RADARSAT-2 for Measuring Glacier Dynamics and Ice Berg Calving flux from Ice Caps in the Canadian high Arctic

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Introduction

- Canadian Arctic contains ~150,000 km^2 of land ice → collectively the largest single area of land ice in the world outside of Greenland and Antarctica
    - Significant source of potential freshwater flux to oceans
    - *IMPACTS* → Global Sea Level Rise, marine ecosystems, ocean dynamics…

- Mass loss from ice caps in the Canadian high Arctic occurs primarily through ***Summer Melting*** and ***Ice Berg Calving***
    - Rates of mass loss due to glacier melting in this region have accelerated exponentially in response to recent summer warming
        - Mass loss due to summer melting since 2005 has been 3-5 times greater than the long term (1960 – 2010) average (Gardner et al., 2011; Sharp et al. 2011)
    - Rates of mass loss due to ice berg calving however are not that well understood
        - ~70% of land ice in the QEI is drained by tidewater glaciers → overall mass budget is sensitive to fluctuations in tidewater glacier behaviour
        - Previous studies have estimated calving has accounted for ~30 % of total loss from selected ice caps *(Burgess and Sharp, 2005[Devon Ice Cap]; Mair et al, 2009[Prince of Wales Ice Field])*
        - This proportional rate however has decreased recently due to reductions in glacier velocity and increases in surface melting

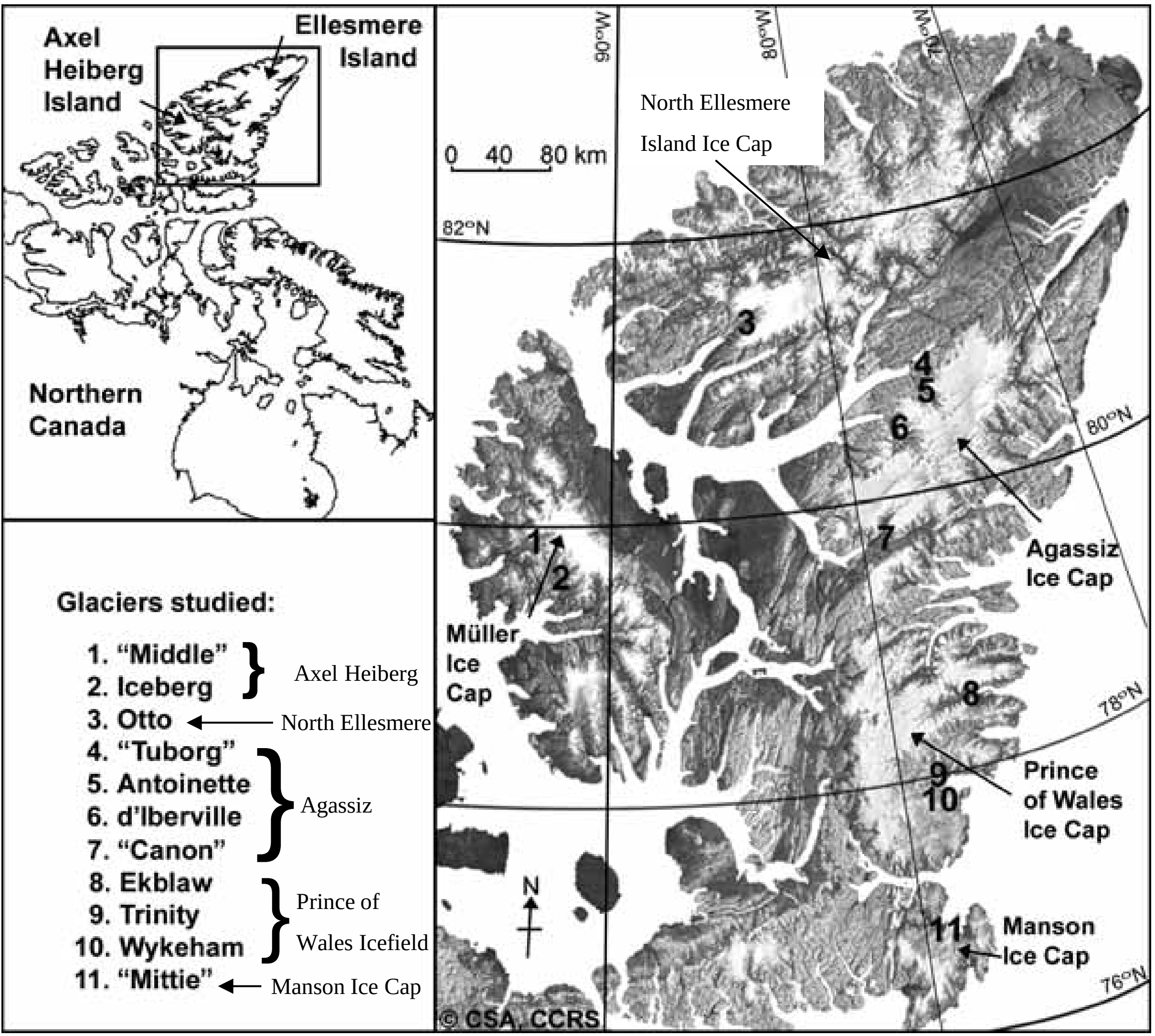
Why Measure Glacier Velocities?

1. Glacier velocity is essential for calculating calving flux
    - Calving Flux = (Glacier Velocity * Cross-Sectional Area)
    - Provides a measure of ice mass loss directly to oceans

2. Knowledge of temporal velocity changes (inter-annual or seasonal) provide valuable information in determining mechanisms controlling glacier flow.
    - ***<u>External</u>***, or climate controlled forcing and ***<u>Internal</u>***, or surge processes
    - Understand how glacier dynamics will respond to future warming

3. Need to discriminate between thickness changes caused by non-steady glacier flow (dynamic thickness changes) and those due to melting at the glacier surface
    - Necessary for a proper interpretation of measurements of mass change from air and space borne altimetry.

