ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE ENGINEERING AND TECHNOLOGY

FUTURE OF ARCTIC MARITIME ACTIVITIES IN THE LIGHT OF CLIMATE CHANGE

M.Sc. THESIS

Mehmet ERSAN

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FOREWORD

The Arctic is the polar region north of the Arctic Circle, or north of the latitude 66° 33' 44" (or 66.5622°) north of the equator. Temperatures average -40°C or -40°F in the winter and under 10°C or 50°F in the summer. The Arctic Ocean dominates the Arctic region. This ocean covers 15,558,000 square kilometers (6,006,977 square miles).

The Artic Region is a one of the *"sui generis"* region of World. Several species of animals and plant are unique to the Arctic. It is also a center of attraction because the Arctic has natural resources wealth which can be exploited to provide economic profit. Some of its known natural resources are gold, crude oil, diamonds and industrial metals. Besides that unknown potential resource of Arctic excite the rest of the World. Even if the Arctic region has been considered an international territory, some of the countries claim that it's their own territory.

Besides that it is very clear that the Arctic region is one of the most affected area due to global warming. In this study, the effects of global warming to the Arctic region has been shown by the ice extent data both in summer and winter between 1979-2014. This situation's possible result as having new Artic Shipping Routes is the subject of the study. Secondry research methodology is chosen as the method of the study.

Moreover, I would like to thank my thesis advisor Assoc. Prof. Dr. Burcu Özsoy who passed her enthusiasm and deep experince about Arctic Region to me from the very begining of my Master education.

Finally, I would like to thank my dear wife Ece; for being so patient and supportive in the period of writing this thesis and my whole life in general.

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TABLE OF CONTENTS

Page

ABBREVIATIONS

AIRSS	: Arctic Ice Regime Shipping System
AMSA	: Arctic Marine Shipping Assessment
AR5	: The 5th Assessment Reportof IPCC
ATAM	: Arctic Transportation Accessibility Model
BC	: Black Carbon
CMIP	: Coupled Model Intercomparison Project
CO_2	: Carbon Dioxide
GCMs	: General Circulation Models
GHG	: Greenhouse Gas
GISS	: Goddard Institute for Space Studies of NASA
IACS	: The International Association of Classification Society
IMO	: International Maritime Organization
IPCC	: Intergovernmental Panel on Climate Change
LME	: Large Marine Ecosystem
NASA	: National Aeronautics and Space Administration
NOAA	: National Oceanic and Atmospheric Administration
NOx	: Nitrogen Oxides
NSR	: North Sea Route
NWP	: Nortwest Passage
OW	: Open Water
PM	: Particulate Matter
RCPs	: Representative Concentration Pathways
SO_2	: Sulfur Dioxide
SOx	: Sulfur Oxides
SRES	: Special Report on Emissions Scenarios
SST	: Sea Surface Temperature
TAR:	: Third Assement Report of IPPC
UN	: United Nations
UNCLOS	: United Nations Convention on the Law of the Sea

LIST OF TABLES

Page

LIST OF FIGURES

Page

FUTURE OF ARCTIC MARITIME ACTIVITIES IN THE LIGHT OF CLIMATE CHANGE

SUMMARY

The Artic Region is a one of the “sui generis” region of World. Even if it seems very far away from the civilization, it’s also a center of attraction because of Arctic has natural resources wealth which can be exploited to provide economic profit. The researchs are mostly focused on the these area but nowadays The Artic Region is more popular due to climate change issues. Recent analyses showed that warming trends is consistent with trends over the past 20-30 years of decreasing sea ice extent in the Arctic Ocean. Beside this negative aspect of global warming, there would be a new perspective of shipping routes over the Arctic region.

This study aims to argue new Arctic Sea Routes in the light of climate change reality. Firstly Arctic Region and sea ice concept is defined in order to frame the study. Subsequently, the Arctic Region’s value is emphasized in terms of maritime routes. Following to this section, climate change as a global phenomenon’s fact and figures are shown by graphics and figures. Increasing of temperature reality as a result of climate change is supported by the ice extent data set. The data set in .csv format is derived from remote sensing platform between 1979-2014. They are provided by Colorado University. According to the data set, peak values of ice extent in summer and winter, seasonal average ice extent values, 10 years period, and 5 years period of ice extent values are analyzed. According to the data, the effects of climate change to sea ice extent are very serious especially after 2000s. In the discussion part, the current shipping route of Arctic and the probable new route are explained. Moreover, the possible risks of Northern Sea Route (NSR) are discussed both in ecologically and economically. At the end of study, safety precautions are presented.

Secondary research method has ben selected for this study and mainly up-to-dated research has been chosen as study sources.

Sea routes are important considering that around %90 of World trade is carried by international shipping industry. The global climate change caused the melting of sea ice in the Arctic region especially in the middle of 2000s. This situation brought in the question if the Arctic region could be navigate. “The Melting Ice Caps and the Economic Impact of Opening The Northern Sea Route” study showed that NSR would be used more frequently than today in the near future. But the results of the Arctic region as a new trade shipping route were not studied yet. Even if the consumption of money, time and fuel would be decrease, the ecologic balance of the Arctic region would be affected seriously considering increase of greenhouse gases emission like CO_2 which was one of the responsible of climate change. Since the sea ice melting trend will not be prevented and the shipping traffic in the Arctic region will increase, the danger will be irreversible for the world.

İKLİM DEĞİŞİKLİĞİ IŞIĞINDA ARKTİK DENİZCLİK AKTİVİTELERİNİN GELECEĞİ

ÖZET

Arktik Bölge, Kuzey Kutbu'nda 66° 33' 44" enleminin kuzeyinde yer almaktadır. Arktik kelimesi "ayı" anlamına gelen Yunanca "ἀρκτικός" (arktikos) kelimesinden gelmektedir. Burada Güneş, 23 Eylül - 21 Mart arasında doğmaz ve 21 Mart-23 Eylül tarihleri arasında da batmaz. Bu nedenle burada 6 ay gündüz 6 ay gece yaşanmaktadır. Söz konusu bölgede sıcaklık kışları -40°C civarında yazları ise 10°C'nin altında kalmaktadır. Adını Arktik 'ten alan ve Dünya'nın 5. Büyük Okyanusu olan Arktik Okyanusu bölgeyi büyük oranda kaplamaktadır. Arktik Bölge'nin kıyılarında Amerika Birleşik Devletleri, Norveç, Kanada, Danimarka ve Rusya bulunmaktadır. Her ne kadar bu beş ülkenin bölgeye sınırları olsa da bölge tam olarak bir ülkenin resmi olarak sınırları içinde yer almamaktadır.

Dünya'nın en "nev-i şahsına münhasır" bölgelerinden biridir. Her ne kadar medeniyetten çok uzakta görünse de sahip olduğu doğal kaynaklar nedeniyle özellikle son dönemlerde birçok ülke için cazibe merkezi haline gelmiştir. Son zamanlarda artan nüfusun talepleri karşılamada yetersiz hale gelen kaynakların bir kısmının bu bölgeden karşılanabileceğinin düşünülmesi de bu bölgenin cazibesini arttırmaktadır. Bununla birlikte bu bölgenin gündemimizde olma nedenlerinden biri de hiç şüphesiz iklim değişikliğidir. Yapılan son çalışmalar iklim değişikliği nedeniyle burada yer alan deniz buzullarının son 20-30 yıllık periyodlara göre erime eğiliminde olduğunu gözler önüne sermiştir.

Tüm bu karamsar tabloya rağmen, deniz buzullarının erimesinin Arktik bölgesindeki denizcilik aktivitelerine yeni bir çerçeve kazandıracağı gerçeği de göz ardı edilemez. Bu çalışmada iklim değişikliği ile beraber olası yeni Arktik Bölge Deniz Seyir Rotaları tartışılmıştır.

Çalışmada ilk olarak Arktik Bölgesi ve deniz buzulu kavramları çalışmanın konusunu tasvir edebilmek için açıklanmıştır. Deniz buzullarının literatürde en sık karşılaşılan 10 farklı çeşidine şekiller eşliğinde yer verilmiştir. Deniz buzullarını ana hatlarıyla açıkladıktan sonra Arktik Bölge'de yer alan deniz buzulları detayı paylaşılmıştır. Özellikle bölgesel ekosistemde önemli yer tutan tuzlu su kanalları (brine channels) bu kısımda ele alınmıştır. Sonrasında bölgenin deniz taşımacılığı açısından önemi sadece tarihsel ve coğrafik olarak değil aynı zamanda yönetimsel ve altyapısal olarak anlatılmıştır. Bölgeden geçen dört temel rota; Kuzey-Batı Geçişi (NWP), Kuzeyli Deniz Rotası (NSR), Kutup Aşırı Deniz Rotası (TSR) ve Arktik Köprü Rotası (ABR) şekilsel olarak bu bölümde yer almaktadır. Aynı şekilde el değmemiş doğası ile bölgenin giderek cazibe merkezi haline gelmesinden sonra, buraya yapılan turistik yolcu gemilerine de bu bölümde değinilmiştir.

İkinci bölüme müteakip, küresel bir fenomen olarak iklim değişikliği konusuna değinilmiştir. Küresel eğilime göre 2000 ile 2100 yılları arasındaki ortalama

ısınmanın 1.4°C ile 5.8°C arasında artması beklenmektedir. Bu ısınmanın başlıca sebeplerinden biri olan sera gazlardan karbondioksit seviyesine de çalışmada yer verilmiştir. Özellikle karbondioksit seviyesindeki artış, Hawai Mauna Loa Gözlemevi tarafından sağlanan şekil ile açıklanmıştır. Bu bölümde Hükümetler arası İklim Değişikliği Panelince 2014 yılında yayınlanan ve beşinci değerlendirme raporunda yer alan Temsili Konsantrasyon Senaryoları (RCPs) ele alınmıştır. Her bir senaryoya 2100 yılındaki olası radyotif zorlama değeri üzerinden isim verilmiştir. (RCP 8.5, RCP 6, RCP 4.5 ve RCP 2.6) Bu senaryolara göre olası sonuçlar açıklanmaya çalışılmıştır. Senaryolara göre en iyi ihtimali içeren RCP 2.6, en kötü ihitmal ise RCP 8.5'tir. RCP yaklaşımı ardışık değil paraleldir. Aynı bölümde iklim değişikliğinin Dünya'nın soğuması için büyük öneme sahip olan Arktik Bölgesi'ne etkilerinden bahsedilmiştir. Bilhassa küresel ısınmanın Arktik Buzullarının erimesine olan ve yakın gelecekte olacak etkisi son derece ciddidir. Yine bu bölümde paylaşılan veriler doğrultusunda yeryüzü sıcaklığının son iki yüzyıldan ortalama 0.6°C yüksek olması sadece Arktik için değil tüm Dünya için önemli sonuçlar doğuracaktır. Yine bu bölümde Arktik Bölge'de yeryüzü ve deniz yüzeyi sıcaklık anormalilerin en düşük ve en yüksek değerleri kombine edilerek grafiksel olarak belirtilmiştir. Tüm bu karamsar yaklaşımların yanı sıra bir grup bilimadamı Arktik Amplifikasyonu (Arctic Amplification) adında bir görüşü de dile getirmektedir. Bu görüşe göre Arktik bölgesindeki ısı artışının pozitif etkileri olacağı varsayılmaktadır. Buzulların erimesiyle beraber havadaki karbon emisyonunu azaltacak yeni plaktonlar bu bölgede yetişebilecektir. Her ne kadar bu görüş farklı temellere dayansa da Arktik İklimi'nin küresel ısınma öncesine benzemeyeceği açıktır.

Bir sonraki bölümde ise 1979-2014 yılları arasında deniz buzullarının uzaktan algılama ile ölçümlenme verileri ele alınmıştır. Tartışmanın altyapısını sağlamak adına Colorado Üniversitesi tarafından sağlanan veri setine göre yaz ve kış aylarındaki en yüksek ve en düşük deniz buzul uzantı değerleri, mevsimsel ortalama deniz buzul uzantı değerleri ile 5 ve 10 yıllık dönemlerdeki deniz buzul uzantı değerleri analiz edilmiş ve grafiklerle açıklanmıştır. Veri setinin .csv formatından alınarak grafiksel ve tablolar halinde anlamlandırılışına da yer verilmiştir. Söz konusu veriler Nimbus7 ve Defense Meteorological Satellite Program (DMSP) adı verilen iki farklı uzaktan algılama platformu tarafından oluşturulmuştur. İlk etapta verilen ham olarak tablolar ile gösterilmiş, tartışmanın zeminini oluşturacak ve çalışmanın danışmanı tarafından belirlenen kırılımlarda (mevsimsel, yaz-kış mevsim karşılaştırmaları, en yüksek ve en düşük tarihler vb.) data üzerinden ilgili tablo ve grafikler hazırlanmıştır. Yine tüm bu veriler 5 yıllık ve 10 yıllık süreçlerde ayrıca incelenmiştir. Bu tablolara göre Arktik Bölgesi'ndeki deniz buzul uzantıları genellikle bahar döneminde en yüksek seviyelere ulaşırken, sonbahar döneminde en düşük seviyelerdedir. Yıllık karşılaştırmalar dikkatle incelendiğinde ise kritik kırılma noktasının 2012'te yaşandığı anlaşılmaktadır. Buna göre 2012 yılında sonbahar ile ilkbahar arasındaki fark 7.998 10^6 km kareyi bulmuştur. En düşük fark ise 1992'de yaşanmıştır. Mevsim bazında veriler incelendiğinde ise ilkbahar aylarındaki en yüksek deniz buzul uzantı değerinin 1979'da 15.243 10^6 km kare iken en düşük değerin 2006 yılında 13.611 10^6 km kare ile olduğu görülmektedir. Yaz mevsimde ise en yüksek değere 10.328 10^6 km kare ile 1982'de rastlanırken en düşük değere ise 7.657 10^6 km kare ile 2012'de rastlanılmaktır. En düşük değerlerin gözlemlendiği sonbahar ayları yıl bazında karşılaştırıldığında, en düşük değer 6.275 10^6 km kare ile yine 2012'de en yüksek değer ise 11.440 10^6 km kare ile 1978'de görülmüştür. Kış aylarında da yapılan bu gözlemler neticesinde en düşük değerin 13.212 10^6 km kare ile 2006 yılında , en yüksek değerin ise 15.305 10^6 km kare ile 1987 yılında olduğu tespit edilmiştir. Verilerin 10 yıllık periyodlara bölünerek incelendiğinde en düşük ortalamanın 7.223 10^6 km kare ile 4. Periyodunun sohbaharında, en düşük ortalamanın 14.989,26 10^6 km kare ile 1. Periyodun ilkbaharında yaşandığı görülmektedir. 5'er yıllık periyodlarda ise benzer şekilde değerlerin sürekli olarak düşme eğiliminde olduğu gözlemlenmektedir. Gün bazında bulunan ham veri incelendiğinde ise söz konusu dönemde görülen en düşük değerin tarihi 16 Eylül 2012'dir. 16 Eylül 2012 Pazar günü yapılan ölçüme göre Arktik Bölge'deki deniz buzul uzantısı değeri sadece 3.340 10^6 km kare'dir. Yine gün bazında bu tarihler içinde tutulan ham veride en yüksek değere ise 1 Mart 1979 Perşembe gününde rastlanmıştır. Bu günde yapılan ölçüme göre en buzul uzantı değeri 16.635 10^6 km kare'dir. Gün bazındaki ham verinin bilgilerine göre Arktik Bölge'deki söz konusu dönemde ortalama deniz buzul uzantısı 11.455 10^6 km kare'dir. Bu alanda yapılan bir diğer çalışma ise Helmholtz Climate Initiative'e aittir. 19 Haziran 2002 tarihinden bu yana Arktik Bölge'deki deniz buzul uzantılarının değerleri uydu aracılığıyla toplanmaktadır. Buradan sağlanan verilere göre de en yüksek ve en düşük değerler 4. Bölümde incelenen verileri konfirme etmektedir.

Çalışmanın tartışma bölümünde öncelikle buzullarda kullanılabilen deniz araçları açıklanmıştır. Bune göre IMO tarafından belirlenmiş buzkıranlar 7 farklı sınıfta kategorize edilir.Arktik Bölge'deki aktif denizcilik rotalarında seyir bu sınıflardaki buzkıranlar ile yapılabilmektedir. Bölümün devamında hali hazırdaki Arktik Bölge seyir rotaları ile olası yeni rotalar açıklanmaya çalışılmıştır. Bununla beraber olası yeni rotaların riskleri hem çevresel hem de ekonomik açıdan açıklanmaya çalışılmıştır. Çalışmanın sonunda Arktik sularda seyir operasyonları, acil durum ihtiyaçları, deniz trafiğinin yönetimi başlıklarında güvenlik önlemlerine yer verilmiştir. Bu üç farklı alanda güvenlik ihtiyaçları karşılanmadan seyir trafiğinin artması bu bölge için geri dönüşü olmayan ekolojik tehlikeler yaratabileceği gibi bölgeye seyir yapan denizcilerin ve bilimadamlarının can güvenliği de ciddi tehdit altında olacaktır.

Çalışmada ikincil araştırma yöntemi benimsenmiş ve genel olarak en güncel araştırma sonuçları çalışmanın kaynakları olarak seçilmiştir.

Dünya ticaretinin %90'nın deniz taşımacılığı ile yapıldığı düşünüldüğünde Dünya Deniz Seyir Rotaları'nın ne denli önemli olduğu ortaya çıkmaktadır. 2000'li yıllara kadar Arktik Bölgesi'de var olan zorlu hava koşulları ve Arktik Okyanusundaki deniz buzulları nedeniyle bu bölge deniz seyir rotalarında yer almamaktaydı. Diğer taraftan iklim değişikliği 2000'li yılların ortasından itibaren Arktik Bölgesi'ndeki deniz buzullarının erimesine yol açmıştır. Bu durum bu bölgenin ticari deniz rotalarına eklenip eklenemeyeceği sorusunu gündeme getirmiştir. Hollanda Ekonomi Bürosu tarafından yapılan "Eriyen Buzullar ve Açılan Kuzey Deniz Rotası'nın Ekonomik Etkileri" adlı çalışma göstermiştir ki bu rota yakın gelecekte bugüne göre çok daha fazla kullanılacaktır. Bununla birlikte bu rotanın ticari amaçlarla daha sık kullanılasının doğuracağı ekonomik ve çevresel sonuçlar henüz tam olarak çalışılmamıştır. İlk bakışta her ne kadar para, zaman ve yakıt açısından bir tasarruf olacağı öngörülse de bu yoğun ticari deniz trafiğinin Arktik Bölge'nin ekolojik dengesine hiç şüphesiz olumsuz etkileri de olacaktır. Özellikle iklim değişikliğinin baş sorumlularından karbondioksit oranının artması bu soruyu gündeme getirmektedir. Deniz buzullarının erime trendi engellenmezse ve Arktik Bölge'deki yeni rotalar güvenlik önlemleri olmaksızın kullanıma açılır ve sonuçları düşünülmeden bu bölgedeki deniz trafiği artarsa, olası tehlikeler sadece bu bölge için değil tüm dünya için kaçınılmaz olacaktır.

1. ARCTIC REGION

The word “Arctic” is derived from the Greek word “ἀρκτικός” (arktikos), which means “near the bear”, in reference to the constellation known as Ursa Major (Big Dipper) the "Great Bear", which is prominent in the northern region of the celestial sphere, or to the constellation Ursa Minor, the "Little Bear", which contains Polaris (the Pole star), also known as the North Star.

The Arctic is a region which is located approximately 66° 34' N and above the imaginary Arctic Circle. The chart shown as Figure 1.1 clarifies three important dimensions of the Arctic; the Arctic Circle, the Celcius isotherm and the tree line. In these area, sun never descents below the western horizon on the summer solstice. Likewise it does not rise on the winter solstice. Day and night durations are equal to 6 months in North pole. Because sun sets and rises once in a year. But at lower latitudes, the day and night durations are shorter than North Pole. [1]

Figure 1.1: Dimension of Arctic (NSIDC All About Arctic Climatology and Meteorology)

The Arctic region is placed in the North Polar Ocean and has a lot of islands such as Greenland, Victoria Island and others. [2] The United States, Norway, Canada, Denmark, and Russia are the coastal countries over the Arctic Ocean. Even if these 5 countries have their borders, this region is not owned by any country. [2] As shown Table 1.1 The Arctic Ocean is in the 5th in size comparison of oceans. Arctic Ocean is also covered with sea ice varies from winter to summer.

