Relationships to Estimate the Magnitude M_S of Historical Earthquakes in Europe from Macroseismic Observations

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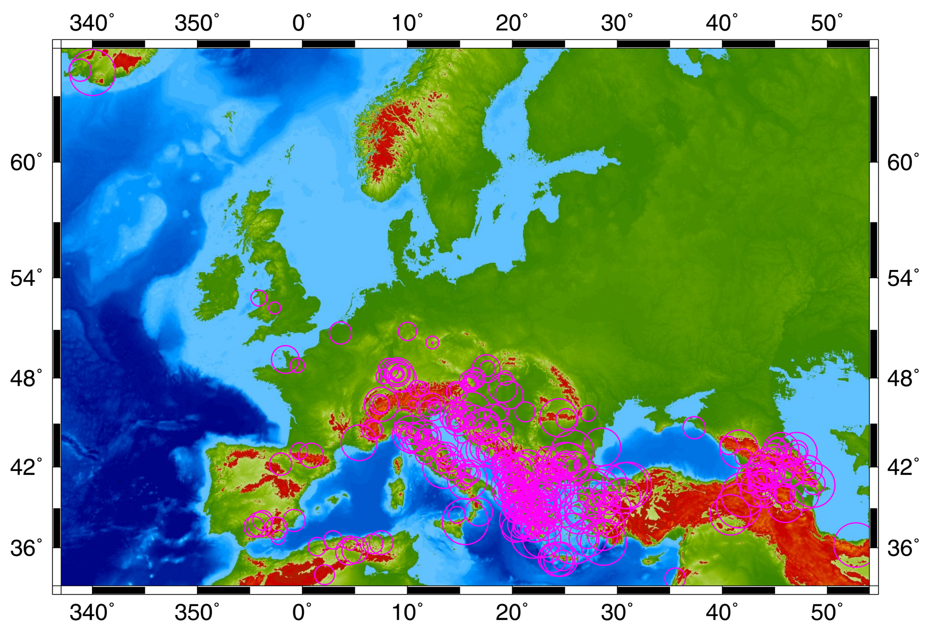

Fig. 1. Epicenters of earthquakes selected for this study from the catalogue of Kárník (1996) - KA96 -for Europe. Diameter of circles proportional to M_S.

