# GEOPOLITICS OF CLIMATE CHANGE: THE ARCTICOCEAN

*Dissertation submitted to Jawaharlal Nehru University*
*in partial fulfillment of the requirements*
*for the award of the degree of*

## MASTER OF PHILOSOPHY


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## DECLARATION

I declare that the dissertation entitled "*GEOPOLITICS OF CLIMATE CHANGE: THE ARCTIC OCEAN*" submitted by me for the award of the degree of **Master of Philosophy** of Jawaharlal Nehru University is my own work. The dissertation has not been submitted for any other University.

SATYENDRA KUMAR UTTAM

## CERTIFICATE

We recommend that this dissertation be placed before the examiners for evaluation.

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~~Dr. S.S. DEORA~~

(Supervisor)

*Dedicated*

*To*

*My Newborn Daughter*

*Shreya*

*"Carbon will be the world's biggest commodity market, and*

*It could become the world's biggest market overall."*

***Louis Redshaw***

# ACKNOWLEDGEMENTS

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*20 July 2009*

*New Delhi* *Satyendra Kumar Uttam*

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# LIST OF ACRONYMS

| | |
|---|---|
| AO | Arctic Oscillation |
| ALA | Alaska |
| ANT | Antarctic |
| ARC | Arctic |
| CDW | Circum polar Deep Water |
| CO2 | Carbon dioxide |
| CO-2/3 | Carbonate |
| DSOW | Denmark Strait Overflow Water |
| GHG | Green house gas |
| GIA | Glacial isostatic adjustment |
| GIN sea | Greenland-Iceland-Norwegian Sea |
| GISP-2 | Greenland Ice sheet Projects-2 |
| GLAMAP | Glacial Ocean Mapping |
| GLOSS | Global Sea Level Observing System |
| GPS | Global Positioning System |
| GRIP | Greenland Ice Core Project |
| GSA | Great Salinity Anomaly |
| Gt | giga tones ( 10 /9 tonnes) |
| HCFC | Hydro cloro floro carbon |
| IABP | International Arctic Buoy Programme |
| IMO | International Meteorological Organization |
| ITCZ | Inter Tropical Convergence Zone |

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**LGM** Last Glacial Maximum

**LIG** Last Inter Glacial

**LLGHG** Long- lived greenhouse gas

**LSW** Labrador Sea Water

**MARGO** Multi proxy Approach for the Reconstruction of the Glacial Ocean Surface

**MSLP** Mean Sea Level Pressure

**M yr.** Million years

**NADW** North Atlantic Deep water

**NEP** net ecosystem production

**NGRIP** North Greenland Ice Core Project

**NH** Northern Hemisphere

**NPA** North Pacific Ocean

**O/2** molecular oxygen

**O/3** Ozone

**OASIS** Ocean Atmosphere Sea Ice Soil

**OLR** Outgoing long wave radiation

**PDO** Pacific Decadal Oscillation

**PMIP** Paleo climatic Modelling Intercomparision Project

**PNA** Pacific-North American pattern

**ppb** parts per billion

**ppm** parts per million

**PSC** Polar Stratospheric cloud

**RCM** Regional Climatic Model

**RSL** relative sea level

**RSS** **Remote Sensing System**

**SAT** **Surface air temperature**

**SCA** **Snow covered area**

**SCM** **Simple Climate Model**

**SH** **Southern Hemisphere**

**SIO** **Scripps Institution of Oceanography**

**SIS** **Small Island States**

**SO** **Southern Oscillation**

**SST** **Sea Surface Temperature**

**STE** **Stratosphere-Troposphere Exchange**

**Sv** **Sverdrup ( 10/6 m/3 s/-1)**

**SW** **Short Wave**

**SWE** **Snow Water Equivalent**

**THC** **Thermohaline Circulation**

**TI** **Total Solar Irridiance**

**UARS** **Upper Atmosphere Research Satellite**

**UCDW** **Upper Circumpolar Deep Water**

**UIO** **University of Oslo**

**UNEP** **United Nations Environment Programme**

**UNFCCC** **United Nations Framework Convention on Climate Change**

**UV** **Ultraviolet**

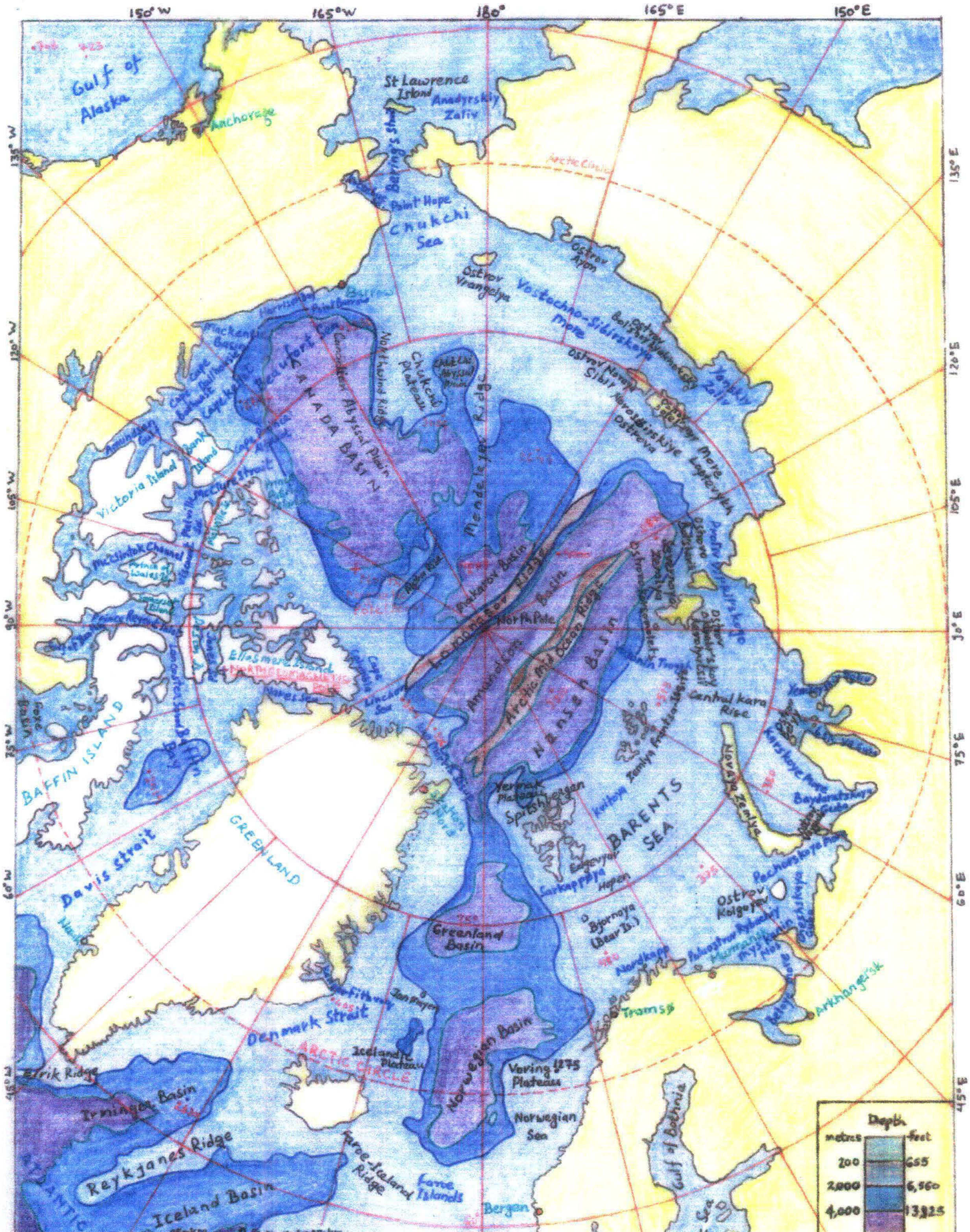
**WCRP** **World Climate Research Programme**

**WDCGG** **World Data Centre for Greenhouse Gases**

**WGMS** **World Ocean Circulation Experiment**

# *CHAPTER 1*

# *INTRODUCTION*




<u>**Map No.1 The Physical Features of the Arctic Ocean**</u>

# CHAPTER I

# INTRODUCTION

## 1.1 Introduction

The Arctic Ocean has the least-known basins and bodies of water in the world ocean owing to their remoteness, hostile weather, and perennial or seasonal ice cover. The ice cover is changing because the Arctic Ocean is exhibiting a strong response to global warming and may be capable of initiating dramatic climatic changes through alternation induced in the oceanic thermohaline circulation by its cold, southward-moving currents or through its effects on the global albedo resulting from changes in its total ice cover. The Arctic is of central importance in the twenty-first century as international interest in the Arctic has steadily increased. The emphasis is being placed on the polar areas, by declaring the year 2007-2008 as International Polar Year. The 2007 United Nations Climate Change Conference took place at Bali International Conference Centre, Nusa Dua, in Bali, Indonesia between December 3 and December 15, 2007. The 'Bali roadmap' initiated a two-year process of negotiation designed to agree a new set of emission targets to replace those in Kyoto Protocol. The road map sets the parameters and aims for further set of negotiations to be finalized by the 2009 UN climate conference, to be held in Denmark. To scrutinize the impact of climate change in polar area, the scientists from around the world are collaborating on researching environmental changes in the Arctic. Fifty countries have already submitted approximately 12,000 proposed studies.

A memorandum of understanding on polar research, signed between National Centre for Antarctic and Ocean Research(NCAOR), an autonomous institute under the Ministry of Earth Sciences, and Norwegian Polar Institute(NPI), has led to commissioning of India's first permanent research station, **Himadri** at 1200 Kms from the North Pole, in the **Ny-Alesund** sector of the Arctic region.

## 1.2 DEFINING THE ARCTIC OCEAN:

The Arctic Ocean is the smallest of the Earth's five oceans, having only a little over one-sixth the area of the Indian Ocean. Its area of 12,257000 Square kms is five times larger than that of the largest sea, Mediterranean. The deepest sounding in the Arctic Waters is 18,050 feet, but the average depth is only 3,240 feet. Nansen first time discovered an ocean in the Arctic. In the Arctic, the geographical pole lies under a frozen sea, at a depth of almost 4,500 meters, in the middle of an oceanic trough covering 13 million square kilometers. The greater part of the area is made up of a permanently drifting ice-pack. This oceanic pole is surrounded by islands or lands with very indented coastlines, inhabited at the north of the Arctic Circle (2 million inhabitants) and supporting several species of land mammals such as the polar bears.

. The Arctic Ocean, bounded on all sides by the continents of Asia, America and Europe, has a D-shaped from with an average depth of 3500 m. and an area equal to one-twelfth of the Pacific Ocean. Its circular shape communicates with the Atlantic through Denmark Bay (800 m. deep) and Baffin Bay and with the Pacific through the Bering Sea (40-60 m. deep). The Arctic is mostly frozen and a 15 feet permanent thick ice is found due to which there are difficulties of sounding the bottom. In 1927 Sir Hubert Wilkins found the deepest sounding of 5440.68 m.; 550 miles north of Point Barrow. By 1940 only 150 sounding were taken.

### 1.2.1Continental Shelf

The shelf along the Arctic is wider in the eastern and northern part-north of Russia and Europe-ranging between 100-400 miles. But in the north of North America and Greenland it is comparatively narrower. The widest shelves in the world are those bordering the Arctic, on which rise the large islands of the Canadian Archipelago, Greenland and most of islands of Europe and Asia. The Barents Sea shelf is 750 miles wide. It is also not very deep. The maximum depth is between 200 and 400 m.

It is supposed that the floor of the Arctic is sagged and downwraped under the pressure of the glaciers. Nansen (1928) in his discussion of the topography of the Arctic said the U-shaped furrows scour the shelf of the ocean. One such trough is noted at the northern coast of Norway.

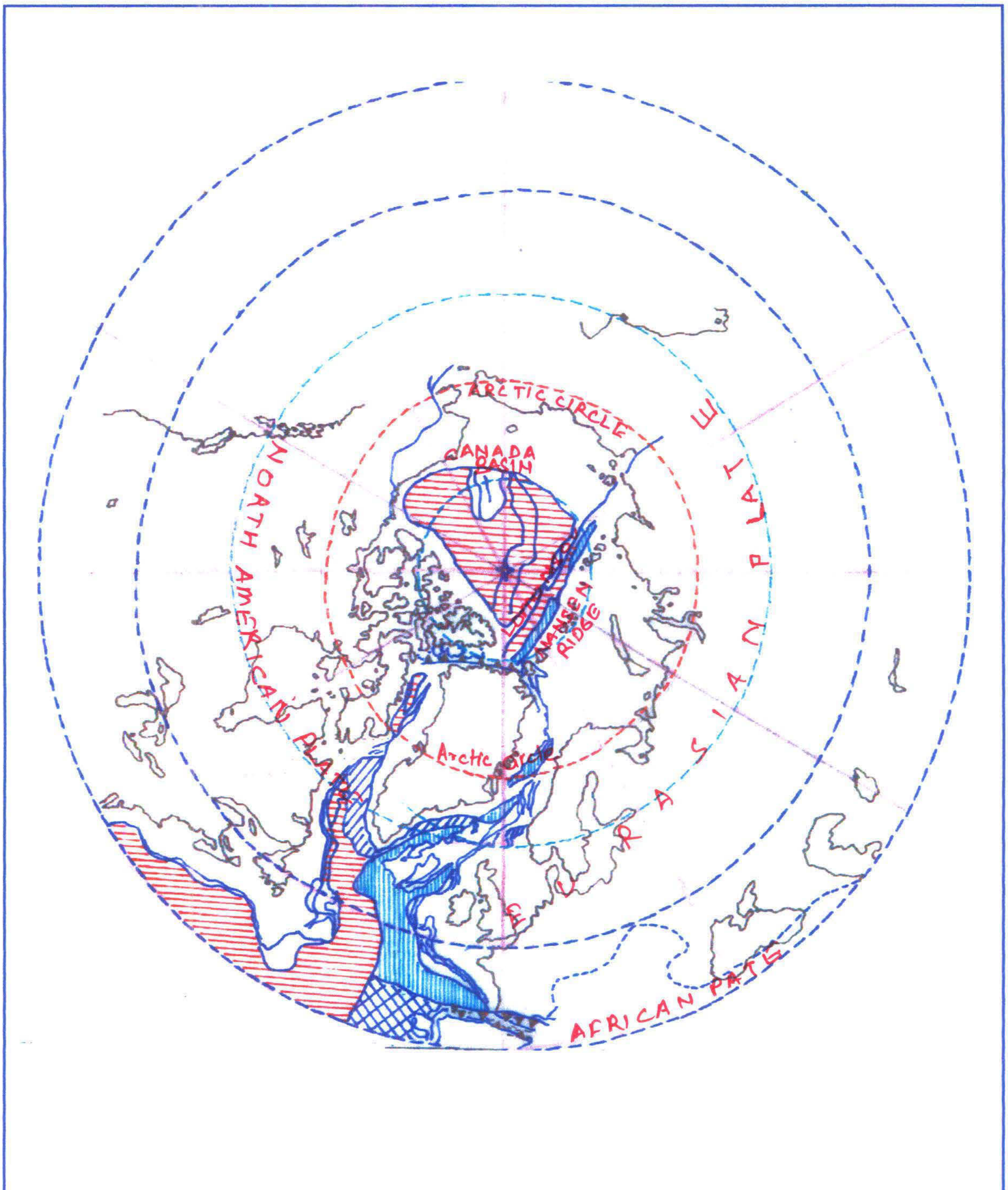



Fig. No.1 The Geological Formation of the Arctic Ocean Floor

These are attributed to the work of glaciers in the period when the sea surface was below the normal level.

### 1.2.2 Ridge:

Till recently it was believed that the Atlantic ridge terminates near Iceland. But the U.S. Coast and Geodetic Survey has found that it continues further in the Norwegian Sea which is in a way a part of the Arctic Ocean. East of Iceland the Faroe-Iceland rise extends from west to south-east along 10" W longitude. This ridge further extends up to 75" N in north-east direction and is known as East Jan Mayen ridge. It then turns abruptly towards the north and forms Spitbergen ridge is less than 1000 m. deep.

### 1.2.3 BASINS :

**Greenland Basin.**

The basin is between 2000-4000 m. deep and extends between Greenland and East Jan Mayen ridge.

**Norwegian Basin**

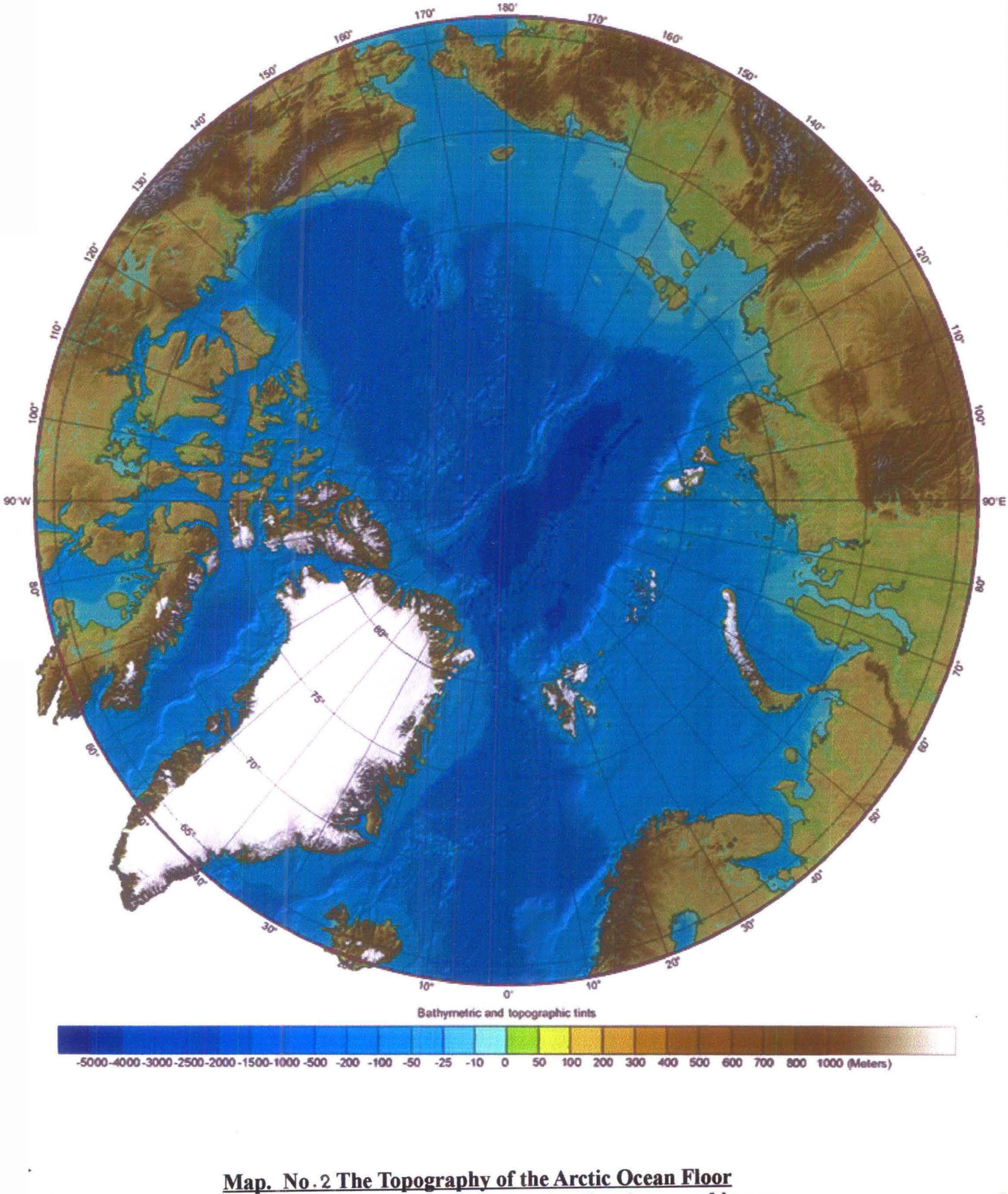
In the midst of the Norwegian Sea this basin extends from the central ridge to the coast of Norway. The sea is 2000-4000 m. deep.

**North Polar Basin**

In spite of less number of investigations in the Arctic, the existence of Polar basin is not refuted. This basin extends in a circular form surrounding the North Pole, with an extended part towards the Beaufort Sea north of the N. American continent. The average depth is between 4000-6000 m. The maximum depth in this basin is found to be 5625.39 m. at 78° N-175° W.

## 1.3 THE TECTONIC HISTORY OF THE ARCTIC BASIN:

In the Cenozoic Era (66.4 million years before the present) is largely known from available geophysical data. It is clear from aeromagnetic and seismic data that the Eurasian Basin was formed by seafloor spreading along the axis of the Nansen Ridge. The focus of spreading began under the edge of the Asian continent the edge of the Asian Continent, from which a



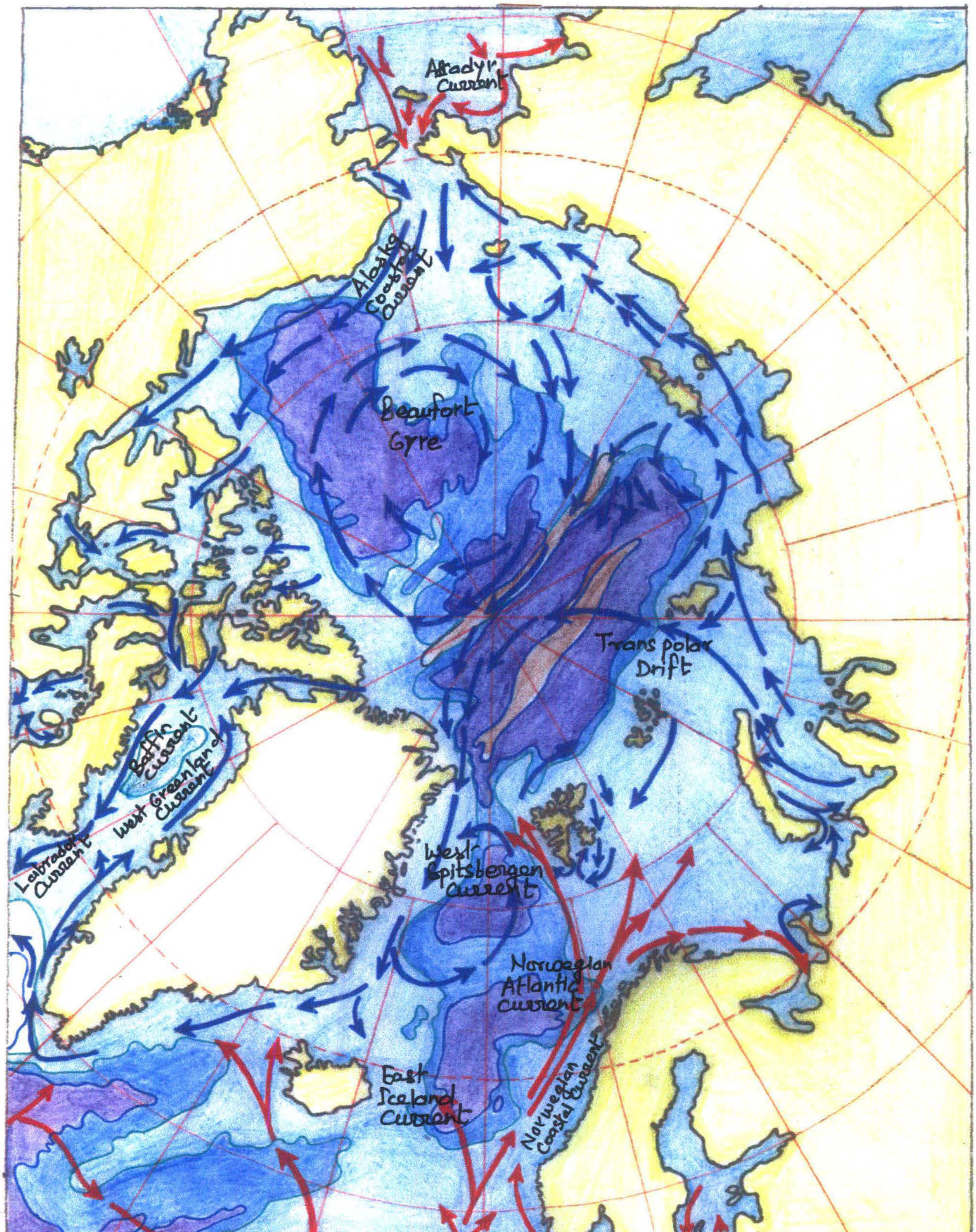

**Map. No.2 The Topography of the Arctic Ocean Floor**
**Source : National geographic- www.nationalgeographic.com**

narrow splinter of its northern continental margin was separated and translated northward to form the present Lomonosov Ridge. The origin of the Amerasia Basin is far less clear. Most researchers favour a hypothesis of opening by rotation of Arctic-Alaska lithosphere plate away from the North American Plate away from the American Plate during the Cretaceous Period (144 to 66.4 million years ago). Better understanding of the origin of the Arctic Ocean's basins and ridges is critical for reconstructing the paleo-climatic evolution of the ocean and for understanding its relevance to global environmental changes.

The sediments of the Arctic Ocean floor record the natural variability of the physical environment, climate, and ecosystems on time scales determined by the ability to sample them through coring and at resolutions determined by the rates of deposition. Of the hundreds of sediment corings taken, only four penetrate deeply enough to predate the onset of cold climatic conditions. The oldest (80-million-year-old black muds and 67-million-year-old siliceous oozes) document that at least part of the Arctic Ocean was relatively warm and biologically productive prior to 40 million years ago. None of available seafloor cores have sampled sediments from the time interval between 35 to 3 million years ago. Thus there is no direct evidence of the onset of cooling that produced the present perennial ice cover. All the other cores collected contain younger sediments that were deposited in an ocean dominated by ice cover. They contain evidence of terrigenous sediments formed by bordering glaciers and transported by sea.

## 1.4 THE TOPOGRAPHY OF THE ARCTIC OCEAN FLOOR :

From the late $19^{th}$ century, when the Norwegian explorer Fridtjof Nansen first discovered an ocean in the central Arctic, until the middle of the $20^{th}$ century, it was believed that the Arctic Ocean was a single large basin. Explorations after 1950 revealed the true complex nature of the ocean floor. Rather than being a single basin, the Arctic Ocean consists of two principal deep basins that are subdivided into four smaller basins by three transoceanic submarine ridges. The central of these ridges extends from the continental shelf off Ellesmere Island to the New Siberian Island, a distance of 1,100mile or 1,770 kilometres. This enormous submarine mountain range was discovered by Soviet scientists in 1948-49 and reported in 1954. It is named the Lomonosov Ridge after the scientist, poet, and grammarian Mikhial Vasilyevich Lomonosov.




Map No.3 The Surface Currents in the Arctic Ocean

## 1.5 ARCTIC OCEAN CURRENTS:

The Arctic Ocean is an enclosed sea bound by the great Eurasian and American land masses, allowing two outlets into the Pacific and the Atlantic oceans. The general drift across the Arctic Ocean is from east to west under the stress of North-East polar winds, confirmed by the drift of the water logged wood. The path of this current may be traced from the coasts of Siberia to the north-east coast of Greenland, passing further through the Hudson Strait into Baffin Bay. The main branch of the current flows down the east coast of Greenland through Denmark Strait to Cape Farewell and enters the Davis Strait. Offshoots from this current are also traced into the North Sea.

In the Arctic Ocean offshoots of the Gulf Stream are also observed. After reaching the northern coast of Norway, gulf water spread out in a fanwise shape. One branch reaches up to 80" N latitude. The second branch moves further north. Near the island there is an easterly flow and on the eastern side a westerly flow. The Arctic cold water flows in the Pacific through the Bering Sea. But there is lesser possibility of mixture in Pacific water due to the narrow passage. The British meteorologist C.E.P. Brooks compares the Gulf Stream with a hot tap and the Labrador and East Greenland current with two cold taps in the Atlantic Ocean. These determine the surface temperature and weather of Europe and Arctic region.

### 1.5.-a,b,c GREENLAND CURRENT, NORWEGIAN CURRENT & IRMINGER CURRENT

The main North Atlantic Drift flowing west of England and Ireland is divided into many branches. Here the current is known as the **Norwegian current**. It flows across the Wyville-Thompson Ridge and enters the Norwegian Sea. The nature of the current is changed from the original though slight warmth remains in it. It has a general salinity of 35.3 % and a temperature varying between 4°C and 8°C. One of the branches moves towards the south of Greenland at 60th parallel. From Iceland it flows to the west and south-west as **Irminger current** with an average velocity of 2.4 miles per day. It runs up to Cape Farewell along east Greenland coast and soon loses its identity. Due to offshore wind from Greenland, the cold east Greenland current invades this warm current region and the cooling effect is felt to the depth between 125 and 250 m. Further, this water is carried into the Davis Strait though the current is changed in nature.

The other current of the Norwegian Sea flows along the coast of Norway and Sweden and thus enters the Arctic Ocean. The velocity of the **Norwegian current** is 30cm/sec. Periodic variations are also noted in this current. Near about 63° N many branches are thrown off from the Norwegian current. One branch turns westward and after crossing small distance it again moves to the south and thus forms a most complicated circulation of numerous eddies and whirls between Iceland, Scotland and Spitsbergen. Just here another branch moves towards south of Svalbard Archipelago and again moves downward in the form of eddies. The major branch of the Norwegian current is found entering the Barents Sea. Some of the left bank eddies of the main – warm & saline-current, sink beneath the cold water of the east Greenland current as a result of increase in its density. Thus a warm layer of 13°C at 550 fathoms depth is found in Arctic Ocean. On the right hand side of the current, numerous whirls are found which are related to the bottom topography. One of the small branches of this current enters the North Sea under the stress of stormy winds and records a counter clockwise circulation. It is joined up in the north by Baltic current flowing out through the north of Denmark. The Baltic current itself is mainly governed by local winds and hence exhibits numerous fluctuations. North of Spitsbergen and east of Greenland the current is also influenced by the winds. Thus the Atlantic water submerges below the Arctic surface water and rest as a warm intermediate layer.

In Barents Sea a counter clockwise circulation of warm water prevails due to which the warm water flows on the eastern side or the right hand side and the cold Arctic on the western part of the sea. Variations are also recorded in the North Siberian shelf due to variable discharge of fresh water by Siberian rivers. Helland-Hansen points out one of the major changes in the current during 1929 when it contained water of high temperature and salinity. On the western part of the Norwegian Sea, owing to the prevailing northerly winds, a cold current flows from the Arctic Ocean along the east coast of Greenland. Water in the current is colder and salinity is low since it contains much of the floating ice. Consequently, as a result of melting of ice, sea level is also higher and light water is found. This current flows along the continental shelf of the east coast and rounds the Cape Farewell moving up to the western coast. The current is here helped by westerly wind and therefore the water is drifted further northward.

### 1.5. d LABRADOR CURRENT:

In the North Atlantic a cold current flows from the Baffin Bay and Davis Strait towards south. It brings about 7.5 million M3/sec. of water but receives little contribution from the cold water that flows down along the east coast of Greenland. Under the stress of the prevailing east, north-east wind the water of low salinity and temperature flows from the sub-polar area along the east coast of America which is also supplanted by other tributary currents coming through the islands. The free communication of water between the Labrador Sea and the Atlantic makes it possible for the Labrador Current to flow with a continuous southerly flow. Above the depth of 1500 m. it carries 5.6 million m3/sec. of water along the Labrador coast. Smith recorded that 1.9 mill. M3/sec. of Labrador water sinks below surface and moves as deep water in the Atlantic. The velocity of the current in the Baffin Bay and Davis Strait is 6.25 sea miles per day. At 53° N off the Labrador coast, it is measured to be 11.8 sea miles per day. Further south, the current strikes the coast of Newfoundland, then flows over the easterly part of the Grand Bank and; merges with the Gulf Stream east of 50°W. Between Halifax and Cape Cod the difference between the Labrador and the Gulf Stream waters is marked by a '**cold wall**'.

In the Arctic, the geographical pole lies under a frozen sea, at a depth of almost 4,500 metres, in the middle of an oceanic trough covering 13 million square kilometers. The greater part of the area is made up of a permanently drifting ice-pack. This oceanic pole is surrounded by islands or lands with very indented coastlines, inhabited at the north of the Arctic Circle (2 million inhabitants) and supporting several species of land mammals such as the polar bear, the wolf and the fox. While eight maritime states have shared the Arctic coasts without any dispute since 1933, there are only two land frontiers: Alaska-Canada and Russia-Norway.

## 1.6 CLIMATE OF THE ARCTIC REGION

To most people the Arctic is simply a cold, bleak region—monotonous, inaccessible and unproductive. However, these stereotypes are contradicted when we consider the region carefully. The Arctic is much milder and much less hostile to life **(Willey Lev 1976).** It is cold enough in winters; temperature of -50°C are common in many places. But at the very polar caps, the Arctic has the moderating presence of the sea just under the ice pack. As a result the coldest spot in the north is no where near the geographic pole but some 2,400 kilometer south in north-eastern Siberia, in an area centering around two town, Verkhoyansk and Oymyakon—There it has touched -68°C.

In Greenland winter is long, cold, still and dark, the sun does not rise above the horizon for a period of about 9 weeks. The darkness is far from absolute however, and twilight exists as long as the sun is not more than 6° below the horizon. Temperatures in still clear weather can fall to -50"C. Not surprisingly all sounds of running water and waves are absent, Snow covers is Patchy and thin.

Spring is a time when the days become increasingly light and sunny. Temperatures are still low until April with a monthly mean below -10°C, and the snow and Ice cover remain intact. The time between spring and early summer is messy. Under bright and weak sunshine the snow first heats up and then only when all the snowpack has reached freezing point, does it disappear. Most low—lying areas become snow-free in late June on the first half of July. Summer months are short, but delightful. Temperatures are suitable for sunbathing for days on end. In the continuous sunlight air temperature may exceed 22°C while rock surface temperatures even exceed 33°C.

The air is filled with noise—the sound of breeding birds up for the season, the rushing water of brooks and glaciers melt water streams, the sound of the grinding pack ice in the fjord and the rumble as ice bugs melt and crumble **(Sudgen,David 1982: 34).** The idyllic weather occasionally broken by spells of rain, while in fjord strong winds can suddenly develop in the clearest weather. In late August, the night-frost occurs; and in a space of a few days autumn arrives. One of the remarkable features is the change of vegetation from green to tints of red and yellow in a matter of days.

In September open water in the fjord between the larger ice floes freezes over each night only to melt the following day, while geese gather noisily and begin to fly south in vast straggling skeins. By Late September winter is fast approaching again.

However this annual climatic rhythm faces several anomalies in the Arctic. The marine coastal areas of the Arctic experience warmer winters and cooler summer. While, the extreme continental climates of north east Siberia experience cooler winter and longer warmer summer.

