METHODOLOGY OF ECOLOGICAL MONITORING DATA APPLICATION TO SEISMIC FORECASTING

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Methodological problems of the ozonometry data application to forecast of severe earthquakes are considered in this paper. Analysis of latent seismic periodicity in the ozonometry data is based on the Maxwell pendulum model. The ozone microhole formation is observed above epicenters of severe earthquakes. The obtained results are proposed to be used in a system of ecological monitoring and climate change observation.

In recent years change of the Earth's climatic system and continuous increase of anthropogenic effect on ecosystems have resulted more common in unfavorable conditions for human vital activity. In this connection, of increasing practical interest is the problem of monitoring of the environment to forecast the development of harmful processes. To solve this problem, applied systems for monitoring of the environment have been created capable of measuring the required atmospheric characteristics and subsequent processing of data obtained. Taking into account the interaction among processes in different Earth's layers, a search for possibilities of application of the data of ecological monitoring of the atmosphere to seismic forecasting is justified.

Severe earthquakes are among the most dangerous natural disasters. Analysis of ecological consequences of such earthquakes is connected with a search for their predictors in the state of geophysical fields of different layers of the Earth as well as with the study of corresponding mechanisms of their interaction. This problem has been considerably developed in the investigations of seismic–ionospheric interaction.[1]

Currently available concepts of the interaction mechanisms of the prognostic disturbances of the lithosphere with the ionosphere are based on two main approaches,[1] namely, on the theory of propagation of internal gravitational waves (IGW) and infrasound and on the interaction being manifested through disturbances of the Earth's electromagnetic field in zones of origin of earthquakes. Analysis of earthquake predictors in a relatively electrically neutral middle atmosphere could refine some characteristics of mechanisms of interaction among geospheres, and taking into account the peculiarities of IGW propagation, optimize the operation of seismological network. These data will be also very useful for solving the problems of ecological and climatic monitoring. However, the results of a search for predictors of severe earthquakes between lithosphere and ionosphere can be very rarely found in the literature.[2,3]

The total content of atmospheric ozone (TCAO) can be used as the characteristic of the state of the middle atmosphere. The above TCAO can be investigated when searching the predictors of severe earthquakes in the stratosphere. In a complex spatial structure of geophysical field, disturbances one can expect more distinct manifestation of prognostic effects above seismotectonic anomalies (STA's) that may be represented as a peculiar kind of membrane consisting of individual self–organizing lithospheric blocks. In this connection, it makes sense to use some results of investigations of the TCAO value above such IGW sources as cyclones and anticyclones.

The results given in Refs. 4 and 5 indicate the decreased TCAO above cyclones and the increased TCAO above the zones of anticyclonic circulation. Cyclones and anticyclones can be considered as giant sources of IGW (also simplified to peculiar kinds of membranes). Variations of TCAO are due to dynamic factors of IGW interaction with zonal flux.

The spectrum and energy of IGW generated by such membranes depend on dimensions, structure, and peculiarities of evolution of baric formations. Taking into account lensing atmospheric properties for IGW propagation, in Ref. 6, on the basis of numerical modeling, a possibility was indicated of the existence of resonance altitudes for IGW energy above baric formations from coherent sources making up the membrane and possessing the elements of similarity. In this connection, the results obtained in Refs. 4 and 5 can be considered as analogs of wave STA activity in the atmosphere.

Consolidation of lithospheric blocks into STA results in the change of its mass and thermodynamic characteristics and in the higher coherence of STA component motions. Analysis of evolution of prognostic effects of severe earthquakes makes it possible to assume the increase of STA motion frequency some weeks before a seismic event as well as possible occurrence of resonance effects of STA motions in the prognostic disturbances of geospheres. Therefore, to predict the periods of enhanced seismic activity we propose to use the results of physico–mathematical modeling of pendulum motions.

The theory of pendulum motions is widely used in the investigations into the theory of creep and long–time strength of materials when describing the processes of stress relaxation. The basis for modeling is provided by the models of the Maxwell and Voigt pendulums. Although they do not show a good fit with the results of laboratory experiments, they reflect qualitatively some aspects of evolution of anomalous stresses in material. These models are the combination of elastic element (spring) and a viscous element (piston) shown in Fig. 1.

