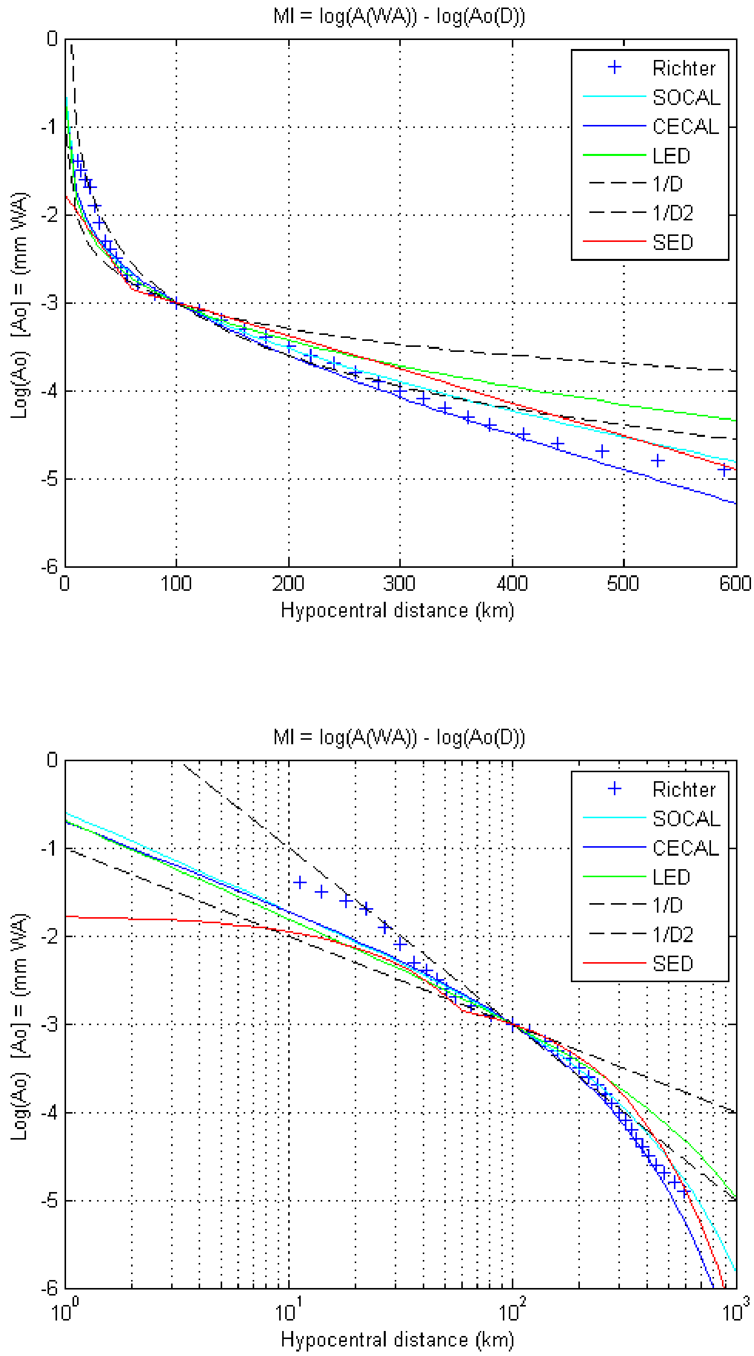

Figure 1: Comparison of the magnitude attenuation relationship used in Switzerland (SED, Kradolfer, 1984) with those of other institutions: Southern California (SOCAL, Hutton & Boore, 1987), Central California (CECAL, Bakun & Joyner, 1984), South-western Germany (LED, Stange, 2006) and Richter (1958). Note that the epicentral distances given by Richter (1958) have been converted to hypocentral distance assuming a focal depth of 10 km. The SED relation is not calibrated for distances below about 20 km, and for distances below 10 km it leads to a severe overestimation of the magnitudes. Between about 20 and 300 km, the relationships used in Switzerland and south-western Germany (Stange, 2006) are very similar.

Magnitudes from broad-band data

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 in order for them to be consistent with the SP magnitudes.

