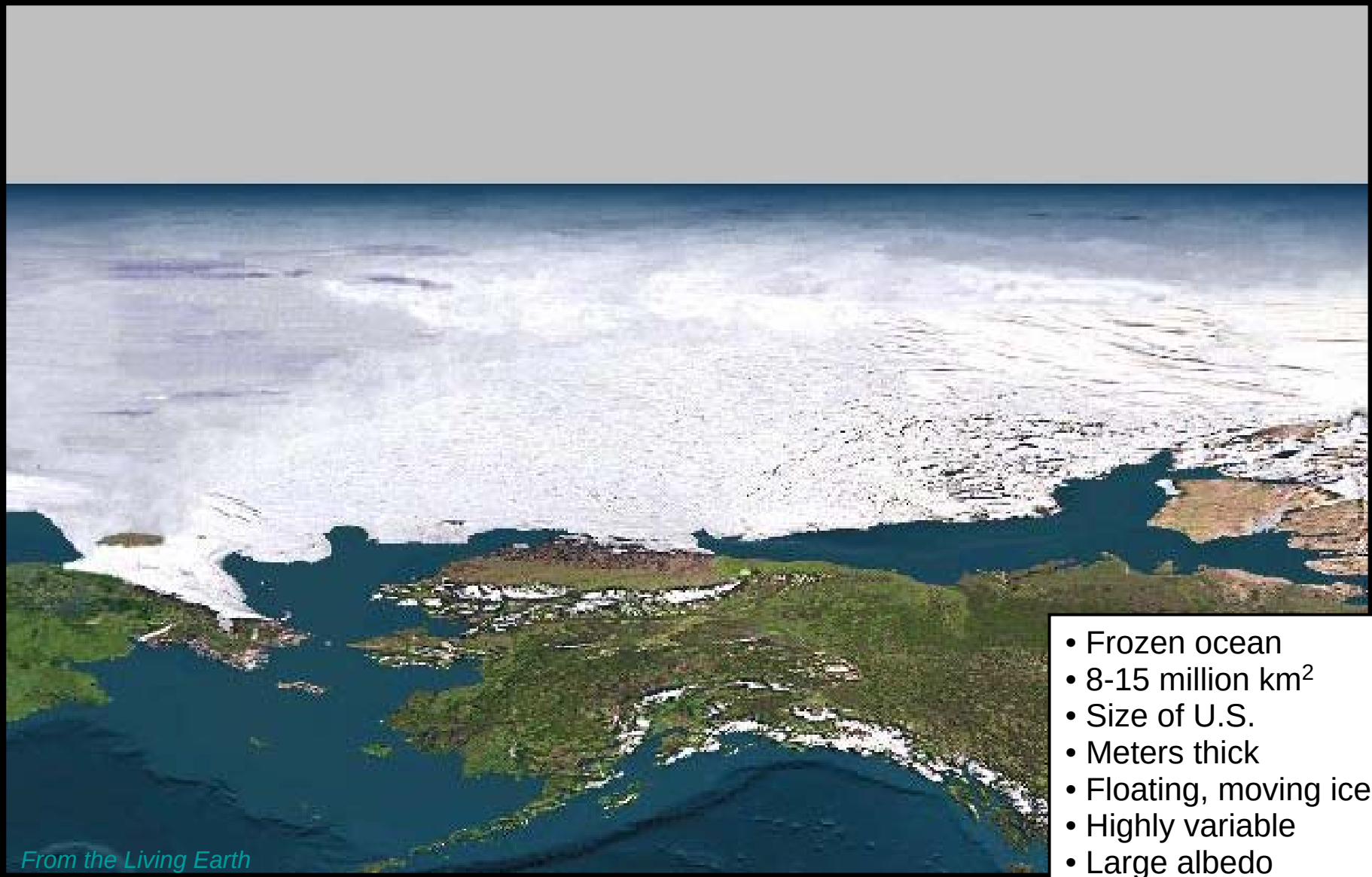
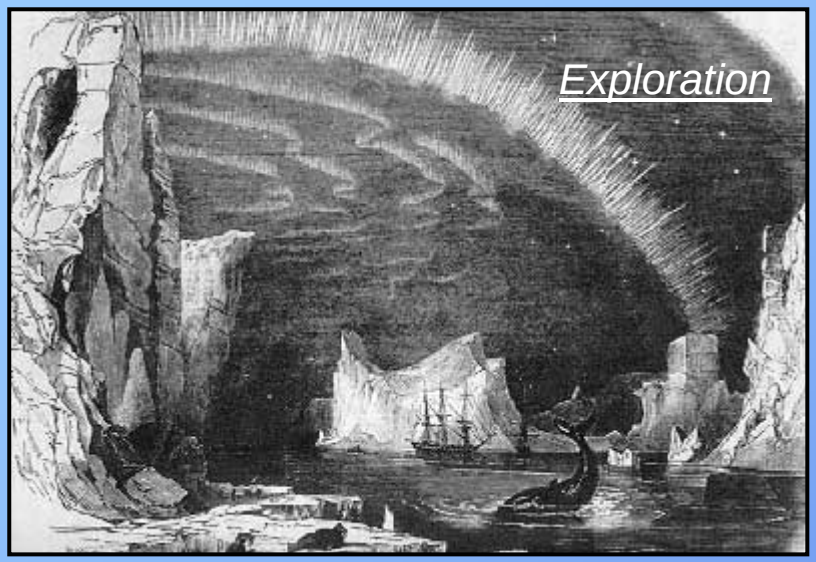
The Arctic Sea Ice Cover

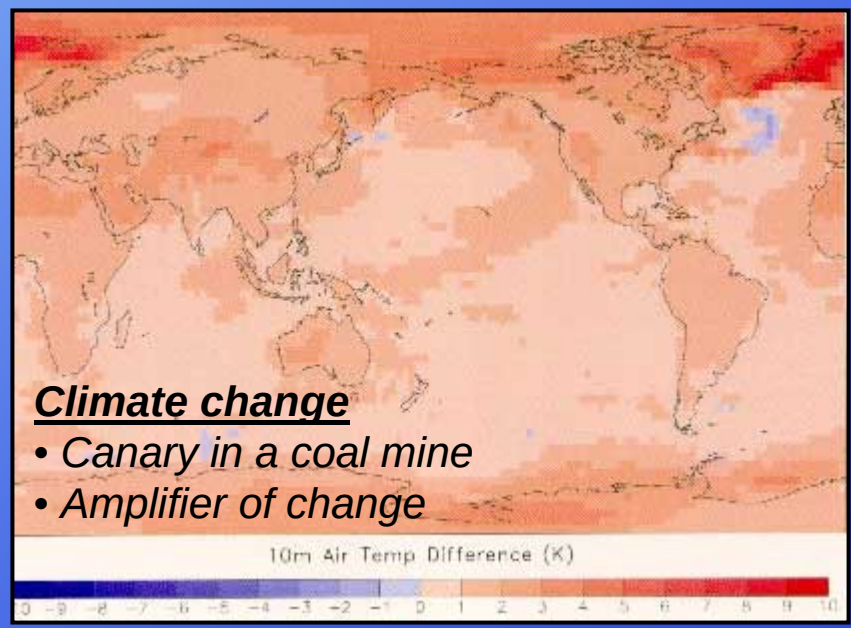


- Frozen ocean
- 8-15 million km^2
- Size of U.S.
- Meters thick
- Floating, moving ice
- Highly variable
- Large albedo

Interface, Impediment, Integrator

Why important





Climate change!

What are the major sea ice questions?

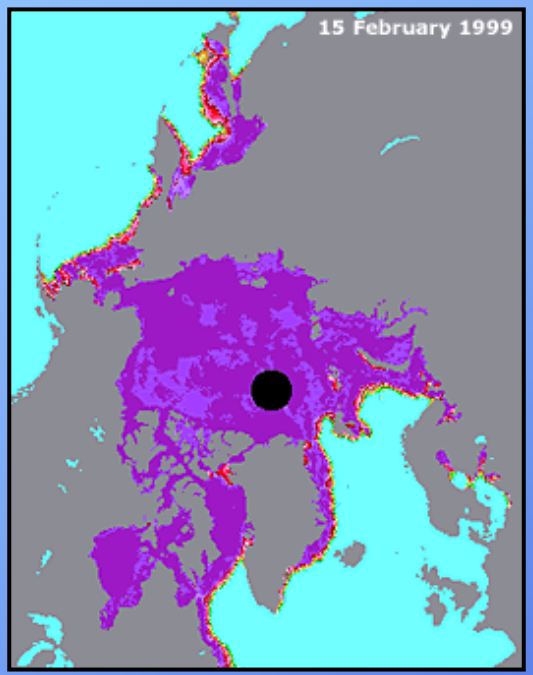
- How much ice is there?
  - areal extent
  - thickness
- How much snow is there?
- How does the ice move?
- What is its mass balance?
- Where does the sunlight go?
- What are its properties?
- How does it interact with other components?