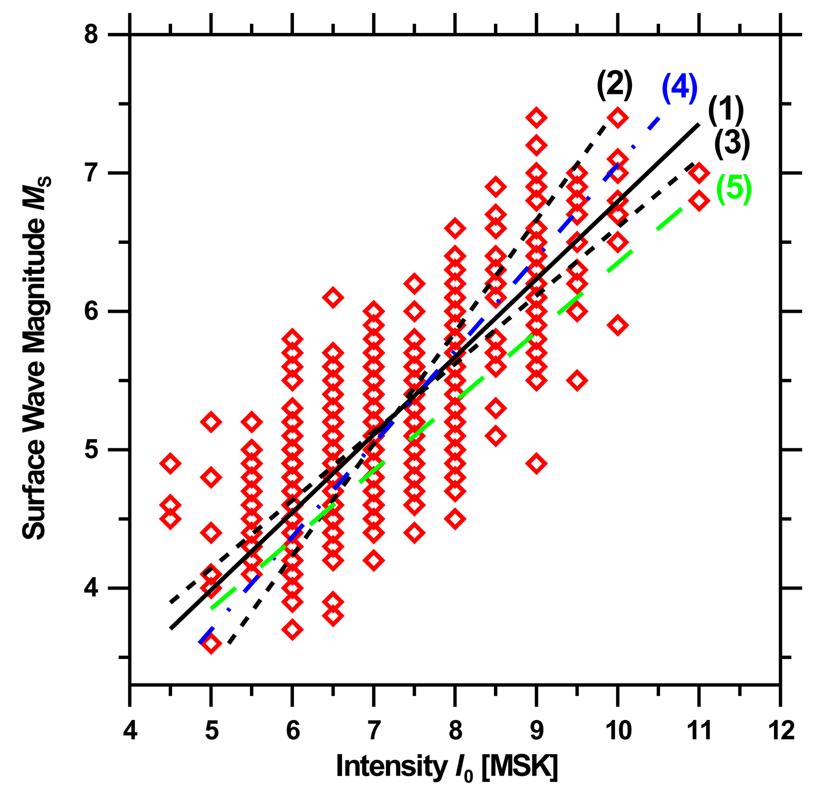

Fig. 3. Surface wave magnitude M_S as a function of epicentral intensity I_0 for 469 earthquakes from KA96.
(1) orthogonal regression: $M_S = 0.55\, I_0 + 1.26$
(2) linear regression, I_0 in error
(3) linear regression, M_S in error
(4) relationship from Schenk et al. (2000)
(5) relationship from Albarello et al. (1995)

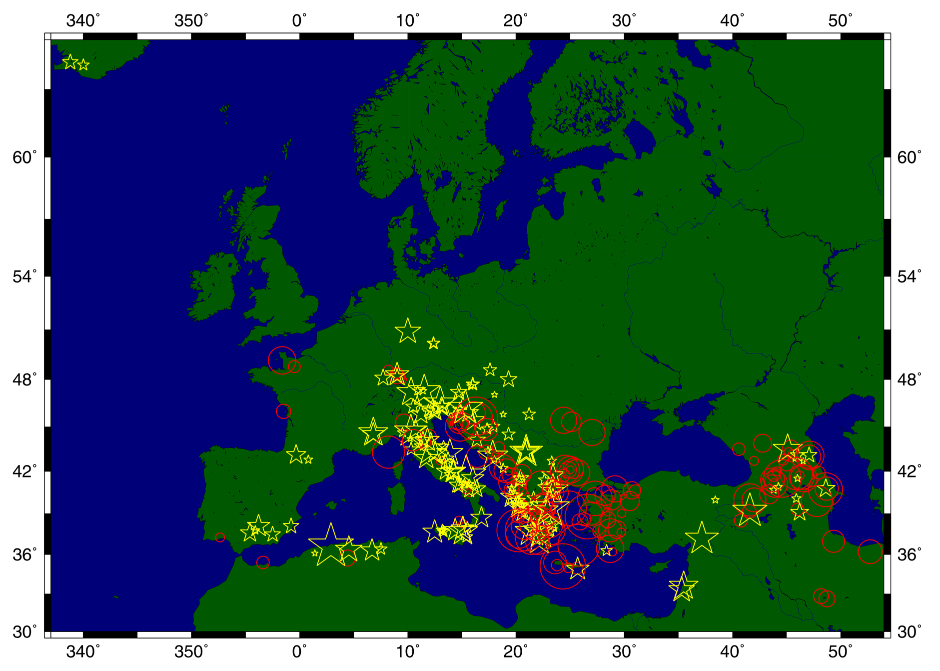

Fig. 5. Regional differences in the relation between M_S and I_0 for the earthquakes shown in Fig. 1. ☆ M_S calculated from eq. (1) larger than the instrumental M_S, i.e. $M_S(I_0) > M_S$. ○ : $M_S(I_0) < M_S$. The size of the symbols is proportional to the residual values $|M_S - M_S(I_0)|$. Note systematic regional variations with predominantly higher values (☆) for $M_S(I_0)$ in Central Europe, the Alps, Italy, Algeria, and lower values in Greece, Bulgaria, Western Turkey, along the western coast of the Adriatic Sea, and in the Caucasus.

