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Evaluating the statistical validity beyond chance of 'VAN' earthquake precursors

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SUMMARY

All predictions of the future can be to some extent successful by chance. This is a crucial issue mostly overlooked in assessing the validity of earthquake precursors. We analyse statistically the effectiveness of VAN predictions *beyond chance* by studying the complete list of predictions for the period 1987 January 1–1989 November 30 recently published by Varotsos & Lazaridou (1991) using any possible combination of the 'rules of the game' that they consider. We find that the apparent success of VAN predictions can be confidently ascribed to chance; conversely, we find that the occurrence of earthquakes with $M_S \geq 5.8$ is followed by VAN predictions (with identical epicentre and magnitude) with a probability too large to be ascribed to chance.

Key words: chance, correlation, earthquake precursors, statistics, VAN.

INTRODUCTION

Since a reliable earthquake model is lacking, earthquake prediction is principally an empirical search for precursors, which are defined as phenomena showing ideally a one-to-one time association with seismic events. The efficiency of a given precursor is usually evaluated in terms of the rate of successful predictions over the total of predictions (*success rate*), and of the percentage of successful predictions over the number of earthquakes (*alarm rate*). In spite of their wide use, these two indexes embody only implicitly the fundamental key factor of how effective a precursor is in practice, i.e. the amount of successful predictions *not* due to chance. In fact, as all gamblers know, the future outcome of a random process can be successfully predicted by chance with some probability, and the very basis of precursor evaluation must be a test of effectiveness *beyond chance*. Barring a few specialized examples (e.g. Vere Jones 1978; Rhoades & Evison 1979; Molchan *et al.* 1990), this problem received little attention in geophysical literature, but recently a general statistical method has been presented (Mulargia 1992). An outline of this technique is given in Appendix A. We apply it to the case of VAN precursors by studying the complete list of predictions for the period 1987 January 1–1989 November 30, which has been recently published by Varotsos & Lazaridou (1991).

THE 'VAN' PRECURSORS

Since 1981 three physicists of the University of Athens: P. Varotsos, K. Alexopoulos and K. Nomicos (VAN), have been reporting the systematic observation of low-frequency electric signals prior to the occurrence of earthquakes in Greece (Varotsos, Alexopoulos & Nomicos 1981). The success was apparently definitive to earthquake prediction, with a 'one-to-one correspondence' between precursors and earthquakes (Varotsos & Alexopoulos 1984b).

Such an outstanding result was enthusiastically saluted by some as a major breakthrough, if not a final solution, to the problem of earthquake prediction. On the contrary, it raised a wave of generalized skepticism in the seismological community (e.g. Burton 1985; Drakopoulos, Stavrakakis & Latoussakis 1989), essentially due to the scanty and somehow contradictory information released about the original precursory signals, to the lack of a convincing physical explanation for the phenomenon, and to the allowed large indetermination in the parameters of the predicted events. The latter has two potential effects: first, combined with the high seismicity of Greece, it can critically increase the importance of chance in determining success; second, it would substantially prevent such precursory signals from being practically useful. In the present paper we focus our attention on the first point, which, as we said, must be the very foundation of any true precursor.

THE 'RULES OF THE GAME'

The obvious pre-requisite for evaluating the effectiveness of a given precursor is a clear statement of the 'rules of the game' for a successful prediction. Namely, in retrospective studies we need the unequivocal definition of (a) the time series of precursors, (b) the time series of earthquakes that occurred which *should have* been predicted, and (c) the time series of earthquakes that *have* been correctly predicted. In the case of VAN we face some serious problems. While a complete list of VAN precursors (i.e. predictions) sufficiently numerous to be statistically analysed has been eventually presented (Dologlou 1990) and published in an international journal (Varotsos & Lazaridou 1991), and while a catalogue of Greek seismicity is readily available, the 'rules of the game' for a successful prediction have never been univocally defined: as customary (*cf.* Varotsos *et al.* 1981; Varotsos & Alexopoulos 1984a, b, 1987; Dologlou 1990), also in Varotsos & Lazaridou (1991), a number of different options is considered more or less explicitly.

In our analysis we refer to the latter work (from now on VL), which contains all the predictions issued in the period 1987 January 1–1989 November 30. In order to reach a conclusion as definite as possible, our strategy is to analyse exhaustively the time association between the list of VAN predictions and the earthquakes that should have been predicted according to *all* the different options for the 'rules of the game' proposed by VL. Let us proceed to examine them.

The first ambiguous definition is represented by the geographical area on which the predictions are operational. This is explicitly defined as the region 36–41°N, 19–25°E excluding Albania (VL, p. 333, 338). However, directivity and region-dependent sensitivity effects have been also advocated (VL, pp. 330–332; see also Varotsos & Alexopoulos 1984a, 1987). Therefore, the sensitivity is possibly non-homogeneous within the region above. The subregion in which the VAN predictions are (most?) effective can be implicitly derived by the set of predictions itself by allowing the claimed indetermination on each predicted epicentre. We therefore perform our analysis according to the options: (a) the whole region 36–41°N, 19–25°E as homogeneous; (b) the subregion, internal to the previous one, defined by the union of the circular regions centred at each predicted epicentre with radius equal to the allowed indetermination; two different values, 30 and 120 km, are considered for this indetermination (see next paragraph).

The second ambiguous definition regards the allowed uncertainties on epicentral position Δr, lead time Δt between precursor and event, and magnitude ΔM. For both the epicentral position and the lead time two values are explicitly considered by VL (Tables 1–3), i.e. 30 and 120 km for Δr, and 11 and 22 d for Δt. The uncertainty on magnitude ΔM is fixed at ±0.7, but it is relative in one place to the predictions (VL; Tables 1 and 2) and in another to the earthquakes (VL; Table 3). This latter point is left implicit in VL, but appears critical. In other words, the two options mean that (a) the earthquakes that should have been predicted are those within ΔM from each prediction (above a given magnitude; see next paragraph), and (b) the predictions operative are those within ΔM from each earthquake (above a given magnitude). We consider each of these two options.

The third ambiguous definition regards the magnitude range in which VAN predictions are effective. This regards all earthquakes within ΔM from each prediction in VL; Tables 1 and 2. It is restricted to earthquakes with $M \geq 5.2$ in the caption of Table 1, and to earthquakes with $M \geq 5.0$ in the caption of Table 2. Finally, the effectiveness of predictions is considered dependent on the magnitude of the earthquakes, with lower thresholds at $M = 5.3$, 5.5, 5.8 and 6.0 (VL, Table 3). We consider each of the above options in our analysis.

A further problem regards the predicted VAN epicentres, which are given in terms of distance L and azimuth A_{12} from a reference station (Athens, Pyrgos, . . .). The azimuth is specified as NNW, SSE etc., i.e. with an uncertainty equal to 1/16 of circle, which gives rise to an additional indetermination in the coordinates of the predicted epicentre proportional to the distance from the reference station approximately equal to $\pm 0.2L$ (i.e. $\simeq$60 km at a 300 km distance). We solve this problem by transforming the given distance—azimuth coordinates of the predicted epicentres in standard geographical coordinates through *Lilly's formula for long lines* with an ellipsoid eccentricity $\epsilon = 0$ (see Appendix B). Conversely, we calculate the distance LS between the predicted epicentre ϕ_3, λ_3 and the epicentre of the earthquake which really occurred ϕ_2, λ_2 through *Robbins' formula* with $\epsilon = 0$ (see Appendix B). The station coordinates have never been given, and we derived them from geographic maps. The ones we use in our analysis are: Athens 37° 59′N, 23° 45′E and Pyrgos 37° 40′N, 21° 27′E.

THE DATA SETS

As we said, for the prediction set we use the complete list of VAN predictions in the period 1987 January 1–1989 November 30 contained in VL, which we also reported in Appendix C. A total of 32 predictions were issued. Two of them (1988 07 18 and 1989 09 15) lack the magnitude estimate and cannot therefore be analysed. A third one (1988 04 21) must be excluded since its magnitude ($M_S = 4.3$), would imply within the global set of 'rules of the game' to analyse events of magnitude below 4.0, for which the catalogue is incomplete. Of the remaining 29, 20 regard alternative predictions, i.e. two couples of epicentral location–estimated magnitudes are given. While obviously both alternative epicentres are included in the set of events that *should have* been predicted, we will not question the issue of alternative predictions and consider a full success if either prediction is correct.

As regards the seismic catalogue against which VAN predictions should be compared, the sole possibility appears to be the catalogue of the Seismological Institute of the National Observatory of Athens (from now on SI-NOA), which, beyond being the best regional catalogue, is also the one used by the VAN group. This latter point appears crucial in the present context for the magnitude estimates. In fact, even if the SI-NOA catalogue were systematically inaccurate, correcting it would imply an identical recalibration of VAN predictions, with a self-cancelling effect. Therefore, consistently with VL, we also adopt $M_S =$

$M_L + 0.5$ and $M_S = M_D + 0.5$ in all cases in which M_S was not provided.

