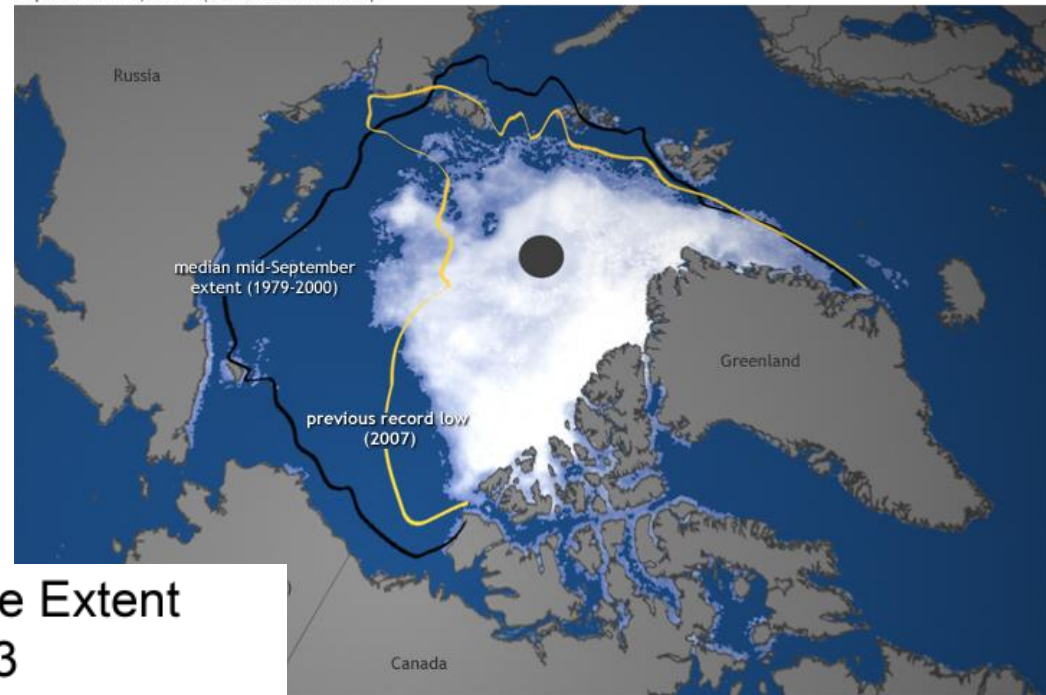


Observing Arctic Sea Ice Change

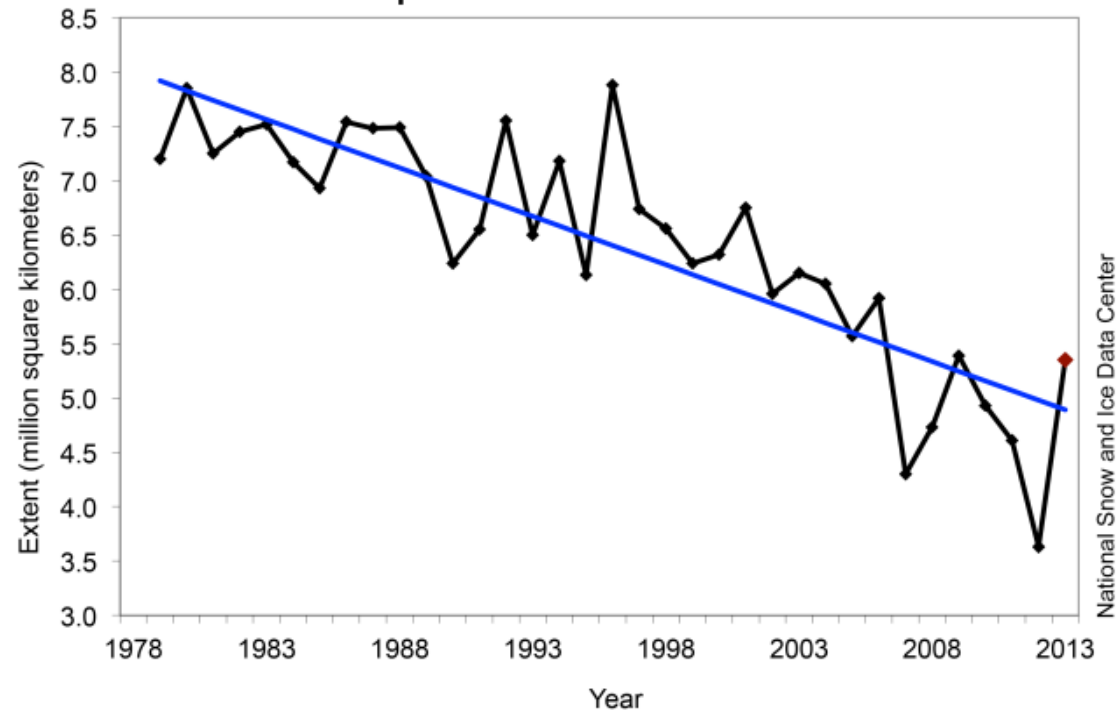
Christian Haas

Decreasing Arctic sea ice extent in September

September 16, 2012 (summer minimum)



Average Monthly Arctic Sea Ice Extent
September 1979 - 2013



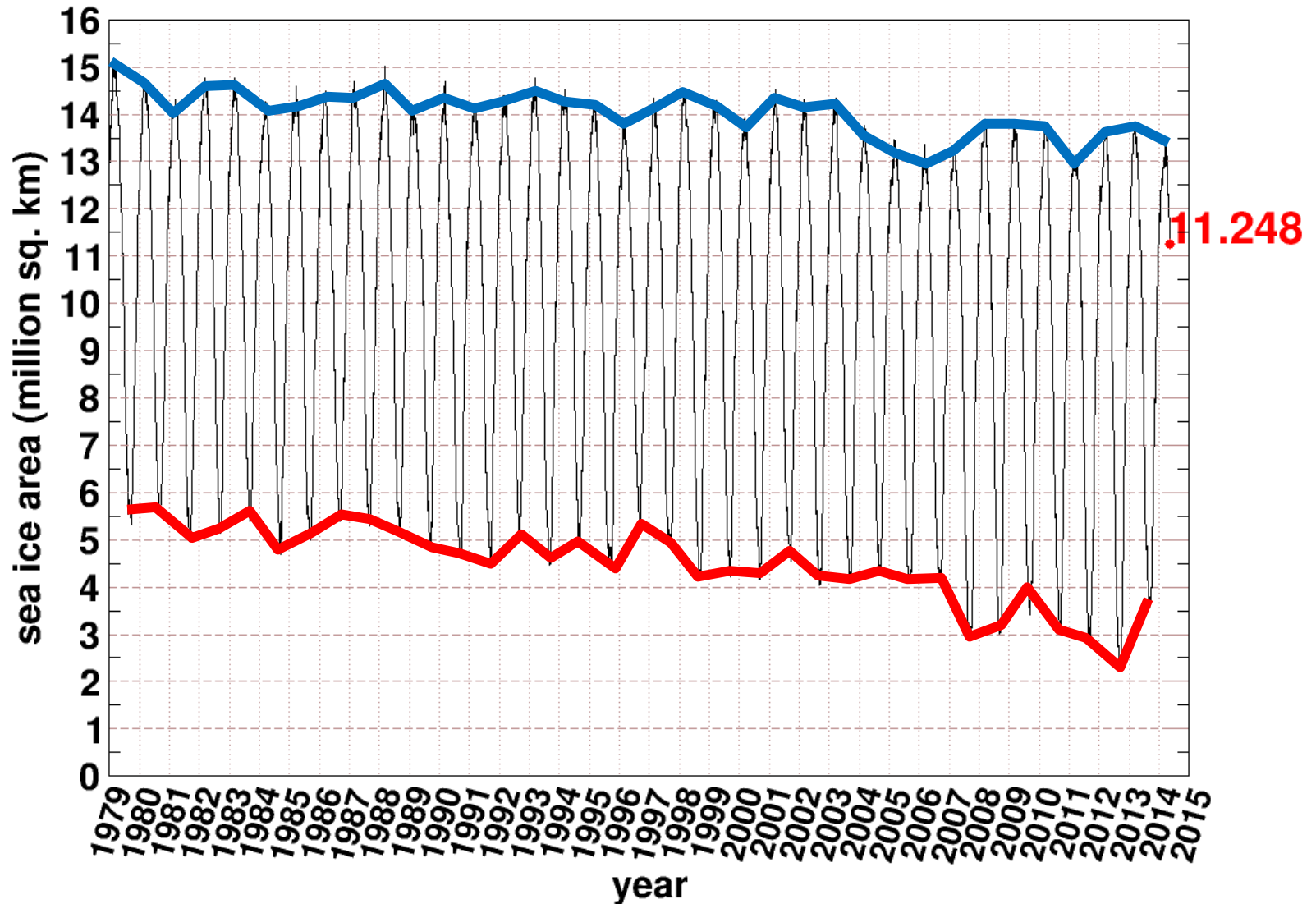
National Snow and Ice Data Center



- Ice extent is decreasing, but regional patterns are very different every year

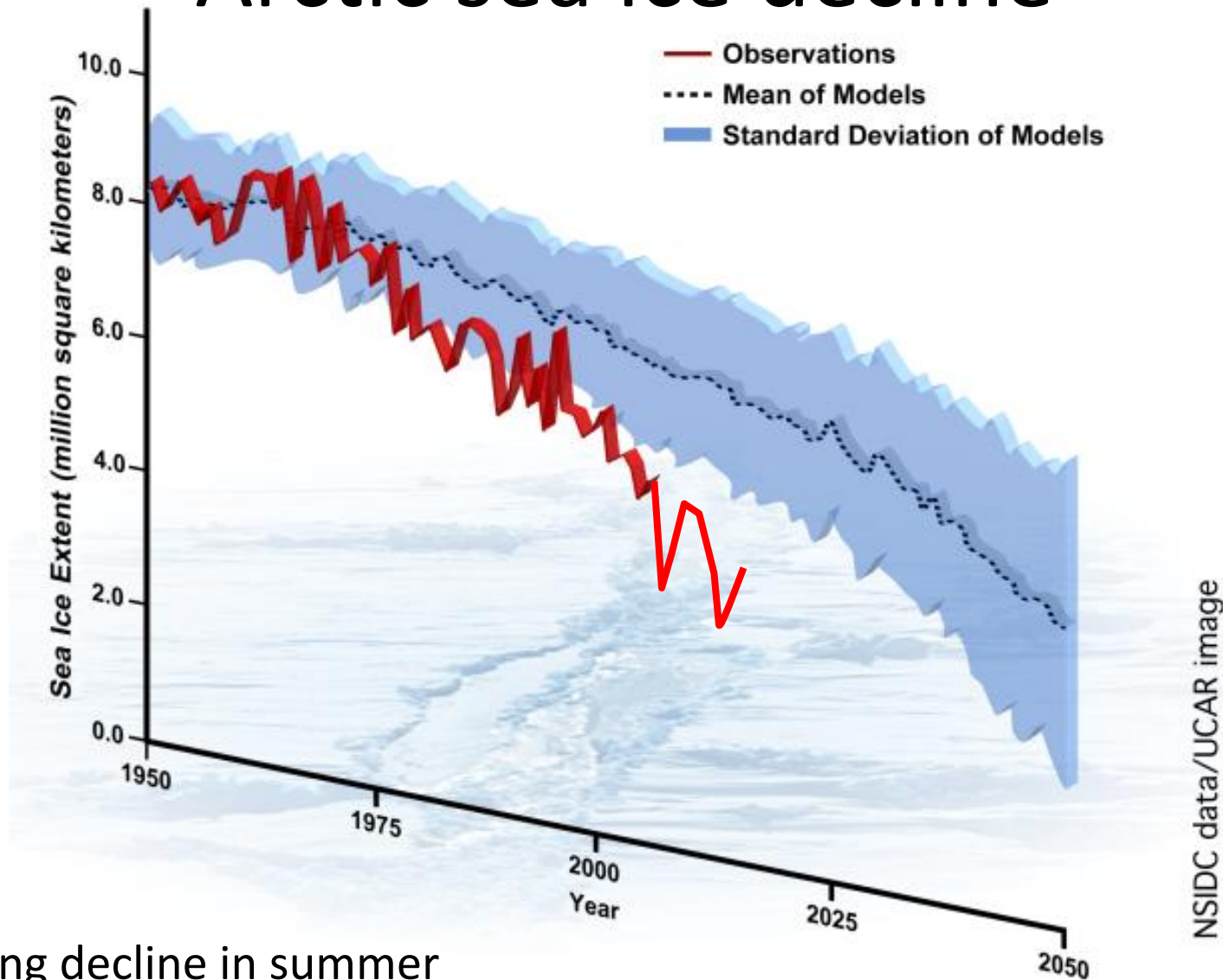
Northern Hemisphere Sea Ice Area

Data provided by NSIDC: NASA SMMR and SSMI



- Strong seasonal variability
- Smaller, decreasing trends in winter

Arctic sea ice decline



- Strong decline in summer
- Climate models (IPCC) underestimate actual rate of decline
- Tipping points?

