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Mathematical simulation of the methane inflow into the atmosphere from the ocean methanhydrates under the ocean warming*

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It is supposed that with the climate variability, the temperature of the ocean surface begins its raising by 0.03 degree annually during 50 years and then decrease up to primal value for 50 years. The climatic model of the ocean with 24 levels on a vertical is further integrated for the period of 1200 years and simulates penetrations of warming from the surface deep into the ocean. A three-dimensional equation of transport of dissolved methane from sources is simultaneously solved, which are included in that moment, when warming reaches the area of methanehydrate stability and raises the temperature by a defined magnitude – tolerance of 0.1 degrees. Two experiments with different sources of methane were carried out. When the sources of methane are located on the shores of the Arctic and the Southern Oceans only, the flux of methane into the atmosphere after 50 years has reached 2.1 Tg and after 82 years it has become maximum 2.64 Tg. In the other experiment, the flux of methane into the atmosphere has exceeded 4.8 Tg after 50 years, and has reached maximum 12.7 Tg after 150 years.

Methane concentration in the atmosphere is increasing at a rate of about 1–2% a year [1]. It is a "greenhouse" gas that has a global warming potential 20 times larger than an equivalent weight of carbon dioxide. One of the largest potential sources of methane emission to the atmosphere is natural gas hydrates [2]. The quantity estimations of methane, which can reach the atmosphere by melting of methanegydrates, and time scale of the phenomenon are the key parameters in this case.

In work [3], for a quantitative evaluation of the scale of a possible methane inflow into the atmosphere from the decomposed sub-bottom methanehydrates a three-dimensional mathematical model of the dissolved gas transport by the ocean currents is used. The three-dimensional climatic large-scale currents field is obtained from a three-dimensional global model of ocean dynamics with 12 levels on a vertical [4]. It is supposed that in an outcome global warming atmosphere the temperature of a surface of the ocean begins to raise under the catastrophic scenario on 0.08 of degree annually. The tolerance varied in different experiments from 0.1 to 2.0 degrees.

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At tolerance 0.1 degrees, the methane flax have exceeded 1 Tg/yr in 4.6 years and in 50 years has reached 8.7 Tg per year. At tolerance 2.0 degrees, the methane flux has exceeded 1 Tg only in 12.5 years and in 50 years has reached only 3.8 Tg.

The experiment modeling oceanic variability is carried out. The variability is expressed in the increase of ocean surface temperature in all grid points linearly on 1.5 grades during 50 years, and further a decrease to primal value also during 50 years. In the given work, the models of a climate of global ocean and model of methane transport were joined.

Advective-diffusion process of transport of the dissolved methane in sea water, whose concentration we designate by the letter C, is described by the equation

$$\frac{\partial C}{\partial t} + \frac{u}{a\sin\theta}\frac{\partial C}{\partial \lambda} + \frac{v}{a}\frac{\partial C}{\partial \theta} + w\frac{\partial C}{\partial z} = \frac{\partial}{\partial z}æ\frac{\partial C}{\partial z} + \frac{\mu}{a^2}\Delta C \tag{1}$$

with boundary conditions

$$z = 0: \qquad C = C^*(\lambda, \theta), \tag{2}$$

$$z = H: \qquad æ\frac{\partial C}{\partial z} = 0. \tag{3}$$

On a part of a side cylindrical surface of ocean Γ_1 the zero methane flux condition is set, and on other part of the side boundary Γ_2, the presence of methane sources is supposed due to the decomposition of the subbottom methanehydrates. The methane concentration on a surface of ocean was set. The distribution, depending only from a latitude was given:

$$C^*(\theta) = (1 + \cos\theta) \cdot 50 \text{ ppb}.$$

A source is understood as a point lying on the ocean boundary or on sea floor, for which the pressure-temperature conditions of methangydrates existence are satisfied [2].

It is assumed that when these conditions will be broken that will begin the process of expansion methanehydrates, which will ensure a raise of concentration in a neighborhood of this point in 100 times on a comparison with background values of concentration 50 ppm characteristic of a surface of the ocean. Such approach proves to be true by dates of measurements of methane concentration, Objirov [5, 6], obtained as a result of study of methane distribution in water columns of the Okhotsk Sea. The sources of dissolved methane are switch on only there and in that moment, where and when warming will reach the area of stability methanehydrates and will raise temperature on defined magnitude – tolerance [7]. The tolerance was equal to 0.1 degrees.

