Determining the spatio-temporal distribution of 20th Century Antarctic Peninsula glacier mass change

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Contents

- Background to study
- Hypotheses
- Aims and objectives
- Data and study area
- Methodology
- Results to date
- Provisional conclusions
- References and contact details

Background: Antarctica

BBC News - Esa's Cryosat

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Esa's Cryosat mission sees Antarctic ice losses double

By Jonathan Amos
Science correspondent, BBC News

Antarctica is now losing about 160 billion tonnes of ice a year to the ocean - twice as much as when the continent was last surveyed.

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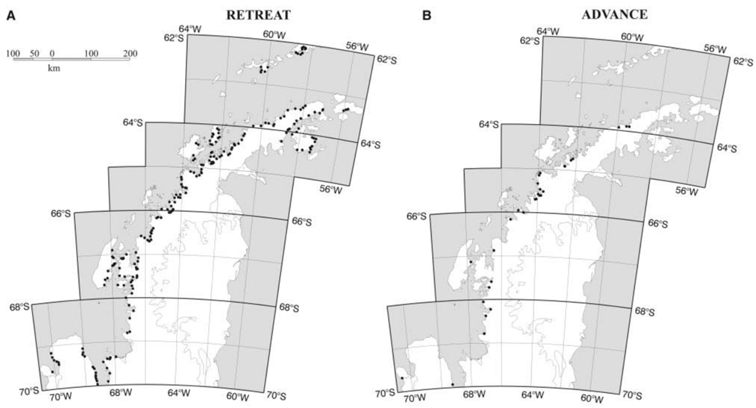
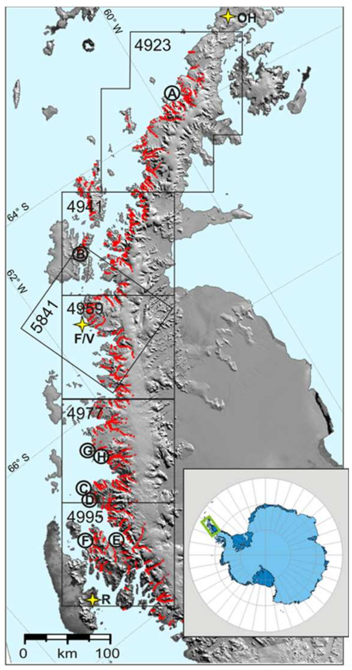
Background: Western Antarctic Peninsula



Cook et al. (2005), Science



Pritchard & Vaughan (2007), JGR

- **Temperature increase**
- **Glacier retreat and acceleration**
- **Surface lowering?**

Scientific hypotheses

- The northern, coastal AP has experienced a loss of grounded ice at lower altitudes and an increase in grounded ice at higher altitudes.
- The onset of this ice loss began in recent decades, first in the north and west of the region, then spreading and accelerating at the end of the 20th Century and in the early years of this century.
- The loss at lower altitudes can be primarily ascribed to increased summer ablation and run-off, due to increased summer melt, but accelerating glacier flow is also a factor. This summer ablation, which began after a cool period in the 1950s to 1960s, is partly mitigated by increased snowfall at higher altitudes.
- The ice-loss is sufficient to be comparable to other near-polar mountain systems and is a significant current contributor to global sea level rise.

Aims and objectives

- Aim
  - To unlock a multi-decadal surface elevation change record from an existing archive of more than 30,000 aerial photographs of the AP, held at BAS and USGS.
- Objectives
  - Identify spatial patterns in the regional distribution of glacier change over time for 50 benchmark glaciers
  - Identify temporal patterns within the wide-area spatial pattern, by more detailed analysis of a sub-sample of nine of the 50 glaciers;
  - Relate the trends and patterns identified to climate, marine temperature, and sea ice records to establish relationships with various forcings.

Methodology

1940s-1980s	**2000s**
• **USGS / BAS aerial photography**	• **ASTER imagery** • **BAS aerial photography** • **Lidar / LVIS / EarthWatch, etc…**

Problem of orientation between archival (USGS/BAS) & modern (ASTER/photography/lidar) data due to lack of ground control or lost calibration data

