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The 20-Second Regional Magnitude M_S(20R) for the Russian Far East

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Abstract—A new modified magnitude scale M_S(20R) is elaborated. It permits us to extend the teleseismic magnitude scale M_S(20) to the regional epicenter distances. The data set used in this study contains digital records at 12 seismic stations of 392 earthquakes that occured in the northwest Pacific Ocean in the period of 1993–2008. The new scale is based on amplitudes of surface waves of a narrow range of the periods (16–25 s) close to the period of 20 s, for distances of 80–3000 km. The digital Butterworth filter is used for processing. On the basis of the found regional features concerning distance dependence for seismic wave attenuation, all the stations of the region have been subdivided into two groups, namely, "continental" and "island-arc." For each group of stations, its own calibration function is proposed. Individual station corrections are used to compensate for the local features.
The magnitude scale M_S(20R) makes it possible to obtain a spectral-determined magnitude estimation at the regional distances and allows us to provide historical continuity with Gutenberg's M_S, classical scale. The single-station rms accuracy of determination of M_S(20R) is 0.22.

Keywords: *earthquake, magnitude scale, surface waves.*
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INTRODUCTION

A new version of magnitude scale has to be elaborated because the standard scales of magnitude determinations based on surface waves M_S(20) and M_S(BB) have several shortcomings. The teleseismic magnitude M_S(20), which is based on the classical magnitude M_S proposed by B. Gutenberg [1945], is determined for wave periods of 18–22 s and epicentral distances of $20° \le \Delta \le 160°$. The shortcoming of this technique is that determination of M_S(20) cannot be determined at regional distances. The broadband magnitude M_S(BB) [Vanek et al., 1962] is determined within a broad range of epicentral distances $2° \le \Delta \le 160°$, but has no clear spectral reference and, therefore, is not completely suitable for such important applications as tsunami destructive potential assessment or analysis of significant ground motions. The shortcomings of commonly accepted magnitude scales based on surface waves have been discussed before [Evernden, 1971; von Seggern, 1977; Panza et al., 1989; Herak M. and Herak D., 1993], and various proposals have been made concerning improvement of calibration curves.

The new modified magnitude scale M_S(20R) allows the teleseismic scale M_S(20) to be expanded to the range of small epicentral distances. The scale is based on amplitudes of narrowband period surface waves (16–25 s) in the neighborhood of the 20-s period for epicentral distances ranging from 80 to 3000 km. The selection of the period range is made using a digital filter.

THE DATA USED AND METHODOLOGY OF CONSTRUCTION OF CALIBRATION CURVE FOR THE MAGNITUDE SCALE M_S(20R)

In our work, 1476 digital three-component records of BH broadband channels, made at 12 stations (PET, YSS, MA2, YAK, KAM, ADK, TIXI, BILL, MDJ, INCN, ERM, MAJO) for 392 earthquakes occurred in the northwest Pacific in 1993–2008, have been used. Digital records were selected from the IRIS DMC archive (http://www.iris.edu/dms/wilber.htm) and from the tsunami database of the Kamchatka Branch, Geophysical Service, Russian Academy of Sciences (KD GS RAS). The focal depth of earthquakes was up to 70 km. Only the earthquakes with an estimate of teleseismic magnitude M_S(20) available in the PDE NEIC catalogue (http://neic.usgs.gov/neis/epic/epic.html) were selected. Processing of the initial digital record was made using the DIMAS program by D.V. Droznin (KD GS RAS).

The seismic stations and epicenters of earthquakes whose records were processed are presented in Fig. 1.

