Bulletin KRASEC. Phys. & Math. Sci. 2016. V. 12. no. 1. pp. 83-93. ISSN 2313-0156

DOI: 10.18454/2313-0156-2016-12-1-83-93

MSC 81V35

RADIATION QUANTITIES AS TRACERS/INDICATORS OF EXTREME PHENOMENA IN THE TERRITORY OF WEST SIBERIA

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The results of monitoring of consistent variations of radiation quantities on the time scales from synoptic to annual ones are analyzed in the paper. Alone or in a certain set, these radiation quantities can serve as indicators of extreme natural and anthropogenic phenomena. It is shown that the balance between the main sources of ionizing radiation in the near ground atmosphere depends on season, and the extremes appear due to processes of melting (formation) of snow cover. A method was developed to determine an optimal set of radiation quantities, which can be reliable tracers/indicators of extreme natural or anthropogenic phenomena when synchronously monitored.

Key words: ionizing radiation, atmosphere, indicator

Introduction

Atmospheric radionuclides, soil radioactive gases and ionizing radiation are widely used and are perspective radioactive tracers of the dynamic processes occurring in the upper layers of the lithosphere and near ground atmosphere, in particular, of extreme natural phenomena. It is determined by their good indicative properties and in most cases by a simpler and more economic procedure of control in comparison to nonradioactive tracers [1-4]. Thus, the government institutions and scientific groups carry out radiation monitoring of the near ground atmosphere and investigation of the activity dynamics of some radionuclides in the soil [2, 3].

However, the environment and climate changes are understudied in many regions of our planet including the territory of Siberia to make forecasts of the observable changes and a valid estimate of the role of natural and anthropogenic factors. Moreover, in the current state of the global climate system, extreme natural and anthropogenic phenomena (EP) occur with an increasing frequency according to the data of the Russian Emergency Ministry.

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In the present governmental systems of radiation monitoring, only one parameter, γ-radiation intensity, is continuously measured. Other radiation quantities, such as, the volumetric activity of radon isotope and that of daughter products of their decay, flux density of α- or β- radiation in the atmosphere, radon flux density from the ground surface, are measured with episodic control [4-7]. It is difficult to refer the recorded anomalous increases in γ- background to an "alarm"signal of a radiation accident without additional information. For example, anomalous bursts in the atmospheric γ- background often occur during cyclone passages and precipitations [5]. These bursts in γ- background are determined by the increase of activity of γ- radiating daughter products (DP) of radon and thoron near the ground surface and not by radiation accident.

It is also important to obtain experimental data and numerical estimates of the degree of external factor effects on the dynamics of field characteristics of ionizing radiation (IR), radon and its DP [8-14]. We should note that the integral background of ionizing radiation in the near ground atmosphere is mainly contributed by: a) soil radon and thoron and their DP; b) radon atmospheric isotopes and their DP. The relation between these sources of ionizing radiation determines the contribution of each of them in the changing weather and geodynamic conditions. Estimates of the characteristics of these sources allow us to make corresponding corrections into the investigation of the bursts and the physical phenomena occurring at the lithosphere-atmosphere boundary and to simulate the processes of lithosphere-atmosphere interaction by regional and global models [10-14].

One of the possible directions allowing us to estimate the degree of impact of anthropogenic, weather and lithospheric factors on the origin and content of ionizing radiation in the near ground layer of the atmosphere is the analysis of radioactive tracer-indicator variations which are the ratio of fluxes of α-, β- and γ- radiations [15, 16]. Analysis of the time variations of tracers/indicators, introduced in [15, 16], allowed us to state the following during the passage of a strong typhoon from the region of Fukushima (Japan) atomic power plant to Kamchatka (Paratunka). During the observations (September-December 2011), a series of strong typhoons was recorded in Paratunka. However, only the typhoon which passed over Paratunka at the end of November also passed over the territory of the emergency Fukushima plant. The appearance of radioactive aerosols of anthropogenic origin in the atmosphere must be accompanied not only by the appearance of new radioactive elements but by the corresponding changes in the variations of atmospheric fields of β- and γ-radiations and, therefore, their ratios. Thus, γ / β-tracer may be quite a sensitive indicator of nonstationary processes associated with extreme weather and anthropogenic phenomena.

The cases considered in [15, 16] referred to separate, quite short, natural and anthropogenic events. Thus, it is quite topical to estimate the variations of tracers/indicators on long time scales, from synoptic to annual ones.