Biased measurements of change

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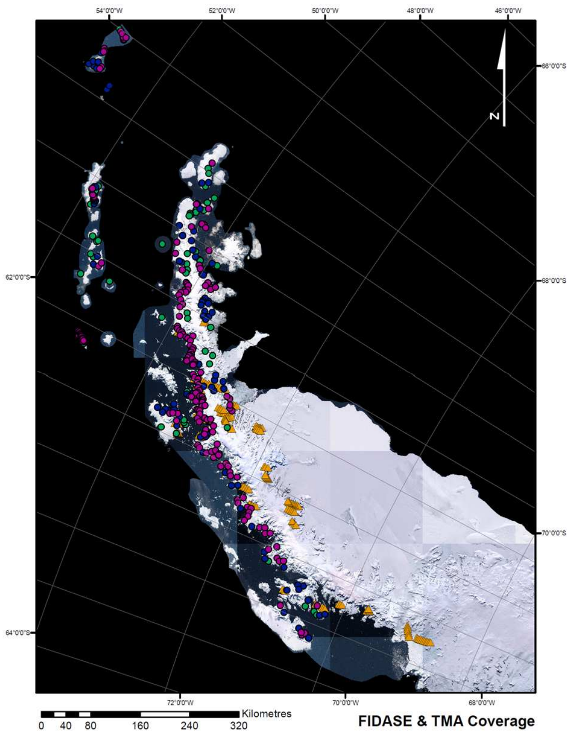
Data and study area



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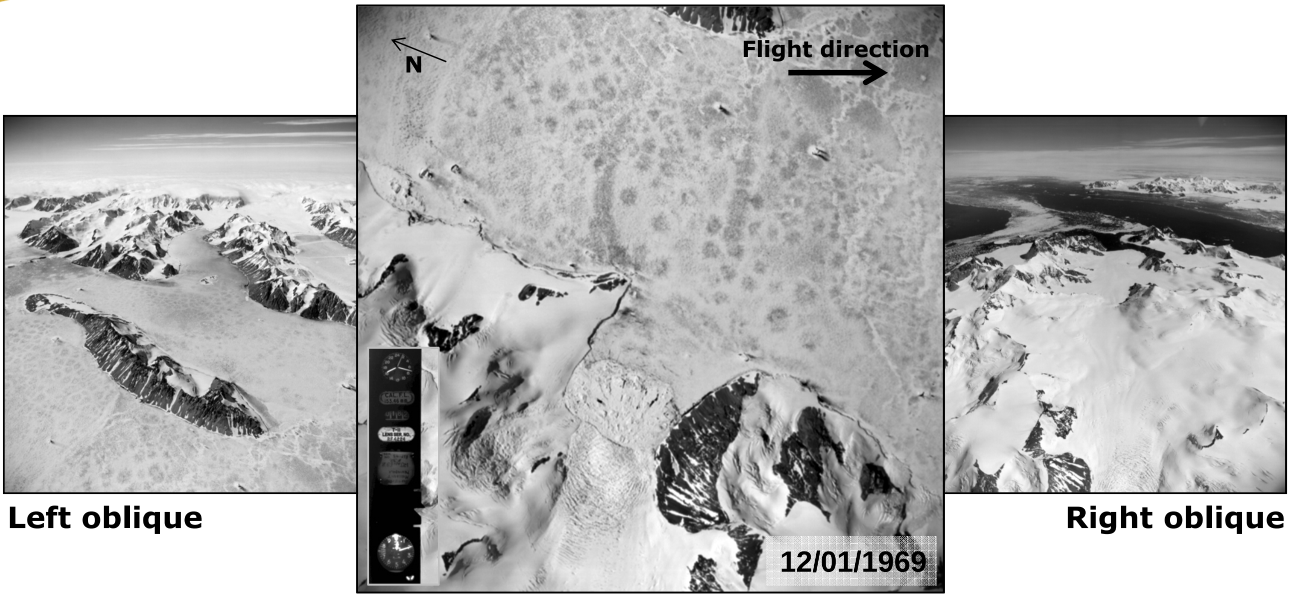
FIDASE imagery