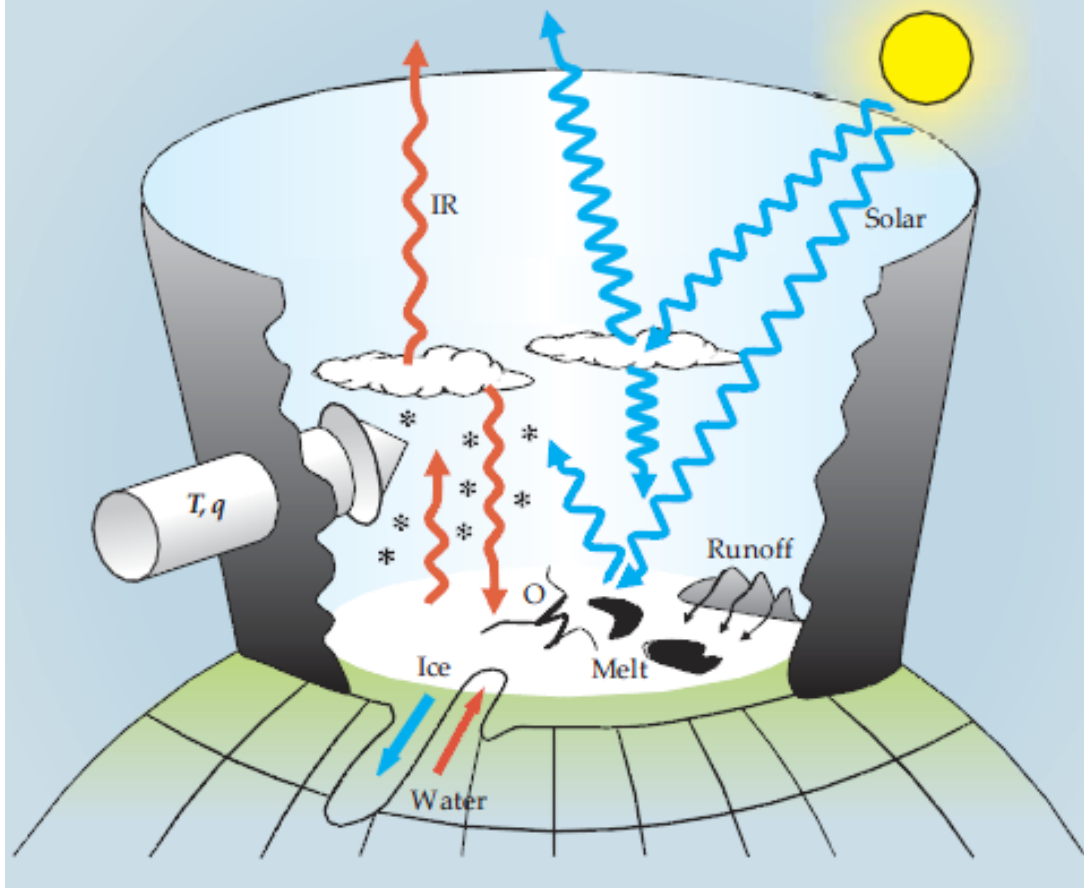
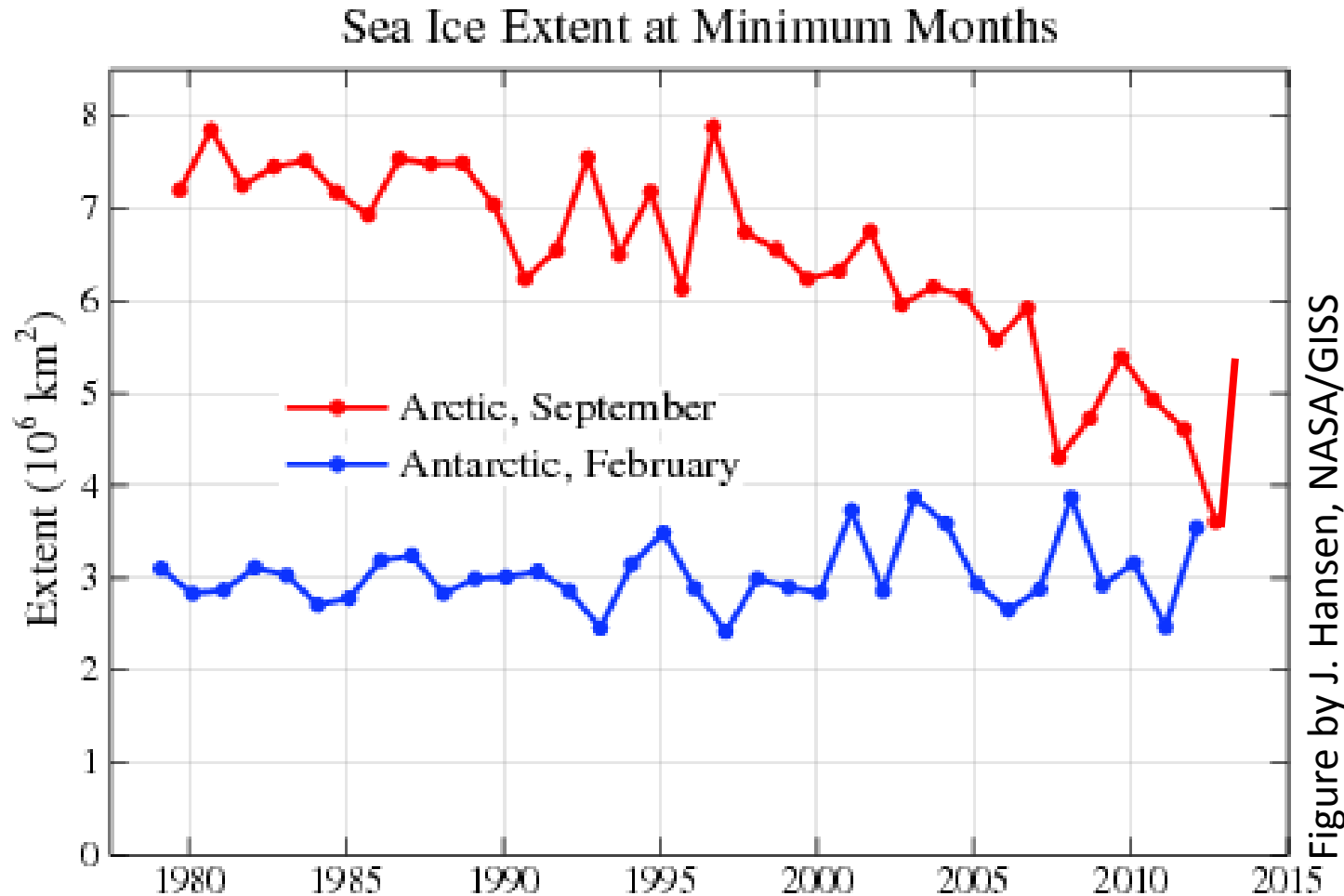


Figure 5. The heat and mass balance of the Arctic Basin. Incoming solar radiation (blue) is partially reflected, absorbed, and transmitted by clouds. The radiation reaching the surface is then partially reflected and absorbed in amounts that depend on the albedo of bare ice, open water (O), and numerous melt ponds formed during summer. River runoffs from surrounding continents feed the Arctic Ocean with fresh water. Infrared radiation (red) is emitted and absorbed by the clouds and the surface. Some of the atmospheric water vapor condenses and falls as snow, adding to the mass of the ice. The general circulation of the atmosphere results in a net influx of sensible and latent heat (T and q) from lower latitudes. The outflow of ice is primarily through the Fram Strait.

- “The surplus heat needed to explain the loss of Arctic sea ice during the past few decades is on the order of 1 W/m^2 . Observing, attributing, and predicting such a small amount of energy remain daunting problems”

Arctic versus Antarctic sea ice trends



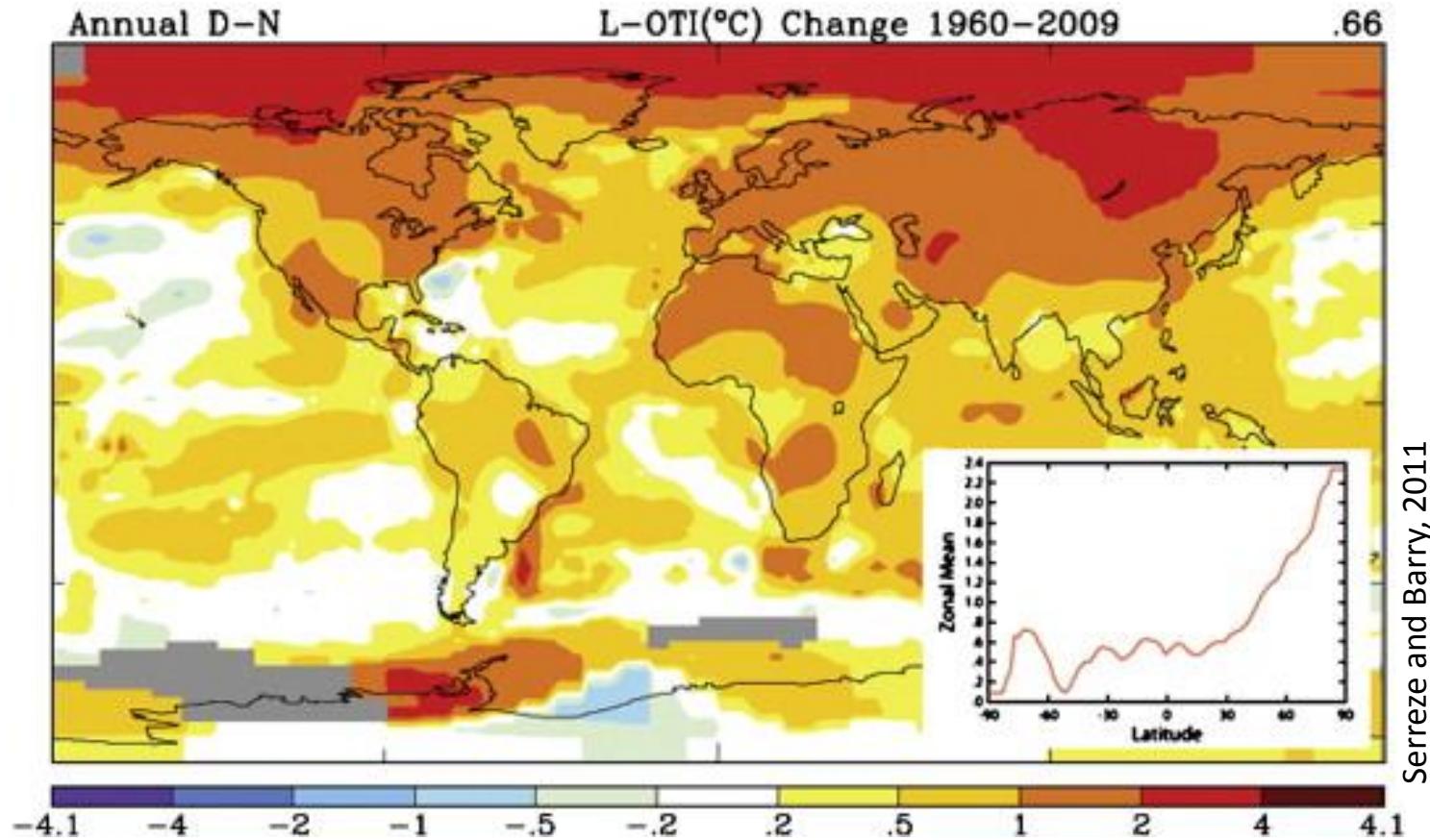
- Arctic sea ice shrinkage due to increasing air temperatures?
- Antarctic expansion related to stratospheric vortex and ozone hole

Why do we care?



- **Arctic Amplification -> impact on ice sheets/caps and permafrost**
- **Better access to the Arctic**
- **Consequences for local, regional, global eco- and human systems**

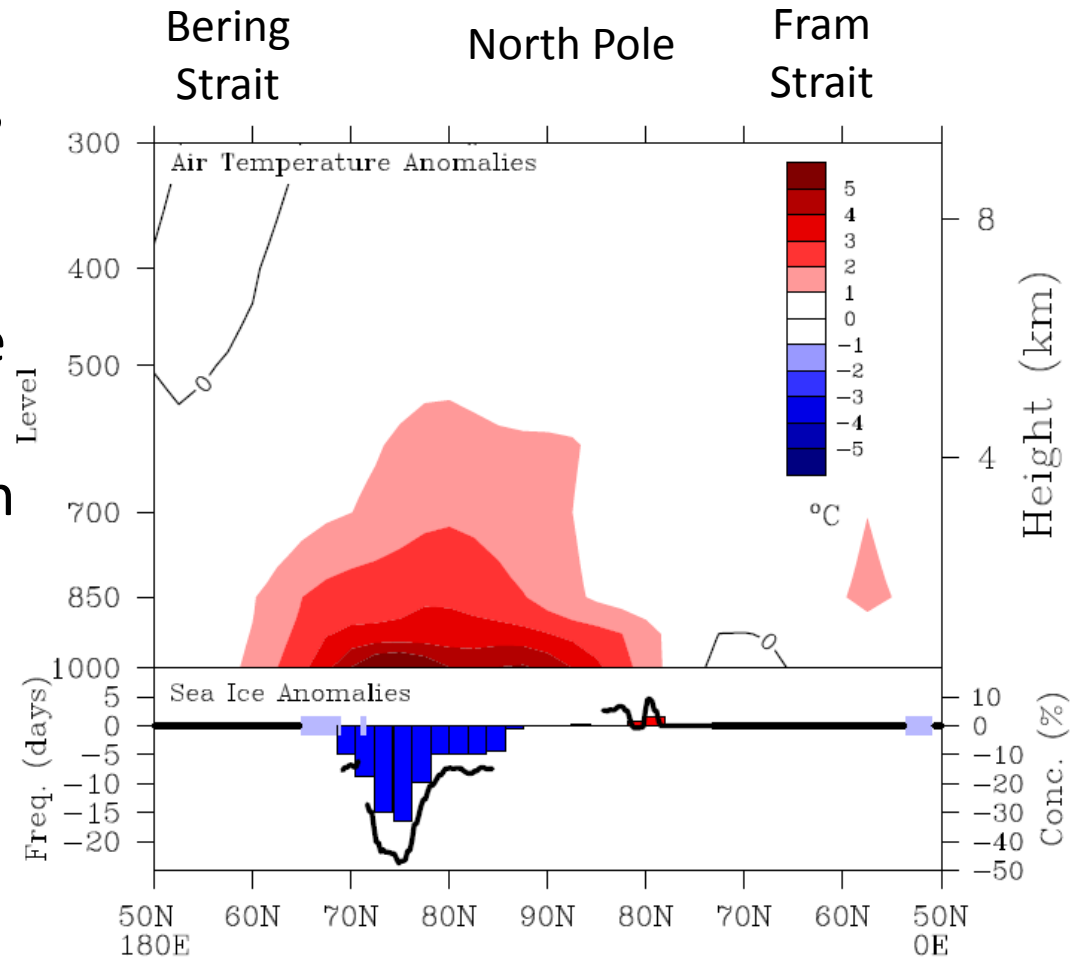
Arctic Amplification



- Through snow and ice-albedo feedback Arctic warms more rapidly than any other region
- Impacts on permafrost, Greenland ice sheet and Arctic glaciers (SEA LEVEL RISE), regional (and global?) weather

