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On the one-dimensional two-phase/many-component convective flows in different geophysical mediums: laboratory method of modeling of fluids bubble boiling

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Abstract

Today, research of different geophysical medium shells' stability is one of the actual problems. We paid our attention to the vertical motions of different fluids heated from below: in the first part there are theoretical aspects of the problem, in the second, experimental part, – original fluid bubble boiling method of modeling of vertical one-dimensional two-phase flow. Supposed laboratory method considers vertical motion of heated from below fluids – main element of convection, which plays important role in extraordinary natural phenomena (thunderstorms, volcanoes, gazer, mantle-plumes, tectonic motions, ionosphere continued waves, solar wind, magnetic storms etc.), and named by us as "bubble boiling method of fluids". Preliminary experiments of modeling of fluid convective motions were successfully conducted at the base of Institute's thermobarochamber. Results were many times repeated and controlled in detail. Graphic and table materials represent in next paper of this issue. Because the convective motions presents in all geophysical shells and analogically the subjects, practical and theoretical activity of the Institute collaborators are connected with each other, perhaps it will be possible to develop and expand it further together.

1. Introduction

This paper focuses on some cases of instability processes taking place in nature, laboratory, and technique. Laminar flows in porous materials and turbulence are similar in the sense that full detailed description of their motion analytically is impossible, and in case of porous materials are added the difficulties connected with the complexity of the geometry [1-18].

The purpose of study of both abovementioned problems consists in mathematical description of flows by means of properly averaged variables. The "theory" of currents in the porous materials essentially is based on generalization of Darcy's empirical observations [1, 4]. We paid our attention to the vertical motions of different fluids heated from below: in the first part there are theoretical aspects of the problem, in the second, experimental part, – original fluid bubble boiling method of modeling of vertical one-dimensional two-phase flow. Supposed laboratory method considers vertical motion of heated from below fluids – main element of convection, which plays important role in extraordinary natural phenomena (thunderstorms, volcanoes, gazer, mantle-plumes, tectonic motions, ionosphere continued waves, solar wind, magnetic storms etc.), and named by us as "bubble boiling method of fluids" [5-18]. Preliminary experiments of modeling of fluid convective motions were successfully conducted at the base of Institute's thermobarochamber.

2. Convection of magnetized, non-conducting fluid [2]

Magnetized liquid is colloidal suspension of suspended particles in fluid-carrier **(**water, kerosene, transformer fluid and others). In Oberbeck–Boussinesq approximation, the equations of complex gravitational and magnetic convection are following [2]:

$$\frac{\partial \vec{v}}{\partial t} + (\vec{v} \cdot \nabla)\vec{v} = -\frac{1}{\rho_0}\nabla p + \nu \nabla^2 \vec{v} + [1 - \alpha(T - T_0)]\vec{g} + \frac{\mu_0}{\rho_0} M(T, H)\nabla H \, ,$$

$$\nabla \cdot \vec{v} = 0 , \; \frac{\partial T}{\partial t} + \vec{v} \cdot \nabla T = a \nabla^2 T \, , \; \nabla \times \vec{H} = 0 \, , \; \nabla \cdot \left(\left(1 + \frac{M(T, H)}{H} \right) \vec{H} \right) = 0,$$

$$\rho = \rho_0 [1 - \alpha(T - T_0)], \quad M = M_0 - K(T - T_0) + \chi(H - H_0), \qquad (2.1)$$

where $\vec{v}$, p, T, T_0, α, a, $\vec{g}$, H, μ_0 are respectively the vector of velocity, pressure, temperature, temperature at which $\rho = \rho_0$, coefficient of volume expansion, coefficient of heat conduction, acceleration due to gravity, magnetic field, magnetic permeability, $M_0 = M(T_0, H_0)$, M is an intensity of magnetization of fluid, $K = \partial M(T_0, H_0) / \partial T$, is pyromagnetic coefficient, $\chi = \partial M(T_0, H_0) / \partial H$ is a susceptibility of fluid, $\rho_0 = \rho(T_0)$, the model is correct at small changing of the temperature and magnetic field near T_0 and H_0, respectively. The term $\mathrm{M}\nabla\mathrm{H}$ is conditioned by magnetic properties of the fluid and characterizes its interaction with the magneto-gradient field. At M = 0 or ∇H = 0 the system (2.1) coincides with the model of usual natural convection model.

