Glacier response to atmospheric warming 1988–2009, northern Antarctic Peninsula

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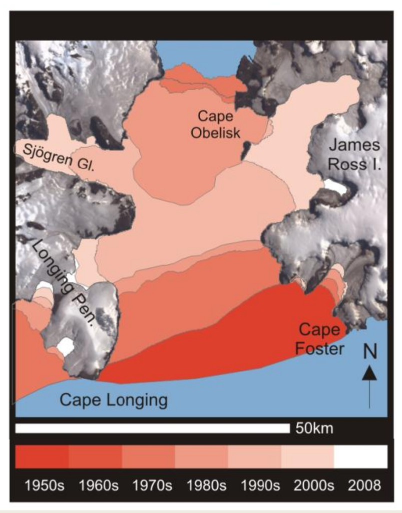
1. Rationale

- Recent rapid rise in air temperature over the Antarctic Peninsula (AP), resulting in the collapse of several major ice shelves (e.g. Larsen B and the Prince Gustav Ice Shelf). The area is therefore very sensitive to climate change. Air temperatures are predicted to continue to rise.
- Prince Gustav Ice Shelf disintegrated in 1995, resulting in the recession of feeder glaciers. Ice-shelf removal was followed by accelerated flow and recession of tributary glaciers (Glasser *et al.* 2011).
- Key Problems:
  - Need to understand future contribution of AP glaciers to sea level rise;
  - Lack of detailed glacier observations & inventories on the northern AP;
  - Long-term glacier response to ice shelf collapse is poorly understood.

Prince Gustav Ice Shelf



Retreat of the Prince Gustav Ice Shelf, which collapsed dramatically in 1995. This was followed by tidewater glacier acceleration and recession. From: Cook and Vaughan, 2010. The Cryosphere 4, 77-98.

2. Aims

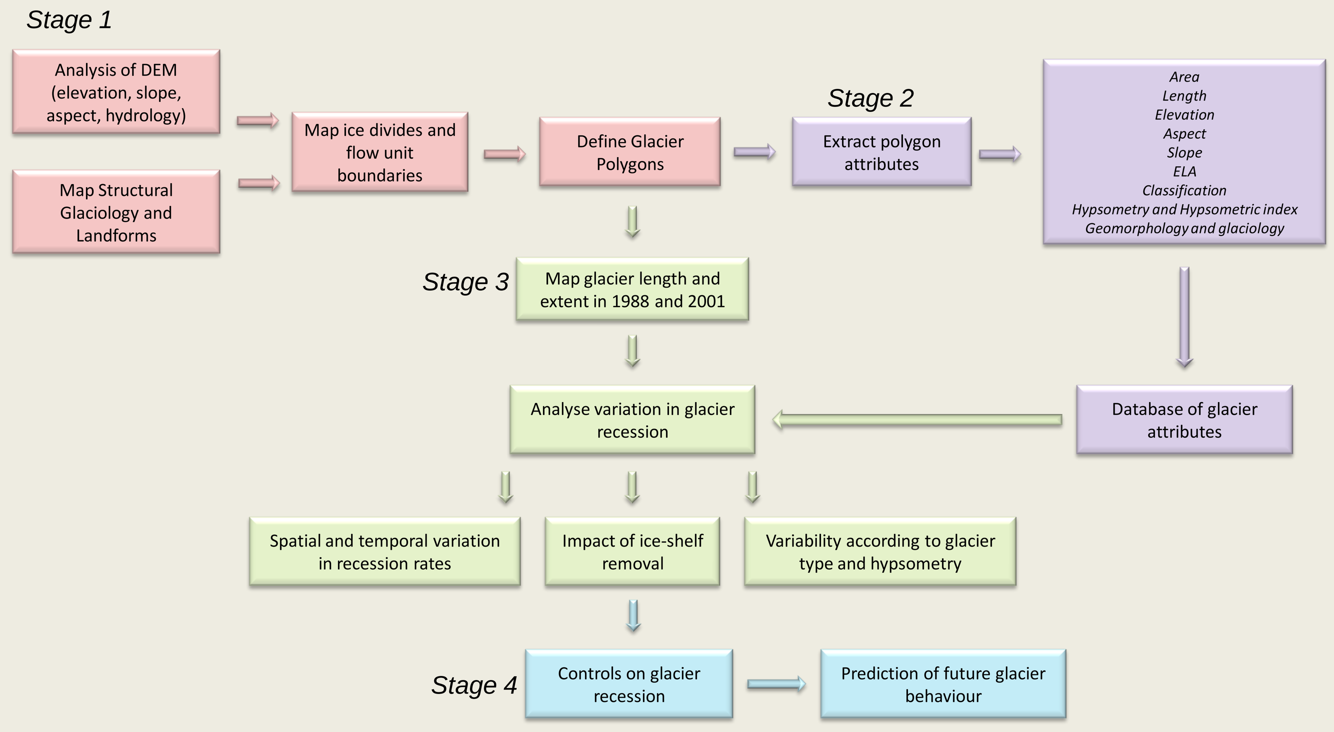
Aim: To inventory, classify and parameterise the glaciers of the northern Antarctic Peninsula.

