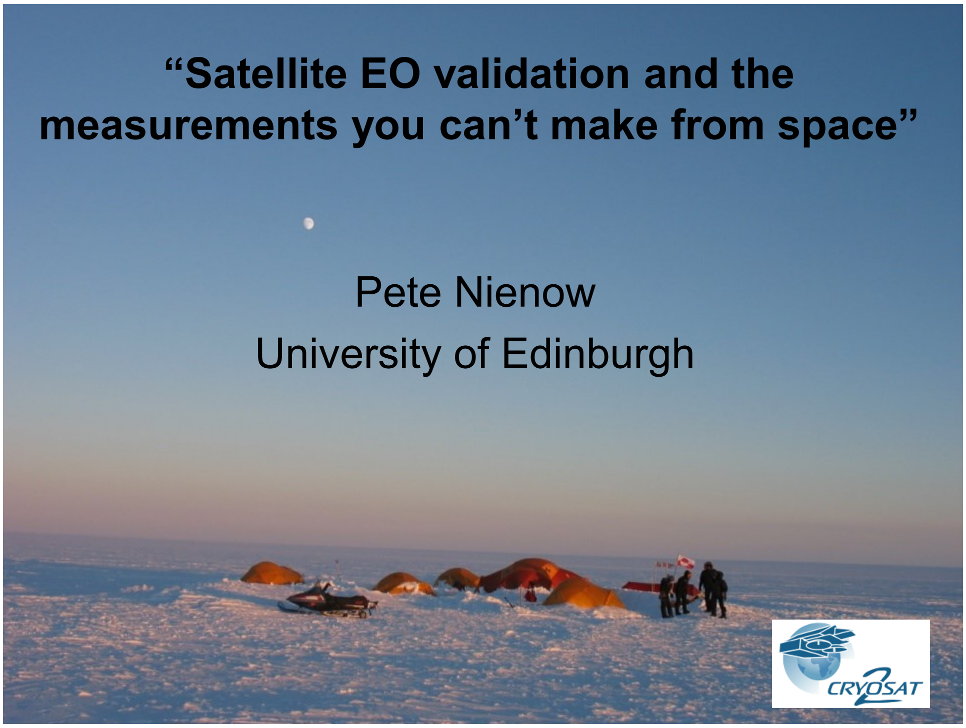
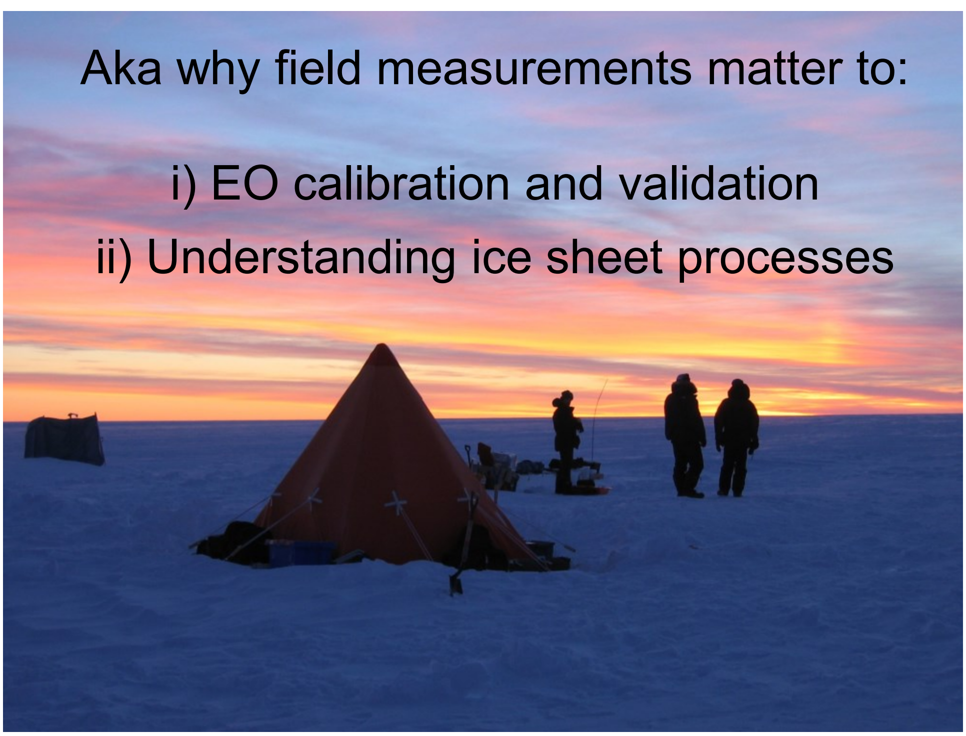
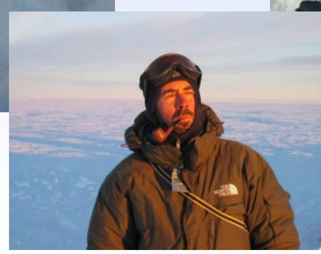
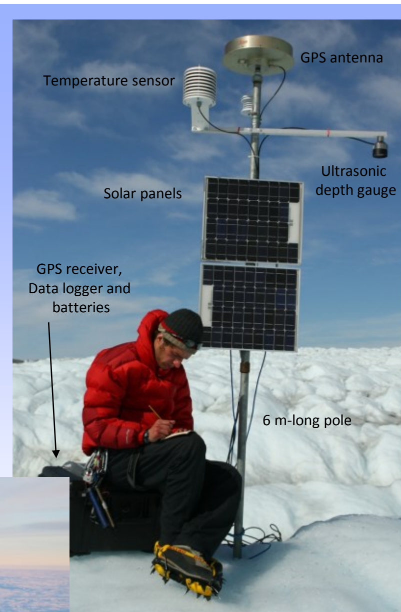

"Satellite EO validation and the measurements you can't make from space"
Pete Nienow
University of Edinburgh
CRYOSAT 2

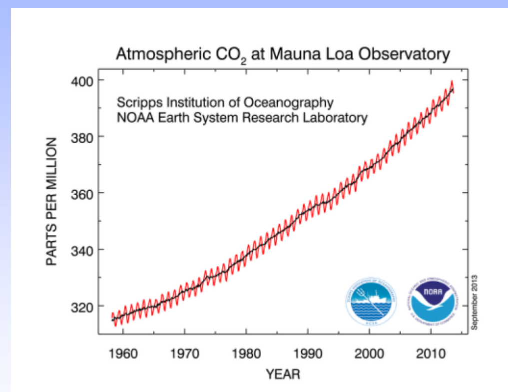

Aka why field measurements matter to:
i) EO calibration and validation
ii) Understanding ice sheet processes



