Technical challenges, viability, and potential environmental impacts of oil production in the Dreki and Jan Mayen Ridge region

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A 10 credit paper that is part of a
Baccalaureus Scientiarum degree in Geology

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Reykjavik, May 2013

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Oil Impact Assessment of the Dreki/Jan Mayen region
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I hereby certify that this paper is written by me and has neither partially, nor fully, been submitted before for a degree of higher education.

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Abstract

On the 4th of January 2013, the National Energy Authority in Iceland issued two licenses for the exploration and production of hydrocarbons in the Dreki Area, there is also a third license being considered at the moment. There are plenty of hazards and risks of a possible oil spill related to the exploration and production of hydrocarbons, this paper looks to address the oceanographic conditions at the Dreki and Jan Mayen Ridge region. It also looks into the use of comparisons, historic events, effects on the ecosystem and then mainly at what area is most likely to be affected should an oil spill occur and what can be done in the event of a spill.

This paper found that conditions at the same latitude, but different longitudes (i.e. East Greenland vs. West Norway) are very different. The complexity of the dynamics between Atlantic and Arctic waters in the Nordic Seas cause these differences and a characteristic of these seas are anti-clockwise eddies. These will factor heavily in the distribution of a potential oil spill and will most likely prevent a spill from flowing to shore in Iceland, Norway or Greenland.

Exploration and production has been conducted at sites that endure similar or more extreme conditions and the use of a floating platform will be integral for any large operations. Health and safety management will have to be held to high standards and frequently reviewed. The main factor that will be problematic for the planned exploration and potential production in the area is its remoteness. Facilities for production and for a disaster response team, equipment and vessels will either have to be established in Iceland or co-ordinated with and on Norway.

Aknowledgements

First, I would like to thank Þórarinn Sveinn Arnarson of the National Energy Authority for accepting the role of my supervisor. His assistance with finding material, his critique and recommendations have helped me greatly.

Also, I would like to thank Professor Ólafur Ingólfsson for supervising me and pointing me in the direction towards Þ. S. Arnarson. The time spent in his classroom was always delightful, and I feel privileged for him overseeing this project.

Finally I would like to thank my parents, Herdís Dögg Sigurðardóttir and Kristinn Johnsen, for the endless support through the years. They have also helped me greatly with the paper by giving feedback and checking my grammar.

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1 Introduction

This paper is written as a BSc thesis in Geology, at the University of Iceland. The subject is an investigation of the Dreki and Jan Mayen ridge region. With a focus on the possible environmental hazards that could accompany the exploration, processing and dismantling of an oil/gas utilization operation. Any conclusive results could then be used for reference by interested parties, e.g. Iceland Geosurvey, the National Energy Authority (í. Orkustofnun), the Icelandic government, or any foreign-based companies looking to partake in the operation. The specific region (Dreki) in question, lies to the north of 67°N, the east of 10°30' W and is then limited by Iceland‘s 200nm EEZ (exclusive economic zone). In 1981, the governments of both Iceland and Norway signed a treaty which covers an area of 12,720 km^2. This treaty includes a mutual clause, which states that should either government issue any license for exploration/production rights within said area, then the other has a right to participate in that license (Ministry of Industry, 2007). A report published by Sagex, which was based on data from an expedition by InSeis in 2001, found that interesting formations with regards to oil and gas exploitation spanned an area of around 4,400 km^2. Of these 4,400 km^2, approximately 800km^2 lie in the Norwegian EEZ, whereas the rest lie within the Icelandic EEZ (Ministry of Industry, 2007). See Figure 1.

In 2007, the Icelandic Ministry of Industry published an extensive proposal detailing a plan regarding the release of licences for exploration/research/processing of oil and gas in the Dreki and Jan Mayen ridge region. Alongside this proposal they also released an environmental assessment for such plans (Ministry of Industry, 2007). Since then there have been expeditions in the area, increasing the amount of collected data on salinity, temperature and the orientation of sea currents in the region. As of today the second licensing round has drawn to a close in Iceland. On the 4th of January, 2013, the National Energy Authority (í. Orkustofnun) published licenses to two consortiums. The licenses published were given to Faroe Petroleum Norge AS and Iceland Petroleum ehf. on one hand and Valiant Petroleum ehf. and Kolvetni ehf. on the other hand. This will give the consortiums the right to exploration and production of hydrocarbons. In addition to this, the Ministry of Petroleum and Energy in Norway has decided to be a 25% shareholder and participant in both licenses, this is done in relation to the treaty signed in 1981 between Iceland and Norway (National Energy Authority, 2013). The participation of the Norwegian state is via a subsidiary of the state run company Petoro AS, named Petoro Iceland AS (Petoro, 2013). In addition to evaluating the applications themselves, the National Energy Authority also asked for opinions and annotations from both the Ministry for the Environment and Natural Resources and the Ministry of Fisheries and Agriculture in correlation to statutes of law. Each applicant was assessed by their technological and geological ability to undertake such a project in addition to their parent company‘s financial ability to back such an operation (National Energy Authority, 2012).

An important factor in the political and economic environment regarding the area is a treaty that is in place between the governments of Iceland and Norway. This entails that if the Icelandic government issues licences then the Norwegian government has the option to become a partner in the licence and vice versa. As mentioned before, the Norwegian government has used this agreement to become a participant in the 2 published licenses.

Norway has also started to take its first steps towards licensing oil and gas operations, the first step being a recently published impact assessment. Now the impact assessment is open to comments by the public and in February of 2013, a geological survey was published, which was subsequently the second step of the opening process. Once both have been assessed they can then be presented to the Norwegian parliament along with a recommendation to either open up the area for licensing or to decline the proposal (Ministry of Petroleum and Energy, 2012). The Oil and Energy Minister, Ola Borten Moe, had planned on submitting a proposal to the Norwegian Parliament before the summer of 2013. He has on the other hand decided to postpone the proposal for a year, to allow for further surveys of the area that will result in a more detailed proposal (Olje- og Energidepartementet, 2013).

The proposal and environmental assessment from 2007 (Icelandic) are the backbone of this paper along with recently published data. The aims of this paper are to answer a few key questions: Does the current exploration and production technology meet the criteria of this area? What would happen if an oil spill were to occur in the Dreki and Jan Mayen ridge region and what can be done to prevent such an incident? What areas are likely to be affected by a possible oil spill? And finally, what measures can be taken to contain and clean up the environmental pollution that would follow?

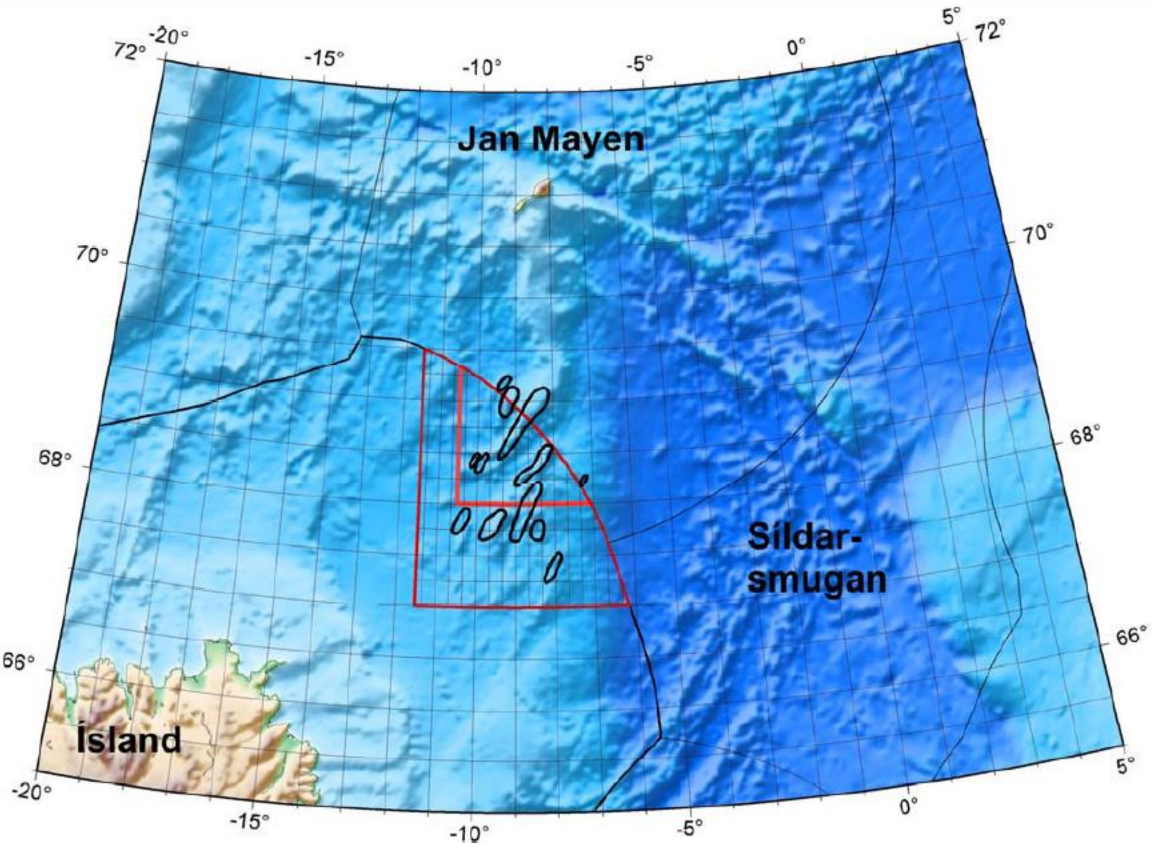

Figure 1. A map of the area northeast of Iceland. The larger sector (dark red line) represents the northern part of the Dreki region. The smaller sector, to the northeast (red line), represents the area which falls under the treaty signed by Iceland and Norway in 1981. Interesting formations with regards to oil and gas are indicated within the irregular shapes shown with a bold black line. Adapted from „Olíuleit á Drekasvæði við Jan Mayen-hrygg," by Ministry of Industry, 2007. p. 23.

2 Oceanography

2.1 General Information

To be able to understand and explain the consequences of an oil spill then it is necessary to consider all factors regarding the oceanography of the area. Properties that can be influential in an oil spill scenario are temperature, salinity, sea currents, wind currents, the extent of sea ice, etc. As the focus area in this paper is the Jan Mayen ridge region, then the sea that would be directly influenced is the Northeast Atlantic Ocean. This area lies between the Arctic Ocean (to its north) and the rest of the Atlantic Ocean (to the south). Henceforth in this paper, this area will be referred to as the Nordic Seas (not to be confused with the North Sea). The Nordic Seas are comprised of the Greenland Sea, Norwegian Sea and the Iceland Sea. The Iceland Sea is the body of water that is bordered by the Denmark/Greenland strait (in the west), the Greenland Sea (in the north) and the Norwegian Sea (to the east). Oceanic flow from the Nordic Seas to the Arctic Ocean is via the Fram Strait and the Barents Sea. Another important feature that affects the Nordic Seas is the elevated ridge that runs from Scotland to Iceland and then to Greenland. This elevated ridge prevents deep sea currents from the Atlantic Ocean from flowing into the Nordic Seas (Stefánsson, 1994). See Figures 2. & 3.

The bodies of water have been located and identified, now on to general information on the bathymetry and surface currents in the region. The Atlantic Ocean flows into the Nordic seas via three notable areas at an estimated volume transport of 9 Sv (1 Sv = 10^6 cubic metres per second). Around 7% of this flows between Greenland and Iceland, ~33% between Iceland and the Faroe Islands, and finally roughly 60% of the flow from the Atlantic to the Nordic Seas is via the area between the Faroe Islands and Scotland. This 60%, due to its geographical location, flows north into the Norwegian Sea and takes a path along the Norwegian coastline. Once it reaches the northernmost reaches of Norway‘s western/north western coastline the current branches off into two directions. Roughly ¼ of the current heads north/northeast into the Barents Sea, whereas the other ¾ head to the north/northwest towards Svalbard and then along its coastline (Stefánsson, 1994).

It is known that the Atlantic Ocean that flows north into the Nordic Seas is much warmer than the seas it is entering. This is due to its origin being from the Gulf Stream. A direct effect of this warmer water flowing into the Norwegian Sea is that it greatly affects the climate and the wildlife in the area. This can be observed when the conditions on the west coast of Norway and then the conditions on the east coast of Greenland at the same latitude are compared. They show clear differences in sea and air temperature as well as differences in weather conditions (Stefánsson, 1994).

Another characteristic of the Nordic Seas are anti-clockwise ocean eddies. These will factor heavily in the spread of oil spills in the region. There are two notable eddies, one in the northern part of the Greenland Sea and another between the northeast coast of

Iceland and Jan Mayen. Other smaller eddies are found in the western part of the Norwegian Sea, see Figure 4. Due to the orientation of the currents, there is warmer water that flows into colder areas, thus causing a cooling and an increase in density. These types of eddies, where the water becomes denser as it progresses inwards are characteristic for cold, boreal ocean areas in the northern hemisphere. Due to the increasing density towards the centre of these eddies, it means that they take on a concave up or bowl-shape form (Stefánsson, 1994).

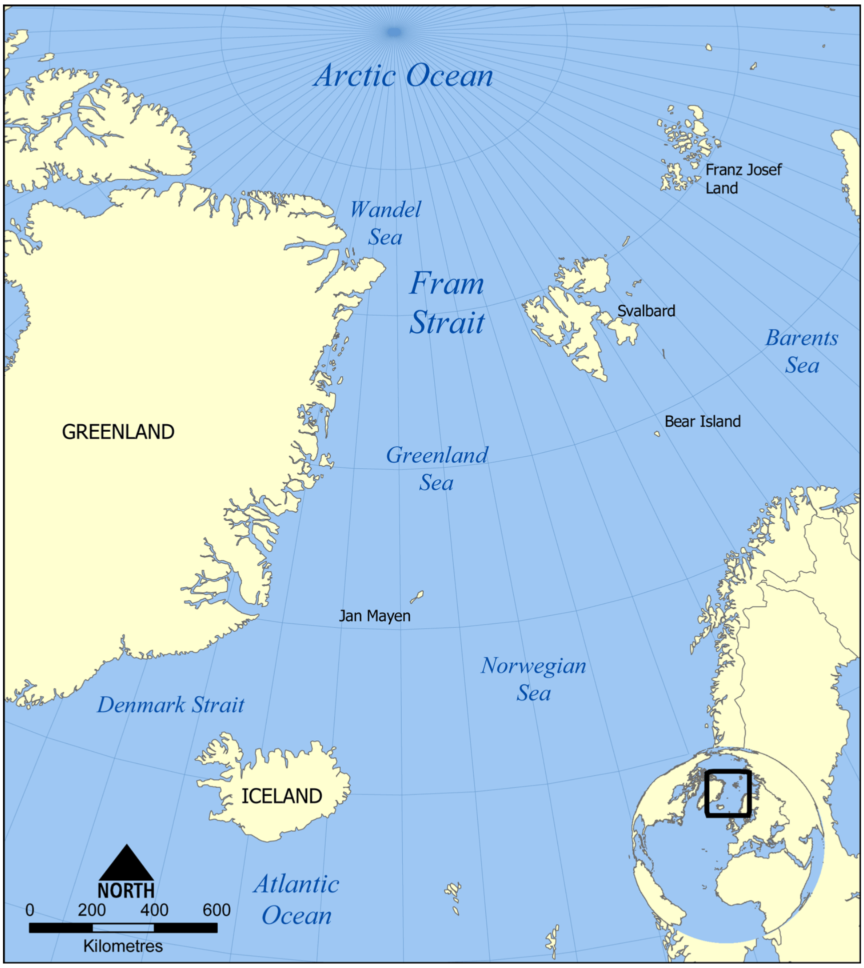

Figure 2. A map of the northeast Atlantic Ocean. Adapted from Wikipedia. Retrieved 18/4/2013, from http://en.wikipedia.org/wiki/File:Fram_Strait_map .png . Copyright 2009 by NormanEinstein. Reprinted with permission.

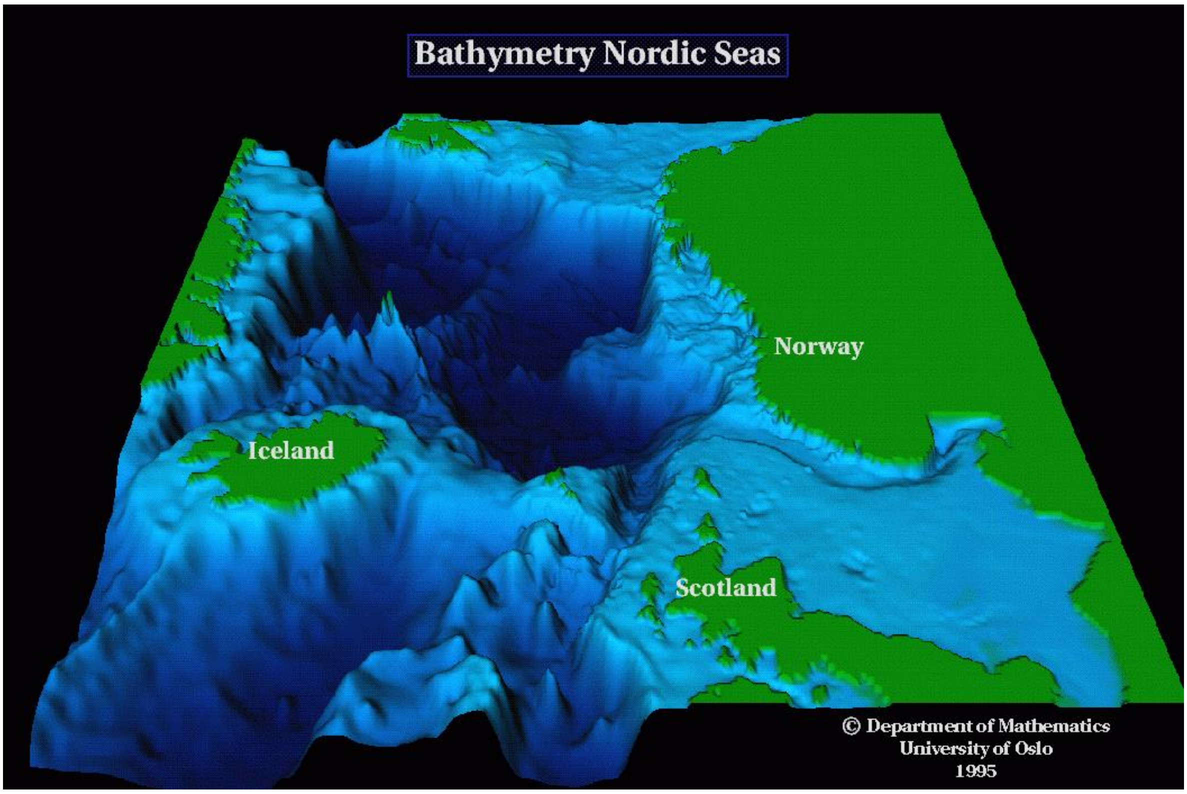

Figure 3. Bathymetric image of the Nordic Seas. Reprinted from Tidal Models for the Nordic Seas, by Department of Mathematics, University of Oslo, 1995. Retrieved 18/4/2013, from http://folk.uio.no/bjorng/tidevannsmodeller/tidebilder/Storeggadyp.gif. Copyright 1995 by University of Oslo. Reprinted with permission.

