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V-VALUE MODEL FOR EARTHQUAKE PREDICTION. AN APPLICATION TO SOME RECENT EARTHQUAKES SEQUENCES IN GREECE

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ABSTRACT

The "v-value" method, which is defined by $(\overline{\tau})^2/\overline{\tau^2}$, where τ is the interval rupture time between two adjacent earthquakes in space and time, has been applied to some recent earthquake series in Greece, in order to search some random, clustered or periodical changes in seismicity.

The analysis revealed, that before the occurrence of strong earthquakes in the investigated areas, relatively low v values have been obtained.

The v-values are supposed to reflect the state of the crustal stress and may be used for monitoring the seismicity changes.

ΣΥΝΟΨΗ

Η μέθοδος "v-value", πού ορίζεται από τον τύπο $(\overline{\tau})^2/\overline{\tau^2}$ όπου τ είναι ο ενδιάμεσος χρόνος διάρρηξης μεταξύ δύο γειτονικών στό χώρο καί στό χρόνο σεισμών, εφαρμόστηκε σε μερικές πρόσφατες σεισμικές ακολουθίες τού Ελληνικού χώρου, με σκοπό να αναζητηθούν τυχαίες, ενεργές ή περιοδικές αλλαγές στη σεισμικότητα.

Η ανάλυση αποκάλυψε οτι πρίν από την εκδήλωση τών μεγάλων σεισμών, παρατηρήθηκαν χαμηλές τιμές στή v-value.

Οι τιμές της v-value, αντιπροσωπεύουν την κατάσταση των τεκτονικών τάσεων μιας περιοχής και ως εκ τούτου είναι χρήσιμο να χρησιμοποιούνται για τον έλεγχο αλλαγών στη σεισμικότητα στην υπό εξέταση περιοχή.

ΕΙΣΑΓΩΓΗ - INTRODUCTION

Changes in the pattern of seismic activity, such as foreshocks or temporary changes in b value prior to the occurrence of large earthquakes, is very important for earthquake prediction studies. The identification, however, of foreshocks and their relation to the magnitude and to the occurrence time of the main shock is very difficult and the discrimination cannot always be made until the main shock occurs. Some prediction algorithms using the number of earthquakes occurring in a certain time window and

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Δ.Παπαναστασίου, Ι.Δρακόπουλος, Γ.Δρακάτος, Ι.Λατουσάκης, και Γ.Σταυρακάκης - Το μοντέλο της "v-value" για πρόγνωση σεισμών. Εφαρμογή του σε μερικές πρόσφατες σεισμικές ακολουθίες της Ελλάδας.

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the distribution of time intervals of earthquakes have been proposed (KEILIS-BOROK, 1978, 1980a,b;) and tested by SAUBER and TALWANI (1980) for identifying foreshocks.

MOGI (1967) concluded that the type of earthquake sequence depends mainly on the structural state of the earth's crust, as well as on the space distribution of the applied stresses. In most earthquake catalogs, three kinds of sequence patterns, namely successive, periodical, and random can be found and may reflect the relation between the tectonic stresses and stress releases during earthquakes. Some characteristic seismic pattern changes, such as quiescence, foreshocks, swarms, and doughnut patterns may be regarded as precursory phenomena and are associated with the mode of the strain release in a seismogenic region (KANAMORI, 1981).

In the view of earthquake prediction, MATSUMURA (1982,1984) developed a new method for describing seismicity patterns in space and time and proposed a new parameter, the "ν-value", which is closely related to the apparent interaction between two successive earthquakes. This parameter is derived on the basis of the Weibull distribution and its values characterize the earthquake sequence as being periodical ($\nu > 0.5$), clustered ($\nu < 0.5$) or random ($\nu = 0.5$).

In this study, the earthquake sequences tabulated in table 1 have been analysed by using the ν-value method to examine whether the large seismic events of the sequences were predictable. The geografical areas of those earthquake sequences are presented in Fig 1 with the same code numbers of table 1.

ΤΟ ΜΟΝΤΕΛΛΟ ΤΗΣ "ν-value" - ΘΕΩΡΗΤΙΚΗ ΕΞΕΤΑΣΗ
THE "ν-VALUE" MODEL - THEORETICAL CONSIDERATION

In the following analysis, it is assumed that the occurrence of an earthquake is treated as a probabilistic phenomenon. The crucial problem in reliability analysis is the determination of the probalilistic distribution of failure-occurrence time, which in our case corresponds to the earthquake occurrence. The Weibull distribution function, which is widely applied to quality control research, has been used by HAGIWARA (1975) to estimate the probability of earthquake occurrence on the basis of crustal strain data in South Kanto District in Japan. Based on this model, MATSUMURA (1982, 1984) defined the ν-parameter to make an unbiased assessment of possible time-dependent changes in seismicity patterns. A briefly description of the ν-value model is made here, following HAGIWARA (1974) and MATSUMURA (1984).