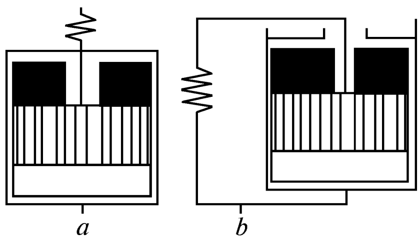

FIG. 1. Pendulum models: a) Maxwell model and b) Voigt model.

Let us consider in detail the Maxwell model as applied to the description of motions of earthquake origin as a pulse oscillator of variable frequency.

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If variations of oscillation frequency of earthquake origin obeyed the regular time dependence, an analysis of successive predictors of signals at a fixed frequency would enable one to correct and determine the date of an expected event. We assume that for the Maxwell model the pendulum mass m varies uniformly and by the instant of earthquake

$$m = \kappa(t - t_0) , \quad (1)$$

where t is the current time, k is the proportionality factor, and t_0 is the start of time count (note that the time decreases by the instant of earthquake).

The spring elasticity coefficient is designated as K_s. We also assume the fulfillment of the law of conservation of the energy:

$$K + P = \text{const} , \quad (2)$$

where K is the pendulum kinetic energy, P is the spring potential energy,

$$K = \frac{m W^2}{2} , \quad (3)$$

where W is the pendulum motion velocity,

$$P = \frac{K_s x^2}{2} , \quad (4)$$

and x is the coordinate of pendulum shift.

Upon differentiating the expression for total energy (2) and introducing the new scale of time

$$\tau = \kappa(t - t_0) , \quad (5)$$

we obtain

$$\frac{d^2x}{d\tau^2} + \frac{1}{2\tau}\frac{dx}{d\tau} + \frac{K_s x}{\kappa^2 \tau} = 0 . \quad (6)$$

Solution of this equation is the following:

$$x = A \sin \beta \sqrt{\tau} , \qquad \beta = 2\sqrt{\frac{K_y}{\kappa^2}} . \quad (7)$$

The oscillation phase

$$\Phi(\tau) = \beta \sqrt{\tau} , \quad (8)$$

and the oscillation frequency according to the theory of nonlinear oscillations is

$$\omega(\tau) = \frac{d\Phi}{d\tau} = \frac{\beta}{2\sqrt{\tau}} . \quad (9)$$

The introduced time scale coincides with the mass dimensionality and from physical reasoning it cannot be negative. Therefore, the equation being studied describes oscillations of decreasing frequency with linear increase of mass. Amplification of high–frequency oscillations in the STA zone just before the earthquake is caused by destruction of the inhomogeneity zone of earthquake origin. This process can be described by the above equation on the assumption that the pendulum mass decreases sharply by the moment t characterizing the instant of the main shock.

Problems of description of STA motions for the Maxwell body model are connected with the uncertainty of data on quantitative characteristics of the process of earthquake origin. In addition, in the systems with spatiotemporal geological scales the inertia forces proportional to the acceleration are insignificant.

For the above model, we may consider the future epicenter as a pulse oscillator with increasing frequency and the observation ozonometric system as a resonator with a stable natural oscillation spectrum. The most distinctive prognostic signal will be related to a resonance between the oscillator and the observation system. If there is a multiple frequency resonance at successive instants of time n and m with the frequency ratio

$$\frac{\omega(\tau_m)}{\omega(\tau_n)} = \frac{n}{m} , \quad (10)$$

where n and m are the integers, then, according to Ref. 7, we obtain

$$\frac{\beta}{2\sqrt{\tau_m}} \cdot \frac{2\sqrt{\tau_n}}{\beta} = \frac{n}{m} . \quad (11)$$

From this it follows that

$$\frac{\tau_n}{\tau_m} = \frac{n^2}{m^2} . \quad (12)$$

For a number of successive predictors by means of the last ratio we may decrease the probability of false alarm in forecasting of earthquake due to random variations of the predictor under consideration. Possible noise may be due to overlapping of prognostic signals from close STA's and their interaction. This important condition should be taken into account when searching for instant of severe primary earthquake. The remaining earthquakes of less size can be subdivided into foreshoks and aftershocks connected with the primary seismic event.

For the above–considered nonlinear model of STA motions developed by analogy with the well–known model of the Maxwell pendulum, the process of earthquake origin has been correlated with a fixed time of its primary shock in the simplest form. This offers definite advantages as compared with a traditional approach based on the theory of linear oscillations, incapable of setting the priority of a primary event over foreshocks and aftershocks since any point of the system may become a starting point of the oscillation process.

