# Imagerie stéréo-optique haute résolution et variations de volume des glaciers.

# Pertes de masse des deux calottes les plus méridionales de l’arctique canadien entre 1952 and 2014

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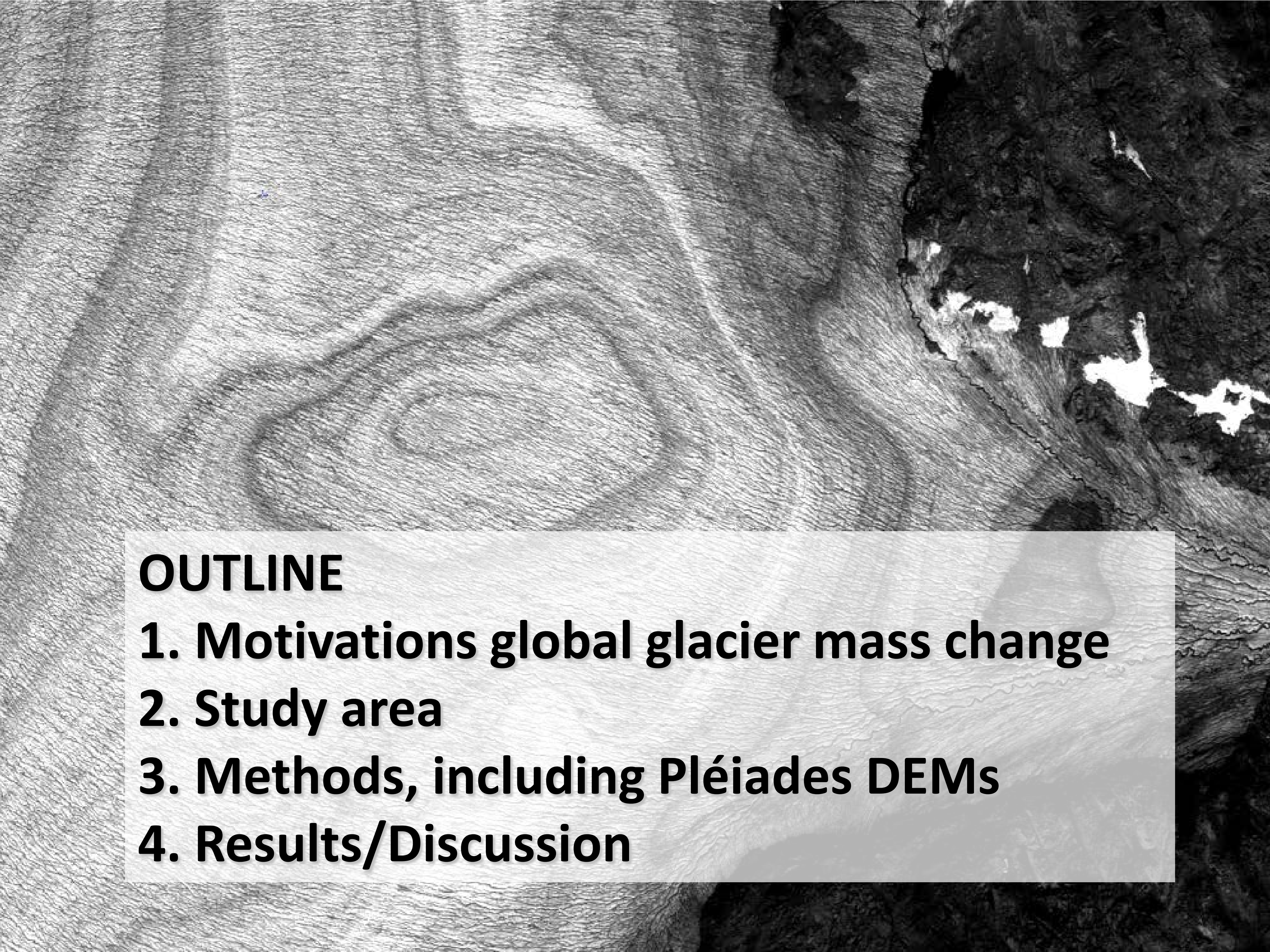
LEGOS

Observatoire Midi-Pyrénées OMP

*Terra Nivae Ice Cap (Pléiades images)*



**OUTLINE**

1. Motivations global glacier mass change
2. Study area
3. Methods, including Pléiades DEMs
4. Results/Discussion

# Motivations

- Glaciers = indicateurs climatiques

  Depuis 2 décennies, forçages anthropiques

  expliquent 70% des pertes des glaciers

  (Marzeion et al., Science, 2014)

- Glaciers = châteaux d'eau

  Forte contribution aux débit des rivières

  en régions arides (Kaser et al., PNAS, 2010)

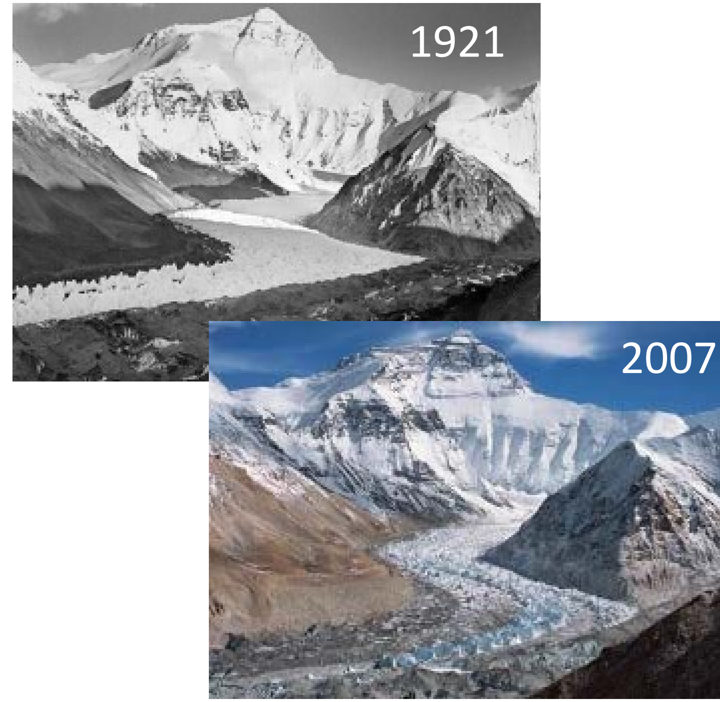
- Glaciers & niveau des mers

  0.8 mm/an SLE (Sea Level Equivalent)

  25% à 30% de la hausse actuelle

  (Gardner et al., Science, 2013)

  Contribution encore très incertaine

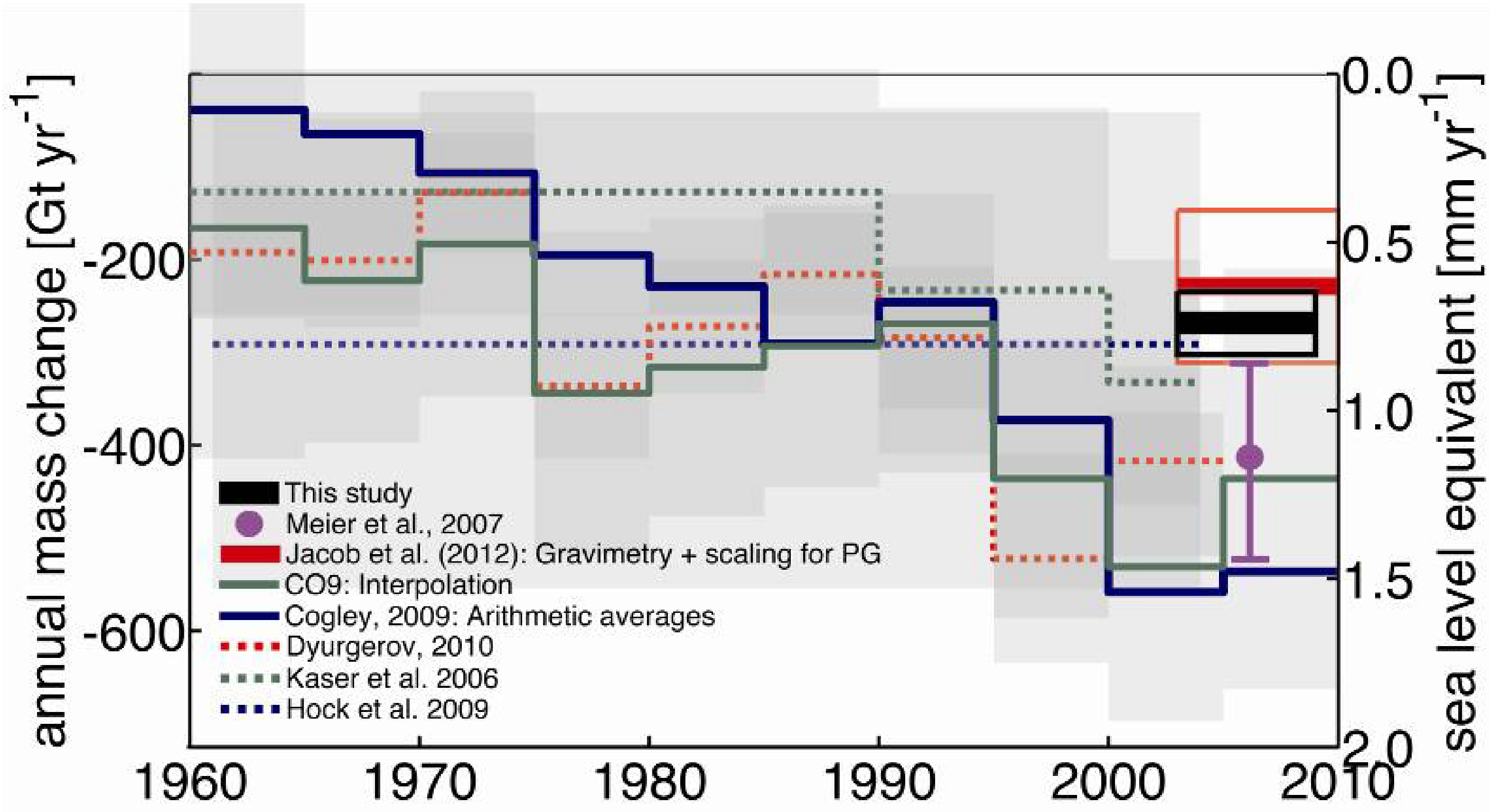



| Hausse observée | ~3.2 ± 0.4 |
|---|---|
| Causes | mm/an |
| 1. Dilatation thermique | +1.1 ± 0.3 |
| 2. Eaux continentales | +0.4 ± 0.1 |
| 3. Calottes polaires | +0.6 ± 0.2 |
| 4. Glaciers | +0.8 ± 0.4 |
| **Somme 1+2+3+4** | **+2.8 ± 0.5** |

