Anomalies of dissolved methane in the Arctic waters according to the observed data and results of numerical modeling

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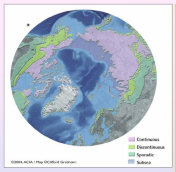
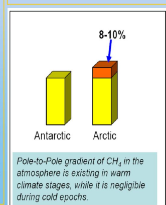
Motivation



- Arctic Ocean is the largest pool of organic carbon (including methane and oil) in the World Ocean.
- Artic Ocean is surrounded with onshore permafrost (contains ~10,000Gt C) and underlain with offshore permafrost which contains a huge reservoir of organic matter and trapped methane, including methane in form of gas hydrates.
- More runoff input than any other ocean.

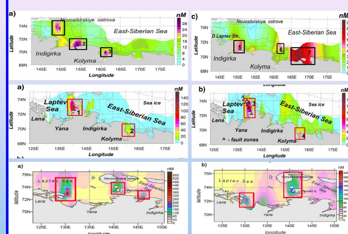
During the warm stages the Arctic is considered to be a source of atmospheric methane, ensuring the existence of the inter-polar CH4 gradient (8–10%); this gradient decreases to a practically negligible value during glacial epochs (IPCC, 2001).
It is the widespread opinion that water-saturated terrestrial arctic ecosystems (wetlands) are primarily responsible for the higher concentrations of methane over the Arctic region.
Arctic region contains a huge amount of organic carbon buried not only inland, but also within the Arctic Ocean sedimentary basin.



Pole-to-Pole gradient of CH_4 in the atmosphere is existing in warm climate stages, while it is negligible during cold epochs.

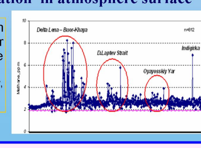
Dissolved methane in the East-Siberian Sea. Observed data

Distribution of dissolved methane in the surface layer (a), and bottom layer (b) (Shakhova and Semiletov, 2007)
- Surface layer maximum: 2003 - 30 nM, 2004 - 115 nM, 2005 – 500 nM
- Bottom layer : 2003 - 87 nM, 2004- 154 nM, 2005 – 220 nM



Methane concentration in atmosphere surface

Methane in the air 2 m above the sea water along the ship route (September, 2005). (Shakhova and Semiletov, 2006).

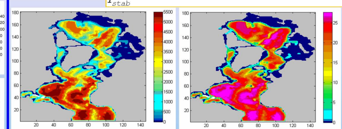


Methane hydrates in the Arctic ocean

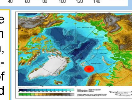
Gas hydrates are an ice-like material comprised of gas molecules entrained by frozen water. They are trapped by sediments in permafrost and on the ocean bottom.
The total amount of methane in the Arctic Ocean sediments is estimated to 540 Gton C (Kvenvolden K.A., 1988), which to a large degree could be released when warmer waters penetrates the shelves.

Thermobaric conditons of the methane hydrate existence

$$\frac{1}{T_{stab}} = 3.79 \times 10^{-3} - 2.83 \times 10^{-4} \log P_{stab}$$



One mechanism to release methane from the ocean sediment is through submarine mud volcanism, (Mazurenko L. L., Soloviev V. A. 2003). Existence of gas hydrate on surface of sediment results in formation of cold methane plum extending in the direction of bottom currents. The flux of methane into water column from seafloor can reach up to 50 m^3 / m^2 a year, (Egorov et al., 1997).



The the Haakon Mosby submarine mud volcano is located at a depth of about 1260 m.

Coupled Ice-Ocean Model

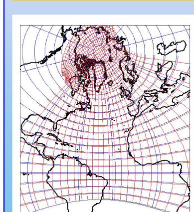
3D World Ocean Circulation Model of ICMMG based on z-level vertical coordinate approach

(Kuzin1982, Golubeva at al.,1992, Golubeva,[2001], Golubeva and Platov,[2007])

- Conservation laws for heat, salt and momentum with Boussinesq, hydrostatic and 'rigid lid' approximations
- Barotropic momentum equations are expressed in term of stream function
- QUICKEST (Leonard, 1992) is used in the latest model version for the T-S advection.
- Two versions of mixed layer parameterization:
  - Vertical adjustment based on the Richardson number
  - Vertical diffusion coefficient based on the stable solution of turbulent energy equation

Ice model-CICE 3.0 (elastic-viscous-plastic)

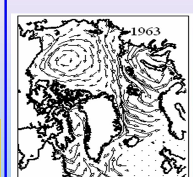
W.D.Hibler ,1979, E.C.Hunke, J.K.Dukowicz,1997, G.A.Maykut 1971 C.M.Bitz, W.H.Lipscomb 1999,J.K.Dukowicz, J.R.Baumgardner 2000,



The model grid has 1x1 degree resolution in the North Atlantic. At 65N, the North Atlantic spherical coordinate grid is merged with the polar grid, which is a result of the spherical coordinate rotation and reprojection of its hemisphere onto the area above 65N (*Murray, 1996*). The horizontal spacing in the polar grid varies from 50 to 34 km.
Vertically, the grid has 33 constant layers, with a higher resolution near the surface. The minimum shelf depth is 50 m.

