ANNALI DI GEOFISICA, VOL. XXXVII, N. 1, April 1994

National borders earthquakes: an attempt at intensity maps unification

Valerio De Rubeis, Alessandra Maramai and Andrea Tertulliani
Istituto Nazionale di Geofisica, Roma, Italy

Abstract
In this paper the problem of unification of macroseismic maps across national borders is discussed. Up to now some attempts in this way have been carried out, evidencing the difficulties present in such analysis. A filter technique working on intensity data is applied on these particular kinds of events, with the goal of homogenizing different macroseismic fields coming from neighboring countries. The filter, already tested on Italian earthquakes, has been used on five European earthquakes of this century, for which different data sets and partial interpretations exist in literature. This approach works well with data sets limited to a single country. Moreover it could be successfully utilized for border events too, wherever a unification of intensity assessment methods has been carried out among neighboring countries.

Key words *macroseismic maps – border earthquakes – trend analysis – filter*

1. Introduction

In macroseismics, the recent development of automatic procedures in data collection and analysis constitutes an important advancement, in particular attaching more importance to the reliability of the data in comparison with their interpretation; such procedures reduce the problems associated with the subjectivity of the traditional drawing of isoseismals.

If we follow from the beginning the steps leading to the macroseismic data assessment, *i.e.* the intensity values for a given point, we note that this path can be influenced by many factors. Many different ways to lead inquiries in the felt area are currently used: questionnaires, direct field surveys, information from newspapers etc., with a sampling which depends on the urbanization, on the used technique and on the nature of the correspondents. Such information can have limits in quality and they are treated either by computer processing or traditionally by personal interpretation (Gasparini *et al.*, 1992). The way of dealing with macroseismic data is linked to the chosen macroseimic scale, often different from country to country. The final step, that is map drawing, risks to concentrate all uncertainties met throughout the whole procedure.

We can summarize the sources of uncertainties in two large categories, that could be called subjective factors (techniques and ways of interpretation), and objective factors (macroseismic scales, in general). As regards earthquakes near national borders, these problems are clearly amplified, giving rise to an important question about the unification of the interpretation of shaking intensity in such areas (Ambraseys and Moinfar, 1988).

The necessity to have comparable methods and parameters is no more negligible for seismic hazard studies. In macroseismics it has been always difficult and complex to produce unique maps and interpretations of earthquakes near countries' borders. This limit of macroseismics makes it difficult to carry out studies on seismotectonic and seismicity in well determinated areas of the world. In particular in Europe, where many traditions of macroseismic data collection and interpretation exist.

Ambraseys (1983) underlined the necessity of providing uniform assessments for earthquakes affecting border territories and consequently common isoseismal maps for the different countries. Approaches to this topic have been proposed by Tertulliani *et al.* (1992) and De Rubeis *et al.* (1992a). A synthesis of macroseismic data from different countries was carried out in the Balkan Catalogue of Earthquakes (Shebalin, 1974), from which we took out some events to be analyzed with our technique.

One of the goals of this paper is to show that it is possible to analyze data pre-existent in literature and in the available catalogues, without making a difficult or impossible re-estimation of intensities from the original sources; besides, the difference between the scales here used can be considered negligible, especially for low degrees (*i.e.* for MCS and MSK-64 scales the difference is half a degree at most) (Shebalin, 1974; Di Maro and Tertulliani, 1990), so we thought that it is correct to treat such intensity values with a statistical method.

The interpretation of isoseismal maps was treated both in the past (Davison, 1921) and in recent times (De Rubeis *et al.*, 1992b), by pointing at the unlikeness of isoseismal maps, as derived by several authors, for the same earthquake.

The approach shown in this paper starts by performing an automatic procedure to draw macroseismic maps.

2. Method

The technique here shown, described in detail by De Rubeis *et al.* (1992a), is based on the filtering of the macroseismic field, with the aim to discriminate the local, noisy component from the regional component (macroseismic signal) of the earthquake.

The initial hypothesis of this algorithm is to consider that the whole data-set is composed of a regional signal plus a random local component (noise). The filtering aims to emphasize a regional signal that could be characteristic of the seismic attenuation.

The regional component of the signal can be considered as a continuous surface where the vertical coordinate represents the macroseismic intensity. Any specific point on this surface receives the contribution of the local component, here denominated as noise, that is certainly not continuous and very variable (*i.e.* having no or little spatial autocorrelation).

Formally we have

$$Z_i = f(x_i, y_i) + \in_i \qquad (2.1)$$

where x_i and y_i are the geographical coordinates (in km) of one $i-th$ specific point, Z_i its intensity and $\in_i$ the local contribute. The regional component is estimated by the polynomial expression

$$f(x_i, y_i) = \sum_{r+s \leq p} a_{rs} x^r y^s \qquad (2.2)$$

where p is the polynomial order, r and s are two positive integer numbers that represent all possible combinations of exponents of x and y giving the polynomial order less or equal to p; a_{rs} are the coefficients of the equation for every pair of r and s; this equation is the base of the trend analysis which has been applied in many areas of earth sciences.

The polynomial estimation represented by eq. (2.2) is efficient when the surface to be fitted is simple and requires a low polynomial order (no more than 4). In general the entire macroseismic field does not match this need, so the whole geographic area has been subdivided into regular small circular overlapping parts, each one characterized by a simpler behavior. In particular, starting from a regular grid, a trend surface of a given order is calculated for each junction, considering the original intensity values within a determined spatial range. This range is large enough to include sufficient data points and to permit overlapping with adjacent points on the grid: in this way each original datum participates in more different trend surfaces. Once the coefficients for one trend surface are calculated, it is possible to represent the filtered values as a smoothed surface inside the considered spatial range. Only the central value of such surface, corresponding to a grid model, is considered for the approximation of original data. The automatic drawing of macroseismic fields uses all node grid values. The great flexibility of filtering is characterized by the possibility of varying the order of the trend surface and the spatial range (radius), proportioning in such way the effect of the filter.

