The Norwegian Scientific Academy for Polar Research

The Arctic Ocean and the Marginal Ice Zone (MIZ)

NVP Summer School

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Abstract

The report combines insights into the Marginal Ice Zone (MIZ), achieved during the PhD/Postdoctoral Summer School organized by the Norwegian Academy for Polar Research (NVP) in Longyearbyen. This report presents the conclusions from the summer school lectures and discussions. We summarize our gained knowledge about different properties of the MIZ, related processes and their implications for economic activities and Arctic governance. We focus on an interdisciplinary approach to understand the MIZ, to highlight that the occurring Arctic change has potentially profound implications for both the natural environment and human activities. The report discusses the MIZ from natural sciences' perspective and focuses on its properties. Additionally, the relations of the MIZ with human activities and governance is also addressed.

We draw on our own (participants) conclusions about how the gained knowledge sheds the new light on our perceptions about future tourism development within the MIZ, as a case study, which was not studied in detail so far. Tourism is a fast-growing industry in the Arctic that requires an adequate understanding of the fast changing and unpredictable MIZ, in order to ensure sustainable development of the region. The relations between the MIZ and tourism are studied in the contexts of natural and built environment, infrastructure development, oil and gas exploration, shipping activities, management and law regulations. It is concluded that tourism in the MIZ should be studied as a complex discipline, which takes into account natural and anthropogenic values and vulnerabilities of the MIZ, as well as challenges and opportunities caused by climate change and technology development.

Supported by the Norwegian Scientific Academy for Polar Research (NVP), together with the University Centre in Svalbard (UNIS), the Arctic University of Norway (UiT), the Nord University, the Norwegian Polar Institute (NPI), Akvaplan-niva, the Nansen Environmental and Remote Sensing Center (NERSC), the Nansen Scientific Society and the Russian Geographical Society (RGS). the Norwegian Research Council (NFR).

UNIS The University Centre in Svalbard · UiT The Arctic University of Norway · NORD University · Norwegian Polar Institute · Akvaplan-niva · NERSC · All-Russian non-governmental organization RUSSIAN GEOGRAPHICAL SOCIETY Founded in 1845 · Nansen Scientific Society

The Arctic Ocean and the marginal ice zone (MIZ). Interdisciplinary research, management practices and policy developments.

An interdisciplinary PhD and Post-Doc summer school in Longyearbyen, Svalbard
31 July - 6 August 2017

Introduction

The consequences of climate change are particularly evident in the Arctic. In recent years, we have witnessed significant changes and reductions in Arctic sea ice distribution and volume. Seized as an opportunity, plans are being made for expansion of economic activities such as shipping, fisheries, petroleum extraction and deep-sea mining. Changes in ice cover and distribution will have consequences for national and international management regimes.

This new situation represents challenges for scientists, managers and policy makers and for the private sector. More and better communication between different parts is required, and the best way forward needs to be further developed for sound management and sustainable use of the Arctic oceans' vast renewable and non-renewable resources.

The international summer school in Longyearbyen, Svalbard 2017 will have a multi- and cross-disciplinary thematic approach to meet challenges and opportunities related to governance of the Arctic Ocean's marginal ice zone. The summer school is hosted by the Norwegian Scientific Academy for Polar Research (NVP), in cooperation with the University Centre in Svalbard (UNIS), UiT – the Arctic University of Norway, the Nord University, the Norwegian Polar Institute (NPI), Akvaplan-niva, the Nansen Environmental and Remote Sensing Center (NERSC), the Nansen Scientific Society and the Russian Geographical Society (RGS). Scientists and experts from Norway and abroad will contribute with lectures and with interactive student and teacher sessions. The participating students will be challenged to start drafting a peer-reviewed publication for an international journal.

Summer school coordinators:

- Professor Willy Østreng; the Norwegian Scientific Academy for Polar research (NVP)
- Lasse H. Pettersson; Director for International Cooperation and Marketing, the Nansen Environmental and Remote Sensing Center (NERSC)
- Jorge Kristiansen; Office Manager, the Norwegian Scientific Academy for Polar research (NVP)

Saturday 29th July: Arrival in Longyearbyen Group 1, transport to Nybyen/UNIS

20.20	SK4494 arrival at LYR - Group 1
20.50	Bus to Nybyen and UNIS Guesthouse. Check in at accommodation.

Sunday 30th July – Registration; Location: UNIS - Kapp Wijk

09.30-11.00:	Group 1 – Orientation / Registration at UNIS – the University Centre in Svalbard (≈3 km from Nybyen, individual walk) - Breakfast – UNIS Kapp Wijk

Monday 31th July, Arrival in Longyearbyen Group 2, transport to Nybyen/UNIS

00.30	SK4496 arrival at LYR - Group 2
01.00	Bus to Nybyen and UNIS Guesthouse. Check in at accommodation.

Monday 31th July, Location: UNIS Lassegrotta / Kapp Wijk
Session 1: Introducing NVP and the Summer School 2017.
Session chair: Lasse H. Pettersson, Director for International Cooperation and Marketing/ NERSC.

08.30-09.00:	Group 2 - Orientation / Registration at UNIS – the University Centre in Svalbard (≈3 km from Nybyen, individual walk)	
09.00-09.30	Breakfast – UNIS Cantina	
09.30-10.10	Welcome and brief information about the NVP President Dr. Anton G. Kjelaas, NVP Organization of the summer school, interdisciplinary approach, and group work. Lasse H. Pettersson, NERSC	
10.10-11.00	Student life at UNIS & Safety briefing: Security and risk in Svalbard. Jorge Kristiansen - UNIS	
11.00-12.00	Lunch – UNIS Cantina	
12.00-14.10	Presentation of the lecturers (2 min) and student participants - (10 min. per person including questions) – presentation - Relevant studies and the relation to the summer school topics.	
	1. Values of the MIZ (6)	**2. Vulnerability of the MIZ (6)**
	Marius Årthun – *Climate predictions.*	Bernhard Schartmüller - *Underwater hyperspectral imaging – Light and algae growth under arctic sea ice.*
	Elena Sukhikh - *Water temperature variability in northern part of the Barents-Kara region and its influence on geothermal measurements results.*	Hanna Kauko - *Windows in Arctic sea ice: optical and biological studies of a refrozen lead.*
	Anastasia Korablina - *Storm surges in the White and Barents Seas: formation, statistics, analysis.*	Robynne Nowicki - *The effects of UV-B radiation on the physiology and biochemical composition of Arctic phytoplankton.*

	Charles Brunette - *Regional and seasonal forecasts of sea ice in the Arctic Ocean.*	Anastasiia Baxhenova - *Risk's concentrate zones on the Arctic and Far East Seas.*
	Anastasiia Mishchenko - *Ecogeochemistry mapping heavy metals and toxical elements in the bottom sediments of the deep central part of Barents Sea.*	Thomas Ronge - *(Ant)arctic affairs.*
	Lisa Griem - *Ocean circulation changes off southern Greenland during the abrupt climate events of mid-to-late MIS 3*	Liudmila Nikanorova - *How climate change affects religious practises of indigenous people?*
14.10-14:30	Coffee break – UNIS Cantina	
14:30-17:00	**3. Exploitation of the MIZ (6)**	**4. Management & Regulations (5)**
	Alix Varnajot - *Arctic tourism development: limits to growth in nature-based tourism – case Iceland and Svalbard.*	Diwarka Poudel - *Managing variable environmental values in the Arctic marginal ice zone, sea ice zone, and polar front.*
	Elena Guk - *Modeling tourist and recreational system for Norilsk region.*	Meri Korhonen - *Hydrography of the Arctic Ocean.*
	Marta Bystrowska - *Cruise tourism in Svalbard: development imperatives.*	Kari Dalen - *Enabling smart and green energy solutions while maintaining security of supply.*
	Sigurd Teigen - *Metocean and Arctic Design.*	Ilker Basaran – *Law and Arctic Shipping Governance.*
	Bimochan Niraula - *Partitioning of Ocean Heat between the Fram Strait and Barents Sea Opening.*	Marina Antonova - *International law on the black carbon mitigation in the Arctic.*
	David Palma - *SINet: Software-defined Intermittent Networking.*	
17.00-18.00	Dinner – UNIS Cantina	
18:00-19:30	Group work: Establishment of student groups	

Tuesday 1st August, Location - NVP Academy – Isdammen

Session 2: Framing the course and introducing the lectures.
Session chair: Professor Phil Steinberg, Durham University.

08:30	*Bus from NyByen to UNIS to Isdammen*
09.00-09.50	The Marginal Ice Zone: Variability and future projection - A brief review. Prof. Ola M. Johannessen, Nansen Scientific Society.
09.50-10.30	Inter-and transdisciplinarity in polar research: Why? Listen to others and understand others. Prof. Willy Østreng, NVP
10.30-10.45	Coffee break
10.45-11.30	Politics and Imaginaries in the Circumpolar North. Prof. Phil Steinberg, Durham University.
11.30 – 12.20	Satellite observation of sea ice - a key to safe operations in the marginal ice zone. Prof. Stein Sandven, NERSC
12.30-13.30	Lunch - Isdammen
13.30-15:30	Group preparations of questions (30 min) Plenary questions from students and discussion with the lecturers.
15.30-17.00	Group work: Preparations of students' reports and presentations for use in peer review article. Plenary discussion among the groups.
17:00-17:30	Walk to UNIS
17.30-18.30	Dinner – UNIS Cantina
18:30-19:00	*A sense of adventure* – The Life of Fritdjof Nansen

Wednesday 2nd August, Location: UNIS – Lassegrotta

Session 3: Marginal Ice Zone Management and Policy Challenges in an international policy context. Session Chair: Professor Dr. Denis Alexeev, Russian State Hydrometeorological University.

09.00-09.40:	The MIZ in the context of the terror balance. Prof. Willy Østreng, NVP
09.40-10.30	Navigating the Arctic and a changing MIZ. Prof. Scott Stephenson, University of Connecticut.
10:30-10:50	Coffee break
10.50-11.40	Russia's foreign and security policy with reference to a changing Arctic and the MIZ. Prof. Dr. Nikita Lomagin, the European University at St. Petersburg.
11.40-12:30	Slippery Ice: Mapping and Knowing the Polar Environment. Prof. Phil Steinberg, Durham University
12.30-13.20	Lunch
13:20-14:10	Future industry development and sea transportation in the Arctic. Prof. Odd Jarl Borch, Nord University
14.10-14:40	Climate variability and change in the Eurasian Arctic, a Norwegian-Russian Project-CLIMARC NORRUSS. Prof. Ola M. Johannessen, Nansen Scientific Society.
14.40-17:30	Group preparations of questions (30 min) Plenary questions from students and discussion with the lecturers (60 min). Group work: Preparations of students' reports and presentations for use in peer review article (30 min).
17.30-18.30	Dinner – UNIS Cantina
18.30-19.30	**Public lecture at UNIS-Lassegrotta** GoNorth – Geosciences in the northern Arctic – a national research initiative. Prof. Matthias Forwick (UiT)

Thursday 3rd August. Location: UNIS – Lassegrotta

Session 4: Marginal Ice Zone Management and Policy Challenges. Local, National and International Management contexts.
Session Chair: Professor Dr. Nikita Lomagin, the European University at St. Petersburg.