To create the calibration curve, we considered how the maximal displacement amplitudes in surface waves selected by a band-pass filter with an center frequency of 0.05 Hz depend on distance. The physically realizable fourth-order Butterworth filter had cutoff frequencies of 0.0625 and 0.04 Hz (16–25 s). The measured amplitudes were normalized to the expected amplitude from a given earthquake at the epicentral distance $\Delta = 20°$, in accordance with the value of teleseismic magnitude M_S(20) published the NEIC

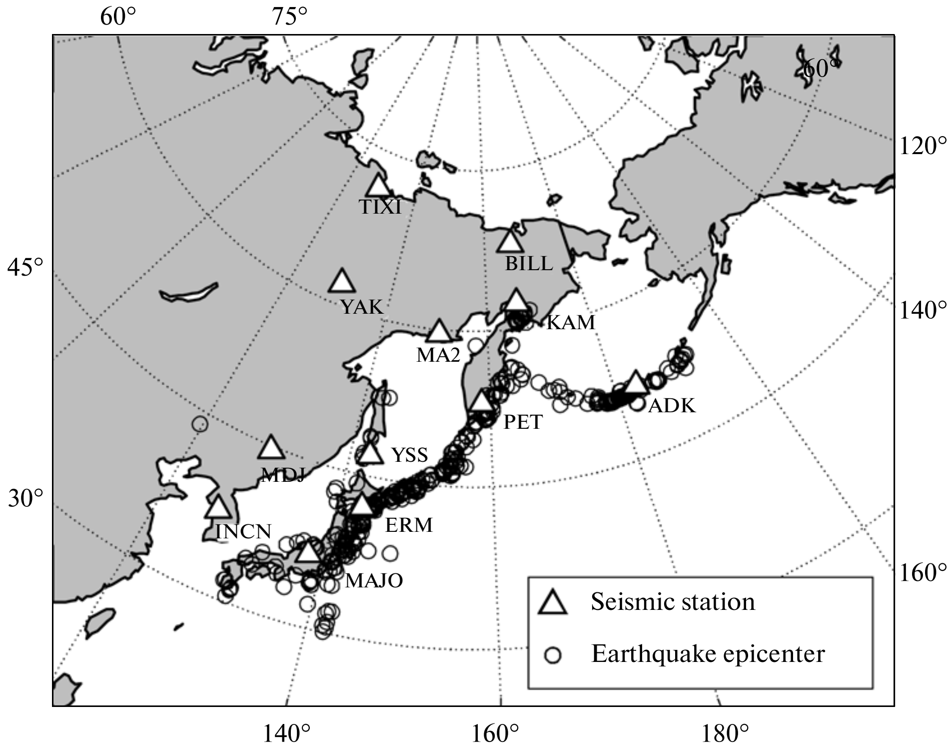

Fig. 1. Map of earthquake epicenters for the period 1993–2008 in the northwest Pacific and digital seismic stations used for constructing the calibration curve.

