Surface Wave Effects on Methane Gas Bubble Escape

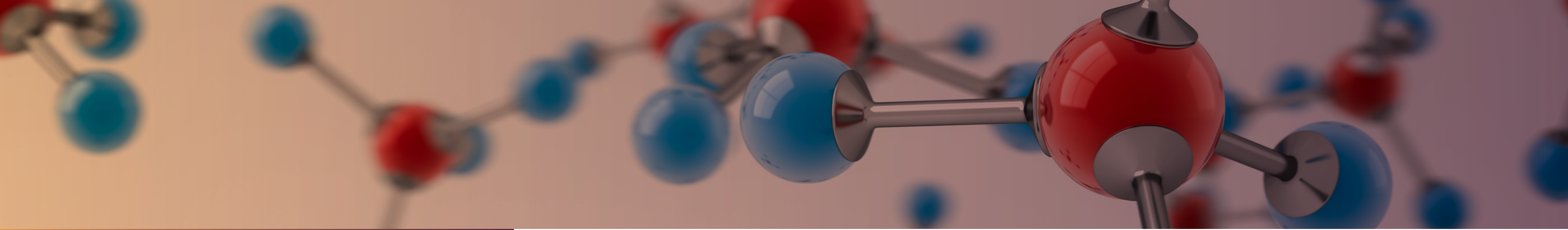
Dr Regina Katsman

AUGUST 2024

doi.org/10.33548/SCIENTIA1062

EARTH & ENVIRONMENTAL SCIENCES

Scientia



Surface Wave Effects on Methane Gas Bubble Escape

Methane is a potent greenhouse gas that traps the sun's heat. It can be added to the atmosphere when gas bubbles escape aquatic sediments and rise through an overlying water column. The controls on gas bubble escape and ascent are not fully understood and require further investigation. Dr Regina Katsman from the University of Haifa has conducted numerical modelling investigating the effects of varying water body conditions on the patterns of ascent of methane gas bubbles.

Aquatic Methane Gas Bubbles

The greenhouse gas methane is abundant in our atmosphere. It traps the sun's heat near the Earth's surface and, in doing so, increases its temperature. Due to its structure, the warming potential of methane over a 100-year period is roughly 25 times greater than that of carbon dioxide. This means that methane is a huge challenge to efforts aiming to reduce global warming.

Methane can be trapped in muddy aquatic sediments that lie beneath bodies of water. The source of this methane can be microbial activity, gas hydrates (a solid-like combination of gas and water), degrading permafrost (ground that remains frozen for more than two years), or even deep-seated coal seams.

This methane is usually released to the overlying water column by a process called gas ebullition – the release of gas bubbles from sediment to an overlying water column – before rising through the overlying water column and escaping to the atmosphere. Ebullition events often coincide with drops in the pressure overlying the methane-bearing sediments. These pressure drops can be caused by, for example, low tides, surface waves, and atmospheric pressure drops.

The overlying pressure affects how gas bubbles ascend through sediments to the overlying water column. If overlying pressures are low (shallow waters), gas bubbles tend to ascend through dynamic fracturing, breaking the surrounding sediment as the bubbles grow and ascend unrestrictedly. Ascent will continue in this manner through the sediment layer until the gas bubbles are released to the overlying water column. Later bubbles can use these fractures as more efficient ascent pathways, providing localised routes through the sediment to the water column.

If, however, the overlying pressure is great (as found in deep waters), gas bubbles tend to ascend in a stable manner and gather at a 'gas horizon' (gas-rich layer) within the sediment. Should there be a later drop in overlying pressure (i.e., low tides, surface waves), bubbles can then be released from this horizon, ascend through the remainder of the sediment layer, and into the water column.