3. Convection of conducting fluids [3]

Let us consider case when the **direction** of the impressed **magnetic field** coincides with the **vertical**. The relevant equations are:

$$\frac{\partial \theta}{\partial t} = \kappa \nabla^2 \theta + \beta w \, , \quad \frac{\partial h_z}{\partial t} = \eta \nabla^2 h_z + H \frac{\partial w}{\partial z} \, ,$$

$$\frac{\partial \xi}{\partial t} = \eta \nabla^2 \xi + H \frac{\partial \zeta}{\partial z} \, , \quad \frac{\partial \zeta}{\partial t} = \nu \nabla^2 \zeta + \frac{\mu H}{4\pi\rho} \frac{\partial \xi}{\partial z} \, ,$$

$$\frac{\partial}{\partial t} \nabla^2 w = g\alpha \left(\frac{\partial^2 \theta}{\partial x^2} + \frac{\partial^2 \theta}{\partial y^2} \right) + \nu \nabla^4 w + \frac{\mu H}{4\pi\rho} \frac{\partial}{\partial z} \nabla^2 h_z \, ,$$

where θ, w, ζ , ξ/4π, κ, η, ν are the temperature, vertical velocity, vorticity, current density, temperature conductivity, electrical resistivity, kinematic viscosity, respectively.

4. Kelvin-Helmholtz instability in porous media: the Darcian flow [4]

Laminar flows in porous materials and turbulence are similar in the sense that full detailed description of their motion analytically is impossible, and in case of porous materials are added the difficulties connected with the complexity of the geometry [1-12].

The purpose of study of both abovementioned problems consists in mathematical description of flows by means of properly averaged variables. The “theory” of currents in the porous materials essentially is based on generalization of Darcy’s empirical observations [1, 4].

Consider parallel flow of two immiscible fluids in an infinite, fully saturated, uniform, homogeneous, and isotropic porous media with constant porosity (φ) and constant permeability (λ). The two fluids are incompressible and have constant properties.

$$\frac{\partial p_i}{\partial x} = -\frac{\rho_i}{\phi}\frac{\partial v_{x,i}}{\partial t} - \frac{\mu_i}{\lambda} v_{x,i} + \rho_i g \sin\alpha ,$$

$$\nabla \cdot \vec{v} = 0 .$$

After linearization of these equations and neglecting nonlinear terms for typical normal mode of wavenumber k in the x direction in the real part of potential of velocity and the disturbed interface the resulting equation for ω is slightly more general than the characteristic equation obtained by [5] is

$$\omega^2 A + \omega B + i\omega k C + ikD + k^2 E = 0,$$

$$A = \rho_1 + \rho_2 ,\ B = \frac{\phi}{\lambda}(\mu_1 + \mu_2) ,\ C = \frac{\rho_1 U_1 + \rho_2 U_2}{\phi} ,\ D = \frac{\mu_1 U_1 + \mu_2 U_2}{\lambda} ,$$

$$E = (\sigma + \sigma_M)k + (1/k)g(\rho_2 - \rho_1)\cos\alpha ,$$

here in general ω is the complex number $\omega = \omega_R + i\omega_I$.

Is it possible to consider Kelvin-Helmholtz instability as a trigger mechanism of light earthquakes? When heating of considered medium from below and Kelvin-Helmholtz instability happen concurrently we must know the numerical value of the Rayleigh number $Ra \geq 10^3$ (for turbulence).

5. Subvertical accumulation of earthquakes hypocenters – seismic "nets" [5]

Having studied data of JMA catalogues of Japan earthquakes, Vadkovsky obtained compact (in space and time) accumulation of earthquakes centres (see Figs. 1a, 1b). Because of distinctive vertically oriented cylinders form Vadkovsky named them seismic "nets".

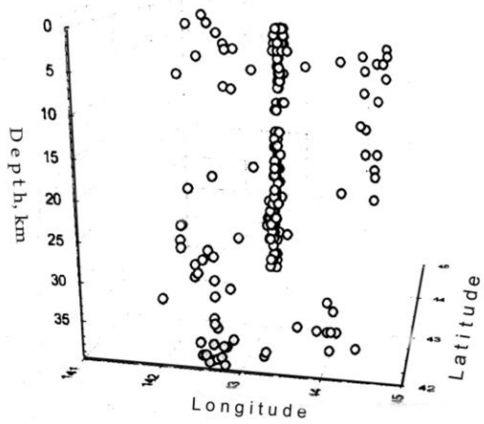


Fig. 1a. Formation of the seismic "net" in region of the Island Hokkaido, [5].