Prior to analysis, we checked catalogue completeness since any difference between real and recorded seismicity would undermine the validity of the results (*cf*. Mulargia & Tinti 1985). The SI-NOA catalogue results are complete in the period analysed above magnitude $M_S = 4.0$.

According to the procedure in Appendix A, we evaluate for each case the significance level (sl) at which the hypothesis of a 'chancy' association between the precursors and the events can be rejected. In statistical jargon, this is equivalent to the lowest possible risk that we must take in rejecting the hypothesis of a merely 'chancy' association. According to statistical decision theory (see any statistics textbook, e.g. Cramér 1946) values of $\mathrm{sl} \leq 0.05$ stand for an association significant beyond chance. Note that the statistical procedure requires both the time series of predictions and that of earthquakes to be stationary stochastic processes (see Appendix A). All the sets we analyse (Appendix C, Appendix D and Tables 1, 2, 4 and 5) were checked to satisfy this requirement.

RESULTS OF THE ANALYSIS

Let us first take the rule $\Delta M = \pm 0.7$ relative to predictions together with the homogeneous region 36–41°N, 19–25°E excluding Albania (see Appendix D for the global list of events). Considering all the 29 predictions, with $\Delta t = 11$ d one prediction is correct out of 547 events that should have been predicted for $\Delta r = 30$ km (Table 1) and 20 predictions are correct (still out of 547 events that should have been predicted) for $\Delta r = 120$ km. Taking $\Delta t = 22$ d four predictions are correct for $\Delta r = 30$ km and 28 predictions are correct (in both cases still out of 547 events that should have been predicted) for $\Delta r = 120$ km. In each of these four cases the success can be very comfortably ascribed to chance ($\mathrm{sl} = 1.000$, see Table 1). Considering the predictions only above a given magnitude does not improve matters. For example, using a lower threshold of 5.0 (with again 29 predictions entering the range due to the alternative issues) and taking $\Delta t = 11$ d yields one correct prediction out of

Table 1. The analysis of the time association between VAN predictions and the seismicity of Greece using a magnitude indetermination $\Delta M = 0.7$ from each prediction. The table shows the total number of predictions, the correct ones, the number of events that should have been predicted and the relative significance level for all the various options analysed: $\Delta t = 11$ and 22 d, $\Delta r = 30$ and 120 km, various magnitude thresholds and the two different geographical regions, 'homogeneous' and 'non-homogeneous' on which the predictions are assumed operative. 'Homogeneous' indicates that the operational area is 36–41°N, 19–25°E excluding Albania, while 'non-homogeneous' stands for the union of the regions identified by the indetermination of each prediction (internal to 'homogeneous'; see text).

Rule of the game: Magnitude of Predictions ± 0.7

			Homogeneous		**Non-homogeneous**	
Prediction range	Total pred.	Correct Pred.	Number of events	Sign. lev.	Number of events	Sign. lev.
		Δt ≤ 11 days, Δr ≤ 30 km				
All	29	1	547	1.000	93	1.000
M ≥ 5.0	29	1	204	1.000	71	1.000
M ≥ 5.3	14	0	80	1.000	18	1.000
M ≥ 5.5	9	0	44	1.000	15	1.000
M ≥ 5.8	5	0	19	1.000	5	1.000
		Δt ≤ 22 days, Δr ≤ 30 km				
All	29	4	547	1.000	93	1.000
M ≥ 5.0	29	4	204	1.000	71	1.000
M ≥ 5.3	14	2	80	1.000	18	0.966
M ≥ 5.5	9	1	44	1.000	15	0.938
M ≥ 5.8	5	1	19	0.859	5	0.403
		Δt ≤ 11 days, Δr ≤ 120 km				
All	29	20	547	1.000	417	1.000
M ≥ 5.0	29	18	204	1.000	190	1.000
M ≥ 5.3	14	6	80	0.973	51	0.745
M ≥ 5.5	9	2	44	0.915	33	0.811
M ≥ 5.8	5	1	19	0.625	14	0.515
		Δt ≤ 22 days, Δr ≤ 120 km				
All	29	28	547	1.000	417	1.000
M ≥ 5.0	29	25	204	1.000	190	1.000
M ≥ 5.3	14	7	80	1.000	51	0.991
M ≥ 5.5	9	3	44	0.988	33	0.944
M ≥ 5.8	5	2	19	0.584	14	0.424

Table 2. The same as Table 1 but relative to a magnitude indetermination $\Delta M = 0.7$ from each earthquake to backward correlation, i.e. with negative Δt (see text).

Rule of the game: Magnitude of Earthquakes ± 0.7

			Homogeneous		**Non-homogeneous**	
Earthquake range	Total pred.	Correct Pred.	Number of events	Sign. lev.	Number of events	Sign. lev.
		Δt ≤ 11 days, Δr ≤ 30 km				
All	29	1	547	1.000	93	1.000
M ≥ 5.0	29	0	31	1.000	14	1.000
M ≥ 5.3	29	0	11	1.000	6	1.000
M ≥ 5.5	29	0	10	1.000	5	1.000
M ≥ 5.8	18	0	5	1.000	2	1.000
		Δt ≤ 22 days, Δr ≤ 30 km				
All	29	4	547	1.000	93	1.000
M ≥ 5.0	29	2	31	1.000	14	0.998
M ≥ 5.3	29	2	11	0.990	6	0.874
M ≥ 5.5	29	2	10	0.983	5	0.800
M ≥ 5.8	18	1	5	0.844	2	0.525
		Δt ≤ 11 days, Δr ≤ 120 km				
All	29	20	547	1.000	417	1.000
M ≥ 5.0	29	9	31	0.581	30	0.542
M ≥ 5.3	29	3	11	0.640	10	0.576
M ≥ 5.5	29	3	10	0.576	9	0.505
M ≥ 5.8	18	2	5	0.238	4	0.171
		Δt ≤ 22 days, Δr ≤ 120 km				
All	29	28	547	1.000	417	1.000
M ≥ 5.0	29	12	31	0.958	30	0.944
M ≥ 5.3	29	5	11	0.786	10	0.714
M ≥ 5.5	29	5	10	0.714	9	0.625
M ≥ 5.8	18	3	5	0.285	4	0.188

Table 3. An example of predictions (right) and events that should have been predicted (left) with the following rules of the game: magnitude indetermination ΔM taken fixed at ±0.7 referred to the earthquakes, homogeneous area 36–41°N, 19–25°E excluding Albania, earthquakes with $M \geq 5.8$, $\Delta r = 120$ km, $\Delta t = 11$ d. True distances from the predicted locations are reported.

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                EVENTS                                                                PREDICTIONS
Year Mo. D.     Time      Lat.  Lon.   Mag.          Distance (km)          Year Mo. D.      Lat.  Lon.     Mag.

                                            <------------------------------+ 1987 Feb 26     37.94 20.32    6.5
1987 Feb 27  23:34   38.37 20.42   5.9                     48              |
                                            -------------------------------+

                                            <------------------------------+ 1987 Apr 27     37.67 21.46    5.5
                                                                           |
                                            -------------------------------+

                                            <------------------------------+ 1987 Jun 13     37.97 21.46    5.2
                                                                           |
                                            -------------------------------+

                                            <------------------------------+ 1988 Apr  2     36.06 21.39    5.5
                                                                           |
                                            <------------------------------+

                                            <------------------------------+ 1988 May 15     37.94 20.32    5.3
1988 May 18   5:17   38.35 20.47   5.8                     47              |
                                            <------------------------------| 1988 May 21     37.94 20.32    5.3
                                                                           |
                                            <------------------------------| 1988 May 30     37.94 20.32    5.4
                                                                           |
                                            <------------------------------| 1988 Jun 10     36.70 22.16    5.1
                                                                           |
                                            <------------------------------+

                                            <------------------------------+ 1988 Jul 10     37.13 21.24    5.2
                                                                           |
                                            <------------------------------+

                                            <------------------------------+ 1988 Sep  1     37.96 21.01    5.8
                                                                           |          or     39.87 21.26    5.3
                                            -------------------------------+

                                            <------------------------------+ 1988 Sep 30     37.96 21.01    5.3
                                                                           |
                                            <------------------------------+

1988 Oct 16  12:34   37.90 20.97   6.0



                                            <------------------------------+ 1988 Oct 21     37.96 21.01    6.4
                                                                           |          or     40.48 20.40    5.5
                                            -------------------------------+

                                            <------------------------------+ 1989 Mar  2     37.94 20.32    5.4
                                                                           |
                                            -------------------------------+

1989 Mar 19   5:37   39.28 23.58   5.8 (*)
                                            <------------------------------+ 1989 Jun  3     37.94 20.32    5.5
                                                                           |
                                            <------------------------------| 1989 Jun 13     37.97 21.46    5.2
                                                                           |
                                            -------------------------------+

1989 Aug 20  18:32   37.22 21.08   5.9
                                            <------------------------------+ 1989 Aug 24     38.62 21.73    5.2
                                                                           |          or     37.13 21.24    5.8
                                            -------------------------------+

                                            <------------------------------+ 1989 Sep 11     38.62 21.73    5.2
                                                                           |          or     37.13 21.24    5.8
                                            -------------------------------+

                                            <------------------------------+ 1989 Oct 18     37.96 21.01    5.5
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                                            -------------------------------+
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204 events that should have been predicted for $\Delta r = 30$ km, and 18 correct predictions (still out of 204) for $\Delta r = 120$ km. Taking $\Delta t = 22$ d yields four correct predictions for $\Delta r = 30$ km, and 25 (both still out of 204 earthquakes that should have been predicted) for $\Delta r = 120$ km. Considering magnitude thresholds of 5.3, 5.5 and 5.8 does not produce any substantial difference: in all cases the successes can be comfortably ascribed to chance since the significance level is always above 0.58 (Table 1).

