Approaching the Critical Point in Earthquake Prediction

Seyia Uyeda and Panyiotis Varotsos at the AGU conference.

Professors Seyia Uyeda and Paniyotis Varotsos have been collaborating on earthquake prediction for three decades. Their joint presentation at the American Geophysical Union (AGU) Fall conference in San Francisco on Dec. 6, 2011 was titled, "Earthquake Prediction in Japan and Natural Time Analysis of Seismicity."

Dr. Uyeda, a professor emeritus at the University of Tokyo, is recognized as one of the founders of the theory of plate tectonics in the 1960s. In 2001, he became the first President of the Inter-Association Working Group for Electromagnetic Studies of Earthquakes and Volcanoes (EMSEV), within the International Union of Geodesy and Geophysics.

Dr. Varotsos is a physics professor at the University of Athens, and one of the founders of the VAN method of earthquake prediction, based on the recording of Seismic Electric Signals from the ground, and the utilization of natural time analysis. The latter is the subject of a recently published book, Natural Time Analysis: The New View of Time *(Springer, 2011).*

Drs. Uyeda and Varotsos were interviewed jointly by Oyang Teng and Alexandra Peribikovsky on Dec. 7, 2011 at the AGU conference.

21st Century: Please introduce yourself, and tell us how you came to the field of earthquake prediction.

Uyeda: I come from Tokyo, and I have long been a professor at Tokyo University. My main job when I was young was developing plate tectonics and these types of theories. Towards the end of my active duty, I switched over to the problem of short-term earthquake prediction, by chance. By chance, I mean that I came across the work of Professor Varotsos at that time, the 1980s.

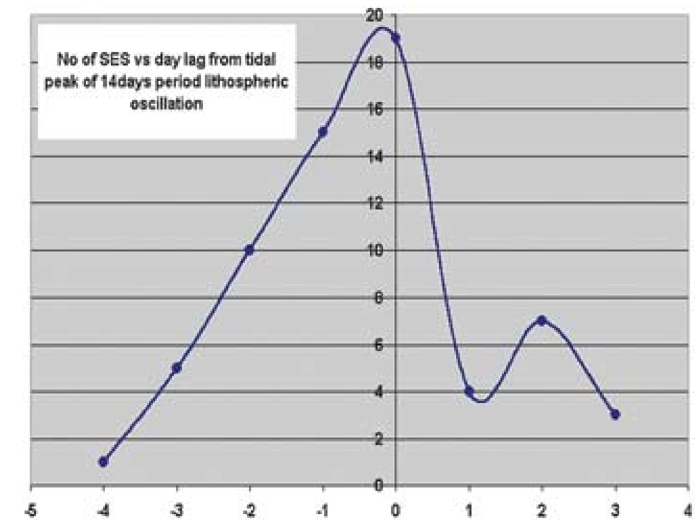
His group had been developing its own method of short-term prediction by monitoring telluric currents in Greece. And I was so much impressed by that, and the method was very unpopular—earthquake prediction is always unpopular—so I switched over to this interesting subject, and I became unpopular too!

Varotsos: I come from the University of Athens. I'm a solid-state physicist, I'm not a seismologist. And in the 1970s, my expertise was thermodynamics for defects in solids, in solid-state physics. And at that time, we concluded that when you increase the stress on a solid, say, a rock, before the rupture, when you reach a critical stress, there is an emission of a precursor electrical signal, which we term a Seismic Electric Signal. And this is emitted a few days, to a few months before an earthquake.

From '81 until today, we have continuously worked on this matter in Greece. We have various stations in Greece, at 10 sites, and we continuously measure the electric field of the Earth. We collect the data, we analyze the data, and when we see that there is an important earthquake, that means, of magnitude 6 or larger, we publicize it well in advance.

In particular, to the ArXiv, to the well known scientific website of Cornell University [www.arxiv.org—ed.]. For instance, the two very strong earthquakes in 2008 that occurred in Greece were both publicized on the Cornell University website, well in advance. The population of course knew about it after this publication.

