

Coastal Ice Rubbles in Isfjorden (Spitsbergen)

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ABSTRACT

Coastal ice rubble is a pretty common phenomenon in the Canadian and Russian Arctic and relatively rare in the Atlantic Arctic, especially in the time of Global warming. Nevertheless, such rubble could create problems for infrastructure and should be investigated to avoid the issue for fragile remote settlements. The rubbles are interesting also for the understanding of peculiarities of coastal ice dynamics.

The coastal ice rubble was observed at the beginning of April 2020 near Longyearbyen town, along the shore of Isfjorden, the largest fjord on the West of Spitsbergen, being under the influence of the North Atlantic Current. There was no such observation in the previous years and after. The rubble appeared after a storm that lasted for several days and left also piles of seaweed onshore 3-4 m above the water level, revealing the wave height.

Two laser scanning sessions (in different tidal phase) were performed to estimate the size of the rubble and ice block composition. The ice rubble existed for more than 10 days and began quickly deteriorating after that. Only one stamukha and two floating ice floes could be observed on the place on the 14th of April 2020.

The main ice rubble had size 250x500m with the sail height of ice blocks up to 6 m above water level. Ice floes constructing the rubble were up to 0.9 m thick. Significant ice presence in Adventfjorden was observed from the beginning of January till the middle of April. Adventfjorden is one of the inner parts of Isfjorden, where Longyearbyen is located. Several times ice created local problems for navigation and port facilities and pushed boats from the water.

In the paper, the observed rubble is analysed on the background of the other ice phenomena in Spitsbergen and continuing warming in the Arctic.

KEY WORDS: Sea Ice; Rubble; Spitsbergen.

INTRODUCTION

Svalbard fjords and the city of Longyearbyen are often featured in media as a place where global warming is most visible and spectacular (Figure 1). Several popular reportages and scientific papers have been devoted to the place in recent years. In 2023, 7 times faster than the whole planet warming was reported (NCCS, 2019, ITV News, 2023). Isfjorden transforms from a regular ice-covered to an ice-free gulf. From the unknown remote area in the Arctic, Isfjorden became to be the place the world looks at with the intention of seeing the future fate of the planet in case of continuous global warming.

However when sea ice is present, it can create problems for citizens and the local community influencing navigation and port facilities (Marchenko and Bråten, 2011). So even not-so-big (on the whole Arctic scale) ice phenomena should be investigated to avoid the troubles for fragile remote settlements.

That's why recent sea ice observations in the Isfjorden are supposed to be relevant and interesting.

ISFJORDEN CHARACTERISTICS AND CURRENT STATE

Isfjorden is the largest fjord on the west of Spitsbergen, the biggest island of Svalbard archipelago, surrounded by the Arctic Ocean in the north, with the Greenland Sea and Fram Strait to the west and the Barents Sea to the east. Isfjorden is located between 78° and 79° N and 13°– 17° E. It goes more than 100 km into the island to the east with a means width of 24 km width and has several large branches (Figure 1).

