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Amplitude-distance curves of *P*, *S* and *L* waves in Central Balkans for short and medium period seismographs

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Abstract
The basic principles for deriving the amplitude-distance curves or calibrating functions at short epicentral distances for the central part of the Balkan region are described. A procedure for unification of magnitude determinations for *P*, *S* and *L* waves is applied on the basis of the teleseismic surface wave magnitude scale. The results for short and medium period seismographs are presented.

Key words *amplitude curves – magnitude determinations – station corrections – Central Balkans*

1. Introduction

The present state of the magnitude determination is characterized by substantial discrepancies in both the individual station estimations and the mean values given by different networks of stations or even by international centers and agencies. The dispersion of the determinations may reach 1.5 magnitude unit, especially in cases of local and regional magnitude scales. For unification of magnitude determinations at short epicentral distances there are at least two important circumstances: achievement of internal compatibility of the determinations by different types of seismic waves and normalization of the local or regional determinations on the basis of some «standard» teleseismic scale, usually on the basis of the determinations by surface waves for shallow events with a depth down to 60 km.

For deriving the amplitude curves or calibrating functions for the Central Balkans the above circumstances are taken into consideration and additional homogeneity is achieved by introducing appropriate station corrections for the different types of seismic waves. The calibrating functions for shallow events at distances up to 10° are constructed for *P*, *S* and *L* waves, separately for the short and medium period seismographs.

The practical use of these calibrating functions during the last three years indicates that a satisfactory agreement between the regional magnitudes and the surface wave determinations at the teleseismic distances is observed.

2. Some principal problems on the unification of magnitude determinations at short epicentral distances

The derivation of reliable amplitude-distance curves or calibrating functions of body and surface waves at short epicentral distances is accompanied by some serious difficulties, mainly due to: 1) the complicate wave composition and amplitude pattern connected with the peculiarities of the Earth's structure, namely with the crust structure in the region, as well as with the influence of the mechanism of the different seismic source zones; 2) the obvious restriction of the number of the «standard» magnide determinations for distant weak events which are a basis for normalization of the amplitude data recorded at near distances; 3) the reduced number of qualitative amplitude records of stronger events at short distances due to the confined dynamic range of the conventional seismographs; 4) the absence of routinely accepted methodology for normalization or standardization of the amplitude curves for short distances regarding the teleseismic magnitude determinations.

In the course of time, for more than twenty years, these problems have been studied for the purpose to get as correct as possible magnitude determinations of local and regional events by the Bulgarian seismic network. A considerable part of the methodological principles and practical results are published in several papers, mainly in Christoskov (1965, 1967a,b, 1969, 1972, 1974), Chalturin and Christoskov (1974), Karnik and Christoskov (1977), Christoskov *et al.* (1978, 1985), Samardjieva and Christoskov (1985), Christoskov and Samardjeva (1988), Christoskov *et al.* (1991), Christoskov (1991a,b).

In all the investigations for the Central Balkans a standard approach for normalization of amplitude field is applied for local and regional distances. As normalizing quantity the surface wave magnitude M_S (later denoted as M) is used, according to the Prague formula (see Vanek *et al.*, 1962) which was officially recommended as a standard one during the Zurich General Assembly of IASPEI in 1967 (see Bath, 1969). The amplitude curves $A(\Delta)$ and the corresponding calibrating functions $\sigma(\Delta)$ are defined on the basis of the fundamental magnitude equation, *i.e.*

$$A_j(\Delta) = -\sigma_j(\Delta) = \log (A/T)_j + S_j - M \qquad (2.1)$$

where j is the wave type (j = PV, PH, PV, Pg, SV, SH, SV, Sg, LV, LH, Lg, Rg); Δ is the epicentral distance (usually $\Delta < 10°$); (A/T) is the maximum particle velocity of the ground in μm/s (A-amplitude, T- corresponding period) and S is the appropriate magnitude correction for a given seismic station. A review of the methods for determination of the station corrections is given in Christoskov (1991a) and for the calibrating functions in Christoskov (1991b). The details and specification for different wave type curves can be found in Christoskov (1967a,b, 1969), Samardjieva and Christoskov (1985), Christoskov and Samardjieva (1988). In some cases additional control is provided by the regional duration magnitudes, as the duration scale is perfectly compatable with the surface wave scale, which means that $M_\tau \equiv M_S$ (see Christoskov, 1966; Christoskov and Samardjieva, 1983; Samardjieva and Christoskov, 1985).