To assess the uncertainty of the Swiss instrumental magnitudes and possible systematic station effects, we analyze the most recent time period covering the years 2002 – 2008, during which data acquisition and analysis procedures did not change and the network configuration was reasonably stable.

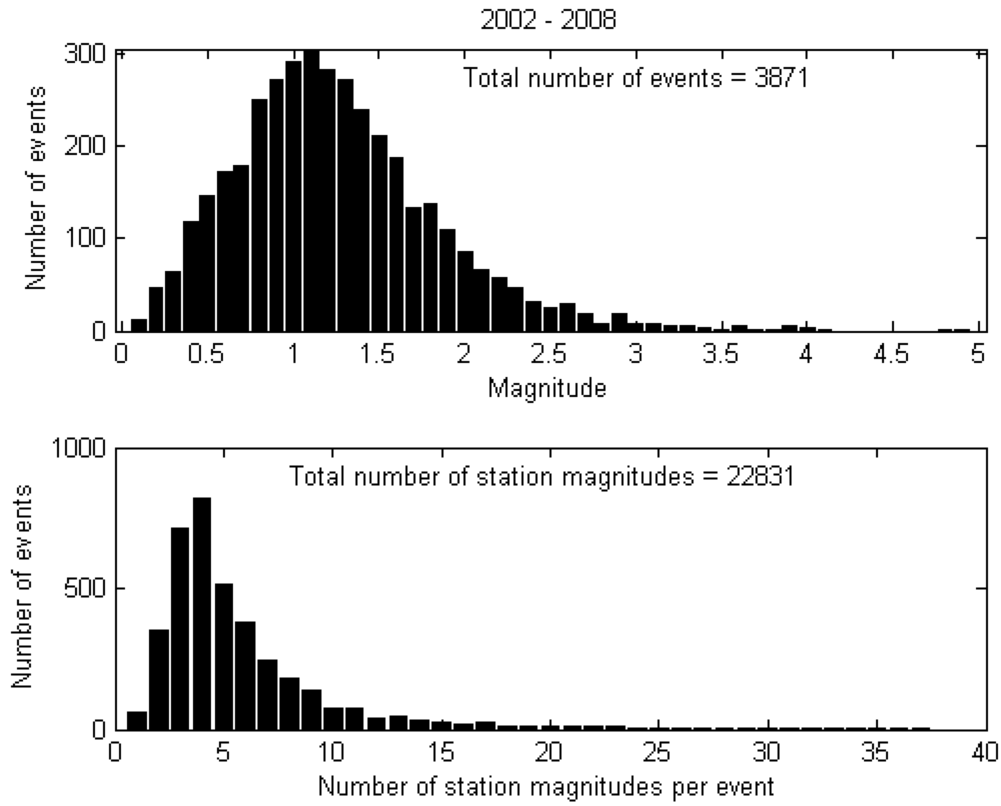

Figure 2: Magnitude histogram and histogram of the number amplitude readings per event for all available events with Ml > 0, for the period 2002 – 2008. The median number of amplitude readings per event is 4.

Data overview

Figure 2 shows the magnitude distribution for this time period for all events with Ml > 0 and without any restrictions on the minimum number of amplitude readings per event. Many events have only a small number of amplitude readings (the median number per event is 4). For a meaningful comparison between individual station magnitudes and the event magnitude calculated from their median, we restrict our data set to those events with at least three amplitude readings. For this data set that comprises 3465 events and 22006 station-distance pairs (the median number of magnitude readings per event is 5), Figure 3 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 hypocentral distance. From this Figure we can draw two important conclusions:

1. except for distances less than about 10-20 km, for which the Swiss attenuation relation was not calibrated, there is no discernible distance bias;
2. the individual station magnitudes scatter with a standard deviation of 0.33 about the median value for each event.

We also note that there are several individual station magnitudes that deviate by more than a whole magnitude unit from the median value. In most cases, these must be ascribed to errors of the analysts and should be regarded as outliers.

