State of Knowledge on Fate and Behaviour of Ship-Source Petroleum Product Spills: Volume 8, Iqaluit, Nunavut

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In response to the Expert Panel of the World Class Tanker Safety System (WCTSS) report (Houston et al., 2013), the Government of Canada commissioned pilot studies aimed to help develop and implement oil spill response plans for high risk areas in Canadian coastal waters. The Centre for Offshore Oil, Gas, and Energy Research (COOGER) published a five-volume report in 2019 focused on providing a general overview of the environmental factors that may influence oil spill fate, behaviour and response in four port areas in Canadian waters (Ryan et al., 2019). As an extension of this initiative, the Government of Canada requested volumes for three additional areas of interest: Prince Rupert and Chatham Sound, British Columbia; Placentia Bay and St. John's, Newfoundland and Labrador and Iqaluit and Frobisher Bay, Nunavut.

This is the eighth volume of the eight volume report and contains information relevant to developing an area response plan for Iqaluit, Nunavut.

RÉSUMÉ

MacIsaac, B.I., King, T.L., and Ortmann, A.C. 2023. State of Knowledge onFate and Behaviour of Ship-Source Petroleum Product Spills: Volume 8, Iqaluit, Nunavut. Can. Manuscr. Rep. Fish. Aquat. Sci. 3254: vi + 19 p.

En réponse au rapport du Comité d'experts du Système de sécurité de classe mondiale pour les navires-citernes (SSCMNC) [Houston *et al.* 2013], le gouvernement du Canada a commandé des études pilotes visant à faciliter l'élaboration et la mise en œuvre de plans d'intervention en cas de déversement de pétrole dans les zones à risque élevé des eaux côtières canadiennes. En 2019, le Centre de recherche sur le pétrole, le gaz et autres sources d'énergie extracôtières (CRPGEE) a publié un rapport en cinq volumes visant à dresser un tableau général des facteurs environnementaux qui peuvent influer sur le devenir et le comportement des déversements de pétrole et les interventions connexes dans quatre zones portuaires canadiennes (Ryan *et al.* 2019). Dans le prolongement de cette initiative, le gouvernement du Canada a demandé des volumes pour trois autres zones d'intérêt, à savoir Prince Rupert et le détroit de Chatham (Colombie-Britannique), la baie Placentia et St. John's (Terre-Neuve-et-Labrador) et Iqaluit et la baie Frobisher (Nunavut).

Le présent volume est le huitième du rapport en huit volumes et contient de l'information pertinente pour l'élaboration d'un plan d'intervention régional pour Iqaluit, au Nunavut.

1 INTRODUCTION

In response to the Expert Panel of the World Class Tanker Safety System (WCTSS) report (Houston et al., 2013), the Government of Canada commissioned pilot studies aimed to help develop and implement oil spill response plans for high risk areas in Canadian coastal waters. The Centre for Offshore, Oil, Gas, and Energy Research (COOGER) published a five-volume report in 2019 focused on providing a general overview of the environmental factors that may influence oil spill fate, behaviour and response in four port areas in Canadian waters (Ryan et al., 2019).

The first Ryan et al. (2019) volume provides an introduction to petroleum products handled in Canadian waters, their physical and chemical properties, fate and behaviour in the event of a spill and response methods used to reduce environmental impact. The information provided in the introductory volume is relevant to any location, and meant to accompany subsequent volumes generated for other pilot areas. The four pilot areas in the Ryan et al. (2019) report include: 1. Saint John, including the Bay of Fundy; 2. Port Hawkesbury and Canso Strait; 3. St. Lawrence Seaway from Montreal to Anticosti; and 4. the Strait of Georgia, including the Juan de Fuca Strait. As an extension of this initiative, the Government of Canada requested volumes for three additional areas of interest:

- Prince Rupert and Chatham Sound, British Columbia
- Placentia Bay and St. John's, Newfoundland and Labrador
- Iqaluit and Frobisher Bay, Nunavut

The focus of this volume is Iqaluit, the capital city of Nunavut located in southeastern Baffin Island at the head of Frobisher Bay. Iqaluit has expanded rapidly over the last 50 years, increasing vessel and air traffic into the region to supply food, fuel, goods, and services to northern communities. Iqaluit is one of few main access points in the Arctic for smaller, more remote communities in the region (Ford et al., 2016). The majority of Arctic shipping activity, including petroleum shipments, take place within a short period of time between June and November (Aarluk Consulting, 2005; Aulanier et al., 2017). Shipments into the area can often be delayed due to Arctic conditions such as high winds, sea ice extent, seasonal periods of low visibility (Aarluk Consulting, 2005). Vessel traffic has been increasing in the Arctic and is expected to increase further with climate induced changes to sea ice extent (Afenyo et al., 2016). There is currently no functional deep water port facility located North of 60° and limited small craft harbour access (Nunavut News, 2021; Aarluk Consulting, 2005). A deep sea port facility is currently being constructed at Inuit Head, just outside the city of Iqaluit (Figure 2; Hatcher et al., 2014). The deep sea port is one of the major infrastructure projects focused on improving accessibly and safety in communities North of 60° (Government of Canada, 2021). The current method for transporting petroleum onshore requires the use of floating pipes to pump the products onshore from tankers anchored offshore. This practice greatly increases the risk of a petroleum spill. In 2008, Tower Arctic was awarded the contract to build a Deep Sea port and small craft harbour in Iqaluit (Nunatsiaq News, 2020). Once complete, the deep water port will be accessible during all tide cycles, providing a more efficient fuel delivery and safe navigation by separating industrial/commercial vessel routes from small scale vessel traffic (Nunavut News, 2021).

2 GEOGRAPHY

Frobisher Bay is located in southeastern Baffin Island, the largest island in the Canadian Arctic region. Southern Baffin Island features significant changes in topography. Three separate mountain ranges spread out across the region reaching Baffin Bay and Labrador Sea as three high relief peninsulas (Figure 1; Hatcher et al., 2014). Frobisher Bay is bordered by the two southernmost high relief peninsulas on Baffin Island; Meta Incognita Peninsula and Hall Peninsula (Fargey et al., 2014). Iqaluit is located at the head of Frobisher Bay (Figure 1) along the northwest coast of Koojesse Inlet (Figure 2; Hatcher at el., 2014).

