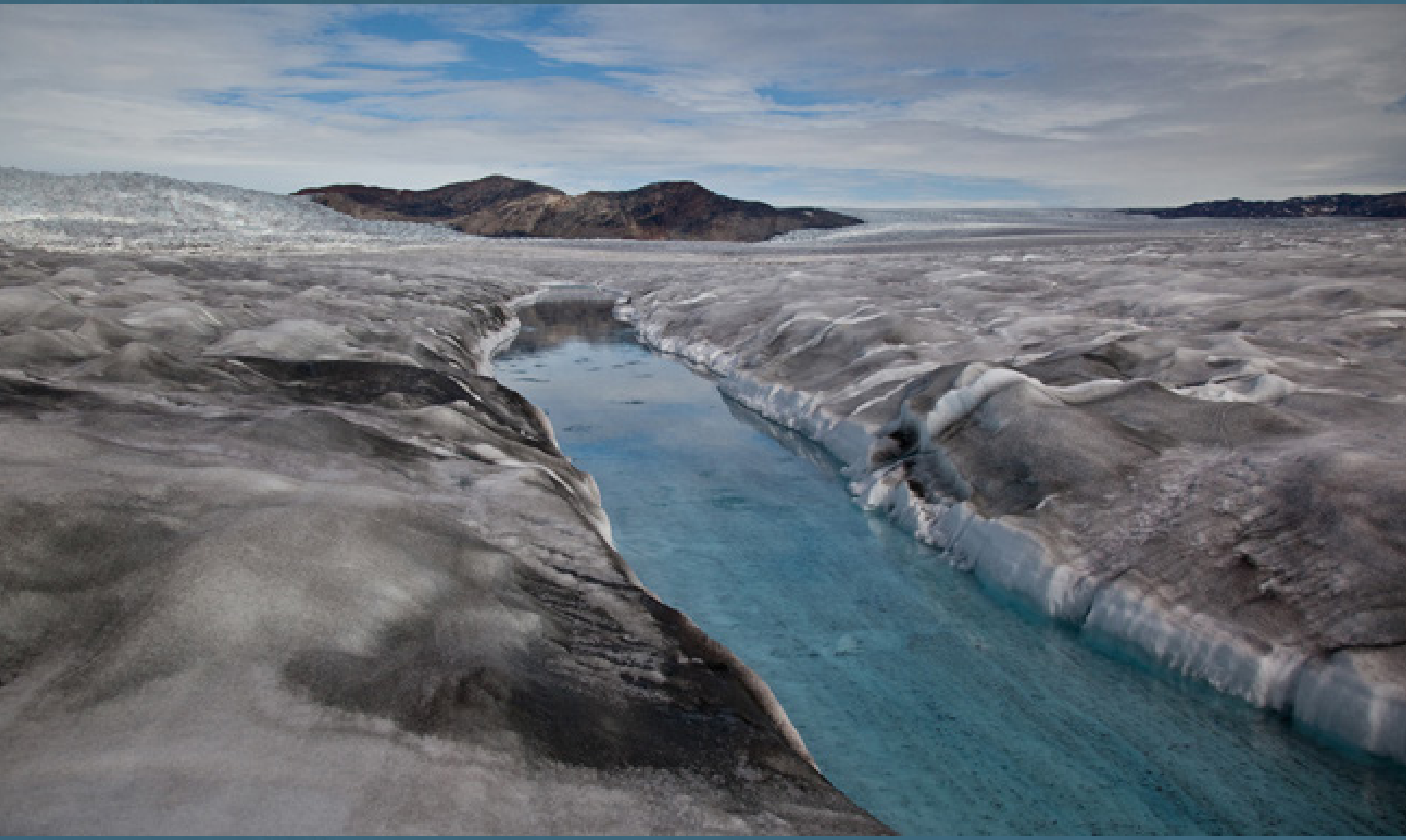
The Impacts of an Arctic Shipping HFO Ban on Emissions of Black Carbon



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Dr Daniel Lack is a atmospheric physicist and chemist with 16 years of experience in the academic and consulting areas of climate science. During a ten-year career at the US National Oceanic and Atmospheric Administration (NOAA) laboratories in Colorado Dr Lack established expertise in the measurement and impacts of black carbon from biomass burning and transport sources. Dr Lack's speciality in the measurement of the particle emissions from commercial ships has lead to established collaborations with local, regional, national and global legislators on ship emission policy. He is now an independent consultant specialising in the measurement and climate impact assessment of transport emissions.

