Hot Science Cool Talks

UT Environmental Science Institute

55

Giant Ice Sheets Threaten Globe!? Climate Change and the Greenland Ice Sheet

Dr. Ginny Catania

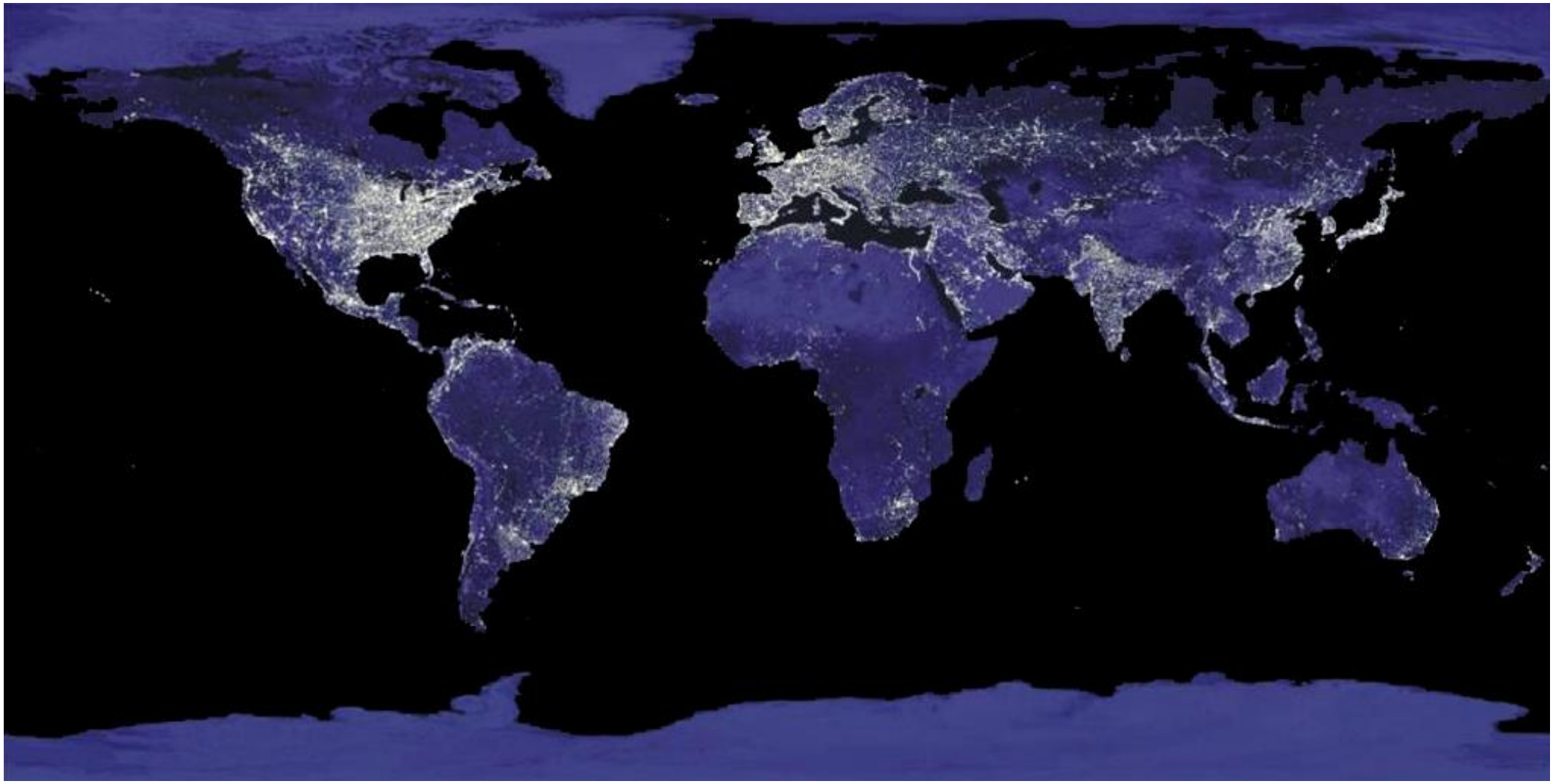
September 5, 2008

Climate change and the Greenland Ice Sheet

Ginny Catania
Institute for Geophysics, University of Texas, Austin

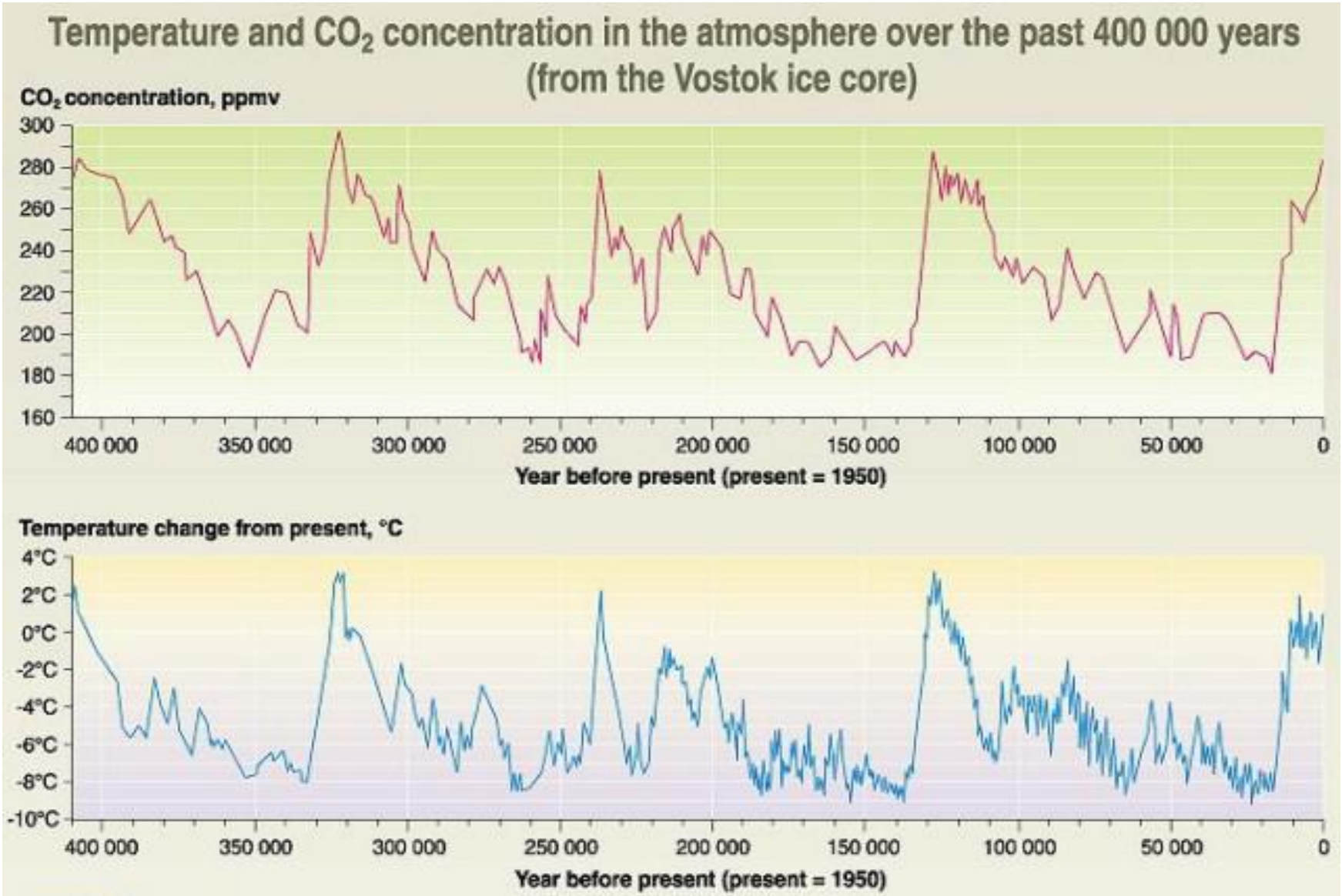
THE UNIVERSITY OF TEXAS AT AUSTIN
JACKSON
SCHOOL OF GEOSCIENCES

Motivation: The changing climate



Earth at Night

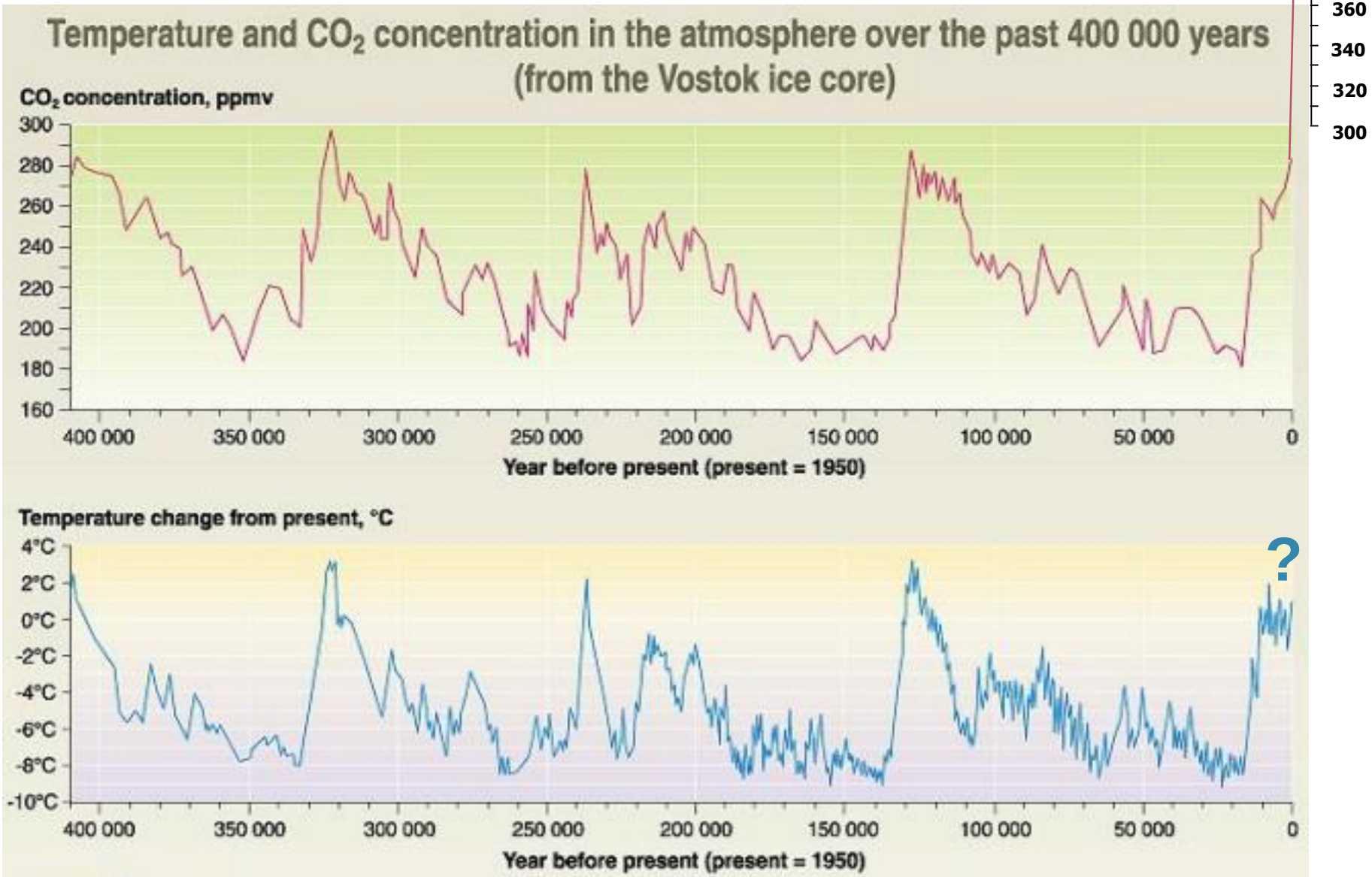
Past Climate Changes



Source: IPCC Report on climate change

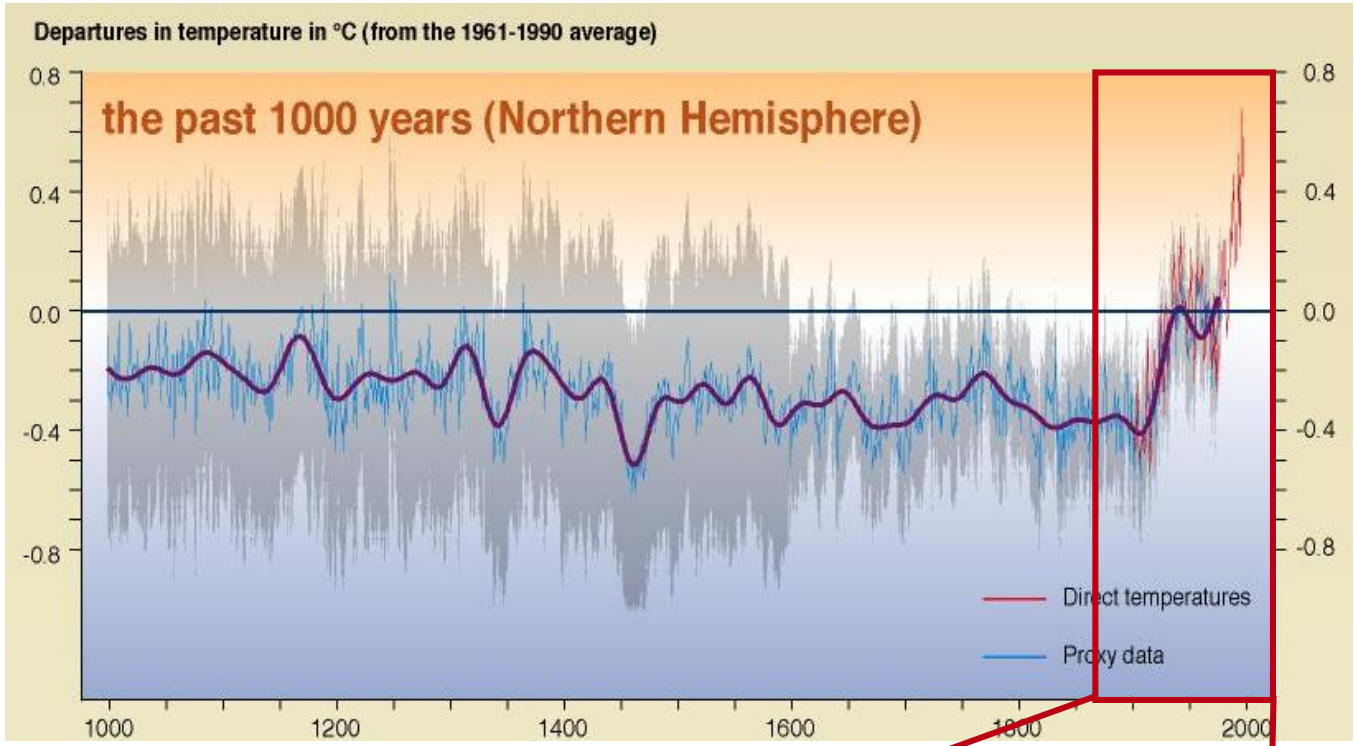
Past Climate Changes

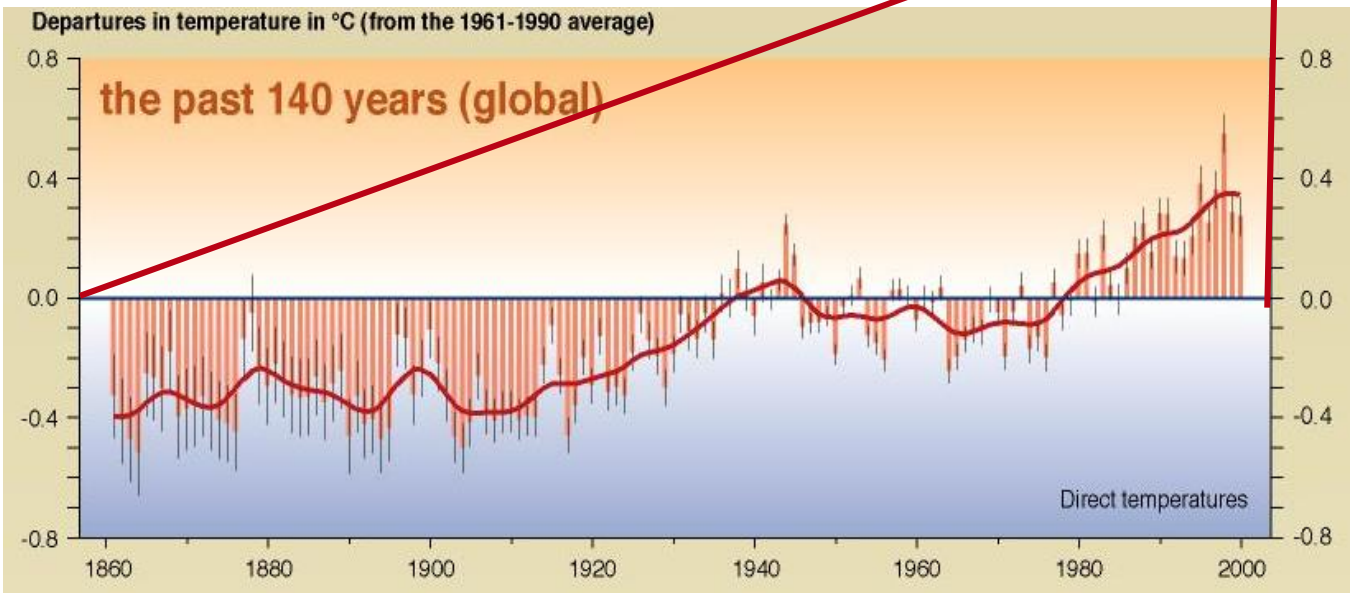
Today's atmospheric CO_2 concentration: **380 ppmv**



Source: IPCC Report on climate change

Recent climate changes



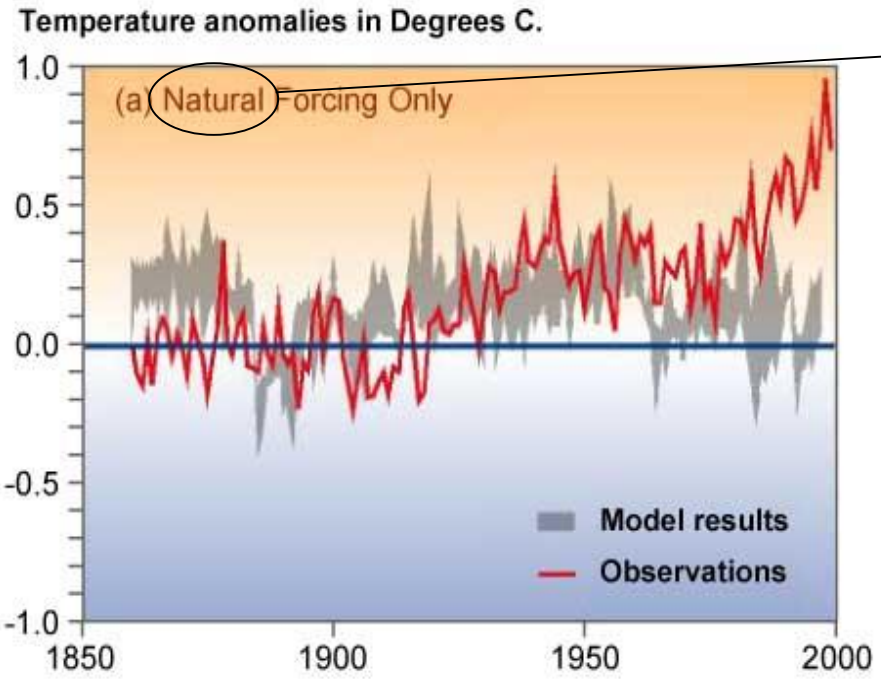


10 warmest years since 1860 have been in the last decade.

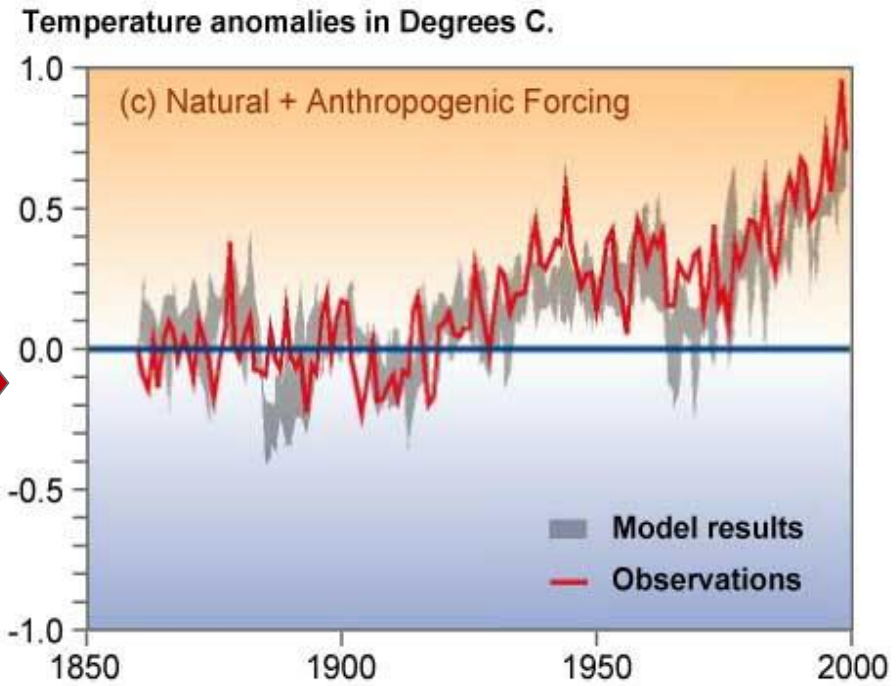
1) 2005
2) 1998
3) 2002
4) 2003
5) 2006
6) 2004
7) 2007
8) 2001
9) 1997
10) 1999

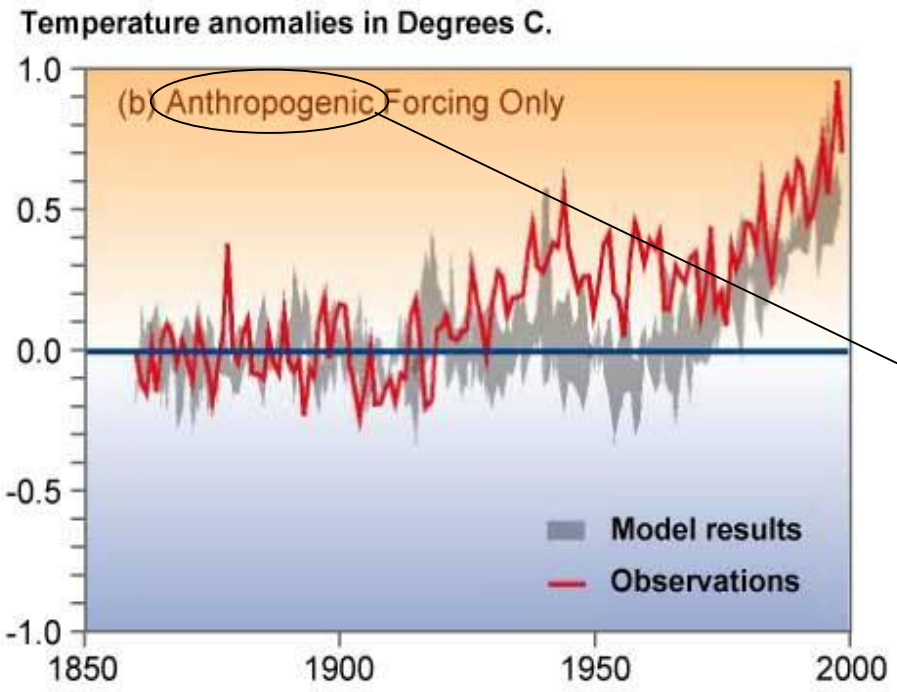
Source: IPCC Report on climate change

What is the scientific consensus?



- volcanoes
- orbital changes
- natural methane emissions





- car emissions
- industrialization

Source: IPCC Report on climate change

What is the scientific consensus?

WMO INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE UNEP

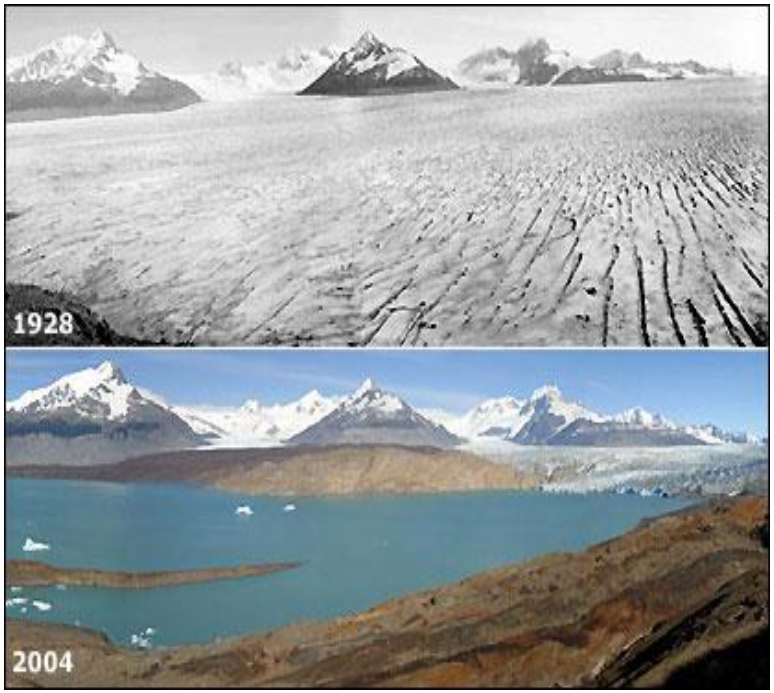
"Warming of the climate system is unequivocal"

"Most of the observed increase in globally averaged temperatures since the mid-20th century is ***very likely*** due to the observed increase in anthropogenic greenhouse gas concentrations. Discernible human influences now extend to other aspects of climate, including ocean warming, continental-average temperatures, temperature extremes and wind patterns."

