**COMITÉ MARITIME INTERNATIONAL**

**International Working Group (Polar Shipping)**

# SUPPLEMENT TO 2014 WORKING PAPER ON LOAD LINES

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| Subgroup | Load lines in polar navigation |
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## INTRODUCTION

At its CMI New York meeting on 3 May 2016, the IWG requested the subgroup to consider the following questions and report back to the IWG:

1. How, if at all, do Arctic States and other key States address load lines requirements for Arctic shipping?
2. How, if at all, do IACS safety requirements address load lines for polar shipping?
3. What does the latest science indicate as possible concerns for load lines in Arctic shipping?

## QUESTION 1:

**How, if at all, do Arctic States and other key States address load lines requirements for Arctic shipping?**

At the outset, it should be pointed out that all of the five Central Arctic Ocean coastal States are parties to the LLC and LLC Protocol.

| Arctic Ocean Coastal State | Load Lines Convention Adopted: 5 April 1966 In force: 21 July 1968 | | Load Lines Protocol Adopted: 11 November 1988 In force: 3 February 2000 | |
|---|---|---|---|---|
| | Signature/Deposit of instrument | Effectivity | Signature or deposit of instrument | Effectivity |
| Canada | 14 January 1970 | 14 April 1970 | 8 April 2010 | 8 July 2010 |
| Denmark | 28 June 1967 | 21 July 1968 | 2 December 1991 | 3 February 2000 |
| Norway | 18 March 1968 | 21 July 1968 | 13 October 1994 | 3 February 2000 |
| Russian Federation | 4 July 1966 | 22 July 1968 | 18 August 2000 | 18 November 2000 |
| United States | 17 November 1966 | 21 July 1968 | 1 July 1991 | 3 February 2000 |

## (a) Arctic waters

### *Canada*[1]

Canada has implemented the LLC through the Load Lines Regulations[2] under the Canada Shipping Act, 2001.[3]

The perspective of one Canadian shipping company consulted is that the load line is not about geography, but about sea conditions. To a certain extent, it does relate to geography because sea and wave conditions are more intense as we get further north. Severity of sea conditions in the North Atlantic are real. The sea state is demonstrably worse in the area west of the UK and is quite often that way in the winter time. However, Canada does not get the same sea conditions in the Canadian Arctic, and certainly not in the Northwest Passage. There may be ice, but not necessarily the heavy seas typical of the North Atlantic in the winter.

As for the different areas of salinity in Arctic waters, different salinity levels are to be expected in any voyage, not just in the Arctic, and that when considering draft and loading conditions at the port of loading, and as part of regular voyage planning, the vessel considers the different areas where the vessel will pass along its route, and the different sea and salinity conditions in determining maximum draft upon leaving the load port (and of course also considering the fuel burn off along the way).

In developing the ship`s Polar Waters Operating Manual, provision should be made for the vessel to take into consideration the varying salinity conditions across the arctic area where the vessel is expected to transit, but this is something which any Chief Mate will be expected to do in any case in preparing the voyage plan. It's not an Arctic-specific issue.

As to what is actually being used, it appears that Arctic vessels load to summer marks or winter marks as seasonally appropriate. They do not consider Winter North Atlantic conditions as they do not apply to the Arctic as a whole. In any event, the shipping company consulted sees no justification for increased freeboard in the Arctic, and does not believe that the risk of ice accretion (and increased draft/reduced freeboard resulting therefrom), would be relevant. The view is that the vast majority of Arctic shipping occurs at times when icing would not be real threat (temperatures above zero).

Another company consulted does not appear to be very much concerned with load lines in the Arctic because of the type of trade they run. They carry mostly volume cargo and never actually reach maximum load line limits in any event, regardless of which limits are used.

[1] This section was contributed by Peter Pamel.
[2] Load Lines Regulations, SOR/2007-99.
[3] Canada Shipping Act, 2001, S.C. 2001, c. 26.

***Denmark (Greenland)***[4]

Denmark (and Kalaallit Nunaat/Greenland), as an Arctic State, addresses load line requirements for shipping in the region. The relevant load line requirements for Greenland are divided in two Winter Seasonal Zones I and II (see definitions below). The Winter Seasonal Zone I approximately covers the south and east coast of Greenland and the Winter Seasonal Zone II is apart from the south coast (approximately) covering the west coast of Greenland. The Danish Maritime Authority has not issued any special load line requirements apart from what is regulated in the Load Lines Convention. As far as it is understood from the Danish Marine Authority, there are no plans to change the current system. The navigation in Greenland waters is, however, always limited by the seasonal ice (including type of ice) and subject to regulations governing a vessel's ice class as defined by the Classification Society concerned.

The Winter Seasonal Zone I is defined or limited by meridian 50° W on the west coast of Greenland (north northwest of Paamiut (Frederikshåb) to 45° N, along latitude 45° N to 15° W, along meridian 15° W to 60° N, along latitude 60° N to Greenwich meridian 0° and from this meridian to the north.