Assuming as geographically operative the union of the indetermination regions for each prediction yields marginally better and still largely insignificant results (Table 1). The best results are relative to the five predictions issued above magnitude 5.8 and with $\Delta t = 22$ d. For $\Delta r = 30$ km one prediction is correct out of five events that should have been predicted, and for $\Delta r = 120$ km two predictions are correct out of 14 events. In both cases the success can be very safely ascribed to chance (sl $\simeq 0.40$).

Slightly better, but nevertheless insignificant results are found by using the rule $\Delta M = \pm 0.7$ relative to earthquakes (Table 2). Also in this case the best results are provided by restricting the analysis to the largest events and assuming as operative the non-homogeneous geographical region. The best overall result is relative to earthquakes with $M \geq 5.8$ in the non-homogeneous region, with $\Delta t = 11$ d and $\Delta r = 120$ km. This implies 18 predictions with $5.1 \leq M \leq 6.3$ (i.e. $5.8 - \Delta M$), and leads to two earthquakes out of four correctly predicted (Table 2). The significance level, equal to 0.17, is still indicative of a merely chancy success. As an example, we show this case in Table 3. It is important to note that the rule $\Delta M = \pm 0.7$ relative to earthquakes implies a reversed situation with respect to the previous case, i.e. with $\Delta M = \pm 0.7$ relative to predictions (Table 1). While many VAN predictions were correct, the vast majority of earthquakes were not predicted, however here many events are correctly predicted, but a large number of predictions turned out to be false alarms.

These results essentially confirm the findings of a preliminary study (Mulargia & Gasperini 1990). There we compared the effectiveness of VAN predictions in the period 1987 February–1989 June with a simulation in which a number of predictions equal to the real one (24) were issued completely at random (according to a stationary Poisson process), with fixed magnitude ($M = 5.0$), and fixed epicentre (38° 10′N, 21° 30′E, which corresponded to the centroid of the seismic epicentres recorded in Greece since the year 1900). Our completely random prediction scheme resulted more effective than VAN predictions.

Table 4. The same as Table 1 but relative to backward time association, i.e. with negative Δt (earthquakes are precursors to predictions with the same epicentre and magnitude; see text).

Rule of the game: Magnitude of Predictions ± 0.7

Backward

			Homogeneous		Non-homogeneous	
Prediction range	Total pred.	Correct Pred.	Number of events	Sign. lev.	Number of events	Sign. lev.
		$\Delta t \leq 11$ days, $\Delta r \leq 30$ km				
All	29	9	547	1.000	93	1.000
M ≥ 5.0	29	9	204	1.000	71	1.000
M ≥ 5.3	14	3	80	0.999	18	0.482
M ≥ 5.5	9	2	44	0.915	15	0.406
M ≥ 5.8	5	2	19	0.257	5	0.028
		$\Delta t \leq 22$ days, $\Delta r \leq 30$ km				
All	29	12	547	1.000	93	1.000
M ≥ 5.0	29	12	204	1.000	71	1.000
M ≥ 5.3	14	3	80	1.000	18	0.892
M ≥ 5.5	9	2	44	0.997	15	0.767
M ≥ 5.8	5	2	19	0.584	5	0.095
		$\Delta t \leq 11$ days, $\Delta r \leq 120$ km				
All	29	23	547	1.000	417	1.000
M ≥ 5.0	29	21	204	1.000	190	1.000
M ≥ 5.3	14	6	80	0.973	51	0.745
M ≥ 5.5	9	2	44	0.915	33	0.811
M ≥ 5.8	5	2	19	0.257	14	0.164
		$\Delta t \leq 22$ days, $\Delta r \leq 120$ km				
All	29	26	547	1.000	417	1.000
M ≥ 5.0	29	22	204	1.000	190	1.000
M ≥ 5.3	14	6	80	1.000	51	0.997
M ≥ 5.5	9	2	44	0.997	33	0.985
M ≥ 5.8	5	2	19	0.584	14	0.424

Table 5. Backward time association as in Table 4, but relative to a magnitude indetermination $\Delta M = 0.7$ from each earthquake.

Rule of the game: Magnitude of Earthquakes ± 0.7

Backward

			Homogeneous		Non-homogeneous	
Earthquake range	Total pred.	Correct Pred.	Number of events	Sign. lev.	Number of events	Sign. lev.
		$\Delta t \leq 11$ days, $\Delta r \leq 30$ km				
All	29	9	547	1.000	93	1.000
M ≥ 5.0	29	6	31	0.900	14	0.246
M ≥ 5.3	29	3	11	0.640	6	0.269
M ≥ 5.5	29	3	10	0.576	5	0.191
M ≥ 5.8	18	2	5	0.238	2	0.054
		$\Delta t \leq 22$ days, $\Delta r \leq 30$ km				
All	29	12	547	1.000	93	1.000
M ≥ 5.0	29	7	31	0.999	14	0.732
M ≥ 5.3	29	3	11	0.960	6	0.696
M ≥ 5.5	29	3	10	0.938	5	0.576
M ≥ 5.8	18	2	5	0.555	2	0.171
		$\Delta t \leq 11$ days, $\Delta r \leq 120$ km				
All	29	23	547	1.000	417	1.000
M ≥ 5.0	29	11	31	0.328	30	0.292
M ≥ 5.3	29	6	11	0.116	10	0.083
M ≥ 5.5	29	6	10	0.083	9	0.056
M ≥ 5.8	18	3	5	0.068	4	0.040
		$\Delta t \leq 22$ days, $\Delta r \leq 120$ km				
All	29	26	547	1.000	417	1.000
M ≥ 5.0	29	13	31	0.927	30	0.907
M ≥ 5.3	29	6	11	0.644	10	0.553
M ≥ 5.5	29	6	10	0.552	9	0.452
M ≥ 5.8	18	3	5	0.285	4	0.188

ARE VAN SIGNALS POST-SEISMIC EFFECTS RATHER THAN PRECURSORS?

There is always the possibility that precursory phenomena are post-seismic effects of previous events. This can be easily ascertained using the above formulation together with a precursory time equal to $-\Delta t$, i.e. events occurring 11 (or 22) d before each prediction. The results, shown in Tables 4 and 5 are very interesting and also rather surprising. We find the existence of a 'backward' time association significantly beyond chance for earthquakes with $M \geq 5.8$ and $\Delta t = 11$ d in the non-homogeneous region taking $\Delta M = \pm 0.7$ from predictions together with $\Delta r = 30$ km ($\mathrm{sl} \simeq 0.03$), and $\Delta M = \pm 0.7$ from earthquakes together with $\Delta r = 120$ km ($\mathrm{sl} \simeq 0.04$). Levels on the border of significance (sl from 0.5 to 0.8) are also apparent in other cases, all relative to the non-homogeneous region taking $\Delta M = \pm 0.7$ from earthquakes and $\Delta t = 11$ d (Table 5): $\Delta r = 30$ km for earthquakes with $M \geq 5.8$ yields a $\mathrm{sl} \simeq 0.05$, while a $\Delta r = 120$ km for earthquakes with $M \geq 5.3$ and $M \geq 5.5$ yields respectively significance levels of 0.08 and 0.06.

DISCUSSION AND CONCLUSIONS

Our analysis provides three main results. First, the claimed success achieved by VAN predictions is just the result of the failure to consider appropriately the rules of the game. Second, this claimed success can be very confidently ascribed to chance. Third, VAN predictions show in all cases a much better association with the events which occurred *before* them. In particular, there is little doubt that the occurrence of a 'large event' ($M_S \geq 5.8$) has been followed by a VAN prediction with essentially identical epicentre and magnitude with a probability too large to be ascribed to chance. Investigating the origin of this peculiar 'post-seismic' effect is beyond the scope of the present paper.