The basis and the initial data of the work was a complex approach for ionizing radiation monitoring which was suggested and has been realized since the end of 2008 [17-19]. The complex approach includes synchronous measurements of time and space (vertical section) dynamics of the characteristics of α-, β- and γ- radiation fields in "soil-near ground atmosphere"system. Simultaneously with that, weather, actinometric and atmospheric-electric quantities are measured. Complex radiation monitoring is meant not only for indication/forecast of extreme climate phenomena but for technogenic accidents, extreme geodynamic processes, for scientific investigations and solution of a number of applied problems in the area of radioecology, geoecology, geophysics, engineering.

The above said determined the aim of the paper that is to analyze the consistent variations of radiation quantities on the time scales from synoptic to annual ones which, alone or in a certain set, may be the indicators of extreme natural and anthropogenic phenomena.

Measuring instrumentation and methodology of the experiment

Tomsk Observatory of radioactivity and ionizing radiation (TORII, Tomsk, Akademgorodok) was created to monitor the structure and the dynamics of radon field characteristics (radon and thoron flux densities from the ground surface, volumetric activity of radon, thoron and their DP) and ionizing radiation fields in "lithosphere-atmosphere-space"system [17-19].

For the investigation we chose the following radiation quantities having "anomalous"reaction during preparation and/or realization of one or several EP:

radon field characteristics in the "soil-atmosphere"system:

- volumetric activity of i-th radionuclide (radon, thoron, daughter products) in the air of the near ground atmosphere at some height or in the soil at the depth of h, A_{Vi}, Bq/m3;

- radon flux density from the ground surface $q_{Rn}(h=0)$, mBq/(m^{2}s);

characteristics of ionizing radiation fields:

- ionizing radiation flux density of type j at the height of h, $P_j(h)$, m^2/s;

- dose ambient equivalent rate $\dot{H}^*(10)$, mkSv/h;

- absorbed dose rate $\dot{D}_j$ of ionizing radiation of the type j, mkGy/h.

The monitoring has been carried out on a test field of TORII since 2008. Its detailed scheme is shown in Fig. 1. Altogether, more than 30 series of data on radiation quantities (radionuclide volumetric activity, IR flux density, dose rate) and weather parameters with the time step of 0.5–10 min are continuously registered. Control of the characteristics of α, β- and γ-radiation fields is carried out at the heights of 10 cm, 1, 5, 10, 25, 30 and 35 m in the near ground air of the atmosphere and at the depths of 10, 20, 50 cm, 1 and 5 m in the soil.

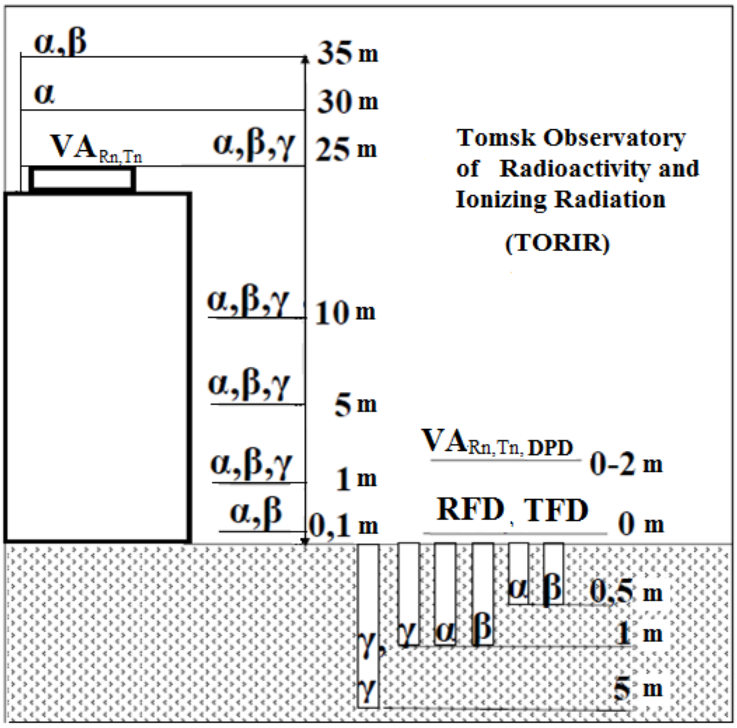

Fig. 1. Structural scheme of control of ionizing radiations and natural radioactivity in the near ground atmosphere and in the near surface layer of soil

To control the flux densities and the absorbed doses of β- and γ-radiations in the near ground atmosphere, we chose gas-discharge counters STS-6 and SBM-19 for γ- and hard β-radiations. The choice of the detectors was made taking into account the requirements for the operation conditions of the devices.