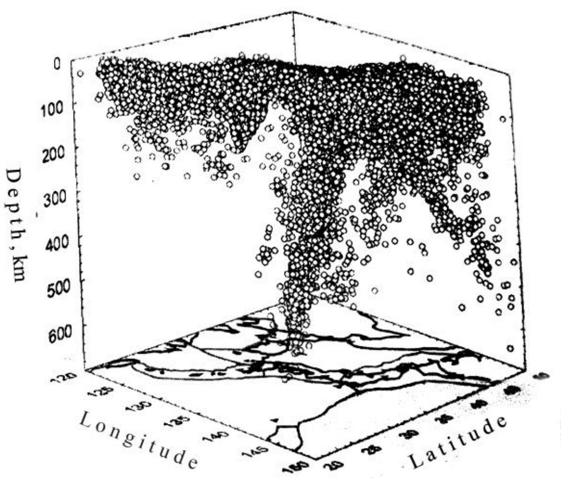
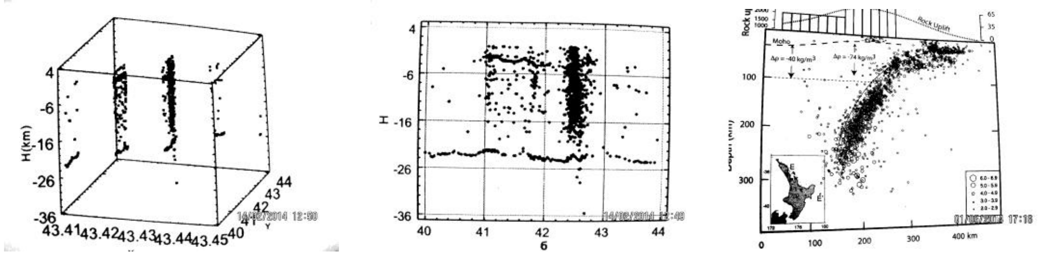


Fig. 1b. Formation of the seismic "net" in region of the Island Hokkaido, [5].



a **b** **c**

Fig. 2 Distribution of hypocenters of earthquakes: **(a)** in Caucasus (3d view under angle of vision 45^0), [6]; **(b)** in Caucasus (vertical plate), [6].

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Similar investigations were made for Georgia, too, and obtained on the base of great number of data of light earthquakes both 3D structure of distribution of hypocenters of earthquakes and subvertical seismic "nets"(see Figs. 2a, 2b).

That seismic "nets" will attract very serious attention of scientists, working on the problem of convective motion because of striking likeness between the vertical distribution of hypocenters of weak earthquakes and vertically oriented chain of air bubbles moving upwards in boiling water (see Figs. 4-). In search of seismic "nets", the 3D, visual, analytical methods of grouping of the earthquakes, technique of investigation Markov's chains, and fractals multitude were used. The data time interval (7 years) is too small one to tell with confidence in space-time characteristics of the "nets". Nevertheless, geometry and speed of formation latter enable to judge on the possible **role of fluids in the process of their formation,** since neither melt nor, of course, any solid phase cannot have such high mobility.

It is possible to say, that the seismic "nets" phenomenon one can with confidence include them into a group of one-dimensional vertical flows, studying by supposed below fluid bubble boiling method (see).

6. Neotectonics: Remarkable plates convergence [7, 8].

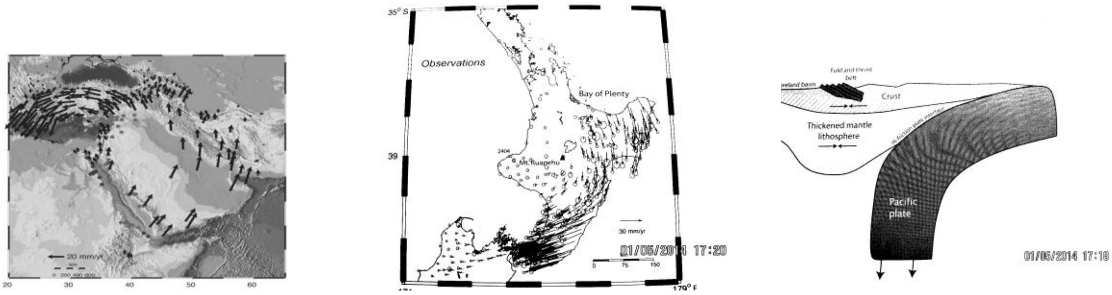
Following fragment from [8] is interesting not only for geologists.

