СЕНСОРИ ТА ІНФОРМАЦІЙНІ СИСТЕМИ

SENSORS AND INFORMATION SYSTEMS

PACS: 42.68.Bz, 47.85.Np, 92.60.hk; UDC 539.192
DOI http://dx.doi.org/10.18524/1815-7459.2017.4.119603

NEW BALANCE APPROACH TO THE MODELING OF MACROTURBULENT ATMOSPHERIC DYNAMICS, SPATIAL DISTRIBUTION OF RADIONUCLIDES IN THE GLOBAL ATMOSPHERE, THEIR ENVIRONMENT IMPACT AFTER THE NUCLEAR ACCIDENT AT FUKUSHIMA NUCLEAR POWER PLANT

A. V. Glushkov, A. V. Romanova, V. V. Buyadzhi, E. V. Bakunina, O. Yu. Khetselius, A. A. Svinarenko, A. S. Belodonov

Odessa State Environmental University, L'vovskaya, 15, Odessa, 65016, Ukraine
E-mail: buyadzhivv@gmail.com

NEW BALANCE APPROACH TO THE MODELING OF MACROTURBULENT ATMOSPHERIC DYNAMICS, SPATIAL DISTRIBUTION OF RADIONUCLIDES IN THE GLOBAL ATMOSPHERE, THEIR ENVIRONMENT IMPACT AFTER THE NUCLEAR ACCIDENT AT FUKUSHIMA NUCLEAR POWER PLANT

A. V. Glushkov, A. V. Romanova, V. V. Buyadzhi, E. V. Bakunina, O. Yu. Khetselius, A. A. Svinarenko, A. S. Belodonov

Abstract. We present the elements of a new advanced non-stationary theory of global mechanisms in atmospheric low-frequency processes, teleconnection effects to modelling global atmospheric behaviour, dispersion of radionuclides, assessing radioactivity impact of the Fukushima (Chernobyl) nuclear accidents on the environment. The approach is based on the energy, moment balance relationships for the global atmospheric low-frequency processes, atmospheric macroturbulence theory, link of tropospheric waveguides with atmospheric moisture circulation and, accordingly, with the shape of the atmospheric circulation over the position of the front sections of (atmospheric fronts as the main drives moisture). Atmospheric moisture cycle is linked with such typical low-frequency process as the angular momentum balance; the latter accounts violation of the atmosphere rotating balance with the Earth, which may be under developing meridional processes with the implementation of the mass transfer of air and steam between the tropical latitudes (with a large linear velocity) and slowly rotating air masses of the polar latitudes (a process of slow teleconnection). The approach is realized and implemented into the new microsystem technology "GeoMath-RadEnv" and focused on the testing and prediction of the air mass (particles) flows in the global atmospheric picture, determination of the new predictors for long-term and very long-forecasts of low-frequency atmospheric processes. PC experiments demonstrated the effectiveness of the approach in applying to modeling the balance of angular momentum, the transfer of atmospheric masses (moisture flow) with respect to the genesis of tropospheric waveguides, the continuity of atmospheric circulation forms (telecommunication, front-genesis). The application of the method to the modeling of global atmospheric behavior, the scattering of radionuclides after accidents at the nuclear power plant in Fukushima (Chernobyl) demonstrates its effectiveness, which is confirmed by the physically reasonable agreement between the predicted and measured spatial distribution of radionuclides in the atmosphere, the direction and dynamics of the flows of air masses (particles).

Keywords: atmospheric low-frequency processes, energy and angular momentum balance, teleconnection, global atmospheric behaviour and dispersion of radionuclides, nuclear power plant accidents and radiation-environmental consequences

НОВИЙ БАЛАНСОВИЙ ПІДХІД ДО МОДЕЛЮВАННЯ МАКРОТУРБУЛЕНТНОЇ АТМОСФЕРНОЇ ДИНАМІКИ, ПРОСТОРОВОГО РОЗПОДІЛУ РАДІОНУКЛІДІВ В ГЛОБАЛЬНІЙ АТМОСФЕРІ, ЇХ ВПЛИВУ НА НАВКОЛИШНЄ СЕРЕДОВИЩЕ ПІСЛЯ ЯДЕРНОЇ АВАРІЇ НА АЕС ФУКУСІМА

А. В. Глушков, А. В. Романова, В. В. Буяджи, Е. В. Бакунина, О. Ю. Хецеліус, А. А. Свинаренко, А. С. Бєлодонов

Анотація. Ми представляємо елементи нового нестаціонарної теорії, що описує глобальні механізми в атмосферних низькочастотних процесах, ефекти телеконнекціі та ін. для моделювання глобальної атмосферної поведінки, просторово-часового розподілу (дисперсії) радіонуклідів, оцінки радіоактивного впливу наслідків аварій на атомних електростанціях Фукусіма (Чорнобиль) на навколишнє середовище. Цей підхід заснований на використанні балансових співвідношень для енергії та кутового моменту в глобальних атмосферних низькочастотних процесах, теорії атмосферної макротурбулентності, атмосферного вологообороту у подальшому зв'язку з генезисом тропосферних радіохвильоводів і наступністю форм атмосферної циркуляції (телеконнекція, генезис фронтів), виявленні нових предикторів в середньо- і довгостроковому прогнозуванні динаміки низькочастотних атмосферних процесів. В рамках теорії виявлений зв'язок так званих тропосферних радіохвилеводів з атмосферним вологооборотом і відповідно з формою атмосферної циркуляції через положення фронтальних розділів (атмосферних фронтів як основних накопичувачів вологи). Атмосферний вологооборот пов'язаний з таким типово низькочастотних процесом як виконання балансу по енергії та кутовому моменту атмосфери. Останній характеризує порушення балансу обертання атмосфери разом із Землею, яке може проходити при розвитку меридіональних процесів із здійсненням перенесення маси повітря і пара між тропічними широтами (з великою лінійною швидкістю) і повільно обертаються повітряними масами приполярних широт (процес повільної телеконнекції). Підхід реалізований у вигляді нової мікросистемної технології "GeoMath-RadEnv" і орієнтований на тестування і прогнозування потоків руху повітряних мас (частинок, радіонуклідів) в глобальній атмосферній картині, визначення нових предикторів для середньо- і довго-строкового прогнозування низькочастотних атмосферних процесів. ПК-експерименти продемонстрували ефективність підходу в застосуванні до моделювання балансу кутового моменту, переносу атмосферних мас (вологообороту) по відношенню до генезису тропосферних радіохвилеводів, наступності форм атмосферної циркуляції (телезв'язок, фронт-генезис). Застосування методу до моделювання глобальної атмосферного поведінки, розсіювання радіонуклідів після аварії на атомній електростанції Фукусіма (Чорнобиль) демонструє його ефективність, що підтверджується фізично розумним згодою між передбаченим і виміряним просторовим розподілом радіонуклідів в атмосфері, напрямком і динамікою потоків руху повітряних мас (часток).