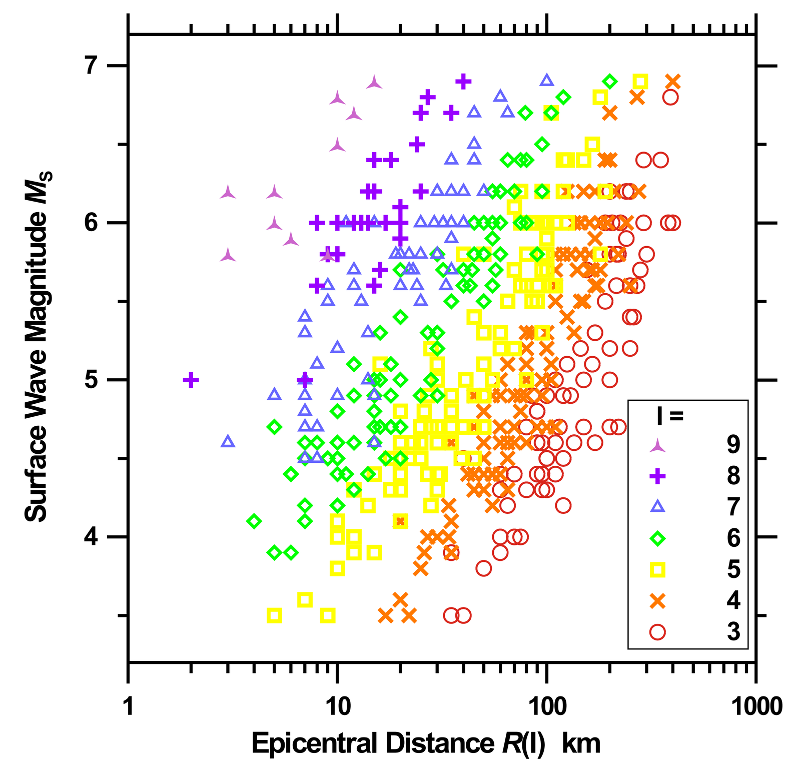

Fig. 7. M_S as a function of epicentral distance to the isoseismal $R(I)$ (490 values) for earthquakes from SH98 shown in Fig. 2.

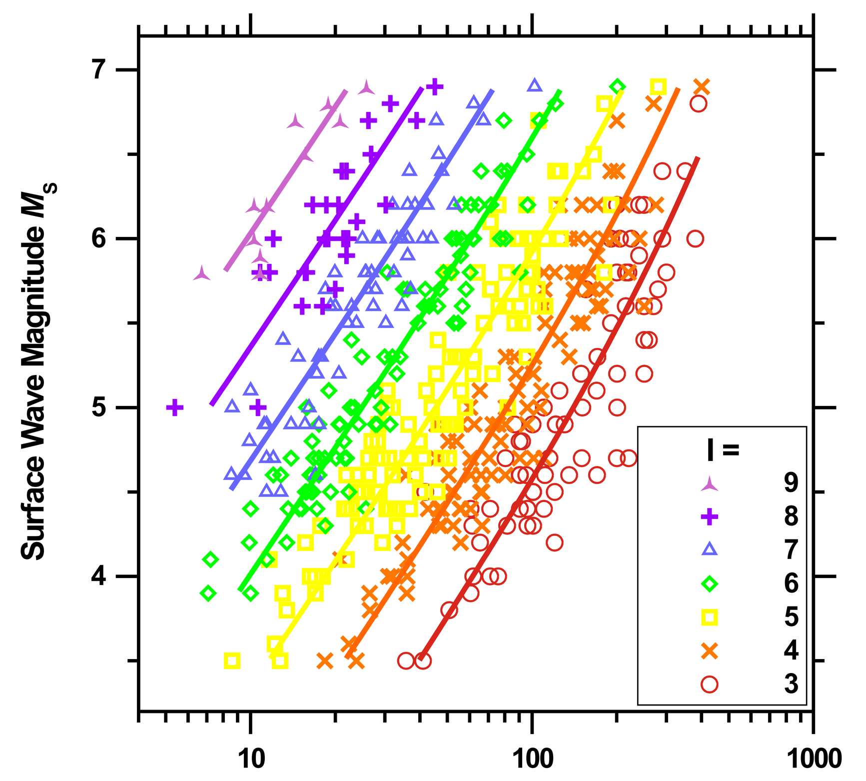

Fig. 8. M_S as a function of hypocentral distance to the isoseismal $S(I)$ for the same earthquakes as in Fig. 7. The lines visualize equation (7) for $I = 3...9$.

