Polar Ice Sheets:
understanding past, present and future

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Why are glaciers and ice sheets important?

- Large volume of fresh water stored in ice masses
- Change in ice volume affects global sea level
- Potential threat to coastal communities

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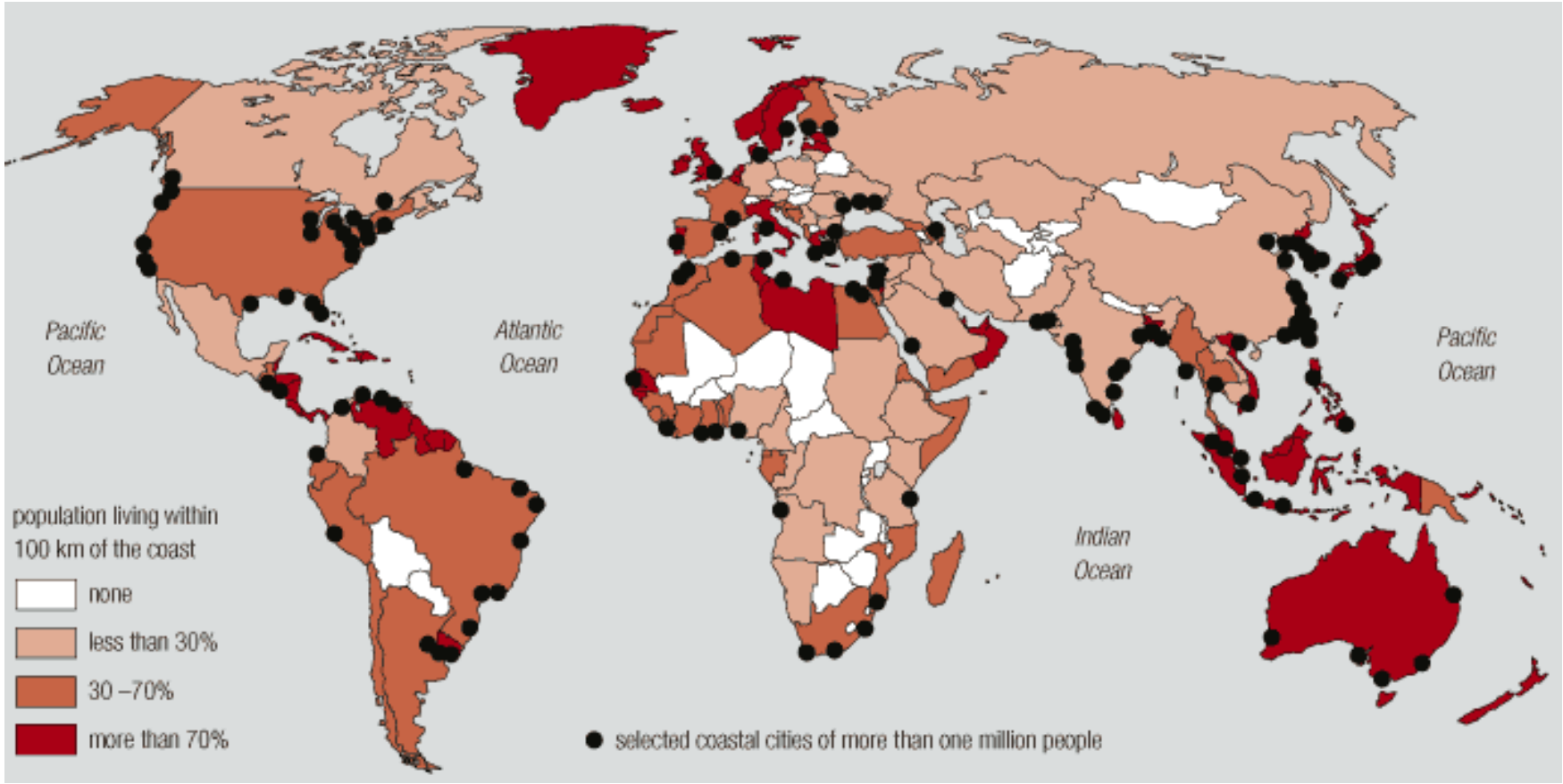

United Nations Environment Programme
GEO: Global Environment Outlook

Living along coasts

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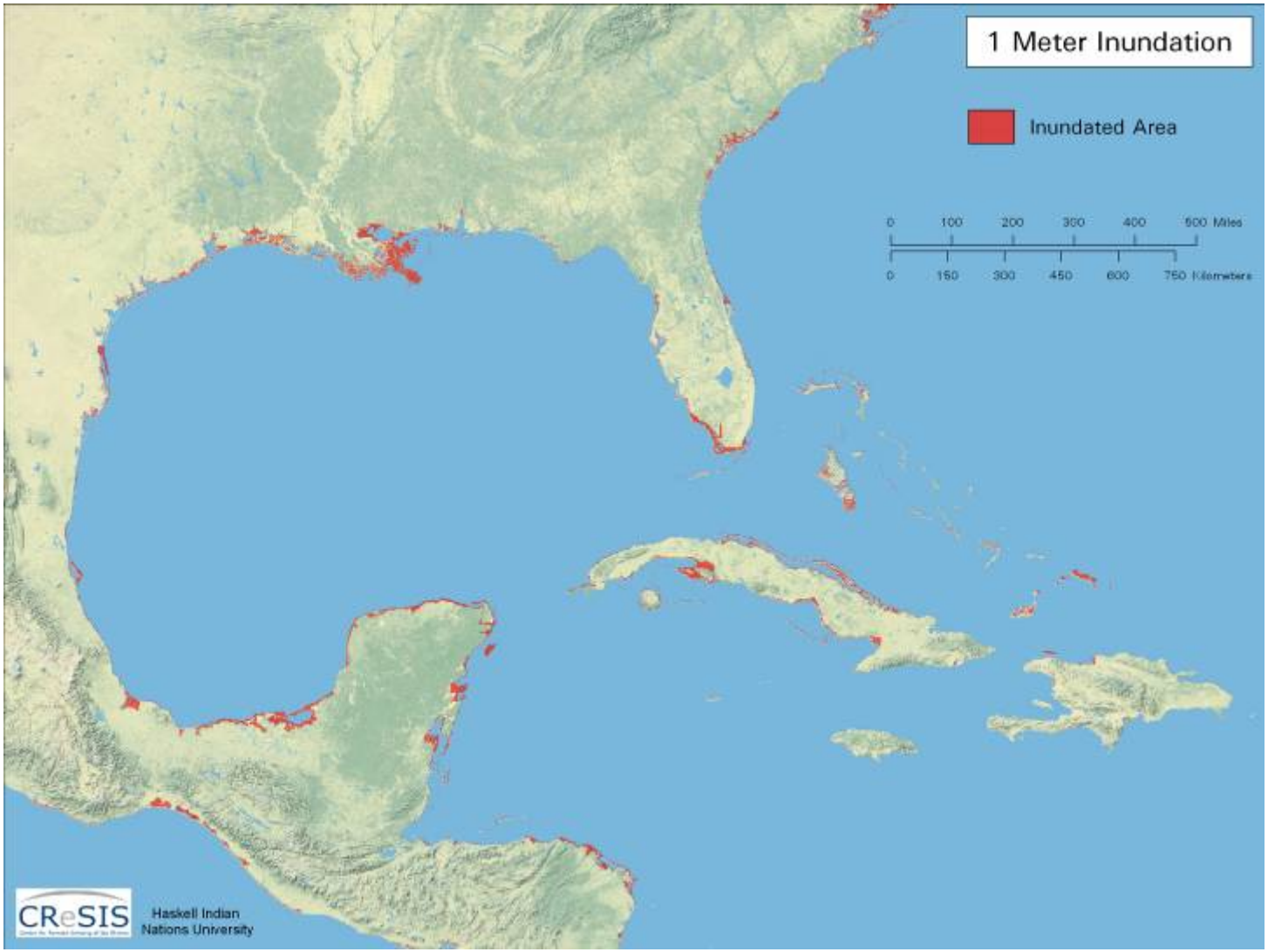
Not all coastal development is a good idea....



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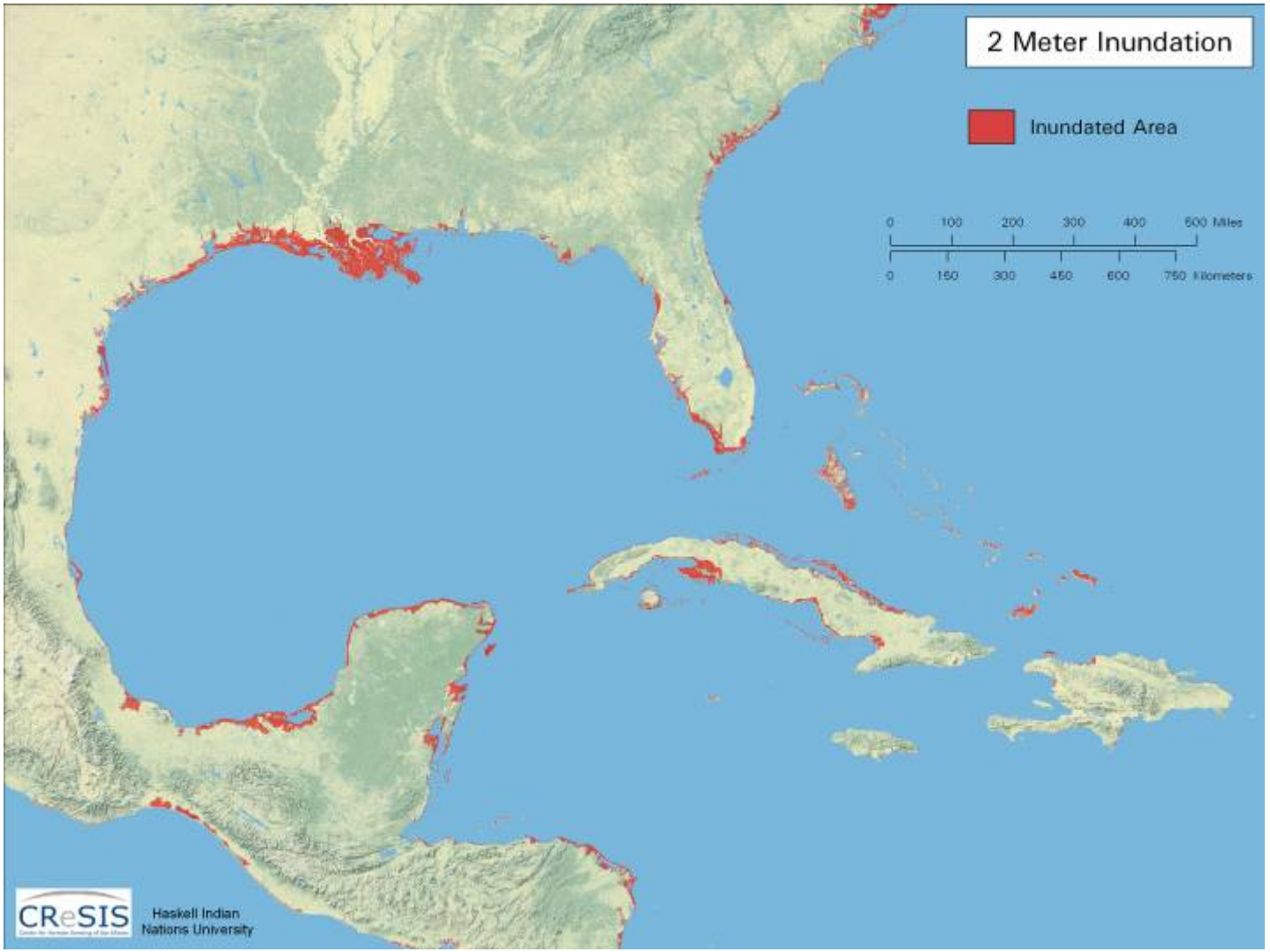