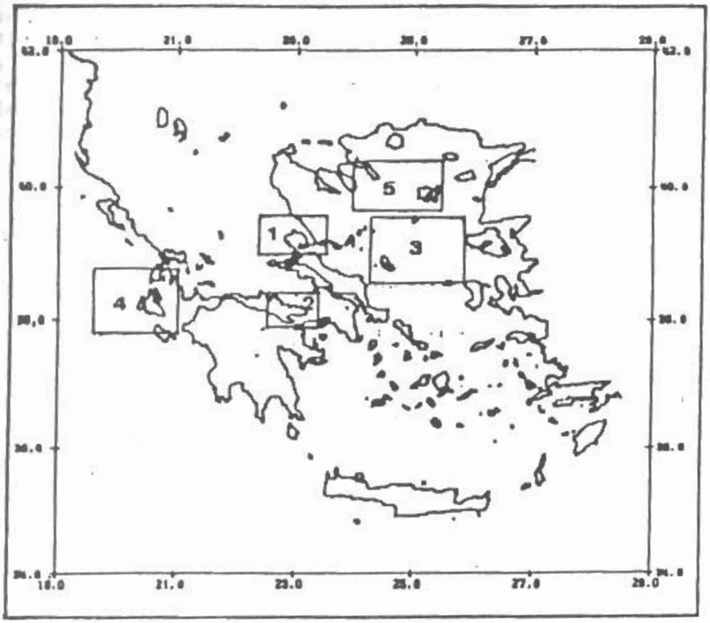
The conditional probability, that the rupture (i.e. earthquake) will occur in a time interval between t and Δt is defined by $\lambda(t)\Delta t$, where $\lambda(t)$ is the hazard rate and is given by

$$\lambda(t) = \lambda_1 t^{p-1} \quad \text{with } \lambda_1 > 0,\ p > 1 \qquad (1)$$

The reliability function is

TABLE 1.

NO	DATE	H-SEC	COORDINATES		MAG	AREA
1	JUL 9 1980	02:11	39.20°N	23.00°E	6.0	MAGNESSIA
2	FEB 24 1981	20:53	38.14°N	23.00°E	6.3	ALKYONIDES
3	DEC 19 1981	14:10	39.20°N	25.30°E	6.3	C. AEGEAN SEA
4	JAN 17 1983	12:41	37.97°N	20.25°E	6.2	IONIAN SEA
5	JAN 18 1982 AUG 6 1983	19:27 15:43	39.90°N 40.08°N	24.50°E 24.81°E	6.4 6.6	N. AEGEAN SEA



Σχ 1. Χάρτης με τις θέσεις των σεισμικών σειρών.
Fig 1. Map with the examined eartquake sequences.

$$R(t) = \exp[-\int_0^t \lambda(t)dt] = \exp[-\lambda_1 t^p/p] \quad (2)$$

and the corresponding density function is

$$f(t) = -dR(t)/dt = \lambda_1 t^{p-1} \exp[-\lambda_1 t^p/p] \quad (3)$$

The mean time interval between t=0 and an instant at which the earthquake occurs is obtained as

$$E[t] = \int_0^\infty t f(t)dt = (\lambda_1/p)-1/p\ \Gamma(1+1/p)$$

$$= (p/\lambda_1)1/p\ \Gamma(1+1/p) \quad (4)$$

$$\text{and } E^2[t] = (p/\lambda_1)2/p[\Gamma(1+1/p)]^2 \quad (5)$$

where Γ is a gamma function.
The mean-square time is given by

$$E[t^2] = \int_0^\infty t^2 f(t)dt = 1/(\lambda_1/p)2/p.\Gamma(1+2/p) =$$

$$= (p/\lambda_1)2/p\ .\ \Gamma(1+2/p) \quad (6)$$

Dividing eqs.(5) and (6) we obtain,

$$E^2[t]/E[t^2] = (p/\lambda_1)2/p\ [\Gamma(1+1/p)]^2\ /\ (p/\lambda_1)2/p\ \Gamma(2/p+1)$$

$$= [\Gamma(1+1/p)]^2\ /\Gamma(1+2/p)$$

$$= (\bar{\tau})^2\ /\ \overline{\tau^2} \equiv \nu \quad (7)$$

where τ is the time interval measured between the occurrence of two successive earthquakes, $\bar{\tau}$ is the mean of τ, and $\overline{\tau^2}$ is the mean of τ^2.

The parameters λ_1 and p of the Weibull distribution (eq.1) express the seismic activity and seismic pattern, respectively. From eq.(7) it is evident that the ν-value is a function only of p, i.e. of the seismic pattern.

ΔΕΔΟΜΕΝΑ ΠΟΥ ΧΡΗΣΙΜΟΠΟΙΗΘΗΚΑΝ ΚΑΙ ΤΡΟΠΟΣ ΥΠΟΛΟΓΙΣΜΟΥ ΤΗΣ "ν-value"
DATA USED AND CALCULATION METHOD OF ν VALUE

The earthquake parameters which are used in this study (origin time, epicenter coordinates, local magnitude) are those listed into the monthly bulletins of the Seismological Institute of the National Observatory of Athens. The lower threshold for the magnitude is 3.0.