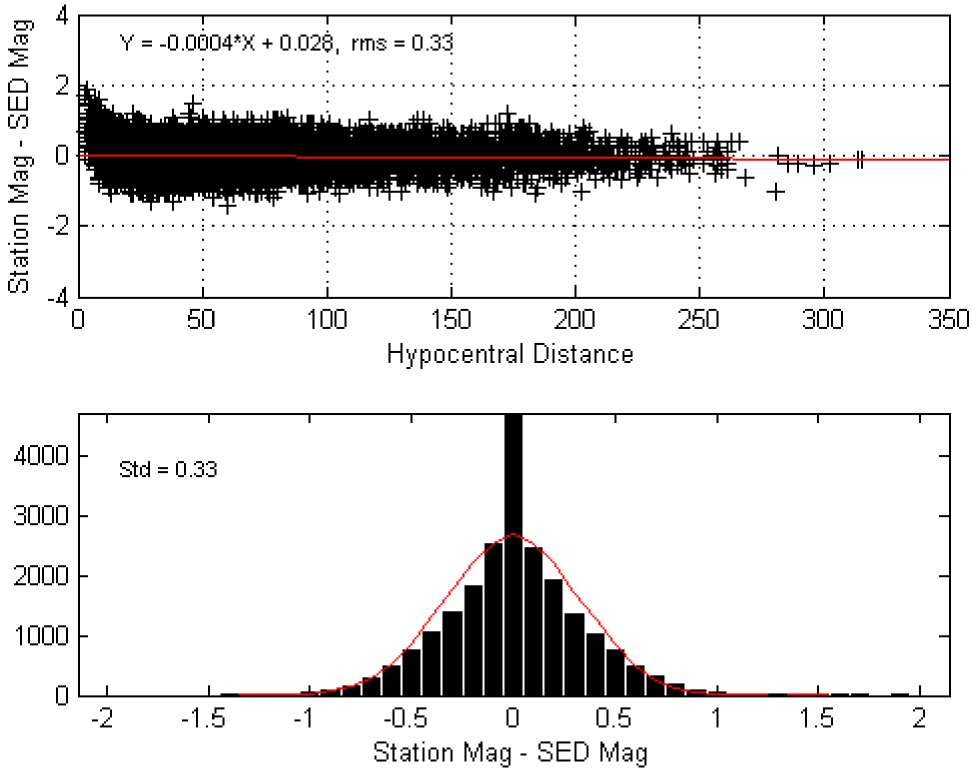

Figure 3: Station magnitudes – SED magnitude as a function of hypocentral distance and as histogram for the years 2002-2008 for all events with at least three amplitude readings. The red curve around the histogram corresponds to a normal distribution with the same standard distribution as the magnitude data. The data set comprises 3465 events and 22006 station-distance pairs. The median number of amplitude readings per event is 5.

Station residuals

For an assessment of station residuals (station magnitude minus event magnitude) it is important to minimize the effect of a possible bias due to poorly constrained event magnitudes and due to clusters of a large number of small co-located events. We therefore limit out analysis to a subset of events comprising only those events with magnitudes >= 2.0 and with at least 7 amplitude readings per event. The histogram of differences between individual station magnitudes and the median magnitude of each event as well as these differences as a function of hypocentral distance for the 360 events and the 5601 station-distance pairs of this data subset is shown in Figure 4.

