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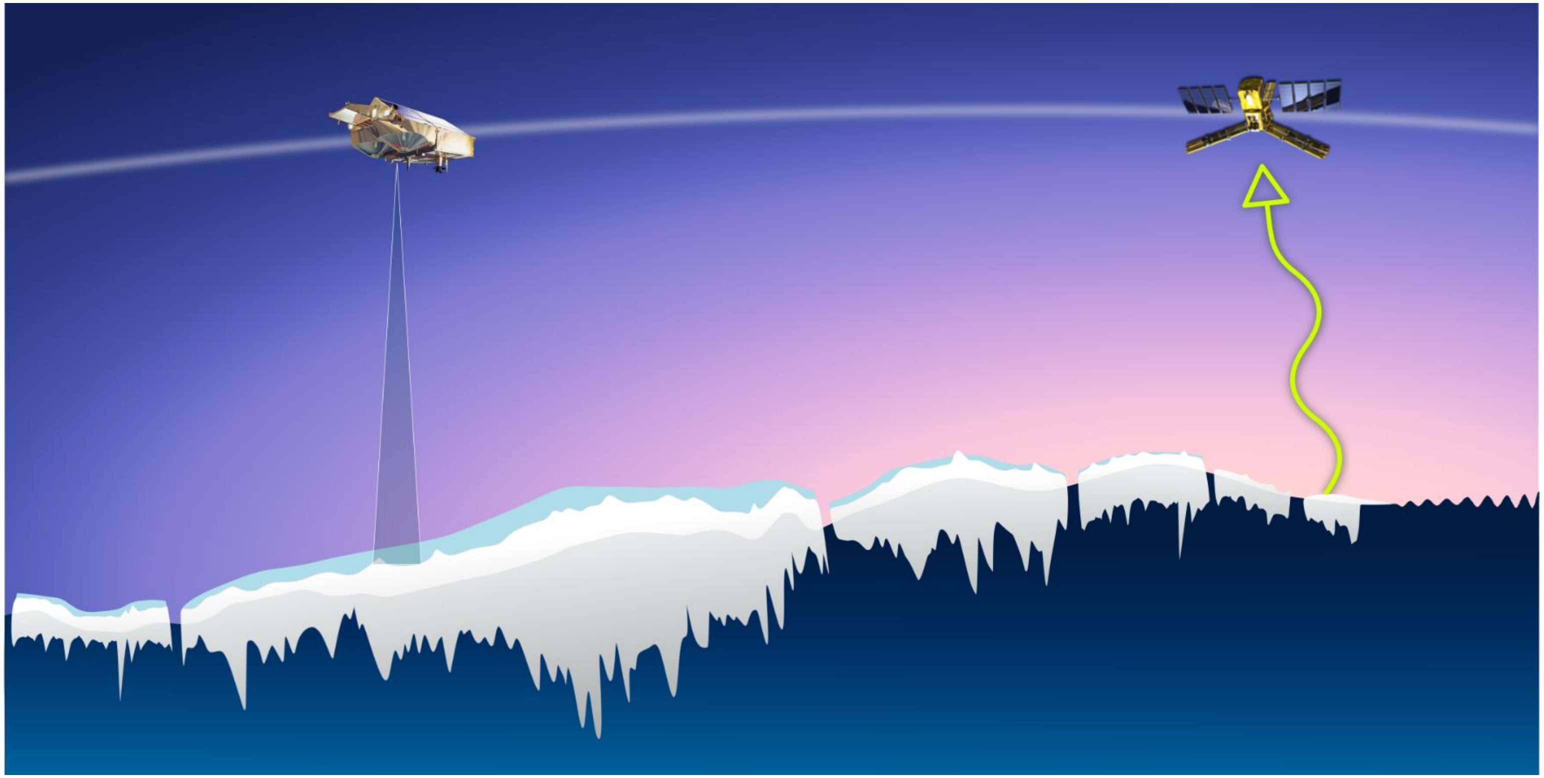
UND MEERESFORSCHUNG



Merged sea-ice thickness product from complementary L-band and altimetry information

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Contributors

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University Hamburg Team	Lars Kaleschke	
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ESA CCI Team	Eero Rinne	FMI
	Stefan Kern	University Hamburg
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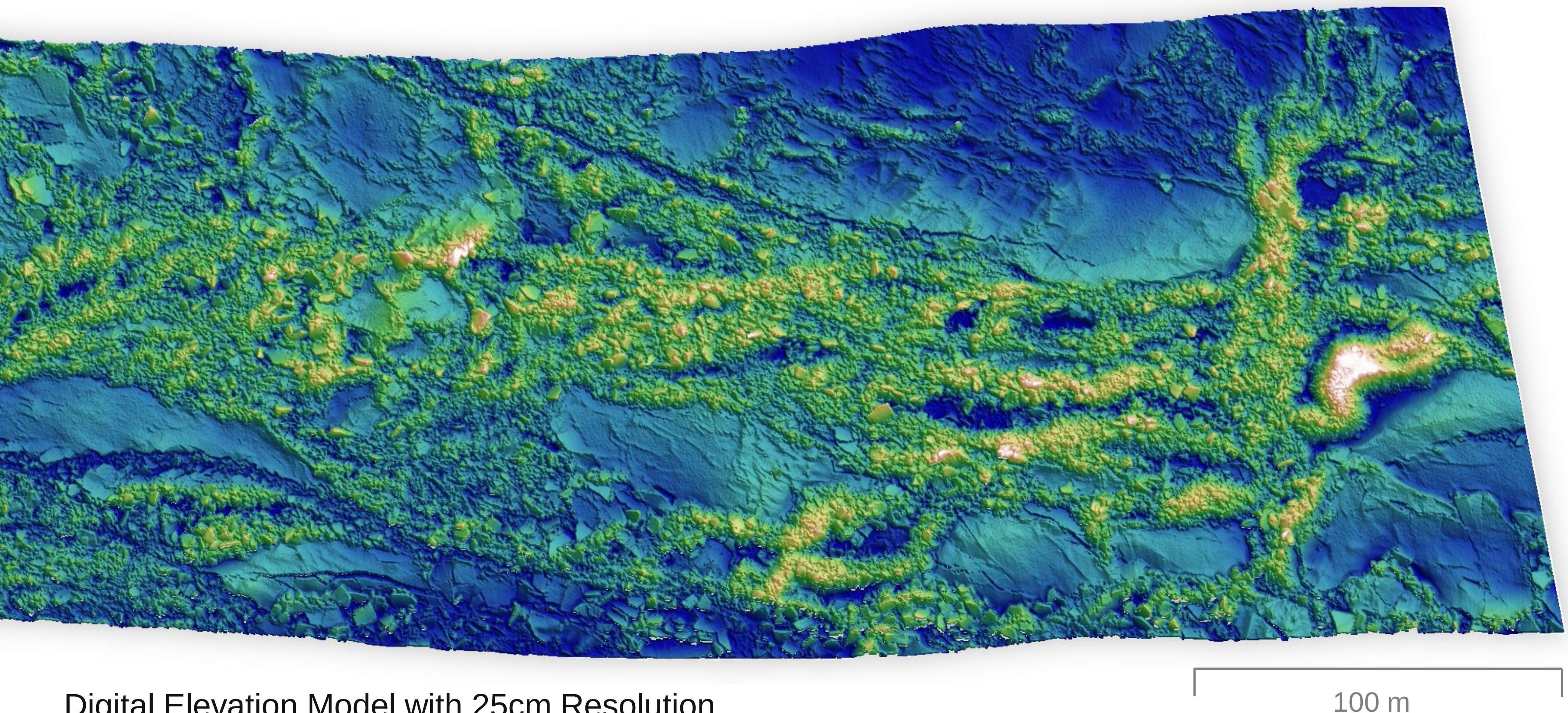
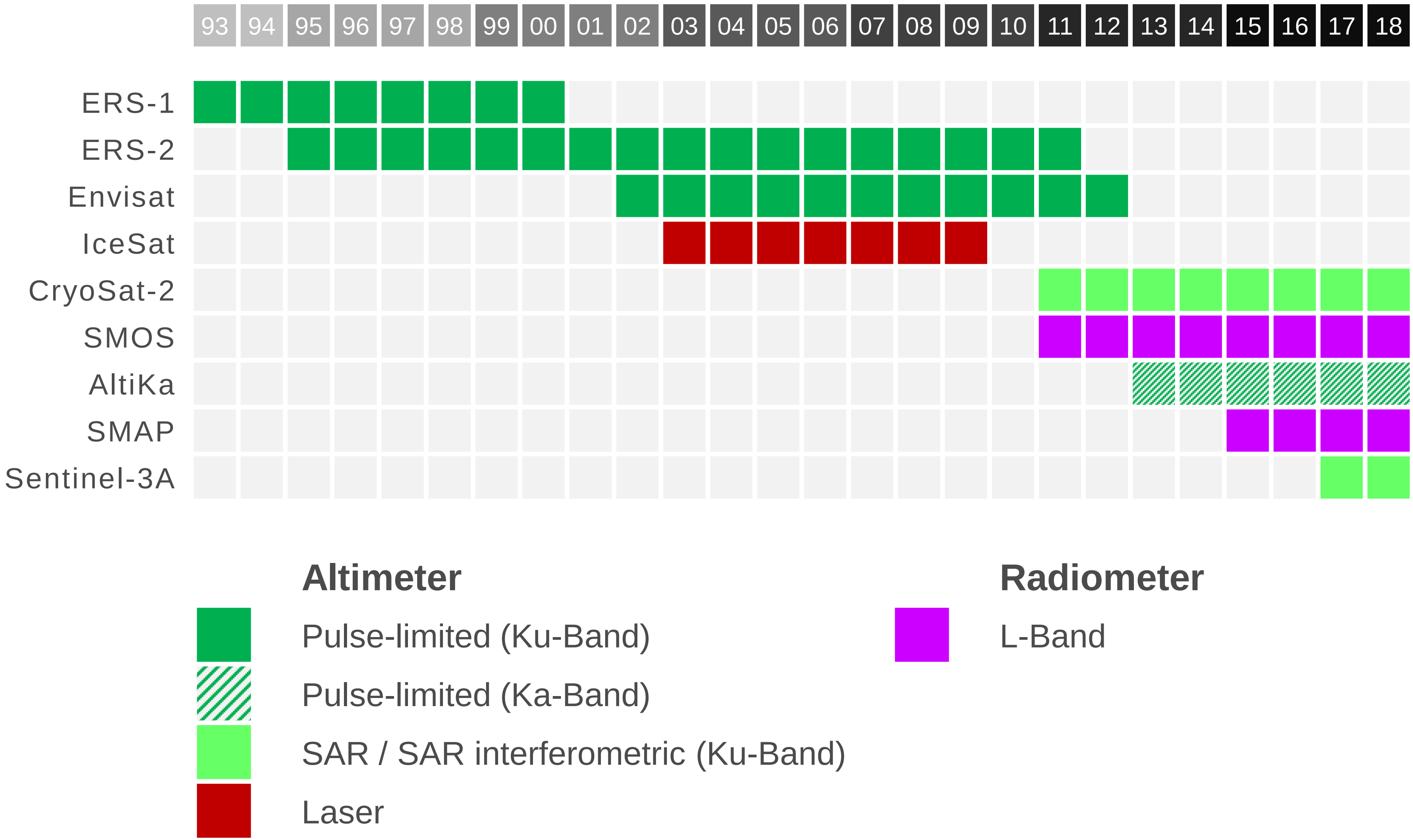
Managing Expectations