- 1956-57 Falklands Islands Dependencies Aerial Survey Expedition

TMA imagery



Left oblique **Right oblique**

Metadata **Vertical**

Freely available at EarthExplorer.usgs.gov

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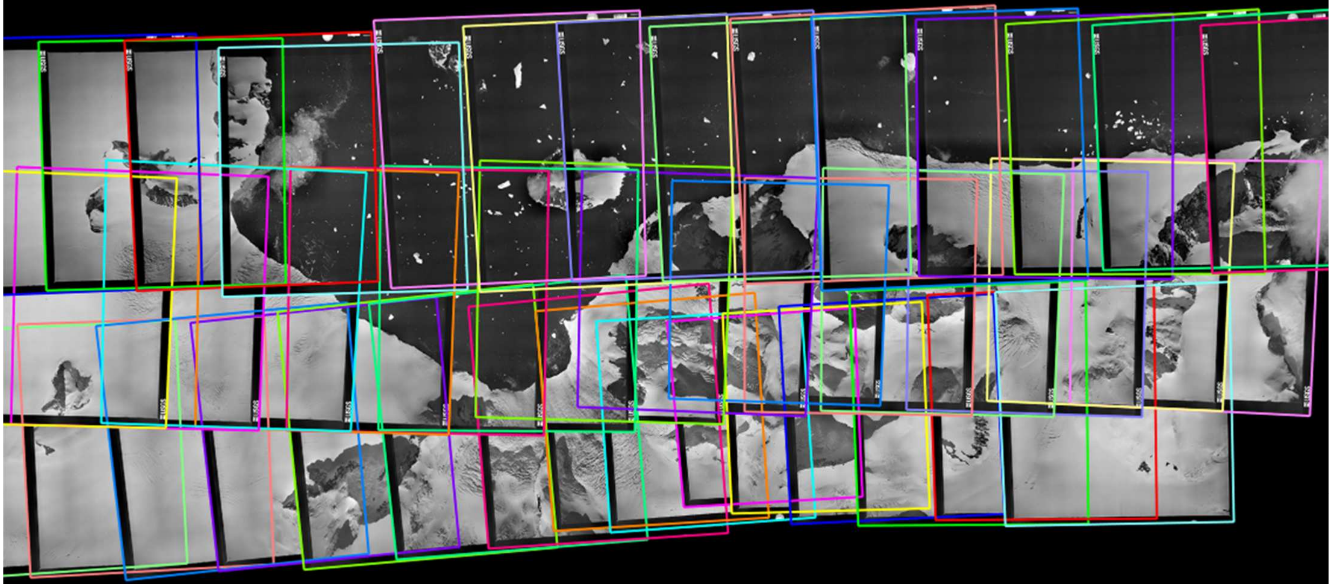
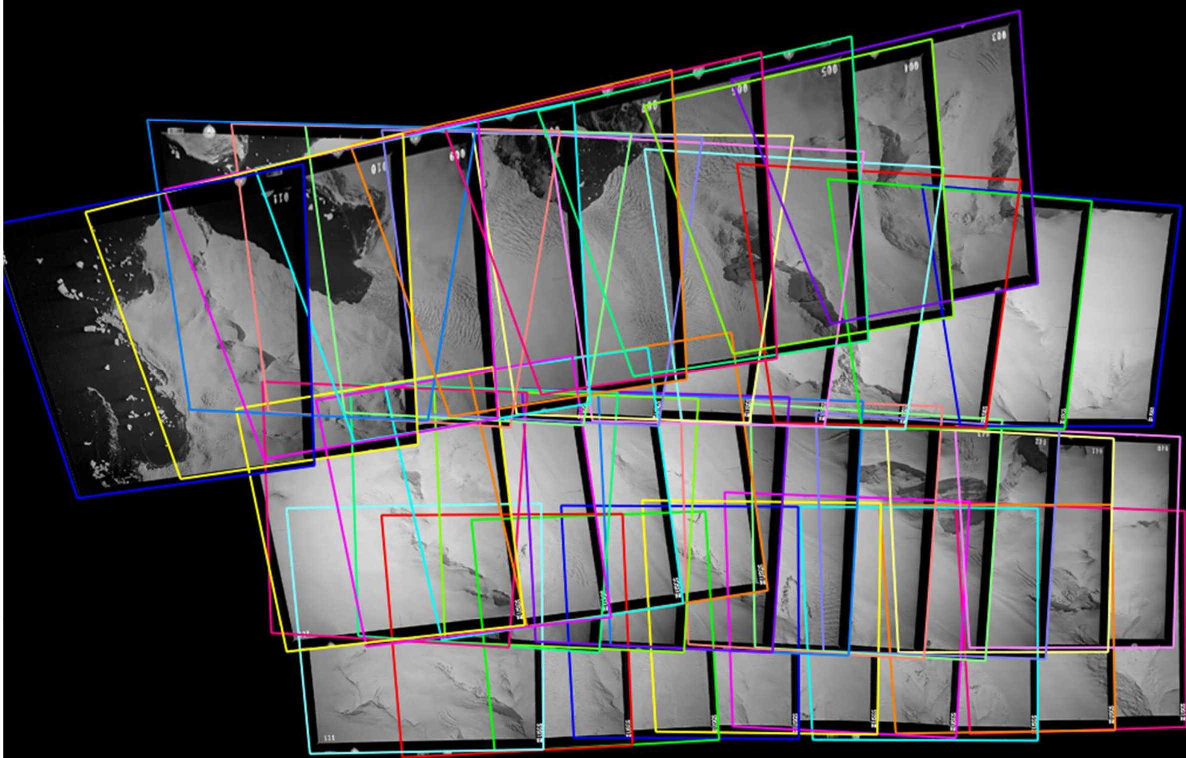
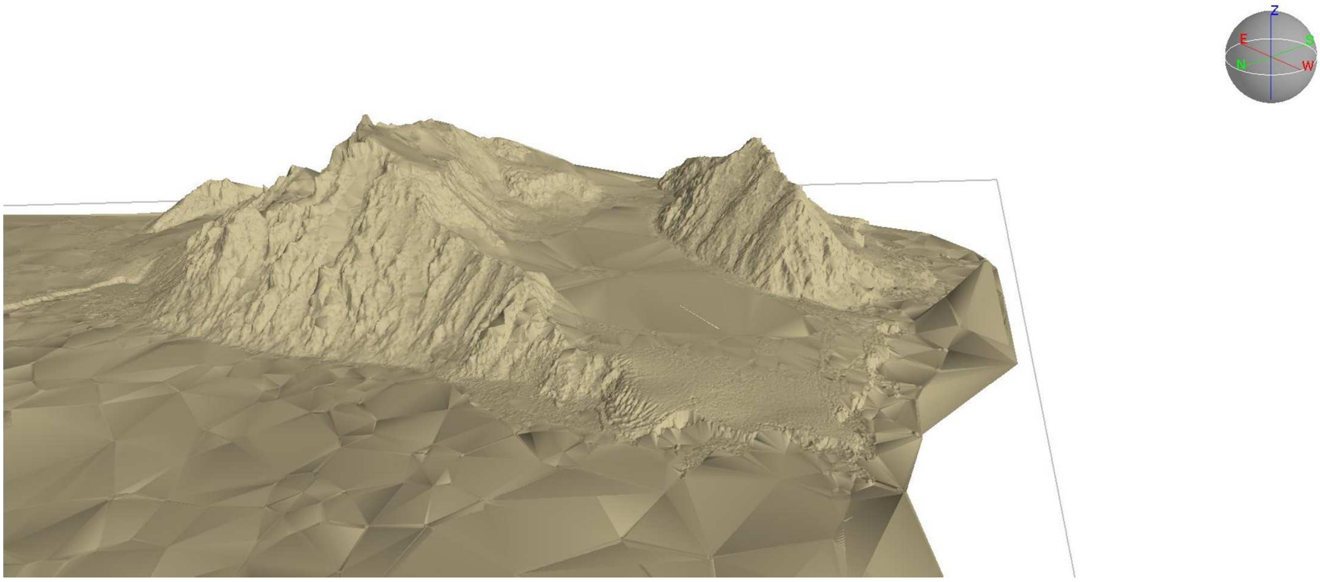
Sheldon and adjacent glaciers