Also the length and darkness of the winter increases towards the Pole. On ice-sheets in interior Greenland winter is more severe and summer non-existent.

The overwhelming characteristic of the polar region is the cold, both in intensity and in durations, several reasons are cited to explain the cold. The first is that the polar region receives less solar radiation than the rest of the world because of the low angle of the sun in relation to the ground surface. Secondly, this region reflects most of the solar radiation it receives, average absorption of solar radiation on earth is about 40 per cent, whereas snow and ice have an albedo of 80 to 90% therefore only 10-20% of the solar radiation is absorbed. Thirdly, the clarity of the atmosphere because of lack of dust and water, air holds ten times less moisture and water and is clear of solid particles. Therefore little long-wave radiation takes place from the earth's surface.

Also polar regions suffer a loss of net radiation, however heat is transferred from the lower latitudes by way of sensible heat usually in form of cyclones, by way of latent heat and thirdly by way of oceanic circulation. Therefore, on a world scale the polar regions are heat sinks, which help the atmosphere to remain in equilibrium **(Weller & Bowling 1975).**

### 1.6.1 ATMOSPHERIC CIRCULATION OVER THE NORTH POLE :

The temperature difference causes air over the poles to be dense and in effect this means that lines of equal density in the atmosphere focus a bowl over the poles high at the perimeter and low at the center. As the air flows down the gradient towards the poles, it is directed by the rotation of the Earth, so that it flows roughly parallel to the contours, forming an anti-clockwise vortex over the North Pole. Surface air movements closely reflect such overall wind directions but are interrupted by irregularities associated with the distribution of land and sea. In the Arctic the alternation of continents and ocean breaks up the continuity and strength of the Westerlies and introduces a more pronounced meridional circulation. The waves associated with each continent, while in contrast warm air over the Atlantic is directed towards the north **(Wily Ley 1985).**

### 1.6.2 TEMPERATURE :

One characteristics of climate is the presence of a temperature inversion above snow or ice surfaces which results from strong radiational cooling. This inversion may be only 10-100 m thick and yet represents a temperature difference of 30°C. It's development is commonly associated with cyclones. The inversion is especially intense and persistent where the cold air is trapped in valleys such as Yukon and north-east Siberia, and this helps to account for the extremely low temperature in terms of distribution of land and sea. To winter the pole is kept anomalously warm in comparison to the surrounding land and sea. To ocean temperature is within a few degrees of freezing and heat is conducted through the ice in winters. The surrounding land areas have no such heat reservoir and temperatures plummet, particularly where cold air drainage leads to the buildup of stable inversion.

### 1.6.3 PRECIPITATION :

Precipitation in the polar-regions is light and indeed most of the zone is arid. Totals in the Arctic basins are generally less than 130mm while the arctic coasts have less than 260mm on the whole. The lowest land values are around 140mm and occur in eastern Siberia and northern Canada and Greenland. Totals generally rise from these areas towards the Atlantic and Pacific to above 600mm. The precipitation-contrast here reflects the distribution of land, sea and high topography. The main spatial precipitation pattern in the Arctic can be explained in terms of proximity to maritime sources of moisture. There is a decline in all directions from the northern Pacific and Atlantic coast, although it is accentuated in a west-east direction of movement of most cyclones. The decline in precipitation inland is more rapid in the case of the North American Cordilleras.

### 1.6.4 EFFECT OF ARCTIC CLIMATE ON HUMAN & ECONOMIC ACTIVITIES :

Climate is an important constraint and independent variable affecting the operation of many smaller-scale systems in the Arctic region. The links between climate and the various geomorphic, oceanographic and bio-geographic systems are quite fundamental. The limits to vegetation productivity are determined ultimately by climate. Low temperatures create problems for normal industrial society and their solutions inevitably involves special design and extra cost, conventional water supply, sewage and heating all would freeze and be inoperable in polar winter and they require extensive and expensive modifications, such as insulation.

## 1.7 SCOPE OF THE STUDY

The oceans play a vital role in controlling the distribution of today's climate on planet earth. Their huge thermal capacity and inertia and their mobility, which enables them to transport heat from equatorial latitudes to polar regions, are critical factors in reducing climate extremes between low and high latitudes and from season to season. Future changes in climate will be related to future changes in ocean behavior. So, these three aspects of ocean dynamics are particularly critical in studies of climate change and its potential impacts. First, we consider ocean circulation, which is driven by winds and thermal forcing. Next we consider the possible role of the oceans as a sink for atmospheric carbon dioxide, a potential control of future greenhouse warming. Finally, we take the implication of global warning for sea level rise and coastal flooding. Each of these three aspects is related to known features of the Arctic Ocean behavior, to various research programmes underway at present, which will improve our understanding of the relationship between oceans and climate change.

## 1.7 Objectives

(1) To examine the critical role of oceans in influencing Climate Change; and to look at some probable impacts; are the basic objectives. Oceans store and distribute vast quantities of heat. They also play an important role in the absorption of atmospheric carbon dioxide by both biological and physical processes. Climate Change will probably accelerate existing rates of sea level rise, increasing the risk of coastal flooding on a global scale.

(2) To examine the possible legal bases for Canada's claim that, the waters of the Canadian Archipelago are internal waters i.e. a historic title and straight baselines on the issue of the possible internationalization of the Northwest Passage.

(3) To study the relationship between environment and development, with regard to climate change in the era of globalization; and to identify strategies and policies for reducing the vulnerability of developing countries; are other objectives of the study.

(4) To understand the framework of Climate Change negotiations at the global level among the developed and developing nation-states and further examine the existing polarization. How fair are existing global agreements?

## 1.9 HYPOTHESIS :

1. **The earth's climate change, due primarily to increased emissions of carbon dioxide & other greenhouse gases, has been particularly intense in the Arctic; which has reduced the extent and thickness of sea ice in the ocean itself and the sea routes on each side; making international shipping in the Northwest Passage a certainty in the foreseeable future. Such shipping raises the question of whether the Passage is or might become an international strait, with the consequent right of transit passage.**
2. **The theory of sector on the issue of claims over Arctic resources & its effective occupation is ambiguous. As the theory affirms that any country through which the Arctic Circle passes has the right to North Pole and whose sides are the meridians corresponding to the extreme of the land frontier.**
3. **Climate Change is fundamentally a developmental issue related to all global environmental problems, including rising sea levels. Hence, the contribution in scientific research on Arctic & climate change; by full-fledged research stations of Norway and India-a club of eleven countries; is going to contribute to the future of the planet ranging from the island nations such as Maldives & Trinidad as well as coastal areas of all continents such as the Netherland. It is a choice between unabated development and sustainable development.**

**1.10 Data Base** : Data for the study were collected from following sources

1. World Development Report-2008, The World Bank, Washington,D.C. for $CO_2$ emissions
2. IPPC, The Climate Change 2007: The Physical Science Basis, edited by Solomon et.al. Cambridge University Press, New York, U.S.A.
3. The Atlas of Climate Changes: Mapping, The World's Greatest Challenge. EARTHSCAN

## 1.11 RESEARCH METHODOLOGY :

This study intends to involve both theoretical as well as empirical aspects in analyzing the mentioned theme for which it will require both primary sources--sources like Govt. documents, reports such as from IPCC, and NGOs like Green Peace etc., country official news (European Environmental Agency), summits (UN Earth Summit), seminars, pacts, newsletter, interview as well as secondary sources like books, articles, websites on internet etc.

The research methodology will be both quantitative and qualitative in nature. This work will be mainly divided into two parts, one to study and analyze the theoretical part to locate the mentioned hypothesis in the research; we use the appropriate research materials. The broad scope of literature on climate change will help in focusing on every dimension of climate change. It can be made to analyze the past developments in correlating the anthropogenic processes leading to climate change, in terms of strategies, processes, policies and programmes initiated by international regimes and national diplomacies.

Data collected from various secondary sources have been analyzed through various statistical methods. The data computation ranges from Statistical diagrams, cartographic techniques like GIS mapping has also been used.

### 1.12 The Themes of the Research :

Climate change is an issue in discussions of politics and the governance of international affairs; it is an issue that threatens progress in making the world more secure and habitable.

***Theme-1***

**OCEAN CIRCULATION AND HEAT BUDGET**

As the oceans are warmed by solar radiation some of the heat is transmitted to the atmosphere largely as latent energy in evaporation, and some is mixed with the deeper layer. Incoming radiation is much greater in the tropics than at polar latitudes and if there is a locally balanced budget of radiation, the tropics will be substantially warmer than they are today and at higher latitudes (polar regions) it will be much colder. The more equable temperature distribution at present is due to the transport of vast quantities of tropical heat to higher latitude. Some of this heat is transmitted by the atmosphere and some by the oceans. Although the atmosphere transmits heat more rapidly, the much higher thermal capacity of the oceans makes them very effective carriers of heat energy. The transfer of heat pole ward varies from ocean to ocean and with latitude **(Carissimo, Dort & Vander Haar, 1985: 82-91.).** There are also variations with time, from year to year and from season to season.

The present day seasonal variability in climate, point to very sensitive responses to long-term trends in climate. The Intergovernmental Panel on Climate Change **(IIPC-1990:26)** Suggested that a warming of 1-2°C throughout the year could occur by 2030. Given that ocean temperatures are now very close to the critical threshold of 28°C for organized convection and precipitation, it is likely that substantial changes could occur in monsoon characteristics.

World Ocean Circulation Experiment (WOCE) is a major oceanographic contribution to the World Climate Research Programme of International Council of Scientific Union and the World Meteorological Organization. It is designed to study the important climate function of the ocean and to develop ocean models capable of predicting climate changes resulting from both natural and anthropogenic causes. For the purpose of observing changes in climate as a result of increasing greenhouse gases it is convenient to consider a 'fast' and a 'slow' component of climate. **(Needler G. 1991:32)** The fast component includes the atmosphere and the upper ocean acting as a coupled system: the effect of evaporation and clouds on the radiation balance is a particularly important feedback process. Prediction of climate changes, by atmospheric circulation models coupled to shallow ocean models, suggest that for a doubling of atmosphere carbon dioxide, global surface temperature could increase from 2ºC to 5ºC----more in polar regions than in the tropics (**Mitchell I. F. B., Manabe S., Tokioka T., Melishko V. *the IIPC Scientific Assessment* 1990 Cambridge University Press)** The slower component is due to the vast heat capacity of global ocean and its slow response to surface changes. Sinking cold polar water circulates slowly at a depth on a time scale which varies from decades to centuries: global warming may be delayed, for the moment, by the thermal inertia of the oceans. Under WOCE observations are collected to allow the development of full-depth ocean models so that the slow component of the response to changing greenhouse gas concentration can be estimated.

***Theme-2***

## POLITICAL ECONOMY OF CLIMATE CHANGE :

Kyoto provided a major watershed into the economics of Climate Change; scientific and technological basis the Green Politics; uncertainties in its political future and efficient policies to slow Climate Change (Norhaus D. William (2005) in "Reflections on the Economics of Climate Change").The process of organization and negotiation in the Kyoto Protocol led to Climate Change conventions and subsequent Bonn Agreement and Marrakesh Accords (Depledge, Joanna (2006) "The Organization of Global Negotiation"). The fact that cost of mitigating Climate Change in the coming decades will surely be borne by higher income group countries but benefits will accrue to future generations in the developing world (Schelling (2005) in "The cost of Combating Global Warning : Facing the trade offs.").It becomes necessary to examine the key economic characteristics of Climate Change and access the argument that economic theory provides a good guidance on the design of an efficient and politically realistic policy (Mc. Kibbin and Wilcoxen (2005) in "The Role of Economics in Climate Change Policy"). The importance of corporate social responsibility and the decision on important policy matters like global climate change should be made on the basis of sound, scientific, technological and economic principles, solid empirical evidence and attention to the need of world's poorest citizens (Paul, Driessen (2005) in his book " Eco –Imperialism: Green Power & Black Death"). The challenges of ensuring that policy responses to Climate Change do not place undue and unfair burdens on already vulnerable population. The issues of burden sharing and equity considerations; becomes critical to the future Climate Change policies (Adger, Paavola, Huq and Mace (2006) in "Fairness in Adaption to Climate Change").

***Theme-3***

**GREEN GEOPOLITICS: INTERNATIONAL CLIMATE CHANGE POLITICS-**

The prominence of climate change as a political issue grew slowly in the 1970s and most of the 1980s.By the end of the 1980s, concern was sufficient to create a demand for an international agreement on global warming and a negotiation process was begun through the UN to produce a treaty on climate change. This process led to the signing of the Framework Convention on Climate Change (FCCC) by representatives of 165 governments at the United Nations Conference on Environment and Development-"Earth Summit", in Rio de Janeiro in 1992. The FCCC called for the "stabilization of GHGs concentrations in the atmosphere at level that would prevent dangerous anthropogenic interference with the climatic system". The FCCC was signed and ratified by more than 175 countries and legally entered into force in March 1994.The representatives of over 150 governments signed the Kyoto Protocol in 1997. The Protocol set binding emission targets for developed countries that would reduce their emissions on average 5.2 percent below 1990 level. The loopholes in the Kyoto Protocol and the challenges for developing a framework for international decision making; with inclusion of the developing world, research & development and flexible provisions for emission reduction; has been incorporated by Schmalensee in his article.(Schmalensee (2005), "Kyoto Unfinished Business"). Potentialities and loopholes of Kyoto Protocol have been further inquired in details by John Brown. and National Concerns"; Brown, John (2004), "Beyond Kyoto").

All aspects of climate change for the developing countries in the new economic order; requirements of a good scientific understanding as well as coordinated action at national and global level are needed to be addressed to meet the challenges of the climate change. (Sathaye, Shukla and Ravindranath (2006), Climate Change, Sustainable Development and India: Global and National Concerns"). The real battles over climate change are being fought over issues of trade and national competitiveness in the context of greenhouse policies (Sagar and Kandlikar (1997) in the article, "Knowledge, Rhetoric and Power-International Politics of Climate Change"). Relations among the developed countries-the United States of America, Europe and

Japan etc ; are strained on the issues of Climate Change and its implications on world politics (Busby W. Joshua (2003), "Climate Change Blues: Why the United States and Europe just can't get along"). Globalization of environmental problems along with globalization of production, trade and telecommunication has altered the way nation states interact. The paradigm built on the previous geopolitical notions is in the state of crisis. There is need for a new geopolitical paradigm for analyzing environmental geopolitics. (Noel Castree (2003) in "The Geopolitics of nature") Apart from blurring out cooperation among nations; the pressures from the developed countries have been perceived as encroachment on sovereignty of the developing countries. These nations pollute environment in their spatial limits but consequences are global in nature. Hence, environment is not only the subject of scientific enquiry, rather active field of global politics. The unprecedented challenges posed by environmental problems and the ecological interdependence of the nation states have produced a new 'ordering principle'. The neo-liberal views in the establishment of Global Environment Facility (GEF) under World Bank; attempt for the possibility of cooperation among nations and NGOs to conserve environment. The functioning of GEF is also politically hindered by the funding nations-states of the North. The role of NGOs in implementation of the policies of GEF also needs to be considered. (Zoe Young (2002), A New Green Order?)

# CHAPTER 2

# THEORETICAL BASE

# CHAPTER-2

# Theoretical Base

## 2.1 Definition of Geopolitics:

Introduced a century ago as a deterministic field of study and a recipe for statecraft, Geopolitics was first offered as a set of geographically determined laws governing a state's strategic destinies and evolved as the geographically underpinning of ***realpolitik***. Geopolitics is a product of its times, and its definitions have evolved accordingly. **Rudolph Kjellen,** who coined the term in 1899, described geopolitics as "the theory of the state as a geographical organism or phenomenon in space."**(Kjellen, Rudlph 1916:106-109).** For **Karl Haushofer**, the father of the German *geopolitik,* "Geopolitics is the new national science of the state,....a doctrine on the spatial determinism of all political processes, based on the broad foundations of geography, especially of political geography. **(Richard Henning in Andrew Gyogry, (1944) *Geopolitics*: 183). Richard Hartshorne** defined geopolitics as "geography utilized for particular purposes that lie beyond the pursuit of knowledge." **(Richard Hartshorne 1939: 404).**

## 2.2 De Seversky (1949) The Airman's View: Azimuthal Equidistant Projection: - Geopolitical Importance of the Arctic Ocean :

Mackinder and Spykman used the Mercator's projection for the cartographic expression of their models. However, azimuthal equidistant projection[1] provides a view in which cold war powers stand face to face across the Arctic Mediterranean, through which air space passes the shortest routes between places in the Heartland and the North America. The impact of the air age upon thought produced geopolitical a variety of views. In1942, George Renner suggested that the air lanes had united the Heartland of Eurasia with a second, somewhat smaller Heartland in Anglo-America, across Arctic ice fields. **(George T. Renner 1942: 152-54)** A major attribute of this new Heartland was the mutual vulnerability of its Eurasian and its Anglo-American portions across the Arctic Ocean. According to Renner, not only would the expanded Heartland be the dominant power center of the world, but it also possessed the advantages of interior air, sea and

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[1] Azimuthal Equidistant Projection : When the globe is viewed from a point vertically on the poles it is called Polar Zenithal, in which the correct bearings or azimuths are preserved. In this projection the distances from the centre of the map truly represent the corresponding distances on the globe.

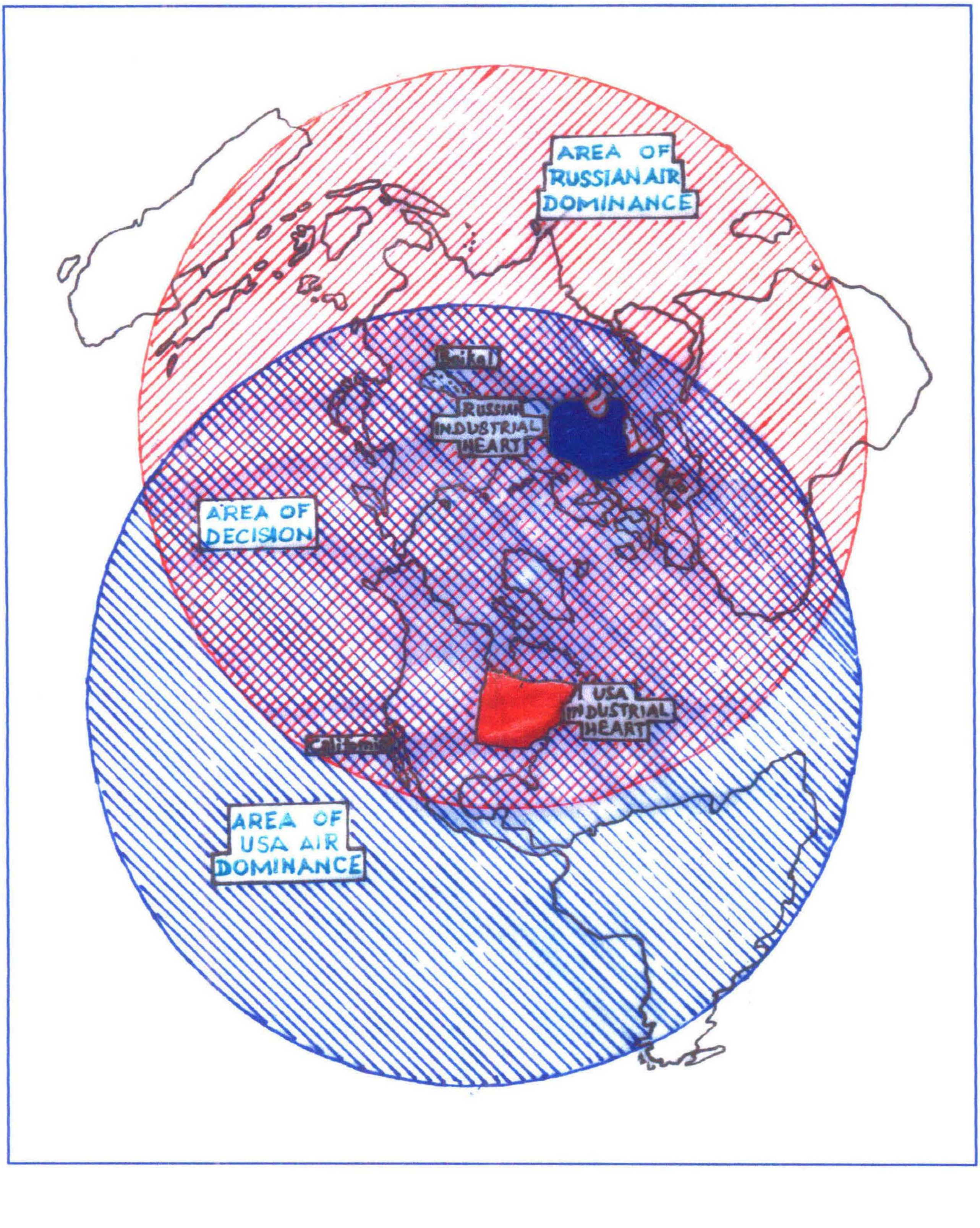


Fig. No.2 The Arctic Ocean lies in the Area of Decision in De Seversky's Concept of Global Strategy in the Air Age.

land routes across the polar world. Thus the Arctic, as the pivotal world arena of movement, was the key to Heartland and therefore to world control.

In opinion of Stephen Jones, the theory of Alexander de Serversky, has been described as "**the airman's global view.**" **(Stephen B. Jones 1954:421-452.)** De Serversky's map of the world, which he presented in 1950, is an azimuthal equidistant projection centered on the North Pole. The western hemisphere lies to the south of the pole, Eurasia and Africa to the north. Here again was an Old World-New World division. North America's area's of **"air dominance"**-its area of reserve for resources and manufacturing-is Latin America; the Russian (USSR in cold war era) area of air dominance is South and Southeast Asia and most of Africa south of the Sahara. De Serversky considered the areas where North American and the then Soviet air dominance overlapped which included Anglo-America, the Eurasian Heartland, Maritime Europe, North Africa, and the Middle East-to be the **"Area of Decision."** According to this view, air mastery and therefore global control could be gained. **(Alexander de Seversky 1950:11&map facing 312)** Major Alexander de Serversky (1894-1974) left enormous influence on government officials as well as the general public through his first work ***Victory Through Air Power (1942).*** This work reviewed the course of the war to that point, declared "the twilight of sea power," deplored the insufficient attention to air warfare being paid by the Allies especially the United States, and advocated a totally new strategy and organization for victory through air power. (De Servesky, Alexander P.: 1942) He advocated defense of the Western Hemisphere, avoidance of small wars as useless sapping of American strength, abandonment of overseas bases as costly. For first time in such geopolitical writings, he used a map, which resulted in a new view of the world, the United States and Canada erected at great expense three lines of radar station and air bases, stretching across Alaska and Canada for the defense of North America against attack from the then USSR by the shortest routes—over the North Pole across the Arctic Ocean.

The Cold War thrust the Canadian Arctic into new strategic prominence. The Distant Early Warning (DEW) Line was constructed as a defense against a transpolar attack and consisted of a series of roughly concentric circles of antiaircraft and antimissile bases in Canada and the northern United States. The North American Aerospace Defense Command (NORAD) became a cornerstone of U.S. strategic policy, as some of its most important base, both defensive and offensive, were placed on Canadian soil. In addition to the air component, American missile-carrying nuclear submarines prowled the waters below the Arctic ice cap as they maintained their watch over the transpolar rival. **(Cohen, S. B., 2003)**

In one sense, the theory of de Servesky was an extension of Renner's argument. In another, however, it led to two different and highly questionable conclusions. The first stems from the distortion of the map projection, which suggest that Africa and South America are so widely separated that they are mutually defensible by their respective senior partners, the then Soviet Union and the United State.

Second, de Seversky's view was that air supremacy, and with it control of the northern hemispheric Area of Decision, could be achieved by one power through all-out aerial warfare. While he spoke of only the United States, the then USSR, and perhaps, the United Kingdom as having the potentialities of Great Power, in theory any country with the necessary military hardware, recuperative strength, and will could achieve dominance. Thus de Seversky's theories lead to two conclusions:

1. **"air isolationism,"** which suggested a viable division of the world into two
2. **"unitary global view,"** suggesting that, in the event of all-out war, the power that led in military hardware, regardless of its location, could dominate the world.

De Seversky's major works, written in 1950, did not anticipate that several powers might achieve the capabilities of mutual deterrent. There are those who held that air power did not add a third dimension to land and sea movement, but simply a complementary dimension to each of these channels. Particularly if all-out nuclear warfare is eliminated, Jones called this view the "air-first moderates" who held that air power could be decisive only as it lends a comparative advantage to land or sea powers. An influential spokesman for this point of view within the North Atlantic alliance was the British Strategist, air force marshal Sir John Slessor. He was a strong advocate of airborne nuclear weapons as **"The Great Deterrent"** against total war. **(John Slessor 1957 : 264-285)**

It is easy to criticize de Seversky's view in an era of intercontinental ballistic missiles and space travel, but at that time it performed a most useful function by tearing us away from our

Mercator-veiw of the world, by developing an interim defence system, and by emphasizing defense instead of expansion as the prime goal of geostrategy.

## 2.3 THEORIES OF CLIMATE CHANGE:

Climate changes are effected by changes in the atmospheric circulation and interaction among five components of the earth –

1. Atmosphere
2. Hydrosphere
3. Lithosphere
4. Biosphere
5. Cryosphere[2]

Wherein the amount of received solar radiation, and the process of distribution, redistribution, and absorption of solar radiant energy at the earth surface are important considerations of the state of climate of an area in specific time period. The causes for such interaction leading to climatic changes are related to outside sources e.g. extraterrestrial sources and Inside sources e.g. earth-atmosphere system or terrestrial sources. The causes and theories of climatic changes are viewed in terms of periodicity of climate changes which are generally of two types

A-short-term climate changes

B-long-term climatic changes

Since the nature and patterns of climatic changes vary temporally and hence the causes of such changes are also of varied nature. This is why no single theory can explain all types and patterns of climate changes and thus we have a host of causes and theories of climatic changes. Since the Industrial Revolution the man's increased economic activities and the application of advance technologies are introducing significant modifications and changes in climatic conditions. This has led to the emergence of a new dimension in climatic changes.



[2] The cryosphere includes snow, ice-sheets, glaciers, sea-ice, and permafrost. i.e. the frozen surface of the earth.

The theories of climate change may be grouped in following three broad categories:

1. Outside or extra-terrestrial sources
2. Inside or terrestrial sources
3. Anthropogenic sources

The significant causes and related theories of climatic changes are:

1. Solar irradiance (variation in solar radiation)
2. Sunspot cycles
3. Astronomical theories
   a. eccentricity of the earth's orbit
   b. obliquity of the ecliptic
   c. precession of the equinoxes
   d. earth-sun relationship
4. Atmospheric dust hypothesis-mainly volcanic eruptions & dusts
5. Carbon dioxide hypothesis
6. Continental drift and pole wandering
7. Tectonic and topographic control theory
8. Ocean variation hypothesis
9. Extra terrestrial bodies collision theory
10. Anthropogenic sources
    a. changes in the earth's surface
    b. changes in atmospheric composition

Out of these ten theories of climate change only one i.e. anthropogenic sources differ from the rest and considers human factors as the main source of climate changes in the past. Climate on the earth has changed on all time scales, even long before human activity. Progress has been made in understanding the causes and mechanism of these climate changes. Changes in the earth radiation balance were the principal driver of climate changes but causes of such changes are varied. For each case, be it the ice ages or the warmth of time of dinosaurs or the fluctuation of the past millennium- the specific cause must be establish individually in many cases, now many past climatic changes may be reproduced by quantitative models. Global climate is determined by the radiation of the planet. There are three fundamental ways the earth's radiation balance can change, thereby causing a climatic change:

1. changing the incoming solar radiation e.g. by changes in the earth's orbit or in the sun itself.
2. changing the fraction of solar radiation that is reflected-Albedo[3]-it can be changed by changes in cloud cover, aerosols or ice cover.
3. Altering the long wave energy radiated back to the space e.g. by Changes in greenhouse gas concentration.

The local climate also depends upon how heat is distributed by winds and ocean currents. All these factors have played a role in past climate changes. A small section of climate scientists have suggested that some kind of natural mechanism regulated our planet's temperature and the level of carbon dioxide in the atmosphere. The scientists, skeptical about human influence about human influence about global warming point to this as the cause for recent climate change.

James Hutton, a Scottish geologist, put forward his theory based on two concepts namely

i. 'Present is key to the past'
ii. 'No vestige of a begging no prospect of an end'

Hutton's principle of uniformitarianism states that the same physical processes and laws that operate today, operate today, operated throughout geological times, although not necessarily always with the same intensity as now'. While pronouncing the concept of uniformitarianism he postulated the cyclic nature of earth's history.

The example of occurrences of ice ages during following glacial periods

i. Pre-Cambrian Period (850-600 million years before present)
ii. Ordovician Period (450-430 million years before present)
iii. Carboniferous-Permian Period (300 million years before present)
iv. Pleistocene Period (2-3 million years before present)

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[3] Albedo: The proportion of solar radiation falling on non-luminous body which the latter reflects, usually expressed as a decimal. The albedo of the earth is approx.0.4 i.e. about 40% of the solar radiation is reflected back intospace,the value is much higher for a snow-covered surface and lower for dark soil.

## 2.4 THE THEORY OF GREAT CIRCLE DISTANCE:

The shortest distance between two points is a straight line. On the curving three-dimensional surface of the spherical earth, however, it is obviously impossible to follow such a straight line. The shortest "straight line" course over the surface between any points on a sphere is the arc on the surface directly above the true straight line. This arc is formed by the intersection of the spherical surface with the plane passing through the two points and the centre of the earth. The circle established by the intersection of such a plane with the surface divides the earth into hemispheres and is called a **great circle**.

The equator is the only complete great circle in the graticule. Since all meridians are one half a great circle in length, pairs of meridians also make up great circle. All parallels other than the equator are called **small circle**. Calculating the great circle distance between any two points A and B on the earth can done using the standard formula in spherical trigonometry:

$$\text{Cos } D = (\sin a . \sin b) + (\cos a . \cos b . \cos |\Delta\lambda|)$$

Where a and b are the geographic latitudes of A and B, and $|\Delta\lambda|$ is absolute value of the difference in longitude between A and B. If A and B are on opposite sides of the equator, the product of the sines will be negative.

## 2.5 THE THEORY OF SECTORS:

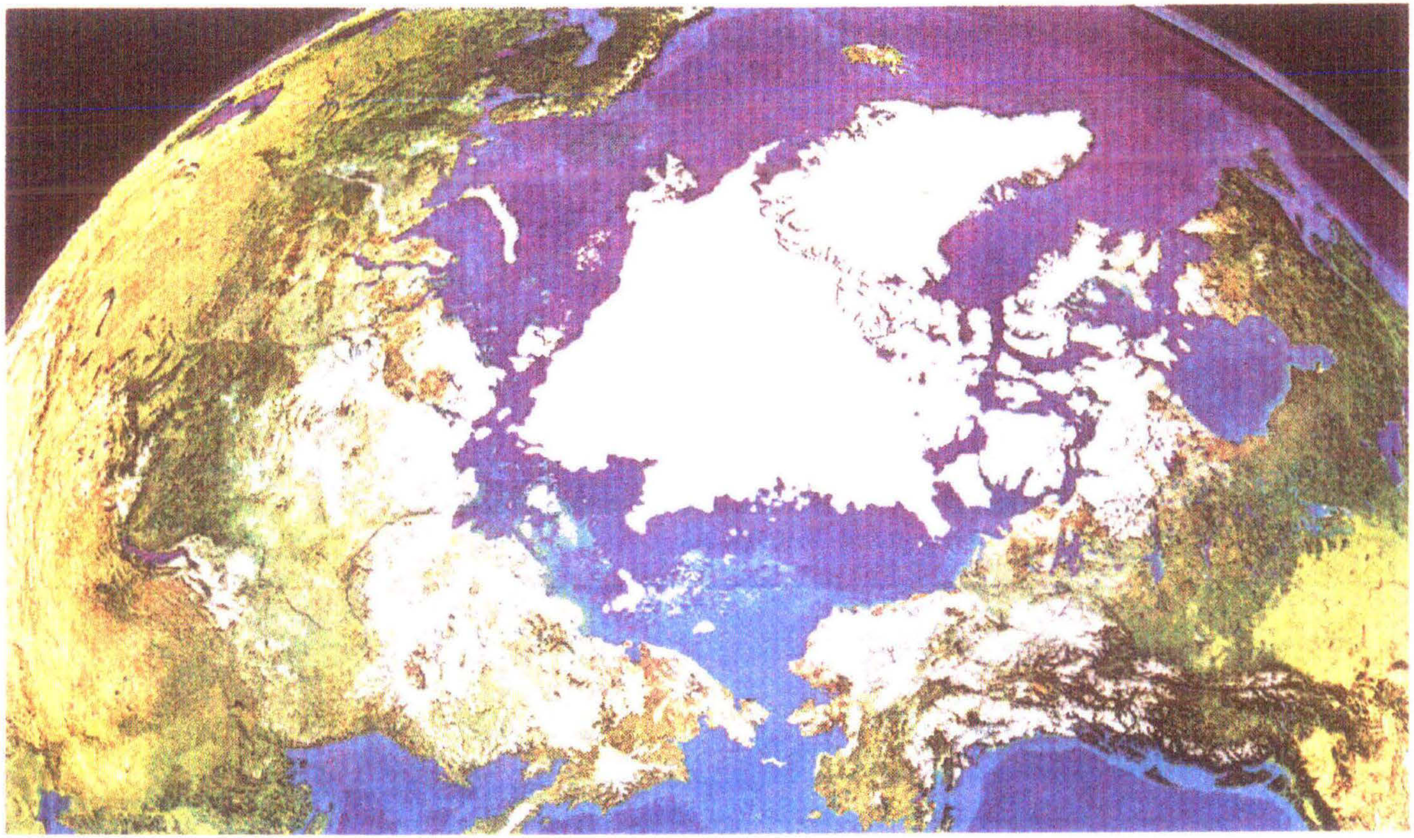
The Theory of Sectors was propounded on 19 February 1907 in the Canadian Parliament by Senator Pascal Poirier. It amounts to affirming that any country through which the Arctic Circle passes has the right to extend its frontiers in the form of a conical triangle whose apex is the North Pole and whose sides are the meridians corresponding to the extreme limits of the land frontiers; this country is exempted from effective occupation in view of the impossibility of implementing this. Formulated at a time when air and submarine navigation, still in their infancy, were not yet able to cover the whole area, and ignorant of the technical possibilities of the submarine exploitation of minerals, and indeed biological resources, the theory of sectors presented a simple, straightforward and seemingly reasonable solution at the time. It was, however, far from being generally accepted, and the countries which invoked or applied it did so neither in particularly clear terms nor using unequivocal procedures.