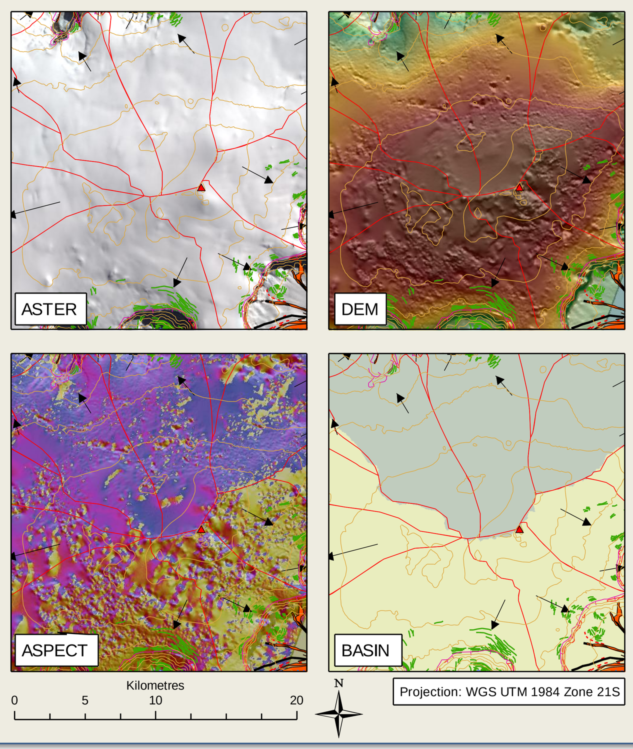
Objectives:

1. Map the *length* and *area* of each individual glacier in 1988, 1997, 2001 and 2009;
2. Identify parameters (*coordinates, elevation, slope, aspect, moraines, classification, equilibrium line altitude, hypsometry, terminal environment, tongue, geomorphology* etc).
3. Establish **rates of recession ,** analyse **spatial and temporal trends** and **controls** thereupon.

3. Methods

Data sources: ASTER images (2009 and 2001); SPOT-5 images and DEM (2006); LANDSAT 7 image (1988); BAS aerial photographs.

