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Imminent Earthquake Forecasting on the Basis of Japan INTERMAGNET Stations, NEIC, NOAA and Tide Code Data Analysis

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Abstract

This research presents one possible way for imminent prediction of earthquakes' magnitude, depth and epicenter coordinates by solving the inverse problem using a data acquisition network system for monitoring, archiving and complex analysis of geophysical variables-precursors. Among many possible precursors the most reliable are the geoelectromagnetic field, the boreholes water level, radon earth-surface concentration, the local heat flow, ionosphere variables, low frequency atmosphere and Earth core waves. The title demonstrates that only geomagnetic data are used in this study. Within the framework of geomagnetic quake approach it is possible to perform an imminent regional seismic activity forecasting on the basis of simple analysis of geomagnetic data which use a new variable S_{ChtM} with dimension surface density of energy. Such analysis of Japan Memambetsu, Kakioka, Kanoya INTERMAGNET stations and NEIC earthquakes data, the hypothesis that the "predicted" earthquake is this with biggest value of the variable S_{ChtM} permits to formulate an inverse problem (overdetermined algebraic system) for precursor's signals like a function of earthquake's magnitude, depth and distance from a monitoring point. Thus, in the case of data acquisition network system existence, which includes monitoring of more than one reliable precursor variables in at least four points distributed within the area with a radius of up to 700 km, there will be enough algebraic equations for calculation of impending earthquake's magnitude, depth and distance, solving the overdetermined algebraic system.

Keywords

Earthquake's Prediction, Reliable Earthquake's Precursors, Geomagnetism, Inverse Problem

1. Introduction

It is well known now that the "when, where and how" earthquake's prediction problem cannot be solved by a

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only analyzing the earthquakes data base [1]-[5].

The role of the Sun-Moon Earth tides as possible earthquake's trigger has been analyzed in [6]-[13]. However the conclusion that the earthquake's time is correlated with the time of tidal extremes is not exact, because in some cases the beginning and the extremes of earthquakes do not coincide. There is an extreme but not an earthquake.

The role of the atmospheric and ionosphere electromagnetic phenomena which can serve as earthquake's precursors in the last time has been researched in many studies. Physical models of the observed phenomena were proposed in [14] and reliability of predictions was analyzed in [15] [16].

The heat released as earthquake's precursor was researched in [17].

The variations of regional water-level reflect fast deformational cycles in lithosphere and may also serve as an earthquake's precursor as one was demonstrated by G.S. Vartanyan [18]. The comparison of the daily geomagnetic fluctuations (geomagnetic quakes) and underground water level demonstrates that borehole water level data may serve as an imminent regional earthquake's precursor in the Caucasus region [19].

The analysis of data for radon concentrations and its fluctuations in the atmosphere and ground-water has been demonstrated in many studies (see [19] [21]). The most accepted result is that anomalous (increased regional concentration) of the radon emission can serve as a precursor of an earthquake.

The research of the correlation between variations of geo-electromagnetic field and impending earthquakes has a long-time history [22]-[36].

A comparative analysis of the two measured values in time of geomagnetic field with the calculation of the standard deviation (dispersion) in the same subintervals-periods of time allowed offering geomagnetic quake as an earthquake precursor [36].

The calculation of the differences (***DayDiff***) between the times of the earthquakes occurred in the region around the monitoring point and the nearest time of tide extremes permit to build the distribution of ***DayDiff***. It was established that this distribution is described well by Gauss curve with a certain width $\boldsymbol{W_{\mathrm{all}}}$.

Introducing a new variable S_{ChtM} with dimension surface energy density, which is a function of earthquake's magnitude, depth and distance to the monitoring point

$$S_{ChtM}(Mag, \mathrm{Depth}, \mathrm{Distance})$$

and the calculation of its value in the monitoring point permits to classify the earthquakes occurred in the monitoring region and in the time period around tide extremes time.

The distribution of ***DayDiff*** for earthquakes with the biggest value of S_{ChtM} is also described with Gauss curve, but with less width W_{pr}.

In the paper [37] the ***DayDiff*** for all world's 62,8873 earthquakes, occurred in the period 1981-2013, with *Mag* >= 3 (International Seismological Centre, http://www.isc.ac.uk/) was calculated and the distribution, described by Gauss curve with width $W_{\mathrm{all}} = 4.46 +/- 0.22$.

The distributions of ***DayDiff*** for earthquakes with the biggest S_{ChtM} calculation from the data of INTERMAGNET stations PAG (Panagurichte, BAS, Bulgaria, 1 January 2008 to 19 January 2013), SUA (SUA, Romania, 1 January 2008 to 17 January 2013) and AQU (L'Aquila, Italy, 1 January 2008 to 30 May 2013) were described by Gauss curves with widths 4.22 +/− 0.62, 4.11 +/− 0.51 and 4.28 +/− 0.67. So, one can say that the appearance of geomagnetic quake forecasts that in the next period around time of tide extreme and monitoring point region means an increase in the seismic activity.

There is a simple intuitive physical explanation [36] [38] of the fact that a geomagnetic quake is an earthquake's precursor:

- The increase of the strain before an earthquake is accompanied by electrochemical and electrokinetic effects which generate electrical currents in the epifocal volume;
- These currents, which can be identified using the geomagnetic quake approach.

The earthquake's preparing continues as follow:

- The preliminary stage of an earthquake is accompanied by negative divergence of the energy due to increased dissipation of tidal waves;
- The maximum of two time daily tides' acceleration leads to the transformation of this non-equilibrium state to a new balance that is closer to bifurcation, which explains the role of tides as an earthquake's trigger.

There is the hope that including the above described research of regional precursors in the common approach for solving the earthquake prediction problem (see the paper [39] and references there) will lead us to a solution.

In Section 2 is describing the approach for forecasting of imminent regional seismic activity on the basis of Japan geomagnetic data and Sun-Moon Earth tide to de data. In Section 3 is demonstrated the reliability of geomagnetic quake approach for the regions (700 km) of Memambetsu, Kakioka, Kanoya stations. In Section 4 is presented the description of precursor signal as a function of earthquake's magnitude, depth and distance. In Section 5 is presented the formulation of inverse problem for forecasting the magnitude, depth and epicenter coordinates of regional imminent earthquake

In **Application 1**, **Table 2** is present data for the stations, earthquake's date, latidude, longitude, depth, magnitude, the value of S_{ChtM} [J/km^2], the distance from station [km], the difference between the predicted time and the time of occurred earthquake [day], the values of experimetal and model precursor signal and its difference (Expt—Th). **Aplication 2** is presented the FORTRAN version of precursor signal function *PrecSigTh* (*Mag*, *Depth*, *Distance*).

2. Forecasting of Imminent Japan Regional Seismic Activity on the Basis of Geomagnetic and Sun-Moon Earth Tide Code Data

In this paragraph the data acquisition system for archiving, visualization and analysis is presented [36]-[38].

2.1. Description of the Approach—Figure 1

The data used:

• The Japan INTERMAGNET geomagnetic stations MMB (Memambetsu, Lat 43.907˚N, Lon 144.193˚E, Altitude = 42 m), KAK (Kakioka, Lat 36.232˚N, Lon 140.186˚E, Altitude = 36 m) KNY (Kanoya, Lat 31.42˚N, Lon 130.88˚E, Altitude = 107 m) minute data (http://www.intermagnet.org/);

