*Group* B. *Poster* # 148, Category: Earthquake Forecasting and Predictability (EFP)

# Global earthquake monitoring system based on the Method of Seismic Entropy (MSE): By example of California


**Samvel Akopian & Anna Bayramyan**

*International Center of the Seismic Risk Global Monitoring (LLC SeiEn), Armenia, Yerevan*

*E-mail:* samvel.akopian49@gmail.com
anna.bay.qa@gmail.com


SCEC *Statewide California Earthquake Center*

**Central Functions**
Welcome to the SCEC business operations website. Visit www.scec.org for more general information about the Center.



**Global earthquake monitoring system based on the method of seismic entropy (MSE):** ***By examples of California***

**Samvel Akopian, Anna Bayramyan**

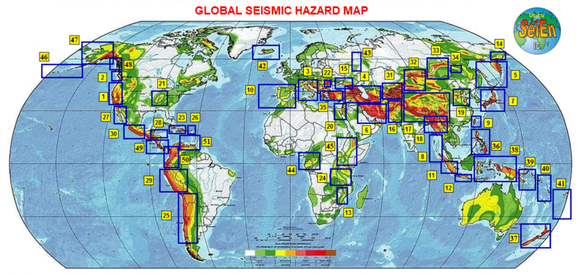
**Abstract.** MSE based on the introduction of new seismic parameters (cumulative energy and entropy), on the concept of a seismic system, and on the law of seismic entropy production. The technology allows to monitor the development of seismic instability in time and space in the specific volume of the geological environment; to monitor and evaluate a possible scenario for the development of seismicity. The theoretical and physical foundations of the method, algorithms and software package have been tested for real regions of the world over the past 36 years. We developed a computer program, which we have been using for global monitoring of strong earthquakes since 2004, expanding the global monitoring system and creating a product – a mobile app, which is currently in the testing phase. At present monitoring covers the highest energy level of all seismically active regions of the world. Monitoring includes the territories of 135 countries of the world and is carried out in the 870 Seismic Systems. The lower threshold for predicted earthquakes begins from magnitudes 5.5. All seismically active regions of the United States are included in the monitoring system.

**Monitoring and Forecasting a Mega-Earthquake (M≥7.8) in California.**
Calculations were performed for the AB, ABC, and BC mega seismic systems.
Although these systems are poorly defined, reliable estimates have been made. In all cases, the hazard is localized in Southern California, northwest of Los Angeles. Here, on the western branch of the SAF, which extends all the way to Santa Barbara, in the Ventura-Pitas Point fault area, a destructive earthquake with a magnitude of M=7.8 is being prepared. The final date of this catastrophic earthquake is estimated at March-April 2027. It is shown why the earthquake, expected since 2006, did not occur and is still delayed. Usually, catastrophic earthquakes in California occur on the SAF. The current situation in the system is unusual. The preparation of this earthquake, which started in 1906, has accumulated abnormally high values of cumulative energy and entropy. This is the result of unusual seismic activity in southern California over the past decades. As a result, the most active SAF fault in the Los Angeles area is "locked up", and the danger has migrated to the western branches of this fault. The predicted earthquake will be unusual, with a predominance of vertical rather than horizontal displacements. This situation was observed in California 800 years ago.