- Winter: 16th October to 15th April.
- Summer 16th April to 15th October

Winter Seasonal Zone II is defined or limited by meridian 68° 30' W from the coast of the United States to 40° N and from there the compass line to the position 36° N, 73° W and along latitude 36° N to 25° W and from this position to Cape Torinana on the Atlantic coast of Spain.

- Winter: 1st November to 31st March.
- Summer 1st April to 31st October

***Norway***[5]

The LLC is directly applicable in Norwegian law and applies to relevant Norwegian flagged vessels also when operating in Arctic waters. This follows from Regulation No. 1072 of 1 July 2014 on the Construction of Ships Chapter 5. The regulation has legal basis in the Norwegian Act of 16 February 2007 No. 9 relating to Ship Safety and Security (Ship Safety and Security Act).[6] Under Section 43 of the Regulation the LLC is made applicable to cargo ships and passenger ships on foreign voyages. Definitions of cargo and passenger ship are found in Section 2. There are some more detailed rules on freeboard (Sections 45-49) that seem to provide exemptions from the LLC.

[4] This section was contributed by Lars Rosenberg Overby.
[5] This section was contributed by Tore Henriksen.
[6] The Act and regulations adopted under it are available in English translation at <https://www.sjofartsdir.no/en/legislation/>.

***Russian Federation***[7]

The Convention on Load Lines (LLC 66) was ratified by the USSR on July 22, 1968. Russia joined the amendments adopted to LLC in 1988 on the basis of the government decree adopted in 2000,[8] and the amendments adopted to the amendments in 2003 entered into force for the Russian Federation on December 4, 2013.

The Convention prohibits the ship's use in international voyage, unless it has been adequately surveyed and supplied with the Load Line Certificate. The Annexes to the Convention establish the rules for the determination of cargo stamps, the conditions of destination and the magnitude of freeboard, the modification of the convention requirements for zones, areas and seasonal periods, as well as forms of the International Load Line Certificate.

The requirement to have a mentioned above certificate contained in Article 14 of the Inland Water Transport Code and in Article 25 of the of Merchant Shipping Code of the Russian Federation. The issuance of certificates for a load-bearing mark allowed it two types:

- an International certificate of a LL issued to each vessel that has been inspected and to which a LL was applied for a period not exceeding 60 months;
- an International certificate of exemption for a LL, which is issued to any vessel that is granted an exemption on the basis of LLC 66;
- an international certificate of exemption for a freight stamp, which is issued to any vessel that is granted an exemption on the basis of LLC 66.

The certificate must be issued by the office of the “Technical supervision and classification of vessels”.

When assigning a freeboard, first of all, the ship's sufficient strength, as well as its stability and unsinkability for the navigation area and operating conditions, must be confirmed, in the range of sediment up to the smallest freeboard in the salt water. Strength, stability and unsinkability are considered sufficient when meeting the relevant requirements of the Regulations on Classification and Construction, the Register's vessels or international standards or the recognized classification society.

It is understood that the vessel is constructed and maintained in a state that meets the requirements of the above Rules and Regulations, and also that it has the necessary information for the captain approved by the Register.

In accordance with the requirements adopted in the Russian Federation, shipowners are responsible for the specification of the period of operation of the vessel in ice and ice conditions of navigation. The required frequency of dock surveys of vessels with ice reinforcements depends on the period and conditions of navigation of the vessel in ice, information that the shipowners must provide.

[7] This section was contributed by Alexander Skaridov.
[8] Decree of the Government of the Russian Federation of July 16, 2000 No. 457 "On the Accession of the Russian Federation to the Protocol of 1988 to the International Convention on Load Lines, 1966".

Rule 46 of Appendix II[9] LLC 66[10] establishes "winter seasonal zones I and II" in the North Atlantic, which are confined to the meridian 50 ° west longitude from the coast of Greenland to 45 °[11] north latitude, and from there along a 45 ° parallel. The boundary of the winter seasonal area in the North Atlantic passes along the meridian 68 ° 30 'west of the longitude from the coast of the United States to 40 ° N, from there in a straight line to the southernmost point of the meridian 61 ° W with the coast of Canada and from here along the east coast of Canada and U.S.A.

The above-noted boundaries of the winter seasonal areaы in the North Atlantic and the North Pacific coincide with those mentioned in 8.1 of the Rules for the Vessels Load Line ND #2-020101-098, adopted by the Russian Maritime Register of Shipping in 2017. Classification of a vessel with a class of another classification authority bearing the sign of the category of ice reinforcement, this sign shall be established taking into account the instructions of the Rules in accordance with the adopted tables, but the use of which does not exclude the need to check the ice strengthened according to the current Rules of the Register for the corresponding category of ice reinforcement.

The documenting of the freeboard corresponding to the accepted limitation of the precipitation on the location of the ice belt is given in the Rules, and the choice of ice reinforcements of the corresponding category is made by the shipowner, depending on the expected operating conditions of the vessel of the certain type.

In addition to self-navigation, the Russian Register establishes rules for hauling and towing, where is noted that:

- a load line for the area of hauling is used within the limits of expediency and feasibility without significant structural changes to the ship, however, alternative solutions should be implemented to ensure safety of navigation and prevent pollution of the environment;
- established navigation area - the navigation area specified in the vessel's documents prior to transfer;
- hauls in high latitudes are referred to one-time sea and ocean expedition towage.