Table 1.1 The Arctic Ocean Comparison (World Atlas, Oceans of World)

	Size(million km²)	Percentage of Earth's Total Surface	Greatest Depth(m)	Average Depth(m)
Pacific	155.557	30.5	10,911	4,300
Atlantic	76.762	20.8	8,605	3,300
Indian	65.556	14.4	7,258	3,900
Southern	20.327	4.0	7,235	4,000-5,000
Arctic	14.056	2.8	5,160	1,050

1.1. Types of Sea Ice

Sea ices are classified by their development stages. The stages show the thickness and age of ice. Most of the scientists define the sea ice types according to its age like first-year ice or multiyear ice. However, rest of them prefer to define the ice types with specific terms in order to use them for navigational purposes. [3]

The sea ice terms' definition has been given at "Glossary of Marine Navigation" [4] They are anchor ice, bergy bit, blue ice, brash ice, bummock, close pack ice, compact pack ice, consolidated pack ice, fast ice, first year ice, floe, floeberg, firn, frazil ice, glacier ice, glaze, glaze ice, grounded ice, hummock, hummocked ice, iceberg, ice-blink, icefoot, land sky, lead, nilas, nipped, old ice, open pack ice, pancake ice, polynya, rafted ice, rotten ice, sastrugi, shuga, stranded ice, tabular iceberg, very close pack ice and water sky. [5]

The sea ice types are derived from their forms. For example; frazil ice, grease ice, slush and shuga form an ice which is weakly frozen called as new ice. Only when they are floating, they have a precise form. The form can be seen as in Figure 1. 2 Another type of sea ice is nilas. It's a slim layer of ice which has up to 10 cm in thickness. Nilas has two subdivision called as dark and light nilas. (Sea ice types by australian antarctic division) Dark one's thickness is less than 5 cm in very dark color while the light nilas' thickness is between 5-10 cm as seen as Figure 1.3

Figure 1.2: New ice forming over open water between floes. (Capt. Andy Armstrong Healy 1202 Research Cruise)

Figure 1.3: Nilas (Swedish Meteorological and Hydrological Institute)

When the ice is between nilas and first-year-ice it becomes young ice like shown in Figure 1.4. Its thickness is about 10-30 cm. It also has two subdivisions as grey ice and grey white ice.

Figure 1.4: Young Ice (Don Perovich, 2005 Healy-Oden TransArctic Expedition (HOTRAX) Cracks in young ice caused by the passage of vessel called the Healy.)

When the ice stand over one winter after being young ice, its thickness becomes about 30 cm. or more. This kind of ice is called as first-year-ice which is seen as in Figure 1.5.

Figure 1.5: First Year Ice Young Ice (University of Texas at San Antonio, SIMBA Website)

Old ice is the ice which stands after one summer melting season at least. Generally this type is smoother than the first-year-ice. Multiyear ice is a subdivison of old ice. A multiyear ice is shown in Figure 1.6

Figure 1.6: Scientists watch from the deck of the U.S. Coast Guard Cutter Healy as it cuts through multiyear sea ice in the Arctic Ocean on July 6, 2011 (NASA/Kathryn Hansen)

The sea ice forms are classified by their length. If it is a piece of ice which is between 30 cm to 3 m in diameter and thickness up to 10 cm, it's a form called as pancake ice. Pancake is shown in Figure 1.7.

Figure 1.7: Pancake Ice (University of Texas at San Antonio, SIMBA Website)

Brash ice is another form of sea ice, which is gathering form fragmented of floating ice. It is about 2 m across and seen as in Figure 1.8

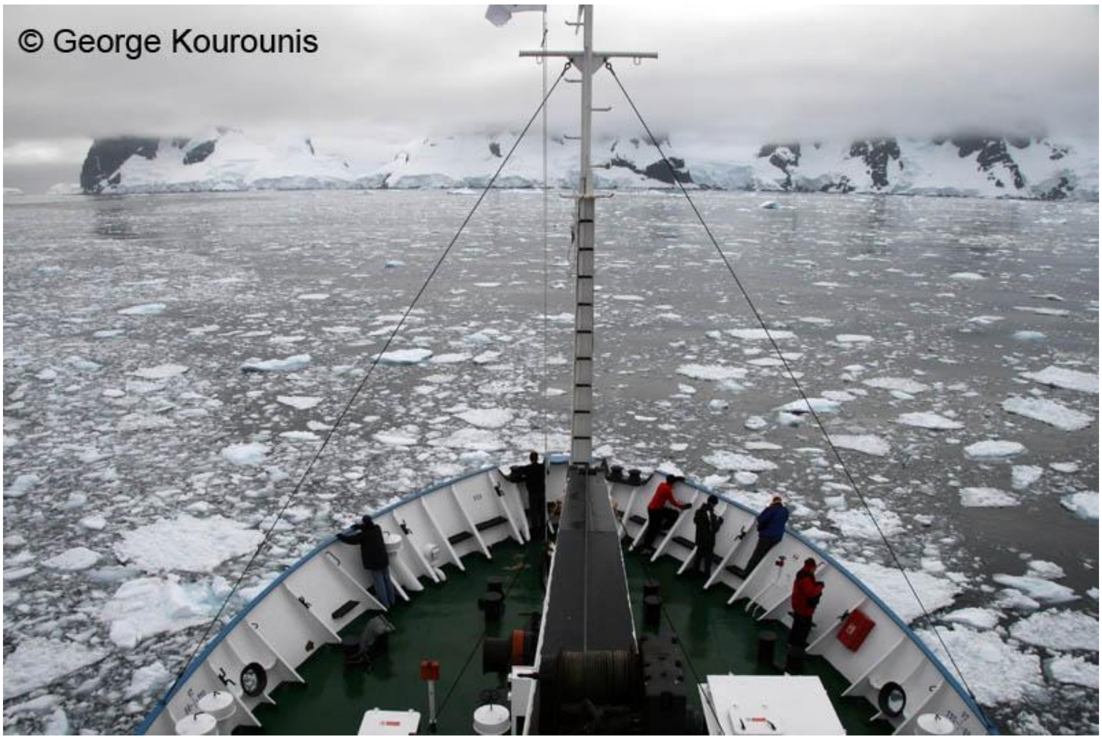

Figure 1.8: Brash Ice (George Kourounis)

If the flat piece of ice is taller than 20 m. across or more, it becomes floe. Floe has five sub-forms according to its horizontal extent. Ice Floe sample is seen as in Figure 1.9.

Figure 1.9: Ice Floe (Tom and Louisa Shields)

Fast ice is the ice form, which survives over the coastline. It moves neither with wind nor water currents. Fast Ice is shown in Figure 1.10.

Figure 1.10: Fast Ice Land (Michael Van Woert, National Oceanic and Atmospheric Administration/Department of Commerce)

1.2. Arctic Sea Ice

Because of harsh weather conditions in Arctic region, water temperature is cold. That's why there is thick ice sheet over the Arctic Ocean surface almost whole year. Although the conditions do not considered as life friendly, its ecosystem is more various than expected. [6]

Sea ice has a different structure than pure water ice. The salt inside of sea water decrease the freezing temperature. The sea water's freezing temperature is about -2°C, whereas pure waters' is about 0°C. [7]

During the winter , air temperature decreases which cause a thick layer of seawater to freeze suddenly. Because of drained salt water, the ice layer transforms to pack ice as a solid unit. During the sea ice formation process, small spaces survive between ice crystals. These spaces are filled with a salty solution called as brine. Ice crystals and brine channels form the sea ice. [8] There are plenty of different microorganisms like bacteria, virus, larvae, worms and micro algae in the water as seen in Figure 1.11 When the temperature decreases the water started to freze with these microorganisms in the brine channels. The brine channels stay alive during the winter in small tube forms and they start to expand when the sea ice are getting melt in the spring. [9] The brine channels begin to inter-connect with each others.

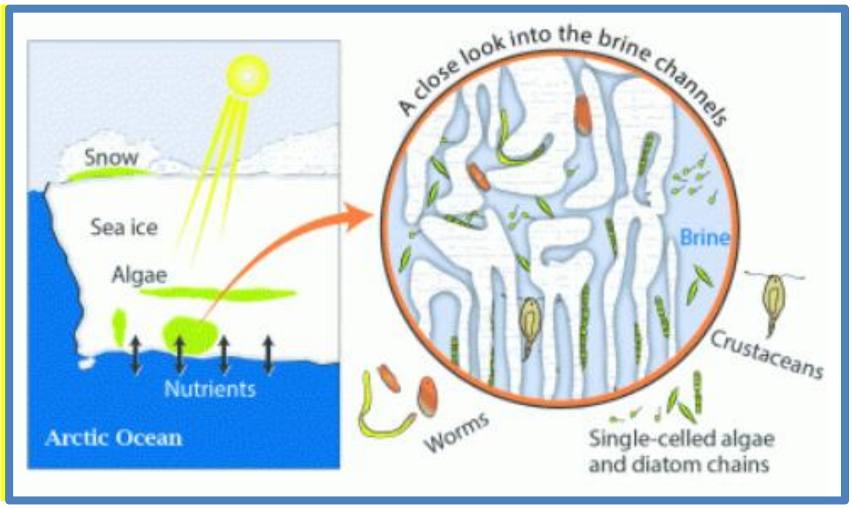

Figure 1.11 The flourishing life within the briny habitat of sea ice **(**Christopher Krembs, Jody Deming "Sea Ice: a refuge for life in polar sea?" pmel.noaa.gov)

For the polar microorganisms, the brine channels provide a habitat which build the basis food net of polar marine ecosystems. Sea ice formation has multiple impacts on balance of ocean habitat. It affects ocean-atmosphere heat transfer and radiation balance. Besides that, in the ocean the thermohaline circulation is also changed by the sea ice formation. This situation helps to the nutrient carriage in there. Because of these reason mentioned above, as a result of brine channel's physical and chemical interaction, they have crucial mission for ocean environment in terms of energy flood and microbiological creatures' metabolic growth. [10]

All the winter long, the pack ice, which exists over the Arctic Ocean, expands and becomes continuous vast sheet during the spring and summer, the pack ice starts to melt down and divides to smaller pieces. [11] as seen in Figure 1.12

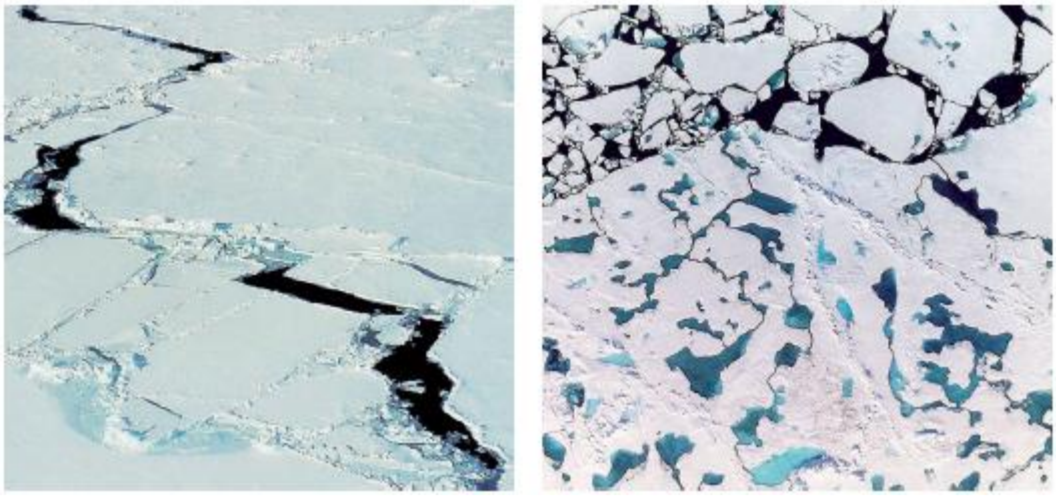

Figure 1.12: The aerial photos of Artic sea-ice cover prior to melt (left) and during the melting season (right) (Don Perovich)

In Arctic Region, two different types of ice pack exists. They are the winter ice pack and multi-year ice. The winter ice pack is the a form of annual ice. Annual ice disappears in the spring and freezes in the fall. Contrary to annual ice, multiyear ice does not melt in the summer. Multi year ice has also two forms. One of them is known as the Arctic which is the massive polar pack. It stays in the center of the Arctic Ocean and moves as a unit in the direction of clockwise. Because of being unit, it moves very slowly. The other form of multiyear ice is the summer ice pack. It stands over the permanent polar pack but it separates in the summer. Even if it separates in the summer it affects these area throughout the year. Because the broken ice parts obstruct some of the Arctic islands' channels. [12]

2. SHIPPING IN ARCTIC REGION

2.1. Arctic Marine Transport History

At the beginning, Arctic Marine Transportation had been started in ice-free region of the Arctic Ocean. In the ice-covered western part of Northern Sea Route (NSR) became the route of transportation at the end of 1970s with some old vessels like seen in Figure 2.1 This route was navigable almost all the year. The past transportation studies about relevant regions provide the regulation framework for transportation to the Arctic Ocean. This studies were not only as a result of international collaboration but also mutual effort of private and public sectors. [13]

Figure 2.1: Photo of historic ship and dogs on ice (Coast Guard Museum NW / Frye Collection)

2.2. Arctic Marine Geography

In the second half of 20th Century, new scientific observations about Arctic sea ice had been shared with the public which showed that the extent and the thickness of sea ice in the Arctic were decreasing day by day. The findings continued in early 21st Century. The simulation of Global Climate Model showed that sea ice decreasing would continue but the winter sea ice should not melt down. But new scenarios are more intimidating than before. One of them mentioned that there is a possibility that within a decade or two the Arctic Ocean will be ice-free all-year round. [14] In this case there will be no sea ice in the summer including multiyear ice. On the other hand, this situation will maintain more longer navigation season and more accessible maritime region over the Arctic which is seen Figure 2.2 and ice condition will be more easier for marine operation.

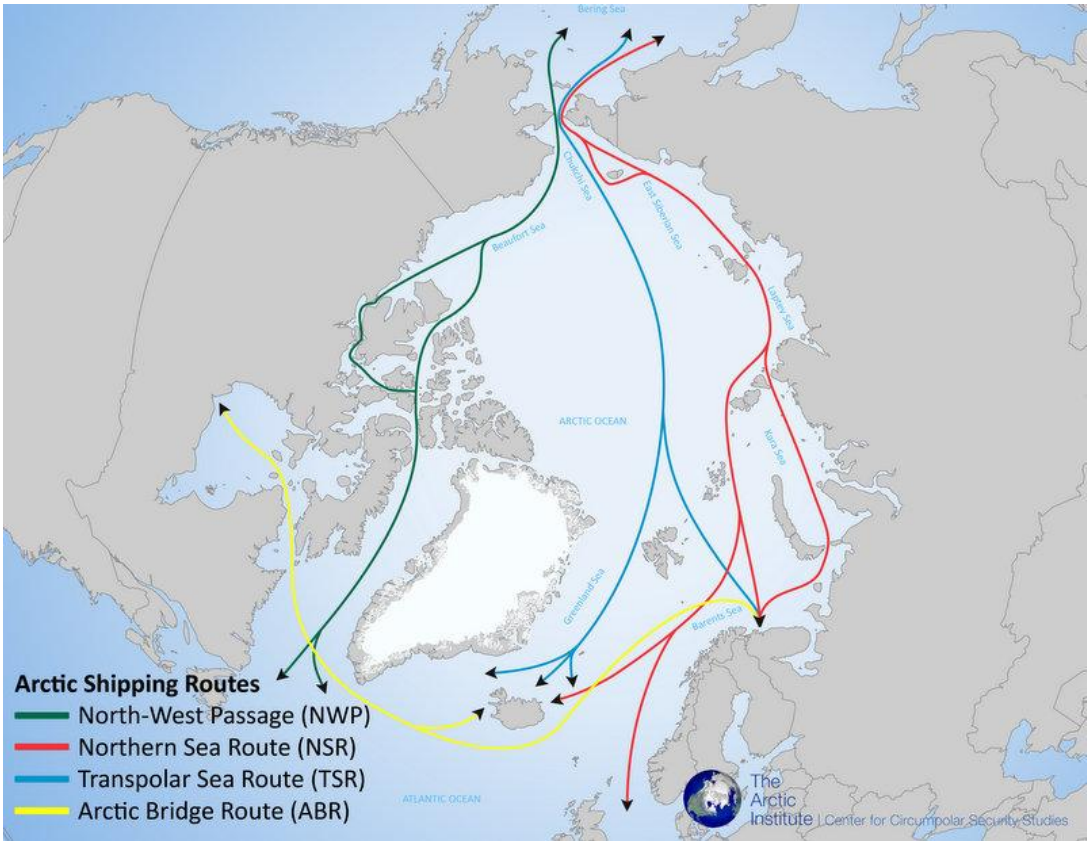

Figure 2.2: Arctic sea routes (Ref: The Arctic Institue)

The comparison between NSR along Russia's Arctic border and route along the Suez Canal shows that the first one is more shorter. This comparison has been proven by Cosco Shipping's vessel called as Yong Sheng in August 2013 [15]

In this case the Arctic Northeast Passage saved 13-15 days than the route through Suez Canal which means $80,000 in fuel cost savings. The comparison among Cape of Good Hope, Suez Canal and Northeast Passage is shown in Table 2.1. And the other benefit of this route is about carrying larger cargos without restrictions. Panamax ship Nordic Orion is an example such as could able to carry more 15.000 tons of coal navigating thought North-West Passage (NWP) route instead of Panama Canal. [16]

Table 2.1: Sailing Distances between Asia and Europe (Polar Geography)

From	Cape of Good Hope	Suez Canal	NEP	Difference between Suez and NEP (%)
Yokohama	14,448	11,133	7010	37
Busan	14,084	10,744	7667	29
Shanghai	13,796	10,557	8046	24
Hong Kong	13,014	9701	8594	11
Ho Chi	12,258	8887	9428	-6

Because of the shorter route, fuel consumption of vessels will decrease obviously; while as emission of Carbon Dioxide (CO_2) will reduce. Speed of vessels will be slower because of bad sea and weather conditions. This situation will provide fuel efficiency to the vessel in addition.

2.3. Governance of Arctic Shipping

The Arctic marine navigation governance is based on the United Nations Convention on the Law of the Sea (UNCLOS), which framework is provided by The Law of the Sea. It allows coastal states the right to adopt and enforce non-discriminatory laws and regulations for the prevention, reduction and control of marine pollution from vessels in ice-covered waters. [17]

As United Nations (UN) Agency The International Maritime Organization (IMO) has responsibility to regulate the international maritime industry. IMO published Guidelines for Ships Operating in Arctic Ice-covered Waters voluntarily. This guideline is in progress. The another international player in maritime domain called as The International Association of Classification Societies (IACS) has established non-mandatory Unified Requirements which define the standards of ship construction of the Polar Classes. This requirements are compatible with the IMO Guidelines. [18]

Even if these kindly initiatives, still there is no unique standards for Arctic safety especially for mariners survival. [19] Besides that lack of mandatory environmental clauses is another issue for Arctic waters. For marine safety and environmental protection in Arctic waters, reflection of UNCLOS could be a solution for the stakeholders. The possibility of marine traffic is increasing in Arctic as mentioned previous section. That means; not only safety and environmental pollution in Arctic but also new species introducing and pathogens from vessel via ballast water will be discussed eventually. [20]

In polar conditions, it is not possible to mention an international regulation for ice navigators and specific emergency rescue plans for mariners. Differently from the other oceans, there is not any precise rules by IMO to protect the environment from ships navigating in Arctic Ocean. Creating the global standards, which is in line with current international legal structures like UNCLOS, could provide the maximum safety for mariners and environment in Arctic region. Increasing marine traffic in Arctic could cause to carry alien species and pathogens by ballast water. Uncontrolled ballast discharge can be harmful to Arctic ecosystem. [18]

2.3.1. Environmental considerations and impacts

Being more accessible to Arctic region because of long season of navigation has also some inconveniences in terms of environment. Releasing oil accidental or illegal discharge from the ships is the most possible menace to the Arctic environment. [21] The other probable threats can be related to marine mammals, alien species and anthropogenic noise which route cause is shipping actions in the Arctic region. [20, p. 186] Moreover, carbon emissions from ships can cause ice melting in this region. Besides that Sulfur Oxides (SOx) and Nitrogen Oxides (NOx) emission of ships may have some unforeseen results for the Arctic. This consequences support to have new guidance or regulation especially environmental domain which can be released by global authority like IMO. [18]

2.4. Arctic Marine Infrastructure

The absence of marine infrastructure in the Arctic is very obvious regarding to heavy ship traffic region of the World. The Norwegian coast and northwest Russia along the Arctic are the exception for this statement. Lack of hydrographic data in the significant part of essential vessel routes is important to maintain proper navigation. [22] Like the other oceans, the Arctic Ocean's meteorological and oceanography data should be improve to provide more safe navigation. Especially sea ice and iceberg information would be very useful to have more safe shipping in Arctic Ocean.