08.45-10.00	The local perspective from Longyearbyen: Challenges and opportunities for sustainable development as a result of the increasing activity in the Arctic. Discussion panel: • Terje Aunevik, Svalbard´s Camber of Commerce • Merete Nordheim, Basecamp Spitsbergen • Ronny Bruvoll, Visit Svalbard Moderator: Dr. Anton G. Kjelaas, NVP
10.00-10.30	Ice Matters: Plans and Probabilities in the Barents Sea. Prof. Phil Steinberg, Durham University.
10.30-10.40	Coffee break
10.40-11.30	The governance of the Arctic and the MIZ as an Object of Regulation. Prof. Willy Østreng, NVP
11.30-12.15	Russian perspectives on international cooperation related to a changing Arctic and the MIZ. Prof. Dr. Nikita Lomagin, the European University at St. Petersburg.
12.15 – 13.00	Group preparations of questions Plenary questions from students and discussion with the lecturers.
13.00 - 13.30	Lunch – UNIS Cantina
13.30-14:20	**Shipping on the Northern Sea Route:** Legal and jurisdictional issues, icebreaking, commercial outlook and drivers, Asian interest in NSR, alternative transportation corridors. Arild Moe, Senior Research Fellow - The Fridtjof Nansen Institute.
14.30-16:30	Visit to SvalSat
17.00-17.30	Dinner – UNIS Cantina
17:30-18.30	Group work: Preparations of students' reports and presentations for use in peer review article.
18.30-19.30	**Public lecture at UNIS-Lassegrotta** Canadian Arctic Policy – A Careful Balance. Bob Paquin; Director - Canadian International Arctic Centre

Friday 4th August, Location: UNIS – Lassegrotta

Session 5: Marginal Ice Zone Management and Policy Challenges, continued. National and International Management contexts.
Session chair: Professor Willy Østreng, NVP.

09.00-09.50:	Monitoring and forecasting of the MIZ. Lasse H Pettersson, Director International Cooperation - NERSC
09.50-10.40	Consequences of MIZ expansion for the Barents Sea ecosystem. Prof. Paul Renaud, Adjunct professor - UNIS and Senior Scientist - Akvaplan Niva.
10.40-11:00	Coffee break
11.00-12.00	The MIZ in the context of Arctic marine ecosystems and ecological sustainability. Prof. Dr. Denis Alexeev, Russian State Hydrometeorological University, St. Petersburg
12.00-12.30	Lunch
12.30-13.00	The Ice Edge and Oil Exploration. Dr. Anton G. Kjelaas, NVP
13:00-13:30	Arctic Safety Centre UNIS. Ann-Christin Auestad, UNIS
13.30-14.45	Group preparations of questions (15 min) Plenary questions from students and discussion with the lecturers.
14.45 -18.00	Group work: Preparations of students' reports and presentations for use in peer review article.
18:00	Dinner – UNIS Cantina

Saturday 5th August. Location: UNIS / Isdammen

08:30-11:00	UNIS Kapp Wijk - Group work: Preparations of students' reports and presentations for use in peer review interdisciplinary article.
11.00-16:00	Outdoor: Hike around Longyearbyen Starting point: UNIS
16:00 – 20:00	Dinner: Summer BBQ – Isdammen (Outdoor)

Sunday 6th August; Location: UNIS – Lassegrotta

Session 6 - Reporting and conclusions
Session chair: Lasse H. Pettersson, NERSC
Moderators: Prof. Willy Østreng, Dr. Anton G. Kjelaas.

08:30 - 12.00	**Reporting, discussion and schedule for finalizing the report/paper from the summer school.**

Departures

13:00	Departure Group 1 - Buss from UNIS to LYR airport for departure.
14:45	Flight SK4425 LYR-TOS-OSL, scheduled arrival in Oslo @ 1900.
	Monday 07.08.17
01:00	Departure Group 2 - Buss from UGH and Nybyen to LYR airport for departure.
02:30	Flight SK4497 LYR-TOS-OSL, scheduled arrival in Oslo @ 05.30.

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List of Acronyms

AIS	Automatic Identification System
AO	Arctic Ocean
AW	Atlantic Water
BC	Black Carbon
BSBW	Barents Sea Branch Water
CO_2	Carbon Dioxide
dGPS	Differential Global Positioning
DP	Dynamic Positioning
FSBW	Fram Strait Branch Water
FYI	First-Year Sea Ice
GEO	Geostationary Earth Orbit
GHG	Greenhouses Gases
HF	High Frequency
HFC	Hydrofluorocarbon
HFO	Heavy Fuel Oil
ICT	Information and Communication Technologies
IMO	International Maritime Organisation
MIZ	Marginal Ice Zone
MF	Medium Frequency
MYI	Multi-Year Sea Ice
N	Nitrogen
NH	Northern Hemisphere
NLS	Noxious Liquid Substances
NSIDC	National Snow and Ice Data Center
OC	Organic Carbon
PAME	Protection of the Arctic Marine Environment
PM	Particulate Matter
SaR	Search And Rescue
SAR	Synthetic Aperture Radar
SIC	Sea Ice Concentration
SLCP	Short-lived Climate Pollutant
SOx	Sulphur Oxides
VHF	Very High Frequency
VOC	Volatile Organic Compound

UNCLOS United Nations Conventions of the Law of the Sea

1 Introduction

This report presents an overview of the Marginal Ice Zone (MIZ) as it stands today, including several different perspectives and the foreseen impact of climate change to the future of the MIZ. This overview is included in Chapter 2, addressing the question of how to define the MIZ and its boundaries. Its importance from the bio-ecological and economic perspectives is also discussed, as well as the foreseen future of the MIZ taking into account climate change and its impact.

The properties of the Marginal Ice Zone are discussed in Chapter 3, addressing key issues of Arctic amplification, namely concerning the constantly evolving MIZ and related aspects, such as ice concentration and threatened biological processes. This discussion raises the question about the importance of the MIZ and its value not only for its surrounding ecosystem but also to the entire planet and humanity.

With all its vulnerabilities, the Marginal Ice Zone provides several different opportunities for exploitation. These opportunities and existing challenges are discussed in Chapter 4, considering both risks to the environment and humans. These risks demand appropriate mechanisms and infrastructures, supported by clear rules and legislation.

The governance of the Arctic region and related legal aspects are discussed in Chapter 5, presenting the current state of international cooperation efforts, as well as the issues of geopolitical shifts due to the receding Marginal Ice Zone.

A case study about the value and exploitation of the MIZ is presented in Chapter 6, describing the potential of Arctic Cruise Tourism, challenges, perspectives and the impact of such activities on host communities and indigenous cultures. In addition, this study covers management and regulation efforts towards sustainable activities and the mitigation of emissions.

Finally, Chapter 7 revisits the key points covered by this report, providing insights and future steps towards better understanding and respecting the Marginal Ice Zone.

2 Background

2.1 What is the MIZ where it can be found?

The Marginal Ice Zone (MIZ) in the Northern hemisphere is a part of the Arctic Ocean highly related to the state of sea ice. Therefore, what the MIZ is cannot be explained without understanding sea ice changes in the Arctic.

The retreating perennial sea ice cover is one of the most visible manifestations of ongoing climate change in the Arctic (Johannessen et al., 2004; Serreze et al., 2007; Johannessen, 2008; Wang and Overland, 2012). The observed changes over the satellite-period since 1979 including 2016 include a $35\,\%$ reduction in Arctic summer (September) sea ice extent, a $15\,\%$ reduction in winter (March) and annual reduction of $10\,\%$[1], a significant thinning (Kwok and Rothrock, 2009), a start of transition from multi-year to first-year ice (Johannessen et al., 1999; Maslanik et al., 2011), and extended melt seasons (Stroeve et al., 2014). Future projections show that the Arctic summer sea ice cover will continue to decline under a warming climate, which could lead to ice-free conditions in the Arctic Ocean in summer under a doubling of Carbon Dioxide (CO_2) (Johannessen et al., 2004) or by the middle of this century (Stroeve et al., 2007; Wang and Overland, 2012; Notz and Stroeve, 2016). The ice volume has also been dramatically reduced, during summer with about $70\,\%$ and during winter about $20\,\%$ (Zhang et al., 2017).

Since 2005, also a rapid northward retreat of winter ice edge has been witnessed (Comiso, 2006; Perovich, 2011). Unlike the summer ice extent, the most remarkable change in the winter ice cover has occurred in the eastern Arctic Ocean, especially in the Barents Sea (Comiso, 2006; Årthun et al., 2012). The reduced ice cover and increased navigability opens new opportunities for human activities, such as tourism, in the MIZ and the Arctic region.

The ice extent is generally defined to include areas where ice concentration exceeds $15\,\%$. However, the transition zone where the gradient of ice concentration changes from open water to consolidated ice pack cannot be drawn with a line but covers a much broader area. This Marginal Ice Zone (MIZ) is a highly dynamic region, where atmosphere, ice and ocean interact including generation of abundant ice edge eddies (Johannessen et al., 1987) important for melting of the ice edge of up to 1–$2\,\mathrm{km}$ per day. Assuming that ice edge eddies are present 150 days per year along the $2000\,\mathrm{km}$ ice edge in the Greenland Sea, this will cause an annual melt of $300\,\mathrm{km}^3$ which is about $10\,\%$ of the annual transport of ice past 79° North (Johannessen et al., 1994). Furthermore, ice edge wind-driven upwelling (Johannessen et al., 1983) take place when the wind direction is parallel with the ice edge when the edge is to the right of the wind direction caused by stronger wind stress over the ice, important for the biological productivity during the light season and for preconditioning of deep water during the winter time. The above results were among the mesoscale process studies achieved during the major international experiments; the NORSEX 79, MIZEX 83-84-87 and SIZEX 89 in the MIZ of the Barents Sea, Fram Strait and Greenland Sea, see Johannessen et al. (1992) for an overview and results from these large experiments (e.g. in MIZEX 84 more than 200 scientists took part from 11 nations using seven ships including three icebreakers, eight remote sensing aircraft, four helicopters and four satellite systems).

[1] `arctic-rose.org`

Since these investigations, which resulted in new fundamental understanding of the MIZ, only small sporadic field investigations have been carried out in the MIZ.