As an example for the last one – towing of objects from the Barents and the White seas by transit along the Northern Sea Route and beyond, and also to the West for the meridian of the North Cape. After the adoption of the Polar Code, the Russian Maritime Register of Shipping adopted the Guidelines for the Application of the Provisions of the International Code for Ships Operating in Polar Waters (ND #2-030101-031), which entered into force on January 1, 2017. The Guidelines are applied for the survey of vessels and shipboard equipment, and also when reviewing project documentation and documentation for vessels in construction and operation for compliance with the requirements of the International Code for Ships Operating in Polar Waters.

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[9] Headed: "Zones, areas and seasonal periods."

[10] As amended on January 1, 2016.

[11] The winter seasonal zone I in the North Atlantic is confined to the meridian of 50 ° West longitude from the coast of Greenland to 45 ° N, from parallel 45 ° N to 15 ° W, from the meridian 15 ° W to 60 ° N, parallels 60 ° north latitude to the Greenwich meridian, from there along this meridian to the north.

In accordance with the Rules of the Russian Maritime Register of Shipping (ND #2-020101-098) "On the load line for the sea-going vessels" (ND #2-020101-098) adopted in 2017, for the designation of a freeboard vessel, the Register shall be provided with the following documentation:

- theoretical drawing;
- determination of the sizes of the connections of the shell structures;
- information on vessel stability control for the ship's master;
- calculation of landing and stability of the vessel with flooded compartments;
- information on loading and ballasting;
- diagram of the arrangement of holes in the hull, superstructures and felling ...;
- calculation of the strength of manhole covers;
- calculation of the freeboard and sketch of the load line.

Survey and marking of the load lines (1.4.2) are carried out by the Register on vessels flying the flag of the Russian Federation, as well as on vessels having a Class of the Register and floating under a foreign flag if the Registry is given an appropriate instruction from the Administration of the flag State. Survey and the imposition of LL on vessels engaged in international voyages may also be carried out by another organization or person, including foreign, but authorized by the government.

The Register can carry out the survey and the imposition of LL on vessels flying a foreign flag, under the authority of the government concerned. In such cases, the government of the country, under the flag of which the vessel is floating, fully guarantees the completeness and thoroughness of the survey and the imposition of cargo stamps.

On the basis of Decree of the Government of the Russian Federation of December 24, 2008 N 1012, the "Rules for granting the exemption (exemption) to the vessel from the fulfillment of the requirements of the International Convention on Load Lines, 1966 ... Based on the noted below “Rules", the procedure for providing a vessel flying the National Flag of the Russian Federation, the exemption (exemptions) from the fulfillment of the requirements of the LLC 66.

In accordance with paragraph 4 of the Rules for the development and approval of administrative regulations for the provision of public services, in 2012 the Ministry of Transport of the Russian Federation adopted the "Administrative Regulations" for the provision of a state service for granting the ship exemption (exemption) from meeting the requirements of the International Convention on Load Lines, 1966. By mentioned "Regulation" the results of this services are: the granting of exemption (exemption) or refusal to grant exemption.

The decision to grant the ship exemption is taken by the Federal Agency for Maritime and River Transport (or the Federal Agency for Fisheries). The classification society within 15 working days from the date of receipt of the copy of the application informs the Federal Agency of Maritime and River Transport about the possibility of granting the vessel exemption or refusal to grant exemption. The decision to grant the ship exemption or refusal to grant exemption is accepted within 30 working days from the date of registration of the application. If it is necessary to conduct technical inspections of the vessel and examination of documents, the decision period can be extended to 60 working days from the date of registration of the application.

In order to provide a state service, the applicant sends by mail, facsimile or email to Rosmorrechflot a statement made in an arbitrary form containing information about the shipowner, the name of the vessel and the request for which is requested exemption (with exemption), indicating the rule by which this requirement is established. If the recognition of the Governments of the States in which the ports are located between which the flights are to be made is necessary for the issue of exemption (exemption), the applicant shall provide copies of such confessions to each ship or several ships, with the International Exemption Certificate being issued only for the passage of flights between indicated in the recognition ports.

Perhaps the above rules and regulations, the use of LLC 66 in Russian law is limited. At the same time, the expansion of Arctic navigation, the use of vessels with new design characteristics and the "desalination" of some water areas will already raise new questions in the near future to classification societies.

For example, the year round use of "Arctic shuttles"[12] a significant proportion of the operating time carrying out independent navigation in ice, are constantly exposed to the danger of damage to the ship's hull, which threatens the loss of buoyancy reserves and requires an immediate response from the skipper. Therefore, the ship's design must have a permanently functioning, sufficiently accurate and reliable system for monitoring the draft of the ship. Or new trends in the equipment of cargo vessels by passenger cabins for business passengers and / or tourists in high-latitude cruises, the use of float sensors to determine the draft of the ship on the stems near the fore and aft perpendiculars and along the sides in the midships with a wireless data transmission system on the running bridge, which allows for constant monitoring of the freeboard, and, hence, for the buoyancy margin in all conditions, especially in conditions of storm and heavy ice.

