Topic	Magnitude determinations
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1 Aim

The exercises aim at making you familiar with the measurement of seismic amplitudes and periods in analog and digital records and the determination of related magnitude values for local and teleseismic events by using the procedures and relationships outlined in 3.2, and the magnitude calibration functions given in DS 3.1.

2 Procedures

The general relationship

$$M = \log (A/T) + \sigma(\Delta, h) \qquad (1)$$

is used for magnitude determination, with A – maximum "ground motion" amplitude in µm (10^{-6} m) or nm (10^{-9} m), respectively, measured for the considered wave group, T – period of that maximum amplitude in seconds. Examples, how to measure the related trace amplitudes B and period T in seismic records are depicted in Fig. 3.9. Trace amplitudes B have to be divided by the respective magnification Mag(T) of the seismograph at the considered period T in order to get the "ground motion" amplitude in either µm or nm, i.e., A = B/M(T).

$\sigma(\Delta, h) = - \log A_o$ is the magnitude calibration function, for teleseismic body waves also called Q(Δ, h) or P(Δ, h). Δ - epicentral distance, for *teleseismic events* (> 1000 km) generally given in degree (1° = 111.19 km), for *local events* (<1000 km) usually given in km. For local events often the "slant range" or hypocentral distance R (in km) is used instead of Δ. All calibration functions used in the exercise are given in DS 3.1.

Note: According to the original definition of the local magnitude scale Ml by Richter (1935) only the *maximum trace amplitude* B in mm as recorded in standard records of a Wood-Anderson seismometer is measured (see Fig. 3.11 and section 3.2.4), i.e.,

$$Ml = \log B(WA) – \log A_o(\Delta). \qquad (2)$$

Accordingly, no period T is measured, and no conversion to "ground motion" amplitude is made. However, when applying Ml calibration functions to trace amplitudes B measured (in mm too) in records of another seismograph (SM) with a frequency-magnification curve Mag(T) different from that of the Wood-Anderson seismograph (WA) then this frequency-dependent difference in magnification has to be corrected. Equation (2) then becomes

$$Ml = \log B(SM) + \log Mag(WA) – \log Mag(SM) – \log A_o. \qquad (3)$$

3 Data

The data used in the exercise are given in the following figures and tables.