When it comes to explaining what the MIZ is, Strong (2012) defined the Marginal Ice Zone (MIZ) as the area where ice concentration changes from 15–80 %. Another definition of the MIZ is based on the distance how far into the pack ice the waves can penetrate before they become attenuated (Squire et al., 1995). By providing energy for breaking up ice floes, the waves determine the floe size distribution in the MIZ, with typically larger floes deeper in the ice pack and smaller floes in the vicinity of open ocean. The MIZ width varies in time and space, typically from 50 to 300 km (Dumont et al., 2011; Strong, 2012)

Currently, the winter ice edge in the eastern Arctic Ocean extends along the Greenland coast south of Denmark Strait. Even in summer, the northern Greenland coast and the western side of Fram Strait stay covered by ice. The area north of Svalbard, however, remains generally ice free even during winter due to the warm Atlantic inflow. In contrast, Franz Josef Land and Novaya Zemlya are typically surrounded by ice while the southern extension of the ice edge in the Barents Sea during winter is limited by the strong topographical Ocean Polar Front (Johannessen and Foster, 1978; Association of Old Crows, 2017) where the ocean temperature changes from freezing temperature to warm water due to the inflow of the warm Atlantic water. In summer, the Franz Josef Land, Novaya Zemlya and Laptev Sea, with some exceptions of fjords and near shore areas, are free from ice while the ice edge in the Barents Sea moves northward.

2.2 Why is the MIZ important/interesting?

2.2.1 Bio-ecological perspectives

The Marginal Ice Zone is highly enriched by several biological, ecological and economic resources, they are extremely dynamic and influenced by climatic and anthropogenic factors in the recent years. The ecosystem host a vast array of over 2000 species of algae, tens of thousands of microbes, over 5000 animal species, large population of seabirds and sea mammals including unique and rare species (Michel et al., 2013), in addition to the other extractable natural resources. The MIZ and ice-edge habitats in general are important for many Arctic, endemic species, and, many of these are red listed nationally and internationally (NPI, 2014). Sea ice provides a unique and valuable habitat (NPI, 2017), crucial for some Arctic marine mammals that are sea ice obligates, meaning their life history events (e.g. reproduction, molting, resting) and feeding depend on sea ice, whereas others use ice but do not depend on it completely (Laidre et al., 2015, 2008). In addition, these habitats concern many migratory species and disturbances may therefore have consequences for the population levels of many species (NPI, 2017). There are at least 11 species of Arctic marine mammals particularly endangered as a result from their dependence on the conditions of sea ice (Laidre et al., 2015, 2008; Kovacs et al., 2011). A large concentration of many species, often in very limited areas in the Marginal Ice Zone, mean that these species are very vulnerable. For instance, in late summer, 80–90 % of the global population of ivory gulls are in the marginal ice zone in the Barents Sea (NPI, 2014).

With the reduction in the sea ice, the mean position of the Marginal Ice Zone is moving steadily further northwards and eastwards. This also affects the ecosystem of the sea ice and the MIZ. The vulnerable species and habitats associated with it are shifting in the same direction (NPI, 2014). The ecosystem of the MIZ is highly vulnerable to climate change, which is the largest threat to Arctic species and ecosystems (CAFF, 2013). A reduction in the area of sea ice available will also have an impact on ice-dependent species, and thus on production conditions and biodiversity in areas with a seasonal ice cover (NMCE, 2016). The climate change affects the health of the marine species and their ecosystem (Burek et al., 2008).

Consequently, changes occurring in the MIZ influence inhabiting species and may pose a threat to the local ecosystems, as well as wider Arctic ecosystems. Besides, it brings further consequences for human activities, including tourism (in a form of natural attractions) and fisheries, as related to biological aspects of the MIZ.

2.2.2 Physical perspective: water mass formation

Atlantic Water (AW) is the main source of heat for the Arctic Ocean (AO). The Arctic sea ice is protected by the halocline layer from the AW heat flux from beneath. In recent years, the thickness of halocline layer was reduced and sea ice has less protection from AW heat. There is a strong negative correlation between AW temperature on the main ocean gateways (Fram Strait and Barents Sea Opening) and sea ice extent for the Eurasian Basin. Also, there are some differences between the features of the two branches of AW expansion in the Arctic Ocean. Fram Strait Branch Water (FSBW) comes to the AO through Fram Strait with average depth near $2400\,\mathrm{m}$. During the propagation to the East under the ice cover, the FSBW conserves its thermal properties. The TS-characteristics of Barents Sea Branch Water (BSBW), which comes through the Barents shelf, depend on a number of factors: bottom topography, ice melting/formation processes and interaction with atmosphere. Therefore, the Barents Sea is one of the major areas for the formation lower halocline water, which is important for the stratification in the Arctic Ocean (Steele et al., 1995). The Barents Sea is also a location where high density water, contributing to the global thermohaline circulation, is produced.

When the ice edge retreats north, the MIZ is removed from the shallow marginal seas to overlay the deep basins. This may have profound effects on the maintenance of the Arctic halocline and deep water formation. Formation of high density water is often associated with polynyas: in the polynyas west of Novaya Zemlya up to $10\,\mathrm{m}$ of ice can be formed annually (Winsor and Björk, 2000). When brine is added into the surface layer, it sinks and accumulates in the bottom of the shallow shelf. Hence the density of the water mass is able to increase before it cascades into the depths of the Arctic Ocean. However, recent years have indicated that warmer Atlantic water is present in the Barents Sea (Skagseth et al., 2008), slowing down or preventing ice (Comiso, 2006; Årthun et al., 2017), and consequently also deep water, formation. In the future, with less ice in Barents Sea, the heat loss to the atmosphere during winter and the presence of more saline Atlantic water might compensate for the brine rejection from the sea ice and some models also predict intensification of deep water formation.

Furthermore, Polyakov et al. (2017) shown that Atlantic Water inflow through the Fram Strait during the recent years has increased into the Eurasian Basin, causing shoaling of the intermediate depth Atlantic Water with increased release of heat which is reducing the winter sea ice cover in the Eurasian Basin which they named “atlantification” of the Arctic climate state. Chatterjee et al. (2017) has also shown that the increased inflow of Atlantic Water in recent years both in the Fram Strait and Barents Sea is closely linked to the barotropic gyre circulation of the Nordic Seas driven by the wind stress curl implying that the Nordic Seas is not only a passive conduit of the Atlantic Water inflow to the Barents Sea and Fram Strait.

2.2.3 Economic perspective: human activities in the Arctic

The MIZ has, next to its physical and biological importance, also profound consequences for human activities in the Arctic. In August 2017 media announced that first tanker crossed Northern Sea Route without support of an ice breaker, opening new debates about Arctic sea ice loss and future of human activities in this part of the world. In the MIZ, several areas of human interest can be considered:

- Natural resources extraction
- Fisheries, including local and indigenous fisheries
- Tourism
- Shipping transportation
- Research
- Military and safety activities

Most of those activities are temporary activities and one of the main reasons for human presence in the Arctic. The Arctic is a home for around 4 million people (Larsen and Fondahl, 2014), but activities in the Arctic Ocean are often conducted by non-local stakeholders, such as international firms. Those stakeholders carry activities in the Arctic Ocean mostly on board of ships or oil and gas infrastructure (as oil platforms). Those varied economic activities can be a source of income for local, regional and national economies, but also pose a threat for sustainability of natural resources in the Arctic Ocean (e.g. oil spills).

Consequently, changes in the MIZ, such as its retreat northward or biodiversity change, pose a question about future human activities in the Arctic Ocean. For example, there are rising expectations for increased shipping activities in the Arctic Lasserre and Pelletier (2011); Pizzolato et al. (2014); Stephenson et al. (2013). When the big concessional cruise Crystal Serenity crossed North-West Passage in 2016, it was confirmed that sea ice is no longer the threat for commercial cruise tourism in the Arctic and the same cruise was planned again in 2017. Also in 2017, the first tanker crossed Northern Sea Route without an ice breaker. Supported by those examples, potential increasing shipping activities in the Arctic would require appropriate governance mechanisms, as well as increased safety measures and infrastructures to ensure successful operations in highly changing and unpredictable environment.

At the same time, human activities may also pose a threat for the environment within the MIZ, in a form of, for example, littering from cruise ships or oil spills and those potential threats should also be taken in future governance and management consideration.

The of changing power and geopolitical constellations in the Arctic are other emerging issues related to the changing MIZ.

2.3 The future MIZ: climate change and its impact on the MIZ

Records of increasing temperatures, melting glaciers, reduction of sea ice, among other indicators, are a reflection of the recent warming in the Arctic. Global temperatures are predicted to increase further during the 21^{st} century. In the Arctic, the temperatures are predicted to increase twice as fast as the rest of the world (Perkins, 2013; New, 2005; Hassol, 2004). *"The average annual temperatures are projected to rise by* 3 *to* 7 °C*, with the greatest warming occurring in the winter months (…) precipitation is projected to increase by roughly* 20 % *(…) snow cover is expected to decrease by* 10 *to* 20 %*"* (de Selliers, 2006). And the sea ice is expected to continue to decline significantly, reflecting less solar radiation and thereby increasing regional and global warming (Hassol, 2004).

Climate change influences the timing of ice formation and ice melt. To this contribute the action of winds, currents and temperature fluctuations, making the sea ice dynamic and resulting in a variety of ice types and features (contributors, 2018). This in turn will affect the timing, location and intensity of production in the water column. In the past 30 years, there has been a clear long-term negative trend in sea ice extent both in the Arctic as a whole and in the Barents Sea. In the Barents Sea, this decline has been observed both in summer and in winter (NMCE, 2016). There is also considerable inter-annual variability in sea ice extent.

As the thick multiyear ice disappears and seasonal ice becomes the dominant ice type in the Arctic Ocean, the ice cover becomes increasingly more sensitive to thermodynamic and dynamic forcing (Kwok and Cunningham, 2010; Perovich, 2011). When the ice concentration decreases and the fraction of open water increases, the amount of absorbed solar radiation by the ocean increases and the ice melt accelerates (Deser et al., 2000; Asplin et al., 2012). During autumn and winter, the heat flux from ocean to atmosphere and ice will keep the surface air temperature elevated and reduce ice formation (Johannessen et al., 2016).

Compared to the continuous ice cover, the loose, and often fragile, ice pack in the MIZ is mobile and fluid (Rampal et al., 2009). Thus, due to relatively small internal ice stress, the wind stress is easily transferred to the ocean through the freely drifting ice, promoting the generation of wind-driven waves (Overland and Preisendorfer, 1982). With the thinning of ice and increasing storm intensity in the Arctic, the ice becomes more easily fractured. Consequently, the MIZ width is predicted to increase (Dumont et al., 2011; Strong, 2012). Seasonal predictions on the location and width of the MIZ could become more difficult in the future as the sea ice cover becomes thinner and inter-annual variability increases (Serreze and Stroeve, 2015) and if the projection of an ice free summer in the middle of this century really will occur, there will be no MIZ for part of the year.

Exchange of momentum and heat at the ocean-atmosphere interface will increase especially during summer. Interestingly, these inflict opposite forces on the surface layer: the momentum will act to deepen the mixed layer (Rainville and Woodgate, 2009) whereas increased sea surface temperature and decreased salinity due to ice melt will act to enhance the stratification by introducing buoyancy. The implications on the vertical structure of the water column will be determined by the balance of these two forces. The vertical structure of the water column further influences the uptake of nutrients from deeper water masses and thus the biological productivity of the MIZ although sporadic windriven ice edge upwelling (Johannessen et al., 1983) will cause vertical transport of nutrients into the surface layer with increased biological production during the light season.

