Marine Operations in Channels through Shallow Ice-Covered Waters

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ABSTRACT

Current trends show decreasing water level in the Caspian Sea. This is a doomsday scenario for marine operations in the Northern part of the sea. Shallowing waters may limit both access to the sea through Volga-Caspian Channel from the world as well as internal cargo transit operations to big existing projects at Kashagan and Prorva areas and several smaller projects scattered in the Kazakh sector of the Northern Caspian. Ongoing dredging initiative along the Volga-Caspian and Prorva Channels is targeted to cope with intensive backfill due to significant sediment transfer. This paper is targeted to address ice related hazards to marine operations in these shallowing conditions during winters. Ice drift across the channels pushing vessels off channel and grounding in surrounding shallower waters is the major scenario of interest to assess in order to forecast event during operations and issue timely alert to operators.

KEY WORDS: Operations in Ice; Grounding Vessels; Ice Drift; Remote Sensing; Wind and Drift Forecast.

INTRODUCTION

The North Caspian Sea is an area of continuously growing marine operations mainly supporting oil and gas activities. Existing projects on the Kazakhstan side include the oil producing field, Kashagan and the transport of modules to Prorva on the eastern coast. Several smaller projects are expected to go operational in the next 10 years or so. These include Pearls, offshore Kalamkas, Zhanbay as well as the next phase of Kashagan development. All these are likely to continue using marine support with the existing fleet that has access to the North-Eastern part of the sea through the Saddle, a shallower area that sets a constraint on vessel draft.

Major projects in the Volga delta area include the Korchagin and Filanovsky oil fields in the deeper waters of the Russian sector and the Volga Caspian channel. The latter project supports Russian oil and gas offshore developments and opens the marine trade route between Caspian states and world markets by providing access to the sea through the network of Russian rivers. These major projects in the Volga delta complete the full picture of anthropogenic activities in the shallow northern Caspian.

The latest studies agree that the most likely scenario is for water level to continue its decreasing trend. This will make already challenging operations in shallow waters even more complex. Figure 1 illustrates water depth at the Saddle and Kashagan East, the two most vulnerable regions with ongoing operations. The plot is based on the historical records of annual average water level until 2017 (derived from Coordination Committee on Hydrometeorology of the Caspian Sea (CCH), 2019) and projected until 2025 with rate of change suggested by Chen et al (2017). The major focus of this study is an analysis of the effect on marine operations in ice for a 3m draft vessel for five categories of accessibility (Red is unpassable. Blue indicates no effect from water depth) and shown in the same figure. A draft of 3 m is typical for the shallow draft ice breaking supply vessels that form the majority of the north Caspian fleet.

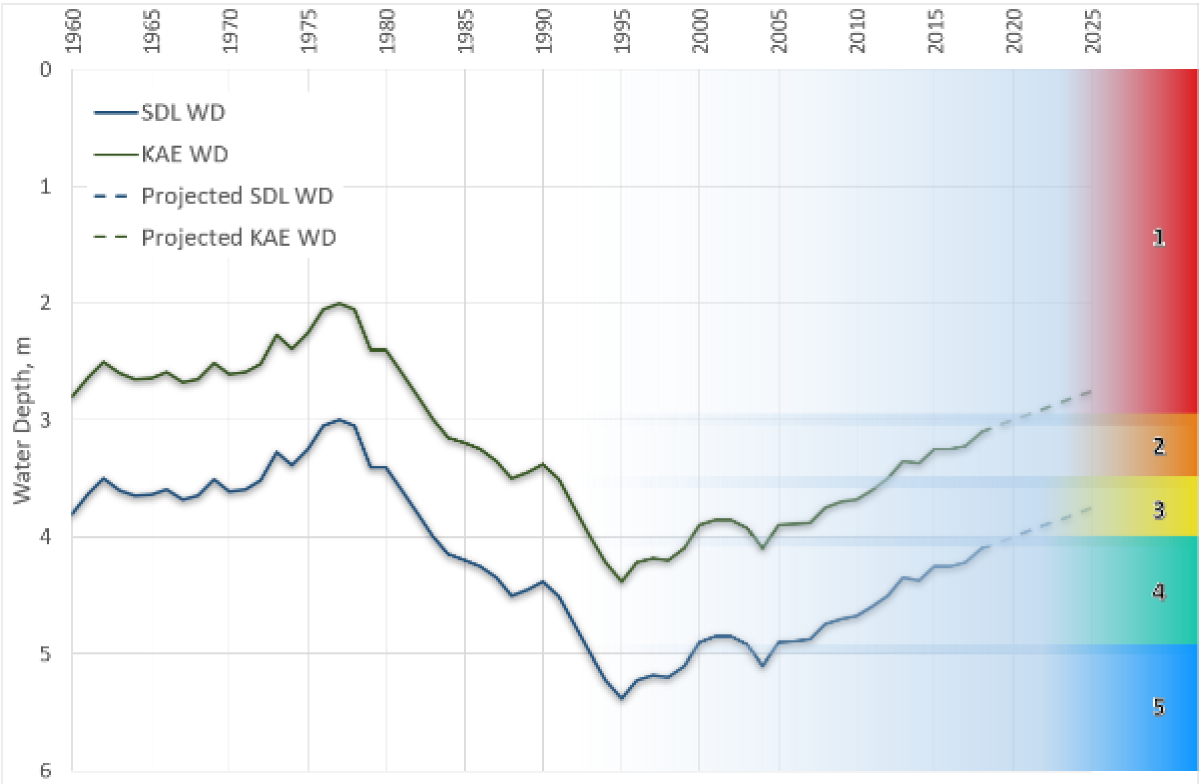

Figure 1: Water Depth at Saddle (SDL) and Kashagan East (KAE) based on annual water level variations in the Caspian Sea derived from CCH, 2019. Accessibility index for a 3m draft vessel: Red (1) – Inaccessible; Orange (2) – Slow cruise speed with intermittent grounding to seabed; Yellow (3) – Slow cruise speed with high risk of grounding; Green (4) – Normal operations in shallow waters (restricted cruise speed); Blue (5) – no restriction.

Figure 2 below illustrates the effect of changing water depth on accessibility to different areas of the Northern Caspian by vessels with a draft of 3 m. The maps illustrate accessibility, using the same colour cade as Figure 1, for annual average water levels ranging from +1.0m Caspian Datum (-28m Baltic Datum) to -1.0m CD. The analysis excludes the effect of both negative and positive water surges due to strong wind events. Accessibility classification is based on distribution of projected water depths. The present-day situation is close to that illustrated for the -0.5m CD water level.

