LETTERS

Claims of Success in Using Geoelectrical Precursors to Predict Earthquakes Are Criticized—and Defended

In the January issue of PHYSICS TODAY (page 9), your readers are informed that Panayiotis Varotsos "predicted most major quakes in recent years in Greece weeks ahead of the actual events by detecting voltage differentials. . . ."

It is my responsibility as director of the institute in charge of monitoring seismic activity in Greece to inform you and your readers that the published assertion is completely wrong. As this is not an appropriate forum in which to elaborate on the scientific arguments that support my statement, I will limit myself to making the following key points:

First, several studies have shown that no main shock has ever been successfully predicted by Varotsos and coworkers (referred to collectively as VAN) on the basis of sound physics evidence.[1]

Second, given Greece's high levels of seismicity, it has also been shown that the apparent success of Varotsos and coworkers in making predictions can be confidently ascribed to chance.[2] After all, anyone can predict aftershocks.

Third, if your readers study the articles in special issues of well-known scientific journals such as *Geophysical Research Letters* and the *Geophysical Journal International*, as well as the authoritative volume entitled *A Critical Review of VAN*,[3] they will readily conclude that the reliability of electrical precursors as predictors is, if anything, very dubious.

It is wrong, therefore, to claim that it has been proved that earthquakes have electrical precursors and that such precursors have been used to predict earthquakes in Greece.

Letters submitted for publication should be addressed to Letters, PHYSICS TODAY, American Center for Physics, One Physics Ellipse, College Park, MD 20740-3843 or to ptletter@aip.acp.org (using your surname as "Subject"). Please include your affiliation, mailing address and daytime phone number. We reserve the right to edit letters.

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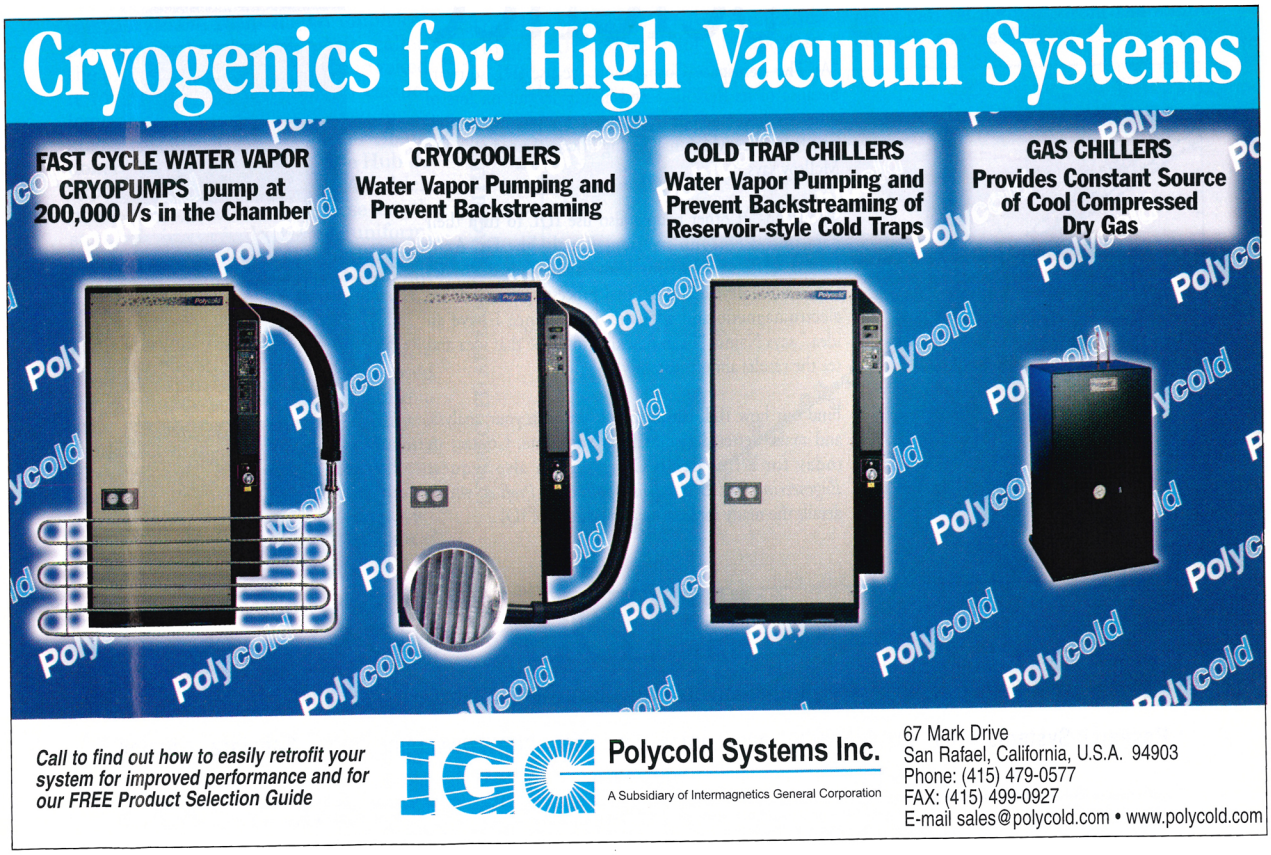

