

НАУКИ О ЗЕМЛЕ И ПЛАНЕТЫ

UDC 551.510.41:546.26:551.583

PREDICTION OF THE CONDITIONS FOR THE CLIMATE CHANGES, ON THE BASIS OF PHYSICOCHEMICAL MODELLING

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Abstract. Prediction of climate change on the planet on the basis of physicochemical (thermodynamic) modeling of greenhouse gas emissions into the atmosphere from natural and anthropogenic sources has allowed us the new, in contrast to previous research, to approach the solution to this problem and skorrekti –rovť equity contribution of the main gases in global warming. A thermodynamic simulation of the emission of carbon, methane, nitrous oxide, and chlorofluorocarbon in the surface layer of the atmosphere has been carried out up to a height of 500 m at an average temperature of the Earth's surface of 15°C and in lower layers of the troposphere at a height of up to 2 km at a temperature of 3°C and corresponding pressures of 1013.25 and 790 hPa. It was ascertained that the planetary temperature might rise to 18.15°C by 2100 with an increase in the CO₂ concentration by two times in the surface atmosphere; with allowance for the additional contribution of CH₄, to 19.42°C; with allowance for N₂O, to 20.08°C; and with allowance for all gasses put together, including chlorofluorocarbons and water vapor, to 22.68°C. In the lower troposphere, with an increase in CO₂, the temperature might rise to 4.63°C; with an additional contribution of CH₄, to 5.83°C; with allowance for N₂O, to 6.50°C; and with allowance for all gases, including chlorofluorocarbons and water vapor, to 7.91°C.

Keyword: Prediction, thermodynamic model, Climate, change, greenhouse gases, atmosphere

Introduction

M. I. Budyko, summarizing the previous studies [6], has written that atmospheric carbon dioxide, along with water vapor, absorbs longwave radiation in the atmosphere, and the altered concentration of this gas leads to the climatic fluctuations; he has also suggested that low content of carbon dioxide in the atmosphere causes the Quaternary periods of glaciation. We [23] have mentioned that if the carbon dioxide concentration rises by 30% (of the values in 1973), the temperature will increase. Our calculations have shown that the carbon dioxide concentration in the atmosphere should be equal to 0.042% for the ice-free regime, whereas for the global glaciation it should be equal to 0.015%.

According to the data on the carbon dioxide concentration [27] prior to the start of the upsurge in the past decade, it was equal to 0.029% (1900-1950). Decrease in the carbon dioxide content to 0.013% in the history of the Earth coincided with the latest glaciation, that led to formation of the inland ice in the Northern Hemisphere. There is no doubt, that the position of the axis of the Earth relative to the Sun repeatedly changed over the Quaternary. Concurrent variations [16] led to the altered conditions of insolation, that had direct impact on the climate. The studies on the radiation regime of the Earth showed that the fluctuations of the carbon dioxide content during that period were sufficient for glaciation, although the contribution of the volcanic activity, accompanied with the emission of large amounts of aerosols into the atmosphere, that led to altered transmission of longwave radiation, reaching the surface of the Earth, is undeniable. Pronounced activity of the subaerial, submarine volcanoes, and the island arcs, is currently observed at 70% of the planet surface (Fig. 1) [25]. The largest eruptions occur in Kamchatka, Japan, Indonesia, the USA, Iceland. 76 of the active volcanoes of the planet are located in Indonesia. The activity of the submarine volcanoes is

more vigorous than the activity of the subaerial ones. The naturally formed components of the atmosphere still comprise a larger proportion of the air than the technogenic ones (Table 1) [20].

The "Intergovernmental Panel on Climate Change (IPCC) Special Report on Emissions Scenarios" [24] provides 4 basic and 36 additional possible scenarios of the emission of greenhouse gases by 2100. These scenarios describe demographic, technological, and economical events as the major driving forces of the emissions. Today, mathematical models, that include the composition and the dynamics of the atmosphere and the ocean, transfer of longwave and shortwave radiation, and various feedback loops of the climate systems [33], but do not factor in thermodynamic conditions of accumulation of greenhouse gases, are generally used for climate predictions. We suggest an integral approach, including physicochemical modelling, based on the geological factors, such as movement of the tectonic plates, major glaciations, strong volcanic eruptions, and changes in the temperature of major ocean currents. It should also be noted that certain amounts of greenhouse gases are emitted into the atmosphere due to the surface fires that, according to the reports of the UN (FAO), annually affect 350 million hectares, leading to additional emission of as much as 35 Gt of carbon per year. Mathematic modelling [14] showed that 4-fold increase in the CO₂ content results in 4.1°C rise in the temperature of the lower atmosphere. Climate changes, related to the increased content of carbon dioxide, primarily occur at high latitudes, whereas in the tropical areas the thermal regime mostly remains unchanged. On the basis of the published data [15], the changes of mean global temperature over the years and the CO₂ concentration were shown. For instance, the carbon dioxide content is projected to increase from 300 to 900

