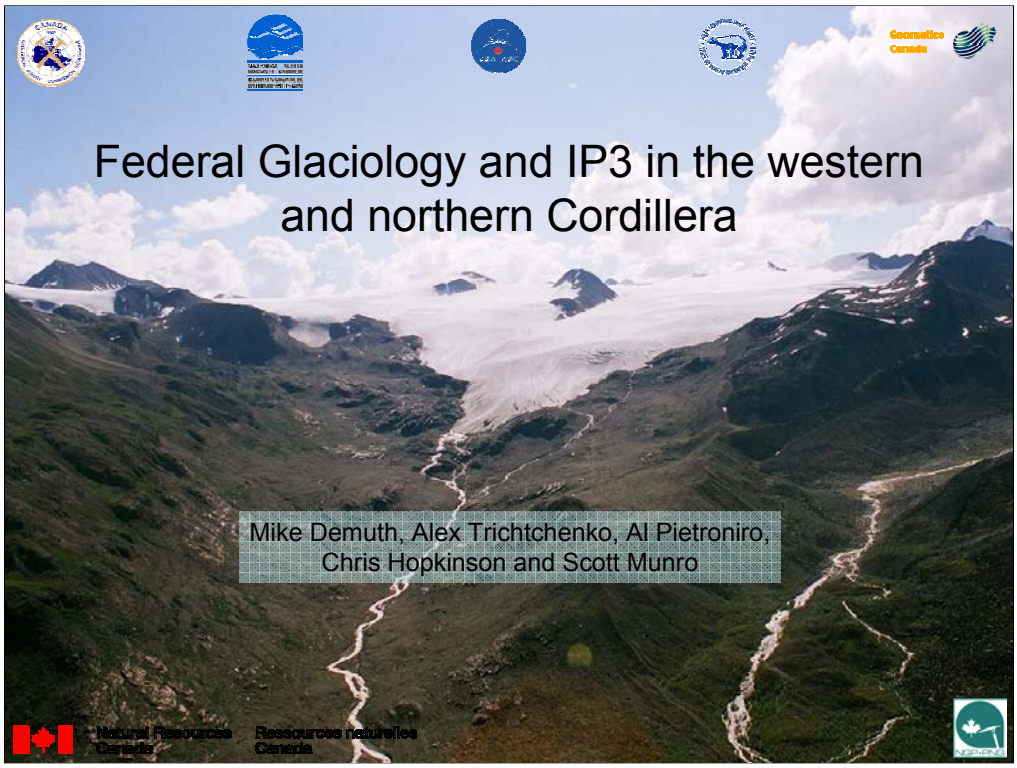
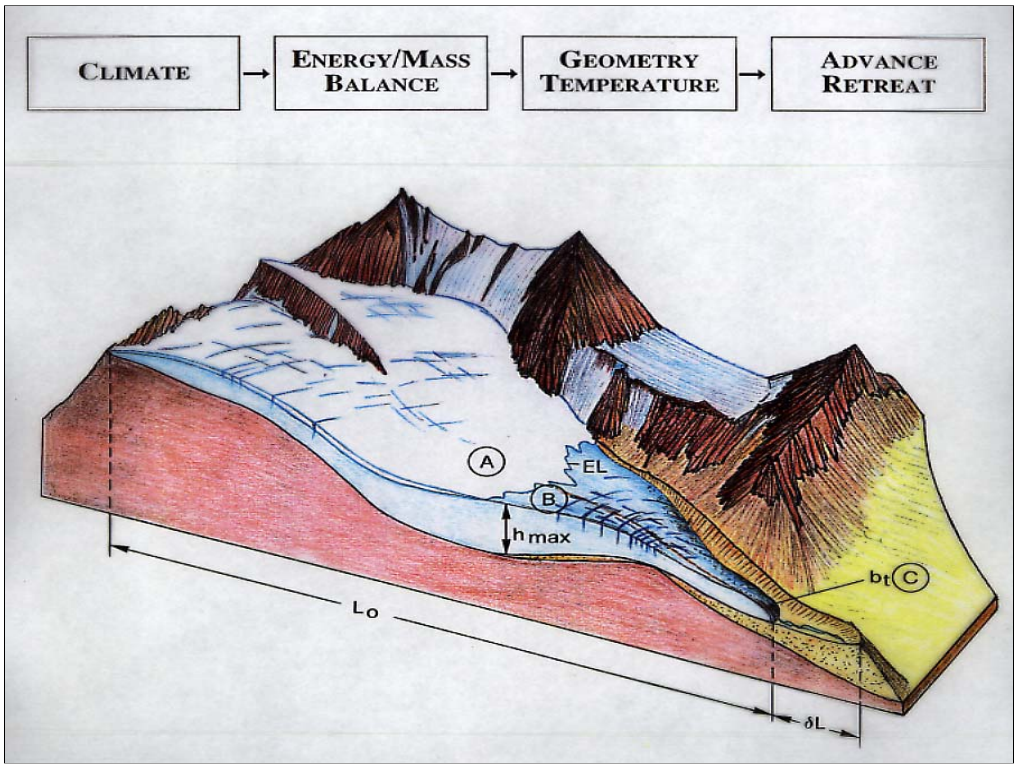

Federal Glaciology and IP3 in the western and northern Cordillera
Mike Demuth, Alex Trichtchenko, Al Pietroniro, Chris Hopkinson and Scott Munro
Natural Resources Canada
Ressources naturelles Canada