In the graphs of figs. 3, 6, 9, 12 and 15 we can see the trends of the *relative goodness of fit* for each polynomial degree and for various spatial ranges defined as

$$F_r = 1 - \frac{\sum_{j=1}^{n} (\hat{Z}_j - Z_j)^2}{\sum_{j=1}^{n} (\bar{Z} - Z_j)^2} \qquad (2.3)$$

where $\hat{Z}_j$ is the calculated value, Z_j the original one while $\bar{Z}$ is the average for all the original data: on this preliminary step the analysis is centered on the original data points only. For each polynomial degree the general trend comprises two branches separated by different slopes which can be interpreted as different components with well defined distance domains (De Rubeis, 1992b). From the *relative goodness of fit* we can choose the appropriate values of the radius, fixing it where the slope of the curve changes, while the degree of the surface is chosen as low as possible. Ranges of low values and elevated degrees of surfaces permit very high approximations of the original data, obtaining a slightly filtered result. On the contrary, using a 0-degree polynomial (that simply gives the average value to the original points) and a radius big enough to permit the inclusion of all original points for every surface, a steady surface equal to the average for all macroseismic intensities is obtained: the filter effect is thus at its maximum.

3. Data set analysis

As already mentioned, to carry out this study we used the data for five border earthquakes which occurred in Europe during this century. These events are particularly representative for the aim of our analysis, because they involve more than two neighboring countries and they also show very interesting macroseismic fields.

We chose these earthquakes because they were quite strong and, therefore, a large number of detailed studies by several authors about them are available in literature. On this ground, the available data (*i.e.* the intensity for each locality), were well selected and do not need any additional careful review.

First of all, we examined the June 14, 1913 earthquake which occurred in Bulgaria (ϕ = 43.1°N, λ = 25.7°E; M_S = 7.0) and was also felft in Rumania, studied by four authors (Rădulescu, 1938; Atanasiu, 1961; Grigorova, 1972; Shebalin, 1974). This event reached the intensity of X Medvedev-Sponheuer-Karnik (MSK) scale in the epicentral area. As shown in fig. 1, taken from the Atlas of isoseismal maps of UNESCO, only Shebalin represented the whole macroseismic field. On the contrary, the other two authors drew isoseismals only for their countries, not considering information from the neighboring countries. Examining fig. 1 we can observe that the mesoseismal area (X MSK) shows a similar trend NE-SW both for Shebalin and for Grigorova studies; in addition, a considerable complexity of isoseismals is shown in the studies of Grigorova and Atanasiu, for Bulgaria and Rumania respectively. In particular we can observe a large number of «bulges» and «islands» that break up the map and make the interpretation quite difficult.

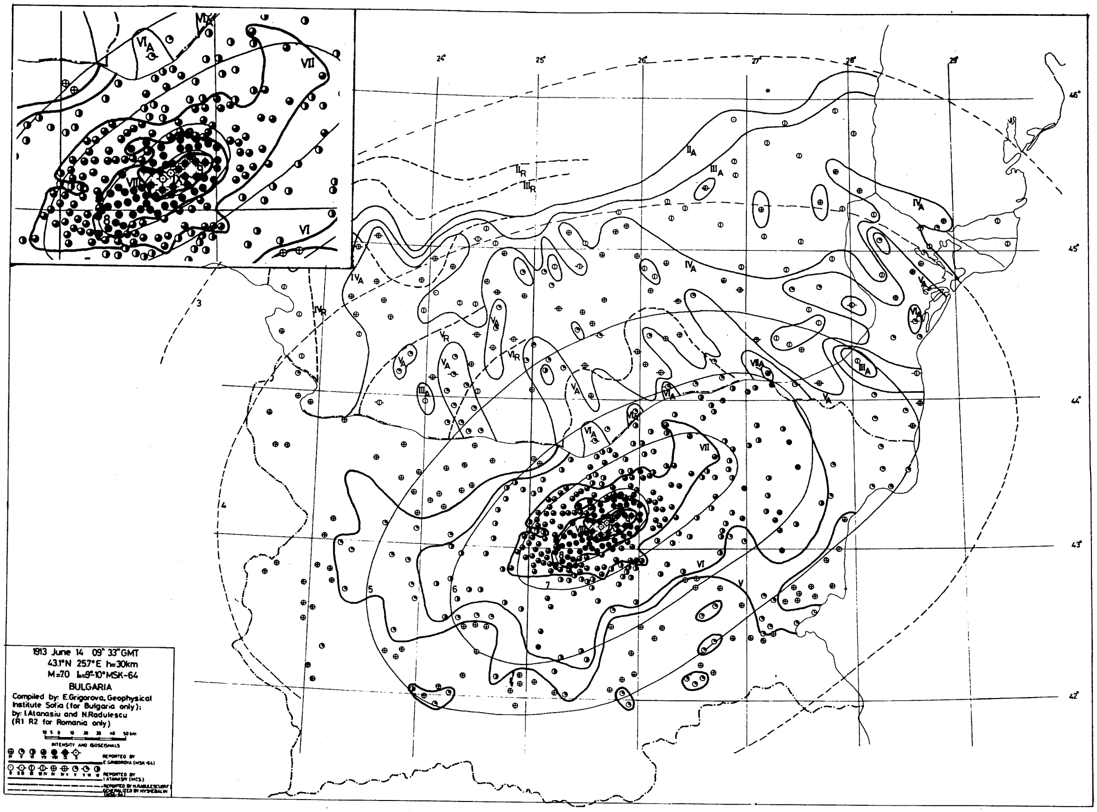


Fig. 1. Macroseismic fields for the June 14, 1913 earthquake (Bulgaria). Isoseismals drawn by Atanasiu (1961) and Rădulescu (1938) only for the Rumanian side (thin and dashed lines). With full lines are reported the isoseismals from Grigorova (1972) for Bulgaria. With thin lines is the generalization by Shebalin (1974), both for Rumania and Bulgaria (after Shebalin, 1974). A particular of the epicentral area is shown in the box.

In fig. 2 the map from filtered data is shown and we can note the loss of the excessive complexity of the Rumanian study. The analysis of the *relative fit* shows the difficulty of the process to well discriminate between the two components of the macroseismic signal, as the change in the slope of the curve (fig. 3) is not clear. Another problem is due to the great difference in the density of the points between the epicentral and the surrounding areas. In order to eliminate this problem, the filter was used with two different values of the range, one for the whole data set (3° polynomial degree, 70 km) and the other (smaller than the previous one) relative to the epicentral area (3° polynomial degree, 40 km).