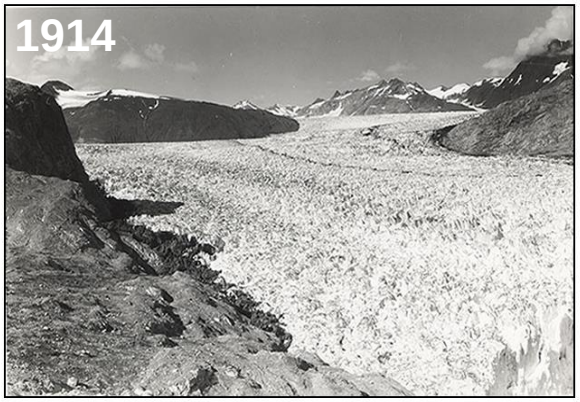
>90% certainty: Humans are changing the Earth's climate

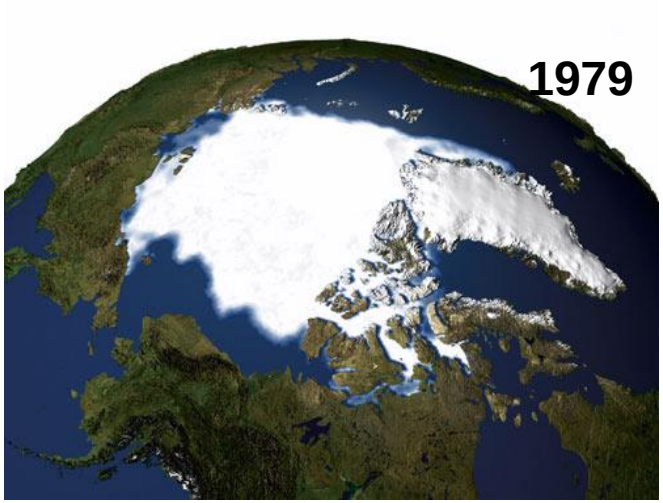
Source: IPCC Report on climate change

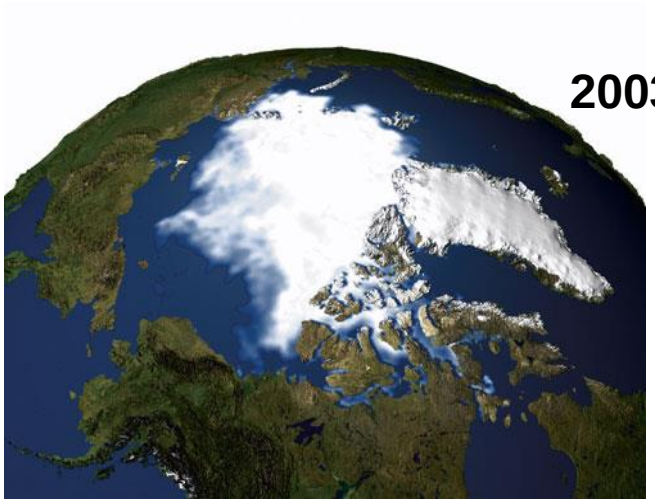
Impact of warming on the cryosphere



Bruce Molina



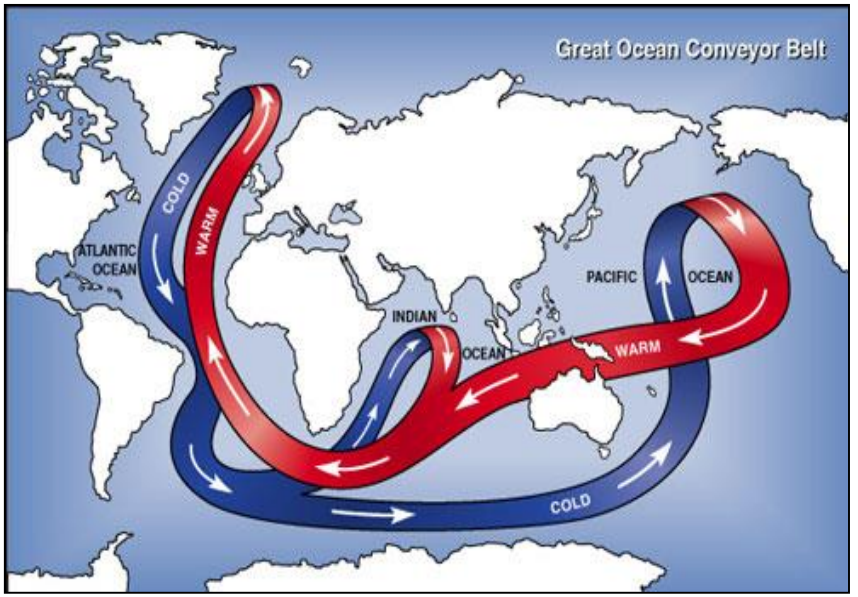


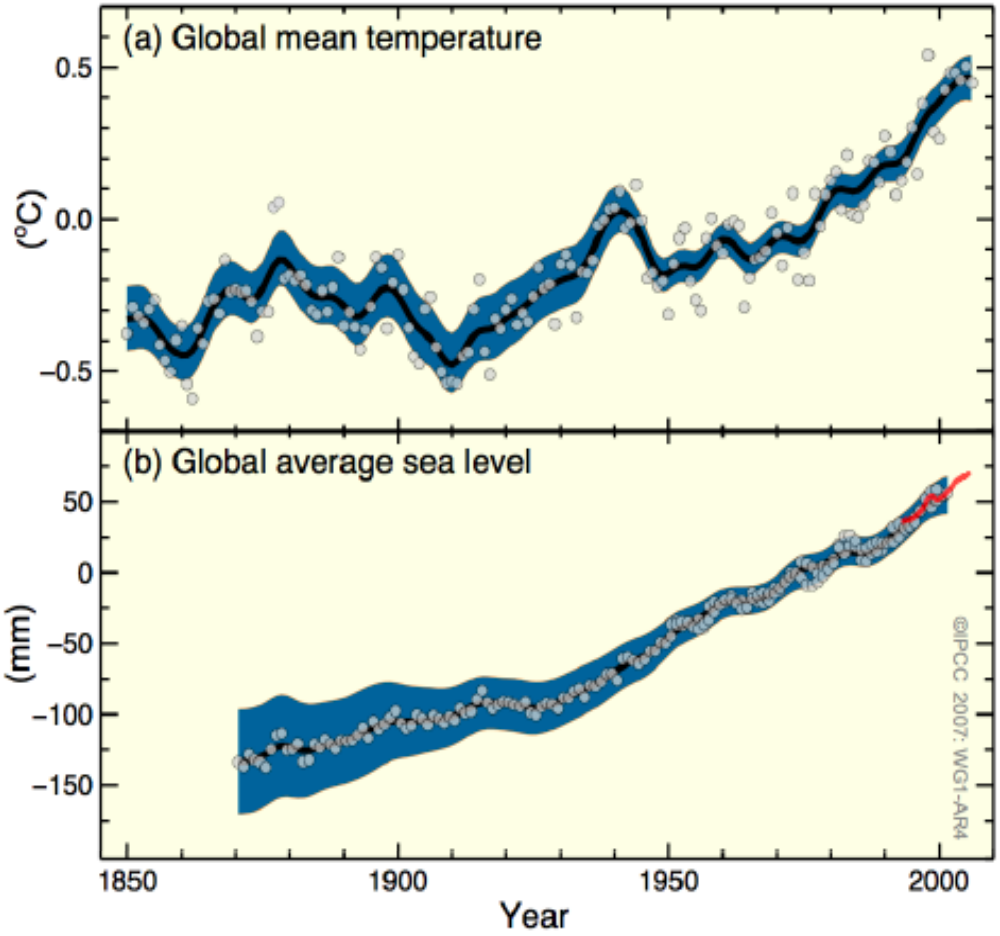


"Chance of an ice-free North Pole this summer is slightly less than 50-50"
J. Zwally (NASA)

Impact of warming on the cryosphere

- Sea-level rise
- Changes to ocean circulation
- Changes to weather patterns
- Changes to habitat

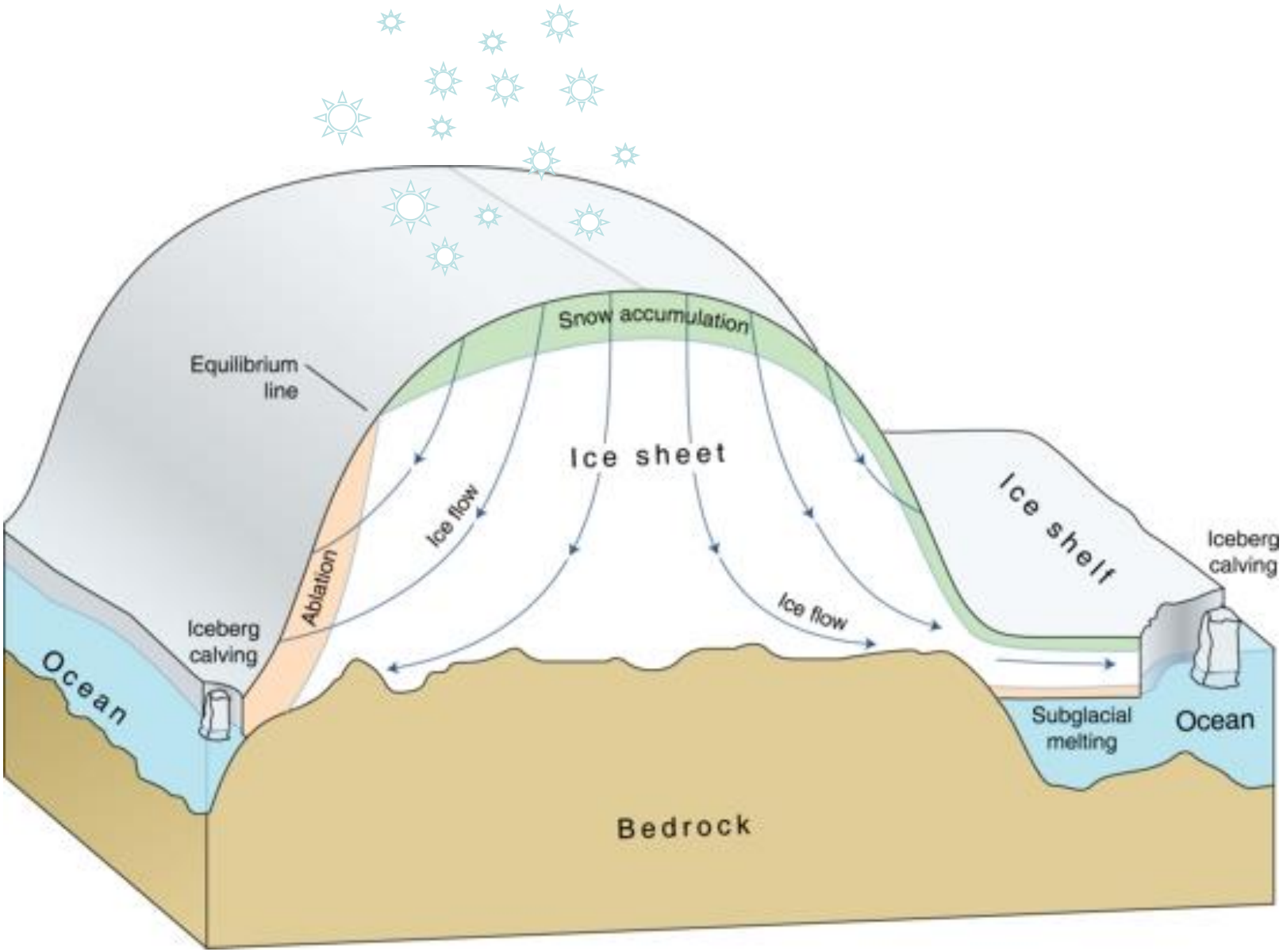




Impact of warming on the cryosphere

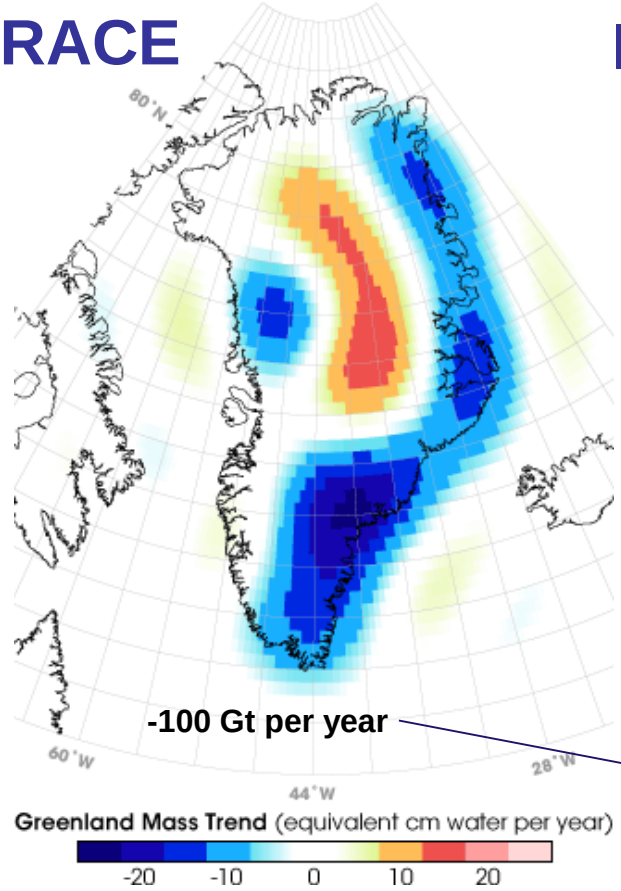
MASS BALANCE = “what goes in” - “what comes out”

If more comes “out” than goes “in”, mass balance is negative

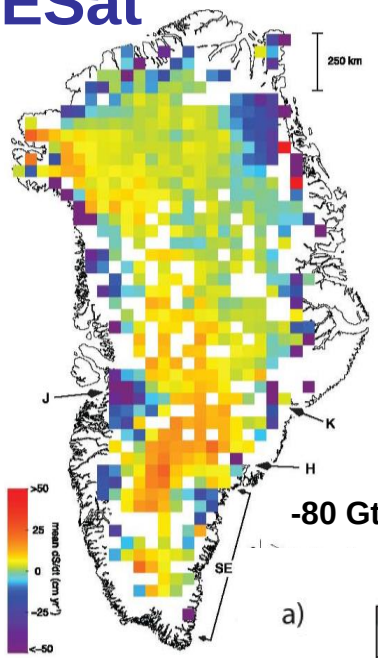


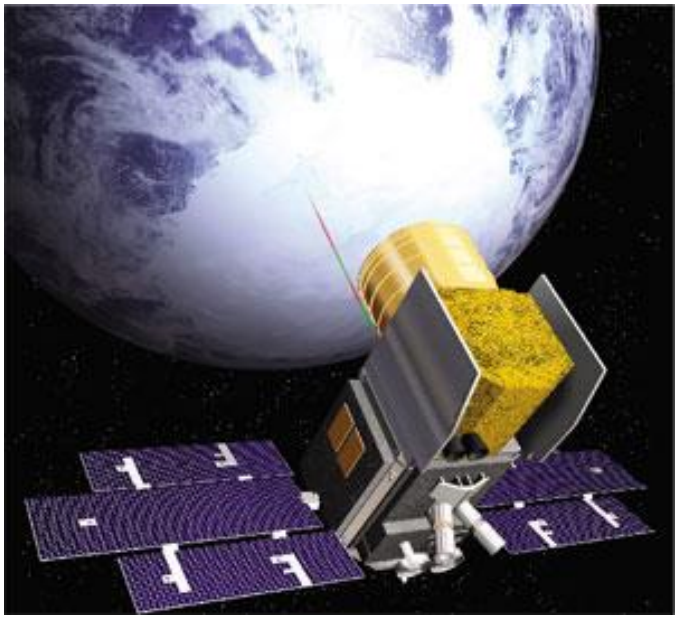
Greenland Mass Balance

GRACE



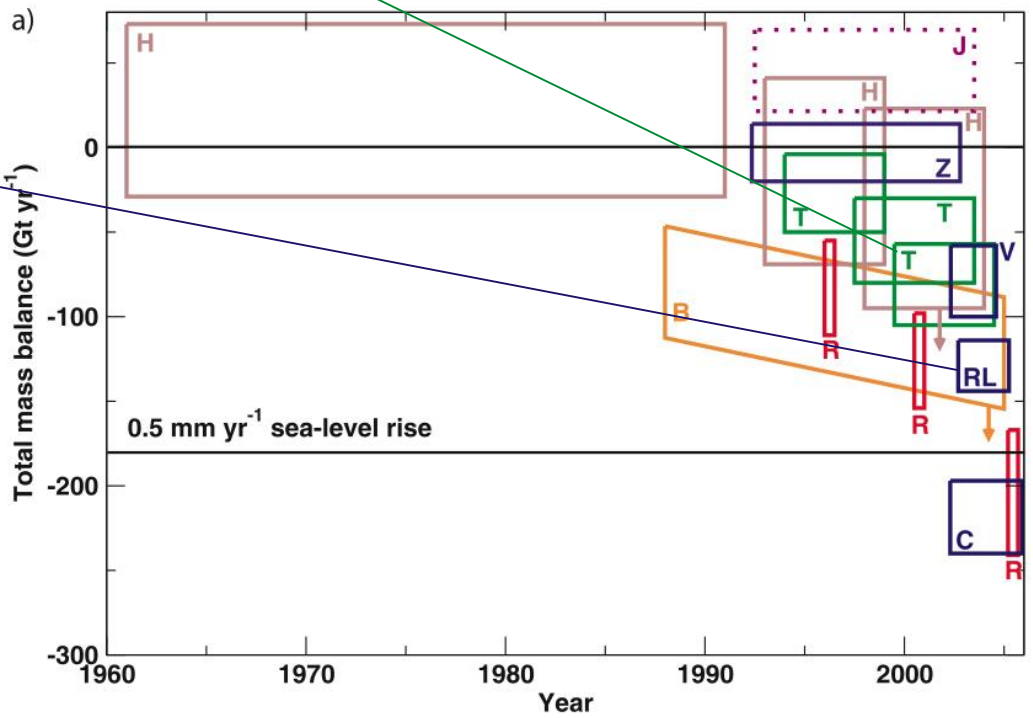
ICESat





-100 Gt per year

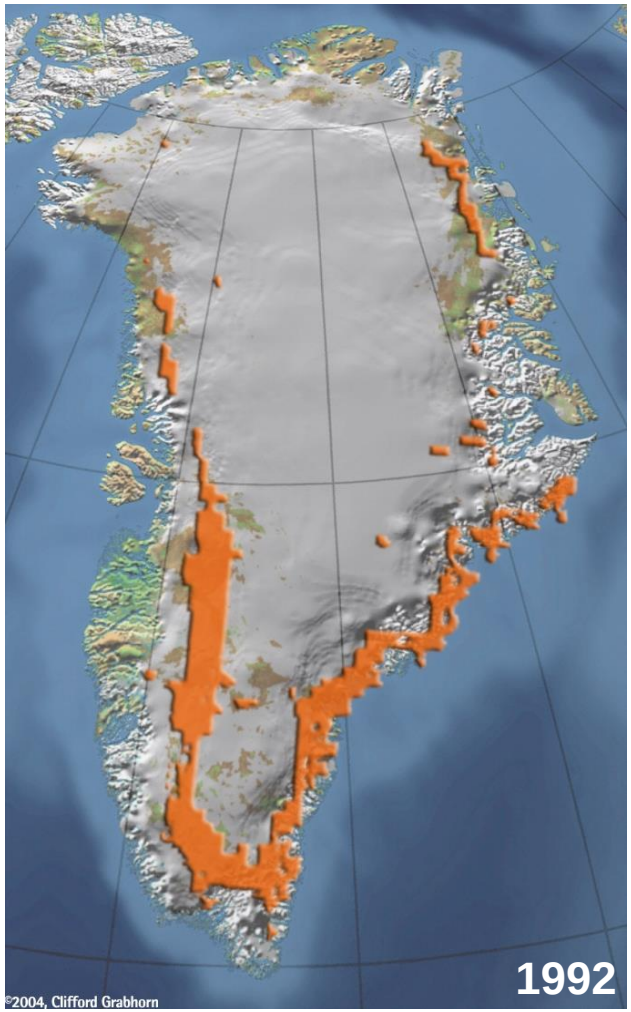
-80 Gt per year

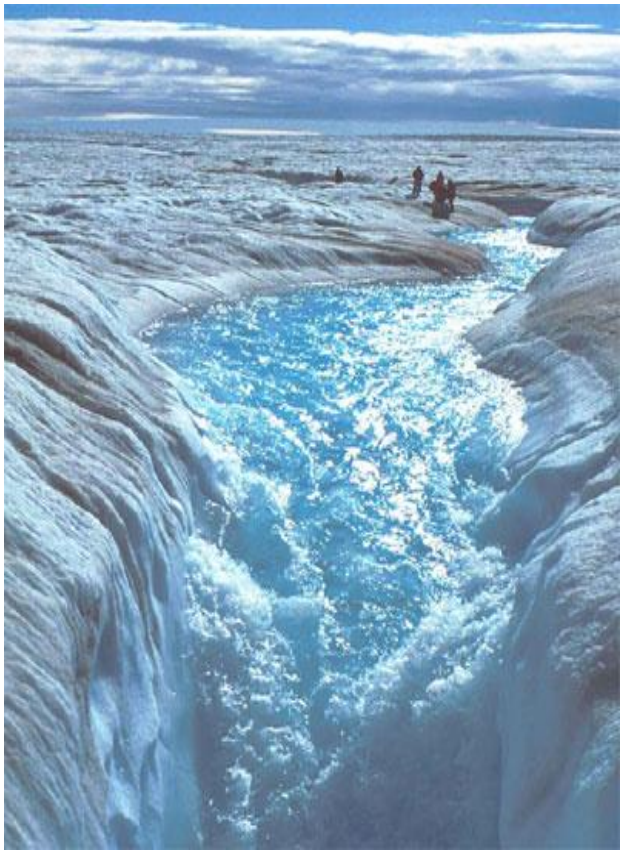


Greenland Ice Sheet = 5 m sea level equivalent

Greenland Mass Balance: Why is it negative?

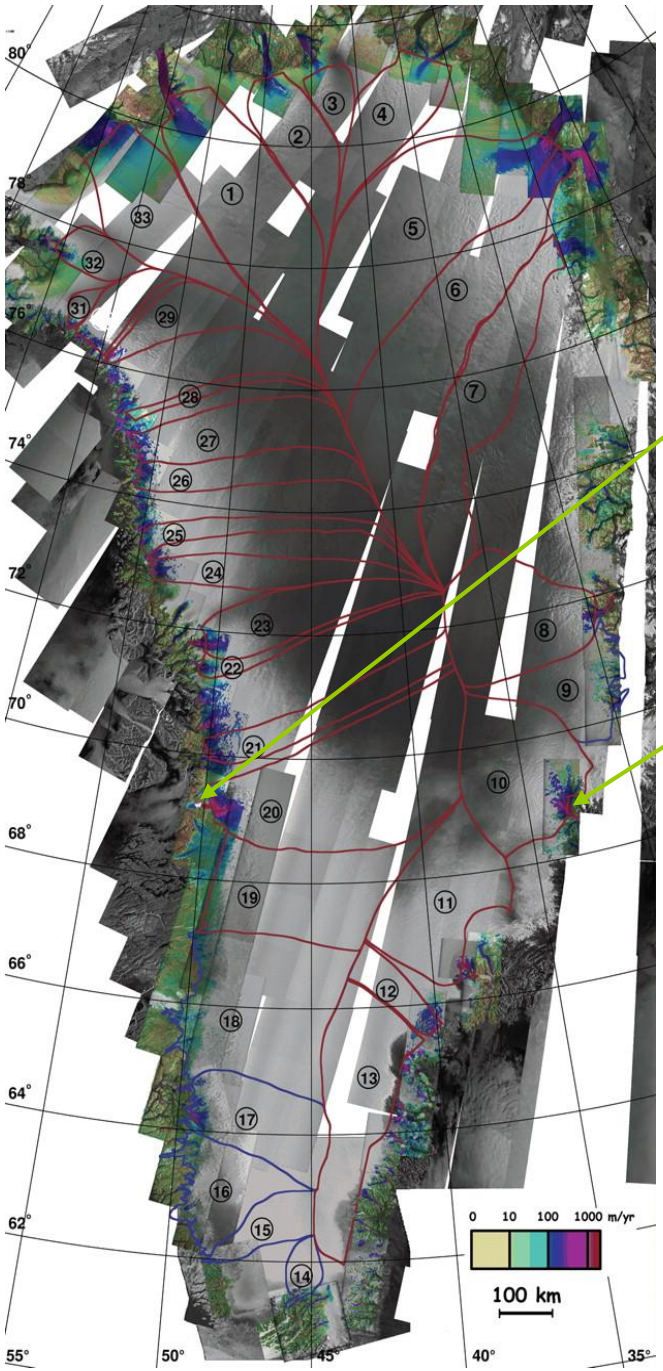
Surface Melt



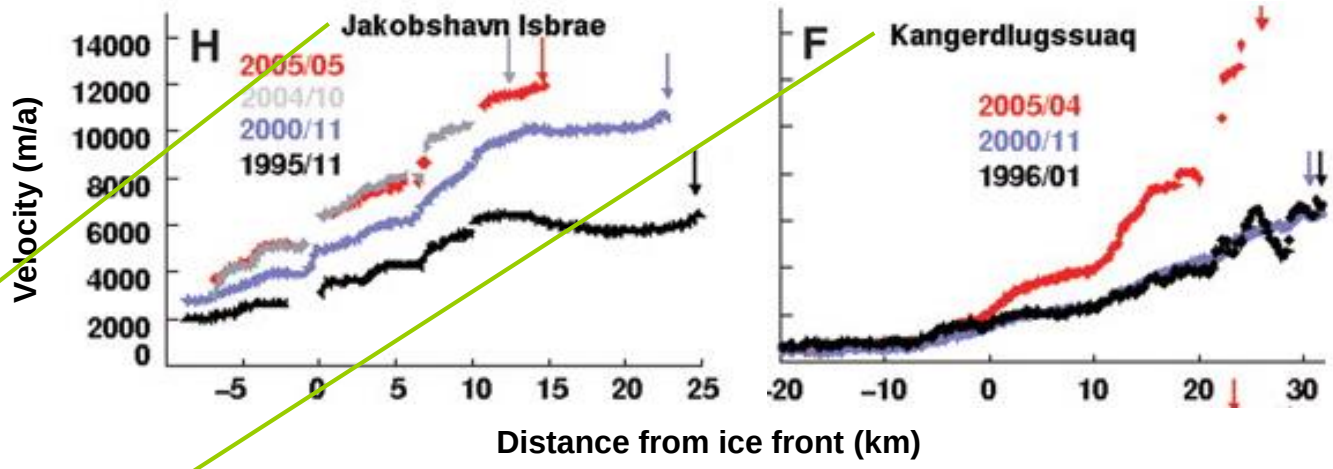


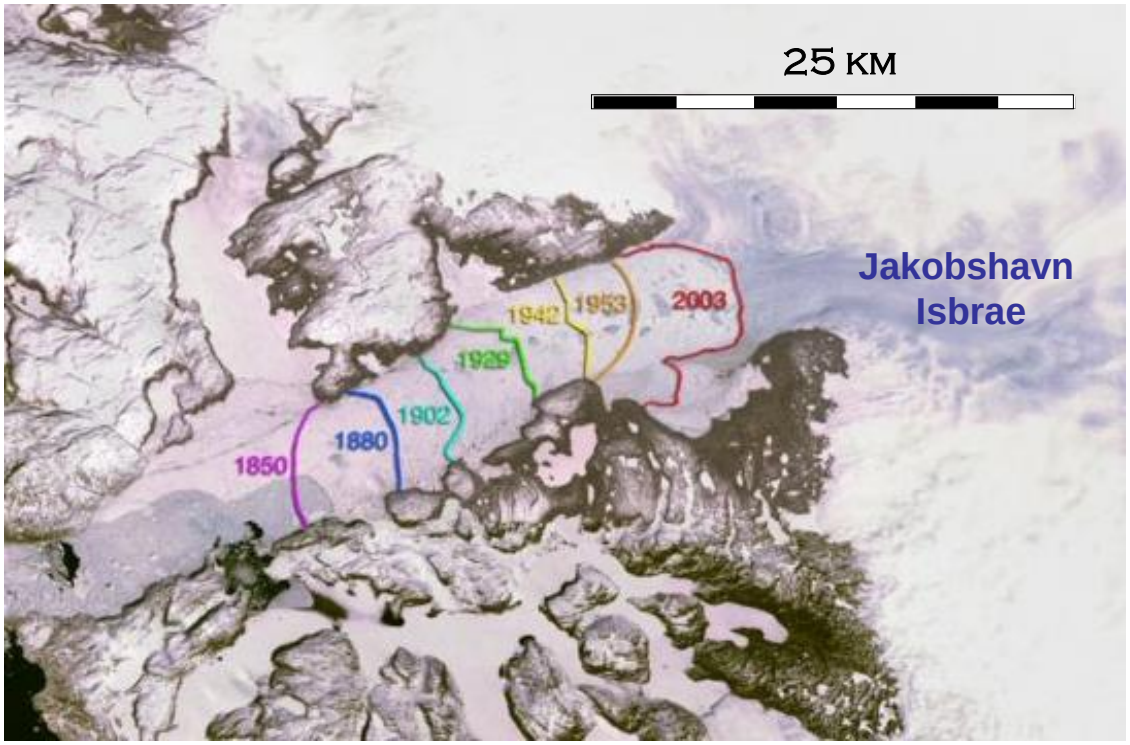
Source: R. Braithwaite; Arctic Climate impact Assessment

Greenland Mass Balance: Why is it negative?



