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Early Freeze-up Scenario in the Caspian Sea

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ABSTRACT

The Northern part of the Caspian Sea gets covered with ice every year and stays frozen for 4-5 months depending on winter severity. Therefore, marine operations are different during winter and open water seasons. The transition between summer fleet and icebreaker supported marine operations is economically feasible. However, this transition needs timely warning for start of demobilization activities making accurate freeze-up forecast an operational requirement. This paper discusses ice appearance event in 2018 that was one of the earliest in the history of the last years. The event is a classic example how rapid ice formation takes place under effect of cold air intrusion associated with high pressure zone developing over Russian Arctic and moving towards the sea. Being a very distinctive weather system, it forms a good algorithm for freeze-up forecasting that aids timely and safe switch from summer to winter mode of marine operations.

KEY WORDS: Operations in Ice; Freeze-up Forecast; Ice Drift; Remote Sensing.

INTRODUCTION

The Caspian Sea is located on the extreme southern threshold of sea ice cover development in the Northern Hemisphere. Ice cover over the Caspian Sea is subjected to significant temporal and spatial variability, influenced by climate conditions, wind fields and water currents, as well as sea morphology (Kouraev et al., 2004). Temporal variations suggest longer duration of open water conditions with economically feasible use of summer fleet with light hulls and lower power of vessels. Several months of ice cover and sub-zero temperatures make operators to demobilize summer fleet forcing them to operate specific vessels with Ice Class and installed power of the offshore vessels (OCIMF, 2014).

Timely switch between summer and winter modes of operations is a necessary part of marine operations in the region that ensures minimal safety and absence of damage to assets resulting from light boats caught in ice conditions that they cannot handle. Such change in operations should be based on reliable insights based on weather forecast and references to historical observations of conditions leading to formation of ice cover in the region. This paper is describing the scenario that was observed in 2018 and ended up with the earliest freeze-up in the latest history as a timeline of events presenting available information at that time.

Areas along the Northern and Eastern shores as highlighted in Figure 1 are of major focus with their ultra-shallow waters (darker grey areas Zhambay (ZHA), Peshnoi (PSH), Emba (EMB), AKK), Prorva (PRV) and Dead Kultuk (DKU) in the same figure) and almost immediate response to consistent negative daily average air temperatures to form new ice. The major focus is given to Prorva area where intensive dredging takes place in channel to Tengiz with operations being sensitive to timely demobilisation before the first ice appearing in the region.