ppmv over the period from 2000 to 2100, whereas the temperature is projected to rise by 2.5 °C.

Substantiation of the problem, methods of solution

Our research showed that the data on the climate parameters, provided in the IPCC special reports, were not always consistent. Therefore, these results require essential adjustments, before they can be used for predicting the probability of natural emergencies. To remedy the situation, one should conduct further research, implementing modern methods, including the physicochemical, or thermodynamic modelling of various systems, which is a valid method, widely used for scientific and practical studies [13, 26].

In terms of thermodynamic analysis of the physicochemical systems, the direction of chemical reactions towards total or partial chemical equilibrium is determined through minimization of the Gibbs free energy (G) of the system for specified values of P , T , and the initial chemical composition vector. The Gibbs free energy at the equilibrium state is equal to

$$G = \sum_{i=1}^k \mu_i x_i$$

where μ_i is the chemical potential, x_i – number of moles composing the component, k – number of chemical components of the system.

Despite the existence of certain published data on the behavior of aerosol particles in thermodynamic systems and their properties [18, 28-34], we decided to create an integral thermodynamic model of gas and aerosol particles emission in the atmosphere and the troposphere. The model was based on the information on man-induced emission, concentrations of CO₂, CH₄, N₂O, chlorofluorocarbons in the atmosphere over the preceding period, given in the emissions scenarios [9, 10, 24]. After the analysis, we chose the A2 scenario, based on the idea of a heterogeneous world, where the economic development is regionally oriented, fertility patterns across different regions converge very slowly, which results in continuously increasing population. The emissions continually increase and reach the maximal values by the end of the century: CO₂ – 28.8 Gt of carbon/year, CH₄ – 912.7 Gt/year, N₂O – 16 Mt of nitrogen/year, CO – 2488 Mt/year [18].

Development of the physicochemical model

The established physicochemical model should be able to provide an answer to the question on how the temperature of the Earth surface will change at different concentrations of carbon dioxide, methane, nitrous oxide, chlorofluorocarbons, ozone, water vapor, compositions of aerosols, pressure, and other natural and anthropogenic factors of the atmosphere. The input data included the results of the analysis of content of aerosol particles in the atmospheric boundary layer and the lower troposphere (Table 2 [17]). Then, the basic physicochemical model was developed [23] on the premises of the modified software system “Selektor-S”, including the thermodynamic databases [26]. The independent components of the matrix of the physicochemical model are Mg-Mn-Pb-Fe-Si-Al-Ca-Ni-Zn-Cu-Cr-Cl-S-Na-K-N-C-Ar-H-O. The model includes the water phase, the gas phase, and the solid phase. The water phase is represented with 535 components. These are, mostly, cationic, anionic, oxide, hydroxide, sulfate, carbonate, halide, nitrate, silicon, and hydrocarbon complexes, consisting of combinations of the independent components. The gas phase contains 286 components, including volatile hydrocarbons C₁-C₂₀, C₄-C₁₂, aromatic hydrocarbons C₆-C₁₀, oxygen-, ozone-, and sulfur-containing complexes, chlorofluorocarbons and halogen-containing compounds, found in the urban atmosphere. The solid phases of aerosols consist of minute mineral particles (total number of 176), mostly hydroxides, carbonates, sulfates, chlorites, hydromicas, mixed-layer minerals, and kaolin-montmorillonite group, i.e., all theoretically possible mineral compounds, that can be observed near the Earth surface and are considered to be nanoparticles of the boundary layer and the lower troposphere [22]. Prior to the model calculations, we checked the consistency of the thermodynamic constants of the substances, obtained from different databases. The equilibrium temperature of the system, as related to the changes in the carbon dioxide concentration under the isobaric conditions at the preset constant enthalpy, was calculated through minimization of negative entropy (thermodynamic potential S_p). The mathematical representation of the problem of minimal S_p can be written as follows [26]:

$$\hat{T} = \arg \min \{f_{S_p}(T) / x \in M^0(S_p), T \in D_T^0\}, \hat{x} = \arg \min \{G(x) / x \in X(S_p), T = \hat{T}\}.$$