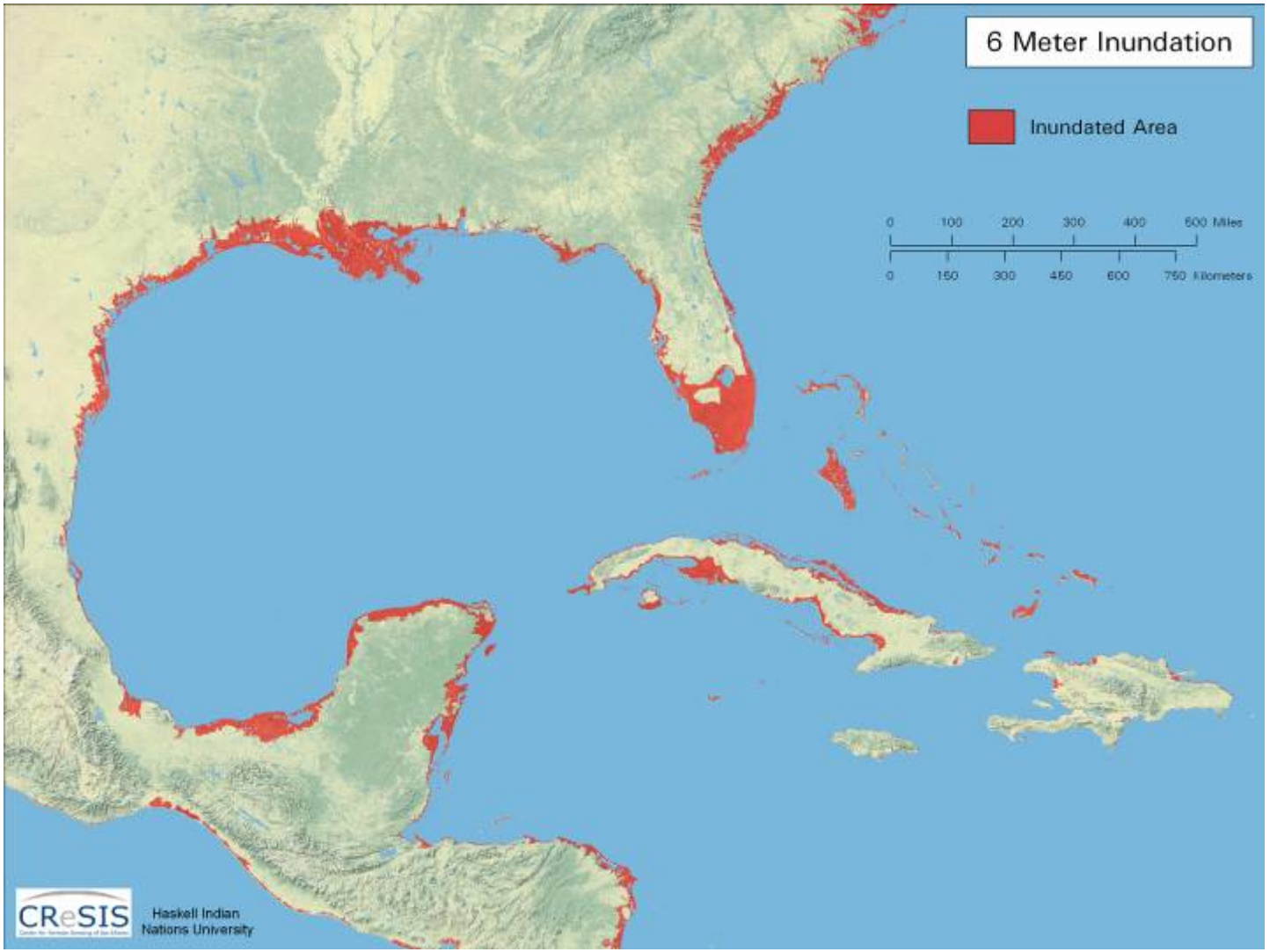
6 Meter Inundation
Inundated Area
0 100 200 300 400 600 Miles
0 150 300 450 600 750 Kilometers
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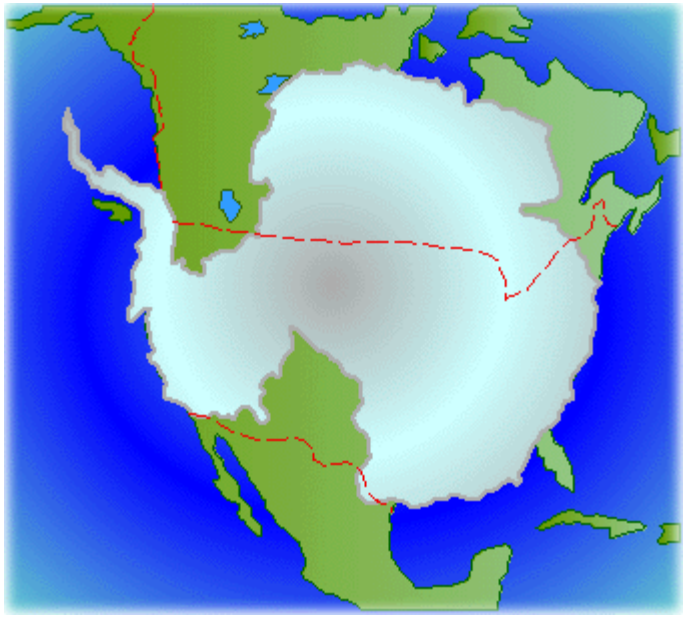
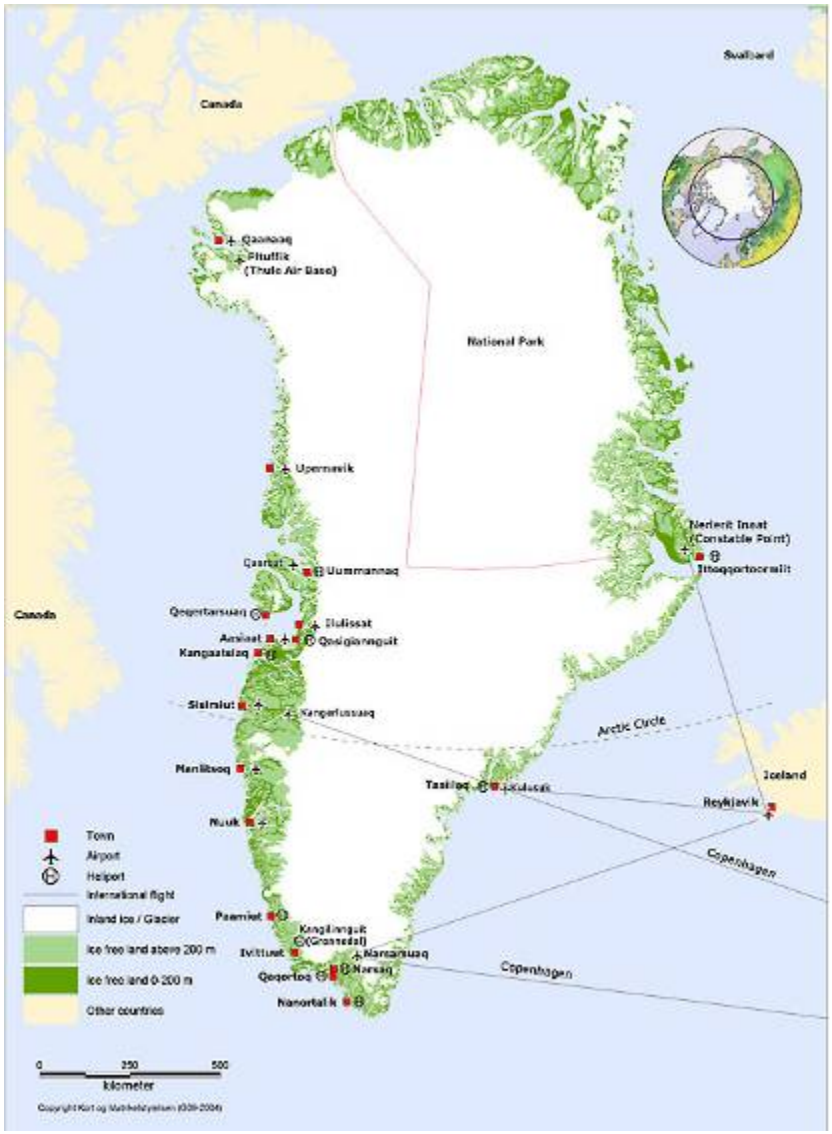
How much ice is on Earth?

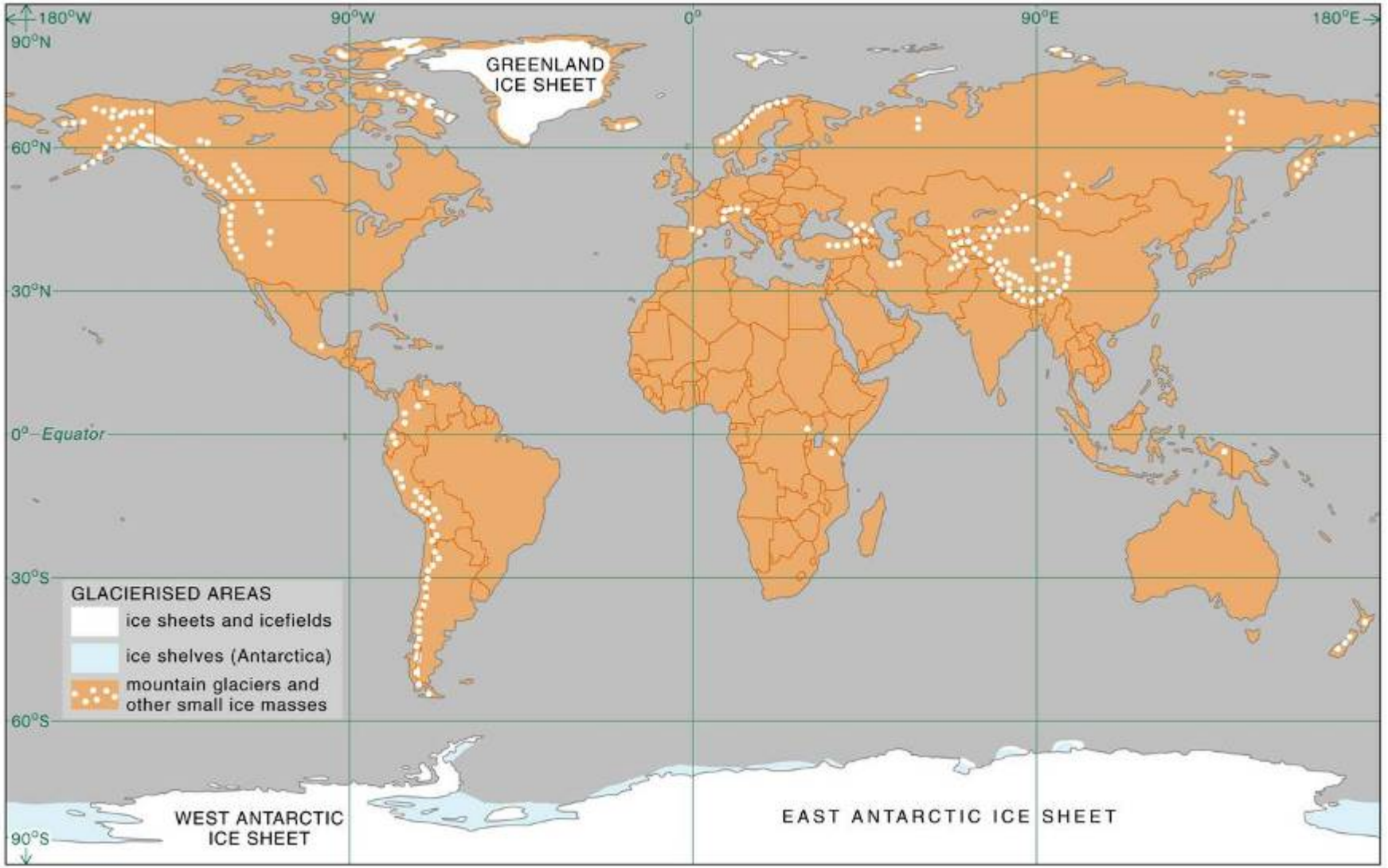
- Antarctica
  - ~70 m sea-level equivalent
- Greenland
  - ~7 m sea-level equivalent
- Mountain glaciers and small ice caps
  - ~0.5 m sea-level equivalent

Antarctica





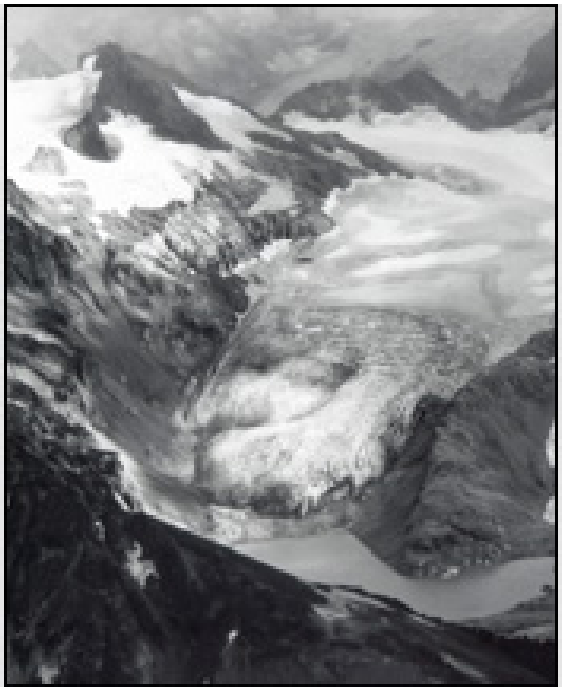
Greenland



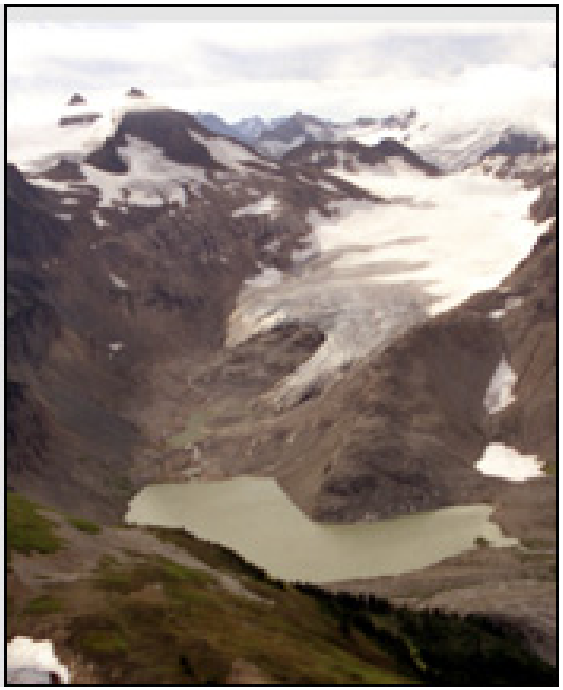
Distribution of mountain glaciers

Retreating glaciers

1928



1979



2003

South Cascade Glacier, WA

The Last Glacial Maximum

	VOLUME (10^6 km^3)	
	present	*LGM*
Antarctica	26	34
Greenland	2.9	3.5
North America	--	33.0
Eurasia	--	13.3

