WHY IT IS OF UTMOST IMPORTANCE FOR THE CLIMATE AND FOR THE GLOBAL BIODIVERSITY TO HALT THE MELTING OF THE ARCTIC – AND HOW COULD IT BE DONE?

Risto Isomäki, 14.4.2026,
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We have for a long time known that what happens in the Arctic may decide the fate of the Earth's climate. The marine ice in the Arctic Ocean and northern land masses that have been for most of the year covered by snow, have acted as a huge planetary mirror, reflecting most of the solat radiation straight back to space before it has been transformed to heat.

What if most of the Arctic will, in the future, be covered by open water or dark soil or coniferous forests for most of the year?

What if also the vast stores of organic carbon and methane in Arctic soils, peatlands, terrestrial and submarine permafrost and in the so called methane clathrate deposits will be released into the atmosphere? (1,2, 3, 4, 5).

The melting of the Arctic would also be a huge catastrophe for the Earth's biodiversity. According to recent research, the big mass extinctions of species during the Earth's long history have not been as dramatic as we have thought on the continents. However, they have repeatedly wiped out more than 90 per cent of all the species living at the bottom of the ocean (6, 7).

This is because the formation of highly saline and very cold water that descends to the bottom of the sea at the northern areas seems to be the factor that keeps the bottom of the deep ocean oxygenated and alive. If the repeated freezing and melting of the surface water in the Arctic Ocean will be disrupted, the formation of oxygen-rich deep water will halt or at least decline, drastically, which could make tens of billions of hectares of deep sea bottom anoxic.

According to random samples there might be something like ten million different multicellular organisms living in the bottom of the ocean, constituting the majority of all multicellular species on Earth. Some studies have extrapolated still much larger numbers (8, 9, 10, 11).

Nobody really knows, because the matter has never been properly studied. In any case most of all these species might become extinct if we will not be able to halt the melting of the Arctic.

Several solutions to the problem have been proposed. However, it may be that we have been neglecting two of the safest and most affordable ways of stabilizing the Arctic climate: the regulation of the sulfur emissions of ocean-going ships crossing the North Pacific or the North Atlantic, and the active reduction of the winter-time cloud cover over the Arctic regions.

THE OCEAN-GOING SHIPS' SULFUR EMISSIONS AND CLIMATE

The International Maritime Organization (IMO) decided in October 2008 that the maximum allowable sulfur content in ship fuel should be reduced to 0.5 per cent by 2020, and to 0.1 per cent in the more stringent Special Emissions Control Areas, or SECAs. Ship fuel at the time contained on average 2.7 per cent sulfur.

A study by Axel Lauer and his colleagues, published in 2009, critisized the decision and voiced concerns abbout its climatic impact. According to Lauer's assessment of the available data sulfur dioxide emissions released by ocean-going ships to North Atlantic and North Pacific had probably masked, in these marine regions, much of the global warming impact of the extra greenhouse gases that had been accumulating in the atmosphere. If the IMO treaty would be implemented, the ships' overall cooling impact might be reduced from 0.58 watt/m2 to 0.27 watt/m2, plus or minus 0.15 watt/m2. In other words global warming would increase by 0.31 watt/m2 (12). This would have been highly significant, because at the time global warming was estimated at 0.85 watt/m2.

Above all: the heating impact would concentrate on the worst possible spot, on the northern marine areas where even a relatively modest amount of extra heating might give birth to highly significant positive feedback loops accelerating the warming trend. Most of the world's ship traffic takes place between Europe and USA or between USA and China (and the other Asian countries) and thus concentrates in the North Atlantic and in the North Pacific, in areas from where ocean currents and prevailing wind systems transport huge amounts of heat further north, into the Arctic Ocean (13),

However, six later studies were all in mutual agreement that the cooling aerosol forcing produced by the ships' sulfur emissions is much smaller. They all estimated it to be somewhere between 0.07 watt/m2 and 0.15 watt/m2 (14). In other words, the estimates provided by these six studies were all eight to four times smaller than the figure used by Lauer and his co-authors.

All these six studies assumed – like IPCC did – that aerosol forcing is more or less linear, meaning that it increases in a linear and predictable way in portion with the amount of sulfur released into the atmosphere (15).