Considering the decreasing water level trend and accessibility analysis above, where -1.0 m CD is possible in the next 10 years, operators in the Eastern part of the Northern Caspian might consider dredging the Saddle (SDL) and the approaches to offshore blocks to ensure continuous access to existing offshore production and exploration facilities. This will allow marine fleet operations to continue to supply existing infrastructure. An alternative means of transportation such as air cushion vehicles could also be used. Both alternatives require significant effort in maintenance and continuous analysis of windows of opportunity for operations to take place.

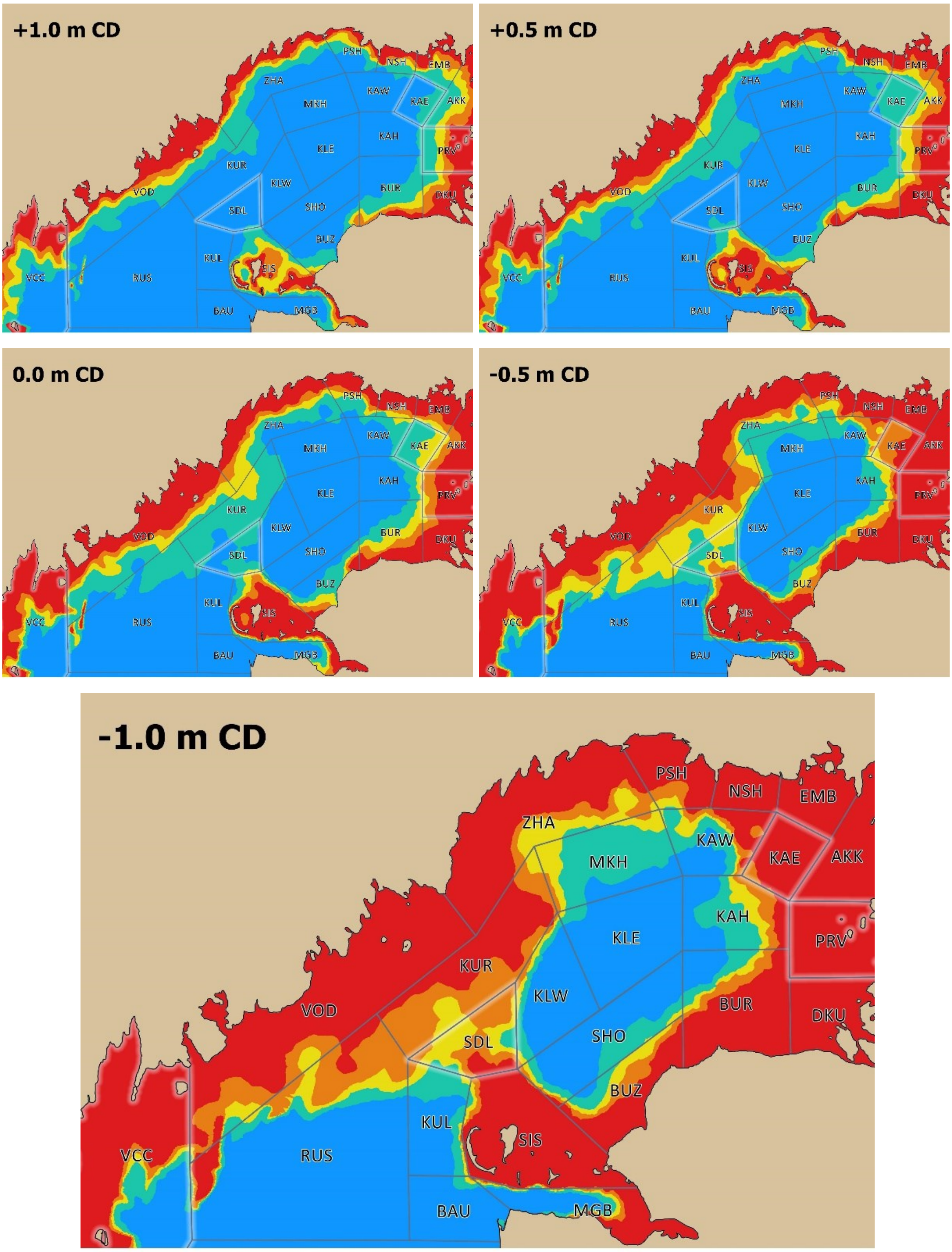

Figure 2: Accessibility analysis for marine operations in the Northern Caspian for vessels with 3 m draft: Blue – no restriction; Green – Normal operations in shallow waters (restricted cruise speed); Yellow – Slow cruise speed with high risk of grounding; Orange – Slow cruise speed with intermittent grounding to seabed; Red – Inaccessible. Crucial areas for operations in the Northern Caspian (VCC -Volga-Caspian Channel, SDL – Saddle, KAE – Kashagan East, PRV – Prorva) are highlighted.

The initiative to build and maintain navigation channels requires continuous dredging due to intensive silting as observed in the Volga Caspian channel. Rigorous Ice Hazards Management systems are also required to avoid impact on marine operations in ice, as discussed in this study. ACVs require significant path finding effort to ensure the smallest ice surface roughness along the route in order to reduce maintenance costs on damaged skirts. ACVs also require quality regional weather monitoring for unfavourable conditions that may lead to ice accretion.

The goal of this particular study is to assess the operability of dredged channels during winters considering ice related hazards associated with drift. Two major scenarios were mentioned in the history of operations along the Volga-Caspian channel:

1) Ice drift across the channel leading to vessels grounding outside the navigable part of the channel;
2) Ridging across channels, stamukhi and large grounded rubble fields formation as shown in Figure 3.

Figure 3: Illustration of ridged grounded features forming in vicinity of Volga-Caspian channel. (Bukharitsin, 2011).

While ridging can be a limiting factor, it can be managed with ice clearing missions within navigable areas, though these are time consuming. This may temporarily disrupt the logistical chain, but the impact is not as dramatic as a vessel being pushed out of the channel into unnavigable areas. This would disable for the season while grounded a vessel in the shallows, with a high potential of damage from recurring drift events. Hence, the major focus of this paper is on ice drift events and their consequences.