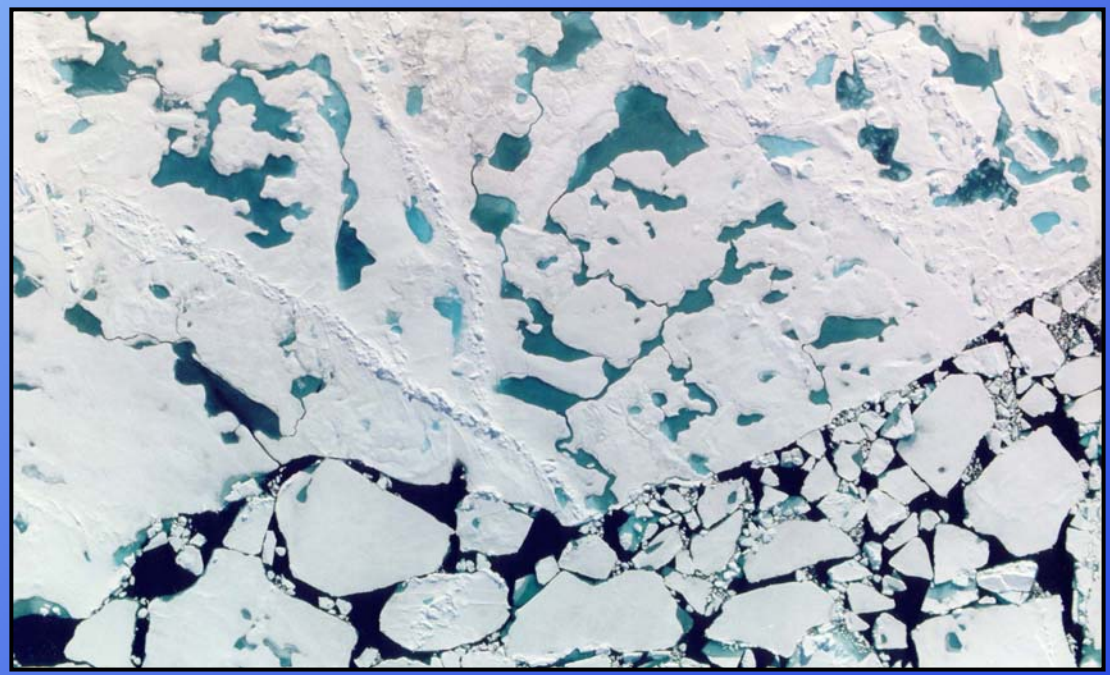
- Is Arctic change related to the Arctic Oscillation?
- Is Arctic change a component of climate change?
- Are feedbacks critical to Arctic change?
- Do physical changes greatly impact Arctic ecosystems and society?
- Which Arctic changes reflect basin-wide, decadal, and long-term processes?
- How are they coupled?
- Have Arctic feedbacks amplified these changes?
- What are the future Arctic change scenarios?
- Determine the extent of the ice cover
- Determine the redistribution of the ice cover due to dynamics and thermodynamcs
- Measure the export of ice from the Arctic basin
- Determine the snow depth and the ice thickness
- Assess large-scale Arctic environmental change.
- Conduct scientific exploration of polar frontiers.
- Observe polar regions in depth.
- Understand human-environmental dynamics.
- Create new connections between science and public.

How are these quantities changing?

What do we need to measure?

- Ice extent
- Thickness distribution
- Snow depth distribution
- Ice motion
- Temperature
- Mass balance
- Albedo and transmission
- Environmental forcing (ocean and atmosphere)

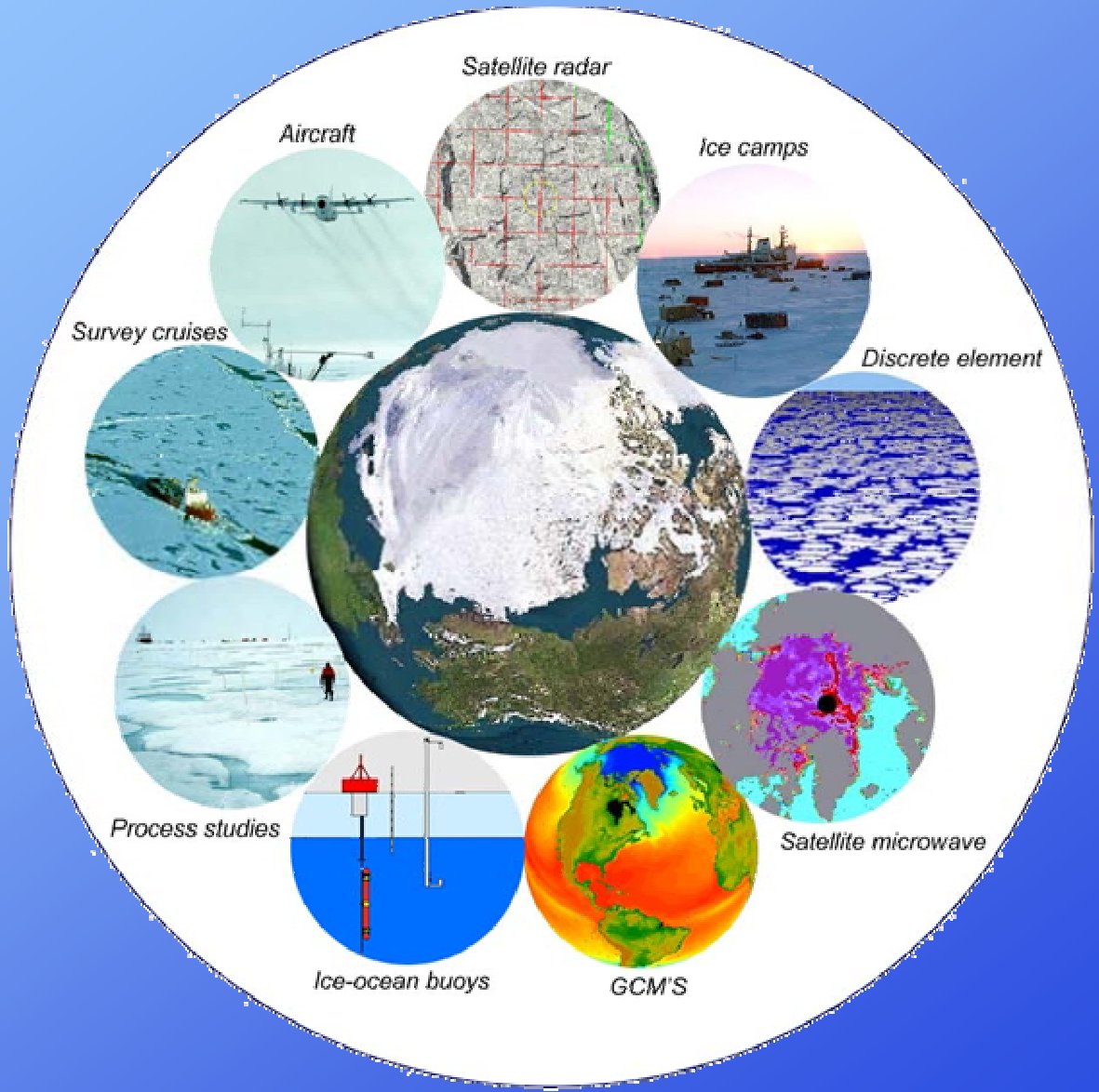




Spatial and temporal variability make it difficult

What tools do we have?

- Archived data
- Field experiments
  - camps
  - cruises
  - submarines
- Remote sensing
  - IPS
  - aircraft
  - satellites
- Models
  - process
  - discrete element
  - large-scale ice
  - GCM