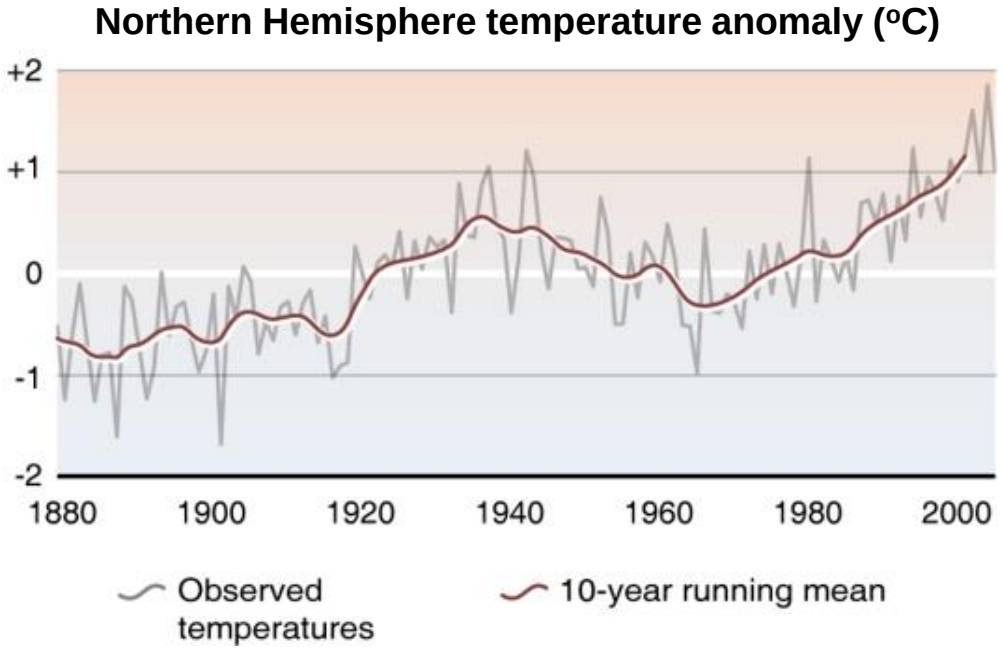
Accelerating glaciers

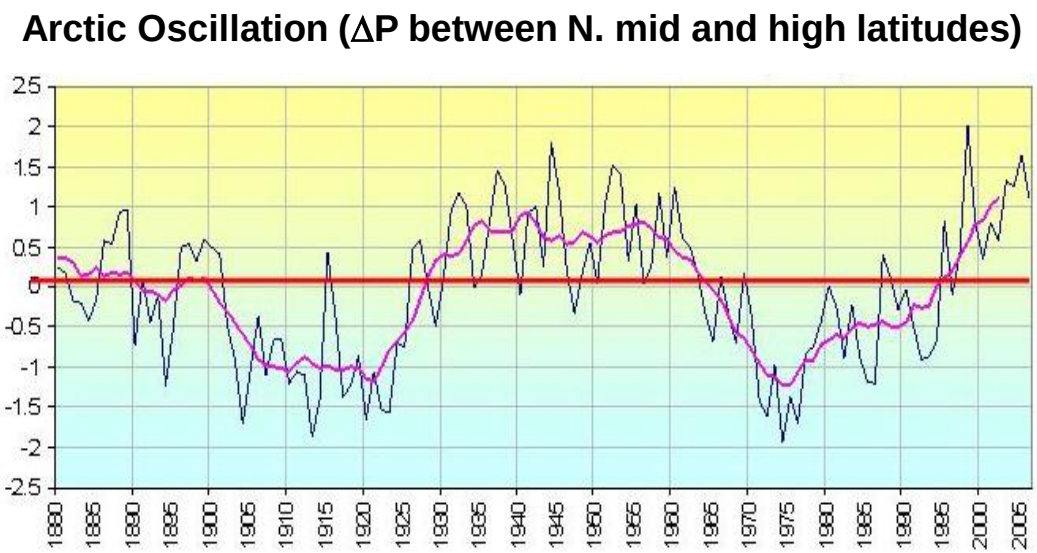




Source: NASA; Rignot & Kanagaratnam, 2006

Greenland Mass Balance: Why is it negative?





- **Natural Variability**
  - *Strong correlation between natural atmosphere-ocean dynamics and observed temperature*

- **Global Warming**
  - **1920's warming isolated in Arctic**
  - **Large 1920's fluctuations not observed today**
  - **Non-NAO controlled regions in Greenland show large warming today**

Conclusion: mass balance is negative due to global

IPCC on the ice sheets

WMO INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE UNEP

Since the TAR, progress in understanding how climate is changing in space and in time has been gained through improvements and extensions of numerous datasets and data analyses, broader geographical coverage, better understanding of uncertainties, and a wider variety of measurements. Increasingly comprehensive observations are available for glaciers and snow cover since the 1960s, and for sea level and ice sheets since about the past decade. However, data coverage remains limited in some regions.

Dynamical processes related to ice flow not included in current models but … could increase the vulnerability of the ice sheets to warming, increasing future sea level rise. Understanding of these processes is limited and there is no consensus on the magnitude. {4.6, 10.7}

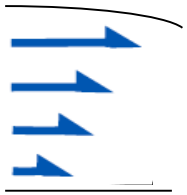
Ice dynamics are important!

Source: IPCC Report on climate change

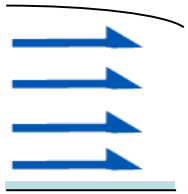
Ice dynamics 101

How ice moves:

internal deformation

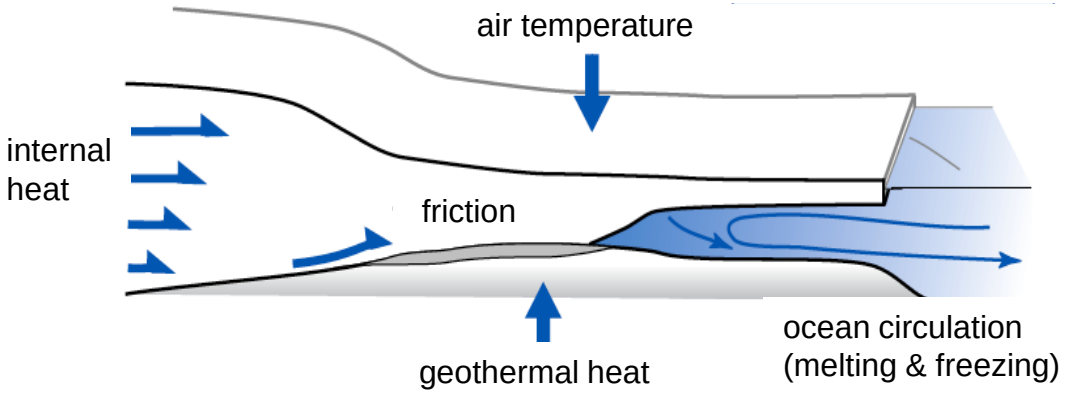


basal sliding

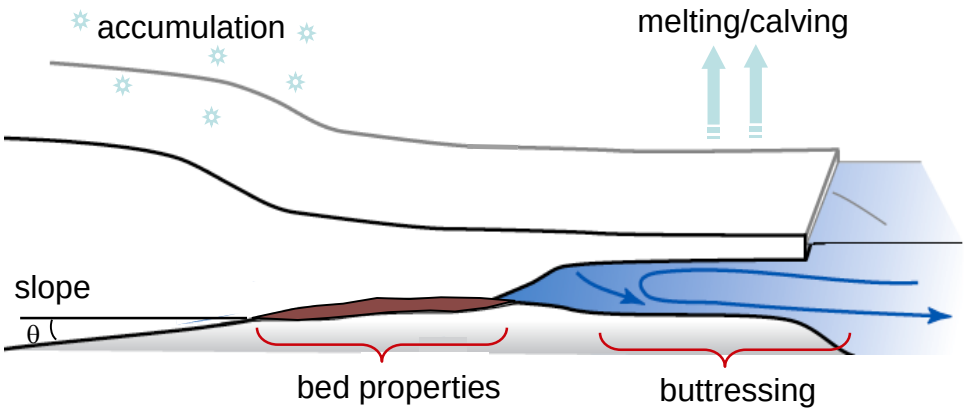


Controls on rate of motion:

thermal controls

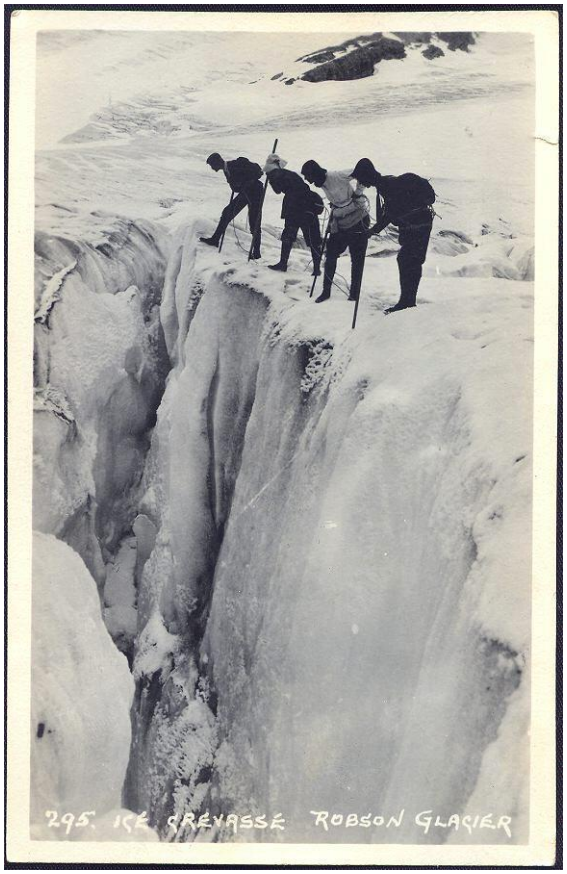


physical controls



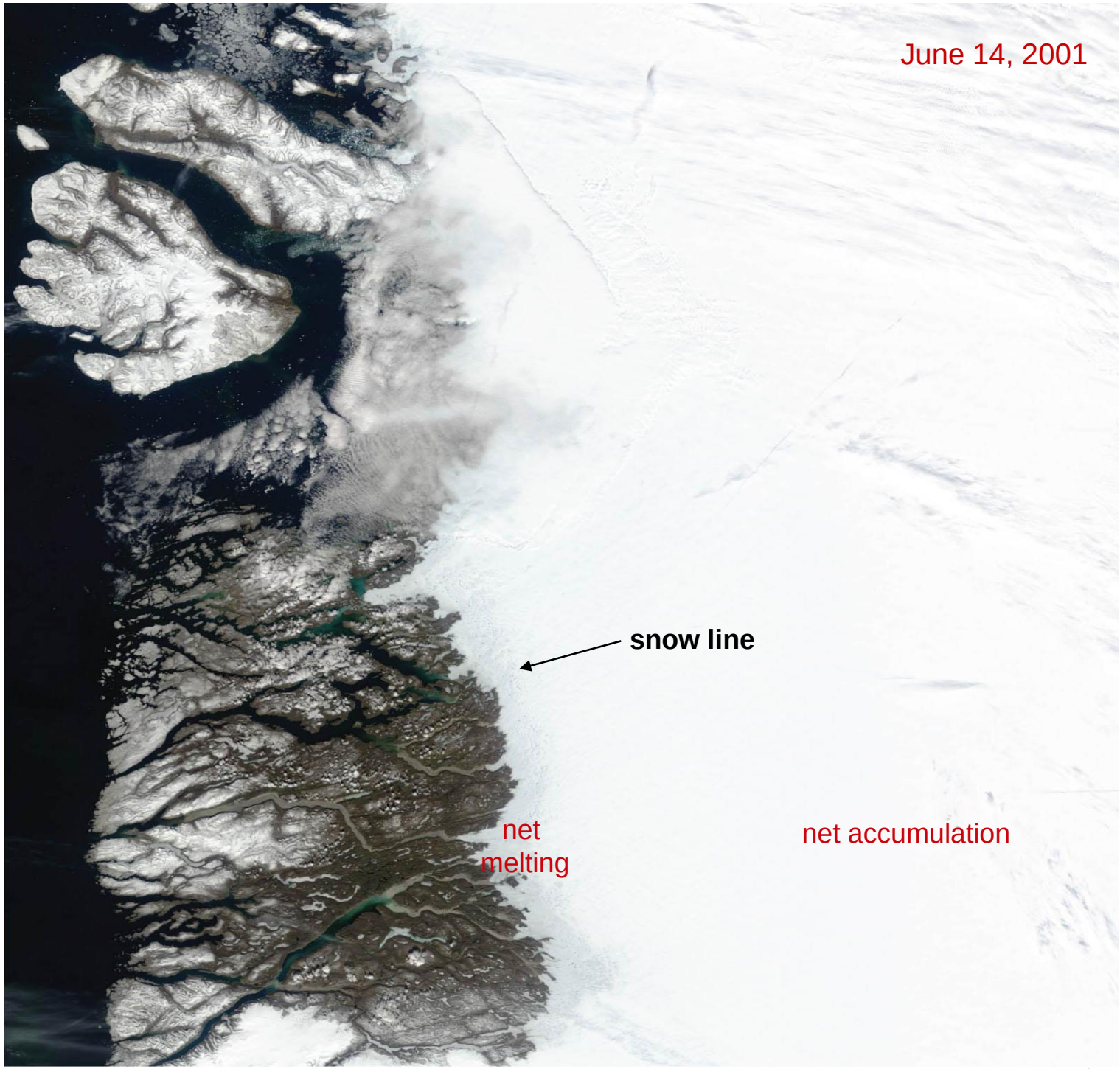
Ice dynamics 101: Physical properties of ice