The following tasks were performed in the scope of the assessment:

1) Investigation of historical records of operations in the Volga-Caspian channel from the Soviet era to the present. These case studies define weather parameters influencing hazardous ice and metocean conditions that resulted in significant impact on operations.
2) Assessment of the likelihood of events occurring based on historical weather records in the areas with high potential to be dredged for channels in future.

Results of this study may facilitate continued safe marine operations in ice with minimum disruption in the supply chain using advanced ice and metocean hazard monitoring systems.

MARINE OPERATIONS AT VOLGACASPIAN CHANNEL

There are several existing records of vessels receiving damages ranging from bent plates to damaged rudders and propellers. As reported by Hydrometeoizdat 1992 there are records of destroyed navigation signs along the channel (1938-39, 1944-45, 1948-49). Removing navigation signs and stopping navigation for winter resulted in financial impact. Majority of incidents in the channel were caused with drift associated with crosswinds. This way MV "Krasnyi Kaspiy" and "Pobeda" were pushed off the channel in December 1950.

Volga-Caspian Channel has the longest operational history on the record with marine operations taking place continuously for a long time with increasing intensity since 1940s. Figure 4 shows position of the channel in the Western part of the Volga Delta.

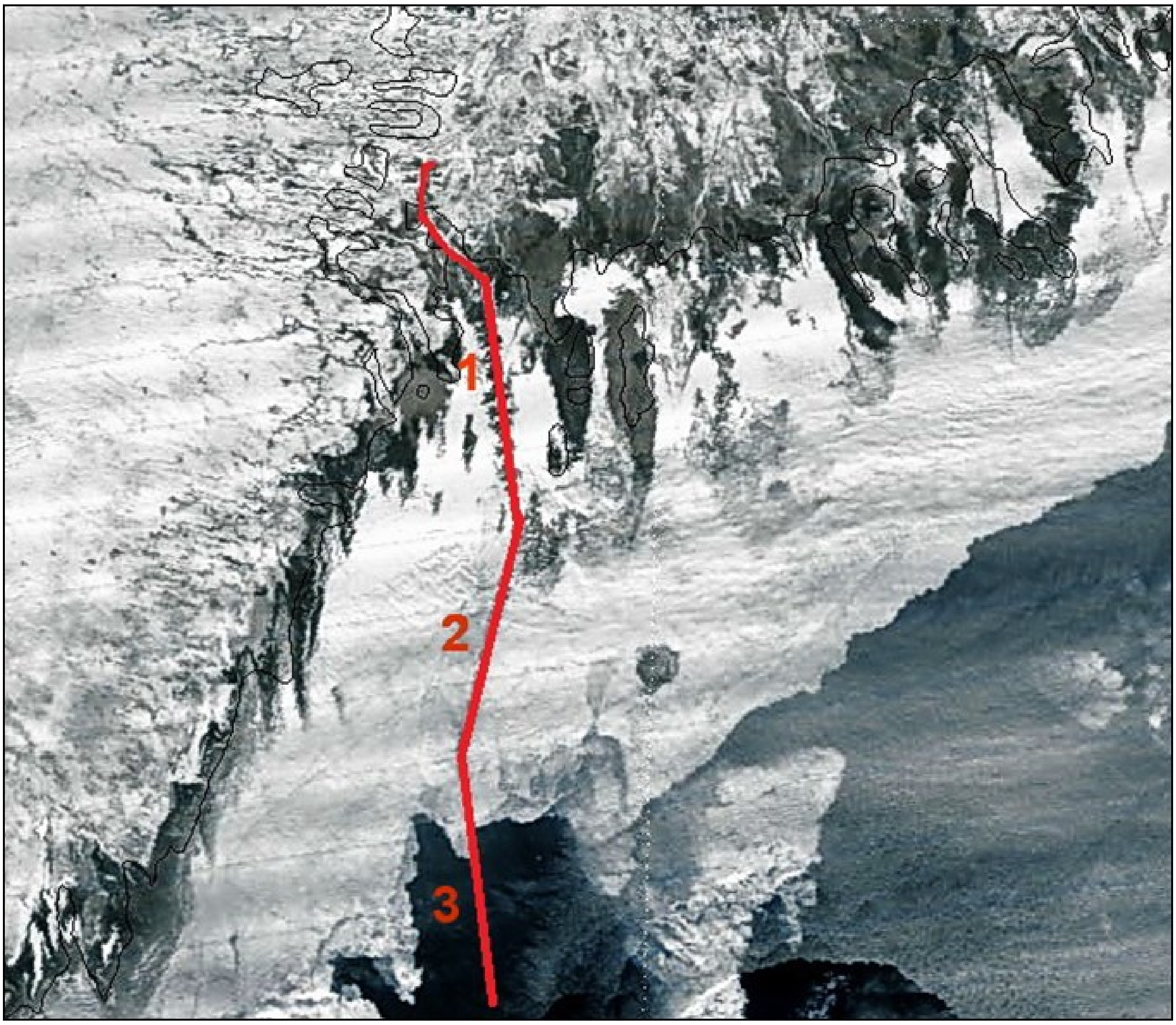

Figure 4: Orientation of Volga-Caspian Channel (1- River part of the channel, 2,3 – Sea part of the channel)

The most dramatic case of ice drift affecting marine operations occurred in 1981 and was observed in the Volga-Caspian Channel. MV Baku was pushed off the channel and grounded in the shallow waters next to it. Figure 5 shows the timeline of events before and after the incident with the vessel as well wind records extracted from ERA5 reanalysis dataset. Figure 6 shows ice charts compiled during the two overflights before and after the grounding incident that indicate extensive new ice formation in front of Volga Delta that ensured continuous supply of ice to be drifted across the channel. Intensive westerly drift across the channel during the period from February 14th to February 18th was associated Eastern wind ranging between 25 and 30 knots gusting up to 40 knots as reconstructed from ERA5 dataset by The European Centre for Medium-Range Weather Forecasts (ECMWF) and correlating with observations by Astrakhan Ice Service, 1981. The drift event persisted with milder North-Eastern winds for several days afterwards that drifted large floes of grey ice towards the western coast from the central part of Volga Delta.