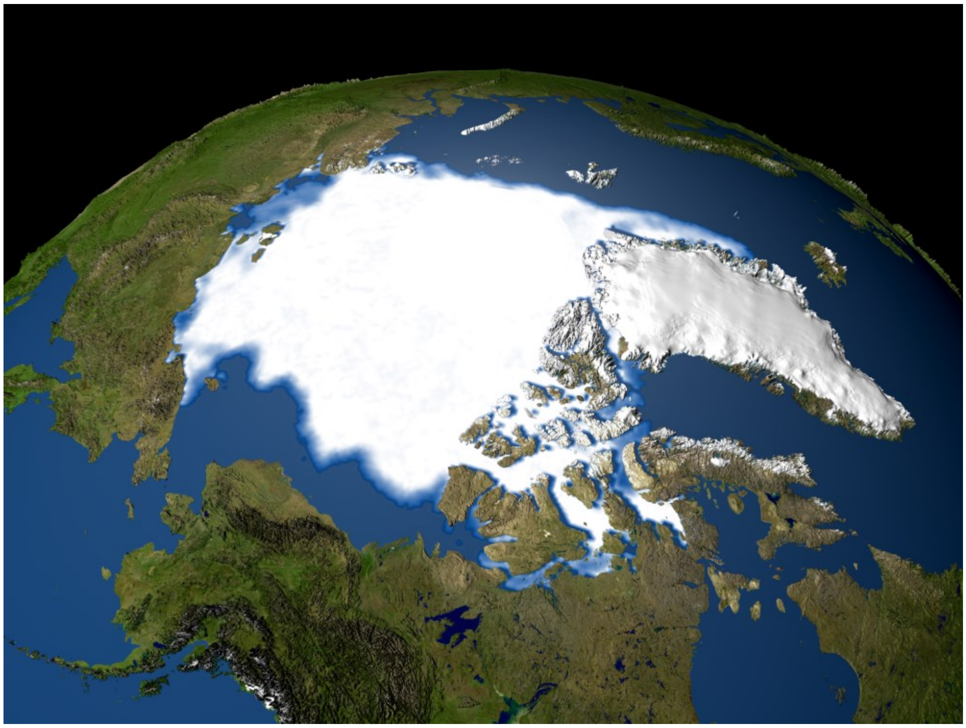


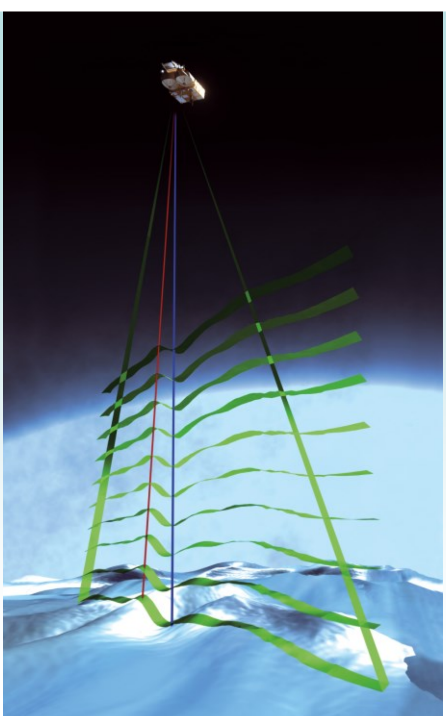
Background in field based glaciology

Especially hydrology and ice dynamics



1998 Haut Glacier d'Arolla, Switzerland 2013



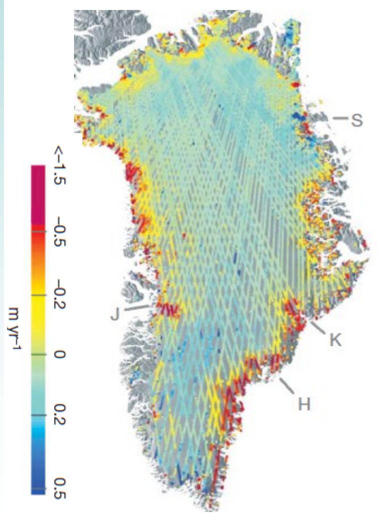


Satellites have revolutionised our understanding of change:

e.g. CryoSat-2, a radar altimeter, for observing surface elevation change

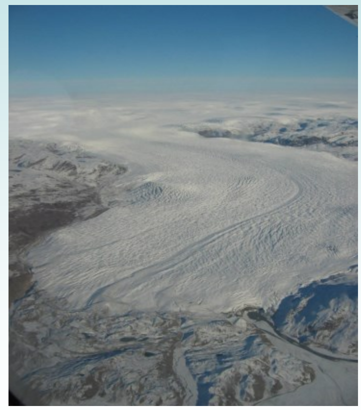
Observations of elevation change

Satellite laser altimetry 2003-2007



Pritchard et al, 2009, *Nature*

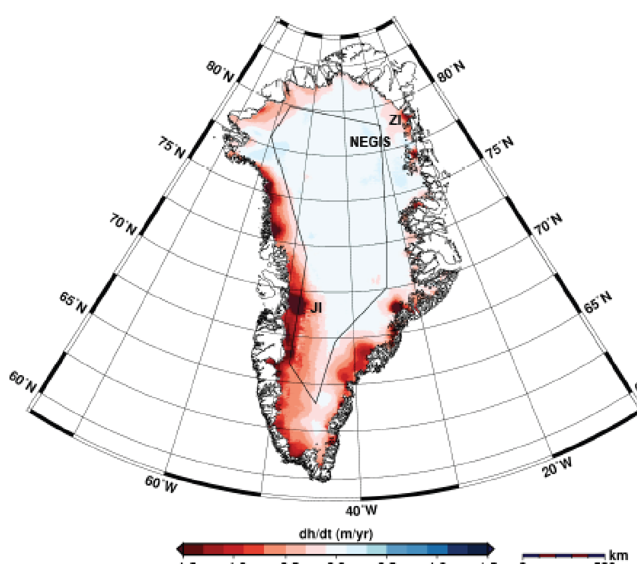
Greenland losing mass due to substantial thinning around the ice sheet margin.



Confirmed by several different methods derived from field and satellite data

Newer results = same pattern but worse

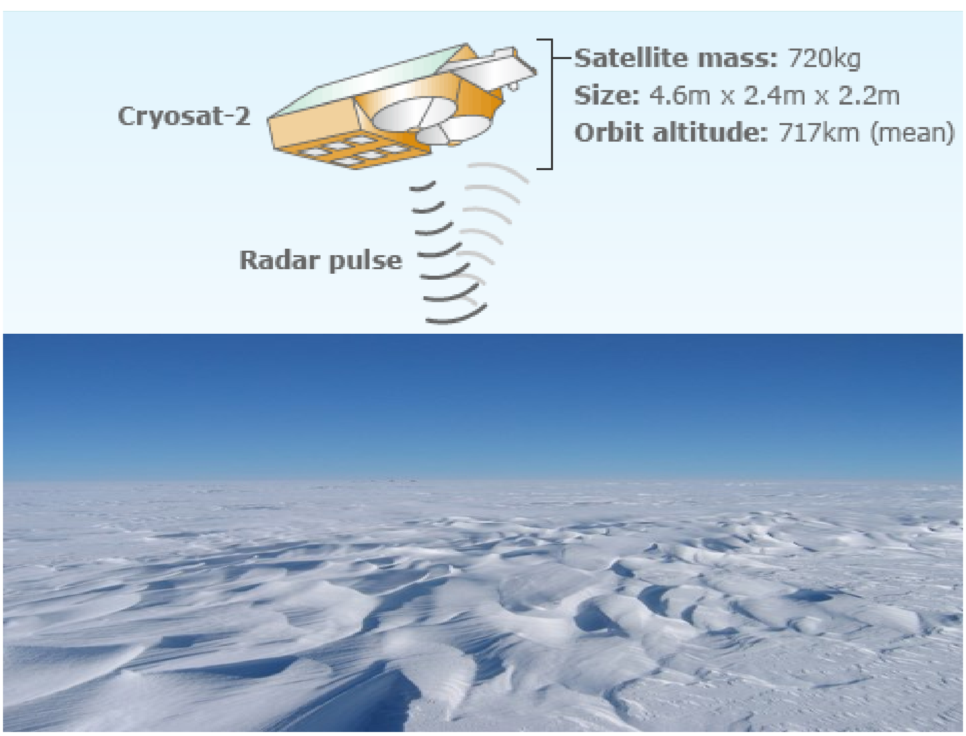
- Helm et al, *TC*, 2014
- Jan 2011 - 2014
- −375 ±24 $km^3\ yr^{-1}$



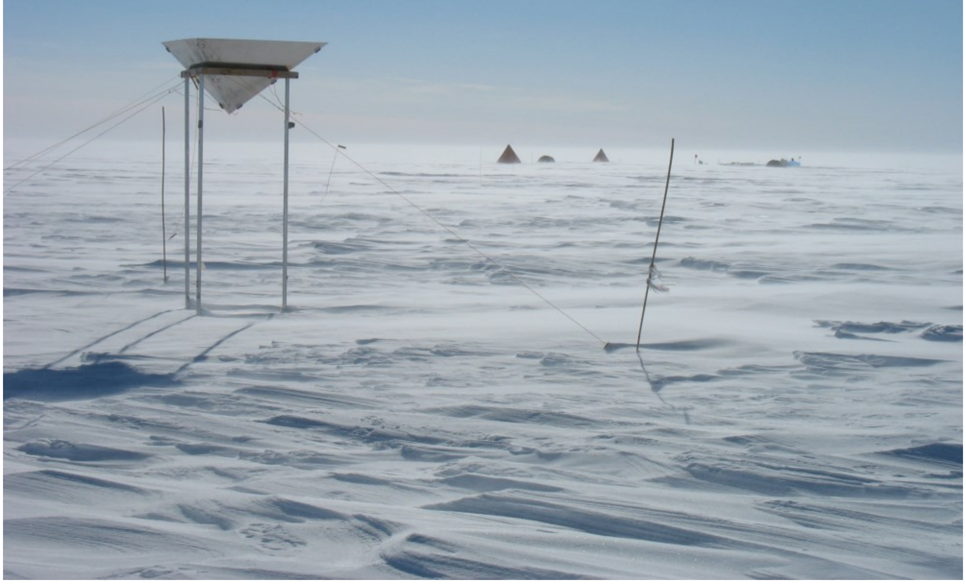
But two significant issues: how do we

i) know that the satellite is measuring the surface elevation (and thus elevation change) accurately to a few cm?

ii) convert this elevation change to mass change?



