Defence Research and Development Canada	Recherche et développement pour la défense Canada

Assessing the impact of infrastructure on Arctic operations

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Key takeaway

This work's main contribution is a methodology that provides insights into the impact of Arctic infrastructure investment/divestment decisions on the CAF ability to respond to a major maritime disaster scenario within Canada's Arctic.

Background

- Climate change and advancing technology are making the Arctic more accessible
  - Increased activity (commercial ventures, research, tourism, foreign actors)
  - Safety and security demands (Search and Rescue (SAR), aid to the civil power) expected to grow
- DND maintains some Arctic infrastructure already
  - Need to know how to prioritize funding
- The Northern Infrastructure Study (NIS) initiated in 2017 in response to CJOC request
  - Address lack of an enterprise-wide view of Arctic infrastructure
  - Assess how that infrastructure can support operations

Background (2)

- Search and rescue (SAR) is multi-jurisdictional in Canada
    - Department of National Defence (DND), Canadian Coast Guard (CCG), provincial/territorial governments, other government departments (OGD)
- Aid to the Civil Power functions (e.g., disaster response) are also the responsibility of the Canadian Armed Forces (CAF)

- CAF may be called upon to response to events in the north
    - Need to understand
        - Limitations due to and importance of existing infrastructure
        - How changes to infrastructure base would affect operations

Background (3) – the Canadian North

- Area of Canada north of 55° N is about the same as that of Europe
  - Total population is approximately 100k
    - Most communities are small and unprepared to cope with a major disaster
    - Little to no road access
    - Most runways are gravel
    - Sea access possible from May to Sept at best
  - Weather is cool at best of times
    - Very changeable
    - Sea surface temperature ~ 4-8°C

July – Mean	High (°C)	Low (°C)
Sachs Harbour	10.0	3.1
Resolute Bay	7.3	1.7
Iqaluit	12.3	4.1

Methodology

- Scenario- and optimization-based approach
  1. Define scenario with inputs and assumptions
  2. Develop optimization model using single reference case of the scenario
     - A simulation model was used to validate the results from the optimization model
  3. Create lists of additional incident locations and Forward Operating Locations (FOLs)
  4. Apply the optimization model to all feasible combinations of incident locations and FOLs
  5. Create variations of the scenario; repeat steps 3-4

Scenario: Major Maritime Disaster

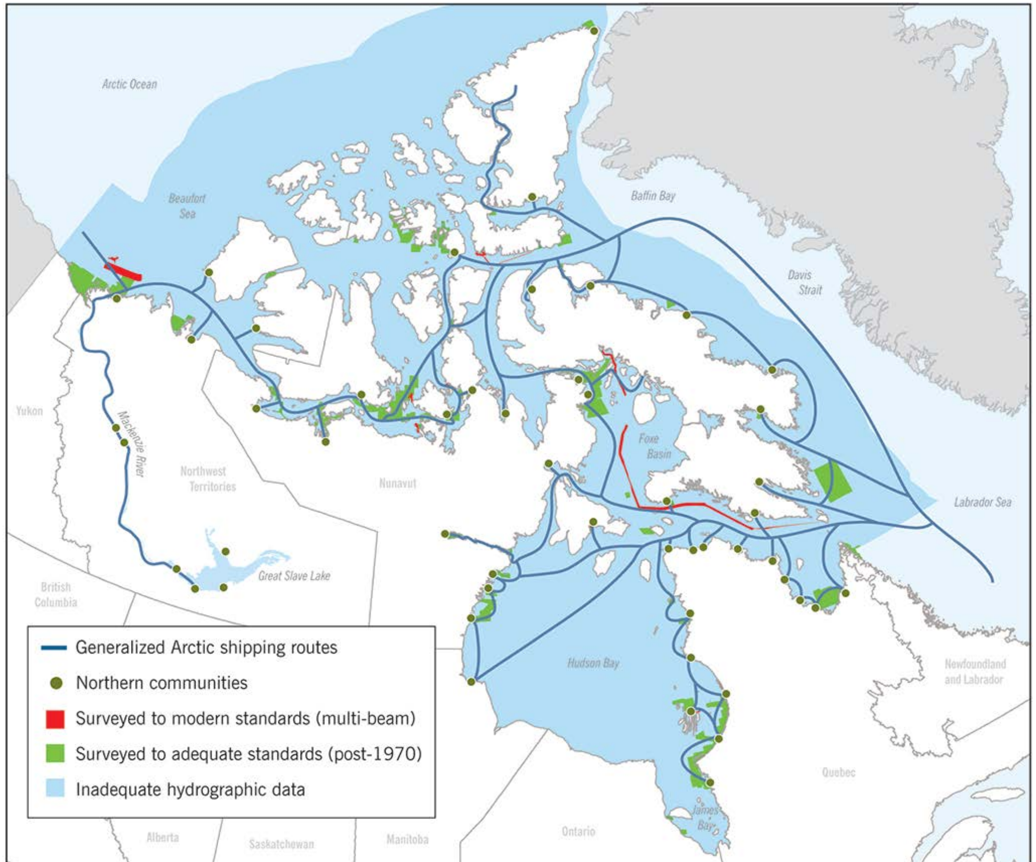
- Location: North-West Passage
- Time frame: June – September
- The *Gemstone Tranquility* with 2000 crew and passengers is travelling from Vancouver to New York via the NWP
  - At some point along its path, it runs aground/strikes an iceberg, suffering catastrophic damage. It begins to take on water and list heavily.
  - Passengers and crew evacuate ship to nearby shoreline
  - Rescue and evacuation of 2000 persons, some injured, is required
- Ends when evacuation is complete or 15 days elapsed

Scenario motivation

- Costa Concordia ran aground in well-charted seas and hospitable climate (2012)
  - 40 km from Grosseto, 139 km (75 nm) from Rome
  - 32 deaths
- Viking Sky experienced engine failure in sea state 7 off coast of Norway (2019)
  - *900 m* from shore
  - 479 persons hoisted from ship over two days using 5 helicopters
- A cruise ship with 1700 persons aboard transited through the North-West Passage (NWP) in 2016
- Hydrographic charts of Canadian Arctic are inadequate (see next slide)