On the other hand, life saving plan and diminution of pollution in case of emergency is another area which is open for improvement except restricted part of he Arctic. Communication via radio and satellite in the Arctic region is restricted and there is limited monitoring and controlling system related to shipping traffic in ice-covered area. The heavy sea and weather conditions make more difficult to build emergency response center in this region compared to the other oceans. [23]

2.4.1. Bulk transport of ore, oil and gas

Regarding to Arctic Marine Shipping Assessment (AMSA) Report, transportation of some bulk cargoes like oil, gas and different type of ore is an important part of whole Arctic ship traffic in quantity of cargo carried. [18] In Figure 2.3, a bulk carrier which can navigate over the Arctic sea ice, is shown. The Arctic has rich underground sources like zinc, nickel, the other ores and oil and gas producing fields in some coastal area over the Arctic. [24]The Red Dog mine in Alaska and The Norilsk Nickel mine in Russia are worldwide resources in terms of zinc and nickel and palladium production. [25]

Figure 2.3: An Arctic vessel (Environment Canada Photo)

Since Arctic has very rich sources, the bulk shipping traffic is mainly internationally outbound. Especially exploration of new natural resources in area became a popular industry. Early 2000s, Russia and USA has initiated this industry. Russia made a bulk oil shipment with an icebreaker vessel called as Varandey in Russian Arctic in 2004. USA had a different attitude than Russia, like conducting offshore lease sale in US Arctic area. The total amount was about 2.7 billion $. And this is meant to be used for Arctic region development. This Project was driven by U.S. Minerals Management Service. [26]

The latest development was about commercial mass shipping navigation in 2013. The very first passage through the NWP has been achieved successfully in the summer of 2013 by eastward transit of a commercial ship. The opposite passage along the westward has been done by another vessel in the next year. [27]

2.4.2. Fishing

Arctic water is very feasible to fishing. It’s one of the more fruitful area in the World. That’s why fishing has an importance section inside of all vessel traffic. Even if there is no up-to-date or regular database according to fishing counts, this area is very well known commercial fishing is inevitable part of the Arctic waters. Actual amount of fishing activity in these area is underrated in AMSA report. Bering and Barent seas, Greenland, Iceland and Faroe Islands are the most popular fishing sections according to the reports.

As shown in the Figure 2.4, Arctic Ocean and the Canadian Arctic Archipelago are the areas which are not very common used for fishing. [28]

Moreover commercial fishing in the global water of the Arctic Ocean is prohibited by five coastal countries in the Arctic Ocean. The Declaration Concerning the Prevention of Unregulated High Seas Fishing in the Central Arctic Ocean was signed in Oslo on 16th of July 2015. The declaration limited commercial fishing in Arctic Ocean. The reason of this limitation is to prevent uncontrolled fishing over the Arctic waters. Declaration was welcomed by the experts who were worried about ecosystem of Arctic region especially after NASA report. [29]

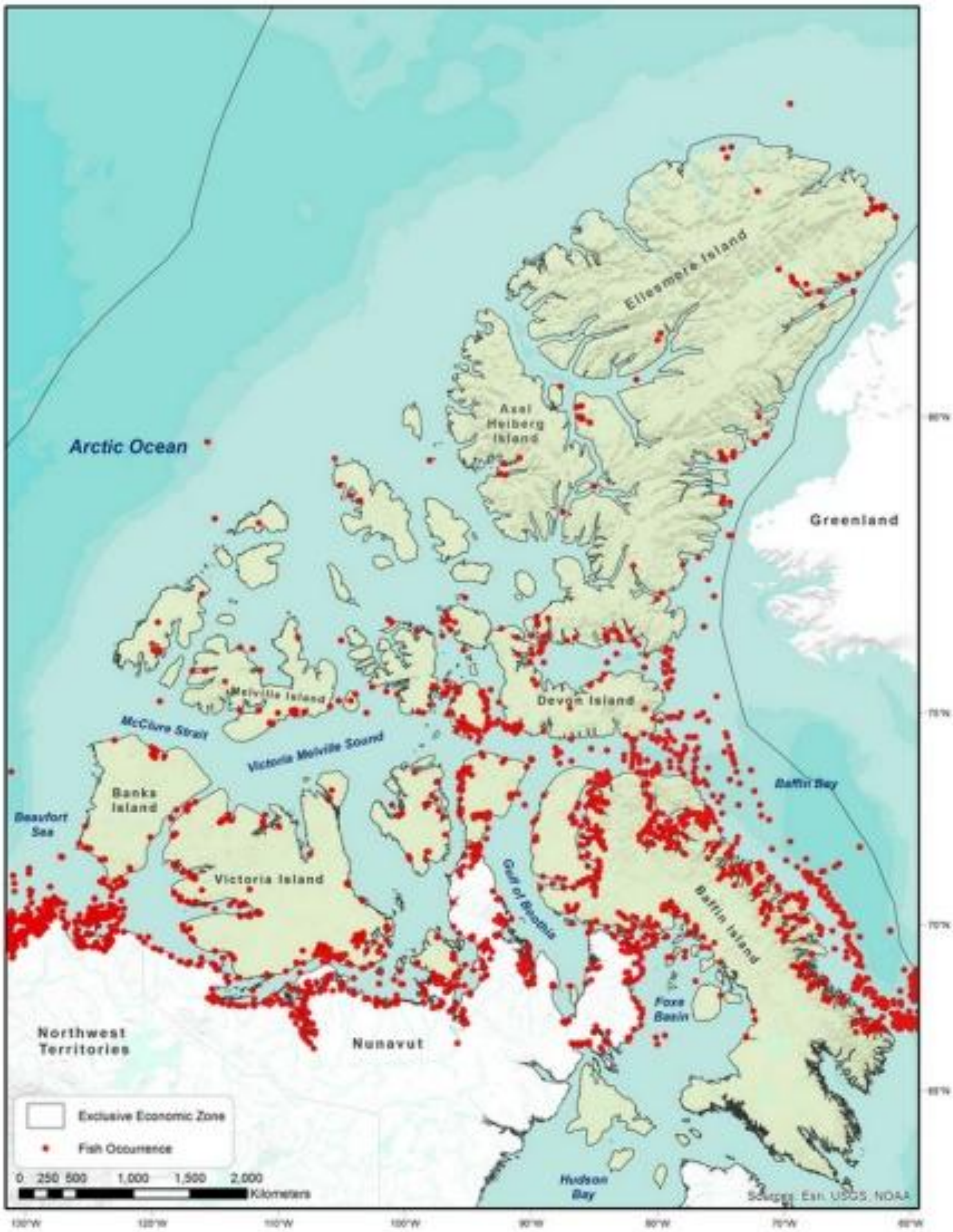

Figure 2.4: Arctic sea fishing regions (Marine Fishes of Arctic)

2.4.3. Passenger vessels and tourism

The Arctic region is one of the attraction center in the World for whom would like to experience its untouched nature. According to AMSA database tourism is another important activity in the region. This report includes ferry services, small and large cruise vessels and any other vessels which are used to transport the people. Even if the number of people who visited the North, mass tourism is about to develop day by day. According to the report which is published by Ottawa university called as "Cruise Tourism in Arctic Canada", common concerns were management, safety and security, infrastructure provision, economic development and protecting Arctic environment and people. [30] In other areas, such as Alaska and the Canadian Arctic, ferry services are non-existent and all passenger traffic would be vessels for marine tourism only.

Figure 2.5: The Crystal Serenity, pictured off the coast of Norway's North Cape. (Crystal Cruises)

Enjoyable weather, an interesting natural landscape and biodiversity are the common points of attraction for the tourism. [31] The tours for Arctic regions do not address to only adventurer but also to tourists who would like to have high standards. The cost of an Arctic journey with the Cruise shown in Figure 2.5 starts from 20.000$ up to 44.000$ per person. Passengers of this cruise will have chance to explore Arctic wild life due to weather and ice conditions. This tour's claims that its' aim to enlighten the guests about climate change. But on contrary, some green activists mention that this kind of cruise would cause carbon footprint three times bigger than an airplane. [32]

3. CLIMATE CHANGE

Since 1950, this trend of global surface temperature has raised and according to the Third Assement Report of Intergovernmental Panel on Climate Change (IPCC), the temperature of 100-year trend between 1906–2005 is more than the temperature of the 1901–2000 years period. The increase ratio from 1850-1899 to 2001-2005 is 0.76°C ± 0.19°C and the average warming rate is almost twice the last 100 years when 0.13°C ± 0.03°C per decade is taken into consideration. [33] In this Figure 3.1 trends in mean surface air temperature are shown between 1960 to 2011. The Arctic region is indicated by red because the air temperature has raised more than 2° C which is more comparing the rest of the World.

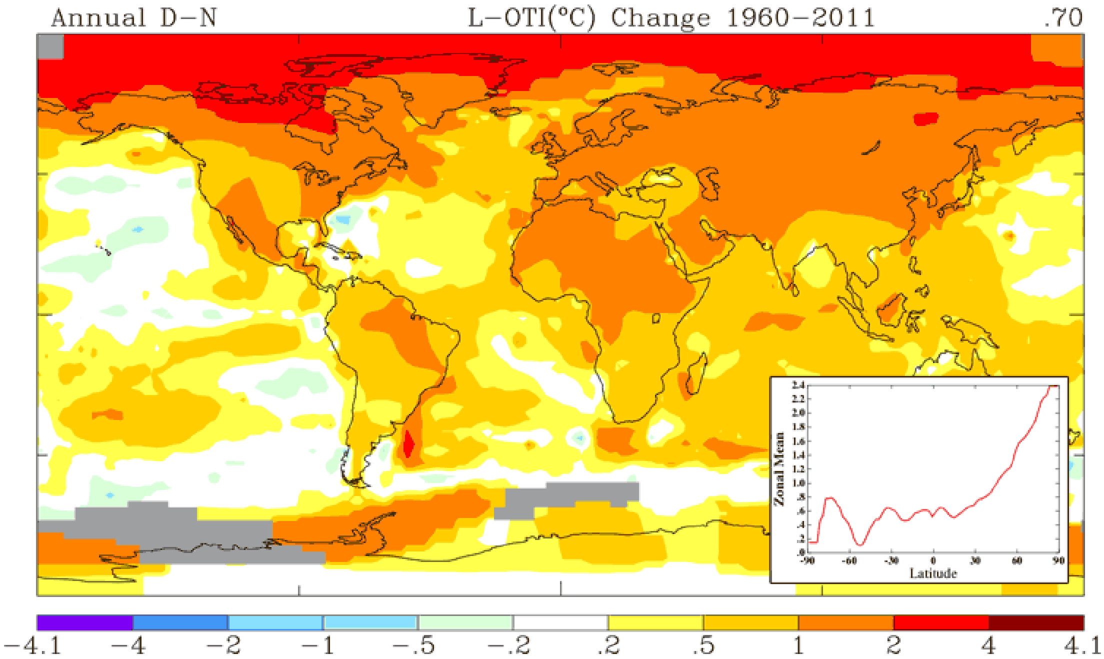

Figure 3.1: Temperature Trends in World (NASA GISS)

3.1. Global Trend

The projected effects on the warming is 1.4°C to 5.8°C between 2000 and 2100. [34] This projection will influence a lot of water related domains like ocean currents, the precipitation volume and sea level all over the World. Undoubtedly this situation will have some effects on human life and ecosystem. [35] The global temperature trend is shown in Figure 3.2.

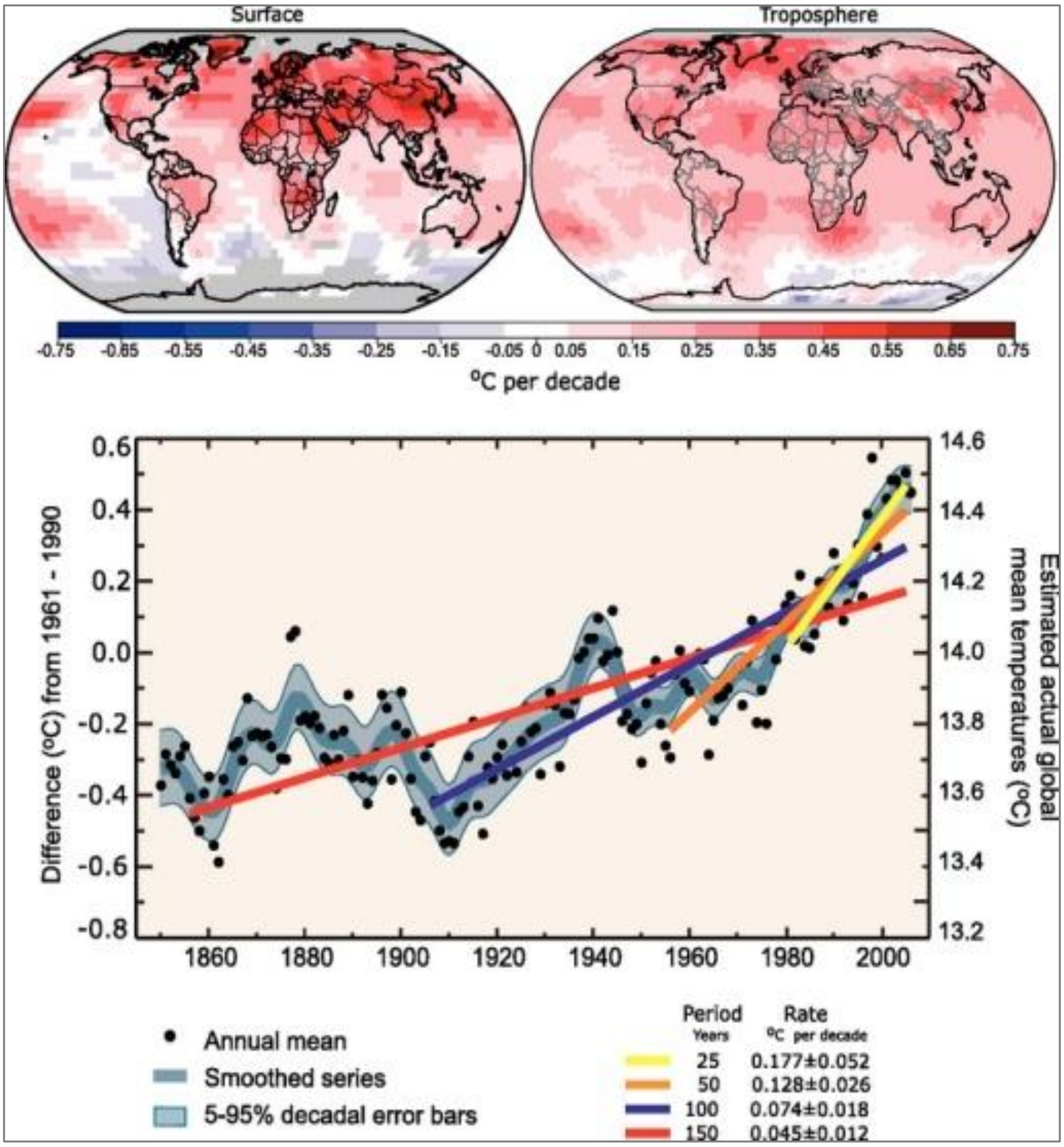

Figure 3.2: Global Temperature Trends (Intergovernmental Panel on Climate Change)

One of the responsible of global warming is greenhouse gas (GHG) releases. Burning fossil fuels is the most used source to supply the energy need in the World. The usage ratio of fossil fuels as an energy supply is about 80%. The side effect of burning fossil fuels is long-standing raised of CO_2 amount in the air. In spite of corrective action to decrease CO_2 emission, it will remain in the atmosphere for centuries and it take a long time to disappear. [36] The CO_2 monthly update values of Mauna Loa Observatory, Hawaii shows the global CO_2 trends as seen in Figure 3.3 the dashed red line with diamond symbols represents the monthly mean values, centered on the middle of each month. The black line with the square symbols represents the same, after correction for the average seasonal cycle.

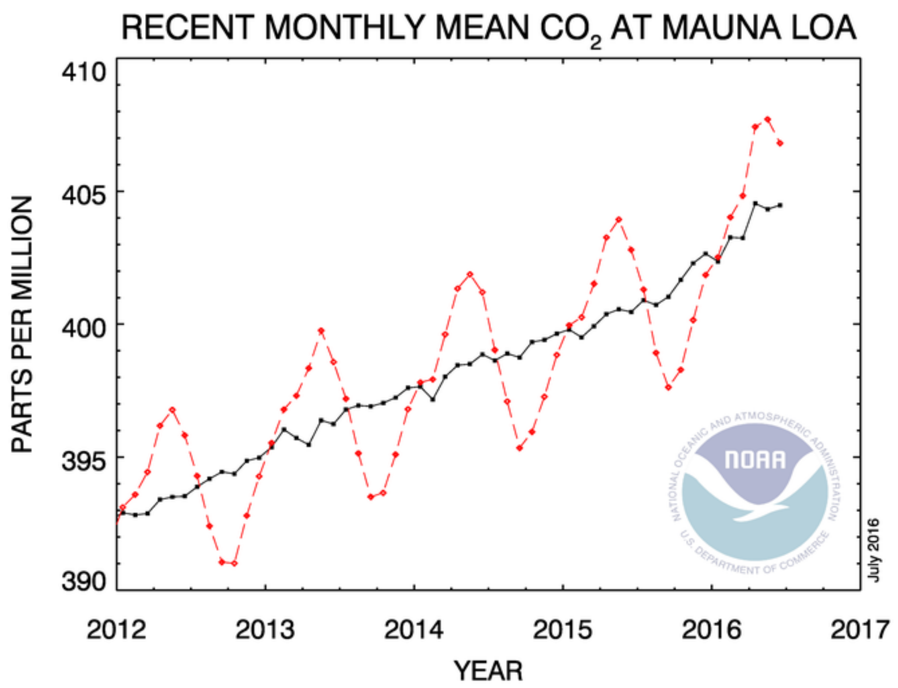

Figure 3.3: Monthly mean CO_2 measured at Mauna Loa Observatory, Hawaii. (Monthly mean CO_2 measured at Mauna Loa Observatory, Hawaii.)

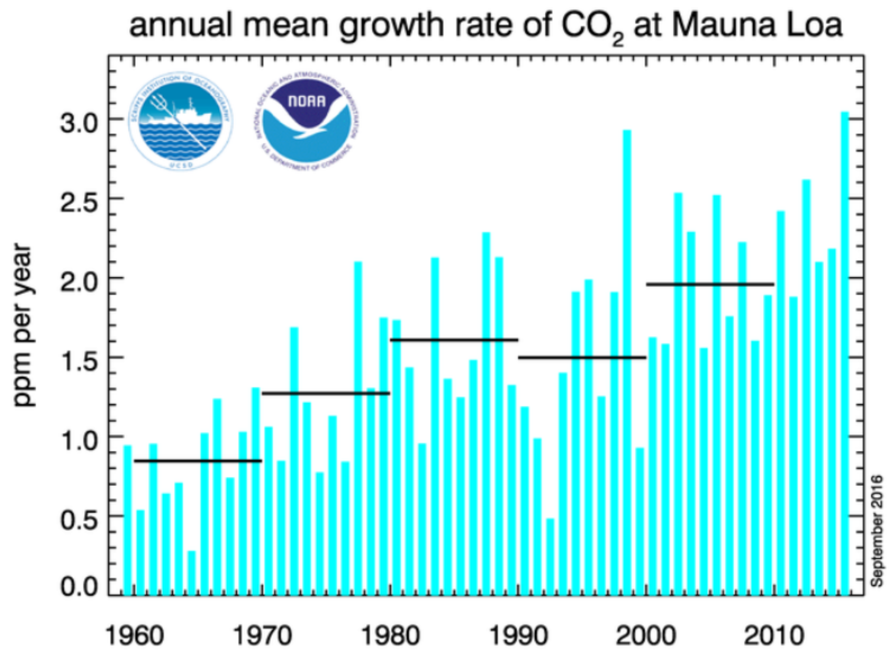

Figure 3.4 Annual Mean Growth Rate of CO_2 at Mauna Loa (http://www.esrl.noaa.gov/gmd/ccgg/trends/gr.html)

The Figure 3.4 shows annual mean carbon dioxide growth rates for Mauna Loa. In the graph, decadal averages of the growth rate are also plotted, as horizontal lines for 1960 through 1969, 1970 through 1979, and so on.

During this process there will be climate changes and their effects for centuries. [37] The past records of sources such as ice cores determine that present warming level is further than natural order.