If you stretch it slowly; ice thins



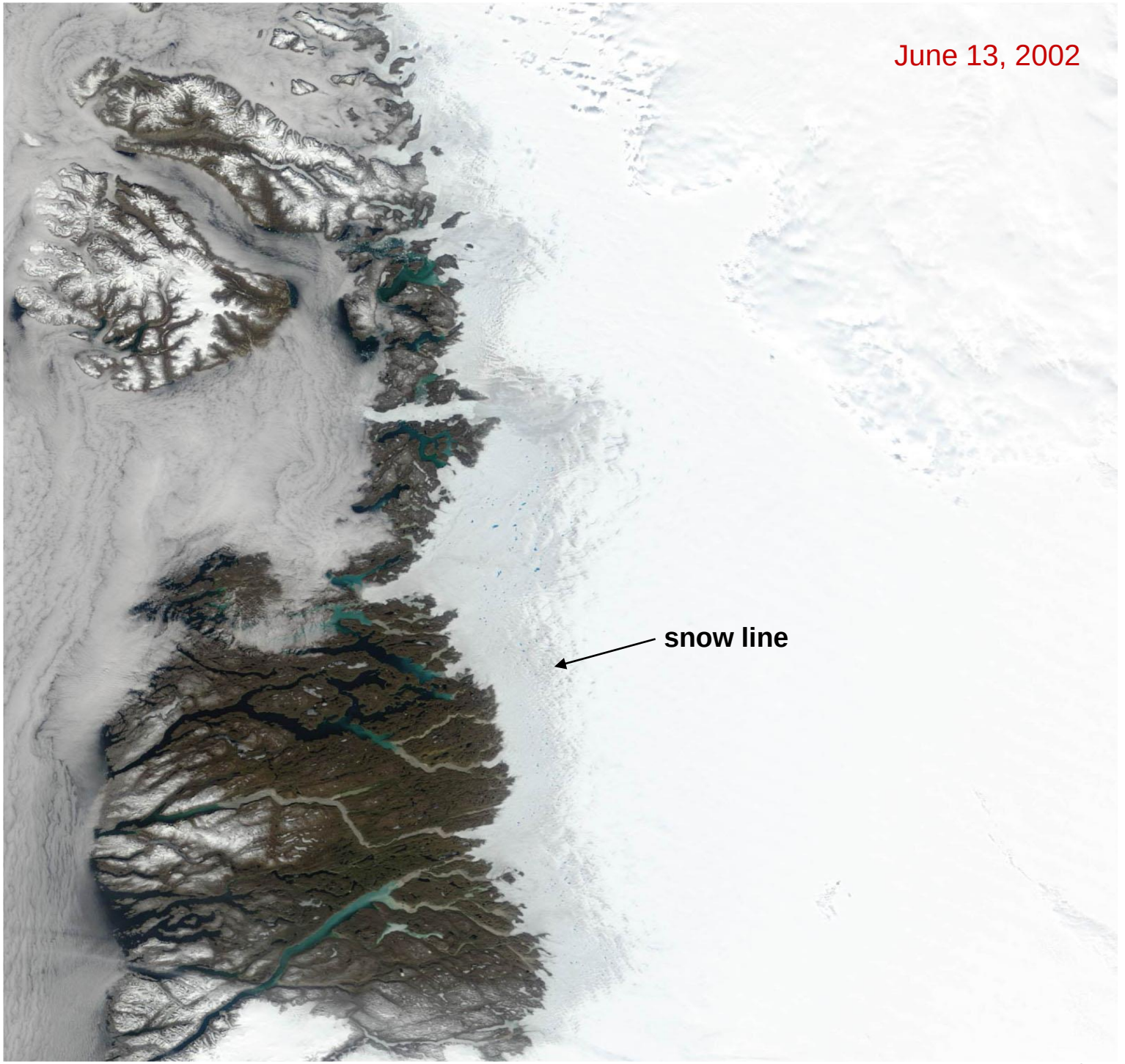
If you stretch it quickly; ice cracks

Ice Dynamics: Processes left out of IPCC



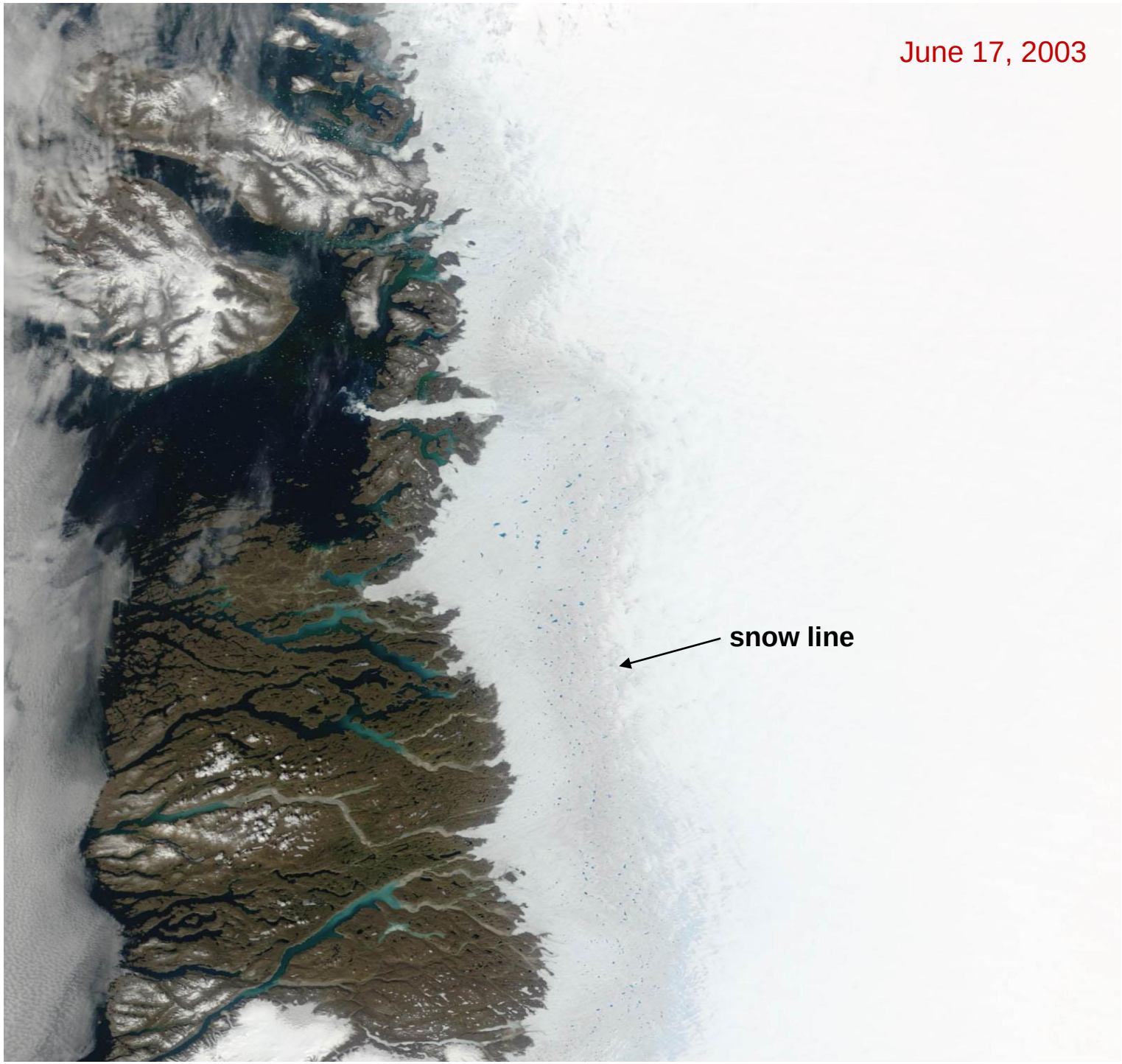
NASA Landsat

Ice Dynamics: Processes left out of IPCC



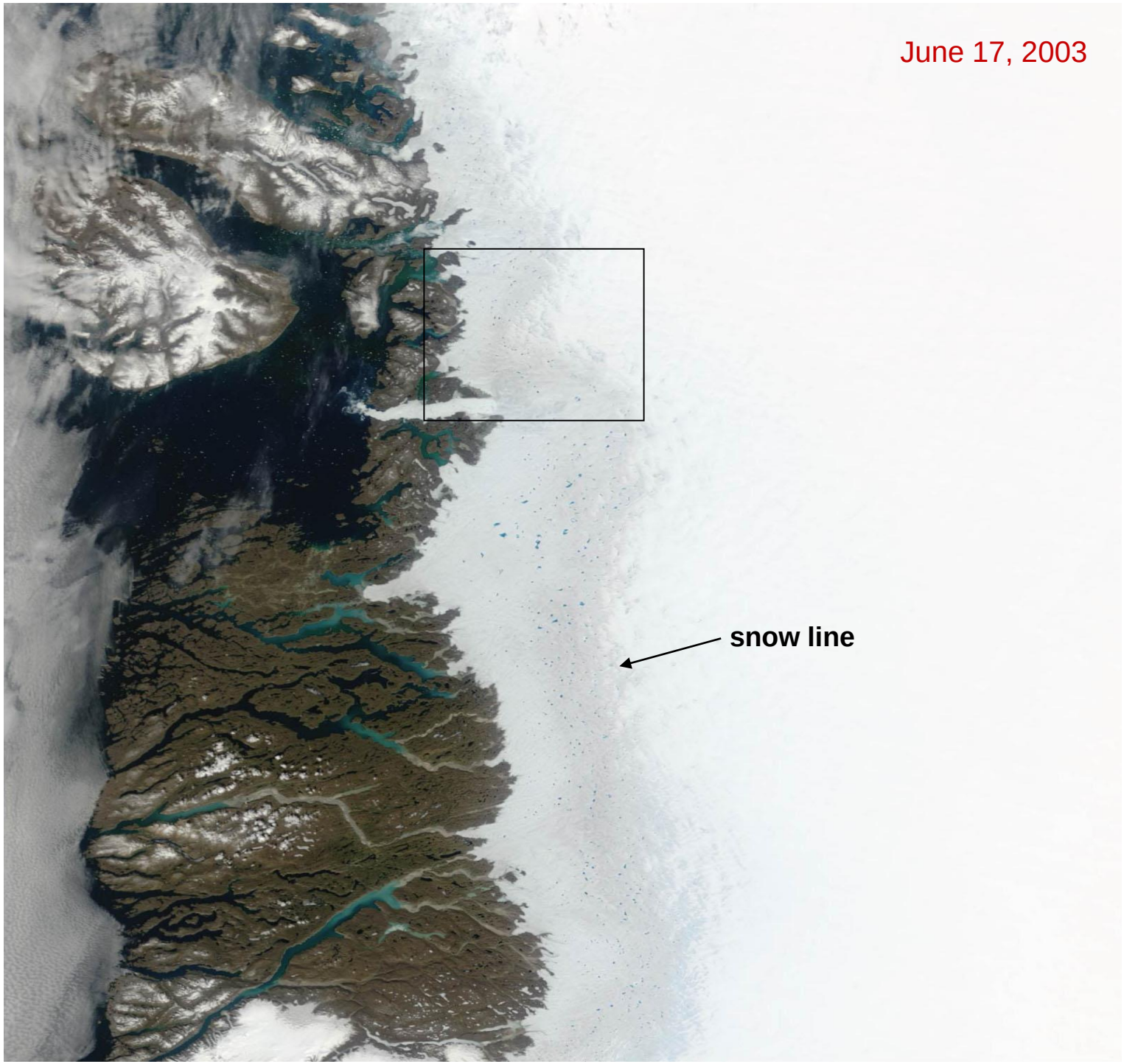
NASA Landsat

Ice Dynamics: Processes left out of IPCC



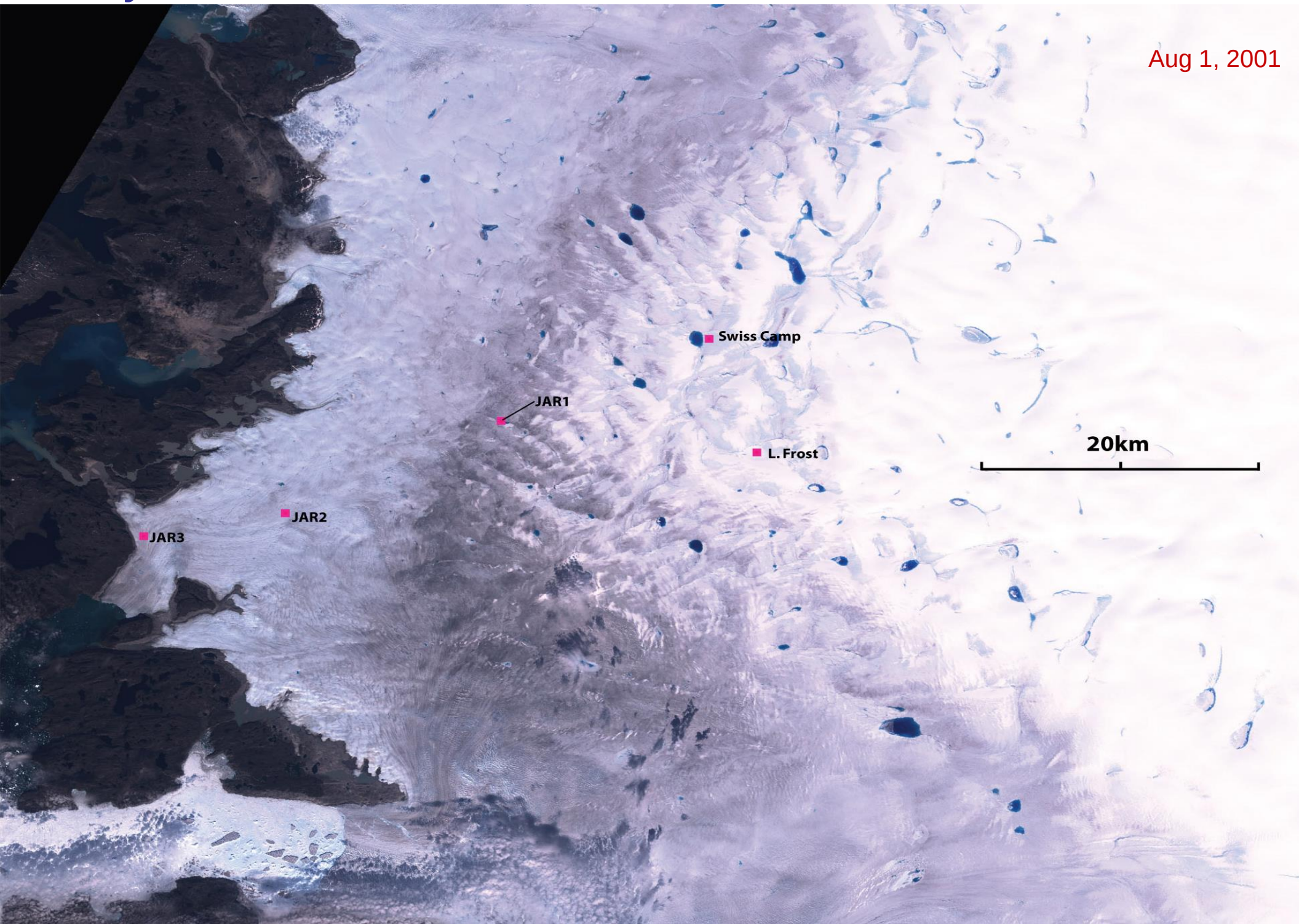
NASA Landsat

Ice Dynamics: Processes left out of IPCC



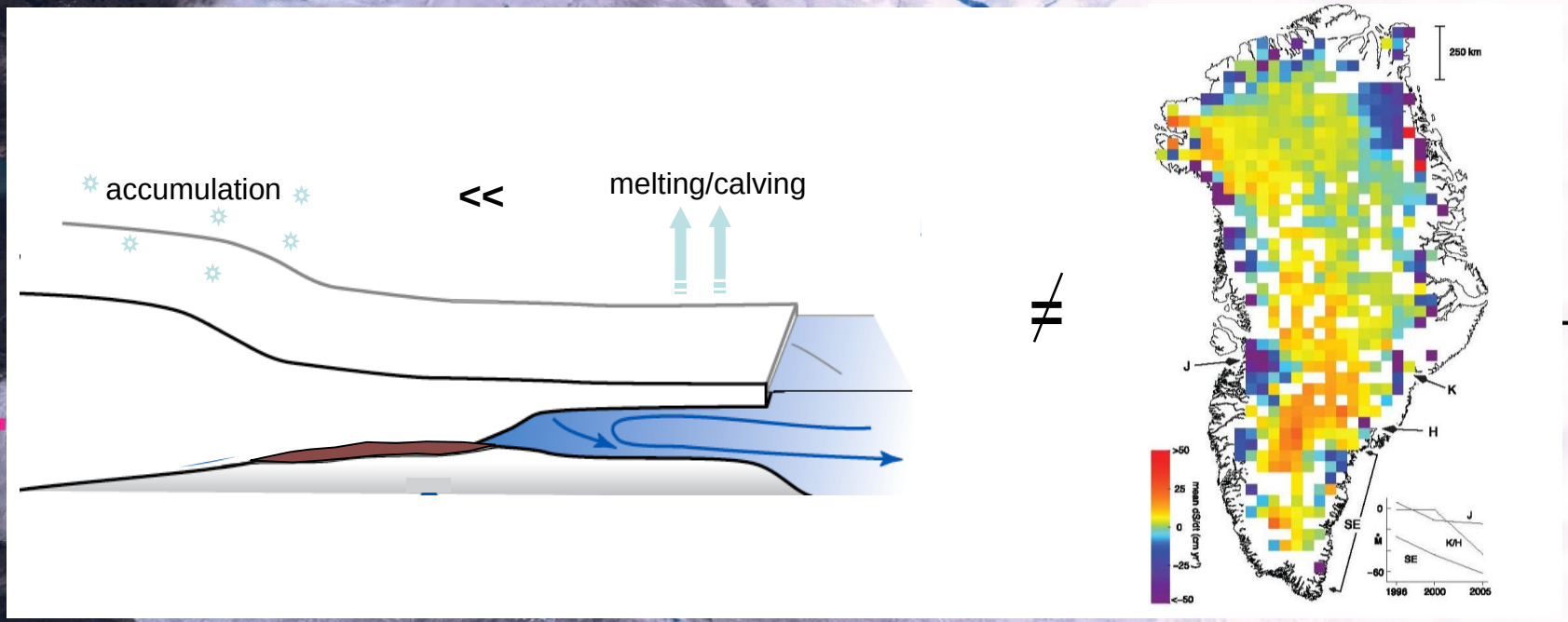
NASA Landsat

Ice Dynamics: Processes left out of IPCC



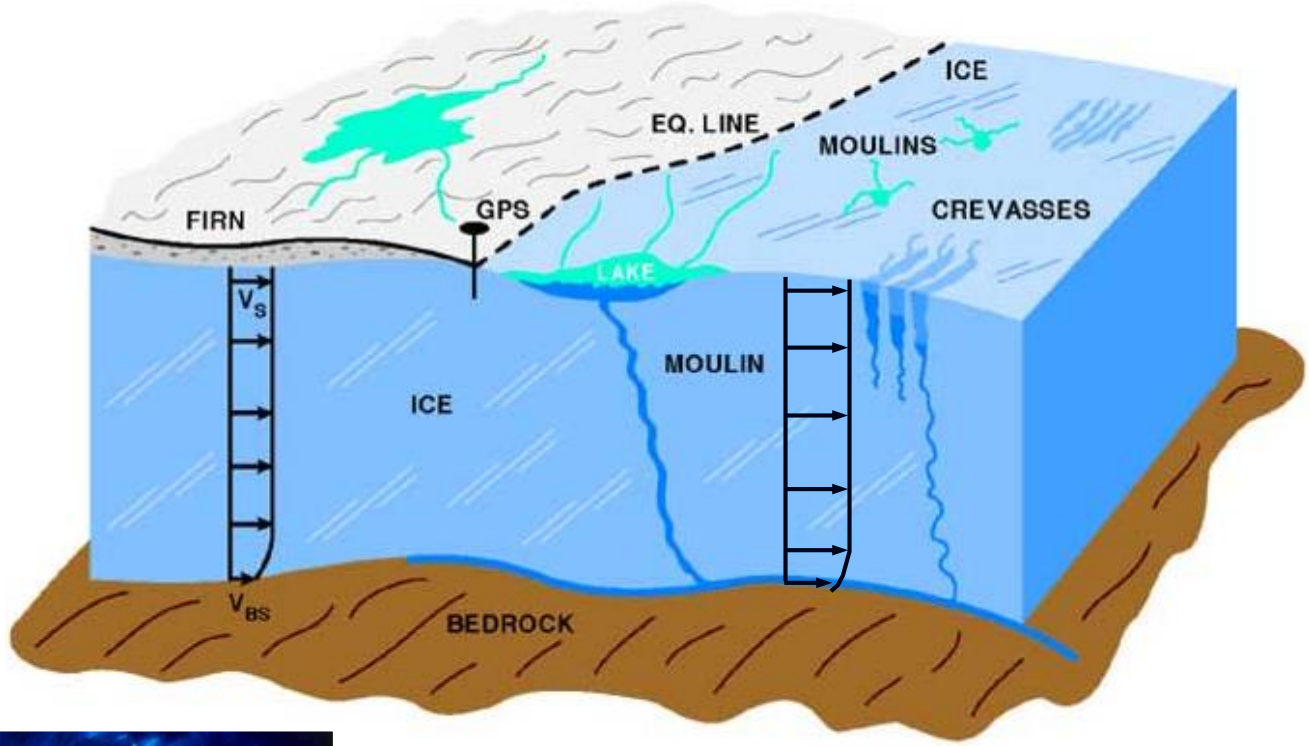
Ice Dynamics: Processes left out of IPCC

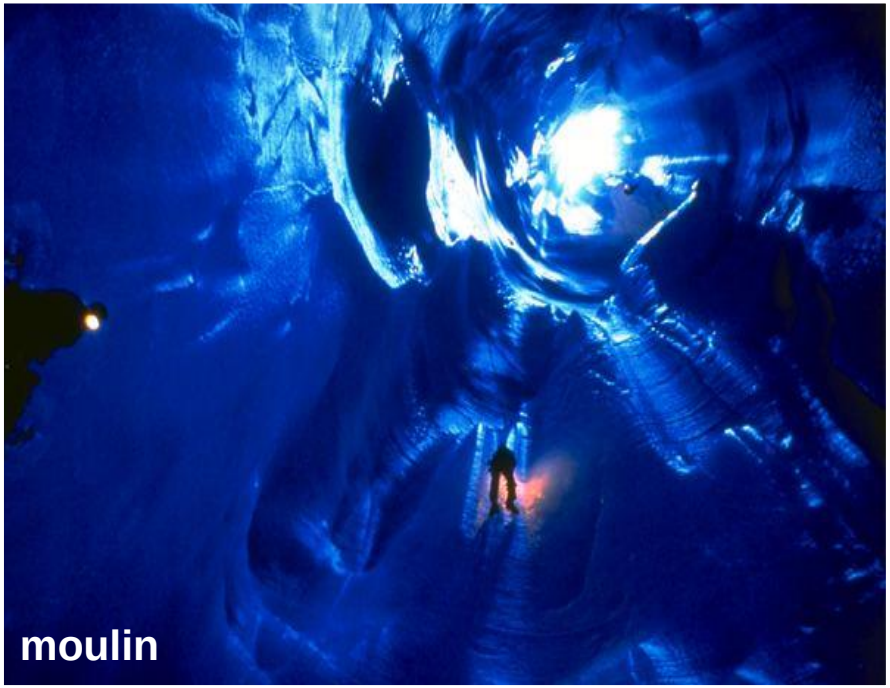
Aug 1, 2001



Ice Dynamics: Processes left out of IPCC

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.





Source: Janot Lamberton; Alberto Behar; Zwally et al. 2002

Greenland Melt-induced Velocity Project

Research Questions:

1. How does surface melt drain to the ice bed?
2. How does ice respond to increased melt?
3. What will happen to rate of ice flow with further warming?

How to proceed?

Greenland Melt-induced Velocity Project

Research Questions:

1. How does surface melt drain to the ice bed?
2. How does ice respond to increased melt?
3. What will happen to rate of ice flow with further warming?

You Have a Research Question!

?

Write a Document:
-plan science
-discuss possible results
-discuss pitfalls

Send it to Funding Agency for Review
-reviewed by 4-6 scientists by email
-reviewed by panel of 6-8 scientists
-budget costs and proposal rank are evaluated by program manager

Awarded!
-planning begins

Do the Work!

Present Results
-go to meetings (critiqued by your peers)
-write up results (also reviewed by 2-4 scientists)

Integration of Research
-ideas get tested and retested until they are accepted by the community
-possibly included in international scientific reports (IPCC)
-possibly considered for policy changes - a girl can hope!

The Team


Jamin Greenbaum (UTIG)
Tom Neumann (UVM)
Julie Rumrill (UVM)


Steve Price (Los Alamos)

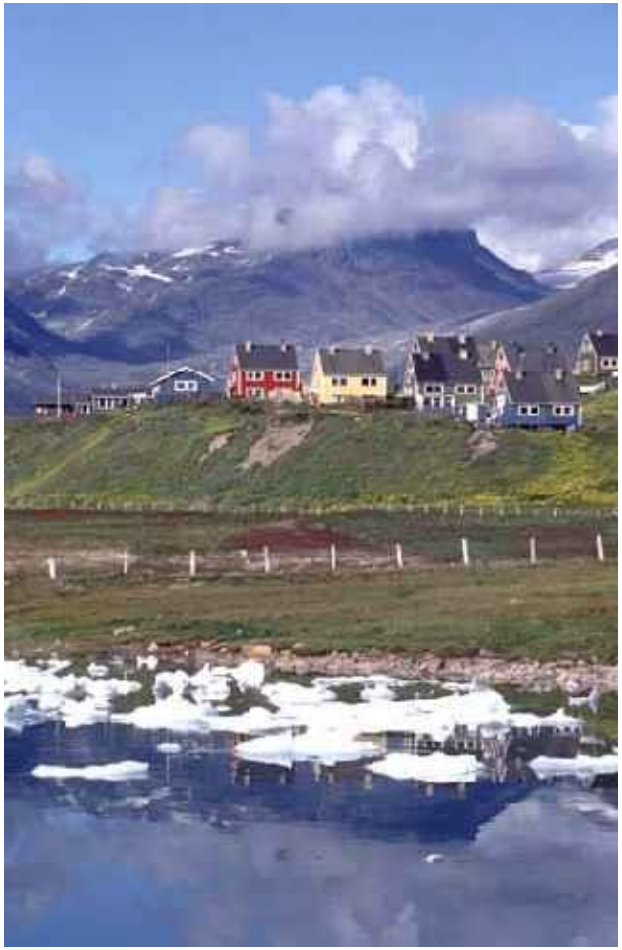

Me

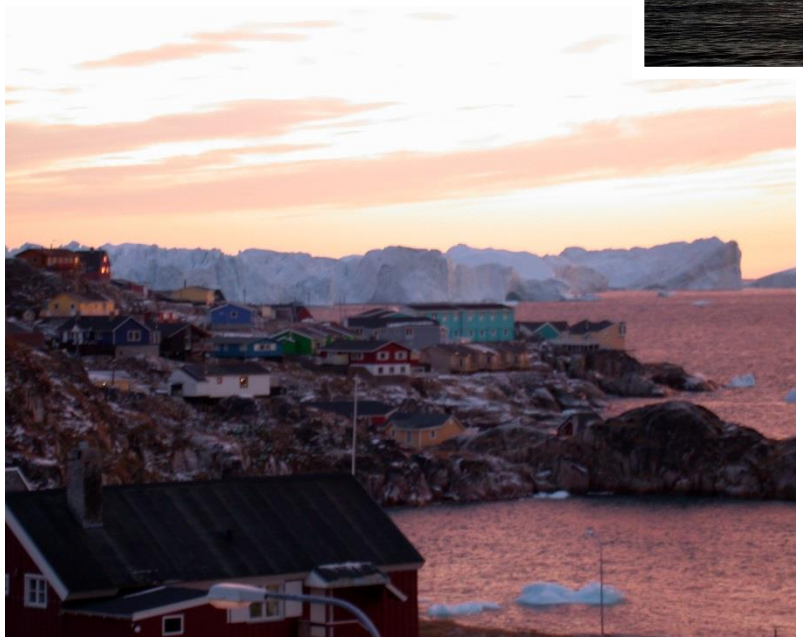
Getting to Greenland

Field Preparations

Clothing

Traveling around Greenland

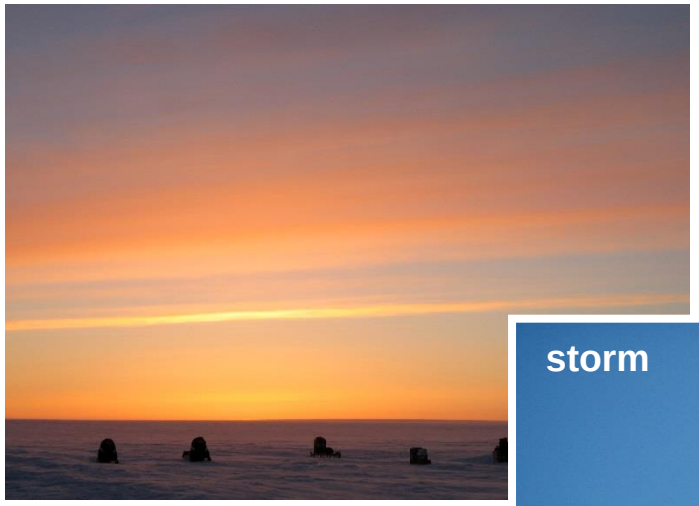




Getting to the field


camp

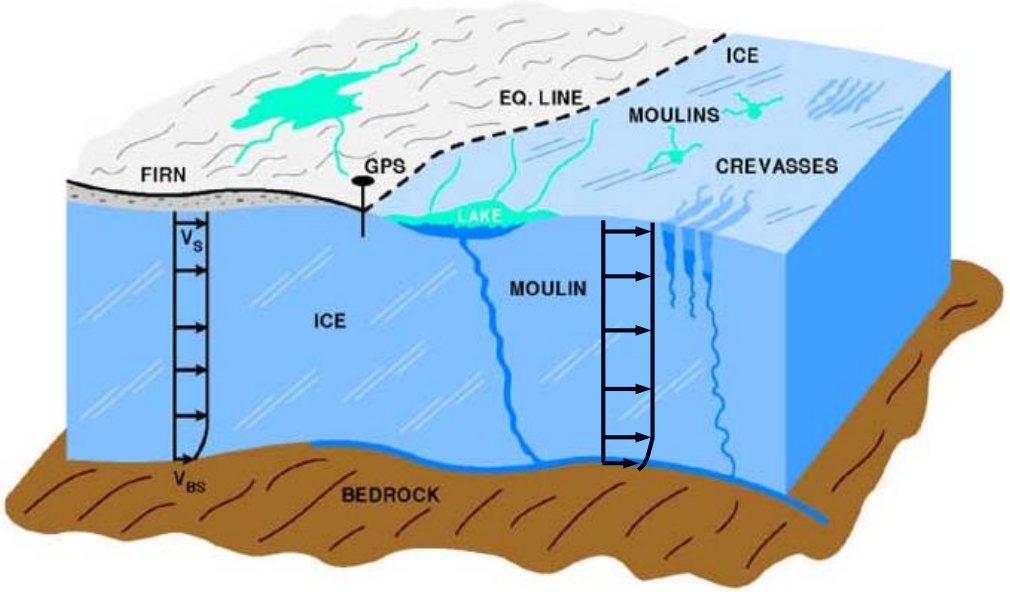
Camping on ‘the ice’



Greenland Melt: Research Questions

1. How does surface melt drain to the ice bed?

2. How does ice respond to increased melt?



3. What will happen to rate of ice flow with further warming?

Greenland Melt-induced Velocity Project

10 km

Swiss Camp

JAR1

JAR2

JAR3

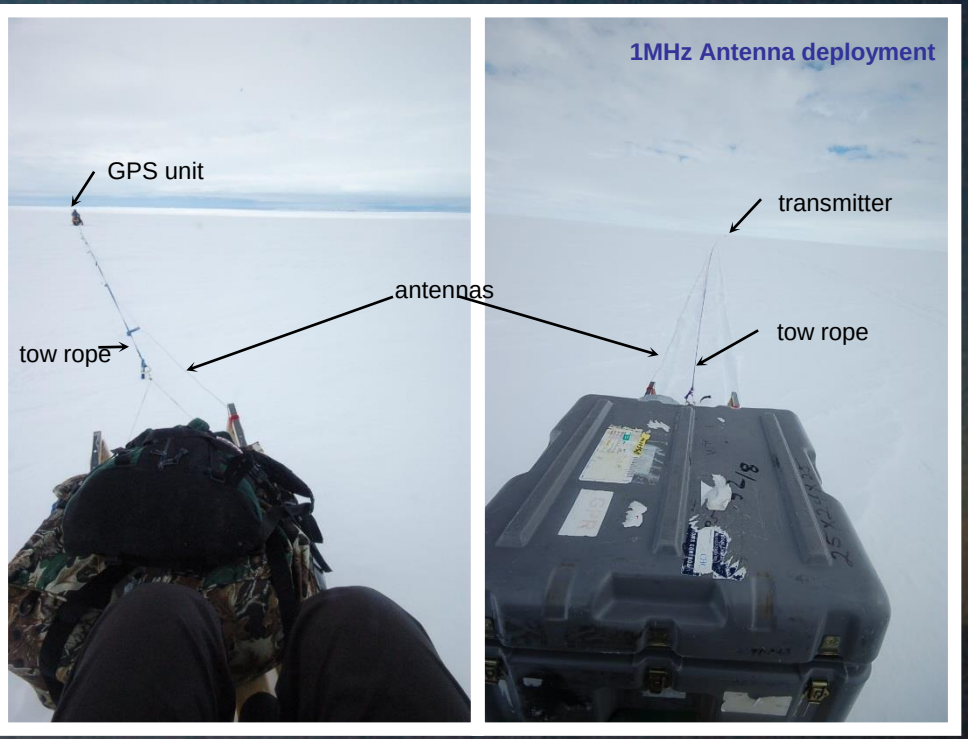
ELA

Jakobshavn Isbrae

Radar profiles

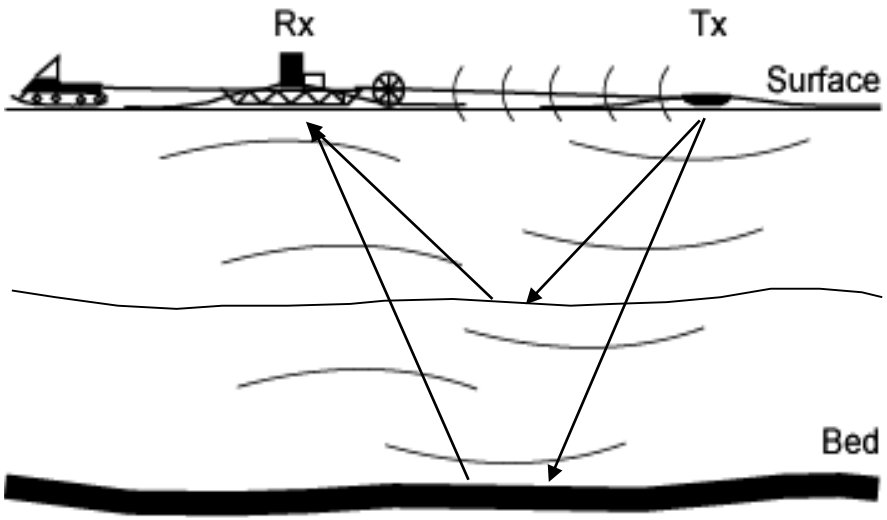
Englacial and subglacial characteristics
Water content of the ice and basal materials