The importance of getting these measurements accurate (reducing uncertainties) resulted in a multi-million pound Calibration Validation experiment (CalVal) for the ESA CryoSat mission



CryoSat CalVal work in the percolation zone of the Greenland Ice Sheet

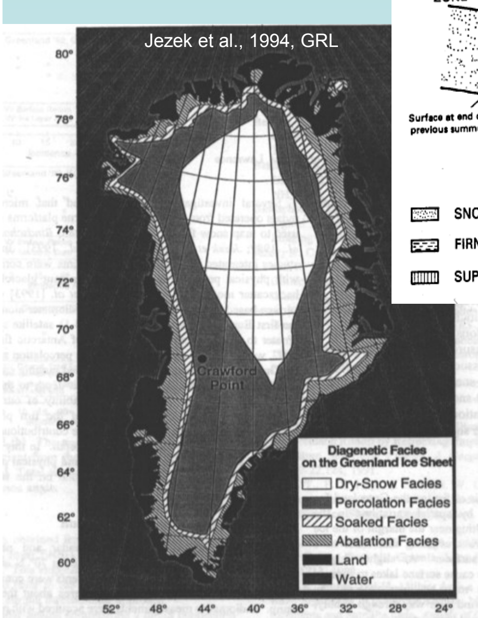
Peter Nienow (1), Douglas Mair (2), Santiago de la Peña (1), Victoria Parry (1), Julian Scott (1,2,3), Veit Helm (4), Liz Morris (5), Rob Cullen (6), Andrew Shepherd (1) and Duncan Wingham (7)

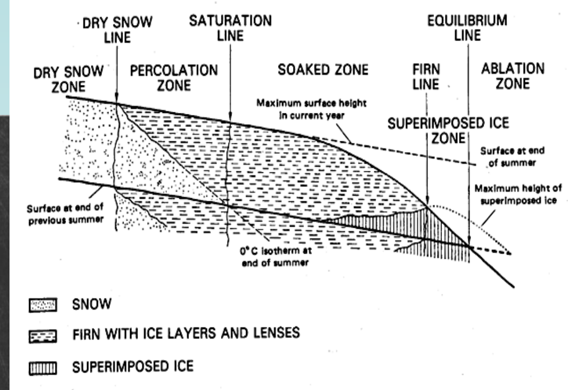
1 - School of Geosciences, University of Edinburgh, UK.
2 - School of Geoscience, University of Aberdeen, UK.
3 - British Antarctic Survey, Cambridge, UK.
4 – Alfred Wegener Institute, Bremen, Germany.
5 – Scott Polar Research Institute, University of Cambridge, UK.
6 – European Space Agency, ESTEC, Holland.
7 – Centre for Polar Observation, University College, London, UK

NATURAL ENVIRONMENT RESEARCH COUNCIL

CRYOSAT 2

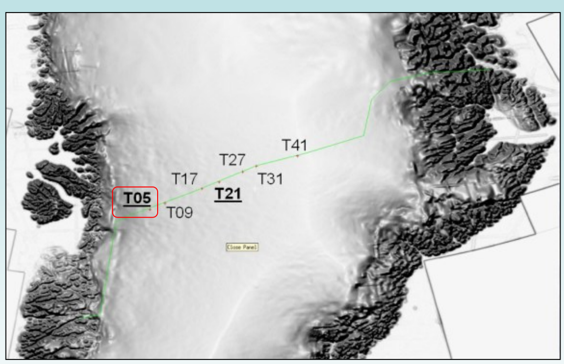
Jezek et al., 1994, GRL





Greenland snow facies, *Benson, 1962*

- CryoSat CVRT – Land Ice – EGIG line, Greenland
- Spring and Autumn 2004, Spring 2006



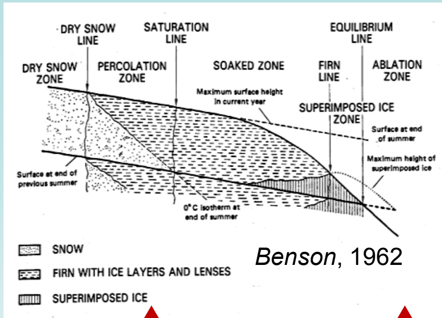
Field Team Members

Nienow[1], Mair[2], Chastin[1], Helm[3] Spring 2004

Nienow[1], Mair[2], Parry[1], Scott[2,1] Autumn 2004, Spring 2006

([1] Univ. of Edinburgh, [2]Univ. of Aberdeen, [3]AWI)

Ambition



Benson, 1962

VHB GPR

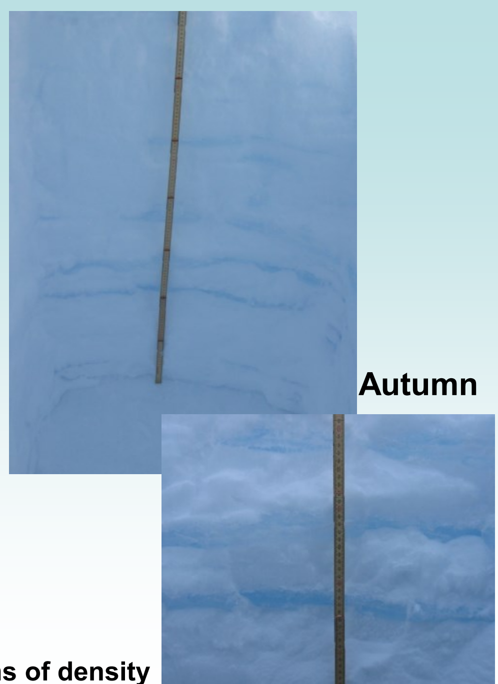
Airborne Radar Altimetry (ASIRAS)

CryoSat-2

First issue:

1) How do we know that the satellite is measuring the surface elevation (and thus elevation change) accurately to a few cm?

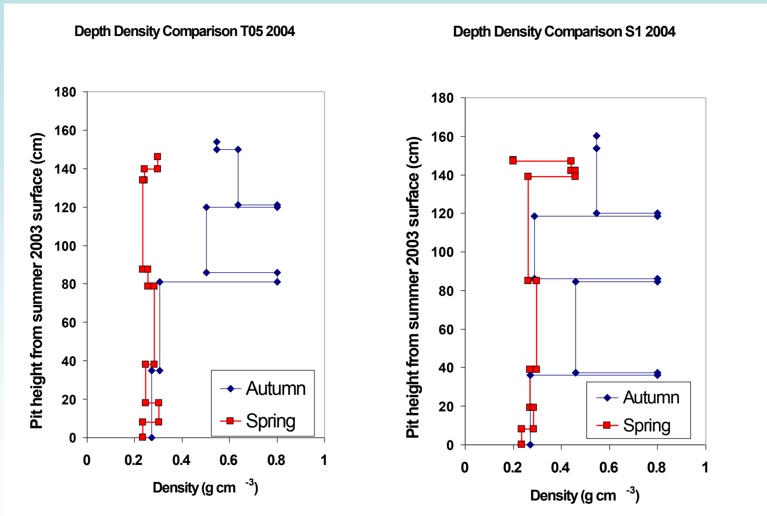
Spring



Autumn

Snow/firn varies seasonally in terms of density

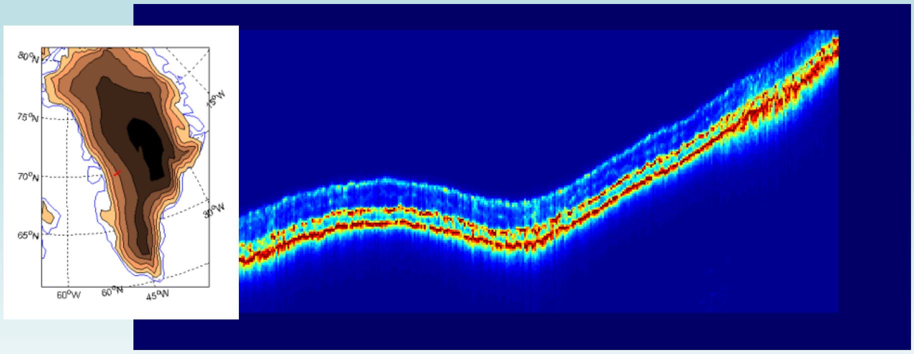
Snowpit density structure - spring and autumn 2004