Tidewater Glaciers Targeted for Velocity Monitoring in the Queen Elizabeth Islands, Nunavut



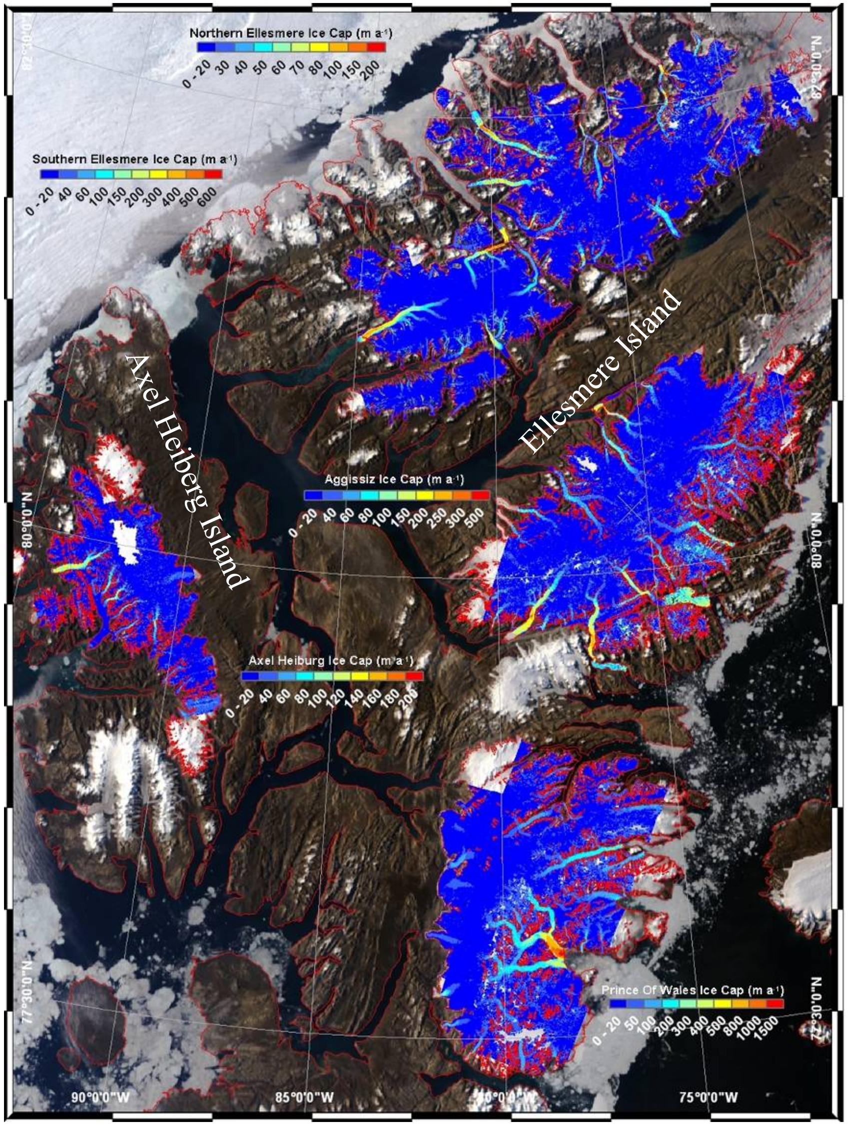
Short and Gray, 2005

- Glacier velocity monitoring began in 2000 (to 2005) using RADARSAT-1 Canada Centre for Remote Sensing
  (N. Short and L. Gray)
- Speckle Tracking Interferometry (Gray et al., 2001)
- 11 target glaciers - well distributed across the QEI → draining ice from all major ice caps except Devon Ice cap
- Mapping of target glaciers continued by the Geological Survey of Canada

  > 2006 – 2007 (Radarsat-1)

  > 2008 – present (Radarsat-2)

Glacier Velocity Fields Derived from RADARSAT-2



2013 Velocity Fields (Van Wychen et al., *in prep.)*

➢ In 2011 this program expanded to map continuous velocity fields across the Canadian Arctic ice caps and glaciers.

➢ Made possible by the availability of Wide - Fine mode RADARSAT-2 data which covers all ice caps with far fewer images.

➢ Allows us to:

→Monitor the flow dynamics and calving rates of all glaciers in the CAA

→ Look at changes to the flow regime of the ice cap interior regions as well as the main outlet glaciers

