LUND UNIVERSITY
Faculty of Science

# Arctic sea ice drift

## A comparison of modeled and remote sensing data

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**Abstract:** The Arctic climate and the sea ice drift are important to study both for the improvement in short-term forecasts and to get a better understanding of the climate change. Short-term forecasts are needed to improve the shipping and offshore industries in the Arctic Ocean. Changes in the ice thickness and concentration can have massive consequences for people and the environment. In the present work, modeled sea-ice drift from a coupled ocean-ice model was compared with observational sea ice drift from remote sensing data with the aim to se if they correspond to each other. Hybrid Coordinate Ocean Model (HYCOM) was used as an ocean model and Los Alamos Sea ice Model (CICE) was the used sea ice model. The data sets were analyzed with Matlab with reason to create plots and easily readable information. The data sets were from year 2015 and showed that sea-ice maximum occurs in late winter and sea-ice minimum appears in late summer.

# Acknowledgements

This bachelor thesis is a collaboration between Lund University and the Danish Meteorological Institute (DMI). DMI supplies data, models and a supervisor with good knowledge of the subject. I want to thank my supervisors Elna Heimdal-Nilsson and Till Rasmussen for all the help and support. I will also like to thank Anna Rosling, Malin Karlsson and Daniel Larsson for supporting me in my writing.

# Table of content

# 1. Introduction

This project investigates the Arctic sea ice drift and its regional differences with focus on modeled sea ice drift and the ability of forecasting in the Arctic Ocean. One reason for sea ice forecasting is that ships and off shore industries want to know where there is ice and where there is no ice. An improvement in forecasting leads to better routes and maybe even to an expansion of off shore industries. This is one reason why the sea ice drift and short term forecasting is of interest to study. The sea ice drift is also related to the climate and an investigation of how the Arctic climate interacts with the rest of the climate system.

Arctic sea ice drift is analyzed with both observations and models and may differ between different parts of the Arctic Ocean. Also ice thickness, strength of currents and wind speed differs between locations. This study will compare modeled and remote sensing data from the Arctic Ocean. Scientific papers about sea ice drift were read and data sets were analyzed in Matlab. Model data from April 2015 – January 2016 and remote sensing data from 2015 were used. The question investigated in this report is "*How well is the ice drift represented in an operational sea-ice coupled model compared to remote sensing data?*". An operational model is a model that makes a short-term forecast, in this case five days. The model is termed operational because it is run at fixed time slots in a safe environment, thus in case of failure it will be rerun.

In this case, a coupled model is a model that runs an ocean model and a sea ice model at the same time. The ocean model in this study is the Hybrid Coordinate Ocean Model (HYCOM) and the sea ice model is the Los Alamos Sea ice Model, also called CICE. DMI runs the coupled model twice a day to forecast the sea ice conditions in the Arctic region. The coupled model does not have an official name but is sometimes referred to as ACOM at DMI. The remote sensing data used is officially called Synthetic Aperture Radar (SAR). SAR observes features of sea ice and matches these at next pass. When similarities are identified SAR can calculate distances travelled.

# 2. Background

## 2.1 General about sea ice drift

Sea ice is frozen ocean water that grows and melts in the ocean. The difference from icebergs and glaciers is that they form and grow on land, sea ice only forms and grows in the ocean. The sea ice drift depends on ice thickness and ice concentration. The definition of ice concentration is the proportion of sea surface covered with ice [1]. Two important concepts when analyzing the sea ice in the Arctic Ocean is Arctic sea ice maximum and minimum. Arctic sea ice maximum is when high concentrations of sea ice are found over the entire ocean. It often occurs at the end of the cold winter season. Arctic sea ice minimum is the opposite, which often happens at the end of the warm summer season. The reason for the sea ice minimum is that the sea ice is melting due to the warm underlying ocean and the export of sea ice [2].

When the ice cover in the Arctic Ocean is studied, sea ice drift is usually also looked at. It has been measured from satellites since the late 1970's. Surface winds and currents in the upper layer of the ocean is one way to describe the sea ice drift (Park and Stewart, 2016). This motion leads to a deformation in the sea ice cover and has a great impact on the sea ice thickness [3].

Shear and convergence motion from sea ice drift influence the sea ice thickness and cause dynamical ice growth. This can cause areas of open water, also called polynyas. Polynya is an area of open water surrounded by sea ice, these are open mainly due to dynamic movement of sea ice [4]. Areas with open water affect the local temperature of the ocean and the surface air temperature because they cause heat exchange between ocean and atmosphere [5]. New and thin ice grows faster than old ice thus openings based on for instance polynyas create more ice [6].

Simulating the sea ice in the Arctic Ocean is difficult because the ice export along Greenland's east coast is hard to predict. A good prediction of the ice export is required for accurate results. The interaction between the cold water in the polar regions and the warm water in the Atlantic Ocean within the current of East Greenland and the effects of local weather systems is also taken into account when the sea ice conditions are simulated [7].

Modeling of the sea ice motion in the Arctic Ocean is based on similar principles as weather prediction. Basic principles in weather prediction are to analyze known patterns, collecting data from measurement stations and analyze satellite and radar pictures. Different parameters can be calculated from common patterns and modeled values. From all these parameters, assumptions of the weather forecasting can be done. Just like weather prediction, sea ice drift can be difficult to predict and there are several reasons for that. For example, the initial state of the sea ice is hard to determine. The internal sea ice strength, resistance to movement depends on thickness, concentration etc. These need to be well known to make a good prediction.

## 2.2 Driving mechanisms

The movement in the Arctic Ocean depends on wind, Coriolis force, ocean currents and internal stress. Details about the internal stress are discussed in section 3.2. The other three are discussed in this section.

The primary mechanism behind the sea ice drift is wind. Wind affects sea ice drift on short term, on a timescale of days to weeks. Surface winds act as a force on sea ice and cause it to drift. The wind speed is an important factor for the impact of the wind on the sea ice drift. High wind speed causes more drift than slow. Also the shape of the sea ice is important for how the wind affects it. Ice with rough surfaces drifts more easily than smooth surfaces [8]. The impact of the wind is taken into account in the modeling sea ice drift with CICE and HYCOM. Wind speed is however not included in the remote sensing data used in this report.

The Coriolis force is one of the driving mechanisms of sea ice drift because it causes objects to accelerate. Due to its effect on moving objects, the Coriolis force has an important role in the movement of sea ice. It is strongest around the poles and non-existent around the equator [8].

