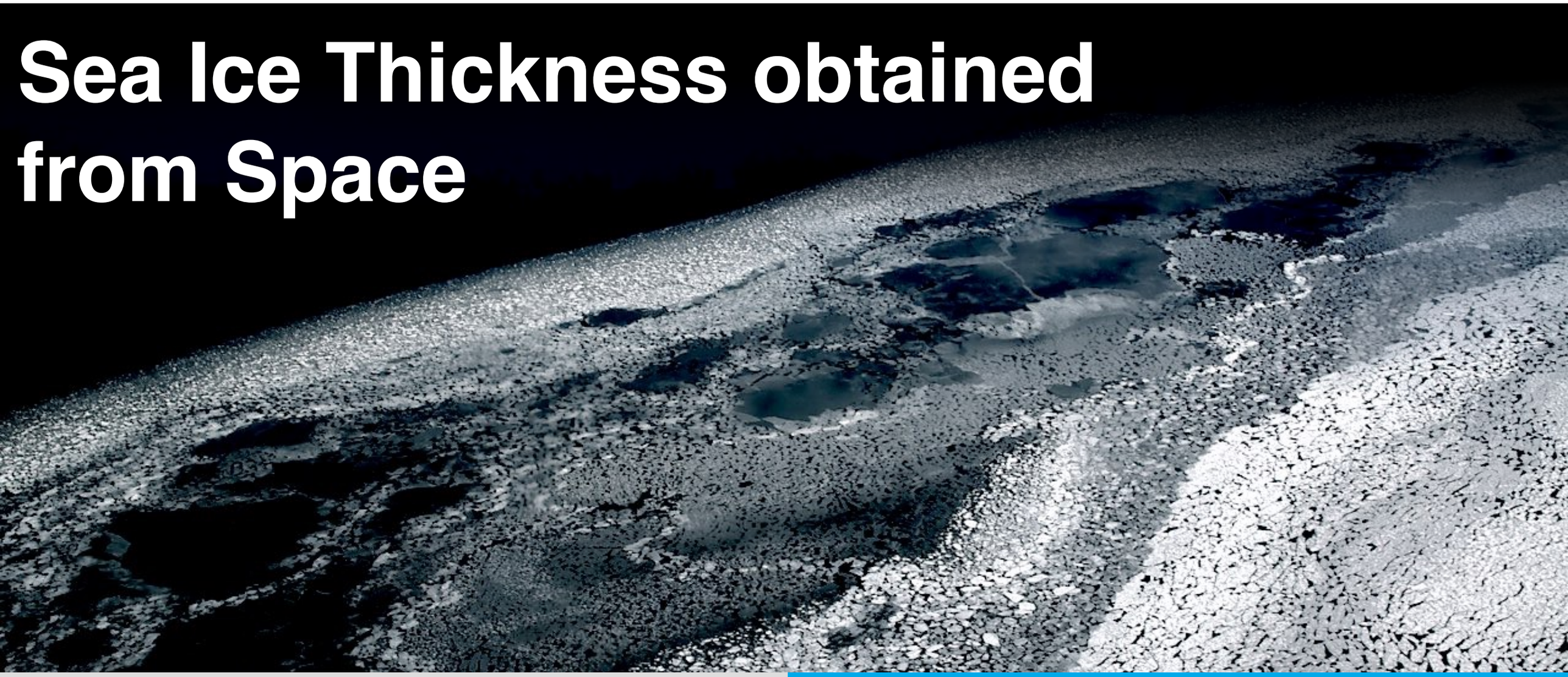
ALFRED-WEGENER-INSTITUT
HELMHOLTZ-ZENTRUM FÜR POLAR- UND MEERESFORSCHUNG

Sea Ice Thickness obtained from Space



Robert Ricker[1], Stefan Hendricks[1], Lars Kaleschke[2], Veit Helm[1]

[1] Alfred Wegener Institut, Helmholtz-Zentrum für Polar- und Meeresforschung, Bremerhaven, Germany

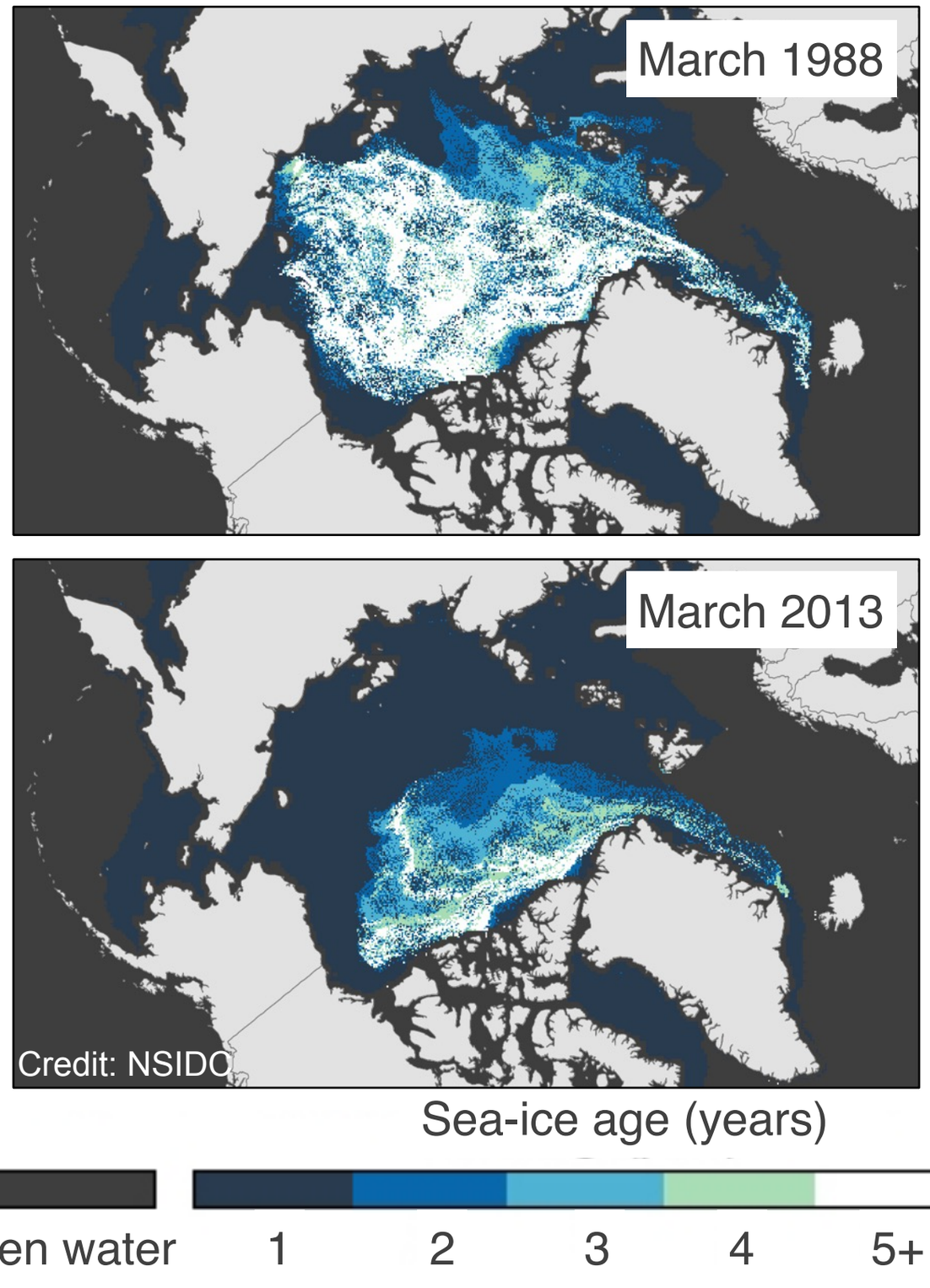
[2] University of Hamburg, Germany

HELMHOLTZ GEMEINSCHAFT

Outline

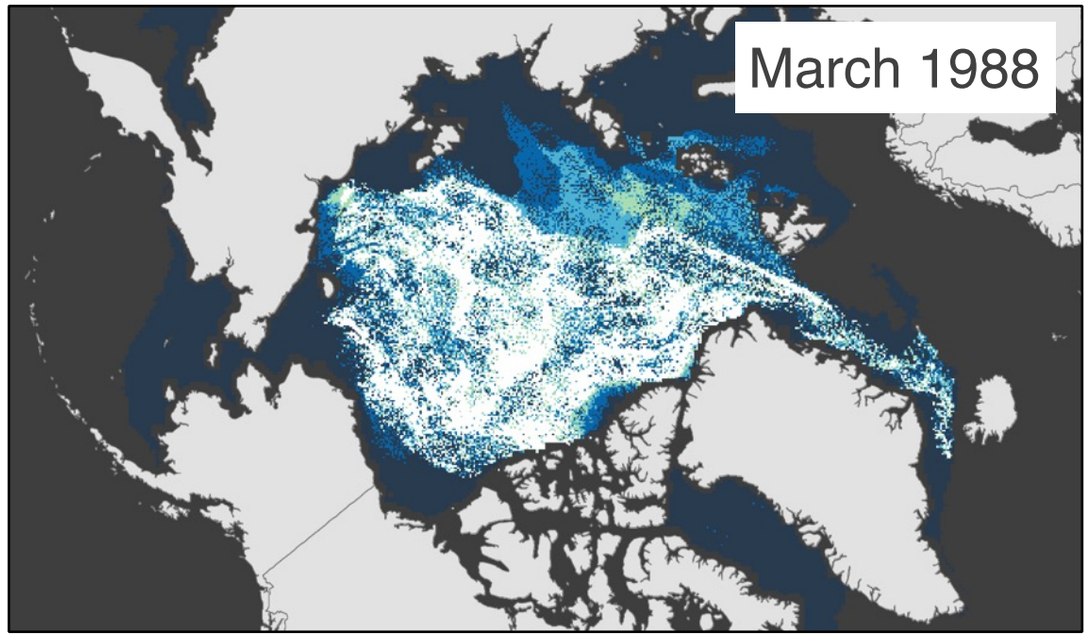
- Introduction
- Methods
- CryoSat-2 Sea Ice Thickness - Validation and Uncertainties
- Merging CryoSat-2 and SMOS Sea Ice Thickness Data
- Summary and Conclusion

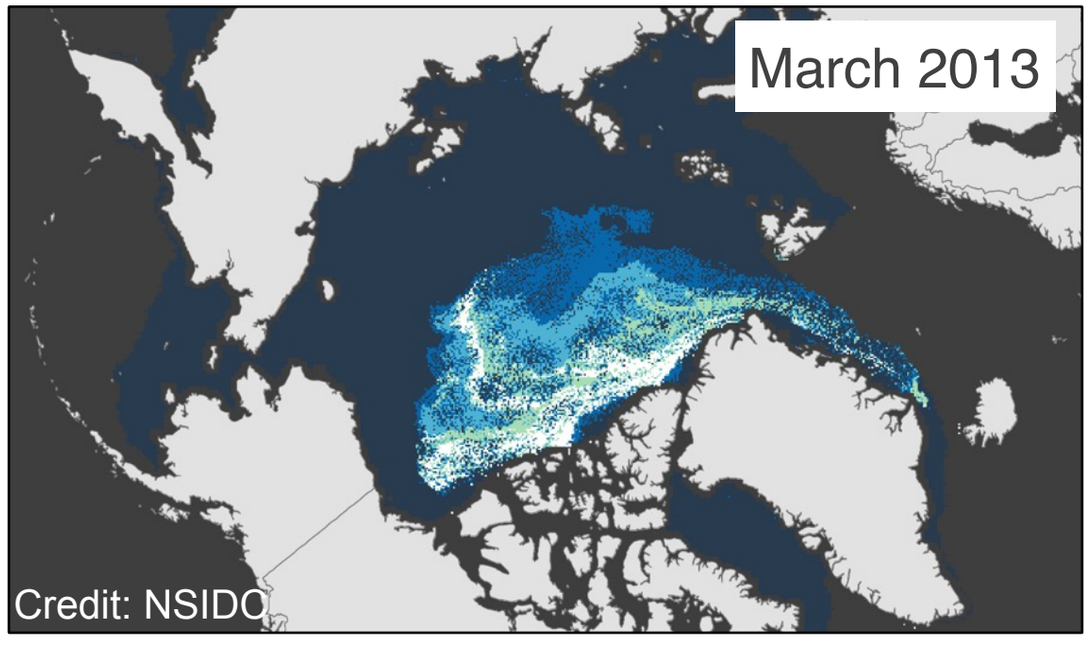
Introduction



Introduction

- The age of ice is a key feature of its state
- Old ice → thicker
- Young ice → thinner





Sea-ice age (years)

open water 1 2 3 4 5+

The Importance of Sea Ice

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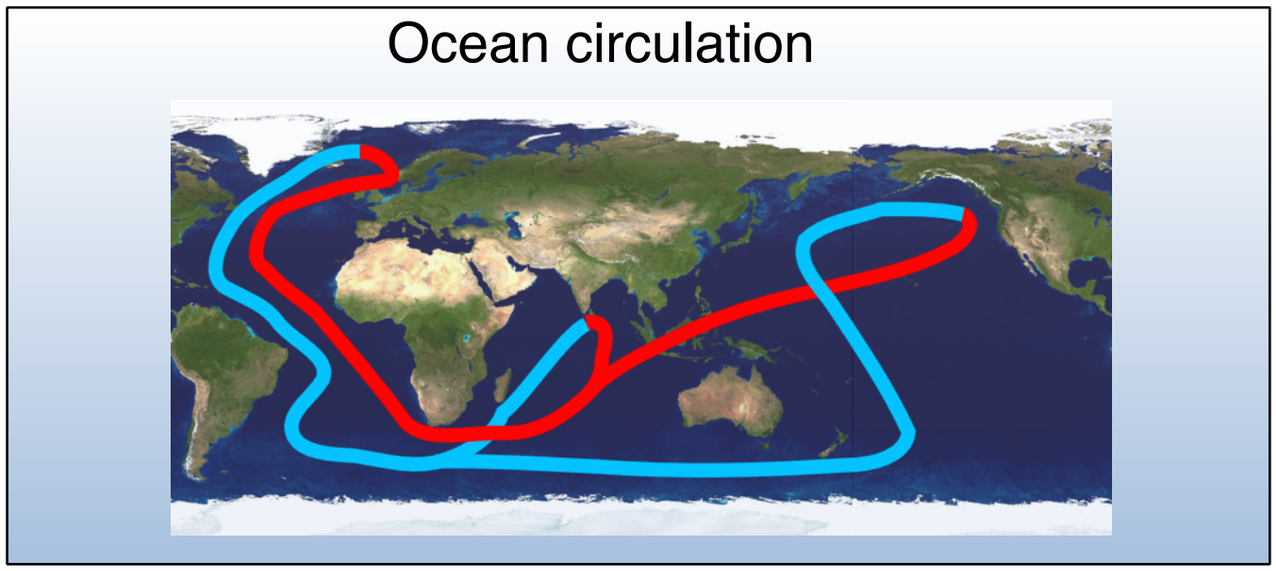
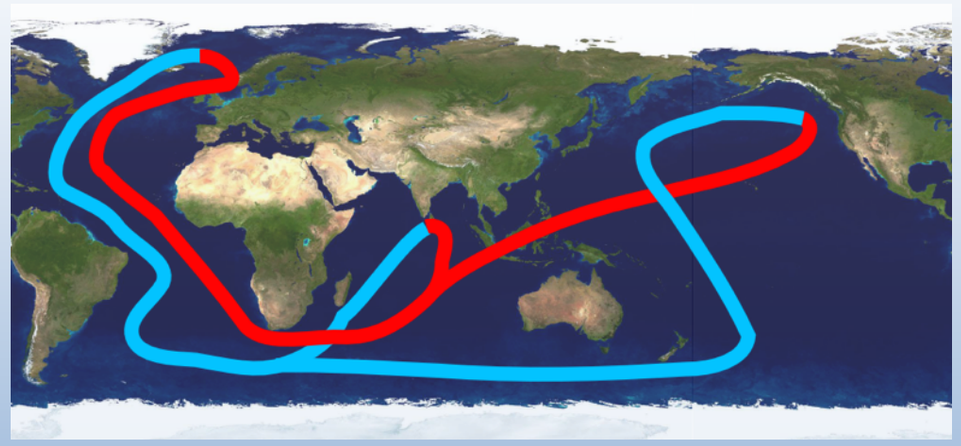
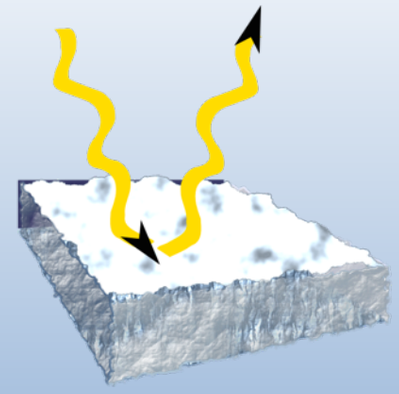


The Importance of Sea Ice

Ocean circulation



Albedo feedback



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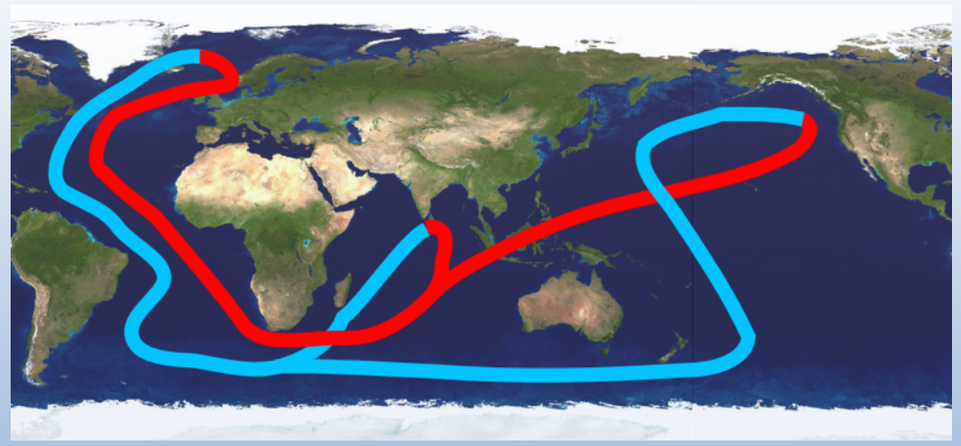

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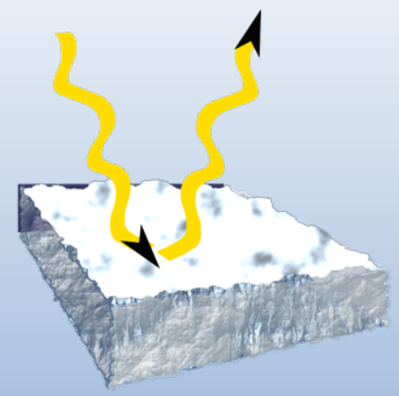
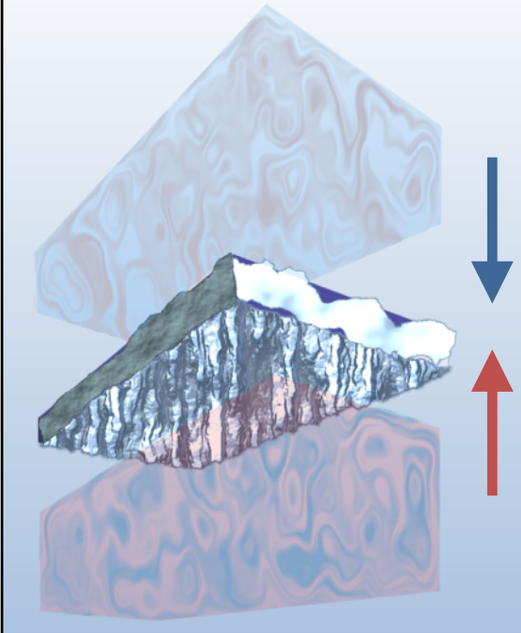


Heat exchange



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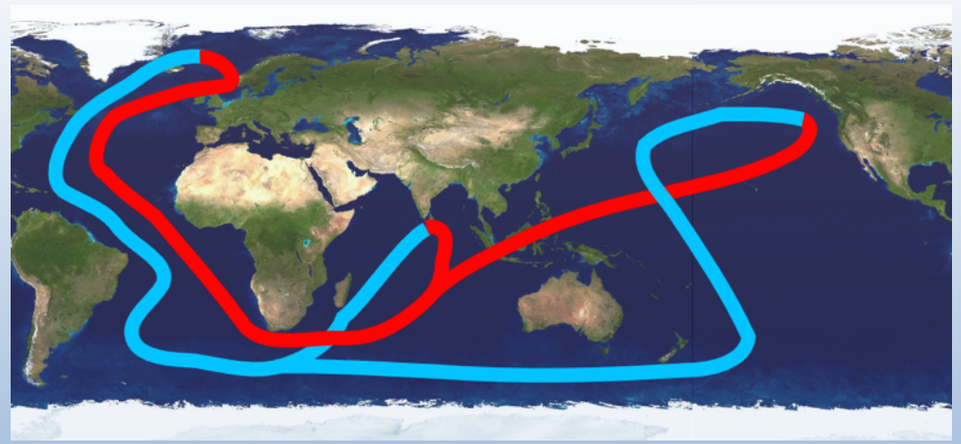

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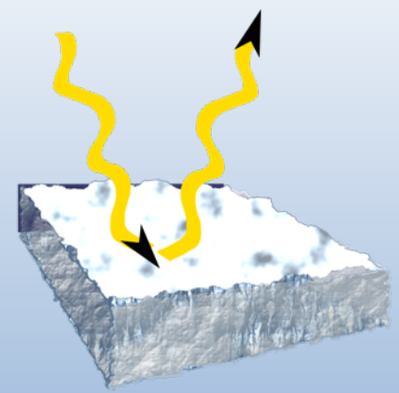

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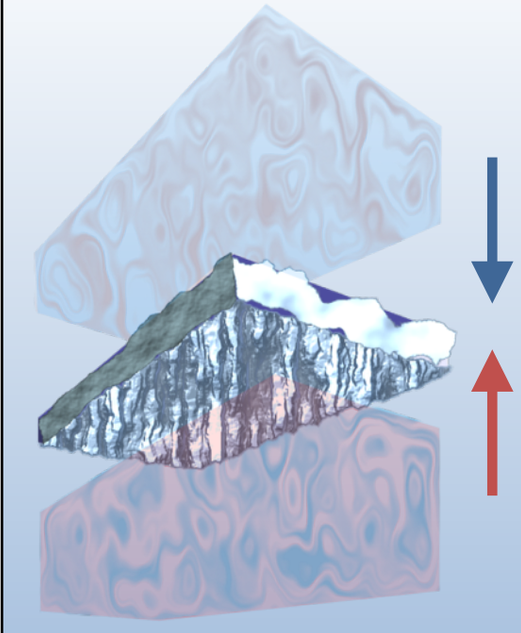
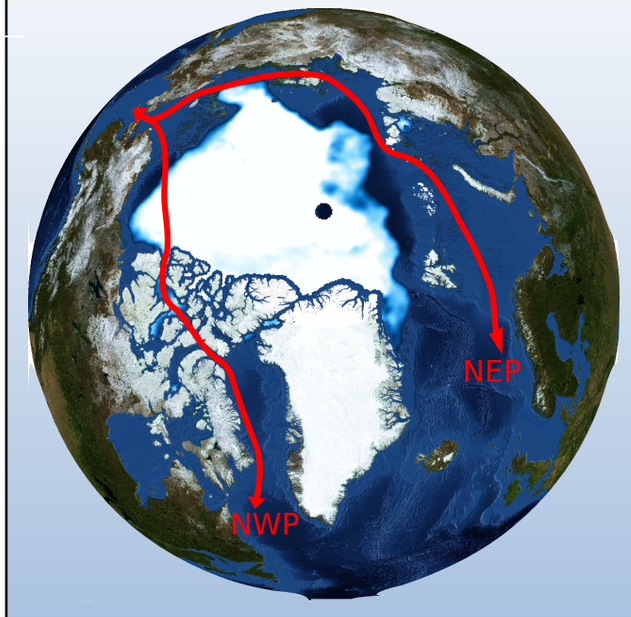


Operations



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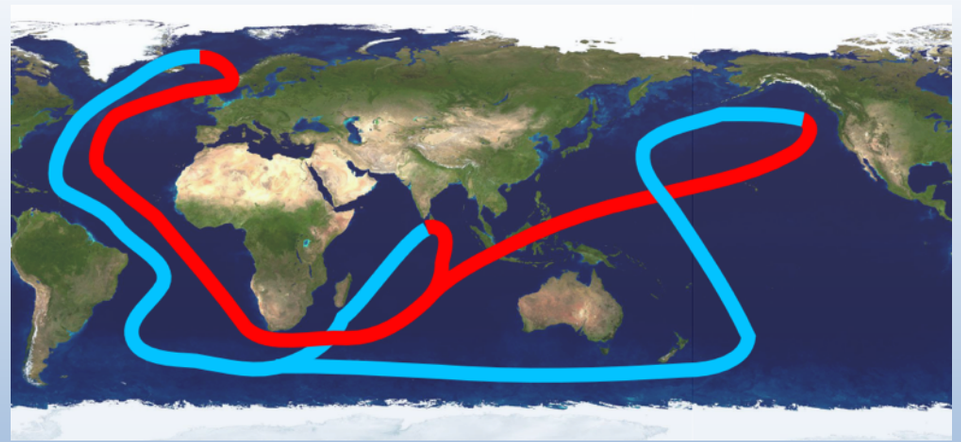

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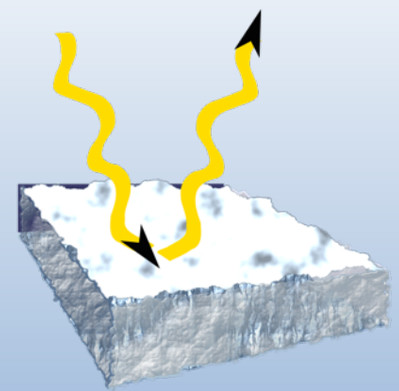