The universal complex includes «AtRad» laboratory bench that consists of a standard meteorological tower of the height of 10 m on which the gas-discharge counters for β- and γ-radiations and IR scintillation detectors are mounted. The counters are connected to a power unit and a device for radiation pulse processing into TTL format. The data collector is a ADC which operates in a counting mode and is made in the form of a PCI plate ("Parsek"company, Dubna).

Each of the 4 gas-discharge counters, measuring the $(\beta+\gamma)$-radiation, is added by one-type counters covered by aluminium and plastic bodies and emitting only γ-radiation. Thus, "clear"β-background was determined by the difference of pulse counting rate between pair counters. Simultaneously with that, time series ofγ- and β-radiation data with the sampling rate of 2 min were obtained.

In order to control and to monitor soil radon by α- and β-radiation, we chose highly sensitive scintillation units BDPA-01 and BDPB-01 (ATOMTEX, Belarus). These detectors were chosen because of the requirements to a wide range of operation conditions, since they operate within the temperature range from minus 30 to 50 °C, and the relative humidity up to 98%. These units as well as the units BDKG-03 for detection of γ - radiation were mounted at the heights of 1, 5, 25, 30 and 35 m (Fig. 1).

The volumetric activity of radon isotopes, that of daughter products, equivalent equilibrium volumetric activity (EEVA), equilibrium coefficient between radon and DP and PAEC values are measured by portable devices for radiation control: radon radiometers RRA-01M-03 and RGA-06P; radon EEVA radiometer RAMON-01N and radon, thoron and DP volumetric activity radiometer RTM 2200 (SARAD, Germany). The radiometer RTM 2200 was mounted at the height of 1 m from the ground surface.

Monitoring of meteorological, actinometric and atmospheric-electric quantities (atmospheric temperature – T, pressure – p, relative humidity – h, wind velocity and direction – w , surface temperature – T_p and under surface temperatures – T_s at the depths) is carried out by an automated information-measuring system at IMKES SB RAS. It includes the atmospheric electric field strength E meter "Pole-2 polar electrical conductivity $L_{\pm}$ meter "Electroprovodnost'-2"and indoor γ-background meter IRF-ZT which are arranged under the measurement test sit. The arriving solar radiation P_r is measured by a pyranometer Kipp & Zonen CM-11 and a phytometer NILU-UV-6T. The measurements are continuous with 1 minute time step. Simultaneously with that, the main weather parameters and turbulence characteristics are carried out with 1 minute time step by an ultrasonic weather station AMK-3. To control the current state of soil active layer and to estimate the variations of convective gas exchange with the atmosphere, soil temperature is measured by resistant temperature detectors arranged on its surface and at different depths (up to 5 meters).

Variations of the main components of ionizing radiation and weather parameters for the period 2011–2015 are shown in Fig. 2. To exclude the variations associated with fast meteorological processes and the phenomena similar in time scale, data aggregation was carried out and all the scales with the periods less than 10 days were filtered out. The scale of 10 days was chosen because it exceeds the scale of the most meteorological processes (cyclones and anticyclones) for the territory of Western Siberia (except for blocking anticyclone).

Consistent variations of ionizing radiation field and weather parameters

The choice and the estimation of an optimal set of radiation quantities from the radiation indicators of EP detected by preliminary measurements should be based on the registration and analysis of deviations of the registered quantities from their undisturbed values in time, frequency and/or space domains. These undisturbed values, in their turn, may experience the variations determined by longer processes. In our case, an annual cycle should be considered as a process with the least period significantly exceeding the scale of extreme phenomena under analysis.

The data base of monitoring of ionizing radiation fields and radioactivity covers the interval from 2009 to the present time. The most complete time-space data were obtained in 2012–2013.

Seasonal variations of the quantities under analysis. Data analysis based on the variations of natural radioactivity fields and weather parameters for 2011-2015, illustrated in Fig. 2, shows that minimal temperatures and maximal values of atmospheric pressure in the annual cycle do not coincide with the minima in the levels of β- and γ- radioactivity.

Approach of winter was accompanied by synchronous decrease of γ- background at all the heights. The dynamics of β- background is almost similar but somewhat different. Snow cover result in the effect that, at first, the levels of β- and γ- background do not depend on height any more and then they begin to increase with height as the snow depth increases.