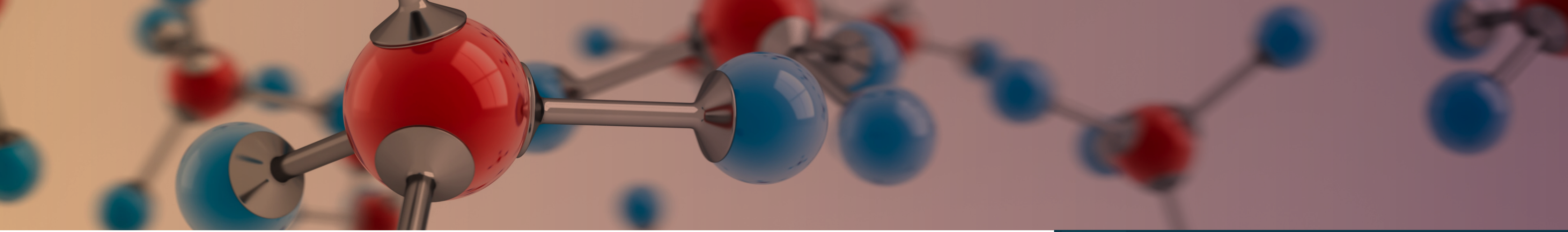
Despite this knowledge, whether bubbles ascend in a 'stable' or 'dynamic' manner and what controls the release of gas bubbles from the gas horizon still requires investigation. Dr Regina Katsman of the University of Haifa has conducted modelling to test the control of water column depth and wave characteristics (i.e., wave height and period) on gas bubble release from the gas horizon.

Modelling Bubbles in Different Conditions

Dr Katsman utilised a single-bubble mechanical reaction–transport numerical model to investigate the controls on methane gas bubble ascent. She modelled the ascent of a sub-vertical (near vertical) gas bubble through a sediment layer under varying conditions – different overlying water column depth, wave period (time for two consecutive wave crests to pass a single point), and wave amplitude (wave height). The simulations compared short and longer wave periods in shallow and deeper water (more specifically, 0.5 to 50 metre) environments.

Gas Bubble Ascent Pattern – Dynamic Versus Stable

Dr Katsman's modelling determined the style of gas bubble ascent (i.e., stable or dynamic) across different water column depths, wave periods, and wave amplitudes. Under short-period waves (10.8 seconds) in shallow water environments (≤ 1-metre water column depth), Dr Katsman demonstrated that a rapid decrease



in wave load (i.e., the removal of some of the overlying pressure as a wave's trough passes over the bubble's location) resulted in gas bubble ascent in a dynamic regime: rapid growth and ascent of gas bubbles through fracturing the surrounding sediment. The gas bubble achieved an ascent of 6.7 centimetres under the decreasing wave load. Gas bubble ascent subsequently continued despite the increase in wave load as a new wave passed over the ascent pathway.

When modelling gas bubble ascent under short period waves in deeper water (10- and 50-metre water column depths), however, gas bubbles ascended in the stable regime and for a significantly less distance (7.5 and 2.2 millimetres) compared to shallower water environments.

Dr Katsman concluded that the contribution of wave loading (as the maximum height, or crest of a wave, passes a point) to the background load (i.e., overlying water column on the sediment layer) influenced the gas bubble ascent regime. Further to these results, Dr Katsman demonstrated that under waves of the same amplitude and water column depths (10 and 50 metres) but for longer wave periods (four hours), gas bubble ascent remained in the stable regime and had a small ascent distance (2.6 millimetres); therefore, the gas bubble remains near the gas horizon.

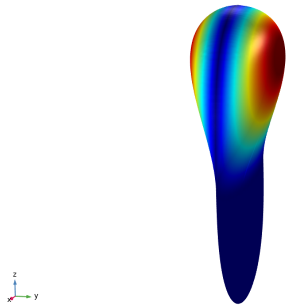
Wave-induced Gas Bubble Ascent

Dr Katsman's simulations demonstrate that the greater the ratio of wave amplitude to overlying load (for example, taller waves in a shallow water environment) and the smaller the wave period, the more chance gas bubbles will be released from the gas horizon and ascend in a dynamic regime. In addition, her results show that gas bubble escape is more likely under shorter period waves than longer ones with the same amplitude. Overall, Dr Katsman determined that the wave load in the deeper water environments was less noticeable or significant on the gas bubble than in the shallower ones.

