University of Stavanger

Faculty of Science and Technology

MASTER'S THESIS

Study program/ Specialization: Offshore Technology/Subsea and Marine technology	Spring semester, 2015 **Open** / Restricted access
Writer: Evgeny Subbotin	……………………………………… (Writer's signature)
Faculty supervisor: **Ove Tobias Gudmestad** External supervisor(s): **Anatoly Borisovich Zolotukhin**	
Thesis title: **Oil offloading solutions for the Pechora Sea exemplified by the Prirazlomnoye field**	
Credits (ECTS): 30	
Key words: The Prirazlomnoye field, the Prirazlomnaya platform, DAT, BLS, tankers and the CUPON system, offloading forecast, the Pechora Sea conditions, resistance of ships in ice, risk analysis, HAZID analysis, bow-tie diagram, ice management, offloading concepts.	Pages: ……101……… + enclosure: ………… Stavanger, ……15.06.2015….. Date/year

Abstract

There are many prospective areas to develop in Arctic and every considered project is unique. Solutions for one oil or gas field might not be appropriate for another. Especially in terms of development of oil and gas fields in the Arctic Region many issues still remain due to lack of experience and incredible harsh conditions as well as safety aspects and high-priced technological solutions.

The Prirazlomnoye field is the pilot Russian Arctic project operated by company Gazprom Neft Shelf. The project covers the process of oil offloading from platform to tankers. There are some tasks to be solved in order to carry out operations safely, economically sound and professionally.

Offloading represents a complex of arrangements that have to be done at appropriate time and with certain accuracy, especially in winter. Challenges that we will pay attention to are weather uncertainties, leading to waste of operation time, ice ridge formation in front of the wall of the platform in winter periods and ice drifting past the platform. Ice ridges can affect the offloading process and cargo operations.

Chapter 1 provides a general description of the Prirazlomnoye field. Chapter 2 contains a brief overview of the Pechora Sea including ice conditions, wave conditions, wind, currents and tidal fluctuations. Chapter 3 contains justification of the chosen kind of oil offloading from the field. The offloading system called CUPON and tankers used for oil transportation are discussed in Chapter 4. Chapter 5 is dedicated to the offloading operation and different scenarios of offloading according to the season of year. It identifies possible threats, risks associated with the operation and gives a comprehensive understanding of tanker movements in the sea. In Chapter 6 offloading forecast and its importance will be discussed. In Chapter 7 requirements for offloading concepts and possible offloading concepts for the Pechora Sea fields will be covered. Resistance of tankers in ice during offloading is calculated in Chapter 8. Chapter 9 is devoted to safety of the offloading operations. In this chapter risk analysis and mitigation measures are carried out helping us to identify conditions for secure and feasible operations. Chapter 10 will cover the cost of offloading delays that give potential economic effect on the early stage of risk identification.

Acknowledgements

I would like to thank professors of UiS for new way of thinking and useful courses during the Autumn semester 2014.

Mainly I wish to express my gratitude to professor Ove Tobias Gudmestad, the supervisor of my Master Thesis, for many pieces of advise.

Also I sincere thank Gazprom Neft Shelf company for invaluable recommendations and information about the ongoing project.

Content

List of abbreviations

BLS – bow loading system
CUPON – direct oil offloading system (in Russian abbreviation)
DAT – double acting tanker
DP – dynamic positioning
ESD – emergency shutdown system
GBS – gravity based structure
HPE – hose passing equipment
MISV - multifunctional icebreaker support vessel

Introduction

The offloading operation in the Arctic region is a very challenging operation. There are many factors, affecting the choice of the offloading option. Nevertheless, any chosen option requires a certain set of the techniques and technologies to keep the offloading going all-the–year-round.

To provide the offloading in ice conditions of different severity categories (depending on the ice thickness) can be a challenge for any company developing oil and gas fields in the offshore Arctic region. The development of offshore oil and gas fields (especially in the Arctic region) results in new challenges for the engineers of oil and gas industry. One of them, in terms of offloading, is ice mobility and constantly changing directions of ice drift. The project covers different aspects of the offloading operation exemplified by the Prirazlomnoye field.

The Prirazlomnoye field is the pilot Russian Arctic project operated by company Gazprom Neft Shelf.

The offloading operation carried out from the Prirazlomnaya platform is provided by means an integrated system of direct oil offloading called CUPON (in Russian abbreviation). Oil is loaded to one of two shuttle tankers named Mikhail Ulyanov and Kirill Lavrov. Each tanker has a dynamic position system and a bow-loading system (BLS). The offloading operation is carried out all-the-year-round.

A multifunctional icebreaker supply vessel (MISV) is required for tanker movement in medium ice conditions, while an atomic icebreaker is supposed to be used for hard ice conditions MISV is used for a duty next to the platform. MISV also provides connecting operation and oil offloading in ice conditions..

The platform itself was designed for simultaneous drilling, operation of vertical, inclined and horizontal wells, as well as for oil storage and offloading from the platform to tankers.

The platform has all essential systems, providing safe conditions of production process implementation, work and rest of the personnel, environmental protection, as well as personnel survival equipment in case of emergency.

The goal of this work is to describe the offloading system, to study the offloading operation in Arctic conditions exemplified by the Prirazlomnoye field in different seasons, to identify dangerous factors affecting the offloading and to create offloading forecast. The scope of this work also includes a short description of existing offloading concepts, suitable for future offshore projects in the Arctic conditions, considerations of the resistance of the tanker during the offloading in ice and the importance of ice management involvement. A risk analysis for the offloading operation has to be carried out as well.

The offloading forecast, representing the tool for investigation of the currents nearby the platform location based on the available wind data, can provide with information about current pattern, current directions changes and the vector of total current for different periods. It could be used to visualize histograms of wind-current, tidal and total current velocities as well wind velocities for the chosen period of time and to estimate available offloading hours in different seasons at each of both CUPON sides. Estimation of pure offloading time gives the foundation for risk evaluation and can be used by the company to mitigate risks by well-timed decision-making. The tool visualizes the processes of current direction change and can be used to understand ice drift direction change, that is very important in spring and winter seasons. Economic analysis will show the importance of the prepared forecast.

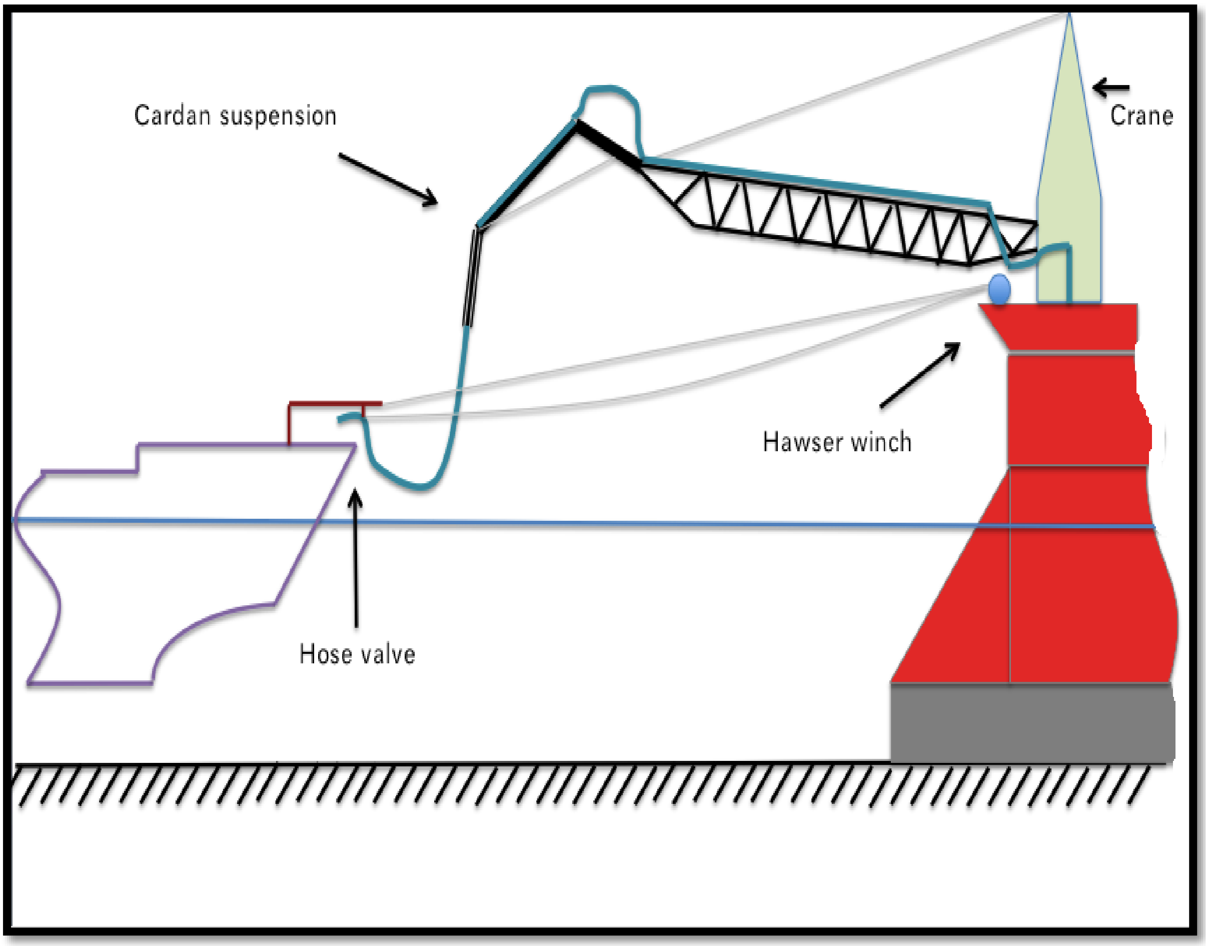

Figure 1: Illustration of the offloading principle of the Prirazlomnaya platform

Chapter 1. General information about the project

The Prirazlomnoye field (Figure 2) is located in the Pechora Sea, 60 km from the Varandey village and 980 km from the Murmansk harbor. It was discovered in 1989. Recoverable resources are estimated as high as 72 mln. tons (C1+C2). Maximum annual production equals 6,6 mln. tons («Gazprom» Public Corporation. Official site, 2015) Oil recovery factor equals to 0,3. The water depth at the place of the platform installation does not exceed 20 meters. Well number is 36 wells including 19 production, 16 injection and 1 absorption well. There are 200 accommodation places in the living module for the platform personnel. Oil production was started in December 2013. The first oil from the field was offloaded in April 2014. All-the-year-round oil offloading operations will be provided by two shuttle tankers with deadweight of 70000 tons. («Gazprom Neft Shelf» LLC, Official site, 2015b)

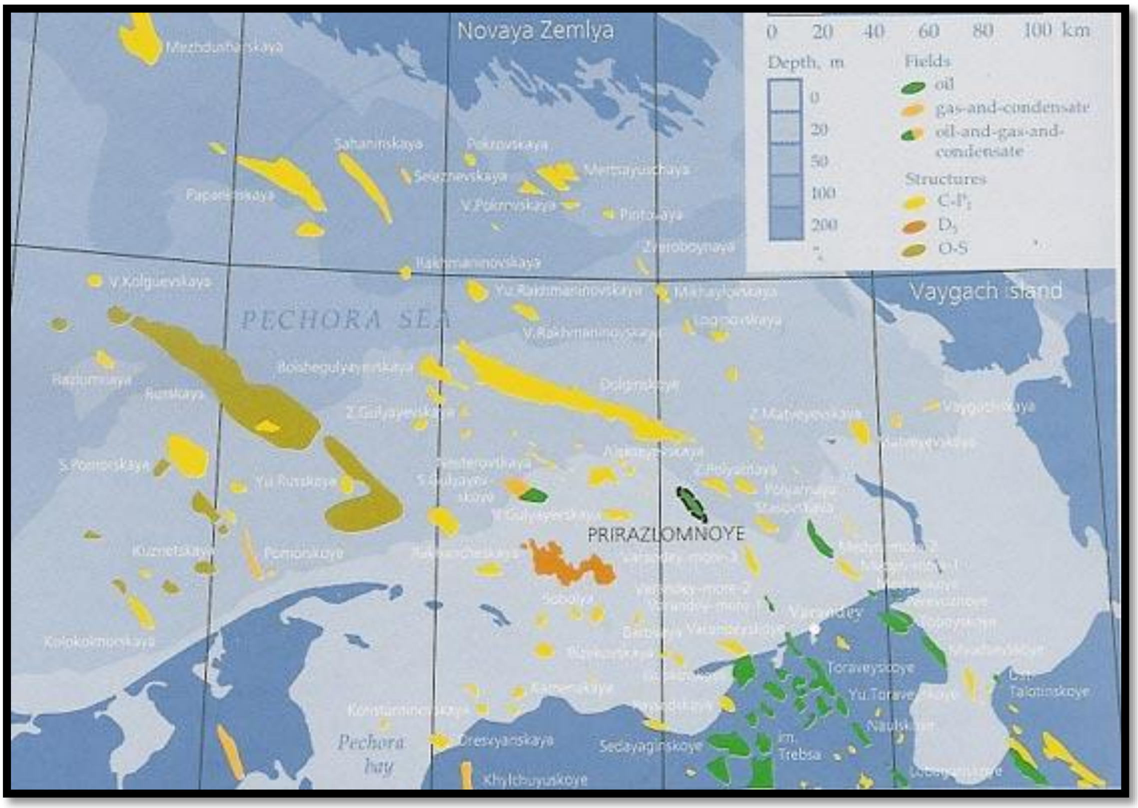

Figure 2: Map of the Pechora Sea fields including the Prirazlomnoye field (Map of Prirazlomnoye, n.d.)

Implementation of all the technological operations, including drilling, production, processing, storage and oil offloading, heat and power generation is being performed from the Prirazlomnaya platform.

The platform is installed in a way, that its north is shifted 90o from the true north. It represents a GBS structure and consists from the following elements (Figure 3):

- Steel caisson (126x126 meters) including oil storage tanks, diesel fuel storage tanks, sea chest, well heads zone, offloading oil pumps and oil return equipment
- Intermediate deck
- Top structure containing the main technological facilities, associated facilities, power system and living zone

The platform is operated in accordance with the “zero discharge” principle. That means used drilling mud, sludge and other technological waste products are injected in the absorption well. It was designed in a way providing maximum oil production safety. The platform is suitable for the operations in the harsh Arctic environmental conditions.

Walls of the caisson are made of clad steel. The wall thickness is 4 cm. A three meters space between walls of the caisson is filled with concrete. («Gazprom Neft Shelf» LLC. Official site, 2015b)

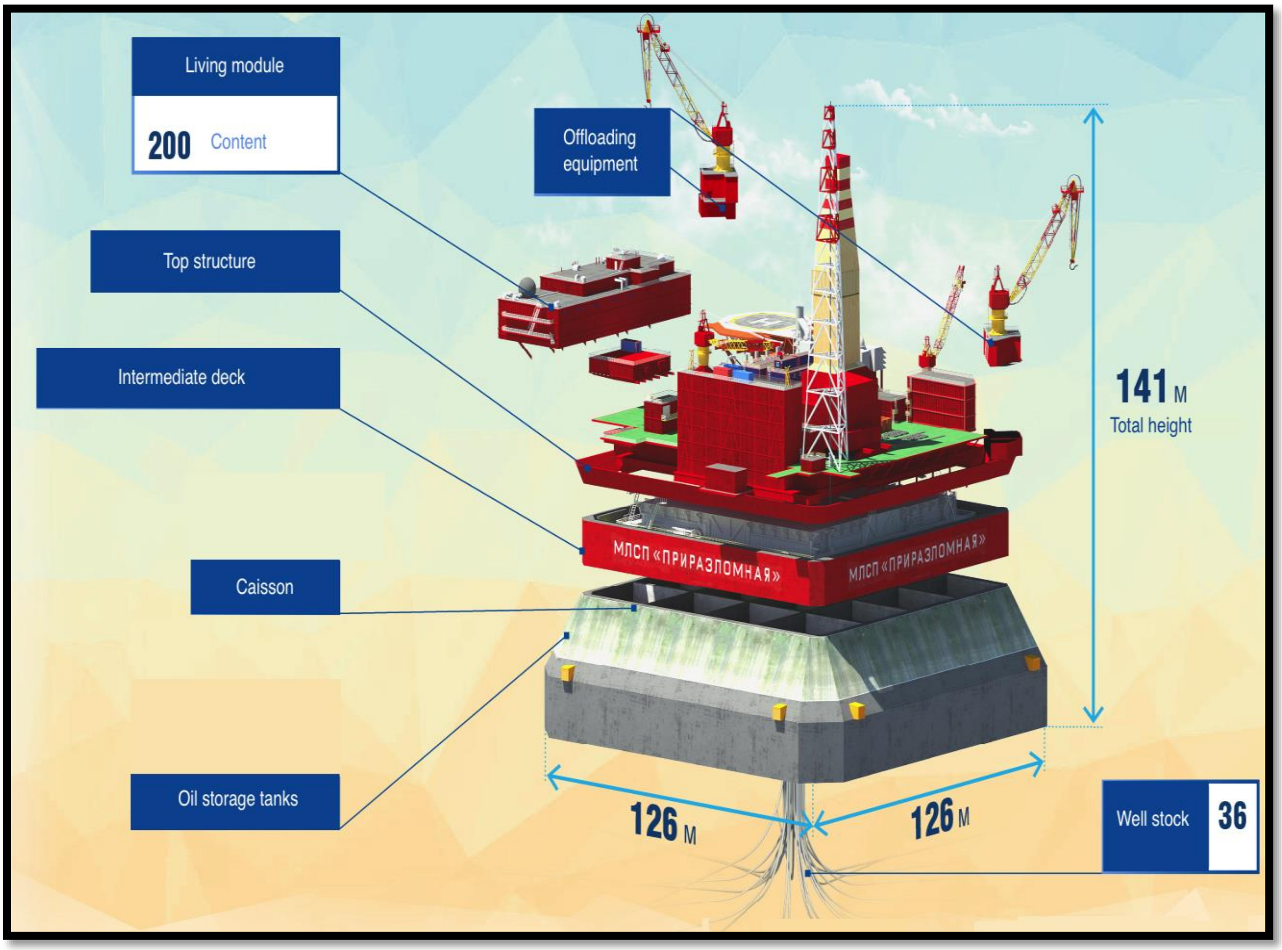

Figure 3: The structure of the Prirazlomnaya platform

Chapter 2. Environmental conditions

2.1 Ice conditions

The presence of ice in the Pechora Seas is defined by the season. The first year ice is one of the characteristics of the Pechora Sea (Gudmestad et al., 1999). Ice covers the sea in winter period and melts away in the summer. The ice period lasts from the end of October/mid November until the end of July/early August (Mironov et al., 1994; Gorshkov and Faleev, 1980). Ice conditions of the western part of the Pechora Sea are milder than in the eastern part. The most extensive ice cover period is observed in March-April, when the whole sea surface is covered with ice (Spichkin and Egorov, 1995).

Taking into account the source of information regarding the Pechora Sea Environment (Bauch et al., 2005) ice parameters for the Pechora Sea are given in Table 1.

Table 1: Ice parameters in the Pechora Sea (Bauch et al., 2005)

Ice Parameters	Early	Average	Late
1. Beginning of ice freeze-up, date	25.10	18.11	23.12
2. Fast freeze-up, date	23.12	22.02	11.04
3. Beginning of fast ice break-up	05.04	23.05	07.07
4. Total disappearance of ice cover, date	10.04	19.05	30.08
5. Duration of ice-covered season, days	131	213	272

Some characteristics of fast and drift ices are shown in the Table 2 created by means the Pechora Sea Environment source (Bauch et al., 2005)

Table 2: Parameters of fast and drift ices (Bauch et al., 2005)

Fast ice	
Extent, km	3-15
Average thickness, cm	110
Drift Ice	
Thickness, cm	
Average	80
Maximum	145
Size of ice fields, km	
Average	1,4
Maximum	17,5
Continuity, units	10
Hummocks, %	60-90

For the Prirazlomnoye Field the ice-free period is about 110 days (Mironov et al., 1996), Figure 4.

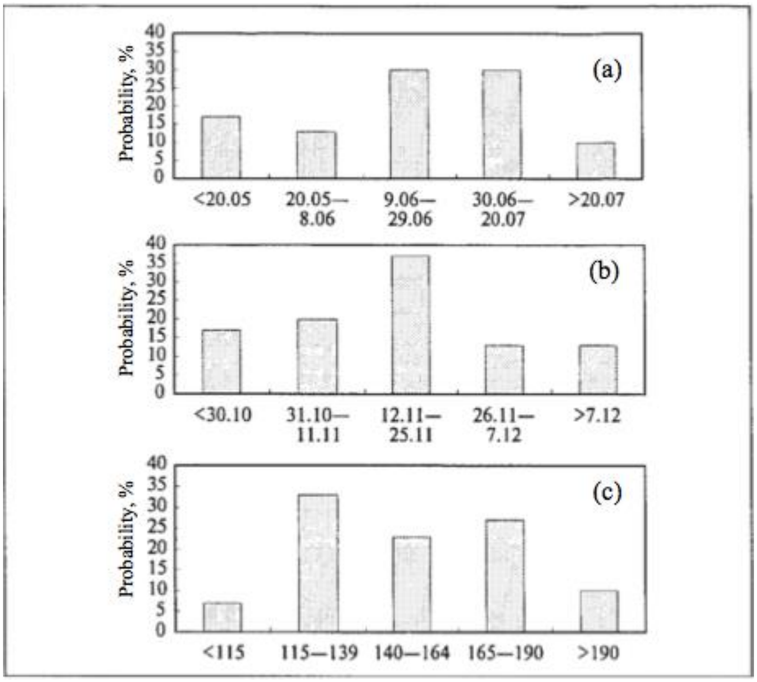

Figure 4: Histograms of dates of a) ice clearance, b) ice formation, c) ice free days in the Pechora Sea (Gudmestad et al., 1999)

Three ice zones can be distinguished in the Pechora Sea. They are Landfast ice, Shear zone and Drift Ice.

The landfast ice is formed in the middle of December at the Prirazlomnoye Field, and the period is over only by the last part of June (Mironov et al., 1994). The formation of a hammock field is possible due to fracturing of fast ice and its interaction with landfast ice at the intermediate (shear) zone. Ridges cover 60-80% of the sea surface at this period of time. The ice thickness varies from 0.8 to 1.1 meter (Gudmestad et al., 1999).

Wind and current generate ice movements having various directions. In winter season the predominant direction is from the north, although in spring the direction is changed, and there are ice movements from the west and southwest.

In the Table 3 below ice drift speeds are demonstrated (Gorshkov and Faleev, 1980; USSR (1986a); Zubakin et al. 1987).

Table 3: Ice drift speeds in the Pechora Sea (Gorshkov and Faleev, 1980)

	Average	Maximum
East	0.09	0.6
West	0.15	1.0

Shear zone is the intermediate zone between the drift ice zone and landfast zone. This zone is the zone of ice interaction, resulting in ridges, stamuchas and hummocks formations.

2.2 Wave conditions

In the Pechora Sea the highest waves occur from the northwest, and the length and period decrease down toward east direction. The active storm season begins in October and ends in December. Random waves called “crowds” may occur due to interaction of storm waves with strong tidal currents. Extreme waves (Tables 4 and 5) may reach up to 11,5 m at water depth 20-30 meters in October-November (Mischenko, 1996) .It means that during the storm season there is a dangerous situation for vessels carrying out marine operations in the open sea, though the average height of predominant waves is about 2-3 meters.

Table 4: Height (h, m) and period (τ, s) of waves in deep water (>25 m); and wind speed (V, m/s) with different probabilities in the part of the Pechora Sea during active storm season (October – December), (Bauch et al., 2005)

Element	Probability, %				Recurrence, time in n years					Recurrence of calms, %
	50	20	5	1	1	5	10	20	50	
69º 40’ N, 57º 00’ E										
H	0.8	1.4	2.2	2.8	3.3	3.7	4.0	4.3	4.5	39
τ	4.4	5.6	6.6	7.2	7.5	8.0	8.2	8.3	8.3	
V	7.5	12.0	17.2	20.0	25.0	28.5	31.0	32.0	33.0	

Table 5: Calculated parameters of designed waves at 1% prob. of exceedance; H0,1% -height of waves at 0,1% prob. of exceedance; τ_m- average wave period;

τ_p - peak wave period (maximum in the wave energy spectrum); λ_m, λ_p - wave lengths corresponding to τ_m, τ_p (SNIP, 1986)

Depth, m	H_s, m	$H_{1\%}$, m	$H_{0,1\%}$, m	λ_m,s	λ_p,s	τ_m,m	τ_p,m
R_p=5 years							
10.0	4.3	6.9	8.2	7.9	9.5	75	94
15.0	5.1	7.3	8.8	8.1	9.7	87	111
20.0	5.2	7.6	9.1	8.2	9.8	94	123
25.0	5.3	7.8	9.4	8.3	10.0	100	133
50.0	5.7	8.4	10.2	8.6	10.3	114	159
R_p=25 years.							
10.0	5.7	8.1	8.4	8.5	10.2	82	102
15.0	6.0	8.6	10.3	8.7	10.4	95	121
20.0	6.2	8.9	10.8	8.8	10.6	105	134
25.0	6.3	9.2	11.1	8.9	10.7	112	146
50.0	6.7	9.9	12.1	9.2	11.0	130	179
R_p=50 years							
10.0	6.1	8.4	8.4	8.7	10.4	84	105
15.0	6.4	9.1	10.9	8.9	10.7	98	124
20.0	6.5	9.4	11.3	9.0	10.8	108	138
25.0	6.7	9.7	11.7	9.1	10.9	116	150
50.0	7.1	10.5	12.7	9.4	11.2	135	185
R_p=100 years							
10.0	6.4	8.4	8.4	8.9	10.7	86	107
15.0	6.7	9.5	11.4	9.1	10.9	101	127
20.0	6.9	9.9	11.9	9.1	11.0	111	141
25.0	7.0	10.2	12.3	9.2	11.1	119	154
50.0	7.5	11.0	13.4	9.5	11.5	139	190

2.3 Wind

The 10 min wind speed for different seasons measured during 30 years at a height 10 meters, 3-4 times a day is represented in the Table 6.

Table 6: Average monthly wind speed and directions (m/s) wind speed standard deviations (m/s), average frequencies during month (%) of these speeds at Kolguev Island. Periods of observation: 1945-1951, 1953-1977 (USSR, 1986a)

Month	Wind parameter	Wind direction							
		N	NE	E	SE	S	SW	W	NW
January	$\bar{U}$	10.0	9.4	9.9	8.5	8.8	10.1	9.4	10.5
	σ_u	5.5	4.6	4.6	4.4	5.2	5.2	5.0	5.4
	$\bar{n}$	7	11	9	15	31	32	11	8
May	$\bar{U}$	7.5	7.4	8.1	8.2	7.1	7.2	6.5	7.2
	σ_u	4.3	3.9	4.3	4.6	3.8	3.6	3.4	4.1
	$\bar{n}$	17	15	16	10	10	17	19	20
July	$\bar{U}$	7.2	6.1	6.4	6.7	6.6	7.0	6.0	6.9
	σ_u	4.1	3.5	3.4	3.4	3.5	3.5	3.1	3.8
	$\bar{n}$	2.1	17	18	14	11	10	14	19
October	$\bar{U}$	10.8	10.3	9.3	7.9	6.9	7.7	7.9	10.4
	σ_u	5.6	4.9	4.9	4.4	4.3	4.4	4.1	5.0
	$\bar{n}$	16	14	9	16	21	32	12	14

According to table 6 prevailing wind directions in the winter period are from the south or southwest, while in summer the wind direction is unstable and varies mostly between the east, northwest and northeast.

2.4 Currents and tidal fluctuations

The system of currents of the southeast part of the Barents Sea stands out against the structure of sea currents in general. Here we can meet the whole spectrum of the water motion: quasi- stationary circulation, storm surges and tides. Tides create very difficult flow pattern. Constant water motion is caused by Kaninskoye, Kolguevskoye and Litke currents. The motion speed varies from 0,02 up to 0,05 m/s (Gorshkov, S.G. and V.I. Faleev, 1980). The main current speeds are caused by wind and tides. Drift speed with tidal current speed together can reach up to 1 m/s (Korppoo et al., 1988)

In the Pechora Sea water moves from the southeast to the northwest at the time of tides and vice versa at the time of ebb tides. (Gorshkov and Faleev, 1980;

Korppoo et al., 1988).

Some parameters regarding average sea level, extreme sea level and current velocity can be found in Table 7 (based on Bauch et al., 2005).

Table 7: Parameters and phenomenon of the Pechora Sea (Bauch et al., 2005)

Parameter and phenomenon	Pechora Sea
Wind speed, m/s	
Mean for 10 minutes	35
Mean for 2 minutes	40
Mean for 3 seconds	49
Average duration of wind with speed exceeding 15 m/s (in hours)	7 (max 60)
Tides, relative to the average sea level, cm	
Minimum	-61
Average	0
Maximum	83
Amplitude	144
Extreme sea level, cm (once in a century)	
Minimum	-170
Average	0
Maximum	222
Current velocity, cm/s	
Tidal	38
Summary	123
Wave height, m	
(0,1% probability)	09-11

The water level fluctuations with return periods in the eastern Pechora Sea are shown in Table 8.

Table 8: Water level fluctuations in the Pechora Sea (USSR, 1986a; USSR, 1990, Korppoo et al., 1988)

Water level	Water level (m), R_p years			
Fluctuation type	1	5	20	50
Circular tide	+/- 0.9	+/- 1.15	+/- 1.2	+/- 1.25
Nonperiodic storm surge	+/- 1.3	+/- 1.85	+/- 2.75	+/- 3.35

Chapter 3. Justification of the tanker transportation system

There are two main alternative systems for oil delivery to the market from the Pechora shelf: loading to tankers and by pipelines. Both of them have pros and cons. Estimation of economic and technological parameters has shown that the most preferable option on the initial stage of a field development is the system of loading to and transportation by tankers.

Oil transportation by pipelines to the market, taking into account the reconstruction of existing pipelines and construction of new pipelines by the company Transneft, and taking into account that pipeline installation will be at the initial stage of a field development, is not economically sound. That is why all the companies developing the Russian Arctic fields consider the possibility of the transportation of oil and also gas by tankers.

Loading and tanker transportation is being considered for the development of the Medyn-more field, the Varandey-more field (the Pechora Sea fields) and the Tambey field (the Kara Sea). Such a system has been chosen for the Prirazlomnoye field. It should be noticed that the project of tanker transportation of oil from off-shore fields through the Varandey offloading terminal has been developed.

The location of the Pechora shelf is such that oil cannot be delivered to the existing Russian oil processing plants. Basically, the Arctic field development projects are export oriented.

A direct transportation system is a system of oil transportation from a platform to the market. A transfer system is a system with an intermediate transfer.

At first sight, the construction of a transfer complex will raise the price, because the installation of the additional system results in increasing the CAPEX with no doubts. However, the specific Arctic conditions, such as ice conditions and shallow water in combination with the remoteness of places of field developments from the market, give an advantage to this transfer transportation system.

The transfer transportation system has a disadvantage, however, because large capacity icebreaker tankers cannot be used due to shallow water of the sea.

The tanker transportation system through a modern export terminal will provide oil transportation from the region to the European and the USA markets in near-term and medium-term outlooks. This will be the optimal option for the export of Russian oil.

Chapter 4. Tankers and the CUPON system

4.1 The tankers discussion

The two ice-resistance tankers (Figures 5, 6 and 7 and tables 9 and10) have been manufactured in Saint-Petersburg by using a design developed by Aker Finnyards (Finland). The tankers have been design as double acting tankers (DAT). More preferable movement in ice conditions is stern first, but prevail movement in ice-free water is bows on. Each tanker has a helipad.

Figure 5: Tanker Kirill Lavrov, stern first movement. (Kirill Lavrov, n.d.)

Figure 6: Tanker Mikhail Ulyanov, bow on movement. (Mikhail Ulyanov, n.d.)

Two bow propulsion units and dynamic position system Kongsberg (DP class 2) have been installed to provide dynamic position near the platform. Electric drive power of each unit is about 2000 kW.

Table 9: Technical characteristics of tankers Mikhail Ulyanov and Kirill Lavrov (Yamshchikov, 2013)

Parameter	Unit of measure	Value
Length	m	257
Width	m	34
Draft	m	13,6
Speed (open water)	knots	16
Max speed, movement is stern first (first year 120 cm ice and snow cover up to 20 cm)	knots	2
Min speed, movement is bows on (first year 50 cm ice and snow cover up to 20 cm)	knots	2
Propulsion	MW	17 (2x8,5)
Total capacity	m^3	87000
Capacity of ballast tanks	m^3	36000

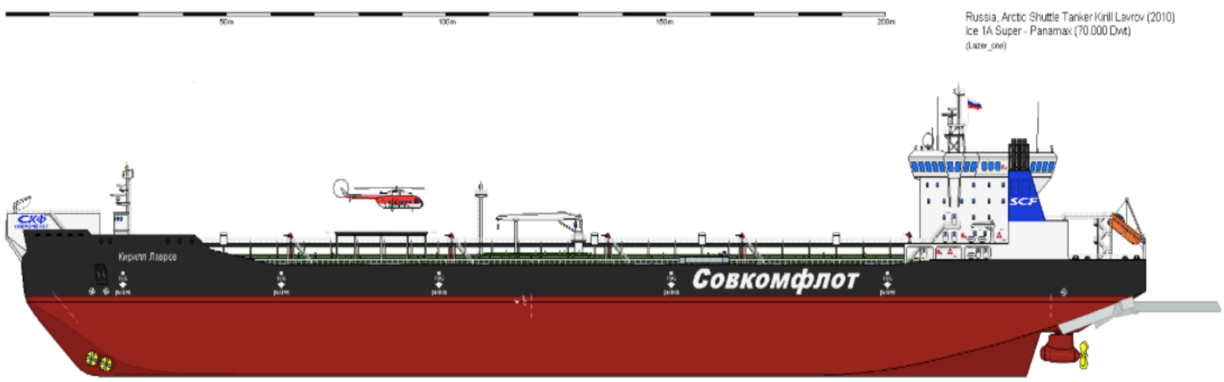

Figure 7: Tanker Kirill Lavrov (MT Kirill Lavrov, n.d.)

Table 10: Main characteristics of the tanker connection system

Parameter	Unit of measure	Value
Releasing load	kN	3000
Breaking load	kN	5700

The platform is oriented in the following manner: the north of the platform is located 90^0 anticlockwise from the true north (Figure 8).

4.2 The CUPON system discussion

There are two CUPON systems on the platform. One of them is located in the southwest part, while another one in the northeast. We need both these systems not because of the simultaneous offloading from the platform to the tanker, but because of the offloading through any of them is depending on the ice drift and direction of wave influence. Offloading time is not less than 7-8 hours. If the direction of current or wind is changed during the operation, disconnection and change of offloading point takes place, if it is possible to carry out the offloading over there.

There is an emergency shut down system to avert oil spills during the offloading procedure. It allows stopping the offloading in 7 seconds (Zorina, S., 2014).

Safety of the offloading operation is provided by an emergency shut down system (ESD). There are three levels of ESD: ESD I, ESD II, ESD III.

ESD I – stop of oil pumps, closing of offloading system valves. When the tanker mooring and connection to the BLS have been done, determinative signals of operation ability are generated. If one signal is lost, then the system responses.

ESD II – automatic initiation of ESD I, emergency disconnection of offloading hose. It happens when two of the following signals are lost: “position of the tanker”, “tension in the offloading hose”, “tension in the mooring cable”.

ESD III – automatic initiation of ESD I-II, and emergency return of mooring cable.

It happens when the tanker exceeds the bounds of available movements.

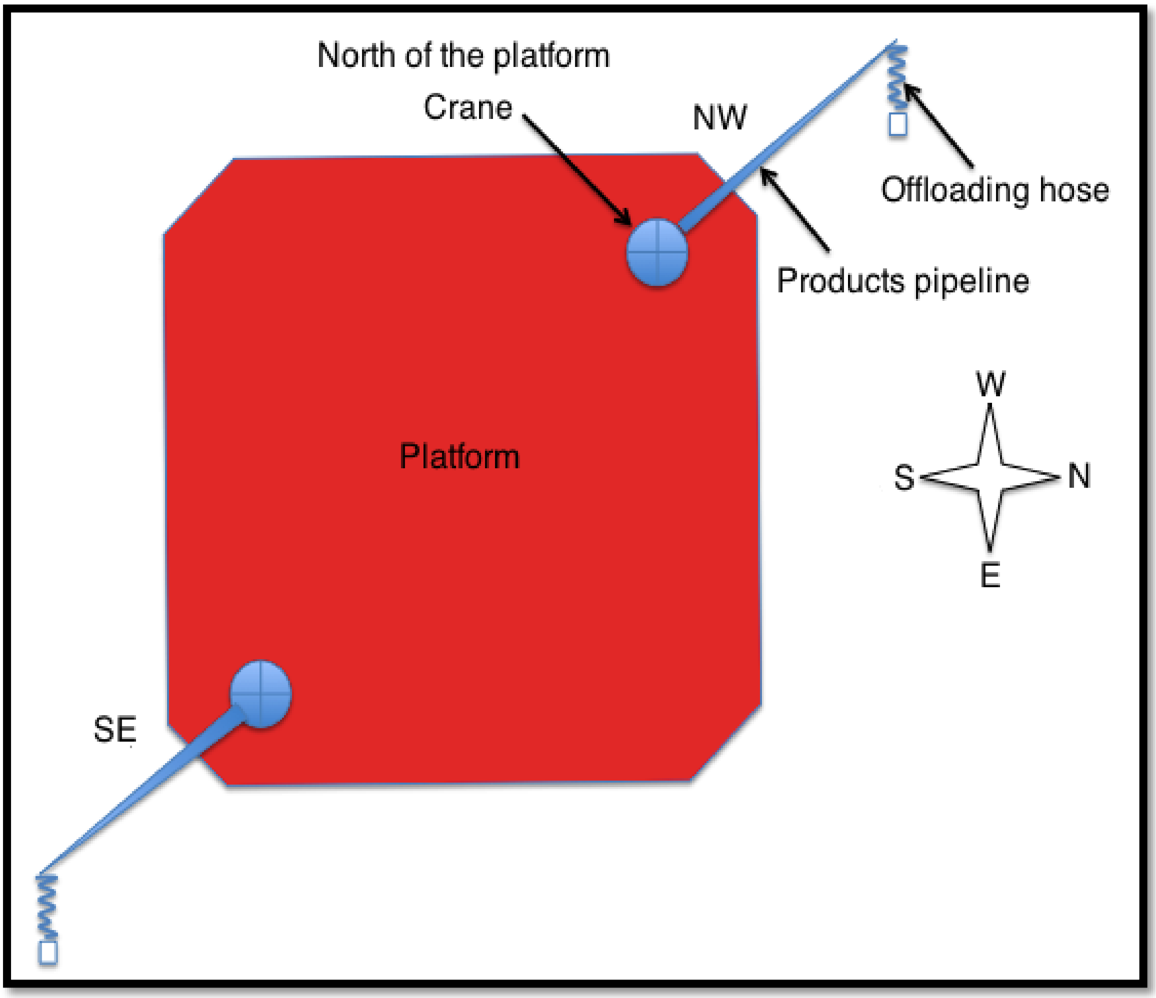

Figure 8: Location of the CUPON systems regarding the platform north and true coordinate directions.

Equipment of the CUPON system

The CUPON system consists of the following equipment:

1) Crane
2) Equipment of oil pipe
3) Flushing equipment of oil pipe
4) Hose passing equipment (HPE)
5) Tanker connecting system
6) Monitoring and management system

The products pipe, including an offloading hosepipe and end valve, connects the tanker with the platform. Maximum production rate during the offloading procedure is equal to 10000 m^3/hour, but current reached production rate is about 8000 m^3/hour. The Monitoring and control system serves as the system of management for all types of duties.

There is an operational window to carry out the operation of offloading. The location of the CUPONs system was based on the study of the prevailing currents of the Pechora Sea.

4.3 Safe and working parameters of the CUPON system and tankers

Safe operation parameters and working parameters of the CUPON system and tankers during offloading are shown in Tables 11 and 12.