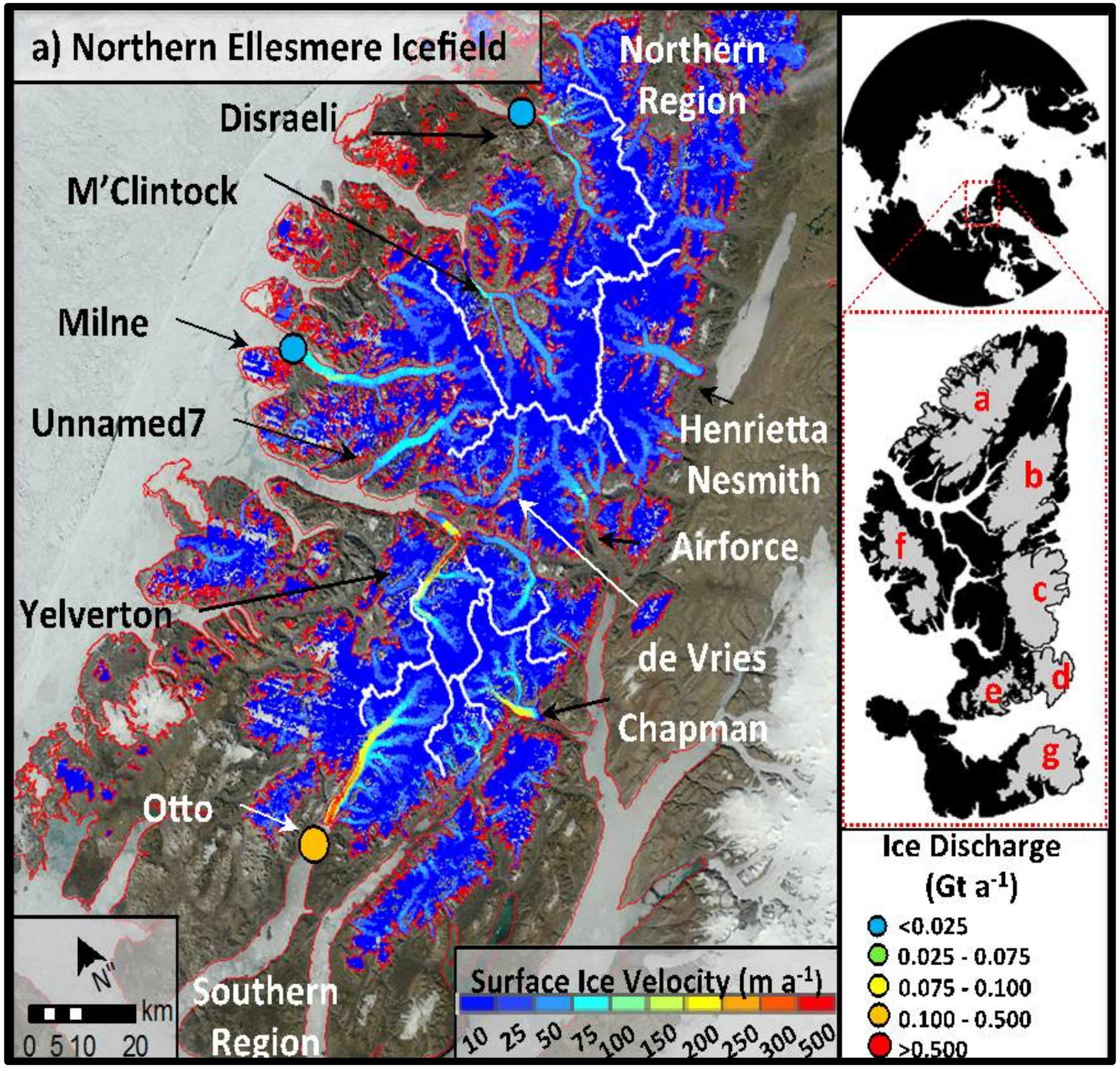
<u>For Entire Time Series (since 2000)</u>

→ Velocity fields derived from winter imagery when no liquid water present to absorb the radar signal

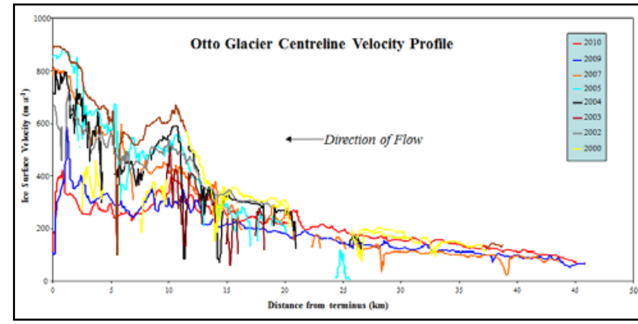
<u>Disadvantage:</u> Conservative estimate of glacier velocity as they exclude potential accelerations in the summer

<u>Advantage:</u> Winter velocities are generally the most stable and better for evaluating inter-annual variations in flow

Otto Glacier, Northern Ellesmere Ice Field



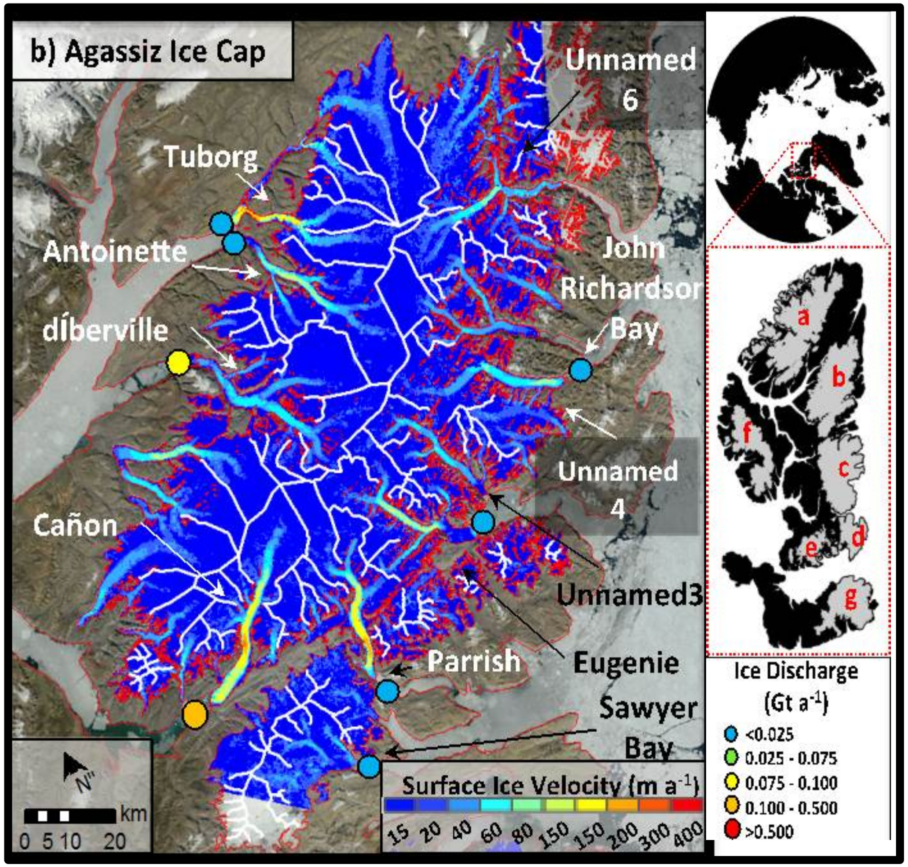
2013 Velocity Fields (Van Wychen et al., *in prep.)*



