

# INFORMATION THEORIC FRAMEWORK FOR THE EARTHQUAKE RECURRENCE MODELS : *Methodica Firma Per Terra* *Non-Firma*

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**Abstract.** This paper first evaluates the earthquake prediction method (1999 ) used by US Geological Survey as the lead example and reviews also the recent models. Secondly, points out the ongoing debate on the predictability of earthquake recurrences and lists the main claims of both sides. The traditional methods and the "frequentist" approach used in determining the earthquake probabilities cannot end the complaints that the earthquakes are unpredictable. It is argued that the prevailing "crisis" in seismic research corresponds to the Pre-Maxent Age of the current situation. The period of Kuhnian "Crisis" should give rise to a new paradigm based on the Information-Theoric framework including the inverse problem, Maxent and Bayesian methods. Paper aims to show that the information- theoretic methods shall provide the required "Methodica Firma" for the earthquake prediction models.

**Keywords:** Earthquake Prediction, Earthquake Probabilities, Earthquake Models, Information-Theoric Methods

## 1.0-) INTRODUCTION

This paper has the "Great Expectations" to end the complaints of the seismologists that the earthquakes are unpredictable and to replace the traditional methodology with the new one based on the Information-Theoric Framework. In words of Charles Dickens (1812-1870) "*It was the best of times,... it was the Age of Wisdom,...*", we are living in an Extraordinary time at the turn of the Millennium, Age of Information...

On 17 August 1999, a destructive magnitude 7.4 earthquake occurred 100 km east of Istanbul on the North Anatolian Fault. What is the probability of an earthquake of  $M=7.4$  will occur before the year 2030 in Istanbul? A group of seismologists found a  $62 \pm 15$  percentage probability of such a strong shaking in the Istanbul area.(Parsons,et.al.,2000)[1]. The US Geological Survey (USGS) estimated the probability of  $M=6.7$  or greater earthquake that will occur in the San Francisco Bay Area to be  $70 \pm 10$  percent before 2030, as cited and analyzed by Freedman and Stark (2000)[2].

International Conference during 1-4 Nov. 2005 in Lisbon, on the occasion of the 250th Anniversary of the 1755 Lisbon Earthquake that influenced not only Portugal but the all Europe and North African countries, was to foster an integrated view of global perception of natural disasters. [<http://www.lisbon1755.org>]

100th Anniversary of the 1906 San Francisco Earthquake was held during 18-22 April 2006 also included the Centennial Meeting of the Seismological Society of America, where the next 10 steps our communities must take to avoid catastrophic disasters. [<http://www.1906eqconf.org>]

According to Geller (1999) [3] "Earthquake prediction", is regarded as an alarm of an imminent large earthquake, with enough accuracy and reliability to take measure such as the evacuation of cities and longer-term forecasts of seismic hazards or statistical forecasts of aftershock probabilities are not to be classified as "predictions". Paper maintains that the attempts to forecast or predict earthquake occurrence can be studied chronologically under 3 types of models:

1-) Models developed between years 1968-1976 can be designated as the "First Generation Models" that were based on earthquake probabilities independent of time and geographical location.

2-) "Second Generation Models" during the next two decades introduced the space and time dimension by considering the local geological and seismological conditions in the estimation of random probabilities.

3-) "Third Generation Models" developed after 2000, in addition to the above considerations, compute probabilities with respect to the "interactions" between the local stress changes and the occurrence of large and small earthquakes.

This paper regards articles by T. Parsons (et.al., 2000) and A. Hubert-Ferrari (et.al., 2000)[4] on the 17.August.1999 earthquake in Istanbul and Izmit provinces as the examples of the above 3rd Generation Models. Both articles take into account the new concepts of earthquake interaction, in which the renewal of stress on faults is perturbed by transfer of stress from nearby events.

## **2.0-) THE US GEOLOGICAL SURVEY (USGS) EARTHQUAKE FORECAST-1999**

Freedman and Stark (2003)[2] in their paper ask "What is the chance of an earthquake of magnitude  $M=6.7$  or greater will occur before the year 2030 in the San Francisco Bay Area?" and interpret the US Geological Survey estimate as  $(0.7 \mp 0.1)$  where 0.1 is an uncertainty estimate. Authors review the "Frequentist" and "Bayesian" approaches, Laplace's "Principles of Insufficient Reason" and suggest that Kolmogorov's mathematical probability axioms seem the most promising ones for the earthquake prediction. Secondly, authors examine the problems in applying standard definitions of probability to earthquakes by taking the USGS-1999 Forecast as their lead example. According to Freedman and Stark's (2003, *ibid*) analyses, the USGS Forecast for the San Francisco Bay Area was constructed in two stages. The first stage constructed a collection of 2000 models, consistent with regional tectonic slip constraints, in order to estimate seismicity rates as a function of magnitude for each seismic source. The second stage aims to estimate the earthquake probability of a large earthquake. The main steps in these two stages can be summarized as follows with simplifications.