For its Fifth [5th] Assessment Report in 2014, the IPCC adopted four possible greenhouse gas concentration scenarios in order to predict the future of global warming. They have replaced the Special Report on Emissions Scenarios (SRES) which had been published in previous reports. [38] Since climate change has various effects, there are some different groups of study which use climate change outcomes in their exploration.

Each RCP contains some socio-economic hypothesis like energy sources, population growth, economic facilities etc. up to 2100. This scenarios also have real world evidences and historic background. The possible scenarios describe four potential climate futures. Each one designs different pathway of emission and cumulative emission concentration by 2100. This pathways have a different approach from previous studies; RCPs' approach is not sequential, it is parallel. Because of this reason the RCPs are not linked with exclusively socio-economic hypothesis or emission plots. RCPs are different combination of economic, technological, demographic, policy, and institutional futures. [39] Besides RCPs The Extended Concentration Pathways (ECP)s also exist regarding to this study. These pathways include possible scenarios until 2300. [40]

In order to focus this study's objective, RCP 2.6, RCP 4.5, RCP 6 and RCP 8.5 will be reviewed.

The 'best case' situation is designated as Representative Concentration Pathways 2.6. (RCP 2.6.) The 'worst case' scenario is RCP8.5. The two others are RCP4.5 and RCP6. The values of +2.6, +4.5, +6.0, and +8.5 W/m2) are based upon the hypothesized values in the year 2100. The 'best case' scenario assumes the annual global greenhouse gas emissions peak between the years 2010 and 2020, with a decline in emissions following. The RCP4.5 emissions hit the highest point in the year 2040 and then fall off, while the RCP6 emissions top out in the year 2080 before diminishing. In the ‘worst case’ scenario, the RCP8.5 emissions continue to rise past the end of the 21st century. [41]

3.2. Climate Change Effects in Arctic Region

The temperature of the Arctic is getting higher comparing to the other region of the World over the past three decades. Scientists agree that Arctic climate is changing because of human activities that warming weather temperature all around the earth. [42]

The Arctic climate change is expected to ruin the balance on the earth in terms of ecology, economy, sociology, physical and politics. Also this changing will increase sea levels by melting sea ice.

2010 was a milestone to the Arctic region. Because National Oceanic and Atmospheric Administration (NOAA) reported that the air temperature was measured as 4° C higher comparing to period of 1968 to 1996. [43] Sea ice in the Arctic melts till middle of the September. Over the past three decades sea ice area in Arctic region has decreased %30 in September according to satellite data. Satellite data also determine that snow cover in the Arctic has reduced, when the glaciers in Denmark and Canada are melting down. Moreover, frozen part in the Arctic has started to dissolve. The scientific exploration of climate change in Arctic was in the 1970s. And the observation continued in early 1980s. [44]

Normally, the Arctic region supports to cool the World. This region’s giving and absorbing heat capacity make the other regions more cooler. Comparing the giving amount of heat to the absorbing shows that the first one is much greater. So climate change in Arctic’s impact cause serious result climate all over the World. Earth surface temperature is 0.6°C on average higher than the last two centuries. [34] This changing on climate has also another effect over the CO_2 levels.

Model simulations of Arctic sea ice extent for September (1900-2100) based on observed concentrations of heat-trapping gases and particles (through 2005) and four scenarios.

Colored lines for RCP scenarios are model averages (CMIP5) and lighter shades of the line colors denote ranges among models for each scenario. [45]

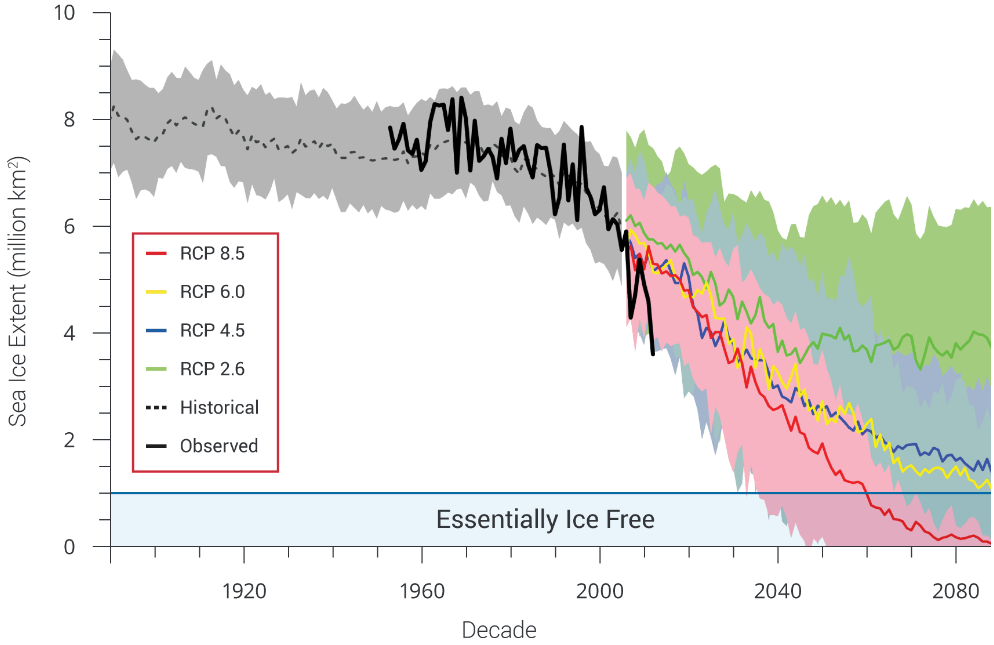

Figure 3.5: Projected Arctic Sea Ice Decline. (CMIP)

Shown in Figure 3.5 dotted gray line and gray shading denotes average and range of the historical simulations through 2005. The thick black line shows observed data for 1953-2012. These newer model (CMIP5) simulations project more rapid sea ice loss compared to the previous generation of models (CMIP3) under similar forcing scenarios, although the simulated September ice losses under all scenarios still lag the observed loss of the past decade. Extrapolation of the present observed trend suggests an essentially ice-free Arctic in summer before mid-century. The Arctic is considered ice-free when the areal extent of ice is less than one million square kilometers. The RCPs are in agreement with a large number of human-induced greenhouse gas footprints. The four RCPs are correspond well with certain socio-economic hypothesis. However they have to be replaced by the shared socio-economic pathways that are expected to ensure future scenarios within each RCP. [45]

Even if it is not very easy to guess the future of climate in Arctic, some of the scientists' perspective is more optimistic. "The Arctic Amplification" is a less pessimist phenomenon of the Arctic climate change. [46] According to the arctic amplification, there might be some positive results like decreasing the effects of warming; as long as temperature of Arctic region warmer, the area will be more favorable to grow up plankton that reduce carbon emission from the air. No matter the positive feedback effects surpass the negative effects, it's clear that Arctic climate will not be the same as before global warming.

Warming trends are proven by three global estimations. The other consistent source is between Sea Surface Temperature (SST) and nighttime water air temperature. The SST anomalies in Arctic are seen as Figure 3.6. There is an intense warming issue in the Arctic that is twice the rest of the World. After the industrial revolution, the warming accelerated due to the human activities. As a result, CO_2 volume in the atmosphere is %35 higher than before industrial revolution. [36]

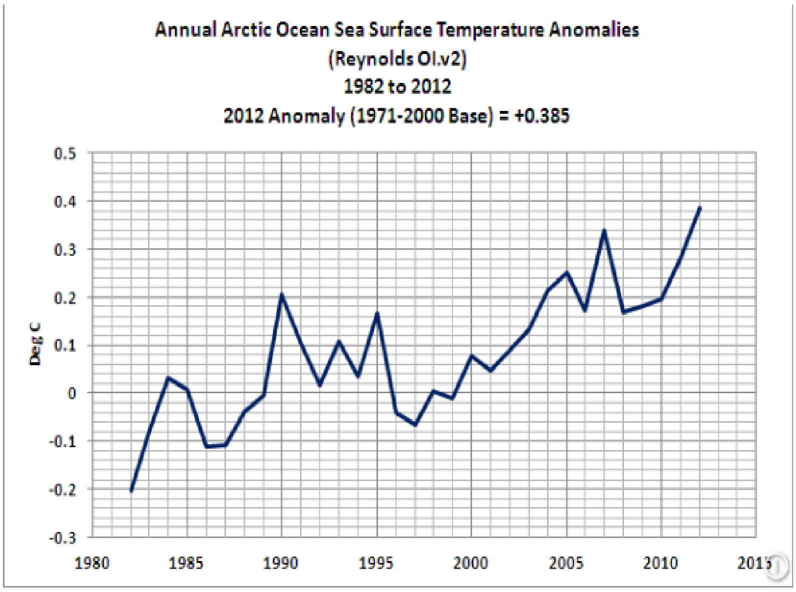

Figure 3.6: Annual Artcitc SST Anomolies. (Bob Tisdale Climate Observations)

In Figure 3.7 and 3.8 the graphics show that comparing of minimum and maximum values of ice extents and Arctic region temperature anomalies by years.

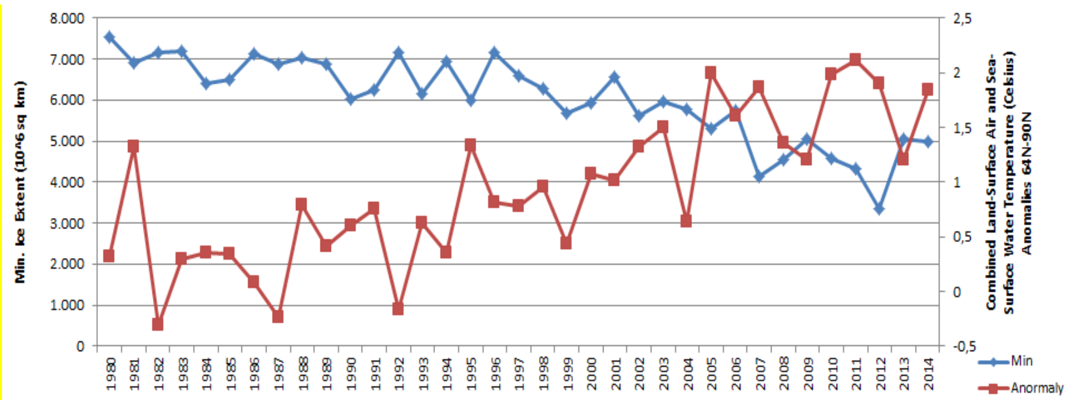

Figure 3.7: Combined Land-Surface Air Temperature and Sea Surface Water Temperature Anomolies 64N-90N with Min. Ice Extent (http://data.giss.nasa.gov/gistemp/tabledata_v3/ZonAnn.Ts+dSST.txt)

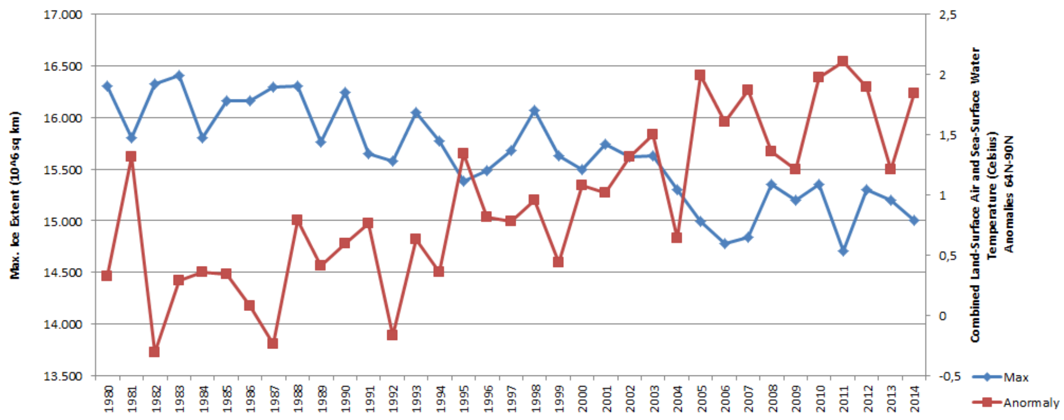

Figure 3.8: Combined Land-Surface Air Temperature and Sea Surface Water Temperature Anomolies 64N-90N with Max. Ice Extent (http://data.giss.nasa.gov/gistemp/tabledata_v3/ZonAnn.Ts+dSST.txt)

Besides the connections between ozone depletion and climate change, another problem is the depletion of the stratospheric ozone layer that chlorofluorocarbons and other manmade chemicals cause. [47] For example, climate change delays the recovery of stratospheric ozone over the Arctic and changes its structure with ultraviolet radiation, and related impacts in the Arctic as shown in Figure 3.9. [48]

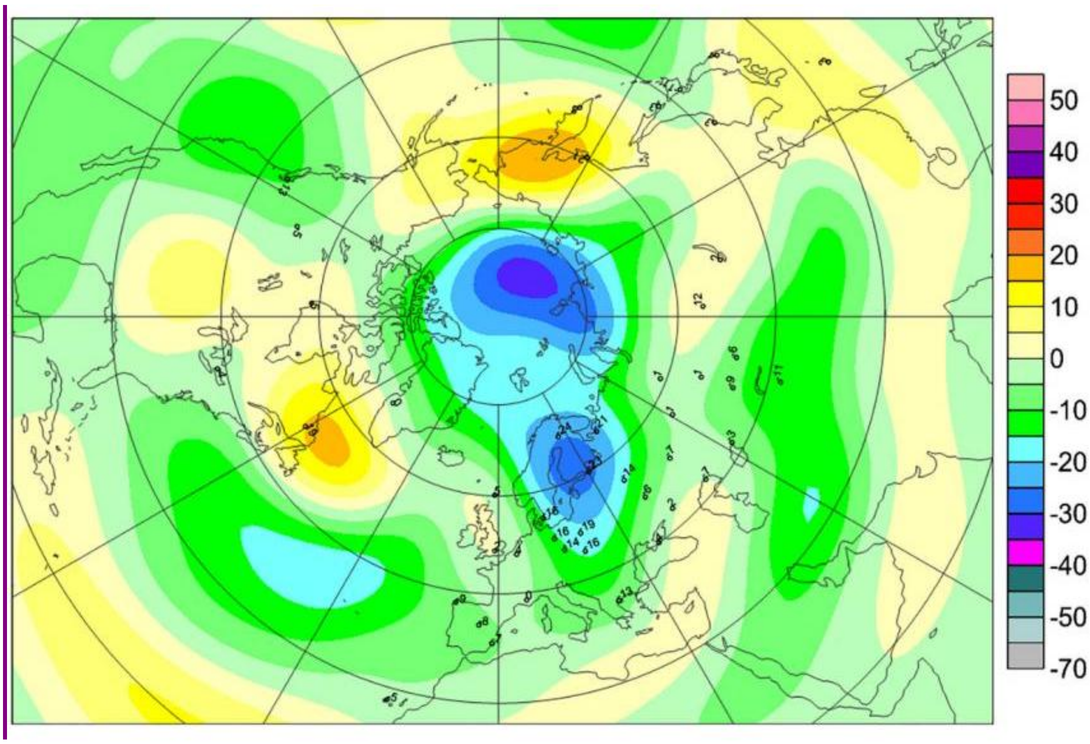

Figure 3.9: Cold weather and a strong stratospheric vortex have allowed a deep Arctic ozone hole to open up. (Science Mag)

4. DATA ANALYSIS OF SEA ICE EXTENT FOR ARCTIC

The scientific studies observed that there is a link between increase of carbon dioxide level and climate change. As mentioned before, the surface temperature is getting increase everyday. The human activities like burning of fossil fuels and clearing land motivate to rise the concentration of greenhouse gases like CO_2, methane etc.

CO_2 concentration is %35 higher than pre-industrial revolution age while the global average temperature is plus 0.6 ˚C. This facts present that industrial revolution has effected both the CO_2 concentration and risen global average temperature. The international scientists agree that main reason of these fact derive from human activities especially over last 50 years. [49]

Following tabular values of Arctic Ice Extent and them graphics are derived from dataset of source web link. [50] The data capturing process is seen as below in Figure 4.1- Figure 4.4