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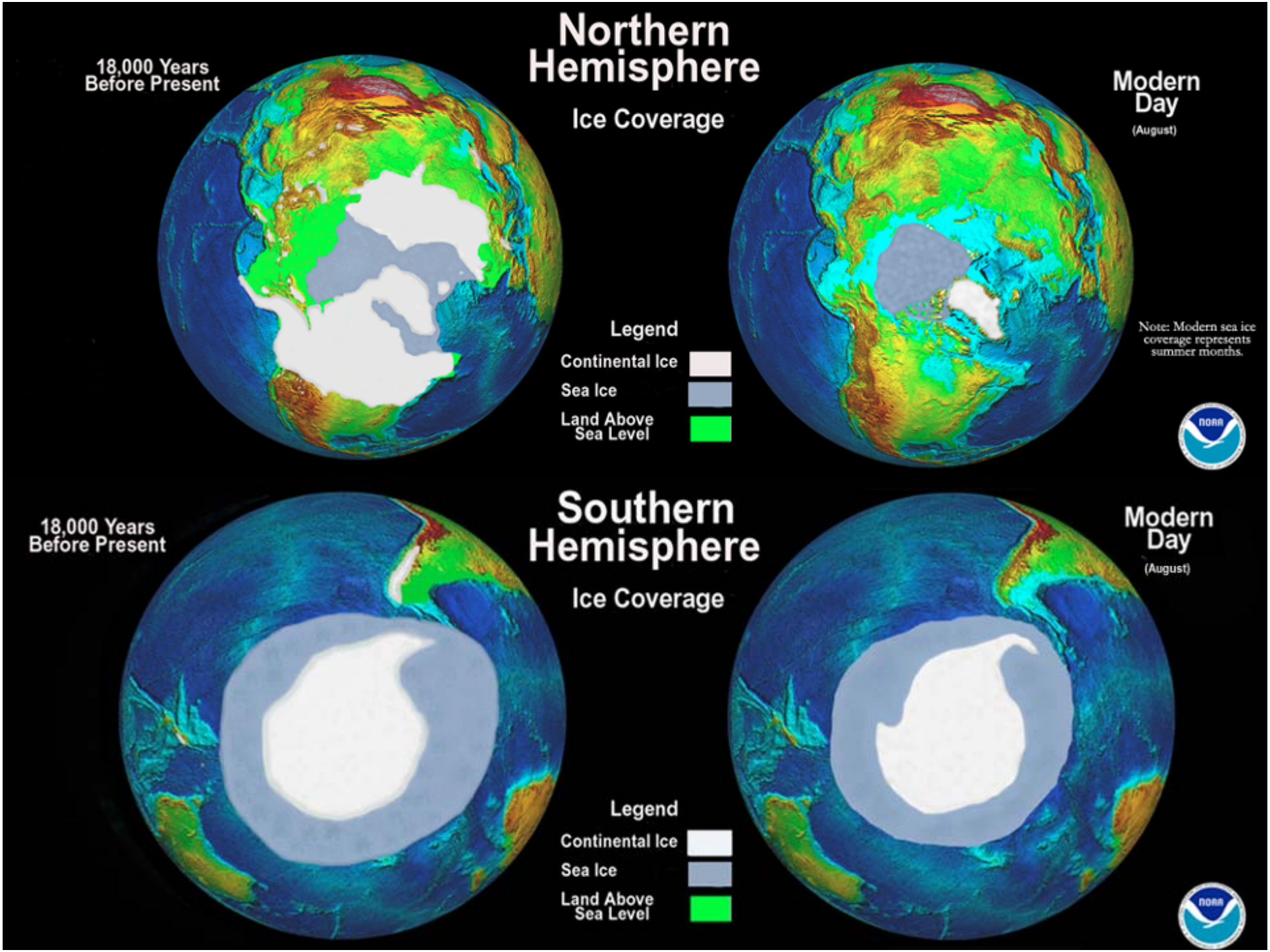
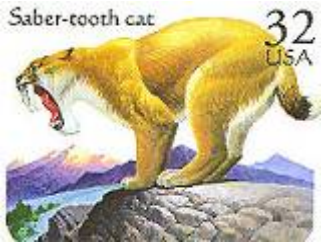
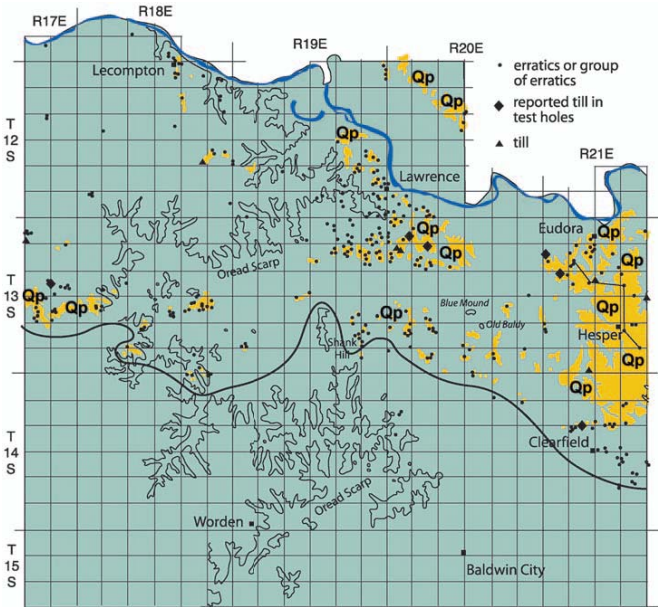

Northern Hemisphere
Ice Coverage
18,000 Years Before Present
Modern Day
(August)
Legend
Continental Ice
Sea Ice
Land Above Sea Level
Note: Modern sea ice coverage represents summer months.
Southern Hemisphere
Ice Coverage
18,000 Years Before Present
Modern Day
(August)
Legend
Continental Ice
Sea Ice
Land Above Sea Level

Glaciers in Kansas





~400,000 years B.P.

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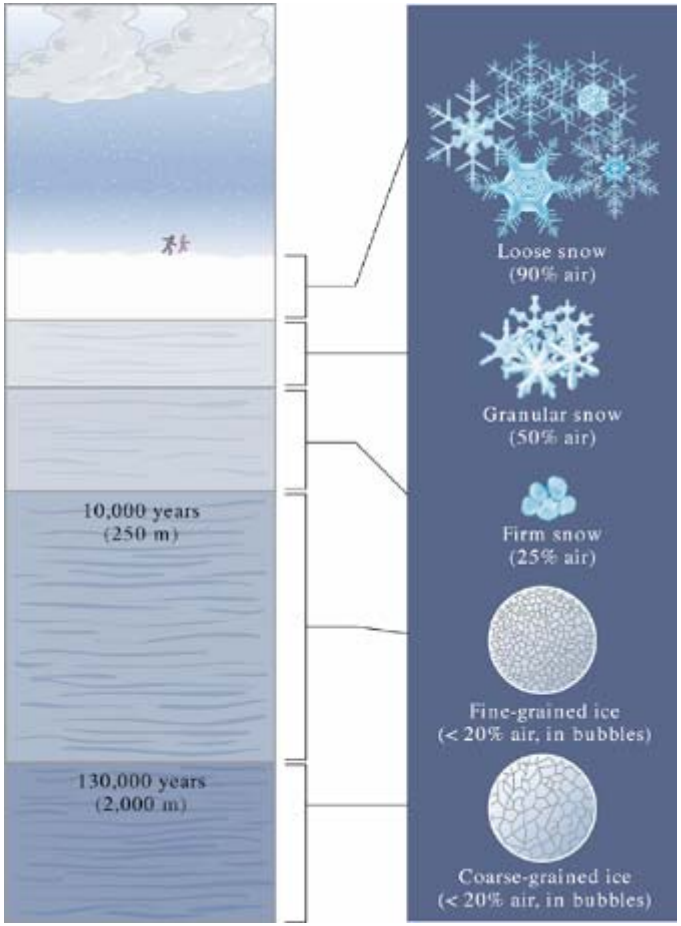
How glaciers form



snow

↓

granular snow

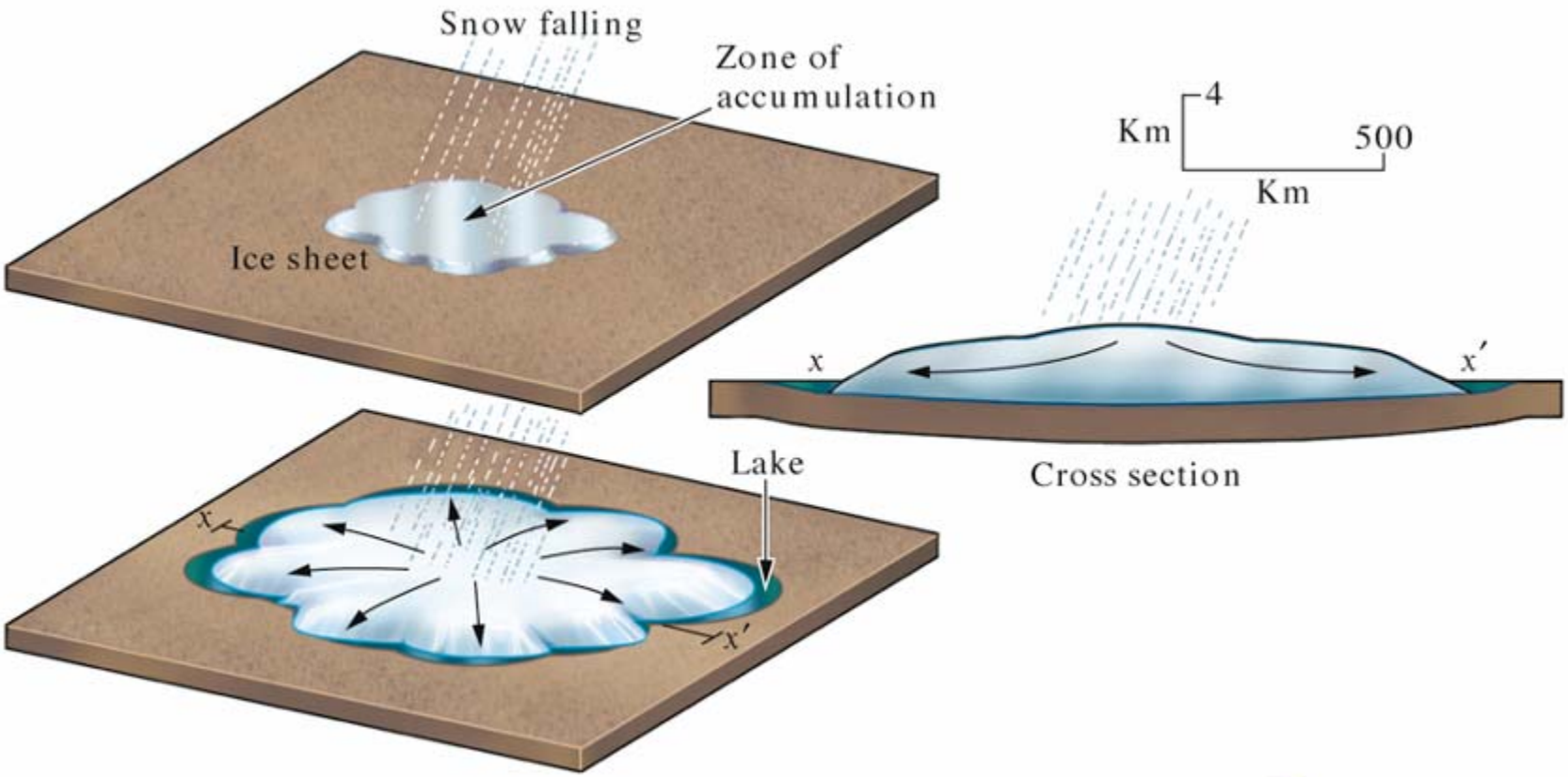
↓

firn

↓

glacial ice

Building an ice sheet



Glacier flow

- Transport material from higher elevations to the margin
- Towards steady state for given climate conditions
- Considerable time delay between climate change and ice-sheet response

