



The Cryosphere & Climate Change

Fall 2010
Textbook pp.75-105

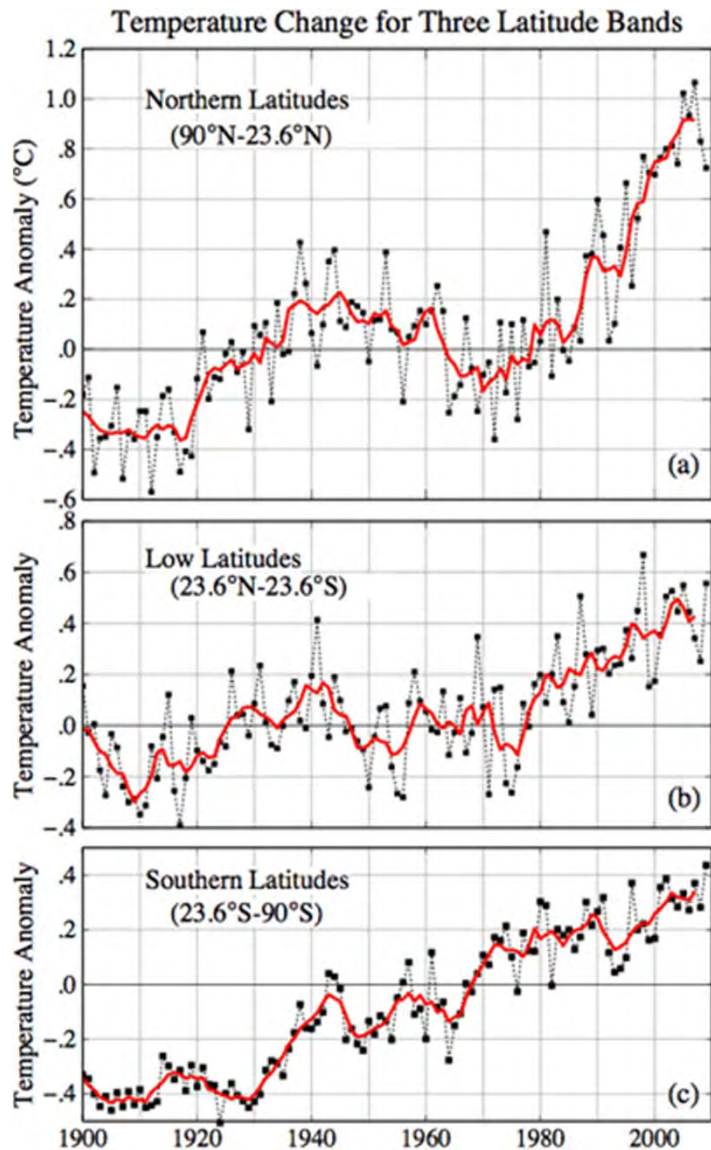
<http://www.youtube.com/watch?v=bYH2Df-evNs>



<http://www.youtube.com/watch?v=2NvwlnKVtU>



Is the Cryosphere Sending Signals About Climate Change?



Current Measurement Techniques

- The dawn of the satellite era (1960's).

- Passive NIR (MODIS)

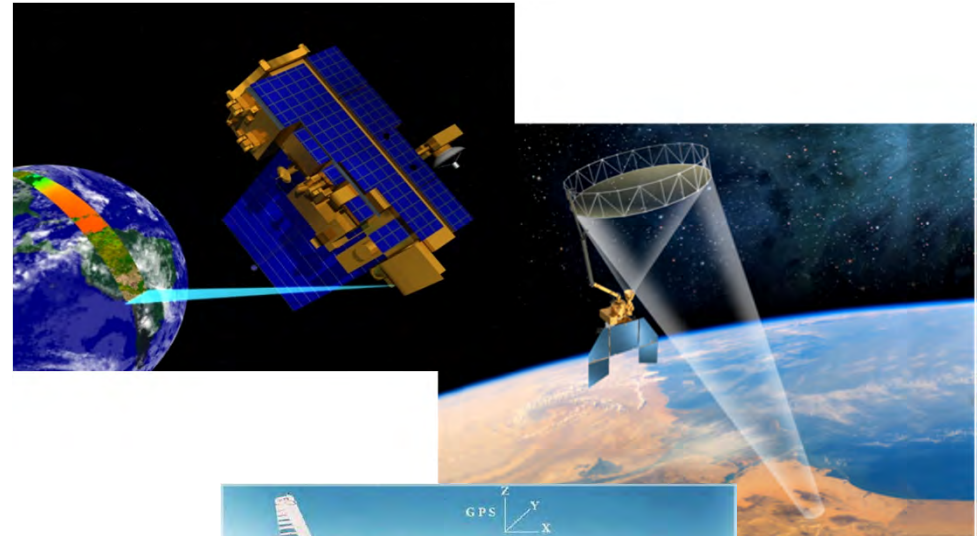
- Snow is relatively cold (+)
 - No cloud penetration (-)
 - No nighttime monitoring (-)

- Passive Microwave

- Cloud Penetration (+)
 - Nighttime Monitoring (+)
 - Microwave Energy level is low (-)

- Active Microwave (RADAR)

- Snow/Ice Depth (+)
 - Limited Range (-)



Current Measurement Techniques



Passive Microwave Example

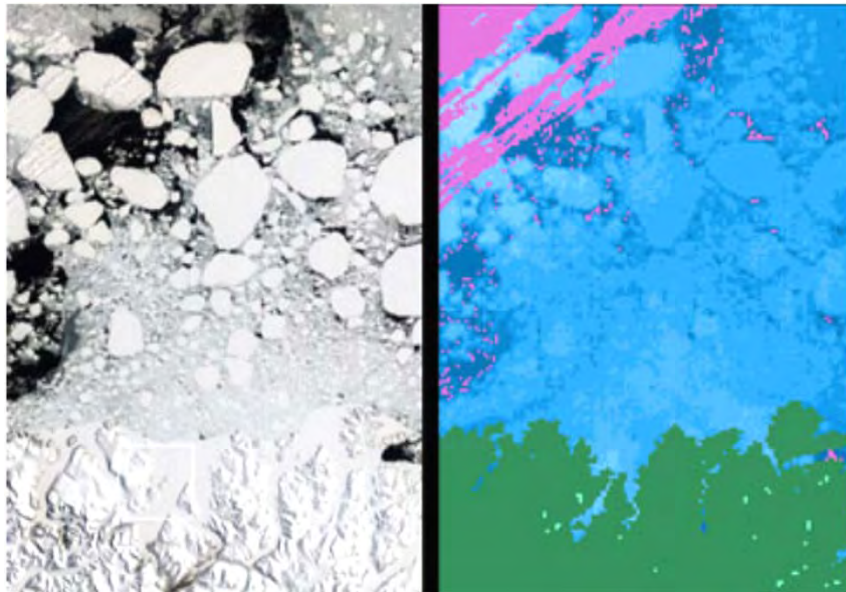
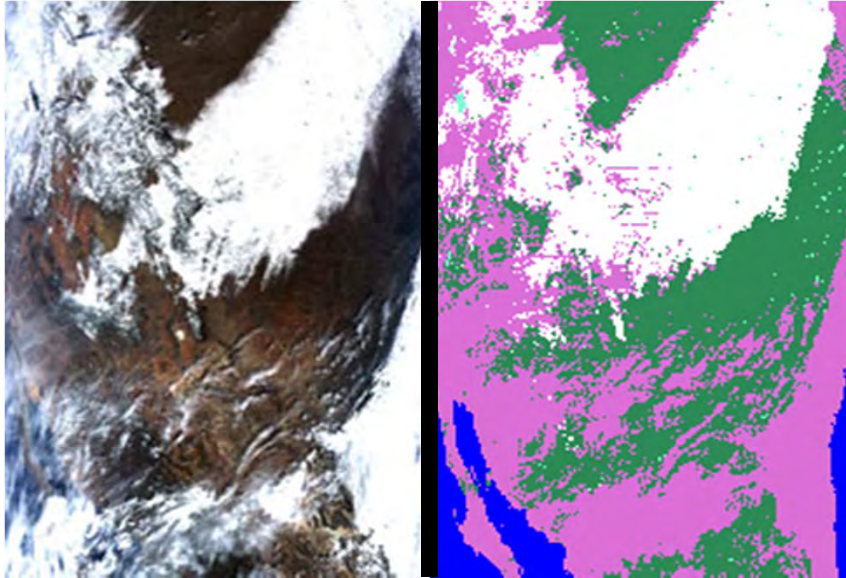
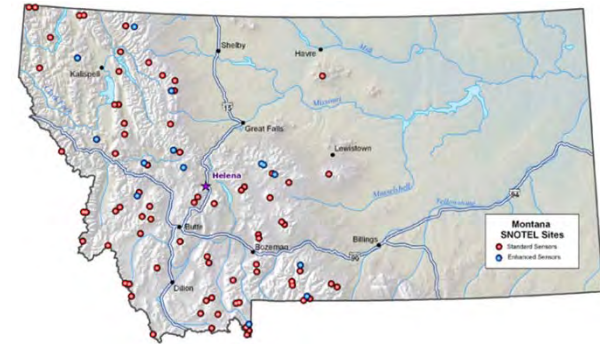


Image Color Legend	
white	snow
pink	cloud
grey	no data / night
green	snow/cloud free land
blue	water

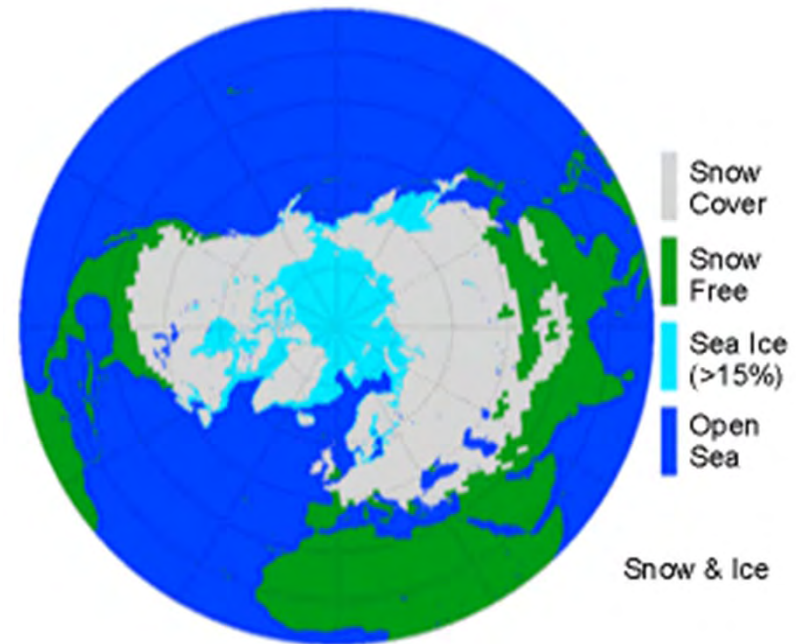
Past Measurement Techniques

- **Submarine Data**
 - Sea Ice
 - 1950's
- **Snowtel Data**
 - Snow Depth
 - 1940's
- **Field Measurement**
 - Glacier Mass Balance
 - 1940's