Table 11: Safe operation parameters for the CUPON system and the tanker

	Parameter	Unit of measure	Value
CUPON	Wind velocity	m/s	20
	Short duration puffs	m/s	26
TANKER	Wind velocity	m/s	Up to 15
	Choppiness	class	4

Table 12: Some working parameters for the CUPON system and the tanker

	Parameter	Unit of measure	Value
Crane working parameters	Maximum working radius of crane arm	m	72
	Speed of the turning movement	Rev/min	0,3
	Sector of rotation from the average horizontal position (oil offloading)	degrees	+/-90
	Time of motion of main arm	min	14
Tanker during offloading	Drift velocity	m/s	0,8
	Horizontal working angles	degrees	+/- 90
	Sway motion	m	+/- 6

	Yaw motion	degrees	+/-10
	Heave motion	m	+/- 3,5
	Position at safe distance from the platform	m	80+/- 6

Chapter 5. Offloading procedure and different scenarios of the operation

5.1 Offloading scenarios

Based on the operational stages for oil offloading stated in of the sources (Patino Rodriguez et al., 2009), the scheme of oil offloading from the Prirazlomnaya platform to the tanker is prepared, breaking up the offloading in 5 stages as it is shown in Figure 9 below.

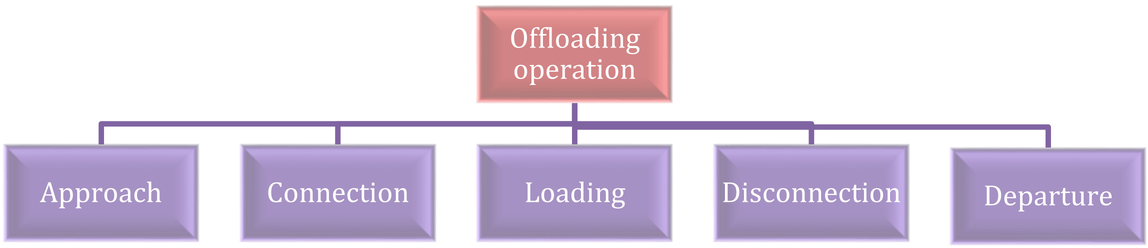

Figure 9: Stages of the offloading operation

First of all a tanker approaches the platform and stops at a certain safe distance. The next stage is connection of the messenger line, hawser and loading hose. The MISV (serving as a tug boat) is attached to the tanker stern. The third stage is loading, where oil is dispensed from the platform to the tanker. The fourth one is disconnection. In this stage the manifold is washed, hawser and loading hose are detached. And the last, but not least is departure stage. Tanker moves away from the platform, and messenger line is sent back.

The Prirazlomnaya platform has dimensions 126x126m at the bottom level and 108x108m at the waterline level. This creates a channel of free ice water behind the platform in ice conditions of the sea. That is why it is reasonable to use this channel to place the tanker for the oil offloading operation. The velocity of the ice fields is mostly defined by semidiurnal tides, because the average currents speed is weak.

The most dangerous wind directions for the offloading procedure are from the northeast and southwest.

As it has been told based on Table 6, prevailing wind directions in the winter period are from the south or southwest, while in the summer the wind direction is unstable and varies mostly between the east, northwest and northeast. Aggregate of wind and current generates ice movement having various directions. In the winter season the predominant direction is from the north, although in spring the direction is changed, and there are ice movements from the west and southwest.

Taking into account the average monthly speed directions, the prevailing wind directions in different seasons, possible scenarios are assumed and we have emphasized the most dangerous of them in different seasons and in general.

They are combined by seasons and shown in Figures 10 to 14 below.

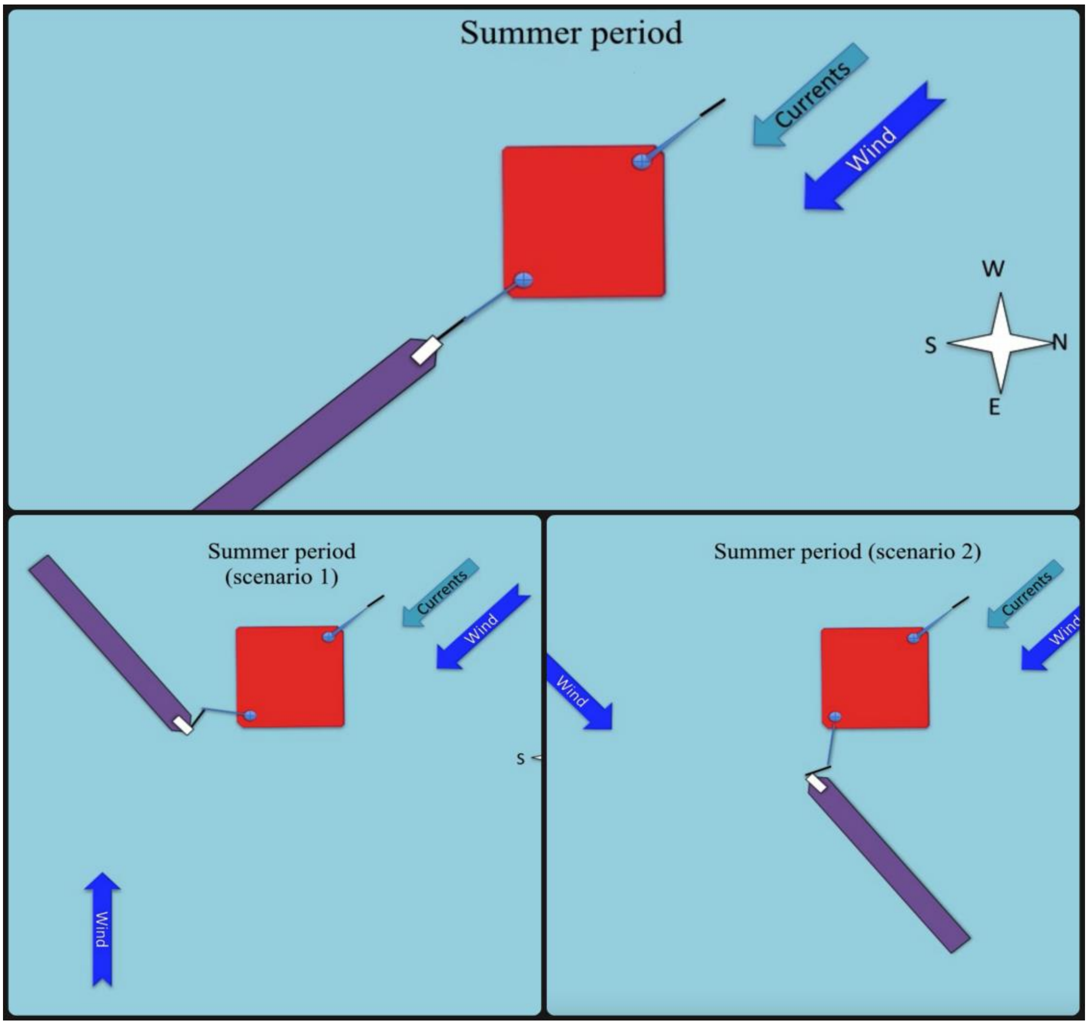

Figure 10: Summer scenarios, offloading is being provided from the southeast CUPON location

As we can see from the visual image above, figure 10, there is two wind directions during the summer period creating difficulties for the offloading procedure: from the southwest and east. If the tanker is not able to keep its position due to strong wind, and the position of tanker oversteps the limits, then it is disconnected. Since it has been disconnected, it is searching for possible options of reconnections depending on the weather forecast and semidiurnal tide direction. That can postpone the offloading for a while.

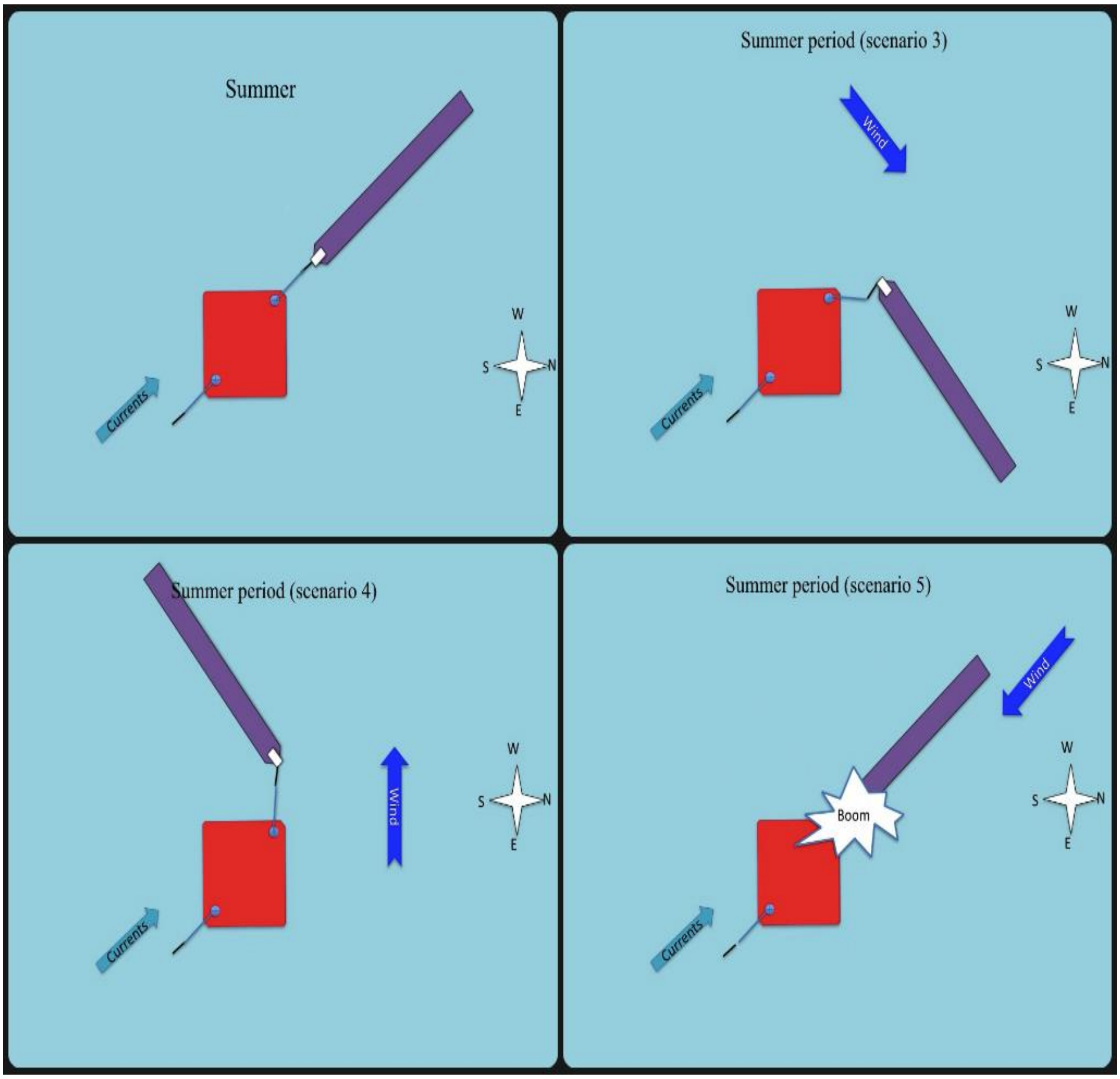

Figure 11: Summer scenarios, offloading is being provided from the northwest CUPON location

If the offloading is being carried out from the northwest CUPON location, Figure 11, then southwest, east and northwest wind directions result in potential risk. Being in the offloading operation, the tanker might collide with the platform, if wind direction changes dramatically and become very strong one from the northwest. This action can be enhanced by change of the current direction to opposite orientation.

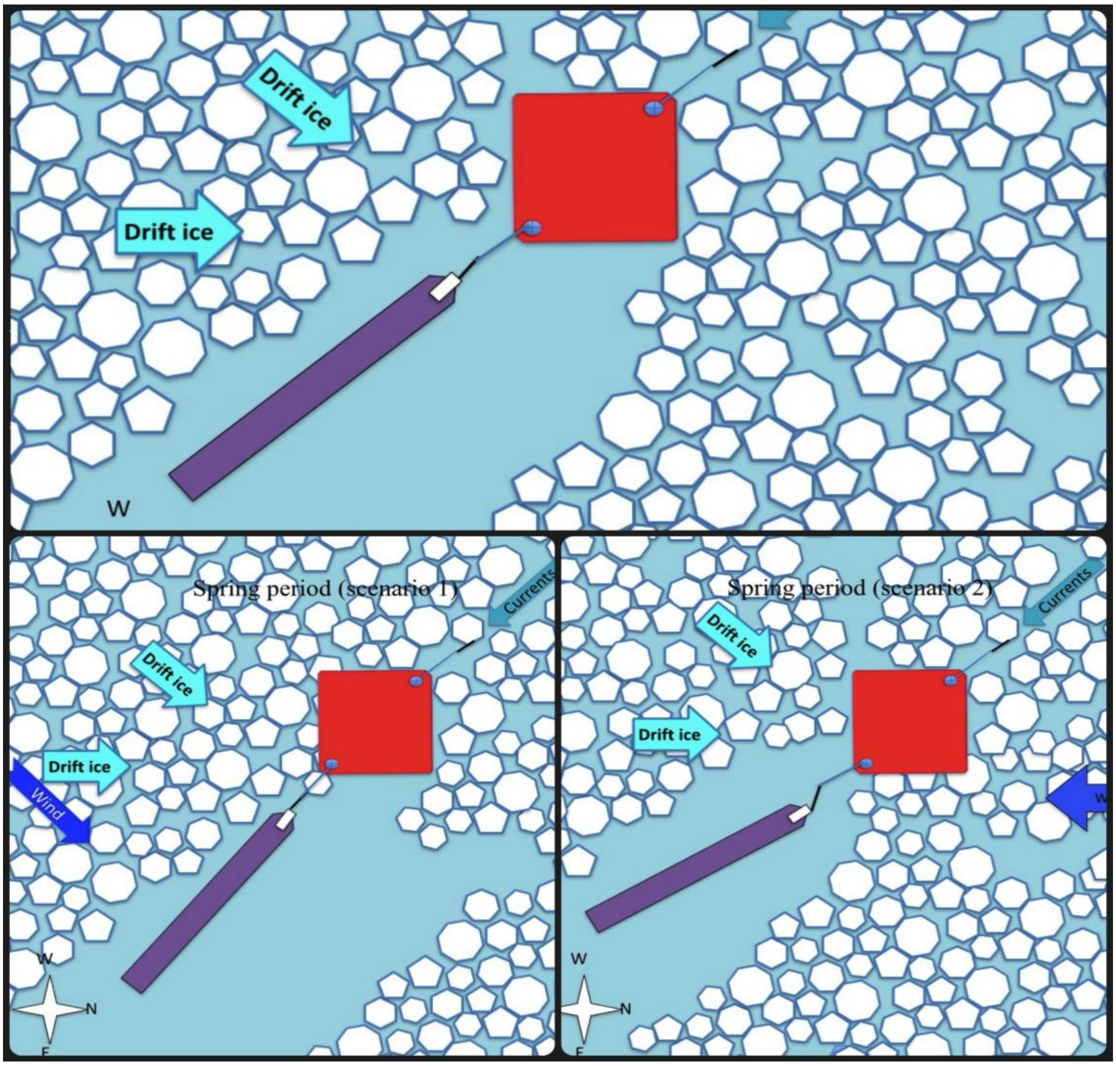

Figure 12: Spring scenarios, offloading is being provided from the southeast CUPON location

Figure 12 shows us that there are prevailing ice drift directions from southwest and from the south during the spring period. The offloading from the southwest is subjected to risk because of possible north and southwest wind directions. If the tanker is not able to keep its position due to some reasons enhanced by strong wind, and position of the tanker oversteps the limits, then it is disconnected. But in the spring period it is much more difficult to manage tanker relocation than in summer one. The wind directions in this area and in this period are unstable. That creates additional uncertainties for the operation.

Ice rubble formation that will be discussed later in the paragraph devoted to ice rubble formation makes the offloading in this period of a year even more challenging.

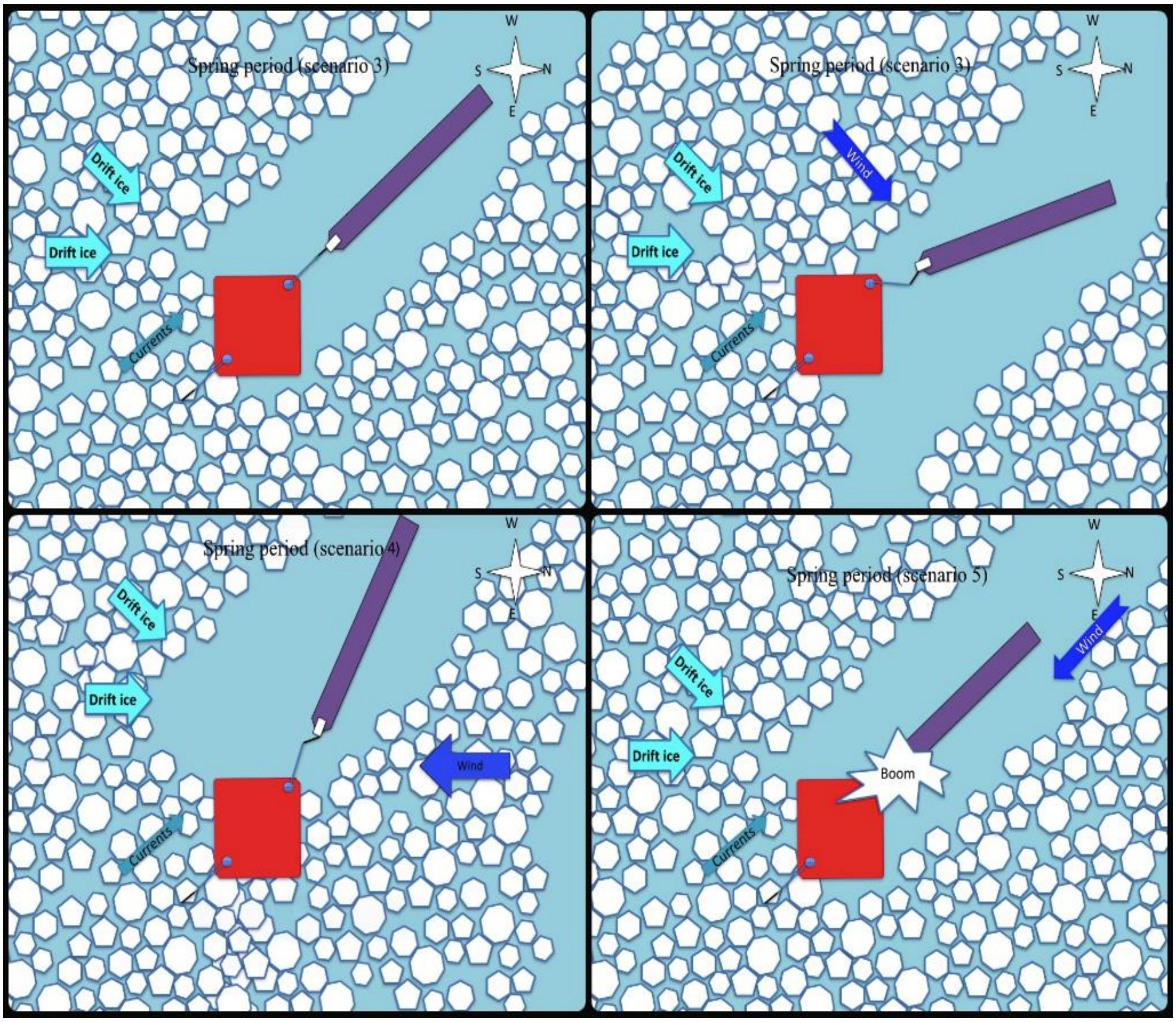

Figure 13: Spring scenarios, offloading is being provided from the northwest CUPON location

Most dangerous wind directions (in terms of risky offloading operation) are from the northwest, the north and the south. Possible scenarios due to the change of wind directions are shown in Figure 13. We consider the offloading in spring period as the most dangerous in during a year. This can be explained by wind instability and presence of drift ice that can influence on the offloading procedure (delay of the offloading, possible collision of the tanker and the platform, oil spills).

In right lower quadrant (Figure 13) we can see one of scenarios that can occur in case of failure of some systems and this can be amplified by the wind as well as by change of current direction.

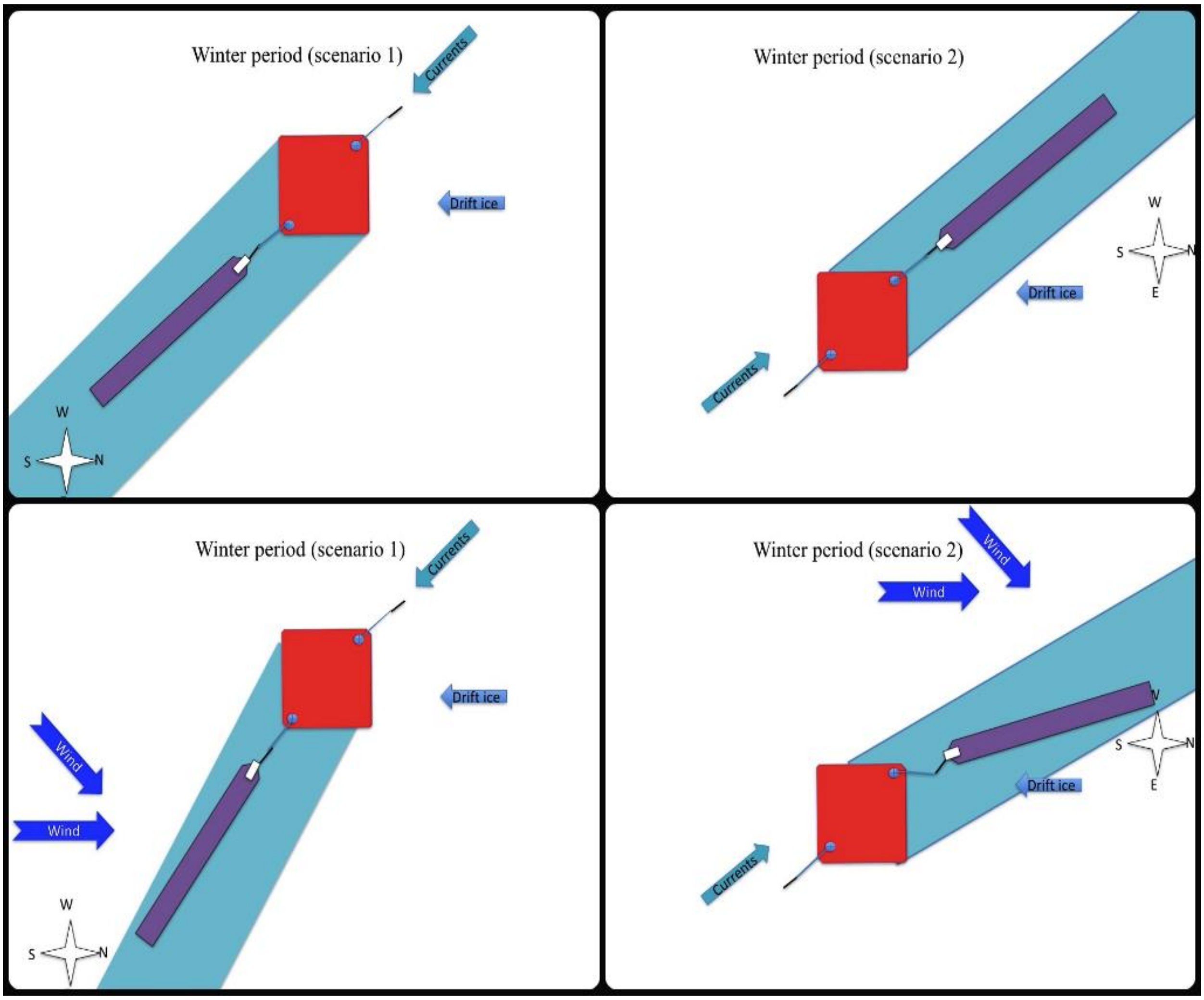

Figure 14: Winter scenarios, offloading are being provided from the southeast and the northwest CUPON locations

According to the picture above (Figure 14), the ice drift direction in winter period is from the north. Also tankers are subjected to influence of the south and the southwest wind during the offloading from the southwest CUPON location as well as from the northwest one.

5.2 Influence of ice rubble formation

In case the water is shallow and ice thickness is relatively high, then grounded rubble fields can occur. As it is shown in Figure 15 below, ice rubble field has been created around the platform Molikpaq. The platform was installed at the Amauligak F-24 site on a sixteen meters high berm in 32 meters water depth. Grounded rubble field formation can be possible for the Prirazlomnaya platform as well because the water at the place of installation is shallow. Extension of the rubble filed depends on the ice thickness and water depth.

The thickness of the rubble field can be significant and the extension of the rubble field as well. That may lead to very difficult organization of offloading operations in the Pechora Sea.

Figure 15: Grounded rubble field surrounding the Molikpaq at the Amauligak F-24 site (Timco et. al., 2006)

The mechanism of the rubble field formation is shown in Figure 15. First of all ice is moving toward the platform then it is accumulated along the front. The ice continues to move further creating rubble along the platform side and a wake behind the platform, Figure 16.

Figure 16: Updrift, alongside directions and wake from the example of the Molikpaq platform (Timco et. al., 2006)

We have a certain distance to carry out offloading operations due to safety requirements and technological limitations (e.g. 70 meters working radius of the crane arm) and, the ice rubble formation (Figure 17) can lead to reduction of this safety distance. It makes the operation even more complex, than it was previously. That is why investigations of the ice rubble formation along the Prirazlomnaya platform sides should be provided.

Figure 17: Ice rubble at the Prirazlomnaya platform (Priralomnaya, n.d.)

Chapter 6. Offloading forecast and its importance

For the offloading procedure the motion of the ice in the place where we operate is the critical issue. Let's us consider four buoys deployed on the drift ice in the Pechora Sea during mid-April 1998 (Loset, S. and D. Onshuus, 1999).

The results of their drift mapping are shown in Figure 18 below.

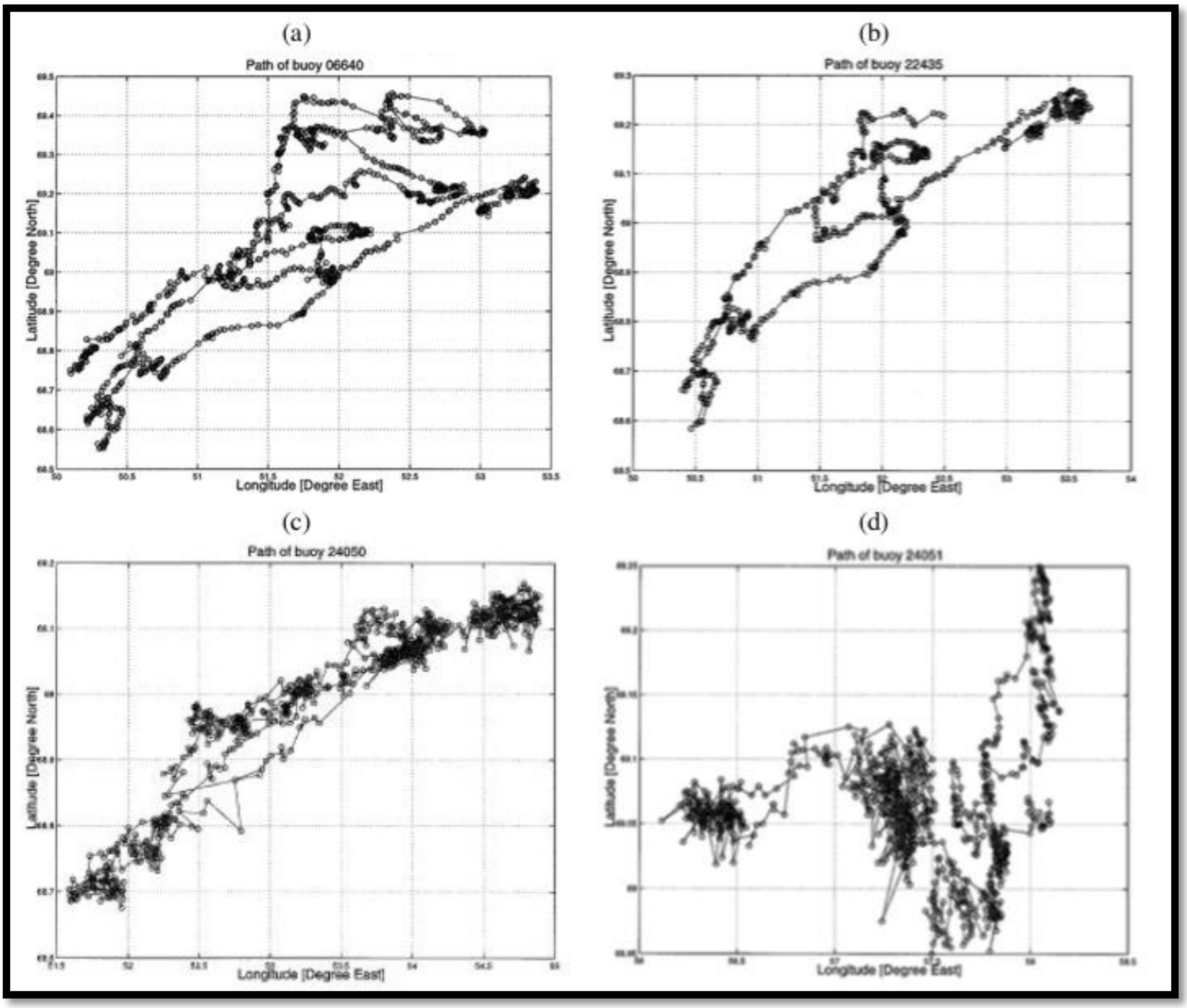

Figure 18: Drift of: (a) Buoy 06640, period 17.04-30.06.98; (b) Buoy 22435, 17.04-30.05.98;(c) Buoy 24050, period 17.04-10.06.98 and (d) Buoy 24051, period 20.04-23.06.98 (Loset, S. and D. Onshuus, 1999).

The results received from the four buoys show us patterns in a large time scale. We can note the main direction of movement, but still there are deviations from the prevailing directions for each of the patterns.

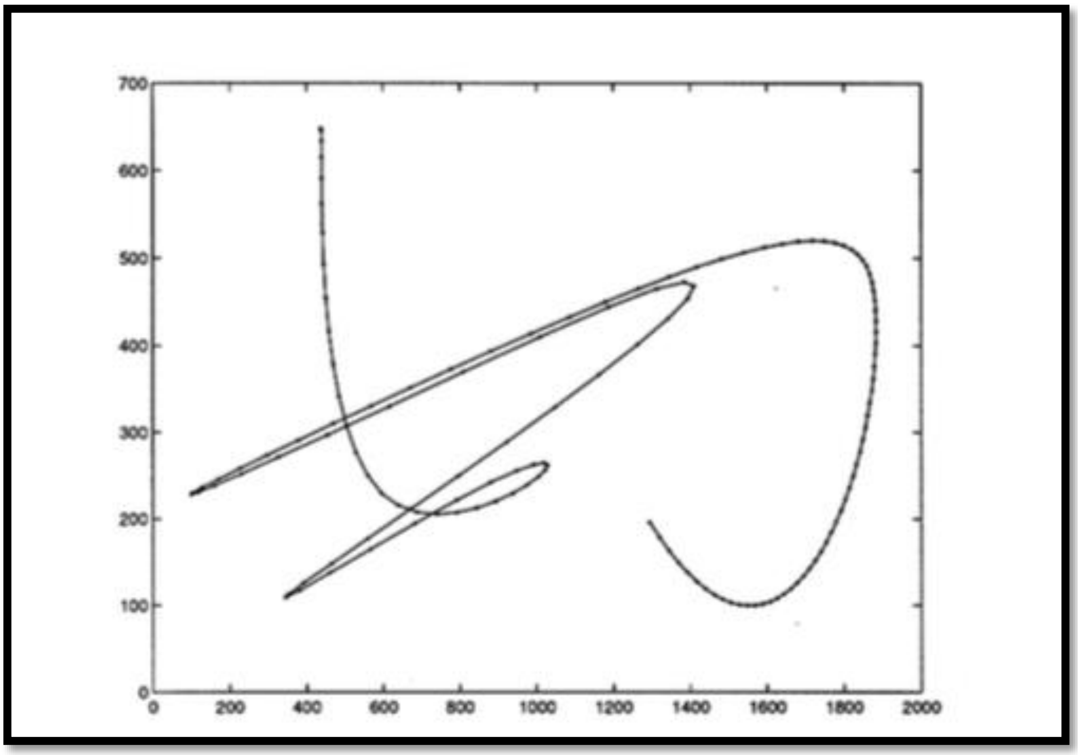

Figure 19: Movement of the ice drift (model). Dots every 10 minutes (Loset, S. and D. Onshuus, 1999).

We can see from the results of modeling, Figure 19 and 20, that the direction of ice drift can be changing very fast (approximately in 30 minutes) to the opposite one.

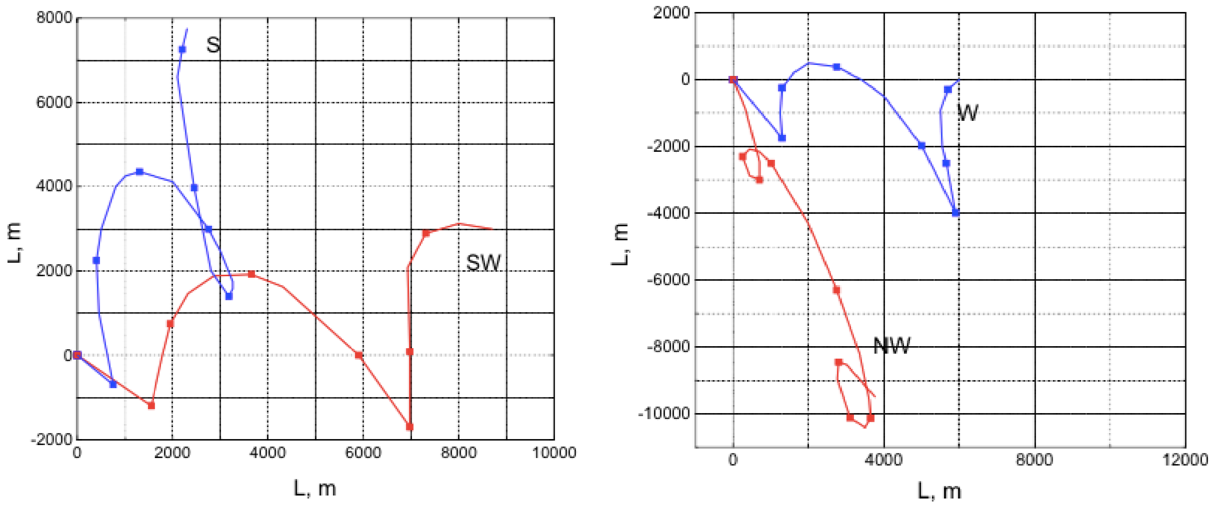

Figure 20: Ice drifts trajectories over twenty-four hour period under weak wind conditions (6-7 m/s) of various directions (as pointed out near the curves) (Karulin, E. B., & Karulina, M. M, 2010)

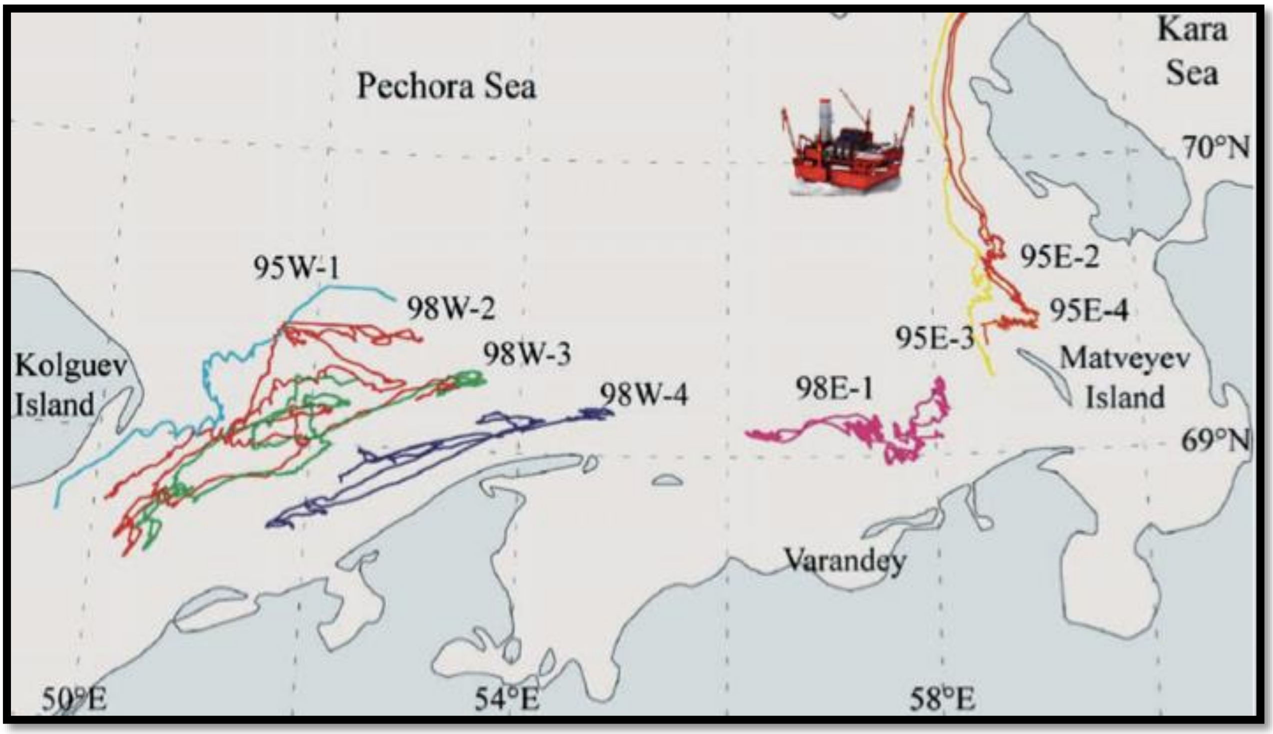

Figure 21: Drift paths of buoys deployed on the sea ice in Pechora Sea in 1995 and 1998 and location of GBS Prirazlomnaya (Bonnemaire, B., 2005a)

Furthermore, as we see from Figure 21, the ice drift direction can be changing from 90 up to 180 degrees. It is significant, that the drift pattern has elliptical paths because of the tidal current and periods of 6 hours. The drift speed at place of the direction change is equal to zero. All said above may be supported by finding that in the eastern Pechora Sea ice drift changes have been detected 1,5 times/day with at least of 135 degrees in less than 15 minutes (Bonnemaire, B., 2005a).

This is huge challenge for the offloading from the Prirazlomnoe, because in case of sudden change of ice drift direction to the opposite one, the tanker will need to disconnect very fast, depart and try to connect to the opposite CUPON location. Easy to say but time consuming to do and quite risky.

6.1 Offloading forecast

If we consider marine operations in terms of different vessels approaches at the Prirazlomnoe field we can divide them into three parts, Figure 22:

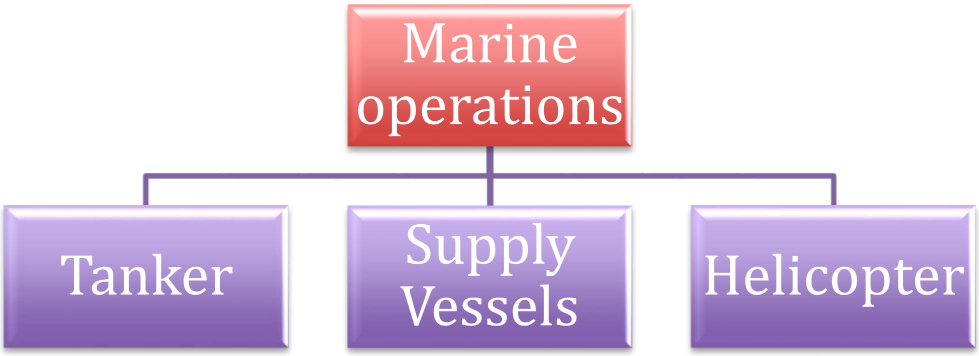

Figure 22: Transportation object affecting marine operations at the Prirazlomnoye field

If we are required to perform several operations at the same time we will not be allowed to do that. The choice of operations is defined by the priority of the operation. As a rule it is the oil offloading that has the highest priority. It is quite clear, as we need to do the operation in a certain "weather window". Supply vessels generally approach the side of the platform and carry out all the operations they are needed for there. Operations performed by supply vessels do not depend so strong on weather conditions and "weather windows" as the tanker does.