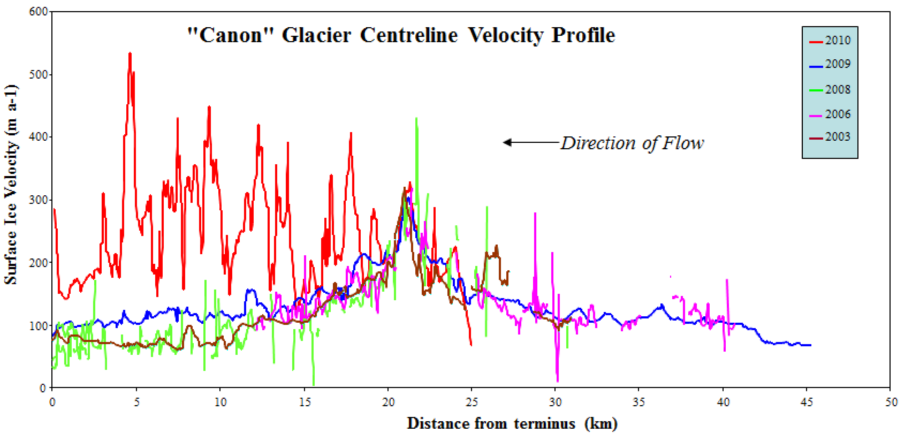
Otto Glacier

- Surge type (Hattersley-Smith, 1969)
- 700 – 900 m a^{-1} (2002-2007)
- Slowed to < 200m a^{-1} (2009 – 2010)
- Currently (2013) at~300m a^{-1}
- Quiescent phase of surge cycle

Canon Glacier, Agassiz Ice Field



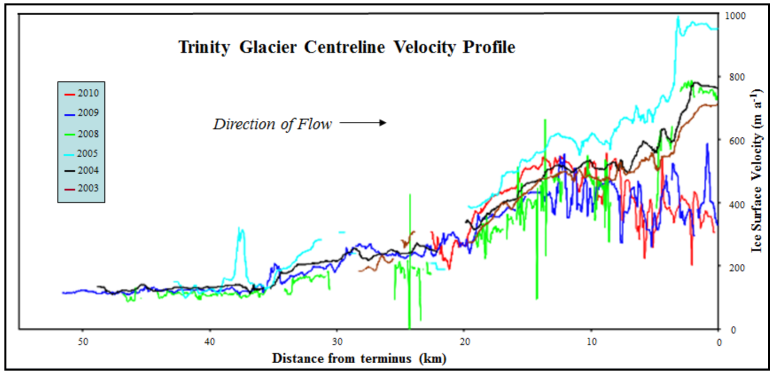
2013 Velocity Fields (Van Wychen et al., *in prep.)*

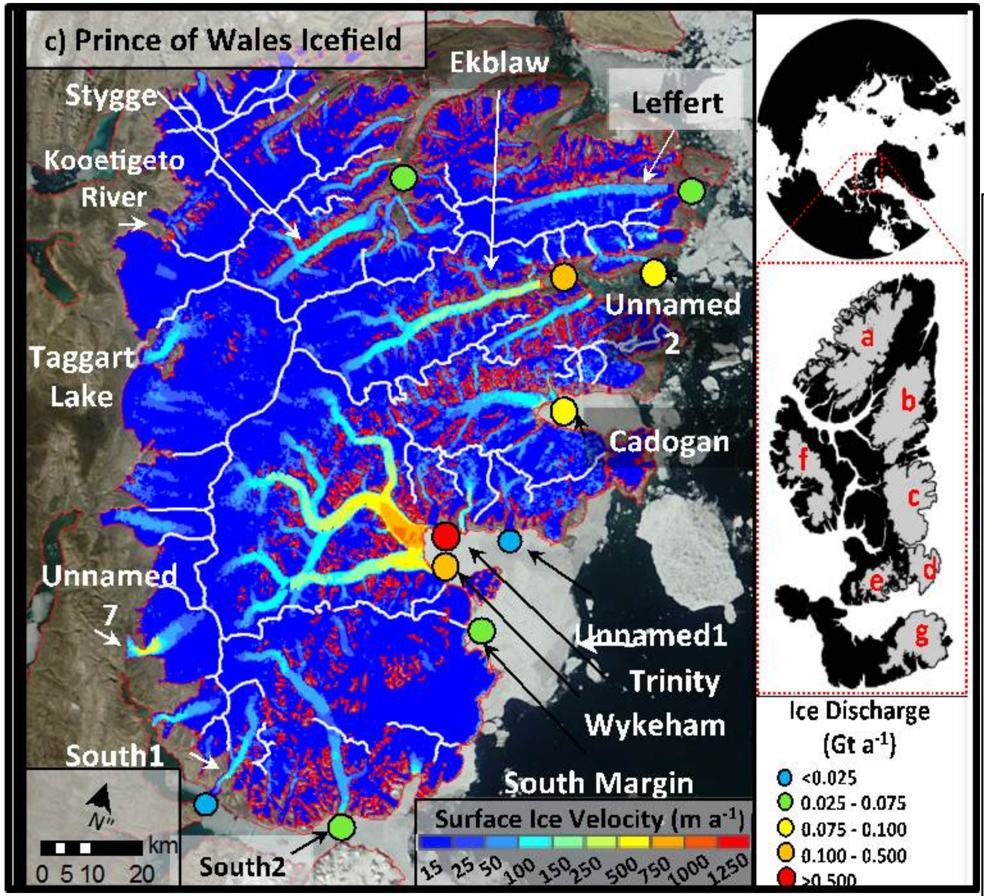


Canon Glacier

- Largest outlet glacier on the Agassiz ice cap
- Relatively constant flow speeds of 50-100m a^{-1} (2004 – 2009)
- 2010 velocities ~290m a^{-1} at terminus
- 2013 velocities ~150 m a^{-1} at terminus

