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VAN: Candidacy and validation with the latest laws of the game

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Abstract. We reassess the set of VAN predictions in the period 1987-1989 with the latest laws of the game [*Varotsos et al.*, 1996]. This reassessment does not modify our previous conclusions: VAN predictions have alarm and success rates too low to accept them as candidate precursors, and a degree of time association with earthquakes which suggests rejection of any precursor nomination. At the same time, this reassessment confirms the tendency of predictions in the period 1987-1989 to significantly follow earthquakes, with 13 earthquakes tracked by a spatially close prediction within 11 days. A validation study of the independent set of VAN predictions in the period 1990-1992, leaving the laws of the game unchanged while restricting the operative region to account for network reduction, denies any significant association of VAN predictions with earthquakes, but confirms the tendency of VAN predictions to follow rather than precede earthquakes.

The latest release of laws of the game

Varotsos et al. [1996] propose new laws of the game for the same set of predictions from January 1, 1987 to November 30 1989. They endorse *Hamada's* [1993] choice of discarding both predictions and earthquakes below magnitude 5.0, and introduce a multiple definition for t: 11 days for standard signals, 22 days for a series of SES, and "of the order of one month" for gradually varying signals (GVEF). No indication is given for r, but they probably share *Hamada*'s choice of 100 km; no change in the assumption that each signal predicts one event is mentioned. Two questions are in order: i) are all the above options usable?; ii) do they warrant treating VAN signals as candidate seismic precursors?

The magnitude cutoff for both earthquakes and predictions at 5.0 is in conflict with the definition of M, but the alternative of taking into account earthquakes below $m = 5.0$ only if they have been correctly predicted makes no sense. A second problem is the redefinition of t for GVEF. Since the latter concerns only the prediction of April 27 1987 but is not mentioned in the original telegram (*Dologlou* [1993]; page 198), and since the published law for GVEF has so far been limited to a few weeks at most, we disregard altogether this prediction as ambiguous [*Mulargia and Gasperini*, 1996].

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As regards the second question, we reevaluate the same set of data according to our formulation, analyzing also the NEIC–PDE catalog (with Hamada's convention of adding 0.3 to m_b) in addition to the SI–NOA. The catalogs are reported in tables 1 and 2 of *Geller* [1996]. To avoid confusion (cf. the Appendix of *Varotsos et al.* [1996] and *Tselentis and Melis* [1996], with the Appendix of *Mulargia and Gasperini* [1996]), we use only the nonhomogeneous operative region definition, which is the only one capable of accounting for the supposed selective antenna effect. We allow t = 22 days for the predictions of September 1, September 30 and October 3 1988, entering equation (1) in *Mulargia and Gasperini* [1996] with the weighted $t = (11 \times 25 + 22 \times 3)/28$. We again use both the extremes of full and no efficiency of postseismic information, i.e. respectively not accounting for and accounting for the limited spatial extent of each prediction by setting the number of earthquakes n that should have been predicted to either the total number of events which occurred within the operative region or to the average number covered by a prediction $\sum_{i=1}^{m} n_i/m$, where n_i events occurred during the whole period of analysis in the prescribed magnitude range and within the area of radius r of the i-th prediction. Limiting this sum to the successful predictions alone yields a better approximation when the predictions refer to regions with different seismicity. While the uniform approximation $P = nt/T$ gives inessential differences, in order not to generate confusion [cf. *Rhoades and Evison*, 1996] we retain here the full expression of the Poisson probability of at least one event within t, $P = 1 - exp(-nt/T)$. We first examine the results for the SI–NOA catalog, which has 35 events in the non–homogoneous operative region, i.e. within 100 km of at least one prediction. Eight predictions (out of 28) are correct (Table 1). The related success and alarm rates, 8/28 and 8/36, immediately suggest withdrawing candidacy as usable precursors. The question would be more subtle if VAN's electrical anomalies were being tested as didactic precursors. Assuming no advantage from postseismic information, i.e. using $n = 102/8$, yields a time association significant at the 0.03 level. On the contrary, assuming full advantage from postseismic information, i.e. taking n equal to 35, gives an insignificant association (0.76 level). This result is apparently contradictory; while the chance set should contain the same postseismic information as the VAN set, a significant time association requires assuming that no use is made of postseismic information. Is this compatible with VAN predictions? A first indication that the latter are incompatible with a random prediction scheme [e.g. *Aceves et al.*,

Table 1. Earthquakes associated with the predictions in Table A1 of [*Mulargia and Gasperini*, 1996] in forward and reverse time