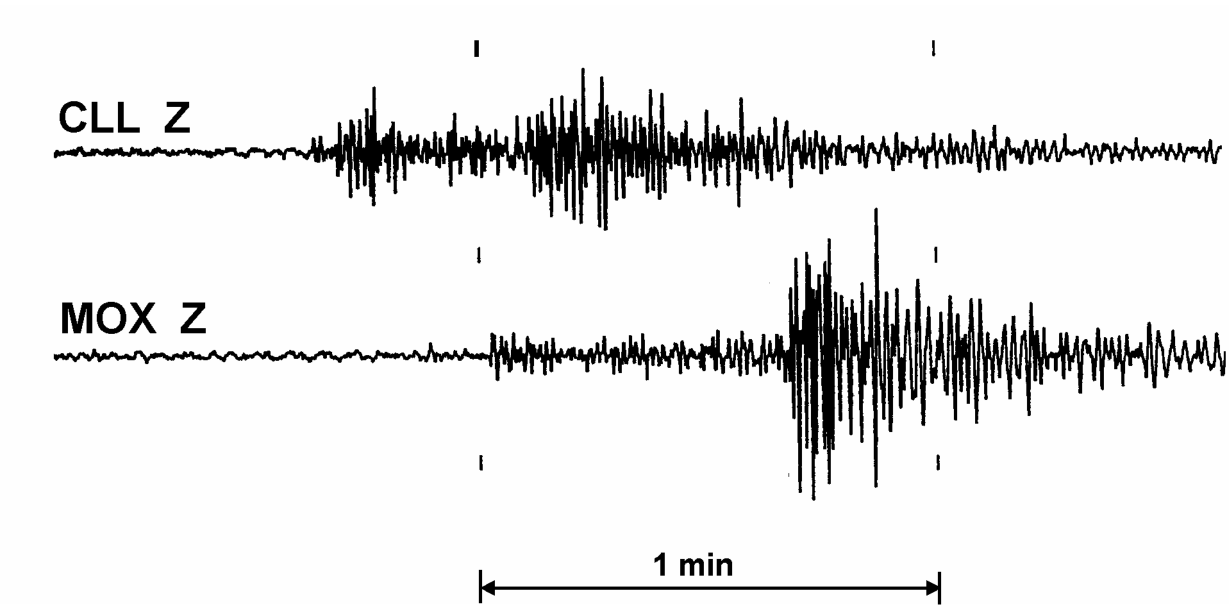


Figure 1 Vertical component records of a local seismic event in Poland at the stations CLL and MOX in Germany at scale 1:1. The magnification values Mag(SM) as a function of period T for this short-period seismograph are given in Table 1 below.

Table 1 Magnification values Mag(SM) as a function of period T in s for the short-period seismograph used for the records in Figure 1 together with the respective values Mag(WA) for the Wood-Anderson standard seismograph for Ml determinations.

T (in s)	Mag(SM)	Mag(WA)	T (in s)	Mag(SM)	Mag(WA)
0.1	35,000	2,800	1.1	190,000	1,100
0.2	92,000	2,700	1.2	180,000	950
0.3	125,000	2,600	1.3	170,000	850
0.4	150,000	2,400	1.4	155,000	750
0.5	170,000	2,200	1.5	140,000	700
0.6	190,000	2,000	1.6	120,000	
0.7	200,000	1,800	1.7	90,000	
0.8	201,000	1,600	1.8	80,000	
0.9	201,000	1,400	1.9	70,000	
1.0	200,000	1,200	2.0	60,000	