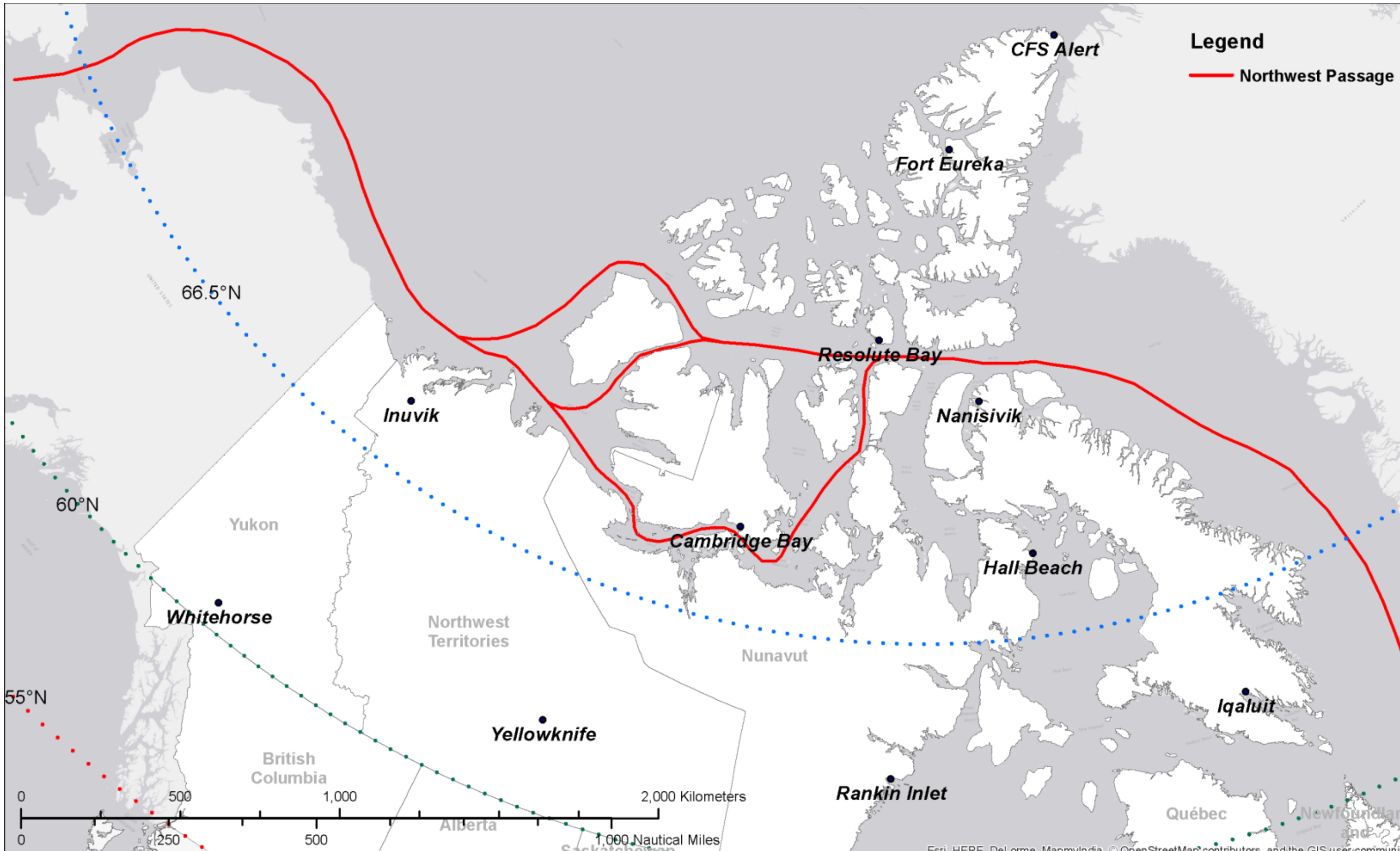
- Size of response required makes a good proxy for large Arctic operations in general

State of hydrographic mapping in the area of interest



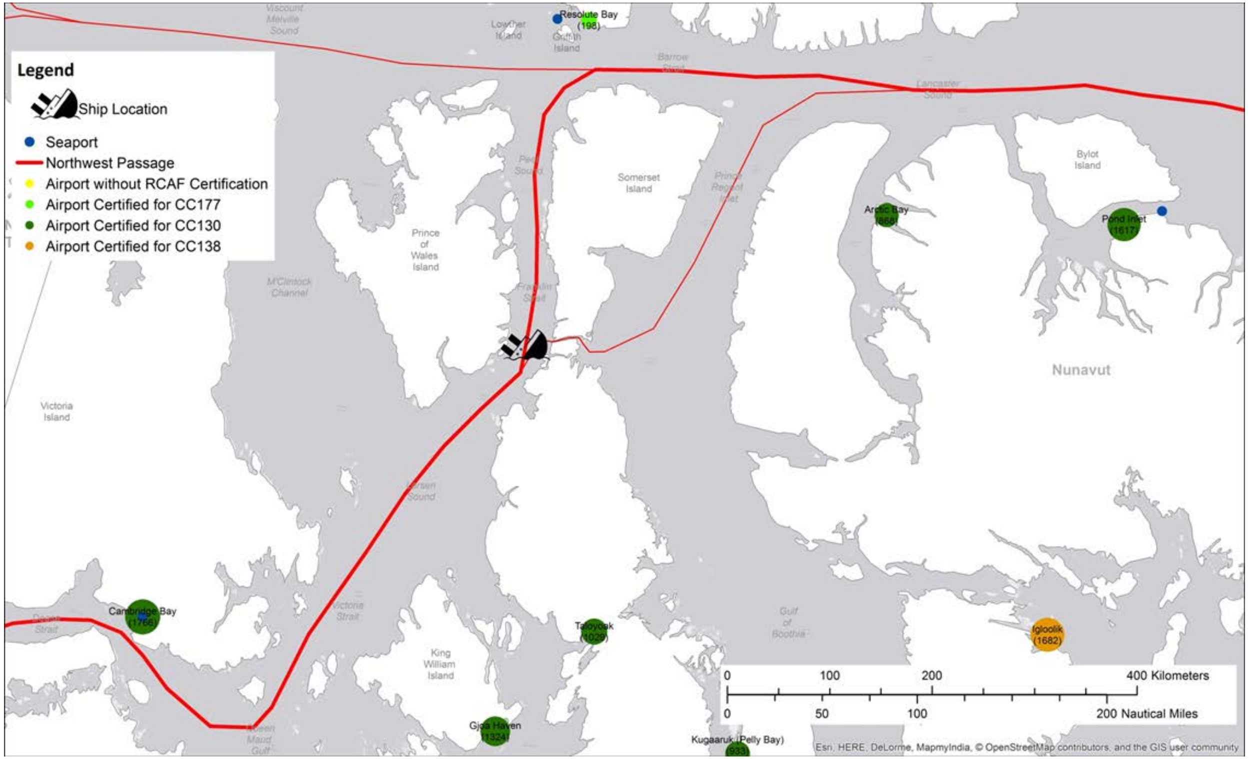
Source: 2014 Fall Report to Parliament of the Commissioner of the Environment and Sustainable Development. Note: Not all northern communities are represented on the map.