**Key words**: Seismic cycle; Mathematical modeling; Seismic Entropy, Instability analysis; Seismicity monitoring

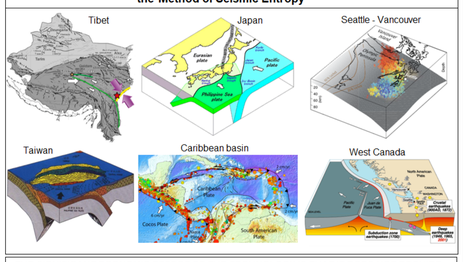

## REGIONS OF THE WORLD WHERE SEISMIC SYSTEMS ARE REVEALED ON THE GLOBAL SEISMIC HAZARD MAP



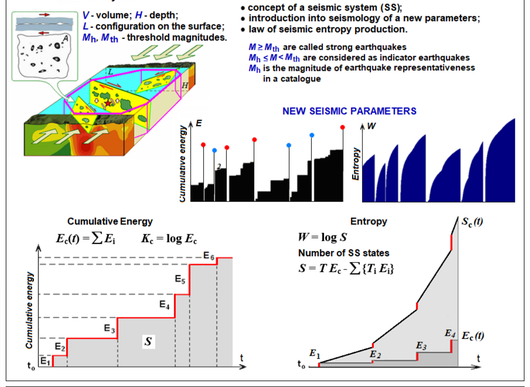
**1.** California; **2.** Gorda & Juan de Fuca plates; **3.** Italy; **4.** Armenian Upland, Caucasus, Caspian sea & Northern Iran; **5.** Sakhalin, Hokkaido, Kuril Is. & Kamchatka; **6.** Southern Iran; **7.** Japan; **8.** Burma plate; **9.** Taiwan; **10.** Azores, Portugal, Spain, Marocco, Algeria; **11.** Sumatra; **12.** Java; **13.** Mozambique; **14.** Koryak; **15.** Crimea, Krasnodar; **16.** Pakistan, Afganistan, **17.** India, China, Nepal, Bhutan, Bangladesh; **18.** Myanmar; **19.** China NE; **20.** Egipt, Israel; **21.** Central USA; **22.** Vrancea (Romania); **23.** Haiti, Dominikan R.; **24.** Malawi, Zambia, Tanzania, D.R.Congo, Burundi; **25.** Chile; **26.** Puerto Rico; **27.** NW Mexico; **28.** Belize, Cayman Is.; **29.** Peru; **30.** Mexico; **31.** Uzbekistan, Tajikistan, Kyrgyzstan, S Kazachstan, NW China; **32.** Altay, Tuva (RF), W Mongolia, NW China; **33.** Baykal (RF), **34.** Amursk (RF); **35.** Turkey, Greece; **36.** Philippines; **37.** New Zealand; **38.** E Indonezia, Timor; **39.** Papua New Guinea, Solomon Is; 40. Vanuatu, Fiji Is.; **41.** Tonga; **42.** Iceland; **43.** Ural (RF); **44.** Gabon,Cameroon; **45.** African Rift; **46.** Aleutian Is. (USA); **47.** Alaska (USA); **49.** Central America; **50.** Columbia; **51.** E&S of the Caribbean Basin.

## COMPLEX SEISMOTECTONIC STRUCTURES

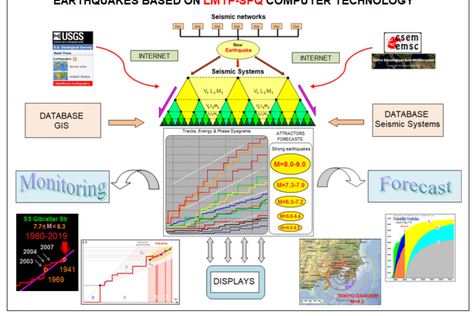
**Only by surface measurement it is impossible to control their dynamics not only now but at least in the next decades. Monitoring of instability and the forecast of strong earthquakes in them can be made today using the Method of Seismic Entropy**



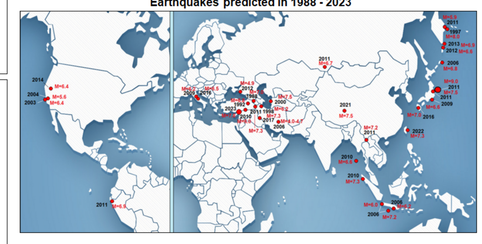

## METHOD OF SEISMIC ENTROPY




## THE SCHEME OF GLOBAL MONITORING AND FORCASTING OF STRONG EARTHQUAKES BASED ON LMTP-SPQ COMPUTER TECHNOLOGY




## Earthquakes predicted in 1988 - 2023



## THE SIGNIFICANT ECONOMIC EFFECT OF THE TECHNOLOGY IS THAT IT DOES NOT RECUIRE THE CREATION OF EXPENSIVE OBSERVATION SYSTEMS

DATA FROM GLOBAL AND REGIONAL SEISMOLOGICAL NETWORKS IS USED AS INPUT INFORMATION FOR ONLINE MONITORING

Data on current earthquakes are available an hour after the event

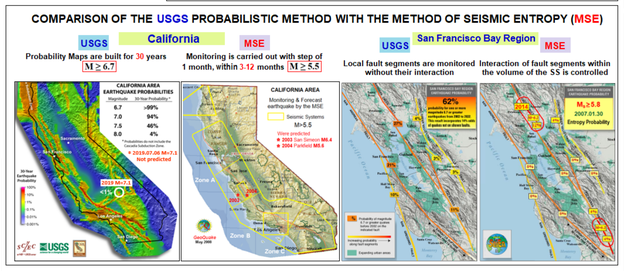
USGS · CSEM EMSC · GFZ · EarthScope Consortium · 気象庁