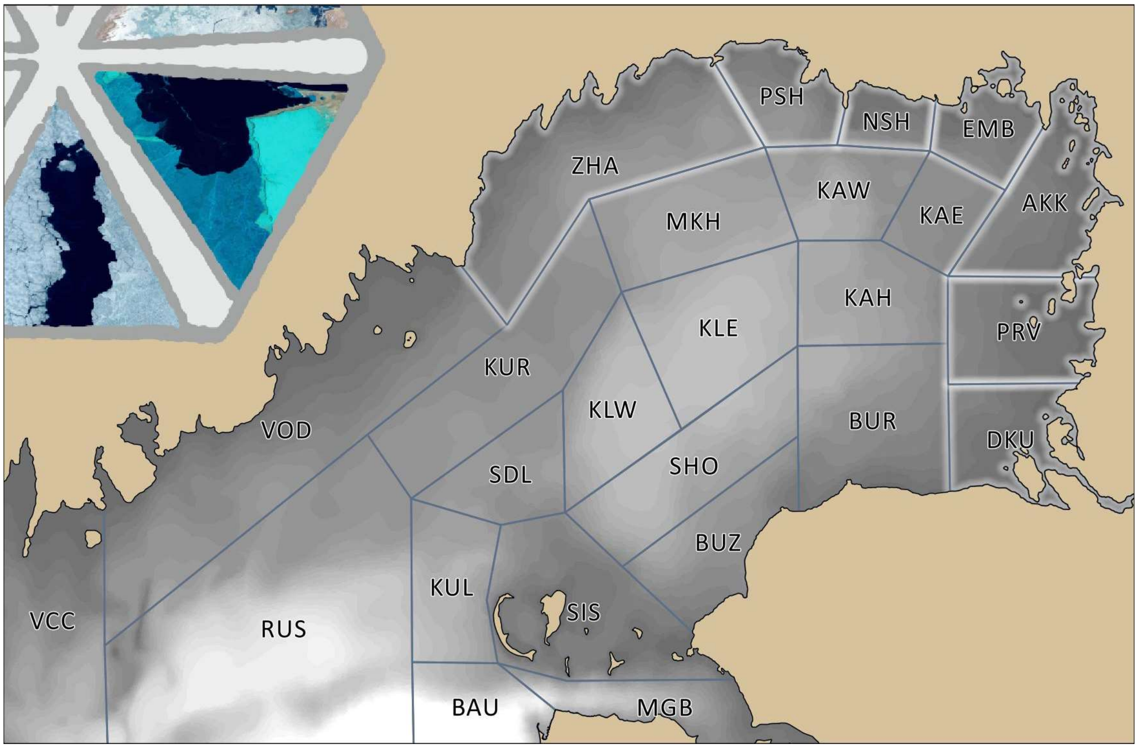

Figure 1. The Northern Caspian Sea zoning and highlighted areas with ultra-shallow water depths along the Northern and Eastern Coasts.

Deeper areas like Kalamkas East (KLE) and West (KLW) as well as transitional zones at Kashagan (KAW KAE KAH) and Makhambet (MKH) have slightly different environmental conditions regulating ice infestation processes. First ice may appear significantly later due to deeper waters and higher number of persisting negative degree-days needed to accumulate cool water column cooling to freezing point. Depending on drift regime during the beginning of ice season, though, the first ice could be drifted into the areas from the pre-coastal zones and contribute to cooling of water with melting ice. As these processes are more complex to model and visualize, they are only partially covered in this paper focusing on areas near shores.

HISTORICAL RECORDS AND SEASON'S FORECASTS

Historical records of air temperature variations in combination with records of first ice appearance dates for each operational area were considered the basis to building long-term outlooks with expected first ice appearance date ranges.

Based on records of the previous years cold air masses were brought with the Easterly winds while a high-pressure system was developing over central Russia and ensuring direct invasion of Arctic air masses into the Caspian region. This weather system being the key indicator for early warning has drawn attention on November 04th (Figure 2) and was confirmed on the next day with ECMWF (The European Centre for Medium-Range Weather Forecasts) model data when persistent negative daily averages were forecast for the period starting November 11th.

Sea Surface Temperature observations acquired with Sentinel-3 indicated that most of the area in the Eastern part of the Caspian Sea was in range from +5°C to +10°C. Although four days of daily air temperature decreasing to around +2°C along the eastern coast resulted in cooling water there to range from +3°C to +5°C. Considering inaccuracy of forecast in 10-day range and possible cold air invasion not being as intensive as forecast on November 05th presence of warm water added uncertainty to forecast and possibility to interpret forecast information as predecessor for temporary new ice formation that could erode with warmer air temperatures expected after the cold snap.