Digital Elevation Model with 25cm Resolution
(Airborne Laserscanner)

No satellite or model can resolve true variability of sea ice

SIT Remote Sensing



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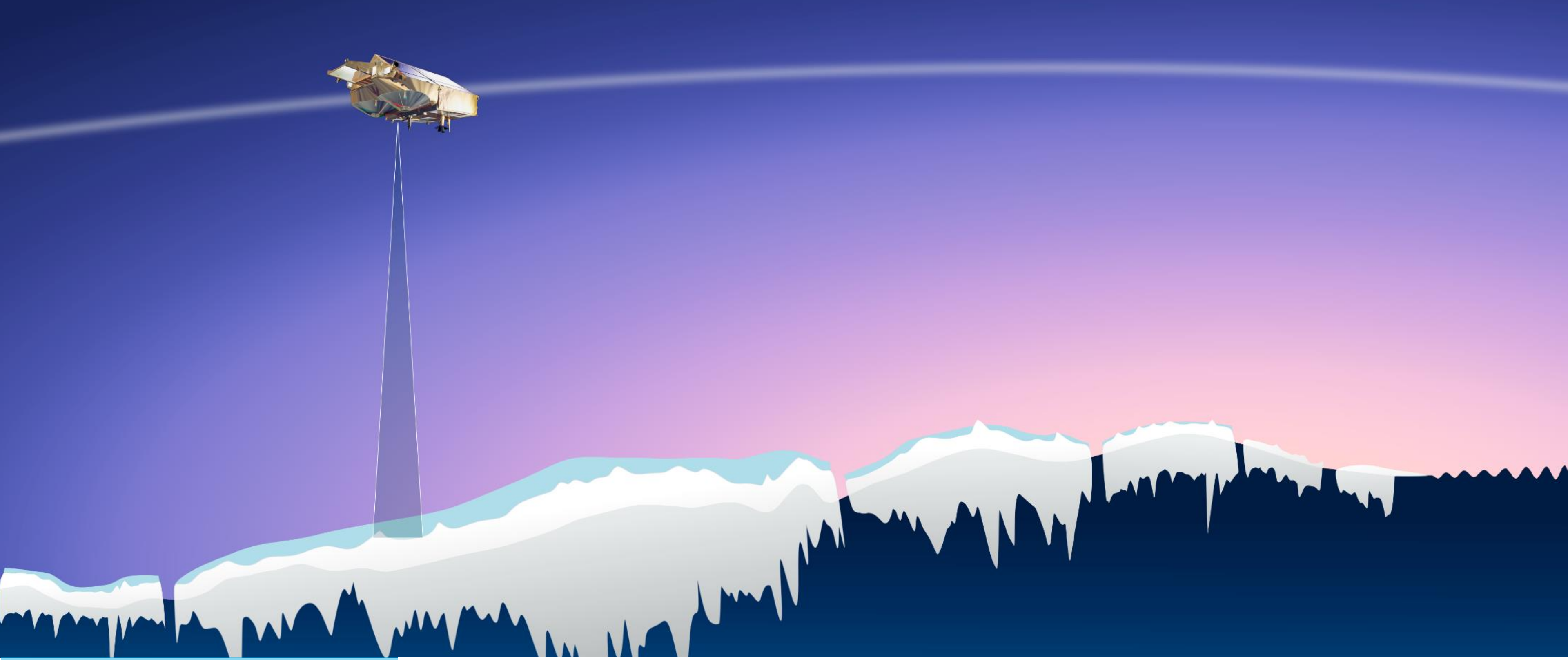


Radar Altimetry

Pioneering work by with ERS (Laxon et al. 2003)

Breakthrough for sea ice altimetry with CryoSat-2

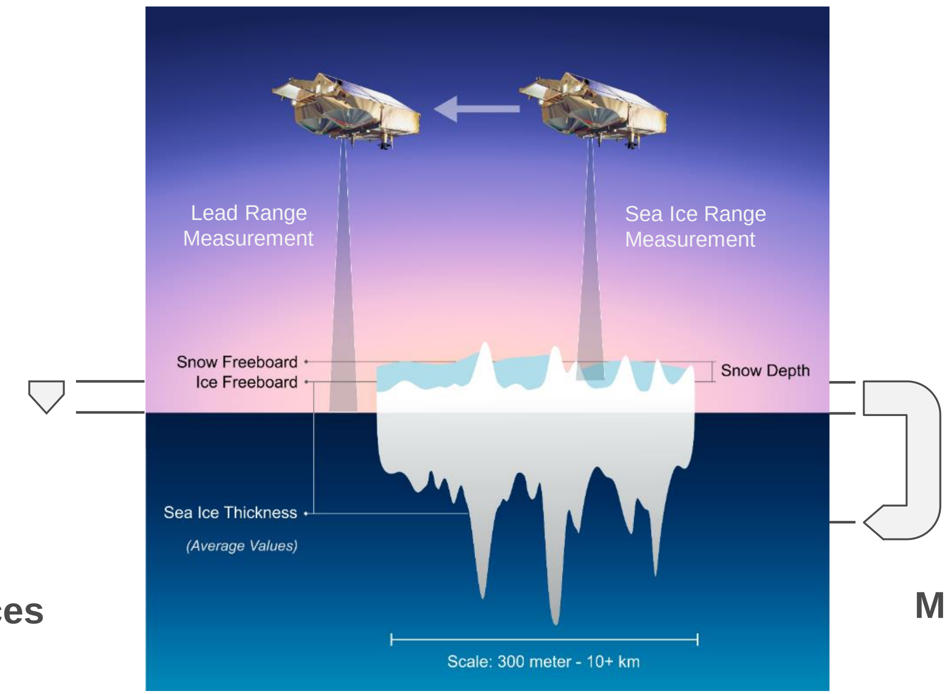
Sea Ice Radar Altimetry

Step 1

Freeboard Retrieval

A Priori Information

- Snow Depth



Main Uncertainty Sources

- Complex radar echos over rough sea ice surfaces
- Potential bias from radar backscatter in snow layer
- Snow wave propagation

