

ΣΥΝΕΔΡΙΑ ΤΗΣ 30<sup>ΗΣ</sup> ΝΟΕΜΒΡΙΟΥ 1989

ΠΡΟΕΔΡΙΑ ΣΟΛΩΝΟΣ ΚΥΔΩΝΙΑΤΟΥ

ΣΕΙΣΜΟΛΟΓΙΑ.— **Earthquake prediction in Greece from seismic electric signals**  
**Period January 1, 1987 - June 30, 1989**, by *P. Varotsos, K. Alexopoulos,*  
*K. Nomicos and M. Lazaridou\**, University of Athens, διὰ τοῦ Ἀκαδη-  
μαϊκοῦ κ. Κάϊσαρος Ἀλεξοπούλου.

A B S T R A C T

During the last 2 1/2 years, twenty six predictions based on the detection of transient variations of the telluric field were issued in the form of telegrams. Twenty two of them were followed by earthquakes; their deviations were smaller or equal to 0.7 units of magnitude and 100 km or less in the prediction of the epicenter.

During the period mentioned 4 events occurred with  $M_s > 5.6$  within or near the perimeter of the 15 measuring stations. Three of them were satisfactorily predicted. The fourth was missed although it gave a precursor signal. During the period mentioned, the seismic activity caused significant damages at different epicentral areas. These activities were all predicted. For two cases the population was informed on the impending earthquakes.

I. INTRODUCTION

In a series of earlier papers (Varotsos and Alexopoulos 1984; 1986, 1987; Varotsos, Alexopoulos, Nomicos and Lazaridou 1986, 1988) predictions achieved by detecting Seismic Electric Signals (SES) on a network of 16 measuring stations were published for the period up to 1986. It is the scope of this paper to present the totality of the predictions issued during the last 2,5 years i.e. the period: January 1, 1987 to June 30, 1989.

---

\* Π. ΒΑΡΩΤΣΟΥ, Κ. ΑΛΕΞΟΠΟΥΛΟΥ, Κ. ΝΟΜΙΚΟΥ καὶ Μ. ΛΑΖΑΡΙΔΟΥ, **Προβλέψεις σεισμῶν κατά τὴν περίοδον 1ης Ἰανουαρίου 1987 ἕως 30 Ἰουνίου 1989.**

All predictions were announced prior to the occurrence of the corresponding earthquakes (EQ) in the form of telegrams. Each telegram usually contains the following scientific information:

- a. the arrival time of the SES,
- b. the station(s) at which the SES was detected,
- c. the epicenter of the impending EQ; its location was given from the epicentral distance (in km) and the direction in regards to Athens (ATH).
- d. the (surface wave) magnitude,  $M_s$ , of the impending EQ.

In view of the fact that since May 15, 1988 the telegrams were also sent to Scientific Institutes in other countries we present our results as follows: the predictions during the period January 1, 1987 to May 15, 1988 are given in Section II and the other ones are described in Section III.

The results are given in the form of tables with the totality of telegrams listed in chronological order with running numbers. The same results are described in the time charts of Fig. 1 where they can be compared to the ensuing earthquakes.

## II. PREDICTIONS DURING THE PERIOD:

JANUARY 1, 1987 - MAY 15, 1988

In Table 1, we list in chronological order the totality of telegrams issued during the period January 1, 1987 until May 15, 1988. For a number of telegrams some comments are appropriate:

a. Concerning the telegram No1 of April 27, 1987 we discriminate that it refers to a Gradual Variation of the Electric Field (GUEF) which appeared at PIR-station. This unusual type of variation sometimes precedes the SES at the same station always with the same polarity and on the same component(s) with the SES (Varotsos and Alexopoulos 1986). As mentioned in the same publication a GUEF (a) usually appears a few weeks before the occurrence of strong EQ i.e. with  $M_s$  of the order of 5.5-units or larger and (b) has an amplitude one order of magnitude larger than that of the corresponding SES. Actually 4 weeks after the initiation of this GUEF an event with  $M_s=5.5$  occurred at PIR-area on May 29, 1987. Two weeks later i.e. on June 10, 1987 another EQ with  $M_s=5.6$  occurred some tens of km far from the previous EQ. The following comment however might be useful. The EQ of May 29 had an SES that was simultaneously recorded on the short and long dipoles of PIR-station in contrast to that of June 10, 1987 the SES of which was recorded only on the long dipoles of the same station.