Northwest Passage

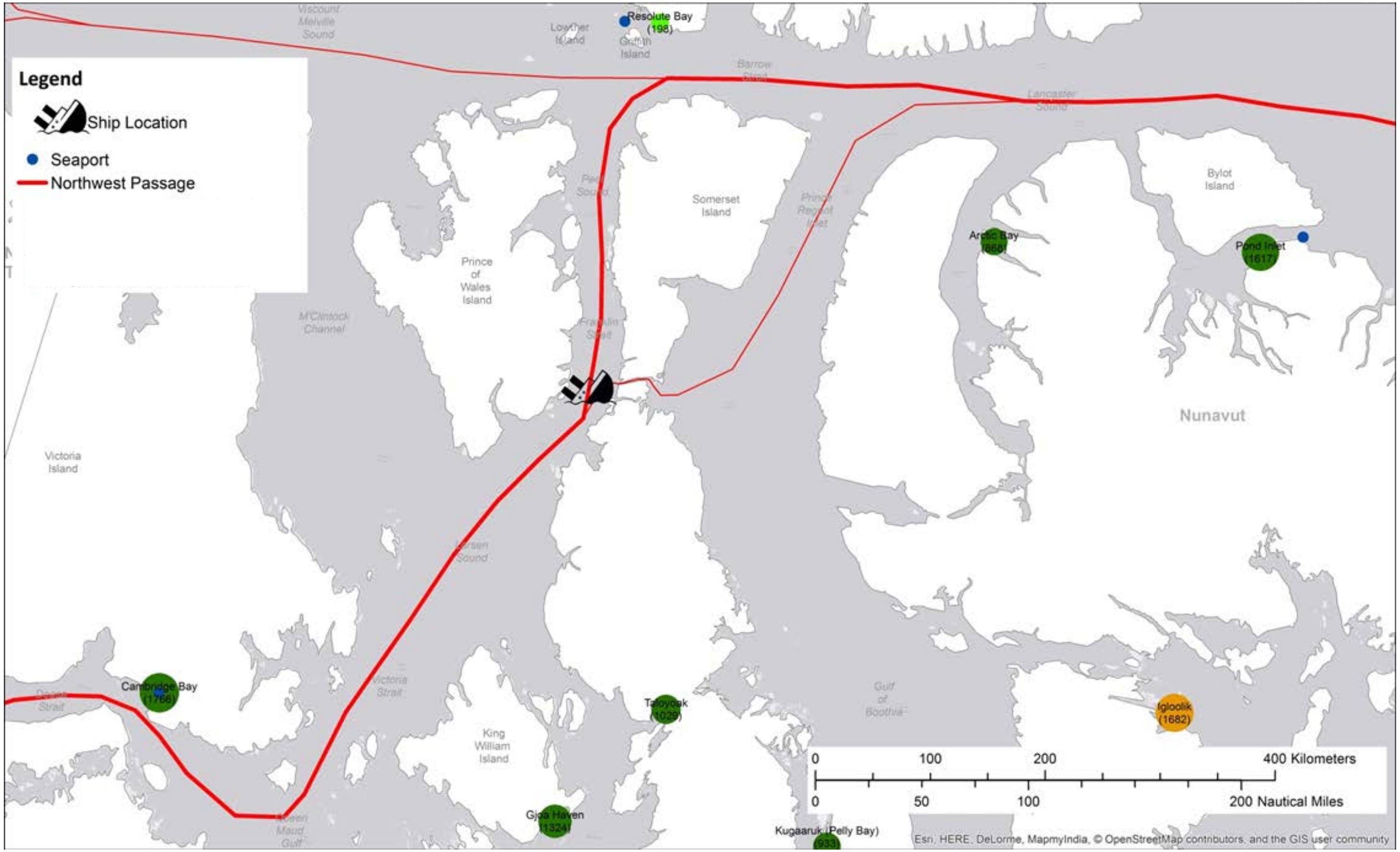


Example of scenario instance

- Incident location in the Franklin Strait
- FOL is Resolute Bay
- Back up FOLs
    - Taloyoak
    - Cambridge Bay



Example scenario



Optimization model

- Two-echelon capacitated vehicle routing problem with pick-up and drop-off over a number of days
  - Modelled as a MILP
  - 1st echelon – incident site ↔ FOL
  - 2nd echelon – FOL ↔ rear-echelon nodes in southern Canada
- Objective: minimize sum of evacuee death-days[†]
- Decision variables:
  - Route selection[‡]
  - Vehicle loads
    - Evacuees – multiple sub-categories
    - Aviation fuel
    - Military personnel
    - Non-fuel supply items

Modelling assumptions

- Evacuees move from the incident site to a FOL and then south
- Fuel, supplies and military personnel move north to the FOL. Further transport possible

- Helicopters deploy to FOL from their main operating base(s) (MOBs)
  - Delay based on response posture and transit time

- Helicopters land to load
  - Fatalities are not evacuated by helicopter

- All fuel required for 1st echelon helicopter operations is delivered by 2nd echelon aircraft
  - Required operational fuel reserve was set to 20% of range