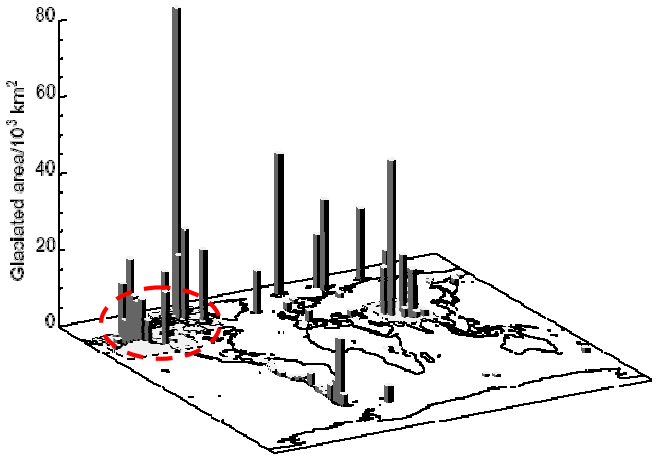


Monitoring and assessing the Glacier-Climate system.

Using:

- seasonally resolved mass balances,
- morphostratigraphic evidence,
- remote sensing and
- advanced geodesy,

The objective being to study contemporary and secular changes in water fluxes, the influence of climate and evidence of climate change



Glacier distribution globally (excluding Ice Sheets)

Canadian Arctic Islands – c. 150,000 km^2

Coastal Mountains, Rocky Mountains and Interior Ranges = c. 50,000 km^2

Excepting the ice sheets, Canada has more glacier cover than any other nation

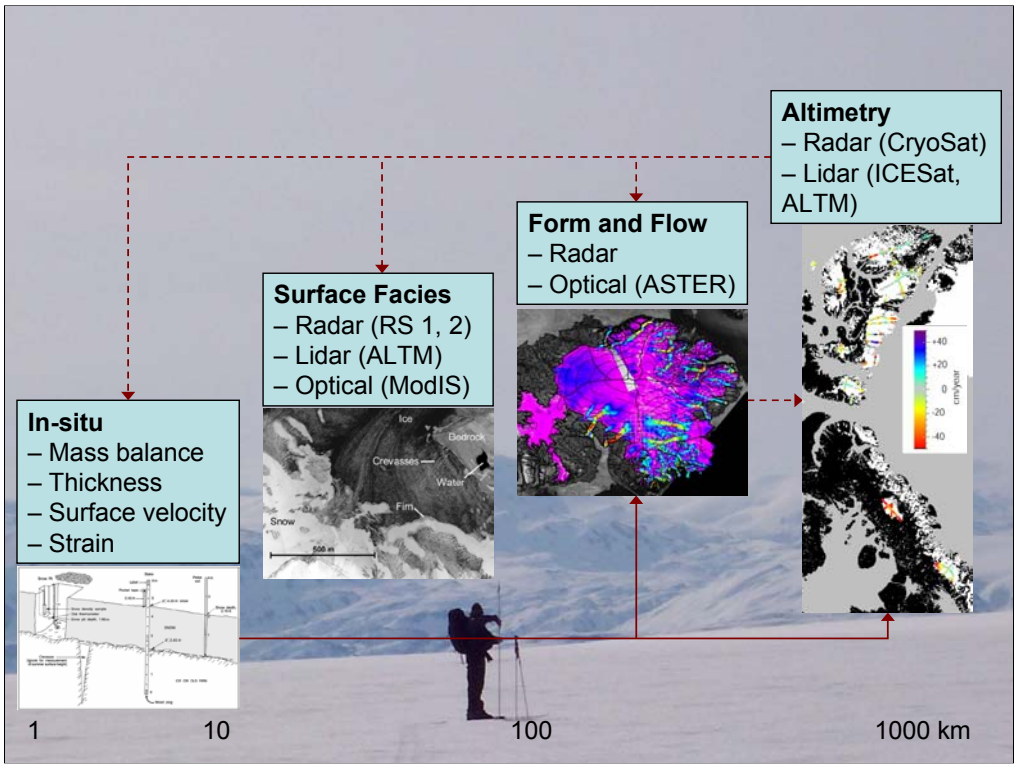
The volume that this represents, however, is poorly known

While the estimated sea level equivalent for glaciers and ice caps is but a fraction of that for the Ice Sheets, NW Pacific (N. BC, YT, AK) glacier mass wastage in the last decade put more freshwater into the ocean than did Greenland.

An inventory of Canada's glaciers is largely incomplete and current records contain only rudimentary data

There are, however, provisions for comprehensive information in the inventory methodology