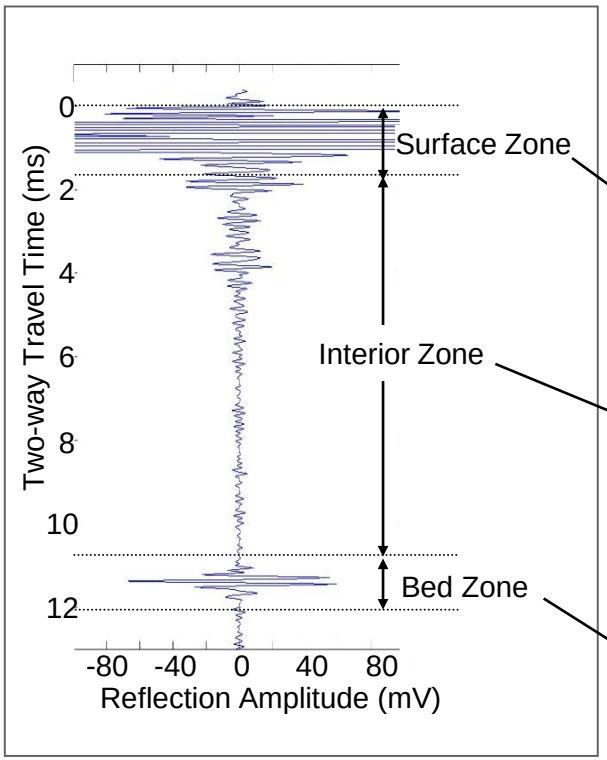
Greenland Melt: Ice-penetrating radar

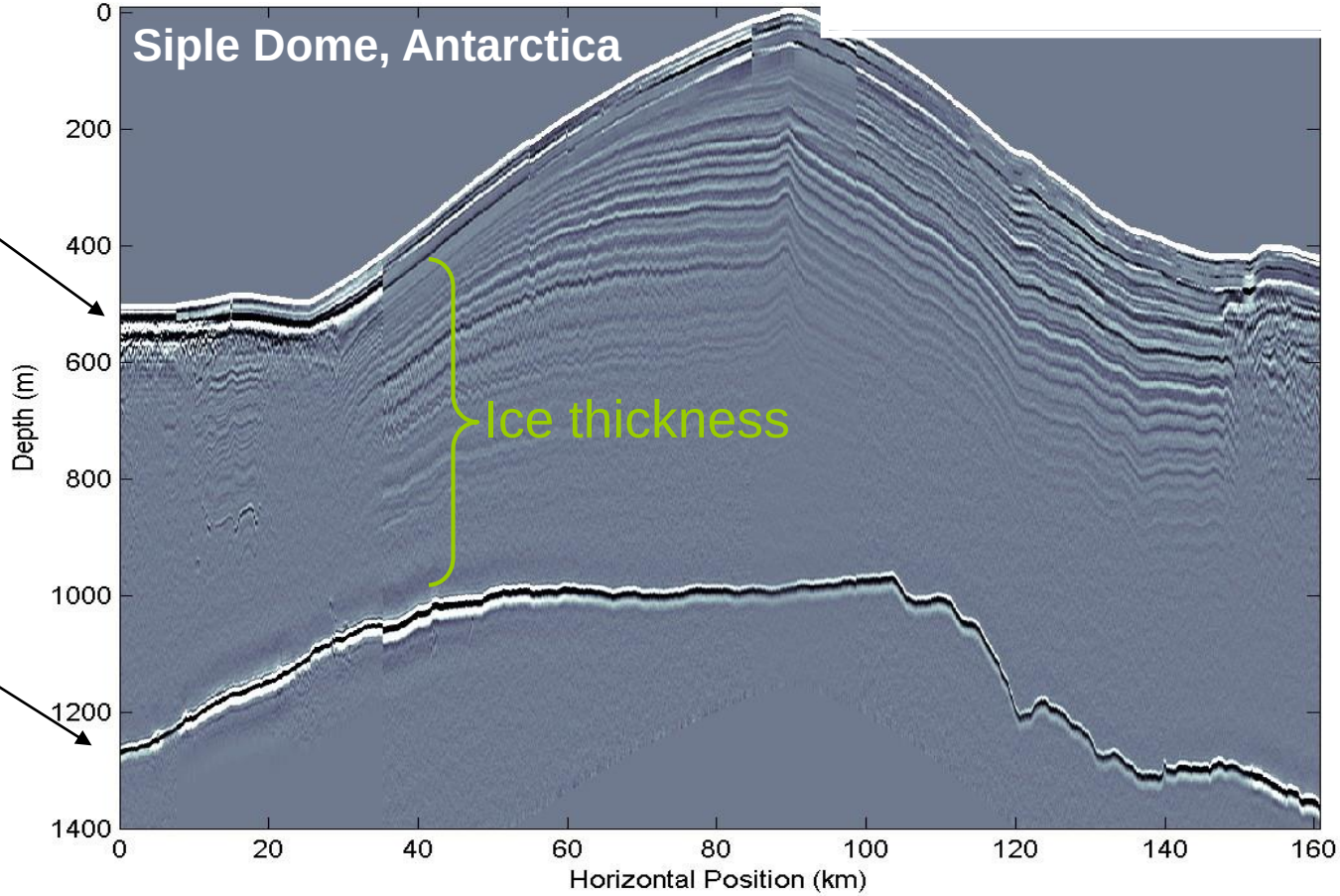


Survival bag
Spares/seat
Receiver
Generators
antennas
Transmitter Sled

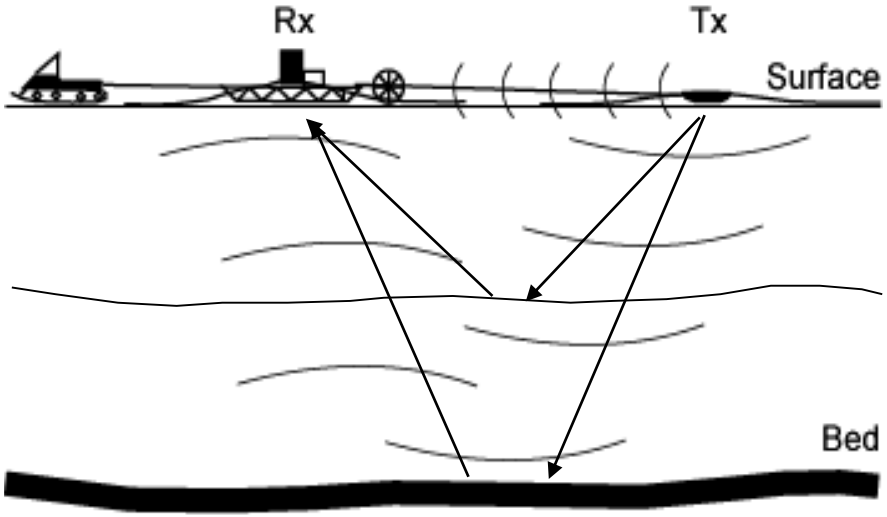
Greenland Melt: Ice-penetrating radar

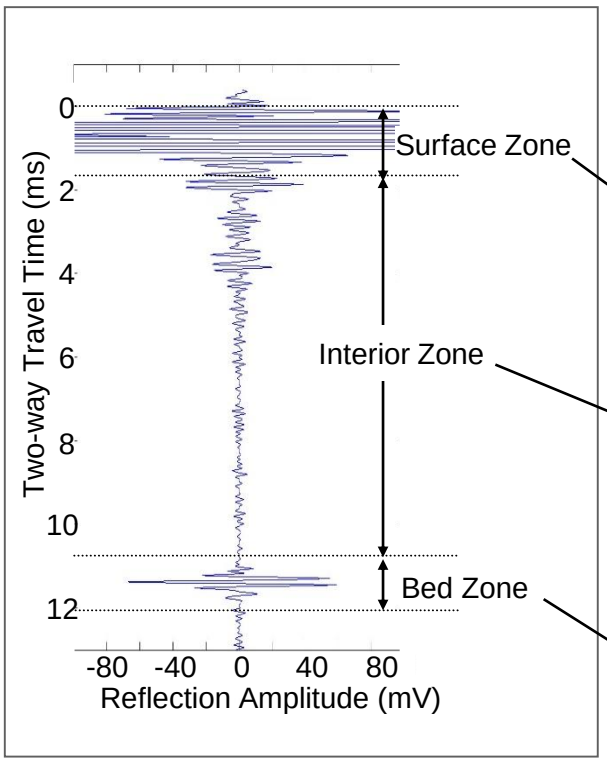


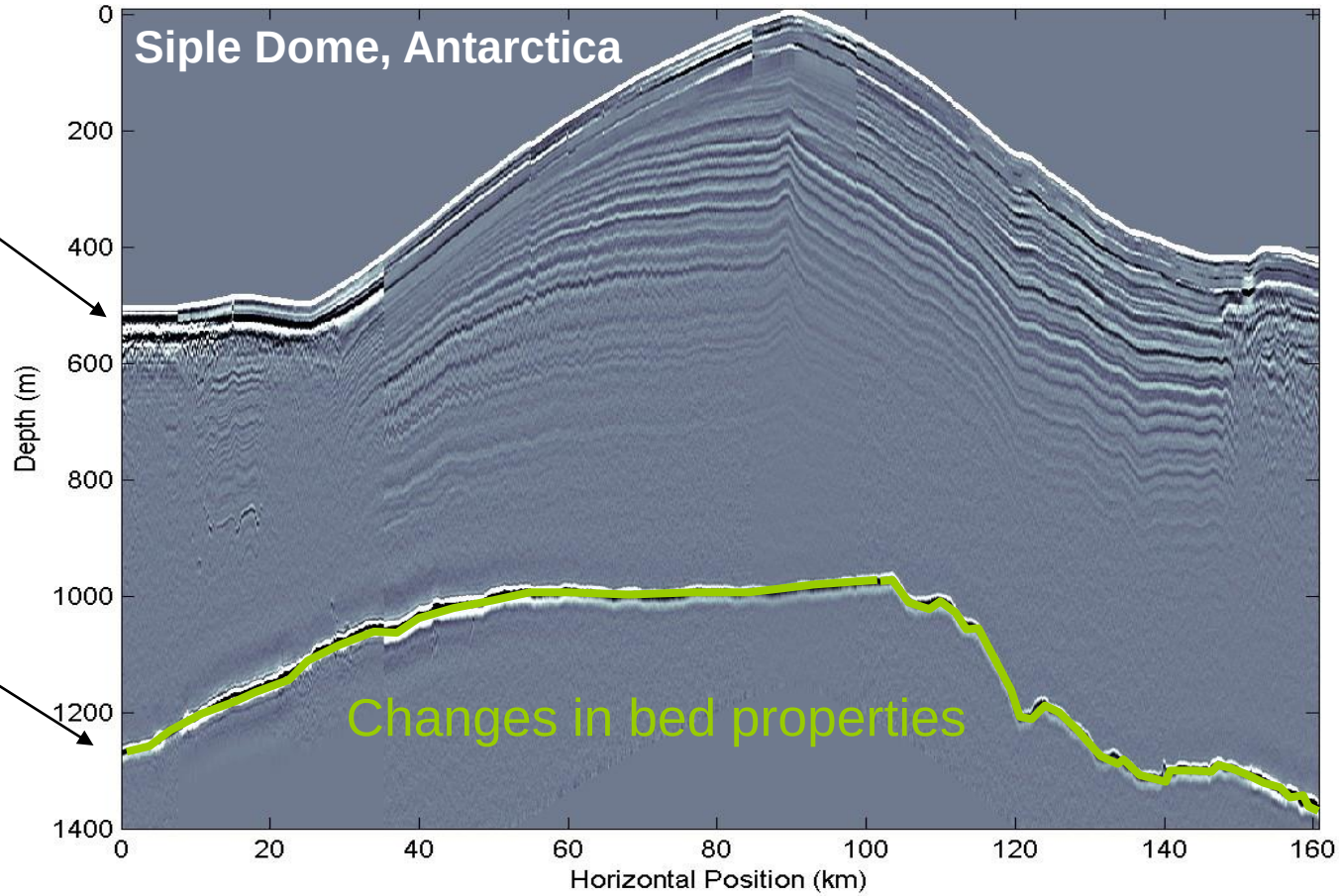




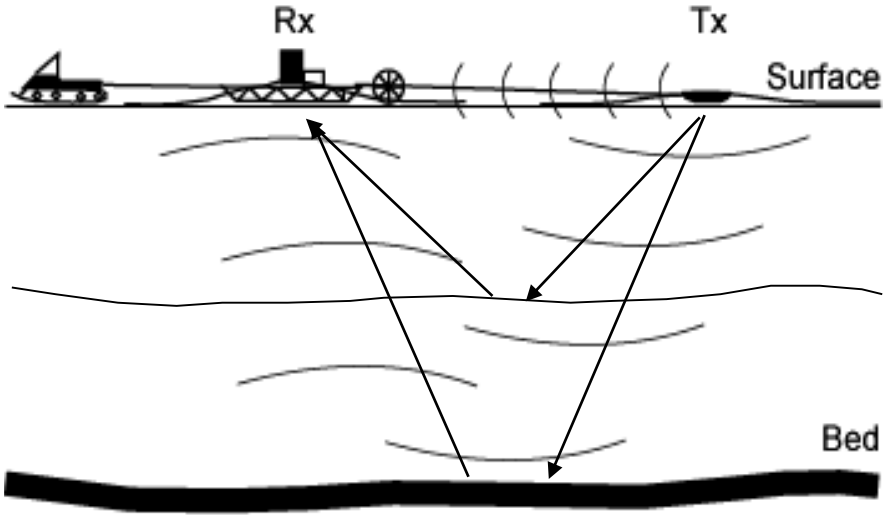
Greenland Melt: Ice-penetrating radar

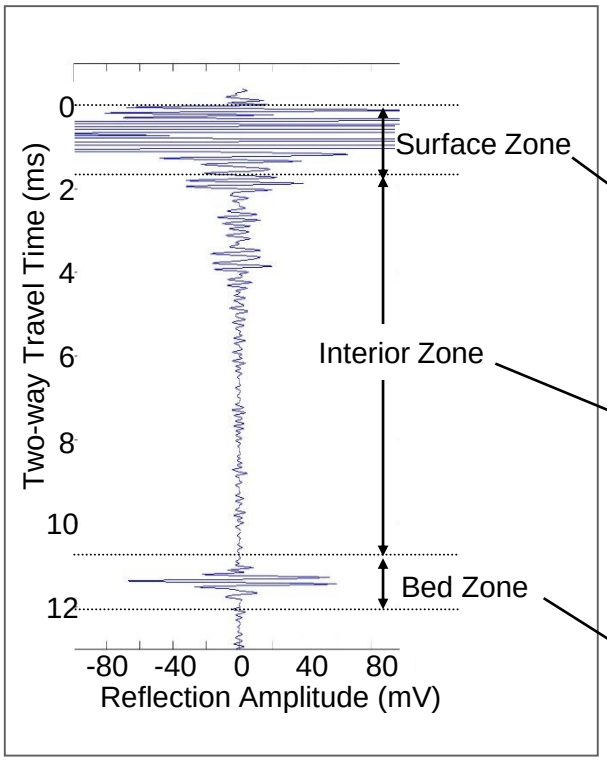


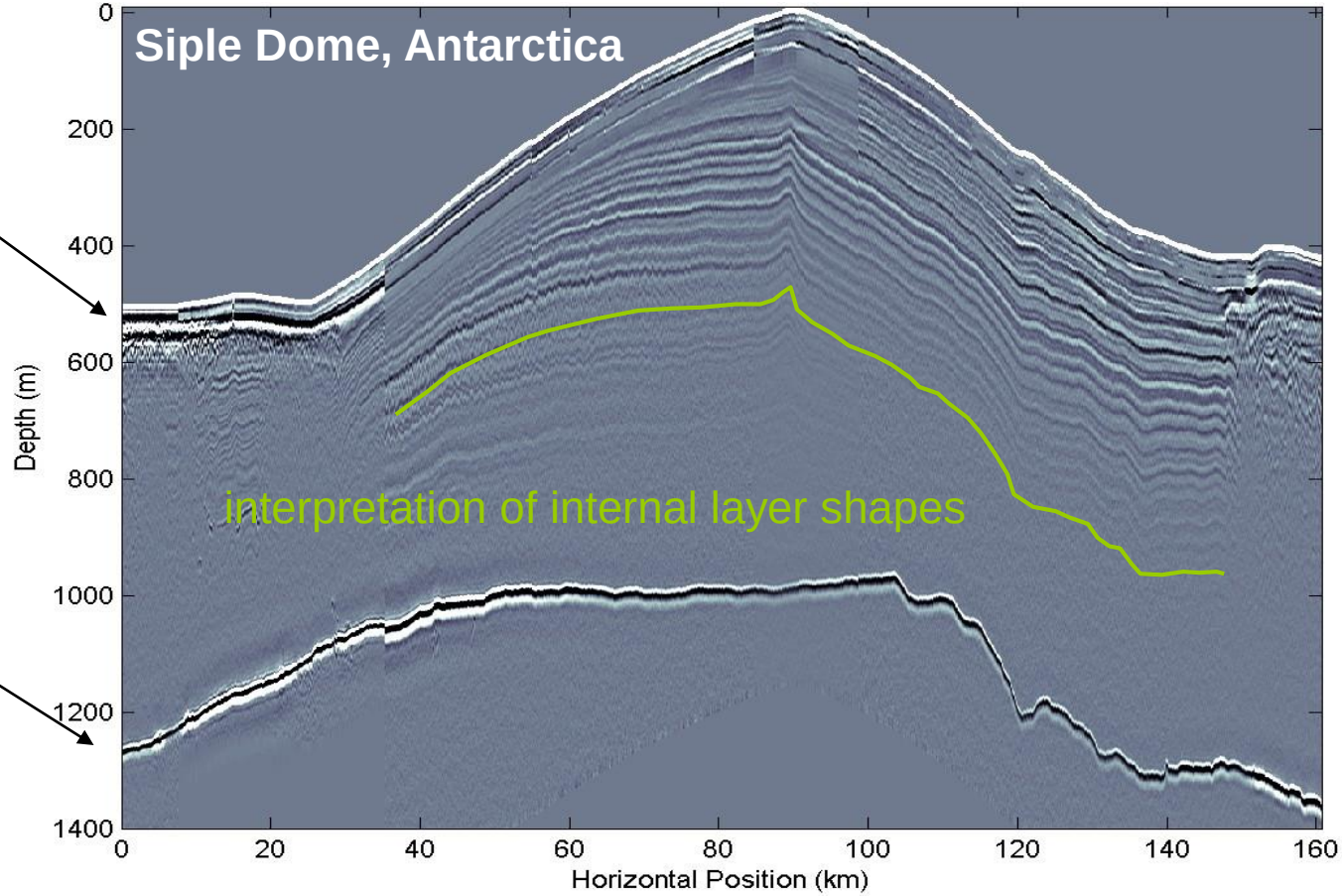


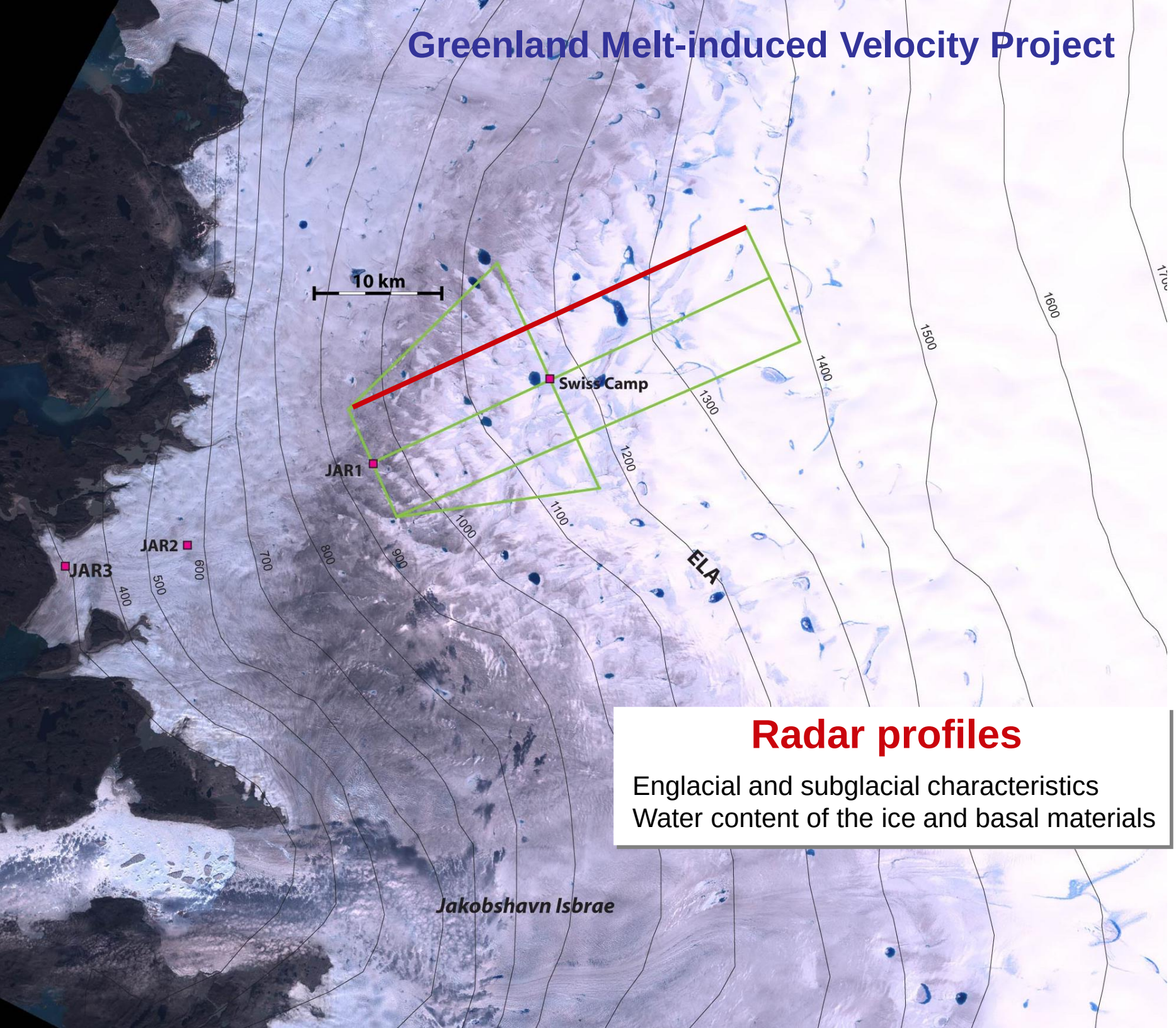


Greenland Melt: Ice-penetrating radar

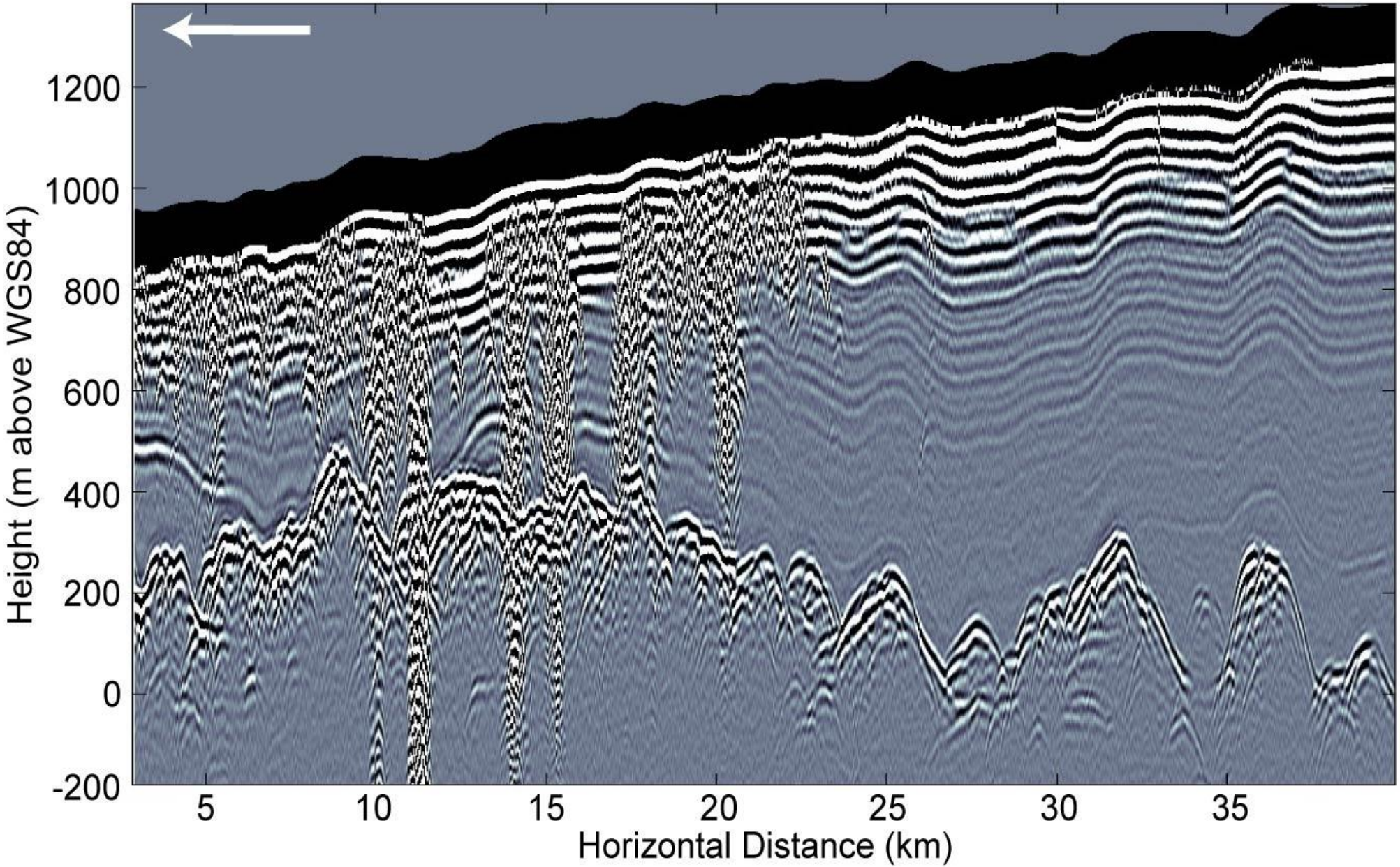




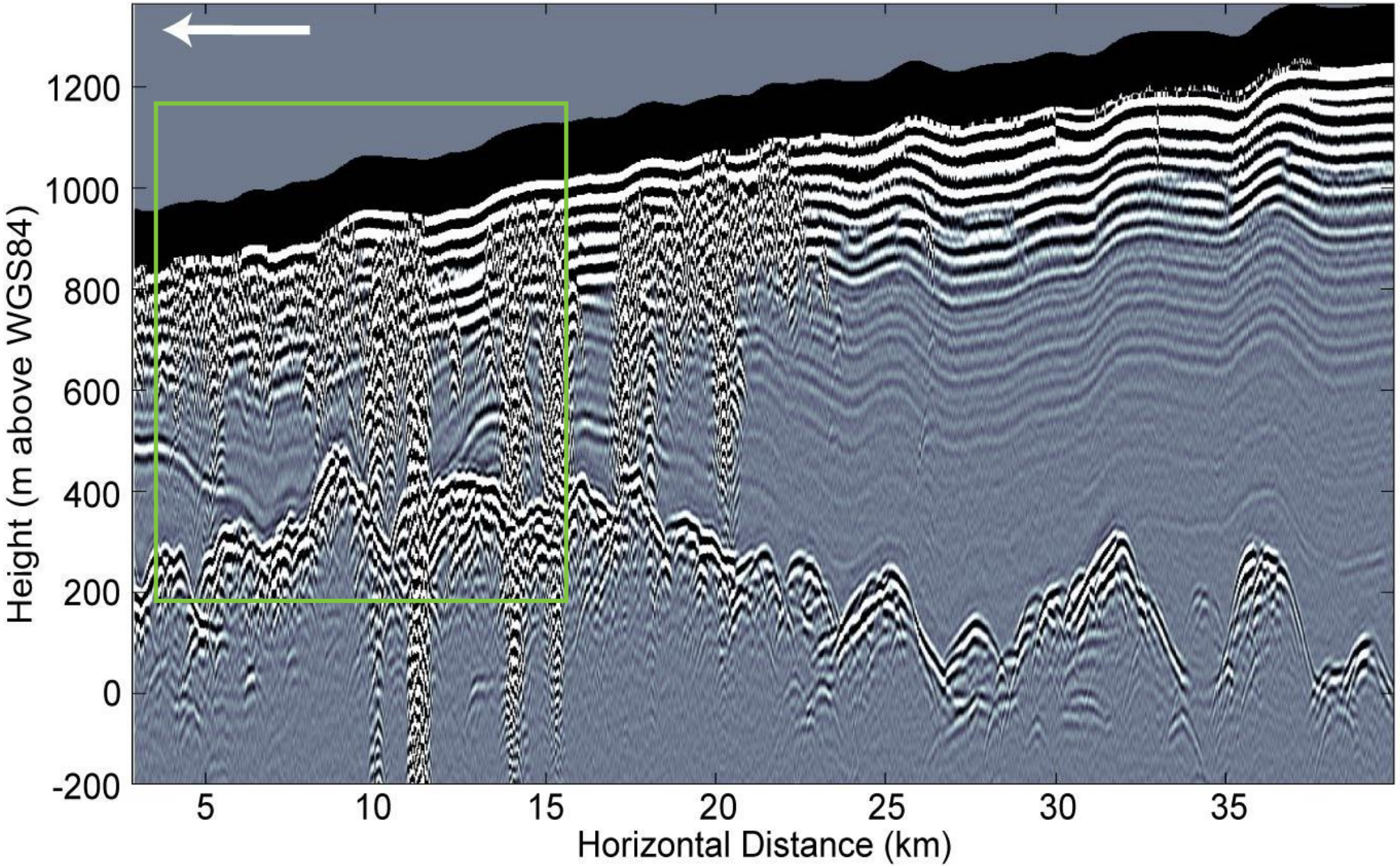



Greenland Melt-induced Velocity Project
10 km
Swiss Camp
JAR1
JAR2
JAR3
ELA
Jakobshavn Isbrae
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
Radar profiles
Englacial and subglacial characteristics
Water content of the ice and basal materials