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LETTERS *(continued from page 15)*

Panayiotis Varotsos and his coworkers (hereafter referred to as VAN) have been claiming since 1981 that they can predict earthquakes in Greece on the basis of geoelectrical observations.[1,2] Your "Physics Update" column (January, page 9) states that "Varotsos predicted most major [earth]quakes in recent years in Greece weeks ahead of the actual events." A subsequent "Physics Update" correction (March, page 9) revising that sentence to read "Varotsos claims to have predicted . . ." misses the real point: VAN's work did not merit being reported in PHYSICS TODAY in the first place, as they have not established a scientifically sound earthquake prediction method. Indeed, to the best of our knowledge, they have never predicted a single earthquake, in the rigorous sense that is usually understood to be implied by the term "earthquake prediction."[3]

In 1981, VAN claimed they could detect one type of precursory geoelectrical signal "a few minutes before each earthquake," and another type "about seven hours before the impending earthquake."[4] By 1984, their claim had degraded to "6–115 h before the earthquake."[5] They currently claim a temporal accuracy of only one or two months.[1,2] This recurrent repositioning of the goalposts makes it both difficult and almost meaningless to conduct an objective evaluation of VAN's hypotheses, which are vague and continually changing.[1]

VAN's "prediction announcements" (see reference 1 for verbatim examples) sometimes fail to quantitatively state the predicted epicenter, magnitude or origin time; almost never specify the acceptable uncertainty for the magnitude and epicenter; almost never state an unambiguous expiration date; do not state the predicted focal depth or focal mechanism; and generally fail to quantitatively and unambiguously state the other criteria for determining the success or failure of the VAN prediction announcements.

It is virtually certain that small events nominally fulfilling such vague announcements will occur in Greece every few days. The occurrence of such an event should automatically deactivate a VAN prediction, but instead, VAN allow the alarm to remain in effect for as long as one or two months. If a substantial event occurs during that time, they publicly claim it—rather than the earlier small event—as the one that had been "successfully predicted." Thus, VAN's claims of which events they have "successfully predicted" are made with the benefit of hindsight. VAN, in effect, are playing a game they can't lose—only the amount of their winnings is uncertain.

VAN claim to have made "successful predictions" of 10 of the 14 earthquakes of magnitude $M \geq 5.8$ in Greece during the 8.5-year period from January 1987 through June 1995 (see table 3 and page 56 in reference 2). Their claim should not be accepted, for the following reasons. First, they ignored earlier small events that should have deactivated the alarms. Second, they acknowledge having issued 63 "predictions" during this 8.5 yr period, of which, in fact, 36 were single predictions, 24 were double predictions, 2 were triple predictions and 1 was a quadruple prediction, giving a total of 94 predicted earthquakes. One could completely span a 10.5 yr period by issuing 63 single predictions at intervals of two months. Since Greece is the most seismically active country in Europe, an occasional "successful prediction" is neither surprising nor meaningful. Third, an independent reevaluation by one of us (Geller)[1] casts doubt on VAN's claim of successfully predicting 10 of the 14 events of $M \geq 5.8$.