Cover picture: Black carbon emitted from ships can settle on ice and snow, darkening the surface and increasing the rate of melting. (Photo: ©Henrik Egede Lassen/Alpha Film, from the Snow, Water, Ice, and Permafrost in the Arctic report from the U.N. Arctic Monitoring and Assessment Programme.)

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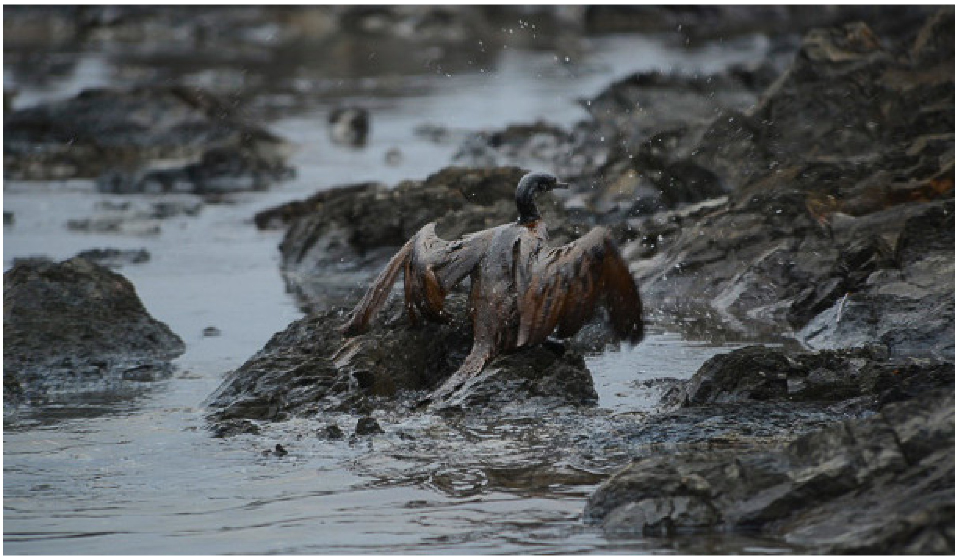
Motivation for Heavy Fuel ban in the Arctic

A ban of the use and carriage of heavy (or residual) fuels onboard ships in the Arctic region is motivated by the potentially harmful effects to the environment of uncontained spills and atmospheric pollution.

Oil spills

Spills of Heavy Fuel Oils (HFO) from commercial vessels mostly occur via collision or grounding, with an estimated average spill rate of approximately 2 per year (for vessels > 60,000 DWT). The relative frequency of such spills is small compared to the millions of miles travelled by vessels world wide, and the trends in increasing trade and decreasing accident rates (ITOPF 2016). Spills of HFO into pristine, and even populated and developed environments, cause significant deterioration and death in coastal communities, fisheries, wildlife and usability of the region, often for decades.

The two interlinked factors of oils spills, the relatively low but persistent risk of spills and the damaged caused by them, focus community, industry and regulators to pre-emptively address these issues. One such example was the 2011 ban of use and carriage of HFO in the Antarctic region "*to protect the Antarctic from pollution by heavy-grade oils*" (IMO 2011). This was an amendment to the International Maritime Organization (IMO) Convention addressing pollution from ships (MARPOL) where the risk to the Antarctic environment was agreed to include the risk of collisions of vessels with ice, of groundings and the remote location limiting containment of oil spills. These are all factors that exist in the Arctic region to the same or higher degree than in the Antarctic. Absolute activity levels will likely be higher in the Arctic due to the drive for commercial activity by the 5 nations who claim Arctic territory, and by the commercial operators seeing advantage to trans-arctic travel.



An oiled seabird resting onshore, following a spill of HFO off the coast of Russia in November of 2015. Photo courtesy of Sakhalin Watch and Club Boomerang.

The ecological, economic and social costs of the use and carriage of heavy fuel oil (HFO) in the Arctic was recently assessed in a report to the European Climate Foundation (ECF) (Deere-Jones 2016). This report concluded that HFO spills in the polar regions "*present the most extreme difficulties for oil spill responders", with "response to these spills being more difficult and more costly in such environments than spills of other oil types.*" "*Such costs `are in excess of those generated by spills of fuel oils and most other liquid hydrocarbons in more temperate and less remote sea areas.*"

Further the report advised that the "precautionary approach dictates the cessation of transport of refinery residual MFO and HFO, by sea, through polar and sub polar seas."

Atmospheric pollution

Shipping emissions, as with other atmospheric pollution sources, have complicated climate warming and cooling impacts depending on geographic location and atmospheric lifetime. The industry is the 6th largest CO_2 emitter, when compared to the emissions of the top 5 CO_2 emitting countries.