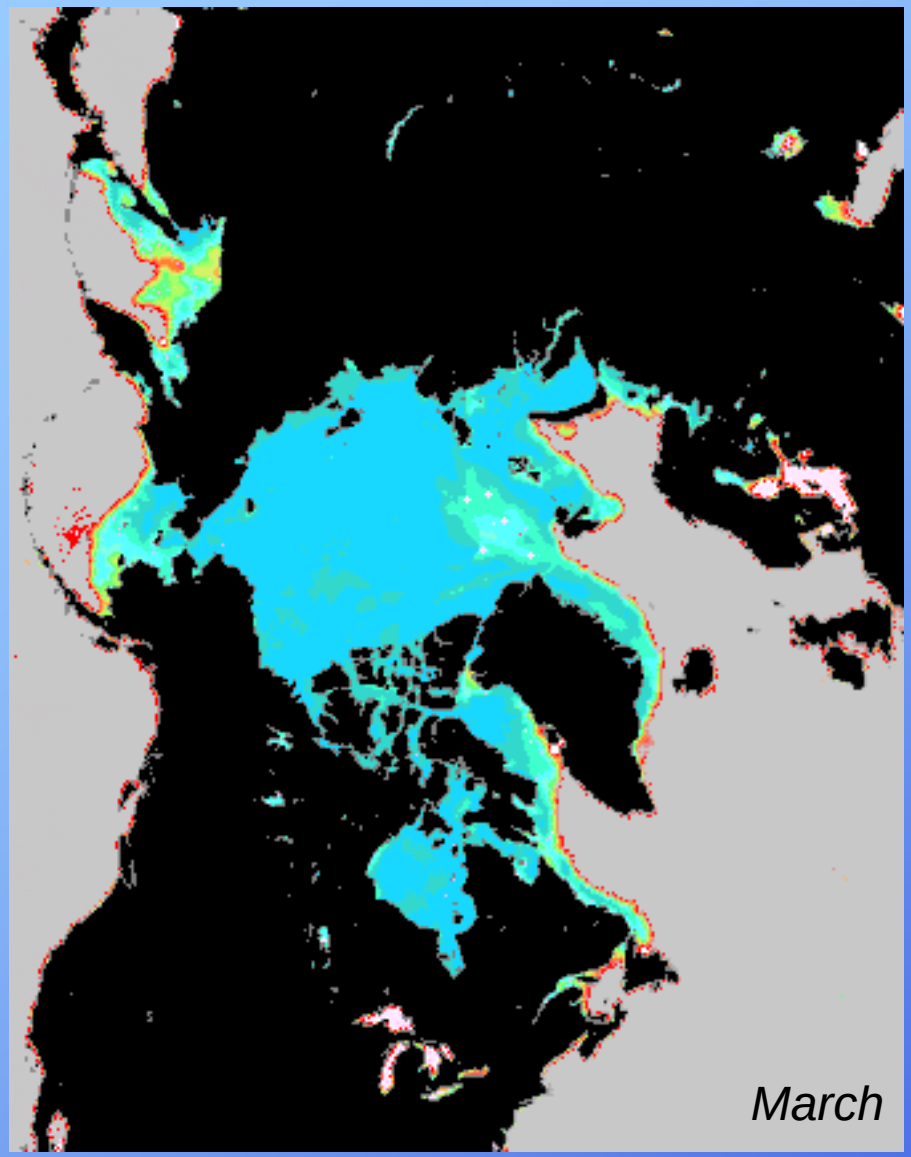


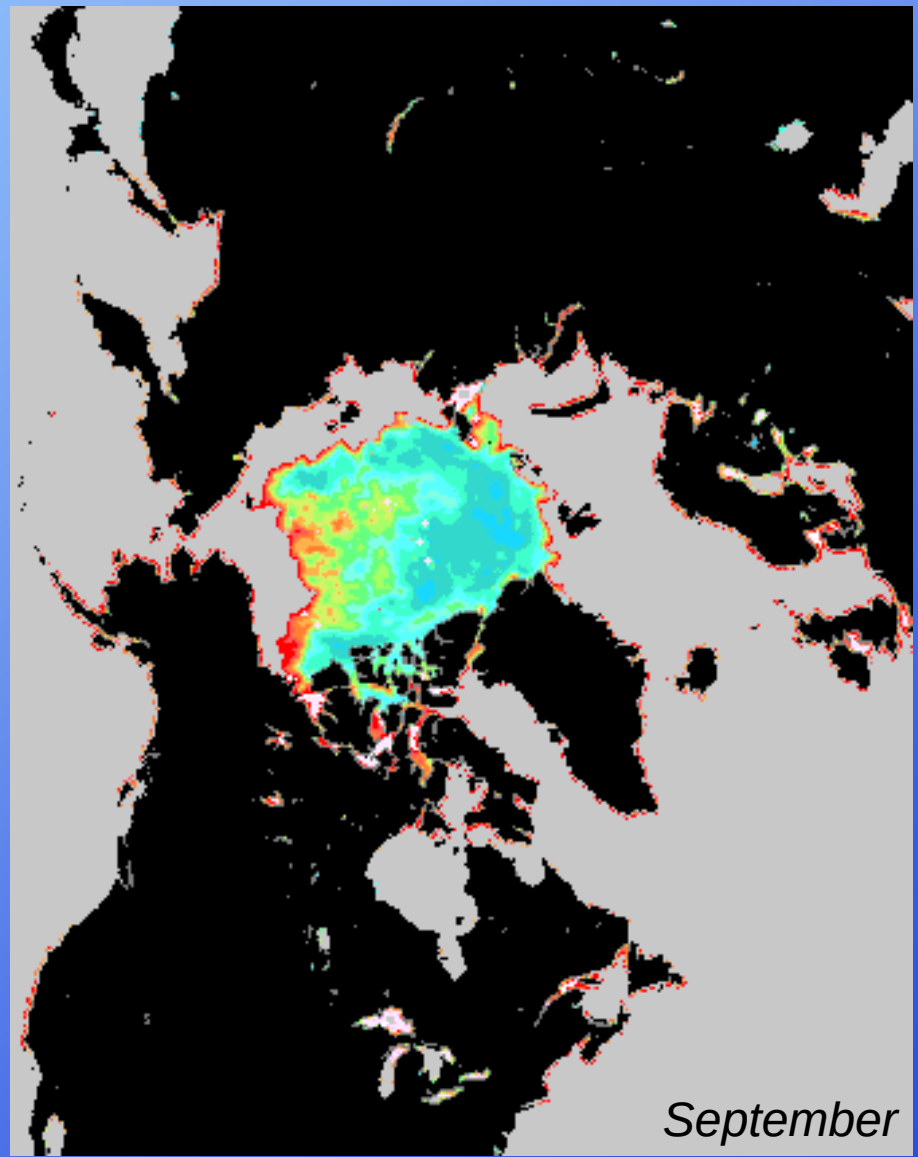
Ice tethered buoys!

What is the ice extent?

★★★★

• *Satellites*





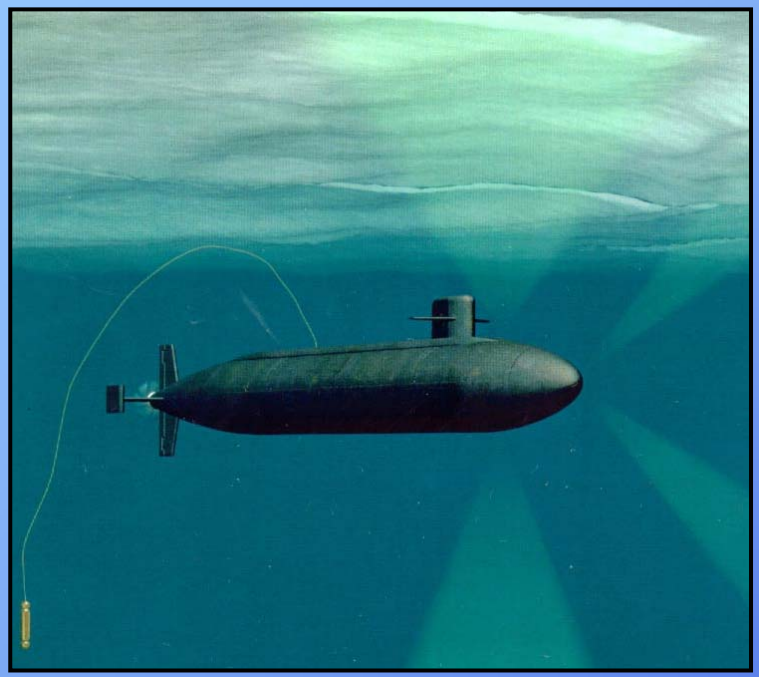
Ice extent is decreasing

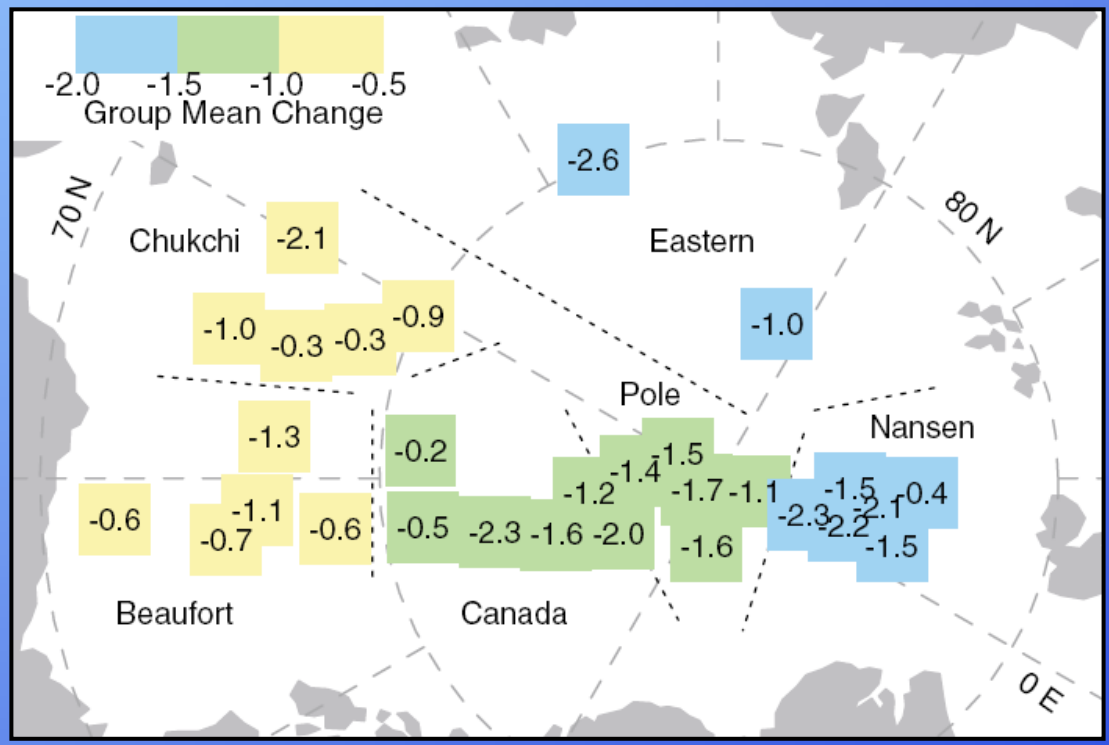
How thick is the ice?

★★

- *Submarines*
- *Moorings*
- *Surface obs*
- *Satellites?*

Changes in summer thickness
Comparing 1958-1976 and the 1990's





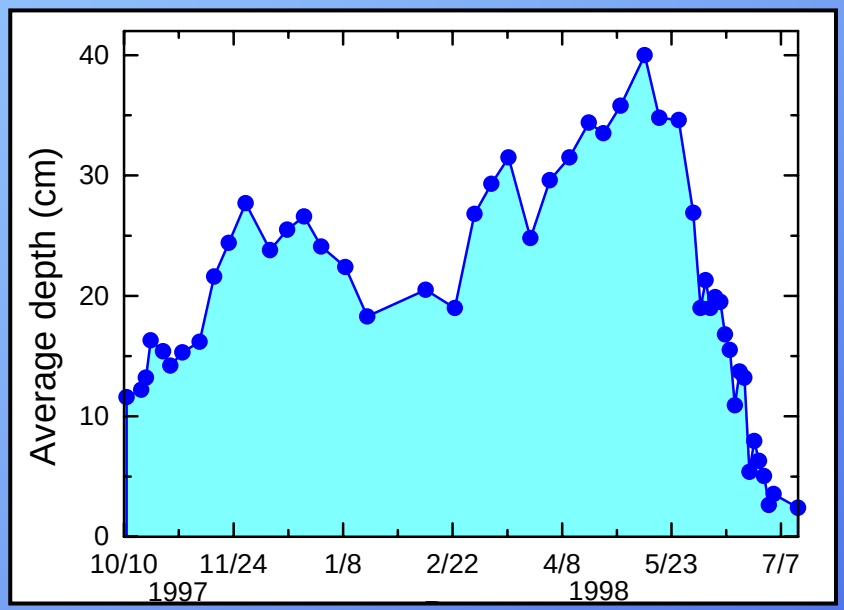
- Rothrock et al. show thinning everywhere!
- Average decrease was 40% from 3 m to under 2 m
- Tucker et al. show similar results for spring