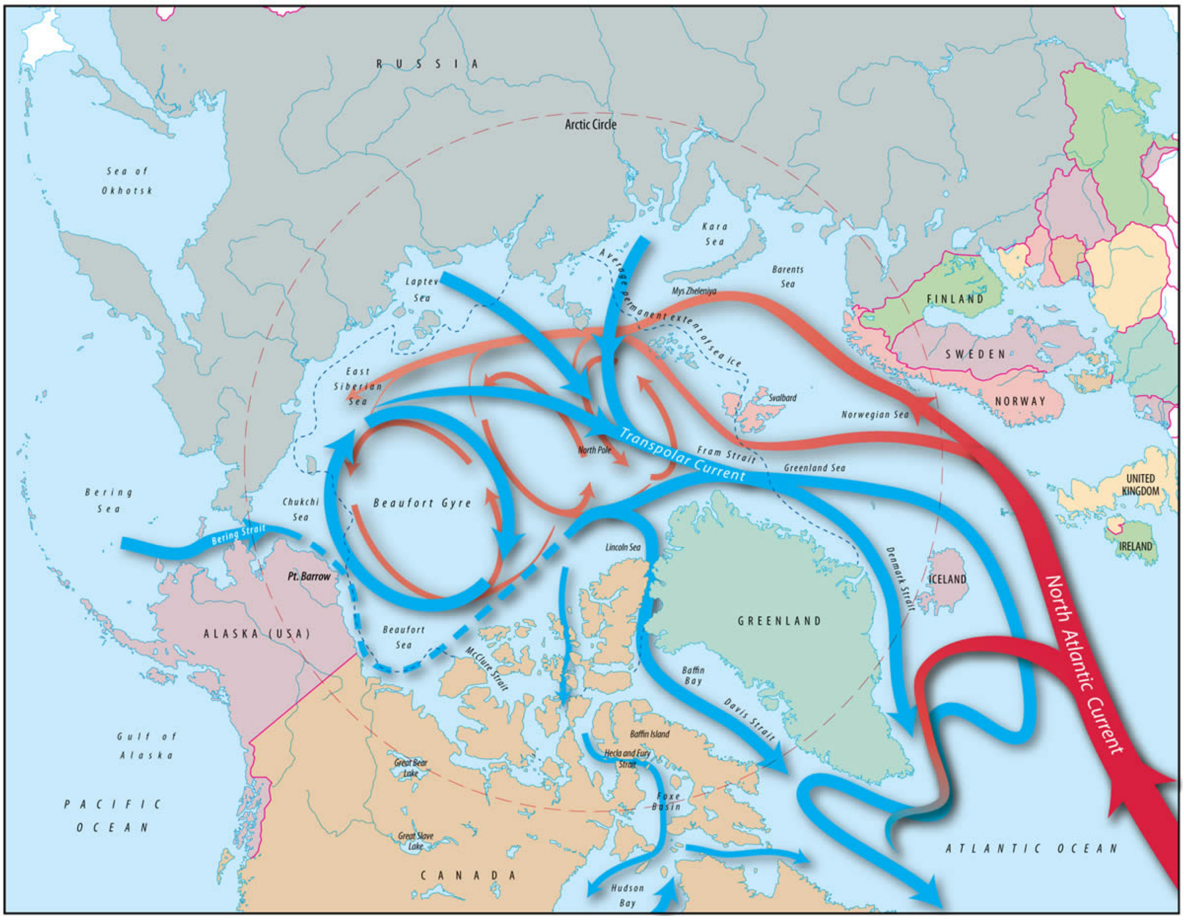


**Figure 1 Map over Arctic Ocean and its movement. Blue arrows represent cold currents of freshwater and red arrows represent warm currents of saltwater from the North Atlantic Current [9].**

In the Arctic Ocean, ocean currents have long-term effect on sea ice drift, often monthly or yearly but in some regions currents are also important for the short-term movement [8]. The location of the currents relevant to this study is seen in Figure 1. The North Atlantic Current is the largest current with big influences on the sea ice drift. This is one reason why the area between Norway and Greenland often is ice-free. Warm currents, marked by red arrows in Figure 1, consist of saltwater from North Atlantic Currents that originally comes from Atlantic Ocean. These warm currents cause sea ice deformation due to heat exchange. Cold currents generate sea ice drift and ice formation. The inflow of cold currents comes from the Barents Sea, and the outflow is into the Atlantic Ocean. Circulations of both warm and cold currents are seen in Figure 1 [5].

## 2.3 Climate change

Arctic sea ice drift is an important factor when analyzing effects of climate change. Not only is the knowledge about climate change limited, models and simulations for sea ice drift are far from perfect. The knowledge of climate change increases and it is now known that sea ice has an important effect due to changes of albedo. Albedo is a quantity that indicates how surfaces reflect solar energy [10]. The albedo is measured from 0.0 to 1.0 where 1.0 reflects the most. White surfaces reflect solar radiation better than black, therefore decreasing sea ice extent leads to a lower albedo.

A graph of the Arctic sea ice extent is shown in Figure 2. During the past years, the sea ice extent in the Arctic Ocean has decreased and temperatures over the entire planet have increased [11]. For that reason, modeled sea ice drift in the Arctic Ocean is important for studies in future research about global warming. Even if temperatures in the Arctic Ocean increase marginally, the warming of the ocean will be significantly larger over a longer period. Global warming leads to sea ice loss [2]. A reduction of the sea ice thickness can result in larger areas with open water. Open water can result in an increase in heat and further reduction of sea ice. This is also known as positive feedback. All these factors affect the sea ice drift and its direction.

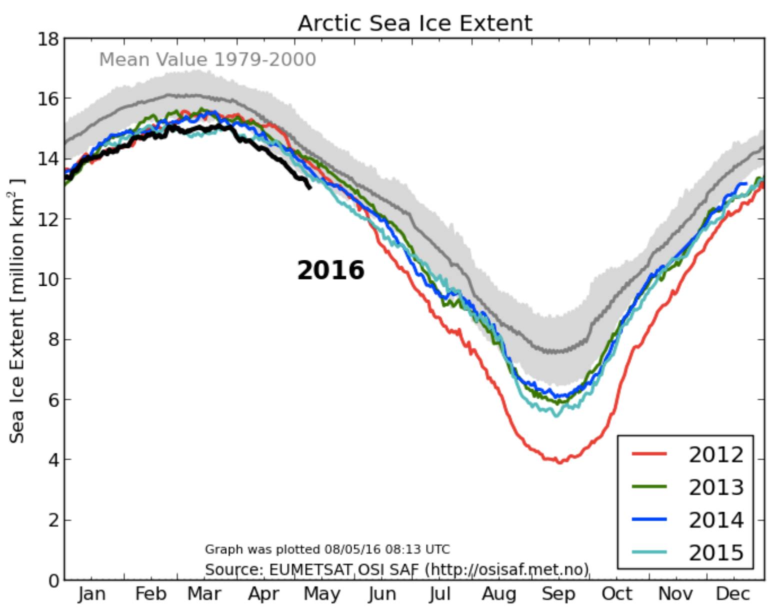


**Figure 2 The Arctic sea extent year 2015-2016 including the mean value from 1979-2000 [12]**

Climate models are in agreement in that the Arctic sea ice extent is decreasing through the 21st century. The IPCC AR4 models indicate that the Arctic ice loss is faster than previous forecasts. The reduction of sea ice is mainly due to climate change. Global warming affects the sea ice loss in Arctic Ocean because surface air temperatures are increasing, which delays the growth of winter and autumn ice. The Arctic region is sensitive and the effects of global warming are more significant there than over the rest of the globe [13].

Not only the ice extent decreases in the Arctic. It has also been shown that the sea ice becomes thinner and that ice that is more than two years old is also melting. Wind and ocean currents are important contributors to the large-scale circulation of sea ice. The large-scale circulation can describe the exchange of sea ice in regional areas and how the motion is transported to oceans at lower latitudes. The small-scale circulation of the Arctic sea ice describes the formation of areas with open water [4].

# 3. Theory

## 3.1 Models

### 3.1.1 Coupled model - ACOM

DMI uses a coupled model between CICE and HYCOM, unofficially called ACOM. It is a so-called coupled ocean-sea ice model and consists of the ocean model HYCOM together with the sea ice model CICE. It uses the sea ice properties from the CICE model and the ocean characteristics from the HYCOM model. ACOM takes both the ocean and sea ice model into account and combines them in the modeling. This coupled ocean-sea ice model runs at DMI twice a day.

### 3.1.2 Sea ice model - CICE

The information about the model in this section is mainly taken from Hunke and Lipscomb's manual [14]. CICE is the Los Alamos Sea ice Model developed at Los Alamos National Laboratory. It is a sea ice model aiming to compute sea ice components for a coupled model that can analyze the atmosphere-ice-ocean-land global climate. The focus of the model has expanded and it is also commonly used as a part of operational model systems. The main parts of the model are ice dynamics, ice thermodynamics and redistribution of sea ice. The growth of snow and ice are computed based on thermodynamics. Boundary conditions for the ice and atmosphere are obtained from ECMWF numerical weather prediction, whereas the ocean and ice interface is described through a flux coupler. CICE itself can also be coupled with given a large number of other climate models. Fluxes for different components and variables are given as inputs to the model. The fraction of ice, $a_i$, is the ice coverage in a grid cell and is described like this in each grid cell of equal size, where $a_i$ is the sum of the fraction of the ice for each category. Specifically $a_i$ is defined as follows:

$a_i = 0$ if there is no ice

$a_i = 1$ if there is no open water

$0 < a_i < 1$ if there is both open water and ice.

Wind stress, Coriolis force and the slope of the ocean surface are important forcing mechanisms for the ice motion and is also called the ice-ocean stress. This is the dynamic part of the model. The ocean model performs its calculation in the way that new ice forms when the temperature of the ocean is below its freezing point, $T_f = -\mu S$, where $\mu$ is the ratio of the freezing temperature of saltwater to its salinity and S is the seawater salinity. The thinnest category of ice is “new ice”, which forms when the freezing temperature is reached.

The freezing potential represents the amount of new ice that forms in one or several layers. If the freezing potential is negative, the ice is melting because the heat from below has already started to warm the ice. On the other hand, new ice forms if the freezing potential is positive. The purpose of the ocean model is to adjust the heat budget while assuming the reminder of the flux is still in the ocean.