	Prediction				Earthquake					
Date	Coordinates		M	Date	Coordinates		M	r	M	t
SI-NOA Forward										
1987/ 2/26	37.94	20.32	6.5	1987/ 2/27	38.37	20.42	5.9	48	0.6	1
1988/ 5/15	37.94	20.32	5.3	1988/ 5/18	38.35	20.47	5.8	48	0.5	3
1988/ 5/21	37.94	20.32	5.3	1988/ 5/22	38.35	20.53	5.5	49	0.2	1
1988/ 5/30	37.94	20.32	5.4	1988/ 6/ 2	38.27	20.37	5.0	37	0.4	3
1988/ 6/ 4	37.94	20.32	5.0	1988/ 6/ 6	38.30	20.48	5.0	43	0.0	2
1988/ 9/ 1	37.96	21.01	5.8	1988/ 9/22	37.98	21.12	5.5	10	0.3	21
1988/ 9/30	37.96	21.01	5.3	1988/10/16	37.90	20.97	6.0	7	0.7	16
1989/ 9/11	38.62	21.73	5.2	1989/ 9/19	39.48	21.33	5.0	100	0.2	8
SI-NOA Reverse										
1987/ 6/13	37.97	21.46	5.2	1987/ 6/10	37.17	21.47	5.5	89	0.3	-3
1988/ 3/10	38.85	20.97	5.0	1988/ 3/ 8	38.82	21.12	5.1	13	0.1	-2
1988/ 4/ 7	40.24	20.75	5.0	1988/ 3/26	40.08	19.85	5.4	78	0.4	-12
1988/ 4/28	37.94	20.32	5.0	1988/ 4/24	38.83	20.33	5.0	100	0.0	-4
1988/ 5/21	37.94	20.32	5.3	1988/ 5/18	38.35	20.47	5.8	48	0.5	-3
1988/ 5/30	37.94	20.32	5.4	1988/ 5/22	38.35	20.53	5.5	49	0.1	-8
1988/ 6/ 4	37.94	20.32	5.0	1988/ 6/ 2	38.27	20.37	5.0	37	0.0	-2
1988/ 7/13	37.98	22.95	5.0	1988/ 7/12	38.78	23.43	5.0	98	0.0	-1
1988/ 9/30	37.96	21.01	5.3	1988/ 9/22	37.98	21.12	5.5	10	0.2	-8
1988/10/21	37.96	21.01	6.4	1988/10/16	37.90	20.97	6.0	7	0.4	-5
1988/10/21	40.48	20.40	5.5	1988/10/14	40.17	19.52	5.1	83	0.4	-7
1989/ 6/13	37.97	21.46	5.2	1989/ 6/ 7	38.00	21.63	5.2	15	0.0	-6
1989/ 8/24	37.13	21.24	5.8	1989/ 8/20	37.22	21.08	5.9	17	0.1	-4
NEIC-PDE Forward										
1988/ 4/28	37.94	20.32	5.0	1988/ 5/ 9	37.70	19.97	5.0	41	0.0	11
1988/ 5/15	37.94	20.32	5.3	1988/ 5/18	38.42	20.48	5.7	55	0.4	3
1988/ 5/21	37.94	20.32	5.3	1988/ 5/22	38.42	20.47	5.3	55	0.0	1
1988/ 5/30	37.94	20.32	5.4	1988/ 6/ 6	38.40	20.45	5.0	53	0.4	7
1988/ 9/ 1	37.96	21.01	5.8	1988/ 9/22	38.02	21.08	5.3	9	0.5	21
1988/ 9/30	37.96	21.01	5.3	1988/10/16	37.93	20.93	5.8	7	0.5	16
NEIC-PDE Reverse										
1987/ 6/13	37.97	21.46	5.2	1987/ 6/10	37.23	21.47	5.5	81	0.3	-3
1988/ 4/ 7	40.24	20.75	5.0	1988/ 3/26	40.18	19.88	5.3	74	0.3	-12
1988/ 5/15	37.94	20.32	5.3	1988/ 5/ 9	37.70	19.97	5.0	41	0.3	-6
1988/ 5/21	37.94	20.32	5.3	1988/ 5/18	38.42	20.48	5.7	55	0.4	-3
1988/ 5/30	37.94	20.32	5.4	1988/ 5/22	38.42	20.47	5.3	55	0.1	-8
1988/ 7/13	37.98	22.95	5.0	1988/ 7/ 5	38.15	22.85	5.3	20	0.3	-8
1988/ 9/30	37.96	21.01	5.3	1988/ 9/22	38.02	21.08	5.3	9	0.0	-8
1988/10/21	37.96	21.01	6.4	1988/10/16	37.93	20.93	5.8	7	0.6	-5
1988/10/21	40.48	20.40	5.5	1988/10/14	40.15	19.73	5.0	68	0.5	-7
1989/ 3/ 2	37.94	20.32	5.4	1989/ 2/26	37.20	20.80	5.1	92	0.3	-4
1989/ 6/13	37.97	21.46	5.2	1989/ 6/ 7	38.05	21.62	5.3	16	0.1	-6
1989/ 8/24	37.13	21.24	5.8	1989/ 8/20	37.28	21.22	5.7	17	0.1	-4