Ключові слова: атмосферні низькочастотні процеси, баланс енергії та кутових моментів, телекомунікації, глобальна атмосферна поведінка та дисперсія радіонуклідів, аварії на атомних електростанціях та радіаційно-екологічні наслідки

НОВЫЙ БАЛАНСНЫЙ ПОДХОД К МОДЕЛИРОВАНИЮ МАКРОТУРБУЛЕНТНОЙ АТМОСФЕРНОЙ ДИНАМИКИ, ПРОСТРАНСТВЕННОГО РАСПРЕДЕЛЕНИЯ РАДИОНУКЛИДОВ В ГЛОБАЛЬНОЙ АТМОСФЕРЕ, ИХ ВОЗДЕЙСТВИЯ НА ОКРУЖАЮЩУЮ СРЕДУ ПОСЛЕ ЯДЕРНОЙ АВАРИИ НА АЭС ФУКУСИМА

А. В. Глушков, А. В. Романова, В. В. Буяджи, Е. В, Бакунина, О. Ю. Хецелиус, А. А. Свинаренко, А. С. Белодонов

Аннотация. Мы представляем элементы нового нестационарной теории, описывающей глобальные механизмы в атмосферных низкочастотных процессах, эффекты телеконнекции и др. для моделирования глобального атмосферного поведения, дисперсии радионуклидов, оценки радиоактивного воздействия последствий аварий на атомных электростанциях Фукусима (Чернобыль) окружающую среду. Этот подход основан на использовании балансовых соотношений для энергии и углового момента для глобальных атмосферных низкочастотных процессов, теории атмосферной макротурбулентности, атмосферного влагооборота в дальнейшей связи с генезисом тропосферных радиоволноводов и преемственностью форм атмосферной циркуляции (телеконнекция, генезис фронтов), выявлении новых предикторов в средне- и долго-срочном прогнозировании динамики низкочастотных атмосферных процессов. В рамках теории выявлена связь так называемых тропосферных радиоволноводов с атмосферным влагооборотом и соответственно с формой атмосферной циркуляции через положение фронтальных разделов (атмосферных фронтов как основных накопителей влаги). Атмосферный влагооборот связан с таким типично низкочастотным процессом как выполнение баланса по энерии и угловому моменту атмосферы. Последний характеризует нарушение баланса вращения атмосферы вместе с Землей, которое может проходить при развитии меридиональных процессов с осуществлением переноса массы воздуха и пара между тропическими широтами (с большой линейной скоростью) и медленно вращающимися воздушными массами приполярных широт (процесс медленной телеконнекции). Подход реализован в виде новой микросистемной технологию "GeoMath-RadEnv" и ориентирован на тестирование и прогнозирование потоков движения воздушных масс (частиц) в глобальной атмосферной картине, определение новых предикторов для средне- и долго-срочного прогнозирования низкочастотных атмосферных процессов. ПК-эксперименты продемонстрировали эффективность подхода в применении к моделированию баланса углового момента, переносу атмосферных масс (влагооборота) по отношению к генезису тропосферных радиоволноводов, преемственности форм атмосферной циркуляции (телесвязь, фронт-генезис). Применение метода к моделированию глобального атмосферного поведения, рассеяния радионуклидов после ядерной аварии на атомных электростанциях Фукусима (Чернобыль) демонстрирует его эффективность, что подтверждается физически разумным согласием между предсказанным и измеренным пространственным распределением радионуклидов в атмосфере, направлением и динамикой потоков движения воздушных масс (частиц).

Ключевые слова: атмосферные низкочастотные процессы, баланс энергии и углового момента, телесвязь, глобальное атмосферное поведение и дисперсия радионуклидов, аварии на АЭС и радиационно-экологические последствия

1. Introduction

In development of earlier works [1-7], in this paper we present the elements of a new advanced non-stationary theory of global mechanisms in atmospheric low-frequency processes, teleconnection effects to modelling global atmospheric behaviour, dispersion of radionuclides, assessing the radioactivity impact of the Fukushima (Chernobyl) nuclear accidents on the environment. The approach is based on the energy, moment balance relationships for the global atmospheric low-frequency processes, atmospheric macroturbulence theory, link of tropospheric waveguides with atmospheric moisture circulation and, accordingly, with the shape of the atmospheric circulation over the position of the front sections of (atmospheric fronts as the main drives moisture). The approach is realized and implemented into the new microsystem technology "RadEnv-Math" and focused on the testing and prediction of the air mass (particles) flows in the global atmospheric picture, determination of the new predictors for long-term and very long-forecasts of low-frequency atmospheric processes. The application of the method to the modelling of global atmospheric behaviour, the scattering of radionuclides after accidents at the nuclear power plant in Fukushima (Chernobyl) demonstrates its effectiveness, which is confirmed by the physically reasonable agreement between the predicted and measured spatial distribution of radionuclides in the atmosphere, the direction and dynamics of the flows of air masses (particles).

It should be noted that at present time there are different, quite consistent approaches to modelling global atmospheric processes and respectively the methods of modelling temporal and spatial dispersion of the radionuclides in atmosphere and other geospheres, (look for example, [1-4]). One should mention such methods as MLDP0 (Modèle Lagrangien de Dispersion de Particules d'ordre 0 e Canada), HYSPLIT (Hybrid Single-Particle Lagrangian Integrated Trajectory Model e United States), NAME (Numerical Atmospheric-dispersion Modelling Environment e United Kingdom), RATM (Regional Atmospheric Transport Model e Japan), and FLEXPART (Lagrangian Particle Dispersion Model e Austria). All the ATDMs are of a class of models called Lagrangian Particle Dispersion Models (LPDMs) and others (see, for example, [7,8] and Refs. therein), nevertheless quantitatively correct description of the global atmospheric processes and modelling temporal and spatial dispersion of the radionuclides in atmosphere after accidents at the nuclear power plants etc remains very important , actual and hitherto unsolved problem. The results on the corresponding modelling demonstrate as partly reasonable agreement of the predicted and measured spatial distribution of radionuclides in the atmosphere, the direction and dynamics of the flows of air masses (particles) as the significant disagreement.