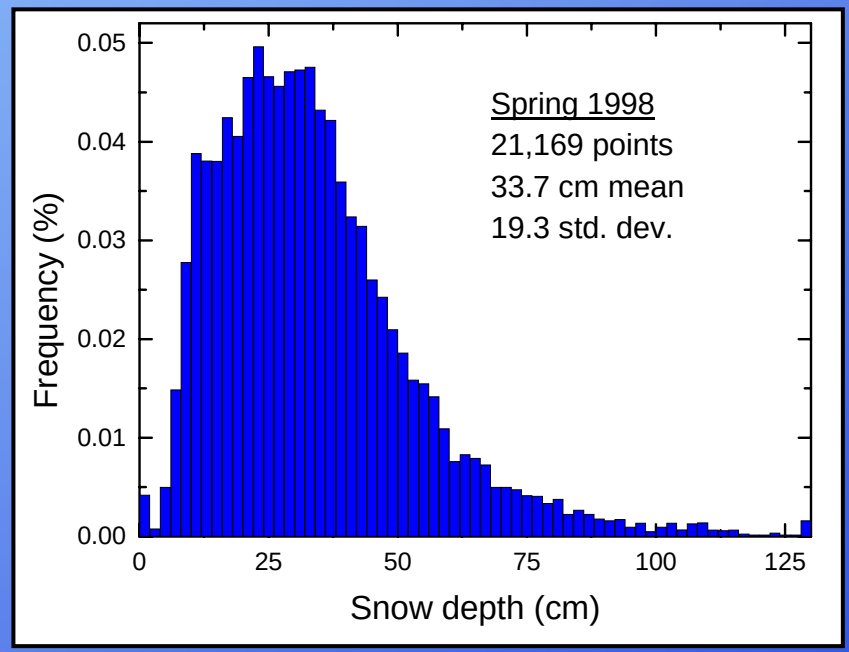
Sea ice is thinning everywhere

How much snow is there?

★★

- *Surface obs*
- *Buoys*
- *Satellites?*

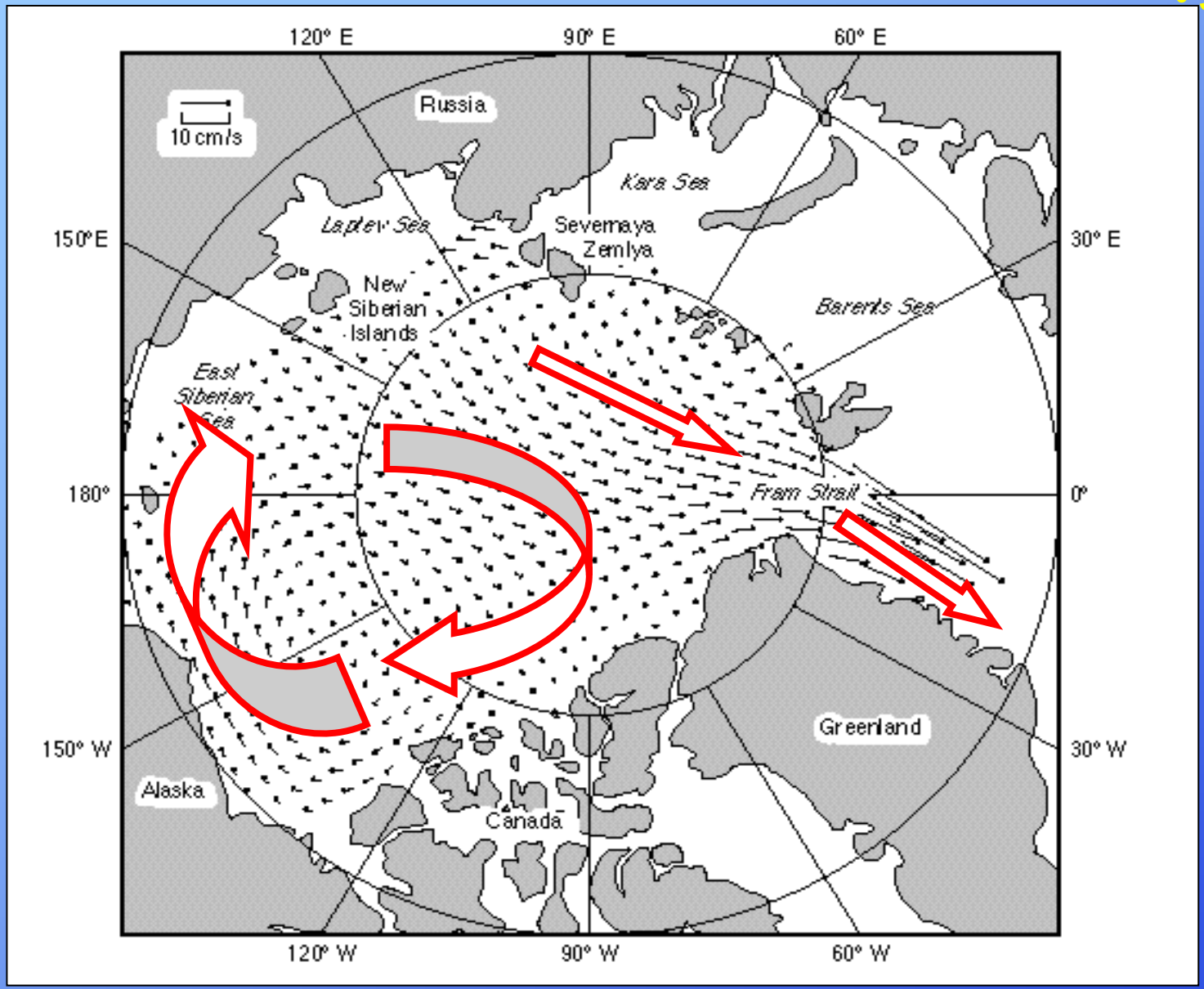




Seasonal evolution and large spatial variability

How does the ice move?

- Buoys
- Satellites



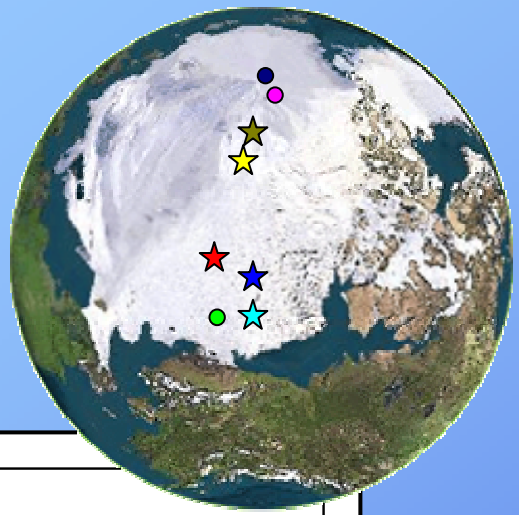
Variations due to changes in forcing

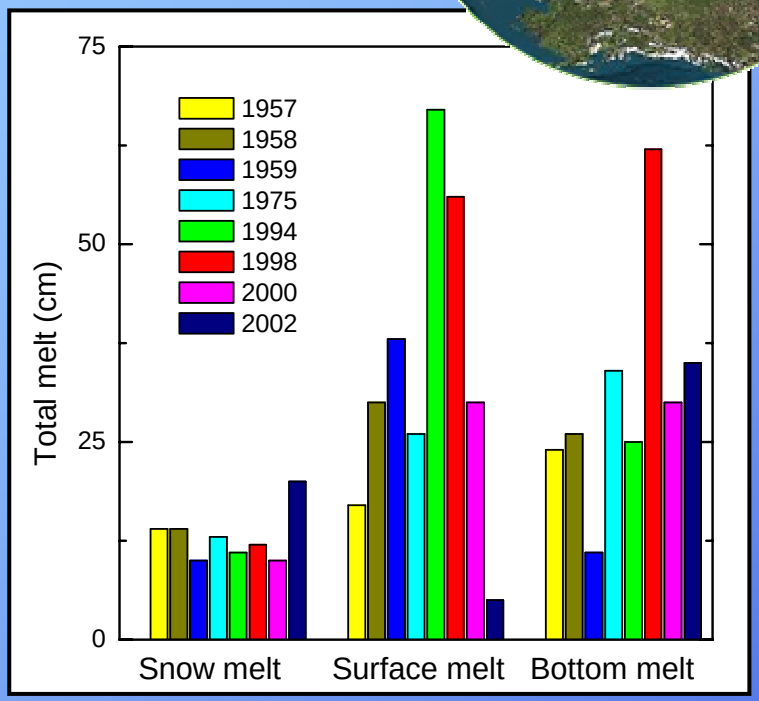
What is the mass and heat budget?