### 3.1.3 Ocean model - HYCOM

HYCOM stands for Hybrid Coordinate Ocean Model, with the aim to optimize the representations of oceanic processes. HYCOM distinguished itself by a hybrid vertical coordinate including sigma (terrain-following), isopycnal and z-level coordinates. Isopycnal means a line connecting spots of potential or specific density. In the open and stratified ocean, the hybrid coordinate is isopycnal. In shallow coast regions, it easily reverts to coordinates that follow the terrain. Stratification is when the temperature, pressure and salinity vary and change the density of water, which creates distinct layers of water with different physical properties. The z-level coordinate is relevant when looking in the mixed layer or in unstratified seas. Each coordinate in the HYCOM model has a reference isopycnal. The model combines the benefits of different types of coordinates in simulating coastal and open water circulation functions. HYCOM is made to simulate the motion in the ocean all over the world, but only the area within Arctic Ocean is relevant for this report [15].

## 3.2 Stress tensor

Major parts of this section are based on Leppäranta's book [16].

The theory behind the sea ice drift is complicated because different ice conditions require different laws. Temperature, density and other macroscopic variables indicate the state of the ice. This is particularly due to the difference in ice thickness and density. Large areas of floes are often due to drift ice. There are several processes involved when ice breaks and form into floes. Some of these processes are thermal stress and isostatic imbalance.

The movement of the sea ice drift is partly driven by the stress tensor. This stress is often referred to as the internal stress, which is a common expression and refers to when something acts across a body. The stress distribution depends on macroscopic quantities such as material and temperature. There are several mechanisms generating stress. For example, flow collisions and break-ups, shear friction between floes and also friction between ice blocks and potential energy production in pressure ice formation. Stress is a symmetric second order tensor where the diagonal components are normal stresses and the other are shear stresses [17]. In Cartesian form, the stress tensor can be written as:

$$\overline{\sigma} = \begin{bmatrix} \overline{\sigma_{xx}} & \overline{\sigma_{xy}} & \overline{\sigma_{xz}} \\ \overline{\sigma_{yx}} & \overline{\sigma_{yy}} & \overline{\sigma_{yz}} \\ \overline{\sigma_{zx}} & \overline{\sigma_{zy}} & \overline{\sigma_{zz}} \end{bmatrix} \qquad 3.1$$

Equation 3.1 can be divided into sub-fields:

$$\overline{\sigma} = \begin{bmatrix} HH & HH & HV \\ HH & HH & HV \\ VH & VH & VV \end{bmatrix} \qquad 3.2$$

$$[HH] = \overline{\sigma_H} = \begin{bmatrix} \overline{\sigma_{11}} & \overline{\sigma_{12}} \\ \overline{\sigma_{21}} & \overline{\sigma_{22}} \end{bmatrix} \qquad 3.3$$

The stress, HH, also written as $\overline{\sigma_H}$, is called the horizontal stress. The horizontal stress is due to the horizontal interactions in the sea ice. The vertical stress transports water and air stress into the ice, this is denoted by VH. HV and VV are the vertical equation of motion, also called the hydrostatic equation when ice is found on the sea surface. If there is no stress, σ=0, which is called free drift.

$$\sigma = \int_{h''}^{h'} \overline{\sigma_H}\, dz \qquad 3.4$$

In sea ice dynamics internal stress is the integration of $\overline{\sigma_H}$. The integration is made through the ice thickness and gives a two-dimensional stress with the dimension force and length.

# 4. Method

## 4.1 Sources

In the beginning of the project, articles about sea ice drift and the Artic Ocean were read to get a better knowledge of the chosen subject [3]-[7], [10], [13]. Statistics and information about sea ice dynamics were taken from National Snow and Ice Data Center (NSIDC) and the climate section at NASA. To get reliable results, information from the peer-reviewed articles was compared with the information for NASA and NSIDC [1], [2], [8], [11], [12], [18], [19]. Manuals for both the sea ice and the ocean model were read to get an overview of how they work [14], [15]. Also books about the sea ice drift with focus on ice dynamics was read to get a better knowledge of the stress tensor and other basic factors in sea ice drift [16], [17]. The used data sets came from DMI and contained both modeled data from the coupled model and observational data from SAR.

## 4.2 Programming

### 4.2.1 Monthly means

The coupled model was used, data were from the 1st of April 2015 to the 31st of January 2016 with measurements every hour to produce the monthly mean of modeled data. Parameters such as the ice thickness, ice concentration and velocity of the sea ice were studied to predict sea ice movement in the Arctic Ocean and plotted in Matlab. Both regional and seasonal variations were analyzed to get a better prediction of the movement of sea ice.

### 4.2.2 Comparison of sea ice drift

This part of the present work was also made in Matlab. Model data were used with the aim to predict the direction of the sea ice drift in the Arctic Ocean. Given data were from the 1st of April 2015 to the 31st of January 2016 with measurements every hour. A Matlab-program was developed to calculate the direction of the sea-ice drift. In Matlab, a map with arrows were plotted to follow the modeled sea-ice drift. To get the arrows in the right direction, the distance between the start and end points were calculated and rotated. Both the longitude and latitude were computed to get start and end points. The model includes wind as a forcing parameter.

Data files from remote sensing were collected from year 2015. The remote sensing data was analyzed in the same way as the modeled data. The data files contained several data points for the sea ice drift.

Known errors from the remote sensing data are that it is hard for the radar to notice the difference between land and sea ice near coastlines. This uncertainty needs to be taken into account when analyzing and comparing the remote sensing data with modeled data. It is difficult to predict the sea ice thickness through remote sensing and the error is predicted to differ around 1-2 meters.

The direction of the modeled and observed results were compared and analyzed. The remote sensing data and modeled data can be analyzed together with the monthly means of ice concentration, ice thickness and the ice velocity. Areas of open water and thin ice are important for the movement of sea ice drift and its direction. The distance travelled based on remote sensing includes wind in the sense that the movement of the sea includes wind.

# 5. Results and discussion

## 5.1 Sea ice thickness and concentration

In this section, figures of the sea ice in April and August are found. Figures for the rest of the year are found in Appendix I. Generally, the sea ice maximum is found in March according to measurements from DMI. NASA's measurements show that 2015's sea ice maximum is reached already in the end of February [18]. But in this study, only data from April 2015 to January 2016 was used, hence maximum thickness is recorded at the start of the studied period. In the present work, sea ice minimum is predicted in August 2015. NASA on the other hand has measured that the sea ice minimum occurred at September 11th [19].

Along the Northern coastline of Greenland and the Canadian Archipelago, the modeled ice thickness is measured to be around 7 meters. This can be seen in Figure 3. It is also seen in Figure 4 that the sea ice covers the entire Arctic Ocean and the concentration of the sea ice is high. This means that only a few areas of open water exist. April is in the end of the cold winter season, which is the reason why the sea ice maximum is found this month.

In Figure 5 and 6, it is shown that the sea ice cover decreased from April until August. These figures show the concentration and thickness of the sea ice in the Arctic Ocean. The sea ice does not cover the entire Arctic Ocean and the Canadian Archipelago is almost ice-free. The sea ice extent has decreased over the entire area, but the ice is still thick along the coastline of Northern Greenland. The yearly minimum is found in late summer because the air and ocean temperatures have increased the whole summer, which leads to melted ice.

In spring, the ice extent is widespread along the whole Arctic Ocean and also around the coasts of Greenland. When analyzing the monthly means, the large areas around Baffin Bay, Fram Strait and the Canadian Archipelago are all ice-free during July to October 2015.

Northern coastline of Greenland and the Canadian Archipelago is covered by thick- and high concentrated ice both in the summer and winter. The area between Greenland and Svalbard is ice-free all year around due to the North Atlantic current, which contains warmer water that melts the ice. This can be seen from the modeled data.

When the sea ice extent is studied geographically, the highest concentration of ice is found in the area around the North Pole. This can be seen for every analyzed month. The cold currents see Figure 1, near North Pole lead to colder temperatures and hence more ice.

In summary, it is during the last years known that the ice extent is decreasing. Partly due to global warming, the sea ice in the Arctic Ocean is melting. Melting ice leads to lower concentration of sea ice and more areas of open water. Larger areas of open water lead to an improved accessibility for ships and off shore industries to use the Arctic Ocean, which can be both negative and positive. A negative consequence is higher sea levels all over the world, which can be devastating for societies near the coast.