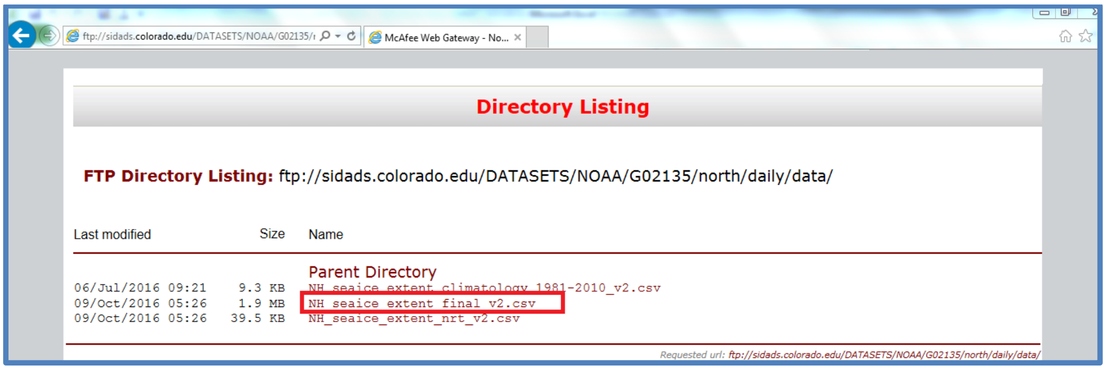

Figure 4.1: Web site directory via web page

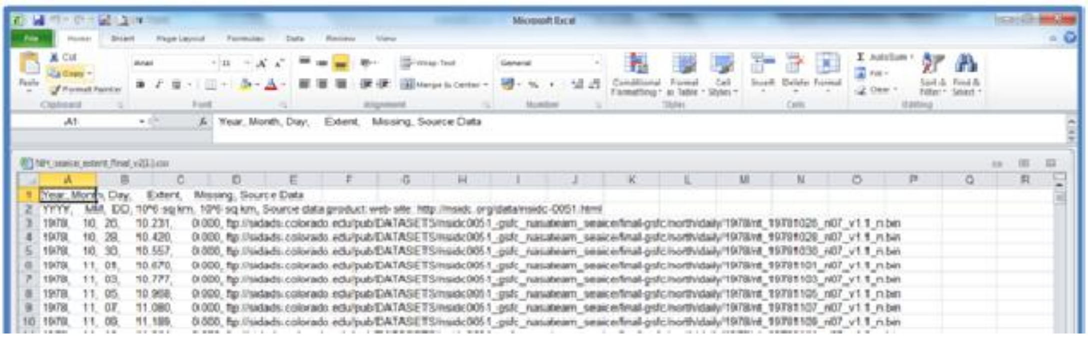

Figure 4.2: Raw data is loaded as .csv format

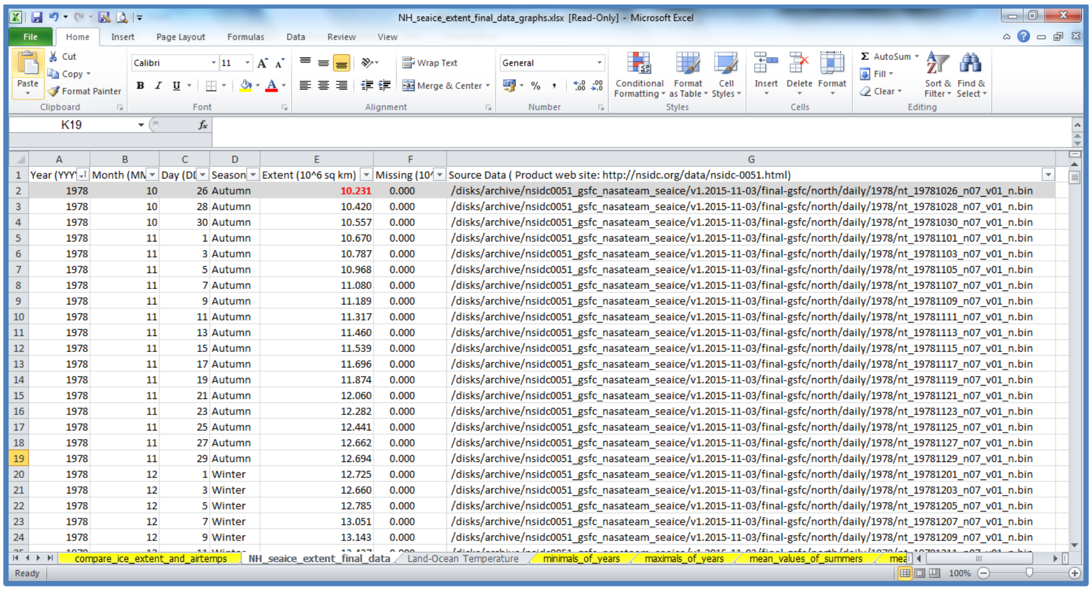

Figure 4.3: Data explanation phase in .xlsx format by text the columns

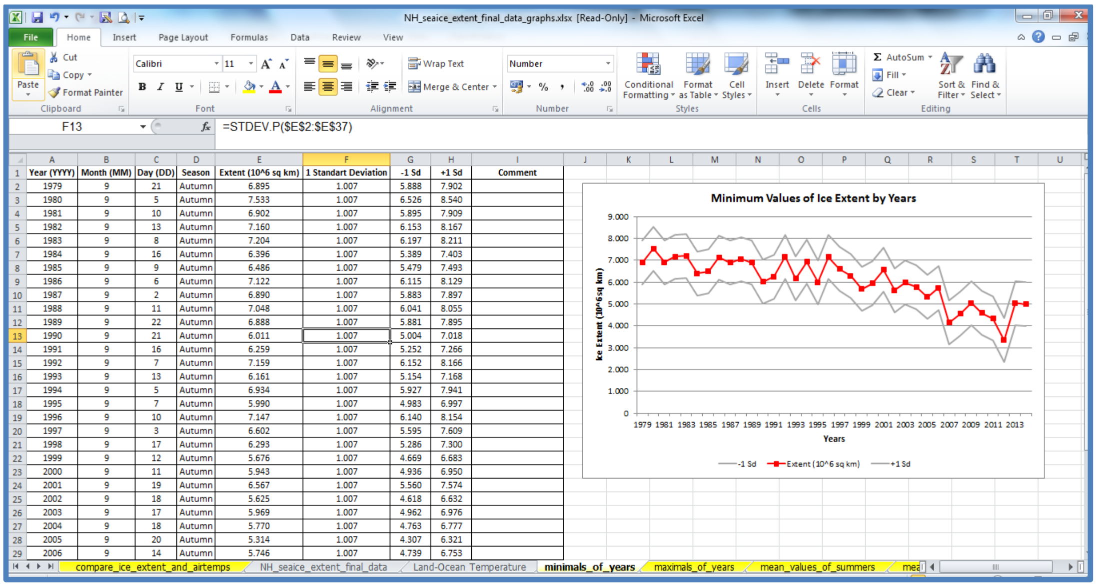

Figure 4.4: Data preparation to make the graphics

4.1. Analysing of The Source Data

The data which is analysed in this study provided by remote sensing platforms called as Nimbus-7 and the Defense Meteorological Satellite Program (DMSP) as shown in Figure 4.5 and Figure 4.6. The data are provided in the polar stereographic projection at a grid cell size of 25 x 25 km. The used sensors are Scanning Multichannel Microwave Radiometer (SMMR) with Nimbus-7 and Special Sensor Microwave/Imagers (SSM/Is) and Special Sensor Microwave Imager/Sounder (SSMIS) with DMSP. The spatial resolution is 25 km. The data are generated by brightness temperature with NASA Team algorithm. SMMR is used between November 1978 and June 1987 while SSM/I ise used between June 1987 and December 2007. The last used sensor SSMIS is used after December 2007. [51]

Figure 4.5: DMSP Image (Lockheed Martin)

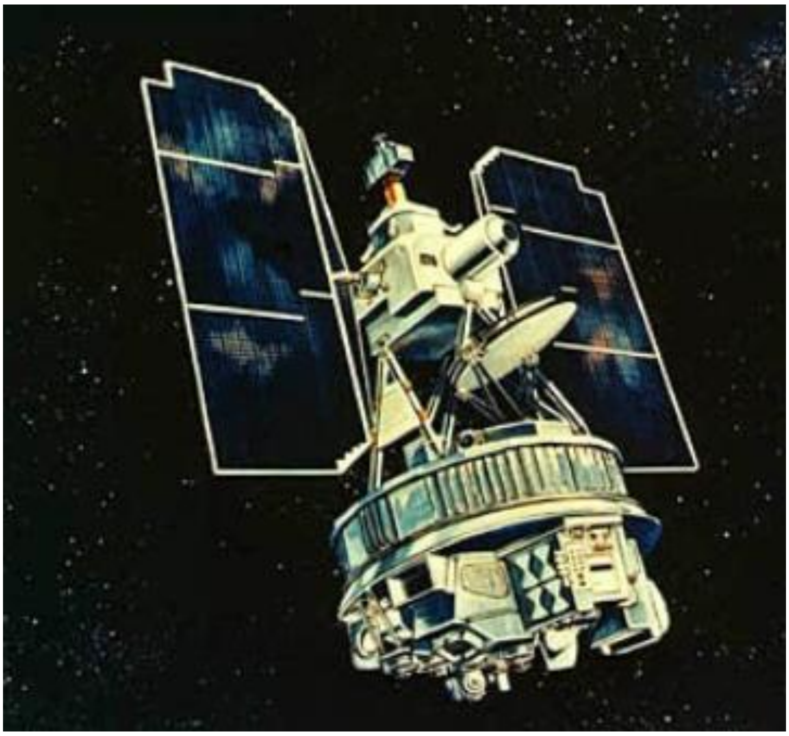

Figure 4.6: Nimbus-7 Image (NASA)

Analysing of the source data for 5 years segmented, seasonal averages of ice extents, peak and mean values of summer and winter values for between 1979 and 2014.

4.1.1. Segmented data of source table

In table 4.1, data are grouped at 5 years and 10 years period by seasons.

Table 4.1: Segments of yearly seasonal average values of source data.

Segments		Years	Extent (10^6 sq km)			
10 Years Period	5 Years Period	Years	Spring	Summer	Autumn	Winter
1	1	1978	No Data	No Data	11440,39	13672,69
1	1	1979	15243,37	10294,52	8911,239	14954,2
1	2	1980	15113,85	10096,78	9405,957	14790,2
1	2	1981	14799,07	10130,91	8975,2	14586,04
1	2	1982	15186,3	10328,41	9449,674	14912,39
1	2	1983	14888,13	10303,59	9396,622	14699,37
1	2	1984	14704,87	9919,152	8736,222	14231,72
2	3	1985	15123,26	9787,609	8751,761	14391,61
2	3	1986	14753,24	9990	9449,2	14586,07
2	3	1987	14949,13	9588,233	9182,473	15305,29
2	3	1988	14877,74	9858,815	9276,835	14696,62
2	3	1989	14265,3	10061,74	8982,385	14582,92
2	4	1990	14580,23	9202	8566,725	14452,6
2	4	1991	14580,35	9652,739	8631,934	14151,23
2	4	1992	14455,5	10109,82	9389,758	14483,03
2	4	1993	14749,34	9535,5	8833,253	14598,76
2	4	1994	14686,53	9836,848	9057,187	14486,6
3	5	1995	14216,43	9040,5	8209,319	14212,38
3	5	1996	14143,63	10121,75	9049,802	14041,73
3	5	1997	14400,83	9453,511	8566,462	14272,58
3	5	1998	14691,13	9519,739	8475,901	14363,77
3	5	1999	14740,49	9472,859	8506,451	14062,98
3	6	2000	14309,27	9424,761	8316,231	13974,62
3	6	2001	14625,1	9305,913	8559,857	13926,73
3	6	2002	14205,3	9125,761	8110,868	14032,2
3	6	2003	14335,87	9227,554	8027,912	14019,54
3	6	2004	13844,58	9220,478	8082,604	13807,66
4	7	2005	13893,74	8677,25	7686,967	13388,9
4	7	2006	13611,57	8600,043	7685,813	13212,52
4	7	2007	13720,99	8135,239	6681,912	13380,2
4	7	2008	14166,28	8571,424	7458,846	13706,24
4	7	2009	14219,01	8611,359	7313,527	13602,71
4	8	2010	14215,75	8152,065	7152,44	13343,86
4	8	2011	13774,78	7961,87	6927,418	13292,32
4	8	2012	14274,16	7657,424	6275,484	13405,02
4	8	2013	14107,28	8470,707	7533,176	13497,26
4	8	2014	13846,1	8377,761	7519,143	13441,04

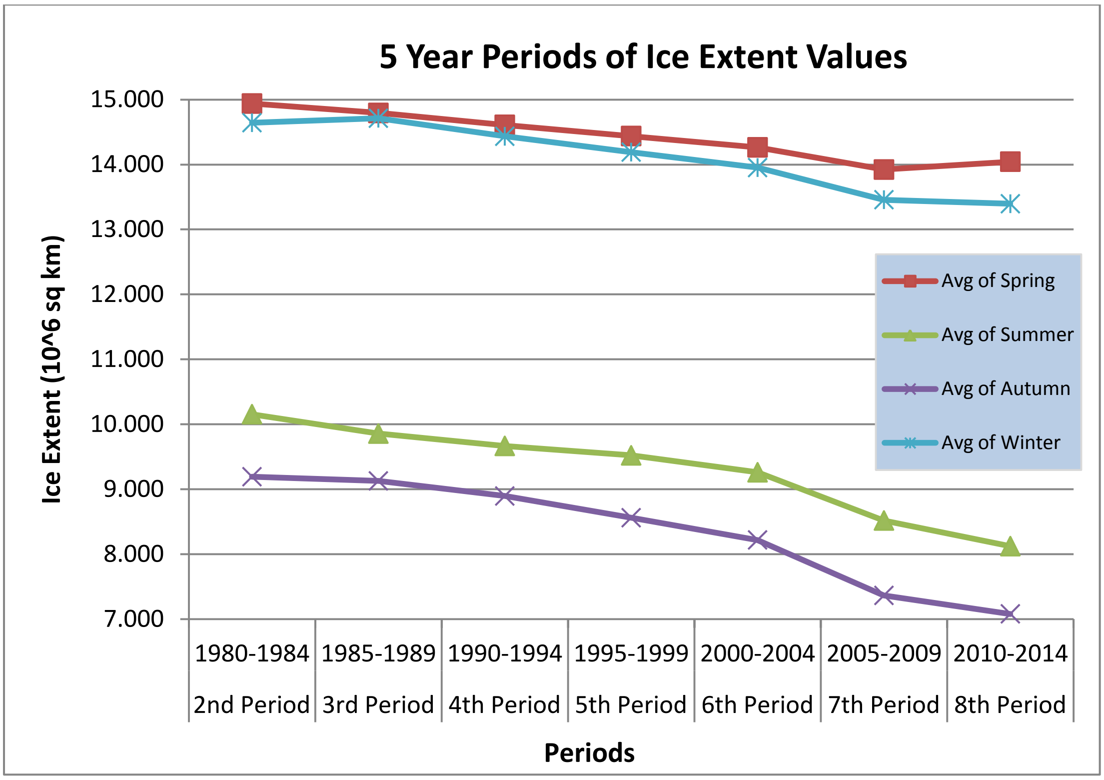

Figure 4.7: Five years period segmented ice extent values graphic of source data.

Like seen in the Table 4.1, the extent volume is in decreasing trend clearly since early 2000s.

Table 4.2: Five years period segmented ice extent values table of source data.

5 Year Periods	Avg of Spring	Avg of Summer	Avg of Autumn	Avg of Winter
1st Period	15.243,37	10.294,52	10.175,81	14.313,45
2nd Period	14.938,44	10.155,77	9.192,73	14.643,94
3rd Period	14.793,73	9.857,28	9.128,53	14.712,50
4th Period	14.610,39	9.667,38	8.895,77	14.434,44
5th Period	14.438,50	9.521,67	8.561,59	14.190,69
6th Period	14.264,02	9.260,89	8.219,49	13.952,15
7th Period	13.922,32	8.519,06	7.365,41	13.458,12
8th Period	14.043,62	8.123,97	7.081,53	13.395,90

Table 4.2 and Figure 4.7 shows the average ice extent values of Arctic Ocean by five years period. The first 5 years period is not included because of not having enough data. Generally the decreasing trend is observed. Except the average of spring at 7th 5 year period, the other seasons' average is the minimum at the 8th five-year period.

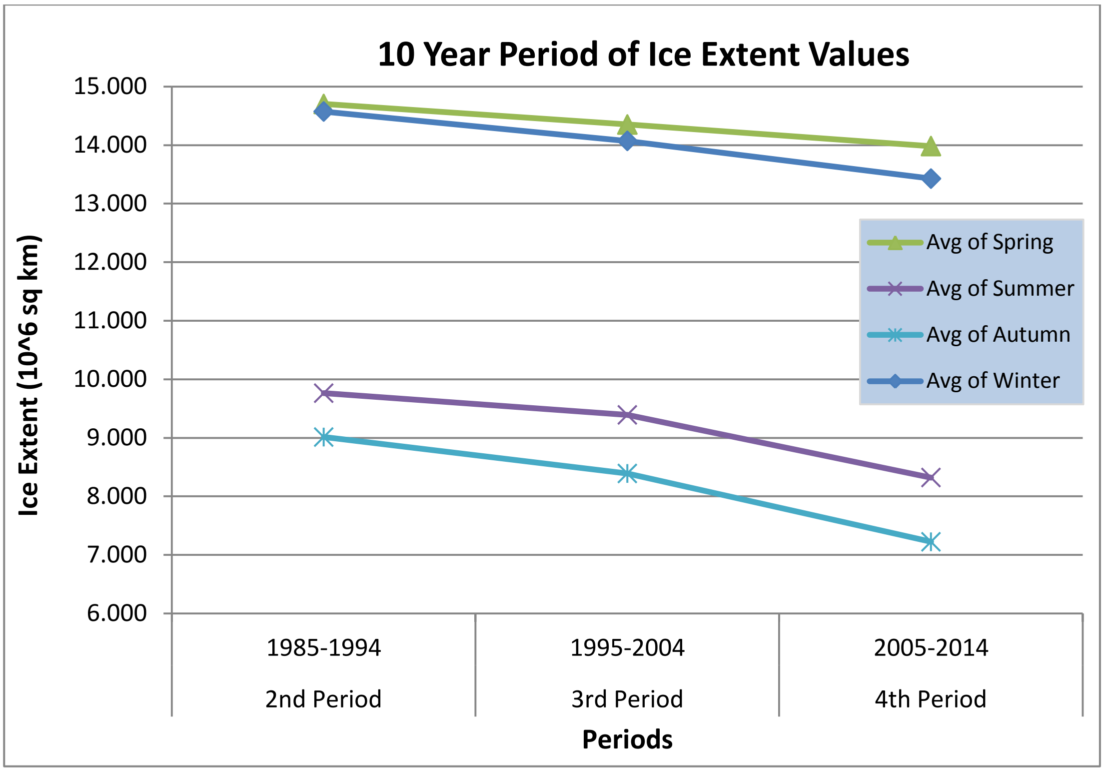

Figure 4.8: Ten years period segmented ice extent values graphic of source data.

Table 4.3: Ten years period segmented ice extent values table of source data.

Ten Years Period	Avg of Spring	Avg of Summer	Avg of Autumn	Avg of Winter
1st Period	14.989,26	10.178,89	9.473,61	14.549,52
2nd Period	14.702,06	9.762,33	9.012,15	14.573,47
3rd Period	14.351,26	9.391,28	8.390,54	14.071,42
4th Period	13.982,97	8.321,51	7.223,47	13.427,01

In Figure 4.8 and Table 4.3 the decreasing trend is shown by 10 years period. The most obvious decreasing value trend is between the 3rd and 4th 10 years period. The 1st 10 years period is not included because of not having enough data.

4.1.2. Seasonal average values of Arctic ice extents

The Arctic Ice Extent values are decreasing yearly because of global warming as seen at the Table 4.1. If seasonal changes of Ice Extent by years are examined, the values are also showing trend to decrease. Results indicates that the highest average value of ice extent occurs in winter of 1987. Autumn of 1995 is the year in which the average ice extent is at minimum level since 1979. The second certain decrease is seen at the winter of 2007. But the minimum value is in 2012.

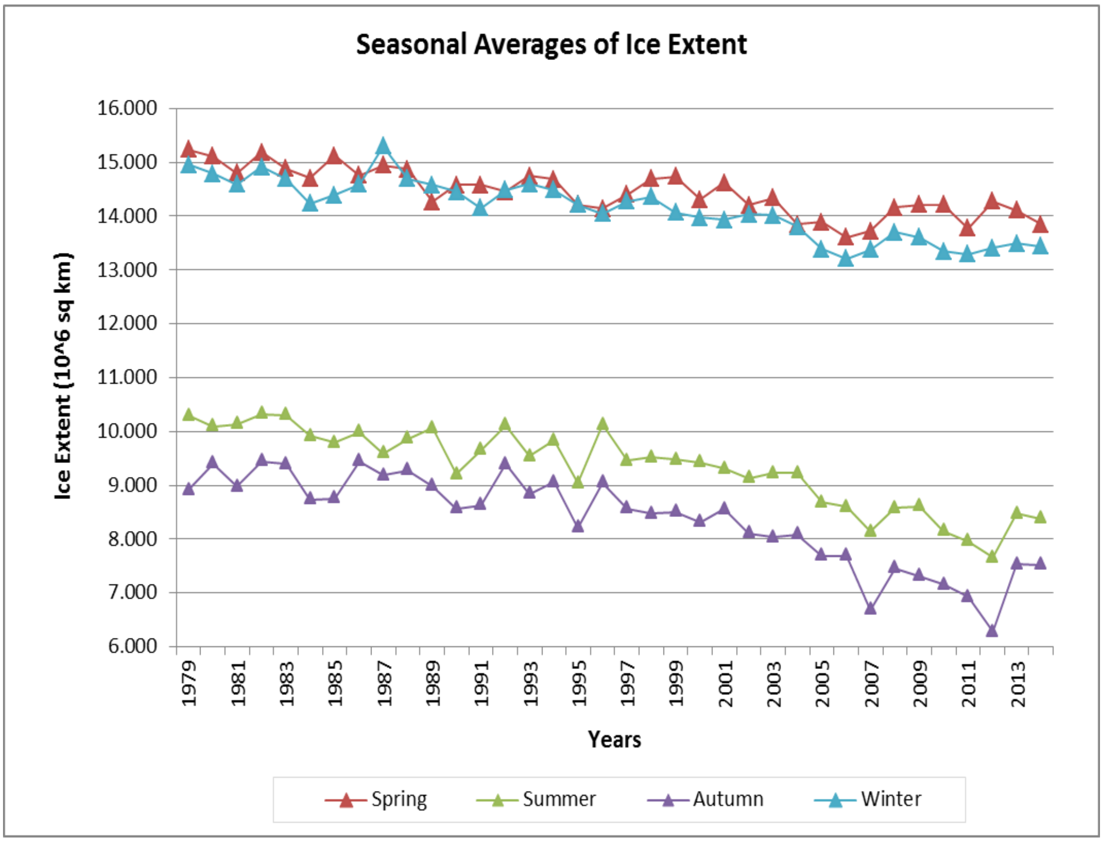

Figure 4.9: Graphic of seasonal average values of ice extent by years.

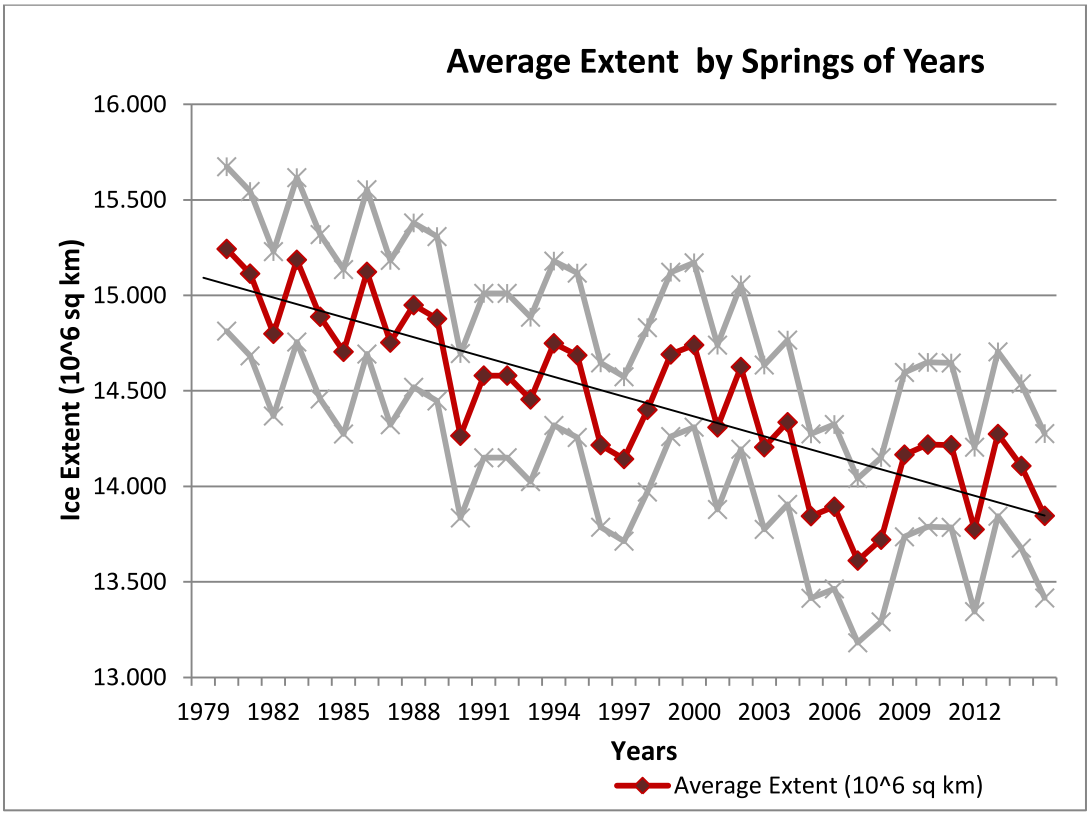

Figure 4.10: Graphic of spring average values of ice extent by years with standard deviations and trendline.

