Comparison of the Siberian shelf seas in the Arctic Ocean

by
Audun Scheide & Marit Muren

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Chapter 1

Introduction

1.1 Arctic Ocean

The Arctic Ocean has a volume of $17 \times 10^6 km^3$, and covers about 1.3 % of the world’s oceans [2]. It is the smallest and shallowest of the world’s oceans, and is often called the Arctic Mediterranean Sea or Arctic Sea. The Arctic Ocean includes the Canadian Arctic Shelf and the Russian Shelf, the latter greatest in extension. In this project we are looking at the differences in the shelf seas lying at the Russian Shelf. This report is covering the differences in temperature, salinity, oxygen content and saturation, along with concentrations of nitrate, silicate and phosphate, in a visualized manner. The Atlantic and Pacific Oceans strongly affects the properties of the shelf seas, which this report also shortly covers.

1.2 Continental Shelf

A continental shelf is an underlying landmass in the extension of a coast line. The shelf results in relatively shallow water near the coast, before the depth rapidly increases (often known as the continental slope) down to the ocean bottom.

![Figure 1.1: Continental shelf](image)
The Russian continental shelf is often called the Arctic shelf because of its great extension in the Arctic Ocean. Figure 1.2 shows the bathymetry of the Arctic Ocean and the area around. The red line indicates 500 m depth, and is where we defined the end of the shelf.

Figure 1.2: Bathymetry of the Arctic Ocean
1.3 The Seas

Figure 1.3 is a map showing the shelf seas we have been looking at in this project. The "dots" on the map is locations where measurements have been made.

Table 1.1 shows that the selected seas are relatively shallow. The exception is the Laptev Sea where only around 50% of the sea is on the continental shelf. As seen on figure 1.3, only the areas on the shelf (< 500m) is included in this project.

<table>
<thead>
<tr>
<th>Sea</th>
<th>Average Depth</th>
<th>Surface Areal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barents Sea</td>
<td>230 m</td>
<td>1,400,000 km²</td>
</tr>
<tr>
<td>Kara Sea</td>
<td>110 m</td>
<td>880,000 km²</td>
</tr>
<tr>
<td>Laptev Sea</td>
<td>578 m</td>
<td>700,000 km²</td>
</tr>
<tr>
<td>East Siberian Sea</td>
<td>45 m</td>
<td>936,000 km²</td>
</tr>
<tr>
<td>Chukchi Sea</td>
<td>50 m</td>
<td>595,000 km²</td>
</tr>
</tbody>
</table>
Chapter 2

Arctic Ocean

2.1 Circulation

The Arctic Ocean connects to the Pacific Ocean and the Atlantic Ocean. The flow rate from the Pacific Ocean through the Bering Strait is around 1 Sv [1]. The Arctic Ocean connects to the Atlantic Ocean on both sides of Greenland. The Fram Strait, between Greenland and Svalbard Island, has a much greater width than the Bering Strait and allow both inflow and outflow. The size of the outflow is around 9 Sv [3]. For this project the inflow between Norway and Svalbard is also important.

The Gulf Stream brings warm and relatively salt water north in the Atlantic Ocean. The North Atlantic Current moves the water into the Arctic Ocean through the Fram Strait and the passage between Norway and Svalbard. The water gets colder as it propagates north and sinks beneath the less dens Arctic surface water, before it leaves through the Fram Strait, as seen on Figure 2.1.

Figure 2.1 also show the Norwegian Coastal current (marked in green). This is relatively warm water with low salinity water, streaming along the coast and towards the Barents Sea.
Cold water with relatively low salinity from the Pacific Ocean flows into the Arctic Ocean through the Bering Strait. This is old water with high amounts of nutrients and silicates.

The so-called Beaufort Gyre is also included in Figure 2.1. This is an anticyclonic circulation [1], driven by strong winds. Because of ice melting and river outflow, the water is relatively fresh.

The Transpolar Drift, also shown on Figure 2.1, is a current connecting the water masses from the Atlantic Ocean and the Pacific Ocean [1]. The current is transporting water and ice from the area around the East Siberian Sea and the Laptev Sea toward the Fram Strait.
2.2 Water distributions

The water distributions in the Arctic Ocean can be divided into three main layers: surface water (0-200 m), intermediate water (200-800 m) and deep and bottom water (800 m to the bottom) [1]. Figure 2.2 shows the main water layers and how water from the Atlantic and the Pacific Ocean affect the water distribution in the Arctic Ocean. Most of the seas covered in this project is so shallow that only the surface layer (the Polar Mixed Layer on Figure 2.2) is present.