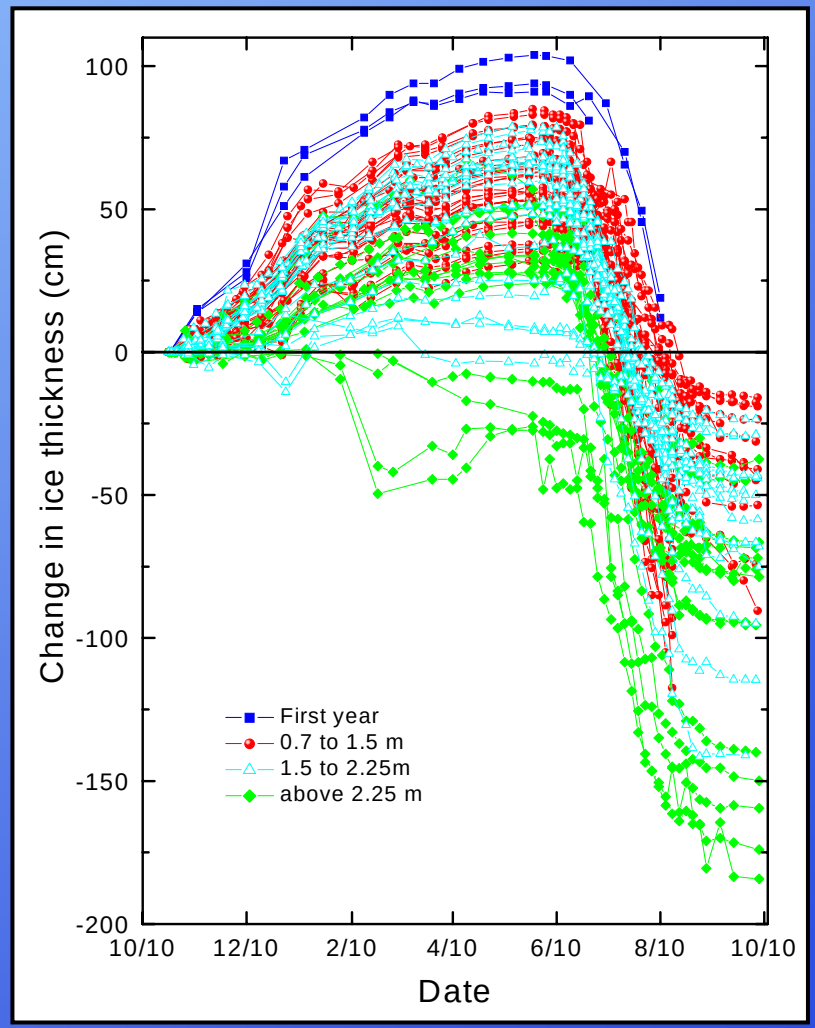
- *Surface obs*
- *Buoys*

Manned camp

Autonomous buoy





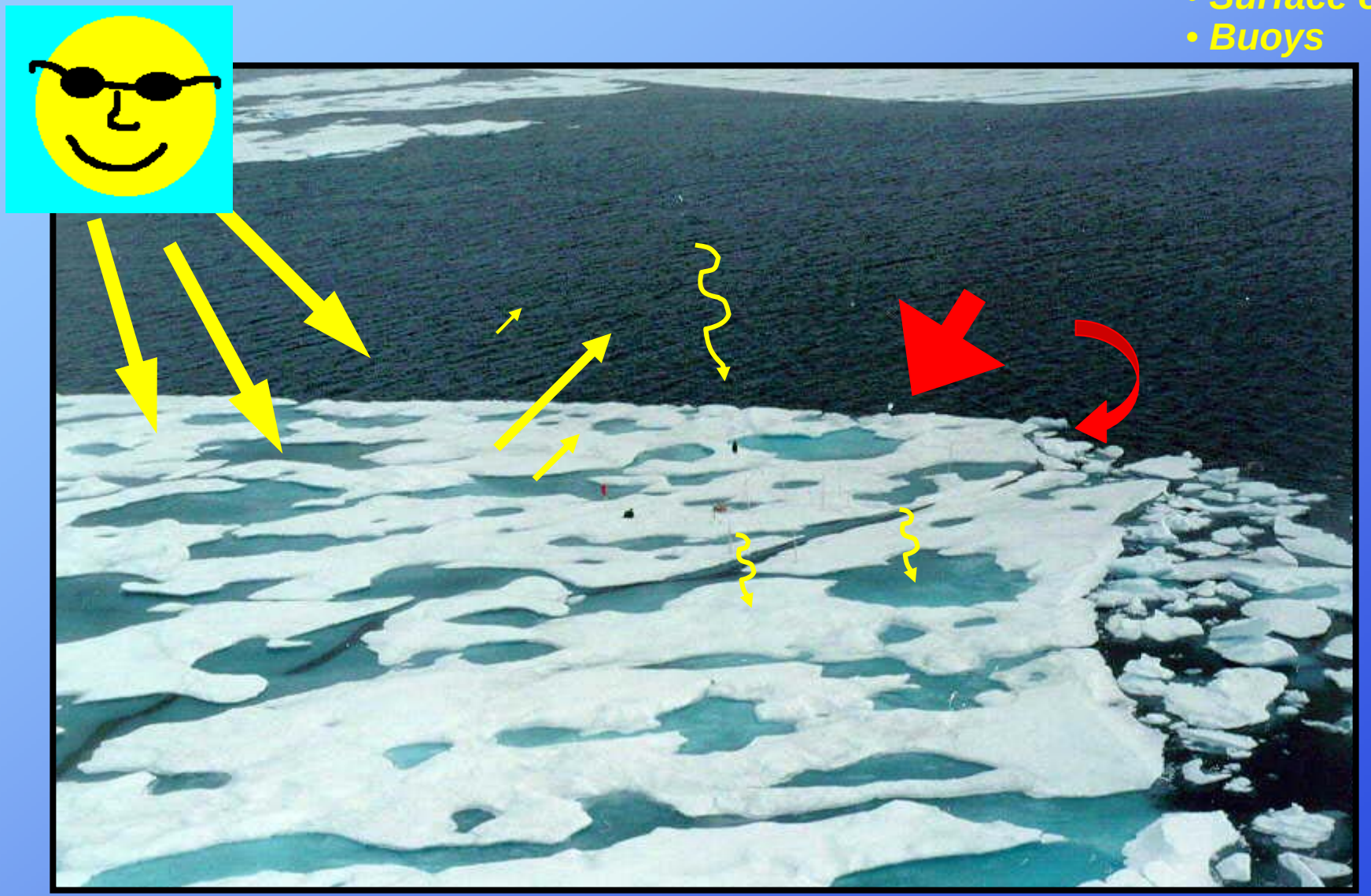


Large variability: spatial and interannual

Where does the sunshine go?

★★

- *Surface obs*
- *Buoys*



Seasonal variability, melt ponds are the key.

What are the ice properties?

★★

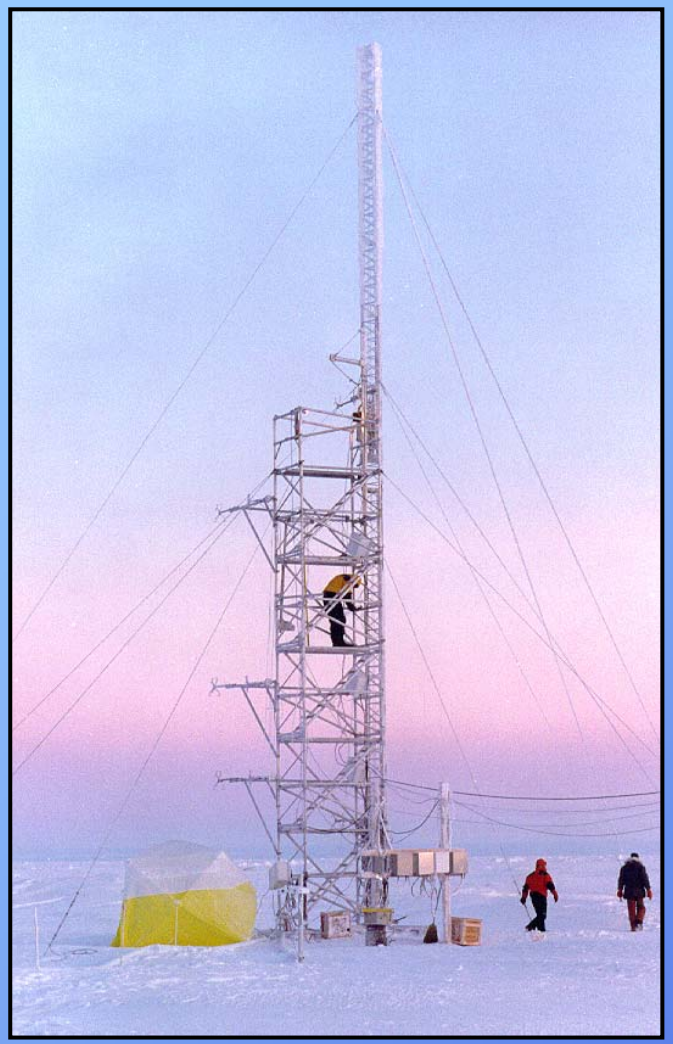
- *Surface obs*
- *Buoys*
- *Satellites*

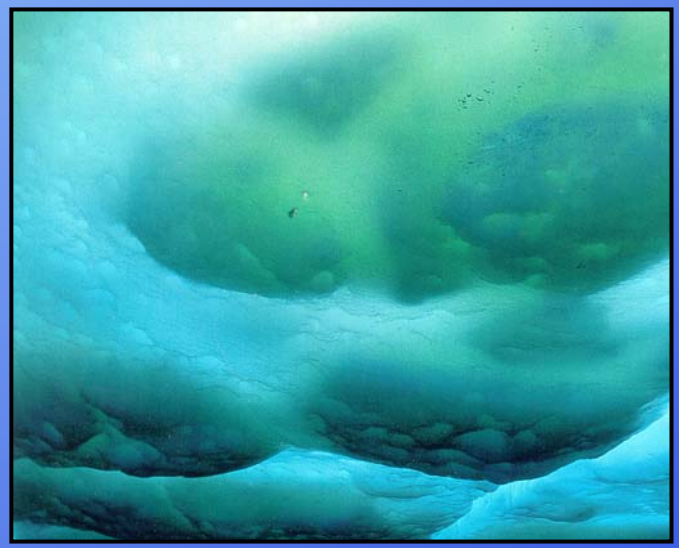
Ice properties impact all parameters

How does it interact?

★

• *Surface obs*





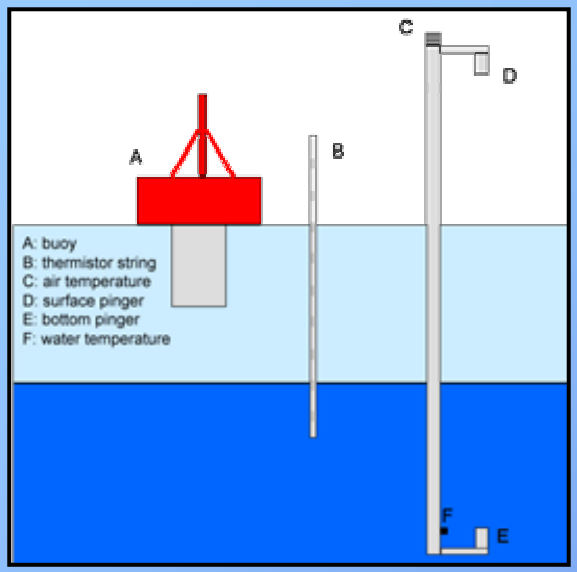
Much work to do.