For every seismic sequence the ν-values have been computed on the basis of a number of successive earhquakes consisting a certain group. This group is successively moved by a window of events till the end of the sequence. The result was plotted at the time of the last event within the window. The vertical arrows indicate the occurrence time of the large examined events (ML ≥ 5.0) with the corresponding local magnitudes.

It should be emphasized that in the present analysis only the time pattern of the sequences has been investigated. Other factors such as source properties have been ignored.

1. Η ΣΕΙΣΜΙΚΗ ΑΚΟΛΟΥΘΙΑ ΣΤΗ ΜΑΓΝΗΣΙΑ, 9 ΙΟΥΛΙΟΥ 1980.
1. THE EARTHQUAKE SEQUENCE OF MAGNESSIA REGION, JULY 9,1980.

On July 9, 1980, an earthquake with magnitude ML=6.0 occurred in the Magnessia region in central Greece. The main shock was followed by two large aftershocks with magnitudes 5.6 and 5.0, on July 9 and July 10 respectively. Totally, about three hundreds aftershocks with magnitude ≥3.0 recorded in the area till the end of 1980.

We calculated the v-value for a time period of three years, that is from the beginning of 1978 till the end of 1980, but only a few decades of earthquakes occurred before the main shock.

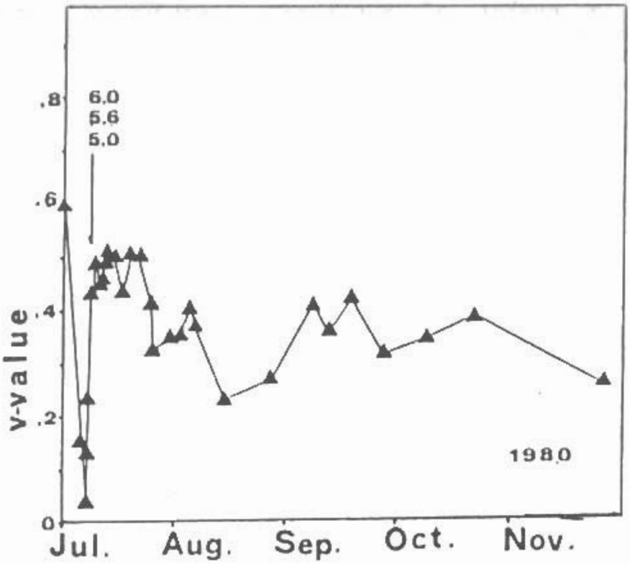
The v-values were determined for this time period, for groups of 30 and 10 shocks which are moved by a window of 10 and 5 shocks respectively. Fig 2a and 2b show the obtained results.

Although the number of earthquakes before July 1980 was not large, we can notice that the v-value for this time decreases and reached a value lower than 0.1. After the occurence of the significant seismic events of this sequence the v-value fluctuates in the range 0.5 and 0.3 showing clustered occurence.

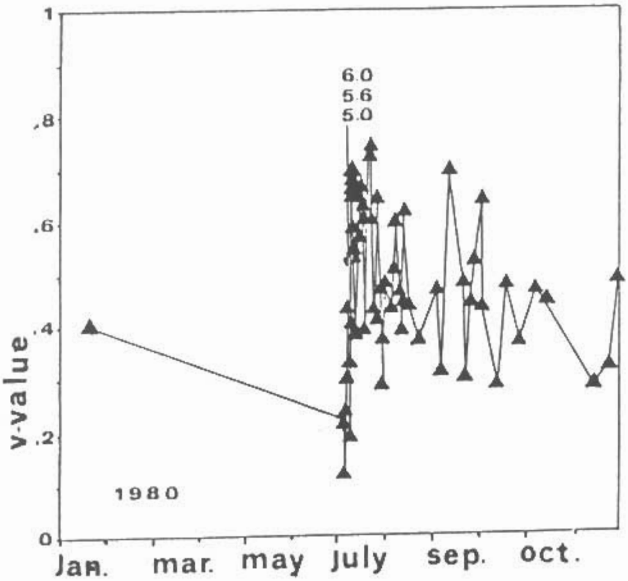
2. Η ΣΕΙΣΜΙΚΗ ΑΚΟΛΟΥΘΙΑ ΣΤΙΣ ΑΛΚΥΟΝΙΔΕΣ, 24 ΦΕΒΡΟΥΑΡΙΟΥ 1981.
2. THE ALKYONIDES EARTHQUAKE SEQUENCE, FEBRUARY 24, 1981.

This earthquake sequence occurred at a distance of 70Km from the city of Athens. The first two large events caused a lot of damages in the major area of central Greece. The large events occurred on February 24 and 25, and on March 4 and 5,with magnitudes ML 6.3, 5.9, 5.8 and 5.6 respectively. 558 events which occurred during the time period from 1975 till the end of 1981 used in the present analysis.