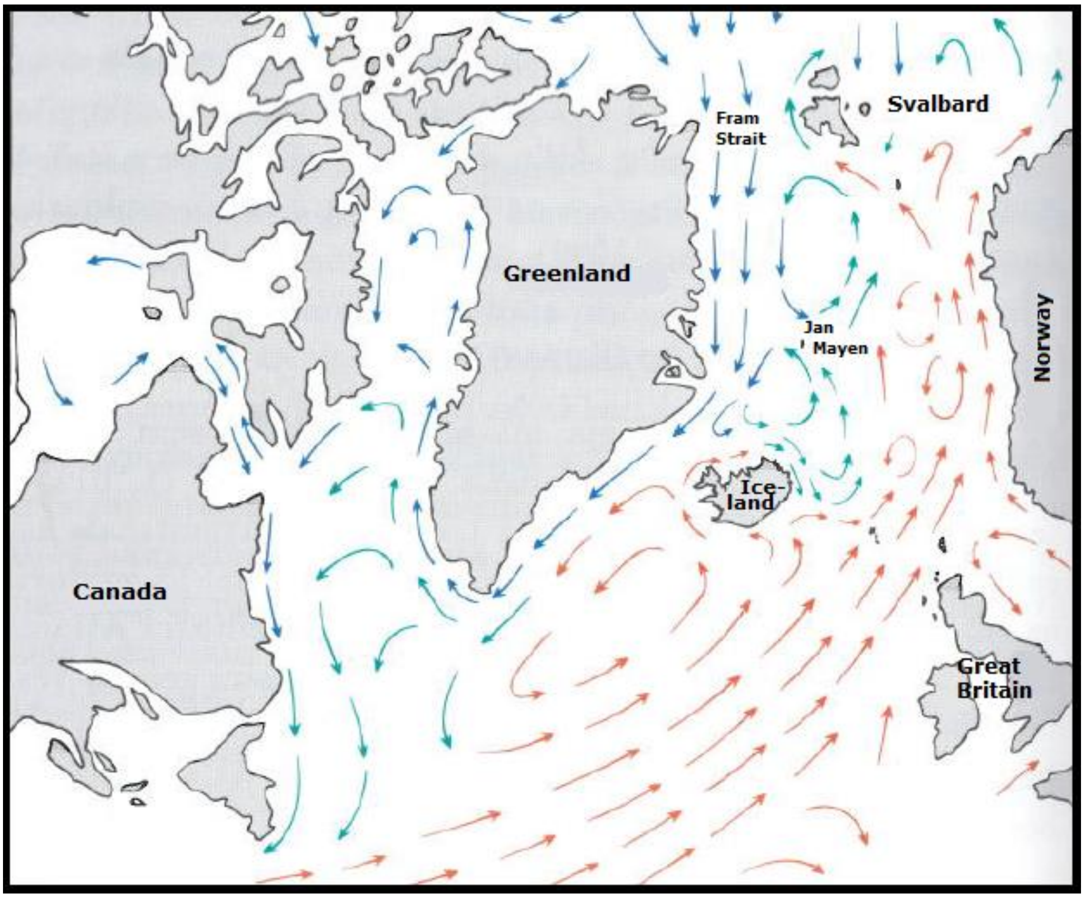

Figure 4. An edited picture that shows the surface currents of the North Atlantic. Red arrows indicate warm currents, blue arrows cold currents and blue-green arrows indicate mixed currents. Adapted from Haffræði II (p. Xxx), by U. Stefánsson, 1994, Reykjavík: Háskóli Íslands and Háskólaútgáfan.

2.2 Current observations

This chapter looks at the observations made by the Institute of Marine Research (IMR, Norway), the Bjerknes Centre for Climate Research (Norway) and the Marine Research Institute (MRI, Iceland). These observations were made with regards to measurements executed between 2007 and 2009, where 3 moorings were deployed to collect data on current velocities and to get a picture of the water exchanges between the Icelandic and the Norwegian Sea. In addition to this there were two sections (along and across the Jan Mayen ridge) that were measured with a CTD at numerous CTD stations. Another cross-section was measured with both a vessel mounted ADCP and a CTD, the location of this cross-section was in the Lyngvi Ridge area. The ADCP measurements were conducted generally 4 times along the section, at an estimated depth of ~50m, measuring and sampling with the CTD was only done once across each section. These measurements were staged in February and June of 2008. Not only was this cross-section measured, there was also a mooring deployed at the site which collected data from November 2007 to June 2008. Other evaluated measurements were the tracks of three ARGO floats during the period of 2005 to 2007.

2.2.1 Findings of the three moorings (JM-1, JM-2, Dreki)

First we shall look into the findings of the moorings, their placements were strategically chosen to look into the dynamics of sharp fronts, where warm saline Atlantic water meets fresh and colder Arctic water. 3 moorings were deployed, 2 of them by the IMR and were codenamed JM-1 and JM-2 and the third mooring was deployed by the MRI and codenamed Dreki. The measurement period for the JM-1 and JM-2 mooring was 2007-2009, whereas the Dreki mooring was functional 2007-2008. On the following page there is a figure that depicts the setup of the JM-1 and JM-2 moorings (see Figure 5). In order to understand the orientation of the measurements and their findings, I present a figure (see Figure 6) that was published in the report which shows the location of all 3 moorings. In the picture you can see the relative position of Jan Mayen and also arrows that indicate Arctic or Atlantic currents. The ones marked with question marks are in the areas of which the investigation aimed to find conclusive answers to and increase knowledge and data of said area (Kjell Arne Mork, 2011).

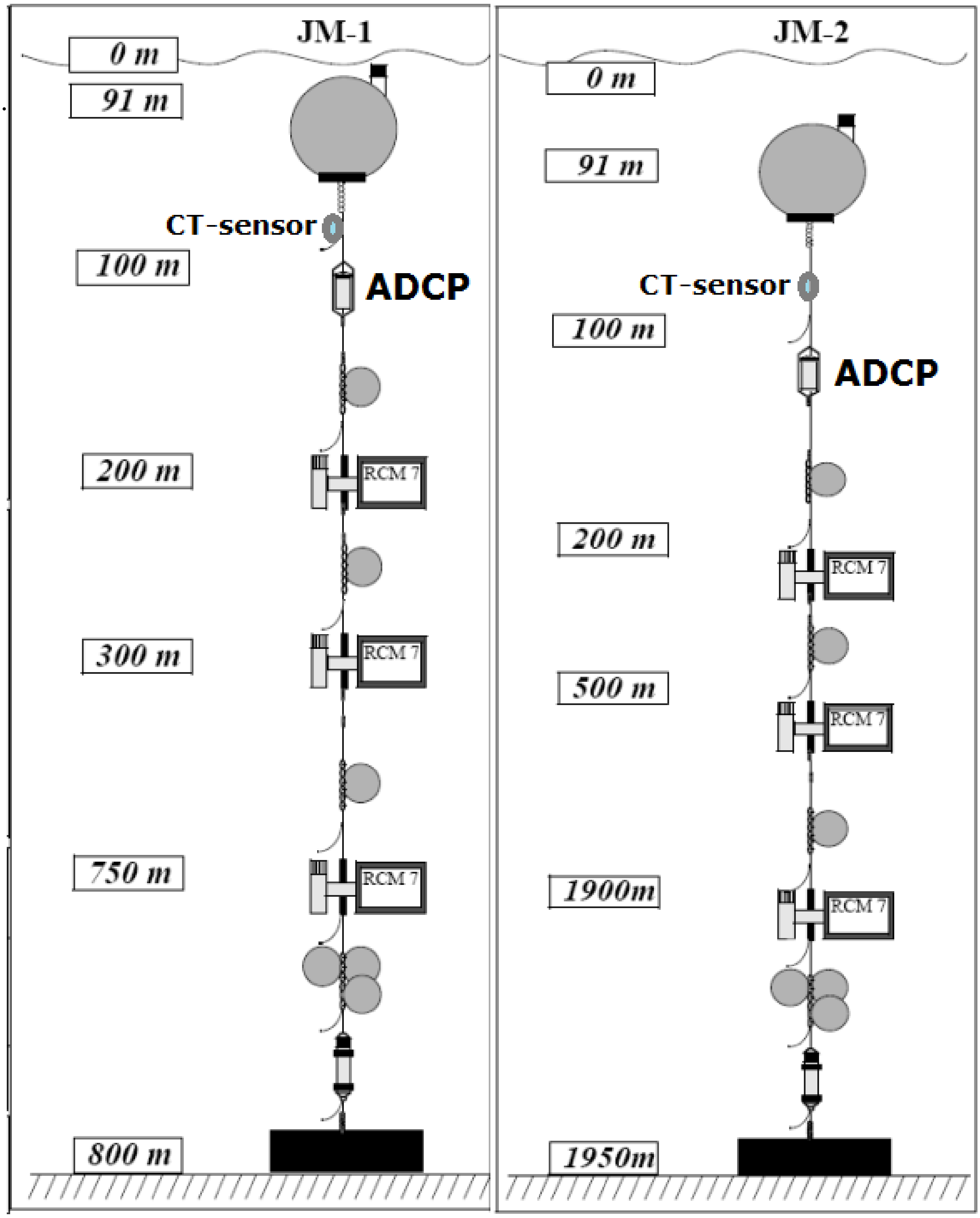

Figure 5. Diagrams of the setup of the moorings at JM-1 and JM-2. The depth of sensors and the total depth at location are indicated in meters. Adapted from „Current observations at the Jan Mayen Ridge,“ by Kjell Arne Mork, K. D., Steingrimur Jónsson, Hédinn Valdimarsson, 2011, p. 5. Paper presented at the ESSAS Open Science Meeting, Seattle.

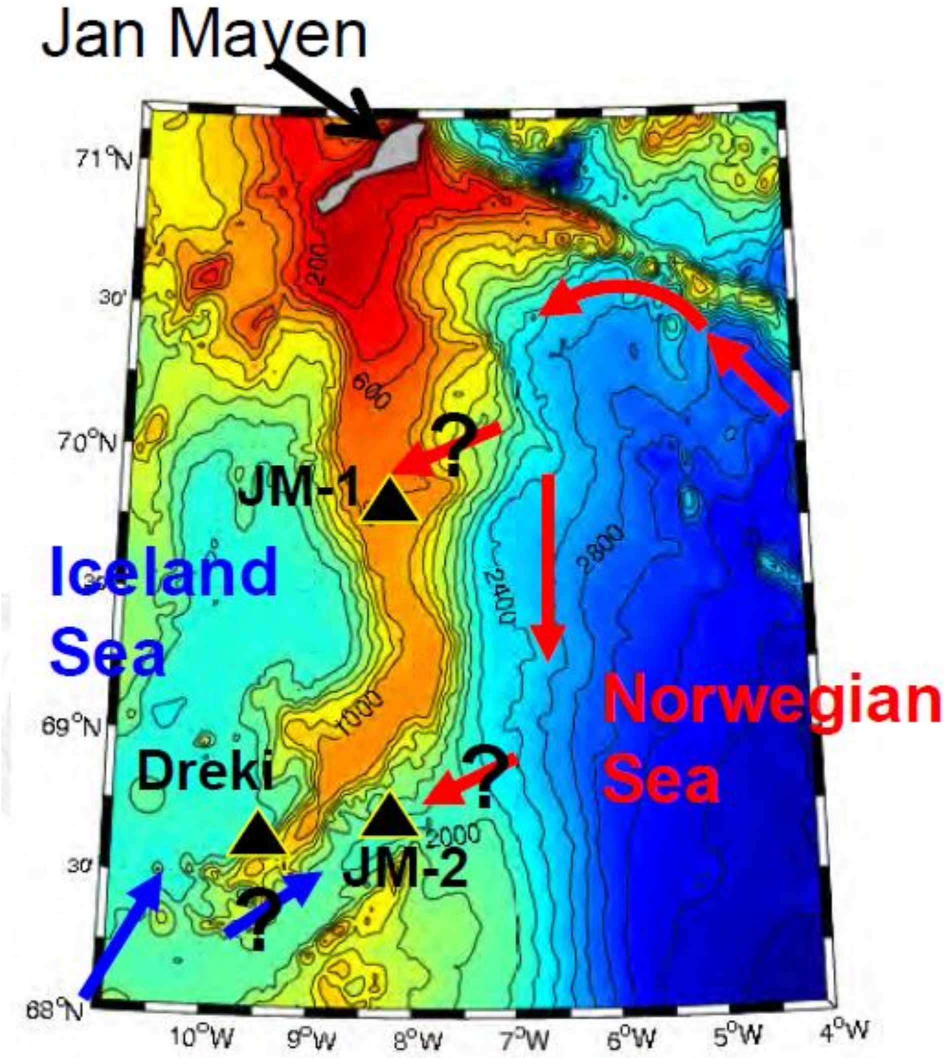

Figure 6. This shows the location of 3 moorings, the location of Jan Mayen and the position of the Iceland/Norwegian Seas. Also shown are contour lines which indicate depth (m). Adapted from „Current observations at the Jan Mayen Ridge," by Kjell Arne Mork, K. D., Steingrimur Jónsson, Hédinn Valdimarsson, 2011, p. 4. Paper presented at the ESSAS Open Science Meeting, Seattle.

The moorings were essentially deployed for one purpose, to measure current velocities and in which direction the currents are flowing. The results are displayed in two manners, the first as vectors. Their orientation depicts the direction of flow and the length of the vector (arrow) depicts the current velocity. The other display of results is with a graph, one axis is the date of measurement and the other is depth (m). Finally the values are put into the graph as colours off a gradient which uses the unit cm/s. This both shows what the velocity is of the current and whether it is flowing eastward or westward. Negative figures, -8 to 0, correspond to a current flowing to the west, into the Iceland Sea. Whereas the positive figures, 0 to 8, relate to a current flowing eastward into the Norwegian Sea. These results were as follows (Kjell Arne Mork, 2011):

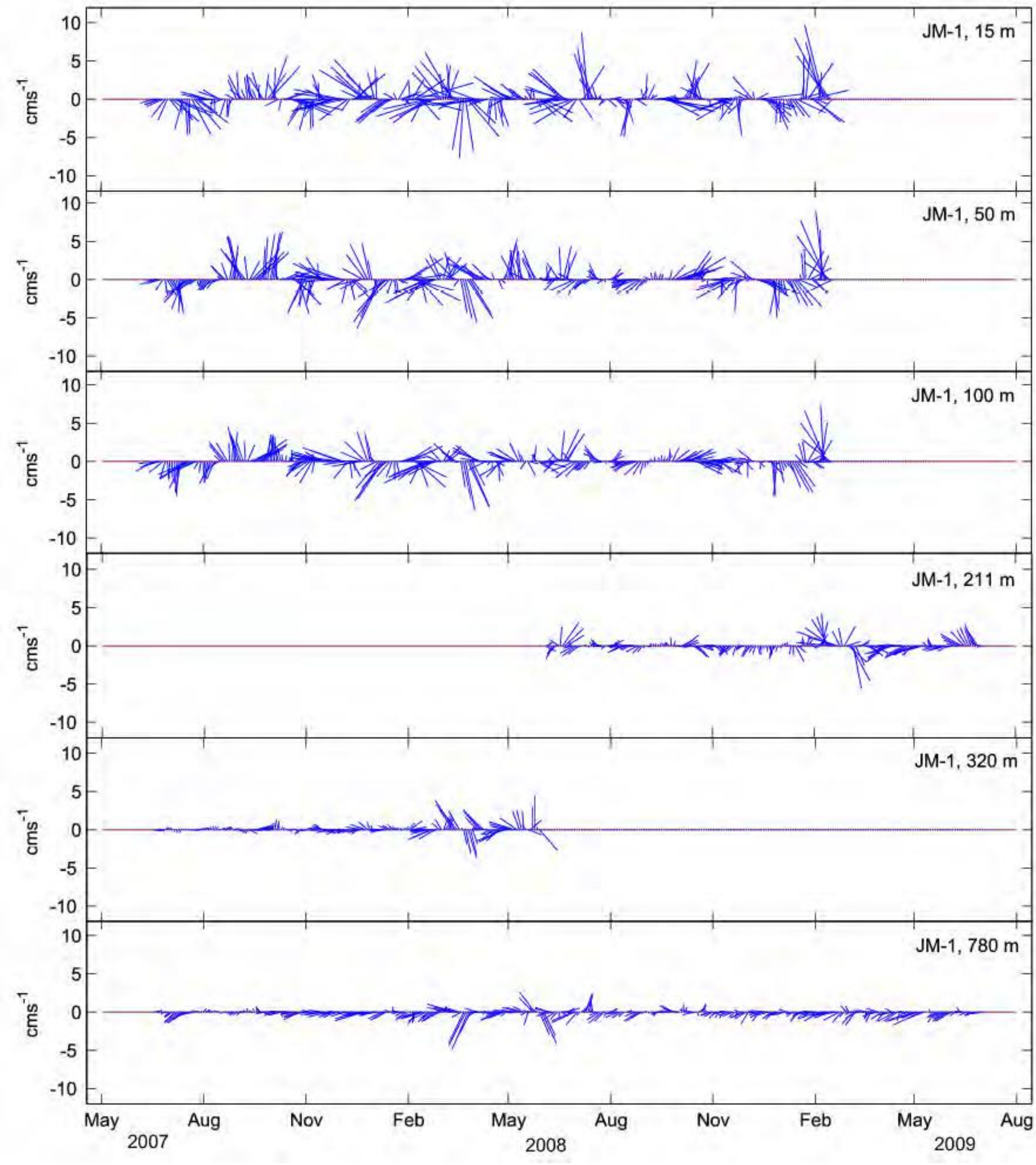

Figure 7. The results from the mooring at JM-1, vectors indicate the orientation of flow and their length indicates current velocity. In the top right corner of each rectangle the depth of measurement is indicated. Data are 7 day moving averages. Adapted from „Current observations at the Jan Mayen Ridge," by Kjell Arne Mork, K. D., Steingrimur Jónsson, Hédinn Valdimarsson, 2011, p. 8. Paper presented at the ESSAS Open Science Meeting, Seattle.