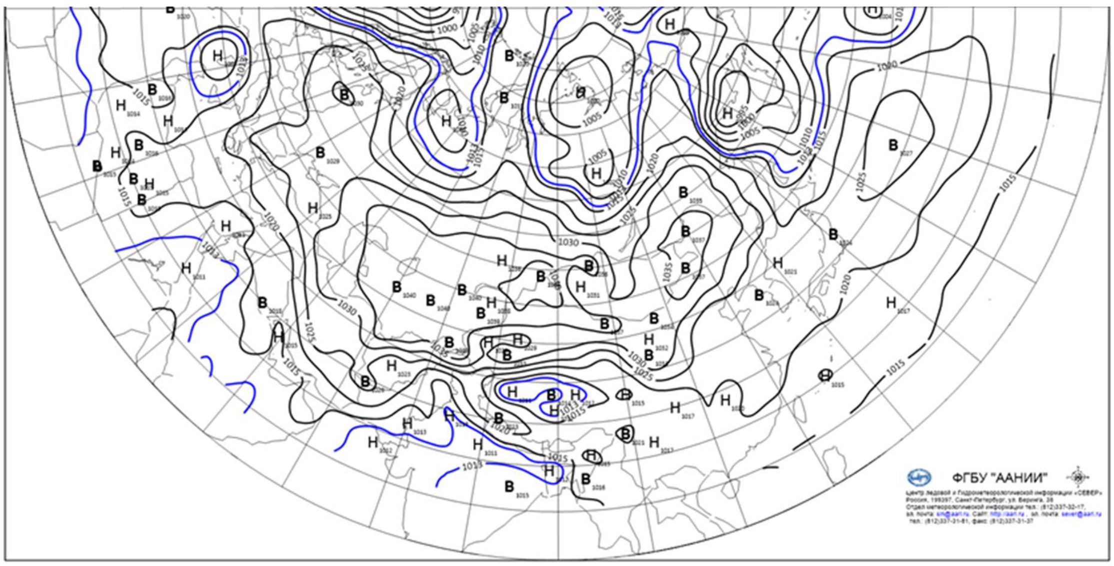

Figure 2: Surface air pressure charts based on GFS data on November 04, 2018 as presented by AARI, 2019.

Figure 3 shows more detailed air temperature analysis supporting freeze-up forecast for Prorva area issued November 05th when confirmation was received that Siberian High-pressure system is developing and likelihood of first ice formation was confirmed. Acting under assumption that only limited number of degree-days is needed to trigger ice formation in the pre-coastal area air temperature analysis summarised in the graph was considered sufficient. Analysis contained the following information:

1. Grey dashed bold lines indicate minimum and maximum daily air temperature for the last 10 years that presumably set seasonal constraints. 10-years record was chosen to remove bias from climate change effect.
2. Grey dashed line and grey bars show expected daily average air temperature development through the season that is derived from daily average (line) and 90% of observations during the last 10 years modified using trends of surface temperature anomalies published by Copernicus Climate Data Centre.
3. Red solid line is daily average air temperature observed in the area and derived from observations at weather stations in the region and ECMWF model data.
4. Red dashed line and bars expected daily average air temperature development over the area during the next 10 days is based on ECMWF model data issued on the day of analysis and modified to correspond to local conditions.

Considering the synoptic situation developing under scenario that has resulted in rapid freeze-up before and persistent negative daily averages in the forecast high likelihood of first ice appearance on November 12th was concluded.

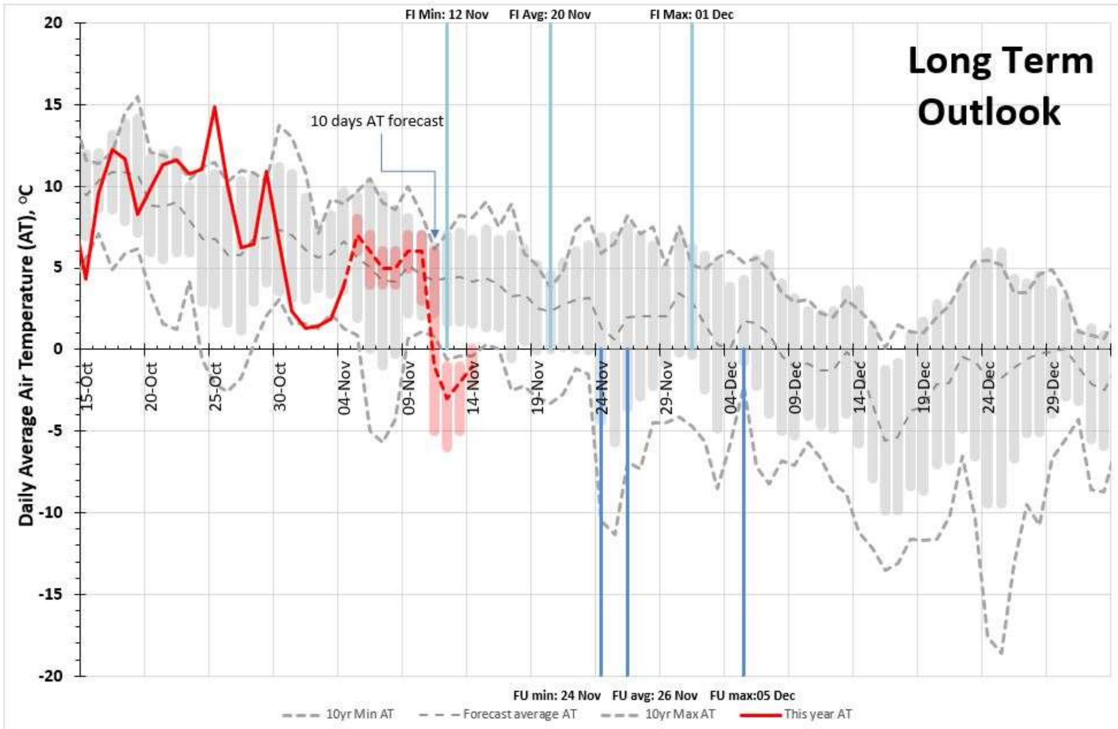

Figure 3: Daily average air temperature generated using Copernicus Atmosphere Monitoring Service information (Climate Data Store, 2019).