Without going into any details, it has to be mentioned that for the determination of station corrections the method of the basic station, respectively of the basic contour had been used (Vanek *et al.*, 1980; Christoskov, 1991a). The station correction for a given station i (i = 1, 2,..., NS) and wave type j, considering a set of readings for NE earthquakes (k = 1, 2, ..., NE), is determined by the relation:

$$S_{ij} = NE^{-1} \sum_k (M_{1k} - M_{ik}) \qquad (2.2)$$

where M_{1k} is the magnitude determination of the basic station. The introduction of the so-called station level SL_j for each wave type j (see Vanek *et al.*, 1980, Christoskov *et al.*, 1991), eliminates the influence of S_{ij} values on the actual level of the corresponding calibrating functions. Therefore, the calibrating functions could be used at any other station in the region (stations not associated in the networks for determining of S_{ij} and $\sigma_j(\Delta)$ respectively), by the simple assumption that its station correction is equal to zero, as initially it is not known.

In this case the eq. (2.1) is modified in the form

$$\sigma_j(\Delta) = M - \log (A/T)_j - S_j - SL_j \quad (2.3)$$

If we consider the value of the calibrating function σ_j in the vicinity of a given epicentral distance $\Delta \pm \delta\Delta$, so that for a sufficiently small $\delta\Delta$, the distance Δ_{ik}, between station i and earthquake k would be bounded by $\Delta - \delta\Delta$ and $\Delta + \delta\Delta$, then the most probable value of σ_j at distance Δ_I could be determined by the expression (see Vanek *et al.*, 1980; Christoskov *et al.*, 1985, 1991):

$$\sigma_j(\Delta_I) = n_I^{-1} \sum_{n_I} \sigma_j(\Delta_{ik}) \quad (2.4)$$

Obviously, $\sigma_j(\Delta_I)$ for $I = 1, 2, \ldots, L$ are the discrete values of the calibrating function between Δ_1 and Δ_L with a constant step of $2\delta\Delta$ ($\Delta_I = \Delta_1 + 2(I-1)\delta\Delta, I = (\Delta_I - \Delta_1)/2\delta\Delta + 1$). A normal filtering of the observed data for $\sigma_j(\Delta_{ik})$ could be applied for excluding the extreme differences $| \sigma_j(\Delta_{ik}) - \sigma_j(\Delta_I) |$ which are greater than a preselected and admissible deviation $\delta\sigma$. The refined values of σ_j are the basis for deriving the smooth in shape and reliable in level calibrating function. In this case the most effective procedure is based on the adapted