Here: $f(S_p) = |H - H_0|$ и

$$M^0(S_p) = \bigcap_{T \in D_T^0} M^*(S_p)$$

where T is temperature, P – pressure, H_0 – enthalpy of the reagents, H – enthalpy of the chemical products, M – point set of the domain of the function $f_s(T)$, D_T – interval of the temperature calculation, $M^*(S_p) = \text{Arg min}\{G(x) / x \in M\}$,

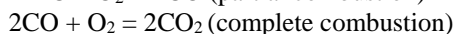
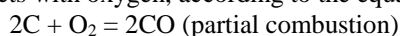
$$T_0 \in D_T^0: X(S_p) = \{x / x \in M, H - H_0 = 0\}, T = T_0, P = P_0.$$

The computational algorithm of the S_p problem solution is based on the approach of single-objective minimization of $f(S_p)$ through the golden section search. The initial parameters included the lower and

the upper limits of the temperature range, confining the simulated process, precision of calculations (degrees Celsius), initial temperature, and the pressure of the reagents.

Results of modelling

Current state of the atmosphere was chosen as the initial state for the physicochemical modelling of the emission of carbon, methane, nitrous oxide, chlorofluorocarbons, ozone, water vapor, and aerosols in the surface layer and the lower troposphere. The initial values were set, as follows: near the Earth surface – mean temperature of 15 °C, atmospheric pressure – 1013.25 hPa, content of carbon dioxide over the period of 2010-2011 – approximately 0.04%; in the lower troposphere, up to 2 km altitude – temperature of 3 °C, pressure – 790 hPa, CO₂ concentration - approximately 0.03%. During the simulation, the initial concentrations of the compounds were changed, imitating the emission of carbon, methane, nitrous oxide, chlorofluorocarbons and other particles in the atmosphere from natural and technogenic sources: volcanic eruptions, fossil fuel, and surface biota. When carbon reacts with oxygen, according to the equations:



carbon is combusted (oxidized), producing carbon dioxide. The CO₂ concentration increases, and the temperature near the Earth surface rises (Fig. 2). The results of simulation were compared to the data on the CO₂ content in the atmosphere, provided by the preceding researchers [4-6, 19, 35]. At the initial steps of modelling certain values were close, but, over the course of time, when other factors were considered, these values became substantially different.

The physicochemical modelling has shown that the temperature of the surface layer of the atmosphere (Fig. 2, a and b) will increase by 1°C, given the upsurge in the carbon dioxide content alone to 0.05% by 2040; at the CO₂ increase to 0.07% by 2080 the temperature will rise by 2°C, while by 2100, when the CO₂ concentration reaches 0.084%, the temperature at the planet surface will be close to 18.16 °C. Average gradient of the temperature changes over a decade is 0.03 °C per year. Certain changes will also occur in the lower troposphere (Fig. 2, c and d) over this period: by 2040, given the CO₂ content of 0.0365%, the temperature at approximately 2 km will increase by 0.3°C, by 2070 – by 0.5 °C, and by 2100 – by 1.62 °C, reaching 4.62 °C.

Decrease in the carbon dioxide concentration in the surface layer of the atmosphere to 0.015-0.010% will lead to fall in the Earth surface temperature to 13.3-13.4 °C. Over the same period, the CO₂ concentration in the troposphere will decrease from 0.02 to 0.01%, leading to the temperature of 1.7 °C, which, according to the results of previous studies [6], can lead to another glaciation. The period of time between the values of the CO₂ concentration changes, from the beginning of the latest major glaciation in the history of the Earth (Lower Pleistocene) to the industrial revolution, is approximately 1 million years long.

Along with carbon dioxide, methane, nitrous oxide, chlorofluorocarbons, water vapor, ozone, and other gases play a certain role in the changes of the planet temperature. One ton of carbon equivalent has been accepted as a unit of greenhouse gases, therefore, prior to introducing the concentrations of these

substances into the model, they were recalculated as additional CO₂ through the valid correction factors (global warming potentials), imposed in 1997 by the Kyoto Protocol [21].