It is known that the international practice of organization of the fleet operation in water areas covered with ice for more than 6 months of the year provides for the rights of the coastal state to establish national navigation rules that ensure both the safe operation of the fleet and the fulfillment of national requirements. While the question of applicability of LLC 66 provisions in the Arctic is not a subject of serious discussions in the Russian Federation. Nevertheless, the urgency of the problem will increase with increasing activity of navigation in high latitudes.

***United States*[13]**

Load lines in the US are regulated by the US Code Chapter 51, which provides for the assignment of load lines, issuance of load line certificates and for certain classes of vessels to be marked with load lines.[14]

The Polar Code amends SOLAS, MARPOL, and STCW, but not the Load Lines Convention. Of course, the Polar Code does require additional stability and structural standards based on the intended operations. While there may be certain conditions (such as lower salinity, lower wave

[12] Arctic shuttle - vessels with icebreakability of at least two meters for the ice class of the vessel Arc7, which can change the draft in active maneuvering when cruising alone.
[13] This section was contributed by Bert Ray.
[14] 46 U.S. Code Chapter 51.

energy) in arctic waters, at this time there is no sufficient justification to propose/require any changes to the current load line zones specifically for the Arctic.

Load line assignments in the Arctic are independent of the nature of the ice cover, and is governed by the Load Lines Convention, insofar as the particular area (in the Arctic) can be considered to be navigable. The Load Lines Convention limitations on the northernmost seasonal areas should not contain a northern boundary.

### (b) Antarctic waters[15]

It appears there is nothing specific with regard to load lines in the Antarctic (beyond the stability and ice accretion requirements touched on in the Polar Code). This may be largely because it has not been seen as a big issue to date. The cargo vessels are essentially government vessels resupplying bases.

For passenger ships, it is not such a major issue unless the ship has gone through a refurbishment that adds to its tonnage, but in that case they would still need to meet the other load line requirements. Ice accretion is not really a problem for passenger vessels as the vast majority of them are visiting areas at a time of year when it is extremely unlikely that they will get into that sort of difficulty.

In so far as the UK is concerned, there do not appear to be load line requirements, as far as vessels licensed by the UK are concerned.

There are some concerns addressed within the IMO's Polar Code and also some issues are covered regarding ice accretion in the Intact Stability Code. Neither of these approaches is Antarctic specific. An approach to Lloyds Register would suggest that they, in common with most IACS ROs, have no specific requirements.

Since there has been no sense of any requirement for anything specific, it would seem that no one has raised this.

Individual flag State licensing in the Antarctic might cover such issues but the licensing arrangements that are in place are not consistent and will vary between issuing States (for example, the UK has a very long checklist which must be completed that includes some ship specific details, though not specifically to load lines).

Much Arctic shipping is domestic and so would be covered by national legislation, whereas the Antarctic is very different with no national authorities other than the flag States of any vessels navigating in that region.

[15] This section was contributed by David Baker and Kim Crosbie.

**QUESTION 2**

**How, if at all, do IACS safety requirements address load lines for polar shipping?[16]**

Particular LLC rules

- Regulation 40 - *Minimum Freeboards*, comma (6) - *Winter North Atlantic freeboard* -, fixes an additional 50 mm to the winter freeboard for ships of length greater than 100 m entering (in winter) "*any part of the North Atlantic"* up to latitude 60°N (see regulation 52).
- Regulation 46 - *Northern Winter Seasonal Zones and Area* - defines the boundaries and the periods of the year.

The following comments are made on these regulations:

- *50 mm i.e. 2 inches*: This increased draft is insignificant for large ships in heavy seas. In my opinion, any adjustment in drafts, to take heavy weather into account, should be better addressed to the classification societies in considering a specific notation allowing navigation in certain rough weather areas. I see it as a conflicting condition of administrations not "satisfied" by ship builders, and willing to grant what they believe would be a safe margin.

- *sea boundaries*: What action can be taken against a ship crossing an ideal boundary at an undue draft in the middle of the Atlantic? These rules (and the boundaries) were established when shipping was not global and the fact itself that the Arctic is now in focus tells a lot. My remark would be to simplify as much as possible navigational restrictions in open waters, reducing sea boundaries to a minimum (just latitude?).

- *c. periods of the year*: Weather is not periodical, especially in recent years and is expected to be even less periodical in the future. Is it reasonable to consider "*seasonal periods*" within the same winter zones? Isn't it complicating life to mariners (and lawyers)?

Water density and freeboard

The extended ice-free sea surface in the Arctic may really mean a new "North Atlantic Winter Seasonal" zone may have to be regulated. The reduced freeboard, in consequence of a higher percentage of fresh water, should be considered for the transits in that area.

On water density and its effects on the freeboard:

- fresh water "weight" is approximately 1 kg per liter
- seawater (salt water) "weight" is approximately 1.032 kg per liter

Any ship "weight" results from the gravity, so it is not changing (not exactly) from zone to zone.

[16] This section was contributed by Nicolò Reggio.