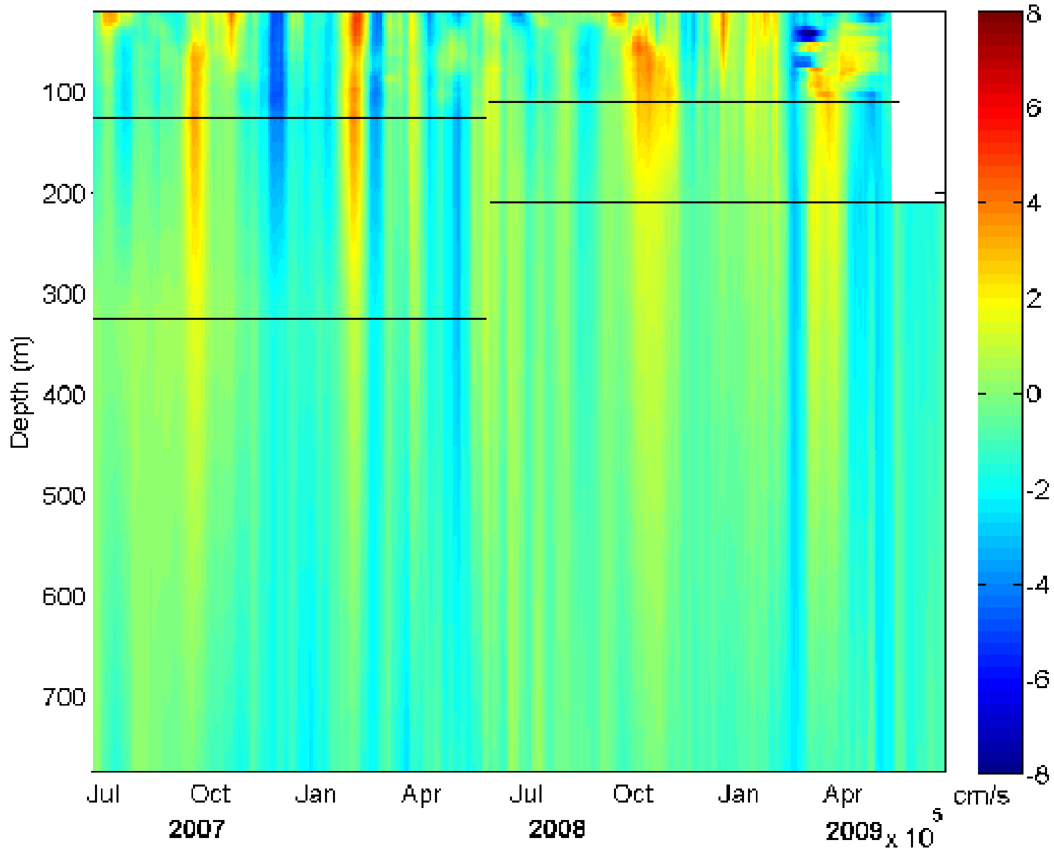

Figure 8. The second representation of the results from the mooring at JM-1. Axes of the graph are depth (m) and date of measurement. Also shown is a gradient, of the unit cm/s, the negative values indicate flow into the Iceland Sea whereas positive values are indicative of flow into the Norwegian Sea. Data are 14 day moving averages. Adapted from „Current observations at the Jan Mayen Ridge,“ by Kjell Arne Mork, K. D., Steingrimur Jónsson, Hédinn Valdimarsson, 2011, p. 9. Paper presented at the ESSAS Open Science Meeting, Seattle.

These were the results (Figures 7. & 8.) for JM-1. The location of which, can be seen in Figure 6. After being analysed the data was considered to show a weak flow (low stability) from the Norwegian Sea into the Iceland Sea. Additionally there were observed seasonal changes in the bottom current (Kjell Arne Mork, 2011). Next, data is shown from the mooring at JM-2 on the following pages.

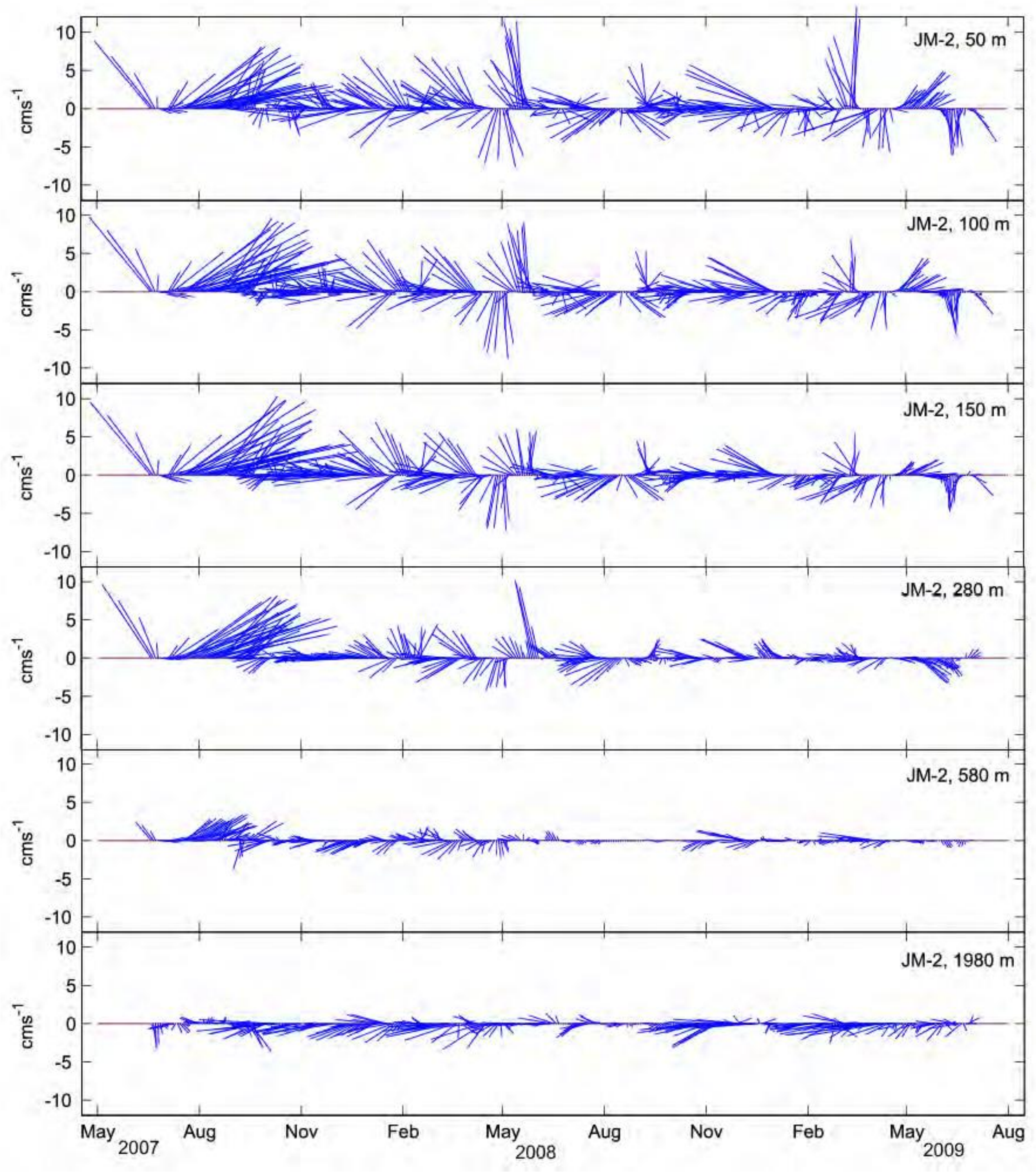

Figure 9. The results from the mooring at JM-2, vectors indicate the orientation of flow and their length indicates current velocity. In the top right corner of each rectangle the depth of measurement is indicated. Data are 7 day moving averages. Adapted from „Current observations at the Jan Mayen Ridge," by Kjell Arne Mork, K. D., Steingrimur Jónsson, Hédinn Valdimarsson, 2011, p. 10. Paper presented at the ESSAS Open Science Meeting, Seattle.

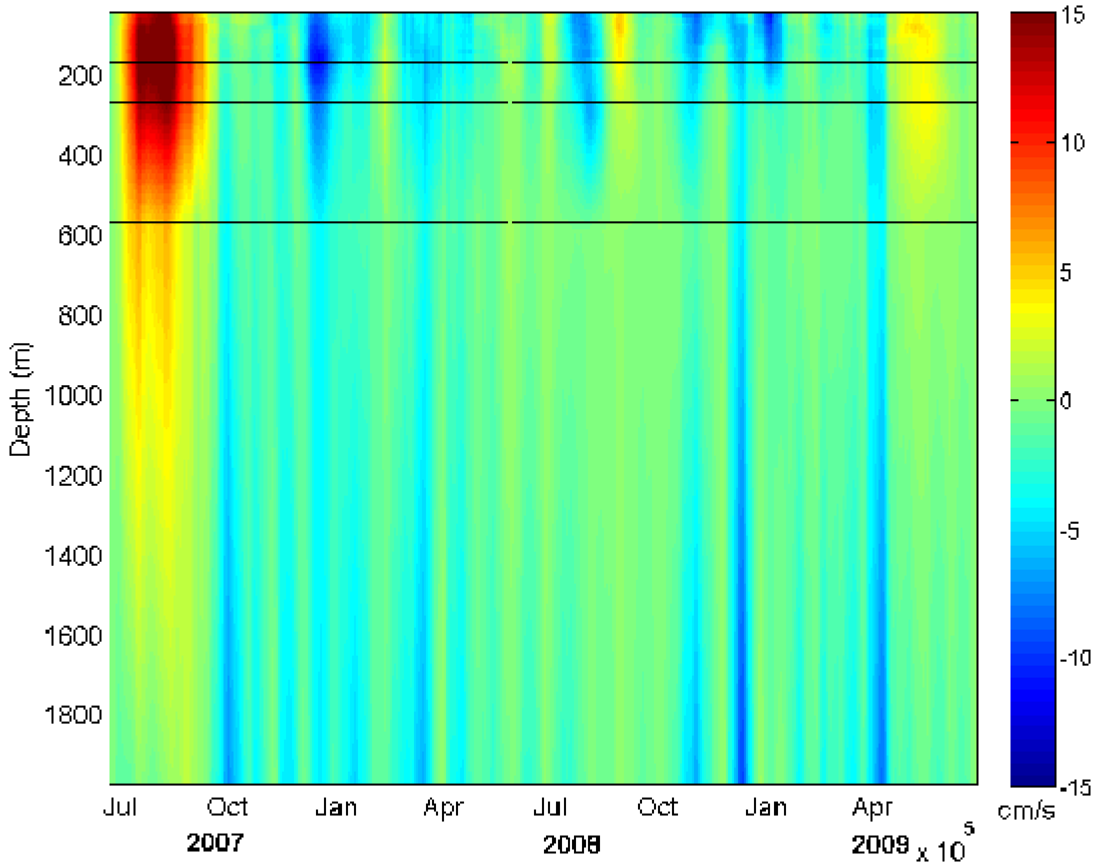

Figure 10. The second representation of the results from the mooring at JM-2. Axes of the graph are depth (m) and date of measurement. Also shown is a gradient, of the unit cm/s, the negative values indicate flow into the Iceland Sea whereas positive values are indicative of flow into the Norwegian Sea. Data are 14 day moving averages. Adapted from „Current observations at the Jan Mayen Ridge,“ by Kjell Arne Mork, K. D., Steingrimur Jónsson, Hédinn Valdimarsson, 2011, p. 11. Paper presented at the ESSAS Open Science Meeting, Seattle.

These were the results (Figures 9. and 10.) of the mooring at JM-2. The location of which, can be seen in Figure 6. Analysis from the report found that in the upper layers there is a winter flow into the Iceland Sea. In contrast the summer flow is from the Iceland Sea, into the Norwegian Sea. The graph clearly shows this strongly in 2007 and also clearly in 2009. Data from 2008 on the other hand show a much shorter period of this flow into the Norwegian Sea, which indicates there can be anomalies to the cycle. The lower layers or deep waters show predominantly a westward flow into the Iceland Sea, both during the summer and winter. And finally, for this sub-chapter, a look at data from the mooring at Dreki (Kjell Arne Mork, 2011). The results were only presented in the vector form and not with a graph.

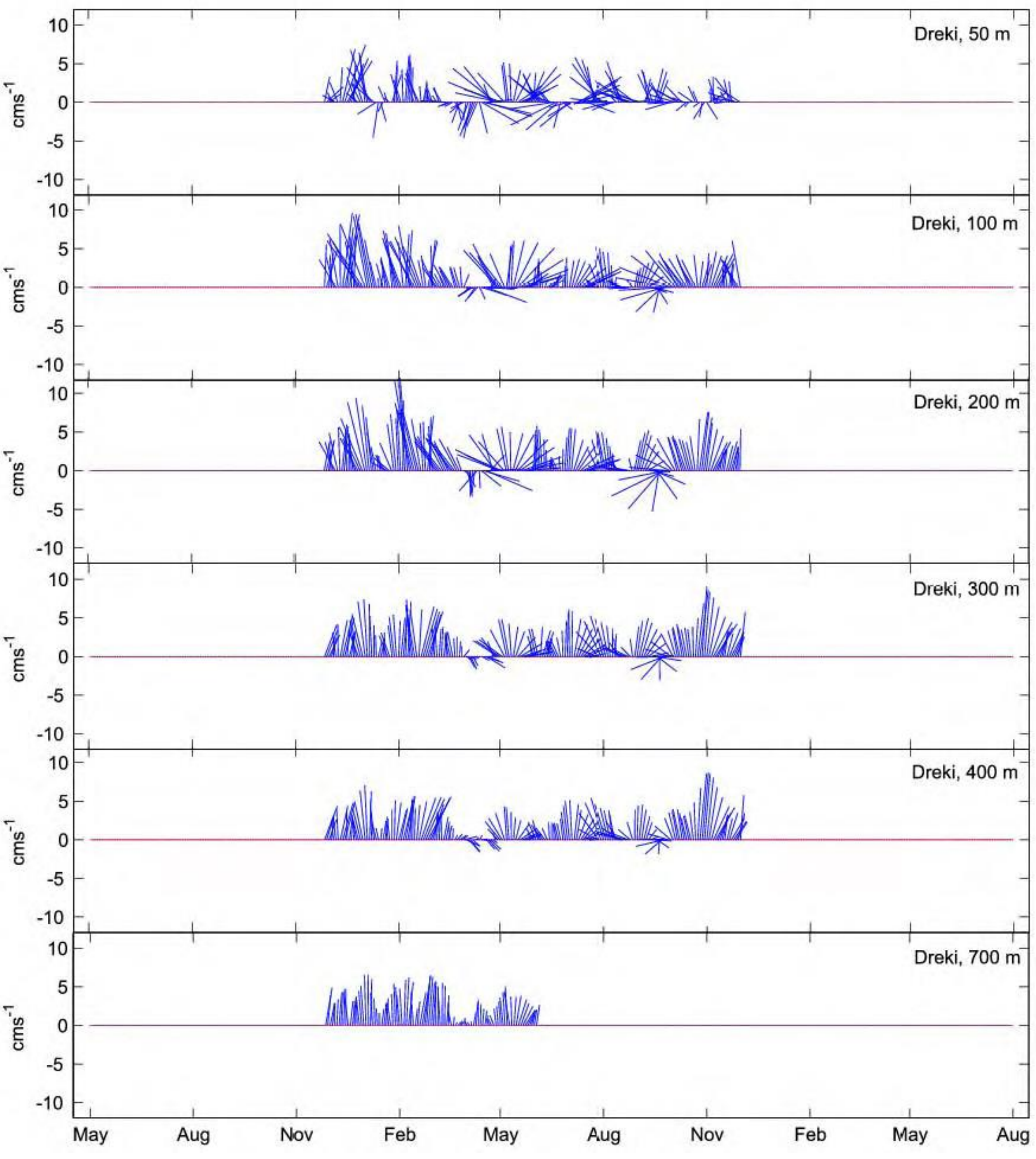

Figure 11. The results from the mooring at Dreki, vectors indicate the orientation of flow and their length indicates current velocity. In the top right corner of each rectangle the depth of measurement is indicated. Adapted from „Current observations at the Jan Mayen Ridge," by Kjell Arne Mork, K. D., Steingrimur Jónsson, Hédinn Valdimarsson, 2011, p. 14. Paper presented at the ESSAS Open Science Meeting, Seattle.

On the previous page you can find the results (Figure 11.) of the data collected with the mooring at Dreki. The vectors indicate a very clear northward current which seems to be prevalent regardless of the season. The report evaluated the flow as northward (barotropic) currents at Dreki (Kjell Arne Mork, 2011).

2.2.2 CTD stations along and across the Jan Mayen ridge

In June of 2007 there were conducted CTD measurements along and across the Jan Mayen ridge. Presented will be a map which shows the CTD measuring stations as black circles with purple outlines. Also on the map is a grey line which indicates the data of which stations were used for the section being presented. Following the map come graphical presentations of the data for temperature and salinity. First a look at the south to north section which runs along the JMR.