Methane is the second most important gas after carbon dioxide, that influences the planet temperature. Its relation to the climate is further discussed in studies [1, 8, 11]. The methane content in the modern atmosphere is 0.0002%, which is 200 times lower than the content of CO₂, yet its contribution to dissipation and accumulation of heat, radiated by the Earth surface, warmed with the Sun, is 21-25 times higher than the contribution of carbon dioxide. Methane is emitted into the atmosphere by natural and anthropogenic sources. Methane spends 8-12 years in the atmosphere in a stable condition, then it is destructed with [OH] group and is removed. It is mostly accumulated in the surface layer, the source of which is ozone, contained in the atmosphere. Considering the combined contribution of methane and CO₂, the temperature of the surface layer of the planet atmosphere (Fig. 2 a, b) in 2000 could be 16.11 °C, increasing to 17.17 °C by 2050, to 18.26 °C by 2080, and to 19.42 °C by 2100. The temperature of the lower troposphere, at the altitude of 2 km, was close to 4 °C (3.96 °C) in 2010, rising to 5 °C in 2090, and almost to 6 °C (5.83 °C) by 2100. Annual increase in the methane concentration will be 0.000013% by 2030, and 0.000025% by 2100. It will undoubtedly lead to alterations in the gas composition of the atmosphere, immediately followed with increasing concentration of ozone in the atmosphere and lower content of hydroxyl.

The third gas influencing the planet temperature is nitrous oxide (N₂O). Its role in the Earth climate system has been studied by a number of researchers [7]. Nitrous oxide is a relatively inert compound and its content in the atmosphere is lower than the concentrations of such radioactively active gases, as methane and carbon dioxide. Current content of nitrous oxide in the atmosphere is 0.00003 %. It is 6 times lower than the methane content, and more than 1000 times lower than the carbon dioxide concentration. Average lifespan of an N₂O molecule in the atmosphere is approximately 180 years. Due to the long residence in the atmosphere and high global warming potential over 100 years (which is 310 times higher than the carbon dioxide potential), nitrous oxide plays certain role in the climate changes. Nitrous oxide is mostly emitted into the atmosphere by natural (60%) and anthropogenic (40%) sources. Considering the N₂O impact in addition to CO₂, the temperature of the surface layer of the planet atmosphere (Fig. 2. a and b) in 2000 was 15.6 °C, rising to as much as 16.2 °C by 2030, to 17 °C by 2060, and to 18.7 °C by 2100. Mean annual input of N₂O to the atmosphere over the period from 2000 to 2100 is 12 ppb (0.0000012%). The temperature of the troposphere at the altitude of 2 km (Fig. 2. c and d) in 2010, considering the impact of nitrous oxide, was 3.6 °C, rising to 4 °C in 2080, and to 5.3 °C by 2100.

Apart from the discussed gases, various halocarbons are emitted by anthropogenic sources to the atmosphere. Chlorofluorocarbons (freons), being a part of this group, are chemically inert. They get into

the lower layers of the troposphere and slowly rise to the stratosphere, where they are decomposed under solar ultraviolet radiation, producing chlorine atoms that destroy the ozone layer. It may take up to 100 years for freons to vanish from the atmosphere. Production, consumption, import and export of freons are regulated by the Montreal Protocol. In order to assess the impact on the global warming and temperature changes, the concentrations of CFC-11 in the atmosphere were studied [9]. This is the most typical of all chlorofluorocarbons, and it was chosen for a reason. The rates of changes of the CFC-11 concentration over the period from 2000 to 2100 vary from -50 pptv to -10 pptv and probably lower. Even at these values, despite higher warming potential than in CO₂, its contribution to the increasing temperature of the surface layers of the atmosphere (Fig. 2. a and b) turns out to be insignificant, and the curves representing the changes in its concentration are similar to those for CO₂. In the lower troposphere (Fig. 2 c, d) its impact is also barely noticeable: by 2020 its combination with CO₂ can increase the temperature by 0.1 °C only, raising it to 4.79 °C by 2100.

Two varieties of ozone can be found in the atmosphere: tropospheric ozone in the surface layer, and stratospheric ozone in the upper troposphere, at the boundary of the stratosphere. The behavior of tropospheric ozone in the atmosphere and its role in the photochemical reactions has been earlier discussed by the researchers [2, 3]. The ozone concentrations in the lower troposphere, according to the projected A2 scenario and the thermodynamic modelling, change from 0.000003 to 0.0001%. Higher concentrations of methane lead to increase in the ozone content in the troposphere. The rise over the past decades was 1-2% per year. The ability of ozone to absorb longwave radiation and reside in the troposphere for several months allows to assess its contribution to the temperature rise without considering the global warming potential. Its future concentrations will depend on the emissions of methane and pollutants.

