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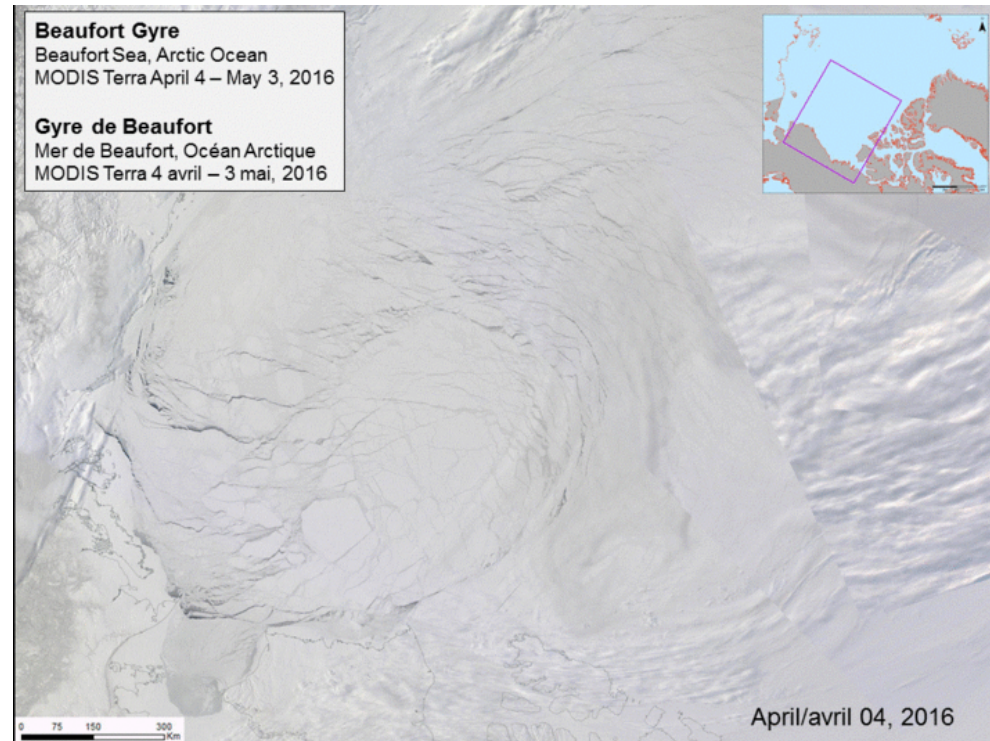


Top of the world: observations of Arctic sea ice

**Stephen Howell
Climate Research Division,
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July 20, 2017**

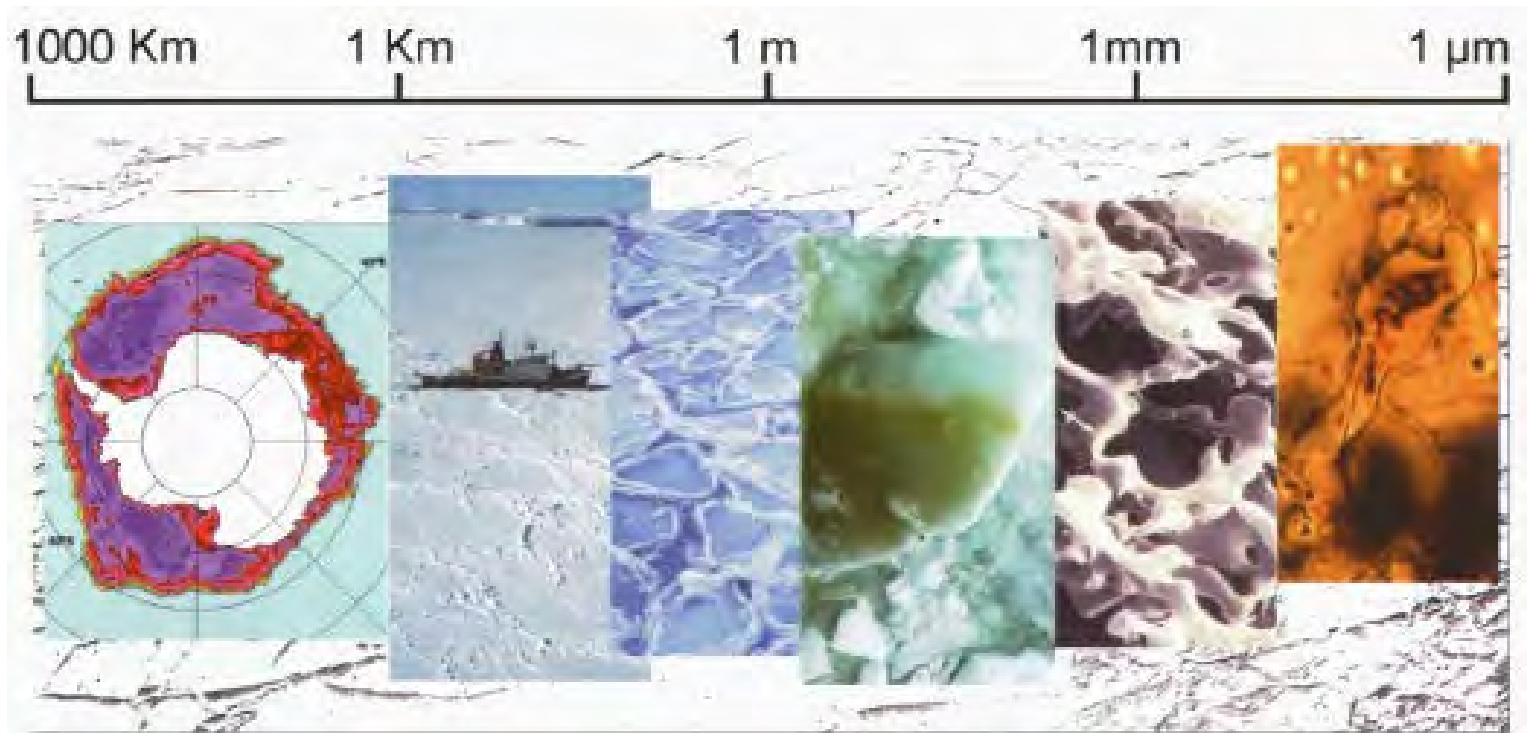
Outline

- Introduction
- Microwave remote sensing
 - passive and active
 - applications
- Altimetry
 - snow radar



Introduction

- Sea ice observations span several orders of magnitude.



Introduction

- In situ measurements of Arctic sea ice are the most reliable but difficult to obtain in time and space for analysis purposes.



Satellite remote sensing



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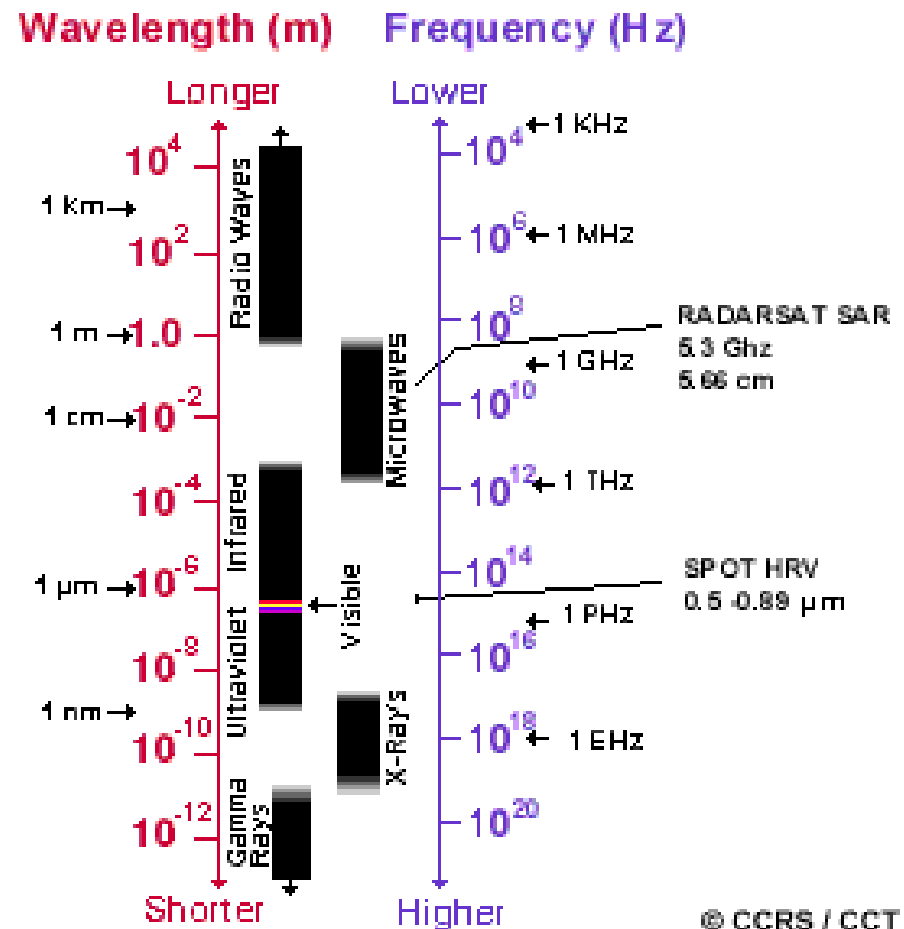
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Microwave Remote Sensing

Microwave remote sensing

- Microwave portion of the spectrum covers the range of 0.1 mm to 1 m in wavelength.
- More common to refer to frequency.
- 1 to 300 GHz but typically between 0.4 and 35 GHz.
- All weather/polar darkness imaging capability.

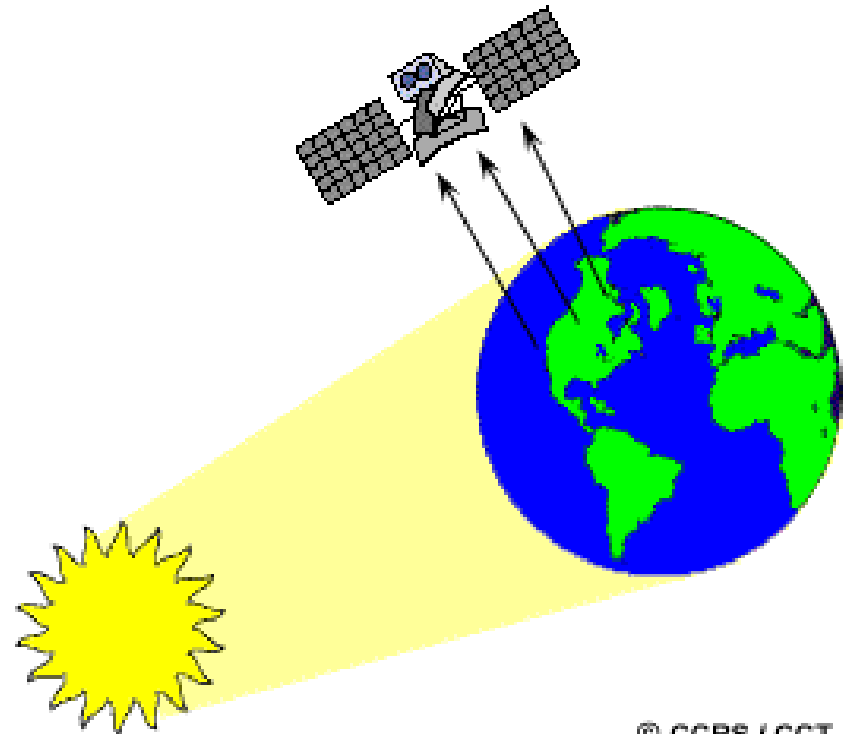


© CCRS / CCT



Passive microwave

- Measures electromagnetic energy reflected or emitted from an external source (the sun, the Earth).
 - low spatial resolution (12-25 km) and higher frequency.
- Observations available since late 1970s.
 - Scanning Multichannel Microwave Radiometer (SMMR)-Special Sensor Microwave Imager (SSM/I).
- “Go-to” dataset for long term variability and trends.