21st Century: Let me ask you both: What do you think is the essential difference in outlook between those who believe that earthquakes are forecastable



SEISMIC ELECTRIC SIGNAL

A precursor electrical signal is emitted before an earthquake, caused by increased stress on rocks before a rupture. Here a graph compiled by the Varotsos group from one of their seismic measuring stations, showing the seismic electric signal variation with tidal changes.

or predictable, and the majority of seismologists who seem to categorically deny that possibility?

Uyeda: It is rather obvious to everybody, or it should be, that what we are interested in is short-term prediction; then you need a precursor, right? Without a precursor, you can tell nothing—except if you are a fortune teller or something, you could do that, but it's not scientific. So you need a precursor.

By definition, a precursor takes place *before* the earthquake, you see? And seismologists—seismology is a science of earthquakes based on seismic records recorded by seismograms. And seismograms only record earthquakes, *not* precursors. So this is obvious to start with.

Therefore, seismologists never say they can predict short-term. They are honest in that respect. But they think they are the only people who understand earthquakes. That's the trouble with the whole thing, in my view.

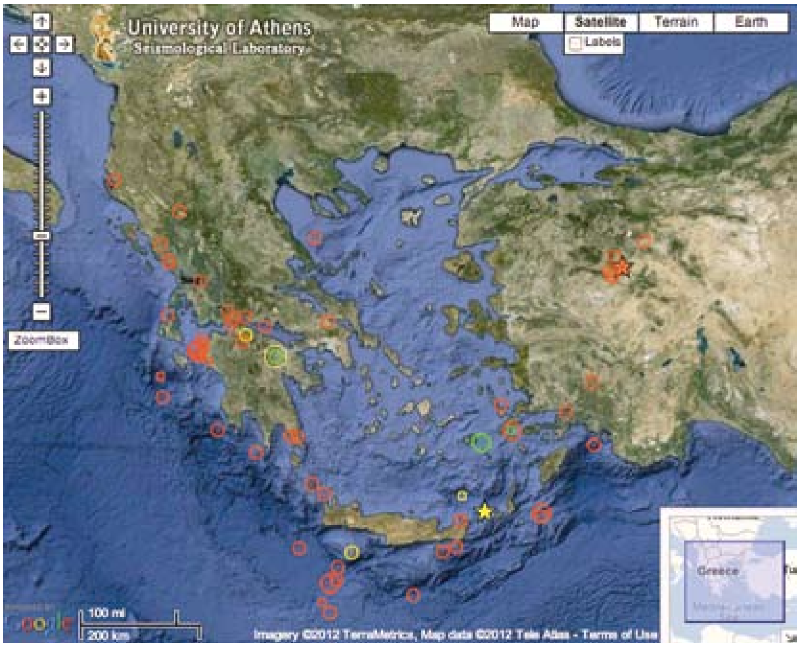
This is very true all through the Japanese program of earthquake prediction. The name of the program is "earthquake prediction," but they think prediction is not possible. And yet the government provides lots of budgeting and everything, because they can't say, "We stop studying earthquake prediction." Then the government itself will be very unpopular.

So the seismologists take advantage of this situation, and they say we will do that sometime, sometime, maybe sometime. That has been the case for over 50 years. This situation is true in Japan, but more or less true for many other countries, including the U.S. too, I think, and Greece.

21st Century: Let me ask you, Professor Varotsos, with your background as a solid state physicist, is there an issue in terms of seismologists being biased against people who aren't in the field of seismology? Is there a methodological issue in terms of what areas of physical processes are actually being studied?