In conclusion, we can apply above theories apply in the Northwest Passage which spans the North American Arctic region from the Atlantic to the Pacific. Proceeding from west to east and starting in the Chukchi Sea, the passage crosses the Beaufort Sea to the Canadian Arctic Archipelago-M'Clure Strait or Amundsen Gulf, Then through Lancaster Sound or Hudson Strait and finally to the Atlantic Ocean via Baffin Bay, Davis Strait and Labrador Sea. Seven routes have been used for transit of the Northwest Passage. Similarly, with its fleet of polar ice breakers, Russia has been able to use its Northern Sea route for up to six months a year. The earth's climatic change, due to increased emissions of carbon dioxide and other greenhouse gases, has been particularly intense in the Arctic. These changes have already reduced the extent and thickness of sea-ice in both the Arctic Ocean itself and the great circle routes[4] on each side. The commercial navigation will definitely take place in the two Arctic waterways; saving in distance of about 5000 nautical miles from Asia to Europe, avoiding the Panama Canal. Such a long distance in commercial maritime transport is saved because these routes follow the above mentioned ***principle of Great Circle*** through the Arctic Ocean.

[4] Great circle routes : a route between any two points on the earth's surface which is the shortest distance between the two points, and often followed by ships at sea, provided that it does not take them into dangerous waters, and also by aircraft on long-distance flights. A great circle route between two places of the same latitude proceeds north of the parallel of latitude in the northern hemisphere.

# CHAPTER 3

## *The Role of the Ocean in Climate Change: A Scientific Perspective*



**A Photo from Aqua Satellite : Shows that Arctic Sea-ice melted to its second-lowest level in the summer of 2007.**
**Source : NASA**

## CHAPTER-3

# The role of the oceans in climate change: A scientific perspective

Arctic oceanography began with pioneering efforts of Fridtjof Nansen(1861-1930). Nansen's interest in the Arctic began with a voyage to Greenland in 1882. In 1888 he returned to Greenland and with five companions made the first crossing of Greenland's great ice cap ( **Tom Garrision 1995)**. The Swedish scientist Svante Ahrrenius discovered in 1898 the causal link between carbon dioxide and global warming, but it was only recognized as a serious environmental concern, when United Nations Environment Programme and the World Meteorological Organisation established the Intergovernmental Panel on Climate Change (IPCC).

The effect of twentieth-century climate change on global snow and ice cover are apparent in many ways, but the responses differ widely as a result of the different factors and timescales involved. Snow cover is essentially seasonal, related to storm system precipitation and temperature levels. Sea ice is also seasonal in the marginal seas of the Arctic Ocean and around much of the Antarctic continent, but the central Arctic has thick multi-year ice Seasonal (or first-year) ice grows and decays in response to ocean surface temperature, radiation balance, snowfall and ice motion due to winds and currents. The loss of multiyear ice from the Arctic is mainly through ice export. Glacier ice builds up from the net balance of snow accumulation and summer melt (ablation), but glacier flow transports ice towards the terminus, where it may melt or calve into water. In small glaciers, the ice may have a residence time of tens or hundreds of years, but in icecaps and ice sheets this increases to 1000to 10000 years.

In the twentieth century, there has been a rapid retreat of most of the world's glaciers. Glaciers in the North Atlantic area near the North Pole, retreated during the 1920s to the mid-1960s and since 1980, due largely to temperature increases, which have the effect of lengthening the ablation season with a corresponding raising of the snowline. In the past ten or fifteen years the freezing level in the troposphere has risen in the inner tropics by 100 to 150m; contributing to rapid ice loss on equatorial glaciers in East Africa and the northern Andes. Also in the past decade or so, some glaciers in maritime climates (western North America and Scandinavia) have shown advances, due to heavier snowfalls during warmer winters. Major alpine glaciers in many areas of the world have lost mass and shrunk since the late nineteenth century, whereas smaller ones show short-term fluctuations in response to climatic variability. There has been accelerated retreat in some areas since the 1970s, especially in Alaska and central Asia. Projections for 2050 AD suggest that a quarter of the present glacier mass may disappear with critical and irreversible long-term consequences for water resources in alpine countries.

Another tendency illustrating world warming is the retreat of Arctic sea ice. Ports in the Arctic remained free of ice for longer periods during the 1920s to 1950s, for example. This trend was reversed in 1960s to 1970s, but since 1978 the annual extent of Arctic ice has decreased by almost 3 percent per decade with large reductions in summer, particularly in the Eurasian Arctic in 1990, 1993 and 1995, north of Alaska in 1998 and in the central Arctic in 2001. Between the 1960s-70s and early 1990s, ice in the central Arctic Ocean thinned but the magnitude of this is uncertain due to spatial and seasonal sampling limitations. The changes may reflect a redistribution of ice mass by shifts in ocean and wind circulations.

Major iceberg calving events have occurred over the past ten or fifteen years. The causes of such calving are more related to the long history of ice shelves and ice dynamics than to recent climatic trends. However, the disintegration of ice shelves in the Arctic polar region is attributed to regional warming of 2.5° C over the past fifty years.

Snow cover extent shows the clearest indication of a response to recent temperature trends. Northern hemisphere snow cover has been mapped by visible satellite images since 1966. Compared with the1970s to mid-1980s, annual snow cover since 1988 has shrunk by about 10 percent. The decrease is pronounced in spring and is well correlated with spring warming. Winter snow extent shows little or no change. Nevertheless, annual snowfall in North America north of 55"N increased between 1950 and, with a decrease of 70 percent over the Great Plains. In alpine areas, snowlines will rise by 100 to 400m, depending on precipitation.

## 3.1 GLOBAL CLIMATE CHANGE & THE OCEANS:

The industrial revolution ushered in a new phase in the history of mankind. Scientific inquiries have stimulated the development of new technologies, which in turn have been effectively utilized by avid entrepreneurs for large-scale production of goods and services ostensibly to enrich the life of people. In spite of a number of break-downs in the process of economic development, the living standard of the average person, at least those not residing in despotic country, seems to have now reached an unprecedented high level. However, advanced technologies and their large-scale applications, if not properly managed, tend to do intense and irrevocable damage to natural environment.

The nature of the new technologies brought in by the industrial revolution is characterized by the massive consumption of fossil fuels, particularly of coal and oil. Recently, a large number of scientific studies have been made to demonstrate that excess burning of fossil fuels disturbs the atmospheric equilibrium and brings about a global warming of the Earth's surface.

This chapter explains the critical role of oceans in influencing Climate Change and looks at some probable impacts. Oceans store and distribute vast quantities of heat. They also play an important role in the absorption of atmospheric carbon dioxide by both biological and physical processes. Climate Change will probably accelerate existing rates of sea level rise, increasing the risk of coastal flooding. Major international programmes are examining these three effects on a global scale. The World Ocean Circulation Experiment (WOCE) aims to determine fluxes of heat and the way in which circulation of water masses influences the climate system on time-scales from ten to one hundred years. The Joint Global Ocean Flux Study (JGOFS) is investigating on a global the processes controlling the flux of carbon and other biogenetic elements in the oceans. Sea level changes are monitored by the Global Sea Level Network (GLOSS); accelerated rates of rise due to global warming have been forecast by computer models of heat absorption and ocean thermal expansion. In all these investigations a balance between ocean observations, process studies, and numerical modeling is essential for effective progress towards a reliable prediction of future climate variability and trends.

## 3.2 OCEAN CIRCULATION AND HEAT BUDGET:

As the oceans are warmed by solar radiation some of the heat is transmitted to the atmosphere largely as latent energy in evaporation, and some is mixed with the deeper layer. Incoming radiation is much greater in the tropics than at polar latitudes and if there is a locally balanced budget of radiation, the tropics will be substantially warmer than they are today and at higher latitudes (polar regions) it will be much colder. The more equable temperature distribution at present is due to the transport of vast quantities of tropical heat to higher latitude. Some of this heat is transmitted by the atmosphere and some by the oceans. Although the atmosphere transmits heat more rapidly, the much higher thermal capacity of the oceans makes them very effective carriers of heat energy. The transfer of heat pole ward varies from ocean to ocean and with latitude. There are variation with time, from year to year and from season to season. **(Carissimo B. C., Dort A. H., Vander Haar T. H., 1985:82-91).**

The present day seasonal variability in climate points to very sensitive responses to long-term trends in climate. The Intergovernmental Panel on Climate Change suggested that a warming of 1-2°C throughout the year could occur by 2030. Given that ocean temperatures are now very close to the critical threshold of 28°C for organized convection and precipitation, it is likely that substantial changes could occur in monsoon characteristics. **(IIPC-1990: 26)**

World Ocean Circulation Experiment (WOCE) is a major oceanographic contribution to the World Climate Research Programme of International Council of Scientific Union and the World Meteorological Organization. It is designed to study the important climate function of the ocean and to develop ocean models capable of predicting climate changes resulting from both natural and anthropogenic causes. For the purpose of observing changes in climate as a result of increasing greenhouse gases it is convenient to consider a 'fast' and a 'slow' component of climate. **(Needler G.1991: 32)**The fast component includes the atmosphere and the upper ocean acting as a coupled system: the effect of evaporation and clouds on the radiation balance is a particularly important feedback process. Prediction of climate changes, by atmospheric circulation models coupled to shallow ocean models, suggest that for a doubling of atmosphere carbon dioxide, global surface temperature could increase from 2°C to 5°C----more in polar regions than in the tropics. **(Mitchell I. F. B., Manabe S., Tokioka T., Melishko V.;**

***Equilibrium Change in Climate Change: the IIPC Scientific Assessment,*** **Cambridge University Press.)**

The slower component is due to the vast heat capacity of global ocean and its slow response to surface changes. Sinking cold polar water circulates slowly at a depth on a time scale which varies from decades to centuries: global warming may be delayed, for the moment, by the thermal inertia of the oceans. Under WOCE observations are collected to allow the development of full-depth ocean models so that the slow component of the response to changing greenhouse gas concentration can be estimated. In WOCE, the ocean measurements are made at sea and from space.

With respect to the polar regions, the Intergovernmental Panel on Climate Change ( **IPCC, 2001)** stated:

" ***Changes in climate that have already taken place are manifested in the decrease in extent and thickness of Arctic sea ice, permafrost thawing, coastal erosion, changes in ice sheets and ice shelves, and altered distribution and abundance of species in polar regions (high confidence).***

***Climate change in the polar regions is expected to be among the largest and most rapid of any region on the Earth, and will cause major physical, ecological, sociological, and economic impacts, especially in the Arctic, Antarctic Peninsula, and Southern Ocean (high confidence). Polar regions contain important drivers of climate change. Once triggered, they may continue for centuries, long after greenhouse gas concentrations are stabilized ,and cause irreversible impacts on ice sheets, global ocean circulation, and sea-level rise (medium confidence)."***

### 3.3 The Geography of Marine Arctic:

The Arctic Ocean forms the core of the marine Arctic. Its two principal basins, the Eurasian and Canada, are more than 4000 m deep and almost completely landlocked. Traditionally, the open boundary of the Arctic Ocean has been drawn along the Barents Shelf edge from Norway to Svalbard, across Fram Strait, down the western margin of the Canadian Archipelago and across Bering Strait. Including the Canadian polar continental shelf (Canadian Archipelago), the total ocean area is 11.5 million km2, of which 60% is continental shelf. The shelf ranges in width from about 100 km in the Beaufort Sea near Alaska to more than 1000 km in the Barents Sea and the Canadian Archipelago. Representative shelf depths off the coasts of Alaska and Siberia are 50 to 100 m, whereas those in the Barents Sea, East Greenland, and northern Canada are 200 to 500 m. A break in the shelf at Fram Strait provides the only deep (2600 m) connection to the global ocean. Alternate routes to the Atlantic via the Canadian Archipelago and the Barents Sea block flow at depths below 220 m while the connection to the Pacific Ocean via Bering Strait is 45 m deep. About 70% of the Arctic Ocean is ice-covered throughout the year.

Like most oceans, the Arctic is stratified, with deep waters that are denser than surface waters. In a stratified ocean, energy must be provided in order to mix surface and deep waters or to force deep-water flow over obstacles. For this reason, seabed topography is an important influence on ocean processes. The term "marine Arctic" is used here to denote an area that includes Baffin, Hudson, and James Bays; the Labrador, Greenland, Iceland, Norwegian, and Bering Seas; and the Arctic Ocean. This area encompasses 3.5 million km2 of cold, low-salinity surface water and seasonal sea ice that are linked oceanographically to the Arctic Ocean and areas of the Nŏrth Atlantic and North Pacific Oceans that interact with them. In this region, the increase in density with depth is dominated by an increase in salinity as opposed to a decrease in temperature. The isolated areas of the northern marine cryosphere, namely the Okhotsk and Baltic Seas and the Gulf of St. Lawrence, are not included in this chapter's definition of "marine Arctic"

Climatic conditions in northern mid-latitudes influence the Arctic Ocean via marine and fluvial inflows as well as atmospheric exchange. The transport of water, heat, and salt by inflows are important elements of the global climate system. Warm inflows have the potential to melt sea ice provided that mixing processes can move heat to the surface. The dominant impediment to mixing is the vertical gradient in salinity at arctic temperatures. Therefore, the presence of sea ice in the marine Arctic is linked to the salt transport by inflows. Approximately 11% of global river runoff is discharged to the Arctic Ocean, which represents only 5% of global ocean area and 1% of its volume **(Shiklomanov et al., 2000).** In recognition of the dramatic effect of freshwater runoff on arctic surface water, the salt budget is commonly discussed in terms of freshwater, even for marine flows. Freshwater content in the marine context is the fictitious oppifraction of freshwater that dilutes seawater of standard salinity (e.g., 35) to create the salinity actually observed. For consistency with published literature, this chapter uses the convention of placing "freshwater" in quotes to distinguish the freshwater component of ocean water from the more conventional definition of freshwater.

The Arctic is clearly a shortcut for flow between the Pacific and Atlantic Oceans. A flow of 800000 m3/s (0.8 Sv) follows this shortcut to the Atlantic via Bering Strait, the channels of the Canadian Archipelago, and Fram Strait **(Melling, 2000)**.The flow is driven by higher sea level (~0.5 m) in the North Pacific **(Stigebrandt, 1984)**.The difference in elevation reflects the lower average salinity of the North Pacific, maintained by an excess of precipitation over evaporation relative to the North Atlantic **(Wijffels et al., 1992).** By returning excess precipitation to the Atlantic, the flow through the Arctic redresses a global-scale hydrologic imbalance created by present-day climate conditions. By transporting heat into the Arctic Ocean at depths less than 100 m, the flow influences the thickness of sea ice in the Canada Basin **(Macdonald R. et al., 2002**).

Much of the elevation change between the Pacific and the Atlantic occurs in Bering Strait. Operating like a weir in a stream, at its present depth and width the strait hydraulically limits flow to about 1 Sv **(Overland and Roach, 1987).** Bering Strait is therefore a control point in the global hydrological cycle, which will allow more through-flow only with an increase in sea level. Similar hydraulic controls may operate with about 0.2 m of hydraulic head at flow constrictions within the Canadian Archipelago. The present "freshwater" flux through Bering Strait is about 0.07 Sv **(Aagaard and Carmack, 1989; Fedorova and Yankina, 1964).**

The Bering inflow of "freshwater" destined for the Atlantic is augmented from other sources, namely rivers draining into the Arctic Ocean, precipitation over ocean areas, and sea ice. The total influx to the marine Arctic from rivers is 0.18 Sv **(Shiklomanov et al., 2000)**, about 2.5 times the "freshwater" flux of the Pacific inflow through Bering Strait. This estimate includes runoff from Greenland, the Canadian Archipelago, and the water-sheds of the Yukon River (carried through Bering Strait by the Alaskan Coastal Current), Hudson Bay, and James Bay. The average annual precipitation minus evaporation north of 60° N is 0.16 m/yr **(Barry and Serreze, 2000)**, corresponding to a freshwater flux of 0.049 Sv over marine areas. The combined rate of freshwater supply to the marine Arctic is 0.3 Sv.

Sea ice has a high "freshwater" content, since it loses 80% of its salt upon freezing and all but about 3% through subsequent thermal weathering. Although about 10% of sea-ice area is exported annually from the Arctic Ocean through Fram Strait, this is not a "freshwater" export from the marine Arctic, since the boundary is defined as the edge of sea ice at its maximum extent.

Freezing segregates the upper ocean into brackish surface (ice) and salty deeper components that circulate differently within the marine Arctic. The melting of sea ice delivers freshwater to the surface of the ocean near the boundary of the marine Arctic. The flux of sea ice southward through Fram Strait is known to be about 0.09 Sv **(Vinje, 2001)**, but the southward flux of seasonal sea ice formed outside the Arctic Ocean in the Barents, Bering, and Labrador Seas; the Canadian Archipelago; Hudson and Baffin Bays; and East Greenland is not known.

The inflows to the marine Arctic maintain a large reservoir of "freshwater" (i.e., diluted seawater and brackish sea ice). Aagaard and Carmack (1989) estimated the volume of "freshwater" stored within the Arctic Ocean to be 80000 km3. A rough estimate suggests that there is an additional reservoir of approximately 50000 km3 in the marginal seas described in the previous paragraph. The total reservoir of "freshwater" equals the accumulation of inflow over about 15 years. The "freshwater" reservoir feeds two boundary currents that flow into the western North Atlantic – the East Greenland Current and the Labrador Current **(Aagaard and**

**Coachman, 1968).**The former enters the Greenland Sea via Fram Strait and the latter enters the Labrador Sea via Davis Strait, gathering a contribution from Hudson Bay via Hudson Strait.

Northbound streams of warm saline water, the Norwegian Atlantic Current and the West Greenland Current, counter the flow of low-salinity water toward the Atlantic. The Norwegian Atlantic Current branches into the West Spitzbergen Current and the Barents Sea through-flow. The former passes through Fram Strait with a temperature near 3 °C and follows the continental slope eastward at depths of 200 to 800 m as the Fram Strait Branch **(Gorshkov, 1980).**The latter, cooled to less than 0 °C and freshened by arctic surface waters, enters the Arctic Ocean at depths of 800 to 1500 m in the eastern Barents Sea **(Schauer et al., 2002).**The West Greenland Current carries 3 °C seawater to northern Baffin Bay, where it mixes with arctic outflow and joins the south-flowing Baffin Current **(Melling et al., 2001).**The inflows via the West Spitzbergen Current and Barents Sea through-flow are each about 1 to 2 Sv. The West Greenland Current transports less than 0.5 Sv. The associated fluxes of "freshwater" are small because salinity is close to 35. All fluxes vary appreciably from year to year.

The Fram Strait and Barents Sea branches are important marine sources of heat and the most significant sources of salt for arctic waters subjected to continuous dilution. The heat loss to the atmosphere in the ice-free northeastern Greenland Sea averages 200 W/m2 **(Khrol, 1992).**The average heat loss from the Arctic Ocean is 6W/m2 of which 2 W/m2 comes from the Atlantic derived water. The impact of the incoming oceanic heat on sea ice is spatially non-uniform because the upper ocean stability varies with the distribution of freshwater storage and ice cover.

### 3.4 The Dynamics of Arctic Ocean

The two branches of Atlantic inflow interleave at depths of 200 to 2000 m in the Arctic Ocean because of their high salinity, which makes them denser than surface waters despite their higher temperature. They circulate counter-clockwise around the basin in narrow (50 km) streams confined to the continental slope by the Coriolis Effect. The streams split where the slope meets mid-ocean ridges, creating branches that circulate counter-clockwise around the subbasins **(Rudels et al., 1994)**. The delivery of new Atlantic water to the interior of basins is slow (i.e., decades).

The boundary currents eventually return cooler, fresher, denser water to the North Atlantic via Fram Strait (Greenland side) and the Nordic Seas. The circuit time varies with routing. The role of arctic outflow in deep convection within the Greenland Sea and in the global thermohaline circulation is discussed in section 9.2.3. In the present climate, Atlantic-derived waters in the Arctic Ocean occur at depths too great to pass through the Canadian Archipelago.

Inflow from the North Pacific is less saline and circulates at a shallower depth than Atlantic inflow. It spreads north from Bering Strait to dominate the upper ocean of the western Arctic – the Chukchi and Beaufort Seas, Canada Basin, and the Canadian Archipelago. An oceanic front presently located over the Alpha-Mendeleyev Ridge in Canada Basin separates the region of Pacific dominance from an "Atlantic domain" in the eastern hemisphere. A dramatic shift of this front from the Lomonosov Ridge in the early 1990s flooded a wide area of former Pacific dominance with warmer and less stratified Atlantic water **(Carmack et al., 1995)**.

The interplay of Atlantic and Pacific influence in the Arctic Ocean, the inflows of freshwater, and the seasonal cycle of freezing and melting create a layered structure in the Arctic Ocean **(Treshnikov, 1959)**.These layers, from top to bottom, include snow; sea ice; surface sea water strongly diluted by precipitation, river discharge, and ice melt; warm summer intrusions from ice-free seas (principally the Bering Sea); cold winter intrusions from freezing seas; cool winter intrusions from ice-free seas (principally the Barents Sea); warm intrusions of the Fram Strait Branch; cool intrusions of the Barents Sea Branch; recently-formed deep waters; and relict deep waters. The presence and properties of each layer vary with location across the Arctic Ocean.

The cold and cool winter intrusions form the arctic cold halocline, an approximately isothermal zone wherein salinity increases with depth. The halocline insulates sea ice from warm deeper water because its density gradient inhibits mixing, and its weak temperature gradient minimizes the upward flux of heat. The cold halocline is a determining factor in the existence of year-round sea ice in the present climate. Areas of seasonal sea ice either lack a cold halocline (e.g., Baffin Bay, Labrador Shelf, Hudson Bay) or experience an intrusion of warm water in summer that overrides it (e.g., Chukchi Sea, coastal Beaufort Sea, eastern Canadian Archipelago).The stability of the cold halocline is determined by freshwater dynamics in the Arctic and its low temperature is maintained by cooling and ice formation in recurrent coastal polynyas. Polynyas are regions within heavy winter sea ice where the ice is thinner because the oceanic heat flux is locally intense or because existing ice is carried away by wind or currents. The locations and effectiveness of these *"ice factories"* are functions of present-day wind patterns **(Winsor and Björk, 2000).**

## 3.5 SNOW AND ICE COVER OVER THE ARCTIC OCEAN:

Sea ice is the defining characteristic of the marine Arctic. It is the primary method through which the Arctic exerts leverage on global climate, by mediating the exchange of radiation, sensible heat, and momentum between the atmosphere and the ocean. Changes to sea ice as a unique biological habitat are in the forefront of climate change impacts in the marine Arctic.

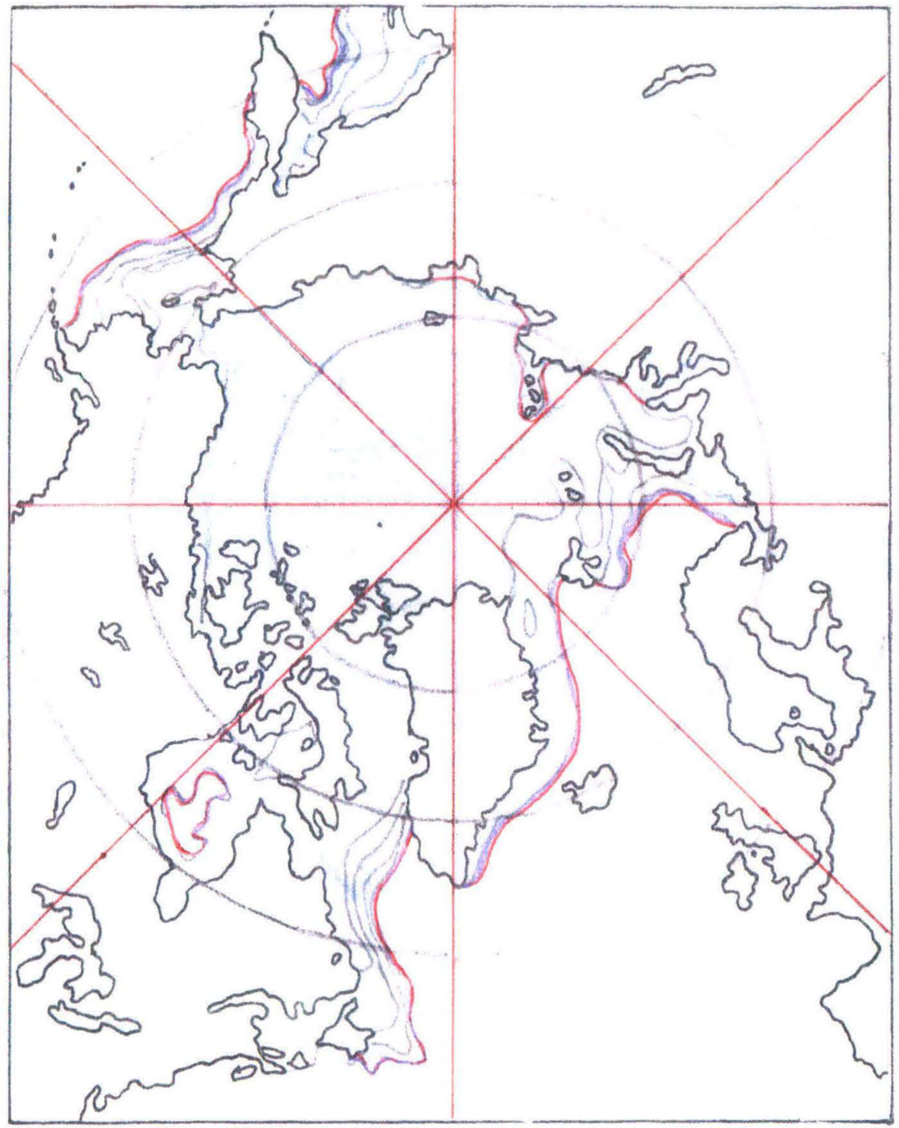
The two primary forms of sea ice are seasonal (or firstyear) ice and perennial (or multi-year) ice. Seasonal or first-year ice is in its first winter of growth or first summer of melt. Its thickness in level floes ranges from a few tenths of a meter near the southern margin of the marine cryosphere to 2.5 m in the high Arctic at the end of winter. Some first-year ice survives the summer and becomes multi-year ice. This ice develops its distinctive hummocky appearance through thermal weathering, becoming harder and almost salt-free over several years. In the present climate, old multi-year ice floes without ridges are about 3 m thick at the end of winter.

The area of sea ice decreases from roughly 15 million km2 in March to 7 million km2 in September, as much of the first-year ice melts during the summer. The area of multi-year sea ice, mostly over the Arctic Ocean basins, the East Siberian Sea, and the Canadian polar shelf, is about 5 million km2. The Nansen Environmental and Remote Sensing Centre in Norway found a 4.6 percent decline in ice extent and a 5.8 percent decline in actual ice area between 1978 and 1994.**(Johannessen O. M., E. Bjorgo, and M.W. Miles, 1996:129)** Tentative results suggest that this decline accelerated between 1987 and 1994. **(Johannessen,O. M. et.al.,1995:126-7).** A transpolar drift carries sea ice from the Siberian shelves to the Barents Sea and Fram Strait. It merges on its eastern side with clockwise circulation of sea ice within Canada Basin. On average, 10% of arctic sea ice exits through Fram Strait each year. Section 6.3 provides a full discussion of sea ice in the Arctic Ocean. The Sea ice also leaves the Arctic via the Canadian Archipelago. Joined by seasonal sea ice in Baffin Bay, it Seas, where northern regions of growth export ice to temperate waters.

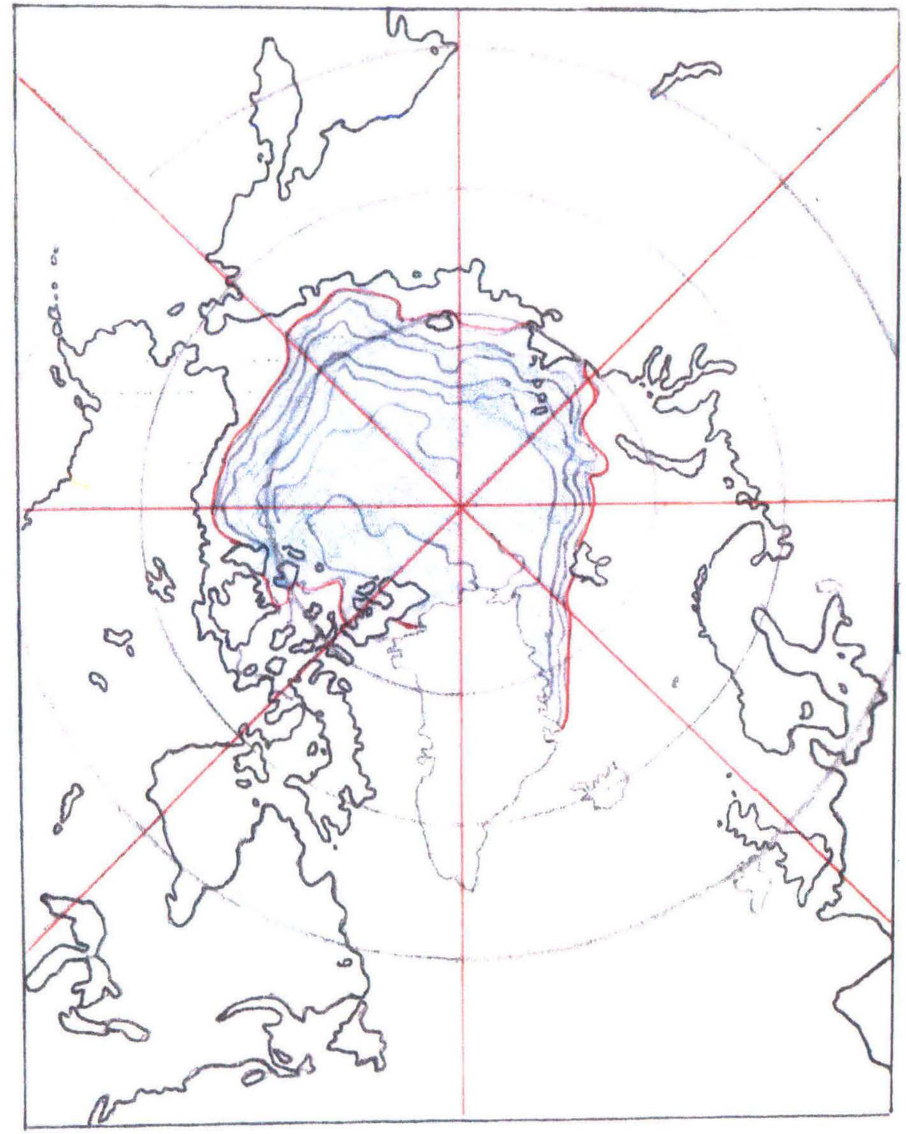
First-year floes fracture easily under the forces generated by storm winds. Leads form where ice floes separate under tension, exposing new ocean surface to rapid freezing. Where the pack is compressed, the floes buckle and break into blocks that pile into ridges up to 30 m thick. Near open water, notably in the Labrador, Greenland, and Barents Seas, waves are an additional cause of ridging. Because of ridging and rafting, the average thickness of first-year sea ice is typically twice that achievable by freezing processes alone **(Melling and Riedel, 1996).** Heavily deformed multi-year floes near the Canadian Archipelago can average more than 10 m thick.

Information on the thickness of northern sea ice is scarce. Weekly records of land-fast ice thickness obtained from drilling are available for coastal locations around the Arctic (Canada and Russia) for the 1940s through the present **(Melling, 2002; Polyakov et al., 2003)**.Within the Arctic Ocean, there have been occasional surveys of sea ice since 1958, measured with sonar on nuclear submarines. In Fram Strait and the Beaufort Sea, data have been acquired continuously since 1990 from sonar operated from moorings. The average thickness of sea ice in the Arctic Ocean is about 3 m, and the thickest ice (about 6 m) is found along the shores of northern Canada and Greenland. There is little information about the thickness of the seasonal sea ice that covers more than half the marine Arctic.

Land-fast ice (or fast ice) is immobilized for up to 10 months each year by coastal geometry or by grounded ice ridges. There are a few hundred meters of land-fast ice along all arctic coastlines in winter. In the present climate, ice ridges ground to form ice ridge in depths of up to 30 m, as the pack ice is repeatedly crushed against the fast ice by storm winds. In many areas, ice ridge stabilize sea ice for tens of kilometers from shore. Within the Canadian



(a) March



(b) September

Fig. No.3 Mean Sea-ice Concentration (1990-1999)
Source : SSM/1 data C. Parkinson

Archipelago in late winter, land-fast ice bridges channels up to 200 km wide and covers an area of 1 million km2. Some of this ice is trapped for decades as multi-year land-fast ice. The remobilization of land-fast ice in summer is poorly understood. Deterioration through melting, flooding by runoff at the coast, winds, and tides are contributing factors.

Many potential impacts of climate change will be mediated through land-fast ice. It protects unstable coastlines and coastal communities from wave damage, flooding by surges, and ice ride-up. It offers safe, fast routes for travel and hunting. It creates unique and necessary habitat for northern species and brackish under-ice migration corridors for fish. It blocks channels, facilitating the formation of polynyas important to northern ecosystems in some areas, and impeding navigation in others (e.g., the Northwest Passage). drifts south along the Labrador coast to reach Newfoundland in March. An ice edge is established in this location where the supply of sea ice from the north balances the loss by melt in warm ocean waters. Sea-ice production in the source region in winter is enhanced within a polynya (the North Water) formed by the persistent southward drift of ice. Similar "conveyor belt" sea-ice regimes also exist in the Barents and Bering. The Great Ocean Conveyor appears to have operated fairly reliably over the past several thousand years. **(Weaver, Andrew J., 1995:135-136 & Rahmstorf, Stefan, 1995:145-149).**However, an examination of ice cores from both Greenland and Antarctica shows that this has not always been the case in the more distant past, and abrupt climatic changes associated with large amounts of sea ice in the North Atlantic and rapid changes in thermohaline circulation may have occurred repeatedly in the past. **(Wallace S. Broecker, 1997: 1582-1588)**

### 3.5.1 Changes in snow, ice, and permafrost

Recent observational data present a generally consistent picture of cryospheric variations that are shaped by patterns of recent warming and variations in atmospheric circulation. Consistent with the overall increase in global temperatures, arctic snow and ice features have diminished in extent and volume. While the various cryospheric and atmospheric changes are consistent in an aggregate sense and are quite large in some cases, it is possible that natural, low frequency variations in the atmosphere and ocean have played at least some role in forcing the cryospheric and hydrological trends of the past few decades.

Model projections of anthropogenic climate change indicate a continuation of the recent trends through the 21st century, although the rates of the projected changes vary widely due to differences in model representations of feedback processes. Models project a 21stcentury decrease in sea-ice extent of up to 100% in summer; a widespread decrease in snow-cover extent, particularly in spring and autumn; and permafrost degradation over 10 to 20% of the present permafrost area and a movement of the permafrost boundary northward by several hundred kilometers. The models also project river discharge increases of 5 to 25%; earlier breakup and later freeze-up of rivers and lakes; and a sea-level rise of several tens of centimeters resulting from glacier melting and thermal expansion, which is amplified or reduced in some areas due to long-term land subsidence or uplift.