A major study published in 2022 provided evidence to indicate that the cooling impact of the ships' sulfur emissions might have been seriously underestimated. It argued that studies focusing only on ship tracks clearly visible on satellite images may have ignored a large number of invisible ship tracks with similar climatic impacts. The authors concluded that their results implied a significantly larger than assumed negative radiative effect from ship tracks than previously reported, between 1.03 watt/m2 and 0.49 watt/m2, with the best fit at 0.76 watt/m2. They emphasized the role of the so called liquid water path (LWP) response in the aerosol cooling produced by the ships' sulfur emissions (16).

Even more importantly, after the reductions in ships' sulfur emissions had been put into practise in 2015 and 2020, northern marine regions started to heat up with an accelerated pace, much faster than anybody had expected.

James Hansen and Mikiko Sato noted this in a famous article named *Faustian Payment Comes Due*, published on 13 August 2021. In the article Hansen and Sato pointed out that according to satellite measurements the rate of global warming seemed to have roughly doubled to approximately 1 watt/m2 after the year 2015. Much of the impact seemed to have concentrated in relatively northern marine regions, in the North Atlantic

and North Pacific, with most of the world's ocean-going ship traffic. Hansen and Sato concluded, that the only plausible explanation for the rapid acceleration in the warming trend were the cuts in the ships' sulfur emissions (17).
Hansen's Faustian Payment Comes Due article was only a tentative wake-up call, but in February 2025 Hansen and his co-workers published a more detailed study of the subject (18).
According to Hansen and his co-authors the recent cuts in the ships' sulfur emissions had offered an unprecedented empirical opportunity to study the climate forcing of sulfur over regions with only a very limited supply of aerosol particles that can act as cloud condensation nuclei. They concluded that in such relatively pristine areas the sulfur aerosol forcing was not behaving in the linear way that had been assumed by IPCC and the studies that had argued for an insignificant impact. On the contrary: it seemed that the relatively small sulfur emissions released in remote marine regions with very little other air pollution or bioaerosols produced by trees and other vegetation had produced an outsized cooling effect.
According to Hansen and his co-authors the relatively moderate emission reductions via the ships' fuel regulations, amounting to around 10 megatons of sulfur dioxide, had reduced the Earth's negative aerosol forcing by as much as 0.5 watt/m2, even more than Axel Lauer's original prediction (0.31 watt/m2).
Hansen's calculations should force governments to rethink, whether ocean-going ships should go back to sulfur-rich bunker oil to save the world from a climatic catastrophe.

USING SULFUR-RICH FUEL IN SUMMER AND NON-SULFUR FUEL IN WINTER?

There is, however, one further option that has not received much attention in the public debate: ships could use sulfur-rich fuel during the summer and non-sulfur fuels, or fuels only containing very little sulfur, during the winter.
We have always known that clouds have a predominantly heating impact during the night and a predominantly cooling impact during the day. In daytime, when the sun is shining, it becomes much colder when clouds come between you and the sun. But cloudy nights are warm and clear nights are cold.
Therefore the cooling impact of the ships' sulfur emissions and the clouds created by them is the sum total of their different heating and cooling impacts. Because the day-time cooling impact is larger than the night-time heating impact, the total impact of cutting the ships' sulfur emissions has been to double the speed of global warming.
In the northern parts of the globe days are longer than nights during the summer and nights are longer than days during the winter, and the difference is the more extreme the closer to the North Pole we get.
Therefore it could be assumed, that the ships' sulfur emissions actually have a heating and not a cooling impact on the climate during the winter, even though the cooling impact of the same sulfur emissions and of the clouds created by them is very strong indeed during the summer.
For these reasons it might be possible to renew the balance of the climate in the northern areas and halt the melting of the Arctic simply by modifying the existing legislation so, that ships traveling in the North Atlantic, in the North Pacific and in the Arctic Ocean would be

compelled to use sulfur-free fuels during the winter (when the clouds produced by the sulfur droplets have a warming impact) but could use cheaper sulfur-rich fuels in the summer (when sulfur and the clouds given birth by it cool the planet).
Unfortunately, nobody has ever studied this option. Therefore we do not know when (at which time of the year) ships should shift from sulfur-less or low-sulfur fuel to sulfur-rich fuel, and vice versa. Also, we cannot quantify the climatic impact of such an intervention.