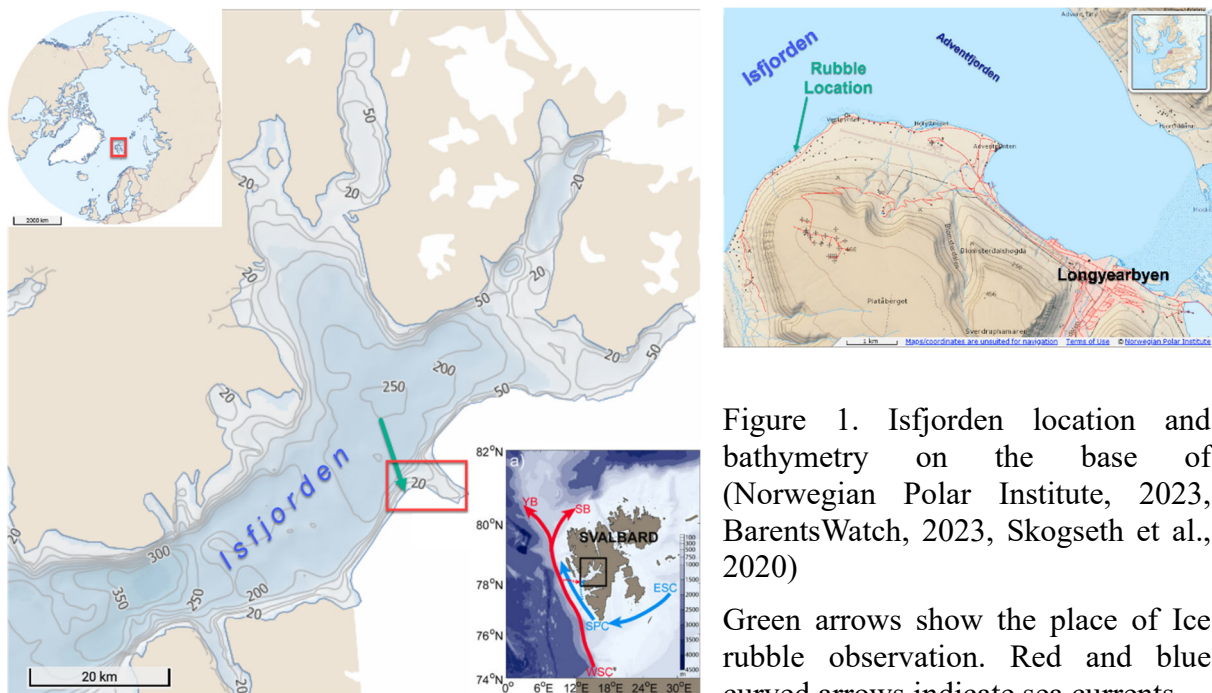


Figure 1. Isfjorden location and bathymetry on the base of (Norwegian Polar Institute, 2023, BarentsWatch, 2023, Skogseth et al., 2020)

Green arrows show the place of Ice rubble observation. Red and blue curved arrows indicate sea currents.

The depth is 100-200 m in the central part and 30-70 m in the branches. Many branches have glaciers at the end. Calving glaciers produce icebergs. The deep mouth trough with a round shape depression Svenssunddjupet (424 m) opens Isfjorden to the influx of external waters (competitive Atlantic or Arctic). The effect of increasing continentality characterizes the east

part of the fjord, with colder winters and warmer summers. Combined with flows of fresh water from the rivers, it leads to the formation of ice covers in the branches in winter. Whereas the Isfjorden was often wholly frozen in the early 20th century, this happens today only in exceptionally cold years. The smaller side fjords on the north side and in the innermost Isfjorden (Billefjorden, Tempelfjorden) still freeze in most winters, although not as reliable as in the 20th century.

Warm West Spitsbergen Current (WSC – Figure 1) contributes strongly to Svalbard's relatively warm climate and causes the eastern Fram Strait to be the northernmost permanently ice-free ocean (Onarheim et al., 2014). Penetration of WSC into Isfjorden makes it ice-free also.

Recently R.Skogseth and coauthors (Skogseth et al., 2020) made detail overview of previous investigations of ocean climate and circulation in the Isfjorden. They analyzed observational data (CTD profiling along transect and cross section, mooring stations) and reanalysis data from 1987 to 2017. In the paper one can find the thorough references and data examination. The authors underline the Isfjorden as an indicator for climate change in the European Arctic and the “competition of Arctic and Atlantic waters” (blue and red curved arrows in Figure 1) in the fjord during the year and in large time scale and show the consequences. In winter the penetration of Atlantic water (WSC) leads to positive trends in the sea surface temperature and to the shift to less fast ice in Isfjorden.

S.Munkenhuber and coauthors (Muckenhuber et al., 2016) analyzed satellite images and ice charts displaying the area of Isfjorden for the period 2000-2014. The mean seasonal cycles of fast ice in Isfjorden show monthly averaged coverage of less than 1% between July and November and maxima in March (35.7 %). A significant reduction of the monthly averaged fast ice coverage from 57.5 to 23.2% during the period is found. The authors introduced a new index, called “days of fast ice” (DFI) for quantification of the interannual variation of fast ice cover, allowing for comparison between different fjords and winter seasons. A distinct shift to lower DFI values is observed in 2006. Calculating a mean before and after 2006 years, they realized a decrease from 50 to 22 DFI for Isfjorden. Fast ice coverage generally correlates well with remote-sensing sea surface temperature and in situ air temperature.