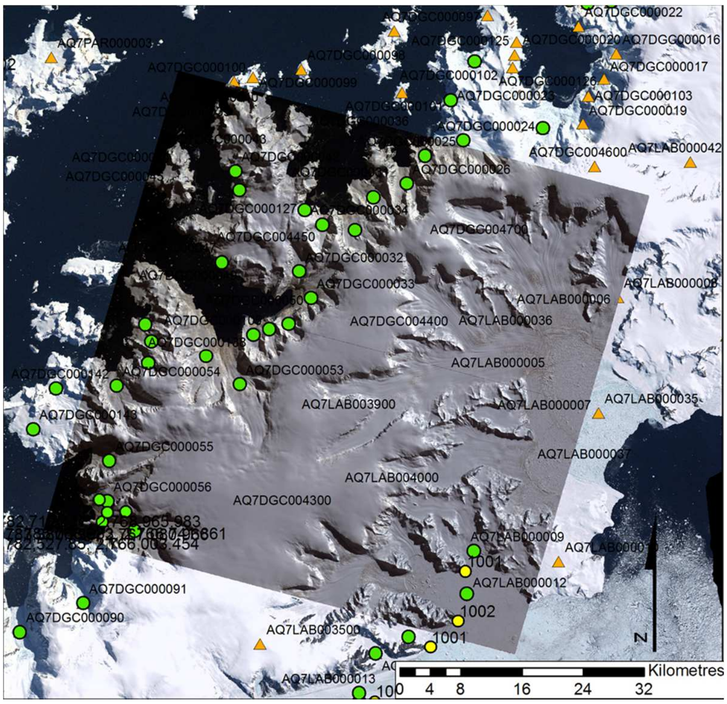
Breguet Glacier



DEM (1m TIN) from FIDASE



ASTER data



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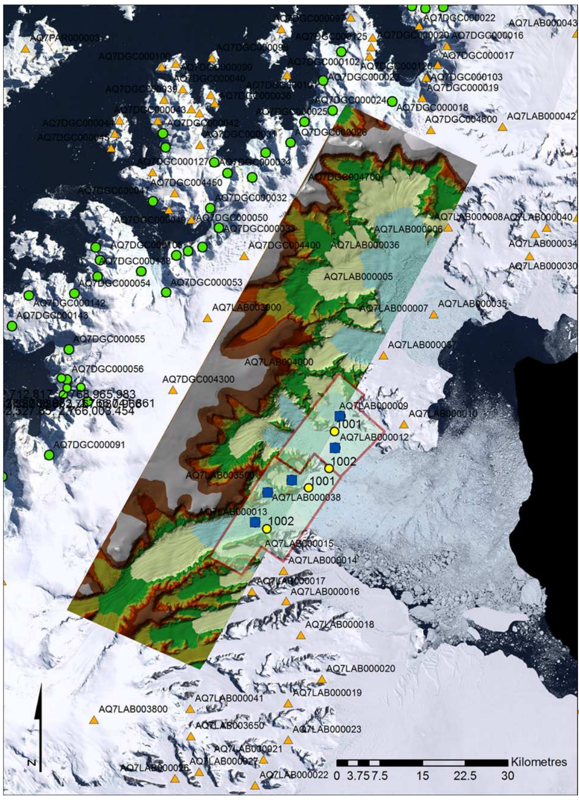
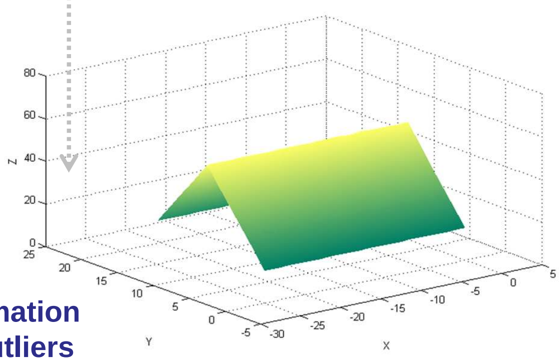
LVIS data



Workflow

DEM extraction

Robust surface matching



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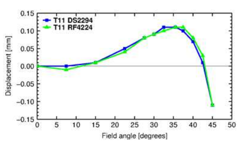
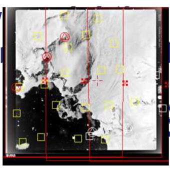


- 7 Parameter transformation
- Dow... of outliers
- Mini... Euclidean distance

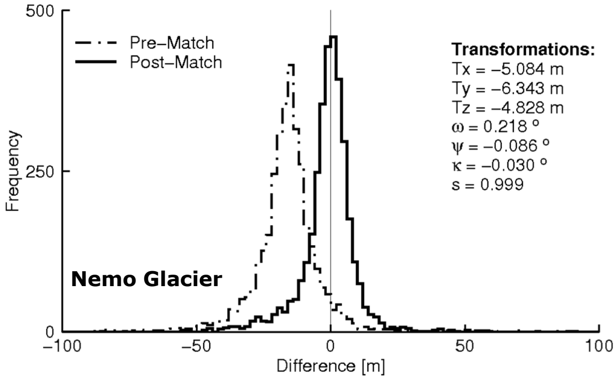


- > 25 tie-points
- Ground control extracted from ASTER DEM to initialise USGS DEM absolute orientation
- RMS 10-50 m

DEM differencing and change measurement

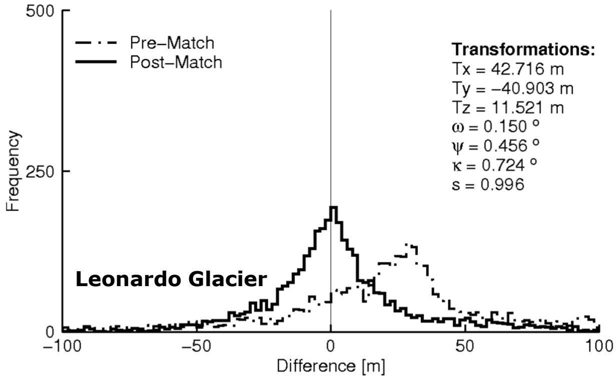
Accuracy improvement

Archival to modern aerial photography DEM



dh	Pre-Match	Post-Match
Mean (m)	-16.17	-0.99
σ (m)	13.13	10.99
RMSE (m)	22.72	14.91
Min. (m)	-89.41	-54.05
Max (m)	90.66	59.08

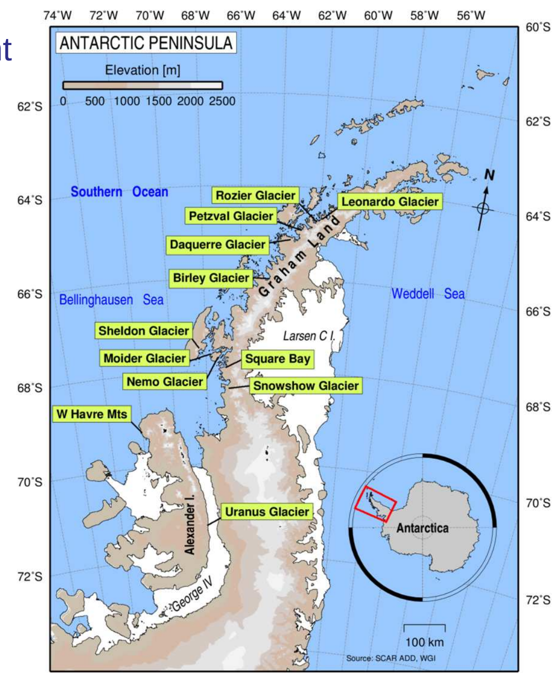
Archival photography to modern ASTER DEM