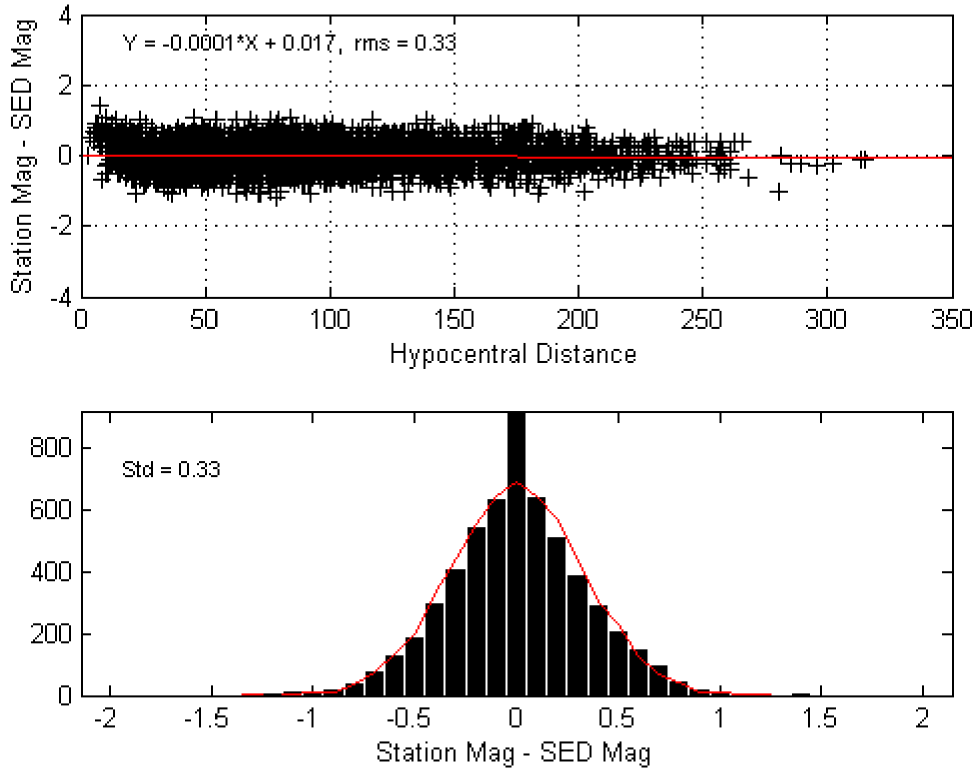

Figure 4: Station magnitudes – SED magnitude as a function of hypocentral distance and as histogram for the years 2002-2008 for all events with Mag(SED) >= 2.0 and at least seven amplitude readings. The red curve around the histogram corresponds to a normal distribution with the same standard distribution as the magnitude data. The data set comprises 360 events and 5601 station-distance pairs. The median number of amplitude readings per event is 14.

The number an size of the outliers are reduced significantly compared to the larger data set shown in Figure 3, but the standard deviation of the individual station magnitudes relative to the event magnitude remains 0.33. Again, there is no discernible distance bias for distances beyond 10-20 km.

Table 1 lists the station residuals based on the reduced data set of Figure 9. As already noted by Braunmiller et al (2005), based on a similar analysis of the 1999 – 2001 data, there is a tendency for foreland stations to have positive residuals (higher magnitudes) and for alpine stations to have negative residuals (lower magnitudes) However, there are several stations that are contrary to this trend. Thus the alpine station CHIR2 (located close to DOETR, NARA and TONGO with residuals of 0.12 – 0.17) has a residual of almost 0.4; ACB and STEIN in the northern foreland (close to WILA, SLE and ZUR with positive residuals of 0.22 – 0.48) have negative residuals between -0.21 and -0.24; SALAN and GRYON with residuals around -0.5 are located in the same region as DIX, EMV, AIGLE and SENIN with average residuals around 0. It is also noteworthy that the residuals of the three stations LIENZ, CHKAM and KAMOR, located within about 1 km from each other, vary between –0.14 and +0.08. Thus differences of 0.2 units are possible even at small scales. However, whether some of the larger discrepancies, such as those of SALAN and GRYON, might be due to erroneous gain settings needs to be checked before drawing any further conclusions from these observations.