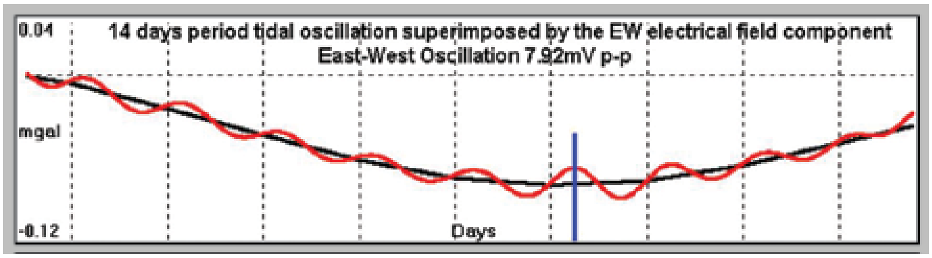
Varotsos: From a purely scientific point of view, how the solid is fractured is a matter of solid-state physics. Purely scientific. From a purely scientific point of view, it's not a matter for a seismologist. This is my scientific response to your question. But irrespective of that, I would say the following: in order to understand, "What is an earthquake?" which, practically, is a phase change, that we approach a critical point, this requires the knowledge of modern physics. And what I mean is new ideas on statistical physics.

For instance, the analysis we use now, which you know is in the recent book about natural time analysis [*Natural Time*



EARTHQUAKE MAP FOR GREECE

A videograb of a real time map of earthquakes in Greece. The colors of the dots indicate the time in a 24-hour period. The size of the dots indicates the size of the earthquake.



ELECTRICAL SIGNALS MEASURED AT ATHENS STATIONS

This is a sample of electric signals measured Feb. 7, 2012, from the Athens station, one of 10 sites where the Earth's electrical field is continuously measured. The changes in the field are analyzed, so that warnings of earthquakes can be given in advance.

That is the basic thought behind the natural time concept. And for some reason, not very easy to explain, by doing this, one can specify some parameters that describe the approach to criticality. That is what Varotsos calls kappa 1. Its value converges as natural time goes on; it converges toward 0.07. That is the time when the system approaches the critical point. That is the backbone, so to speak, of his natural time analysis.

Analysis: The New View of Time, Springer 2011—ed.], it allows us to count the events event-by-event, and you will understand when the system, which is a complex system, like the case of the Earth, approaches a critical point. This requires knowledge of statistical physics.

21st Century: Can you elaborate on what you mean for a process to reach a critical point and say a little bit about what you mean by natural time? What kind of analysis is needed for that?

Varotsos: Maybe Professor Uyeda has a more simple way to describe it. We suggested it in the beginning of this decade, but Professor Uyeda has the ability to say it in simpler words.

Uyeda: Well, the whole idea of natural time, is that time proceeds when something happens. If nothing happens, nobody knows time is going on. So time is specific to the process, you see? So, in the case of earthquakes, when the earthquake takes place, time proceeds. During the inter-earthquake period, nothing happens, there is no time increase. So we disregard the interval of time, and just put them in order: this happens, this happens, this happens.

21st Century: What type of events do you order? Earthquakes?

Uyeda: Earthquakes. Small earthquakes, for instance. And this can be compared to the way people can remember what happened by order in their life. I was born some time, then I became a boy, and went to school, and so forth, and got married , and had children.

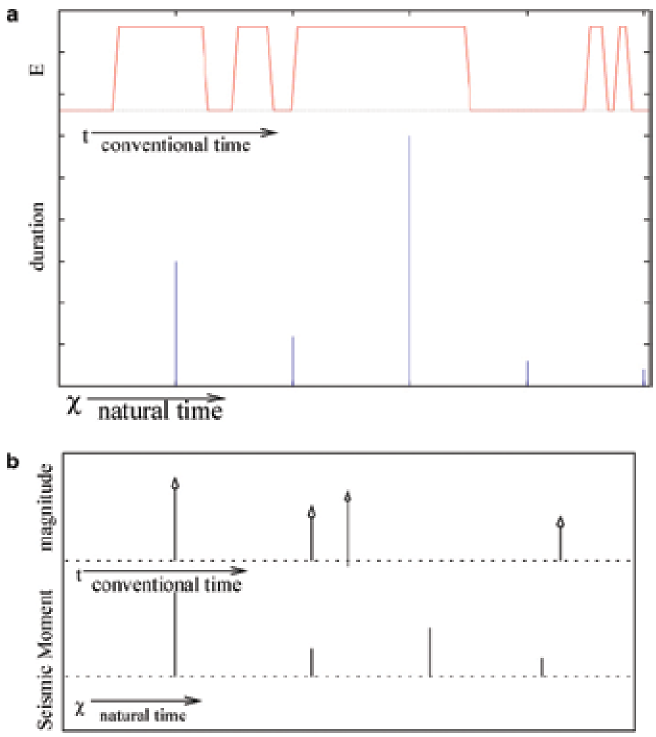
But you don't exactly remember the dates, of course, unless you take notes or something. You can remember what happened by what order; so the importance of the event and the order are important factors.