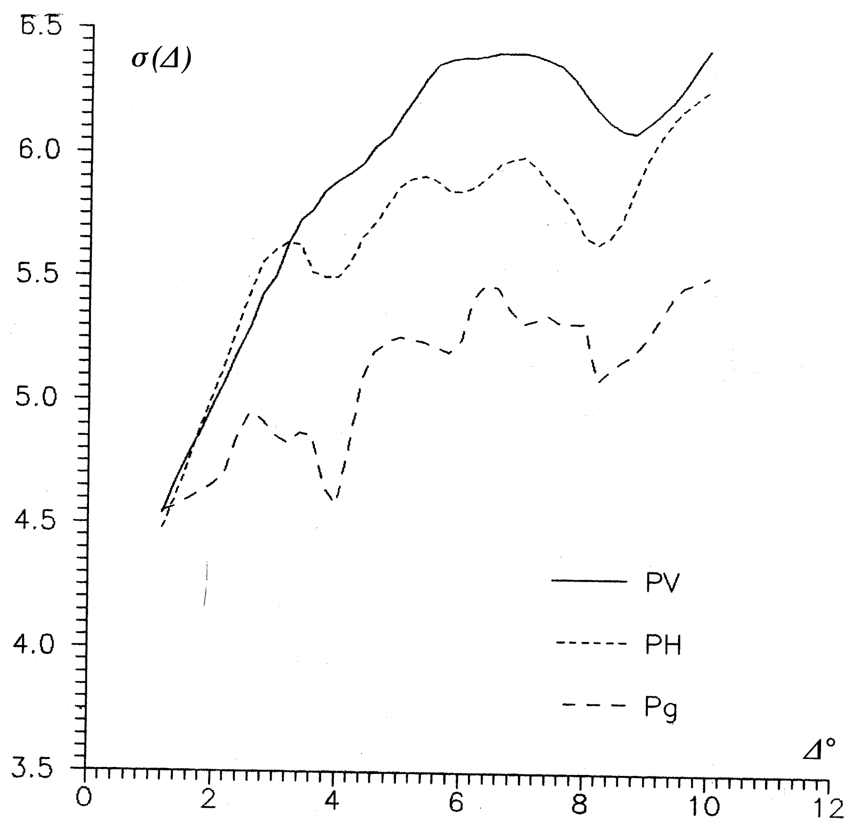

Fig. 1. Calibrating curves $\sigma(\Delta)$ for *PV*, *PH* and *Pg* waves (medium period seismographs).

versions of the method of moving averages – graphical, numerical or combined (Vanek *et al.*, 1980; Christoskov *et al.*, 1985).

3. Calibrating curves for the Central Balkans

Initially the set of the calibrating curves of *PH, Pg, SH, Sg* and *LH* waves for medium period seismographs (horizontal components only) were derived after the inclusion of station Sofia (SOF) in the Middle European Magnitude System – MEMS (Christoskov, 1965, 1967a,b, 1969). At that time the MEMS (see Vanek and Stelzner, 1961) had a unique network of stations in Europe for unified magnitude determinations, in fact normalized by the surface wave magnitudes. This initial set of calibrating functions had been reconsidered and practically proved (Vanek and Christoskov, 1971; Christoskov, 1972, 1974; Chalturin and Christoskov, 1974; Karnik and Christoskov, 1977) and additionally completed with the calibrating functions for vertical seismographs (Karnik and Christoskov, 1977; Christoskov *et al.*, 1985; Christoskov, 1991b). The available calibrating curves for *P* waves are drawn in fig. 1 and for *S* and *L* waves in fig. 2. The numerical values of these curves are presented in the Appendix with a step of 0.2° for distances between 1° and 10°. These calibrat-

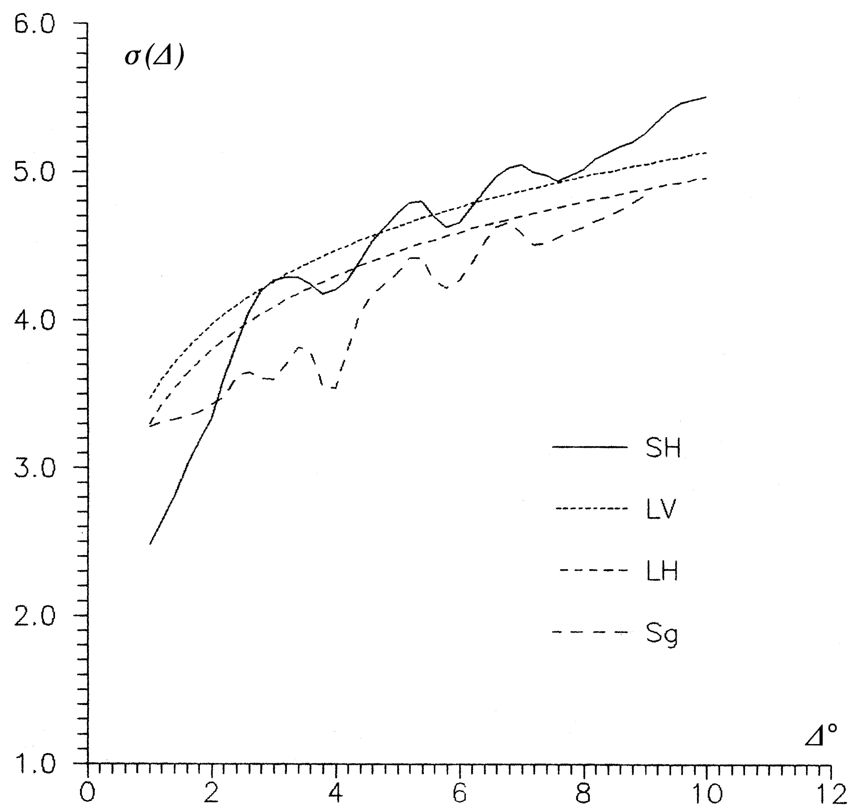

Fig. 2. Calibrating curves $\sigma(\Delta)$ for *SH, Sg, LV* and *LH* waves (medium period seismographs).