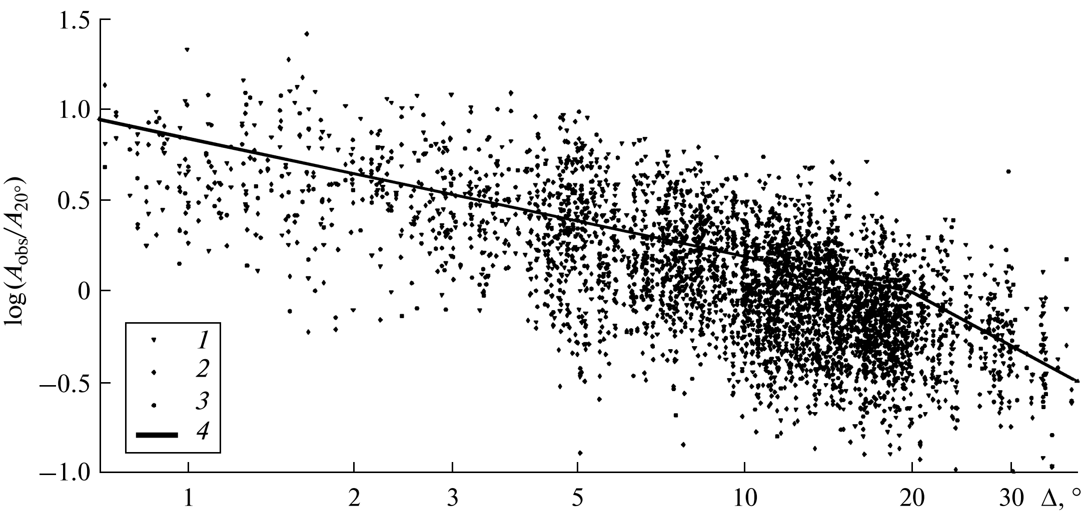

Fig. 2. Observed maximal displacement in the filtered surface wave reduced to the value at epicentral distance $\Delta = 20°$ on the basis of $M_S(20)$ of a given earthquake, as a function of epicentral distance. *1–3*, components: *1*, *E*; *2*, *N*; *3*, *Z*; *4*, $Q_1(\Delta)$ version of the calibration curve.

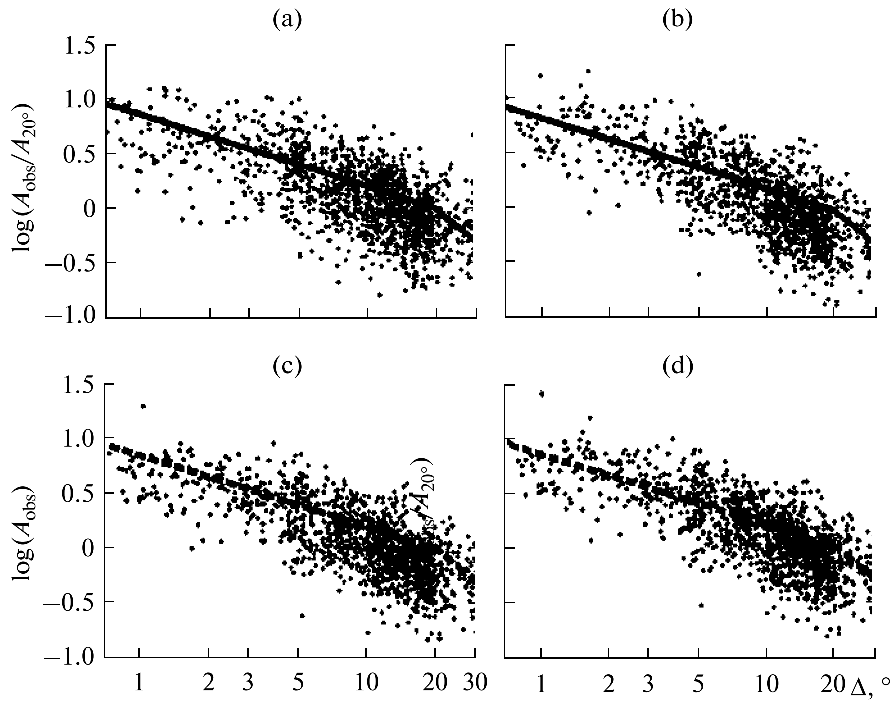

Fig. 3. Reduced maximal displacement amplitude in the filtered surface wave as a function of epicentral distance. Points resulted from different versions of selection and averaging of station data; the solid line is the $Q_1(\Delta)$ calibration curve. (a) vertical component Z; (b) root mean square value of horizontal components E and N; (c) mean value of logarithms for three components (E, N, Z); (d) root mean square value of three components (E, N, Z).

catalogue (Fig. 2). Maximal amplitudes were measured in the time window $[t_S, t_S + 600\text{ s}]$, where t_S is the shear wave arrival time. Maximal values in three channels were measured at independent time moments.