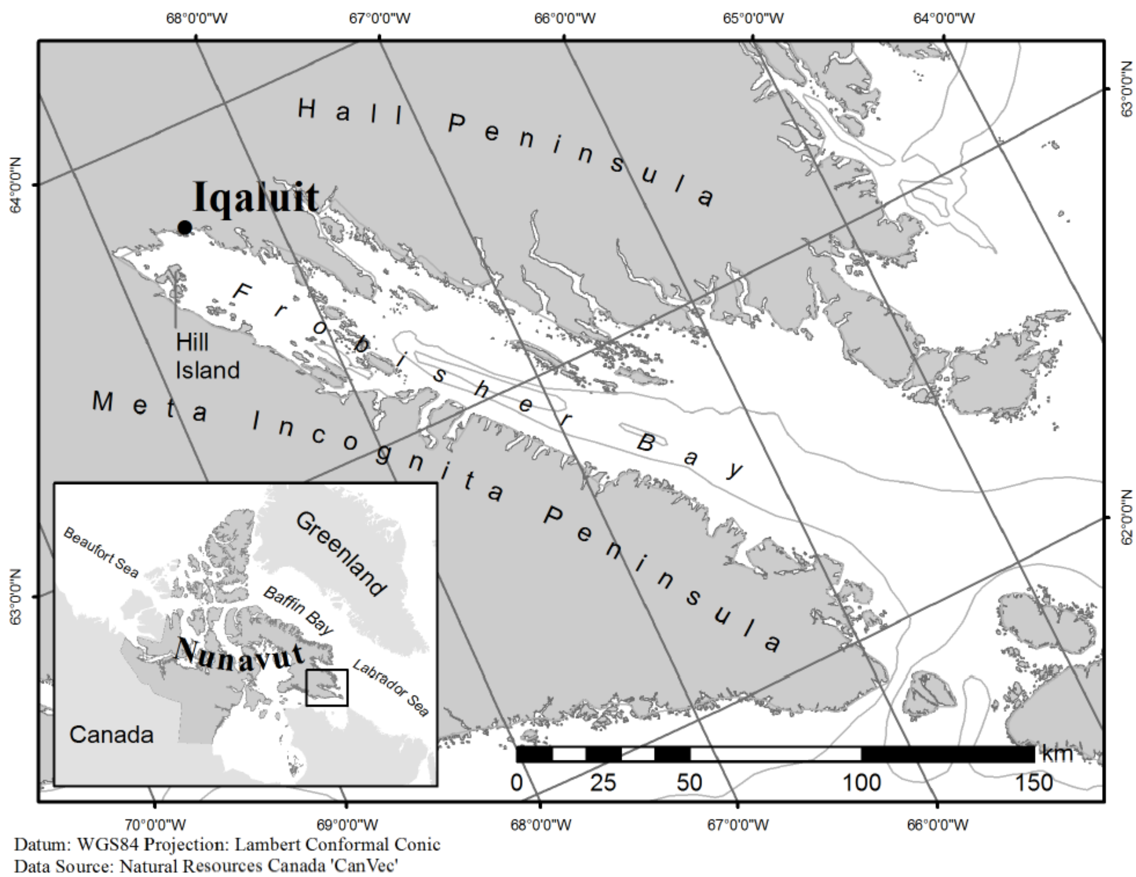

Figure 1. Location of southeastern Baffin Island, Frobisher Bay and Iqaluit in Nunavut (Hatcher et al., 2014)

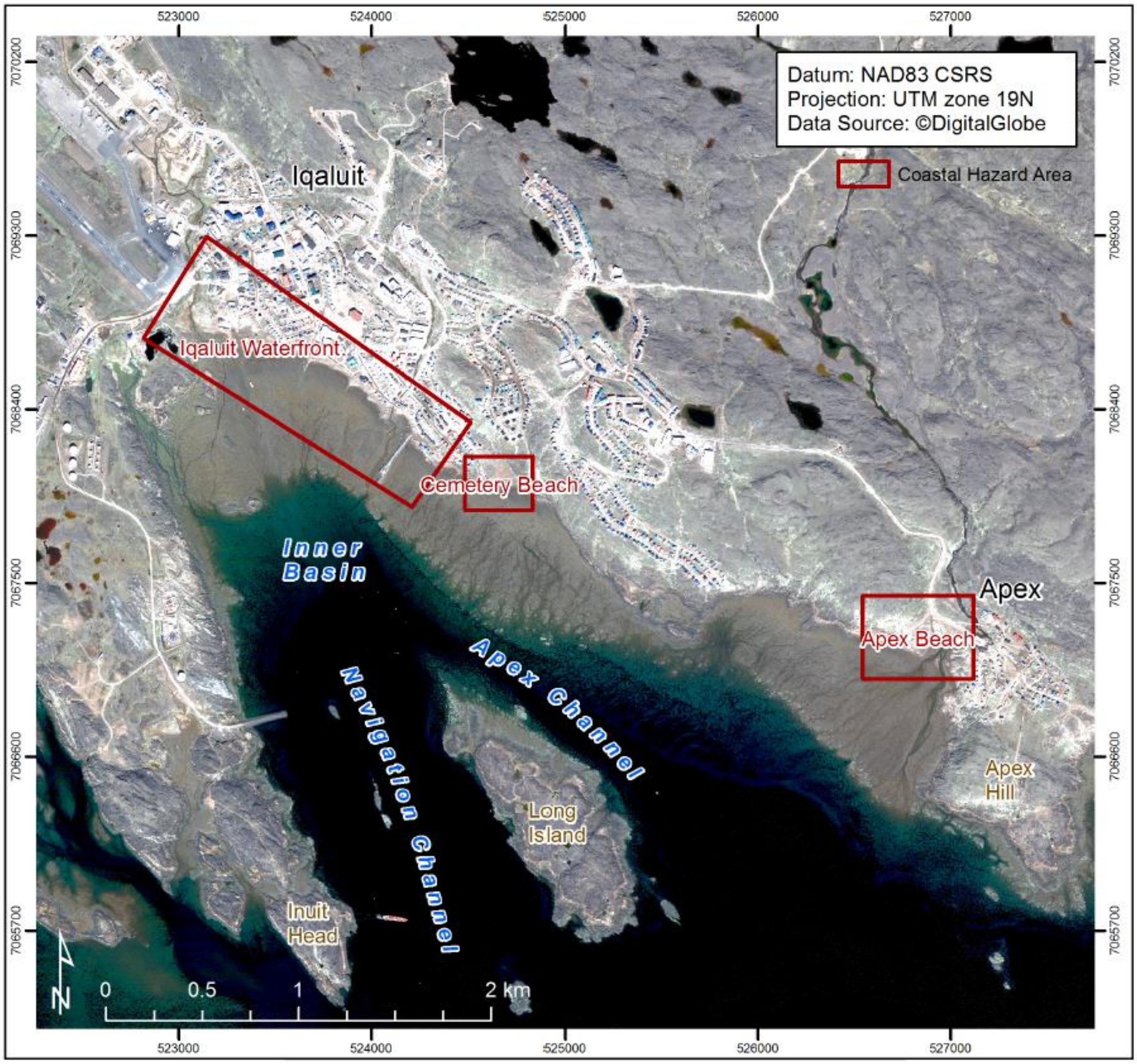

Figure 2. Koojesse Inlet at the head of Frobisher Bay. Iqaluit is located on the northwest shore. Red box indicates coastal hazard areas from Hatcher et al. (2014)

2.1 SHORELINES

Frobisher Bay orients northwest – southeast. The outer Frobisher Bay shoreline is comprised of steep, rocky bedrock platforms (Miller and Locke., 1980; Samuelson, 2001). Topographic imagery in Figure 3 depicts a steep backshore rising rapidly along both sides of the outer bay, reaching maximum heights of 700 m (Meta Incognito Peninsula) and 1000 m (Halls Peninsula) (Gascon et al., 2010).