International shipping accounts for 2.2% of global CO_2 emissions and 2.8% of global greenhouse gas warming potential, when other climate warming and cooling emissions and their lifetimes in the environment are considered (IMO 2014). These emissions include components such as SO_2, NO_2, ozone and particulates (PM) that contribute to up to 60,000 premature deaths annually (Corbett et al. 2007). CO_2, N_2O and CH_4 emissions are gas phase emissions that contribute 2.8% of the climate warming mentioned above. Emissions of particulate black carbon (BC) which also account for about 2% of global BC emissions (Lack et al. 2008), warm the climate by absorbing radiation in the atmosphere and when deposited to snow and ice surfaces. Organic particles may also absorb or reflect some radiation depending on the wavelength of light, and SO_2 can be rapidly converted to particulate sulphate (SO_4), which can lead to a cooling impact on climate. When the organic and sulphate particles coat BC, upon emission from the engine or in the atmosphere, the warming by BC can be enhanced due to a lensing effect of the radiation through the SO_4 or organic material.

The warming impact of BC is increased by at least a factor of 3 in the Arctic region, compared to over the open ocean, because of two significant physical effects of the reflective surface. The BC particles absorb incoming radiation from above, as well as reflected radiation from below, immediately doubling the warming impact. When the BC particle falls to the snow and ice surface after days or weeks in the atmosphere, radiation scattered from the snow and ice hit the deposited BC particles and cause further warming. It is this added potency that makes BC a troubling climate warmer, which overall is believed to contribute to approximately half that of the climate warming contribution of CO_2 (Bond et al. 2013, Pachauri et al. 2014). However, because of the short lifetime of BC in the atmosphere (of days to weeks), it means that control of BC emissions will have immediate impacts to the climate.

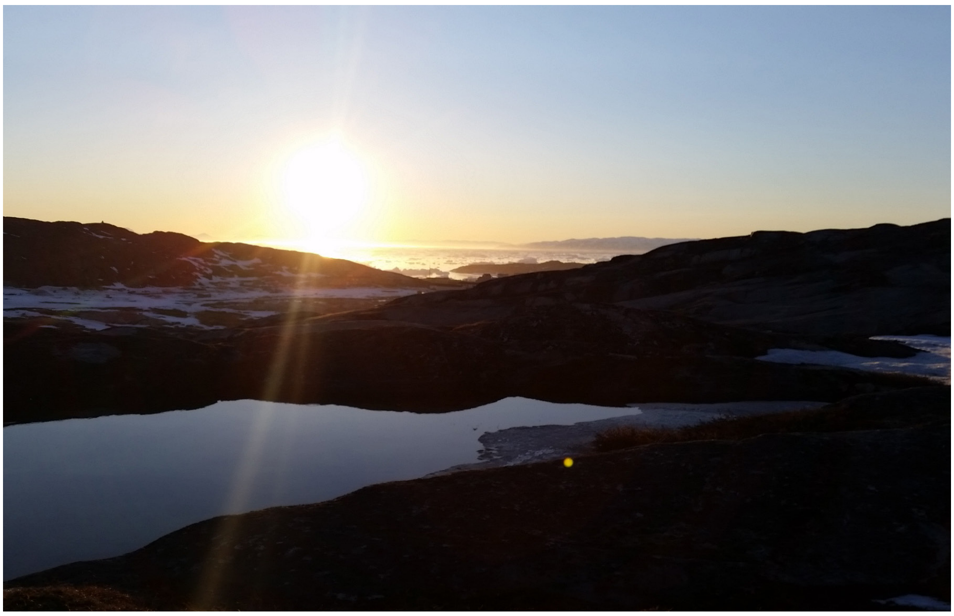
A rise in shipping traffic, motivated by expanded access to trans-Arctic shipping routes and possible commercial development, will increase the amount of atmospheric pollution from ships, in particular the emissions of BC. Current estimates suggest that shipping activity north of 60 degrees accounts for 5% of global shipping BC (DNV 2013). Mitigation strategies for reduction of this potential current and future source of BC is the focus of this, and other reports submitted to the European Climate Foundation.

IMO action on atmospheric pollution

International shipping accounts for about 2-3% of global CO_2 emissions and have put focus on CO_2 reduction strategies. Likewise, the industry accounts for about 2% of global BC and will have a disproportionate effect in the Arctic suggesting equivalent or increased efforts at BC reduction are warranted.