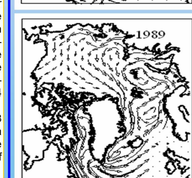
Numerical results. Two basic modes of the surface circulation of the Arctic Ocean

Firstly, a numerical run aimed at simulation of large-scale ocean circulation was conducted. Dynamics of surface waters of the Arctic pool is subject both seasonal, and to interannual changes which are defined mostly by dynamics of atmosphere. Two modes of surface circulation of waters, have been reproduced during numerical experiment.



Anticyclonic mode

1960, 1961, 1963, 1965, 1966, 1969, 1970 -1973, 1977-1980, 1982 -1983, 1985 - 1986, 1988, 1992, 1994, 1996, 1998, 2001



Cyclonic mode

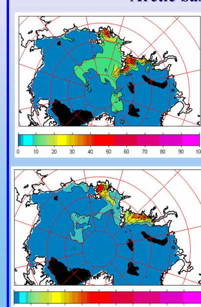
1967, 1968, 1981, 1984, 1989, 1993, 1995, 1997, 1999, 2000, 2002, 2003

The Siberian rivers as methane sources

Lateral borders are set according to available data about seasonal change of the Arctic rivers discharge, taken from project AOMIP.

$$-\mu_s \frac{dS}{dn} + u_n S = Q, \qquad Q = -\frac{S\ \mathrm{Tr}}{A},$$

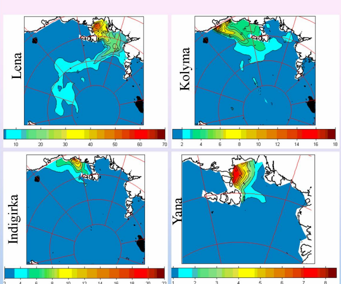
Distribution of the dissolved methane in the Arctic basin



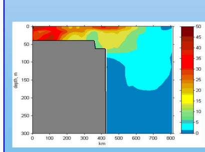
The dissolved methane is transported in the Arctic ocean according to the system of currents and depends on the considered period.

- The tracer propagate to the central part of the Arctic and then is transported by the Transpolar Drift to the Greenland.
- The tracer is blocked in the shelf zone and only small part penetrates to the central Arctic.

Distribution of the dissolved methane arriving into the ocean from the rivers

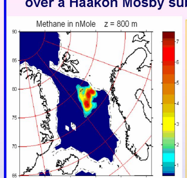


Vertical profiles of the dissolved methane in the vicinity of the Lena river runoff, in nMole

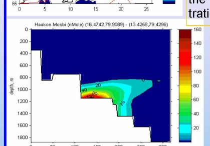


Large concentration of the dissolved methane in the surface water can lead to a methane flux in atmosphere and to formation of abnormal concentration in an atmosphere surface layer in the river runoff area.

Modelling of the methane concentration in water over a Haakon Mosby submarine mud volcano

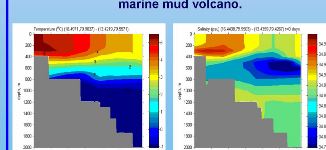


The transport of the dissolved methane by ocean currents from an submarine volcano is investigated. On the depth of 1000 m the methane concentration in water reaches 50 nM. On the depth of 800 m plum starts to spread in a horizontal plane, forming a layer with the raised methane concentration.



On a vertical cut it is possible to see, that plum on depth about 800-1000 m spreads in a horizontal plane, and does not spread in a vertical direction.

Thermohaline circulation around the Haakon Mosby submarine mud volcano.



Conclusions

- ⇒ The stability zone of the subbottom methane hydrates in the Arctic pool begins down from the sea depths of 200-250 m. Considerable part of methane hydrates decomposition are endangered at a small rise in temperature (1-5 °C) (first of all adjournment of the continental Arctic shelves)
- ⇒ On the basis of numerical modeling of the water masses area with high methane concentration as a result of unloading of gas from the Haakon Mosby submarine mud volcano is obtained. It is shown, that the area is located on the depth below 700 m and apparently cannot be an additional source of methane to atmosphere in this region.
- ⇒ The accumulation and stability of high dissolved methane concentration in the Arctic Ocean obtained in the model in agreement with the measurements of Shakhova, Semiletov 2007. It is shown that runoff of the Lena River may give an essential income into forming of the high methane concentration in the Dmitry Laptev Strait. The reason of this is the system of the currents and the coastal line outline.
- ⇒ The results of the numerical simulation show that the propagation of dissolved methane from the rivers into the Arctic basin is realized by two ways according to the atmospheric regimes.