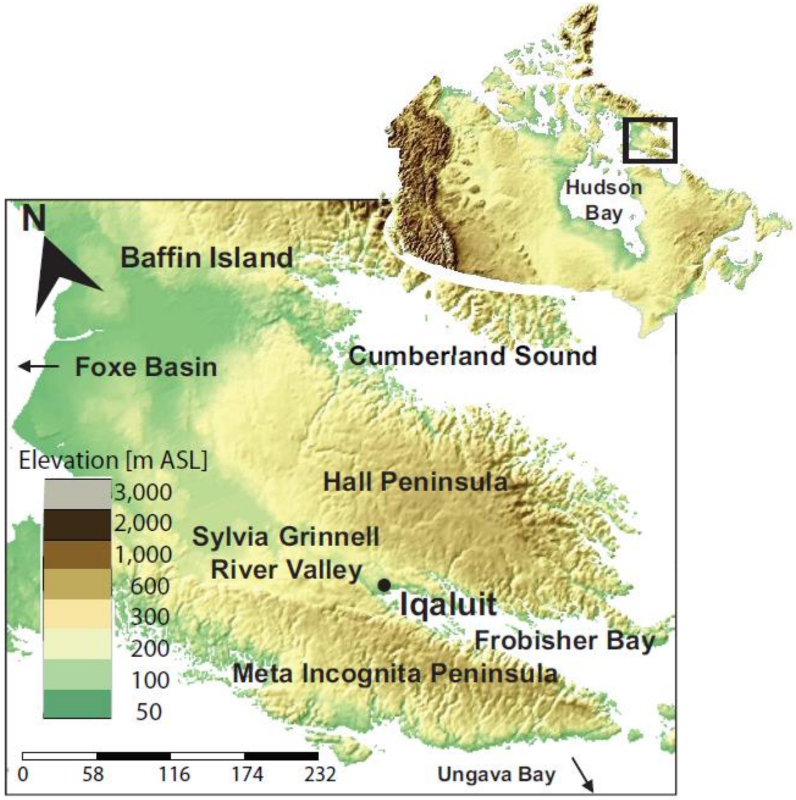

Figure 3. Topographic relief map of southern Baffin Island in Nunavut (Gascon et al., 2010)

The head of the bay exhibits a more gradual shoreline incline (Figure 4) but there are steep sections on the north and south shore of the inner bay. The inner bay is sheltered behind numerous islands and the shoreline is comprised of sediment beaches, estuaries and tidal flats. Iqaluit has a low-lying beach backshore with an extensive intertidal zone that stretches out for over 1 km, visualized in Figure 2 (Hatcher et al., 2014; Misiuk et al., 2019).

In Frobisher Bay, ice is present on average 8 - 9 months of the year and generally reaches a maximum thickness of approximately 2 m (Samuelson, 2001). An ice foot, a belt of ice along the shore at or below the low-water mark, is present during winter months. Large ice sheets are often marooned on the tidal flats and beaches during low tides. The presence of ice will impact oil spill weathering and recovery methods if oil was to reach the shoreline in Frobisher Bay. Permafrost is also present on the shoreline above the high tide line. Little research has been done on how permafrost impacts oil weathering which may lead to additional challenges in oil spill response and recovery.

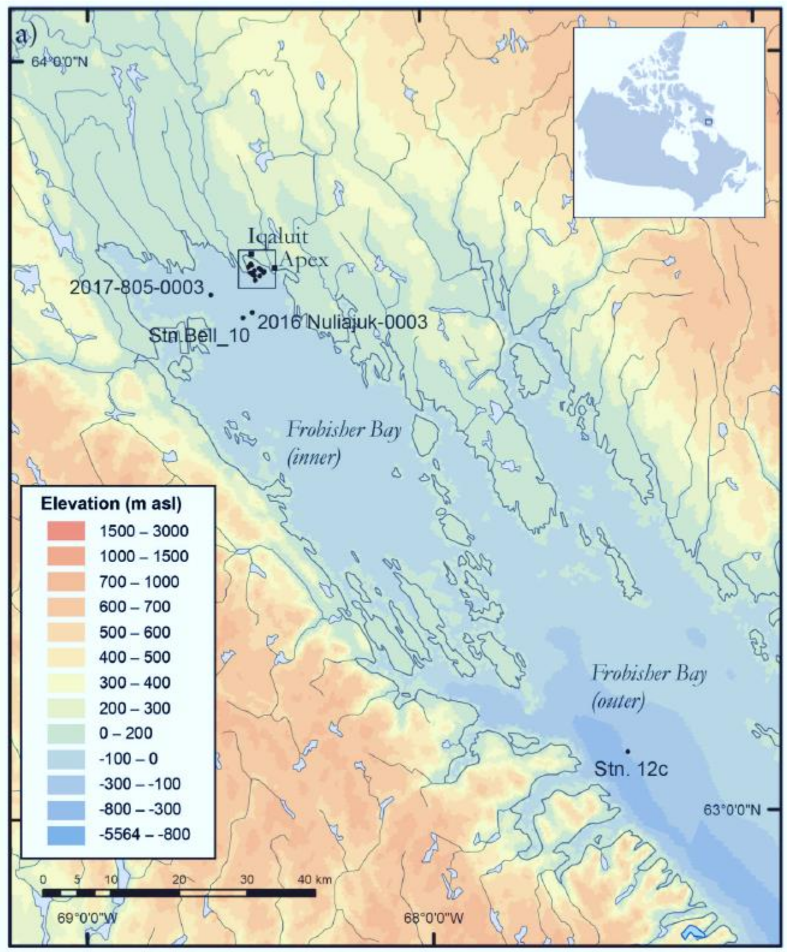

Figure 4. Digital elevation model and bathymetry for inner Frobisher Bay. Figure modified from Tremblay et al. (2020)

3 HYDROGRAPHY

3.1 BATHYMETRY

Frobisher Bay is approximately 265 km in length and can be characterized into distinct areas: the outer and inner bay, separated by a chain of islands (Figure 4; Tremblay et al., 2020) (Deering et al., 2018; Misiuk et al., 2019). The width of the bay narrows from ~66 km at the entrance to ~20 km at the head (Deering et al., 2018). The outer bay is over 200 km long, encompassing a larger area than the inner bay (Misiuk et al., 2019; Tremblay et al., 2020). The sill at the mouth of Frobisher Bay is 300 m deep. Most of the outer bay is less than 300 m with some deep sections reaching ≥800 m (Misiuk et al., 2019). A broad shelf (Calanus Shelf) is located to the northeast off the coast of Halls Peninsula in the outer bay (Dunbar, 1958; Dinn et al., 2019). A long trough cuts through the south coast, extending headward as deep as 600 m. The mid-bay islands are connected by shallow channels and a large trough that exceeds 260 m deep.