It is important to note that the IMO has actively sought to understand the environmental impact of shipping with multiple studies (Litehauz et al. 2012, IMO 2014) and changes to the international convention for the prevention of pollution from ships (MARPOL Convention) (IMO 2011). Design codes that address NOX pollution and fuel quality standards have been implemented that reduce PM pollution for health benefits (IMO 2008). The IMO greenhouse gas studies have revealed that the international shipping industry contributes between 2 to 3 % of global CO_2 and GHG warming. With this contribution in mind, the IMO and member nations have implemented emission reduction strategies. The shipping environmental efficiency design index (EEDI) is one such move by the IMO to address the climate warming impacts of the industry. Striving for up to 30% reductions in CO_2 emissions from design requirements for new ships, the IMO recognized through international consensus that action on the industries CO_2 emissions was a necessary step to address it's contributions to global pollution. Likewise, the ban on the use and carriage of HFO in the Antarctic recognized that a fragile ecosystem required special protection from some of the unique aspects of the shipping industry, namely the dangers of spills of HFO in pristine and remote regions despite the absolute current contribution to oil spills and emissions in that region being small.

With these past actions in mind, it is essential that similar consideration be given to the impacts of international shipping on the Arctic region.



Midnight sun at the Ilulissat Fjord, Greenland. Photo credit: Dmitry Yumashev

Heavy Fuel: its emissions and regulatory environment

International regulation will stipulate the use of < 0.5% sulphur fuel globally by 2020.

HFO is the end stage product of petroleum refining and contains much higher concentrations of sulfur, ash and polycyclic/high molecular weight hydrocarbons compared to refined fuels such marine distillates or on road diesel. The emissions of SO_2 and particulate sulphate (PM SO4), which have acid-rain and human health impacts, are directly linked to the concentrations of sulphur in the fuel. Emissions of organic PM are linked to the fuel sulfur content also, through the use of lubricating oils that are used to neutralize the acidic nature of the high sulfur (Lack et al. 2009). The complexity of the hydrocarbons is the predominant cause for BC emissions, whereby higher molecular weight and polycyclic hydrocarbons have a more complicated structure for combustion, leading to reduced combustion efficiency. Ash content can provide sites of incomplete combustion leading to BC formation.

The overall emissions of BC from an engine will be determined by many factors, such as fuel quality, engine load, engine maintenance, combustion pressures and temperatures etc. however the experiments performed in multiple environments suggest that BC emissions decrease as fuel sulfur levels drop. However fuel sulphur is just a proxy for fuel quality, whereby reduced sulfur in fuels tend to correlate to less complicated hydrocarbons and less ash content. A review of this data on BC emissions with fuel quality is included in the sections below.

At present the IMO has regulations in place for a fuel sulfur cap of 3.5%, with the global average of fuel sulfur of HFO in use thought to be around 2.7% (ICCT 2015). By 2020 this cap is set to drop to 0.5%, although a proposal by the industry to delay this by five years will be assessed by the end of 2016. This proposed drop from 3.5% to 0.5% fuel sulfur is aimed at significant reductions in SO_2 and SO_4 PM due to the impact on human health. Ships operating within emission control areas (ECAs) are currently required to burn fuel with a sulfur content of less than 0.1%.

Current use of Heavy Fuels in the Arctic

75% of fuel carried by the 1347 vessel in the Arctic during 2012 was HFO.

Shipping activity in the Arctic for 2012 was investigated by the Arctic Council (DNV 2013) and showed that of the 1347 vessels in the Arctic region (see DNV report for geographic distribution) 27.5% (371) of them were operating on HFO. 17.5% of the total (235) were cargo carrying vessels that contributed to almost 50% (44%) of total sailing distance. 10% of fishing vessels, which make up 42% of total Artic shipping traffic, were operating on HFO. Estimates of total HFO carried by these 1347 vessels, HFO consisted of 75% of the total fuel mass.

In an expansion to the HFO use of the Arctic report (DNV 2013), shipping activity in the Bering Sea was assessed and found that 84% of vessels (total of 2934 vessels) were using HFO and accounted for 90% of the sailed distance in that region. Bulk carriers and container vessels dominate the shipping activity on the Bering Sea while fishing vessels currently dominate the sailed distance in the Arctic. Passenger ships, oil tankers, container vessels and general cargo are the next most dominant vessels by sailed distance.

These figures indicate that the peripheries of the Arctic, where sea ice conditions are more favorable, there is a dominance of shipping dedicated to movement of goods, while within the Arctic ocean itself this type of shipping is not yet dominant. With further development of favorable trans-Arctic routes, the distribution of ships using HFO will progress to that currently seen in the Bering Sea.

Ships at Spitsbergen, Svalbard. Photo by Hannes Grobe via Wikipedia

Shipping Black Carbon in the Arctic

Shipping BC currently constitutes a small fraction of total Arctic BC due to accessibility. Future emissions will rapidly increase due to trans-Arctic and local Arctic industrial shipping activity.