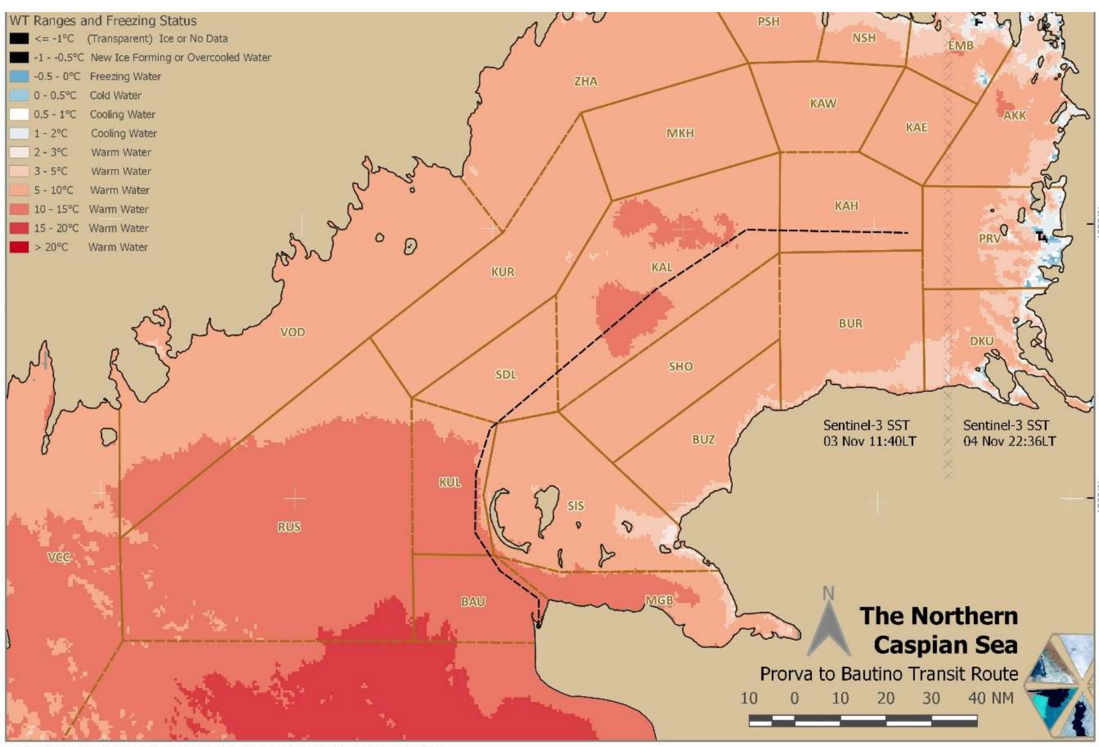

Figure 4. Sea Surface Temperature derived from Sentinel-3 images (acquired through EUMETSAT, 2019) acquired on November 3rd and November 4th, 2018.

ICE AND WEATHER OBSERVATIONS

Daily average air temperature development during the period starting November 01st to November 20th at the ultra-shallow areas along the Northern and Eastern coastlines are summarised in Figure 5. Air temperature data used for operational analysis at the time was extracted for each area from ECMWF model output that gives generally warmer observations for the region and modified to adjust to local conditions based on algorithm developed internally based on remote sensing observations and data from WMO stations in the region (ICEMAN.KZ, 2019). It was retrospectively verified to ERA5 reanalysis data by ECMWF to confirm reliability of operational analysis in remote areas without physical observations from weather stations.