Step 2

Freeboard to Thickness Conversion

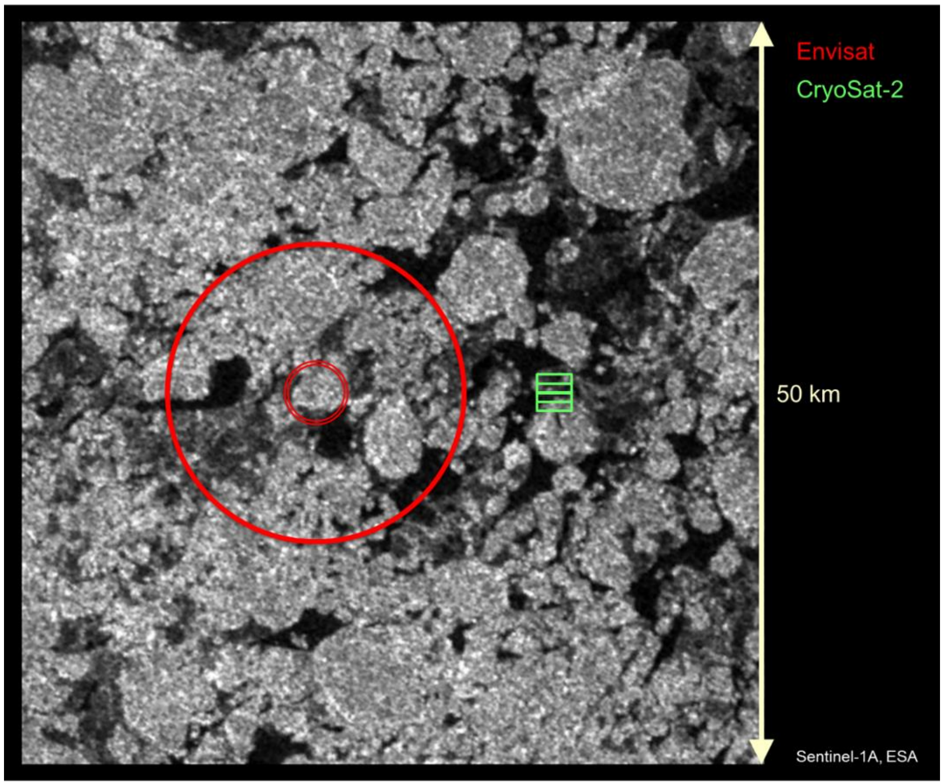
A Priori Information

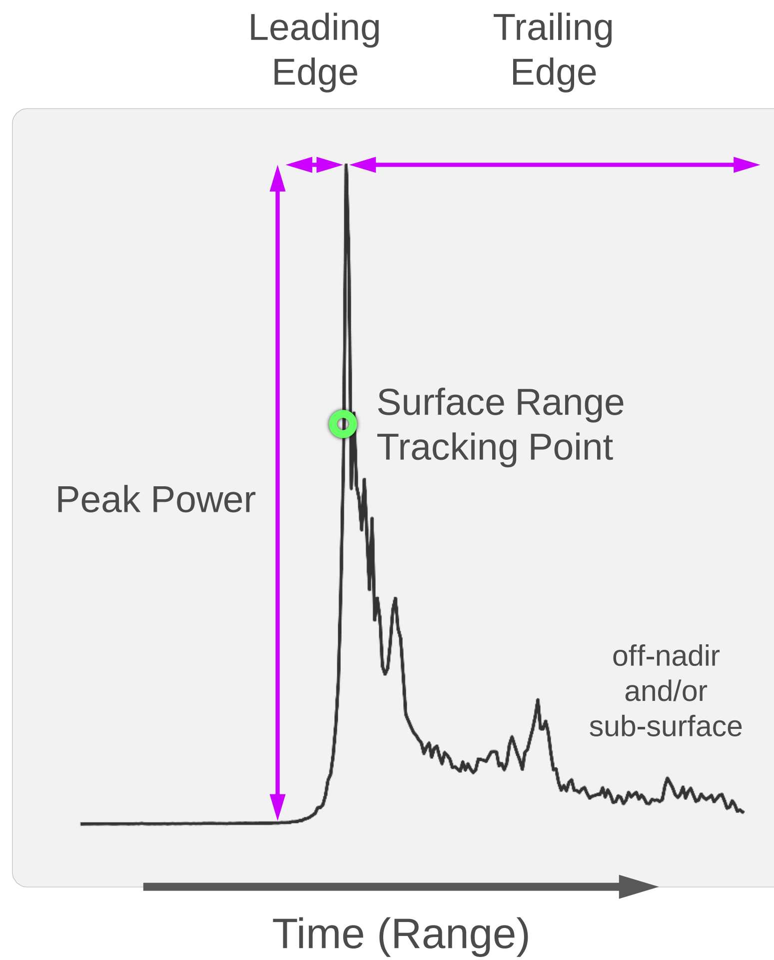
- Snow Depth
- Snow Density
- Sea Ice Density
- Water Density

Main Uncertainty Sources

- Freeboard uncertainties
- Unknown regional and temporal variability of snow depth, snow density and sea ice density

Radar Echo Waveforms





Evolving radar altimeter concepts

(Improved footprints ▷ less surface type mixing)

Per echo waveform surface type and range

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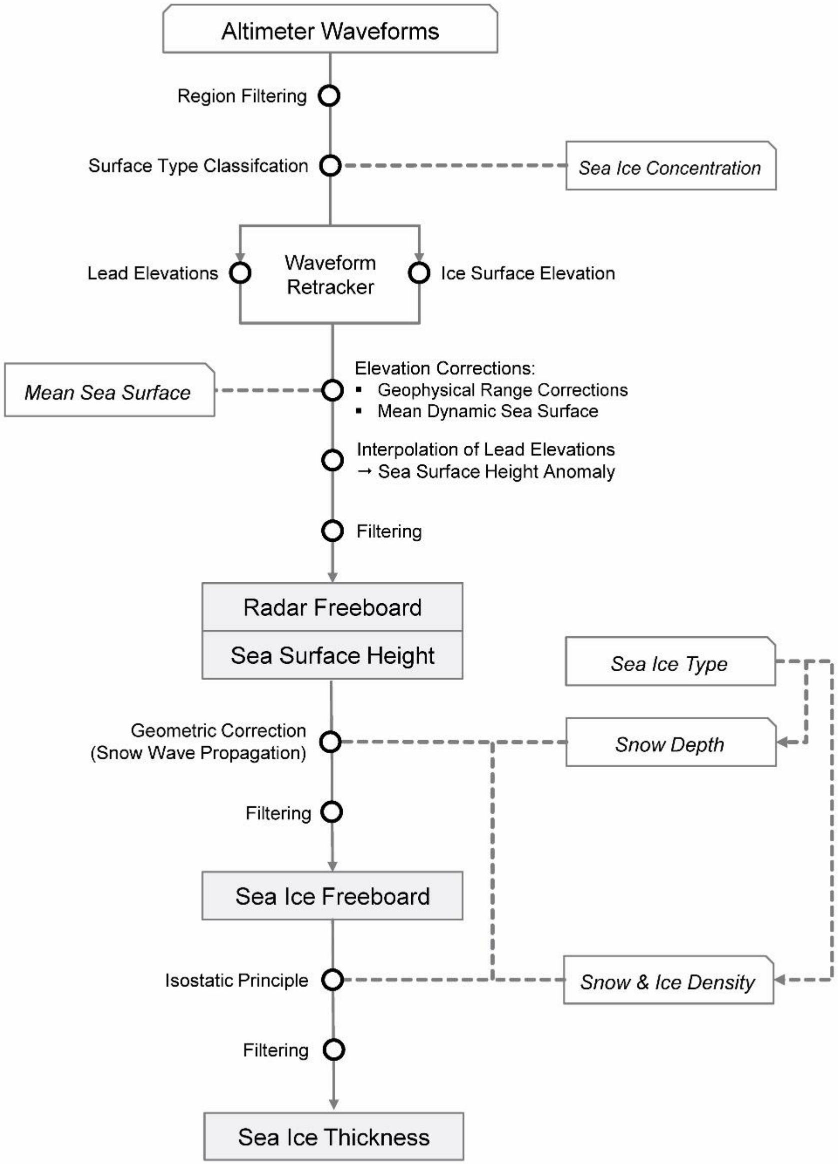
Radar Altimeter Processing Chain