Support vessels can wait till the tanker will be full or till it goes to the cargo zone at the distance of about 0,5 miles (as it is shown in Figure 23 and Table 14) to wait for a command allowing repeating the operation. A helicopter is able to deliver the crew of the platform or other specialists only in daytime according to safety rules of flights. In such a situation we may have the overlapping of several operations. Currently implementation of offloading operations is not that sensitive as the numbers of offloading operations are relatively few. But it will be in future, especially when the company will reach the production peak (after 8 years of the field exploitation) and offloading will be performed twice a week.

Table 13: Safety zones next to the Prirazlomnaya platform, ref also Figure 23

Zone A	Cargo Zone	R <0,5 miles
Zone B	Maneuvering zone	R= 1,5 miles
Zone C	Limit zone	R= 3 miles

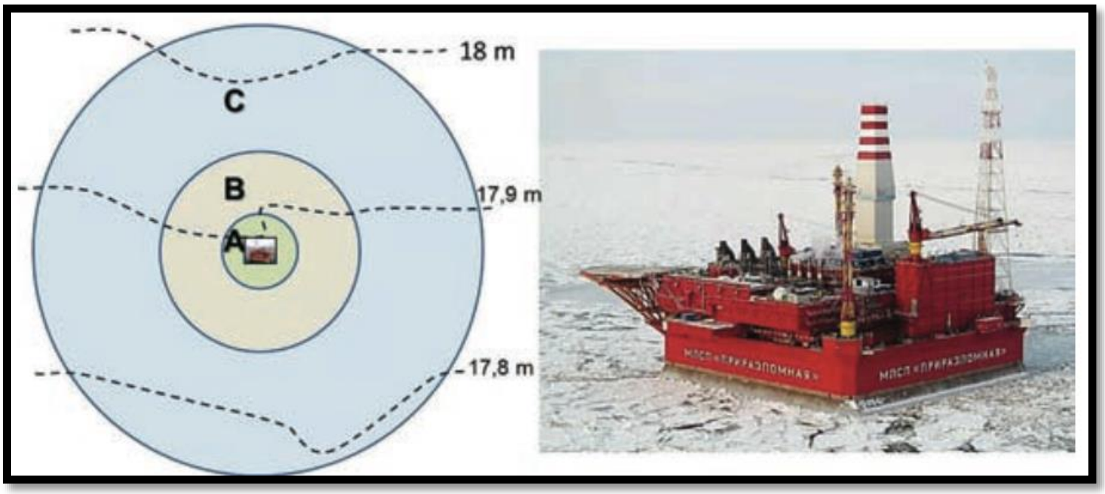

Figure 23: Safety zones next to the Prirazlomnaya platform. Offloading operations. (Valdman, N. A., 2014).

That could be a challenge for the company, because the offloading in winter and spring seasons is a very difficult operation and, in accordance with the experience of the company, “weather windows” may be 3-5 hours and we need to reconnect the tanker 3-4 times and wait even for 5 hours windows.

If oil is not loaded for certain period of time in years of high oil production level we will need to stop the platform. The consequences of this are large. It influences the company profit and possibly on the reservoir characteristics.

Basically we are looking for “weather windows” not less than 5 hours. This is connected with the spent time for the approaching/departure, connection/disconnection, nitrogen purging and offloading itself.

All the procedures, described above take about two and a half hours, meaning that in case a “weather window” equals to 5 hours we have only two and a half hour for the actual offloading. Further this condition will be used for further analysis in this report.

To predict the amount of weather windows in the following months we use weather forecast sources. But anyway for an operation we need to have a more accurate forecast. One of the weather forecast sources used by the tanker crew is meant for 48 hours. They know directions of wind, current and their speeds. Being aware of this information they draw the total vector of the force. And if current does not change dramatically for at least 5 hours and wind speed does not exceed the critical limit for the offloading and taking into account all the rules for the offloading, the crew decides if the offloading will be carried out or not, according to restrictions for the operation.

There are no problems to carry out the offloading in summer and fall seasons as there is no ice, or in the fall season the ice doesn't affect the offloading so much. But in winter season, when ice coverage is 100%, and in spring season, when we should expect the thickest ice in the year (Tables 14 to 16), we have to be more careful for the offloading operation and pay more attention to weather windows.

Table 14: Monthly probability of ice occurrence, % («Gazprom» document, Environmental conditions at the Prirazlomnoye field, 2005)

Months	X	XI	XII	I	II	III	IV	V	VI	VII	VIII
P	2	45	93	100	100	100	97	83	63	25,5	2,7

Table 15: Statistic parameters of calculated thickness of level drift ice (cm) at the Prirazlomnoye field («Gazprom» document, Environmental conditions at the Prirazlomnoye field, 2005)

Ice thickness characteristics	Month				
	XII	I	II	III	IV
50% probability	30	51	64	72	79
Maximum	63	86	113	125	145

Table 16: Thickness and occurrence of level ice

Ice conditions	Level ice thickness, m	Occurrence, %
Light	0,55	0,45
Medium	0,5-0,9	0,35
Hard	0,9-1,2	0,2

The ice drift direction depends on tidal currents and wind currents. Velocities and directions of wind currents depend on baric situation and atmospheric conditions. For instance, in summer when cyclonic activity in the Pechora Sea is rather low, wind currents are relatively weak especially in the shallow areas where they are slowed down by friction between water and seabed. The velocity of tidal currents strongly depends on the moon phases. It grows during syzygy and reduces during neap, Figure 24. That means tidal current velocity grows during conjunction of the sun with the moon and reduces during opposition of the sun with the moon (Bauch et al., 2005).

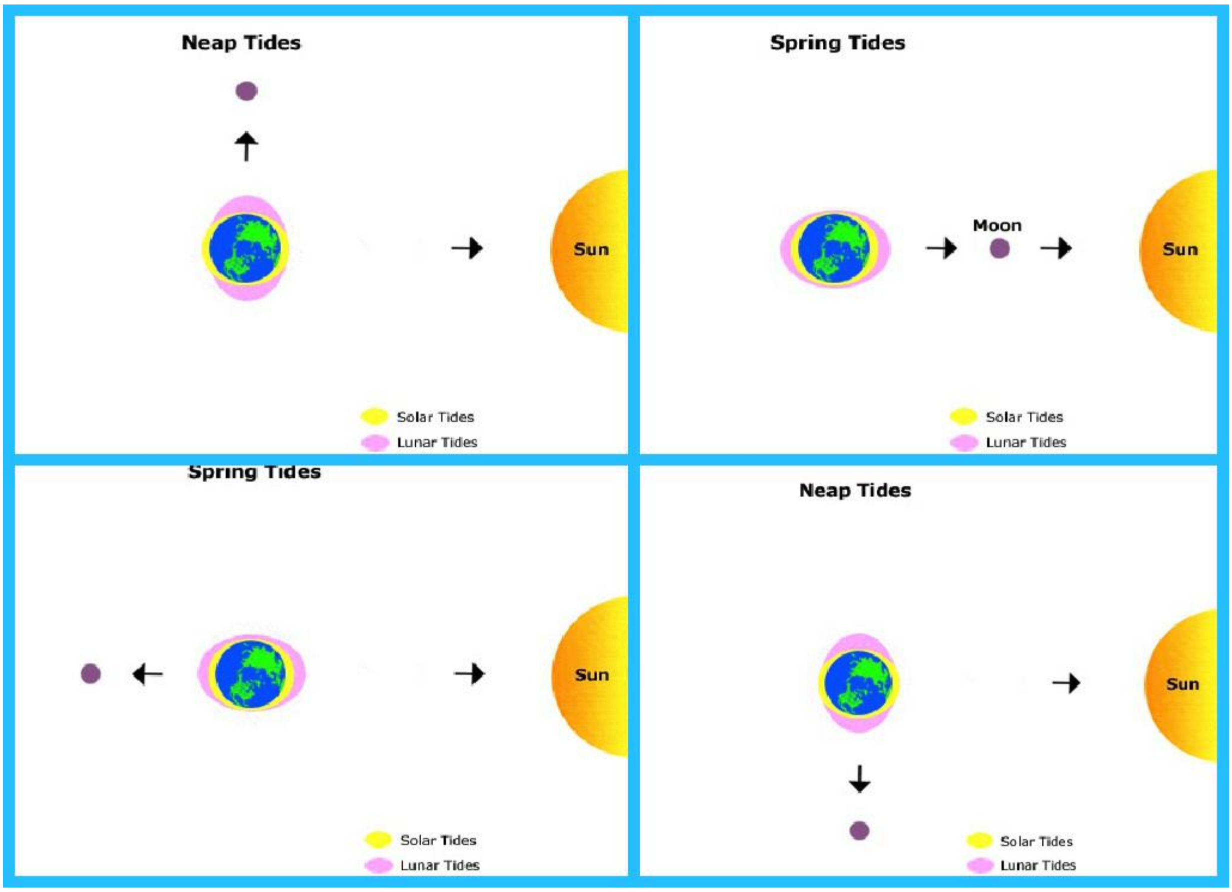

Figure 24: Neap and spring tides (National Ocean Service, 2015)

The sun and the moon act on the Earth's tides on a monthly basis. At time of the new or full moon, solar tide and moon tide combined is creating high tides and low tides. Both of them are called spring tides (upper right corner and lower left one in Figure 24). In one week after spring tides solar tide reduces, creating tides called neap tides (upper left corner and lower right one in Figure 23), (National Ocean Service, 2015)

In the Pechora Sea water moves from the southeast to the northwest at the time of tides and vice versa at the time of ebb tides. Average current velocity is 38 cm/s. Ice drift velocity due to wind can be estimated as:

$$\vartheta_{ice\ w} = (0{,}03 - 0{,}04) \cdot \vartheta_{wind} \qquad (1)$$

where $\vartheta_{ice\ w} - velocity\ of\ ice\ drift\ due\ to\ wind, m/s$
$\vartheta_{wind} - wind\ velocity, m/s$ (Gudmestad et al., 1999)

In open areas the characteristic wind-generated current velocities at still water level may, if statistical data are not available, be taken as;

$$\vartheta_{C,wind} = 0.03 \cdot U_{(z,tmean)} \qquad (2)$$

$U_{(z,tmean)}$ *is the wind velocity,*

where

$t_{mean} = 1[hr]$,

$z = 1[hr]$ (Offshore standard, DNV OS-H101, 2011)

The wind current direction is deflected from the wind direction to 45^0 to the right in the north latitudes not depending on the wind velocity. (Flot, 1998-2015)

Calculations by using this equation give satisfactorily results for the open part of an ocean on the assumption of uniform wind and permanent density of water.

Taking into account tidal currents changes and their velocities as well as the equation for wind currents, and being aware of wind velocities and directions given from data since April 2014 to April 2015 models of the total currents for 48 hours and one year, respectively, (based on the assumptions listed above) will be created.

In order to get a start point for the tidal currents action, according to Government Oceanography Institute, 2012, we are choosing the closest location of tidal registration – Varandey, as the initial point for high and low tides has been identified, Figure 25.

The tides delay for each day approximately equals to 50 minutes. This phenomenon is called moon delay. (Federal Portal, United collection of digital educational resources, 2015). For simplicity of calculations it will be taken into account in the simulation as an hour delay, because the main idea is to visualize the process of total current direction change and estimate possible delays in the offloading operation.

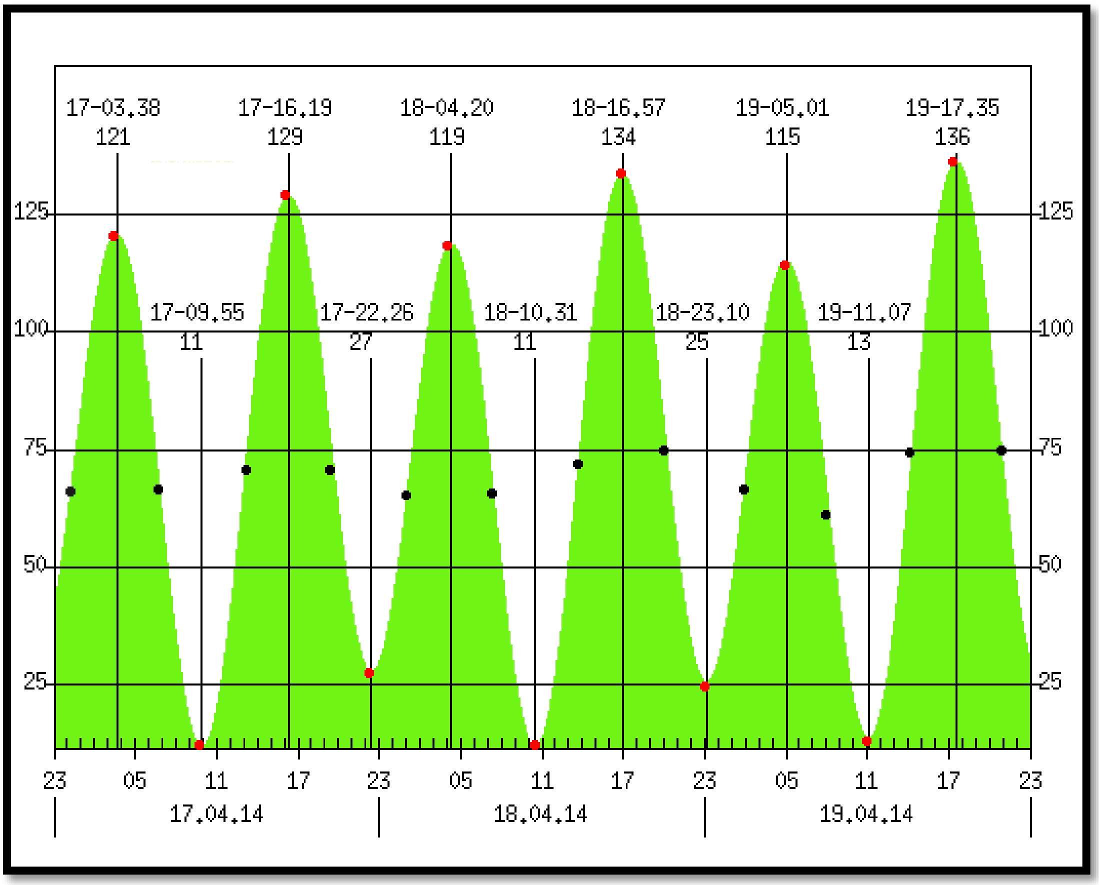

Figure 25: Diagram of sea level changing and nonharmonic constants at station Dolgiy (69.22-59.27), 17.04.2014 (the Barents Sea) (Government Oceanography Institute, 2012)

Maximum current velocities are marked by black dots, Figure 25, the minimum ones by red dots. The period of maximum velocities equals to 6 hours as well as the period of minimum ones.

In the Pechora Sea, spring tidal currents velocity is 1.5 to 2.5 times greater than that of neap tidal currents. The tide is asymmetrical: rising tide equals 5.3 hours, falling tide equals 6.7 hours (Bauch et al., 2005). To simplify the calculations let's assume the rising one equals 5 hours and the falling one equals 7 hours.

In order to visualize the true current directions, the velocity and its pattern as well as calculating the possible number of weather windows the process of the surface current direction will be simulated. Using the simulated current forecast we can calculate the amounts of successful offloading operations from each of both offloading corners and estimate the possible downtime.

The wind data available (April 2014 to April 2015) is assumed to be the same for the year of peak production from the field. Of course, it will not mean that this is the case how it is going to be, but the forecast of the total current is based on reasonable assumptions and existing data of wind directions and velocities can show us the importance of the interruption in the existing concept of the offloading from the Prirazlomnoye field. Moreover, this will lead to decision making of future logistic and/or development of technologies for offloading in the Arctic and so on. The earlier we start to work on the challenge the better will be results for the existing project, helping to implement the future ones in the best way.

6.1.1 The 48 hours forecast

The captain of the tanker does all the calculations very fast and accurate. He also gets some data sources about changing of weather and ice movement at place and makes a decision (together with other specialists) if the tanker approaches now the platform for the offloading or not.

The idea is to make it simple for understanding. Then everyone, who is not familiar with decision making procedure at place, will be able to look at the forecast and to get it very fast and effective. It will be significant for leaders of the company. This forecast will allow to optimize logistic for whose, who works at office and automatize the process of calculation. Visualization of the changing of the total force next to the platform will be allowable as well.

The idea is the following:

- To get all the data we usually receive in *one Excel document* (with certain set of data on each sheet);
- To load this document into Matlab;
- The set of data represents the following information for the next 48 hours:
  - Wind directions and speeds;
  - Tidal current directions and speed for the next 48 hours.
- To get the corrected vector of the current (as well as its magnitude) taking into account the wind component;
- To visualize it with the platform (bird view);
- To single out intervals without dramatic changing of current for at least 5 hours
- To count the number of such "safe" intervals and define continuation of each interval as a potential "weather window".
- Being aware of the time for connection/ disconnection, nitrogen purging we can identify the actual offloading time for each interval
- To sum it we will know how much oil we can offload during the next 48 hours. According to the direction of total force for each interval we will define at which CUPON location the offloading will be performed.

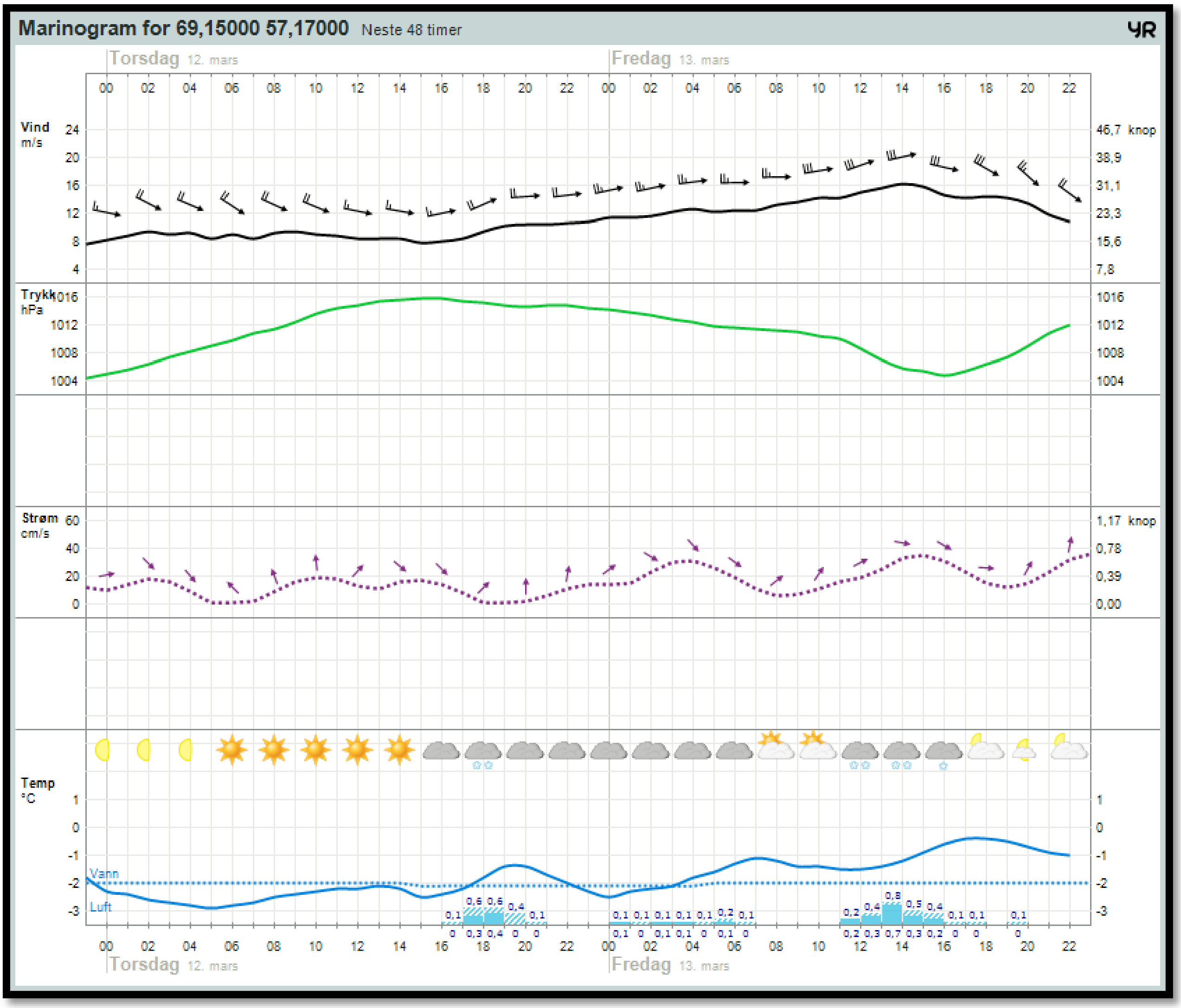

Figure 24: Example of data used for offloading forecast (Norwegian Meteorologisk Insitutt, 2014)

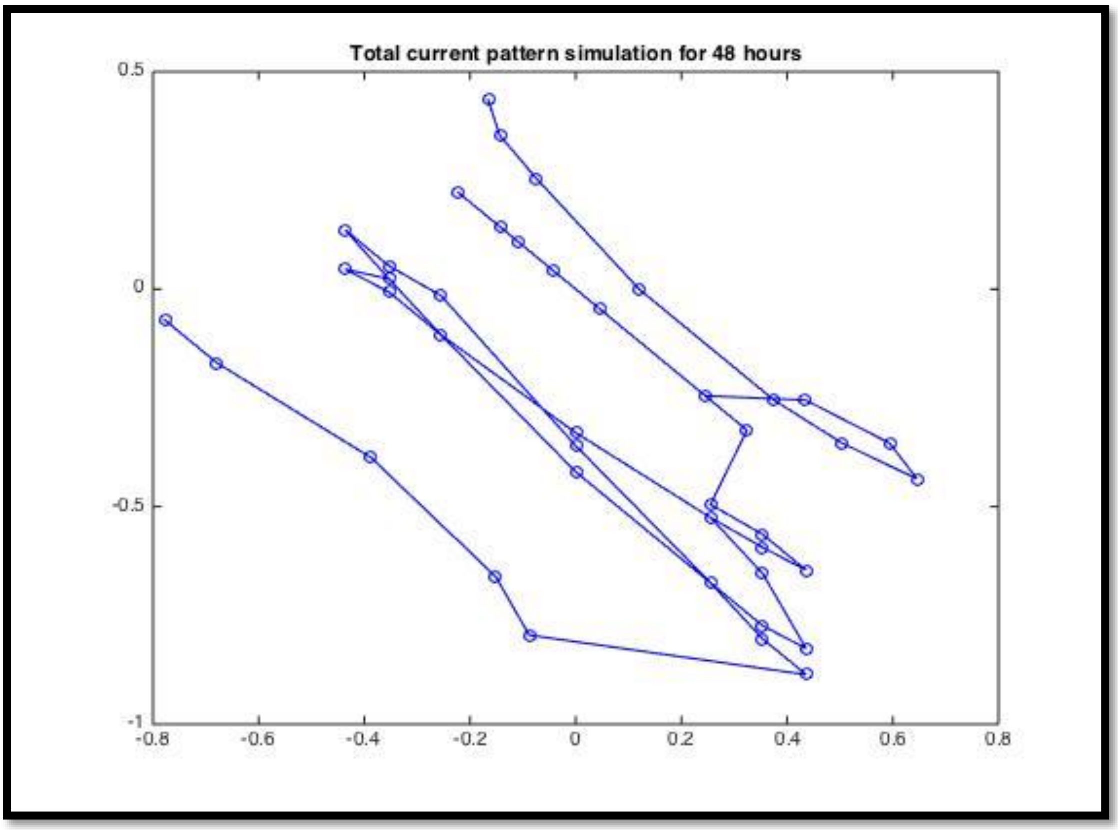

Figure 25 – Total current pattern simulation for 48 hours, dots every hour

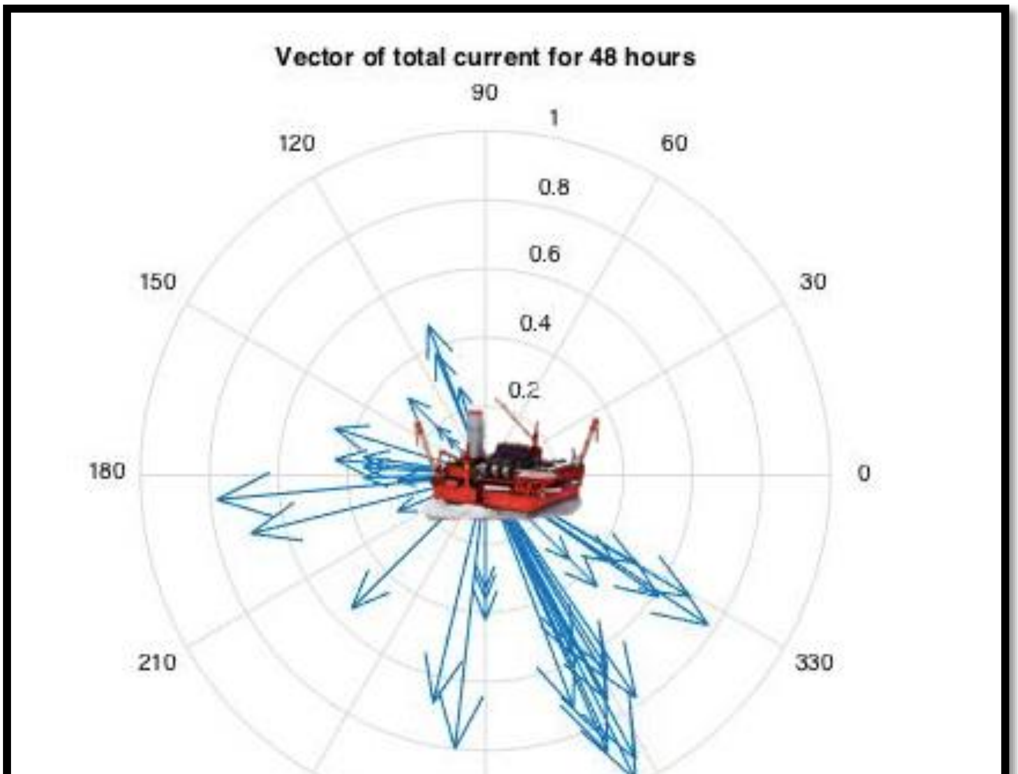

Figure 26: Vector of total current directions for each of 48 hours

6.1.2 Yearly forecast

For the 1year forecast we use the following data for simulation of offshore loading operations:

- Hourly wind direction
- Hourly wind speed
- Average tidal current speed – 38 cm/s
- Rising tidal direction
- Falling tidal direction

The total simulated current speed over a period of one year is shown in Figure 27.

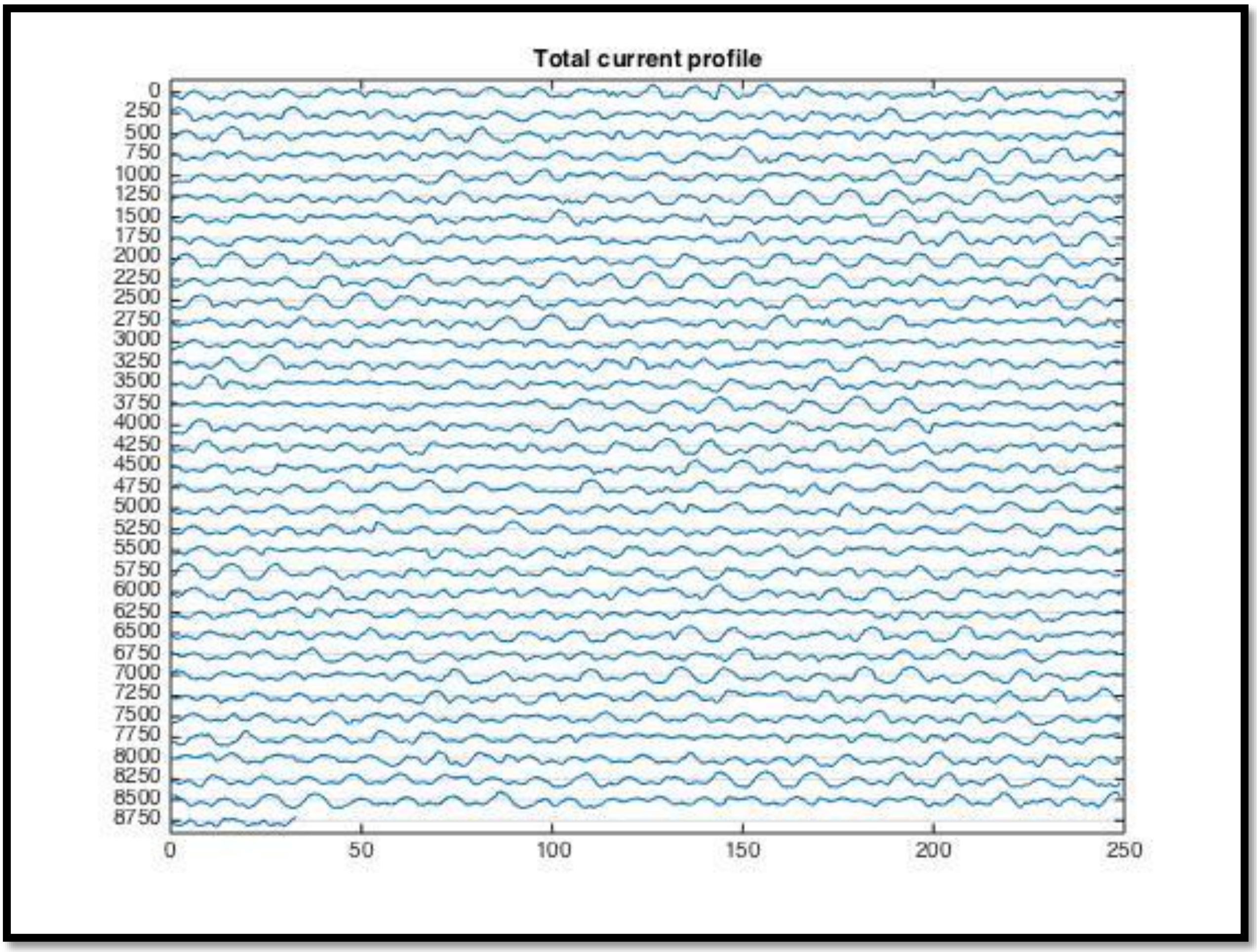

Figure 27: Total simulated current speed over a period of one year

We can see some intervals, where due to wind action the profile is not changing so much and stay stationary for a long time.

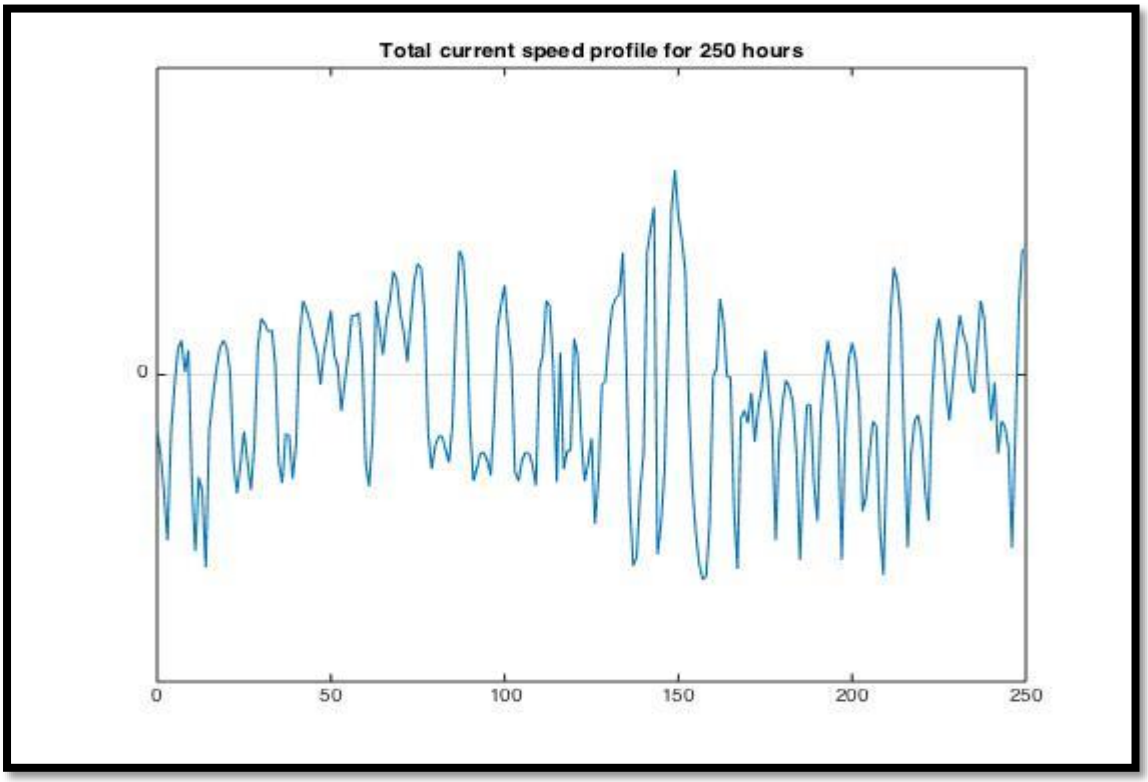

Figure 28: Total current speed profile for 250 hours.

Representation of total speed profile for 250 hours is shown in Figure 28

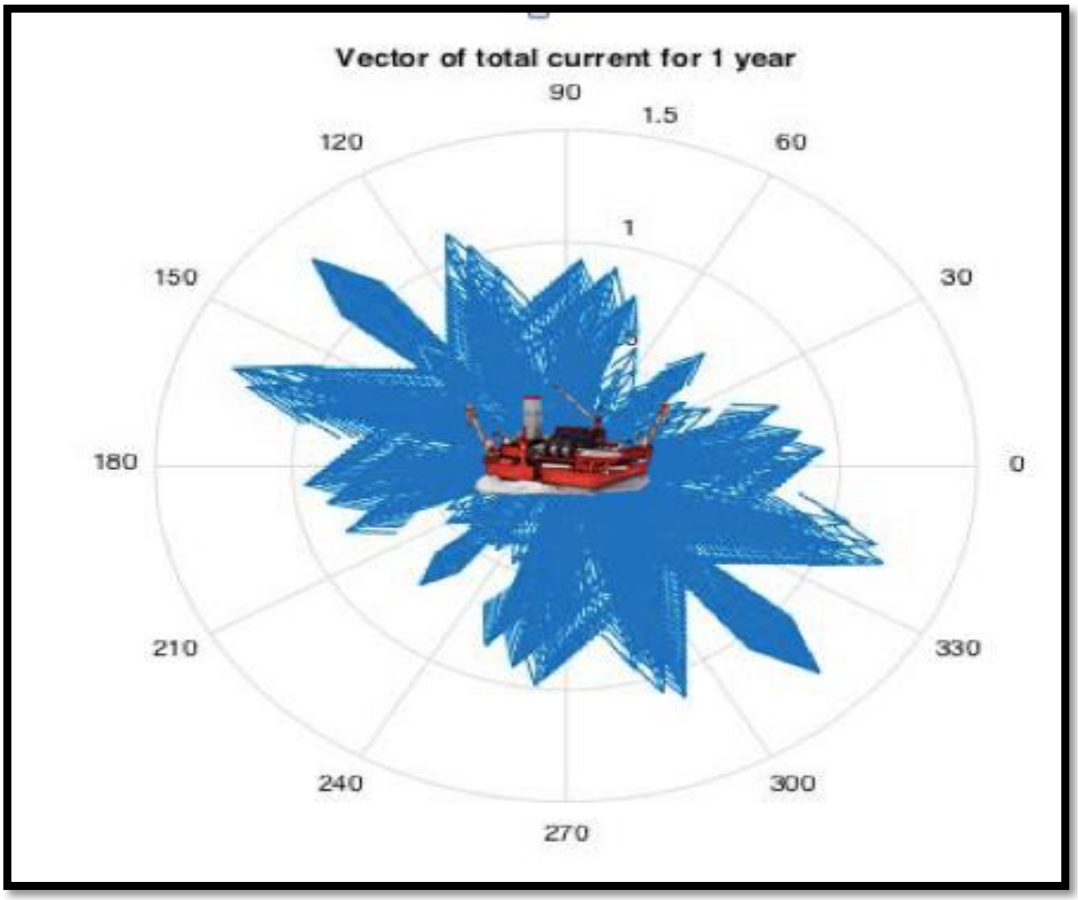

Figure 29: Simulated vector of total current directions for 1 year period (1 hour step)

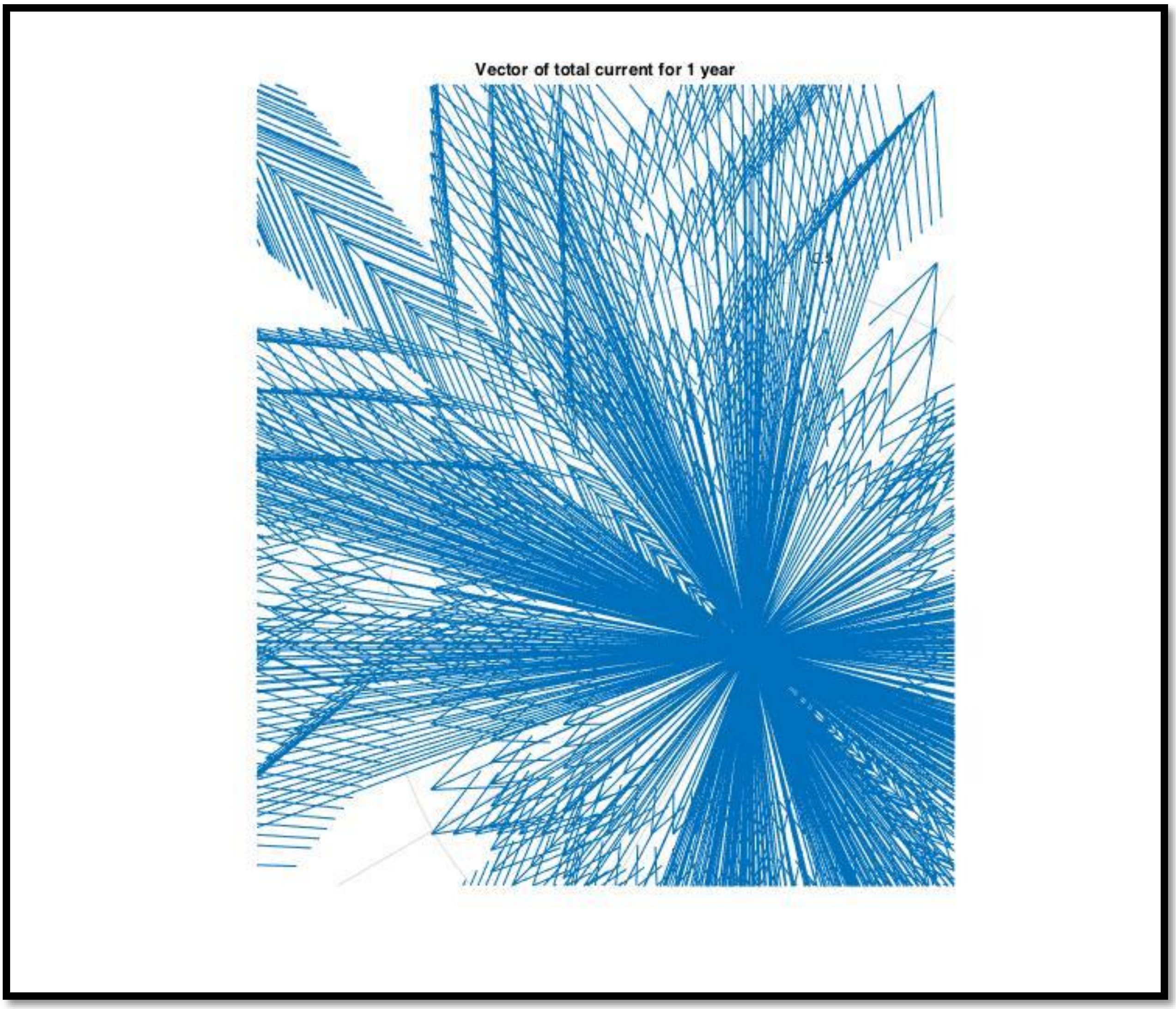

Figure 30: Scaled simulated vector of total current directions for 1 year period (1 hour step)

We can see how the direction of the total current is changed due to wind and tidal current activities, Figure 29 and Figure 30. There is a whole spectrum of its directions.