2. Global mechanisms in atmospheric low-frequency processes, balance of the angular momentum of the Earth, teleconnection effects: Effective approach

Here we present the fundamental basis's of a new advanced non-stationary approach to global mechanisms in atmospheric low-frequency processes, the balance of the Earth angular momentum, teleconnection effects and atmospheric radio waveguides. The approach has been realized as a new geophysical microsystem technology "Geo-Math-RadEnv" [1-4]. The topics studied are of a great interest for modern physics of large-scaled atmosphere processes (see also Ref. [3-10]). As the key elements of our theory were in details presented earlier, here we are limited only by the key advanced aspects. An advanced non-stationary angular momentum balance equation of in the planetary dynamic movements of air masses is written in the following standard integral form [2,4]:

$$\frac{\partial}{\partial t}\int \rho M dV = \int_{\varphi_1}^{\varphi_2}\int_0^H\int_0^{2\pi} \rho v M d\varphi dz d\lambda + \int_0^H\int_{\varphi_1}^{\varphi_2}\int_0^{2\pi}\left(p_E^i - p_W^i\right)a\cos\varphi dz d\varphi d\lambda + \int_{\varphi_1}^{\varphi_2}\int_0^{2\pi}\int_0^H \tau_0 a\cos\varphi d\varphi d\lambda 2\pi, \quad (1)$$

where M = $\Omega a^2\cos\varphi + ua\cos\varphi$ - angular momentum; Ω - the angular velocity of rotation of the Earth; a - radius of the Earth; φ - Latitude (φ_1 - φ_2 - separated latitudinal belt between the Arctic and polar fronts); λ - longitude; u, v - zonal and meridional components of the wind velocity; ρ - air density; V - the entire volume of the atmosphere in this latitude belt from sea level to the average height of the elevated troposphere waveguide - H (in notations [139] H = ∞); $p_E^i - p_W^i$ - the pressure difference between the eastern and western slopes of the i-th mountains; z - height above sea level; τ_0 - the shear stress on the surface.

From the point of view of physics, the cycle of balance of angular momentum in the contact zones with the hydrosphere and lithosphere becomes a singularity. This singularity can be detected through the occurrence of zones of fronts and soliton-type front. Then the kernel of equation (1) can be defined in the density functional ensemble of complex velocity potential [2,3]

$$f = \overline{v_\infty} z + \frac{1}{2\pi}\sum_{k=1}^{n} q_k \ln\left(z - a_k\right) + \frac{1}{2\pi}\sum_{k=1}^{p}\frac{M_k e^{\alpha_k i}}{z - c_k} - \frac{i}{2\pi}\sum_{k=1}^{m}\Gamma_k \ln\left(z - b_k\right) \quad (2)$$

and the complex velocity, respectively, will be

$$v = \frac{df}{dz} = \overline{v_\infty} + \frac{1}{2\pi}\sum_{k=1}^{n}\frac{q_k}{z - a_k} - \frac{1}{2\pi}\sum_{k=1}^{p}\frac{M_k e^{\alpha_k i}}{\left(z - c_k\right)^2} - \frac{i}{2\pi}\sum_{k=1}^{m}\Gamma_k / \left(z - b_k\right), \quad (3)$$

where w – complex potential; v_∞ – complex velocity general circulation background (mainly zonal circulation); b_k – coordinates of vortex sources in the area of singularity; c_k – coordinates of the dipoles in the area of singularity; a_k – coordinates of the vortex points in areas of singularity; M_k – values of momenta of these dipoles; α_k – orientation of the axes of the dipoles; Γ_k, q_k – values of circulation in the vortex sources and vortex points, respectively.

In the scheme by Oort [9] the Hadley circulation cell in angular momentum in the north part runs into a zone of the Arctic front, and at the time of the lithosphere it is included in the coverage of the polar front. Convergence of these atmospheric fronts could then close the cycle of atmospheric angular momentum balance in the same frequency range of atmospheric fluctuations without giving effect by an ocean and the lithosphere. Of course, the Hadley tropical cell carries teleconnection of the polar front with southern process by means of the link mechanism which is similar to link between the tropical and polar fronts or the Hadley tropical cell with a cell Hadley of temperate latitudes. The balance of angular momentum in conditions of the close convergence of the Arctic and Polar fronts over the ocean (which is almost always in all seasons and over the continents in the summer and in the transition seasons) is largely respected by centrifugal "pull" moisture along the front section of the polar front to south of the center of the cyclonic-depressive these. The physical features of the atmospheric ventilation predetermine the necessary modification of the well-known Arakawa-Schubert model. The model includes the budget equations for mass, moist static energy, total water content plus the equations of motion (look details in [10]). In [10] it is also defined a cloud work function which is an integral measure of the buoyancy force in the clouds. If *A* is a work of the convective cloud then it consists of the convection work and work of down falling streams in the neighbourhood of a cloud:

$$dA/dt = d\,A/dt_{conv} + dA/dt_{downstr}, \qquad dA/dt_{downstr} = \int_0^{\lambda_{\max}} m_B(\lambda')K(\lambda,\lambda')d\lambda'. \quad (4)$$

Here λ is a velocity of involvement, $m_B(\lambda)$ is an air mass flux, $K(\lambda, \lambda')$ is the Arakawa-Schubert integral equation kernel, which determines the dynamical interaction between the neighbours clouds. The actual form of $K(\lambda, \lambda')$ and $F(\lambda)$ as well as their derivations are given in Appendix B [10]. If

$$\left.\frac{dA}{dt}\right|_{downstr.} = F(\lambda)$$

$$\int_0^{\lambda_{\max}} K(\lambda,\lambda')m_B(\lambda')d\lambda' + F(\lambda) = 0 \qquad (5)$$

is an mass balance equation in the convective element (thermal), then one could write [2]:

$$m_B(\lambda) = F(\lambda) + \beta \int_0^{\lambda_{\max}} m_B(\lambda')K(\lambda,\lambda')d\lambda' \,. \qquad (6)$$