Those are just the examples of the future changes and its implications for local ecosystems. Profound consequences are related to the whole Arctic Ocean physical and biological environment, as well as for human activities. In the further parts of the report, properties of the MIZ, its changes and implications are discussed in more detail. The aspects related to tourism activities are highlighted as a case study example. This case study was chosen to avoid over-load of information by discussing all the other human activities, as well as because of being an emerging industry in the Arctic which is both highly related to the state of the MIZ (transport, routes, attractions) and to what influences the MIZ (e.g. pollution). It also represents shipping activity with conclusions that can be transferred also on other shipping activities in the Arctic.

3 Properties of the Marginal Ice Zone

The MIZ has several impacts across different domains, including human accessibility (Strong et al., 2017) and related activities. This requires the appropriate considerations regarding its physicality, biologic processes among others, regardless of the different existing views of the MIZ. In this section, we discuss in more detail what is the MIZ and its properties. We focus on the physical properties and related processes, which shape that state and development of the MIZ. We focus on the sea ice and Arctic amplification as the most profound manifestations of the occurring Arctic change. We also draw on the characteristics and changes related to its biological sphere, as crucial dimensions from both natural environment and human activity perspective.

3.1 Arctic Amplification: the reason for the changing and dynamic MIZ

On a global scale, average temperatures of 2005 to 2009 were higher by about $0.54\,°\mathrm{C}$, compared to the average of 1954 to 1980[1]. However, Arctic temperatures increased by $\approx 2\,°\mathrm{C}$ to $4\,°\mathrm{C}$ over the same time period. In a recent paper Johannessen et al. (2016) showed that the strongest increase of up to $3\,°\mathrm{C}$ occurred during winter time in the recent years compared the temperature of the Northern Hemisphere (NH) with now significant amplification during summer time compared to the NH. Several geophysical aspects, which are unique to the high latitudes, cause this effect, called the Polar or Arctic Amplification. Arctic amplification can be seen as one of the main triggers of changing the MIZ, so understanding this process is crucial to grasp why the MIZ is so unpredictable and fast-changing zone.

To understand Arctic amplification, we need to start with the realization that the incoming solar radiation is either absorbed or reflected by different terrestrial or marine bodies, such as sea ice. The ability of a body to reflect incoming solar radiation (light) is called albedo. Hence, the "whiter" an object is and/or the smaller the angle of the object to the light source (sun) is, the higher is the albedo or the objects reflectiveness. Due to the Earth's spherical shape, the Polar Regions have a much higher albedo and a larger area per incoming radiation, compared to the lower latitudes. These factors are the essential precondition for the permanent formation, and accumulation, of ice and snow in these areas. Compared to "blue" oceans and "green" land, ice and snow have a much higher albedo, meaning that the cryosphere is absorbing much less energy than the other systems. Increased solar intensity (e.g. by more atmospheric CO_2) may result in increased melting of ice and snow. If, for example, the sea ice is melting, the area of energy-absorbing water is increasing, while the albedo is decreasing, a so called a positive (self-enhancing) feedback; less sea ice resulting in increased melting. This process was coined Polar amplification, as temperature changes in the high Polar regions are amplified during fall, winter and spring (Johannessen et al., 2016) due to this positive feedback.

In addition, sea ice is acting as a lid, insulating the atmosphere from higher oceanic temperatures. This lid is effectively reducing the heat flow between the ocean and the atmosphere by about two orders of magnitude. This effect is of great importance for the latent and perceptible exchange of warmth between the ocean and the atmosphere, which controls the high variability of the MIZ to a large extend.

[1] meereisportal.de

With respect to the above-mentioned factors, the MIZ is particularly vulnerable as it is 1) occupying lower latitudes than the central Arctic, hence the general albedo of this area is lower; and 2) its patchy pattern of sea ice and open water allows for a higher heat flow in this area.

In the light of the current climate change and globally increasing temperatures, the combination of factors 1 and 2 position the MIZ into one of the most sensitive areas worldwide.

3.2 Properties of the sea ice within the MIZ

Vessels travelling to or through the Marginal Ice Zone (MIZ) have to take into account the physicality of it, especially related to the state, concentration and extent of the sea ice in the MIZ. In its most generic definition, the MIZ is a transition region between the pack ice and open ocean, but in between there is floating ice, which triggers numerous processes, as well as rises questions for human activities. To better understand what the MIZ is, we need to get more insight into Arctic sea ice and its characteristics. First order delimitations of the MIZ can be achieved by considering Sea Ice Concentration (SIC) and sea ice types.

3.2.1 Sea ice concentration

SIC is defined as the fraction of a reference area covered by sea ice. Sea ice concentration is generally retrieved via satellite measurements. A SIC of $0\,\%$ corresponds to an area of open water, while a SIC of $100\,\%$ corresponds to a fully ice covered parcel. SIC is therefore a parameter highly relevant for navigability. A choice of SIC threshold to define edges of ice can be made. Sea ice with concentration of $80\,\%$ and above is considered to be close ice (Hassol, 2004). It behaves like the continuous ice pack, with floe-floe interaction being very important when considering the momentum balance of sea ice. At lower SIC, sea ice is essentially driven by forcing from the winds and the oceanic currents and is considered to be in free drift. A conventional SIC threshold of $15\,\%$ is often used to discriminate whether an area is ice covered or ice free. This is for instance the threshold used by the National Snow and Ice Data Center (NSIDC) in the production of maps of sea ice extent. The SIC threshold used to define extent of sea ice can vary according to the needs or intentions of a research project or end-user. For example, the Canadian Ice Services use a $10\,\%$ threshold on SIC. Based solely on SIC, a generic definition of the MIZ could include all the ice with SIC $15\,\%$-$80\,\%$ that is located in the periphery of the ice pack. As mentioned, ice at lower concentration is responsive to wind and ocean forcing, hence making the MIZ a very dynamical area, down to weather timescales. However when the wind is lower ice edge eddies developed along the whole ice edge extent (Johannessen et al., 1987) causing upwelling in the center of the eddies, important for vertical transport of nutrient up into the surface layer. The same occurs for ice edge upwelling (Johannessen et al., 1983).

The MIZ can also be defined as the portion of ice covered seas that is significantly affected by open ocean waves (Dumont et al., 2011; Wadhams, 1986). Various other mathematical tools have been developed to assess width of the MIZ from concentration (Strong et al., 2017), but will not be investigated here.

3.2.2 Types of ice

Distinctions need to be made between different sea ice types and categories to better understand the nature of the MIZ. Multi-Year Sea Ice (MYI) consists of sea ice that survived at least one melt season, with thickness ranging from 2 to $5\,\mathrm{m}$, in contrast with First-Year Sea Ice (FYI), which is younger, with thickness from 30 cm to 2 m. The MIZ can be composed of a mix of ice floes of different shape, size, thickness and stage of development. Frazil ice is made of fine ice crystals, which then gather into grease ice, forming a slushy layer. When it thickens to approximately 10 cm, the resulting thin crust of ice is called nilas. Nilas will break under waves, swell and pressure, and the floes of various sizes can collide with each other, thickening and ridging. Pancake ice designs the round-shaped floes of about 10 cm thickness that display a rim made of other ice debris resulting from floe-floe collision. When the ice thickness reaches 30 cm it is considered to be FYI. A particularly hazardous type of ice for navigation is ridged ice, which results from convergence of ice floes and can result in thick ridges that reach several meters in thickness. The multiple manifestations of sea ice in the MIZ need to be considered as they respond differently to environmental forcings. The different types of sea ice consist of first-order physical constraints on biological processes and a challenge in terms of human activities in the MIZ.

3.3 Biological processes in the MIZ and its implications

Algal biomass and primary production in the marginal ice zone is seasonally high (Engelsen et al., 2002), which makes the area important. Light penetration is greater than in the pack ice and melting of the ice in the spring stabilizes the water column enabling the phytoplankton remain enough time in the photic zone, where nutrients were replenished during the winter (Leu et al., 2011; Sigler et al., 2016).

Changes in the Arctic sea ice cover, and its impacts on the ecosystem are exhaustively reviewed in Meier et al. (2014). Changes to the location or timing of this phytoplankton spring bloom can affect the higher trophic levels i.e. grazers (Leu et al., 2011; Sigler et al., 2016). Zooplankton ascending from the deeper water after the winter diapause and subsequent egg laying may be adapted to a certain time of the year, and shifting of the bloom peak (because of earlier light availability and water column stratification) could result in a mismatch between zooplankton consumption and food availability. Zooplankton in turn is food for e.g. fish and in that way, transfer the energy from primary production further in the food web. On the other hand part of the production sediments to sea floor and fuels the benthic food web, for which the location of the spring bloom is determining (Cochrane et al., 2009). Changes in the food web also affect the characteristics Arctic marine mammals like the polar bear (Ursus maritimus) (Meier et al., 2014).

Future trends in Arctic primary production are thus highly relevant for various of fields, but also largely unknown. Light availability in the Arctic is expected to increase because of decreasing and thinning ice cover (Nicolaus et al., 2012; Arrigo and van Dijken, 2015). However the nature (snow or water) and timing (before or after ice floe formation) of precipitation in future Arctic is important for snow pack height (Hezel et al., 2012) and thus for light transmittance through the snow and ice pack, as snow cover has a determining role in the light transmittance (Grenfell and Maykut, 1977; Perovich, 1990; Hamre et al., 2004). Nutrient dynamics in the Arctic ocean set the frame for the primary production (Tremblay et al., 2015). Mixing patterns are affected e.g. by the greater wind stress because of larger open water areas in future Arctic (Meier et al., 2014). The physical factors can affect both the community composition (Assmy et al., 2017) and the level of primary production (Arrigo and van Dijken, 2015), with implications for the ecosystem.The aforementioned unique and highly productive characteristics of the MIZ lead to a high-energy input to the food web, supporting a multitude of higher trophic levels. The productivity of the MIZ supports a wide range of annual endemic species and many migratory species who come to exploit the rich spring bloom every year.

Arctic endemic species utilize the productivity of the MIZ, in the otherwise harsh and barren region. Among these are charismatic megafauna such as belugas and narwhals, and of course the iconic polar bear. Ringed seals use the MIZ as a plentiful source of fish to feed and likewise, polar bears then feed on the seals. As well as this, polar bears depend on the MIZ as the connection between the land, where they den and give birth, and the pack ice, their primary habitat. However, as the MIZ retreats northwards due to warming waters as a result of climate change, the seals follow and polar bears are unable to follow their food source northwards across increasingly large areas of open water.

Migratory species, predominantly sea birds, are also being affected by changes in the MIZ due to climate change. As mentioned above, trophic mismatch between earlier spring blooms and zooplankton phenology may lead to a reduction in secondary production (i.e. zooplankton) and therefore fish stocks. This will affect the many migratory sea birds that feed on these organisms and has the potential to have wide spread effects on populations.