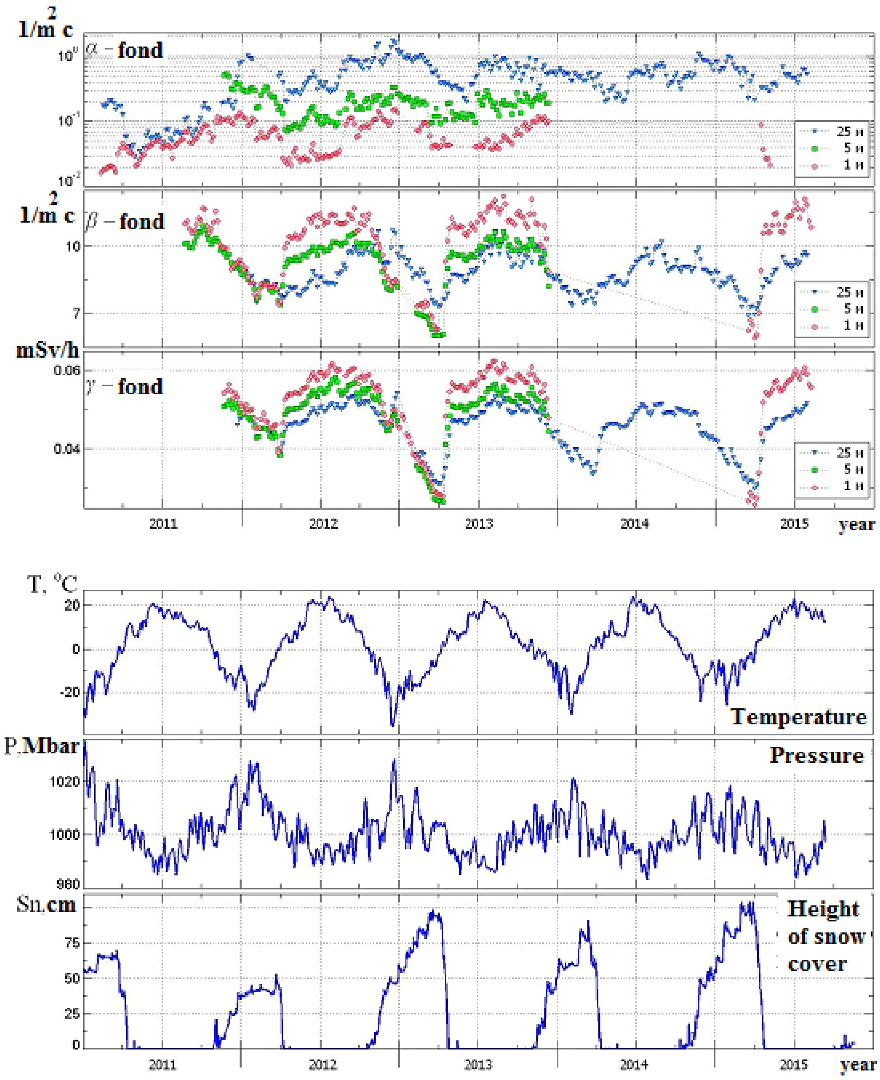

Fig. 2. Variations of α-, β- and γ- components of radioactive background and weather parameters in the near ground atmosphere (2011–2015). Here: T is the temperature of the near ground atmosphere, P is pressure, S_n is the snow depth

Growth of the snow depth from 0.5 m to 1 m resulted in the formation of a "dip"in the levels of β- and γ- radiations. In summer, the levels of β- and γ- radioactivity has a weak maximum in the annual cycle.

Analysis of monitoring data showed: a) a clear dependence between the level of snow depth and the levels of α-, β-, γ- radioactivity; b) a clear shift between the variations of α- and β-, γ-

radioactivity in the annual cycle; c) appearance of the show cover causes the change of the sign vertical gradients of β- and γ- background.

For α- radioactivity, spread of values at different heights is significant. Though, there is almost not any annual variation for it, we may distinguish a weak minimum of α-radioactivity falling within the II quarter of a year. Large dispersion in the data at different heights is firstly associated with the fact that the level of α-radioactivity in the near ground layer of less than 20-25 m is strongly affected by local objects (trees, buildings etc.) due to the small range of α-particles of decaying isotopes. At the heights of more than 20-25 m, this effect vanishes in the result of mixing. According to the monitoring data at the heights of 25 and 35 m, the levels of α-radioactivity almost coincide.