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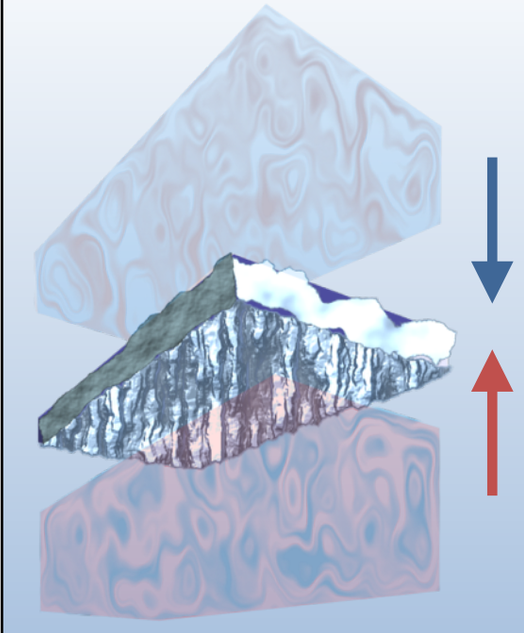

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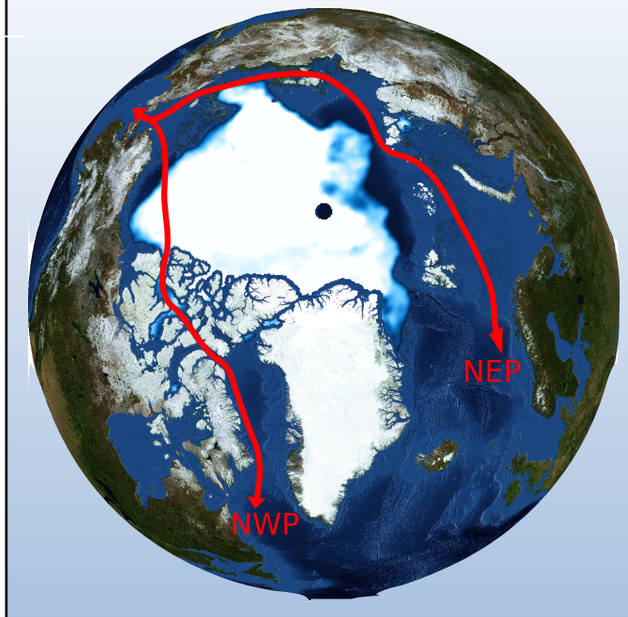
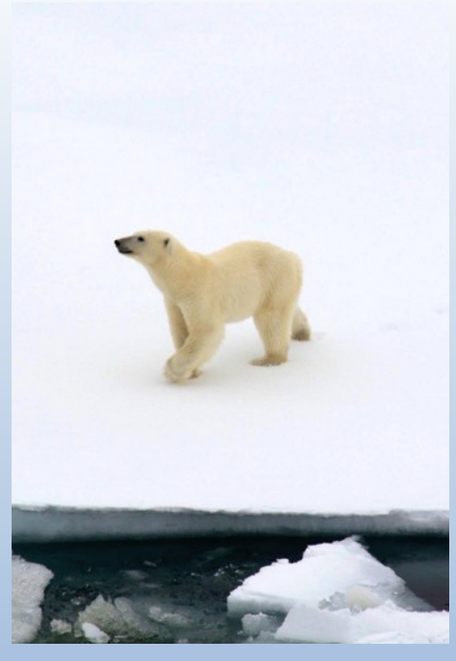


Wildlife



Sea-Ice Thickness observed from Space

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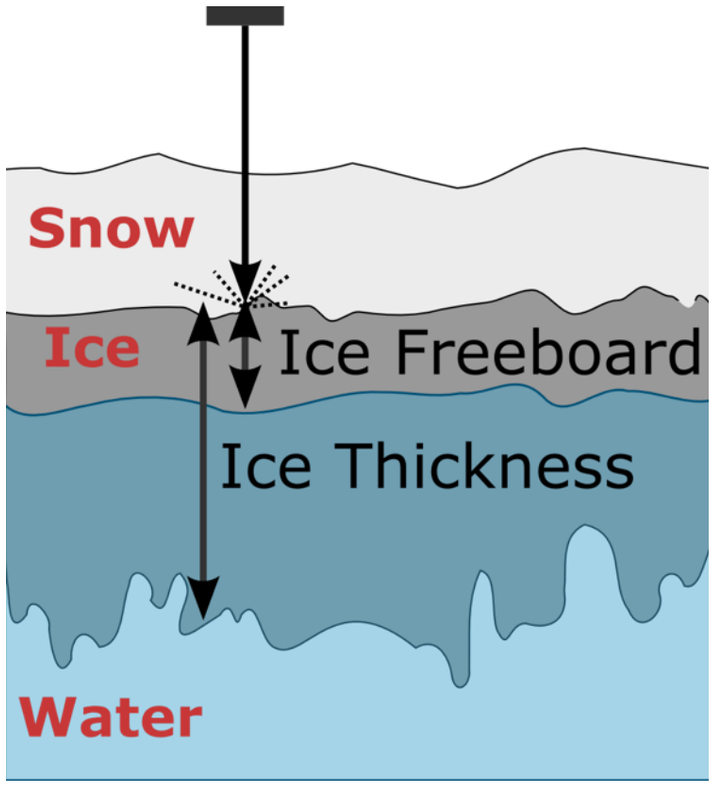
- Satellite altimeters sense the **sea-ice freeboard**, the height of the ice surface above the water level



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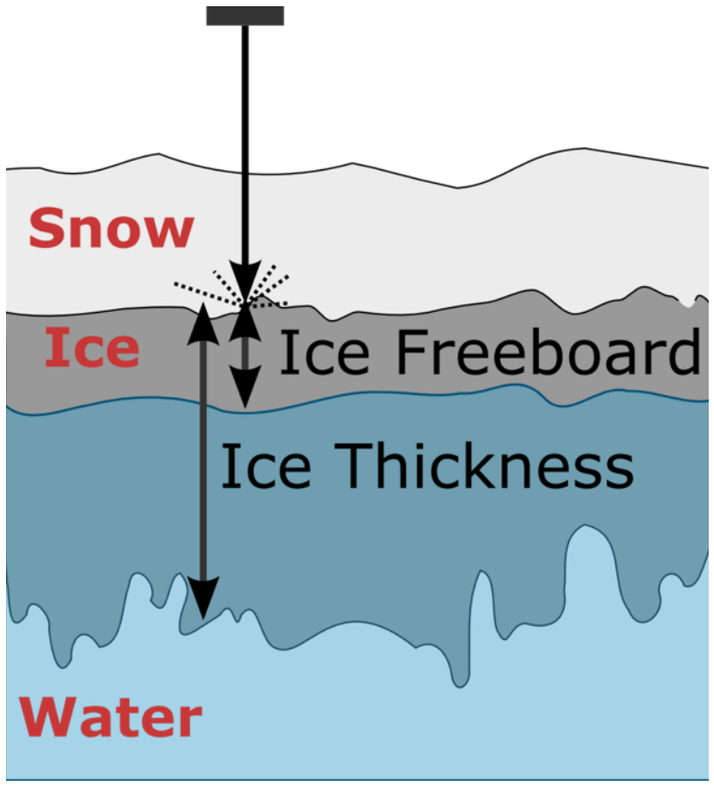

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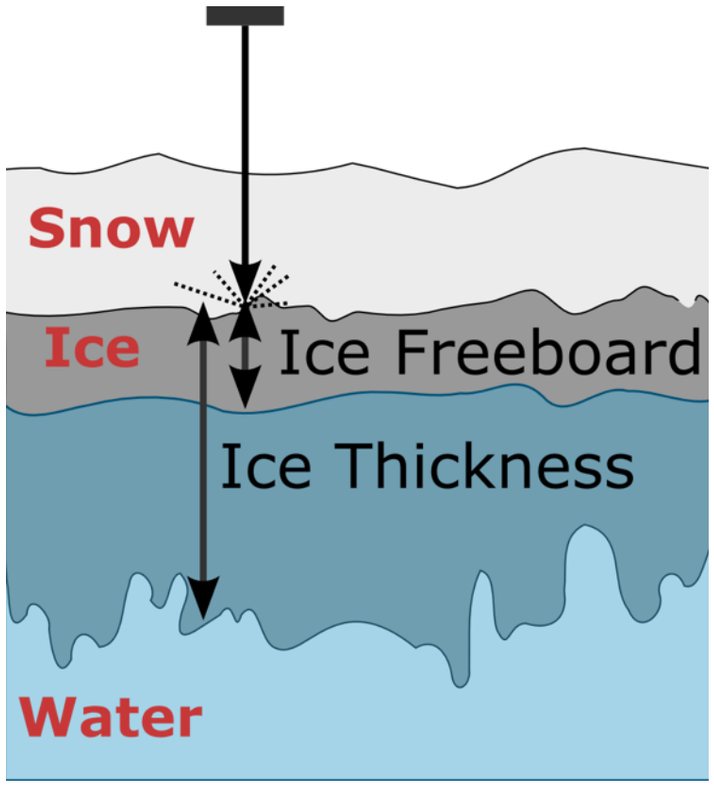

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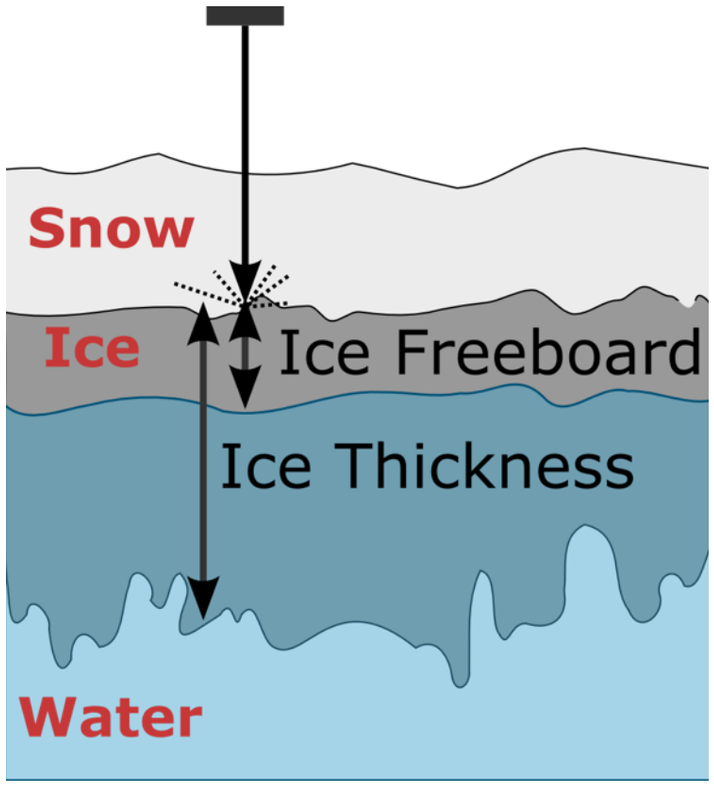
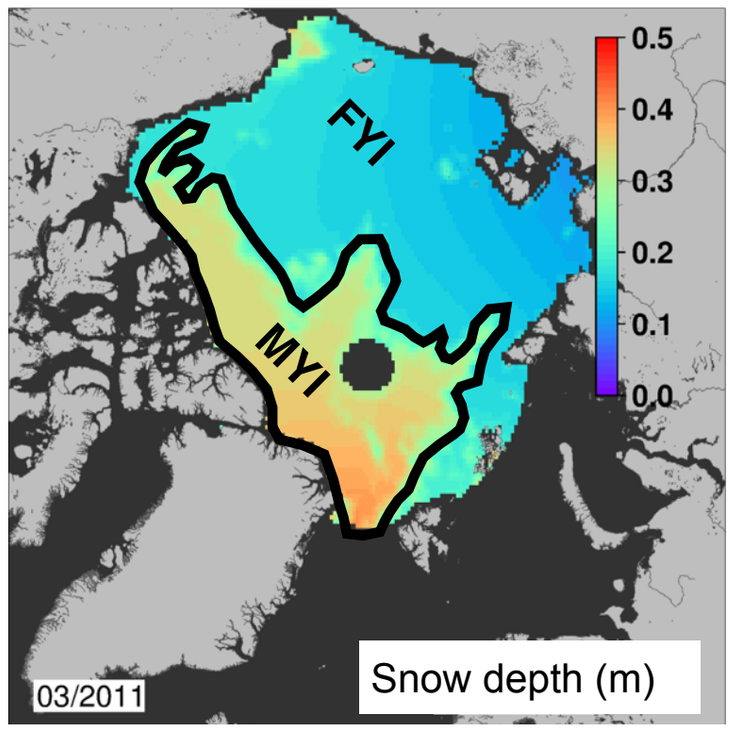


- **Snow depth** is a key parameter for the conversion

- The only available dataset which covers the entire Arctic is the **Warren climatology**



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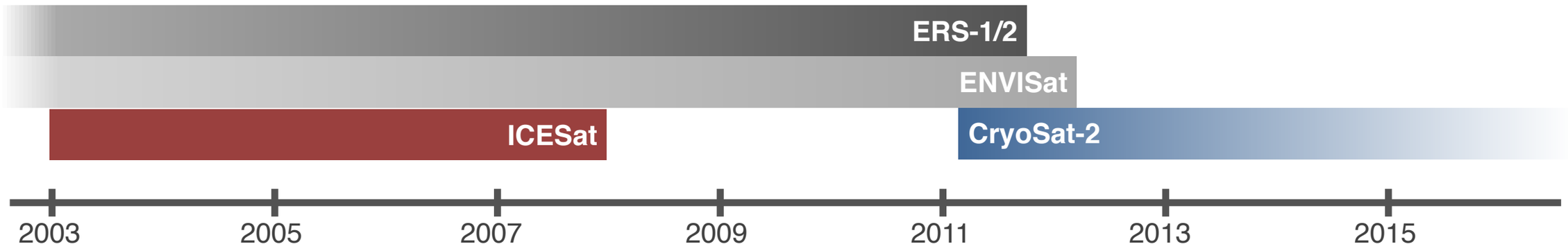
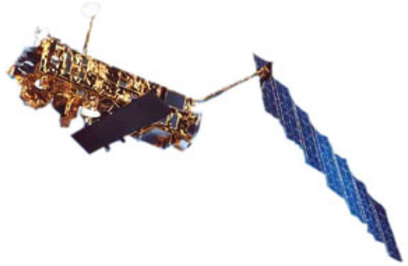
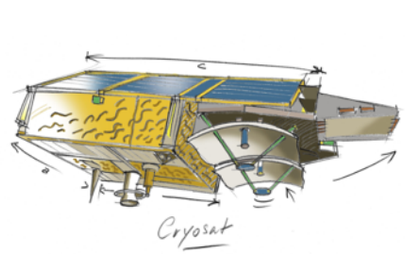
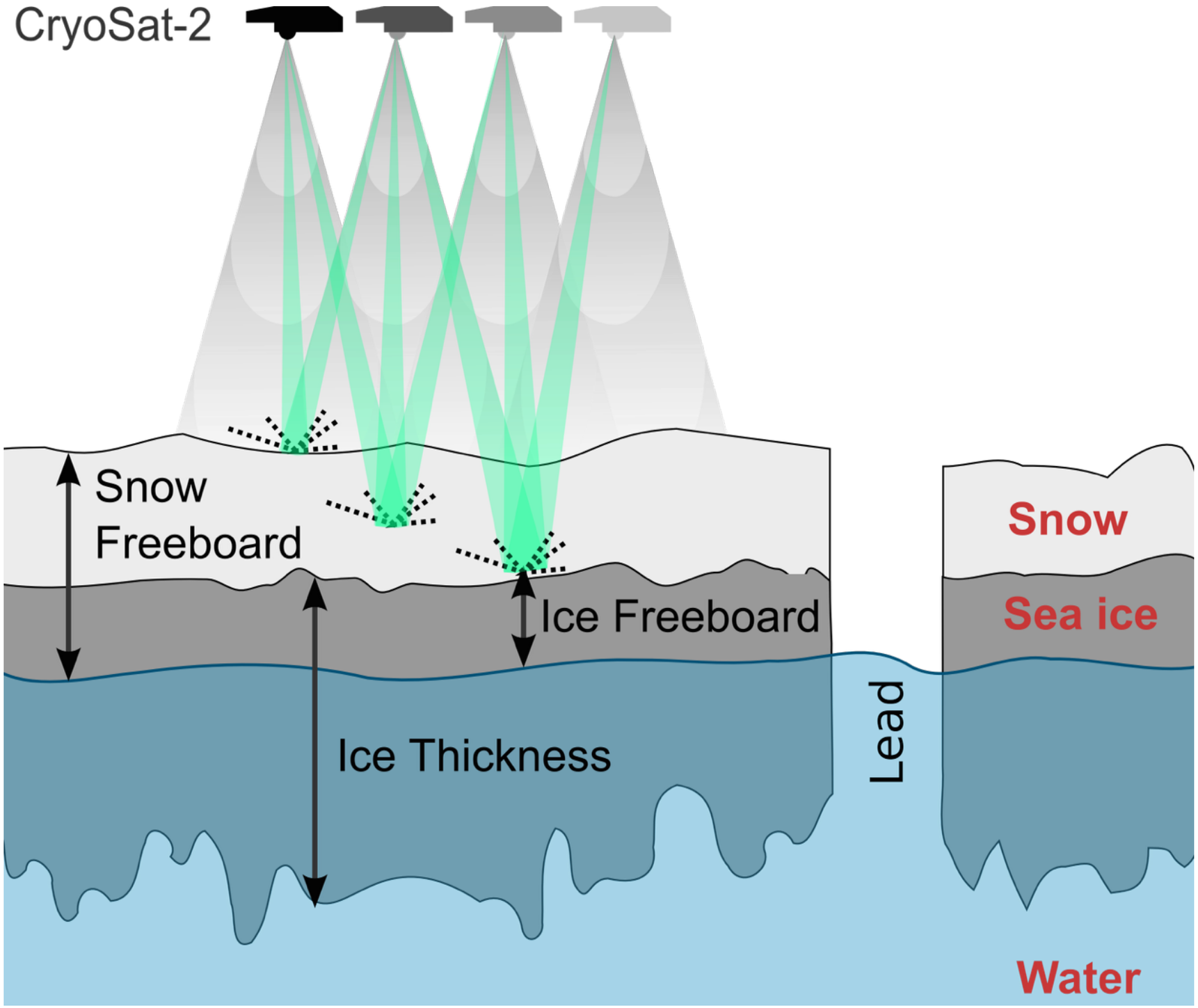






	ERS-2	ENVISat	ICESat	**CryoSat-2**
Altimeter Type	Radar K_u-Band	Radar K_u-Band	Laser	**Radar K_u-Band**
Max Latitude	81.5°	81.45°	86°	**88°**
Footprint	10 km	10 km	70 m	**300x1650 m**

Measuring Sea-Ice Freeboard



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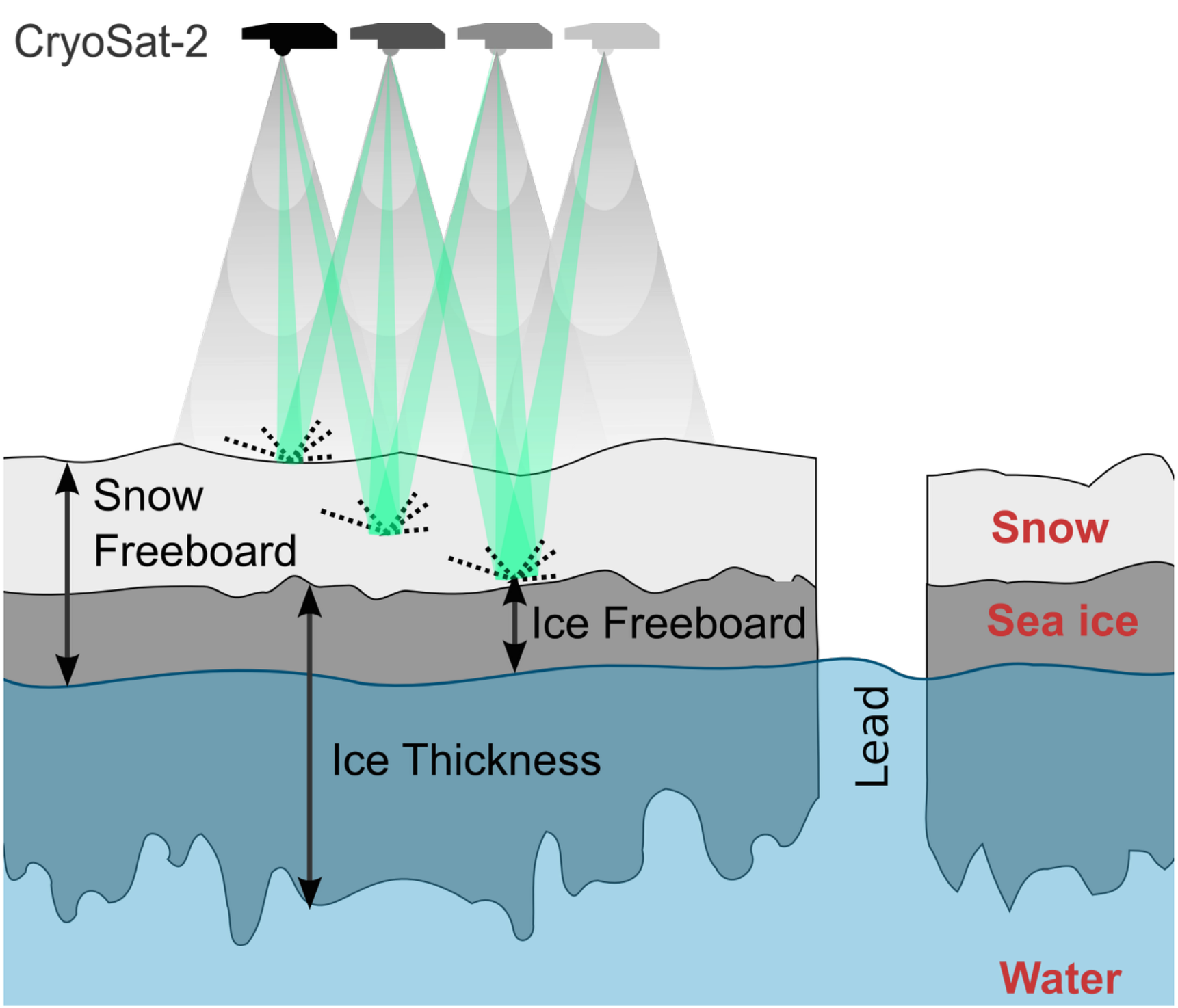

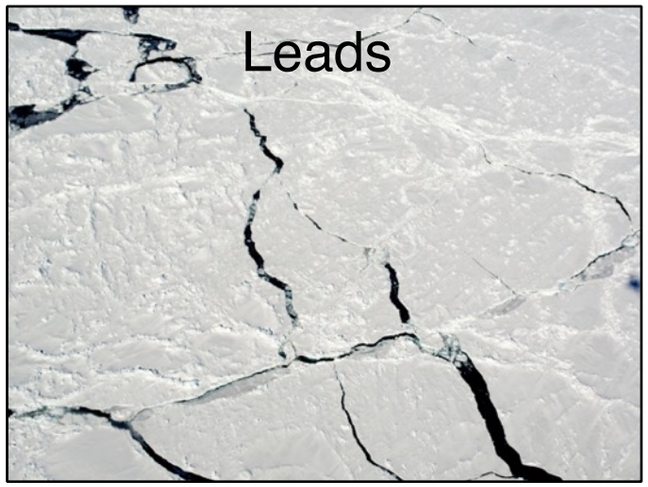

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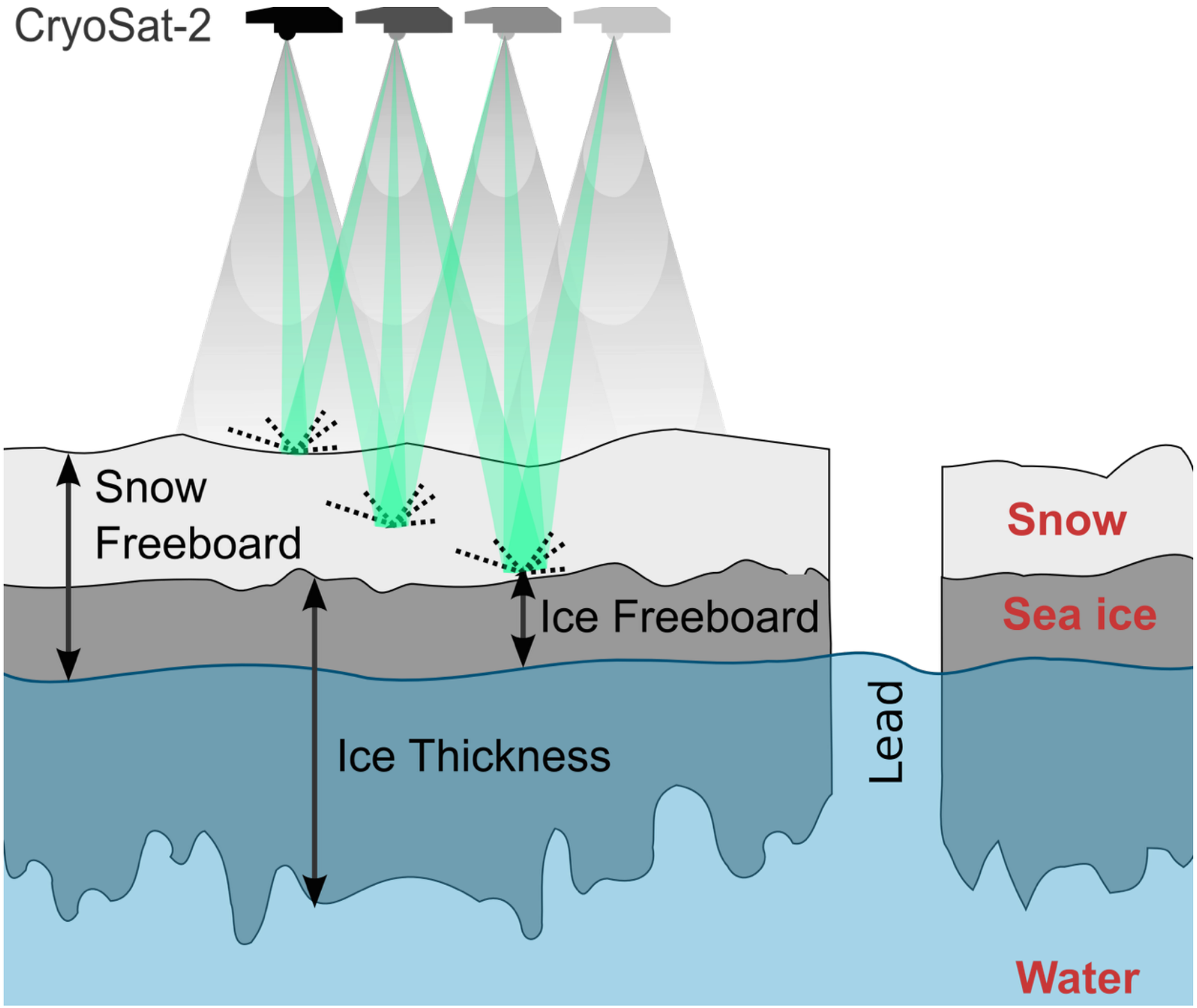