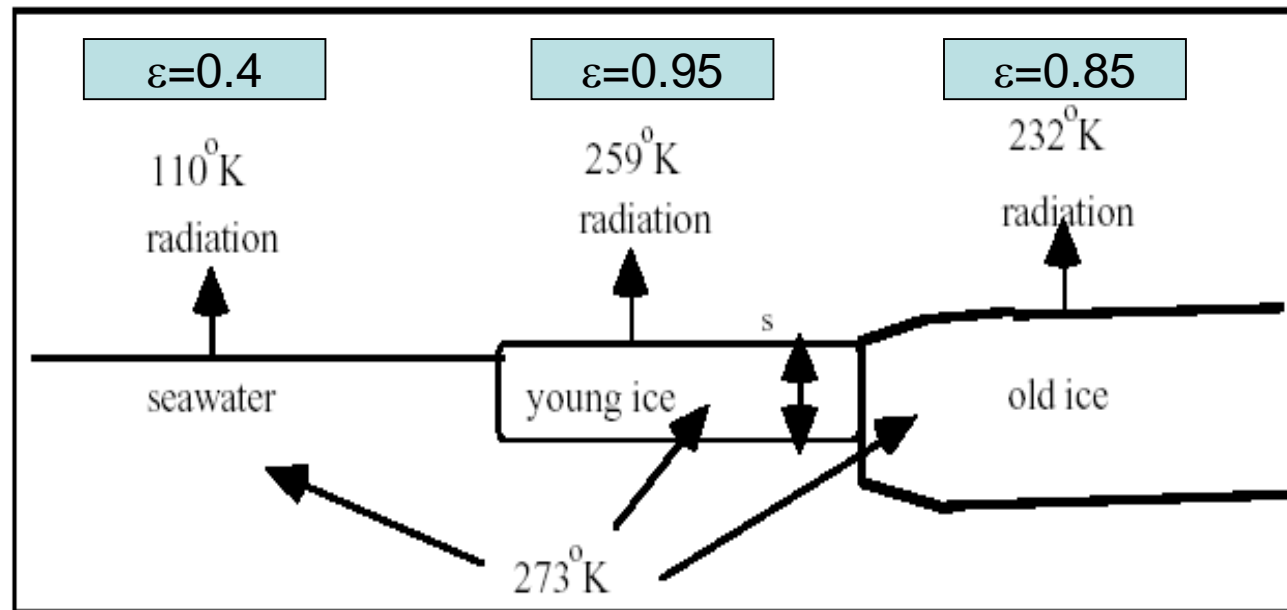


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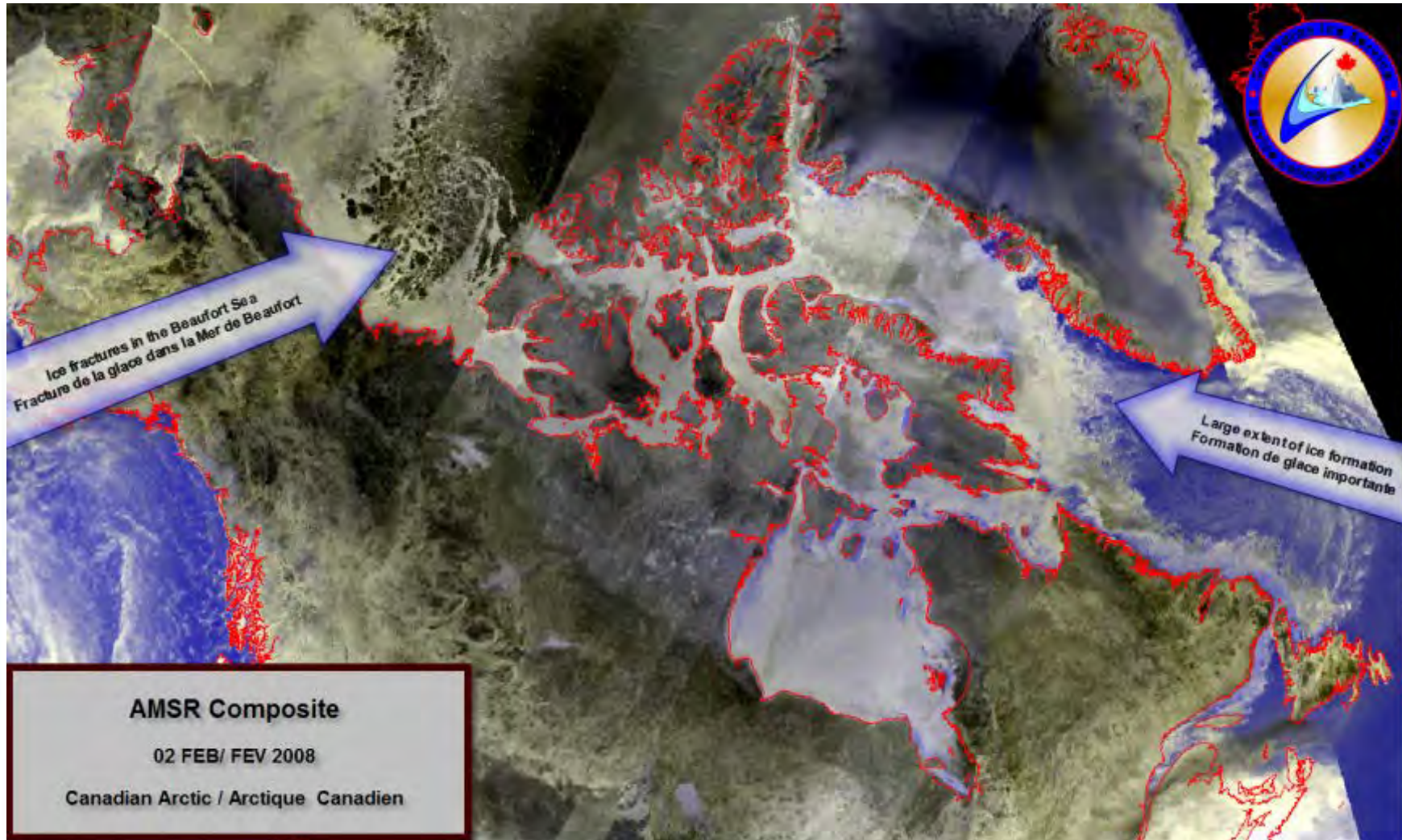


Passive microwave: sea ice type

- Microwave brightness temperature (T_B) of the Earth's surface depends on the electrical properties of the surface, embodied in its emissivity (ϵ) and the physical temperature of the radiating portion on the surface (T_s) given by: $T_B = \epsilon T_s$
- Useful for sea ice:
 - ice type; concentration



Passive microwave: sea ice type



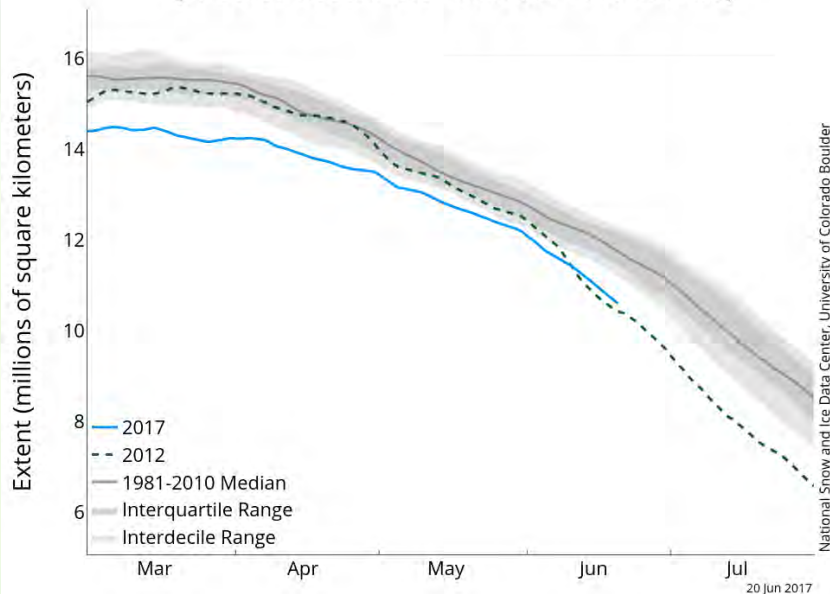
Passive microwave: sea ice concentration (C)

$$T_B = (1 - C)e_W T_W + C e_I T_I$$

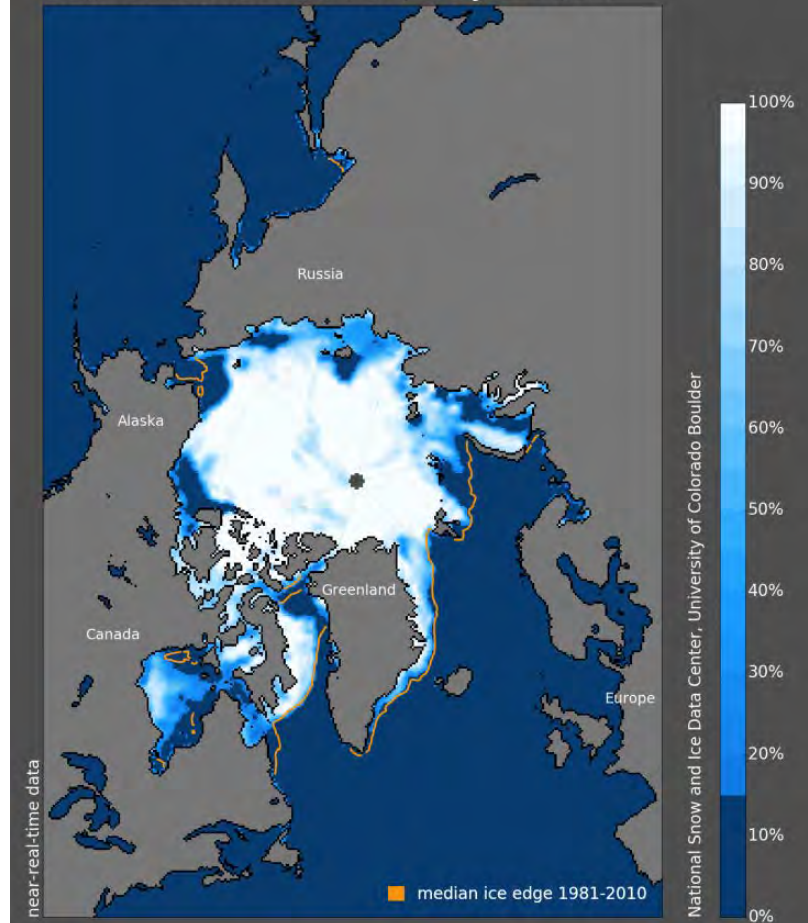
$$C = \frac{T_B - e_W T_W}{e_I T_I - e_W T_W}$$

W=water; I=ice

Arctic Sea Ice Extent
(Area of ocean with at least 15% sea ice)