![Figure 2.2: Water masses in the Arctic Ocean [3]](image)

2.2.1 Arctic Surface Water

The Arctic Ocean is partly covered with year-round ice and almost completely covered in ice during the winter. Ice formation and melting causes variations in salinity and temperature, but in average the Arctic Ocean has the lowest salinity of the world’s oceans. Other than ice formation, the low salinity is caused by low evaporation due to cold climate and high freshwater inflow from rivers. This phenomena causes the surface layer to generally have a lower temperature and salinity content than the rest of the ocean. The surface layer is able to remain stable due to the fact that salinity has a dominant impact on density.
Chapter 3

Properties of the shelf seas

3.1 Obtaining data

The data used in this project were plotted using the Java OceanAtlas (JOA) software. The data and measurements were taken from the World Ocean Atlas from 2005 (WOA05). The World Ocean Atlas 2005 is a set of different objectively analyzed (1 grid) climatological fields [8].

By marking out a North-Pole map from 65°N to 90°N (in JOA) and using a poly-tool marker it was possible to crop out the areas of interest, i.e. each shelf sea. The five different shelf seas each have its own data set with calculated values for salinity, temperature, oxygen content and saturation, nitrate, phosphate and silicate, as well as the nitrate:phosphate ratio, at each WOA05 grid point. All results were made as an integration of the upper 200 m of the water column, in order to be able to compare seas of different depth.

After separately collecting and calculating all necessary data the five different data sets were combined into one and plotted so the differences easily could be visualized. The following sections discuss the differences in the various seawater properties for all the shelf seas.
3.2 Salinity

Upper 200 meter salinities are significantly higher in the Barents Sea than in the other arctic shelf seas. Figure 3.1 shows the salinity mean of the upper 200 m of the sea column. There are a couple of reasons for the increase in salinity in the Barents Sea but the main reason is due to the amount of Atlantic water present. Atlantic water is relatively warm with high salinity and propagates as explained in Chapter 2.1.

![Salinity](image)

**Figure 3.1: Salinity**

Salinities in the Arctic shelf seas are generally significantly affected by river runoffs and thawing of ice. The more remoteness from the Atlantic and Pacific oceans gives a more Arctic climate. This remoteness explains the low salinity content in especially the Laptev Sea, which is the most remote of the shelf seas.

The Chukchi Sea has a slightly higher salinity content than the Laptev and East Siberian Sea mainly due to lower runoffs and the presence of the cold Alaska winds, which freezes the surface water and push the ice into the Pacific Ocean. This process leaves dense and saltier water in the Chukchi Sea [9].
3.3 Temperature

The Arctic Oceans are persistent cold with small temperature variation, which characterizes a polar climate. Figure 3.2 shows the mean temperature for the upper 200 m of the water column. In the winter a large percent of the total area is covered with ice and thus less observations and cruises have been done during the coldest time of the year. This is probably why the shown temperatures are higher than the actual annual mean sea temperature.

Temperature variates mainly between $-2^\circ C$ and $+1^\circ C$. The Atlantic water, which is warm compared to the Arctic water, contributes to an increase in upper 200 m temperature in the shelf seas from $0^\circ E$ to around $90^\circ E$.

The slight increase in the upper 200 m temperature in the eastern Chukchi Sea is due to the warm Alaskan Coastal Current that flows through the Bering Strait. The current is warm and fresh and present during the summer until late fall.
3.4 Oxygen, $O_2$

3.4.1 Oxygen concentration

Dissolved oxygen is added into the water from photosynthesis and diffusion from the surrounding atmosphere. Isolated waters may have low dissolved oxygen. Cold waters hold substantially more oxygen than warm waters. Thus the mapping of oxygen concentration may look like a negative correlation with the temperature.