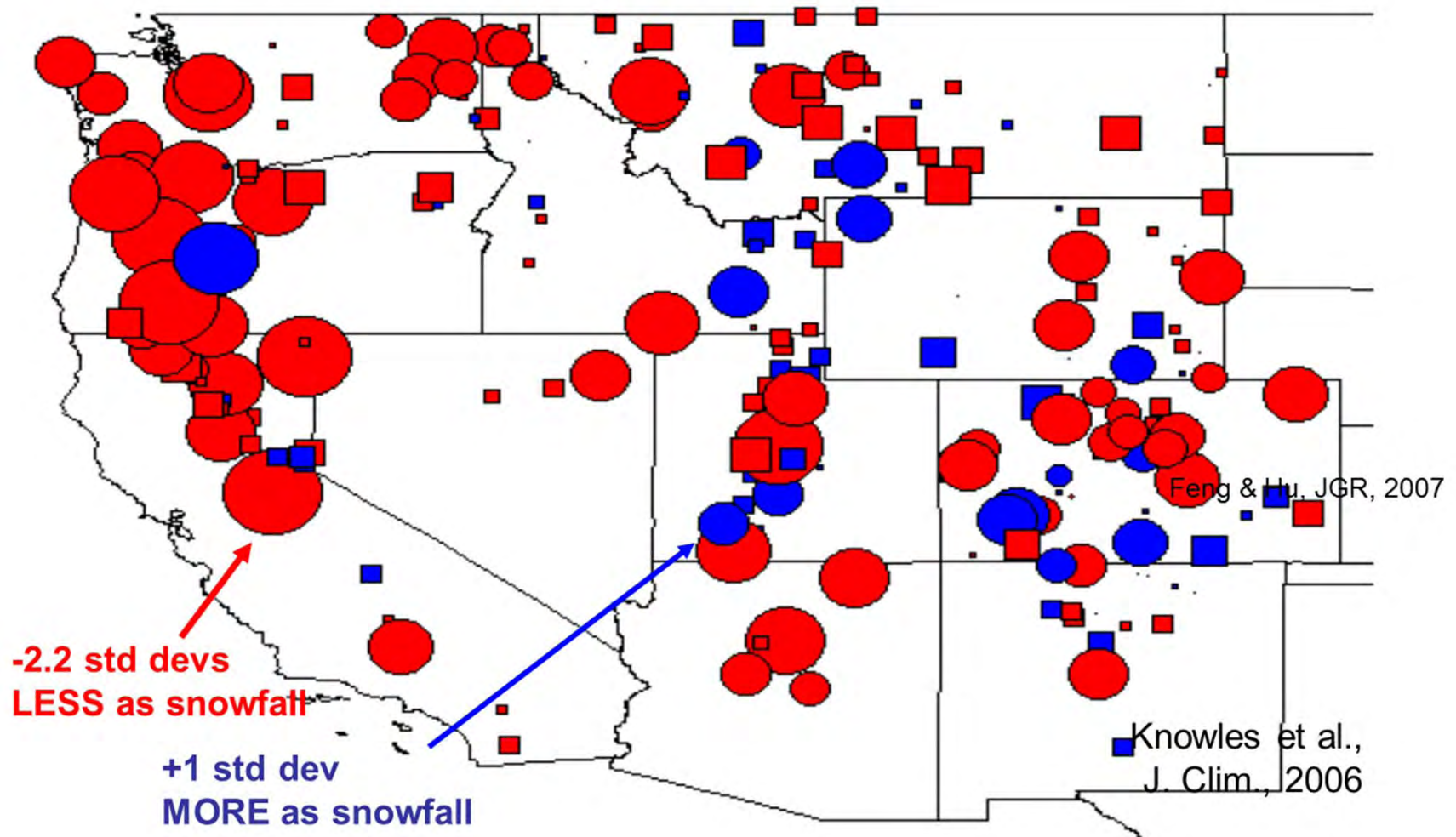
Snow Cover Extent

- Seasonal Snow cover is the largest single component of the Cryosphere.
 - Areal extent of 47 million km².
 - Snow can cover > 40% of the NH's land surface.
 - 98% located in the Northern Hemisphere!

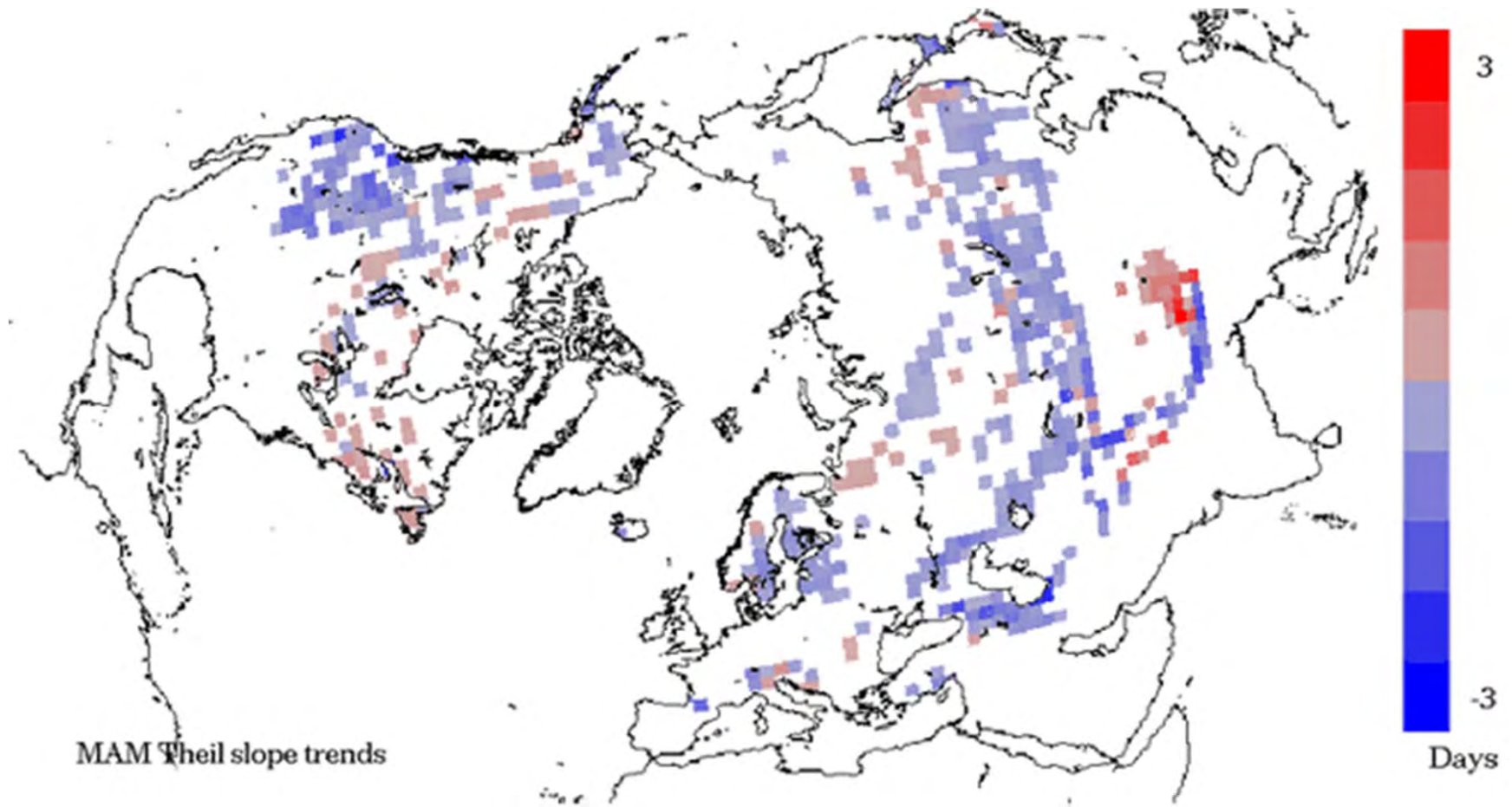


Northern Hemisphere snow extent map:
Image from Northern Hemisphere EASE-Grid Weekly Snow Cover and Sea Ice Extent Version 3 product.

Montana Snow Cover Anomaly



Global Snow Cover Anomaly

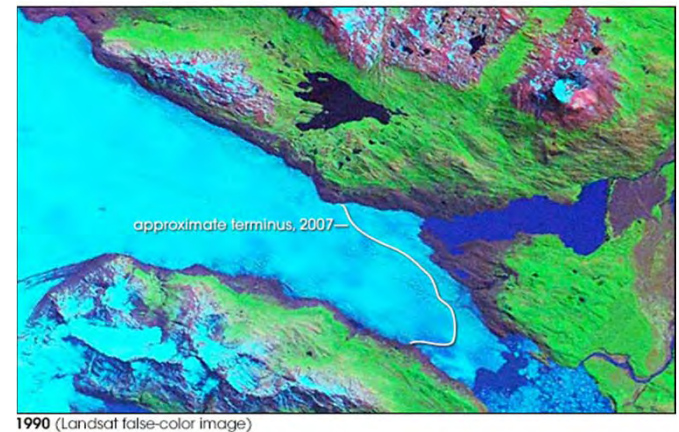


Spring duration of snow cover: This map shows per decade trends derived from visible and passive microwave satellite data, 1978-2006.

Image by Richard Armstrong and Mary Jo Brodzik, National Snow and Ice Data Center, University of Colorado, Boulder.

Glacial Extent

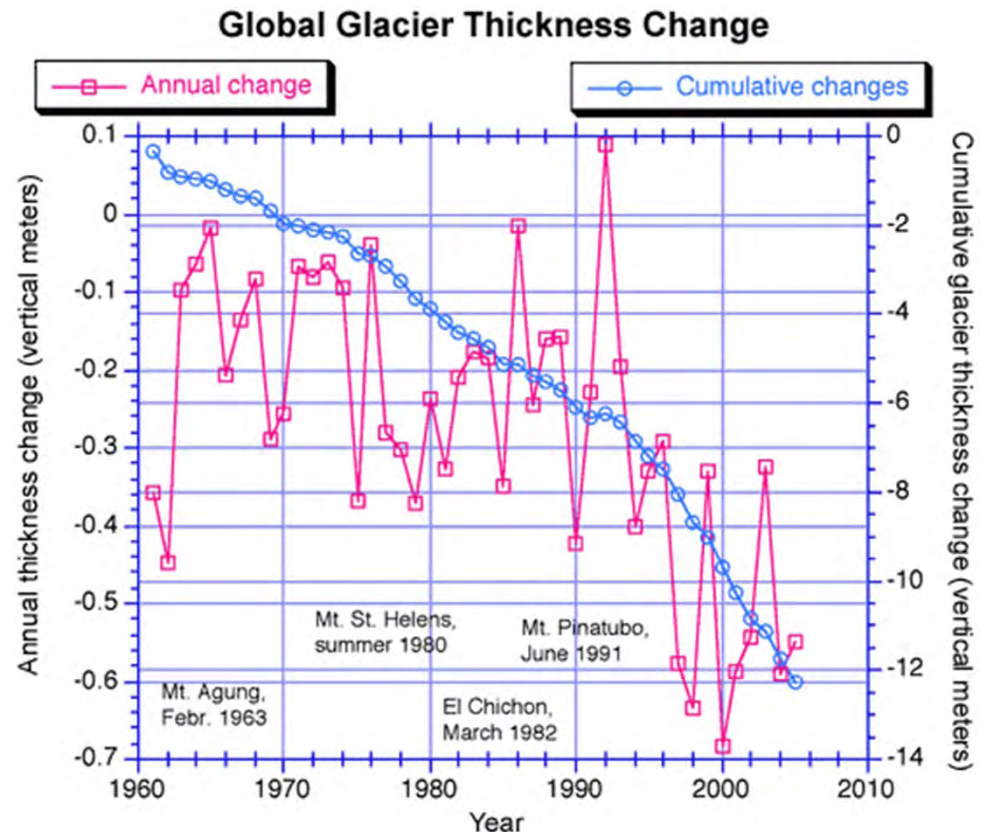
- Occur on all continents except Australia.
- Total Area: 525,000 km².
- Glaciers Continually Move:
 - Carry mass downhill
 - Advance/retreat
- Mass Balance:
 - Winter Accumulation
 - Summer ablation



Tyndall Glacier, located in the Torres del Paine National Park in Chile, has a total area of 331km² and a length of 32km.

Global Glacial Mass Anomaly

- Since 1946 more than 300 glaciers have been monitored via mass balance techniques.
- With few exceptions, glaciers have retreated at unprecedented rates.



Global Glacier Thickness Change: This shows average annual and cumulative glacier thickness change, measured in vertical meters, for the period 1961 to 2005. Mark Dyurgerov, Institute of Arctic and Alpine Research, University of Colorado, Boulder

Montana Glaciers

Grinnell Glacier Glacier National Park, MT



1938

T. J. Hileman photo
Courtesy of GNP Archives



1981

Carl Key photo
USGS



1998

D. Fagre photo
USGS



2009

Lindsey Bengtson photo
USGS

Oblique view of Grinnell Glacier taken from the summit of Mount Gould, Glacier National Park. The relative sensitivity of glaciers to climate change is illustrated by the dramatic recession of Grinnell Glacier while surrounding vegetation patterns remain stable.