Water vapor emerges in the atmosphere as a result of evaporation from the water surface, moist soil, and plants. The content of water vapor in the air near the Earth surface is 0.2% on average at high latitudes, under low humidity, and 2.5% in the tropical areas. After evaporation of water from the Earth surface into the atmosphere, it is condensed, thus transferring as much as 40% of heat to the lower layers of the troposphere (due to convection). Therefore, at first, evaporating water slightly decreases the temperature of the Earth surface, later warming the surface layers of the atmosphere and the Earth surface up (due to the emission of heat during the vapor condensation). Water vapor, carbon dioxide and methane form strong feedback loops, that lead to indirect influence of water vapor on global warming.

Concerning the simulation of water evaporation from the land and the ocean to the atmosphere, it should be noted that, under the changes of the ratio of the gas phase and the liquid phase, the air is saturated with water vapor, given pH from 10.832 to 8.390 and Eh from 0,633 to 0,734 V (Table 3). The water vapor

content changes from 0.11 to 1.09%, whereas its partial pressure – from 1.7 to 17.2 hPa. These processes occur under the relative air humidity ranging from 10 to 100%, and the absolute air humidity – from 1.3 to 12.9 g/m³. Over the whole range of parameters, the water phase contains sulfates (moles): CaSO₄⁰ - 10⁻⁹, NaSO₄⁻ - 10⁻⁹, SO₄⁻² - 10⁻¹¹, chlorides CaCl₂⁰ - 10⁻⁸, MgCl⁺ - 10⁻⁹, carbonates MgCO₃ - 10⁻⁸, and other compounds in lesser concentrations.

It should be noted that the mechanism of SO₂ oxidation here, in the cloud droplets, is strongly influenced by oxygen-containing complexes, such as OH⁻, H₂O₂ and ozone, gradually transforming SO₂ to H₂SO₄, which is present in the system in significantly lower concentrations than the previously mentioned compounds. As pH of the solution decreases, the rate of SO₂ oxidation drops. Nanoparticles of chalcedony, chlorite, and seladonite are observed in the solid phase of the atmosphere; under the sub-alkaline, close to neutral conditions – only chlorite and seladonite. Close to 100% content of gas in the atmosphere at the relative humidity of less than 10 % corresponds to the arid hot climate of the southern tropical areas, whereas at the relative humidity of 90-100% – to a very humid climate.

Continuous circulation of the air currents in the atmosphere, saturated with aerosols, that can be considered small independent three-phase physicochemical systems, is accompanied with alterations of the thermodynamic conditions (T, P, C, pH, Eh, and phase composition), leading to decay of aerosols, subsequent nucleation, coagulation and transfer. These are the reasons for the changes in the composition of aerosols and in the concentrations of the components in the atmosphere. The analysis shows that the sulfate aerosols have the strongest impact on the climate changes of the planet. During the atmospheric transfer, submicron particles of the sulfate aerosol dissipate a certain part of radiation back to the surrounding space, whereas the particles of industrial carbon absorb large proportion of shortwave solar radiation and influence the flow of longwave radiation from the Earth. Large amounts of aerosols have an impact on the vertical stability of the atmosphere. The aerosol particles falling on the surface decrease the snow albedo, eventually leading to climate changes.

The absence of aerosols of volatile hydrocarbons in the surface layers of the atmosphere and the troposphere in the solution, obtained through thermodynamic modelling, can be explained by their high reactive capacity and transfer rates, which is why these substances are easily dissipated and, due to their low concentrations (except for methane), almost do not participate in chemical reactions, and thus are not observed in the form of stable products.

Conclusion

Thermodynamic modelling of the greenhouse gases emission to the atmosphere allowed us, in the contrast to the preceding researcher [12], to implement a new approach to the solution of this problem and to adjust the contributions of the major gases to the global warming.