Primary Data

Geolocated Radar Echoes

External Auxiliary Data

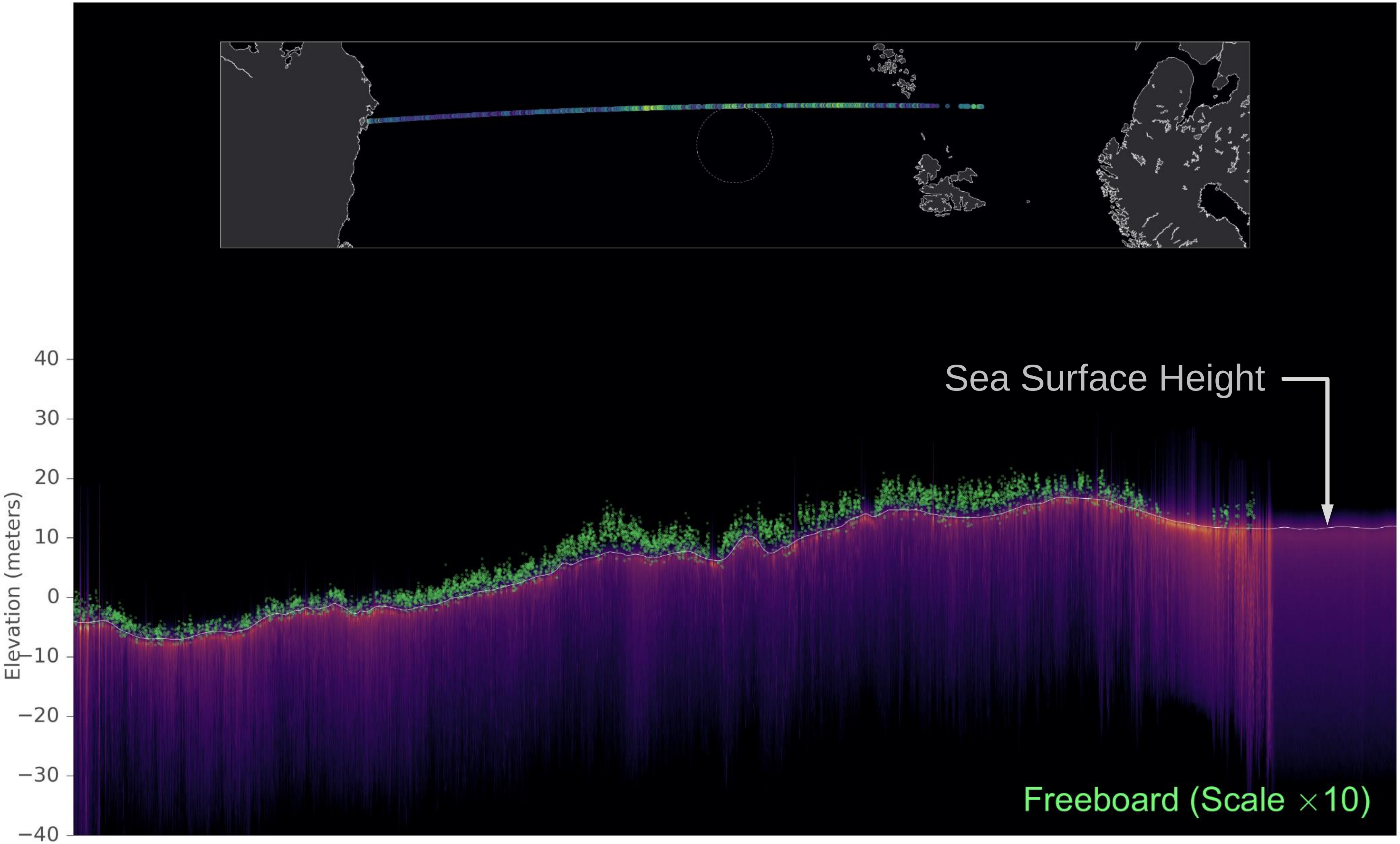
Mean Sea Surface

Sea ice type / MYI area fraction

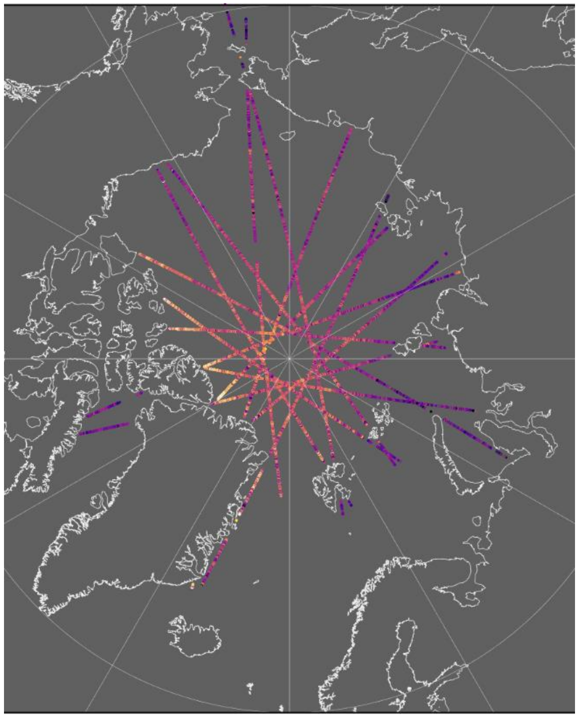
Sea Ice Concentration

Snow Depth / Density

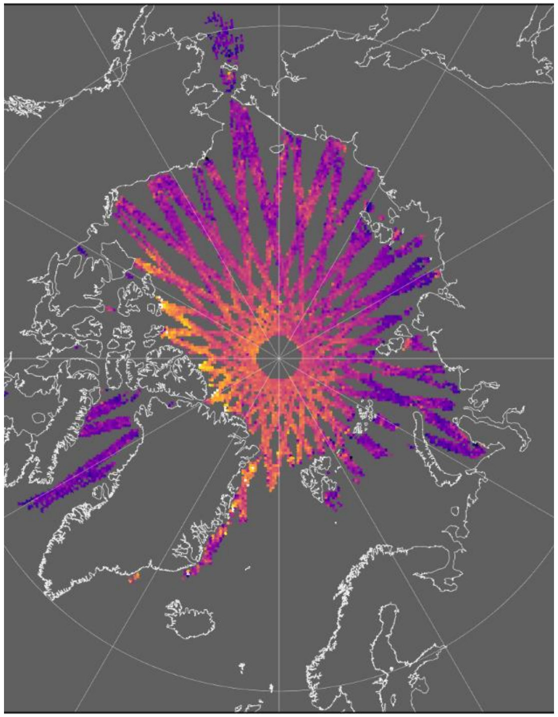
Orbit Freeboard Example



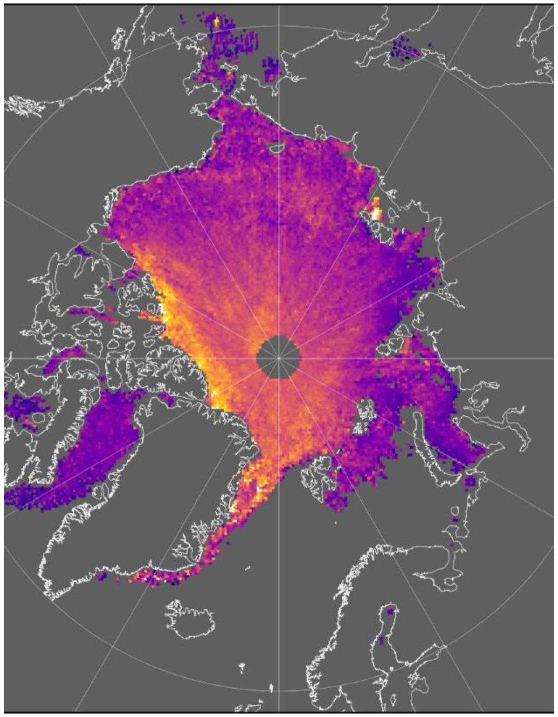
Radar Altimetry - Coverage



Daily Trajectory

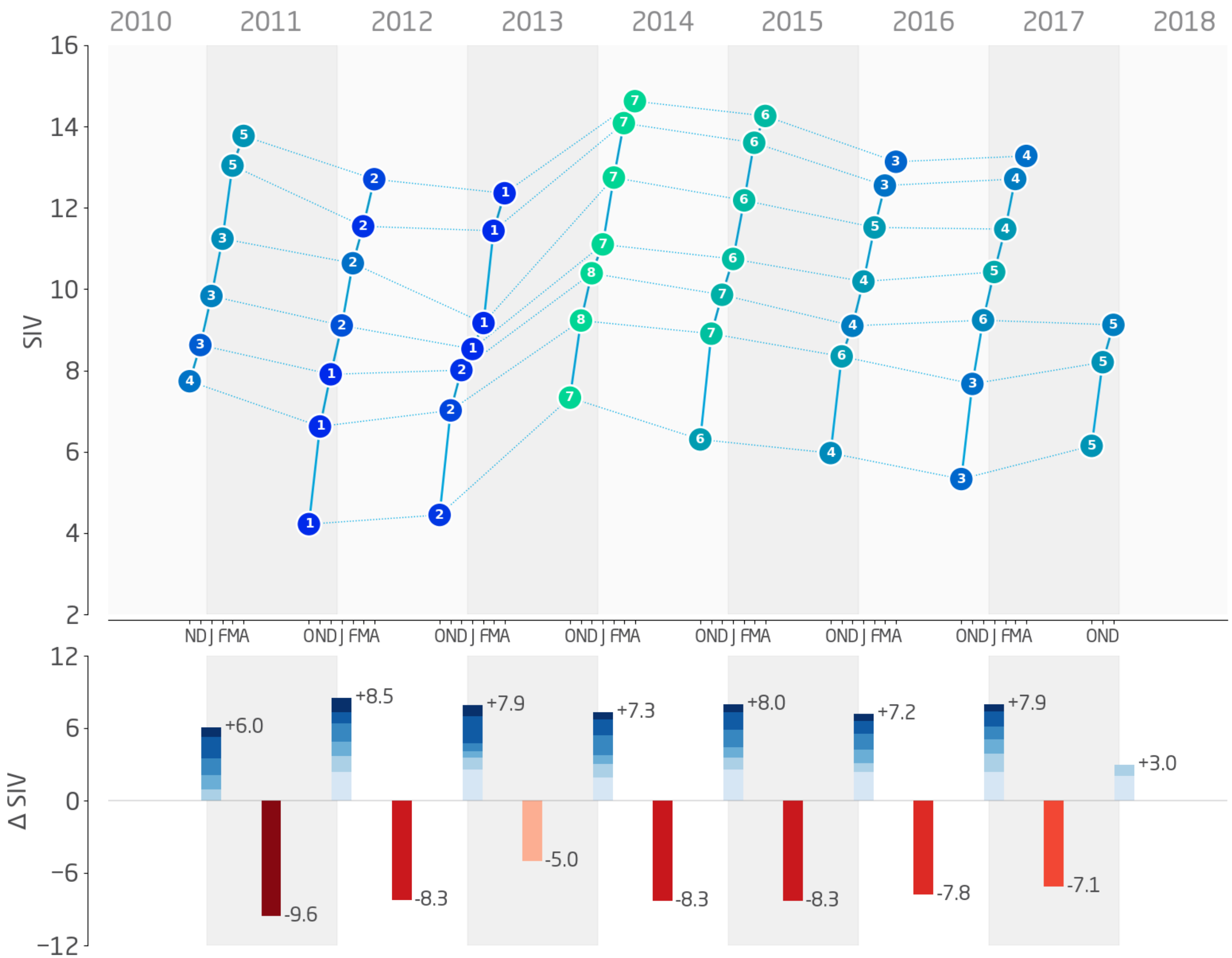


Weekly Grid



Monthly Grid

CryoSat-2 – Central Arctic Volume



SIV : Central Arctic Ocean (< 88N°) Sea Ice Volume in 1000 km^3

January 2018 (cs2awi v2.0)