- 500 military personnel and 100 pallets of dry cargo moved to FOL

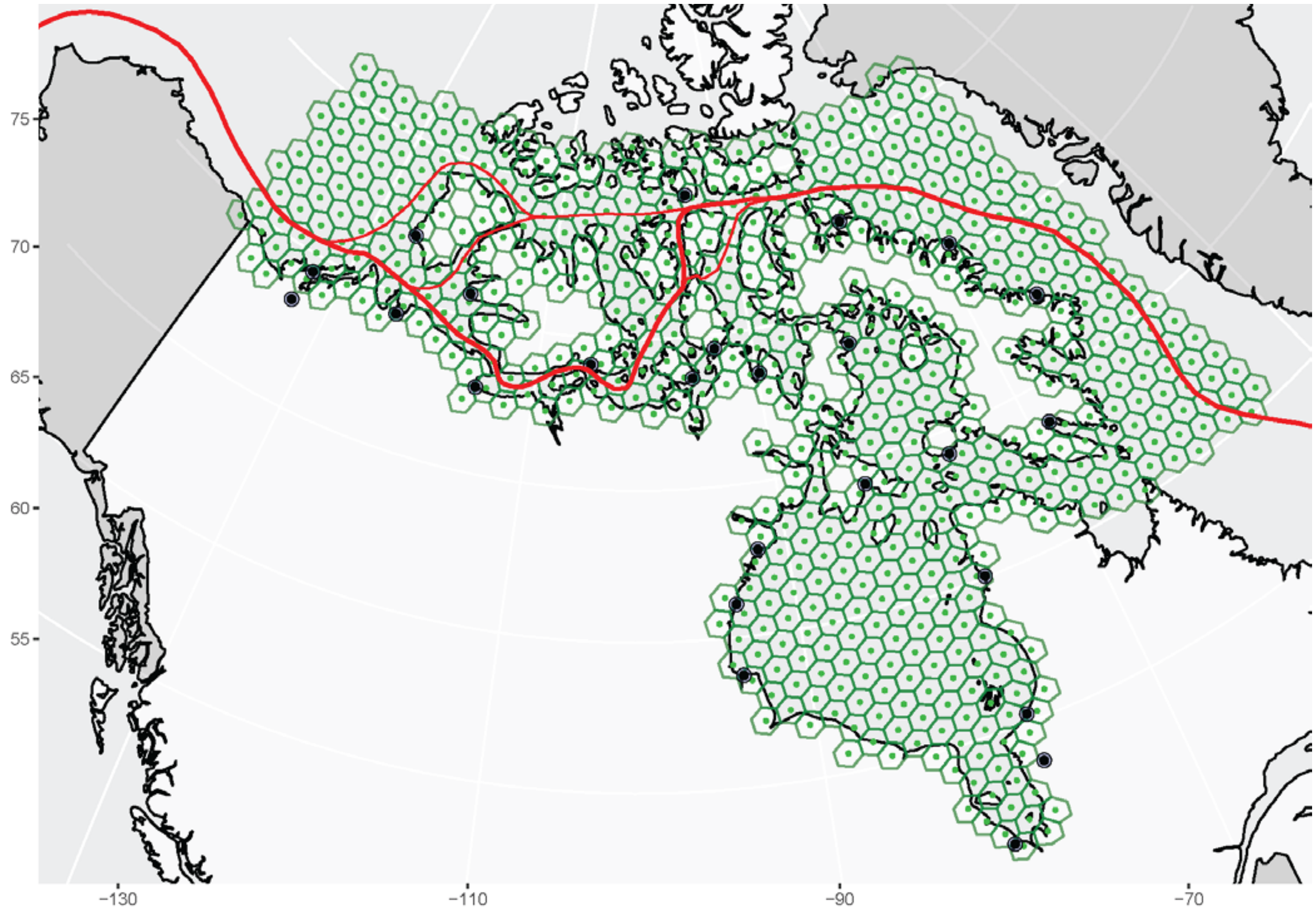
Modelling of evacuee medical condition

- Half-life decay model
  - Calculated on a daily basis for the persons at incident site and FOLs as a function of their location at the end of the day

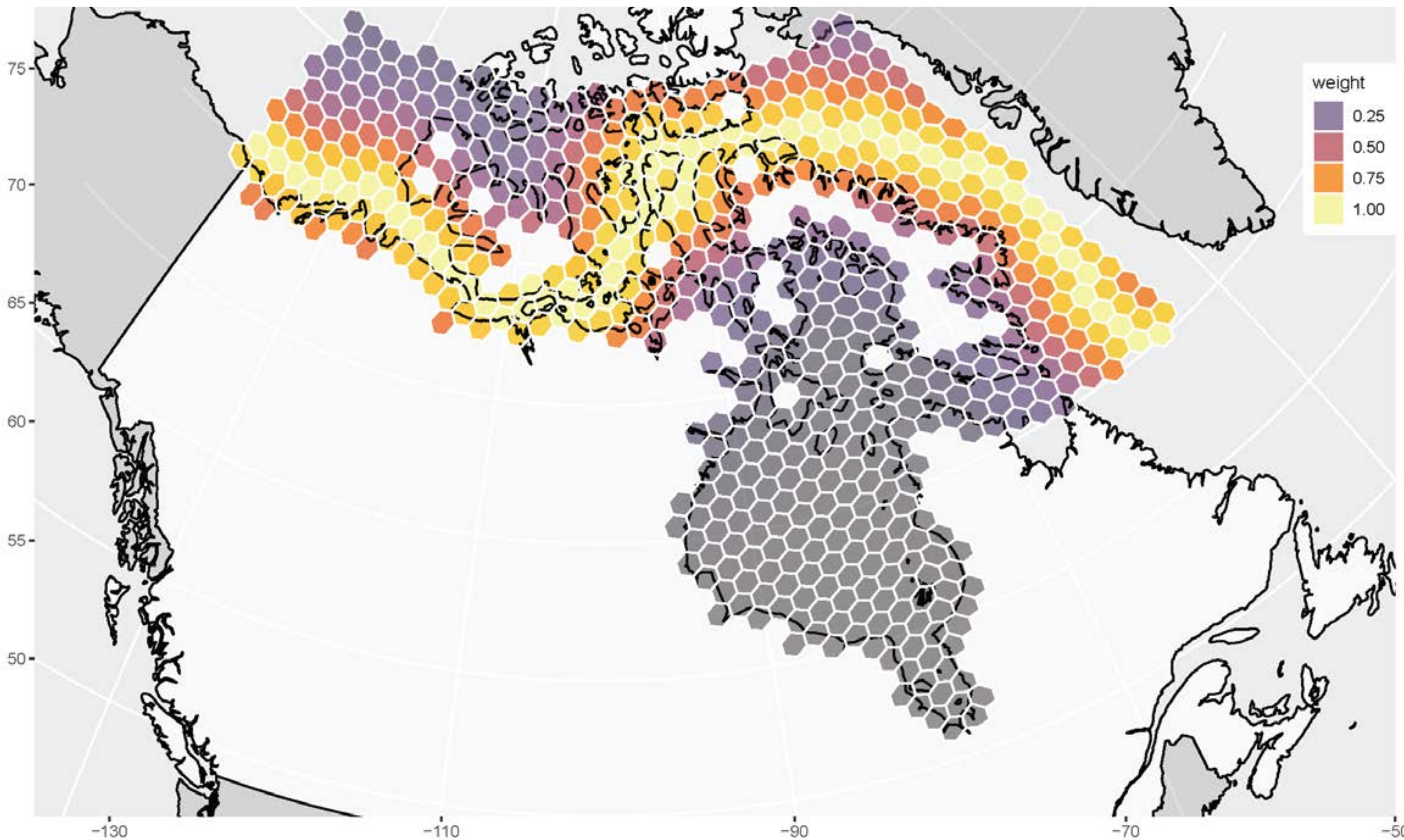
- Evacuees are always in one triage category: white, green, yellow, red or black
  - Initial distribution between categories is fixed as an input

- Transitions are one-way; no-one gets better
  - Transition stops once evacuee reaches a rear-echelon location