b) Telegram No 2 refers to an SES that was again recorded only at the large dipoles of PIR-station. This telegram was followed by a  $M_s=5.0$  EQ on June 21, 1987

that had an epicenter close to that of the EQ of June 10, 1987. (according to USGS the epicenter of the event of June 21 was at 21.32°E; 37,23°N).

c) Telegram No9 (April 21, 1988) refers to a relatively small magnitude,  $M_s=4.3$ . Although in general telegrams are sent only for EQ with  $M_s$  around 5-units or larger, this telegram was sent upon special request of the official services motivated by a weak event with  $M_s=3.7$  that was felt at ATH on April 17, 1988.

d) The values given in the parenthesis of column 3 refer to alternative solutions mentioned in the telegrams. In these cases the data were not sufficient for a unique solution. Some of these telegrams (e.g. Nos 5, 6 and 8) were followed by two EQ that could fit the prediction issued; these two EQ are inserted in the table in chronological order without intending to correlate the EQ having the smallest deviation to the corresponding solution which might be a logical assumption.

### III. PREDICTIONS DURING THE PERIOD:

MAY 15, 1988 TO JUNE 30, 1989

In Table 2 we give in chronological order the totality of telegrams issued during the period May 15, 1988 until June 30, 1989. As already mentioned these telegrams were addressed (*p r i o r* to the EQ) not only to the Greek Government but also to: a) Earthquake Research Institute, University of Tokyo (Prof. S. Uyeda), b) Commissariat a l'Energie Atomique, Laboratoire de Detection et de Geophysique (Dr B. Massinon), c) Prof. Haroun Tazieff (former Minister of France for Major Natural Disasters) and d) Dr. J. Labeyrie (Paris. France).

The 16 telegrams of table 2 happened to be nonuniformly distributed in time and space and can be classified in four categories A, B, C, D according to the epicentral area that was preannounced and later became active:

A) Kefallonia-area i.e. 300 km West of Athens. Five telegrams (Nos 11, 12, 13, 14 and 16) of May 15, May 21, May 30, June 4 and June 21, 1988 predicted this activity.

B) Killini-area i.e. 240 km West of Athens; the 3 telegrams Nos 20, 21 and 22 issued on Sept. 1, Sept. 30 and October 3, 1988 correspond to an epicentral area that lies between the Northwestern coast of Peloponese and Zakynthos.

C) Patras-area i.e. 180-200 km West of Athens for which telegrams Nos 25 and 26 of June 3, 1989 and June 12, 1989 have been issued.

D) Other seismic areas for which 6 telegrams (Nos 15, 17, 18, 19, 23 and 24) of June 10 1988, July 10, 1988, July 13, 1988, July 18, 1988, October 21, 1988 and March 2, 1989) have been issued.

The above four categories will be discussed below separately. The first three categories (Kefallonia, Killini, Patras) refer to events that caused damages. For the most destructive of them (Killini case) public warnings were made.

#### 1. KEFALLONIA - AREA

A  $M_s=5.8$  EQ occurred on May 18, 1988 and caused minor damage in Akarnania and Aitolia provinces. This event was isolated in time and space if one considers that no other EQ with  $M_s \geq 5.5$  had occurred within the area  $35-42^\circ\text{N}$  and  $19-28^\circ\text{E}$  during the previous 14 months.

Confirmation of the prediction of this event was made by scientists participating in the Conference on Nuclear Test Ban Verification (Linköping, Sweden, May 17-19, 1988). At this Conference the first author (P. Varotsos) presented on May 17 a copy of telegram No 11 addressed to the Greek Government on May 15, 1988. On May 18, 1988, the Conference participants witnessed the predicted EQ in the Conference room. An on-line connection to the Swedish seismological array stations (Hagfors) and also to the German array stations (Grafenberg) had been made to the Conference room by Swedish and German scientists. The participants were thus able to follow the accumulated recordings of the earthquake on a real-time basis as they were transmitted.

The  $M_s=5.8$  event of May 18, 1988 was followed by a number of weaker events three of which had a  $M_s$  between 5.0 and 5.4. These events occurred on May 22, June 2 and June 6 and were preceded by telegrams Nos 12, 13 and 14, expedited on May 21, May 21, May 30 and June 4 respectively.