Here β is parameter which determines disbalance of cloud work due to the return of part of the cloud energy to the organization of a wind field in their vicinity, and balance regulating its contribution to the synoptic processes. The solution of the Eq. (6) with accounting for air stream superposition of the synoptic processes can be determined by a resolvent method (see [2-5]:

$$m_B(\lambda) = F(\lambda) + \beta \int_0^{\lambda_{\max}} F(s)\Gamma(\lambda,s;\beta)ds, \qquad (7)$$

where $\Gamma(x,s;\beta)$ is an resolvent of the integral Eq.(7):

$$\Gamma(\lambda,s:\beta) = \sum_{m=1}^{\infty} \beta^{m-1}K_m(\lambda,s); \qquad (8)$$

$$K_m(x,s) = \int_0^{\lambda_{\max}} \ldots \int_0^{\lambda_{\max}} K(x,t_1)K(t_1,t_2)\ldots K(t_{m-1},s)dt_1dt_2\ldots dt_{m-1}. \qquad (9)$$

The key idea [2] is to determine the resolvent as an expansion to the Laurent series in a complex plane ζ. As result, one could obtain a representation for resolvent by the following Fourier expansion:

$$\Gamma = \sum_{n=-\infty}^{\infty} c_n(\zeta - a)^n$$

$$c_n = \frac{1}{2\pi i} \oint_{|\zeta|=1} \frac{f(\zeta)d\zeta}{(\zeta - a)^{n+1}} \qquad (10)$$

where a is centre of convergence ring of the Laurent series.

Further we consider an advanced spectral analogue for equation of motion for dynamics of the atmosphere in the low frequency range. As it is well known, the shape of the atmospheric circulation changes its position in space, and the intensity of manifestations varies in the period up to several days, while inside it implemented processes, lasting a few minutes, such as precipitation. Hydrodynamic equations are set to reasonably high-frequency processes in the atmosphere of the evolution of the cyclonic type of education in the period up to two days, but it is not able to well describe the low-frequency processes such as change of the circulation forms.

At the same time the macroturbulent atmosphere equations are low-frequency ones in its basis and there is a lot of experience of their decision on the basis of spectral methods (see [1-3]. This allows you to use them for our purposes for the mathematical modeling of the changing forms of circulation and, respectively, for the mathematical parameterization homologues circulation [1-3].

In order to solve this task, one should involve coupling moments forecasting model, which we know from the system of the Reynolds equations with implemented average and fluctuation motion.

The method for calculating a turbulence spectra should be based on the standard tensor equations of turbulent tensions. As usually, it is convenient to partition velocity $\boldsymbol{u}(v_x, v_y, w)$, pressure p, temperature θ etc into equilibrium and departures from equilibrium values (for example: $p=p_0+p'$etc). One could write the system of equations for the Reynolds tensions, moments of connection of the velocity pulsations with entropy ones and the corresponding closure equations. The technique of using Reynolds tension tensors of the second rank is well known (for example, in the form of an analytical representation). The circuit equations with accounting the Coriolis force in the analytical form can be rewritten as (according [2,3]:

$$\frac{\partial V'^2}{\partial t} = -\frac{i}{a}\left[\overline{V'^2}L_1(\bar{V}) + 2\bar{V}\overline{V'L_1(V')} + \overline{V'^2 L_1(V')}\right] -$$
$$-\frac{i}{a}\left[L_2(\bar{V})\overline{V'U'} + \bar{V}\overline{U'L_2(V')} + \bar{U}\overline{V'L_2(V')} + \overline{V'U'L_2(V')}\right] +$$
$$+ 4\omega i \cos\theta\overline{V'^2} + \frac{2i}{a}\overline{V'L_6(\Phi')}\,, \qquad (11a)$$

$$\frac{\partial U'^2}{\partial t}=-\frac{i}{a}\left[\overline{V'U'}L_3\left(\overline{U}\right)+\overline{V}\,\overline{U'L_3\left(U'\right)}+\overline{U}\,\overline{V'L_3\left(U'\right)}+\overline{V'U'L_3\left(U'\right)}\right]-$$
$$-\frac{i}{a}\left[\overline{U'^2}L_4\left(\overline{U}\right)+2\overline{U}\,\overline{U'L_4\left(U'\right)}+\overline{U'^2L_4\left(U'\right)}\right]-$$
$$-4\omega i\cos\theta\overline{U'^2}+\frac{2i}{a}\overline{U'L_5\left(\Phi'\right)}, \tag{11b}$$

$$\frac{\partial\overline{V'U'}}{\partial t}=-\frac{i}{2a}\left[\overline{V'^2}L_3\left(\overline{U}\right)+2\overline{V}\,\overline{V'L_3\left(U'\right)}+\overline{V'^2L_3\left(U'\right)}\right]-$$
$$-\frac{i}{2a}\left[\overline{V'U'}L_4\left(\overline{U}\right)+\overline{U}\,\overline{V'L_4\left(U'\right)}++\overline{V}\,\overline{U'L_4\left(U'\right)}+\overline{V'U'L_4\left(U'\right)}\right]+ \tag{11c}$$
$$+\frac{i}{a}\overline{V'L_6\left(\Phi'\right)}-\frac{i}{2a}\left[\overline{U'^2}L_2\left(\overline{V}\right)+2\overline{U}\,\overline{U'L_2\left(U'\right)}\right]-$$
$$-\frac{i}{2a}\left[\overline{U'V'}L_1\left(\overline{V}\right)+\overline{U}\,\overline{V'L_1\left(V'\right)}++\overline{V}\,\overline{U'L_1\left(V'\right)}+\overline{V'U'L_1\left(V'\right)}\right],$$

where, as usually:

$$L_j=\frac{\partial(...)}{\partial\theta}-\left(-1\right)^j\frac{i}{\sin\theta}\frac{\partial(...)}{\partial\lambda}+b_j\operatorname{ctg}\theta(...),$$

b_j=1, j=1,4; b_j=-1, j=2,3; b_j=0, j=5,6.

The simplified modelling (see for example, [2]) supposes remaining only two operators, say, in the equation (11c):

$$\frac{\partial\overline{V'U'}}{\partial t}=\frac{i}{a}\overline{V'L_6\left(\Phi'\right)}, \tag{12}$$

expressing Φ' through φ complex potential of the velocity f, and the velocity components V' - in terms of functions ψ of the same velocity potential. We suppose that this procedure should be replaced by more consistent one that provides an advanced level of a theory.

