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SIGNALS, ANIMAL RESPONSE AND EARTHQUAKE

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ABSTRACT

Most of the modern researches on animal behavior dates back to the mid seventies. There is no significant design or method for understanding "animal behaviour for earthquake prediction", though international researches have been carried out especially in China, Japan and USA. These researches mainly rely on particular animal behaviour changes due to several simulated earthquake environment and based on previous earthquake statistics. However, animal produces numeral behaviours, and it is ambiguous to rely on particular behaviour rather than elaborate system. This paper aims to describe the circular model of energy flow during earthquake, similar to a damping oscillator. The energy flow is compared to a power inverse law .The energy spread at long distances are linked to animal sensitivity level. Animal signals are produced in the form of acoustic, chemical, electromagnetic signals. These signals are important in applying for recognition of nearby calamities such as earthquake. Then methods of data collection for such parameters are emphasized along with the reason for targeting a group of species as reference - rather than many. Animals are sensitive to weak signals which are often unnoticed even by the subtle instruments and measuring techniques. So a method for earthquake prediction based on signal variations in nature and animal responses is proposed. The explicit reason for animal based prediction model is explained in terms of biological and physical factors. The data collection and processing method is an integrated model of different types of signal analysing techniques. An integrated processing method increases efficiency of the system through comparison and mathematical analysis. Animals react to environmental changes and their reaction accompanies different behaviour changes. This response to stimuli involves pheromone secretions and homoeostasis rate variations. An earthquake induces such changes to highly sensitive species. An integrated analyser can be used to detect pheromone level along with other environmental variations to forecast a nearby disaster.

Keywords: *Animal reactions, Bessel function of first kind, Kleiber's law, Earthquake.*

1. INTRODUCTION

Prediction system used by seismologists has primary goals of determining the fault zones. Prediction by statistics of previous earthquakes needs record of destructive earthquakes. This requires collection of data from seismic events. Data of this sort has gathered slowly because such events are rare, limited range of the instruments and large number of data that could be recorded[1.]
Earthquakes generally, not necessarily, are preceded by some signals[2]. Animals detect environmental signals down to the thermal noise limit [Block, 1992].Multimodal communication (involving more than one sensory mode - e.g. chemical, acoustic, seismic, visual, and/or tactile) is common throughout the animal kingdom [*Bradbury & Vehrencamp 1998; Partan & Marler 1999*].Animals from a wide range possesses magnetic sense and use magnetic compasses to orient [*Wiltschko and Wiltschko, 2006*].Sea turtles are thought to use geomagnetic field to migrate (Light et al, 1993). Non-migratory animals like rats [*Burda et al. 1990*], mice [Mather and Baker1981] also possess magnetic sense. Previous studies for earthquake prediction system were based on behaviour rather than signals. And much of the studies on such topic are inadequate due to lack of funding and risk of professional reputation [*Tributsch et.al, 1982*].Scientists lack of interest for research on this field is because the main topic is linked to geophysics while animal behaviour is mainly studied by biologists. The ultimate signals found after detection adds a lot of noise in its path and original signals are hard to recover [*Fundamentals of earth.pred, Cinna Lomnitz*].So

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the introduction of new methods is a demand of time.

Although, animals behave abnormally prior to an earthquake, this paper describes the fundamental forms of animal signals .The reason behind this is signals are based on some primary forms. And signals carry information, while some signals may be triggered in an environment by the result of behavioural response. Through course of random mutation and natural selection, even a rare fraction of species might evolve to avoid events that cause death or reduce fitness .For many organisms, behavioural action taken prior to earthquake could reduce mortality[1].

2. ANIMALS AND EARTHQUAKE

Animals are sensitive to stimulus. In certain cases it outreaches Human precision .The following graph shows the estimated "Frequency ratio"(ratio of total number) of animals reacting to earthquake at different distances from epicentre. The distances are in kilometres. Data collected from [*Buskirk et al.1981*]

Table1: The table shows the approximate proportion of animals reacting to earthquake at different distances from epicentre.

Approximate distance	Approximate frequency distribution of animals reacting
Epicentre area	*39*
20-50km	*26*
70-100km	*21*
150-200km	*15*
Greater than 250km	*6*

The graphical representation of the above data is shown in a two dimensional graph with the vertical axis for approximate frequency distribution of animals reacting;
the horizontal axis shows the approximate distance from epicentre. The curve is approximate and data collected from many sources [Buskirk et al,1981]

The curve is similar to a energy distribution system with decreasing energy. The similarity is further compared in later sections.