4 Challenges and Opportunities of Exploiting the MIZ

In the previous section, we discussed physical and biological properties of the MIZ. In this section, we add human component and discuss opportunities and challenges (both from human and natural environment perspectives) related to increasing human activities in the Arctic Ocean (AO). We focus on most recognizable activities, such as oil and gas exploitation and cargo shipping, not forgetting however, that there are also other activities, such as fisheries and tourism (which has a separate case study chapter at the end of the report).

4.1 Pollution and the MIZ

The retreat of sea ice is opening up the Arctic for anthropogenic waste. The floating objects investigated in the Barents Sea and Fram Strait are plastic waste, plastic bags and items from fisheries. The number of debris is slightly higher than in the Antarctic Ocean but still a lot lower compared to lower latitudes. At the same time, changes occurring around the MIZ and in the Arctic Ocean, together with rising human activities there pose a question about possible increases in floating trash and thus lesser attractiveness for tourism activities. Most of the litter has been found between $69°$ and $74°$N and $25°$ and $45°$E because it gets transported/collected by the main currents, the North Cape and Murman Currents. It seems that the MIZ is still hindering the spread of the plastic to even remoter places in the AO. Most plastic items have a low density and will therefore float whereby $50\,\%$ of municipal waste is denser than seawater and will therefore sink down to the seafloor without fouling process or deposition materials. Strong winds and storms can also increase the sinking rate of the debris. The easier access in the future will increase the pollution of the AO. Additionally, the litter gets transported by surface currents of the North Atlantic and will float until it pollutes the beaches of the Arctic countries or sinks down in Arctic waters (when not frozen) (Bergmann et al., 2015).

Tekman et al. (2017) state that *"... observations account only for $1\,\%$ of the total volumes of plastic assumed to enter the marine ecosystem from land... "* so, where are the other $99\,\%$ of plastic coming from? On the seafloor, the number of litter is one to two orders of magnitude higher than the floating litter. The number of litter at the prospected area ($2500\,\mathrm{m}$ deep) doubled in a period of 12 years (2002-2014) and is positively correlated to the retreating summer sea ice, ships entering the harbour of Longyearbyen, but also docking days of tourism vessels in particular. Hereby, the MIZ is not just controlling how far north the litter gets distributed but also dumps litter, that has been left on the ice, during melting events (there are some nice figures in this publication showing trends, maybe useful for the publication). At the same time, tourism in the marginal ice zone can be an opportunity to trash in the Arctic. Increasing number of cruise companies participate in the so called "Clean-up Svalbard" project. It is a project run by the Governor of Svalbard, where expedition cruise participants are taken to the remote beaches around Svalbard and collect garbage. The project is successfully run for the last few years, and there are initiatives to repeat it in other areas of the Arctic, such as Franz Josef Land (Arctic Russia).

4.2 Air Pollution in the MIZ

The global climate change is a key figure of modern environmental issues. It has recently caused a change of an old image of the Arctic from "the remote forgotten place in the corner of the world" to "the center of political, economic, scientific, and touristic interests of international society on the top of the world". The warming of the planet drastically affects the vulnerable Arctic environment. Arctic amplification is creating a loop of feedbacks, which are resulting more dramatic scenarios of our future.

Mainly the change of climate can be sensed by the warming of the atmosphere, which is also caused by the emission of the air pollutants from tourist ships, which have different origins: Greenhouses Gasess (GHGs), CO_2, Nitrogen (N), Sulphur Oxides (SOx), Short-lived Climate Pollutants (SLCPs), and others, emitted anthropogenically and naturally. Climate change has stronger effect on the polar regions because they receive and concentrate the contaminants from low/mid-latitudes. The pollutants which are produced in the Arctic and sub-Arctic areas cause greater damage.

The risks of environmental catastrophe for the planet, and the Arctic in particular, are only rising due to the planned economic development of the region: increase of shipping, including tourist cruises, extraction of mineral resources, and other activities will become the sources of the air pollutants, one of the most dangerous of which is a black carbon.

Air pollution is the direct or indirect anthropogenic introduction of *"substances into the air resulting in deleterious effects of such a nature as to endanger human health, harm living resources and ecosystems and material property and impair or interfere with amenities and other legitimate uses of the environment"* (of America and Canada, 2015). Pollutants of all types (liquid, solid, gaseous substances) can bring harm to people and ecosystems. They can be produced close to the surface level (primary), or can form in the air as a result of atmospheric chemistry between primary pollutants (secondary).

SLCPs are greenhouse gases and particulates that cause indirect warming influence on global climate, including the Arctic, and their short time presence in the atmosphere lasts for a few days, up to a decade. Main SLCPs are: black carbon, methane, tropospheric ozone and some Hydrofluorocarbons (HFCs) (AMAP, 2015). They are the second contributor of greenhouse effect after CO_2.

Mitigation of CO_2 emissions is the essential part of environmental policies but it will take decades to see the outcomes because CO_2 has long atmospheric lifetime. On the other side, it is believed that reduction of SLCPs' emissions, and black carbon in particular, will have rapid positive results, that will be quickly observed because of their short lifetime in the atmosphere. Implementation of such regulations will reduce global warming by $0.5\,°C$ by 2050 (Shindell et al., 2012).

Black Carbon (BC) is a key component of soot, a solid particle (Particulate Matter (PM)[1]) with a tiny size ($2.5\,\mu m$ or smaller) that is produced as a result of incomplete combustion of fossil fuel and biomass (Bond et al., 2013). Regardless of its short lifetime (no more than a few weeks), it impacts on human health (causes respiratory and cardiovascular diseases, premature deaths), ecosystems (accelerates ice/snow melt, changes the precipitation, and disturb cloud formation), and agriculture (crops loss).

[1] "Particulate matter" or "PM" is an air pollutant consisting of a mixture of particles suspended in the air. These particles differ in their physical properties (such as size and shape) and chemical composition. Unless otherwise stated, all references to particulate matter in the present Protocol refer to particles with an aerodynamic diameter equal to or less than $10\,\mu m$ (PM10), including those with an aerodynamic diameter equal to or less than $2.5\,\mu m$ (PM2.5) (Article 1 of UNECE UNFCCC Gothenburg Protocol, 2012 version) Available at: https://www.unece.org/fileadmin/DAM/env/documents/2013/air/eb/ECE.EB.AIR.114_ENG.pdf

Primary sources of BC are: residential and commercial biofuel and coal burning for cooking and heating, diesel-engines (transport and industrial vehicles and vessels), industrial facilities (coal and brick burning kilns), burning biomass (forest/field fires, including agricultural burns), and others.

Black carbon makes three types of impact on the climate: direct effect, it can deposit on snow and ice, and as every dark body it decreases the planetary albedo, primarily the snow/ice albedo, and speeds up the melting; while floating in the air it absorbs solar radiation and convert it to the heat, thereby warming the atmosphere; it also reacts with clouds, changes their formation, and results their instability, changes the rain patterns, darkens them, and decreases the scattering abilities (cloud albedo). For these reasons the polar and mountain regions are highly vulnerable for the BC emissions[2].

Due to its short lifetime, it does not stay long in the atmosphere, and the emissions from the Southern regions do not reach the Arctic, and climate effects are local and regional (C2ES and Solutions, 2010). But it does not mean that they are not contributing to the global and Arctic climate change. In can react with other substances in the atmosphere and form aerosols, consequently, contribute to the ozone depletion and global warming. Besides that, there are local emissions of BC in the Arctic, and it influences directly to the Arctic warming and ice/snow melting; their climate forcing impact is stronger than the effect of CO_2 (Ramanathan and Carmichael, 2008; Forster et al., 2007), which is the leading pollutant.

On top of that, there is still an uncertainty about the BC's contribution to the climate warming because the scientific methods of measurements in the air and snow are limited, first of all because of the lack of measurement sites around the Arctic. Another reason for that is that BC has different effects depending on the altitude in the atmosphere, the location of the sources and transport pathways. Generally, at high altitude of the Arctic it can have a "cooling" response, while in the low altitude it has great warming impact, and also "blacks" the snow.

During the process of formation of the BC, it is emitted with other particles and Volatile Organic Compound (VOC), that makes the regulation of BC emissions controversial. For example, the Organic Carbon (OC) is a particle, which is mostly emitted during biomass burning along with the BC, has a "cooling effect" for the atmosphere, due its ability to reflect the sunlight in the atmosphere. But in the soot, emitted from the fossil fuel and biofuel has more of the BC.

There is a high amount of emissions of BC from touristic vessels, including cruise ships. Effects of these emissions depend on the routes of these ships, which are usually navigating close to glaciers and the marginal ice zone. These areas are particularly susceptible to the effect of BC, resulting strong and direct negative interactions with snow and ice.

Moreover, both short and long-term influence of the PM 2.5 impacts on human health. Particles of BC enter the human body through the lungs during breathing, the digestive tract with food and drinks, and the skin pores and mucous membranes. Simply meaning that passengers of the cruise ships are the first people to be influenced.

4.3 Safety of human activities within MIZ

4.3.1 Infrastructural issues

As previously mentioned, infrastructures in the MIZ and in the areas affected by the reduction of ice and improved navigability, need to cope with the increasing demand of human activities, such as tourism. These include not only scaling infrastructures but also the use of different new resources,

[2] http://www.grida.no/resources/7550

such as improved Search and Rescue vessels or improved communication links and coverage. The International Maritime Organisation (IMO) provides guidelines for activities in polar environments, referring to these additional demands imposed on vessels (Jensen, 2016). Such demands include the support of better navigation mechanisms, communication systems, improved life-saving equipment, among other challenges.

Concerning the MIZ, as well as regions at high latitudes, challenges exist for navigation and limitations in telecommunications and coverage require special attention, since they are crucial for safety and response to unexpected incidents (NMCE, 2016). The design and implementation of new maritime digital communication systems for Polar waters is currently lacking (MEPC, 2015a), being Iridium the only system globally available service. However, Iridium only offers limited bandwidth capacity not being suitable for many operations (MarSafe, 2011).

Currently existing communication systems rely mostly on Very High Frequency (VHF) for short distances (within line of sight), which are limited in bandwidth and normally used only for voice communication. High Frequency (HF) and Medium Frequency (MF) radios are existing alternatives to coverage issues, but are mainly used on emergency solutions due to their limited bandwidth. Other solutions for supporting data transmission can be found in close to shore stations, and other infrastructures, such as the Automatic Identification System (AIS) or VHF, but that are limited in Arctic regions and in the MIZ. Moreover, typical satellite services based on Geostationary Earth Orbits (GEOs) are limited by the instabilities in signal quality, which are not considered as reliable in areas above 75° north (MarSafe, 2011).