Introduction

Magnitudes of earthquakes earlier than 1900 are derived from macroseismic observations, i.e. the maximum intensity I_0, felt area, or isoseismal radii $R(I)$ of different intensities I and the focal depth h. The purpose of our study is to compare the importance of I_0 and $R(I)$ as input parameters for the estimation of the surface wave magnitude M_S of historical earthquakes in Europe and to derive appropriate empirical relationships.

Data

This study relies on carefully selected instrumental parts (since 1900) of 2 earthquake catalogues: KA96 - Kárník (1996): M_S determined from at least 4 stations, h 50 km, reliable I_0 (**Fig. 1**). SH98 - Shebalin et al. (1998): instrumentally determined M_S with errors $\Delta M_S = \pm 0.3$, 5 km h 50 km with errors Δh ±2 km or Δh (h/1.2 to 1.2h) km, ΔI_0 ±0.5 (**Fig. 2**).

Method

In order to derive relationships we use the orthogonal regression because we presume that all parameters are in error. This method has the additional advantage that it provides a reversible regression equation (Gutdeutsch et al. 2000, 2002).

Estimation of M_S from I_0 and h

As correlation analysis of KA96 shows no significant influence of h on the relation between M_S and I_0 (see **Fig. 4**), we obtain (**Fig. 3**):

$$M_S = 0.55\, I_0 + 1.26 \qquad (1)$$
$$\delta M_S = \pm 0.44,\ \delta I_0 = \pm 0.86.$$

Here and in the following δ denotes the derived equivalent standard error. The practical use of this relationship (1) is limited due to the rather large errors. In addition we observe systematic regional variations (**Fig. 5**) which need further investigation.

We were able to apply much more stringent selection criteria to SH98 and found a substantial improvement of the correlation when considering the influence of h [km] (partial correlation coefficient $r(I_0, M_S/\log(h)) = 0.96$), which is in contrast to our results using KA96. By orthogonal regression using 112 earthquakes (**Fig. 6**) we obtain:

$$M_S = 0.65\, I_0 + 1.90 \log(h) - 1.62 \qquad (6)$$
$$\delta M_S = \pm 0.21.$$

Because of the very high correlation coefficient and small standard error we consider this equation as reliable and recommend it for application.

Estimation of M_S from $R(I)$

In order to establish a relationship between M_S and average isoseismal radii $R(I)$, we apply a physically based model which takes into account both exponential decay α and geometrical spreading factor γ:
$M_S = \mathrm{A}\, I + \mathrm{B}\, Y + \mathrm{C}$
$Y = \gamma \log(S(I)) + \alpha\, S(I)$
α = exponential decay [1/km]
γ = geometrical spreading factor
$S(I)$ = focal distance [km] $= (h^2 + R(I)^2)^{1/2}$
A, B, C = free parameters determined by linear orthogonal regression

Using 490 isoseismal radii from SH98 (**Fig. 7**) a best fit is gained by orthogonal regression, where α/γ is varied in order to minimize the orthogonal error. The data does not allow to determine α and γ separately. With $\alpha = 0.002$ km^{-1} and $\gamma = 1.3$ we find (see **Fig. 8**):

$$M_S = 0.673\, I + 2.44 \log(S(I)) + 0.00163\, S(I) - 2.48$$
$$\delta M_S = \pm 0.28,\ r(M_S, Y/I) = 0.93,\ I = 3\ldots 9. \qquad (7)$$

Because h in most cases is not accurately known for historical earthquakes, we also derive an equation using the epicentral distance to the respective isoseismal $R(I)$ instead of $S(I)$ and obtain
$$M_S = 0.695\, I + 2.14 \log(R(I)) + 0.00329\, R(I) - 1.93$$
$$\delta M_S = \pm 0.32,\ r(M_S, Y/I) = 0.91,\ I = 3\ldots 9. \qquad (8)$$
With these equations it is possible to reliably estimate M_S and we recommend them for application.