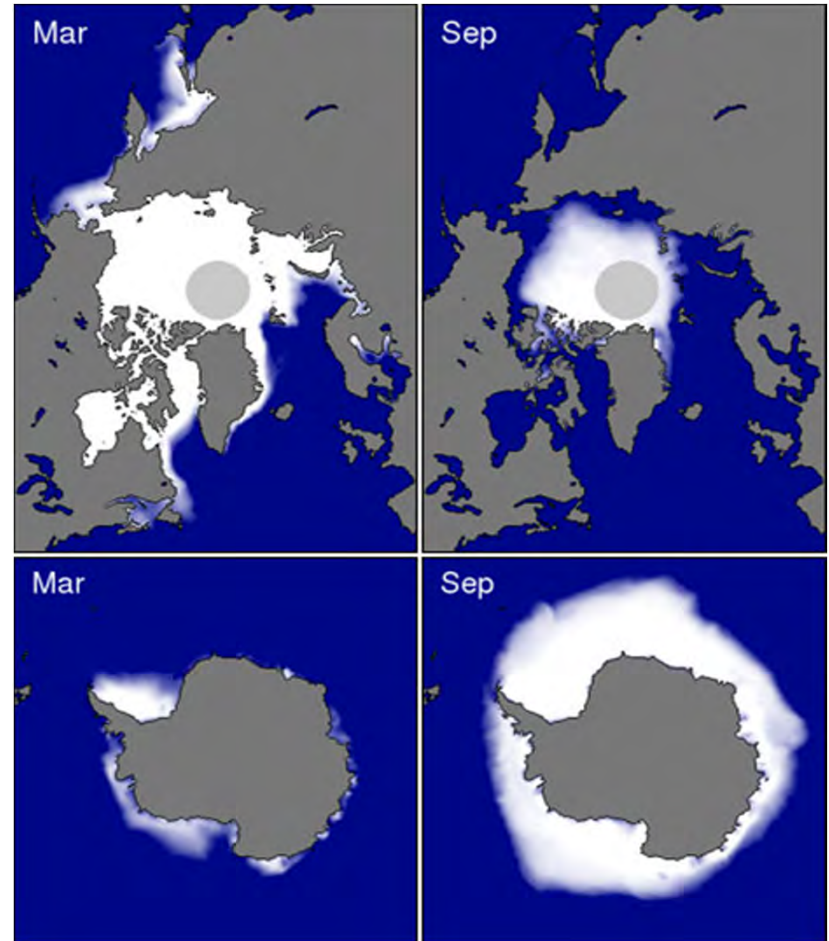


USGS Repeat Photography Project
<http://nrmsc.usgs.gov/repeatphoto/>



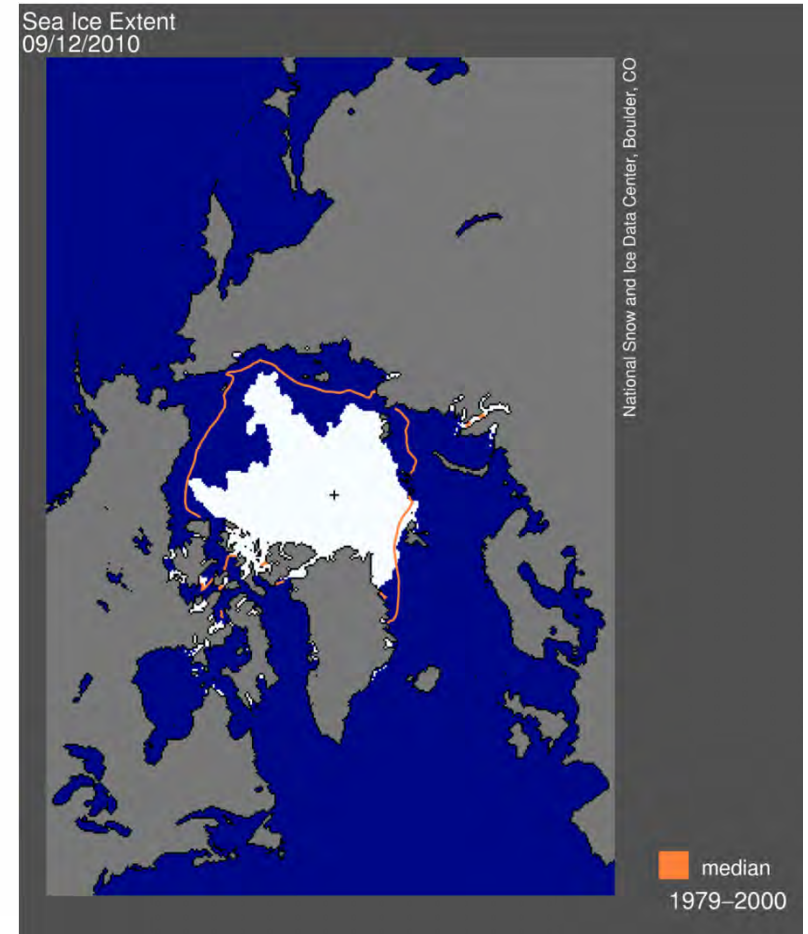
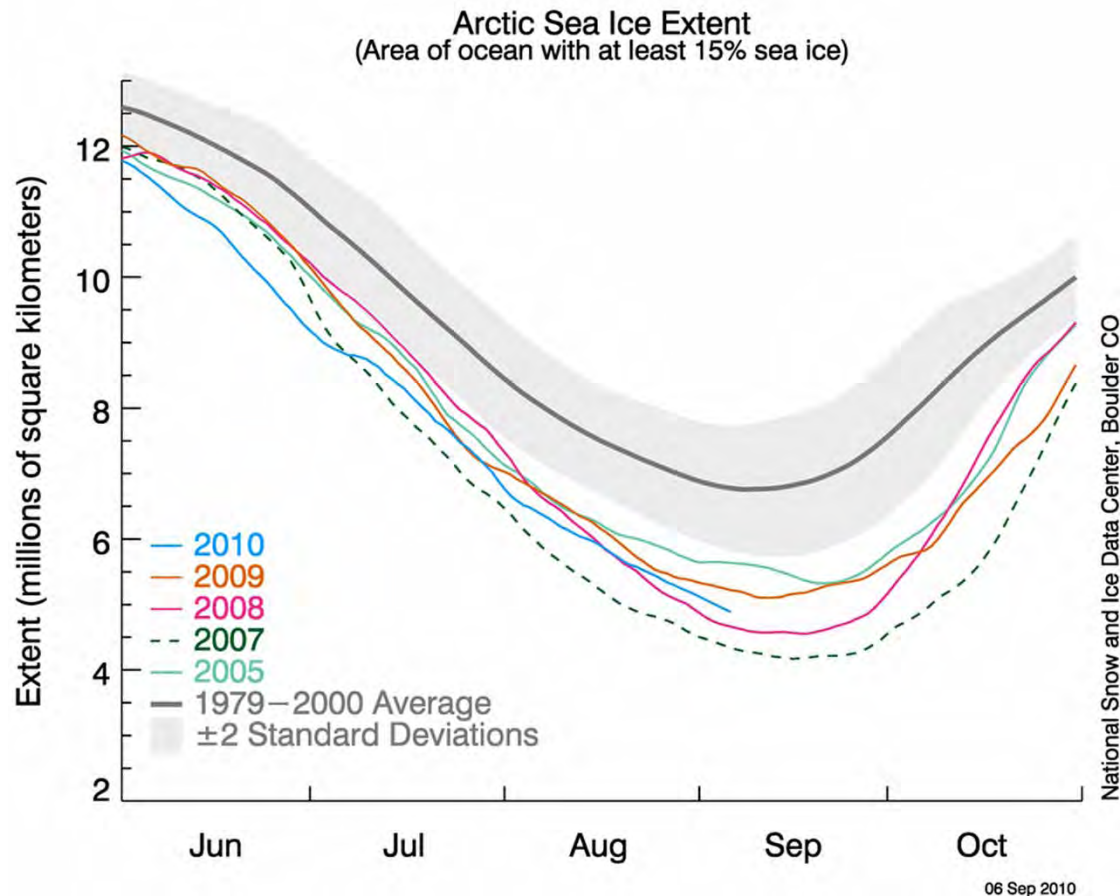
Sea Ice Extent

- Sea Ice is the frozen sea water that floats on the ocean surface.
- Forms and melts with polar season, affecting both human activity and biological habitats.
- **Arctic**
 - Max: 14-16 million km²
 - Min: ~7million km²
- **Antarctic**
 - Max: 17-20 million km²
 - Min: 3-4 million km²



Arctic and Antarctic sea ice concentration at the approximate seasonal maximum and minimum levels based on passive microwave satellite data. Image provided by National Snow and Ice Data Center, University of Colorado, Boulder.

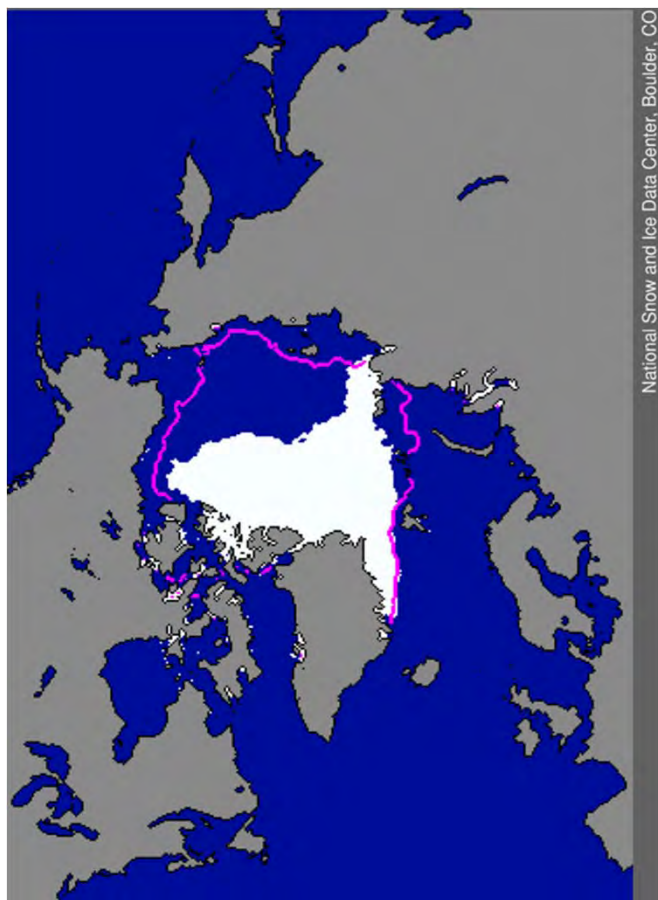
NH Sea Ice Seasonal Dynamic



[Extent comparisons](#): This graph compares 5-day running means for Arctic sea ice extent (area of ocean with ice concentration of at least 15 percent) to the long-term mean (1979-2000). Image provided by National Snow and Ice Data Center, University of Colorado, Boulder

Sea Ice Area Anomaly

Since 1979 winter Arctic ice extent has decreased by about 4.2 % per decade. Interestingly, Antarctic sea ice is increasing but the trend is small.



The September minimum sea ice extent reached new record lows in 2002 (15.3%), 2005 (20.9%), and 2007 (39.2%).