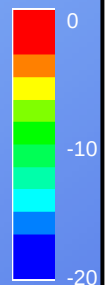
Ice tethered systems: ice measurements

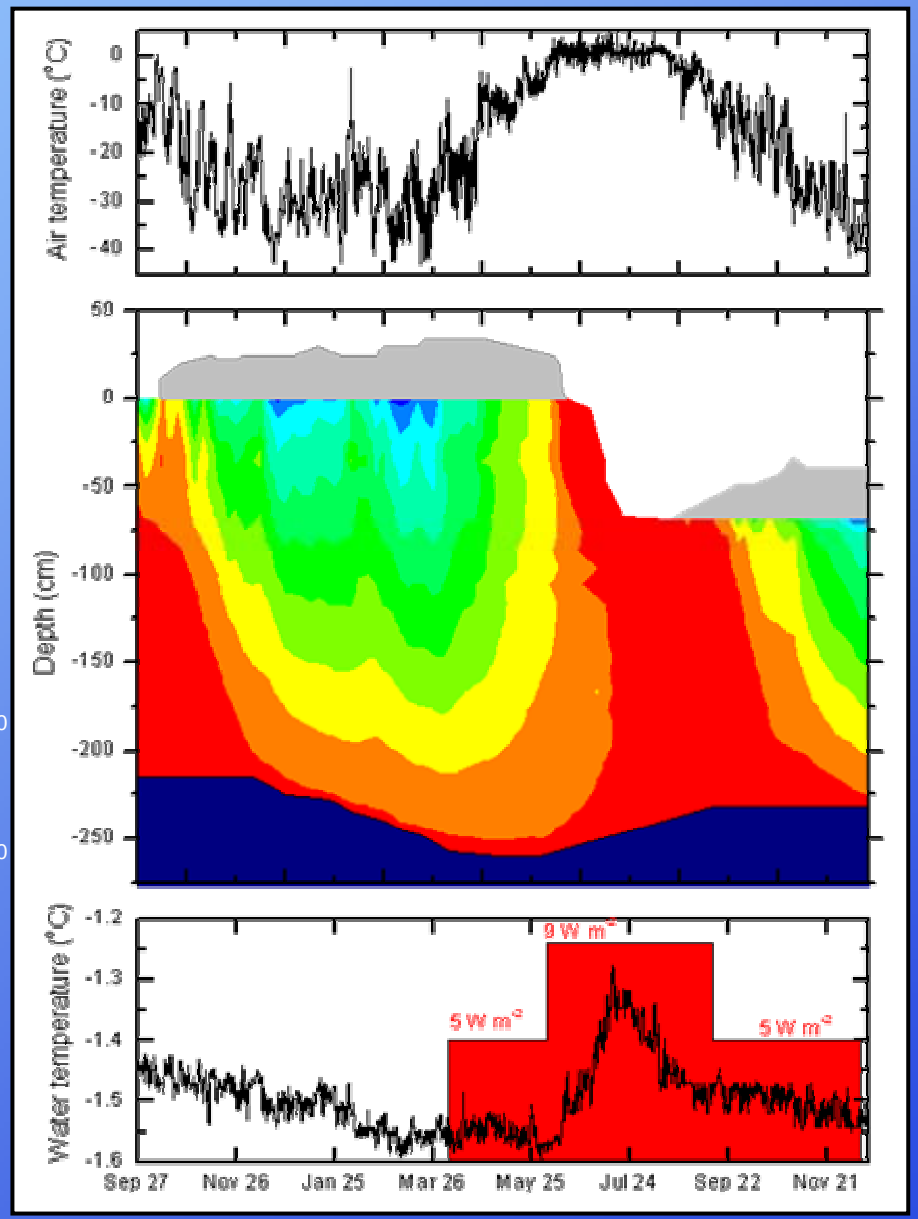
1. Air temperature	1. Thermistors
2. Ice temperature	2. Thermistors
3. Upper ocean temperature	3. Thermistors
4. Snow depth	4. Acoustic sensor
5. Ice thickness	5. Acoustic sensor
6. Ice mass balance	6. Acoustic / thermistors
7. Surface conditions	7. Web cams – above,below
8. Solar partitioning	8. Spectroradiometers
9. Ice position	9. GPS

Ice tethered systems can make major contributions

Sample ice buoy results





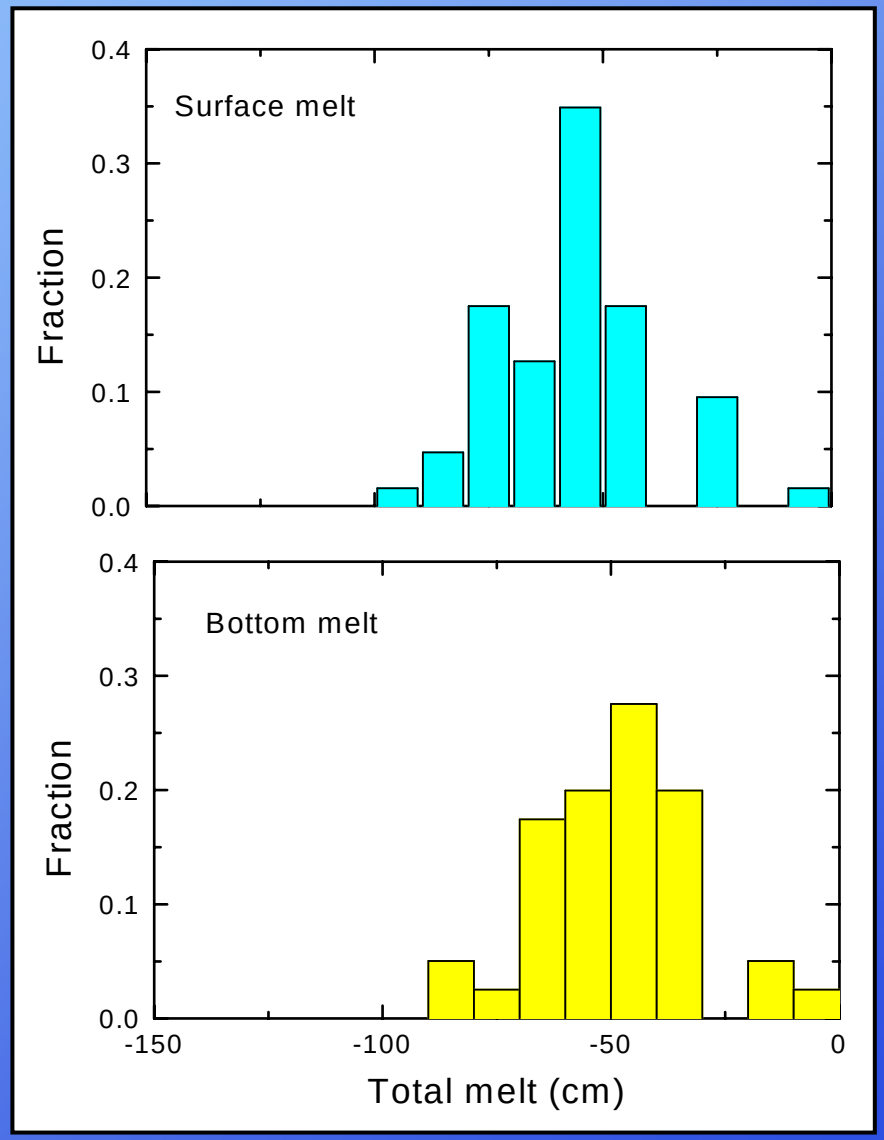


Almost as good as being there.

Spatial variability

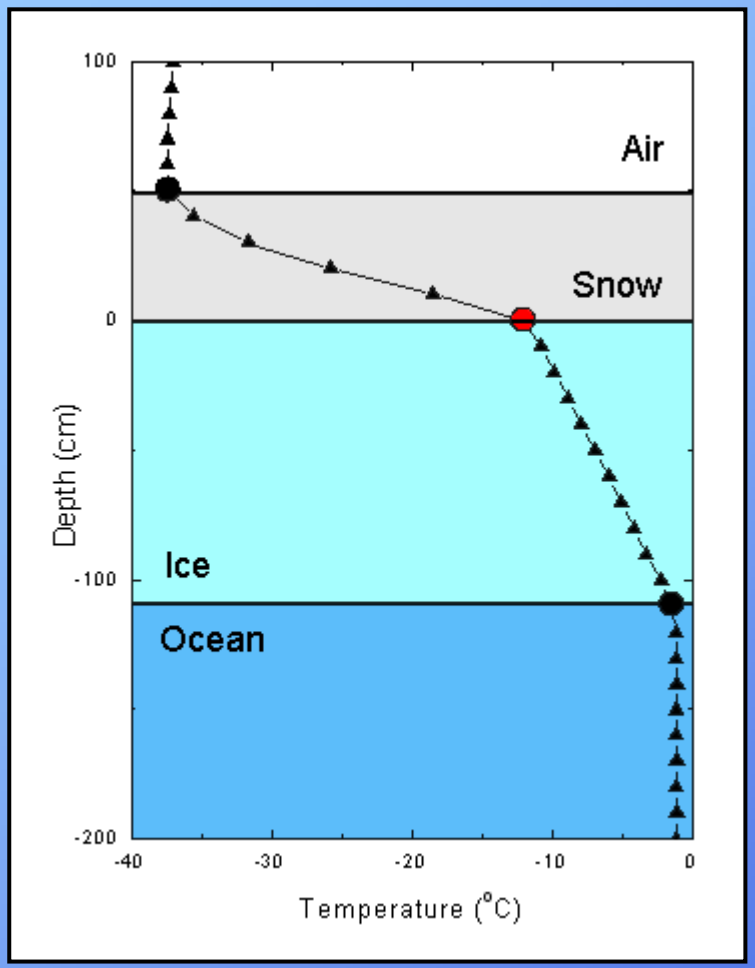
Snow depth, ice thickness, ice conditions