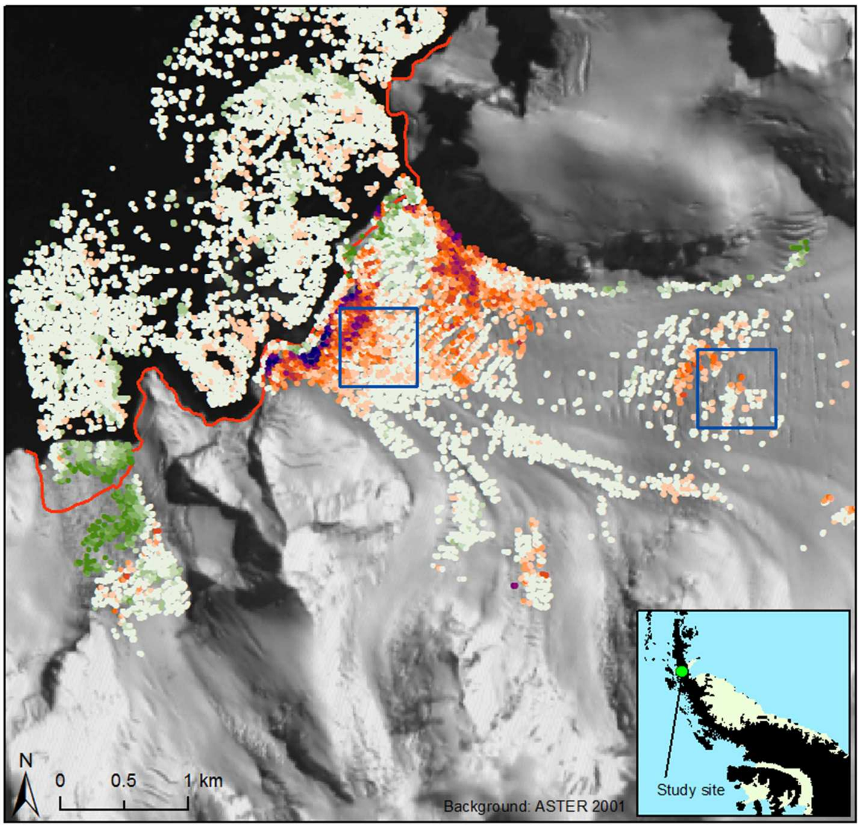
dh	Pre-Match	Post-Match
Mean (m)	17.93	0.58
σ (m)	47.94	24.87
RMSE (m)	51.18	28.63
Min. (m)	-220.71	-166.0
Max (m)	178.18	147.26

Results to date

- 12 sites with coverage of the glacier front (located between 64° S and 71° S)
- No glacier wide coverage due to widely spaced flight line pattern of historic imagery
- 38 USGS Antarctic Single Frames (min. three per site, no ground control data)
- DEMs from aerial imagery generated in BAE SOCET GXP with NGATE Module
- ASTER DEMs generated from Level 1B data in ITT ENVI with DEM Extraction Module



Leonardo Glacier



Mean rate of surface elevation change:
Lower part -0.3 m/yr
Upper part -0.2 m/yr

Note: for main glacier

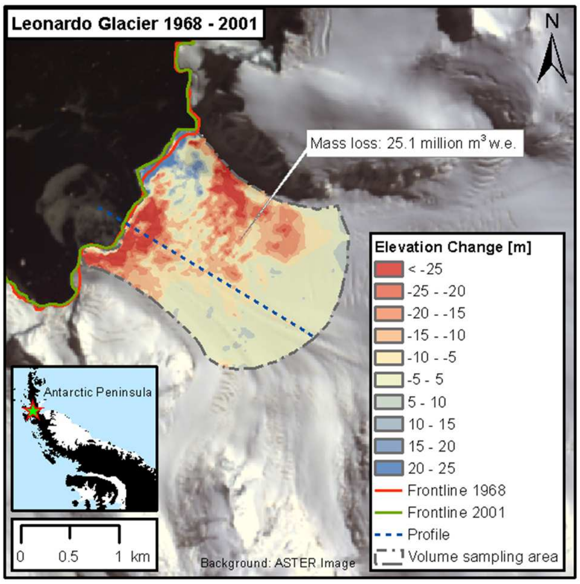
Surface elevation change [m]
30 - 35
25 - 30
20 - 25
15 - 20
10 - 15
10 - -10
-10 - -15
-15 - -20
-20 - -25
-25 - -30
-30 - -35
-35 - -40
-40 - -45
-45 - -50
-50 - -55
< -55

