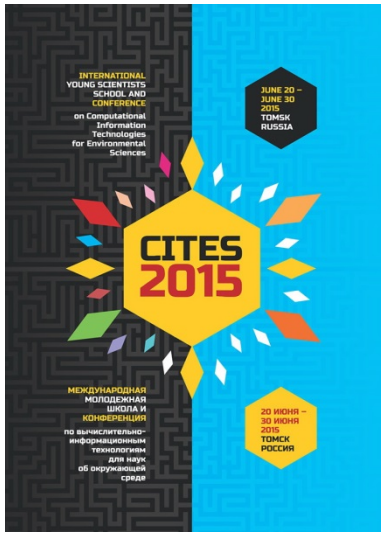
MODELING OF THE SUBMARINE PERMAFROST DYNAMIC AND GAS HYDRATE STABILITY ZONE IN THE ESAS

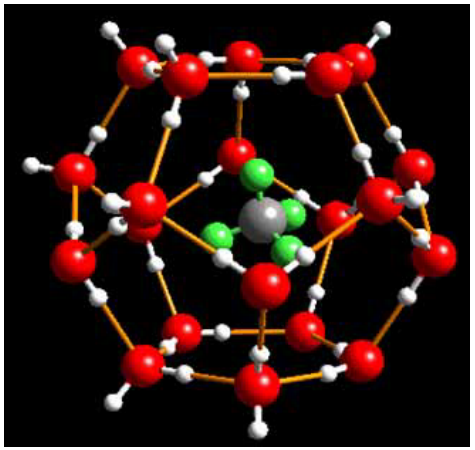
V.V. Malakhova
ICM&MG SB RAS, Novosibirsk



"CITES-2015"
Tomsk, Russia, 20 – 30 June, 2015

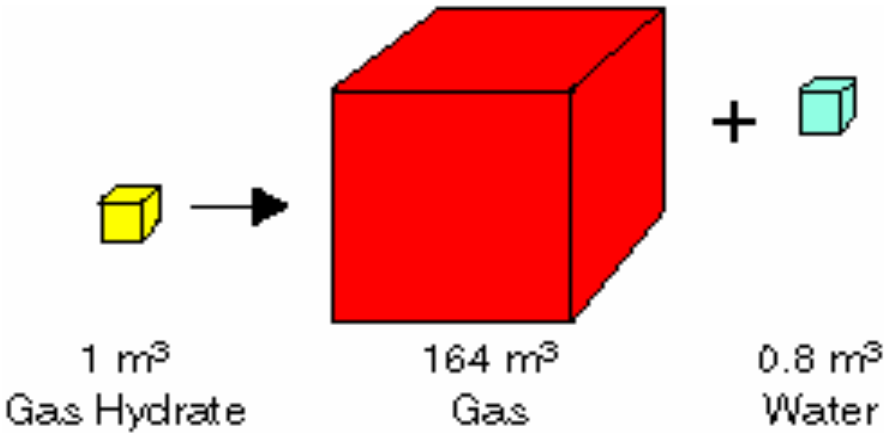
What is methane hydrate?

- A gas hydrate is a crystalline solid. This it is similar to ice, except that the crystalline structure is stabilized by the guest gas molecule within the cage of water molecule
- Water molecules form the cage-like structure and methane molecules are contained in it



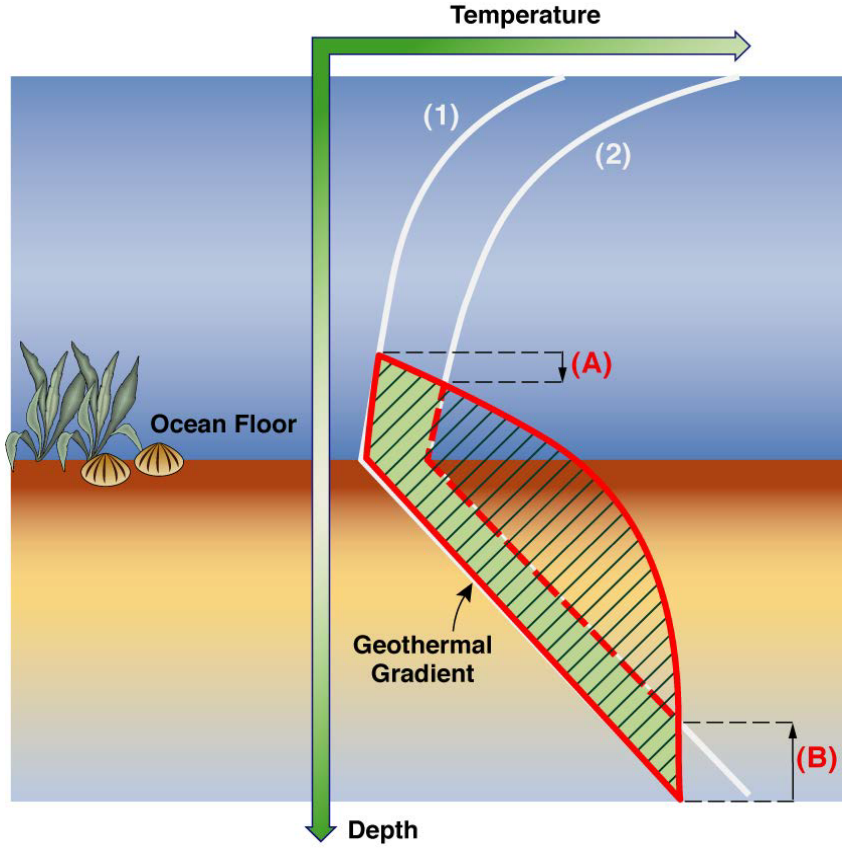
$$(CH_4 \cdot 6H_2O)_{solid} \rightarrow (CH_4)_{gas} + 6(H_2O)_{water}$$

1 m³ of methane hydrate dissociates to approximately **160 – 170** m³ (at 0ºC and 1 atmosphere) of methane gas

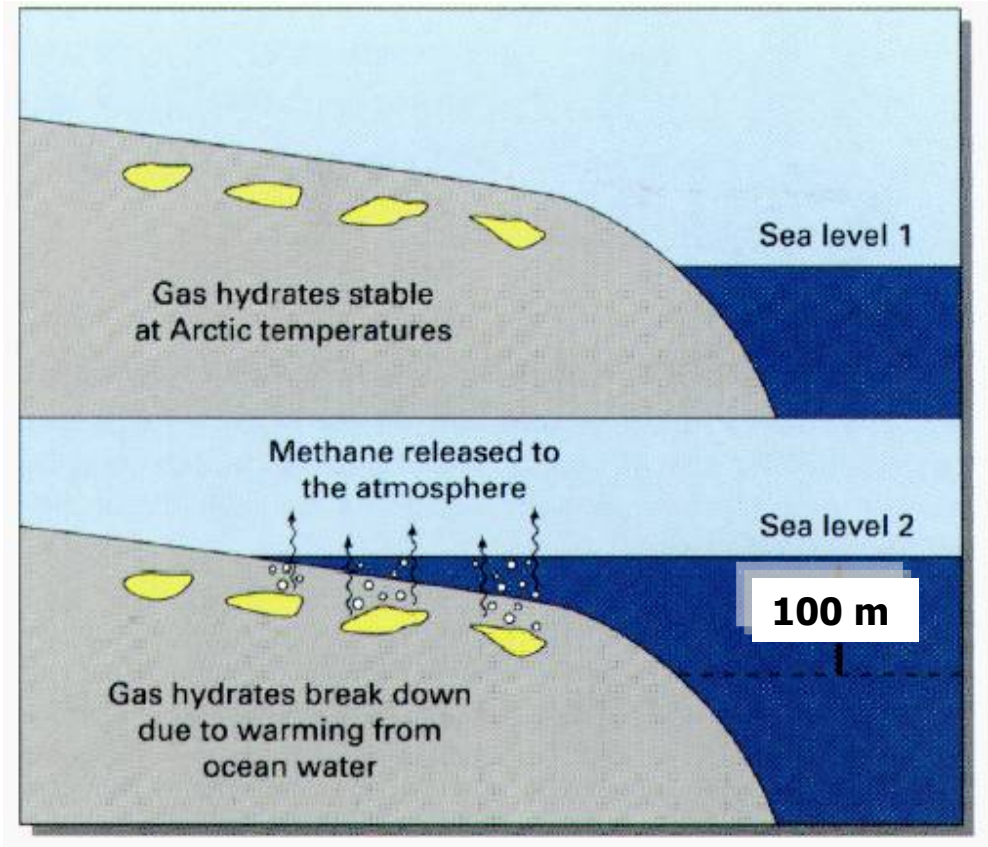


Hydrate dissociation

Climate change alters ocean temperature (and geothermal gradient)