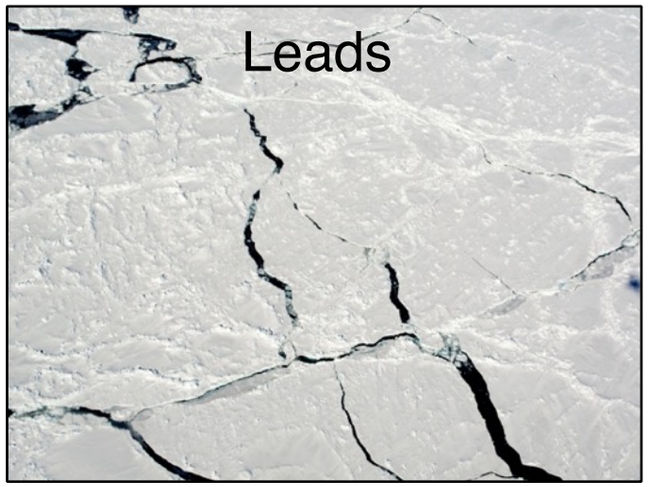

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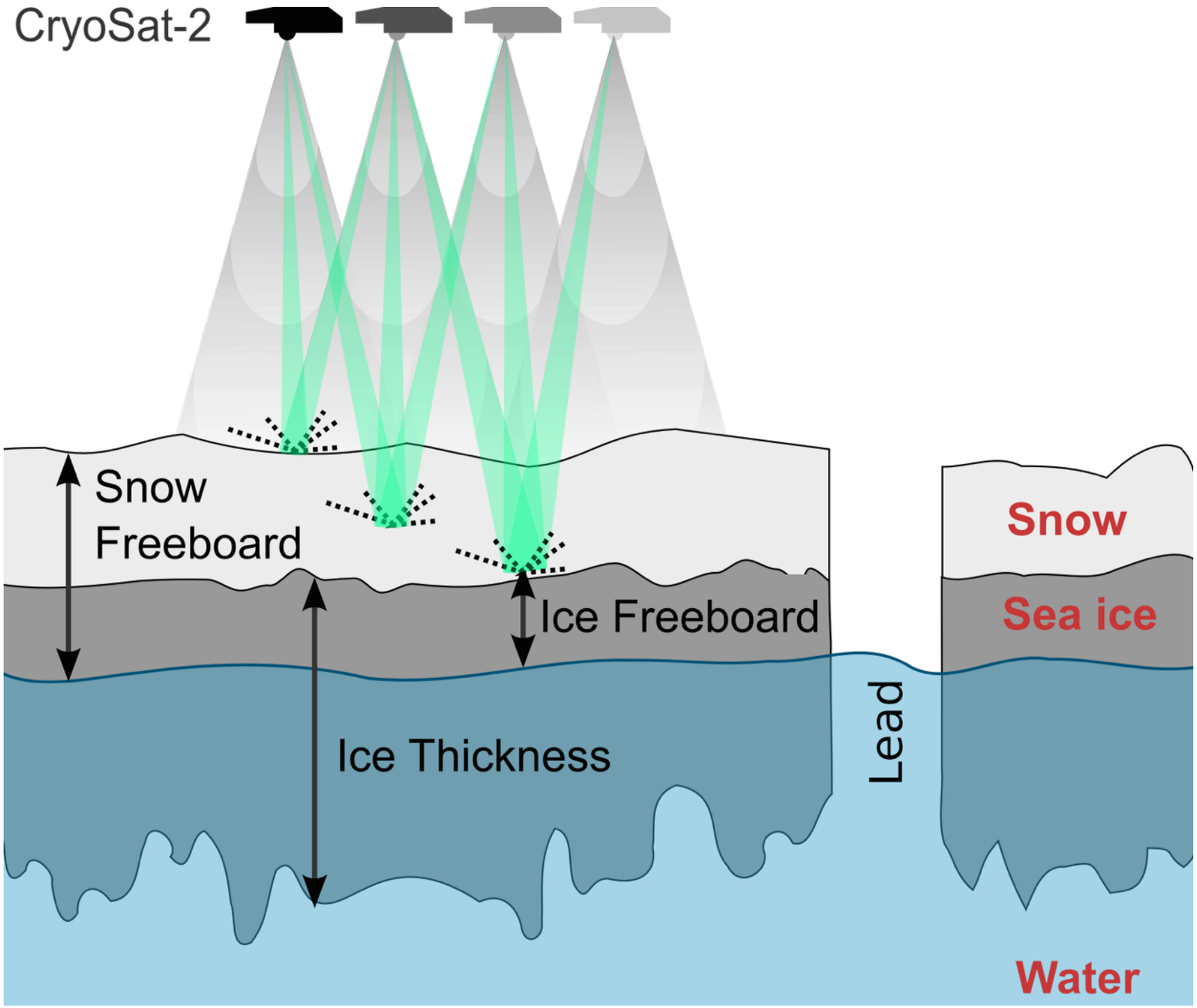
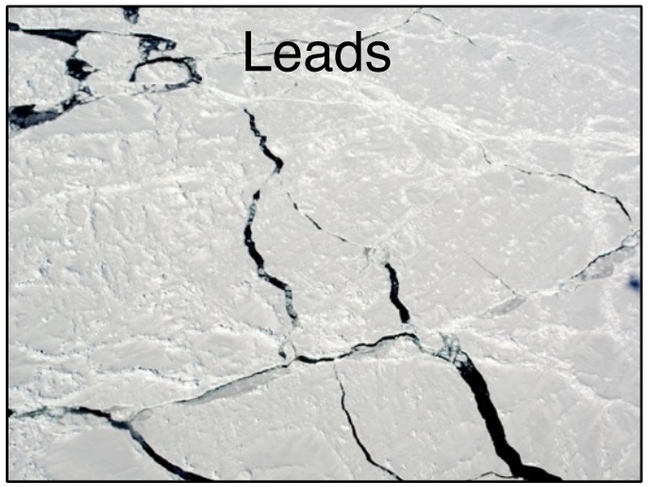
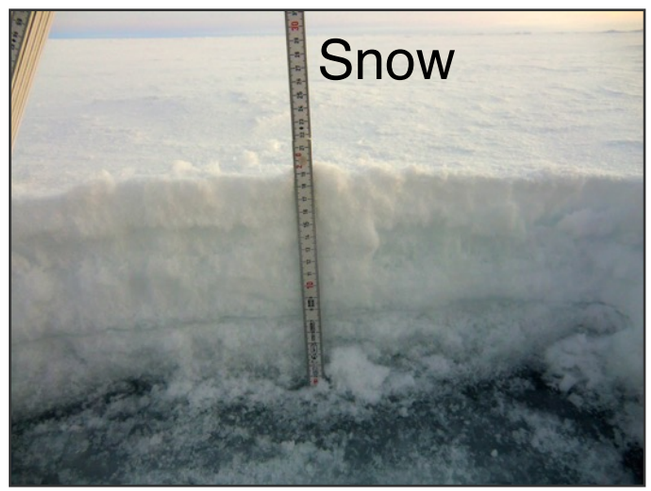
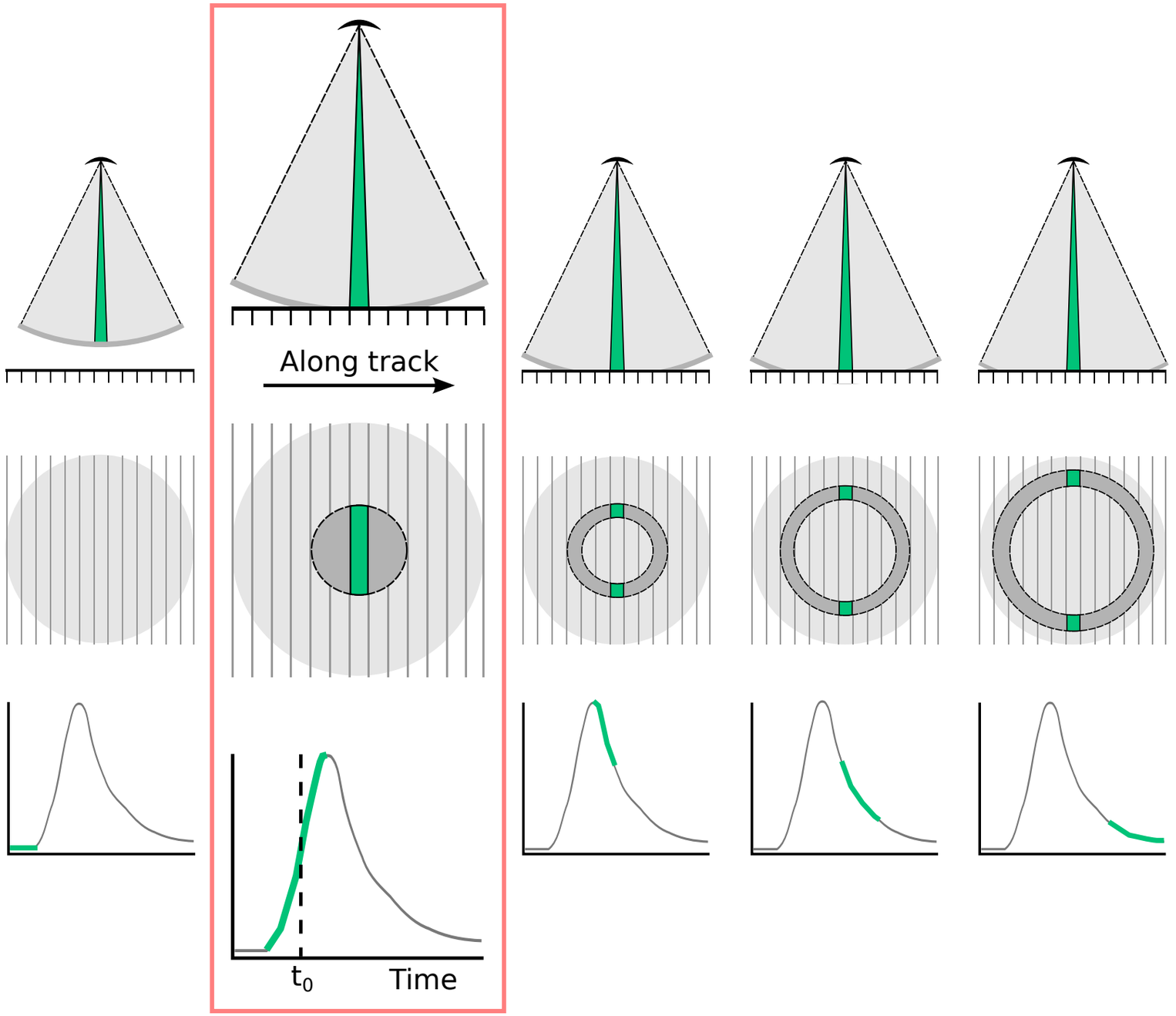