"Weight" is counterbalanced by buoyancy (Archimedes). Buoyancy is the result of hull volume multiplied by the density of the fluid: for planes it is air, for ships it is water. Roughly speaking, the hull volume is length by width by draft, whereas the only dimension which can change is draft.

- weight = density x (L x B x T)
- weight/density = (L x B x T)

This means that the higher the density the lower the draft (or, alternatively, the higher the freeboard).

Looking at the difference in density between fresh water and seawater, you can take into consideration a variation of the freeboard in the range of 3%: a ship having a 15 m draft can achieve a 15,48 m draft by transiting from seawater to fresh water.

<u>Antarctic and Arctic waters</u>

They are now defined by SOLAS, Chapter XIV "*Safety measures for ships operating in polar waters"*, Regulation 1 "*Definitions*", sub 2 and sub 3. Polar waters limits, for the scopes of the Polar Code, are different from the ones defined in Annex II of the Load Lines Code, being englobed in the "*Winter Seasonal Zones*", as appropriate.

<u>Polar Code provisions</u>

Sub 3.1 of Article 3 "*Sources of hazards*" of the "*Introduction*" explains that the

> "*Polar Code considers hazards which may lead to elevated levels of risks due to increased probability of occurrence, more severe consequences, or both:*
>
> > *…omissis …*
> >
> > *.2 experiencing topside icing, either potential reduction of stability and equipment functionality;*
> >
> > *…omissis*".

The Code refers to the assessment of the ship and of its equipment in order to establish that they are suitable to operate in Polar waters, thus considering potential operational restrictions as resulting, for our consideration, from "*top side icing*".

The Polar Code introduces the "*Polar Water Operational Manual (PWOM)*", Chapter 2, which "*shall include information on the ship-specific capabilities and limitations in relation to the assessment*", (sub 2.2.2) as noted above.

A quick reference to the "*Ship Structure*" is made in Chapter 3, however simply referring to approved scantling in order to withstand "*global and local structural loads anticipated under the foreseen ice conditions*".

Chapter 4 "*Subdivision and stability*", sub 4.3 "*Regulations*", para 4.3.1 "*Stability in intact conditions*" deals with ice accretion on deck and provides for additional calculations to be taken into the PWOM to be accounted for in the intact stability evaluation while navigating in Polar waters.

No mention is made to any consequences on the free board, hence on the Load Line.

In general it seems that the Polar Code addresses the ice accretion issue in terms of on board procedures for "*icing prevention and de-icing*", (Appendix II, Chapter 5 "*Procedures to maintain equipment and system functionality*"), so to be considered in the preparation of the PWOM, as above referred to.

Question: what can be classified as an icing prevention procedure? Heating? Heated decks, hatches, cranes, winches …? Or suitable weather decks design, for example, so that snow/water cannot be retained?

Actually, since all IMO codes and regulations are under continuous revision and updating, it might be useful to promote a joint wider approach by RO's, flag administrations, and any other involved parties to anticipate potential criticalities affecting liabilities, in the end, and a common understanding by legislators and operators.

Comments from one classification society consulted

Instructions for surveyors with regard to the Polar Code are currently in preparation. Since the Polar Code is goal based, they are working on interpretation and limits/minimum requirements. Classification societies will act as ROs on behalf of the different flags and they are involved with different flags they will align interpretations.

On ice strengthening of ships, the society consulted applies the IACS PC rules and the Baltic ice Class Rules. These are more or less similar for all the major Class Societies, so likely will not need much additional interpretation.

With regard to the functional based rules in the Polar Code, there will be a need for future common interpretation. As this is not in place yet, they have developed their "own" interpretation, based on long experience and knowledge of the rationale behind the requirements in the Polar Code. For each new project, they are discussing their interpretation with the flag State authorities to ensure their interpretation is aligned with the flag State's. Letters of compliance with the Polar Code have been issued.

For ships going to operate in polar waters, they have voluntary Ice Class Notations, WINTERIZED Notations and DAT notation for materials. They have current plans to update the PC rules, but the Winterized Notations will be updated by including the IMO Polar Code requirements.

The society consulted is not aware whether ice accretion and zero salinity issues present a significant additional risk that should require an update of the Polar Class rules. They have not considered this to date. If the IWG has any information about these issues, they would be interested in hearing more to consider whether rule updates are needed.

Concluding remark

There is a need for cross references among guidelines, codes, and rules (either from RO and from UR) in order to avoid any conflicting wording and to develop perspective modifications which should take into account the unavoidable increased drafts from ice accretion on deck and from the zero salinity waters while on Polar routes passage.

## QUESTION 3

### What does the latest science indicate as possible concerns for load lines in Arctic shipping?[17]

The latest science appears to substantially indicate consistent trends in increase of freshwater (FW) in surface Arctic waters. This was observed by de Steur et al (2009; 2013) and Rabe et al. reported in the first draft of the load lines working paper have been noticed in other major research which confirmed the increasing FW trends in surface waters. However, at this time, it appears that the connection between levels of FW and navigational impacts has not yet been made, at least in the scientific literature. The scientific literature appears to have been mostly concerned with currents, circulation, acidification and other climate change impacts.