"Recent geodynamics of Georgia and adjacent territories of the Black Sea-Caspian Sea region, as a whole, are determined by its position between the **still-converging** Eurasian and Africa-Arabian plates" (Fig. 3a). Analogical picture of block rotation rates, volcanic arcs, and distribution of epicentres and hypocenters of earthquakes in Australia (Fig. 3b) (as result of interaction between the Australian plate and the Pacific plate (Fig. 3c)).

Furthermore, according to geodetic data of Caucasus, the order of **rate** this **convergence** is ~ 20-30 mm/yr (Fig. 3a). The same order convergence rates showed in Fig. 3b (the authors of [18], when interpreting of rotations represents following examples of there calculations: 200, 100, and 20 mm/yr for Japan, Ligurian Sea, and North Island, respectively).

All of these examples of natural extraordinary convective phenomena we consider only from the standpoint of vertically directed convective one-dimensional flows, caused by Archimedes' buoyancy force. It discoveries in the form of thermals in atmosphere and ocean, mantle plumes in the liquid core of the Earth, etc. We tried to visualize considered process of heating fluid below and illustrate this report correspondingly, as far as possible. Simultaneously, to describe it from new point of view we suggest experimental method. Proceeding from essential peculiarity of these extraordinary phenomena, we began to study peculiarities of bubble-boiling process of chemical solution (glucose) of different density. Method allowed obtain some important thermodynamical and thermochemical properties of boiling solutions, clearing and confirming some of natural facts. Therefore, the first was named by us "fluids bubble-boiling modelling laboratory method".

50 km



0
20 30 40 50 60 km

(a) (b) (c)

Fig. 3. Present-day GPS- derived station velocities: **(a)** – the zone of interaction of the African**,** Arabian, and Eurasian plates from data spanning the period 1988-2005, [7]; **(b)** GPS velocities field in the North Island and northwestern South Island based on a decade of observations [18]; **(c)** according to [18] beneath Wanganui Basin might be the general case of young active continental margin before back-arc extension and volcanism begin. It is noteworthy that this area (Fig. 3a) contains sites of the strongest Caucasian earthquakes – 1988 Spitak (Armenia) and 1991 Ratcha (Georgia) [8].

Continuing this phrase, we note that because of small Reynolds number there is possibility of laboratory modelling of such motions fluids in the mental (details of theory and experiment see in [14]). Then, for good reason one may contend that this **tectonic rate field is** directly / exactly **connected with molten mantle convective motion**. The latter was considered in detail in our article [14].

It is necessary to note that represented in Fig. 4b and Fig. 4c volcanoes in detail studied in the article [15]. There was calculated volume of materials discharged during the main phases of volcano's activity during the 1955-2009 (Kamchatka). Authors of [16] studied explosive activity with great variations in the frequency and energy of explosions; magma as it was moving along the conduit was stratified to form a set of vertical filaments; the leading explosive mechanism during that period was a fragmentation wave that was produced in a gas-charged, viscous, porous magma during decompression. One notices that the shape of some shock waves in air indicates the occurrence of air blasts above the crater (in our modeling bubble-projectile boiling of fluid (!)). The air blasts have been caused by combustible volcanic gases such as carbon monoxide and hydrogen (CO and H_2) which entered the atmosphere in sufficient amounts (see Fig. 4b).

a **b** **c**

Fig. 4. (a) – Subglacial volcanic eruption [17]; (b) – eruption of volcano Bezymyannyi [Internet]; (c) – eruption of volcano Kluchevskaya Sopka – [Internet].

Fig. 4c shows two interesting cases of independent convective thermals (plumes) – small cumulus cloud and volcano's first burning hot muddy-gas eruption, – the phenomena, which we model in laboratory by fluid bubble boiling method (see below).