21st Century: What are the physical processes that characterize this specific critical process in terms of the Earth currents? To the best of your understanding, how does this actually function?

Varotsos: You are asking about the generation of the electric signals?

21st Century: Right.

Varotsos: You see, it is absolutely sure that when you have a rock there are electric dipoles inside the rock. No question about it. But the electric dipoles, need



EARTHQUAKES AND NATURAL TIME

Varotsos models the properties of earthquakes in what he calls natural time, where the seismic moment and energy emitted, for example, are graphed together in a time evolution. Or, shown here, the electrical pulses during an earthquake are graphed in conventional time (red in the upper panel) and then in natural time (blue, in the lower panel). The duration in natural time is indicated on the vertical axis. E = the electrical field. By using the natural time concept, Varotsos et al. can describe when various earthquake precursor parameters approach a critical point.

Source: P. Varotsos, "Is Time Continuous?," in http://arxiv.org/pdf/cond-mat/0605456v1.pdf time to change their orientation. This is called relaxation time. When you apply a stress, and this stress gradually increases as time goes on, the relaxation time of the dipole may decrease. And when this relaxation time becomes very short, all the dipoles, all together, can change the orientation. They cooperate, let me say, and they achieve the same orientation.

Therefore, when you have a cooperative orientation from a random orientation, this change in physics means the emission of an electric current. This is the electric current that we measure before an earthquake. And we know very well that this is a fact, because it has been repeatedly observed in lab experiments. There are many scientists in the world, who have measured it: There are electric signals before the rupture of a solid. There is no question about it.

21st Century: How easy is it to see those electrical signals, or to find them?

Varotsos: It's not such an easy job. I'll tell you why. The most difficult thing is to find the proper sites on the surface of the Earth at which we can record electric signals. It's not an easy job, because the Earth is inhomogeneous, and only specific sites are sensitive to the recording of electric signals. And you need experience.

For instance, in Greece, we tried 10 sites, we installed 10 stations; we waited for a period of time, say one or two years, and after accumulating enough experience, we find which of them is the sensitive point. And then we change.

21st Century: Is there something that's common to the sensitive sites, which characterizes them?

Varotsos: Yes. Now we understand why. And the understanding is quite simple. Because it happens that the earthquakes happen in faults. And nowadays we know that the faults are conductive corridors; it's a conductive channel, as we say. Therefore, when the current starts from the focus, it follows this corridor and it arrives at some point on the surface of the Earth. You must measure very close to the outcrop of these channels.

21st Century: Is it basically where the current leaks out to the surface?

Varotsos: Exactly. Nowadays we understand why there are sensitive points and insensitive points on the surface of the Earth. This is why you need very careful experimentation to find these sites.

Uyeda: Actually, their field work involves a tremendous amount of work. And nobody else has followed that way. We tried to do that in Japan, starting in 1996, when for two or three years, we put many stations in Japan; and some of them were found to be sensitive. But generally the island of Japan is full of electric trains, which is a source of noise, and to deal with this is a big fight, and very difficult on the mainland.

So the only place of success was on far-away islands, and the islands are sensitive sometimes, which is very good, but very few people live there, so practically that doesn't help people too much. But physically, we found the same thing happens in Japan also, and that is important for us.