Table I. Magnitude corrections *S* for medium period seismographs.

Station	S_{PV}	$S_{PH} = S_{Pg}$	S_{SV}	$S_{SH} = S_{Sg}$	S_{LV}	S_{LH}
SOF	−0.12	−0.30	−0.14	−0.08	−0.14	+0.01
VTS	+0.08	−0.10	+0.06	+0.12	+0.06	+0.21
VTS_T (*)	+0.28	+0.10	+0.26	+0.32	+0.06	+0.21

(*) For seismographs installed in the station tunnel.

ing functions are derived from a set of amplitude and period data of earthquakes with surface wave magnitudes $M \geq 3.5$ and therefore they could be used for classification of seismic events of the same lower threshold. The observed magnitude corrections for station SOF and the calculated corrections for station Vitosha – VTS (see Christoskov, 1993) are given in table I.

The curves for short period seismographs are obtained after the establishment of the national telemetric network (NOTSSI). The NOTSSI stations are equipped with short period seismographs *S*-13 of Teledyne Geotech. The dynamic range of each station is of the order of 80 db as low and high gain channels are in operation, but the collective dynamic range of NOTSSI as a network is considerably higher. The active frequency band of the response characteristics for the *S*-13 channels is 1.25-10 Hz or 0.1-0.8 s.

The consecutive steps in the elaboration of the short period duration magnitude scale and in deriving the calibrating functions for *PVs*, *SVs* and *LVs* waves are described in Samardjieva and Christoskov (1985) and in Christoskov and Samardjieva (1983, 1988). The effective classification of near events by the duration magnitudes M_τ is confined up to $M_\tau \leq M = 5.5$, but there are no restrictions for stronger events in case of body or surface wave magnitudes if the records are not clipped for the corresponding wave group.

The short period calibrating curves for vertical components of *P*, *S* and *L* waves denoted as *PVs*, *SVs* and *LVs* (*Rgs*) are shown in fig. 3 and the corresponding numerical values are given in the Appendix. The most important fact is that these calibrating curves are quite similar in shape and level in contrast with the same curves for medium period instruments which also display a principle likeness in the shape but considerably differ in the level (see figs. 1 and 2). This means that for the short period narrow band seismic channels the dynamic of the seismic waves is «suppressed» as only a small portion of the higher frequency spectral amplitudes could be recorded of full value.

The latter fact reflects on the values of the magnitude station corrections which do not differ for *PVs*, *SVs* and *LVs* waves. For some of the NOTSSI stations the corresponding magnitude corrections are given in table II. It has to be emphasized that these station corrections differ in no way from the teleseismic magnitude corrections (at least for *PVs* wave) determined independently within the Eurasian Homogeneous Magnitude System – HMS (see Vanek *et al.*, 1980; Christoskov *et al.*, 1978, 1991).

The overlapping stations of the NOTSSI magnitude system and the HMS which are included in table II are DIM, KDZ and PVL (PVL_T).

The calibrating functions for short and medium period seismographs and the corresponding sets of station corrections are successfully used for discrimination between local quarry blasts and weak earthquakes and partially for identification of