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APPENDIX A

Ascertaining the existence of a time association between two time series is of interest in several geophysical problems. The procedure presented by Mulargia (1992) can be outlined as follows. Given two stationary stochastic point processes without multiple events, M and N, the association between the two is described by the *intensity cross product*

$$p_{MN}(u) = \lim_{h,h' \to 0} \mathrm{Prob}\left\{\frac{\text{point } M \text{ in } (t+u-h,\, t+u+h)}{4hh'}\right.$$

$$\text{and } \left.\frac{\text{point } N \text{ in } (t-h',\, t+h')}{4hh'}\right\}, \tag{A1}$$

where t is the independent variable and u the shift; in the case of time series these represent respectively the elapsed time and the time lag. For $h, h' \neq 0$ and small

$$\mathrm{Prob}\,\{\text{point } N \text{ in } (t-h',\, t+h')\} \simeq p_N 2h', \tag{A2}$$

and

$$\mathrm{Prob}\,\{\text{point } M \text{ in } (t+u-h,\, t+u+h)$$

$$\text{and point } N \text{ in } (t-h',\, t+h')\} \simeq p_{MN} 4hh'. \tag{A3}$$

Since the total number $n(u, h)$ of events associated by both chance and true association is the number of S_i such that

$$t_j + u - h \leq S_i \leq t_j + u + h \qquad \text{for some } j, \tag{A4}$$

the intensity cross product p_{MN} for a given realization is estimated by

$$p_{MN} = \frac{n(u,h)p_N}{N(T)2h} = \frac{n(u,h)}{2hT}, \tag{A5}$$

where $(0, T)$ is the observation interval. Note that p_{MN} is in general a function of both u and h.

The intensity cross product due to chance p_{MN0} is defined identically to p_{MN}, but accounts only for the $n_0(u, h)$ associations which take place by mere chance. It can be estimated by

$$p_{MN0} = \frac{n_0(u,h)p_N}{N(T)2h} = \frac{n_0(u,h)}{2hT}. \tag{A6}$$

Practical estimates of p_{MN0} are found through two general independent processes M and N appropriate for geophysical time series. Calling $M(T)$, $N(T)$ the total number of events M and N, the union of the $M(T)$ intervals of amplitude $2h$ centred at each M event defines on the time axis a set Ω of total normalized length approximately equal to $M(T)2h/T$ if few M events occur with an interevent time smaller than h, i.e. if

$$h < [t_{j+1} - t_j] \quad \text{for most } j; \quad j = 1, \ldots, M(T) - 1. \tag{A7}$$

The independence of the processes M and N can be obtained using this constraint without any assumption on the distribution of M events, but provided that the N events occur according to a stationary Poisson process, which is appropriate for most geophysical time series. The number $n_0(u, h)$ of events N which fall in Ω follows then by definition a binomial distribution with parameters $p = M(T)2h/T$ and $n = N(T)$. This also implies that if $M(T)2h/T$ is small and $N(T)$ is large, $n_0(u, h)$ follows a Poisson distribution with mean $\mu = M(T)N(T)2h/T$.

The presence of a true association, if $2hM(T) \ll T$ and $N(T) \gg 0$ can then be assessed in terms of decision theory by testing the null hypothesis H_0 that the association is due to mere chance $p_{MN} \equiv p_{MN0}$, or equivalently that $n(u, h) \equiv n_0(u, h)$, through

$$H_0: n(u, h) \text{ is Poisson with mean } 2hp_Mp_N/T, \tag{A8}$$

with the alternative of true association. The level of statistical significance sl of true association (the risk of being wrong in rejecting the hypothesis of an association merely due to chance) is therefore readily evaluated one-tailed on the upper part of the cumulative Poisson curve

$$\sum_{x=n(u,h)}^{\infty} \frac{(2hTp_Mp_N)^x}{x!} e^{-(2hTp_Mp_N)}. \tag{A9}$$

This distribution is tabulated in a number of textbooks and is also included in computer libraries.

APPENDIX B

The *Lilly's formula for long lines* with an ellipsoid eccentricity $\epsilon = 0$ is (*cf*. Bomford 1977):

$$\sin\phi_2 = \sin\phi_1 \cos(L/v_1) + \cos\phi_1 \sin(L/v_1)\cos A_{12}, \tag{B1}$$

$$\sin(\lambda_2 - \lambda_1) = \sin A_{12} \sin(L/v_1)\sec\phi_2, \tag{B2}$$

where ϕ_1, λ_1 are respectively the coordinates of the reference station (i.e. 37.987N, 23.746E for Athens and 37.677N, 21.458E for Pyrgos), ϕ_2, λ_2 those of the predicted epicentre, and v_1 is the radius of a spherical Earth (6371 km).

The *Robbins' formula* with an ellipsoid eccentricity $\epsilon = 0$ is (Bomford 1977)

$$\cot A_{32} = [\cos\phi_3 \tan\phi_2 - \sin\phi_3 \cos(\lambda_2 - \lambda_3)] \times \operatorname{cosec}(\lambda_2 - \lambda_3), \tag{B3}$$

$$\sin\sigma = \sin(\lambda_2 - \lambda_3)\cos\phi_2 \operatorname{cosec} A_{32}, \tag{B4}$$

$$L = v_1\sigma, \tag{B5}$$

where A_{32} is the azimuth between the epicentres. Note that both the above formulae neglect the non-spherical corrections, which are small over the range of distances analysed (less than a kilometre for distances ≤500 km).

APPENDIX C

The complete list of predictions issued by Varotsos & Lazaridou (1991, tables 1, 2 and 4) in the period 1987 January 1–1989 November 30. Predictions marked with an asterisk cannot be used in the present analysis (see text).

	Date of telegram	Predicted Epicenter	Predicted Magnitude
	1987 02 26	W 300	6.5 (VL caption Table 2)
	1987 04 27	50 km from Pyrgos	5.5
	1987 06 13	W 200	5.2
	1988 02 01	NE 200	5.0
	1988 03 10	NW 350	5.0
		or WNW 260	5.0
	1988 04 02	W 250	5.0
		or SW 300	5.5
	1988 04 03	N 100	5.0
	1988 04 07	WNW 250	5.0
		or NW 360	5.0
(*)	1988 04 21	40 km from Athens	4.3
	1988 04 28	W 300	5.0
		or WNW 300	5.0
	1988 05 15	NW 330	5.0
		or W 300	5.3
	1988 05 21	W 300	5.3
		or NW 350	5.0
	1988 05 30	W 300	5.4
		or NW 350	5.0
	1988 06 04	W 300	5.0
	1988 06 10	SW 200	5.1
		or 40 km from Athens	4.7
	1988 06 21	W 300	5.0
		or NW 350	4.8
	1988 07 10	W 170	4.7
		or WSW 240	5.2
	1988 07 13	W 70	5.0
(*)	1988 07 18	NNW 80	uncertain
		or SW 100	uncertain
	1988 09 01	W 240	5.8
		or NW 300	5.3
	1988 09 30	W 240	5.3
		or NW 330	5.0
	1988 10 03	W 235	5.3 (VL p. 338)
	1988 10 21	W 240	6.3-6.5
		or NW 400	5.5
	1989 03 02	W 300	5.4
		or NW 330	5.0
	1989 06 03	W 300	5.5
		or NW 330	5.0
	1989 06 13	W 200	5.2
		or NW 350	4.8
	1989 07 23	NE 40	5.0
	1989 08 16	WNW 200	5.0
	1989 08 24	WNW 190	5.2
		or WSW 240	5.8
	1989 09 11	WNW 190	5.2
		or WSW 240	5.8
(*)	1989 09 15	ASS-THESS	uncertain
	1989 10 18	NW 300	4.8
		OR W 240	5.5

APPENDIX D

The global list of events in the SI-NOA catalogue that should have been predicted according to the most general option of the 'rules of the game', i.e. (see text) taking as operative the geographical region 36–41°N, 19–25°E excluding Albania, and earthquakes within $\Delta M = \pm 0.7$ from the issued predictions. All the other 'rules of the game' considered can be readily deduced as subsets of this one. The only difficulty may be represented by the seismic events which pertain to the area above but are external to the union of the indetermination circles from each prediction (Fig. 1; selectivity of VAN predictions). To this extent, earthquakes belonging to such 'homogeneous' area only have been marked 'HO'.