Contributions of the greenhouse gases to the global warming (%) in the surface layers of the atmosphere are: CO₂ - 41, H₂O - 32, CH₄ - 16, N₂O - 7, chlorofluorocarbon - 3, and ozone - less than 1; in the lower troposphere: CO₂ - 33, H₂O - 25, CH₄ - 24, N₂O - 14, chlorofluorocarbon - 4, and ozone - less than 1. As for the influence of the aerosol nanoparticles on climate, it is mostly related to the process of cloud formation and precipitation, and depends on the aerosol composition, changing under the impact of the environmental factors - solar radiation, water vapor, and other gases. If sulfate complexes, dissipating the greenhouse gases, prevail in the composition of the aerosol particles, they can even impede the global warming.

This scenario implies slow global warming that can cause flooding of the marginal areas of the continents and retraction of permafrost 100-200 km to the North. Only the natural factors can promote the global warming in this case. For instance, larger amounts of aerosols in the atmosphere due to intense surface or coincident, evenly distributed over the planet volcanic eruptions, decreasing albedo due to urbanization of the Earth surface will lead to increase in the surface temperature and can influence the climate of the Earth over a century. As for the technogenic factors (even if we admit possible development of certain regions, surface fires, and emergencies at large industrial objects), they will not lead to 1.5-2-fold increase in the carbon dioxide emissions into the atmosphere over the stated period of time.

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Table 1

AMOUNT OF SUBSTANCES RELEASED INTO THE ATMOSPHERE OF THE EARTH

Particles < 20 microns-radius	Number, n x10 ⁶ , tons/year
Natural	
Soil dust and products of rock weathering	100-500
Smoke of fires and waste incineration	3-150
Sea salt	300
Particles of volcanic eruptions	25-150
Particles, resulting from interactions of gaseous components	345-1100
Including:	
sulfates from hydrogen sulfide	130-200
ammonium salts from ammonia	80-270
nitrates from nitrogen oxides	60-430
hydrocarbons from plants	75-200
Technogenic	
Dust	10-90
Particles of gaseous components	175-325
Including:	
sulfates from sulfur dioxide	130-200
nitrates from nitrogen oxides	30-35
hydrocarbons	15-90

Table 2

CONTENT OF ELEMENTS IN AEROSOLS, μG/M³

Sampling area	Mg	Mn	Pb	Fe	Si	Al	Ca	Ni	Zn	Cu	Cr	Cl	S	Na	K
Surface layer	1.2	0.02	0.07	1.5	5.0	0.4	1.7	0.03	0.1	0.03	0.03	1.52	0.24	0.38	0.34
Lower troposphere	0.2	0.003	0.008	0.6	1.0	0.15	0.2	0.07	0.15	0.008	0.001	0.21	0.11	0.14	0.09

Table 3

SATURATION OF THE AIR WITH WATER VAPOR

Phase composition of the atmosphere, %			pH	Eh, B	Content in the air, %		Partial pressure of water vapor, hPa	Relative humidity, %	Absolute humidity, g/m ³
gas	liquid	solid			water vapor	dropping-liquid water			
99.99	$7.8 \cdot 10^{-7}$	(1.8- $2.0 \cdot 10^{-7}$)	10.83	0.63	0.11	$8.0 \cdot 10^{-8}$	1.7	10	1.3
99.99	$8.2 \cdot 10^{-7}$	(1.6- $2.0 \cdot 10^{-7}$)	10.56	0.64	0.23	$1.1 \cdot 10^{-7}$	3.5	20	2.7
99.99	$1.7 \cdot 10^{-6}$	(1.8- $2.4 \cdot 10^{-7}$)	9.97	0.67	0.33	$3.5 \cdot 10^{-7}$	5.1	30	3.9
99.99	$1.9 \cdot 10^{-6}$	(1.8- $2.0 \cdot 10^{-7}$)	9.84	0.67	0.43	$4.6 \cdot 10^{-7}$	6.8	40	5.1
99.99	$2.1 \cdot 10^{-6}$	(1.8- $2.0 \cdot 10^{-7}$)	9.69	0.67	0.58	$6.7 \cdot 10^{-7}$	9.1	53	6.7
99.99	$2.2 \cdot 10^{-6}$	(1.8- $2.0 \cdot 10^{-7}$)	9.63	0.68	0.65	$7.9 \cdot 10^{-7}$	10.3	60	7.7
99.99	$2.2 \cdot 10^{-6}$	(1.8- $2.0 \cdot 10^{-7}$)	9.49	0.68	0.78	$1.3 \cdot 10^{-6}$	12.4	72	9.3
99.99	$2.7 \cdot 10^{-6}$	(1.8- $2.0 \cdot 10^{-7}$)	9.40	0.68	0.87	$1.9 \cdot 10^{-6}$	13.7	80	10.3
99.99	$3.3 \cdot 10^{-6}$	(1.8- $2.0 \cdot 10^{-7}$)	9.14	0.69	0.91	$3.2 \cdot 10^{-5}$	16.4	90	11.5
99.99	$3.3 \cdot 10^{-5}$	(1.8- $2.0 \cdot 10^{-7}$)	8.39	0.73	1.09	$2.2 \cdot 10^{-3}$	17.2	100	12.9