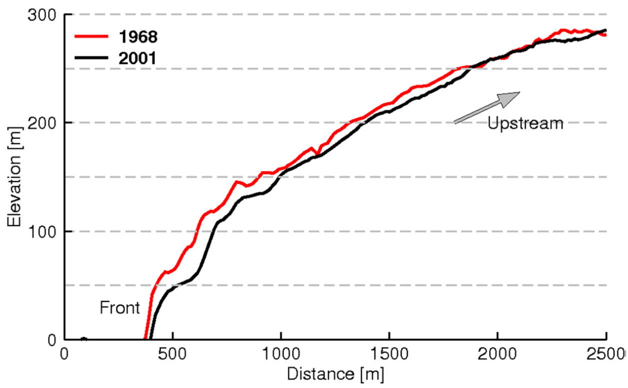
1968 Frontline

Reference:
ASTER DEM 2001

Comparison:
USGS DEM 1968 (Precision +- 16.6 m)

Glacier surface lowering





- Significant frontal lowering (up to 50 m)
- Surface thickening at advanced glacier parts
- Negative surface mass balance at glacier front
- No glacier wide mass balance

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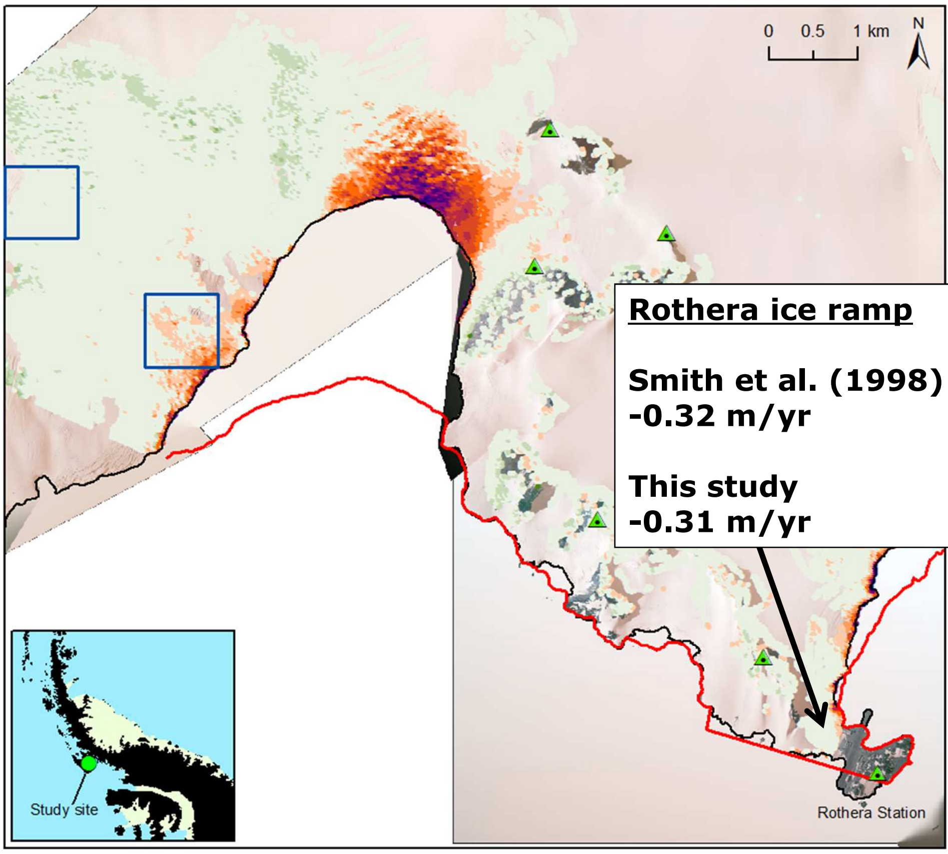
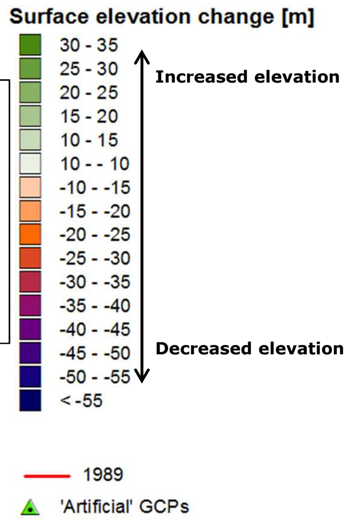
Sheldon Glacier (1989 - 2005)