KA96 gives isoseismal radii for I = 3 and 5 (**Fig. 9**). The scatter in the data is larger than in the SH98 data set, probably in part due to regional variations in the ralationship between M_S and $R(I)$ (Kaiser, Gutdeutsch 2002). Therefore we fix α and γ to the values found above and obtain:

$$M_S = 0.808\, I + 2.84 \log(S(I)) + 0.00190\, S(I) - 3.71$$
$$\delta M_S = \pm 0.65,\ r(M_S, Y/I) = 0.72. \qquad (9)$$

Compared to eq. (7), relation (9) predicts slightly larger values for M_S for large ($M_S > 6$) earthquakes (**Fig. 10**).

Conclusions

- The use only of high quality data as input in the regression analysis provides reliable relationships to estimate magnitudes.
- The magnitude estimation of a historical earthquake from the epicentral intensity gives reliable results only if the focal depth is known exactly.
- The relation using isoseismal radii is of greater practical importance as it allows more reliable magnitude estimations of historical earthquakes.
- Regional variations in the relationships between magnitude, epicentral intensity and isoseismal radius have to be considered.

References

Albarello, D., Berardi, A., Margottino, C., Mucciarelli, M. (1995): Macroseismic estimates of magnitude in Italy. *PAGEOPH* **145**, 297-312.
Gutdeutsch, R., Kaiser, D., Jentzsch, G. (2000): Schätzwerte der Magnitude eines Erdbebens auf Grund der Maximalintensität und anderer Herdparameter aus Erdbebenkatalogen. *Mitt. Deutsche Geophys. Ges.* 4/2000, 3 -13.
Gutdeutsch, R., Kaiser, D., Jentzsch, G. (2002): Estimation of earthquake magnitudes from epicentral intensities and other focal parameters in Central and Southern Europe. *Geophys. J. Int.* (accepted).
Kaiser, D., Gutdeutsch, R. (2002): Beziehungen zwischen Magnitude und Isoseistenradien. 62. Jahrestagung der Deutschen Geopysikalischen Gesellschaft, Hannover.
Kárník, V. (1996): Seismicity of Europe and the Mediterranean; edited by K. Klima. Academy of Sciences of the Czech Republic StudiaGeo s.s.r.o. and Geophysical Institute Praha.- KA96 -
Shebalin, N.V., Leydecker, G., Mokrushina, N.G., Tatevossian, R.E., Erteleva, O.O., Vassiliev, V.Y. (1998). Earthquake Catalogue for Central and Southeastern Europe 342 BC - 1990 AD. European