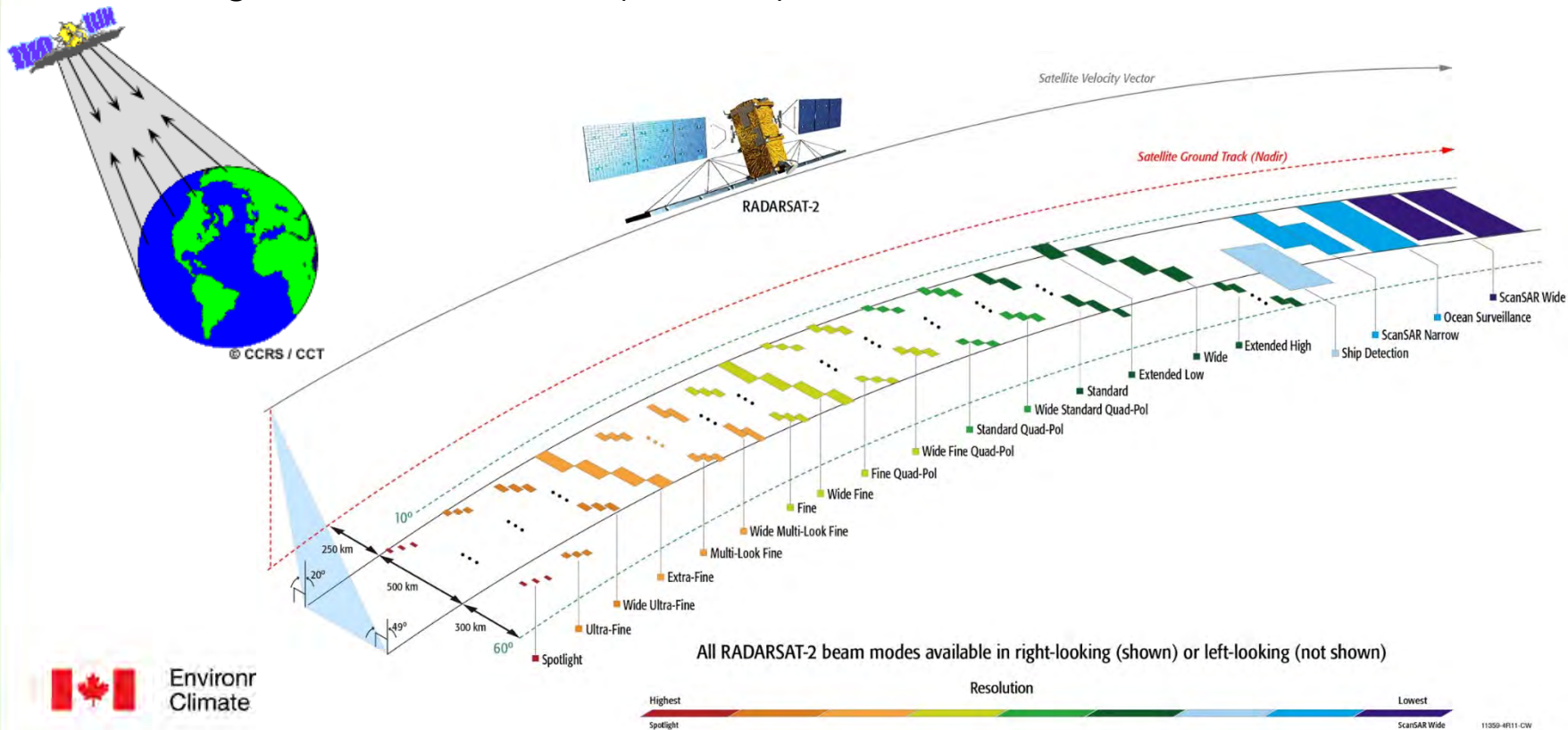


Sea Ice Concentration, 20 Jun 2017



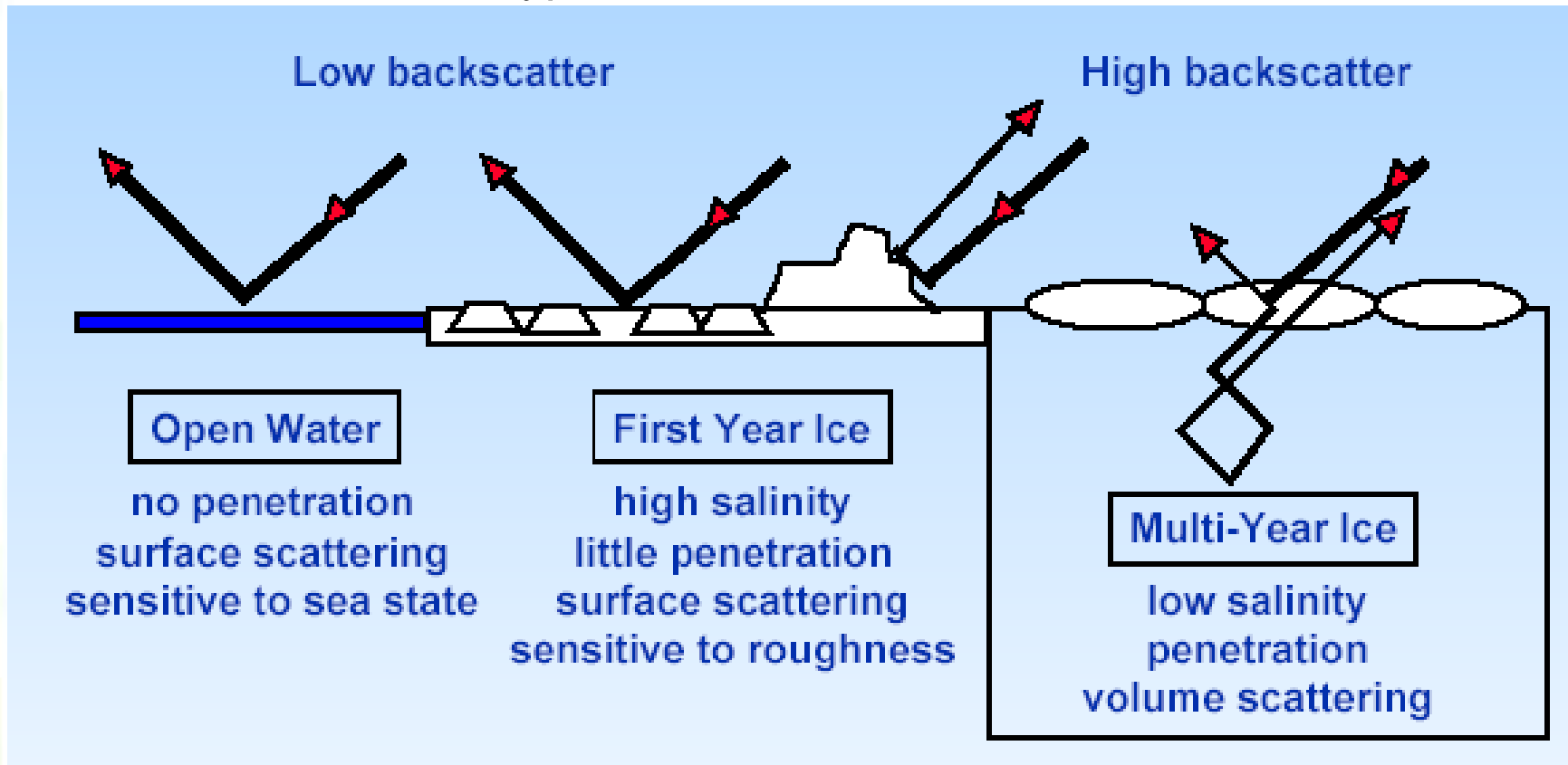
Active microwave

- Active systems carry their own source of electromagnetic radiation.
 - high spatial resolution (50-100 m) and lower frequency.
 - e.g. active microwave (RADAR); LiDAR.



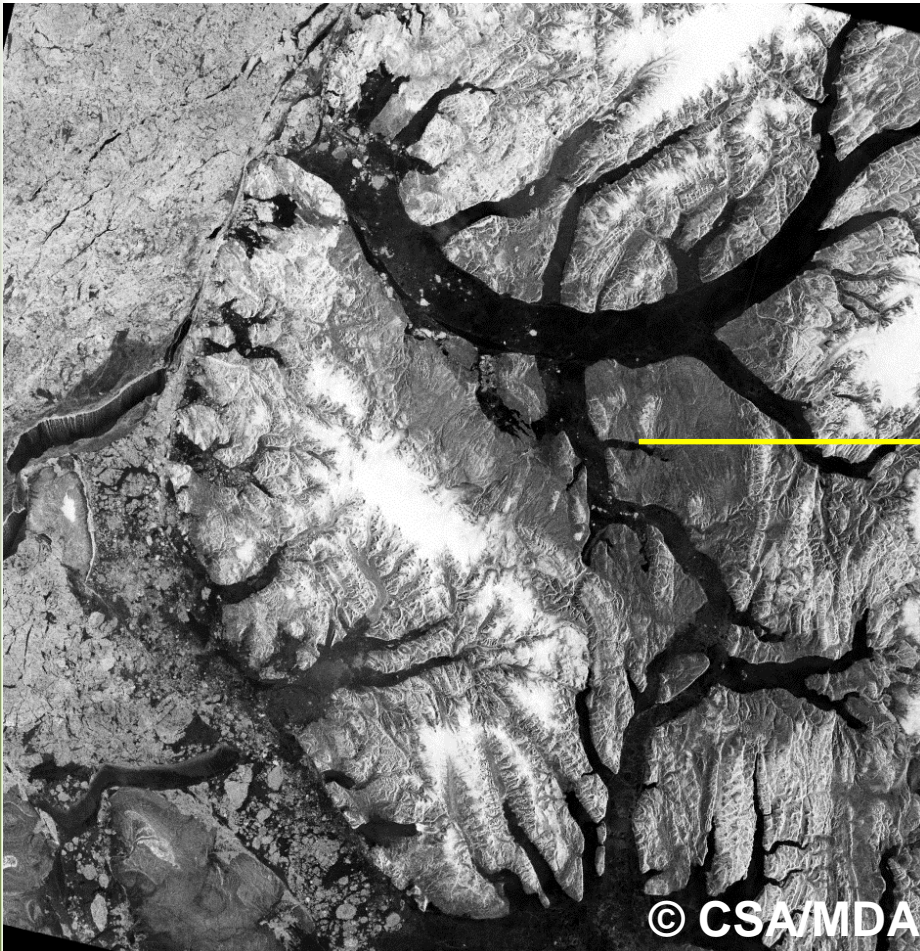
Active microwave: sea ice type

- Amount of energy (in dB) returned to the sensor, backscatter coefficient (σ^0) depends on the dielectric constant, incidence angle and surface roughness.
- Also useful for ice type and ice concentration.