… information needed to assess past changes and model future extents



How do we monitor: multi-modal, multi-scale

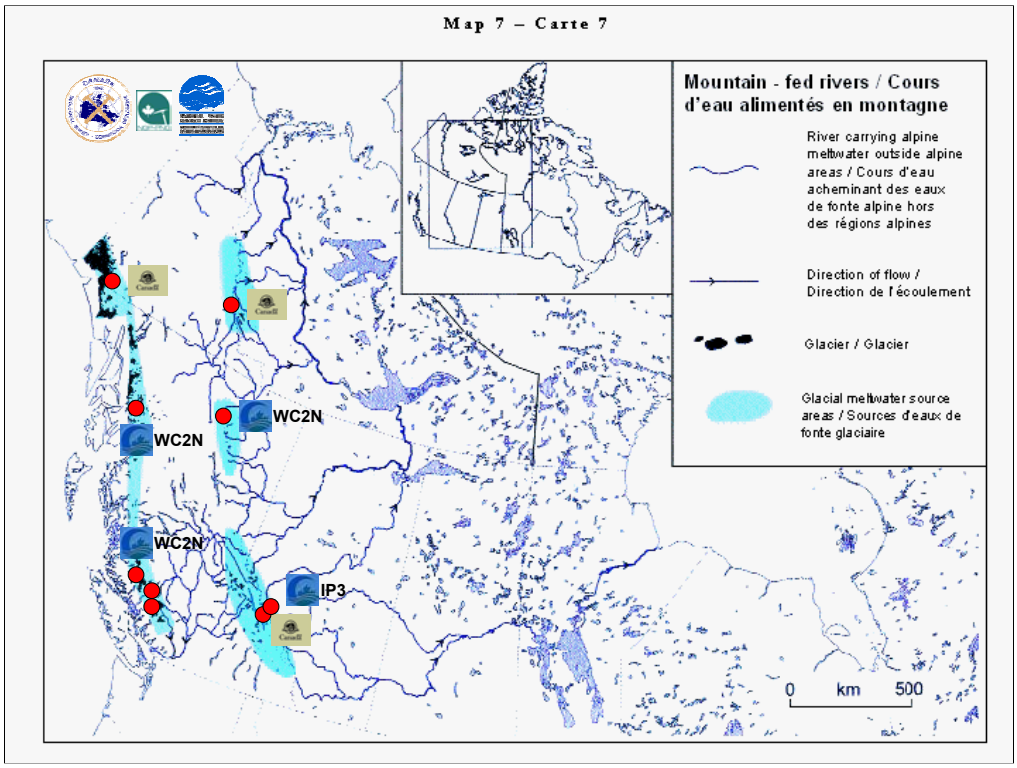
- in-situ

- theoretical up-scaling to provide regional perspectives

- RS-based strategies to provide regional perspectives

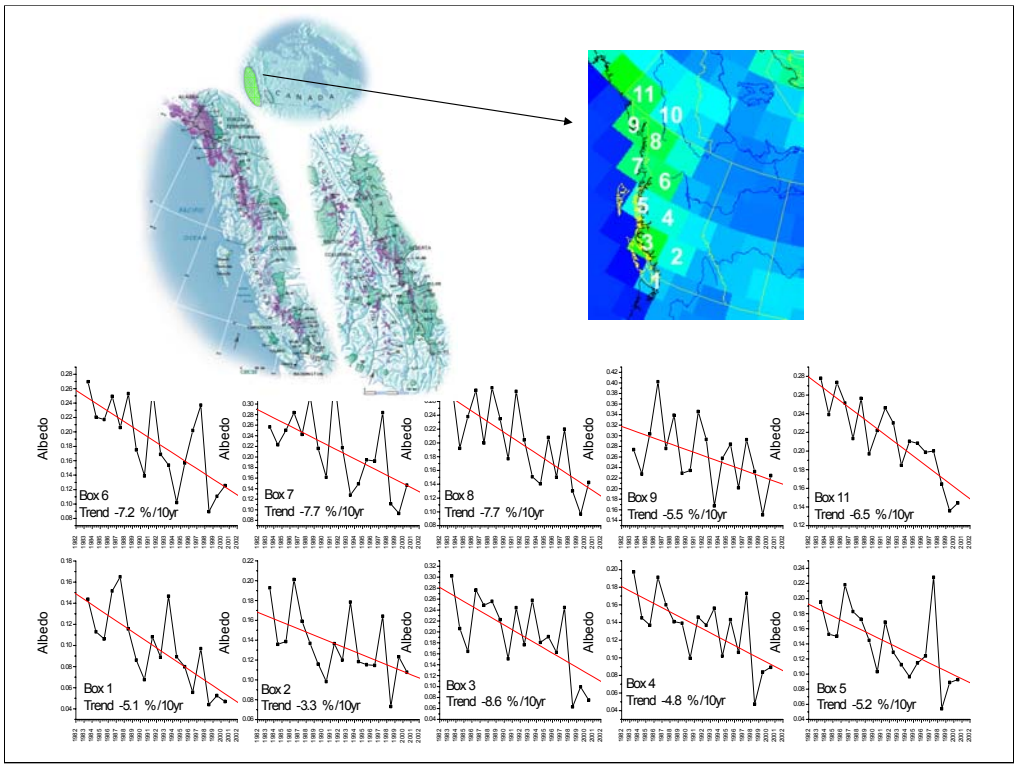
- Feed forward and feed back connecting lines indicate Strategy elements that are needed methodologically and/or for validation and interpretation

The objective being to constrain mass balance/water fluxes in relation to water resource supply/timing and Sea-Level Change, and their errors.