Arctic Amplification “Thin ice feedback”

- Figure shows observed Sep-Nov temperature anomalies (2003-2007 minus 1979-2007), and corresponding September anomalies in the number of days with ice cover (dark blue bars) and in ice concentration (black line)
- Warming due to
 - longer ice-free season
 - thinner ice



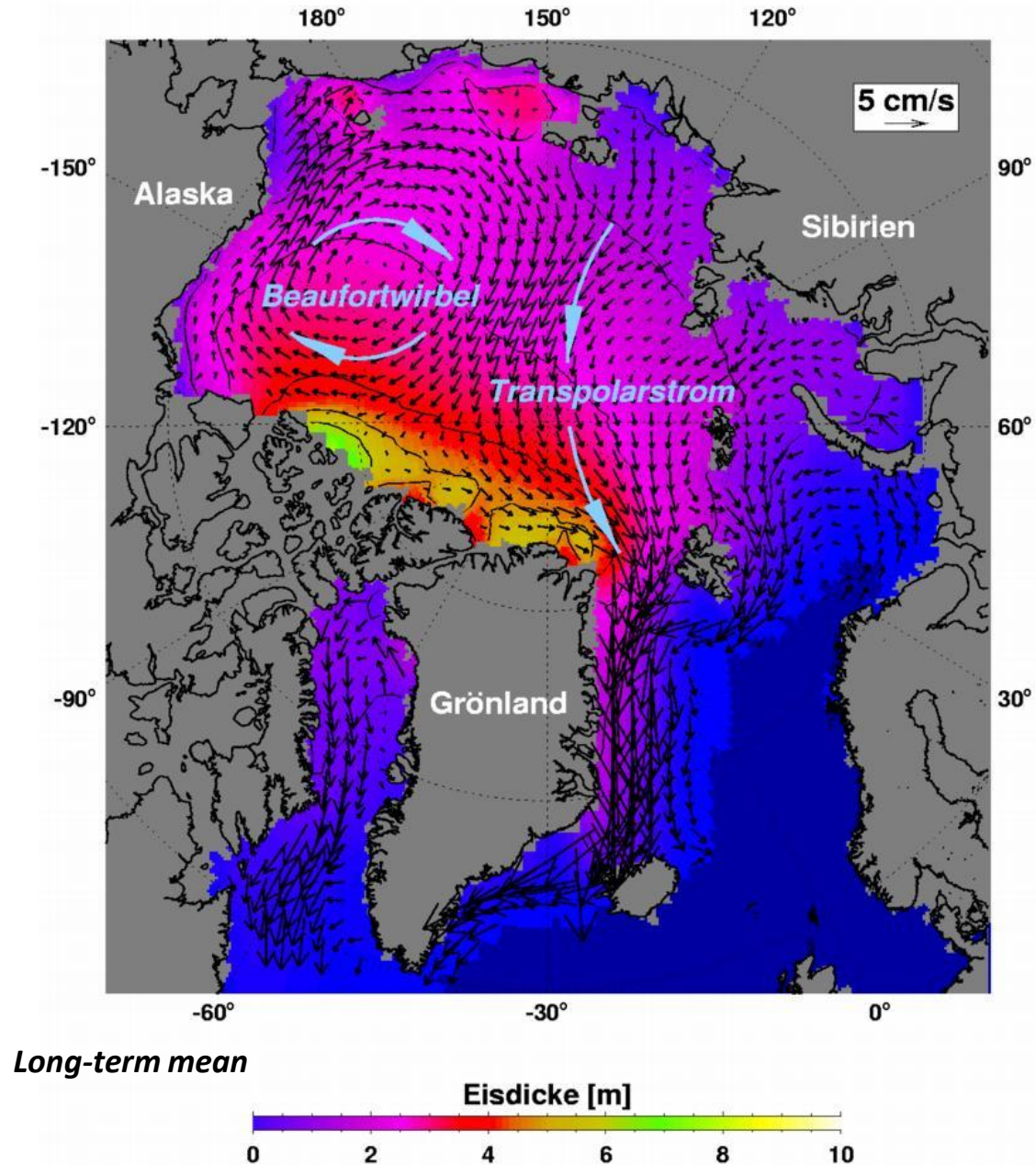
Other observations of sea ice change

An aerial photograph of a vast sea ice field, showing a complex network of dark, winding leads and smaller, irregular ice floes. The ice has a textured, greyish-blue appearance, with some areas appearing more compact and others more fragmented. The horizon is visible in the upper portion of the image, under a clear sky.

- Ice drift
- Ice age
- Ice thickness

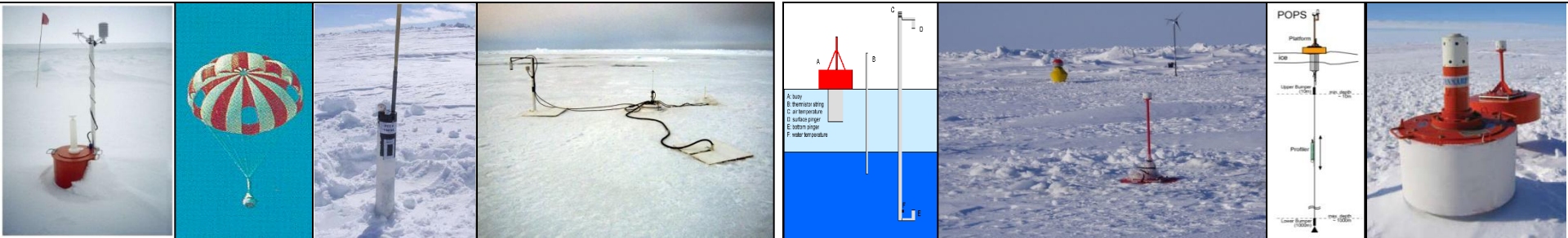
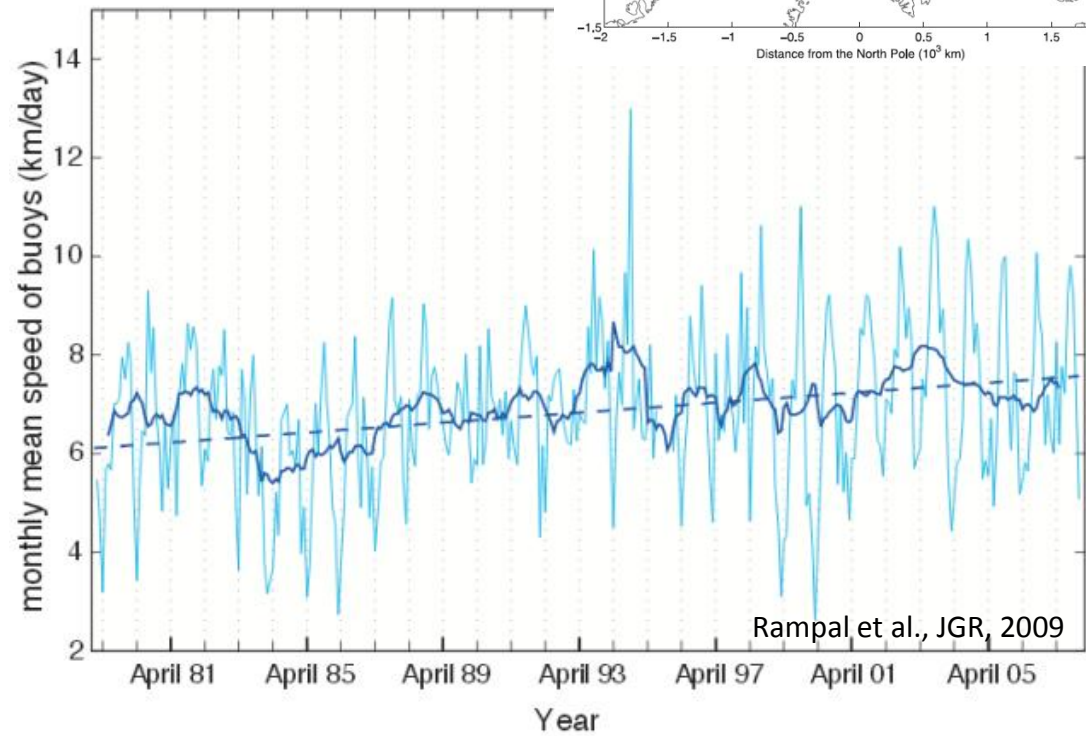
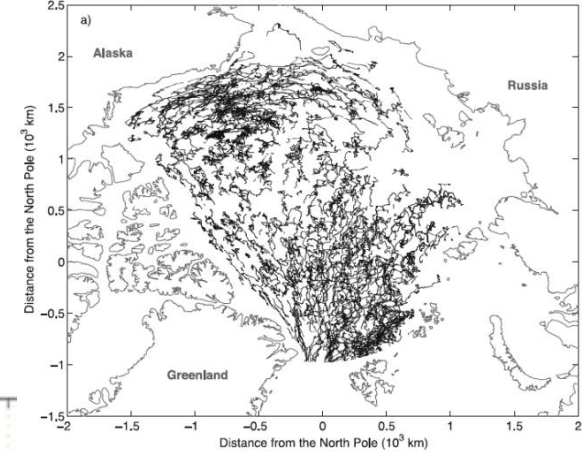
Ice drift and thickness

- Ice drift mainly governed by mean wind patterns
- Dependent on sea level pressure

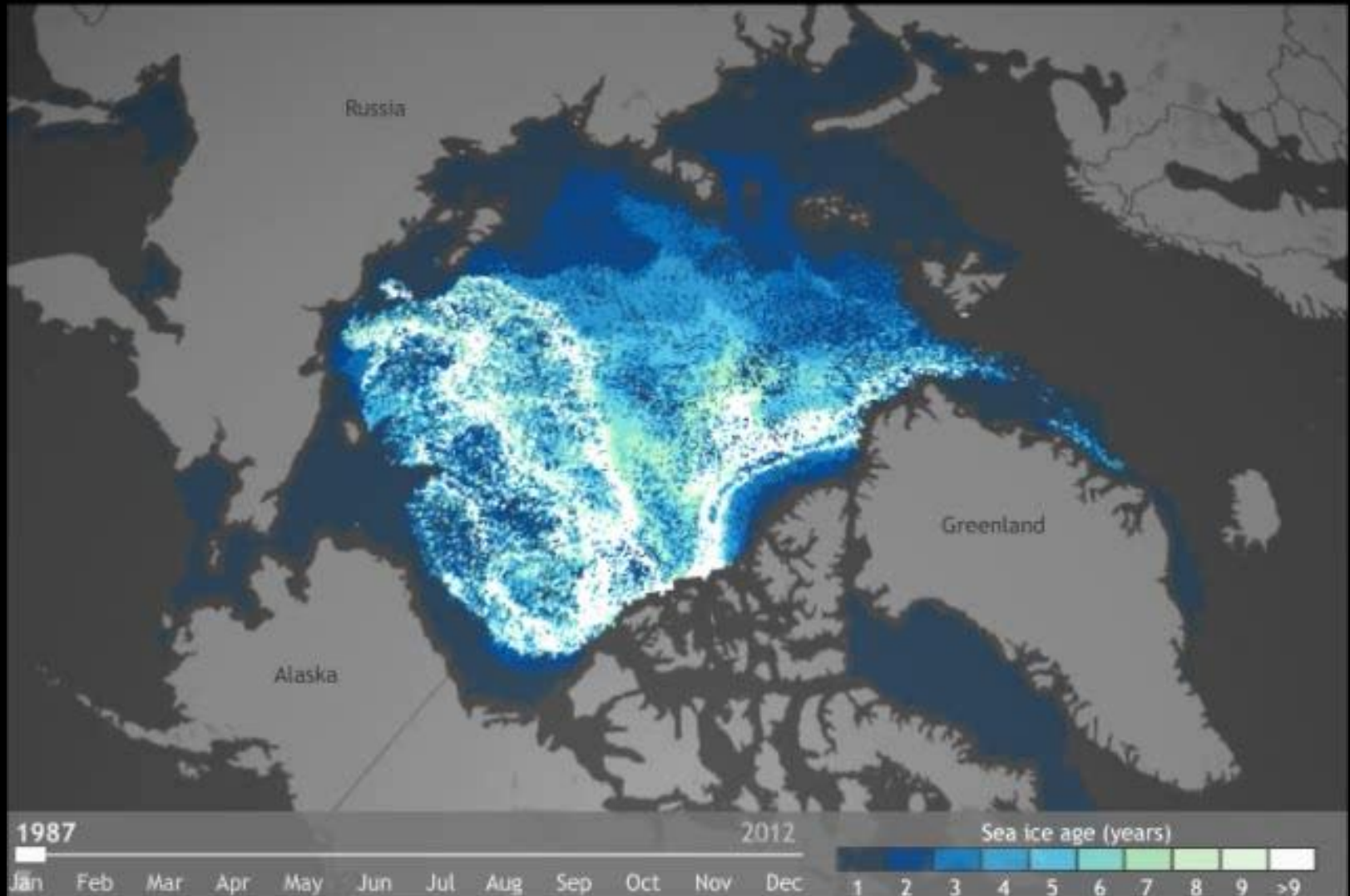


Increased ice drift speed and deformation

- International Arctic Buoy Program Data
- Ice mean speed has increased over the last 29 years: +17% per decade in winter, +8.5% in summer
- Changed ice rheology?