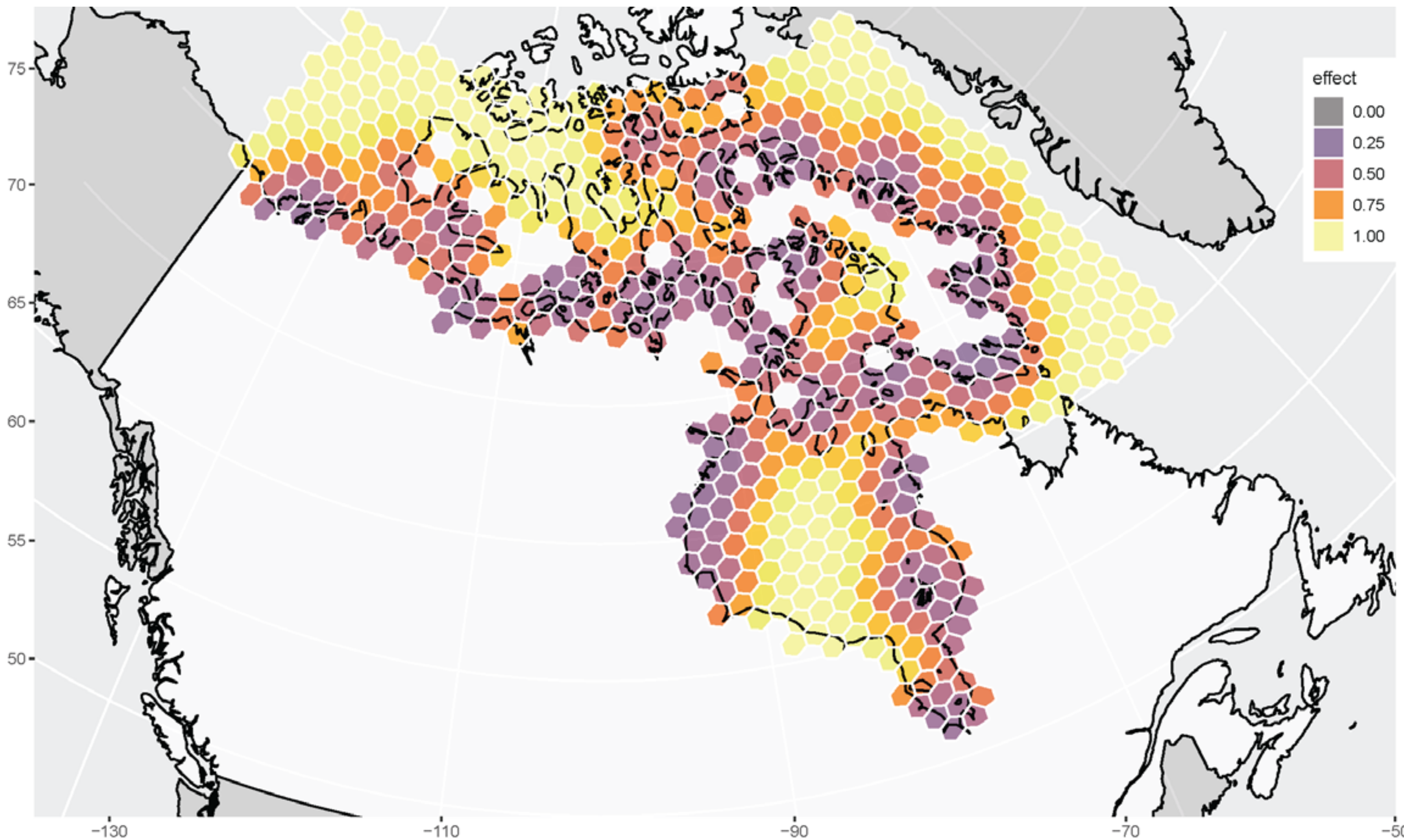
Analysis grid



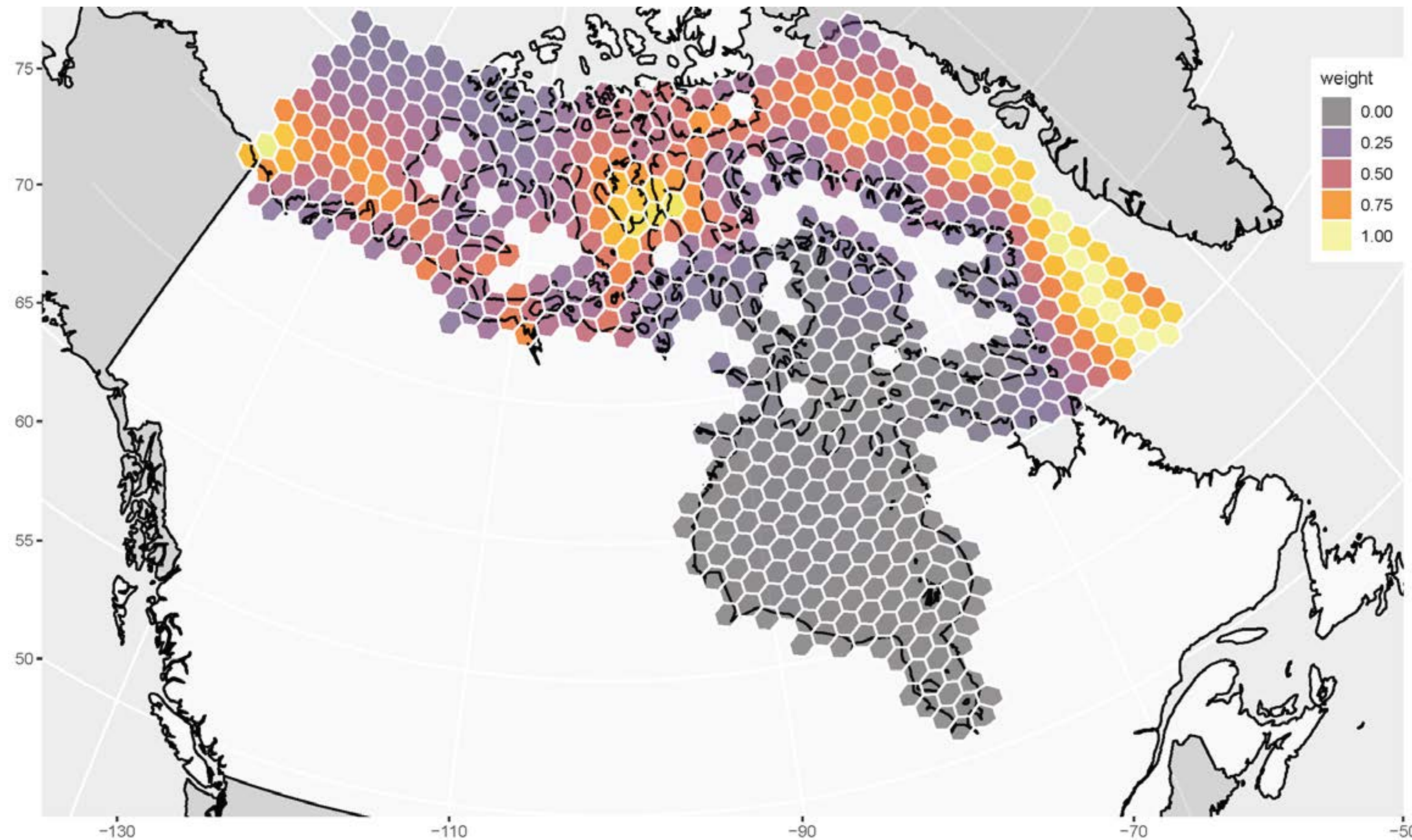
Route weighting



Risk reduction multiplier due to community proximity



Final cell weights – product of