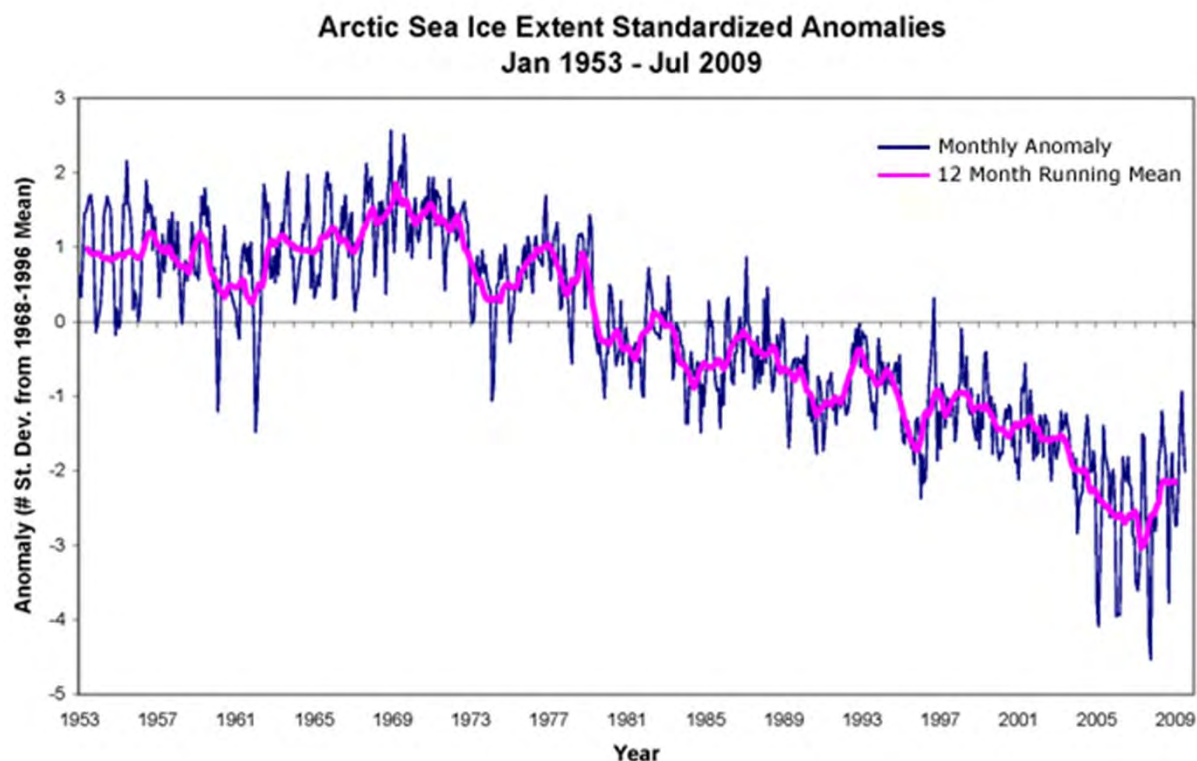
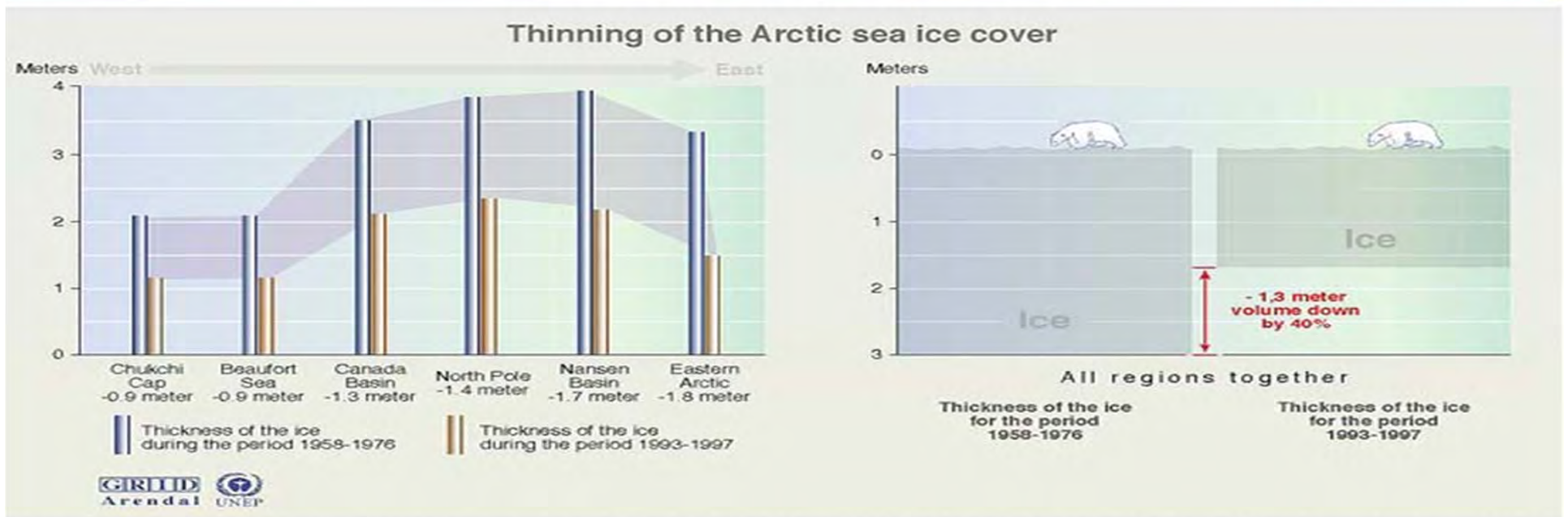
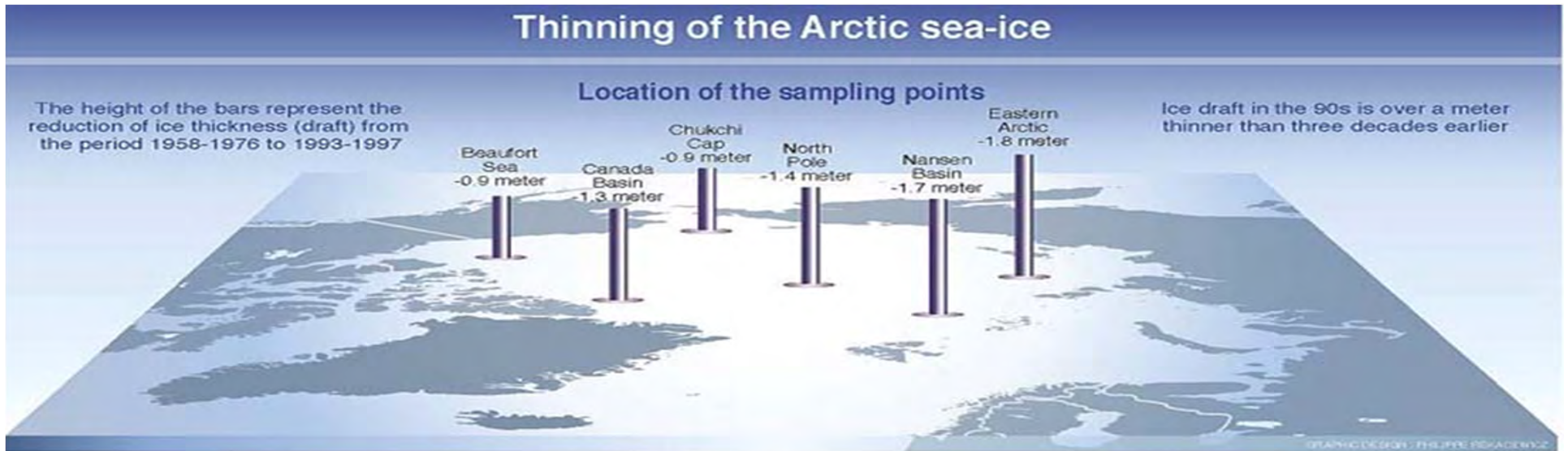


Image by Walt Meier and Julienne Stroeve, National Snow and Ice Data Center, University of Colorado, Boulder.

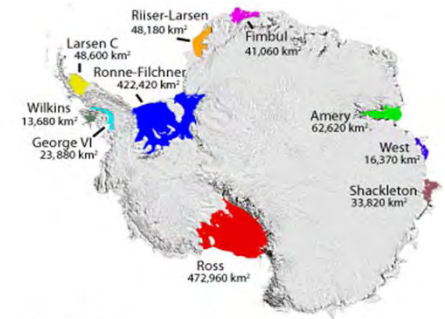
Sea Ice Mass Anomaly



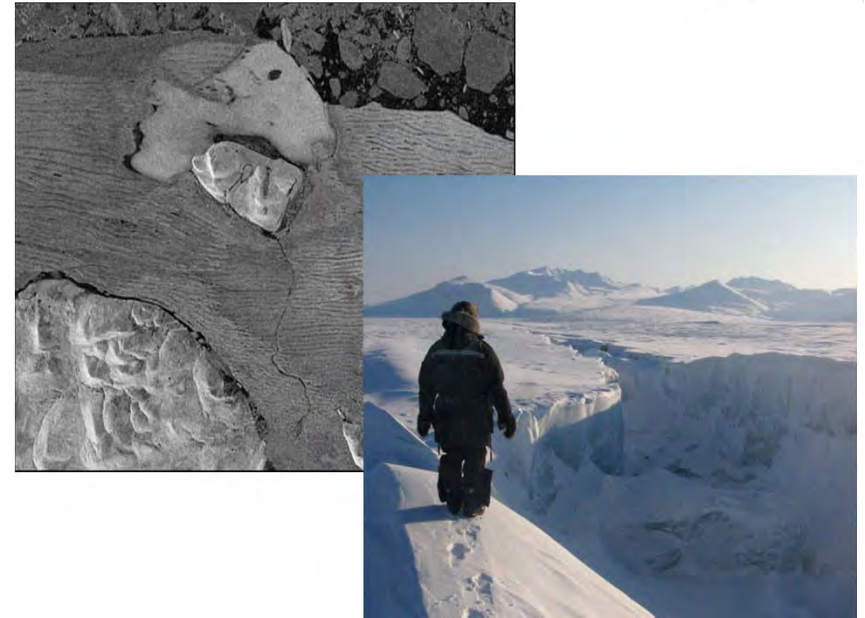
Note: comparison of sea-ice draft data acquired on submarine cruises between 1993 and 1997 with data from 1958-1976 indicates that mean ice draft at the end of the melt season has decreased by 1.3 m (from 3.1 m to 1.8 m). Value is down by 40%

Sources: D.A. Rothrock, Y. Yu and G.A. Maykut, Thinning of the Arctic sea-ice cover, University of Washington, Seattle, 1999.

Ice Shelves



- **Three Categories:**
 - Glacier Fed
 - Created by Sea Ice
 - Composite
- **Most of the world's ice shelves are fed by glaciers.**
- **Two types of events occur on ice shelves:**
 - Calving
 - Disintegration



Ward Hunt Ice Shelf, Ellesmere land, Nunavut, Canada: This ice shelf is an example of a shelf made from compressed sea ice.



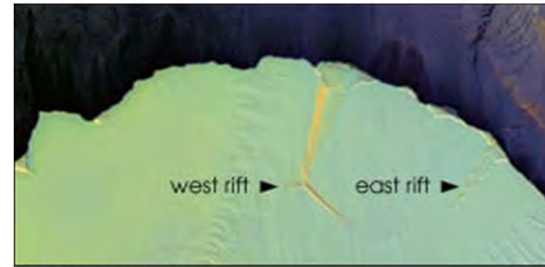
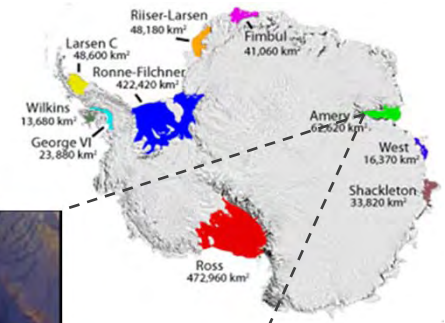
Ice Shelves Calving

- **Rift Calving**

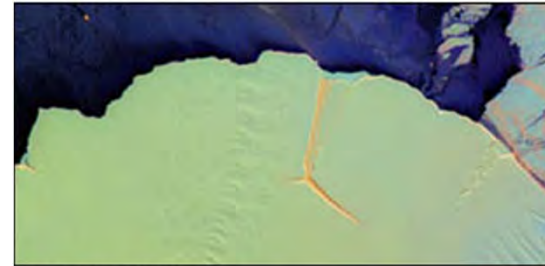
- Huge tabular icebergs
- Decadal timescale

- **Crevasse Calving**

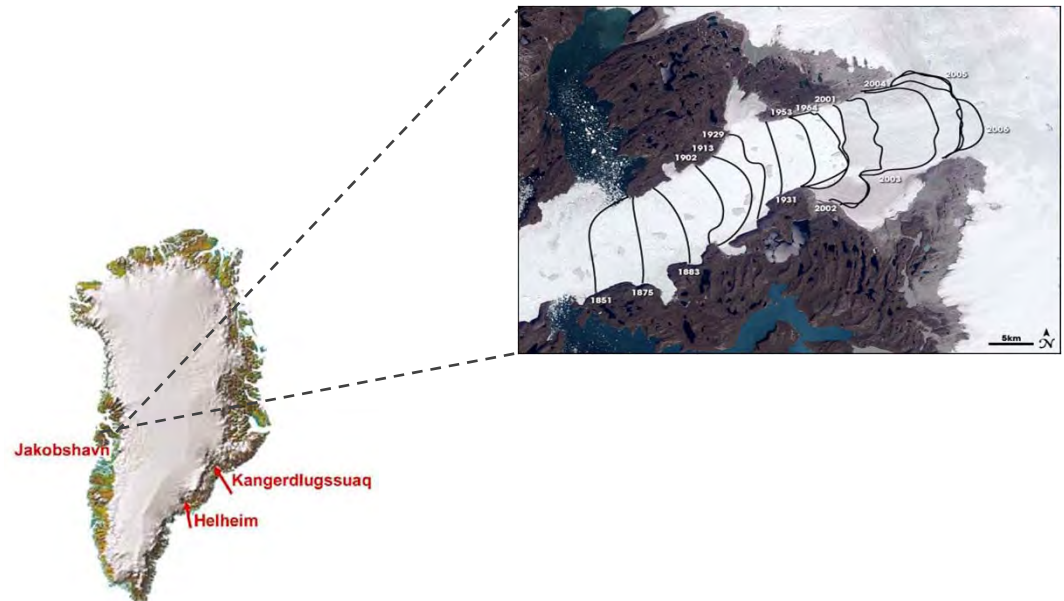
- Armadas of smaller icebergs
- Tracked by the National Ice Center