Overall, the last 20 years, air and sea temperatures rose up in and around Svalbard, especially in winter. This has resulted in a reduced sea ice cover in the fjords. In the years with ice in Isfjorden and its side fjords, its thickness is much less and cover unstable, because warm Atlantic water has displaced the cold and fresh Arctic water, and temperatures are well above the freezing point of seawater (approx. -1.8°C). So in some years the fjord has open water throughout winter. But in some winters as 2019/2020 most low-pressure systems went directly into the Barents Sea, which was common in the “old days”. North winds formed cold air masses and surface lighter and fresher water prevailed. That prevented penetration of warm and salty Atlantic Ocean water and facilitated ice formation. Air temperature in January-April 2020 was significantly lower than in previous years. Meteorological station at Svalbard Airport registered average month temperature 2.5–4.2 °C lower than normal (average) temperature for last 30 years in January-March (NMO, 2023). March 2020 was even 0.5 °C colder than climate normal before global warming 1961-1990 (see Table 1).

Table 1. Average month air temperature registered at Svalbard Airport Meteostation, according to (NMO, 2023)

	Average month temperature	Deviation from normal. 1991-2020	Deviation from normal. 1961-1990
January 2020	-13.4	-2.5	1.9
February 2020	-15.5	-3.9	0.7
March 2020	-16.2	-4.2	-0.5
April 2020	-8.9	-0.1	3.3

SEA ICE OBCERVATIONS IN SPRING 2020

As it was mentioned above, sea ice in Isfjorden is quite seldom phenomena after 2006. The set of ice map, provided by Norwegian Polar Institute, for the beginning of April 2016-2021 is presented in Figure 2. The place where the rubble was discovered in 2020 is marked by a red arrow. As special maps for Isfjorden are provided only since late April 2017, for 2016-2017 we show the map for the whole Svalbard. One can see that sea ice was in the proper Isfjorden only in 2020. Only branches had fast ice in the inner parts and ice of various concentrations closer to the mouth in the other years. In 2022 there was more ice in the branches but less in the proper Isfjorden compared to 2021. In 2023, the situation was similar to 202, with only a very open drift ice area, crossing Isfjord in the western part. But in 2020 sea ice was observed in Isfjorden the whole winter up to end of April, as it is shown in sea ice maps provided by Norwegian Meteorological Institute (Norwegian Meteorological Institute, 2023). There were several periods when close drift ice with compactness more than 7/10ths covered more than 1/3 of Isfjorden – several days around 6th and 27th of January, 18-20th, 27th of March- 3rd of April. From 23rd of March till 8th of April, the thin strip of fast ice is shown on ice map in the place there the rubble was observed.