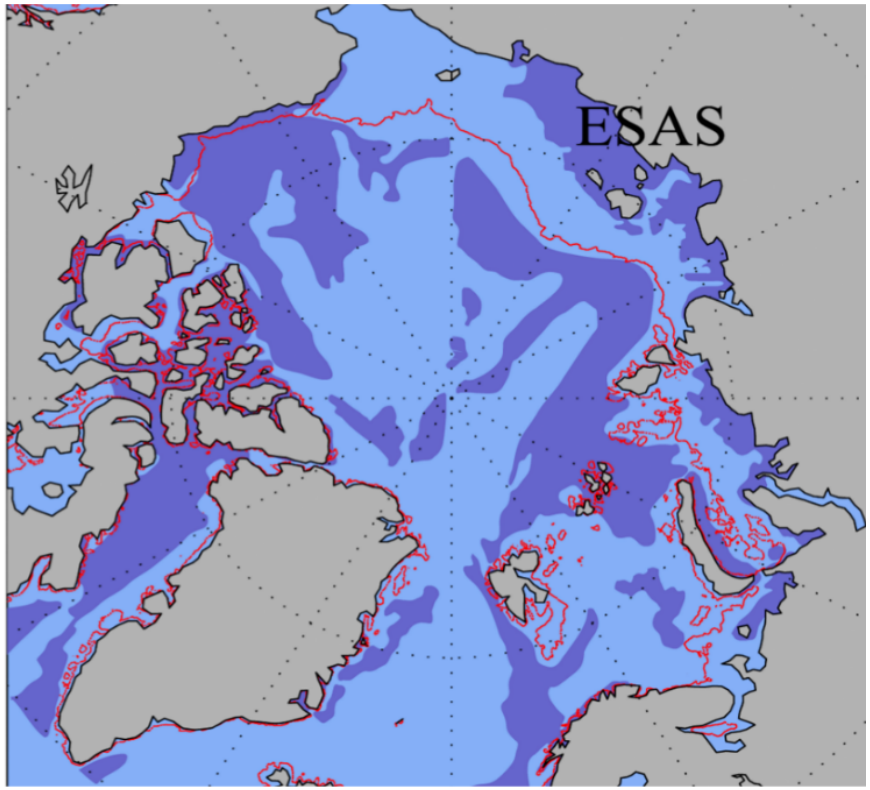


Mechanism for sea-level rise to destabilize hydrate



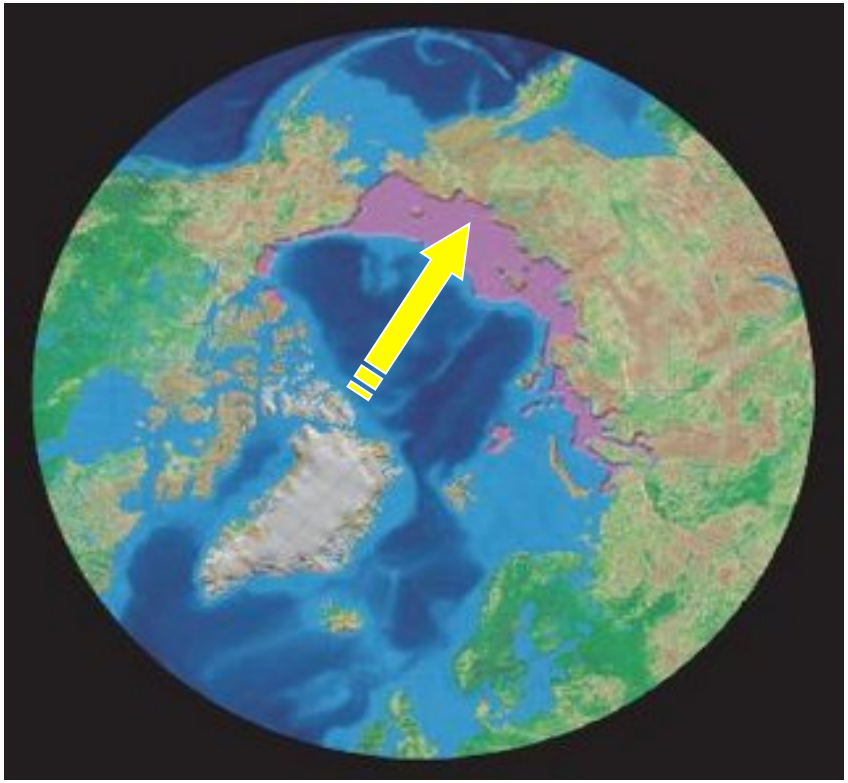
Global warming may cause hydrate destabilization through a rise in ocean bottom water temperatures. The increased methane content in the atmosphere in turn would be expected to accelerate warming, causing further dissociation, potentially resulting in run away global warming

Arctic Shelf Seas host subsea permafrost regions



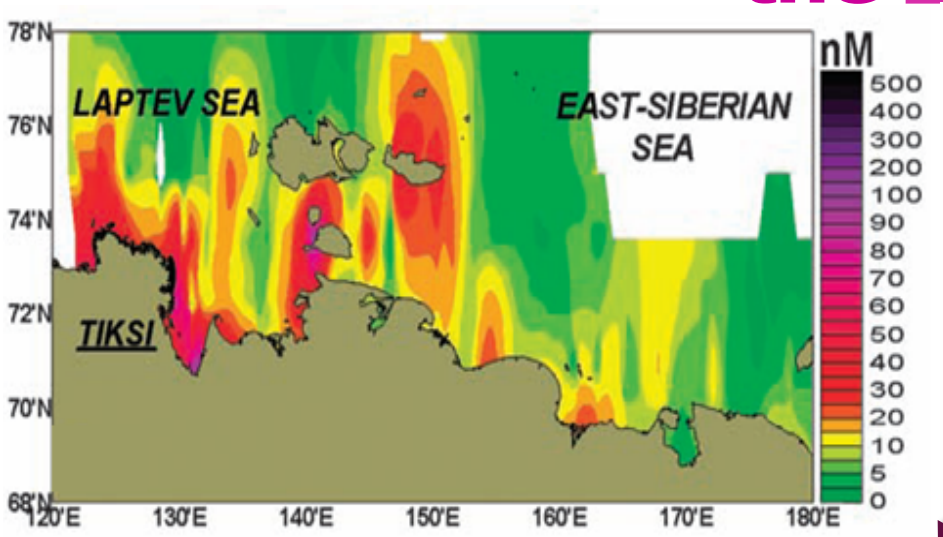
Methane hydrates are predicted along the slopes of the shelf [Soloviev et al., 1987]

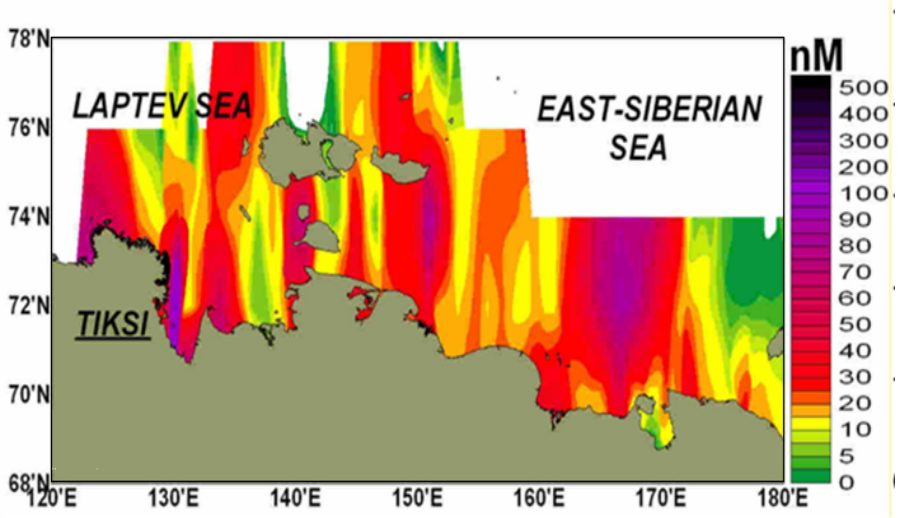
- ***80%*** **of the total area of sub- sea permafrost (shown in lilac) is in the ESAS;**

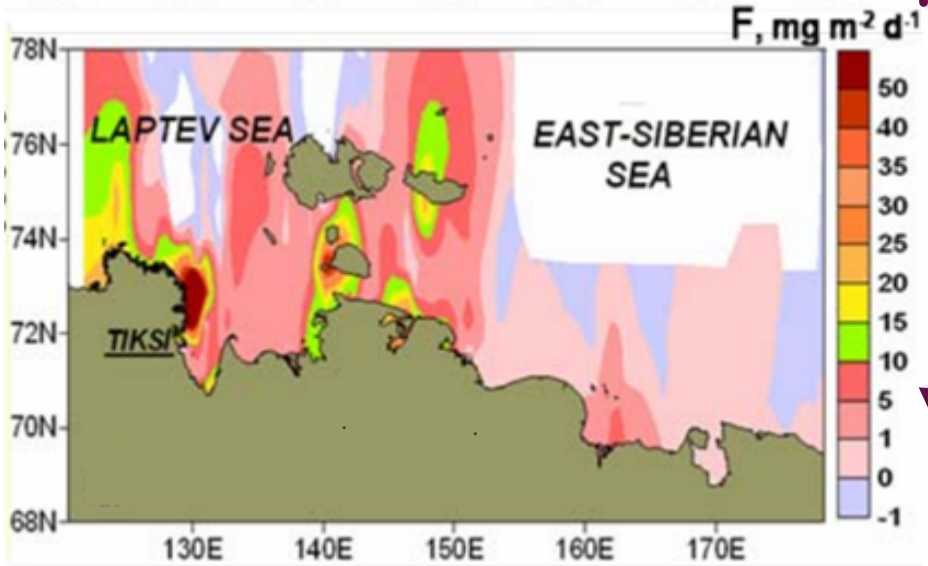


Stability of sub-sea permafrost is key to stability of permafrost-related hydrate deposits