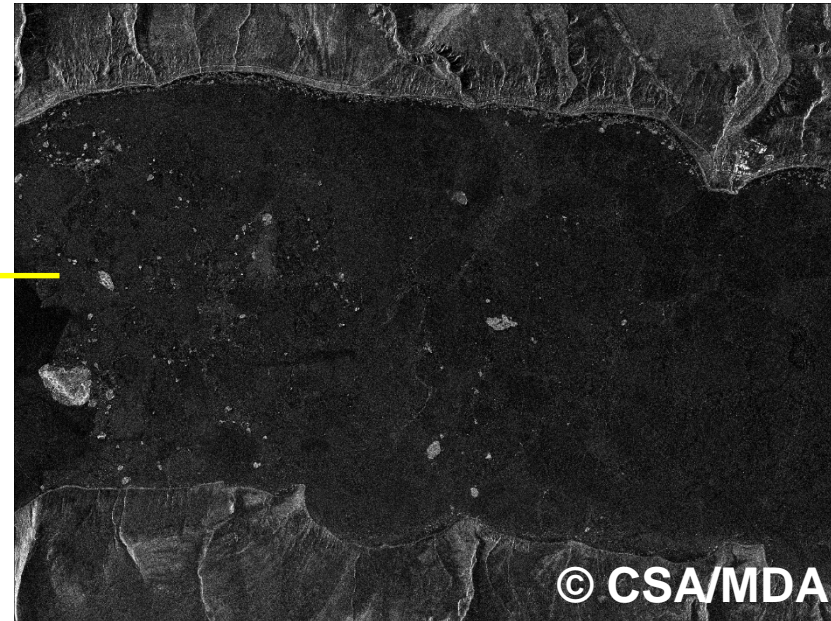
Active microwave: sea ice type

ScanSAR 100 m



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Spotlight 0.5 m



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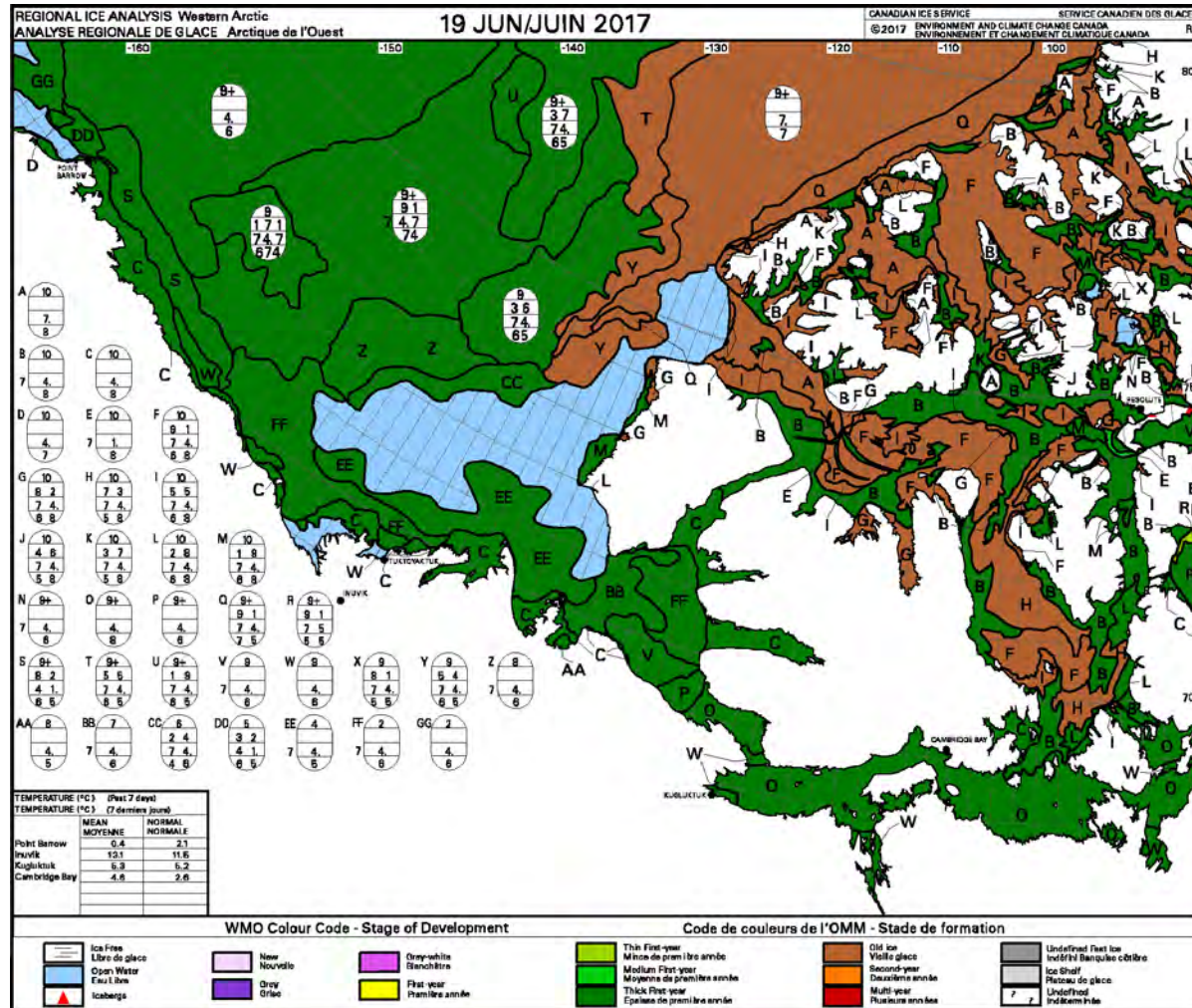
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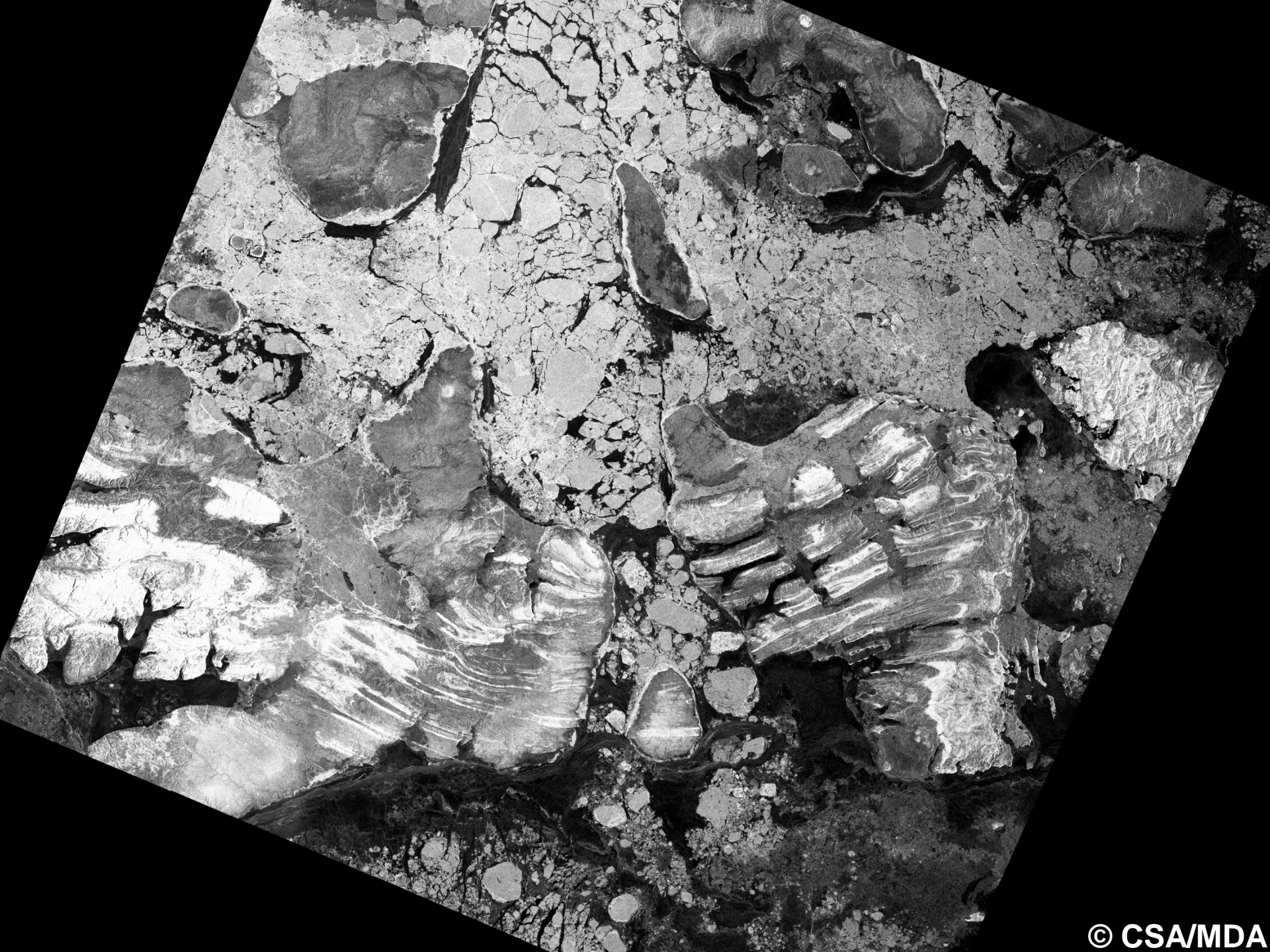
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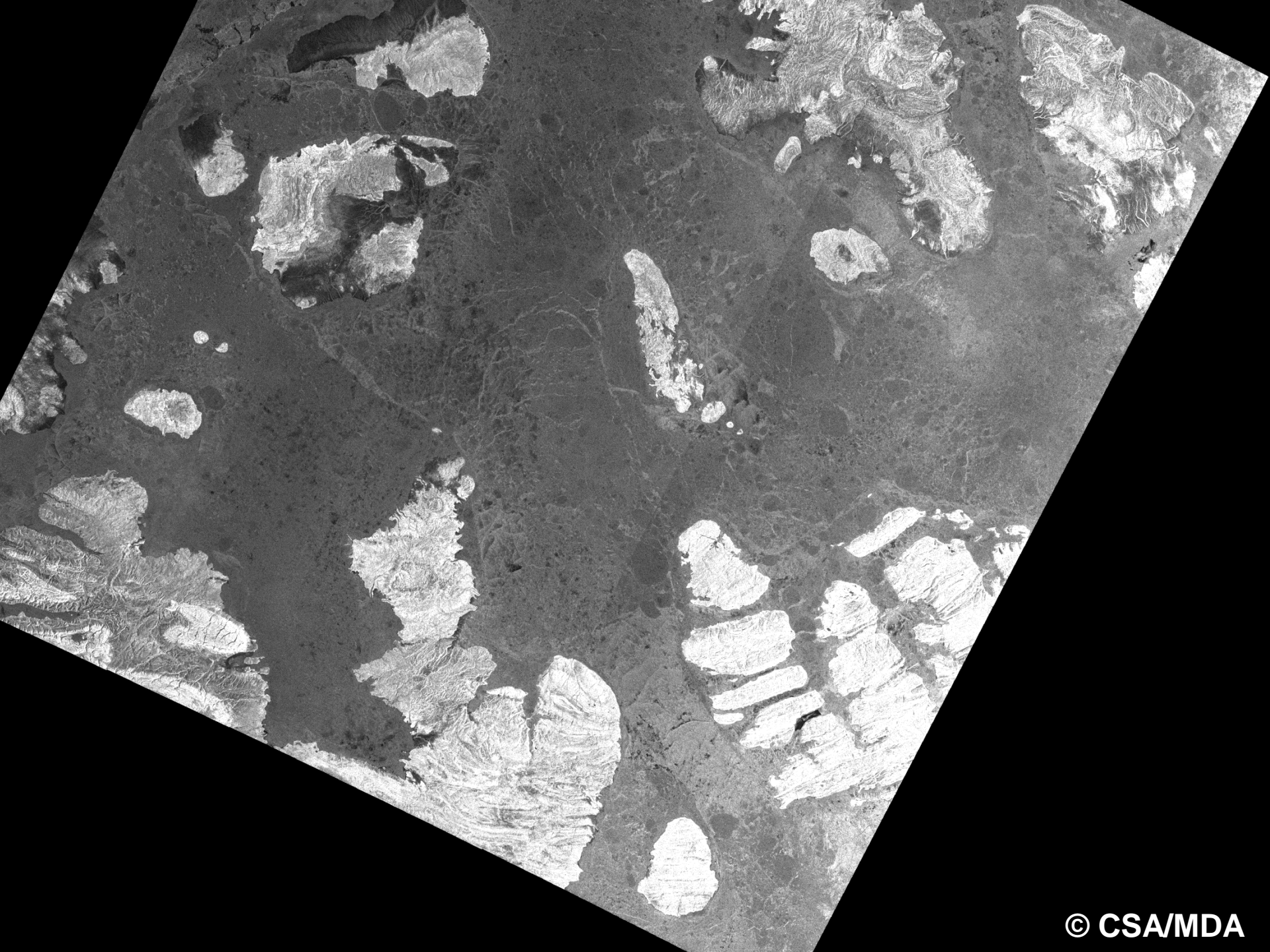