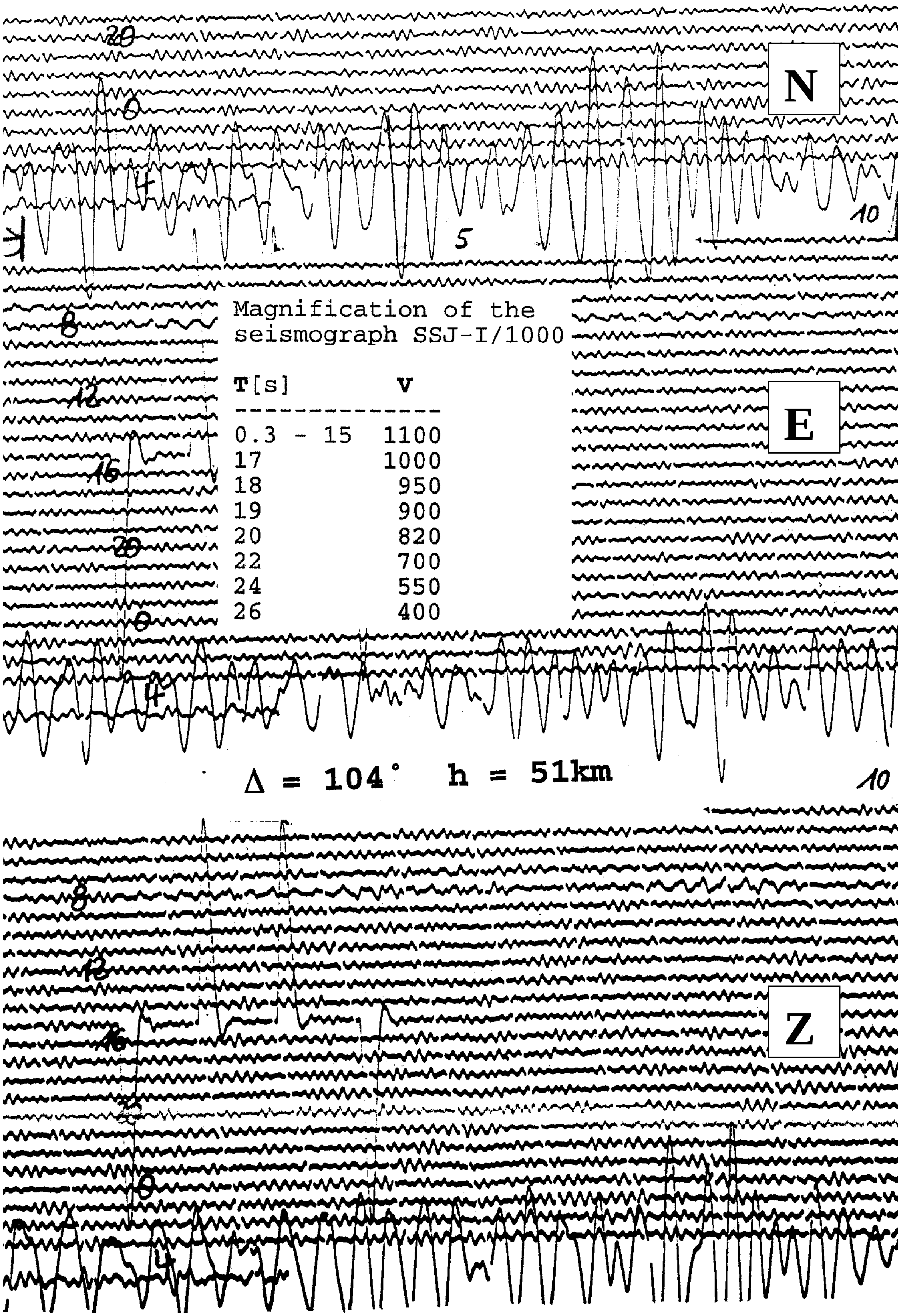
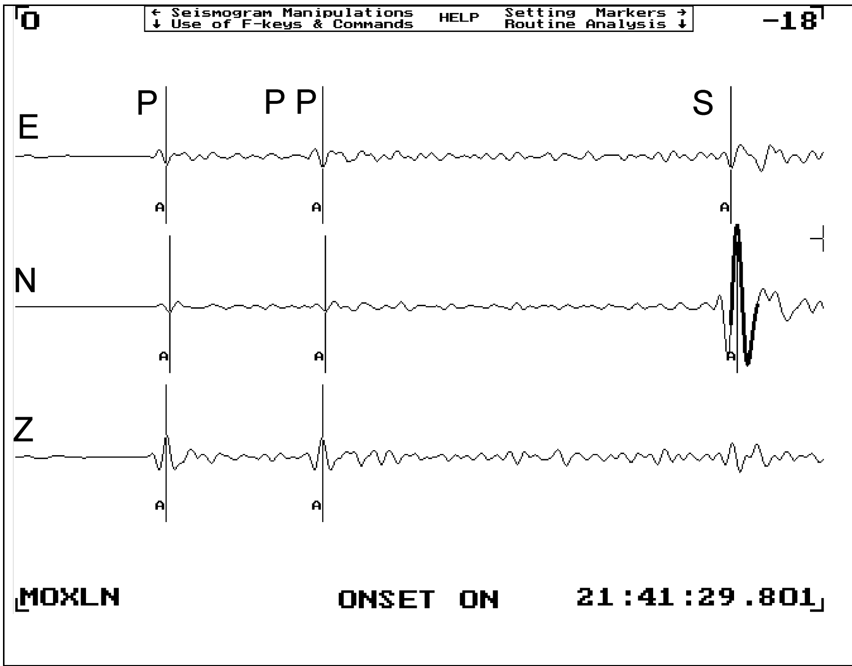