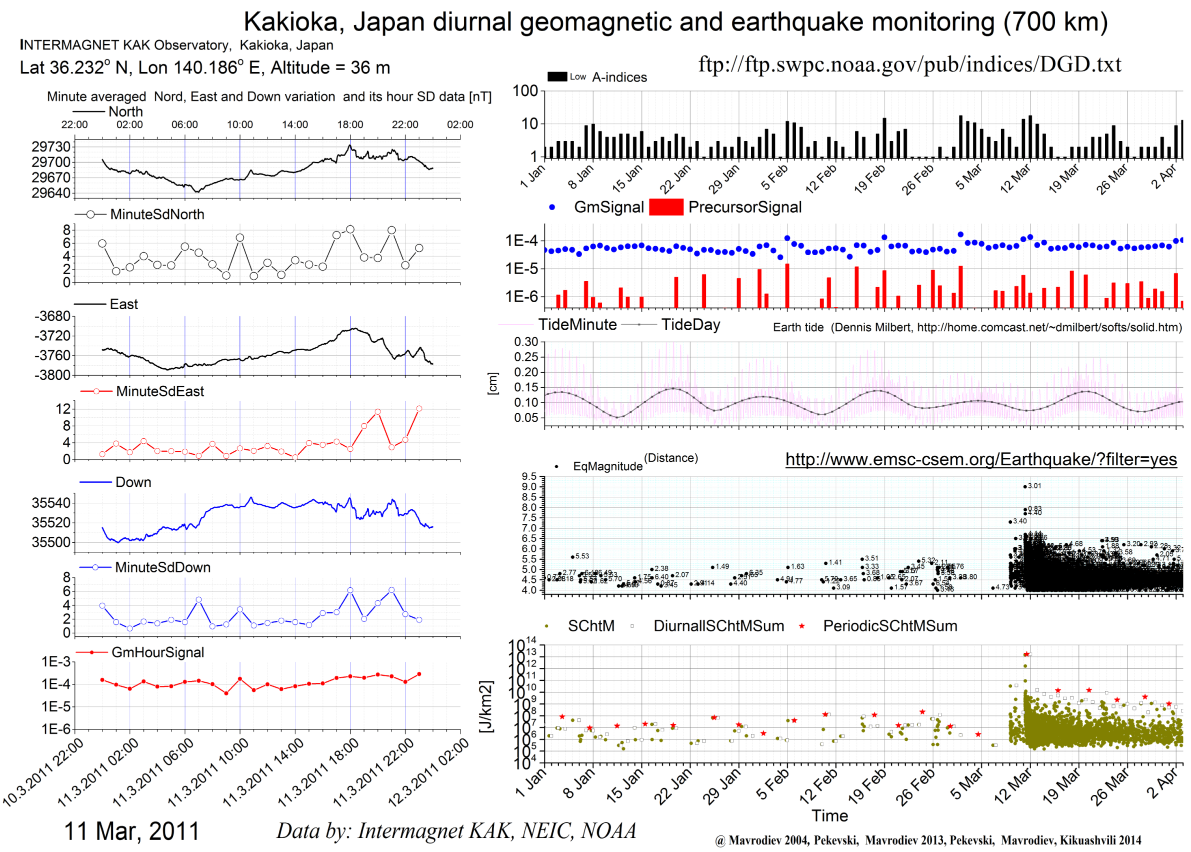

Figure 1. Kakioka diurnal geomagnetic and earthquakes monitoring in the time period around the Fukushima earthquake with geomagnetic field on 11 March 2011.

- The software for calculation of the daily and minute Earth tide behaviour [40] (Dennis Milbert, NASA);
- The Earth tide extremes (daily average maximum, minimum and inflexed point) as a trigger of earthquakes;
- The data for World A-indices, www.swpc.noaa.gov.

The geomagnetic signal is calculated as a simple function of relative standard deviations of the components of the geomagnetic vector. The precursor signal is the difference between today and yesterday's geomagnetic signal corrected by the A- indices values. As the increase of precursor signal means increase of geomagnetic field variability, we call such positive leap a geomagnetic quake in analogy with an earthquake. The analysis of the correlation between the earthquakes occurred and the time of Sun- Moon Earth tide extremes on the basis of the variable earthquake's surface energy density $\boldsymbol{S_{ChtM}}$ permits to forecast the imminent regional seismic activity. The calculation of the day differences (***DayDiff***) between the time of the earthquakes occurred and the time of the nearest Tide extreme permits to build the curve of ***DayDiff*** and its Gauss fit. The comparison of Gauss widths for all the earthquakes occurred and those with the biggest $\boldsymbol{S_{ChtM}}$ is basis for formulation the hypothesis for "predictable" earthquakes.

2.2. The Simple Mathematics and Description of Variables

The simple mathematics for the calculation of the precursor signal, the software for illustrating the reliability of forecasting and its statistic estimation and the variables in **Figure 1** are described as follows.

The Geomagnetic field components $\text{North}_m, \text{East}_m, \text{Down}_m$, m = 1440, are the minute averaged values of the geomagnetic vector F, and the variables $Sd\text{North}_h$, $Sd\text{East}_h$, $Sd\text{Down}_h$ are their standard deviation, calculated for 1 hour, $h = 1, \cdots, 24$):

$$Sd\text{North}_h = \sqrt{\frac{\sum_{m=1}^{60}\left(\overline{\text{North}_h} - \text{North}_m\right)^2}{60}} \tag{1}$$

where

$$\overline{\text{North}_h} = \frac{\sum_{m=1}^{60}\text{North}_m}{60} \tag{2}$$

The geomagnetic signal $Geom\text{Hour}Sig_h$ is the geometrical sum of hour standard deviation normed by the module of hour geomagnetic vector:

$$Geom\text{Hour}Sig_h = \sqrt{\frac{Sd\text{North}_h^2 + Sd\text{East}_h^2 + Sd\text{Down}_h^2}{\overline{\text{North}_h}^2 + \overline{\text{East}_h}^2 + \overline{\text{Down}_h}^2}} \tag{3}$$

The ***A*** indices are the Low, Medium and High indices, calculated by the NOAA, Space weather prediction center: www.swpc.noaa.gov. In this paper we use A_{low};

The variable $GmSig_{\text{day}}$ is the diurnal mean value of $Gm\text{Hour}Sig_h$:

$$GeomSig_{\text{day}} = \frac{\sum_{h=1}^{24} Geom\text{Hour}Sig_h}{24} \tag{4}$$

and $\text{Precursor}Sig_{\text{day}}$

$$\text{Precursor}Sig_{\text{day}} = 2\frac{GeomSig_{\text{day}} - GeomSig_{\text{yesterday}}}{Alow_{\text{day}} + Alow_{\text{yesterday}}} \tag{5}$$

The indices of earthquake's magnitude value are the distance in hundred km between the epicenter and the monitoring point.

The variable S_{ChtM} is the modified earthquake's surface energy flow density in the monitoring point:

$$S_{ChtM} = \frac{10^{(1.4Mag+4.8)}}{(40+\text{Depth}+\text{Distance})^2}\left[\text{J/km}^2\right] \tag{6}$$

The variable $\text{Periodic}S_{ChtM}\text{Sum}$ [J/km^2] is the sum of the variable S_{ChtM} for all earthquakes occurred in the time period +/− 2.7 days before and after the tide extreme in the 700 km region around the monitoring point. Obviously, its value can serve as estimation of the regional seismic activities for the time period around the tide's extreme.

The variable $\text{Diurnal}S_{ChtM}\text{Sum}$ [J/km^2 per day] is the sum of the variable S_{ChtM}, calculated for all earthquakes occurred during the day in the 700 km region around the monitoring point. This variable can serve as a quantitative measure of diurnal regional seismicity.

One has to note that the explicit form of the variable S_{ChtM} was established in the framework of inverse problem [41] [42] with the condition to have a clearer correlation between the variable $\text{Precursor}Sig_{\text{day}}$ and $\text{Periodic}S_{ChtM}\text{Sum}$.

The variable ***Tide Minute*** [cm] is the module of tide vector calculated every 15 minutes;

The variable ***Tide Day*** [cm] is the diurnal mean value in time calculated in the analogy of mass center formulae in many bodies' classical mechanics:

$$\text{Time}_{\text{TideDay}} = \frac{\sum_{m=1}^{360} m\text{TideDay}_m}{\sum_{m=1}^{360} \text{TideDay}_m} \quad (7)$$

Note: For seconds and more samples per second, the generalization has to calculate geomagnetic field characteristics for every minute and correspondingly the values of $\text{GmSig}_{\text{day}}$ have to be the average for 1440 minutes.

The positive value of the variable $\text{Precursor}Sig_{\text{day}}$ means that the geomagnetic field variability, which is calculated via standard deviations of geomagnetic fileld components, is increasing. In analogy with earthquake we call such increase a geomagnetic quake.

As one can see from **Figure 1**, after the appearance of a geomagnetic quake, in nine of twelve cases (75%), the regional seismic activity is increasing (the bigger value of the $\text{Periodic}S_{ChtM}\text{Sum}$ variable) in the time period aroundthe followingtide extreme. So, the geomagneticquake approach described can serve as a forecast of imminent regional seismic activity.

In **Figure 1** the values of the variable $\text{Periodic}S_{ChtM}\text{Sum}$ are calculated not only in the time periods around the extremes, but also in the time period between them. We can see that its values in almost every extreme period are higher.

The use of the above described analysis for a longer time period with calculation of distribution of day difference between the "predicted" earthquakes (earthquakes with the highest value S_{ChtM}) can demonstrate the reliability of the approach for forecasting imminent regional seismic activity for regions with seismic risk.