*Budget 1993 et 2010 de la hausse du niveau de la mer (IPCC, 2013).*

**Pas de mission spatiale dédiée aux glaciers**

# Motivation : Global glacier mass change

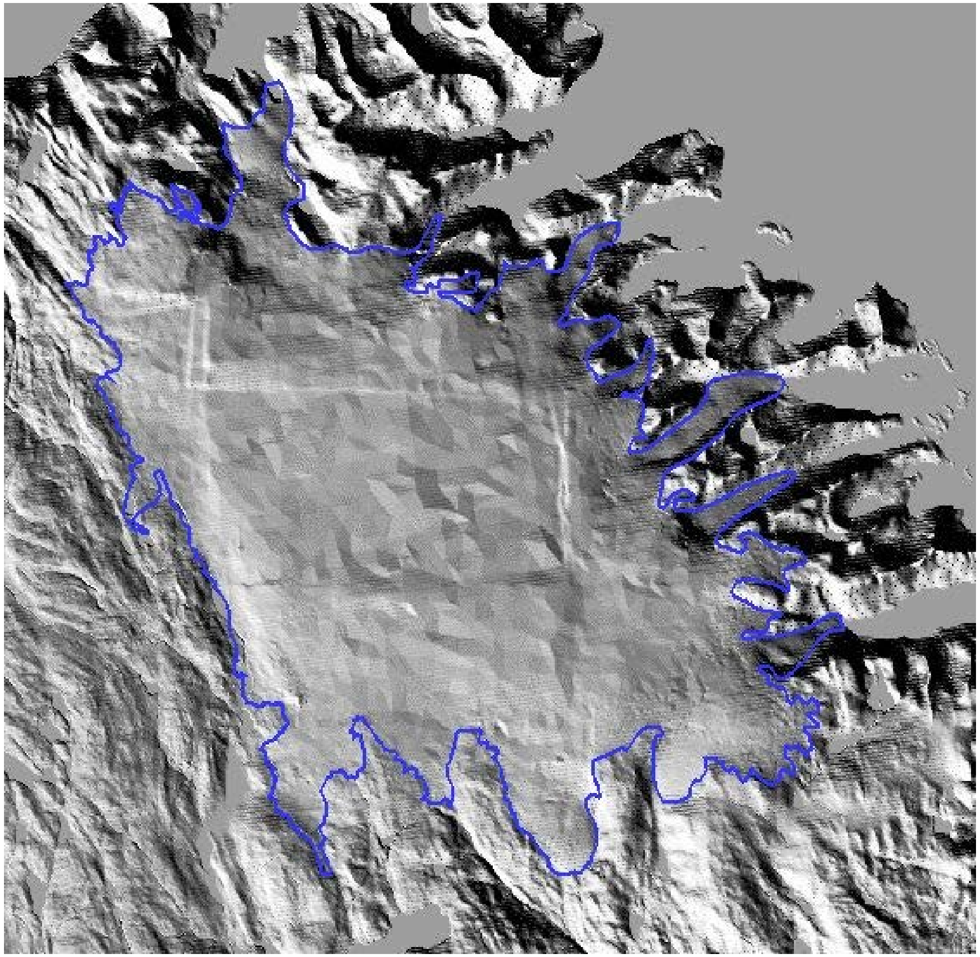



*Global glacier mass change since 1960 [Gardner et al., Science, 2013]*

- 2003-2009: strong (x2) overestimation of the mass loss extrapolating glaciological (field-measured) mass balances. Only 6 yr. And before ?
- Need for geodetic measurements over multi-decadal time periods, well before the satellite era. Also useful to verify/constrain modelling efforts.

# Extending our sample of observed geodetic mass balances before the satellite era

- A vast archive of aerial photographs acquired since the 1950s in many countries + stereo-photos from spy satellites
- DEMs have been derived already (NED in US, CDED in Canada and in many others areas) and used to measure multi-decadal glacier mass loss
- But these DEMs do not take advantage of modern photogrammetric methods and often lack good geodetic control or present some artefacts



*Shaded relief image of the CDED DEM of Grinnell Ice Cap computed from 1958 aerial photos*

# Goal of our study

- Apply state-of-the-art remote sensing techniques to derive a modern DEM of two small ice caps in the Canadian archipelago
- Use this accurate dataset as a source of ground control points to measure glacier volume change
- Infer the magnitude of the acceleration of glacier mass loss during recent years

The Cryosphere
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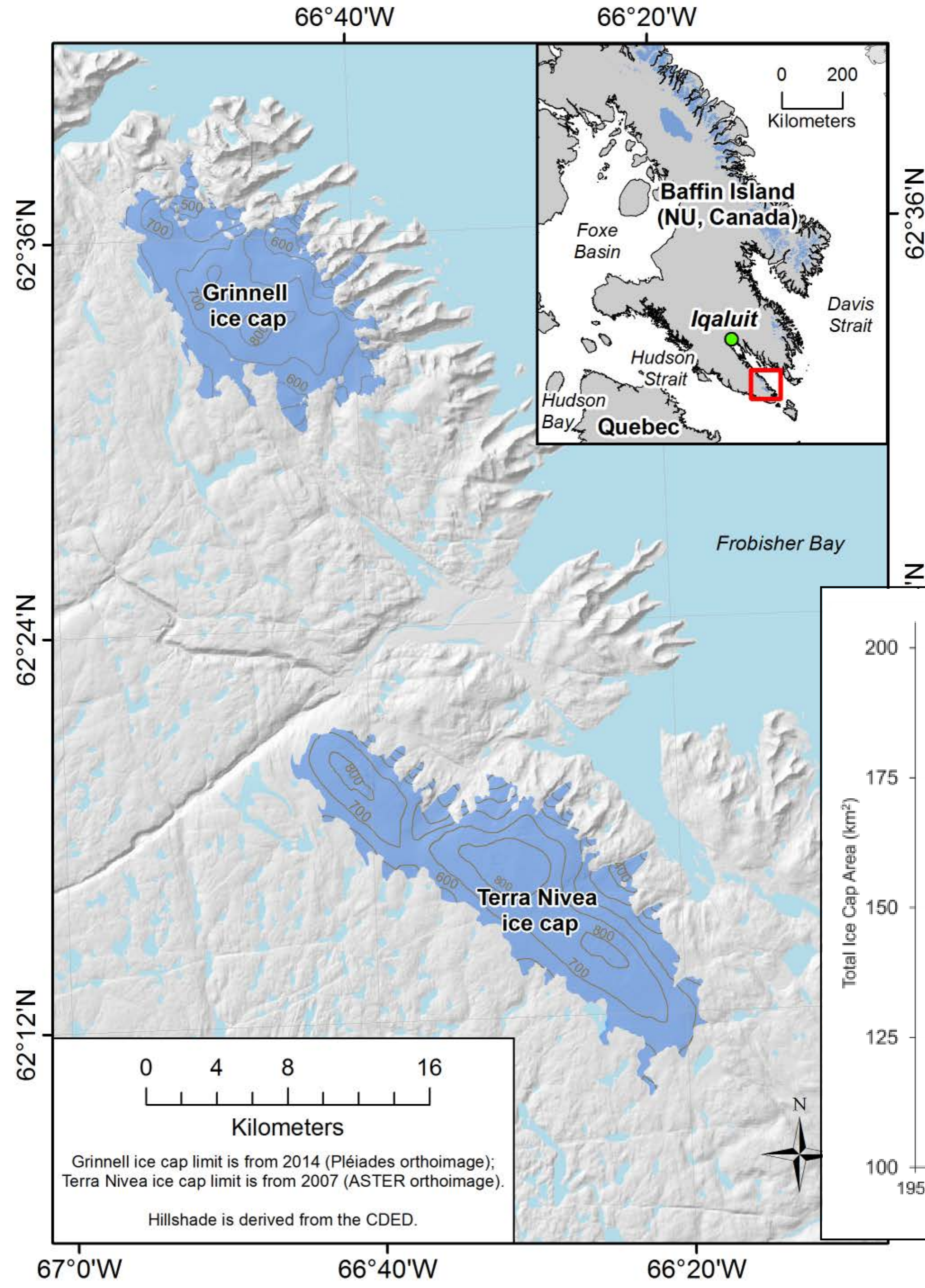
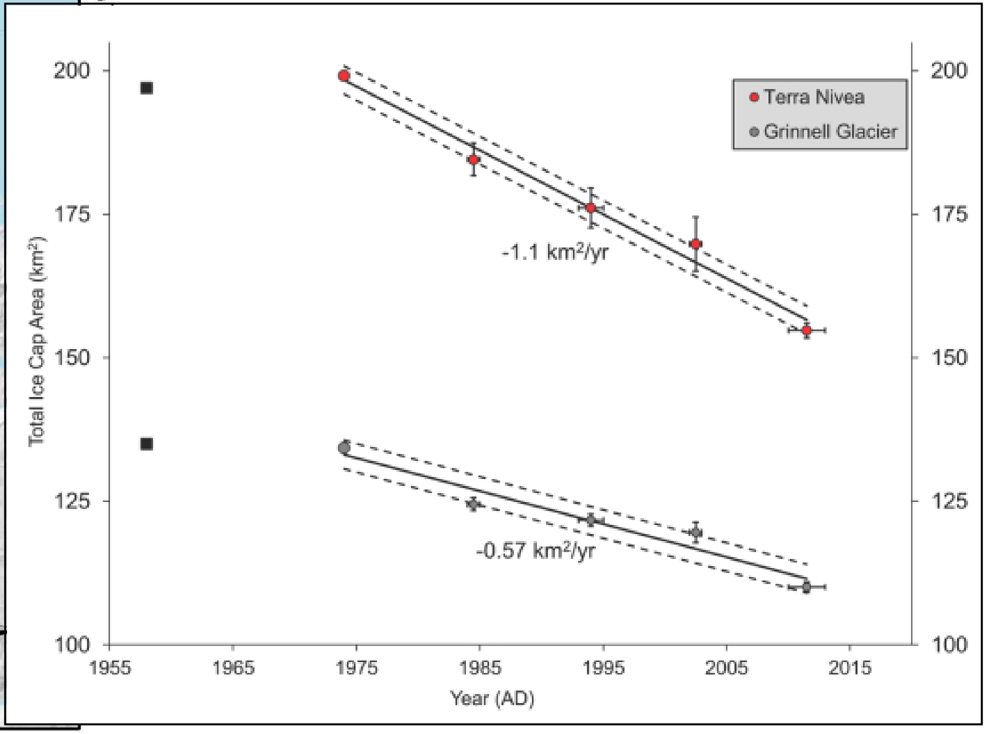
**Area, elevation and mass changes of the two southernmost ice caps of the Canadian Arctic Archipelago between 1952 and 2014**