Methane plumes have been observed in the the ESAS



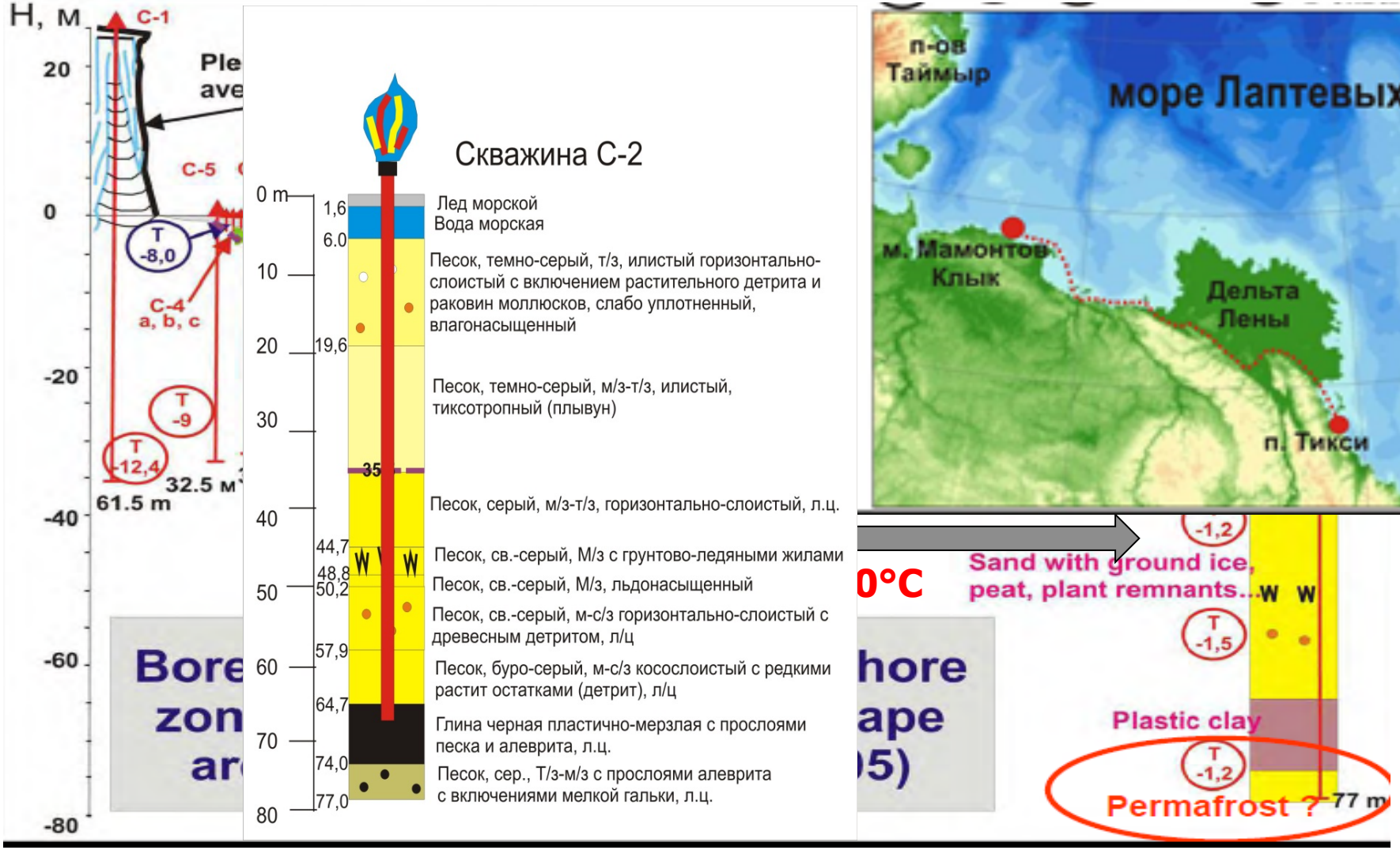




Surface and Bottom water methane concentration in the ESAS as reported by Shakhova et al. [2010a]

Observational data suggest >80% of the ESAS sea floor serves as a source of methane to the water column and the atmosphere

- **Drilling of subsea permafrost in the Laptev Sea Region: distribution** (M. Grigoriev , 2014)



(M. Grigoriev , 2014)

- The trend of sub-sea permafrost table degradation at the near-shore zone (for the different types of the shoreface) is about 1-20 cm/year, depending on sea water depth and the period of flooding

Numerical models

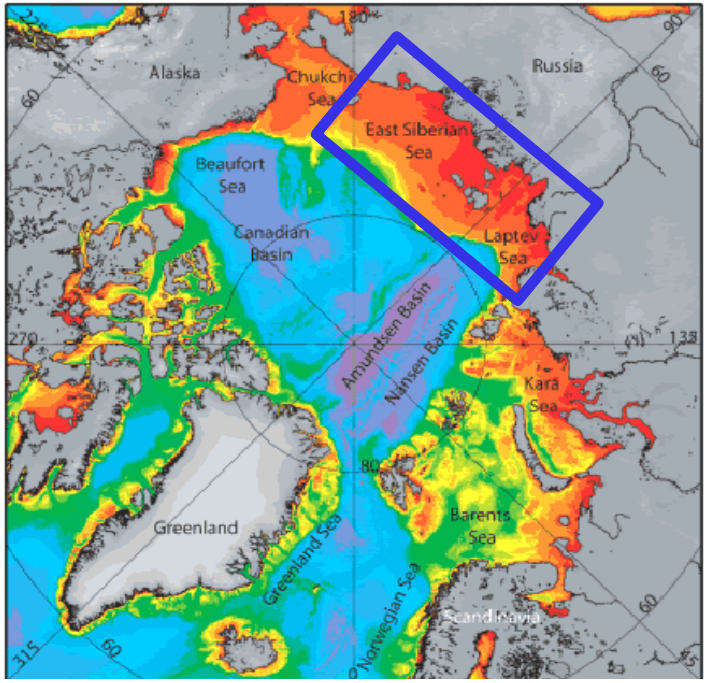
- **3D World Ocean Circulation Model of ICMMG based on z-level vertical coordinate approach** *(Golubeva and Platov,2007, Голубева,2008)*
- **Ice model-CICE 3.0 (elastic-viscous-plastic)** *(W.D.Hibler ,1979; E.C.Hunke, J.K.Dukowicz,1997; G.A.Maykut 1971 C.M.Bitz, W.H.Lipscomb 1999,J.K.Dukowicz, J.R.Baumgardner 2000, W.H.Lipscomb, E.C.Hunke 2004)*
- **Atmospheric data from the NCEP/NCAR reanalysis**

- **The IAP RAS permafrost model**

[Аржанов М.М., Елисеев А.В., Демченко П.Ф. и др., 2008]

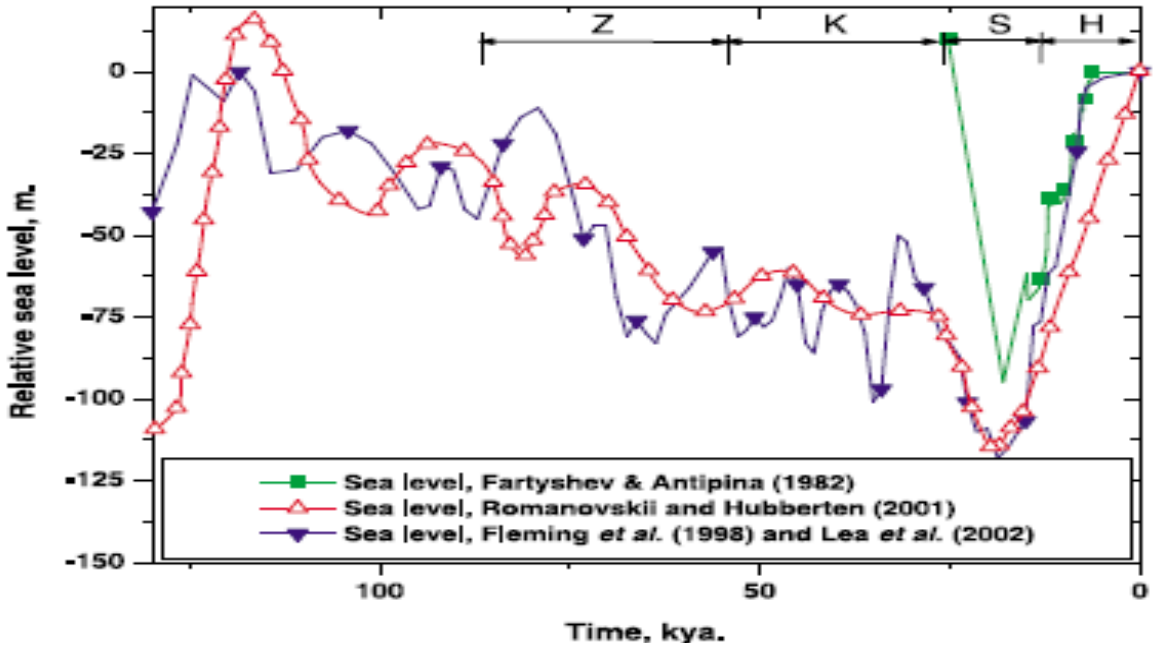
- **The Paleogeographic Scenario for subsea permafrost**
- **P-T relationships hydrate stability**
- **«HydrateResSim»**

[Reagan M. T., Moridis G. J., 2008]