Variations of smoothed values of β- and γ- radioactivity have high degree of mutual correlation $R_{max}(\tau \sim 0) = +0.8$ and real absence of a shift τ between the series. The values of standardized coefficients of mutual correlation between the variations of α- and β- background and between α- and γ- background do not exceed $R_{max}(\tau \sim 0) \leq +0.6$. Delay of α- background variations relatively the β- and γ- background variations τ is: $\tau_{\alpha\beta} \sim 40$ days, $\tau_{\alpha\gamma} \sim 40$. The variation of normalized functions of mutual correlation is illustrated in Fig. 3.

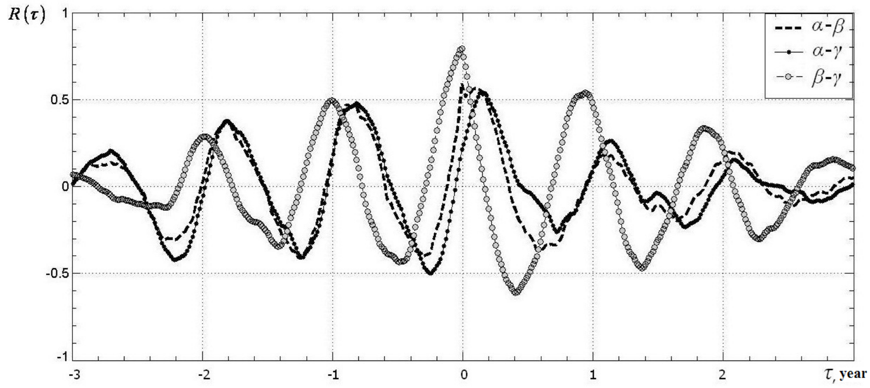

Fig. 3. Normalized functions of mutual correlation $R_{max}(\tau)$ between the series of α-, β- and γ- background. A shift τ in years is plotted on abscissa axis.

Dynamics of the ionizing radiations affects the seasonal variations of radiation tracers introduced in [15, 16]. We turn to the analysis of the seasonal dynamics of radiation tracers which may be suggested based on the results of monitoring of natural ionizing radiation field characteristics.

The dynamics of tracers-indicators in the annual cycle is shown in Fig. 4.

In Fig. 4, the height of sensor arrangement, that is 25 m, is taken as the basic one. This height exceeds those of the closest local buildings and trees. The data of $\beta/\gamma, \gamma/\alpha, \beta/\gamma$ tracers, shown in Fig. 4, are normalized to the average values of corresponding tracers. It follows from the analysis of monitoring data, which are partially shown in Fig. 4, that α/β and α/γ tracers have similar behavior regardless of arrangement of the sensors for β- and γ- radiations. Reverse tracers $\beta/\alpha, \gamma/\alpha$ have a similar behavior in the annual cycle. Such a similarity is determined by the fact that the range of α- particles in the atmosphere is an order less than that of β- particles and of γ- quanta.

For β/γ tracer, the maxima in the annual cycle are determined by the processes of snow cover melting and formation. The main maximum in the annual cycle is associated with snow cover melting. Just like for the variations of α, β- and γ-radiation levels, there is a clear delay for the tracers-indicators between β/γ- tracer and α- tracers (β/α and γ/α) in spring-summer season and an advance in autumn-winter season (Fig. 4).

Analysis of the data on the dynamics of the tracers-indicators located at the same heights showed that radiation background variations decrease that indicates the importance of consideration