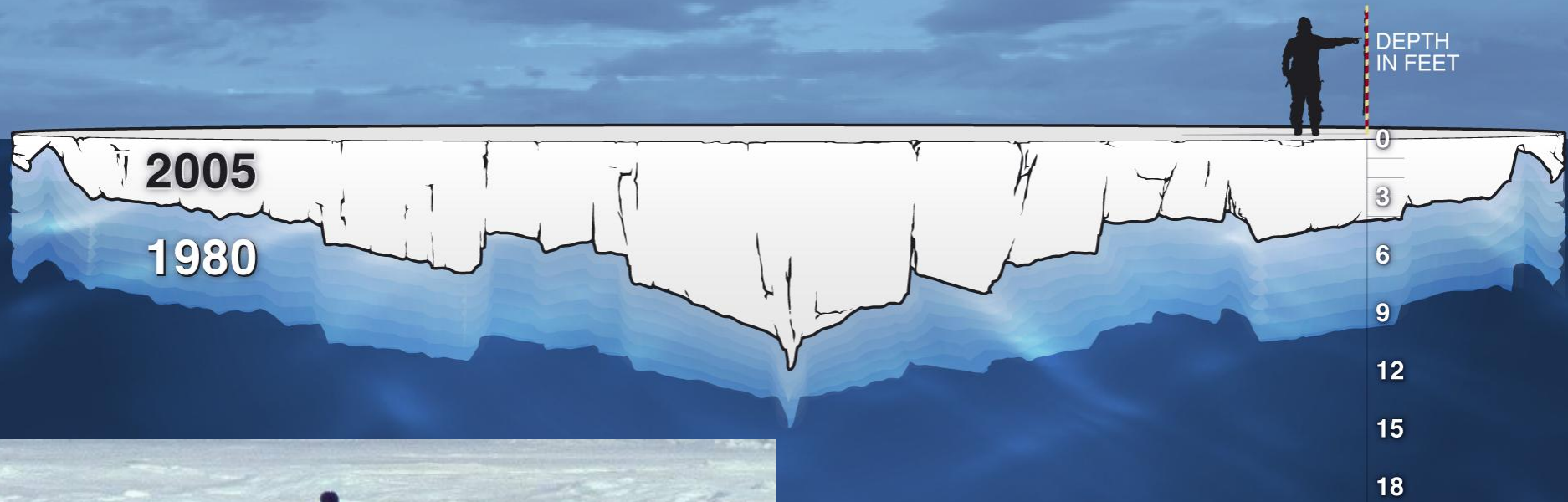


Retreat of the oldest, thick multiyear ice



Arctic Sea Ice Is Thinning

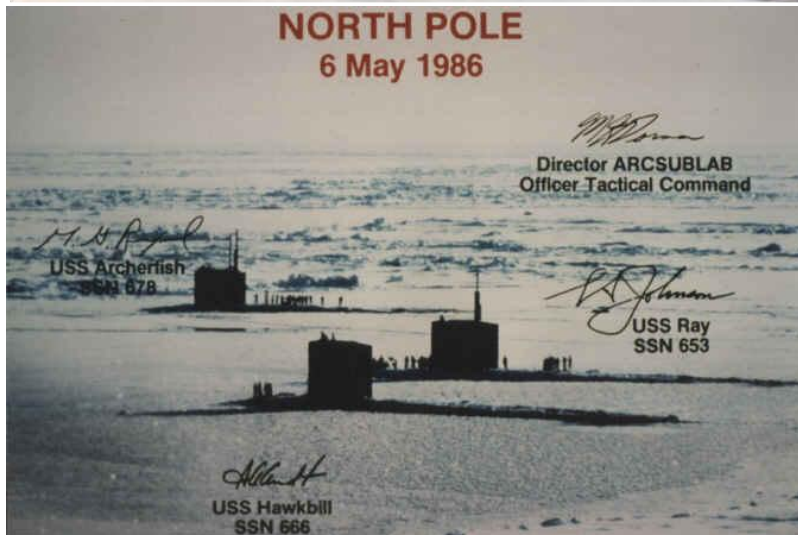
Ice depth levels in autumn



Upward looking sonar (ULS): Military nuclear submarines of USA & UK since 1958



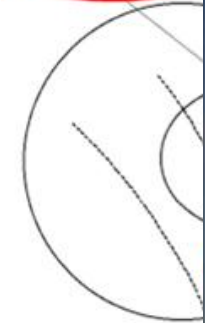
NORTH POLE
6 May 1986



EM thickness sounding



Transmitter coil



$$Z_i = \alpha_{EM} - \alpha_{Laser} \text{ (snow + ice)}$$

© Seymour Laxon, UCL

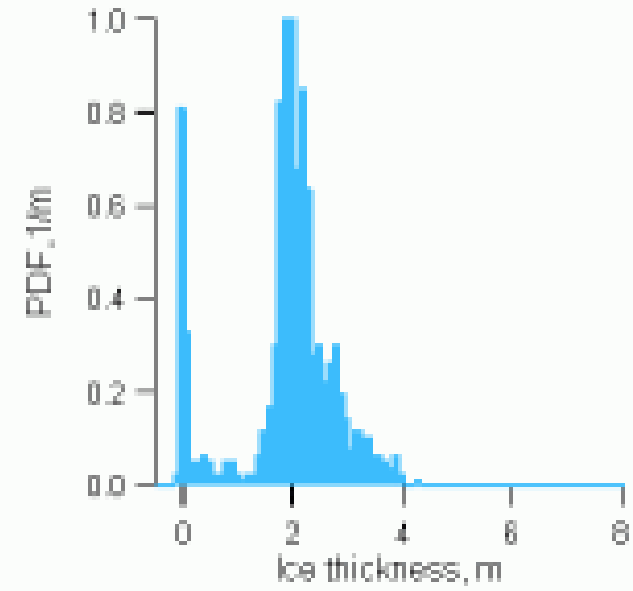
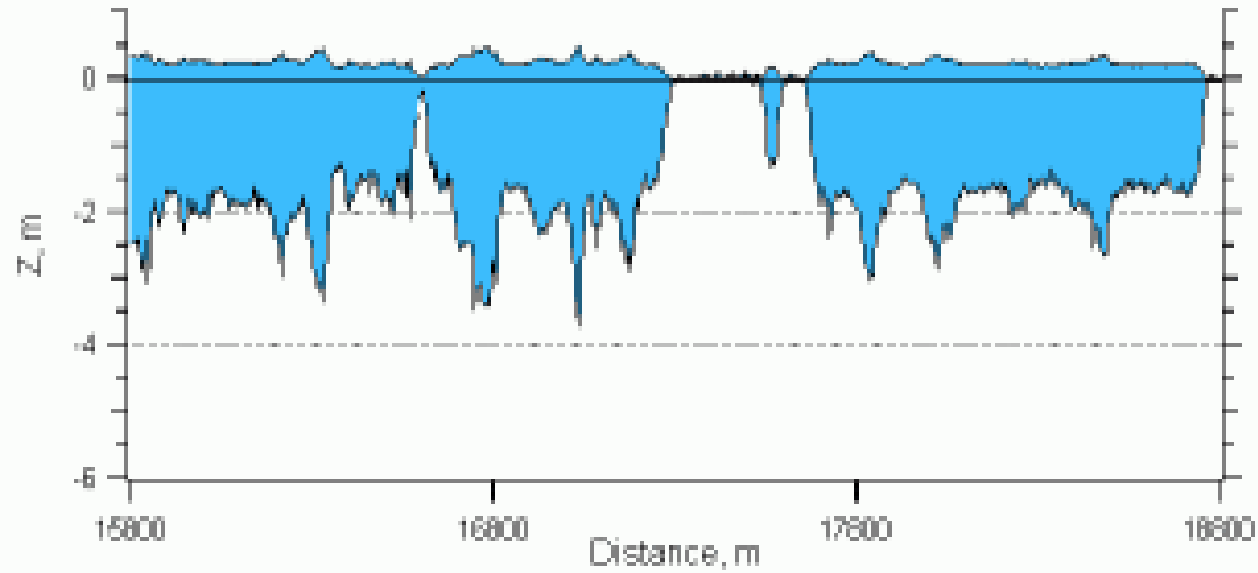


Airborne Sea Ice Observatory

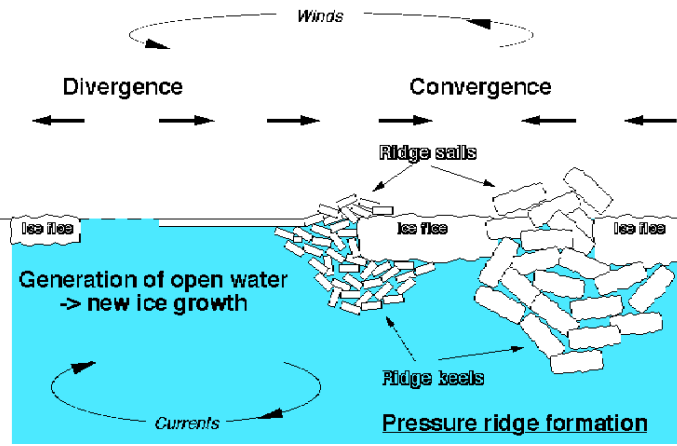


- Real-time ice thickness surveying and other airborne and satellite remote sensing
- Buoy deployments to observe sea ice drift (TC approved)

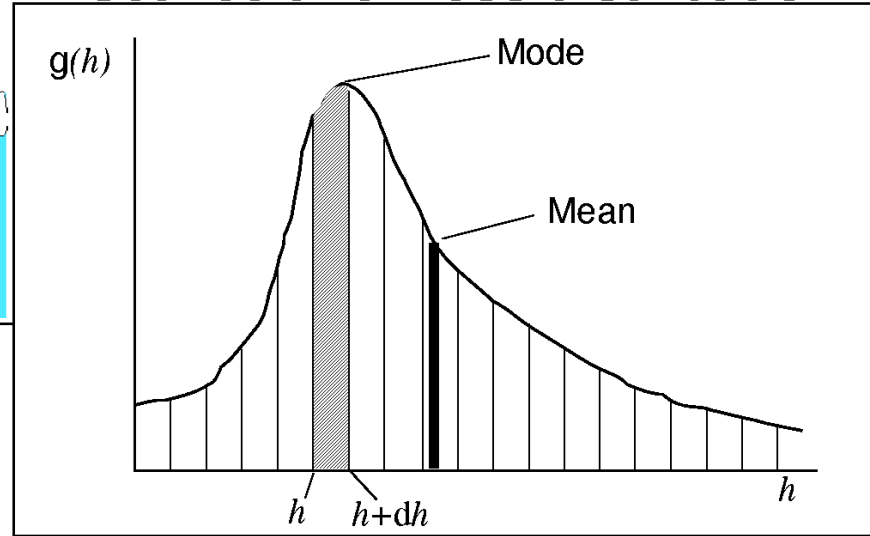
Typical AEM thickness profile



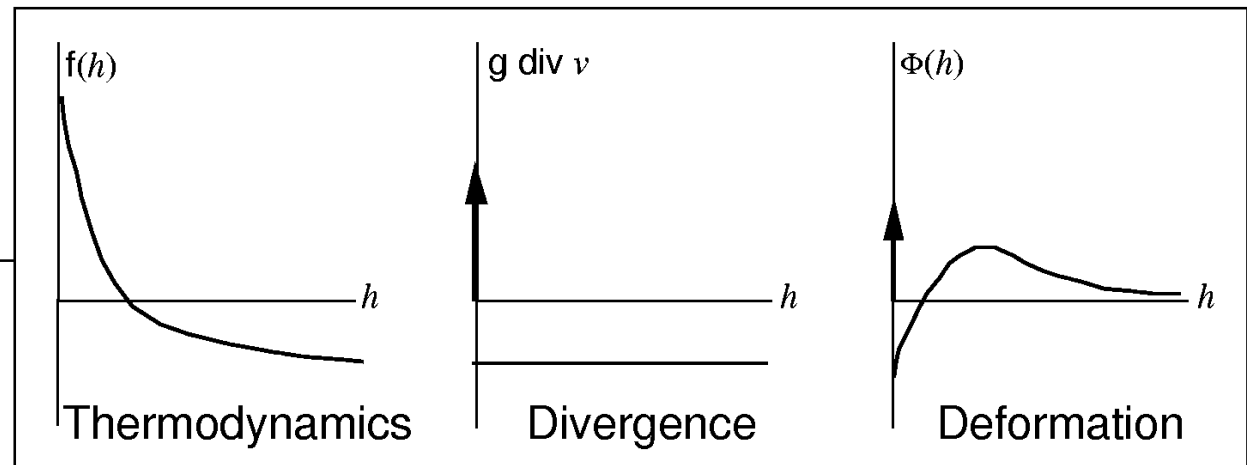
Processes changing the ice thickness distribution