VAN's self-evaluation nominally used retrospectively chosen windows of $\Delta r \leq 100$ km for the epicentral distance and $|\Delta M| \leq 0.7$ for the magnitude.[2] In the same article, VAN mention time windows such as "of the order of one month," "11 days" and "at least three weeks," as well as four weeks sometimes followed by "an additional period of 2–3 weeks," but they fail to state an unambiguous value for their time window. A time window of $\Delta t \leq 1$ month was used in Geller's independent reevaluation. The results show that for almost all of the alleged successes, at least one of the three windows (spatial, temporal or magnitude) was violated, and that one of VAN's claims to have issued a "prediction" was insufficiently documented.

Some studies have reported that VAN's "successful predictions" are statistically significant. However, those studies had flaws such as overly generous crediting of successes, using strawman null hypotheses and failing to account properly for *a posteriori* "tuning" of parameters. Appropriately conducted statistical analyses show that VAN's predictions are not successful beyond random chance.[6] VAN's rebuttals[7] seem unconvincing.

The correlation between VAN's geoelectrical signals and earthquakes is much stronger in reverse time than in forward time.[8] In other words, the case is weak that the geoelectrical signals are earthquake precursors, but there is a strong case that VAN's "prediction announcements" were issued preferentially after seismic activity was already under way in Greece. This finding suggests an alternative hypothesis: When issuing their prediction announcements, VAN are consciously or subconsciously taking cues from seismological data in addition to, or perhaps even instead of, geoelectrical data.

The following three arguments suggest that VAN's methods are not physically sound.

First, the absence of simultaneous geodetic or seismological precursors at the time of VAN's transient geoelectrical signals, and the absence of coseismic (at the time of the earthquake) geoelectrical signals of the same type as the alleged geoelectrical precursors are reasons to doubt the existence of a causal physical connection between the geoelectrical signals and earthquakes.[9]

Second, many of VAN's observations of allegedly precursory geoelectrical signals have been made at their Ioannina observatory at epicentral distances of over 100 km and for widely varying azimuths. In many of these cases, though, VAN have not observed similar signals simultaneously at their other observatories in Greece. If the signals at Ioannina were really geoelectrical precursors of earthquakes, there would thus have to be a multitude of hitherto unknown high electrical conductivity channels from Ioannina to the various epicentral regions. However, geophysical studies in the vicinity of Ioannina show no evidence for such channels.[9]

Third, independent geoelectrical observations near Ioannina showed that some of VAN's geoelectrical signals were artifacts due to nearby sources, probably of industrial origin; a more recent study suggests that many of those signals appear to be noise generated by nearby digital radio-telecommunication transmitters.[10] This finding underscores a serious flaw in VAN's research: They failed to identify and eliminate ambient natural and artificial geoelectrical noise sources before claiming to have observed geoelectrical precursors of distant earthquakes.[11] VAN have proposed rules for discriminating between alleged earthquake precursors and noise, but several studies[10,11] suggest that these procedures are inadequate.

In summary, it seems highly unlikely that VAN are observing geoelectrical signals generated by hypotheti-

cal precursory processes of distant earthquakes, and VAN's claims to have made "successful predictions" of earthquakes remain unconvincing.

In other areas of science, erroneous claims of important physical effects have often been based on threshold signals. Polywater, cold fusion and the fifth force are recent examples. It was in your own pages (October 1989, page 36) that the late Nobel laureate in chemistry Irving Langmuir was quoted as having called such research "pathological science, the science of things that just aren't so." VAN's research also appears to fall into this category.

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The claims that Panayiotis Varotsos and coworkers (referred to hereafter as VAN) have made since the early 1980s of having predicted most major earthquakes in Greece have been flatly and repeatedly rejected by most Greek officials and scientists.