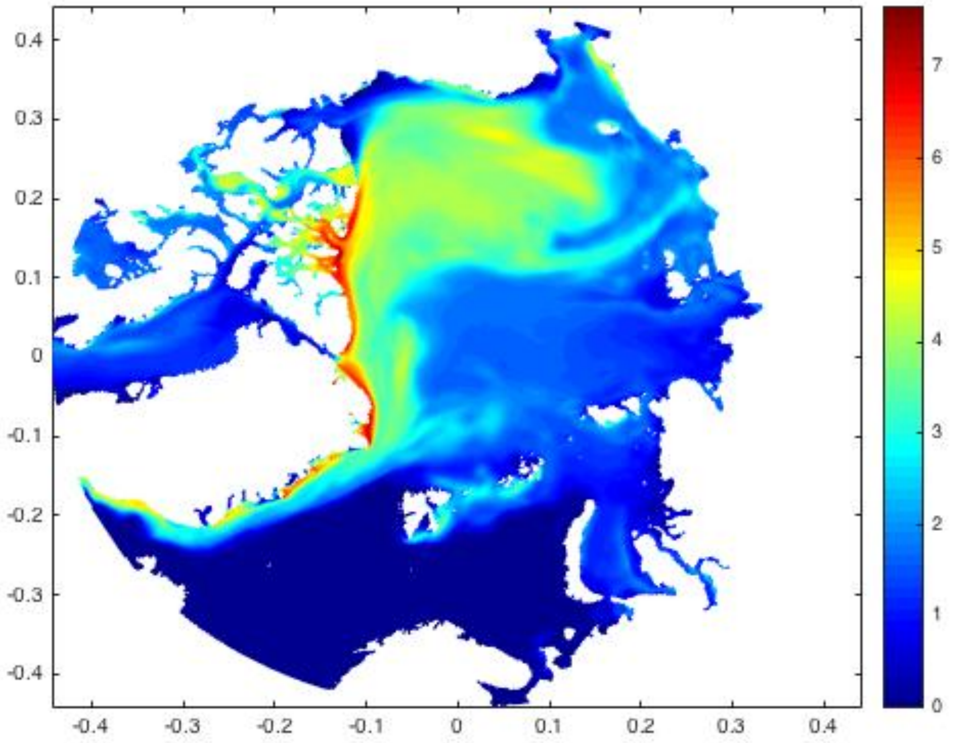


**Figure 3 Ice thickness in April 2015.**

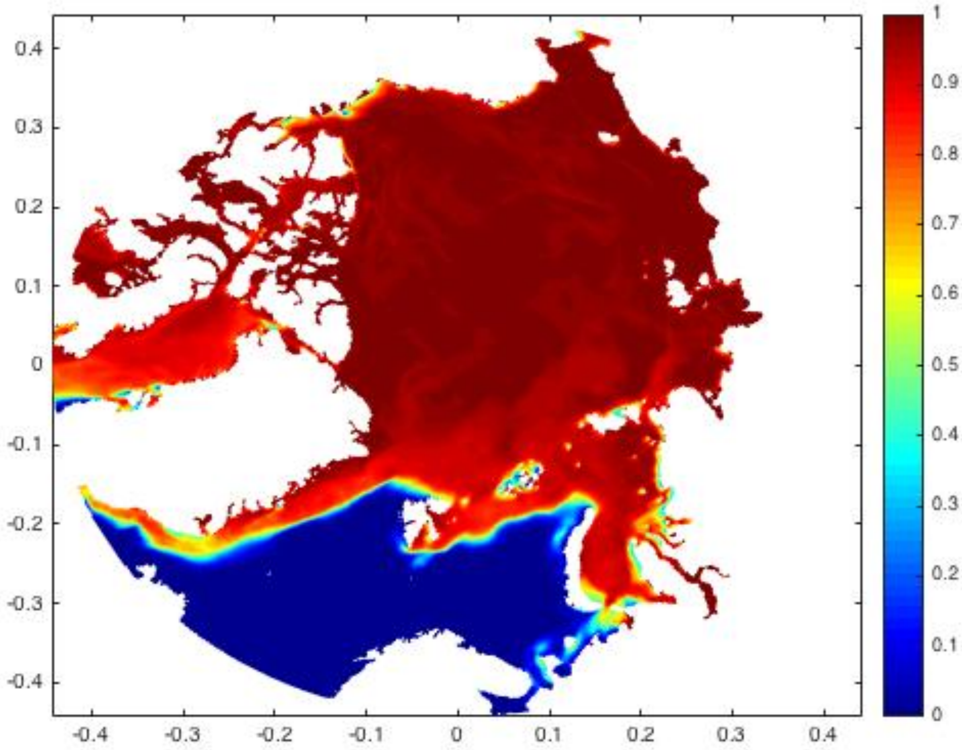


**Figure 4 Ice concentration in April 2015.**

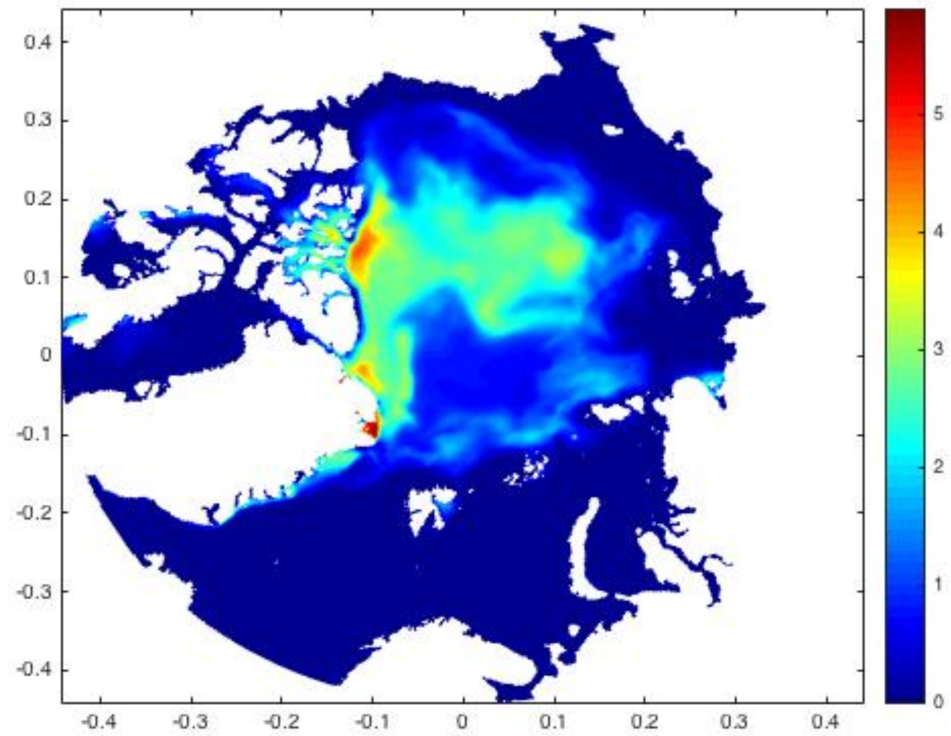


**Figure 5 Ice thickness in August 2015.**

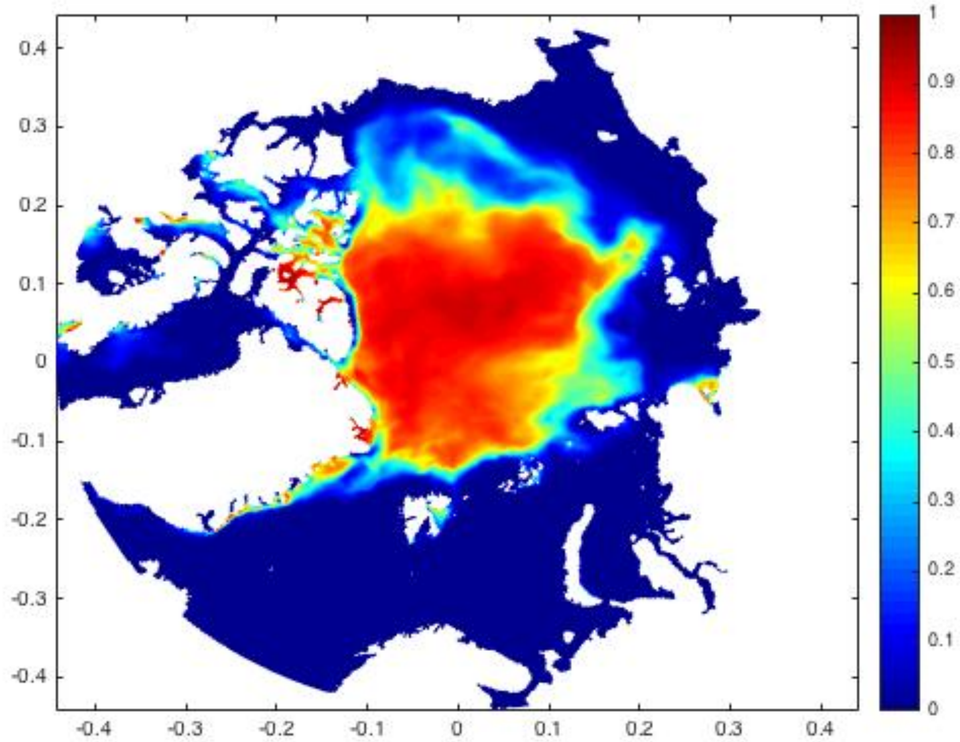


**Figure 6 Ice concentration in August 2015.**

## 5.2 Modeled sea-ice drift

*Velocity*

Figures 7-15 show the predicted velocity of the moving sea ice in the Arctic Ocean. It is important to remember that modeled predictions only are estimations of the sea ice movement. Negative values for the velocity indicate westerly movement and positive values indicates easterly movement. By comparing Figure 7-15, it is shown that the sea ice predicted to be fast along Greenland's east coast. As mentioned in section 2.1, the ice export is difficult to predict in this area. When comparing the sea ice movement with the sea ice extent in Figure 3-6, it is seen that the areas covered with sea ice basically are in movement all year around. The sea ice movement along the coast of Northern Greenland is more or less none. That area consists of thick ice and high ice concentrations which can be the reason to the lack of sea ice drift.