400 m

Active microwave: ice charts

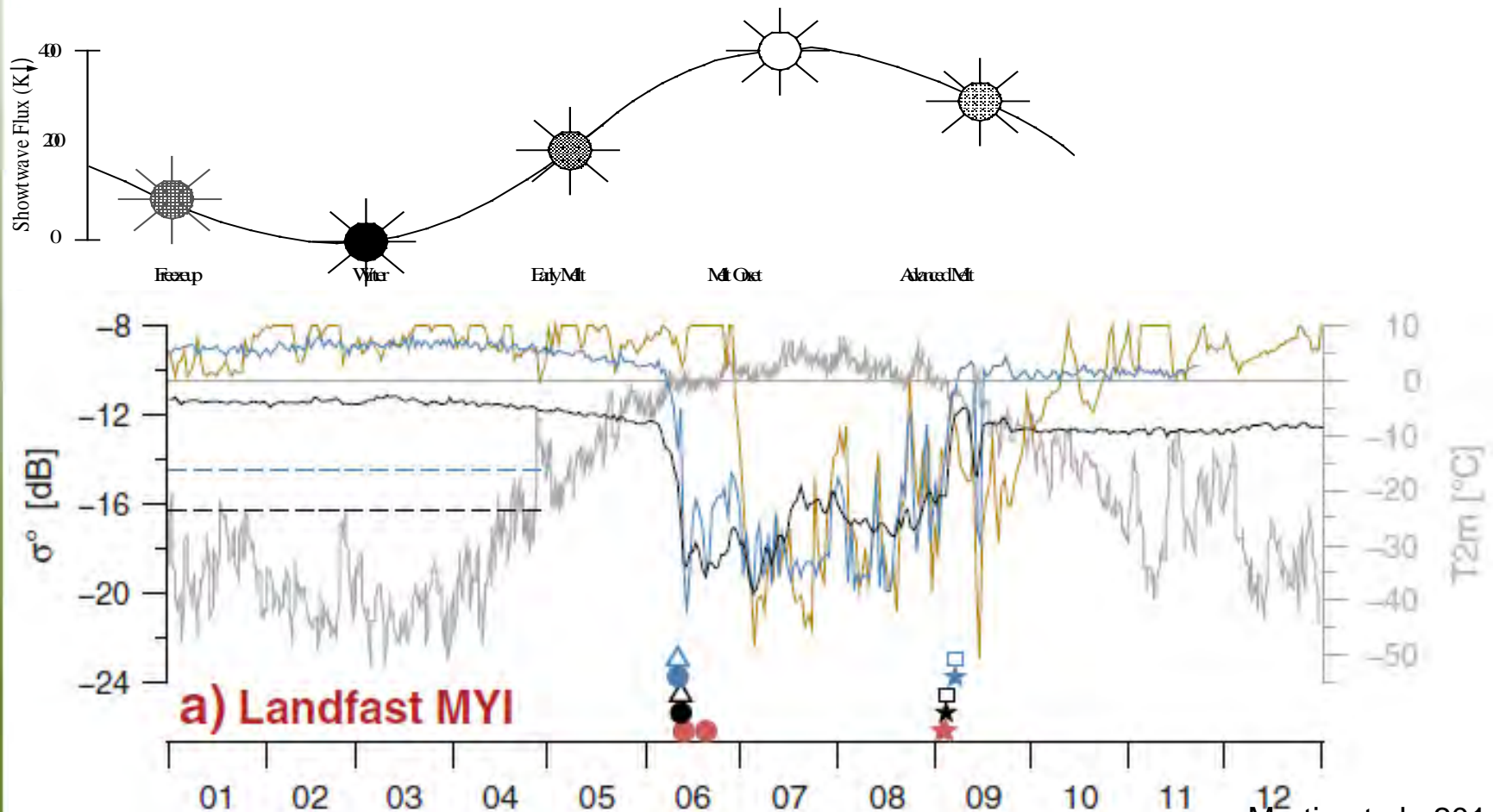




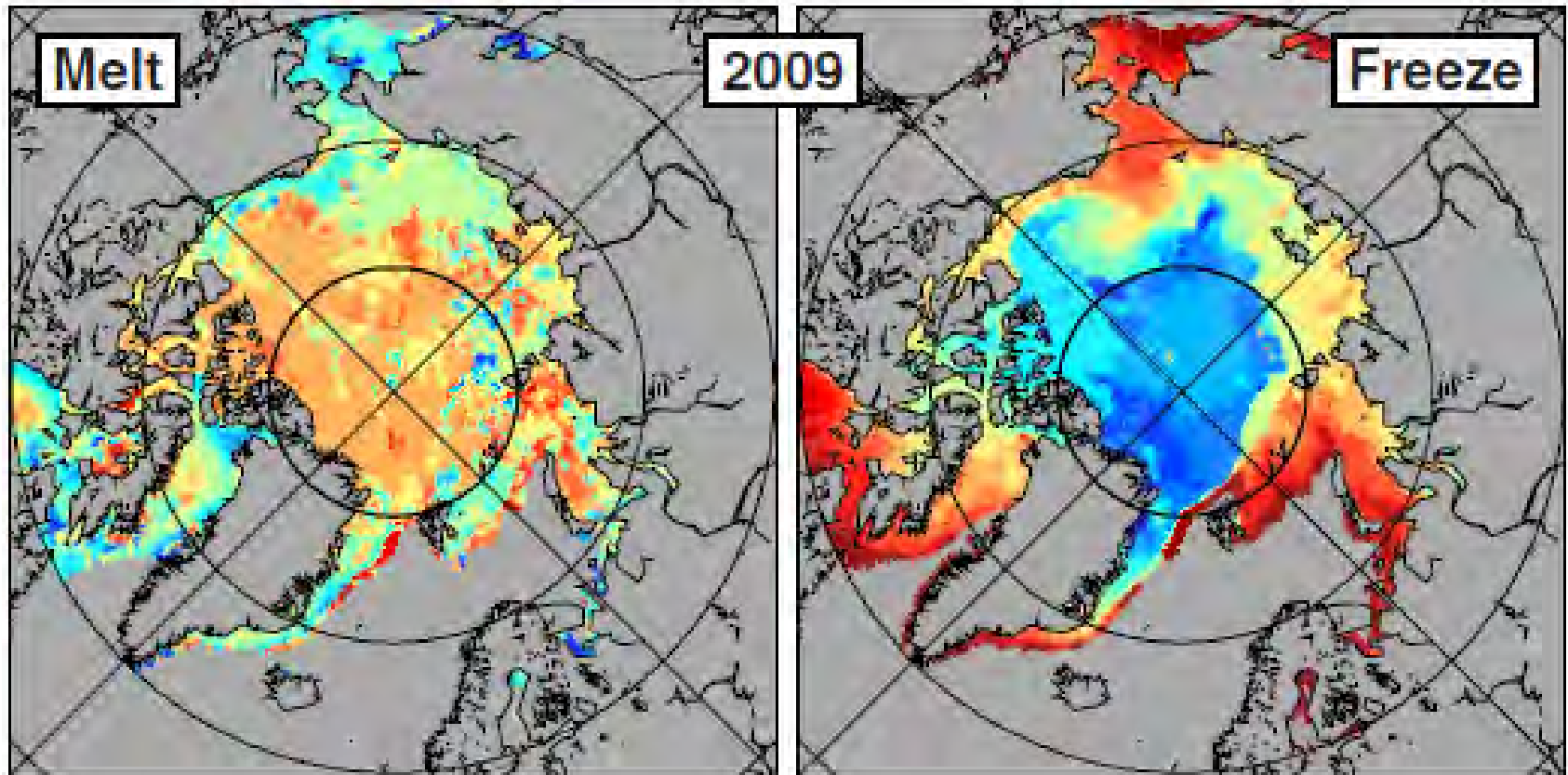


Detecting stages of ice melt

- Using the time series approach, σ^0 and/or T_B 's very useful for identifying stages of melt.



Detecting stages of ice melt: melt freeze maps



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Mortin et al., 2014

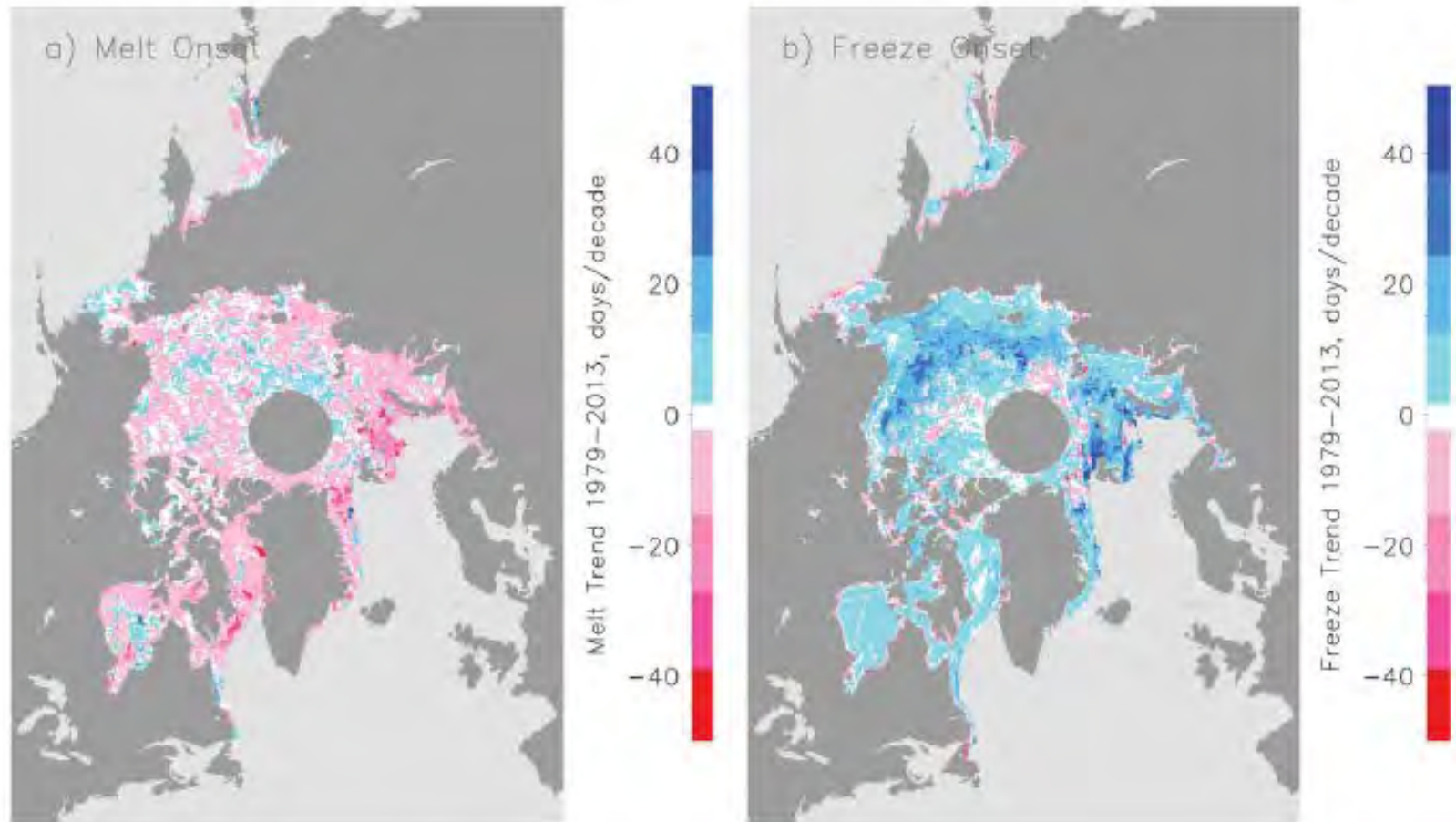


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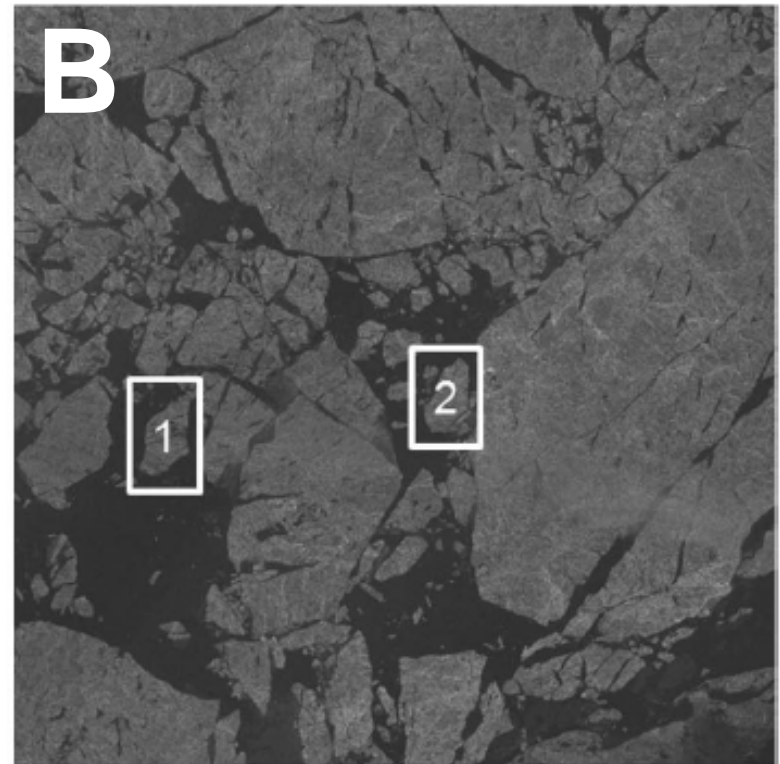
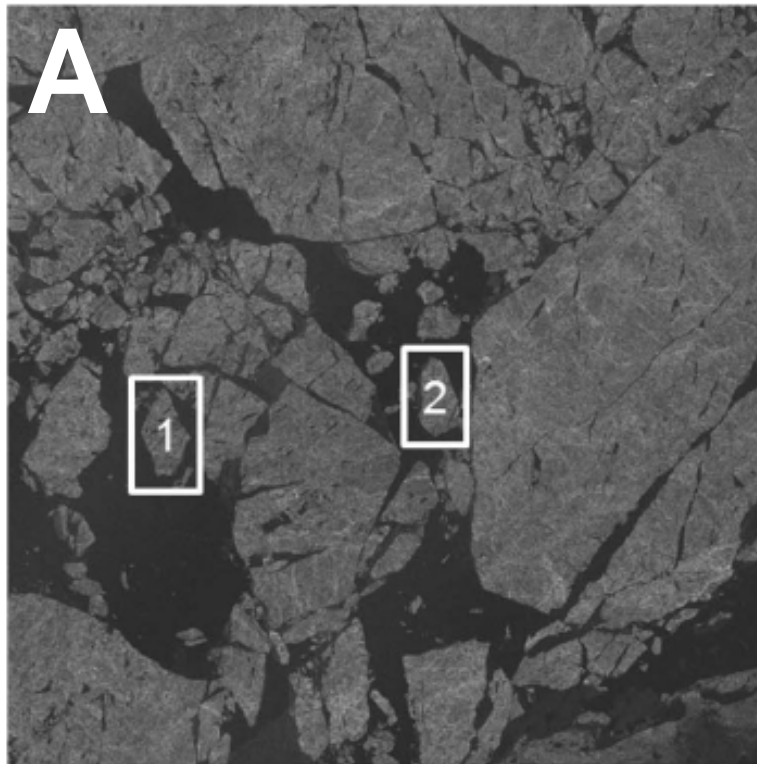
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Long term changes in Arctic sea ice melt-freeze transitions



Estimating sea ice motion

- Iterative approach that finds the location (features) of image A in image B and computes there shift vector.