The second analysed event is the November 20, 1932 earthquake which occurred in the central part of Holland (ϕ = 51.7°N, λ = 5.6°E; M_S = 4.5), involving three neighboring countries: Holland, Germany and Belgium. This event, less strong than the previous one, was felt in North Brabant, with maximum intensity VI MSK and was studied by Ambraseys (1985). Fig-

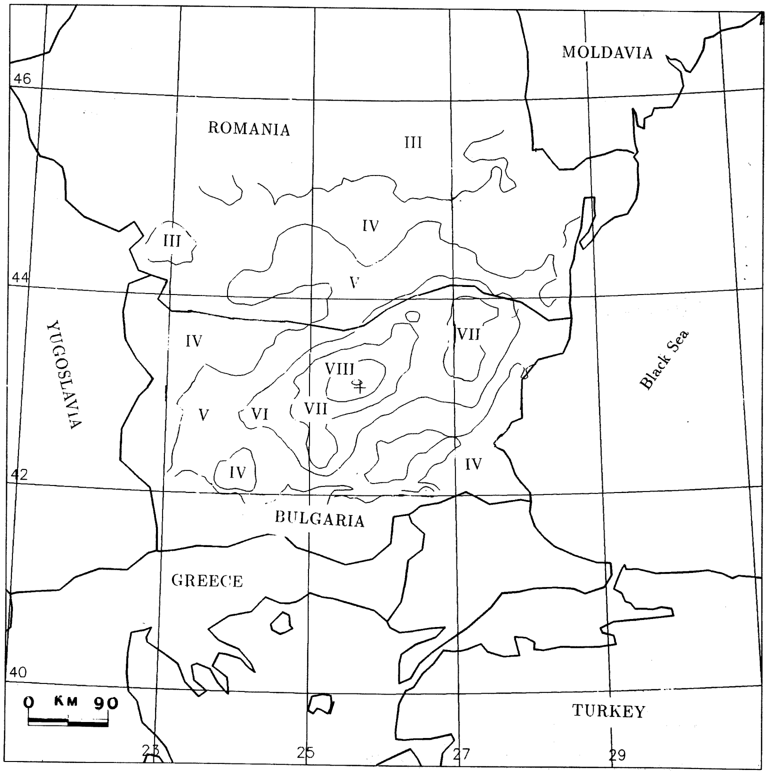
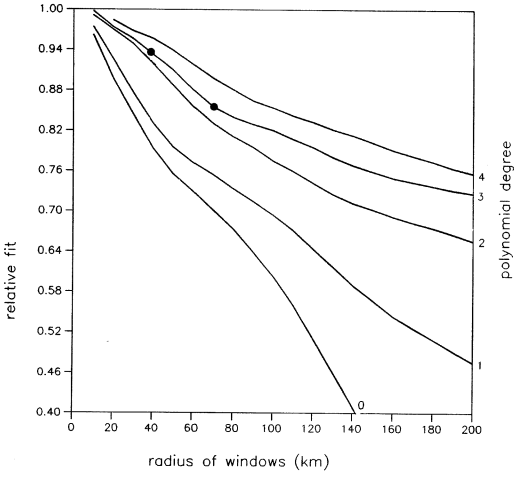


Fig. 2. Filtered isoseismal map of the June 14, 1913 earthquake. The epicentral area data have been filtered separately.



ure 4 shows that the intensity values reported are regularly distributed, except for a few data of V MSK degree in the Low Rhine valley. Probably, this is due to the unusually high density of population that could give an anomalous pattern in the distribution itself (Ambraseys, 1985).

Fig. 3. Graph of the *goodness of fit* vs the radius of windows. The paths of the fit computed for various spatial ranges and polynomial degrees are shown. As filter parameters have been used a polynomial of 3° degree and a radius of 70 km for the whole data set while for the epicentral area the parameters are 3° polynomial degree and 40 km.

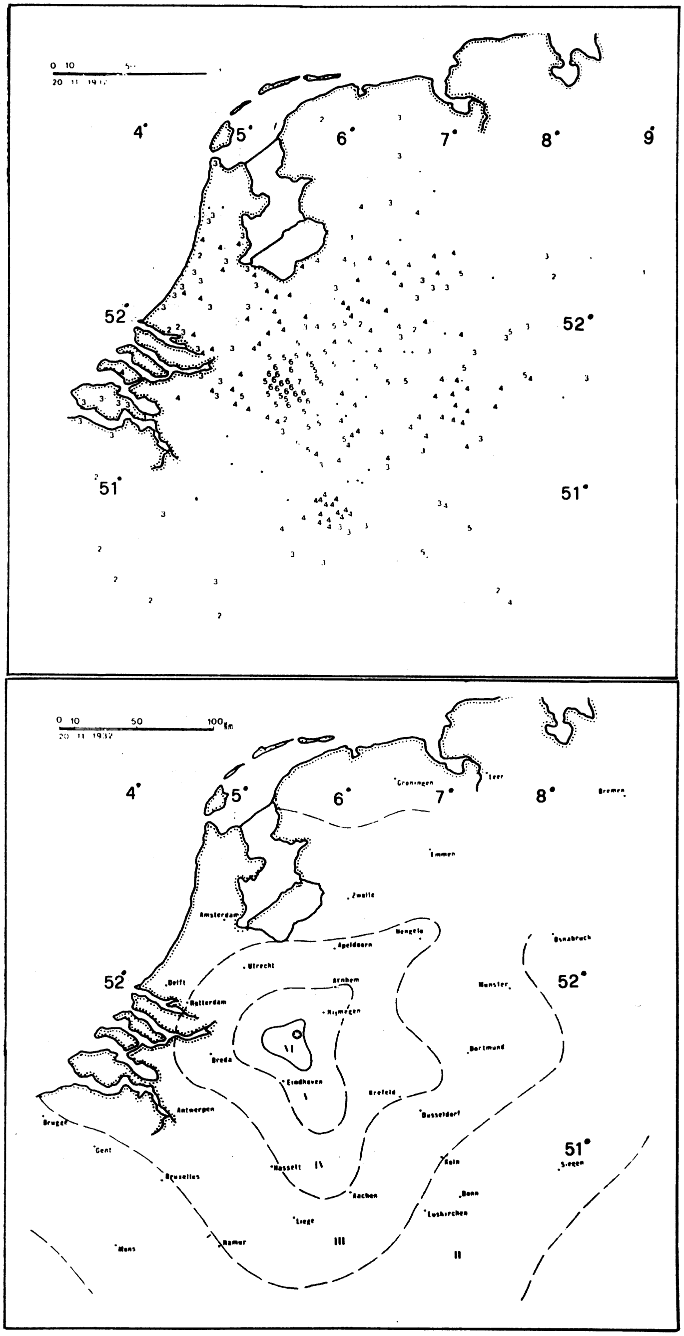


Fig. 4. Macroseismic field and isoseismal map for the November 20, 1932 earthquake (Holland) (from Ambraseys, 1985).