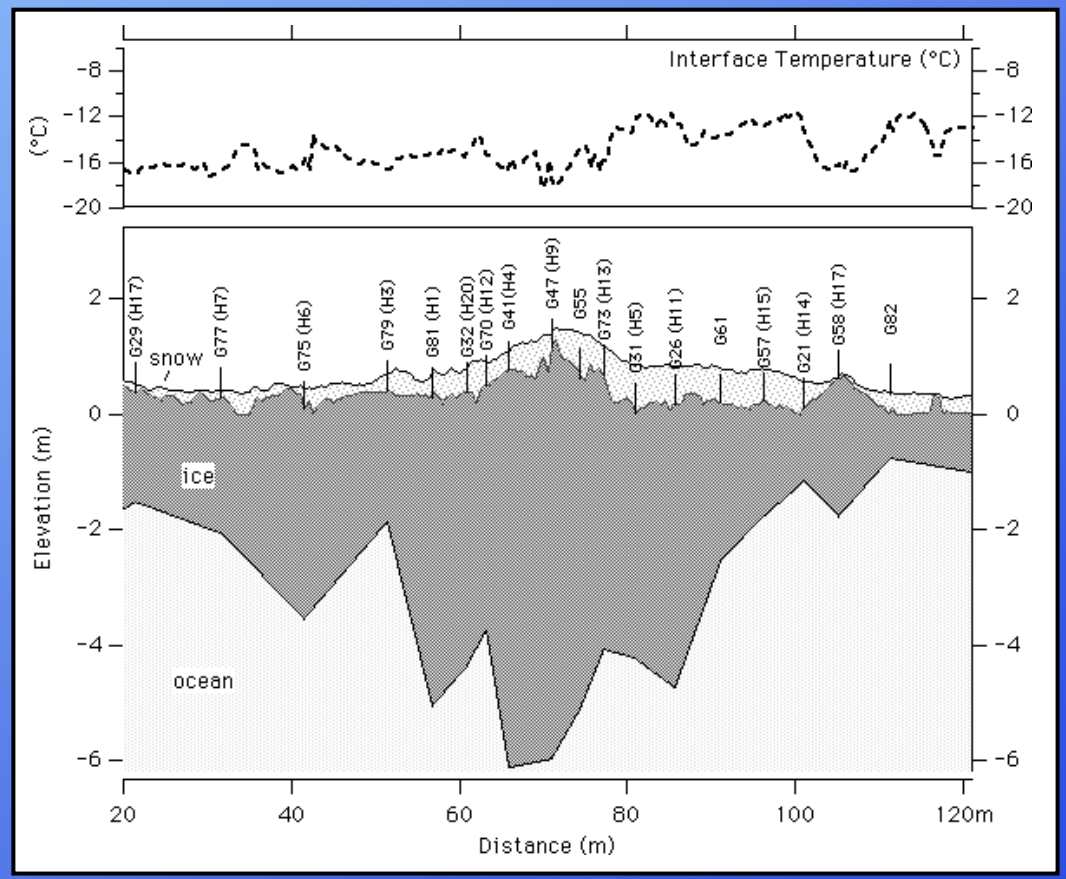
What good is a point measurement?



Pretty good if… you carefully select location

Smart motes





Snow-ice interface temperature tells all

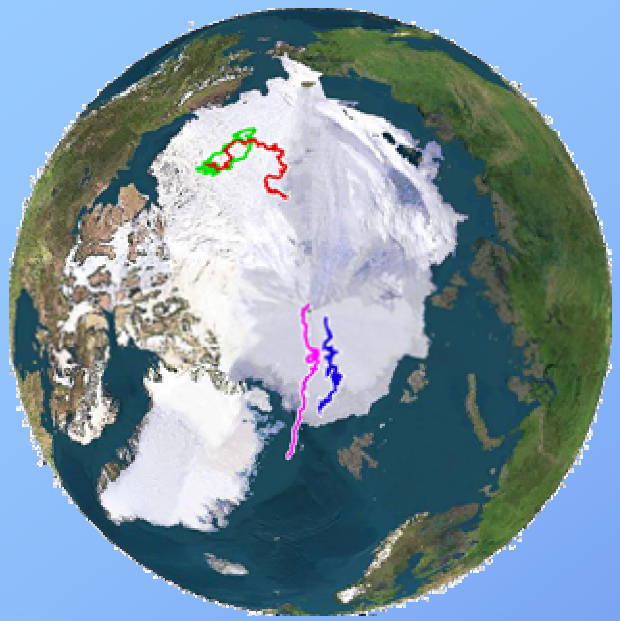
Installation measurement festival

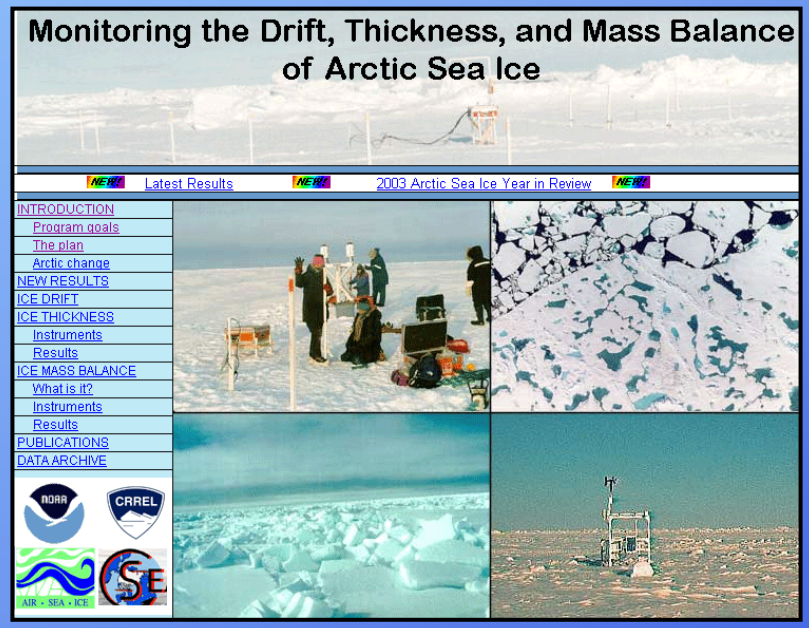
Explore spatial variability

- Aerial photographs
- Snow depth
- Pond depth
- Ice thickness
- Surface types

Characterize area during buoy installation

Remember outreach





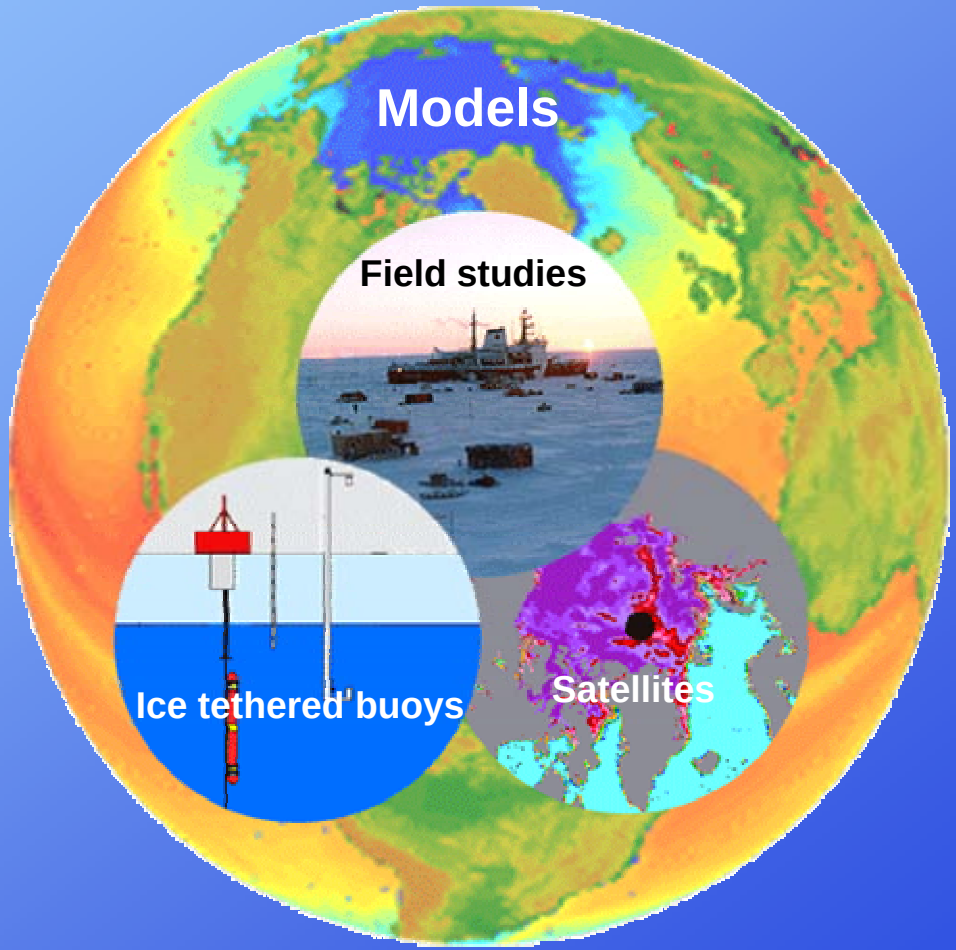
Classroom visits, media outreach, web cams and pages

Integration coordination, and synthesis

3 levels of coordination and integration

- Integrate all buoy elements (ice, ocean, atmosphere, biology, geochemistry).
- Integrate tethered buoys with other components of an Arctic Ocean observing system (satellites, moorings, stations)
- Coordinate with other studies (process studies, field studies, models)