3. Reliability of Geomagnetic Quake Approach Based on the Analyses of INTERMAGNET Data from MMB (Memambetsu), KAK (Kakioka) and KNY (Kanoya) Stations Located in Japan (Figures 2-12)

In the following **Table 1** we present the sum of the variable S_{ChtM} for all earthquakes occurred in the station's region (700 km) and the sum of S_{ChtM} for predicted one, their division in persent and the widths of ***DayDiff*** distribution Gauss fitfor all earhquakes, including the ones predicted.

The values of divisions near to 100% for all the three stations confirm the reliability of the imminent regional seismic activity forecasting. The values of Gauss fit widths can be interpreted as a confirmation of our hypotesis about "predicted" earthquakes: the stronger the earthquake is, the higher is the probability that after the precursor signal it will occur in the region in the time period (+/− 1.97 days) around the time of the following Tide's extreme.

Table 1. Illustration of reliability.

Station	PrEqs S_{ChtM} Sum [J/km^2]	AllEqs S_{ChtM} Sum [J/km^2]	Pr/All %	Gauss fit width all [day]	Gauss fit width PrEqs [day]
MMB	4.01E+12	4.11E+12	97.6	5.14+/−0.56	4.32+/−0.72
KAK	1.48E+13	1.68E+13	88.1	4.89+/−0.60	3.75+/−0.37
KNY	1.96E+10	1.98E+10	99.0	5.44+/−0.0	3.74+/−0.51

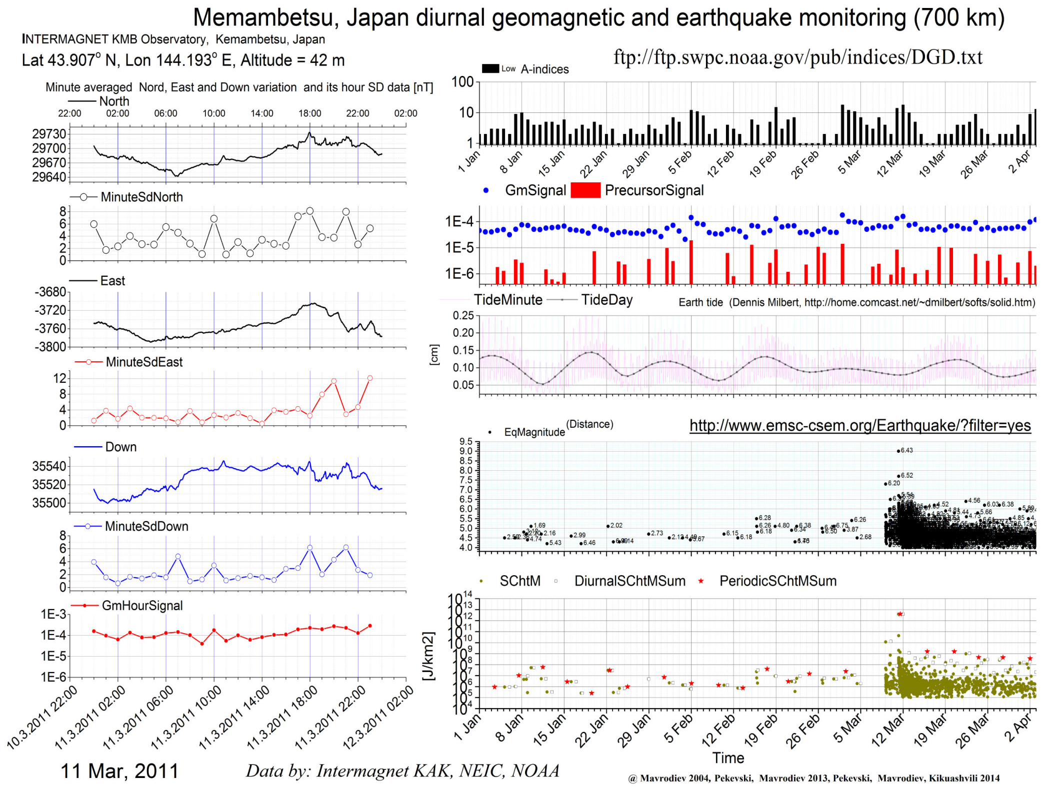

Figure 2. The Memambetsu diurnal geomagnetic and earthquakes monitoringin the period around the time of the Fukushima earthquake with geomagnetic field on 11 March 2011.

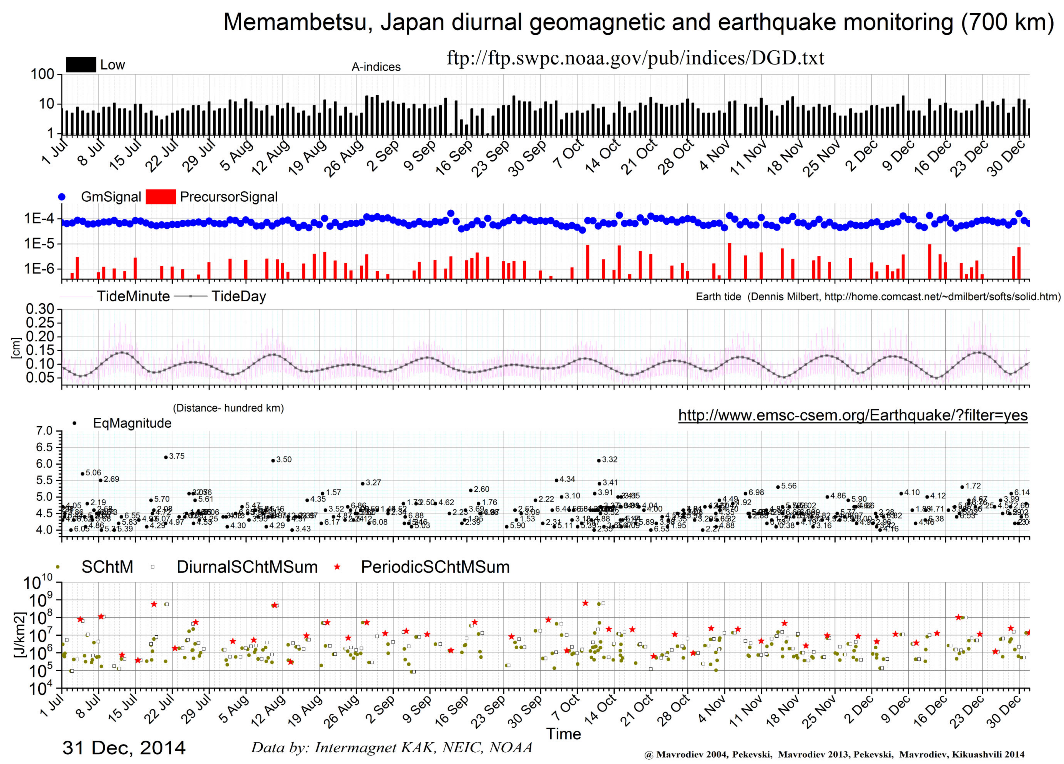

Figure 3. Memambetsu diurnal geomagnetic and earthquakes monitoring for the period 1 July 2014-1 January 2015.

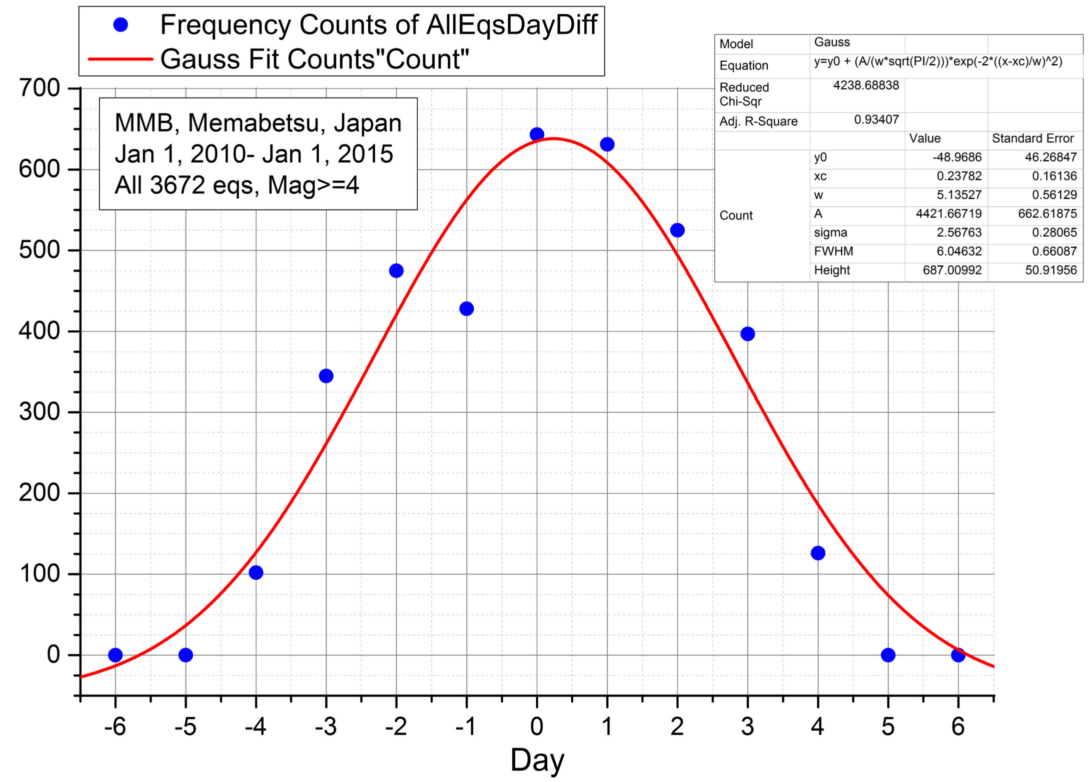

Figure 4. The distribution and its Gauss fit of *DayDiff* for all earthquakes occurred in Memambetsu (700 km) region.