Naturally, the equations for tensor of the turbulent tensions:

$$\frac{\partial\overline{u'_iu'_j}}{\partial t}+\frac{\partial}{\partial x_k}\left(\overline{u_k}\cdot\overline{u'_iu'_j}+\overline{u'_ku'_iu'_j}\right)+\frac{\partial\overline{p'u'_i}}{\partial x_j}+\frac{\partial\overline{p'u'_j}}{\partial x_i}=$$
$$=-\overline{u'_iu'_k}\frac{\partial\overline{u_j}}{\partial x}-\overline{u'_ju'_k}\frac{\partial\overline{u_i}}{\partial x}+\overline{p'\left(\frac{\partial u'_i}{\partial x}+\frac{\partial u'_j}{\partial x}\right)}. \tag{13}$$

The important parameter of the turbulent processes is the kinetic energy of turbulent vortices $b^2=\overline{u'_ku'_k}$, which can be found from the equation (with physical explanations of any term):

$$\underbrace{\frac{\partial b}{\partial t}+\frac{\partial u_kb^2}{\partial x_k}}_{\text{Advection}}+\underbrace{\frac{\partial}{\partial x_k}\left(\overline{u'_ku'_iu'_j}+2\overline{u'_kp'}\right)}_{\text{Turbulent diffusion / Effect of forces of tension}}=\underbrace{-2\overline{u'_ku'_i}\frac{\partial u_i}{\partial x_k}}_{\text{Interaction of the Reynolds tension and averaged motion}}\underbrace{-2\frac{g}{\theta_0}\overline{w'\theta'}}_{\text{Generation for account for swimming forces}} \tag{14}$$

Here g is the magnitude of the acceleration vector due to the planet's gravity, θ_0 is the equilibrium potential temperature, θ', p' are departures from equilibrium values. The physical content of any term is presented in Eq. (14).

Velocity's correlates are determined as follows [2]:

$$\overline{u'_iu'_ju'_k}=-b\lambda_1\left(\frac{\partial\overline{u_iu_j}}{\partial x_k}+\frac{\partial\overline{u_iu_k}}{\partial x_j}+\frac{\partial\overline{u_ju_k}}{\partial x_i}\right);$$
$$\overline{u'_ku'_j\theta'}=-b\lambda_2\left(\frac{\partial\overline{u'_k\theta'}}{\partial x_j}+\frac{\partial\overline{u_j\theta'}}{\partial x_k}\right);$$
$$\overline{u_i\theta'^2}=-b\lambda_3\left(\frac{\partial\overline{\theta'^2}}{\partial x_i}\right);$$
$$\overline{p'\frac{\partial\theta'}{\partial x_i}}=-\frac{b}{3l_1}\overline{u_i\theta'}-\frac{1}{3}\sigma_{i3}\frac{g}{\theta_0}\overline{\theta'^2}; \tag{15}$$
$$\overline{p'\left(\frac{\partial u_i}{\partial x_j}+\frac{\partial u_j}{\partial x_i}\right)}=-\frac{b}{3l_1}\left(\overline{u_iu_j}-\frac{1}{3}\sigma_{ij}b^2\right)+cb^2\left(\frac{\partial\overline{u_i}}{\partial x_j}+\frac{\partial\overline{u_j}}{\partial x_i}\right).$$

Here c, l_1, λ_i are constants which define the scales of turbulent vortexes and measure of their influence on the averaged motion and atmosphere turbulence anisotropy. Components of tensor of the turbulent tensions are ($v_{l,n}$ - spectral modes of velocity field) [2]:

$$\hat{V}^2=\sum_{k=1}^{\infty}\sum_{s=-k}^{k}V_{k,s}T_{1,s}^k\left(\sum_{q=1}^{\infty}\sum_{j=-q}^{q}V_{q,j}T_{1,j}^q\right)=$$
$$=\sum_{k=1}^{\infty}\sum_{s=-k}^{k}\sum_{q=1}^{\infty}\sum_{j=-q}^{q}V_{k,s}V_{q,j}\times \tag{16}$$
$$\times\sum_{\nu=|k-q|}^{k+q}\sigma_{1,1,2}^{k,q,\nu}\sigma_{s,j,s+j}^{k,q,\nu}T_{2,s+j}^{\nu}=\overline{v'_1v'_1}=b^2.$$

An effective approach to determination of the atmospheric flow velocity can be given by method of a plane complex field theory in a full analogy with the known Karman vortices chain model:

$$v_x-iv_y=\frac{df}{d\xi}=\frac{\Gamma}{2\pi i}\left[\frac{1}{\zeta-\zeta_0}+\sum_{k=1}^{\infty}\left(\frac{1}{\zeta-\zeta_0-kl}+\frac{1}{\zeta-\zeta_0+kl}\right)\right]+$$
$$+\frac{d}{d\zeta}\left[\sum_{k=1}^{n}\Gamma_k\ln\left(\zeta-b_k\right)\right]. \tag{17}$$

Here Γ_k –circulation on the vortex elements, created by clouds, b_k – co-ordinates of these elements, Γ – circulation on the standard Karman chain vortices of, l – distance between standard vortices of the Karman chain, ζ - co-ordinate of the convective perturbations line (or front divider) centre, ζ_0 - kl – co-ordinate of beginning of the convective perturbation line, ζ_0+kl – co-ordinate of end of this line. Equating the velocity components determined in the global circulation model and and model (6), we find the spectral matching between the wave numbers that define the functional elements in the Fourier-Bessel series with the source element of a plane field theory.

It is also worth to remind that any vector field u can be separated into rotational and divergent parts, i.e.,

$$u = \nabla \psi + u_f \tag{18}$$

(the Helmholtz's theorem). If the vector field is a horizontal wind, one can define a current function ψ, to express the rotational part, and a velocity potential f, to express the divergent part. Namely these parameters are of a great interest in applied analysis of an global atmospheric ventilation. Below we present the results of test computing the atmospheric ventilation for a few synoptic situations in the Pacific ocean region. All calculations are performed with using of the "GeoMath-RadEnv" and "Quantum" PC codes [1-5,11-16].