## MONITORING COVERS THE HIGHEST ENERGY LEVEL OF ALL SEISMICALLY ACTIVE REGIONS OF THE WORLD

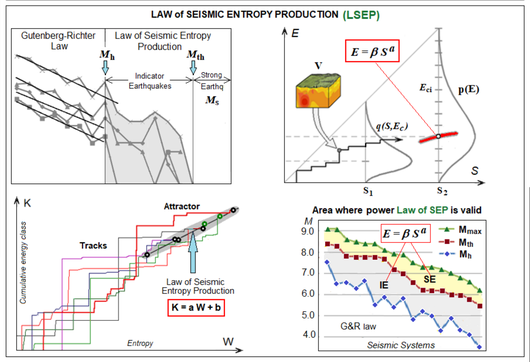
| | |
|---|---|
| ➢ Monitoring includes territories of | 135 countries of the world |
| ➢ Monitoring is carried out in | 870 Seismic Systems |
| ➢ Lower threshold of earthquakes begins | from magnitudes 5.5 |
| ➢ Monitoring of weak seismicity includes | 20 countries of the Europe |
| ➢ Threshold magnitudes for Armenia | reduced to M=4.0 |

Monitoring and Forecasting Bulletin is issued quarterly

## COMPARISON OF THE USGS PROBABILISTIC METHOD WITH THE METHOD OF SEISMIC ENTROPY (MSE)



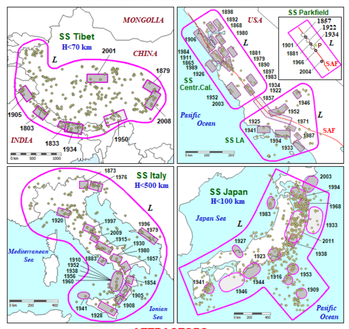

## LAW of SEISMIC ENTROPY PRODUCTION (LSEP)



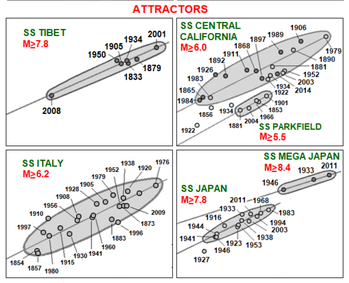

- **SS is the volume of lithosphere responsible for the preparation of strong earthquakes;**
- **The SS is considered to be found if the Law of SEP is satisfied;**
- **The Law of SEP established a relationship between SE and the cumulative parameters of IE;**
- **The Law of SEP states that SE completely discharge the volume of SS.**

**Discrete threshold magnitudes (5.8, 6.2, 6.6, 7.0, 7.5, 7.8, 8.4, 8.8) for the SS play a fundamental role in seismology**