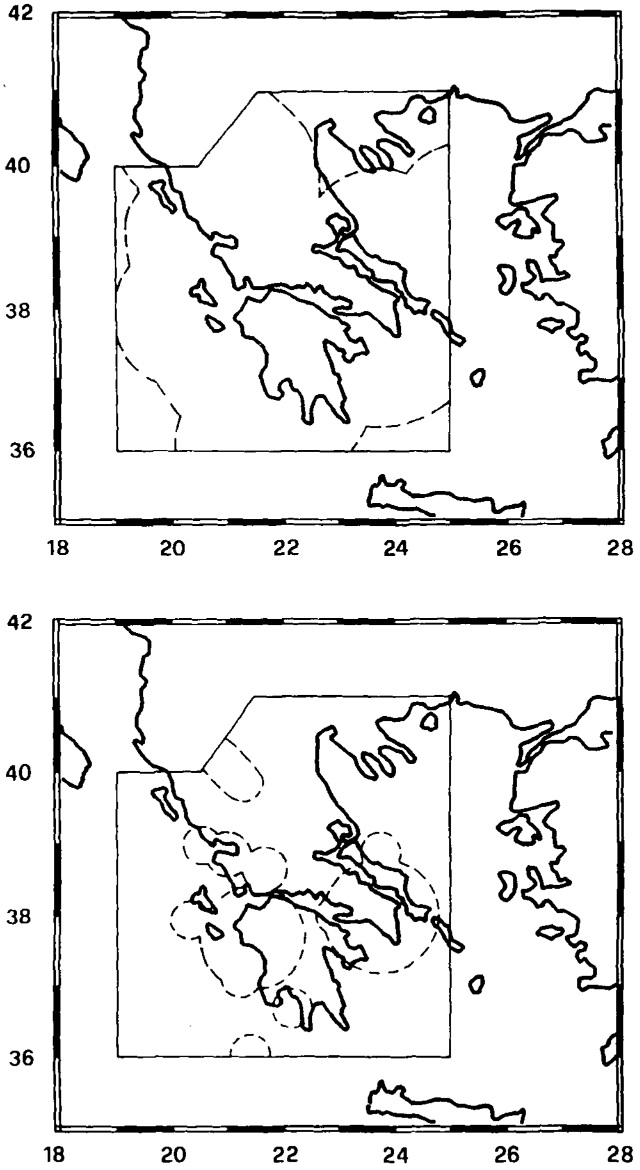

Figure 1. The geographical regions operative for predictions. The three alternatives considered are: (i) the region 36–41°N, 19–25°E excluding Albania (thin solid line in both figures); (ii) the subregion inside it defined by the union of the indetermination regions with a 120 km radius from each predicted epicentre (dashed line in upper figure); and (iii) the same but with a radius of 30 km from each predicted epicentre (dashed line in lower figure).

	YEAR	MO	DA	HO	MI	LAT	LON	MAG
	1987	1	10	16	56	37.83	21.28	4.4
	1987	1	10	20	44	37.88	20.93	4.0
HO	1987	1	17	0	27	40.05	24.42	4.0
HO	1987	1	17	0	30	39.93	24.27	4.5
	1987	1	17	6	40	38.13	20.55	4.1
HO	1987	1	31	1	29	40.40	24.02	4.1
	1987	2	1	5	35	37.87	21.77	4.9
HO	1987	2	7	1	21	39.77	24.27	4.2
	1987	2	19	22	41	40.40	21.32	4.7
	1987	2	22	10	22	38.18	20.73	4.2
	1987	2	24	20	14	38.22	22.23	4.1
	1987	2	27	23	34	38.37	20.42	5.9
HO	1987	2	27	23	42	38.37	20.42	4.1
HO	1987	2	28	22	26	38.32	20.50	4.1
HO	1987	3	1	11	4	38.32	20.38	4.0
	1987	3	1	12	17	39.03	22.25	4.2
HO	1987	3	7	5	25	38.27	20.32	4.0
HO	1987	3	8	3	31	38.37	20.20	4.1
	1987	3	8	17	38	39.38	20.78	4.6
	1987	3	8	17	42	39.52	20.35	5.0
	1987	3	9	19	50	39.42	20.53	4.1
	1987	3	13	13	57	37.22	23.02	4.0
HO	1987	3	14	13	50	36.47	21.28	4.1
HO	1987	3	15	15	54	38.37	20.37	4.0
	1987	3	19	7	30	38.82	24.98	4.0
HO	1987	3	25	10	55	38.35	20.45	4.1
	1987	3	28	6	14	39.28	19.93	4.3
	1987	4	17	6	45	37.70	20.52	4.0
HO	1987	4	18	3	22	36.55	21.07	4.1
HO	1987	4	18	7	21	36.32	21.12	4.0
	1987	4	27	21	57	37.27	20.93	4.0
	1987	5	14	6	29	38.13	22.07	4.4
	1987	5	16	0	2	39.68	20.82	4.1
HO	1987	5	27	3	24	38.28	20.32	4.2
	1987	5	27	11	59	37.02	23.03	4.2
	1987	5	29	18	40	37.53	21.60	5.5
	1987	5	31	5	10	36.83	24.07	4.2
	1987	6	10	14	50	37.17	21.47	5.5
HO	1987	6	10	22	16	36.40	21.22	4.1
HO	1987	6	13	12	7	36.45	21.57	4.0
	1987	6	21	6	13	37.13	21.42	4.7
	1987	6	22	8	20	37.10	21.42	4.1
	1987	6	29	8	54	37.43	21.62	4.2
	1987	6	30	11	39	38.92	23.37	4.1
	1987	7	30	22	13	37.38	21.27	4.6
	1987	7	31	2	13	38.20	22.08	4.0
	1987	7	31	14	11	37.38	21.23	4.0
	1987	8	3	4	26	38.52	20.60	4.4
	1987	8	3	11	11	38.55	20.63	4.6
HO	1987	8	3	16	3	38.47	20.58	4.0
	1987	8	7	15	57	37.47	21.35	4.1
HO	1987	8	15	9	38	38.12	20.42	4.1
HO	1987	8	15	11	36	38.00	20.32	4.1
	1987	8	27	16	46	38.93	23.82	5.3
	1987	9	10	14	5	37.62	20.82	4.1
	1987	9	12	0	14	37.75	20.13	4.5
	1987	9	15	7	59	37.53	21.68	4.3
	1987	9	16	1	18	36.70	21.62	4.8
	1987	9	16	14	1	38.90	23.90	4.1

	YEAR	MO	DA	HO	MI	LAT	LON	MAG
	1987	9	28	21	15	39.55	24.18	4.1
HO	1987	10	8	23	21	36.75	21.48	4.0
	1987	10	16	1	11	37.73	20.98	4.3
	1987	10	16	2	12	37.68	20.90	4.0
	1987	10	16	11	28	37.07	22.13	4.2
	1987	10	18	18	2	37.28	21.08	4.1
HO	1987	10	18	21	48	36.97	20.83	4.1
	1987	10	18	23	56	37.58	20.73	4.3
	1987	10	20	11	32	38.58	23.48	4.0
	1987	10	21	7	15	37.00	21.33	4.0
	1987	10	24	4	48	39.47	20.62	4.2
	1987	10	28	12	48	38.97	21.47	4.0
	1987	10	28	20	28	38.95	21.67	4.2
	1987	10	29	5	0	38.95	21.43	4.0
	1987	10	29	15	16	38.97	21.48	4.0
	1987	11	5	18	31	37.20	21.68	4.0
	1987	11	7	6	44	37.53	21.57	4.3
	1987	11	9	23	3	38.95	20.80	4.2
	1987	11	14	23	46	38.47	23.88	4.1
	1987	11	30	4	19	39.32	22.87	4.4
	1987	11	30	15	50	37.97	21.93	4.0
	1987	12	1	17	40	38.38	20.48	4.3
HO	1987	12	2	17	55	38.32	20.35	4.0
	1987	12	7	1	57	36.62	21.72	4.6
	1987	12	7	2	26	38.28	22.13	4.0
	1987	12	8	19	31	38.55	23.42	4.2
	1987	12	10	22	51	36.65	21.68	5.2
	1987	12	13	21	22	37.35	20.57	4.6
	1987	12	21	20	55	39.52	19.97	4.6
	1987	12	23	9	38	37.98	20.57	4.0
	1987	12	24	21	20	38.18	20.72	4.0
	1988	1	4	18	51	39.77	20.22	4.5
	1988	1	14	23	47	39.72	20.42	4.3
	1988	1	17	21	6	40.42	21.17	4.2
	1988	1	18	14	47	39.32	20.47	4.2
	1988	1	21	5	32	39.33	20.53	4.3
	1988	1	22	6	18	38.63	21.02	5.1
	1988	2	6	22	48	38.22	20.63	4.2
HO	1988	2	9	2	19	36.77	21.77	4.3
HO	1988	2	13	1	39	36.10	23.42	4.1
	1988	2	18	11	11	39.12	23.47	5.1
	1988	2	21	21	26	39.10	23.53	4.0
	1988	2	26	4	8	38.78	21.00	4.1
	1988	3	8	11	38	38.82	21.12	5.1
	1988	3	18	21	45	38.73	21.25	4.4
	1988	3	29	11	12	37.70	20.63	4.1
	1988	3	30	10	33	37.03	21.23	4.0
	1988	3	31	12	29	36.95	21.62	4.2
	1988	3	31	14	43	37.48	20.83	4.3
HO	1988	4	1	12	26	36.43	21.75	4.2
	1988	4	2	20	6	38.02	23.93	4.1
	1988	4	2	21	57	38.13	24.13	4.5
	1988	4	3	3	35	38.08	22.82	4.4
	1988	4	3	8	56	39.45	20.13	4.7
	1988	4	3	14	22	39.37	20.25	4.2
HO	1988	4	5	17	50	38.27	20.47	4.1
	1988	4	8	5	57	37.72	21.33	4.0
HO	1988	4	8	20	12	38.03	20.35	4.2
	1988	4	9	18	9	37.43	20.95	4.2