To those who have followed VAN's predictions and practices, it is clear what has been happening. Greece is a country where, on average, a magnitude 5 earthquake occurs about every 20 days and a magnitude 5.5 earthquake occurs about every two months.[1] VAN's so-called predictions consist of ambiguously worded telegrams and faxes sent to public officials or selected laboratories or researchers. These messages have no clearly stated time windows (which, depending on the case, VAN has claimed—usually after the event—to be anywhere from a few days to one or two months), and typically indicate possible epicentral areas with a characteristic length scale of hundreds of kilometers. This approach allows VAN to claim almost any subsequent earthquake as a success.[2]

Unfortunately, VAN's vague pronouncements do not in any way contribute to reducing seismic risk, as they cannot be practically utilized. However, they do generate extensive publicity for the predictors and provide exclusive front-page stories for reporters hungry for sensational news. Moreover, VAN's alarming claims and carefully worded messages result in pressure being brought to bear on public officials, who face the risk of being accused of inaction in the face of danger.

Here is just one example. On 22 January, the Greek newspaper *Vradyni* ran this bold, front-page headline: "Exclusive: Awaiting Magnitude-6 Earthquake: Confidential Message Sent by VAN to Ministry of Public Works." The article reported that VAN had sent yet another prediction to the Greek government on 20 December. In this case, not only was there no earthquake at all, but it also turned out that VAN's prediction had been based on data available to Varotsos as early as 15 November. According to the Greek news media, Varotsos refused to participate in a meeting of experts called by the Greek authorities to assess this prediction. As happened in similar meetings previously, the panel of experts concluded that the information supplied by Varotsos was not sufficient for them to make any assessment of the prediction.

In fact, Varotsos generally refuses to participate in scientific committees set up to evaluate his oracle-like declarations (as I learned firsthand when, as a board member and subsequently chairman of the Greek Earthquake Planning and Protection Agency, I was extensively involved in such reviews). On the other hand, he readily appears in the media to publicize his work.

Such tactics have served VAN well, as it has been able to obtain generous funding outside normal channels for peer-reviewed proposals, or by overriding (on grounds of "social importance") low review rankings.[3] On the other hand, the group has been strongly and openly criticized by knowledgeable scientists in official positions.

It is regrettable that PHYSICS TODAY has unwittingly given unwarranted credit to a group whose practices have often caused widespread rumors, confusion and anxiety in Greece since the early 1980s and also have flagrantly violated the codes of ethics for earthquake predictions established by the Seismological Society of America[4] and by the Council of Europe.[5]

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VAROTSOS, SARLIS AND LAZARIDOU REPLY: Robert Geller *et al.*, George Stavrakakis and Stavros Anagnostopoulos (hereinafter called GSA) are repeating claims that have already been published,[1] and that we have already proved to be incorrect.[2,3] Not only have they not tried to counter our already published proofs, but they now proceed to describe the facts involved inaccurately.

Our field observations of the earthquake electrical precursors known as seismic electric signals (SES) have been motivated by aspects of solid-state physics relating to the thermodynamics of defects.[4] SES analysis enables us to estimate the magnitude (M) of an impending earthquake with a tolerance of $\Delta M = 3\sigma = 0.7$ units (compare the reported M values after an earthquake, which often differ by

0.3–0.4 units), and the epicentral area with an accuracy of $\Delta r \sim 100$ km (compare the rupture lengths of large earthquakes, which are several tens of kilometers). The time window may reach several weeks, depending on the type of the electrical precursor.[5] We forward the predicted parameters (magnitude, epicenter, time window) to Greek authorities and to 30 international institutes well in advance of each event we predict.

Concerning GSA's statistical claims, several studies by independent groups in the US, Japan and Europe[6] have shown that our predictions are statistically significant and that the alarm rate increases dramatically with the magnitude (see, for example, the papers by Seiya Uyeda and by Kazuo Hamada in reference 6). Geller *et al.*'s assertions that "VAN's predictions are not successful beyond chance" violate basic principles (see first two citations in reference 2) and are marred by serious mistakes, as noted by independent researchers.[7]