It was varying between +4°C and +5°C at the Eastern coast (left) with almost no variability between forecast areas indicating homogeneous air masses intruding the region from the East until November 10th. Variation was slightly higher along the Northern coast ranging from +4°C to +7°C with warmer air temperature observed in the Western-most area of Zhambay (ZHA) during the same period. Air temperature dropped to range from 0°C to -2°C on November 11th and to range from -4°C to -6°C on the next day in almost all areas except for western-most Zhambay at the Northern coast where it reached only just below -2°C.

Actual air temperature development records shown below fall into ranges of forecast 10-days expectations illustrated in Figure 3 above confirming reliability of First Ice date expectations one week before the event arrival for Prorva area. Although too early in the season and falling out of constraints set by the history of the last 10 years temporary first ice appearance as perceived at that time this cold snap resulted in ice cover formation that lasted for the rest of the season.

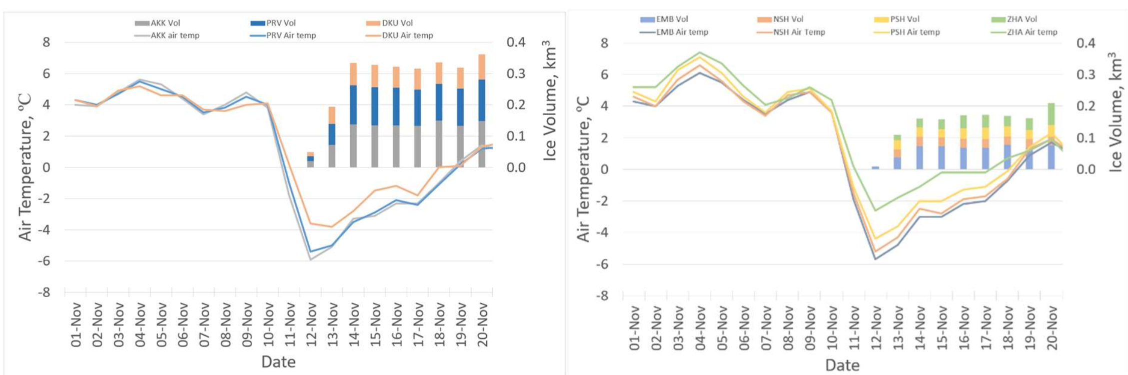

Figure 5. Daily average air temperature generated using Copernicus Atmosphere Monitoring Service information (Climate Data Store, 2019) and ice cover volume (ICEMAN.KZ, 2019) development over Eastern coast areas (left) and Northern coast (right) during the period from November 12th to November 20th in 2018.

Ice volume development (ICEMAN.KZ, 2019) was intensive during the first three days after November 12th and maintained at almost the same level until November 20th. Volumetrically there was slightly more ice generated in the AKK area in the North-Eastern part of the region than all other areas indicating the place of the most intensive effect of cold air invasion. Zhambay being the furthest to the West and with the lowest FDD accumulated has acquired the least of ice during the cold snap.

Figure 6 illustrates Ice Edge evolution from the first day of first ice formation on November 12th to November 15-20th when it varied at the maximum extent reached during the first cold air invasion into the region in 2018. It can be observed the most progress of ice extent development took place in the first days of the cold snap. Slight variation of Ice Edge extent in front of the Northern Coast was associated with continuous drift taking place with the Easterlies during the time. Although Ice Edge has propagated all the way to Seal Islands (SIS) by November 15th erosion of newly formed ice was observed during the next 5 days. This observation is most obvious over deeper part of Buzachi (BUZ) where Ice Edge has retrieved back to the coastline. Effects of warmer deeper waters limiting further ice edge propagation to the west is explained with water temperature still being significantly above freezing point as discussed below.