C. Papasodoro[1,2], E. Berthier[3], A. Royer[1,2], C. Zdanowicz[4], and A. Langlois[1,2]

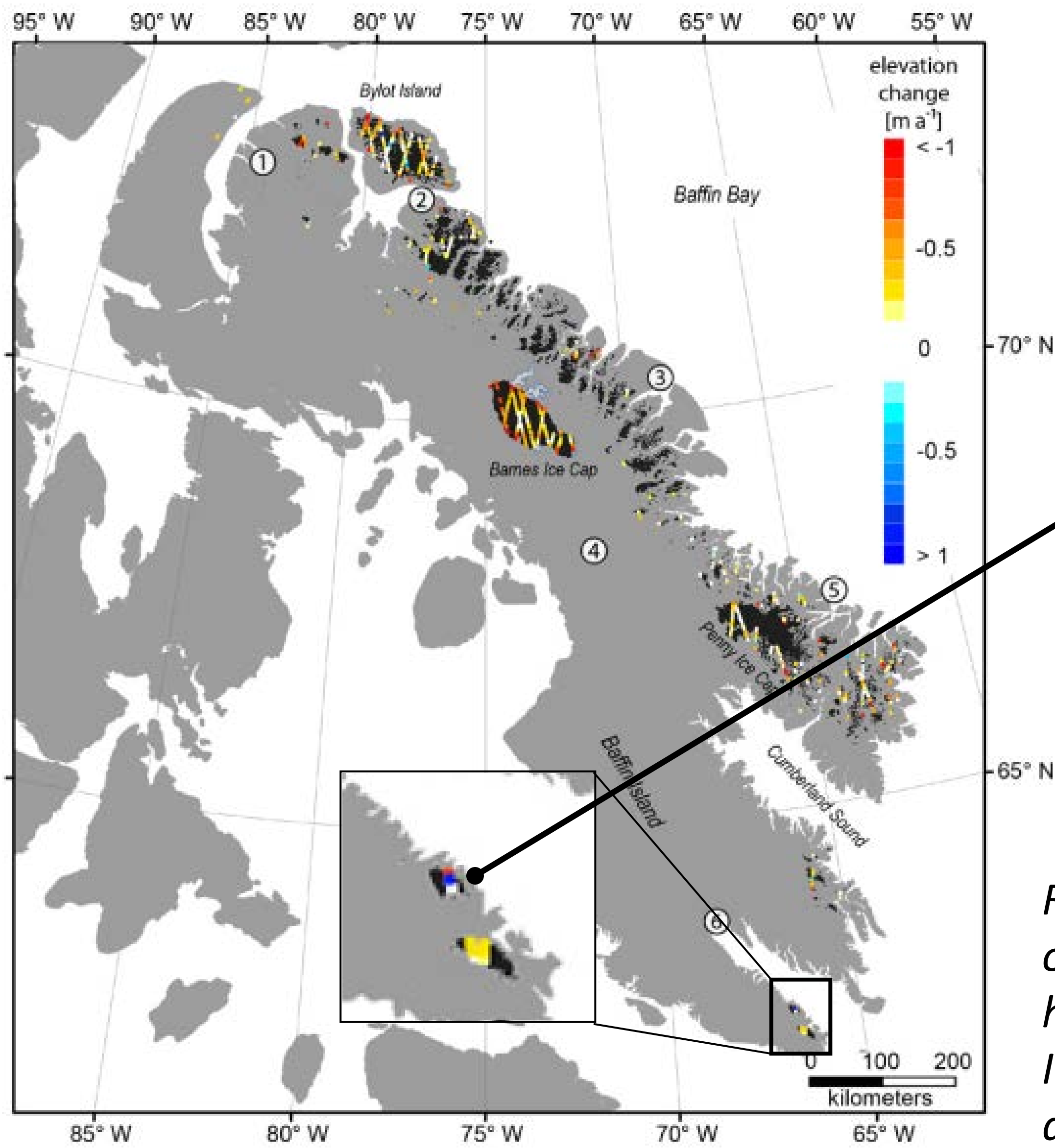
# STUDY AREA and earlier work

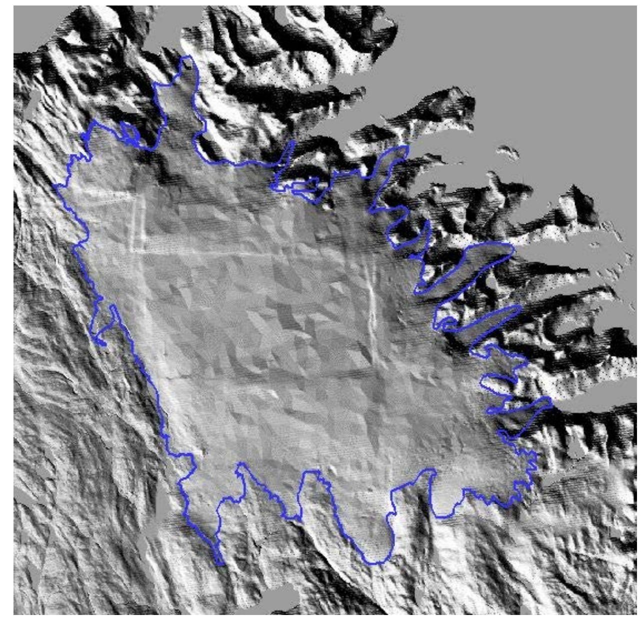



- Grinnell Ice Cap. 104 km²
- Terra Nivae Ice Cap. 150 km²
- Strong retreat of the two ice caps over the last decades. Way, 2015



# Further motivation. A seemingly contrasted behaviour



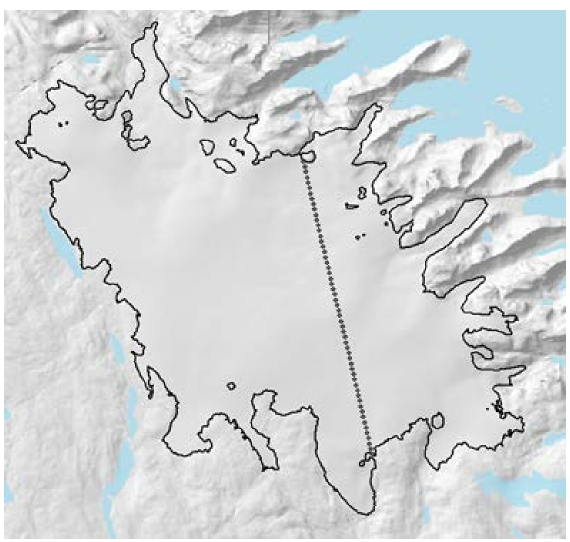



*Rate of elevation difference (m/a) over Baffin Island by comparing historical DEM (1950s) and recent ICESat data (2000s). Gardner et al., TC, 2012*

# DATA. Elevation changes measurements

## Grinnell

- Aerial photographs August 1952
- 3 GPS tracks from April 2004
- ICESat elevation data between 2003 and 2007
- Pléiades stereo-pair August 2014

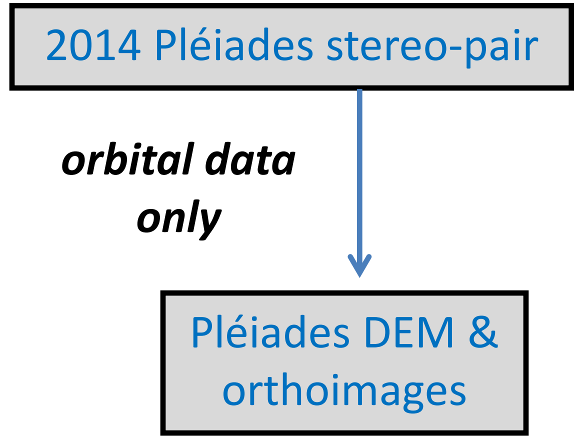


## Terra Nivae

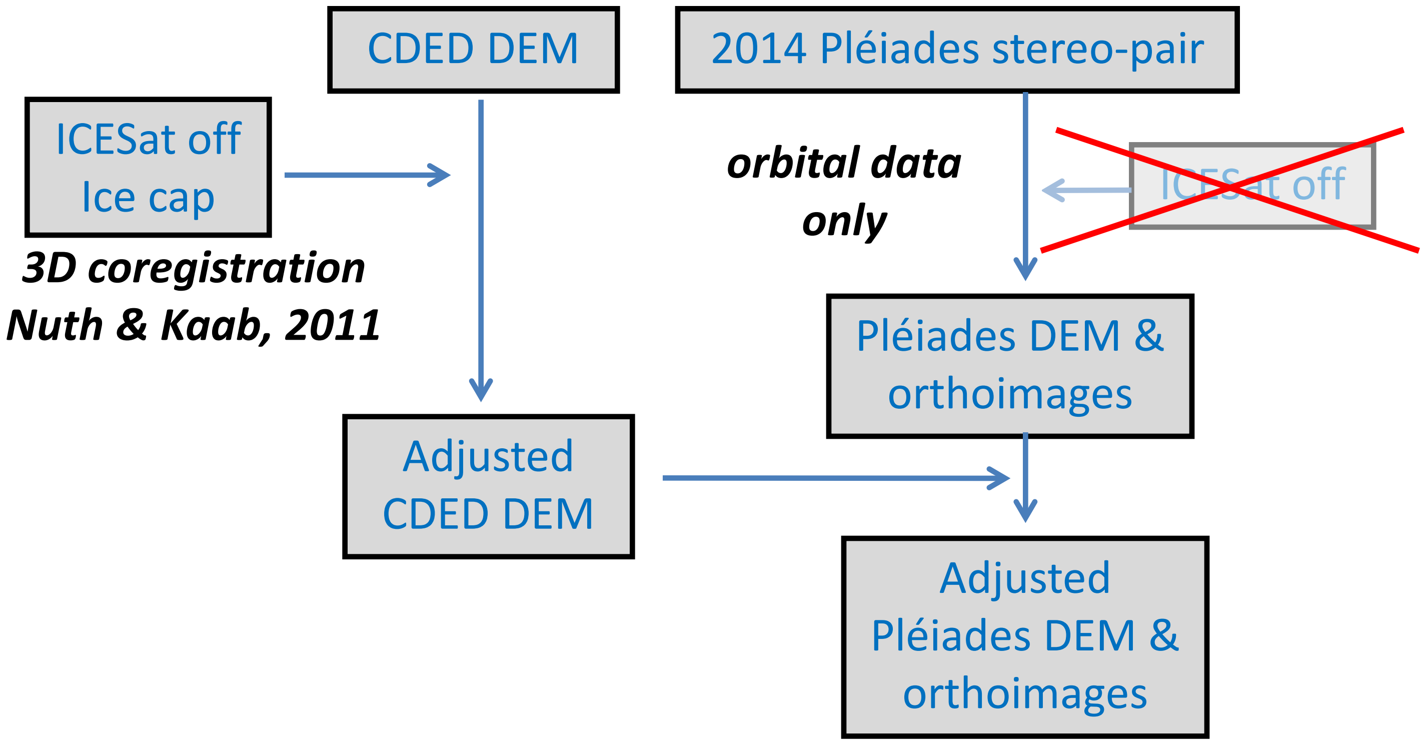
- CDED DEM from 1958 (OK)
- ICESat elevation data between 2003 and 2007
- ASTER DEM August 2007
- Pléiades stereo-pair August 2014

*Images of the two ice caps illustrating the sparse sampling from ICESat*

# METHOD. Grinnell Ice Cap



# METHOD. Grinnell Ice Cap



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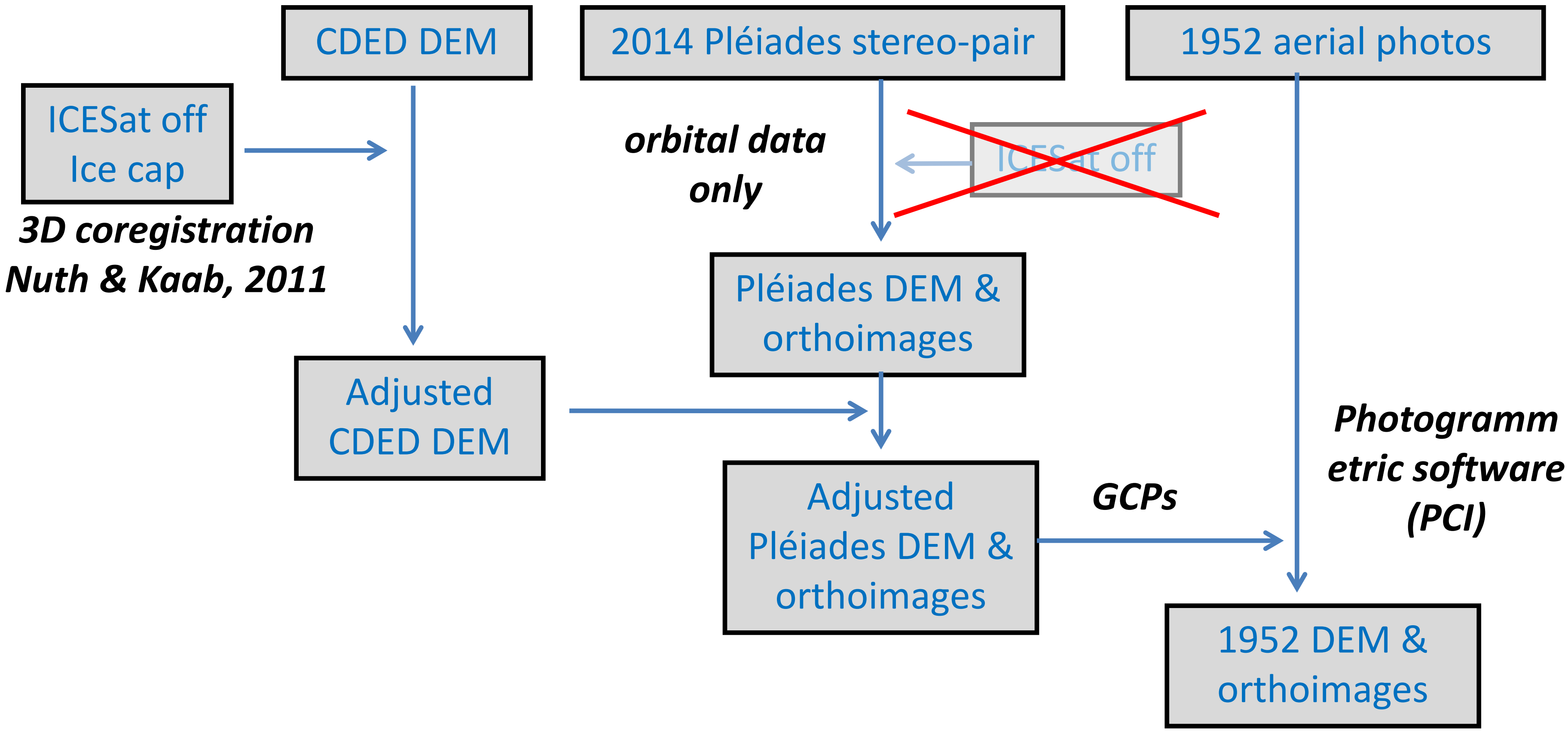