Sea ice thickness distribution

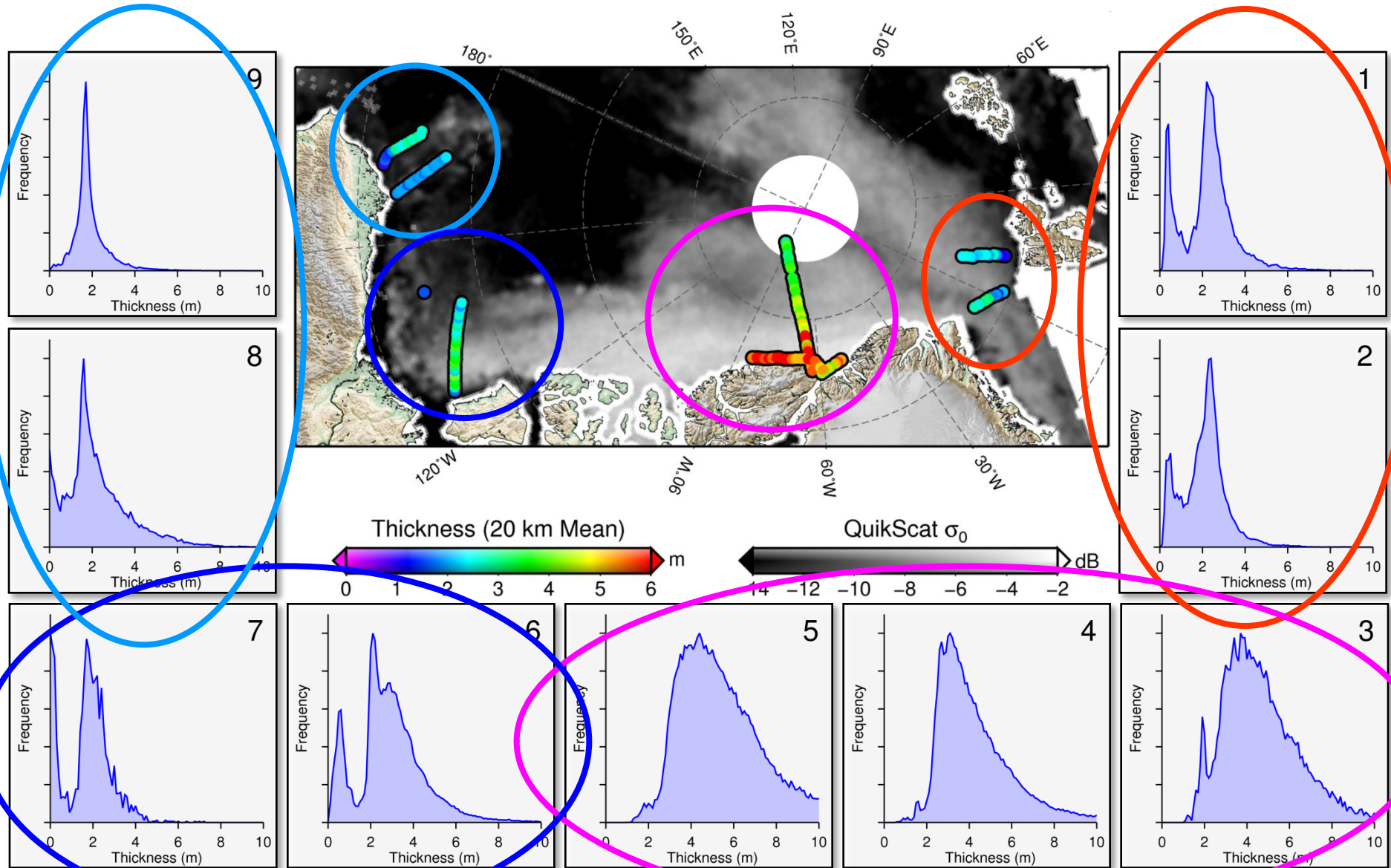


Processes that alter the thickness distribution



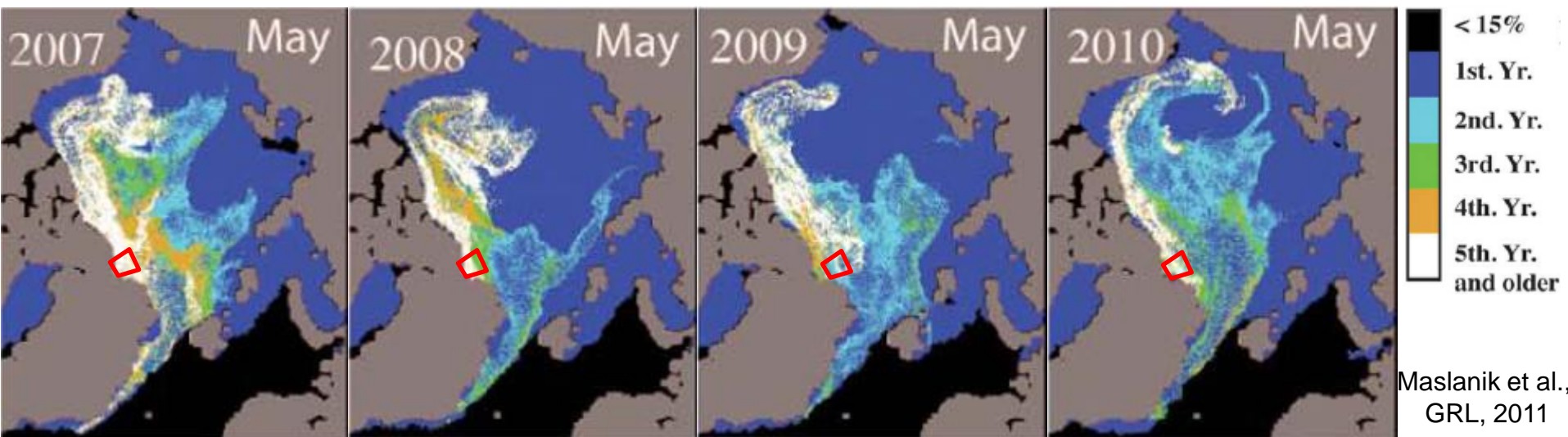
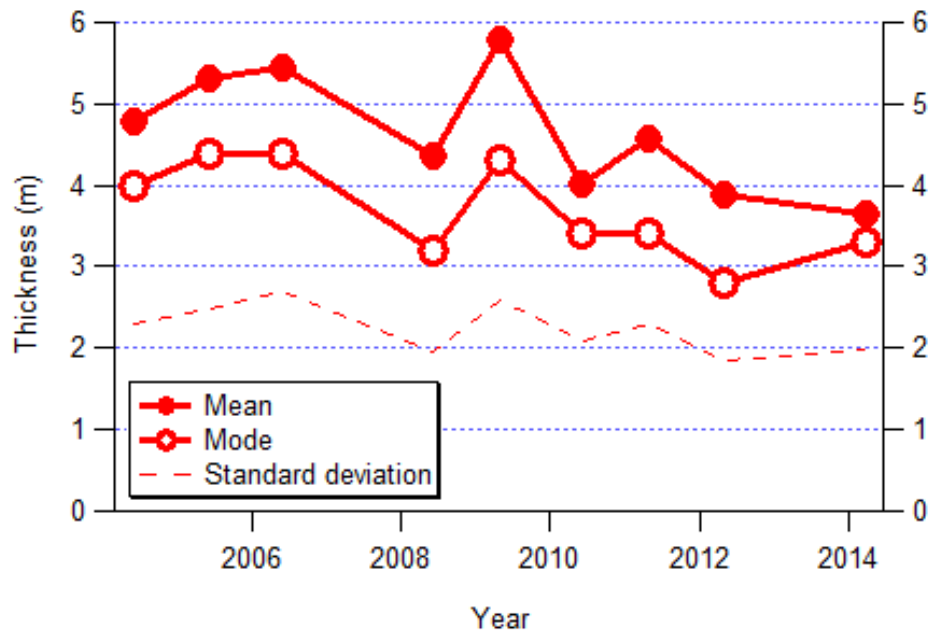
Thorndike et al., 1975
 Flato & Hibler, 1995
 Hopkins, 1998
 etc

Arctic thickness snapshot, April 2009



Ice thickness north of Ellesmere Island between 83°N and 84°N, 2004 - 2014

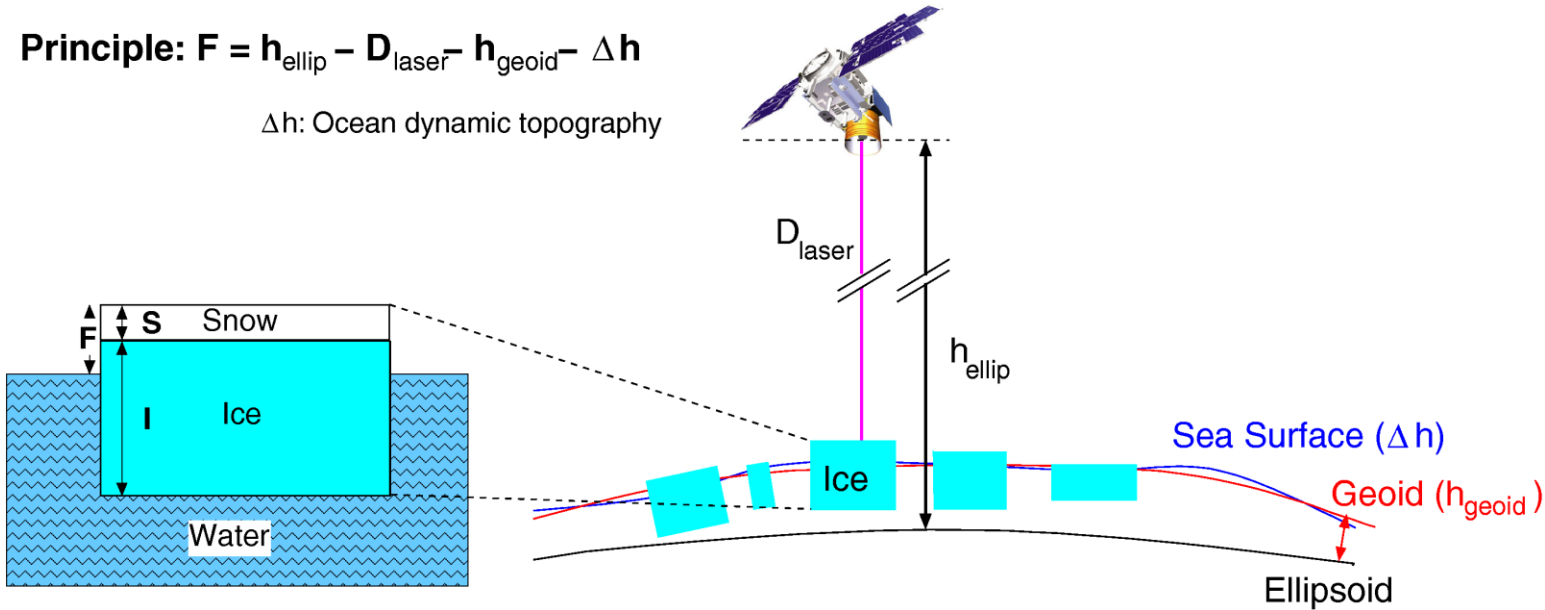
- Mean thickness decreased from 5+ m to <4 m
- Modal thickness decreased from >4 m to <≈3 m
- Large variability in 2008-2010 may be due to redistribution of old MYI



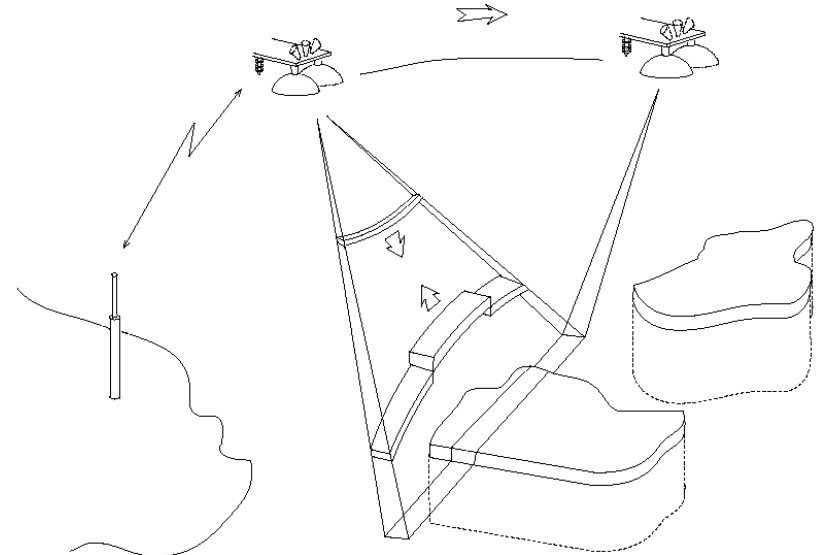
Satellite laser and radar altimetry

Principle: $F = h_{\text{ellip}} - D_{\text{laser}} - h_{\text{geoid}} - \Delta h$