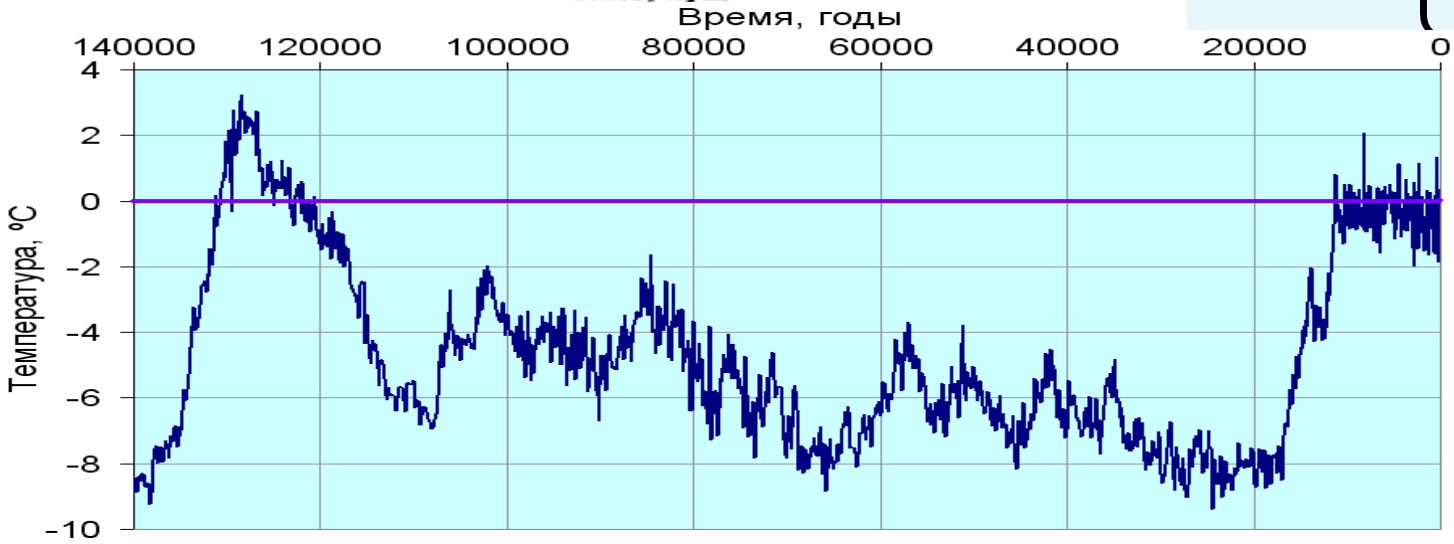
Map of investigated area including bathymetric data

Sea level and air temperature reconstruction over the last glacial cycle

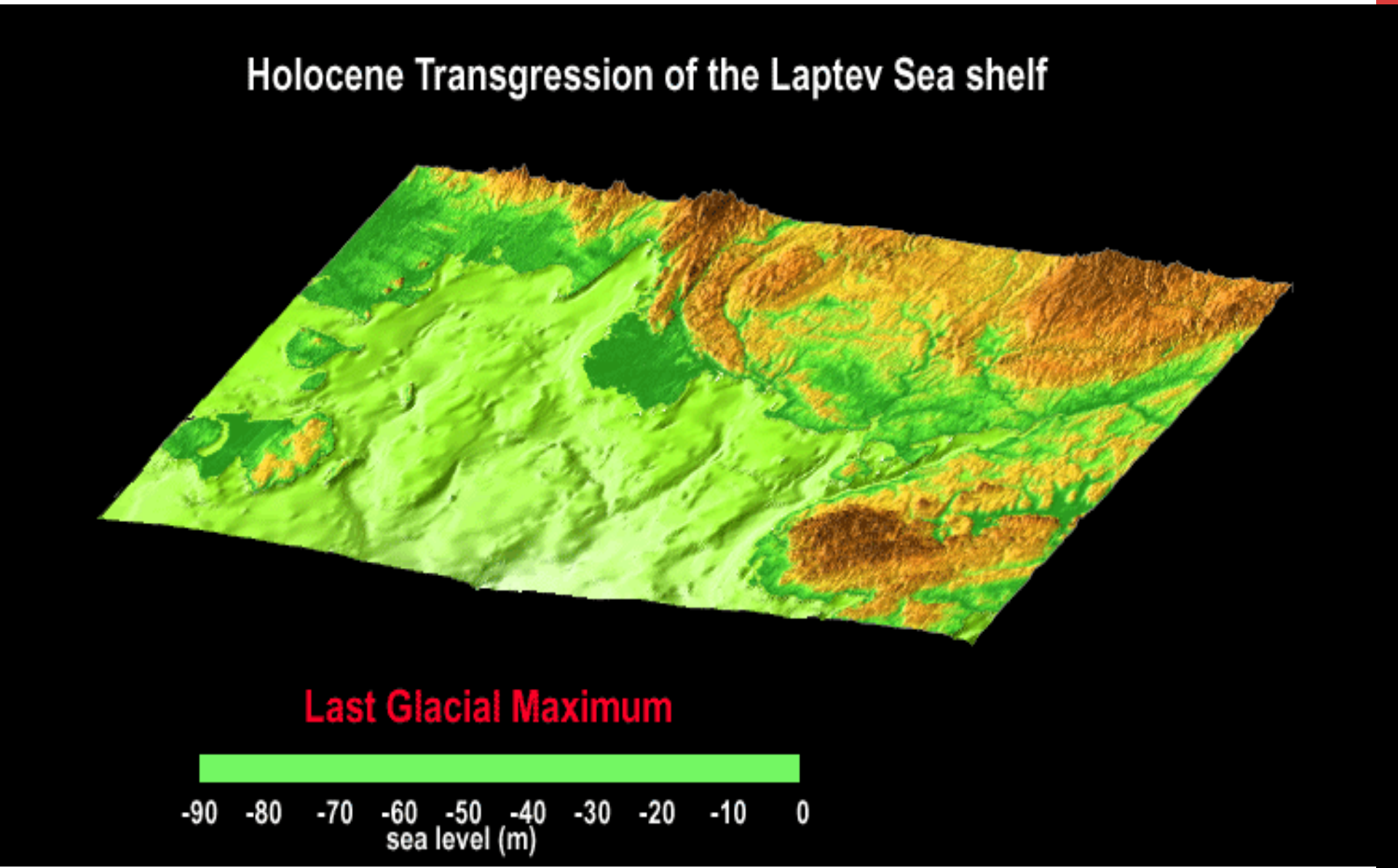


A sea level curve (based on the models) determines the time interval for inundation in the ESAS

$$T_B = \begin{cases} T_{BW} \\ T_A + \Delta T_{Pal} \end{cases}$$

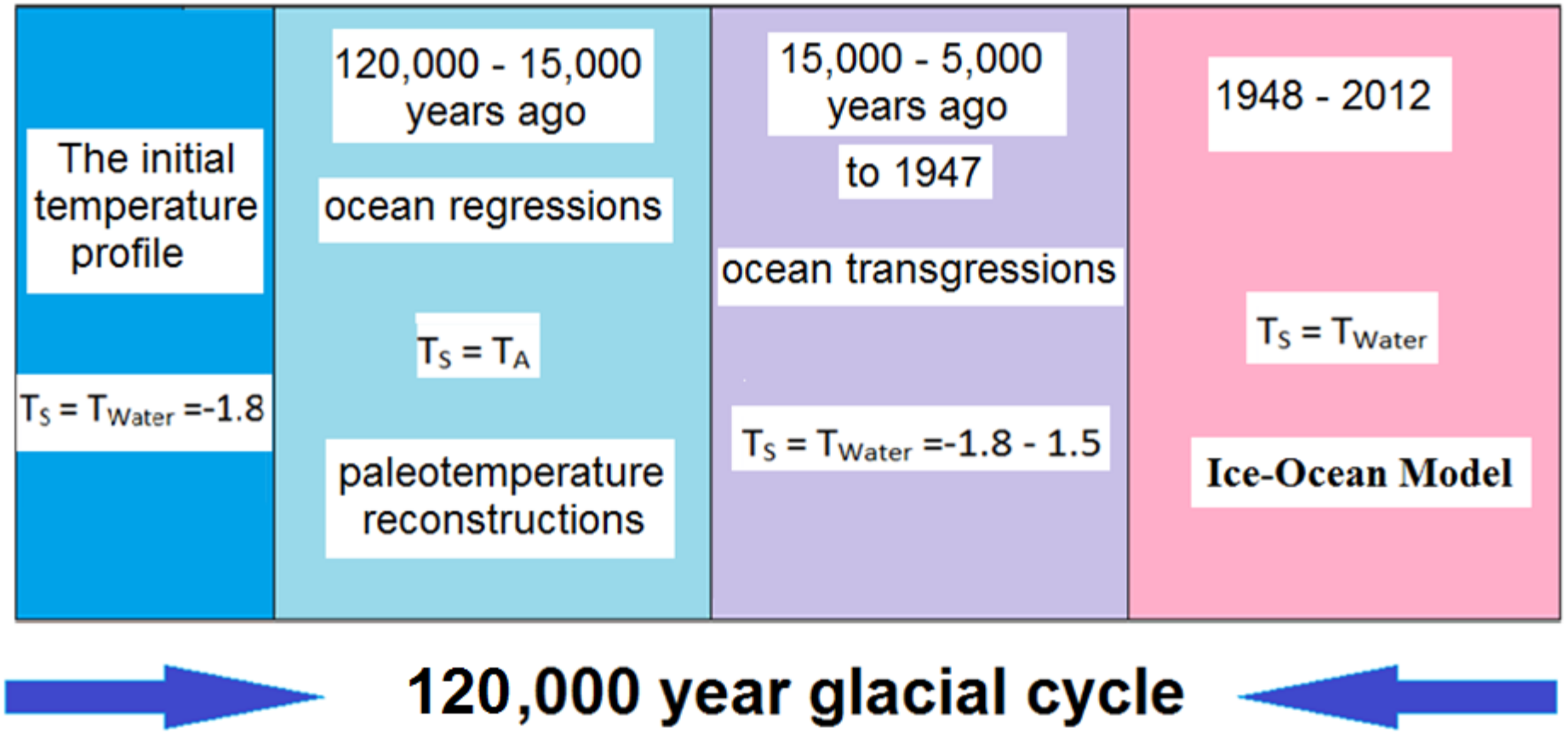


Petit J.R., 1999 Climate and atmospheric history of the past 420,000 years from the Vostok ice core, Antarctica



Bauch H.F. et al.Chronology of the Holocene transgression at the Northern Siberia margin // Global and Planet. Change, 2001, vol. 31, p. 125–139.