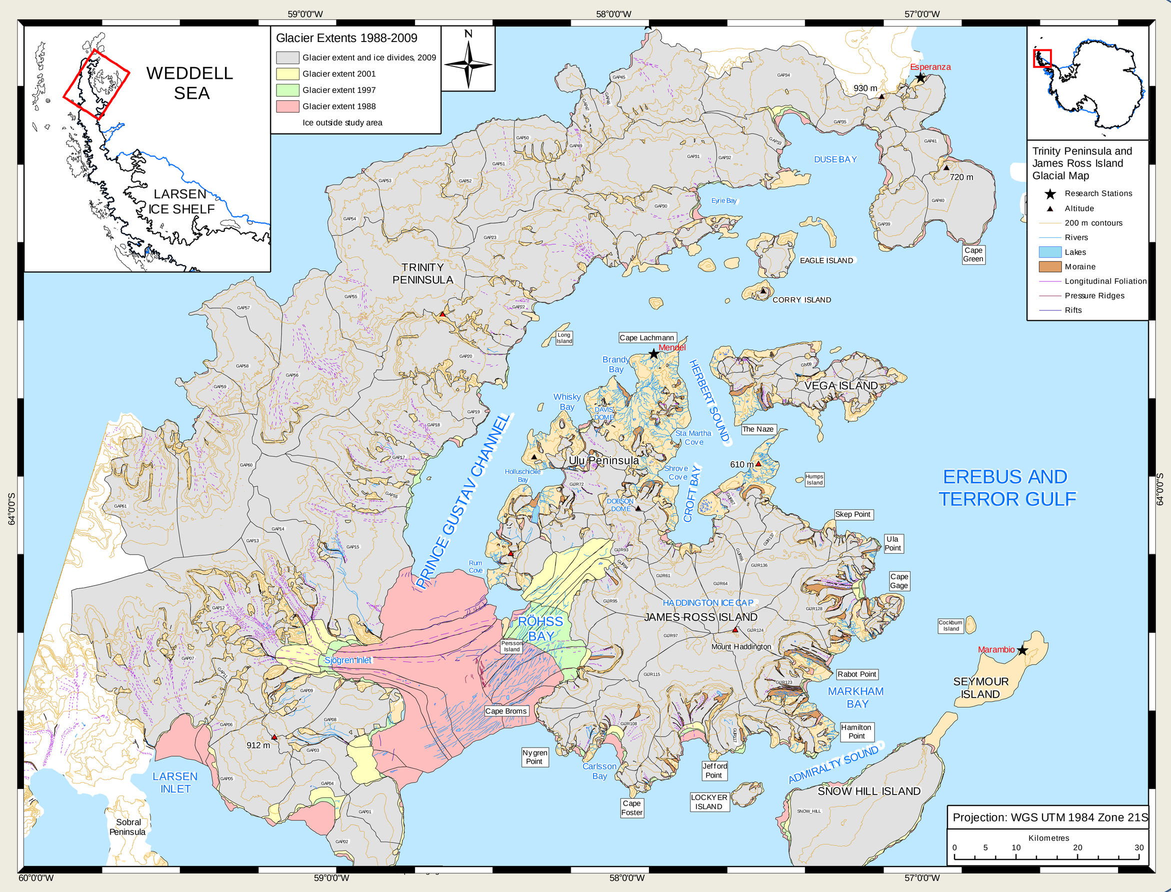




LEFT: Mapping of ice divides on Mount Haddington Ice Cap, James Ross Island.

Delineation used a combination of structural glaciological mapping, analysis of a DEM to give topographic highs and lows, models of aspect and slope and automatic drainage basin delineation using hydrological tools in ArcMap.

RIGHT: Glacial map of the study area, showing ice divides, glacier drainage basins, and glacier extents in 1988, 1997, 2001 and 2009.

