Immediately after the official establishment of SEPI, the above-mentioned two Departments of Solid State Physics of the University of Athens and the University of Ioannina (UoI) in close cooperation installed a network of measuring electrical dipoles around the Katsimitros camp (in the area of Perama, Ioannina) which recorded after a few months and specifically on 18 &19 April 1995 intense Seismic Electrical Signal (SES) activities. These signals were followed by the earthquake of magnitude (M)6.6 in the area of Grevena-Kozani which was considered "aseismic" (for more than 1000 years there had been no such earthquake in this area). The relevant precursory information was sent in advance to both the Greek State and the Royal Society (London) where an international conference was held on 11-12 May (just before the occurrence of the 6.6 earthquake) co-organized by the aforementioned UN Scientific Committee on Natural Disasters and the Royal Society (London).

It should be noted that two other large earthquakes occurred in Greece in 1995, i.e. in Chalkidiki on 4-5-1995 with a magnitude of 6.0 and in the area of Erateini-Aigio on 15-6-1995 with a magnitude of 6.5 for which SES (that had been forwarded well in advance to both the Greek State and the Royal Society) were also recorded.

The aforementioned 3 major earthquakes of 1995 attracted intense international interest. For example, the leading American scientific journal *Science* dedicated an extensive article in the issue of November 10, 1995 (volume 270, pages 911-912, attached, Appendix A) entitled "Quake Prediction Tool Gains Ground" presenting also a map of our country that indicated the epicenters of all these 3 earthquakes, thus highlighting internationally the research carried out in our country.

Since then the objectives of our Institute are systematically implemented with the cooperation of the two Sections of NKUA and UoI. (Whenever there is a problem in the operation system and in the recording of the electric dipoles in the area of Perama, this is usually repaired either by personnel from UoI or from the NKUA.) In fact, this close cooperation between the two Sections has been extended to an additional research direction as will be explained below:

In 2001, Varotsos, Sarlis and Skordas from the Physics Department of the University of Athens proposed a new concept of time - called Natural Time [*Practica of Athens Academy*, **76**, 294-321, 2001; *Phys. Rev. E*, **66**, 011902, 2002; *Phys. Rev. E*, **67**, 021109, 2003; *Phys. Rev. E*, **68**, 031106, 2003] as described in the Natural Time Section http://sepi.edu.gr/natural-time-analysis/achievements-during-the-last-15-years - which achieves the estimation of when a complex system approaches a dynamic phase transition. In the case of earthquakes, for example, the corresponding critical point is the event of a main (significant) earthquake where this earthquake is considered as the new phase. As a second example, we mention the function of the human heart, where a "sudden cardiac death" (SD) can occur even when a person's electrocardiogram (ECG) shows - in the usual way of "reading" - that he is a healthy person. In this case, the corresponding critical point is exactly when the "sudden cardiac death" occurs. ECG analysis using the Natural Time method showed that this critical point can be satisfactorily approached. The relevant research carried out during the last five years in collaboration with the two aforementioned Sections (NKUA and UoI) with the Second Cardiology Clinic of the UoI, is of course compatible with the objectives of the Institute, since it also aims at the protection of the population.

On the initiative of members of the UoI Section, a model recording system based on photoplethysmography (PPG) was designed and constructed, which has the ability to replace electrocardiography devices in the context of detecting serious heart diseases. This system is shown in the figures below (details can be found in the relevant Doctoral Thesis - no. 4 Annex B - of the University of Ioannina) both in the case of wired communication with a Personal Computer (PC) (Figure 1) and in the case of wireless communication with a PC (Figure 2).