It is assumed that in the climate variability, the temperature of a surface of the ocean begins to raise on 0.03 degree annually for the period of 50 years. Thus for surface waters, which all year are covered with ice, temperature is not increased. Next 50 years the temperature of a surface begins to decrease on 0.03 degree annually. The climatic model of ocean further is integrated for the period of 1200 years and reproduces the process of a penetration warming from a surface deep into of ocean. Simultaneously, on each time step, the three-dimensional equation of dissolved methane transport from sources is solved. The initial methane concentration is obtained from equation (1) with a field of currents from the stationary climatic state with boundary conditions (2).

Two experiments with different sources of methane were carried out. In the first experiment, the sources of methane existence were supposed only in high latitudes of the South and Arctic Oceans, i.e., to the north $62.5°N$ and to the south $62.5°S$. In the last experiment, the sources are located on all ocean boundary and sea floor, where the conditions of methangydrate stability are fulfilled.

Figure 1 shows ocean temperature, methane concentration, and summarized methane flux in the atmosphere as functions of time on period of 1200 years of integration. In the first experiment, the flux of methane into the atmosphere after 50 years has reached 2.1 Tg and after 82 years it has become maximum 2.64 Tg. In the other experiment, the flux of methane into the atmosphere has exceeded 4.8 Tg after 50 years and has reached maximum 12.7 Tg after 150 years.

In the variation of the horizontally average, methane concentration from time of experiment is shown in Figure 2. So, if after 10–50 years the maximal methane concentrations are disposed on depth 200–500 m, through after 1200 years the methane concentration grows with depth and reaches the maxima for an ocean bottom on depths more than 3500 m.

In Figure 3, the distribution of the dissolved methane concentration on depth of 251 meters after 10, 50, 100, and 1200 years is shown. We can see that after 50 years of warming methanhydrates begin decomposing on all the coasts of Arctic and Antarctic Continent.

Isolines of methane concentration at depth of 251 m in other experiment are given in Figure 4. The areas of decomposed methanehydrates considerably increase with rising of the sources.

The methane concentrations values are quantitatively comparable with values of the previous accounts [3]. One can see that methanhydrates have begun to be decomposed on all coasts of Siberia, Canada, and Antarctic Continent, and also in tropics of Atlantic Ocean, in western coasts of Pacific, in gulf of Arabian and Bengal. The fast penetration the warm surface water deep into of ocean at hair latitude happens due to fall-winter convective mixing, the warming in tropics is connected to a field of a vertical velocity.