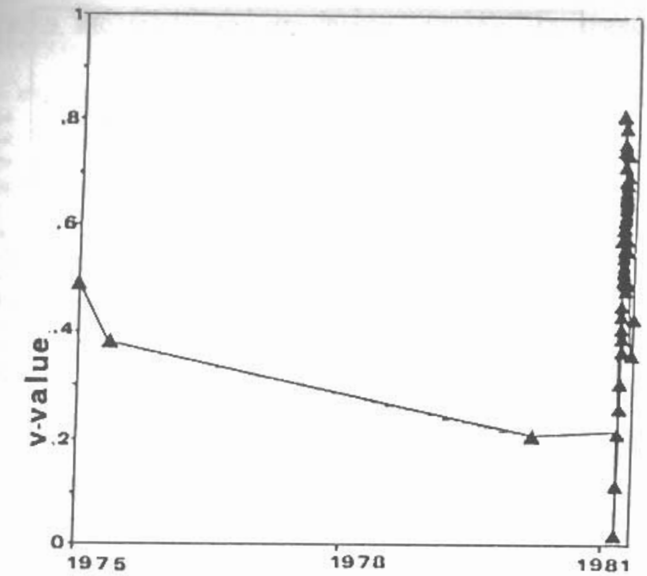
We calculated the v-value with different combinations of number of earthquakes consisting the groups (30, 20, 10) and the moving windows (10 and 5).(see fig 3a, 3b, 3c). In all these plots the behavior of v-value before the occurrence of the main shock and the large aftershocks is remarcable. The v-value drops at very low levels, in some cases is almost 0 and then abrupt increases is followed. The large shocks occurred during or just after those v-value increases.



Σχ 2a. Αλλαγές της "v-value" για την σεισμική σειρά της Μαγνησίας για ομάδα 30 σεισμών μετακινούμενη κατά 10 σεισμούς.
Fig 2a. Changes of "v-value" for the Magnissia sequence for group of 30 successive shocks and moving window of 10 shocks.

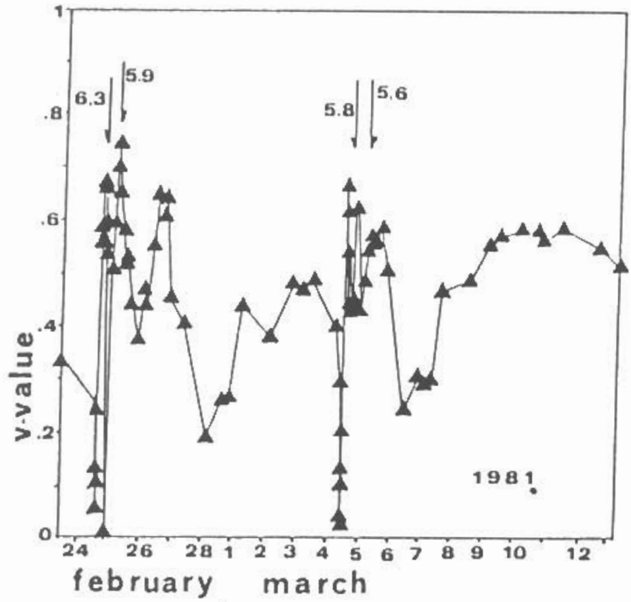


Σχ 2b. Αλλαγές της "v-value" για την σεισμική σειρά της Μαγνησιας για ομάδα 10 σεισμών μετακινούμενη κατά 5 σεισμούς.
Fig 2b. Changes of "v-value" for the Magnissia sequence for group of 10 successive shocks and moving window of 5 shocks.



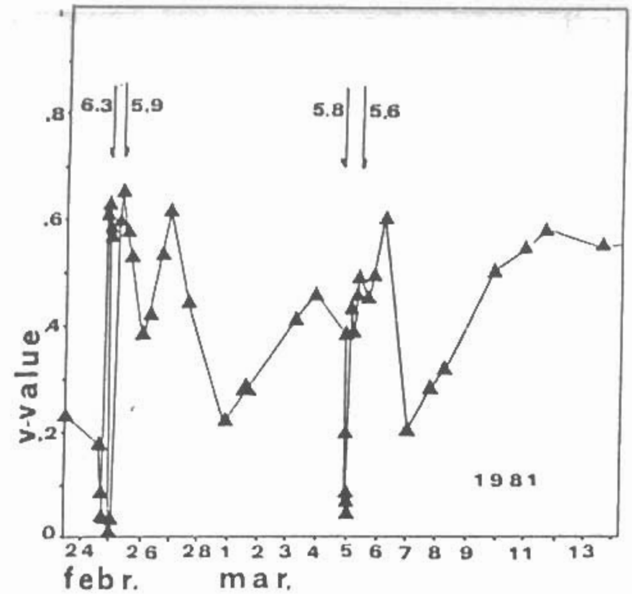
Σχ 3a. Αλλαγές της "v-value" για την σεισμική σειρά των Αλκυονίδων για ομάδα 10 σεισμών μετακινούμενη κατά 5 σεισμούς.

Fig 3a. Changes of "v-value" for the Alkyonides sequence for group of 10 successive shocks and moving window of 5 shocks.