- Collaborate with other efforts
- Synthesize results



Integration is the key

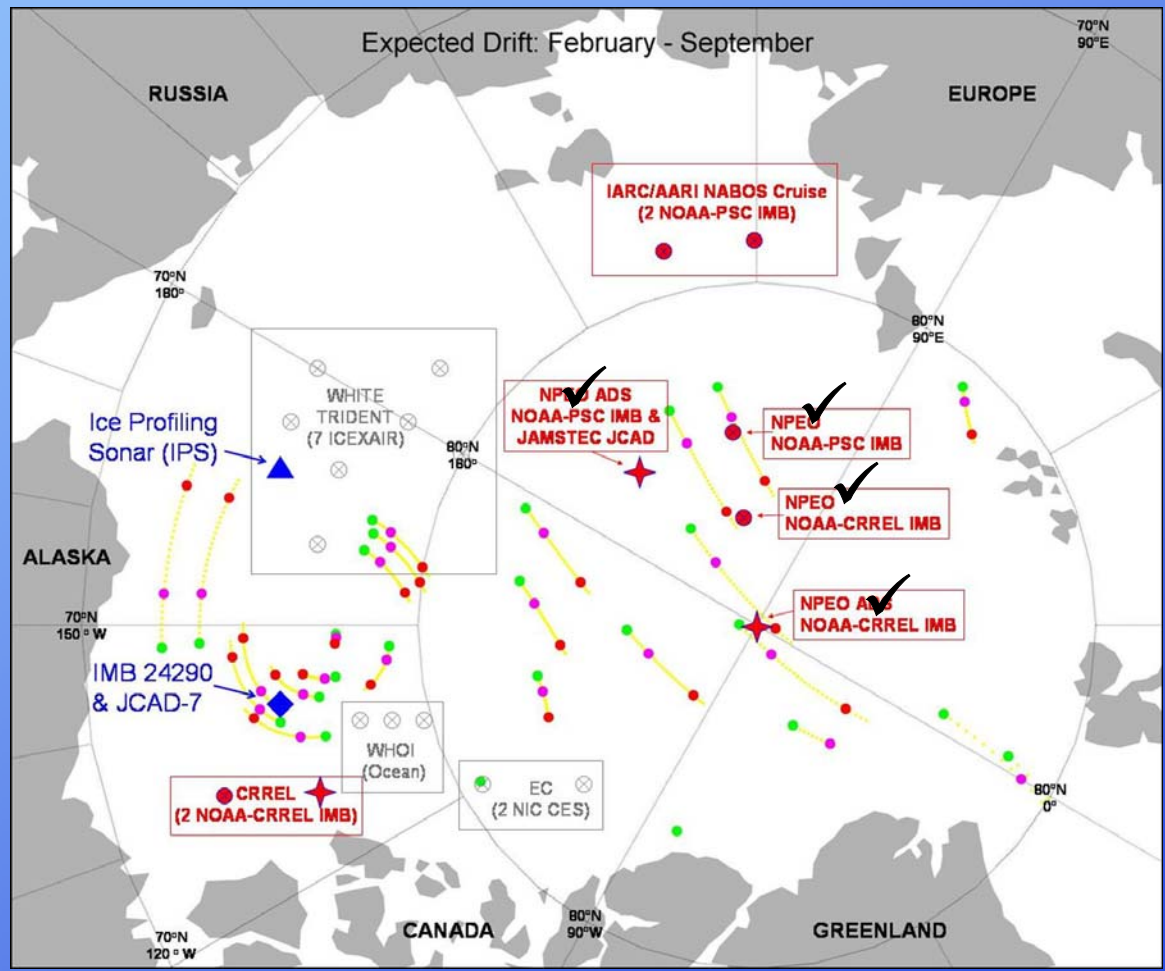
Summary

- How much ice is there?
  - areal extent
  - thickness – ***Yes!***
- How much snow is there? – ***Yes!***
- How does the ice move? – ***Yes!***
- What is its mass balance? – ***Yes!***
- Where does the sunlight go? – ***Yes!***
- What are its properties? – ***Yes!***
- How does it interact with other components? – ***Yes!***

Can ice tethered buoys help answer the questions – YES!

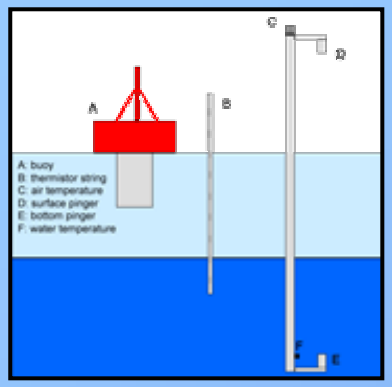
SEARCH ice mass balance activities

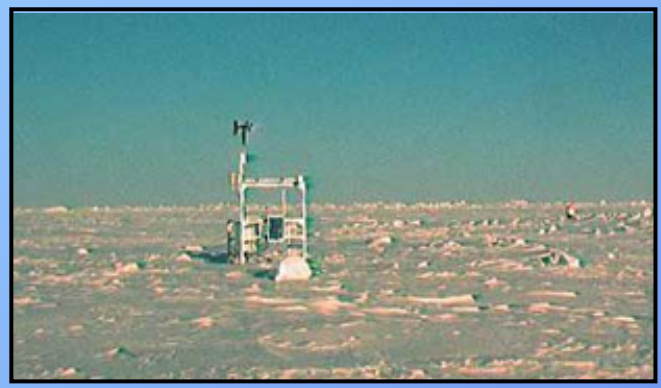
- Sponsored by NOAA and NSF
- Ice mass balance buoys
- Deployments defined by
  - Maximum coverage
  - Models and observations
- Eight buoys this year
- Expected life 1-3 year
- Coordinated with moorings
  - Ocean instruments
  - Ice profiling sonar
- Collaboration with other efforts

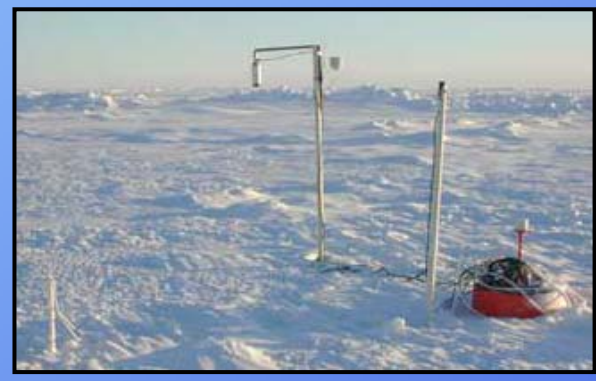


Location, location, location

Mass balance observations

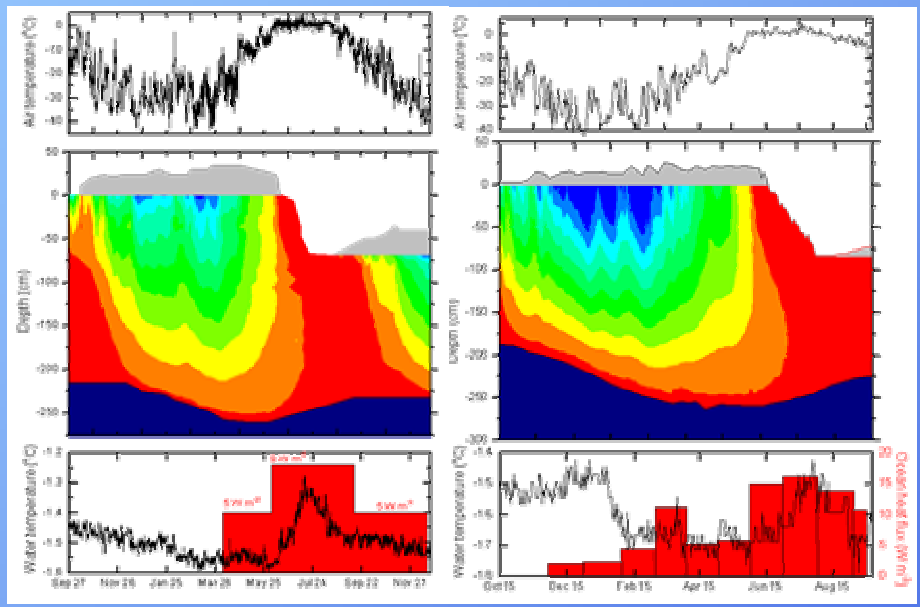






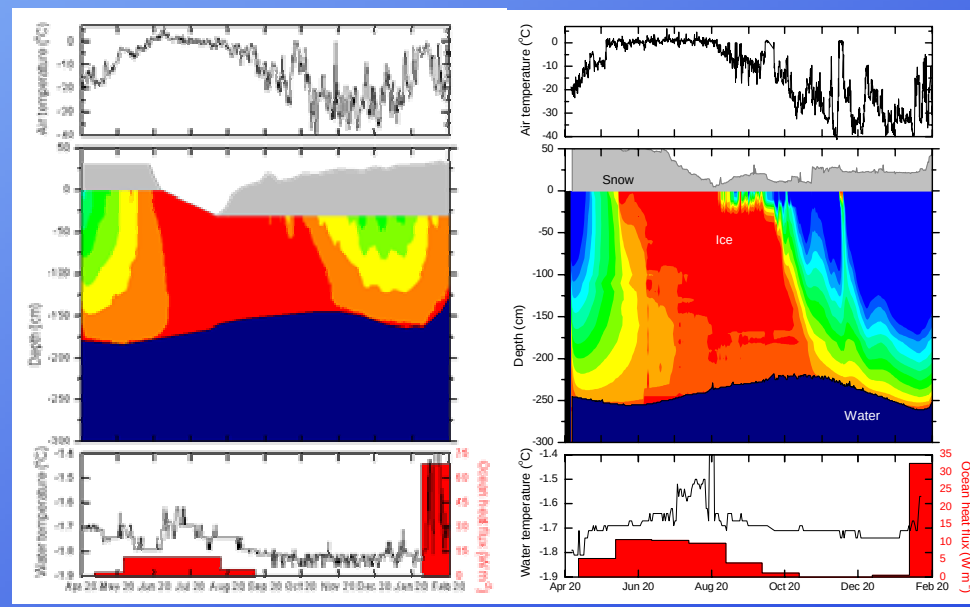
Beaufort Sea

North Pole



1993 - 1994

1997 - 1998



2000

2002

Autonomous field experiment in a box