Consider the following three examples. First, Geller *et al.* have confused the expected number of earthquakes within a time period with the probability of one prediction coming true by chance; hence, in their calculations, they have unconsciously implied probability values as high as 11, which, of course, would violate the definition of probability (see reference 7 and third citation in reference 2). Second, in using Poisson distributions, which are valid[2,7] only for independent events, in their cited studies,[1] they have included a large number of aftershocks (dependent events) in their calculation of mean values. Third, Geller *et al.* have simply compared the mean numbers of earthquakes and the predictions, and (in addition to the aforementioned Poisson-related flaw) have failed to recognize that each prediction has a limited spatial extent—that is, in dealing with a large test area S consisting of 1000×1000 km^2, they did not take into account that one must issue $S/\pi(\Delta r)^2 \sim 30$ predictions to predict the epicenter of just one main shock by chance.

As we have explained elsewhere,[3] Geller *et al.* have employed a biased procedure to repudiate our successful predictions. Consider the following example. If we were to predict that a magnitude 7 earthquake would occur within a radius of 100 km in the next few weeks, and if such an earthquake were then to happen, Geller *et al.* obviously would reject our prediction if small events happened to occur before the main event, declaring that "earlier small events . . . should have deactivated the alarms."

When Geller *et al.*'s statistical analysis is applied to a fictitious, ideally perfect earthquake prediction method, which, by definition, successfully predicts all earthquakes above a certain magnitude threshold, with no false alarms, several paradoxes emerge.[3] Chief among them is that ideal precursors become misinterpreted as "postseismic" signals, thus leading Geller *et al.* to falsely conclude that "VAN's 'prediction announcements' were issued preferentially after seismic activity was already under way."

We dispute Geller *et al.*'s arguments that "VAN's methods are not physically sound." Some eminent American physicists[8] have suggested well-founded mechanisms for explaining SES generation without the need for (as Geller *et al.* demand) simultaneous and detectable geodetic or seismological precursors. Also, "the absence of coseismic geoelectrical signals of the same type as the alleged geoelectrical precursors" (for which Geller *et al.* fault us) can be naturally understood as follows: Laboratory measurements report that "the preseismic signal did not contain high-frequency components" while "higher frequency components appeared with higher amplitude at the onset of the coseismic signals."[9] As our field measuring system[5,10] uses filters that do not permit us to record changes faster than around 0.1 Hz, it cannot record the coseismic electrical disturbances lying in a higher frequency range. Moreover, when signals are transmitted within Earth, the "skin depth" (using a typical resistivity of 4000 ohm meters[11]) for a frequency of 0.1 Hz is around 100 km; therefore, signals with frequencies of greater than 0.1 Hz (and hence the coseismic signals) are strongly attenuated[10] with distances of that order (and hence cannot be observed), while SES, with frequencies of less than 0.1 Hz, can be detected.

Our observation that SES are detectable only at certain sites on Earth's surface (for example, at the Ioannina observatory) has recently been explained by us as follows: Earthquakes "occur by slip on faults which may have lengths of several tens of kilometers. . . . The faults have been found to be . . . 100–1000 times more conductive than the surrounding medium. . . . Thus, in the case of SES the emitting source should lie at a small distance D from a conductive path. . . . . If the conductive path terminates close to the earth's surface, at a distance [say] d = 100 km, the electric field can reach measurable values at such remote sites, but may be not at shorter [distances from the source because] the electric field should be enhanced by a factor almost equal to the conductivity ratio [of the path and the host medium] in the vicinity of the outcrop (edge effects)."[12] Recent geophysical studies by Japanese researchers have confirmed that the Ioannina observatory is located at the more resistive side (and in the vicinity) of a significant resistivity gap.