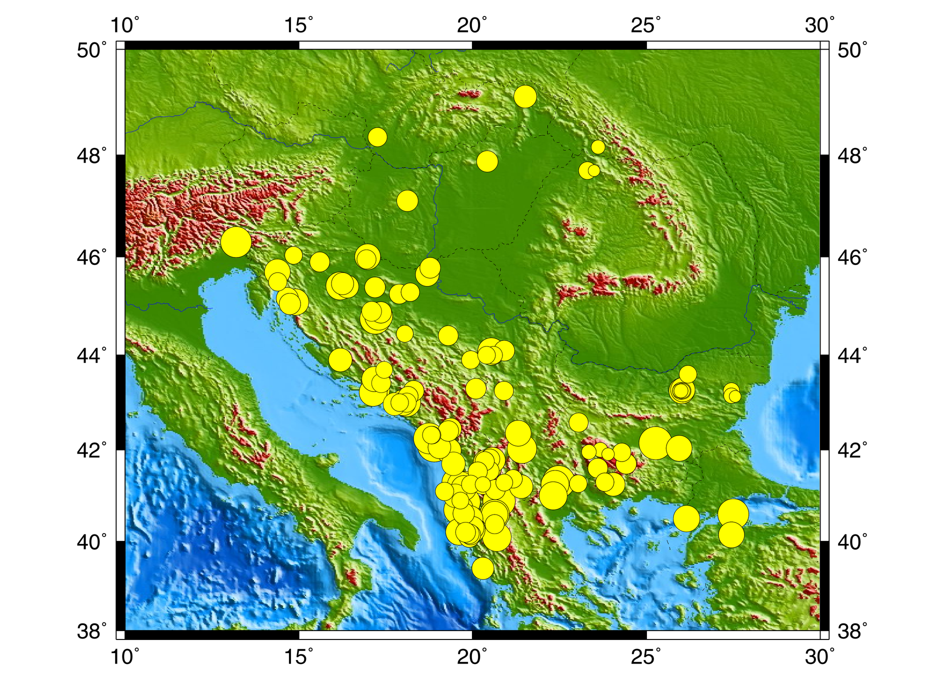

Fig. 2. Epicenters of earthquakes selected for this study from the catalogue of Shebalin et al. (1998) - SH98 - for Central and Eastern Europe. Diameter of dots proportional to M_S.

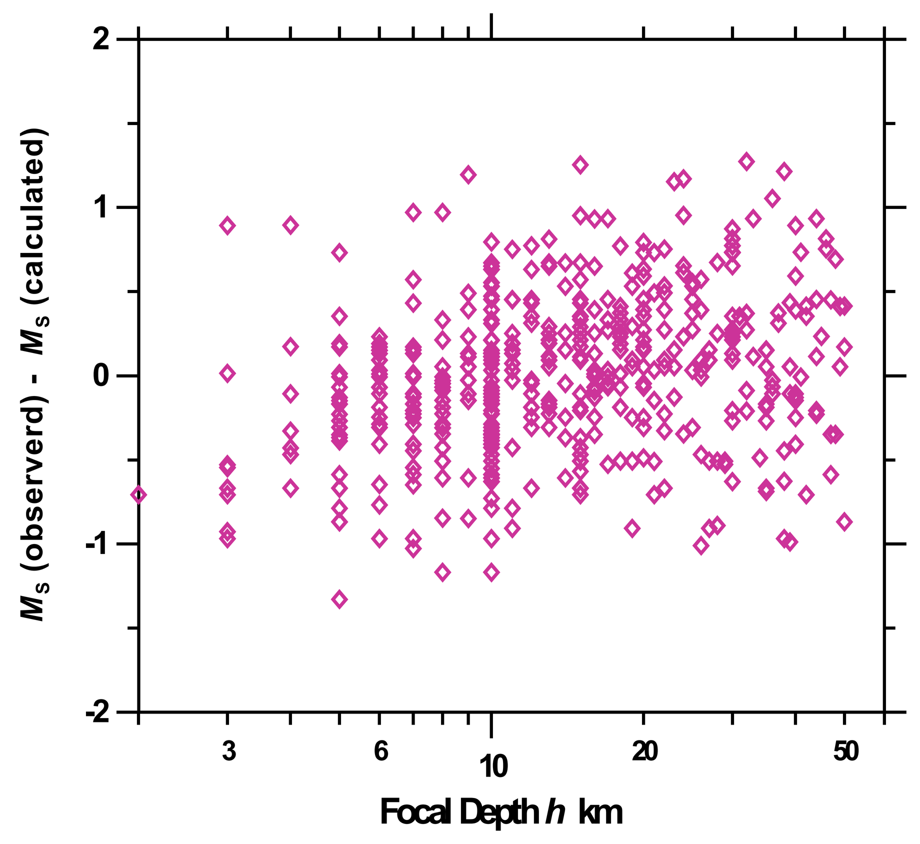

Fig. 4. Difference between instrumentally determined M_S and M_S estimated from I_0 using eq. (1) as a function of focal depth for the earthquakes in Fig. 3.