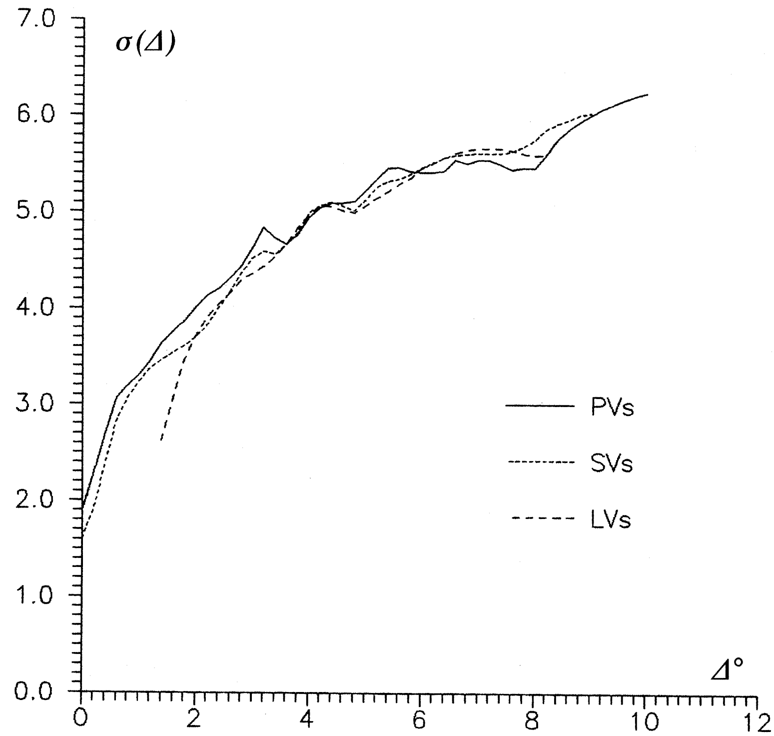

Fig. 3. Calibrating curves $\sigma(\Delta)$ for *PVs*, *SVs* and *LVs* waves (short period seismographs).

Table II. Magnitude corrections *S* for short period seismographs.

Station	Correction *S*
DIM	−0.09
PSN	−0.14
SOF	−0.40
KDZ	+0.10
PVL	−0.05
VTS	+0.04
MMB	+0.23
PVL_T (*)	+0.16
VTS_T (*)	+0.24
PLD	+0.12
RZN	+0.22

(*) For seismographs installed in the station tunnels regarding only *PVs* and *SVs* magnitude determinations.

underground explosions (see Deneva *et al.*, 1988; Milev and Christoskov, 1988; Christoskov *et al.*, 1988).

4. Concluding remarks

The reviewed set of calibrating curves for the Central Balcans seems to be the only complete set for uniform magnitude determinations from short and medium period instruments in this geographic region. The magnitude determinations are compatible with the standard surface wave teleseismic magnitudes. The calibrating functions are of «zero station level» types (see Christoskov *et al.*, 1991; Christoskov, 1991b,

1993) which means that they can be used at any seismic station within the region by the most probable assumption that initially its station correction is equal to zero prior to its proper determination. From the data in table I and table II one can conclude that the values of magnitude corrections vary in average within +0.25 magnitude units or even less. The exception for the short period correction of station SOF is due to the specific soft layers near the Earth surface.

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Appendix. Calibrating functions for Central Balkans at epicentral distances up to 10° (*).