Where: western and northern Cordillera

Reference GSC sites + fortification with Parks Canada, CFCAS partners and component activities



Some results 1: from the Surface Facies Strategy - glacier SW albedo tracking

- A generalized reduction of SW albedo over mountains in late summer

- Data represent weekly AVHRR (1 km) preliminary results for cartesian blocks acquired at same imaging week in late summer

- Spatial and temporal noise being reduced by using a glacier mask and the interactive selection of image week (i.e. reduce bias from mixed pixels and late summer ephemeral snowfall)

- New effort using national scale, weekly MoDIS data (250 m)

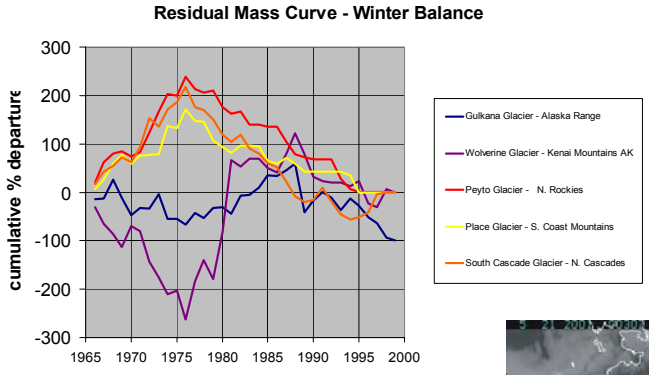
- Related to recent marked changes in the extent of perennial snow and ice

- Depletion of firn pack leads to earlier and increased exposure of glacier ice

- Hydrological significance

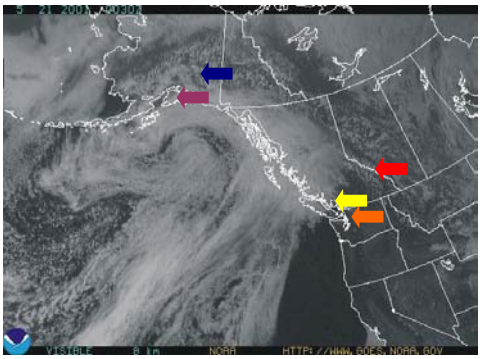
- Fuelled the rapid general retreat of glaciers observed in the Cordillera, in-part influenced by variations in winter accumulation

North versus South – PDO switch



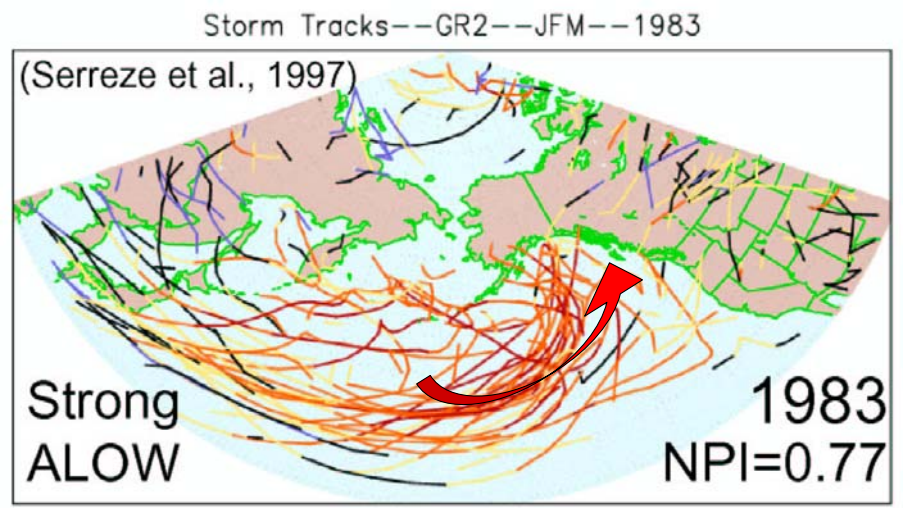
$$B_i \uparrow\downarrow = 100 \sum_{i=1}^{Ny} \left[\frac{B_i}{\langle B \rangle} - 1 \right]$$

After Demuth and Keller 2006, with additional data from USGS-Water Resources Division (R.M. Krimmel, D. Trabant, R. March)

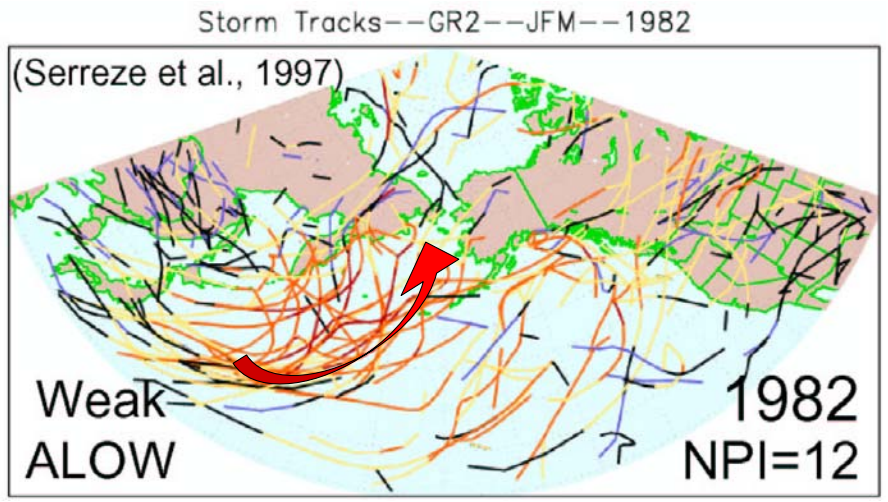


Some results 2: In-situ Strategy - variations in winter balance/accumulation

Strong (deeper) Aleutian Low : More frequent cyclone tracks steered towards Gulf of Alaska => **Increased meridional moisture advection towards Cordillera**