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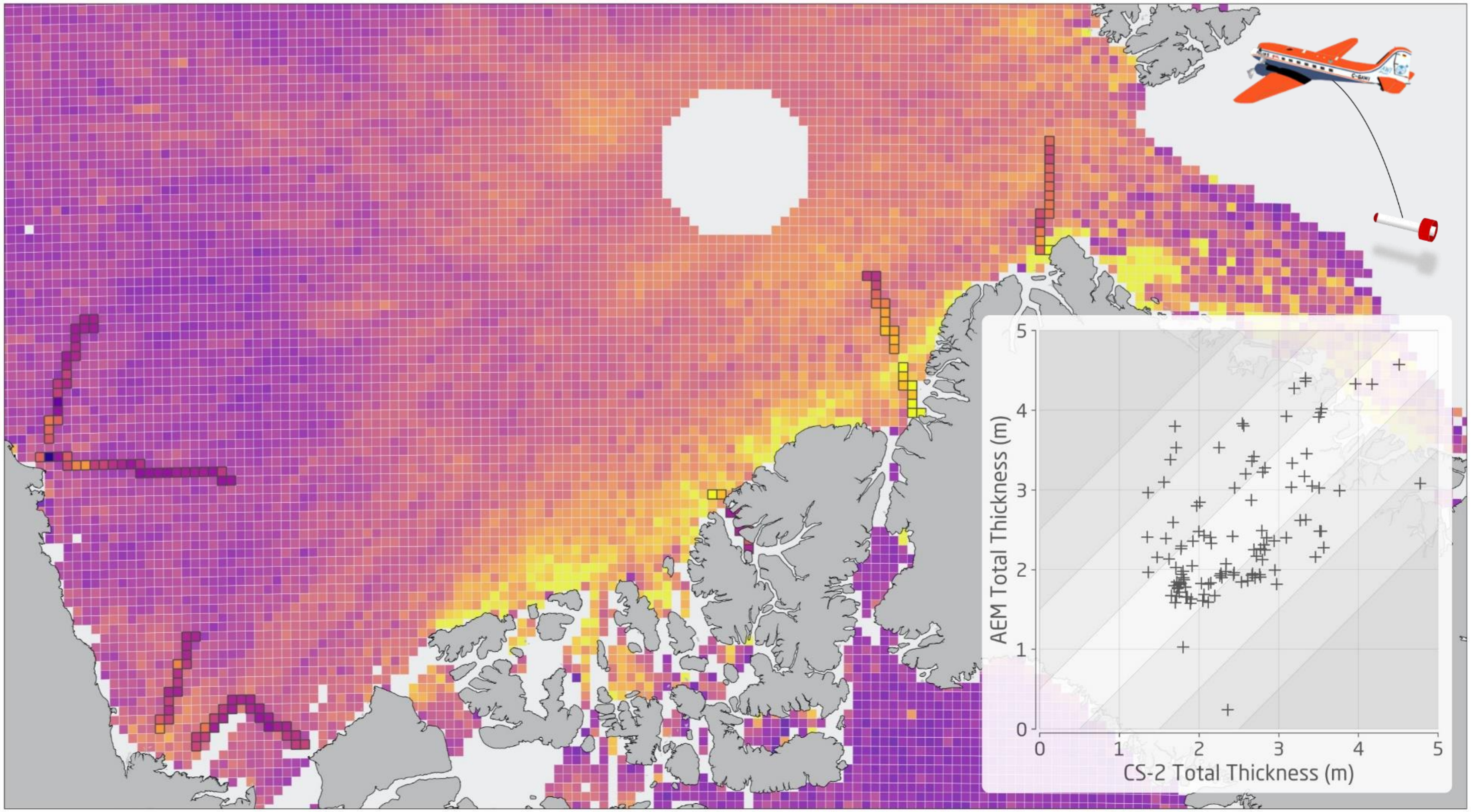
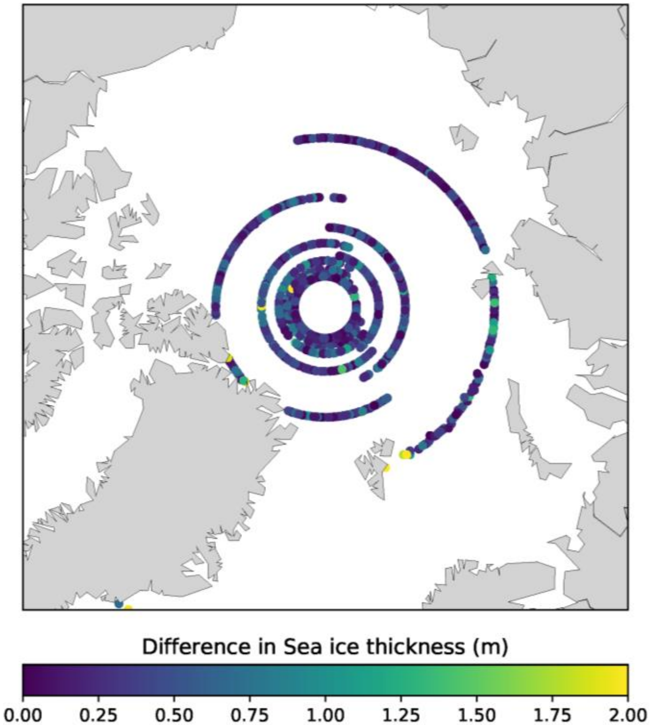
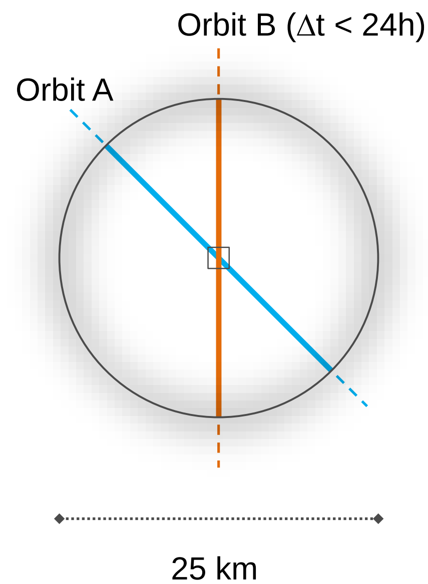
Radar Altimetry – Validation

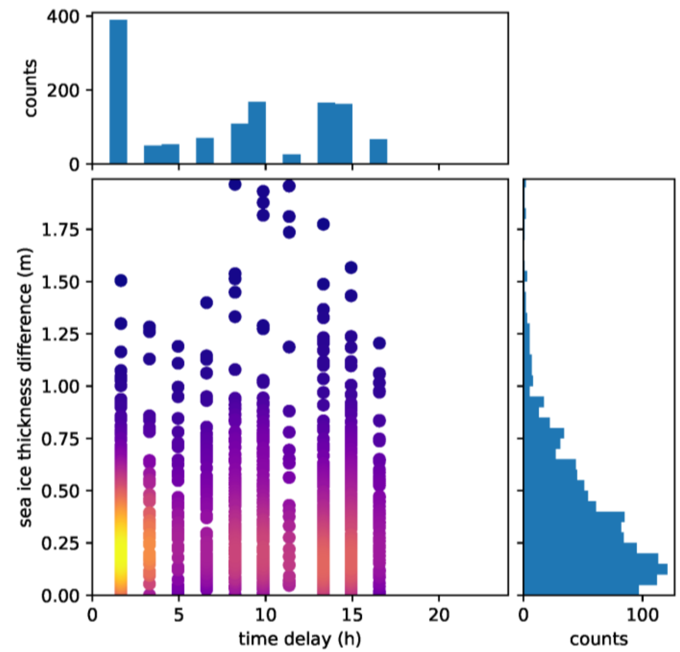


Airborne Validation March/April 2017 (CryoSat Mean: 2.57m, Airborne-EM Mean: 2.65m)

Radar Altimetry – Precision





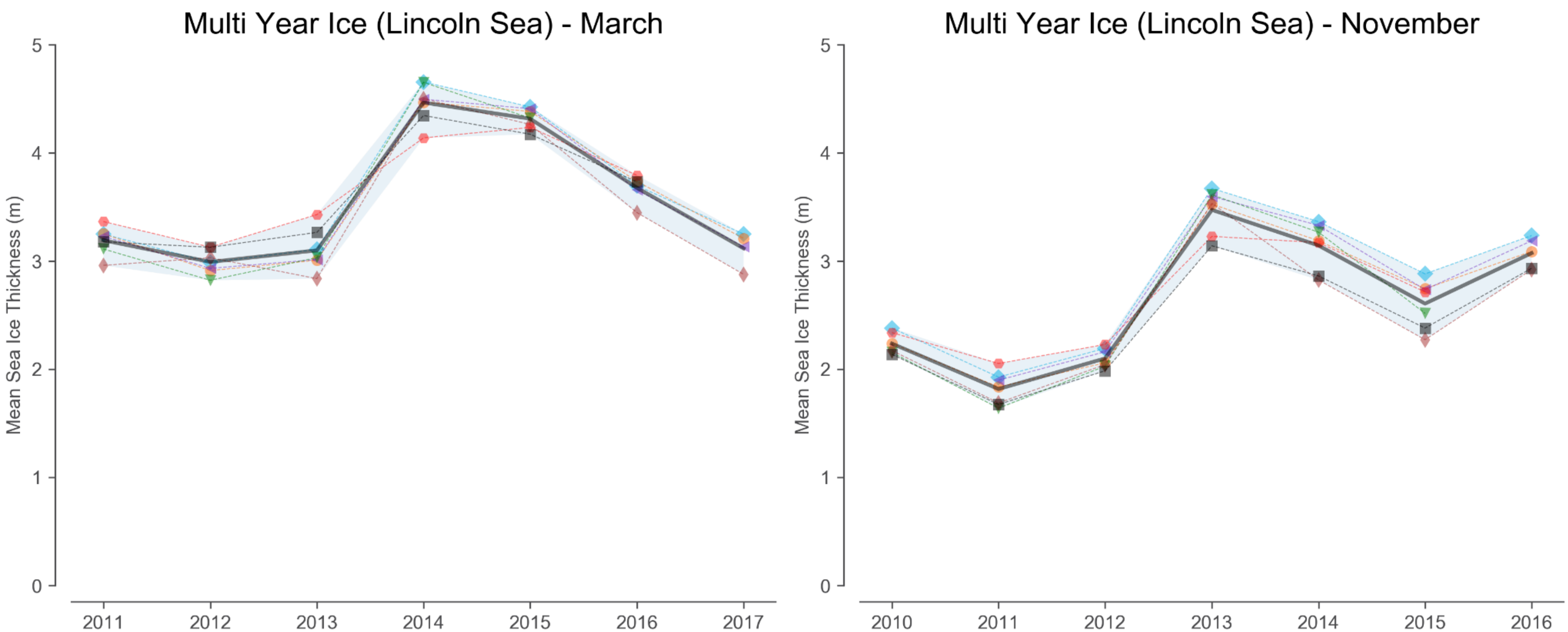


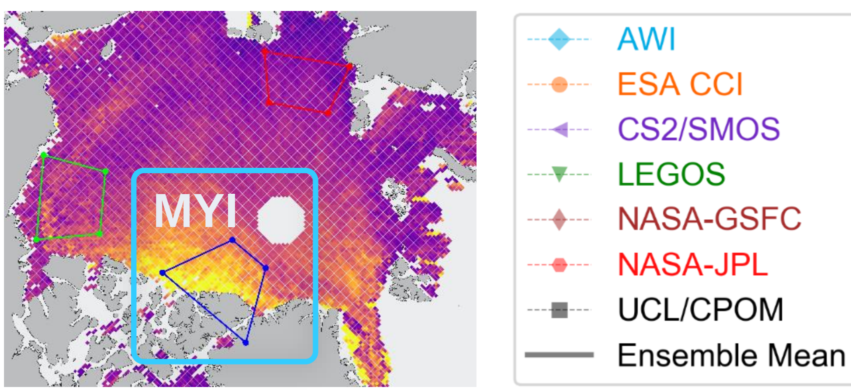
Monthly collection of daily cross-overs (25km window SIT differences)