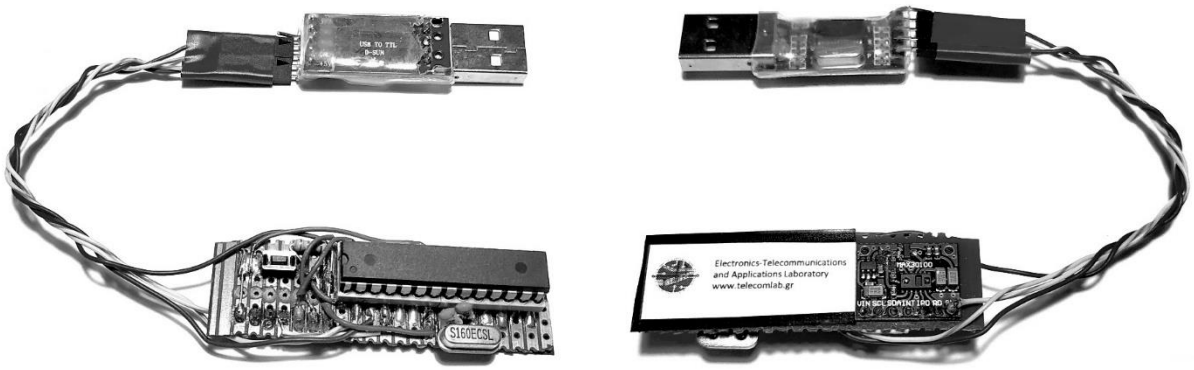


Figure 1. Top and bottom view of the wired computer communication system, via USB, which was built in the Department of Physics of UoI.

Figure 2. The wireless computer communication system, via Bluetooth, which was built in the Department of Physics of UoI.

The first results of comparison-calibration of this system were presented at the MOCAST 2018 conference held in Thessaloniki at the paper:

G. Baldoumas, D. Peschos, G. Tatsis, C.I. Votis, S.K. Chronopoulos, V. Christofilakis, P. Kostarakis, N.V. Sarlis, E.S. Skordas, K.K. Naka, A. Bechlioullis, "Comparison of the R-R intervals in ECG and Oximeter signals to be used in complexity measures of Natural Time Analysis," 2018 7th International Conference on Modern Circuits and Systems Technologies (MOCAST), Thessaloniki, 2018, pp. 1-4.doi:10.1109/MOCAST.2018.8376587.

Where complexity measures related to the entropy in natural time are used to study the heart rate in the original oximeter device built for this purpose in the UoI Section. The first results are very encouraging as the values of the complexity measures resulting from the original PPG device are compatible with those resulting from the ECG.

The results of the use of this prototype recording system based on photoplethysmography constructed in UoI were published in the paper:

G. Baldoumas, D. Peschos, G. Tatsis, S.K. Chronopoulos, V. Christofilakis, P. Kostarakis, P. Varotsos, N.V. Sarlis, E.S. Skordas, A. Bechlioulis, L.K. Michalis and K.K. Naka, "A Prototype Photoplethysmography Electronic Device that Distinguishes Congestive Heart Failure from Healthy Individuals by Applying Natural Time Analysis ", *Electronics*, Vol. **8** (2019), 1288; doi:10.3390/electronics8111288

which presents both the prototype PPG device constructed in the UoI Section and the results for distinguishing people suffering from congestive heart disease (CHF) from healthy (H) by applying the analysis in natural time. The data were collected simultaneously with a conventional three-electrode electrocardiography system and with the prototype PPG device by H and CHF volunteers at the Second Cardiology Clinic of the Medical School of the University of Ioannina. The statistical analysis of the results in natural time shows a clear separation of CHF from H for both the conventional electrocardiographic system and the prototype PPG system, with a much better distinction for the latter, which also has the advantages of a low-cost portable device. Specifically, using machine learning methods, it is possible for patients suffering from congestive heart disease (CHF) to be separated (diagnosed) from healthy (H) people with sensitivity of 97.7%.

Four doctoral dissertations (3 were supported at the University of Athens and 1 at the University of Ioannina) (Appendix B) were conducted and completed in SEPI. In addition, plethora of scientific papers of the members of the Institute published in the last decade in authoritative international scientific journals after review, five of which have received specific distinctions from the respective Editors (Appendix C).

Regarding the international response of SEPI research activities, this emerges - in addition to the high h-index of our researchers - from the following fact: In 2016, the method of "Nowcasting earthquakes" was introduced to assess the current seismic risk in an area by distinguished researchers of leading US Universities and Research Institutes such as California: Institute of Technology, Pasadena; University of California, Davis California; Santa Fe Institute, New Mexico; University of California, Irvine. These researchers explain in their relevant work (*Earth and Space Science***, 3**, 480-486 (2016)) that the method is founded on the basis of the natural time proposal that as mentioned above has been formulated for the first time by the researchers of our Institute in 2001. This method has meanwhile (i.e. in the last five years) been applied internationally in dozens of projects to assess the seismic risk in

many regions of the world with very interesting results. It should be noted that in all 3 review articles this year in prestigious journals -*Reports on Progress in Physics* **84**, 076801 (2021); *Surveys in Geophysics* doi.org/10.1007/s10712-021-09655-3; *Earth and Space Science* (doi.org/10.1029/2021EA001757)- emphasizes the fundamental importance of Natural Time in the application of "Nowcasting Earthquakes" which is considered internationally today as frontal research in the assessment of seismic risk.