II. Fluids bubble-boiling modelling laboratory method: intensive one-dimensional vertical convective motion (extraordinary phenomena of nature)

A. Purpose and scope of this method.

Preliminary experiments of laboratory modeling of fluid thermo-chemical convection were carrying out at Thermo-baro-chamber of Institute of Geophysics. There were observed and measured: (1) differentiation of solutions; (2) generation layers with boundaries containing high concentration of accumulated pollution; (3) thermodynamic parameters changing in space and time; T, Q, S, ρ, P, V, α, β, ν, κ, Ra; (4) the many-layer fluids system and (5) formation and velocity of Stokes' size bubbles at the bottom of heating vessel with water sugar solution, oil, (6) their fast vertical motions in the mass of slow ascending infinitesimal air bubbles; (photography and video-recording) They were photographed during bubble boiling of chemical solution.

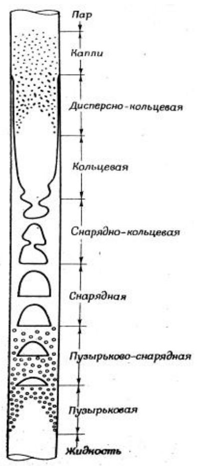
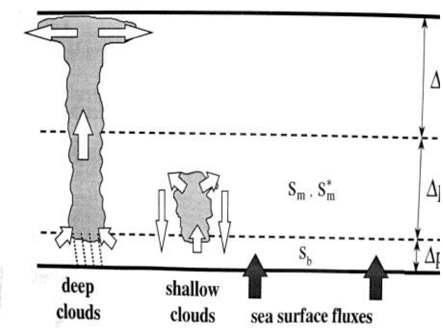


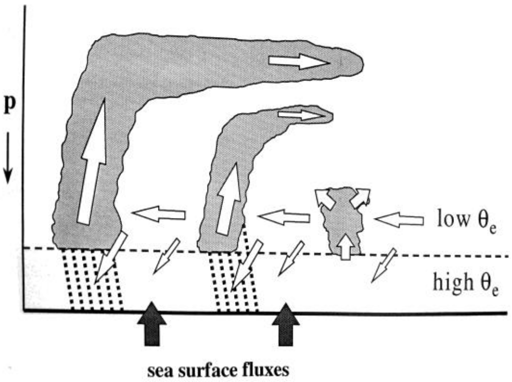
Fig. 5a. Structurs of fluid heated from below: fluid; bubble; bubble-slug; slug; slug-annular; annular; dispersed-annular; drops; vapor. Approximate sequence flow structures in vertical evaporator tube [9].

Fig.5b. A schematic illustration of the vertical directed main geothermal flows; hot gazer (left); main boiling fluid Na-Cl, pH neutral; hot steam, surface oxide, solutions; oxidation; zone of precipitation [10].

B. Calculated clouds. Computer calculations have correctly reflected the vertical one-dimensional two-phase flows of convective motions in nature (compare Figs. 6a-b and Figs. 7a-b), one of which is given in [12] (Emanuel (1989) [12])



a



b

Fig. 6. Vertical structure of Emanuel's hurricane model: "**(a)** – **deep clouds** transfer mass from the subcloud layer to the top layer; **shallow clouds** exchange entropy between the lower troposphere and the subcloud layer without producing a net mass flux; **(b)** illustration of airflow in a developing Emanuel's tropical cyclone model; for a cyclone to spin up, lower tropospheric air above the boundary layer must flow inward; this air has a relatively low moist entropy, and if it were to ascend directly into the vortex core, the core entropy would reduce, the core would cool, and the cyclone would decay. Instead, the air descends within shallow clouds, within precipitating downdrafts, and outside of clouds because of Ekman suction. This descent of relatively dry air reduces the entropy of subcloud layer. The vortex core can become warmer than its environment only if the surface fluxes are large enough to offset this drying effect on the subcloud air parcels flow inward in the lower troposphere, sink downward in downdrafts , receive entropy from the ocean, and then ascend in deep convective clouds" [12].

C. Natural clouds (photographs, Tbilisi, Georgia. – by A.G.).

a b

Fig. 7. Convective clouds, thermals, moving slowly: (a) westward (Tbilisi, 14/08/13; 12:29); (b) eastward (Tbilisi, 11/08/13; 11:01).

Together Figs. 1-9 illustrate complete result of action of vertically oriented well-known Archimedes buoyancy force in nature.

a **b**

Fig. 8. Three-layer thermodynamic system – glucose syrup layer (bottom), thick intermediate bubbles and population (IP) layer, oil layer (it's well seen group of large air- bubbles), thin intermediate bubble and IP layer, and air-steam layer (top): **(a)** photograph shows oblique view of the solution topography; **(b)** photograph shows view from side (after 2 min).