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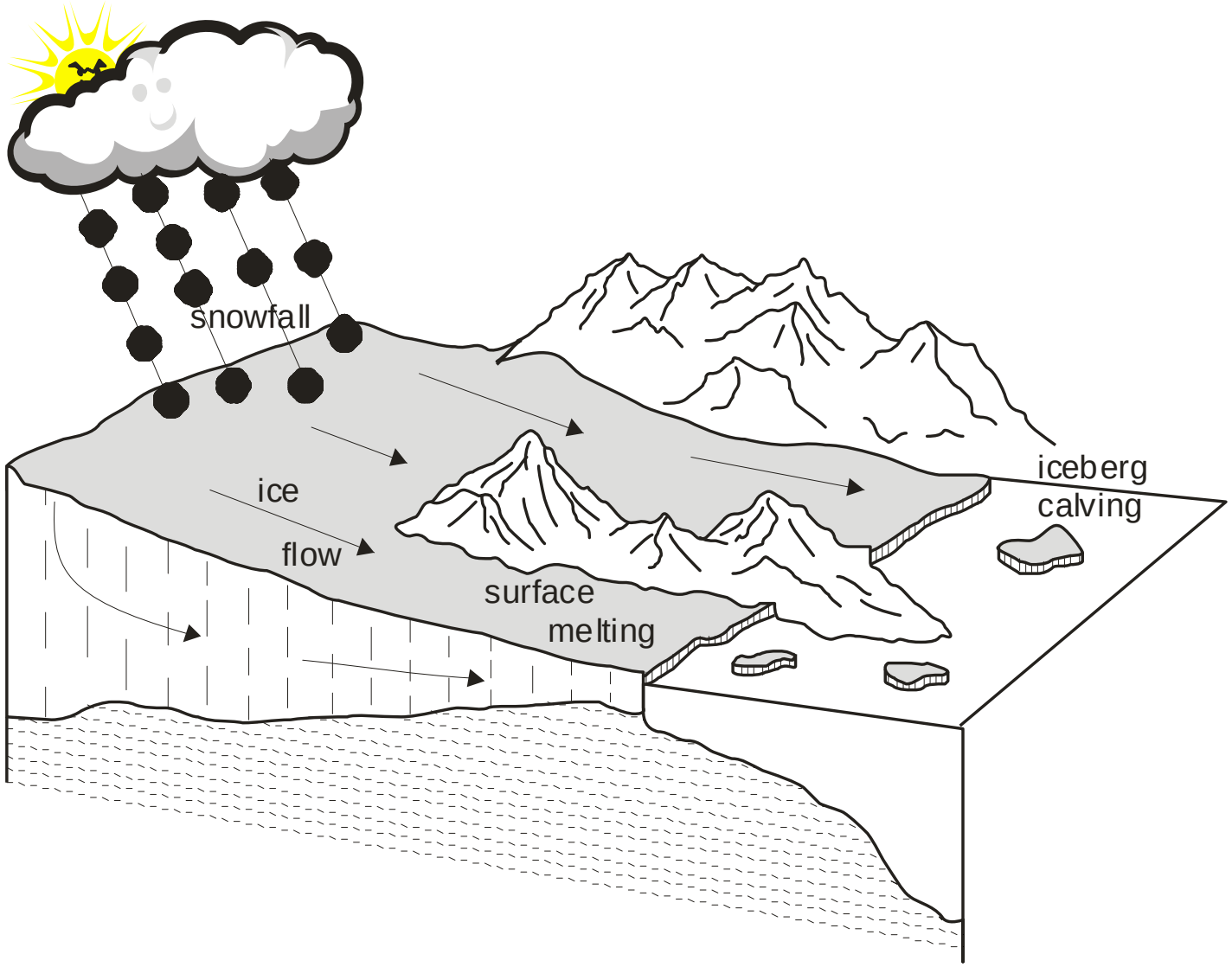

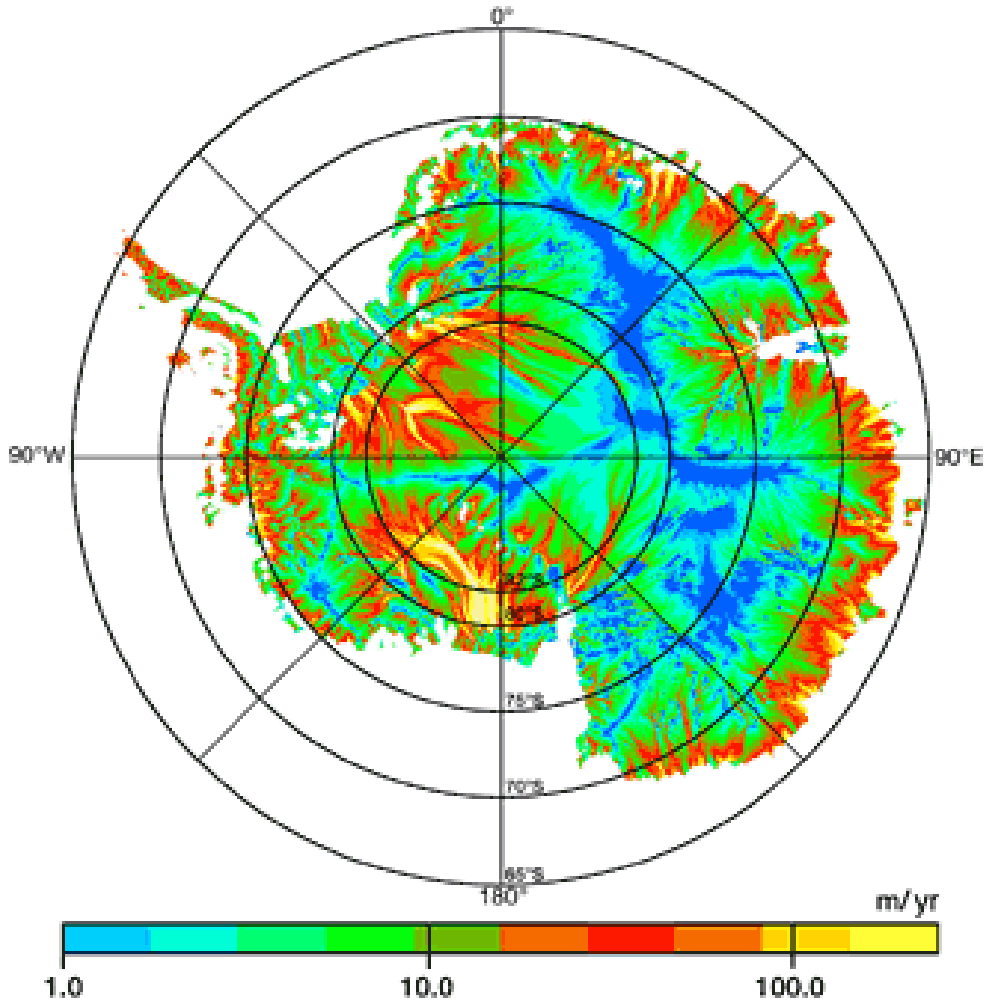

Ice velocities, Antarctica

Monitoring Ice Sheets

- Mass balance
  - Growing or shrinking?
- Ice velocity
  - Speeding up?
- Basal conditions
  - What is happening at the bed of the ice sheets?

Observing Ice Sheets

- Field-based campaigns
  - Time and labor intensive
  - Small areas covered
  - Restricted to summer
- Remote sensing (airborne or satellite)
  - Ice-sheet wide coverage
  - Continuous observations possible

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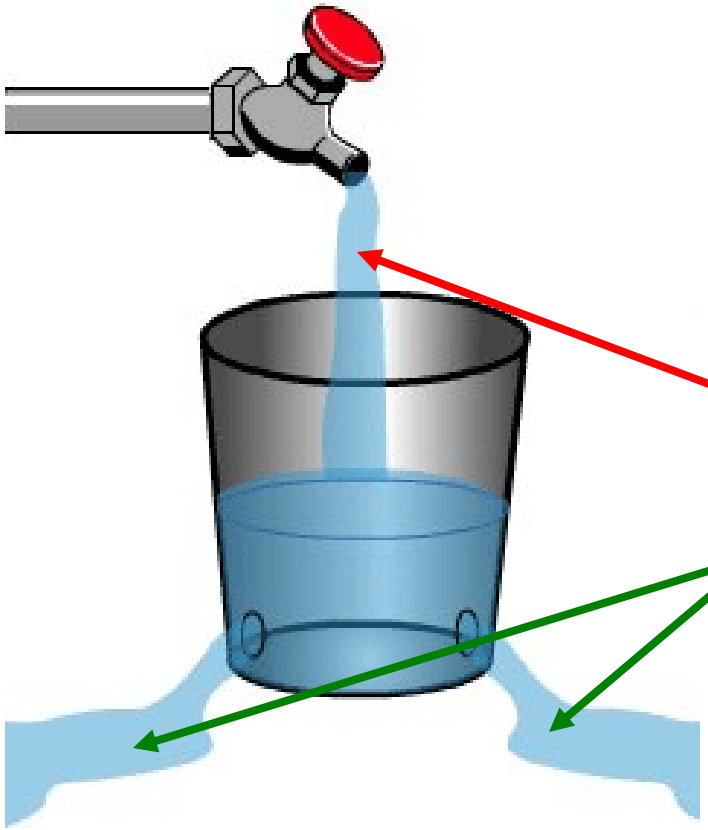
Determining glacier mass balance (1)



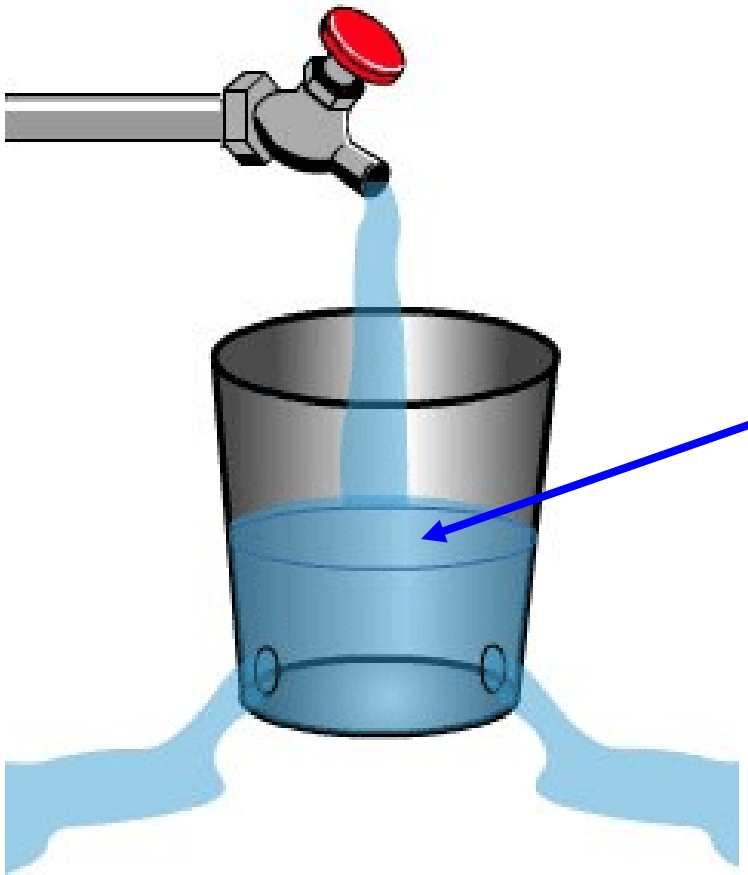
Hydrological method:

Mass balance =

Mass input (snowfall) -

Mass loss (melting and calving)

Determining glacier mass balance (2)

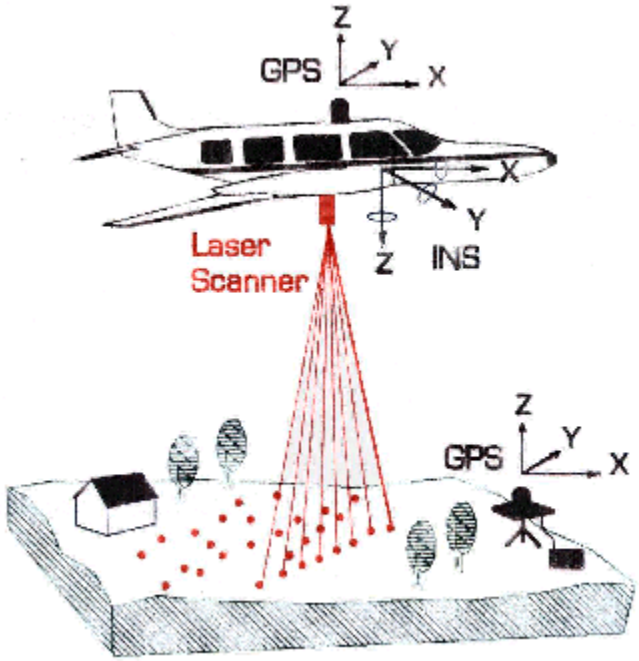


Geodetic method:

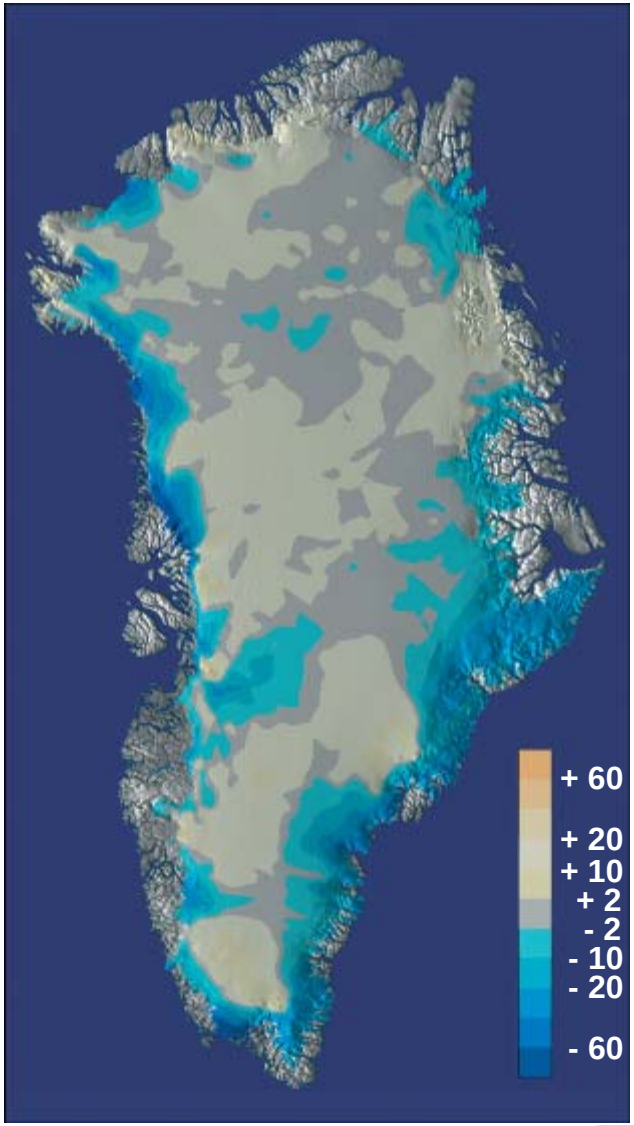
Mass balance =

Change in water level
(elevation of ice surface)

Measuring changes in surface elevation



Laser altimetry



Elevation changes in cm/yr on the Greenland Ice Sheet from airborne laser altimetry

(NASA Wallops Flight Center)

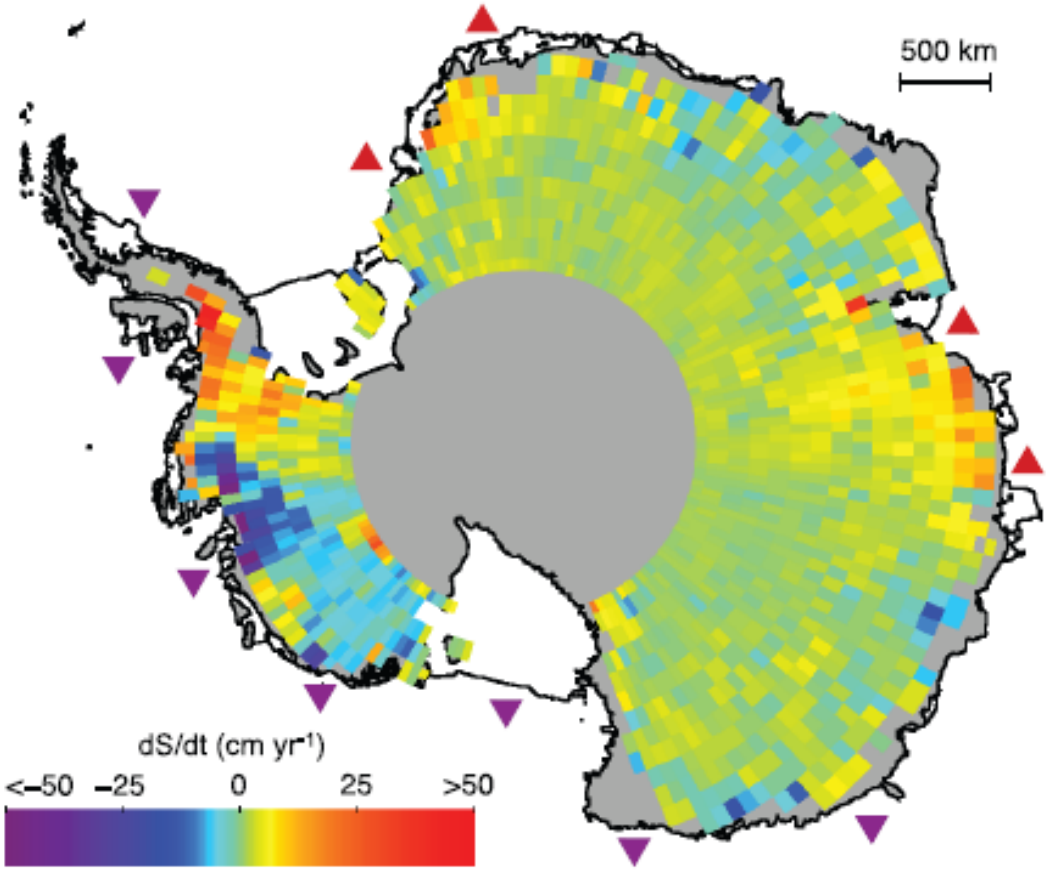


Figure 4.19. *Rates of surface elevation change (dS/dt) derived from ERS radar-altimeter measurements between 1992 and 2003 over the Antarctic Ice Sheet (Davis et al., 2005). Locations of ice shelves estimated to be thickening or thinning by more than 30 cm yr^{-1} (Zwally et al., 2006) are shown by red triangles (thickening) and purple triangles (thinning).*

Current state of balance of glaciers and ice sheets

- Antarctica

  Slightly negative (IPCC, 2007), largest thinning in West Antarctica

- Greenland

  Interior close to balance, outlet glaciers thinning rapidly

- Mountain glaciers

  worldwide retreat

Wildcard in the deck….

- Ice-shelf break-up in the Antarctic Peninsula
- Rapid thinning of outlet glaciers in Greenland
- Increased velocities on outlet glaciers

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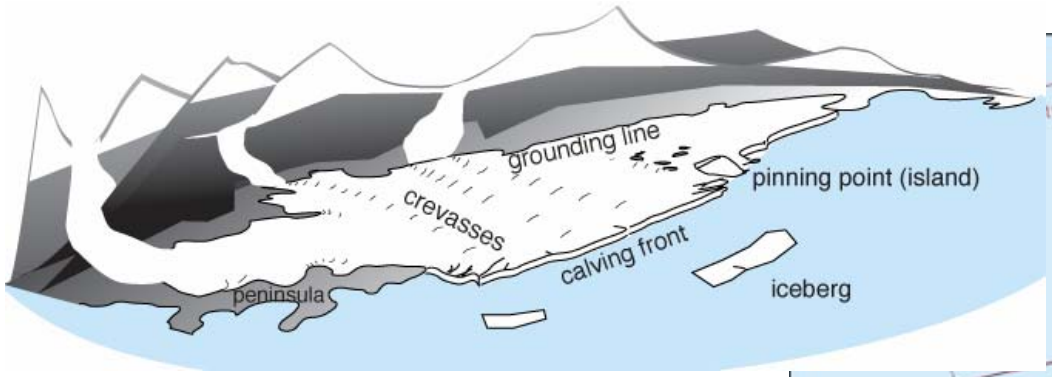
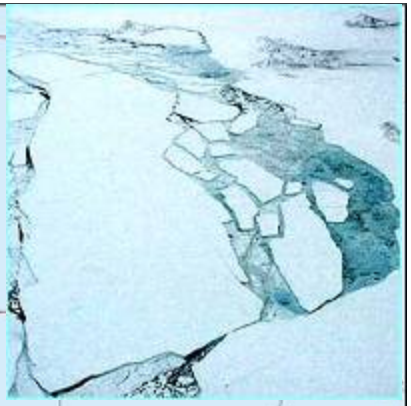
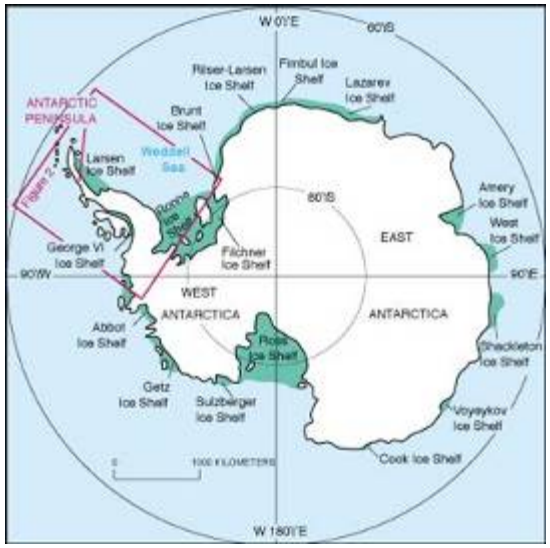
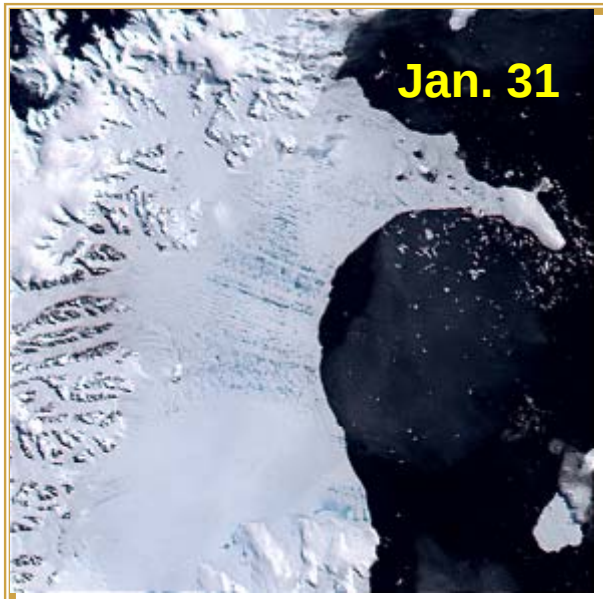
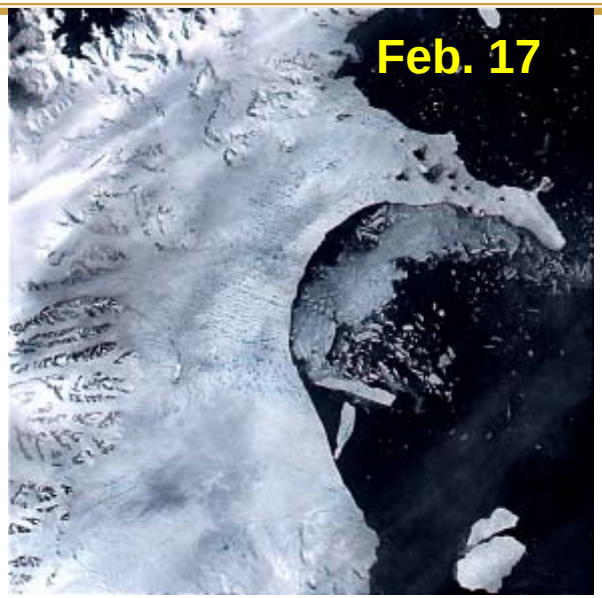