1996, who use also a random sampling for magnitudes], and that a careful optimization of epicenter selection has been made, comes from the fact that each prediction, during the whole interval, covers on average a region in which occurred $\sim$ 13 epicenters out of 36 for the SI–NOA catalog and $\sim$ 18 out of 35 for the PDE catalog. A clearer evidence is provided by analyzing the time association in reverse time, which shows that 13 predictions have been issued within 11 days (12 of which within 8 days) of a predicted epicenter within 100 km of an earthquake (Table 1). In the parts of Table 1 labeled "Forward" the predictions (on the left) precede the earthquakes (on the right) but in the "Reverse" sections each "earthquake" precedes the corresponding "prediction." The related significance levels, $\simeq 6 \times 10^{-6}$ for $n = 166/12$ and $\simeq 0.02$ for $n = 35$, argue strongly against the candidacy of VAN signals as didactic precursors.

The results for the NEIC–PDE catalog, which lists 33 events in the non–homogeneous operative region, are similar. Six predictions are found to be successful, giving success and alarm rates respectively equal to 6/28 and 6/33, which deny any usable precursor candidacy. Accounting for or not accounting for the limited extent of each prediction (i.e. using either $n = 109/6$ or n=33) makes no difference with a time association never reaching significance (the significance levels are respectively 0.44 and 0.92). Also in this case a significant backward association is apparent, with 12 earthquakes followed by predictions within 100 kilometers and 11 days, 11 of which within 8 days (Table 1).

In summary, the very low values found for success and alarm rates show that the VAN signals are not acceptable candidates for usable precursors, and their insignificant association with earthquakes disqualifies them as candidates for didactic precursors. On the other hand, the VAN predictions show a significant association with earthquakes in reverse time, a result which is also less biased because the laws of the game were optimized for precursory behaviour.

Two alternative interpretations are possible. First, the VAN group, either deliberately or unconsciously, incorporated postseismic information (possibly a foreshock–main event–aftershock chase [cf. *Stavrakakis and Drakopoulos*, 1996]), in its predictions but had only a few hits (yet related to the some large events; cf. Table 1 in forward and reverse) due the modest degree of clustering which really occurred [cf. *Kagan*, 1996]. Second, the VAN signals might have a postseismic origin, which is not unlikely if they are really due to stress redistribution within the focal zone [cf. *Varotsos et al.*, 1993a], since this would be more prevalent after an earthquake than before.

A validation attempt

Varotsos et al. [1993b] published a complete list of predictions relative to the 29 month period following the one analyzed above, covering all the telegrams issued after the period analyzed above [cf. *Varotsos et al.*, 1993a; 1993b].

This list, while limited in size, has the great advantage of providing a set independent of the learning set. Therefore, if the new set is used together with the above laws of the game, it allows a validation (even if not strictly forward in time). In this period only four VAN stations were in operation so that the operative region must be restricted to the map given by *Varotsos et al.* [1993a]. Conservatively, we further restrict it to the non–homogeneous region at no more than 100 km distance from one of the issued predictions.

While the original telegrams are not shown, the text reported for the predictions appears particularly fuzzy (Tables 1 and 5 of *Varotsos et al.* [1993b]). We have interpreted them according to the following scheme, which leads to the list in Table 2:

Table 2. List of VAN earthquake predictions for the period 1990-1992 according to the issued telegrams

No	Date	Coordinates		*M*
*1	1990/ 4/26	37.96	21.35	5.8
2	1990/ 5/28	37.96	21.35	5.8
3	1990/10/20	37.95	20.78	5.6
*4	1991/ 1/02	40.90	23.00	5.5
5	1991/ 2/23	40.00	21.50	6.0
*6	1991/12/27	37.96	21.01	5.7
		40.50	20.00	5.0
7	1992/ 1/27	37.96	21.01	5.2
*8	1992/ 2/22	38.00	20.50	5.0
*9	1992/ 2/22	38.62	21.73	5.0
*10	1992/ 2/22	37.17	21.35	5.4
		36.51	21.93	6.0
*11	1992/ 3/13	37.98	25.23	5.4
		40.05	26.49	5.4
12	1992/ 3/31	37.96	21.01	5.3
*13	1992/ 4/22	37.40	21.25	5.5
		38.20	21.40	5.0

* signifies series of SES predictions [*Varotsos et al.*, 1996].