THE IMPLICATIONS FOR PUBLIC HEALTH

It has often been said, in this context, that it has been imperative to reduce the ships' sulfur emissions because air pollution causes, every year, from seven to nine million premature human deaths (19, 20, 21, 22).
Remarks about millions of deaths annually caused by air pollution have, in this context, been somewhat misleading, perhaps even purposefully so, promoted by industries with a vested economic interest in the matter.
Most air pollution deaths are still caused by indoor air pollution, by small particles and other pollutants released inside people's homes by old-fashioned cooking stoves burning wood, cowdung or coal.
In India alone there are still, according to a relatively recent assessment, 166 million traditional cooking stoves using solid fuels. Traditional cooking stoves are not equipped with chimneys, because this would make them too expensive for poor families. The combustion of biomass in traditional cooking stoves is only partial and produces siignificant quantities of suspended particulate matter and at least 400 different volatile chemicals. For partly cultural but mostly practical reasons most cooking in the Global South is done inside the kitchens, it is very hot indeed to cook outside in direct sunlight. Particulate matter concentrations in the air inside Indian kitchens using traditional biomass cooking stoves can be extremely high. The average has been estimated to be around 7,000 micrograms of suspended particulate matter per cubic meter during cooking, but concentrations can reach an almost incredible 56,600 micrograms per cubic meter of air during monsoon, when the ventilation hatches are closed (23, 24). In Helsinki concentrations of 10 or 15 micrograms of suspended particulate matter in the air already produce major spikes in the graphs.
In Gujarat the average cooking time is three hours and in Maharashtra it can extend to six hours (25). This means that hundreds of millions of Indian women and grirls in the 166 million households using traditional cooking stoes are exposed to mind-boggling amounts of particulate matter and other pollutants.
The smoke produced by the traditional cooking stoves is also responsible for a somewhat poorly quantified percentage of the three million or so annual air pollution deaths caused by outdoor pollution, together with a large spectrum of other factors, including the pollution released into the air by numerous different traditional and modern industries, coal-fired power plants, traffic and the annual burning of 7-12 billion dry tons of biomass to produce charcoal, to get rid of crop residues or weeds on cultivated fields or grazing lands, or in connection of shifting cultivation.
Serious studies have attributed between 18,000 and 50,000 annual deaths on the ships' sulfur and particle emissions (26), and even this might be an overestimate, influenced by vested economic interests.

Nobody is making a big noise about the up to 6 million deaths annually caused by air pollution released inside poor people's homes by crude wood-burning cooking stoves, because the world's poorest families, using the traditional cooking stoves, only earn 0,36 euros per day per capita, without the computational purchasing power parity correction. Because they can afford to pay less than 10 euros for an advanced cooking stove, reducing air pollution deaths caused by traditional cooking stoves has not been and still isn't a lucrative economic opportunity. It has been more interesting to talk about the air pollution deaths caused by the ships' sulfur emissions, but this has drawn attention off from the real issues.

In any case, it is eminently possible to use the regulation of the sulfur emissions of ships equipped with scrubbers to slow down global warming without causing any air pollution deaths.

Ship-owners have been able to choose from a number of alternative technological solutions, when forced to reduce the sulfur emissions of their vessels. One way of achieving IMO's goal has been to shift from bunker oil to liquefied natural gas (LNG), that contains practically no sulfur. Another has been to use so called VLSFO diesel (very low sulfur fuel oil) that is more expensive than bunker oil but contains less than 0.5 per cent sulfur. A third option has been to equip the ship with a scrubber that can remove between 95 and 99 per cent of the sulfur from the fuel oil.

Scrubbers have been the most affordable method, because with them ships can use ordinary bunker oil, containing an average 2.7 per cent of sulfur, which is much cheaper than VLSFO or LNG.

Straight after the adoption of the IMO treaty the price difference between bunker oil and VLSFO was on average 550 USD per ton and it was still expected to rise to 700 USD per ton (27, 28). With such a price difference, the implementation of the IMO treaty by shifting to VLSFO or LNG would have cost USD 300 billion per year in increased fuel costs, alone. Because the avegae cost of installing a scrubber into a ship was USD 1.3 million, it was a very cost-effective way of dealing with the matter.