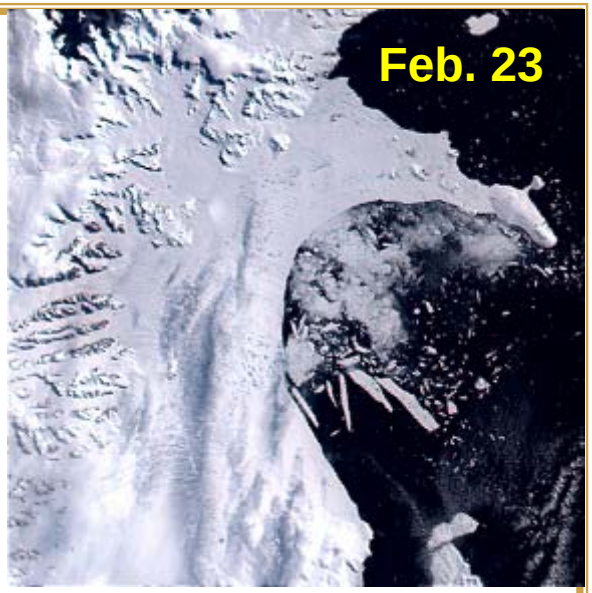


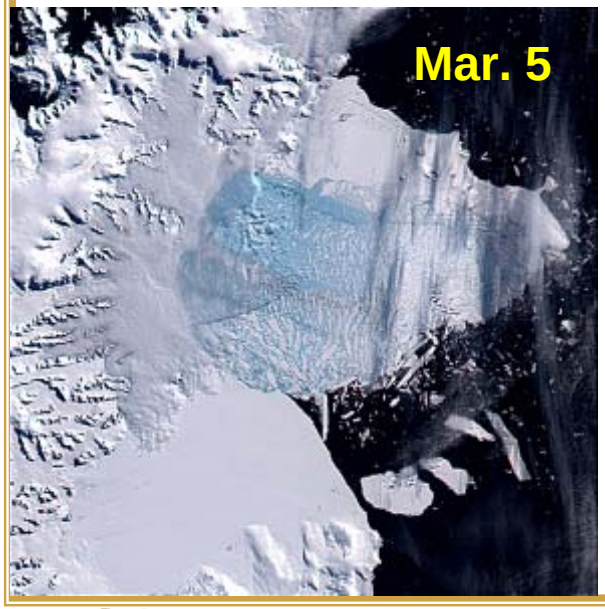


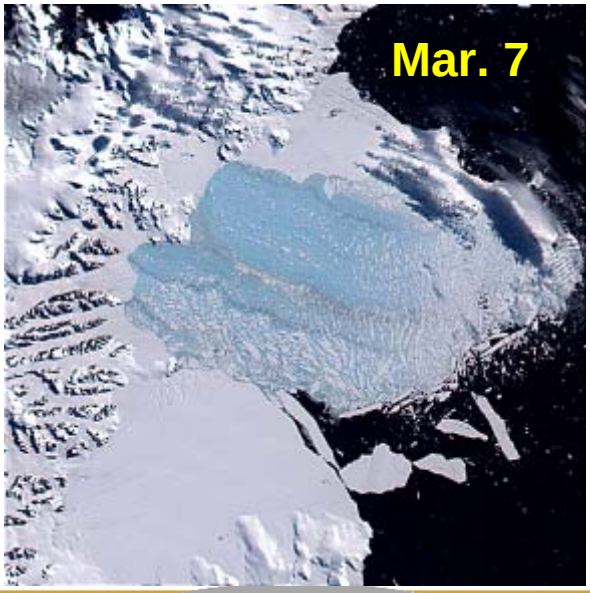
Antarctic Peninsula



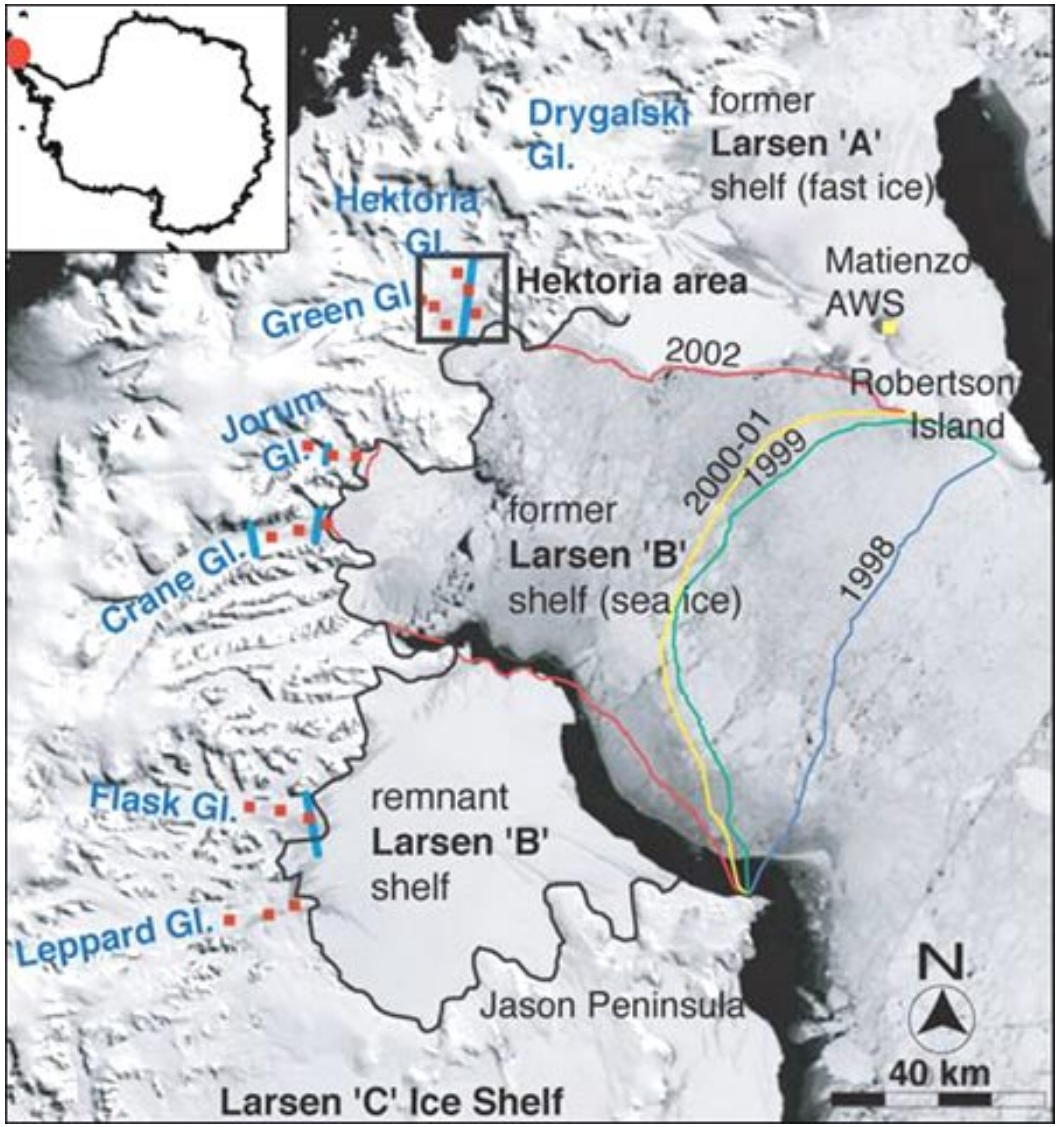








Larsen B Ice Shelf, 2002



Jet Propulsion Laboratory
California Institute of Technology

Increased discharge after break up of Larsen B

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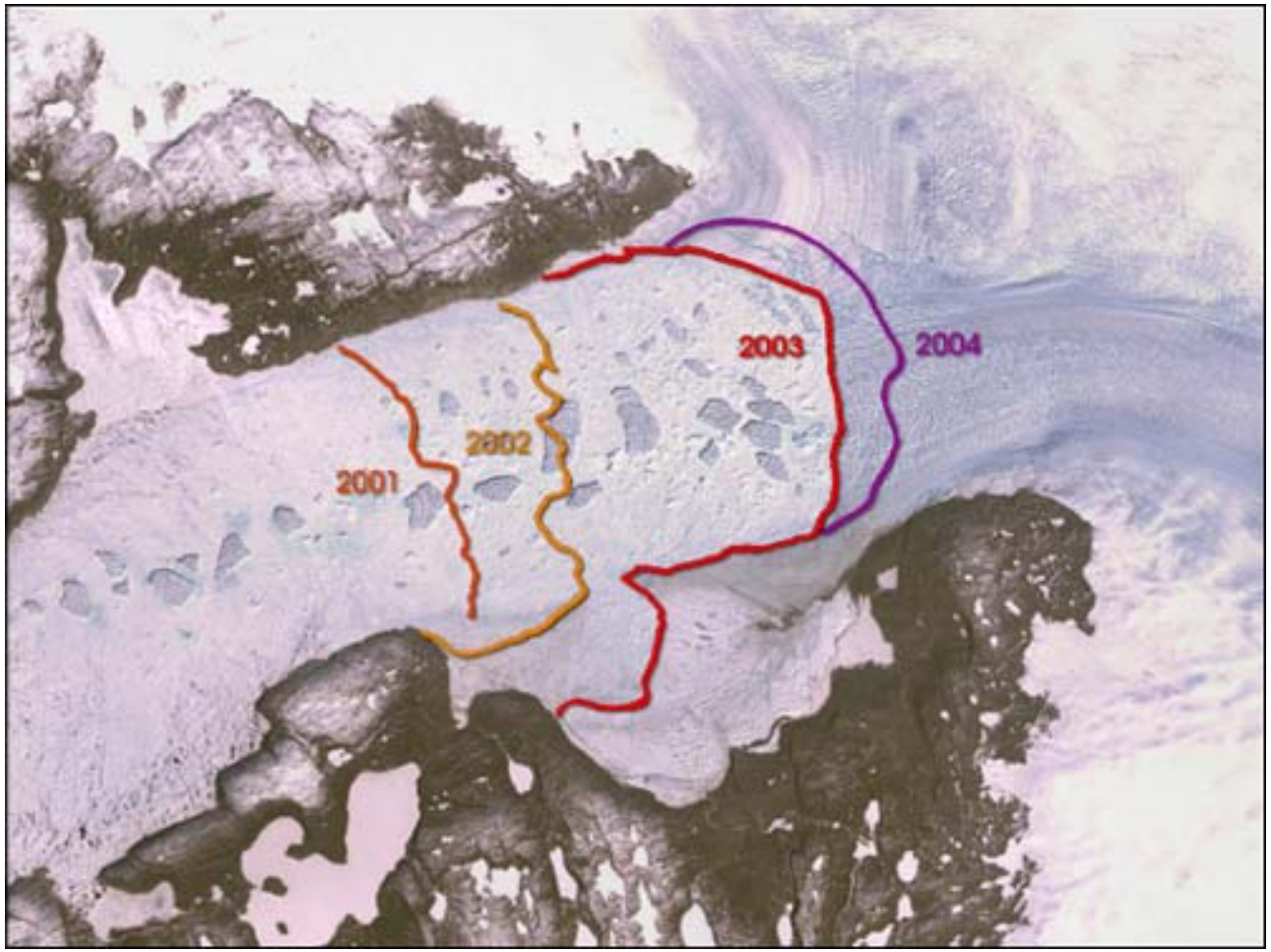
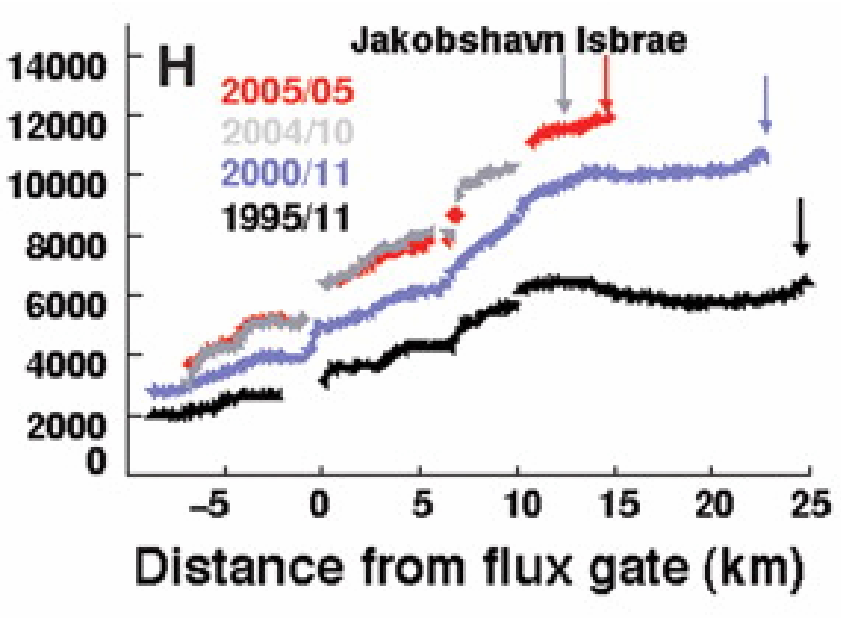


Retreat of calving front of Jakobshavns Glacier



Greenland's mass loss doubled in the last decade:

- 0.23 ± 0.08 mm slr / yr in 1996
- 0.57 ± 0.1 mm slr / yr in 2005

- 2/3 of the loss is caused by ice dynamics
- 1/3 is due to enhanced runoff

Jakobshavn discharge:

- 24 km^3 / yr in 1996
- 46 km^3 / yr in 2005

Rignot and Kanagaratnam, Science (2006)

Is there a threshold?

- Conventional theory predicts slow ice-sheet adjustments to changes in climate
- Recent observations indicate rapid changes are possible
- Can polar ice sheets become unstable?