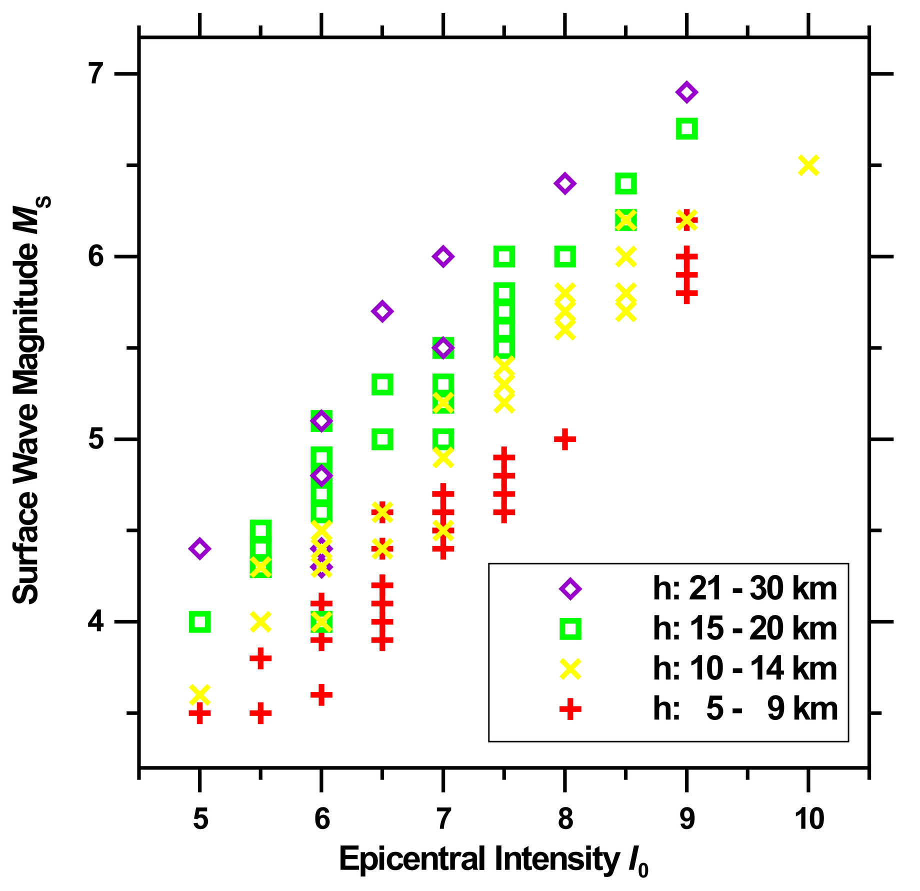

Fig. 6. Surface wave magnitude M_S as a function of epicentral intensity I_0 for 112 earthquakes from SH98. Note the clear dependance on focal depth.