STN	TS	N	MR	STD
WILA	F	182	0.48	0.23
CHIR2	A	35	0.39	0.29
SLE	F	211	0.35	0.24
TORNY	F	154	0.32	0.26
ZUR	F	140	0.30	0.25
BALST	F	194	0.23	0.22
SULZ	F	190	0.23	0.29
MUO	A	169	0.18	0.24
DOETR	A	40	0.17	0.19
NARA	A	40	0.16	0.25
TONGO	A	29	0.12	0.16
HASLI	A	200	0.11	0.23
BRANT	F	124	0.10	0.19
KAMOR	A	43	0.08	0.25
LKBD2	A	73	0.07	0.20
DIX	A	140	0.04	0.31
WEIN	F	89	0.03	0.24
GIMEL	F	128	0.02	0.27
APL	A	44	0.01	0.20
AIGLE	A	151	0.01	0.21
EMV	A	144	-0.00	0.29
TRULL	F	78	-0.01	0.23
BOURR	F	154	-0.03	0.26
DAVOX	A	142	-0.03	0.31
MUGIO	A	168	-0.03	0.22
SENIN	A	171	-0.03	0.28
FUSIO	A	222	-0.04	0.21
CHKAM	A	37	-0.05	0.20
FLACH	F	94	-0.06	0.24
RITOM	A	31	-0.09	0.23
BNALP	A	215	-0.10	0.23
WIMIS	A	159	-0.12	0.20
VDL	A	155	-0.12	0.22
MMK	A	148	-0.13	0.31
PLONS	A	179	-0.13	0.31
FUORN	A	141	-0.13	0.28
BERNI	A	132	-0.13	0.29
LIENZ	A	67	-0.14	0.28
ACB	F	102	-0.21	0.24
STEIN	F	80	-0.24	0.20
LKBD	A	163	-0.28	0.27
LLS	A	170	-0.31	0.26
GRYON	A	101	-0.48	0.27
SALAN	A	122	-0.55	0.30

Table 1. Mean station residuals sorted in descending order for the period 2002 – 2008, based on events with Mag(SED) >= 2.0 and with at least seven amplitude readings per event. STN: station name, TS: tectonic setting (A = Alps, F = Foreland), N: number magnitude values per station, MR: Mean station residual (station magnitude – median event magnitude), STD: standard deviation of the residuals relative to the mean. The data set comprises 358 events and 5596 station magnitudes. The median number of amplitude readings per event is 14. The two simple dashed lines separate those stations with absolute residuals greater than 0.2 magnitude units from the rest.

Error assessment

The uncertainty of the median magnitude value for each event is a direct function of the uncertainty of each station magnitude and of the number of amplitude readings from which the median value for each event was calculated. If this information were available for every event, an estimate of the corresponding magnitude uncertainty would be straightforward. From the analysis of the scatter of the station magnitudes about the median value, we can deduce an estimate for the mean uncertainty of a single station magnitude of 0.33 magnitude units (one standard deviation). The number of amplitude readings that go into the calculation of the median value for each event is known for almost al the events in the period 2002-2008. For the years between 1999 and 2001 this information is available only for some of the events, and for the years before 1999 it is missing almost entirely. Thus, in the following, to attribute a consistent quality attribute to the catalog magnitudes as a whole, we derive a magnitude-dependent error estimate.