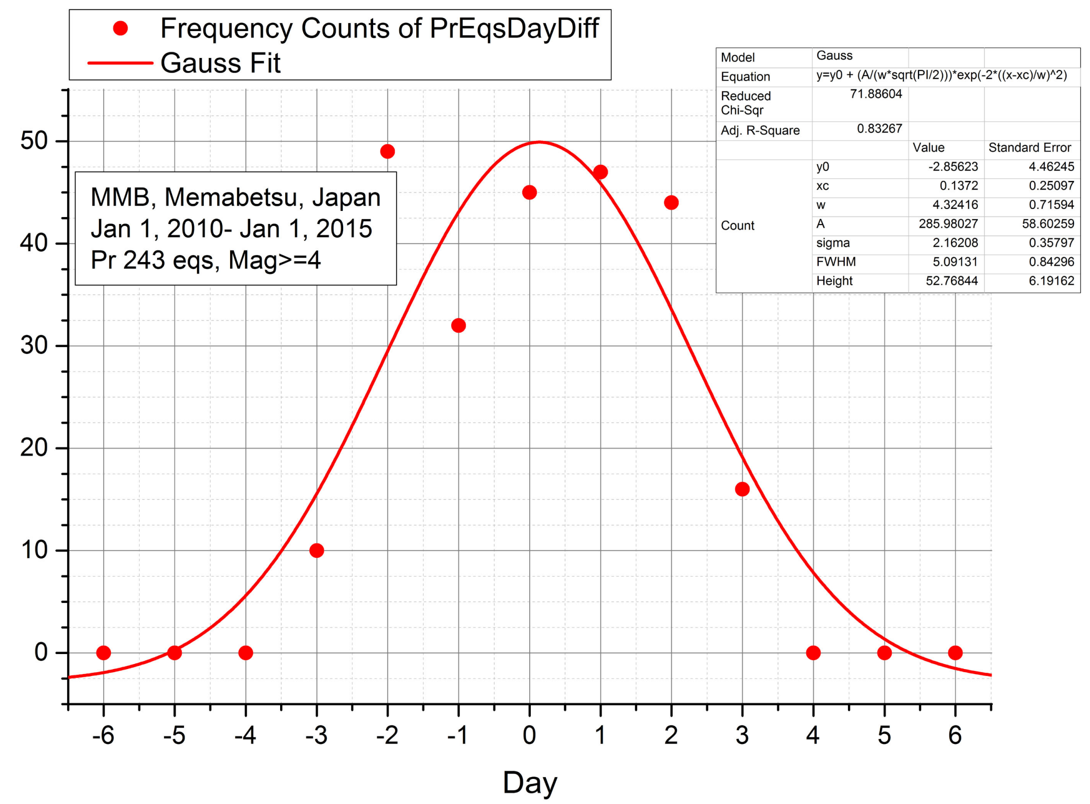

Figure 5. The distribution and its Gauss fit of *DayDiff* for predicted earthquakes in Memambetsu (700 km) region.

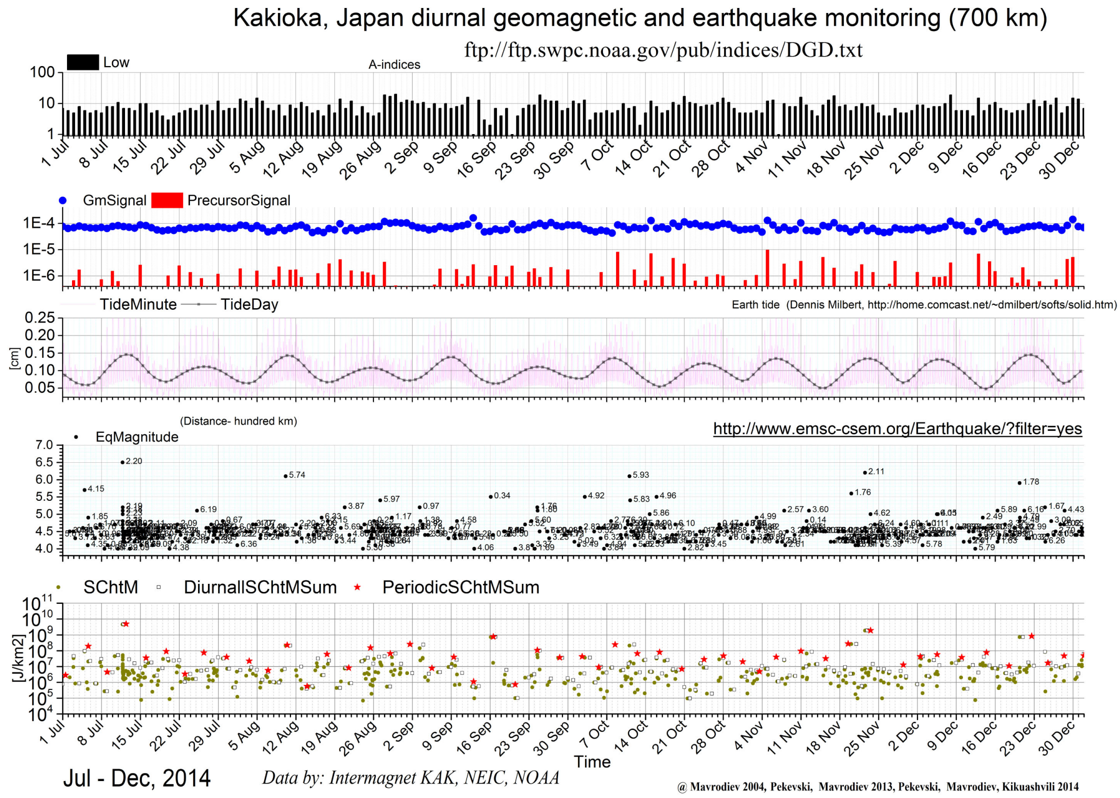

Figure 6. Kakioka diurnal geomagnetic and earthquakes monitoring for the period 1 July 2014-1 January 2015.