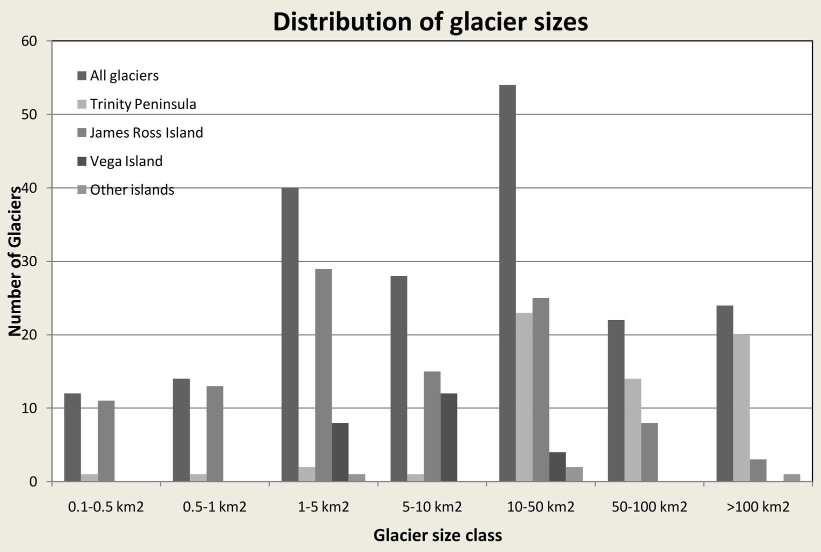


4. Glacier Inventory Results

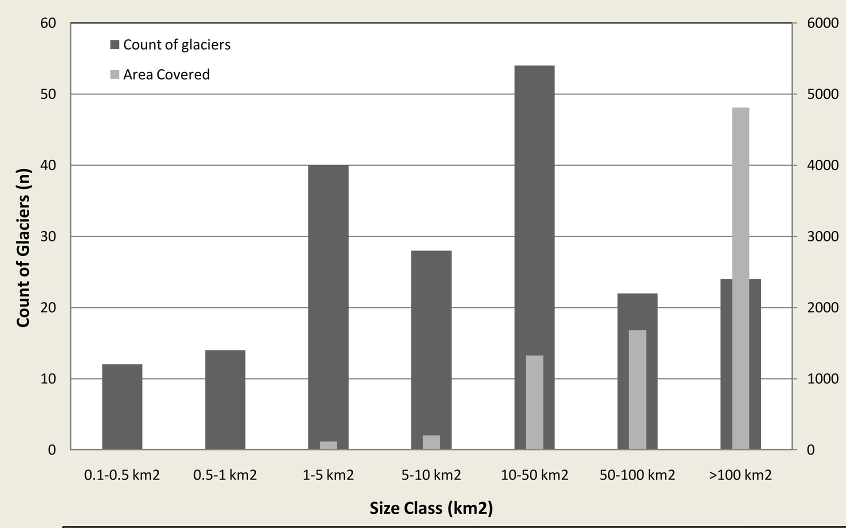
We provided important new data regarding northern Antarctic Peninsula glaciers. James Ross Island is 75 % glacierised – a 5 % reduction since the first survey in 1977 (Rabassa et al. 1982).

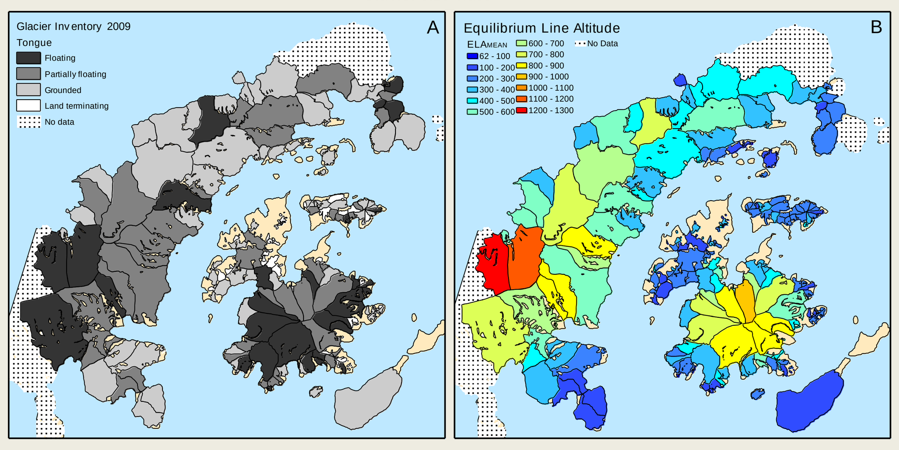
The largest glaciers occur on Trinity Peninsula, where just 20 glaciers occupy most of the glacierised area.