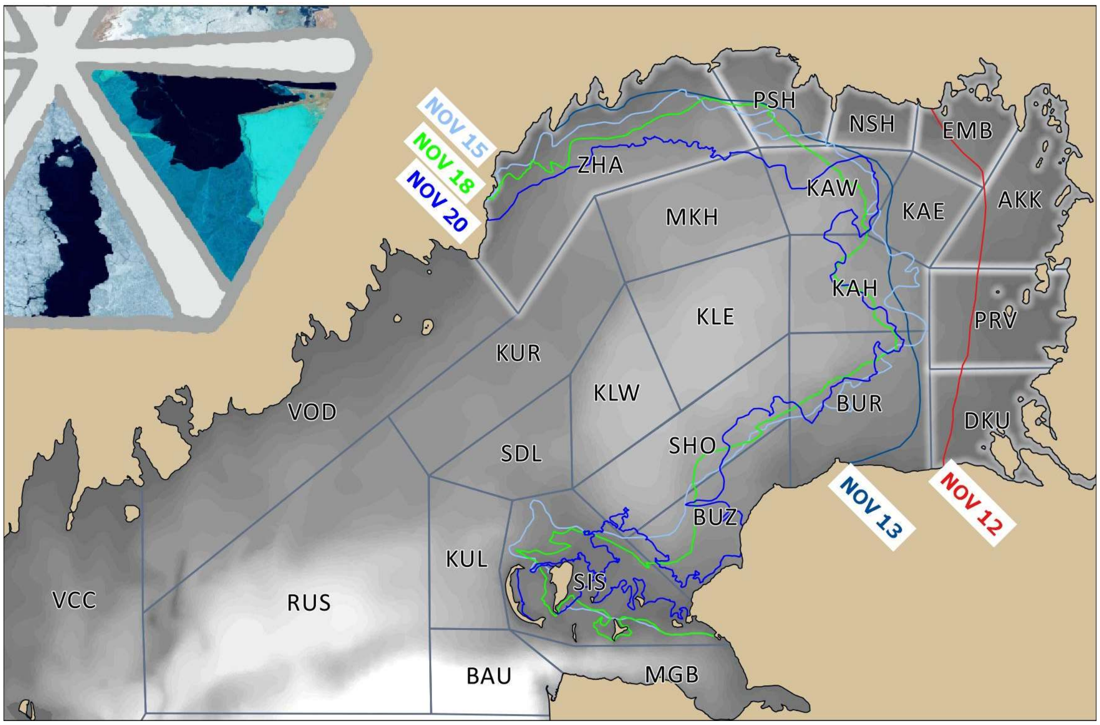

Figure 6: Ice Edge development during the period from November 12th to November 20th.

SEA SURFACE TEMPERATURE AFTER FIRST ICE FORMATION

Sea surface temperature derived from Sentinel-3 SLSTR data was used operationally to assess Ice Edge development and forecast its position operationally. Although cloud cover dependent when a cloudless day happens as it did on November 14th and November 20th (see operational analysis for these days in Figure 8 and Figure 8) SST data classed by cooling rates that are appropriate to current negative air temperature intensity gives good understanding of thermal processes taking place over the whole region. For air temperatures ranging around -2°C as it was during the two SST observations on the figures below 0.5°C step near freezing point corresponds to a day's change of ice edge assuming air temperature remains at the same level.

November 14th SST observations shown in Figure 7 indicate Kalamkas (KAL) waters were above +5°C and surrounding waters were in range from +3°C to +5°C at Makhambet (MKH) and down to near freezing just below 0°C at Kashagan West (KAW) and Kashagan Highway (KAH) along the Eastern borders of the areas. Blue pixels indicating freezing waters and surrounding ice floes at Kashagan East (KAE) illustrate scenario of ice cover present over warmer waters that limit new ice formation and cool down with melting floes drifted into the area from the shallower and colder area in the East.

