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GEOPHYSICS

Predicted Methane Emission on the East Siberian Shelf

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Based on the quantitative assessment of present-day methane emission on the East Siberian shelf with presumablly the world's shallowest gas hydrate deposits, its predicted growth is expected to follow two possible scenarios: smooth due to the gradual growth of methane diffusion from bottom reservoirs through sedimentary sequences and sharp owing to mass destruction of bottom methane deposits. It is shown that a smooth annual emission growth by 5% should result in a total emission of 50 Gt over 50 years. The sharp growth in methane emission (50 Gt over 1–5 years) from destructed gas hydrate deposits of the East Siberian shelf should result in an increase in the global surface temperature by 3.3°C by the end of the current century instead of the expected 2°C. Such temperature growth may culminate in catastrophic consequences for the climate system.

The East Siberian shelf is characterized by a unique geological history. It represents an element of the Siberian maritime lowland constituting >80% of its area during cold climatic periods and becoming the shallowest and most spacious shelf of the World Ocean in warm climatic epochs owing to the sea-level rise by >100 m. The last flooding of the East Siberian shelf occurred ~7–15 ka ago during the Holocene transgression [1, 2]. Its recent size is almost three times larger as compared with that of the Siberian tundra, which represents the main natural source of methane emission into the atmosphere of the Northern Hemisphere [3]. The recent works [4–6] demonstrate that the East Siberian shelf supplies methane into the atmosphere as well, although the scale and possible climatic role of this emission has not been estimated so far. In this communication, we estimate quantitatively the methane flow based on original and published data to predict its potential emission in line with four possible variants: smooth emission growth due to a gradual increase in the methane flux from bottom reservoirs (smooth diffusion through sedimentary sequences, Scenario 1); rapid emission increase (total quantity of 50 Gt) owing to mass destruction of bottom methane deposits: methane release during short (scenarios 2, 3, 4) and long periods (scenarios 2a, 3a, 4a). The climatic effect of the rapid methane emission (methane forcing) is estimated in terms of the expected growth of the global surface temperature.

MATERIAL AND METHODS

The methane emission (flux, F) from shelf waters into the atmosphere was calculated using the method in [7] as a function of dissolved methane concentration in the surface water layer reduced by the value of methane concentration occurring in equilibrium with that in the atmosphere (ΔC), methane properties under various water temperature and salinity (Schmidt number, Sc), and wind velocity (v):

$$F = 0.31 v^2 \left(\frac{\mathrm{Sc}}{600}\right)^{-0.5} \Delta C.$$

The Sc values were calculated using the method in [8]. Scenario 1 was realized in line with the following algorithm: the smooth methane emission growth (without account for bubble emission) should occur over the subsequent 90 years due to increase in the surface temperature by 2°C owing to the increment of carbon dioxide concentrations [3]. Such an increase should result in 5% annual growth of methane production in northern ecosystems [9] or its tenfold increase over 50 years. In addition, the temperature growth should intensify the energy and heat exchange between the ocean surface and atmosphere, which should result in the secondary growth of the methane emission. Moreover, the distribution of areas with different

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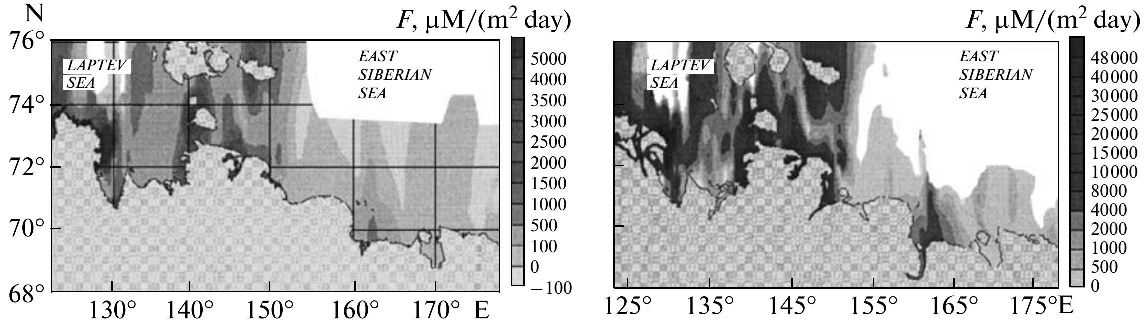

Fig. 1. The predicted methane emission according to scenario 1: (a) recent distribution of East Siberian shelf areas with different methane emission rates; (b) the emission increase after 50 years. Calculations are based on the diffusion methane transport without account for the bubble emission, the contribution of which may substantially exceed the former.

emission intensities should correspond to the present-day one [10].