Trinity Glacier, Prince of Wales Ice Field





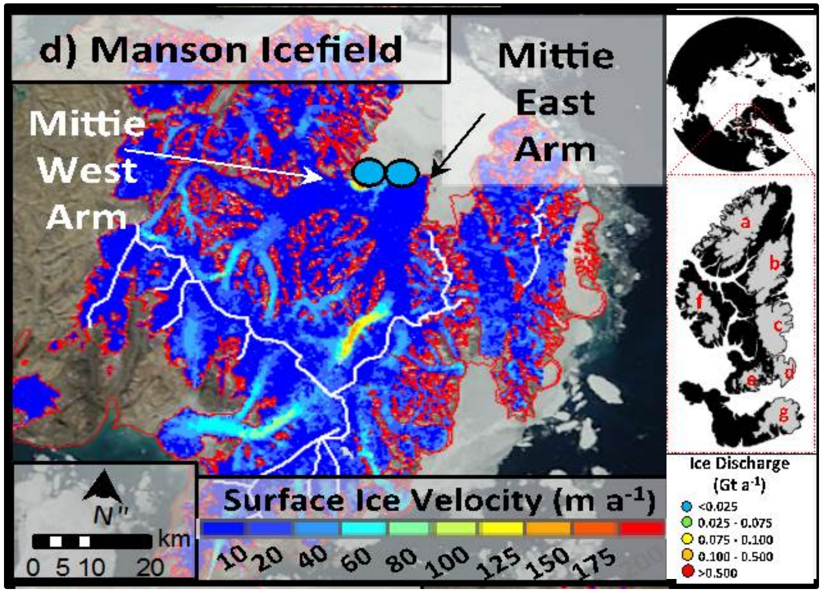
2013 Velocity Fields (Van Wychen et al., *in prep.)*

Trinity Glacier

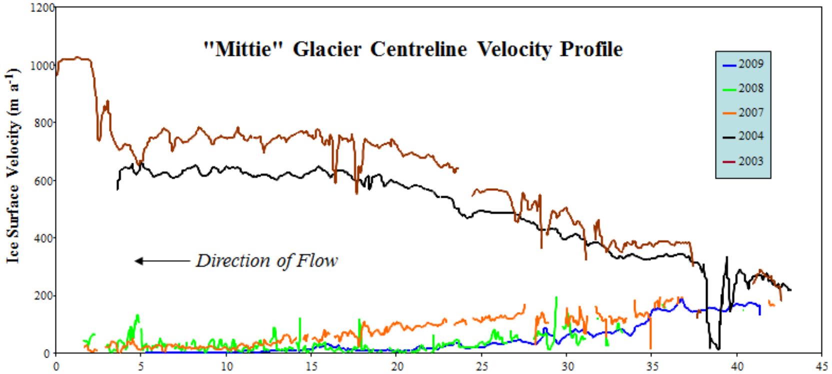
- Accounts for 80% of ***total amount calved*** from the POW ice field
- Trinity / Wykham complex accounts for 50% of all ice calved in the QEI
- Terminus velocities accelerated from ~700-950 m a^{-1} (2003-2005)
- Velocities slowed to ~390 m a^{-1}in 2009 - 2010
- Most recent velocities of ~750 m a^{-1} at the terminus

→ Not a surge glacier, but does exhibit significant variation of inter-annual flow rates

Mittie Glacier, Manson Ice Field



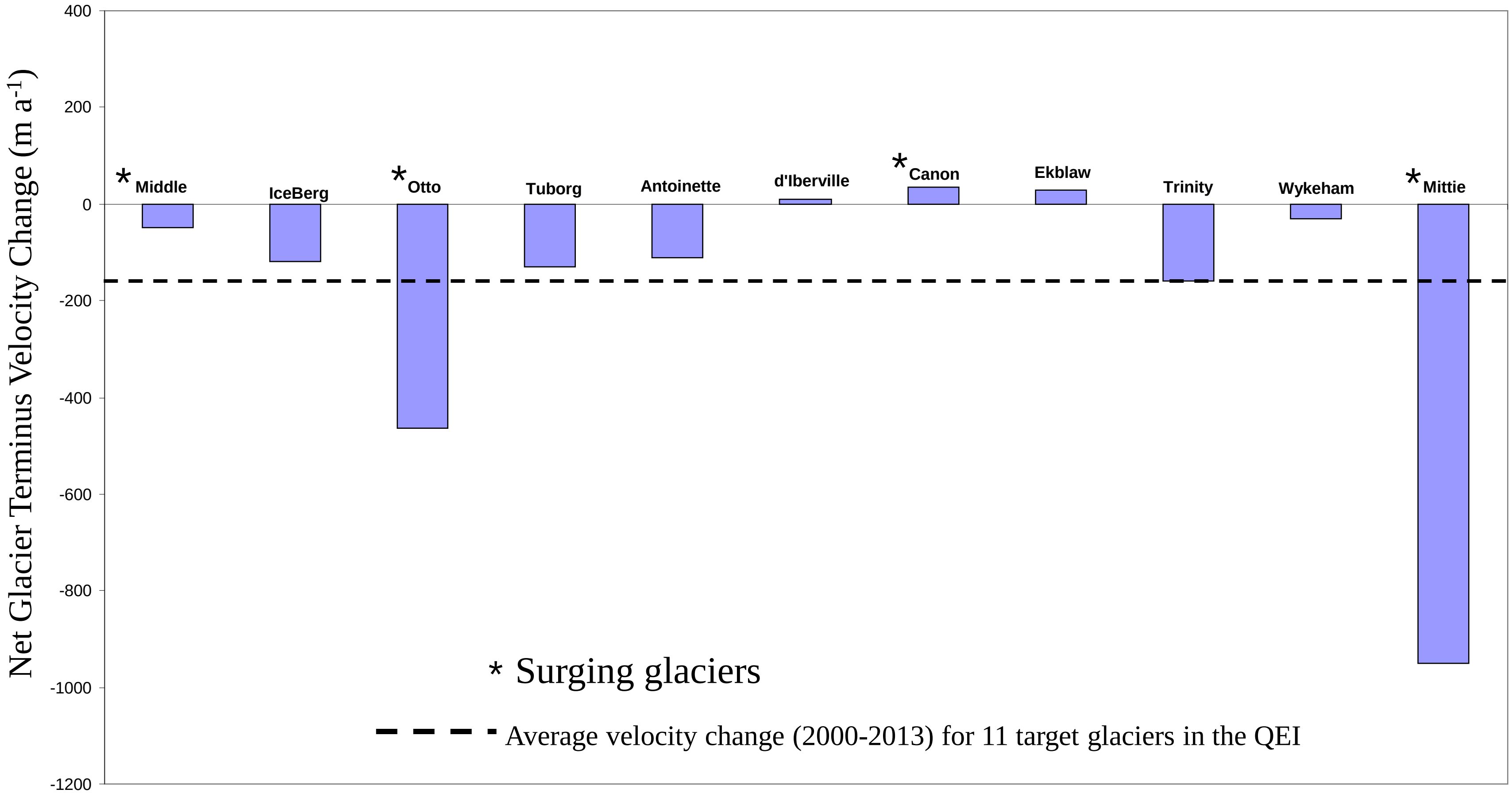
2013 Velocity Fields (Van Wychen et al., *in prep.)*