Shipping accounts for approximately 2% of global BC emissions, a similar magnitude to the 2.2% of global CO_2 emissions. One report estimates that 5% of global shipping BC is currently emitted into the Arctic (DNV 2013), which currently constitutes a small total percentage of global shipping BC. It is also estimated that shipping contributes about 1% of total BC north of 60 degrees (Corbett et al. 2010), those emissions being dominated by biomass burning (58%) and gas flaring (33%) (Stohl et al. 2013). These small contributions to shipping are to be expected because of the current inaccessibility to shipping. However these emissions contribute a much larger source of anthropogenic BC emissions, when naturally occurring biomass burning emissions are excluded and will progress to a higher significance as shipping routes open to allow the direct emission and deposition of BC to the region. For example Corbett et al. (2010) estimate by 2030 BC emissions will triple. In some regions of the Arctic it is estimated that 11% of BC is sourced from shipping (Eckhardt et al. 2013). Finally it is worth noting that the Arctic shipping BC contribution (by % of the total) are of the order of the global contribution of shipping to CO_2, which, as discussed above has been actively pursued by the IMO for reductions through the EEDI. A global contribution of a few percent ranks the shipping industry as one of the 6th largest emitters (ranked by country) and so the IMO has been active in addressing its contribution to global climate change, for which Arctic shipping will rapidly evolve to being a larger contributor.

Shipping in the Arctic. Photo source: http://www.bluebird-electric.net/

Impact of a ban of HFO use on Black Carbon emissions

The dimensions to BC formation from shipping fuel

BC emissions from HFO vary due to many factors including crude oil quality, fuel sulfur level, ash content, hydrocarbon complexity and heavy metal content.

The balance of available evidence suggests that a switch from low quality to high quality fuels for shipping is accompanied by a reduction in BC emissions (Lack and Corbett 2012, Litehauz et al. 2012). Some of the experiments reviewed in these publications, and some experiments since have showed no, or slightly increased BC emissions with improved fuel quality. The proposed mechanism for BC reduction, and explanations for the variability is multifactorial and an important dimension to the analysis of the available evidence.

In diesel combustion research it is accepted that the fuel impurities can act as points of cooler combustion and particle nucleation, leading to BC formation (Maricq 2007). Impurities include heavy metals, salts, sulfur, and water and hydrocarbon sediment (American-Bureau-of-Shipping 2001). In addition, the complexity of the hydrocarbon determines how fast and efficiently it combusts, which can influence BC formation. Simple hydrocarbons, such as methane, allow for fast and complete combustion and are converted almost entirely to energy, CO_2 and H_2O. As the hydrocarbons become more complicated, via multiple aromatic rings, and sulfur or nitrogen bonding the efficiency of combustion is reduced. The reduced combustion efficiency can lead to the production and emission of different polycyclic aromatic hydrocarbons, and BC. High sulfur fuels also contain sulfur and bound water that quickly react to form sulfuric acid that can damage the engine. The acid is neutralized by alkaline lubricating oils, which may combust, or may be emitted as oil, or combust inefficiently to form BC (Lack et al. 2009). There is a complexity in the use of HFO as a fuel. Its impact on the efficiency of the engine combustion can lead to variable emissions of BC. As fuel quality improves, via higher quality crude oil, better refining or dilution of HFO with distillate fuel sulfur and ash content drop and hydrocarbon complexity decline.

It is therefore important to highlight that BC emissions from HFO will vary due to:

- Fuel sulfur level
- Ash content
- Hydrocarbon complexity
- Heavy metal content
- Use of alkaline lubricating oil
- Engine operation and efficiency (maintenance)
- Crude oil quality

For these reasons is essential that an analysis of the impact of fuel quality on BC emissions is not isolated to a single experiment, rather an assessment of as much experimental data as possible.

Changes in BC emissions when switching from low to high quality fuel

Despite a range of values across over 20 studies, the balance of evidence suggests that a shift from low quality high sulphur residual fuels to high quality low sulphur distillate fuels will result in a 50% reduction in BC emissions.

The review of Lack and Corbett (2012) showed 19 experiments where the same ship engines were used to produce emissions from HFO and higher quality fuels. The review concluded that this shift in fuel quality reduces BC emissions by an average of 50% (range of 30% to 80%). This observed reduction is consistent with a well-established link between fuel quality and BC emissions for on-road diesel engines (Maricq 2007). Some of the trials reviewed did show increases in BC emissions when moving to cleaner fuels however inconsistencies in the measurement results for many of those cast uncertainty on those measurements. Recent data on fuel switching trials on a single vessel show variable results with increased BC emissions (30% - 50%) at low loads for a switch to cleaner fuel, and inconclusive or decreased BC emissions (35 – 45%) at high loads for the switch to cleaner fuel (results were reported for both auxiliary and main engines) (Miller et al. 2010). The conclusions of the review of Lack and Corbett (2012) and data from other-sector literature do, however, provide a balance of evidence that a switch from high sulphur residual fuels to low sulphur distillates, at high loads in particular, will lead to BC reductions. Certainly more research is required using reliable measurement tools to increase the statistics on such a conclusion, however, this report utilises the current evidence to provide its recommendations.