## EXAMPLES OF SEISMIC SYSTEMS




## ATTRACTORS

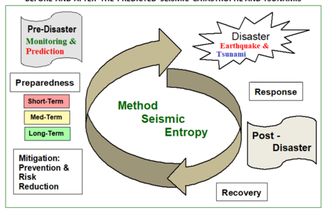



Countries where 870 seismic systems and subsystems have been identified

| | | | | | |
|---|---|---|---|---|---|
| Afghanistan | Colombia | Georgia | Lebanon | Philippines | Taiwan |
| Albania | Congo | Greece | Liechtenstein | Portugal | Tajikistan |
| Algeria | Costa Rica | Guatemala | Madacascar | Puerto Rico | Tanzania |
| Argentina | Croatia | Guyana | Malawi | Romania | Thailand |
| Armenia | Cuba | Haiti | Malaysia | Russia | Timor |
| Austria | Cyprus | Honduras | Mexico | Rwanda | Tonga |
| Azerbaijan | Djibouti | Iceland | Mongolia | Samoa | Turkey |
| Banglades h | Dominican Republic | India | Montenegro | Sao Tome & Principe | Turkmenistan |
| Belize | DR Congo | Indonesia | Morocco | Saudi Arabia | Tuvalu |
| Bhutan | Ecuador | Iraq | Mozambique | Serbia | United Arab Emirates |
| Bolivia | Egypt | Israel | Myanmar | Slovenia | Uganda |
| Bosnia&Herzegovina | El Salvador | Italy | Nepal | Solomon Islands | United States of America |
| Botswana | Equatorial Guinea | Jamaica | New Zealand | Somalia | Uzbekistan |
| Brazil | Ethiopia | Japan | Nicaragua | Somaliland | Vanuatu |
| Burundi | Eritrea | Jordan | North Macedonia | South Africa | Venezuela |
| Cameroon | Fiji | Kazakhstan | Pakistan | South Sudan | Vietnam |
| Canada | France | Kenya | Papua New Guinea | Spain | Yemen |
| Chile | French Guiana | Kyrgyzstan | Panama | Suriname | Zambia |
| China | Gabon | Laos | Peru | Switzerland | Zimbabwe |

**Totally: 135 Countries including 21 small Caribbean countries**

## MANAGEMENT BEFORE AND AFTER THE PREDICTED SEISMIC CATASTROPHE AND TSUNAMIS

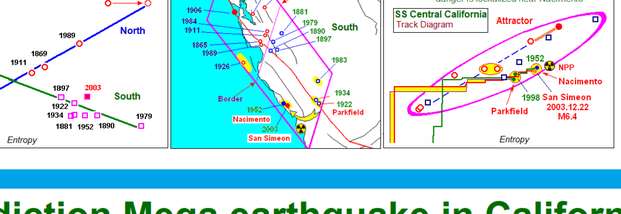


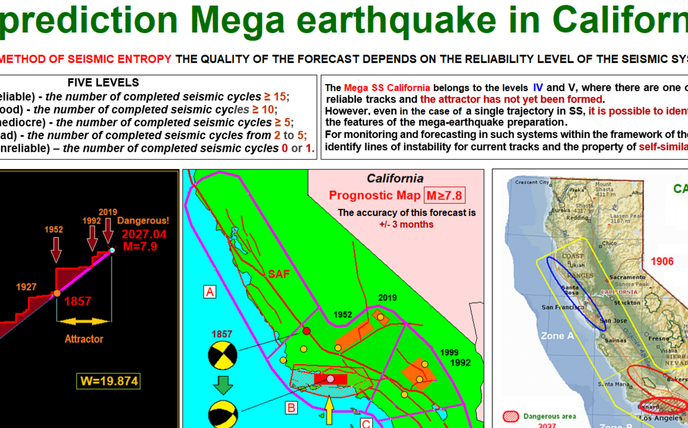

Such management includes an assessment of the expected damage from the forecasted earthquake, offers a set of necessary measures and estimates the amount of financial and economic assistance at different stages before and after the disaster (in the organization of rescue and recovery operations). Management before and after a possible disaster will be automatically compiled on-line depending on the predictive location, strength and time of the expected earthquake, taking into account the level of development and national peculiarities of those countries potentially caught in the impact zone of the predicted catastrophe.

## SS Central California M5.8+ and SubSystem Parkfield M5.5+

**San-Simeon 22.12.2003, Ms=6.4 and Parkfield 22.09.2004, Ms=5.6 earthquakes prediction**

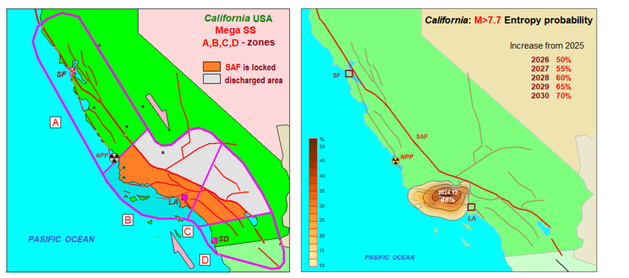
An explanation was given "Why the Parkfield experiment in California (1985-1988) failed?"