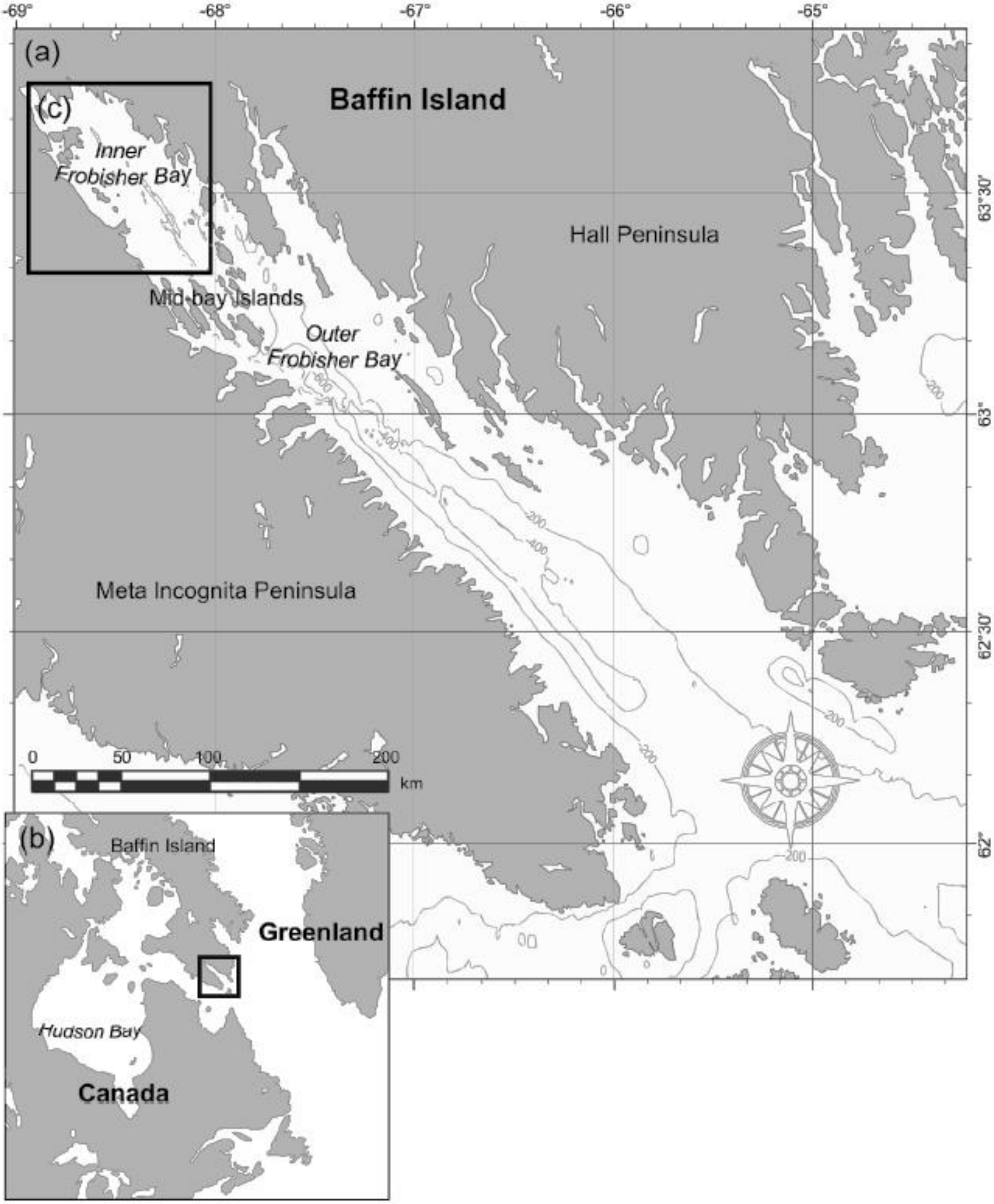

Figure 5. (A) Bathymetric map of Frobisher Bay contoured at 200 m (B) Location of Frobisher Bay on Southeastern Baffin Island (C) Inner Frobisher Bay (Misiuk et al., 2019)