Simulated tidal current direction and wind-current vectors are shown in Figure 31 and 32, respectively.

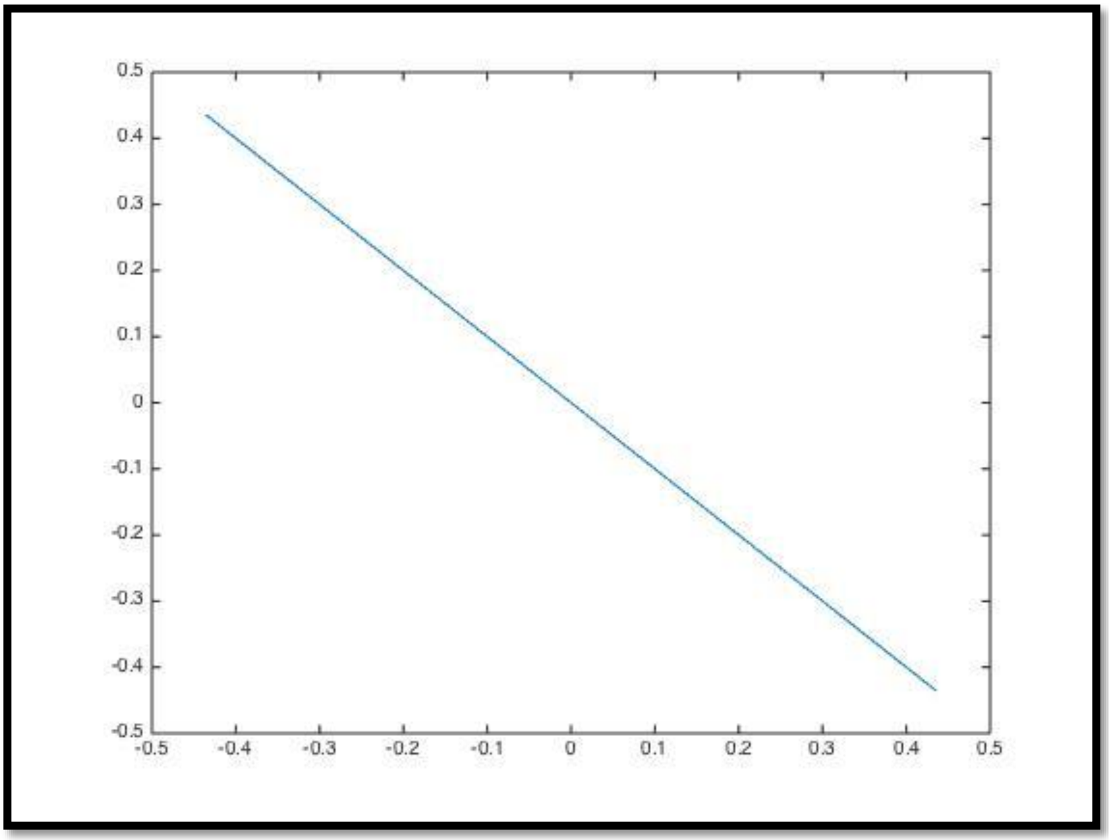

Figure 31: Tidal current pattern

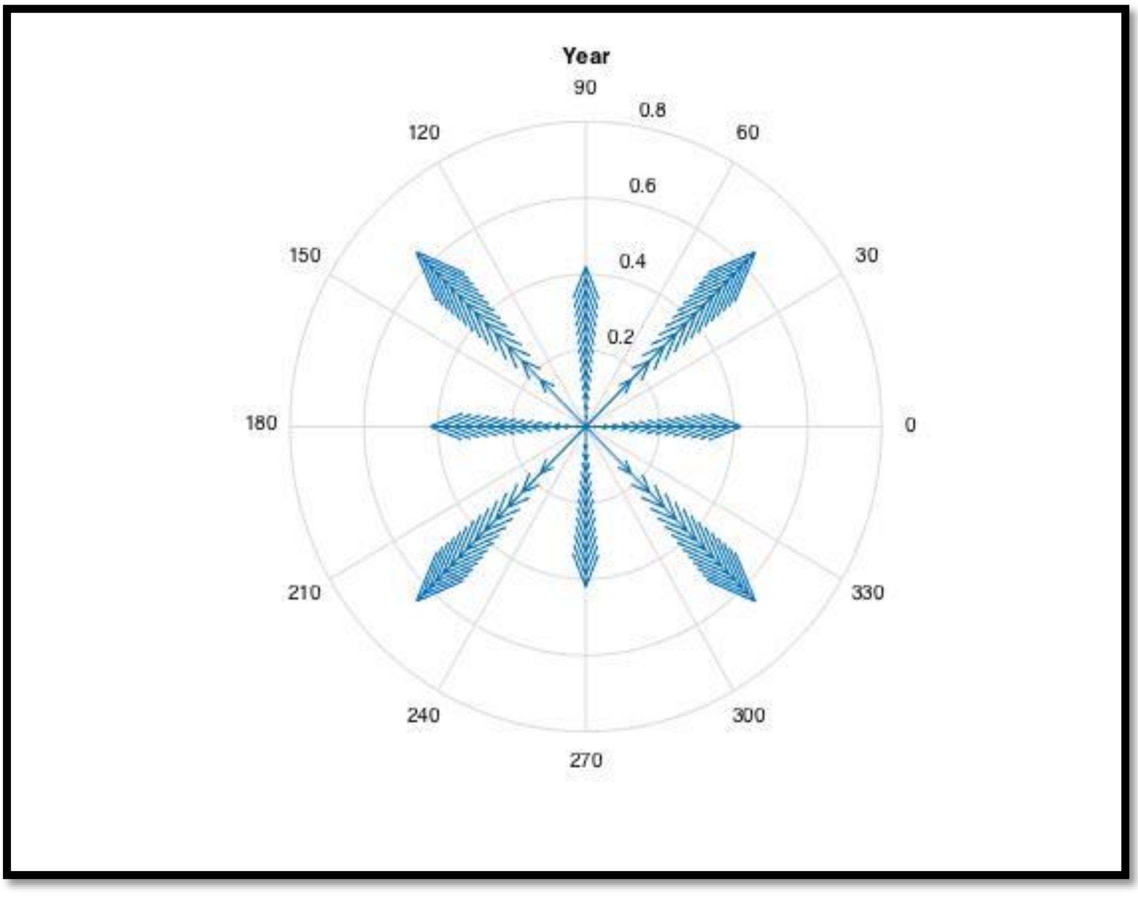

Figure 32: Simulated wind-current vectors due to actual wind data for 1 year

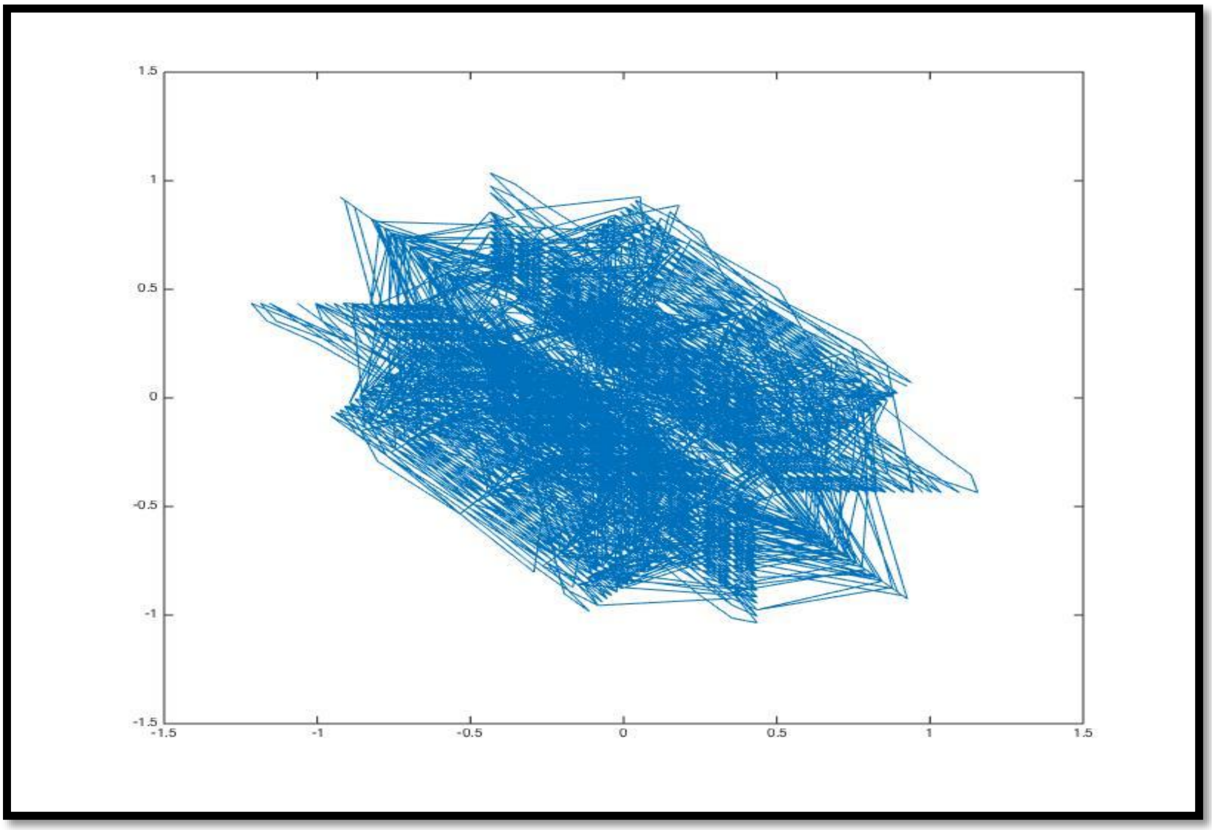

Figure 33: Total current pattern for 1 year

The pattern shown above indicates very difficult movements of the surface waters in the Pechora Sea, Figure 33.

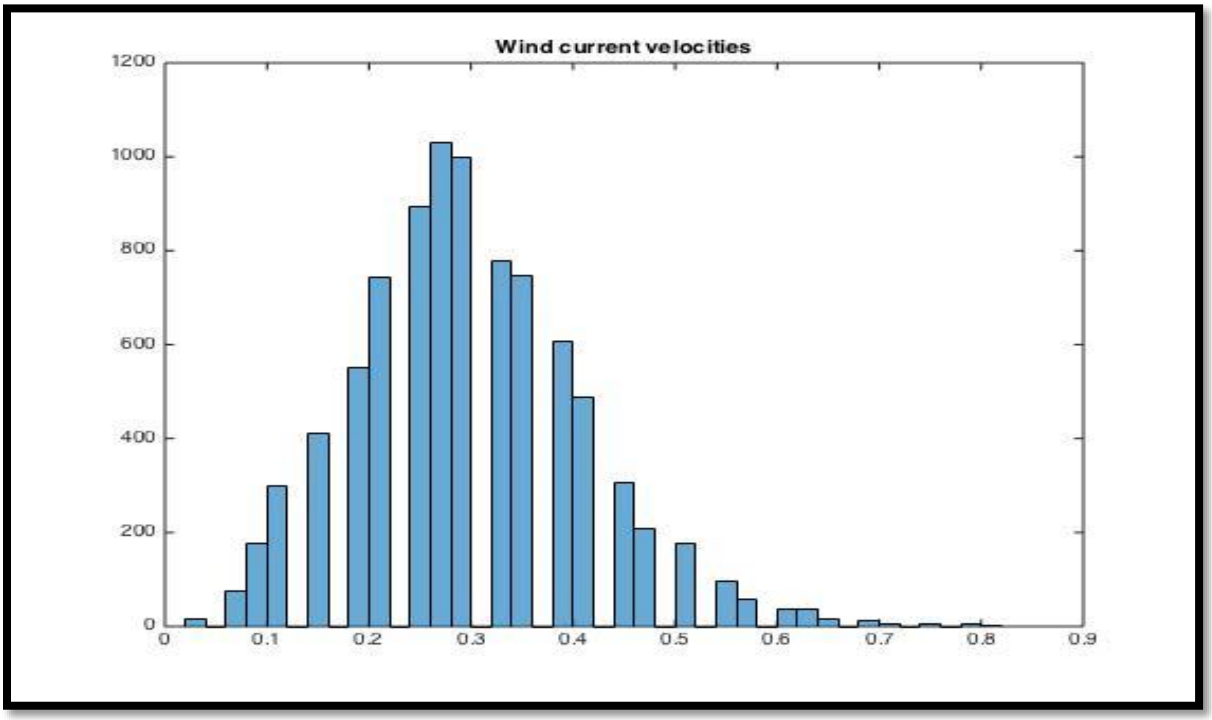

Figure 34: Histogram of wind-current velocities

Wind-current velocities do not exceed 0,8 m/s, but mean value equals to 0,3 m/s, Figure 34.

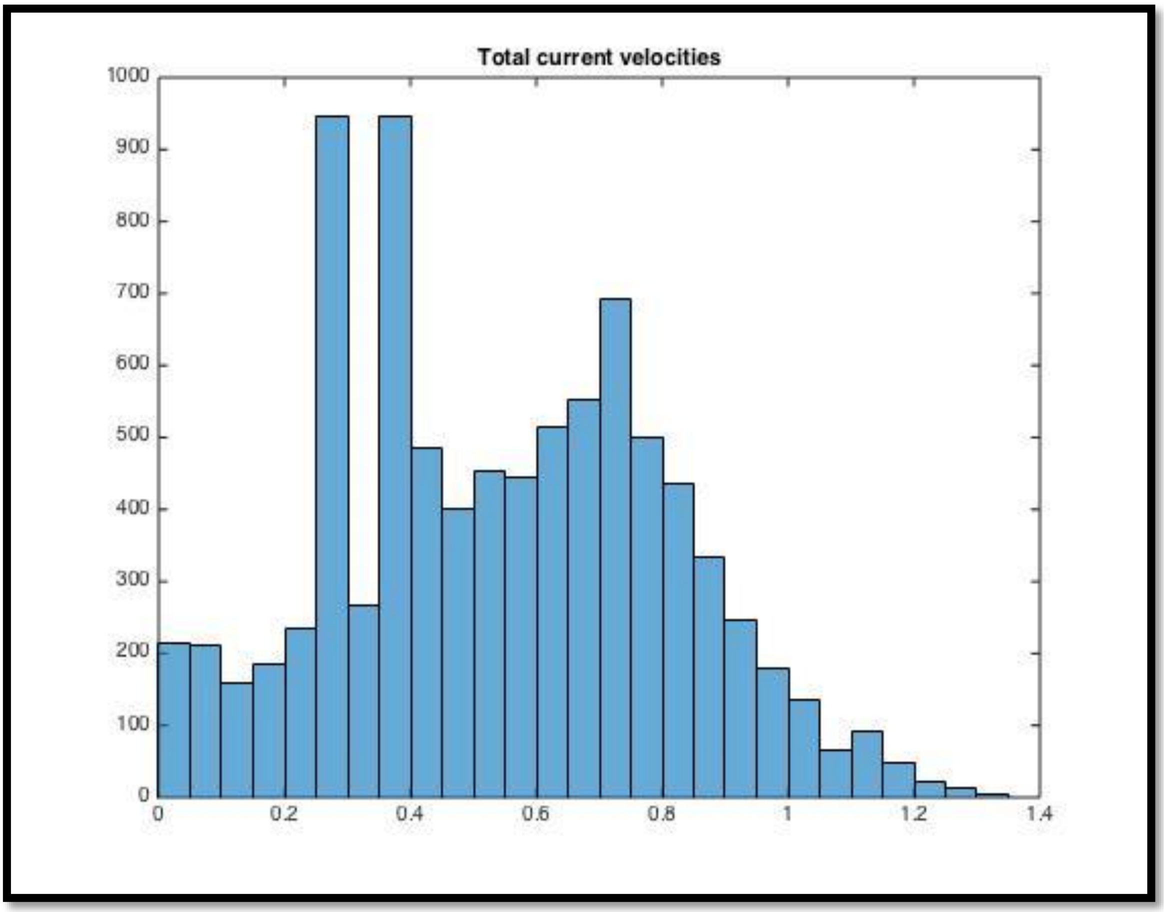

Figure 35: Histogram of total current velocities

The mean value of total current velocities equals to 0,54 m/s. The velocity exceeds 1 m/s in some cases, Figure 35.

The plot of total current velocities changes is shown in Figure 36 below.

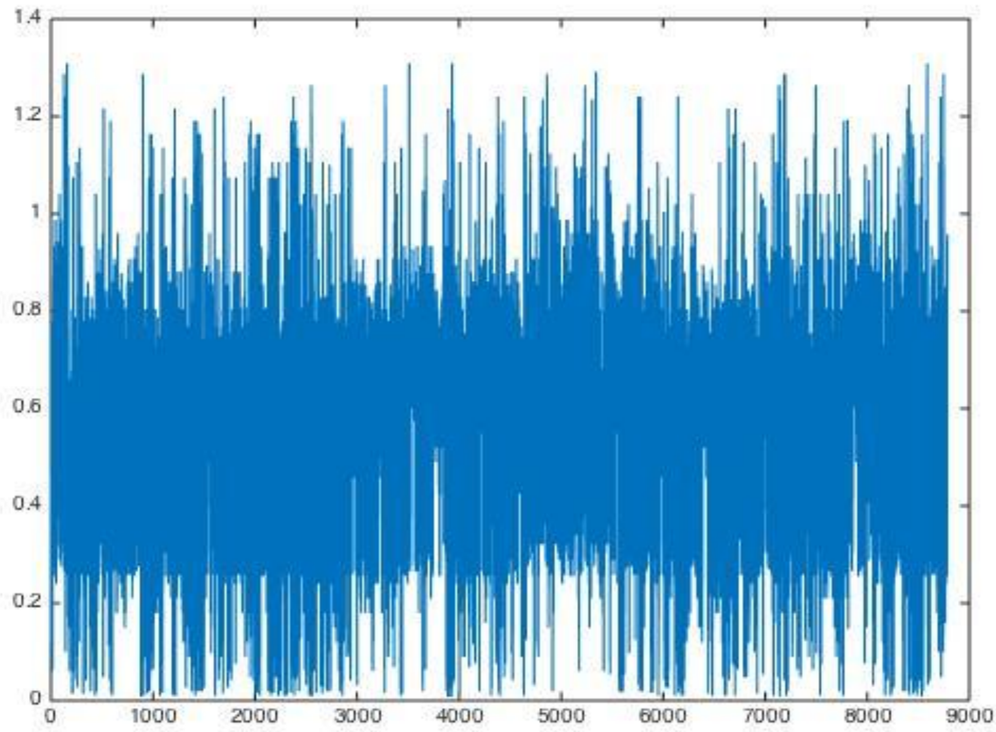

Figure 36: Plot of total current velocity changes

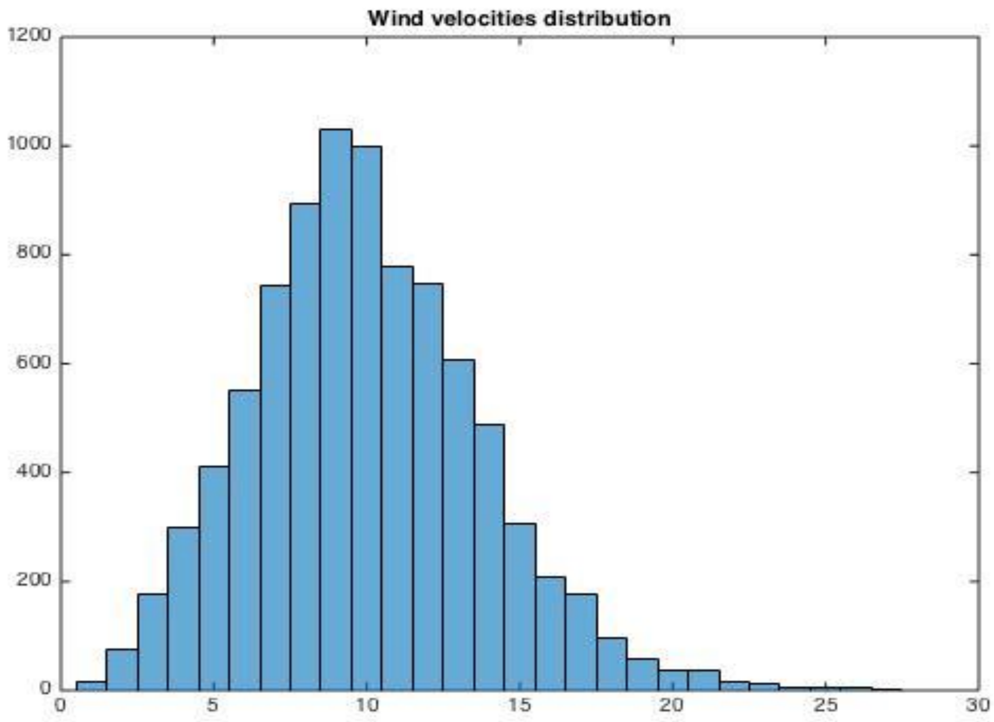

Figure 37: Histogram of wind velocities

The mean value of the actual wind speed equals 9,84 m/s. Maximum wind speed used in the simulation equals 27 m/s, Figure 37. Several restrictions have been put on the offloading operation according to Tables 11 and 12:

- Wind speed during offloading should not exceed 15 m/s
- Current velocity during offloading should not exceed 0,8 m/s

6.2 Offloading forecast for seasons of the year

The same analysis, as used in subchapter 6.1, have been done for different seasons of the year.

6.2.1 Forecast for spring

Simulated vectors of total current directions, simulated wind-current pattern due to actual wind data, total current pattern, histogram of wind current velocities, plot of total current velocities changes and histogram of wind velocities for the spring are shown in Figures 38-43.

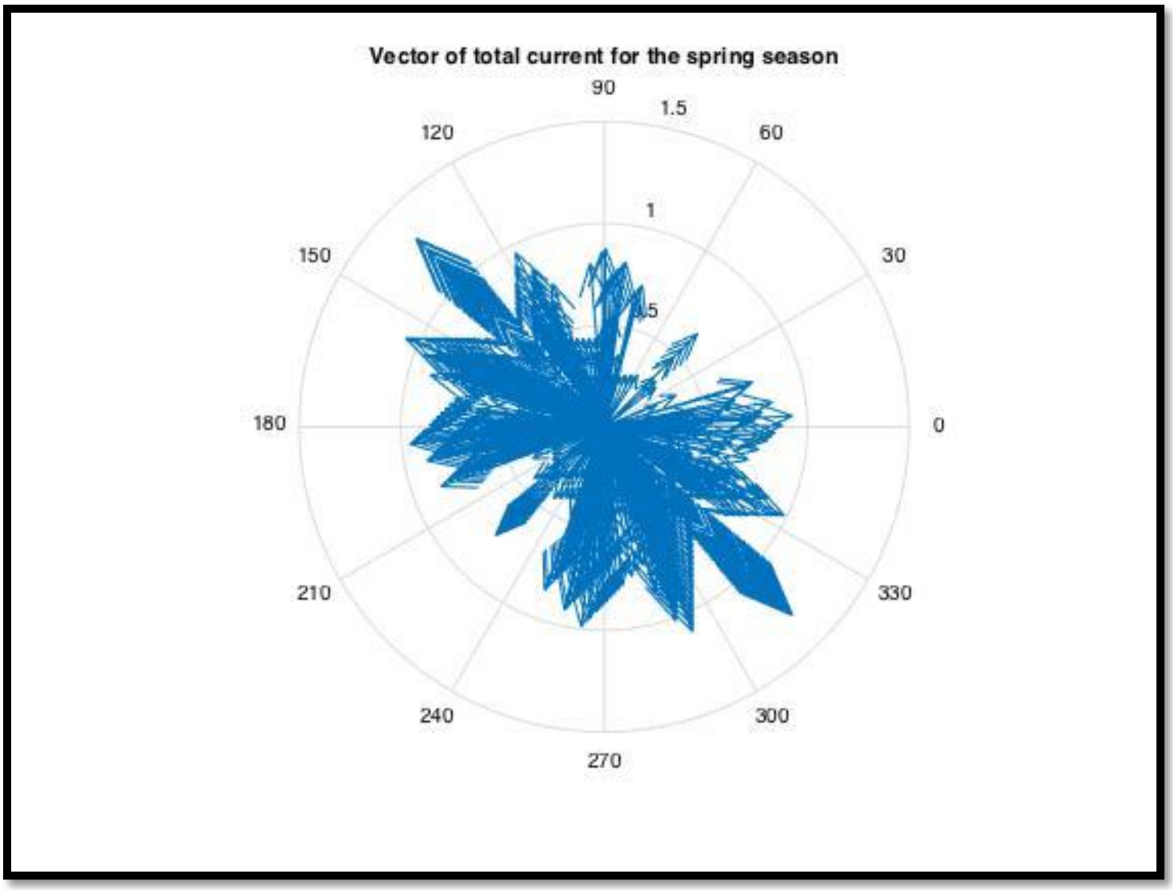

Figure 38: Simulated vector of total current directions for spring (1 hour step)

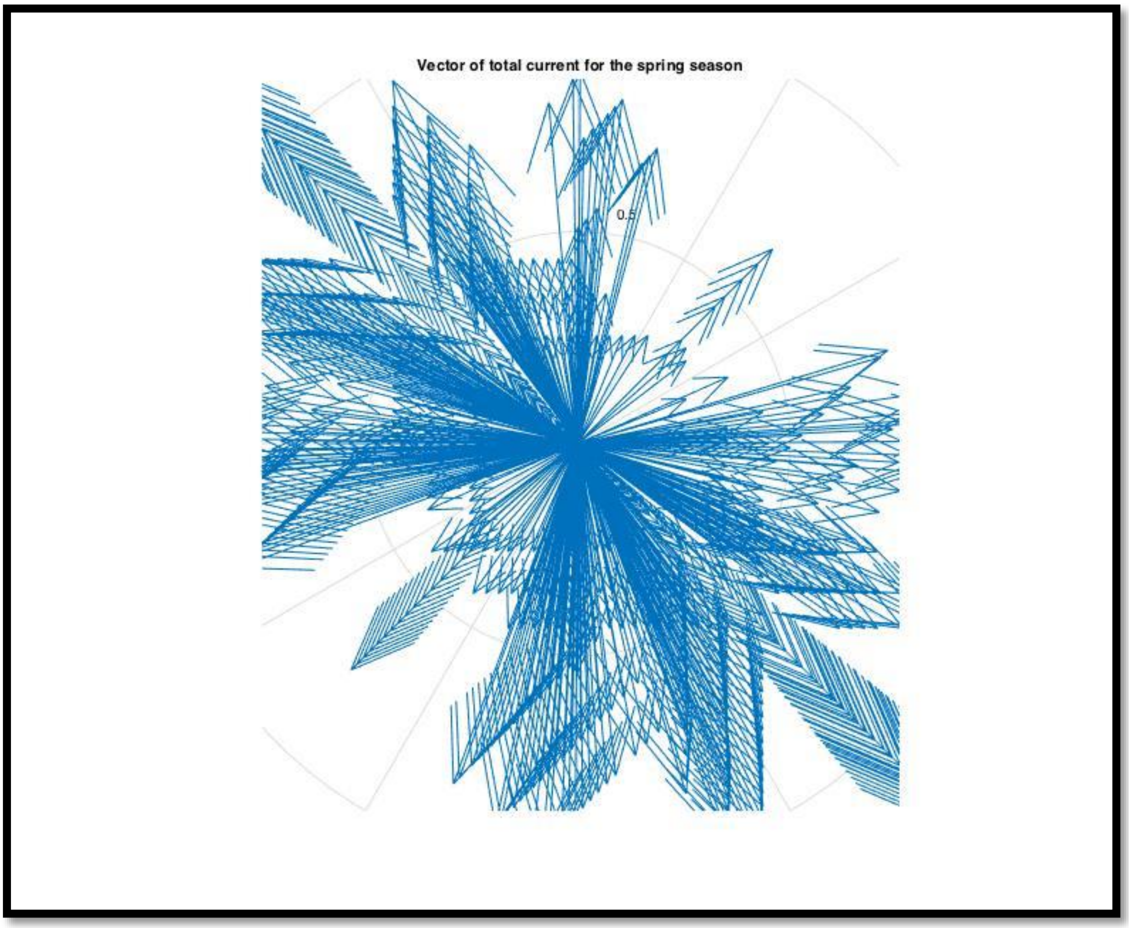

Figure 39: Scaled simulated vector of total current directions for spring (1 hour step)

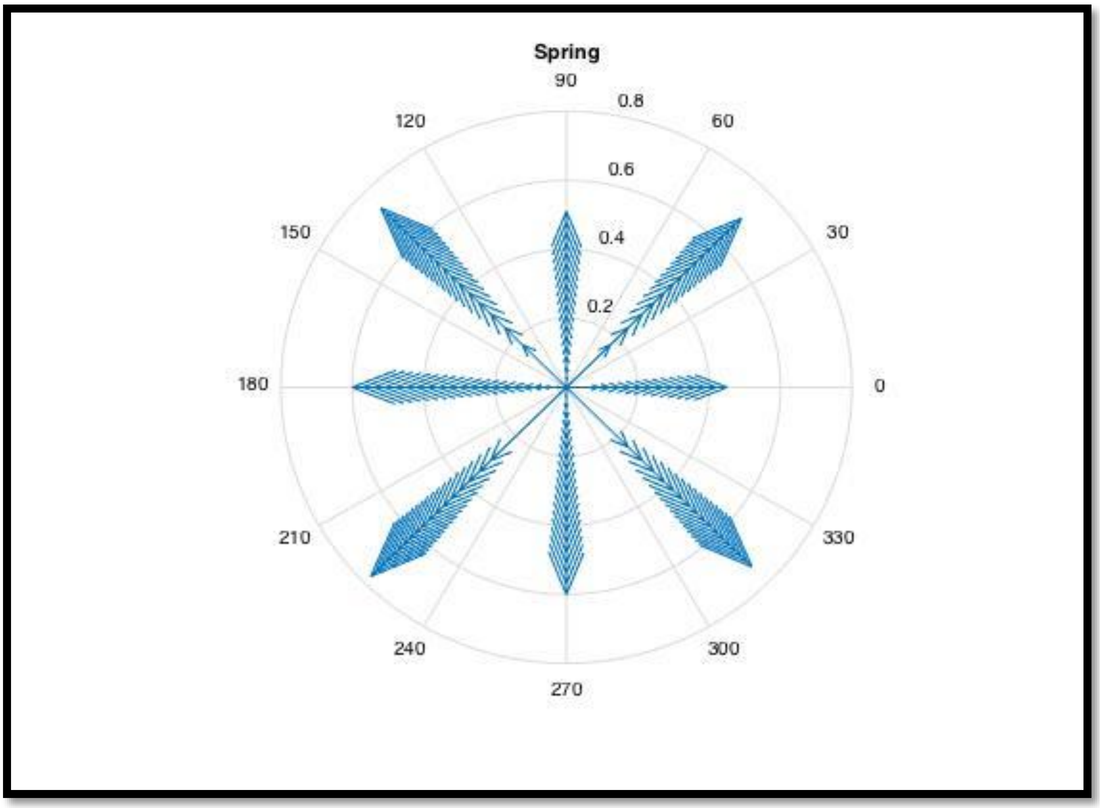

Figure 40: Simulated wind-current pattern due to actual wind data for spring

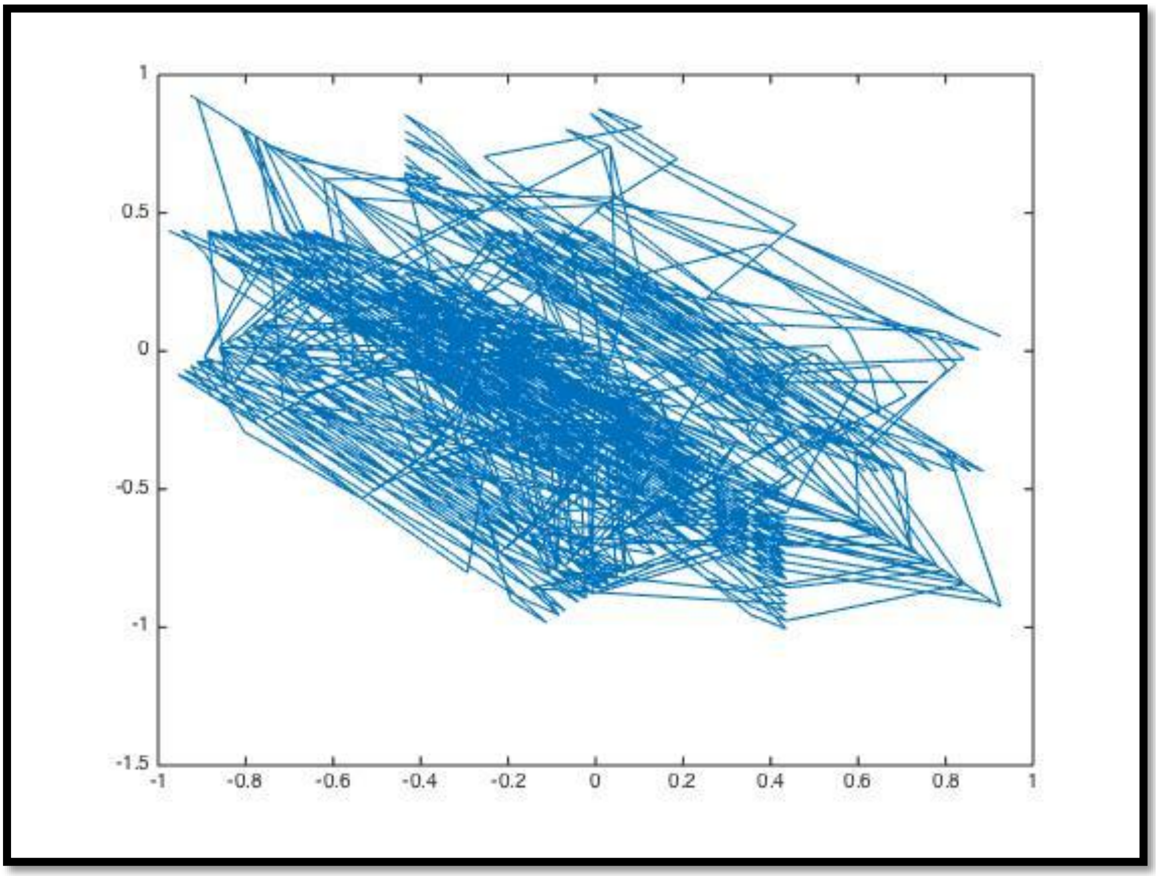

Figure 41: Total current pattern for spring

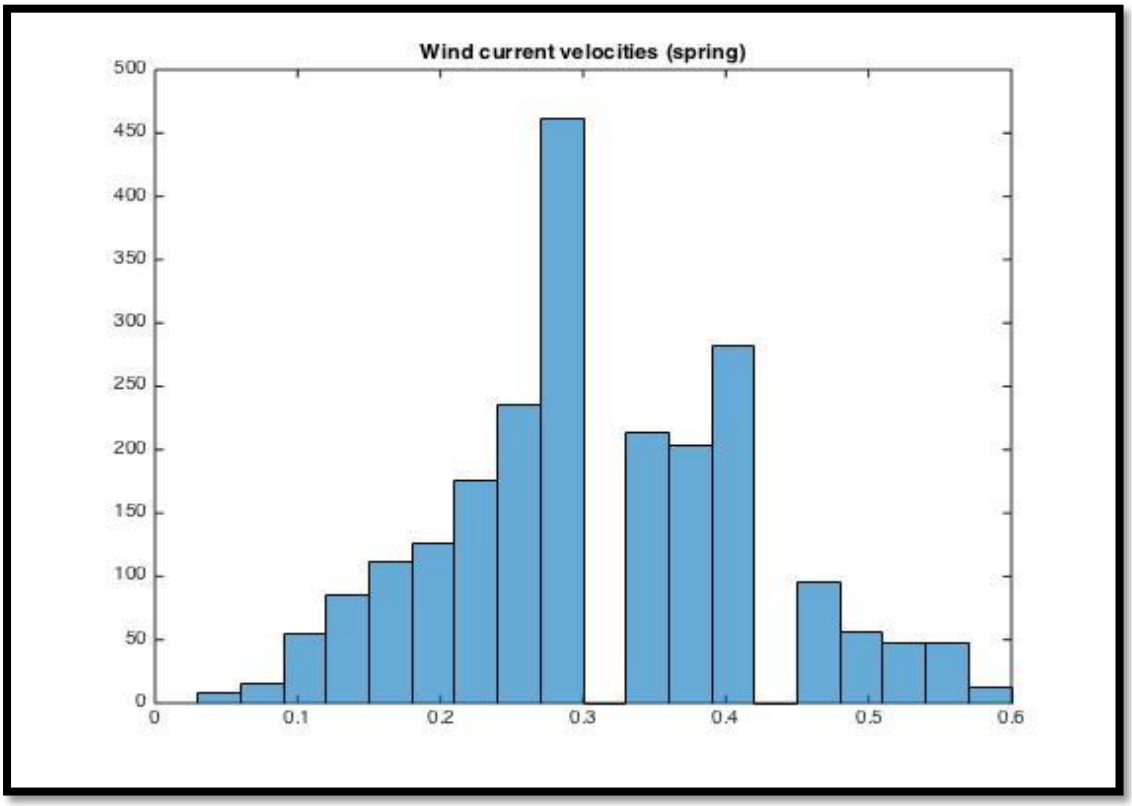

Figure 41: Histogram of wind-current velocities (spring)

Wind-current velocities do not exceed 0,6 m/s, but mean value equals to 0,3 m/s, Figure 41.