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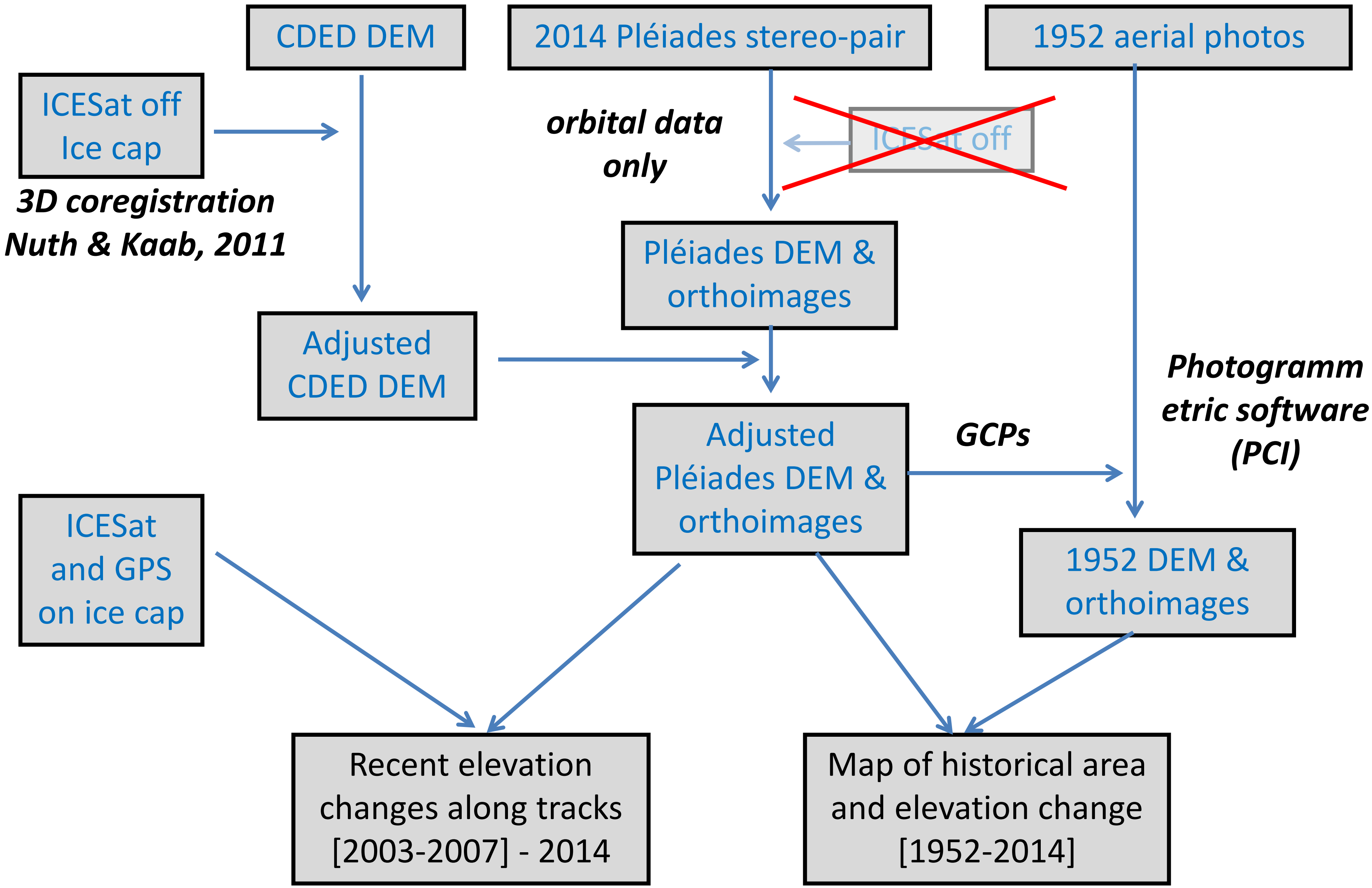
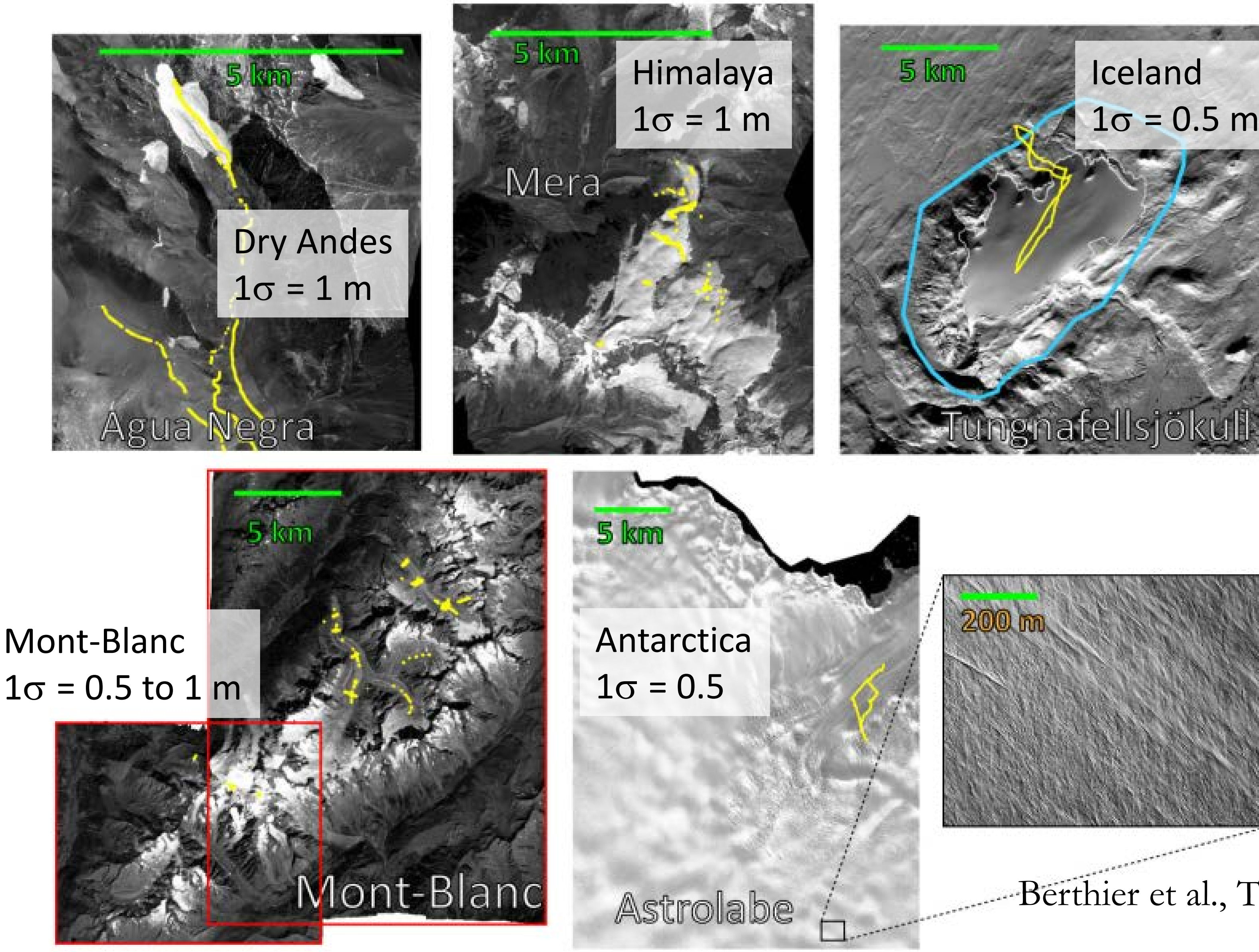


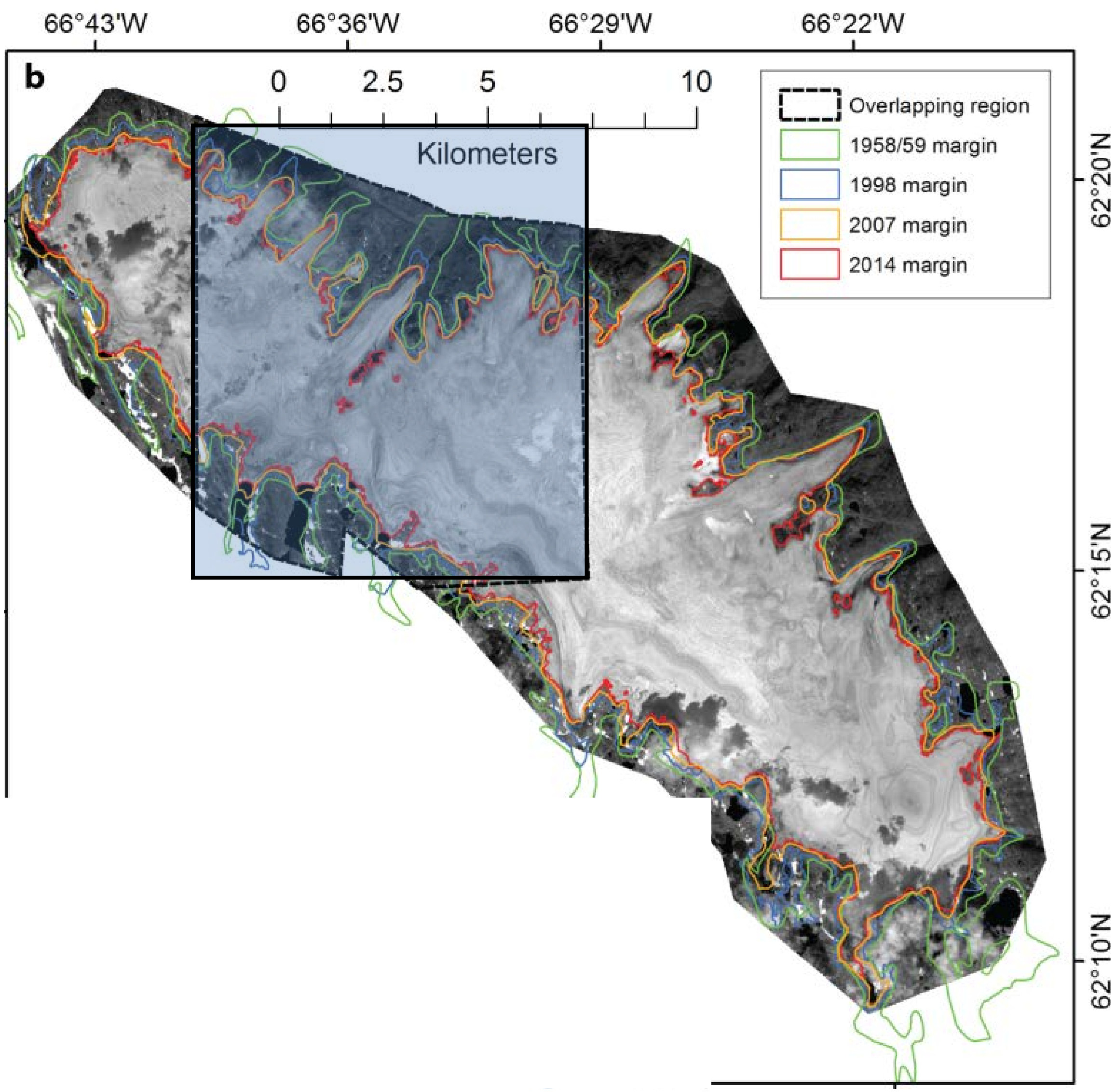
# Validation of Pléiades DEM in various context