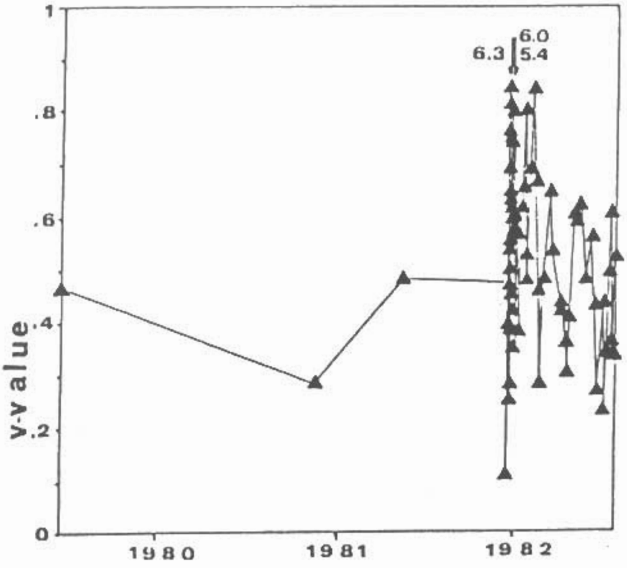


Σχ 3b. Αλλαγές της "v-value" για την σεισμική σειρά των Αλκυονίδων για ομάδα 20 σεισμών μετακινούμενη κατά 5 σεισμούς.

Fig 3b. Changes of "v-value" for the Alkyonides sequence for group of 20 successive shocks and moving window of 5 shocks.



Σχ 3c. Αλλαγές της "v-value" για την σεισμική σειρά των Αλκυονίδων για ομάδα 30 σεισμών μετακινούμενη κατά 10 σεισμούς.
Fig 3c. Changes of "v-value" for the Alkyonides sequence for group of 30 successive shocks and moving window of 10 shocks.



Σχ 4a. Αλλαγές της "v-value" για την σεισμική σειρά του κεντρικού Αιγαίου για ομάδα 10 σεισμών μετακινούμενη κατά 5 σεισμούς.
Fig 4a. Changes of "v-value" for the central Aegean sea sequence for group of 10 successive shocks and moving window of 5 shocks.

3. Η ΣΕΙΣΜΙΚΗ ΑΚΟΛΟΥΘΙΑ ΤΟΥ ΚΕΝΤΡΙΚΟΥ ΑΙΓΑΙΟΥ, 19 ΔΕΚΕΜΒΡΙΟΥ 1981.
3. THE CENTRAL AEGEAN SEA EARTHQUAKE SEQUENCE, DECEMBER 19,1981.

This sequence started on December 19, 1981, with a strong earthquake with magnitude ML=6.3. Two large aftershocks of magnitudes 6.0 and 5.4 occurred on December 27 and 29, respectively.

We determined the v-value for the time period from the beginning of 1979 till the end of 1982. In this time period more than four hundred events occurred in the investigated area. The v-values calculated for groups of 10 and 30 earthquakes which are moved by a window of 5 and 10 events, respectively. In Figures 4a and 4b the obtained results are illustrated. It is very clear that the v-value is rather low (between 0 and 0.2) some days before the occurence of the main shock, and the two large aftershocks. After the occurrence of the large events the v value fluctuates in the range 0.4 and 0.6, showing nearly random occurrence

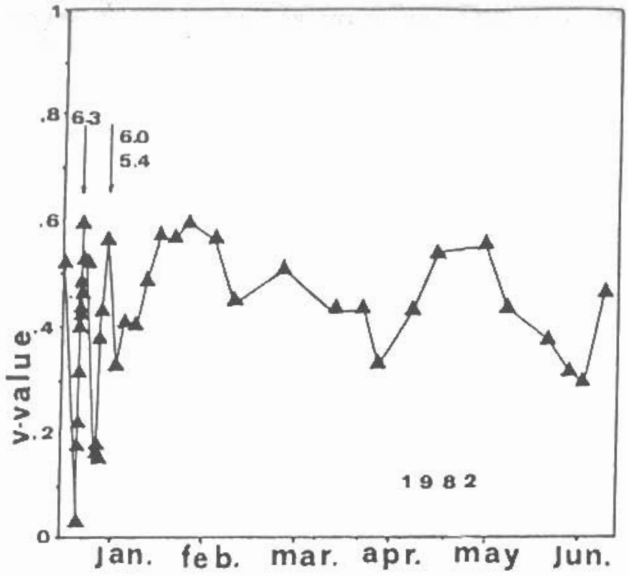
4. Η ΣΕΙΣΜΙΚΗ ΑΚΟΛΟΥΘΙΑ ΤΟΥ ΙΟΝΙΟΥ, 17 ΙΑΝΟΥΑΡΙΟΥ 1983.
4. THE IONIAN SEA EARTHQUAKE SEQUENCE OF JANUARY 17, 1983.