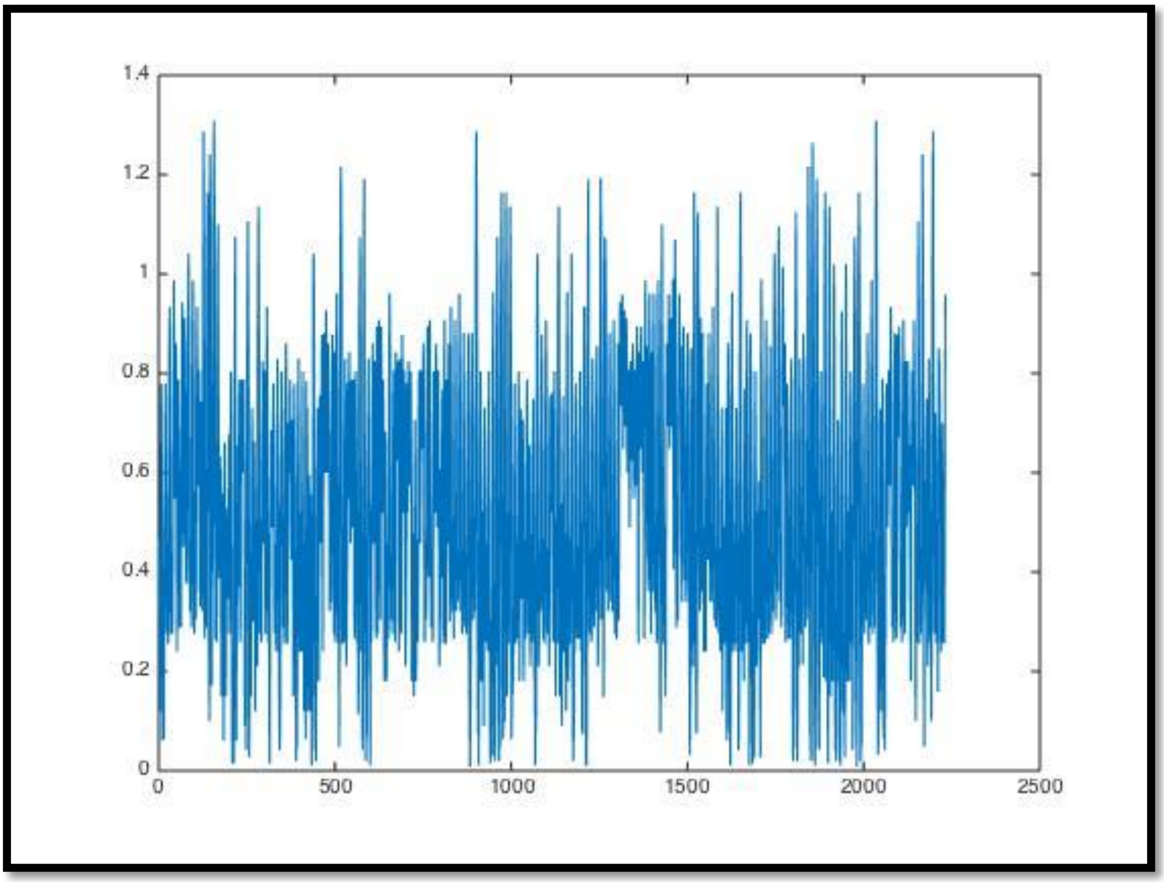

Figure 42: Plot of total current velocities changes (spring)

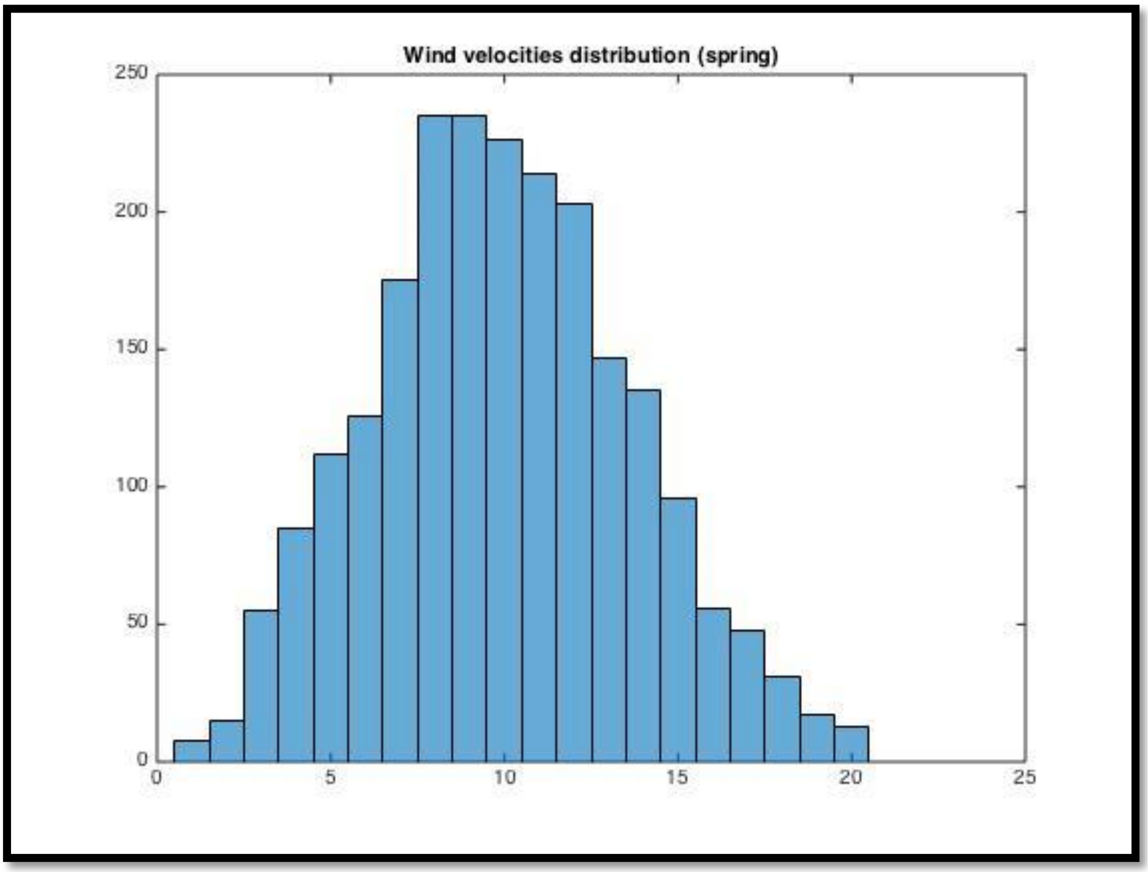

Figure 43: Histogram of wind velocities (spring)

The mean value of the actual wind speed equals 9,94 m/s. Maximum wind speed used in the simulation equals 20 m/s, Figure 43.

6.2.2 Forecast for summer

Simulated vectors of total current directions, simulated wind-current pattern due to actual wind data, total current pattern, histogram of wind current velocities, plot of total current velocities changes and histogram of wind velocities for summer are shown in Figures 44-50.

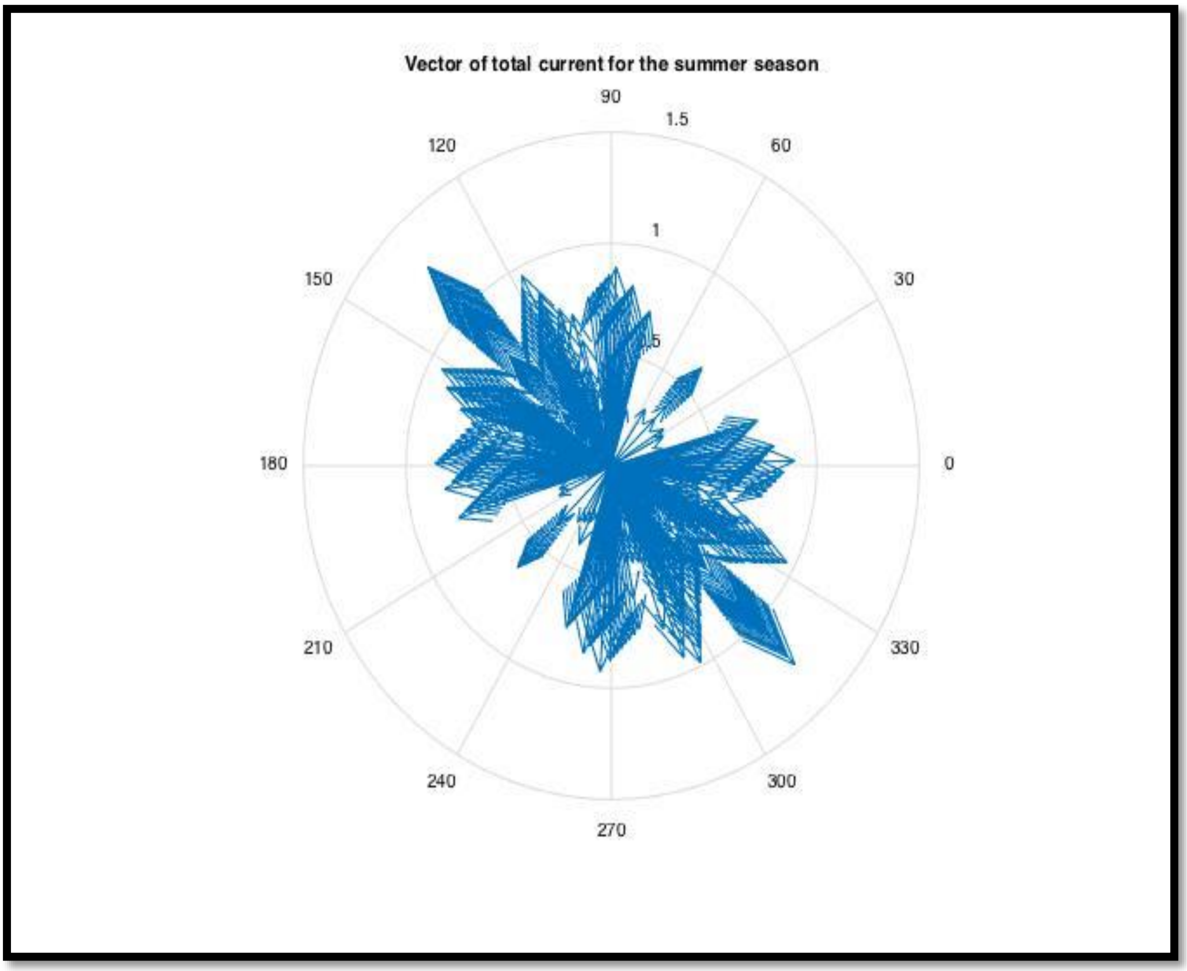

Figure 44: Simulated vector of total current directions for summer (1 hour step)

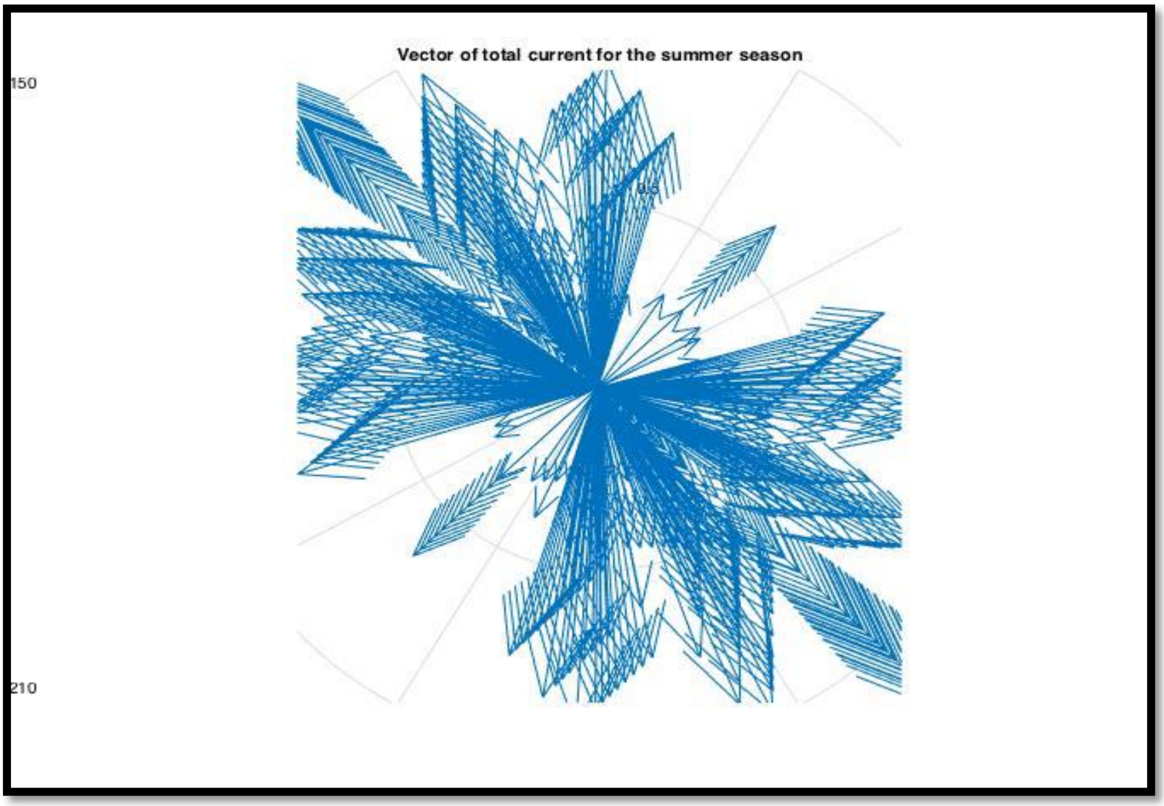

Figure 45: Scaled simulated vector of total current directions for summer (1 hour step)

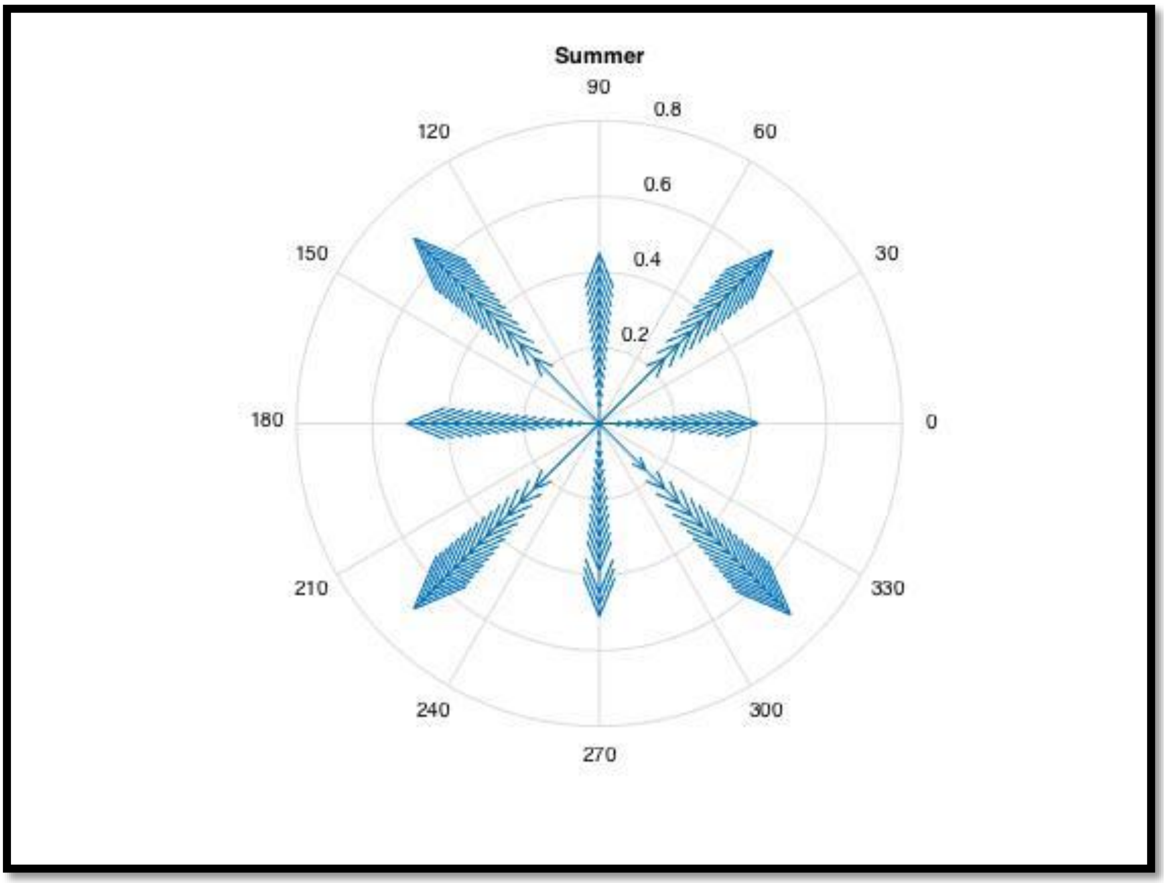

Figure 46: Simulated wind-current pattern due to actual wind data for summer

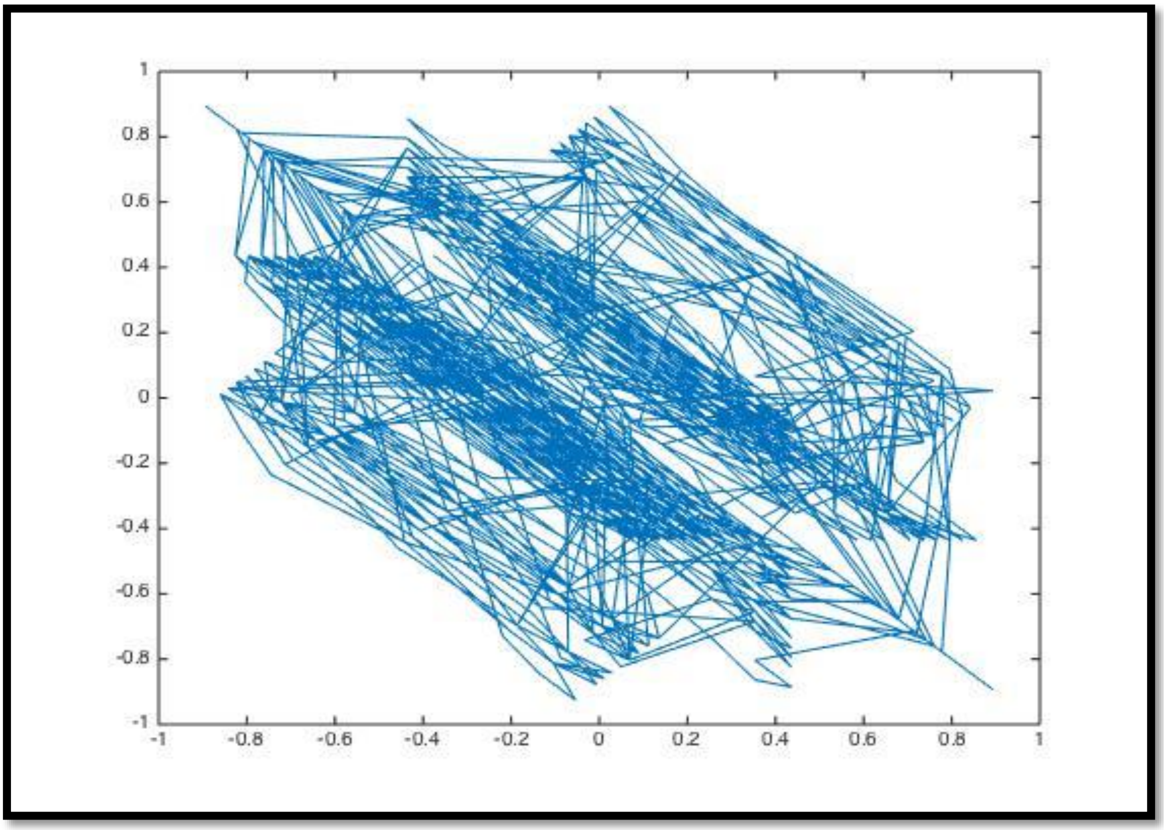

Figure 47: Total current pattern for summer

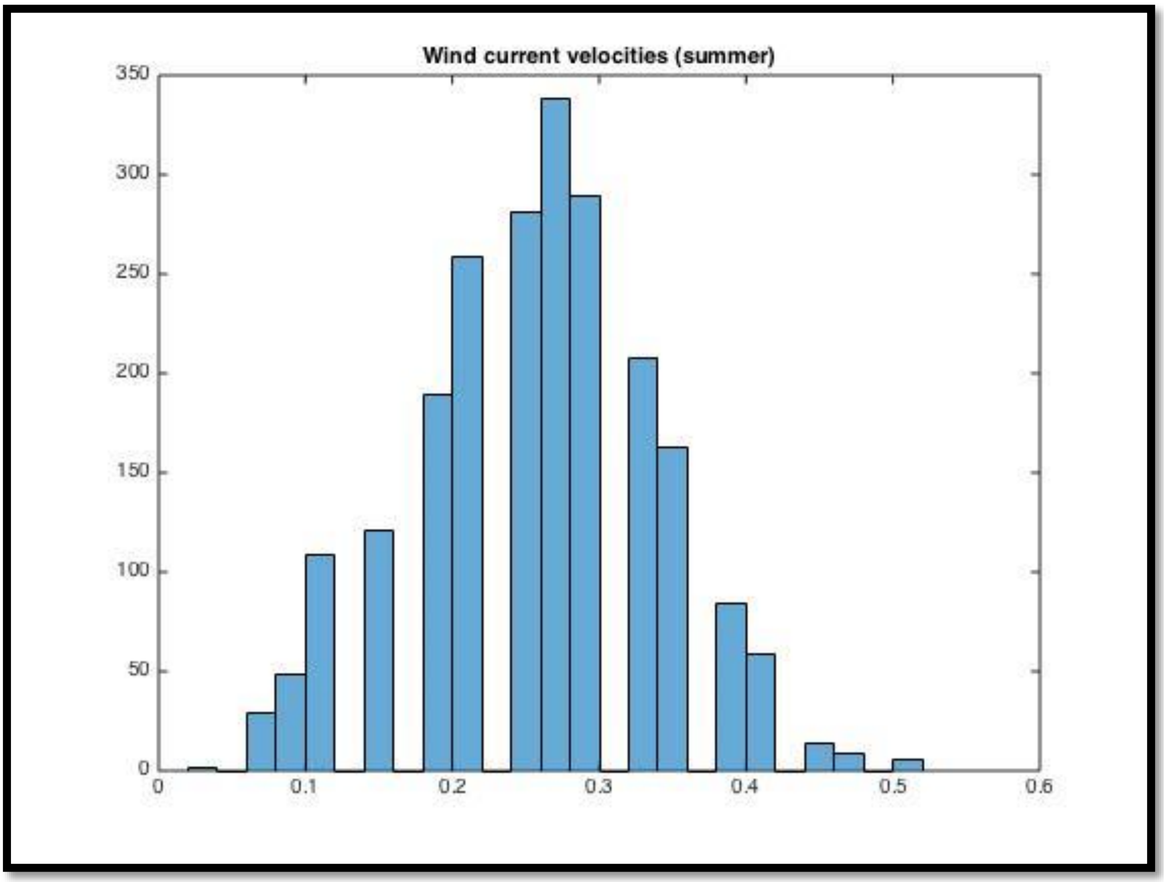

Figure 48: Histogram of wind-current velocities (summer)

Wind-current velocities do not exceed 0,52 m/s, but mean value equals to 0,26 m/s, Figure 48.

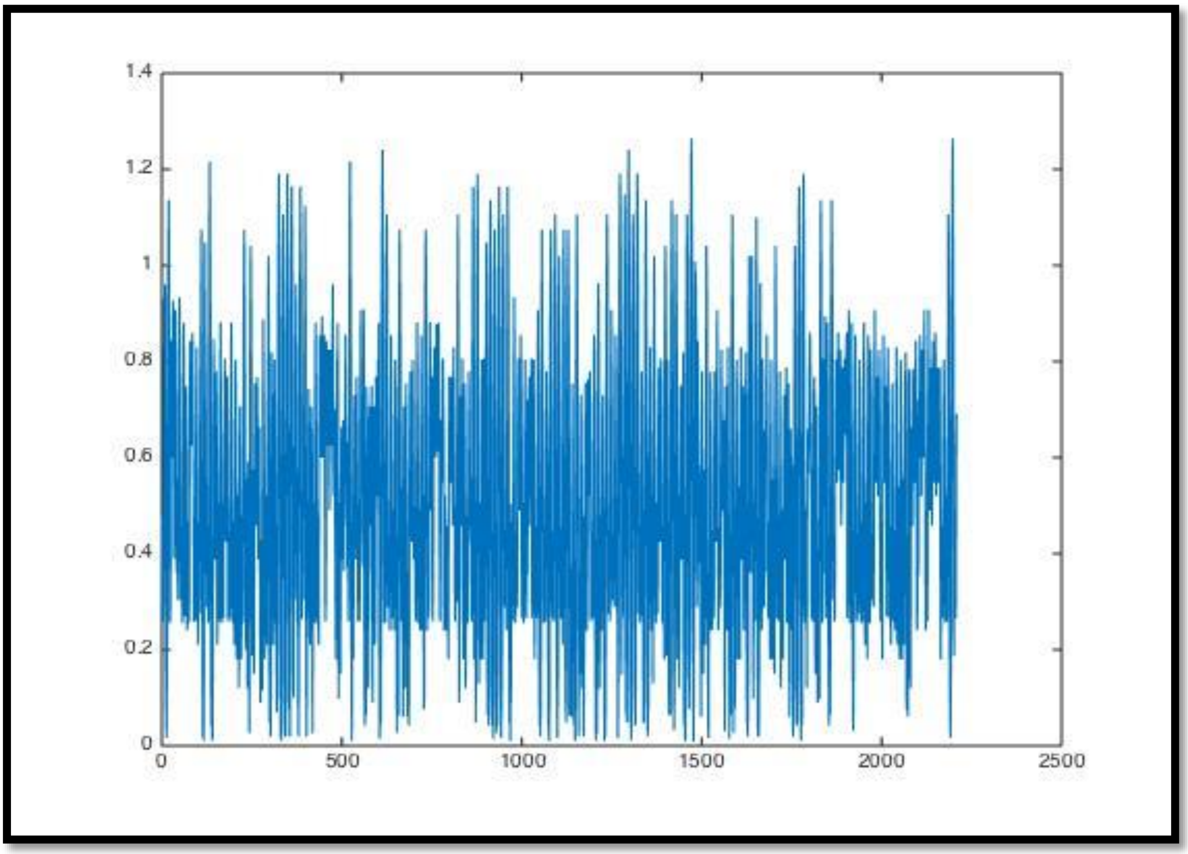

Figure 49: Plot of total current velocities changes (summer)

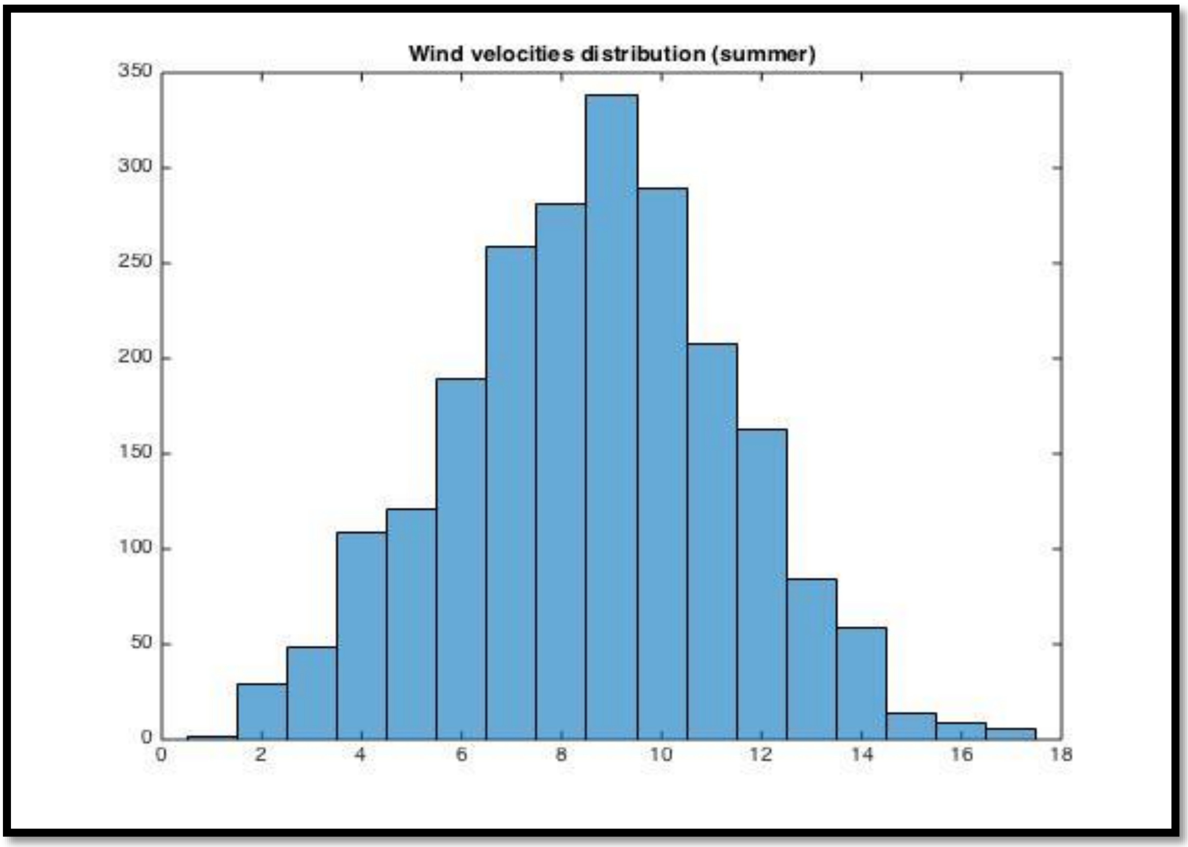

Figure 50: Histogram of wind velocities (summer)

The mean value of the actual wind speed equals 8,6 m/s. Maximum wind speed used in the simulation equals 17 m/s, Figure 50.

6.2.3 Forecast for fall

Simulated vectors of total current directions, simulated wind-current pattern due to actual wind data, total current pattern, histogram of wind current velocities, plot of total current velocities changes and histogram of wind velocities for fall are shown in Figures 51-57.

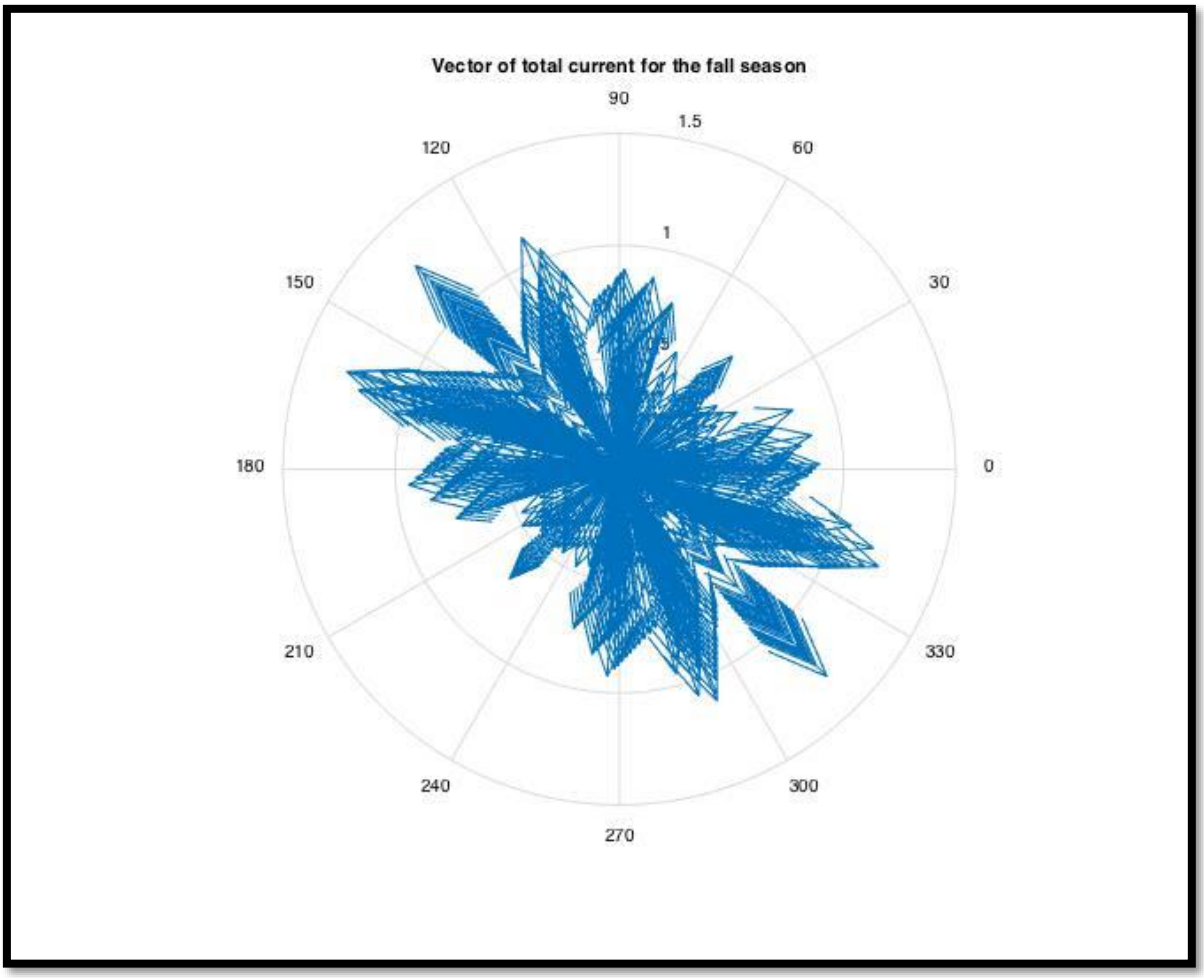

Figure 51: Simulated vector of total current directions for fall (1 hour step)

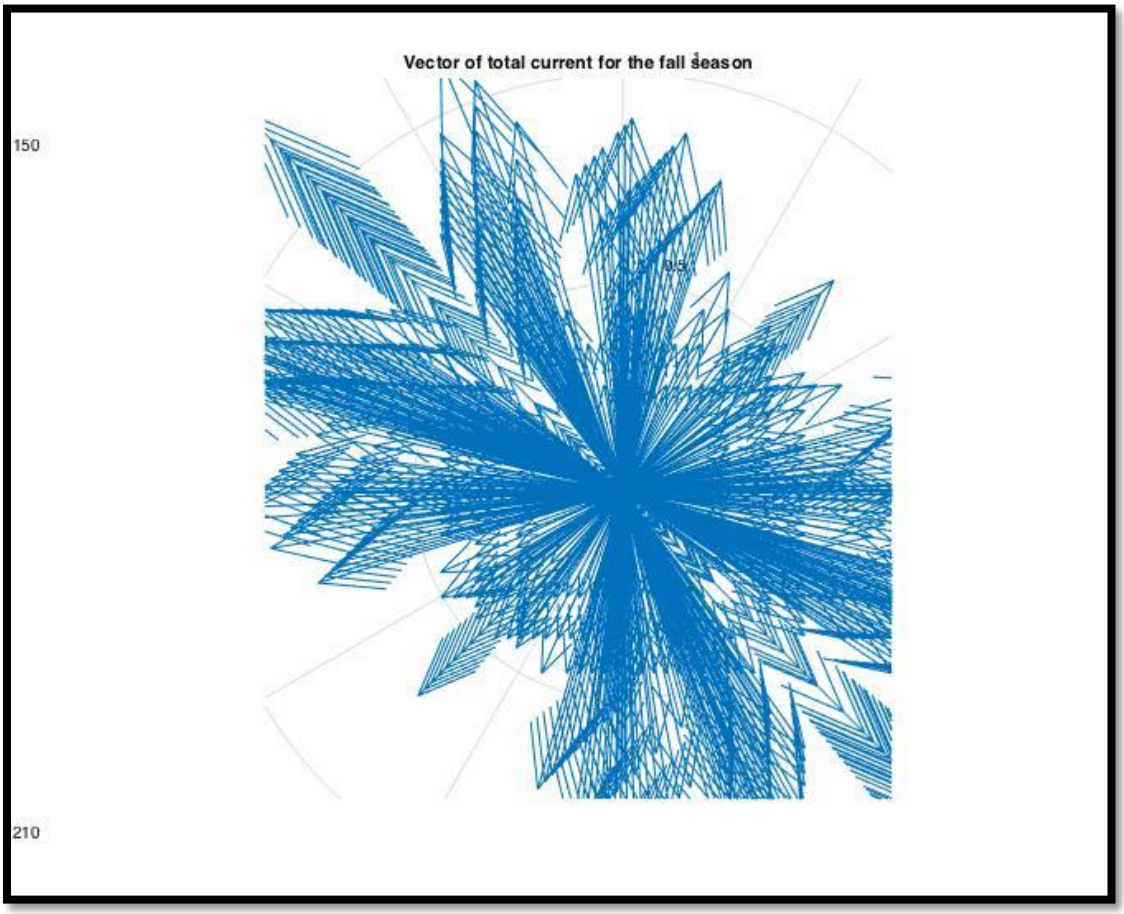

Figure 52: Scaled simulated vector of total current directions for fall (1 hour step)

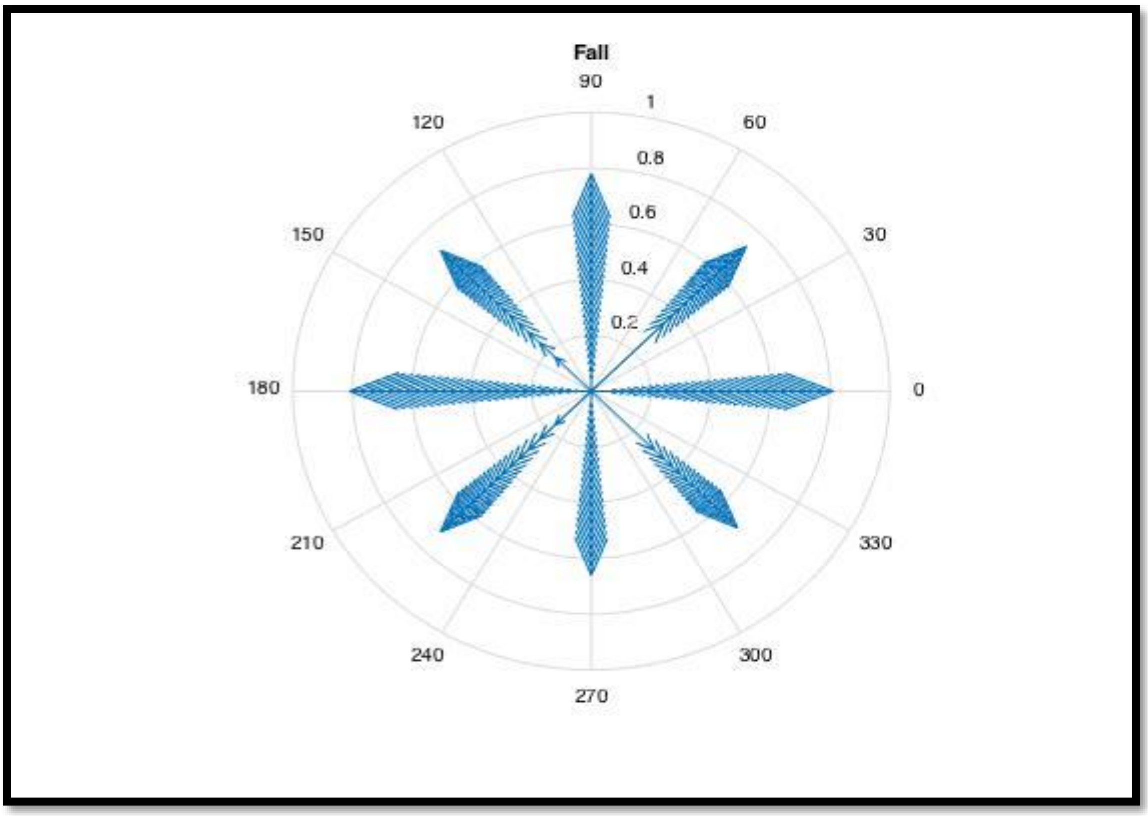

Figure 53: Simulated wind-current pattern due to actual wind data for fall

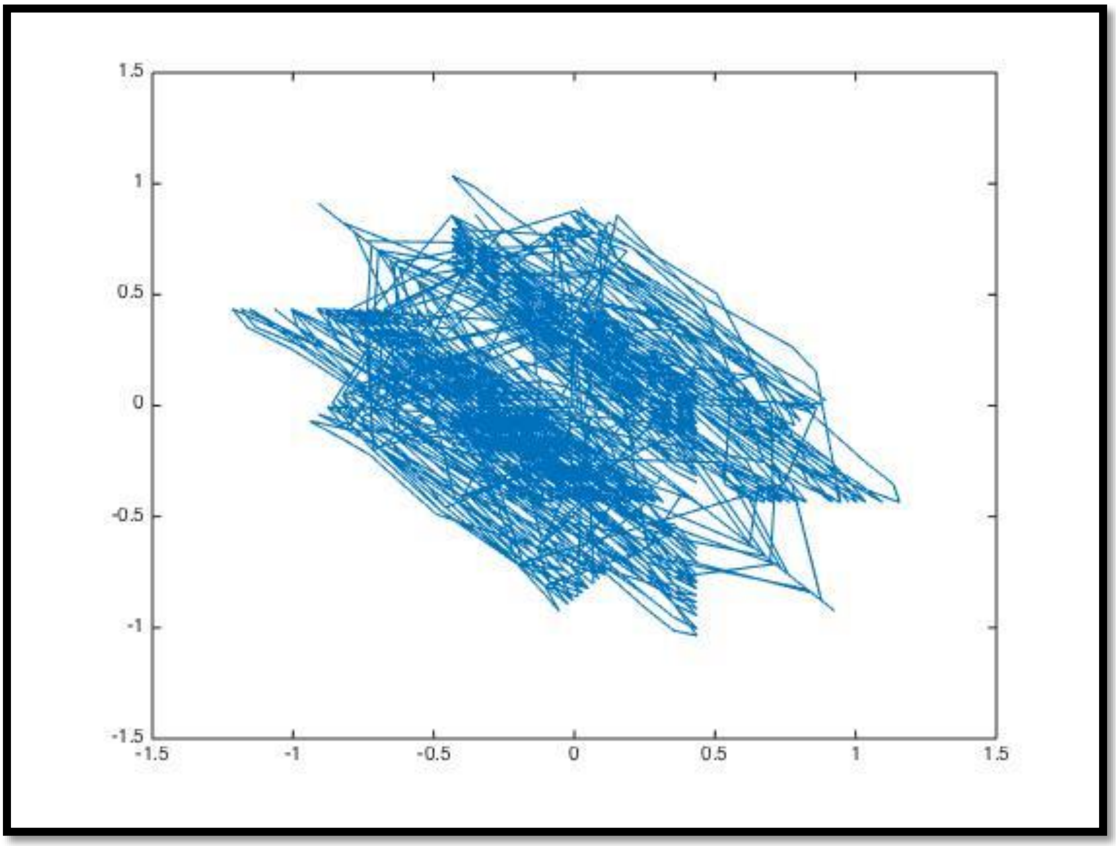

Figure 54: Total current pattern for fall

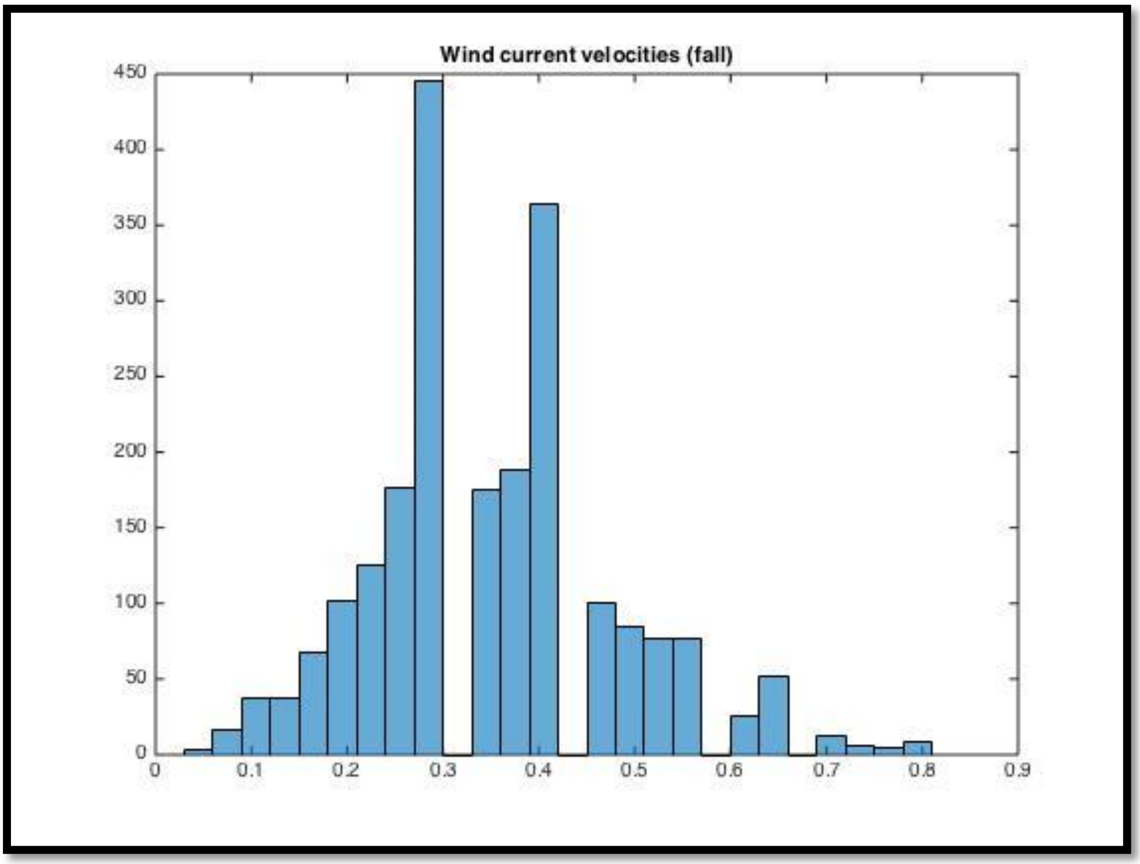

Figure 55: Histogram of wind-current velocities (fall)

Wind-current velocities do not exceed 0,8 m/s, but mean value equals to 0,34 m/s, Figure 55.