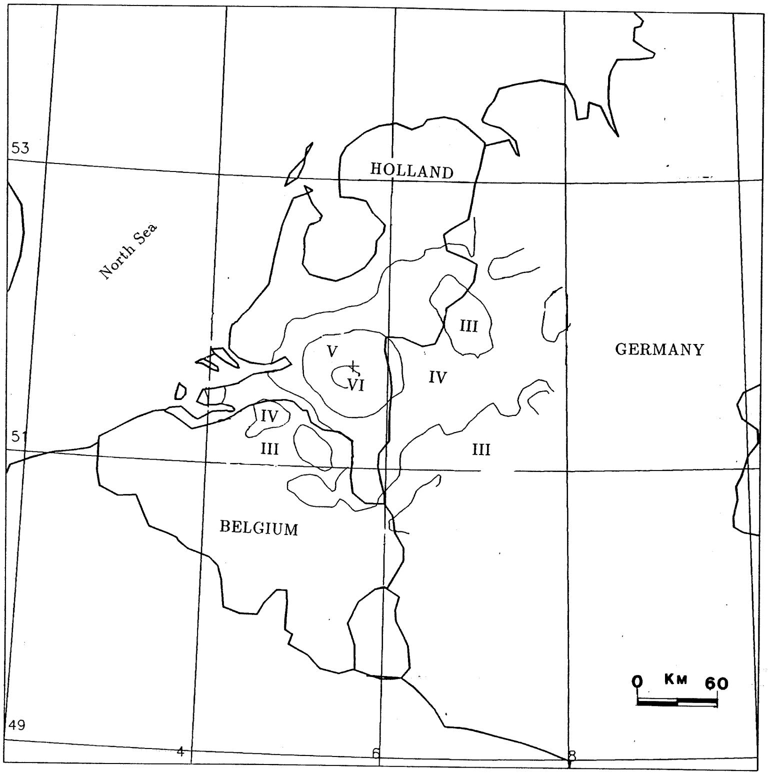


Fig. 5. Filtered isoseismal map of the November 20, 1932 earthquake.

Figure 5 shows the filtered field obtained from the whole data set: note that the isoseismals in the epicentral area are more regular than those from Ambraseys, which seem to be quite «noisy», particularly as regards the easternmost part of the region. On the graph of the *relative fit* for this earthquake (fig. 6), the best choice of the

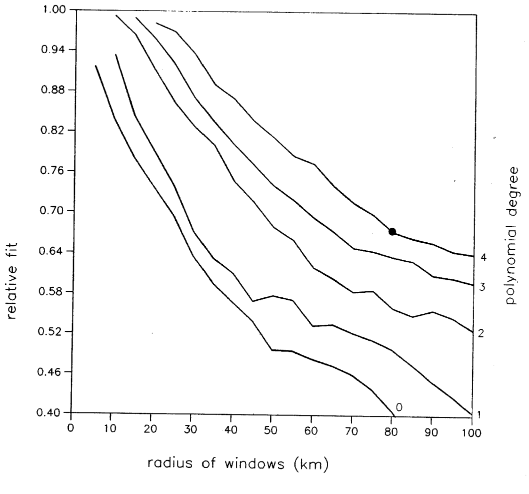


Fig. 6. Graph of the *goodness of fit* relative to the November 20, 1932 event. The chosen parameters are 80 km of radius and a 4° order polynomial degree.

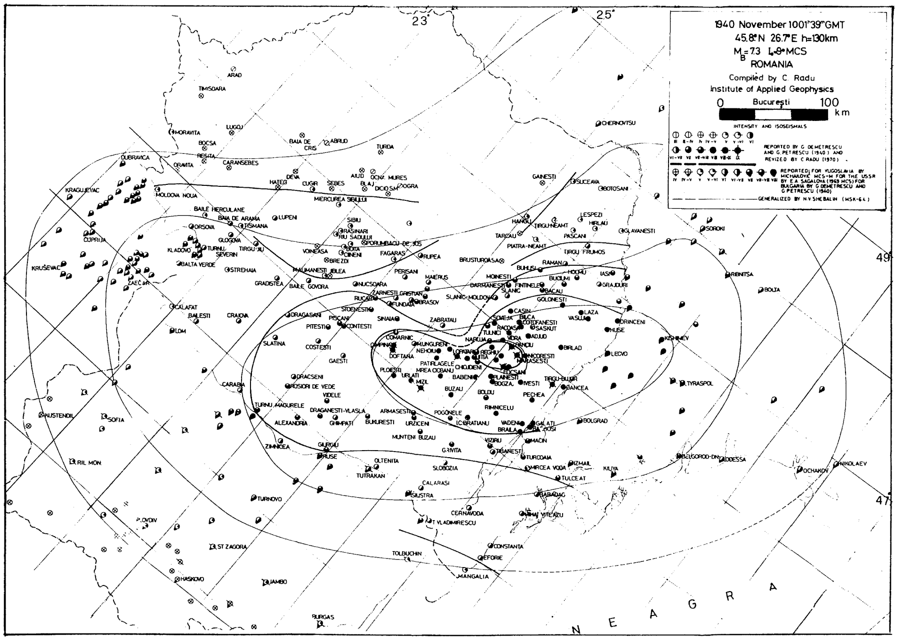


Fig. 7. Macroseismic fields of the November 10, 1940 earthquake (Rumania). The thin lines are the Shebalin'(1974) isoseismals, obtained from data collected by several authors. The thick lines represent isoseismals only for Rumania, by Radu (1971) (after Shebalin, 1974).