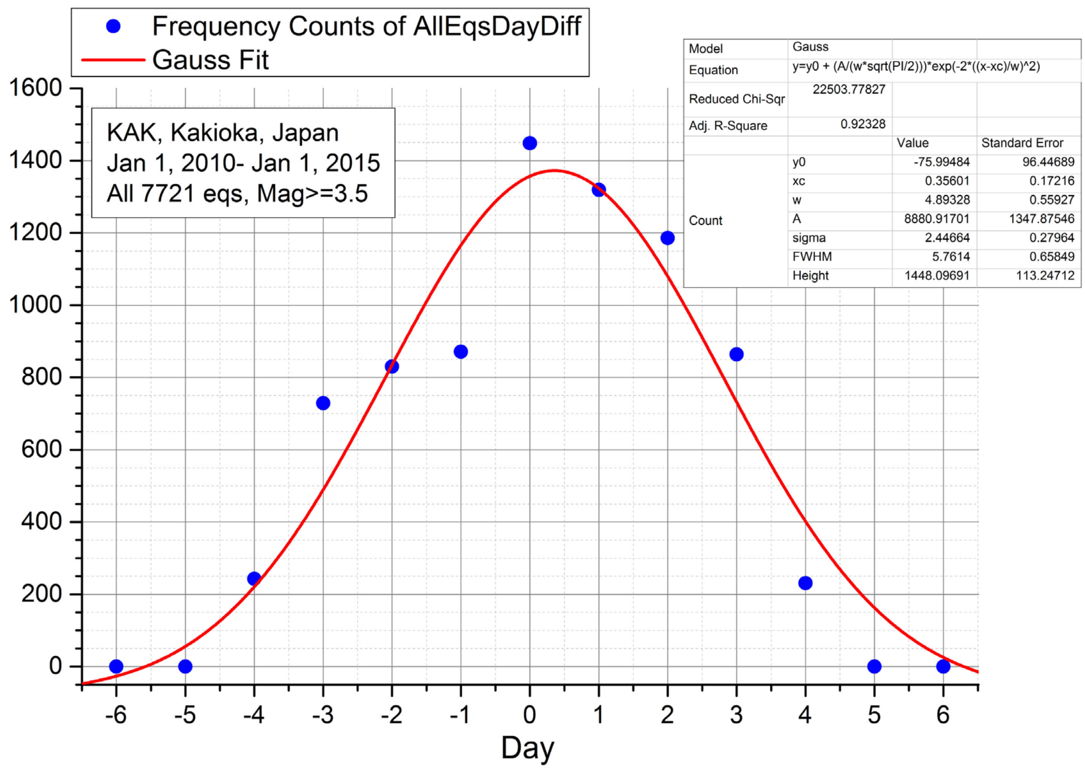

Figure 7. The distribution and its Gauss fit of *DayDiff* for all earthquakes occurred in Kakioka (700 km) region.

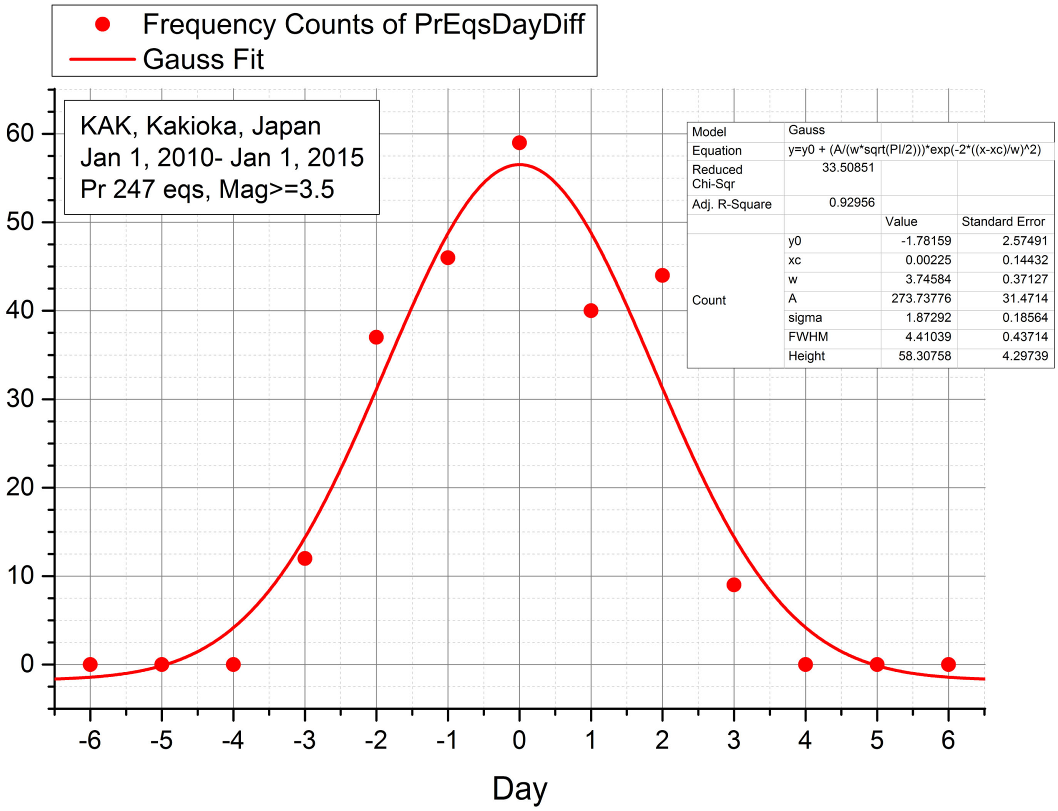

Figure 8. The distribution and its Gauss fit of *DayDiff* for predicted earthquakes in Kakioka (700 km) region.

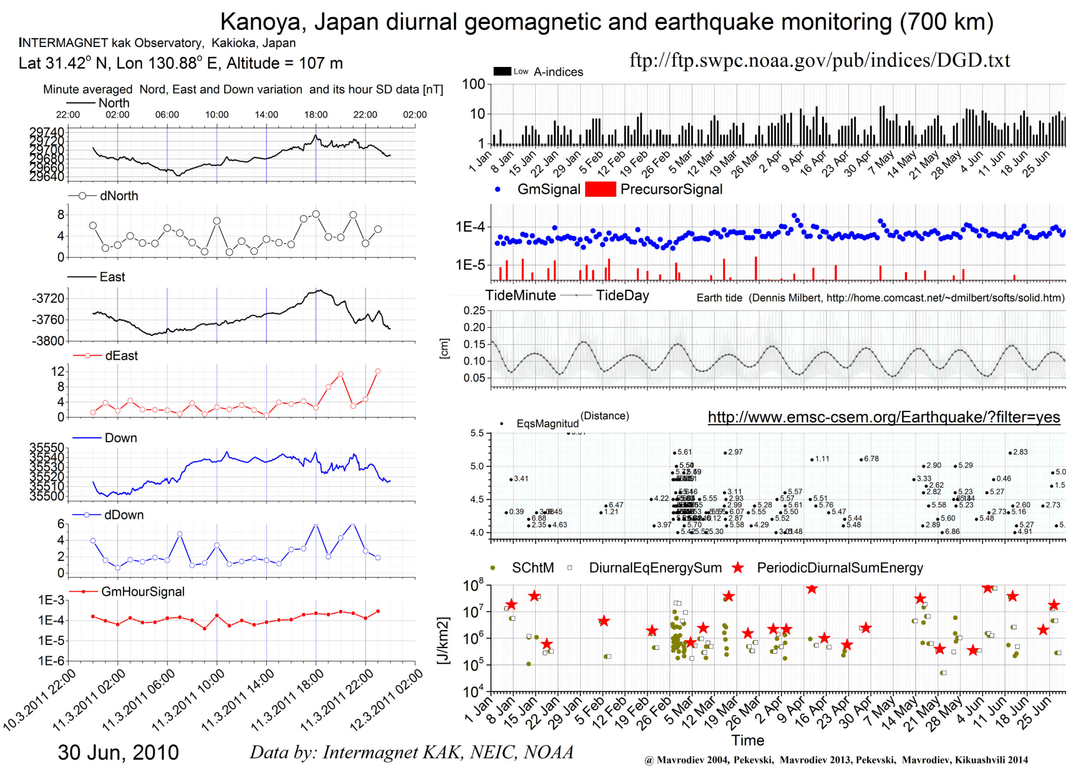

Figure 9. Kanoya diurnal geomagnetic and earthquakes monitoring with geomagnetic field on 30 June 2010.