Also, challenging research is carried out internationally in the aforementioned analysis of electrocardiograms using the method of Natural Time with the active participation of members of the two Sections of the University of Athens and UoI and members of the Second Cardiology Clinic of the UoI. This analysis has attracted international interest since 2004, e.g. the magazine *New Scientist* in the issue of April 3 dedicated a special article (see Appendix D) that commented on the results of our upcoming work *Physical Review E* **70** (2004) 011106 and *Physical Review E* **71** (2005) 011110. As mentioned above, the method allows the early detection of "sudden cardiac death" as well as the distinction of healthy people from those with serious heart diseases. In the current research, in which with the aforementioned prototype PPG device constructed in the UoI Section where the relevant software was also developed, more than 200 clinical trials have already been carried out at the Second Cardiology Clinic of the UoI with a success rate of more than 95%. The additional capabilities of wireless communication of the prototype PPG device and its possibilities for remote sensing are investigated in the recent work:

Baldoumas, G.; Peschos, D.; Tatsis, G.; Christofilakis, V.; Chronopoulos, S.K.; Kostarakis, P.; Varotsos, P.; Sarlis, N.V.; Skordas, E.S.; Bechlioulis, A.; Michalis, L.K.; Naka, K.K. “Remote sensing natural time analysis of heartbeat data by means of a portable photoplethysmography device”, *International Journal of Remote Sensing*, Vol. **46** (2021), 2292-2302l; doi: 10.1080/2150704X.2020.1847351

In this work it is suggested to use the wireless PPG device for remote sensing of the heart rhythm of patients as it does not show sensitivity to body movements (which affect other remote sensing systems built for this purpose). As all modern devices such as smart phones allow connection via Bluetooth, it is possible to easily and directly connect the prototype PPG device to them and from there to further promote the information for remote sensing. In addition, this recent 2021 paper includes a follow-up study of the paper published in Electronics, Vol. 8 (2019) 1288, which highlights that the complexity measures recorded based on the photoplethysmography method have the same predictive ability (in addition to diagnostic) as those calculated on the basis of the electrocardiogram to characterize the risk of sudden cardiac death.

In summary, the encouraging results so far of this close cooperation between the two Sections of NKUA and UoI with the Second Cardiology Clinic of the UoI suggest that this cooperation should be continued unprofitably for the benefit of the protection of the population.

RESEARCH NEWS

Quake Prediction Tool Gains Ground

Seismologists don't fully understand a controversial Greek prediction scheme, and some think its "successes" are just luck. But it is enticing many researchers

Each time researchers have flirted with a possible scheme for predicting earthquakes, they have ended up regretting it when the scheme failed to live up to expectations. Now they are being tempted again. This time, the attraction is strange electrical signals in the ground that, according to proponents, heralded three large earthquakes in a row this spring in Greece. And, in spite of those past disappointments, some researchers are wondering whether this might be the real thing.

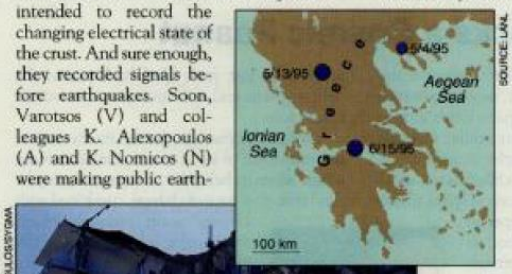
Although long disparaged by Greek seismologists, a prediction scheme based on those signals is now attracting interest, and some enthusiasm, in Japan and the United States, after the Royal Society of London and the University of California (UC), Berkeley, recently held workshops examining it. "It's bedevilingly intriguing," says Berkeley's Thomas McEvilly.