### *3.5.1.a Snow cover*

Recent trends in the 21$^{st}$ century for the arctic cryosphere shows that the snow-cover extent in the Northern Hemisphere has decreased by 5 to 10% since 1972. Snow-cover extent is projected to decrease by about 13% by 2071–2090 under the projected increase in mean annual temperature of about 4 °C. The projected reduction is greater in spring. Owing to warmer conditions, some winter precipitation in the form of rain is likely to increase the probability of ice layers over terrestrial vegetation.

### *3.5.1.b Glaciers*

Glaciers throughout the Northern Hemisphere have shrunk dramatically over the past few decades, contributing about 0.15 to 0.30 mm/yr to the average rate of sea-level rise in the 1990s.The loss of glacial mass through melting is very likely to accelerate throughout the Arctic, with the Greenland Ice Sheet also starting to melt. These changes will tend to increase the rate of sea-level rise.

*3.5.1.c Permafrost*

Permafrost[5] temperatures in most of the Arctic and subarctic have increased by several tenths of a degree to as much as 2 to 3 °C (depending on location) since the early 1970s. Permafrost thawing has accompanied the warming. Over the 21st century, permafrost degradation is likely to occur over 10 to 20% of the present permafrost area, and the southern limit of permafrost is likely to move northward by several hundred kilometers.

*3.5.1.d Sea ice*

Summer sea-ice extent decreased by about 7% per decade between 1972 and 2002, and by 9% per decade between 1979 and 2002, reaching record low levels in 2002.The extent of multi-year sea ice has also decreased, and ice thickness in the Arctic Basin has decreased by up to 40% since the 1950s and 1960s due to climate-related and other factors. Sea-ice extent is very likely to continue to decrease, particularly in summer. Model projections of summer sea-ice extent range from a loss of several percent to complete loss. As a result, the navigation season is projected to be extended by several months.

### 3.6 Arctic atmosphere

The arctic atmosphere is highly influenced by the overall hemispheric circulation, and should be regarded in this general context. This chapter we examine Northern Hemisphere circulation using the National Centers for Environmental Prediction/National Center for Atmospheric Research reanalyzes for the period from 1952 to 2003. Because much of the observed change in the Arctic appears to be related to patterns of atmospheric circulation, it is important that these modes of atmospheric variability be described.

Atmospheric circulation and weather are closely linked to surface pressure. The Northern Hemisphere seasonal mean patterns of sea-level pressure in winter include the oceanic Aleutian and Icelandic Lows, and the continental Siberian High with its extension into the Arctic (the Beaufort High).The sea-level pressure distribution in summer is dominated by subtropical highs in the eastern

[5] **Permafrost: Ground that is permanently frozen, occurring extensively in polar-regions, sometimes, as in Siberia, to a depth as great as 600m. A shallow layer of soil may thaw during the summer, while the ground below remains frozen; the contraction and expansion caused by the seasonal thawing and freezing there seriously complicates the construction of roads, buildings etc.**

Pacific and Atlantic Oceans, with relatively weak gradients in polar and sub-polar regions. The seasonal cycle of sea-level pressure over the mid-latitude oceans exhibits a summer maximum and winter minimum. By contrast, the seasonal cycle of sea-level pressure over the Arctic and subarctic exhibits a maximum in late spring, a minimum in winter, and a weak secondary maximum in late autumn. The climatological patterns and seasonal cycle of sea level pressure are largely determined by the regular passage of migratory cyclones and anticyclones, which are associated with storminess and settled periods, respectively. Areas of significant winter cyclonic activity (storm tracks) are found in the North Pacific and North Atlantic. These disturbances carry heat, momentum, and moisture into the Arctic, and have a significant influence on high-latitude climate.

The Arctic is affected by extremes of solar radiation. The amount of solar radiation received in summer is relatively high due to long periods of daylight, but its absorption is kept low by the high albedo of snow and ice. The amount of solar radiation received in winter is low to non-existent. The Arctic is obviously a very cold region of the Northern Hemisphere, especially in winter when the seasonal mean temperature falls well below -20 °C. Temperature inversions, when warm air overlies a cold surface, are common in the Arctic. At night, especially on calm and clear nights, the ground cools more rapidly than the adjacent air because the ground is a much better emitter of infrared radiation than the air. The arctic winter is dominated by temperature inversions, due to the long nights and extensive infrared radiation losses. Arctic summers have fewer and weaker temperature inversions. On the hemispheric scale, there exist large north–south gradients of atmospheric temperature and moisture. In winter, the continental landmasses are generally colder than the adjacent oceanic waters, owing to the influence of warm surface currents on the western boundaries of the Atlantic and Pacific Oceans.

### 3.6.1 Arctic/North Atlantic Oscillation

The North Atlantic Oscillation (NAO) has long been recognized as a major mode of atmospheric variability over the extratropical ocean between North America and Europe. The NAO describes co-variability in sea level pressure between the Icelandic Low and the Azores High. When both are strong -higher than normal pressure in the Azores High and lower than normal pressure in the Icelandic Low, the NAO index is positive. When both are weak, the index is negative. The NAO is hence also a measure of the meridional gradient in sea-level pressure over the North Atlantic, and the strength of the westerlies in the intervening mid-latitudes. The NAO is most obvious during winter but can be identified at any time of the year. As the 20th century drew to a close, a series of papers were published arguing that the NAO should be considered as a regional manifestation of a more basic annular mode of sea-level pressure variability, which has come to be known as the Arctic Oscillation (AO).The AO is defined as the leading mode of variability from a linear principal component analysis of Northern Hemisphere sea-level pressure. It emerges as a robust pattern dominating both the intra-seasonal (e.g., month-to-month) and inter-annual variability in sea-level pressure.

There is considerable month-to-month and year-to-year variability, as well as variability on longer timescales. The AO/NAO index was at its most negative in the 1960s. From about 1970 to the early 1990s, there was a general increasing trend, and the AO index was more positive than negative throughout the 1990s.The physical origins of these long term changes are the subject of considerable debate. A recent study has suggested that increased concentration of greenhouse gases in the atmosphere, in addition to warming the lower atmosphere, will prevent heat from rising into the upper atmosphere. In particular, lower stratospheric temperatures over the Arctic will accelerate ozone depletion and delay any recovery. ( **Shindell D,T., D. Rind, and P. Lonergan, 1998, Nature 392:589-592** )

Increased rates of spring ultraviolet radiation may have significant impacts on Arctic ice-dependent micro-organisms. Fyfe et al. (1999) and Shindell et al. (1999) have shown that positive AO trends can be obtained from global climate models using scenarios of increasing radiative forcing due to rising GHG concentrations. Rodwell et al. (1999) and Hoerling et al. (2001) have shown similar positive trends using global climate models run with fixed radiative forcing and observed annually varying sea surface temperatures. Rodwell et al. (1999) argued that slowly varying sea surface temperatures in the North Atlantic are locally communicated to the atmosphere through evaporation, precipitation, and atmospheric heating processes. On the other hand, Hoerling et al. (2001) suggested that changes in tropical sea surface temperatures, especially in the Indian and Pacific Oceans, may be more important than changes in sea surface temperatures in the North Atlantic. They postulated that changes in the tropical ocean alter the pattern and magnitude of tropical rainfall and atmospheric heating, which in turn produce positive AO/NAO trends. Regardless of the causes, it must be noted that AO/NAO trends do not necessarily reflect a change in the variability mode itself. As demonstrated by Fyfe (2003), the

AO/NAO trends are a reflection of a more general change in the background, or "mean", state with respect to which the modes are defined. The sea-level pressure anomaly pattern associated with the AO/NAO time series, as derived from a principal components analysis. The pattern shows negative anomalies over the polar and sub-polar latitudes, and positive anomalies over the mid-latitudes. The anomaly center in the North Atlantic, while strongest in the vicinity of the Icelandic Low, extends with strength well into the Arctic Basin. Not surprisingly, these anomalies are directly related to fluctuations in cyclone frequency.

The summer and fall of 1990 may be an example of future conditions. Strong winds in May carried unusually warm air masses from Siberia out over the Arctic Ocean. Continued warmth in June promoted early breakup and consistent winds in July pushed ice away from the Siberian coast and towards the North Pole. By August, ice cover was 21 percent below normal. The low ice conditions persisted into September, which was 19 percent below normal. Almost all of this reduction occurred in the East Siberian Sea, with lesser reductions occurring in the adjacent Chukchi and Laptev seas. **(Mark C. Serreze, James A. Maslanik, Jeffrey R. Key, and Raymond F. Kokaly, 1995: 2183-2186).** Serreze et al. (1997) noted a strong poleward shift in cyclone activity during the positive phase of the AO/NAO, and an equatorward shift during the negative phase. In the region corresponding to the climatological center of the Icelandic Low, cyclone events are more than twice as common during the positive AO/NAO extremes than during negative extremes. Systems found in this region during the positive phase are also significantly deeper than are their negative AO/NAO counterparts. McCabe et al. (2001) noted a general poleward shift in Northern Hemisphere cyclone activity starting around 1989, coincident with the positive trend in the AO/NAO time series. The pattern of surface air temperature anomalies associated with the AO/NAO time series anomalies centered in Davis Strait are consistent with southeasterly advection of cold arctic air by the AO/NAO-related winds. Easterly advection of warmer air, also linked to AO/NAO-related winds, accounts for the pattern of positive anomalies in surface air temperature over Eurasia.

### 3.6.2 Pacific Decadal Oscillation

The Pacific Decadal Oscillation (PDO) is a major mode of North Pacific climate variability. The PDO is obtained as the leading mode of North Pacific monthly surface temperature. As with the AO/NAO time series, the PDO time series displays considerable month-to-month and year-to-year variability, as well as variability on longer timescales. The PDO was in a negative (cool) phase from 1947 to 1976, while a positive (warm) phase prevailed from 1977 to the mid-1990s. Major changes in northeast Pacific marine ecosystems have been correlated with these PDO phase changes. As with the AO/NAO, the physical origins of these long-term changes are currently unknown.

The sea-level pressure and surface air temperature anomalies associated with the PDO time series, as derived from a principal components analysis. The sea-level pressure anomaly pattern is wave-like, with low sea-level pressure anomalies over the North Pacific and high sea-level pressure anomalies over western North America. At the same time, the surface air temperatures tend to be anomalously cool in the central North Pacific and anomalously warm along the west coast of North America. The PDO circulation anomalies extend well into the troposphere in a form similar to the Pacific North America pattern -another mode of atmospheric variability.

## 3.7 Carbon storage and carbon cycling

### 3.7.1 *Global importance of carbon in the Arctic*

The Arctic contains large stores of carbon that have historically been sequestered from the atmospheric carbon pool. Estimates of arctic and boreal soil carbon (C) in the upper meter of soil vary considerably, ranging from 90 to 290 Pg C in upland boreal forest soils, 120 to 460 Pg C in peatland soils, and 60 to 190 Pg C in arctic tundra soils. There is also a general sparsity of high-latitude carbon data for aquatic ecosystems relative to arctic terrestrial systems, but some estimates from boreal lakes indicate that reserves can be significant (120 Pg C). An additional 450 Pg of organic C is stored as dissolved carbon in the Arctic Ocean. Estimates of carbon stored in the upper 100 meters of permafrost are as high as 10 000 Pg C. In any case, the carbon stored in northern boreal forests, lakes, tundra, the Arctic Ocean, and permafrost is considerably greater than the *global* atmospheric pool of carbon, which is estimated at 730 Pg C (IPCC, 2001). In addition, up to 10 000 Pg C in the form of CH4 and CO2 is stored as hydrates in marine permafrost below 100 m, however, this figure is a maximum of estimates that span several orders of magnitude.(**Semiletov, I.P.,1999 in Journal of Atmospheric Sciences, 56(2):286–306.)**

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | **Carbon Dioxide Emissions** | | | | | **Energy use per capita** | | | |
| | | *(metric tons per capita)* | | | | | *(kg oli equivalent)* | | | |
| | | ***1990*** | ***2000*** | ***2005*** | | | ***1990*** | ***2000*** | ***2005*** | |
| | *WORLD* | | | | | | | | | |
| | | | | | | | | | | |
| **Low income economies** | | 0.8 | 0.8 | 0.8 | | | 464 | 485 | 513 | |
| with a GNI(Gross National Income) | | | | | | | | | | |
| per capita of $875 or less in 2005 | | | | | | | | | | |
| | | | | | | | | | | |
| **Low & middle income** | | 2.4 | 2.1 | 2.4 | | | 1,008 | 944 | 1,068 | |
| **economies** | | | | | | | | | | |
| with GNI per capita | | | | | | | | | | |
| of$ 1,753 in 2005 | | | | | | | | | | |
| | | | | | | | | | | |
| **Lower middle income** | | 2.4 | 2.3 | 2.9 | | | 953 | 947 | 1,175 | |
| **economies** | | | | | | | | | | |
| with GNI per capita | | | | | | | | | | |
| of $ 1,923 in 2005 | | | | | | | | | | |
| | | | | | | | | | | |
| **Middle income economies** | | 3.5 | 3.1 | 3.6 | | | 1,349 | 1,249 | 1,451 | |
| with a GNI per capita of | | | | | | | | | | |
| $3,465 | | | | | | | | | | |
| | | | | | | | | | | |
| **Upper middle income** | | 8.1 | 6.3 | 6.4 | | | 2,980 | 2,474 | 2,583 | |
| **economies** | | | | | | | | | | |
| with GNI per capita | | | | | | | | | | |
| of $ 5,634 in 2005 | | | | | | | | | | |
| | | | | | | | | | | |
| | * Source: *World Developme* | | IBRD/ THE WORLD BANK 1818 H STREET,N.W. Washington, D. C. 20433 U.S.A. | | | | | | | |

TABLE No.1 CARBON DIOXIDE EMISSIONS & ENERGY USE PER CAPITA

Within the Arctic, carbon storage generally decreases from south to north. On land, this represents parallel decreases from boreal forest to tundra to polar desert and from southern isolated, sporadic, and discontinuous permafrost to continuous permafrost in the north; in freshwater ecosystems there is a decrease from peatlands and lakes with high concentrations of dissolved organic carbon to tundra and high-arctic ponds with low dissolved organic carbon; and in the marine environment there is a decrease from areas of high organic matter production and sedimentation in the south and at the ice margin to relatively clear waters in the Arctic Ocean. Marine permafrost and gas hydrates show a different pattern in that they are concentrated in the area of continental shelves, which are particularly extensive along the northern coastlines of the arctic landmasses.

### 3.7.2 Processes involved in carbon storage and release

Over thousands of years, an imbalance between photosynthesis and decomposition has led to storage of carbon in lake and ocean sediments, and in forest and tundra soils. On land, this imbalance was created because low temperatures, particularly when combined with high soil moisture, retarded microbial decomposition more than photosynthesis. In the marine environment, atmospheric carbon is dissolved as inorganic carbon in surface waters and stored at depth as a result of the physical pump; death and decomposition of organisms also lead to carbon storage in the form of dissolved and particulate organic carbon. Low ocean temperatures have resulted in high solubility of carbon, while extensive sea-ice cover has reduced the duration and area for carbon exchange between air and surface waters and thus photosynthesis.

Because low temperatures have been so important for the capture and storage of atmospheric carbon in the Arctic, projected temperature increases have the potential to lead to the release of old and more recently captured carbon to the atmosphere, although the older the stored carbon, the less responsive it will be to projected climate changes. The release of stored carbon will increase atmospheric GHG concentrations and provide a positive feedback to the climate system. However, increased temperatures are also likely to increase the photosynthetic capture of atmospheric carbon if other environmental conditions do not become limiting. On land, plants will grow faster and more productive vegetation will successively replace less productive vegetation at higher latitudes and altitudes. In freshwater ecosystems, reduced duration of ice cover over lakes and ponds and increased temperatures are likely to increase primary production. In the marine environment, primary production is expected to increase as areas where production has been limited by sea-ice cover become more restricted in extent. Also, it is likely that more carbon will be buried as deposition shifts from the continental shelves where primary production is currently concentrated to the deeper slope and basin region as the ice edge retreats.

The balance between the opposing processes of increased carbon capture and release will determine future changes in the carbon feedback from the Arctic to global climate. However, there are great uncertainties in calculating this balance across permafrost, terrestrial soil, ocean, and freshwater systems and no quantitative integrative assessment has been performed to date.

### 3.7.3 Changes in carbon storage and release to the atmosphere

There is a consensus from the trace-gas measurement researchers that the terrestrial Arctic is presently a source of carbon and radiative forcing, but is likely to become a weak sink of carbon during future warming. Modeling approaches suggest that circumpolar mean carbon uptake is likely to increase from the current 12 g C/m2/yr to 22 g C/m2/yr by 2100 and that carbon storage is likely to increase by 12 to 31 Pg C. However, the uncertainties are great: the projections are limited to terrestrial ecosystems and do not include carbon stored in permafrost and gas hydrates. Potential increases in human and natural disturbances are further uncertainties. The marine environment has been suggested as a weak sink, but the amount of carbon that the Arctic Ocean can sequester is likely to increase significantly under scenarios of decreased sea-ice cover, both through surface uptake and increased biological production, although there may be an abrupt release of CO2 and CH4 from thawing permafrost in marine sediments.

In the marine environment, there are vast stores of CH4 and CO2 (at least 10 000 Pg C in the form of gas hydrates in marine permafrost below 100 m (**Semiletov, I.P., 1999:** 286–306). As there are currently about 4 Pg C in CH4 in the atmosphere, even the release of a small percentage of CH4 from gas hydrates could result in an abrupt and significant climate forcing. The process of CH4 release from gas hydrates under continental shelves could already be occurring due to the warming of earlier coastal landmasses during Holocene flooding. On land, however, natural gas hydrates are found only at depths of several hundreds of meters and are relatively inert.

### 3.7.4 The future of climate change :

The annual temperatures show a fairly uniform warming of 2 to 4 °C throughout the Arctic by the end of the century, with a slightly higher warming of up to 5 °C in the East Siberian Sea. Summer temperatures are projected to increase by 1 to 2 °C over land, with little change in the central Arctic Ocean, where sea ice melts each summer, keeping the ocean temperature close to 0 °C **(Nakicenovie, N. and Swart, 2000).** Winter temperatures show the greatest warming: about 5 °C over land, and up to 8 to 9 °C in the central Arctic Ocean, where the feedback due to reduced sea-ice extent is largest.

Changes in the Arctic affect the global system in several ways. Global climate change is influenced by feedback processes operating in the Arctic; these also amplify climate change in the Arctic itself. Apart from the well known and often quoted ice- and snow-albedo feedback, another important arctic feedback is the thawing of permafrost, which is likely to lead to additional GHG releases. Arctic cloud feedbacks are also important but are still poorly understood. Some of these arctic feedbacks are adequately represented in general circulation models while others are not. Changes in the Arctic also affect the global system in other ways. Climate change is likely to increase precipitation throughout the Arctic and increase runoff to the Arctic Ocean; such a freshening is likely to slow the global thermohaline circulation with consequences for global climate. The melting of arctic glaciers and ice sheets is another effect of climate change that contributes to global sea-level rise with all its inherent problems, which will have the global implications, as these feedbacks indicate.

### 3.8 Ozone and UV radiation change

Atmospheric ozone is vital to life on earth. The stratosphere contains the majority of atmospheric ozone, which shields the biosphere by absorbing UV radiation from the sun. Anthropogenic chlorofluorocarbons are primarily responsible for the depletion of ozone in the stratosphere, particularly over the poles. Atmospheric dynamics and circulation strongly influence ozone amounts over the poles, which in normal conditions tend to be higher than over other regions on earth. During conditions of ozone depletion, however, ozone over the polar regions can be substantially reduced. This depletion is most severe in the late winter and early spring, when unperturbed ozone amounts are typically high. Ozone losses over the Arctic are also strongly influenced by meteorological variability and large-scale dynamical processes. Winter temperatures in the polar stratosphere tend to be near the threshold temperature for forming polar stratospheric clouds, which can accelerate ozone destruction, leading to significant and long-lasting depletion events. Because climate changes due to increasing GHGs are likely to lead to a cooling of the stratosphere, polar stratospheric cloud formation is likely to become more frequent in future years, causing episodes of severe ozone depletion to continue to occur over the Arctic.

Decreases in stratospheric ozone concentrations are very likely to lead to increased UV radiation levels at the surface of the earth. Clouds, aerosols, surface albedo, altitude, and other factors also influence the amount of UV radiation reaching the surface. Achieving an accurate picture of UV radiation doses in the Arctic is complicated by low solar elevations and by reflectance off snow and ice. Ultraviolet radiation has long been a concern in the Arctic, as indicated by protective goggles found in the archaeological remains of indigenous peoples. Depletion of ozone over the Arctic, as has been observed in several years since the early 1980s, can lead to increased amounts of UV radiation, reaching the surface of the earth, exposing humans and ecosystems to higher doses than have historically been observed. These higher doses are most likely to occur during spring, which is also the time of year when many organisms produce their young and when plants experience new growth. Because ecosystems are particularly vulnerable to UV radiation effects during these stages, increased UV radiation doses during spring could have serious implications throughout the Arctic.

As for observed and projected changes in atmospheric ozone and surface UV radiation levels is concerned, satellite and ground-based observations since the early 1980s indicate substantial reductions in ozone over the Arctic during the late winter and early spring. Between 1979 and 2000, mean spring and annual atmospheric ozone levels over the Arctic declined by 11 and 7%, respectively. During the most severe depletion events, arctic ozone losses of up to 45% have occurred. Although international adherence to the Montreal Protocol and its amendments is starting to lead to a decline in the atmospheric concentrations of ozone depleting substances, ozone levels over the Arctic are likely to remain depleted for the next several decades. Episodes of very low spring ozone levels are likely to continue to occur, perhaps with increasing frequency and severity because of the stratospheric cooling projected to result from increasing concentrations of GHGs. These episodes of very low ozone can allow more UV radiation to reach the earth's surface, suggesting that people and ecosystems in the Arctic are likely to be exposed to higher-than-normal UV radiation doses for perhaps the next 50 years.

To summarize some of the major aspects of changes in ozone and UV radiation levels; observed and projected trends in ozone and ultraviolet radiation levels and factors affecting levels of ultraviolet radiation in the Arctic can be analyzed.

### *3.8.1 Observeved Ozone and UV radiation trends*

Combined satellite and ground-based observations indicate that mean spring and annual atmospheric ozone levels over the Arctic declined by 11 and 7%, respectively, between 1979 and 2000.These losses allowed more UV radiation to reach the surface of the earth. Individual measurements suggest localized increases in surface UV radiation levels, although high natural variability makes it difficult to identify a trend conclusively. Future ozone levels over the Arctic are difficult to project, partly owing to the link with climate change. Current projections suggest that ozone over the Arctic is likely to remain depleted for several decades. This depletion would allow UV radiation levels to remain elevated for several decades. The elevated levels are likely to be most pronounced in spring, when many ecosystems are most sensitive to UV radiation exposure.

### *3.8.2 Observed Low ozone episode*

Low ozone episodes Multi-week episodes of very low ozone concentration (depletion of 25 to 45%) have been observed in several springs since the early 1990s. Decreasing stratospheric temperatures resulting from climate change may cause low ozone episodes to become more frequent.

### *3.8.3 Observed Seasonal variations in ozone and UV radiation levels*

There is high seasonal and inter-annual variability in arctic ozone levels, due to atmospheric processes that influence ozone production and distribution. Over the Arctic, stratospheric ozone levels are typically highest in late winter and early spring, when ozone depletion is most likely to occur. Surface UV radiation amounts vary with solar angle and day length throughout the year. In general, UV radiation doses are highest in summer, but can also be significant in spring due to ozone depletion combined with UV radiation enhancements from reflection off snow.

### *3.8.4 Albedo effects*

Changes in snow and ice extent affect the amount of UV radiation reflected by the surface. Reflection off snow can increase biologically effective UV irradiance by over 50%. In addition, high surface albedo affects UV radiation amounts incident on vertical surfaces more strongly than amounts incident on horizontal surfaces. Snow-covered terrain can substantially enhance UV radiation exposure to the face or eyes, increasing cases of snow blindness and causing potential long-term skin or eye damage. Climate changes are likely to alter snow cover and extent in the Arctic. Reduced snow and ice cover means less reflection of UV radiation, decreasing the UV radiation levels affecting organisms above the snow.

### *3.8.5 Snow and ice cover*

Snow and ice cover shields many arctic ecosystems from UV radiation for much of the year. Climate changes are likely to alter snow cover and extent in the Arctic. Reduced snow and ice will increase the UV radiation levels experienced by organisms that would otherwise be shielded by snow or ice cover.

### *3.8.6 Arctic-wide Impacts of increased UV radiation levels*

Ultraviolet radiation effects on organisms in human health and on terrestrial and aquatic ecosystems include skin cancer, corneal damage, immune suppression, sunburn, snow blindness. Ultraviolet radiation also damages wood, plastics, and other materials widely used in arctic infrastructure.

### *3.8.7 Sea-level rise*

Global average sea level rose between 10 and 20 cm during the 20th century. This change was amplified or moderated in particular regions by tectonic motion or isostatic rebound. The glacier contributions to sea level rise will accelerate in the 21st century. Combined with the effects of thermal expansion, sea level is likely to rise by 20 to 70 cm (an average of 2 to 7 mm/year) by the end of the 21st century.

To summarize observed and projected trends in the snow and ice features of the Arctic, including snow cover, glaciers, permafrost, sea ice, and sea-level rise, it can be said that the snow and ice features of the Arctic are not only sensitive indicators of climate change but also play a crucial role in shaping the arctic environment; any changes in these features are very likely to have profound effects on the environment, biota, ecosystems, and humans.

## 3.9 INDIAN SCIENTIFIC MISSION TO ARCTIC: HIMADRI

The first Indian Arctic expedition marks a beginning of long term scientific research by Indian scientists in yet another arena of global scientific collaborative research in the polar regions, since the first Indian scientific expedition landed in Antarctica in 1981. In August 2007, the Union Minister for Science and Technology and the Earth Sciences launched the first Indian Arctic Expedition as the National Flag was handed over to Rasik Ravindra, Director of the National Centre for Antarctic and Ocean Research (NCAOR), Goa, who will lead a team.

Union Minister of Science and Technology and Earth Sciences recently inaugurated the Indian research base in the Ny-Alesund sector of Arctic region. The base to be called "Himadri" and equipped with state of art facilities will be carrying out round the year scientific research in contemporary fields of Arctic Science with special emphasis on climate change. Ny-Alesund is only 1200 kms from the North Pole and offers the ideal land-based entarance to the Arctic. 'Himadri' will be managed by the National Centre for Antarctic and Ocean Research (NCAOR), an autonomous institute under the Ministry of Earth Sciences.

Currently, Norway, Germany, France, Britain, Italy, Japan, the Republic of Korea and China, have their research stations in Ny-Alesund for Arctic Research.

The Research team from India worked in collaboration with the Norwegian Polar Research Institute, at Ny-Alesund for a period ranging from two weeks to four weeks during August and September 2007 on these projects.

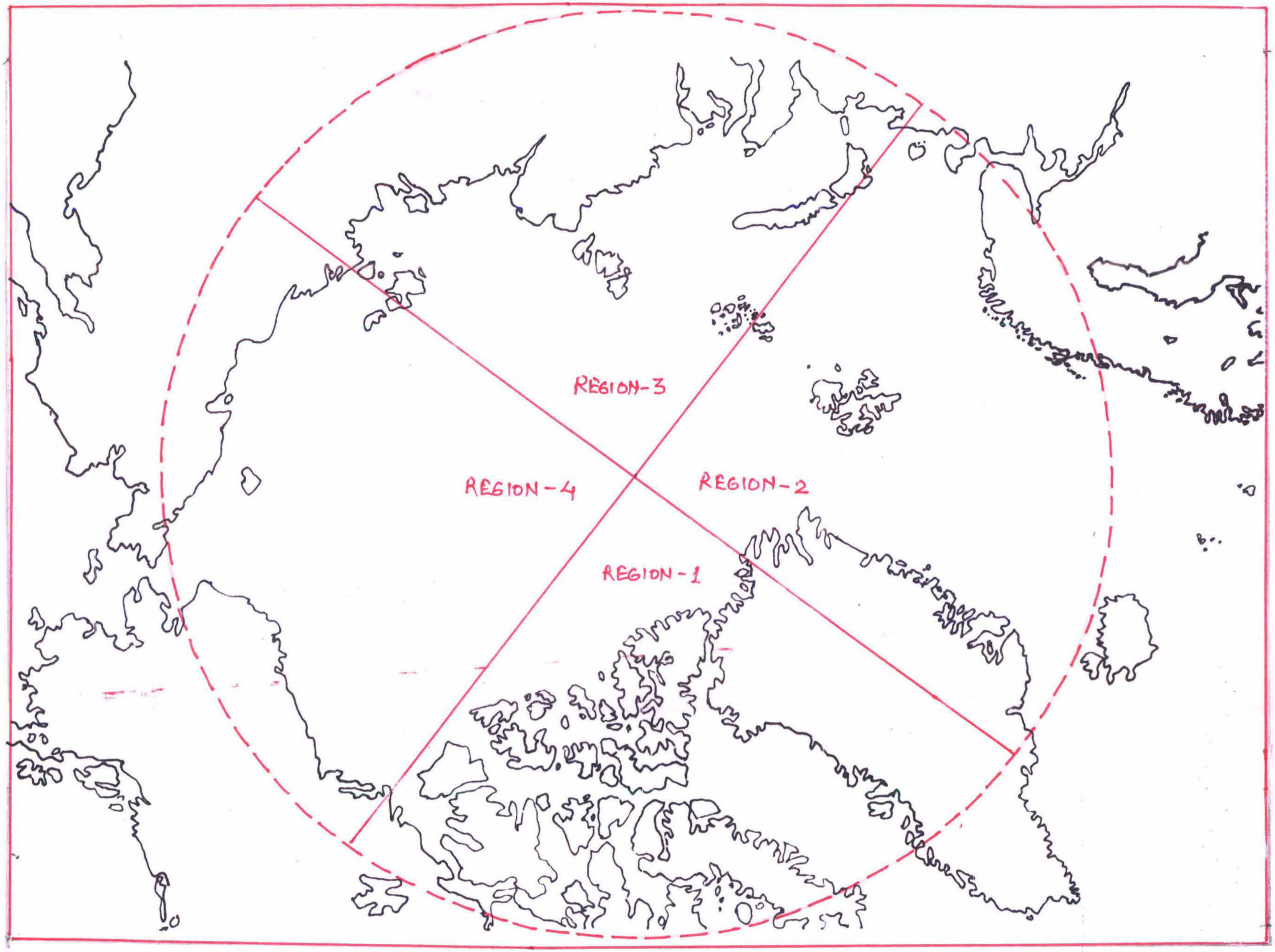
1. Arctic microbe as work horses of biotechnology
2. Measurement of atmospheric aerosols and ions in the Arctic region
3. Earth Science studies at Svalbard

The second phase, following four projects were worked on in February 2008

1. Snowpack production of carbon monoxide and its diurnal variability
2. Sea ice microbial communities project
3. Carbon-cycling in the near-shore environments of Kongsfjorden
4. Understanding the link between the Arctic and tropical Indian Ocean climatic variations.

# CHAPTER 4

# *A Regional Assessment of the Arctic Climate Change*




Sk. No. 4 The Four Natural Geopolitical Regions for the Regional Analysis

## CHAPTER-4

# A Regional Assessment of the Arctic Climate Change

This chapter is a synthesis of impacts on a local and regional basis, providing details on the different regions of the Arctic. A regional emphasis is necessary because the Arctic covers a large area and so experiences significant regional variations in the changes in climate that will lead to different impacts and responses. Different regions also have different social, economic, and political systems, which will each be influenced differently, causing vulnerability and impacts to differ to a large extent on the basis of geopolitical and cultural boundaries. The four natural geopolitical regions are:

- Region 1: ***East Greenland, the North Atlantic and northern Scandinavia,***
- Region 2: ***the northwestern Russia and Siberia***
- Region 3: ***the Bering Sea, Alaska, and the western Canadian Arctic***
- Region 4: ***the Canadian Arctic, the Labrador Sea, Davis Strait, and West Greenland.***

The rationale for selecting these four broad regions includes climatic, social, and other factors. The final part of the chapter addresses issues that are important in the Arctic. These include the carbon cycle, biodiversity, and extreme and abrupt climate change. Changes in climate and UV radiation in the Arctic will not only have far-reaching consequences for the arctic environment and its peoples, but will also affect the rest of the world, including the global climate. The connections include arctic sources of change affecting the globe, e.g., feedback processes affecting the global climate, sea-level rise resulting from melting of arctic glaciers and ice sheets, and the changes in the global thermohaline circulation of the ocean. The Arctic is also important to the global economy. There are large oil and gas and mineral reserves in many parts of the Arctic, and arctic fisheries are among the most productive in the world, providing food for millions. Climate change is likely to benefit north–south connections, including shipping, the global economy, and migratory birds, fish, and mammals that are important conservation species in the south. The Arctic plays a unique role in the global context and climate change in the Arctic has consequences that extend far beyond the Arctic.


**Map No. 4 The political boundaries of the countries around the Arctic Ocean**

The main objective of this chapter is to examine impacts within a more regional setting. A spatial division is necessary because the Arctic is very large and different regions are likely to experience patterns of climate change in the coming decades that are significantly different. Different regions of the Arctic are also distinguished by different social, economic, and political systems, which will mediate the impacts of and responses to climate change. These distinctions are captured broadly by the above mentioned four regions defined for the analysis.

Differences in large-scale weather and climate-shaping factors were primary considerations in selecting the four regions. Observations also indicate that the climate is presently changing quite differently in each of these regions, and even within them, especially where there are pronounced variations in terrain, such as mountains versus coastal plains. There are also large north–south gradients in climate variability within each region. The scale is roughly appropriate given that a larger number of smaller regions would not have been practical for this analysis, or compatible with a focus at the circumpolar level.

## 4.1 Region 1: East Greenland, the North Atlantic and northern Scandinavia

This region includes East Greenland, northern Scandinavia, and northwestern Russia, as well as the North Atlantic with the Norwegian, Greenland, and Barents Seas. This region is projected to experience similar types of changes because the entire area is under the influence of North Atlantic atmospheric and oceanic conditions, particularly the Icelandic Low.

### *4.1.1 Changes in climate*

Most of Region 1 experienced a modest increase in mean annual temperature (about 1 °C) between 1954 and 2003, with slightly higher winter temperature increases over this period, except for Iceland, the Faroe Islands, and southern Greenland, where there has been some cooling. From 1990 to 2000, greater warming was observed in northern Scandinavia, including Iceland, Svalbard, and East Greenland, but cooling was observed in other areas such as the Kola Peninsula.