Table 3. List of earthquakes from PDE catalog for the period 1990-1992, with magnitude larger than 5.0 (see text) and epicenter internal to the selectivity map given by *Varotsos et al.* [1993a] and sited at less than 100 km from at least one of the predictions in Table 2

No	Date	Coordinates		$m_b + 0.3$
	yr/mo/da	Lat., N	Lon., E	
1	1990/ 2/ 4	37.47	20.97	5.3
2	1990/ 4/26	41.02	19.78	5.1
3	1990/ 5/14	40.68	19.82	5.0
4	1990/ 5/17	38.42	22.18	5.1
5	1990/ 7/ 3	37.58	20.95	5.1
6	1990/ 7/31	37.25	21.47	5.1
7	1990/ 8/ 8	37.45	21.67	5.1
8	1990/12/21	41.00	22.30	6.1
9	1991/ 2/19	37.55	20.90	5.1
10	1991/ 4/21	37.97	19.95	5.0
11	1991/ 6/26	38.43	21.10	5.3
12	1991/10/12	40.20	25.63	5.1
13	1992/ 1/23	38.35	20.32	5.4
14	1992/ 1/23	38.35	20.30	5.3
15	1992/ 3/13	37.58	20.82	5.0
16	1992/ 5/30	38.08	21.40	5.2

i) the prediction date is assumed to be that of the telegram (the date of signal detection is often lacking);

ii) each prediction is assumed to predict one earthquake;

iii) telegram 28 predicts three different events, one of which with alternative epicenters: we file three different predictions;

iv) some cases specify only a maximum magnitude value, which we use as central;

v) the recording of a series of SES, which entitles the option $t = 22$ days, was inferred from the text in all cases where the verbs "record" or "predict" was at plural; this occurs in 8 cases out of 13;

v) telegrams 29 and 30 give two alternative magnitude values for the same prediction: we take in each case the average value;

vi) the coordinates of the predicted epicenters are computed in the usual way except for:

telegram 25: the predicted epicenter is assumed to coincide with the location of the ASS station (40.9 N 23.0 E);

telegram 26: the predicted epicenter is taken at 40.0 N 21.5 E, i.e. along the thick (partially broken) line in figure 8 of *Varotsos et al.* [1993b];

telegram 27: the predicted epicenter for the second alternative is taken at 40.5 N 20.0 E, i.e. centered in the southern part of Albania;

telegram 31: the location of the two alternative epicenters are obtained by displacing by 70 km in SE and ENE directions the location of the April 18 1992 earthquake (37.88 N 20.83 E).

Since the SI-NOA catalog for this period is not available to us, we restrict the analysis to the NEIC-PDE alone. The operational area contains 16 earthquakes with $M_s (= m_b + 0.3) \geq 5.0$ (see Table 3). Only two of these have been correctly

Table 4. Earthquakes associated with the predictions in Table 3 in forward and reverse time

Prediction Date	Coordinates		M	Earthquake Date	Coordinates		M	r	M	t
NEIC-PDE Forward										
1990/ 4/26	37.96	21.35	5.8	1990/ 5/17	38.42	22.18	5.1	89	0.7	21
1992/ 2/22	38.00	20.50	5.0	1992/ 3/13	37.58	20.82	5.0	54	0.0	20
NEIC-PDE Reverse										
1990/ 5/28	37.96	21.35	5.8	1990/ 5/17	38.42	22.18	5.1	89	0.7	-11
1991/ 1/ 2	40.90	23.00	5.5	1990/12/21	41.00	22.30	6.1	60	0.6	-12
1992/ 1/27	37.96	21.01	5.2	1992/ 1/23	38.35	20.30	5.3	76	0.1	-4
1992/ 3/31	37.96	21.01	5.3	1992/ 3/13	37.58	20.82	5.0	45	0.3	-18

predicted by the 13 predictions, with a corresponding value of $n = 17/2$. Taking and not taking into explicit account the limited extent of each prediction yields a significance level respectively equal to 0.64 and 0.91. In reverse time, four events occur in the 17 days before predictions and within 100 km from the predicted epicenter (Table 4), which, with $n = 31/4$, results in a not significant ~ 0.10 level.

Conclusions

A reappraisal of VAN predictions in the period 1987–1989 with the latest laws of the game confirms that available data vote against a candidacy of VAN signals as seismic precursors, and provides further support for the hypothesis that predictions follow rather than precede earthquakes. Analyzing with the same laws of the game the independent set of VAN predictions for the period 1990–1992 confirms this result.

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