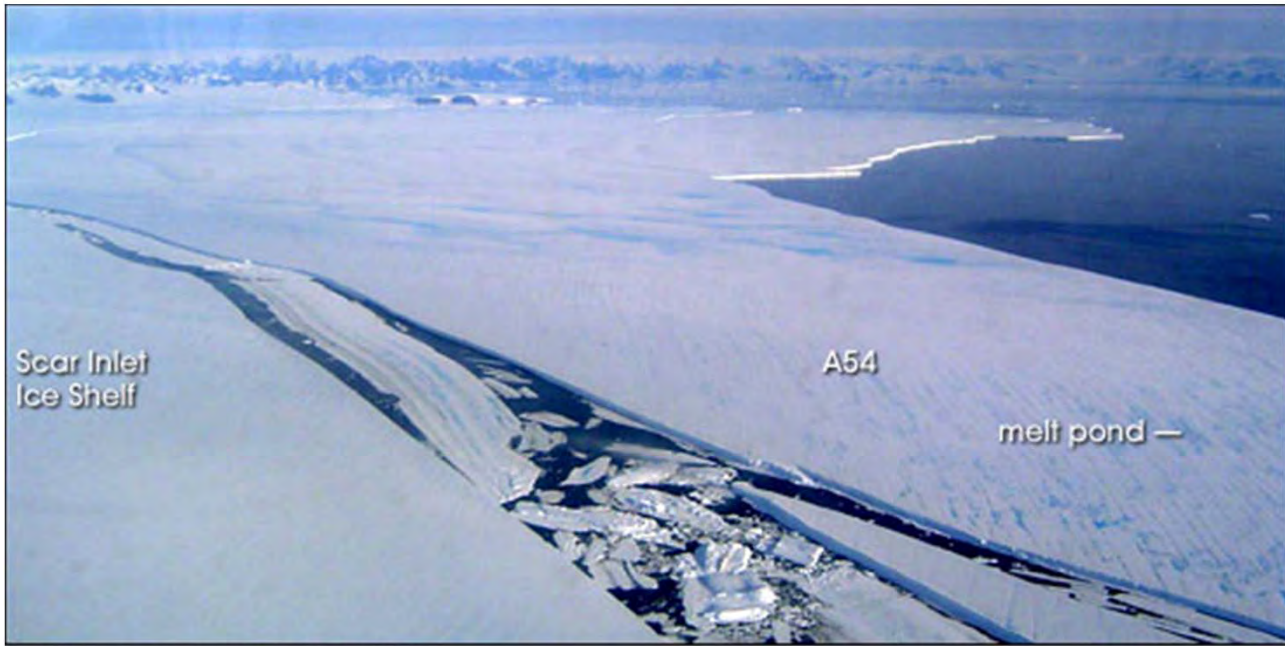
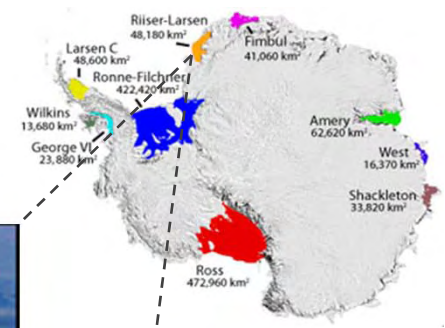


October 6, 2001

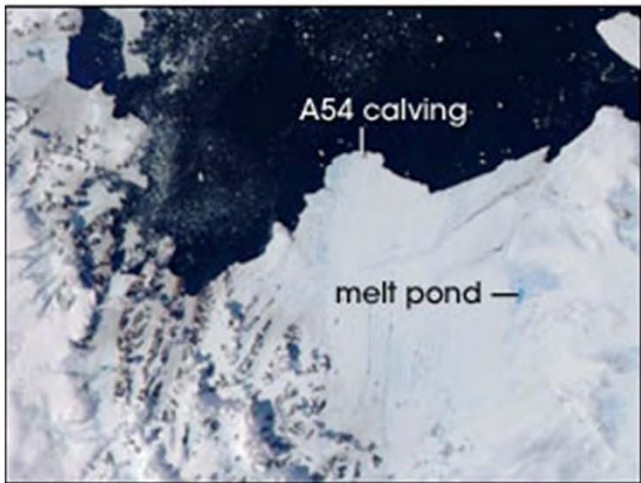


September 29, 2002

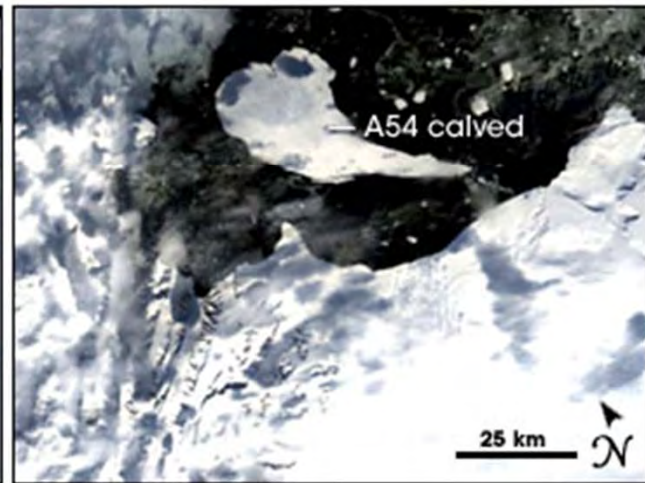




Aerial photo: February 11, 2006



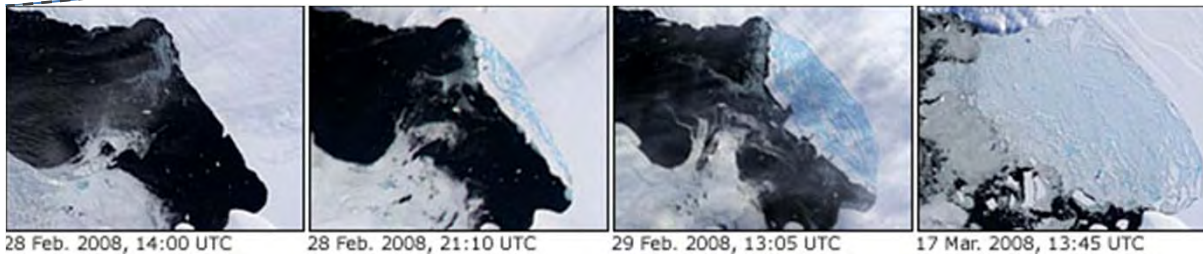
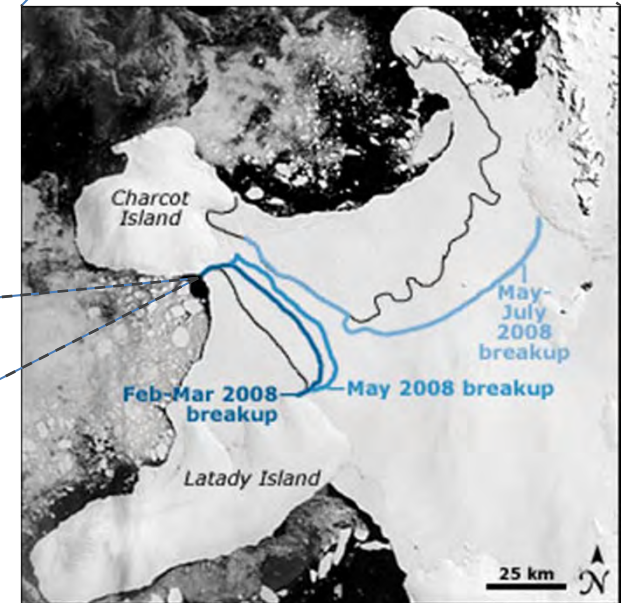
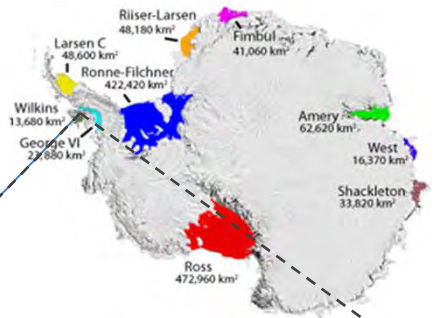
MODIS: February 7, 2006



March 5, 2006

Ice Shelf Disintegration

While calving is a natural event, disintegration has only been observed as a result of warming.



Wilkins Ice Shelf Disintegration, summer 2008: The summertime breakup of the western Wilkins Ice Shelf occurred in a matter of days. NASA Moderate Resolution Imaging Spectroradiometer images courtesy NASA Earth Observatory.

Wilkins Ice Shelf: Black lines indicate the approximate ice shelf front at the beginning of 2008. Blue lines indicate new shelf fronts after retreat events in 2008. Image courtesy Antarctic Glaciological Data Center.

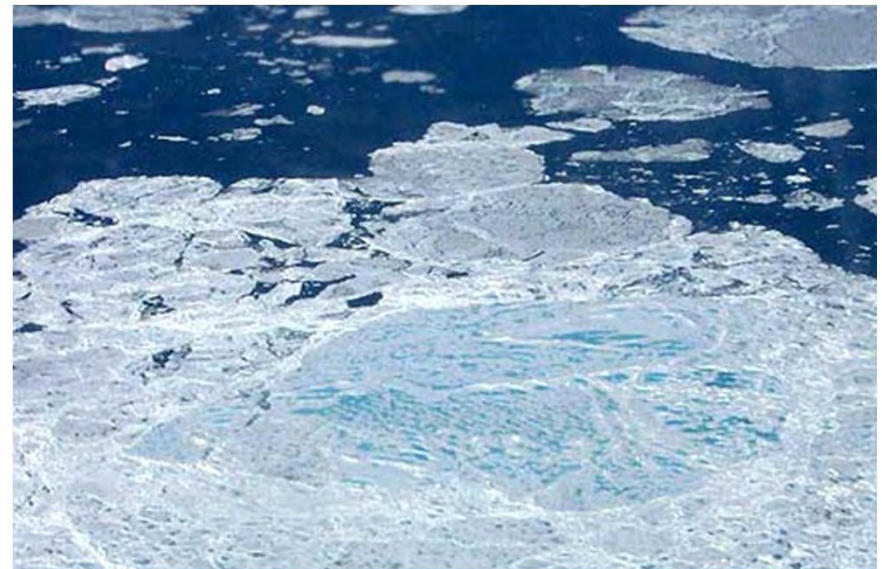
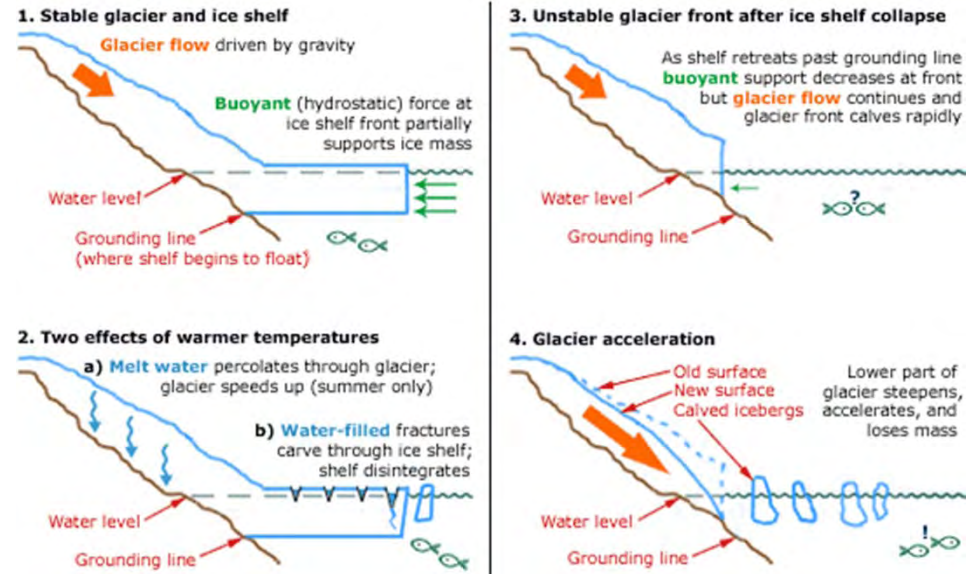
Climate and Ice Shelves