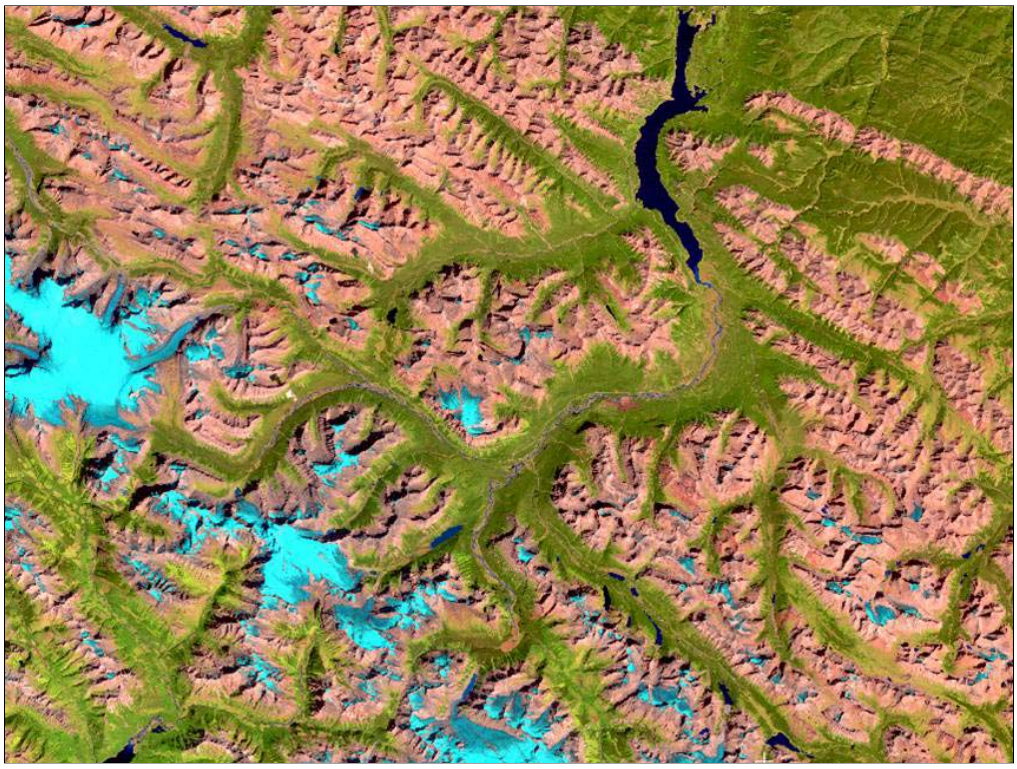


Weaker (shallower) Aleutian Low : Fewer cyclone tracks steered towards Gulf of Alaska => **Weaker meridional (i.e., more zonal) moisture transport in North Pacific**

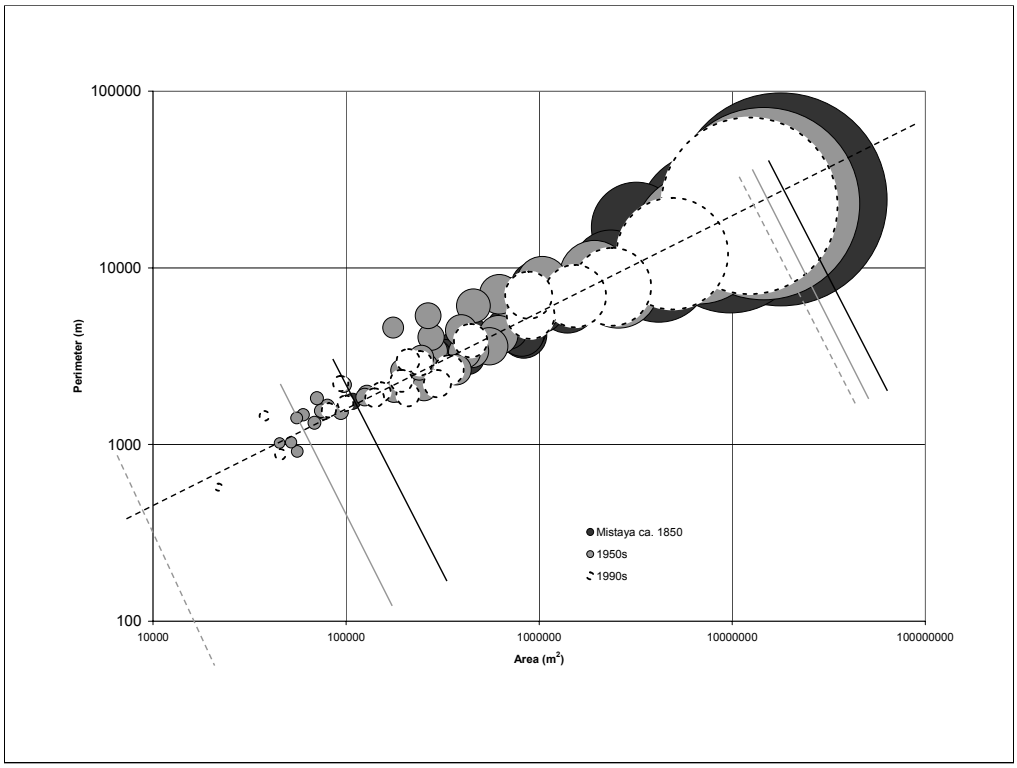


- At the 50 year to Century time scale, headwater extension tends to reduce the buffering capacity of glacier-derived melt during late Summer P-ET deficit conditions.