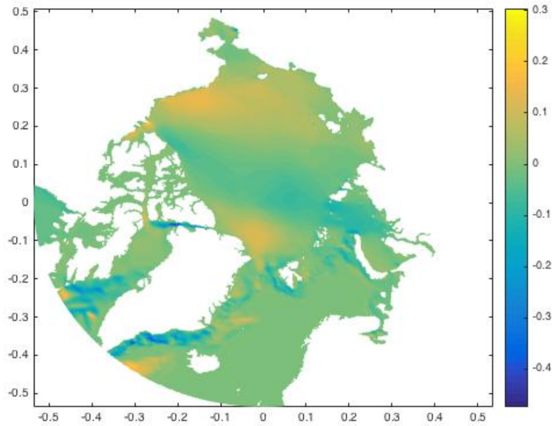

**Figure 7 Sea ice velocity in April 2015**

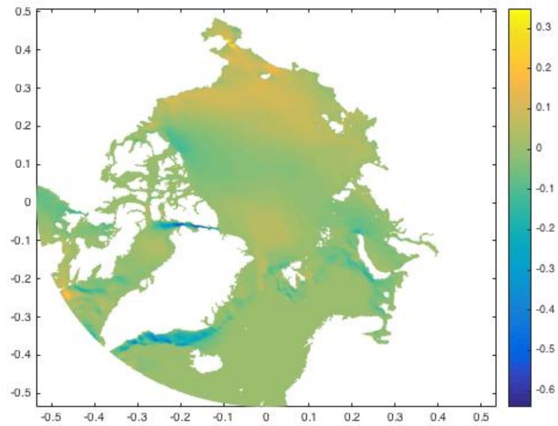

**Figure 8 Sea ice velocity in May 2015**

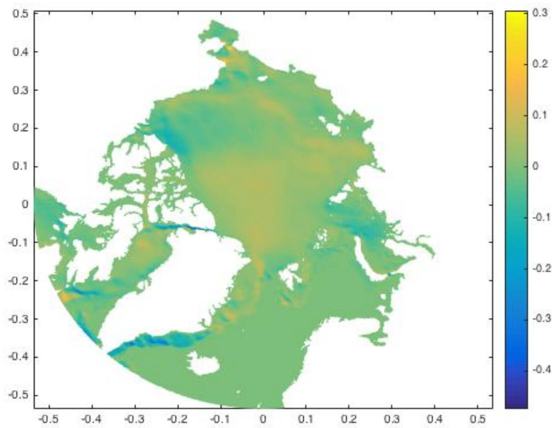

**Figure 9 Sea ice velocity in June 2015**

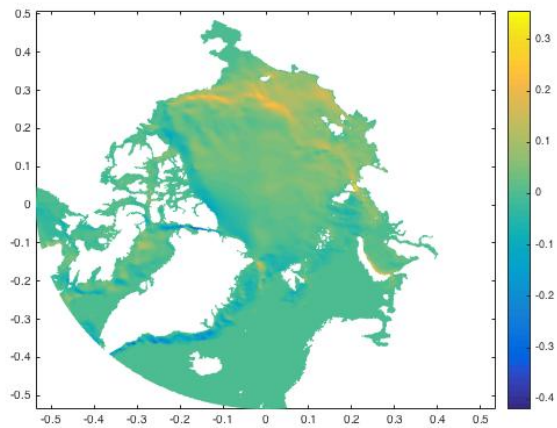

**Figure 10 Sea ice velocity in July 2015**

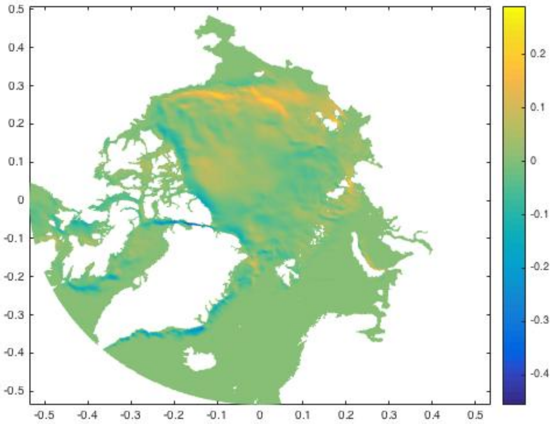


**Figure 11 Sea ice velocity in August 2015**

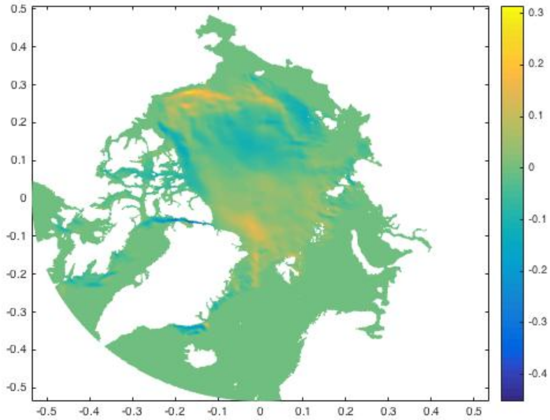


**Figure 12 Sea ice velocity in September 2015**

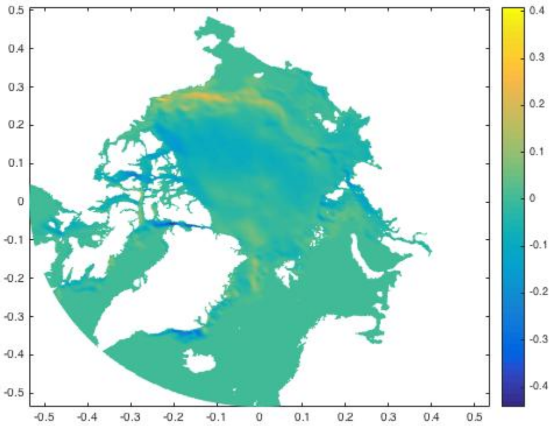


**Figure 13 Sea ice velocity in October 2015**

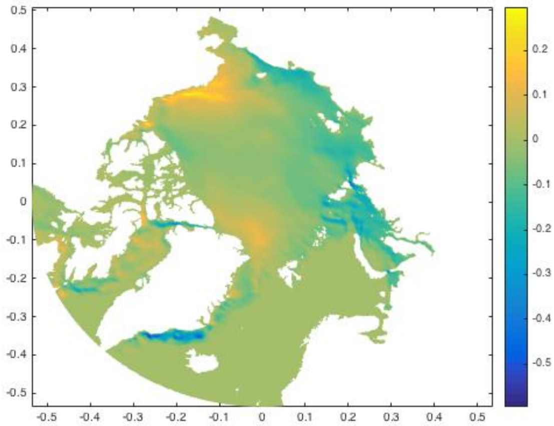


**Figure 13 Sea ice velocity in November 2015**

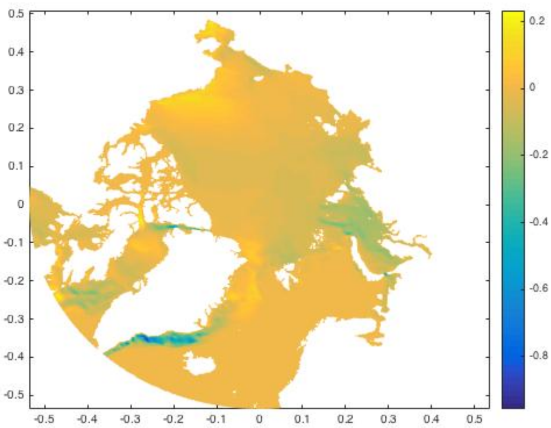


**Figure 14 Sea ice velocity in December 2015**

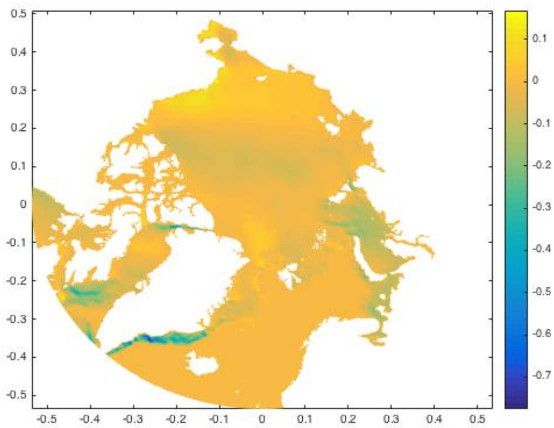


**Figure 15 Sea ice velocity in January 2016**

*Direction*

Arrows were plotted on a map over the Arctic Ocean to show in which direction the sea-ice drift is heading in Figure 16. The arrows show the direction of the drift calculated from a start value in April 2015. The starting value for the sea ice drift is computed from the remote sensing data to get a better comparison, see the comparison in section 5.3. From this starting value, the sea ice movement can be followed for the rest of the year. The location for the start values for both the model and the observations is seen in Figure 17. These locations were used both for the model and for the observations.

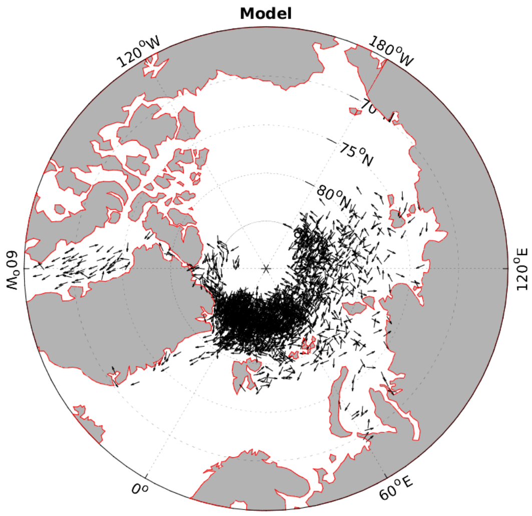


**Figure 16 Modeled data for April 2015 - Jan 2016. The arrows are showing the movement from the starting point taken from the first calculated observation point.**

Not every measured movement of the sea ice is included in Figure 16. It was too many points for each month, so to get it readable only 2310 points were selected. This could cause minor errors in the measurements and can be one reason to why the correlation between the observations and model is not perfect.

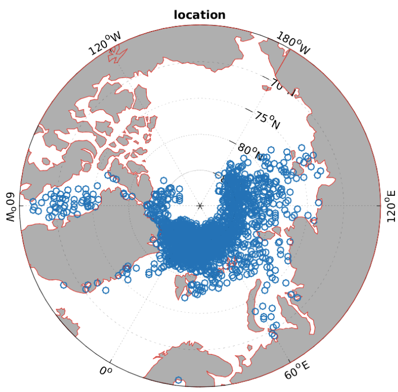


**Figure 17 Location of the arrows for both modeled and observed calculations.**

## 5.3 Comparison of modeled and observed sea ice drift

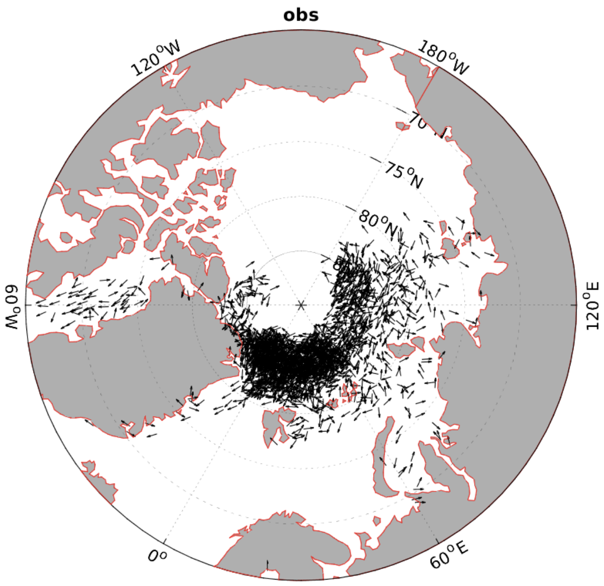