Models of sub-sea permafrost evolution



Pore water salinity

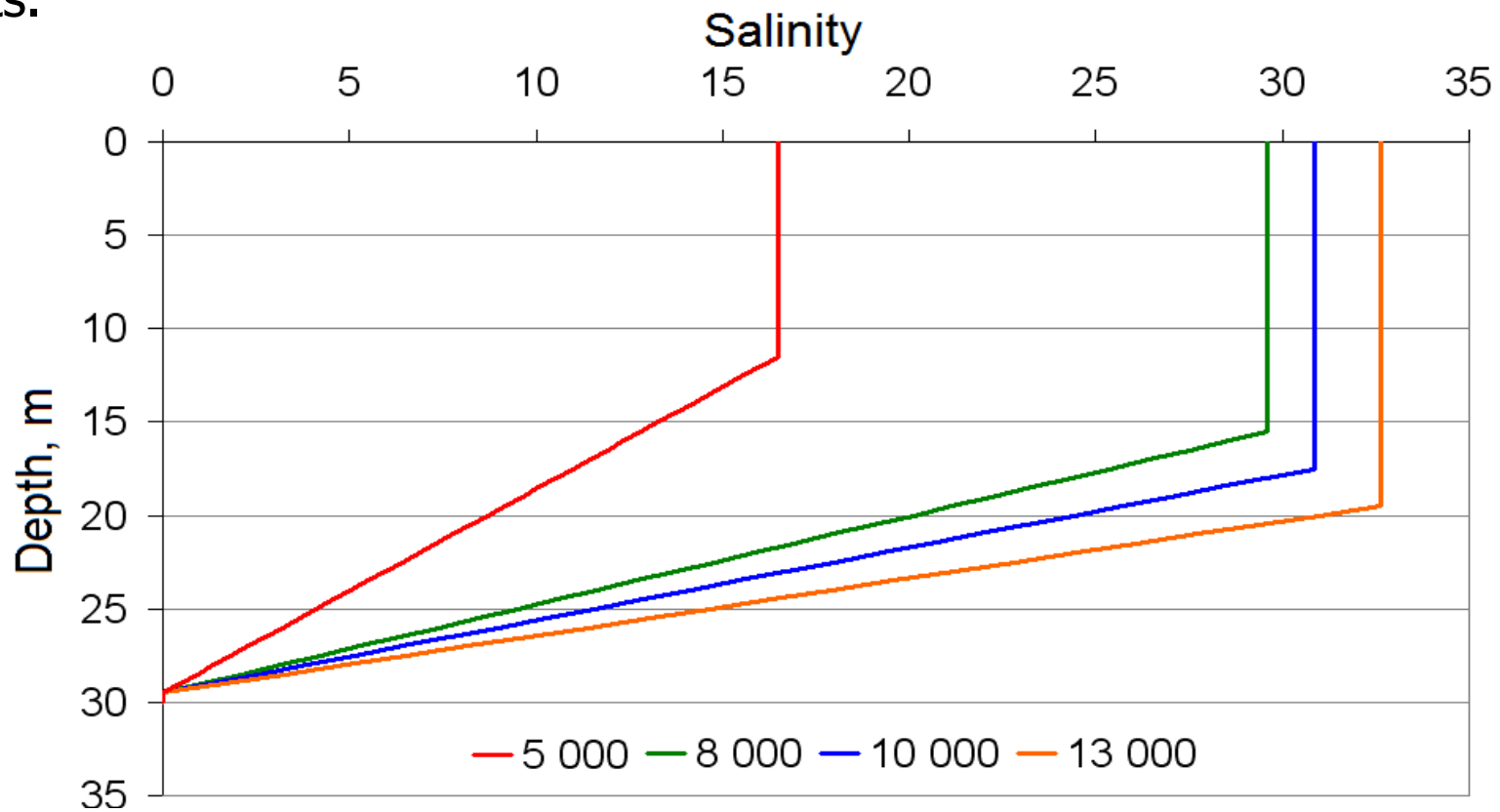
Increasing concentration of dissolved salts in the soil depresses the freezing point of the pore water. This phenomenon is important wherever pore water is saline and may be particularly significant in controlling ice-bonding of coastal sediments.

$$S(z_S, t) = S(0, t)$$

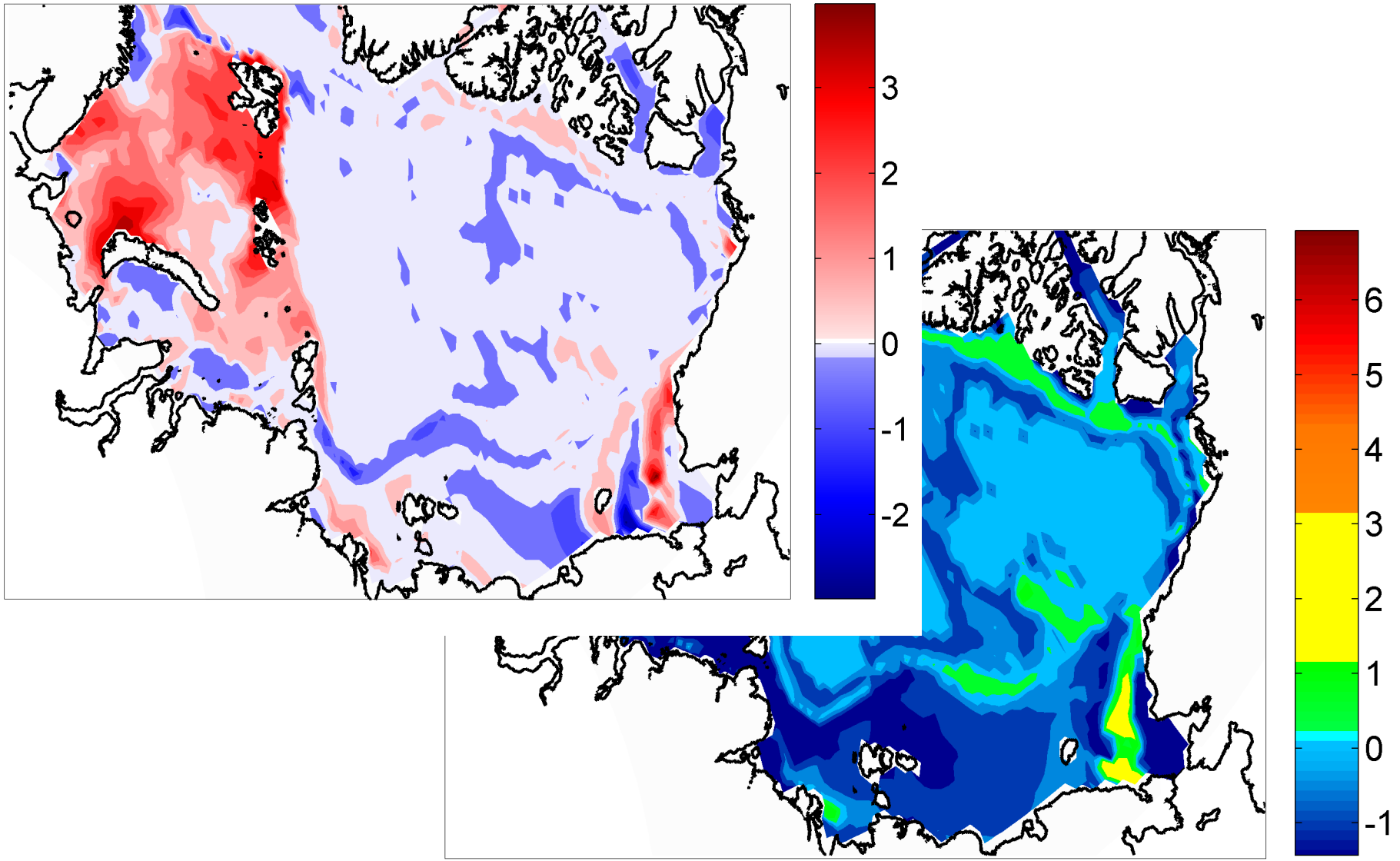
$$Z_S = \sqrt{Dt_P}$$

$D=10^{-9}$ м^2/с

(С. О. Разумов и др., 2014)