In addition to the challenges in communication and connectivity, the MarSafe Project[3] has also identified issues with Dynamic Positioning (DP) and the coverage offered by Differential Global Positioning (dGPS). These systems, among others requiring high-availability of communication, are crucial for tourism and other maritime operations. In fact, Information and Communication Technologiess (ICTs) play an important role in the sustainable management of vulnerable, nature-based touristic sites, such as in the Arctic. In this sense, conducted operations are typically supported by different sources of data, including scientific data, collected by tourism operators in-situ. This presents not only a unique opportunity for assessing tourism resources, but also to cooperate with science. Ultimately, better models for understanding the MIZ can be achieved, complementing remote-sensing data sets and benefiting both tourism and local communities.

4.3.2 Search and Rescue

An increasing volume of cruise traffic is venturing into progressively remote and harsh environments of the Arctic. One telling example is the Crystal Serenity, which ventured through the North West Passage in 2016 and has a new cruise scheduled from 15 August to 16 September 2017. Maritime safety in the Arctic must be prioritised to avoid the likelihood of accidents occurring with the rising activity level. Two important factors that affect probability of survival from maritime accidents in Arctic conditions are exposure to the harsh environment (low air and sea temperature) and the time to rescue (Solberg et al., 2016). The Maxim Gorkiy and MV Explorer accidents may serve as examples of cruise ship accidents in the MIZ, which under slightly altered circumstances could have had catastrophic consequences:

- The cruise vessel Maxim Gorkiy carrying 995 passengers collided with a sea ice tongue west of Svalbard on June 19, 1989. Passengers were salvaged to lifeboats and on nearby ice floes,

[3] http://www.sintef.no/projectweb/marsafe/

eventually being picked up by the coastguard vessel KV Senja, which happened to be close by (Solberg et al., 2016). For example, (Johannessen et al., 1994) has observed several ice tongues with Synthetic Aperture Radar (SAR). One of this ice tongue extended 40 km out from a well-defined and sharp ice edge west of Svalbard in the Greenland Sea. This ice tongue consist of multiyear ice and had a width of few km and is difficult to observed from the ship in particular when you do not expect such a tongue to exist so far away from a well-defined ice edge. To monitor such ice tongues, which frequently are present along the ice edge and is dangerous for tourist ships, you have to do this with real time SAR radars, since prediction of such tongues are very difficult, if not impossible in the coming years.

- MV Explorer struck a growler (small iceberg fragment) in the MIZ of the Southern Ocean. The cruise vessel eventually sank, but all passengers and crew were rescued from open life boats after five hours by the nearby vessel MS Nordnorge (Longrée and Hoog, 2014).

Additionally, opening up of new shipping areas due to retreating ice and changing the MIZ together with still not well-known Arctic ocean bathymetry, bring uncertainty and risk to the shipping operations. The current Search And Rescue (SaR) *"... infrastructure in the Arctic, while varying between regions, is limited. (...) A survey of search and rescue resources among Arctic states indicate limited availability of fixed wing aircraft and helicopters in most of the region. Some survey responses included icebreakers and seasonal patrol vessels that can be used for SaR when near enough to an incident. However, in general, there are shortages of critical SaR response assets, such as long distance, heavy-lift capacity helicopters. The usefulness of these assets is often limited by weather and other operating conditions."* (Ellis and Brigham, 2009)

The MarSafe High North project (MarSafe, 2011) studied the environmental challenges within maritime operations in the High North and concluded about insufficiency and gaps in response systems and infrastructure. The MarSafe High North project pointed out, inter alia:

- *"Escape, Evacuation and Rescue equipment are unfit to handle harsh Arctic environmental conditions;"*
- *"Long distances combined with few SaR and emergency preparedness resources and poorly developed surveillance system infrastructures leads to long response time in critical situations;"*
- Limited SaR resources versus large distances and areas of responsibility reduce safety at sea in the High North;
- Ships operating in Arctic waters must have strong focus on autonomous solutions both regarding operational conditions as well as in a distress, since they often must rely on themselves in an emergency situation.

As part of the EU funded project ACCESS, Arctic Escape, Evacuation and Rescue was assessed (Longrée and Hoog, 2014). The study raises the question of whether local Search and rescue capacity is sufficiently scaled to handle an incident involving a large number of people in a remote location. The Arctic Search and Rescue Agreement[4] was the first legally binding agreement among the member states of the Arctic Council. The agreement states that:

"*The increased use of Arctic waters for tourism, shipping, research and resource development also increases the risk of accidents and, therefore, the need to further strengthen search and rescue capabilities and capacity around the Arctic Ocean to ensure an appropriate response from states to any accident,*[5]"

[4] The Nuuk Agreement, signed in 2011 and came into force in 2013. Link to agreement: https://oaarchive.arctic-council.org/handle/11374/531

[5] Ilulissat Declaration 2008

The Polar Code, which has been adopted by IMO and entered into force on the 1^{st} of January 2017, is intended to reduce the risk of maritime accidents in the Arctic. In a field exercise (SARex) north of Svalbard in 2016 (Solberg et al., 2016), the gaps between using currently approved SOLAS equipment and following the requirements in the Polar Code were investigated. The Polar Code requires that life-saving appliances shall provide safe evacuation during a maximum expected time of rescue set at minimum five days. The exercise demonstrated that heat loss in both lifeboats and life rafts could become an issue for survivability under the environmental conditions considered.

Taking the above discussions under considerations, future shipping activities would require necessary investments and improvement in SaR infrastructure, solutions and regulations. In the light of growing interest in tourism activities in the Arctic, more cooperation and scenario building would be necessary to ensure safe operations within the north-moving MIZ. Arctic Council Search and rescue agreement, is still “hanging in the air”, as it was concluded during Summer School discussion. Only exercises have been done under this agreement. Even though responsibilities are clearly set, governments are still lagging behind commercial operations, which needs more coordination between various types of stakeholders.

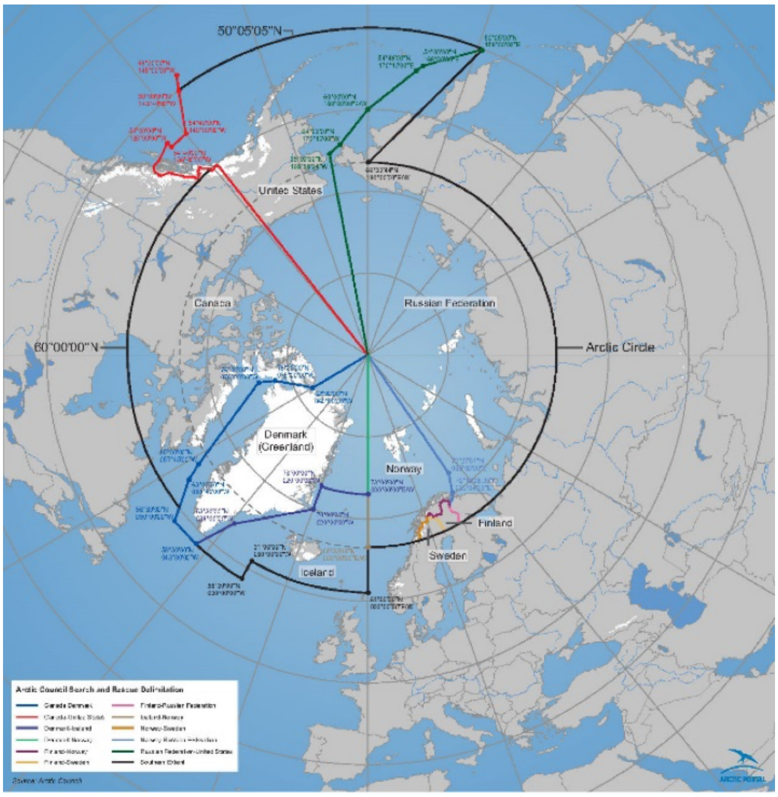

Figure 4.1: Division of search and rescue responsibilities among the Arctic states

5 Arctic Governance

5.1 Legal Aspect of Navigation in the Arctic Marginal Ice Zones

Due to global warming and sea ice retreat in the Arctic Ocean, we have started to notice more and more ships travelling the region for either domestic or transit purposes. This, rather quick, boom in Arctic shipping has created numerous concerns for safety and environmental protection. Particularly, shipping in Marginal Ice Zones, either by route selection or shuttle operation to carry oil and gas in and out of drilling platforms, pose the greatest challenge because navigation around the flooding ice floes can easily be described as the most difficult navigational task.

International community, particularly the Arctic Council and the International Maritime Organisation (IMO), have long been working to address these challenges by putting rules and regulations in place. And as a result, after almost a quarter of a century effort, the IMO has created its historical new regulatory regime, namely the IMO Polar Code.

Even though, the IMO Polar Code addresses the regulatory regime in navigation in the Marginal Ice Zone (MIZ), we still have to consider the variability character of the MIZ in Polar Code enforcement context because enforcement of the Code will be through either coastal states or flag states, and we have to first answer the question of who has the jurisdiction to enforce the Code. Additionally, the United Nations Conventions of the Law of the Sea (UNCLOS) Article 234 must be analysed in defining the regulatory regime because there might be additional, complementary, measurements taken by the coastal states to address the security or environmental challenges. And lastly, we need to address possible shortcomings of the Code in a broader concept because this would help us create further, proactive, measures to provide better safety and environmental protection for the future.

As a result, we have a regulatory regime with the IMO Polar Code in place, but we still have to go through complexities of the MIZ and international marine transportation regulations to provide the full picture in terms of legality of navigation in the MIZ.

6 The Value of the MIZ: Case Study of Arctic Cruise Tourism

In the previous sections, we discussed various properties of the MIZ and its consequent values, as well as most crucial opportunities and challenges related to its exploitation, based on the discussions from the summer school.

In this section, we present our own investigation and analytical endeavour on the importance and implications of the MIZ for the Arctic cruise tourism, as an emerging industry in the Arctic. During the summer school, we have been discussing various crucial activities such as oil and gas exploitation or military activities, gaining an interesting insight from experts and mentors. Those discussions inspired us to look at tourism as a new, so far not well analysed, aspect of exploring the MIZ. Therefore, in the below analysis we tried to use knowledge and expertise gained during the summer school to draw on potential scenarios and grasp complexity of the processes that occur in the MIZ. The below analysis aims to grasp context of natural properties of the MIZ, economic activity, including impact on local culture, as well as governance. Therefore, we find tourism as an appropriate example of the complexity and inter-relations that occur in the Arctic Ocean, with the conclusions being further extrapolated also to other human activities within the changing MIZ.

6.1 Tourism activities within the Marginal Ice Zone in the Arctic

Tourism is one of the fastest growing industry in the Arctic. Arctic tourism can be defined as all tourism and recreational activities occurring north of the Arctic Circle (N66°33′) (Hall and Saarinen, 2010a). It includes a variety of activities both on lands and on seas during the summer season, as well as during the summer season (Viken, 2013). In addition, seaborne tourism is the fastest growing segment of polar tourism (Snyder, 2008; Stonehouse and Snyder, 2010; Steinicke and Albrecht, 2012). Then, tourism has become one of the main reasons for human presence in the Arctic (Larsen and Fondahl, 2015), and in it this context is sensitive to the changes happening due to climate change, especially within the Marginal Ice Zone (MIZ) and in the whole Arctic ocean.