The scientific literature observing "freshening" of the Arctic Ocean, including increasing fresh water in surface waters, comprise the following, among others:

Carmack et al. (2015):

- "Currently, the Arctic Ocean is freshening [Proshutinsky et al., 2009; McPhee et al., 2009; Rabe et al., 2011; Haine et al., 2015], warming [Polyakov et al., 2005, 2012; McLaughlin et al., 2009], losing sea ice [Kwok et al., 2009; Stroeve et al., 2012a, 2012b; Cavalieri and Parkinson, 2012; Comiso, 2012], and its ice cover is changing properties and moving faster [Barber et al., 2009; Rampal et al., 2009, 2011; Kwok et al., 2013; McPhee, 2013]."
- "In the Arctic Ocean interior, FW is stored in distinct, water mass reservoirs with different depth ranges, biogeochemical characteristics, and residence times. Significant changes in FW reservoirs have been observed in the 2000s: an increase in liquid FW, mostly in the Beaufort Gyre, and a decrease in the solid FW phase. Future loss of sea ice and increases in net precipitation, runoff, and Bering Strait FW flux are expected. Export of FW from the Arctic Ocean will also increase but by less than the increase in FW inputs. Resulting increase of 50% in FW storage is projected by the end of this century [Haine et al., 2015]. This implies that the Arctic Ocean becomes of increasing importance in global FW cycle as a reservoir and as a deliverer."

Alkire, Morison & Andersen (2015):

- Estimated that the freshwater volume of the Canada and Makarov Basins observed during 2008 represented an increase of 8500 km3 whereas the Eurasian Basin experienced a

[17] This section was contributed by Aldo Chircop as assisted by Elizabeth Edmondson.

decrease of 1100 km3 compared to prehistoric levels

- As both spatial and temporal variations in the freshwater composition observed in the Central Arctic corresponded to changes in the general circulation and/or the specific freshwater composition in source waters decade of bottle chemistry observations collected from the Central Arctic Ocean indicated significant spatial and inter-annual variability in the contributions of meteoric water, net sea-ice meltwater, and Pacific water. In addition to this variability, a mean annual decrease in meteoric water of -389 km3 $yr^{-1}$ was mostly balanced by an increase in sea-ice meltwater fresh water of 292 km3 $yr^{-1}$ between 2000 and 2012.

de Steur et al. (2015):

- Between 2011 and 2013 meteoric water contributed the most freshwater on the Greenlan shelf and in the core of the East Greenland Current west of the Eastern Greenland Polar Front
- In Greenland and Iceland seas, sea ice melt was highest as far north as Fram Strait

Haines et al. (2015):

- Despite flux increases from 2001 to 2011, it is uncertain if the marine freshwater source through Bering Strait for the 2000s has changed, as observations in the 1980s and 1990s are incomplete.
- The Arctic liquid freshwater content increased rapidly during the 2000s by about 10%.

Freeland, H. (2014):

- Something odd in the Gulf of Alaska: change in salinity in 2014, 3 standard deviations below mean.
- Low salinity and high temperature results in low surface density (4.4 standard deviations).

Huntington et al., (2014):

- The Arctic in the Anthropocene: Emerging Research Questions
- A major driver of the cyclonic circulation of the Atlantic Water is the salinity contrast between the high salinity Atlantic Water flowing in the boundary currents and the low-salinity shelf water entering the basin (Spall, 2013).
- Implies that the response of the Arctic Ocean depends critically on several issues; 1) processes in the North Atlantic Ocean that establish the thermohaline properties and mass transport of the Atlantic Water entering the Arctic Ocean, 2) the fluxes through the Bering Strait (which depend upon North Pacific Ocean processes), and 3) mixing and dispersal of the riverine discharges rimming the basin. The latter two contributions are subsequently modified upon crossing the continental shelves surrounding the basin.

Davis, Lique, & Johnson (2014):

- Within the Arctic Ocean itself, more than 70 000 km3 of freshwater is stored within a very fresh surface layer, which is separated by a strong halocline from the relatively warm and saline Atlantic-derived layer beneath.

- Largest freshening of water seen in the Beaufort Gyre, which may be accelerating.

Bourgain et al. (2013):

- Investigated 2008-2010 AO index changes in the upper Canadian Basin.
- Canadian Basin – near-surface temperature maximum (Bourgain et al., 2013):
    - Ice-free upper layer – a shallow seasonal halocline due to ice melt
    - 25-35 m with salinities less than 31 psu
- Collections were made during summer months.
- Double halocline feature in Canadian basin due to winter pacific water (above 32.4 psu) and summer pacific water (31 psu – 33psu).
- Freshwater in the Arctic Ocean comes from Pacific water, river runoff and ice meltwater and net precipitation.
- About 45,000 $km^3$ of freshwater (relative to the salinity S = 34. 8 psu), representing 60% of the total oceanic freshwater content of the Arctic Ocean, is stored in the Beaufort Gyre, an extensive anticyclonic gyre in the Canada Basin north of Alaska (Aagaard and Carmack, 1989; Serreze et al., 2006).
- Freshening of Canadian and Makarov basins noted.
- Proshutinsky et al. (2009) estimated the freshwater content positive trend to be 178 cm yr−1 (when calculated with S = 34. 8 psu as the reference salinity) south of 80_ N for the 2003–2007 time period.
- Bourgain and Gascard (2011) observed an intensification of the surface salinity freshening in 2007–2008
- Beaufort Gyre and Siberian river runoff have had a major influence on the freshwater content variability.
- Large scale freshwater content noted between 2008 and 2010