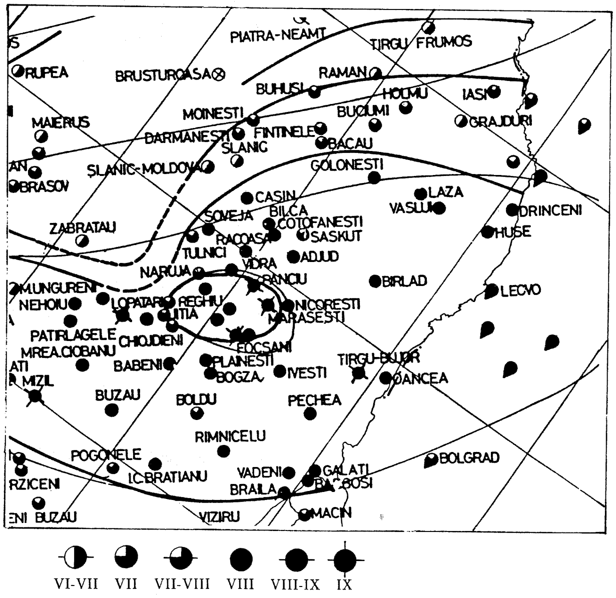


Fig. 7a. Detail of the maximum intensity area (IX MCS) for the November 10, 1940 earthquake (after Shebalin, 1974).

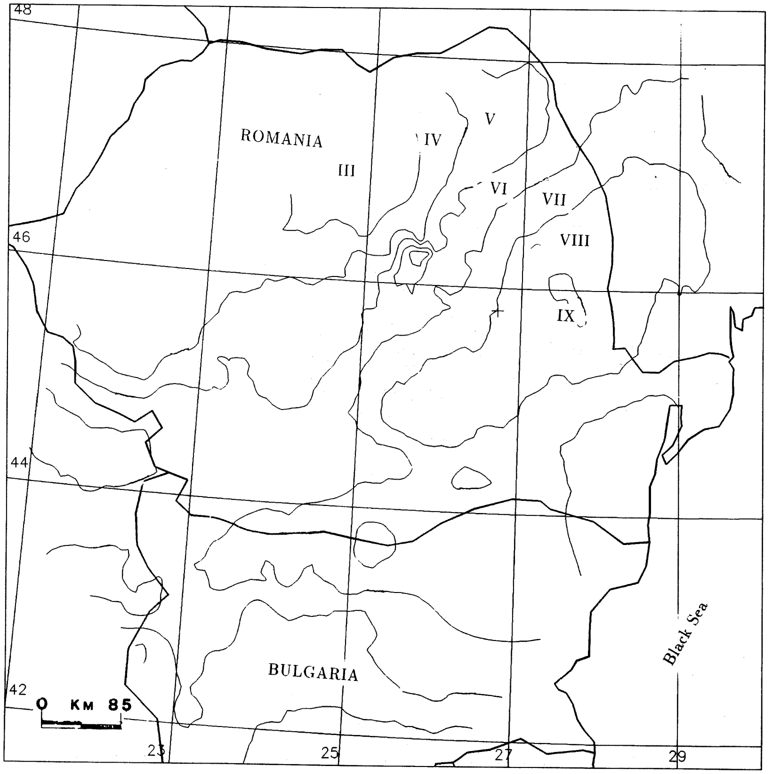


Fig. 8. Filtered field for the Rumanian event on November 10, 1940.

filter parameters seems to be 80 km. of radius and a trend surface of 4° degree.

In the next example we examined a very strong earthquake (M_B = 7.3) which occurred on November 10, 1940 in Rumania (ϕ = 45.8°N, λ = 26.7°E) that had maximum intensity value of IX Mercalli-Cancani-Sieberg (MCS) scale. Because of its high magnitude, this event affected the

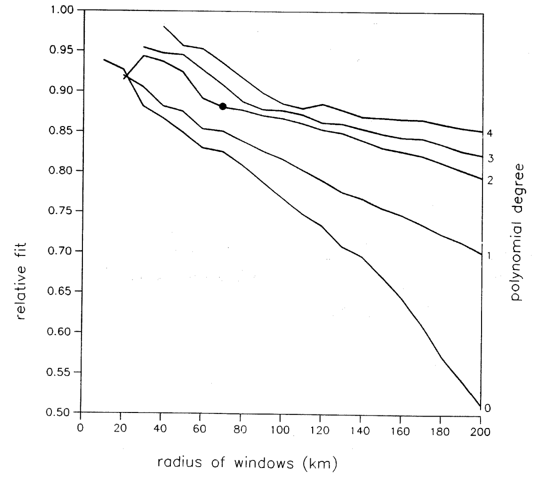


Fig. 9. Graph of the *goodness of fit* relative to the November 10, 1940 Rumanian earthquake. The chosen parameters are 70 km of radius and a 2° order polynomial degree.