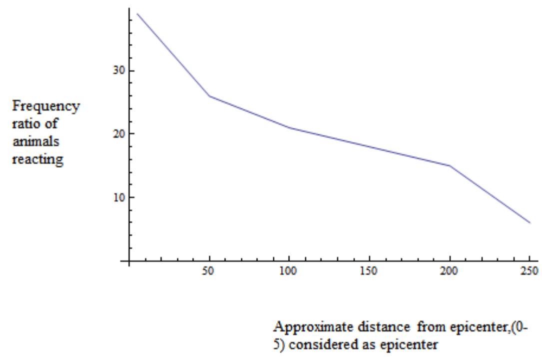

Figure 1: Graphical representation of Table 1.

3. ENERGY DISTRIBUTION

The earth can be compared as a sphere. The earthquake is a result of energy flow along the plates of the earth. The process of energy flow can be compared to a heat flow process along a sphere.

Let, the initial temperature is T_0 and reaches a temperature T_1. The r is the distance from the centre. The equation for unsteady state heat transfer to a sphere is given by:

$$\frac{\partial^2 T}{\partial r^2} + \frac{2}{r}\frac{\partial T}{\partial r} = \frac{1}{\alpha}\frac{\partial T}{\partial t}$$

Boundary conditions;

$$T = T_0 \quad \text{at } t = 0, r > 0$$

$$T = T_1 \quad \text{at } t = \infty, r > 0$$

$$\frac{\partial T}{\partial r} = 0 \quad \text{at } r = 0, t > 0$$

In terms of parametric equations we can derive as follows.

$$T = f(r)g(\theta)$$

therefore;

$$f''g + \frac{2}{r}f'g = \frac{1}{\alpha}fg'$$

which forms

$$\frac{f''}{f} + \frac{2}{r}\frac{f'}{f} = \frac{1}{\alpha}\frac{g'}{g} = -\lambda$$

The final equation is a Bessel's form ;

$$r^2 f''(r) + 2rf'(r) + \lambda r^2 f(r) = 0$$

The energy flow in earthquake can be thus compared to a distribution of the Bessel's function. The energy is a absolute term, so here only the

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positive values of the Bessel's function are taken .The iso-seismal graph on the following figure shows the lines with similar intensity of earthquake. The animal response curve is also similar to the gradients of the Bessel's solution of first kind.

Bessel's function of first kind:

f[x]= x^2 y''[x]+x y'[x]+(x-n)(x+n)y[x]==0

Derivative:

f'[x]=(-n+x)y[x]+(n+x)y[x]+y′[x]+(-n+x)(n+x)y′[x]+3xy′′[x]+x2 y"'[x]==0

Plot of the above function is below :

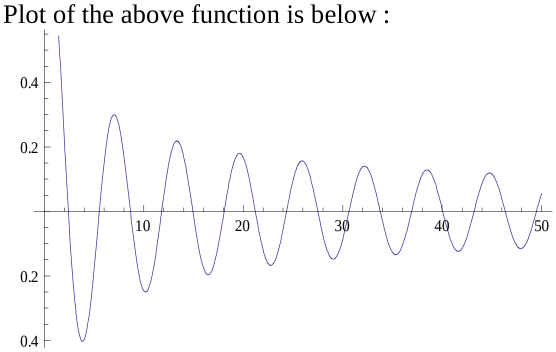

Figure 2: The maximum points for gradient zero are derived and list plotted on graph.

The maximum or peak values are plotted to show the gradient of the positive y axis of the above curve. The values inside braces are the x and y co-ordinates respectively.
{7.01559, 0.300116},
{13.3237, 0.218359},
{19.6159, 0.180063},
{25.9037, 0.156725},
{32.1897, 0.140606}

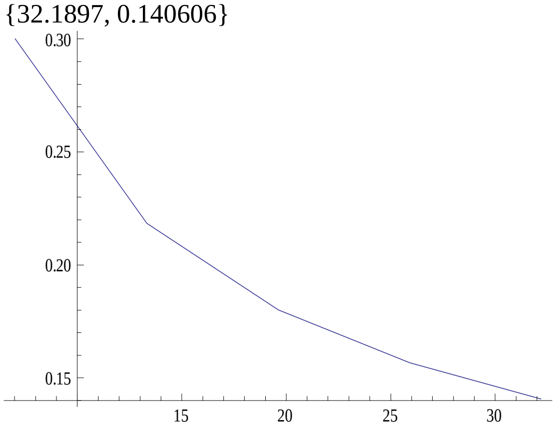

Figure 3: This figure has similarity to the Figure1.