However, when scrubbers were installed to more numerous ships, the price difference between VLSFO and bunker dropped to 200 – 220 USD per ton, and when the war between Ukraine and Russia disrupted the exports of bunker oil from Russia – which was the world's largest producer – the price of bunker increased so much that the price difference declined further and was, at its lowest, only USD 80 per ton (29).

This has slowed down the speed by which scrubbers have been installed on ships, but at the same time the average price of scrubbers has declined to USD 800,000 because of the development of serial production of the equipment (30).

At the beginning of 2026 scrubbers had already been installed, according to a global statistics, to 13 per cent of all ships, and more than one half of the largest ships had them, including 37 per cent of the container ships. Even more importantly, scrubbers were being installed to 71 per cent of all new ships already during their construction phase (31). The percentages in North Atlantic and North Pacific, only, are higher.

Because the average time a freightship in North Atlantic or North Pacific is used on these waters is roughly three decades, most of the ships travelling in the northern waters will soon be equipped with scrubbers – including a very large majority of the largest ships, consuming most of the fuel and producing or not producing most of the sulfur emissions. Ships can easily use their scrubbers in winter-time but cut them off during the summer, except when approaching harbours or densely inhabited coastal areas. Also, they can put the scrubbers on even farther at the sea even in summer, when a strong wind is blowiing towards inhabited areas. But when a ship is farther at the sea in summer and the wind is blowing towards areas where there are no people, no steel plate roofs or marble buildings,

no shallow lakes and not a single tree, there is no point of not countering the heating of the Arctic by releasing the sulfur into the air. In the ocean sulfur is one of the key nutrients necessary for all life and often in short supply.
The same mpcat can also be achieved with double-fuel systems and with various kinds of combinations of diesel-fuelled and electric engines.
In other words: it would be possible to transform the world's already existing fleets of freight and passenger ships to a kind of "geoengineering vessels" with major negative costs.

REDUCING THE WINTER-TIME CLOUD COVER IN THE ARCTIC BY OLD RAIN-MAKING METHODS?

Another safe and very affordable way to halt the melting of the Arctic might be to reduce the extent and density of the cloud cover over the Arctic region during the winter. This could be done by "seeding" the clouds with silver iodine, carbon dioxide ice, ordinary water ice crystals or sea water. If the temperature is cold enough, even any ordinary dust will do the trick.
There has been a growing amount of attention towards reducing the Earth's cover of cirrus clouds, which are currently estimated to be heating the planet with an average efficiency of 5.1 watt/m2 (32).
However, cirrus clouds are not that dense and exist 6-13 kilometres above the ground. During the winter of the Arctic low-level clouds have a much larger heating impact. Measurements collected during the Coordinated Eastern Arctic Experiment (of NOAA) for autumn and winter indicate an increase in downwelling longwave radiation under cloudy skies of about 90 w/m2, an average (33). Low-level clouds mostly consisting of tiny, often supercooled water droplets exist at a much lower altitude, typically between 0 and 3,000 meters, and are thus much easier and cheaper to reach with numerous different methods. Besides, the world's governments and military already have a lot of experience about seeding this kind of clouds and dropping them down as rain or snowfall (34).

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ANNEX

THE MYSTERY OF THE DEEP SEA BOTTOM'S BIODIVERSITY

We all know that what happens in the Arctic may be crucially important for the climate, for two different reasons.
First, there are huge marine and terrestrial areas in the Arctic whose reflectivity or albedo could change, in a dramatic way, due to global warming. Floating marine ice reflecting most

solar radiation straight back to space can be replaced by open water, absorbing more than 90 per cent of solar radiation. Terrestrial areas can be covered with highly reflective snow for shorter periods of the year. Dark coniferous forests can spread to tundra. Even when they are only a meter in length, stands of spruce trees can absorb much more solar radiation than the original vegetation of the tundra, consisting of mosses, lichens and low shrubs.