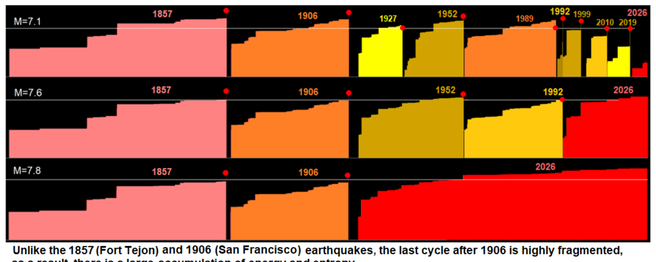


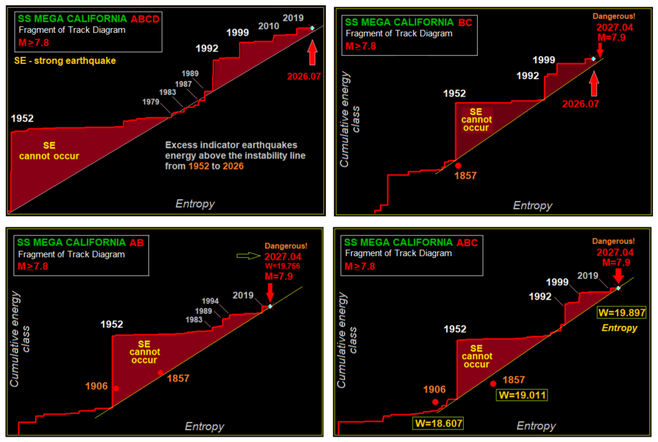

## Monitoring & prediction Mega earthquake in California by the MSE

## CALCULATIONS FOR THE CALIFORNIA ABCD, AB, ABC, BC MEGA SYSTEMS




Unlike the 1857 (Fort Tejon) and 1906 (San Francisco) earthquakes, the last cycle after 1906 is highly fragmented, as a result, there is a large accumulation of energy and entropy




The large accumulated entropy values compared to the mega earthquakes of 1857 and 1906 mean that SAF is locked

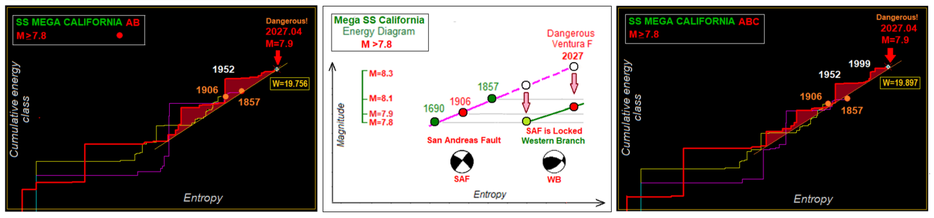
## IN THE METHOD OF SEISMIC ENTROPY THE QUALITY OF THE FORECAST DEPENDS ON THE RELIABILITY LEVEL OF THE SEISMIC SYSTEM

**FIVE LEVELS**

I level (reliable) - *the number of completed seismic cycles* ≥ 15;
II level (good) - *the number of completed seismic cycles* ≥ 10;
III level (mediocre) - *the number of completed seismic cycles* ≥ 5;
IV level (bad) - *the number of completed seismic cycles from* 2 to 5;
V level (unreliable) – *the number of completed seismic cycles* 0 or 1.

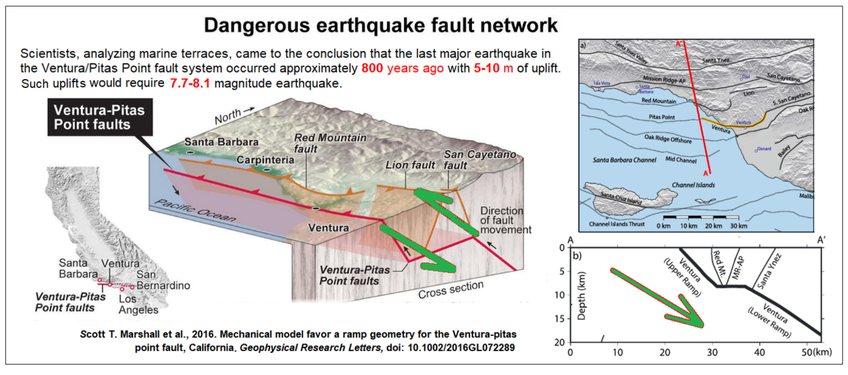
**The Mega SS California belongs to the levels IV and V, where there are one or two reliable tracks and the attractor has not yet been formed.**
**However, even in the case of a single trajectory in SS, it is possible to identify the features of the mega-earthquake preparation.**
**For monitoring and forecasting in such systems within the framework of the MSE, we identify lines of instability for current tracks and the property of self-similarity SSs.**