### ***2.1-) Stage-I: Main Steps***

- (i) Map faults and identify fault segments with slip rates at least 1mm / year.
- (ii) Represent uncertainty in fault segment lengths, widths and slip factors as independent Gaussian random variables with zero mean. Draw a set of slip factors at random from that probability distribution.
- (iii) Choose at random one of the 3 generic relationships between fault area and moment release to characterize magnitudes of events. Represent the uncertainty in the generic relationship as Gaussian with zero, independent of fault area.
- (iv) Using the chosen relationship and assumed probability distribution for its parameters, determine a mean event magnitude by Monte Carlo simulation.
- (v) Adjust the relative frequencies of each seismic source and its geologic slip rate.
- (vi) Repeat the steps until 2000 regional models meet the slip constraint.
- (vii) There are background events not associated with those faults. Estimate the background seismicity as a marked Poisson process. Extrapolate the Poisson model to  $M \geq 6.7$

### ***2.2-) Stage-II: Main Steps***

The second stage fits Poisson, "Brownian Passage Time" and "Time-Predictable" stochastic models for earthquake recurrence to long-term seismic rates estimated in the first stage. At the end, these 3 types of stochastic models are combined to estimate the probability of a large earthquake.

"Brownian Passage Time Model" has been developed by Matthews (1988) in which earthquakes occur when a state variable reaches a fixed threshold ( $Y_f$ ), at which time a state variable returns to a fixed ground state ( $Y_0$ ). In the model, the loading of the system has two components, a constant-rate loading component ( $\lambda t$ ), and a random component, ( $\varepsilon(t)$ ), that is defined as Brownian motion or random walk (Ellsworth, et.al., 1999)[5].

The Poisson and BPT models were used to estimate the probability that an earthquake will rupture each fault segment.

A "Time-Predictable Model" was used to estimate the probability that an earthquake will originate on each fault segment where the calculations needed the state of stress before the date of the last event and the slip during the last event. However, this model could not be used for many Bay Area fault segments because of the lack of such data. The conclusions by Freedman and Stark (2003) for the USGS (1999) earthquake forecast method can be summarized as follows:

- (i) Many steps involve models that are largely not testable,
- (ii) Frequencies are equated with probabilities; outcomes assumed to be equally likely,
- (iii) None of the standard interpretations of probability applies.
- (iv) Subjective probabilities used in ways that violate Bayes' Rule.
- (v) Many sources of error have been overlooked in the uncertainty estimate (0.1) in the USGS forecast ( $0.7 \mp 0.1$ ).
- (vi) Another large earthquake in the Bay Area is inevitable. Instead of making forecasts, the USGS could help to improve building codes.

### **3.0-) ARE EARTHQUAKES PREDICTABLE?**

Can the time, location and magnitude of future earthquakes be predicted reliably and accurately? On this issue, there is a continuing debate between the optimistic and pessimistic views. This section briefly summarizes the claims of both sides.

#### ***3.1-) Claim-1: "Earthquakes cannot be predicted"***

(i) Because large earthquakes release huge amounts of energy, many researchers have thought that there ought to be some precursory phenomena and used as the basis for making reliable predictions. There are strong reasons to doubt that such precursors exist. Large numbers of observations of allegedly "anomalous" phenomena like seismological, geodetic, hydrological, geochemical, electromagnetic, animal behavior and so forth, have been claimed as earthquake precursors, but in general, the phenomena were claimed as precursors only after the earthquakes occurred. There are no objective definition of "anomalies", no quantitative physical mechanism links the alleged precursors to earthquakes; statistical evidence for correlation is lacking. (Geller, et.al., 1997).[6]

(ii) There was intense optimism about prediction in the late 1960s and mid-1970s, because "plate tectonics" was regarded as the explanatory theory of the seismic source of earthquakes. However, plate tectonics do not allow either short-term or long-term prediction with success beyond random chance; although some controversy still lingers. (Geller, 1999a) [7].