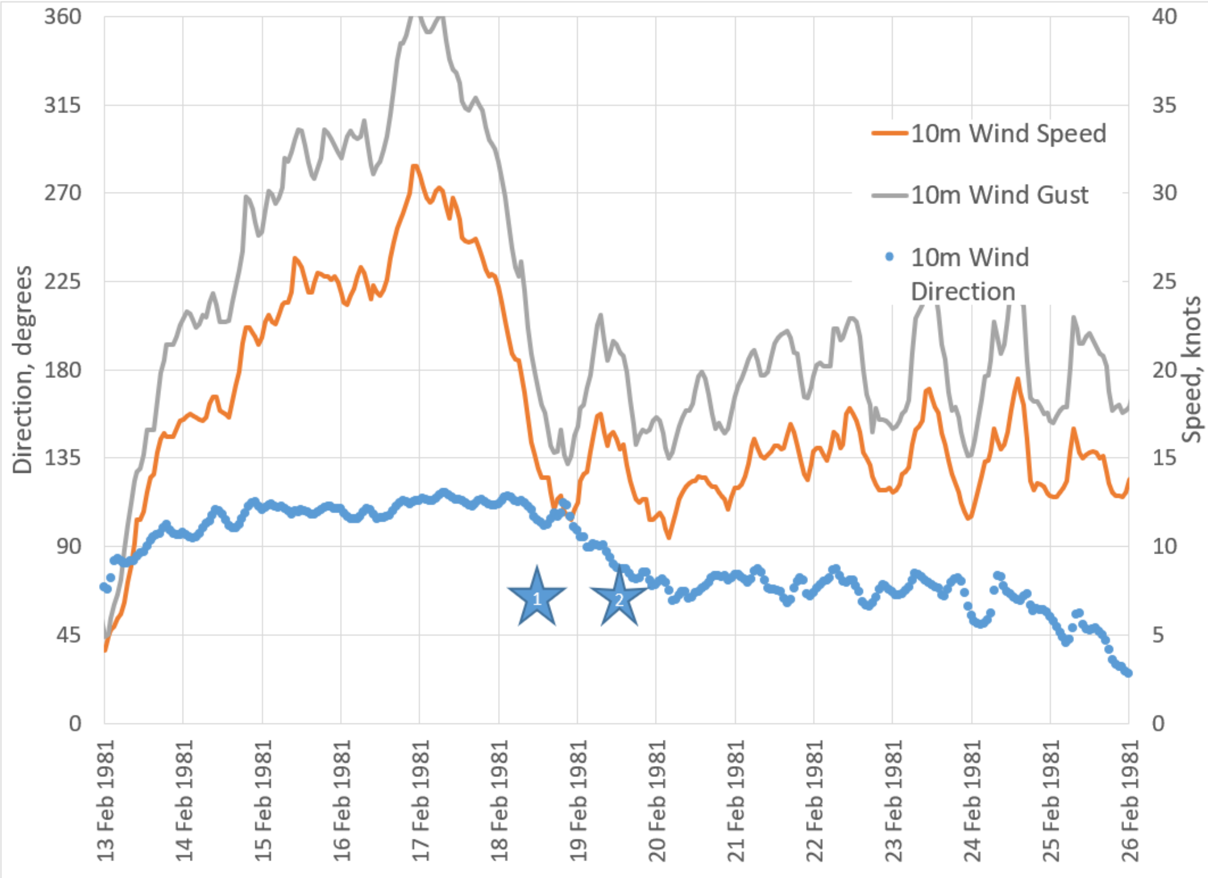

Figure 5: Wind Direction, Speed and Gust before and after grounding event with Baku (1) generated using Copernicus Atmosphere Monitoring Service information, 2019. 2 – Aerial Ice survey along the channel confirming ice conditions and capturing consequences of the incident with MV Baku.