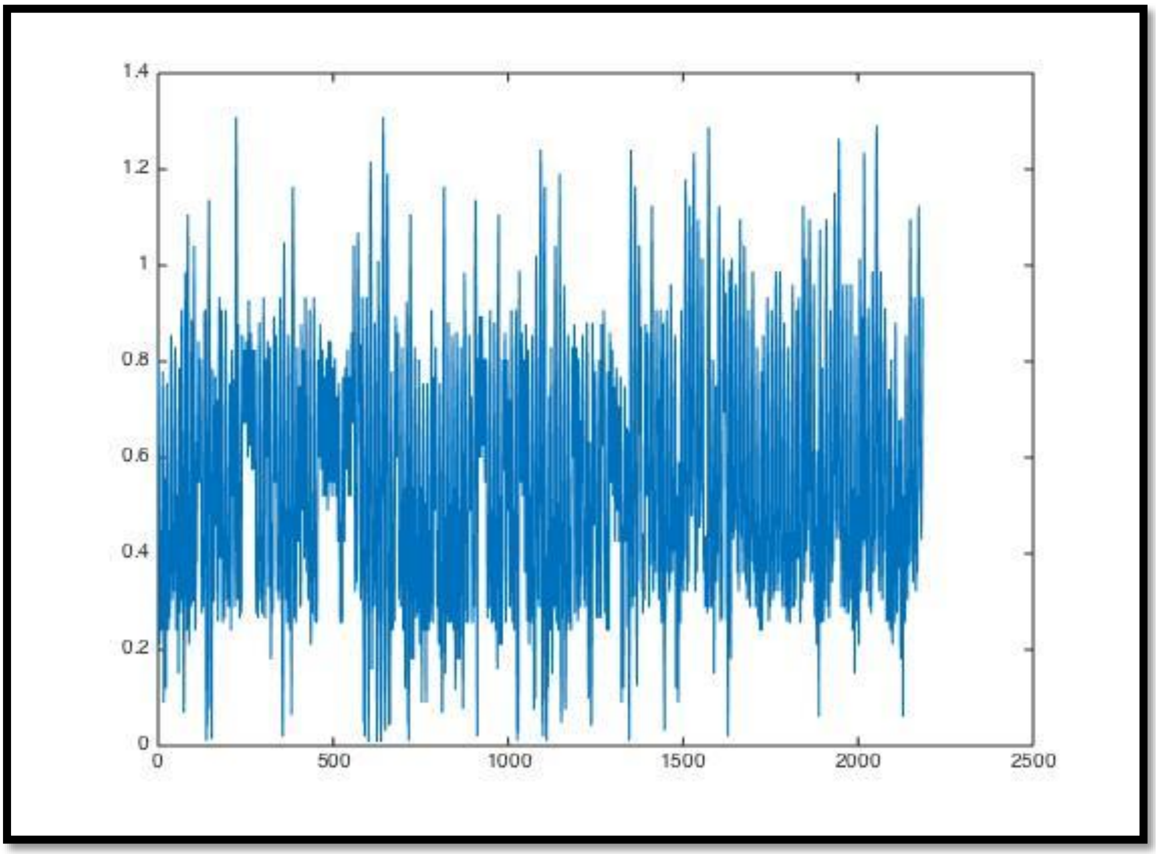

Figure 56: Plot of total current velocities changes (fall)

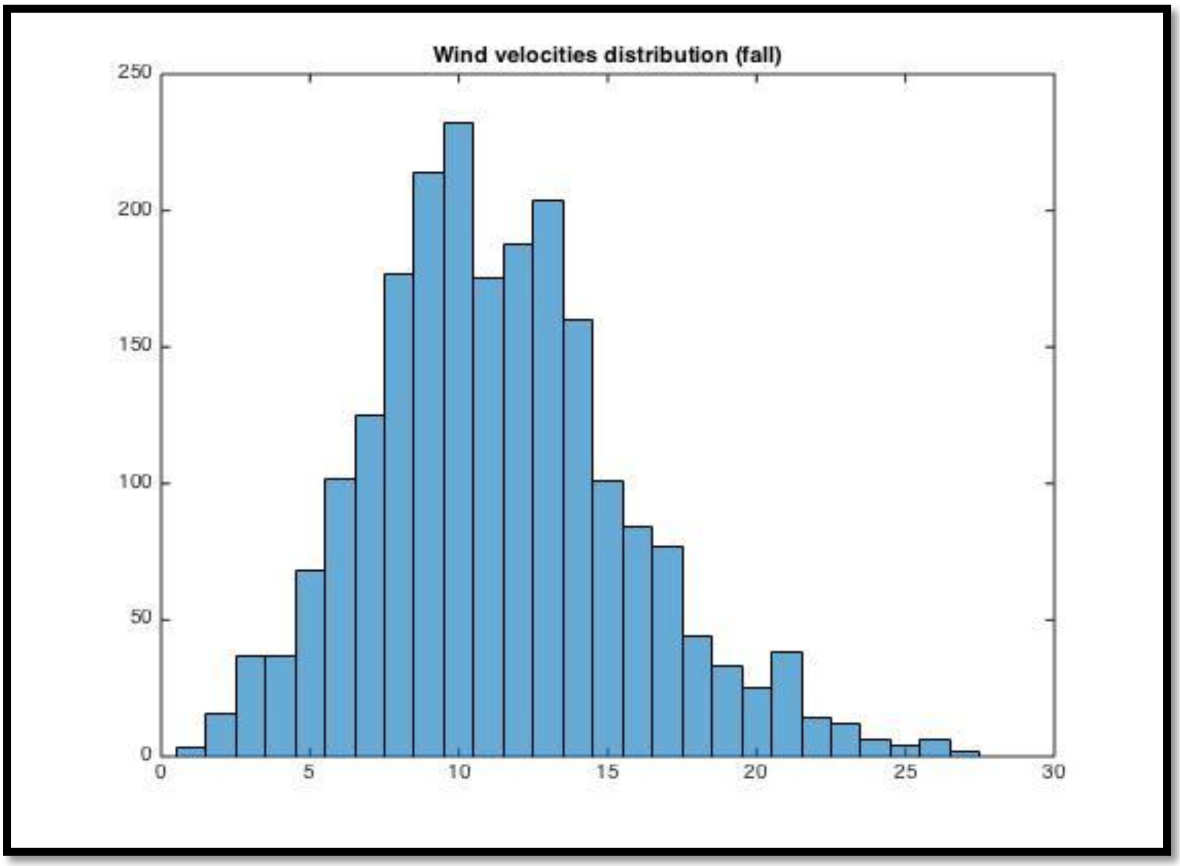

Figure 57: Histogram of wind velocities (fall)

The mean value of the actual wind speed equals 11,34 m/s. Maximum wind speed used in the simulation equals 27 m/s, Figure 57.

6.2.4 Forecast for winter

Simulated vectors of total current directions, simulated wind-current pattern due to actual wind data, total current pattern, histogram of wind current velocities, plot of total current velocities changes and histogram of wind velocities for winter are shown in Figures 58-64.

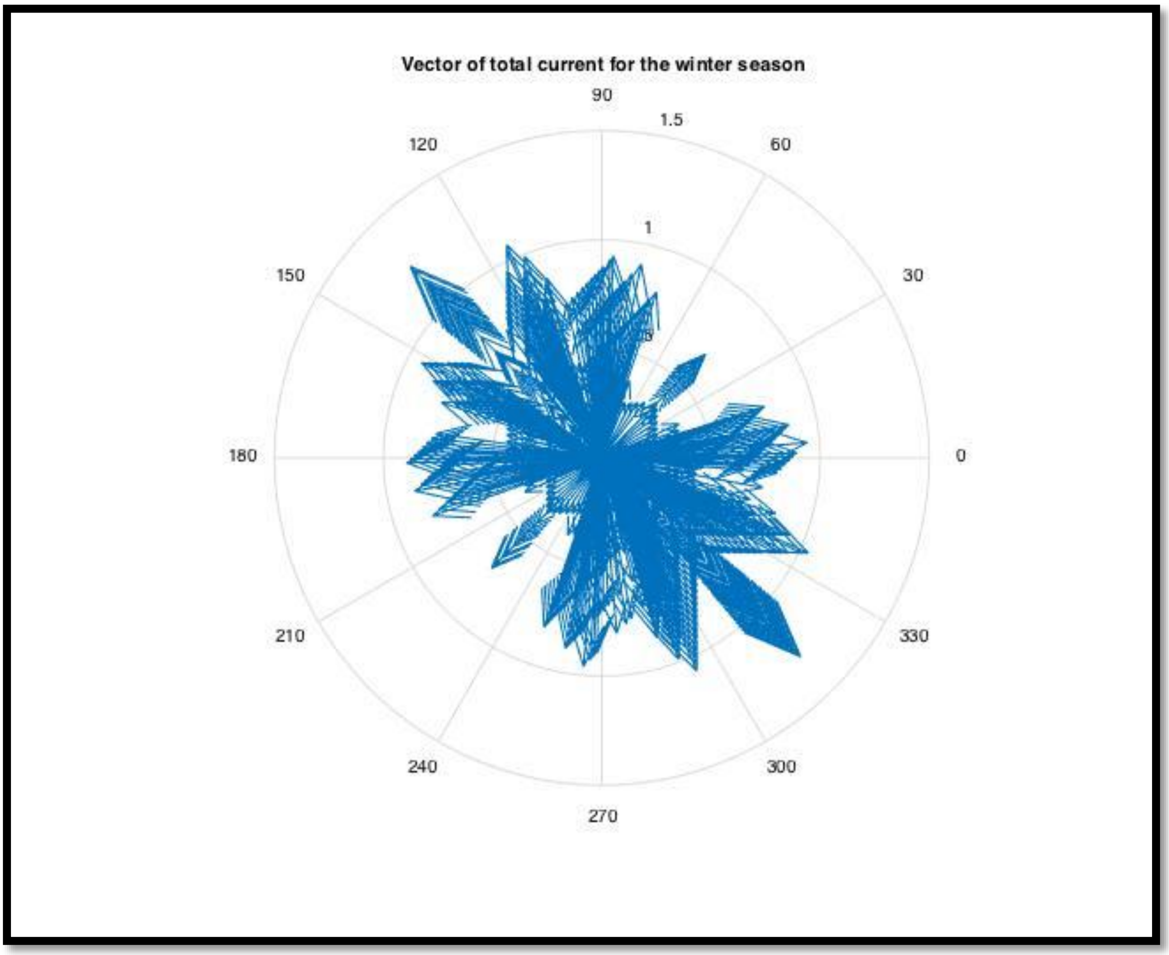

Figure 58: Simulated vector of total current directions for winter (1 hour step)

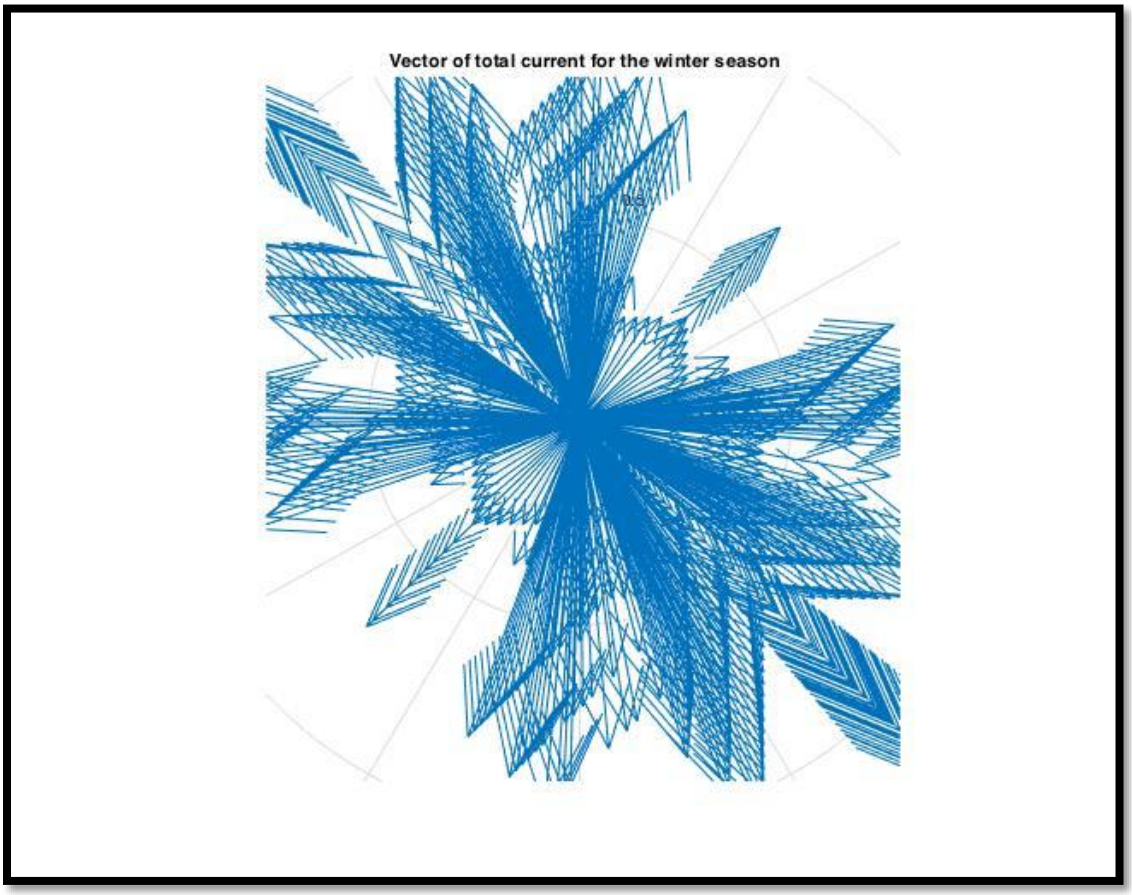

Figure 59: Scaled simulated vector of total current directions for winter (1 hour step)

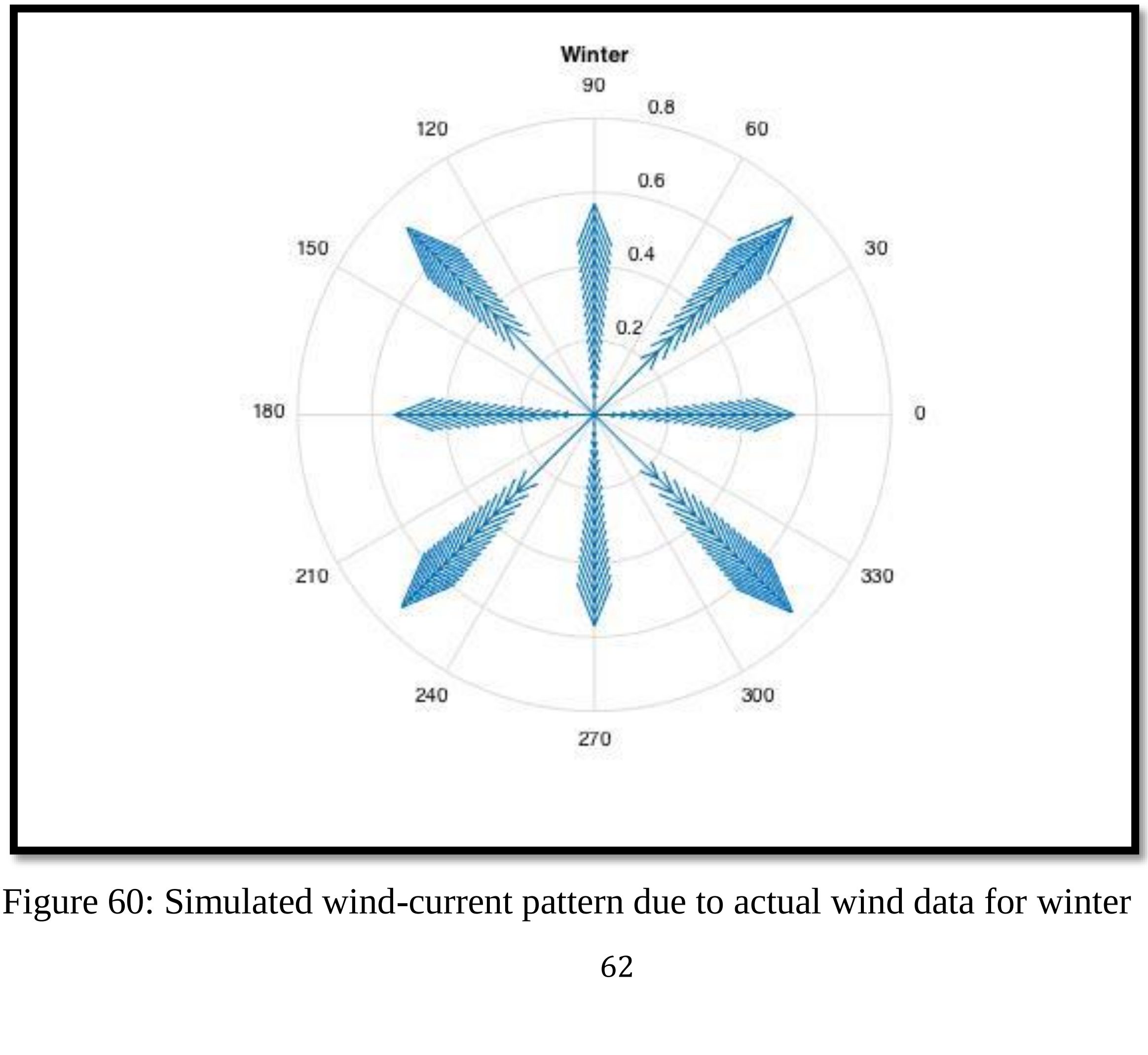

Figure 60: Simulated wind-current pattern due to actual wind data for winter

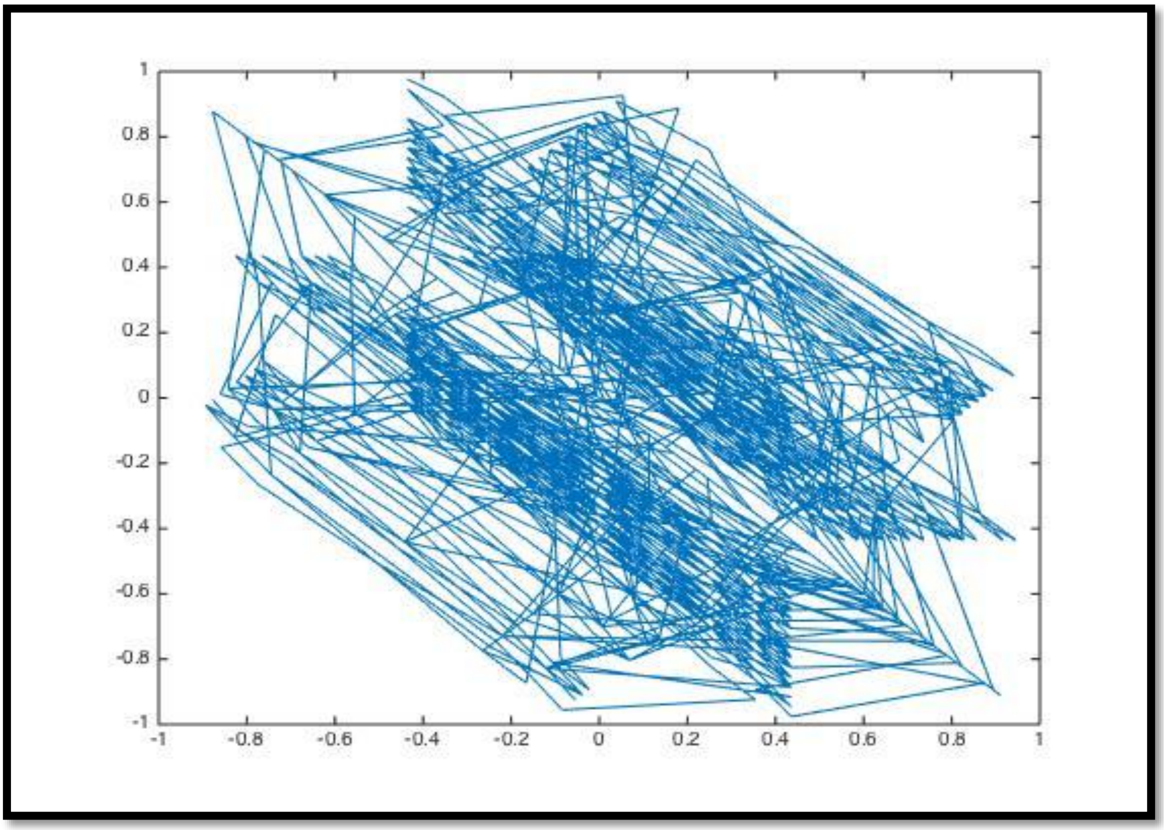

Figure 61: Total current pattern (winter)

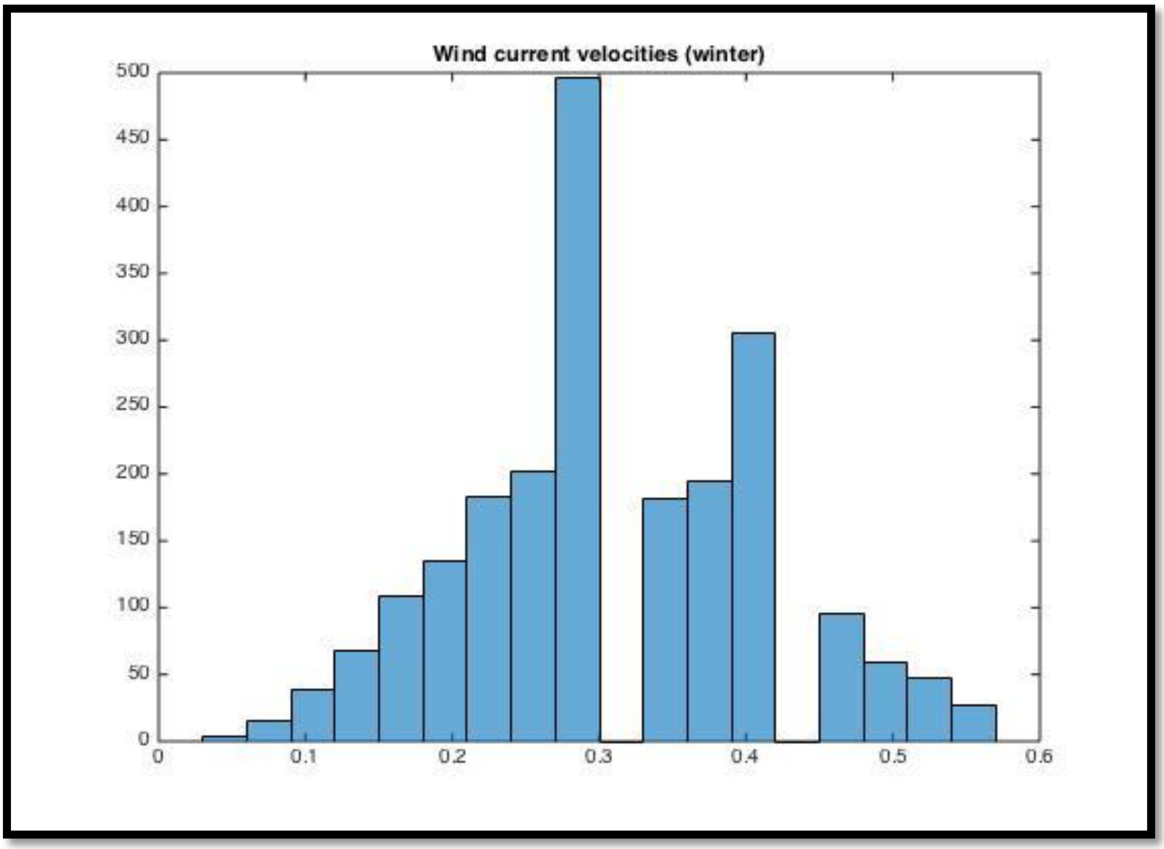

Figure 62: Histogram of wind-current velocities (winter)
Wind-current velocities do not exceed 0,54 m/s, but mean value equals to 0,3 m/s, Figure 62.

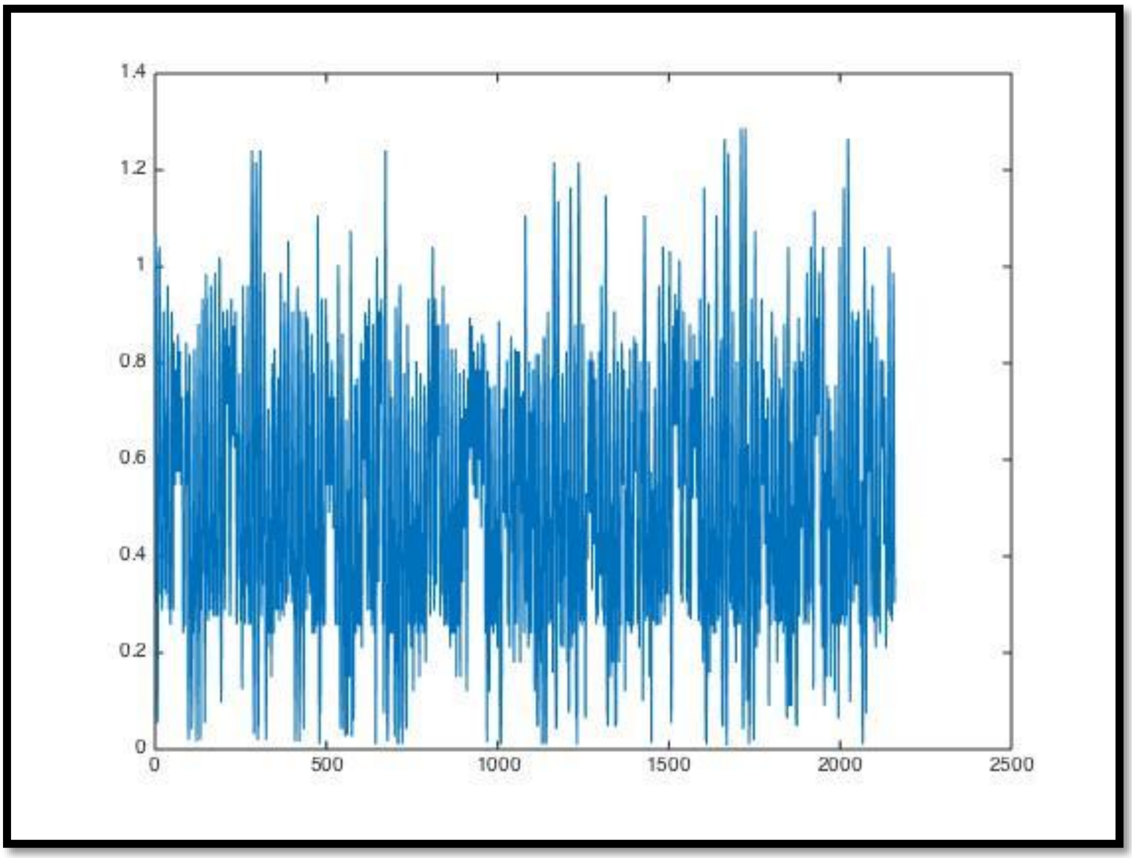

Figure 63: Total current velocities changes (winter)

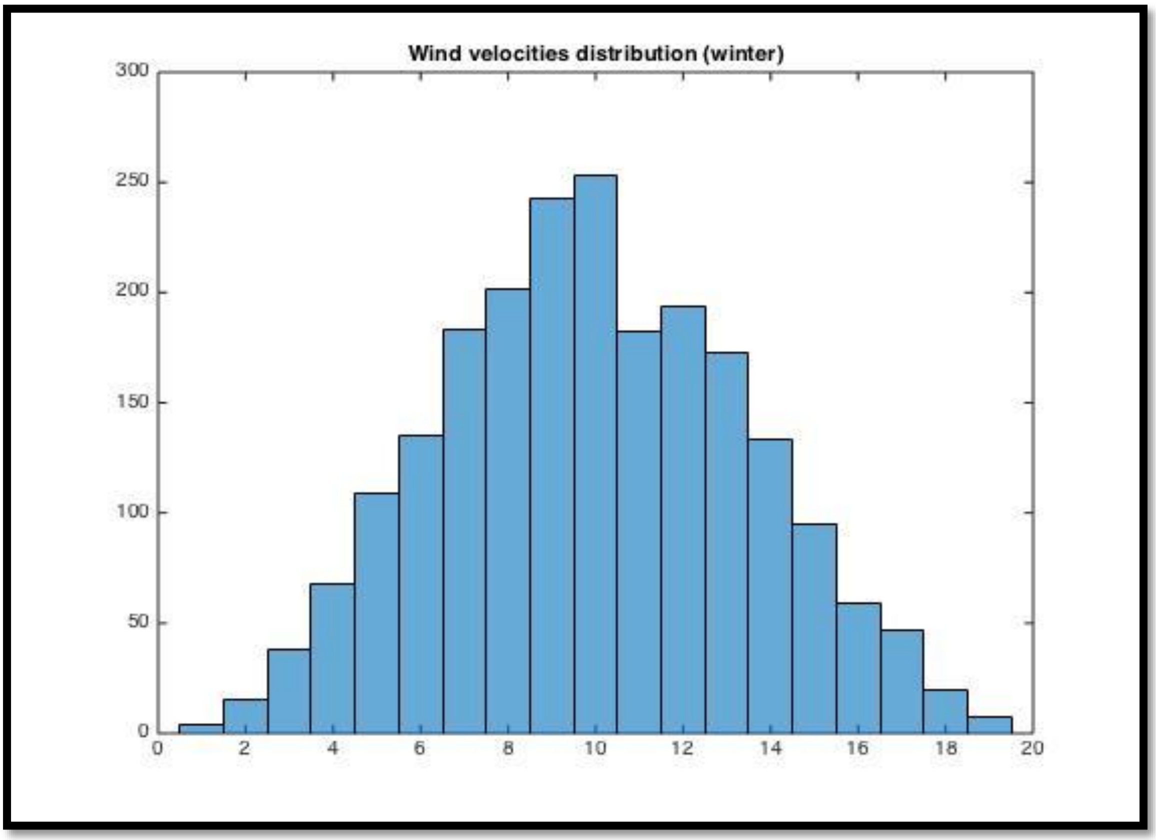

Figure 64: Histogram of wind velocities (winter)

The mean value of the actual wind speed equals 10 m/s. Maximum wind speed used in the simulation equals 19 m/s, Figure 64.

Results of the simulation for seasons demonstrate difficult current pattern for each season of the year. Maximum number of hours with wind speed exceeding 15 m/s is observed in fall (about 500), spring and winter seasons take second and third place (about 250 hours), summer season is characterized by the minimum windy hours exceeding 15 m/s among all seasons of the year (about 70).

The mean value of wind speed is almost at the same level for spring, fall and winter (10-11 m/s), while for summer a bit less (8,6 m/s), meaning summer season can be characterized by calmer wind conditions. The maximum wind speed during the year is observed in fall season (27 m/s).

Bigger number of hours of wind speed exceeding 15 m/s and mean value of wind speed equals 11 m/s result in stronger wind-current speed and more difficult total current pattern in fall season in comparison with spring, summer and winter. But for winter and spring we have to take into account ice conditions affecting the offloading. Especially in spring season, when we have the thickest ice in the year.

6.3 Pure offloading time calculations

As was described earlier, the period considered as weather window should be at least 5 hours. Time for connection, disconnection, system recognition and so on is about 2,5 hours. Intervals we are interested in have been singled out and the identified number of intervals with different duration and we got the following information for NW and SE offloading systems as shown in Tables 18 and 19.

The formula used for pure offloading time calculation is given below

$$t_{off} = \sum_{i=1}^{k} \left(t_{ww\,i} - t_{op}\right) \cdot n_i \qquad (3)$$

Where

t_{off} - pure offloading time for one of CUPONs, hours

$t_{ww\,i}$ - weather window duration, hours

t_{op} - time for connection, disconnection, nitrogen purging and so on

n_i - number of weather windows of i intervals

i – number of certain interval

k – number of intervals

Table 18: Pure offloading time calculation for CUPON NW

	Weather window duration, hours	Number of weather windows
CUPON NW	5	81
	6	17
	7	7
	8	2
	9	2
Pure offloading time, hours	379,5	

Table 19: Pure offloading time calculation for CUPON SE

	Weather window duration, hours	Number of weather windows
CUPON SE	5	92
	6	21
	7	10
	8	3
	9	3
	12	1
	15	1
Pure offloading time, hours	475	

So, the total pure offloading time during the simulated year from both CUPONs equals to 864,5 hours.

6.4 Results application

In order to estimate needed number of offloading pumps for the operation varying the total pumps capacity installed number of pumps on the platform have to be taken into account. There are 8 pumps for his purpose. Varying the capacity, needed number of offloading hours for the operation will be obtained. There is certain pump capacity coefficient taking into account not simultaneous start of all pumps due to different reasons. The first one can be connected with lack of work experience in stiff conditions and statistic. The second one is connected with needed time to reach certain level of capacity.

The experience of the platform exploitation shows, that current pump capacity coefficient equals to 0,82. Getting the statistic data and experience in offloading operations this coefficient can be increased up to 0,9. Taking into account both of them, the dependence between needed number of the pumps and needed offloading hours is shown in Table 20. Comparing those needed hours for the offloading with available due to weather windows the conclusion on the possibility to offload all the oil volume can be made.

For this purpose we need the following formulas:

Number of needed offloading hours:

$$n_{oh} = \frac{Q_{annual} \cdot 1000}{\rho_{oil} \cdot Q_{pumps}} \tag{4}$$

where

n_{oh}*- number of needed offloading hours*
Q_{annual}*- maximum annual production, tons*
ρ_{oil}*- oil density, kg/m*^{3}
Q_{pumps}*- total offloading pupms capacity, m*^{3}*/hour*

$$Q_{real} = \frac{Q_{pumps}}{\gamma} \tag{5}$$

where

Q_{real}*-real total offloading pumps capacity, m*^{3}*/hour*
Q_{pumps}*- total offloading pupms capacity, m*^{3}*/hour*
γ*- pumps coefficient*

Number of pumps, taking into the coefficient

$$n_{pumps} = \frac{Q_{real}}{Q_1} \tag{6}$$

where

n_{pumps}*- number of pumps, taking into the coefficient*
Q_{real}*-real total offloading pumps capacity, m*^{3}*/hour*
Q_1*=1250 m*^{3}*/hour, maximum pump capacity*

In Table 20 minimum needed hours for the offloading operations are marked by yellow. This case means the total capacity of pumps is on maximum level, and used number of pumps is maximum. Number of pumps exceeding installed on the platform is marked by red.