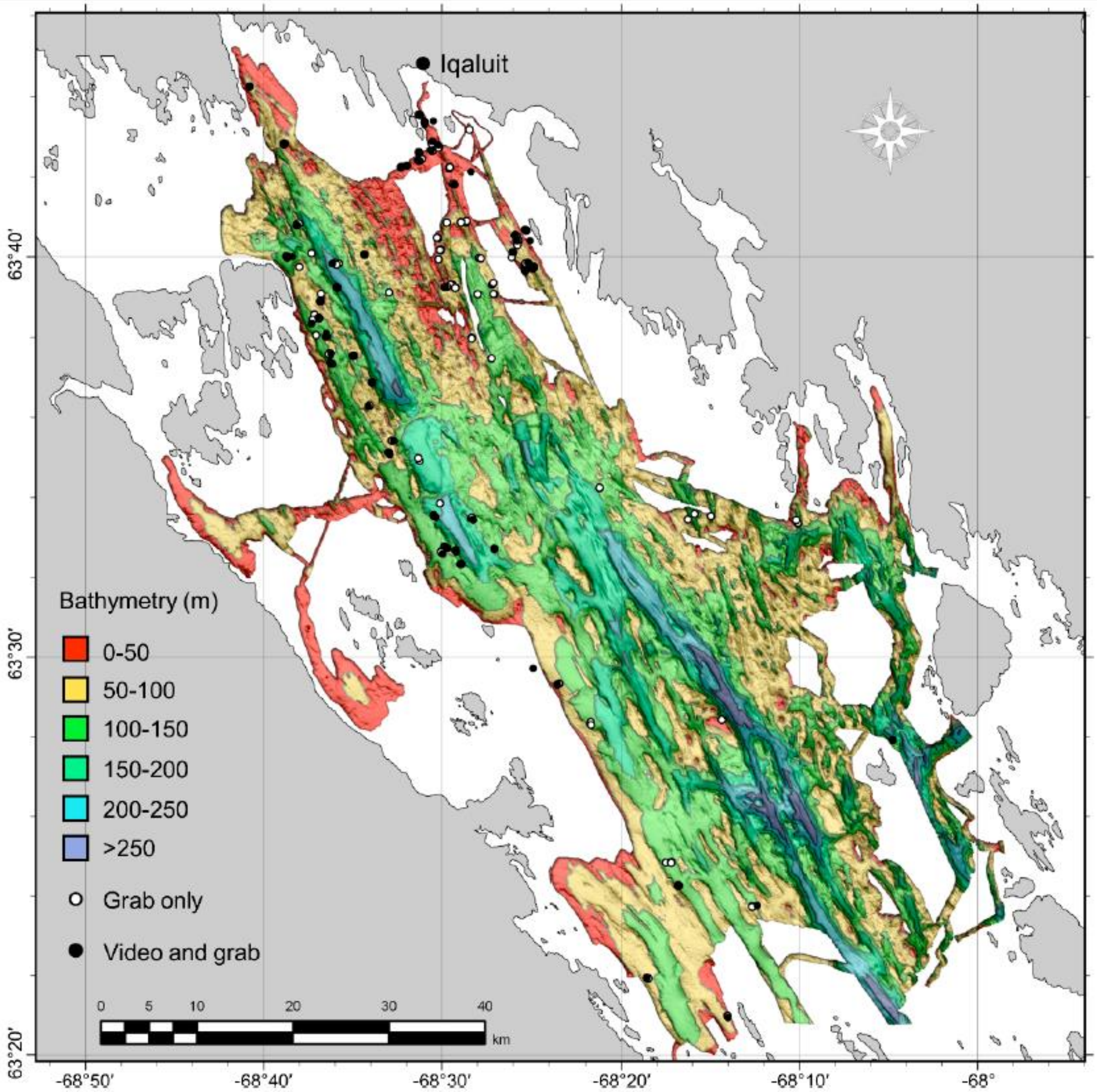

Figure 6. Inner Frobisher Bay multibeam echosounder (MBES) bathymetry contoured at 50 m (Misiuk et al., 2019)

Figure 6 is a multibeam echosounder bathymetry map of inner Frobisher Bay from the Misiuk et al. (2019) study. The inner bay is mostly less than 100 m with shallow bedrock ridges that sit at 30 m (Misiuk et al., 2019). The area experiences a tidal range maximum of 11.6 m, exposing extensive tidal flats at the head of the bay (Hatcher et al., 2014). The tidal flats in Koojesse inlet are wider on the eastern side (~1100 m) than on the western side (~150 m) (as seen in Figure 2) and covers approximately 6.4 km^2 (Misiuk et al., 2019; Tremblay et al., 2020). The trough that extends from the outer bay into the inner bay reaches a maximum depth of 260 m.

The inner bay consists of mud and sandy deposits and minimal exposed bedrock. The tidal flats in Koojesse Inlet are comprised of mud, mixed sand and very little gravel (less than 5%) with large boulders scattered throughout the intertidal zone (Samuelson, 2001; Hatcher et al., 2014; Deering et al., 2018). The seafloor in the outer bay consists of exposed bedrock and mud/sandy deposits infilling small troughs and basins (Mate et al., 2015; Todd et al., 2016; Dinn et al., 2019; Misiuk et al., 2019). If an oil spill was to occur in the inner bay around Koojesse Inlet, it is likely the oil will interact with the shoreline and sediments suspended during the tide cycle making clean up efforts more difficult.

3.2 CIRCULATION AND CURRENTS

Baffin Island Current and West Greenland Current cross the mouth of Frobisher Bay, subjecting this isolated embayment to sub-Arctic water mass influences (Bedard et al., 2015). Little previous work has been published focused on Frobisher Bay and recent circulation studies largely focus around Iqaluit in Koojesse Inlet. Field research seasons are short and typically occur during warmer months, making it challenging to observe seasonal changes in circulation and determine how those changes may impact oil spill fate and behaviour at different times of the year. Although much of the outer bay has not been well documented in peer reviewed publications, the bay has been a part of annual Arctic expedition to collect data on the Arctic environment. There is evidence of a strong bottom current that influences bottom currents outside the embayment at NE Saglek Bank and Hatton Basin, tied to macrotidal oscillation of Frobisher Bay (Desmarais et al., 2021).

In general, surface waters enter Frobisher Bay on the southeast side, move headward and exit on the northeast side of the bay (Dunbar, 1958). The tidal cycle plays an important role in the inner reaches of Frobisher Bay (Hsiao, 1992; Spares et al., 2012). Approximately 17 km^3 of water is transported out of inner Frobisher Bay during a single high tide, moving predominantly towards the north-northwest during flood tides and south-southeast during ebb tides (Hsiao, 1992; Government of Nunavut, 2017). The rapid exchange of water during the tidal cycle forces currents with a mean speed of 1 ms^{-1} between the inner and outer bay (Spares et al., 2012). Surface currents in Koojesse Inlet range from 0.10 ms^{-1} to 0.20 ms^{-1} and generally do not exceed 1 ms^{-1}, unless under extreme circumstances (Hatcher et al., 2014). Figure 7 shows simulated model results that were a part of the Government of Nunavut dredged material disposal report. The simulation runs for a period of two weeks in September 2016 in order to estimate the non-exceedance of current speeds at a location 500 m offshore of South Polaris Reef (Government of Nunavut, 2017). The results show that flood currents are consistently stronger than ebb currents at this location, as high as 0.20 ms^{-1} during flood and 0.15 ms^{-1} during neap (Government of Nunavut, 2017). The Samuelson (2001) environmental disturbance study documented poor circulation inside Koojesse Inlet. There is evidence that urban contaminants get trapped on the tidal flats during low tide (Samuelson, 2001); a likely fate if an oil spill was to occur around Koojesse Inlet or other estuarine environments in Frobisher Bay.