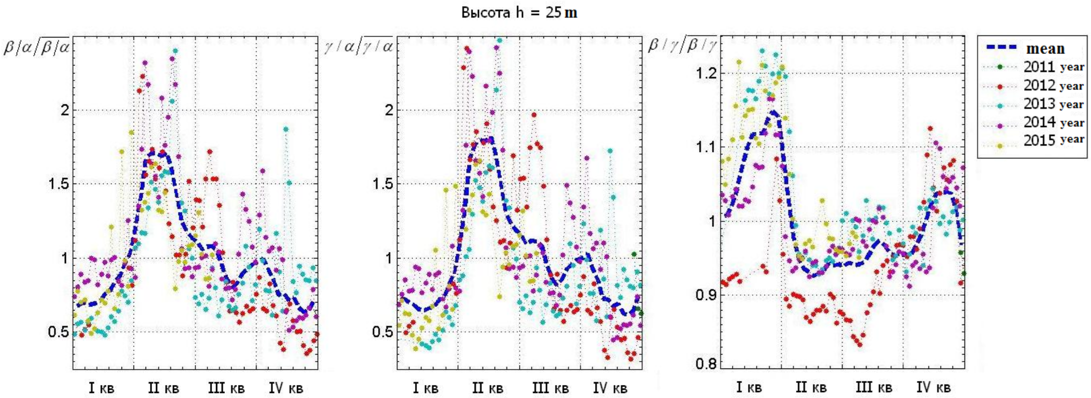

Fig. 4. Normalized seasonal variations of tracers-indicators of ionizing variations, the height is $h = 25$ m. Dashed line is an averaged seasonal variation in the time interval of 2011-2015

of spatial distribution of ionizing radiation field characteristics. It follows from the data presented that the highest similarity in the annual cycle was registered for the tracers$\alpha/\beta, \alpha/\gamma$ and the reverse tracers $\beta/\alpha, \gamma/\alpha$.

The presented information show the following. The balance between the major sources of ionizing radiations in the near ground atmosphere (soil and atmospheric isotopes of radon and their DP) is determined by a season. Their maxima are associated with the processes of melting (formation) of the snow cover.

Variations of synoptic scale quantities under analysis

We consider the time scales of tracer time variations, radiation and meteorological values exceeding the diurnal scale. In order to do that, we group the extreme phenomena according to the genetic principle as follows:

- anomalously long periods without precipitation, of extremely high or low temperatures determined by blocking anticyclones;
- passage of cyclone (anticyclone) series;
- EP associated with visibility constraint S_m, for example, haze, smoke from forest fires etc.

Within the monitoring period, long decrease of mean diurnal temperature to -40 °C was recorded from December 10 to 20, 2012. Variations of ionizing radiation tracer-indicator series during the temperature decrease and anomalously high pressure are shown in Fig. 5a. The lower panels of Fig. 5a illustrate the data on pressure and temperature.

For β/β and β/γ tracers, the pressure increase and temperature decrease cause the growth of corresponding tracer values and then their saturation. For the tracer $\gamma(25\text{м}/\beta(25\text{м}))$ a reverse situation was registered. First, the tracer value decreases and then it becomes saturated. For the tracers γ/β, gradual increase of tracer values is observed at the heights of 1 and 5 m which is changed by a decrease at the end of the period under analysis. For the tracer $\alpha(25\text{м})/\alpha(5\text{м})$, there was no reaction on temperature decrease and pressure increase. And for the tracer $\alpha(25\text{м})/\alpha(1\text{м})$, the reaction is similar to that of the tracer $\beta(25\text{м})/\beta(5\text{м})$. The values of tracers under analysis undergo quasiperiodic variations with the period of 2-3 days. The reason of occurrence of such variations was not determined. In the variations of the main weather parameters, this period was not recorded. No precipitation was registered from December 10 to 18, 2012 (period of the lowest average diurnal temperatures). On the whole, according to the data presented, the reaction of the tracers β/β and β/γ at the series of heights on the extreme temperature decrease and pressure increase is similar.