(iii) The Earth's crust, where almost all earthquakes occur, is highly heterogeneous, as in the distribution of strength and stored elastic strain energy. The earthquake source process seems to be extremely sensitive to small variations in the initial conditions. There is complex and highly nonlinear interaction between faults in the crust, making prediction yet more difficult. (Geller, 1999) [3].

(iv) The prediction scenarios were not stated as testable hypotheses. (Geller,et.al., 1997) [6].

(v) The field is not yet sufficiently mature to address the uncertainty in most cases.

(vi) We don't have sufficient numbers of events to establish cause -and- effect relationship.( Aceves and Park,1997 ) [8].

#### ***3.2-) Claim-2: "Earthquakes can be predicted"***

(i) Prediction efforts in other fields, such as weather prediction have slowly made progress in the face of great difficulties, why should earthquake prediction cannot be the same?

(ii) There are no enough data available to say whether or not earthquakes are predictable. We need new observations to find earthquake precursors. However, there are examples of clearly formulated even tested hypotheses (Wyss, 1997)[9]. We should continue searching statistical methods to evaluate claims to test hypotheses quantitatively.

(iii) The proponents of the claim that "Earthquakes cannot be predicted" should have added "with the current knowledge" to their claim. (Wyss, 1997 *ibid.*).

#### **4.0-) RECONCILING THE DEBATE: INFORMATION THEORIC FRAMEWORK**

The brief summary of the current state of the earthquake prediction shows that there are profound differences of views between the supporters of claims above. The continuing fiery debate reminds us T. Kuhn's (1970)[10] accounts of scientific activity where he argued that, contrary to the common opinion, progress in the Natural Sciences has not been "cumulative", i.e., building of advances one on top of another but by "scientific revolutions" that contributes to "paradigm change". A "paradigm" represented the existence of a coherent, unified viewpoint, a kind of *Weltanschauung* which determines the way a group of practitioners function during times of what Kuhn calls "Normal Science" sooner or later, problems of a quite different order arise. Things begin to go wrong. A period of "Extraordinary Science" or "Crisis" sets in. The scientific community focuses on the perceived "Anomaly" and is forced to reexamine its own paradigm. A new paradigm is established by a reconstruction of the field from new fundamentals as a response to crisis. The Kuhnian view of scientific growth can be represented as follows:

Existing Paradigm → Normal Science → "Anomalies" → Crises → Extraordinary Science → "Scientific Revolution" → New Paradigm

In short, by considering the controversial views on the earthquake prediction methods, it can be argued here that we are living in a state analogous to Kuhnian "Extraordinary Science" period. As Kuhn (1970, pp.111-135) points out, a change in the paradigm involves not just the discovery of new facts; but seeing the old "facts" in a new way, e.i., as in a Gestalt Switch, a true change in overall Worldview. For the maxent scientific community, it is clear that the prevailing debate on the predictability of earthquake probabilities and USGS methods, as described in this paper, depend on the traditional probability concepts of the Pre-Maxent Age. In other words, the controversial claims on the earthquake predictability describe a "Crisis" period that shall and should lead to the adoption of the information-theoric framework as the new paradigm. Such an expected achievement shall establish the scientific ground for the emergence of the Fourth-Generation Models, introducing also Bayesian and inverse problem methods to the field of seismic studies.

As Ellsworth (et.al.,1999) [5] explains, a number of candidate statistical models have been proposed for the computation of probabilities of future earthquakes, such as Poisson, Double Exponential, Gamma, Gaussian, Weibull and Log-Normal.

Ellsworth (et.al.,1999) complaint that "At the present, it is not possible to discriminate between such candidate models. The prediction obtained from these specific models differ significantly from one another". Yet, the memoryless Exponential distribution is the basis of new US National Earthquake Hazard Map. (Freedman and Stark, 2003).

Definitely, Maxent provides the required toolkit to solve such problems. Long time ago, Tribus (1962) [11] has shown us how to select among the candidate generic probability distribution models that are "*maximally consistent with the known information*".

## 5.0-) CONCLUSIONS

The following conclusions can be drawn from the above descriptions and explanations :

(i) The methods used by USGS, up to this date, are based on the "Frequentist" approach in developing earthquake recurrence models. It seems that similar traditional methods are used by the "Working Groups on Long-Term Earthquake Probabilities" at research organizations in other countries also.

(ii) There is a continuing debate on the predictability of earthquake probabilities. The existing situation can be resembled to the "Crisis" period, in Kuhnian (1970) terminology.

(iii) For the resolution of the debate and the selection of appropriate earthquake probability distribution models, information-theoric methods are to be introduced to the field of seismic research: *It is the best of times to start...*

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