Chernyavskaya et al. (2013):

- Significant salinification of the upper Eurasian Basin began in 1989.
- Aim was to distinguish the most significant factors that lead to recent changes in upper layer salinity patterns.
- Note that 2007 was a "tipping" year, when the spatial structure of salinity in the Arctic Ocean sharply changed. The points of the phase portrait for the period 2007.
- In the Canadian Basin there has been a significant freshening of the surface layer.
- Contribution to prior work is a statistical approach which can be used for analyzing inter-annual variability of Arctic Ocean surface layer salinity.
- Large spatial gradients between the Eurasian and Canada Basins – predict freshened water from the Beaufort Gyre will move westward along the Siberian continental slope in 2013-2014.

de Steur et al., 2013:

- Freshening of the Lincoln Sea was observed during 2008-2010, caused by a change in the mean upper ocean salinity. The total increase in FW volume was estimated to be 1100 +/- 250 $km^3$ which was exported completely from the Lincoln Sea again by 2011. The anomaly was characterized by a combination of fresh waters from the northern Canada Basin extending to the western Lincoln Sea, and from the Makarov Basin north of the Mendejeev Ridge in the central to eastern Lincoln Sea

Newton et al. (2013):

- Canadian basin freshwater sources and changes: Results from the 2005 Arctic Ocean Section.
- Most of the water in the Arctic Ocean is derived from North Atlantic sources, with a relatively constant salinity between about 34.9 and 34.95 psu.
- The authors take the point of view that the basic water mass is North Atlantic water, to which Pacific Inflow, precipitation and river runoff have been added. Since North Pacific water is significantly fresher than North Atlantic water (S ~ 32.5 versus S ~ 34.9); all three of these additions are freshwater sources.

Rabe et al. (2013):

- Paper & Workshop Presentation
- Surveys between June and September.
- Liquid freshwater content above the 34 isohaline.
- Positive trend of about 600Å}300 km3 yr-1 (12000 km3) between 1992 and 2012
- Fresh and cold waters from the upper Arctic Ocean are transported southward by the East Greenland Current (EGC) in the Western Fram Strait, over the continental slope and the Greenland shelf. The EGC transports liquid freshwater and ice from the Arctic to the Nordic Seas, the Denmark Strait and the North Atlantic. Once in the North Atlantic, this freshwater and ice melt have the potential to influence deep convection and the thermohaline overturning (Rabe et al., 2013).
- Findings
    - southward liquid freshwater transport between 10.6 W and 4E of 100± 23 mSv (3160± 730 km3 yr−1 ), relative to a salinity of 34.9.
    - Recent observations of increasing liquid freshwater storage in the Arctic Ocean since the 1990s and model simulations suggest a decreased export of liquid freshwater; results from the six surveys do not suggest a trend in Arctic liquid freshwater export through the upper Western Fram Strait.

Somavilla, Schauer & Budeus (2013):

- Temperature and salinity have increased in the deep Greenland Sea originating from the advection of the Arctic Ocean deep waters and the necessary transports – in waters below 2000m.
- Absence of deep water convention in Greenland Sea deep water means Eurasian Basin

water providing fresher and colder waters are accumulating in the deep Greenland Sea. Expect to acquire properties of Eurasian Basin deep water within about 10 years.

Spall, M.A. (2013):

- On the Circulation of Atlantic Water in the Arctic Ocean.
- [article provides a good overview of the Arctic ocean topography].
- Arctic Ocean is semi enclosed marginal sea, connected to lower latitude oceans through several shallow and/or narrow passages – Fram Strait, Barents Sea.
- Surface waters over the shelves in the Arctic are much fresher than the Atlantic water entering through Fram Strait (due to water coming in from Barents Strait, river runoff and precipitation).
- The halocline is perhaps the most prominent feature of the Arctic hydrography. The model produces a strongly stratified, fresh surface layer that overlies the deep, weakly stratified warm and salty Atlantic Water.
    - Halocline has a salinity surface of 34.6.
    - Influence of freshwater flowing from the western basin into the eastern basin over the northern ridge gap is evident and leads to a deepening of the halocline in the eastern basin.
- Recirculation of Atlantic water in the eastern basin driven by strong gradient in upper ocean salinity in the basin interior.
- Total salt content nearly constant in the basin interior.
- The freshwater content is zero where the Atlantic Water flows into the basin and gradually increases cyclonically around the basin. This is partly a result of vertical diffusion bringing freshwater downward below the restoring region, which maintains low salinity in the upper 50m.
- Finding that freshwater fluxes are driving forces of circulation of Atlantic Water into Arctic Basin. The exchange and mixing is regulated by the ability of eddies to transport water from the boundary current into the basin interior.