Model projections indicate that this region is likely to experience additional increases in mean annual temperature of 2 to 3 °C in Scandinavia and East Greenland and up to 3 to 5 °C in northwestern Russia by the late 21st century. Although changes in atmospheric and oceanic circulation contributed to some cooling of the region during the 20th century, warming has occurred in recent decades and is projected to dominate throughout the 21st century. Precipitation has increased slightly and is projected to increase further by up to about 10% by the end of the century.

### 4.1.2 *Impacts on the environment*

The geography and environment of Region 1 are dominated by the North Atlantic Ocean, which has extensive connections with the Arctic Ocean via the Norwegian, Greenland, and Barents Seas. The North Atlantic Ocean separates Greenland in the west from the Fenno-scandian, European, and western Russian landmasses in the east. Relatively isolated islands of Iceland, the Faroe Islands, and the Svalbard and Franz Josef archipelagos span the low to high arctic latitudes. The land areas are characterized by a north–south climatic contrast between low-arctic environments in the south isolated by ocean from the high-arctic environments of the high latitude islands, and by an east–west climatic contrast between the Scandinavian landmass, which is uncharacteristically warm for its latitude, and East Greenland in the west of the region, which is heavily glaciated. The continuous south–north land corridors for movement of terrestrial and freshwater species and people found in Region 2, for example, are missing.

The Greenland, Iceland, Norwegian, and Barents Seas constitute a major part of this region. This vast oceanic area is influenced by the inflow of relatively warm Atlantic water, which enters along the coast of Norway and is the most northward branch of the Gulf Stream. Variability in the volume of this inflow, as experienced in the past and as projected by models for the future due to global climate change, is expected to have major consequences for the physical and biological regimes of the region. Sea surface temperature is expected to increase, and the Barents Sea is expected to be totally ice free in summer by 2080. Changes in the distribution of important fish stocks are expected to occur. Past integrative impact assessments of climate change in this region include publications by Lange et al. for the Barents Sea **(Lange et al. 2003: 470).**

The arctic seas in Region 1 are projected to experience a temperature increase that will lead to a decrease in sea ice cover, especially in summer, as well as earlier ice melt and later freeze-up. Unless compensated for by an increase in low-level cloudiness, decreases in sea-ice cover would reduce the overall planetary albedo of the region and provide a positive feedback to the global climate. The reduction in sea ice is likely to enhance primary productivity, lead to increases in zooplankton production, and possibly to increased fisheries production. Such changes would also lead to decreased natural habitat for polar bears and ringed seals to an extent that is likely to threaten the survival of their populations in this region. Conversely, more open water is expected to favor some whale and seabird species. Biodiversity is high in Region 1: around 6000 marine and terrestrial species have been recorded for Svalbard.**(Prestrud, P., S. Hallvard and H.V. Goldman 2004: 137)** and around 7200 species have been recorded for 22705 km2 between 68° and 70° N in northern Finland **(Callaghan et al., 2004: 35-58).**

The European Arctic and subarctic are important breeding areas for many bird species overwintering in more temperate regions. Excluding the Russian Arctic, over 43% of the European bird species pool occurs in Region 1.Observations indicate very variable climate trends and ecological responses to them in Region 1. Treelines in northern Sweden increased in altitude by up to 40 m during the first part of the 20th century, and a further 20 m during the warming of the past 40 years, giving recent rates of treeline increase of 0.5 m/yr and 40 m/°C. In northern Finland, the pine treeline is increasing in altitude and density, and in the Polar Ural Mountains, treeline has advanced. However, there is little evidence of a northward shift of the latitudinal treeline west of the Polar Ural Mountains. Unexpectedly, evidence shows a southward movement of the treeline in parts of the forest tundra of the Russian European Arctic, a change that appears to be associated with localized pollution, deforestation, agriculture, and the growth of bogs leading to tree death. In the Faroe Islands, there has been a lowering of the alpine altitudinal treeline in response to a cooling of 0.25 °C during the past 50 years. In some areas of Finland and northern Sweden, there is evidence of an increase in rapidly changing warm and cold episodes in winter that lead to increasing bud damage in birch. Recent warming in northern Sweden and Finland has led to a reduction in the extent of discontinuous permafrost in mires and a change in vegetation resulting in increased $CH_4$ flux to the atmosphere **(Christensen,T.R. et al. 2004).**

Recent warm winters have resulted in unusual conditions -causing ice layers in the snow unfavorable for reindeer and wildlife, and leading to an absence of lemming population peaks, and on Svalbard, a decline in wild reindeer through decreases in the availability of food resources. Changes in animal populations also include reductions in arctic fox and snowy owl as well as several other bird populations on mainland Fennoscandia but a northward migration of larger butterflies and moths, the larvae of some being defoliators of trees and shrubs. Moose, red fox, and the invasive species mink are increasing in the east of the region and muskoxen, wolves, and pinkfooted and barnacle geese are increasing in northeast Greenland

If warming occurs as projected, the deciduous mountain birch forest that forms much of the present treeline in the region, the boreal conifer forest and woodland, and the arctic and alpine tundra are very likely to begin shifting northward and upward in altitude. The potential for vegetation change within the region is perhaps greatest in northern Scandinavia, where large shifts occurred in the early Holocene in response to warming. Here, pine forest is projected to invade the lower belt of mountain birch forest. The birch treeline is projected to move upward and northward, displacing shrub tundra vegetation, which in turn is projected to displace alpine tundra. Alpine species in the north are expected to be the most threatened because there is no suitable geographic area for them to shift toward in order to avoid being lost from the Fennoscandian mainland. In Iceland, a warmer climate is likely to facilitate natural regeneration of the heavily degraded native birch woodland as well as aid current and future afforestation efforts. Model projections suggest that arctic tundra will be displaced totally from the mainland by the end of the $21^{st}$ century, although in practice, the bogs of the western Russian European Arctic may prevent forests from reaching the coast. Model projections of change from tundra to taiga between 1960 and 2080 (5.0%), and of change from polar desert to tundra (4.2%), are the lowest of any of the four Arctic regions because of the lack of tundra areas and the separation of the high Arctic from the subarctic.

While the climate is changing, local forest damage is projected to occur as a result of winters that are warmer than normal. Warmer winters are likely to lead to an increase in insect damage to forests and decreases in populations of animals such as lemmings and voles that depend upon particular snow conditions for survival. These changes, in turn, are likely to cause decreases in populations of many existing bird species and other animals, with the most severe effects on carnivores, such as Arctic foxes, and raptors, such as snowy owls. Heathland and wetland areas are likely to be partially invaded by grasses, shrubs, and trees, and mosses and lichens are expected to decrease in extent. Unlike other arctic areas, fire is not likely to play a major role in controlling vegetation dynamics. Any changes in land-use patterns, including increased agriculture and domestic stock production in a warmer climate, will encroach on wildlife habitats and further threaten large carnivores.

Some areas in this region, such as East Greenland and the Faroe Islands, have experienced recent cooling, and future warming is expected to reverse the present downward vegetation shifts in the mountains of the Faroe Islands. The island settings in this region, particularly those of Greenland, Svalbard, Franz Josef Land, and Novaya Zemlya, are likely to delay the arrival of immigrant species and substantial change other than expansion and increased growth of some current species.

### 4.1.3 Impacts on the economy

**Region 1** has abundant renewable and non-renewable resources e.g. timber, fish, ore, oil, and natural gas. The highly productive marine life makes this region one of the most productive fishing grounds in the circumpolar North. Higher ocean temperatures are likely to cause shifts in the distribution of some fish species, as well as changes in the timing of their migration, possible extension of their feeding areas, and increased growth rates. The occurrence of several "warm years" or "cold years" in a row, which is a sequence that could occur more frequently as a result of continuing global climate change, seems likely to lead to repercussions on the major fish stocks and, ultimately, the lucrative and productive fisheries in the region. Provided that the fluctuations in Atlantic inflow to the area are maintained, along with a general warming of the North Atlantic waters, it is likely that annual recruitment in herring and Atlantic cod will increase from current levels and will be about the same as the long-term average during the first two to three decades of the 21st century. This projection is also based on the assumption that harvest rates are kept at levels that maintain spawning stocks well above the level at which recruitment is impaired.

Impacts of climate change on the fisheries sector of the region's economy are difficult to assess, however. A scenario of moderate warming could result in quite large positive changes in the catch of many species. A self-sustaining cod stock could be established in West Greenland waters through larval drift from Iceland. Past catches suggest that this could yield annual catches of about 300 000 t. Should that happen, it is estimated that catches of northern shrimp will decrease to around 30% of the present level, while those of snow crab and Greenland halibut might remain the same. Such a shift could approximately double the export earnings of the Greenlandic fishing industry, which roughly translates into the same amount as that presently paid by Denmark to subsidize the Greenland economy. Such dramatic changes are not expected in the Icelandic marine ecosystem. Nevertheless, there would be an overall gain through larger catches of demersal species such as cod, pelagic species like herring, and new fisheries of more southern species like mackerel. On the other hand capelin catches would dwindle, both through diminished stock size and the necessity of conserving this very important forage fish for other species. Effective fisheries management will continue to play a key role both for Greenland and Iceland, however. Little can be said about possible changes under substantial climate warming because such a situation is outside any recorded experience.

**4.1.4 Forestry and agriculture are important in Region 1** :

Both have been affected by climate change in the past and impacts are likely to occur in the future. Longer growing seasons are likely to improve the growth of agricultural crops. While growth (net carbon assimilation) of forests and woodlands is likely to increase, this will not necessarily benefit the forestry industry as forest fires and pests will also increase. Forest pest outbreaks have been reported for the Russian part of the region, including the most extensive damage from the European pine sawfly, which affected a number of areas, each covering more than 5000 ha. The annual number of insect outbreaks reported between 1989 and 1998 was 3.5 times higher than between 1956 and 1965. The mean annual intensity of forest damage increased two-fold between 1989 and 1998. Factors other than climate change are also important to forest-based economies. For example, while most of the region has seen modest growth in forestry, Russia has experienced a decline due to political and economic factors. These socio-economic problems are expected to be aggravated by global climate change, which in the short term will have negative effects on timber quality owing to fire and insect damage and on infrastructure and winter transport when permafrost thaws.

### 4.1.5 Impacts on people's lives

The prospects and opportunities of gaining access to important natural resources, both renewable and nonrenewable, have attracted a large number of people to Region 1.The relatively intense industrial activities, particularly on the Kola Peninsula, have resulted in population densities that are the highest throughout the circumpolar North. Impacts of climate change on terrestrial and marine ecosystems and implications for the availability of natural resources may lead to major changes in economic conditions and subsequent shifts in demography, societal structure, and cultural values.

Because they would affect food, fuel, and culture, changes in arctic ecosystems and their biota are particularly important to the peoples of the Arctic. Reindeer herding by the Saami and other indigenous peoples is an important economic and cultural activity and the people who herd reindeer are concerned about the impacts of climate change. Observations have shown that during autumn the weather in recent years has fluctuated between raining and freezing so that the ground surface has often been covered with an ice layer and reindeer in many areas have been unable to access the underlying lichen. These conditions are quite different from those in earlier years and have caused massive losses of reindeer in some years. Changes in snow conditions also pose problems. Since reindeer herding has become motorized, herders relying on snowmobiles have had to wait for the first snows to start herding. In some years, this has led to delays up to the middle of November. Also, the terrain has often been too difficult to travel over when the snow cover is light. Future changes in snow extent and condition have the potential to lead to major adverse consequences for reindeer herding and those aspects of health -physical, social, and mental; relating to the livelihood of reindeer herders.

The beneficial effects of a warmer climate on people's recreational and leisure activities (camping, hiking, and other outdoor activities) should not be overlooked. Even relatively modest warming will improve people's mental and physical health. A warmer climate is also likely to reduce heating costs.

## 4.2 Region 2: Russia and Siberia:

**Region 2** includes Central Siberia, from the Urals to Chukotka, and the Barents, Laptev, and East Siberian Seas. This region represents the coldest part of the Arctic and is under the influence of the Siberian high-pressure system during winter.

### 4.2.1 *Changes in climate*

**Region 2,** which experiences the coldest conditions in the Arctic, has experienced an increase in mean annual temperature of about 1 to 3 °C since 1954, and an increase of up to 3 to 5 °C in

**UV radiation**

***Observed climate change***

The climate of the Arctic has undergone rapid and dramatic shifts in the past and there is no reason that it could not experience similar changes in the future. Past changes show climatic cycles that have occurred regularly on time scales from decades to centuries and longer and are most likely to have been caused by oceanic and atmospheric variability and variations in solar intensity. Examples of long-term cooler and warmer climates were the Little Ice Age and the Medieval Warm Period, respectively, while short-term decadal cycles like the North Atlantic Oscillation and Pacific Decadal Oscillation, among others, have also been found to affect the arctic climate. Since the industrial revolution in the 19th century, anthropogenic greenhouse gas (GHG) emissions have added another major climate driver. In the 1940s, the Arctic experienced a warm period, like the rest of the planet, although it did not reach the level of the warming experienced in the 1990s.The IPCC stated that most of the global warming observed over the last 50 years is attributable to human activities **(IPCC, 2001),** and there is new and strong evidence that in the Arctic much of the observed warming over this period is also due to human activities, as has been about the arctic climate system and observed changes in arctic climate over recent decades. Many types of observations indicate that the climate of the Arctic is changing. For example, air temperatures are generally warmer, the extent and duration of snow and sea ice are diminishing, and permafrost is thawing.

Reconstruction of the history of arctic climate over thousands to millions of years indicates that there have been very large changes in the past. Based on these indications that the arctic climate is sensitive to changes in natural forcing factors, it is very likely that human induced factors, for example the rise in GHG concentrations and consequent enhancement of the global greenhouse effect, will lead to very large changes in climate, these changes that will be much greater in the Arctic than at middle and lower latitudes. The observed temperature changes in the Arctic over the five-decade period from 1954 to 2000. Owing to natural variations and the complex interactions of the climate system, the observed trends show variations within each region. Mean annual atmospheric surface temperature changes range from a 2 to 3 °C warming in Alaska and Siberia to a cooling of up to 1 °C in southern Greenland. Winter temperatures are up to 4 °C warmer in Siberia and in the western Canadian Arctic. For the Arctic as a whole, the 20th century can be divided into two warming periods, bracketing a 20-year cooling period - approximately 1945 to 1966; in the middle of the century. This pattern is less evident in northern Canada than in some other areas of the Arctic. The Canadian\Archipelago and West Greenland did experience some cooling mid-century, although even then, there was substantial winter warming. The warming has been significant over the past few decades (1966 to 2003), particularly in the Northwest Territories – continuing the band of substantial warming across northwest North America that also covers Alaska and the Yukon – reaching an increase of 2 °C per decade. This warming is most evident in winter and spring.

Observations of arctic precipitation are restricted to a limited network of stations. Available records indicate 20thcentury increases in precipitation at high latitudes on the North American continent but little if any change in precipitation in the watersheds of the large Siberian rivers. Rapid changes in regional climates --regime shifts are also evident in the climatic record. For example, in 1976 in the Bering Sea region there was a relatively sudden shift in prevailing climatic patterns, which included rapid warming and reduction in sea-ice extent. Such shifts have led to instantaneous impacts on biota and ecosystems, as well as impacts on human communities and their interactions with the environment. Although such fluctuations are not fully understood and are therefore difficult to predict, regime shifts can be expected to continue to occur in the future, even as the baseline climate is also changing as a result of global warming.

### 4.2.2 *Adaptation by Indigenous people to the recent changes in climate*

Indigenous observations of climate change contribute to understanding of climate change and associated changes in the behavior and movement of animals. Through their various activities, which are closely linked to their surroundings, the indigenous peoples of the Arctic experience the climate in a very personal way. Over many generations and based on direct, everyday experience of living in the Arctic, they have developed specific ways of observing, interpreting, and adjusting to weather and climate changes. Based on careful observations, on which they often base life and death decisions and set priorities, indigenous peoples have come to possess a rich body of knowledge about their surroundings. Researchers are now working with indigenous peoples to learn from their observations and perspectives about the influences of climate change and weather events on the arctic environment and on their own lives and cultures. These studies are finding that the climate variations observed by indigenous people and by scientific observation are, for the most part, in good accord and often provide mutually supporting information. The presently observed climate change is increasingly beyond the range experienced by the indigenous peoples in the past. These new conditions pose new risks to the lifestyles of the indigenous populations. The magnitude of these threats is critically dependent on the rate at which change occurs. If change is slow, adaptation may be possible; if however, change is rapid, adaptation is very likely to be considerably more difficult. Recent observations by the indigenous peoples of the Arctic of major changes in the climate and associated impacts & weather patterns are changing so fast that traditional methods of prediction are no longer applicable.

Models project that the mean annual temperature of Region 2 is likely to increase by a further 3 to 5 °C by the late 21st century, and by up to 5 to 7 °C in winter. In the far north, winter warming of up to 9 °C over the Arctic Ocean as a result of reduced sea-ice extent and thickness is projected. The summer warming over the land areas is projected to be 2 to 4 °C by the end of the century, but there is likely to be very little change in summer over the Arctic Ocean.

### 4.2.3 *Impacts on the environment*

This region has the largest continuous land mass, which stretches from the tropical regions to the high Arctic. It is very likely to experience major changes as the boreal forest expands northward, but tundra will persist, although with reduced area. For example, extensive tundra is likely to remain in the Taymir region but is likely to be displaced completely from the mainland in the Sakha region.

The large Siberian rivers draining into the Arctic Ocean are projected to experience major impacts. Projected increases in winter precipitation, and more importantly in precipitation minus evaporation, imply an increase in water availability for soil infiltration and runoff. The total projected increase in freshwater supplied to the Arctic Ocean could approach 15% by the latter decades of the 21st century. An increase in the supply of freshwater has potentially important implications for the stratification of the Arctic Ocean, for its sea-ice regime, and for its freshwater export to the North Atlantic. In addition, increased freshwater input into the coastal zone is likely to accelerate the degradation of coastal permafrost.

On land, the projected increase in precipitation is likely to lead to wetter soils when soils are not frozen, wetter active layers in summer, and greater ice content in the upper soil layer during winter. To the extent that the increase in precipitation occurs as an increase in snowfall during the cold season, snow depth and snow water equivalent will increase, although the seasonal duration of snow cover may be shorter if, as projected, warming accompanies the increased snowfall.

The projected changes in terrestrial watersheds will increase moisture availability in the upper soil layers in some areas, favoring plant growth in areas that are presently moisture-limited. The projected increase in river discharge during winter and spring is likely to result in enhanced fluxes of nutrients and sediments to the Arctic Ocean, with corresponding impacts on coastal marine ecosystems. Higher rates of river and stream flow are likely to have especially large impacts on riparian regions and flood plains in the Arctic. One important consequence is that the vast wetland and bog ecosystems of this region are very likely to expand, leading to higher CH4 emissions.

### 4.2.4 *Impacts on the economy*

A potentially major impact on the economy of **Region 2** and on the global economy could be the opening of the Northern Sea Route (Northeast Passage) to commercial shipping. Model projections of ice cover during the 21st century show considerable development of ice-free areas around the entire Arctic Basin. Most coastal waters of the Eurasian Arctic are projected to become relatively ice free during September by 2020, with more extensive melting occurring later in the century. Ships navigating the Northern Sea Route would clearly benefit from these ice-free conditions. In addition, if winter multi-year sea ice in the central Arctic Ocean continues to retreat, it is very likely that first-year sea ice will dominate the entire maritime Eurasian Arctic, with a decreasing frequency of multi-year ice intrusions into the coastal seas and more open water during the summer.

Such changes in sea-ice conditions are likely to have important implications for ship design and construction and route selection along the Northern Sea Route in summer and even in winter. The need for navigational aids, refueling and ship maintenance, and sea-ice monitoring will require major financial investment, however, to assure security and safety for shipping and protection of the marine environment.

The coal and mineral extraction industries in Region 2 are important parts of the Russian economy, but climate change is likely to have little effect on the actual extraction process. On the other hand, transportation of coal and minerals will be affected in both a positive and negative sense. Mines in Siberia that export their products by ship will experience savings resulting from reduced sea-ice extent and a longer shipping season. However, mining facilities relying on transport over roads on permafrost will experience higher maintenance costs as the permafrost thaws.

Forestry, another important sector of the Siberian economy, is likely to experience both positive and negative impacts. A potentially longer growing season and warmer climate are likely to enhance productivity. However, more frequent fires and insect outbreaks are likely as the climate warms and insects invade from warmer regions. Drying of soils as permafrost thaws is also likely to affect forest productivity in some areas. To meet the demands of the global economy, forestry is likely to become more important and transportation of wood and wood products to markets will improve as reduced sea-ice extent facilitates marine transport along the Siberian coast.

### 4.2.5 *Impacts on people's lives*

The change to a wetter climate is likely to lead to increased water resources for the region's residents. In permafrost-free areas, water tables are very likely to be closer to the surface, and more moisture is projected to be available for agricultural production. During the spring when enhanced precipitation and runoff are very likely to cause higher river levels, the risk of flooding will increase. Summer soil moisture changes remain an open question since the models do not give clear signals. It is possible that lower water levels will occur in summer, as projected for other regions; for example the Mackenzie River in Region 3, affecting river navigation in some areas, increasing the risk of forest fires, and affecting hydropower generation.

Other major environmental impacts projected for Region 2 are associated with thawing permafrost and melting sea ice. Warming during the 20th century produced noticeable impacts on permafrost, causing deeper seasonal thawing and changes in the distribution and temperature of the frozen ground. For example, from the late 1980s to 1998, temperatures in the upper permafrost layers increased by 0.1 to 1.0 °C on the western Yamal Peninsula. Permafrost degradation in the developed regions of northeast Russia, coupled with inadequate building design, has led to serious problems. For example, in 1966 a building affected by thermo-karst and differential thaw settlement collapsed in Norilsk, killing 20 people. In Yakutsk, a city built over permafrost in central Siberia, more than 300 structures, including several large residential buildings, a local power station, and a runway at the airport, have been seriously damaged by thaw-induced settlement. Considerable advances in knowledge and technology for building on permafrost have been made in recent decades. Nevertheless, as global climate change continues to intensify changes in arctic climate, detrimental impacts on infrastructure and therefore on the economy, health, and well-being of the population throughout the permafrost regions are expected to increase.

## 3.Region 3: the Bering Sea, Alaska, and the western Canadian Arctic

**Region 3** includes Chukotka, Alaska, the western Canadian Arctic to the Mackenzie River, and the Bering, Chukchi, and Beaufort Seas. This region is largely under the influence of North Pacific atmospheric and oceanic processes and the Aleutian Low.

### 3.1 *Changes in climate*

Alaska experienced an increase in mean annual temperature of about 2 to 3 °C between 1954 and 2003. The temperature increase was similar in the western Canadian Arctic, but was only about 0.5 °C in the Bering Sea and Chukotka. Winter temperatures over the same period increased by up to 3 to 4 °C in Alaska and the western Canadian Arctic, but Chukotka experienced winter cooling of between 1 and 2 °C.

All the models project that the warming is likely to be greater in the north, reaching up to 7 °C in winter. In the central Arctic Ocean, winter temperatures are projected to increase by up to 9 °C as a result of reduced sea-ice extent and thickness, but there is likely to be very little change in summer temperature. Trends in and future projections of ozone and UV radiation levels follow the Arctic-wide patterns.

### 3.2 *Impacts on the environment*

The entire region, but particularly Alaska and the western Canadian Arctic, has undergone a marked change over the last three decades, including a sharp reduction in snow-cover extent and duration, shorter river- and lake ice seasons, melting of mountain glaciers, sea-ice retreat and thinning, permafrost retreat, and increased active layer depth. These changes have caused major ecological and socio-economic impacts, which are likely to continue or worsen under projected future climate change. Thawing permafrost and northward movement of the permafrost boundary are likely to increase slope instabilities, which will lead to costly road replacement and increased maintenance costs for pipelines and other infrastructure. The projected shift in climate is likely to convert some forested areas into bogs when ice-rich permafrost thaws. Other areas of Alaska, such as the North Slope, are expected to continue drying. Reduced sea-ice extent and thickness, rising sea level, and increases in the length of the open-water season in the region will increase the frequency and intensity of storm surges and wave development, which in turn will increase coastal erosion and flooding.

Warmer temperatures have resulted in some northward expansion of boreal forest, as well as significant increases in fire frequency and intensity, unprecedented insect outbreaks, and a 20% increase in growing-degree days. The latter has benefited both agriculture and forestry. The expansion of forests in most areas and their increased vulnerability to fire and pest disruption are projected to increase. One simulation projects a three-fold increase in the total area burned per decade, destroying coniferous forests and eventually leading to a deciduous forest dominated landscape on the Seward Peninsula in Alaska, after a warmer climate has led to forestation of the present tundra areas. Shrubbiness is already increasing in this area, a trend that is likely to continue.

Observations in the Bering Sea have shown abnormal conditions during recent years. The changes observed include significant reductions of seabird and marine mammal populations, unusual algal blooms, abnormally warm water temperatures, and low harvests of salmon on their return to spawning areas. Some of the changes observed in the 1997 and 1998 summers, such as warmer ocean temperatures and altered currents and atmospheric conditions, may have been exacerbated by the very strong El Niño event, but the area has been undergoing change for several decades. While the Bering Sea fishery has become one of the world's largest, the abundance of Steller sea lions has declined by between 50 and 80%. Northern fur seal pups on the Pribilof Islands – the major Bering Sea breeding grounds – declined by 50% between the 1950s and the 1980s.There have been significant declines in the populations of some seabird species, including common murre, thickbilled murre, and red- and blacklegged kitti wakes. Also, the number of salmon has been far below expected levels, the fish were smaller than average, and their traditional migratory patterns seemed to have altered.

Differentiating between the various factors affecting the Bering Sea ecosystem is a major focus of current and projected research. Well-documented climatic regime shifts occurred in the

Bering Sea during the 20th century on roughly decadal time scales, alternating between warm and cool periods. A climatic regime shift occurred in the Bering Sea in 1976, changing the marine environment from a cool to a warm state. Information from the contrast between the warm and subsequent cool period forms the basis of projected responses of the Bering Sea ecosystem to scenarios of future warming. These projections show increased primary and secondary productivity with greater carrying capacity, pole-ward shifts in the distribution of some cold-water species, and possible negative effects in ice-associated species.

### 3.3 *Impacts on the economy*

Large oil and gas reserves exist in Alaska along the Beaufort Sea coast and in the Mackenzie River/Beaufort Sea area of Canada. To date, climate change impacts on oil and gas development in Region 3 have been minor but are likely to result in both financial costs and benefits in future. For example, offshore oil exploration and production is likely to benefit from less extensive and thinner sea ice, allowing savings in the construction of platforms that must withstand ice forces. Conversely, ice roads, now used widely for access to offshore activities and facilities, are likely to be less safe and useable for shorter periods; the same applies for over-snow transport on land given projected reductions in snow depth and duration. The thawing of permafrost, on which buildings, pipelines, airfields, and coastal installations supporting oil development are located, is very likely to adversely affect these structures and greatly increase the cost of maintaining or replacing them.

It is difficult to project impacts on the lucrative Bering Sea fisheries because many factors other than climate are involved, including fisheries policies, market demands and prices, harvesting practices, and fisheries technology. Large northward changes in the distribution of fish and shellfish are likely with a warmer climate. Relocating the fisheries infrastructure, fishing vessels, home ports, processing plants; may be necessary, and would incur substantial costs. Warmer waters are likely to lead to increased primary production in some regions, but a decline in cold-water species such as salmon and pollock.

Other economic sectors in this region, including forestry and agriculture, are far less developed and currently less important than oil and gas and fish and wildlife. Owing to this, economic impacts on forestry and agriculture resulting from climate change are unlikely to be significant, except locally. Impacts on tourism, which is a large economic sector in this and other regions, are more difficult to assess, largely due to the relationship between tourism and economic conditions and social factors outside the Arctic. It is also unclear which features of Region 3 are primarily responsible for attracting tourists – large, undeveloped landscapes will not be directly affected by climate change, whereas marine mammal populations and accessible glaciers are likely to experience major changes. Whether such changes will reduce tourist interest is difficult to assess without more information.

### 3.4 *Impacts on people's lives*

Traditional lifestyles are already being threatened by multiple climate-related factors, including reduced or displaced populations of marine mammals, seabirds, and other wildlife, and reductions in the extent and thickness of sea ice, making hunting more difficult and dangerous. Indigenous communities depend on fish, marine mammals, and other wildlife, through hunting, trapping, fishing, and caribou/reindeer herding. These activities play social and cultural roles that may be far greater than their contribution to monetary incomes. Also, these foods from the land and sea make significant contributions to the daily diet and nutritional status of many indigenous populations and represent important opportunities for physical activity among populations that are increasingly sedentary.

Climate change is likely to have significant impacts on the availability of key marine and terrestrial species as food resources. At a minimum, salmon, herring, char, cod, walrus, seals, whales, caribou, moose, and various species of seabird are likely to undergo shifts in range and abundance. This will entail major local adjustments in harvest strategies and allocations of labor and equipment. Changes in diet, nutritional health, and exposure to air-water and food-borne contaminants are also likely. Adjustments in the balance between the "two economies" of rural areas will be accelerated by climate change. This suite of changes will be complex and largely indirect because of the mediating influences of market trends, the regulatory environment, and the pace and direction of rural development.

## 4.Region 4: the Canadian Arctic, the Labrador Sea, Davis Strait, and West Greenland

**Region 4** includes the central and eastern Canadian Arctic east of the Mackenzie River, the Queen Elizabeth Islands south to Hudson Bay, and the Labrador Sea, Davis Strait, and West Greenland. The region's weather systems are connected to large-scale North American and western North Atlantic weather patterns.

A major integrative impact assessment for the region was published by Maxwell (1997) for the Canadian Arctic (encompassing the regions of the Northwest Territories and Nunavut **(Maxwell, B. 1997: 82).** The Mackenzie River watershed assessment, mentioned in the summary for Region 3, also covers Region 4 **(Cohen, 1997).** A number of studies of the traditional ecological knowledge of indigenous peoples of Region 4 have been conducted and are cited in earlier chapters. Detailed studies of integrated climate impacts in Greenland, on the other hand, have not been conducted.

### 4.1 *Changes in climate*

Temperature changes over the past decades have varied across Region 4.The amount of change depends on the time period chosen and, the warming has been pronounced since 1966. Between 1954 and 2003, mean annual temperatures across most of arctic Canada increased by as much as 2 to 3 °C while temperatures in northeastern Canada, including Labrador and adjacent waters, showed little change. The southern part of West Greenland, including the surrounding ocean cooled by about 1 °C while northern Greenland warmed by 1 to 2 °C. Winter temperature trends over the same period were noticeably warmer in the west and colder in the east than the annual trends The landmass to the west of Hudson Bay warmed by up to 4 °C in winter while the area around Labrador, Baffin Island, and southwest Greenland experienced winter cooling of more than 1 °C.

Annual precipitation in Region 4 has increased over the past 50 years or so, and while seasonal differences were evident around the middle of the century, increases in precipitation have been evident in all seasons over the past few decades.

The physical complexity of the Queen Elizabeth Islands and the orography of Greenland create particular challenges for modeling past, present, and future arctic climate. Models project warming throughout Region 4 during the 21st century, with no cooling projected in any season. Figures 18.5a and 18.5b illustrate annual and winter temperature changes for the period 2071–2090 relative to the 1981–2000 baseline. Projected winter warming in the Canadian areas of Region 4 ranges from about 3 °C up to about 9 °C, with the greatest warming projected to occur around southern Baffin Island and Hudson Bay, and substantially less warming projected in other seasons. Greenland is also projected to warm but the warming is weaker, up to about 3 °C by 2071–2090 and more consistent across seasons.

Precipitation increases are projected to be greatest in autumn and winter, and the areas of greatest increase, up to 30% by the end of the 21st century; generally correspond with the areas of greatest warming. Almost all areas of Region 4 are projected to experience some increase in precipitation after the first few decades of the 21st century.

**4.2** ***Impacts on the environment***

The Canadian part of Region 4 has significant areas of warm permafrost that are at risk of thawing with rising regional air temperatures. The boundary between continuous and discontinuous permafrost is projected to shift poleward, following, but with a lag in timing, the several-hundred-kilometer movement of the isotherms of mean annual temperature over the 21st century. This is likely to result in the disappearance of a substantial amount of the permafrost in the present discontinuous zone. Areas of warm permafrost are also likely to experience more widespread thermokarst development where soils are ice-rich, and increases in slope instability. In areas of remaining continuous and cold permafrost, increases in active-layer depth can be expected.

The maximum northward retreat of sea ice during summer is projected to increase from its present range of 150–200 km to 500–800 km. The thickness of fast ice in the Northwest Passage is likely to decrease substantially from its current value of 1 to 2 m.

The Greenland Ice Sheet is presently losing mass in its ablation zone and is likely to contribute substantially to sea-level rise in the future. While precipitation is projected to increase, it is possible that increased evaporation rates will lead to lower river and lake levels during the warm season.

In general terms, and consistent with results for other regions, the biomes of arctic Canada and Greenland are expected to change. Reductions in the area covered by polar deserts in Canada and Greenland are likely to result from the northward shift of the tundra, while reductions in the areas covered by arctic tundra are very likely to result from the northward shift of the treeline. Polar deserts in the region are extensive, and these areas could sequester large amounts of carbon dioxide ($CO_2$) if tundra vegetation displaces polar deserts. A reduction in polar desert area of about 36% by 2080 is projected, leading to the greatest projected carbon gain of any region. In contrast, increases in temperature and precipitation are likely to lead to relatively small increases in the area of taiga compared with other regions.

Many treelines, such as those in northeast Canada, have been relatively stable for the last few thousand years. A widespread and consistent observation from the late 20th century has been the infilling of sparse stands of trees near the tundra edge into dense stands that no longer retain the features of the tundra. Movement of the treeline northward is likely when climatic conditions become favorable, but the actual movement of trees will lag the climate warming considerably in time. The forests of northwestern Canada have recently experienced forest health problems driven by insects, fire, and tree growth stress that are all associated with recent mild winters and warmer growing seasons. These findings for Region 4 complement those of Region 3 and accord with very large-scale environmental changes in the western North America subarctic. It is very likely that such forest health problems will become increasingly intense and widespread in response to future regional warming.

The Canadian High Arctic is characterized by land fragmentation within the archipelago and by large glaciated areas, leading to constraints on species movement and establishment. In West Greenland, loss of habitat and displacement of species in combination with time delays in species immigration from the south will ultimately lead to loss of the present biodiversity. However, Region 4 contains relatively few rare and endemic vascular plant species and threatened animal and plant species, compared with the other three regions.