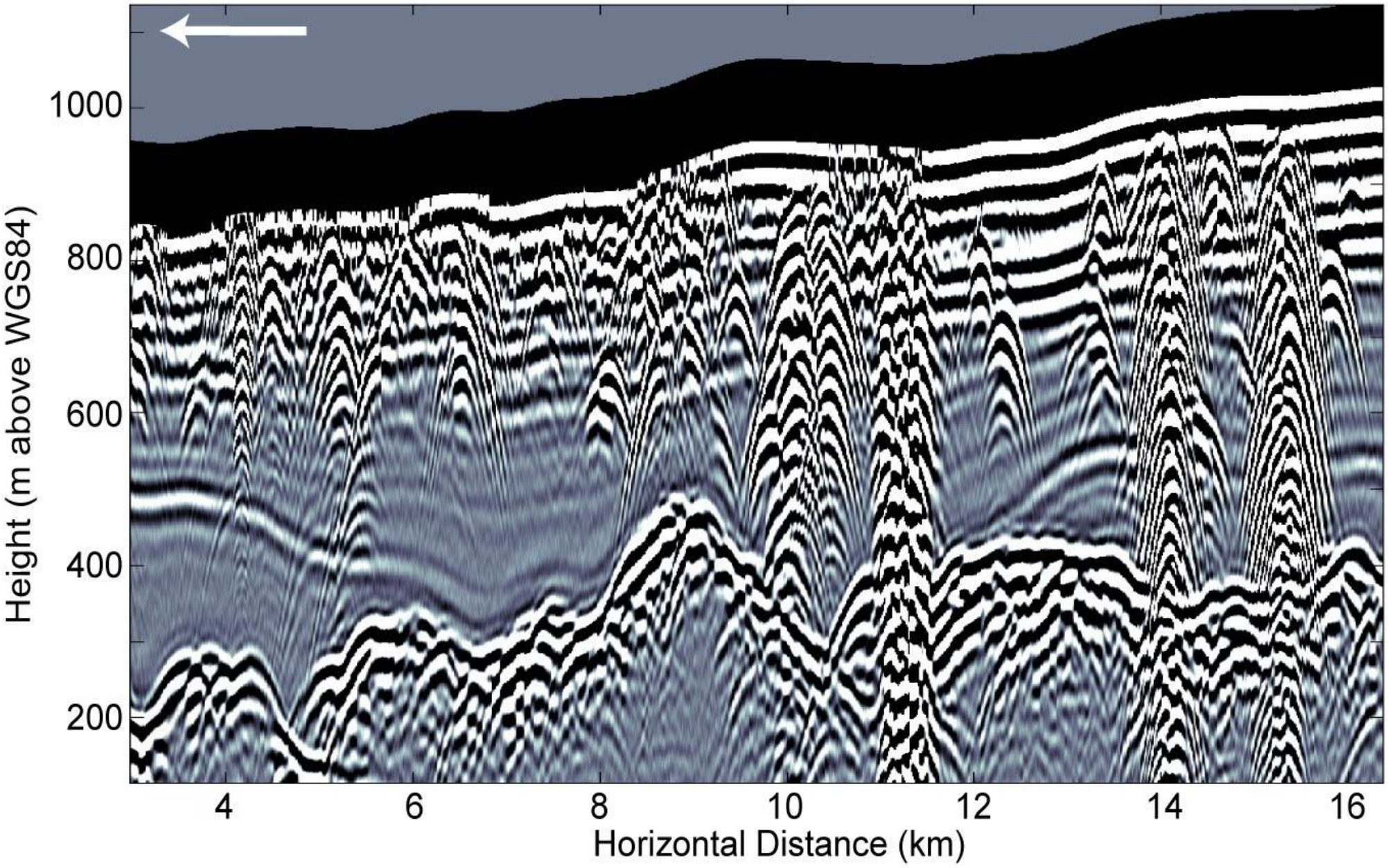
Greenland Melt: Ice-penetrating radar



Greenland Melt: Ice-penetrating radar

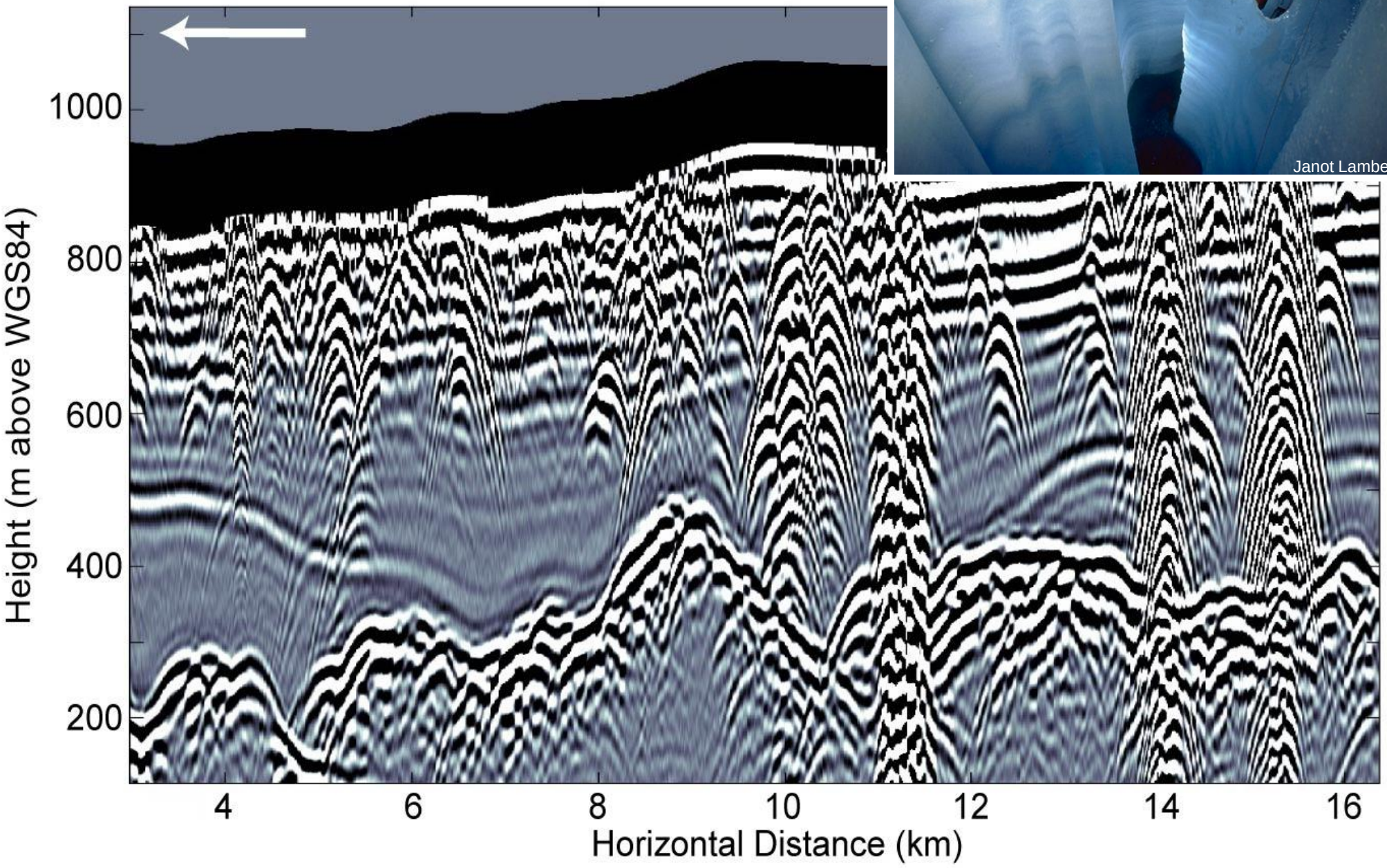


Greenland Melt: Ice-penetrating radar



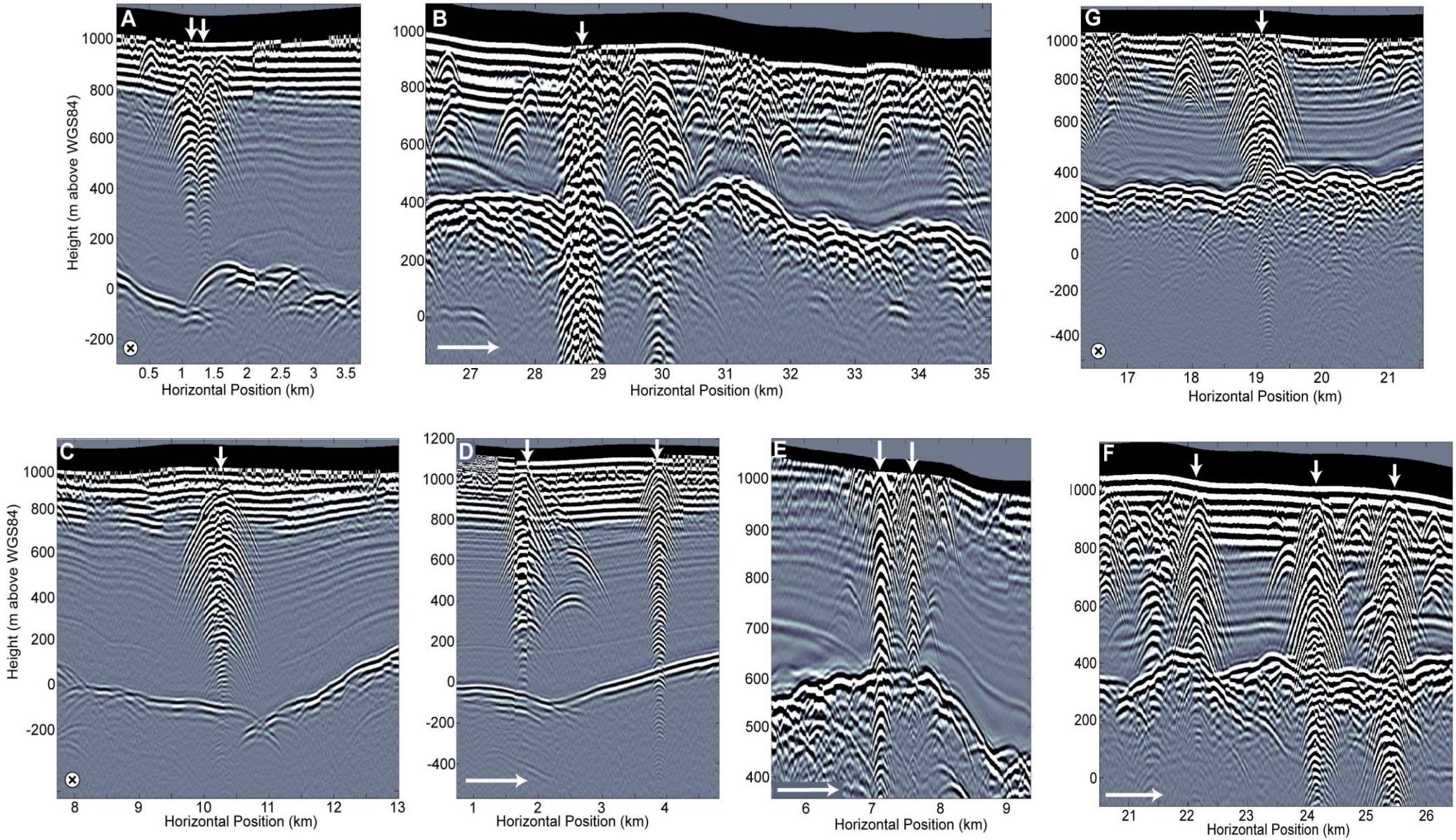
Greenland Melt: Ice-penetrating radar

Working hypothesis: moulins!



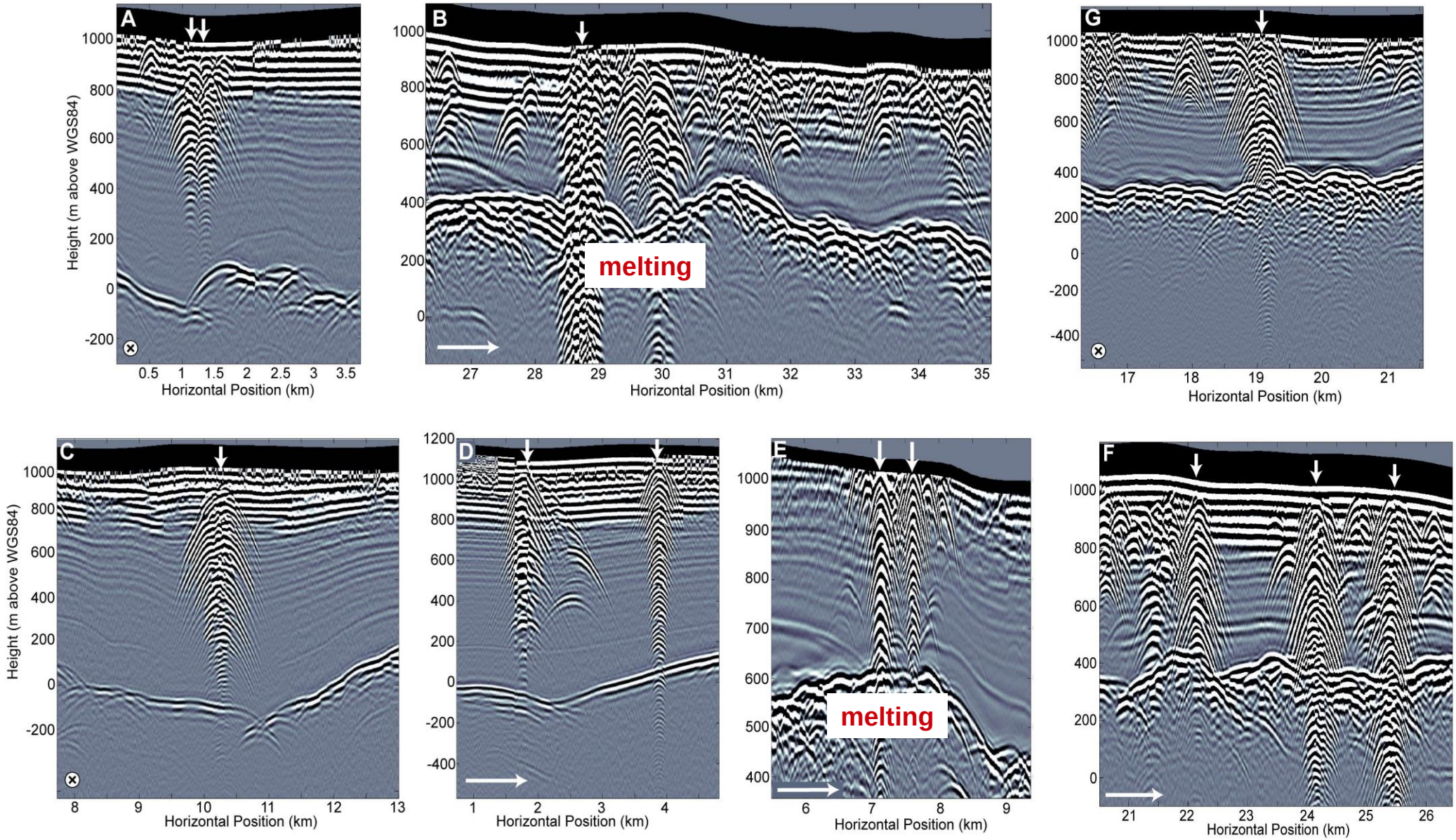
Greenland Melt: Ice-penetrating radar

- features are complex
- sometimes hyperbolae get narrower with depth
- some have multiple returns below the bed
- some are associated with dipping internal layers (*implies vertically oriented*)

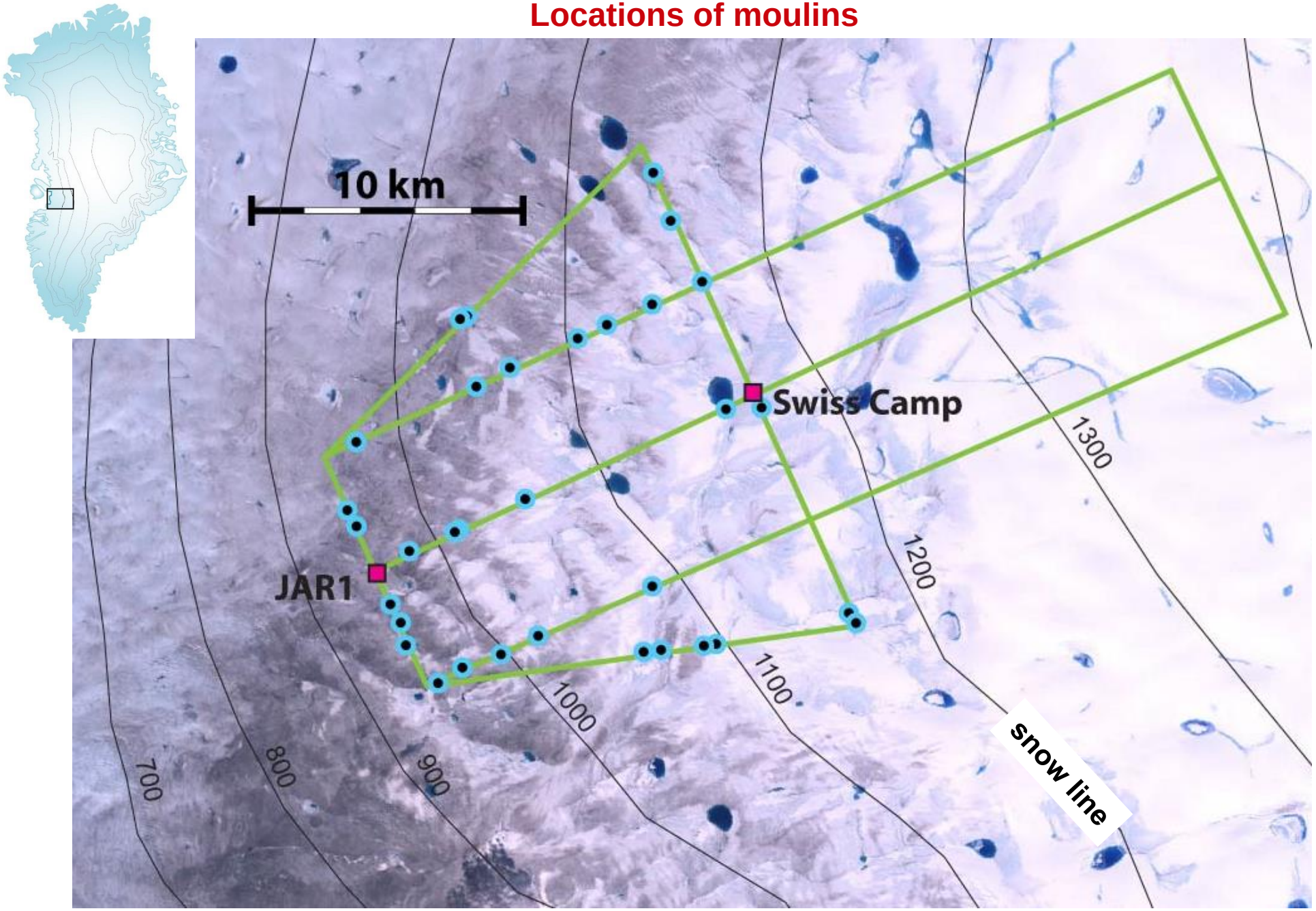


Greenland Melt: Ice-penetrating radar

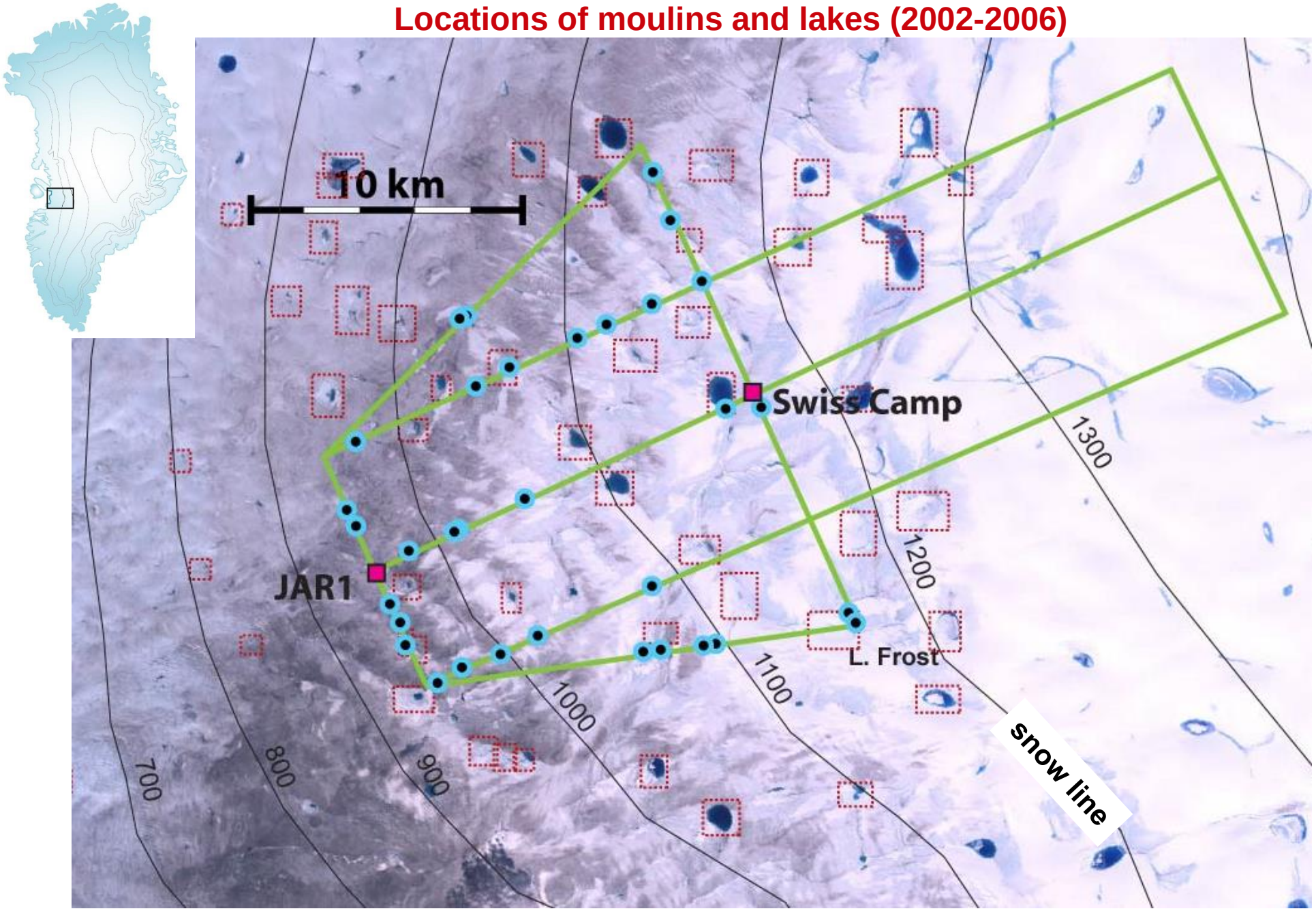
- features are complex
- sometimes hyperbolae get narrower with depth
- some have multiple returns below the bed
- some are associated with dipping internal layers (*implies vertically oriented*)