This sequence is the most complete, as concern the number of earthquakes and the used time period, of all the examined cases. We covered a time period from 1973 till the end of 1983, in which 1235 events are included. The sequence contains 3 large events which occurred on January 17, 19 and on March 23, 1983 with local magnitudes 6.2, 5.5, and 5.7, respectively. One large event with magnitude ML = 5.5 on June 28, 1981, is also included in the examined time period. Because of the great number of events and the large time interval, the v-value is calculated for groups of 50 earthquakes with moving window of 20 and 15 shocks and also for groups of 20 earthquakes and moving window of 10 shocks, in order to compare the results.(fig 5a, 5b, 5c). In all these cases, the behavior of the v-value is similar to the previous examined sequences. Low v-values (between 0 and 0.2) have been estimated for the period of some days before the occurence of the large shocks. After the occurrence of the shocks and during the interval time the v-value fluctuates in the range 0.3 and 0.6 showing random occurrence.

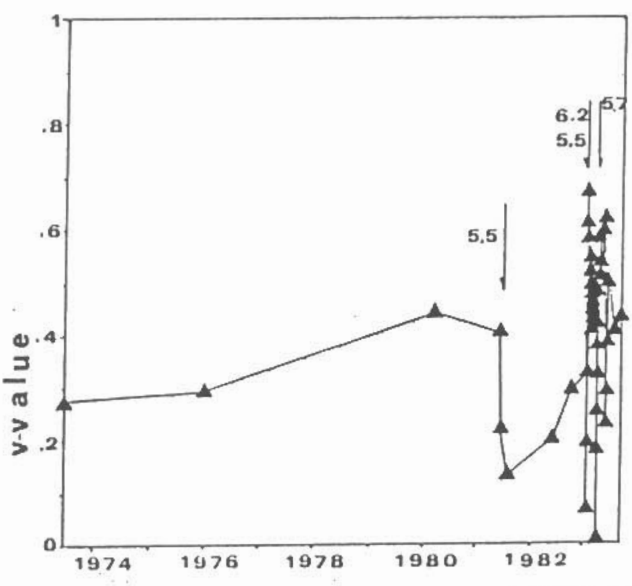
5. ΟΙ ΣΕΙΣΜΙΚΕΣ ΑΚΟΛΟΥΘΙΕΣ ΤΟΥ ΒΟΡΕΙΟΥ ΑΙΓΑΙΟΥ, 18 ΙΑΝΟΥΑΡΙΟΥ 1982, και 6 ΑΥΓΟΥΣΤΟΥ 1983.
5. THE NORTH AEGEAN SEA EARTHQUAKE SEQUENCES, JANUARY 18, 1982 and AUGUST 6, 1983.

In this case there are in the same area two earthquake sequences. The first one has two large events those of January 18, 1982 with magnitudes ML = 6.4 and 5.2 and the second one the event of August 6, 1983 with ML = 6.6.

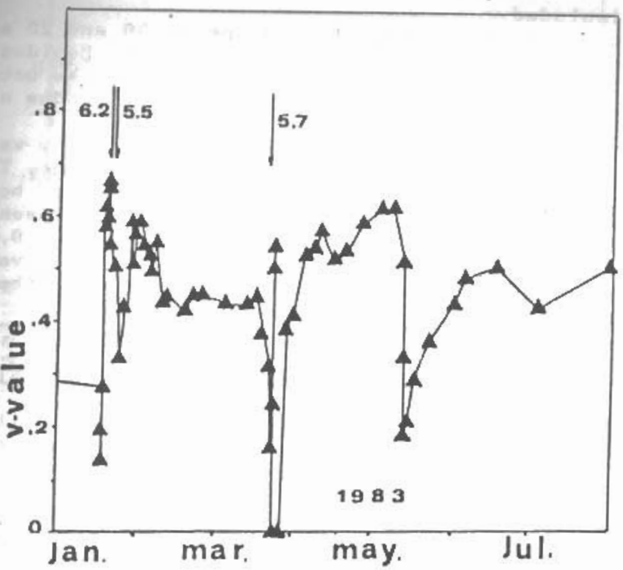
The time period which is used to calculate the v-values starts from 1978 till the end of 1983. More than four hundred



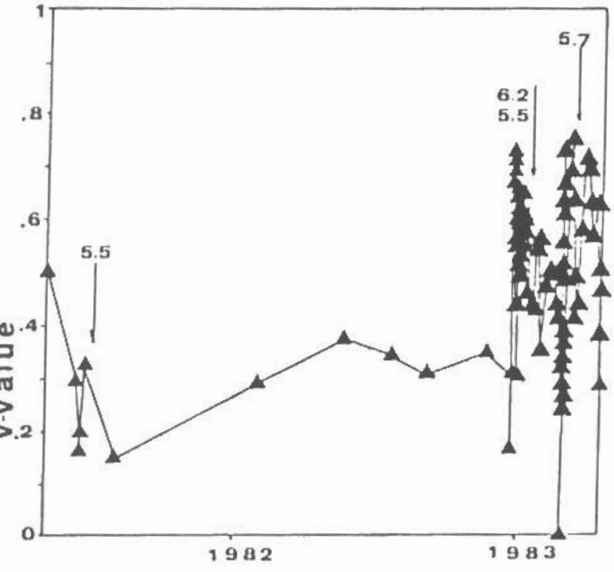
Σχ 4b. Αλλαγές της "v-value" για την σεισμική σειρά του κεντρικού Αιγαίου για ομάδα 30 σεισμών μετακινούμενη κατά 10 σεισμούς.
Fig 4b. Changes of "v-value" for the central Aegean sea sequence for group of 30 successive shocks and moving window of 10 shocks.