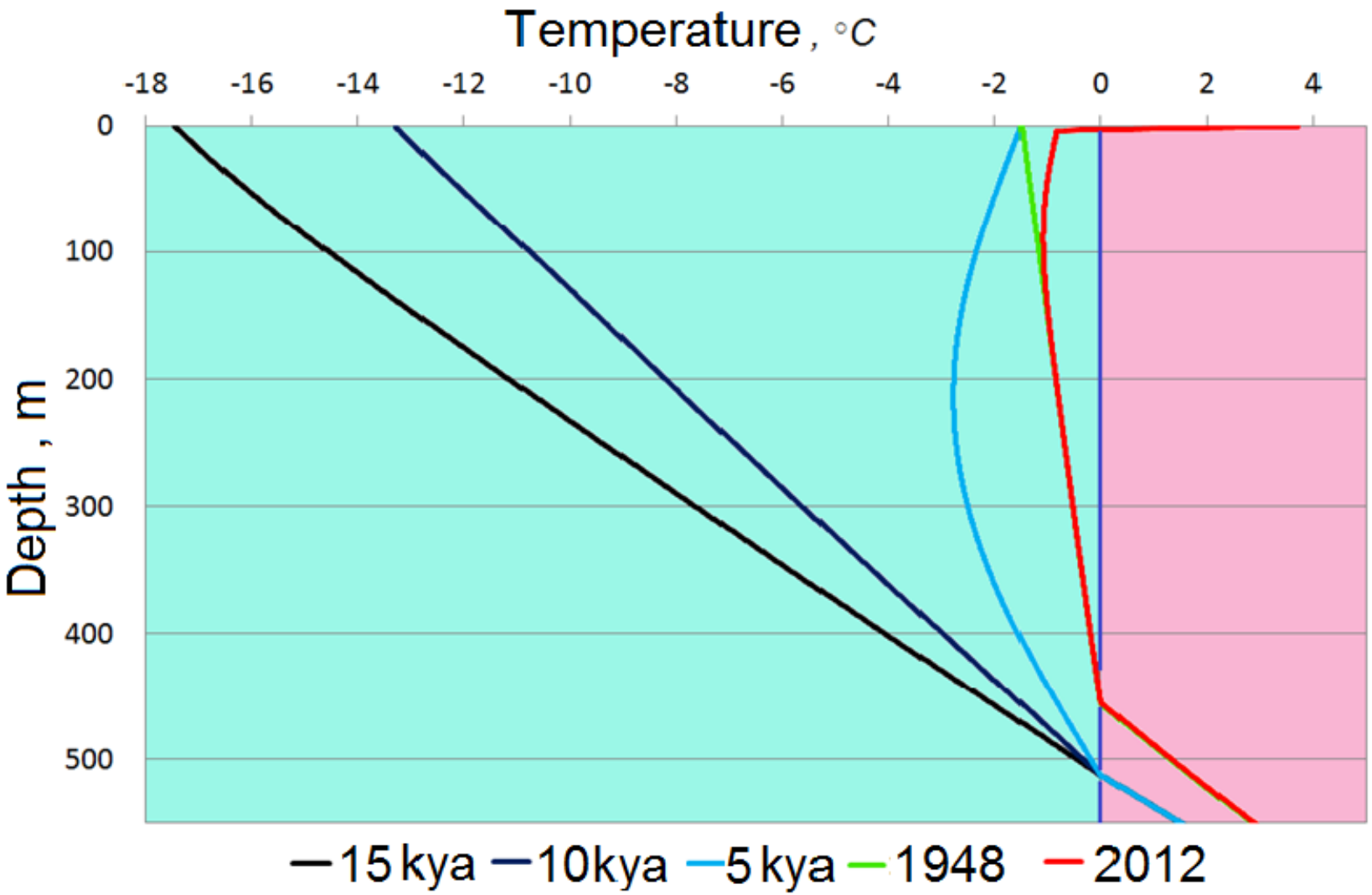


Near-bottom water warming in the Arctic 1950-2012

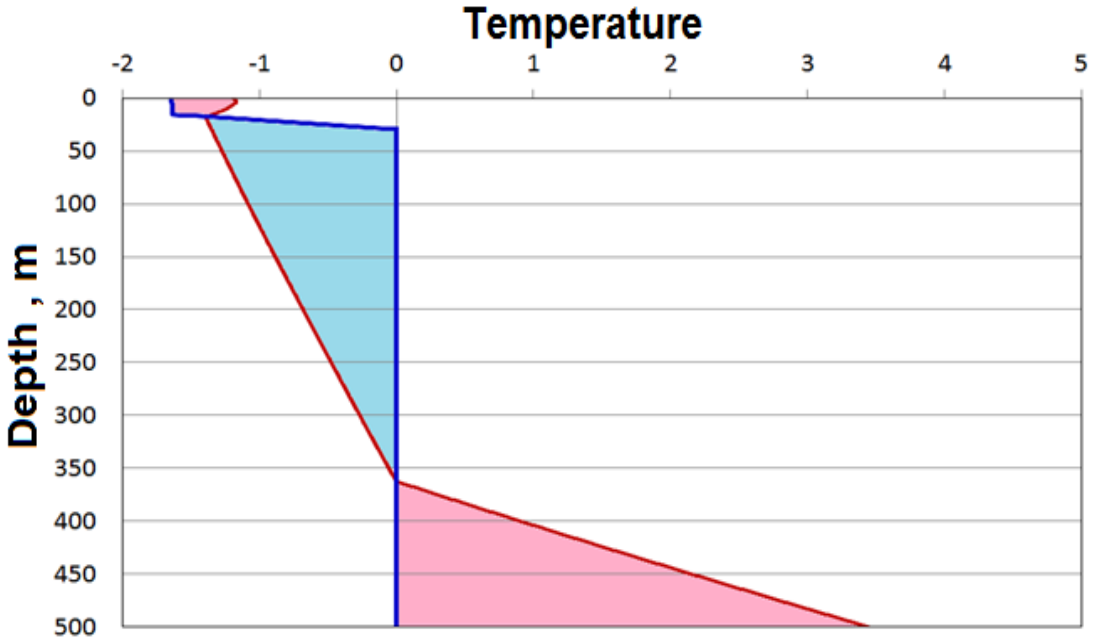


MODELING RESULTS:

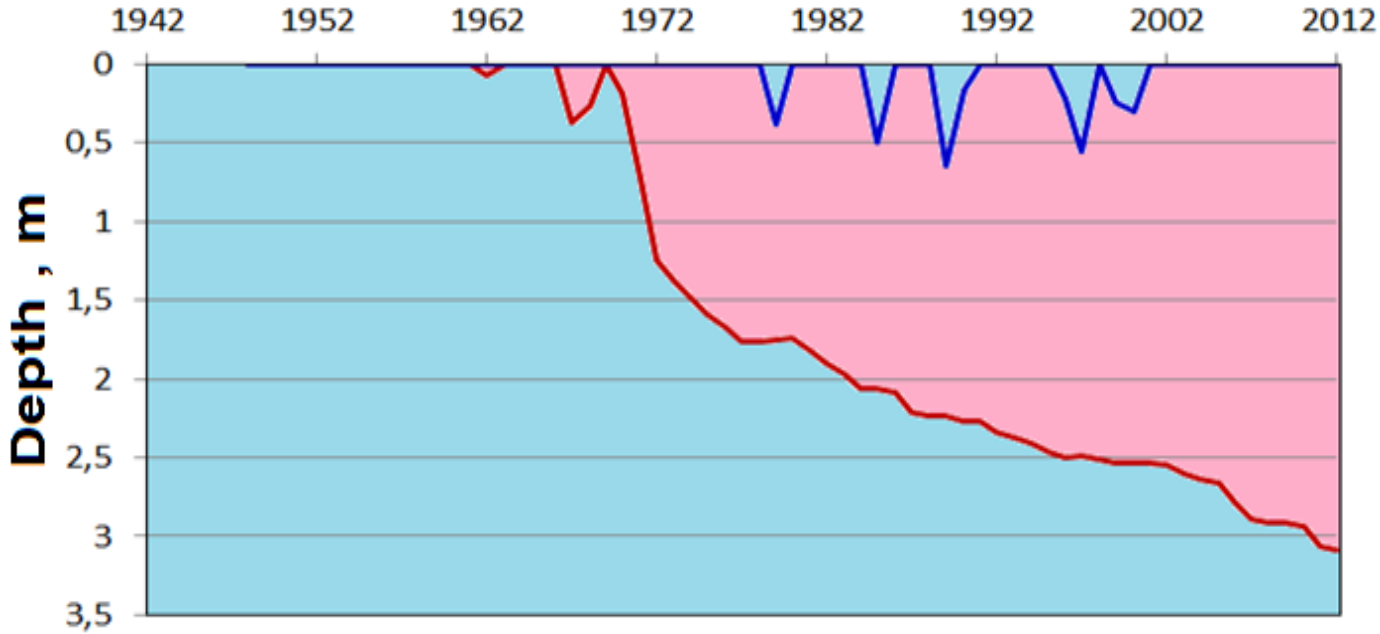
Time history of sediment temperature



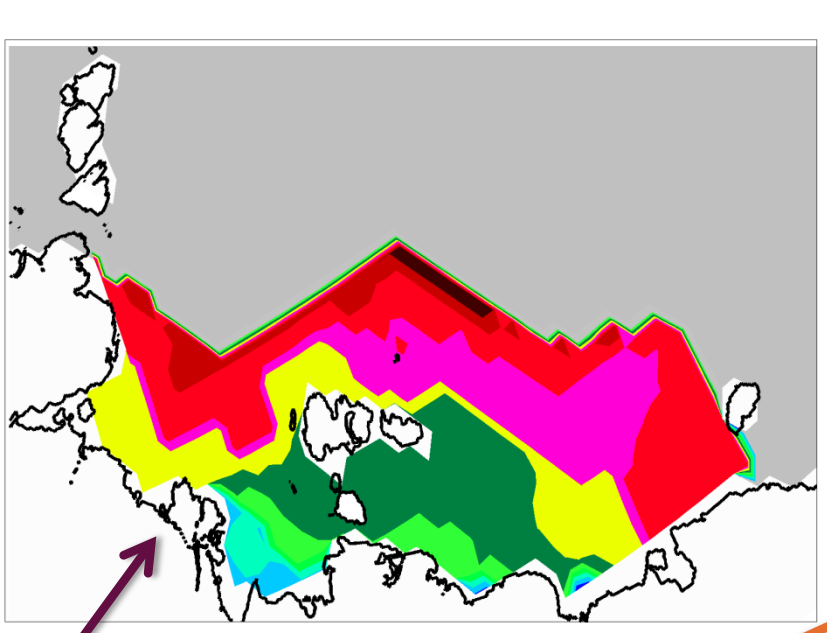
Phase transitions between frozen and thawed zone