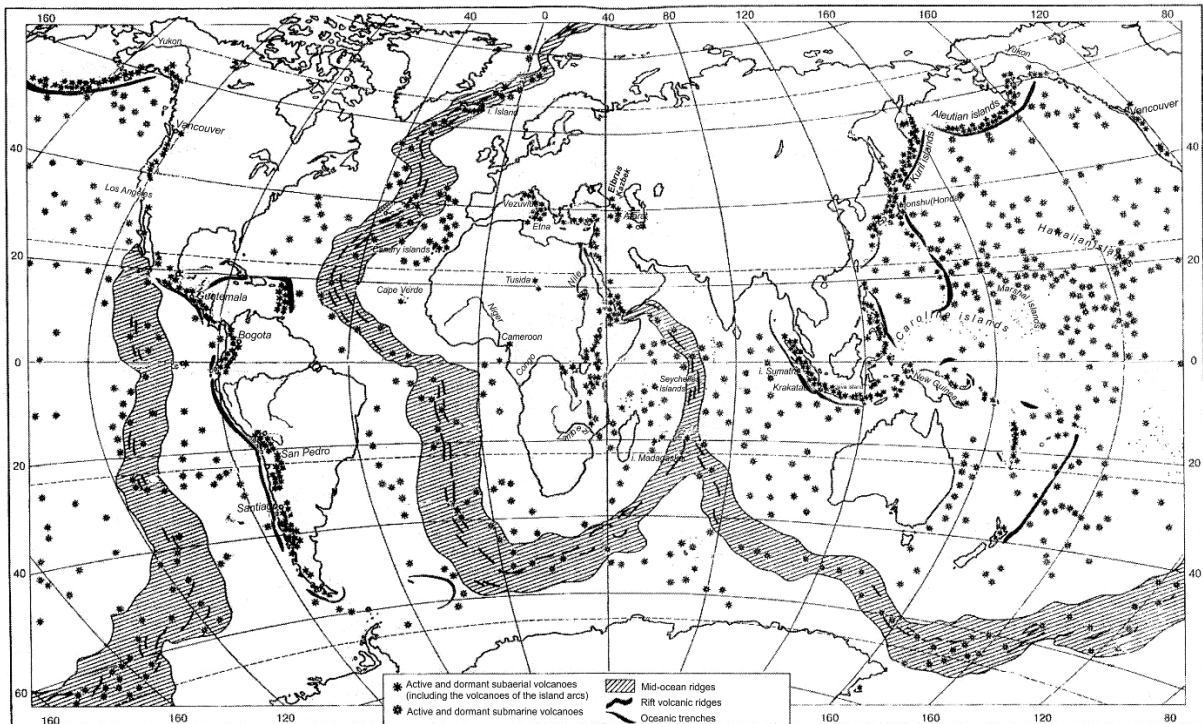


Fig. 1. Geographic distribution of volcanoes (Physiographic Atlas of the World 1964)