Table 20: Calculation of number of needed offloading hours depending on the offloading pumps capacity rate

Year of peak production	Average oil density, kg/m^3	Coefficient of pump capacity / efficiency			
	906	0,82		0,9	
Total offloading pumps capacity, m^3/hour	Number of needed offloading hours	Real total offloading pumps capacity, m^3/hour	Number of pumps, taking into account the coefficient	Real total offloading pumps capacity,m^3/hour	Number of pumps, taking into account the coefficient
6000	1214	7317,1	6	6667	6
6100	1194	7439,0	6	6778	6
6200	1175	7561,0	7	6889	6
6300	1156	7682,9	7	7000	6
6400	1138	7804,9	7	7111	6
6500	1121	7926,8	7	7222	6
6600	1104	8048,8	7	7333	6
6700	1087	8170,7	7	7444	6
6800	1071	8292,7	7	7556	7
6900	1056	8414,6	7	7667	7
7000	1041	8536,6	7	7778	7
7100	1026	8658,5	7	7889	7
7200	1012	8780,5	8	8000	7
7300	998	8902,4	8	8111	7
7400	984	9024,4	8	8222	7
7500	971	9146,3	8	8333	7

Table 20: Calculation of number of needed offloading hours depending on the offloading pumps capacity rate (continuation)

Year of peak production	Average oil density, kg/m^3	Coefficient of pump capacity / efficiency			
	906	0,82		0,9	
Total offloading pumps capacity, m^3/hour	Number of needed offloadin g hours	Real total offloading pumps capacity, m^3/hour	Number of pumps	Real total offloading pumps capacity, m^3/hour	Number of pumps
7600	959	9268,3	8	8444	7
7700	946	9390,2	8	8556	7
7800	934	9512,2	8	8667	7
7900	922	9634,1	8	8778	8
8000	911	9756,1	8	8889	8
8100	899	9878,0	8	9000	8
8200	888	10000,0	8	9111	8
8300	878	10122,0	9	9222	8
8400	867	10243,9	9	9333	8
8500	857	10365,9	9	9444	8
8600	847	10487,8	9	9556	8
8700	837	10609,8	9	9667	8
8800	828	10731,7	9	9778	8
8900	819	10853,7	9	9889	8
9000	809	10975,6	9	10000	8
9100	801	11097,6	9	10111	9
9200	792	11219,5	9	10222	9
9300	783	11341,5	10	10333	9
9400	775	11463,4	10	10444	9
9500	767	11585,4	10	10556	9
9600	759	11707,3	10	10667	9
9700	751	11829,3	10	10778	9
9800	743	11951,2	10	10889	9
9900	736	12073,2	10	11000	9
10000	728	12195,1	10	11111	9

Table 20 shows us, that for coefficient of pump capacity equals 0,82 number of needed offloading hours equals 888 (more than simulated 864,5 offloading hours) , while for coefficient of pump capacity equals 0,9 needed offloading hours equals 809 (less than simulated 864,5 offloading hours).

If wind and current conditions will be almost as simulated or worse, having the pump coefficient at the same level we will have the offloading problems. We need to aspire to increase this coefficient and foresee some additional procedures or technologies for that.

We have to think about possible threats and try to avoid or reduce them. We will consider this situation as a risky event in the chapter regarding safety and risk analysis.

Chapter 7. Analysis of possible concepts of offloading terminal for the Pechora Sea fields

7.1 Requirements for different offloading concepts

The offloading terminal should be designed taking into account the environment where it will operate. Mostly this includes an ice motion. It should be noted, that the tanker has to be designed in accordance with ice conditions it will operate in. Standard ISO was used to distinguish the difference between the concepts (ISO 19906:2010).

We can divide offloading terminals into several categories.

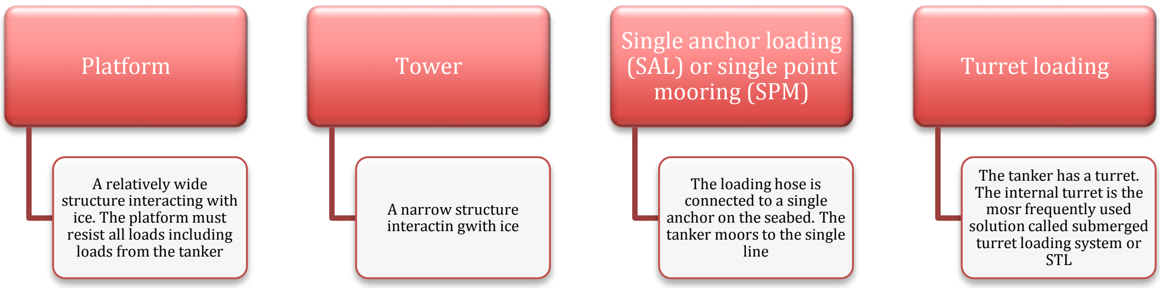

Figure 65: Offloading concepts

Platform

Usually it is the production platform creating the wake, where the tanker connects to the loading arm mooring to the platform. The tanker has a limited capability to stay in the protection zone. Since ice drift direction is changed the tanker has to be disconnected several times before the offloading operation is finished.

Tower

The tower can be placed some distance away from the production platform or the vessel like FPSO. The loading arm is installed on the tower designed to withstand all ice loads.

Single anchor loading

The loading line and the hose are lowered on the seabed when they are not used. There are designs of the loading hawser with protection and without it. The design without protection implies reinforcement of the hawser.

The weak point of this concept is limited capacity to resist ice actions. This implies ice management for safe offloading operation.

Turret

The system should withstand all loads to the mooring system. Ice ridges represent additional challenge for the concept. This implies robust design of the riser system subjected to loads from ice floes and ice pieces under the tanker as well (ISO 19906, 2010).

In the Arctic conditions with harsh environment and areas of increased requirements for safety, health, environment the offloading option with fast and safe disconnection at the same time is more preferable.

Let us consider disconnecting concepts for offloading in the Arctic conditions (Figure 66). According to severity of sea conditions and surrounding environment (ice ridges, ice coverage) downtime will be different for different concepts with disconnection.

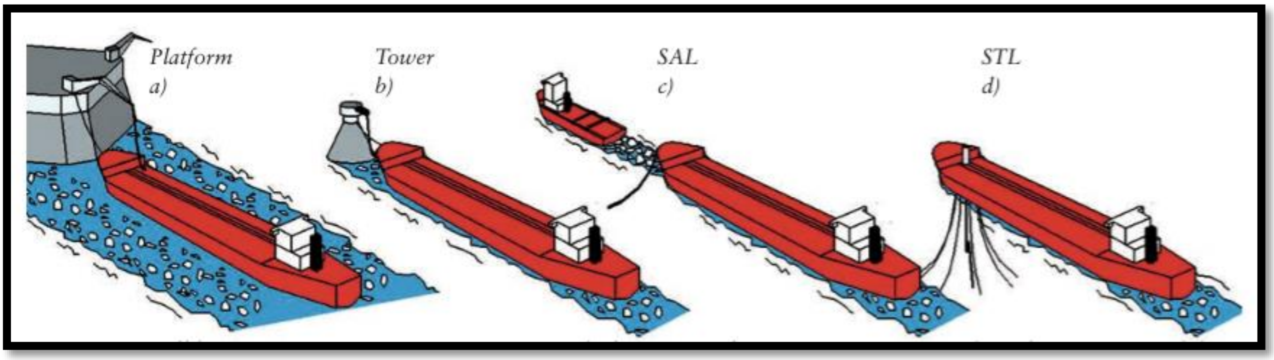

Figure 66: Different mooring concepts in the Arctic (a- mooring at a platform corner, b- tower mooring, c- SAL (single anchor mooring), d- STL (submerged turret loading))

For the concept with the offloading at the platform corner (even with the implementation of ice management) ice drift downtime is higher than for other concepts. According to made ice drift analysis suggested relation of ice drift downtime versus minimum loading window is shown in Figure 67 as well as risk matrix based on the difference of described concepts.

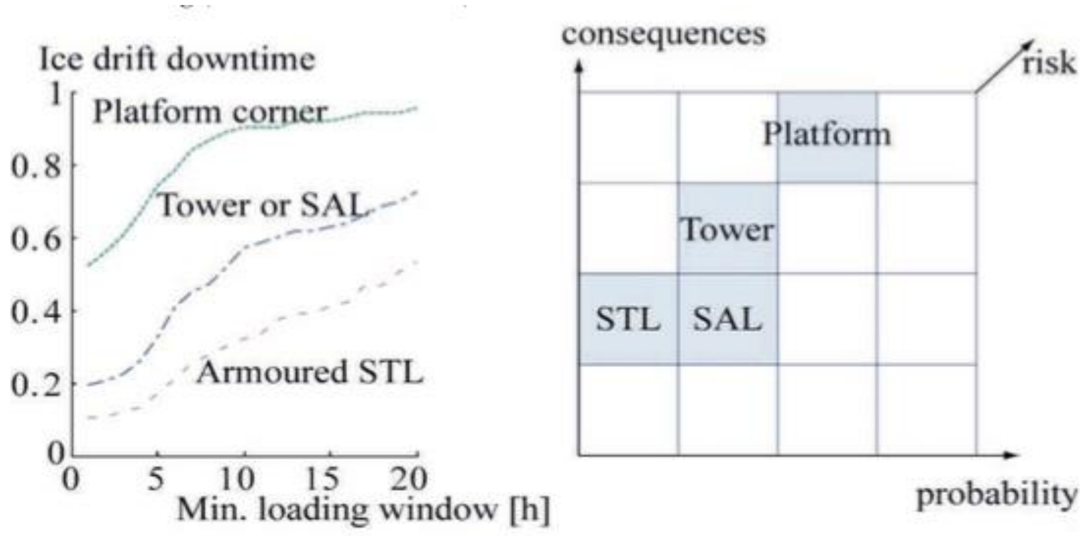

Figure 67: Ice drift downtime vs. minimum loading window and risks matrix for different concepts of offloading (Analysis of ice drift measurements at the Prirazlomnoye field in 1998, Bonnemaire, 2005b)

Let’s analyze the left diagram in the Figure 67. For the concept of offloading at a platform corner and minimum loading time equals 5 hours, as in case of the Prirazlomnoye field, ice drift downtime equals 0,7 hours, meaning that it will be higher as loading window at minimum (Bonnemaire B., 2005b)

As we see from the Figure 67 probability of hazard events and its consequences vary depending on the concept chosen for offloading. In case of the concept with the platform – risks associated with the offloading are higher because of the frequency of tanker relocations and critical drift events, consequences of such events are higher due to possibility to collide with the structure and because of the loading line rapture in case of critical drift events.

There is another option that can be implemented for the transport of hydrocarbons in the Pechora Sea conditions. It is not the offloading from the terminal, but subsea completion and hydrocarbon transportation by pipelines. Every possible solution for the offloading has to be considered in details taking into account the set of affecting factors as well as economical, technical and technological feasibility.

There is one more idea to develop the Pechora Sea fields called cluster fields development. It includes identification of suitable place for installation of ice-resistant terminal and connection of production platforms to the terminal. The advantage of this concept is possibility to load oil to tankers, which can rotate around the terminal during offloading without restrictions on working angles of the system (Efimkin, 2015)

Factors influencing on the ice drift downtime and on risks associated with offloading are shown in Figure 68 below.

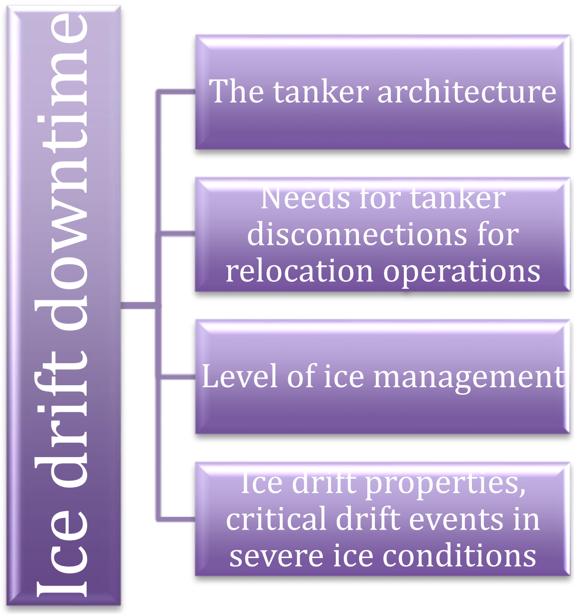

Figure 68: Factors affecting ice drift downtime

7.2 Ice management

Ice management is the sum of all activities where the objective is to reduce or avoid actions from any kind of ice features. (Yulmetov, 2014)

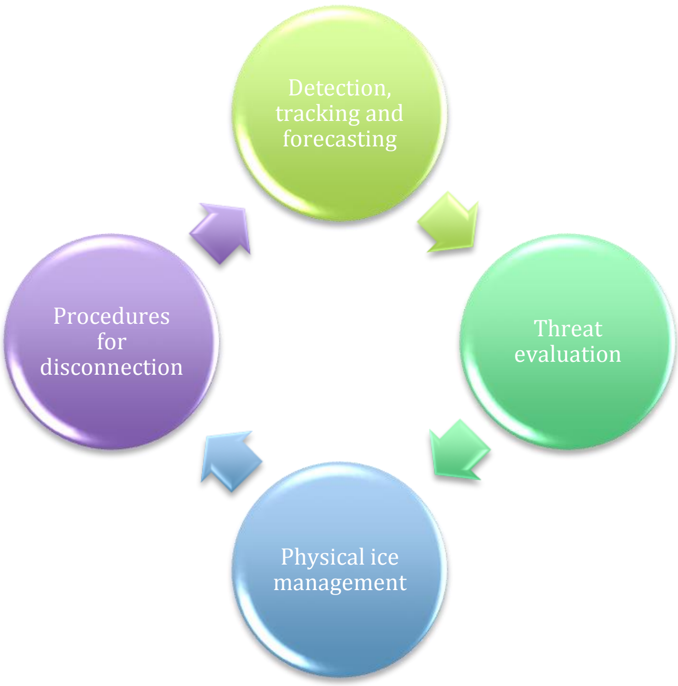

Figure 69: Ice management cycle

Ice management can solve the problem of ice ridges presence, the change of ice drift direction and icebergs presence. Necessary volume of ice management can be chosen based on the existing experience of offshore field development. It can be re-estimated during the field development, improving the cost and efficiency of each project in particular.

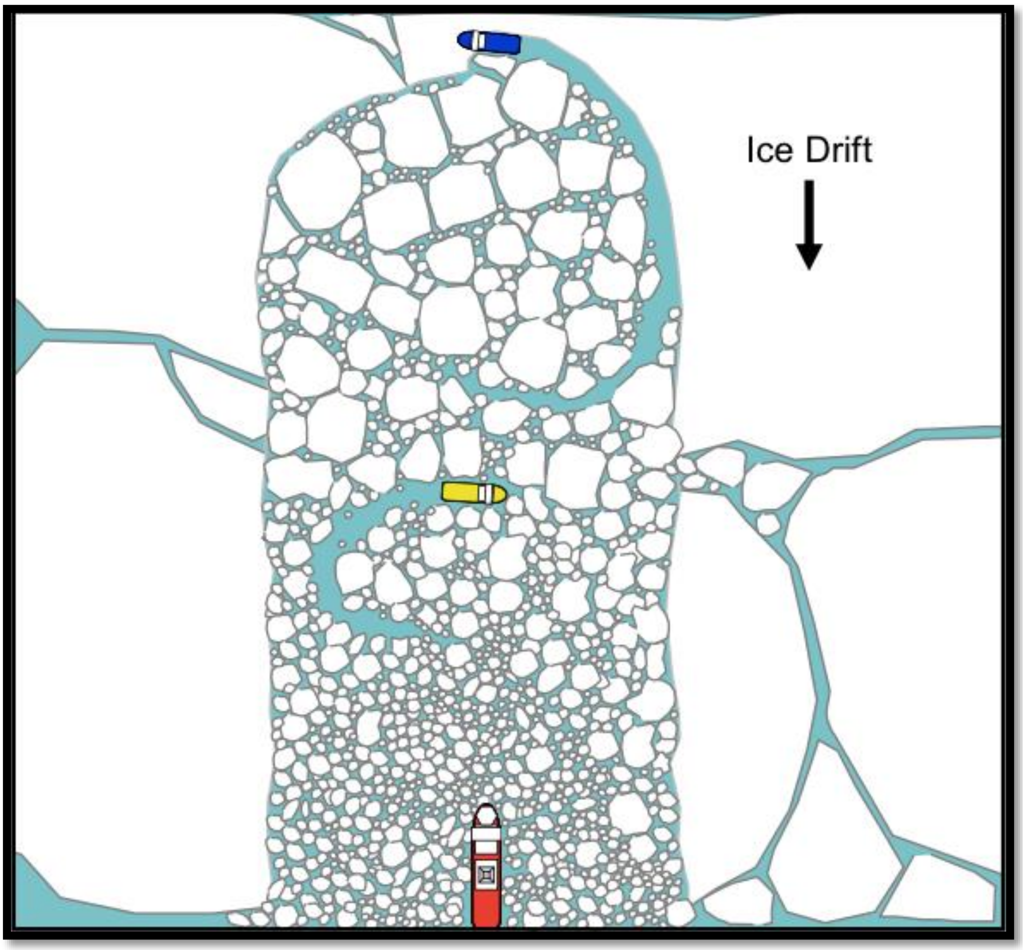

Figure 70: Two staged ice management, where the reduction of ice floes sizes leads to safe offloading due to acceptable loads on the vessel in operation (Hamilton et al., 2011)

There are two supply vessels, Figure 70, acting for ice management by reduction of ice floes sizes in several stages. The blue one breaks ice into relatively big floes, while the yellow one does it in much smaller floes. Thus, the red one, making the offloading, is protected against big ice loads and can operate safe and efficiently. This is just the example of how it can be done in real conditions. But nowadays we have quite huge set of technologies making implementation of marine operations more simple and robust. (Hamilton et al., 2011)

Chapter 8. Resistance of ships in ice

Great efforts has been made for estimation of the performance of ships in ice conditions. They are based on empirical relations. These empirical relations can be obtained from full-scale data, when ships move in ice, or model-scale data, when the data can be obtained from tests in ice basins. We will use an algorithm we consider is the most suitable. (UNIS AT-327/827 Arctic Offshore Engineering, Svalbard, 2014)

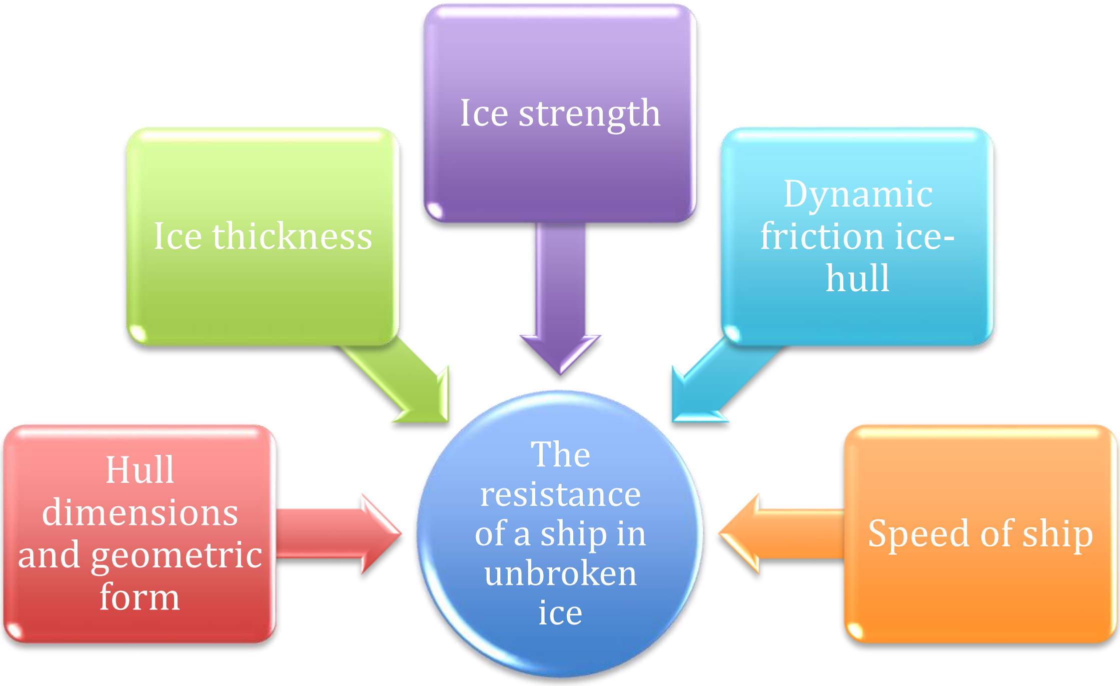

Figure 71: Main parameters affecting the resistance of a ship in unbroken ice

Other factors are snow cover on the ice, its temperature and wetness.

8.1 Resistance calculation

For calculations let’s use Table 9 and ice drift thickness in the range from the range 0,55-1,2 shown in Table 16.

Model 1: resistance in unbroken level ice.

This model (1) is based on data acquired from a number of sea trials with ships (Keinonen; 1991, 1996) covering a range of ship sizes and bow forms as well as ice conditions. It takes into account:

- ship size
- bow form

- type of propulsion
- friction
- snow conditions
- ice conditions.

1) The prediction equation for resistance (units MN) in unbroken level ice, normalized to a speed of 1 m/s, has the following form.

$$\begin{aligned} R_{ice} &= 0.015 HC \cdot S & (7) \\ &\times B^{0.7} L^{0.2} D^{0.1} h^{1.5} & \leftarrow \textit{ship size term} \\ &\times (1 - 0.0083(T + 30)) & \leftarrow \textit{friction term} \\ &\times (0.63 + 0.00074\sigma_f) & \leftarrow \textit{ice strength term} \\ &\times (1 + 0.0018(90 - \gamma)^{1.6}(1 + 0.003(\beta - 5)^{1.5}) & \leftarrow \textit{bow form term} \end{aligned}$$

where

HC – hull condition factor

S – factor for salinity of water

B – ship beam (m)

L – ship waterline length

D – draft (m)

h – equivalent ice thickness;

$h = h_i + h_s$ *(m)*

where hi (m) and hs (m) is ice and snow thickness

T – ice surface temperature (°C)

σ_f *- flexural strength of ice (kPa)*

γ – average bow flare angle at waterline (°)

β – average buttock flare angle at waterline (°)

The ship size terms are displayed in Figure 72.

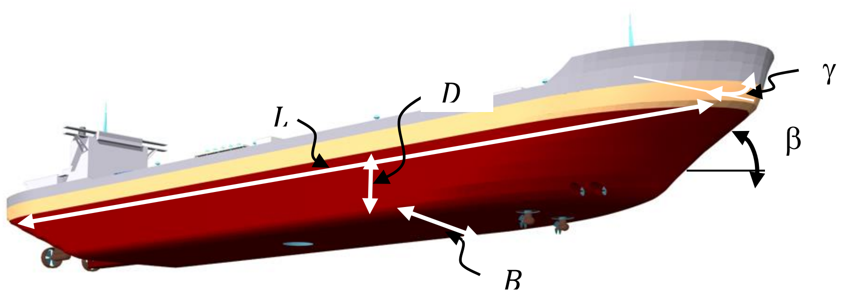

Figure 72: Characteristic ship hull parameters

For the situation of ice drift direction change during the offloading, as it is shown in Figure 83, we assumed ice drift speed normalized to 1 m/s and the tanker location is not changed under the control of DP system during offloading. Ice is starting to act on the board of the tanker. Basically the idea is the same. Tanker thrusters need to act against exerted resistance, where the ice is moving, but the tanker is keeping the position.

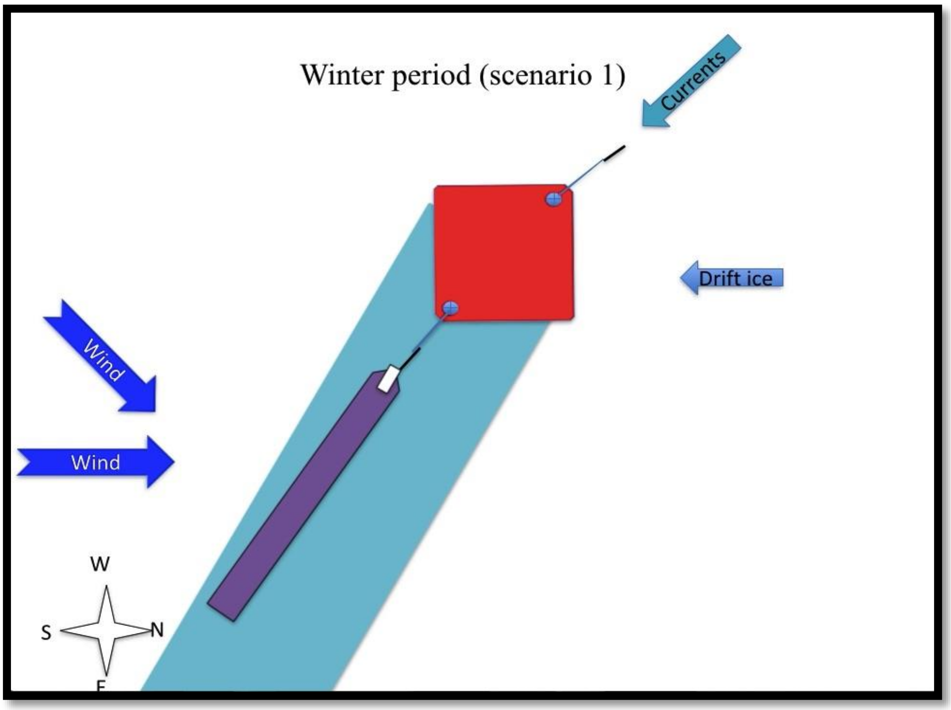

Figure 73: Winter scenario, unbroken ice. Sudden change of ice drift direction due to wind

So, the resistance of the tanker in unbroken level ice at speed 1m/s :

$$R_{ice} = 1{,}1 \text{ MN}$$

2) Keinonen (1996) has also modified Eq. (2.1) to include the influence of speed. The additional resistance at speeds greater than 1 m/s is given by the following relation (units in MN):

$$\begin{aligned} R_{ice}(V > 1\,m/s) = 0.009HC\,(\Delta V/(gL)^{0.5}) & \\ \times B^{1.5}D^{0.5}h_i & \quad \leftarrow \textit{ship size term} \\ \times(1-0.0083(T+30)) & \quad \leftarrow \textit{friction term} \\ \times(1+0.0018(90-\gamma)^{1.6}(1+0.003(\beta-5)^{1.5}) & \quad \leftarrow \textit{bow form term} \end{aligned} \tag{8}$$

where

$\Delta V = V - 1$ *(units m/s)*

g = 9.81 m/s

Note that the velocity dependent component of resistance is linear in both V and h_i

In the case of ice drift speed equals to 1 m/s this term will be equal to zero.

$$R_{ice}(\mathrm{V} > 1) = 0 \text{ MN}$$

The open water resistance (MN) is given by

$$R_{ow} = (Displ)^{1.1}(0.025F_n + 8.8F_n^5)/1000 \qquad (9)$$

where

$Displ = \rho_w LBDC_b$ (tons)

ρ_w - density of sea water (1.03 tons/m3)

Cb – block coefficient

$F_n = V/\sqrt{gL}$ (Froude number)

The total resistance is given by the sum of Eq. (2.1-3).

$$R = R_{ice} + R_{ice}(V > 1\, m/s) + R_{ow} \qquad (10)$$

Note that equations 7,8 and 9 will differ for different hull shapes.

Thrust calculation

Open water thrust at maximum power absorbed (units MN) is

$$T_{ow} = 0.75P_s(0.122 - 0.0057V) \qquad (11)$$

$$T_{ow} = 1{,}48 \text{ MN}$$

where P is shaft power (units MW). Note that for an open fixed pitch propeller only 75 % of shaft power is absorbed at maximum speed.

Running in ice is an overload situation and the maximum thrust is given by

$$T_{max} = P_s(1 - 0.25V/V_{\max})(0.111 - V(0.0057V_{\max} - 0.011)/V_{\max}) \qquad (12)$$

For ice drift speed of 2 m/s maximum thrust equals to 1,64 MN

Note that equations 11 and 12 will differ for different propulsion systems.

The maximum speed, Vmax, in ice is determined when maximum thrust from equation (12) and the total resistance from equation (10) are in balance.

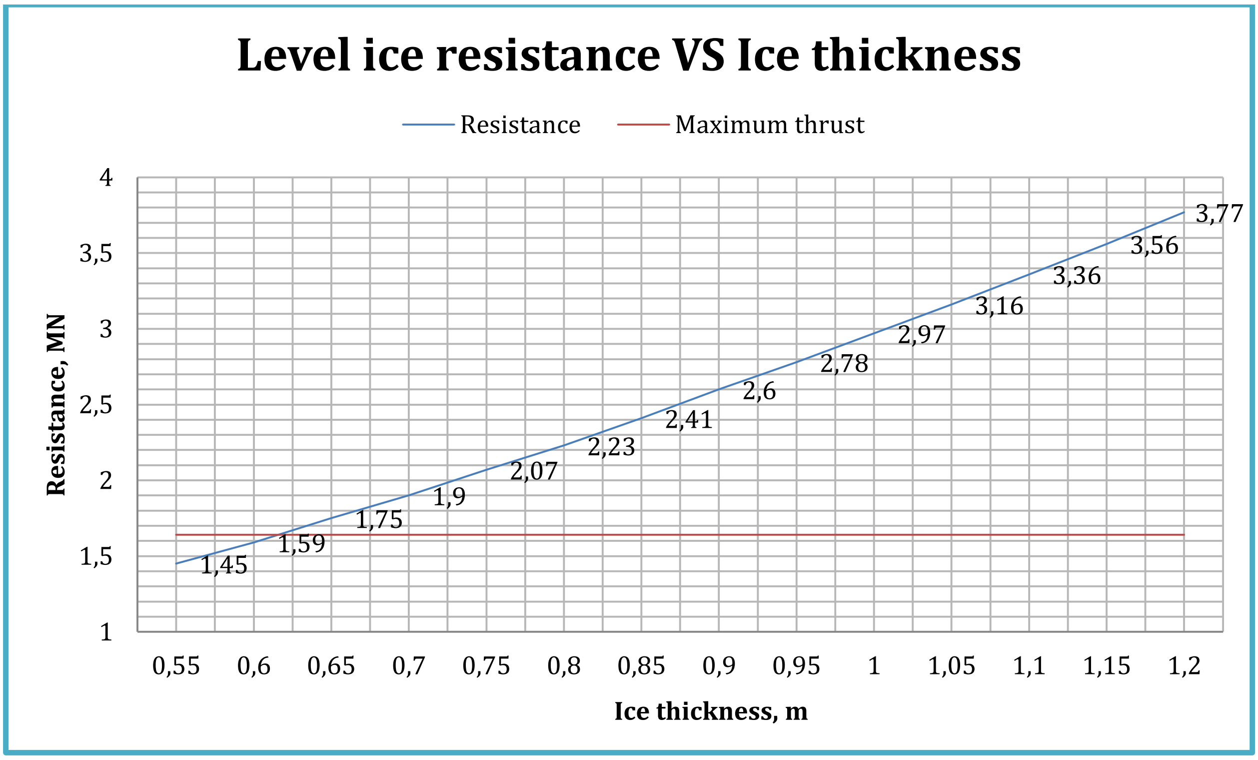

Figure 74: Relation between ice thickness and level ice resistance for the tanker

As we see from Figure 74, for the case when ice acts on the tanker board, the maximum possible ice thickness of level ice where thrust is equal to resistance equals 0,62 meters. Otherwise the tanker will be shifted from the kept position.

Thus, tanker needs either multifunctional icebreaker support vessels assistance for the operation or disconnection.

Chapter 9. Safety of the offloading operation

If to take into account conditions of the field development and oil transportation from the Prirazlomnaya platform according to its complexity and structure of technical facilities involved in the transportation, it has no analogs in the world practice.

As it has been said safety of the offloading operation is provided by three levels emergency shut down system (ESD).

Training session has been organized by “Gazprom Neft Shelf” LLC to adjust approach of the tanker “Kirill Lavrov” to the platform. It was done on the basis of Krylov State Research Centre training complex. This training complex is equipped with virtual models of all objects participating in oil offloading. There is also a possibility to imitate the work of the CUPON system and deck-mounted cranes. During the training session collaboration of the shuttle tanker crew, MISV crew and the platform crew were worked through approach operations, mooring, hose connection, retention of the tanker in prescribed sector during the offloading and departure of the tanker. All operations have been carried out in dynamic conditions of the sea. All operations have been worked through normal mode as well as emergency operation.

In order to keep the platform in operational conditions all-the-year-round in high ice conditions two multifunctional icebreaker supply vessels (MISV) have been constructed by request "Gazprom Neft Shelf" LLC. They are "Vladislav Strizhov" and "Yurii Topchev". They are designed to provide all-year service of the platform and to keep tankers during offloading operations. Planner of these vessels is the company Moss Maritime (Norway). Manufacturer is the company Havyard AS (Norway). Each MISV has a dynamic positioning system as well as ability to move stern first in ice conditions. They also have modern system of navigation and control (Yamshchikov, 2013).

Two MISV are needed for safety implementation of the offloading in ice conditions. One of them is supposed to be a tug in case of the tanker propulsion system failure, while another one is ice-breaking support (Gazprom Neft shelf» LLC, 2014a). In case of the failure of one of the MISV the third MISV, that is called "Vengery", was engaged in operation in January 2014. The vessel has all needed equipment satisfying the world's standards. The vessel also can be used for accident elimination such as oil spills in ice-free water as well as in ice conditions (Gazprom Neft shelf» LLC, 2014b).

Six offloading operations have been already done (Gazprom Neft shelf» LLC, 2015a). It means that practical experience of the company is limited. The experience will be used for the development of future projects. Now it is more important do not get bad experience, but prevent emergency situations.

To carry out risk analysis as well as to take measures on increasing of the system reliability are incredibly important in order to be able to provide safety operation.

9.1 Qualitative risk analysis

In this part of the project the oil offloading operations from the platform Prirazlomnaya to one of the shuttle tankers is considered. Let's introduce some definitions needed further.

Hazard is something that can be dangerous for safety, health, environment, assets and reputation.

Risk is something we can specify as the probability of the event and its consequence.

Acceptance criteria used as a foundation for decisions about acceptable risks of the offloading operations are listed below.

- ***Safety for personnel***

It is impossible to exclude accidents at all. It can be described by choosing fatal accident per 10^8 hours (FAR). For offloading operations a FAR < 2 is accepted (for a rig <10).

- ***Environment***

It is allowable to have spills not exceeding the level, which will cause long-term exposure for environment and will cause significant influence on marine inhabitants and ecology of the region in general (acceptable level of spilled oil is less than 500 liters). But anyway we must minimize the level of pollution to the zero level.

- ***Assets (including reputation)***

Equipment of the tanker, equipment of the platform, the CUPON system, the tanker itself and the platform has to be in operating conditions all the time. It is unacceptable to loss something from the listed above, stop production and waste time due to huge influence to the company reputation. The acceptable level could be a small damage; short delay in the operation, loss is not more than $35,000 in money equivalent.

Event, that has certain probability to occur, may have several causes with different probabilities. That is why we need to find conditions calling the hazardous event, to define occurrence and to determine risk reduction procedures.

Table 21: Probability of hazard events

Description	Definition
Very unlikely	Should not be excluded from the hazards. Occurrence of this event for the operation during the lifetime of the field is extremely unlikely
Unlikely	Should not be excluded from the hazards. Occurrence of this event for the operation during the lifetime of the field is unlikely
Possibly	One occurrence of this event for the operation during the lifetime of the field
Likely	Occurrence of this event for the operation during the lifetime of the field is more than once
Very likely	Frequent occurrence of this event for the operation during the lifetime of the field

Then we have to specify severity of hazardous events. This task has been divided into three categories. The fist one is for safety for personnel. The second one is for assets (equipment, installations on the shuttle tanker). And the third one is for environment (any negative influence on the ecosystem, inhabitants of flora or fauna).

Table 22: Severity criteria for hazardous events

Description	Personal	Assets	Environment
Negligible	Insignificant harm to personnel	Insignificant damage of equipment and installations	Negligible level of environment contamination
Slight	Slight harm to personnel	Slight damage of equipment and installations (insignificant cost of repair)	Environment contamination is between minimum and medium levels
Medium	Medium harm to personnel	Medium damage of equipment and installations (average cost of repair)	Medium level of environment contamination
High	High harm to personnel	High damage of equipment and installations (high cost repair is possible)	Environment contamination is between medium and maximum levels
Very High	Very high harm to personnel	Significant damage of equipment and installations (repair is not possible or it will take long time)	Maximum level of environment contamination

Risk matrix is going to be done based on five levels of probability of hazardous events and five levels of severity criteria for hazardous events shown above in Table 21 and Table 22. It looks like it is shown in Figure 75 below.

5	Very High	Medium	Medium	High	High	High
4	High	Medium	Medium	Medium	High	High
3	Medium	Low	Medium	Medium	Medium	High
2	Slight	Low	Low	Medium	Medium	Medium
1	Negligible	Low	Low	Low	Medium	Medium
Hazard Severity category	Descriptive words	Probability rating				
		A	B	C	D	E
		Very unlikely	Unlikely	Possibly	Likely	Very likely

Figure 75: Risk Matrix

Studying 5 stages of offloading operation for dynamic positioning shuttle tanker Patino Rodriguez has identified in the her work (Patino Rodriguez et al., 2009) 56 hazardous events that can be categorized according to the stage of operation.

For the stage “approach”- 8, for “connection”- 19, for “loading”- 9, for “disconnection”- 14, for “departure”- 6.

Connection and disconnection stages represent the highest number of hazardous events. Dramatic changes of weather and sea conditions can either amplify the severity of possible hazardous events or be the reason.

9.2 HAZID analysis

HAZID (hazard identification) is a systematic review of the possible causes and consequences of hazardous events (Brandsaeter, A., 2002). This analysis can be done in two ways. They are from the bottom to the top, and from the top to the bottom. The first one is carried out as the consideration from consequences to causes. The second one is carried out as the consideration from causes to consequences. Let us define possible causes and consequences of hazardous events.

Table 23: HAZID analysis

Causes	***Undesired event number***	***Consequence***	***Mitigating measures***
○ Generator failure ○ Problems in lubricating oil system ○ Unsuitable maintenance ○ Worn-out components	1. Auxiliary engine failure	○ Inability to transmit electricity for systems of shuttle tanker ○ Collision of the tanker with the platform ○ Offloading operation delay	○ Three on duty MISVs ○ Fast response of personnel ○ Training of personnel ○ Close adherence to the rules in such situation
○ Change of wind, waves, current conditions ○ Inaccurate weather forecast ○ Unforeseen changes in climate conditions	2. Change of environment conditions	○ Offloading operation delay ○ Collision of the tanker with the platform	○ Preplanned actions of personnel to carry out needed procedures ○ Three on duty MISVs ○ Preplanned time for that
○ Errors of the program of shuttle tanker automatic system ○ Human factor	3. Accomplishment of risky maneuver	○ Overloading of the tanker propulsion system ○ Collision of the tanker with the platform	○ Preplanned actions of personnel to carry out needed procedures ○ Three on duty MISVs
○ Thruster failure ○ Control and navigation system failure ○ Electric system failure	4. DP system failure	○ Collision of the tanker with the platform ○ Offloading operation delay	○ Three on duty MISVs ○ Fast response of personnel ○ Close adherence to the rules in such situation
○ Electric supply failure ○ Hook failure	5. Tug failure	○ Offloading operation delay	○ Three on duty MISVs ○ Fast response of personnel ○ Close adherence to the rules in such situation
○ Worn-out cable ○ Excessive loads	6. Towing cable failure	○ Offloading operation delay ○ Propulsion loss	○ Three on duty MISVs ○ Fast response of personnel Close adherence to the rules in such situation

 ○ Environmental conditions ○ Unaccounted factors in the project ○ Equipment limitations ○ The platform equipment or tanker failure ○ The platform stop ○ Marine exercises	7. Oil offloading delay	○ Influence on the company reputation ○ Penalties ○ Production stop	○ Preliminary planning of the situation ○ Getting of the experience by the platform crew in the field of offloading operations in stiff conditions ○ Efforts to load oil in shorter weather windows, if possible ○ Offloading preparations procedures in advance ○ Close adherence to the rules ○ Keeping all the equipment in operational conditions 24/7 ○ Envisage the situation in the contract and exclude positions that don’t usually depend on the company (severe environmental conditions, marine exercises)

If undesired event occurs the severity of the consequence will depend on the distance of the tanker from the platform, meaning the stage of offloading operation.