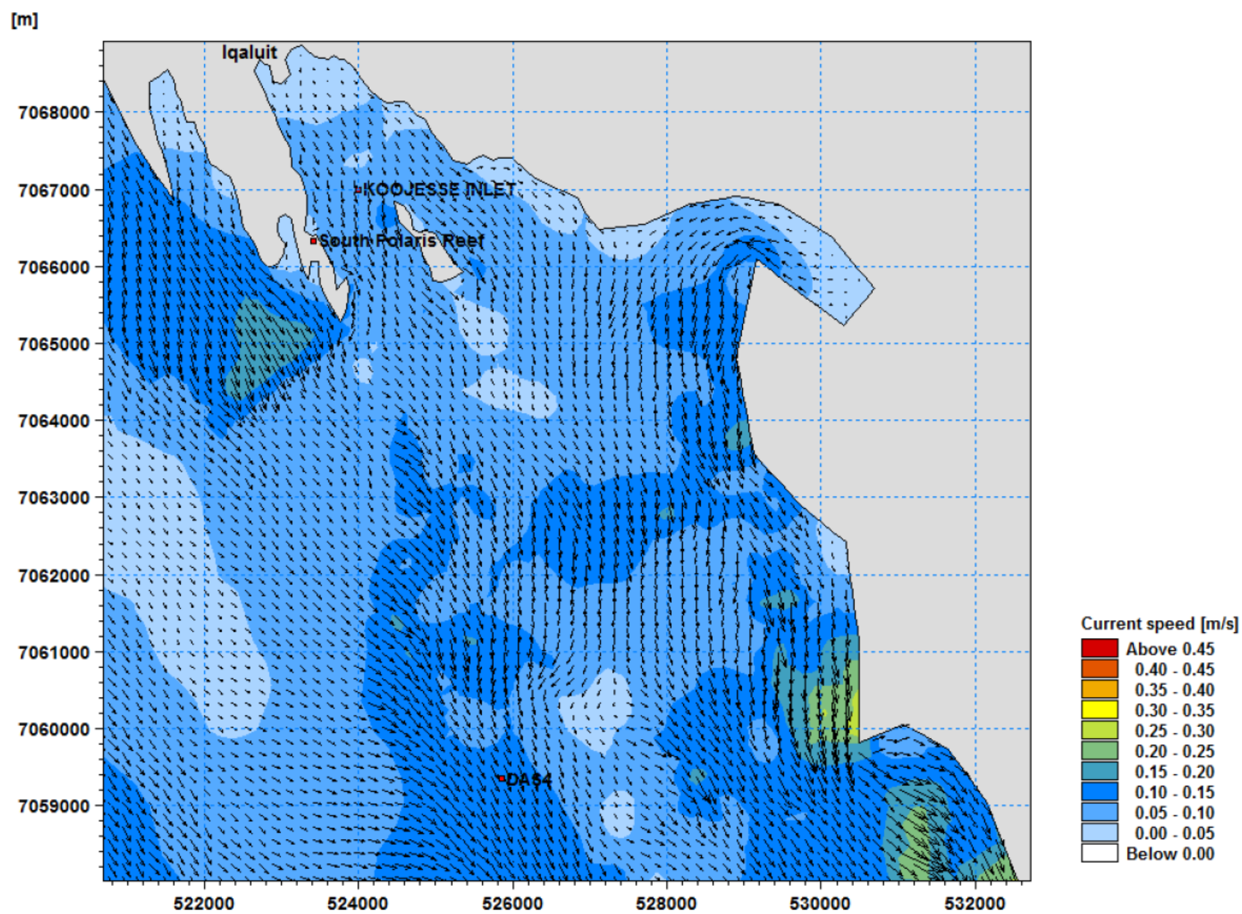

Figure 7. Simulated maximum depth averaged current speeds (m/s) near Koojesse Inlet for a period of two weeks in September, 2016. Red marker indicates location of dredge site where Deep Sea Port is being constructed (South Polaris Reef) and dredge material disposal site (DA54) (Government of Nunavut, 2017)

3.3 TIDES

Tides in Frobisher Bay are semidiurnal with a mean tidal range of 7.8 m and maximum tidal range of 11.6 m (Hatcher et al., 2014). The tidal range increases headward, exposing large intertidal flats during low tide. For example, at the lowest of low tides, more than 5 km^2 of intertidal zone is exposed in Koojesse Inlet (McCann et al., 1981) and 12 km^2 exposed at the Bay of Two Rivers estuary on the southwestern shore of inner Frobisher Bay (Spares et al., 2012).

3.4 WATERSHED

There are a number of small rivers and streams that drain into Frobisher Bay. Iqaluit is located in a small drainage basin (Samuelson, 2001). Sylvia Grinnell River drains outside of Koojesse Inlet at a monthly mean rate of 33.3 m^3s^{-1}, peaking between June and September (Government of Canada, 2022). Apex River and Carney Creek are two small watercourses that drain close to Iqaluit (Spares et al., 2012). In addition to river flow, urban run off drains into Koojesse Inlet from the Iqaluit sewage lagoon and dumpsite (Samuelson, 2001). As noted, Koojesse Inlet can experience poor drainage and contaminants can get trapped in the tidal flats for several days (Samuelson, 2001).

3.4 SALINITY AND TEMPERATURE

Few studies have been published on the long term salinity and water temperature trends in Frobisher Bay. Available published information was obtained from geological and biological studies conducted during spring and summer. The Coastal Environmental Baseline Program (CEBP) has created a network of collaborators collecting water samples throughout inner Frobisher Bay in Koojesse Inlet and Peterhead Inlet. CEBP collaborations are helping fill information gaps in the region. For example, the Ocean Network Canada collaboration works with local fishers to collect CTD data that is uploaded in real time to their interactive data mapping program[1]. While there is little published on salinity and temperature trends in Frobisher Bay, we can highlight some general trends observed over the spring and summer months, when vessel traffic is the highest in the region.

Frobisher Bay is influenced by open ocean exchange with the Labrador Sea and sub-Arctic water masses Baffin Island Current and West Greenland Current crossing the mouth of Frobisher Bay, however the interaction has not well documented in the literature (Bedard et al., 2015). Water that flows around the boundary of the Labrador Sea can be warmer below the surface due to their salt content. Amundsen Science CCGC Amundsen Arctic Expeditions measurements collected in Frobisher Bay in July from 2016 to 2021 recorded consistently colder water temperatures at the outer Frobisher Bay station (1.1 – 1.2 ^{o}C) than readings taken outside the embayment at the NE Hatton Basin (4.8 – 6.0 ^{o}C) and NE Saglek Bank (3.8 – 4.6 ^{o}C) at similar depths (~550 m – 600 m) (Perez et al., 2016; Wilhelmy, et al., 2018; Wilhelmy, et al., 2019; Desmarais et al., 2021).

For the inner bay, water temperatures are altered by tides, creating a warm and cold water cycle during the summer months. Mean surface temperatures in inner Frobisher Bay rarely exceed 4 ^{o}C except intertidal waters that can reach a mean temperature above 6 ^{o}C in the summer (Spares et al., 2012). The warm upper layer can extend for up to 4 km, decreasing in size as it moves seaward. Surface temperatures drop to a mean of 3 ^{o}C in subtidal waters (Spares et al., 2015). Below depths of 3 m, the water temperature decreases from 3.0 to $<0^{o}$C extending down to the bottom.

Frobisher Bay experiences a salinity range between 24 – 33, depending on the tide cycle (Hsiao, 1992; Spares et al., 2012). In the inner bay, salinity can decrease at high tide to 24 – 26 and increases to 31 – 32 at low tide. Stratification can occur in the inner bay at the surface during flood tides but it is unclear how these short periods of stratification change between seasons (Hsiao, 1992). The inner bay estuaries contain brackish water with a mean salinity of 15.5 (Spares et al., 2015). Mean salinity in subtidal waters range between 30 – 33 within inner

[1] Ocean Network Canada Geospatial Map - Oceans 3.0

Frobisher Bay and between 32 – 33 in outer Frobisher Bay (Hsiao, 1992; Tang et al., 2004; Spare et al., 2012). Samples taken in outer Frobisher Bay recorded salinity levels of 33.2 at both the surface and at depths of 500 m (Wilhelmy, et al., 2018).