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Flow of glaciers

- Internal deformation
- Basal sliding
- Sediment deformation

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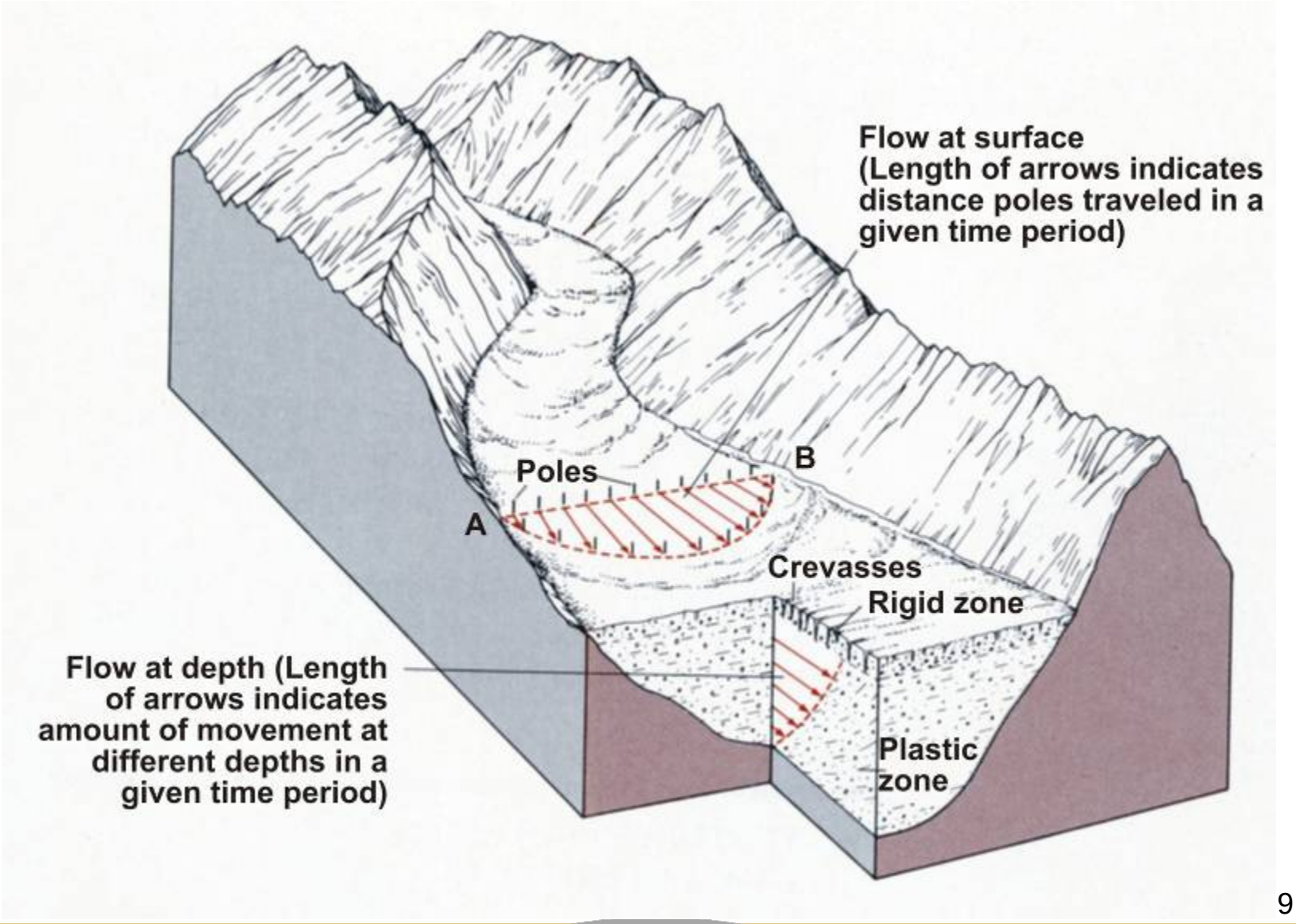
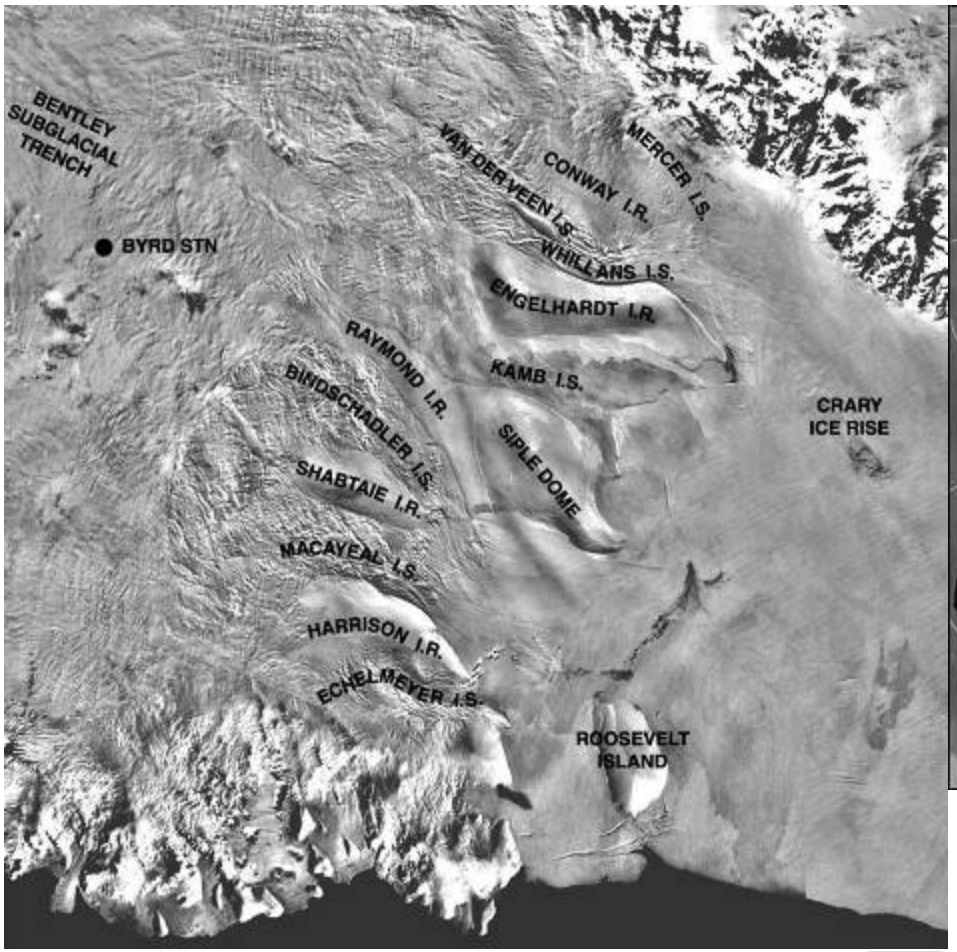
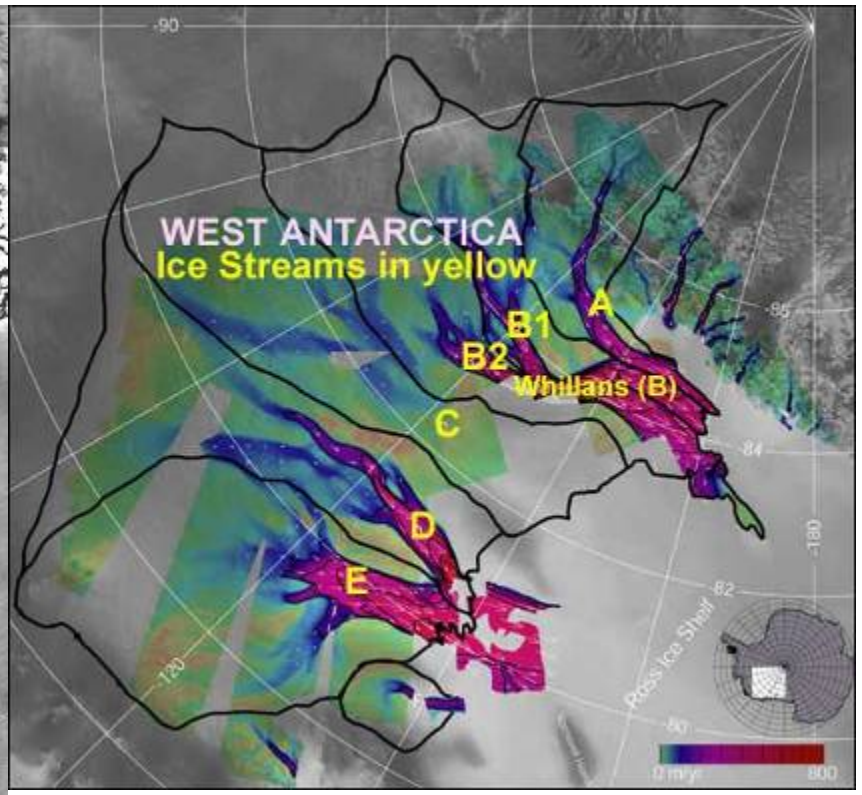


Internal deformation

- Slow flow (1 – 100 m/yr)
- Caused by ice deforming under its own weight
- Glacier frozen to the rock
- Traditional model for flow of polar ice sheets

Reevaluating the flow of ice sheets





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Basal sliding

- Lubrication at the glacier bed (meltwater or soft sediments)
- Reduced friction allows glacier to slide downhill
- High velocities (up to several km/yr)

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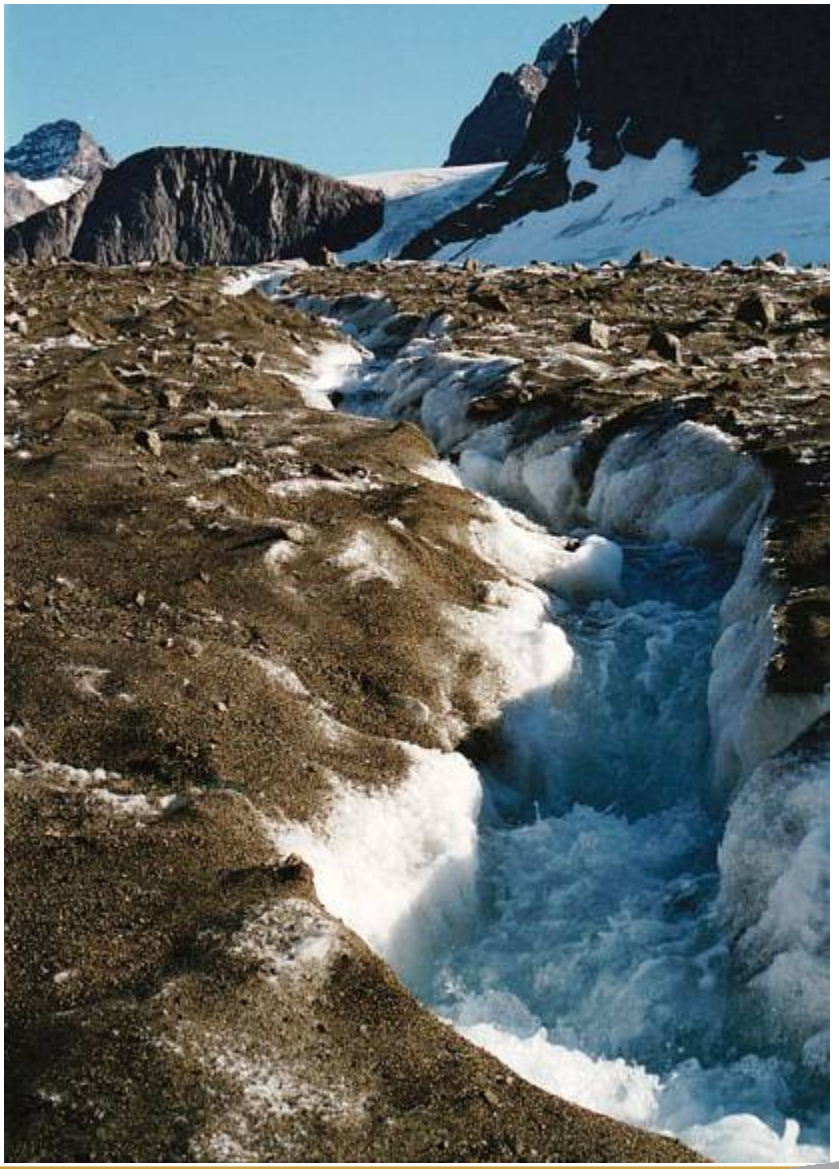