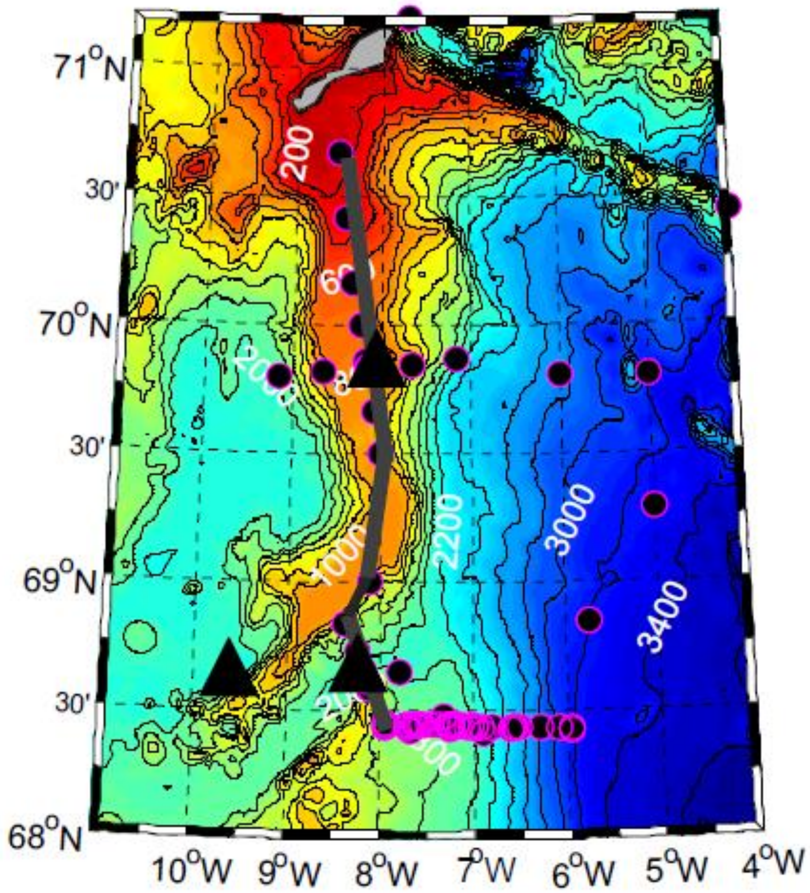

Figure 12. A map showing points at which CTD measurements were conducted, they are shown as the black circles with a purple outline. The triangles represent the mooring stations previously discussed in chapter 2.2.1. The grey line shows which stations data were used for the section (South-North). Adapted from „Current observations at the Jan Mayen Ridge," by Kjell Arne Mork, K. D., Steingrimur Jónsson, Hédinn Valdimarsson, 2011, p. 6. Paper presented at the ESSAS Open Science Meeting, Seattle.

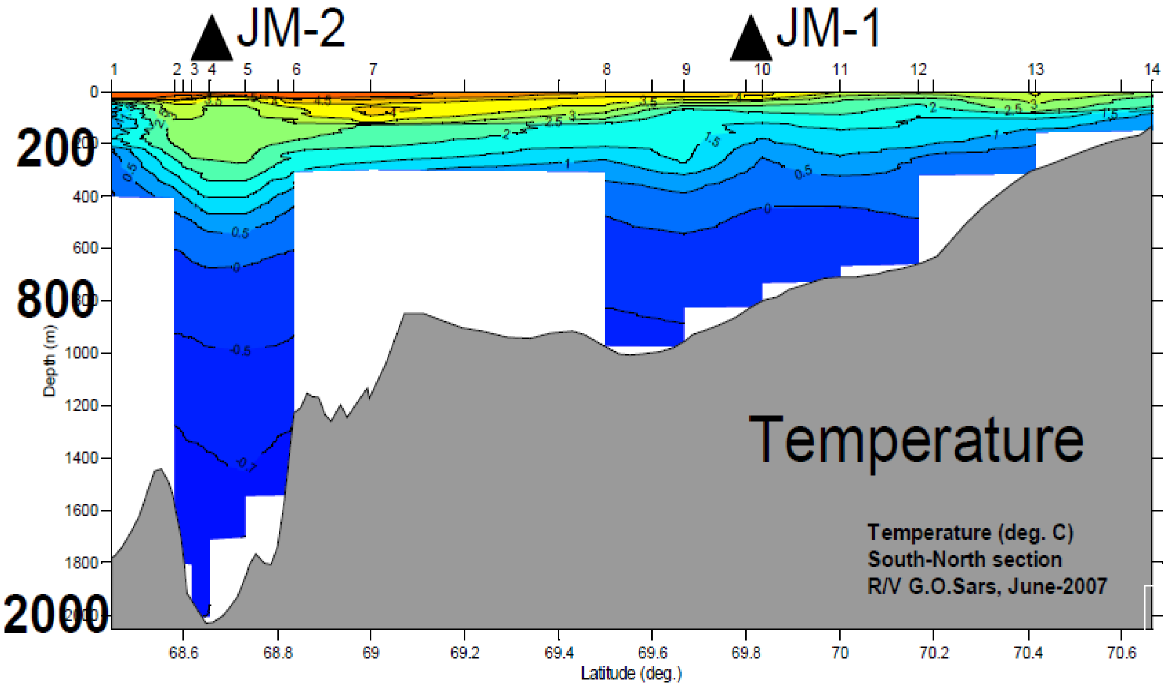

Figure 13. A graphic presentation of the temperature data collected for the South-North section. Along the y-axis there is depth (m), and on the bottom x-axis the latitude in degrees. Up top there are numbers which indicate the CTD station and also the relative position of moorings JM-1 and JM-2. Temperature is shown in colour and there is a use of contour lines to show the layering and values of different temperatures. Adapted from „Current observations at the Jan Mayen Ridge," by Kjell Arne Mork, K. D., Steingrimur Jónsson, Hédinn Valdimarsson, 2011, p. 6. Paper presented at the ESSAS Open Science Meeting, Seattle.

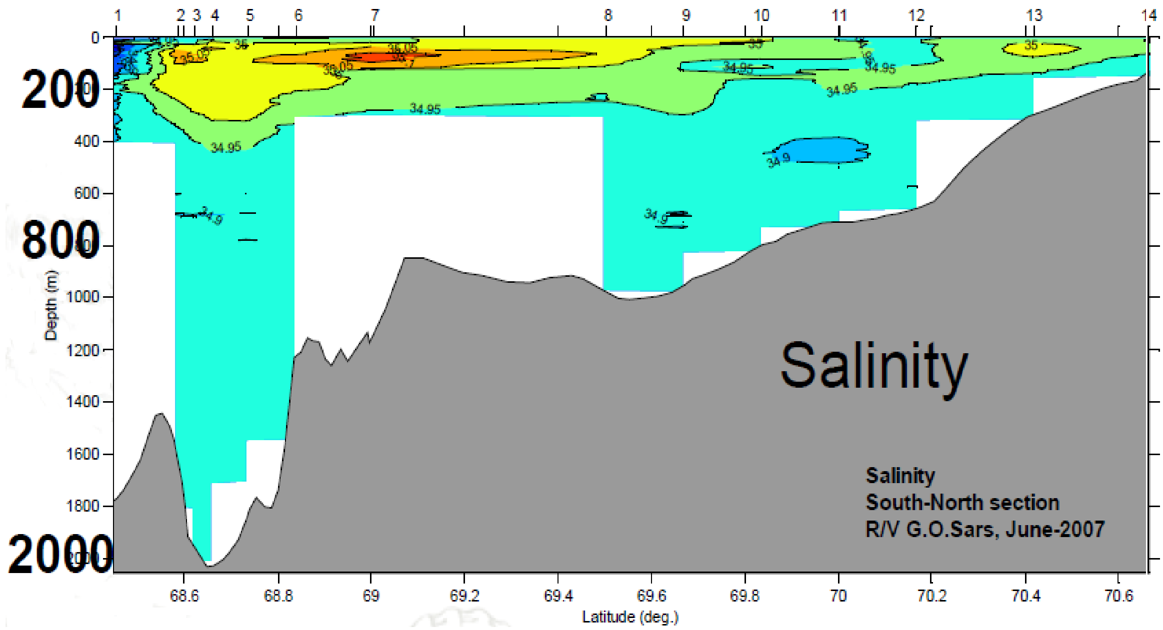

Figure 14. A graphic presentation of the salinity data collected for the South-North section. Along the y-axis there is depth (m), and on the bottom x-axis the latitude in degrees. Up top there are numbers which indicate the CTD station. Salinity is shown in colour and there is a use of contour lines to show the layering and values of different salinity concentrations. Adapted from „Current observations at the Jan Mayen Ridge," by Kjell Arne Mork, K. D., Steingrimur Jónsson, Hédinn Valdimarsson, 2011, p. 6. Paper presented at the ESSAS Open Science Meeting, Seattle.

Through Figures 13 and 14 you can draw a number of conclusions. One thing that is evident, is that below 400m depth there is very little change in temperature and in salinity. Seawater below this depth is already mixed and takes on its own properties, whereas the top layers can still give indications to their place of origin via their temperature and salinity values. When looking at the data for the top 200 meters on the other hand, then there are clear differences. The data shows that the temperature in the top layers decreases as you go further north, similarly you can see that the salinity also decreases in the top 200m as you progress further north. These 2 factors indicate that there is a higher concentration of water from the Norwegian Sea to the south on this section. And as you progress northwards, there is increasingly more water originating from the Iceland Sea or has been in the Nordic seas for a longer period and thus has cooled and mixed with water that is of a lower salinity. Now a look at the West-East section that was compiled.

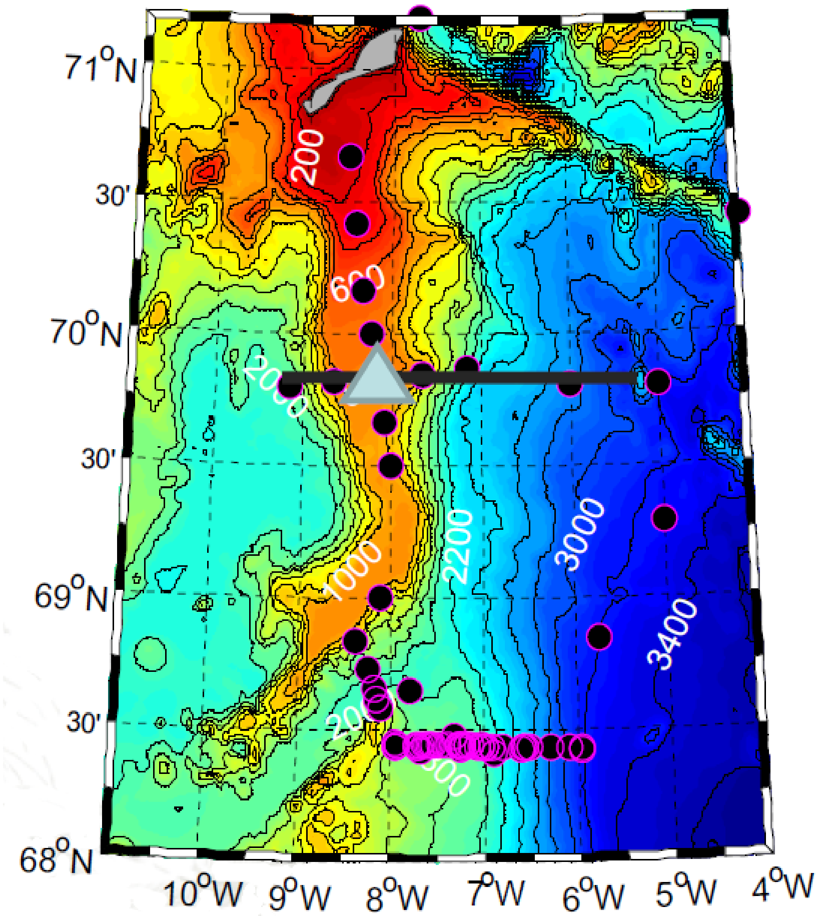

Figure 15. A map showing points at which CTD measurements were conducted, they are shown as the black circles with a purple outline. The triangles represent the mooring stations previously discussed in chapter 2.2.1. The dark grey line shows which stations' data were used for the section (West-East). Adapted from „Current observations at the Jan Mayen Ridge," by Kjell Arne Mork, K. D., Steingrimur Jónsson, Hédinn Valdimarsson, 2011, p. 7. Paper presented at the ESSAS Open Science Meeting, Seattle.

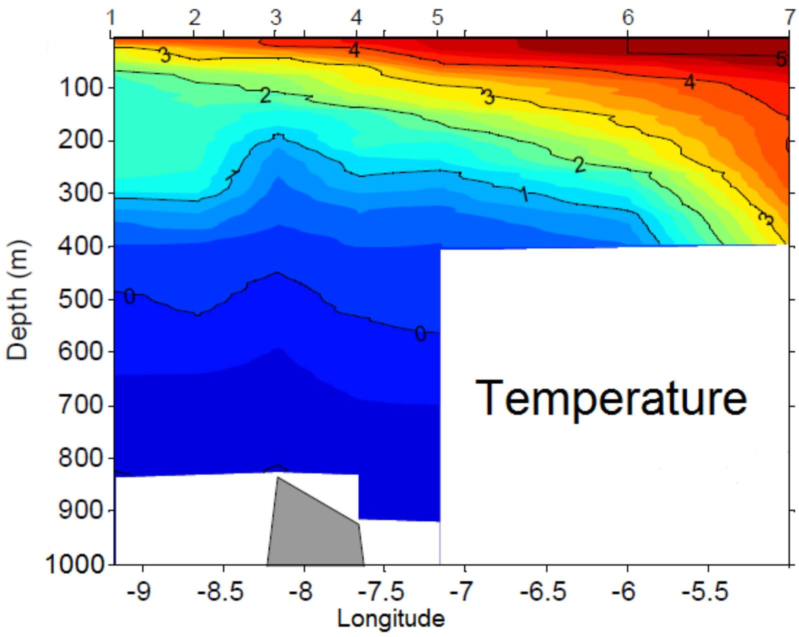

Figure 16. A graphic presentation of the temperature data collected for the West-East section. Along the y-axis there is depth (m), and on the bottom x-axis the latitude in degrees. Up top there are numbers which indicate the CTD station. Temperature is shown in colour and there is a use of contour lines to show the layering and values of different temperatures. Adapted from „Current observations at the Jan Mayen Ridge," by Kjell Arne Mork, K. D., Steingrimur Jónsson, Hédinn Valdimarsson, 2011, p. 7. Paper presented at the ESSAS Open Science Meeting, Seattle.

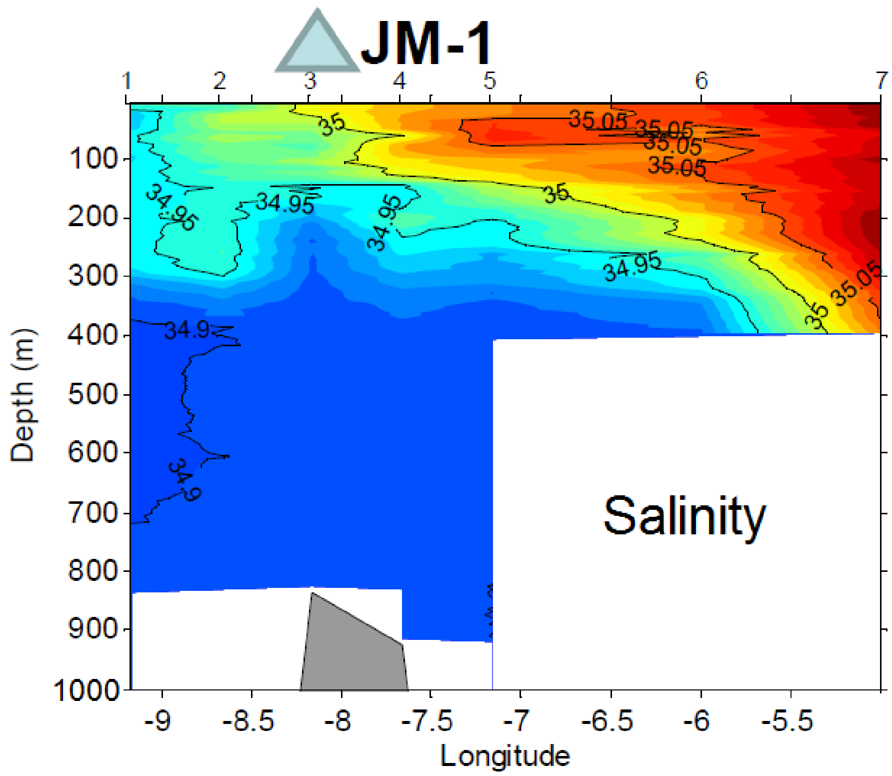

Figure 17. A graphic presentation of the salinity data collected for the West-East section. Along the y-axis there is depth (m), and on the bottom x-axis the latitude in degrees. Up top there are numbers which indicate the CTD station and the relative position of JM-1. Salinity is shown in colour and there is a use of contour lines to show the layering and values of different salinity concentrations. Adapted from „Current observations at the Jan Mayen Ridge," by Kjell Arne Mork, K. D., Steingrimur Jónsson, Hédinn Valdimarsson, 2011, p. 7. Paper presented at the ESSAS Open Science Meeting, Seattle.

Figures 16 and 17 present the data on temperature and salinity of the West-East section observed. As expected, both visual presentations are almost identical due to the correlation in seawater between temperature and salinity. With data missing from the eastern half of the section, below the depth of 400m, comparisons can‘t be made although properties will pretty much be the same across the whole section at this depth. The top 400m on the other hand show obvious differences. With the top 200m being the most different, a closer look at the western most point shows a temperature of ~3.5°C at 0m and of ~1.5°C at 200m. The values for salinity do differ but with the scale of the graph being too abstract then the salinity values of these two points are around 34.95 but the actual values are hard to evaluate. Then a look at the eastern most point, the temperature at this point was ~5°C at 0m depth and ~3.75°C at 200m depth. Salinity values are around 35.05 but accurate values aren‘t discernible. The important thing about the salinity graph is how well it corresponds to the temperature graph. From the information above it is most obvious to use the temperature values for examination. It is interesting to note, that at station 1 (to the west) the difference in temperatures between 0m and 200m was ~2°C (ΔT) whereas at station 7 (to the east) the difference was only ~1.25°C (ΔT). This indicates a much more gradual cooling with depth at station 7 which is visible via the larger distance between contour lines than at station 1, where cooling with depth is much more abrupt (contour lines closer together) in the top 100m. Also the surface temperature values, ~3.5°C at station 1 and ~5°C at station 7 show much warmer surface water towards the east. This is a sign that the origin of the waters to the east are from the Norwegian Sea.