As for Geller *et al.*'s claims that some of the SES at Ioannina may be attributed to noise, they have already been proved to be incorrect.[13] To discriminate SES from nearby industrial sources (and radio-telecommunication transmitters), we long ago applied a set of criteria for using a combination of measuring dipoles that are short (50 to 100 meters) and long (a few to several kilometers).[4] Those criteria were exhaustively discussed at two conferences in California (Lake Arrowhead, 1992; Berkeley, 1995) and favorably reviewed by American experts.[14] Furthermore, Japanese experts independently checked our criteria and concluded that their results "clearly [showed] the objectivity of VAN's criteria."[14]

Anagnostopoulos's claim that "there [was] no earthquake at all" associated with the SES recorded on 15 November 1997 is inaccurate. What really happened was that, after a period of almost two years during which we made no predictions and there were no major earthquakes, a series of SES were recorded on 3–5 October and 15 November 1997, and significant earthquakes ($M \geq 5$) occurred on 5 November, 18 November and 14 December close to the predicted areas. We have discussed the magnitude deviations for each case in recent papers.[15]

During the period 1987–95, we successfully predicted 10 out of the 14 larger earthquakes in Greece,[5] and the predictions were within all the tolerances mentioned above. The largest two, of magnitude 6.6 and magnitude 6.5, occurred on 13 May 1995 and 15 June 1995, respectively. (In fact, the first one struck an aseismic area where there had not been such an event in more than a thousand years.) Both shocks occurred just after an international meeting was held on 11–12 May at the Royal Society in London to critically review our efforts. The meeting chairman, James Lighthill, included the following conclusion in the conference proceedings (published several months later): "The earthquakes occurring after the

meeting (on 13 May in northern Greece and on 15 June in Egion, which were the two largest in Greece for over a decade) are carefully related to the corresponding VAN predictions (those received by myself, for example—along with other interested scientists—on 2 May and on 20 May 1995). It is noteworthy that the distinguished seismologist, Professor H. Kanamori, was influenced partly by these events, as well as by the proceedings of the review meeting . . . to give the view . . . that for the largest earthquakes in Greece the VAN group appears to have usefully identified SES precursors."[16] This conclusion alone invalidates most of GSA's claims.

As we have demonstrated above, Geller *et al.* and the two other letter writers are biased to such an extent that they could reject even an ideal earthquake prediction method. Nor does their questioning of the physics of our methodology stand up to stringent examination. In fact, our experimental results encourage us to intensify our efforts, which include our becoming involved in a newly established university research institute (supported by the Greek government), that will enable us to try to better understand the physics of the phenomenon.

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US Groups Used the Rights Stuff to Support Fired Cubans

In a letter opposing scientific exchanges with Cuba (PHYSICS TODAY, October 1997, page 140), Carlos Delgado wonders "whether any American scientists condemned [the] injustice" of the Cuban government's summary firing in 1992 of himself and 17 other professionals for having demanded official respect for human rights in Cuba.

Your readers have a right to know that immediately after learning of that injustice, many major American scientific groups wrote strong letters to President Fidel Castro, Minister of Higher Education Fernando Vecino and other Cuban authorities to protest the dismissals and ask that the 18 individuals be reinstated.

The letters were from groups including the Human Rights of Scientists Committee of the New York Academy of Sciences (I'm the committee chair), the Committee on International Freedom of Scientists of the American Physical Society, the Committee of Concerned Scientists and the Science & Human Rights Program of the American Association for the Advancement of Science.

Their letters were never answered. However, it is to be hoped that the letters did restrain the Cuban authorities from taking even more severe reprisals against the 18 professionals.

The New York Academy of Sciences, APS, CCS and AAAS, together with other major scientific organizations, are committed to the United Nations doctrine called the Free Circulation of Scientists. Promulgated by the International Council of Scientific Unions, this doctrine is intended to enable all scientists, and humanity everywhere, to benefit from scientific advances made anywhere. Thus, we strongly support the exchange of scientists, including Cuban scientists coming to the US. We equally strongly oppose and protest violations of human rights of scientists in Cuba and elsewhere.

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Corrections

April, page 52—The last footnote in the table summarizing the funding for the National Science Foundation's physics-related programs is incorrect in stating that the US contributes 20% of the total cost of the Gemini telescopes. The US contribution is 50%.

March, page 75—To clarify several points in the brief about Ghassam Asrar, the current name for the Mission to Planet Earth is the Earth Science Enterprise, and Asrar now heads NASA's Office of Earth Science, the principal component of which is the Earth Observing System.

March, page 81—The brief about the on-line survey of dual-career couples should have mentioned that the survey is being sponsored by the American Physical Society. ■