Tracking the Main Scattering Horizon

Side view/
Radar pattern

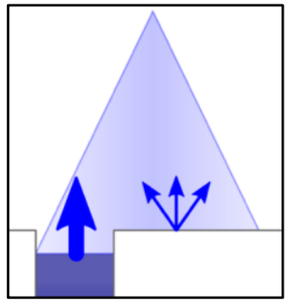


Footprint

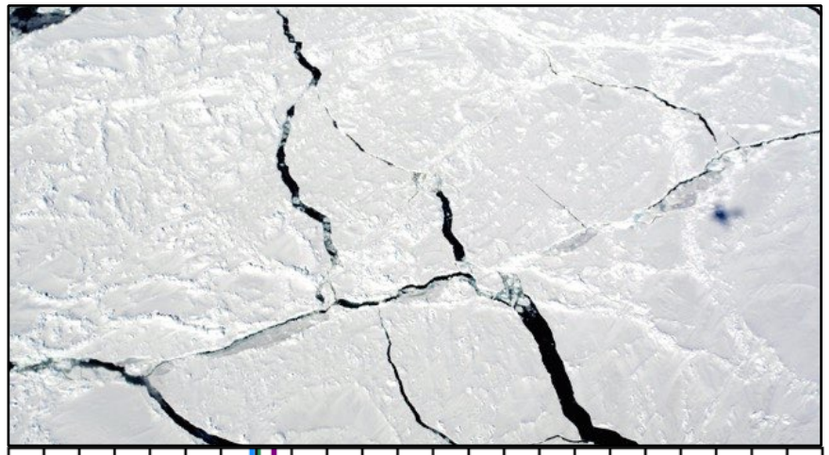
Echo power/
Waveform

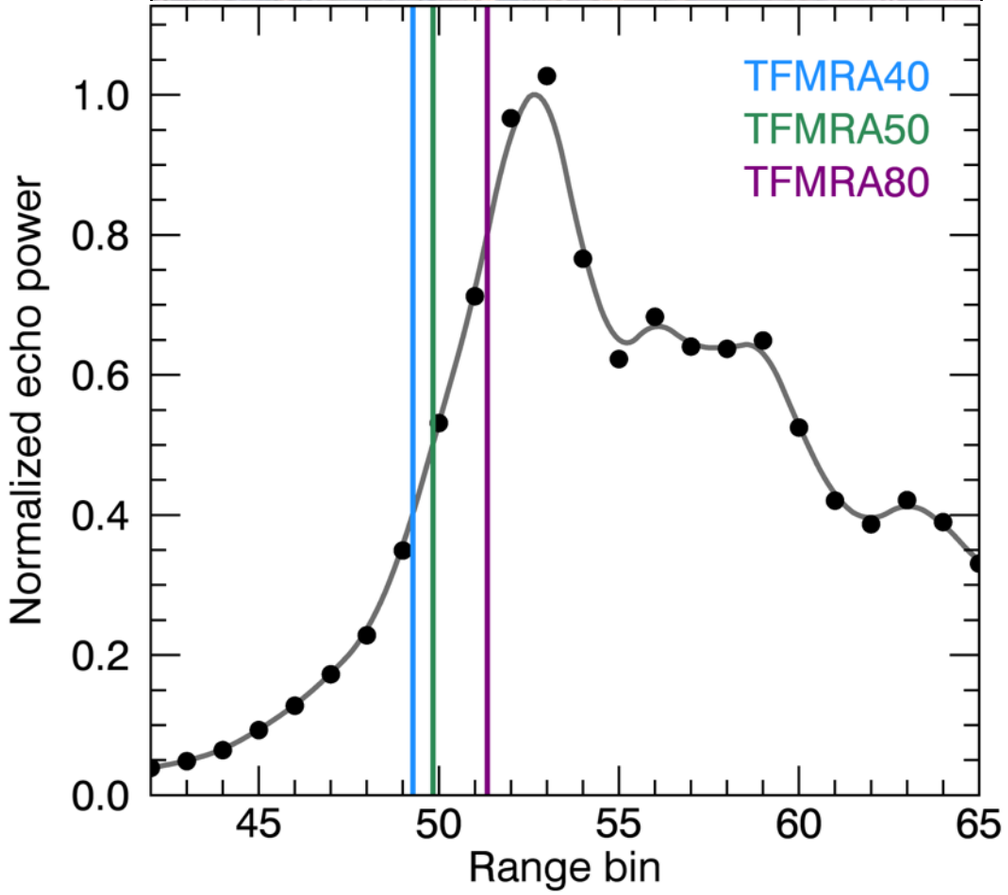
CryoSat-2 Waveforms

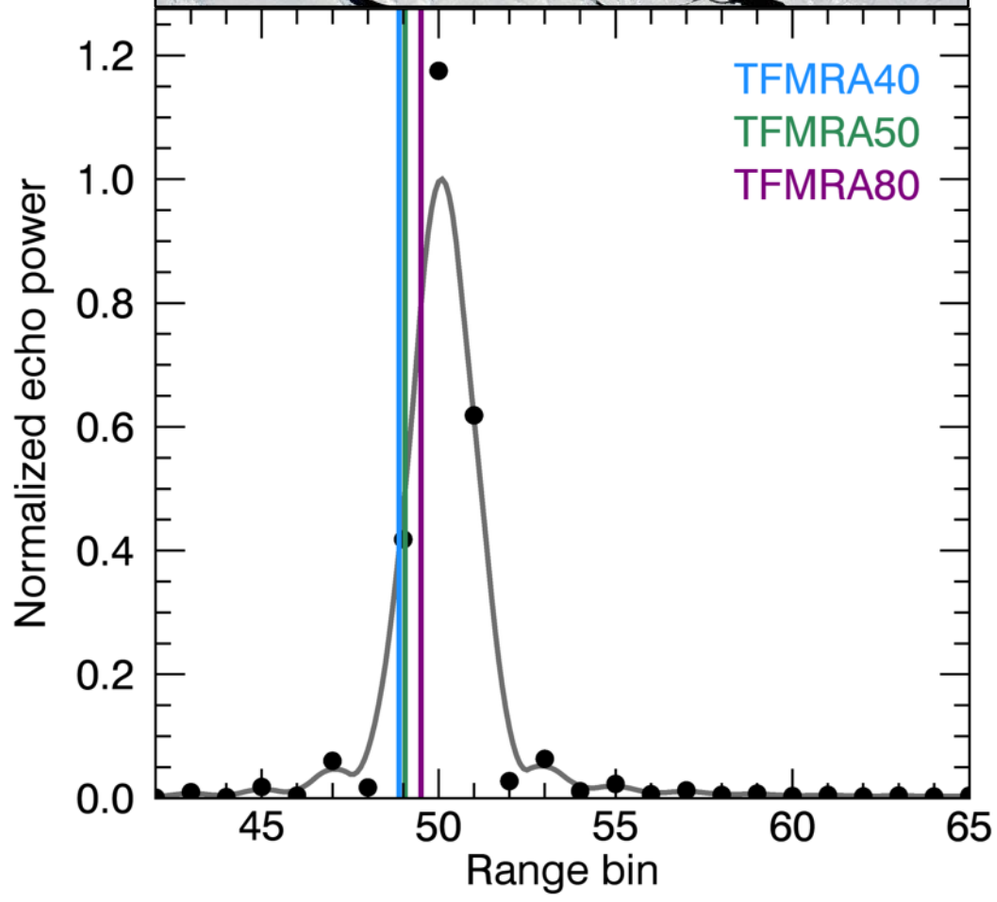
waveform over sea ice



waveform over sea ice + lead



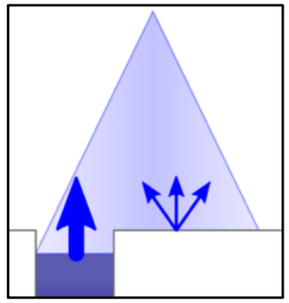




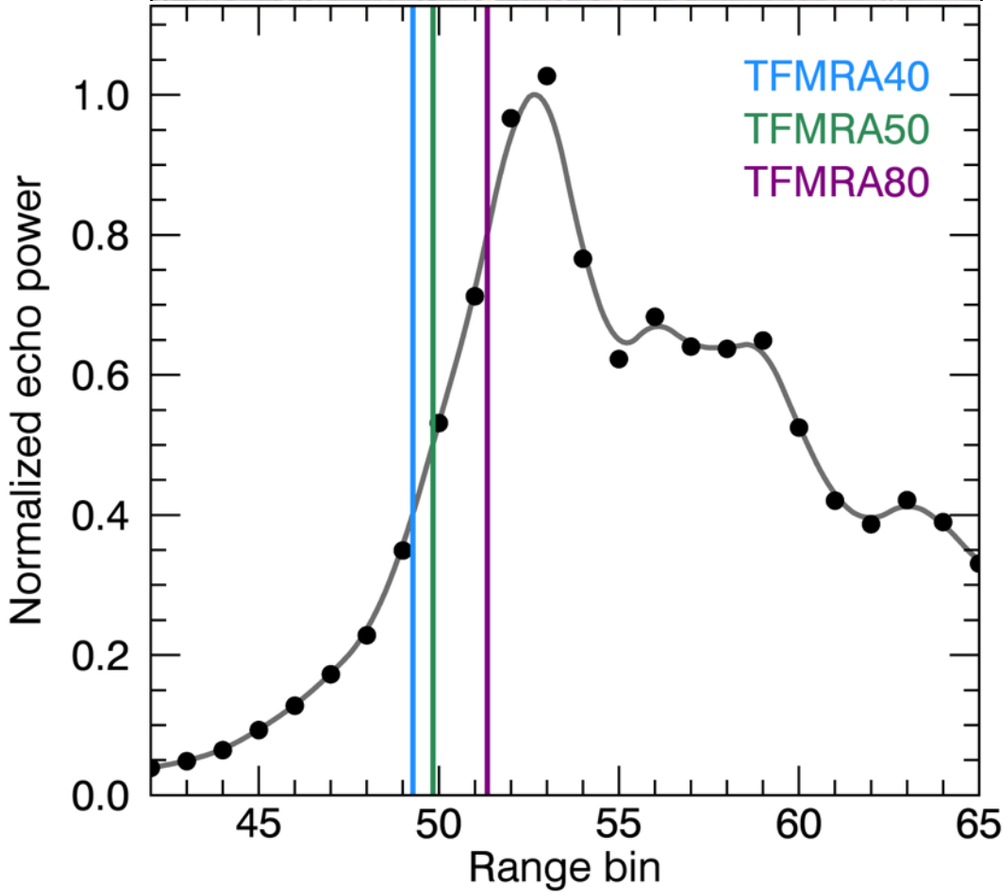
Ricker et al. (2014), TC

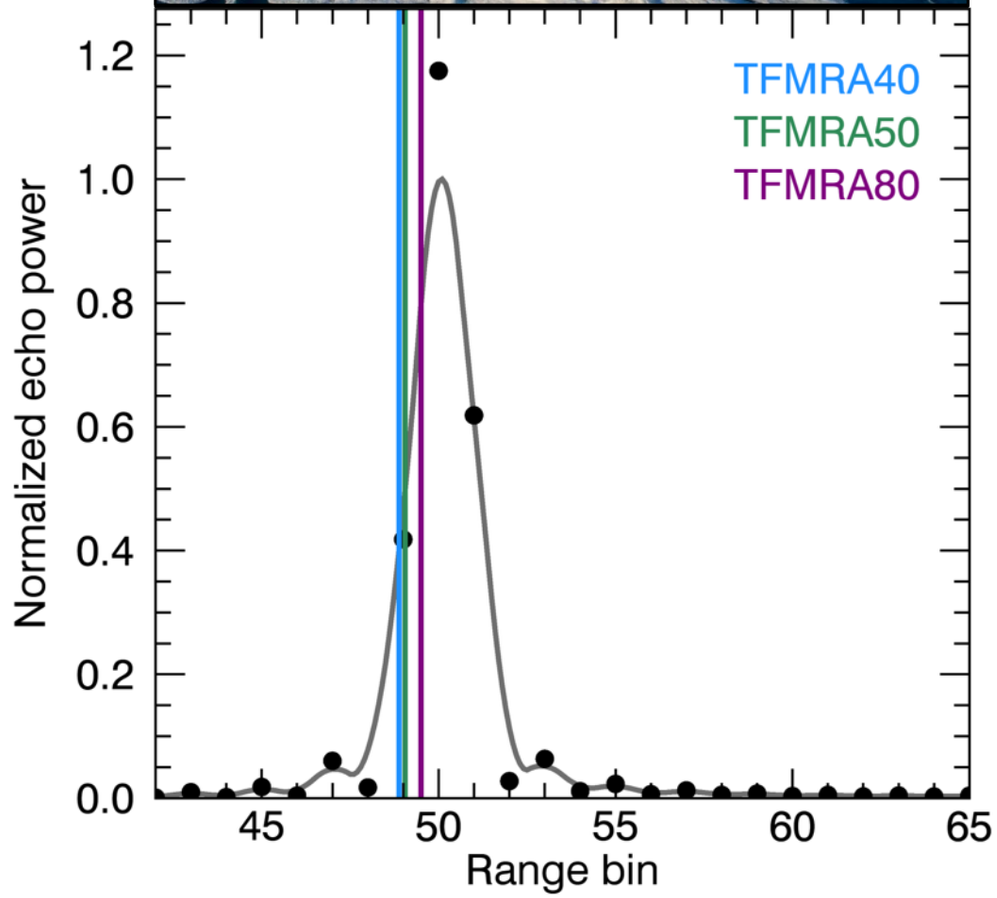
CryoSat-2 Waveforms

waveform over sea ice



waveform over melt ponds



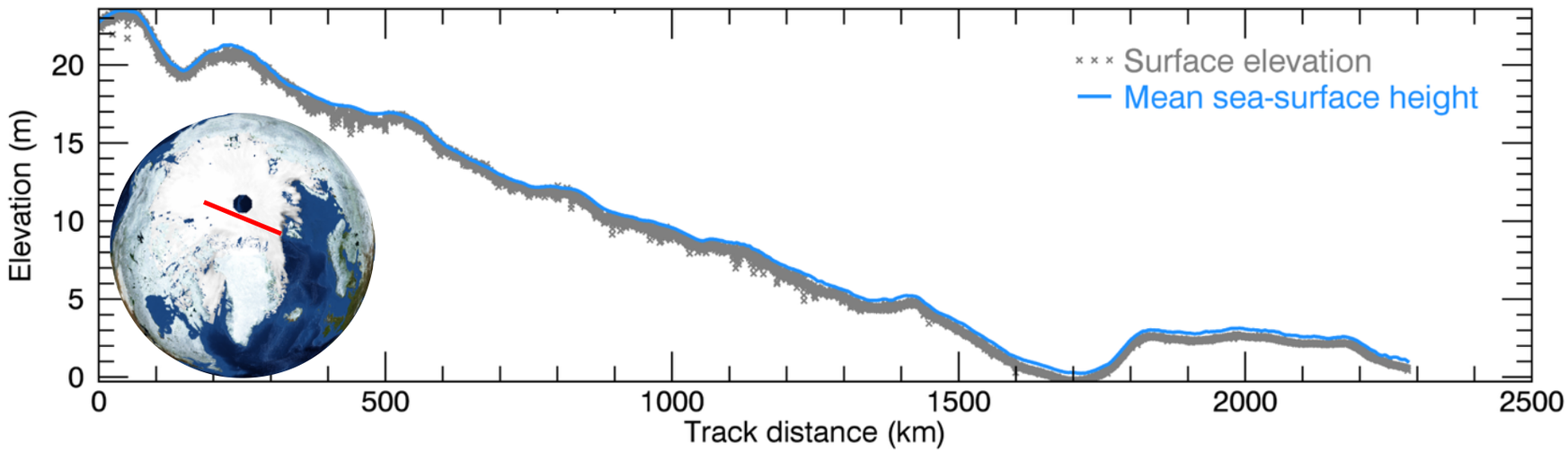


Ricker et al. (2014), TC

Calculating Freeboard along Track

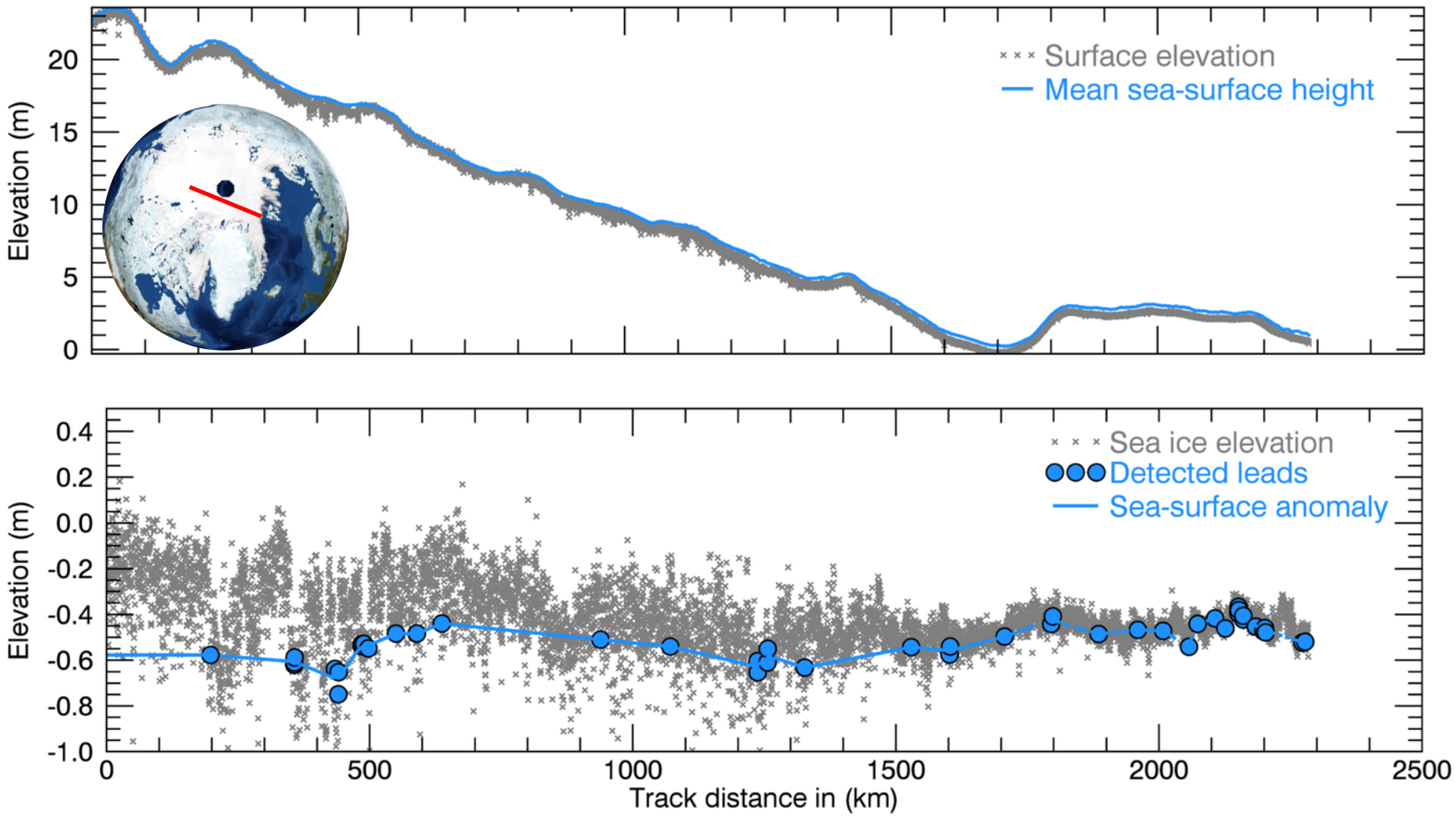
Calculating Freeboard along Track

- Subtracting mean sea-surface height



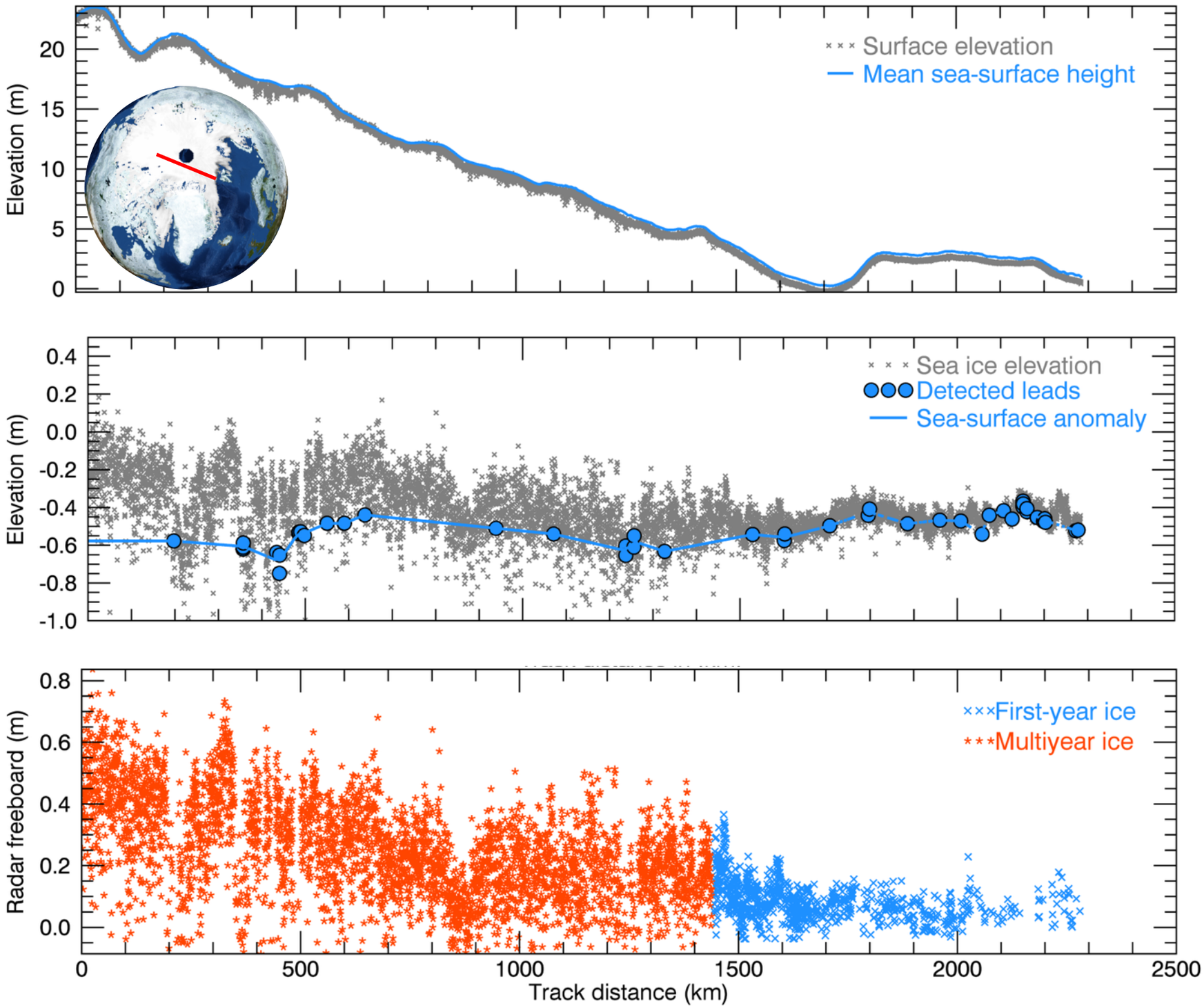
Calculating Freeboard along Track

- Subtracting mean sea-surface height
- Lead detection



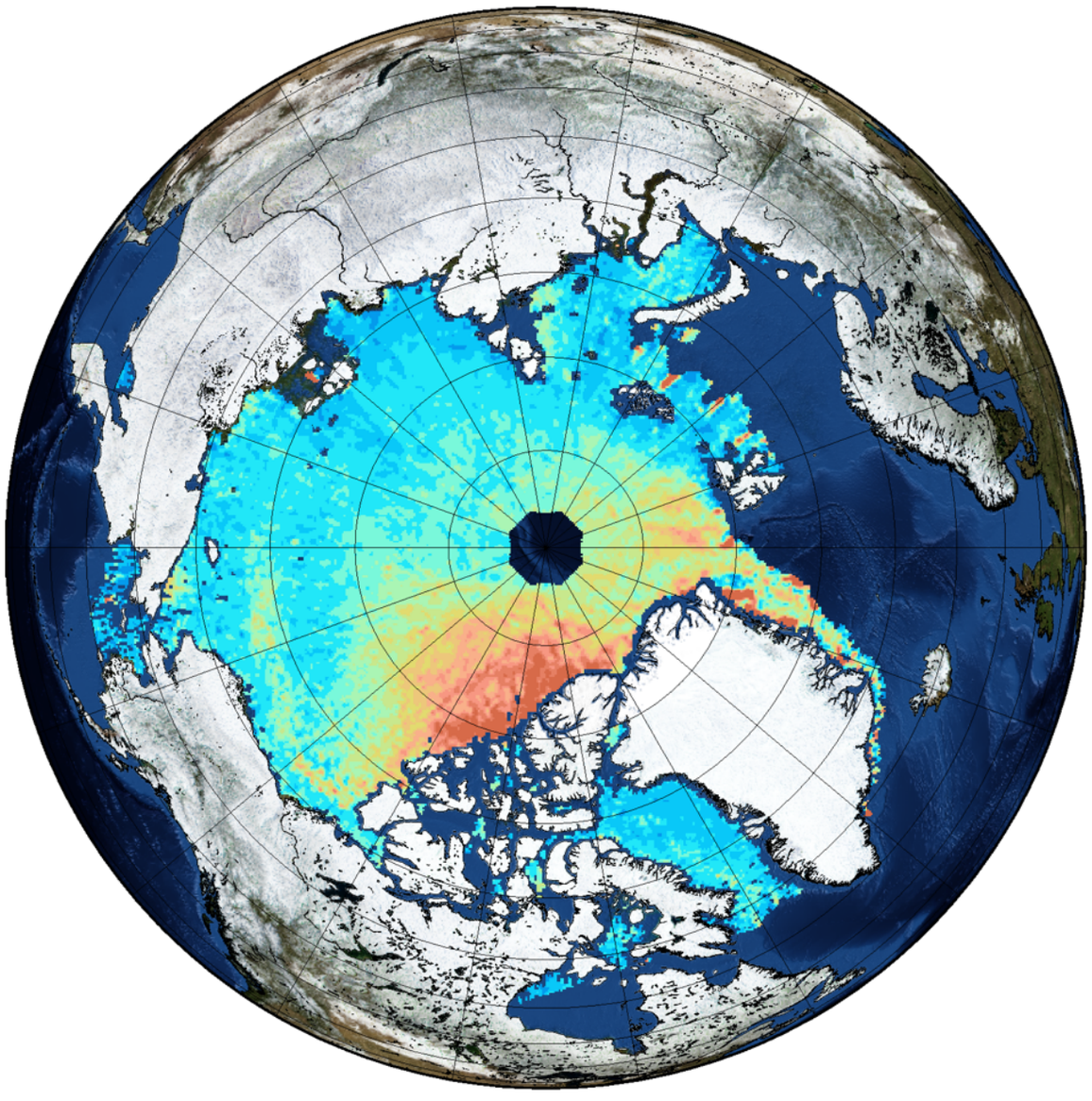
Calculating Freeboard along Track

- Subtracting mean sea-surface height
- Lead detection
- Subtracting interpolated sea-surface anomaly



Monthly Sea-ice Freeboard Retrieval

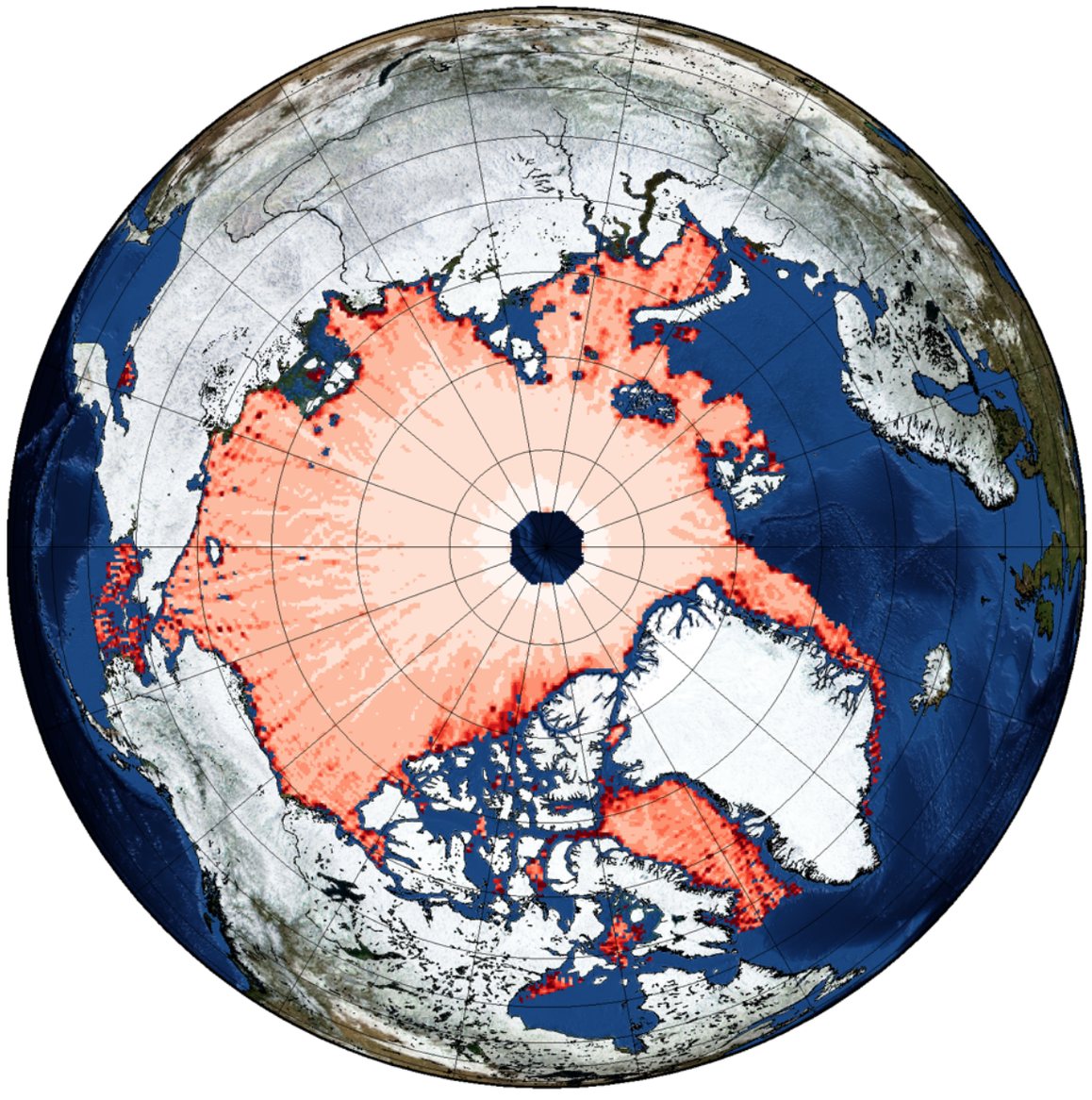
March 2015



sea ice freeboard (m)

0.0 0.1 0.2 0.3 0.4 0.5 0.6

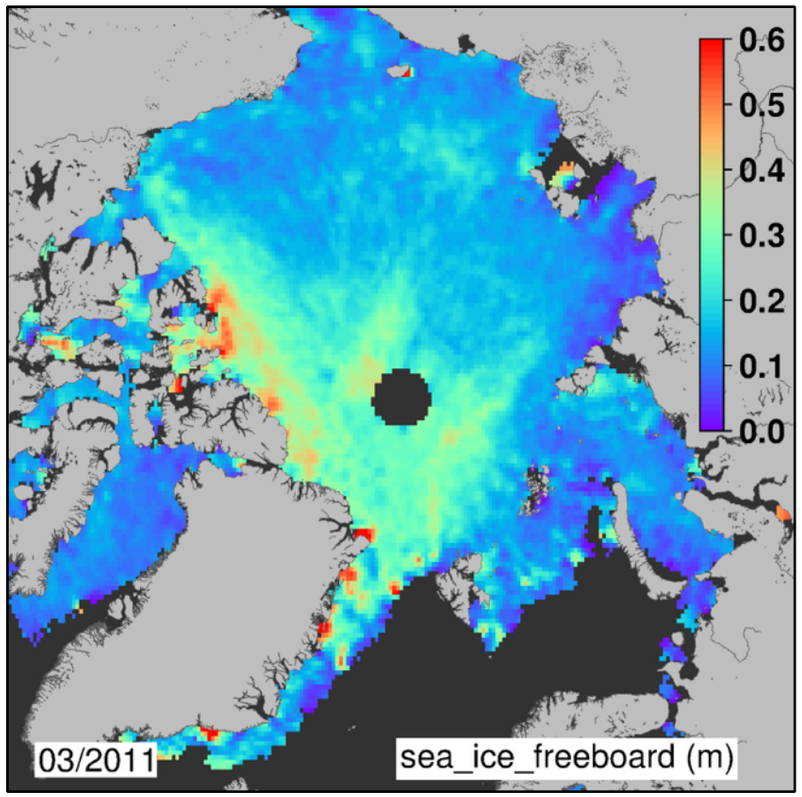
March 2015



freeboard uncertainty (m)

0.00 0.02 0.04 0.06 0.08

Airborne Validation



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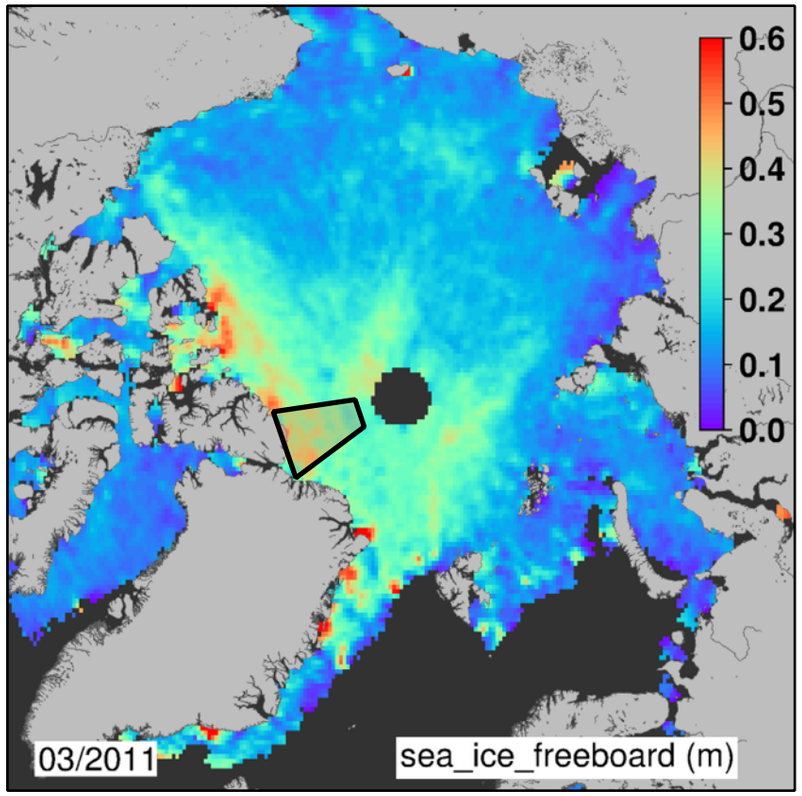
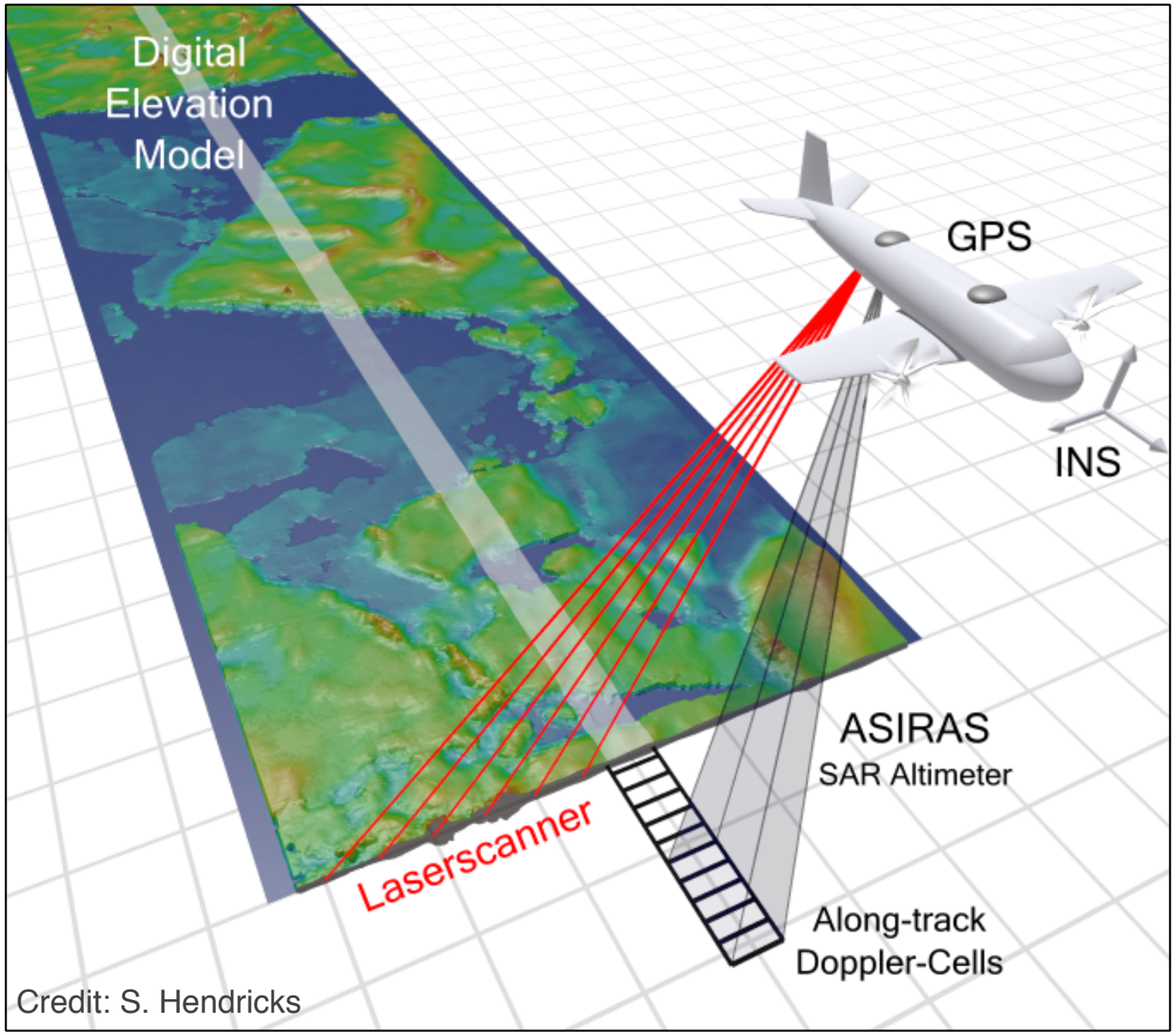
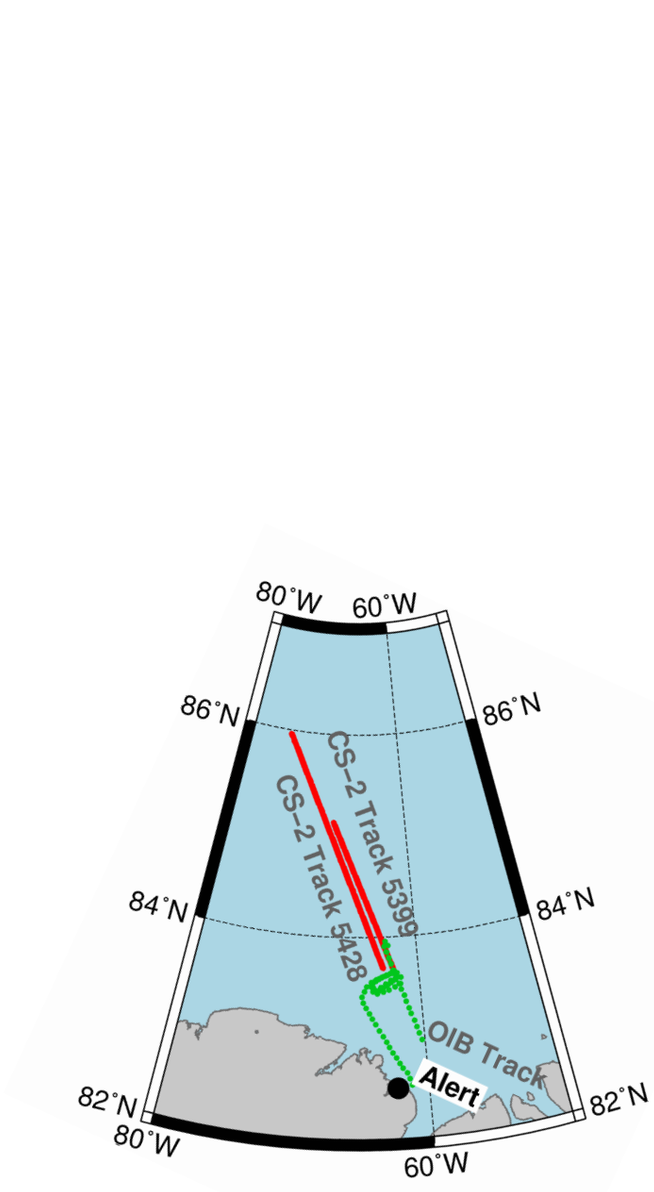
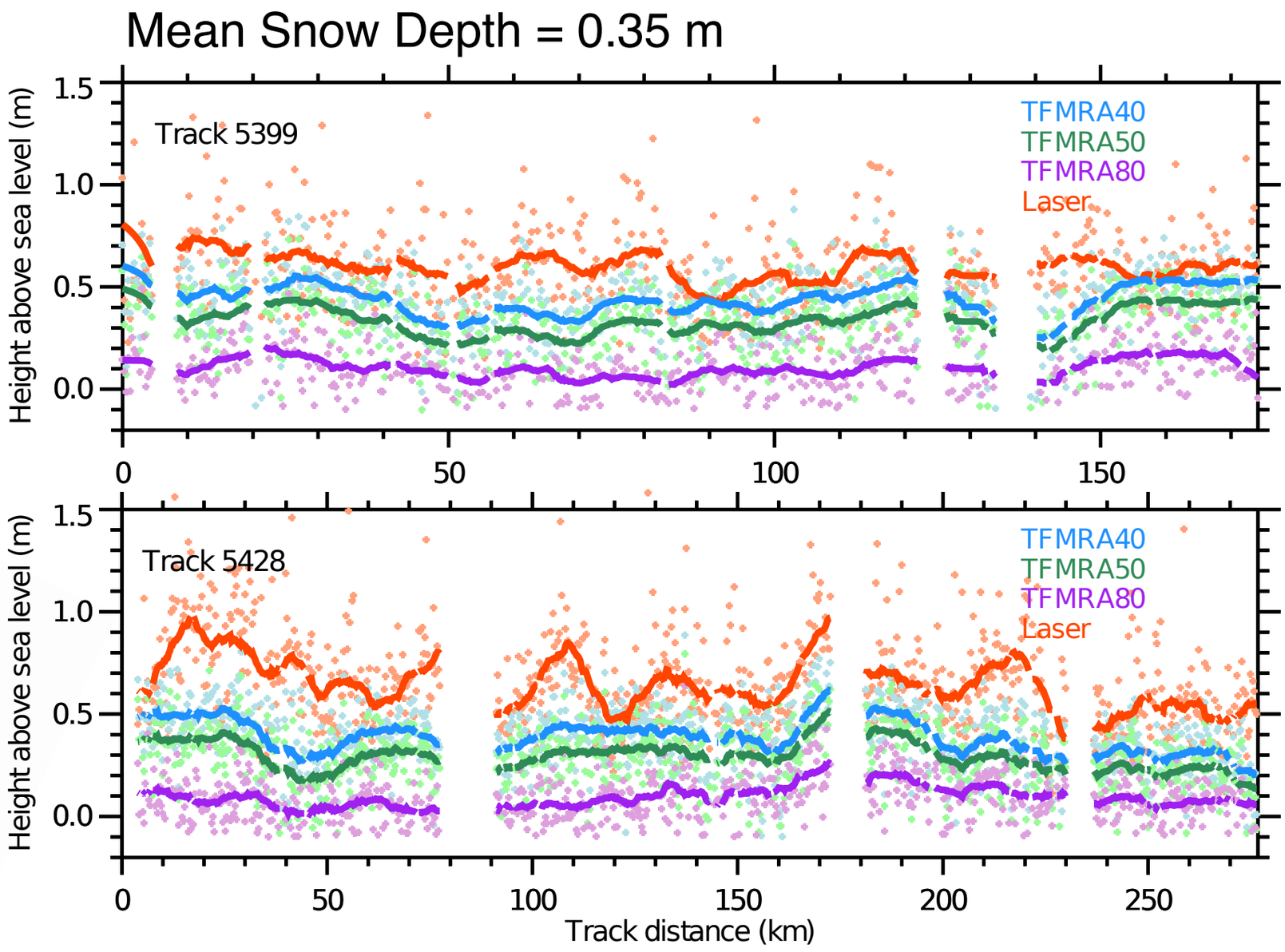