Most seismologists are still skeptical, arguing that the apparently successful predictions are just lucky guesses, aided by the vagueness of the predictions and the abundance of earthquakes in Greece. "But you just keep getting sucked back toward the apparent—though fuzzy—successes, especially those in the last year," says McEvilly. Hiroo Kanamori of the California Institute of Technology, a prominent seismologist and a longtime skeptic of simplistic approaches to earthquake prediction, adds that the statistical criticism "is probably valid. But that doesn't mean the whole thing is invalid," he says. "My feeling is there is something to it."

Geophysicists who study the electromagnetic properties of the crust tend to think so too, in part because they have been working along the same lines. For decades Chinese researchers have been searching for electrical precursors that might signal changes in fluid flow or rock properties leading up to an earthquake. And in the United States, researchers have been looking for magnetic precursors, especially since Antony Fraser-Smith of Stanford University detected a striking burst of magnetic noise just before the Loma Prieta earthquake of 1989 in California (*Science*, 22 December 1989, p. 1562).

Solid-state physicist Panayiotis Varotsos of the University of Athens and his colleagues got into the business in the mid-1980s as a result of laboratory experiments in which they squeezed dry rocks while monitoring their electrical properties. Just before fracturing, the rock would generate a transient electrical current as crystal imperfections caused a separation of charges. Because earthquakes are much larger versions of rock fractures, Varotsos and his colleagues reasoned, they should generate precursory electrical signals in the crust.

Greece has more than its share of earthquakes, making it a good testing ground for the idea. So Varotsos and his physicist colleagues began setting up what amount to giant voltmeters—wires as long as 3 to 4 kilometers connected to electrodes stuck in the ground—intended to record the changing electrical state of the crust. And sure enough, they recorded signals before earthquakes. Soon, Varotsos (V) and colleagues K. Alexopoulos (A) and K. Nomicos (N) were making public earthquake predictions using the "VAN" method.




L. PAPADOPOULOS/SYGMA

Threesome foretold? VAN came close to predicting three quakes, including a 15 June event in southern Greece *(photo)*.

Few seismologists were seduced by the VAN group's early claims that they were successfully predicting quakes. "The experiment was not convincing, say 10 years ago, that Varotsos was measuring anything but electrode noise or some other problem with the sensors," says electrical geophysicist Stephen Park of UC Riverside. But since then, say Park and others, Varotsos has altered his equipment to compensate for instrumental noise and the crustal currents induced by fluctuations in Earth's own magnetic field. "Now we're convinced that it is a signal from the Earth," says Park.

That still leaves the question of whether these signals, dubbed "seismic electric signals," or SES, actually have anything to do with earthquakes. Varotsos believes they do, although he notes that the connection isn't simple. He has learned that SES aren't always detected at the location of an impending earthquake but often are recorded at distances of up to 100 kilometers and more. The reason, he says, is that the current has to reach the surface by way of conductive channels in the crust, which may carry it long distances.

Park and other geophysicists think such long-distance transmission is unlikely, because it would require too much energy at the source. And most geophysicists are skeptical of Varotsos's belief that crustal rock on the verge of fracturing generates current. Instead, speculates Kanamori, the signals might be generated as water and gas surge through the crust, triggering electrical changes and other precursors over a wide area and weakening a major fault until it ruptures.

But whatever their genesis, Varotsos converts the signals into a prediction based on the distribution of sites detecting them, the number of signals, and their amplitudes. And the results, Varotsos told *Science*, have been consistently successful. In the past 9 years, he says, 14 earthquakes of magnitude 5.8 or larger have struck Greece, three of which fell outside his network. Of the remaining 11, 10 were predicted weeks in advance, he says; only one prediction failed, and there were one or two false alarms.

Park sees it a little differently. When he and Richard Aceves and statistician David Strauss of UC Riverside include smaller, more abundant quakes in the magnitude range covered by VAN, the picture looks less impressive. "Varotsos has only issued predictions for 10% of the earthquakes that have actually occurred," he says. But of the predictions issued, "he's had a success rate of about 65 to 70%. Our results have shown it's very unlikely this could be produced by random chance. To me, that says that this is a physical phenomenon worth studying."

Seismologist David Jackson of UC Los Angeles disagrees. "I think [VAN] has gotten

APPENDIX B

DOCTORAL DISSERTATIONS

Doctoral dissertations.