**Figure 18 Observational data for April 2015 - Jan 2016. The arrows are showing the movement from the starting point taken from the first calculated observation point.**

The modeled data was compared with remote sensing data from the same period. The comparison was done to see if they correspond with each other or not. The map in Figure 18 shows the direction of the sea ice in the Arctic Ocean predicted by remote sensing data for each month in the study. Like the modeled data, only 2310 were used in the plot. The aim of this report is to compare the direction of the movement in Figure 17 with Figure 18. A comparison was done in Figure 19, where all the used data points are plotted, and a trend line is drawn. The data points were the total sea ice drift. It was calculated from the eastern and northern movement with units of km/day.

If the modeled and observational data correlate perfectly, the slope of the plot would be 1. Unfortunately, this is not the case. In real life, observations and modeled data rarely match. This is also seen in Figure 19, an easy comparison between observations and the model. One point represent one measurement and the modeled drift can be seen on the x-axis and the observed drift on the y-axis. A desirable result would have been to get the slope equal to 1, in other words x=y which means that the observations is equal to the model. But that is not really case, the slope in Figure 19 differs a bit.

The comparison is based on sea ice velocity from the same period, April to December 2015. They accuracy for the modeled movement is not perfect, but neither far from perfect.

The predicted model could always be improved, and the reliability can be increased. The answer to the question of this report, *How well is the ice drift represented in an operational sea-ice coupled model compared to remote sensing data?*, should therefore be quit good, but not perfect. The data from the coupled-model is considering to be reliable and an accurate prediction of the weather in the Arctic Ocean. But as mentioned earlier, there is always room for improvement.

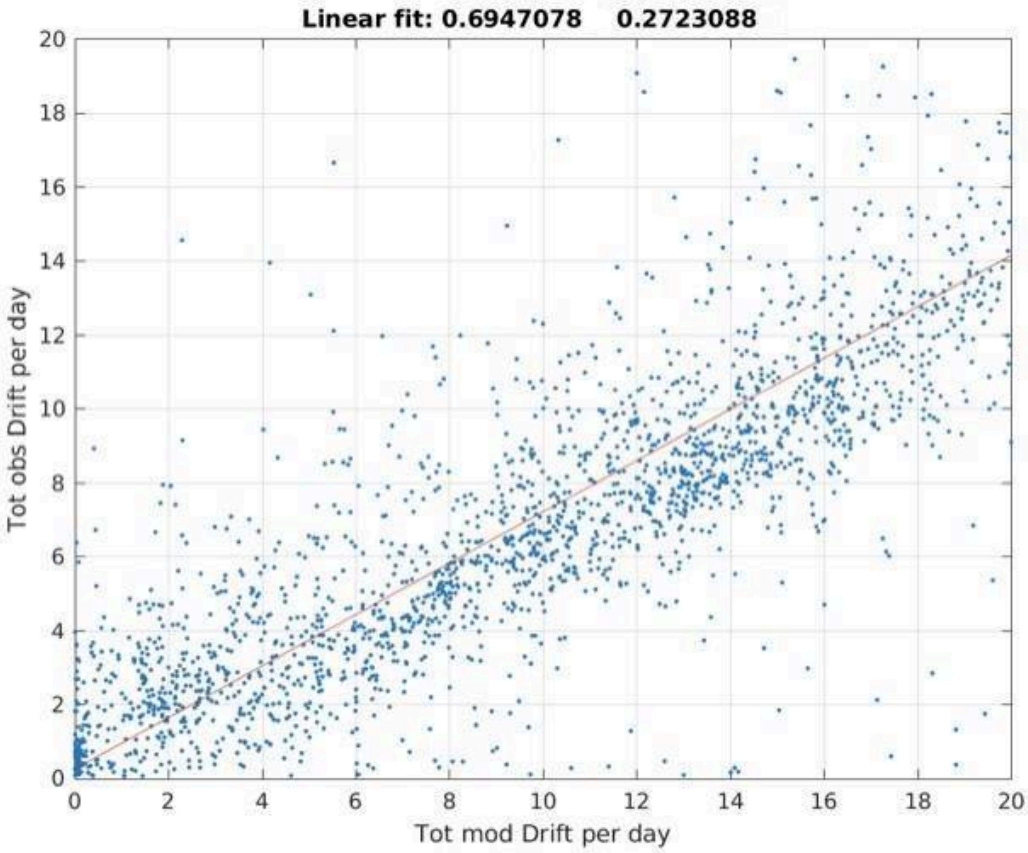


**Figure 19 Diagram showing the relationship between the model and observational data, units in km/day. The total drift was calculated for both observations and the model.**