Considering the peripheral location of the Arctic and the various logistical constraints involved in travelling there, marine tourism is a popular way of visiting this part of the world. Just over two decades ago, there were 1.2 million cruise passengers visiting Arctic locations; by 2007, there were over 4.5 million (Ellis and Brigham, 2009), and today that number is even higher. Arctic cruises are becoming popular to such an extent that cruise liners are planning to build several ships within 2020. The French cruise liners Ponant announced the construction of four new ships designed for luxury expeditions. Those boats would be able to carry up to 200 passengers. Two of them should join the fleet in summer 2018, while the two others should be ready to sail in Arctic waters for summer 2019. The Norwegian cruise liner Hurtigruten started the building of the “Roals Amundsen”, the world’s first Arctic hybrid cruise boat. This new boat should be ready by summer 2018, while another one, the “Fridtjof Nansen” should be ready to sail for summer 2019 (see their respective website). The common type of sailing in the Arctic is by expedition vessels, which are smaller vessels that carry up to 300 passengers and are suitable for navigating in Northern waters. Those types of cruises often encounter icy conditions around the MIZ and are interested in those areas, as ice and Arctic marine wildlife around it is a part of experience product those companies sell.

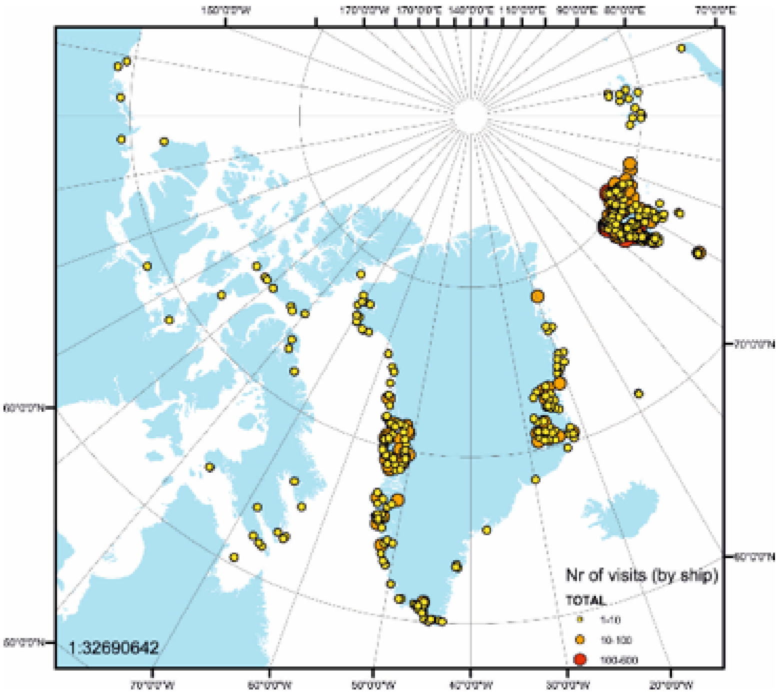

Figure 6.1: Distribution of expedition cruises in the Arctic (Bystrowska and Dawson, 2017)

Cruise ships are sailing all over the Arctic, from the ice free waters as south as the Arctic Circle to as north as the MIZ, that represents a natural barrier for regular boats. The ice pack being threatened of disappearing during summer months in the coming decades, revealed a need for some tourists to see the sea ice before it disappears or is irrevocably changed. It is called "last chance" or "doom" tourism (Lemelin et al., 2010; Dawson et al., 2011; Hall and Saarinen, 2010b). The MIZ has logically became a touristic attraction, based on the expectations of viewing ice-dependent wildlife (Stewart et al., 2007). The retreat of the ice pack, and thus of the MIZ, has led to a better access for remote location that can today embrace growing tourism as the summer season gets longer (Hassol, 2004; Hall and Saarinen, 2010a). Indeed, according to Stewart et al. (2007), cruise tourism in the Arctic can be consider as one of the few positive outcome associated to climate change.

Changing the MIZ conditions, especially related to retreating sea ice have profound consequences for tourism activities, best example being Canadian Arctic. Traversing North West Passage highly depends on sea ice conditions and the mile stone in commercial use if Northwest passage for cruising was successful travel by Crystal Serenity in 2016. Trends in Canadian cruising are related to the increasing accessibility of Northwest Passage, due to summer sea ice decline (Dawson et al., 2014). The melting sea ice cover has been expected to accelerate cruise tourism development in the Arctic (Johnston et al., 2012; Lamers and Amelung, 2010; Stewart et al., 2007). It relates to different types of cruises: big conventional cruises, up to few thousand passengers, expeditions ships with up to 300 passengers and smaller pleasure crafts.

6.2 Opportunities and challenges for tourism development within the MIZ: summary

However, despite growing interest in newly opening Arctic waters (result of the retreating MIZ) and the evident role of sea ice, the sea ice melt cannot be treated as the only factor influencing the cruise development. There are few studies on the relations between Arctic sea ice melt and cruise tourism activities (Stewart et al., 2007; Stewart and Draper, 2009; Lasserre and Têtu, 2015; Luck et al., 2010). Those studies show that marine tourism development in the Canadian Arctic is in part related to the sea ice decrease, but there are also numerous other factors, such as ships availability that contribute significantly (Lasserre and Têtu, 2015). The changes within the MIZ and consequent sea ice retreat pose both opportunities and threats for future cruise tourism development in the Arctic. The evidence from the Canadian Arctic shows that sea ice melt facilitates marine tourism by increasing traffic, better ship access and new destinations for cruise liners, but, on the other hand, the presence of sea ice is critical to Arctic cruise tourism, which relies on ice-covered landscapes and opportunities to spot ice-dependent marine wildlife, such as polar bears and walruses (Luck et al., 2010).

Changes in the MIZ can lead to the reduction of attractiveness of tourism sites, which represent one of the greatest challenges for cruise companies. Resilience and adaptation are thus required for the cruise companies in order to pursue their activities. Areas which so far were attractive for, especially expedition, cruises can lose attractiveness as wilderness spots, due to lack of sea ice and wildlife, being part of experience product. It is already observed on Svalbard, that some cruise operators (informal talks) confirm that they consider giving up their Svalbard program as it is less attractive there, due to lacking typical “Arctic” touch. It is often main attraction of expedition cruises to spot ice-related wildlife, such as polar bears, walrus, whales. Changes in the ecosystems, related to food chain and biology pose a threat for sustainability of those animals in certain areas, which could influence attractiveness of Arctic location for cruise tourism. Stewart et al. (2007) rose the following question: if the MIZ’s wildlife disappear or move somewhere else, will tourists keep visiting those areas? Another challenge is the sea-ice forecasts due to future uncertainty and variability of the MIZ conditions, as well as the melting sea ice increasing risks for safety from floating icebergs collisions (Jung et al., 2016). Search and rescue operations are becoming more and more challenging the further north the MIZ moves, as the more north cruises go, and the more north infrastructures lack (c.f. Section 4).

6.3 Perspectives of tourism development within the MIZ: energy perspective (the case of power emission from shore to reduce emission from cruise ships)

In 2015, the EU Parliament published a study with emission reduction targets for international aviation and shipping[1]. It suggests that shipping will be contributing to 17 % of total CO_2 emissions in 2050 if left unregulated, raising from today’s up to 3 % of global total. Shipping greenhouse gas emissions has increased 70 % since 1990.

Shore-side power is one measure to reduce emissions, both while being at berth and for powering batteries on board to be used during transit. The Clean Power Directive (2014/94/EU) has set a deadline to implement shore-side power by 2025, *“unless there is no demand and the costs are disproportionate to the benefits, including environmental benefits”* (Art. 4.5).

[1] http://www.europarl.europa.eu/RegData/etudes/STUD/2015/569964/IPOL_STU(2015)569964_EN.pdf

In a study from 2015, ECOFYS has calculated the potential for shore side electricity in Europe[2]. They point to that business case for shore-side power is most attractive for ships that have a high electricity demand per berthing, including cruise ships, container ships and Roll-of-Roll-off ships (RoRo).

In the Norwegian Government's letter of budget allocation for 2017 to the Norwegian Coastal Administration, it is pointed out the Government will monitor the development with implementing the Clean Power Directive. However, Svalbard is not mentioned, nor is the management plan for the Barents sea – Lofoten mentioning the use of clean power in vessels operating in the area, including the MIZ. Implementing power from shore in Longyearbyen would reduce local pollution, still, it would heavily increase the pressure on the local electricity supply since a cruise ship could amount 10–20 MVA. With the cruise ship season in Svalbard being from March to September, the presence of cruise ships does not coincide with the coldest period in Svalbard, where the local energy demand is the highest.

6.4 Tourism in the MIZ: impact on host communities and indigenous culture

6.4.1 Impact on indigenous cultures

Reduced sea ice and major changes of the marginal ice zone allow increasing opportunities for tourism. Tourist companies operating services within the MIZ offer not only wilderness nature experiences, but also 'chances to experience indigenous traditions'[3].

The Marginal Ice Zone across the Arctic is inhabited by various indigenous peoples of Canada, Russia, Greenland and United States. Indigenous culture is marketed by both indigenous and non-indigenous operators contributing to the general attractiveness of the area. Tourism offers alternative ways of living for indigenous people in the contemporary world. Economic benefits can be seen as liberating and empowering for indigenous people as they give opportunities for developing infrastructure and transportation, which is beneficial for the host communities. Despite the fact that many indigenous groups endorsed tourism positively, a significant number remain rather sceptical. A study of Inuit perceptions of tourism development in Clyde River (Baffin Island, now in Nunavut) revealed indigenous support for the growth of tourism as long as its development was gradual and the community maintained control of the industry (Nickels et al., 1991).

One of the most controversial issues connected with the indigenous tourism is the expectations and the global image of the indigenous peoples. The long history of colonialism across the Arctic states positioned indigenous people to the marginal statuses. The classic academia portrayed the authentic cultures and traditions of indigenous peoples. Created stereotypical images of indigenous people are often what tourists expect, wish to experience and willing to pay for. However, indigenous culture, as any other culture is dynamic and not static, meaning that traditions develop, transform and adapt throughout the time. The challenge is that rarely indigenous culture is perceived to be flexible and integrated with the modern world. Tourists expect certain experiences that matches with their images of what is 'indigenous' which may have a serious impact on the contemporary indigenous culture. Some indigenous and non-indigenous companies adapt and offer services that are recognized commonly as stereotypically indigenous, while other companies try to empower indigenous cultures from the burden of authenticity by presenting contemporary livelihood of indigenous peoples. Thus, tourism industry can be seen both as the continuation of the colonialism of indigenous people, and,

[2] http://www.ecofys.com/files/files/ecofys-2014-potential-for-shore-side-electricity-in-europe.pdf

[3] www.arctic.ru

in opposite, as a way to educate masses about the modern indigenous cultures from the indigenous peoples themselves.