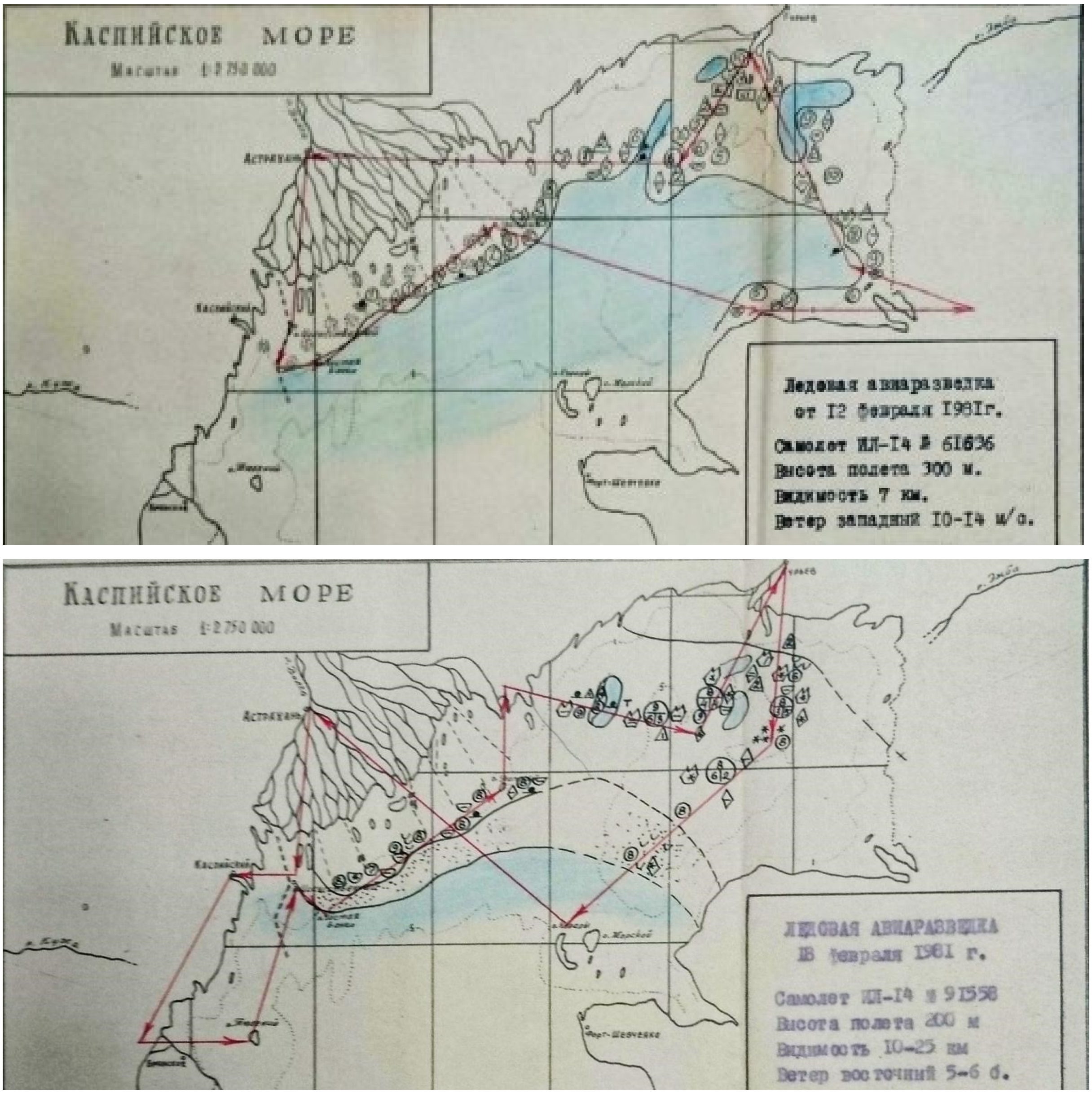

Figure 6: Aerial Ice Reconnaissance charts confirming ice conditions conducted on 12th and 18th of February 1981. Astrakhan Ice Service, 1927-1997.

The bulk carrier MV Baku was in shore bound Icebreaker supported convoy through the marine part of the Volga Caspian Channel, when it was pushed off the channel with westerly drift on February 18th, 1981 that was. The vessel kept drifting with ice for the next two days while the upsurge caused by the Easterlies allowed her advancing through the shallows. Aerial survey has confirmed position, where she stopped drifting when grounded to seabed 10 km away from the channel (see Figure 7). Water level recovering to its normal state after upsurge flooding the area along the western coast made the grounding even more intensive. While Ice Breakers servicing the channel were not able to assist the rescue operation due to draft prohibiting to operate outside the channel only Shallow Draft Tug could provide assistance. As the tug did not have enough power to unground the vessel it stayed there until the next upsurge event later in the season.

Figure 7: Bulk Carrier MV Baku on seabed and SDT attempting to unground the vessel. Photo by Bukharitsin P.I. 1981.

DRIFT EVENTS SCENARIOS

Case studies from the Volga-Caspian Channel allowed identifying three scenarios to be considered in the project with major wind parameters and ice conditions that can lead to occurrence of hazardous ice drift events across channels:

#1: Assuming East West orientation of potential channel at Saddle Southerly and Northerly winds are likely to cause drift across the channel. Being close to Ice Edge with highly mobile ice cover in the area it is very responsive to wind. However, 2-days persistence is set to ensure cases leading to significant drift events is chosen;

#2: This scenario is targeted to define frequency of downsurge events that may cause significantly higher speeds of drift across channel and, thus, higher loads on vessels in channel with recovering water level afterwards (Figure 8).

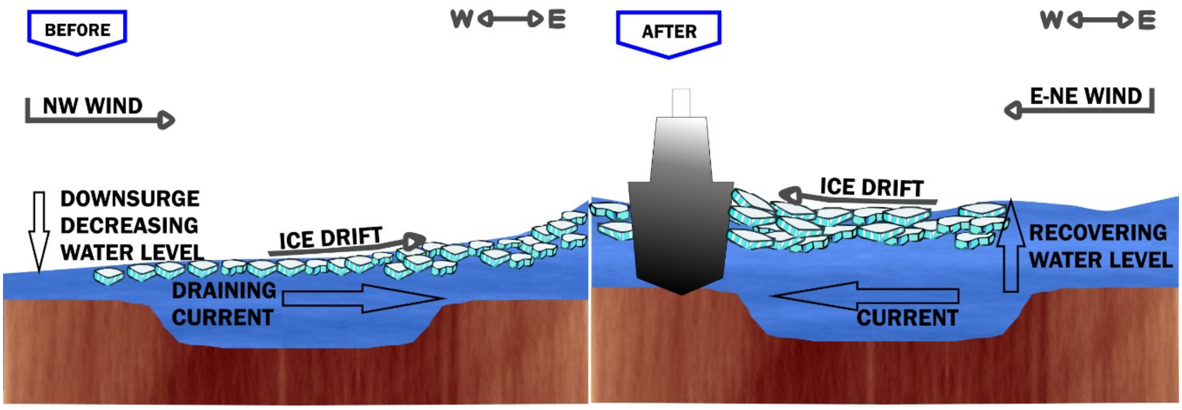

Figure 8: Schematic view of coinciding environmental phenomena described in VCC#2 scenario (VCC#2).

#3: this scenario is targeted to define frequency of wind events that may cause cross drift in the channel. Considering they have led to significant consequences such as case with MV Baku discussed above they are of major interest to operations. For the same reason it is used for verification to existing records of drift derived from satellite imagery versus wind records for the area.

Wind parameters that are used in further analysis are summarised in Table 1 below.

Table 1: Wind parameters used to assess possibility of ice drift across existing Volga-Caspian channel and projected channel through Saddle.

Scenario	#1	#2	#3
Area	Saddle (SDL)	Volga Caspian Channel (VCC)	Volga Caspian Channel (VCC)
10m Wind speed, knots	Above 15	Above 20	Above 15
10 m Wind Direction, degrees	300-60, 120-240	270-360	30-150, 210-330
Wind persistence, days	2	2	2
Scenario Description	Crosswind at channel	Downsurge leading to currents across channel with recovering water level	Crosswind at channel

ANALYSIS OF WIND AND DRIFT EVENTS OCCURRENCE

ERA5 atmospheric reanalysis of the global climate by ECMWF was used to extract records of wind at 10m. This reanalysis combines model data with observations from across the world into a globally complete and consistent dataset using the laws of physics spanning back several decades. Being publicly available at sufficient spatial resolution and relatively reliable records this dataset was chosen to perform the study. Historical records starting from 1979 were used to perform persistence analysis following conditions laid out for the three scenarios discussed above during periods starting in the beginning of November and finishing end of March each season. Presence of ice during the date ranges with weather conditions that are likely to cause drift was confirmed with visual observation of ice cover using remote sensing data (MODIS) since 2000, aerial ice reconnaissance charts from 1979 to 1991 and NOAA between 1991 and 2000 with low reliability due to extremely low resolution.