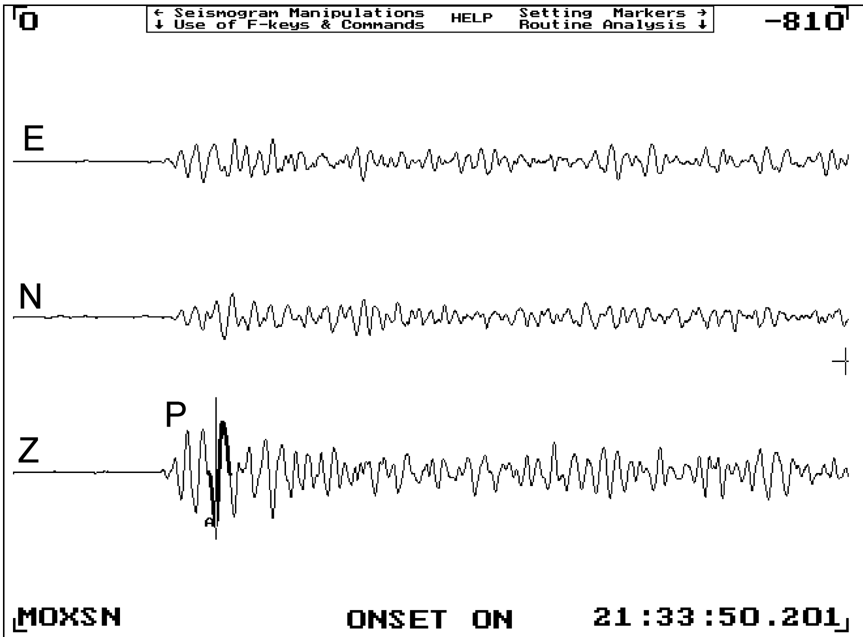
Figure 2 Analog record at scale 1:1 of a Kirnos-type seismograph from a surface-wave group of a teleseismic event. Scale: 1 mm = 4 s; for displacement Mag = V see inserted table.



	P	PP	S
E	14 s 2.8 µm	14 s 3.4 µm	22 s 31 µm
N	16 s 2.0 µm	14 s 1.8 µm	21 s 5.5 µm
Z	14 s 7.9 µm	15 s 6.8 µm	

$\Delta = 52.76° \approx 53°$
$t_{S\text{-}P}$ = 7 min 27 s

Figure 3 Display of the long-period (10 to 30 s) filtered section of a broadband 3-component record of the Uttarkasi earthquake in India (19 Oct. 1991; h = 10 km) at station MOX in Germany. The record traces are, from top to bottom: E, N, Z. Marked are the positions, from where the computer program has determined automatically the ground displacement amplitudes A and related periods T for the onsets (from left to right) of P, PP and S. For S the respective cycle is shown as a bold trace. The respective values of A and T for all these phases are saved component-wise in the data-pick file. They are reproduced in the box on the right together with the computer picked onset-time difference S - P and the epicentral distance Δ as published for station MOX by the ISC.



	T	A
Z	2.0 s	1,300 nm

$\Delta \approx 53°$

Figure 4 As for Figure 3, however short-period (0.5 to 3 Hz) filtered record section of the P-wave group only. Note that the amplitudes are given here in nm (10^{-9} m).

4 Tasks

Task 1:

1.1 Identify and mark in the records of Figure 1 the onsets Pn, Pg and Sg. Note that Pn amplitudes are for distances < 400 km usually smaller than that of Pg! Then determine the hypocentral ("slant") distance R in km from the rule of thumb t(Sg-Pg)[s] $\times$ 8 = R [km] for both station CLL and MOX. Note, that for this shallow event the epicentral distance Δ and the hypocentral distance R are practically the same.

1.2 Determine for the stations CLL and MOX the max. trace amplitude B(SM) and related period T and then, according to Equation (3), the equivalent log trace amplitude when recorded with a Wood-Anderson seismometer, i.e., log B(WA) = log B(SM) + log Mag(WA) – log Mag(SM).