![Oxygen concentration diagram](image)

**Figure 3.3:** Oxygen concentration

3.4.2 Oxygen saturation

Since the oxygen is highly related to the temperature, it is appropriate to have a look at the saturation. The saturation is the amount of $O_2$ in the water, regulated for the temperature. It is predicted that the total oxygen saturation is somehow constant for the Arctic Ocean. In Figure 3.4 we can see that the oxygen saturation in the Arctic shelf seas are mainly around 96-99%. A well mixed upper layer will tend to be fully saturated, so the results indicate that the water in the marginal seas are well mixed.
3.5 Nutrients

Nutrient concentrations in the upper layers can be strongly affected by productivity in the waters, which uses up nutrients, especially nitrate. In general productivity is limited by light, nutrients and physical factors such as stability and mixing.

3.5.1 Nitrate, NO$_3$

The concentrations of dissolved nutrients in the upper 200 m depend on biological activity and how well the admixture of deep waters is and its nutrient content [5]. Some of the Arctic shelf seas, like the East Siberian Sea, also has year ice shelf break that limits the wind driven upwelling at the shelf edge. Long distances to deep waters and excessive river runoffs also lowers the concentration of nutrients in the shelf seas.
The North Pacific waters are nutrient rich. The areas of the Chukchi Sea with highest concentration of nutrients receive water from this source. High concentrations of nitrates can also be found around the western part of the Barents Sea. The source of this water is not clear, but it might be a local source of nutrients. Atlantic Arctic waters are somehow low in nutrients since it receives north-flowing water that is biologically spent [5].
3.5.2 Phosphate, PO$_4$

Phosphates originates from soil and rocks in the nature but also has its human sources. Ice formation and melting has a large impact on the chemical conditions in the shelf seas, along with the internal circulations.

The high concentration of phosphates in the Chukchi and East Siberian Sea is mainly due organic material input from river runoff to the west. The high concentrations to the east is due to inflow from the Pacific Ocean. River runoffs and streams directs this low-concentrated water out from the East Siberian shelf so it don’t propagate further into the Laptev sea.
3.5.3 Nitrate / Phosphate ratio

The Nitrate/Phosphate ratio is known as the Redfield ratio. It is used for understanding the biochemical cycles of the ocean, like formation of blooms. The Redfield ratio also help determine which nutrients that are limiting in a localized system. When nutrients are not limiting, the Nitrate/Phosphate ratio is generally about 16:1[6]. In Arctic waters the ratio ranges from 11:1-16:1.

![Figure 3.7: Nitrate / Phosphate ratio](image)

Figure 3.7 shows that the ratio is very variable. The reason why the ratios is below 16 in some areas may be due to high nitrate uptake by plankton or in isolated, low-oxygen waters to bacterial denitrification. From the results it may also seem like some Arctic rivers are low in nitrate and high in phosphate and silicate.

From the result plot the shelf seas generally has low amount of nutrients, and the areas with high amount of phosphate has a ratio as low as 0.5:1.
3.6 Silicate, $\text{SiO}_3$

Silicate occurs in forms of sand, sandstone, granite and may also be found in skeletal parts of various animals and plants. Water passing through or over the earth dissolves silica. High silicate contents found in the Arctic are mainly from the Pacific Ocean.

Anomalies in the Kara Sea occurs due to strong river runoff from the Yenisei river that increases the silicate content. Areas in the Laptev and East Siberian Sea with higher concentrations of silicate are also due to river runoff, from the river Lena and Kolyma respectively [7].
Chapter 4

Summary

Chapter 3 describe the differences in salinity, temperature, oxygen, nutrients and silicate in the Russian shelf seas. Although the seas are relatively close geographically, it is easy to spot some differences. The most severe differences are found in the Chukchi and Barents Sea and is clearly due to impacts from the Atlantic and the Pacific Ocean. The East Siberian, Kara and Laptev Sea are quite similar, with some exceptions, especially the ratio nitrate/phosphate and oxygen saturation.

The most remarkable differences is found in the nutrient concentrations and nitrate/phosphate ratios. The low nutrient concentration in the Kara, Laptev and East Siberian Sea may indicate high biological activity that uses the nutrients (especially nitrates), along with ice formation that isolates the sea surface. The Chukchi Sea is rich in nutrients but have a nitrate/phosphate ratio similar to the Barents and parts of the Kara sea, which have lower concentrations of nitrates. Ratios under 2:1 could be found in the East Siberian Sea and the Laptev sea, which is due to high phosphate and low nitrate concentrations.
Bibliography


Read: 11/12-14

Read: 11/07-14


Read: 11/10-14


[8] https://www.nodc.noaa.gov/OC5/WOA05/pr_woa05.html
Read: 11/17-14