	YEAR	MO	DA	HO	MI	LAT	LON	MAG
	1988	4	12	2	18	37.83	20.52	4.0
	1988	4	12	19	48	37.78	20.32	4.5
	1988	4	22	0	42	38.80	21.10	4.0
	1988	4	24	10	10	38.83	20.33	5.0
HO	1988	4	30	4	28	38.43	20.43	4.1
HO	1988	5	3	0	42	38.38	20.38	4.1
HO	1988	5	4	5	26	38.38	20.52	4.0
HO	1988	5	4	8	6	38.40	20.38	4.0
	1988	5	6	3	6	38.17	20.67	4.0
HO	1988	5	7	19	34	38.33	20.42	4.1
HO	1988	5	7	20	41	38.40	20.47	4.2
	1988	5	9	16	52	37.68	19.93	4.9
HO	1988	5	11	17	46	38.38	20.33	4.1
	1988	5	11	20	20	37.58	20.67	4.2
HO	1988	5	11	23	43	38.37	20.37	4.0
HO	1988	5	13	4	6	38.22	20.28	4.2
	1988	5	14	8	16	37.75	21.15	4.0
HO	1988	5	16	15	38	38.57	20.53	4.0
	1988	5	18	5	17	38.35	20.47	5.8
HO	1988	5	18	6	6	38.30	20.43	4.2
HO	1988	5	18	7	10	38.30	20.47	4.2
	1988	5	18	9	9	38.32	20.48	4.8
	1988	5	18	11	40	38.25	20.50	4.1
	1988	5	18	14	9	38.25	20.57	4.1
	1988	5	18	16	54	38.32	20.52	4.1
	1988	5	19	0	29	38.32	20.53	4.1
	1988	5	19	0	53	38.23	20.47	4.3
	1988	5	19	4	16	38.22	20.48	4.5
	1988	5	19	13	51	38.18	20.72	4.0
	1988	5	20	11	29	38.28	20.55	4.2
HO	1988	5	20	18	48	38.28	20.48	4.2
	1988	5	21	5	10	38.18	20.58	4.1
	1988	5	21	12	3	38.28	20.57	4.1
	1988	5	21	14	33	38.33	20.57	4.1
	1988	5	21	23	52	38.20	20.17	4.3
	1988	5	22	3	11	38.30	20.57	4.0
	1988	5	22	3	44	38.35	20.53	5.5
	1988	5	22	4	33	38.25	20.35	4.5
	1988	5	22	6	26	38.30	20.57	4.1
	1988	5	22	22	47	38.28	20.58	4.5
	1988	5	23	7	4	38.28	20.57	4.2
	1988	5	23	23	39	38.37	20.53	4.3
HO	1988	5	25	9	12	36.62	21.43	4.0
	1988	5	25	10	11	37.15	22.12	4.2
	1988	5	26	0	0	38.33	20.57	4.1
HO	1988	5	26	0	33	38.23	20.43	4.1
HO	1988	5	26	1	37	38.28	20.42	4.1
HO	1988	5	26	13	10	38.38	20.47	4.2
	1988	5	27	15	44	37.28	20.02	4.5
HO	1988	5	27	18	34	38.37	20.45	4.2
HO	1988	5	29	3	28	38.32	20.32	4.2
HO	1988	5	30	10	55	38.27	20.47	4.0
	1988	6	1	13	21	37.33	20.83	4.0
	1988	6	2	10	35	38.27	20.37	5.0
HO	1988	6	2	14	11	38.40	20.28	4.2
	1988	6	2	17	19	38.32	20.58	4.1
	1988	6	3	18	37	38.28	20.42	4.5
	1988	6	4	10	57	38.28	20.42	4.5
	1988	6	4	11	15	38.32	20.57	4.1

	YEAR	MO	DA	HO	MI	LAT	LON	MAG
HO	1988	6	4	17	5	38.32	20.45	4.2
	1988	6	6	5	57	38.30	20.48	5.0
	1988	6	6	13	22	38.28	20.48	4.3
	1988	6	6	16	9	38.27	20.52	4.1
	1988	6	7	3	28	38.33	20.58	4.1
	1988	6	8	0	14	38.32	20.55	4.2
HO	1988	6	9	23	4	39.88	23.75	4.0
	1988	6	10	8	55	38.28	20.53	4.1
	1988	6	11	10	36	37.68	21.42	4.2
	1988	6	11	10	38	37.72	21.43	4.0
	1988	6	13	20	32	37.18	21.60	4.0
	1988	6	16	3	12	38.32	20.47	4.3
HO	1988	6	17	19	39	38.27	20.37	4.2
HO	1988	6	21	1	50	40.00	23.97	4.3
HO	1988	6	23	11	55	39.78	23.78	4.1
	1988	6	26	6	5	38.32	20.40	4.5
	1988	6	27	3	43	38.32	20.55	4.1
	1988	6	27	6	55	38.30	20.53	4.0
	1988	6	28	1	13	38.28	20.57	4.0
	1988	6	29	9	18	38.28	20.55	4.1
HO	1988	7	1	0	5	38.33	20.07	4.2
HO	1988	7	1	7	49	39.97	23.73	4.0
	1988	7	5	20	34	38.10	22.85	4.7
	1988	7	6	3	38	39.23	20.07	4.3
HO	1988	7	7	2	41	40.87	22.12	4.2
HO	1988	7	8	4	59	39.23	20.03	4.2
	1988	7	12	2	26	38.78	23.43	5.0
	1988	7	12	5	39	38.68	23.25	4.4
	1988	7	13	10	39	38.78	23.47	4.4
	1988	7	14	5	43	38.72	23.58	4.0
	1988	7	14	12	5	38.67	23.28	4.5
	1988	7	14	13	18	38.72	23.37	4.3
	1988	7	14	18	6	38.72	23.38	4.2
	1988	7	15	19	49	38.68	23.78	4.1
	1988	7	16	1	54	37.42	22.87	5.0
HO	1988	7	16	17	56	40.02	23.82	4.0
	1988	7	23	9	19	36.85	21.87	4.5
	1988	7	24	2	19	38.27	20.53	4.0
HO	1988	7	29	13	37	40.48	22.93	4.1
HO	1988	8	3	19	35	36.05	23.30	4.0
HO	1988	8	9	7	21	40.02	24.07	4.2
HO	1988	8	11	10	4	40.05	23.78	4.0
HO	1988	8	11	12	45	39.98	24.03	4.3
	1988	8	11	20	54	38.17	20.28	4.3
HO	1988	8	13	7	26	40.02	23.98	4.6
HO	1988	8	13	17	48	39.97	24.03	4.1
	1988	8	14	4	49	38.68	20.18	4.4
HO	1988	8	14	16	56	39.93	24.03	4.0
HO	1988	8	16	2	52	40.13	23.97	4.0
	1988	8	16	21	34	39.93	24.02	4.7
HO	1988	8	18	5	33	40.13	23.63	4.0
HO	1988	8	20	18	10	39.97	23.97	4.2
	1988	8	22	17	28	37.38	20.88	4.1
HO	1988	8	24	9	47	36.83	21.05	4.1
HO	1988	8	25	15	15	36.92	21.40	4.1
HO	1988	8	27	0	19	39.97	24.02	4.1
	1988	8	27	21	52	37.98	21.12	4.0
HO	1988	8	31	5	12	36.08	22.53	4.0
	1988	8	31	18	47	38.13	20.67	4.1