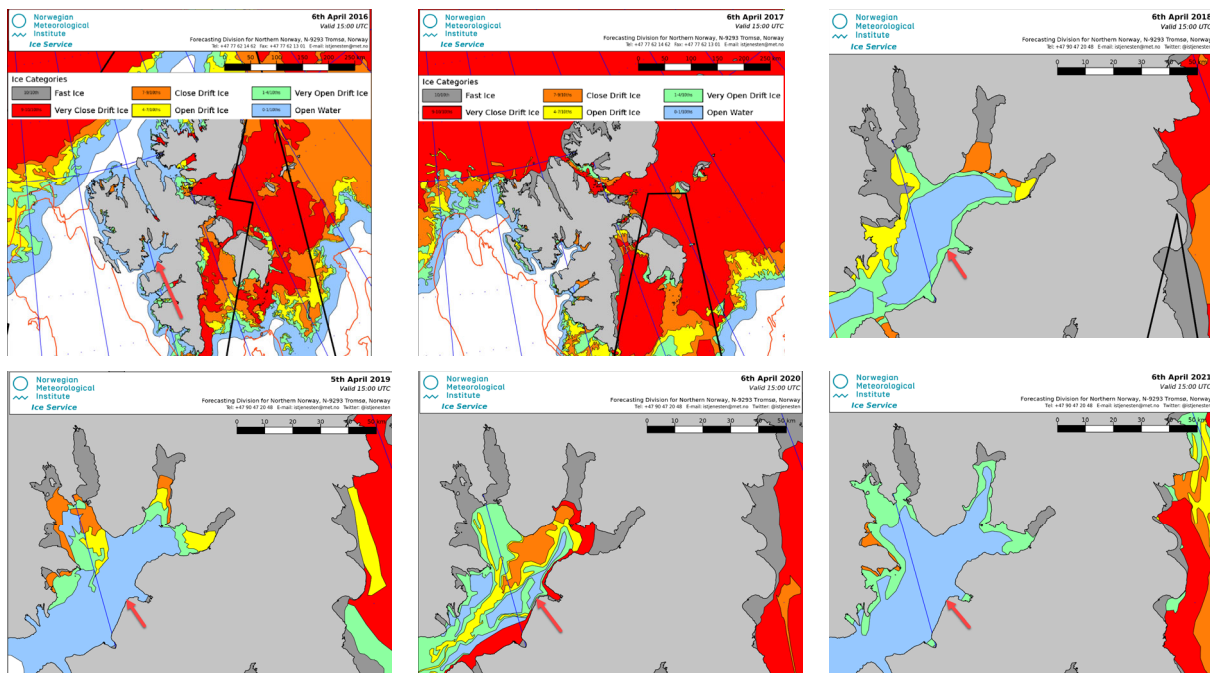


Figure 2. Sea Ice in Svalbard and Isfjorden for 6th of April through 2016-2021 (Norwegian Meteorological Institute, 2023)

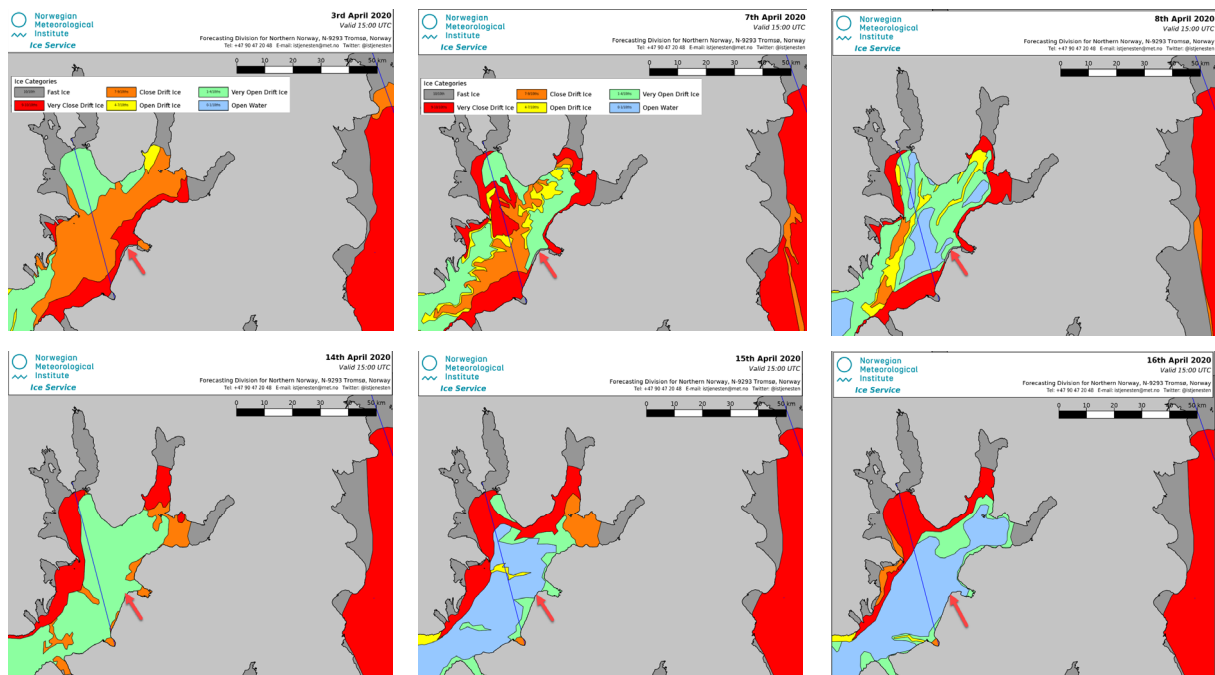


Figure 3. Sea Ice in Isfjorden from 3rd of April till 16th of April 2020 (Norwegian Meteorological Institute, 2023).