Σχ 5a. Αλλαγές της "v-value" για την σεισμική σειρά του Ιονίου για ομάδα 50 σεισμών μετακινούμενη κατά 20 σεισμούς.
Fig 5a. Changes of "v-value" for the Ionian sea sequence for group of 50 successive shocks and moving window of 20 shocks.



Σχ 5b. Αλλαγές της "v-value" για την σεισμική σειρά του Ιονίου για ομάδα 50 σεισμών μετακινούμενη κατά 15 σεισμούς.
Fig 5b. Changes of "v-value" for the Ionian sea sequence for group of 50 successive shocks and moving window of 15 shocks.



Σχ 5c. Αλλαγές της "v-value" για την σεισμική σειρά του Ιονίου για ομάδα 20 σεισμών μετακινούμενη κατά 10 σεισμούς.
Fig 5c. Changes of "v-value" for the Ionian sea sequence for group of 20 successive shocks and moving window of 10 shocks.

events are included.

We calculated the v-value for groups of 30 and 20 earthquakes and moving window of 10 events:(Fig 6a and 6b). Besides this, and especially for the time period before and during the occurrence of every sequence groups of 10 shocks with moving window of 5 shocks are used. (Fig 7a and 7b).

For the second sequence the decrease of the v value before the main shock is obvious, but not for the first one. This may be attributed to the fact that few events occurred before this sequence and v-value estimation is biased. Between the two sequences we estimated v-values larger than 0.5 showing periodical occurrence. During these sequences, the v-value shows the same behaviour with the abrupt changes like the other examined earthquake sequences.

ΑΠΟΨΕΙΣ ΚΑΙ ΣΥΜΠΕΡΑΣΜΑΤΑ - DISCUSSION AND CONCLUSIONS

The v-value, which is related with the time pattern of an earthquake sequence and characterizes the earhquake occurrence as being clustered, random or periodical, has been examined for some recent earthquake sequences in Greece.

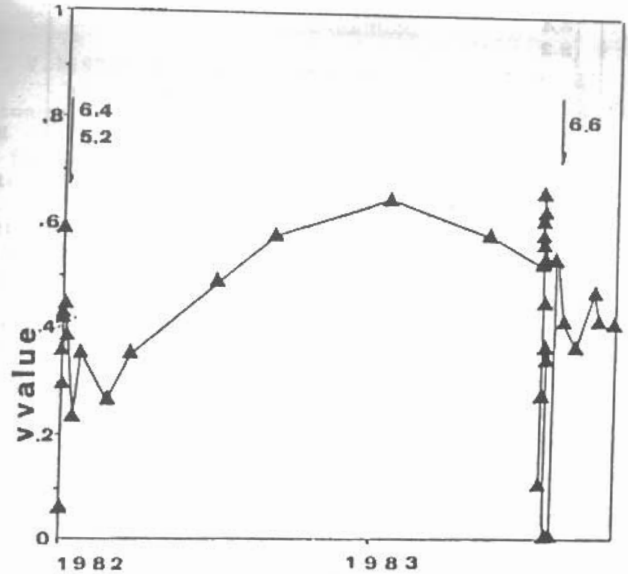
The results show that almost all the significant events of the earthquake sequences were preceded by small v values. The decrease in v-value started some hours or few days prior to the earthquake occurrence. These time windows seem useful for a single precursory phenomenon.

Althought the examined earthquake series spatially occurred at different seismotectonic enviroment of Greece, and the time period which is used for the calculation of v-value differs between the series, it is quite promising that the precursory time interval appeared more or less at all the investigated large seismic events.

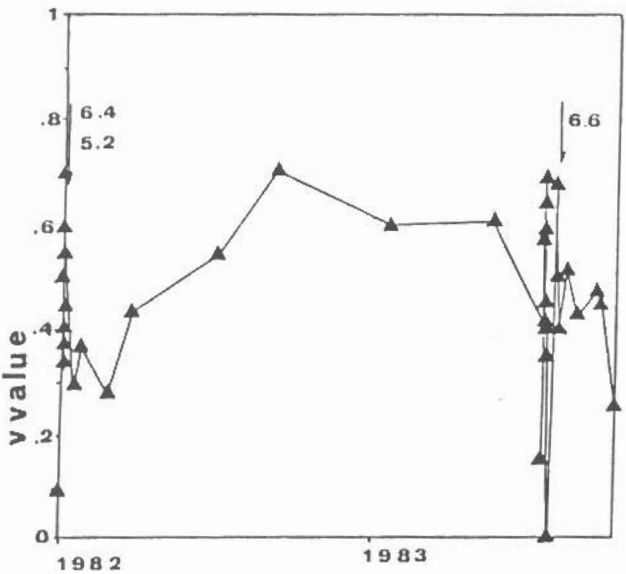
It should be emphasized that the v-value seems to depend strongly upon the number of successive earthquakes which are included in a certain group and upon the moving window of the events.