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Controls on ice flow

- Properties of the glacier bed:
  - Topography
  - Meltwater
  - Soft sediments

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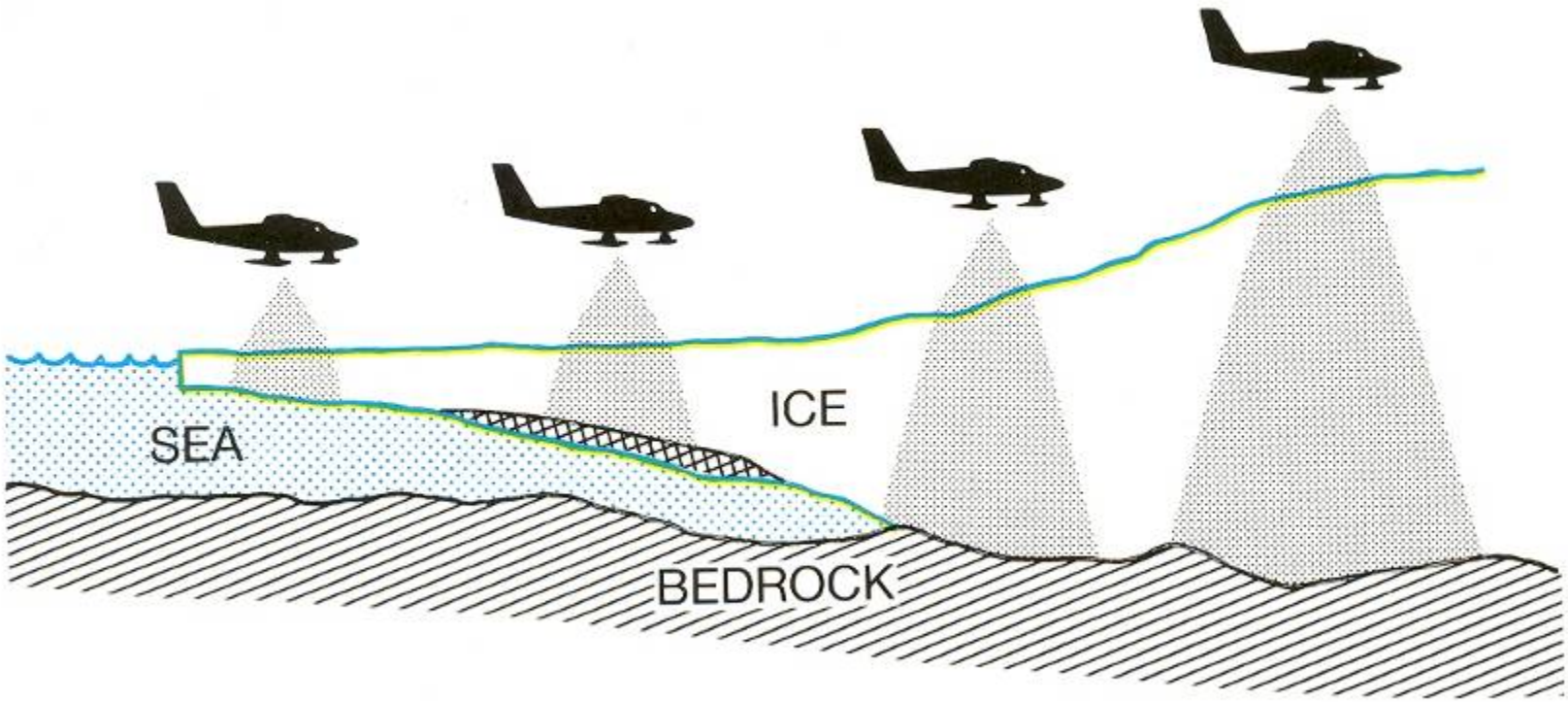
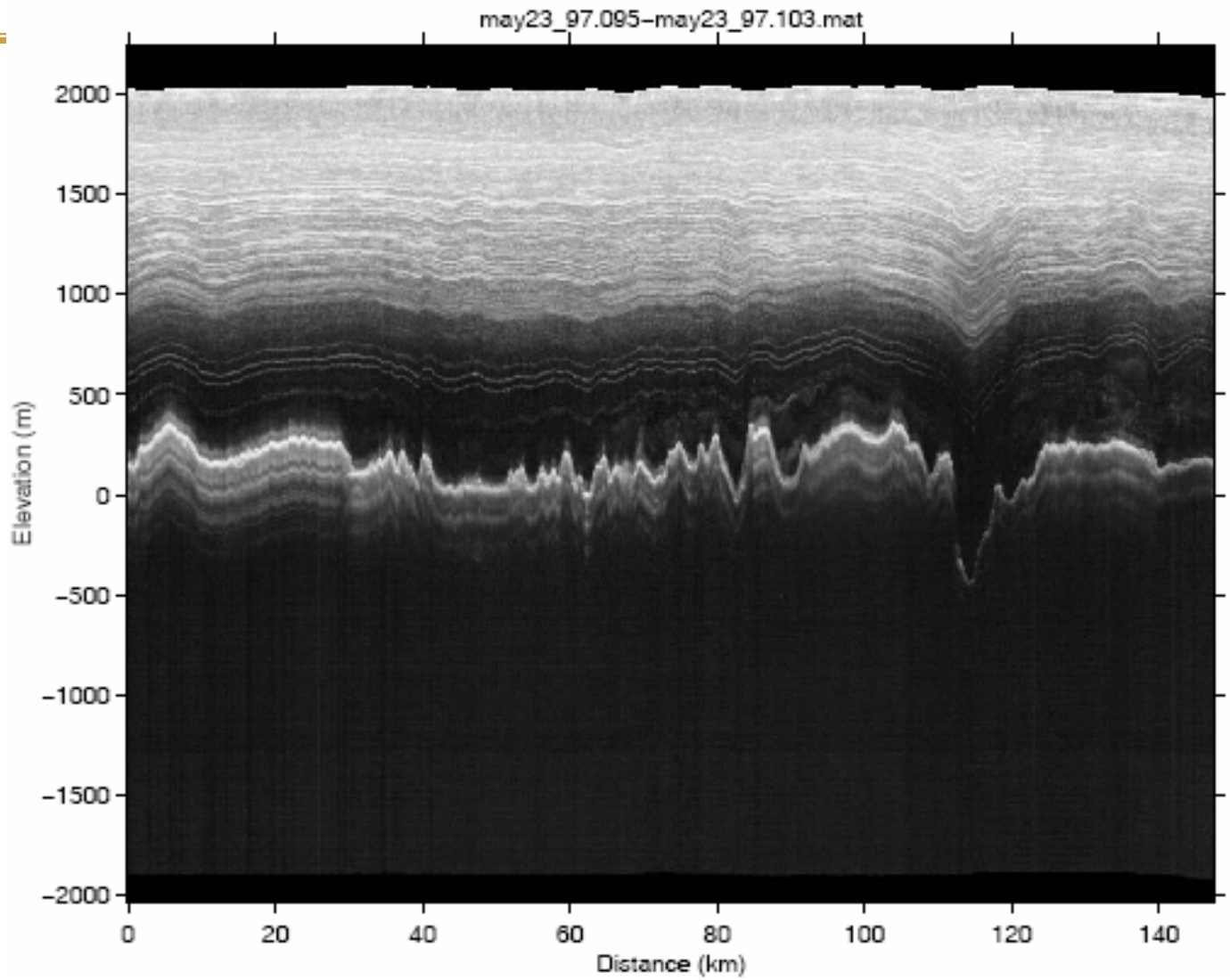
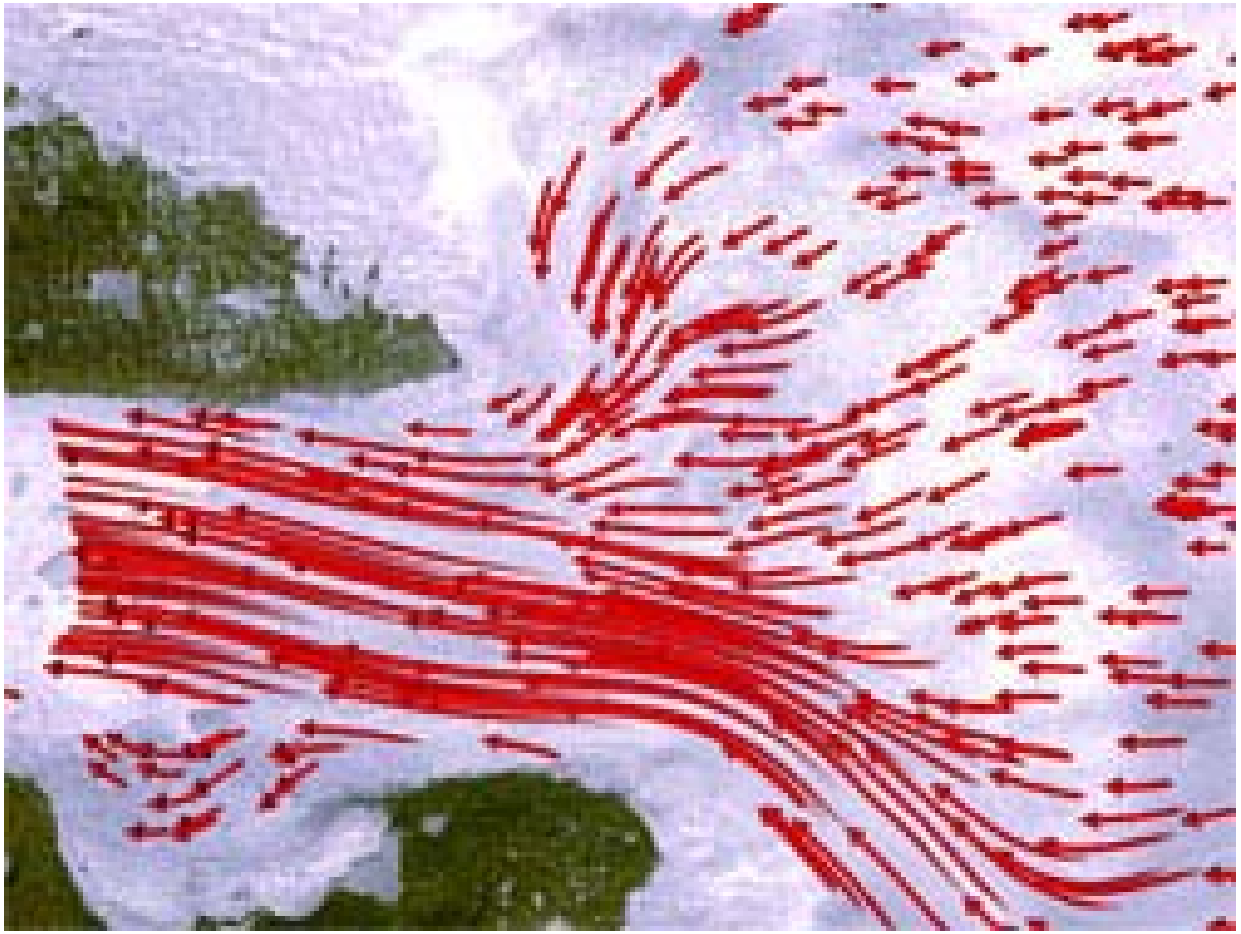
Looking through the ice



Airborne radar sounding



Studying glacier dynamics



Use ice velocities to estimate forces resisting the flow of glaciers, and to infer conditions at the glacier bed

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Obtaining longer-term records

- Observed changes apply to the last decade or so
- How significant are these changes?
- Need to place what is going on now in a broader time context
- Need to construct longer histories of glacier change

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Obtaining longer records of glacier change

- Aerial photographs
- Glacial geomorphology

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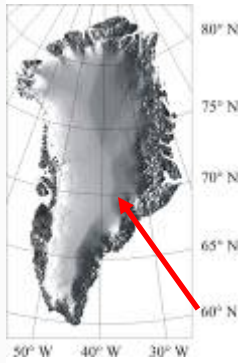
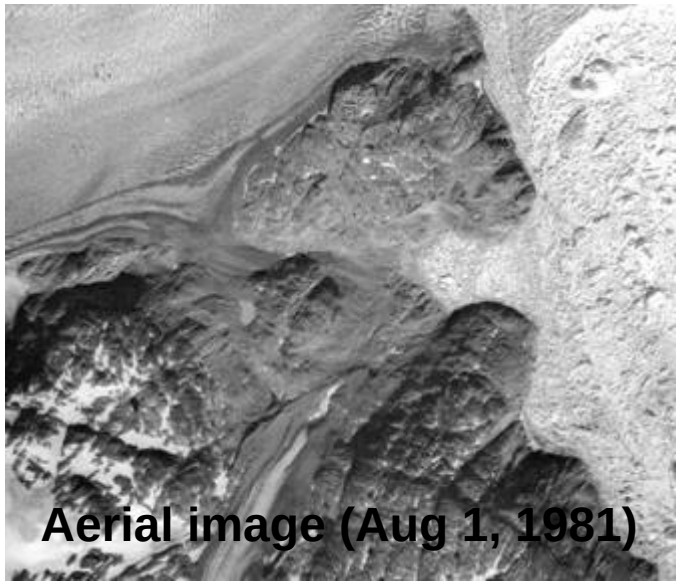
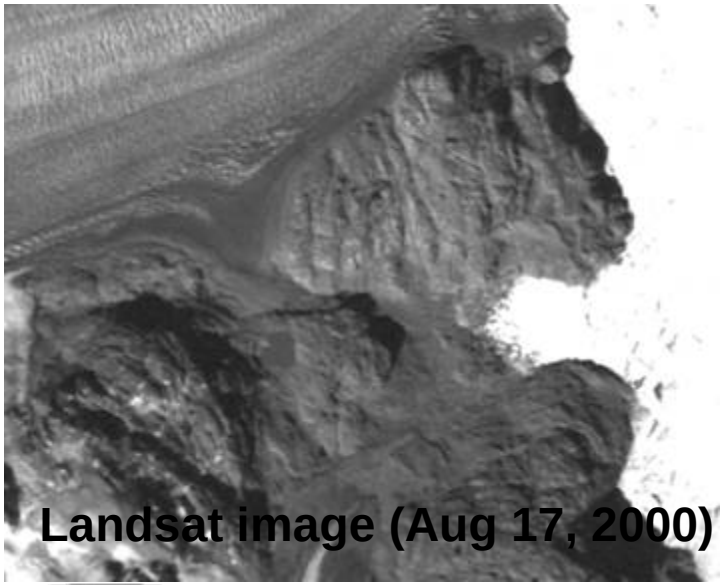
Aerial image (Jun 6, 1947)

DISP image (Jun 23, 1966)





Aerial image (Aug 1, 1981)



Landsat image (Aug 17, 2000)

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Goals of glacier studies

- Measure what ice sheets are doing
- Understand the cause for ongoing changes
- Predict future changes

Interdisciplinary approach needed

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Any questions ?
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