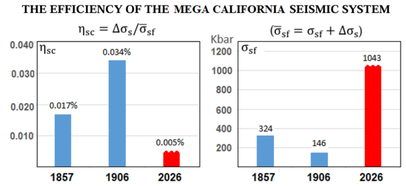

## Dangerous earthquake fault network

Scientists, analyzing marine terraces, came to the conclusion that the last major earthquake in the Ventura/Pitas Point fault system occurred approximately 800 years ago with 5-10 m of uplift. Such uplifts would require 7.7-8.1 magnitude earthquake.




Scott T. Marshall et al., 2016. Mechanical model favor a ramp geometry for the Ventura-pitas point fault, California, *Geophysical Research Letters*, doi: 10.1002/2016GL072289

## THE EFFICIENCY OF THE MEGA CALIFORNIA SEISMIC SYSTEM




The efficiency coefficient of the seismic system determined by the MSE (Akopian 1995)

$$\eta_{sc} = E_s / (\xi \ln(10)\, S \lg(S) + E_s) \quad \text{where} \quad \xi = E_s/(E_s + E_t)$$

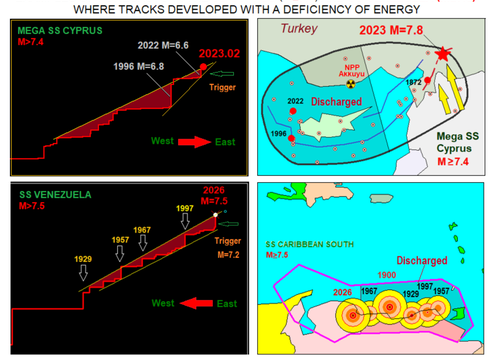
It differs significantly from the efficiency coefficient of an earthquake source in seismology (Kasahara 1985;Wiss & Brune 1971). A new interpretation is that the preparation of a strong earthquake occurs not locally in the source zone, but in the volume of the SS. The lower the coefficient $\eta_{sc}$, the greater the effort required by the system to generate a strong earthquake.

Calculations show that for the **1857** and **1906** earthquakes with focal strike-slip mechanisms associated with the SAF, the efficiency coefficients were high (dissipations were low), while now in **2026** it is very small. As a result, enormous stresses accumulated in the SS.

From our experience, we know that in such cases, transform faults become locked and faults with thrust mechanism begin to activate, requaring greater forces from the system.

A similar situation we observed in the Mega SS Armenian Upland during the preparation of the Van earthquake of 2011.10.23, M=7.1 with thrust mechanism, when the North Anatolian Transform Fault was locked.

## EXAMPLES OF FORECASTS IN THE SS CYPRUS (M≥7.4) AND SS VENEZUELA (M≥7.5) WHERE TRACKS DEVELOPED WITH A DEFICIENCY OF ENERGY



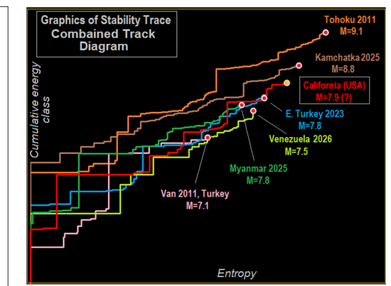

**Mega SS CALIFORNIA: earthquake prediction with $M_S$>7.8.**

Mega SS California ABC belongs to the category of poorly defined. There were two catastrophic earthquakes in 1857 and 1906. The trajectory preparation of the catastrophic earthquake at the 2026 already bypassed zones of instability these earthquakes and accumulated abnormaly high values of cumulative energy and entropy. The hazard is localized in Southern California, NW of Los Angeles.

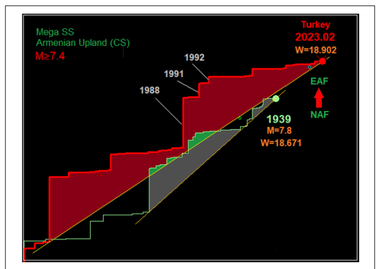
Estimates based on the MSE and its latest developments show that the San Andreas Fault's segment in the Los Angeles area **is locked** and the instability is localized in the fault area of Ventura-Pitas Point to Santa Barbara. Here **by April 2027** a catastrophic earthquake with **M=7.9** with a near-vertical displacement (by thrust mechanism) can be prepared.