3. Some numerical results and conclusions

Regarding the Fukushima Nuclear power plant accidents, it is well-known [8] that on March 11th 2011, an earthquake of magnitude 9.0 occurred off northeastern Japan, causing a tsunami and damaging the Fukushima Daiichi Nuclear Power Plant (FNPP1). As a result, radioactive products were released in the atmosphere and other geospheres (ocean, soils etc). A summary of the meteorological conditions during the critical phases of the atmospheric emissions is given in the WMOTT report (WMO, 2013) and by several other researchers. According to [8], from March 9th to 12th a weak low pressure trough over eastern Japan caused light rain to be observed and then a high pressure system moved eastward along the south coast of the main island of Japan from the 12th through the 13th; from March 14th to 15th another weak low pressure trough moved eastward off the southern coast of the main island then moved toward the northeast while developing rapidly after the 15th. In particular, rain was observed in the Fukushima prefecture during the night from 1700 JST1 March 15 to 0400 JST March 16 (Kinoshita et al., 2011), a time corresponding with significant emissions. High pressure dominated on March 18th and 19th and the winds were generally from the west. A low pressure system passed over the main island from March 20th to the 22nd causing moderate rain near Tokyo. It is well known that the deposition, dispersion of the of radionuclides in the atmosphere mainly depended upon many factors such as the source term characteristics including source magnitude and source height, meteorological condition, atmospheric circulation on different temporal and spatial time-scales, the physical and physicochemical property of specific radionuclide. Regading the Fukushima nuclear plant accidents, the behavior of Fukushima-derived radionuclides is attributed to the large scale atmospheric low-frequency processes (circulation) as according to Refs. [2,5-7] the Fulushima accidents radionuclides were detected in the northern hemisphere and southern hemisphere within 20 day and one month after the accidents [8].

Further let us present some of our modelling results taking into account that as we have very limited space available for this paper. All necessary input data parameters are taken from Refs. [1-4-7]. Below as illustration, we present the results of our numerical simulation and experiments and their analysis is given. Calculation of changes in the height of elevated tropospheric wave guide in the form of circulation, M1 (look Figure 1 and Ref. [2]) gave the average height of tropospheric waveguide according to the season within the 1500-2500 m; changes desired heights are in the range of 50-500 m. It is important for long-term forecasting only a sign of abnormality of heights of the radiowaveguide and not their numerical characteristics.

The negative anomalies are observed near the Asian and American continents, and positive anomaly - over the Pacific Ocean (Fig. 1). Figure 2 corresponds to wind flows presented an anomaly of the stream function, where the direction of the velocity vector corresponds to the positive values that were left of the stream (Figure 1b numbers marked velocity values in m× c^{-1}; the corresponding values of changes in the function of the current make - maximum value: ~20×10^6 m^2s^{-1}, ~1.2×10^6 m^2s^{-1}). Analysing results in Figures 1,2, one could see that a transfer of angular momentum along the horizontal moisture transfer goes from east to west, which corresponds to a calculated scheme [9], with the main stream of the West account for the breadth of the Aleutian Islands, which also corresponds to the results by Oort et al [9]. Similar results are obtained in Refs. [2,9] for the shape of the M1, but for the cold half of the year. It has been found that the rise height of the raised radio waveguides is shifted to the north, with a maximum over Japan. This can be explained by the increase of the temperature contrast of "Pole - Equator" and the corresponding displacement of the Arctic and polar fronts. It is important to note that the results obtained here differ from the analogous results of the corresponding stationary theory and simplified non-stationary one on about 10-15%. This fact confirms that a real theory of the studied phenomena should be by non-stationary one.

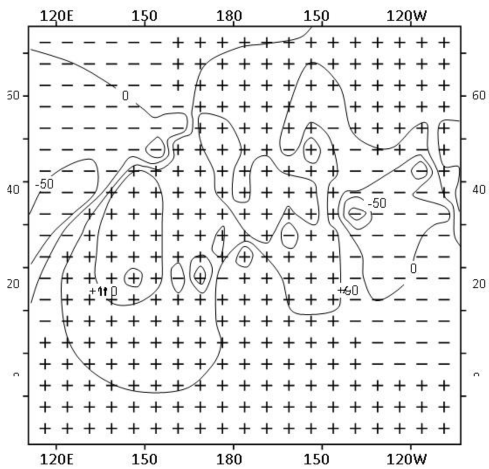

Figure 1. Changing the height of the tropospheric radiowaveguide (see text).

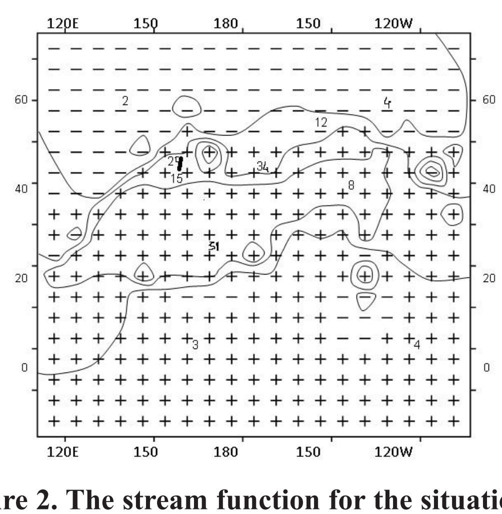

Figure 2. The stream function for the situation depicted in the Figure 1 (see text).

In Figure 3 we present our data on the average wind velocity (in knots) and the stream function (continuous lines) at 500 hPa, computed for the period from 11 March to 22 March, 2011. The analogous data for the wind velocity and the stream function have been presented in Ref. [8]. In whole there is quite complex picture of air flows and its predetermined that particles, which were released from Fukushima in different times and different altitudes above the earth surface had various trajectories in a full correspondence with data [8]. The stream has been influencing significantly the particles spreading at upper atmospheric levels (in absolute values the average wind velocity of the jet stream reached the values of about 20 m× s^{-1}). Analysis of the presented data show that the modelling results are in a physically reasonable agreement, though do not reflect in a full degree the observed picture. Nevertheless, the main atmospheric dynamical aspects in the studied period are reflected quite acceptably.

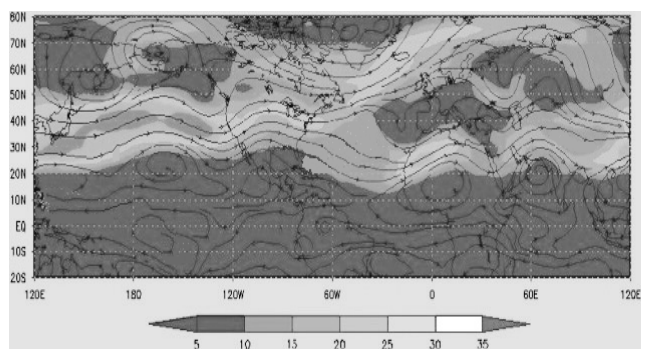

Figure 3. The data on the average wind velocity and stream function (lines) at 500 hPa, computed for the period 11-22 March, 2011.

