



Multibeam sonar mapping of Siberian seeps: Evaluating trends in methane flux from shallow sub-sea permafrost

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The East Siberian Arctic Shelf (ESAS) contains an estimated 1400 GT (109 tons = 1 GT) of carbon sequestered within and beneath a sub-sea permafrost unit that is overlain by thin sediments. This carbon pool includes methane (CH₄) as free and dissolved gas, potentially extensive methane hydrate deposits, and carbon dioxide (CO₂), yet its contribution has traditionally been ignored in global carbon stocks because of its assumed stability. The ESAS is very shallow averaging < 50 m depth over its 2x10⁶ km² area, 80% of which is predicted to contain originally sub-areal permafrost unit, now submerged due to transgression. Associated with transgression was a new thermal regime including enhanced heat transfer from warming Arctic Oceans and terrestrial riverine waters to the submerged permafrost, as well as from exothermic oxidation reactions and geothermal sources. As a result, large areas of integrity loss have been identified from widespread bubble ebullition and enhanced aqueous methane levels well above atmospheric equilibrium. The resulting thaw sediments (taliks) and structural breaches facilitate fluid and gas migration within the permafrost to overlying sediments where some microbial methane oxidation occurs. These destabilizing features may also provide a mechanism for enhanced heat transfer to methane hydrate deposits.

The shallow nature of the ESAS means ascending bubbles in the water column experience minimal dissolution before venting to the atmosphere. Additionally, storm mixing extends to the seabed so that virtually all dissolved methane gas from bubbles and sediment fluid exchange is stripped from the oceanic waters and vented to the atmosphere prior to the microbial oxidation. Emission of CH₄ and CO₂ largely remain unquantified but potentially contribute significantly to atmospheric budgets. Further, rapid Arctic warming suggests these gas emissions could present a significant positive warming feedback.

Given the rapid climate changes occurring and predicted to occur in the Arctic, there is a strong need for baseline measurements of ebullition to allow identification of emission trends. Baseline data were collected in Fall 2009 using multibeam sonar surveying techniques developed at UCSB. Data analysis has identified spatial and temporal controls on seepage bubble flux including geologic structure, and currents.

Two sonar techniques were used in the ESAS. The first method used a pole-mounted 260 kHz 120° X 3° Imagenex Delta-T, which recorded two weeks of data continuously while steaming. The transducer swath was pitched forward of vertical to better discriminate vertical plume structures and the complete water-column returns were logged. A seabed-tracking depth window from each ping was summed vertically to account for the discontinuous nature of bubble plumes and lessen the representation of non-bubble sonar returns. Data were geo-rectified and mapped. Numerous bubble streams in shallow (6-20 m) water were identified using sonar in areas predicted to be underlain by permafrost.

The second method used a vessel-tethered stationary frame on the seabed with the Delta-T sonar rotating continuously through 330° around a vertical axis with the swath arrayed vertically and the beams spanning from below the seabed to above the sea surface. This 4D method is a major improvement over multibeam sonar measurement in a horizontal plane, allowing for automated segregation between fish and seeps, improved gas flux calibration, current profile estimation, and measurement of wave characteristics, wave-driven bubble plumes, and

bathymetric repeat mapping of the seabed.