For the above–described model of earthquakes in Kamchatka in 1972–1989, the calculations were done of latent seismic periodicity in classified data of ozonometry. To do this, we used a specially introduced coherence coefficient in analogy with the correlation coefficient proposed in Ref. 8. Its value must reflect the interconnection among local extrema in classified ozonometry and periodicity determined from the relationship among resonance oscillations. In this case, the true value of the coefficient is not required, and, therefore, we used the ratio

$$A(\kappa, t) = \sum_{n>m} \frac{\nu(\tau_m)\,\nu(\tau_n)}{L} \quad (13)$$

as the coherence characteristic, where $\nu(\tau_m)$ and $\nu(\tau_n)$ are the recurrence of local extrema at the reference time $t_0 = \text{const}$ and during the examined variable time interval t and L is the sum of terms in the numerator, which can be represented in terms of the number of combinations of m and n.

Figure 2 shows one of a series of plots of the coefficient $A(k = 1.5, ..., 2.5,\ t_0 = 7$ days) of correlation among local minima in the data of ozonometry for small–focus earthquakes (SFE) observed in Kamchatka against the background of natural variations obtained from an independent sample.

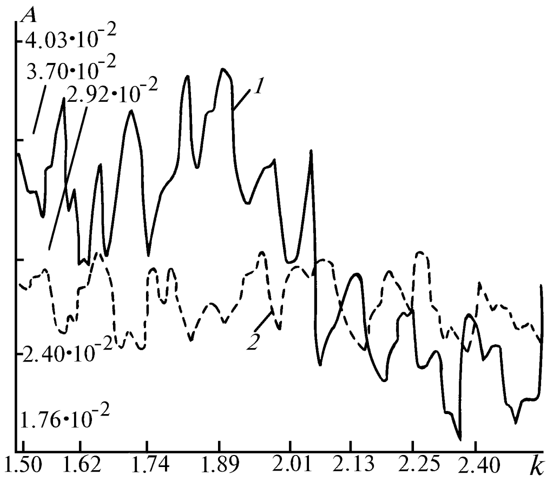

FIG. 2. Variation of correlation among local minima in the ozonometry data for small–focus earthquakes: correlation coefficients (1) and background disturbances (2).

The start of time count $t_0 = 7$ days before SFE was chosen because of increased recurrence of local minima on this day, twice its background value. In the range $\kappa = 1.8, ..., 1.9$, the correlation coefficient of seismic ozonometry exceeds its natural variations almost by a factor of 1.5. This confirms the legitimacy of the use of the Maxwell pendulum model for forecasting of earthquakes.

Using the plots of the type shown in Fig. 2 that illustrate the occurrence of seismic resonances in the ozonometry data obtained at the Petropavlovsk–Kamchatskii station, the optimal ranges k were selected that were implemented in the program of the block of analysis of seismic periodicity in the current ozonometry data.

The seismic periodicity in the ozonometry data is indicative of the litho–strato–ionospheric interaction mechanism being manifested through IGW. Therefore, the studies on climatic consequences of seismoozone effects are of considerable interest. The use of the simplest model of the Maxwell pendulum has made it possible to select the seismic periodicity in the ozonometry data. On their basis, we can develop the technique of short–range forecast (some days or a month before severe earthquake) of periods of enhanced seismic activity. Preliminary assessment of correctness of this technique in Kamchatka varied from 50% to 70%. The results of the above forecast are no worse than those obtained by the other techniques.[9] However, term of forecast of severe earthquake is much longer.

As a result of investigations of seismoozone effects, we have found feasible the use of not only modeling and search for latent regularities, but also the TCAO data normalization and classification. For the SFE in Kamchatka, the test of a hypothesis that anomalous seismic prognostic overshoots of TCAO were caused by their anomalous natural variations from an independent sample has made it possible to estimate the suitability of prognostic effects 49, 48, and 47 days before the instant of small–focus earthquake (the probability of distinguishing was no less than 80%), 46(95), 33 and 29(80), 28 (no less than 95%), and 21 days (80%) before the earthquake start.

The formation of ozone microhole over the epicenter is of particular interest. This effect is supported by results of investigations in Kamchatka, Middle Asia, California, the Caucasus, and Japan.

The results obtained provide a basis for the formulation of thematic request for proposal for a system of seismic regime monitoring using the ozonometry data intended for a global ground–based and spaceborne system of ecological monitoring and climate change observation.

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