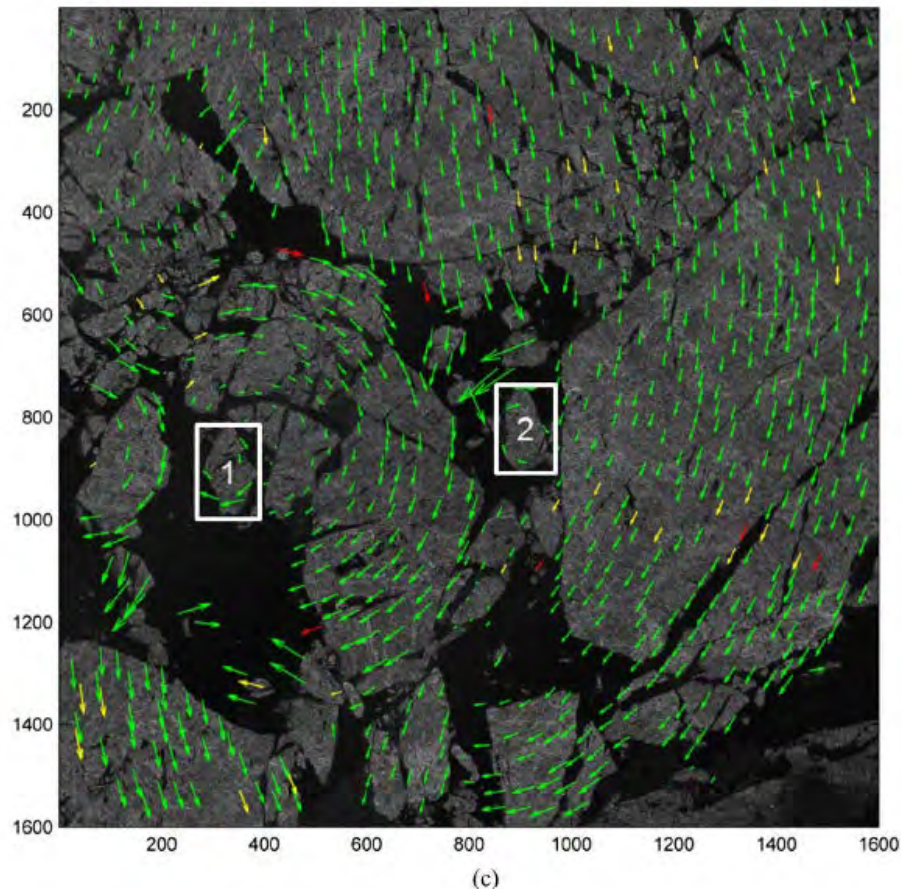
Komarov & Barber, 2014

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Estimating sea ice motion

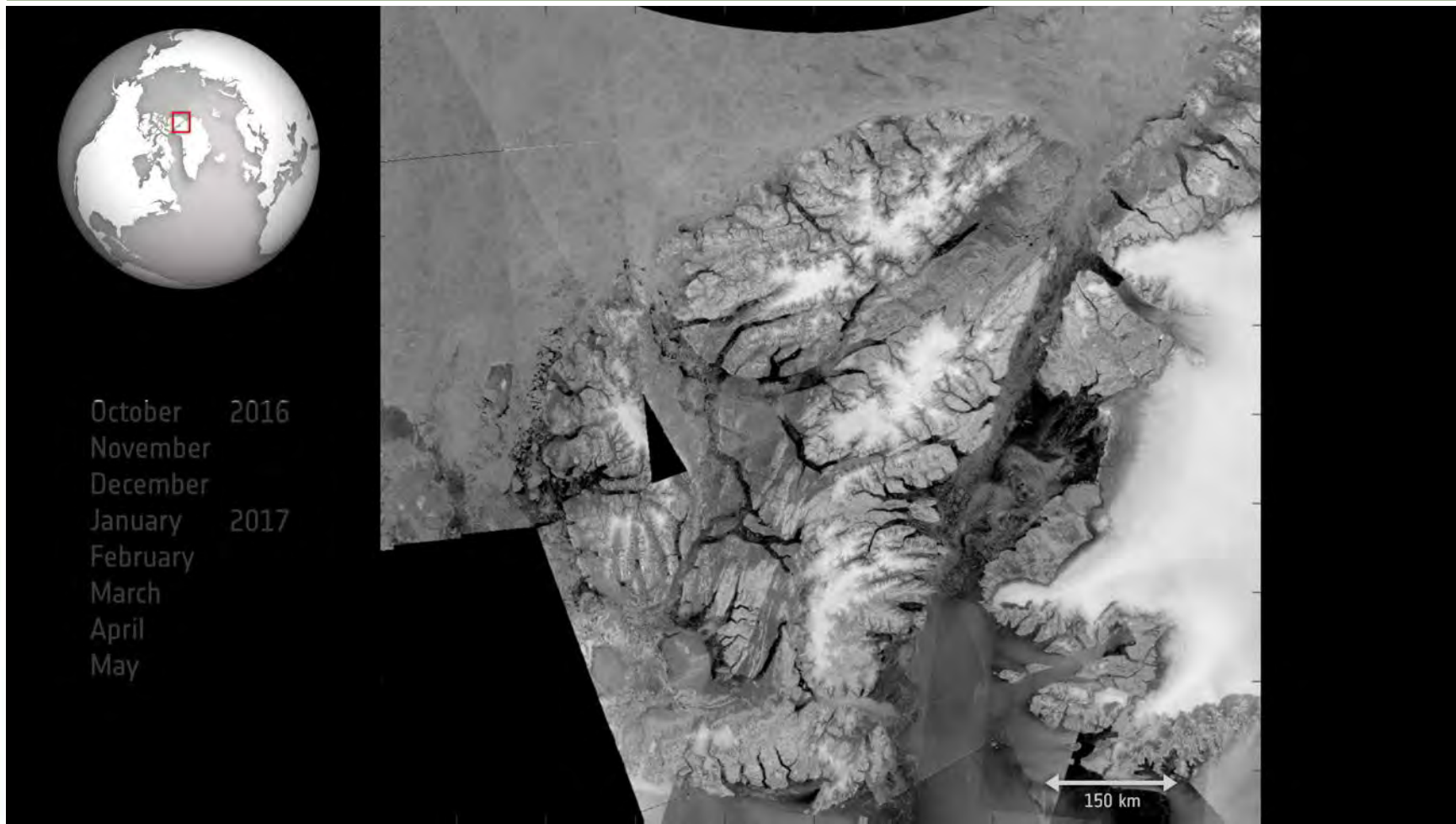
- Iterative approach that finds the location (features) of image A in image B and computes there shift vector



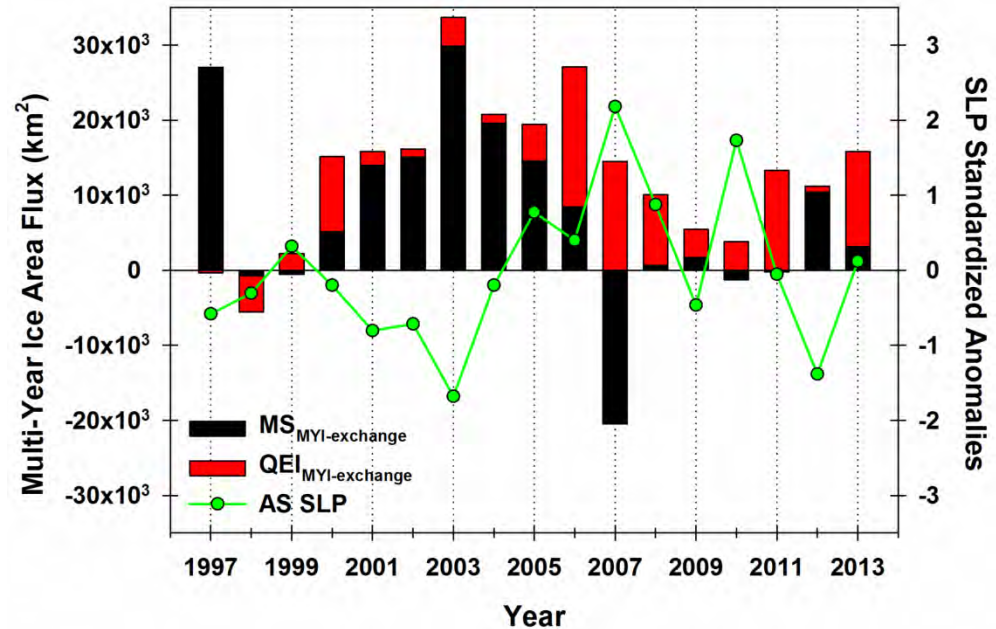
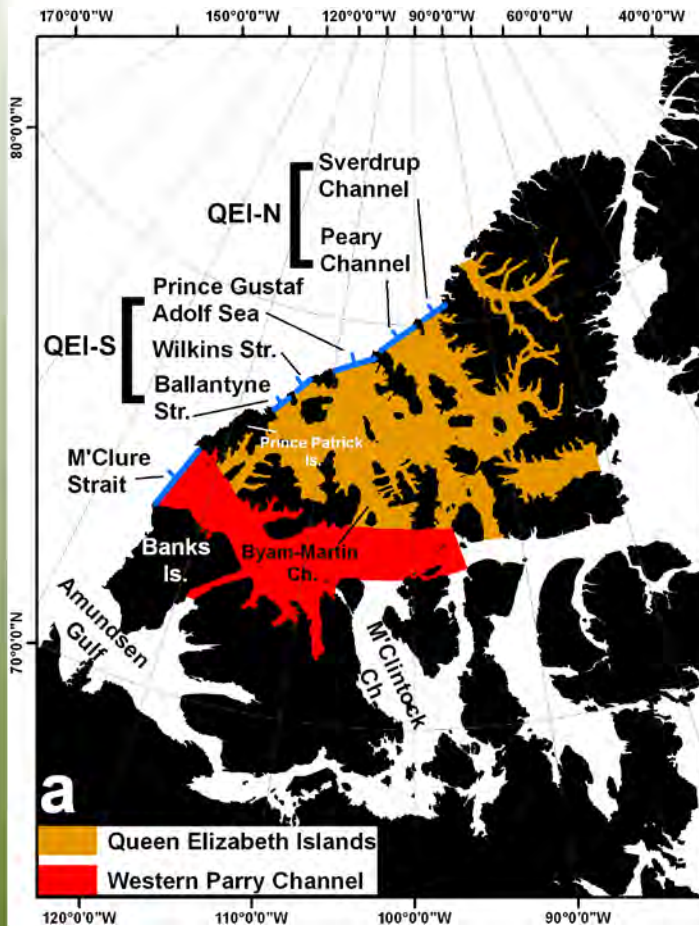
Komarov & Barber, 2014



Sea ice motion: ice flux



Sea ice motion: ice flux through the Canadian Arctic Archipelago



- Warmer still climate facilitates multi-year ice flux through the Canadian Arctic.
- Multi-year ice is perhaps even thicker.



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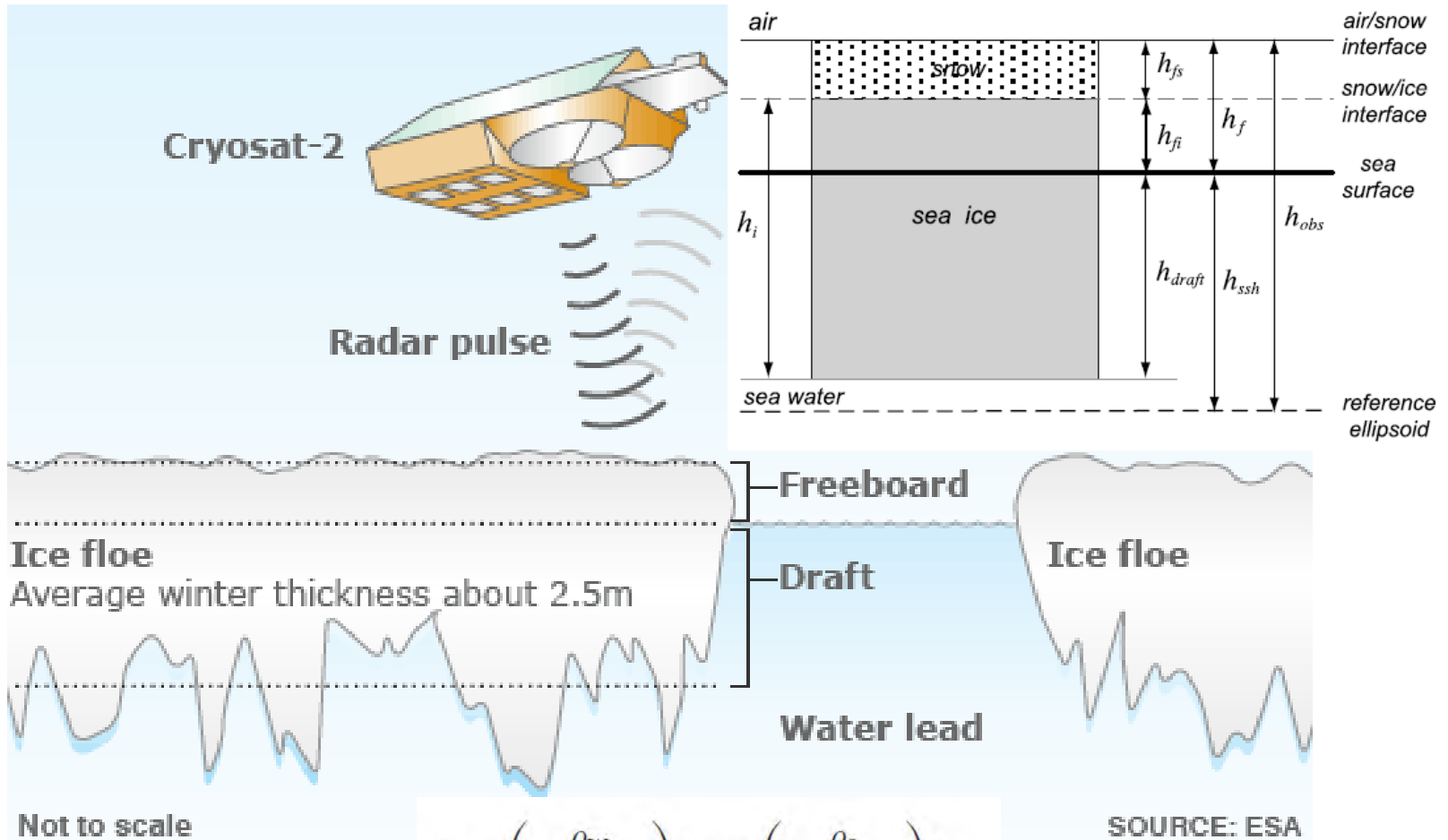
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Altimetry (+snow radar)