Scenarios 2, 2a, 3, 3a, 4, and 4a were calculated in the following manner. It is assumed that the methane flux growth occurs due to destruction of bottom methane deposits (gas hydrates) with the release of 3% or 50 Gt (1 Gt = 10^{15} g) of its assumed reserves (1750 Gt). The assessed area of the East Siberian shelf with possible destabilization of gas hydrate deposits is substantiated by modeling, according to which development of taliks among the permafrost region is possible in rift zones, which constitute 3–5% of the latter [2]. In scenarios 2, 3, and 4, the methane release should occur over 5 years: according to scenario 2, the methane release grows up to maximal values during the first year to gradually decrease over the subsequent four years; according to scenario 3, the methane release occurs regularly with an annual rate of 10 Gt, and scenario 4 is characterized by a single-stage blowout of 50 Gt of methane in a stepwise manner. In scenarios 2a, 3a, and 4a, the emission types are similar to their counterparts in scenarios 2, 3, and 4 with the methane release period being 90 years long. The rapid release (or series of blowouts) of methane into the atmosphere should result in its increased concentrations in the latter. The climatic effect of such an increment should be reflected in the enhanced greenhouse effect or radiation forcing, which should, in turn, result in further increase of the surface temperature. The radiation forcing value (ΔF) was calculated using the following equation:

$$\Delta F = \beta(M^{1/2} - M_0^{1/2}) - [f(M, N_0) - f(M_0, N_0)],$$

where ΔF is radiation forcing in W/m^2, β is the climatically sensitive constant equal to 0.036, $M_0 = 700$ ppb, $N_0 = 270$ ppb,

$$f(M, N) = 0.47\ln[1 + 2.01 \times 10^{-5}(MN)^{0.75} + (5.31 \times 10^{-15}M(MN)^{1.52}].)$$

For details, see site http://www.esrl.noaa.gov/gmd/aggi/.

RESULTS

Figure 1a demonstrates the spatial distribution of areas with different intensities of recent methane emission in the East Siberian shelf. As follows from the figure, most of the shelf (80–90%) is characterized by emission intensity ranging from 1 to 1000 μM/(m^2 day). In the remainder of the East Siberian shelf, the emission intensity is substantially higher varying from 1000 to 5400 μM/(m^2 day). The recent annual methane emission is as high as 5 Tg (Tg = 10^{12} g). Under the emission growth in line with scenario 1, >50, >30, and approximately 15% of the East Siberian shelf should be characterized by its intensity exceeding 1000, 4000, and 20 000 μM/m^2/day, respectively. The integral annual emission should be 50 Tg of methane (for comparison, the present-day methane emission from the tundra is as high as 42 Tg [3]).

Figure 2 illustrates the growth of the global methane emission and corresponding climatic forcing calculated for scenarios 2, 3, and 4. Inasmuch as methane entering the atmosphere becomes gradually oxidized in its upper layers (lifetime of methane in the atmosphere is accepted to be five years), the period during which methane is supplied into the atmosphere is of determining significance. When emission growth occurs over a long period (scenarios 2a, 3a, and 4a), a significant share of methane is oxidized, which reduces the radiation effect. When methane emission increases rapidly, the latter is entirely consumed by the increasing radiation effect (scenarios 2, 3, and 4). Owing to such a phenomenon, the increase in the global surface temperature owing to the methane release described in scenarios 2, 3, and 4 is three times higher as compared with that determined by the emission growth in scenarios 2a, 3a, and 4a (Fig. 3).

As follows from Fig. 3, the climatic consequences of scenarios 2, 3, and 4 will be practically the same: rapid methane release will be accompanied by a spas-

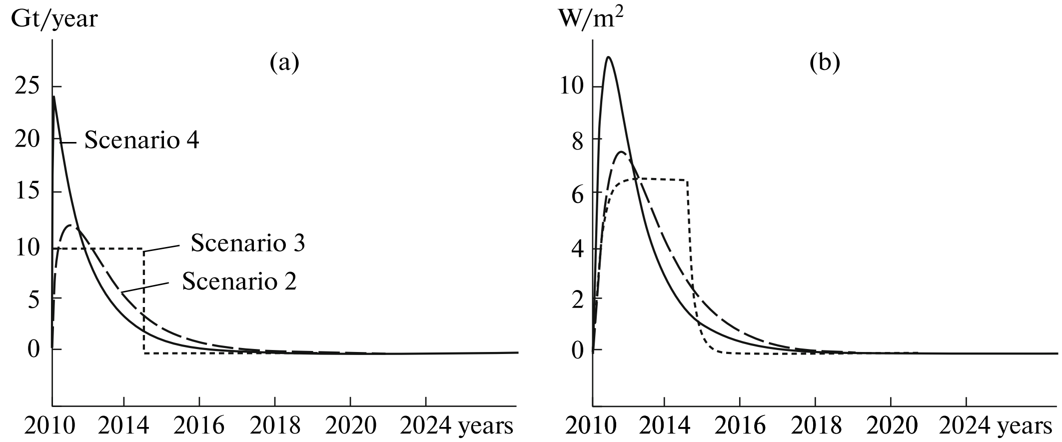

Fig. 2. The assumed methane flux (a) and related climatic forcing (b). Designations of curves corresponding to different scenarios are the same as in Fig. 2a.