Comparing the figures which correspond to groups of 50, 30, 20 and 10 seismic events, a remarkable difference may be observed. The v-value for groups with smaller number of seismic events shows higher fluctuations . It is believed that these values are due to the insufficient number of events consisting the groups. It is suggested, however, that using large number of earthquakes in each group, the estimation of the v-value becomes more reliable. This also was found in another application of the v-value model in the area of Greece. (PAPANASTASSIOU et al 1987).

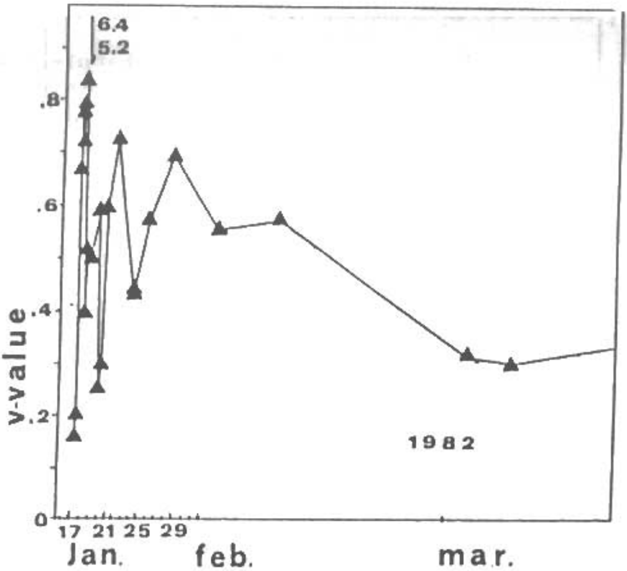
Although MATSUMURA (1982,1984) and HAMADA (1987) used microearthquakes to investigate changes in seismicity pattern by means of the v-value, the obtained results in the present study show that the v-value model could be applied for earthquake sequences with higher lower-limit of magnitudes in high seismicity regions.



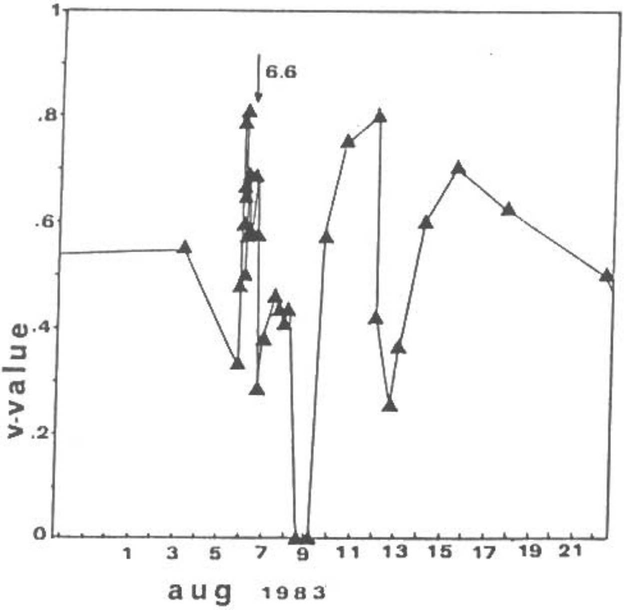
Σχ 6a. Αλλαγές της "v-value" για τις σεισμικές σειρές του βορείου Αιγαίου για ομάδα 30 σεισμών μετακινούμενη κατά 10 σεισμούς.
Fig 6a. Changes of "v-value" for the north Aegean sea sequences for group of 30 successive shocks and moving window of 10 shocks.



Σχ 6b. Αλλαγές της "v-value" για τις σεισμικές σειρές του βορείου Αιγαίου για ομάδα 20 σεισμών μετακινούμενη κατά 10 σεισμούς.
Fig 6b. Changes of "v-value" for the north Aegean sea sequences for group of 20 successive shocks and moving window of 10 shocks.



Σχ 7a. Αλλαγές της "v-value" για την σεισμική σειρά του βορείου Αιγαίου (Ιανουάριος 1982) για ομάδα 10 σεισμών μετακινούμενη κατά 5 σεισμούς.
Fig 7a. Changes of "v-value" for the north Aegean sea sequence (January 1982) for group of 10 successive shocks and moving window of 5 shocks.



Σχ 7b. Αλλαγές της "v-value" για την σεισμική σειρά του βορείου Αιγαίου (Αύγουστος 1983) για ομάδα 10 σεισμών μετακινούμενη κατά 5 σεισμούς.
Fig 7b. Changes of "v-value" for the north Aegean sea sequence (August 1983) for group of 10 successive shocks and moving window of 5 shocks.

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