2.2.3 Lyngvi Ridge cross-section and mooring

This sub-chapter brings forth the findings of a short presentation published by the University of Akureyri and the MRI (Marine Research Institute, Iceland). The presentation was based on findings of research conducted by the MRI. First a look at the topography of the area, in June 2008 the MRI conducted a multibeam survey of the area which gave the following topographical map (Figure 18.). Indicated on said map, is the location of a mooring, with a red cross. This mooring is at the same location as the one named Dreki in the chapter 2.2.1. Also you can see the place names of three different features of the area. Then on the next image (Figure 19.) you can see the collected data from the mooring site over the period from November 2007 to June 2008. The presented data shows the detided currents at different depths. The interpretation of this data indicates that the flow observed is a highly barotropic northward flow (Jónsson, 2009).

Also in the same area there was a cross-section observed. On this cross-section there were conducted vessel mounted ADCP measurements (measuring upper layer currents) and CTD measurements (measuring temperature and salinity along and across the ridge) (Jónsson, 2009).

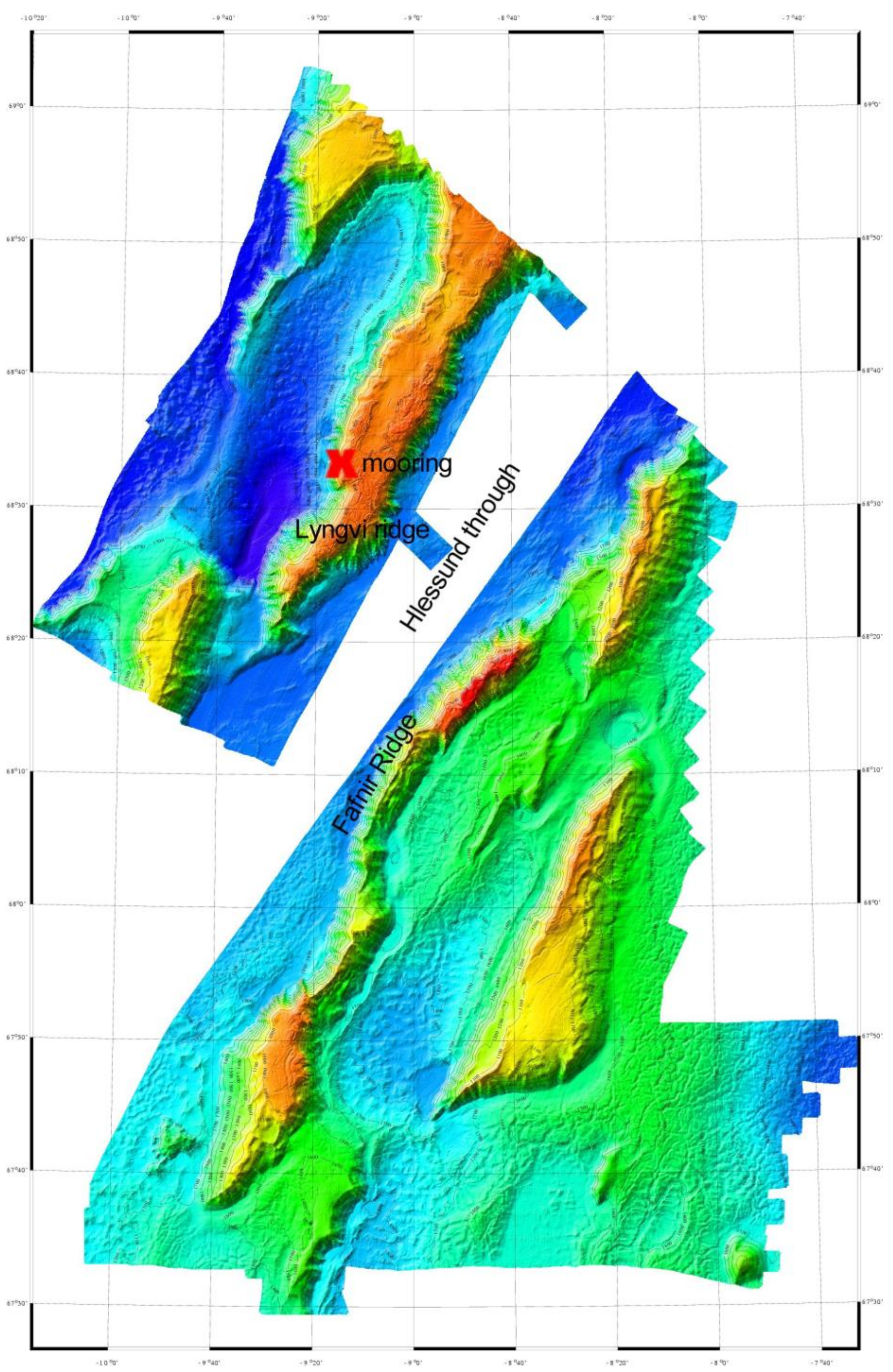

Figure 18. A topographic map acheived through a multibeam survey. The area in question is the Lyngvi ridge area, that is south of Jan Mayen. Visible on the map is the location of a mooring that was placed and is marked with a red cross. This is the same location as the Dreki mooring in 2.2.1. Also visible are a few place names to help with identifying the area. *Adapted from „Currents* ***and hydrography on the Dreki area," by Hédinn Valdimarsson & Steingrimur Jónsson, , 2009. Poster presented at the Ocean and Marine Biota conference, Reykjavik.***

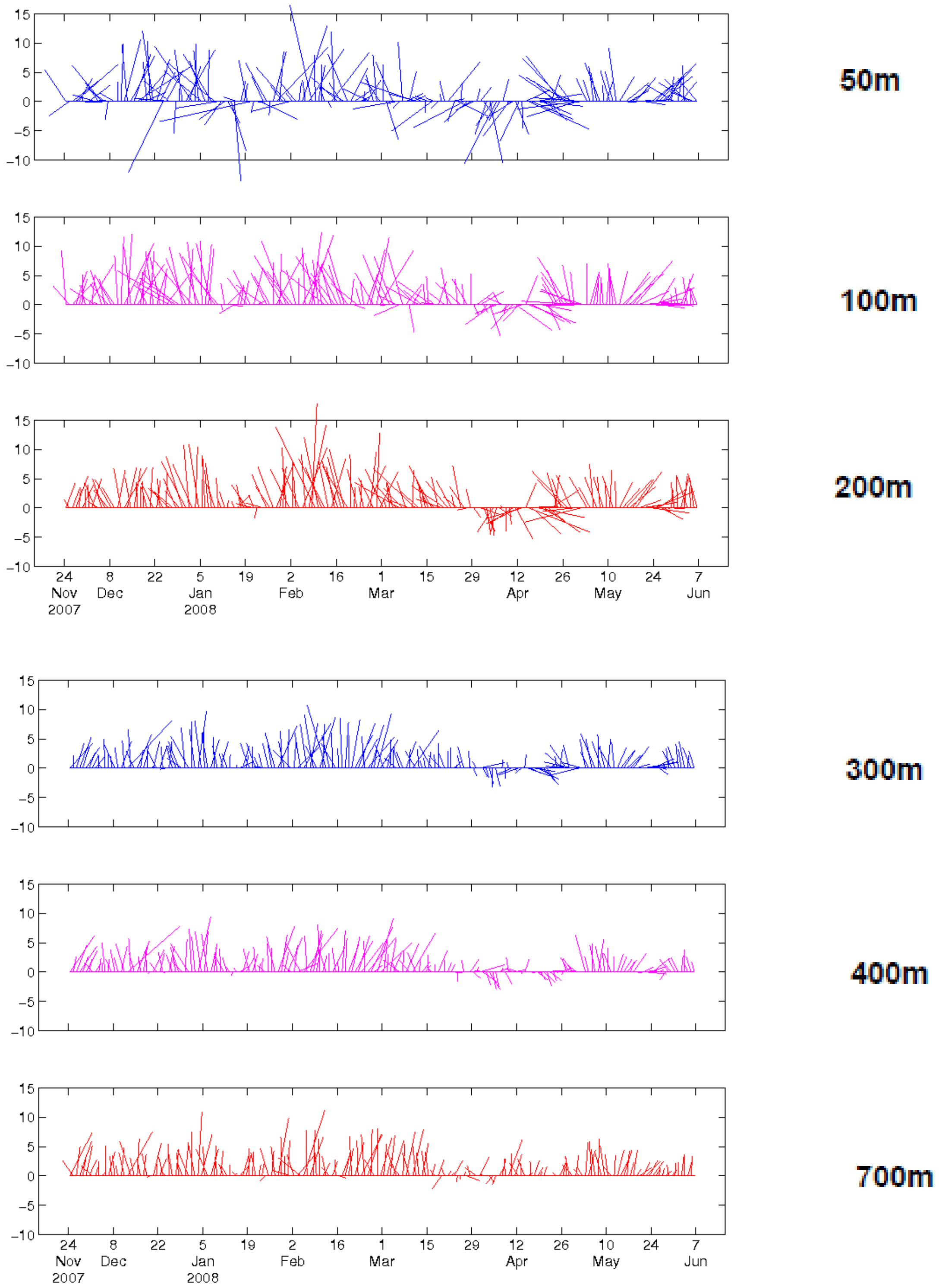

Figure 19. A presentation of data collected at the mooring on Lyngvi Ridge. Data has been detided and shows the currents at different depths. Data was collected between November 2007 and June 2008. Adapted from „Currents and hydrography on the Dreki area," by Hédinn Valdimarsson & Steingrimur Jónsson, , 2009. Poster presented at the Ocean and Marine Biota conference, Reykjavik.

For each of the two sections observed, there were executed four vessel mounted ADCP measurements and CTD measurements once along each section at various points. The location of the sections, along with the CTD stations can be seen in Figure 20. First a look at the vmADCP results, the vmADCP measured the currents at a depth of around ~50 m. Results were then calculated and presented as the mean of four transects. These you can see in Figure 21. , which shows the results from measurements conducted in February 2008 and in June 2008. The results show clearly that there is a northward flow along the Lyngvi Ridge. Also that there is a south westerly flow through the Hlessund channel, the relative positions of these two places can be seen in Figure 18. Finally, for the Lyngvi Ridge there is also Temperature-Salinity (T-S) data that can be taken into consideration thanks to the CTD measurements. When comparing the vmADCP data of the section which lies across or perpendicular to the ridge, to the T-S data it is easy to see that the south westward flow through the Hlessund channel is slightly warmer and more saline water than the northward flowing water, which flows along the Lyngvi Ridge. The T-S data can be seen in Figures 22. and 23. (Jónsson, 2009).

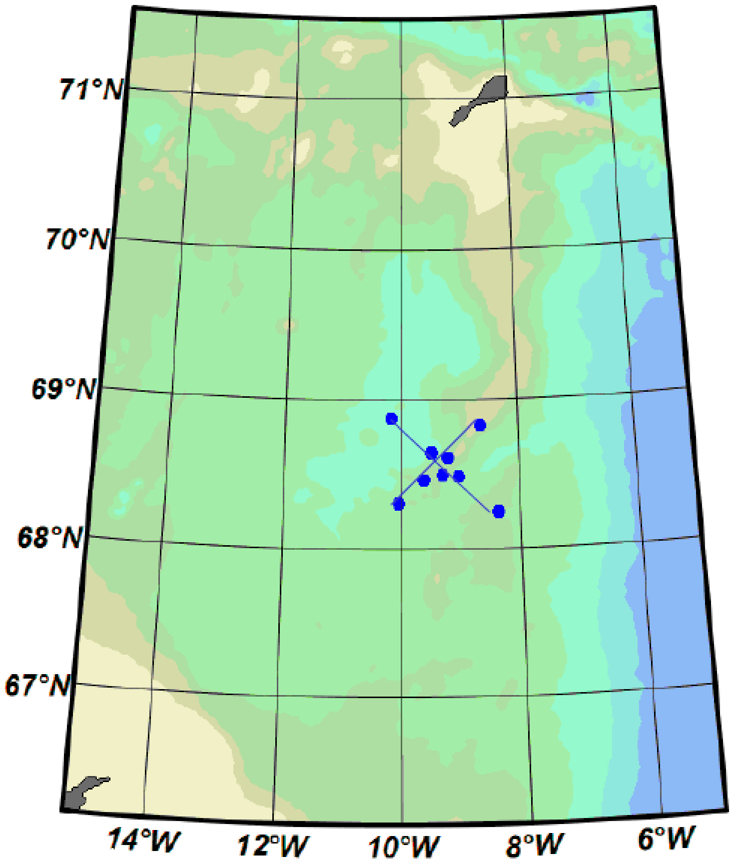

Figure 20. A map of the area between Jan Mayen (top right) and Langanes, Iceland (bottom left). Indicated on this map are the stations at which there were CTD measurements conducted (dots). Also shown are two lines, they indicate the two cross sections where vmADCP measurements were conducted. Adapted from „Currents and hydrography on the Dreki area,“ by Hédinn Valdimarsson & Steingrimur Jónsson, , 2009. Poster presented at the Ocean and Marine Biota conference, Reykjavik.

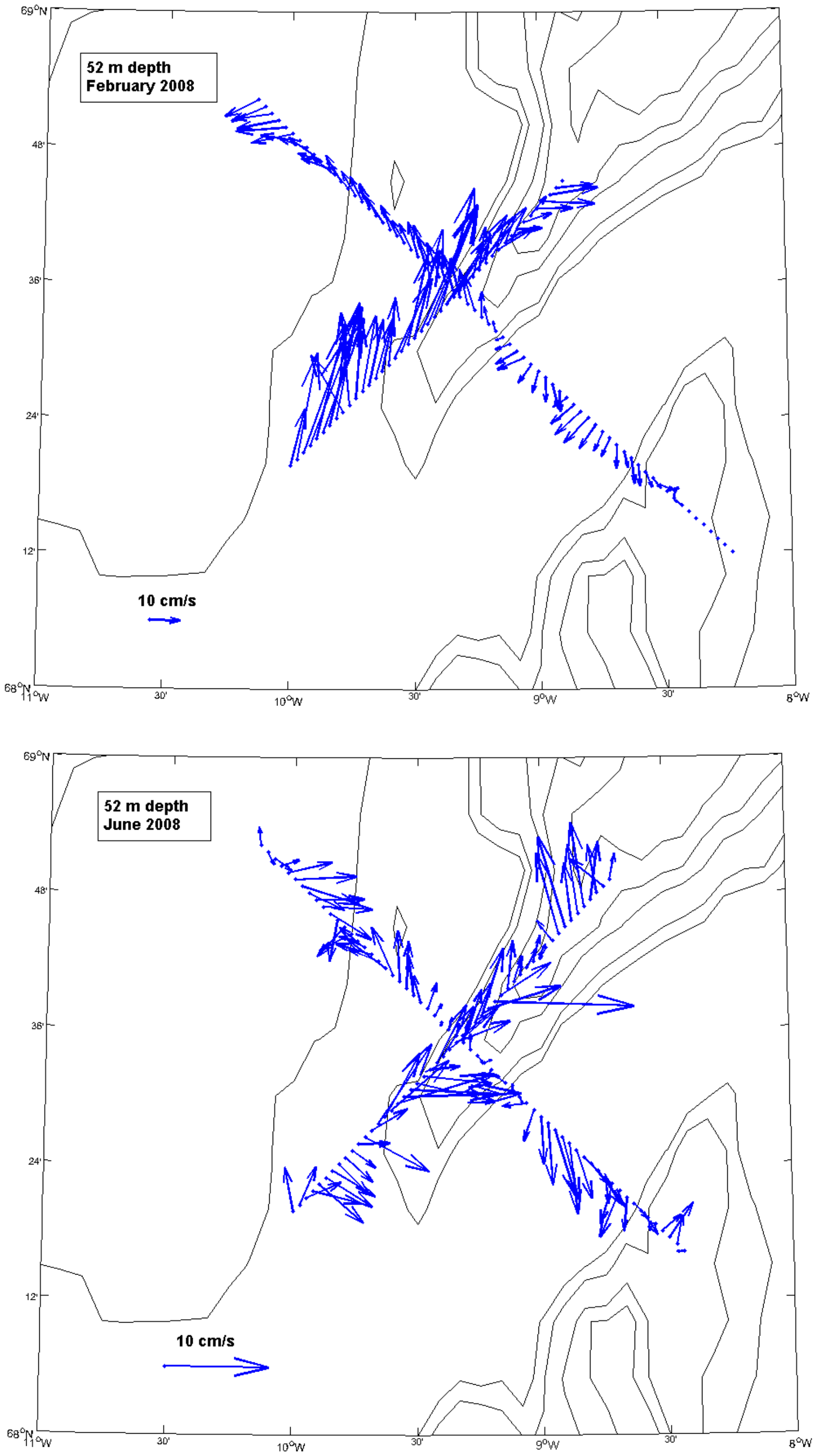

Figure 21. Results of the vmADCP measurements along and across the Lyngvi Ridge. Upper layer currents were being observed at an approximate depth of 50m. The indicated results are a mean of four transects of each cross-section. Adapted from „Currents and hydrography on the Dreki area,“ by Hédinn Valdimarsson & Steingrimur Jónsson, , 2009. Poster presented at the Ocean and Marine Biota conference, Reykjavik.

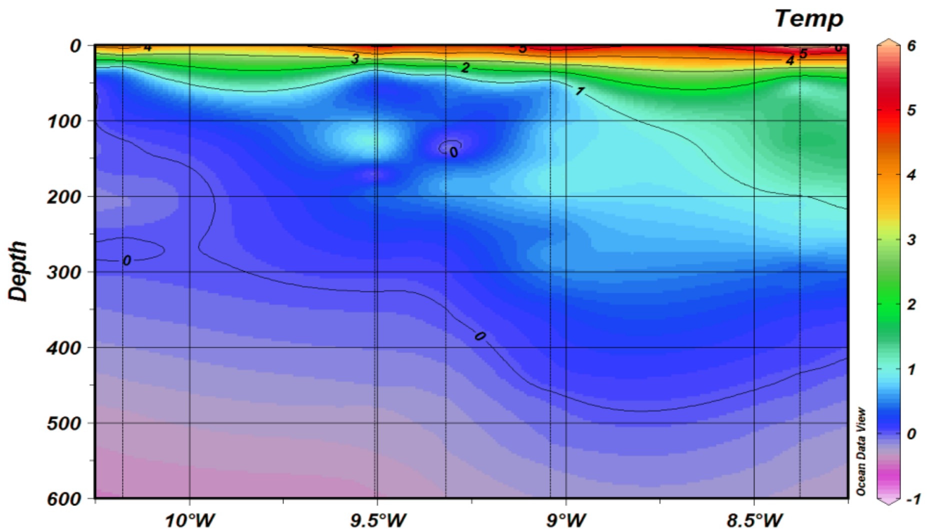

Figure 22. A graphic representation for Temperature data collected along the section which lies across Lyngvi Ridge. Along the bottom x-axis there are longitudinal values, on the y-axis there are values for depth in meters. To the right hand side of the graph, there is a gradient which shows how the temperature values are represented on the graph. Adapted from „Currents and hydrography on the Dreki area," by Hédinn Valdimarsson & Steingrimur Jónsson, , 2009. Poster presented at the Ocean and Marine Biota conference, Reykjavik.