	YEAR	MO	DA	HO	MI	LAT	LON	MAG
HO	1988	9	5	0	39	37.48	20.47	4.0
	1988	9	6	3	26	38.37	21.78	4.0
HO	1988	9	11	14	57	37.78	20.10	4.2
	1988	9	11	21	45	38.15	23.22	5.0
	1988	9	19	9	29	39.88	21.10	4.3
	1988	9	22	12	5	37.98	21.12	5.5
	1988	9	22	16	13	37.93	21.08	4.0
	1988	9	23	4	41	38.02	21.03	4.3
	1988	9	23	6	11	37.95	21.02	4.2
	1988	9	23	8	24	37.97	21.03	4.3
	1988	9	23	9	58	37.92	21.03	4.3
	1988	9	24	16	4	37.90	20.98	4.0
	1988	9	25	3	47	37.90	21.00	4.2
	1988	9	25	19	44	37.62	20.57	4.2
	1988	9	25	23	53	37.68	20.78	4.0
	1988	9	28	16	17	37.85	20.98	4.0
	1988	9	30	11	3	37.72	21.37	4.5
	1988	9	30	13	2	37.68	21.33	4.7
	1988	10	6	4	3	39.02	19.93	4.4
	1988	10	13	4	14	38.73	20.37	4.5
	1988	10	15	7	0	37.47	21.58	4.8
	1988	10	15	7	4	37.23	21.30	4.6
	1988	10	16	12	34	37.90	20.97	6.0
	1988	10	16	12	42	37.87	20.93	4.3
	1988	10	16	12	43	37.80	20.67	4.4
	1988	10	16	12	44	38.17	20.98	4.7
	1988	10	16	13	26	37.57	20.48	4.3
	1988	10	16	14	22	37.82	20.93	4.1
	1988	10	16	14	25	37.72	20.83	4.0
	1988	10	16	14	28	37.82	20.62	4.1
	1988	10	16	14	32	37.62	20.68	4.0
	1988	10	16	15	12	37.62	20.63	4.4
	1988	10	16	16	45	37.85	20.83	4.4
	1988	10	16	16	54	37.73	20.88	4.0
	1988	10	16	17	52	37.73	20.83	4.1
	1988	10	16	18	35	37.58	20.58	4.3
	1988	10	16	19	17	37.77	20.87	4.0
	1988	10	17	1	49	37.85	20.97	4.5
	1988	10	17	2	3	37.63	20.72	4.1
	1988	10	17	2	30	37.82	20.92	4.3
	1988	10	17	3	26	37.67	20.67	4.0
HO	1988	10	17	7	21	37.57	20.48	4.1
	1988	10	17	16	16	37.57	20.63	4.1
	1988	10	17	19	58	37.32	23.22	4.5
	1988	10	17	22	47	37.85	21.03	4.4
	1988	10	17	23	46	37.85	21.03	4.2
	1988	10	18	10	31	37.83	21.02	4.0
	1988	10	18	15	41	37.83	20.98	4.0
	1988	10	18	18	22	37.78	20.97	4.1
	1988	10	18	19	28	37.85	21.02	4.2
	1988	10	19	0	27	37.87	20.98	4.4
	1988	10	19	0	32	37.83	20.97	4.3
	1988	10	19	6	41	37.88	21.03	4.0
	1988	10	19	12	23	39.87	20.60	4.5
	1988	10	19	23	2	37.88	20.98	4.1
	1988	10	20	0	33	37.95	21.00	4.0
	1988	10	20	2	29	37.90	20.98	4.0
	1988	10	20	5	11	37.83	20.88	4.3
	1988	10	20	13	32	37.87	21.02	4.2

	YEAR	MO	DA	HO	MI	LAT	LON	MAG
HO	1988	10	20	14	0	40.53	22.93	4.7
	1988	10	20	18	54	39.38	23.75	4.1
	1988	10	21	10	4	37.83	21.03	4.0
	1988	10	22	2	50	38.88	24.93	4.4
	1988	10	22	7	34	37.75	20.98	4.1
	1988	10	22	8	53	37.93	20.93	4.5
	1988	10	22	9	34	37.98	21.13	4.5
	1988	10	22	11	54	37.78	20.98	4.0
	1988	10	22	14	58	37.88	21.02	4.5
	1988	10	23	3	17	37.88	21.03	4.3
	1988	10	23	7	29	37.97	21.07	4.4
	1988	10	23	15	29	37.87	21.05	4.0
	1988	10	23	17	1	37.82	20.98	4.0
	1988	10	23	22	34	39.85	20.58	4.5
	1988	10	25	11	37	37.87	21.03	4.4
	1988	10	25	17	21	37.82	21.03	4.0
	1988	10	26	10	42	37.72	20.83	4.1
	1988	10	27	0	5	37.77	21.00	4.0
	1988	10	28	5	49	37.82	20.97	4.4
	1988	10	28	19	28	38.12	20.55	4.2
	1988	10	30	7	25	37.83	20.97	4.2
HO	1988	10	30	10	9	38.57	20.42	4.1
HO	1988	10	30	12	30	38.55	20.37	4.2
	1988	10	31	2	50	37.82	20.98	4.3
	1988	10	31	2	59	37.85	21.02	4.8
	1988	10	31	3	16	37.87	20.98	4.2
	1988	10	31	6	10	37.85	21.00	4.3
	1988	11	2	21	2	37.37	20.52	4.6
	1988	11	3	5	16	40.23	21.72	4.2
	1988	11	7	8	31	37.08	21.38	4.1
	1988	11	8	8	17	36.77	22.67	5.0
	1988	11	9	5	13	38.32	20.53	4.2
	1988	11	11	17	52	37.98	20.38	4.9
	1988	11	11	18	50	37.72	21.80	4.2
	1988	11	13	17	19	37.25	22.12	4.1
	1988	11	14	20	59	37.72	20.97	4.1
	1988	11	27	16	38	37.88	20.98	4.3
HO	1988	12	1	5	39	36.32	21.67	4.1
HO	1988	12	2	17	43	40.63	22.60	4.6
HO	1988	12	8	9	26	40.78	22.42	4.5
HO	1988	12	11	6	12	40.97	22.27	4.5
	1988	12	13	11	0	37.75	21.23	4.7
	1988	12	14	9	45	39.77	20.32	5.1
	1988	12	20	23	6	37.82	21.07	4.1
	1988	12	22	9	56	38.33	21.75	5.0
	1988	12	31	12	25	39.63	20.93	4.1
HO	1989	1	3	8	19	38.43	19.80	4.0
	1989	1	3	11	56	39.82	20.93	4.3
	1989	1	6	19	52	38.00	20.93	4.0
HO	1989	1	9	2	50	36.63	22.05	4.0
	1989	1	11	20	57	38.88	24.92	4.1
	1989	1	20	18	31	40.27	21.47	4.1
	1989	1	23	9	27	38.97	20.68	4.1
HO	1989	1	26	22	59	36.17	21.65	4.2
HO	1989	1	28	5	27	40.13	23.80	4.0
	1989	1	29	15	26	38.12	19.62	4.5
	1989	2	3	23	7	37.77	21.00	4.0
	1989	2	6	11	37	39.18	24.52	4.4
	1989	2	10	14	17	40.52	21.10	4.1
	1989	2	16	16	3	36.58	21.57	4.0
	1989	2	16	23	16	37.68	21.33	4.1
	1989	2	17	2	24	38.73	22.67	4.7
	1989	2	19	1	50	40.33	21.82	4.2
	1989	2	19	8	52	40.35	21.95	4.2
	1989	2	26	3	26	37.12	20.78	4.4
	1989	2	26	22	6	39.13	24.58	4.0
	1989	2	26	23	54	39.15	24.55	4.8
	1989	2	27	0	20	39.13	24.53	4.3
HO	1989	3	1	9	59	36.85	20.22	4.2
	1989	3	2	2	17	37.25	21.38	4.2
	1989	3	8	5	40	39.03	20.85	4.1
HO	1989	3	8	6	54	38.23	20.45	4.2
	1989	3	10	19	32	37.38	20.78	4.0
	1989	3	16	3	13	37.57	20.98	4.0
	1989	3	18	21	27	39.27	23.55	4.9
	1989	3	18	21	36	39.23	23.48	4.0
	1989	3	19	0	19	39.25	23.53	4.1
	1989	3	19	0	31	38.07	22.93	4.0
HO	1989	3	19	5	37	39.28	23.58	5.8
	1989	3	19	5	42	37.63	23.67	4.1
	1989	3	19	5	48	39.32	23.62	4.5
	1989	3	19	5	49	38.77	23.75	4.6
	1989	3	19	5	57	39.20	23.58	4.5
	1989	3	19	6	7	39.02	23.73	4.0
	1989	3	19	6	35	39.32	23.58	4.1
	1989	3	19	6	43	39.23	23.40	4.0
	1989	3	19	7	41	39.25	23.70	4.5
	1989	3	19	8	20	39.28	23.62	4.1
	1989	3	19	8	23	39.30	23.58	4.6
	1989	3	19	8	52	39.33	23.62	4.6
	1989	3	19	9	16	39.27	23.63	4.7
	1989	3	19	9	51	39.27	23.88	4.0
	1989	3	19	11	31	39.23	23.63	5.0
	1989	3	19	13	47	39.25	23.47	4.1
	1989	3	20	4	5	39.58	23.93	4.4
	1989	3	20	4	53	39.25	23.57	4.4
	1989	3	20	9	55	39.28	23.47	4.0
	1989	3	20	10	39	39.23	23.62	4.9
	1989	3	20	13	41	39.25	23.52	4.1
	1989	3	21	21	30	39.27	23.53	4.3
	1989	3	24	18	22	39.23	23.43	4.0
HO	1989	3	27	21	21	38.83	20.47	4.0
HO	1989	3	28	20	1	36.48	24.87	4.1
HO	1989	3	30	0	48	36.38	24.72	4.1
HO	1989	4	7	4	33	38.08	20.38	4.1
	1989	4	8	23	51	37.72	20.82	4.0
	1989	4	12	10	5	38.07	21.93	4.8
	1989	4	12	10	46	39.17	23.48	4.0
	1989	4	12	13	53	38.03	22.02	4.5
	1989	4	12	19	24	38.08	21.97	4.4
	1989	4	12	21	43	39.27	23.58	4.1
HO	1989	4	13	20	4	36.28	24.08	4.0
	1989	4	14	5	57	37.55	20.83	4.1
HO	1989	4	14	10	15	40.03	20.88	4.0
	1989	4	18	0	47	39.27	23.62	4.2
	1989	4	21	12	10	38.37	22.05	4.0
	1989	4	23	2	25	39.22	23.67	4.6
	1989	4	26	6	12	39.23	23.25	4.0