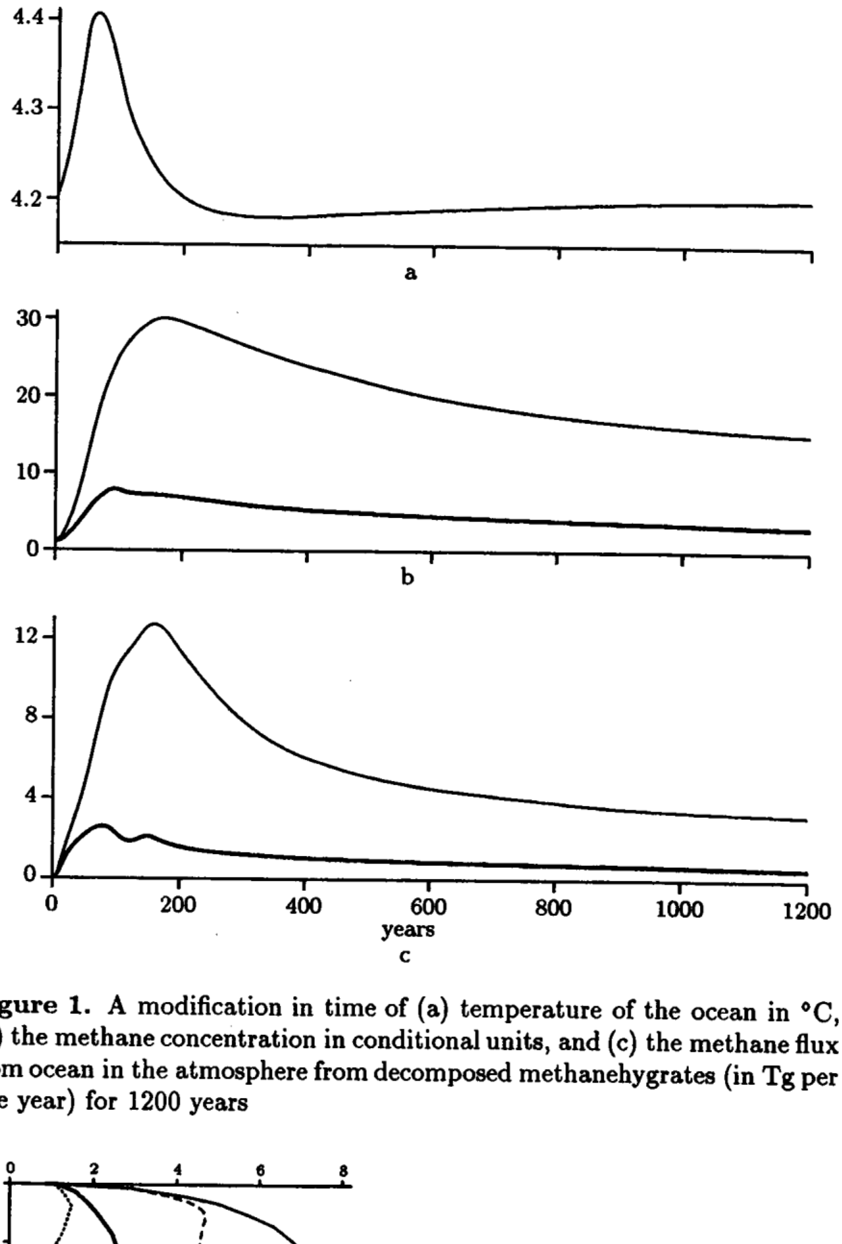


Figure 1. A modification in time of (a) temperature of the ocean in °C, (b) the methane concentration in conditional units, and (c) the methane flux from ocean in the atmosphere from decomposed methanehygrates (in Tg per one year) for 1200 years

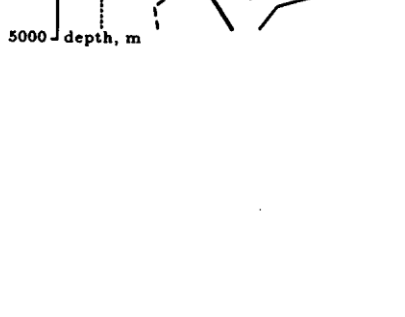
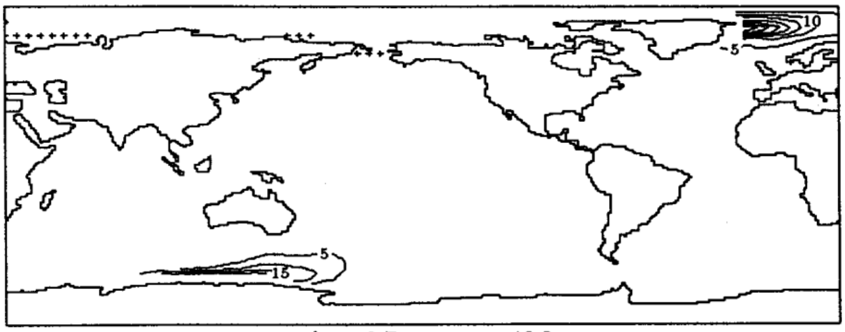
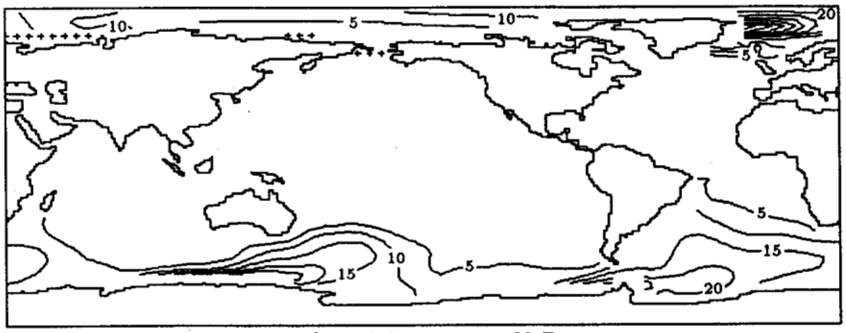