Second, there are vast stores of carbon and methane that could be liberated into the air by global warming. There is the carbon in the vast northern peatlands and in forest soils. There is the carbon in terrestrial permafrost. There is the carbon in submarine permafrost, that may cover one third of the bottom of the Arctic sea (= huge parts of the Arctic Ocean are actually parts continental shelves, but at the moment under a thin bed of water). And we have the so called methane clathrates at the bottom of the ocean and under the permafrost, slightly mysterious formations in which huge amounts of methane have been trapped inside molecular cages of ice.

All these factors could give birth to positive feedback loops accelerating the warming process -- and strenghtening each other. The worst-case-scenarios are quite frightening.

Scientists have been trying to model all the related scenarios and put numbers on how much warming each positive feedback loop and their different combinations could cause, but in the real world we do not really know. It could be worse, even much worse than we think.

The halting of the melting of the Arctic could be the most important single thing we have to do to stabilize the climate.

But it could also be the most important thing we have to do to prevent the so called Sixth Extinction. Partly because of the indirect impacts on terrestrial fauna and flora via global warming, and partly because an even much more direct impact on oceanic biodiversity, especially the species living in the oceanic sea bottom.

The standard wisdom currently is that there has been five huge mass extinctions of species during the Earth's long history, during which most of all the species living on our planet have died. They have been caused by natural phenomena, but we could now produce a Sixth Mass Extinction by ourselves.

However, according to recent research, the five big mass extinctions of have not been as dramatic as we have thought on the continents. However, each of the five mass extinctions has wiped out more than 90 per cent of all the species living at the bottom of the ocean – and there have probably been many more than five mass extinctions here. Meaning among the fauna of the oceanic sea bottom.

This is because the conveyor belt of ocean currents and the formation of highly saline and very cold water that descends to the bottom of the sea at the polar areas, especially in the Arctic Ocean and the most northern parts of the North Atlantic and North Pacific, in practise keeps the bottom of the deep ocean oxygenated and alive.

The main engine of this process is the repeated freezing and melting of the surface water in the marine areas close to the North Pole. If this mechnism is disrupted, the formation of oxygen-rich deep water will halt or at least decline, drastically. It seems that when this happens, tens of billions of hectares of deep sea bottom can become hypoxic or even anoxic, and that the problem can hit enormous areas of deep sea bottom in a very short period of time.

How many species would we then lose?

There is a very simple, short and extremely accurate answer to this question: nobody knows.

Marine biologists have always concentrated on he shallow seas that can be reached easily, by scuba gear or even schnorkeling.

It is often said that we might lose one eight of all living species on Earth, perhaps one million species, with corals.
But we know much less about the species living in the deep sea bottom because we only have a handful of submarines that can reach the bottom of the deep sea. And they can only descend to the bottom quickly, spend a little bit time down, studying a minuscule area, before they have to come up again. The humanity has only seen approximately one millionth of the deep sea bottom with its own eyes.
First it was assumed that there is no life in the deep sea. Then it was said that all right, there might be some strange creatures down there, but probably not so many different species.
The first serious effort to find out was made in 1984. US marine biologists then took samples of the mud in the sea bottom close to the coast of Delaware and New Jersey, and catalogued all the species that were found. Even though the samples were taken from areas that were close to the densely populated coast of USA, 50 per cent of all the species were unknown to science.
Frederick Grassle and Nancy Maciolek analyzed how quickly species seemed to change to other species and estimated, in 1992, that there might actually be roughly one multicellular species for each square kilometer of deep sea bottom. Meaning that there could be, alltogether, 300 million or so species living there. (J. Frederick Grassle ja Nancy J. Maciolek: Deep-Sea Species Richness. Regional and Local Diversity Estimates Based from Quantitative Bottom Samples. American Naturalist 139 (2): 313-341, 1992.)
Other marine biologists said that this cannot be and that Grassle's and Maciolek's estimate was a wild exaggeration. So Grassle and Maciolek reduced their estimate first to 30 million and then to 10 million species. Only.
Slightly later John B. Lambshead and his colleagues estimated that there might be 100 million different species of nematode worms, alone, living at the sea bottom. Lambshead's estimate was also attacked and he lowered it down, first to 10 million and then to 1 million.
I have never really understood whether Lambshead, Grassle and Maciolek reduced their estimates because they were criticised so much by their colleagues or because they really thought that they had been wrong.
In 2019 the experiment was repeated, on the Pacific side. US marine scientists again took samples from the bottom of the seabed and investigated, very carefully, what was in them. They isolated alrogether 347 000 organisms from the samples. Everybody assumed that the percentage of creatures unknown to science would be less than 1984, but it was actually 80 per cent. Four fifths of all the species were unknown to science. A modelling effort once again produced a figure of one hundred million or so species. (Kennedy, Brian R.C. et al. The Unknown and Unexplored Insights into the Pacific Deep-Sea Following NOAA CAPSTONE Expeditions, Frontiers in Marine Science 6 (480), 2019).
So whenever samples are taken from the deep sea bottom, most species that are found are unknown to science. And scientists also find new genera, new families and even new classes of species. Birds are a class, reptiles are a class, mammals are a class, reptiles are a class. It is an absolutely impossible idea that a new class of animals would be found on some of the continents. But in the oceanic sea bottom… it is not big news.
So the biodiversity in the deep sea bottom, biodiversity that we are in danger of losing if we fail to halt the melting of the Arctic, is… astonishing.
But how can this be? How can there be so many different species living at the sea bottom? Why? The deep sea bottom is flat. Why haven't the same species spread over all of it? What drives the diversification of species? Why isn't the deep sea bottom like the boreal forest zone, with the same species everywhere, both in northern Eurasia and in northern