Berthier et al., TC, 2014

*Study sites were Pléiades DEMs have been evaluated against dGPS data*

# Overlapping area between Pléiades images




*Mosaic of the two Pléiades images acquired over Terra Nivae Ice cap*

14 August 2014, eastern part

26 August 2014 western part

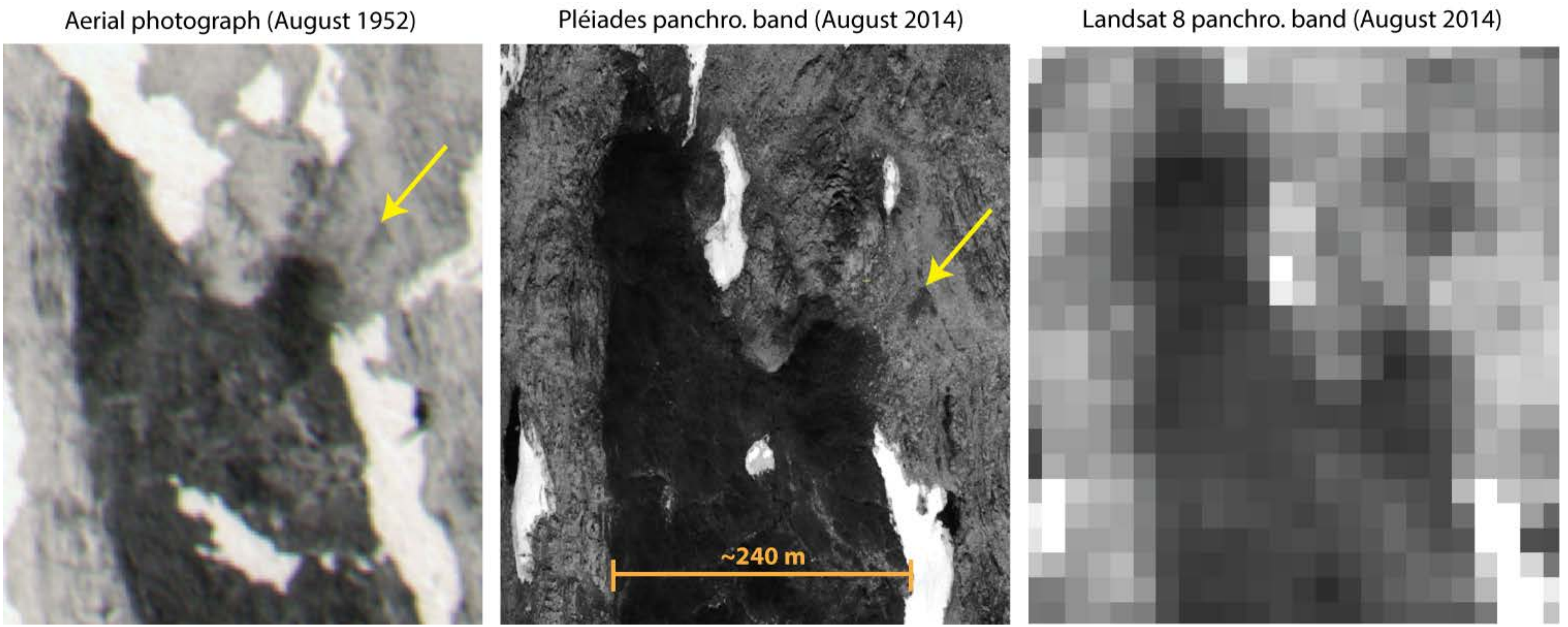
Coregistered independently to CDED data

Mean difference:

Off Ice = +0.1±2.1 m

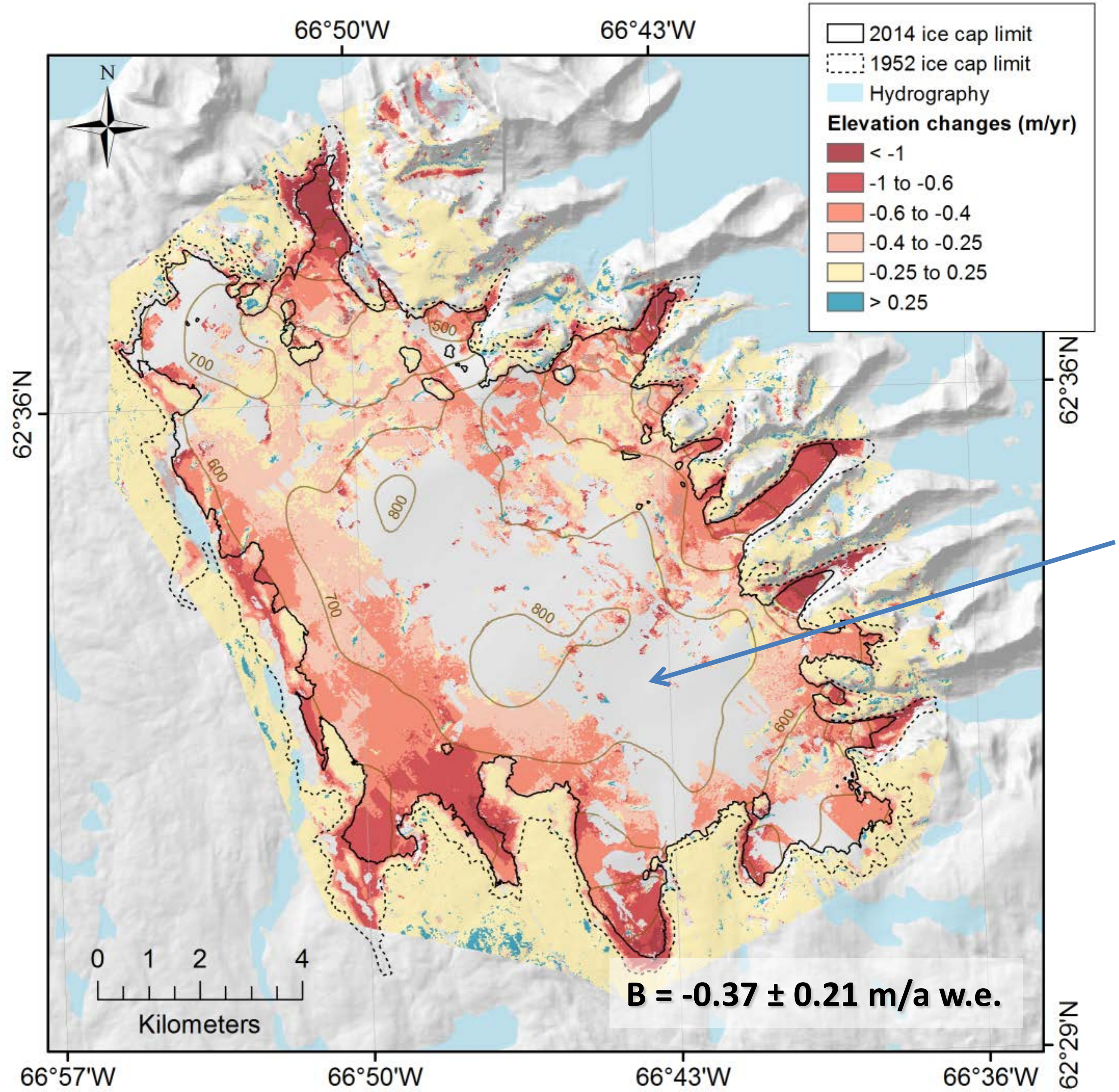
On Ice = -0.6 ±2.2 m (partly due to thinning)

# METHOD. Pléiades as source of GCPs



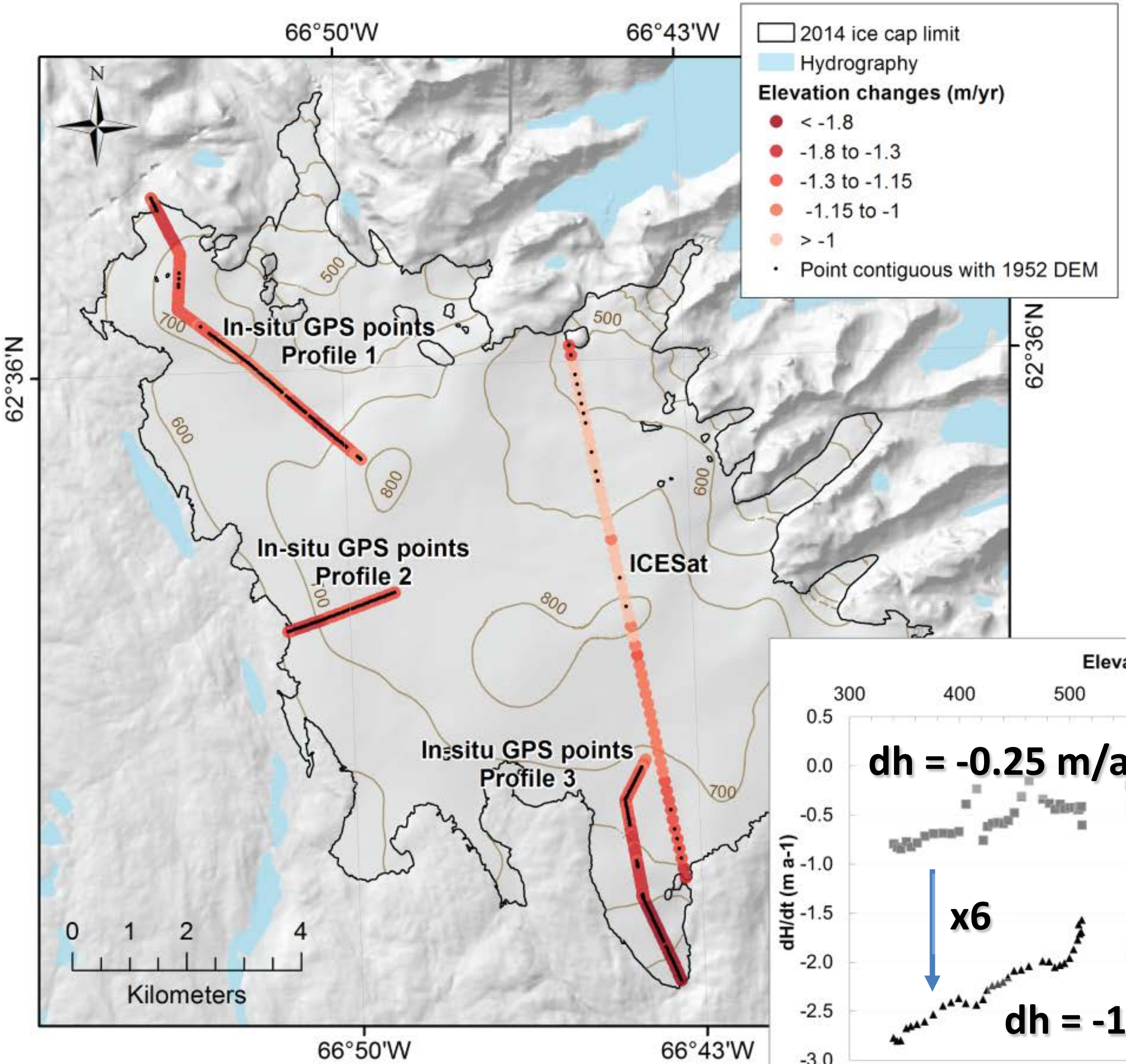

*The same geomorphological feature on ice-free terrain surrounding the Grinnell Ice Cap seen in the aerial photos (left), Pléiades (center) and Landsat 8 (right)*