Changes in timing and abundance of forage availability, insect harassment, and parasite infestations will increase stress on caribou, tending to reduce their populations. The ability of high-arctic Peary caribou and muskoxen to forage may become increasingly limited as a result of adverse snow conditions, in which case numbers will decline, with local extirpation in some areas. Direct involvement of the users of wildlife in its management at the local level has the potential for rapid management response to changes in wildlife populations and their availability for harvest.

Arctic freshwater systems are particularly sensitive to climate change because many hydro-ecological processes respond to even small changes in climatic regimes. These processes may change in a gradual way in response to changes in climate or in an abrupt manner as environmental or ecosystem thresholds are exceeded. Pronounced potential warming of freshwater systems in the autumn is particularly important because this is typically when these systems along the coastal margins currently experience freeze-up. Such warming is projected to delay freeze-up by up to 25 days in parts of Region 4. Also, high-latitude cold-season warming is likely to lead to less severe ice breakups and flooding as the spring flood wave pushes northward along arctic rivers. Hence, future changes in the spring timing of lake- and river-ice breakup and the export of freshwater to the Arctic Ocean are likely.

With respect to freshwater ecosystems, significant shifts in species range, composition, and trophic relations are also very likely to occur in response to the projected changes. Salmonids of northern Québec and Labrador, such as native Atlantic salmon and brook trout and introduced brown trout and rainbow trout, are likely to extend their ranges northward. Because of these range extensions, the abundance of Arctic char is likely to be reduced throughout much of the southern part of Region 4, and brook trout are likely to become a more important component of native subsistence fisheries in rivers now lying within the tundra zone. Lake trout are also likely to disappear from rivers and the shallow margins of many northern lakes, and northern pike are expected to reduce in both numbers and size throughout much of their current range.

Marine mammal populations are likely to decline as the sea ice recedes but the populations of beluga and bowhead whales could increase; depending on the extent to which these whales become more vulnerable to predation as sea-ice cover decreases. If the Arctic Ocean becomes seasonally ice free for several years in a row, it is possible that polar bears would become extinct. Sea-level rise will change the location and distribution of coastal habitats for seabirds and some species of marine mammals e.g., walrus haul-outs may become inundated.

### 4.3 *Impacts on the economy*

Oil and gas extraction and mining are active industries in Region 4. Diamond mining is underway in the Northwest Territories, and the development of a large nickel deposit in Voisey's Bay, Labrador, has recently been announced. Many rivers in the northern parts of Québec, Ontario, and Manitoba have been dammed for their hydroelectric potential. Roads, airstrips, and ports have been constructed and are essential to the economic infrastructure supporting these activities. Any expansion of oil and gas activities, mining, agriculture, or forestry is likely to require expansion of supporting infrastructure, including air, marine, and land transportation systems. Ice roads in near shore areas and over-snow transport on land, systems that are important and are even now experiencing shorter seasons, are likely to be further curtailed in the future because of reduced extent and duration of sea ice and snow.

With reduced summer sea-ice extent, the shipping season in Canadian arctic waters is likely to be extended, although sea-ice conditions are likely to remain very challenging. Extension of the shipping season will result in costs and benefits, both of which are speculative. Benefits are likely to result from increased access to the natural resources of the region. As sea level rises, this will also benefit shipping by creating deeper drafts in harbors and channels. On the other hand, increased costs would result from greater wave heights, and possible flooding and erosion threats to coastal facilities. Increased rates of sediment movement during longer, more energetic open-water seasons are likely to increase rates of port and harbor infill and increase dredging costs. Increased ship traffic in the Northwest Passage will increase the risks and potential environmental damage from oil and other chemical spills.

Warmer air temperatures would be expected to reduce the power demand for heating, reduce insulation needs, and increase the length of the summer construction season. Other infrastructure likely to be affected by climate change includes northern pipeline design (negative); pile foundations in permafrost (negative but depending on depth of pile); bridges, pipeline river crossings, dikes, and erosion protection structures (negative); and open-pit mine wall stability (negative).

Impacts on marine fisheries in the eastern part of Region 4, under a moderate gradual warming, are likely to include a return to a cod–capelin system with a gradual decline in northern shrimp and snow crabs. Under more modest assumptions of ocean warming, the range of demersal species those that tend to live near the bottom are expected to expand northward. If ocean warming is more extreme, it is likely that the southern limit of the range of the demersal species would move northward. Many existing capelin spawning beaches are likely to disappear as sea levels rise. If there is an increase in demersal spawning by capelin in the absence of new spawning beaches, capelin survival may decline. Seals may experience higher pup mortality as sea ice thins. Increases in regional storm intensities may also result in higher pup mortality. A reduction in the extent and duration of sea ice is likely to permit fishing further to the north and is likely to shorten the duration of Greenland halibut fisheries that are conducted through fast ice.

Impacts on freshwater and anadromous fisheries, and their economic benefits, such as tourism and local economic development, will vary across Region 4 and will depend on the local present-day and future species composition. Initially, local productivity associated with present-day freshwater and anadromous species is likely to increase, but as critical thresholds are reached e.g., thermal limits and as new species move in to the area, arctic-adapted species such as Arctic char are likely to experience declines in abundance and ultimately become extirpated. Loss of suitable habitat will result in decreased individual growth and declines of many populations, with resulting impacts on sport fisheries and local tourism.

4.4 ***Impacts on people's lives***

The changes in climatic and environmental conditions projected for Region 4, and already being observed in some parts, affect people's lives in many ways. Seasonal unpredictability throughout Region 4 has already created dangerous environmental situations. For example, for the Inuit west of Hudson Bay, changing wind patterns and snow conditions make it difficult to build igloos as the snow is packed too hard. As a result, Inuit report increasing difficulty in building shelters during unexpected storms. In areas of Nunavik and Labrador the snow changes can differ, for example the type of snow now seen does not pack well enough. Changes in weather and ice conditions, such as earlier spring melt, later freeze-up, and formation of more cracks, such as those reported in the Kitikmeot region of Nunavut, result in increasingly difficult travel conditions and sometimes shifts in regular travel and harvesting times.

The changes in local environments experienced by the people in the Canadian part of Region 4 include thinner sea ice, early breakup and later freeze-up of sea ice and lake ice, sudden changes in wind direction and intensity, earlier and faster spring melt periods, decreasing water levels in mainland lakes and rivers, and the introduction of non-native animal and bird species. These changes affect lifestyles through changes in the timing of animal migrations as well as in the numbers and health of some animal populations, and in the quality of animal skins and pelts. The distribution and quality of animals and other resources will affect the livelihoods, and ultimately the health of northern communities in Region 4. For example, a shorter winter season with increased snowfall and less extensive and thinner sea ice is likely to decrease the opportunity and increase the risks for indigenous people to hunt and trap.

Other health impacts may arise from the introduction of new or increasingly present zoonotic and/or vectorborne diseases e.g., potential spread of West Nile virus into warmer regions in the western Arctic, changes in exposure to UV radiation and contaminants that already threaten confidence in and safety of traditional diets, and the associated social and cultural impacts of this combination of changes. Relocation of low-lying communities may be forced by rising sea levels, with serious social impacts. Where these challenges to health already exist, and where infrastructure and support systems are stretched, the effects are likely be experienced to a greater extent and at a faster pace than elsewhere.

Many changes are reported and are currently experienced by Inuit, Dene, Gwitch'in, and other indigenous peoples in Region 4.These changes represent challenges to aspects of northern indigenous cultures and lifestyles that have existed for centuries. The ability of communities to cope with and adapt to climate-driven changes is also influenced by a number of other factors and is constrained by current social and economic aspects. For example, moving people to follow shifting resources is no longer an option with permanent settlements. Other factors complicating adaptations to change include regional resource regulations, industrial development, and global economic pressures. Climate change interacts with such forces and must be considered in assessing local risks and responses. As existing adaptation strategies become obsolete, new adaptations to climate impacts must develop as northern communities adjust to the many social, institutional, and economic changes related to land claim settlements, changes in job opportunities, and the creation of new political and social structures in the North.

## Impact of the Climate change in the Arctic

Summarizing above mentioned details we can say that; in European Arctic, Winters are warmer. Seasonal patterns have changed. Rain/snow Rain is more frequent in winter than before. There are more freeze–thaw cycles, thus more trouble for reindeer grazing in winter. Ice on lakes and rivers is thinner. New species are moving into the region. In Canada and Greenland, Winters are warmer. There has been cooling in Hudson Strait/Baffin Island area, but greater variability. Snow is melting earlier and some permanent snow patches disappear. There is less snow and more wind, producing snow conditions that do not allow igloo building. Water levels in lakes and rivers are falling on the Canadian mainland. Thinner river ice affects caribou on migration (they fall through). Permafrost is thawing, slumping soil into rivers and draining lakes. Caribou suffer from more insects; body condition has declined. Caribou migration routes have changed. In Alaska, Weather patterns are changing so fast that traditional methods of prediction are no longer applicable. There are more storms and fewer calm days. Winters are shorter and warmer. summers longer and hotter. There is less snow. Sea ice is thinner and is forming later. There is increased coastal erosion due to storms and lack of ice to protect the shoreline from waves. . Lakes/rivers/ permafrost Lakes and wetlands are drying out. Permafrost thawing is affecting village water supply, sewage systems, and infrastructure. Trees and shrubs are advancing into tundra. There are die-offs of seabirds and marine mammals due to poor body condition. New species of insects are observed. Sea ice is thinner and is forming later.

Taken together, the body of observations from people residing across the Arctic presents a compelling account of changes that are increasingly beyond what their experience tells them about the past. Indigenous observations of climate and related environmental changes include many other effects on plants and animals that are important to them. These observations provide evidence of nutritional stresses on many animals that are indicative of a changing environment and changes in food availability. New species, never before recorded in the Arctic, have also been observed. The distribution ranges of some species of birds, fish, and mammals now extend further to the north than in the past. These observations are significant for indigenous communities which will have both negative and positive impacts on the culture and economy of arctic peoples.

## The Changing Biodiversity in the Arctic

### *5.1 Background*

The diversity of species in terrestrial, freshwater, and marine ecosystems of the Arctic is fundamental to the life support of the residents of the region and to commercial interests such as fishing at lower latitudes. Diversity is also important to the functioning of arctic ecosystems: productivity, carbon emissions, and albedo are all related to specific characteristics of current arctic species. While the Arctic contains some specialist species that are well adapted to the harsh arctic environment, it also contains species that migrate and contribute to the biodiversity of more southerly latitudes. Each year, whales, dolphins, and hundreds of millions of birds migrate from the Arctic to warmer latitudes. The Arctic is an area of relatively undisturbed and natural biodiversity because of generally lower human impacts than elsewhere on earth. However, at its southern border, human impacts are greater and particular areas, such as old growth forests on land, preserve biodiversity that is endangered in managed areas.

### 5.2 *Patterns of diversity in the Arctic*

The diversity of living organisms at any one time in the Arctic is a snapshot of complex, dynamic physical and biological processes that create habitats and opportunities or constraints for species, and genetically distinct populations of particular species, to colonize them. The current diversity of organisms in the Arctic has been shaped by major climatic and associated changes in physical and chemical conditions of the land, wetlands, and oceans over past glacial and interglacial periods. Changes are presently occurring that are also driven by direct human activities such as fishing, hunting, and gathering, changes in land use, and habitat fragmentation, in addition to indirect human activities such as anthropogenic climate change, stratospheric ozone depletion, and trans-boundary movement of contaminants.

On land, and in freshwater and the marine environment, the fauna and flora are young in a geological context. Recent glaciations resulted in major losses of biodiversity, and recolonization has been slow because of the extreme environmental conditions and overall low productivity of the arctic system. On land, of at least 12 large herbivores and six large carnivores present in steppe–tundra areas at the last glacial maximum, only four and three respectively survive today and of these, only two herbivores (reindeer and musk ox) and two carnivores (brown bear and wolf presently occur in the arctic tundra biome. Arctic marine mammals to a large extent escaped the mass extinctions that affected their terrestrial counterparts at the end of the Pleistocene because of their great mobility. However, hunting in historical times had severe impacts on several species that were exterminated (great auk, sea cow) or almost harvested to extinction (walrus; bowhead whale; sea otter). Polar bears, all the Great Whales, white whales, and many species of colonially nesting birds were dramatically reduced.

The youth of arctic flora and fauna, together with the harsh physical environment of arctic habitats and to some extent over-harvesting, have resulted in lower species diversity in the Arctic compared to other regions. This results in arctic ecosystems, in a global sense, being "simple". Some of the species are specialists that are well adapted to the Arctic's physical environment; others were pre-adapted to the arctic environment and moved north during deglaciation. Overall however, many arctic species – marine, freshwater, and terrestrial – possess a suite of characteristics that allows them to survive in extreme environments. However, these characteristics, together with low diversity and simple relationships between species in food webs, render arctic species and ecosystems vulnerable to the environmental changes now occurring in the Arctic and those projected to occur in the future.

Although diversity of arctic species is relatively low, in absolute terms it can be high: about 6000 marine, freshwater, and terrestrial species have been catalogued in and around Svalbard **(Prestrud et al., 2004: 137)** and about 7200 terrestrial and freshwater species have been recorded in a subarctic area of northern Finland. About 3% (around 5900 species) of the global flora occurs in the Arctic. The diversity of arctic terrestrial animals beyond the latitudinal treeline (6000 species) is nearly twice as great as that of vascular plants and bryophytes. The arctic fauna accounts for about 2% of the global total. In the arctic region as defined by CAFF (Conservation of Arctic Flora and Fauna), which includes forested areas, some 450 species of birds have been recorded breeding, and around 280 species migrate. The diversity of vertebrate species in the arctic marine environment is less than on land. Species diversity differs from group to group: primitive species of land plants such as mosses and lichens are well represented in the Arctic whereas more advanced flowering plants are not; primitive species of land animals such as springtails are well represented whereas more advanced beetles and mammals are not. In contrast, although most taxonomic groups of freshwater organisms in the Arctic are not diverse, some groups such as fish have high diversity at and below the species level. One consequence of the generally low species diversity is that species will be susceptible to damage by new insect pests, parasites, and diseases. For example, low diversity of boreal trees together with low diversity of parasites and predators that control populations of insect pests exaggerates the impacts of the pests.

The number of species generally decreases with increasing latitude. The steep temperature gradient that has such a strong influence on species diversity occurs over much shorter distances in the Arctic than in other biomes. North of the treeline in Siberia, mean July temperature decreases from 12 to 2 °C over 900 km, whereas a 10 °C decline in July temperature is spread over 2000 km in the boreal zone, and July temperature decreases by less than 10 °C from the equator to the southern boreal zone. Patterns of species diversity in the Arctic also differ according to geography. With its complicated relief, geology, and biogeographic history, there are more species on land in Beringia at a given temperature than on the Taymir Peninsula. Taymir biodiversity values are intermediate between the higher values for Chukotka and Alaska, which have a more complicated relief, geology, and floristic history, and the lower values in the eastern Canadian Arctic with its impoverished flora resulting from relatively recent glaciation. Within any region, biological hot spots occur, for example below predictable leads in the sea ice, polynyas, oceanographic fronts, areas of intense mixing, and the marginal ice zone in the marine environment; in delta areas that lie at the interface between rivers and lakes or oceans; and at the ecotone between tundra and taiga on land where elements of both forest and tundra floras and faunas mix. Such hotspots are centers from which species with restricted distributions can expand during climatic warming.

An important consequence of the general decline in numbers of species with increasing latitude is an increase in abundance and dominance. For example, on land, one species of collembolan, may constitute 60% of the total collembolan density in the polar desert. In freshwater ecosystems, midge and mosquito larvae are particularly abundant but species-level diversity is low. These "super-dominant" species, such as lemmings in peak years of their population cycles, are generally highly plastic, occupy a wide range of habitats, and generally have large effects on ecosystem processes. Similarly, arctic fish communities of the marine environment are dominated by a few species, several of which are commercially important, while the abundance of fish, marine mammals, and birds attracted hunters and fishing enterprises in historical times. Loss/reduction of one or more of these species, particularly fish species, will have disproportionate impacts on economy and ecosystem function.

### 5.3 *Characteristics of arctic species related to the arctic environment*

Several physical factors make arctic marine systems unique from other oceanic regions including: a very high proportion of continental shelves and shallow water; a dramatic seasonality and overall low level of sunlight; extremely low water temperatures (but not compared with arctic terrestrial habitats); presence of extensive permanent and seasonal sea-ice cover; and a strong freshwater influence from rivers and ice melt. Arctic freshwater environments are also characterized by extreme seasonality and low levels of incident radiation, much of which is reflected due to the high albedo of snow and ice. In addition, the thermal energy of a substantive part of this incoming radiation is used to melt ice, rendering it unavailable to biota. However, large arctic rivers with headwaters south of the Arctic act as conduits of heat and biota.

On land, low solar angles, long snow-covered winters, cold soils with permafrost, and low nutrient availability in often primitive soils limit survival and productivity of organisms. Many species of marine and terrestrial environments migrate between relatively warm wintering grounds in the south and the rich, but short-lived, feeding and breeding grounds in the Arctic. In freshwater ecosystems, some fish are highly migratory, moving in response to environmental cues. Those species that do not migrate have a suite of characteristics (behavior, physiology, reproduction, growth, development) that allow them to avoid the harshest weather or to persist. Two characteristics common to marine, freshwater, and terrestrial arctic organisms are a protracted life span with slow development over several years to compensate for the brevity and harshness of each growing/feeding/ breeding season, and low reproductive rates. These characteristics render arctic organisms in general vulnerable to disturbance and environmental change.

### 5.4 *Responses of biodiversity to climate and UV radiation change*

The past and present patterns of biodiversity in the Arctic, the characteristics of arctic species, together make it possible to infer the following likely changes to arctic biodiversity. The total number of species in the Arctic will increase as new species move northward during warming. Large, northward-flowing rivers are conduits for species to move northward. New communities will form. Present arctic species will relocate northward, as in the past, rather than adapt to new climate envelopes, particularly as the projected rate of climate change exceeds the ability of most species to adapt. However, some species, particularly freshwater species, may already be pre-adapted to acclimate successfully to rapid climate change.

Locally adapted species may be extirpated from certain areas while arctic specialists and particular groups of species that are poorly represented in the Arctic – some through loss of species during earlier periods of climate warming – will be at risk of extinction. Examples of arctic specialists at risk include polar bears, and seals of the ice margins in the marine environment, and large ungulates and predators on land. Presently super-abundant species will be restricted in range and abundance with severe impacts on commercial fisheries, indigenous hunting, and ecosystem function. Examples on land include lemmings, mosses and lichens, and some migratory birds. On land, shifts in major vegetation zones such as forests and tundra will be accompanied by changes in the species associated with them. For example, tree seed-eating birds, and wood-eating insects will move northward with trees.

Low biodiversity will render ecosystems more susceptible to disturbance through insect pest infestations, parasites, pathogens, and disease. At the small scale, changes will be seen in the representation of different genetically separate populations within species. In cases such as Arctic char, the species may remain but become geographically or ecologically marginalized with the potential loss of particular morphs.

Changes in UV radiation levels are likely to have small effects on biodiversity compared with climate warming. However, UV radiation has harmful effects on some fish larvae, on those amphibians that might colonize the Arctic, and on some microorganisms and fungi. In freshwater ecosystems, increased UV radiation levels could potentially reduce biodiversity by disadvantaging sensitive species and changing algal communities. All the projected changes in biodiversity resulting from changes in climate and UV radiation levels are likely to be modified by direct human activities. Protection and management of some areas have led to the recovery of some previously declining species while deforestation, extractive industries, and pollution have prevented forests and associated species from moving northward during recent warming in some areas. Protection of ecosystems from the impacts of changes in climate and UV radiation in the long term is difficult and perhaps impossible

## 5.5 Abrupt climate change and extreme events

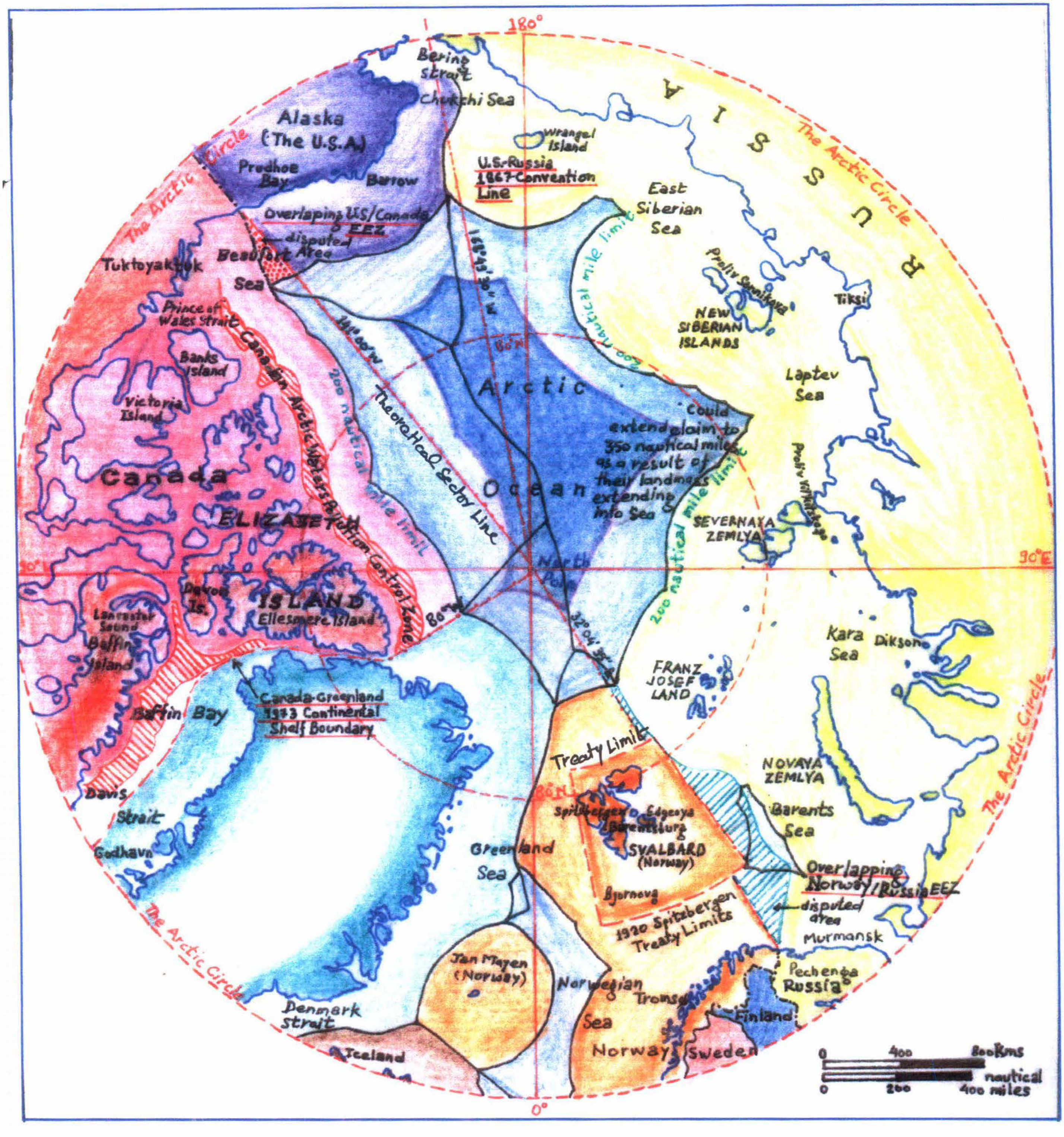
Human activities are causing atmospheric concentrations of CO2 and other GHGs and aerosols to change slowly from year to year, thereby causing the radiative forcing that drives climate change to shift slowly. However, the resulting changes in climate and associated impacts do not necessarily have to change slowly and smoothly. First, the natural interactions of the atmosphere, oceans, snow and ice, and the land surface, both within and outside the Arctic, can cause climatic conditions to fluctuate. These variations can cause months, seasons, years, and even decades to be warmer or cooler, wetter or drier, and even more settled or more changeable than the multi-decadal average conditions. Intermittent volcanic eruptions and variations or cycles in the intensity of solar radiation can also cause such fluctuations. These types of fluctuations can be larger than the annual or even decadal increment of long-term anthropogenic global climate change. Present model simulations project a slow and relatively steady change in baseline climate while natural factors create fluctuations on monthly to decadal scales. As the baseline climate changes, the ongoing fluctuations are very likely to cause new extremes to be reached and the occurrence of conditions that currently create stress are likely to increase significantly.

The climatic history of the earth shows that instead of climate changing steadily and gradually, change can be intermittent and abrupt in particular regions – even very large regions. Reconstructions of climatic variations over the last glacial cycle and the early part of the current interglacial some 8000 to 20000 years ago suggest that temperature changes of several degrees in the large scale , long-term climate occurred over a relatively short period. For example, ice cores indicate that temperatures over Greenland dropped by as much as 5 °C within a few years during the period of warming following the last glacial. These changes were apparently driven by a sharp change in the thermohaline circulation of the ocean, which probably also prompted changes in the atmospheric circulation that caused large climatic changes over land areas surrounding the North Atlantic and beyond. Over multi-decadal time periods, persistent shifts in atmospheric circulation patterns, such as the North Atlantic and Arctic Oscillations, have also caused changes in the prevailing weather regimes of arctic countries, contributing, for example, to warm decades, such as the 1930s and 1940s, and cool decades, such as the 1950s and 1960s.

A recent example of a rapid change in arctic climate was the so-called regime shift in the Bering Sea in 1976, which had serious consequences and impacts on the environment. In 1976, mean annual temperatures in Alaska experienced a step-like increase of 1.5 °C to a lasting new high level, shown as the average of several measuring stations. Sea-ice extent in the Bering Sea showed a similar step-like decrease of about 5% . An analysis by Ebbesmeyer et al. (1991) gave statistical measures of deviation from the normal of 40 environmental parameters in the North Pacific region, as a consequence of this rapid change. Parameters included air and water temperatures, chlorophyll, geese, salmon, crabs, glaciers, atmospheric dust, coral, CO2, winds, ice cover, and Bering Strait transport. It can be concluded that ***"apparently one of the Earth's large ecosystems occasionally undergo large abrupt shifts".***

CHAPTER 5

# Geopolitics of Climate Change in melting Arctic Ocean




<u>**Map. No.5 The Dispute Hotspots and the Claim over the Arctic Ocean.**</u>

## CHAPTER-V

# Geopolitics of Climate Change in melting Arctic Ocean

Geopolitics has played an important part in the Arctic affairs since the beginning of the Cold War era. Up to then the technology necessary for operating in the area was largely lacking, but advances during and after World War-II have opened the way to many types of activities in the Arctic. The Arctic Ocean is a short of enclosed ice-capped water body between the two powers long supposed most likely to be in conflict. Thus each side feared air attack across the Arctic Ocean and built chains of radar stations at high latitude in its own territory to give warning. In the North America four such chains were built successively—the Pine tree line, the mid-Canada line, the Distant Early Warning (DEW) Line, and the Ballistic Missile Early Warning System (BMEWS).

De Servesky advocated a totally new strategy and organization for victory through air power. He advocated defense of the Western Hemisphere, avoidance of small wars as useless sapping of American strength, abandonment of overseas bases as costly. For first time in such geopolitical writings, he used a map, which resulted in a new view of the world, the United States and Canada erected at great expense above mentioned three lines of radar station and air bases, stretching across Alaska and Canada for the defense of North America against attack from the then USSR by the shortest routes—over the North Pole across the Arctic Ocean **(De Servesky, Alexander P., 1942).**

The Cold War thrust the Canadian Arctic into new strategic prominence. The Distant Early Warning (DEW) Line was constructed as a defense against a transpolar attack and consisted of a series of roughly concentric circles of antiaircraft and antimissile bases in Canada and the northern United States. The North American Aerospace Defense Command (NORAD) became a cornerstone of U.S. strategic policy, as some of its most important base, both defensive and offensive, were placed on Canadian soil. In addition to the air component, American missile-carrying nuclear submarines prowled the waters below the Arctic ice cap as they maintained their watch over the transpolar rival **(Cohen, S. B., 2003).**

Another strategic advantage of the Arctic Ocean derives from its solid surface, which offers protection to submarines operating under the ice. Both the U.S.A. and the then Soviet submarines made numerous and extensive patrols in this areas; and mastery of the technique allowed the then Soviet missile-firing submarines to target any part of the U.S. territory from an ice-covered location in the Arctic Ocean, within the close reach of their main base at Murmansk. The former Soviet government took advantage of the remoteness factor to locate a nuclear weapons testing ground on the north island of Novaya Zemlya.

All land areas in the Arctic are subject to the sovereignty of one of the eight countries concerned, and there is no possibility of a new discovery of land. In the Arctic, the geographical pole lies under a frozen sea, at a depth of almost 4,500 metres, in the middle of an oceanic trough covering 13million square km. The greater part of the area is made up of a permanently drifting ice-pack. This oceanic pole is surrounded by islands or lands with very indented coastline coastlines, inhabited at the north of the Arctic Circle (2 million inhabitants). But for sea areas, nation-states claim rights in the sea areas adjacent to their coasts; which have caused problems at international level. In particular, the boundary line at sea between two countries' exclusive economic zones (EEZ) has not in every case been agreed upon. The most important of these is the division between Norway and Russia of the Barents Sea continental shelf, an area that contains hydrocarbons. The question of sovereignty over the frozen sea-ice cover is another unresolved issue. The Theory of Sectors was far from being generally accepted, and the countries which invoked or applied it did so neither in particularly clear terms nor using unequivocal procedures

### 5.I.1. Position of the United States

The United States declined, in 1924, to proclaim its sovereignty over a sector at the north of Alaska; there is no land in this region, so there is no way of knowing whether the Washington Government considered the theory applicable at least to the emerged lands. The equidistant line between Canada and Alaska certainly favours the United States in the Beaufort Sea, near Prudhoe Bay, where hydrocarbon can be advantageously exploited. The demarcation line between the United States and Russia is maritime; the 1867 Convention established this along two straits. The first runs from off Kamtchaka in a north-easterly direction to the middle of the Bering Strait. The other, starting from this point, follows the 168"49'30" meridian West through the Chukchi Sea, giving it the appearance of beginning of a sector line; in 1867 the theory of sectors did not exist.

At a meeting held at the Naval Ice Center on 7 July, 2000 with representatives from the National/Naval Ice Center, the Oceanographer of the Navy (N096), the Office of Naval Research (ONR), MEDEA, the Arctic Research Commission, and U.S. Coast Guard the national and strategic issues surrounding operations in an ice-free, or ice-diminished Arctic were framed. It was recommended that a forum be established to evaluate the Naval implications of operating in an ice-free Arctic. In order for this forum to succeed it was deemed essential that the views of nationally recognized experts on Arctic climate change be presented to the Navy in order to assure a sound scientific basis for future planning. The US Arctic Research Commission undertook to survey the community of experts in the field and to present their views to the Navy as a basis for further planning. The following is an edited compilation of the views of that panel of experts convened by the United States Arctic Research Commission to assist the Navy in considering the effects of climate change on their operations in and around the Arctic Ocean in the mid to late Twenty First Century.

#### 5.I.1.2 Position of Denmark

Denmark has not adopted the theory of sectors which would, moreover, have been extremely difficult to apply to the west on the Canadian island of Ellesmere is situated to the north of Greenland. An arrangement between Canada and Denmark in 1973 established a line dividing the continental shelf based on the principle of equidistance, though without applying the theory of sectors strictly.

#### 5.I.1.3 Position of Norway

Norway does not recognize the theory of sectors, by which it would lose a substantial area of continental shelf and of its economic zone in the Barents Sea.

### 5.1.1.4 Position of Canada

The theory was born of Senator Poirier's proposal for a formal declaration leading to taking possession of "the lands and islands situated at the north of the Dominion and extending to the North Pole". But the senator was more ambiguous in his comments; at certain points about the lands situated in the sector, according to his statements any country contiguous to the Arctic regions would simply extend its possession up to the North Pole. There was a time when Newfoundland and Labrador were not part of Canada. The Norwegian Amundsen had been first to conquer the North-West Passage (1903-1906), another Norwegian, Nansen, had reached the 86$^{th}$ latitude North in 1893, and the American Peary was to reach the North Pole in 1990.

Although Canada invoked the theory on 10 June 1925, when it proclaimed its sovereignty in the direction of Pole, an appropriation of the waters and ice-packs beyond the territorial sea was never officially stated. The remarks made by Members of Parliament or the Authorities have no legal value. The existence of official Canadian maps showing sector lines may not be sufficient in itself, even the decision of the International Court of Justice on the case concerning the sovereignty of certain border regions did attach some worth to official maps.

The passage of the American tanker ***Manhattan*** through the waters bordering the north of Canada to Alaska in 1969 confirmed the possibility of international navigation in these regions. It also led the Canadian Government to promulgate the law on the prevention of pollution of the Arctic for protection and preservation of the marine environment. The preamble of the Canadian Arctic Waters Pollution Control Law refers to "the Arctic waters contiguous to the continent and islands of the Canadian Arctic", whereas Article 3 makes the law applicable within the zone delimited by the sixtieth parallel of latitude North, the hundred and forty-first meridian of longitude and a line at sea each point of which is at a distance of one hundred sea miles from the nearest Canadian land; with this restriction that, in the zone situated between the islands of the Canadian Arctic and Greenland, at the point where the line equidistant from the islands of Canada and Greenland is less than one hundred sea miles, this equidistant line will be substituted . We can conclude that Canada does not claim jurisdiction in the name of protection of the Arctic ecosystem. A possible explanation for Canada's circumspection and ambiguity on the subject of the theory of sectors could be the fact that its two Arctic neighbours, the United States and Denmark, do not accept it.

**5.I.1.5 Position of Russia**

No sooner had the Swede Nordenskjold forged through in the **North-East Passage** (1878-1880) than Russia turned its attention to controlling navigation in these regions. At the time of the Russo-Japanese War in 1905 it had already developed its maritime activities there. Russia alone formally applied the theory of sectors, on 15 April 1926, by proclaiming its sovereignty in the direction of the North Pole. It affirmed this sovereignty, however, only over those lands and islands situated between 32" 04' 35" longitude East, 168" 49' 30" longitude West and the North Pole, which amounted to applying the theory to the zone comprised between the Finno-Russian land frontier of the time and the middle of the Bering Strait, extending the line established by the 1867 Convention between the United States and Russia. The annexation of the Finnish coastline after the Second World War does not appear to have led to any official modification to the boundary of this sector.