Jackson, Williams & Carmack (2012):

- Winter sea-ice melt in the Canada Basin, Arctic Ocean.
- Results from ITP1 show the presence of a near surface temperature maximum that is about 0.3°C above the freezing temperature at a depth of 10– 25 m from at least mid-August through the beginning of October.
- Observations from ITP1, ITP18, and ITP33 suggest several mechanisms that enable the erosion of the summer halocline and the release of heat from the NSTM into the SML (between 2007 and 2010).
- The gradual weakening of the summer halocline throughout winter. This weakening is likely caused by the cumulative effect of wind and ice mixing and brine rejection. Data from ITP1, ITP18, and ITP33 suggest that the summer halocline is weakest in spring, sometime between March and May.

Morrison et al. (2012):

- Changing Arctic Ocean freshwater pathways.
- The upper waters of the Canada Basin were 1–3 practical salinity units fresher in 2008 than the pre-1990s climatology and 1–2 units saltier in the Makarov Basin. The changes were found to be due to a re-routing of Siberian river runoff associated with changes in the phase of the Arctic Oscillation.
- Show a change in average freshwater inventories in the top 195 m of the Beaufort Sea are 0.6m of sea ice melt, 20.8m of Pacific water and 3.6m of Eurasian runoff, with a total increase of 3.4 m.
- Freshwater content changes are dominated by strong increases in the Canada basin balanced by decreases in the Eurasian basin and along the Russian shelf-break, reflecting change in Eurasian runoff pathways. Findings reveal the freshwater changes were due to a cyclonic (anticlockwise) shift in the ocean pathway of Eurasian runoff forced by strengthening of the west-to-east Northern Hemisphere atmospheric circulation characterized by an increased Arctic Oscillation9 index.
- Results confirm that runoff is an important influence on the Arctic Ocean and establish that the spatial and temporal manifestations of the runoff pathways are modulated by the Arctic Oscillation, rather than the strength of the wind-driven Beaufort Gyre circulation.

Rabe et al. (2011):

- Liquid freshwater in the Arctic Ocean consists of input from Eurasian and North American river runoff, coastal the Norwegian coastal current via the Eurasian shelves, precipitation, ice melt and the inflow from the Pacific through the Bering Strait.
- Sinks of LFW are the export through the Canadian Arctic Archipelago and the western Fram Strait, and the formation and export of sea ice. In flow of saline Atlantic Water (AW) occurs through the eastern Fram Strait and, in modified form, via the Barents Sea.
- Subsequent to 1995, the model studies show an accumulation of LFW in the Arctic Ocean and a decrease in LFW export up to 2001. Over the whole Deep Arctic Ocean, the observed LFWC increased by 8400km3 between the time periods1992–1999 and 2006–2008. Over the whole domain, changes in the observed depth of the 34 isohaline lead to a redistribution of LFW and did not significantly influence the LFW content overall. In many regions, the changes in the depth of the 34 isohaline lead to changes in LFW. The observed LFW changes were largely due to a freshening of the layer above the 34 isohaline (summer).

Timokhov, L. et al. (2011):

- Extreme Variations of the Arctic Ocean during and after IPY 2007/2008
- Focus is on extreme changes from 2007-2010.
- The most distinct variations of the hydrographic conditions were observed in the Canadian Basin. In general, the maximum of the AW temperature decreased in 2009 relative to 2007 and the upper boundary became shallower by 50 to 150 m the Eurasian Basin. The AW salinity in 2007-2009 was not exceptional during the International Polar Year.
- The seasonal range of the water temperature in summer of 2007 was 4.0 °C, which is 15 to 20 times larger, compared to average values for this region while the seasonal variation

of salinity was in the range of 2.0-2.5, which is five times greater than the average variability in the region- in the Canadian Basin.

- extreme salinity anomalies observed in summer 2007 – southern part of Makarov Basin and in Canadian Basin.
- The total volume of Atlantic Water with a temperature above 0 °C and salinity of more than 34.6 increased in 2007 by 22 % compared to the 1970-1979 decade.
- The analysis performed allows the conclusion that after 2007, the signs of temperature and salinity anomalies of the surface layer in the Eurasian and Canadien basins were in general preserved, although the areal distribution varied and the intensity of the anomalies also changed. The basin scale differences of the salinity in the surface layer decreased. The above analysis suggests that the thermohaline structure of the surface layer in 2008 and 2009 returned to an average climatological state.

Jackson et al. (2010):

- Identification, characterization and change of the near-surface temperature maximum in the Canada Basin, 1993-2008.
- NSTM forms when sufficient solar radiation warms the upper ocean. A seasonal halocline forms in summer once enough sea ice melt has accumulated to separate the surface mixed layer from the NSTM. The NSTM becomes trapped below the summer halocline, thereby storing heat from solar radiation.
- Pacific Summer Water has a salinity of 31-33.
- Distinction between the winter mixed layer, which has near- uniform salinity and temperatures near the freezing point, and the summer upper layers (the layer that occupy the upper ~ 50 m), which are freshened by ice melt and river inputs and warmed solar radiation and are thus highly stratified.