Figure 2 illustrates the dependence of the given maximal displacement amplitudes ($A_{obs}/A_{20°}$) on the epicentral distance Δ for all three components. Here, the initial version of the new calibration curve $Q_1(\Delta)$ is also demonstrated for the distances of $0.7° < \Delta < 20°$. According to this approximation, the amplitude of 20-s surface wave decreases in the interval of $0.7° < \Delta < 20°$ as $Q_1(\Delta) \sim \Delta^{-0.65}$. The segment of the calibration curve at $\Delta > 20°$ is a standard decay of amplitudes according to the Gutenberg–Solov'ev formula with the slope of −1.66.

To assess the quality of amplitude trend approximation with distance, the residuals of the station magnitude estimates were examined. Different versions of station data selection and averaging were considered (Fig. 3). As a result, station magnitudes were decided to be calculated based on the root mean square value of given maximal amplitudes in three components (maximums were measured in independent time). Such a technique of uniting amplitude data in components and wave types appears to be the most satisfactory. In calculation of residuals, the teleseismic magnitude estimate $M_S(20)$ for a given earthquake from the NEIC catalogue was considered as "true."

TESTING OF THE INITIAL VERSION OF SCALE ON THE DATA FROM PARTICULAR SEISMIC STATIONS

After testing of the magnitude scale initial version, regional peculiarities of seismic wave attenuation with distance were revealed. All the regional stations were subdivided into two large and geographically distinctive groups designated hereafter as "continental" and "island-arc." The calibration curve $Q_2(\Delta)$ is suggested for the "island-arc" group, while the initial curve $Q_1(\Delta)$ appeared to be the optimal for the "continental" group. The difference between the curves is small and located only within the limited distance range of 7–27 s, with the maximal discrepancy being 0.10.

In addition to this, the necessity to introduce station corrections for small amplitude anomalies at some stations has been found. The derived estimates of station corrections are given in the table.

Thus, magnitude estimate M_S(20R) should be performed by the following algorithm.

For the "continental" group of stations (KAM, TIXI, BILL, YAK).

$$M_S(20R) = \begin{cases} \text{not defined} \quad (\Delta < 0.7°) \\ \log(A/T) + 0.65\log\Delta + 4.61 + d_{\text{sta}} \ (0.7 \le \Delta \le 20°), \\ \log(A/T) + 1.66\log\Delta + 3.30 + d_{\text{sta}} \quad (\Delta > 20°), \end{cases}$$

Characteristics of distribution for station magnitude residuals and accepted station corrections d_{sta}

Seismic station	Number of events	Median	Mean	Standard deviation	Accept correction d_{sta}
"Island-arc" stations					
PET	283	–0.07	–0.08	0.20	0.1
YSS	256	–0.01	–0.03	0.24	–
MA2	59	–0.01	–0.05	0.25	–
ADK	76	–0.06	–0.07	0.19	0.1
ERM	113	0.05	0.04	0.27	–
INCN	113	–0.01	–0.04	0.22	–
MAJO	220	–0.12	–0.12	0.22	0.1
MDJ	144	–0.04	–0.05	0.20	–
"Continental" stations					
BILL	28	–0.05	0.00	0.20	–
TIXI	6	–0.10	–0.07	[0.10]	–
YAK	24	0.04	–0.03	0.20	–
KAM	28	0.04	–0.01	0.20	–