1.3 Use Equation (2) above, and the values determined under task 1.2, for determination of the local magnitude Ml for the event in Figure 1 for both station CLL and MOX using the calibration functions $-\log A_o$:

a) by Richter (1958) for California (see Table 1 in DS 3.1);
b) by Kim (1998) for Eastern North America (vertical comp.; see Table 2 in DS 3.1);
c) by Alsaker et al. (1991) for Norway (vertical comp., see Table 2 in DS 3.1).

1.4 Discuss the differences in terms of:

a) differences in regional attenuation in the three regions from which Ml calibrations functions were used;
b) amplitude differences within a seismic network;
c) uncertainties of period reading in analog records with low time resolution and thus uncertainties in the calculation of the equivalent Wood-Anderson trace amplitude B(WA).

Task 2:

2.1 Measure the *maximum* horizontal and vertical trace amplitudes B in mm and related periods in s from the 3-component surface-wave records in Figure 2. Note, that the maximum horizontal component has to be calculated by combining vectorially B_N and B_E, measured at the same record time, i.e., $B_H = \sqrt{(B_N^2 + B_E^2)}$.

2.2 Calculate the respective maximum ground amplitudes A_H and A_V (in µm; vertical V = Z) by taking into account the period-dependent magnification of the seismograph (see table inserted in Figure 2)

2.3 Calculate the respective surface-wave magnitudes Ms according to the calibration function

a) $\sigma(\Delta)$ as published by Richter (1958) (see Table 3 in DS 3.1, for horizontal component H only);
b) $\sigma(\Delta)$ as given for H and V by the Prague-Moscow –Sofia group in Table 4 of DS 3.1;
c) $\sigma(\Delta)$ as given by the Prague-Moscow formula $Ms = \log(A/T)_{max} + 1.66 \log \Delta + 3.3$ which has been accepted by IASPEI as the standard formula for surface-wave magnitude determinations.

Note: Differentiate between surface-wave magnitudes from horizontal and vertical component records by annotating them unambiguously MLH and MLV, respectively.

Task 3:
Use the computer determined periods and amplitudes given in the right boxes of Figures 3 and 4 for the body-wave phases P, PP and S recorded from the shallow (h = 10 km) teleseismic earthquake in India in order to determine the respective body-wave magnitudes according to the general relationship (1):

3.1 Compare the epicentral distance calculated by the ISC for MOX (Δ = 52.76) with your own quick determination of Δ using the "rule of thumb" Δ (in °) = [t_{S-P}(in min) - 2] × 10.

3.2 Compare the differences in Q(Δ) according to Table 6 in DS 3.1 when using the "exact" distance given by the ISC with your quick "rule of thumb" estimation of Δ.. Assess the influence of the distance error on the magnitude estimate and draw conclusions.

3.3 Calculate MPV, MPH; MPPV, MPPH and MSH using the calibration functions Q(Δ) given in Table 6 of DS 3.1, the amplitude-period values given in Figure 3 and Δ = 53°. Discuss the degree of agreement/disagreement and possible reasons.

3.4 Calculate m_b for the short-period P-wave recording in Figure 4 using

a) Q(Δ, h) as depicted in Figure 1a of DS 3.1 for the vertical component of P and
b) P(Δ, h) as depicted in Figure 2 of DS 3.1.
c) Discuss the difference between a) and b).

5 Solutions

Note: Your individual readings of times, periods and amplitudes should not deviate more than 10 % and your magnitude estimates should be within about ± 0.2 units of the values given below.