4. ISO-SEISMAL GRAPH

The iso-seismal curve is similar to the nucleus of an atom, where some irregularities arise from the plate factors and fractals. So the energy distribution is ideally a spherical distribution. The Power law where a and k are constants

$$Logf[x] = kLog[x] + Log[a]$$

The pareto-distribution can be plotted from "mathematica" to show such relationship.

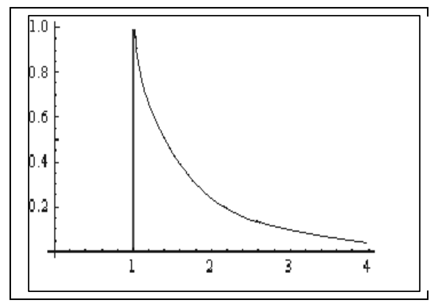

Figure 4: Pareto-distribution.

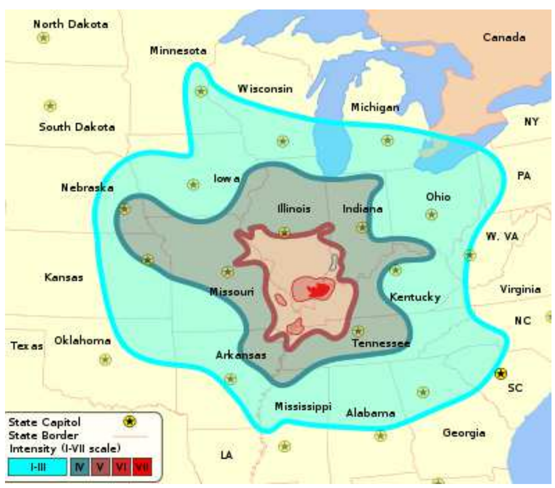

Figure5:*1968,Illinoisearthquake.*Source:,*http://earthquake.usgs.gov/regional/states/ev)*

The iso-seismal curve shows distribution of earthquake energy is a pareto-distribution process and often explained by power inverse law.Figure1 and Figure 3 has great similarity showing a relation between earthquake energy flow and animal response.

Image of the Recent Earthquakes by "Global Earth ExplorerGEE",12ly2011

The figure below shows the concentration of earthquake regions in a radial map. The triangles representing the earthquake regions are mostly around the circular line. Some of the epicentre

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extends outside the figure so some are not seen clearly on the following image.

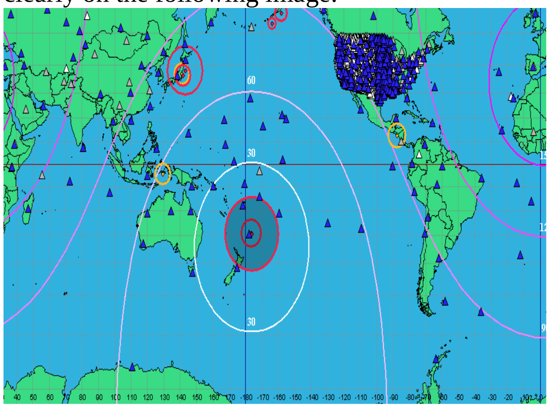

Figure 6: Radial mapping of recent earthquake.

Most of the events are located at some circular boundaries of the epicentre. To show the radial distribution of energy the above figure is shown.

5. BIOLOGICAL SIMILARITY

According to Modified Kleiber's law

Homeostasis rate ∞ (Body Mass) $^{3/4}$

The homeostasis rate decreases proportionately with mass increase. The figure illustrates the distribution.