Research shows that the last catastrophic earthquake occurred here about 800 years ago.

The accuracy of the forecast in time +/- 3 months, in magnitude +/-0.1.
The predicted earthquake will not have a strong foreshocks.




Combining the California Mega Earthquake preparation track with the tracks of recent mega earthquakes in the world.

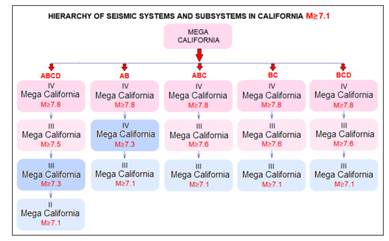



The current seismic situation in Southern California is very similar to that of Eastern Turkey. Calculations in the Mega SS Armenian Upland have shown that the preparation of catastrophic earthquakes in Eastern Turkey on Feb.6 with M=7.8 and M=7.5 was caused by significant activation in the Caucasus through the Spitak earthq. of 1988, M=7.0 and two Georgian earthquakes, Racha on 1991, M=6.6, and Barisasakho on 1992, M=6.4. The figure shows that, unlike the preparation of the Erzincan earthquake 1939, these three earthquakes significantly lifted the track and contributed to the accumulation of relatively higer entropy values by 2023.

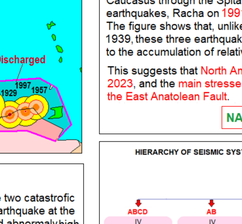
This suggests that North Anatolean Fault had already been locked by 2023, and the main stresses on the eastern Anatolean Plate migrated to the East Anatolean Fault.

NAF ⇒ EAF

## HIERARCHY OF SEISMIC SYSTEMS AND SUBSYSTEMS IN CALIFORNIA M≥7.1




## Entropy, Seismology and the View of Cosmology: *Origin and Evolutionary Theory*




**The theory of Entropy Seismology described in detail in the book and articles**

**Geophysical Journal International**

Samvel Akopian and Armen Kocharian
**Critical behaviour of seismic systems and dynamics in ensemble of strong earthquakes**
*Geophys. J. Int.* **2014**, **196**, 580-599
doi: 10.1093/gji/ggt398

Samvel Akopian
**Open dissipative seismic systems and ensembles of strong earthquakes: energy balance and entropy funnels**
*Geophys. J. Int.* **2015**, **201**, 1618-1641
doi: 10.1093/gji/ggv096

## ACCURACY OF THE SEISMIC ENTROPY METHOD

- **Time:** 6 months to 1 week, depending on the specific situation;
- **Magnitude:** ± 0.1M, large deviations in magnitude are discussed separately;
- **Location:** epicenter and depth is limited by the size of the seismic system and can reach the characteristic size of the source of the expected earthquake.

## A NEW APPROACH TO FORECASTING

- If there is a forecast of strong earthquake within a seismic system, then a strong earthquake is automatically excluded in other places within the seismic system;
- depending on the development of the seismic situation, the forecast results may change and be refined over time. Instability can migrate within the seismic system from one fault zone to another, the predicted waiting time for an earthquake can move away or get closer and, accordingly, the magnitude of the expected earthquake can change;
- depending on the level of knowledge about the region and earthquake data, SSs are divided into five levels: reliable, well-defined, mediocre, poor, and unreliable, and the forecast quality is subdivided accordingly.
- elements of the seismic system in a limited time interval (from 1 to 6 months) may be in an unstable state, and if during this time a strong earthquake does not occur, then after this period the system returns to a stable state.

## ADVANTAGES OF THE METHOD

- does not require the creation of new monitoring networks;
- allows to create dynamic maps of seismic hazards and improve the construction standards;
- allows to control induced seismicity;
- allows to monitor both land and seabed during all stages of earthquake preparation;
- the monitoring parameters are stable and reliable, and calculated based on data from global and local seismological networks;
- allows to visualize the process of preparing strong earthquakes;
- allows to improve the accuracy of forecasts over time;
- allows to increase the efficiency of existing methods of earthquake prediction.