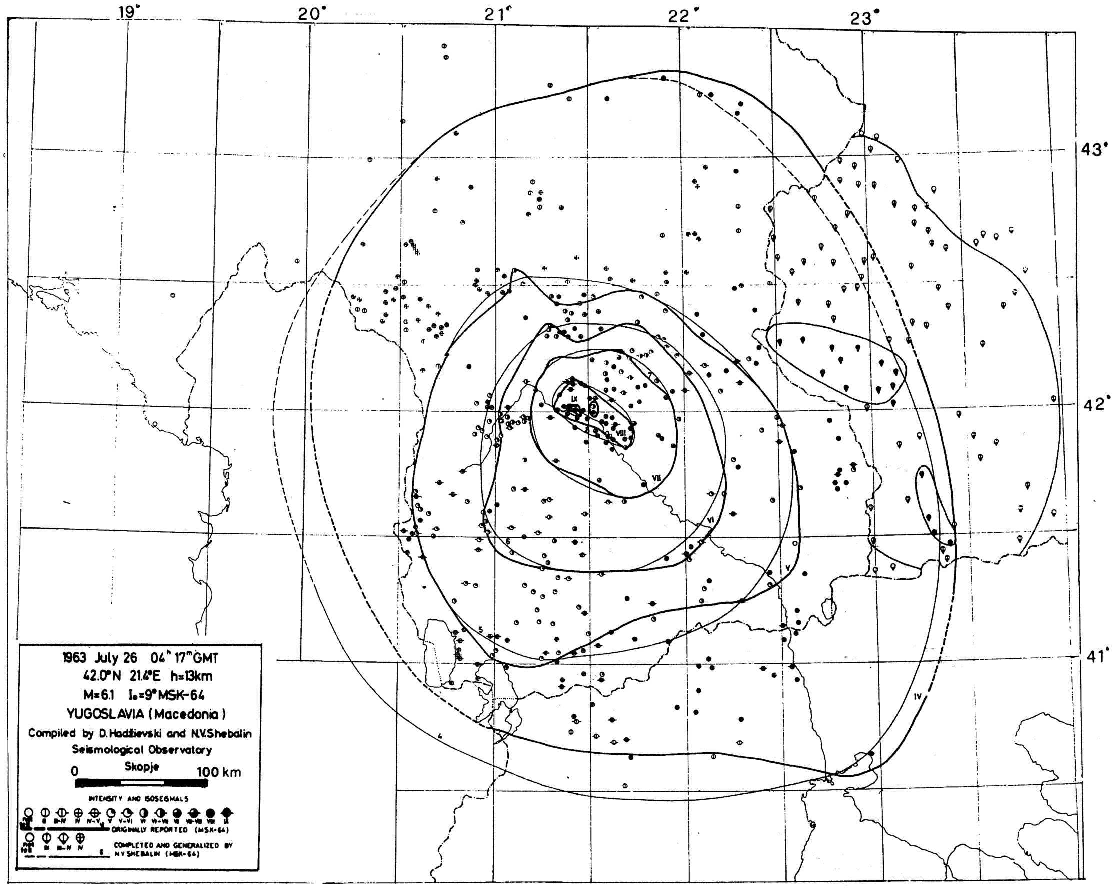


Fig. 10. Isoseismal map for the July 26, 1963 earthquake (Macedonia). The Hadžievski's interpretation (1971) is reported with thick lines and the field drawn by Shebalin (1974) with thin lines (after Shebalin, 1974).

whole of Rumania, Bulgaria, part of Yugoslavia and Moldavia: it was studied by several researchers, whose data have been used by Shebalin (1974). He produced a complete macroseismic field, on the basis of the MSK scale, taking into account all countries involved by the earthquake. Besides, Radu (1971) drew isoseismals only for Rumania and the intensity values reported by this author referred to the MSK scale, while intensity values for Yugoslavia are expressed in MCS modified by Mihailovic (Shebalin, 1974). Figure 7 shows, in general, a quite regular trend on both isoseismal maps and intensity values reported by the above mentioned authors.

In addition, a more evident trend NE-SW of isoseismals in all three studies is observed, even if from the distribution of intensities in the epicentral area the drawing of the maximum intensity isoseismals (fig. 7a) appears to be arbitrary.

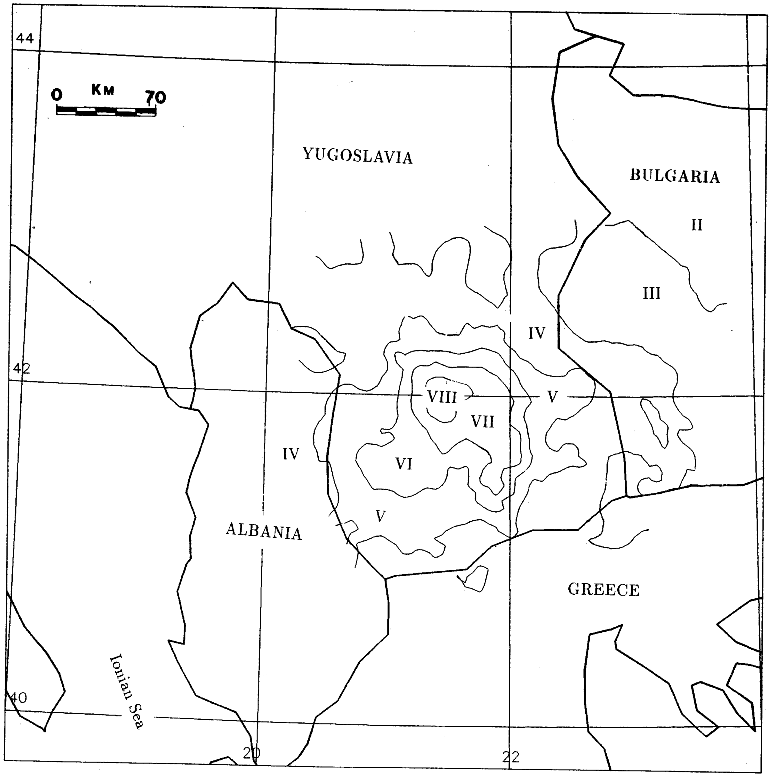
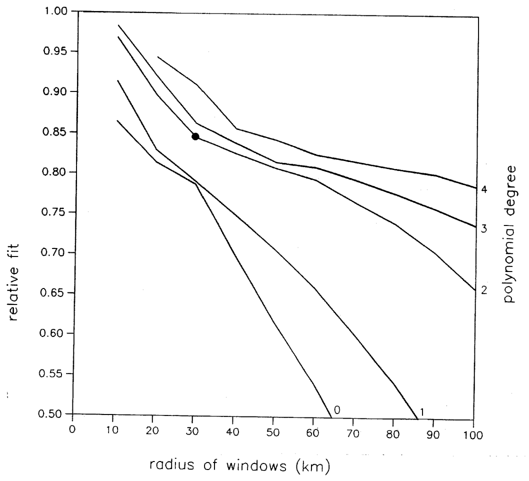


Fig. 11. Filtered field of the July 26, 1963 Macedonian event.



The big Rumanian earthquake shows the same regular trend, NE-SW, also in the filtered version (fig. 8), except for the mesoseismal area (IX MSK) that presents, on the contrary, an evident trend almost N-S. This trend contrasts with the theoretical one suggested by Radu (personal communication, 1994), according to the direction of the rupture plane (N 35°E). A careful ex-

Fig. 12. Graph of the *goodness of fit* for the July 26, 1963 Macedonian earthquake. The chosen parameters are 30 km of radius and a 2° order polynomial degree.