In addition to these results the review of Lack and Corbett (2012), and further defined in Buffaloe et al. (2014), showed results from two studies that sampled 34 slow speed diesel (SSD) vessels in California running <0.1% sulphur fuel and 41 SSD vessels in the gulf of Mexico running fuel that averaged over 1.6% sulphur. The comparison of BC emission factors between these studies showed that BC emissions were 57% higher in the region burning higher sulphur fuel. It was recognized by all authors that this difference is subject to many variables, including those mentioned above, however due to the minimal data available for this area of work, it is essential to consider this in the bigger picture of BC emissions from ships burning high and low quality fuel.

A recent study by Streibel et al. (2016) investigated emissions of BC from a 4-stroke diesel engine burning HFO and standard diesel and showed that at stable load condition of 75%, that BC emissions were twice as large for diesel compared to HFO, in contrast to the findings of the review of Lack and Corbett (2012). In addition it was found that as the engine load decreased the BC emission from HFO increased significantly, while the opposite was the case for diesel. This is an important consideration for operation of ships in highly variable load conditions such as the Arctic. It is uncertain how these results should be interpreted given the use of a 4-stroke engine as opposed to the traditional 2-stroke slow speed engines found on most large ships running HFO.

Finally, an energy content benefit of 5-8% is gained by switching to distillate fuels (Miller et al. 2010, Lack et al. 2011, CIMAC 2014), compared to HFO, which would contribute to a further 6-8% reduction in fuel use and subsequently 6-8% reduction in BC emissions.

As concluded in the review of Lack and Corbett (2012) the effect of a shift from low (>2% fuel S) to high quality fuel (<0.1% fuel S), although showing some variable results, appears to be accompanied by a reduction in BC emissions of 50% or more. Most of the studies reviewed used a low sulphur fuel consisting of a distillate fuel. Some recent studies utilizing a single engine have shown the opposite effect, however utilizing the balance of evidence of over 150 measurements it must be concluded that BC emissions decrease with a switch from low to high quality fuel. In addition, a recent study has suggested that BC emissions from HFO increase substantially at low loads, which can be expected in Arctic operations.

Current fuel sulphur regulations and impacts of BC emissions

Impending 2020 IMO regulations of 0.5% fuel sulphur will likely result in a 10% reduction in BC emissions in the Arctic, while assigning ECA status to the Arctic, requiring 0.1% sulphur fuel will result in a 50% drop in BC emissions.

International regulations have limited global fuel sulfur levels to 3.5% until 2020 after which they will drop to 0.5% (IMO 2016). Sulfur levels for fuel used inside ECAs is limited to 0.1%. These regulations will have an impact on BC levels according to the review of data presented above.

The BC reductions of 50% (with a range of 30 to 80%) found from the review of literature is for a switch of high sulfur fuel of approximately 2.5% (close to the global average of HFO) and < 0.1%. Given the complexity of BC formation from HFO, with contributions from fuel sulfur level, ash content, heavy metal content and hydrocarbon complexity, and the small amount of available data it is difficult to predict the trend of BC reductions with fuel sulfur content. If we assume that a 25-fold decrease in fuel S (from 2.5% to 0.1%) results in a 50% BC reduction, a 5 fold decrease from (2.5% to 0.5%) will result in a 10% BC reduction. This assumes that fuel sulfur content represents the trend in other contaminants.

Changes in BC emissions with engine load

A report on the effects of the Arctic environment on vessel operations, engine load and BC emissions are provided to the ECF in a companion report (Lack 2016).

Impact of a ban of HFO use on other emissions

CO_2

A switch from low to high quality fuel will result in a 5-8% decrease in CO_2 emissions.

Because distillate fuels have 5-8% more energy density (Miller et al. 2010, Lack et al. 2011, CIMAC 2014) it can be expected that CO_2 emissions will drop by this amount.

SO_X

A switch from low to high quality fuel will result in a 95% decrease in SO_2 emissions.