- **Calving Rate**

- Warming ocean water
- Basal Melting
- Increased rifting
- $0.1^{\circ}\text{C} = 10 \text{ m/yr}$

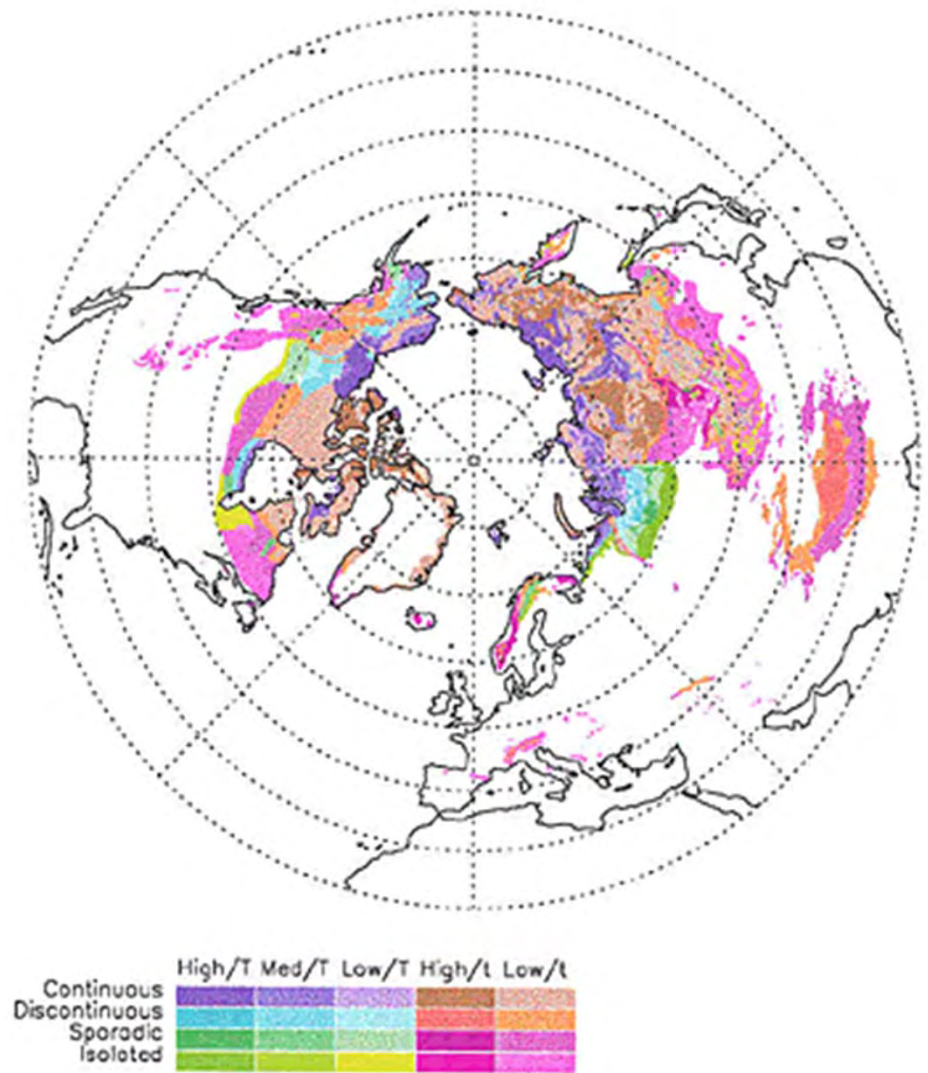
- **Disintegration**

- Melt Ponds
- 6 m deep crevasses can crack through full shelf thickness

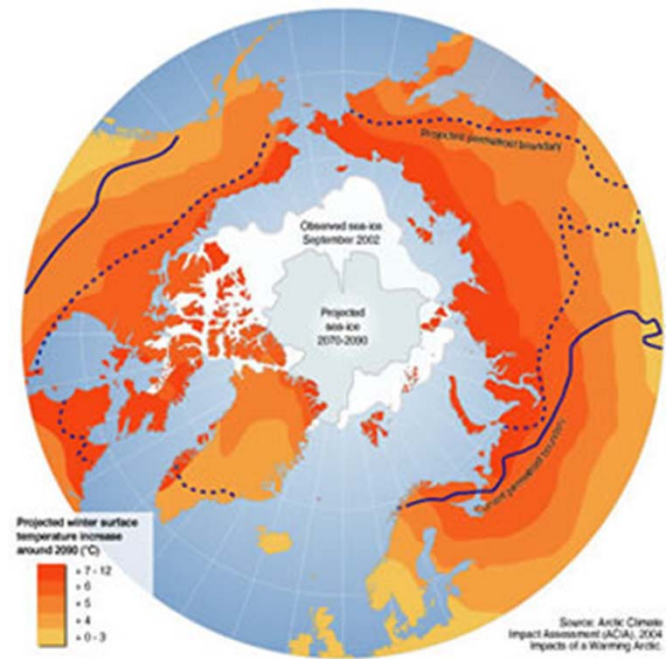
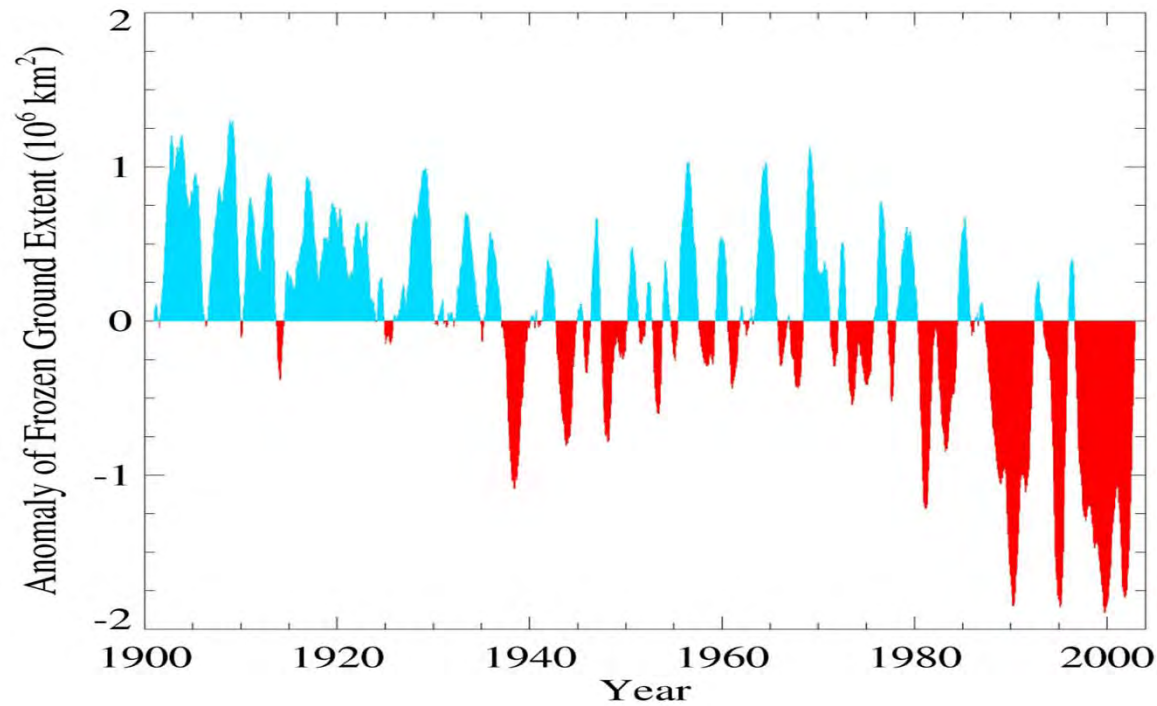


Permafrost

- Soil, sediment, or rock that remains at below $0^{\circ}\text{C} > 2$ yrs.
 - 22.79 Mkm² (24% NH)
 - Exists close to its melting point!
- In Summer, an upper layer of permafrost can thaw creating an active layer.
- Characterization
 - Continuous
 - Discontinuous
 - Sporadic
 - Isolated

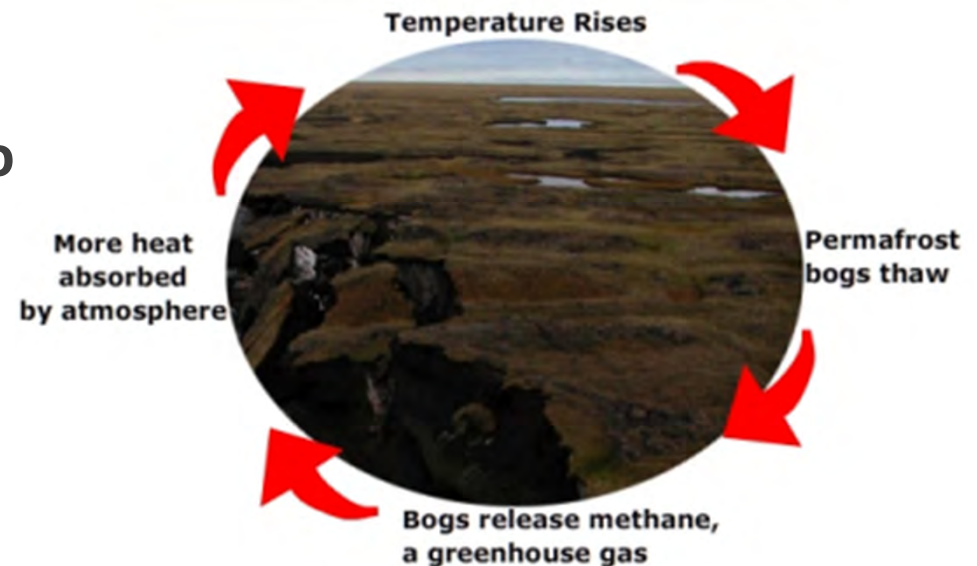
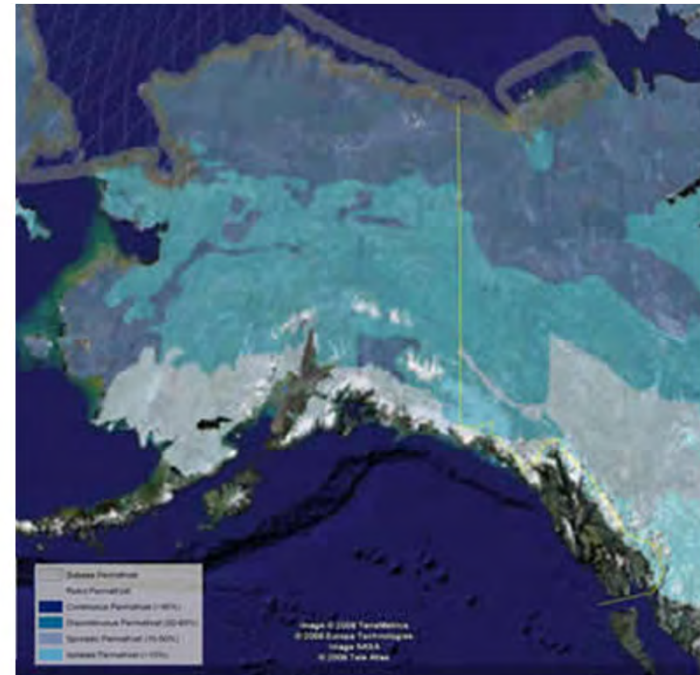