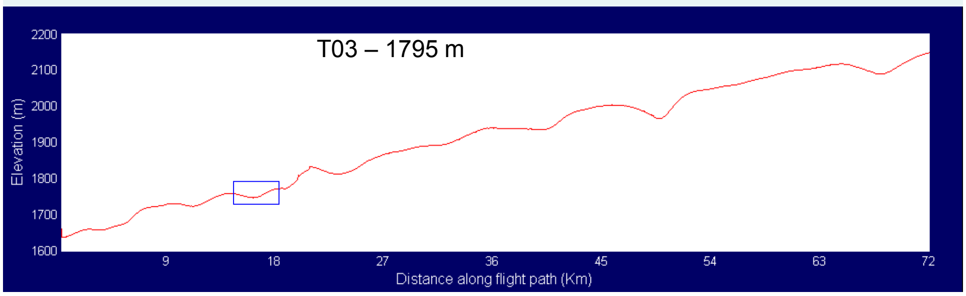


Parry et al, *Annals of Glac.*, 2007

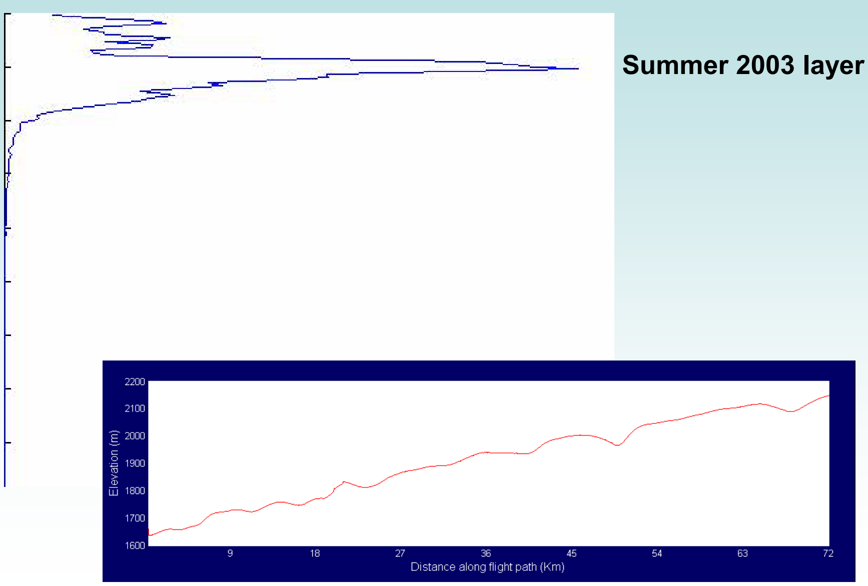
Ground and airborne radar experiments reveal…

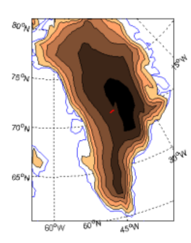
Percolation zone – spring 2004



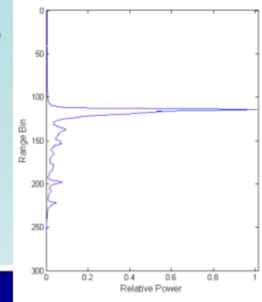


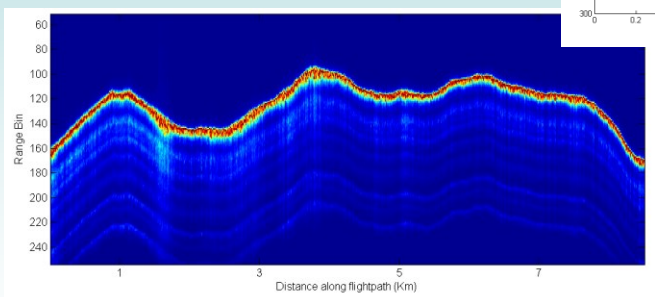
Spring 2004 – strongest radar return is from depth in the snowpack





Percolation zone – autumn 2004



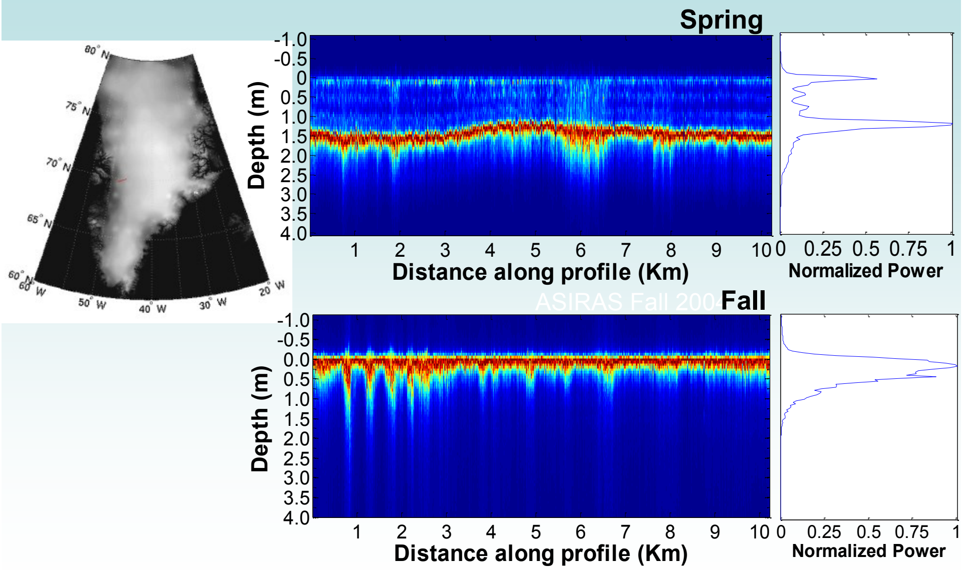


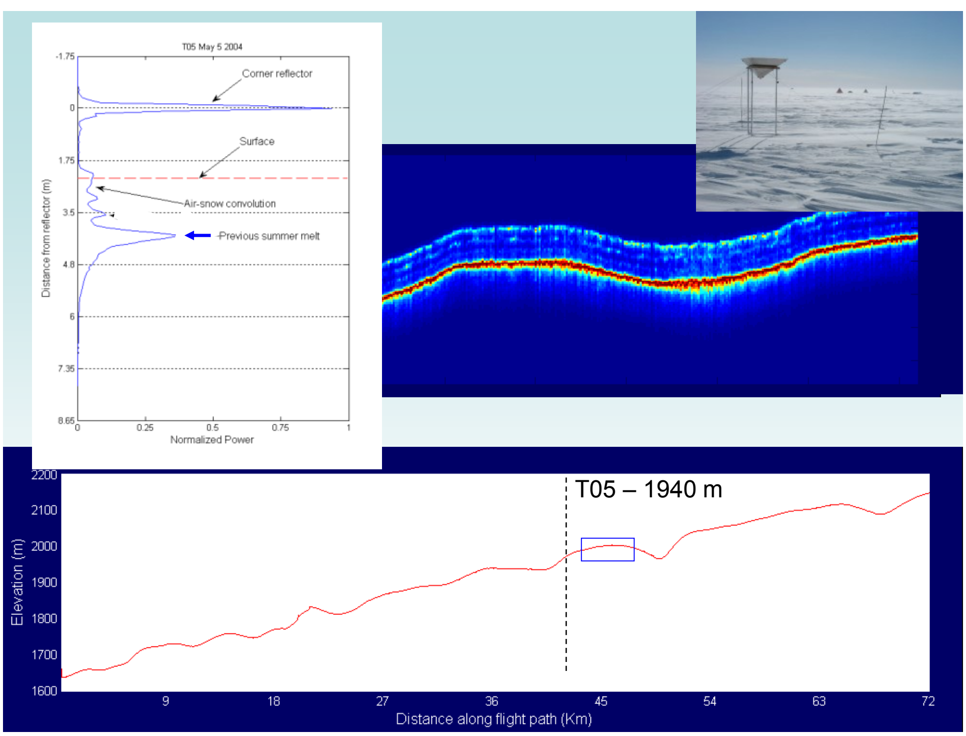
End of melt season – strongest radar return from the surface

Understanding revealed by comparing ground with airborne (ASIRAS) data

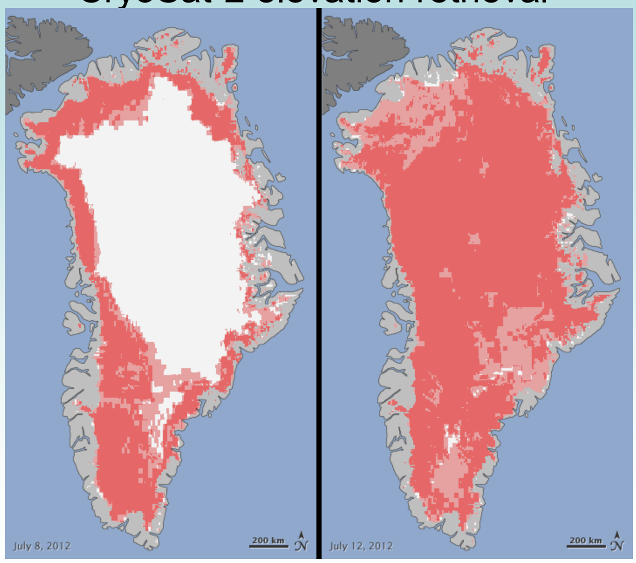
2004 - ASIRAS over the percolation zone (T5) of the GrIS