Many Russian press agencies or authors have maintained, from as far back as 1928, that the peculiar nature of these regions justified the appropriation of the high seas therein. The Russian authorities do not seem to have protested when American Submarines, having navigated under the ice, emerged at the North Pole, where the Russian sector necessarily ends. Nor have they done so when American aerial activities have over flown this sector or when drifting scientific stations have moved into it on the high seas. The fact that Russian authors have used expressions such as "internal waters", "historic bays" or "enclosed seas" when describing the coastal regions of the Russian Arctic does not help to elucidate the problem; these expressions are not compatible with the strict theory of sectors, but rather with that of a sovereignty limited in the sector to the emerged lands only, as affirmed by the decree of 1926. The seas of Eastern Siberia, Laptev and Kara in particular, without prejudice to the theory of sectors, do not comply with the definitions in Article 122 of the 1982 Convention of enclosed or semi-enclosed seas; as for the "historic bays", these have never been the subject of any accepted definition, nor are they mentioned in the Conventions of 1958 or 1982. Only the White Sea complies with the geographical definition of an enclosed or semi-enclosed sea, but as it is not surrounded by several States, the provisions of Part IX of the 1982 Convention do not apply to it.

## 5.I.1.6 SPITSBERGEN

Spitsbergen archipelago (Svalbard in Norwegian) was for a long time without any legal status and could be considered as *res nullius,* though it was contested at the beginning of seventeenth century by fishermen from England, the Netherlands, Denmark and Hamburg. Norway had attempted without success in 1871-1872 and again in 1907-1908 to put the question of the status of the Arctic, and Spitsbergen in particular, officially to international opinion. It was only after the First World War that the Paris Treaty of 9 February 1920 relating to the Status of Spitsbergen was concluded.

Concluded between the United States, the United Kingdom, Denmark, France, Italy, Japan, the Netherlands, Norway and Sweden, the Paris Treaty was open to accession by other States at the invitation of the French Government; some forty other States are at present bounded the Treaty. The Treaty recognizes "subject to the stipulation of the present Treaty" Norway's "full and absolute" sovereignty over the Spitsbergen archipelago and Bear Island, comprising all the islands situated between longitudes 10 and 35 East and latitudes 74 and 81 North. Despite the terms quoted above, this is not an unconditional sovereignty; it is affected with various constraints.

Article 2 of the Treaty establishes the principle of freedom of access, fishing and hunting rights for the ships and nationals of the Contracting Parties. Article 3 affirms equality in the pursuance of all maritime, industrial, mining and commercial enterprises, both on land and in the territorial waters. Article 9 prohibits the establishments of naval bases or fortifications, or the use of the archipelago for warlike purposes. Article 8 provides for mining regulations which shall exclude all privileges, monopolies or favours; it permits a taxation system only if the income from this is devoted to the Spitsbergen region; the mining regulations drawn up by the Norwegian Government should be submitted to other Contracting Parties and in the event of disagreement to an international commission which will examine them and take its decisions by a majority vote.

Russia was in fact the only Power directly interested in the exploitation of Spitsbergen; its rights have been guaranteed by Article 10, which sets forth that:

"Until the recognition by the High Contracting Parties of a Russian government shall permit Russia to adhere to the present Treaty, Russian nationals and companies shall enjoy the same rights as nationals of High Contracting Parties." The accession of the Russia to the Treaty on 7 May 1953 has undoubtedly strengthened the special status thus established for Spitsbergen.

The 1920 Treaty on Spitsbergen was concluded at a time when the law of the sea recognized no jurisdiction over areas of sea other than territorial waters, traditionally fixed at 4 nautical miles in the Scandinavian countries, which limit was, moreover, formally accepted by the United Kingdom in 1951 when the case of the Anglo-Norwegian fisheries was brought before the International Court of Justice.

The 1920 Treaty establishes the sovereignty of Norway, which has the right to legislate in Spitsbergen and to ensure respect for its laws therein. However, several constraints lay an obligation on Norway to treat the nationals of the other Contracting Parties on an equal footing. For this reason the Norwegian law of 17 July 1925, which affirms that Spitsbergen forms part of the Kingdom of Norway, lays down that Norwegian legislation is not automatically applicable there.

Norway maintains that its sovereignty cannot be called into question by extensive interpretation going beyond the formal provisions of Articles 2,3 and 8, that the Treaty applies to the islands and their territorial waters of 4 nautical miles and that consequently the continental shelf on which the islands stand falls within the jurisdiction of ordinary Norwegian law, set out in the Royal Resolution of 8 December 1972 on the continental shelf, and not that of specific rules governing Spitsbergen. Furthermore, it stresses that the archipelago, situated on Norway's continental shelf, does not have any continental shelf of its own. It applies the same line of reasoning to the exclusive economic zone, a new concept which has been integrated into general international law, but which is not covered by the provisions of the 1920 Treaty.

This line of argument does not appear convincing to others. It omits the most important fact that the 1920 Treaty applies not only to the emerged lands and their territorial waters, but also to the whole area falling between the 74th and 81st parallels' North and the 10th and 35th meridians of longitude East, taking in large areas of what in 1920 were the high seas. More than 600km of high seas separates the southernmost point of the largest island from the south-eastern angle of the zone. Any extension of the jurisdiction of the coastal State in this zone must perforce be subject to the application of the provisions of the Treaty; it would be unreasonable to think that the Contracting Parties enjoyed equal treatment with regard to mineral, hunting and fishing activities on those lands and in those territorial waters, the treaty states "territorial waters" without determining the limits of these; subject to the "full and absolute" sovereignty of Norway, but did not benefit from this in zones where the latter only exercised sovereign rights for stated purposes.

**5.I.2.1 <u>The Scramble for Arctic Resources</u>:**

The scramble among countries near the Arctic seabed or navigation rights and control of oil resources in the Arctic is related to recent reports on melting of the Arctic ice cover –three times faster than earlier believed. But as Russia, Canada, the United States and other countries stake claim to the Arctic basin which has huge untapped oil and gas reserves, the urgent need is to protect the fragile, life-sustaining region. In August 2007, the Russians planted their flag beneath the ice at the North Pole, Canada has announced plans to build a docking facility and the United States has dispatched a mission to survey the controversial seabed. The contention is over the 1800-km Lomonsov Ridge from Greenland near Norway to the Siberian coast and the Northwest Passage waterway that passes through Canada and can cut by a third the sea route between Asia and the United States east coast.

While the South Pole has been recognized as an arena for scientific cooperation where military activity is forbidden under the Antarctic Treaty system, the North Pole is open to territorial claims by the industrialized countries. But under international law, the countries have to furnish scientific evidence to back their territorial claims within a decade of applying as per the UN Convention on Law of the Seas.

It is not clear whether and to what extent the continental shelf of the countries extends up to the disputed spots. Where the United States of America is concerned, it has not even ratified the UN Convention.

### 5.I.3 The Russian Efforts

Four Russian and two foreign explorers abroad a pair of deep-sea submersibles: Mir-1, Mir-2 made an unprecedented journey in August 2007 to probe the remote seabed beneath the North Pole. To symbolize Moscow's claim to the polar territory and all its resources, they planted a tricolor Russian flag made of rust-proof titanium in the "yellow muck" nearly 4,300 metres below the Pole, before returning safely to the small fleet of research ships on the icebound surface.

Before making the dive, Chilingarov, Russia's most famous Arctic explorer and a deputy speaker of parliament, made clear that the effort is not just about expanding the horizons of science. "We are here to define the outer limit of Russia's territory", he said. The issue of who owns the North Pole, now days administered by international Seabed Authority, has long been regarded as academic since the entire region is locked in year-round impenetrable ice. But with global warming thinning the icecaps at, by some accounts, as much as 9 per cent a year, the question has vaulted to the front burner.

As milder temperatures make exploration of the Arctic seafloor possible for the first time, Russia's biggest-ever polar mission appears to have beaten all potential rivals in the race to stake out a claim at the Earth's cap. The rock samples and other data gathered by the submarines will be used to support Russia's claim to own 1.2 million 59 km of hitherto international territory in a region estimated to contain 25 per cent of the world's undiscovered oil and gas reserves.

The US Geological Survey estimates that one-quarter of the world's undiscovered oil and gas reserves lie beneath the Arctic Ocean, Experts at the Russian Institute of Oceanography calculate that the saddle-shaped territory that Russia is planning to claim may contain up to 10 billion tons of petroleum, plus other mineral resources and vast, untapped fishing stocks. The 1982 Law of Sea Convention establishes a 12-mile off-shore territorial limit for each country, plus a 200 nautical mile "economic zone" in which it has exclusive rights. But the law leaves open the possibility that the economic zone can be extended if it can be proved that the seafloor is actually an extension of a country's geological territory.

It is for first time that man dived so deep into the ocean and the first time that he reached seabed at the North Pole. The issue of who owns the North Pole, now administered by the International Seabed Authority, has long been regarded as academic since the entire region is locked in year-round impenetrable ice. But with global warming thinning the icecaps, the question has come to the fore. According to international law, five countries Russia, the United States, Canada, Norway and Denmark have territory inside the Arctic Circle.

The first submarine to travel to the North Pole was the United States' submarine – USS Nautilus in 1958. But it did not stop on sea floor. Similarly, a planned Russian expedition in 1998 could not materialize as the Russian financial markets crashed at that point of time. The Russian claim over the 1.2 million km square of the Arctic territory is based on the argument that the Lomonosov Ridge is based on the argument that the Lomonosov Ridge is an extension of continental Russia. The five Arctic countries control an economic zone within 200 nautical miles of their coastline.

But a group of Russian scientists returned from a six-week Arctic mission in June 2007 insisting that' they had uncovered solid evidence to support the Russian claim. That paved the way for the August 2007 expedition, led by the Russia's most famous Arctic explorer Artur Chilingarov, which included the ***Rossiya***, the giant nuclear- powered icebreaker, the huge research ship ***Akademik Fyodorov,*** two Mir deep sea submersibles previously used to explore the wreck of the ***Titanic*** and about 130 scientists. The dive beneath the North Pole involved collecting evidence about the age, sediment thickness, and types of rock, as well as other data-all of which will be presented to the United Nations Commission on to support Russia's claim to the territory.

### 5.1.3. The Lomonosov and Alpha-Mendeleev Ridges :

The Lomonosov and the Alpha-Mendeleev Ridge transverse the Arctic Ocean, from the margin of Siberia to that of Greenland and North America. The locations of morphological breaks need to be explained if the ridges are to be characterized as natural prolongation. The termination of these ridges against the edges of the Eurasian and Amerasian continental margins would seem to qualify them as natural prolongations of those margins. Indeed, it would appear that the central Arctic component of the Russian Federation's submission of 2001 was predicted on precisely that assumption. Informal indications suggest that CLCs (The commission on the limits of the continental shelf) rejected this interpretation, in part because of morphological breaks that were perceived to separate the ridges from the adjacent continental margin.

### 5.I.4 Submarine Elevations and Ridges of the Arctic Ocean

The seafloor visualization shown in the accompanying figures are derived from the ETOPO2 world bathymetric model (National Geophysical Data Centre 2001).It should be noted that the CLCS will not accept submission that are based on the ETOPO2 model because it consists for the most part of depths that are derived from observations of satellite imaginary altimetry and which are poorly resolved both horizontally and vertically. On the other hand, the representation of the bathymetry of the Arctic Ocean is drawn from the International Bathymetry Chart of the Arctic Ocean **(Jakobsson M., N.Cherkis, J.Woodward, R.Macnob & B.Coakley. 2000 : 81 ,89, 93, 96. respectevily)** which is based on acoustic observations of depth and which may prove more acceptable to the CLCS.

#### 5.I.4.1 The Reykjanes Ridge Iceland

The characterization of the Reykjanes Ridge has long been recognized as a significant challenge. As a component of globe-girdling mid-ocean ridge (MOR), it is clearly an oceanic structure but at the same time, it may be fairly viewed as a natural prolongation of the landmass of Iceland which is itself an uplifted segment of the MOR. It remains to be seen what combinations of formula and constraint lines will meet with the CLC's approval when considering a proposal continental self over this feature.

#### 5. I.4.2 Orphan knoll and the Newfound land Ridge, Canada

Orphan knoll and the Newfoundland Ridge are considered to have originated in two very different fashions, and therefore to vary significantly in their geological character orphan knoll is a continental fragment that was entrained eastward on the opening of the north Atlantic, then stranded at some distance from the margin of the present day grand banks whether or not orphan knoll qualifies as a natural prolongation will likely depend on the nature of the crust between it and the grand banks. The newfound land ridge, on the other hand is believe to have developed as a magmatic extrusion along the line of a transform fault during the opening of the north Atlantic .There can be little doubt that it is a natural prolongation, however, there could be some debate over the combination of formula and constant lines that would be most appropriate for defining the outer limit.

### 5.I.4.3 The South Greenland Ridge

The south Greenland ridge may have formed during the separation of Greenland from Labrador in eastern Canada and then to have active as a depositional centre for sedimentary material that was swept southward along the east coast of Greenland. Similar to lomonosov and alpha-mandeleev ridges in the arctic ocean. The south Greenland ridge features a morphotological discontinuity that could disqualify it as a natural prolongation. Unless further investigation establishes a deep geological connection with the island's landmass. The commission on the limits of the continental shelf has attempted to clarify matter in chapter seven of its scientific and technical guidelines (United Nations,1999). In a discussion in which i9t acknowledges the impracticality of pre classifying the types of ridges structures and that are likely to be encountered during national implementation of article 76, the CLS's concludes by declaring that "the issue of ridges will be examined on case-by-case basis."

In qualifying the term "submarine elevations" the CLCs makes a distinction between active and passive margins. In an active margin setting material that is transported from elsewhere and which is accreted to the continental margin is to be considered as a natural component of that margin. In a passive margin setting, a sea floor elevation consisting of material that has been newly created in situation is to be similarly viewed if it is integral to the prolongation of the coastal state's landmass. In neither case it clear what to do if such an elevation assumes the form of a ridge.

## <u>5.I.4.4 The Lomonosov and Alpha-Mendeleev Ridges , Arctic Ocean</u>

Lomonosov Ridge and the Alpha-Mendeleev Ridge traverse the Arctic Ocean, from the margin of Siberia to that of Greenland and North America **(V.A.Poselov, A.N.Minakov, V.Y.Glebovsky and A.A.lickhachev, 2007).** The locations of morphological breaks that need to be explained *<u>if the ridges are to be characterized as natural prolongation.</u>*

The termination of these ridges against the edges of the Eurasian and Amerasian continental margins would seem to qualify them as natural prolongations of those margins. Indeed, it would appear that the central Arctic component of the Russian Federation's submission of 2001 was predicted on precisely that assumption. Informal indications suggest that CLCS UNCLOS- United Nations Convention of the Law of the Sea rejected this interpretation, in part because of morphological breaks that were perceived to separate the ridges from the adjacent continental margin. The Russian Federation has since mounted two major field expeditions over the Mendeleev and lomonosov ridges to refute the CLC's view and to confirm the existence of geological links between these ridges and the Siberian margin **(Kaminsky, V.A. Poselov, V.Y. Glebovsky, A.V. Zayonchek and V.V Butsenko; 2007).** This episode has underscored the generally poor understanding that exist of the region's geological framework and tectonic history, suggesting that the CLCS- The commission on the limits of the continental shelf; needs to create carefully when formulating its recommendations in such areas.

Submarine elevations and ridges present an array of definitional uncertainties to coastal states that are engaged in the high- slakes process of delimiting extended continental shelves. Faced with the imprecise terminology of Article 76, with the non specific wording of the scientific and technical guidelines of the commission on the limits of continental shelf (CLCS), and with the commission's rule of confidentiality that hamper the open exchange of information concerning ridge and elevation assessment in previous continental shelf implementations, a coastal state needs to develop its own evaluation of what might and might not pass the "test of appurtenance." Significant components of a continental shelf submission might thus be formulated on the basis of these national evaluations. Only to have CLCS question them, which could necessitate a potentially expensive and time- consuming reworking of the submission **(Macnab, Ron; 2008: 223-224).**

One of the more vexing aspects of Article 76 of the UNCLOS- United Nations Convention of the Law of the Sea, is the challenge of determining whether a specific submarine elevation or ridge meets the "test of appurtance" (i.e ,it a legitimate natural prolongation of a coastal state's land territory?) The wording of Article 76 is manifestly unhelpful in referring to entitles such as "Oceanic ridges", "Submarine ridges", "Submarine elevation" and plateaux, rises, caps, banks and spurs; While offering no formal definitions that describe their morphological characteristics.

## 5.II.SNOW AND ICE COVER OVER THE ARCTIC OCEAN

The effect of twentieth-century climate change on global snow and ice cover are apparent in many ways, but the responses differ widely as a result of the different factors and timescales involved. Snow cover is essentially seasonal, related to storm system precipitation and temperature levels. Sea ice is also seasonal in the marginal seas of the Arctic Ocean and around much of the Antarctic continent, but the central Arctic has thick multi-year ice Seasonal (or first-year) ice grows and decays in response to ocean surface temperature, radiation balance, snowfall and ice motion due to winds and currents. The loss of multiyear ice from the Arctic is mainly through ice export. Glacier ice builds up from the net balance of snow accumulation and summer melt (ablation), but glacier flow transports ice towards the terminus, where it may melt or calve into water. In small glaciers, the ice may have a residence time of tens or hundreds of years, but in icecaps and ice sheets this increases to 1000to 10000 years.

In the twentieth century, there has been a rapid retreat of most of the world's glaciers. Glaciers in the North Atlantic area near the north pole, retreated during the 1920s to the mid-1960s and since 1980, due largely to temperature increases, which have the effect of lengthening the ablation season with a corresponding raising of the snowline. In the past ten or fifteen years the freezing level in the troposphere has risen in the inner tropics by 100 to 150m; contributing to rapid ice loss on equatorial glaciers in East Africa and the northern Andes. Also in the past decade or so, some glaciers in maritime climates (western North America and Scandinavia) have shown advances, due to heavier snowfalls during warmer winters. Major alpine glaciers in many areas of the world have lost mass and shrunk since the late nineteenth century, whereas smaller ones show short-term fluctuations in response to climatic variability. There has been accelerated retreat in some areas since the 1970s, especially in Alaska and central Asia. Projections for 2050 AD suggest that a quarter of the present glacier mass may disappear with critical and irreversible long-term consequences for water resources in alpine countries.

Another tendency illustrating world warming is the retreat of Arctic sea ice. Ports in the Arctic remained free of ice for longer periods during the 1920s to 1950s, for example. This trend was reversed in 1960s to 1970s, but since 1978 the annual extent of Arctic ice has decreased by almost 3 percent per decade with large reductions in summer, particularly in the Eurasian Arctic in 1990, 1993 and 1995, north of Alaska in 1998 and in the central Arctic in 2001. Between the 1960s-70s and early 1990s, ice in the central Arctic Ocean thinned but the magnitude of this is uncertain due to spatial and seasonal sampling limitations. The changes may reflect a redistribution of ice mass by shifts in ocean and wind circulations.

Major iceberg calving events have occurred over the past ten or fifteen years. The causes of such calving are more related to the long history of ice shelves and ice dynamics than to recent climatic trends. However, the disintegration of ice shelves in the Arctic polar region is attributed to regional warming of 2.5" C over the past fifty years.

Snow cover extent shows the clearest indication of a response to recent temperature trends. Northern hemisphere snow cover has been mapped by visible satellite images since 1966. Compared with the1970s to mid-1980s, annual snow cover since 1988 has shrunk by about 10 percent.

### 5.II.1 The melting of the Arctic Ocean and geopolitics of the Northern Sea Route

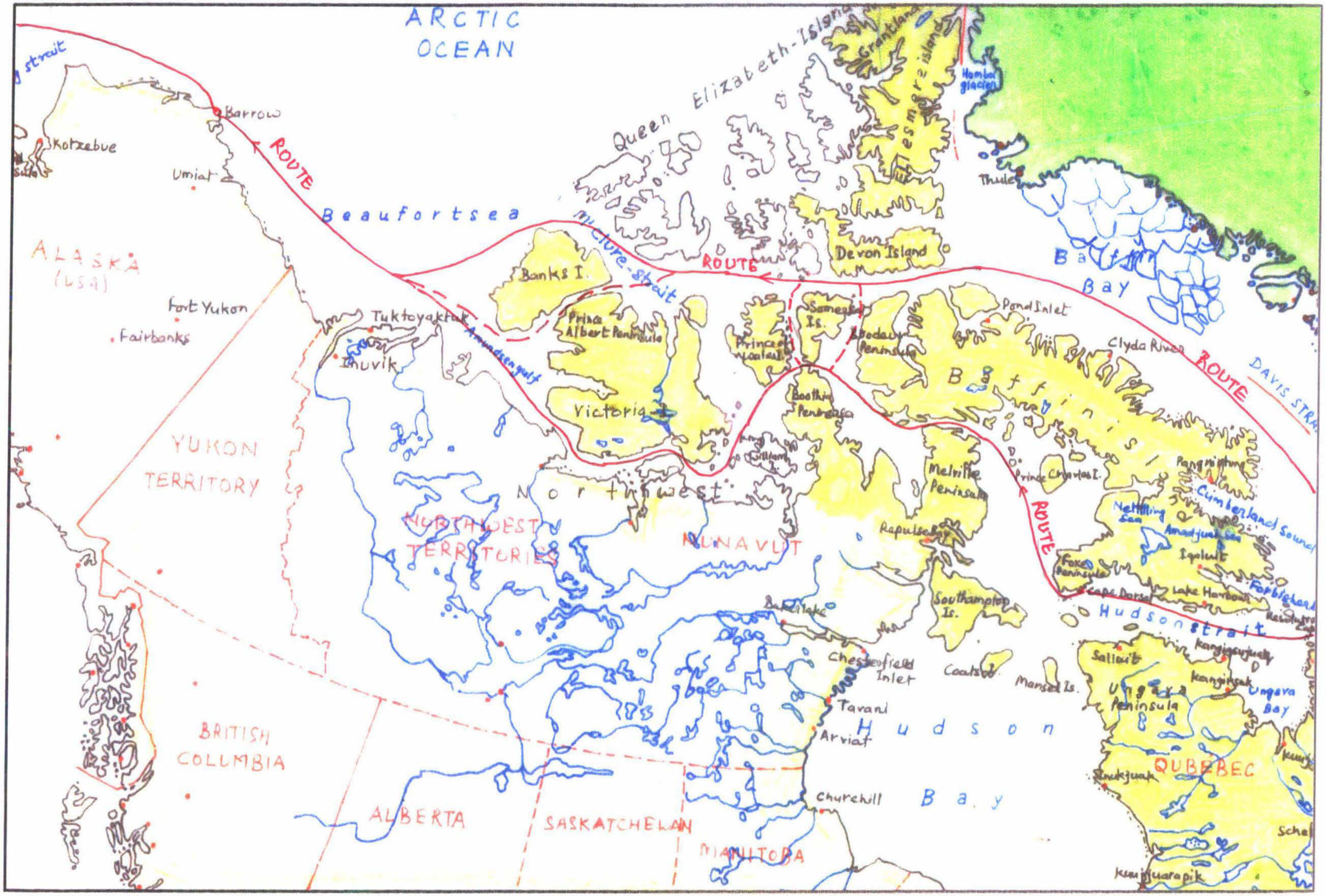
Recent Arctic environmental changes, in particular changes in the area and thickness of sea ice, can fundamentally impact Arctic marine transportation. Longer melt seasons, thinning ice covers, and reductions in multiyear ice have key operational implications, for example, greater access and longer navigation seasons for shipping around the Arctic basin. Notably the Northeast Passage, or the Northern Sea Route (NSR) from a more formal Russian perspective, across the north of Eurasia has experienced reductions in the sea ice cover. In addition, the administration, regulation and overall operation of Russia's NSR have undergone considerable changes during the past decade following the end of the Soviet Union. The combination of regional environmental change and new management of the NSR and Russia's Arctic fleet pose potential implications for the United States and naval operations. The end of the USSR has brought great change to all aspects of the NSR. Total cargo tonnage along the NSR has been reduced to less than 2.0 million tons, less than a third of what it reached during the heyday of the Soviet Union. This reduction in cargo and ship traffic is primarily a consequence of changes in the industrial complex at Noril'sk. However, year-round marine operations across the Kara Sea to Dudinka -port city for Noril'sk were maintained throughout the 1990's. This was accomplished using the capable, but aging icebreaker fleet, both nuclear and non-nuclear, of Murmansk Shipping Company. In November 1998 controlling interest in MSC was acquired by the Russian oil company, Lukoil; fresh capital from Lukoil has allowed the recent buildup of a domestic Arctic tanker fleet. Comprehensive and official regulations for navigation along the NSR remain in effect; navigation control, mandatory pilotage, mandatory icebreaker escort in Vilkitskiy, Dmitry Laptev, Sannikov and Shokalskiy straits and rules for escort represent a considerable effort to control domestic and foreign shipping along the NSR. There are continued differences between the US and Russia concerning the NSR. The US continues to assert that the ice-covered straits of the NSR are international and subject to the right of transit passage; Russia continues to claim the straits as internal waters. This is likely to remain a contentious political issue between the US and Russia despite future access to the Russian Arctic under more favorable climatic conditions.

NSR's technological and environmental challenges are no longer absolute obstacles to commercial shipping; the EU and oil/gas interests are conducting pilot studies for Arctic marine routes between the Kara Sea and Europe; Russia needs to better accommodate the concerns and requirements of international shipping (NSR tariffs require considerable adjustment); and, the NSR's physical and operational infrastructure must be further developed to attract increased commercial use. The impacts of future reductions of sea ice along the NSR on extending the navigation seasons and future requirements for icebreaker support need to be discussed. One significant question remains unresolved: will future Arctic commercial ships navigate along the NSR independently -without icebreaker support, if ice conditions continue to improve? Recent evidence from satellite observations confirms that the areal extent of Arctic sea ice has decreased approximately 3 % per decade. The largest decrease derived from historical records has been recorded for summer since 1950, a key observation for seasonal shipping along the NSR and other Arctic marginal seas. The Siberian Arctic has experienced sea ice reductions during the last decades of the twentieth century. Parkinson has shown regional sea ice reductions in the NSR area for 1978-1996: a 17.6 % decrease per decade in summer for the Barents and Kara seas, and a 3.7% decrease per decade for a large Arctic Ocean area including the Chukchi, East Siberian and Laptev seas. Record summer sea ice reductions in the Russian Arctic for 1990, 1993 and 1995 have also been identified; a record sea ice retreat was observed in 1998 for the Beaufort and Chukchi seas. The area of winter fast ice in the Russian Arctic -Kara Gate to Long Strait; decreased by 11.3% for 1975-93 and there have been reductions in total and old ice areas in the East Siberian Sea during 1972-94. Johannessen has observed a 14% decrease in winter multiyear ice in the central Arctic Ocean for 1978-98 and Rothrock has calculated ice thickness reductions (40%) from submarine data across the Arctic Ocean. These significant transformations and the regional trends noted for the Siberian Arctic, if continued, portend improved conditions for Arctic navigation along the NSR. Several implications for the US are apparent with regard to the changing nature of Russia's Northern Sea Route:

1- Potential greater marine access along the Russian Arctic coast for domestic and international commercial shipping;

2- Continued US and Russian differences in the application of the LOS to the Arctic and NSR;

3- Closer collaboration between the EU and Russia in development of Western Siberia by oil/gas interests and use of the NSR as a regional marine route -between the Kara Sea and Europe




**Map No. 5 The Routes of the North-West Passage**

4- Potential use of the NSR for through transit (Atlantic to Pacific and return) of hazardous wastes and other sensitive cargoes;

5- Lukoil's dominant position as owner of both icebreakers and Arctic tankers, and the exclusion of other domestic & foreign competitors (for example Finnish tankers);

6- The continued exclusion of US research ships from operating in the Russian Arctic for collaborative science.

## 5.II.2 Internationalization of the Northwest Passage & Canada's Claim to Historic Internal Waters :

Climate change has reduced the extent and thickness of sea ice in the Arctic, making international shipping in the Northwest Passage a virtual certainty in the foreseeable future. The Northwest Passage was found to be a reality by McClure and Franklin. In 1903 Amundsen, the greatest Norwegian explorer, sailed down Peel Sound in his tiny yacht ***Gjoa*** and passed around the east side of King William Island, where he spent two winters taking magnetic and other scientific observations. After a third winter spent west of the Mackenzie, he passed through the Bering Strait in 1906, the first to navigate the Northwest Passage. It was navigated again in 1940-42 and 1944 by Henry A. Larsen of the Royal Canadian Mounted Police in the ***St. Roch*** west-east by way of Bellot Strait and east-west in one season by Prince of Wales Strait.

In 1954 the first passage by a deep-drought vessel was made by HMCS Labrador, a Canadian naval icebreaker. In 1969 the ***Manhatten***, the largest and most powerful commercial ship ever built in the United States to that time, smashed through 650 miles of ice between Baffin Bay and Point Barrow, Alaska, to assess the commercial feasibility of the passage. The future of the Northwest Passage as a regular commercial route raises the question of whether the Passage is or might become an international strait, with consequent right of transit passage. There are the two possible legal bases for Canada's claim that the waters of the Canadian Arctic Archipelago are ***internal water:*** *a historic title and straight baselines.* The Northwest Passage is navigable for about 4 months of the year, but a warmer Arctic climate normally should extend the navigation season ( **Pharand, Donat ;2007:3-69**).

## LIST OF COUNTRIES BY EMISSIONS

| Rank | Country | Annual CO/2 Emissions *( in thousands of metric tons)* | Percentage of total Emission |
|---|---|---|---|
| | | | |
| 1. | United States | 5,844,042 | 24.3% |
| 2. | EU | 3,682,755 | 15.3% |
| 3. | China | 3,263,103 | 14.5% |
| 4. | Russia | 1,432,513 | 5.9% |
| 5. | India | 1,220,926 | 5.1% |
| 6. | Japan | 1,203,535 | 5.0% |
| 7. | Germany | 804,701 | 3.3% |
| 8. | UK | 543,633 | 2.3% |
| 9. | Canada | 5i7,157 | 2.1% |
| 10. | South Korea | 446,190 | 1.8% |
| 11. | Italy | 433,018 | 1.8% |
| 12. | Mexico | 383,671 | 1.6% |
| 13. | France | 368,315 | 1.6% |
| | **World Total** | **24,126,416** | 100% |

Source: World Development Report,2005,TheWorldBank

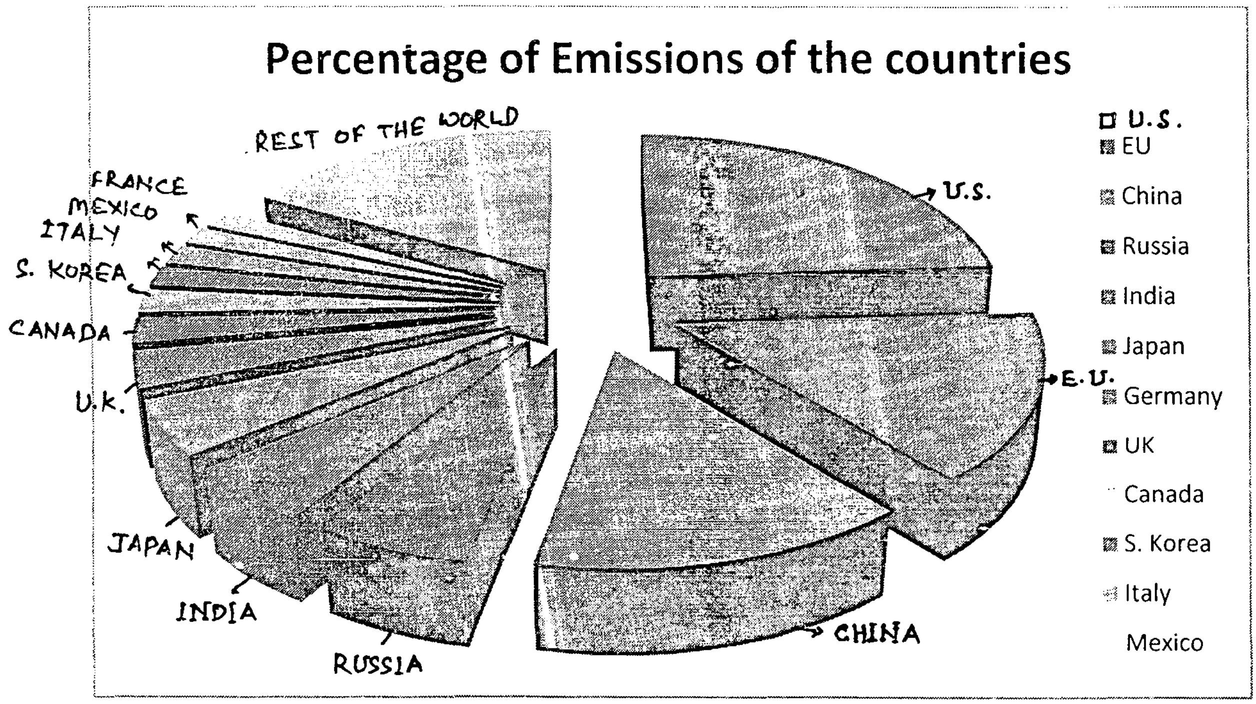



TABLE No.2 PERCENTAGE OF EMISSIONS OF THE COUNTRIES

## 5.III . Environmental Policies and Perspectives : International Dialogue on Climate Change

In the 18th century the industrialization gained the peace and the rate of exploitation of nature and environmental pollution began to increase sharply and started showing consequences on the health of nature and its inhabitants. This led to the rise of environmental concerns among the people and began movements in late 1850's. But these were on the individual basis and limited in terms of local space. Visionaries like Henry David Thoreau, John Muir in America and John Ruskin, Edward Carpenter in Britain were the initiators of the environment conservation. Henry David Thoreau's classic book *Walden* in 1848 and John Muir's *Sierra Club* in 1892 to encourage USA to protect the environment were some of the early works in the field of environment. Later 1949 Aldo Leopold's *A Sand Country Almanac* raised enormous debates. Rachel Carson's *Silent Spring* in 1962 spread awareness all over the United States and initiated the Kennedy administration to enquire into the environmental issues. In 1971, two NGOs Green Peace and Friends of the Earth made significant contribution to take environmental issues at the global level. These events initiated the way for the Earth Summit by the United Nations.

The first summit called as the *UN Conference on Human Environment* was held in 1972 Stockholm, Sweden. Later in 1987, the famous Brundtland Commission Report titled "**Our Common Future**" led to the emergence of the theme of Sustainable Development. In 1992 at Rio de Janeiro in Brazil UN held the Earth summit. The most important documents of this summit were the ***United Nations Convention on Environment Development*** and ***agenda 21***. Ten years later in 2002 at Johannesburg, the ***Rio +10 World Summit on Sustainable Development*** was held. In all these summits the *North- South divide* has been pronounced. As a result, cooperation among nations seems to be blurring out. The pressures from the developed countries have been perceived as encroachment on sovereignty by developed countries. A nation is sovereign within limits, in so in spatial limit but consequences are global in nature. Hence, environment is not only the subject of scientific enquiry, rather active field of geo-politics.