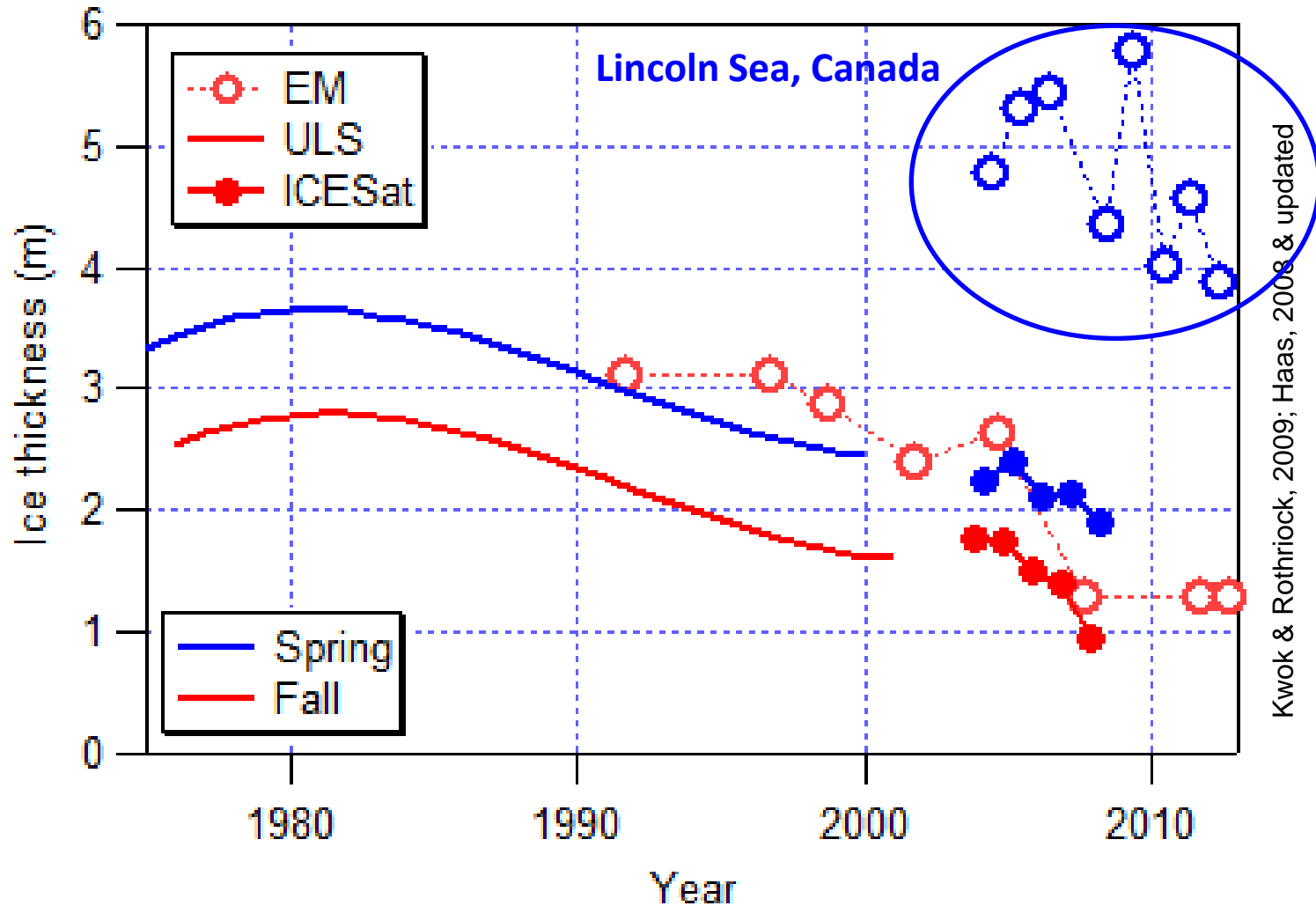
Δh : Ocean dynamic topography



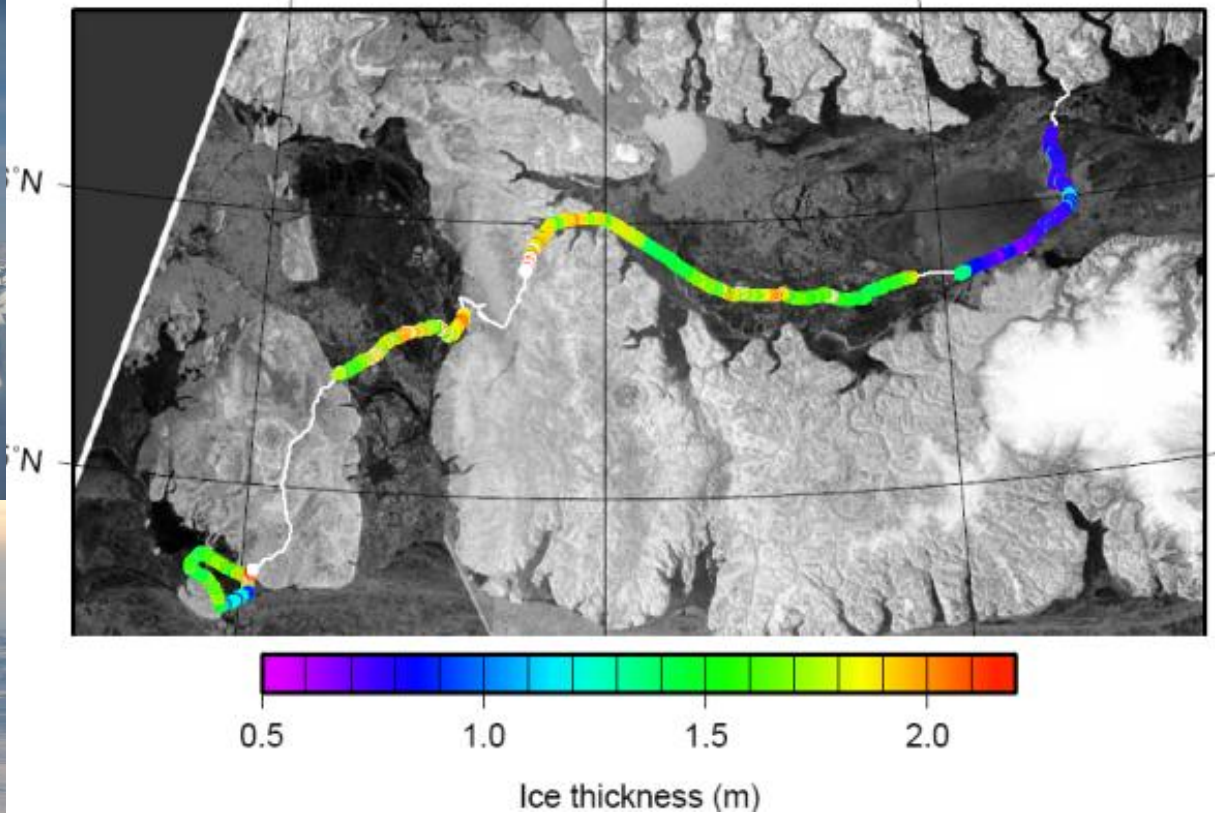
- “ICESat” & “CryoSat”
- NASA & ESA
- Method relies on assumptions of snow and ice density and snow thickness



Synthesis of North Pole ice thickness changes from ULS, ICESat, and EM



- Note seasonal and regional differences

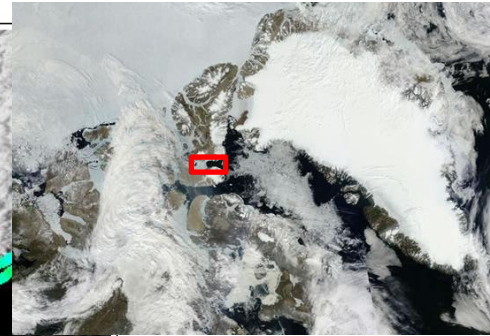
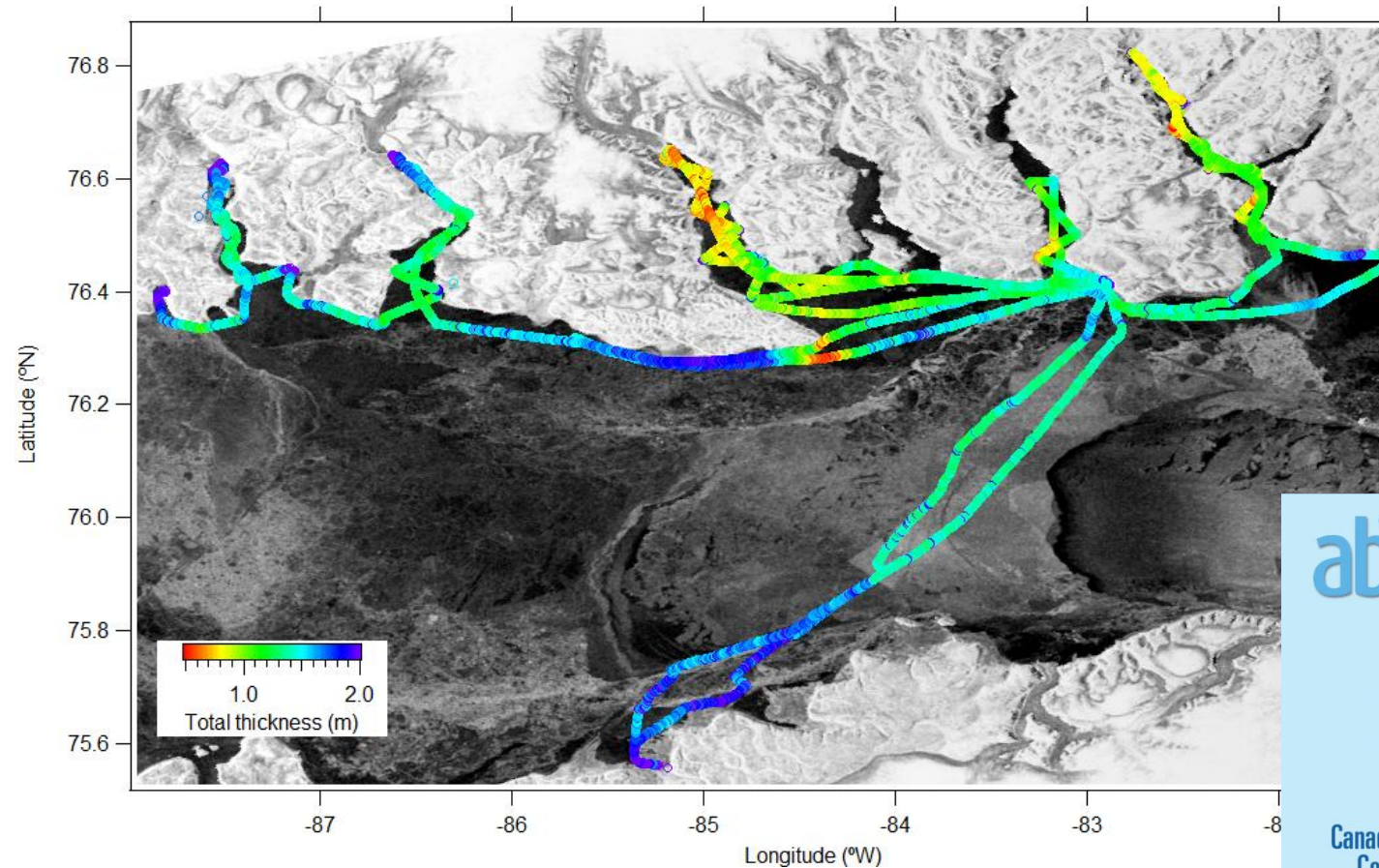


Skidoo EM thickness surveys

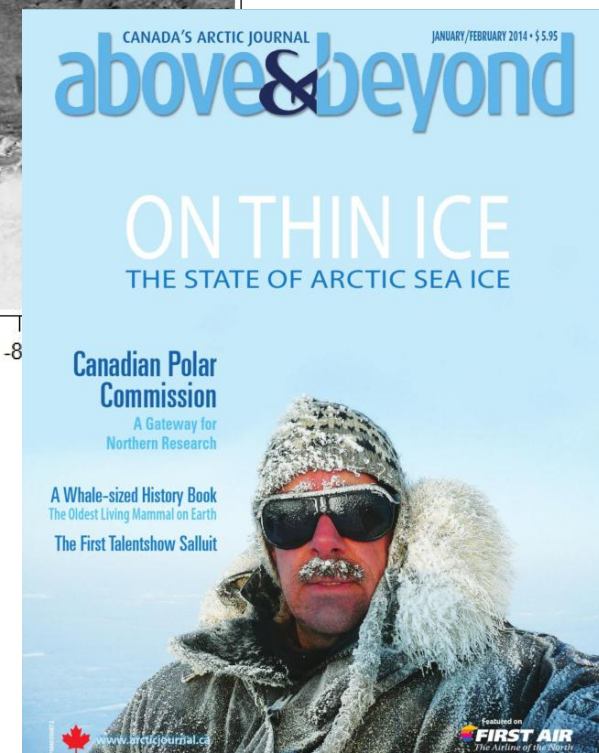
- “Community based” observations in Canadian Arctic
- Close collaboration with local hunters and Canadian Rangers