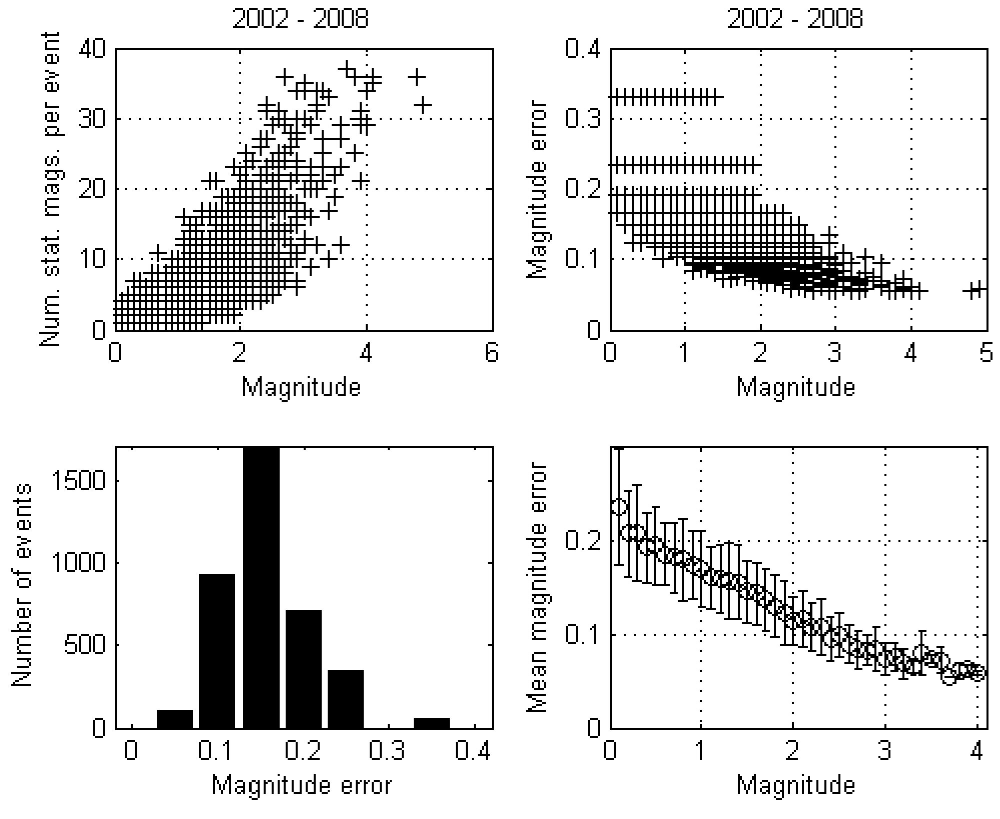

Figure 5: Error estimates of the broad-band magnitudes for the period 2002 – 2008; top left: number of amplitude readings per event vs. magnitude; top right: magnitude error for each event vs. magnitude; bottom left: histogram of magnitude errors (mean error = 0.16); bottom right: mean magnitude error and standard deviation of the event magnitude errors per 0.1 magnitude bins vs. magnitude. Note that each cross in the two top panels can represent multiple data points.

For the broad-band data of 2002-2008, Figure 5 (top left) shows how in general the number of amplitude readings increases with increasing event magnitude. Assuming that the scatter of the station magnitudes about the median value corresponding to the event magnitude, can be approximated by a normal distribution with mean 0 and standard deviation 0.33, we can assign an expected error to each event magnitude by dividing 0.33 by the square-root of the number of magnitude readings for each event. The result is shown in the top right panel of Figure 5. The bottom left panel of Figure 5 shows the distribution of these errors in bins of 0.05 magnitude units. The mean error over all events and all magnitudes is 0.16 magnitude units. As expected, the mean error decreases as the number of magnitude readings per event Increase: for the data set in Figure 3 (at least 3 amplitude readings per event) the mean error is 0.15 and for the data set in Figure 4 (at least 7 readings and magnitudes >= 2.0) the mean error is 0.09. The bottom right panel of Figure 5 shows mean errors and their standard deviations for magnitude bins of 0.1 units as a function of event magnitude, based on the data in the top right panel of Figure 5.

Given the fact that event magnitudes are median values rounded to one decimal, the formally computed errors smaller than 1 for magnitudes > 2.5 in Figure 5 are deemed unrealistic in practice. For the purpose of assigning uncertainties to the local magnitudes of the entire instrumental catalog, based on these results, we therefore propose the following errors (one standard deviation):

Ml <= 1.0:	+/- 0.20
1.0 < Ml < 2.0:	+/- 0.15
Ml >= 2.0:	+/- 0.10

Magnitudes from short-period data

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 below by the natural frequency of the seismometers (0.5 - 1 Hz) and above 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, the dominant period is assumed to be 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).

Comparison between short-period and broad-band magnitudes

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 magnitude >= 1.0 recorded between January 1999 and December 2001 in Switzerland and surroundings.

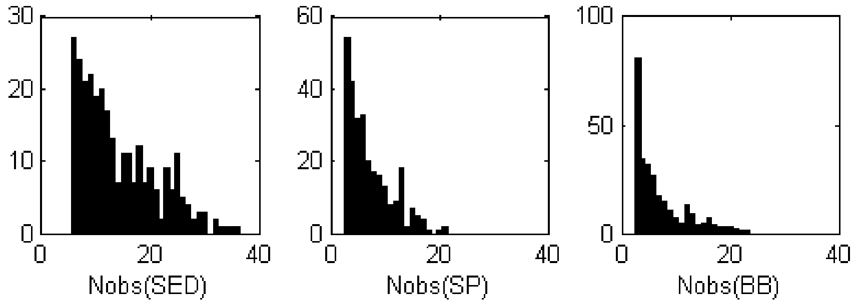

Figure 6: Histograms of the number of observations per event for calculating the overall magnitude (SED) and based only on short-period data (SP) or broad-band data (BB) used for the SP and BB magnitude comparison for the years 1999-2001. The data set includes only events with at least three amplitude readings.