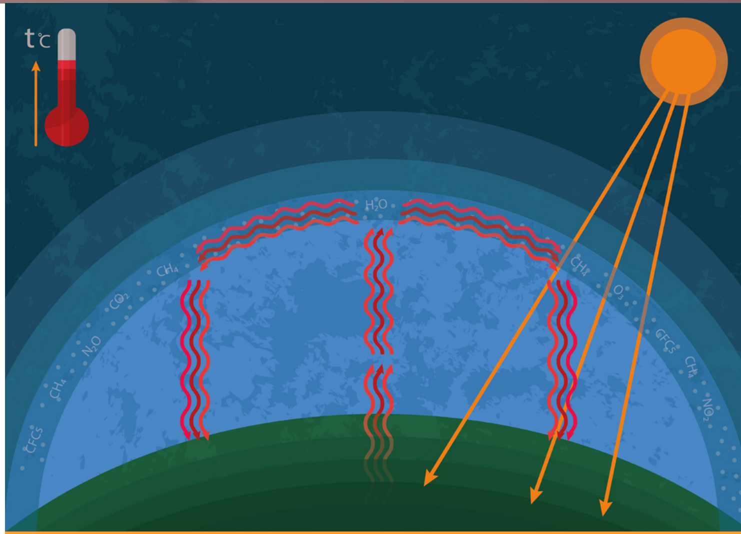
Implications for Global Warming

Dr Katsman has investigated how methane gas bubbles escape aquatic sediments using numerical modelling. She has demonstrated that methane gas bubbles will escape the gas horizon in a dynamic manner (fracturing surrounding host sediment) under taller (high amplitude) waves with short time periods (time between waves) in shallower water environments. Further, her results suggest that sea level drops over longer timescales (hundreds to thousands of years) would lead to gas bubble ascent in a stable manner and control the location of the gas horizon within the aquatic sediment.

Being able to understand the behaviour and control of the ascent of methane gas bubbles from aquatic sediments will allow for a better understanding of the flux of this potent greenhouse gas to Earth's atmosphere, which could help with efforts to reduce the increasing warming of our planet.



Credit: Regina Katsman



"Dr Katsman's simulations demonstrate that the greater the ratio of wave amplitude to overlying load (for example, taller waves in a shallow water environment) and the smaller the wave period, the more chance gas bubbles will be released from the gas horizon and ascend in a dynamic regime.

MEET THE RESEARCHERS

Dr Regina Katsman, Dr. Moses Strauss Department of Marine Geosciences, University of Haifa, Haifa, Israel

Dr Regina Katsman obtained her BSc and MSc from the Kyiv National University of Construction and Architecture, Ukraine, in 1990. Subsequently, she received an MSc and PhD in Building Sciences from The Technion – Israel Institute of Technology, Israel, in 1995 and 1999, respectively. In 2000, she joined the National Research Council of Canada as a Postdoctoral Fellow. At her second postdoctoral tenure at Weizmann Institute of Science, Israel (2001–2005), she switched to the fields of geology and geophysics, which she continues now. Currently, Dr Katsman is based at the University of Haifa, where she is a Senior Lecturer at the Dr. Moses Strauss Department of Marine Geosciences, Leon H. Charney School of Marine Sciences, as well as the Head of the Laboratory of Computational Physics in Marine Sciences. She is a member of several academic professional associations, including the European Geophysical Union, the Israel Geological Society, and the Israel Association of Computation Mechanics. Dr Katsman's research interests include understanding the behaviour of methane gas bubbles in aquatic sediments using numerical and analytical multiphysical modelling methods.

CONTACT

rkatsman@univ.haifa.ac.il

https://marsci.haifa.ac.il/en/regina-katsman%E2%80%8B%E2%80%8B/

https://sites.google.com/marsci.haifa.ac.il/advanced-physics-katsman/home

https://scholar.google.co.il/citations?user=bgpBkvUAAAAJ&hl=en

https://www.researchgate.net/profile/Regina-Katsman

https://loop.frontiersin.org/people/1345059/overview

KEY COLLABORATORS

Boris Katsnelson, Dr. Moses Strauss Department of Marine Geosciences, Leon H. Charney School of Marine Sciences, University of Haifa, Haifa, Israel

Ernst Uzhansky, Department of Oceanography, Dalhousie University, Halifax, Nova Scotia, Canada

Andrey Lunkov, Prokhorov General Physics Institute of the Russian Academy of Sciences, Russia Moscow, Russia

FUNDING

Israel Science Foundation

U.S.–Israel Binational Science Foundation

FURTHER READING

R Katsman, Methane Bubble Escape From Gas Horizon in Muddy Aquatic Sediment Under Periodic Wave Loading, *Geophysical Research Letters*, 2019, 46(12), 6507–6515. DOI: https://doi.org/10.1029/2019GL083100

Leon H. Charney School of Marine Sciences UNIVERSITY OF HAIFA