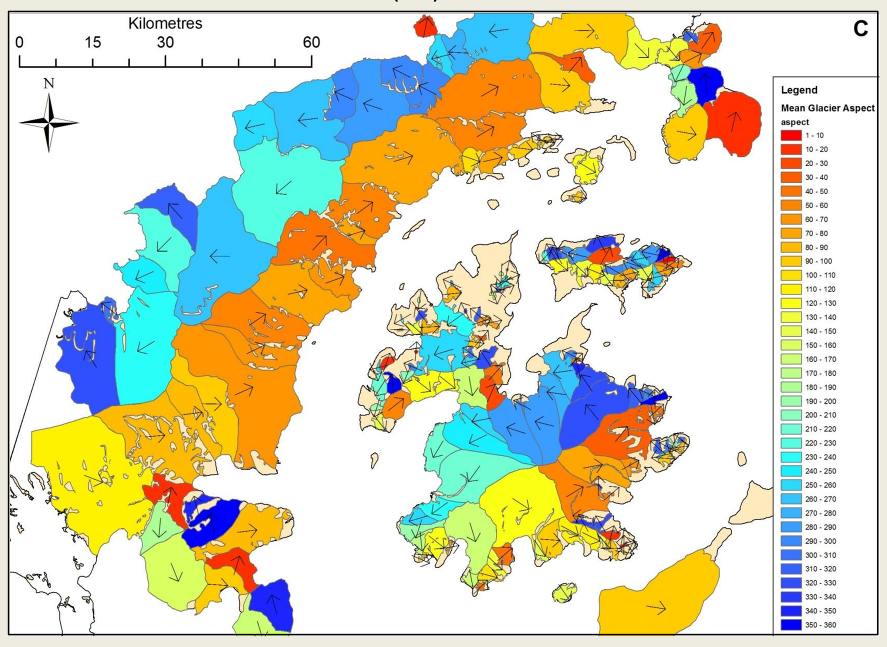
Distribution of glacier sizes



Size Classes and Area Covered



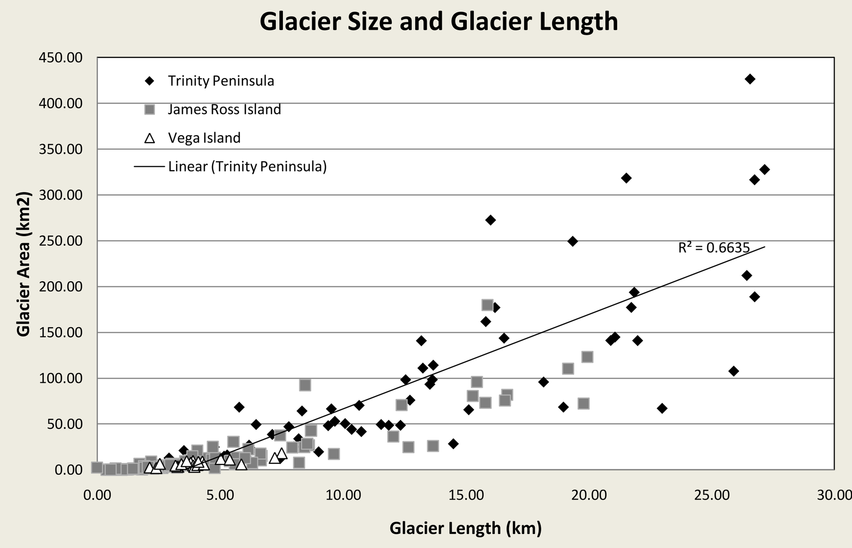




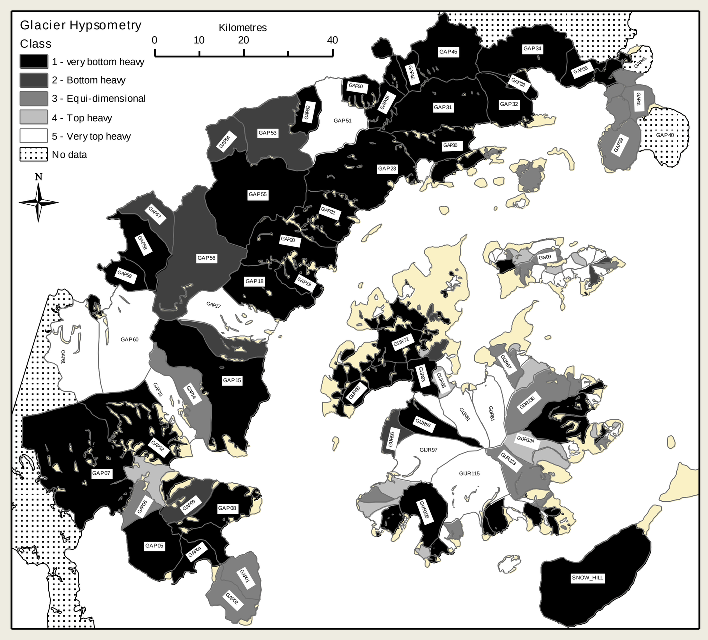
The terminal environment of a tidewater glacier (floating, grounded, or partially grounded, may be an important control on glacier recession, and is an important parameter for numerical simulations.

ELA is predicted from a number of topographic variables (AAR, toe to headwall ratio, median altitude).

Glacier Size and Glacier Length

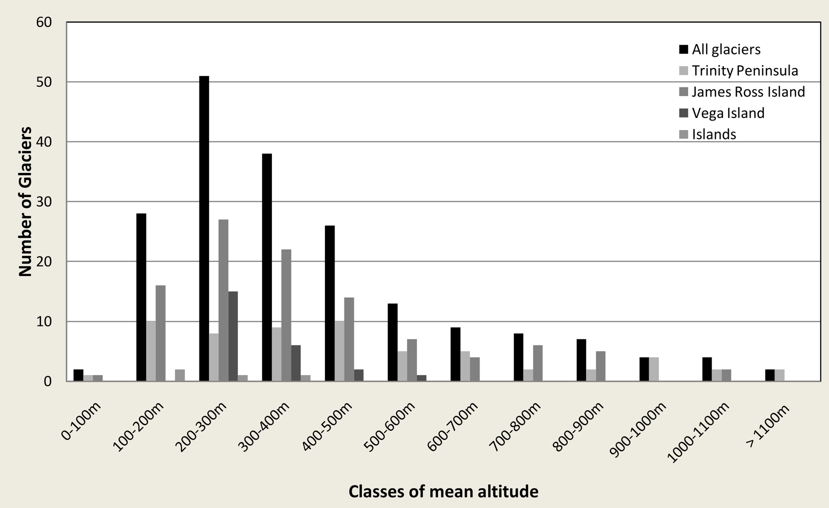


There is a good correlation between glacier size and glacier length.