route and community proximity weights

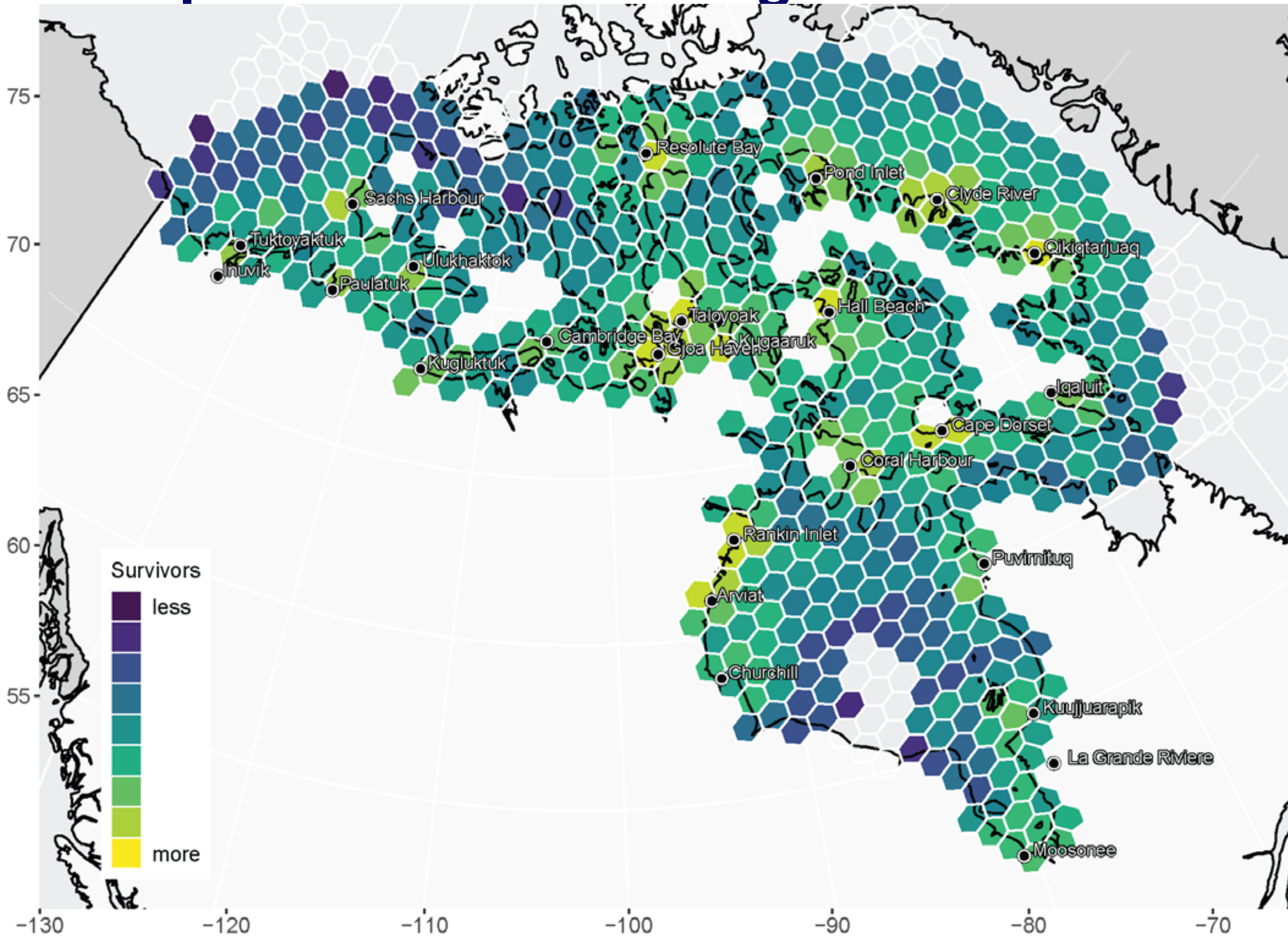


Results – general findings

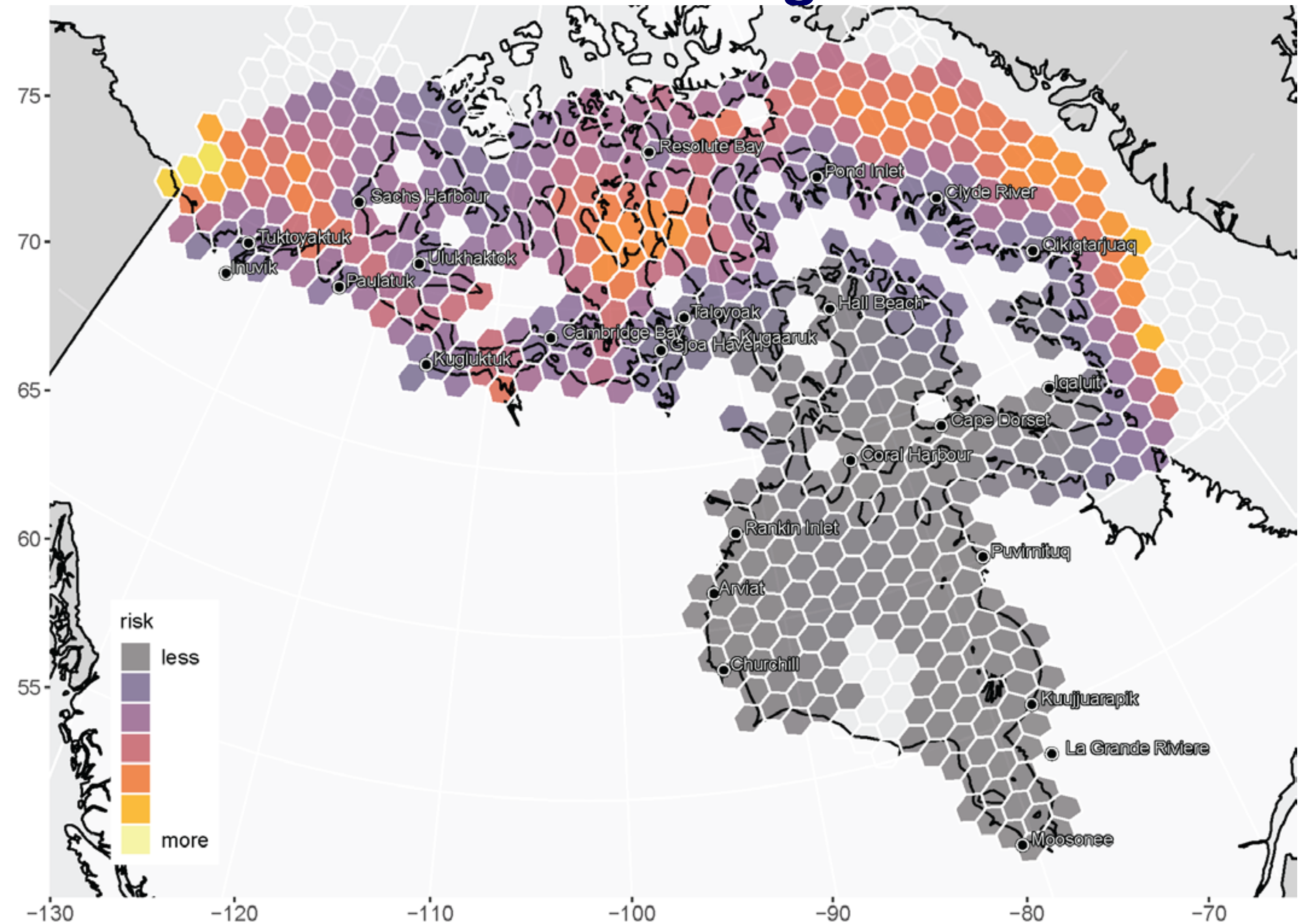
- It can be seen that some areas are worse than others