The developing of sea ice in Isfjorden at the beginning of April 2020 is presented in Figure 3 by the set of ice map from 3rd of April till 16th of April. One can see that on the 3rd of April the whole fjord was covered by ice in various concentrations, increasing from 1-4/10ths till 9-10/10ths. Ice was blown away from the east part of Isfjorden and pushed to the north-west on the 14-15th April. Floating ice disappeared from Isfjorden at the end of April. But fast ice covered the branches as long as till the beginning of June.

COASTAL ICE RUBBLE IN APRIL 2020

The Ice Rubble was discovered on 4th of April 2020 near Longyearbyen town, along the south-east coast of Isfjorden. The location is marked in Figures 1 green arrows, in Figures 2 and 3 by red arrows. It is visible that land fast ice is shown in ice maps in this place (Figure 3). Local citizens living in huts nearby said that they did not remember such ice piles in this place for the last ten years. They were surprised and paid a lot of attention to such seldom phenomenon. The author does not remember something similar since 2006, being on Svalbard. Such phenomenon was not observed in 2021-2023. The Ice Rubble appeared after a storm that lasted for several days and left also piles of seaweed onshore 3-4 m above the water level, revealing the scale of waves. The meteorological station of Longyearbyen airport reported north-west wind 10 m/s with gust up to 15-20 m/s (see (NMO, 2023)). Actually, the ice piles were observed along the all coast at the exit (mouth) of Adventfjorden, where the fast ice marked on ice map. But in the pointed place the ice strip was much wider, ice blocks bigger and piles higher. This “main ice rubble” had size 250x500m with the sail height of ice blocks up to 6 m above water level. Ice floes constructing the rubble were up to 0.9 m thick (Figure 4-8).



Figure 4. Panorama of Ice Rubble on the 4 of April 2020.



Figure 5. Panorama of Ice Rubble on the 9 of April 2020 features laser scanning procedure.

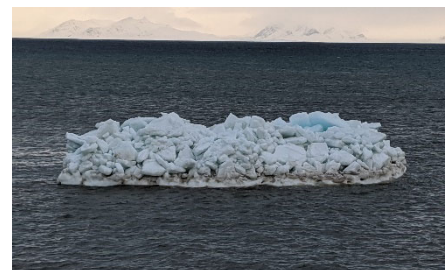
On the 11th of April the wind changed to the eastern and together with high tides it contributed to the rubble destruction and carrying away the ice blocks composed the rubble. On the 14th of April only one stamukha and two floating ice floes presented the disappearing rubble (Figure 6).



5 April 2020



9 April 2020



14 April 2020

Figure 6. Appearance of Ice Rubble on 5-14 of April 2020.

Laser scanning with Riegl VZ 1000 was performed from 2 points on the hill to obtain the 3D point cloud (Figure 7 and 8) on the 5th and 9th of April. Data is published in the form of ASCII and las. files and can be found in Norwegian Polar Institute data Centre (Marchenko, 2023a, Marchenko, 2023b).

The tidal variations significantly influence sea ice dynamic in the coastal line. In the period from 4th to 9th April the difference between low and high tide increased from 67 cm (59-126 cm) to 200 cm (-16-184 cm), creating considerable ice dynamics. All ice blocks and hummocks were lying on the bottom in low tide (Scan on 9th of April – Figure 8) and the difference in elevation between levelled internal part and ridged boundaries exceeded 6 m. In high tide, only the most significant ice blocks and hummocks were grounded. The flat and small ice floes floated and elevation difference was less (4.5 m during the scan on the 5th of

April, when the water level was sinking and reached 40 cm). This also contributed to the moving of floating ice by wind and waves and their removal from the place of accumulation near the coast.