The prediction of the sea ice in Arctic Ocean needs to be improved for future forecasting and knowledge of the climate change. To improve the models, better predictions of the factor transferring the ice need to be done. To get an exact modeling of the ice is nearly impossible. It will always be some uncertainties, both when predicting modeled values and measuring observed values. To predict for example the sea ice from SAR is difficult and has an uncertainty of around 1-2 meter. This is a high uncertainty when the sea ice itself has a thickness of 0-10 meters. Considering the modeled ice drift, it is just a rough estimate from the provided conditions and factors. The observed sea ice drift also includes uncertainties. The remote sensing data is synthetic aperture radar that has a large uncertainty when measuring different parameters of the sea ice near coastlines. This can lead to a lack of the reliability of the sea ice drift in these kinds of areas. In this case could it be for example along the coasts of Greenland and in the Canadian archipelago.

An improvement of the models will lead to a better correlation between the observed and modeled sea ice drift. Globally, it will lead to a better investigation of the interacting between the climate in the Arctic Ocean with the climate in the rest of the world. The researching and fascination for the Arctic climate has interested humans for centuries. Investigations with ships, radar and measurement stations are important to improve the knowledge of the Arctic nature. Arctic has a large wild life of animals not living anywhere also. The increasing temperature is a threat for their living and future.

# 6. Conclusion and outlook

When analyzing the monthly means of the sea ice extent in the Arctic Ocean, it can be concluded that the maximum concentration of ice is present during April and minimum during August. Wind, ocean currents, stress tensor, Coriolis force and sea surface tilt are the driving mechanisms for sea ice drift.

It is hard to measure sea ice thickness in the Arctic Ocean with remote sensing data, it has an uncertainty on around 1-2 meters. The sea ice extent in the Arctic Ocean has decreased during the past years. A good precision is required to get exact results. It is hard to make an exact modeling of the sea ice drift.

The sea ice drift is accurate represented in the coupled model comparing to the remote sensing data, but not perfectly represented. A comparison was made through a scatterplot with modeled and observed data. The modeled sea ice drift differs from the observed sea ice drift. This is the answer to the question of issue.

An improvement in the modeling sea ice drift is important knowledge to prevent the global warming. It is well known that sea ice is decreasing and this was also proven in this report. Better weather prediction in the Arctic Ocean leads to an improvement in the knowledge of climate change.

A reduction in the sea ice itself will not cause higher ocean water levels or threatening societies near coastlines. The decreasing sea ice is however a threat against the animals living on the North Pole. An improvement in short-term forecasting is important for future studies and understanding in the Arctic sea ice drift. Short-term forecasting is required for offshore industries and shipping.

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# I. Appendix A

The pictures below show the sea ice concentration and thickness the studied months in year 2015.