# Results. Grinnell. dh/dt. 1952-2014

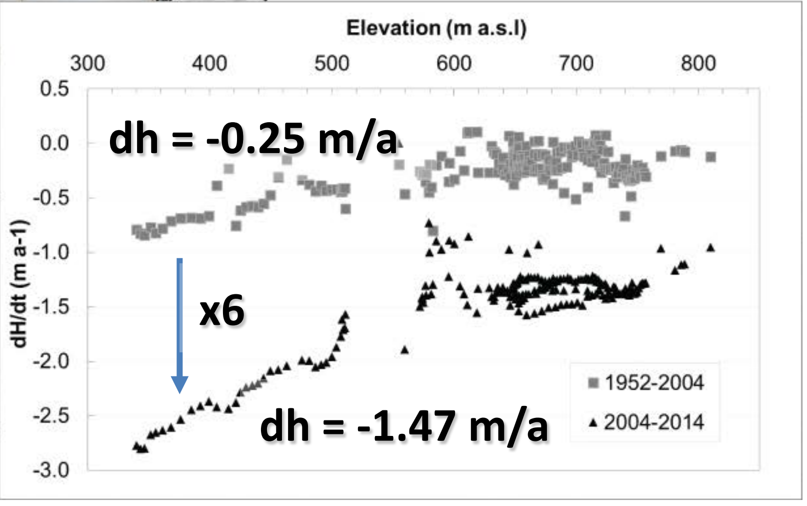



***Data gaps due to poor contrast in the aerial photos***

# Results. Grinnell. 1952-2004-2014

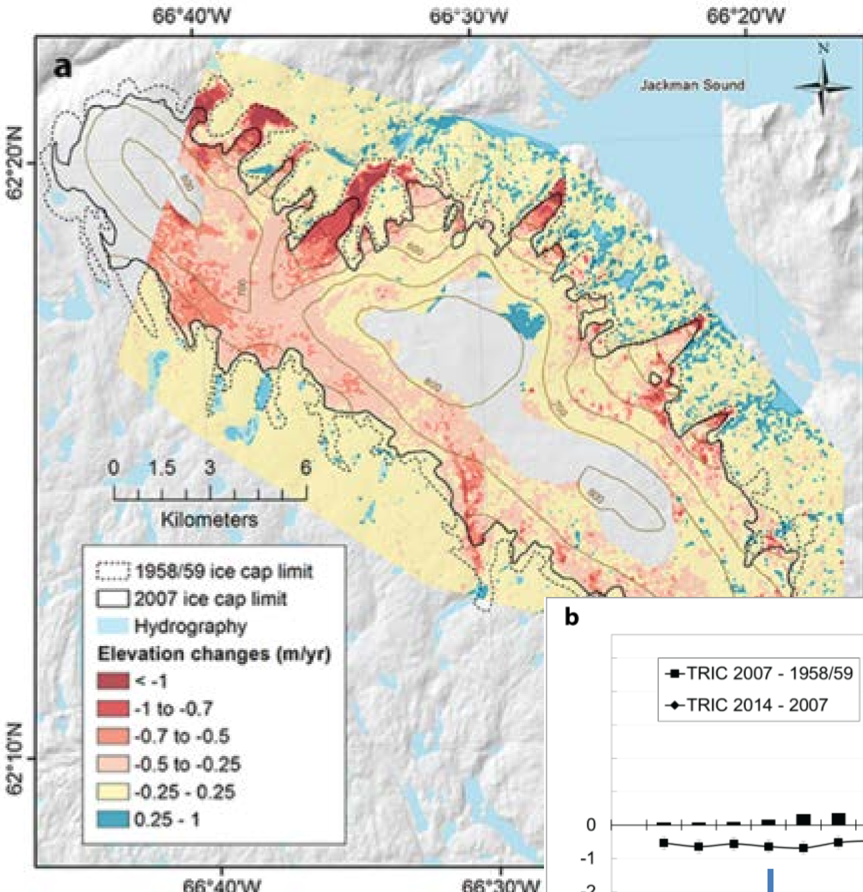



*N=203 common points in 1952, 2004 & 2014*

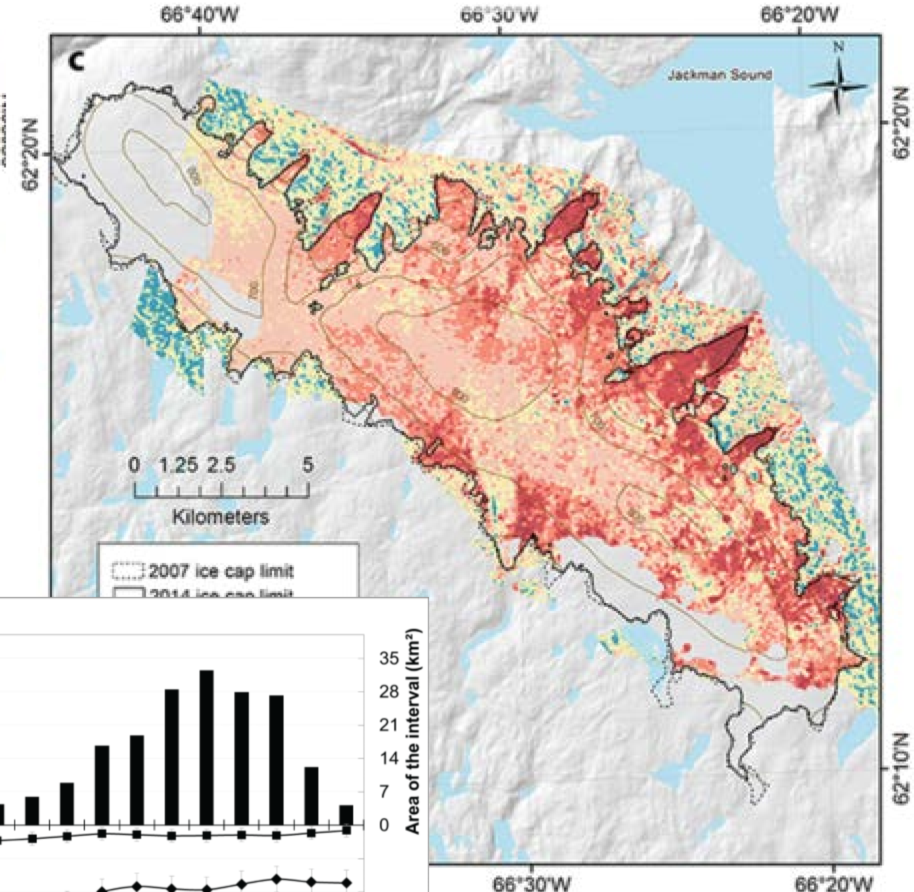


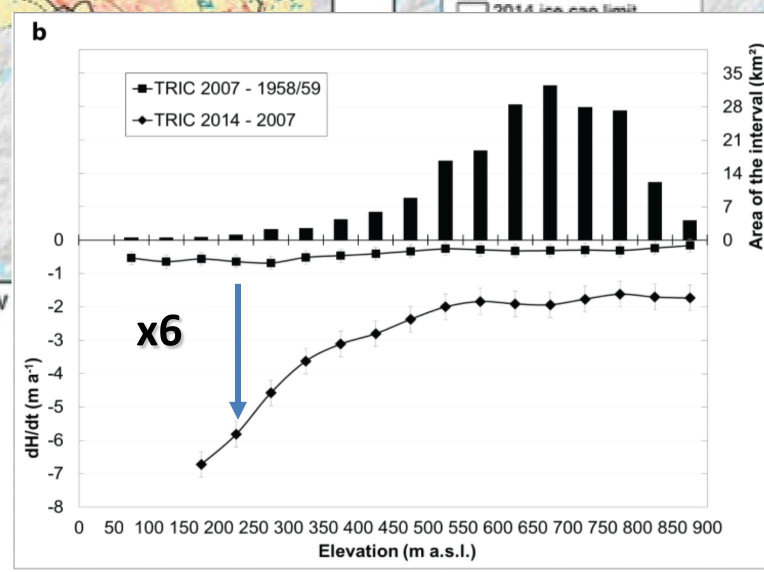
# Results. Terra Nivae. 1958-2007-2014

1958-2007




2007-2014

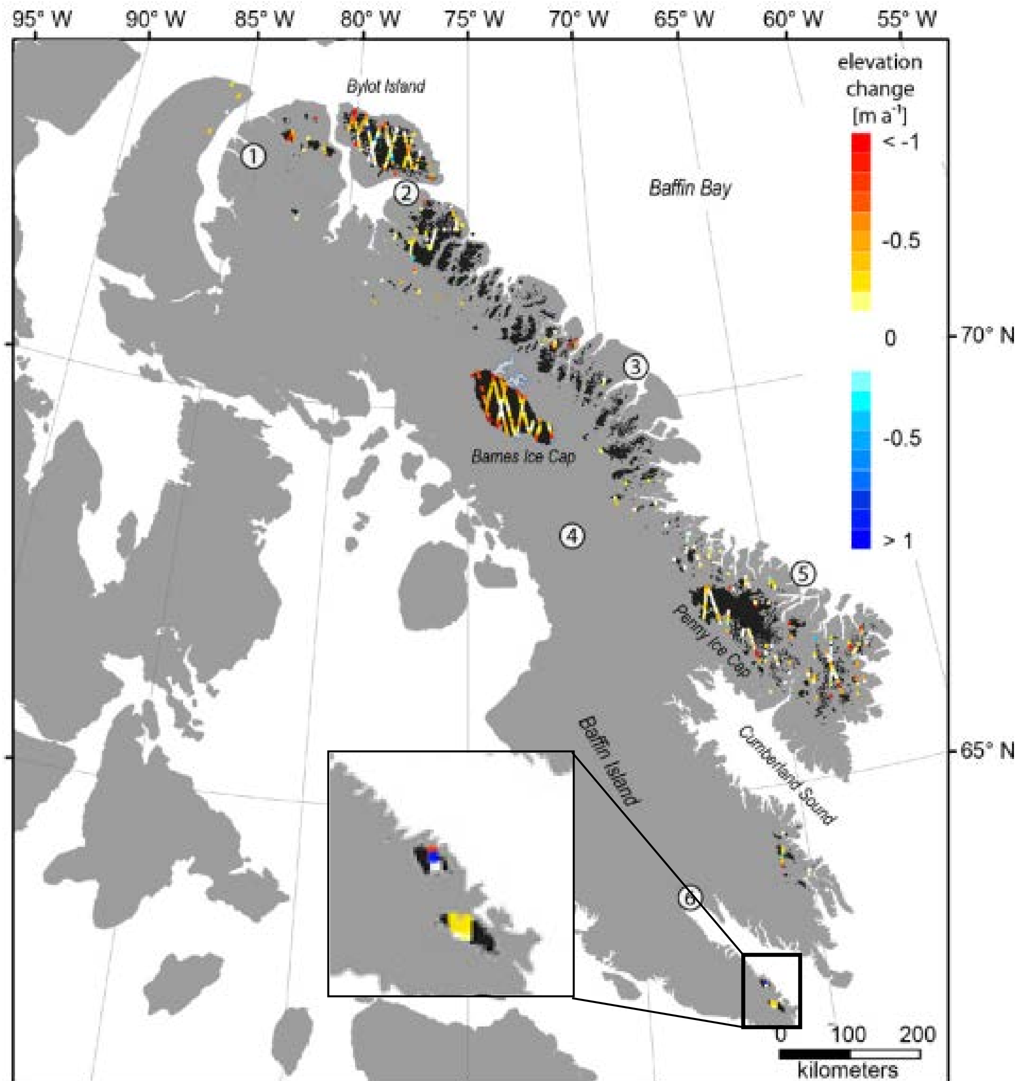


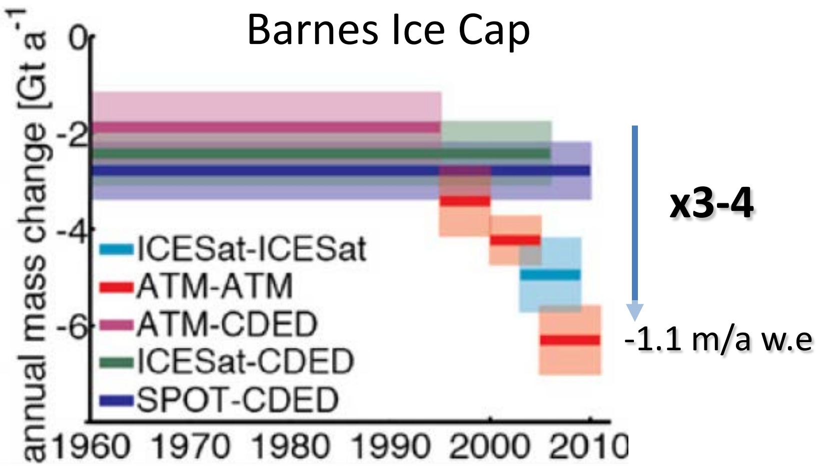

**B = -0.30 ± 0.19 m/a w.e.**

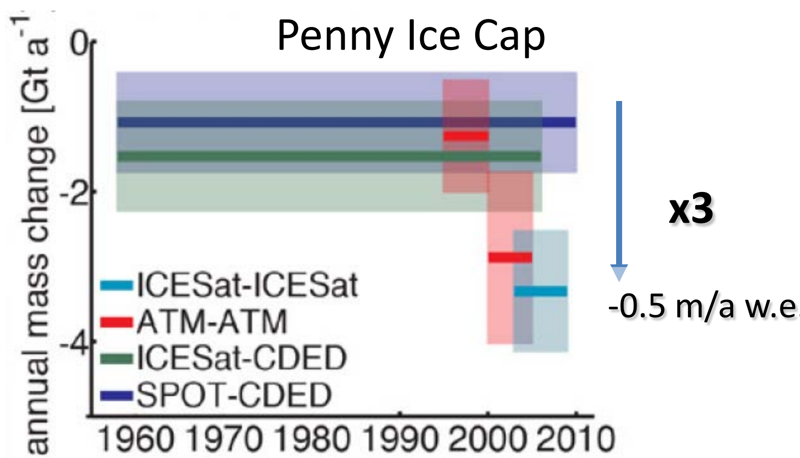
**B = -1.77 ± 0.36 m/a w.e.**

# Discussion. Comparaison to published geodetic mass balances over Baffin Island

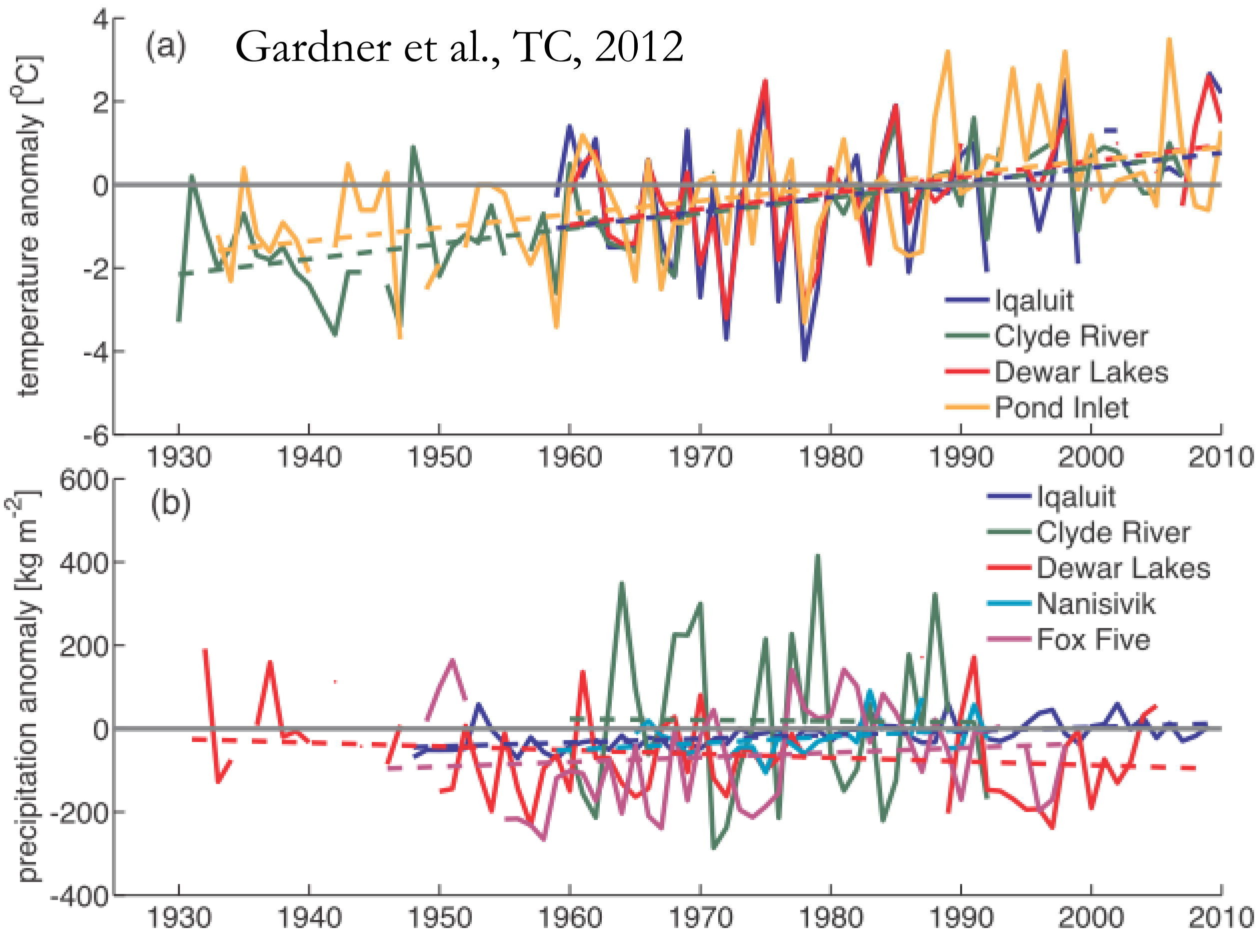



Gardner et al., TC, 2012



# Discussion. Origin of the accelerated mass loss




*Summer (June, July, August) temperature and (b) annual precipitation anomalies relative to the 1981–1990 mean*

**Causes :**

- **Augmentation de la T estivale**
- **Allongement de la saison de fonte notamment en automne (peu au printemps)**

# Conclusions

1. Pléiades (or similar VHR stereo satellites) are efficient tools to unlock the archive of old aerial photographs

2. Strong acceleration of the mass loss during the last decade (x6). Among the most negative glacier-wide mass balances on Earth.

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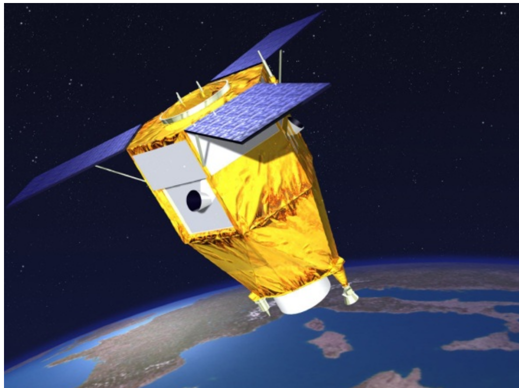
**Acknowledgments**