Variable radar signature caused by a stratified snowpack structure





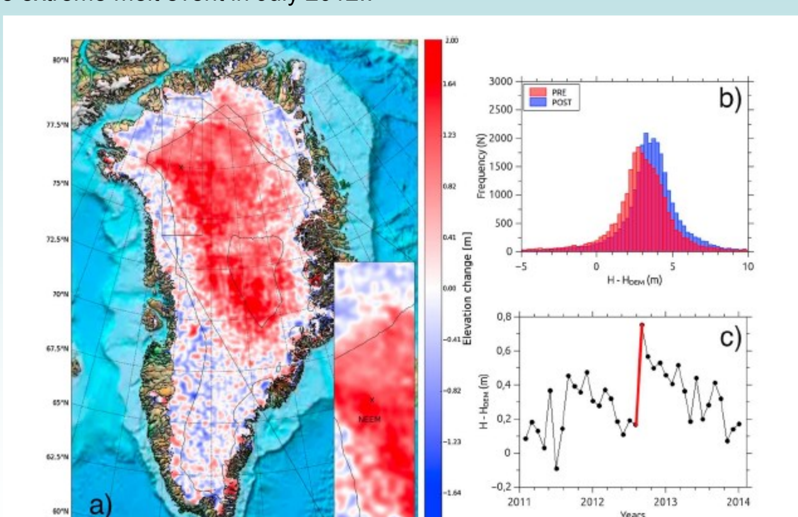
And evidence of changing reflecting horizon on CryoSat-2 elevation retrieval



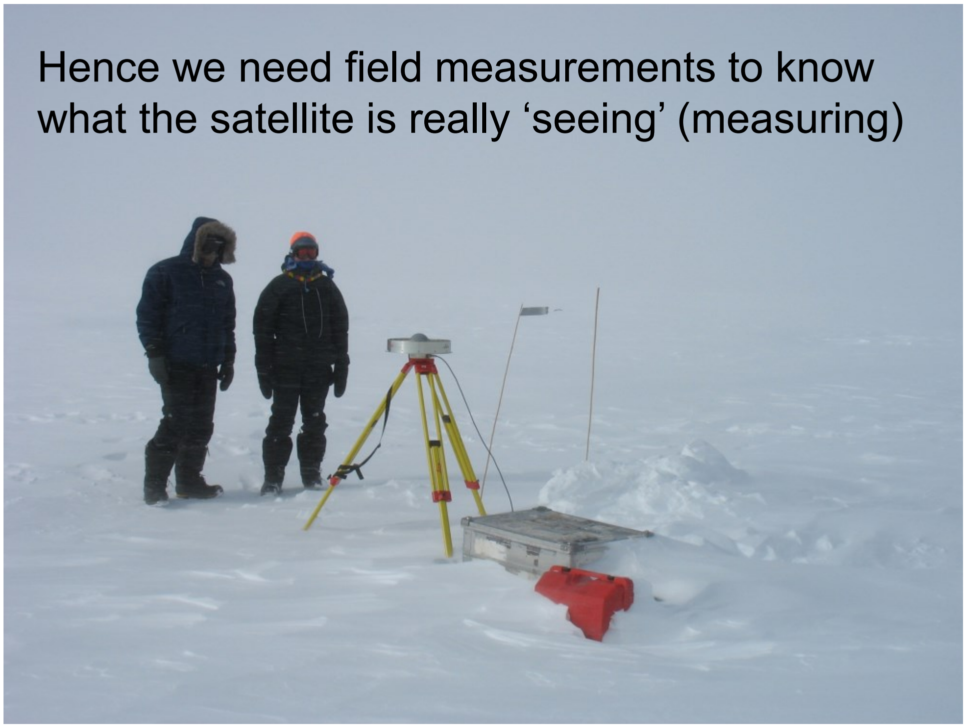
8 July 2012 12 July 2012

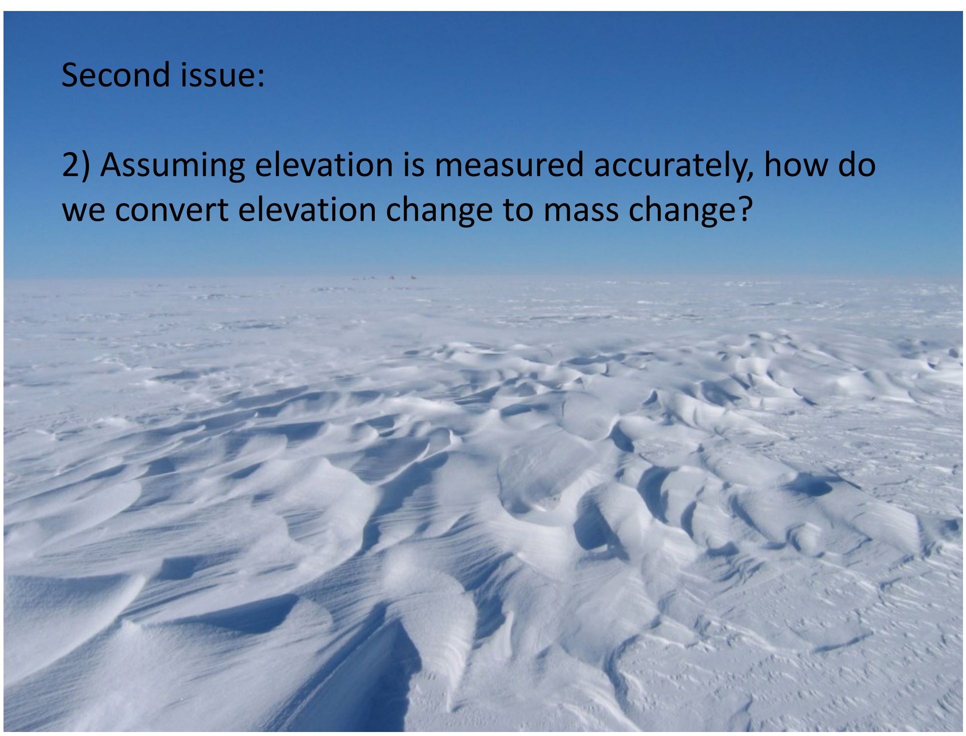
Implications for satellite measurements

An apparent elevation increase of 56±26 cm in Greenland's accumulation zone between June and September 2012 from CryoSat-2 L2i data following the extreme melt event in July 2012..

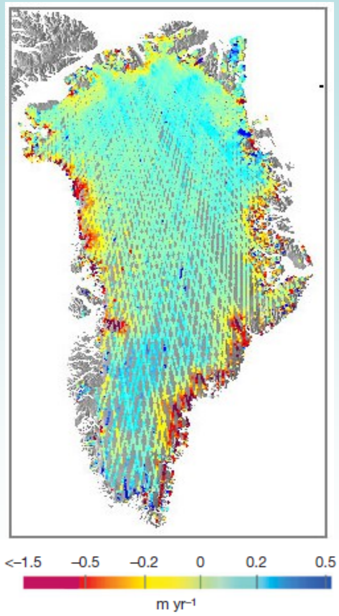


Nilsson et al, 2015, *GRL*


Hence we need field measurements to know what the satellite is really 'seeing' (measuring)


Second issue:
2) Assuming elevation is measured accurately, how do we convert elevation change to mass change?