9.3 Probability and consequence analysis

Hazard Severity category	Descriptive words	Probability rating A Very unlikely	B Unlikely	C Possibly	D Likely	E Very likely
5	Very High	1	4			
4	High		2	7		
3	Medium	3	5,6			
2	Slight					
1	Negligible					

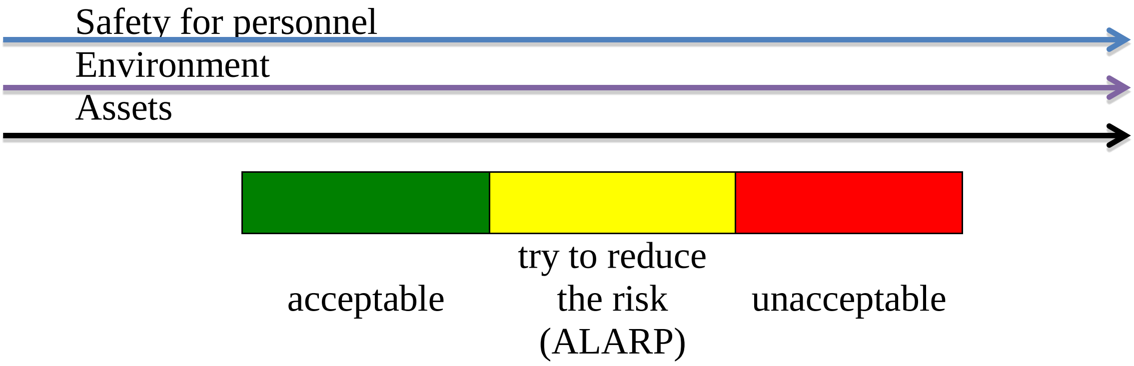

Figure 76: Risk matrix for the offloading operation with reference to undesirable event number placed in the risk matrix

According to the analysis we may sum up:

The offloading operation practically can be carried out, because we have no such an event, locating in the unacceptable (red) zone of the matrix. Therefore, there is a zone, where we have to try to reduce risks. This zone is the yellow one. We have to think about risk reduction, especially for those, marked by fat line in the matrix. It is so important, because they are very close to the unacceptable zone. But we have to figure something out before the offloading operation starts.

The most dangerous events are DP system failure and change of environment conditions as well as oil delivery delay.

Risk uncertainties

First of all one of risk uncertainties is database used by specialists. For example, data base OREDA for reliability of details. Moreover, different specialists themselves have different background and estimate some risks according to their experience. Some of them may have significant experience in the field, but some not.

The weather forecast we use for prediction of weather conditions can be changed in time perspective. We usually believe in it, but it does not mean that it is true. Also the weather forecast for remote regions can be a big challenge.

Even If the weather forecast is ok, we can meet a fog, as an example. This can lead to the difficulties or delay of the operation.

To estimate the human factor can be a rather difficult task and can represent uncertainty as well.

Risk reduction

To reduce risk we can do the following:

- To create united database
- To use the same standards for companies working on the project
- To use at least several sources of the weather forecast
- To follow strictly to the safety measures, instructions, regulations and so on
- To carry out personnel training for comprehensive understanding of the whole operational process

9.4 Bow-tie diagram

Let’s consider the bow-tie diagrams for the most dangerous events that have been identified in the risk matrix for the offloading operation, see Figures 77 to 79. Figure 80 summarizes the discussion.

For bow-tie diagram hazard event are required, causes of this event, consequences of the event and barriers to limit causes and consequences.

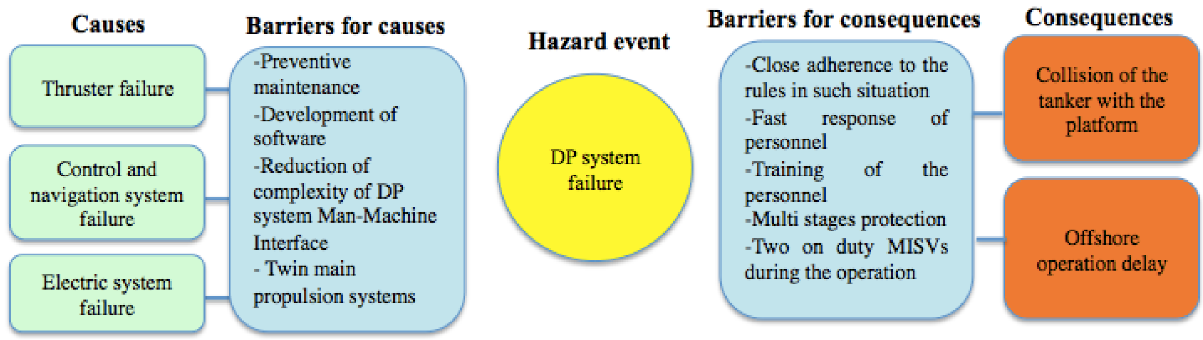

Figure 77: Bow-tie diagram for the offloading operation (DP system failure as a hazard event)

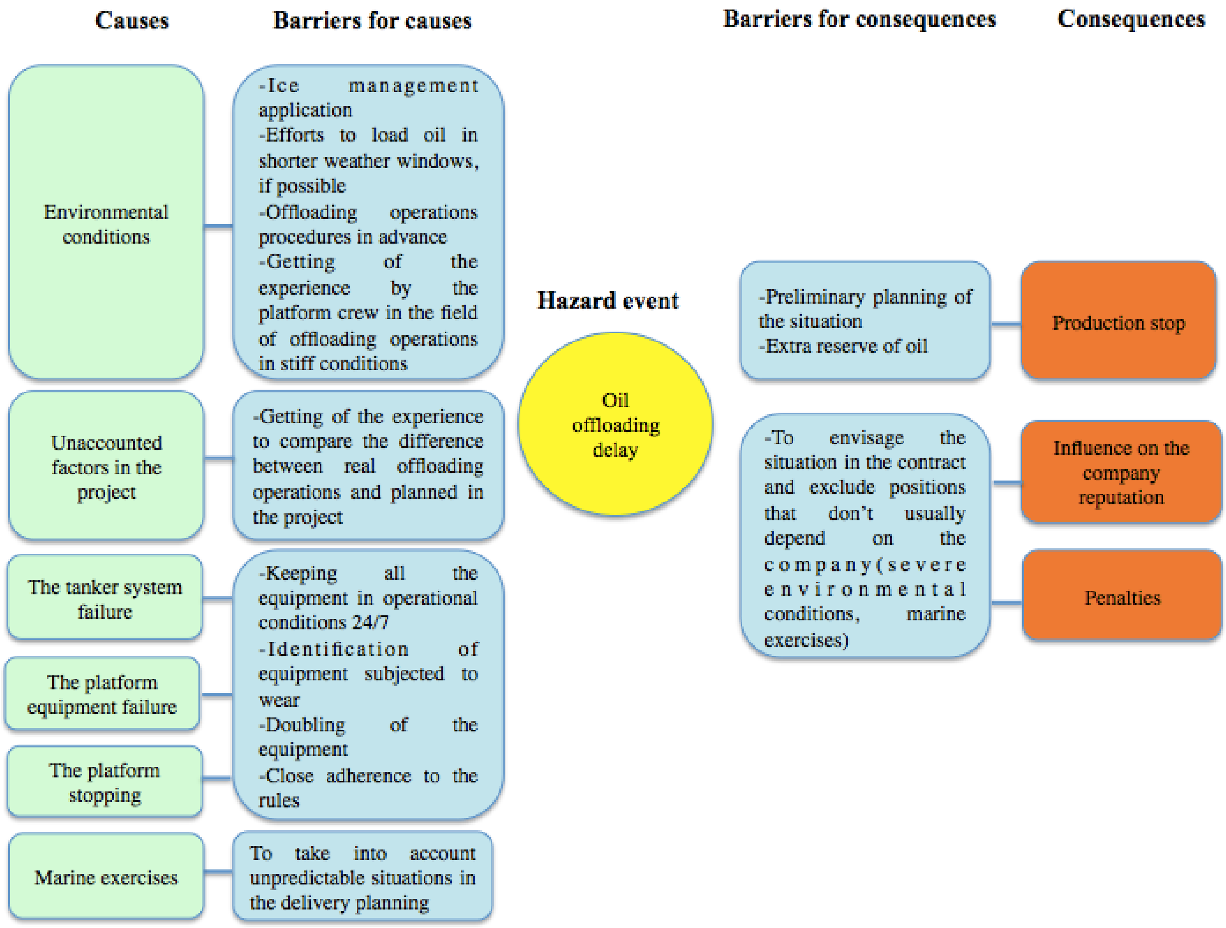

Figure 78: Bow-tie diagram for the offloading operation (Oil delivery delay as a hazard event)

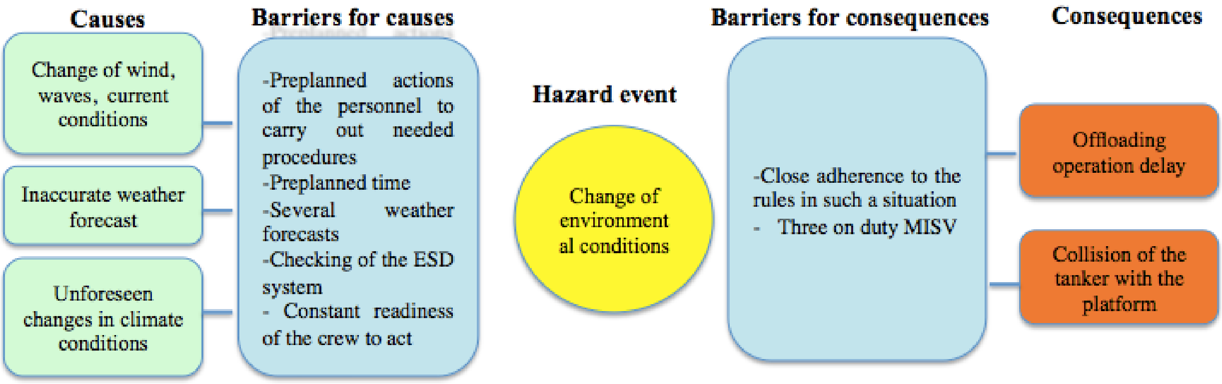

Figure 79: Bow-tie diagram for the offloading operation (Change of environmental conditions as a hazard event)

Hazard Severity category	Descriptive words	A Very unlikely	B Unlikely	C Possibly	D Likely	E Very likely
5	Very High					
4	High	4				
3	Medium		2,7			
2	Slight					
1	Negligible					

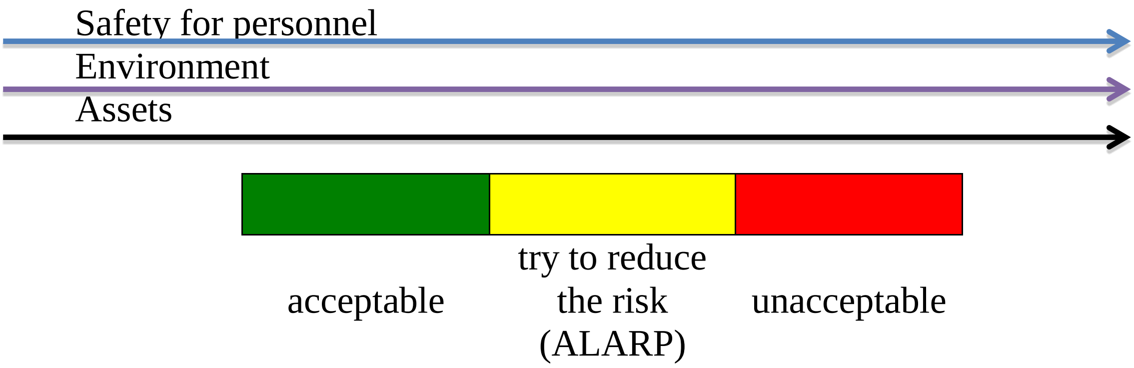

Figure 80: Risk matrix for the offloading operation (the most dangerous events) with reference to undesirable event number placed in the risk matrix (after taken measures)

Chapter 10. Economic analysis

This chapter is dedicated to estimating the potential loss of money due to oil offloading delays. As it has been identified in Chapter 6, in years of high oil production rates (especially, the year of peak production), we may face the problem connected with oil delivery delays. This result from challenges connected with the offloading operation due to difficult ice drift pattern and restrictions for the operations.

Obviously, any delays in an offshore field development operation is very expensive. The loss from daily oil delivery delays can be roughly estimated taking into account four components. They include charges for the tanker rent, charges for tanker fuel, average daily salary of the tanker crew and demurrage, Figure 81.

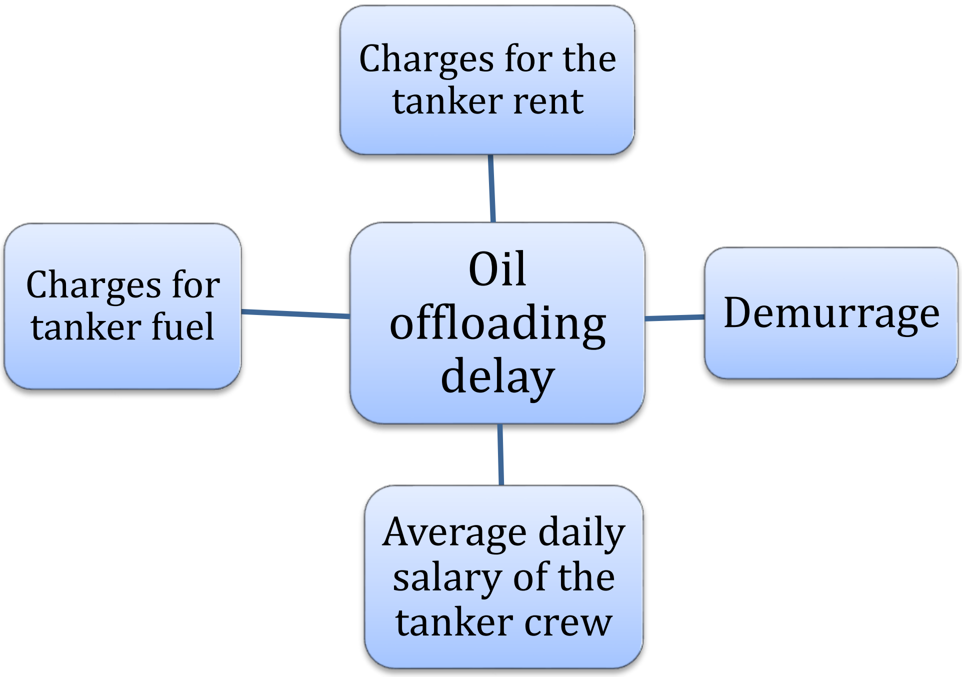

Figure 81: Cases in which monetary loss may occur due to oil delivery delays

Daily charges for the tanker rent has been taken assuming the rent price as in (Offshore Magazine (Russia), 2015)

Daily charges for tanker fuel has been calculated using the equation (13):

$$C_{fuel} = P_f \cdot Q_{fuel} \cdot K_{fuel} \quad (13)$$

where

C_{fuel}- Daily charges for tanker fuel;

P_f- Price of fuel oil (1 ton), $

Q_{fuel}- Daily fuel oil consumption, tons

K_{fuel}- Assumed coefficient of fuel consumption during offloading

The Coefficient of fuel consumption accounts for the difference between fuel consumption when running and when loading. It has been assumed as 0,5.

Daily average salary of the tanker crew can be estimated using the equation (14)

$$S_{crew} = S_{worker\ (av.)} \cdot N_{crew} \qquad (14)$$

where

S_{crew} - Daily average salary of the tanker crew, $

$S_{worker\ (av.)}$ - Average salary of one worker per day, $ $N_{workers}$ - Tanker crew

Number of personnel in the tanker crew has been taken as 25

Total daily charges for the tanker operation can be estimated as shown below, equation (15)

$$C_{total} = C_{tanker} + C_{fuel} + S_{crew} \qquad (15)$$

where

C_{total}- Total daily charges for the tanker operation, $

C_{tanker}- Daily charges for the tanker rent, S;

C_{fuel}- Daily charges for tanker fuel, S;

S_{crew} - Daily average salary of the tanker crew, $

The data given in Table 24 will be used in order to show the potential loss of money due to oil delivery delays exemplified by the Prirazlomnoye field.

Table 24: Initial data for oil delivery delay calculation, Total daily charges for the tanker operation

Daily charges for the tanker rent, $	25000
Daily fuel oil consumption, tons	50
Price of fuel oil (1 ton), $	400
Assumed coefficient of fuel consumption during offloading	0,5
Daily charges for tanker fuel, $	10000
Tanker crew, number	25
Average salary of one worker per day, S	180
Daily average salary of the tanker crew, $	4500
Total daily charges for the tanker operation, $	39500

According to the Russian Legislation: item 5, section 28, The Legislation of Russian Federation from 07.02.1992 №2300-1 “Concerning the Protection of Consumers' Rights“ in case of breach of treaty obligations in the part of time constraints a contractor pays a demurrage to a consumer for every day (hour, if the term is defined in hours) of delay at the rate of 3% of the price of performing the work (facilitation). But if the price of performing the work is not determined by the contract then a higher price demurrage can be charged («Legal Services in Kursk», 2015).

In order to estimate daily demurrage we can assume, that the daily demurrage equals 3% of price of the transported oil. Table 25 shows the calculation of costs the value) of delayed oil production.

The volume of delayed annual oil production can be calculated using the following formula:

$$V_{d.o.p.} = Q_{real} \cdot \Delta t_{offloading} \quad (16)$$

where

$V_{d.o.p.}$- Volume of delaying the oil production, m^3

Q_{real} - Real pumps capacity, m^3/hour

$\Delta t_{offloading}$- Difference between possible and needed offloading hours

To convert the Volume of delayed oil production from m^3 to barrels we have to multiply on 6,29. Multiplication of Volume of delayed oil production on the Price for barrel of oil ($) we will get the Costs (value) of the annual delayed oil production ($).

Table 25: Calculation of volume of annual delayed oil production

Possible pure offloading hours	864,5
Needed offloading hours	888
Difference between possible and needed offloading hours	23,5
Capacity of pumps (pump efficiency coefficient 0,82), m^3/hour	8200
Volume of delayed the oil production, m^3	192700
Volume of delayed oil production, barrels	1212083
Price for barrel of oil, $	64
Costs of delayed oil production., $	77573312

So, daily demurrage can be estimated by the following equation (17)

$$D_{daily} = 0{,}03 \cdot C_{oil} \quad (17)$$

where

D_{daily}- Daily demurrage, $

C_{oil}- Costs of annual delayed oil production, $

0,03 – coefficient taking into account 3% of price of transported oil

Using the data from Tables 24 and 25 charges for the tanker operation and demurrage as well as the Total value of money due to oil delivery delay are calculated, Table 26.

Oil delivery delay has been assumed for the range of days from 0 to 20.

Table 26: Calculation of total value of money due to oil delivery delay

Number of delayed days	Charges for the tanker operation, $	Demurrage, $	Total value of money, $
0	0	0	0
1	39500	2327199	2366699
2	79000	4654399	4733399
3	118500	6981598	7100098
4	158000	9308797	9466797
5	197500	11635997	11833497
6	237000	13963196	14200196
7	276500	16290396	16566896
8	316000	18617595	18933595
9	355500	20944794	21300294
10	395000	23271994	23666994
11	434500	25599193	26033693
12	474000	27926392	28400392
13	513500	30253592	30767092
14	553000	32580791	33133791
15	592500	34907990	35500490
16	632000	37235190	37867190
17	671500	39562389	40233889
18	711000	41889588	42600588
19	750500	44216788	44967288
20	790000	46543987	47333987

According to Table 26, the total value of oil delivery delays equals $2366699/day. If the number of delayed days in the year of peak production is 20, then the total value of money will be about $47333987. Value of oil delivery delay is shown in Figure 82.

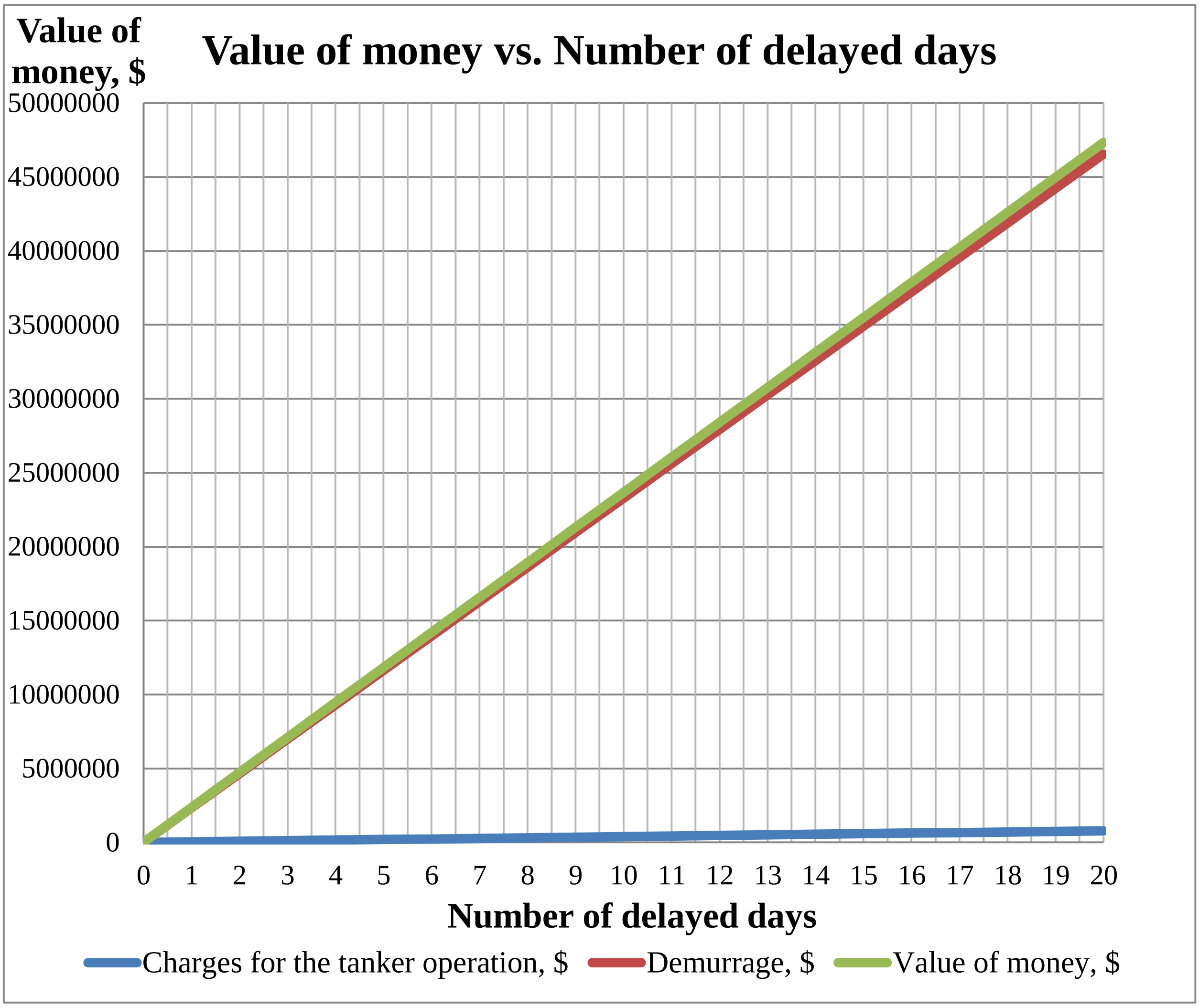

Figure 82: Potential value of oil delivery delay vs. Number of delayed days

So, being aware of the value of costs of delaying the oil production and the potentially lost money due to delay in the year of peak production, (assuming the number of delayed days per year equals 20), we can calculate the ratio between the potentially lost money due to delays and costs of delaying the oil production, Table 27 and Figure 83.

Table 27: Calculation of share of potentially lost money due to oil delivery delay

Costs of delaying the oil production, $	77573312
Value of oil delivery delay, $	47333987,2
Ratio between Value of money due to delivery delay and Costs of delaying the oil production	0,38

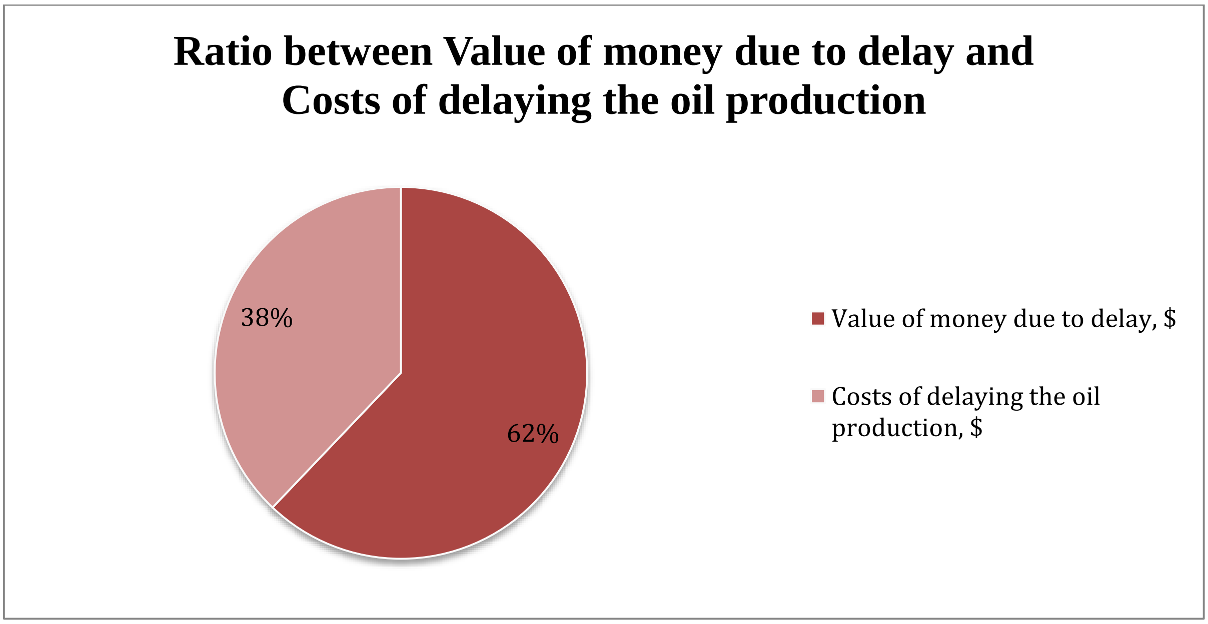

Figure 83: Ratio between Value of money due to delay and Costs of delaying the oil production

Conclusions

The offloading operation in different seasons from the Prirazlomnaya platform has been studied in this project, including working parameters and restrictions of the tanker and the CUPON system for oil offloading in the Arctic conditions.

Dangerous factors, affecting the offloading, have been identified. Seasonal offloading forecast has been carried out for the operation as well as yearly offloading forecast.

The forecast helps us to study components of the total current affecting the offloading operation. It shows current directions changes and the vector of total current for different periods. We can visualize histograms of wind-current, tidal and total current velocities as well as wind velocities. This information can be used for deeper understanding of ice drift direction changes, as it is very important information, especially in spring and winter seasons. Moreover, we must be aware of the information about restrictions of the operations, time for approaching, connection, disconnection, for checking of parameters needed for safety implementation of the operation, and the needed weather window for the operation. Putting this information into the simulation program, we can obtain the available pure offloading time for the operation according to the feature of current direction changes. This forecast can be used to estimate the difference between available pure offloading hours and needed offloading hours for given period of time. Simulation shows, that there is a challenge for the year of peak production, because more offloading hours are required to load the planned oil volume. So, the challenge has been identified and some suggestions have been made to reduce or mitigate risks in the chapter devoted to risk analysis.

Risk analysis for the offloading operation has been carried out. Probability and consequences analysis shows, that DP system failure, oil offloading delay and change of environmental conditions are the most dangerous events among the considered events.

Resistance and thrust of the tanker during offloading in ice have been calculated. According to the obtained results recommendations for the tanker have been made. The estimate can be used for the offloading keeping its position without additional support in ice with thickness not more than 0,63 meter.

Offloading concepts, suitable for future offshore projects in the Pechora Sea conditions, have been considered, and the importance of ice management involvement has been discussed.

Economic analysis shows a potential economic effect on the early stage of development and can be used by the company to mitigate risks by well-timed decision-making.

List of references

Ayyub, B.M. (ed.) 2011, Vulnerability, Uncertainty, and Risk : Analysis, Modeling, and Management, ASCE, Reston, VA, USA, pp. 385-391. Available from: ProQuest ebrary. [13 November 2014].

Bauch, H. A. et al., eds., (2005). Pechora Sea Environments: Past, Present, and Future [pdf], ePIC (electronic Publication Information Center). Available at: <http://epic.awi.de/26680/1/BerPolarforsch2005501.pdf> [Accessed 21 September, 2014]

Bonnemaire B. (2005a): Arctic Offshore Loading: Submerged Turret Loading and Loading Downtime in Drifting Ice. Doctoral Theses at NTNU, 2005:158, 116pp.

Bonnemaire B. (2005b): Arctic Offshore Loading Downtime due to Variability in Ice Drift Direction. Journal of Navigation, Vol 12, pp. 9 - 26.

Brandsaeter, A., 2002. Risk assessment in the offshore industry. SAFETY SCIENCE, 40(1-4), pp. 231-269.

Flot, 1998-2015 [online] Available at: <http://flot.com/publications/books/shelf/vasiliev/20.htm?print=Y> [Accessed 20 March 2015]

Efimkin, I., 2015. Offshore ice-resistance gravity based terminal for the cluster development of the Pechora Sea. Master Thesis. University of Stavanger and Gubkin Russian State University of Oil and Gas, 2015

«Gazprom» document, Environmental conditions at the Prirazlomnoye field location, 2005. Документ Газпрома, Природные условия в районе Приразломного месторождения , 2005.

«Gazprom» document, Integrated system of direct oil offloading system (CUPON). Engineering manual and service instruction, 2010; Документ Газпрома, Комплексное устройство прямой отгрузки нефти (КУПОН). Техническое описание и инструкция по эксплуатации, 2010

«Gazprom Neft Shelf» LLC. Official site, 2014a. Marine transport-technological system of the project. Морская транспортно-технологическая система проекта. [online] Available at: <http://shelf-neft.gazprom.ru/about/working/morskaya-transportno-tekhnologich/> [Accessed 8 November 2014]

«Gazprom Neft shelf» LLC. Official site, 2014b. News. Новости. [online] Available at: <http://shelf-neft.gazprom.ru/press/news/2014/01/> [Accessed 12 November 2014]

«Gazprom Neft shelf» LLC. Official site, 2015a. News. Новости. [online] Available at: < http://shelf-neft.gazprom.ru/press/news/2015/04/> [Accessed 25 April 2015]

«Gazprom Neft Shelf» LLC. Official site, 2015b.GBS Prirazlomnaya. МЛСП Приразломная [online] Available at: <http://shelf-neft.gazprom.ru/about/working/mlsp-prirazlomnaya/> [Accessed 8 April 2015]

Gorshkov, S.G. and V.I. Faleev, Eds. (1980): Atlas of the Oceans. The Arctic Ocean. USSR Ministry of Defence, Moscow.

Government Oceanography Institute, 2012. Государственный Океанографический Институт, 2012 [online] Available at: <http://esimo.oceanography.ru/tides/index.php?endsea=2&station1=4&jdate=1426539600&date=02%3A08%3A2014&x=9&y=9 > [Accessed 22 March 2015]

Gudmestad O.T., Zolotukhin A.B., Ermakov A.I., Jakobsen R.A., Michtchenko I.T., Vovk V.S., Loeset S., Shkhinek K.N. (1999). Basics of Offshore Petroleum Engineering and Development of Marine Facilities with Emphasis on the Arctic Offshore. Stavanger/Moscow/St. Petersburg/Trondheim. Publishing house "Oil and Gas", 1999, pp.112-115, 124-126

Hamilton, J., Holub, C., Blunt, J., Mitchell, D., & Kokkinis, T. (2011, January 1). Ice Management for Support of Arctic Floating Operations. Offshore Technology Conference, OTC 22105, Houston, Texas, USA, 7–9 February 2011, doi:10.4043/22105-MS

ISO 19906:2010, Petroleum and natural gas industries - Arctic offshore structures, pp.283-284, ISO, Geneva, Switzerland.

Karulin, E. B., & Karulina, M. M. (2010, January 1). Performance Studies for Technological Complex Platform "Prirazlomnaya" - Moored Tanker in Ice Conditions. Proceedings of the Ninth (2010) ISOPE Pacific/Asia Offshore Mechanics Symposium Busan, Korea, November 14-17, 2010

Keinonen, A, Browne, R.P, Revill, C.R., Bayly, I.M (1991) Icebreaker Performance Prediction. AKAC, Calgary, Alberta, Canada.

Keinonen, A, Browne, R.P, Revill, C.R., Reynolds, A (1996) Icebreaker characteristics synthesis. AKAC, Calgary, Alberta, Canada.

[Kirill Lavrov] n.d. [image online] Available at <http://shelf-neft.gazprom.ru/d/textpage/65/101/kirill-lavrov.jpg> [Accessed 18 October 2014]

Korppoo, S., S. Kobus and P. Salonen (1988): Problems of Using Floating Production Units in Arctic Conditions. Proceeding of the International Conference on Technology of Polar Areas (Polartech), Trondheim, Vol. 2, pp. 507-521.

Kvitrud, A., Kleppestø, H., & Skilbrei, O. R. (2012, January 1). Position Incidents During Offshore Loading With Shuttle Tankers On the Norwegian Continental Shelf 2000-2011. Proceedings of the Twenty-second (2012) International Offshore and Polar Engineering Conference, Rhodes, Greece, June 17–22, 2012

«Legal Services in Kursk», 2015. [online] Available at: <

http://olegumerenkov.ru/razmer-neustojjki-za-narushenie-sroka-okazaniya-uslug-ispolnitelem/> [Accessed 15 May 2015]

Loset, S. and D. Onshuus (1999): Analysis of speeds of drift ice in the Pechora Sea. Proceeding of the 4th International Conference Development of the Russian Arctic Offshore (RAO'99) Saint Petersburg, July 6-9, 1999, Vol.1, pp. 248-253

Loset, S. Concepts for offloading of hydrocarbons in icy waters. 2008. 17th June, 2008, St.Petersburg. [pdf] Available at <http://www.forskningsradet.no/servlet/Satellite?blobcol=urldata&blobheader=application%2Fpdf&blobheadername1=Content-Disposition%3A&blobheadervalue1=+attachment%3B+filename%3DWorkshopNFRRussia170608-SL.pdf&blobkey=id&blobtable=MungoBlobs&blobwhere=1274460396014&ssbinary=true> [Accessed 26 March 2015]

Mandel, A., 2011.Prirazlomnoe field: Creation of the infrastructure to develop the shelf maximum safe, *Neftegazovaya vertical*, #23-24 [online].Мандель, А., 2011.Приразломное: Создание инфраструктуры для освоения шельфа при максимальной безопасности, *Нефтегазовая вертикаль*, #23-24Available at <http://shelf-neft.gazprom.ru/d/aboutcompanypost/15/21/7..pdf > [Accessed 9 November 2014]

[Map of Prirazlomnoye] n.d. [image online] Available at < http://www.offshore-technology.com/projects/prirazlomnoye/prirazlomnoye5.html

> [Accessed 10 April 2015]

Meteorologisk Insititt, 2014. [online] Available at: <http://www.yr.no/sted/Hav/69,15000_57,17000/> [Accessed 12 March 2015]

[Mikhail Ulyanov] n.d. [image online] Available at <http://shelf-neft.gazprom.ru/press/news/2014/04/22/> [Accessed 18 October 2014]

Mironov, E., V.A. Spichkin and Egorov (1994): Season Variability and Their Variations in the Region of Mastering of the Barents and Kara Seas Offshore. Proceeding of the First International Conference on Development of the Russian Arctic Offshore (RAO-93), St.Petersburg, September 21-24, 1993, pp. 110-121

Mironov, E., V.A. Spichkin and Y.D. Bychenkov (1996): Provision of Safety and Efficiency for Constructing Offshore Structures on the Shelf of the Barents and Kara Seas Based on Monitoring and Forecasting of the Ice State. Proceeding of the Polar. Tech. Conference, St. Petersburg, 1996, Vol. 4, pp. 161-169.

Mischenko, S.M. (1996): Wave Parameters in the Kara and Pechora Seas. Report at St. Petersburg State Technical University, 21p.

[MT Kirill Lavrov] n.d. [image online] Available at <http://www.shipbucket.com/images.php?dir=Real%20Designs/Russia/MT%20Kirill%20Lavrov.png> [Accessed 13 October 2014]

National Ocean Service, 2015. [online] Available at: <http://oceanservice.noaa.gov/education/kits/tides/media/supp_tide06a.html> [Accessed 18 March 2015]

Norwegian Meteorologisk Insitutt, 2014 [online] Available at < http://www.yr.no/sted/Hav/69,15000_57,17000/> [image online]

Offshore standard, DNV OS. H101 (2011). Marine Operations, General. October, 2011, p.26, Oslo, Norway

Offshore Magazine (Russia). News, 2015. [online] Available at: < http://www.offshore-mag.ru/news_item.php?ID=452.> [Accessed 30 April 2015]

Patino Rodriguez, C.E., Souza, G.F., and Martins, M.R. (2009). Risk-based analysis of offloading operations with FPSO production units. Proceedings of COBEM. Gramado: ABCM.

[Prirazlomnoe] n.d. [image online] Available at < http://shelf-neft.gazprom.ru/press/news/2014/06/> [Accessed 12 November 2014]

SNIP (1986): Construction Codes and Regulations. Loads and Forces of Hydrotechnical Facilities (Influence of Ice, Sea waves and Ships). SNIP 2.06.04-82. Gosstroy of USSR, Moscow: 1986, 34 pp.

Spichkin,V. and A. Egorov (1995): Dangerous Ice Phenomena in the Barents and Kara Seas Offshore. Proceeding of the Second International Conference on Development of the Russian Arctic Offshore (RAO-95), St.Petersburg, 1995

Standards Norway, 2010. NORSOK standard Z-013. Edition 3, October 2010. Risk and emergency preparedness assessment. [online] Available through: <http://www.standard.no/pagefiles/955/z-013.pdf > [Accessed 6 October 2014]

Timco, G.W., Wright, B.D., Barker, A., Poplin, J.P., Ice damage zone around the Molikpaq: Implications for evacuation systems, Cold Regions Science and Technology, Volume 44, Issue 1, January 2006, Pages 67-85, ISSN 0165-232X, http://dx.doi.org/10.1016/j.coldregions.2005.08.001 Available through: University of Stavanger Library website < http://ezproxy.uis.no> [Accessed 7 November 2014].

Federal Portal, United collection of digital educational resources, 2015. Федеральный портал, Единая коллекция цифровых образовательных ресурсов, 2006-2015 [online] Available at: <http://files.school-collection.edu.ru/dlrstore/1db6eb9f-10eb-7c5f-b177-124aa70ce912/1000402A.htm> [Accessed 22 March 2015]

UNIS AT-327/827 Arctic Offshore Engineering, Svalbard, 2014

USSR (1986a): Hydrometeorological Conditions of the Offshore Zone of the USSR Seas. Reference Book Vol. 6, Barents Sea Issues 1 and 2. Leningrad Gydrometeoizdat, 253 pp.

USSR (1990): Hydrometeorology and Hydrochemistry of the USSR Seas (in 10 Volumes). Vol.1, Barents Sea. Vipysk 1. Hydrometeorological Conditions. Leningrad Gydrometeoizdat, 1990, 280 pp.

Valdman, N. A. (2014, August 7). Methodical Approaches and Results of Safety Analysis for Offshore Transport & Technological Systems. The Twenty-fourth International Ocean and Polar Engineering Conference, 15-20 June, Busan, Korea35)

Yamshchikov, D., 2013. “Prirazlomnaya” platform: the first experience of oil production in the Arctic Shelf. Security and safety of offshore operations on the continental shelf of the Russian Federation by the example of oil filed “Prirazlomnoe”. *Neftyanaya promishlenost*, №2, The security and safety of fuel and energy complex facilities [online]. Ямщиков, Д., 2013. “Приразломная”: первый опыт нефтедобычи на Арктическом шельфе. Безопасность морских операций на континентальном шельфе Российской Федерации на примере нефтяного месторождения “Приразломное”. *Нефтяная промышленность*, №2, Безопасность объектов ТЭК. Available at: <http://shelf-neft.gazprom.ru/d/aboutcompanypost/1c/28/statya-o-bezopasnosti-morskikh-operatsij.-2-2013.pdf > [Accessed 4 October 2014]

Yulmetov, R., Arctic Offshore Technology Course, UNIS, NTNU, SAMCoT AT-327/827. Svalbard, 2014

Zorina, S., 2014. Outlook. Siberian Oil, №1/108. Зорина, С., 2014. Перспектива. Сибирская нефть, №1/108 [online] Available at:< http://www.gazprom-neft.ru/files/journal/SN108.pdf> [Accessed 13 October 2014]

Zubakin, G.K., V.V. Denisov and D.R. Soboleva (1987): Some Results of Investigations of Currents and Ice Drifting in the South-East Part of the Barents Sea. Tr. AARII, t. 410, pp. 64-75.