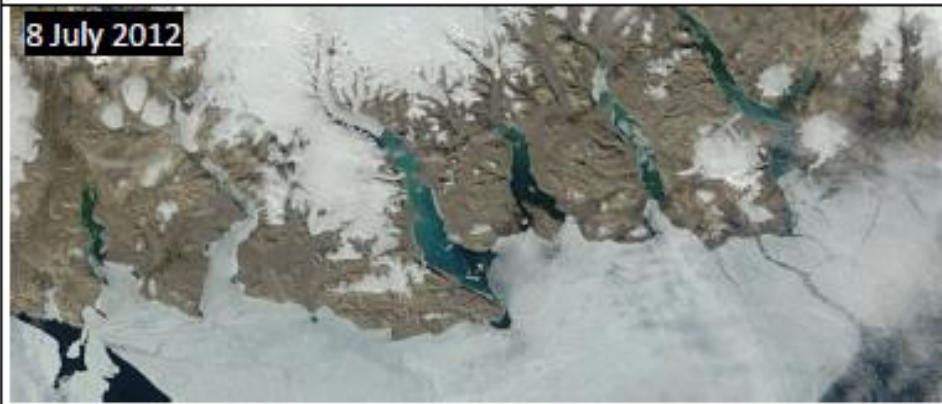
Thin ice in Jones Sound



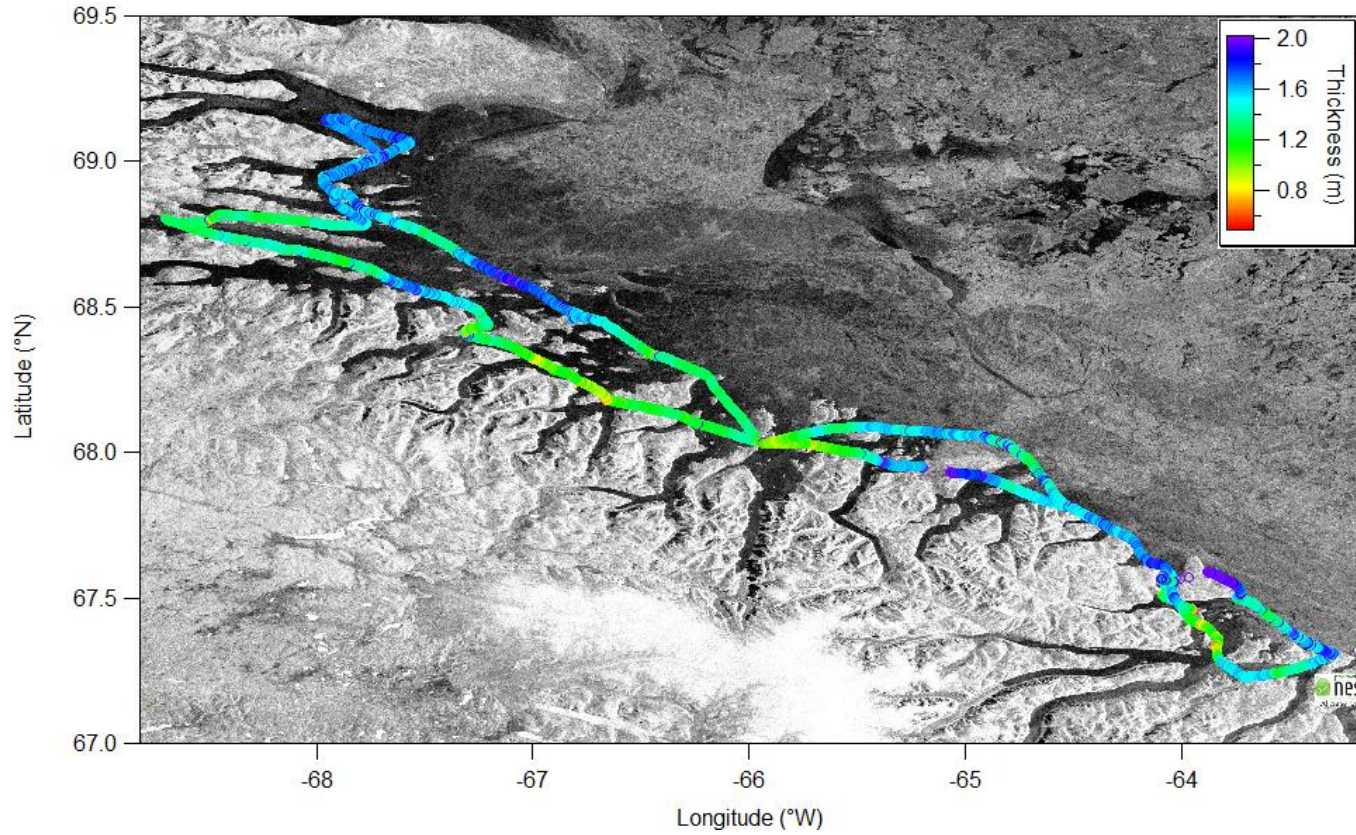
- “Discovery” of thin ice in fjords
- Due to enhanced ocean heat flux
- Possible future polynyas?



Polynyas and primary productivity



Home Bay, Baffin Island (May 2014)

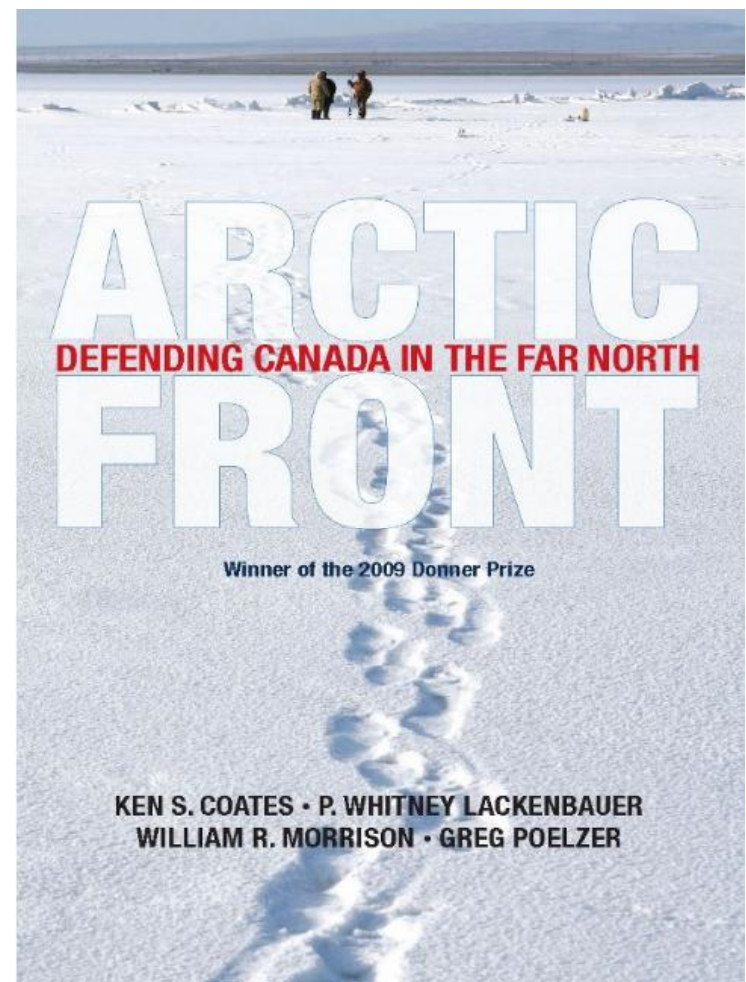


The Future



Consequences

- Easier shipping?
- Better access to natural resources?
- Threat to Canadian Sovereignty?
- “Last refuge” for sea ice



WWF Global Sign In Help

Home » What We Do » Priority Places » Arctic » The Last Ice Area

• What We Do
• Priority Places
• Arctic
• The Last Ice Area
◦ Sailing to Siku
• Arctic wildlife
• Our Solutions
• News & Blog
• Publications
• Contact

The Last Ice Area

As the climate warms, Arctic sea ice is disappearing.

Almost every summer, the amount of remaining ice gets smaller. That summer ice is vitally important to a whole range of animals from tiny shrimp to vast bowhead whales, and to local people.

One stretch of ice is projected to remain when all other large areas of summer ice are gone. This is the Last Ice Area.

[About the Last Ice Area](#)

Northwest Passage & Northern Sea Route



(Financial) Freedom: Retreating ice is revealing up to 31 billion barrels of oil and natural gas off Greenland's eastern coast, plus signs of enormous mineral deposits—gold, diamonds, zinc, and more—on land. Keen to establish their rights to these resources, 57,000 Greenlanders (most of them Inuit), whose territory has been protected by Denmark since 1721, will vote this month on a referendum for self rule. Greenland will probably become the first country born from climate change.

Polar Express: The fabled Northwest Passage opened this summer for the second time in history—and the second year in a row. The Northeast Passage (also called the Northern Sea Route) over Eurasia first fully opened in 2005; shipping is already extensive within that region, particularly in the Barents Sea. Yet both routes, sought by ancient mariners, are likely to be used for only a few years. By 2025, if not before, most ships in the Arctic will likely sail straight over the pole, avoiding coastal-state jurisdictions and shaving still more miles off their journeys. Much of the world's international shipping will reorient itself as a result.

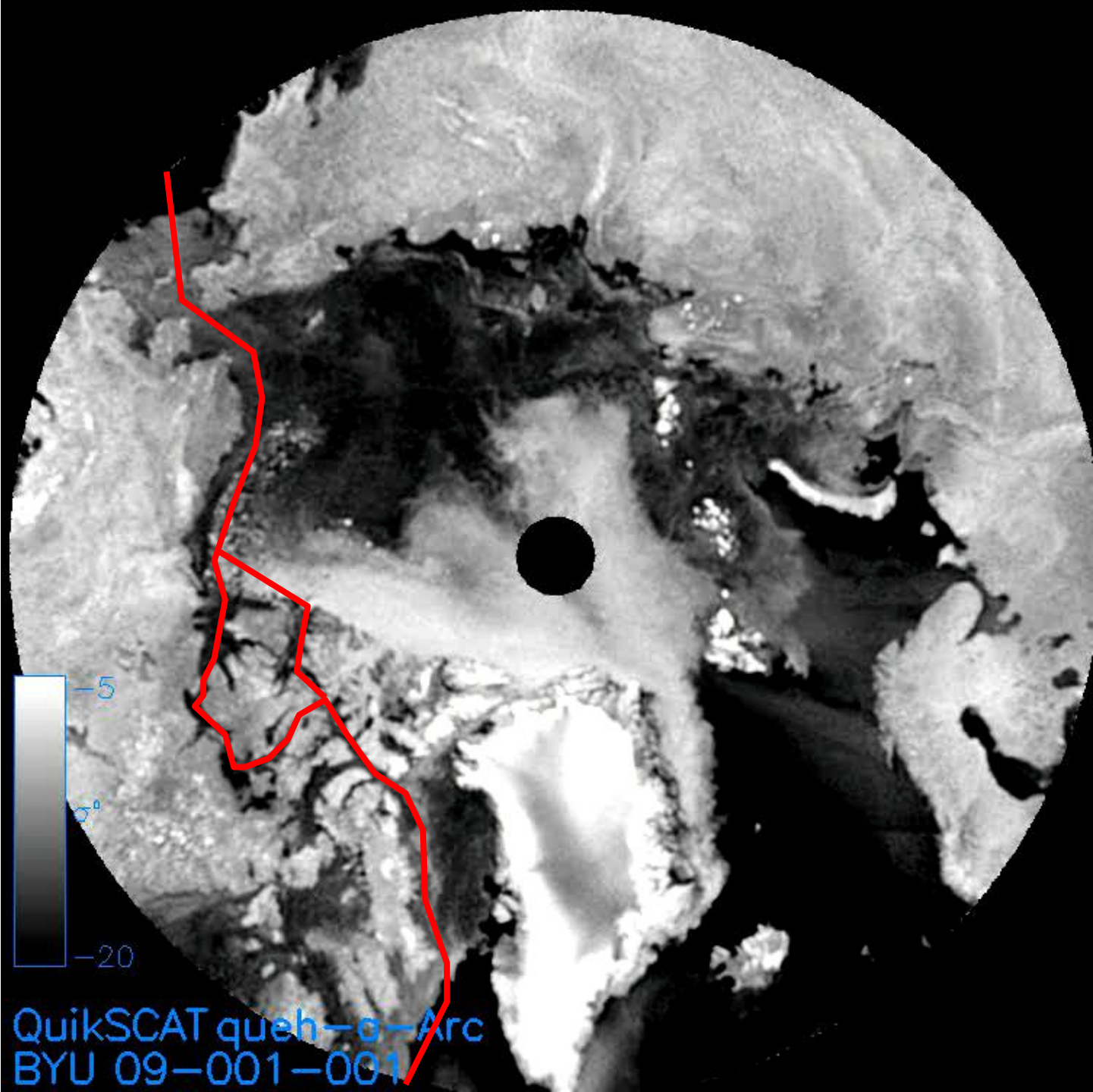
The New Entrepôts: Singapore's location, amid key shipping lanes from East Asia to Europe, has enabled the country to become the richest in Southeast Asia. As sea lanes like the Bering and Davis straits become busier, port towns like tiny Dutch Harbor, Alaska (population 4,000), and Hammerfest, Norway (population 9,000), are likely to grow from out-of-the-way fishing depots into key shipping hubs. Russia recently committed \$7 billion to port development in Murmansk. Places like Singapore or Panama (which is currently investing more than \$5 billion to expand its canal) may see trade disappear from their doorsteps.

Snow Forts: To defend its claims in the Arctic, Canada plans to build a deepwater naval port in Nanisivik and a new cold-weather-combat training center in Resolute Bay, while also expanding satellite surveillance. Other countries are rattling sabers in the region. Russia, for example, has resumed strategic-bomber flights over the Arctic and last summer dispatched two military vessels to the disputed waters off the Svalbard Islands.