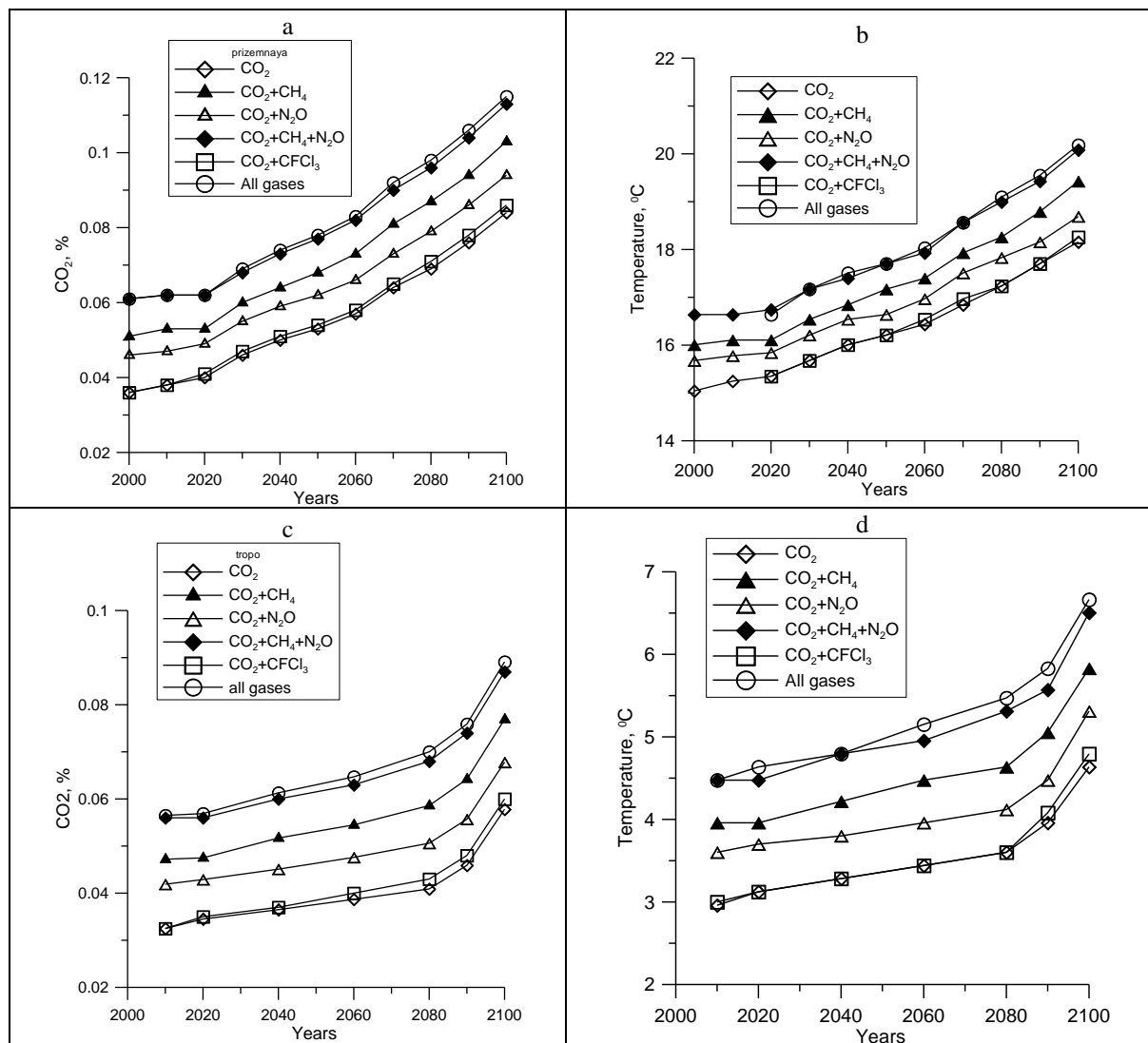


Fig. 1. Geographic distribution of volcanoes [25].

Fig. 2. Changes in the concentrations of the gases in the atmosphere and the temperature over the years, calculated on the basis of thermodynamic modelling. a, b – the surface layer of the atmosphere; c, d – the lower troposphere.

GEOSTRUCTURAL WAY OF COMBUSTIBLE GAS MIGRATION INTO DONBASS COAL MINES

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Abstract. Theoretical and practical prerequisites for connection of migration zones and combustible gas accumulation in coal-rock mass with the features of crystalline basement geology and subsurface stress state are considered.

Patterns, criteria, and principles of formation of a minefield with abnormal gas content caused by the influx of hydrocarbon gases from deep –laid deposits have been identified. Considering this, early forecast of the presence of areas with abnormal accumulation of hydrocarbon gas becomes possible.

Keywords: Geological structures, gas anomaly prediction, mine gas explosions, mine safety.

Coal mining industry of any country is a critical component of the fuel and energy complex; it provides the raw materials to power sector, metallurgy, chemical sector, and other industrial sectors. Coal mining industry, having been victim of the severe situation related to reconstruction, sees a steady increase of the volumes of coal mining after long—term period of

production output fall, and thus it is becoming one of the key branches of economy.

But, to do the extended mining works on the depth they are currently performed at including severe subsurface conditions, several significant problems related to production and science are to be reviewed. Among most critical ways to solve the problems in