Figure 4.9 shows that the ice sea extent is at highest value generally in spring and at the lowest value in autumn. The average seasonal difference between spring and autumn is 6.090 10^6 sq km. There are 15 years in which the difference is above than the average rate. Except 4 of them are before 2000s. 2012 is the year in which the difference between spring and autumn is 7.998 10^6 sq km as the highest value in the chart. The lowest difference has been occurred in 1992 as 5.065 10^6 sq km.

The spring is generally the season that the ice extent volume is at highest value except 1987, 1989 and 1992. Figure 4.10 shows that the average value of springs is 14.378 10^6 sq km. The highest value is 15.243 10^6 sq km. in 1979 while the lowest value is 13.611 10^6 sq km. in 2006. The years in which ice extent values are below the average are mostly after 2000.

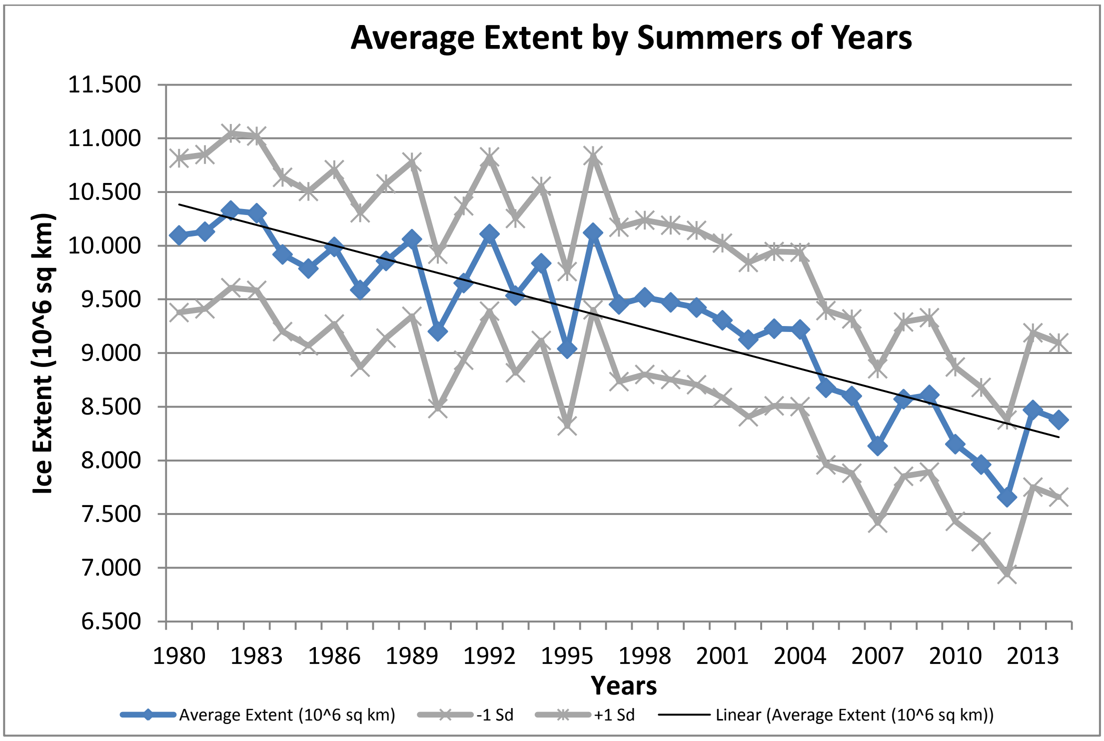

Figure 4.11: Graphic of summer average values of ice extent by years with standard deviations and trendline.

The summer average value of sea ice extent is 9.228 10^6 sq km. As shown in Figure 4.11 the highest value is 10.328 10^6 sq km. in 1982 while the lowest one is 7.657 10^6 sq km. in 2012. Only 1990 and 1995 are the years in which the value of sea ice extents are below the average.

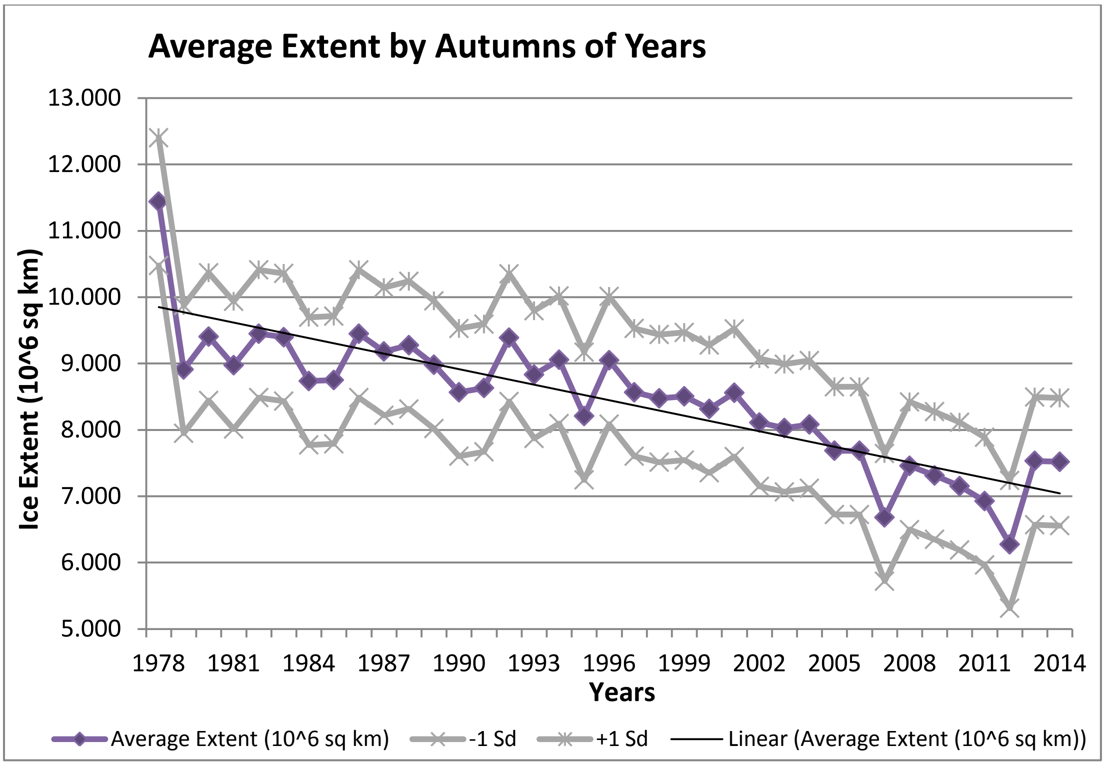

Figure 4.12: Graphic of autumn average values of ice extent by years with standard deviations and trendline.

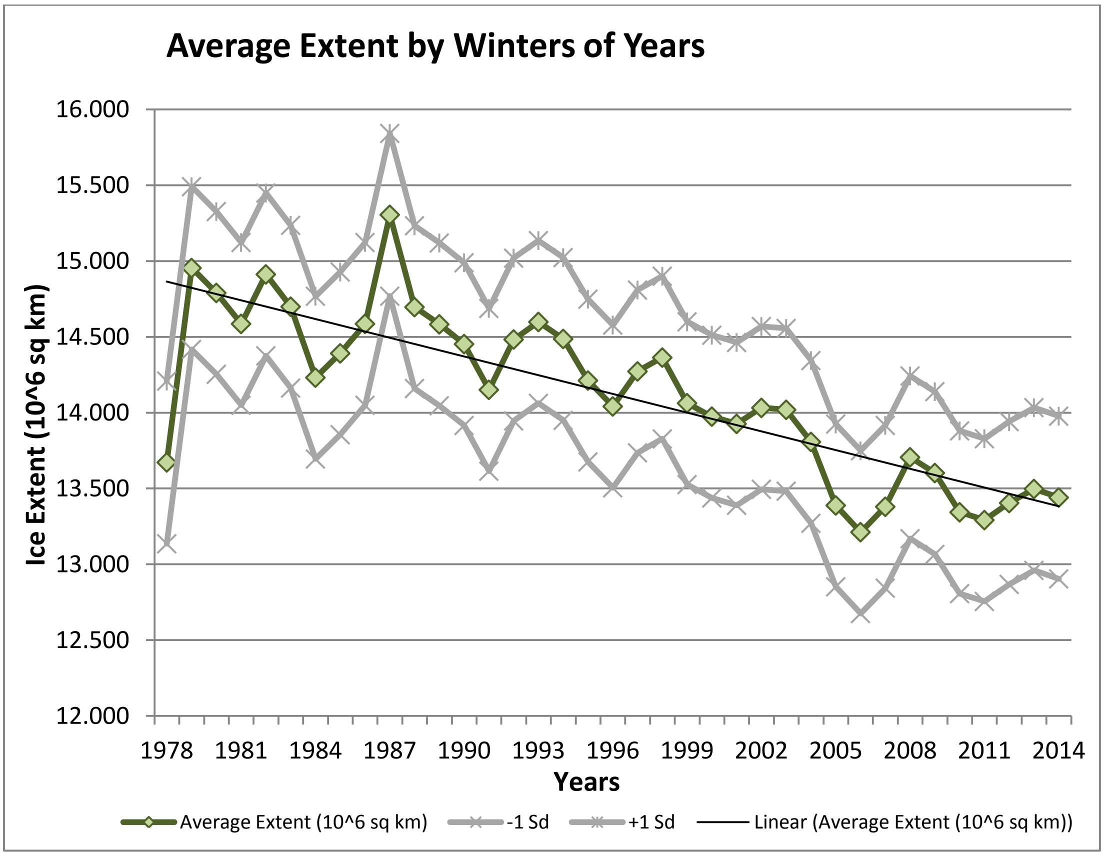

Figure 4.13: Graphic of winter average values of ice extent by years with standard deviations and trendline.

The autumn are the season in which the values are in the lowest volume. Figure 4.12 shows that the average sea ice extent is 8.288 10^6 sq km. The highest value is 11.440 10^6 sq km. in 1978 while the lowest one is 6.275 10^6 sq km. in 2012. The one and the only year is 1995 in which the value of ice sea extent is below the average before 2000.

The average sea ice extent value in winters is 14.041 10^6 sq km. which is shown in the Figure 4.13. The highest value is 15.305 10^6 sq km. in 1987 while the lowest one is 13.212 10^6 sq km. n 2006. Generally the average value of winters is the second row after the springs among the seasons exceptionally in 1987, 1989 and 1992. In the mentioned years, the average value of sea ice extent of winters are higher than the springs' value.

4.1.3. Min., max. and mean values of summers and winters values

When the values of minimum, maximum and mean values of summer and winter are derived from dataset, there would be seen decreasing of ice extent as shown in Table 4.4. So the effects of global warming are approved from Arctic Ice Extent values. 1978 values are not included because of not having enough data.

Table 4.4: Arctic ice extents yearly minimum, maximum values and meanly values of summers and winters.

	Arctic Ice Extent (10^6 sq km)			
	Minimals	Maximals	Mean Values of Summers	Mean Values of Winters
1978	10.231	14.604	No Data	13.682
1979	6.895	16.635	10.256	14.968
1980	7.533	16.302	10.203	14.771
1981	6.902	15.801	10.127	15.484
1982	7.160	16.325	10.264	14.901
1983	7.204	16.412	10.214	14.648
1984	6.396	15.809	9.929	14.237
1985	6.486	16.163	9.839	14.421
1986	7.122	16.158	10.010	14.628
1987	6.890	16.293	9.580	15.299
1988	7.048	16.309	9.939	14.211
1989	6.888	15.766	10.104	14.548
1990	6.011	16.249	9.160	14.497
1991	6.259	15.647	9.594	14.141
1992	7.159	15.576	10.133	14.481

Table 4.4 (Continue): Arctic ice extents yearly minimum, maximum values and meanly values of summers and winters.

	Arctic Ice Extent (10^6 sq km)			
	Minimals	Maximals	Mean Values of Summers	Mean Values of Winters
1993	6.161	16.048	9.488	15.611
1994	6.934	15.770	9.821	14.476
1995	5.990	15.384	9.042	14.258
1996	7.147	15.484	10.172	14.037
1997	6.602	15.684	9.512	14.258
1998	6.293	16.070	9.523	14.321
1999	5.676	15.627	9.430	14.044
2000	5.943	15.498	9.454	13.970
2001	6.567	15.742	9.344	13.882
2002	5.625	15.624	9.081	13.980
2003	5.969	15.629	9.237	14.036
2004	5.770	15.300	9.185	13.794
2005	5.314	14.993	8.687	13.383
2006	5.746	14.777	8.601	13.210
2007	4.147	14.842	8.195	13.367
2008	4.548	15.354	8.617	13.678
2009	5.047	15.195	8.573	13.586
2010	4.590	15.351	8.117	14.322
2011	4.333	14.704	7.955	13.331
2012	3.340	15.307	7.705	13.404
2013	5.040	15.196	8.386	13.474
2014	4.988	15.007	8.378	13.456

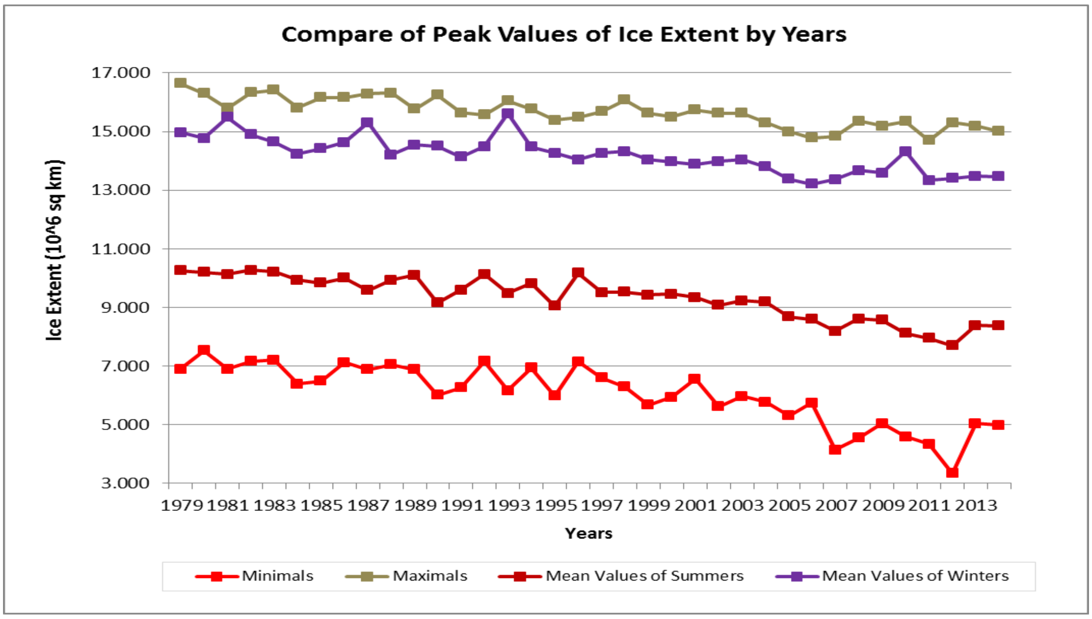

Figure 4.14: Comparison of peak and mean values graphic of Arctic ice extents by years.

As seen in Figure 4.14, the highest sea ice extent value is in 1979 as of 16.635 10^6 sq km. while the lowest value is in 2012 as of 3.340 10^6 sq km.

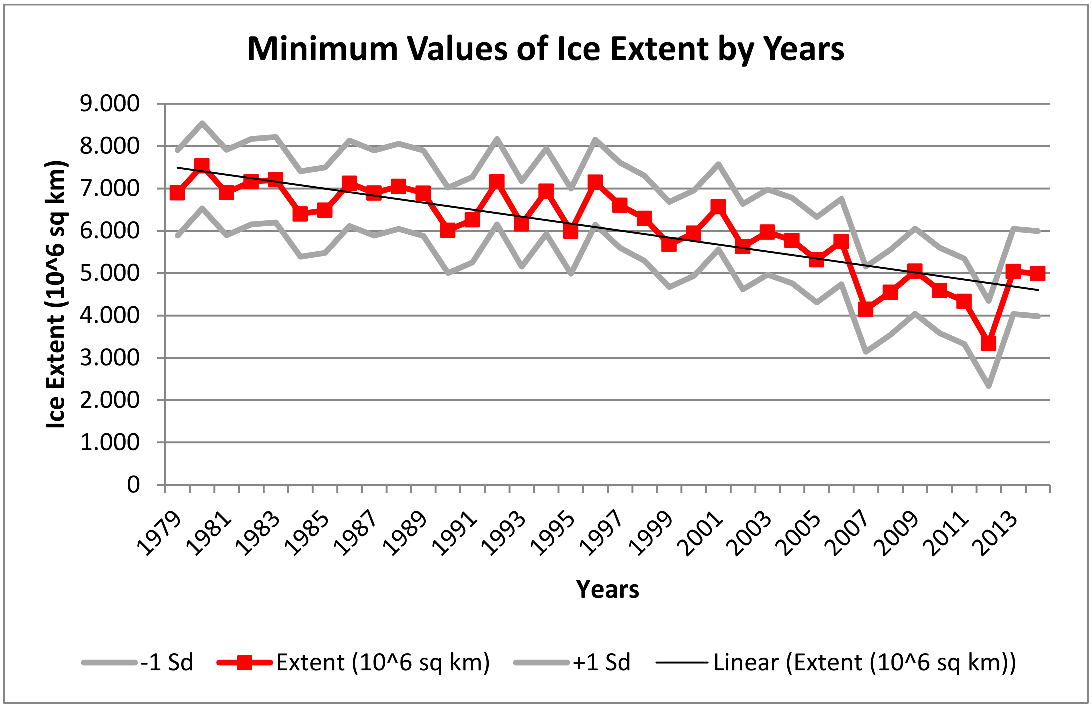

Figure 4.15: Minimum values graphic of Arctic ice extent by years with standard deviations and trendline.

The minimum value of sea ice extent derives between 3.340 and 7.533 10^6 sq km.as shown in Figure 4.15. The minimum value is 3.340 10^6 sq km. at 16th of September 2012 while the highest value of minimum values is 7.533 10^6 sq km. at 5th of September 1980. The lowest value of sea ice extent occurs in the middle of September (like 13th of September).

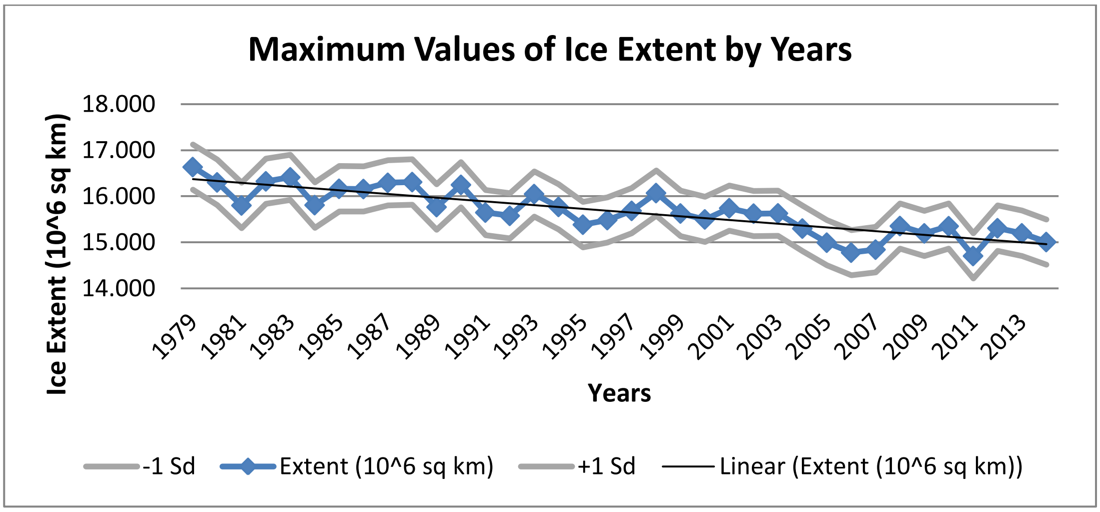

Figure 4.16: Maximum values graphic of Arctic ice extent by years with standard deviations and trendline.