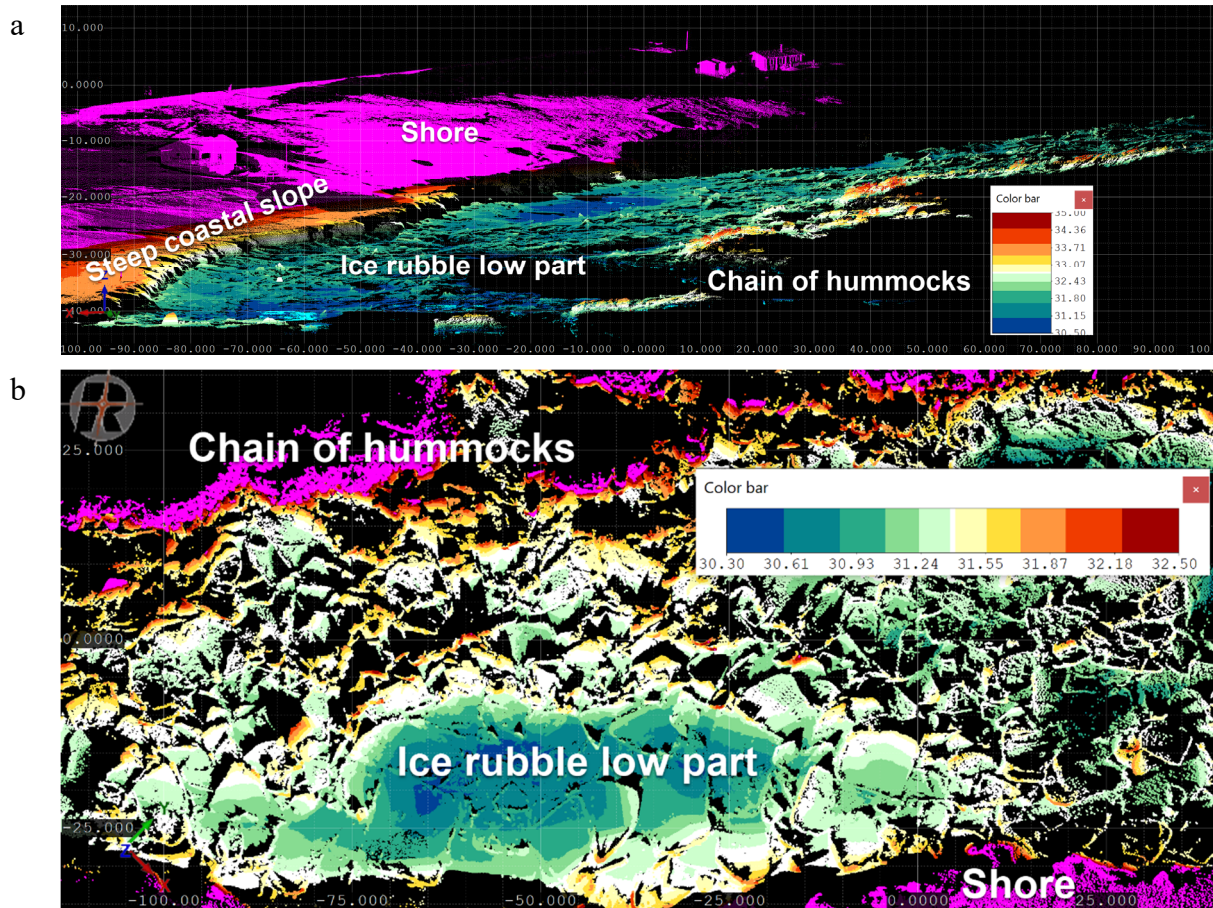


Figure 7. Laser Scanning of Ice Rubble on 5 of April 2020 at 16.30. Water level is 40 cm. a. 3D point cloud. View from the rubble to the shore. b. 3D point cloud. View from above. Color bar is in the Scanner project coordinate system. Pink color is for elevation above the scale.