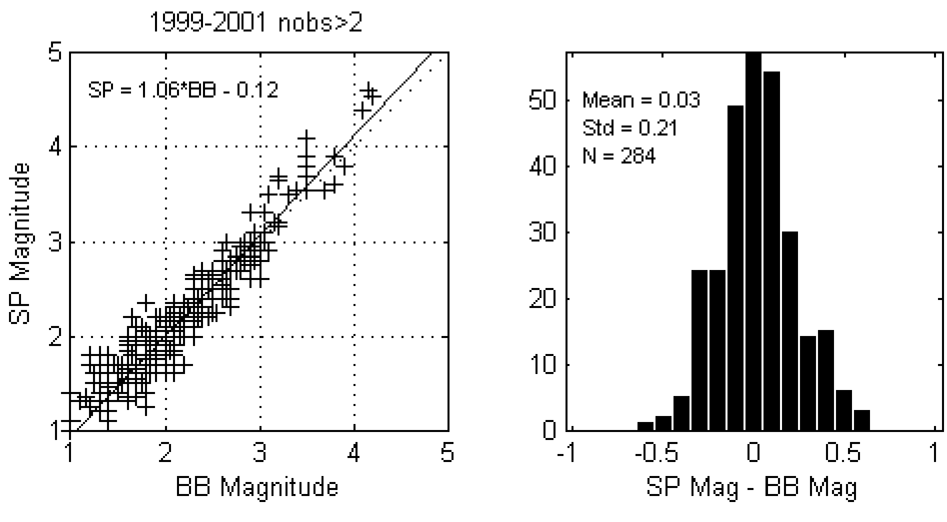

Figure 7: Comparison of event magnitudes for the years 1999-2001 calculated from short-period (SP) and broad-band (BB) records for events with Mag(SED) >= 1.0 and with at least three amplitude readings.

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 three stations of both types. This condition is met by 284 events (see Figure 6 for histograms of the number of amplitude readings per event for each data set). Figure 7 shows a plot of the corresponding SP- vs. BB-magnitudes as well as a histogram of the magnitude differences. The resulting regression coefficients, for mag(SP) = a * mag(BB) + b, are

$$a = 1.06 +/- 0.02, b = -0.12 +/- 0.04$$

The mean and standard deviations of the differences are 0.03 and 0.21.

The regression between SP and BB-magnitudes was calculated on the basis of the magnitude-dependent errors of 0.1 - 0.2 units for both variables. Although the regression coefficient is close to 1, SP magnitudes tend to be slightly higher than BB magnitudes for events larger than 3. 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. 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 0.21 magnitude units. This scatter would be expected for the difference between two data sets with a standard deviation of about 0.15 each, which is consistent with the previously derived average uncertainty of the broad-band data.