As **Neol Castree 2003)** says,"...unprecedented challenges posed by environmental problem ...and ecological interdependence of states .........has produced *new 'ordering principle'-**Environmental Geopolitics.**"*

Another dimension of the politics of environment, as pointed earlier, is the divide between developed Global North and underdeveloped South. The rift between the North and the South is evident when they come together to discuss environmental problems. Global North has been far ahead in innovations of exploiting resources. Incidentally they are also to blame for the present environmental crisis. United States which has kept itself away from the environmental protocols happens to be the highest CO2 emitter. The matter of the fact is that the developed countries release the bulk of CO2 emission, but they are not ready to bear their burden. ***Clean Development Mechanism*** and ***Carbon Trading*** clauses were added under the pressure from the industrial lobby of developed countries. These clauses are nothing but a way to bypass the obligations of cutting down on the emissions. In new economic era and in the age of globalization economics donor agencies and international conventions like Kyoto Protocol, have certainly an important role to play. However, funded by the developed states the autonomy of these bodies is doubtful.

In a 'Free Trade' era to remain competitive, costs are to be minimized and clean technologies come at a premium; the result being the 'Forced Trade'. Developing countries differ in perception of environmental problems from the developed countries. They perceive deforestation, poverty and underdevelopment, health, hunger as more important than the biodiversity, ozone depletion, global warming as perceived by developed countries. Developing countries see this new concern on environment by the developed North as nothing but ***'Ecological Imperialism'***. On the one hand North wants the South to use clean technologies and on the other they want it to specialize in environmentally hazardous industries like "ship breaking". It will not be too late when South will turn into a dump yard of the North.

Moreover, the environmental problems come under two categories; the first type is transnational environmental problems, having implications on the overall environment of the globe, for instance Green House Gases and global warming. The second type is referred to as 'Local Leaky'- that is, problem originating in country but having repercussions on the environmental health of whole set of other countries like building a dam. Hence, the type of environmental problem also determines the way politics of environment will unfold.

### 5.III.1 From Rio(1992) to Copenhagen Summit(2009):

The United Nations Framework Convention on Climate Change (UNFCCC) was opened for signature at the United Nations Conference on Environment and Development (UNCED) conference in Rio de Janeiro-the Earth Summit. On June 12, 1992, the United Nations Conference on Environment and Development (UNCED) conference in Rio de Janeiro 154 nations signed the UNFCCC, that upon ratification committed signatories' governments to a voluntary "non-binding aim" to reduce atmospheric concentrations of greenhouse gases with goal of "preventing dangerous anthropogenic interference with Earth's climatic system". These actions were aimed primarily at industrialized countries, with the intention of stabilizing their emissions of greenhouse gases at 1990 levels by the year 2000; and other responsibilities would be incumbent upon all UNFCCC parties. These parties agreed in general that they would recognize "common but differentiated responsibilities" with greater responsibility for reducing greenhouse gas emissions in the near term on the developed and industrialized countries, which were listed and identified in Annex I of the UNFCCC and thereafter referred "Annex I" countries. According to terms of the UNFCCC, having received over 50 countries' instruments of ratification, UNFCCC entered into force on March 24, 1994.

Since the UNFCCC entered into force, the parties have been meeting annually in conference of the parties (COP) to assess progress in dealing with climatic change, and beginning in the mid-1990's, to negotiate the Kyoto Protocol to establish legally binding obligations for developed countries to reduce their greenhouse gas emissions. After completion of the Protocol in 1997, COP meetings focused on formulating the operational rules that would prevail as nations attempted to meet their obligations to reduce emissions. These rules were essentially agreed upon at COP-7 in 2001.

On February 16, 2005, the Kyoto Protocol entered into force. At that time, 141 nations had ratified it, including 35 of the 38 Annex B industrialized countries. As of July 10, 2006, some 164 nations had ratified and accepted the Kyoto Protocol.

First time, the UNFCCC Conference of Parties met in Berlin, Germany in the spring of 1995, and voiced concerns about the adequacy of countries' abilities to meet commitments under the Convention. These were expressed in a U.N. ministerial declaration known as ***"Berlin Mandate,"*** which established a two-year *Analytical and Assessment Phase (AAP),* to negotiate a "comprehensive menu of actions" for countries to pick from and choose future options to address climate change which for them, individually, made the best economic and environmental sense. The Berlin Mandate exempted non-Annex I countries from additional binding obligations, in keeping with the principle of ***"common but differentiated responsibilities"*** established in the UNFCCC---even though, collectively, the larger, newly industrializing countries were expected to be the World's largest emitters of greenhouse gas emissions 15 years hence.

The Second Conference of Parties to UNFCCC (COP-2) met in July 1996 in Geneva, Switzerland. Its Ministerial Declaration was adopted July 18, 1996 accepted the scientific findings on climate change proffered by the Intergovernmental Panel on Climate Change (IPCCC) in its second assessment (1995); rejected uniform *"harmonized policies"* in favour of flexibility; and called for *"legally binding mid-term targets."*

**5.III.2 <u>The Kyoto Protocol on Climate Change :</u>**

The Kyoto Protocol to the United Nations Framework Convention on Climate Change was adopted by COP-3, IN December 1997 in Kyoto, Japan, after intensive and tense negotiations. Most industrialized nations and some central European economies in transition-all defined as Annex B countries in the Protocol, a list that closely resembles Annex I of the UNFCC, agreed to legally binding reductions in greenhouse gas emissions of an average of 6%-8% below 1990 levels in the years 2008-2012, defined as the First emissions budget period.

COP-4 took place in Buenos Aires in November 1998. It had been expected that the remaining issues unresolved in Kyoto would be finalized at this meeting. However, the complexity and difficulty of finding agreement on these issues proved insurmountable, and instead the parties adopted a *two-year "Plan of Action"* to advance efforts and to devise mechanisms for implementing the Kyoto Protocol, to be completed by 2000. The 5$^{th}$ Conference of Parties to the U.N. Framework Convention on Climate Change met in Bonn, Germany, between October 25 and November 4, 1998. It was primarily a technical meeting, and did not reach major conclusions.

When COP-6 convened November 13-25, 2000, in The Hague, Netherlands, discussions evolved rapidly into a high-level negotiation over the major political issues. These included major controversy over the United States' proposal to allow **credit for carbon "sinks"** in existing forests and on agricultural lands, satisfying a major proportion of the U.S. emissions reduction in this way; disagreements over consequences for non-compliance by countries that did not meet their emission reduction targets; and difficulties in resolving how developing countries could obtain financial assistance to deal with adverse effects of climate change and meet their emission reduction target. In the final hours of COP-6, despite some compromises agreed between the United States and some EU countries, notably the United Kingdom, the EU countries as a whole, led by Denmark and Germany, rejected the compromise positions, and the talks in The Hague collapsed. Jan Pronk, the President of COP-6, suspended COP-6 without agreement, with the expectation that negotiations would later resume. It was later announced that the COP-6 meetings would be resumed in Bonn, Germany, in the second half of July. When the COP-6 negotiations resumed July 16-27, 2001, in Bonn, Germany, little progress had been made on resolving the differences that had produced an impasse in The Hague. However, this meeting took place after the U.S. had rejected the Kyoto Protocol in March. As a result, the U.S. delegation to this meeting declined to participate in the negotiated the key issues, agreement was reached on most of the major political issues, given the low level of expectations that preceded the meeting. The agreements included:

**(1)- Mechanisms**—the "flexibility" mechanisms which the United States had strongly favored as the Protocol was initially put together, including emissions trading; joint implementation; and the Clean Development Mechanism(CDM), which provides funding from developed countries for emissions reduction activities in developing countries, with credit for the donor countries. One of the key elements of this agreement was that there would be no quantitative limit on the credit a country could claim from use of these mechanisms, but that domestic action must constitute a significant element of efforts of each Annex B country to meet their targets.

**(2)-Carbon sinks**---credit was agreed to for broad activities that absorb carbon (carbon sink) from the atmosphere or store it, including existing forest and cropland management, and revegetation, with no overall cap on the amount of credit a country could claim for sinks activities. In the case of forest management, an Appendix Z establishes country-specific caps for each Annex-I country; for example a cap of 13 million tons could receive credit only for carbon sequestration increases above 1990 levels.

**(3)-Compliance**---final action on compliance procedures and mechanism that would address noncompliance with Protocol provisions was deferred to COP-7, but broad outlines of consequences for failing to meet emissions targets would include a requirement to "make up" shortfalls at 1.3 tons to 1; suspension of the right to sell credits for surplus emissions reductions; and a required compliance action plan for those not meeting their targets.

**(4)-Financing**--- three new funds were agreed upon to provide assistance for needs associated with climate change; a least-developed-country fund to support National Adaptation Programme of Action; and a Kyoto Protocol adaptation fund supported by a CDM levy and voluntary contributions.

At the COP-7 meeting in Marrakesh, Morocco, October 29-November 10, 2001, negotiators in effect completed the work of the Buenos Aires Plan of Action, finalizing most of the operational details and setting the stage for nations to ratify the Protocol. A target date for bringing the Protocol into force was not met. The main decisions at COP-7 included operational rules for international emissions trading among parties to the Protocol and for the CDM and joint implementation; a compliance regime that outlines consequences for failure to meet emissions targets but defers to the parties to the Protocol after it is in force to decide whether these consequences are legally binding; accounting procedures for the flexibility mechanisms; and a decision to consider at COP-8 how to achieve a review of the adequacy of commitments that might move towards discussions of future developing country commitments. In COP-8, New Delhi, 2002; these meetings of the conference of parties to the UNFCCC, attempts were made to consider next steps after the 2008-2012 commitment period, but these attempts encountered resistance from developing countries and some other parties.[6]

The announced reluctance of Russia at the Milan 2003, to undertake ratification of the Kyoto Protocol called into question whether or when the Protocol might enter into force. Without U.S. participation, the required 55% of baseline emissions of parties would not be achieved if Russia did not ratify. Just before the COP-10 meeting, Russia did ratify the Protocol on November 18, 2004. Thus it became possible for the Kyoto Protocol to enter into force 90 days later, on February 16, 2005. The meeting centered on largely technical issues, and avoided major substantive declarations; what "next steps" involving developing countries should be remained a controversial issue, and was not resolved. The meeting was held in Montreal, Canada, November 28-December 9, 2005. This was a concurrent meeting—the 11th meeting of the parties to the UNFCCC, and the first meeting of the parties (MOP-1) to the Kyoto Protocol. One of the key outcomes of the Kyoto Protocol MOP was adoption of the ***"Marrakesh Accords,"*** which outline what the Secretariat terms the "rule book" for the Protocol. Among other things, it formally launches emissions trading, and outlines the operational rules for the ***Clean Development Mechanism*** and ***Joint Implementation***, both of which provide for credit to developed countries for projects to reduce emissions or augment sinks in developing or other eligible countries. Other rules adopted include how emissions are accounted for, guidelines on data systems needed, rules for a compliance system, and rules governing how absorption of carbon dioxide by agricultural soils and forests is to be measured. Discussions of "next steps" were considered under both the Protocol and the Convention. Negotiations under the Protocol were agreed upon that could lead to new binding commitments for Kyoto Protocol parties after 2012; and a decision under the framework Convention was made to open a non-binding ***"dialogue on long-term cooperative action,"*** which could include all parties to the Convention.

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[6] John R. Justus and Susan R. Fletcher (2006) ***Global Climatic Change: Major Scientific and Policy Issues***, Resources, Science, and Industry Division (Congressional Research Service Report )

| | | Carbon Dioxide Emissions | | | | | Energy use per capita | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | *(metric tons per capita)* | | | | | *(kg oil equivalent)* | | | |
| | | ***1990*** | ***2000*** | ***2005*** | | | ***1990*** | ***2000*** | ***2005*** | |
| | ***WORLD*** | 4 | **3.8** | 4 | | | 1,685 | 1,689 | 1,793 | |
| East Asia and Pacific | | 1.9 | 2 | 2.7 | | | 722 | 846 | 1,124 | |
| | | | | | | | | | | |
| Europe and Central Asia | | 10.2 | 6.6 | 6.9 | | | 3,726 | 2,644 | 2,847 | |
| | | | | | | | | | | |
| Latin America and the Caribbean | | 2.4 | 2.5 | 2.4 | | | 1,050 | 1,170 | 1,186 | |
| | | | | | | | | | | |
| Middle East and North Africa | | 2.5 | 3.2 | 3.4 | | | 861 | 1,080 | -,189 | |
| | | | | | | | | | | |
| South Asia | | 0.7 | 1 | 1 | | | 394 | 460 | 486 | |
| | | | | | | | | | | |
| Sub-Saharan Africa | | 0.8 | 0.7 | 0.8 | | | 693 | 668 | 703 | |
| | | | | | | | | | | |
| | | | | | | | | | | |
| | | | | | | | | | | |
| | * Source: ***World Developme*** | IBRD/ THE WORLD BANK 1818 H STREET,N.W. Washington, D. C. 20433 U.S.A. | | | | | | | | |

TABLE No. 3 CARBON-DIOXIDE EMISSIONS BY DIFFERENT REGIONS

### 5.III.3 Asia-Pacific Partnership on Clean Development and Climate

On July, 2005, a six-nation partnership was announced at the South East Asian Nations forum---the Asia-Pacific Partnership on Clean Development and Climate (APP). This partnership agreement included six nations-the United States, Australia, China, India, Japan, and South Korea. The participant described the focus of the partnership as technology development and reduction of greenhouse gas intensity, with voluntary participation. Representatives of the six nations met in Sydney, Australia, in early January 2006, and spelled out the purpose and provided a work plan for the partnership in statements on January 12, 2006. The purposes that have been identified include to "Create a voluntary, non-diffusion, deployment, and transfer of existing, emerging and longer-term cost effective, cleaner, more efficient technologies and practices among the Partners through concrete and substantial cooperation so as to achieve practical results." The charter for partnership states: "The partnership will be consistent with and contribute to our effort under the UNFCCC and will complement, but not replace the Kyoto Protocol.

The United Nations climate change conference was held in **Poznan, Poland** from 1 to 12 December 2008 where eleven thousand participants from 170 countries attended the Poznan meeting which discussed the key issues of international cooperation on future climate change regime. According to UNFCCC Executive secretary, Y vo de Boer; decisions adopted at COP - 14 meeting paved the way to UN Climate summit to be held in Copenhagen, Denmark in December 2009, as Kyoto Protocol expires in 2012 and there is need to enter a new climate agreement.

### 5.III.4 2007 United Nations Climate Change Conference :

The 2007 UNCCC took place at the Bali International Conference Centre, Nusa Dua, In Bali, Indonesia, between December 3 and December 15, 2007. Representatives from over 180 countries attended, together with observers from intergovernmental and nongovernmental organizations. The conference encompassed meetings of several bodies, including the 13th Conference of the Parties to the United Nations Framework Convention on Climate Change (COP-13), the 3rd Meeting of the Parties to the Kyoto Protocol (MOP-3 OR CMP-3), together with other subsidiary bodies and a meeting of ministers.

Negotiations on a successor to the Kyoto Protocol dominated the conference. A meeting of environment ministers and experts held in June, 2007 called on conference to agree on a road-map timetable and 'concrete steps for the negotiations' with a view to reaching an agreement by 2009.

### *5III.4.1 Significance of the Bali meet*

For the first time the deliberations were dominated by the findings of the IPCC report. There was a complete absence of any questioning of the scientific assessment of climate. Though a couple of countries questioned the extent of required the cuts that a new global agreement should incorporate, a compromise was reached supporting deep cuts in emissions and a time table for a draft plan of action to be completed.

India urges the rich to walk the talk on climate change; at the Bali meet. India with more than a billion people, is the world's third biggest emitter behind the China and the United States; and is projected to account for a rising share of global carbon emissions as it burns more fuel to try to end poverty. But India defended its policies. Saying its per capita emissions were far below the global average. India has promised that per capita emissions will never reach those of developed nations. The country's per capita emissions were low at 0.25 tonnes of carbon in 2001,a quarter of the world average and 22 times less than the US . While this is so, the US is blocking progress at bail says Al Gore, the former US Vice President and Noble laureate. He was referring to the US refusal to accede to the guidelines being proposed for adherence by 2020. He was hoping the new treaty to be completed by December 2009 in Copenhagen.

### **5.III.5 IPCCC Strategies unfair to the South :**

Before the Earth Summit, a framework for a climate change convention was formulated by an intergovernmental negotiating committee, which was in eventually signed by many heads of states at Rio. Another parallel exercise was carried out by the intergovernmental panel on climate change (IPCC), which constituted three working groups whose reports are published in three volumes. Several hundred professionals were involved in preparing the three reports the first two of which are intended to be objective scientific assessments. But the third, on response strategies, contains a lot of subjective assumption, many of which do not do justice to do developing countries (the 'south'). This volume deals with' how to reduce CO2 emissions, in which regions and with what possible measures. Because CO2 emissions are largely connected with the use of fossils fuels and to some extent deforestation and land degradation, the debate is about energy use in future by different world regions. Energy is an important ingredient for development and if fossil fuel use. The main energy source of most developing countries, has to be restricted, development will be retarded or made more expensive. After examining which world region emits how much, IPCC projects probable CO2 emissions models up to 2025 for different regions.

It is well known that of the 5.6 billion tonnes of carbon emitted during 1988, more than70% is contributed by the developed countries (the 'north'). Because carbon accumulates over 100 years, the North's share in accumulated carbon since the industrial revolution is more than 85%; hence its responsibility in precipitating the 'greenhouse effect' is in the same proportion. The cost of CO2 emission reduction in the United States alone is estimated to be in trillions of dollars for next century. It is therefore essential that the South's need to develop is kept in view, together with the fact that the North has the major responsibility in bearing the financial burden of reducing CO2 emissions.

. IPCC uses a simple model to project future emissions up to 2025 based on past emissions as initial conditions and asset of future growth rates for different world regions. It calls asset of model results for different world regions a scenario. Obviously, the 'scenario' will depend on the inputs (future growth rates). Because no one knows the future growth rates, subjective assumptions are always involved. Fairness requires that the assumption concerning future growth rates of worlds regions for the reference scenario should be guided by the considerations about whose responsibility it is to reduce emissions, who needs more energy for economic growth and development, and who has reached a stage where emission growth rates are already reduced.

Instead, IPCC assumes that the present inequalities among different world regions will increase considerably. The annual per capita carbon emissions in North America will increase from 5.08 tonnes in 1985 to 7.12 tonnes in 2025, a 77% rise in total emissions and 40% rise in per capita emissions. This is inconsistent with falling carbon emissions per unit GDP. The IPCC results show that in terms of per capita emissions, emissions in North America will equal 13.2 Africans or 11.1 South East Asians or 7.8 Latin Americans even in 2025. It is possible that emission growth rates will decline as a matter of course due to new technologies and conservation efforts. These expectations can be legitimately built in to inputs for reference scenarios.

The signing of a convention which would begin to tackle the threat of human-induced climate change is expected to be a centerpiece of June 1992 UN Conference on Environment and Development (UNCED). Negotiations to date have already revealed serious divisions of interest, of which those dividing North and South still predominate. There are prospects for building an effective long-term regime will from seeking to develop non-traditional alliances across the North-South divide so as to form a central coalition that more reluctant states will ultimately have to accept. The convention to be signed at Rio will not solve the greenhouse problem, but it could form the basis for negotiations that effectively to address it.

The UNCED, to be held in June 1992 in Rio de Janeiro, has been portrayed as the point at which states will states will start to act collectively over global environmental problems. It marks the final appearance of environmental problems as part of the normal diplomatic agenda. Its business will range from the general principles governing the responsibilities of states in pursuing the goal of sustainable development, to the conclusion of specific, separately negotiated agreements on the preservation of biodiversity and the problem of human-induced climatic change. Of all the issues involved, climate change is widely believed to be the acid test of whether or not countries are serious, because the responses required to limit and manage climatic change could go to the heart of their political and industrial structure **(Matthew Paterson & Michel Grubb;1992: 293-310).**

Climate change became a major political issue during 1988. A series of scientific conferences during the 1980s built up a consensus that human emissions of carbon dioxide ($CO_2$) and other gases would lead to a warming of the earth's surface, with associated climatic changes that could produce substantial detrimental effects on human society. These possible effects include sea-level rise, changed rainfall and storm patterns, with consequent desertification and flooding, agricultural migration, and perhaps other unpredicted impacts.

In Conclusion we can say, the nature of environmental hazards is not limited in space and time; whole earth has to face drastic changes which might not augur well for the future of human beings and other living organisms. The whole ecological balance is in danger and once imbalanced it would not be possible to reverse it with present state-of-the art technology and knowledge. So these issues certainly need an attention, thought and appropriate action to curb them for the betterment of whole world. Around 200 nation states representing their diverse and different problem and issues such as threat to human life, health, food security, water supply, peace and security, environmental migrations etc. have made cooperation between nations a very difficult proposition. The input costs are very high and returns are marginal. Individual and developing countries have very low support in resolving the environmental issues so there remains only one way i.e. cooperation between developed and developing nations. As the time passes by this problem will become more intense and will severely affect not only cooperation but economic, sociological, ideological and political contradictions.

# *CHAPTER 6*

# *Conclusion*

CHAPTER-6

# Conclusion

The oceans play a vital role in controlling the distribution of today's climate on planet earth. Their huge thermal capacity and inertia and their mobility, which enables them to transport heat from equatorial latitudes to polar regions, are critical factors in reducing climate extremes between low and high latitudes and from season to season. Future changes in climate will be related to future changes in ocean behavior. So, these three aspects of ocean of ocean dynamics are particularly critical in studies of climate change and its potential impacts. The ocean circulation is driven by winds and thermal forcing. The role of the oceans as a sink for atmospheric carbon dioxide is a potential control of future greenhouse warming. The implications of global warning for sea level rise and coastal flooding are immense. Each of these three aspects is related to known features of the Arctic Ocean behavior, to various research programme underway at present, which will improve our understanding of the relationship between oceans and climate change.

The Arctic Ocean plays a critical part in driving the global thermohaline circulation, through its influence on the Atlantic thermohaline circulation. It is possible that increased precipitation and runoff of fresh water and the melting of glaciers and ice sheets, and thawing of the extensive permafrost underlying northern Siberia, could freshen arctic waters, causing a reduction in the overturning circulation of the global ocean and thus affecting the global climate system and marine ecosystems. The IPCC 2001 assessment considers a future reduction of the Atlantic thermohaline circulation as likely, while a complete shutdown is considered as less likely, but not impossible. If half the oceanic heat flux were to disappear with a weakened Atlantic inflow, then the associated cooling would more than offset the projected heating in the 21st century. Thus, there is the possibility that some areas in the Atlantic Arctic will experience significant *regional* cooling rather than warming, but the present models can assess neither its probability, nor its extent and magnitude.

Increased runoff from major arctic rivers and increased precipitation over the Arctic Ocean are very likely to decrease its salinity. A slow-down of the global thermohaline circulation is likely as a result of increased freshwater input from melting glaciers and precipitation. This is likely to delay warming for several decades in the Atlantic sector of the Arctic as a result of reduced ocean heat transport.

There is possibility of substantial reductions in sea-ice extent and likely opening of the Northern Sea Route to shipping during summer. Some of the models project an entirely ice-free Arctic Ocean in summer by the end of the 21st century. Greater expanses of open water will also increase the positive feedback of albedo change to climate. Reduced sea-ice extent and more open water are very likely to change the distribution of marine mammals-particularly polar bears, walrus, ice-inhabiting seals, and narwhals and some seabirds -particularly ivory gulls, reducing their populations to vulnerable low levels. It is likely that more open water will be favorable for some whale species and that the distribution range of these species is very likely to spread northward.

Ultraviolet radiation can act in combination with other stressors, including pollutants, habitat destruction, and changing predator populations, to adversely affect a number of aquatic species. In optically clear ocean waters, organisms living near the surface are likely to receive harmful doses of UV radiation. Sustained, increased UV radiation exposure could also have negative impacts on fisheries. Changes in the distribution and migration patterns of fish stocks are likely. It is possible that higher primary productivity, increases in feeding areas, and higher growth rates could lead to more productive fisheries in some regions of the Arctic. New species are moving into the Arctic and competing with native species. The extinction of existing arctic fish species is unlikely.

Serious coastal erosion problems are already evident in some low-lying coastal areas, especially in the Russian Far East, Alaska, and northwestern Canada, resulting from permafrost thawing and increased wave action and storm surges due to reduced sea-ice extent and sea-level rise. Ongoing or accelerated coastal-erosion trends are likely to lead to further relocations of coastal communities in the Arctic. The Arctic is home to a large number of distinct groups of indigenous peoples and the populations of eight nations. Between two and four million indigenous and non-indigenous people live in the Arctic, depending on how the Arctic is defined. Most live in cities; in Russia large urban centers include Vorkuta and Norilsk with populations listed as exceeding 100000, and Murmansk with about 500000 people, although the population of these cities has decreased in recent years. Arctic towns in Scandinavia and North America are smaller; Reykjavik has around 110000 inhabitants and Rovaniemi about 65000. In total there are probably around 30 towns in the Arctic with more than 10 000 inhabitants.

The social impacts of climate change and UV radiation on the people of the Arctic. Climate change is only one, and perhaps not the most important, factor currently affecting people's lives and livelihood in the Arctic. For example, the people living in Russia's Far North have experienced dramatic political, social, and economic changes since the collapse of the former Soviet Union; and Europeans, Canadians, and Alaskans have experienced major changes resulting from the discovery of minerals, oil and gas reserves, and the declines or increases of some of the northern fisheries.

Reduced sea ice is likely to facilitate some offshore operations but hamper winter seismic work on shore-fast ice. Later freeze-up and earlier melting are likely to limit the use of ice and snow roads. Reduced extent and thinner sea ice are likely to allow construction and operation of more economical offshore platforms. Storm surges and sea-level rise are likely to increase coastal erosion of shore facilities and artificial islands. The costs of maintaining infrastructure and minimizing environmental impacts are likely to increase as a result of thawing permafrost, storm surges, and erosion. Reduced extent and duration of sea and river ice are likely to lengthen the shipping season and shorten routes -including trans-polar routes. Permafrost thawing is likely to increase pipeline maintenance costs.

The costs of maintaining infrastructure and minimizing environmental impacts are likely to increase as a result of thawing permafrost, storm surges, and erosion. Reduced extent and duration of sea ice are likely to lengthen the shipping season. Thawing permafrost is likely to affect roads and infrastructure.

The Arctic has large oil and gas reserves. Most are located in Russia: oil in the Pechora Basin, gas in the Lower Ob Basin, and other potential oil and gas fields along the Siberian coast. In Siberia, oil and gas development has expanded dramatically over the past few decades, and this region produces 78% of Russia's oil and 84% of its natural gas. Canadian oil and gas fields are concentrated in two main basins in the Mackenzie Delta/Beaufort Sea region and in the high Arctic. Oil and gas fields also occur in other arctic waters, for example the Barents Sea. The oil fields at Prudhoe Bay, Alaska, are the largest in North America, and by 2002, around 14 billion barrels had been produced at this site. There are also substantial reserves of natural gas and coal along the North Slope of Alaska. The Arctic is an important supplier of oil and gas to the global economy. Climate change impacts on the exploration, production, and transportation activities of this industry could have both positive and negative market and financial effects.

The Arctic has large mineral reserves, ranging from gemstones to fertilizers. Russia extracts the greatest quantities of these minerals, including nickel, copper, platinum, apatite, tin, diamonds, and gold, mostly on the Kola Peninsula but also in the northern Ural Mountains, the Taymir region of Siberia, and the Far East. Canadian mining in the Yukon and Northwest Territories and Nunavut is for lead, zinc, copper, gold, and diamonds. In Alaska, lead and zinc are extracted at the Red Dog Mine, which sits atop two-thirds of US zinc resources, and gold mining continues in several areas. Coal mining occurs in several areas of the Arctic. Mining activities in the Arctic are an important contributor of raw materials to the global economy and are likely to expand with improving transportation conditions to bring products to market, due to a longer ice-free shipping season

The cost of transporting products and goods into and out of the Arctic is a major theme of the potential impacts of climate change on many of the economic sectors described above. While climate change will affect many different modes of transport in the Arctic, the likelihood of reduced extent and duration of sea ice in the future will have a major impact. The projected opening of the Northern Sea Route-the opening of the Northwest Passage is less certain to longer shipping seasons will provide faster and therefore cheaper access to the Arctic, as well as the possibility of trans-arctic shipping. This will provide new economic opportunities, as well as increased risks of oil and other pollution along these routes. Other regions of the Arctic will also benefit from easier shipping access due to less sea ice.

In conclusion, we can say that the scientific evidence beyond dispute indicates that climate change is one of the greatest challenges of the 21st century. There is need to introduce a national cap-and trade mechanism for carbon emissions and to catalyse private initiatives in solar, wind, next generation bio- fuel and clean coal technologies. The great hope now is that this significant change of stance will enable the United Nations Framework Convention on Climate Change (UNFCCC) to produce a balanced, equitable, effective, and ratifiable protocol for the future. Such a protocol can convince wary developing countries like India to commit themselves to a cut in their growing carbon emissions. India, which used to bring up action on climate change, announced its own National Action Plan on Climate Change in 2008 with eight component missions.

There are several technical areas that need to be brought under the ambit of the post-Kyoto agreement for 2013, including the new treaty on deforestation and 'carbon sinks' such as grazing lands and farms. As per UNFCCC estimates to achieve its 'most stringent scenario', a new treaty must persuade industrialized countries that by 2020 they must cut emissions by 25 to 40 per cent from 1990 levels. That goal will require huge additional investments. The European Commission has pointed out that if developing countries were also to cut their emissions significantly, about $ 224 billion a year would need to be spent. These estimates underscore the need to devise, fund- raising mechanisms based on the 'polluter pays' principle. In this context, the developing countries have raised a legitimate demand that the developed countries must transfer technology liberally and set up funding mechanisms of scale for mitigation and adaptation. A revamped Clean Development Mechanism that supports the best technologies is an imperative. China, India and Brazil have launched proactive schemes to reduce emissions.

The International Polar Year is a large scientific programme focused on the Arctic and Antarctic from March 2007 to March 2009. The International Polar Year, organized through the International Council for Science (ICSU) and the World Meteorological Organization (WMO), is actually the fourth polar year, following those in 1882-83, 1932-33 and 1957-58. In order to have full and equal coverage of both the Arctic and Antarctic, the International Polar Year 2007-08 covers two full annual cycles from March 2007 to March 2009 and will involve over 200 projects, with thousands of scientists from over 60 nations examining a wide range of physical, biological, and social research areas. It is also an unprecedented opportunity to demonstrate, follow and get involved with, cutting edge science in real-time.

The International Polar Year's aim is to provide better observation and understanding of the Earth's polar regions, and to focus the world's attention on their importance. Fifty years ago, the international Geophysical Year paved the way.

The global climate system has been examined by the Intergovernmental Panel on Climate Change (IPCC) in depth including thorough discussion on the impact of climate change in the Arctic. With different ecological and physical climatic parameters, the climate of the Arctic is a collection of the frozen surface of the of the earth i.e.-**Cryosphere**. The cryosphere of the Arctic includes snow, ice-sheets, glaciers, sea-ice, and permafrost. The regional character of the Arctic climate includes special physical properties such as high reflectivity, low thermal conductivity and the high latent heat to change ice to water. In this chapter, we focus on the northern areas i.e.-66.5" N and the interaction of the Arctic cryosphere's interaction with southerly areas through the atmosphere and ocean.

Unusually large and rapid climate in the Arctic signals towards the process of the **Arctic Oscillation (AO)** is an important feature of the Arctic atmosphere due to its connections with global climate. The positive phase of the AO in recent decades is possibly the result of increased radiating effect because of anthropogenic greenhouse gas (GHG) emissions which results in variations in sea surface temperatures. The Arctic Ocean is the core of the Arctic. The marine Arctic in the form of sea-ice exerts strong leverage on global climate through the exchange of radiation, sensible heat and interactions between the atmosphere and the ocean.

For about 400 years after Industrial Revolution man has gone for ruthless exploitation of nature. In return, environment on its part has posed far greater challenges, which threaten the very existence of man. The task of reconciliation with the nature is beyond the capacity of any single nation, thus making it dependent on the dynamics of environmental politics in coming future. The globe is warming, forests are shrinking, water is getting polluted, and so is air. Meanwhile, '*development*' goes on, GPDs are growing, and global trade relations are expanding, but how long and how far? Scientists and researchers are coming with 'doomsday' warnings-act now before it is too late. Is anyone listening? World is fragmented, characterized by inequality and situation demands a collective effort. Environment is not contained or confined within the boundaries of nation states. The resources which are considered to be in the domain of sovereignty are in fact the collective resources not only of mankind, but of all the living beings.

Today every nation is trying to maximize the benefits by utilizing resources in their domain to the fullest, irrespective of the consequences of such reckless exploitation. The materialistic society and the Western lifestyle which is projected as the ideal society, have serious repercussions on the capacity of the earth to regenerate and revitalize. There is certain challenge is to strike a balance between environment conservation and maintaining current level of consumption. The need is to develop a new value system in the society, which is sensitive towards and willing to live in harmony with the environment.

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## Physical feature and points of interest:

### CAPES:

1. Aldrich cape-Canada-Ellesmere Island
2. Alexander cape-
3. Farvel Cape-
4. Morris Jesup Cape
5. North (Nord) Cape-

### PENINSULA:

1. Boothia Peninsula
2. Kola(Kolsky) Peninsula
3. Melville Peninsula
4. Taymyr Peninsula

### BASINS:

1. Amerasia Basin
2. Canada Basin
3. Eurasia Basin
4. Foxe Basin
5. Frame Basin
6. Greenland Basin
7. Makarov Basin
8. Nansen Basin
9. Norwegian Basin

### TROUGHS:

1. St. Anna Trough
2. Trough

**SOUND:**

1. Lancaster Sound
2. Scoresby Sound
3. Smith Sound
4. Viscount Melville Sound

**STRAITS:**

1. Bering Strait
2. Davis Strait
3. Denmark Strait
4. Hudson Strait
5. Nares Strait
6. Victoria Strait

**SEAS:**

1. Baltic Sea
2. Barent Sea
3. Beaufort Sea
4. White(Beyloye)Sea
5. Chukchi Sea
6. Greenland Sea
7. Kara(Karskoye) Sea
8. Labrador Sea
9. Laptev (Laptevvykh) Sea
10. Lincoln Sea
11. Norwegian Sea
12. Vostochno-Sibirskoye(East Siberian Sea)

**BAYS**

1. Baffin Bay
2. Disko (Qeqertarsuup Tundra Bay)
3. Frobisher Bay
4. Hudson Bay
5. James Bay
6. Ungava Bay

**GULFS**

1. Amundsen Gulf
2. Queen Maud Gulf
3. Gulf of St. Lawrence

**ICE CAPS:**

1. Banes Ice cap
2. Greenland Ice cap
3. Penny Ice cap

**GLACIERS:**

1. Malaspina Glacier

**SHELF:**

1.Beafort Shelf