4 CLIMATE

4.1 AIR TEMPERATURE AND PRECIPITATION

Iqaluit has a tundra climate dominated by Arctic air currents. The winters are cold and long while the summers are cool and short (Drinkwater, 1986). Figure 8 shows the normal temperature and precipitation record at the Iqaluit Airport weather station between 1981 - 2010 (Environment Canada, 2019). Iqaluit experiences a mean monthly temperature range of 8.2 °C to -27.5 °C, with the warmest month being July and the coldest February (Environment Canada, 2019).

Southern Baffin Island experiences the highest amount of precipitation in the Canadian Arctic (Farey et al., 2014). More than half (57%) of the precipitation is snow, most of which falls from October to May but rainfall does occur between June and September (Kjikjerkovska., 2016; Environment Canada, 2019). Iqaluit receives an annual average rainfall of over 403 mm (Environment Canada, 2019). Dry atmospheric conditions dominate the Arctic region between December and March, making it more difficult to sustain storm conditions during this time of year (Gascon et al., 2010). Periods of low visibility can occur between June and July when the ice begins to break up, forming ice fog. Visibility in the winter months (December – March) can be reduced (<1 km) due to prolonged periods of darkness, snowfall, ice fog and seasonal wind conditions (Gascon et al., 2010; WWF, 2017; Environment Canada, 2019).

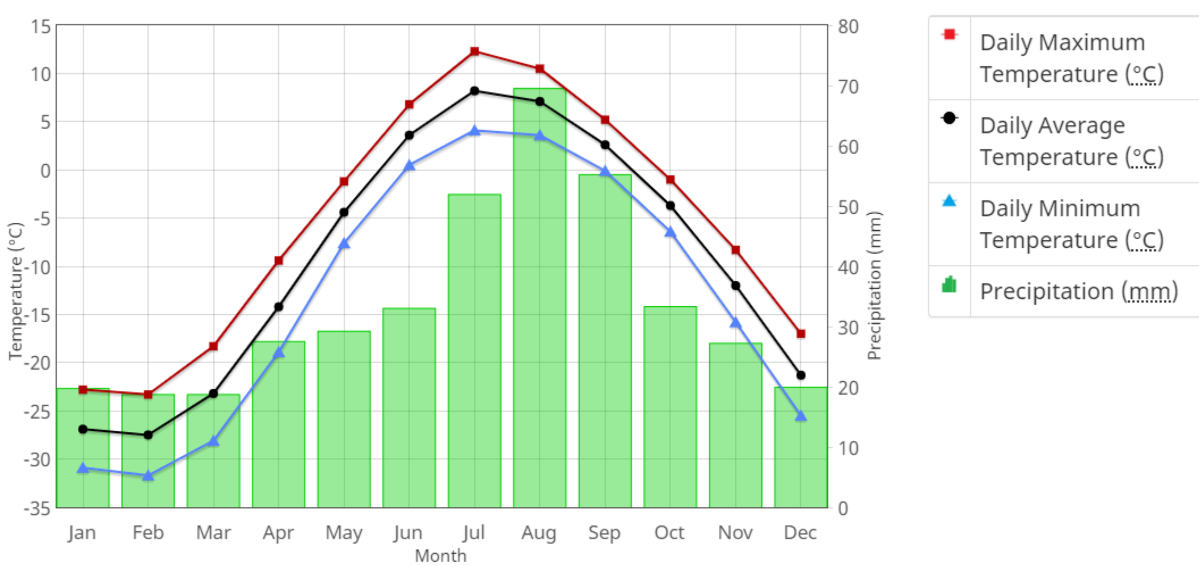

Figure 8. Temperature and precipitation chart for 1981-2010 Canadian climate normals at Iqaluit Airport (Environment Canada, 2019)

Climate change is impacting the Arctic environments and way of life. The Nunavut Impact Review Board (2019) Inuit community engagement report noted warmer temperatures and decreases in the size of *anuivat* (permanent snow patches). Multiyear ice extent has decreased as well as permafrost extent and thickness (Ford et al., 2016). Inuit in Iqaluit have identified new open water areas, thinner sea ice conditions and earlier break up (Nunami Stantec Ltd., 2018). A prolonged ice free season will impact the wave climate, circulation, air and sea surface temperatures in Frobisher Bay. The ice free season has been expanding approximately 1.0 – 1.5 days per year since 1979 (Hatcher and Forbes, 2015). The sea ice extent has decreased at a rate of 2.9 – 10.4 % per decade (Ford et al., 2016). Relative sea level rise will pose a greater risk for low-lying areas of Iqaluit and neighbouring community of Apex (Rencz, 2010). Apex already experiences periodic flooding around limited coastal infrastructure during extreme tides and storm surge events (Rencz, 2010). SmartICE[2] has been monitoring ice thickness and extent alongside partners The Indigenous Knowledge Social Network (SIKU[3]) to upload near real-time information for Inuit to use for safety, research, education and planning.

4.2 WINDS AND SURFACE WATER WAVES

The shape of Frobisher Bay channels winds through the coastal fjord. The prevailing wind direction shifts seasonally from northwest in the winter to southeast in the summer, experiencing a mean annual wind speed of 5 ms^{-1} (18 kmh^{-1}) (Nawri and Stewart, 2006). Turbulent wind shear occasionally occurs when northwest surface winds are trapped under northeast winds (Newri and Stewart, 2006). Strong surface winds (> 10 ms^{-1} or 36 kmh^{-1}) are more likely to occur in the fall and winter months and most (80%) of occurrences are from the northwest and southeast direction (Hanesiak et al., 2013). Wind conditions are weakest in the summer experiencing low wind speeds < 5 ms^{-1} most frequently and strong winds > 10 ms^{-1} less frequently (Nawri and Stewart, 2006). Southeast winds influence sea levels and sea ice extent in the inner reaches of the Bay. Most of the major storm events in the region occur between April to November (Gascon et al., 2010). Storms can originate from the Arctic, Greenland and central North American but the most frequent occurrences originate from the South and Atlantic region (Gascon et al., 2010).

There is little published research focused on the wave climate in Frobisher Bay. There have been some short term studies conducted in the inner reaches but few of these studies include information about outer Frobisher Bay. Observed wave height from Hatcher et al. (2014) reached 0.7 m on the tidal flats and 1 m in deeper areas of Koojesse Inlet. As mentioned, the inner reaches of Frobisher Bay is sheltered from most ocean swells but large southeast waves can reach Iqaluit, when extratropical cyclones come up from the Labrador Sea (Nawri and Stewart, 2006; Hatcher and Forbes, 2015).

[2] SmartICE - Sea Ice Monitoring and Information Inc.
[3] SIKU - The Indigenous Knowledge Social Network

The wave climate is also subject to change as the ice free season expands with the changing climate. Inuit in Iqaluit have also observed a change in direction, strength and frequency of wind conditions over the years (Ford et al., 2008). More data is needed to understand seasonal wind and wave conditions will change in order to get a better sense of how a petroleum products will respond in the event of a spill. Shifting wind conditions may make it difficult to contain an oil spill.