The maximum value of sea ice extent derives between 14.704 and 16.635 10^6 sq km.as shown in Figure 4.16. The maximum value is 16.635 10^6 sq km. at 1st of March 1979 while the minimum value of maximum values is 14.704 10^6 sq km. at 7th of March 2011. The lowest value of sea ice extent occurs in the middle of March and the late February.

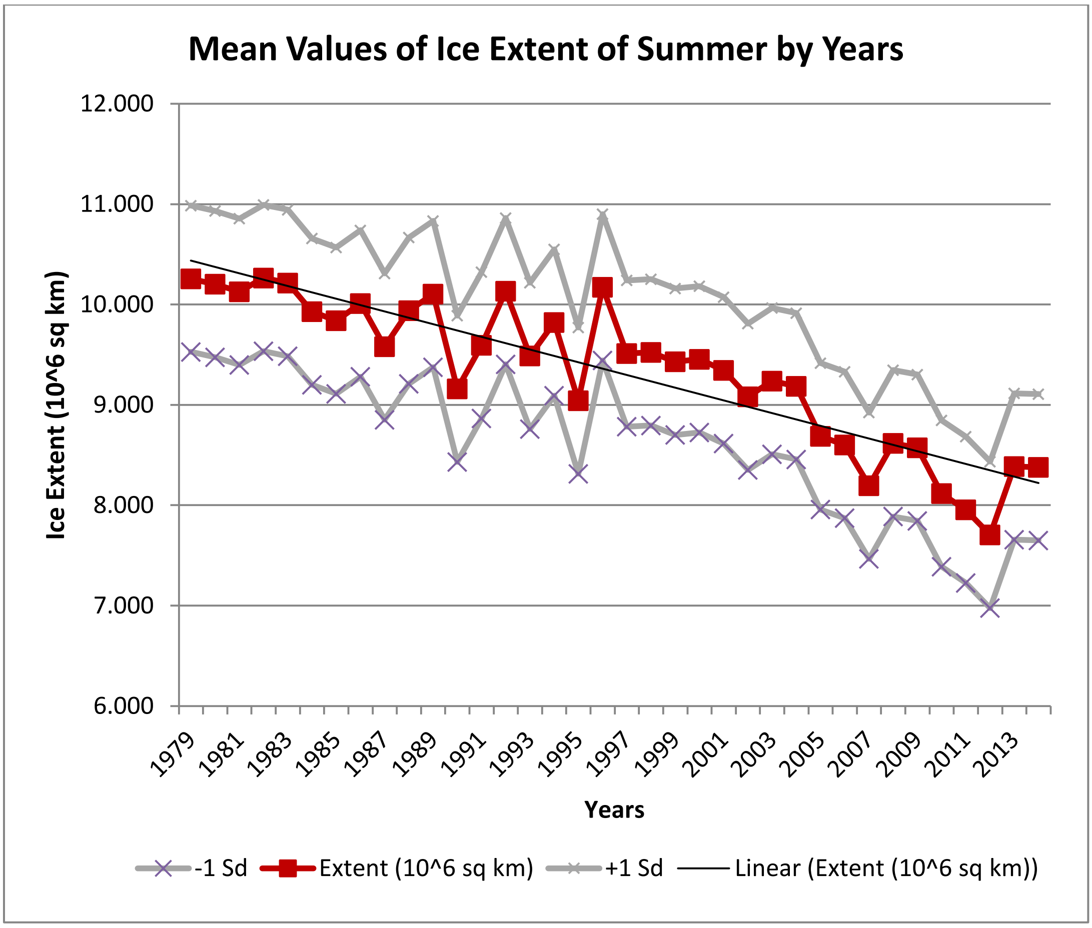

Figure 4.17: Mean values graphic of Arctic ice extent of summer by years with standard deviations and trendline.

The mean value of sea ice extent of summers changes between 7.705 and 10.264 10^6 sq km. shown as in the Figure 4.17. The trend is decreasing like the others figures. The significant decreasing value is shown in the year of 1990 as first time. 1995 is another milestone among decreasing values with 9042 10^6 sq km. as of 15th of July. The constantly decreasing trend has been started by 2004. The values after 2004 never reach the level of 8.700 10^6 sq km. The lowest value is 7.705 10^6 sq km. at 15th of July 2012. It's the July in which the mean value of sea ice extent in summers happens.

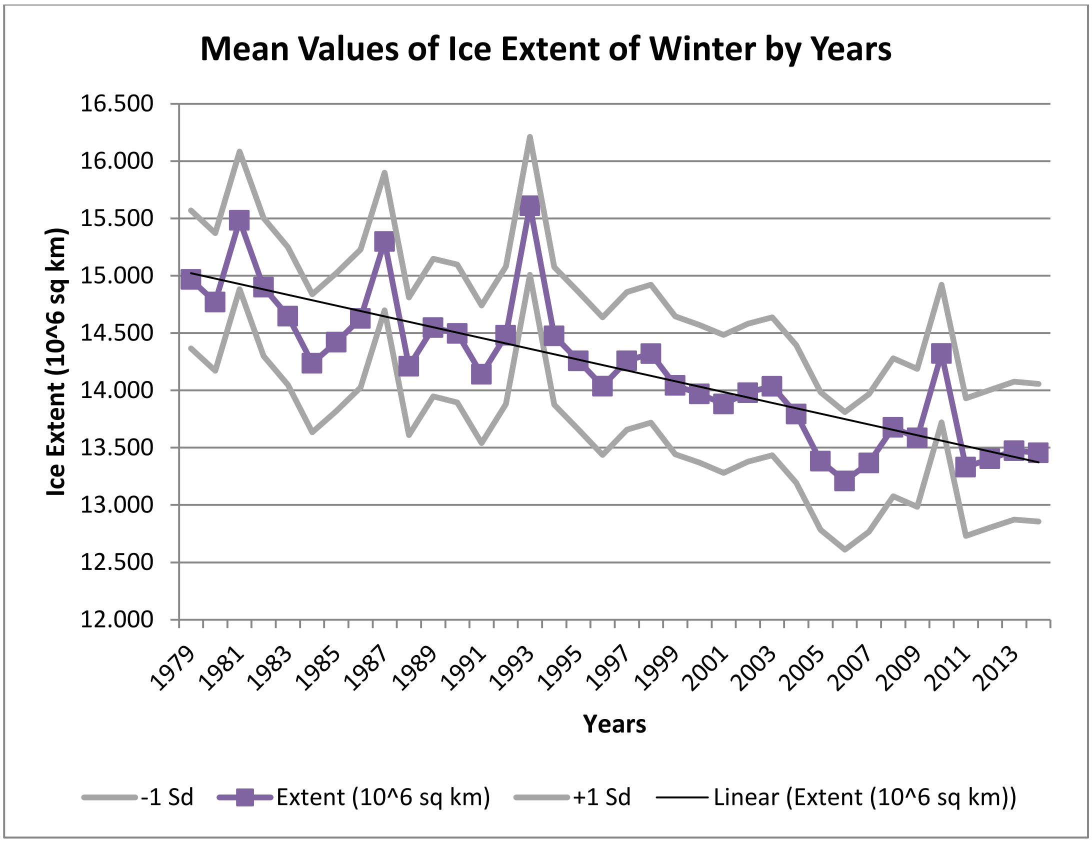

Figure 4.18: Mean values graphic of Arctic ice extent of winter by years with standard deviations and trendline.

The mean value of sea ice extent of winters changes between 13.210 and 15.611 10^6 sq km. shown as in the Figure 4.18. The trend is decreasing like the others figures. The significant decreasing value is shown in the year of 1984 as first time. 2006 is the lowest value among decreasing values with 13.210 10^6 sq km. as of 2nd of January. The constantly decreasing trend has been started by 2010. The values after 2010 never reach the level of 14.500 10^6 sq km. It's the January in which generally the mean value of sea ice extent in winters happens.

Helmholtz Climate Initiative (REKLIM), the Alfred Wegener Institut, Helmholtz Centre for polar and marine research created an initiative in cooperation with the University of Bremen. This initiative aims to collect the most current data about sea-ice. The initiative has a web portal address as *"meereisportal.de/seaiceportel.de"*. Theweb site provides daily basis sea ice extent and concentration data which are taken from satellite since 19 June 2002. In Figure 4.19 and Figure 4.20 shows the minimum and maximum sea ice extent days as high solution map since 19 June 2002 until today. [52] These figures included to confirm our results and findings.

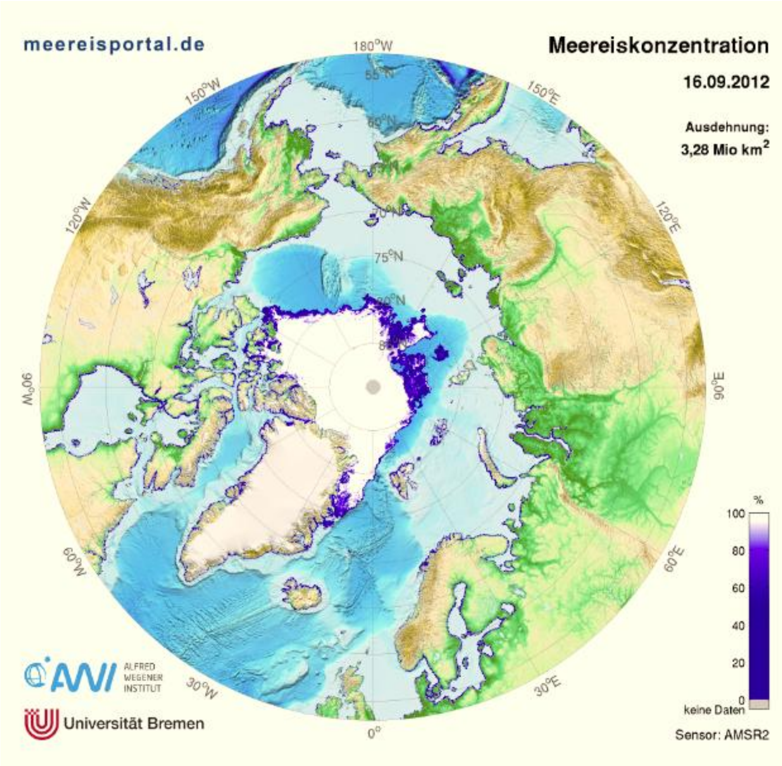

Figure 4.19: The minimum sea ice extent day 16 September 2012 since 19 June 2002. (Meereisportal.de)

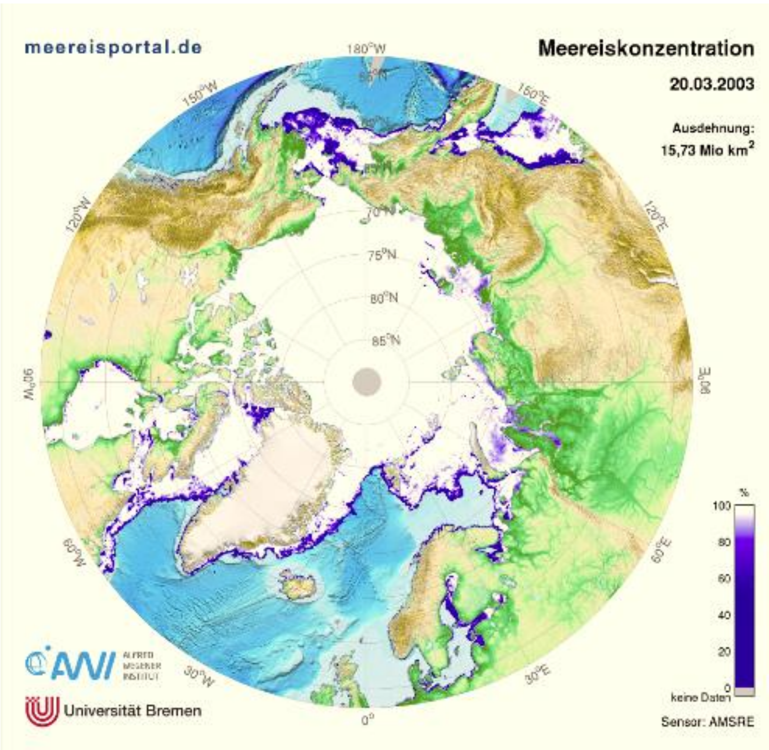

Figure 4.20: The maximum sea ice extent day 20 March 2003 since 19 June 2002. (Meereisportal.de)

5. DISCUSSION

5.1. Shipping Routes In Arctic

According to IMO there are 7 type of ice breakers which can navigate thought the ice-covered waters. This classification is shown at Table 5.1 The classes change depend on the ability to navigate on the different characteristic of sea ice especially thickness.

Table 5.1: Classes of Arctic ships. (IMO, Rules for Classification and Construction)

Polar Class	Ice Description (based on WMO Sea Ice Nomenclature)
PC1	Year-round operation in all polar waters
PC2	Year-round operation in moderate multi-year ice conditions
PC3	Year-round operation in second-year ice which may include multi-year ice inclusions
PC4	Year-round operation in thick first-year ice which may include old ice inclusions
PC5	Year-round operation in medium first-year ice which may include old ice inclusions
PC6	Summer/autumn opeartion in medium first-year ice which may include old ice inclusions
PC7	Summer/autumn opeartion in thin first-year ice which may include old ice inclusions

Open Water vessel is another type of ship class which does not exist in IMO classification. It's accepted that it has the capacity of the breaking up ice with 15 cm thickness in fully concentrated ice, that's why traditional OW vessel does not contain ice strengthening. 6 ice types with associated thickness were identified by the AIRSS framework and the thickness scale is as follows: gray (10–15 cm), gray-white (15–30 cm), thin first-year first stage (30–50 cm), thin first-year second stage (50–70 cm), medium first year (70–120 cm), and thick first year (first-year ice over 120 cm). In Figure 5.1 could seen Arctic shipping routes with ship types.

Figure 5.1: Arctic shipping routes today.

The researchers' recommendations and coastal countries' Arctic navigation approach are similar. Even if the territory is not owned by any kind of authority or country, the countries bordering - Russia, Norway, Canada, Denmark, and the U.S - the Arctic have some claims. One of the conflict sample is about the Northwest Passage. Canada demands that this is Canadian waterway. But the US. and Russia differ with Canada. [53] According these two, the passage is international.

5.2. New Shipping Routes In Arctic

Summer sea ice extent in Arctic is decreasing and this data is retrieved from satellite mapping since 1979 as this study included satellite observations. The trend of decreasing summer ice extent determine that in last 6 years record are the lowest. [54] The projection is shown below in Figure 5.2

The scenarios provided by the climate models announce that the trend will go on unceasingly and afterwards a seasonal ice-free[1] Arctic Ocean would be possible later this century. [55]

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[1] Ice-Free Season: having less sea ice than 1 km^2 in September

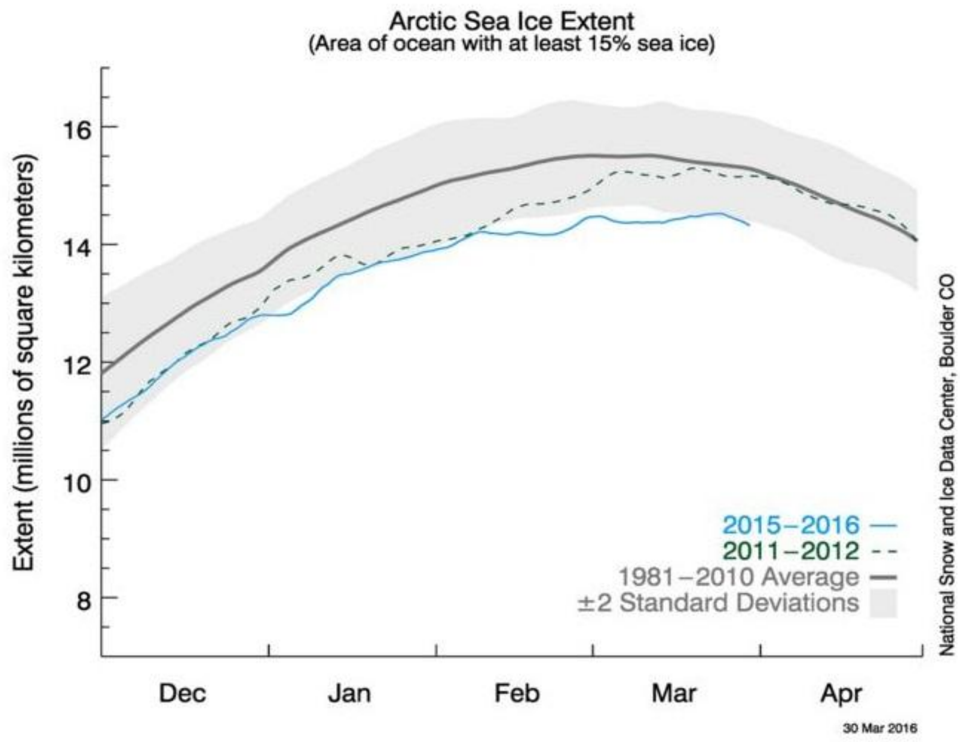

Figure 5.2: Arctic Sea Ice extent graphic dated 30 March 2016, (National Snow and Ice Data Center)

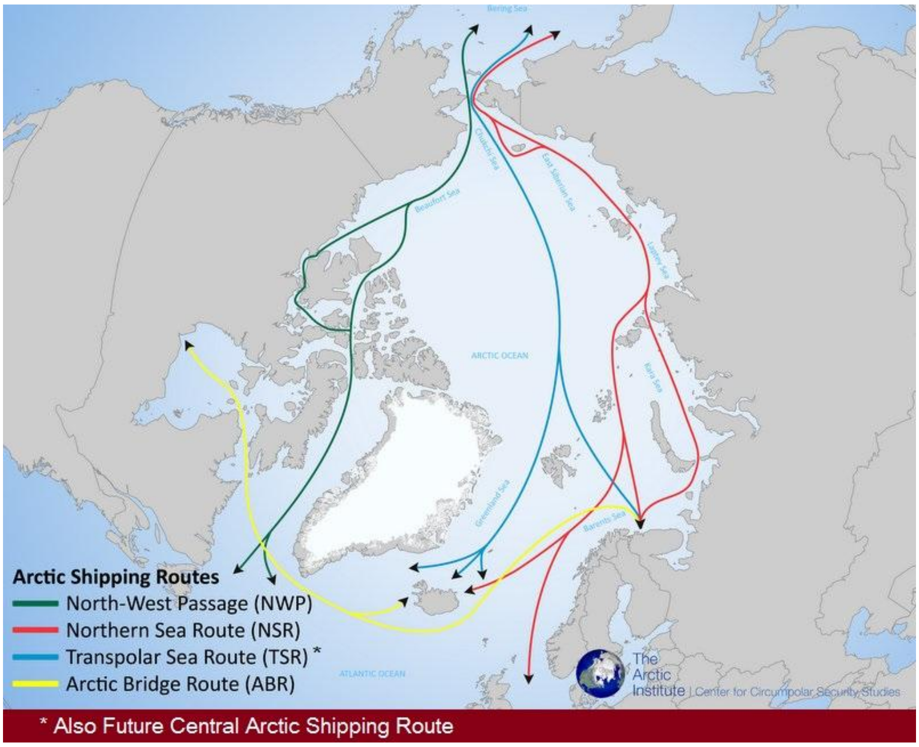

Figure 5.3: Map of Possible Shipping Routes in the Arctic (NATO Parliamentary Assembly, Committee Report, 2010 Annual Session.)

According to climate changes in near future shows, that New Arctic shipping routes, which are shown in Figure 5.3, will open and these routes will support the companies and countries in terms of saving time and money. Exclusively sea ice melting assists to initiate new commercial routes between the Atlantic and Pacific Oceans.