modic growth of the global surface temperature by 1.0–1.3°C. Thus, the sum temperature growth by the end of the current century should be equal to 3.3°C instead of the previously predicted 2°C [3]. Such growth may activate other nonlinear processes related to warming in the Arctic region such as ice cover reduction and increase in duration of the ice-free period, which, in turn, should result in intensified methane emission into the atmosphere. The increase in the seasonally degraded permafrost layer will result in methane growth in terrestrial ecosystems (tundra, lakes) and, correspondingly, further intensification of methane release into the atmosphere. According to available estimates, the global surface temperature increase by 3°C may result in destabilization of most (~85%) oceanic gas hydrate deposits and release of ~4000 Gt of carbon [11]. The climatic consequences of this process are difficult to assess. For comparison,

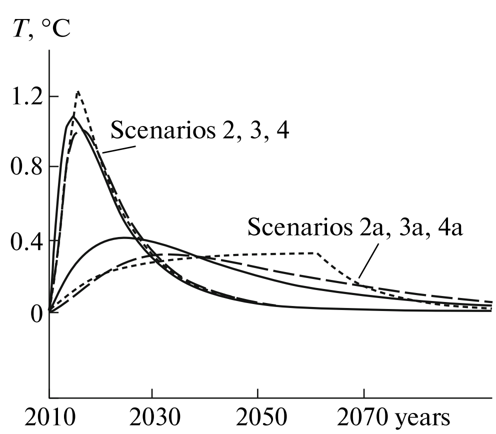

Fig. 3. Changes in the global surface temperature under the influence of the climatic forcing determined by the methane emission increasing in line with scenarios 2, 3, 4, 2a, 3a, and 4a. For designation of curves corresponding to different scenarios, see Fig. 2a.

it should be mentioned that carbon reserves (in form of methane and carbon dioxide) in the present-day atmosphere are only 760 Gt.

The above-mentioned scenarios of the growth of methane emission in the East Siberian shelf allow the inference that the rapid methane release from destructed gas hydrate deposits significantly increases the probability of a climate catastrophe. The East Siberian shelf represents the most probable candidate for such methane release taking into consideration the fact that the latter encloses the world's shallowest gas hydrate deposits (Fig. 4b), which were already being destabilized 7–15 ka after their last flooding [12] and that warming in this region is now maximal (Fig. 4a). Nevertheless, recent knowledge of the problem prevents assessing the probability of such a release in the near or distant future. The difficulty of the assessment is determined by the fact that the stability of Arctic gas hydrates depends on the state of the underwater permafrost, which is poorly known so far. It is obvious that the available modeling data on the underwater permafrost, according to which the latter is stable and impermeable to gas in most of the East Siberian shelf, are inconsistent with natural observations. They show unambiguously that >50% of the shelf may supply methane into the atmosphere.

It is conceivable that degradation of the underwater permafrost due to global warming is more rapid than is admissible by model scenarios. In addition, it is of importance that the transition of frozen rocks into the thawed state and, consequently, the transition from the gas-impermeable to the gas-conductive state occurs in a spasmodic manner. This means that the catastrophic release of methane from gas hydrate deposits of the Arctic shelf cannot be excluded. Such catastrophic events accompanied by a blowout of methane into the atmosphere of the Earth, which resulted in global warming and extinction of many

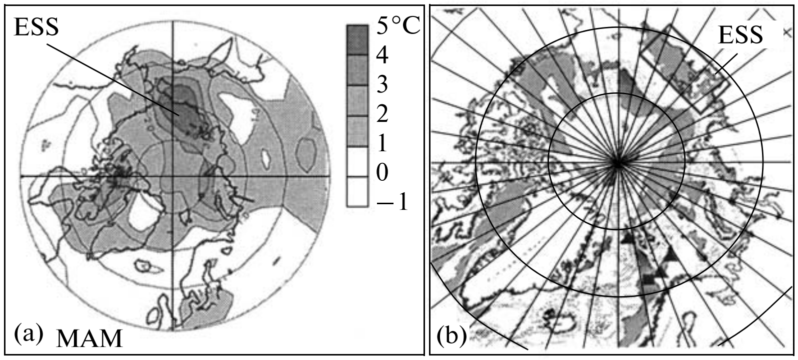

Fig. 4 (a) Climatic map of the Arctic region demonstrating warming during the period of 2000–2005 as compared with the period of 1970–1999 (http://www. eoearth.org/article/State of the Arctic Report; (b) map of presumed gas hydrate reserves in the Arctic Ocean (V.A. Solov'ev, 1999). (ESS) East Siberian shelf.

biological species, are recorded for the past geological epoch, such as, for example, the Early Paleocene [13].

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