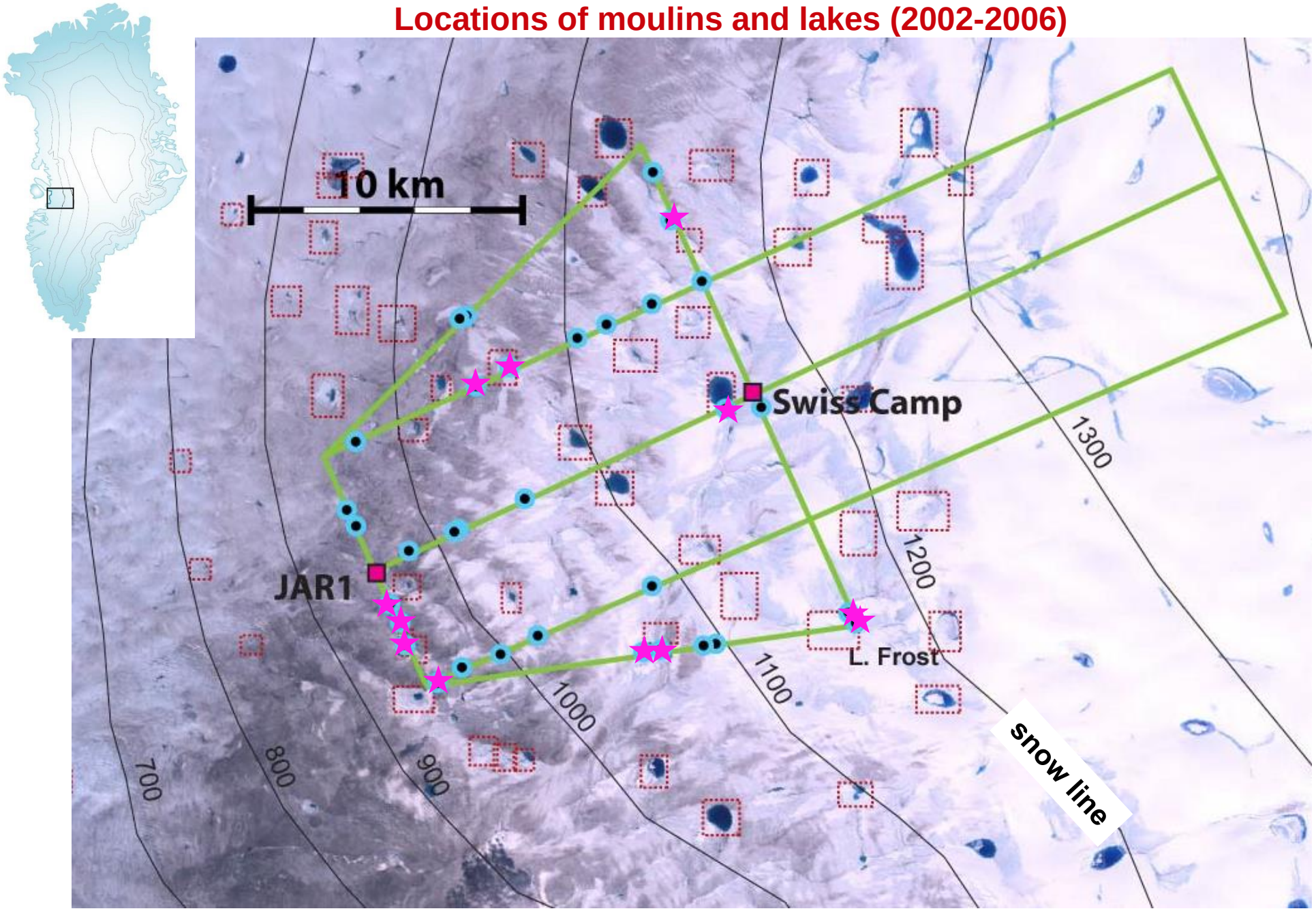
Greenland Melt: Ice-penetrating radar



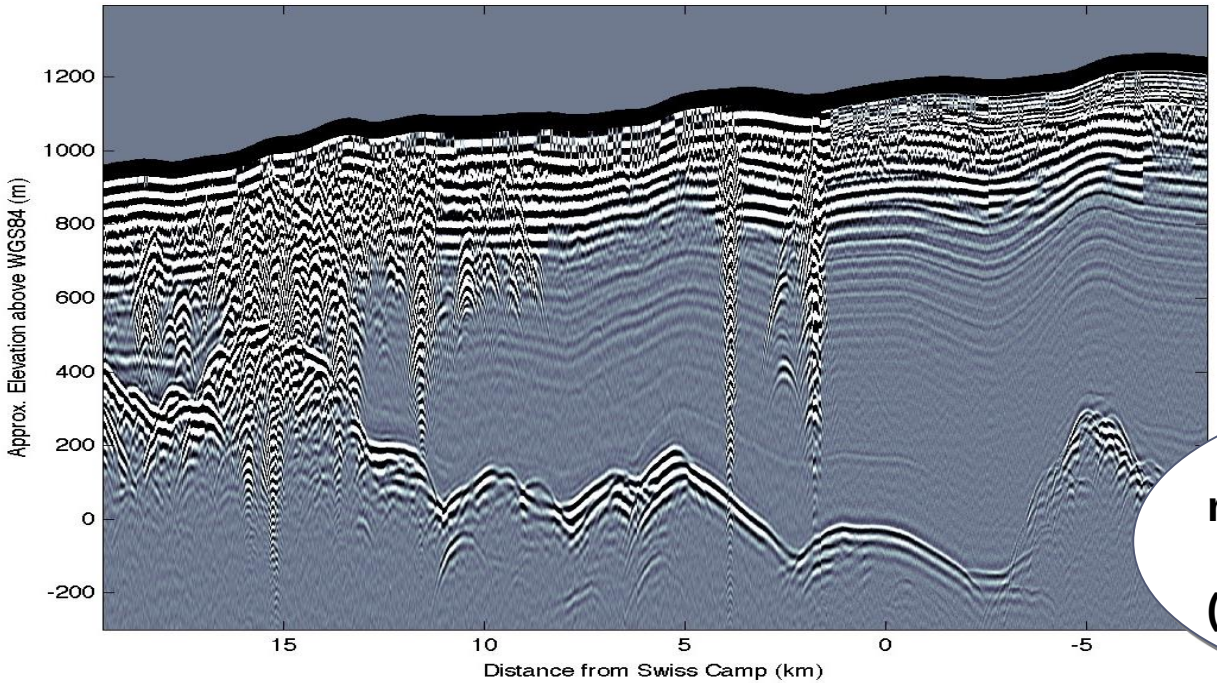
Greenland Melt: Ice-penetrating radar



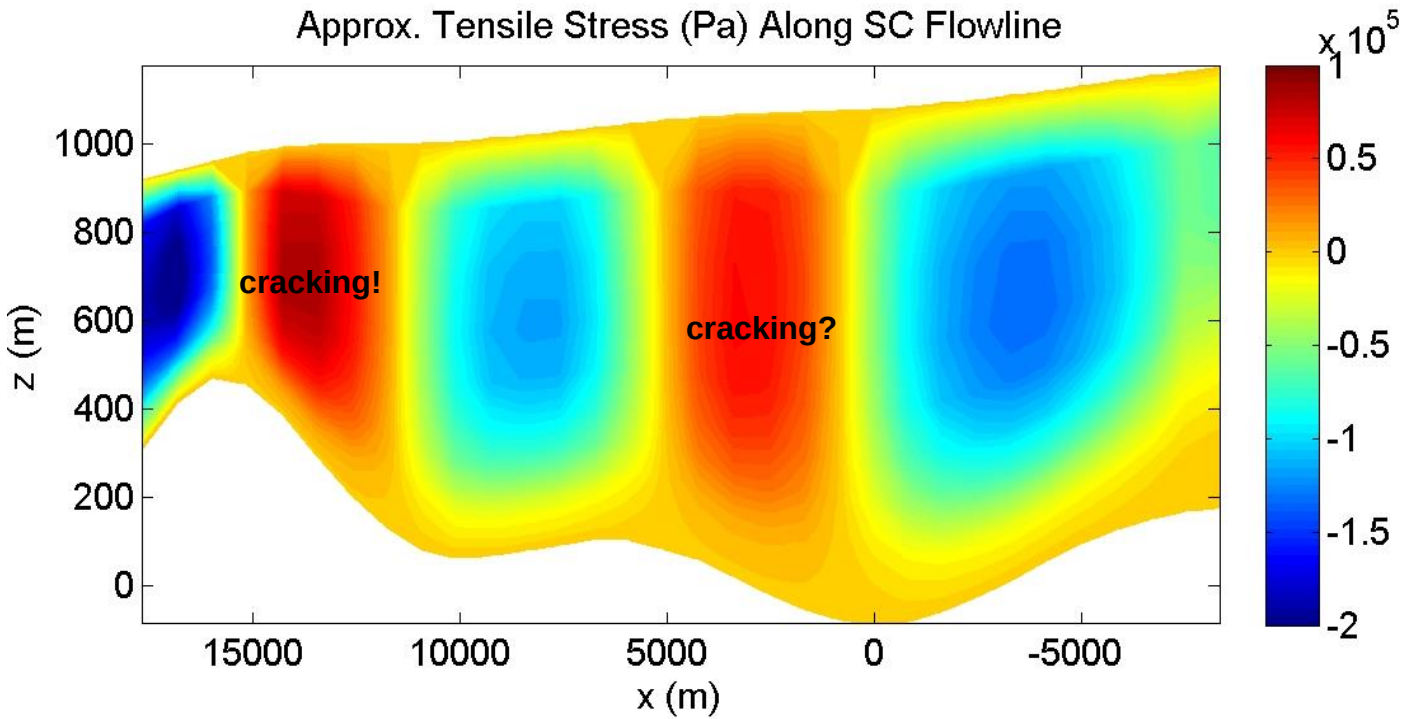
Greenland Melt: Ice-penetrating radar



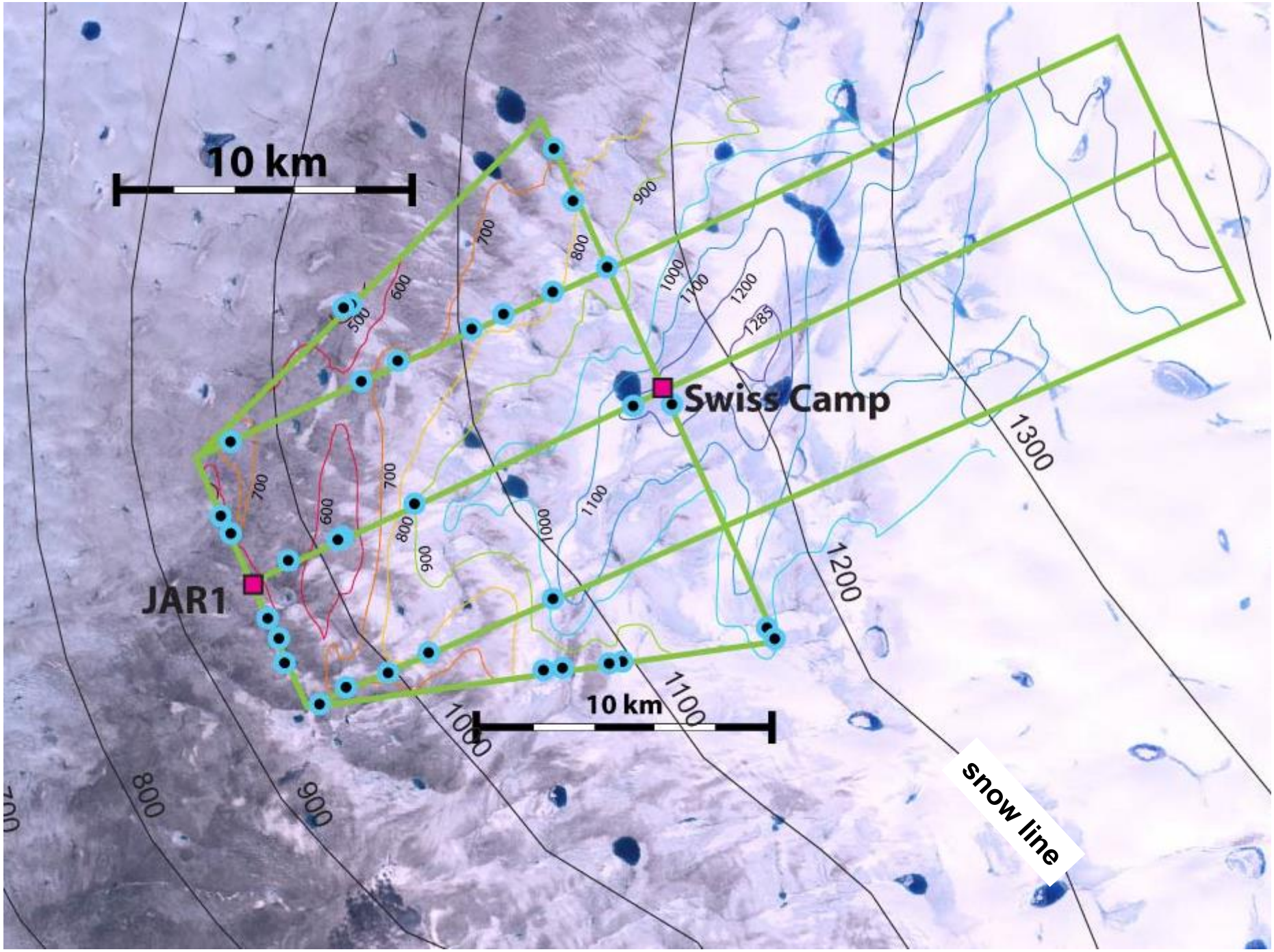
Greenland Melt: Crevasse locations



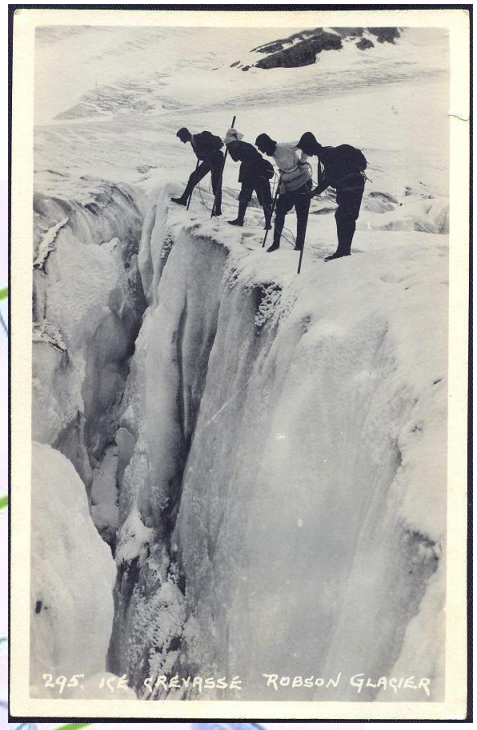
Critical tensile stress required for crevassing
~100 kPa
(Nath & Vaughan, 2001)



Greenland Melt: Crevasse locations



Greenland Melt: Crevasse locations

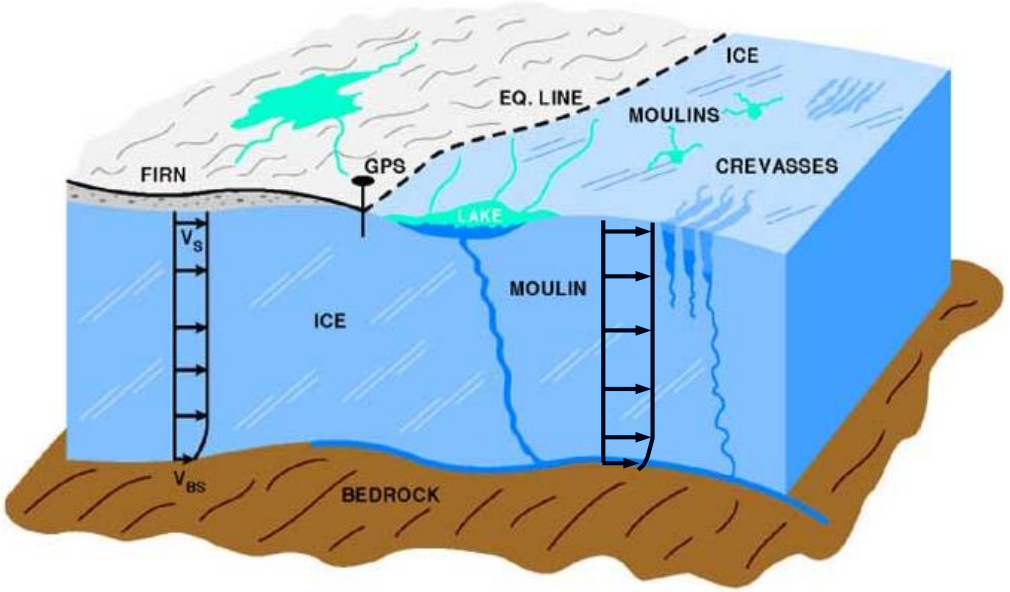


Greenland Melt: Research Questions

1. How does surface melt drain to the ice bed?

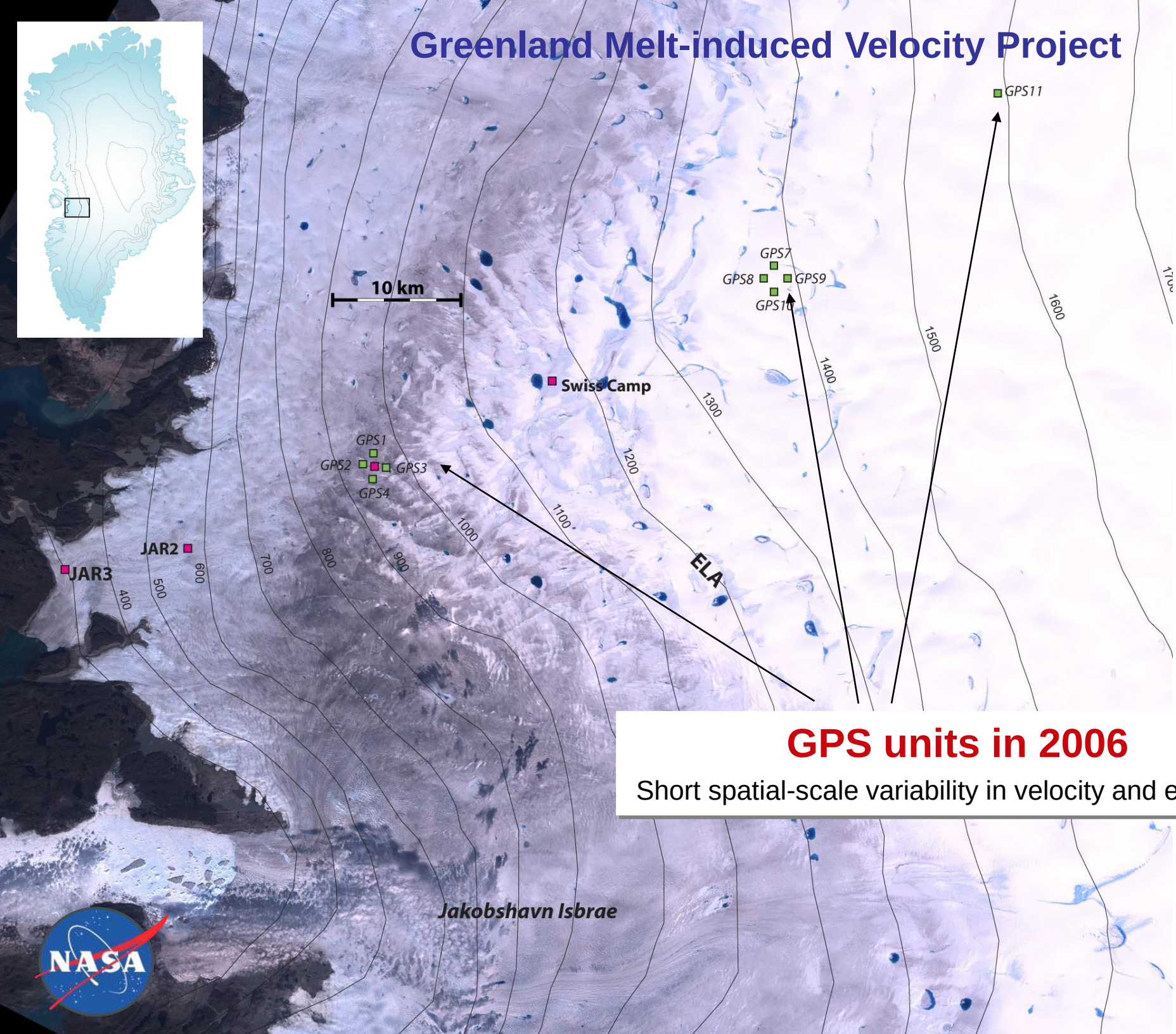
- **good evidence for moulins which allow rapid drainage of surface water to the base of the ice**
- **we only see moulins in the ablation zone (where net melting occurs)**
- **not perfectly correlated to where lakes are on the surface**
- **better correlated to where surface cracks are**
- **occur in ice that is relatively thin <800 m**

2. How does ice respond to increased melt?



3. What will happen to rate of ice flow with further warming?

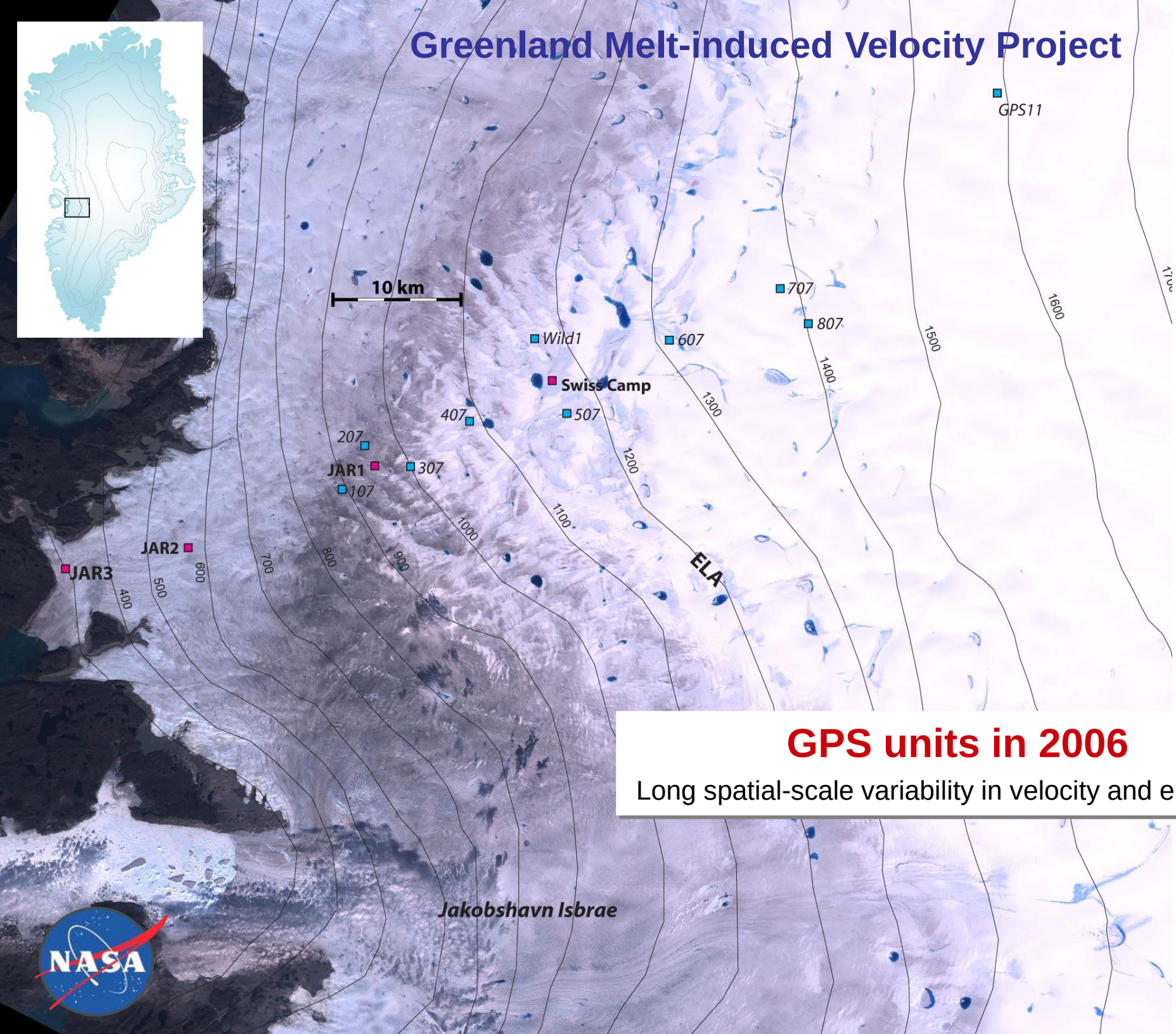
Greenland Melt-induced Velocity Project



GPS units in 2006

Short spatial-scale variability in velocity and elevation

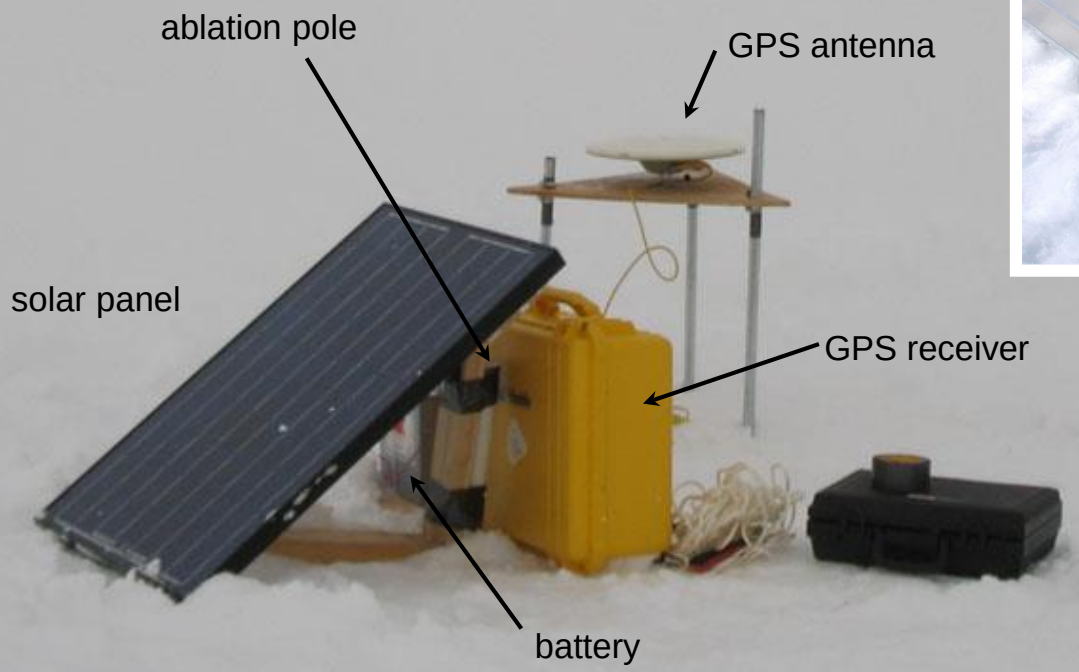
Greenland Melt-induced Velocity Project



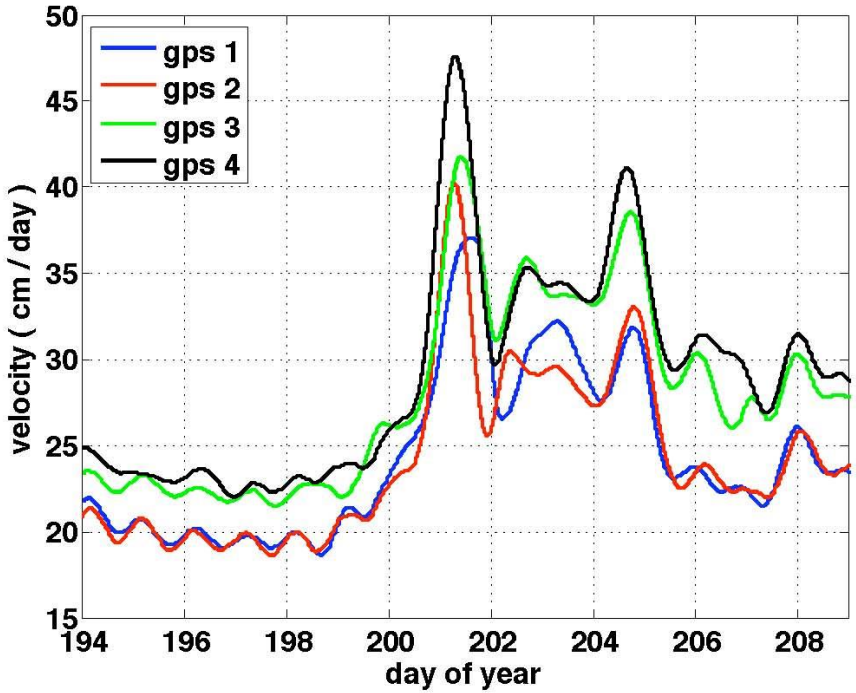
GPS units in 2006

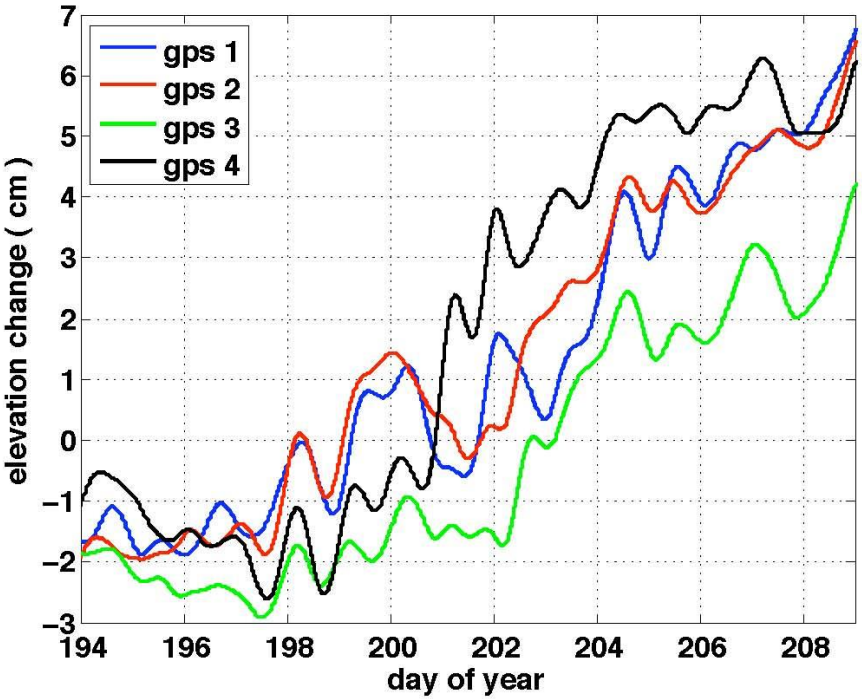
Long spatial-scale variability in velocity and elevation

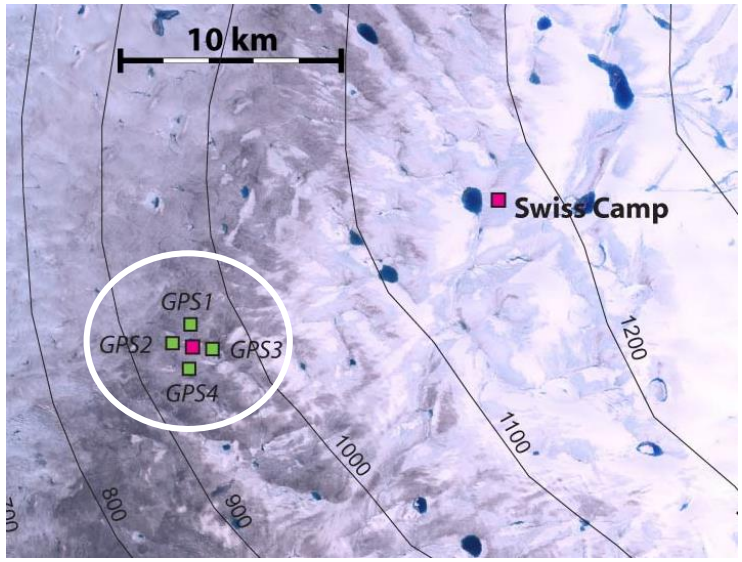
Greenland Melt: GPS deployment



Greenland Melt: 2006 GPS results

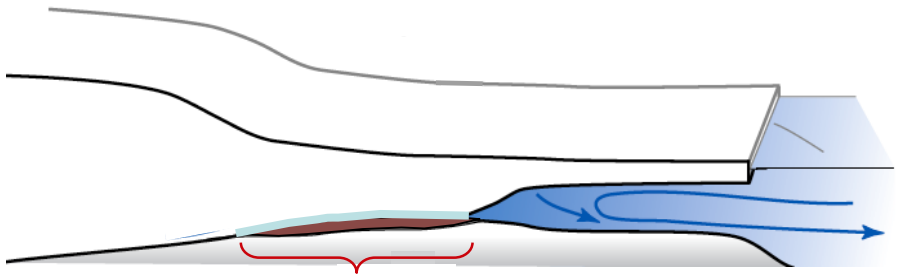




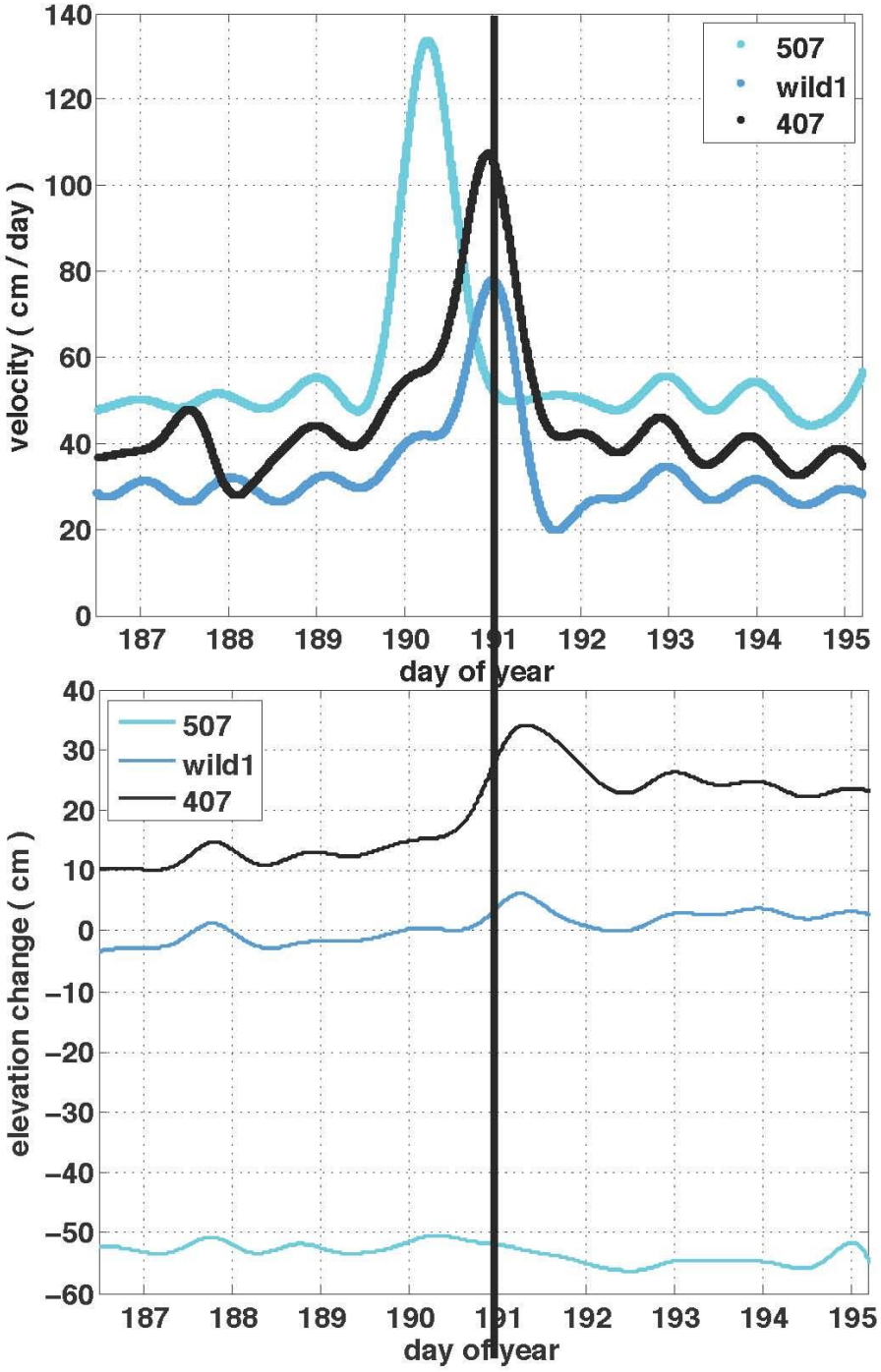


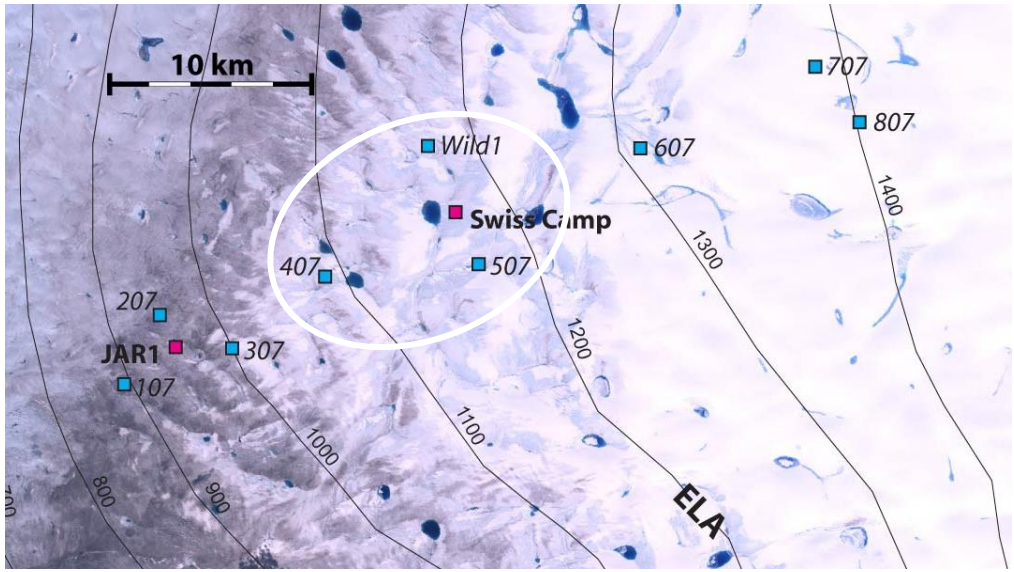
Short spatial scale events

- abrupt
- synchronous over ~1km scale
- near-doubling of horizontal velocity over 6-8 day period through the summer
- systematic elevation increase in ablation region indicative of adding water at the base of the ice