- This effect reported for the southern Cordillera by Demuth and Pietroniro 2003, Stahl and Moore 2006, Pietroniro et al. 2006

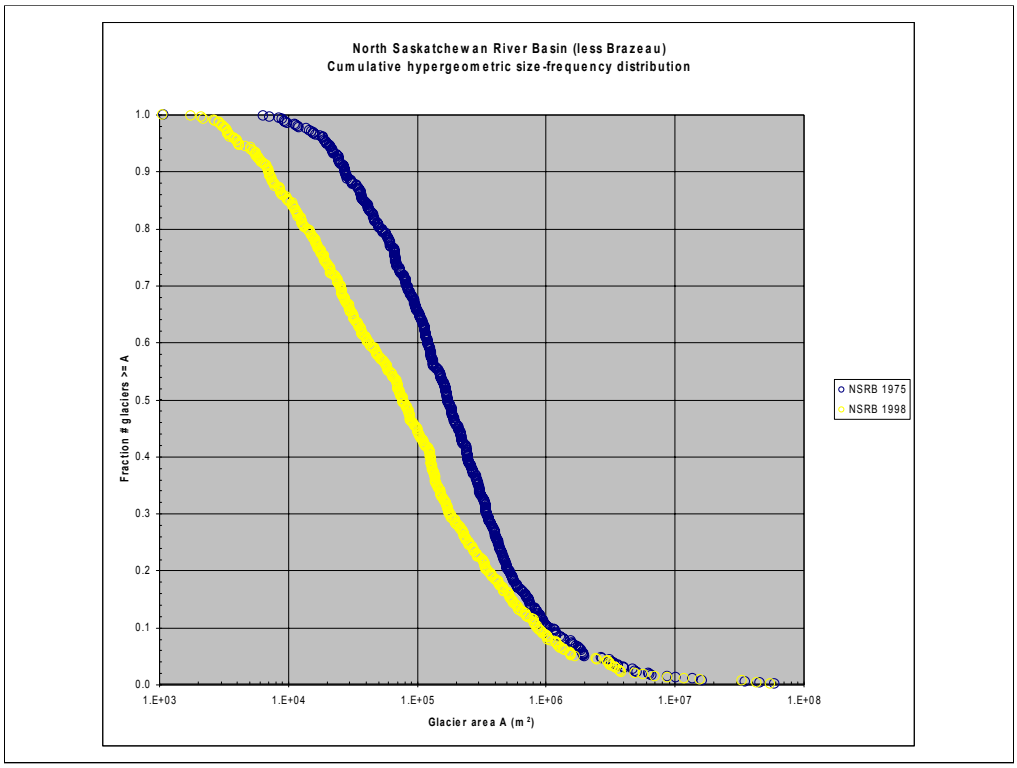


- Case Study: NSRB and Abraham Lake/Bighorn Generating Station

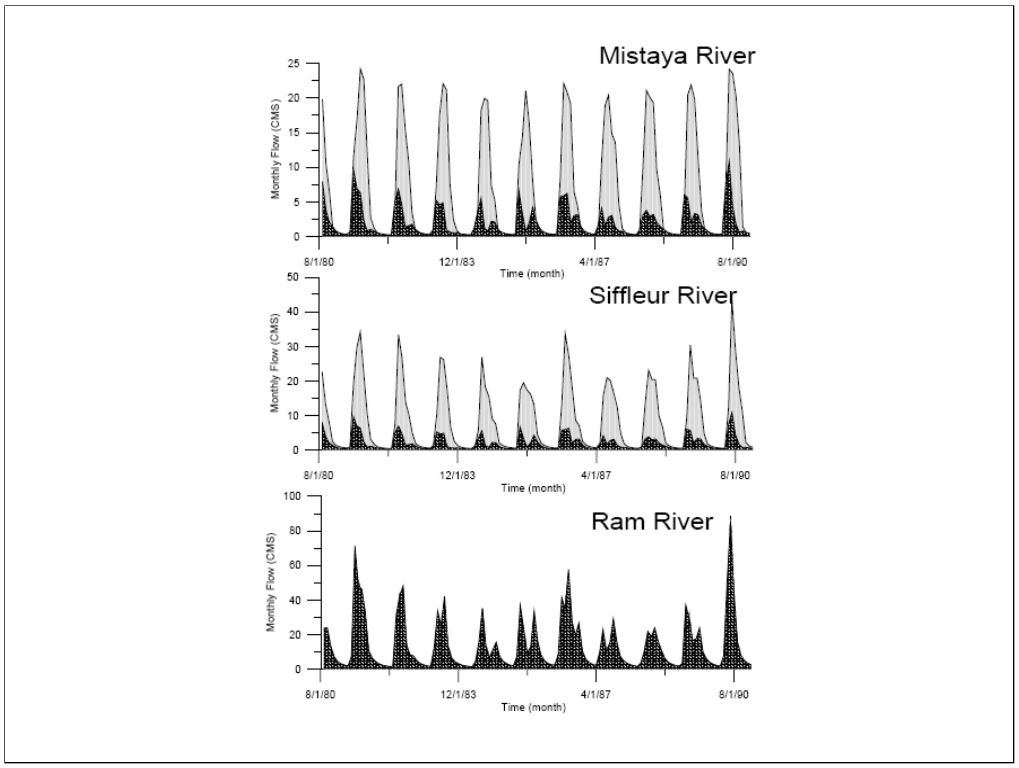


- Fiducial lines indicate trajectory of the largest and smallest (still existing in the 1990s) glacier in the sample

- Balloon size proportional to time original area



- Alternatively, change expressed as a cumulative hypergeometric size-frequency distribution



- End member – glacier cover absent (refer to Al's presentation re RS/GIS hydrological models)

#1: can we model historical flows ?