Mittie Glacier

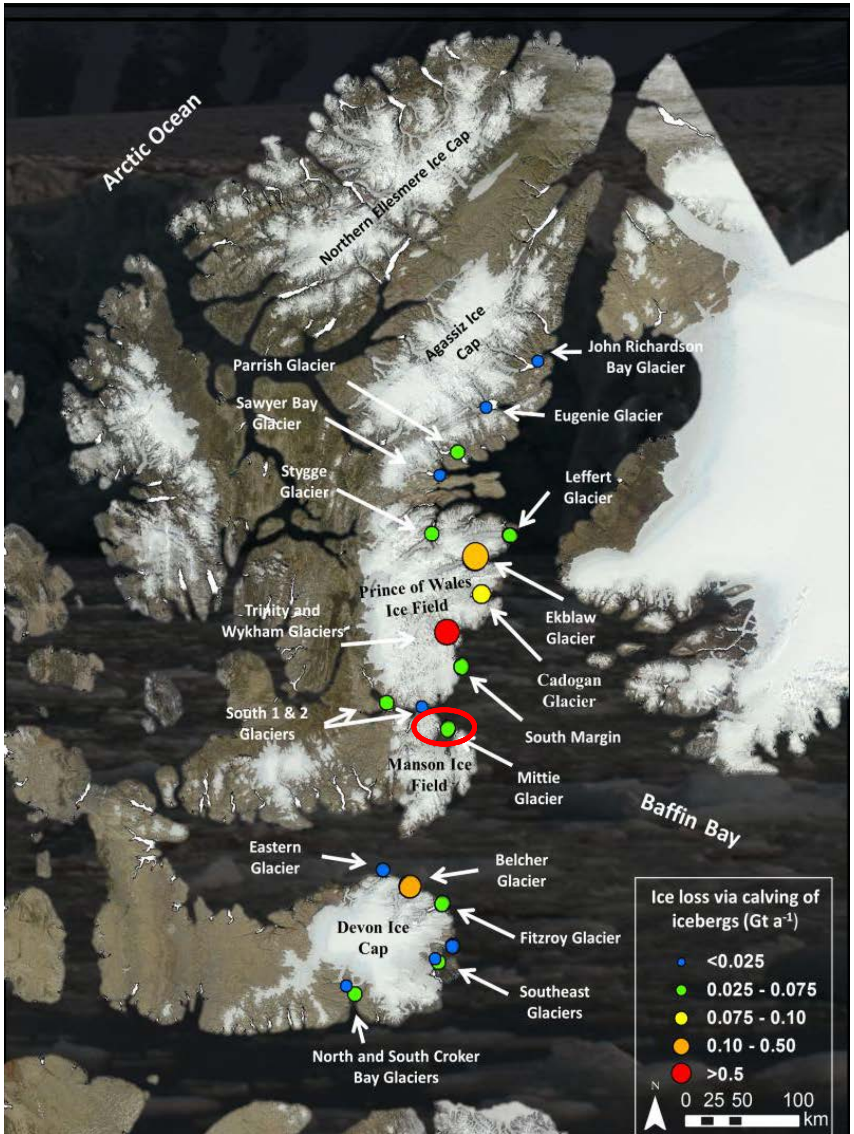
- Surge type glacier (Copland et al, 2005)
- Dramatic shutdown along entire glacier starting in 2007.
- Remains stagnant in 2013
- Between 2003-2009, the terminus has retreated by up to 3 km
- Retreat continues into 2013 with break-off of large (few sq km) portions of the Mittie terminus (*L. Copland/T. Wohleben, pers comm.)*

Net Glacier Terminus Velocity Change: Early 2000's - 2013



- Net velocity change of 11 target glaciers over the period of observation
- Most glaciers have slowed down over the past ~10 years → average net reduction of ~180 m a^{-1} for all glaciers observed
- Dominated by surge glaciers entering 'quiescent' mode → Re-acceleration and increased calving in the future is expected

Source of Ice-berg Production (2012) into Baffin Bay from the Queen Elizabeth Islands, Canada



Van Wychen et al. 2012 – ArcticNet poster presentation

• Combining surface velocities with available ice thickness data at tidewater termini has allowed us to map the point sources of ice discharge into Baffin Bay from Canada

• Knowledge of ice flux into this region is important due to shipping and exploration activity, and the fact that ice calved from these glaciers represents >90% of the ice lost through calving from the entire QEI.

• Ice berg production into BB is derived mainly from the Devon, Manson, Prince of Wales, and Agassiz ice caps
  - Important point sources being the Trinity/Wykham complex and Ekblaw glacier (POW) and the Belcher glacier (Dv)

• Total mass discharged into Baffin Bay in 2012 was 2.6 Gt → equivalent to ~2.8 cubic kilometers of ice.