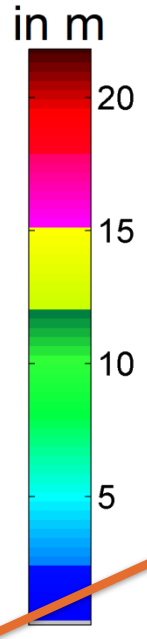


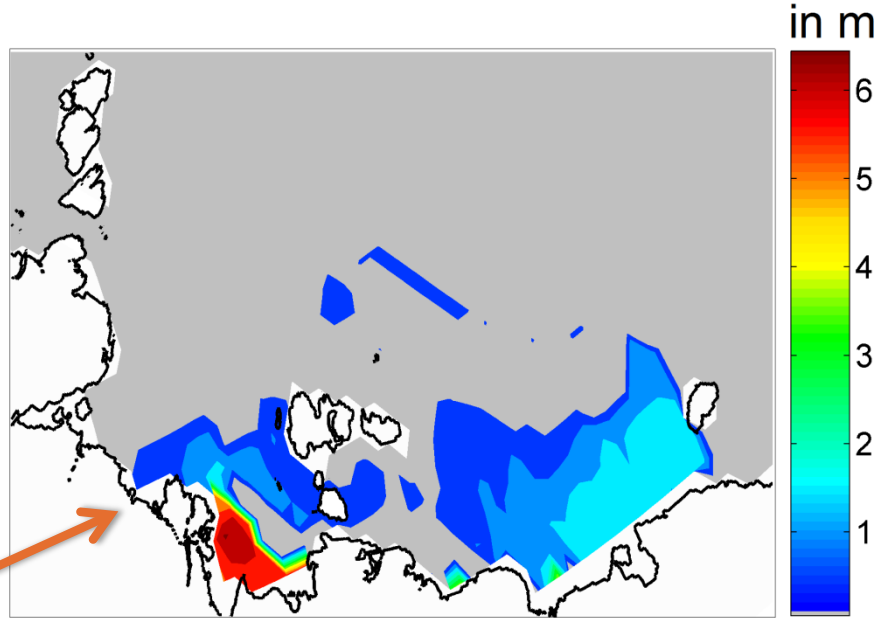
The salinity field greatly influences the evolution of submarine permafrost. Dissolved solutes depress the freezing temperature for water



Sub-sea permafrost dynamics

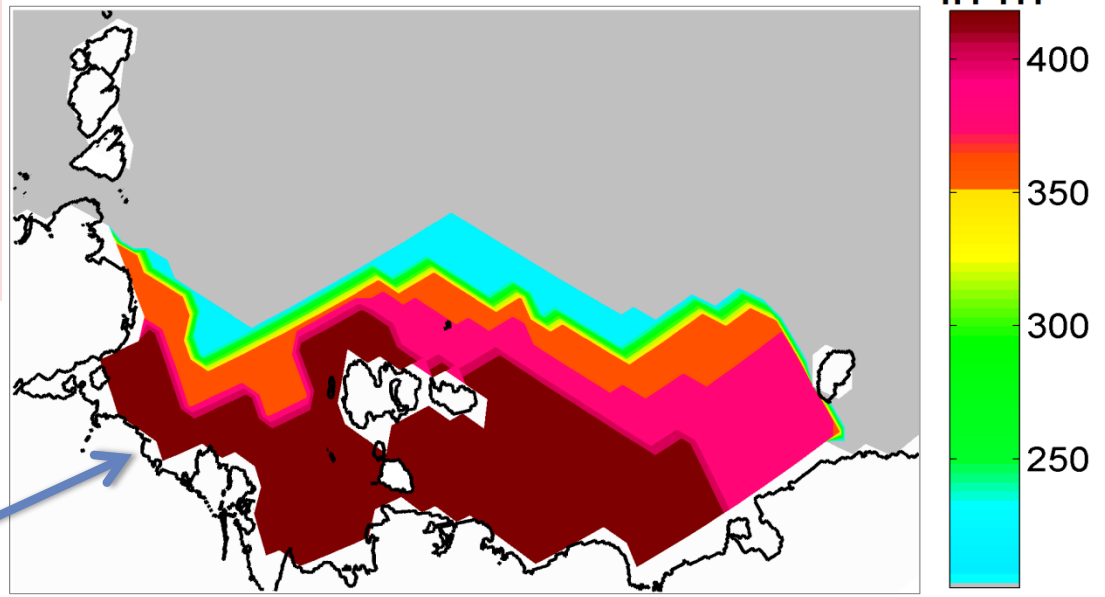






SIMULATED LOCATIONS OF THE TOP BOUNDRY

As water temperature rises, the top boundary moves down



THE PERMAFROST THICKNESS

P-T relationships

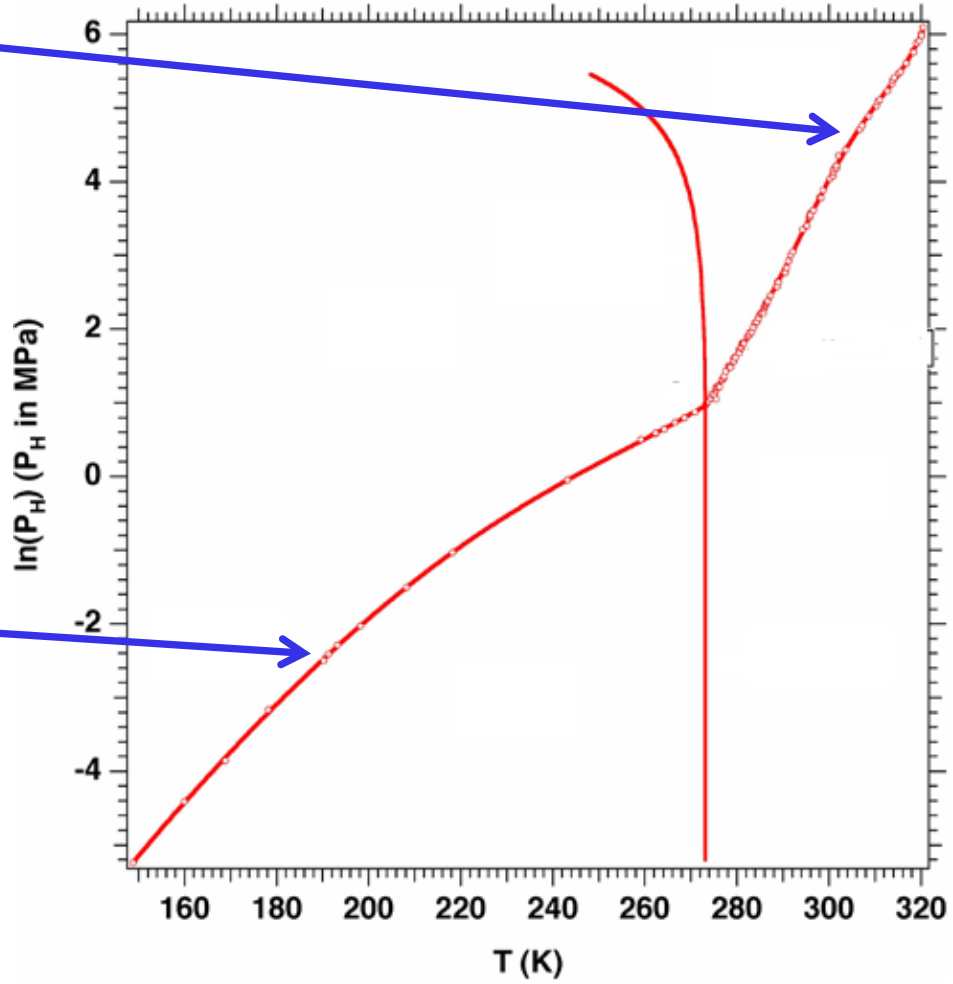
- «HydrateResSim» [Reagan M. T., Moridis G. J., 2008]

For $T > 273.2\ ^0K$:

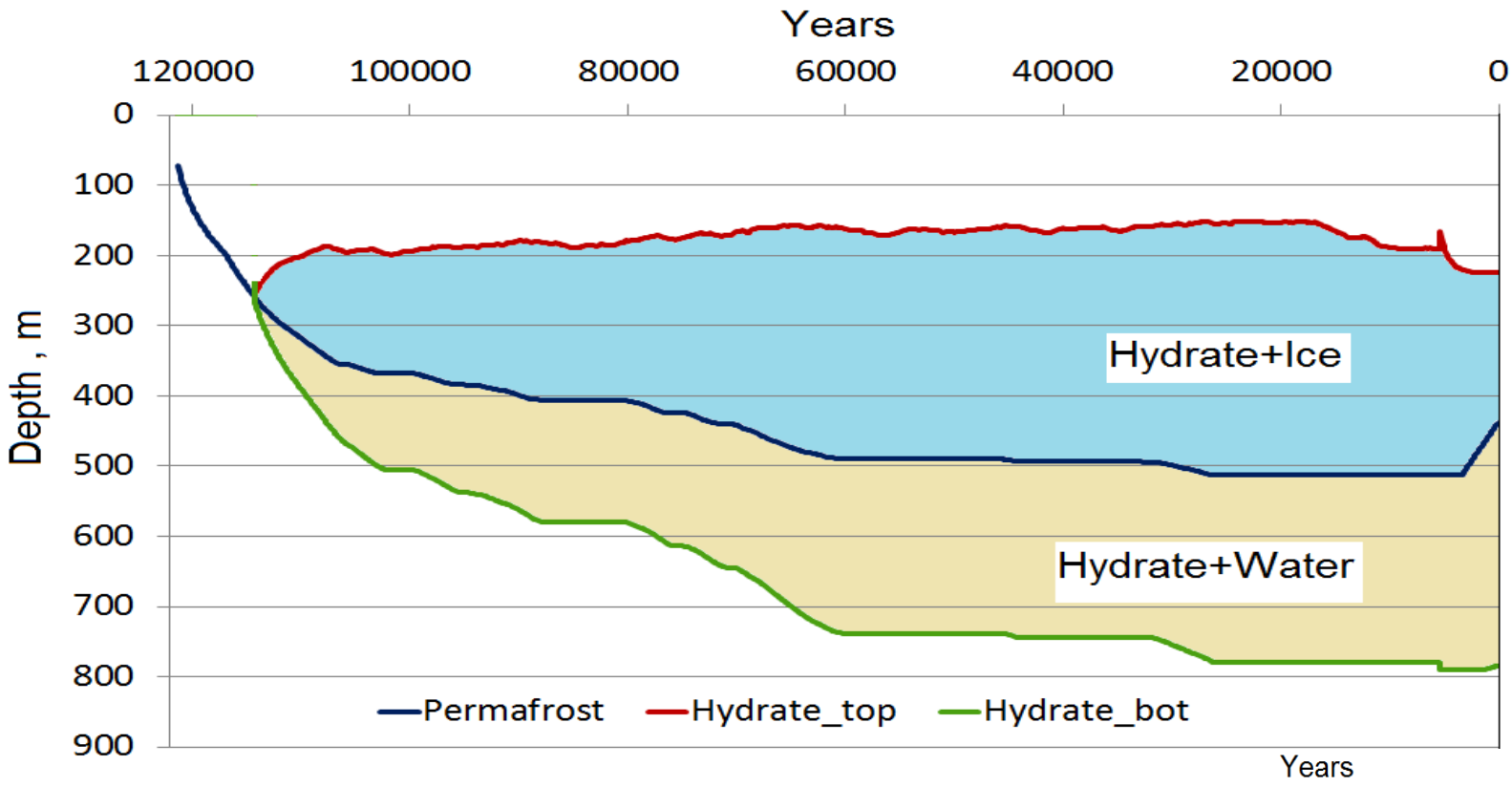
$$\ln(P_e) = -1.94138504464560 \times 10^5 + 3.3101821339792 6 \times 10^3\, T - 2.25540264493806 \times 10^1\, T^2 + 7.67559117787059 \times 10^{-2}\, T^3 - 1.30465829788791 \times 10^{-4}\, T^4 + 8.86065316687571 \times 10^{-8}\, T^5$$