Here and below photographs show side views of the solution in glass vessel.

a b

Fig. 9. Photographs show the same thermodynamic system as in Fig. 8, but here glucose solution colored by coffee: (a) it is well seen two large air bubbles fast vertically ascend upward (~ 40 cm/s); **(b)** large bubbles made their way through the thick intermediate bubbles and population (IP) layer (after 14 sec).

Conclusions

Here was used wide interval of solution density; thanks to suggested method of bubble boiling for laboratory investigation of thermo-chemical convection between existing layers were obtained intermediate layers with high concentration of accumulated pollution; discovery of second kind discontinuity of temperature-time dependence at the point $T_{bf}(t)$ of intensive infinitesimal air bubbles formation till the point $T_{bb}(t)$ of solution bubble boiling (note, that $T_0(t)$ - $T_{bf}(t)$ is linear, and $T_{bf}(t)$ - $T_{bb}(t)$ is near to parabolic). Analyze and discussion of physical aspects of this point and elliptic curve are given in our joint paper of this issue of JGGS/2013-2014. Preliminary experiments of modeling of fluid convective motions, which were successfully conducted at the base of Institute's thermobarochamber, must be continued.

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Об одномерных двух-фазных/много-компонентных конвективных движениях жидкостей в различных геофизических средах: лабораторный метод моделирования пузырькового кипения жидкости

А. И. Гвелесиани

Резюме

В настоящей работе основное внимание сосредоточено на вертикальных конвективных движениях различных геофизических сред, подогреваемых снизу. Первая часть работы – теоретическая; вторая – экспериментальная. Предлагается новый метод лабораторного моделирования конвективных двух-фазных много-компонентных движений в естественных условиях (облака, вулканы, гейзеры, ментл-плюмс, тектонические сдвиги, ионосферные непрерывные волны, солнечные вспышки, магнитные бури и т.д.), названный нами методом пузырькового кипения жидкости. Получены обнадёживающие результаты предварительных экспериментов, проведённых на базе экспериментального комплекса термобарокамеры Института геофизики. Поскольку конвективные движения присутствуют во всех геофизических оболочках, а тематика, практическая и теоретическая деятельность сотрудников института прямо или косвенно связанаы с ними, то можно было бы начатые исследования совместно расширить и развить далее.

ერთგანზომილებიანი ორფაზოვანი /მრავალკომპონენტიანი სითხის მოძრაობა სხვადასხვა გეოფიზიკურ გარემოში: სითხის ბუშტოვანი დუღილის ლაბორატორიული მოდელირების მეთოდი

ანზორ გველესიანი

რეზიუმე

წინამდებარე სტატიაში მოკლედ განიხილება სხვადასხვა გეოფიზიკურ თხევად არეში ვერტიკალური კონვექციური მოძრაობების თავისებურებანი გამოწვეული მისი ქვემოდან გათბობის ან სხვა ბუნების ვერტიკალური არაერთგვაროვნების შემქმნელი მიზეზის გამო (ღრუბლები, ვულკანები, გეიზერები, მანტიის მენტლ–პლუმები, ტექტონიკური მოძრაობები, იონოსფერული უწყვეტი ტალღები, მზის პლაზმის ამოფრქვევები, მაგნიტური ქარიშხლები და სხვ.). პირველ ნაწილში სქემატურად მოცემულია პრობლემის ზოგიერთი თეორიული ასპექტი, მეორეში –კონვექციური მოძრაობის მოდელირების სითხის ბუშტოვანი დუღილის ლაბორატორიული მეთოდი. მოყვანილია პირველადი ცდების ზოგიერთი შედეგი. მოდელირების ექსპერიმენტები ჩატარებულია ინსტიტუტის თერმობაროკამერის ბაზაზე.

კონვექციურ მოვლენებს ადგილი აქვს პლანეტის ყველა გარსში და ისინი დაკავშირებული არიან ერთიმეორესთან. ინსტიტუტუტის სექტორულ–თემატიკური ფუნქცინირებაც ამგვარია. გამომდინარე აქედან, შეგვიძლია ვისურვოთ, ინსტიტუტის სათანადო სექტორების დაინტერესების შემთხვევაში, აღნიშნული კვლევების გაფართოება და განვითარება.

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