• During the active surge phase of the Mittie Glacier (2002-2007) the overall calving rate for the QEI was ~ 3.5Gt of ice, or 25% greater

• This shows that the amount of ice discharged from individual calving glaciers can:

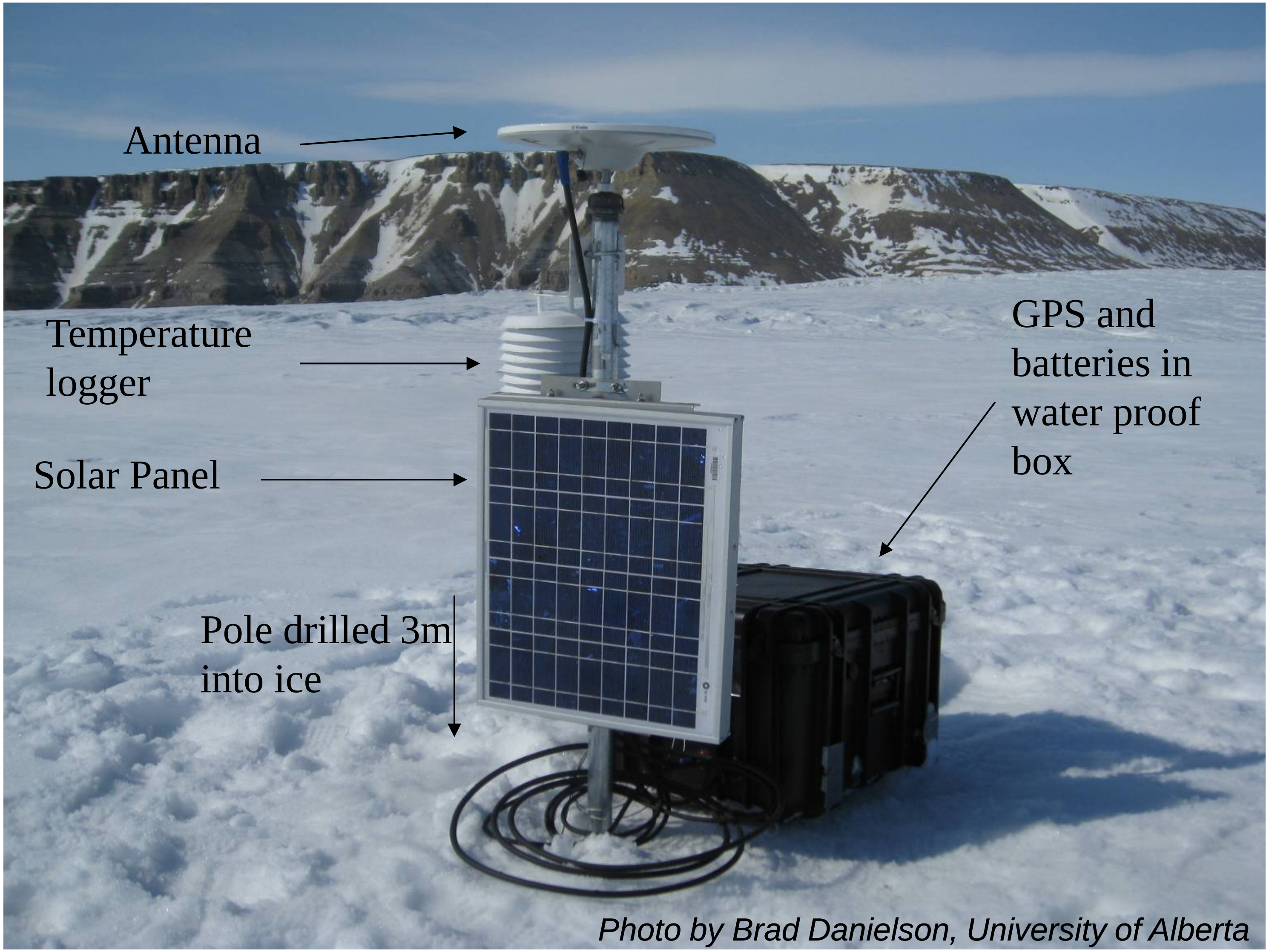
→ vary significantly over relatively short periods of time

→ Have a relatively large impact on the overall mass loss rates from the QEI

→ Calving flux must therefore be estimated at least annually to be useful for ***ice cap mass balance*** and for reliable information on hazards related to the ***shipping industry*** or ***marine infrastructure.***

Seasonal Velocity Changes

GPS to Track Glacier Velocity
North Croker Bay Glacier, Devon Ice Cap



- Since 2008 GSC and U of Alberta have had several GPS units deployed on outlet glaciers that drain the Devon ice cap.
- Operate year-round collecting ***hourly data*** on horizontal and vertical glacier motion.
- Most flow variations observed so far occur in the late spring/early summer

Water Enhanced Glacier Flow

• Most likely driven by meltwater that water reaches the glacier bed through moulins fed by supra - glacial lakes and or streams.

• The presence of water at the glacier bed reduces friction through lubrication and or hydraulic jacking