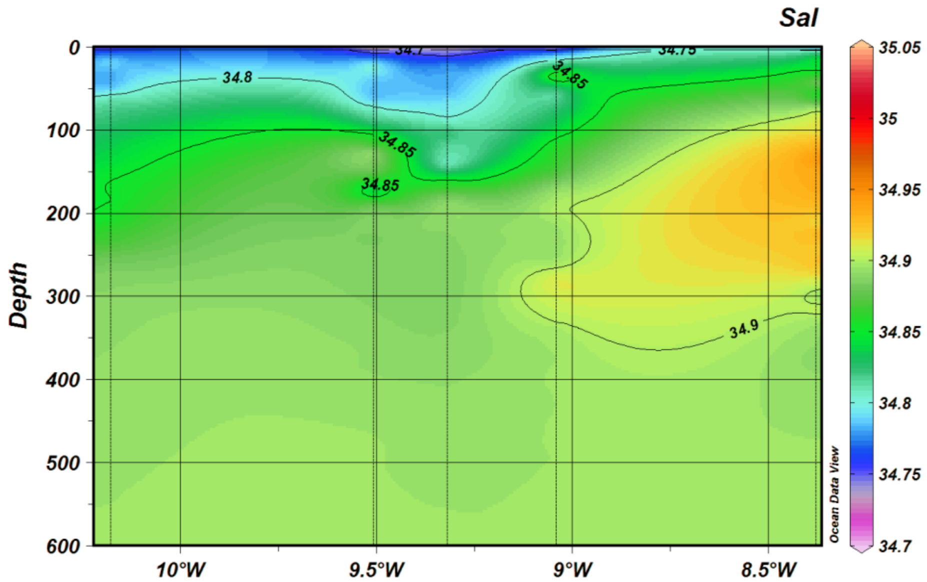

Figure 23. A graphic representation for Salinity data collected along the section which lies across Lyngvi Ridge. Along the bottom x-axis there are longitudinal values, on the y-axis there are values for depth in meters. To the right hand side of the graph, there is a gradient which shows how the salinity values are represented on the graph. Adapted from „Currents and hydrography on the Dreki area," by Hédinn Valdimarsson & Steingrimur Jónsson, , 2009. Poster presented at the Ocean and Marine Biota conference, Reykjavik.

2.2.4 Argo float data from the Iceland Sea

The Argo project is an international collaboration which results in three different types of data. By tracking its location each time it surfaces you can map the currents in the ocean at a certain depth. An Argo float also collects temperature and salinity data each time it surfaces and therefore is highly important for oceanographic research around the world. The floats themselves are autonomous and battery-powered, they spend most of their time in the sea at a certain depth, at which they are neutrally buoyant. This is achieved by them having a density equal to the ambient pressure at the determined depth and a compressibility that is lower than that of sea water. Typically, at 10-day intervals, the float pumps fluid into an external bladder and then rises to the surface after around 6 hours. During its rise to the surface the float takes temperature and salinity measurements and then once at the surface, sends all of its data to a satellite which in turn determines its location. The bladder then deflates and the float sinks back to its former depth where it resumes floating along with the currents of that depth (Argo).

The data which this paper will be looking at, is the tracks of three floats in the Iceland Sea, over the period of 2005-2007. The markers which are indicated along the paths, represent 50 day intervals (see Figure 24.). Circulation in the Iceland Sea is generally cyclonic and this statement is confirmed in the results of current meters (Jónsson, 2009).

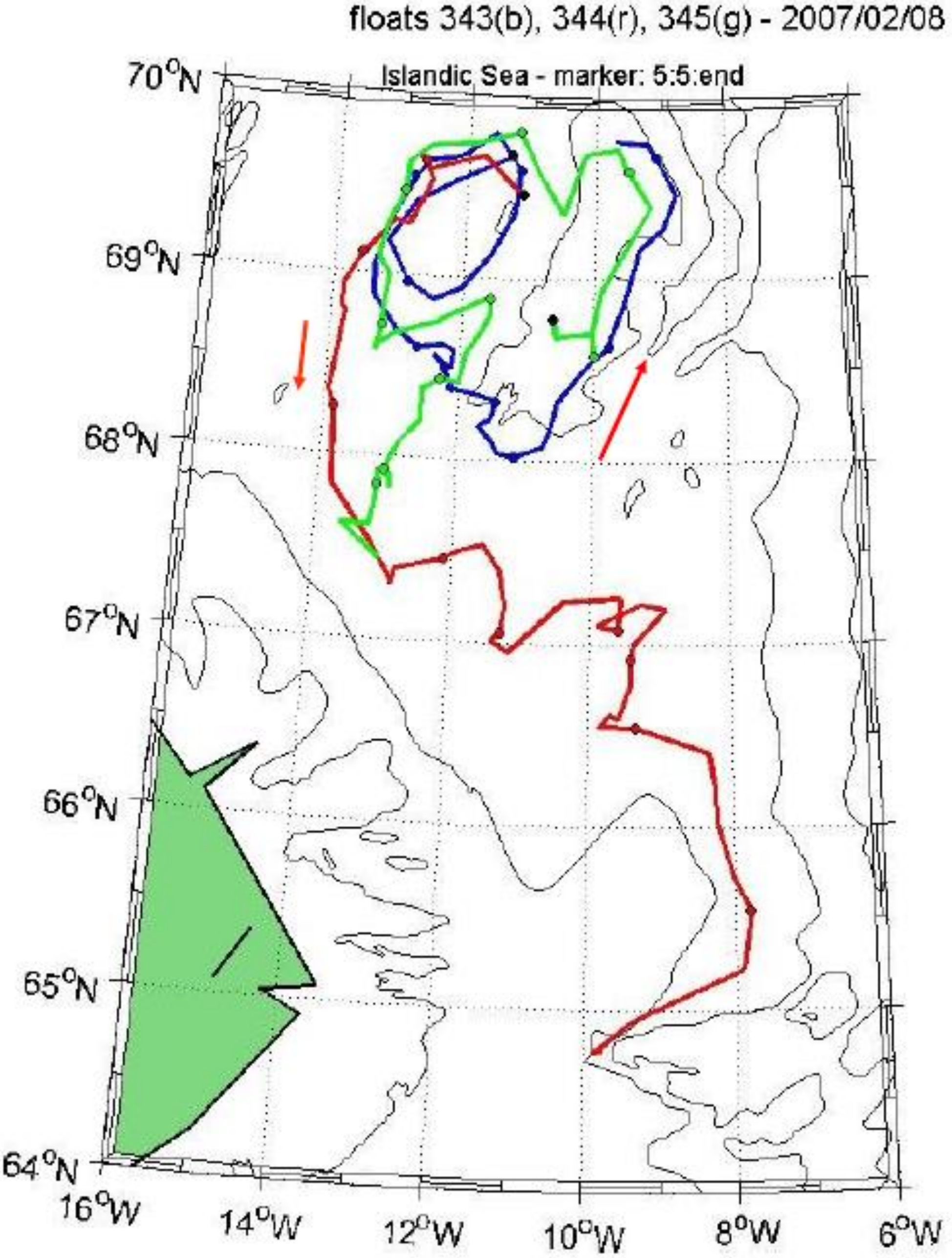

Figure 24. Visible are the tracks of three floats, 343 (blue), 344 (red) & 345 (green). They were deployed in the Iceland Sea between 2005-2007. Markers (dots) along the paths are used to indicate 50 day intervals. Also shown are the latitudes and longitudes on the map. Adapted from „Currents and hydrography on the Dreki area," by Hédinn Valdimarsson & Steingrimur Jónsson, , 2009. Poster presented at the Ocean and Marine Biota conference, Reykjavik.

3 Exploration/Production facilities

3.1 Benchmarking

When planning for any type of business model, benchmarking is a useful tool while comparing previous models to your prospective one. To benchmark, you must decide on the criteria you would like to compare. At the 2008 Iceland Exploration Conference, Jan Egil Arneberg presented benchmarking comparisons to oil drilling sites in: North-Western Europe, the Gulf of Mexico, offshore Brazil and offshore Western Africa. The criteria used were reservoir depth, water depth, minimum seabed temperature, maximum sea currents, minimum surface temperature, sea ice, 100-year wave height, wind speed design criteria, distance to shore and gas off-take (Arneberg, 2008). See Table 1.

Table 1. A table displaying along the left side, the criteria used for benchmarking. Along the top line are the different sites being compared and below them is the data.

Criteria	Dreki Area	North-Western Europe	Gulf of Mexico	Offshore Brazil	Offshore Western Africa
Reservoir depth (m)	3 000 – 3 500	1 400 – 5 500	700 – 10 000	2 000 – 4 000	2 000 – 4 000
Water Depth(m)	1 000 – 2 000	10 – 2 000	0 – 3 000	0 – 3 000	0 – 3 000
Minimum sea bed temperature (C)	-1	-1	4	4	4
Maximum sea currents (m/s)	~1,0	~1,0	6-8 Lube currents	~1,0	~1,0
Minimum surface temperature (C)	-2 (-15)	~-10	Not relevant	Not relevant	Not relevant
Sea ice	Occasional pack ice	Not relevant	Not relevant	Not relevant	Not relevant
100-year wave height, Hs (m)	12	15-18	15	8	4
Wind speed design criteria (m/s)	36	36	40(54)	20	20
Distance to shore (km)	200 - 400	0 - 300	0 - 300	0 - 300	0 - 300
Gas off-take	No regional market & infrastructure	Regional market & infrastructure	Regional market & infrastructure	Regional market & infrastructure	No regional market & limited infrastructure

Note. From Drilling and Production at the Jan Mayen Ridge Challenges and Solutions. Presented 2008 by Jan Egil Arneberg.

Almost all of the Dreki Area criteria have matches with one or more of the other drilling sites. Reservoir depth is considered to be in the region between 3000 and 3500 meters. All of the other sites have potentially deeper reservoirs but they can also be shallower. Water depth is in the 1000 to 2000 m depth range, operations have been conducted in deeper waters than this and it‘s therefore not a problem. The minimum seabed temperature of -1°C could pose complications, but in North-Western Europe there are drilling sites with the same seabed temperature. Maximum sea currents of the area are said to be 1.0 m/s, this corresponds to the current speed at all other sites apart from the Gulf of Mexico. Which has a current velocity of about 6-8 m/s due to the loop current. The minimum surface temperature is around -2°C but can in extreme cases reach -15°C. On 3 of the other sites this temperature is not relevant but in the North-Western Europe sites the surface temperature can fall to -10°C (Arneberg, 2008).

Sea ice extent is not relevant in any of the sites other than the Dreki area site. There are notable fluctuations, on a year to year basis, in the amount of sea ice in the Eastern Greenland Current (EGC). This is both due to differing amounts of sea ice from the Arctic and also due to differing amounts of new sea ice forming in the more southern reaches. Icebergs that break off from creeping glaciers on Greenland usually follow the EGC but in some cases they can wander from the path. So the occurrence of them in the Jan Mayen ridge region are probably low but not zero (Auðunsdóttir, 2007). The relevant area for this paper is quite a bit to the east of the annual maximum sea ice extent of 2013 which was reached in March 2013. It also is outside the median line for sea ice extent between 1979-2000 for that month (Vizcarra, 2013)(see Figure 25.). Therefore other than some occasional ice packs, then the area is pretty much sea ice free. Abnormally high amounts of sea ice in the Eastern Greenland Sea have been known to cause the drifting of sea ice south between the 15°W and 10°W longitudes. This happened last during the years of 1965-1971 and also during the late stages of winter in 1979 (Auðunsdóttir, 2007). With the warming of earth’s climate and consequent thinning of Arctic ice, the sea ice probability of the area is constantly lower. Of course if there should be a very cold winter then there is always a possibility of sea ice in the area. Therefore any facilities used in the area must be adequately able to handle such a situation.

The 100 year wave height is around 12m, whereas in North-Western Europe it‘s 15-18m and in the Gulf of Mexico it‘s 15m. So this is not a problem that stands out and should be easily handled with the correct type of technology. Wind speed design criteria indicates wind speeds of up to 36 m/s, again both N-W Europe and the Gulf of Mexico deal with equal or stronger winds and therefore it isn’t a huge problem (Arneberg, 2008).

The last two criterias connect to an extent, distance to shore can be from 200km and up to 400km, depending on the position of the well. Generally, the maximum distance that is feasible is around 300km due to the maximum range of helicopters to and from a destination. Custom adjustments such as removing seats and adding fuel tanks can enhance the range of a helicopter and could be necessary in this case. In addition to the range of helicopters then the distance to shore is also a large factor in the decision making process of which technology to use when transporting gases/liquids from the well to a processing plant. The last criteria used in this benchmarking process is Gas off-take, Iceland currently doesn‘t have a regional market or infrastructure for this industry. Ideas have been put forth for the foundation of such facilities on the North-East corner of Iceland, Raufarhöfn, Þórshöfn and other municipalities being mentioned in this regard. This is definitely a criteria that must be met and options must be explored from the get-go (Arneberg, 2008).

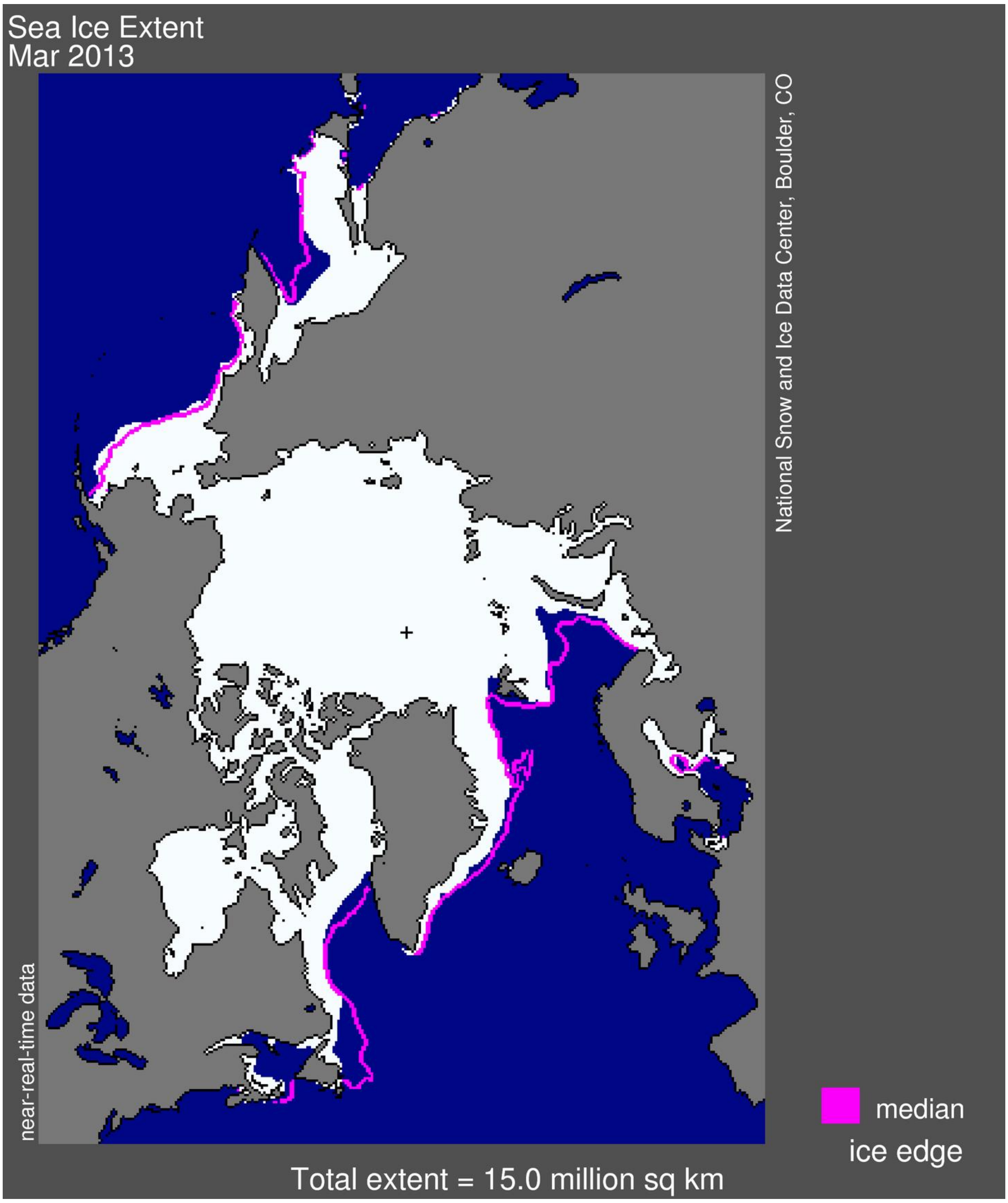

Figure 25. Average sea ice extent in the arctic for March 2013. The magenta line represents the median line for that month between 1979 and 2000. The black cross indicates the geographic North Pole. Adapted from Arctic Sea Ice News & Analysis. Retrieved 1/5/2013, from http://nsidc.org/arcticseaicenews/files/2013/04/Figure1.png. Published 2013, by National Snow and Ice Data Center.

3.2 Feasible production technologies

With the water depth being 1000-2000m then any wells in use will be subsea wells. Such wells can either be connected via flow lines to a platform or through a pipeline straight to the shore. Products of the well, will be unprocessed and therefore the resulting flow will be multi-phase. This means a mixture of oil, gas, water and sometimes solids. With the distance to shore being between 200 and 400 km then a pipeline to the shore is not an option with the present day technology we have. This leaves the choice of flow lines to a platform. The common practice in this situation is a subsea tie-back to a nearby platform. This has been done at a deeper depth than in the Dreki and Jan Mayen ridge region, which was 2300m at the Coulomb field in the Gulf of Mexico. One advantage of such a system is that many subsea well tiebacks can then be connected to one platform (Sagex, 2006).