Figure 9 illustrates results of persistence analysis where frequency of identified events occurrence satisfying criteria laid out above is distributed by month of a season and season when they were observed regardless of ice presence. Each sector in a record indicates one event, absence of circle indicates no events answering scenario were identified. Fully coloured circle indicates there were four events observed at that month of corresponding season. There is only one such record (March 1995-1995 VCC#3) in the pivot chart that has 5 events. Season duration was set to start on November 01st and finish on March 31st. It should be noted here that occurrence of the events is uneven from season to season. So, for Saddle (SDL#1) and downsurge at VCC (VCC#2) scenarios that have boundary conditions of rare events, as example, there were seasons when events occurred rarely or didn’t happen at all for two or three seasons in a row.

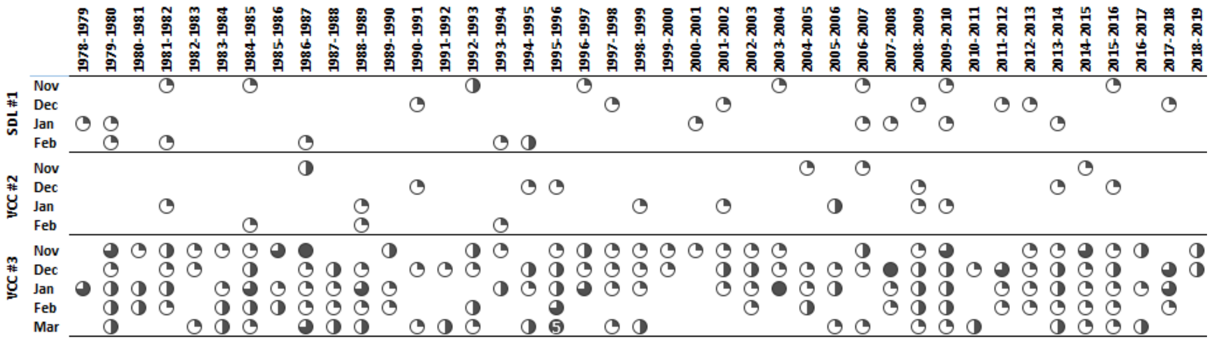

Figure 9: Frequency of occurrence for events answering conditions of scenarios distributed by winter months and seasons when they were observed. Each quarter of a circle is one event that falls into a month of a season.

Scenario 1 – SDL Crosswind

Persistence analysis has shown that there were 29 events during the last 40 years that might lead to cross drift events at Saddle. This confirms dominating winds in the region coincide with assumed channel orientation and unlikely or very rare events of persisting winds in Northern or Southern sectors. Figure 10 (top left) shows their distribution of occurrence by month of a season indicating even distribution through the season. The same figure indicates the same events when cross wind events coincided with significant ice confirmed present over the area totaling overall 18 events. Depending on winter severity ice was present only once out of nine observed events in November and four events out of seven in December. Ice was present for all events in January and February and there were no such conditions in the history of the last 40 years that could cause crosswind drift in March.

Scenario 2 – VCC Downsurge

This is the other rare event scenario that has identified only 22 events in the history. 15 cases coincided with ice presence (Figure 10 top right). Ice presence coinciding with weather parameters that could cause the event was observed only once in November and there were no such conditions observed in March at all. There was no ice observed when event could happen for at least one case for December January and February.

Scenario 3 – VCC Crosswind

This scenario contained the most common conditions that were observed in the region. There were 225 cases that have answered persistence analysis criteria for crosswind conditions in the Volga Caspian Channel area. 137 events observed during the last 40 years including the one with MV Baku coincided with ice presence. Generally lighter ice conditions in the western part of the Northern Caspian resulted in only 8 cases out of 47 and around half of cases in December and March to take place with ice presence in November.