Line = model

Shade = measured

#2: glaciers absent

Glacier observing/interpretation challenges - "mass balance (*B*)" -

True/hydrological $B \neq$ reference/climatological B

- The recurrence intervals of hydrologically significant climate regime shifts are generally several times shorter than the volume-response times for most medium – large glaciers,…

… which are therefore responding to both the current climate and a diminishing series of regime shifts of varying magnitude.

- System driver trends, therefore, prevent establishing simple relationships between true/hydrological balances and the climate.

- Reference *B* is the suggested method for analyzing the response of glaciers to climate… (one holds the glacier hypsometry constant from t_0)

$$B_r = \frac{\partial A_{t_0} / \partial h \times \partial b / \partial h}{A_{t_0}}$$

- One simply determines the balance gradient

- Best accomplished using a simplified stake network for sites where elevation is the principal control on *b* (i.e. low spatial noise)

- Most, but not all, benchmark sites in the Cordillera meet this criteria

- There is evidence that mass balance time series for Canadian benchmark sites have a mix of true and reference values

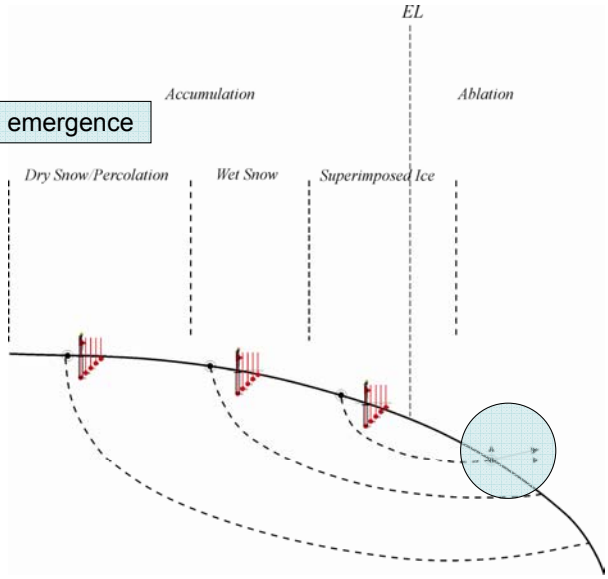
- Periodic reassessments should address the challenging problem of predicting how a glacier will respond to real changes in climate

- Thes will require a knowledge of the volume response time and reference surface mass balances applied to a long time-series of measured values that contain hydrologically significant variations

What then of measuring point values of *b* ?

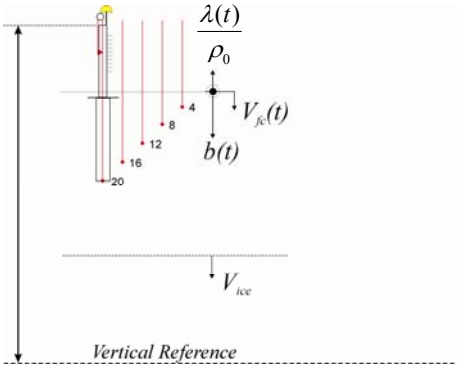
$$\frac{dh}{dt} \neq \frac{db}{dt}$$

Ablation zone – ice emergence



… with current trend of employing altimeters aboard aircraft and artificial satellites to "measure" mass balance

Accumulation zone - vertical strain, compaction

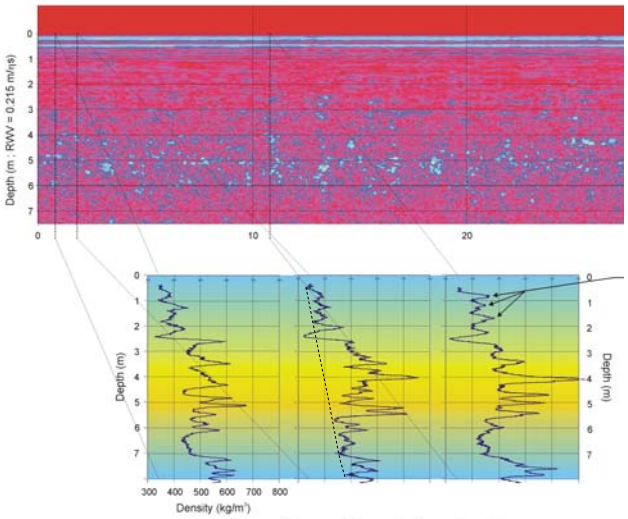


$$\frac{dh(t)}{dt} = \frac{\lambda(t)}{\rho_0} - V_{fc}(t) - b(t) - V_{ice}$$

- Changes in surface elevation measured relative to a vertical reference is related to the mass balance history only after accounting for the effects of accumulation rate, near-surface density and vertical strain history. Far field ice velocity at the F.I.T is taken as negligible compared to processes near the surface

- Vertical strain is measured with DGPS L1/L2 relative to the same reference framework used by the altimeter.