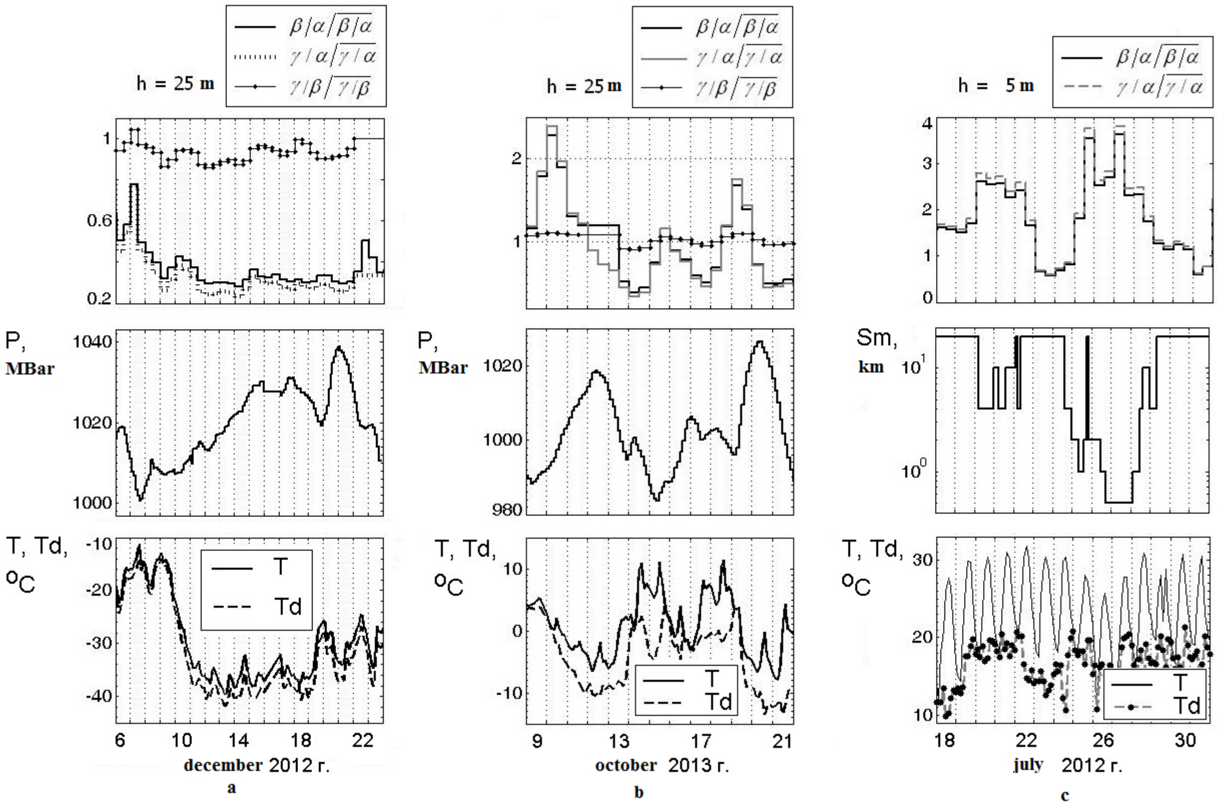

Fig. 5. Reaction of normalized tracers-indicators on extremely low temperatures and extremely high atmospheric pressure (a), passage of a cyclone series (b), atmospheric smoke from intensive summer forest fires (c). Here: T_d – dewpoint temperature, S_m – visibility, h – height of scintillation sensor location. Averaging interval of the data on ionizing radiations is one day; that of meteorological data is 3 hours

Tracer variations during the passage of cyclone formations is shown in Fig. 5b). In this case, consistent quasiperiodic oscillations of β/γ - tracer, temperature and pressure were recorded. For the tracers $\alpha(25\text{м})/\alpha(5\text{м})$ and $\alpha(25\text{м})/\alpha(1\text{м})$, there was almost no reaction on the cyclone passage. Variations of the tracers $\gamma(25\text{м})/\gamma(5\text{м})$ and $\gamma(25\text{м})/\gamma(1\text{м})$ are cophased with temperature variations and antiphased with pressure variations. Similar behavior was recorded for other tracers. Light precipitation almost does not affect the dynamics of the tracers under analysis (when filtering out the variations with the periods of less than a day).

Thus, for the variations with the periods of more than a day, the least ratio between pressure and temperature variations was detected for $\alpha(h_n)/\alpha(h_m)$-tracers. Variations of other tracers under consideration are connected with the changes of pressure or temperature and are cophased (or antiphased) with the variations of these weather parameters.

Visibility restrictions caused by the smoke from forest fires also result in the change of radioactivity background level and, consequently, that of tracers. Aerosol, including the radioactive one, together with greenhouse gases is an important climate forcing affecting the Earth radiation balance [6]. Detailed investigations of the near ground atmosphere were carried out during long forest fires in the territory of Western Siberia in summer 2012 [20]. Forest fires 2012 in the Siberia lasted from June till August, covered vast territories and caused great damage. The most extreme smoke conditions in the atmosphere were in the third decade of July (July 24-27, 2012) when the smoke plume from remote fire sources remained in Tomsk territory and the meteorological visibility decreased to tens-hundreds of meters. The synoptic situation within this period over the whole eastern part of Western Siberia was determined by low-gradient pressure field. Air temperature varied from +15 °C at nighttime to +30° C by day. The wind was weak (1–3 m/s) from northern direction. There was no precipitation.