In any case the modelling demonstrated the effectiveness of the approach in applying to studying the large scale atmospheric behaviour, provided by the energy and angular momentum balance, the transfer of atmospheric masses (moisture flow) with respect to the continuity of atmospheric circulation forms (telecommunication, front-genesis). The application of the method to the modelling of global atmospheric behaviour, the scattering of radionuclides after accidents at the nuclear power plant in Fukushima (Chernobyl) demonstrates its quite acceptable potential, which is confirmed by the preliminary, physically reasonable agreement between the predicted and measured spatial distribution of radionuclides in the atmosphere, the direction and dynamics of the flows of air masses (particles). These data in details will be presented separately.

To conclude, we present the elements of a new advanced non-stationary theory of global mechanisms in atmospheric low-frequency processes, teleconnection effects to modelling global atmospheric behaviour, dispersion of radionuclides, provided by a radioactivity impact of the Fukushima (Chernobyl) nuclear accidents on the atmospheric environment. The approach is based on the energy, moment balance relationships for the global atmospheric low-frequency processes, atmospheric macroturbulence theory, link of tropospheric waveguides with atmospheric moisture circulation and, accordingly, with the shape of the atmospheric circulation over the position of the front sections of (atmospheric fronts as the main drives moisture). Atmospheric moisture cycle is associated with the typical low-frequency performance of the process as the balance of an energy, entropy and angular momentum. Last imbalance characterizes the rotation of the atmosphere together with the Earth, which may lead to the development of meridional processes with the implementation of the mass transfer of air and steam between tropical latitudes (with a linear velocity) and slowly rotating air masses of polar latitudes (in fact it is a slow process teleconnection). Imbalance on the energy and atmosphere angular momentum can not remain without consequences in the atmosphere due to the rather large forces involved in the desired dynamics. Naturally imbalance causes the effects of the singularity, i.e. sharp reaction of the atmosphere in an attempt to eliminate it. In any case, such a serious impact on the atmosphere, in principle, can largely cause change in the form of atmospheric circulation, which allows quickly to redress the energy and angular momentum imbalance organization sufficiently rapid moisture transport etc.

References

[1]. Glushkov A. V., Renorm-group and fractal approach to turbulence spectrum in planetary atmosphere system, “cosmic plasma – galactic cosmic rays”//Ukrainian Hydrometeorology Journal-2013. - № 12.- C. 25-30.

[2]. Glushkov A. V., Ambrosov S. V., Entropy, energy and angular momentum balances and long-term forecasting a whether.-Odessa; OHMI: 1998.

[3]. Glushkov A. V., Efimov V. A., Kivganov A. F., Modelling climate as a problem of interaction of the solitons triplete//Meteorology, Climatology and Hydrology.-1999.-Issue 38.-P. 3-8.

[4]. Khokhlov V. N., Glushkov A. V., Tsenenko I. A. Atmospheric teleconnection patterns and eddy kinetic energy content: wavelet analysis// Nonlinear Processes in Geophysics.-2004.-Vol. 11.-P. 295–301.

[5]. Glushkov A. V., Khetselius O. Yu., Ambrosov S. V., Bunyakova Yu. Ya., Mansarliysky V. F., The use of microsystems technology “Geomath” to modeling the balance of the angular momentum of the earth, atmospheric processes and parameters of radio waveguides: III. Nonstationary theory. //Sensor Electronics and Microsystems Technologies-2013.- Vol. 10, N1-P. 22-28.

[6]. Glushkov A. V., Khokhlov V. N., Bunyakova Yu. Ya., Prepelitsa G. P., Svinarenko A. A., Tsenenko I. A. Sensing the nonlinear interaction between global teleconnection patterns: micros technology “Geomath”//Sensor Electr. and Microsyst. Techn.-2006.-Vol. 3, N1.-P. 64-70.

[7]. Rusov V. D., Glushkov A. V., Vaschenko V. N., Myhalus O. T., Bondartchuk Yu. A. etal Galactic cosmic rays – clouds effect and bifurcation model of the earth global climate. Part 1. Theory// Journal of Atmospheric and Solar-Terrestrial Physics (Elsevier).-2010.-Vol. 72.-P. 498-508.

[8]. Povinec P. P., Gera M., Holý K. et al, Dispersion of Fukushima radionuclides in the global atmosphere and the ocean//Applied Rad. And Isotopes.-2013.-Vol81.-P. 383-392

[9]. Peixoto J. P., Oort A. H. Physics of Climate – N.-Y. : AIP.-1992. –520p. ;

[10]. Arakava A., Shubert W. H., Interaction of cumulus cloud ensemble with the lerge-scale environment//Journ. of Atm. Sci.-1974.-Vol. 31.-P. 674-701

[11]. Glushkov A. V., Relativistic Quantum Theory. Quantum mechanics of Atomic Systems.-Odessa: Astroprint, 2008.- 700P.

[12]. Glushkov A. V., Malinovskaya S. V., Chernyakova Yu. G., Svinarenko A. A. Cooperative laser-electron-nuclear processes: QED calculation of electron satellites spectra for multi-charged ion in laser field//Int. Journ. Quant.

Chem.- 2004.-Vol. 99, N6.-P. 889-893.

[13]. Glushkov A V, Ambrosov S V, Loboda A V, Chernyakova Yu, Svinarenko A A, Khetselius O Yu, QED calculation of the superheavy elements ions: energy levels, radiative corrections, and hfs for different nuclear models// Nucl. Phys. A. : nucl. and hadr. Phys.-2004.-Vol. 734.-P. 21

[14]. Khetselius O. Yu., Relativistic perturbation theory calculation of the hyperfine structure parameters for some heavy-element isotopes//Int. Journ. of Quantum Chemistry.-2009.-Vol. 109, N14.-P. 3330-3335.

[15]. Glushkov A., Khetselius O., Lovett L., Electron-β-nuclear spectroscopy of atoms and molecules and chemical environment effect on the β-decay parameters// Advances in the Theory of Atomic and Molecular Systems Dynamics, Spectroscopy, Clusters, and Nanostructures. (Springer).-2009.-Vol. 20.-P. 125-152.

[16]. Malinovskaya S., Glushkov A., Dubrovskaya Yu., Vitavetskaya L., Quantum calculation of cooperative muon-nuclear processes: discharge of metastable nuclei during negative muon capture// Recent Advances in the Theory of Chemical and Physical Systems (Springer).-2006.-Vol. 15.-P. 301-307.

Стаття надійшла до редакції 01.12.2017 р.