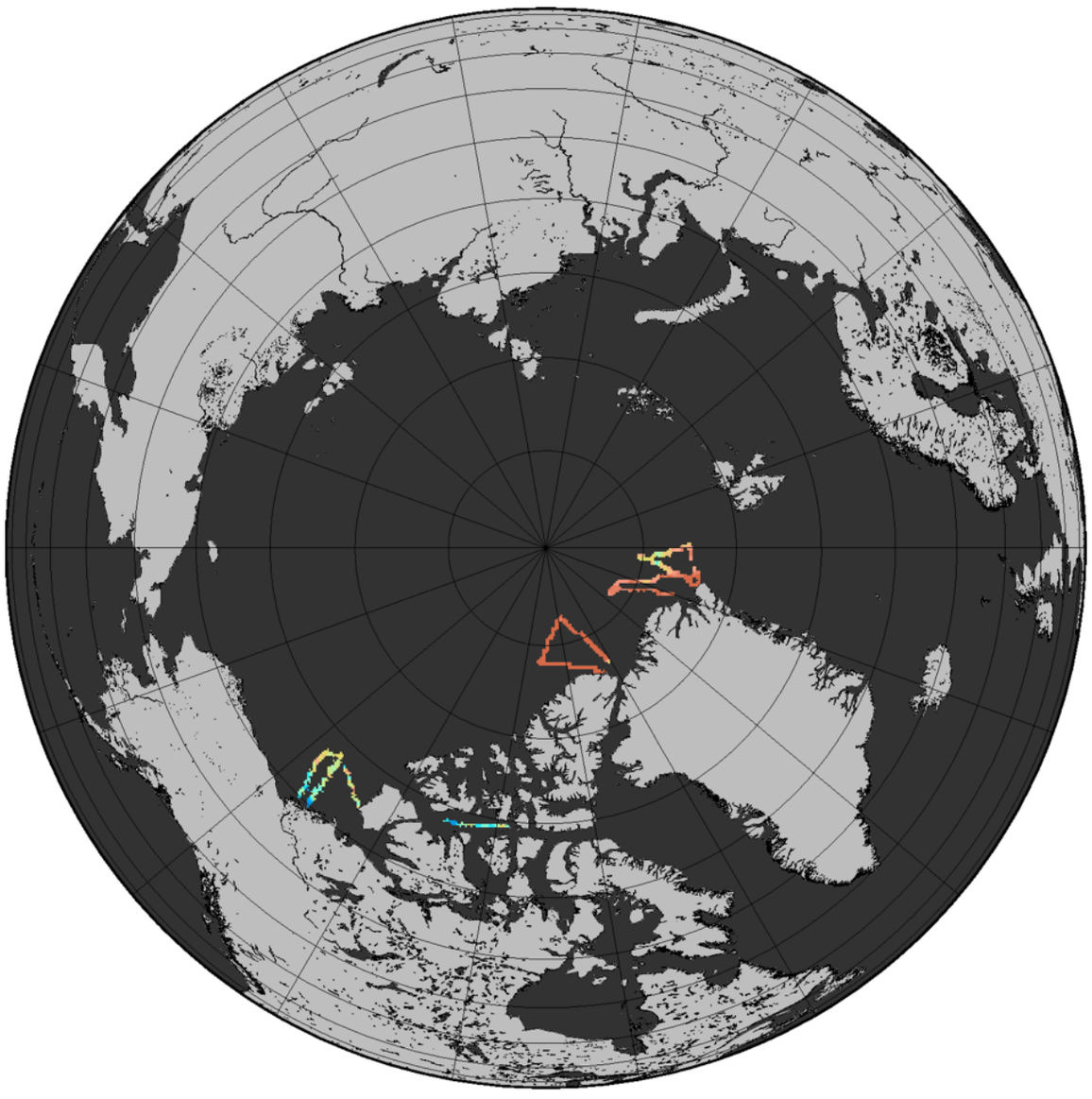
Laser Scanner vs. CryoSat-2





Laser Scanner vs. CryoSat-2

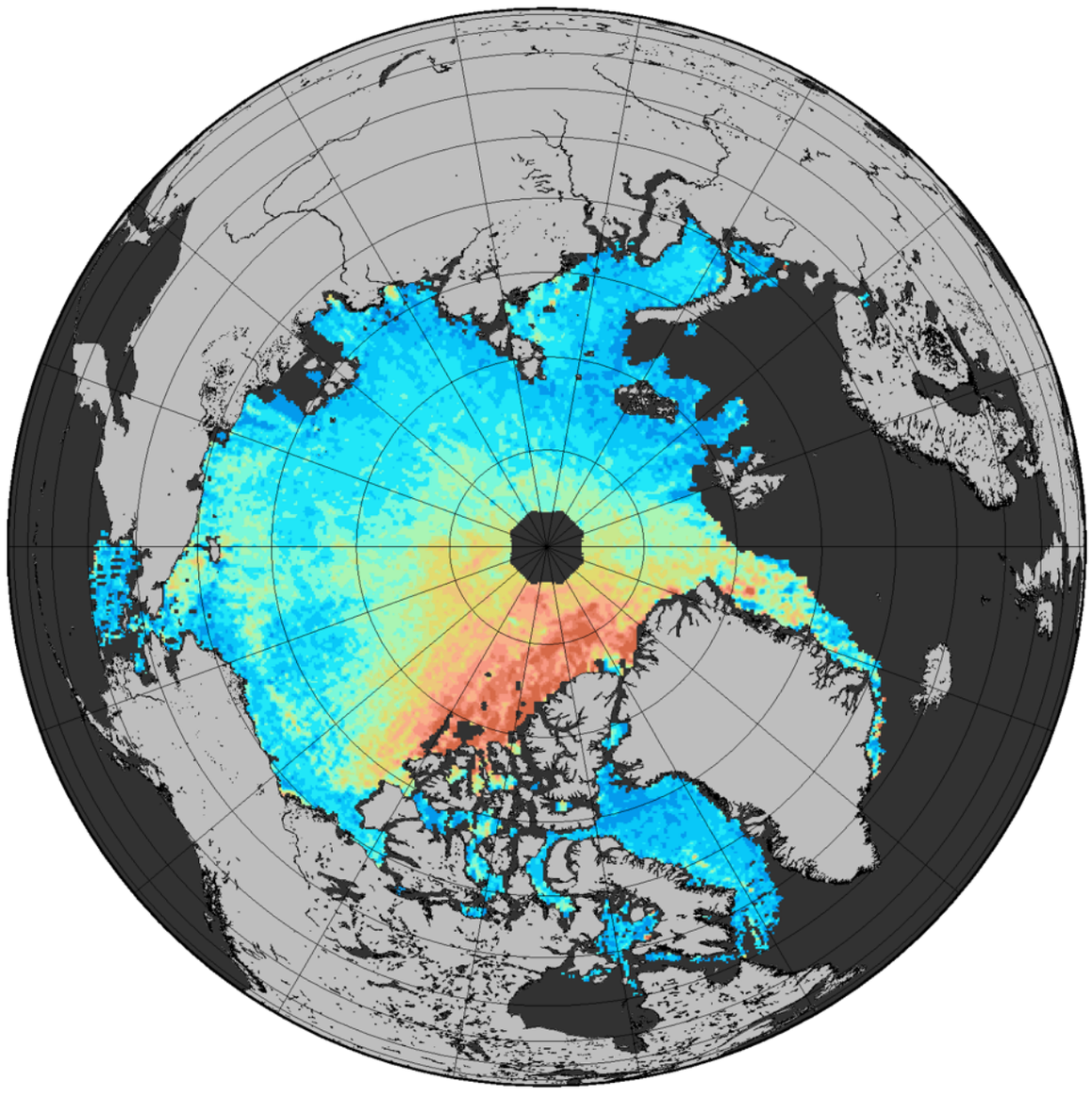
Airborne Laser Scanner: March 2013



Sea ice freeboard (m)

0.0 0.1 0.2 0.3 0.4 0.5 0.6

CryoSat-2: March 2013



Sea ice freeboard (m)

0.0 0.1 0.2 0.3 0.4 0.5 0.6

Sea-ice Thickness Retrieval

- Converting freeboard into thickness by assuming hydrostatic equilibrium

$$T = \frac{\rho_w}{\rho_w - \rho_i} F_{\mathrm{I}} + \frac{\rho_s}{\rho_w - \rho_i} S$$

T Sea-ice thickness

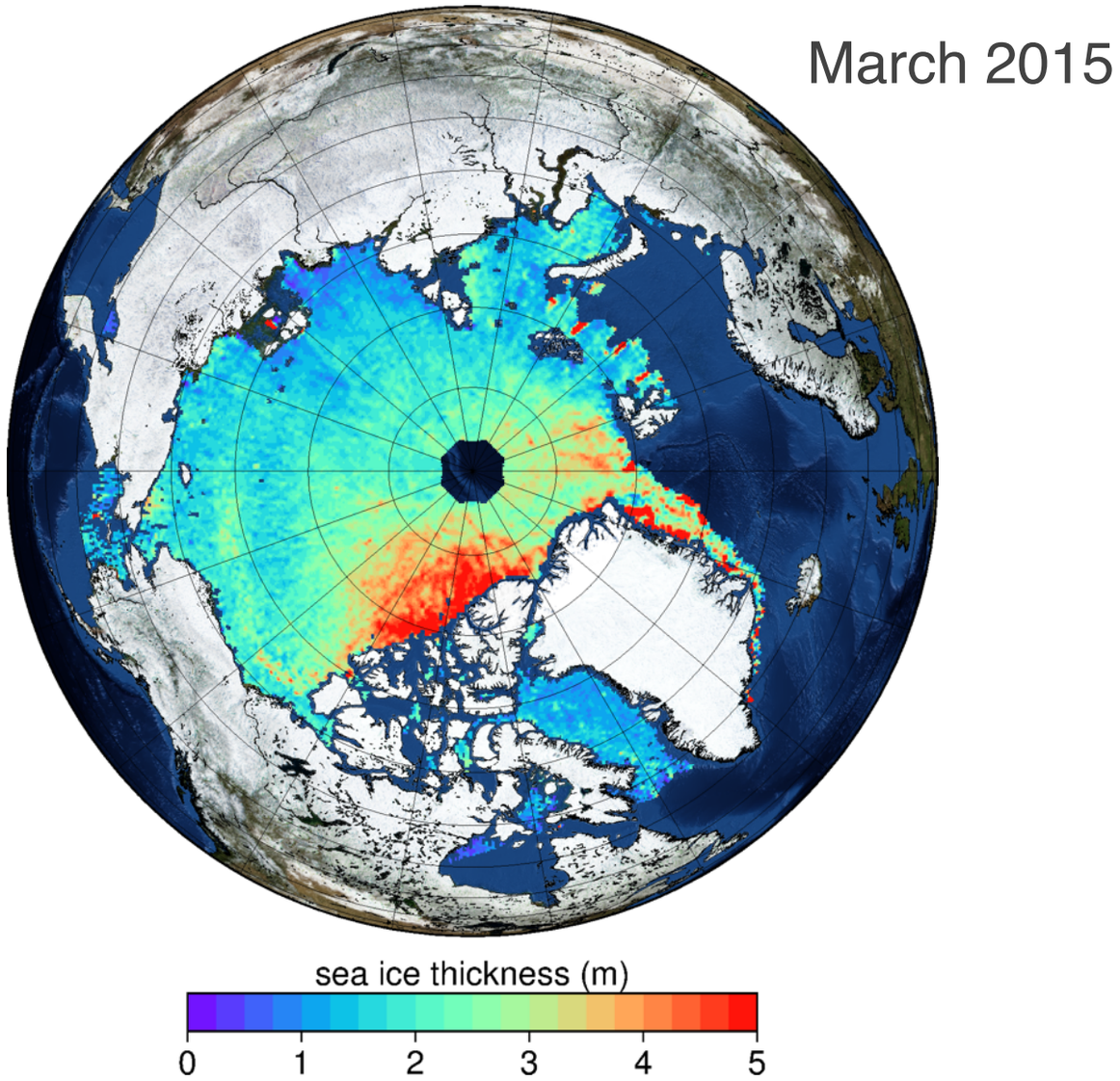
F_I Sea-ice freeboard

S Snow depth

ρ_w Water density

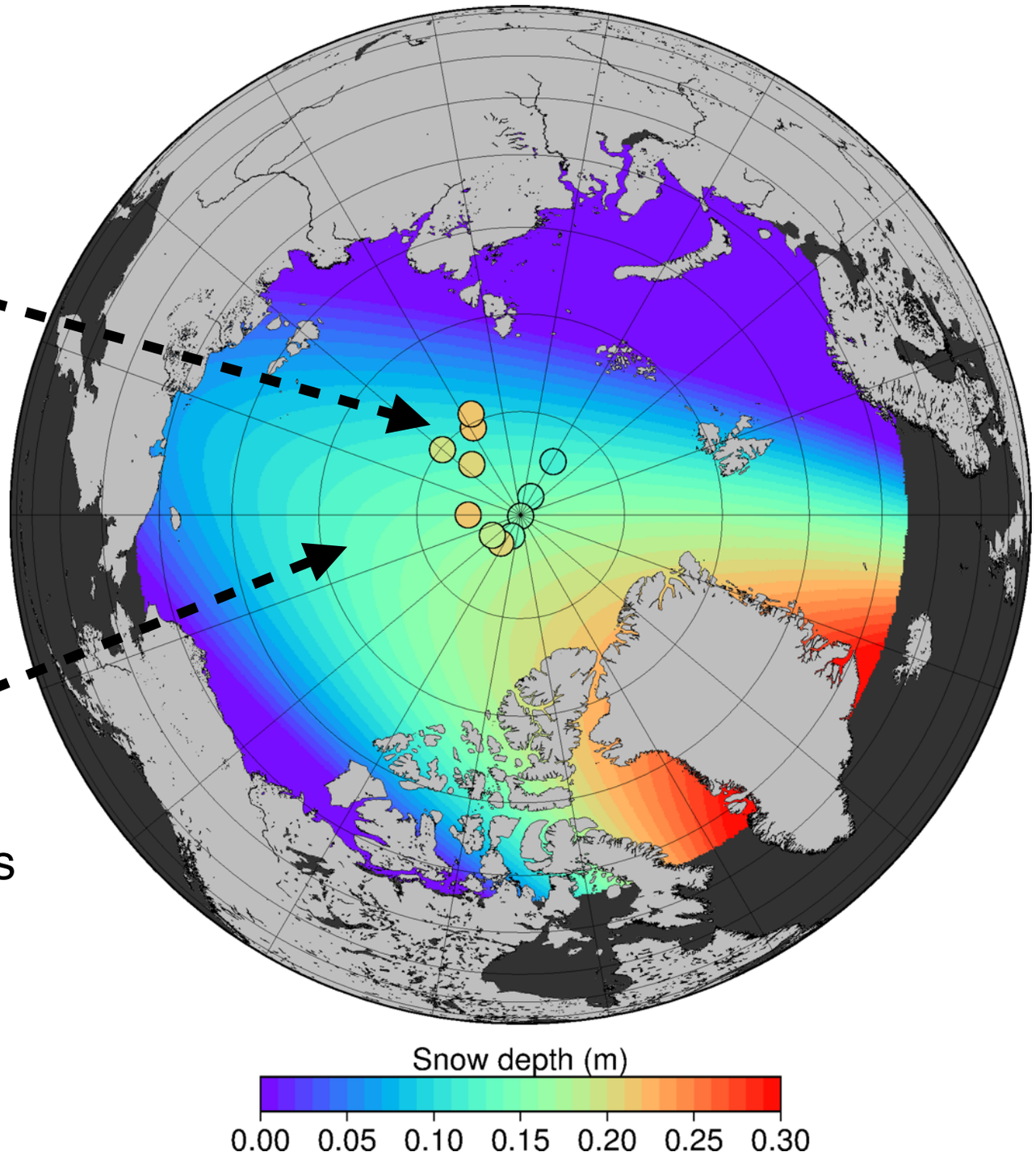
ρ_i Ice density

ρ_s Snow density



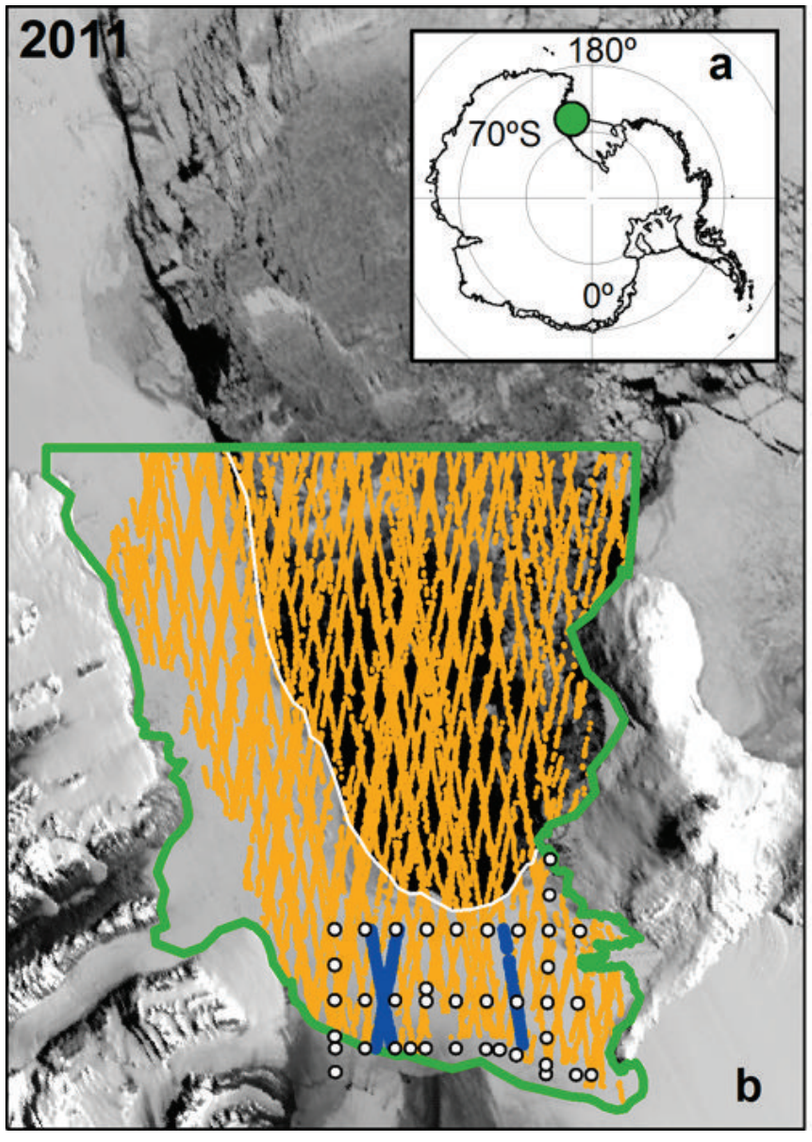
The Variability of Snow Depth

Warren snow climatology:
Snow depth and density were measured at Soviet drifting stations on multiyear Arctic sea-ice for 37 years (1954-1991)