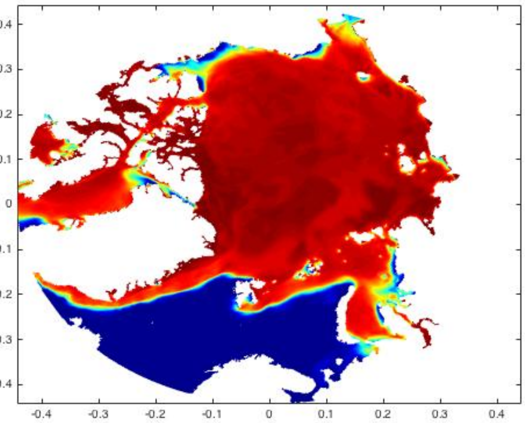

**Figure 20 Ice concentration in May 2015**

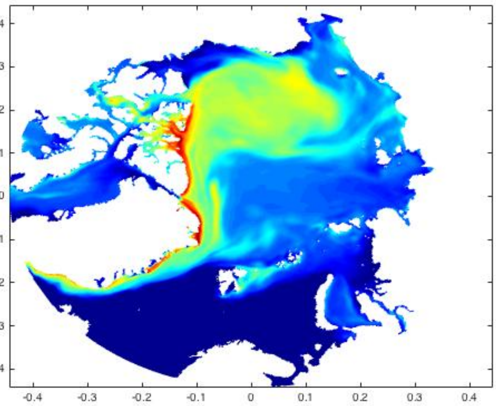

**Figure 21 Ice thickness in May 2015**

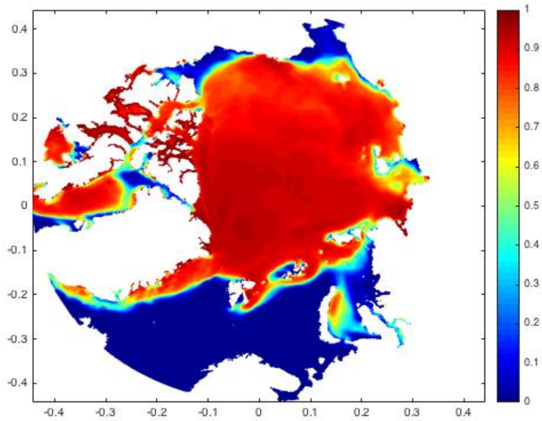

**Figure 22 Ice concentration in June 2015**

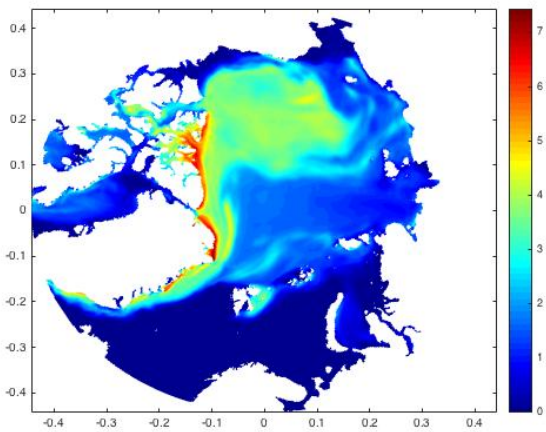

**Figure 23 Ice thickness in June 2015**

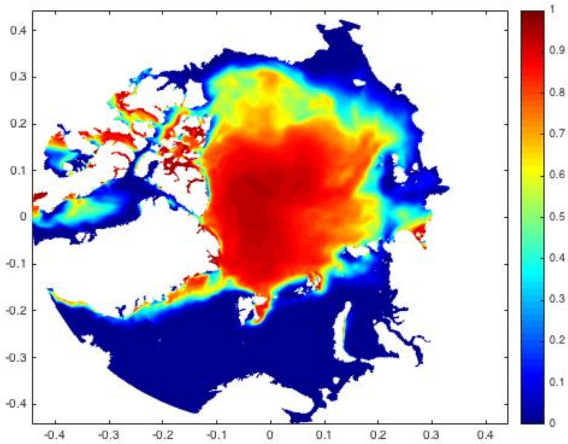

**Figure 24 Ice concentration in July 2015**

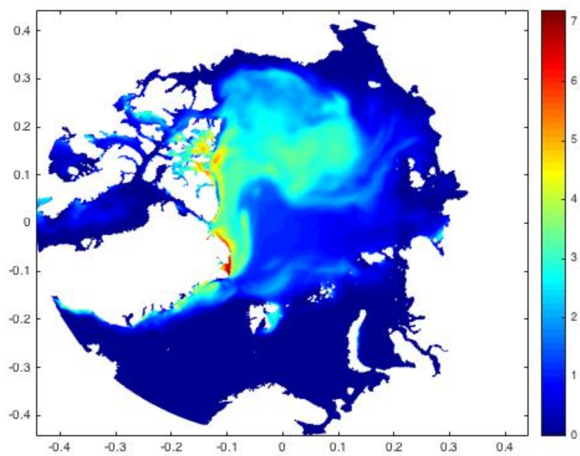

**Figure 25 Ice thickness in July 2015**

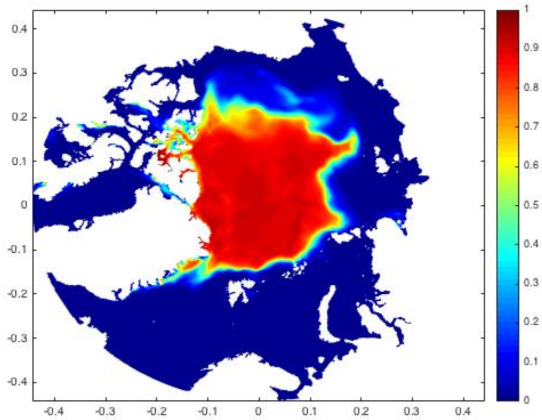

**Figure 26 Ice concentration in September 2015**

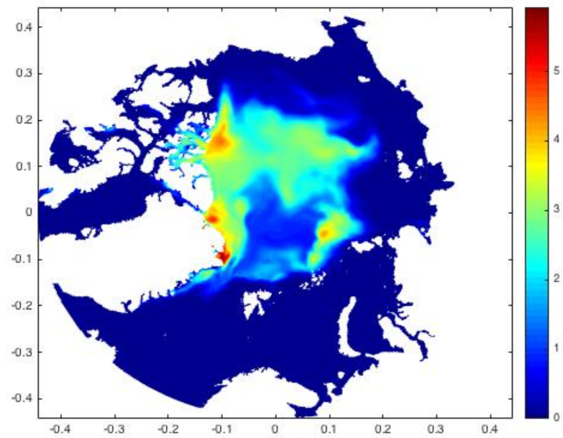

**Figure 27 ice thickness in September 2015**

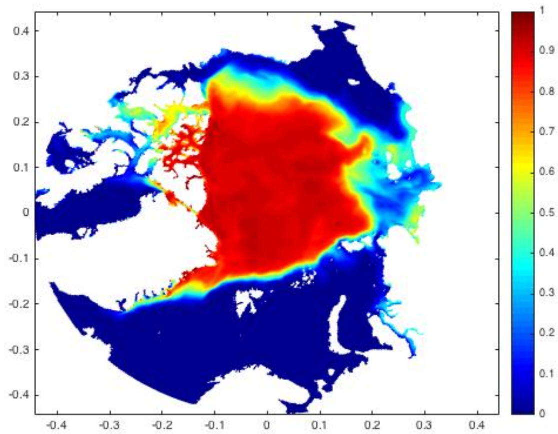

**Figure 28 Ice concentration in October 2015**

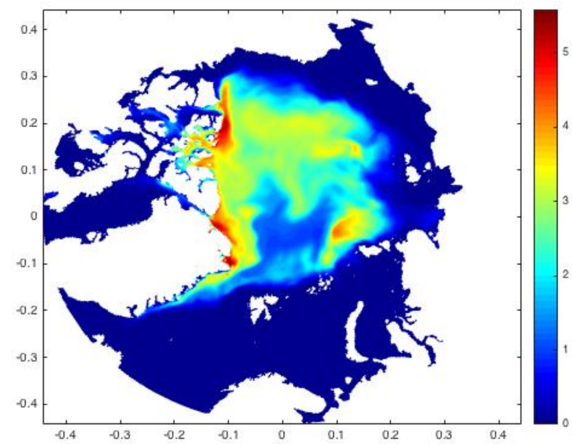

**Figure 29 Ice thickness in October 2015**

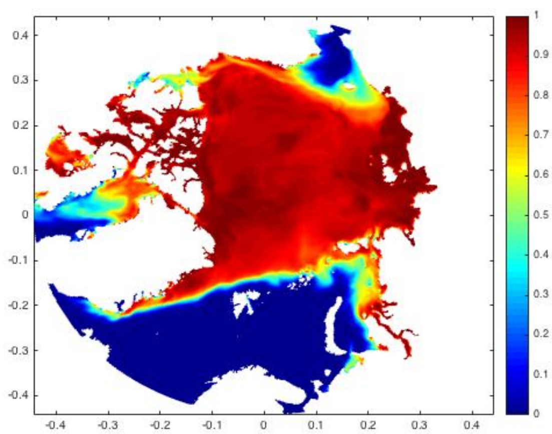

**Figure 30 Ice concentration in November 2015**

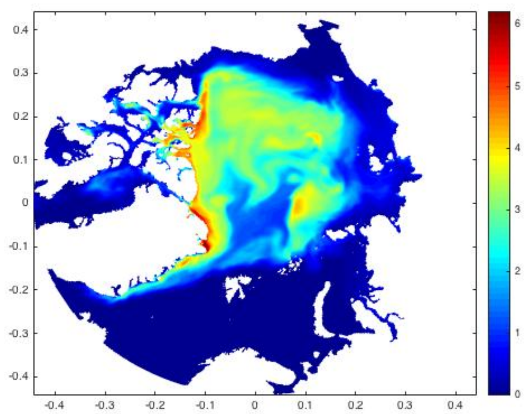

**Figure 31 Ice thickness in November 2015**

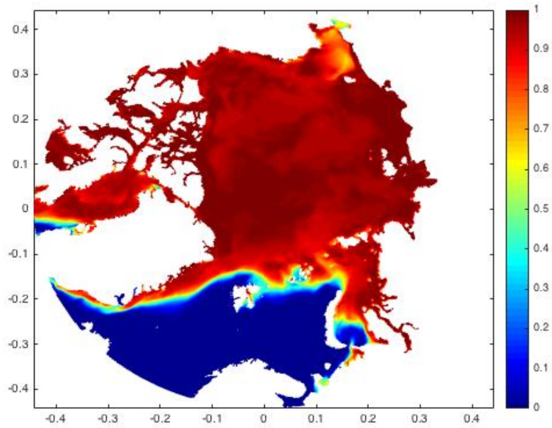

**Figure 32 Ice concentration in December 2015**

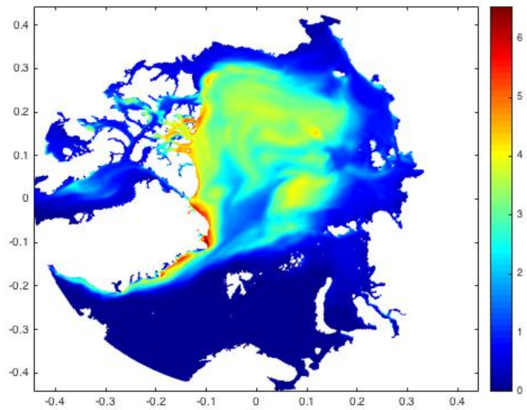

**Figure 33 Ice thickness in December 2015**

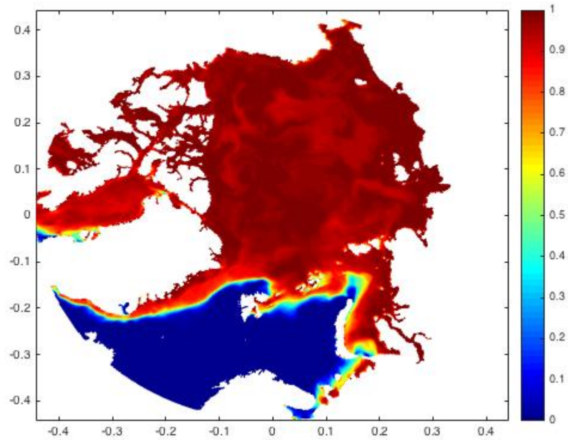

**Figure 34 Ice concentration in January 2016**

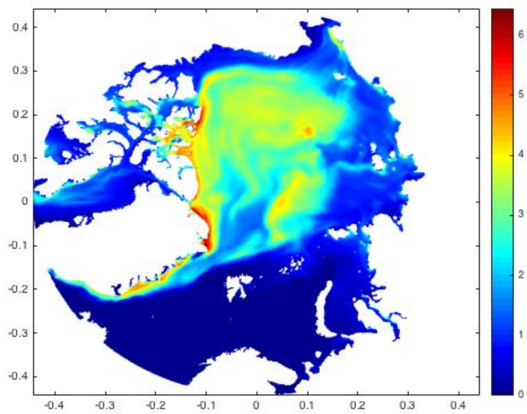

**Figure 35 Ice thickness in January 2016**