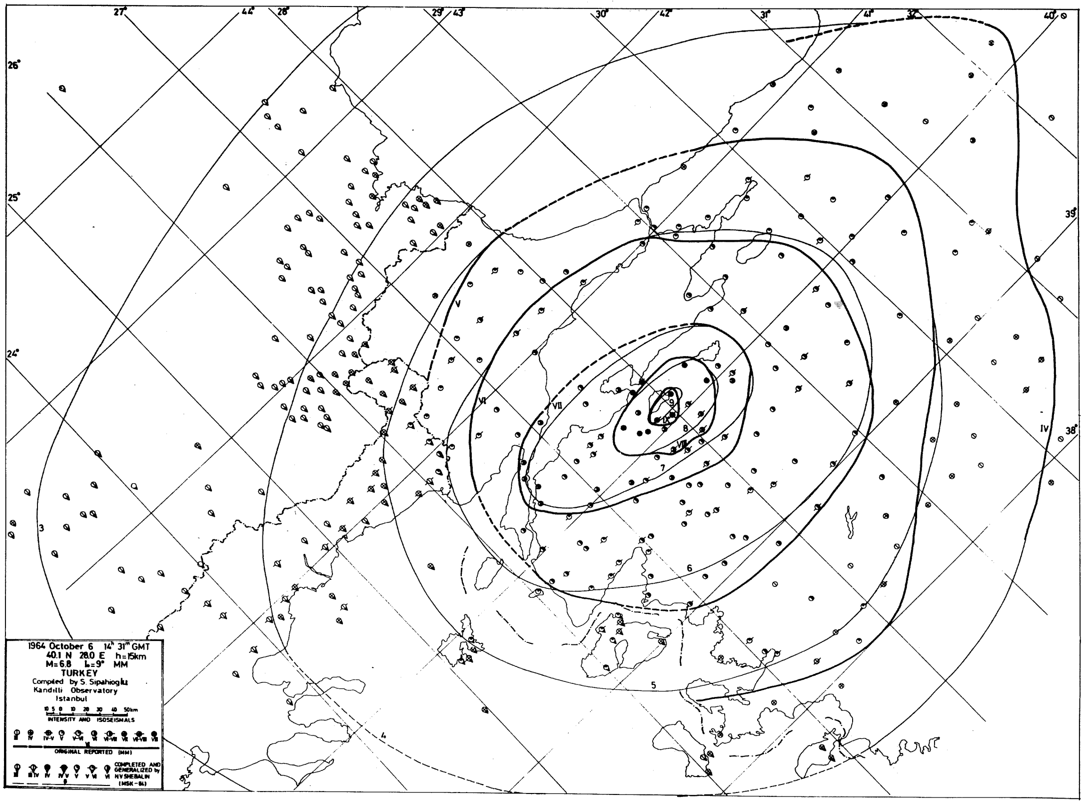


Fig. 13. Macroseismic field for the October 6, 1964 event (Turkey). Thin lines are isoseismals from Shebalin (1974) while thick lines represent the Sipahioglu (1973) version, only for Turkey (after Shebalin, 1974).

amination of the intensity distribution in the epicentral area points out the presence of a relatively large zone (elongated NW-SE) affected by intensity VII, that sharply breaks the general trend of the higher degree area. We can also observe that in the whole data set no particular behavior emerges due to the use of different macroseismic scales. For this earthquake, as shown in fig. 9, the choice of the best filter parameters is 70 km of radius and a trend surface of 2° degree.

The fourth event studied is the July 26, 1963 earthquake, which occurred in the southern part of Yugoslavia (Macedonia), with epicentral coordinates ϕ = 42.0°N, and λ = 21.4°E, involving four neighboring countries: Yugoslavia, Greece, Albania and Bulgaria. This event (M_S = 6.1) reached the intensity of IX MSK in the epicentral area and was analysed by Hadževski (1971) and subsequently by Shebalin (1974). Both authors produced very similar macroseismic fields, with almost circular isoseismals (fig. 10).

For this earthquake, the filtered field (fig. 11) is obtained using a radius of 30 km and a trend surface of 2° degree

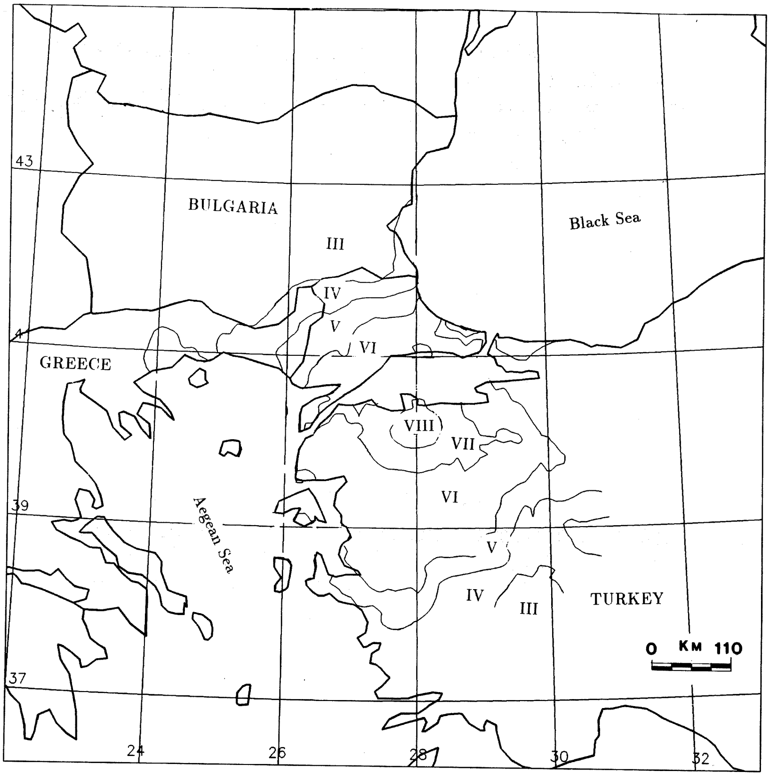


Fig. 14. Filtered field for the Turkish earthquake on October 6, 1964.

(fig. 12) corresponding to a clear change in the slope of the curve; in fact, after an evident fall of *fit*, it can be noted that the slope of the curve tends to be more horizontal increasing the radius of windows, probably due to a relative greater resistance of the original data to the large radius filter in respect to small radius filter values.

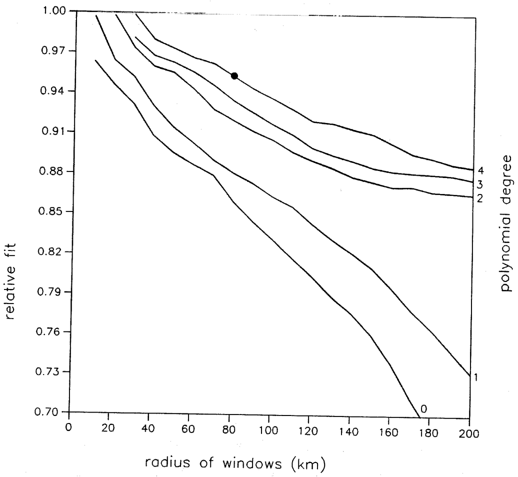


Fig. 15. Graph of the *goodness of fit* for the October 6, 1964 event. The chosen parameters are 80 km of radius and a 4° order polynomial degree.