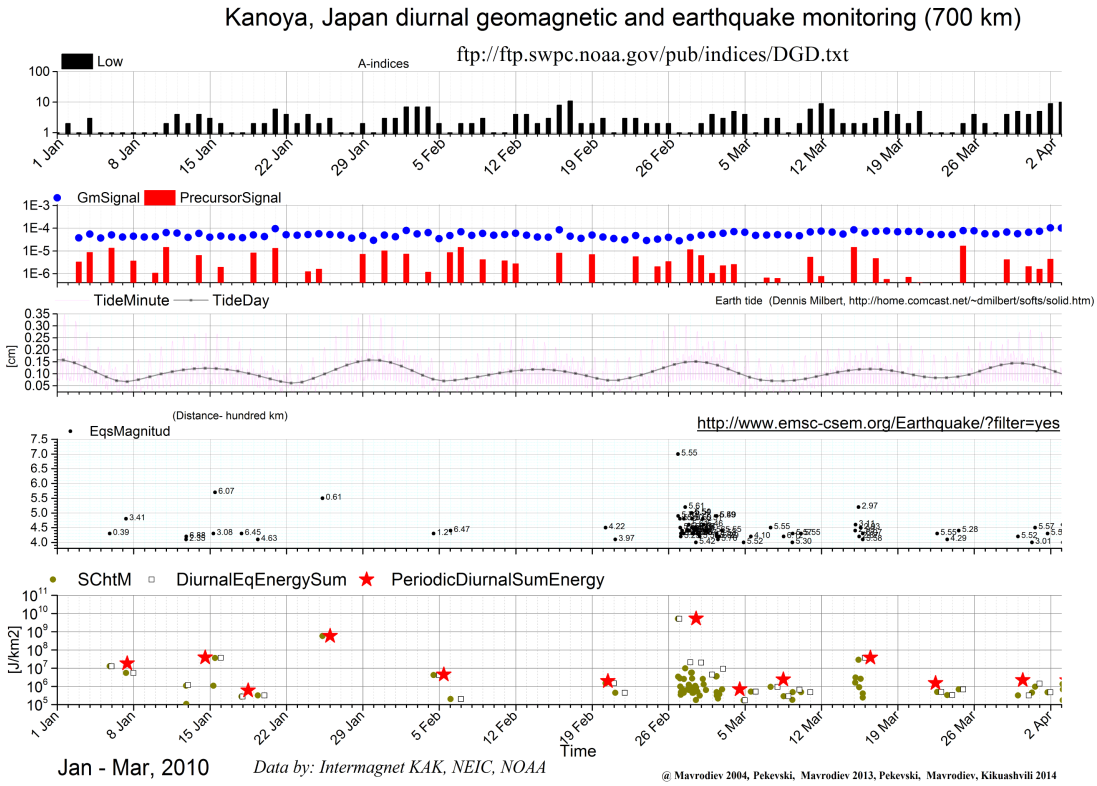

Figure 10. Kanoya diurnal geomagnetic and earthquakes monitoring with geomagnetic field in the period Jan-Mar, 2010.

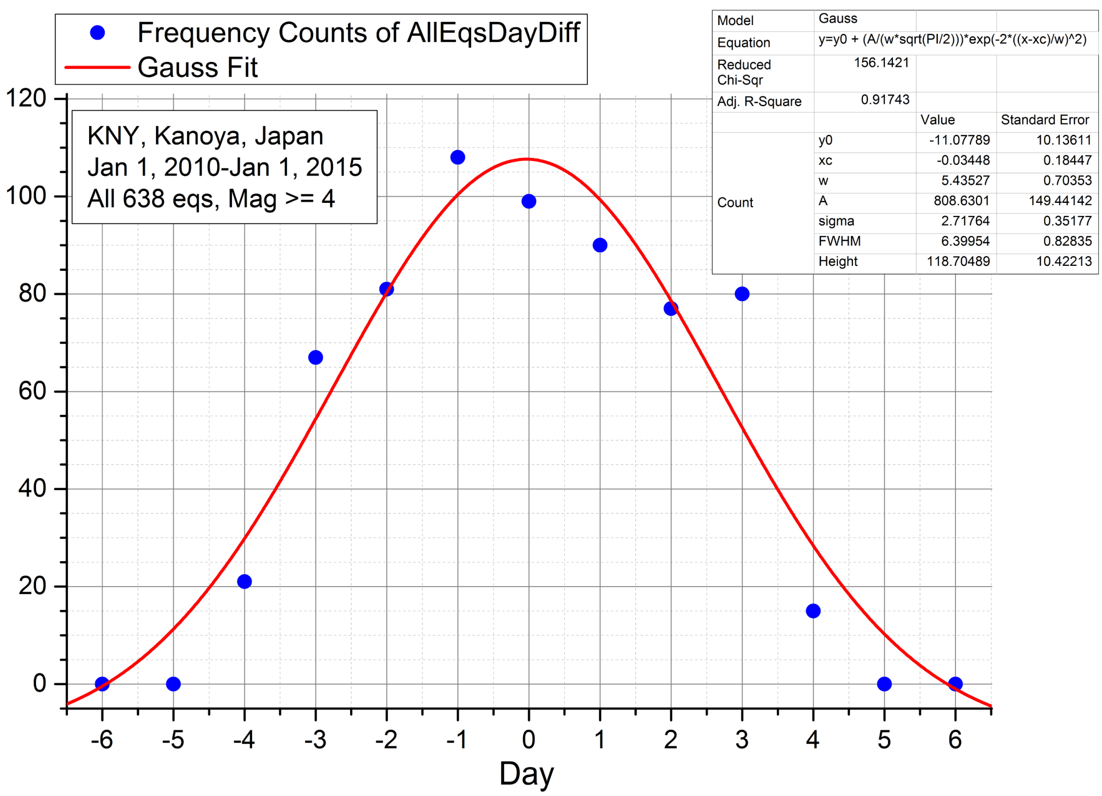

Figure 11. The distribution and its Gauss fit of *DayDiff* for all earthquakes occurred in Kanoya (700 km) region.

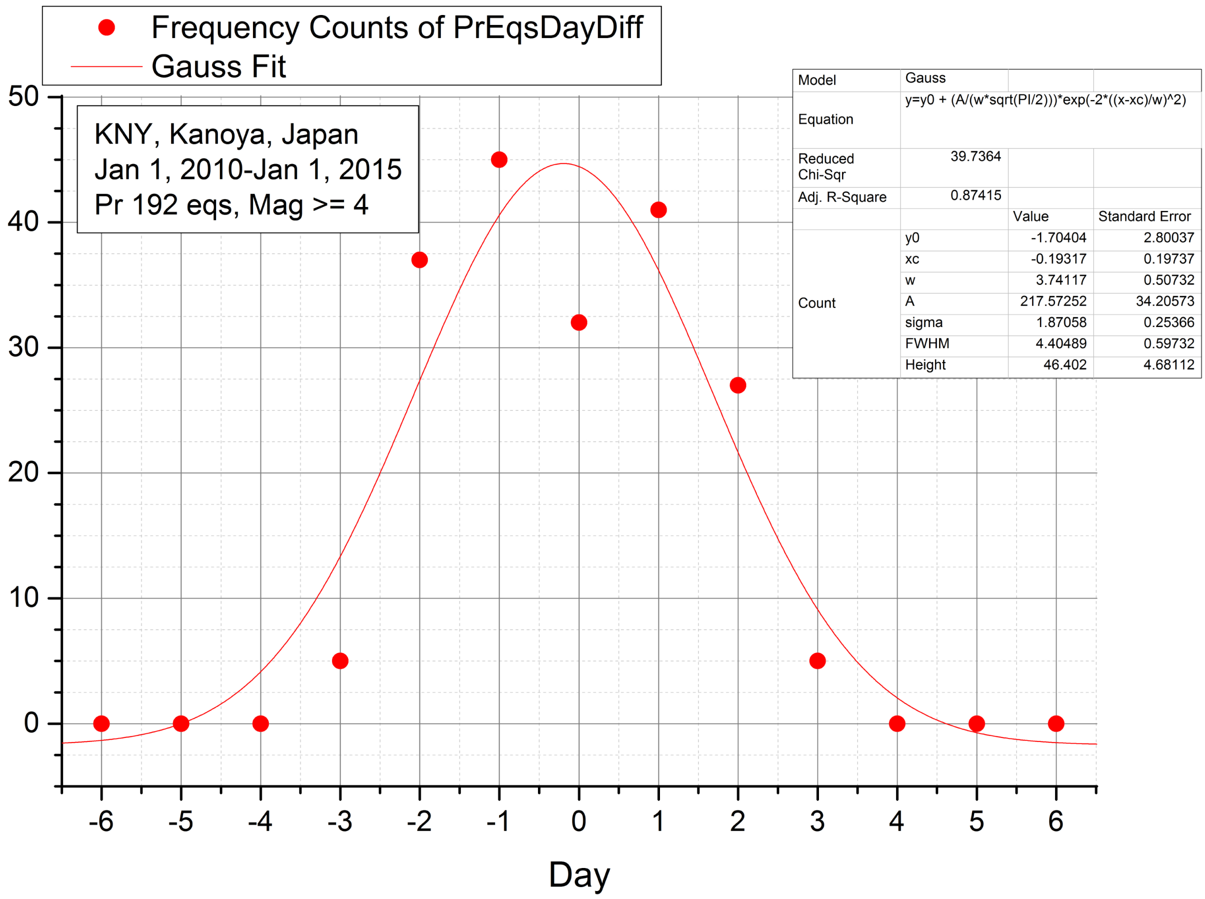

Figure 12. The distribution and its Gauss fit of *DayDiff* for the earthquakes predicted in Kanoya (700 km) region.