Satellite/Airborne Altimetry

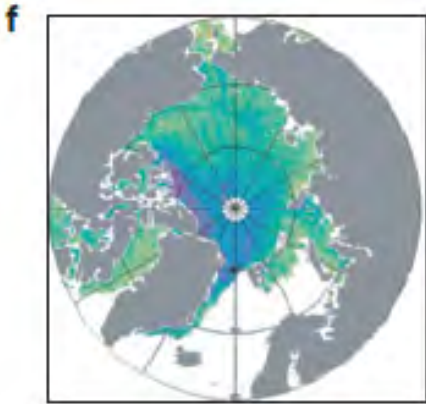


$$h_i = \left(\frac{\rho_w}{\rho_w - \rho_i} \right) h_{fi} + \left(\frac{\rho_s}{\rho_w - \rho_i} \right) h_{fs}$$

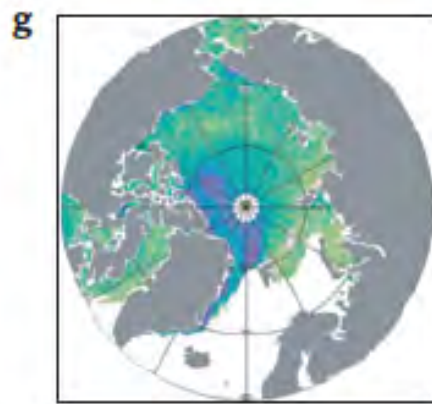


Satellite/Airborne Altimetry: ice thickness

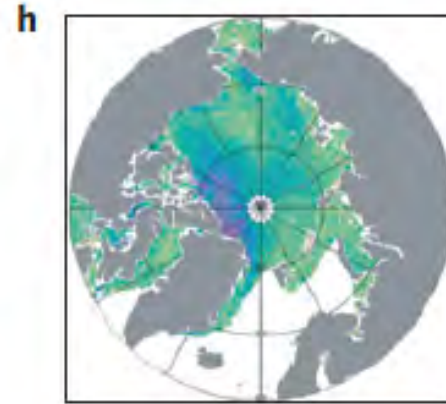
2011



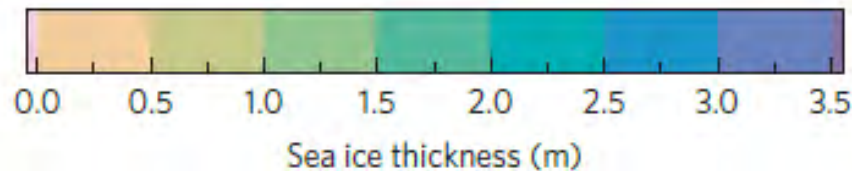
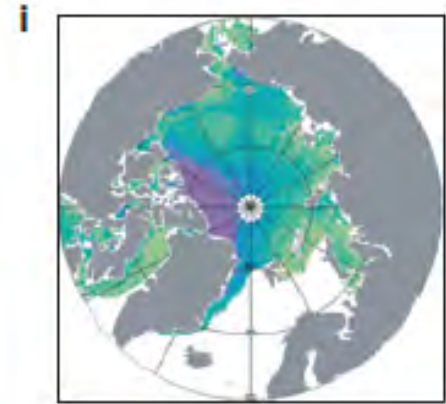
2012



2013



2014

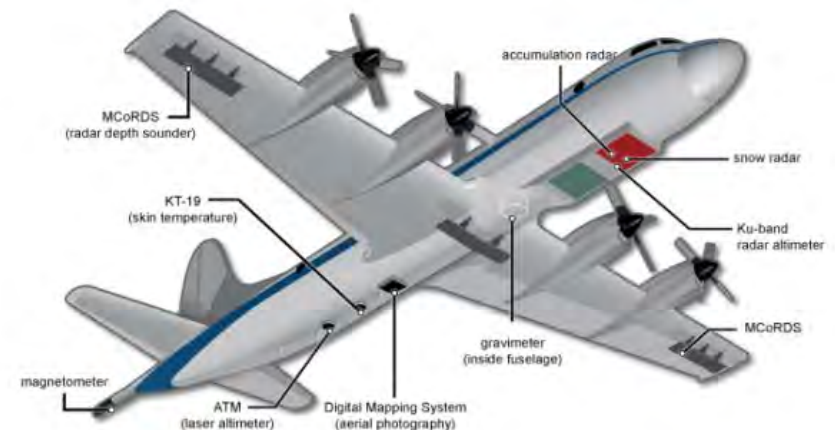
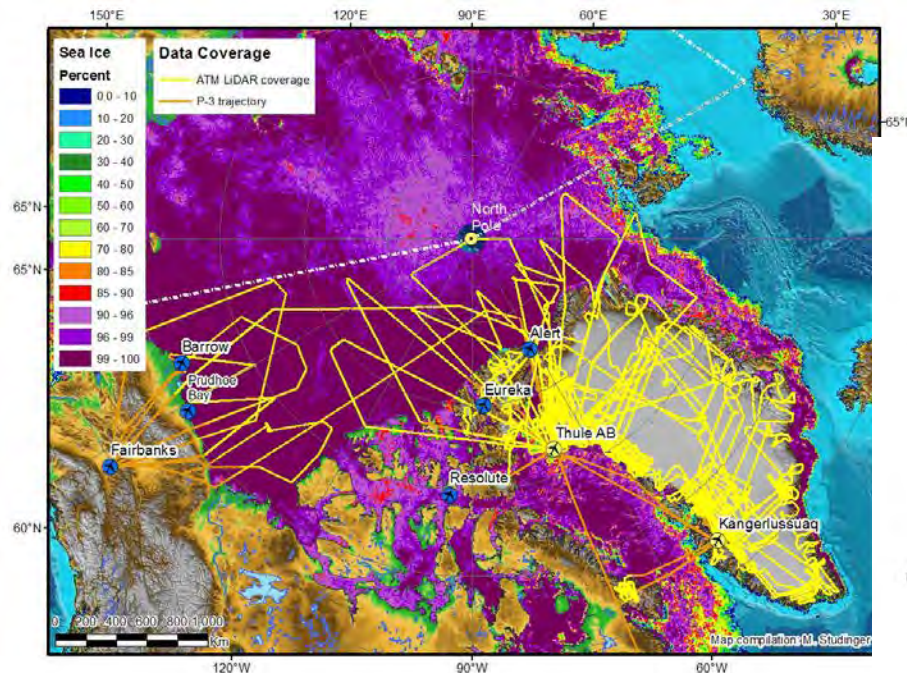


- March-April mean ice thickness from CryoSat-2
- Need to the snow depth to get the ice thickness correct!
 - 11 cm uncertainty in snow is ~76 cm error in ice thickness

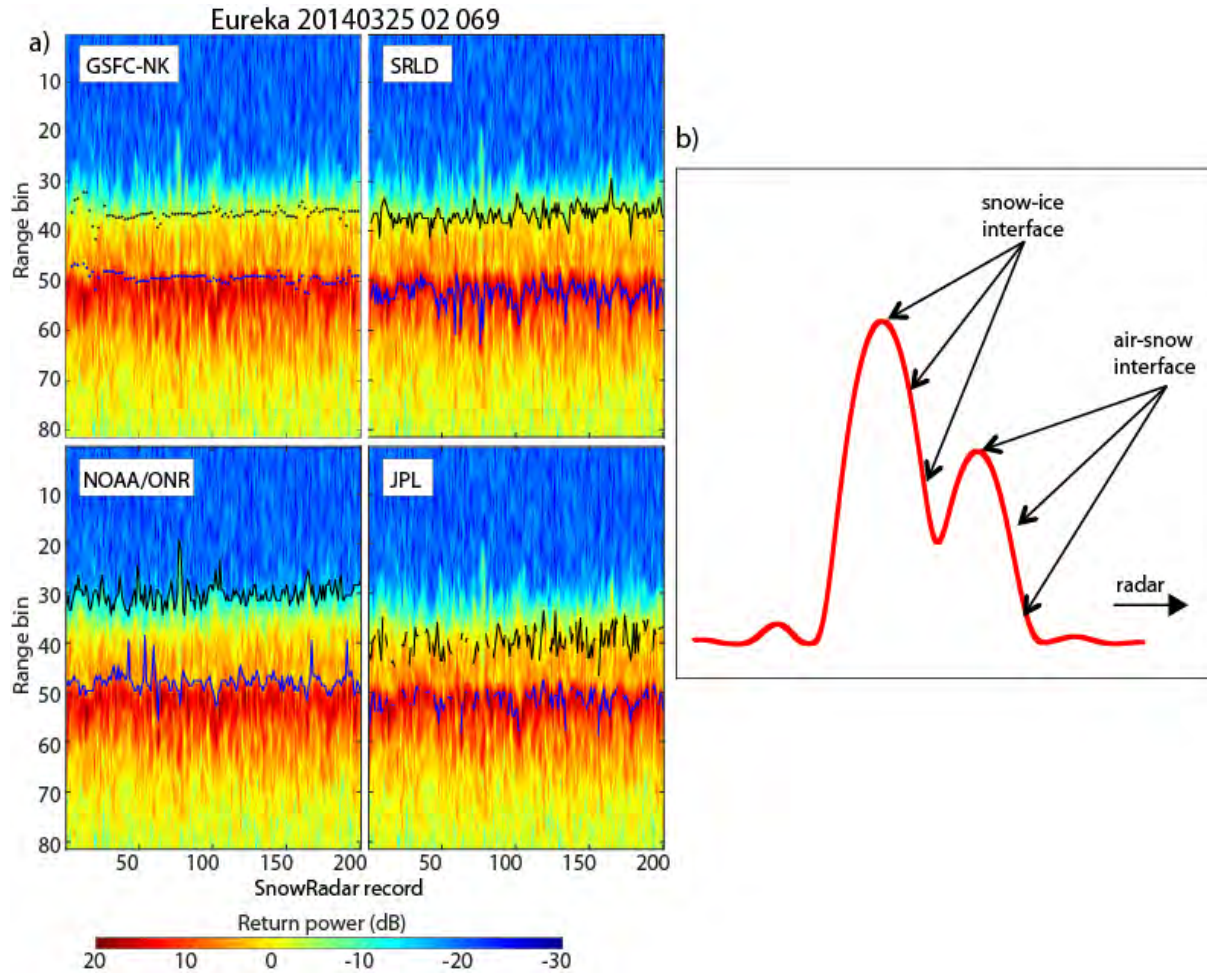


Snow depth on sea ice: Operation Ice Bridge

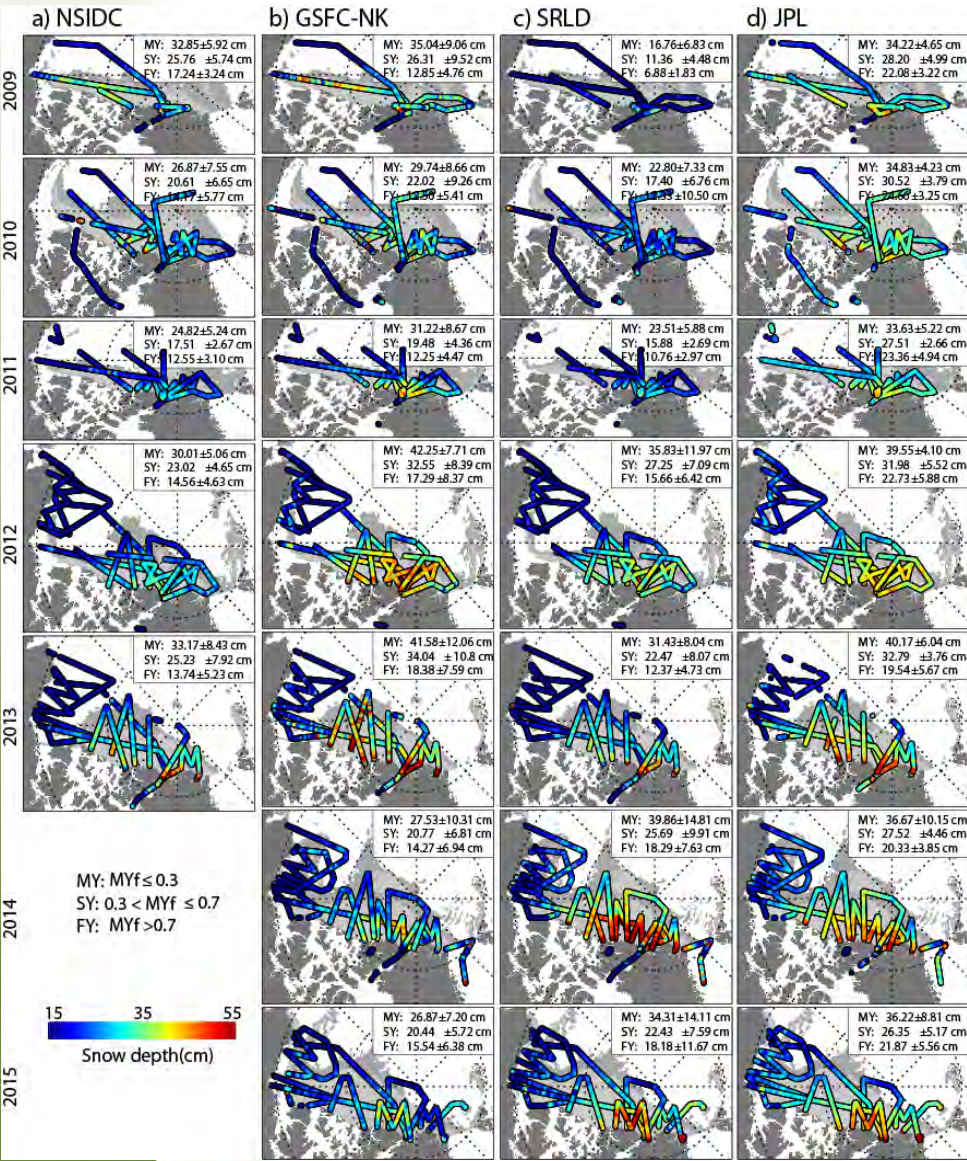
- University of Kansas Center for Remote Sensing of Ice Sheets (CReSIS) Snow Radar:
 - 2-8 GHz frequency modulated continuous wave radar
 - ~14.5 m along track and 11 m across track resolution
- Retrieval relies on identification of returns from the air-snow and snow-ice interfaces to determine thickness of the snowpack.