A chain of high hummocks bordered the heap of ice floes from the outside and rather abruptly broke off into the water. And the space between the hummock and the shore was filled with ice floes the size of 2-15 m – bigger and flatter close to the shore and smaller and more ridged close to the boundary. See ice floe composition on 3D point cloud (Figure 7b)

The observed ice phenomenon should be classified as a "rubble field" according to ISO 19906 (ISO, 2019) and WMO (WMO, 2015), which we named for shortness as rubble.

The investigated rubble is much smaller than the one discovered in 2016 on the east of Svalbard, stretching on several kilometres with a vertical wall 3 m high and Icebergs inclusion with heights up to 9.5 m, and forming regularly along the north-east coast of Edge Island (Marchenko and Marchenko, 2017).

Rubble observation in Isfjorden, facing to the west and being under Atlantic warming, is rather unique and has utterly another dimension.

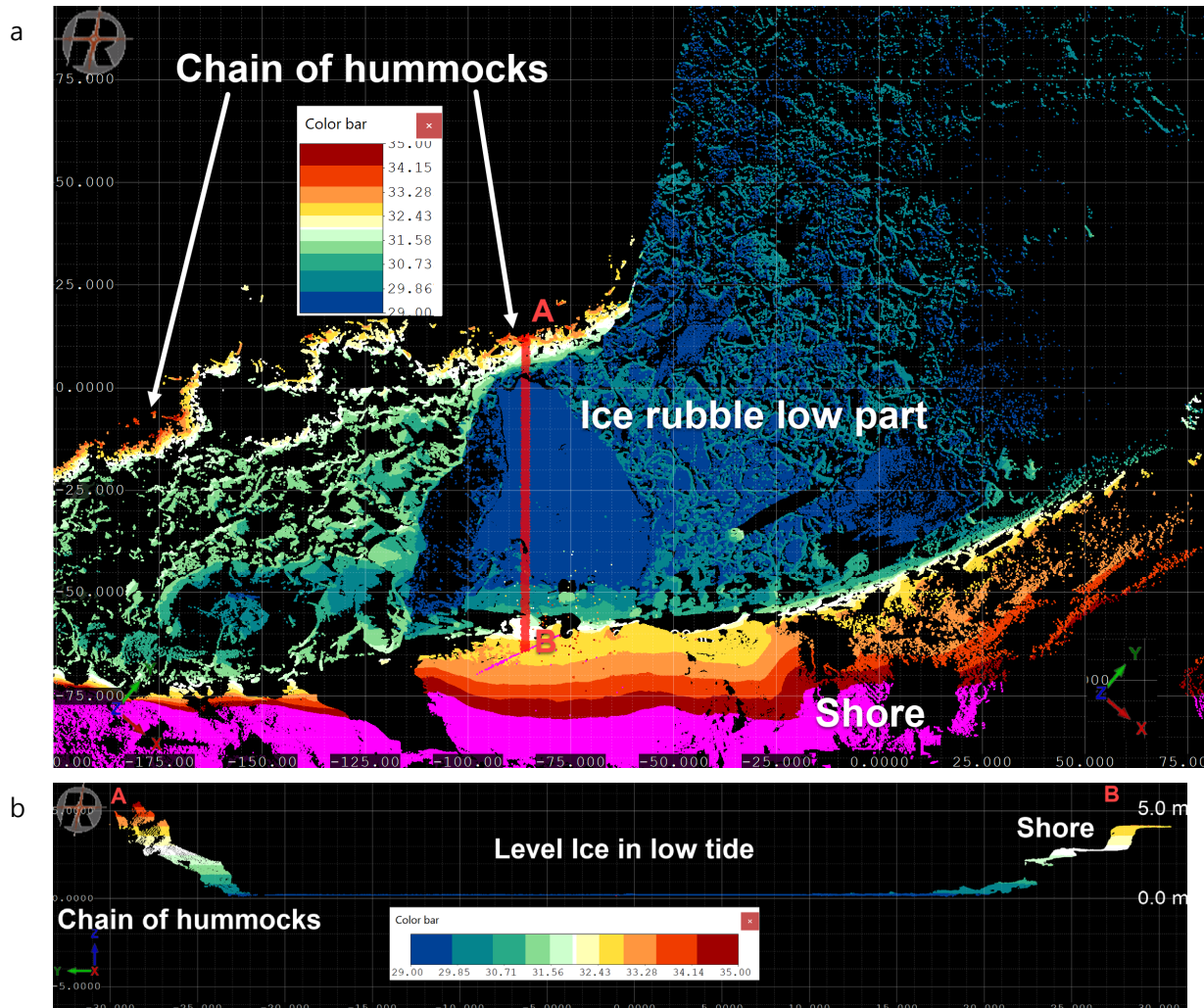


Figure 8. Laser Scanning of Ice Rubble on 9 of April 2020 at 21.10. Water level is -16 cm a) 3D point cloud. View from above, b) 3D profile along A-B line. Color bar in the Scanner project coordinate system. Pink color is for elevation above the scale.

OTHER ICE PHENOMENA IN SVALBARD

Among the other notable ice phenomena in Isfjorden are appearance of icebergs in May 2015 and shore rubble fields in 2022 – both in quite warm winter.

Rather large for Isfjorden icebergs appeared in Longyearbyen area on the 17th of May and stayed until the beginning of June, attracting much attention from local citizens and tourists. They had fancy shapes and travelled in the fjord following tidal variation and local water circulation. The small ones melted in the place, and the biggest crashed during thawing and were driven away from Adventfjorden by currents. We followed after several iceberg movements, fixing position by photos and orientation with connection with surrounding mountains and objects on the shore. The movement and appearance of one of the icebergs are

presented in Figure 9. Laser scanning of one of the large icebergs grounded near a Coal port showed horizontal size 20x35 m and an elevation above the water of 7 m.



a. Iceberg and its movement in Adventfjorden in May 2015

b. Big iceberg with ship on background in Isfjorden in 25 May 2015

Figure 9. Icebergs in Isfjorden in May 2015