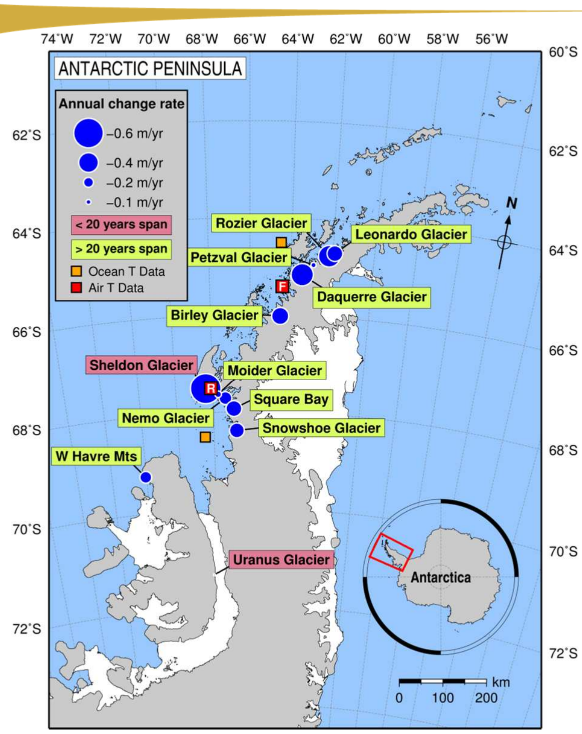
Mean rate of surface elevation change:
Lower part -0.57 m/yr
Upper part +0.20 m/yr

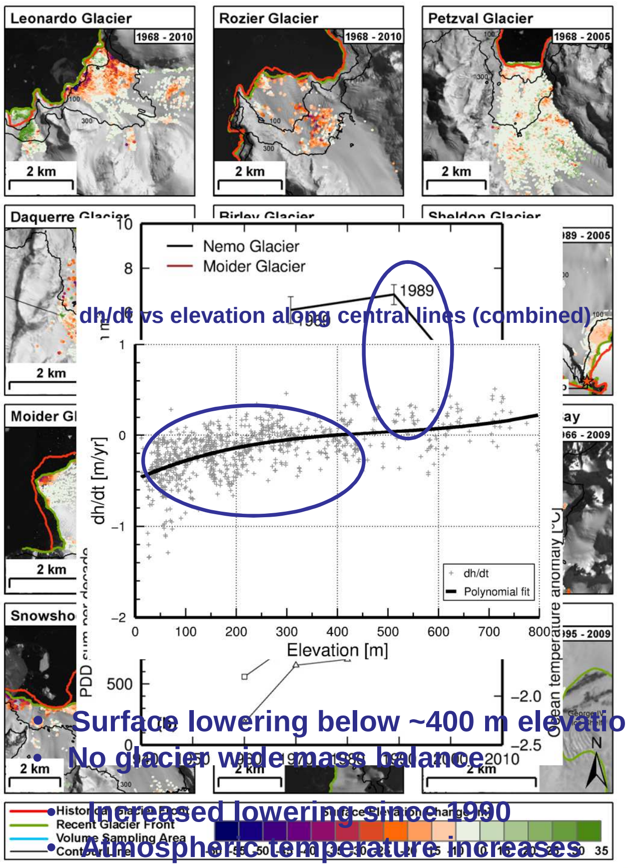


Reference/Background image:
Aerial Photography - BAS 2005

Comparison:
Aerial Photography - 1989 (Precision +- 11.8 m)

Pattern of change





- Surface lowering below ~400 m elevation
- No glacier wide mass balance
- Increased lowering since 1990
- Atmospheric temperature increases

Provisional conclusions

- Successful measurement of glacier surface elevation changes from historical USGS/BAS data and modern ASTER imagery
- Application of surface matching enables precise measurements
- Multi-decadal frontal surface lowering observed (up to ~50 m), with a mean lowering rate at glacier front of 0.28 $\pm$ 0.03 m/yr over an average period of 37 years (1969-2007)
  - Nine glaciers demonstrated frontal retreat, two advanced
- Two glaciers show increased accumulation at higher elevation, but mean response (over areas sampled) is lowering
- Increased lowering since 1990 and higher lowering rates in the northern AP in agreement with increased atmospheric temperatures

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References

Kunz, M., Mills, J. P., Miller, P. E., King, M. A., Fox, A. J. and Marsh, S., 2012. Application of surface matching for improved measurements of historic glacier volume change in the Antarctic Peninsula. *International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*, 39(B8): 579–584.

Kunz, M., King, M. A., Mills, J. P., Miller, P. E., Fox, A. J., Vaughan, D. G. and Marsh, S. H., 2012. Multi-decadal glacier surface lowering in the Antarctic Peninsula. Geophys. Res. Lett., 39, L19502, doi:10.1029/2012GL052823.

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