Snow depth on sea ice: Operation Ice Bridge



Snow depth on sea ice: Operation Ice Bridge

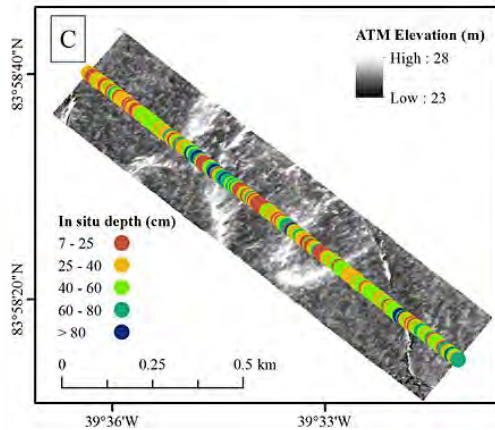
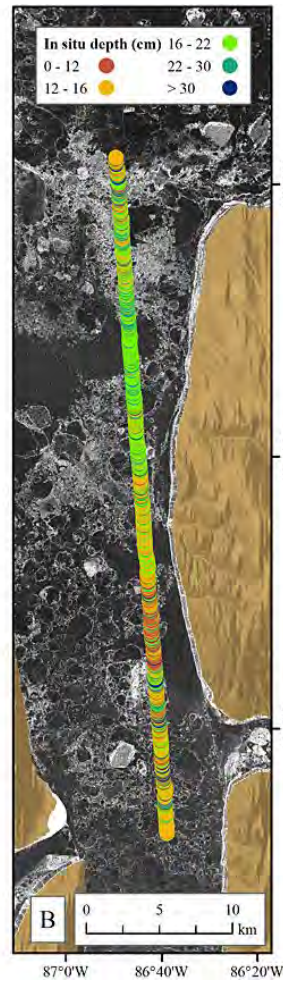
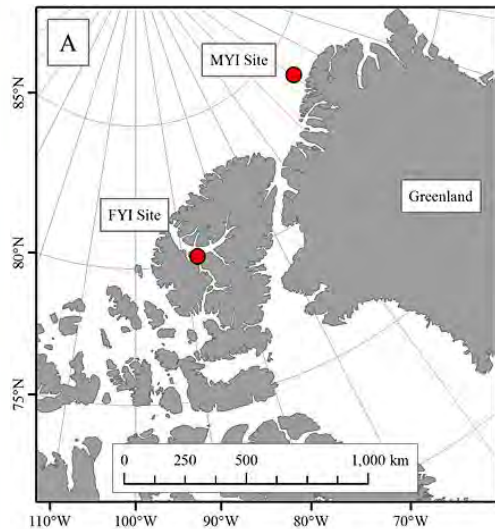


- Known uncertainties involving both physical (snow and ice surface topography) and system properties (flight path characteristics, radar side lobe).
- ~5.7 cm uncertainty (Kurtz et al., 2013).
- 3.5 – 5 cm uncertainty (Kwok et al., 2011).
- Limited datasets to validate retrieval.

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Snow depth on sea ice: validation



- Intensive field campaigns in 2014 and 2016



Snow depth on sea ice: validation



Eureka Sound, Ellesmere Island, NU: Magna probe – snow depth survey using automated GPS-tagged snow depth probes. photo credit: Peter Toose



Snow depth on sea ice: validation

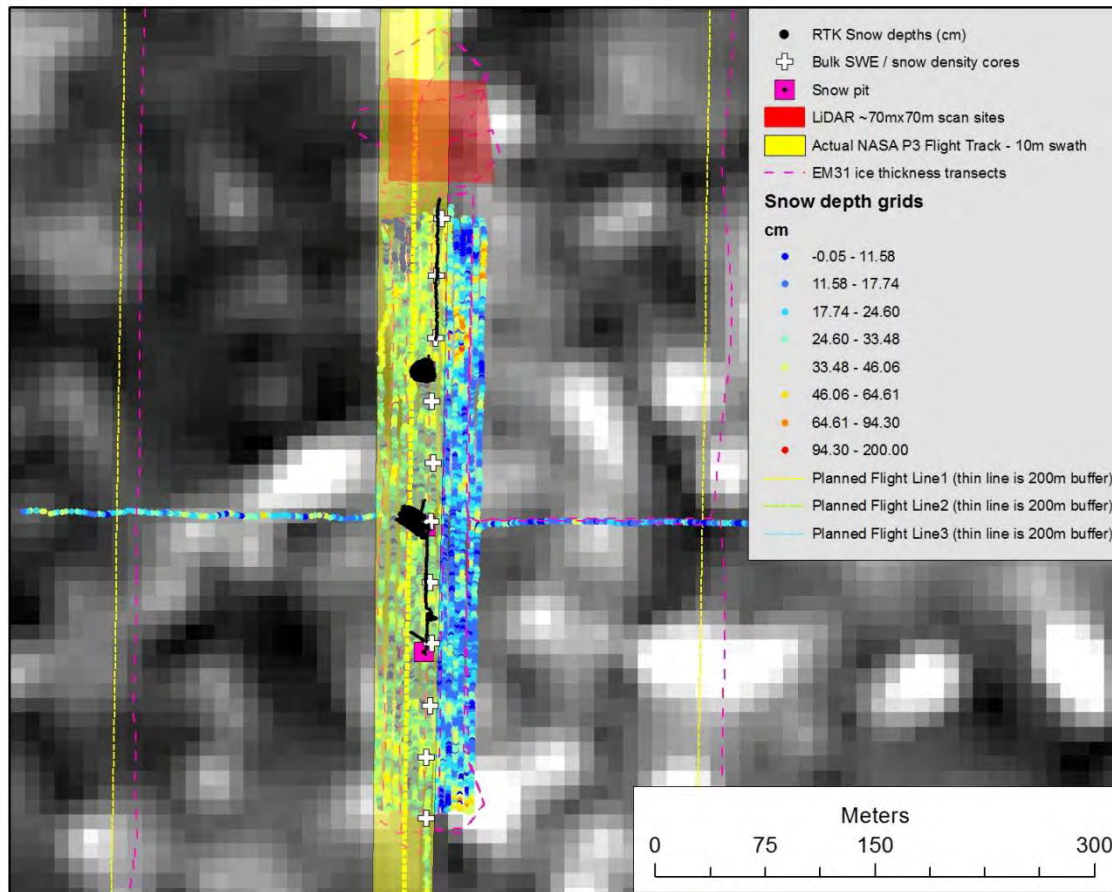


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Snow depth on sea ice: validation



Snow Depths:
n=5058
avg = 22.7 cm
STDV = 10.0 cm

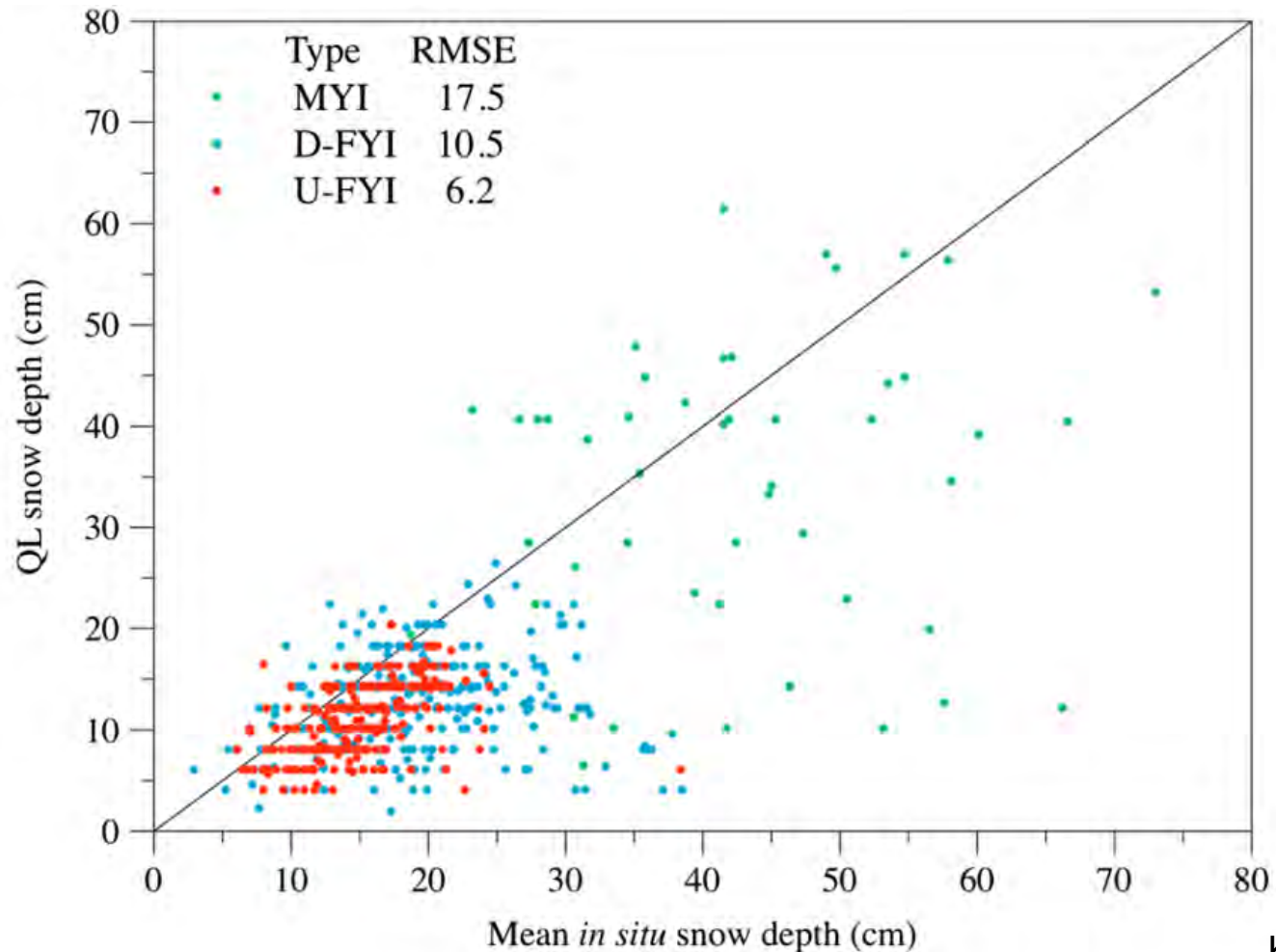
ESC-30 cores
n = 18

Bulk Density
Avg = 0.296 (g/cm³)
STDV 0.043 (g/cm³)
Avg SWE = 81mm
STDEV SWE = 35mm

SMP Transect

April 11th – This was a rough first year ice site. The NOAA P3 flight overlaps the western half of the snow grid and LiDAR scan sites. There are EM31 ice thickness measurements ~200 m either side of this grid, as well as up and down this grid site. A LiDAR scan was at the northern end of the grid – No magna depths within scan.

Snow depth on sea ice: validation



King et al., 2015



Next Lecture: Sea ice in the Canadian Arctic



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