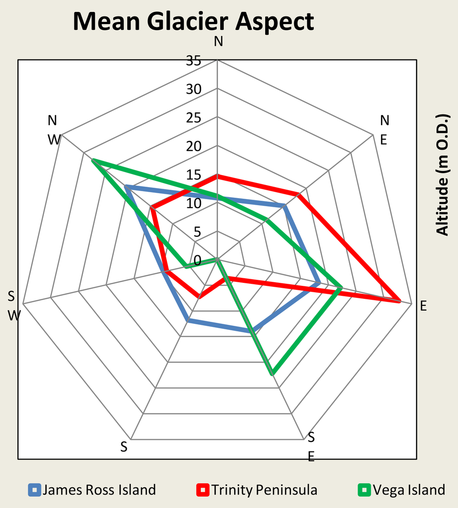
Hypsometric index of glaciers in the study region. Note considerable inter-catchment variability. Glaciers on the eastern Trinity Peninsula are largely bottom-heavy.

Mean elevation distribution

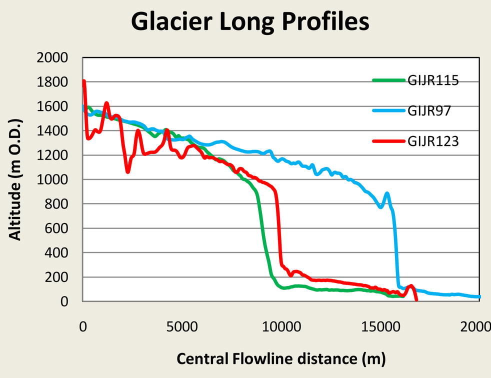


Mean Elevation is skewed towards a preferential 200-300 m.

Mean Glacier Aspect



Glacier Long Profiles



Tidewater glaciers on James Ross Island have large, low-lying floating tongues.

Glacier mean aspect

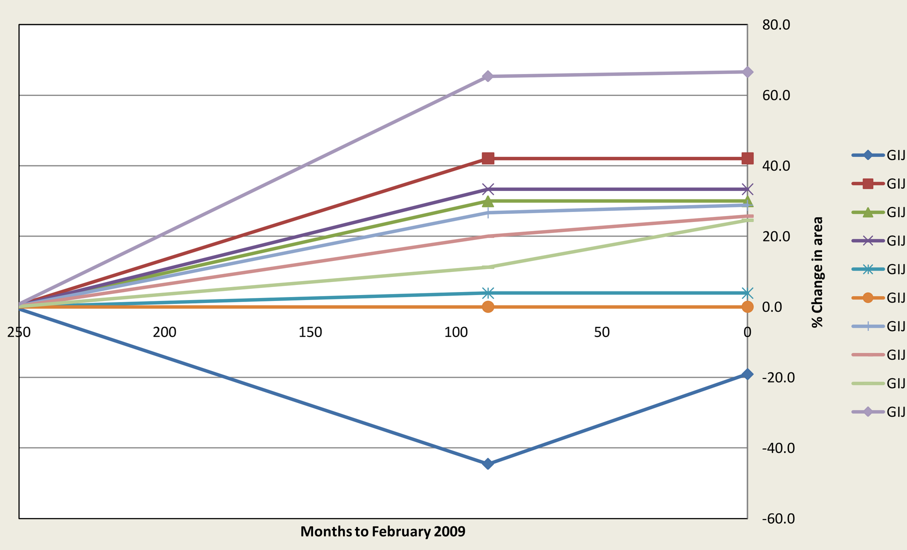
Glacier aspect is useful for modelling, particularly when used with glacier altitude. Aspect was automatically derived through decomposition of the sine and cosine values in GIS.

Glacier polygons are coloured as to their mean aspect. There is a preference for NW-facing glaciers on James Ross Island. On Trinity Peninsula, the glaciers display asymmetry over their surface area, which may be a result of solar radiation and topographic shading.