#### 2. KILLINI - AREA

On September 22, 1988 an EQ with  $M_s=5.2$  (to 5.5) occurred between Zakynthos Island and the northwestern coast of Peloponese (i.e. at Killini-area  $37.9^\circ\text{N}$ ,  $20.9^\circ\text{E}$ ) and caused extensive destruction. During the following weeks a number of smaller shocks happened and on October 16 a  $M_s=6.0$  EQ destroyed many hundreds of houses; the latter event occurred practically at the same site  $37.9^\circ\text{N}$ ,  $21.0^\circ\text{E}$  i.e. 240 km West of Athens.

We turn now to the electric signals that preceded the above seismic activity. Strong transient variations of the electric field i.e. SES started on August 31, 1988 and were recorded on both components of IOA-station. These variations provoked the expedition of telegram No 20 on Sept. 1 announcing that a  $M_s=5.8$  EQ was anticipated with an epicenter 240 km West of Athens (in the same telegram an alternative possibility was given i.e. a  $M_s=5.3$  EQ at 300 km NW of Athens). After the occurrence

of the EQ on September 22 new series of SES were recorded that obliged us to issue two more telegrams, Nos 21 and 22, on Sept. 30 and October 3 drawing the attention that the seismic activity will continue at the same area with predicted magnitudes of around 5.3.

As already mentioned the above telegrams were also sent to scientists in Japan and France. Professor H. Tazieff, after the receipt of our first telegram and based on his personal experience on the matter announced publicly on Sept. 3 (through Antenne 2 of French television) that a destructive earthquake was expected in the western part of Greece. After the first destructive EQ of Sept. 22 a public declaration of Greek seismologists claimed that no further destructive events were expected in that area. Prof. Tazieff in view of our telegrams Nos 21 and 22 of Sept. 30 and October 3 proceeded to a second public warning insisting that the destructive activity will continue, the latter announcement was fulfilled on October 16, 1988.

#### C. PATRAS - AREA

The EQ that occurred on June 7, 1989 caused extensive damage of 173 houses mainly at villages between Patras and Pirgos. The expedition of telegram No24 on the morning of June 3, 1989 was based on an SES that was recorded at IOA-station. A second SES (No 26) that was recorded at the same station on June 12 was followed by a  $M_s=4.5$  - event on June 17 from the same area.

#### D. OTHER SEISMIC AREAS

From the telegrams that refer to other seismic areas telegram No 23 of October 21, 1988 showed a large error (at least 0.9 mag-units and 120 km in the epicenter). For this case we give in Table 2 the list of events with  $M_s \geq 4.9$  that followed this telegram within 20 days. The prediction was based on a series of SES that was recorded on both components of IOA-station; as explicitly stressed in the telegram the epicenter was shifted because the ratio of the two components was different than that observed for the cases of SES of Nos 20, 21 and 22 which were characteristic of Killini-area. This variation in the ratio was interpreted by our group to be an indication of a displacement of the epicenter of the previously active area (i.e. 240km West of Athens) by some tens of km. If this interpretation is correct one should not correlate this telegram with the events that occurred on Oct. 22, Oct. 31 and Nov. 11, 1988 and had epicenters in the Killini-area. Under this restriction one might correlate this telegram with the 5.4-event that occurred on Nov. 8 and had an epicenter 150km far from the previously active area. In such a case however the deviation between the predicted magnitude and that announced from SI-NOA remains unusually large.

## IV. EVALUATION OF THE RESULTS

By disregarding the case of the telegram No 9 of April 21, 1988 (which corresponds to a weak EQ) we see that 25 telegrams were issued during a period of 2.5 years i.e. January 1 1987 to June 30, 1989. An inspection of these results leads to the following conclusions:

1) Three telegrams (out of 25) Nos 7, 17 and 23 can be considered as false non successful predictions; in these three telegrams although they were followed by earthquakes the deviation between the predicted and the real parameters is large.

2) In 22 telegrams (out of 25) the difference between the predicted and the real magnitudes was (at the most) 0.7-units or smaller whereas the deviation between the predicted epicentral coordinates and the real ones was of the order of 100km or smaller.