PACS: 42.68.Bz, 47.85.Np, 92.60.hk; UDC 539.192
DOI http://dx.doi.org/10.18524/1815-7459.2017.4.119603

NEW BALANCE APPROACH TO THE MODELING OF MACROTURBULENT ATMOSPHERIC DYNAMICS, SPATIAL DISTRIBUTION OF RADIONUCLIDES IN THE GLOBAL ATMOSPHERE, THEIR ENVIRONMENT IMPACT AFTER THE NUCLEAR ACCIDENT AT FUKUSHIMA NUCLEAR POWER PLANT

A. V. Glushkov, A. V. Romanova, V. V. Buyadzhi, E. V. Bakunina, O. Yu. Khetselius, A. A. Svinarenko, A. S. Belodonov

Odessa State Environmental University, L'vovskaya, 15, Odessa, 65016, Ukraine
E-mail: glushkovav@gmail.com

Summary

We present the elements of a new advanced non-stationary theory of global mechanisms in atmospheric low-frequency processes, teleconnection effects to modelling global atmospheric behaviour, dispersion of radionuclides, assessing radioactivity impact of the Fukushima (Chernobyl) nuclear accidents on the environment. The approach is based on the energy, moment balance relationships for the global atmospheric low-frequency processes, atmospheric macroturbulence theory, link of tropospheric waveguides with atmospheric moisture circulation and, accordingly, with the shape of the atmospheric circulation over the position of the front sections of (atmospheric fronts as the main drives moisture). Atmospheric moisture cycle is linked with such typical low-frequency process as the angular momentum balance; the latter accounts violation of the atmosphere rotating balance with the Earth, which may be under developing meridional processes with the implementation of the mass transfer of air and steam between the tropical latitudes (with a large linear velocity) and slowly rotating air masses of the polar latitudes (a process of slow teleconnection). The approach is realized and implemented into the new microsystem technology «GeoMath-RadEnv» and focused on the testing and prediction of the air mass (particles) flows in the global atmospheric picture, determination of the new predictors for long-term and very long-forecasts of low-frequency atmospheric processes. PC experiments demonstrated the effectiveness of the approach in applying to modeling the balance of angular momentum, the transfer of atmospheric masses (moisture flow) with respect to the genesis of tropospheric waveguides, the continuity of atmospheric circulation forms (telecommunication, front-genesis). The application of the method to the modeling of global atmospheric behavior, the scattering of radionuclides after accidents at the nuclear power plant in Fukushima (Chernobyl) demonstrates its effectiveness, which is confirmed by the physically reasonable agreement between the predicted and measured spatial distribution of radionuclides in the atmosphere, the direction and dynamics of the flows of air masses (particles).

Keywords: atmospheric low-frequency processes, energy and angular momentum balance, teleconnection, global atmospheric behaviour and dispersion of radionuclides, nuclear power plant accidents and radiation-environmental consequences

PACS: 42.68.Bz, 47.85.Np, 92.60.hk; УДК 539.192
DOI http://dx.doi.org/10.18524/1815-7459.2017.4.119603

НОВИЙ БАЛАНСОВИЙ ПІДХІД ДО МОДЕЛЮВАННЯ МАКРОТУРБУЛЕНТНОЇ АТМОСФЕРНОЇ ДИНАМІКИ, ПРОСТОРОВОГО РОЗПОДІЛУ РАДІОНУКЛІДІВ В ГЛОБАЛЬНІЙ АТМОСФЕРІ, ЇХ ВПЛИВУ НА НАВКОЛИШНЄ СЕРЕДОВИЩЕ ПІСЛЯ ЯДЕРНОЇ АВАРІЇ НА АЕС ФУКУСІМА

А. В. Глушков, А. В. Романова, В. В. Буяджи, Е. В. Бакунина, О. Ю. Хецеліус, А. А. Свинаренко, А. С. Бєлодонов

Одеський державний екологічний університет, Львівська 15, Одесса, 65016
E-mail: glushkovav@gmail.com

Реферат

Ми представляємо елементи нового нестаціонарної теорії, що описує глобальні механізми в атмосферних низькочастотних процесах, ефекти телеконнекціі та ін. для моделювання глобальної атмосферної поведінки, просторово-часового розподілу (дисперсії) радіонуклідів, оцінки радіоактивного впливу наслідків аварій на атомних електростанціях Фукусіма (Чорнобиль) на навколишнє середовище. Цей підхід заснований на використанні балансових співвідношень для енергії та кутового моменту в глобальних атмосферних низькочастотних процесах, теорії атмосферної макротурбулентності, атмосферного вологообороту у подальшому зв'язку з генезисом тропосферних радіохвильоводів і наступністю форм атмосферної циркуляції (телеконнекція, генезис фронтів), виявленні нових предикторів в середньо- і довго-строковому прогнозуванні динаміки низькочастотних атмосферних процесів. В рамках теорії виявлений зв'язок так званих тропосферних радіохвилеводів з атмосферним вологооборотом і відповідно з формою атмосферної циркуляції через положення фронтальних розділів (атмосферних фронтів як основних накопичувачів вологи). Атмосферний вологооборот пов'язаний з таким типово низькочастотних процесом як виконання балансу по енергії та кутовому моменту атмосфери. Останній характеризує порушення балансу обертання атмосфери разом із Землею, яке може проходити при розвитку меридіональних процесів із здійсненням перенесення маси повітря і пара між тропічними широтами (з великою лінійною швидкістю) і повільно обертаються повітряними масами приполярних широт (процес повільної телеконнекції). Підхід реалізований у вигляді нової мікросистемної технології «GeoMath-RadEnv” і орієнтований на тестування і прогнозування потоків руху повітряних мас (частинок, радіонуклідів) в глобальній атмосферній картині, визначення нових предикторів для середньо- і довго-строкового прогнозування низькочастотних атмосферних процесів. ПК-експерименти продемонстрували ефективність підходу в застосуванні до моделювання балансу кутового моменту, переносу атмосферних мас (вологообороту) по відношенню до генезису тропосферних радіохвилеводів, наступності форм атмосферної циркуляції (телезв’язок, фронт-генезис). Застосування методу до моделювання глобальної атмосферного поведінки, розсіювання радіонуклідів після аварії на атомній електростанції Фукусіма (Чорнобиль) демонструє його ефективність, що підтверджується фізично розумним згодою між передбаченим і виміряним просторовим розподілом радіонуклідів в атмосфері, напрямком і динамікою потоків руху повітряних мас (часток).

Ключові слова: атмосферні низькочастотні процеси, баланс енергії та кутових моментів, телекомунікації, глобальна атмосферна поведінка та дисперсія радіонуклідів, аварії на атомних електростанціях та радіаційно-екологічні наслідки