Permafrost Anomaly

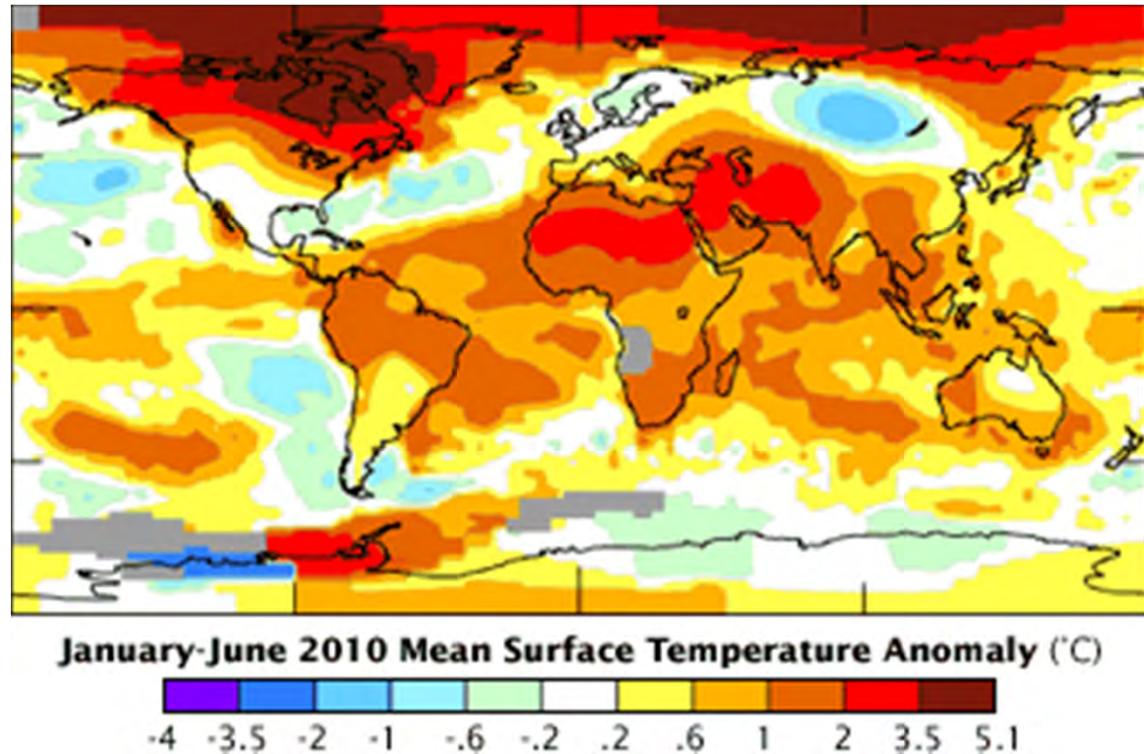
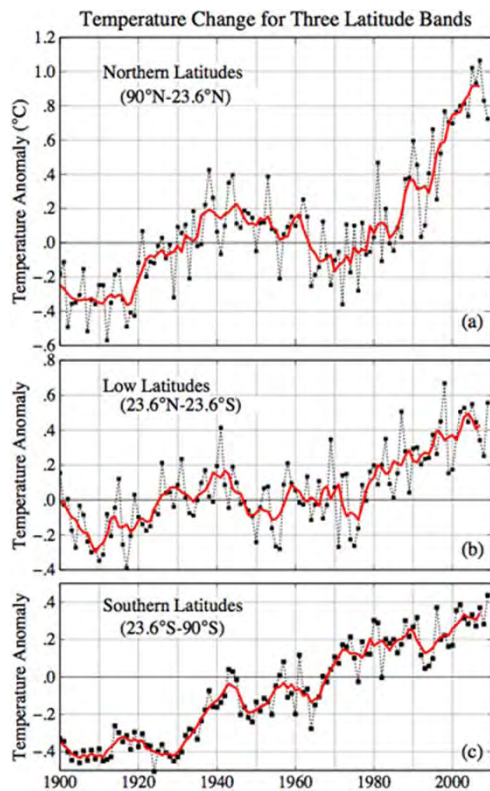


Permafrost and the Carbon Cycle

- During the Pleistocene period (1.8 Mya – 10 Kya) carbon was trapped in permafrost (relict permafrost).
- Positive Feedback
 - Relict permafrost thaws and releases CO₂ and methane to the atmosphere.
 - Further driving warming

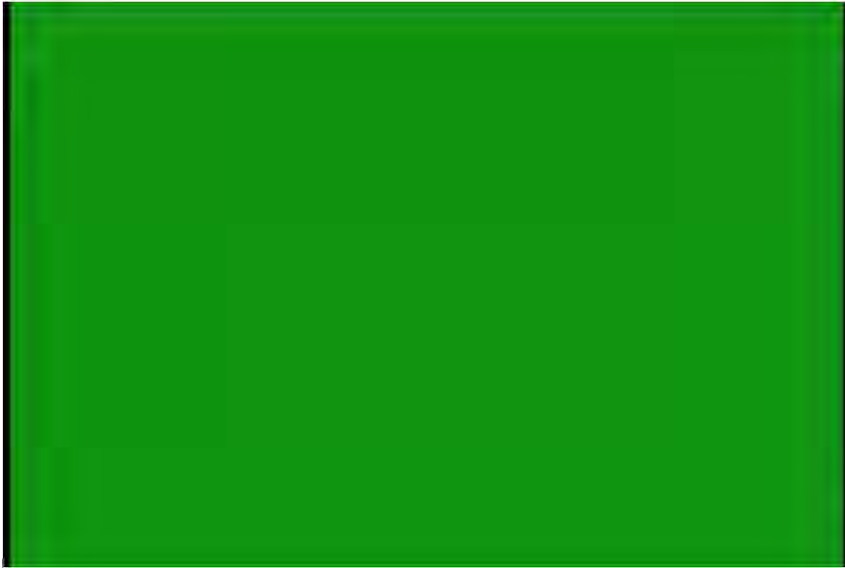


Why is the Arctic Warming Faster than Lower Latitudes?



Ice / Albedo Feedback

<http://www.youtube.com/watch?v=fJ999LIWvJk>

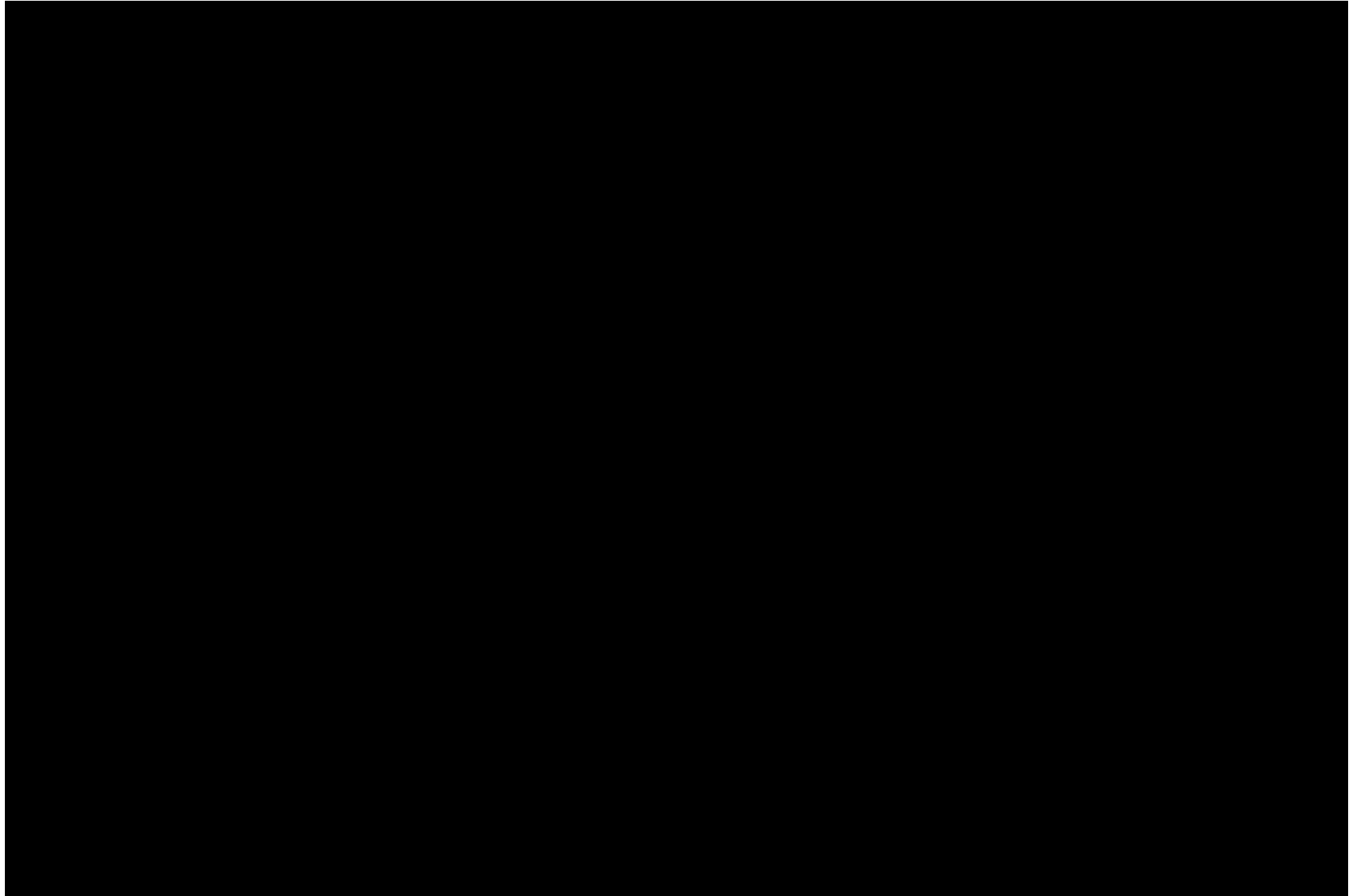


Other processes driving Increased polar warming:

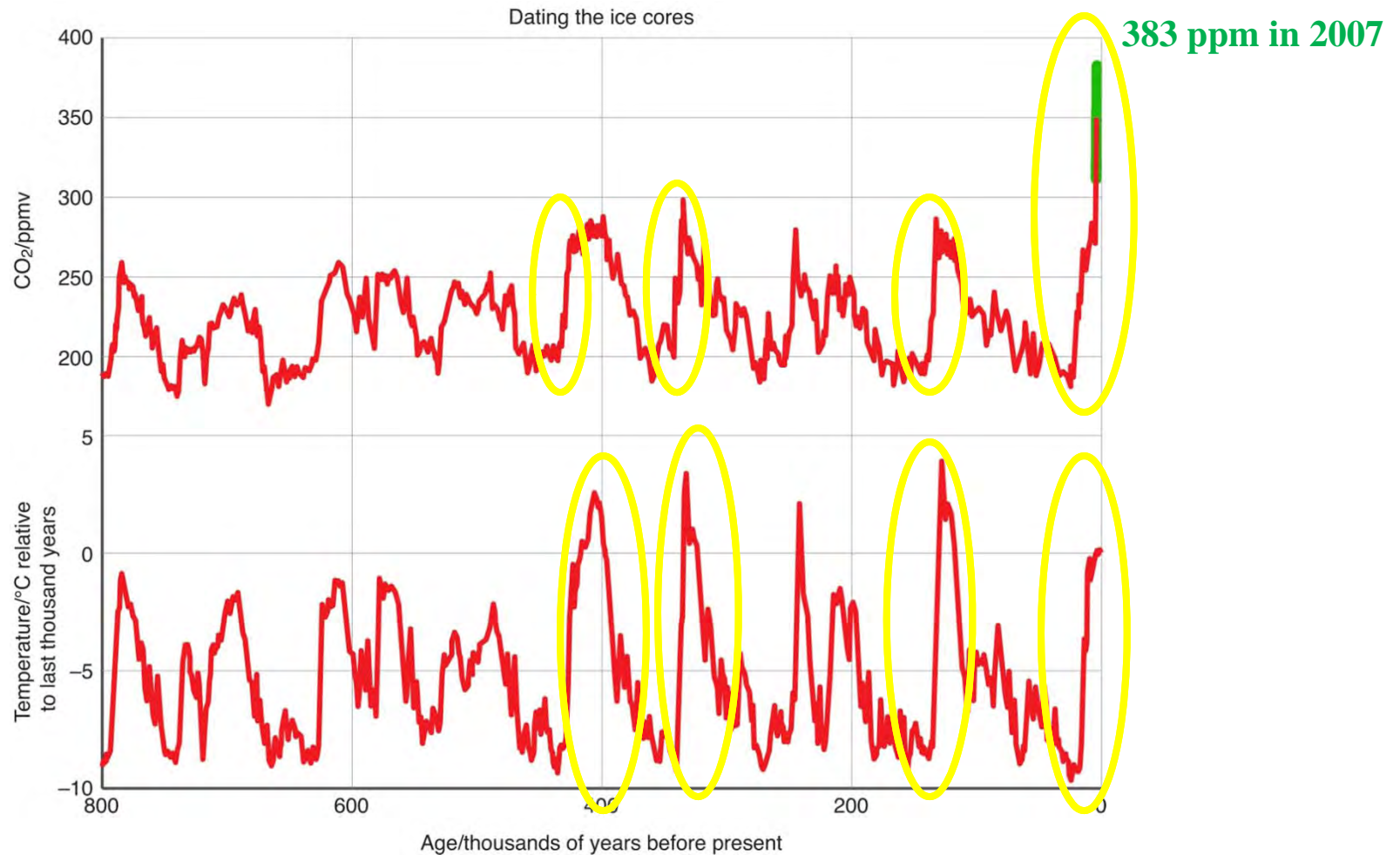
- Reduced Polar Evaporation Rates
- Polar Atmospheric Depth
- Increased summertime energy storage