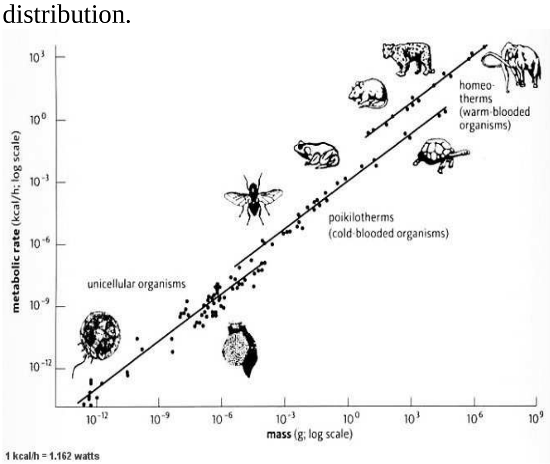

Figure 7: The figure illustrates the distribution.

The reason for stating Kleiber's law is for showing the relevance for targeting a group of species for earthquake prediction. The smaller sized animals comparatively produce more chemicals than bigger sized animals. So targeting them is important for recognising abnormality in environment.

The energy produced by an earthquake is assumed to be *E*.

Let two different animals- smaller one with body radius *r*, and larger one with *R*.

Here the energy is same as the work done on particular animal by the earthquake. So, Work done (W) = E=Force (F)*Distance

$$F_1 = \frac{W}{r}; \qquad F_2 = \frac{W}{R};$$

It is found :$F_1 > F_2$

Force on smaller body is greater and moment is greater for same earthquake energy. This means a weak signal which is unnoticed by big animals produces significant moment in smaller animals. As small animals produces observable chemical signals compared to large animals it is still important to analyse them for getting information at long distances from earthquake epicentre.

6. CLASSIFICATION OF ANIMAL SIGNALS

Animal sensitivity can be gleaned from: 1) Ground Tilting, 2) Humidity Changes, 3) Electrical Currents, 4) Magnetic field vibrations [1].

These might produce certain vibrations, electrical signals, electrostatic changes and electromagnetic field variations. And these are understandable by animals as already stated.

Acoustic signals- Variations among different species of birds are observed using audio spectrograms. Some of these techniques included filters, discrete Fourier transforms, cross-correlation, wavelets, cepstral analysis, and audio spectrograms [*Cai et al., 2007; Lee et al., 2006*].

The first signal processing technique necessary to identify sound is filtering. There are several filters Low-pass filter, High-pass filter, Band-pass filter, Band-reject filter .We choose the filter which suits the requirement. To identify weak signals Low-pass filters may be used. In identifying high frequency sounds a High-pass filter may be used. Band-pass and Band-reject filter may be used for a group of frequencies.

The second signal processing technique the team used was discrete Fourier transforms (DFTs).

The sequence of N complex numbers $x_0, \ldots, x_{N-1}$ is transformed into the sequence of N complex numbers $X_0, \ldots, X_{N-1}$ by the DFT.

According to the formula, where i is the imaginary unit and is a primitive N^{th} root of unity:

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Equation: Discrete Fourier Transform

$$X_k = \sum_{n=0}^{N-1} x_n e^{\frac{2\pi ikn}{N}} \qquad k = 0,....,N-1$$

Another signal processing technique used is cross-correlation. Cross-Correlation is a measure of similarity of two waveforms, also known as a sliding dot product or inner-product. Similarly, for discrete functions, the cross-correlation is defined as:

Equation: Cross Correlation

$$(f \star g)[n] \stackrel{\text{def}}{=} \sum_{m=-\infty}^{\infty} f^*[m]\ g[n+m].$$

Cross-correlation involves finding match between two signals. It is similar to the convolution of two functions but instead of reversing a signal before Multiplying and shifting it, correlation only involves multiplying and shifting (Cross-correlation).
The following correlation using "Sound_Analysis" shows the similarity between two different sounds "tutor" and "pupil" .The spectral analysis of both the samples are done using the above mathematics .And the similarity scores can be used to justify the matches of the signals to the reference one.