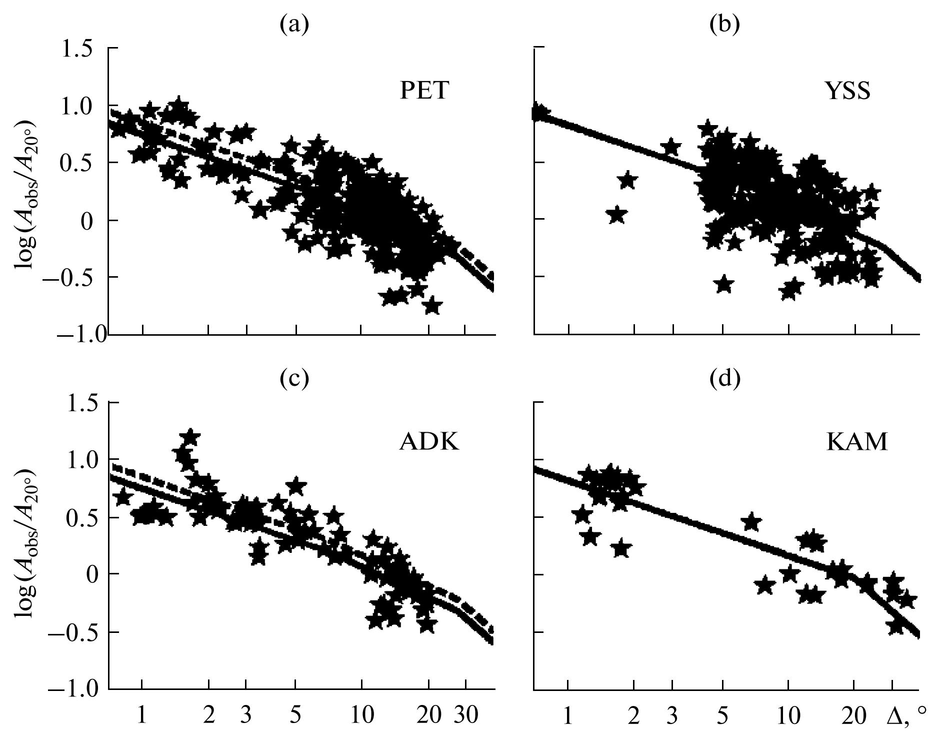

Fig. 4. Distance dependences of reduced maximal displacement amplitudes for the "island-arc" seismic stations PET (a), YSS (b), ADK (c), and for the "continental" station KAM (d). The root mean square value of the three components is shown. Solid lines indicate calibration curves $Q_2(\Delta)$ (for a, b, and c) and $Q_1(\Delta)$ (for d). Calibration curves before introduction of station corrections are indicated by dashed lines for the PET and ADK stations.

where Δ is the epicentral distance in degrees; A is the maximal displacement amplitude in the surface wave at the filter output (μm) in the time window [t_S, t_S + 600 s] (t_S is the shear wave arrival time); $T = 20$ s; d_{sta} is the station correction.

For the "island-arc" group of stations (PET, ADK, MA2, YSS, MDJ, INCN, ERM, MAJO):

$$M_S(20R) = \begin{cases} \text{not defined} & (\Delta < 0.7°) \\ \log(A/T) + 0.65\log\Delta + 4.614 + d_{sta} & (0.7 \le \Delta < 7°) \\ \log(A/T) + 0.87\log\Delta + 4.429 + d_{sta} & (7° \le \Delta \le 27°) \\ \log(A/T) + 1.66\log\Delta + 3.30 + d_{sta} & (\Delta > 27°). \end{cases}$$

The dependences of given maximal displacement amplitudes on distance, presented in Fig. 4 for several seismic stations, show that the data are quite consistent with the elaborated calibration curves.

The standard deviation of new magnitude M_S(20R) estimates from the accepted calibration curves is 0.22, on average, and 0.20–0.27 for particular stations (see table), which is consistent with the typical precision values of station magnitude estimates based on surface waves.

CONCLUSIONS

The suggested measurement method and calibration curves under the conditions of the northwest Pacific can be considered a satisfactory approximation to the spectrally stable regional magnitude scale based on surface waves. It is important that systematic determination of the spectrally determined magnitude for weak earthquakes (magnitude range of 3.5–5) becomes possible. In this case, such a magnitude allows to produce a low-distorted estimate of moment magnitude M_W not defined, without coincidence to it. The obtained result will enable us to improve significantly the characterization of earthquake sources in the Russian Far East. It can be expected that the method based on the new calibration may be applicable in other regions of Russia and the world.

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