<http://www.youtube.com/watch?v=r2RGQfmLI4E>

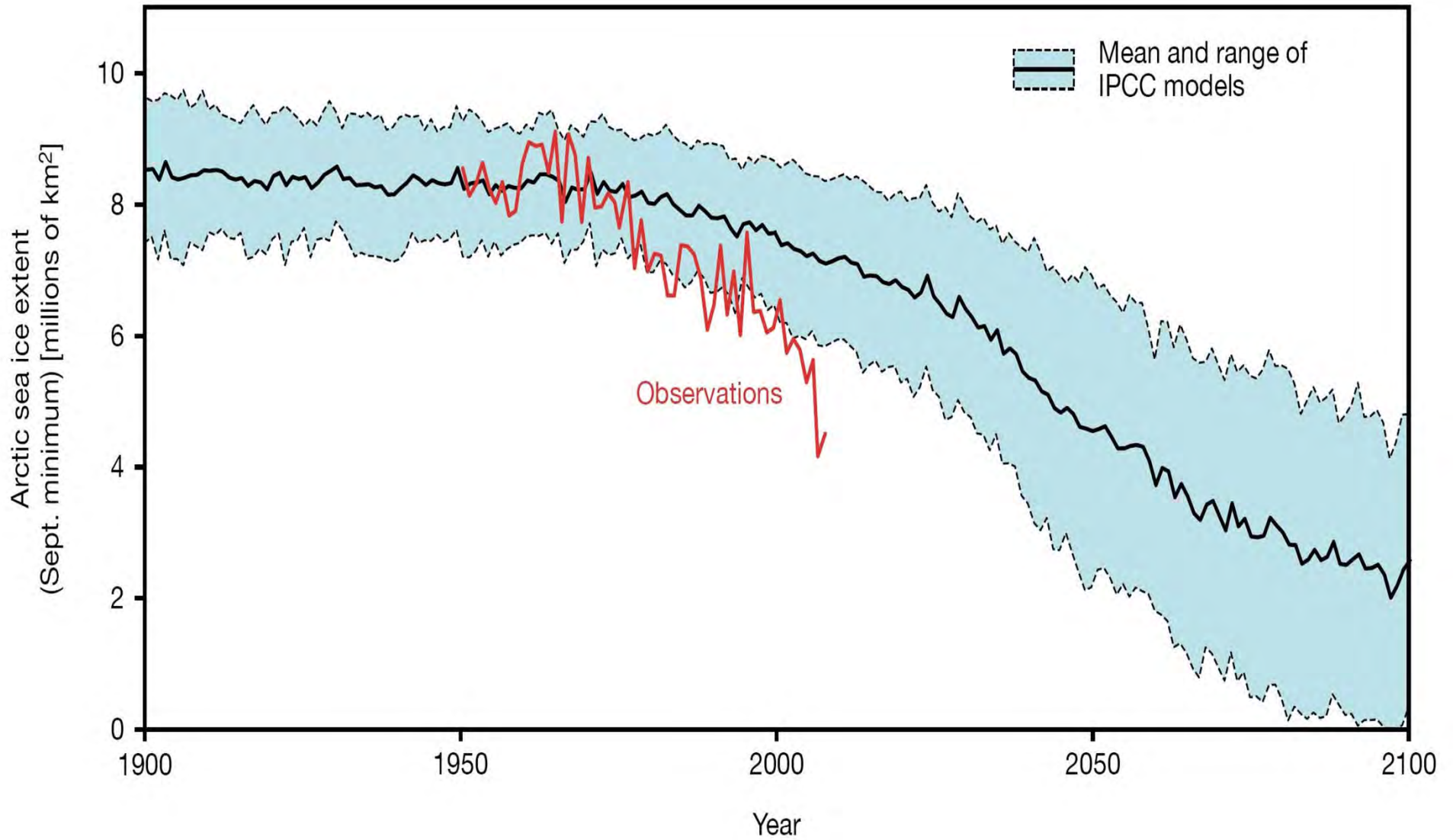


Evidence of positive feedback in the long-term climate record



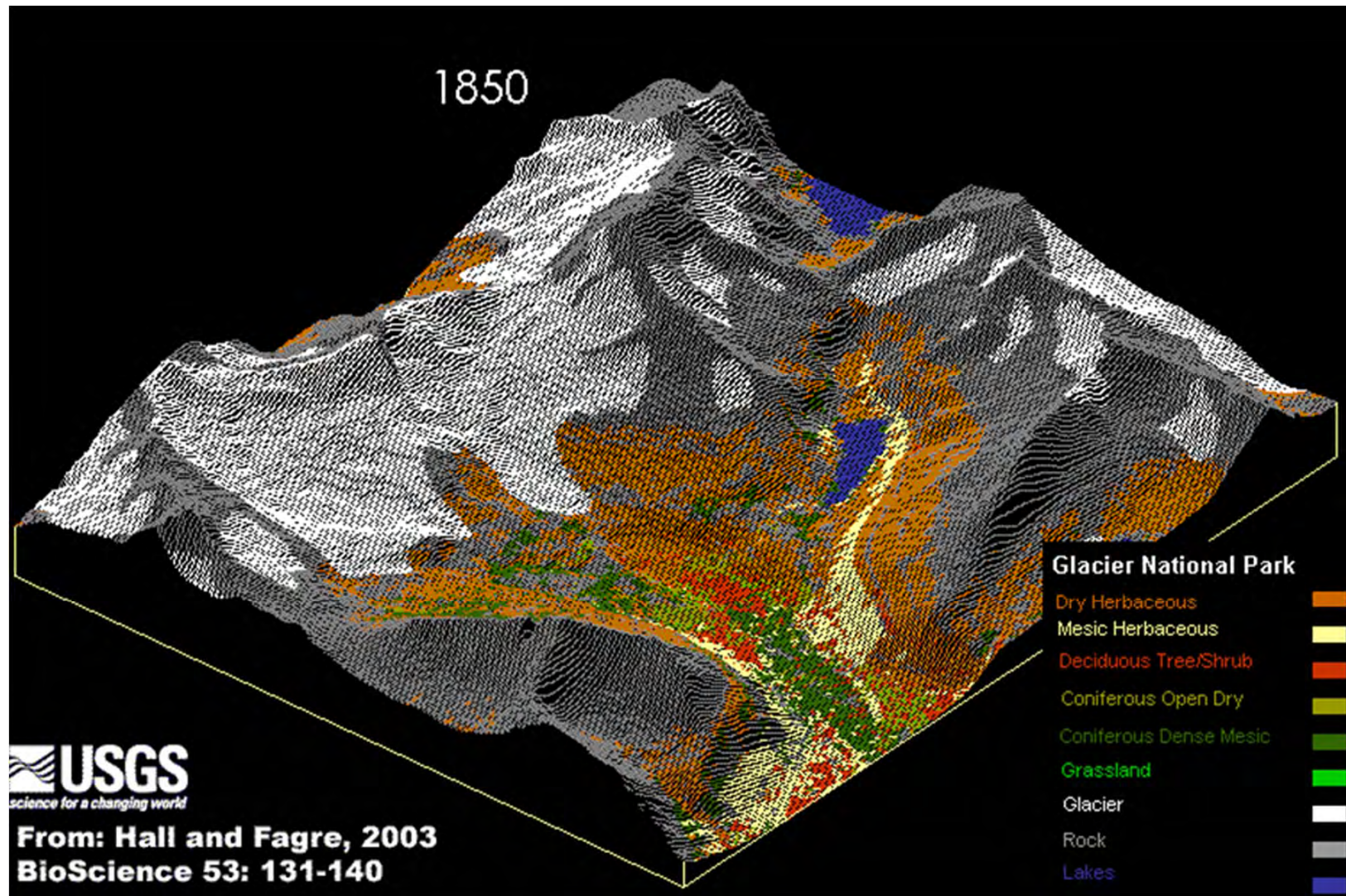
Plots courtesy of EPICA. Data from Luethi et al 2008 (CO₂) and Jouzel et al 2007 (temperatures).

Projected Sea Ice Extent

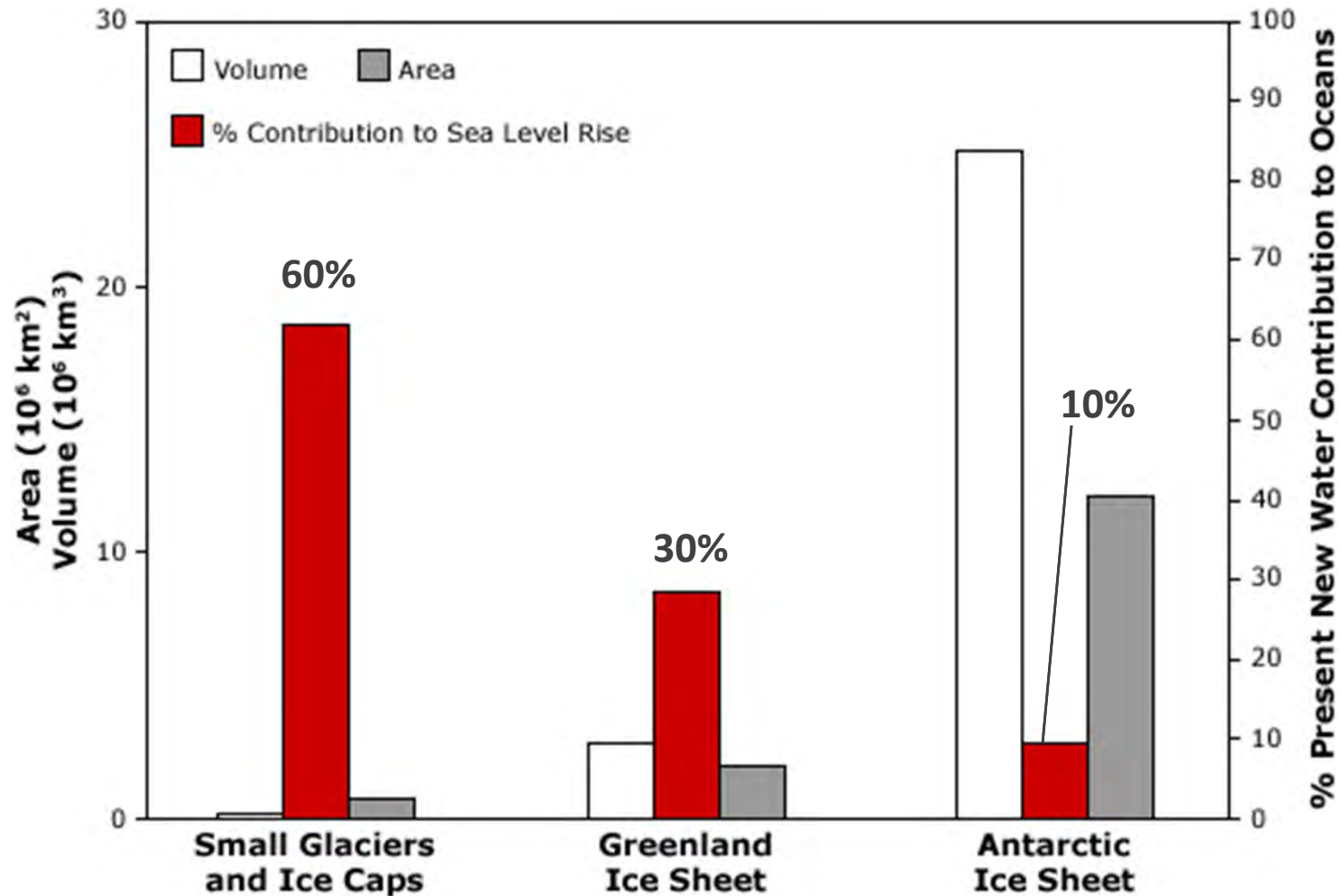


Projected Glacial Melt

http://www.nrmsc.usgs.gov/files/norock/research/glacier_animation.gif



Sea Level Rise



Sea level rise contributors: Comparison of volume (white), area (grey) and percent contribution to sea level rise (red) by small glaciers and ice caps, and the Greenland and Antarctic Ice Sheets. Image courtesy (Meier et al., 2007).