We consider the variations of natural radioactivity level from June 29 to July 30, 2012. This interval includes several longest time periods of intensive smoke (from two days and more). Based on the joint analysis of the variations of ionizing radiation levels and the visibility S_m we discovered the following. Intensive smoke and the decrease of S_m associated with it causes consistent decrease of α- background level. For β- and γ- background, gradual increase of background level during intensive smoke was registered. The dynamics of the tracers under investigation is shown in Fig. 5c. The data on meteorological visibility S_m are shown in the middle panel.

Detection of an optimum set of radiation quantities

Complex monitoring carried out at TORII (Tomsk) is redundant for the bulk copying by other scientific groups. Data analysis of long-term monitoring allowed us to develop a method for detection of an optimum set of radiation quantities which may serve as tracers/indicators of extreme climate phenomena when monitored synchronously. According to this method, for a reliable identification of one or several EP considered above, the installed instrumentation should work continuously to measure the following values: a) flux densities of alpha- and beta- radiations at not less than tree heights of 1–1,5 m, 5–10 m and 25–40 m with a time step from 1 to 10 min; b) dose ambient equivalent rate of γ - radiation at not less than two heights of 1–1,5 m and 25–40 m with a time step from 1 to 10 min; c) radon flux density from the soil surface with the time step of not less than 30 min; d) volumetric activity of radon in the soil at not less than two depths of 0,4–0,6 m and 0,8–1,2 m with a time step of not more than 60 min; e) volumetric activity of isotopes of radon and their DP in the air of the near ground atmosphere at not less than two heights from 0,9–1,5 m and 25–40 m with a time step of not more than 60 min.

The choice of the number of heights for control and the recommended ranges of heights for IR detectors are reasoned by the fact that the change of atmospheric turbulence changes significantly the profile of volumetric activity of radon, thoron and their daughter products, particularly by the ground surface. Consequently, it causes considerable variations of IR field characteristics. The number of depths (wells) for control and the recommended ranges of depths for IR detectors are reasoned by the fact that at the depths up to 1 meter, radon activity may significantly change with time and depends on weather conditions, state of the atmosphere and the soil. Furthermore, the radioactive equilibrium in the natural series of ^{238}U, ^{232}Th after radon isotopes is disturbed. It is the result of radon isotope "outflow"from the soil into the near ground atmosphere.

At the same time, it is necessary to monitor the following meteorological quantities with the time step from 0.5 to 1 min: a) air temperature, atmospheric pressure, relative humidity of the atmosphere, wind velocity and direction in the near ground layer of the atmosphere; b) surface and under surface temperatures; c) soil humidity; d); electric field strength and polar electric conductivities; e) arriving solar radiation; f) atmospheric turbulence characteristics.

From the chosen set of quantities of ionizing radiation and their ratios, we should leave those which satisfy the following criteria: a) having anomalous reaction in not less than 95% of cases on EP; b) if more than one radiation quantity or their ratio have anomalous reaction on an EP, we should minimize their number leaving those which allow us to identify unambiguously a certain EP; c) at least one radiation quantity or their ratio should be in a set; it should show reliably that the anomalous reaction is caused by an EP and not by radiation accidents or stress-deformation state of the Earth crust.

Conclusions

Analysis of monitoring data of ionizing radiation variations and weather parameters in the territory of Western Siberia on the time scales from synoptic to annual ones allowed us to:

- state that the balance between the main sources of ionizing radiations in the near ground atmosphere depends on a season, and extremes are associated with the processes of snow cover melting (formation);
- detect the reaction of tracers-indicators on extremely low temperatures and extremely high atmospheric pressure, on series of cyclones and on atmospheric smoke from forest fires;
- detect radiation quantities having similar reaction on certain EP that allowed us to suggest a method to detect an optimal set of radiation quantities which may serve as tracers/indicators of extreme climate phenomena when monitored synchronously.

On the whole, the obtained results indicate strong effect of external conditions on the contribution of different sources into the total level of ionizing radiation of the near ground atmosphere. The principle significance of the detected effects is associated with the role which the ionizing radiation plays both in the formation of weather conditions and in bio-system processes.

The paper was supported by FTsP No. 14.575.21.0105.

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For citation: Nagorskiy P. M., Cherepnev S. M., Yakovleva V. S., Yakovlev G. A. Radiation quantities as tracers/indicators of extreme phenomena in the territory of west Siberia. *Bulletin KRASEC. Physical and Mathematical Sciences* 2016, vol. **12**, no **1**, 83-93. DOI: 10.18454/2313-0156-2016-12-1-83-93

Original article submitted: 20.03.2016