4. Description of Precursor Signal as a Function of Earthquake's Magnitude, Depth and Distance

Upon analysing the data for predicted earthquakes presented in **Figure 5**, **Figure 8** and **Figure 12**, it was established that there are sixteen earthquakes which are predicted from the signal in two stations simultaneously (see **Table 2** in **Application 1**). So, we have 32 equations for precursor signals, earthquake's magnitude and depth as well as for the distances between the epicenters of the earthquakes occurred and the monitoring points, in which 16 magnitudes and depths have equal values. In this way we have enough data to formulate the inverse problem—solving the overdetemined system:

$$\text{PrecursorSig}_i^{Expt} = Th\left(Mag_i, \text{Depth}_i, R_i, A\right) \tag{8}$$

where $i = 1, \cdots, 32$, the distance between the epicenter x_i, y_i and the corresponding monitoring point x_0, y_0 is $R_i = R\left(x_i, y_i, x_0, y_0\right)$ and $A(a_i,\ i = 1, \cdots, n)$ is a set of unknown digital parameters which define the behaviour of the explicit form of function $Th\left(Mag_i, \text{Depth}_i, R_i, A\right)$. The discovery of its explicit form and the values of parameter was performed with program code REGN [41]-[45] and its Fortran version is presented in **Application 2**. One has to note that to facilitate the solution of the system we normed the values of $\text{PrecursorSig}_i^{Expt}$ by 10^6.

The accuracy of description of the experimet is presented in the following **Figure 13** by variable Res_i:

$$Res_i = \left(\text{PrecursorSig}_i^{Expt} - Th\left(Mag_i, \text{Depth}_i, R_i, A\right)\right) / \text{PrecursorSig}_i^{Expt}$$

where $i = 1, \cdots, 32$, (**Figure 14** is the map illustration of **Figure 13**).

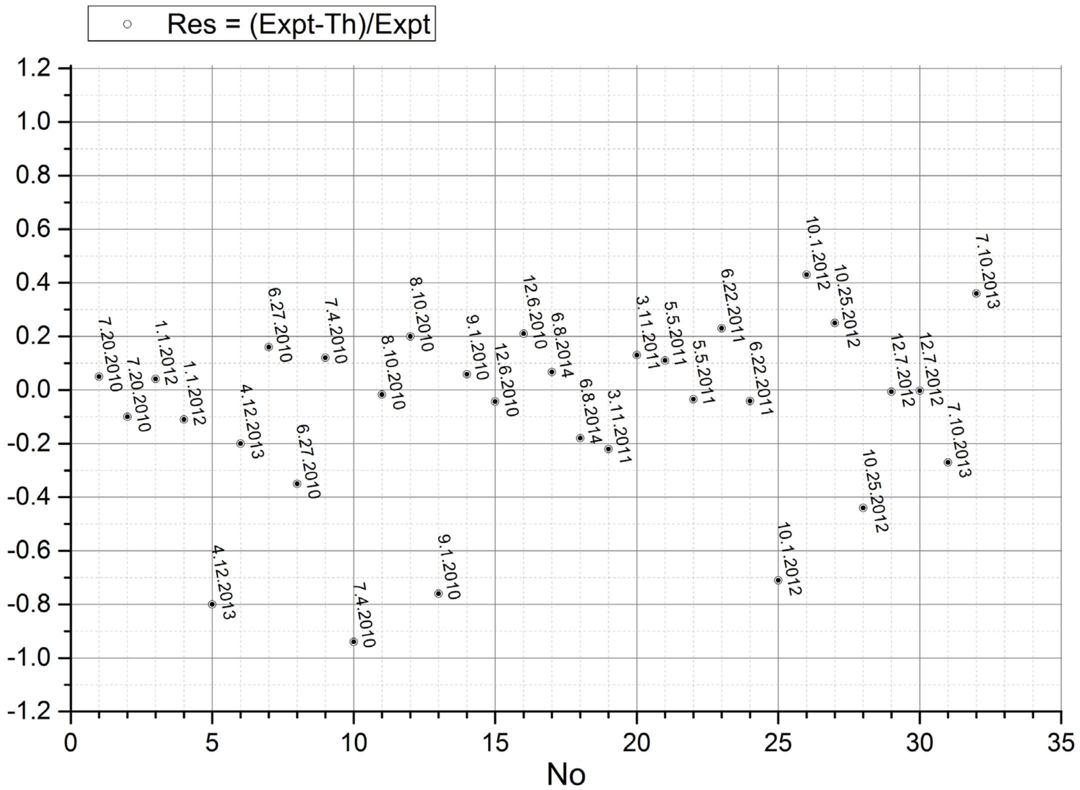

Figure 13. The description of precursor signal as afunction of earthquake's magnitude, depth and distance.

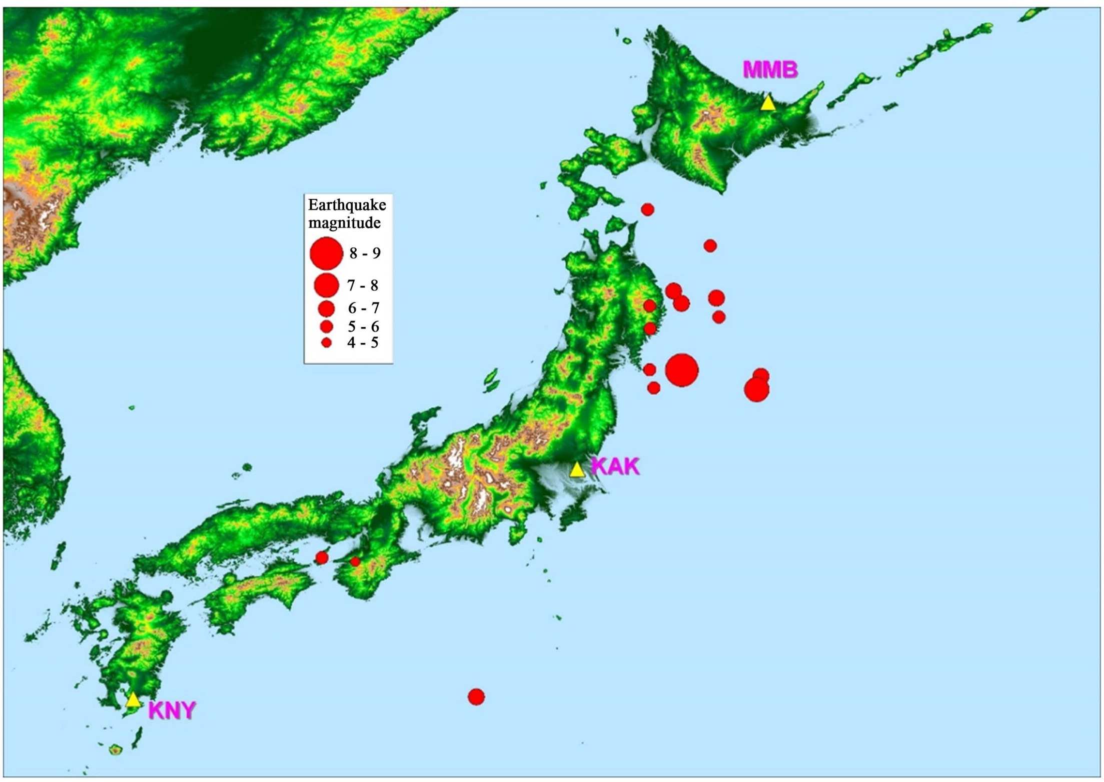

Figure 14. The map illustration of **Figure 13**.

5. Formulation of Inverse Problem for Regional Imminent Forecasting the Magnitude, Depth and Epicenter Coordinates of Earthquake

In this section we will present apossibility for solving the inverse problem for the parameters established for an incoming earthquake—the time period, magnitude, depth and epicenter coordinate.

If our hypotesis for predicted earthquake is true, itmeans that after a geomagnetic quake in the following tide extreme with anaccuracy equal to +/− 2 days al leas one earthquake in the region will occur.

From the previous section we know the explicit form of precursor signal depending on the magnitude, depth and coordinates of the epicenter—4 variables. It means that the number of unkonwn parameters N is

$$N = 2 + 2 \cdot G$$

where ***G*** is the number of geomagnetic monitoring points.

But the number of equations is *G*, which means that with a Network for only one precursor it is not possible to solve the problem for calculation of Mag, Depth and Coordinates of an incoming earthquake.

The condition to have sufficient data for defining the overdetemined system of equations is:

$$2 + 2 \cdot G \le P \cdot G \quad (9)$$

where ***P*** is the number of precursors (Earth Geomagnetic field, Earth currents field, Borehole water level, Radon concentration, Soil temperature, Atmosphere and Earth core low frequency waves, Ionosphere variability). which has a solution if $P \ge 3$ at $G > 2$.