Sulphur exists bound to carbon and oxygen in fossils fuels and upon combustion is converted to various oxides of sulphur. Sulphur dioxide (SO_2) is the dominant product (> 95%), while a few percent of sulphur is converted to SO_3 radicals, dependent on combustion temperature. SO_2 is converted to H_2SO_4 after emission over various timescales and via multiple reaction pathways. SO_2 emissions are only dependent on fuel sulphur content so reductions of fuel sulphur from 2.5% to 0.5% or 0.1% will reduce SO_2 emissions by a factor of five or 25 respectively.

Sulphate PM

A switch from low to high quality fuel will result in a 93% decrease in particulate SO_4 emissions.

SO_3 radicals, are immediately converted to SO_4^{2-} and can form liquid H_2SO_4 droplets or combine with ammonia to form $(NH_4)_2SO_4$ particles. Emissions of SO_3 are dependent on fuel sulphur levels and temperature of combustion and so reductions due to fuel sulphur changes may not follow the same relationship as SO_2. Lack et al. (2009) measured the emissions of SO_4 from the stacks of 100s of vessels and found an approximate factor of 3 drop of SO_4 emissions with a drop in fuel sulphur from 2.5% to 0.5%, and an approximate factor of 15 drop of SO_4 emissions with a drop in fuel sulphur from 2.5% to 0.1%.

Organic Matter

A switch from low to high quality fuel will result in a 75% decrease in particulate organic emissions.

Lack et al. (2009) found that organic matter (OM) emissions are linked to the fuel sulphur content. Alkaline lubricating oil is used to neutralize the acid produced from the SO_3. Not all of this oil is consumed and is emitted as unburned oils. The data Lack et al. (2009) show that a drop of fuel sulphur content from 2.5% to 0.5% will result in a 50% drop in OM emissions, while a drop of fuel sulphur content from 2.5% to 0.1% will result in a 75% drop in OM emissions.

Technical considerations of a HFO ban

Fuel switching is regularly undertaken in the ECAs in North America and Europe. Barriers to successful fuel switching are minimal with written protocols, training, and minimal equipment retrofits required.

Use of higher quality fuels on ships designed for HFO raises a number of technical issues associated with lower fuel viscosity, lubricity of the fuel, lubrication oil choice, and the procedures for fuel change over (ABS 2014, CIMAC 2014). These factors can potentially lead to equipment damage due to less lubrication or the use of incorrect lubricating oils for neutralization of the acidic emissions of HFO. There is also the potential for leaking of less viscous distillate fuels. The American Bureau of Shipping (ABS 2014) and the International Council on Combustion Engines (CIMAC 2014) addresses these issues and solutions mostly encompass development of procedures for monitoring lubrication, the change over of lubricating oils, and the change over of the fuels themselves. Equipment retrofits of fuel pumps and other components at risk of leaking as well as automated fuel switch systems. Neither ABS nor CIMAC discuss situations where fuel switching is not possible or dangerous, when inspections, necessary retrofits and operational procedures are implemented.

Many shipping companies including the Maersk Line have undertaken fuel-switching operations since 2008 in Californian waters. In 2013, following 8000 vessels performing fuel switches, 15 experienced loss of propulsion (Einemo 2014). Although this is a small number (just 0.17%), large ships without power near a coastline could cause major incidents such as grounding or collisions. It must be noted that these loss of power incidents were due to switching to low sulphur fuel, not due to operation on low sulphur fuel. In addition, many cruise vessels operating in Antarctic and Arctic waters are successfully operating on low sulphur fuel (Maritime-Executive 2016).

Financial considerations of a HFO ban

The use of 0.5% sulphur fuel will lead to a maximum increase in fuel costs of 45% above the use of high sulphur HFO. The incremental cost increase of using 0.1% sulphur fuel after the 2020 0.5% fuel sulphur regulations will be 10%.
Transits of the Arctic in 2030 via the NSR and NWP would provide a 27% and 0% cost benefit if 0.1% sulphur fuel was used after 2020, instead of 0.5% sulphur fuel.

Any ban on HFO in the Arctic should be implemented as a regional or international agreement so there is no economic disadvantage to any nation operating in the area. Because of the 2020 IMO regulation to implement a 0.5% fuel sulphur ban, which will provide a level playing field for all operators, the cost of ECA level fuel sulphur limits (0.1%) is of more interest. The current cost of a ton of HFO, 0.5% residual fuel and 0.1% MGO is $USD 283 per ton, $USD 410 per ton and $USD 452 per ton [http://shipandbunker.com/prices].