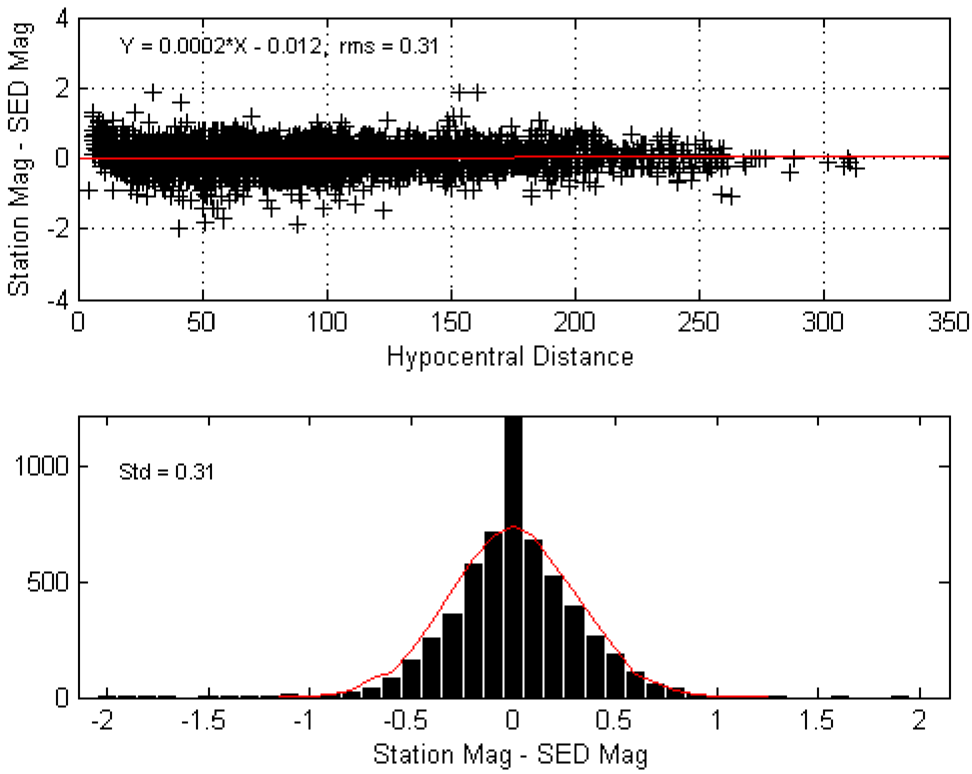

Figure 8: Station magnitudes – SED magnitude as a function of hypocentral distance and as histogram for the years 1999-2001 with Mag(SED) >= 1.0 and with at least three amplitude readings per event. The red curve around the histogram corresponds to a normal distribution with the same standard distribution as the magnitude data. The data set comprises 284 events and 5758 station-distance pairs (3303 SP and 2455 BB).

Figure 8 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 hypocentral distance. The data comprise 1758 single station magnitudes. The results do not provide any evidence for a systematic dependence of station magnitudes on hypocentral distance. This conclusion is supported also by similar analyses restricted to events with magnitudes greater than 2.3 or to hypocentral distances greater than 20 km. Thus for magnitude determinations from stations at distances beyond about 20 km, 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.

Conclusions

1. From an analysis of the broad-band data collected over the period 2002-2008, individual station magnitudes scatter with a standard deviation of 0.33 about the median value for each event and except for distances less than about 10-20 km, for which the Swiss attenuation relation was not calibrated, there is no discernible distance bias.

2. Uncertainties of event magnitudes are larger for small magnitudes and smaller for larger magnitudes. For the purpose of assigning uncertainties to the local magnitudes of the entire instrumental catalog, we therefore propose the following errors (one standard deviation): +/- 0.2 for Ml <=1.0, +/- 0.15 for 1.0 < Ml < 2.0 and +/- 0.1 for Ml >= 2.0

3. 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.

4. 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 & Collins (1990), the SED magnitudes are probably systematically higher by about 0.2 relative to the original Ml as defined by Richter.

References

Bakun W.H., Joyner W.B.: The Ml scale in central California. Bull Seis Soc Am 74:1827–1843, (1984).
Hutton L.K., Boore D.M.: The Ml scale in southern California. Bull Seis Soc Am 77:2074–2094, (1987).
Kradolfer, U.: Magnitudenkalibrierung von Erdbebenstationen in der Schweiz. Diplomarbeit, ETH Zürich (1984).
Richter C.F.: Elementary Seismology. W. H. Freeman and Co., San Francisco, pp 578, (1958).
Stange S.: Ml determination for local and regional events using a sparse network in southwestern Germany. J. of Seismology, 10, 247-257, (2006)
Uhrhammer, R.A., Collins E.R.: Synthesis of Wood-Anderson seismograms from broadband digital records, Bull. Seism. Soc. Am. 80, 702 – 716, (1990)