21st Century: Where the signal leaks out, is that where the epicenter of the earthquake is?

Uyeda: Close to the epicenter, not always very close, but usually rather close, of course. But sometimes if the channel goes through in a strange way, it can go 100 km, for instance.

Varotsos: But the method allows you to determine the epicenter and the magnitude.

21st Century: How do you get the magnitude?

Varotsos: From the amplitude of the signal. If the signal has a larger amplitude, you can calibrate your station and you estimate the magnitude. This is the way.

21st Century: There are a whole range of precursory signals that different groups are studying, everything from low frequency electromagnetic radiation, to the thermal anomalies that some are connecting to radon gas emission, to others that are only now being looked at. Are these other precursors that are being measured related directly to this ground current? What's the best approach in terms of all these different parameters, for precursor analysis?

Varotsos: The current we are measuring, as I said before, may be recorded two months before, for instance. And after the emission of the current, as the time goes on, and you approach the critical point, that means a few days or one week before the main event, how do we understand it? We understand it from natural time analysis.

We have the way to understand when we approach the time [of criticality]. But at that time when you approach the critical point, maybe other phenomena, as you said before, may also occur. Near the critical point, there is a phrase in physics, when we say that long-range correlations always appear. And therefore maybe lights may appear, or radon gas, for instance.

21st Century: How long is this critical point usually? Does it vary depending on the magnitude of the earthquake?

Varotsos: No, empirically we have observed, that from the time we see a condition as Professor Uyeda said to be valid, the main shock occurs within a few days up to one week. This is the accuracy we now have for the prediction of the time.

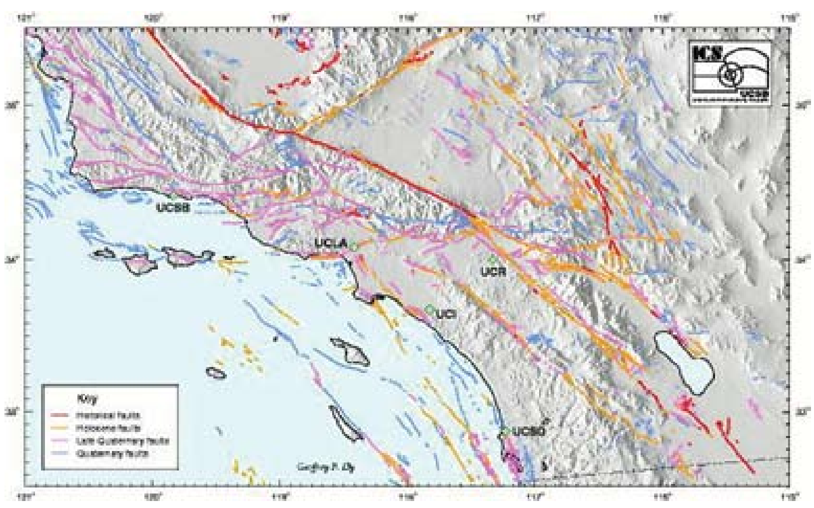
Uyeda: That is for his method, of course. You're also asking about other methods, right? All other frequency problems, they have their own specific mechanism, slightly different. So their lead time before the main shock may differ. But sometimes they are common. So it varies, of course. And technically, the observations of electromagnetic waves for instance, are much easier than the VAN method. The VAN method, as Varotsos explained, is a very difficult operation. Lots of work is needed, tremendous work, really.

21st Century: Is most of the difficulty in getting the measurements?

Uyeda: Yes. And finding the sensitive sites. But for the radio measurements, all you need are antennas, and you can put them anywhere. It's much easier, so everybody jumps on that; that's why it's very popular now.

As to your question of mechanism: these mechanisms are not very well known, I must say.... People like Pulinets, they all have their own hypotheses, gathering all the kinds of data, and some more or less reasonable-looking theory, yes. So they may be right, but it's not completely sure. But the phenomena are without doubt, I think. They do exist.