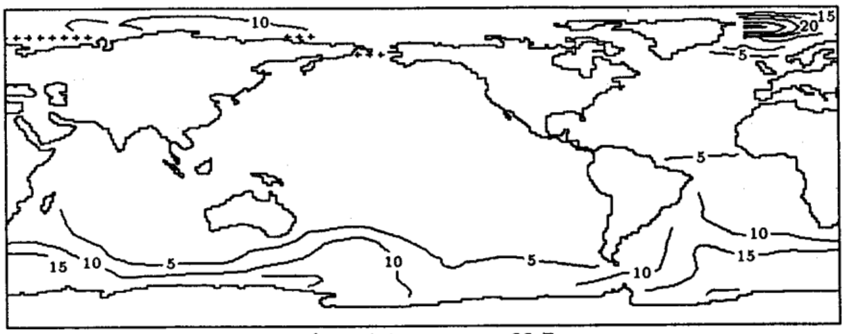
Figure 2. Vertical profiles of the methane concentration in the ocean after 10 (dotted line), 50 (dashed line), 100 (thin solid line), and 1200 years (thick solid line) in conditional units (1 conditional unit = 50 ppm)



min = 0.7, max = 46.3
a

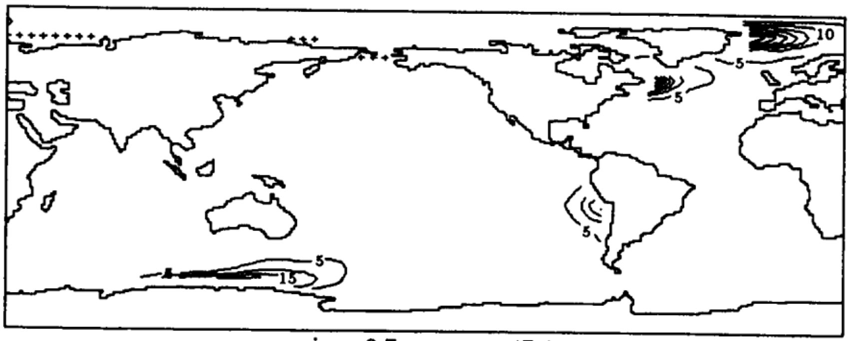


min = 0.9, max = 62.7
b



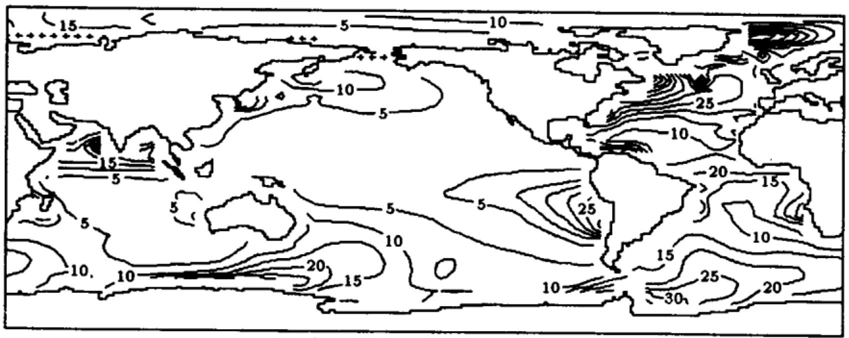
min = 1.1, max = 39.7
c

Figure 3. Isolines of dissolved methane on depth of 251 m in (a) 10, (b) 50, and (c) 100 years after the beginning of climate variability in first experiment (the values on isolines are indicated in conditional units: 1 conditional unit = 50 ppm)



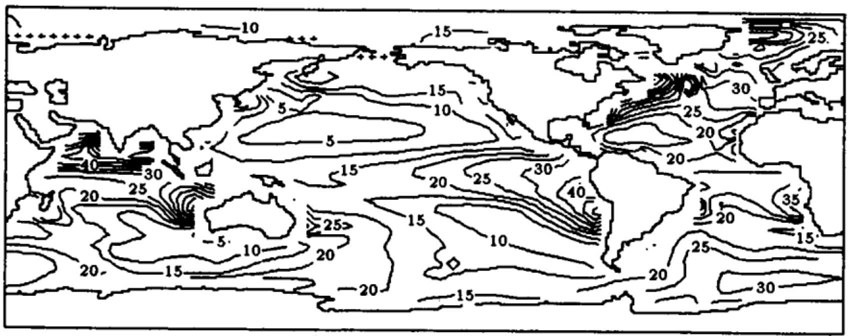
min = 0.7, max = 47.4

a



min = 1.3, max = 66.7

b



min = 1.3, max = 66.8

c

Figure 4. Isolines of dissolved methane on depth of 251 m in (a) 10, (b) 50, and (c) 100 years after the beginning of climate variability in second experiment

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