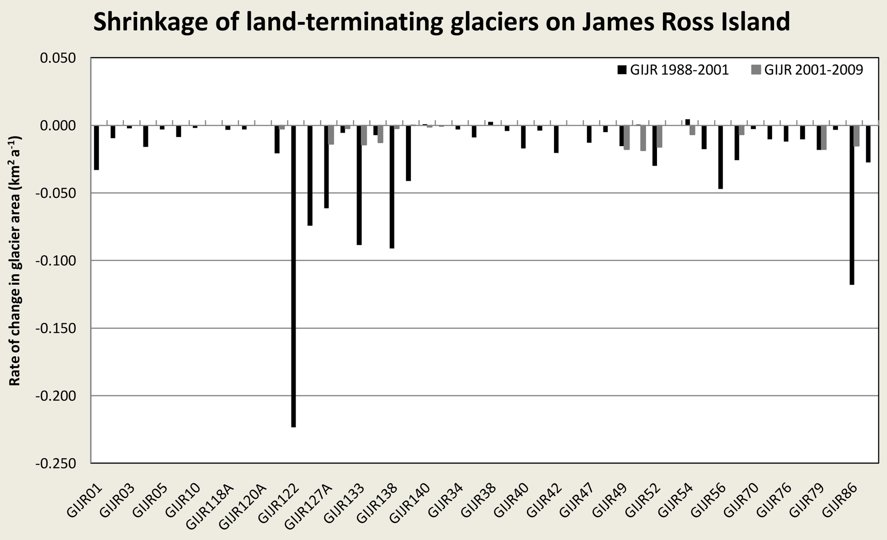
5. Analysis of Glacier Change

5.1 Land Terminating Glaciers

% Glacier change for selected land-terminating glaciers < 1 km2, James Ross Island



Shrinkage of land-terminating glaciers on James Ross Island

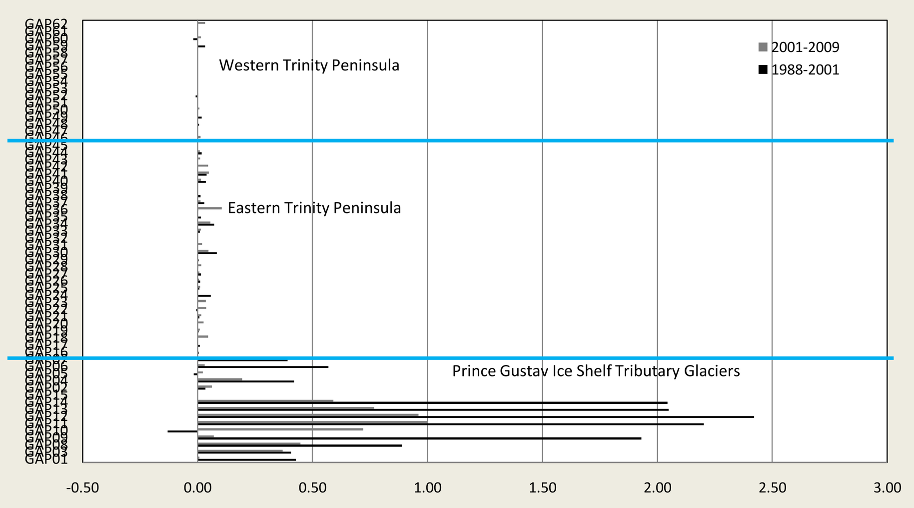


Land-terminating glaciers on James Ross Island had their most rapid annual rates of recession from 1988-2001.

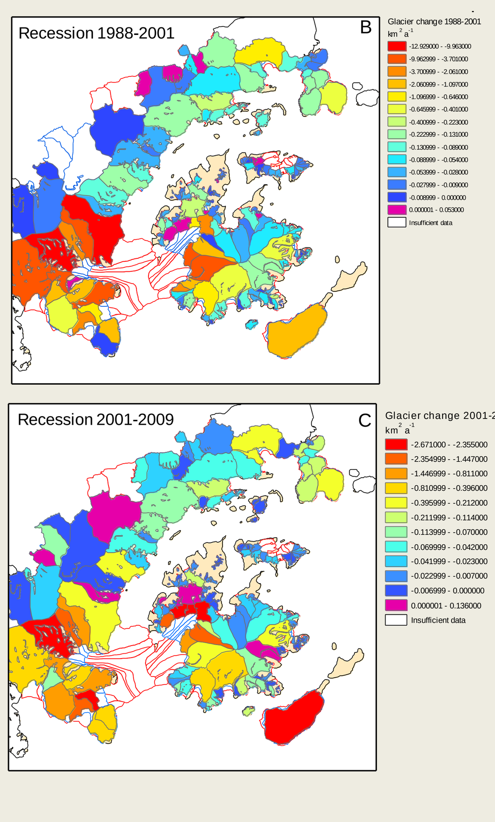
This may be due to the climatological impact of the collapse of the Prince Gustav Ice Shelf.