21st Century: What seems clear is that very few people understand what does actually occur when you look at an earthquake. You're not just looking at an event in itself. It seems a lot of the work of what the precursors are based on, is



FORESHOCKS AND AFTERSHOCKS IN TOHOKU EARTHQUAKE, 2011

The foreshocks are shown in green, and the main shock and aftershocks are in red. Uyeda and Varotsos note that there was an obvious increase in small shocks before the Tohoku earthquake.

Source: USGS

that you're looking at something that is occurring over several months, and it's not just about fault lines rupturing, but you have various other gases, ionosphere changes, perhaps even solar changes that are occurring at the same time: you have a whole entire system. So the real question is, what is this process? What is the entire process that to our senses simply appears as an earthquake?

Varotsos: No question, the whole process is very complex. And you know, let me explain that in physics during the last two decades, we have a new branch in physics: the physics of complex systems. It is in order to understand these complex phenomena. And the physics of complex systems, brings into light a lot of new laws which were unknown previously.

That means you need tedious study to see a few months before an earthquake what is going on. But in order to understand it, you need to follow carefully which physical laws you should apply. This is not an easy job.

For instance, you should see if the earthquakes, the small shocks that occur, are correlated or not. This is a very modern part of statistical physics. And what we presented yesterday in our joint paper [Earthquake Prediction in Japan and Natural Time Analysis of Seismicity—ed.], we have seen that before the Tohoku catastrophic earthquake. Our result was, from a random orientation, exactly this point: to see how the small events before the Tohoku earthquake gave an obvious increase a few weeks before the main event.

But this needs a careful physical study between all the correlations between the small shocks. It's not so easy. This is not a seismological study. This is a study within the frame of modern physics. It's not a work for seismologists.

Uyeda: Seismic waves are very useful for sounding the internal structure and internal process, of the Earth. It's very useful. But as far as the seismogenic process is concerned, they only study how stress is applied or exerted, and what process causes plate pushing. This is a matter of plate tectonics, more or less.

Anyway, after the big earthquake, most of the Japanese seismologists were very depressed. They could not even think of this kind of thing. But it's not their job. Nobody is expecting them to be able to predict that a magnitude 9 will take place, because in Japanese history it has never happened, according to the seismological records. So they don't have to be so depressed. They're okay. But it's not their job.

The other thing is, precursors do not necessarily cause the earthquake. The only thing is that they occur before the earthquake; nobody actually thinks that telluric currents cause earthquakes, so that's why seismologists are not interested—it has nothing to do with the stress accumulation with which they're interested. It's just current flows.

And that is one aspect why seismologists are not interested in us. It's very natural: it's out of their field. They are interested in how stress accumulates to become high, and so forth. Many of the precursors have nothing to do with this. Maybe it's a by-product of the same process—earthquakes and precursors, the whole process.

21st Century: In terms of international policy, it seems like this type of work needs international collaboration. Earthquakes don't respect national boundaries. Where do you think we need to go in terms of collaboration in advancing this work, as a matter of international policy, national security, and also basic science?

Uyeda: As far as earthquakes are concerned, and geophysics is concerned, there is an international organization called IUGG, International Union of Geodesy and Geophysics; it's the largest science group organization. We now have a working group called EMSEV, Electromagnetic Studies of Earthquakes and Volcanism, and this was established 10 years ago. I was one of the founders.

This is essentially an international, interdisciplinary working group. Because those who are active in this type of work are generally not seismologists. They can be atmospheric physicists, purely solid-state physicists, and so forth, and their language is different, they cannot talk to each other. Something that is very common sense to one discipline, is entirely unknown in the others.

But the common point is, we are interested in precursors so we needed this type of organization, and this organization has been very active, very, very active. So that is one thing.

Varotsos: International collaboration is very important. And from our point of view, we have a very close collaboration with the group of Professor Uyeda in Japan. We have an exchange of data, of information, and so on, every day. And we said today in this meeting, we have this collaboration on a daily basis. This is of key importance for such a matter. We all must be united. We must intensify our efforts.