Accumulation zone – internal accumulation



Impulse Radar Record (1GHz)

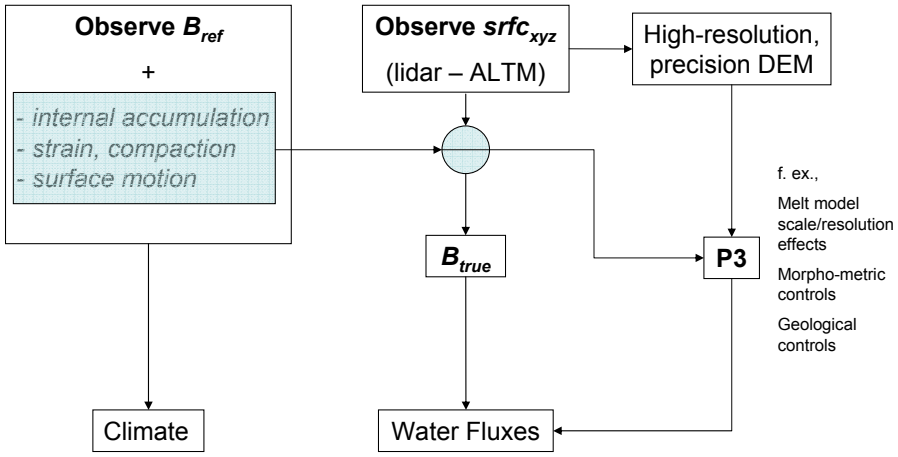
Density profiles determined from neutron-scattering logs

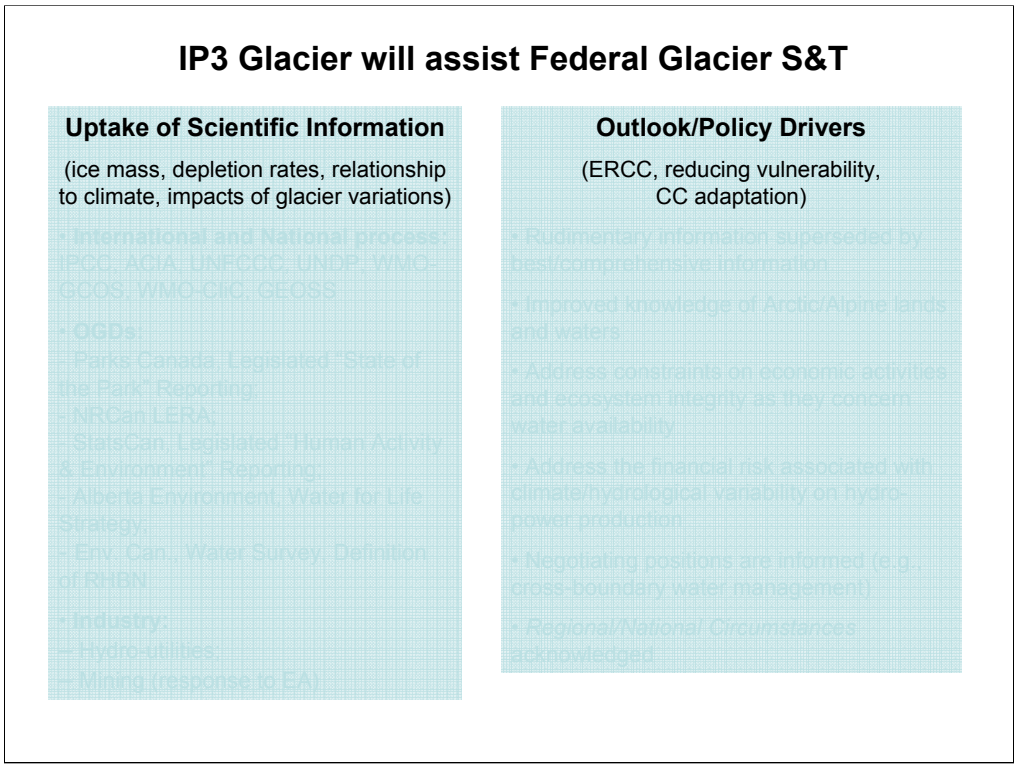
Peaks correspond to summer surfaces

*Extreme excursions correspond to ice layers and **internal accumulation** where at once an annual stratigraphic unit may not contain its original SWE, but also SWE percolating from a newer unit*

- Extreme excursions correspond to ice layers and internal accumulation, where at once an annual stratigraphic unit may not contain its original SWE, but also contain SWE percolating from a newer unit

How can meeting these challenges assist Glacier P3 outcomes ?





"ERCC" is the acronym for NRCan-ESS' current Climate Change Program – Enhancing Resilience in a Changing Climate

Uptake of Scientific Information

International and National process: IPCC, ACIA, UNFCCC, UNDP, WMO-GCOS, WMO-CliC, GEOSS

OGDs: Parks Canada, Legislated "State of the Park" Reporting; NRCan LERA; StatsCan, Legislated "Human Activity & Environment" Reporting; Alberta Environment, Water for Life Strategy; Env. Can., Water Survey, Definition of RHBN

Industry: Hydro-utilities; Mining (response to EA)

Outlook/Policy Drivers

- Rudimentary information superseded by best/comprehensive information

- Improved knowledge of Arctic/Alpine lands and waters

- Address constraints on economic activities and ecosystem integrity as they concern water availability

- Address the financial risk associated with climate/hydrological variability on hydro-power production

- Negotiating positions are informed (e.g., cross-boundary water management)

- *Regional/National Circumstances* acknowledged