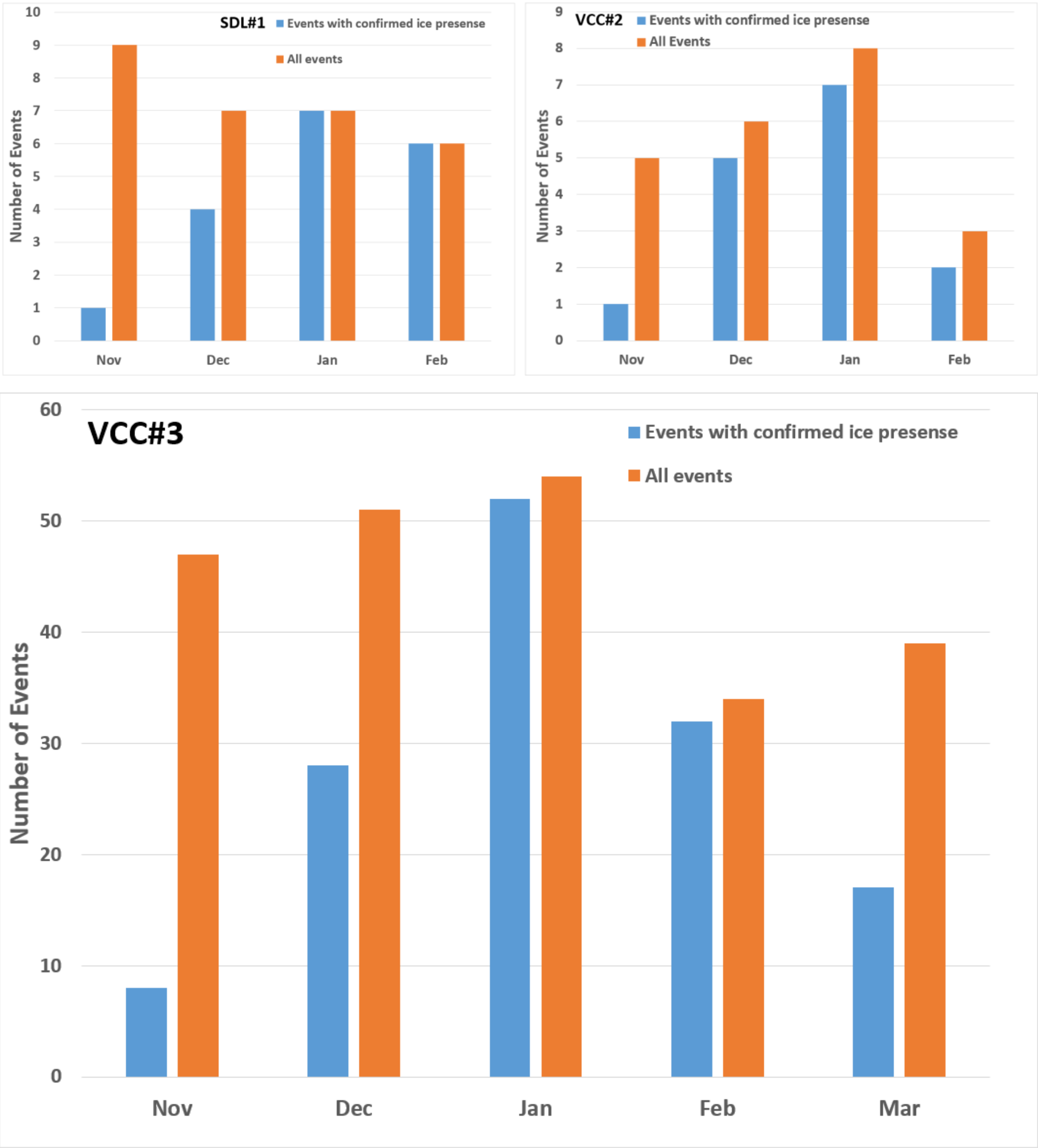

Figure 10: Number of events per month and number of events with confirmed presence of significant ice in the area as observed at Saddle during the period from 1979 to 2019 for Saddle (SDL) Case#1 – Top Left; Volga Caspian Channel (VCC) Case #2 – Top Right; Volga Caspian Channel (VCC) Case #3 – Bottom.

WIND TO DRIFT ANALYSIS

Ice drift records for Volga Caspian channel area during the period from 2010 to 2018 were extracted from ICEMAN.KZ database (Kadranov et al, 2017). Comparison algorithm of drift to corresponding wind observations from ERA5 reanalysis by ECMWF is described in detail by the same authors. Figure 11 shows timeseries of wind and drift directions and speeds records for several cases in 2012 and illustrates cases when directions of drift and wind closely match or have deviations from each other either due to effect of proximity to obstacles (Coast, seabed configuration, stamukhi) or flaws in data acquisition program. The flaws are normally associated with longer periods between start and end of drift displacements used to derive drift versus more frequent wind observations as can be seen with the right most record in the figure.

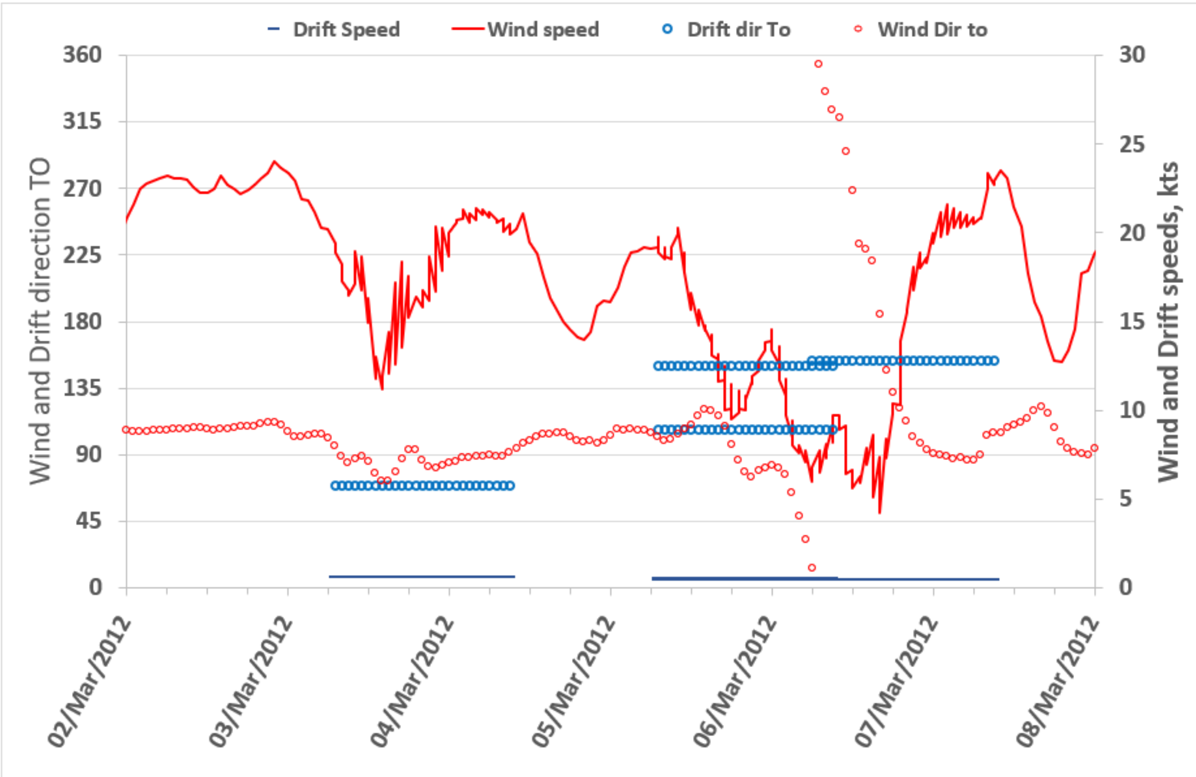

Figure 11: Example of Wind and Drift Direction and speed timeseries for some of the records in 2012.

Comparison of all the records has shown almost no deviation of persistent drift direction from corresponding wind direction except for rare cases for wind blowing to sector from South to West as shown with scatter plot in Figure 12. The match confirms that majority of drift events have wind drag origin and have little effect from other forces as it is observed in the Arctic pack ice, where 30° deviation of drift from wind is normal, for example. Thus, historical persistence analysis of scenarios containing wind direction and speed as boundary conditions as discussed in the sections above is very close to what can be expected in the resulting drift.