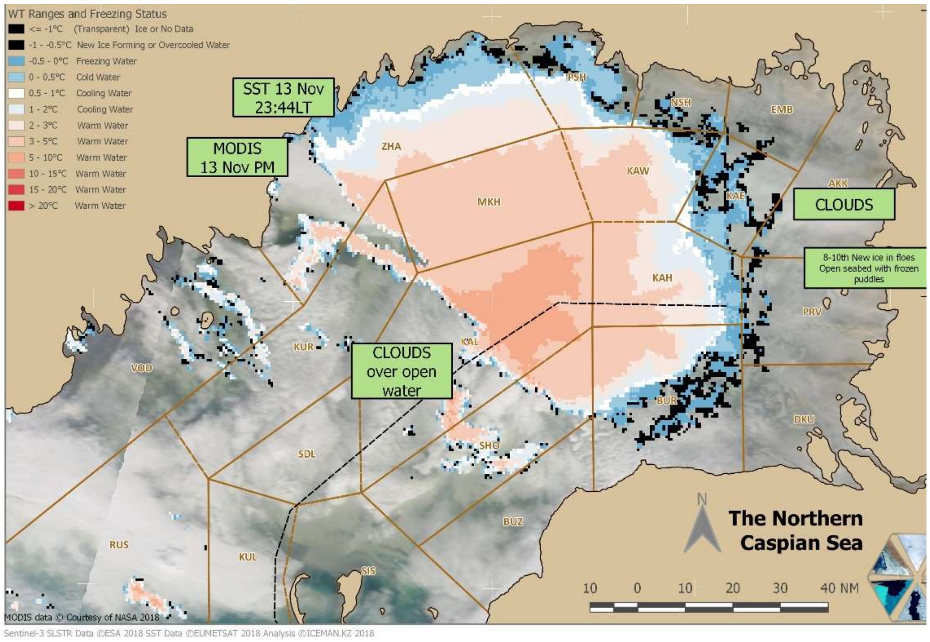

Figure 7: Operational SST analysis illustrating likelihood of ice edge development on November 14th based on Sentinel-3 SST data (EUMETSAT, 2019).

Figure 8 shows how SST evolved under effect of drifting ice and negative daily average air temperatures persisting over the Eastern part of the Northern Caspian Sea until November 18th and slightly above 0°C until November 20th when SST data was acquired. While most of the deeper part in the central deeper basin of North-Eastern part of the sea has decreased to range between +1°C and +3°C (2 to 4 degrees lost in less than a week) eroding ice that drifted to the deeper part of Buzachi (BUZ) has cooled it down to near freezing point.

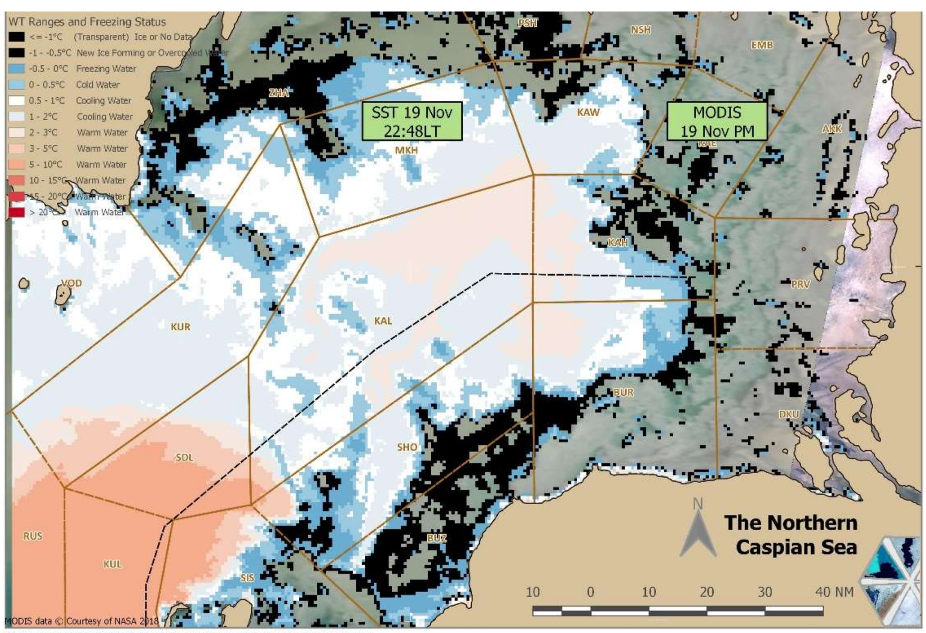

Figure 8: Operational SST analysis illustrating likelihood of ice edge development on November 20th based on Sentinel-3 SST data (EUMETSAT, 2019).

SST observations and ice cover extent during these two days illustrate water depth effect on first ice appearance and further freeze-up development. Ultra-shallow pre-coastal areas cool down rapidly during the first days of cold air invading the region for the first time in the season and start generating new ice along coasts. Considering scenario with weather system involving high-pressure zone establishing North of the region and leading to persistent strong Easterlies newly formed ice drifted to the West ensuring faster cooling of water in deeper neighboring areas.