- 46 vessels used NSR in 2012. 34 in 2011, 4 in 2010
- 53% cargo increase from 2011
- Included first fully loaded LNG tanker

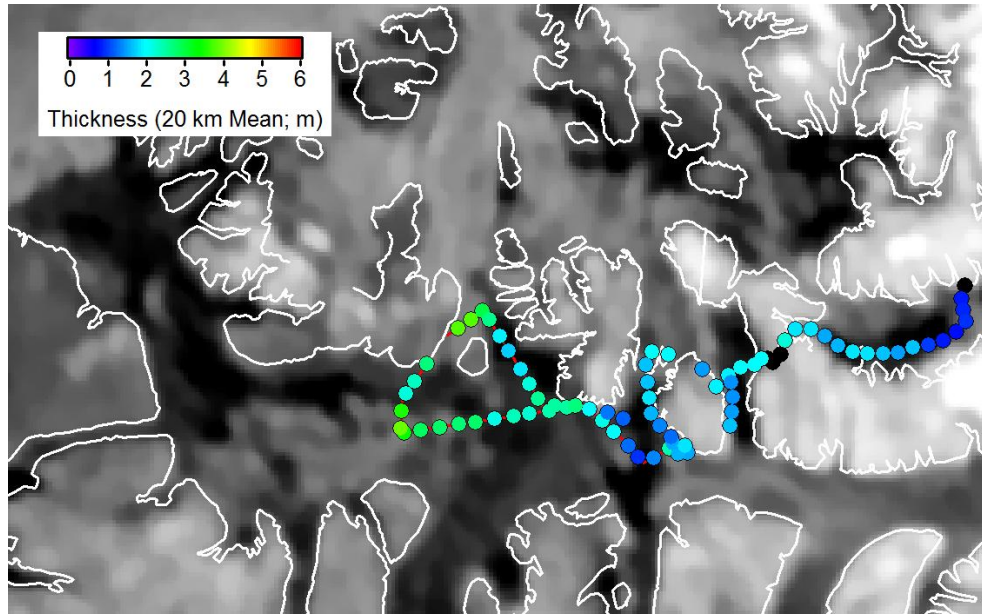
Shipping distance from Yokohama, Japan, to Rotterdam, Netherlands (nautical miles)

Over the North Pole	5,618 miles
Through the Suez Canal	11,209 miles
Through the Panama Canal	12,250 miles
Around the Cape of Good Hope	14,735 miles

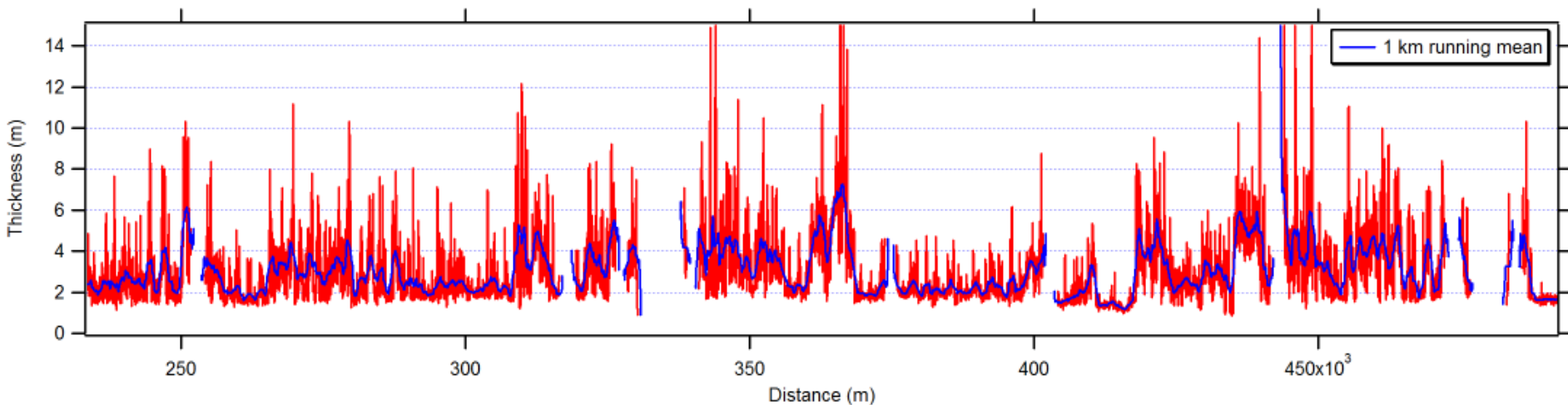


QuikSCAT queh - σ - Arc
BYU 09-001-001

Multiyear ice in the Northwest Passage



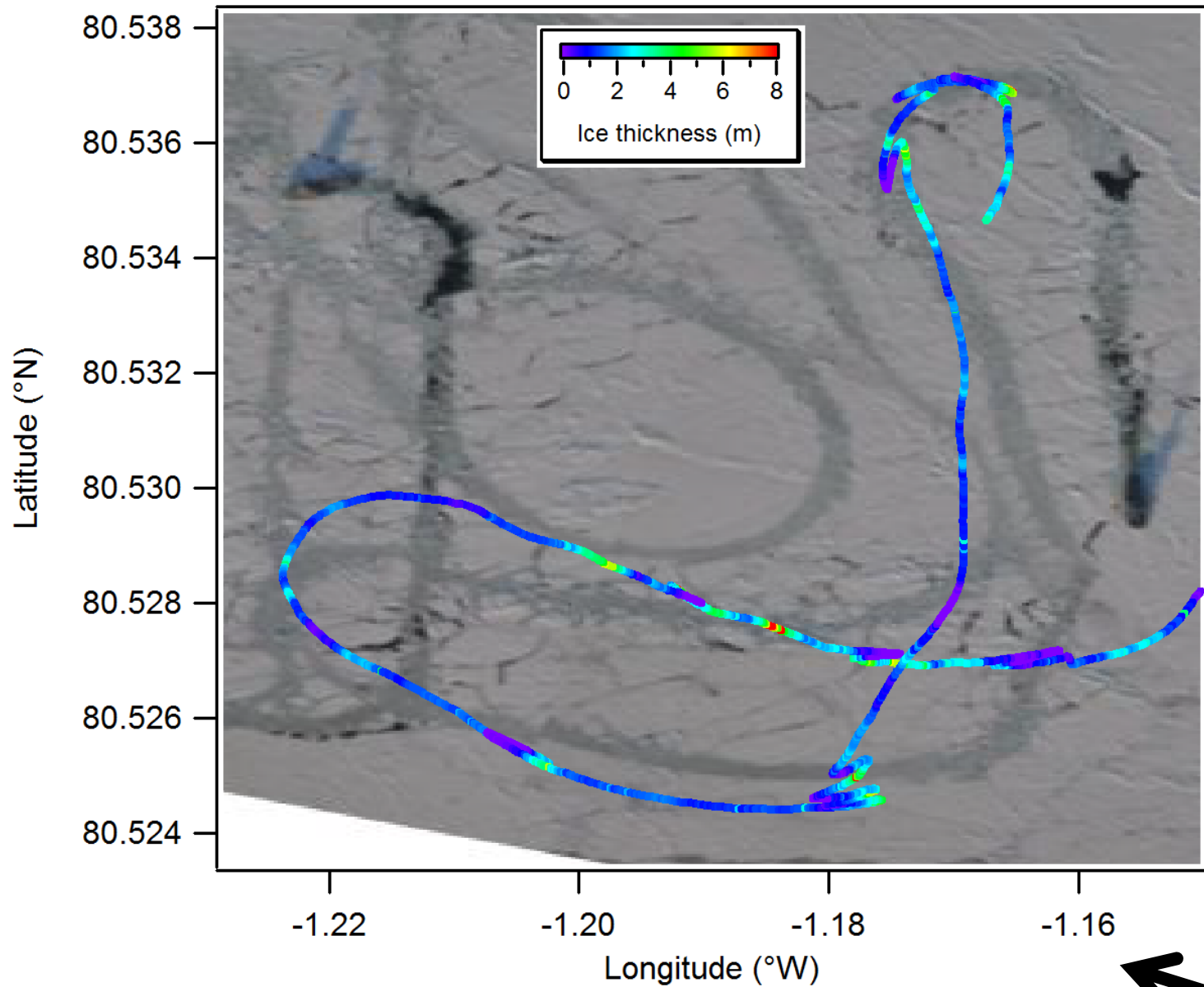
Ice thickness survey in 2011



Ship-based ice thickness surveys

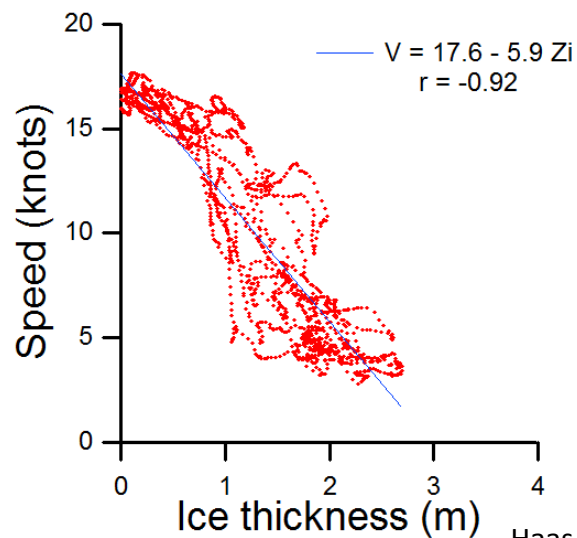
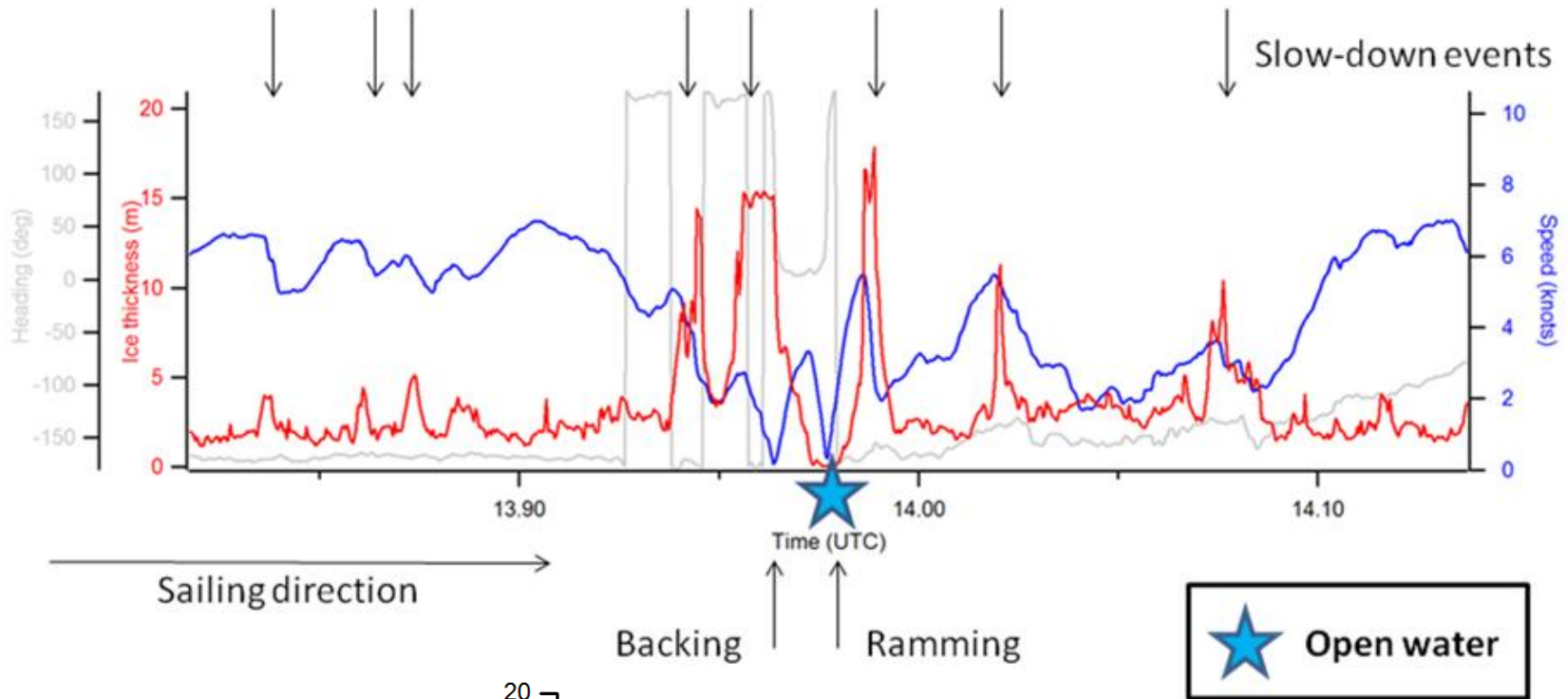
- Ship performance & design; Exploration activities & ice management





← Ice drift

Ship performance and ramming



Observing Arctic Sea Ice Change

- **Sea ice is an important part of the climate system and closely interacts with and controls the Arctic atmosphere**
- **Disappearance of Arctic sea ice in summer seems likely – just when is completely unclear**
- **Present trend is a consequence of preconditioning towards thinner, younger ice and superimposed interannual variability**
- **Need for observation system comprising in-situ, airborne, and improved satellite data of the ocean-ice-atmosphere system**