North America? Why isn't the oceanic sea bottom a bit like Finland, where we only have one endemic species, the ringed seal of Saimaa.
My own hypothesis is that it might be the sea mounts and especially the sea mounts that have been partially or complerely buried in loose sediments, that are driving the diversification of species.
If we only count the separate, isolated sea mounts that are taller than one kilometre and which do not belong to underwater mountain ranges known as oceanic midridges we only have about 100 000 of them. But if we count also the shorter ones and the ones in the oceanic midridges the best current estimate is 25 million.
Actually, even this could be a gross underestimate. In the Island of Pico in the Azores that I know very well there are 550 volcanic cones of different sizes in an area of 460 square kilometers. Pico is probably a representative sample of oceanic midridges and it should be remembered that all of the oceanic sea bottom either belongs to current oceanic midridges or areas that used to be oceanic midridges.
Because the whole sea bottom is like a very slow conveyor belt, making one full round in a few hundred million years. New sea bottom is being created in the Oceanic midrifts, in the middle of the midridges, and old sea bottom is descending into the mantle in the trenches. So, if we use Pico as a baseline, there could be up to 200 or 300 million ancient sea mounts buried in the loose sediments, in the oceanic sea bottom.
I have been investigating a line of three small, less than 50-meter-high volcanic cones in the Pico island. In spite of their small size they each have their own, actually dramatic craters and cave systems. The walls of the craters drop steeply far down, so that you cannot see the bottom even with a strong flashlight. You do not want to go very close to the edge of the fall. One of the lava tubes linked to the complex has a 800 meters-long section that humans can pass through.
There is a slightly similar structure in shallow water, 80 kilometers South of Pico, the Princesa Alice sea mount. It has three eroded peaks rising up to almost 30 meters from the surface. Each of the peaks is only a few tens of meters wide.
Could it be that when such volcanic cones and their craters and cave systems and the piles of boulders that are created when they collapse, are buried into the sediments, they become partly isolated ecosystems that begin to develop their own, endemic species?
If this is the case there could be tens or even hundreds of millions of tiny spots of extreme biodiversity at the sea bottom, and a gradually lessening gradient of diversity when we move away from each of them.
If the actual biodiversity hot spots cover only a small fraction, perhaps only one thousandth of the area of the deep sea bottom, the very few samples taken from it have probably not yet hit any of the real hot spots.
For example Aranda could perhaps identify a few spots where an ancient sea mount has been buried in the sediments, and then investigate whether there is a small but diverse biodiversity hot spot directly on top of this ancient, mud-covered peak. With many endemic species in a tiny area, just like there can be in some ancient trees belonging to rare species in a tropical rainforest.
I think this is a fascinating and super-interesting thought. But the most important thing is that we could lose *really* a lot of biodiversity if we will not be able to halt the melting of the Arctic.