With the water depth being between 1000m and 2000m, the option of a fixed platform is not available. Therefore some sort of floating technology must be considered. There are 4 relevant types of units for this project: Semi-submersible platform, tension leg platform (TLP), spar platform, ship-shaped floating production storage and offloading unit (FPSO). Following is a short description of each type:

- *Semi-Submersible Platforms*

  „A semi-submersible platform has a hull consisting of pontoons with vertical columns placed on top. The deck is placed on the columns. The whole structure is anchored to the seafloor with spread mooring lines, i.e. catenary mooring lines (typically 12 or 16 of them) extending in a star-shaped pattern from the corners of the platform." (Sagex, 2006, 30).

- *Tension Leg Platforms (TLPs)*

  „A TLP is characterised by its unique mooring system. The TLP is anchored to the seabed with vertical tendons, or "tension legs". After fixing the bottom ends of the tendons to the seabed and the top ends to the hull, a tensioning mechanism installed in the hull is used to tighten the tendons so that the floating hull is pulled slightly down in the water. The buoyancy forces will then keep the tendons constantly in tension and the platform is anchored like an "inverted pendulum". The result is a floating platform with no vertical movement (only horizontal)." (Sagex, 2006, 31)

- *Spar Platforms*

  „A Spar platform, sometimes also referred to as a deep draft caisson vessel, consists of a large vertically floating column, often with a truss section connecting the column to a ballast tank at the bottom. The structure is anchored with a spread mooring system similar to the one used for semi-submersibles." (Sagex, 2006, 32)

- *Floating Production, Storage and Offloading Units (FPSOs)*
„An FPSO has a ship-shaped hull. In most cases it is moored with a so-called turret mooring system. This consists of catenary mooring lines attached to a vertical cylinder-like construction around which the whole vessel can rotate, or "weather-vane". The mooring lines and cylinder stays in the same position, while the vessel is rotated according to the weather. The turret can be either an internal turret, located centrally in the hull, or an external turret, located in an extension to the bow of the vessel. The former is used in new build FPSOs while the latter is used in tankers converted into FPSOs." (Sagex, 2006, 33)

Every one of the aforementioned technologies are eligible options. Each one has its advantages and disadvantages in comparison to another. Therefore more detailed knowledge of the area and reserves will be needed before a decision is made. Economics will also play a big role in this decision process, set-up costs, running costs and maintenance costs being the main interest area. Also the capacity for expanding an operation will factor into it. Otherwise unknown reserves could be discovered and then the facility must be able to accommodate further extensions. An FPSO would be the typical choice for a small oil field, whereas a floating platform would suit larger oil fields due to their ability of supporting a larger number of wells. With the lack of both pipeline and facility infrastructure in the area and on Iceland, then the use of either an FPSO or FSO would be necessary. An FPSO or FSO could then transport oil to a shuttle tanker that would then transport the oil either to a new terminal in Iceland or an existing one in Europe. As for gas, then re-injection is likely to be the most economic option. If, on the other hand, large amounts of gas are found then transport via a pipeline to Norway, the North Sea grid or the UK is not considered a possibility with today's technology. Therefore gas liquefaction would be the only option. There are two types of gas liquefaction, Liquefied Natural Gas (LNG) or Gas To Liquids (GTL). The production of such products can either be located on a floating platform or onshore Iceland. If processing of gas is to be located on Iceland then facilities would first have to be built and then a pipeline from the gas field to the onshore facilities (Sagex, 2006).

3.2.1 An example of recent platform technology

In 2009, the first platforms of the Aker H-6e type were delivered. Described by the manufacturer, Aker, to be operational in ultra-deep waters, harsh environments, extreme temperatures and at long distances from supply infrastructure. This description, if proven to be true, meets many of the main concerns raised surrounding oil and gas operations in the Dreki and Jan Mayen ridge region. These platforms are large and modern and have been designed to operate in waters with depths of up to 3,000 metres and to drill wells that are up to 10,000 metres deep. They have a significant storage capacity causing less emphasis on frequent supply deliveries (Aker Solutions, 2013). This is of course just one option of many.

3.3 What could go wrong? A look at the Deepwater Horizon incident

Deepwater drilling can pose numerous health & safety issues, both to personnel and to the environment. Major incidents are not a common occurrence, but in the year 2010 one such incident occurred. On April the 20th workers on BPs Deepwater Horizon were working on the temporary abandonment of the Macondo well. A series of failures and human error led to the upwelling of hydrocarbons from the well into the semi-submersible platform, which then ignited and caused fatal explosions killing 11 workers. This disaster has been heavily reviewed by a number of parties and the BP *Deepwater Horizon Accident Investigation Report (2010)* lists 8 key findings regarding the incident. All of these factors must be used as a lesson for future drill sites to be wary of, including any potential drilling in the Dreki and Jan Mayen ridge region. Here is a short summary of these 8 key findings:

1. *“The annulus cement barrier did not isolate the hydrocarbons“ (BP, 2010, 33)* – The barrier failed to prevent the migration of hydrocarbons into the wellbore and was likely caused due to the use of nitrified cement slurry. This could have led to nitrogen breakout and migration which in turn would cause an incorrect cement density. Also the use of a cement evaluation log could have foreseen the problems experienced, but wasn‘t carried out (BP, 2010).

2. *“The shoe track barriers did not isolate the hydrocarbons“ (BP, 2010, 36)* – Ingress of hydrocarbons to the wellbore was evaluated to have been via the shoe track barriers. It is not fully known what attribute was to blame for this failure or whether it was a combination of attributes. Failure of the cement could have been due to design, contamination by mud, mixing with nitrogen that had broken out from the annulus cement barrier or swapping of the shoe track cement with the mud at the bottom of the well (BP, 2010).

3. *“The negative-pressure test was accepted although well intregrity had not been established“ (BP, 2010, 38)* – It is thought that the combination of a lack of flow in the kill line and the wrong explanation for the 1,400 psi on the drill pipe, led site leaders and crew members to draw the wrong conclusion that the negative-pressure test was successful. These contradicting numbers should have raised alarms. Also, the guidelines for negative-pressure testing, didn‘t provide detailed steps nor expected bleed volumes for a successful/unsuccessful test (BP, 2010).

4. *“Influx was not recognized until hydrocarbons were in the riser“ (BP, 2010, 41)* – After analysis, it was found that the first implications of flow from the well can be seen in real-time data at 20:58. However mud loggers and rig crew were either not monitoring or did not recognize the indications until after the hydrocarbons entered the riser at around 21:38. The first responses were issued likely at 21:41. Company policy states that wells must be monitored at all times, although it doesn‘t specify how it should be monitored during end-of-well activities (BP, 2010).

5. *“Well control response actions failed to regain control of the well“ (BP, 2010, 43)* – It seems that no actions were taken in regards to well control, until hydrocarbons

were already in the riser. Consequently, the actions taken did not regain control of the well. An annular preventer was activated at around 21:41 but didn‘t seal the annulus until 5 minutes later. During this time more hydrocarbons flowed into the riser. Had the fluids been diverted overboard instead of into the MGS, crew may have had more time to respond and reduce the extent of the accident. On-board protocols did not fully address how to respond in high-flow emergencies and the actions of the crew prior to the explosion suggest that they weren‘t adequately prepared to deal with a situation of this nature (BP, 2010).

6. *“Diversion to the mud gas separator (MGS) resulted in gas venting onto the rig“ (BP, 2010, 45)* – The MGS can only separate small amounts of gas from the mud, which it then vents to the atmosphere. As the hydrocarbons, mud and water were flowing up to the surface the hydrocarbon gas was gradually expanding on the way up. This in turn increased the flow rate (accelerated) and it is thought that, at 21:41, the crew diverted the hydrocarbon flow to the MGS. The accelerating flow far exceeded the design limits of the MGS and the system was overwhelmed. At the terminus of the MGS there was a goose necked gas vent. This vent directed the outgoing gas down onto the rig (BP, 2010).

7. *“The fire and gas system did not prevent hydrocarbon ignition“ (BP, 2010, 46) –* The fire and gas system failed in preventing ignition. On Deepwater Horizon there were secondary levels of protective systems and the electric classification of certain areas. This was due to the nature of working with hazardous substances. Once gas levels exceed an acceptable limit, the fire and gas system initiates warning alarms. For the electrically classified areas there is also an automated function that shuts off the heating, ventilation and air conditioning (HVAC) system so that gas doesn‘t enter the area. As Deepwater Horizon was drilling exploration wells and not producing, the probability of hydrocarbons being present was supposed to be low and therefore few areas electrically classified. The engine room wasn‘t one such area and shutting off the HVAC had to be done manually. It is likely that the HVAC system transferred a gas-rich mixture to the engine room, causing at least one engine to over speed and potentially becoming a source of ignition (BP, 2010).

8. *“The BOP (blowout preventer) emergency mode did not seal the well“ (BP, 2010, 47)* – There is more than one emergency method for operating the BOP to shear and sell the wellbore. But they aren‘t fully independent and therefore one of them failing can cause another to also fail. Basically it all comes down to one component, the blind shear ram (BSR) that must shear the drill pipe and seal the wellbore. The emergency disconnect sequence (EDS) requires that a signal be sent down one of two multiplex (MUX) cables. An attempt was made 7 minutes after the first explosion, but the explosion and fire most likely damaged the MUX cables. Then there is the automatic mode function (AMF) of the BOP that activates the BSR if certain conditions are met. The damaging of the MUX cables is one condition that could trigger this and also witness accounts say that the BOP control panel indicated a loss of hydraulic power, this is another condition that would activate the AMF. On the BOP there are two independent control pods, at least one must be functioning for the AMF to activate. Yet post-examinations of the pods show that the yellow pod had a failed solenoid valve 103, furthermore a non-original equipment part was found on the valve. The blue pod was found to have an insufficient charge on the 27-volt AMF battery bank. The conclusion was that the

maintenance records were not accurately reported and that the maintenance management system lacking (BP, 2010).

These were the 8 key findings of the *Deepwater Horizon Accident Investigation Report (2010)*, it is important that companies operating in the offshore drilling industry take note of this disaster and take measures to prevent a re-occurrence of such an incident.

3.4 Recent developments in preventative measures

At the recent OSPAR Offshore Industry Committee on the 14th of March, 2013, a directive was presented for safety and environmental protection against EU offshore major accidents. Regardless of not being an EU member state then Iceland is in the European Economic Area (EEA) and has adopted a large amount of EU legislature. Also being a member of the OSPAR countries, there is an intent of co-operation between all parties.

It was noted that although the industry is highly capable, it can be improved. A strong safety culture isn‘t embedded throughout the industry and should be. Also there is a clear lack of transparency or sharing of information. This applies both to governments and to private companies. There should be an aim for consistent best practices, upholding this could be done via a formal risk assessment and the setting of goals for safety and the environment. The directive suggests the implementation of independent expert regulators in each member state and that they co-operate and co-ordinate amongst themselves and with non-EU countries. There should be a joint emergency preparedness and response plan between all offshore countries and a duty to co-operate in major incident responses. The scope of environmental liability and compensation practices must also be clarified and improved (Directorate General for Energy, 2013).

For this directive to be successful there would have to be active co-operation between involved parties and the regulators in their region. This would include well notifications to the regulator prior to the start of operations and consequently weekly well reports to the regulator. A comprehensive safety management system (SMS) would need to be established that would include schemes for independent verification of critical safety elements and well plans. The protection of whistle-blowers and co-operation of the workforce would also need to be secured. Improving regulation standards could be developed between independent regulators and the EU regulators group (EUOAG). The integrity of control systems should be ensured by continual assessment through the SMS. An important point put forth, was that safety & environment regulation should be independent from economic regulation (Directorate General for Energy, 2013).

This directive from the EU was achieved with a political agreement (Parliament & member states) on the 21st of February 2013 with hope of a plenary approval in late May of the same year. After which member states have 2 years to transpose the directive into their legislation. There will be further accommodation for existing installations of up to 5 years (Directorate General for Energy, 2013).

4 Effects on the ecosystem, affected areas due to an oil spill and cleanup procedures

4.1 Effects on the ecosystem due to operations or oil contamination

Due to this being an area that is otherwise un-affected by human activities, then it is important to be mindful of the ecosystem when planning exploration and production procedures. South of Jan Mayen there are no islands or skerries that rise from the sea, therefore the focus should be on life forms in the sea. Of course birdlife needs to be considered too, as birds do fly over the area in search for food on their way to other regions (Ministry of Industry, 2007).

Results have shown that phytoplankton production in Icelandic waters is very variable but in the area to the northeast of the shelf it is one of the lowest around Iceland. There, the number of different species and their volume is considered low. This has been attributed to the cold seas of the area, in contrast to warmer Atlantic waters around Iceland. It has been hard to evaluate the full extent of phytoplankton distribution just south of Jan Mayen due to the regularity and blanketing of clouds. This makes satellite imagery not as effective as in other areas (Ministry of Industry, 2007).

When it comes to zooplankton, information is considered extensive enough. There is also additional data available to compile even more detailed information on the amount and types of species of zooplankton south of Jan Mayen. Many zooplanktons do have locomotive abilities but are very restricted and therefore their main mode of travel is by drifting along currents. In areas where water transitions are consistent, the zooplankton don‘t linger for a long time. This means that they aren‘t a good subject for measuring localized pollution. Zooplanktons are vulnerable to oil pollution as they consume PAH (polycyclic aromatic hydrocarbon) materials. The effects of PAH‘s can differ on zooplankton, it can change their behaviour, metabolism, growth, evolution and reproduction and in more serious cases cause their death. Zooplankton is part of the capelin‘s diet and the capelin has been found in the proposed exploration areas in the past. Therefore it would be a good idea to collect data on the amount of PAH‘s in zooplankton species of this area before exploration and production. Then to re-collect data on the PAH levels after exploration and production to monitor the effects (Ministry of Industry, 2007).

Protection of benthic species is based on their rarity, the habitats of benthic species can take a long time to evolve and Iceland has treaties with both the EEA and OSPAR to protect certain benthic species and habitats (Ministry of Industry, 2007). Explicit mapping of the bathymetry and bottom types were conducted in 2008 by the MRI, bottom types were identified and benthic species found with the use of an underwater camera (Helgadóttir, 2008). Now an evaluation on whether the species and their habitat are protected and whether they will be affected needs to be done.

There is very little data on bottom fish in the area, but this doesn‘t mean there aren‘t any just that there is little known in the area. There are 3 pelagic species of fish that are typically found to the north of Iceland. Only 2 of these are considered likely in the proposed exploration/production area. These are capelin and herring. The capelin was prevalent in the area in the 1980‘s but has since migrated and is found in the west Iceland Sea and in the Greenland Strait. It isn‘t known whether they might migrate back to the area between Iceland and Jan Mayen and therefore it is important to minimize and prevent the disturbance of the capelin‘s living conditions. The Norwegian-Icelandic herring is known to be found in and around the exploration area. Negative effects of exploration and production in this area on fish could be through seismic surveys or the leakage of oil. Effects of seismic surveys on fish aren‘t known, they could be harmless or they could be negative. It hasn‘t been established yet that oil or hydrocarbons have any effect on fully grown herring, but they could affect their larvae and smolt. On the other hand this area is an unlikely destination for larvae and smolt, it is primarily an area the herring visits in its endeavour for food. Consequently it is believed that should an oil spill occur it isn‘t likely to affect the herring population much (Ministry of Industry, 2007).

The effects of exploration and production on whales isn‘t very well known. Should an oil spill occur then it is more likely that it will affect whales through their diet rather than via direct effects. Research has also shown that the noise from airguns used in the process can scare off whales up to 20 km away. Further research is needed to know the extent of these effects and whether they would influence any rare species of whale. Activities south of Jan Mayen wouldn‘t influence a large area, but the region is said to contain a large number of whales of which the most common are the northern bottlenosed whale, fin whale and killer whale (Ministry of Industry, 2007).

4.2 Likely areas to be affected

An oil spill event won‘t necessarily occur during any operations in the Dreki/Jan Mayen ridge region, but should it happen then there must be a contingency plan in place. There are many scenario‘s or stages where an oil spill could happen. It could happen during the exploration process, the production process or anytime during the transferral process (to the production facility, to storage or to an onshore installation). The nature of the spill would of course dictate the volume and severity of the event. Should an accident happen when an FPSO/FSO vessel leaks oil, then the amount spilled would be limited by the capacity of the vessel. Whereas should an exploration well (f. Ex. Deepwater Horizon incident) or a production well start leaking oil then there is no knowing how long it will flow until the well can be sealed. Should there be a leak from a well, then the distribution of the oil spill will mainly be influenced by the surface currents. As mentioned in chapter 2.1, a characteristic of the Nordic Seas are counter-clockwise ocean eddies. The proposed areas for likely hydrocarbon reservoirs are located in between two such eddies. Unless, due to wind forcing, an oil spill migrates out of the eddies then it should to an extent contain the spread of oil. In Figure 26. I propose the most likely areas to be affected. The red highlighted area is the eddy which lies just south of Jan Mayen. The green highlighted area is an adjacent ocean eddy. In between the two highlighted areas lie many of the proposed reserves and therefore both eddies are likely areas to be affected. The proposed reservoirs can be seen in Figure 1. These reserves lie between the latitudes 67°N and 69°30‘N and between the longitudes 11°W and 7°W. Due to the lack of research in this field, the spread of an oil spill can‘t be verified until further data and research has been published. Extensive modelling needs to be done to more accurately predict the consequences of such an event. Criteria that would need to be factored into such a model are time of year, surface currents, wind currents, temperature, salinity, sea ice coverage and other factors.