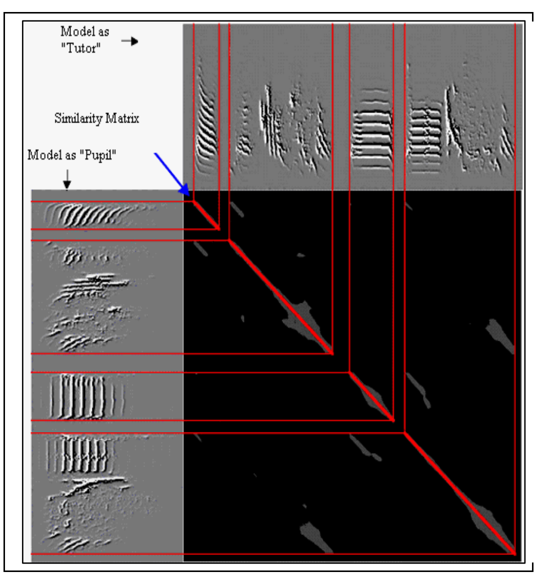

Figure 8: Cross-Correlation.

7. THE SYSTEM BLOCK DIAGRAM ALGORITHM FOR SOUND RECOGNITION-FLOWCHART

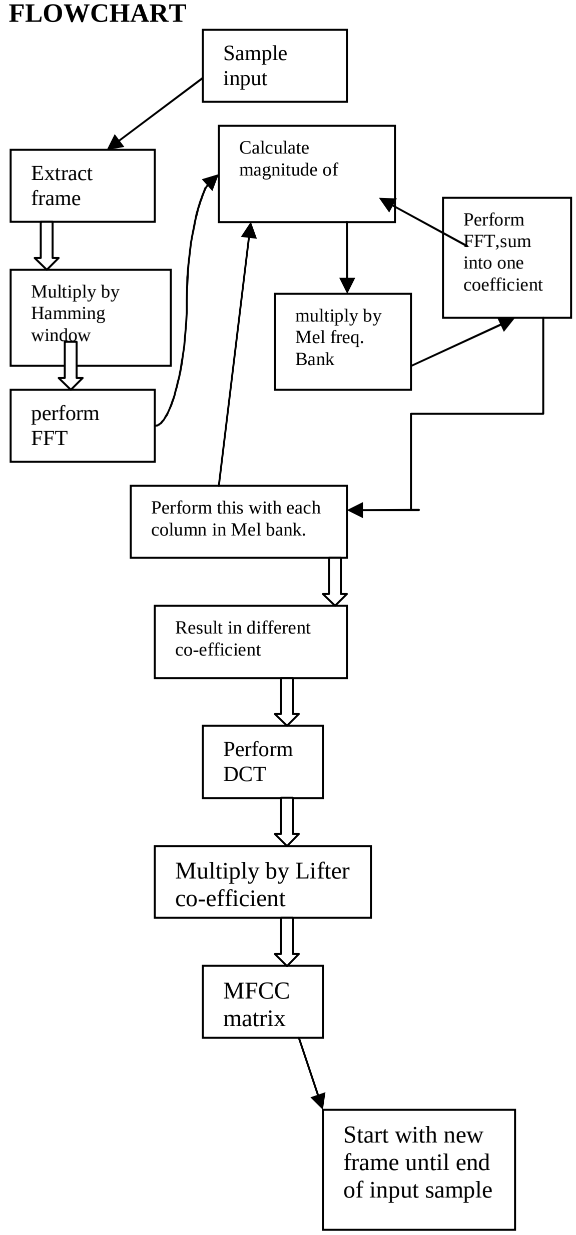

Figure 9: Sound Signal Analysis.

Source:("http://www.wpi.edu/Academics/Projects")
The elaborate process of a similar existing system for sound analysis is shown above.

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Chemical signals-
Although well established, the above introduced biochemical analytical methods such as chromatography, electrophoresis and mass spectrometry can only be used for the analysis of finite, discrete and time invariant samples. However, all biochemical processes in the real world involve some forms of continuous change and are actually dynamic processes[5].

Table2: Analogy

Basic Variables	Electrical circuit analysis	Fluid/circuit analysis
Variable 1	Voltage *V*	Pressure *P*
Variable 2	Current *I*	Volume flow rate *Q*
Variable 3	Resistance *R*	Hydraulic resistance

The animals like crustaceans produce pheromones and these chemicals diffuse in the air around them. The chemical concentration in certain environment varies for pheromone secretion. The concentrations are weak and often needs advanced analysis. The process is shortly given below:

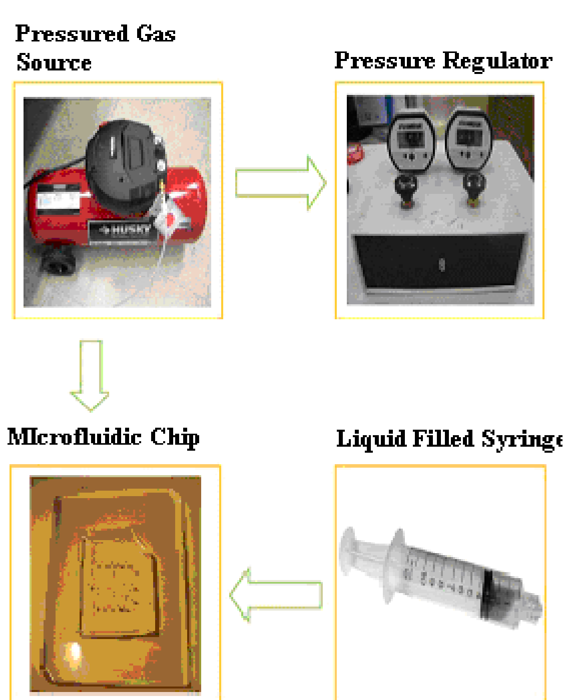

Figure 10: Chemical Signal Analysis.

Electromagnetic signals
Electrostatic magnetic signals can be observed directly from satellite using field variation map. Appearances of magnetic anomalies have been verified[10].The anomalies observed by a nearby source often accompanies animal electromagnetic signals. The cells react to electromagnetic changes[11].
Animal that responds to sound might produce sound signals. Crustaceans and smaller insects produce pheromones. Pheromones are often just one of the sensory channels (modalities) involved in communicating a signal[3]. Aquatic animal can sense low frequency signals well and produce electric and visual signals. Chemical reactions can be induced due to propagation of electromagnetic signals [11].

8. ANIMAL RESPONSE COMPARED TO HUMAN AND MACHINES

Tilt precursors appear to be in the range of few micro-radians acting over several hours before earthquake[1]. Human need at least tilts of approximately 0.1 radian or more from vertically to react to this stimulus [*Bisdroff et al.1996*], while animals are sensitive to such tilts [1].

9. INTEGRATED ANALYSER

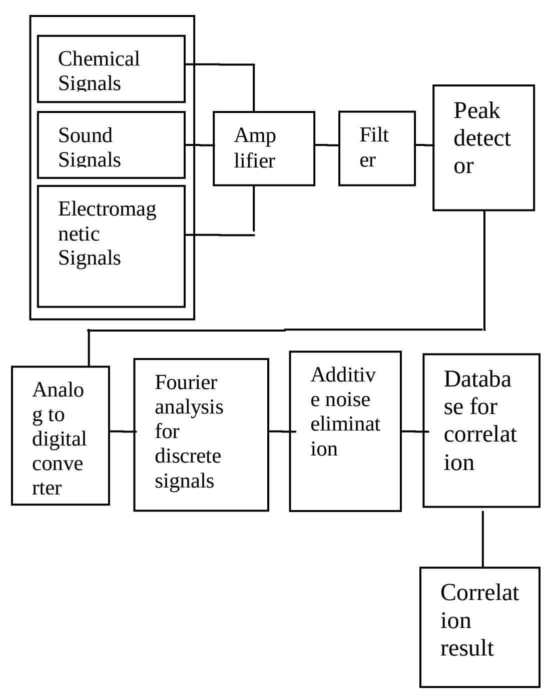

Figure11:Integrated Analyser Block Diagram.

The data collection process identifies the chemical, sound or electromagnetic signals. The amplified

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signal is filtered according to type of data .The peak detector checks the threshold of the data. It is further analysed and more methods can be added for further precision. Previous database is used to observe changes in environment and forecast earthquake.

10. CONCLUSION:

Our study of animal behaviour has found significant response by animal at large distances from the epicentre. So if the earthquake is predicted during the P-wave or if the earthquake is shifting in a direction this prediction model can be used to predict earthquake at time,

t=distance/speed, before the earthquake reaches that area. The energy is usually in the form of radiation and vibration. So speed is approximately the speed of electromagnetic waves. So if this system allows observing significant animal signals at a long distance, a successful prediction for earthquake is possible .Although, animal based prediction method is ignored according to history and geologist "*Jim Berkland*", it can be very useful

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