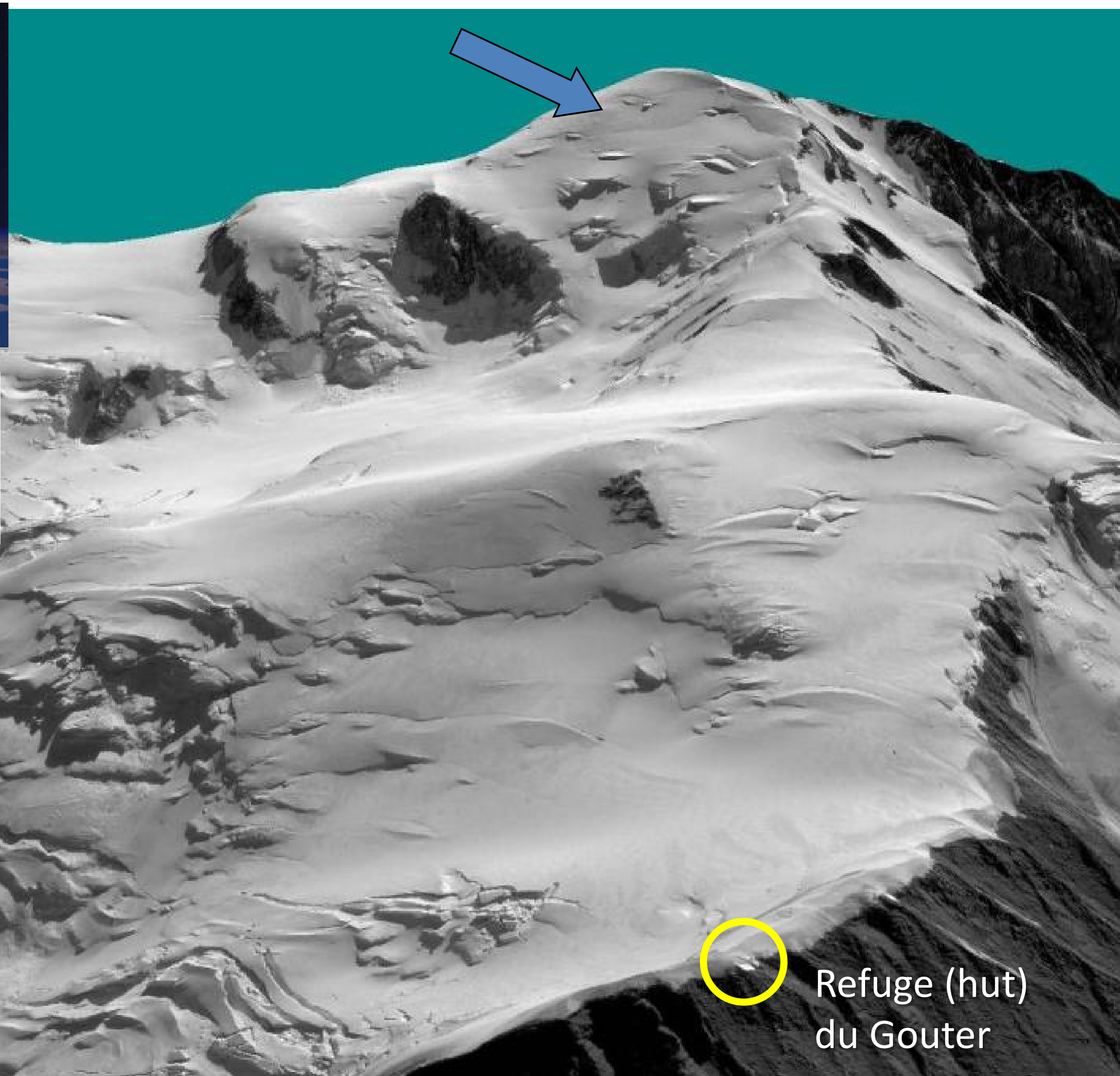
→ ISIS program from CNES

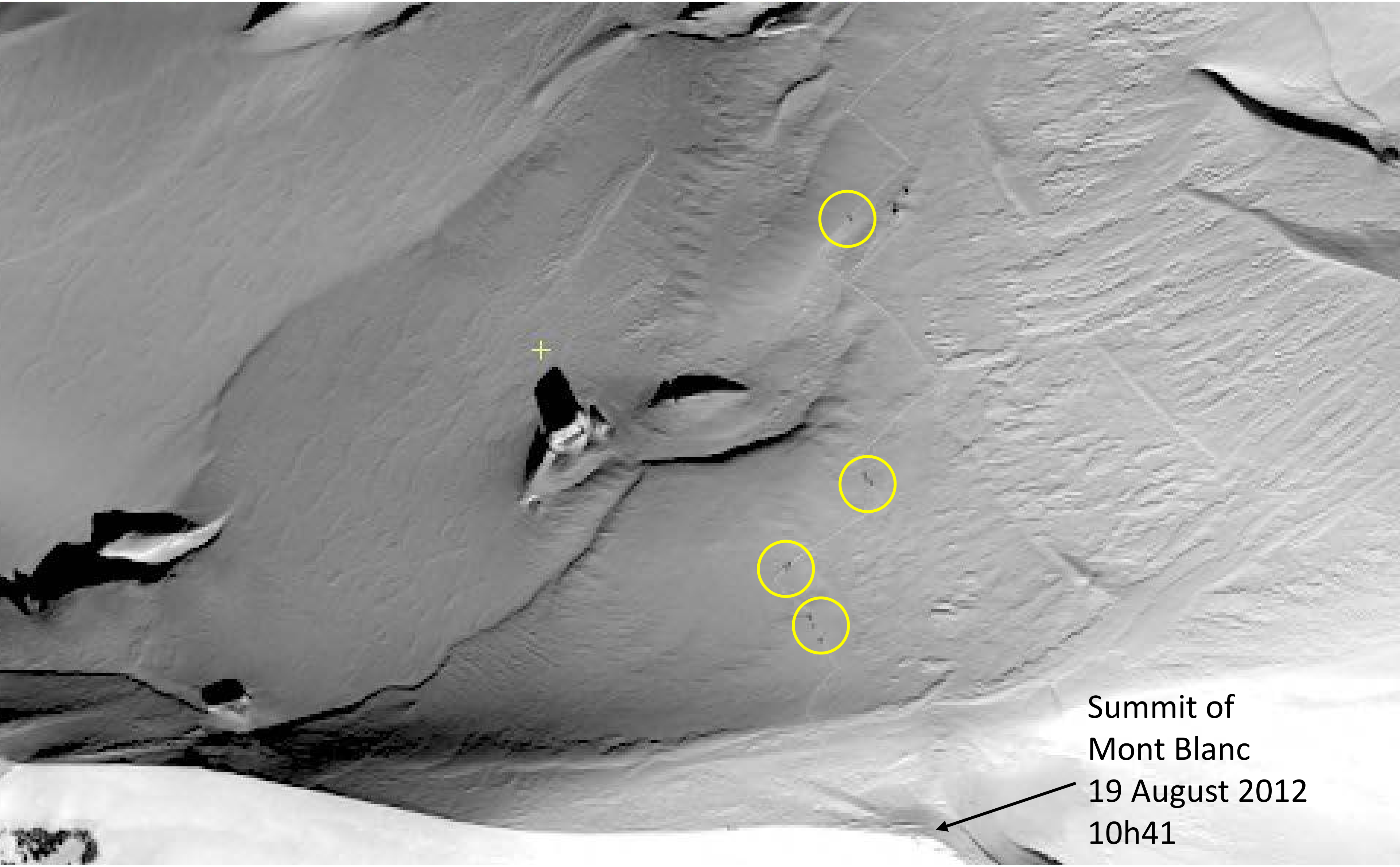
→ TOSCA (CNES)

# 3D view of Mont-Blanc by Pléiades



Pléiades 1A & 1B, 0.7 m
Along-track stereo
satellite agility



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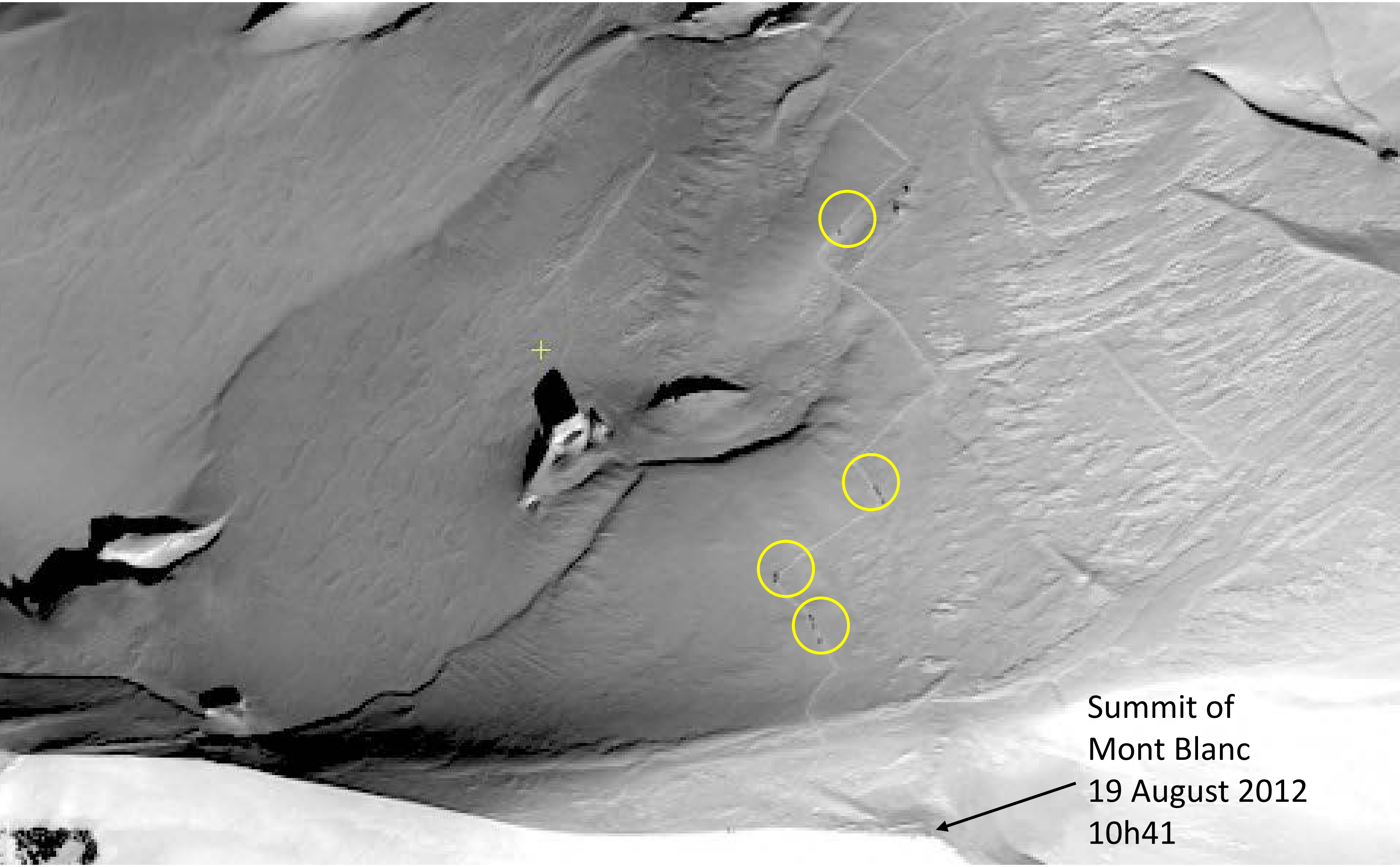
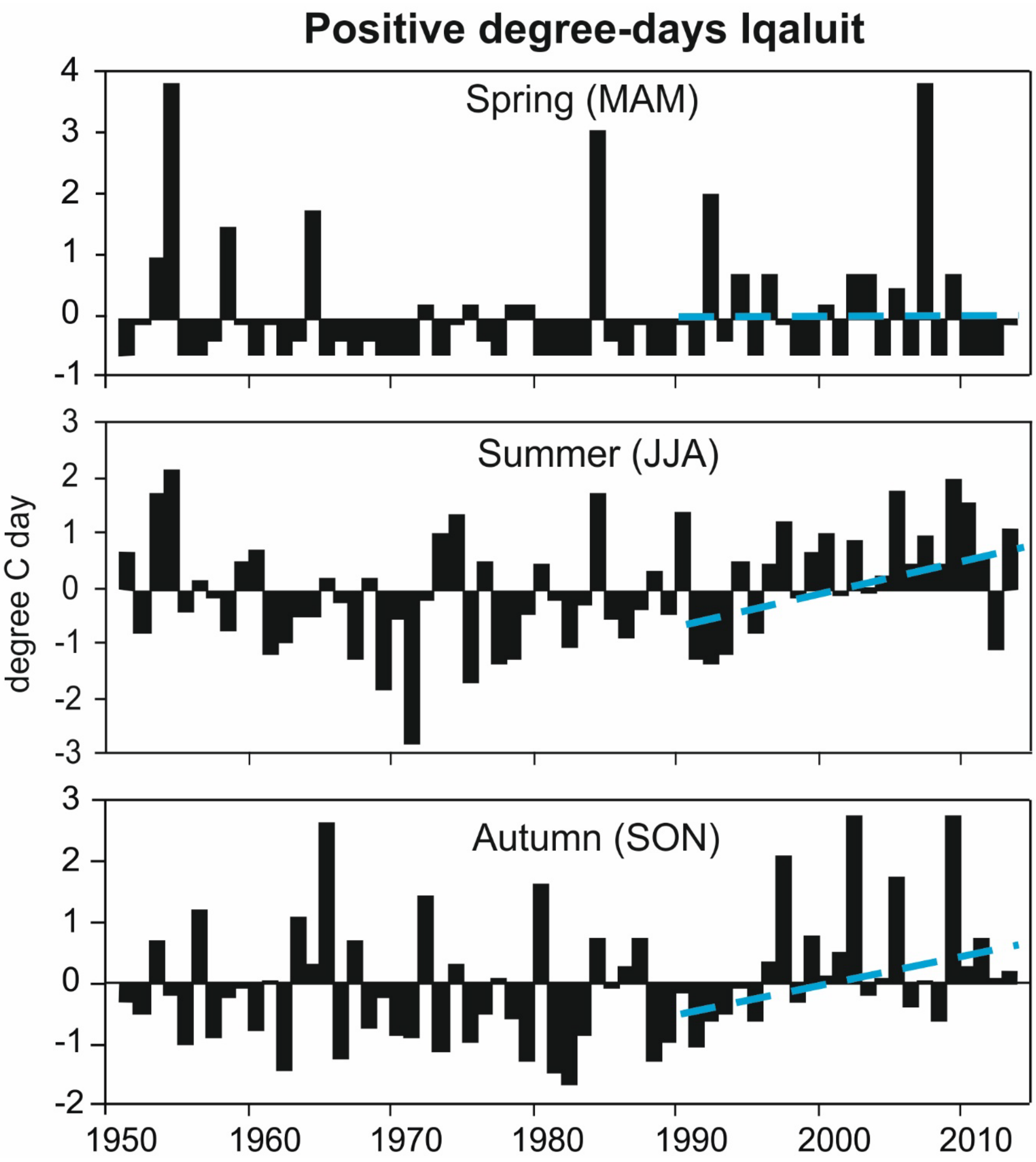



**t + 27 sec**




Trends in **cumulative positive degree-days (PDD)** for spring, summer and autumn,

The largest positive changes have been in summer and in autumn (primarily Sept and Oct), and not in the spring, in which there are few PDD.

Slide by C. Zdanovic