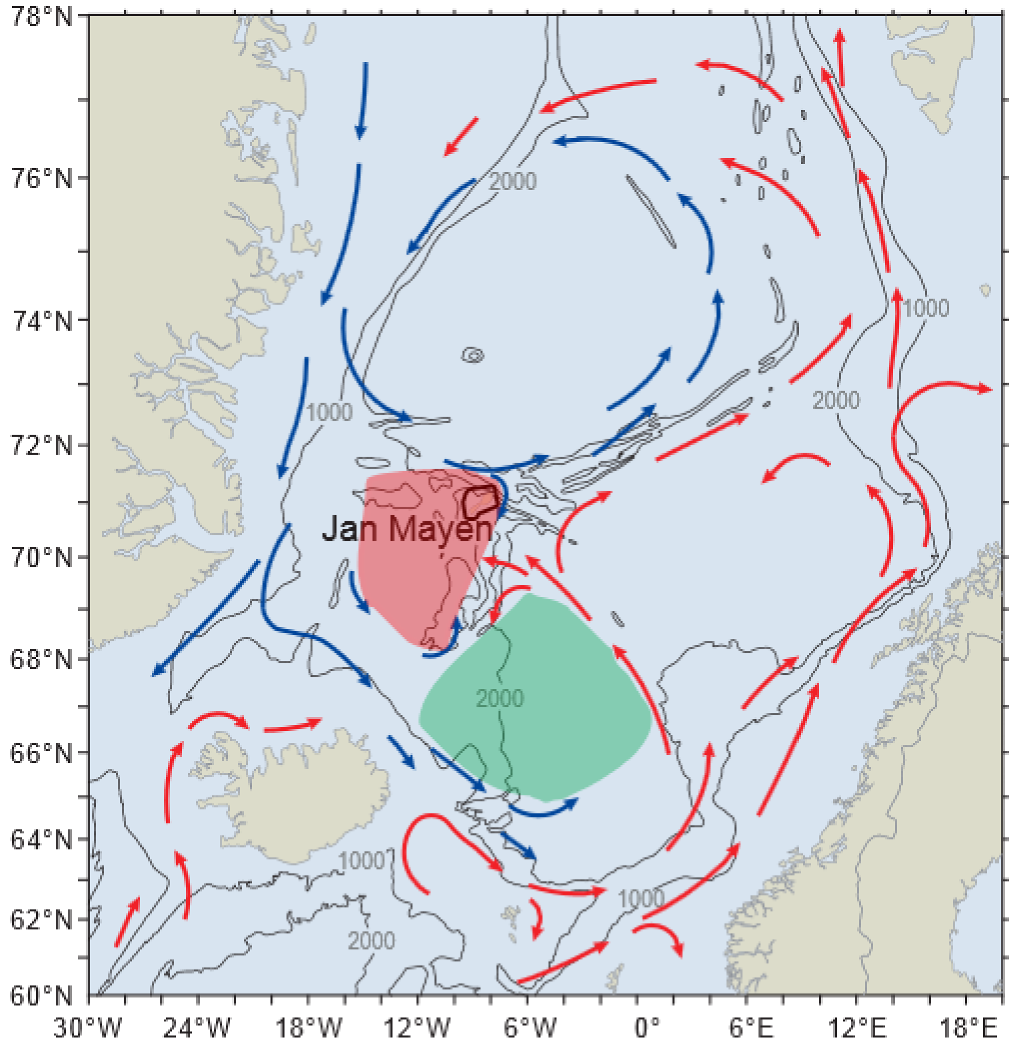

Figure 26. Surface currents in the Nordic Seas. Red arrows indicate atlantic water, blue arrows indicate arctic water. The black „circle“ is to indicate the position of Jan Mayen. The red highlighted area shows an ocean eddy south of Jan Mayen. The green highlighted area shows an adjacent ocean eddy. Adapted from „Åpningsprosess for petroleumsvirksomhet i havområdene ved Jan Mayen,“ by Olje- og Energidepartementet, 2012. p. 21.

4.3 Oil Spill Cleanup

As mentioned before, should an oil spill occur then it is necessary to have a contingency plan. For the plan to be effective then the response options need to be tested regularly. Most contingency plans usually include the following (Fingas, 2001):

- The persons and agencies that should be contacted immediately after a spill
- An organization chart that lists response personnel and their responsibilities, in addition to that what actions they should take in the first hours after an incident
- „Area-specific action plans“ (Fingas, 2001, 29)
- A communications network that makes sure that the response team can co-ordinate response efforts
- „protection priorities for the affected areas“ (Fingas, 2001, 29)
- Operational procedures for the control and cleanup of a spill
- Sensitivity maps, technical data and any other relevant information about the area
- „procedures for informing the public and keeping records“ (Fingas, 2001, 29)
- „An inventory or database of the type and location of available equipment, supplies and other resources“ (Fingas, 2001, 29)
- Different scenarios for typical spills and a list of response actions, for example chemical treating or in-situ burning

(Fingas, 2001)

A training program is necessary for response personnel at every level. This is to familiarize them with their responsibilities and equipment, and minimize the risk of injury during response procedures. Regular training and courses also help to maintain and upgrade the workers skillset (Fingas, 2001).

Containment is the process of either preventing the oil spreading, diverting it to another area or to concentrate it for recovery or any other type of treatment. The most basic and frequently used equipment for containment are containment booms. They are generally the first equipment utilized and are then used throughout the operation. Most booms consist of four components: a floatation device, a freeboard member which prevents the oil from flowing over the boom, a skirt to prevent the oil from flowing under the boom and then one or more tension members to support the boom. Booms also have connectors on each end so that one or more booms can be connected together. Many booms are also designed with ballasts or weights to maintain their upright position, although nowadays many are without and maintain their upright position by balancing forces on the top and bottom of the boom. There are many types of booms and the typical types can be seen in

Figure 27. When booms are used for containment then they are generally arranged in a U, J or V configuration, the U configuration being the most commonly used (Fingas, 2001).

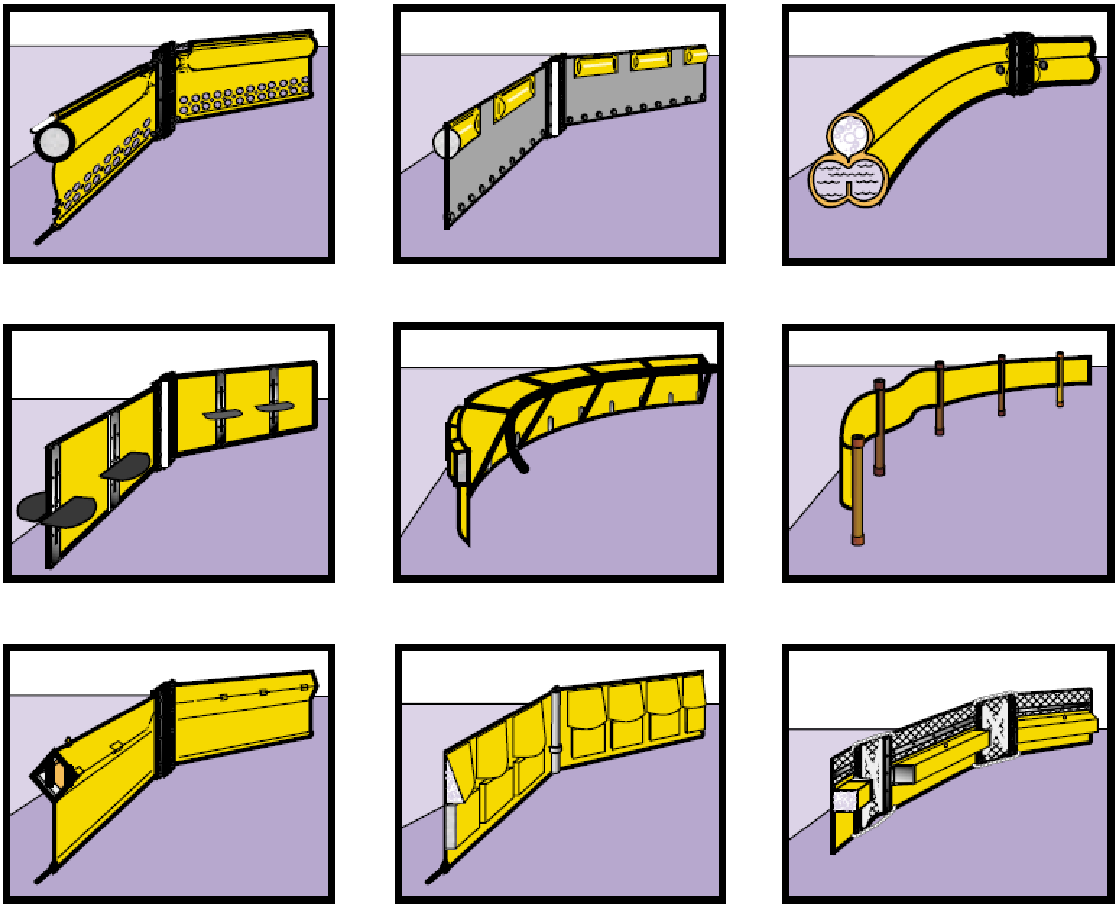

Figure 27. These are typical types of booms. Adapted from „The Basics of Oil Spill Cleanup (2nd edition)," by Merv Fingas, 2001. p. 84.

Following the containment process the next step is recovery, often these two phases are carried out simultaneously. It is more favourable to recover oil the thicker the oil layer is, this is why containment and concentration of the oil is important. Once the oil spreads and weathers, recovery becomes less feasible and in some cases impossible. There are three primary approaches to the recovery of oil; they are skimmers, sorbents and manual recovery. Skimmers are mechanical devices and come in a variety of forms. They can be independent units that are mounted on a vessel or containment device and can also serve as units that operate in a stationary or mobile mode. Skimmers are designed to separate oil from the water surface and are classified in respect to the area where they are used. Sorbents are utilized for the final cleanup or for a small spill. They are materials that use adsorption or absorption to retrieve the oil and are made from synthetic materials (plastic), organic materials (peat moss) or inorganic materials (clay). They are made into pads, booms, rolls, blankets plus other forms and can also be used as loose material. Some sorbents are treated with oleophilic (attracts oil) and hydrophobic (repels water) agents, in order to increase their efficiency. This can also increase their floatability. Manual recovery is sometimes used on small spills or remote locations, most shoreline cleanup is done through manual recovery. Equipment used for this method are for example shovels, rakes, the cutting of oiled vegetation and hand bailers (small buckets on the end of a handle). This form of recovery is time consuming and physical and can pose injury risks from falls on the shore (Fingas, 2001).

After containment and recovery, the process of separation and disposal must commence. Water and debris must be separated from the oil before it is re-used or disposed of. It is critical that there be adequate storage capacity for the recovered oil, the capacity needed will be larger than the initial volume of oil due to the presence of water and debris. As oil is less dense than water, generally gravity is the most effective way of separation by letting water settle down to the bottom of the storage unit. Outlets are usually installed on the bottom of tanks so that water can be drained out. Disposal is one of the most difficult aspects of the oil spill cleanup process. Any form of disposal is subject to a system of legislation by which the process must adhere to. If the recovered oil can‘t be re-used then one option that is often used is incineration. Incineration comes with high costs and high levels of emission. Regulatory authorities have guidelines that must be followed and they must approve the incineration process before it is initiated. In some cases spill disposal will be exempt from regulations due to the necessity of the disposal process. Oiled debris, beach material and sorbents can be disposed of, at landfill sites. But these materials cannot contain free oil that could migrate from the landfill site and contaminate groundwater or soil. Testing (leach-ability test) must be done to establish whether the material will release oil. There are also stabilization processes that can be used to ensure that free oil doesn‘t contaminate the groundwater, one such process uses quick lime that will form a cement-like material with free oil that it interacts with (Fingas, 2001).

In-situ burning is another technique that can be used to cleaning up an oil spill, the burning of the oil is then at or near the site of the spill. This method can be the only option when spills occur far from the proper facilities and equipment needed for the recovery phase. It‘s main advantage is that it can rapidly remove large amounts of oil when conducted under the correct conditions. It is also believed to be more efficient than the other techniques, for example skimming. A series of tests off of Newfoundland in 1993 showed efficiency rates of 98% to 99%. But of course there are disadvantages too, so when considering in-situ burning you must weigh up the pro‘s and con‘s in order to decide on whether or not to proceed with the operation. The main disadvantage is of course the toxic emissions and the second is the conditions that must be met for the burning to be successful. Another angle though, is that when oil is recovered it is often too contaminated for re-use and therefore must be incinerated anyway. The most important factor for the burning of an oil slick is that it must be at least 2-3 mm thick for it to ignite. It is also preferable that winds are under 20 m/s, winds greater than this can be problematic. If an oil slick has started to spread and is thinner than 2-3 mm, then special fire-resistant booms can be used to contain and concentrate the slick to achieve a thicker layer. Also if oil is leaking from a tanker, then the oil that is to be burned must be isolated from the oil that is left in the tanker, this is also done via the use of fire-resistant booms. If the burn would not be isolated and reached the tanker then a much larger spill could occur, so planning is the key to a successful in-situ burn (Fingas, 2001).

Finally, there is the issue of from what location response teams would embark with all the necessary equipment and vessels. If an oil spill incident is rather small, then cleanup efforts can be conducted by workers on the platform. But should the spill be a significant one, then due to the location, there are only 2 options available. Facilities could be established on the northeast coast of Iceland with a response team on standby but that would be a costly choice. There is another option of asking for assistance from Norway, they have established response teams and expert experience in this field. Not to mention the equipment and vessels needed already. It has been proposed that Iceland and Norway increase their co-operation especially with regards to monitoring the traffic of vessels between the two countries‘ exclusive economic zones. In addition to this, Iceland is the member of a number of international treaties regarding emergency anticipation and response to environmental disasters. Through this, Iceland can call for assistance from the Nordic countries and from the EU (Ministry of Industry, 2007).

5 Conclusions

The aim of this paper was to answer a number of key questions and possibly gain insight into other fields regarding the exploration and production of oil and gas. The first question that I posed was whether the current exploration and production technology meets the criteria of the Dreki/Jan Mayen Ridge region. An effective way of reaching the answer to this question is by comparing the criteria of the region to other up and running operations. This was done via benchmarking, where a large number of criteria were compared. This process showed that almost all the problems faced by a potential operation in the region have already been solved by operations elsewhere in the world. This indicates that the conditions do not pose obstacles that can‘t be overcome. There were only 3 criteria that weren‘t similar or more extreme for the operations used in comparison. Sea ice extent was one, the maximum sea ice extent doesn‘t extend to this region but it is possible that occasional pack ice could drift into the area. This must be kept in mind when considering what design of platform should be used. Another criteria not matched was the large distance to shore, which can be from 200 km to 400 km depending on the well location. This is mainly a problem with regards to emergency response and how to transport unprocessed or processed oil and gas. A customized helicopter could handle the distance for emergency pickup and an alternative to using pipelines (for example an FPSO) can overcome these problems.

The final criteria needing attention is the lack of a regional market and a lack of infrastructure for gas off-take. If production isn‘t conducted in an onsite facility, then facilities must be constructed on Iceland. Due to the distance the best location would be somewhere on the northeast coast of Iceland. With regards to gas, should there be a large enough amount in the fields discovered, there isn‘t a gas distribution network in Iceland. This would mean transporting gas in a gas to liquid form either from an onsite processing operation or from an onshore facility in Iceland. It would then need to be transported to a distribution network in Europe. All of these problems can be overcome and it will depend on cost/profit calculations whether the production of gas would be worthwhile or should simply be pumped back down. Also with every new generation of platform, the technology and capabilities improve. One platform manufacturer from Norway, Aker Solutions, has already made a platform to operate in depths of up to 3000m in harsh environments of extreme temperatures. The technology is already available and a platform for the Dreki/Jan Mayen Ridge region can also be customized with certain aspects in mind.

Another question posed, was what would happen if an oil spill should occur in the region and what can be done to prevent such an incident. Also, what areas were likely to be affected by one. An oil spill can occur due to a large number of incidents, a well blowout, human error, equipment failure, the transferral of oil from a facility to a container and vice versa, and plenty of other things. To prevent such an incident it is highly important to keep equipment maintained and monitored on a regular basis. Cost cutting by using sub-par components should never be practised. This is perhaps the reason for the failure of the BOP emergency mode at Deepwater Horizon that could have prevented the leakage of the

Macondo well. Staff must go through regular training to prepare them for any scenario and there must be strict guidelines for the monitoring of wells that are being sealed/closed. These are preventative measures that seem to have been lacking in the 2010 oil spill and must be improved upon for any potential operation in the area. What would happen and what areas would be affected, relies upon in which way a failure would occur and the location of the well/platform. My main focus is the event of an oil spill, and the distribution of an oil spill depends highly on its location. The proposed oil and gas reservoirs lie in an area that is between two eddies south and southeast of Jan Mayen. Eddies in the North Atlantic characteristically flow in an anti-clockwise direction. I believe that should an oil spill occur, then the oil that is leaked would become entrapped in either one of the eddies. Perhaps in both should the oil spill surface right in between the two but the event of that happening seems rather unlikely to me. This would mean that oil reaching shore on Iceland, Norway or Greenland would not happen but could possibly affect the shores of Jan Mayen.

The last question I was seeking to answer is how an oil spill could be contained and the cleanup process that would follow. I found out that the first step of a cleanup process is the containment of the spill. This is typically done with the use of booms, they can be used in a few different ways. One way is to anchor them with the intent of protecting a delicate environment, for example a shoreline or bay. Another is to encircle a leaking vessel with booms to prevent the distribution of a spill or to encircle a spill that has been concentrated with the aim of in-situ burning. And the third most used method is to have two boats pull a line of booms between them to collect and concentrate the spill. The recovery part of the cleanup process is usually conducted by skimmers which skim the top layer of the sea and collect the oil from the surface. What is relevant to this paper is the knowledge of what equipment and vessels are needed on standby, ready to respond to an oil spill incident. Norway already has the equipment and expertise and we could look to them for the role of a response team. Should the Icelandic authorities decide to rely on themselves primarily, for responding to a spill, then they will have to invest in the necessary equipment and vessels. There will also be a need for facilities that deal with separation and disposal, large tanks for the settling process to separate water from oil and an incinerating facility to deal with non re-usable oil. As for the protection of the Jan Mayen shoreline, the possibility of storing emergency response equipment on the island should be looked into.

With all the special conditions facing the exploration and production in this region, I don‘t see any problems that can‘t be overcome. Planning, training and keeping everything up to date should be at the top of the priority list. The technology used will have to be state of the art to deal with the conditions this far north and this might impact the economic viability of the operation. Something I haven‘t ventured into, in this paper, but is an important factor is the stance of the Icelandic government. A new government was formed near the end of May 2013, in their manifesto they state their desire to enable the exploration and production should there be sufficient oil and gas reserves. Thus, I believe there is nothing standing in the way of the exploration of oil and gas and once the necessary preparations have been completed, the process could commence.

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