Greenland Melt: 2007 GPS results

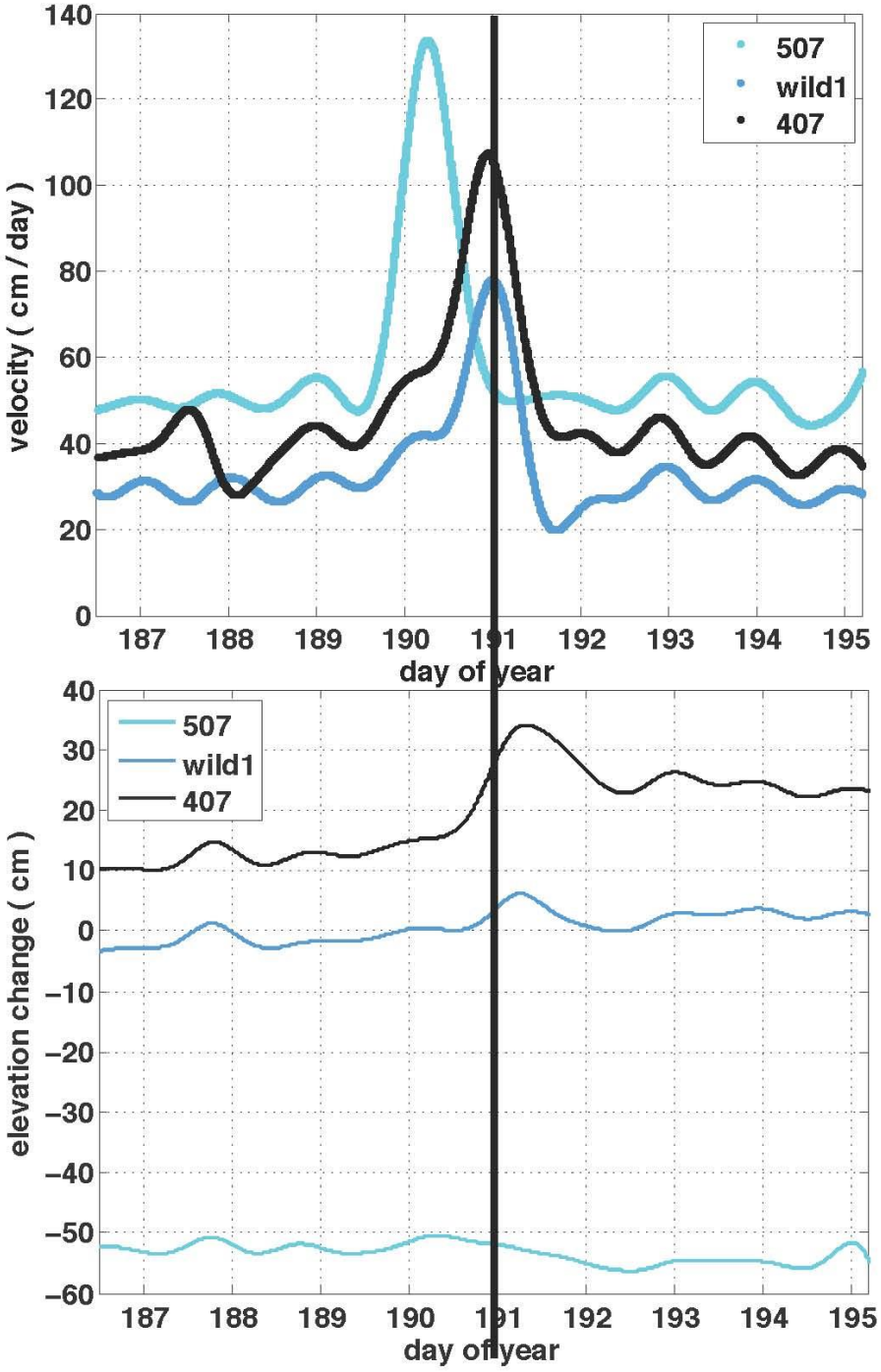


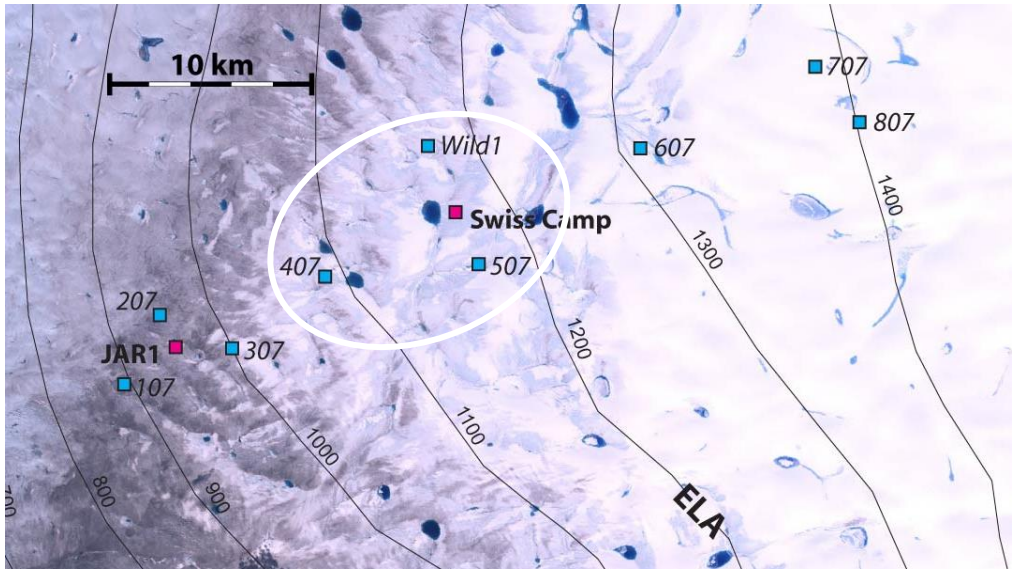


Long spatial scale events

- abrupt
- asynchronous (indicates location of event)
- some events have large-scale impact (~10 km^2 region)
- elevation increase at some sites but draw-down at others is indicative of some degree of stretching of the ice

Greenland Melt: 2007 GPS results





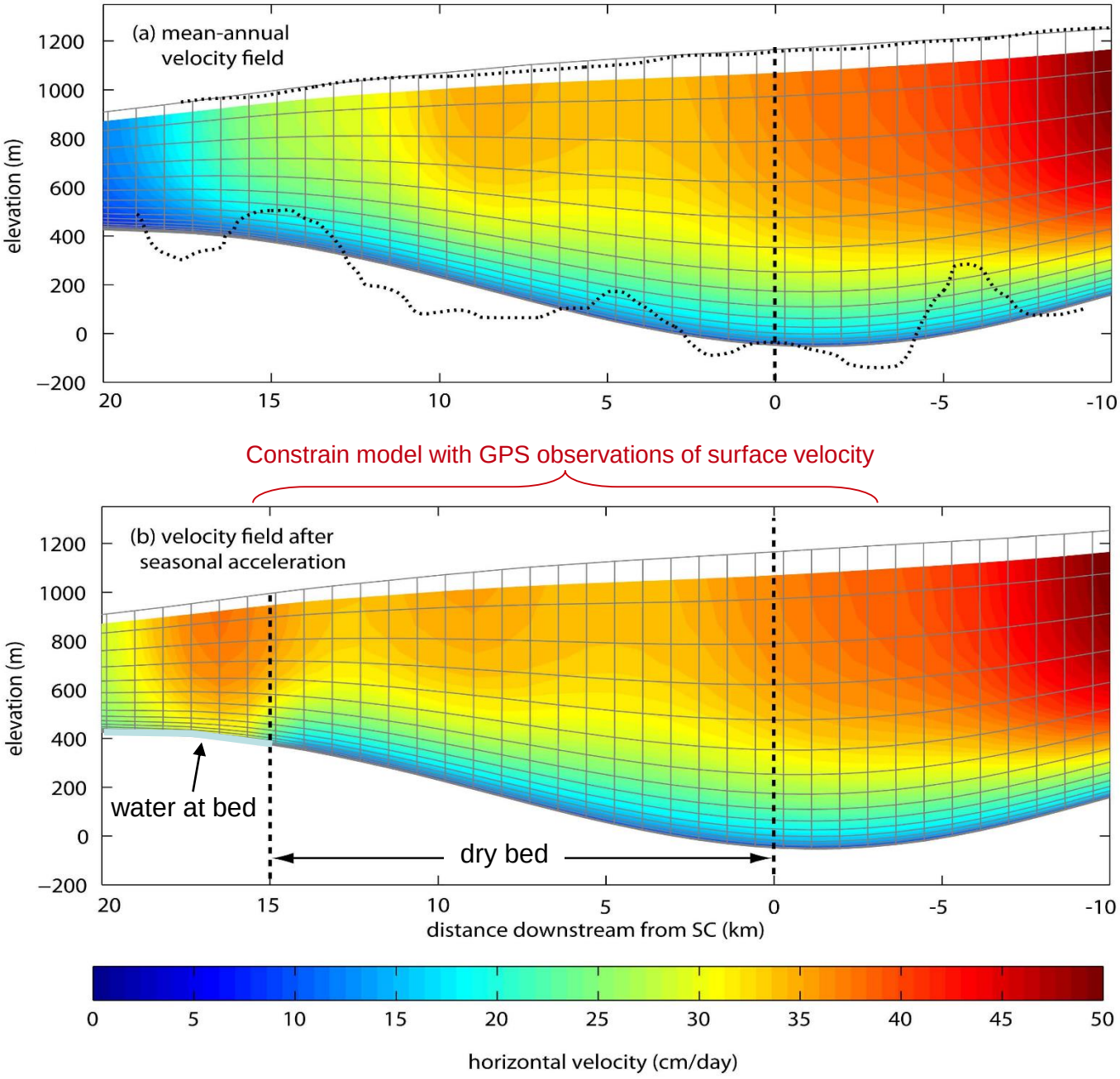
Long spatial scale events

- abrupt
- asynchronous (indicates location of event)
- some events have large-scale impact (~10 km^2 region)
- elevation increase at some sites but draw-down at others is indicative of some degree of stretching of the ice

Consistent with period melt water input in the ablation region

Subglacial drainage accommodates increased input over time

Greenland Melt: Modeling the GPS results

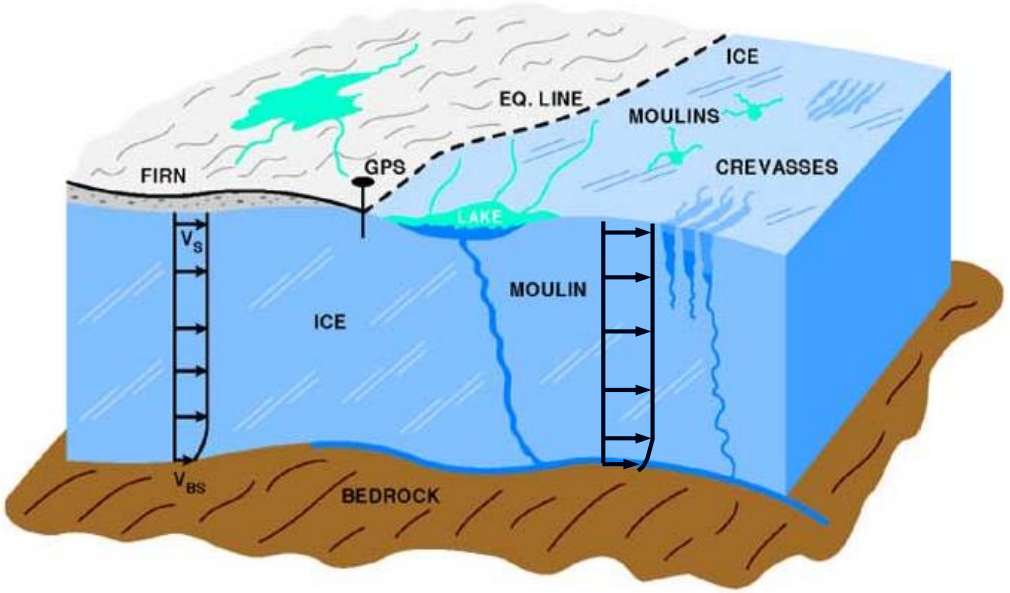


- *Some of the observed velocity increase can be explained by along-flow stretching*
- *Ice downstream starts to move faster and it pulls the ice further upstream*
- *This causes increased speeds and thinning further upstream than where water is input*

Greenland Melt: Research Questions

1. How does surface melt drain to the ice bed?

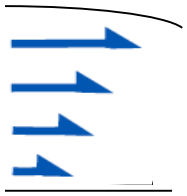
- **good evidence for moulins which allow rapid drainage of surface water to the base of the ice**
- **we only see moulins in the ablation zone (where net melting occurs)**
- **not perfectly correlated to where lakes are on the surface**
- **better correlated to where surface cracks are**
- **occur in ice that is relatively thin <800 m**



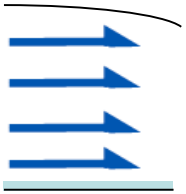
2. How does ice respond to increased melt?

- **water lubricates the bed and allows ice to move faster**

internal deformation



basal sliding

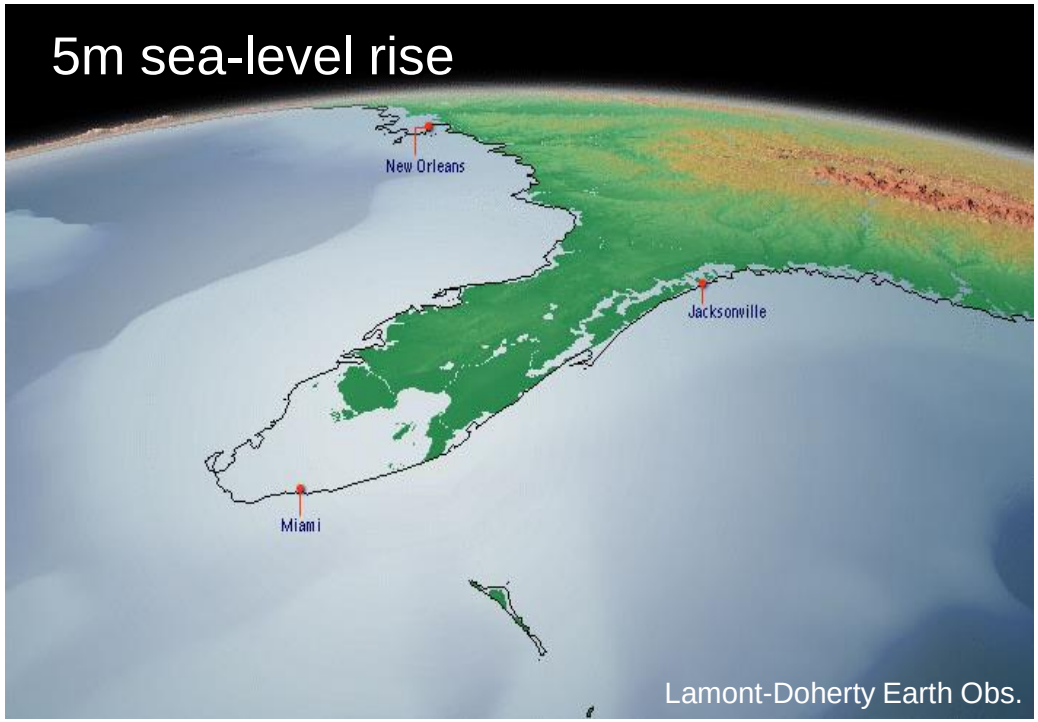


- **over time speeds reduce indicating that the drainage system learns to accommodate water input**
- **some of the ice is thinning because it's stretching**

3. What will happen to rate of ice flow with further warming?

Greenland Melt: Future Predictions

Giant Ice Sheets Threaten Globe!!



News Front Page > Environment

Greenland Melt May Swamp LA, Other Cities, Study Says

Stefan Lovgren
for National Geographic News
April 8, 2004

Published on Tuesday, May 14, 2002 by Reuters

Antarctic Ice Melt Poses Worldwide Threat
by Michael Byrnes

Greenland Melt: Future Predictions

News Media

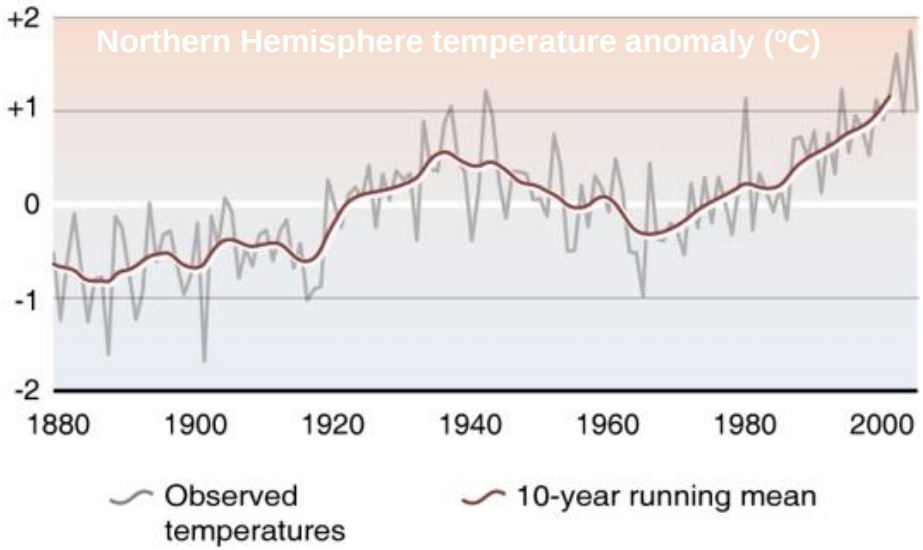
Policy Experts

News media wants a good (dramatic) story
Government wants certainty before policy is dictated

Greenland Melt: Future Predictions

*However, **uncertainty** in how the system behaves is very large*

Natural variability



Maybe the ice can accommodate increased water supply to the bed?

Future Predictions: What we need

BOTTOM LINE NEEDS:

1. *more data in particular areas*
2. *better understanding of important processes*
3. *better integrated global climate models (that include ice sheets)*

But, this is what we know…

FACT: Earth is warming due to greenhouse gases

FACT: CO2 has a lifetime of ~100 years (ACT NOW!)

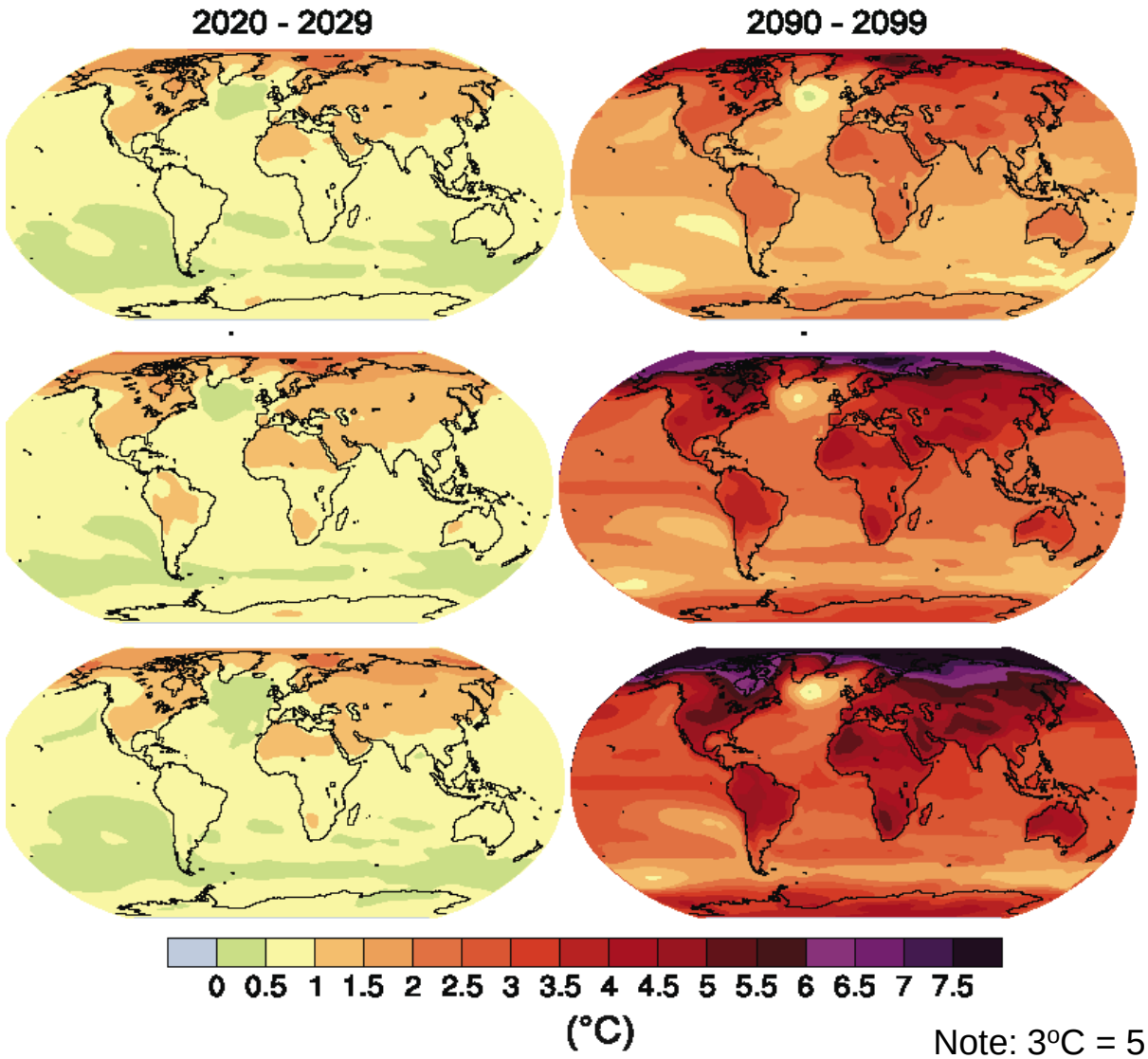
FACT: Ice melts!

Future Predictions: The BIG experiment

Eco-friendly integrated world

Moderately eco-friendly

Business as usual



Note: 3ºC = 5.4ºF

WHICH FUTURE DO WE CHOOSE?

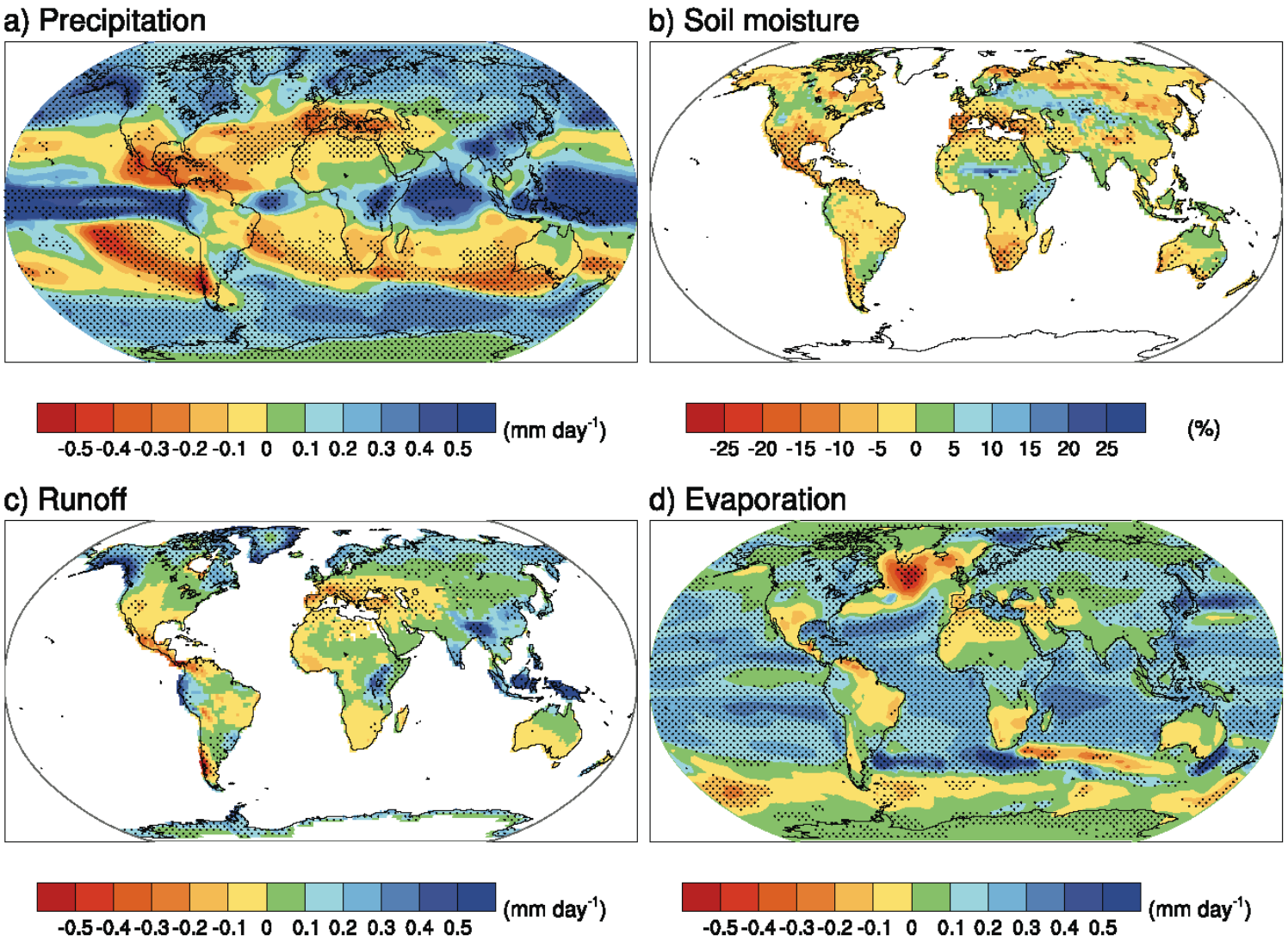


Figure 10.12. *Multi-model mean changes in (a) precipitation (mm day^{-1}), (b) soil moisture content (%), (c) runoff (mm day^{-1}) and (d) evaporation (mm day^{-1}). To indicate consistency in the sign of change, regions are stippled where at least 80% of models agree on the sign of the mean change. Changes are annual means for the SRES A1B scenario for the period 2080 to 2099 relative to 1980 to 1999. Soil moisture and runoff changes are shown at land points with valid data from at least 10 models. Details of the method and results for individual models can be found in the Supplementary Material for this chapter.*

Dr. Ginny Catania

Ginny Catania is a glaciologist with the Institute for Geophysics at The University of Texas at Austin. She joined the faculty at The University of Texas at Austin in 2005, after completing her Post-Doctoral Research at the University of California at Santa Cruz. She won the Jackson School of Geosciences Excellence in Research Award in 2007 and the University of Minnesota's Outstanding Teaching Award in 1998.Catania specializes in understanding ice sheet motion using ice-penetrating radar and GPS. She is originally from Canada but enjoys living in the warmth of Texas when she's not conducting field work in Greenland and Antarctica. She is currently researching the importance of meltwater to the peripheral thinning of Greenland's ice sheet for NASA.