5 PAST OIL SPILLS

The Transportation Safety Board of Canada (TSBC) maintains a database of air, marine, rail and pipeline incidents and accidents, collectively called occurrences (Transportation Safety Board of Canada, 2019). The marine occurrence database contains information on the vessels involved, cargo, location, summary of occurrence, reported pollution and more, dating back to 1975. Since then, reporting requirements have changed leading to an increase in the number of occurrences entered into the database. Statistics have been compiled for marine occurrences of interest for the entire span of the database (1975 – 2019) (Transportation Safety Board of Canada, 2014).

Marine occurrences were compiled into four different types of events: 1) occurrences involving cargo vessels, either tanker or barges, that transport petroleum products; 2) occurrences in which pollution was reported or any type of cargo was lost overboard; 3) occurrences in which petroleum products were reported spilled on board or into the water; 4) occurrences in which vessels were sunk, capsized or otherwise seriously damaged beyond repair, and expected to release fuel into the environment.

The following statistics encompass Frobisher Bay extending out into the Labrador Sea. Statistics were compiled by filtering for occurrences in the Territory of Nunavut or in international waters within the latitudinal range of 61.00^{o}N to 62.50^{o}N, and within a longitudinal range of 64.00^{o}W to 69.00^{o}W. This boundary corresponds with main vessel traffic routes in and out of the Iqaluit. Statistics only includes marine occurrence reports up to September 4th, 2019.

There is a limited number of TSBC occurrences logged within this boundary. It is unclear if this is an accurate reflection of vessel occurrences in the area or if there are undocumented events. Only 25 TSBC occurrences were logged in this boundary, and of the 25, only one fits the reporting criteria. This event occurred in 1990, when a valve broke on a ship and sprayed oil onboard. There is no information about the type of vessel involved. There is limited data available for most of the occurrences in the TSBC database for the region. The absence of vessel name and type limits the ability to determine if a vessel is carrying petroleum products other than fuel. There are no logged occurrences of vessels sinking, capsizing or being destroyed within the boundary. Of the 25 logged TSBC occurrences that have occurred, 18 involved damage to vessels from ice floes. According to the database, none of the occurrences resulted in pollution or cargo loss.

5.1 IQALUIT: CURRENT PRACTICES AND ASSOCIATED RISKS

In the event of an oil spill occurring in Frobisher Bay, Iqaluit has the advantage of being one of the few Arctic communities where a Canadian Coast Guard base station is located and oil spill response equipment is stored. As the Territory of Nunavut is dependent on imported petroleum products, there are concerns about the response if a large spill was to occur offshore.

The Government of Nunavut controls the supply of petroleum products into the region. Shipments take place in the summer months and are stored in holding tanks at various locations across Baffin Island including Iqaluit which has one of the primary storage facilities. Tankers moving into the area can carry up to 4,500 tonnes of diesel and 18,000 tonnes of fuel oil (WWF, 2017). The main products shipped into the region are diesel (heating and electrical generation), gas (vehicles) and jet fuel (aircrafts) (Nunavut Impact Review Board, 2019). Each of these petroleum products are physically different, composed of a variety of chemical compounds that would weather differently if released into Frobisher Bay.

Vessel traffic is anticipated to increase in the region with climate induced sea ice extent changes and the completion of the Deep Sea Port in Frobisher Bay. An increase in vessel traffic will heighten the risk of ship sourced oil spill occurring in the region.

Additional capacity concerns include: discrepancies in response standards when compared to south of 60^{o}, accessibility of response equipment, inconsistent maintenance schedule for equipment, lack of hazardous waste holding facility, and limited number of people trained to respond in the area (WWF, 2017).

6 MODELLING

Nunavut Impact Review Board (2019) identified a gap in chemical and physical oceanography knowledge for the Davis Strait and Baffin Island, including Frobisher Bay. The lack of oceanographic data in Frobisher Bay makes it challenging to create reliable circulation models for the region which are necessary to determine oil spill trajectories. Although operational models may exist for infrastructure development and planning purposes, the results have not been documented in scientific publications. Models that exist focus on the larger region, making it difficult to simulate small scale processes in Frobisher Bay due to low model resolution.

Few oil spill experiments have been conducted in the Canadian Arctic, all of which occurred outside of the scope of this report. There is a need to understand how oil weathers and is transported in ice covered waters. Little research has been done to understand how different types of oils behave under a variety of ice conditions in arctic environments (Afenyo et al., 2016). Currently, no oil spill models exist for ice covered environments. An oil spill occurring in water containing ice will behave differently depending on the thickness. Generally it is known that the spread of oil is reduced in ice covered waters compared to open ocean conditions, which limits weathering and creates its own set of challenges for oil spill clean up efforts (Afenyo et al., 2016). If oil is trapped under multiyear ice the oil can become encapsulated if the ice flow grows (Afenyo et al., 2016). Ice found in Davis Strait and Frobisher Bay is typically first year ice which means weathering can occur quicker than multiyear ice, creating melted pools through the ice sheet (Afenyo et al., 2016).

7 CONCLUSION

The Deep Sea Port in Iqaluit is expected to be completed by September 2022 (Nunavut News, 2021). Vessel traffic is expected to increase in the Artic, including Frobisher Bay, increasing the risk of a ship sourced oil spill event occurring. The Arctic environment limits the ability to respond to an oil spill: sea ice conditions, reduced visibility, colder air and sea temperatures, strong winds and high waves will impact the rate of weathering and movement of an oil spill.

There is a lack of reliable, long term oceanographic data for Frobisher Bay, making it challenging to confidently predict oil fate and behaviour in the bay or force oil spill modelling to support environmental incident planning and recovery efforts. Most of the research that looks at water characteristics and composition takes place during the spring/summer months, which does not reflect all conditions in Frobisher Bay. If a spill was to occur in the inner reaches of Frobisher Bay, it would likely reach the shoreline in this macrotidal environment. Open ocean influence on outer Frobisher Bay will impact weathering but will also create its own set of challenges for oil recovery.

Further work is also needed to expand our knowledge of petroleum product fate and behaviour in arctic and ice covered waters (Afenyo et al., 2016). As a part of the national Oceans Protection Plan, the Coastal Environmental Baseline Program was launched in 2016 to collect comprehensive data for six potential high vessel traffic areas, including Iqaluit. Through this program, various collaborations and partnerships were established to gather baseline data to better changes in the environment, which includes water sampling programs, intertidal surveys, sea ice monitoring and circulation studies. Information and data from these projects will be made publicly available through external partners and open government portals as the data is processed. The St. Lawrence Global Observatory (SLGO)[4] is working on making their data collected publicly available.

[4] Datasets OGSL/SLGO

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