The Northern Sea Route will decrease sailing duration between Rotterdam and Yokohama as much 40 % shorter. The Northwest Passage and the Trans-Polar Route are popular for the same reasons – in case they are able to navigate. [53]

5.2.1. Transpolar sea route as new ship route of Arctic

Shipping lanes through the Arctic Ocean won't put the Suez and Panama canals out of business anytime soon, but global warming will make these frigid routes much more accessible than ever imagined by melting an unprecedented amount of sea ice during the late summer.

By mid-century, even ordinary shipping vessels will be able to navigate previously inaccessible parts of the Arctic Ocean, and they will not need icebreakers to blaze their path as they do today.

In 2007, 2008 and in 2009, route between the North Atlantic Ocean and the Pacific Ocean known as the Northwest Passage was able to navigate for two weeks. And according to sciencetists' prediction, ice-free Arctic summer season could possible as of 2013 [56] The same situation was observed for the Northern Sea Route near Russia's coast.

These new navigation routes between Europe and Asia will change the sailing duration. The duration will be shorter than before because the vessels will navigate via short cuts by saving thousand of miles. For example, navigation duration will decrease by %25 from Rotterdam to Seattle with new shipping routes.

Regarding to "Melting Ice Caps and the Economic Impact of Opening The Northern Sea Route" study [57] international shipping industry will be obviously changed after melting of Arctic icecap. It assumes that NSR will be fully used by 2030. This analyse compares SSR and NSR with using trade models but not only water transportation but also water and land multi-modal transportation. For each country, one port is chosen according to its trade volume. For instance, to make an estimation between China and Netherlands; Shanghai Port is decided for China while Rotterdam Port is for Netherlands as shown Table 5.2

Table 5.2: (Melting Ice Caps and the Economic Impact of Opening The Northern Sea Route)

From	To	Great-circle formula (km)	SSR(km)	NSR(km)	NSR against SSR % change
China	Netherlands	7,831	19,942	15,436	_23%

Regarding to this modal, the three Asian countries; China, Japan and South Korea will take advantage of NSR.

8% of world trade use Suez Canal for the transportation. According to this study, only one-thirds of this volume will be remained via Suez Canal after NSR. This situation will have also negative economic impact on SSR countries like Egypt and Singapore and South and East Europe.

The study estimates CO_2 emissions too, which is directly, has relation with volume of water-based transporation. It is projected that techonology between production, consumption and emission will be remaining same as today. Essentially, the reduction of fuel costs and emission are expected because of shorter shipping route of NSR. Nevertheless, the increasing volume of trade will cause increasing of CO_2 emission in the future. Consequently, the study predicts that the CO_2 emission will lightly increase as total of 14.23 million MT. [57]

The other benefit of new shipping route will be in safety domain considering that piracy is a possible trouble for the vessels which navigate through existing route like Gulf of Aden. This also means operation cost will reduce. Moreover, decreasing emission and energy consumption will support to increase the commercial volume with reduced marine traffic in traditional passage over the continents. [58]

Two German merchant ships passed the Northern Sea Route, escorted by icebreakers, in September 2009 and transported her cargo to destination port in Japan, South Korea and Russia. In this route vessels reported that they saved more 4,000 km by using new route. This example proved how NSR feasible would be.

Another voyage achieved by a Russian tanker, which was the first passage for the trade tanker, via NSR in September 2010.

Three possible route over the Arctic were presented by Laurence C. Smith and Scott R. Stephenson of the University of California Los Angeles, at the 2015 meeting of the American Geophysical Union: the Trans-Polar Route over the North Pole, the Northern Sea route along the northern coast of Russia, and the Northwest Passage through the Canadian Arctic.

The data that subjected to article of Stephenson and Smith and this thesis are recorded data since 1979, satellite mapping has revealed an overall trend of decreasing late-summer sea ice extent in the Arctic.

To address this deficiency, Stephenson and Smith applied the Arctic Transportation Accessibility Model (ATAM) [59] to individual and ensemble averaged datasets of projected sea ice thickness and concentration from seven respected coupled atmosphere–ocean general circulation models (GCMs), assuming two different climate forcing scenarios and vessel types at present (2006–2015) and by mid-century (2040–2059) It is shown in Figure 5.4 and Figure 5.5.

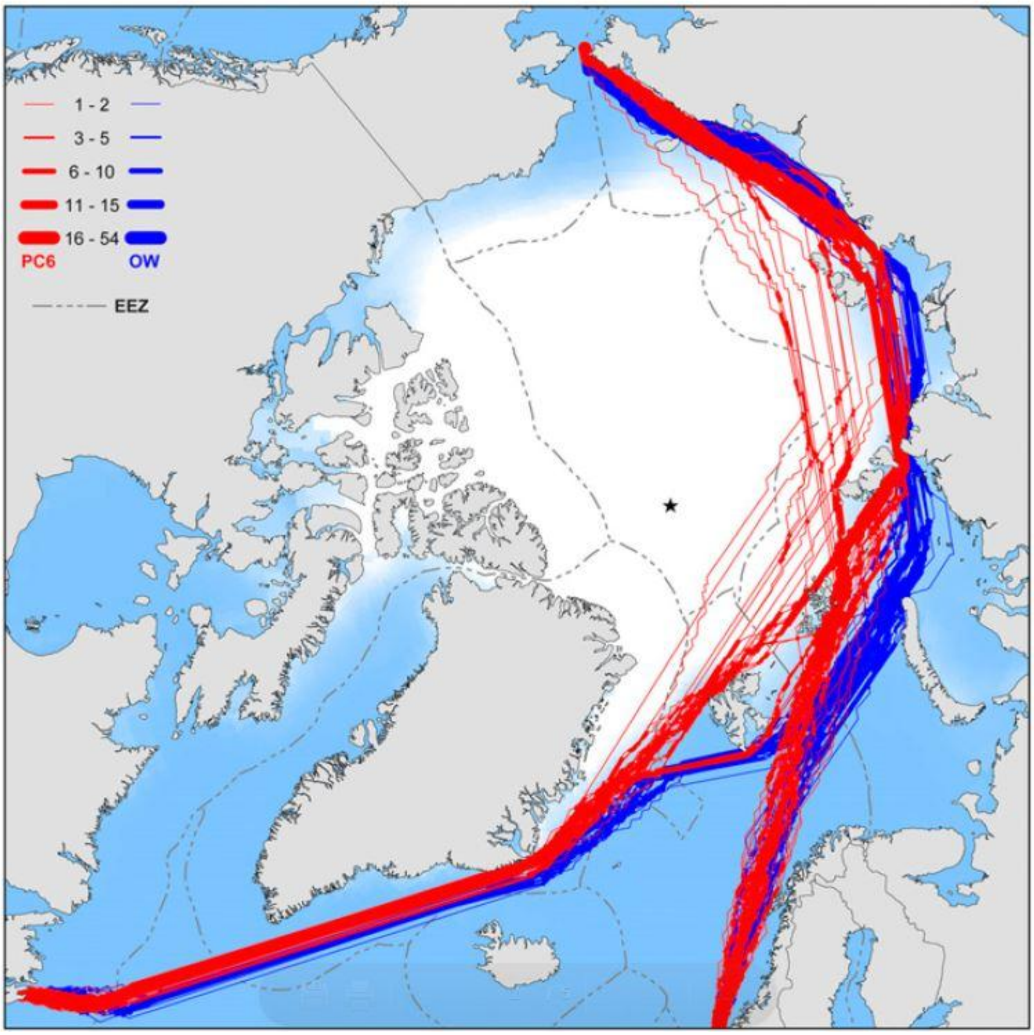

Figure 5.4: The possible September navigation routes between Netherland and Pacific (ATAM.)

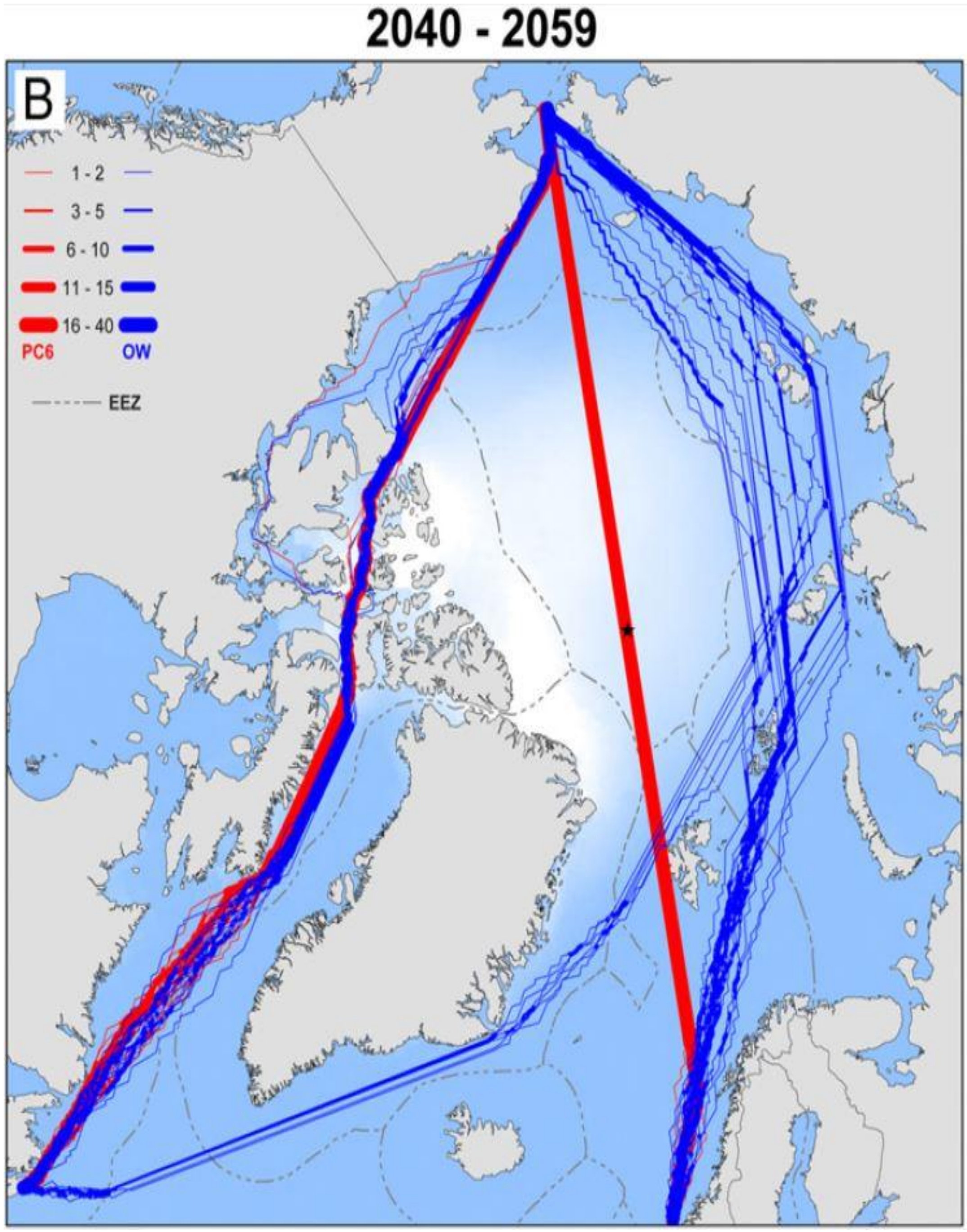

Figure 5.5: The projected navigation route between Netherlands and Pacific in 2040-2059 (ATAM)

5.2.2. Pollution of shipping in the Arctic

As mentioned above, new shipping route over the Arctic will increase the number of ships undoubtedly. Considering that the Arctic region has a harsh and hazardous conditions, the increase of ship navigation in Arctic poses environmental risks in different areas like noise, collision of wildlife, invasive species, air pollution, ice destruction, dangerous cargo and oil spills.

Air pollution is one of the most possible and dangerous risk over the Arctic Ocean. Marine vessels produce Black carbon (BC) that is constitute of particulate matter (PM) through unfinished oxidation of diesel fuel. Annual BC emission created by international shipping is between 71 000 and 160 000 metric tons. About % 15 of total PM in the World is from ships and about %2 of it is from all other source 609 tons of BC was released in the Arctic in 2004. [60] This amount may seen low compared to global emission, but number of the vessels travelling in that region is increasing. As a result of heavy shipping traffic, the ice is melting and the region is warming. More research should be done in order to determine the connection between BC reductions from ships and the benefits of mitigation. But the results of using Arctic region as a new trade shipping route are not well studied yet. The shipping activities have effects on high emission of gases. Future emission could impact negatively to Arctic environment and regional air pollution. [61]

According to AMSA study, the Bering Sea Region, Iceland, the Norwegian Coast and the Barent Sea are regions with the heaviest CO_2 and BC emissions. Ship emission can be reduced effectively by means of the application of feasible and best available Technologies, air emission techniques and effective implementation of relevant IMO regulations [13]

The other biggest pollution reason can be oil spills from ships in Arctic Ocean. Groundings, shipwrecks, accidents or fires are the possibilities of oil spills.

In Figure 5.6, the ship accidents are listed between 1995-2004 in Arctic Region.

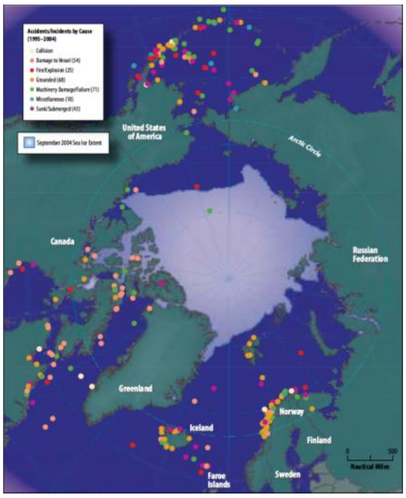

Figure 5.6: Arctic shipping accidents and incidents causes, 1995-2004.(Llyod’s Marine Intelligence Unit Sea Searchers Database

Since Arctic Region is very far away from the shore assistance, the duration of cleaning will be longer than any other region. Besides that, the hazardous conditions in the region will prevent the assistance crew to reach on-scene and perform properly. Moreover, the hydrocarbons break hardly in cold weather, which means another danger for the wildlife.

The possible scenario of oil spill is shown in Figure 5.7.

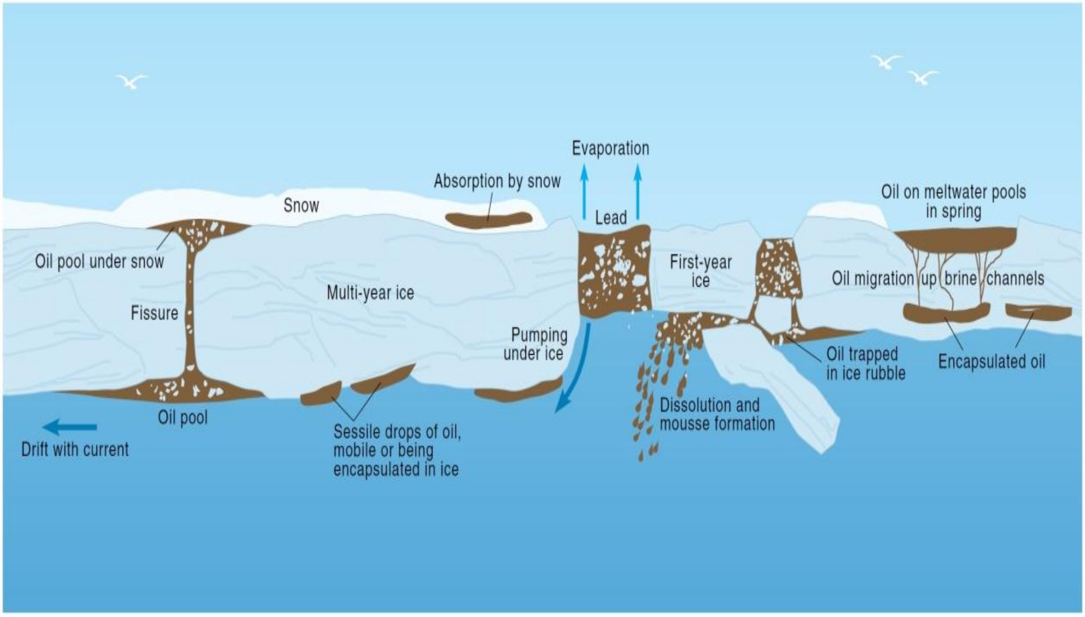

Figure 5.7: Possible interactions between HFO(Heavy fuel oil) and Arctic Sea Ice in the event of an oil-spill (AMAP assessment) report: Arctic Pollution Issues (after original figure by Bobra and Fingas)

5.3. Safety Issues of Shipping in Arctic

Having hard weather condition, being away from nearest assistance and increasing ship traffic occur the safety issues over the Arctic Region. In the this study, the safety issues are divided in three parts as Critical Needs of Ship Operations in Arctic Waters, Critical Needs Of For Ensuring Adequate Emergency Response In Arctic Waters and The Needs Of Vessel Traffic Management

5.3.1. Critical Requirements of Ship Operations in Arctic Waters

- Improved navigation charts with comprehensive depth contours,
- Updated electronic charts with imbedded navigation aids,
- Increased AIS coverage in Arctic waters,
- Accurate tide and current data,

- Improved ice assessment and forecasting,
- Improved weather data and more accurate local forecasts,
- Implemented traffic management scheme for the Unimak Pass and Bering Strait,
- Established ice operation guidelines,
- Improved satellite and local communications,
- Established safe harbors of refuge,
- Improved emergency response and SAR capabilities, and
- Improved ice breaking capabilities.

5.3.2. Critical Requirement of for Ensuring Adequate Emergency Response In Arctic Waters

- Reliable shore-based communications networks,
- SAR assets within reasonable response time frames,
- Emergency towing assets,
- Aviation search-and-lift assets within 24 hours of large-ship operations, and Partnerships among cruise vessel operators with similar regional visits.
- Developing VTS-type real-time monitoring of vessels in the Arctic region,
- Maintaining crews trained and experienced in ice management and transit,
- Providing continuous ice and weather data and daily ice analysis,
- Establishing an ice management plan for each vessel, and
- Establishing cooperative procedures among all operators in a particular area.
- Gathering real-time information of all ships transiting the area;
- Conducting local, regional, and national drills and exercises;
- Preparing an up-to-date inventory of assets;
- Establishing a stockpile and pre-positioning equipment;
- Developing international, national, regional, and local response plans;
- Developing up-to-date charts;
- Enhancing seasonal air support and facilities;
- Developing port infrastructure; and
- Enhancing the Polar Code and UNCLOS III

5.3.3. The Vessel Traffic Management Requirement

In order to maintain or improve vessel traffic safety and orderly operations in Arctic (especially congested) waters; the needs of vessel traffic management are considered as follows;

- Establishing safe offshore distances for deep draft ships,
- Establishing safety fairways,
- Providing information for ice avoidance. [13, pp. 3-7]

6. CONCLUSION

In this study, the future of Arctic maritime activities have been argued according to the global climate change. First of all, the Arctic region, sea ice and sea ice types have been defined in order to explain the subject of the study. Afterwards, the importance of the Arctic region in terms of shipping sea route has been clarified not only historical and geographical but also governmental and infrastructural. Following to the second section, climate change were demonstrated as a global phenomenon with its heavy result on the Arctic region. In the next section, the satellite data about sea ice extent on the Arctic region, which provided by Colombia University, have been analysed in five years and ten years periods. The dataset contains the sea ice extents as .csv format. The seasonal average sea ice extent has been shown by graphics. According to the data, the effects of climate change to sea ice extent are very serious especially after 2000s. In the discussion, the current shipping route of Arctic and the probable new route have been explained. Moreover, the possible risks of Northern Sea Route (NSR) were discussed both in ecologically and economically. At the end of study, safety precautions has been shared.

Sea routes are important considering that around %90 of World trade is carried by international shipping industry. But the Arctic region was not feasible to navigate because of harsh weather condition and sea ices around the Arctic Ocean until 2000s.

On the other hand, the global climate change caused the melting of sea ice in the Arctic region especially in the middle of 2000s. This situation brought in the question if the Arctic region could be navigate. "The Melting Ice Caps and the Economic Impact of Opening The Northern Sea Route" study showed that NSR would be used more frequently than today in the near future. Even if the consumption of money, time and fuel would be decrease, the ecologic balance of the Arctic region would be affected seriously considering increase of greenhouse gases emission like CO_2 which was one of the responsible of climate change. Since the sea ice melting trend will not be prevented and the shipping traffic in the Arctic region will increase, the danger will be irreversible for the world.

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