Analyzing the field in fig. 11, we can notice that it seems less regular that the general elliptical trend NW-SE noticeable in fig. 10 as well. It is remarkable that the automatic procedure does not take into account the Albanian side because of a lack of information for this country.

Finally, we took into consideration the October 6, 1964 earthquake ($M_B = 6.8$) with its epicenter in Turkey ($\phi = 40.1°N$, $\lambda = 28.0°E$). This event was also felt in some regions of Bulgaria and Northeastern Greece. Its epicentral intensity was IX Mercalli modified (MM) scale; it was studied by Sipahioglu (1973) as regards Turkey and by Shebalin (1974) for all the three countries. As shown in fig. 13, the macroseismic fields present very regularly drew isoseismals, almost circular to the lowest intensity values and with an evident elongation E-W for the epicentral area; the results of the studies of the two above mentioned authors are very similar.

The filter worked well (fig. 14) using parameters values of 70 km of radius and a trend surface of 4° degree, as shown in fig. 15. We can point out that in the filtered field the isoseismal of IX degree does not obviously appear, infact it was drawn by Shebalin (1974) and Sipahioglu (1973) on the basis of only one observation.

4. Conclusions

This is a first systematic attempt at the unification of different countries macroseismic data using an automatic procedure, applied to a little sample of earthquakes. The analysis of the results achieved, emphasizes once again that the technique here used, extensively tested both for historical and recent events, allows us to overcome some of the problems due to the dishomogeneity of the macroseismic data, particularly as regards border earthquakes, often partially studied only .

The problem of unification of different data was dealt with by Shebalin (1974), who redrawned isoseismal maps merging different countries and authors data; however his macroseismic fields are probably too much smoothed, not giving prominence to eventual important trends. On the contrary, some papers available in literature attach too much weight to the single intensity value, drawing very complex maps which become hard to be used (*i.e.* fig. 1). In other cases one demonstrates that without a co-operation of the agencies from different countries involved in the event, it is impossible to merge the isoseismal maps (Ambraseys and Moinfar, 1988). The use of the filter technique here shown, allows us to delete such redundancies, preserving the regional component of the «macroseismic signal».

This method has a high versatility and shows that dishomogeneities due to the use of different methods of investigation and drawing criteria, can be treated like *noise* and, consequently, they can be eliminated. It is opportune to underline that, like each statistical method, its success depends on the goodness and completeness of the input data.

Regarding the treatment of intensities assessed through different macroseismic scales, our technique can not solve the problem in general terms. However using MCS and MSK scales, that are very similar, particular difficulties seem not to arise, like in the cases shown here.

In conclusion the application of the filter procedures with the original intensity data sets, makes possible to emphasize particular trends in the distribution of intensity: such trends resist the filtering and they can be considered as regional characteristics of the macroseismic field, and constitute a starting point for more detailed studies.

The trend analysis performed on macroseismic data comes out relevant both for the macroseismic re-evaluation of historical earthquakes and for a quick, acritical analysis of the macroseismic fields for recent events.

Finally, it emerges that future goals of macroseismics will be both the spreading of automatic techniques of data processing and the unification of the principles of intensity assessment.

REFERENCES

AMBRASEYS, N. (1983): Notes on historical seismicity, *Bull. Seismol. Soc. Am.*, **73**, 1917-1920.

AMBRASEYS, N. (1985): Intensity-attenuation and magnitude-intensity relationships for Northwest European earthquakes, *Earthquake Eng. Struct. Dyn.*, **13**, 733-778.

AMBRASEYS, N. and A.A. MOINFAR (1988): Isoseismal maps across national frontiers: the Caldiran (Turkey) earthquake of 24 November 1976, *Eur. Earthquake. Eng.*, **1**, 15-21.

ATANASIU, I. (1961): *Cutremurele de pamint din Rumania*, Academia RPR, Bucuresti.

DAVISON, C. (1921): On scales of seismic intensity and on the construction and use of isoseismal lines, *Bull. Seismol. Soc. Am.*, **11**, 94-129.

DE RUBEIS, V., C. GASPARINI, A. MARAMAI, M. MURRU and A. TERTULLIANI (1992a): The uncertainty and ambiguity of isoseismal maps, *Earthquake. Eng. Struct. Dyn.*, **21**, 509-523.

DE RUBEIS, V., C. GASPARINI and P. TOSI (1992b): Determination of the macroseismic field by means of trend and multivariate analysis of questionnaire data, *Bull. Seismol. Soc. Am.*, **82**, 1206-1223.

DI MARO, R. and A. TERTULLIANI (1990): The relation between intensity and magnitude for Italian earthquakes, *Pageoph*, **132**, 711-718.

GASPARINI, C., V. DE RUBEIS and A. TERTULLIANI (1992): A method for the analysis of macroseismic questionnaires, *Natural Hazards*, **5**, 169-177.

GRIGOROVA, E. (1972): *Catalogue of earthquakes occurred in Bulgaria after 1900* (manuscript), UNDP-UNESCO Survey of the seismicity of the Balkan region. Skopje.

HADŽIEVSKI, D. (1971): *Earthquake in SR Macedonia, 1900-1970* (manuscript), UNDP-UNESCO Survey of the seismicity of the Balkan region, Skopje.

RADU, C. (1971): *Catalogue of earthquakes occurred on the territory of Romania during the period 1901-1970* (manuscript), UNDP-UNESCO Survey of the seismicity of the Balkan region, Skopje.

RĂDULESCU, N. (1938): *Oltenis seismică*, Foçsani.

SHEBALIN, N. (Editor) (1974): *Catalogue of earthquakes*, UNDP-UNESCO Survey of the seismicity of the Balkan region, Skopje.

SIPAHIOGLU, S. (1973): *Catalogue of earthquakes, Turkey – Western Part*, Kandilli Observatory (computer output), Istanbul.

TERTULLIANI, A., A. MARAMAI, V. DE RUBEIS, P. HOANG TRONG and G. HERQUEL (1992): French-Italian border earthquakes, in *Proceedings of the Second AB Workshop on Macroseismic Methods, October 15-19,1990 Poliče*, edited by I. CECIĆ, Ljubljana, 29-45.

(received September 20, 1993;
accepted April 14, 1994)