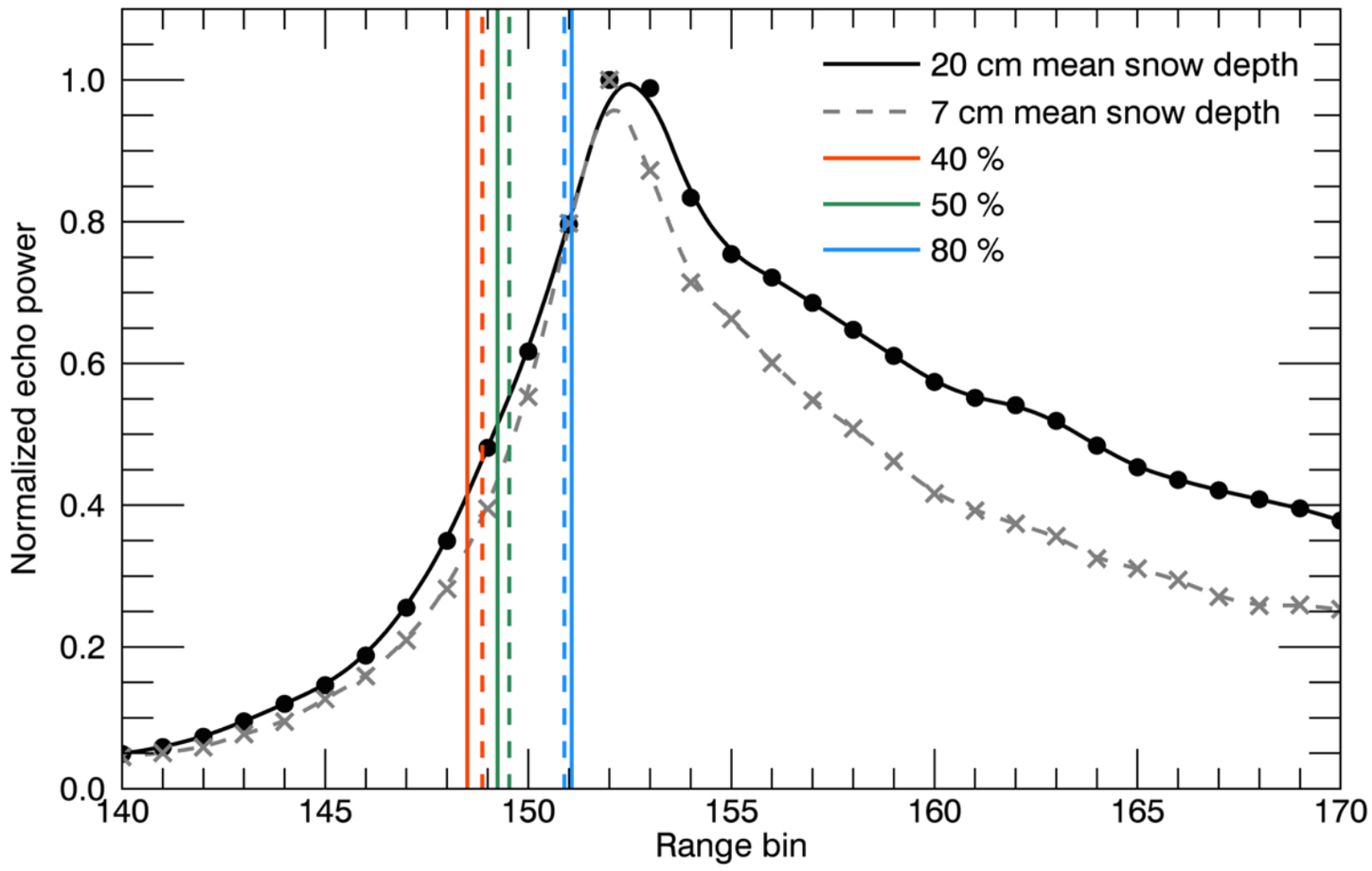
The Impact of Snow on Waveforms

CryoSat-2 validation lines on fast-ice in McMurdo Sound (Antarctica):



Price et al. (2015): *Evaluation of CryoSat-2 derived sea ice freeboard over fast-ice in McMurdo Sound, Antarctica.*

Different power thresholds applied on two stacked CryoSat-2 waveforms:

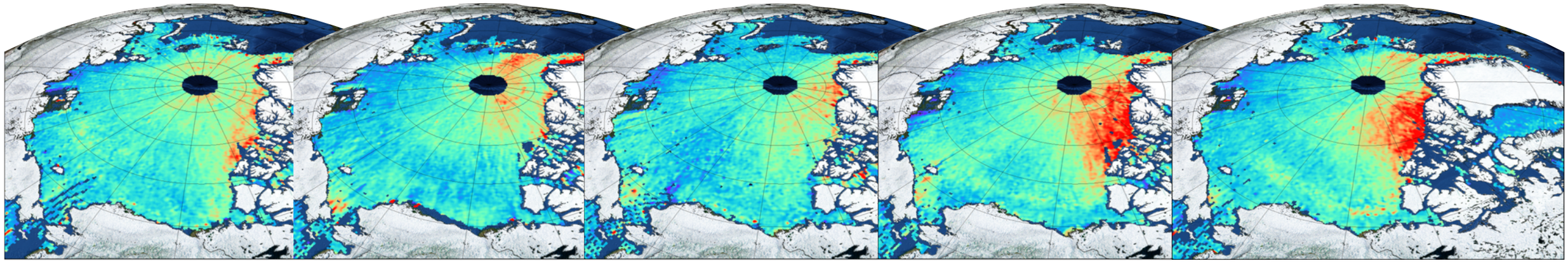


re-plotted, Price et al. (2015)

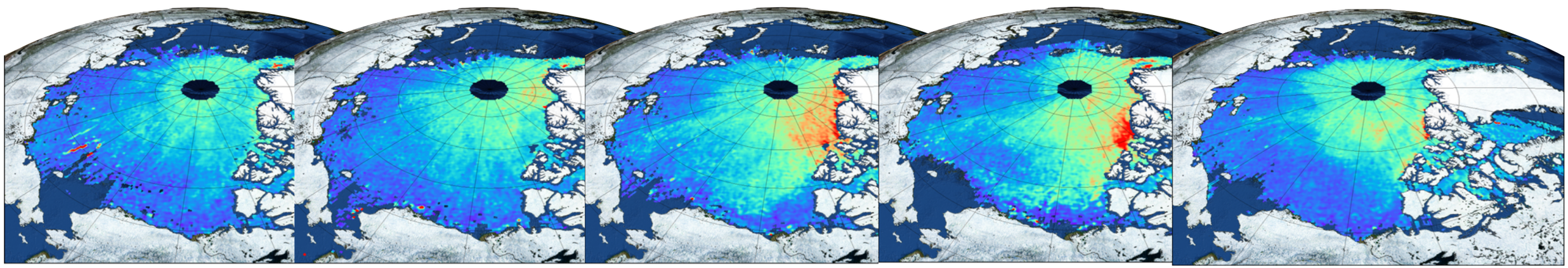
Sea-ice Thickness Time Series

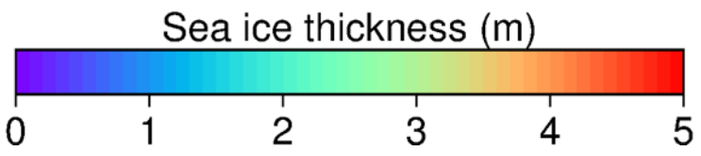
CryoSat-2 along-track measurements are averaged within 1 month on a 25 x 25 km EASE2 grid. Time series from 2011-2015 reveal strong inter-annual variations:

March 2011 2012 2013 2014 2015

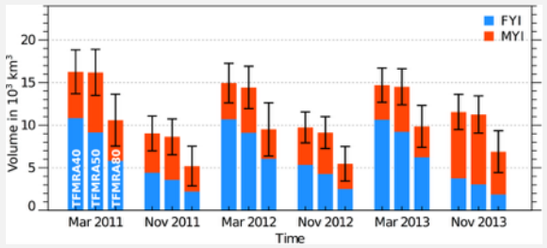
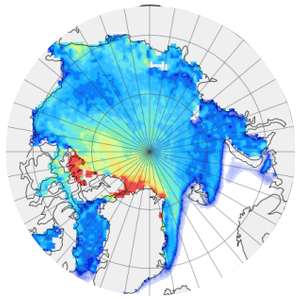
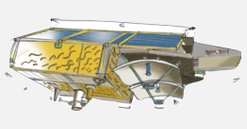
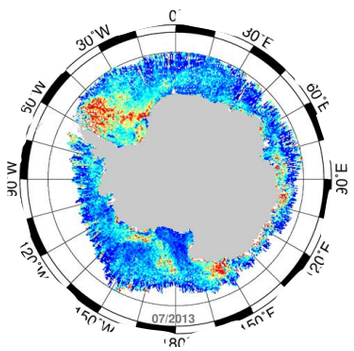


November

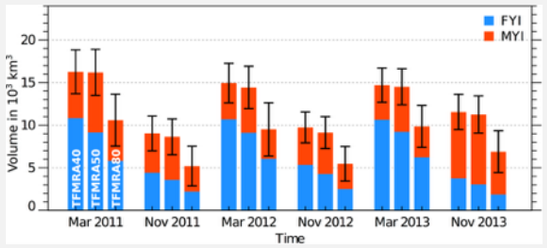
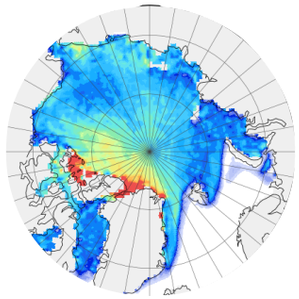
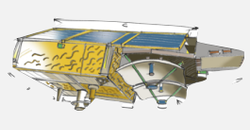
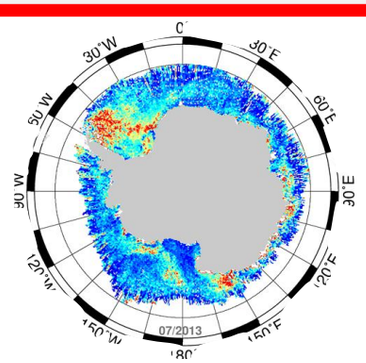




Applications

Ice Volume estimates		**Sensitivity of CryoSat-2 Arctic sea-ice volume trends on radar-waveform interpretation** *(Ricker et al., 2014)*
Model Optimisation/ Evaluation		**Arctic Climate Change, Economy and Society:** Report on the assessment of forecast skill *(Credit: Frank Kauker, 2015)*
Data Fusion	 CryoSat-2 + SMOS thickness retrievals	**Sea Ice Outlook 2013 -** Sea Ice Thickness from CryoSat-2 and SMOS *(Credit: Kaleschke and Ricker, 2012)*
Antarctic Sea-ice Thickness		**Sea Ice Climate Change Initiative:** Report on Cryosat-2 Antarctic freeboard retrieval & assessment *(Credit: Schwegmann et al., 2015)*

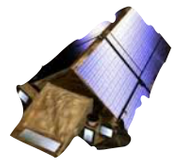
Applications

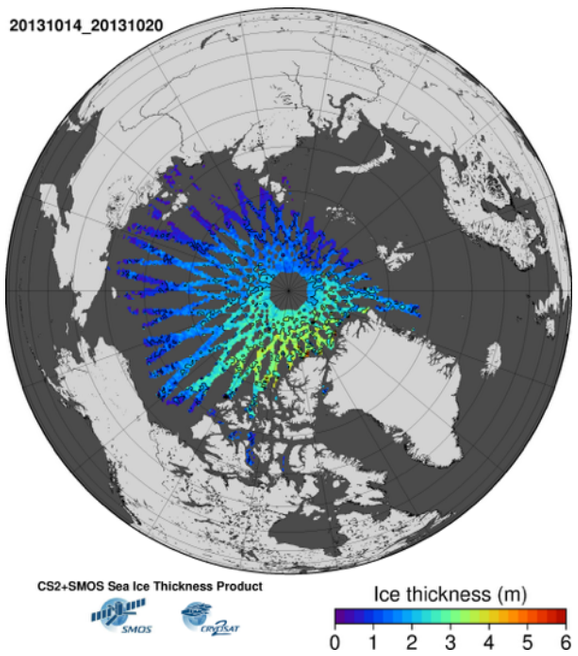
Ice Volume estimates		**Sensitivity of CryoSat-2 Arctic sea-ice volume trends on radar-waveform interpretation** *(Ricker et al., 2014)*
Model Optimisation/ Evaluation		**Arctic Climate Change, Economy and Society:** Report on the assessment of forecast skill *(Credit: Frank Kauker, 2015)*
Data Fusion	 CryoSat-2 + SMOS thickness retrievals	**Sea Ice Outlook 2013 -** Sea Ice Thickness from CryoSat-2 and SMOS *(Credit: Kaleschke and Ricker, 2012)*
Antarctic Sea-ice Thickness		**Sea Ice Climate Change Initiative:** Report on Cryosat-2 Antarctic freeboard retrieval & assessment *(Credit: Schwegmann et al., 2015)*

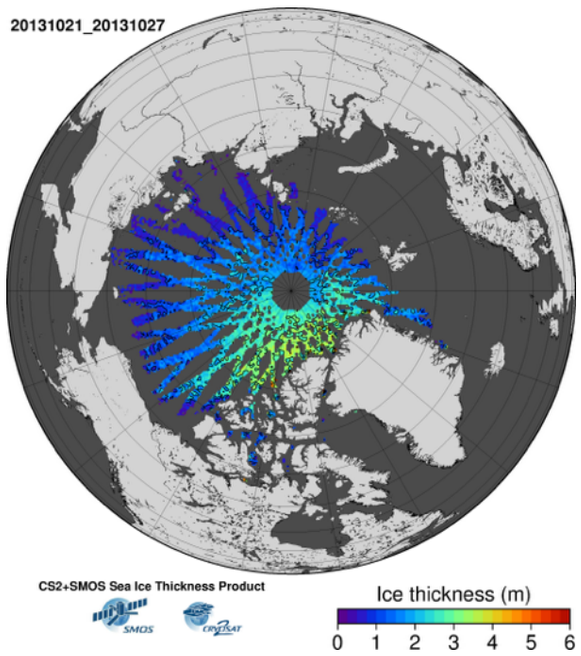
Bridging Temporal Scales

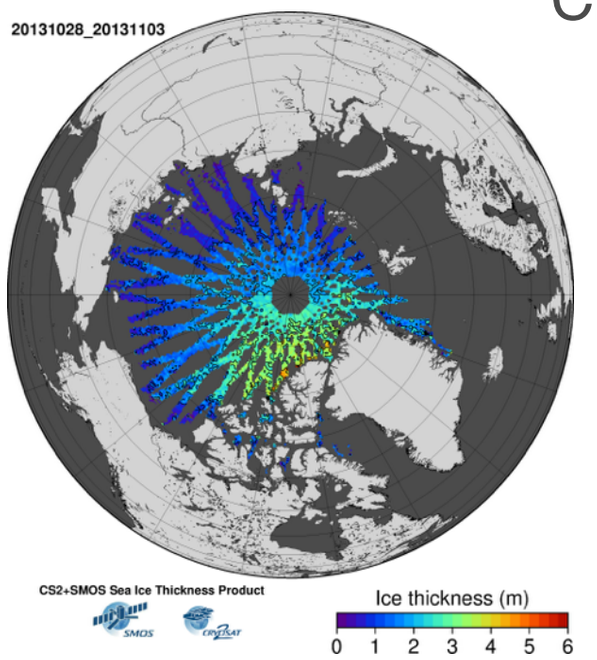
3 weeks: 14. October – 03. November 2013

CryoSat-2

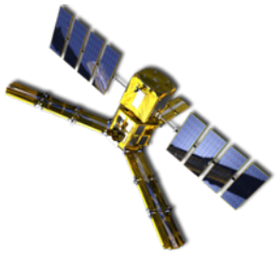


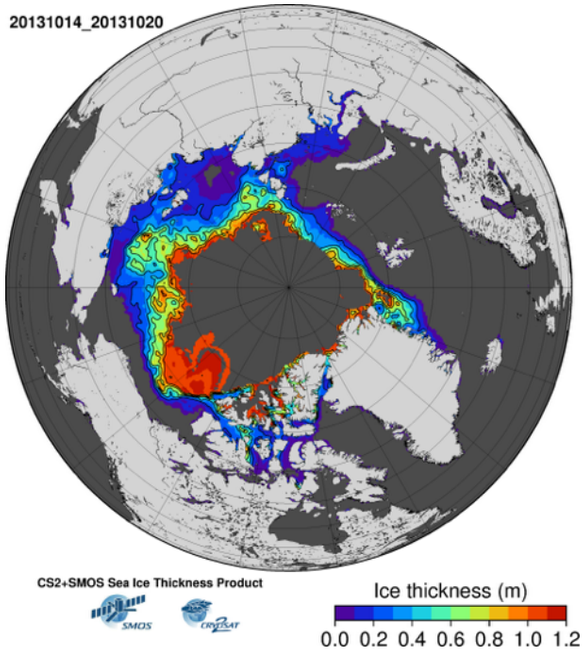


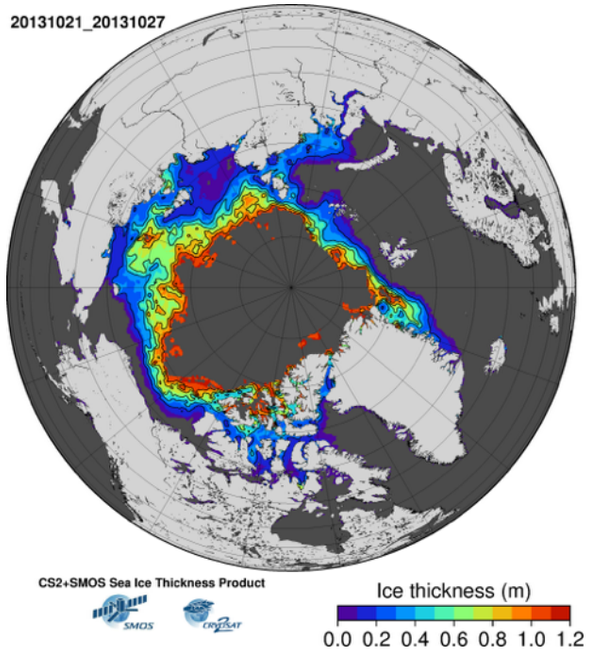


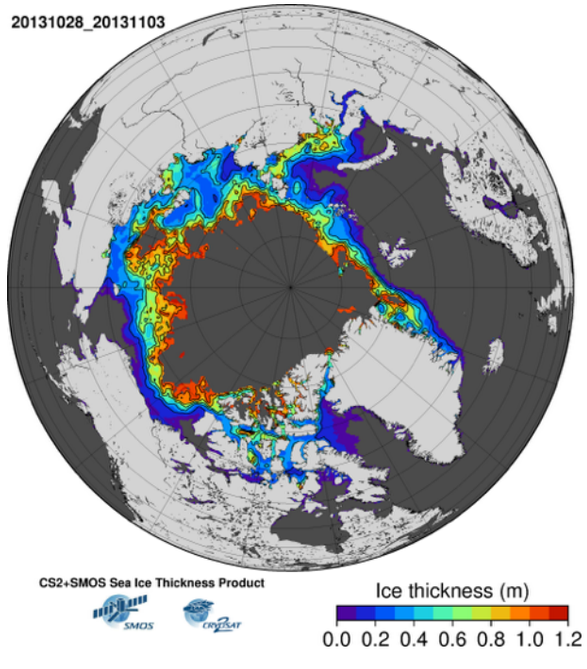


SMOS









Optimal Interpolation

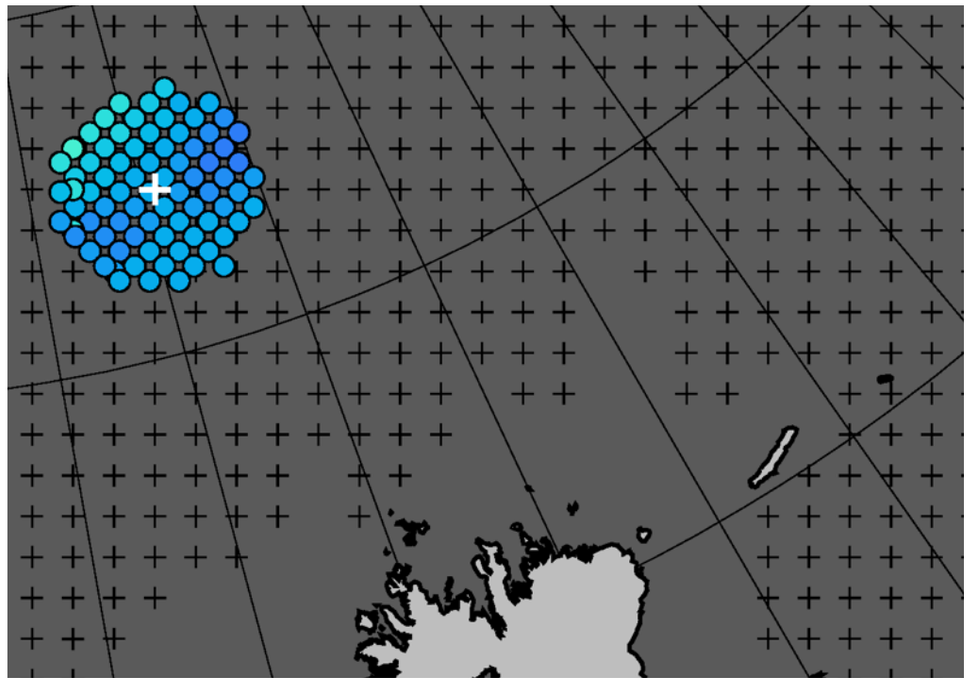
What is needed?

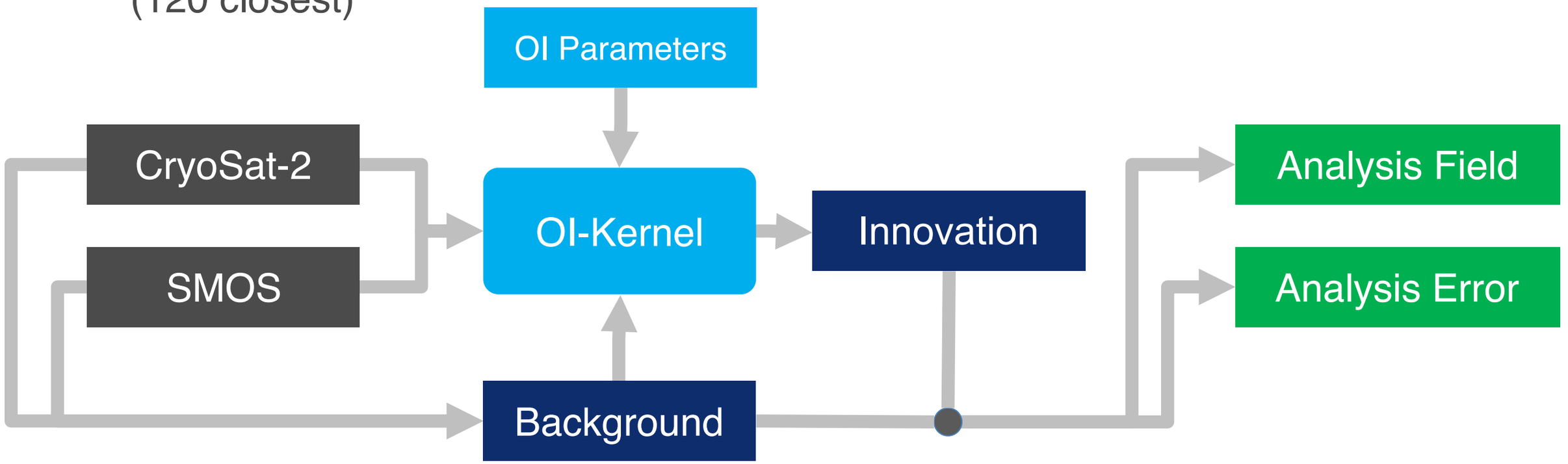
Observations + Uncertainties

Error covariances

OI Parameters

- Radius of influence (120 km)
- Correlation length scale
- Max number of observations (120 closest)