1. Christopoulos, Stavros-Richard of Georgios "Complex dynamical systems and natural time: applications in seismicity" NKUA 2014 Three-member committee: N. Sarlis, P. Varotsos, E. Skordas.

2. Papadopoulou, Konstantina of Andreas "Pre-earthquake changes of the earth's electric field: seismicity and natural time" NKUA 2019 Three-member committee: E. Skordas, P. Varotsos, N. Sarlis.

3. Mindzelas Apostolos of Christos "Study of complex systems with the help of natural time" NKUA 2019 Three-member committee: N. Sarlis, P. Varotsos, E. Skordas.

4. Baldoumas Georgios of Ioannis "Reception and processing of ppg biosimages and prediction of impending cardiac dysfunctions" UoI 2021 Three-member committee: D. Peschos, P. Kostarakis, N. Sarlis with the following seven-member examining committee appointed by the Assembly of the Department of Medicine of the University of Ioannina at the meeting of no. 970/29-6-2021:

1) Peschos Dimitrios Professor of Physiology, Department of Medicine, University of Ioannina.

2) Kostarakis Panayiotis, Professor Emeritus of the Department of Physics of the University of Ioannina.

3) Sarlis Nikolaos, Professor at the Department of Physics of the University of Athens

4) Varotsos Panayiotis, Professor Emeritus of the Department of Physics of the University of Athens

5) Naka Aikaterini, Associate Professor of Cardiology, Department of Medicine, University of Ioannina

6) Tsamis Konstantinos, Assistant Professor of Physiology at the Department of Medicine of the University of Ioannina.

7) Christofilakis Vasileios, Assistant Professor at the Department of Physics of the University of Ioannina.

APPENDIX C

The paper N. V. Sarlis, E. S. Skordas, P. A. Varotsos, T. Nagao, M. Kamogawa, and S. Uyeda, "Spatiotemporal variations of seismicity before major earthquakes in the Japanese area and their relation with the epicentral locations", **Proceedings of the National Academy of Sciences of the United States of America,** Vol.112 (2015), 986–989 was selected from the Editorial Board of the National Academy of Science (USA) to be mentioned in the frontpage of the issue as well as to be commented on by a relevant Commentary by Profressor Qinghua Huang of the University of Peking under the title «Forecasting the epicenter of a future major earthquake», **Proceedings of the National Academy of Sciences of the United States of America,** Vol. 112 (2015), 944-945.

The paper N. V. Sarlis, E. S. Skordas, and P. A. Varotsos, "A remarkable change of the entropy of seismicity in natural time under time reversal before the super-giant M9 Tohoku earthquake on 11 March 2011", **EPL**, Vol. 124 (2018), 29001 was selected from the Editorial Board of EPL to be included in the Highlights of the year 2018 (https://iopscience.iop.org/journal/0295-5075/page/Highlights-of-2018?utm_medium=email&utm_source=iop&utm_term=&utm_campaign=15845-41333&utm_content=Read%20the%20Highlights).

The paper P.A. Varotsos, N.V. Sarlis, and E.S. Skordas, "Natural time analysis: Important changes of the order parameter of seismicity preceding the 2011 M9 Tohoku earthquake in Japan.", **EPL**, Vol. 125 (2019), 69001 was selected from the Editorial Board of EPL to be included in the Highlights of the year 2019 (https://iopscience.iop.org/journal/0295-5075/page/Highlights-of-2019?utm_medium=email&utm_source=iop&utm_term=&utm_campaign=18449-46076&utm_content=Highlights of 2019&Campaign+Owner=Gemma+Hougham).

The P.A. Varotsos, E.S. Skordas, and N.V. Sarlis, "Fluctuations of the entropy change under time reversal: further investigations on identifying the occurrence time of an impending major earthquake", **EPL**, Vol. 130 (2020), 29001 was selected from the Editorial Board of EPL to be included in the Highlights of the year 2020 (https://iopscience.iop.org/journal/0295-5075/page/Highlights-of-2020)

The paper P.A. Varotsos, N.V. Sarlis, and E.S. Skordas, "Perspective: Self-organized Criticality and Earthquake Predictability: A long standing question in the light of natural time analysis", **EPL**, Vol. 132 (2020), 29001 was published as a Perspective after special invitation from the was selected from the EPL Editorial Board.