2003-2007 elevation change rate for the Greenland Ice Sheet

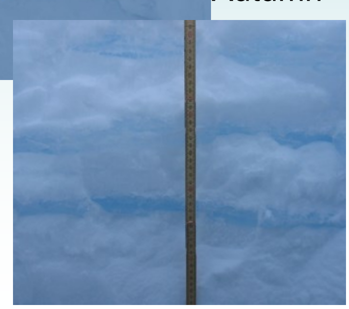


What does this elevation change plot mean for mass change (and thus sea level rise)

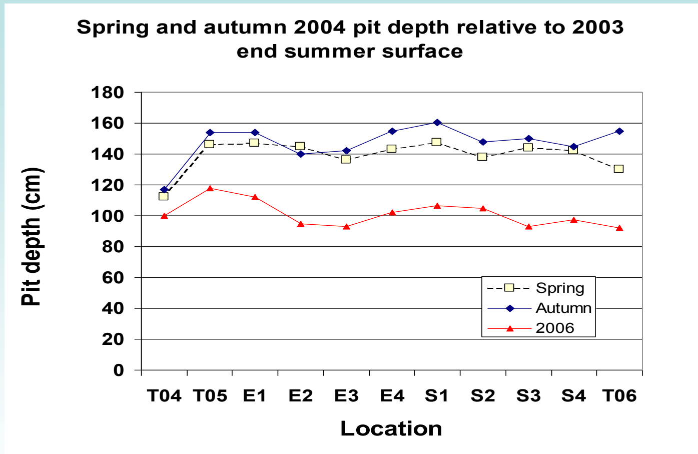
Pritchard et al., *Nature 2009*

Spring

Autumn



Spring and autumn snow depths



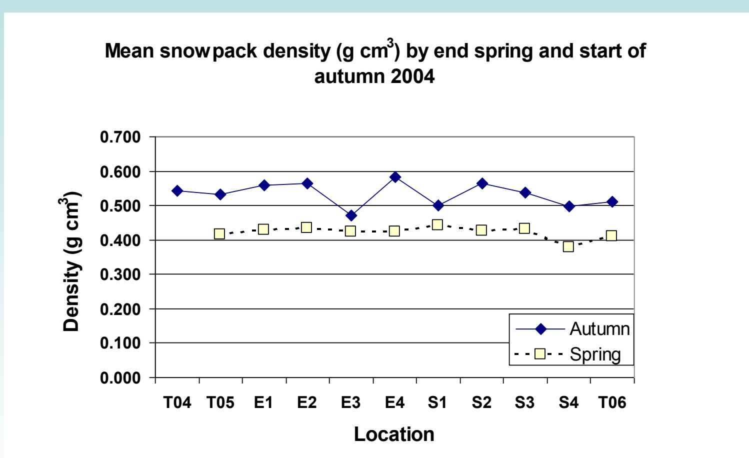
	Spring	Autumn	**2006**
Mean	139.1	147.3	**101.3**
SD	10.4	11.8	**8.1**
%	7.5	8.0	**9.6**

2004

2004 autumn snowpack ~ 5% thicker c/w spring

Parry et al, *Annals of Glac.*, 2007

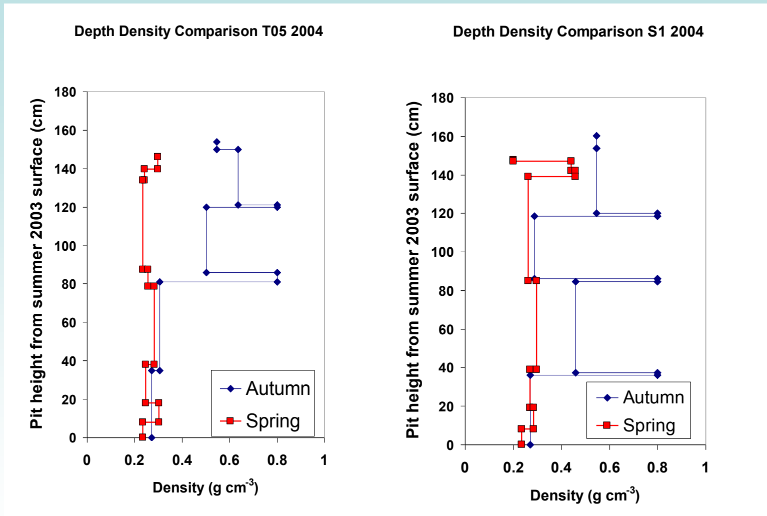
Spring and autumn mean snow densities



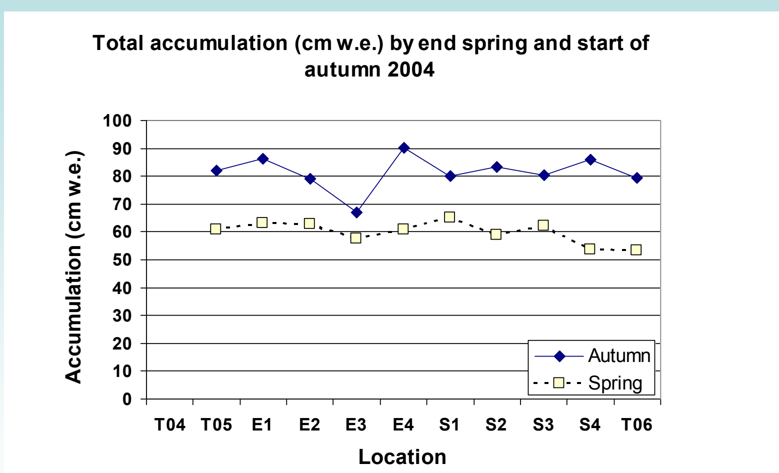
	Spring	Autumn
Mean	0.410	0.532
SD	0.018	0.036
%	4.34	6.772

Autumn snowpack ~ 23% denser

Snowpit density structure - spring and autumn 2004



Spring and autumn water equivalents



	Spring	Autumn
Mean	59.8	81.4
SD	4.0	6.1
%	6.9	7.6

Summer = 26.5% annual accumulation

Parry et al, *Annals of Glac.*, 2007

Hence, we need to know how density changes between measurements to be able to convert height change to mass change – **this requires fieldwork**.

And the density used for converting volume change to mass change has huge implications for mass balance and sea level rise estimates?

See current debate re latest Zwally et al (*J.Glac*. 2015) estimates of Antarctica mass balance

***Tempora*l and *spatial* resolution of satellite data often means that they are not ideal for inferring ice-sheet processes**

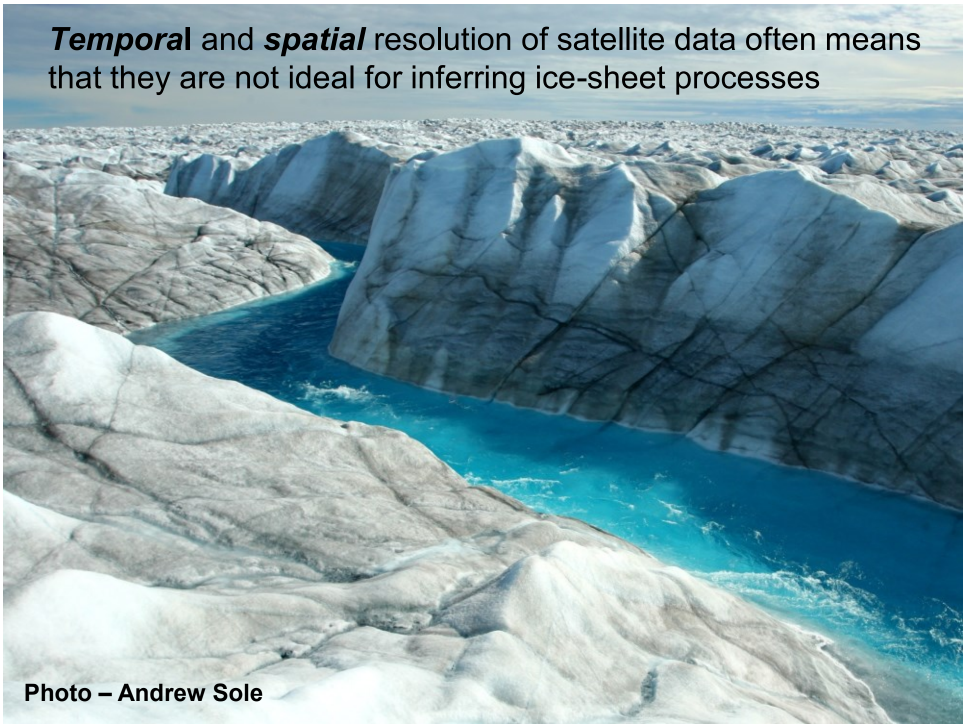


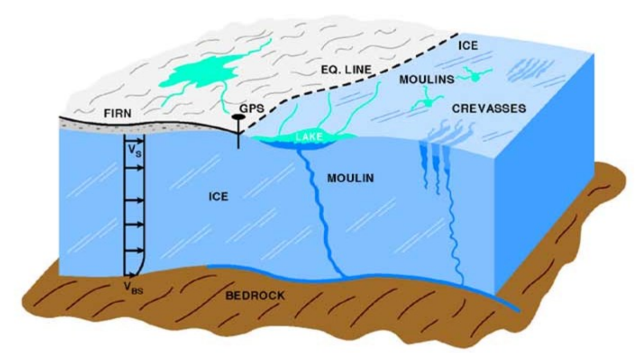
Photo – Andrew Sole

The example of supra-glacial lakes

Numerous in summer on the margins of the Greenland Ice Sheet.

Images from http://www.whoi.edu/oceanus

Lakes may be important for the future dynamic response of the ice sheet?