- Potential error sources: Range Noise | Sea-Surface Height | Selection Bias

▷ **Average CryoSat SIT precision: ~ 40 cm**

Product Intercomparison





Sea Ice Mass Reconciliation Exercise (SIMRE)

ESA Arctic+ Theme 2 (Ice Mass)

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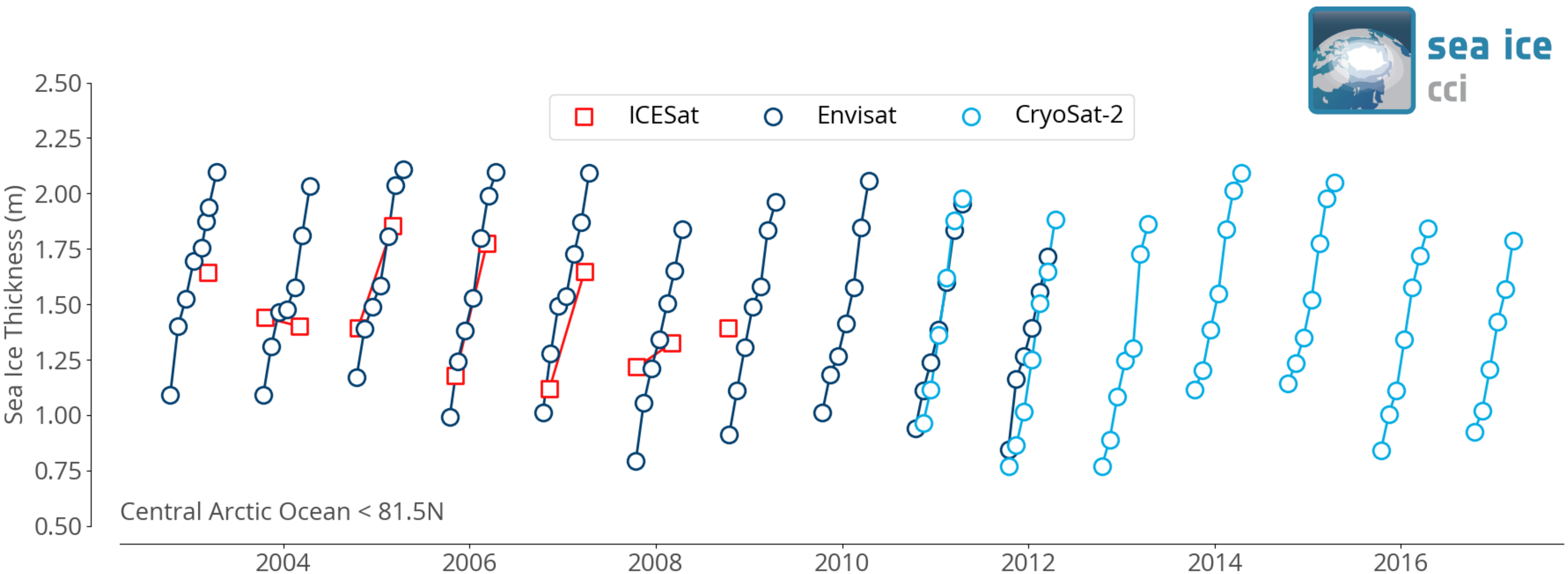
Long-Term Data Records

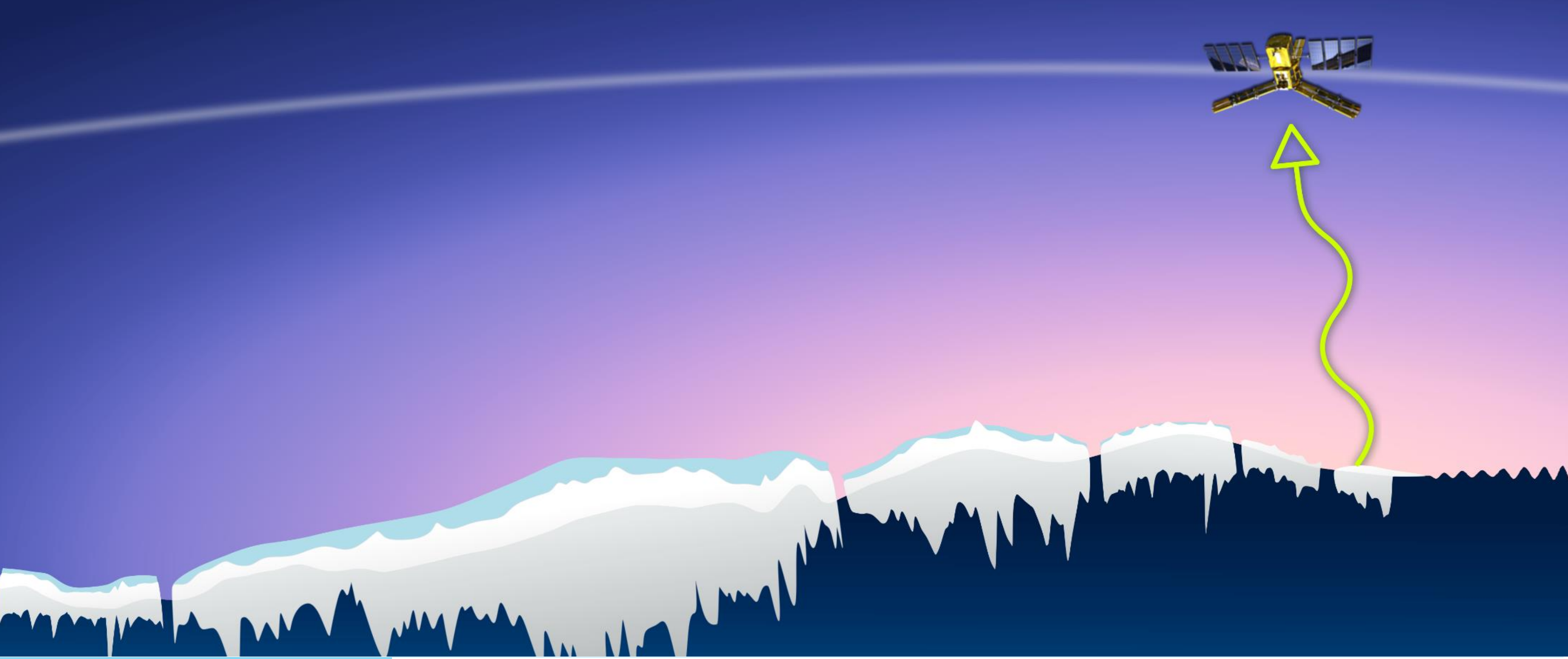


Envisat thickness retrieval

- calibrated at Envisat / CryoSat-2 overlap
- consistent auxiliary datasets and snow assumptions

Radar Altimetry Summary

	Strength / Opportunities	Weaknesses / Threats
Data Record	▪ Longest continuous (2002 - …) ▪ ERS back to 1993 ▪ Sentinel-3 program ▪ Dual-Band Altimetry	▪ No summer data (May – Sept.) ▪ Sentinel-3 not high inclination (S3/Envisat pole hole)
Uncertainty	▪ No indication of large scale bias in spring (CryoSat) ▪ Auxiliary data may improve	▪ Local uncertainty significant ▪ Thin ice under-represented ▪ Snow is not an observation ▪ „uncertainty of uncertainty“
Operational Status	▪ Several centers ▪ Copernicus Climate Change Service (C3S) in prep	
Timeliness	▪ CryoSat-2 (2 days) Sentinel-3 (3 hrs)	