3) During the last 2.5 years, 4 events with  $M_s$  larger than 5.6-units occurred either within or (outside but) close to our telemetric network. For one of them, with  $M_s=5.8$  (March 19, 1989 with an epicenter at  $39.3^\circ$  N,  $23.6^\circ$  E that lies outside our network) a telegram was not issued because the authors were absent. For the other three EQ (with  $M_s=5.9$ , 5.8 and 6.0-units on Febr. 27, 1987, May 18, 1988 and October 16, 1988 respectively) telegrams No 1, 11 and 22 were issued with satisfactory accuracy.

TABLE 1

Period: 01-01-87 until May 15, 1988.

No	Date of Telegram D M Y	Prediction	Date of EQ	Time of EQ	Epicenter of EQ	Magnitude of EQ
1	26-2-87	W 300-6.5	27-2-87	23:34	W 295	5.9
2 $\alpha$	27-4-87	50km from PIR-station with Ms 5.5	29-5-87 10-6-87	18:40 14:50	30km from PIR 70km from PIR	5.5 5.6
3	13-6-87	W 200-5.2	21-6-87	06:13	WSW 240	5.0
4	01-2-88	NE 200-5.0 two SES	10-2-88 18-2-88	10:08 11:11	ENE 287 N100	4.3 5.1
5	10-3-88	NW 350-5.0 (or WNW 260-5.0)	16-3-88 26-3-88	20:02 20:35	NW 396 NW 438	4.6 5.5
6	02-4-88	W 250-5.0 (or SW 300-5.5)	03-4-88 05-4-88	08:56 06:24	NW 370 W 200	4.8 4.3
7*		N 100-5.0	05-4-88	09:17	ENE 144	3.8
8	07-4-88	WNW 250-5.0 (or NW 360-5.0)	08-4-88 12-4-88	05:57 19:48	WSW 290 W 300	4.4 4.5
9b	21-4-88	40km from ATH-4.3	23-4-88	10:28	NE 95	3.5
10	28-4-88	W 300-5.0 (or WNW 300-5.0)	09-5-88	16:52	W 350	5.0

\* False prediction

a. Detection of GUEF at PIR-station; this type of variation is usually detected a few weeks before the occurrence of strong (i.e.  $MA \geq 5.5$ ) events.

b. Sent after request of the Government.

TABLE 2

Complete list of telegrams issued after May 15, 1988 until June 30, 1989

No	Date of Telegram D M Y	Prediction	Date of EQ	Time of EQ	Epicenter of EQ	Magnitude Of EQ
11	15-05-88	NW 330-5.0 (or W 300-5.3)	18-05-88	05:17	W 310	5.8
12	21-05-88	W 300-5.3 (or NW 350-5.0)	22-05-88	03:44	W 290	5.4
13	30-05-88	NW 350-5.0 (or W 300-5.4)	02-06-88	10:35	W 300	5.0
14	04-06-88	W 300-5.0	06-06-88	05:57	W 300	5.0
15	10-06-88	SW 200-5.1	13-06-88	20:32	SW 240	4.3
16	21-06-88	W 300-5.0 (or NW 350-4.8)	26-06-88	06:05	W 300	4.5-4.7
17*	10-07-88	W 170-4.7 (or WSW 240-5.2)	12-07-88	02:27	NNW 95	5.0
18	13-07-88	W 70-5.0	16-07-88	01:54	SW 100	4.9
19	18-07-88	NNW 80-un- certain (or SW 100)	23-07-88	09:20	SW 200	4.4
20	01-09-88	NW 300-5.3 (or W 240-5.8)	22-09-88	12:05	W 250	5.2-5.5
21	30-09-88	W 240-5.3 (or NW 330-5.0)	30-09-88	13:03	W 215	4.9
22	03-10-88	Number of SES from area W 235 attention activity has not finished.	15-10-88	07:00	W 235	4.9
			16-10-88	12:34	W 240	6.0



TABLE 2 (Cont.)

23*	21-10-88	Some tens of km	22-10-88	09:34	W	250	4.9
		far from W	31-10-88	03:00	W	230	4.9
		240-6.3-6.5	08-11-88	08:18	SW	170	5.4
		(or NW 400-5.5)	11-11-88	17:52	W	270	5.0
24	02-03-89	W 300-5.4	05-03-89	16:44	NW	440	4.7
		(or NW 330-5.0)	08-03-89	05:57	NW	470	5.0
25	03-06-89	W 300-5.5	07-06-89	19:45	W	200	5.4-5.2
		(or NW 350-5.0)					
26	12-06-89	W 200-5.2	17-06-89	20:56	W	200	4.5
		(or NW 350-4.8)					

Note: A 5.8 EQ on 19-3-89 was missed.