Marginal Ice Zone is precisely the area where some indigenous peoples as Chukchi, Inuit and Yup'iks practice their traditional livelihood, such as whale hunting. Intensive tourist traffic and movement of the MIZ can put in danger the reliability of indigenous peoples on the whale meat. The lack of reliable sources for living push indigenous peoples towards urbanization and emigration. The Arctic is experiencing demographic changes and the major trend in most Arctic regions is migration losses (of both indigenous and non-indigenous people with a higher percentage of young women out-migrating) to the urban and southern regions impacting household size (Ministerradet, 2011), and migration gains by people seeking work in resource extraction and the service sectors (Heleniak and Bogoyavlenskiy, 2013). The outmigration trend is projected to continue, with traditions and resources being jeopardized both by direct climate change impacts and the increasing value of their resources for market purposes.

6.4.2 Impact on non-indigenous local communities: case study of Russia

Population of the marginal ice zone consists not explicitly of indigenous communities. In the 20^{th} century, many areas of traditional land use in Russian Arctic were turned into new industrial areas, concentrating on mining, oil exploration and shipping. Cities of Vorkuta, Norilsk, Tiksi and others were established and/or developed in the area. The population of these cities was formed from either former gulag prisoners and young people coming to the north due to soviet "distribution" system, consisting mainly from ethnic Russians and Ukrainians. The current population of newly built or developed settlements is more than 200,000.

Remoteness of the newly built areas in combination with hazardous climate and industry triggered emergence and development of local recreational practice. Tourism and recreation should be studied there in a combination because of their high interconnectivity in the region, and main purpose of travel for local people – within the region or out of it – is to recover and improve their health. Thus, tourism in local communities means not just incoming (cruise) flow but also, or moreover, local recreational activities which are caused by infrastructural reasons – economical, geographical and informational.

In Russia, where cruise tourism is rarely presented, local recreation takes the larger segment of tourism market. From the marketing point of view, local recreation can be divided into three segments. The first is *mass-market* – designed for and used by locals. The second is elite, aimed mainly at non-local tourists (which come primarily from other parts of Russia than from abroad due to legal restrictions) – e.g. visiting Putorana Plateau. As for outgoing tourism, transport connection of remote areas with central and southern regions of Russia is strong travel limiting factor due to insufficient capacity and expensiveness, even being partly subsidized. Consequently, local tourism and recreation are on demand, although the quality of environment, both natural and built, can degrade with proximity to mining and oil exploration areas.

In Russian Arctic, in changing economic and social conditions local tourism and recreation has showed its resilience: the case of Norilsk Region (Isachenko et al., 2015) shows that it remains an essential part of everyday life and determinant of well-being of region inhabitants, not only due to its necessity for healthcare in ecological conditions but also because of underdevelopment of other services, including public transportation (both interregional and local), and ways of spending free time. Thus, tourism and recreation plays important role in sustainability of northern regions as an activity that helps to balance economic priorities of mining/oil companies, natural environment and human well-being.

6.5 Management and regulation of tourism activities in the MIZ

Tourism in the Arctic is expanding, and the Protection of the Arctic Marine Environment (PAME) is looking at measures and guidelines to promote sustainable marine tourism (NMCE, 2016). The PAME Working Group has conducted an assessment of Arctic shipping that use/ carriage of Heavy Fuel Oil (HFO). PAME has also assessed the need to designate areas in the high seas area of the Arctic Ocean that warrant protection from the risks posed by shipping, and has identified possible measures to reduce the risk of environmental damage (Veritas, 2013). Tourism poses a risk to the environment and is also a human risk in the event of a serious shipping incident in which the many thousands of tourists on a single vessel are likely to strain rescue operations (Triggs, 2011). *"In response to the concern that tourists adversely affect the places they visit, IAATO developed a code of conduct for tourists that attempts to minimize their effects on the environment. Visitors on board IAATO member expeditions are reminded, for example, to stay with the group when ashore and to leave nothing behind, and cautioned not to disturb wildlife, walk on fragile plants, interfere with protected areas or scientific research, enter historic huts unless escorted by an authorized person, or smoke during shore excursions*
(. . .)
Additional IAATO guidelines require tour operators to be familiar with the Act and to abide by it, to be aware of protected areas, to enforce the visitor code of conduct, to hire a professional team of expedition leaders, to provide a qualified lecturer/naturalist guide for every 20-25 passengers to supervise small groups ashore, and to limit the number ashore at any one place and time to 100 passengers
(. . .)
In the Arctic, growing concerns about the relationship between tourism and the environment have begun to be addressed through the World Wide Fund for Nature's Arctic Tourism Project (1995–2000), which aimed to use tourism to promote conservation and to maximize benefits of tourism to local communities (Humphreys et al., 1998; Mason, 1997). Furthermore, a number of communities and governments have implemented restrictions appropriate to their individual circumstances and concerns for example, such as Svalbard. The implementation and effectiveness of efforts has become an additional focus. A combination of codes of conduct and an evolving legislative framework has much to offer an Arctic-wide strategy (Johnston, 1997)
(. . .)
Along these lines, the approach to nature management in Svalbard, commonly touted in Norway as the best managed wilderness in the world, offers insights for Arctic management" (Stewart et al., 2005).

Polar code: The polar code that entered into the force from 1 January 2017 related to the protection of the environment in flowing ways.

1. It applies to ships operating in Arctic waters: additional to existing MARPOL (Organization, 1973) requirements:
2. It provides for safe ship operation and protects the environment by addressing the unique risks present in polar waters but not covered by other instruments

Specific to the Polar Code, *"discharge into the sea of oil or oily mixtures from any ship is prohibited (. . .) double hull and double bottom required for all oil tankers, including those less than* 5000 dwt *(A/B ships constructed on or after 1 January 2017) (. . .) heavy fuel oil is banned (. . .) ships are encouraged not to use or carry heavy fuel oil in the Arctic and consider using non-toxic biodegradable lubricants or water-based systems in lubricated components outside the underwater hull with direct* *seawater interfaces (...) measures to be taken to minimize the risk of invasive aquatic species through ships' ballast water and biofouling (...) no discharge of sewage in polar waters allowed (except under specific circumstances (...) discharge is permitted if ship has an approved sewage treatment plant, and discharges treated sewage as far as practicable from the nearest land, any fast ice, ice shelf, or areas of specified ice concentration (...) sewage not comminuted or disinfected can be discharged at a distance of more than* $12\,\mathrm{M}$ *from any ice shelf or fast ice (...) comminuted and disinfected sewage can be discharged more than* $3\,\mathrm{M}$ *from any ice shelf or fast ice (...) all disposal of plastics (... and) animal carcasses is prohibited (...) discharge of food wastes onto the ice is prohibited (...) food wastes which have been comminuted or ground (no greater than* $25\,\mathrm{M}$*) can be discharged only when ship is not less than* $12\,\mathrm{M}$ *from the nearest ice shelf, or nearest fast ice (...) cargo residues, cleaning agents or additives in hold washing water may only be discharged if: they are not harmful to the marine environment; both departure and destination ports are within Arctic waters; and there are no adequate reception facilities at those ports (...) discharge of Noxious Liquid Substances (NLS) or mixtures containing NLS is prohibited in polar waters"* (MEPC, 2015b).

Fairbanks Declaration 2017 (Council, 2017), welcomes the entry into force of the Polar Code to ensure safe and environmentally sound Shipping in the harsh Arctic marine environment, and encourage continued engagement by Arctic States, *"to facilitate harmonized Implementation and enforcement of the Polar Code"* (Council, 2017). It also welcomes *"the Arctic Protected Area Indicator Report, adopt the Marine Protected Area Network Toolbox, and encourage additional work to help implement the Framework for a pan-Arctic Network of Marine Protected Areas in order to strengthen marine ecosystem resilience And to foster the conservation and sustainable use of marine resources"* (Council, 2017).

7 Conclusions and Future Steps

The uncertainty of the Marginal Ice Zone (MIZ) and its physical properties, combined with heterogeneity of stakeholders and interactions between them, creates a complex scenario that requires a flexible and overarching approach to existing challenges and opportunities in the MIZ.

Currently existing knowledge already allows bounded definitions of the MIZ, providing confidence intervals for decision-making entities, communities and stakeholders in the Arctic region. This allows progress to take place, not only from a short-term point of view, but also from a long-term and sustainable effort to develop activities tightly connected to the MIZ.

Despite the existing developments, there is still a strong need for improved knowledge in Arctic regions, namely from a biological point view, ensuring that further activities exploiting existing living marine resources are conducted in a sustainable fashion. This concern arises from the sparse existing research and fast occurring changes intrinsic to this region.

Technological developments have the potential to improve the understanding of the MIZ, complementing not only the efforts conducted by the scientific community, but also of other stakeholders such as tourism operators. This will require the establishment of new infrastructures and the cooperation between different entities, focusing on the sustainable development of the Arctic.

Considering the increasing interest in exploiting resources around the MIZ, and its unpredictable character, more attention to planning and management is required in order to support safe maritime operations, for example Search and Rescue.

The current unpredictable state of the MIZ and operating tourist activities, including their larger effect on the ecosystems, environment and local communities, require more flexible and adaptive strategies for solution making. Tourism as an industry, especially at the MIZ area, needs to be acknowledged as having a higher risk of temporality and unpredictability. Thus, heavy economic reliability in tourism should also come with the understanding of the multiple risks and willingness for extreme social mobility, taking into account external flows as well as local demand. This requires tourism in the MIZ to be formulated in the terms of sustainable development of local communities since tourism influences their well-being and life conditions, as well as new opportunities and their associated challenges. On the one hand, the raising demand and melting sea ice leads to increased output from the tourism industry: economical, environmental and social (both for indigenous and non-indigenous people). On the other hand, the development of tourist infrastructures and access to recreational resources should also consider the need of the local people.

Considering the increasing tourism in the MIZ area, there is great potential to use tourist expeditions for science outreach and citizen science. Science outreach programs onboard cruise vessels with resident scientists as well as with presentations and workshops, contribute to the understanding of the general public about the ecosystem. Additionally, in citizen science projects ordinary citizens contribute to, for example, scientific data collection via simple observing of the environment and through smart phone apps, further contributing to gathering additional data, while simultaneously raising awareness to the public.

Tourism in the Arctic Ocean is currently a negative effect regarding the condition of sea ice. But these issues might be solved in future by the application of sustainable measures. For instance, the International Maritime Organization, the current organization making the rules for maritime navigation in polar areas, is addressing the importance of air pollutants mitigation in polar regions, because of the aforementioned expected increase of maritime navigation's volume in the Arctic. On top of that, modern technologies and practices allow the development of control measures and, for instance, reduce black carbon emissions by $80\,\%$ by 2030 (in case if they will be implemented globally). Adoption of these alternatives will have positive impact on climate and public health.

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