Task 1:

1.1	CLL	t(Sg-Pg) = 26 s	R = 208 km	
	MOX	t(Sg-Pg) = 40 s	R = 320 km	
1.2	CLL:	B(MS) = 10 mm	T = (0.5s?)	log B(WA) = -0.888
	MOX:	B(MS) = 18 mm	T = 1 s	log B(WA) = -0.967
1.3	CLL:	Ml(Richter) = 2.7	Ml(Kim) = 2.6	Ml(Alsaker) = 2.4
	MOX:	Ml(Richter) = 3.1	Ml(Kim) = 2.8	Ml(Alsaker) = 2.6

1.5 California is a tectonically younger region and with higher heat flow than Eastern North America and Scandinavia. Accordingly, seismic waves are more strongly attenuated with distance. This has to be compensated by larger magnitude calibration values – logA_o for California. But even within a seismic network amplitude variations may be, depending on different conditions in local underground and azimuth dependent wave propagation, in the order of a factor 2 to 3 in amplitude, thus accounting for magnitude differences in the order of up to about ± 0.5 magnitude units between the various stations. This scatter can be reduced by determining station corrections for different source regions. Note also, that the period reading is rather uncertain for CLL. If we assume, as for MOX, also T = 1 s then log B(WA) = -1.222, i.e., the magnitudes values for CLL would be even smaller by 0.3 units.

Task 2:

2.1 B_N = 20. 5 mm, T_N = 22 s; B_E = 12 mm, T_N = 20 s $\rightarrow$ B_H = 23.8 mm, $\overline{T}$ = 21 s
B_Z = 23 mm, T_Z = 18 s

2.2 A_H = 31.3 µm for T = 21 s $A_Z = A_V$ = 24.2 µm for T = 18 s

2.3.1 a) MLH(Richter) = $\log A_{Hmax} + \sigma(\Delta)_{Richter}$ = 1.5 + 5.15 = 6.65

b) MLH(IASPEI) = $\log(A/T)_{max} + \sigma(\Delta)_{Prague}$ $\rightarrow$ MLH = 6.82 and MLV = 6.78 ≈ 6.8

c) Ms = $\log(A/T)_{max} + 1.66 \log \Delta + 3.3$ $\rightarrow$ MLH = 6.82 and MLV = 6.78 ≈ 6.8

Task 3:

3.1 The "rule of thumb" yields Δ = 54,5°. This is only 1.7° off the ISC determination. Generally, the rule-of-thumbs allows to estimate Δ in the range 25° < Δ < 100° with an error not larger than ± 2.5°.

3.2 The deviations in Q(Δ) and thus between magnitude estimates based on either Δ values from NEIC/ISC calculations or quick S-P determinations at the individual stations and using the "rule of thumb" are generally less than 0.2 units. They are even smaller, when correct travel-time (difference) curves are available. This permits sufficiently accurate quick teleseismic magnitude estimates at individual stations even with very modest tools and without the need to wait for the event locations and distance determinations of the world data centers.

3.3 MPV = 6.45, MPH = 6.36, MPPV = 6.36, MPPH = 6.24; MSH = 6.75
The magnitude values for P and PP, horizontal and vertical components, agree within 0.1 magnitude units. This speaks of a good scaling of the respective Q(Δ) calibration functions. MSH is significantly larger. This is obviously related to the different azimuthal radiation pattern for P and S waves and was one of the reasons, why Gutenberg strongly recommended the determination of the body-wave magnitudes for all these phases and averaging them to the unified magnitude value *m*. The latter provides more stable and less azimuth dependent individual magnitude estimates.

3.4 a) Q_{PZ} (53°, 10 km) = 7.0, log(A/T) = -0.19 (with A in µm!) $\rightarrow$ MPV = mb = 6.8
b) P_Z (53°; 10 km) = 3.4, log(A/T) = 3.1 (**with 2A in nm**!) $\rightarrow$ MPV = mb = 6.5
c) P_Z(Δ, h) yields, for the same ratio log(A/T), slightly lower magnitude values as compared to Q_{PZ}(Δ, h), for deep events, in particular. This also applies for other distance ranges (see Figures 1a and 2 in DS 3.1). Note that P_Z, although specifically developed for the calibration of short-period P-wave amplitudes, is not yet a recommended standard calibration functions.