This week

Heartbeats warn of sudden death risk

DUNCAN GRAHAM-ROWE

HOW do you tell a healthy heart from one that could stop without warning? By measuring variations in the length of the heartbeat, according to a team of researchers in Greece.

The finding could provide a way to screen for people at risk of sudden cardiac death. Such people's heartbeat often looks perfectly healthy by conventional criteria. Yet a quarter of a million people die each year in the US alone when their heart suddenly stops and, like the soccer player Marc-Vivien Foé who collapsed and died last year while playing for Cameroon, many of them have had no history of heart problems.

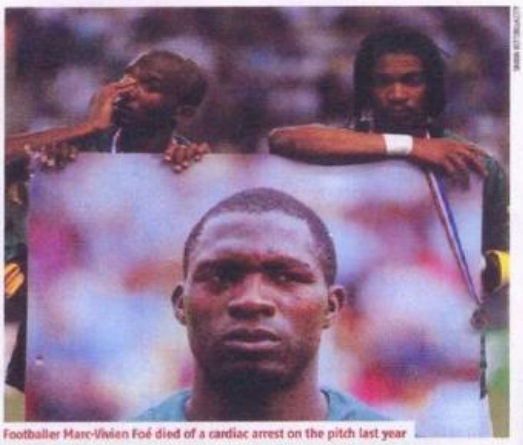
Even a person's ECG, or electrocardiogram, can look normal for much of the time. In patients with Brugada syndrome, for example, abnormal electrical signals sporadically stop their hearts from pumping properly. Long QT syndrome is a similar condition, which can strike young, fit adults, and has also been linked to cot death.

Standard approaches to analysing ECGs tend to focus on the peaks and troughs of the trace. Instead, Panayiotis Varotsos of the University of Athens has been studying the variation in the length of time it takes for the heart to complete one beat (see Graphic, below).

The amount of variation in the rate of heartbeats is already used to measure aerobic fitness, with more variation meaning a fitter heart. However, for Varotsos the crucial test is the variation in the length of each beat, and whether this variation is random. He adapted equations he had previously used to describe physical systems such as earthquakes to predict that, in a healthy heart, these variations will have some degree of order. But if there is something wrong with the heart, however subtle, it should disrupt that order, making the variation more random.

To test the theory, Varotsos and his colleagues analysed 95 sample ECGs taken from public databases of people with various heart conditions and 10 from healthy patients. He found that the beats of the diseased hearts did indeed vary more randomly and the results are to be published in a future issue of *Physical Review E*. Varotsos says the method could be used as an initial screen to flag up all types of heart problems. "In principle our method should be applied to all causes of cardiac arrest."

"The method could be particularly useful for screening those who have a family history of sudden cardiac death"



Footballer Marc-Vivien Foé died of a cardiac arrest on the pitch last year

A lot of research has gone into discovering ways to identify cardiac diseases from an ECG. Some have used data mining techniques – screening blind for any effect that comes up, while other studies have looked for chaotic signatures that might distinguish unhealthy hearts from healthy ones (*New Scientist*, 3 January 1998, p 20).

But so far no method has stood up to scrutiny in clinical trials, says Arun Holden, a computational biologist at the University of Leeds, UK. Varotsos believes his discovery has a better chance of turning out to be real because he used a physical model of how the heart works to predict a specific effect.

However, as Tim Bowker of the British Heart Foundation points out, there is no way of knowing more about the patients whose ECGs were used in the database. "Without knowing this, one doesn't know that it applies to any group other than these 105," he says. So the jury will remain out until the method is tested to see if it is able to predict cardiac health.

If it proves reliable, the method could be particularly useful for screening those who have a family history of sudden cardiac death. In the UK, about 3500 people die from this syndrome each year. This may not be enough to give rise to a nationwide screening programme.

Instead, Varotsos suggests that cardiologists could apply his method to Holter monitors – the portable ECG devices that are used to monitor patients thought to be at risk. ●

HEART ATTACK WARNING?

Varotsos and colleagues studied ECG traces and found that the more random the variation in Q-T interval, the higher the risk of sudden cardiac death

P – Atrial depolarisation: top chambers contract QRS – Ventricular depolarisation: larger, lower chambers contract
ST – Ventricular repolarisation: cells in the lower chambers recharge, in preparation for the next contraction