WIND-DRIVEN DOWNSURGE EFFECT

As an additional factor that increased effects of cold air invasion was significant water level drop associated with persisting Easterlies over the region. Figure 9 shows zoom-in Landsat image acquired on November 15th into the North-Eastern corner of the Caspian. Significant areas of seabed are revealed along the Eastern coastline with water level drop caused by the wind.

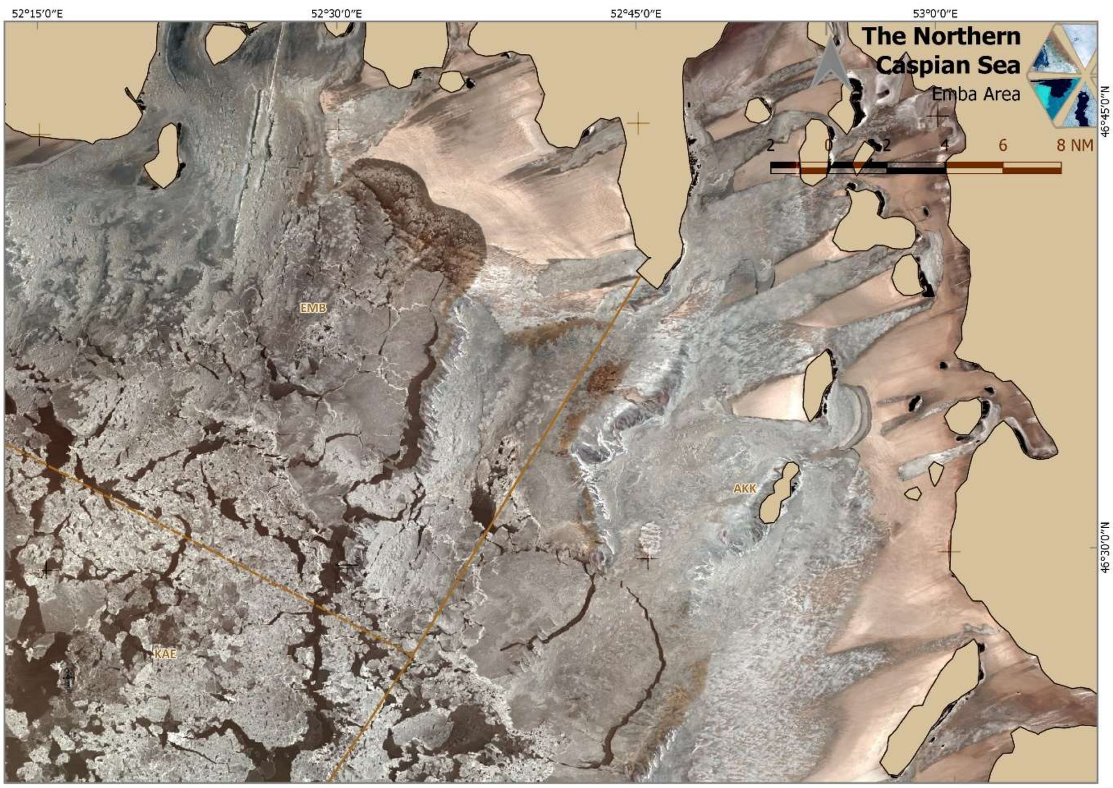

Figure 9: Landsat-8 image by USGS/NASA acquired on November 15th in the NE corner of the Caspian.

Overcooled water from shallower area along the Eastern coast being drained towards deeper areas of the sea with westerly currents facilitated ice cover formation in deeper waters. This can also be observed with pattern of SST change between November 14th and 20th observed in figures above.

DISCUSSION

Following the timeline of forecasting first ice appearance in the Caspian region in November 2018 that it is possible to raise first warning 8 days and confirm with high level of confidence in one week before the event occurring in pre-coastal areas under conditions Siberian high-pressure is noticed developing. Analysing other seasons and identifying similar patterns that can be used as predictors of first ice formation could be an asset for operators to plan timely summer fleet demobilisation activities with sufficient warning to start action.

This analysis has identified several factors to consider while developing first ice forecasting algorithms for deeper areas away from coast:

- first ice appearance due to persisting wind
- water temperature variations with surface currents due to surge events
- faster cooling of water due to erosion of drifted ice.

Considering increasing access to historical high resolution both temporally and spatially that is provided with Copernicus data services further development into seasonal forecasting over this region will continue in our group.

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