In case this condition is respected, the first stage of research allows to estimate the epicenter coordinates using simple triangulation, the condition (9) is

$$2 + G \le P \cdot G \quad (10)$$

with solution $\boldsymbol{P} > 2$ and $\boldsymbol{G} >= 2$.

Of course, one has to note that the proposed scheme will take place after the reliability test of earthquake's precursors (mentioned in many papers) as Earth electric current, borehole water level, radon concentration, soil temperature, ionosphere behaviour, low frequences wave in the atmosphere and the Earth core will be performed.

6. Conclusions

The approach proposed for solving the problem of regional imminent "how, where and when" earthquake's prediction does not except the commonly accepted investigations based on seismology, geology, geoelectromagnetism and JPS data.

The reliability test of the Earth currents, Borehole water level, Radon concentration, Atmosphere and the terrestrial low frequency waves as demonstrated in this paper geomagnetic quake reliability for forerecasting the regional seismic activity, after including them in a regional network, will give data for discovering the explicit forms of different precursor signal functions. After collecting enough statistics for a suffucient number of earhquakes occurred in the network region and solving the overdetermined systems defined from conditions (9) or (10), we will have data for estimating the prediction accuracy for earthquake's time period, magnitude, depth and epifocal coordinates prediction accuracy.

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Application 1

Table 2. Fit data.

No	St1St2	Date	Lat	Long	Depth	Mag	SChtM	Distance R	TimeDiff	PrecSignal	Th	Res	Def
		MM.DD.YYYY			km		J/km^2	100 km	Day			(Expt-Th)/Expt	Expt-Th
1	KNYKAK	7.20.2010	34.28	135.533	34.28	4.90	2.70E+06	6.13	2.25	8.81E+00	8.37E+00	0.05	0.44
2	KAKKNY	7.20.2010	34.28	135.533	34.28	4.90	4.20E+06	4.75	2.27	4.76E+00	5.24E+00	−0.10	−0.48
3	KNYKAK	1.1.2012	31.456	138.072	31.46	6.80	8.20E+08	6.96	0.18	8.00E+00	7.67E+00	0.04	0.33
4	KAKKNY	1.1.2012	31.456	138.072	31.46	6.80	1.10E+09	5.66	0.80	4.54E+00	5.03E+00	−0.11	−0.49
5	KNYKAK	4.12.2013	34.369	134.828	34.37	5.80	8.00E+07	5.75	2.42	2.26E+00	4.06E+00	−0.80	−1.80
6	KAKKNY	4.12.2013	34.369	134.828	34.37	5.80	9.30E+07	5.29	2.42	2.77E+00	3.34E+00	−0.20	−0.57
7	MMBKAK	6.27.2010	41.662	141.657	41.66	5.30	3.00E+07	3.25	2.44	4.22E+00	3.54E+00	0.16	0.68
8	MMBKAK	6.27.2010	41.662	141.657	41.66	5.30	3.00E+07	3.25	2.44	2.62E+00	3.54E+00	−0.35	−0.92
9	MMBKAK	7.4.2010	39.697	142.369	39.70	6.30	5.70E+08	4.93	1.41	5.50E+00	4.84E+00	0.12	0.66
10	KAKMMB	7.4.2010	39.697	142.369	39.70	6.30	7.20E+08	4.31	0.30	2.73E+00	5.30E+00	−0.94	−2.60
11	MMBKAK	8.10.2010	39.406	143.148	39.41	5.90	1.40E+08	5.09	0.79	4.45E+00	4.53E+00	−0.02	−0.08
12	KAKMMB	8.10.2010	39.406	143.148	39.41	5.90	1.80E+08	4.39	0.19	5.83E+00	4.68E+00	0.20	1.20
13	MMBKAK	9.1.2010	37.925	141.788	37.93	5.20	6.50E+06	6.96	1.81	1.45E+00	2.55E+00	−0.76	−1.10
14	KAKMMB	9.1.2010	37.925	141.788	37.93	5.20	3.90E+07	2.36	1.78	4.37E+00	4.11E+00	0.06	0.26
15	MMBKAK	12.6.2010	40.904	142.967	40.90	5.70	1.30E+08	3.49	0.79	5.67E+00	5.91E+00	−0.04	−0.24
16	KAKMMB	12.6.2010	40.904	142.967	40.90	5.70	5.50E+07	5.73	0.77	5.52E+00	4.36E+00	0.21	1.20
17	MMBKAK	6.8.2014	39.164	141.709	39.16	5.20	8.10E+06	5.67	2.70	4.34E+00	4.05E+00	0.07	0.29
18	KAKMMB	6.8.2014	39.164	141.709	39.16	5.20	1.70E+07	3.53	1.62	4.70E+00	5.53E+00	−0.18	−0.83
19	MMBKAK	3.11.2011	38.297	142.373	38.30	9.00	3.90E+12	6.43	0.29	5.94E+00	7.23E+00	−0.22	−1.30
20	KAKMMB	3.11.2011	38.297	142.373	38.30	9.00	1.50E+13	3.01	0.23	9.20E+00	8.05E+00	0.13	1.20
21	MMBKAK	5.5.2011	38.17	144.032	38.17	6.00	1.30E+08	6.39	0.18	4.20E+00	3.74E+00	0.11	0.46
22	KAKMMB	5.5.2011	38.17	144.032	38.17	6.00	3.10E+08	4.03	1.21	2.60E+00	2.69E+00	−0.03	−0.09
23	MMBKAK	6.22.2011	39.955	142.205	39.96	6.70	2.40E+09	4.70	0.65	4.55E+00	3.52E+00	0.23	1.00
24	KAKMMB	6.22.2011	39.955	142.205	39.96	6.70	2.60E+09	4.50	0.69	3.49E+00	3.64E+00	−0.04	−0.14
25	MMBKAK	10.1.2012	39.808	143.099	39.81	6.10	3.30E+08	4.65	1.39	2.65E+00	4.54E+00	−0.71	−1.90
26	KAKMMB	10.1.2012	39.808	143.099	39.81	6.10	3.20E+08	4.73	2.43	7.87E+00	4.51E+00	0.43	3.40
27	MMBKAK	10.25.2012	38.306	141.699	38.31	5.60	2.80E+07	6.58	1.98	5.73E+00	4.30E+00	0.25	1.40
28	KAKMMB	10.25.2012	38.306	141.699	38.31	5.60	1.20E+08	2.67	1.93	2.94E+00	4.23E+00	−0.44	−1.30
29	MMBKAK	12.7.2012	37.89	143.949	37.89	7.30	1.00E+10	6.70	0.94	5.38E+00	5.41E+00	−0.01	−0.03
30	KAKMMB	12.7.2012	37.89	143.949	37.89	7.30	2.70E+10	3.82	0.91	4.09E+00	4.10E+00	0.00	−0.01
31	MMBKAK	7.10.2013	39.638	141.705	39.64	5.30	1.40E+07	5.18	1.78	2.01E+00	2.55E+00	−0.27	−0.54
32	KAKMMB	7.10.2013	39.638	141.705	39.64	5.30	2.00E+07	4.02	1.80	4.83E+00	3.08E+00	0.36	1.80

Application 2: The FORTRAN Version of Precursor Signal Function

```
Function PrecSigTh (aMag, Depth, Distance)
IMPLICIT DOUBLE PRECISION (A-H, O-Z)
DIMENSION A (16)
DATA A/0.653118375493643180E+04, 0.239327649144353849E+02, −0.441055930229294688E+03,
−0.190062527379474363E+04, &
−0.195894833103010524E+04, −0.514929656067517226E+04, −0.745560820661331309E+04,
0.421788002467532533E+04, &
0.420599862430744270E+04, 0.319880390225624069E+04, −0.583971362592100718E+01,
0.536940127973910677E+02, &
0.510487668346017074E+03, 0.287881656908347106E+00, −0.264988287827522662E+01,
−0.614005144491253532E+02/
DepL = dlog(Depth); DisL = dlog(Distance)
Str1 = a(2)*aMag + a(3)*DepL + a(4)*DisL
Str2 = a(5)/aMag + a(6)/(DepL+1.d0) + a(7)/(DisL+1.d0)
Str3 = a(8)/aMag**2 + a(9)/(DepL+1.d0)**2 + a(10)/(DisL+1.d0)**2
Str4 = a(11)*aMag**2 + a(12)*DepL**2 + a(13)*DisL**2
Str5 = a(14)*aMag**3 + a(15)*DepL**3 + a(16)*DisL**3
PrecSigTh = (eexp(a(1) + Str1 + Str2 + Str3 + Str4 +Str5))
RETURN
END
```