- Results are driven by
  - Availability of heavy lift helicopters
    - Response posture (notice to move)
    - Travel time to FOL (deployment distance)
  - Distance from FOL to incident site
  - Medical state transition rates
    - Influencing the transition rates could compensate for response and travel time; Expert input needed

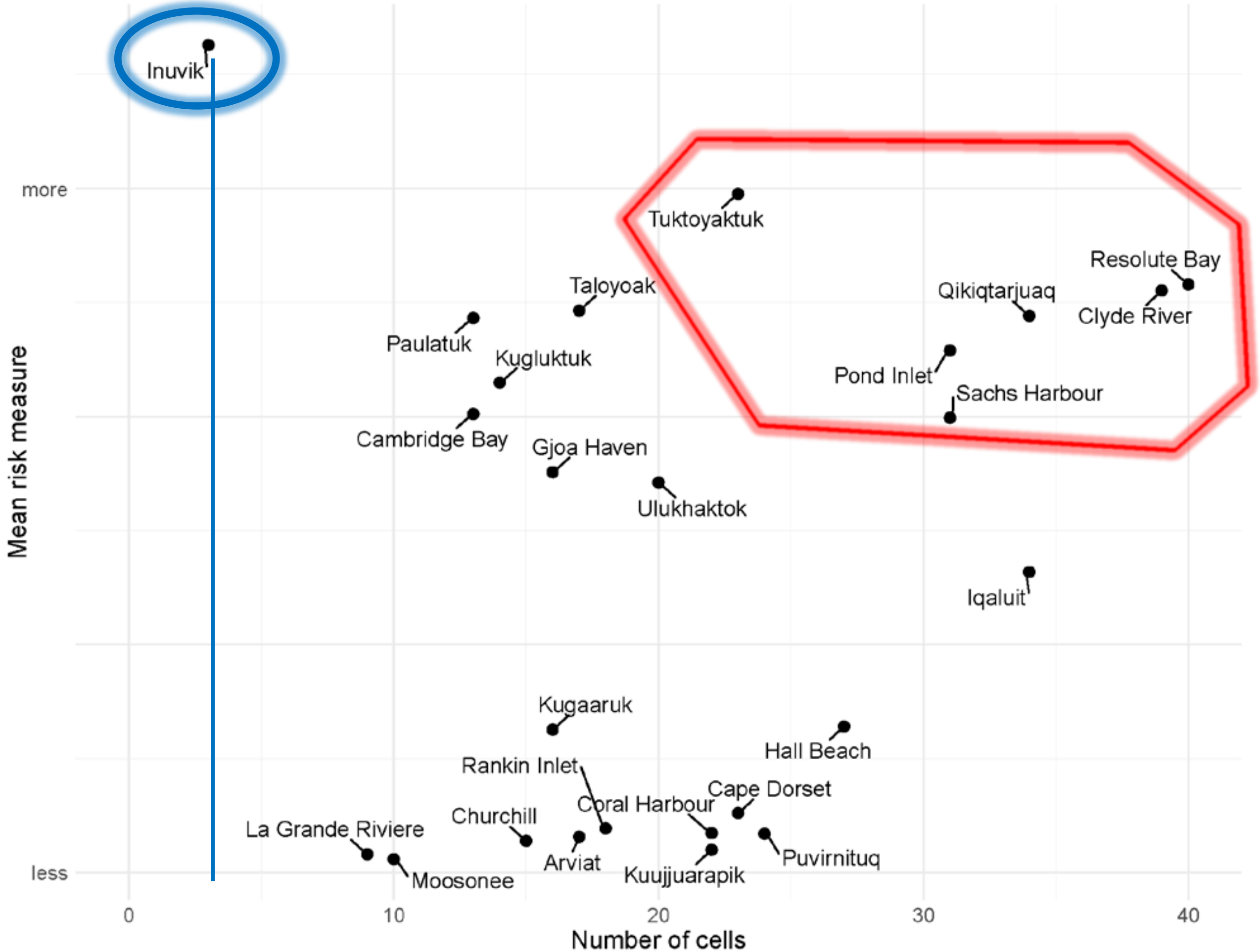
Baseline CAF performance across grid – survivors