Background Field

CryoSat-2

± 2 week composite

full coverage

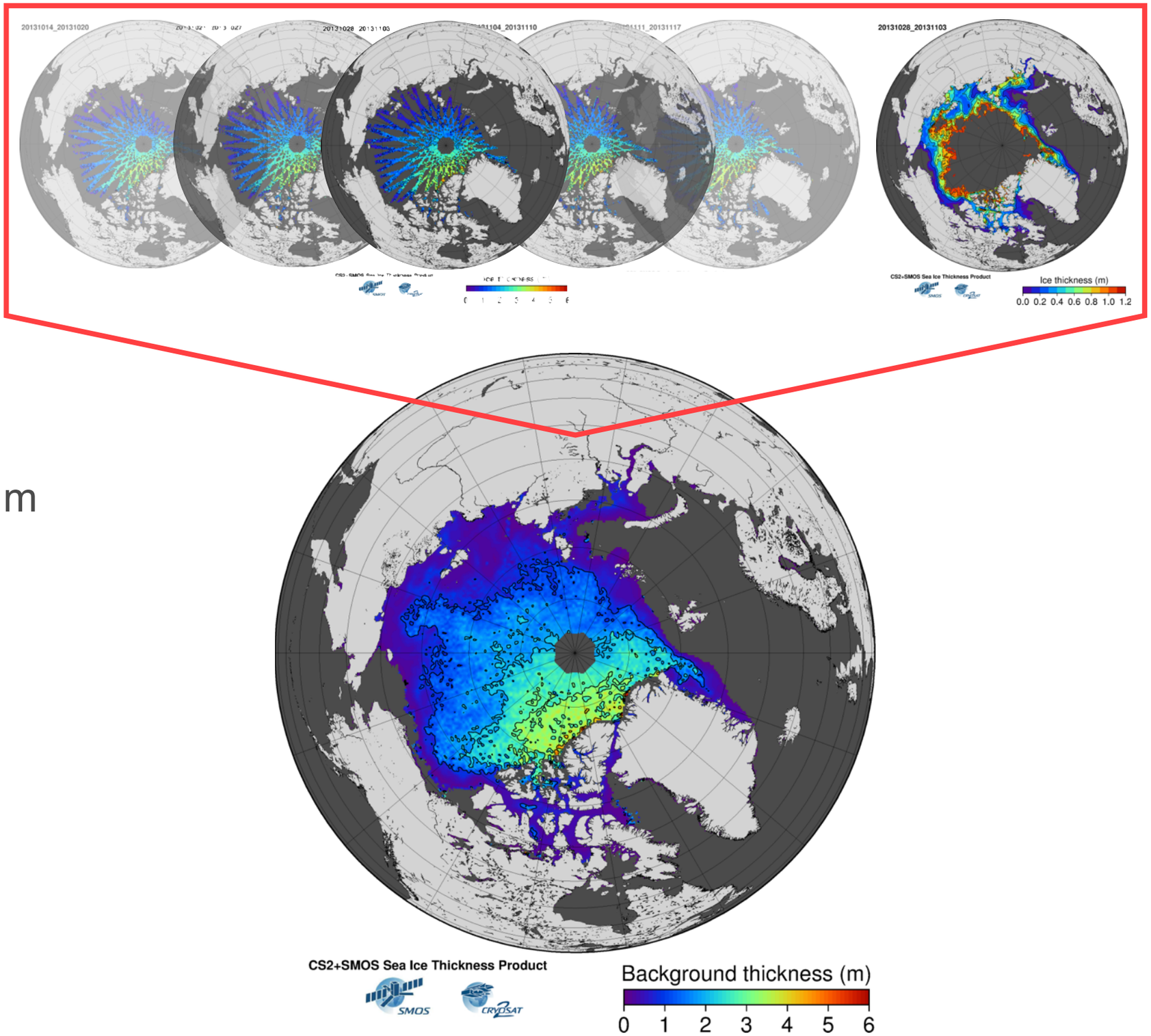
SMOS

7 day composite

Eliminate thicknesses > 1 m

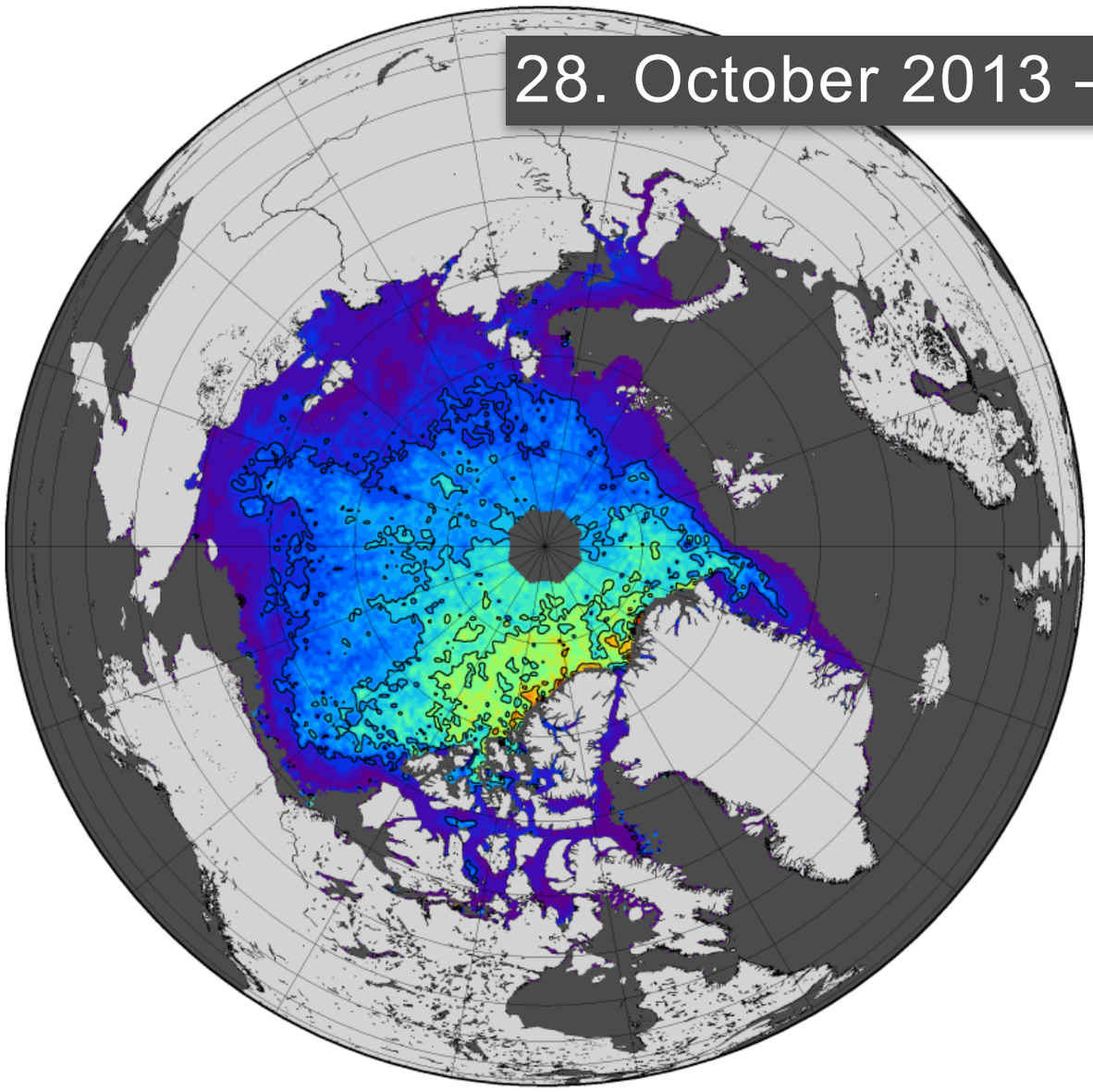
Weighted Average

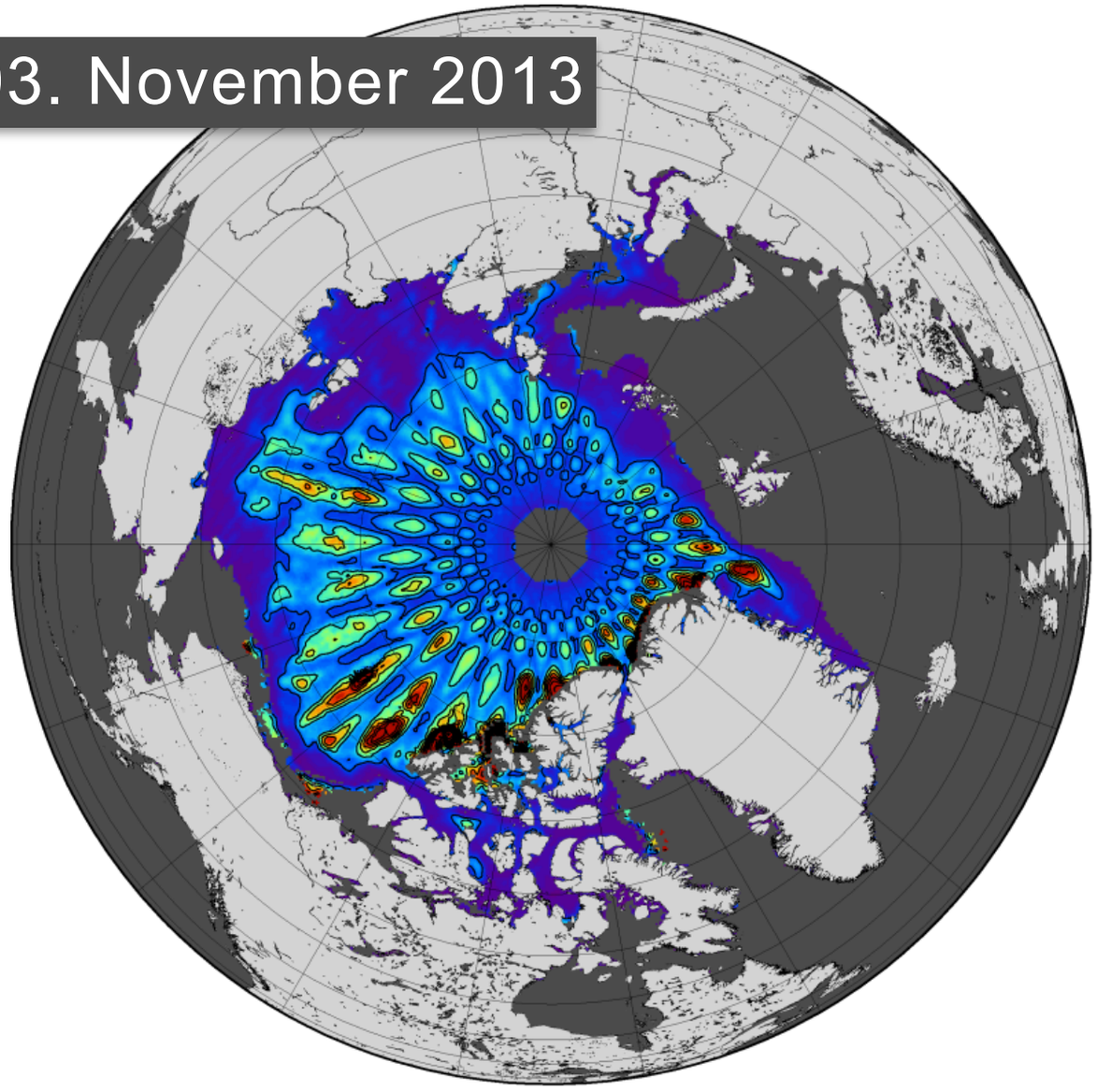
Background Field



Freeze-up 2013

28. October 2013 – 03. November 2013





CS2+SMOS Sea Ice Thickness Product

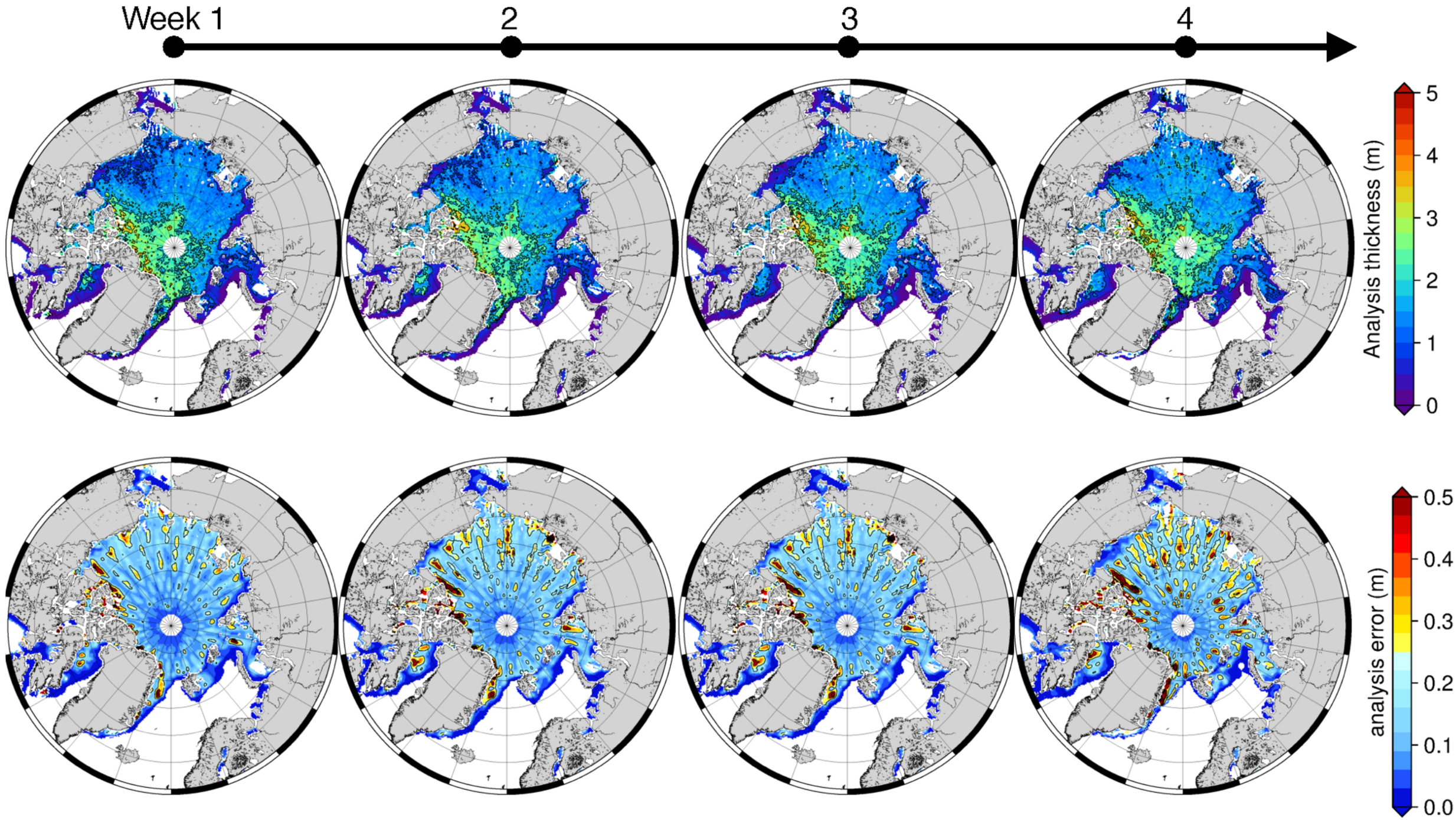
Analysis thickness (m)

0 1 2 3 4 5 6

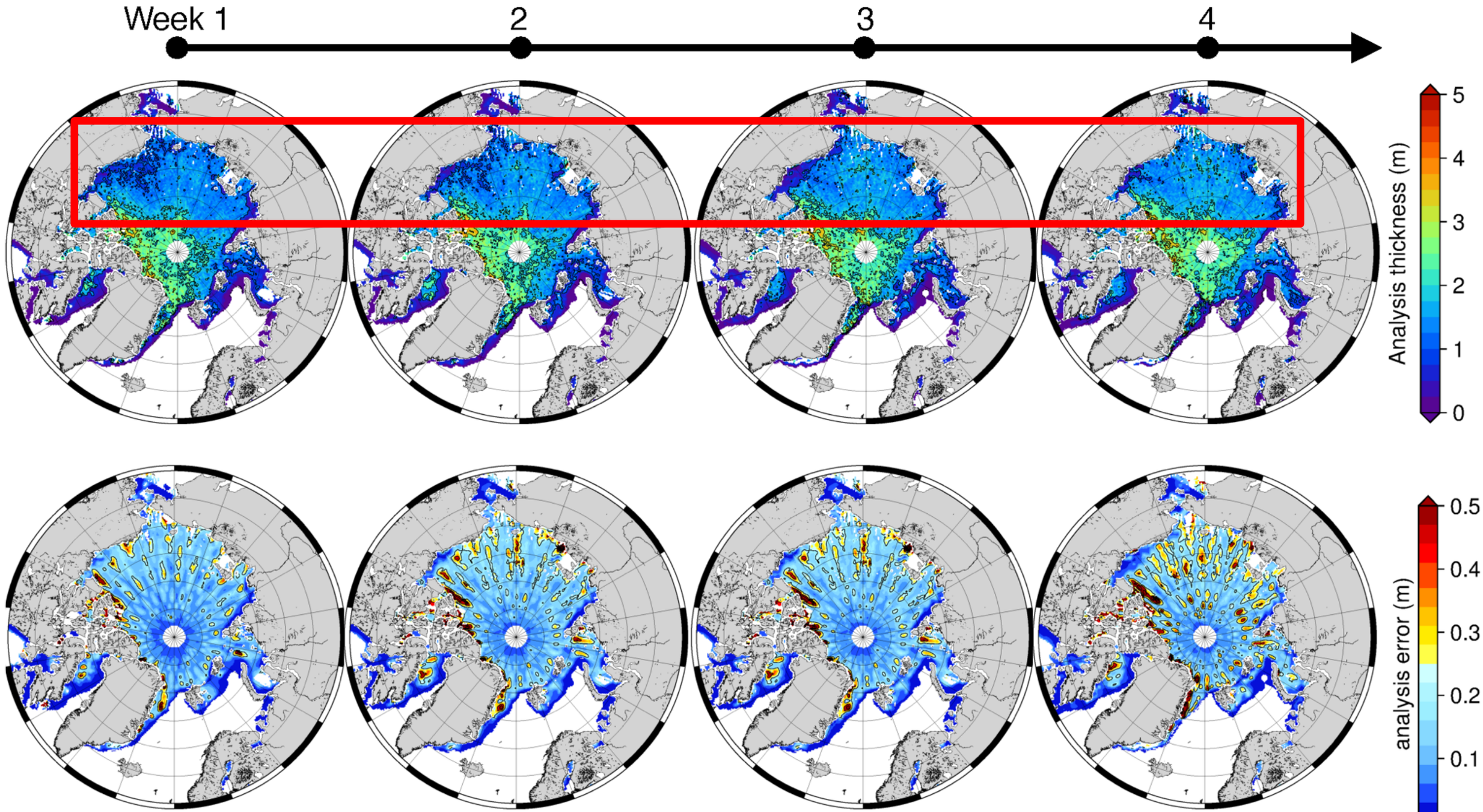
analysis error (m)

0.0 0.1 0.2 0.3 0.4 0.5

January 2011



January 2011

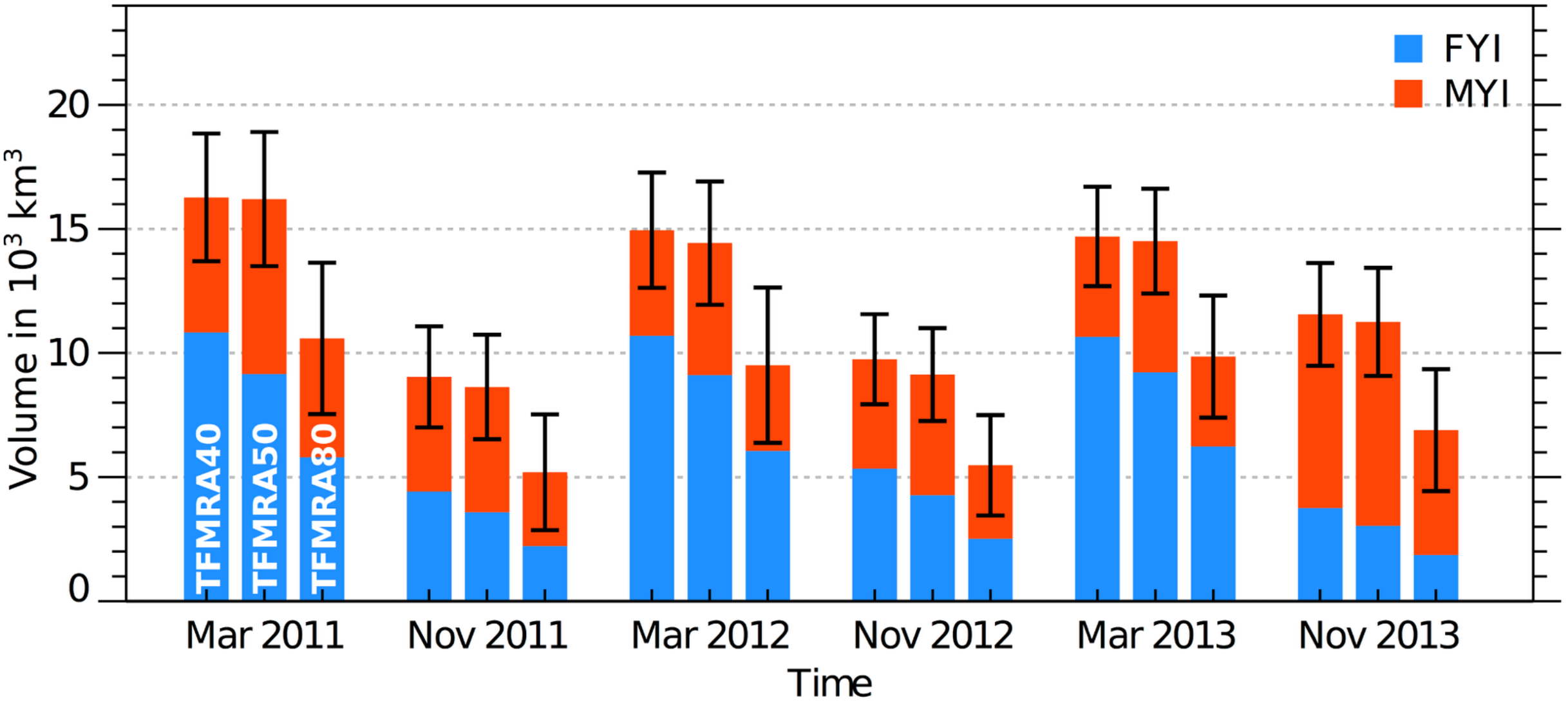


Summary and Conclusion

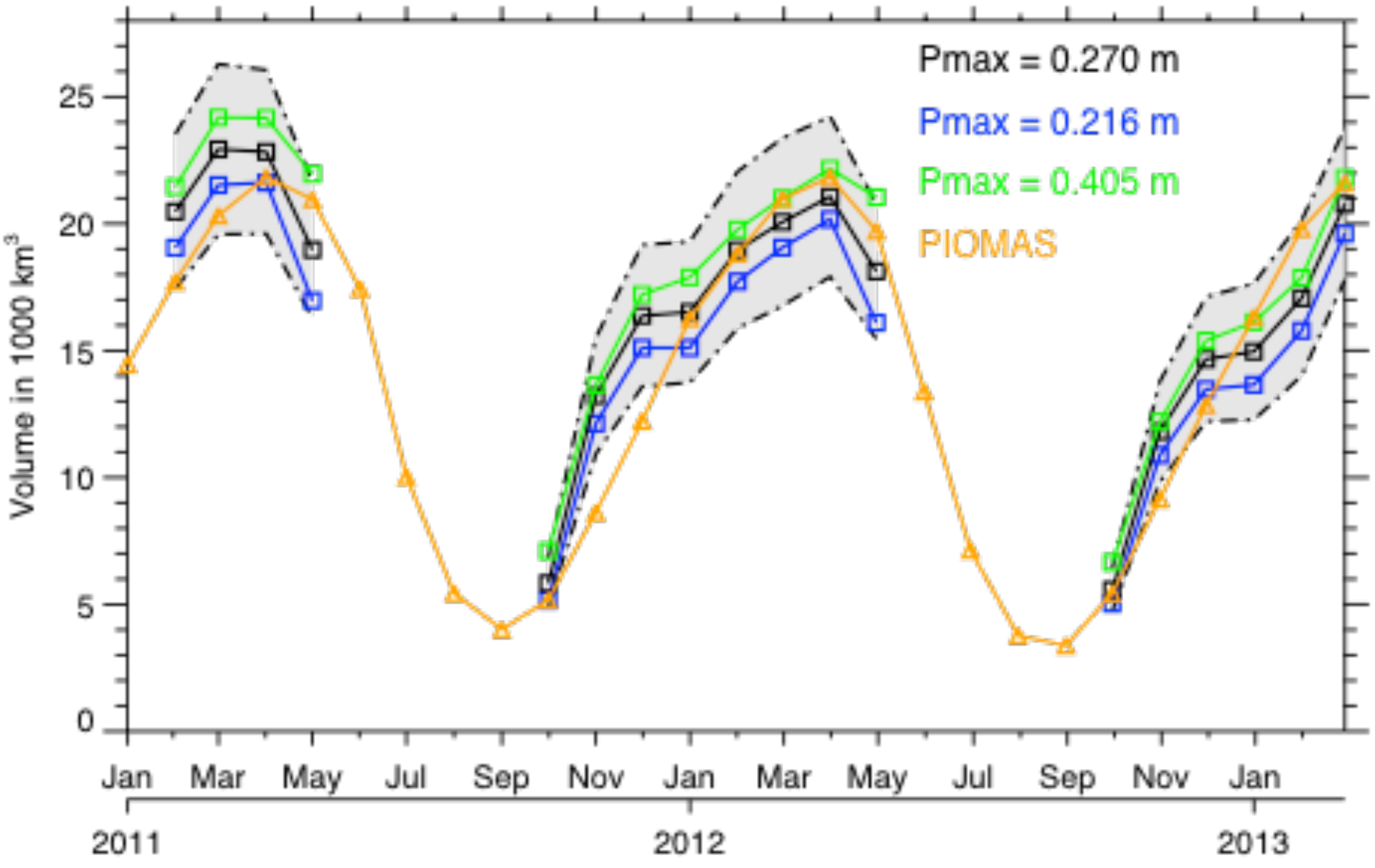
- CryoSat-2 freeboard and thickness maps retrieved from waveforms
- Random uncertainties mainly depend on instrument noise and the interpolated sea-surface anomaly along the flight track, but are reduced by averaging
- Systematic uncertainties due to retracking algorithms/thresholds, parameter assumptions and volume scatterring in the snow layer
- A better Arctic snow depth product containing inter-annual variability is required
- Optimal Interpolation of CryoSat-2 and SMOS data has potential to improve:
  - range of ice thicknesses resolution
  - temporal resolution of sea-ice thickness without data gaps