For $T < 273.2\ ^0K$:

$$\ln(P_e) = -4.38921173434628 \times 10^1 + 7.76302133739303 \times 10^{-1}\, T - 7.27291427030502 \times 10^{-3}\, T^2 + 3.85413985900724 \times 10^{-5}\, T^3 - 1.03669656828834 \times 10^{-7}\, T^4 + 1.09882180475307 \times 10^{-10}\, T^5$$

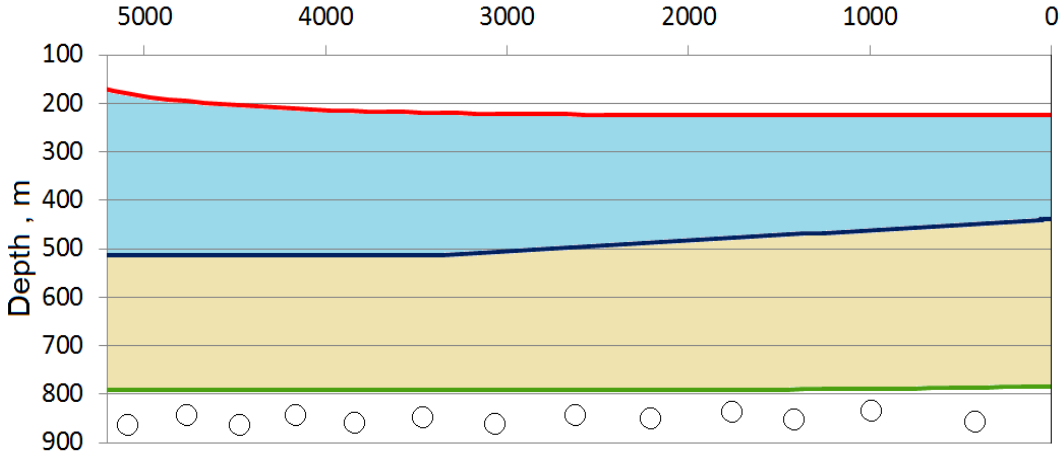


GAS HYDRATE Stability zone

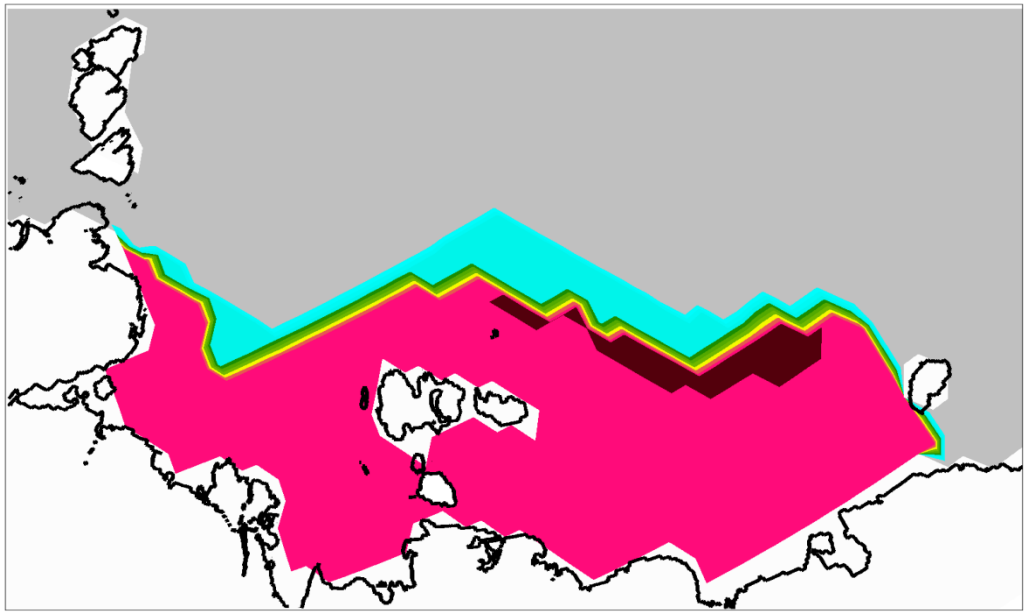


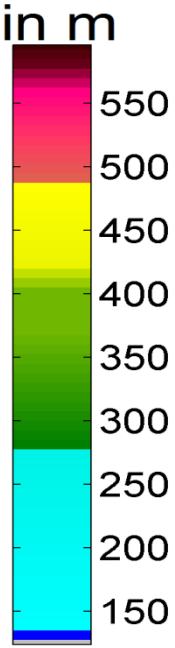
Arctic shelf hydrate formation: Cold climate epoch

Time history of methane hydrate stability zone in regions of continuous permafrost at the ESAS.



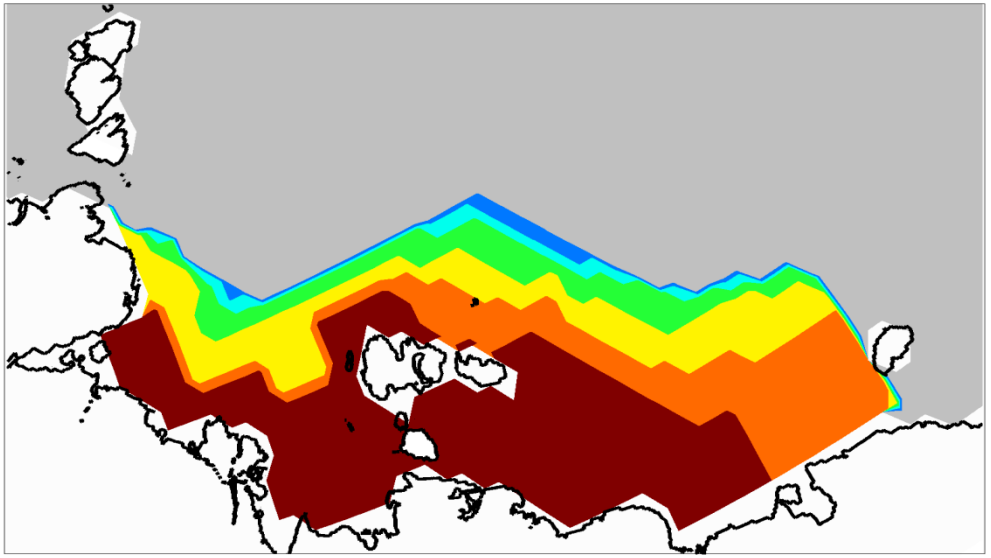
Model locations of methane hydrates

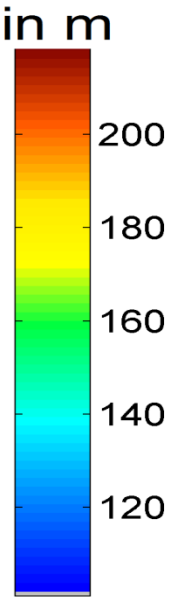




Gas Hydrate Stability Zone

Gas Hydrate Stability Zone: upper boundary





V.V. Malakhova, E.N. Golubeva
Modeling of the dynamics subsea permafrost in the East Siberian Arctic Shelf under the past and the future climate changes
Proceedings of SPIE. 9292, 2014

А.В. Елисеев, В.В. Малахова, М.М. Аржанов, Е.Н. Голубева, С.Н. Денисов, член-корреспондент РАН И.И. Мохов
Изменение границ многолетнемёрзлого слоя и зоны стабильности гидратов метана на арктическом шельфе Евразии в 1950-2100 гг.
ДАН. 2015. (в печати)

Summary

- Increasing temperature of the bottom waters can result in the thawing of the frozen bottom sediments.
- Based on this numerical study, hydrate deposits should also be stable within and below intact continuous permafrost layers.
- The fact that the MHS zone is not expected to change for several thousands of years after submergence, indicates its resilience.

- Because of their shallow depth, permafrost-associated methane hydrate deposits along the Arctic continental shelf are much more susceptible to climate change and warming than deep oceanic hydrates.
- Continuing studies on permafrost-associated gas hydrate reservoirs will allow us to better understand the Arctic's contribution to the global methane budget and global warming


Thank You