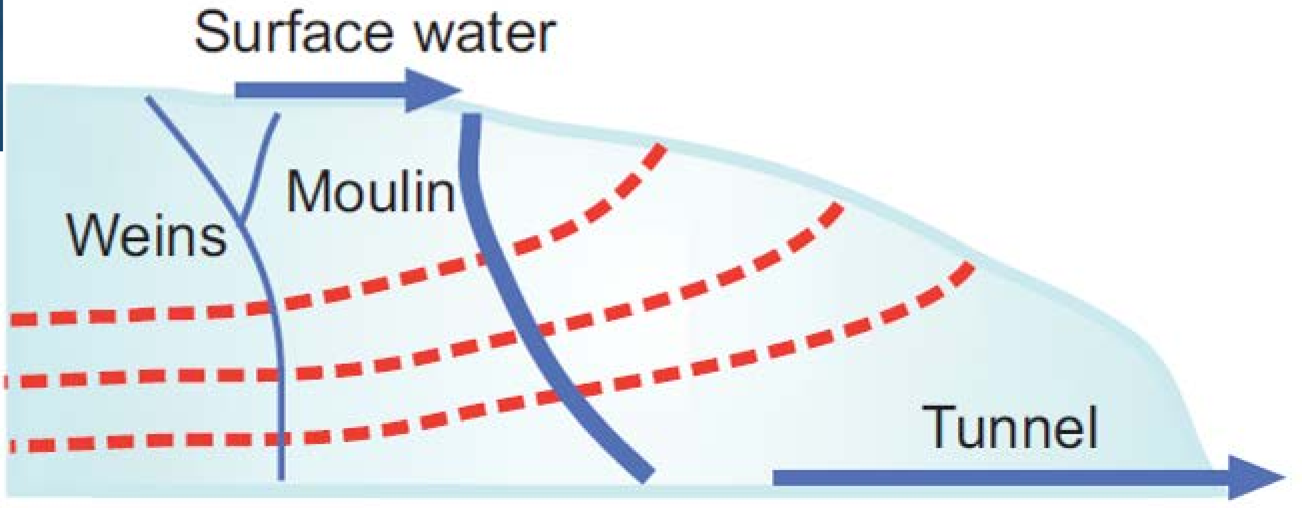
→Temporary (seasonal) speed-up in glacier velocity

• Magnitude and duration of speedup is controlled by:

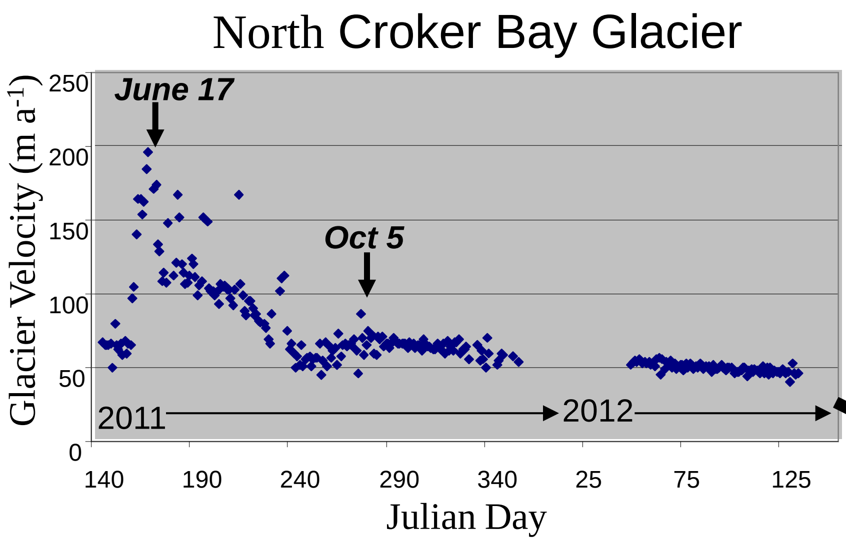
→ the amount of water reaching the bed

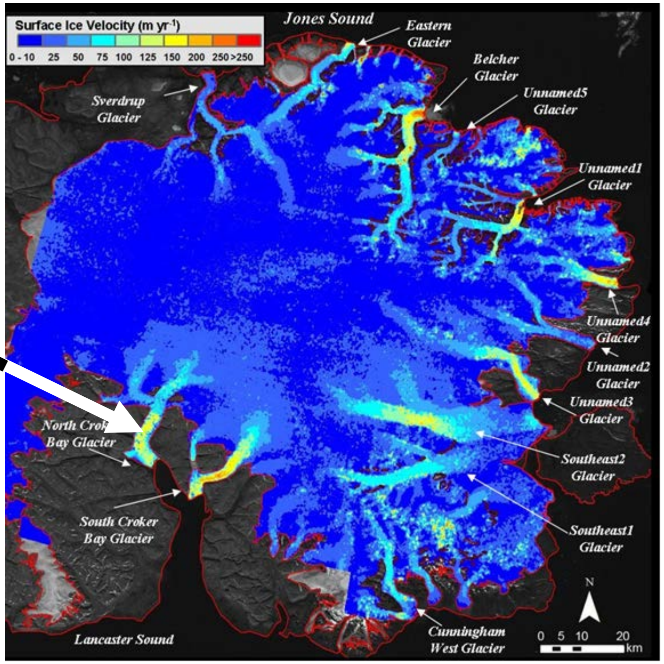
→ Timing of the onset of spring melt (rapid or slow)

→ efficiency of the sub-glacial hydrological system



GPS Validation of North Croker Bay Glacier Velocities from RADARSAT-2





- GPS winter velocities match speckle tracking (Feb/march) velocities of ~50m a^{-1} along North Croker Bay Glacier.
- During summer months, GPS shows velocities up to 200m a^{-1} → increase by 3-4 times winter flow rates.
- Timing of this event suggests that surface meltwater is likely responsible for the enhanced flow – ground measurements not available for validation.
- Annual velocities as measured from GPS are ~25% greater than winter velocities.

→ important to know when computing annual ice berg calving rates from glacier velocities derived from winter-time remote sensing data.

Summary

- Accumulated a 13-year annual time series of surface velocity measurements from several important tidewater glaciers across the QEI from RADARSAT-1 / 2 data

- The average flow rate of 11 target glaciers indicates a net decrease in velocity by ~180 m a^{-1} over the period of record.
  - Primarily a result of the Mittie and Otto glaciers entering a quiescent of their surge cycles

- Flow (and calving flux) rates can vary significantly from one year to the next
  - Important implications for estimating annual ***ice flux to oceans***, ***ice cap mass balance*** and understanding potential hazards to the ***shipping*** industry.

- Summer accelerations may contribute significantly to annual velocities that are not captured by our winter speckle tracking measurements
  - This is an area of active research between the GSC, Universities of Alberta and Ottawa

Thank You!

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