Questions …

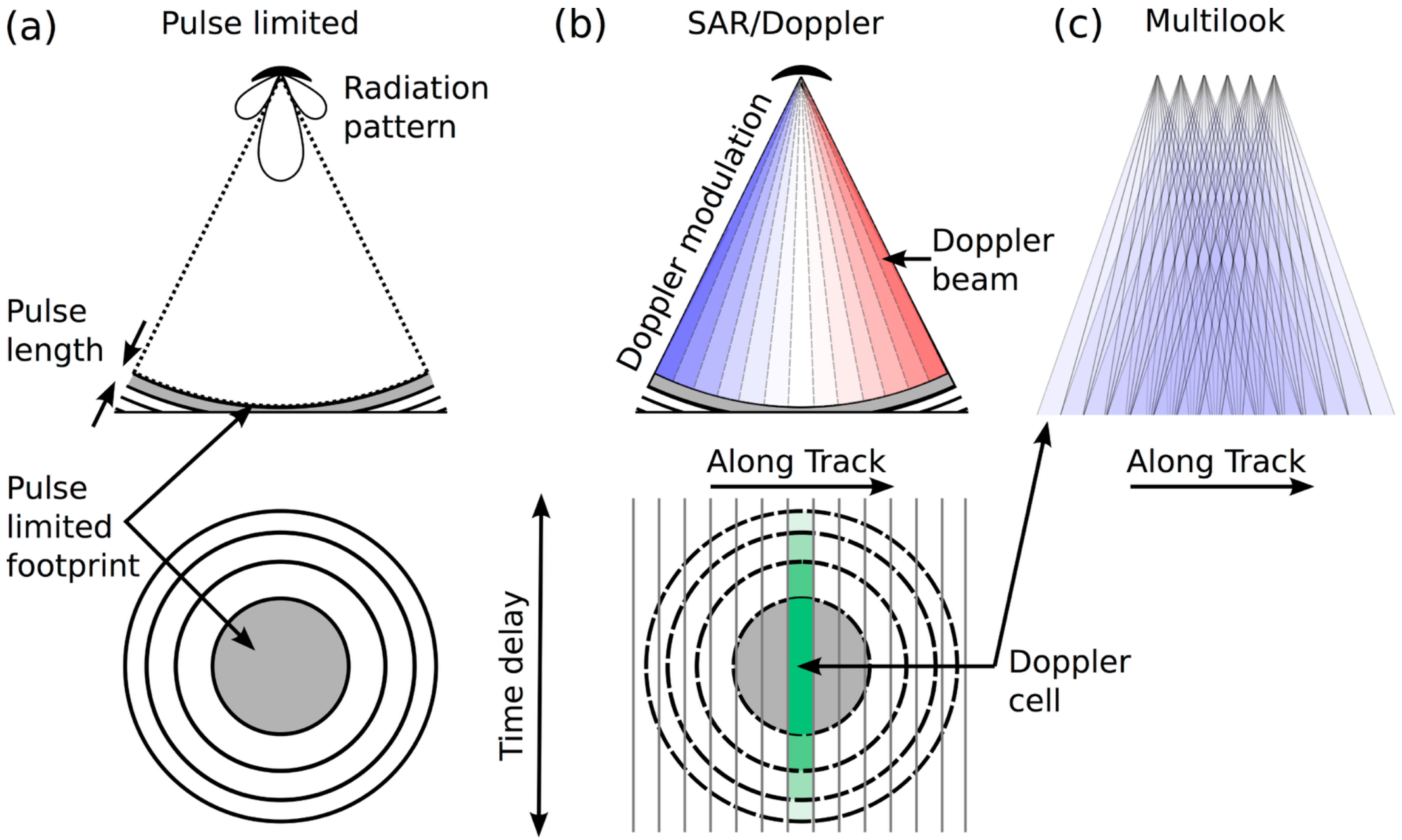
Ice volume trends



Ice volume trends

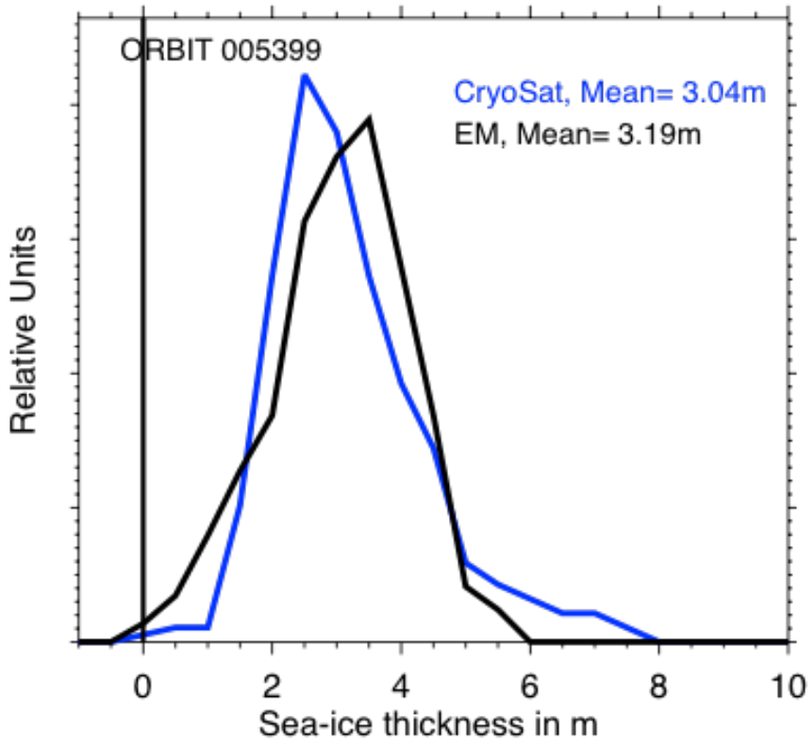


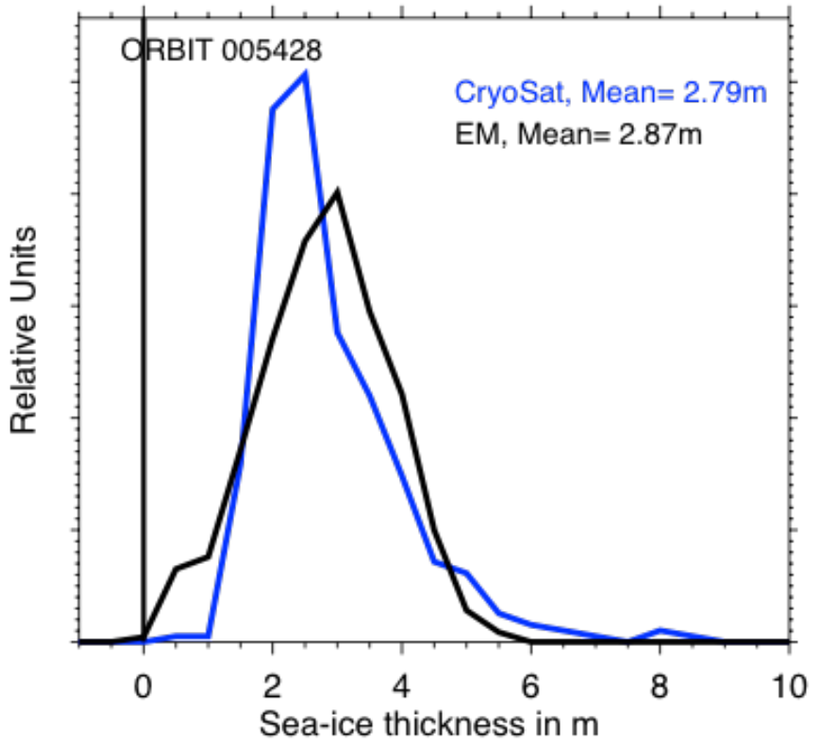
SAR/Doppler altimetry

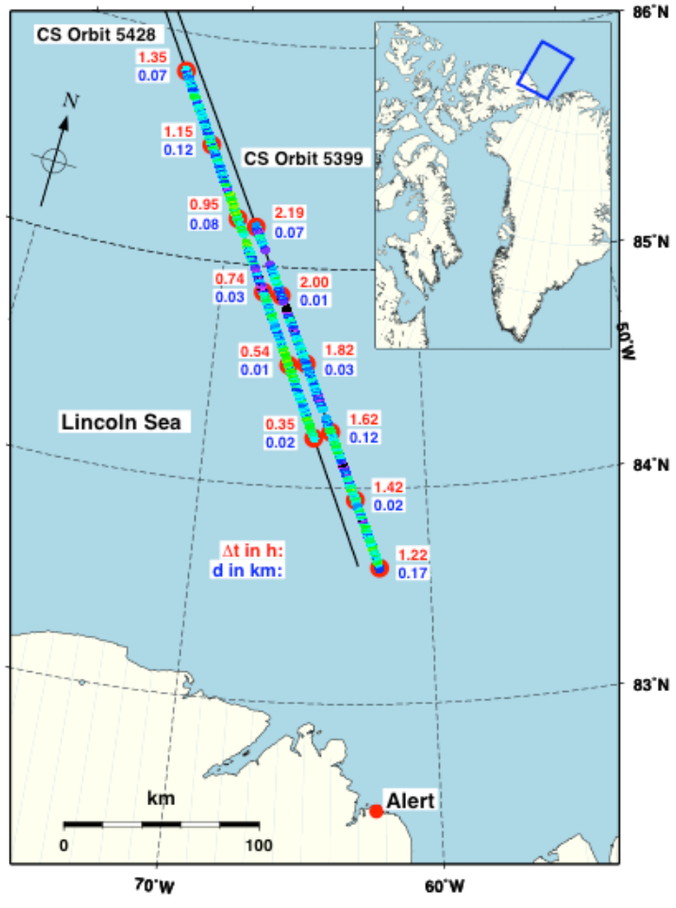


Validation of Thickness with AEM

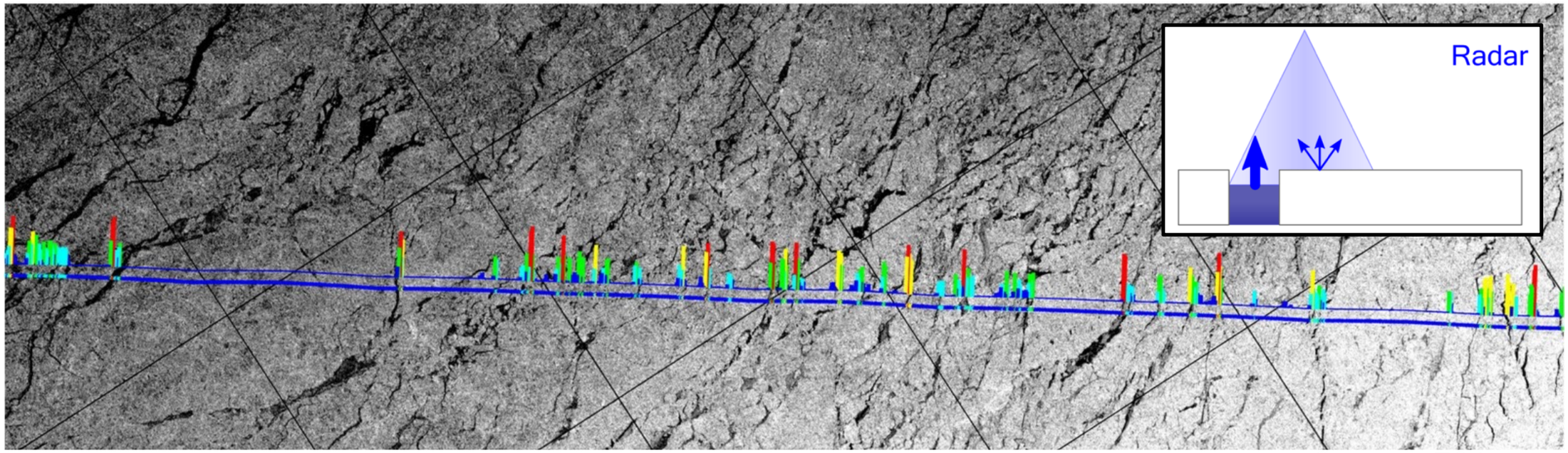
- Track to track comparison between CryoSat-2 and CryoVEx 2011/04 over Lincoln Sea:



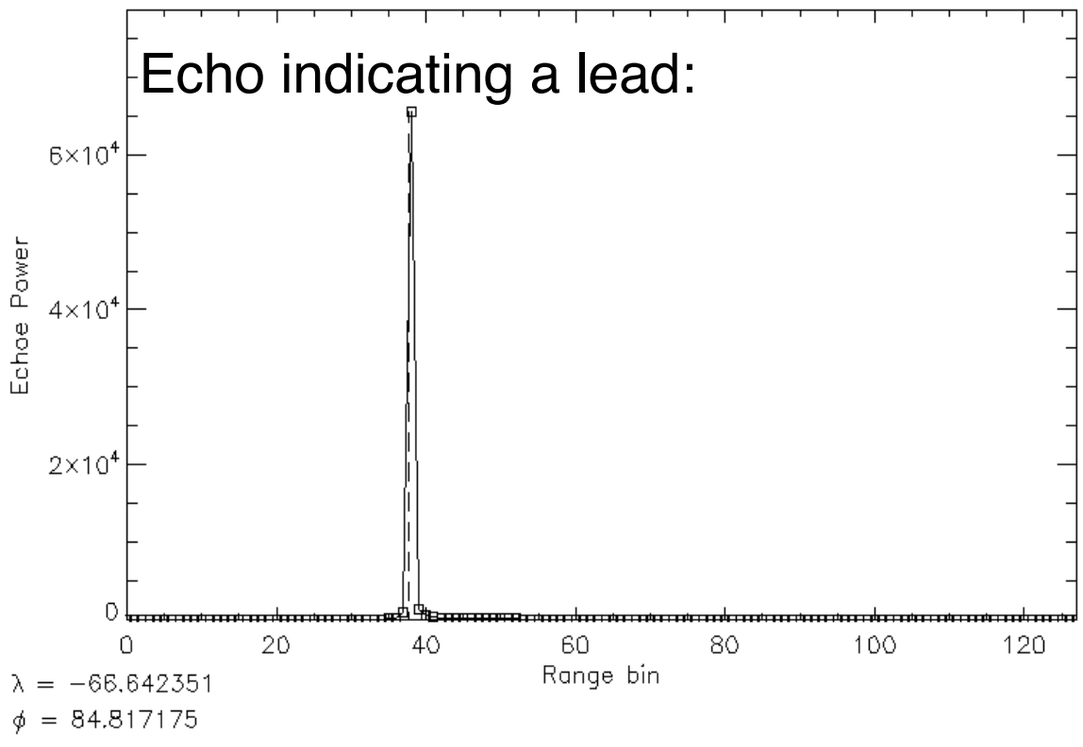


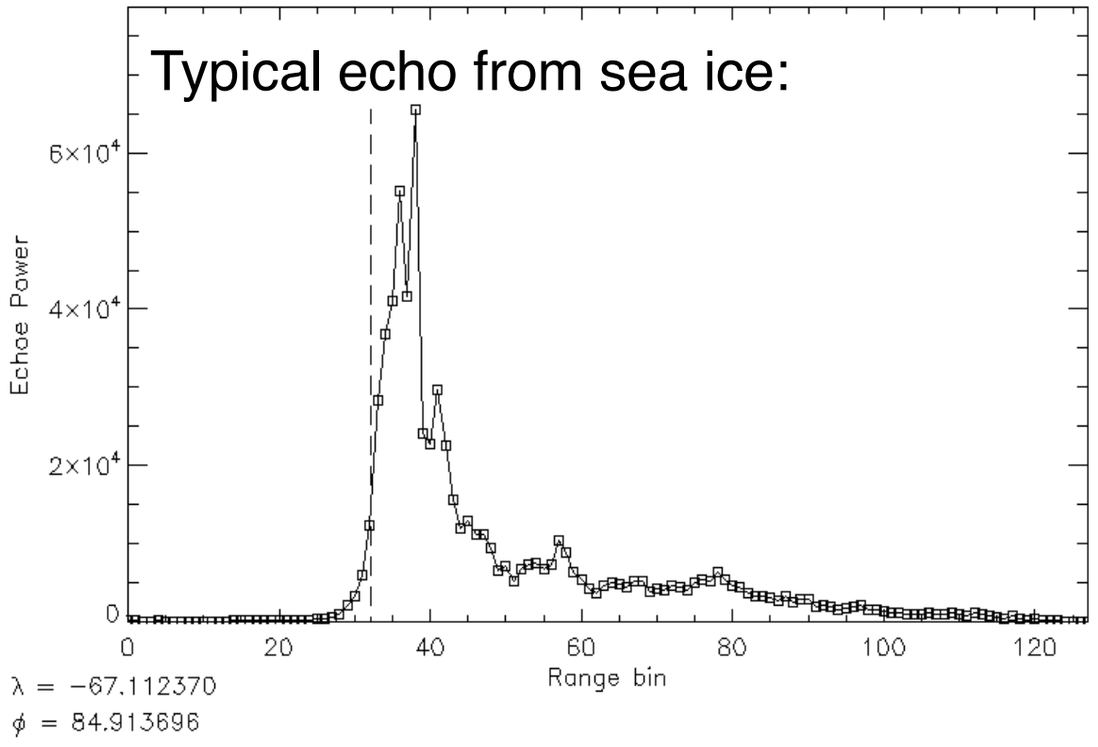


Lead detection

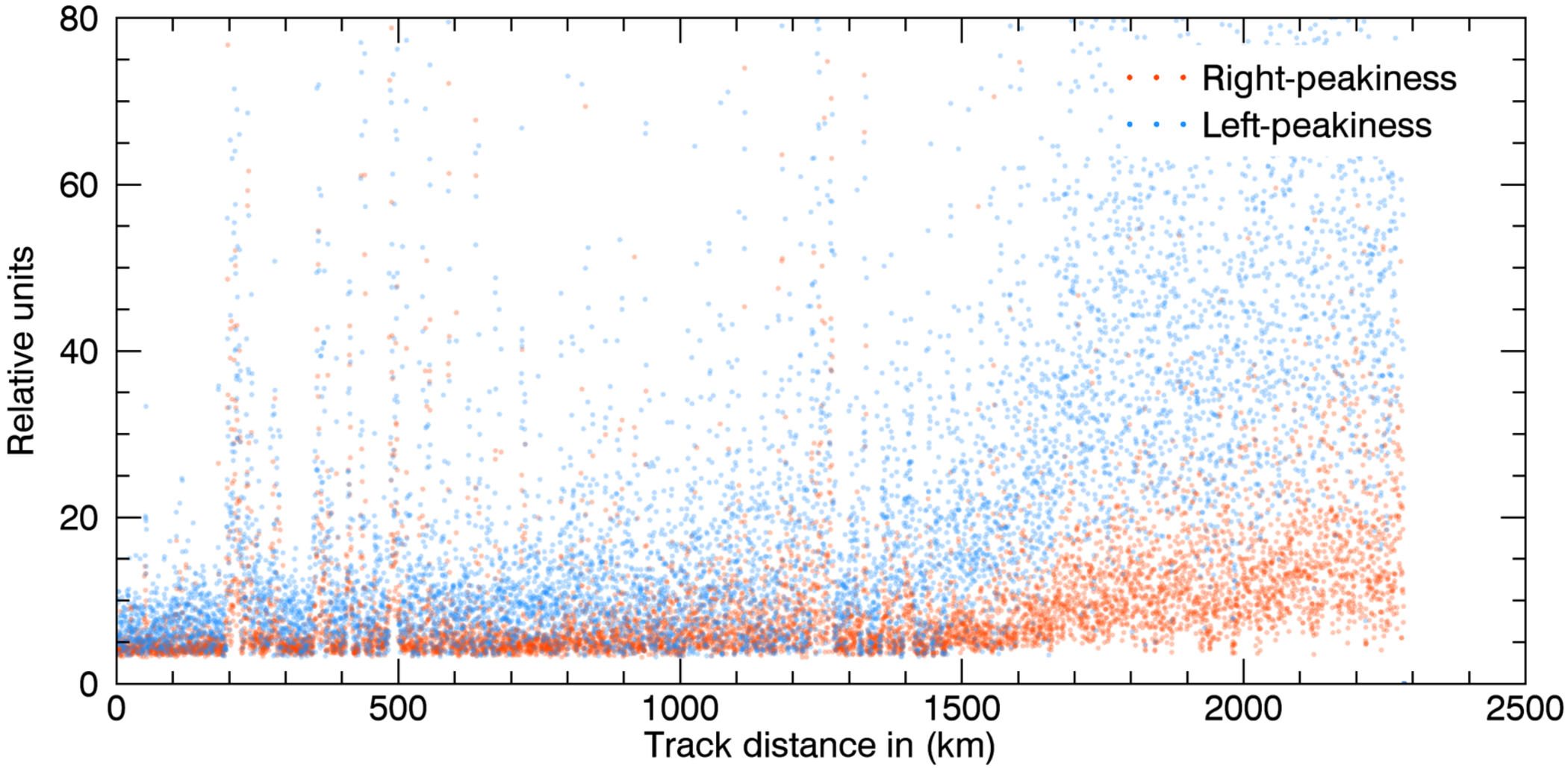


Source: ESA

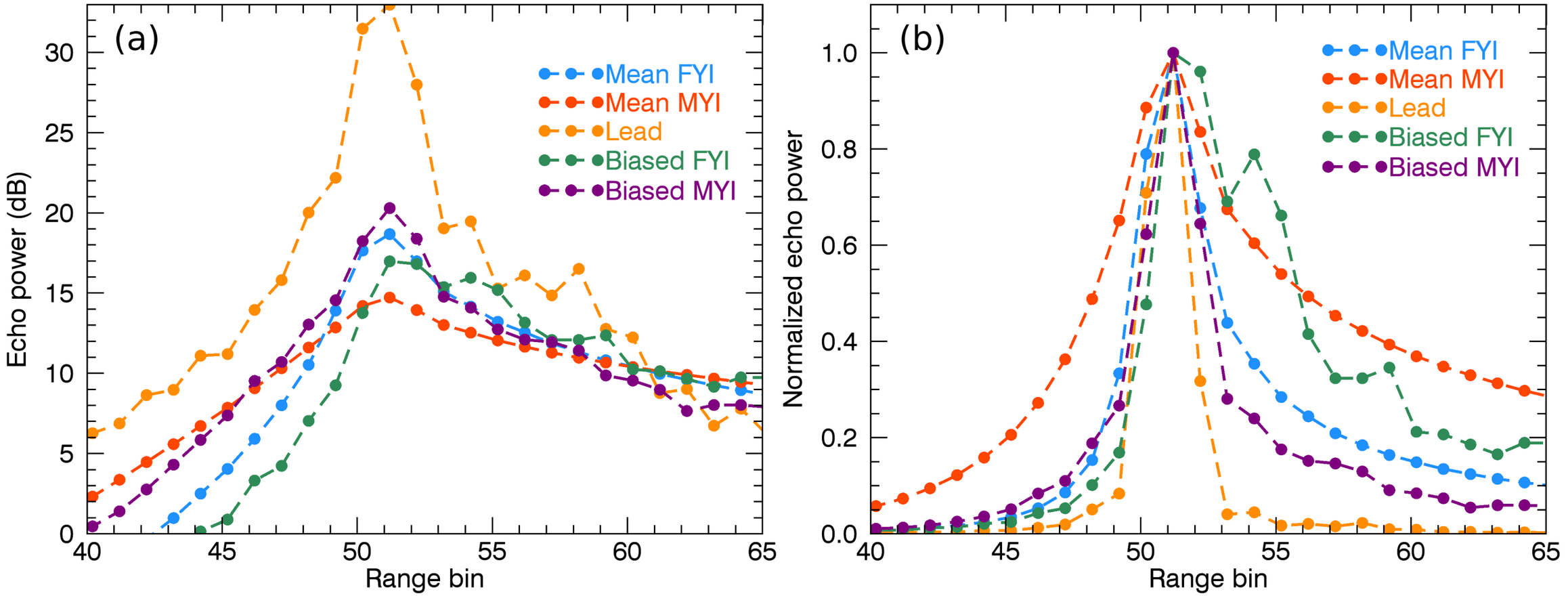




Pulse peakiness

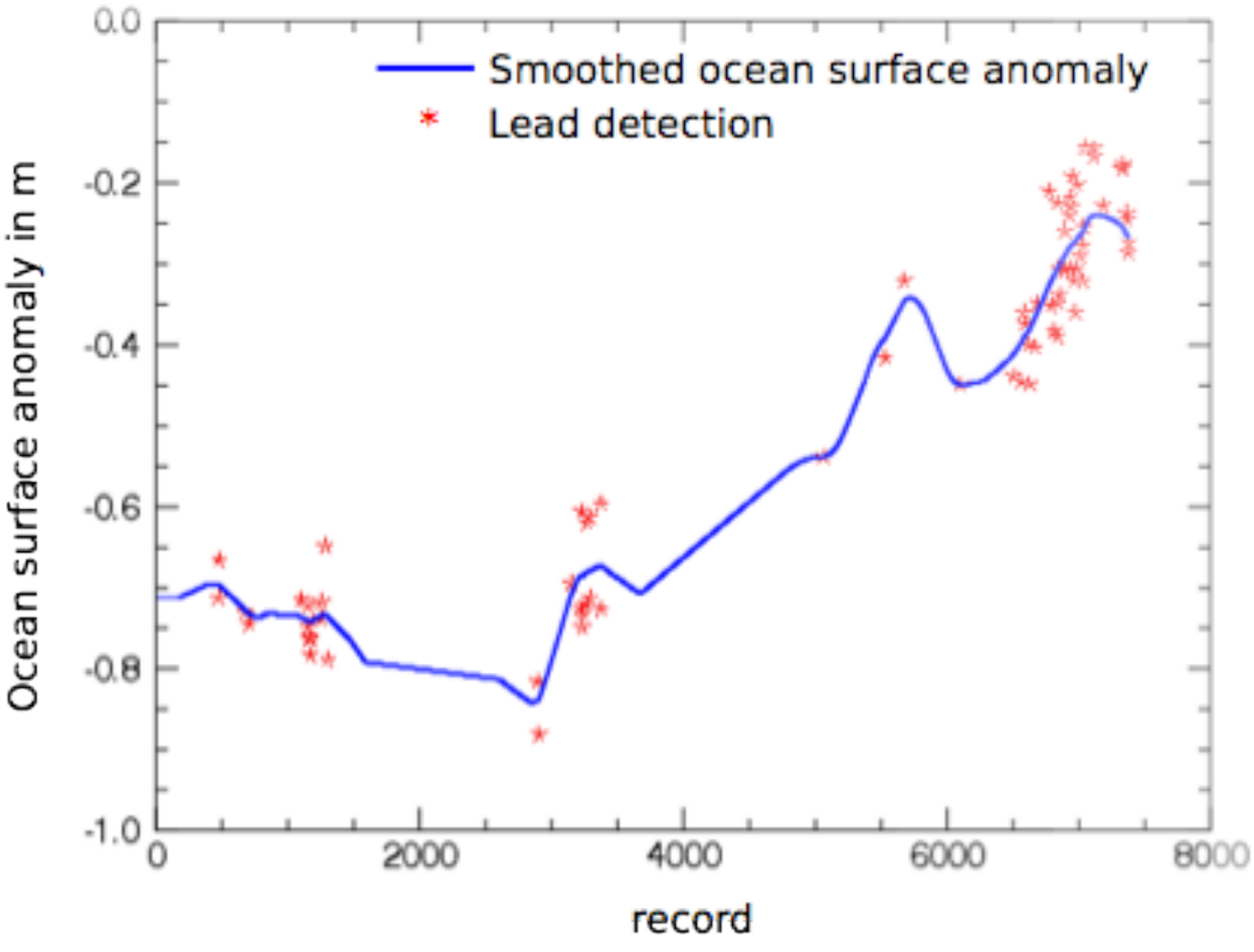


CS-2 waveform classification



Sea-surface anomaly (SSA)

Sea-surface anomaly along one CryoSat-2 track:



Product Processing