In a recent study on the costs of goods transport via the Suez Canal or via the Northern Sea Route (NSR), Lindstad et al. (2016) estimated that a ton of goods via the Suez Canal would cost $USD 29 while the same via the NSR would cost $USD 18. These estimates were for 0.5% sulphur fuel. Lindstad et al. (2016) did not provide estimated cost of using 0.1% sulphur fuel (MGO) through the NSR. This study included charter cost, depreciation, operating costs, fuel costs, engine power and engine loads for both sailing routes.

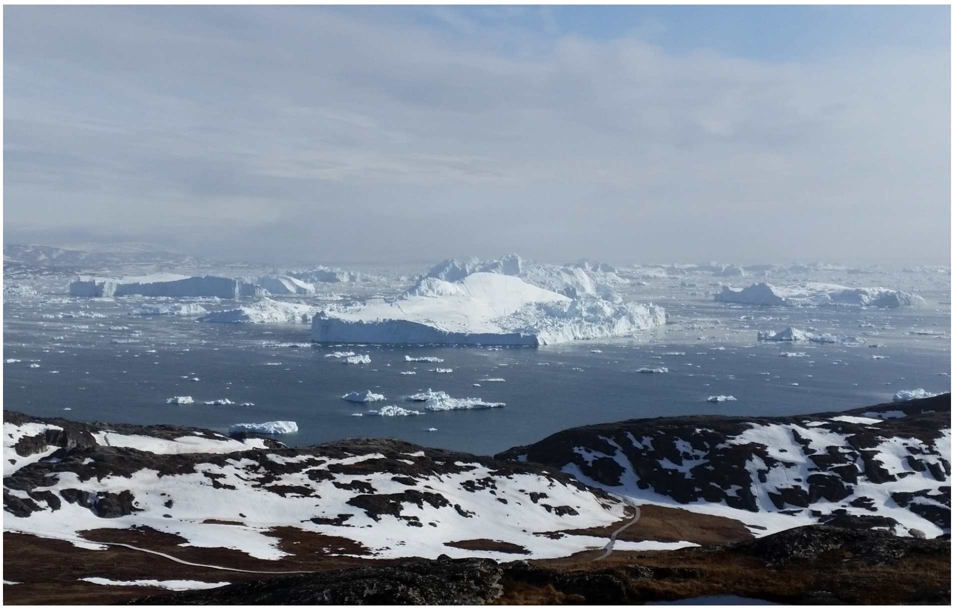
As an alternative and less accurate estimate, using the prices of 0.1% MGO stated above, the use of 0.1% sulphur fuel in the NSR could add no more than 10% ($USD 42 price differential between 0.5% and 0.1% sulphur fuel) to the total cost. It would therefore cost ~$USD 20 per ton of goods moved using 0.1% sulphur fuel.

Fuglestvedt et al. (2014) recently investigated the climate impacts of shifting global shipping routes to the Northern Sea Route (NSR) and North West Passage (NWP) and found that climate benefits from reduced CO_2 emissions due to the shorter routes only accrued after 150 years. The first 150 years was dominated by increased warming due to CO_2 savings taking time to offset the shipping CO_2 already in the atmosphere and short term Arctic warming due to BC and ozone emissions. In addition they found that fuel savings of 37% and 10% would result from the shorter distances travelled in the NSR and NWP respectively, for 2030 conditions and regulatory environment. A shift, therefore from 0.5% sulphur fuel to 0.1% sulphur fuel as a BC mitigation strategy would make the NWP cost neutral compared to it's longer route, and provide a 27% cost saving via the NSR. Time savings would likely still result for both routes.

0.5% vs 0.1% fuel sulphur: Considerations for the details of a HFO ban

Enforcement of the use of 0.1% sulphur distillate fuel will ensure greater emissions reductions, as well as ensuring all emission reductions benefits are achieved.

Fuel quality, rather than just fuel sulphur content drives BC emissions, therefore any consideration for a ban on HFO use in the Arctic must be done so with fuel quality in mind. 0.5% sulphur fuels may be produced by catalytic desulphurization of HFO (Einemo 2013) rather than blending with higher quality distillate fuels. This process reduces sulphur content, but may not have any impact on the ash or heavy metal, or hydrocarbon complexity, which also contribute to BC emissions. BC reduction benefits may not result from burning fuel that has undergone this desulphurisation process. 0.1% sulphur fuel is more likely to be a distillate fuel, that has a reduced fuel sulphur content as well as reduced ash and heavy metals and less hydrocarbon complexity. However, it is possible that 0.1% sulphur fuel will be produced as a blend of desulphurised HFO and distillate, which will introduce uncertainty into the likely BC emissions reductions achievable.



Icebergs at the Ilulissat Fjord, Greenland. The amount of icebergs being discharged here is the largest across all ice fjords in the Northern Hemisphere. Photo credit: Dmitry Yumashev

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