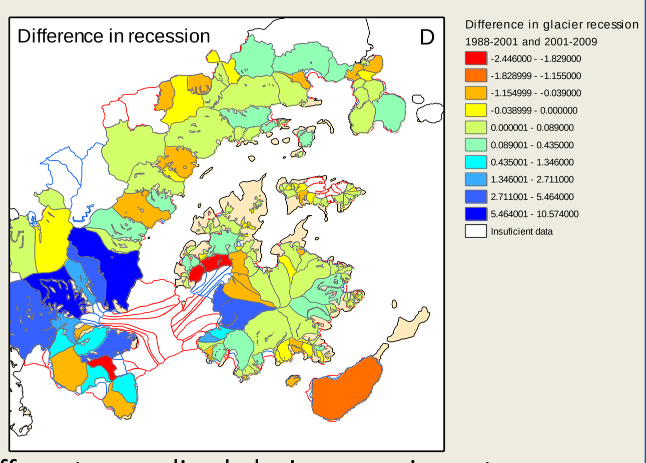
5.2 Tidewater Glaciers

Rates of glacier length change on Trinity Peninsula



5.3 Spatial and temporal trends





Different annualised glacier recession rates. Glaciers in red retreated fastest.

In Panel 'D', glaciers in blue retreated fastest 1988-2001; glaciers in red, 2001-2009.

Glaciers on the western Trinity Peninsula have had only very low recession rates. Glaciers on the eastern Trinity Peninsula generally retreated faster 2001-2009. Ice-shelf tributary glaciers retreated fastest 1988-2001.

6. Discussion and conclusions

- The Antarctic Peninsula is a zone of rapid warming, which has resulted in the collapse of the Prince Gustav Ice Shelf.
- A rise of 2°C could be reached in this region by 2040, and could result in a rise in ELA position of 204 m.
- This is the first research to document the changes in all the glaciers in the region during and after ice-shelf disintegration.
- We parameterised for the first time the characteristics of 194 glaciers.
  - 104 glaciers on James Ross Island cover 1781 km^2
  - 62 glaciers on Trinity Peninsula cover 5827 km^2
  - 24 glaciers on Vega Island cover 365 km^2
  - 4 island ice caps cover 365 km^2
- Topographic equilibrium line altitudes were calculated for the first time, but require testing against mass balance data.
- There are three eras in the study: 1988-1997 (ice-shelf collapse era); 1997-2001 (period of immediate adjustment); 2001-2009 (period of stabilisation and development of new boundary conditions).
- Almost all glaciers have retreated during the study period, but:
  - Small land-terminating glaciers retreated fastest 1988-2001;
  - Ice-shelf tributary glaciers also retreated fastest 1988-2001;
  - On the eastern Trinity Peninsula, glacier recession accelerated after 2001;
  - On the western Trinity Peninsula, there has been little glacier recession.
- We therefore conclude that:
  - Glacier recession is strongly controlled by local precipitation and temperature gradients;
  - Glacier recession on the eastern Trinity Peninsula is accelerating, probably due to rising atmospheric and sea-surface temperatures.
  - The recession of floating glaciers on eastern Trinity Peninsula may slow once these glaciers reach their grounding lines.
  - The collapse of the Prince Gustav Ice Shelf affected local climate, causing sensitive land-terminating glaciers to retreat faster 1988 to 2001;
  - Inter-catchment variability in glacier recession is controlled by hypsometry and whether the glacier tongue is floating;
  - Ice-shelf tributary glaciers initially retreated very rapidly. After 2001, they pinned in the narrow fjord mouths and reached a new dynamic equilibrium. They are likely to stabilise once they have reached their grounding lines, and will retreat in concert with the rest of the eastern peninsula.
  - The low-lying flat, glacier tongues on James Ross Island means that the tidewater cirque glaciers may retreat very rapidly if the ELA rises as a result of climate change.