	TYPES OF SEISMIC WAVES									
Δ°	*PV*	*PH*	*Pg*	*SH*	*Sg*	*LV*	*LH*	*PVs*	*SVs*	*LVs*
0.0	–	–	–	–	–	–	–	1.90	1.60	–
0.2	–	–	–	–	–	–	–	2.26	1.91	–
0.4	–	–	–	–	–	–	–	2.67	2.36	–
0.6	–	–	–	–	–	–	–	3.06	2.82	–
0.8	–	–	–	–	–	–	–	3.19	3.06	–
1.0	–	–	–	–	3.28	3.47	3.30	3.30	3.23	–
1.2	4.54	4.48	4.55	2.64	3.31	3.60	3.43	3.44	3.37	–
1.4	4.67	4.61	4.57	2.81	3.33	3.71	3.54	3.63	3.46	2.62
1.6	4.78	4.74	4.60	3.02	3.35	3.81	3.64	3.76	3.53	3.06
1.8	4.87	4.89	4.63	3.18	3.38	3.89	3.72	3.86	3.61	3.46
2.0	4.98	5.02	4.66	3.34	3.43	3.97	3.80	4.01	3.70	3.71
2.2	5.08	5.15	4.71	3.60	3.48	4.04	3.87	4.13	3.82	3.90
2.4	5.20	5.30	4.86	3.84	3.62	4.10	3.93	4.20	4.00	4.04
2.6	5.30	5.44	4.95	4.06	3.65	4.16	3.99	4.31	4.17	4.16
2.8	5.43	5.56	4.92	4.20	3.61	4.21	4.04	4.43	4.36	4.29
3.0	5.50	5.61	4.86	4.27	3.60	4.26	4.09	4.63	4.52	4.36
3.2	5.63	5.64	4.83	4.29	3.70	4.31	4.14	4.84	4.59	4.43
3.4	5.73	5.63	4.87	4.29	3.82	4.35	4.18	4.73	4.56	4.54
3.6	5.77	5.52	4.86	4.25	3.79	4.39	4.22	4.67	4.66	4.67
3.8	5.85	5.50	4.65	4.18	3.55	4.43	4.26	4.76	4.78	4.83
4.0	5.89	5.50	4.58	4.21	3.54	4.47	4.30	4.94	4.99	4.96
4.2	5.92	5.56	4.81	4.27	3.80	4.50	4.33	5.04	5.06	5.07
4.4	5.96	5.66	5.09	4.40	4.05	4.54	4.37	5.09	5.10	5.05
4.6	6.03	5.72	5.20	4.53	4.18	4.57	4.40	5.09	5.06	5.01
4.8	6.07	5.80	5.24	4.63	4.25	4.60	4.43	5.11	5.01	4.99
5.0	6.15	5.87	5.26	4.72	4.32	4.63	4.46	5.22	5.12	5.06
5.2	6.22	5.90	5.25	4.79	4.42	4.66	4.49	5.34	5.26	5.14
5.4	6.30	5.91	5.24	4.80	4.42	4.69	4.52	5.45	5.32	5.21
5.6	6.36	5.89	5.22	4.70	4.27	4.71	4.54	5.46	5.34	5.29
5.8	6.38	5.85	5.20	4.63	4.22	4.74	4.57	5.42	5.39	5.35
6.0	6.39	5.85	5.25	4.66	4.27	4.76	4.59	5.41	5.45	5.46
6.2	6.39	5.87	5.42	4.76	4.38	4.79	4.62	5.41	5.51	5.50
6.4	6.40	5.91	5.48	4.87	4.52	4.81	4.64	5.43	5.56	5.56
6.6	6.41	5.96	5.46	4.97	4.63	4.83	4.66	5.54	5.59	5.61

Appendix. (*continued*) Calibrating functions for Central Balkans at epicentral distances up to 10° (*).

	TYPES OF SEISMIC WAVES									
Δ°	*PV*	*PH*	*Pg*	*SH*	*Sg*	*LV*	*LH*	*PVs*	*SVs*	*LVs*
6.8	6.41	5.98	5.37	5.03	4.66	4.85	4.68	5.50	5.60	5.64
7.0	6.41	5.99	5.32	5.05	4.59	4.87	4.70	5.54	5.61	5.66
7.2	6.40	5.95	5.33	5.00	4.51	4.89	4.72	5.54	5.61	5.66
7.4	6.38	5.88	5.35	4.98	4.52	4.91	4.74	5.49	5.61	5.66
7.6	6.36	5.84	5.32	4.94	4.56	4.93	4.76	5.44	5.63	5.64
7.8	6.31	5.77	5.32	4.98	4.60	4.95	4.78	5.46	5.68	5.61
8.0	6.24	5.67	5.32	5.02	4.63	4.97	4.80	5.46	5.75	5.59
8.2	6.18	5.64	5.09	4.67	4.67	4.99	4.82	5.59	5.86	5.59
8.4	6.13	5.67	5.13	4.70	4.70	5.00	4.83	5.76	5.92	–
8.6	6.10	5.74	5.17	4.74	4.74	5.02	4.85	5.86	5.96	–
8.8	6.09	5.87	5.20	4.79	4.79	5.04	4.87	5.94	6.01	–
9.0	6.13	5.99	5.26	4.84	4.84	5.05	4.88	6.01	6.03	–
9.2	6.17	6.07	5.34	5.07	–	5.07	4.90	6.07	–	–
9.4	6.22	6.14	5.42	5.09	–	5.09	4.92	6.12	–	–
9.6	6.28	6.19	5.47	5.10	–	5.10	4.93	6.17	–	–
9.8	6.36	6.23	5.49	5.12	–	5.12	4.95	6.21	–	–
10.	6.43	6.27	5.51	5.13	–	5.13	4.96	6.24	–	–

(*) *V* = vertical component; *H* = horizontal component; *s* = indication of short period data.