In spring 2022 several large shore rubble fields were observed in Western Spitsbergen in and near Isfjorden. The piles of ice block stretched several tenth meters in length (60 m near Diabasoden and 170 m near Kapp Schollin – Figure 10a and 10b) along the sea line on the coast and had high more than 3 m. Ice blocks with different shape looked like the pieces of flat floes and had thickness 40 cm. There are two examples in Figure 10 with scooter and scooter driver for the scale. The process of formation was shore ice ride up rather seldom in Western Spitsbergen.



Near Diabasoden, 13 March 2022
(78°21' 21"N 16°11'20" E)



Near Kapp Schollin, 1 May 2022
(77°46'01"N 14°41'32" E)

Figure 10. Shore rubble fields in Spring 2022. Photo courtesy of Dina Brode-Roger.

The observed shore rubble fields are much smaller than ones in the Alaska, Canadian and Russian Arctic. Nevertheless, it can be compared with last observations there. For example, a 8 times taller than a human pressure ridge formed in shore fast sea ice near Utqiagvik, Alaska in May 2020 (NSIDC, 2020) and “mountains” of ice formed at Fort Erie, Ontario in February 2019 when towering piles of ice were tossed over barriers and walls by waves and winds gusting over 100 km/h at the mouth of the Niagara River. In some places, the ice is 10-30 feet

(3-9 m) high (Taekema, 2019). The overview of pressure formations up to 3–5 m high on shore in middle and subarctic latitudes (Gulf of St. Lawrence, the Baltic, Black, Caspian Seas, and Sea of Japan, White Sea, the Gulf of Bothnia and the Sea of Okhotsk) and their impact on the land with coast destruction and the restructuring of the processes of relief formation is presented in (Maznev and Ogorodov, 2020).

CONCLUSIONS

Despite continuing warming in Svalbard, which is much bigger than in the Arctic and the world, interesting sea ice phenomena have been observed in the last years. They reveal environmental processes' complexity and should be noted and investigated. Some of them can create difficulties for local infrastructure and should be followed up.

We analyzed the sea ice situation in Isfjorden in the last years and described and measured precisely (by laser scanning) the dimension of large coastal ice rubble, located close to Longyearbyen town. Such description and measurement could be used in engineering applications and for 3D modelling and will be continued for relevant phenomena.

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