\* : False prediction.

## REFERENCES

- Varotsos P. and Alexopoulos K., *Tectonophysics*, **110**, 73-125, 1984.  
 Varotsos P. and Alexopoulos K., in *Thermodynamics of Point Defects and their Relation with Bulk Properties*. North-Holland, Amsterdam, 1986.  
 Varotsos P. and Alexopoulos K., *Tectonophysics*, **136**:335-339 (1987).  
 Varotsos P., Alexopoulos K., Nomicos K. and Lazaridou M., *Nature*, **322**: 120 (1986).  
 Varotsos P., Alexopoulos K., Nomicos K. and Lazaridou M. *Tectonophysics*, **152**: 193-196 (1988).

## ΠΕΡΙΛΗΨΙΣ

**Προβλέψεις σεισμών κατά την περίοδον 1ης 'Ιανουαρίου 1987 έως 30 'Ιουνίου 1989**

Κατά τὰ τελευταῖα 2 1/2 ἔτη εἴκοσι πέντε προβλέψεις σεισμῶν βασιζόμεναι εἰς τὴν παρατήρησιν προσκαίρων μεταβολῶν τῶν γηίνων ἠλεκτρονικῶν πεδίων ἐξεδόθησαν ὑπὸ μορφὴν τηλεγραφημάτων. Ἐξ αὐτῶν 22 ἠκολουθήθησαν ὑπὸ σεισμῶν αἱ ἀποκλίσεις ἦσαν μικρότεροι ἢ ἴσαι πρὸς 0,7 μονάδες μεγέθους καὶ 100 χιλιομέτρων ὡς πρὸς τὸ ἐπίκεντρον.

Κατὰ τὴν ἴδια περίοδον συνέβησαν 4 σεισμοὶ μεγέθους μεγαλυτέρου τῶν 5,6 μονάδων ἐντὸς ἢ πλησίον τῆς περιμέτρου τῶν 15 σταθμῶν τοῦ δικτύου. Ἐξ αὐτῶν προεβλέφθησαν ἐπιτυχῶς οἱ τρεῖς.

Ὁ τέταρτος εἶχε προκαλέσει σῆμα τὸ ὁποῖον ὁμως δὲν ἀνεγνωρίσθη.

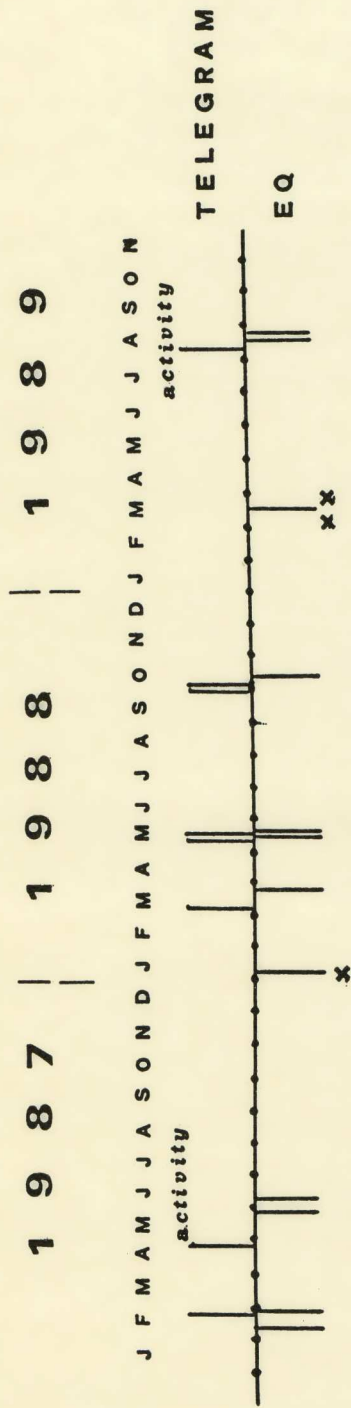


Fig. 1. Time chart for the period Jan. 1, 1987 - Nov. 30, 1989  $MS \geq 5.5$ .