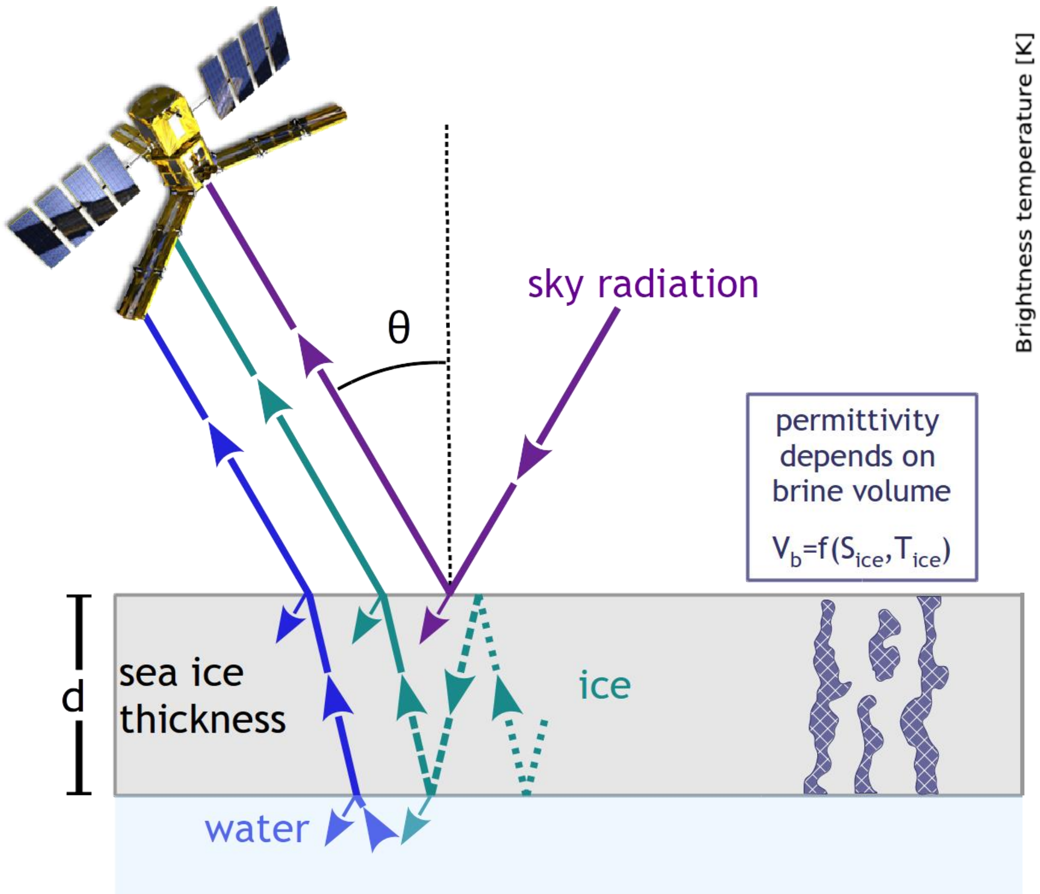


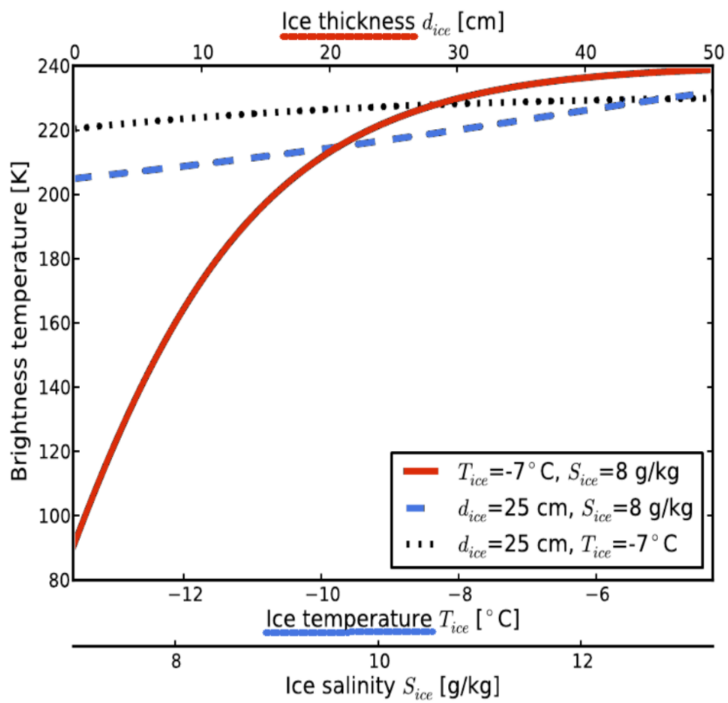
L-Band Radiometry

SMOS ice thickness: Support to Science Element

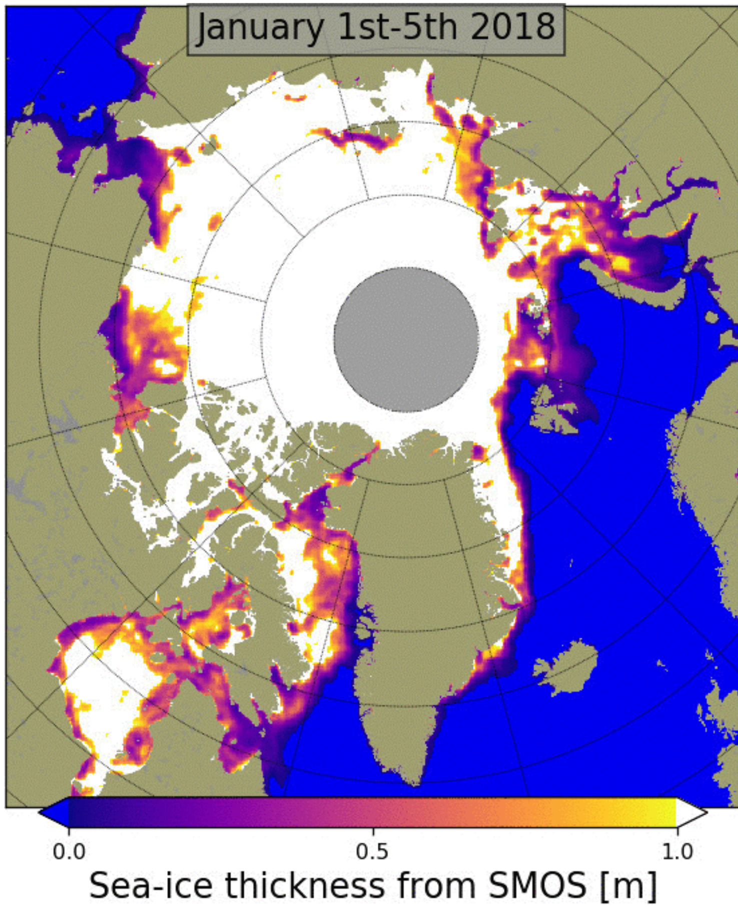
Utilize low-frequency radiometry for sea ice