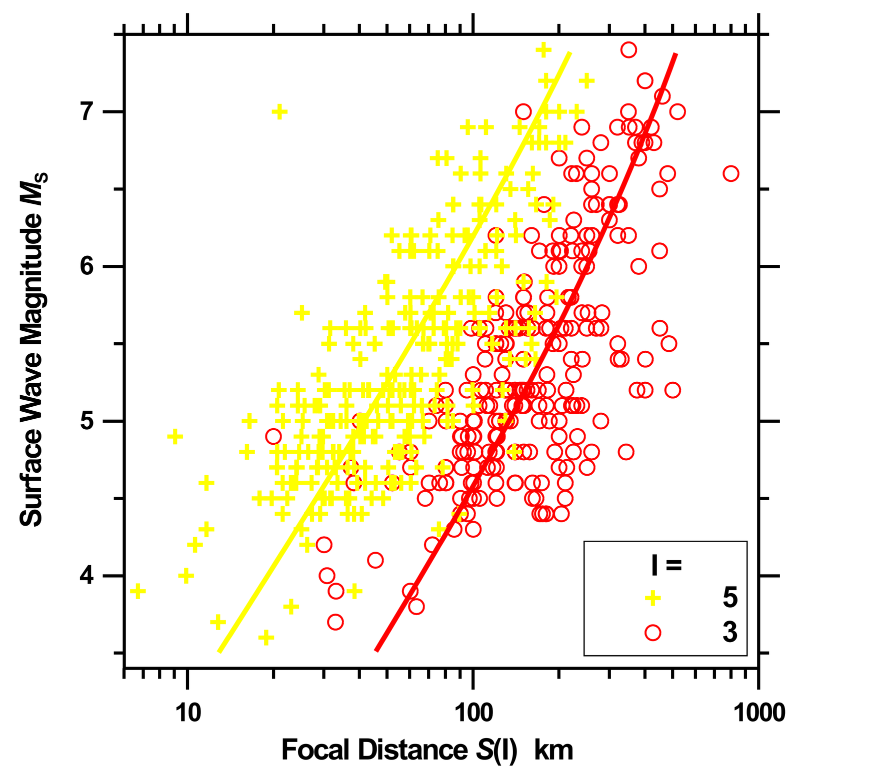

Fig. 9. M_S as a function of hypocentral distance to the isoseismal $S(I)$ for 249 values of $S(I=3)$ and 281 values of $S(I=5)$ from KA96.

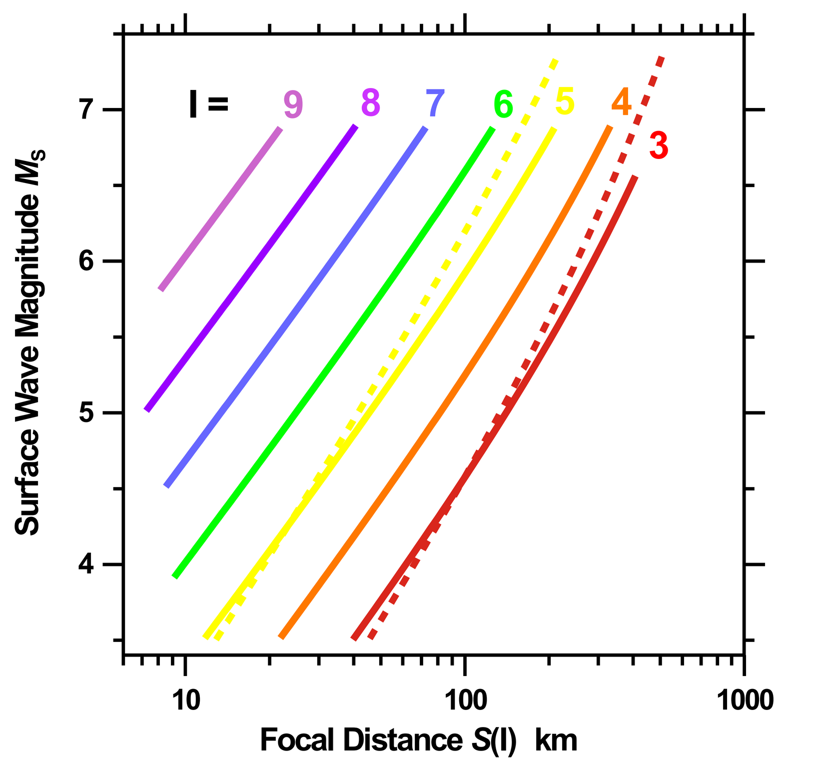

Fig. 10. Comparison between relationships (7) (solid lines) and (9) (dashed lines).

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