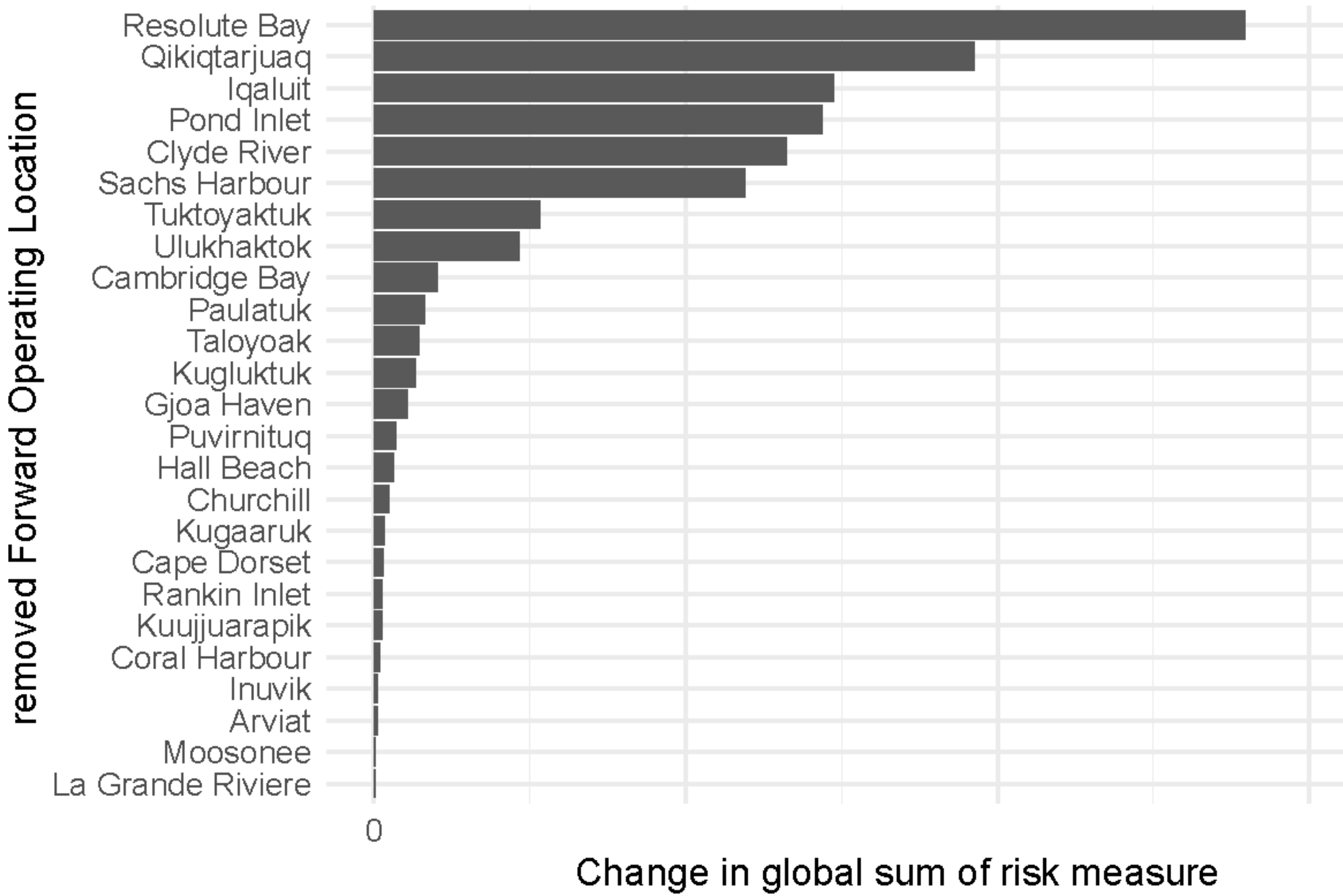
Baseline risk – casualties × cell weight



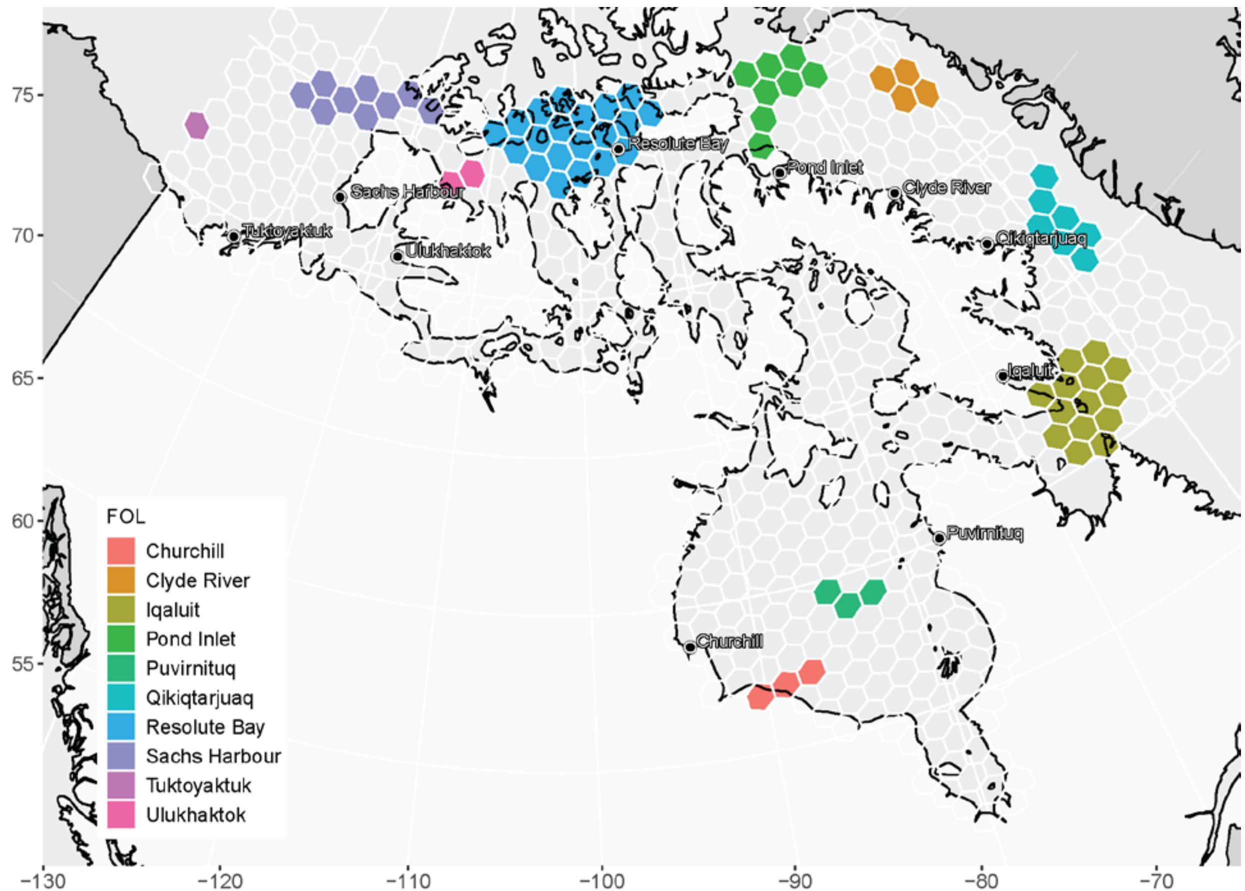
Grouping by FOL – mean risk versus coverage area



Impact of loss of FOL



Non-redundant coverage



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Known issues

- Medical state transition modelling
  - Expert input needed
- Weather has been assumed clear
  - Requires a different approach
- Helicopters
  - No breakdowns

Possible model additions

- FOL limitations
  - Storage capacity – fuel and shelter
  - Runway load limits
  - Ramp space / basing limits
- Military personnel
  - Subdivide by task (medical, air crew, ground crew)
    - Penalties on activities and survival rates until delivered
- Logistics
  - Fuel and supply consumption by survivors and military personnel
    - Penalties for shortfalls
- RCN and CCG ships

Conclusion

- Can calculate change in performance due to location additions, deletions and/or modifications
    - Provide means for weighting and prioritizing infrastructure decisions

- Model makes vehicle loading decisions by evacuee triage state
    - Results do not follow current SOP – may be worth comparing with current policies

- Future directions
    - Other scenarios
    - Approximate dynamic programming

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Sum of risk by FOL