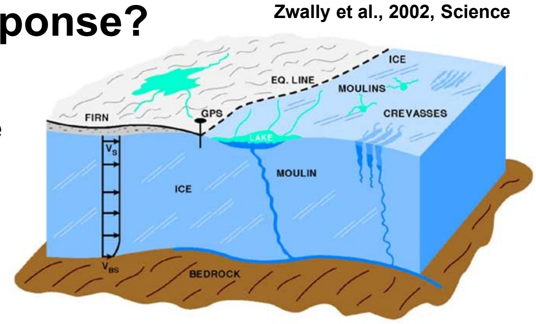


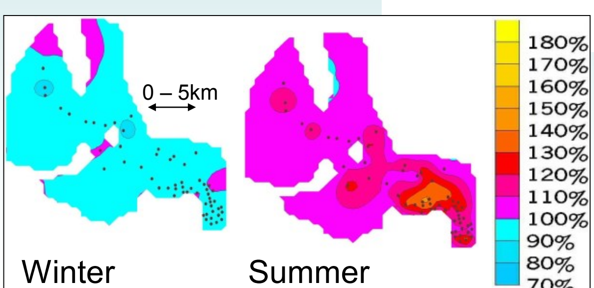
Zwally et al., 2002, Science

Future dynamic response?

- Will the ice sheet interior/margin accelerate with climate warming?
- Hypothesis: melt increases runoff, enhancing basal sliding

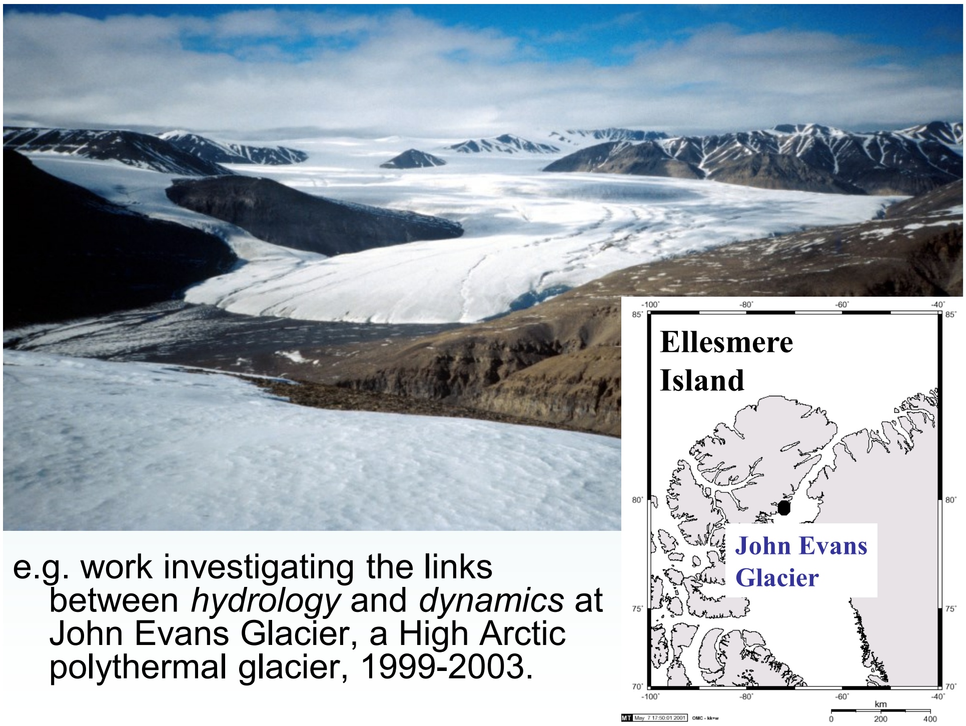
Zwally et al., 2002, Science





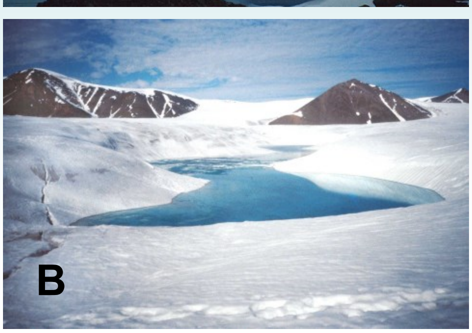
- Behaviour typical of polythermal and temperate glaciers

Glacier velocity (% increase/decrease from annual mean) **Bingham et al.,** ***2003, Ann. Glac.***



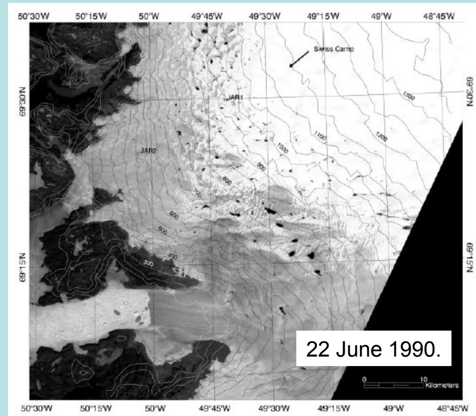
e.g. work investigating the links between *hydrology* and *dynamics* at John Evans Glacier, a High Arctic polythermal glacier, 1999-2003.

Speed-up driven by supraglacial meltwater inputs



Supra-glacial lakes

During summer, lakes up to several kilometers square form on the surface of the ice near the ice sheet margin.



Landsat image in Zwally et al., 2002, *Science.*

Image from http://www.whoi.edu/oceanus

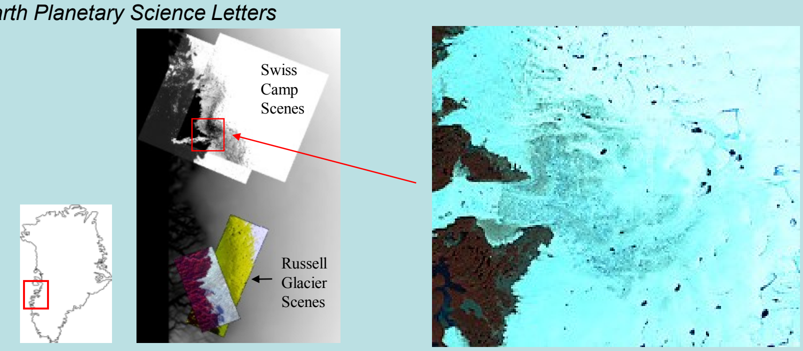
How do these lakes behave during the course of a melt-season?

Remote Sensing Data

Comparison of images from two sites in W Greenland – early July 2001 and early August 2001.

Survey of lake area conducted for lakes > 0.01 km^2 on both dates.

McMillan et al, 2007
Earth Planetary Science Letters

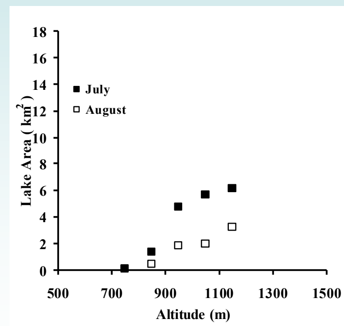


Landsat scene, 7th July 2001

Substantial drainage of lakes observed

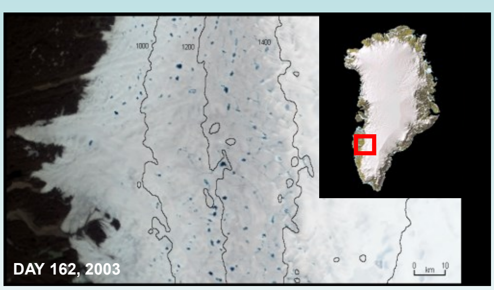
Drainage at ~950 m on Russell Glacier

Russell Glacier lake aerial extent

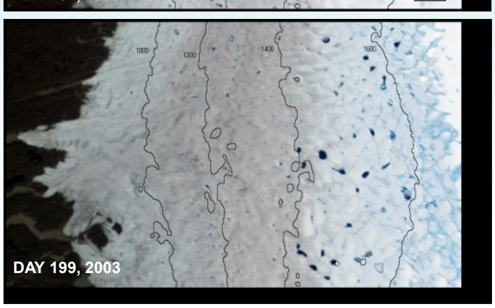


McMillan et al, 2007
Earth Planetary Science Letters

A more extensive study of lake drainage was undertaken by Sundal et al. using MODIS data