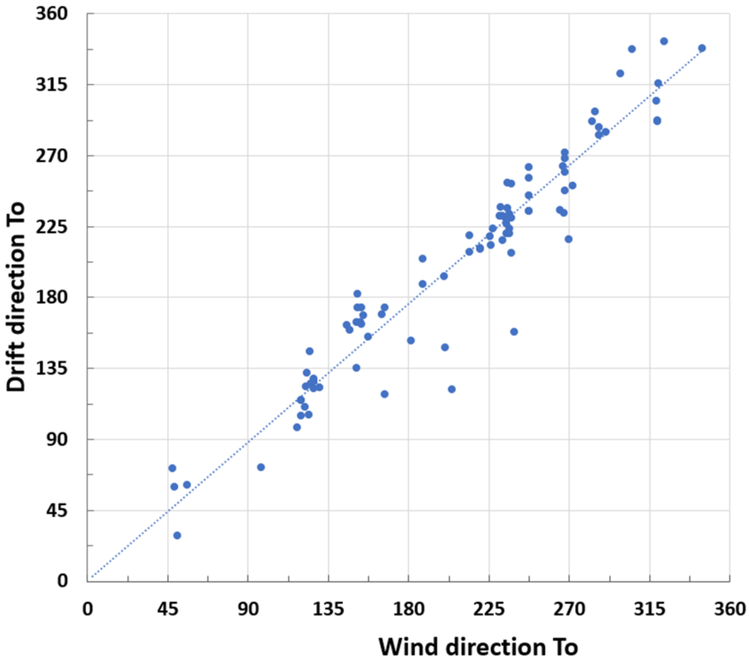

Figure 12: Distribution of ice drift direction by wind direction for corresponding observations in the area.

Ice drift and Wind speed by distributions are illustrated in Figure 13. These distributions indicate the effect of proximity to coast with generally lower drift speed records in westerly directions although significant number of wind records indicate wind was blowing that way. It should be noted that there is low number of Northerly drift records in the area showing the direction is unfavourable due to configuration of the coastline reducing likelihood of ice drifting up the channel. Considering the correlation of wind and drift directions discussed above it should be noted that wind rose indicates the strongest winds correspond to the fastest drift speeds observed in ESE sector. Greater speeds in this direction can also be explained with unconstrained drift seawards in that direction.

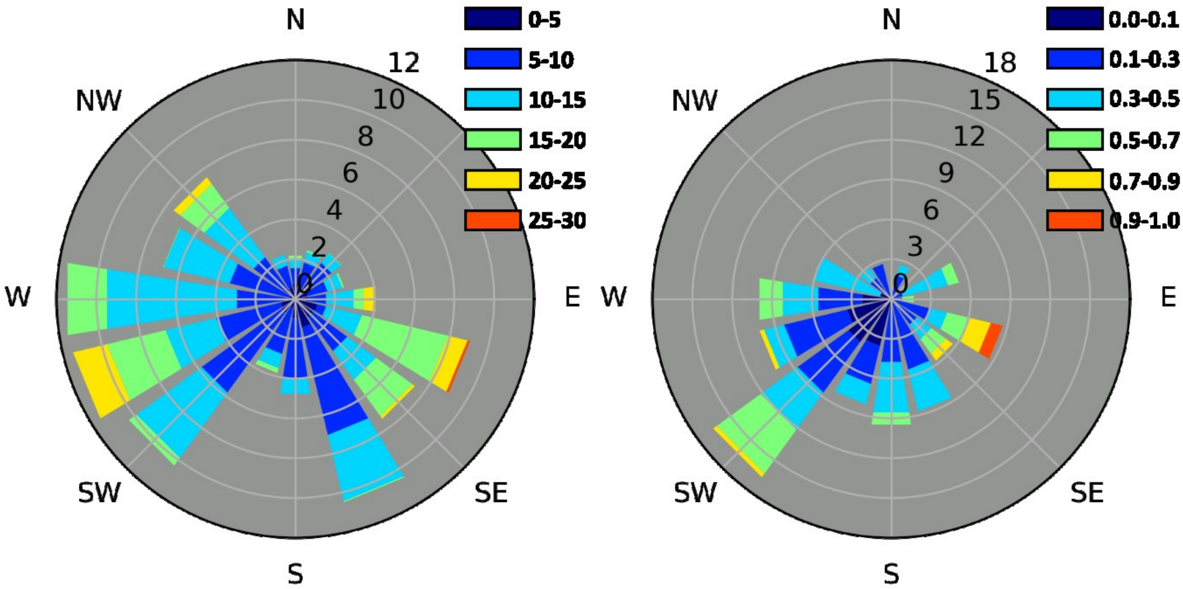

Figure 13: Wind speed (left) and Drift speed (right) distribution by direction TO (both for drift and wind) for observed drift events in vicinity of Volga Caspian Channel.

DISCUSSION

The study of weather records during the last 40 years shows that unfavourable conditions for vessels crossing an E-W oriented channel through Saddle are rare (only 29 events in the history) and may not occur for three seasons in a row. The other scenario when drift is caused by combined action of wind drag and currents associated with recovering water level after downsurge is a rare occasion too. Although there were only 22 such events observed in the history for the given period cumulative effect of both driving forces causing drift may lead to higher impact on marine operations and should not be neglected.

As for more critical cross wind scenario in the Volga Caspian Channel that runs across predominant directions of wind observed in the region it is a normal occasion. It should be expected at least once each month of a season that ice drift poses risk to push a transiting vessel off the navigable part of the channel as it happened with Baku.

Analysis of drift data derived from satellite imagery over Volga Caspian Channel confirmed the most critical drift events involving highest ice displacements across the channel were wind driven with little effect from other factors. Although some caution is needed to interpret wind persistence analysis for areas where proximity to anchoring points and coastline has significant effects on drift.

In order to perform economic feasibility study of dredging activities and following channel operations, this analysis can be enhanced to take into consideration wind surge events that affect water level over shallower Eastern part of the Caspian, where dominating Easterlies keep water at generally lower levels than average that is considered in this study. Adding records on spatial distribution of mobile and stable zones as well as records of drift speed estimated over vast areas may clear uncertainties with drift occurrence due to wind events and help to estimate cumulative downtime expectations.

At the first glance, as authors see the results of this study, the risks of operating channels in shallow Caspian waters will require rigorous ice hazards management program to monitor current and forecast near future ice and weather conditions and to keep operations aware of expected hazards to make decisions on transits. Expanding the analysis into older historical records when water level was at critically low levels in the end of 70s and subdividing records by proximity to ice edge and major indicators characterising winters in the region such as Freezing Degree Days (FDD) and Thickness distribution, Ice Coverage and Volume, Mobility will increase forecasting accuracy of the events occurrence during future operations and, thus, improve overall safety of operations as well as decrease downtime of fleet in transit saving costs and increasing efficiency.

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