	YEAR	MO	DA	HO	MI	LAT	LON	MAG
	1989	4	27	10	15	37.52	20.82	4.4
	1989	4	28	4	2	39.27	23.57	5.2
	1989	4	28	5	15	39.07	23.67	4.0
	1989	4	28	15	29	39.48	24.00	4.1
	1989	4	30	5	11	39.27	23.62	4.6
	1989	5	1	7	24	39.75	21.25	4.1
	1989	5	1	21	3	37.18	21.23	5.1
	1989	5	2	23	9	39.25	23.58	4.3
	1989	5	2	23	16	39.27	23.63	4.1
	1989	5	4	9	3	37.38	21.40	4.0
	1989	5	4	20	10	37.77	20.87	4.0
HO	1989	5	5	9	1	38.22	20.12	4.2
HO	1989	5	6	11	19	36.13	24.62	4.5
	1989	5	7	10	36	38.27	22.60	4.0
	1989	5	7	10	46	38.28	22.67	4.6
	1989	5	7	13	40	39.83	20.43	4.7
	1989	5	15	9	22	38.28	21.75	4.8
	1989	5	16	4	38	37.67	21.03	4.0
	1989	5	18	2	12	38.03	20.53	4.1
HO	1989	5	18	17	37	39.12	21.75	4.0
	1989	5	19	18	0	36.97	23.13	4.5
	1989	5	21	10	40	40.53	21.60	4.1
	1989	5	23	17	19	37.73	20.97	4.4
	1989	5	24	16	28	37.43	21.13	4.1
	1989	5	25	18	4	38.48	20.68	4.1
	1989	5	27	6	49	39.92	19.97	4.4
	1989	5	31	2	56	38.08	20.57	4.1
	1989	6	2	10	0	39.82	21.18	4.3
	1989	6	3	17	38	39.47	19.87	4.5
	1989	6	4	5	24	37.42	21.08	4.0
	1989	6	7	19	13	37.78	20.87	4.0
	1989	6	7	19	45	38.00	21.63	5.2
	1989	6	10	19	9	36.65	22.98	4.0
HO	1989	6	11	8	50	36.07	22.95	4.1
	1989	6	11	16	55	37.28	20.78	4.2
	1989	6	17	20	56	37.98	22.12	4.4
	1989	6	18	3	15	38.33	20.52	4.5
HO	1989	6	19	4	17	40.38	23.95	4.0
	1989	6	22	6	53	40.35	21.47	4.1
	1989	6	23	7	17	37.65	20.62	4.1
	1989	6	23	20	4	39.72	20.33	4.5
	1989	6	26	8	38	37.75	20.90	4.0
HO	1989	6	26	18	40	36.25	21.52	4.1
	1989	6	26	19	3	37.72	20.72	4.0
HO	1989	6	28	8	15	38.15	20.28	4.0
	1989	6	29	2	41	39.38	19.68	4.6
HO	1989	6	30	2	30	40.75	22.63	4.0
	1989	7	4	9	49	40.35	21.87	4.4
	1989	7	4	22	20	39.02	21.43	4.3
	1989	7	5	0	37	39.67	20.33	4.5
	1989	7	9	8	38	37.78	20.58	4.0
	1989	7	10	7	23	37.63	19.82	4.5
HO	1989	7	10	10	3	38.25	20.17	4.1
	1989	7	15	0	19	38.95	23.38	4.1
	1989	7	17	8	0	37.05	21.77	4.1
	1989	7	18	12	53	39.80	22.13	4.1
	1989	7	22	10	17	39.83	22.12	4.2
	1989	7	29	3	12	40.53	21.62	4.1
	1989	7	29	10	38	40.18	21.62	4.4
	1989	8	1	2	23	39.20	23.63	5.0
	1989	8	1	3	21	38.23	22.18	4.0
	1989	8	2	9	47	40.33	21.58	4.3
	1989	8	2	16	21	37.68	20.78	4.1
	1989	8	6	11	53	37.13	23.10	4.6
	1989	8	7	0	35	38.95	21.08	4.1
	1989	8	7	0	38	38.93	21.12	4.4
	1989	8	7	0	42	38.95	21.03	4.1
	1989	8	7	0	44	38.95	21.08	4.1
HO	1989	8	7	1	0	38.93	21.08	4.0
HO	1989	8	7	13	57	36.63	21.43	4.1
	1989	8	7	17	40	39.43	21.35	4.1
	1989	8	10	12	36	38.00	20.18	4.5
	1989	8	10	21	24	37.60	21.47	4.1
HO	1989	8	16	0	49	37.02	20.75	4.1
	1989	8	20	18	32	37.22	21.08	5.9
HO	1989	8	20	19	39	36.98	19.30	4.7
HO	1989	8	20	20	57	39.97	23.95	4.5
	1989	8	21	9	31	37.25	21.27	4.0
	1989	8	22	3	54	37.42	21.42	4.3
	1989	8	22	19	53	37.17	21.28	4.2
	1989	8	24	2	13	37.92	20.12	5.7
	1989	8	24	2	38	38.07	20.15	4.6
	1989	8	24	6	56	38.02	20.17	4.3
HO	1989	8	24	19	27	38.32	20.38	4.2
	1989	8	26	7	56	37.98	20.22	4.6
	1989	8	27	3	52	37.57	20.77	4.7
	1989	8	28	10	40	40.43	21.62	4.1
HO	1989	8	31	0	32	38.02	20.43	4.0
	1989	8	31	18	43	37.57	20.93	4.2
	1989	8	31	21	29	38.17	21.82	4.8
	1989	9	2	11	11	36.85	23.50	4.0
	1989	9	6	12	18	37.98	20.20	4.3
	1989	9	7	8	22	37.23	21.23	4.3
	1989	9	9	21	59	37.42	21.07	4.0
	1989	9	11	20	51	37.37	21.22	4.0
HO	1989	9	12	16	11	40.25	22.33	4.0
HO	1989	9	13	9	2	39.18	20.37	4.0
HO	1989	9	13	12	18	40.48	22.47	4.1
HO	1989	9	13	12	20	40.47	22.47	4.0
	1989	9	16	5	50	37.37	21.30	4.5
	1989	9	19	7	57	39.48	21.33	5.0
HO	1989	9	19	10	29	36.37	20.63	4.1
	1989	9	19	22	51	40.38	22.43	4.1
HO	1989	9	20	6	53	39.45	20.63	4.0
	1989	9	20	6	55	39.50	20.68	4.2
	1989	9	23	11	41	37.17	24.12	4.0
	1989	9	25	7	35	36.87	21.63	4.7
	1989	9	25	7	38	36.78	21.53	4.6
	1989	9	29	9	32	37.03	21.23	4.3
HO	1989	10	2	13	44	36.42	21.77	4.0
	1989	10	3	10	8	38.48	23.43	4.3
	1989	10	5	15	4	38.78	21.27	4.3
	1989	10	5	15	32	38.77	21.32	4.0
	1989	10	6	17	39	39.77	20.42	4.5
	1989	10	7	15	41	37.57	21.13	4.0
	1989	10	12	21	10	37.82	21.02	4.1
HO	1989	10	18	13	4	40.73	24.03	4.3
HO	1989	10	19	8	19	39.98	23.68	4.0

	YEAR	MO	DA	HO	MI	LAT	LON	MAG
	1989	10	29	19	34	39.28	21.15	4.2
	1989	10	29	19	35	39.33	21.08	4.5
HO	1989	10	29	20	5	38.95	21.12	4.0
HO	1989	10	31	7	20	36.67	21.47	4.1
HO	1989	11	1	3	59	36.52	21.10	4.1
	1989	11	1	13	32	38.28	21.68	4.0
	1989	11	2	19	25	37.23	20.68	4.3
	1989	11	3	6	24	37.32	20.93	4.2

	YEAR	MO	DA	HO	MI	LAT	LON	MAG
HO	1989	11	4	20	57	36.73	21.28	4.0
HO	1989	11	5	1	27	36.58	21.22	4.1
	1989	11	5	2	41	36.62	21.20	4.4
	1989	11	6	6	33	38.03	23.02	4.1
	1989	11	6	10	40	39.27	21.57	4.2
	1989	11	8	21	6	37.33	20.78	4.2
HO	1989	11	18	9	38	37.27	20.60	4.0
HO	1989	11	26	16	43	36.18	21.52	4.0