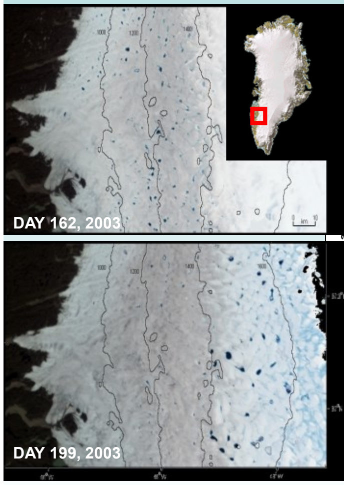
~10 June

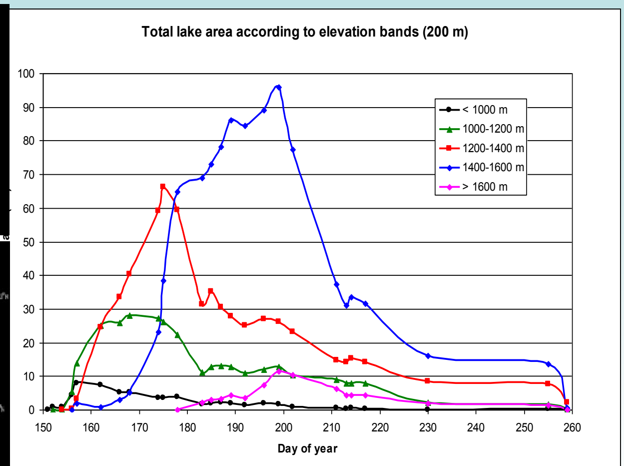


~20 July

Sundal et al, 2009
RSE

Supra-glacial lakes





Evolution in supra-glacial lake area according to elevation above sea level in the 'Russell' catchment, W. Greenland, during the 2003 melt season.
Sundal et al, *RSE,* 2009

These observations tell us about evolution in lake area but nothing about:

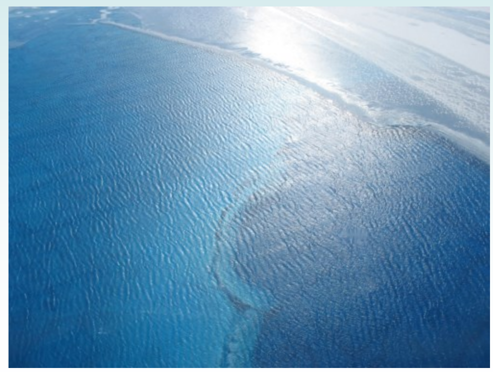
1) the processes involved in lake drainage or of
2) their importance for ice sheet dynamics

July

Detailed study of lake drainage by Das et al, 2008 (*Science*)

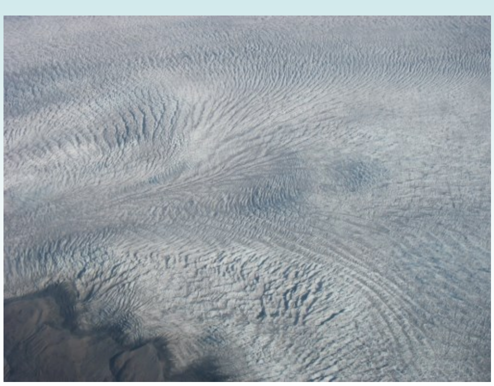
Field based study in west Greenland in 2006

- Monitored two lakes located at ~1000m
- Max diameters ~ 2 km
- Cold ice
- Ice ~1km thick
- Western margin of Greenland Ice Sheet



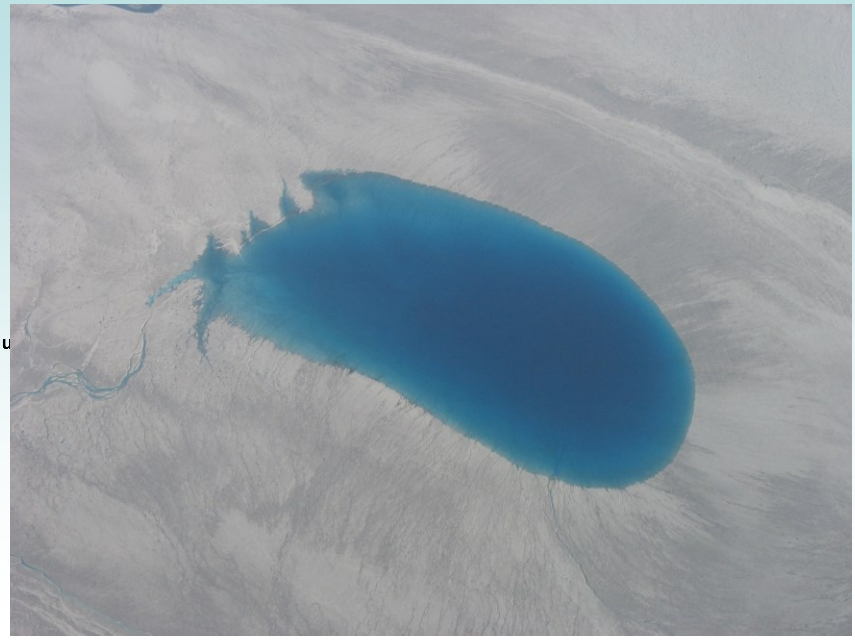
Concluded the cause of drainage = hydrofracture

- Ice sheet uplift and acceleration = drainage to ice-bed interface
- Average flow rate: 8700 m^3/s (exceeds that of the Niagara Falls)

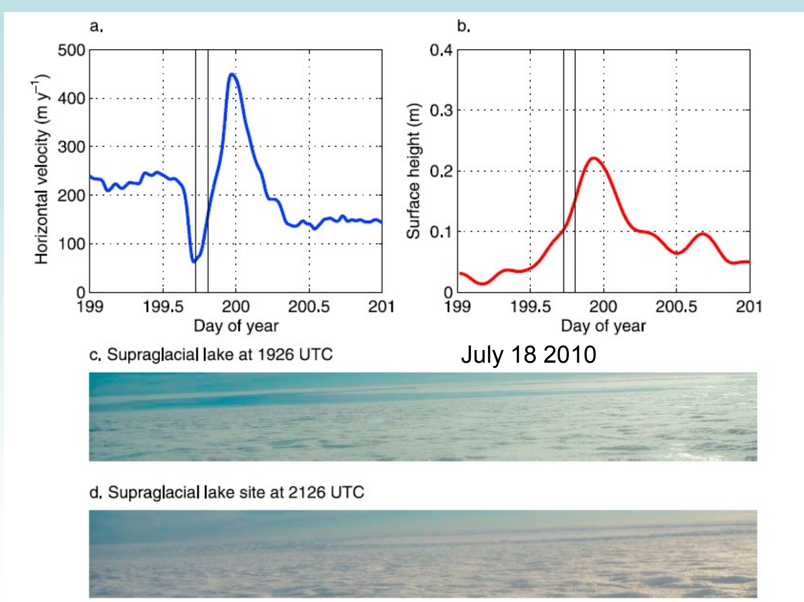


And the implications for ice sheet dynamics?

Ju



Ice motion from lake drainage = short-lived and not important

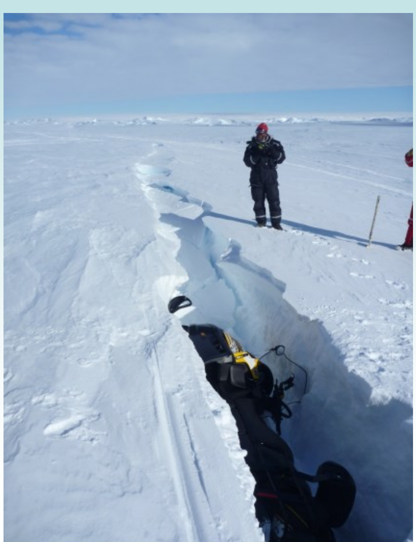


Bartholomew et al, JGR, 2012

Again, detailed field based observations needed to understand process and significance

Take home message is a cautionary tale

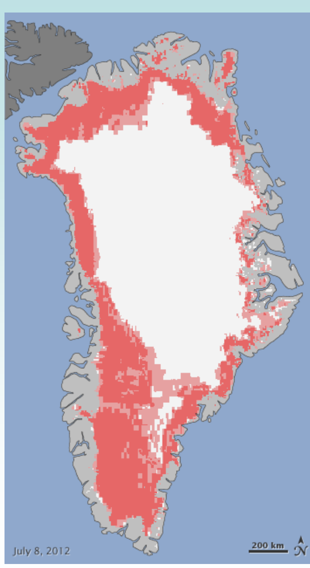
Satellites are very important for enhancing our understanding of global processes but …..



i) they need to be calibrated to be accurate and provide reliable data and

ii) fieldwork is still essential for understanding most landscape processes because of the limited temporal and or spatial (i.e. detailed) resolution of most satellites.

So please make sure you're familiar with both the field literature as well as the satellite literature!



8 July 2012


THANKYOU