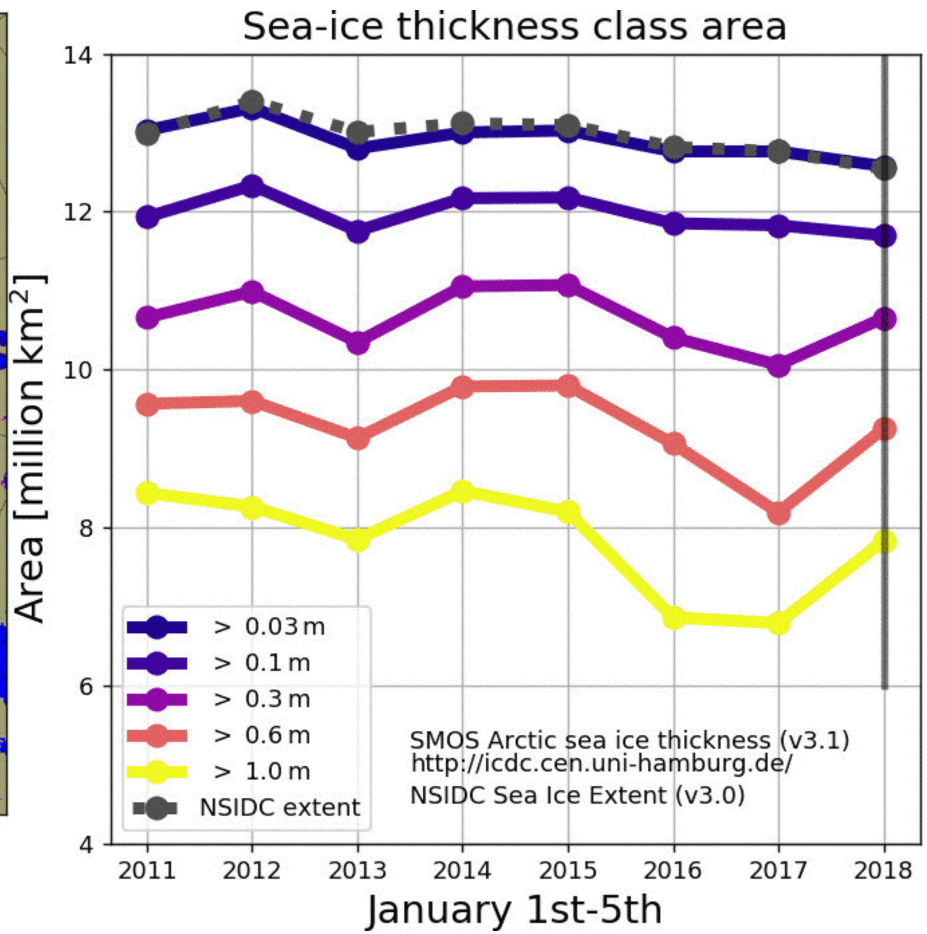
Principle of L-Band Radiometry





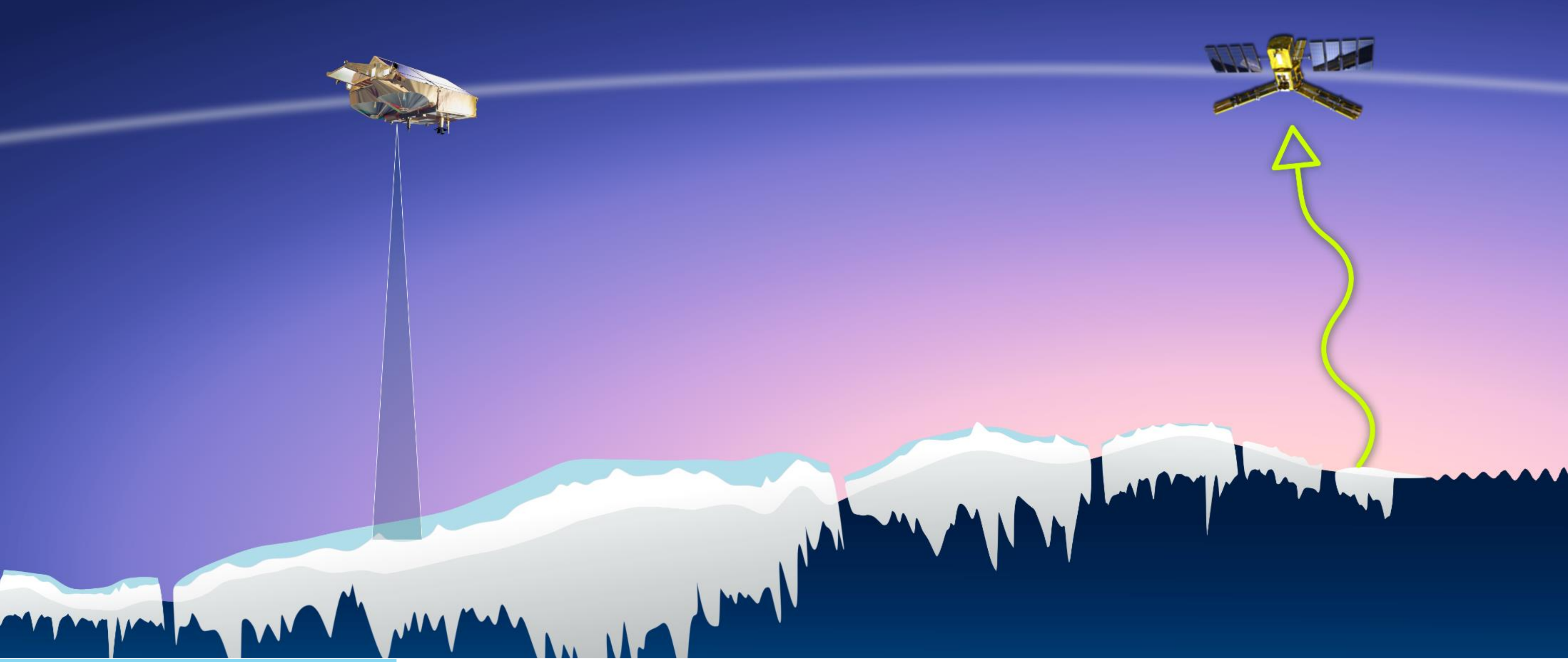
SMOS Data Examples





L-Band Radiometry Summary

	Strength / Opportunities	Weaknesses / Threats
Data Record	▪ Daily global coverage	▪ No summer data ▪ SMOS follow-on?
Uncertainty	▪ Impact of snow might lead to snow depth information	▪ Upper thickness limit ▪ Large footprint
Operational Status	▪ Operational (U. Hamburg)	
Timeliness	▪ SMOS (2 days)	

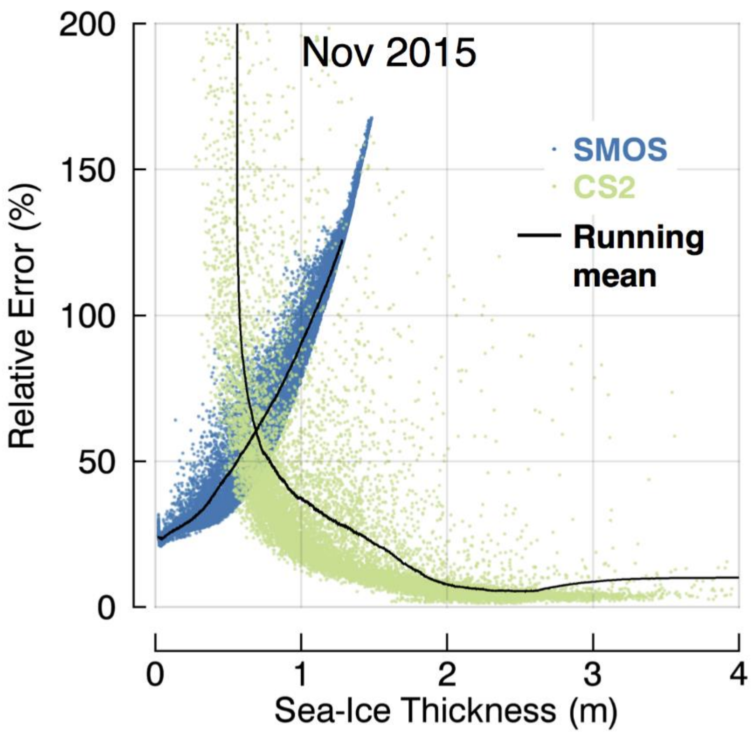


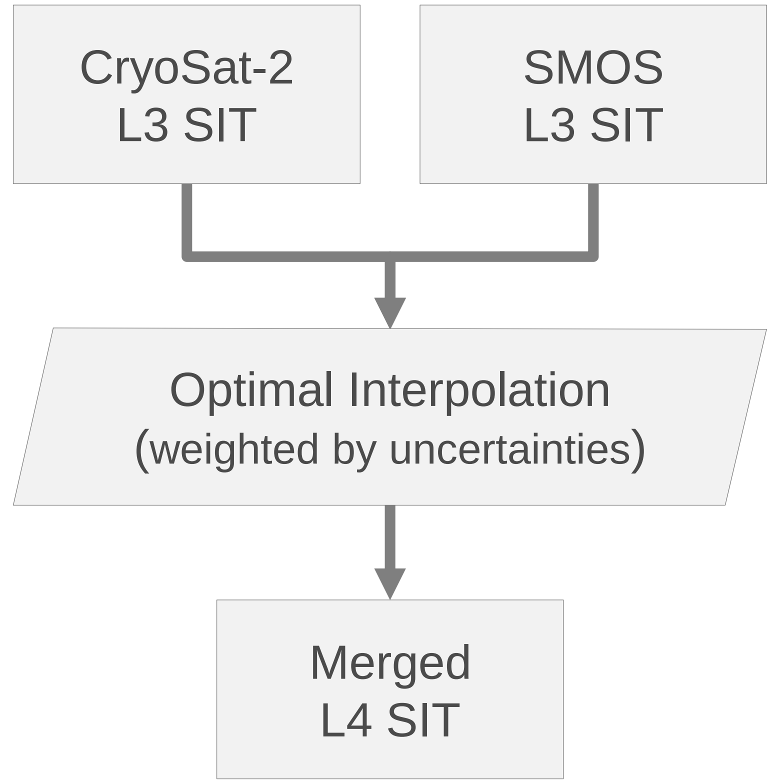
CryoSat-2 / SMOS Data Fusion

ESA Project: SMOS+ Sea Ice

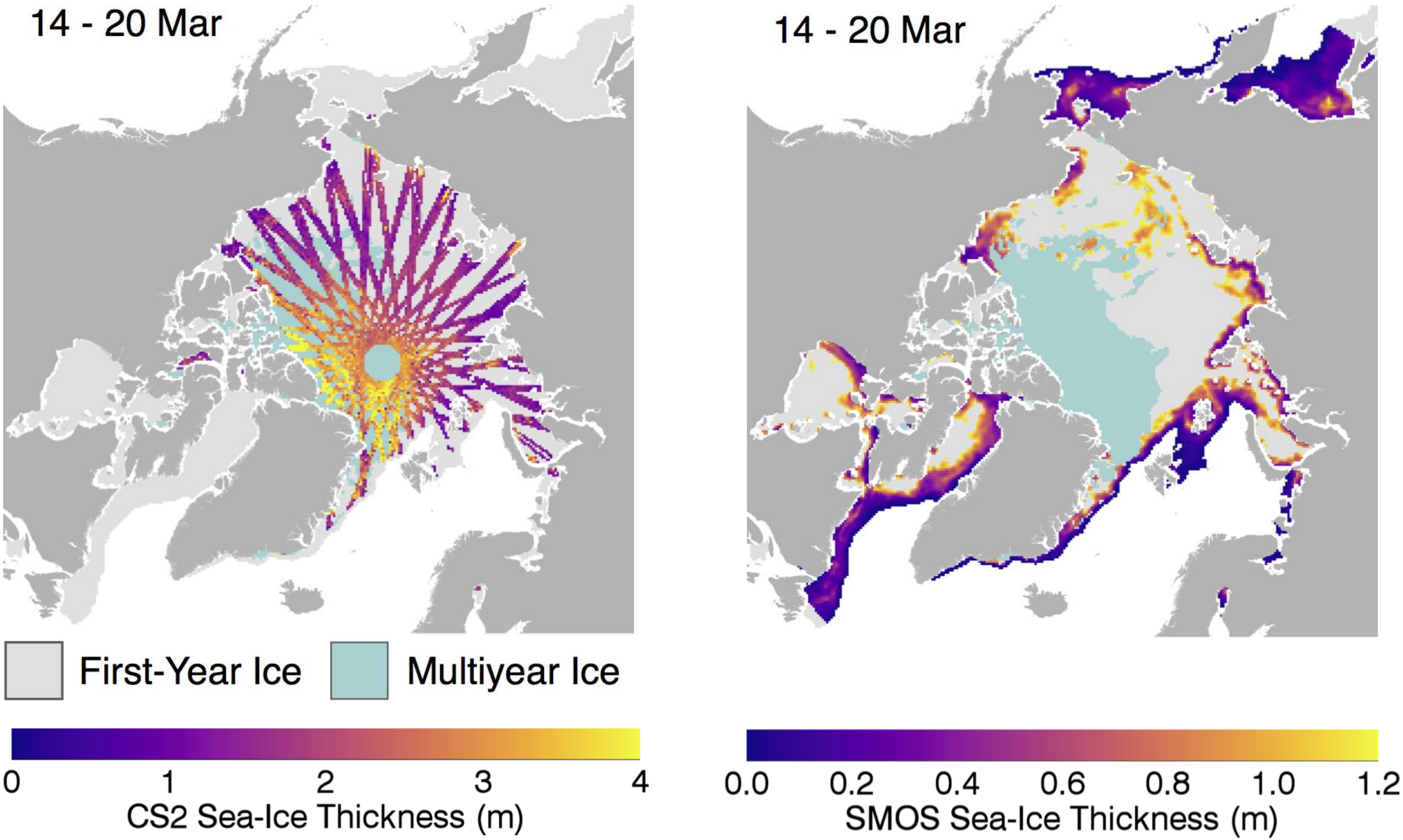
Develop merged thickness prototype

Data Fusion Concept

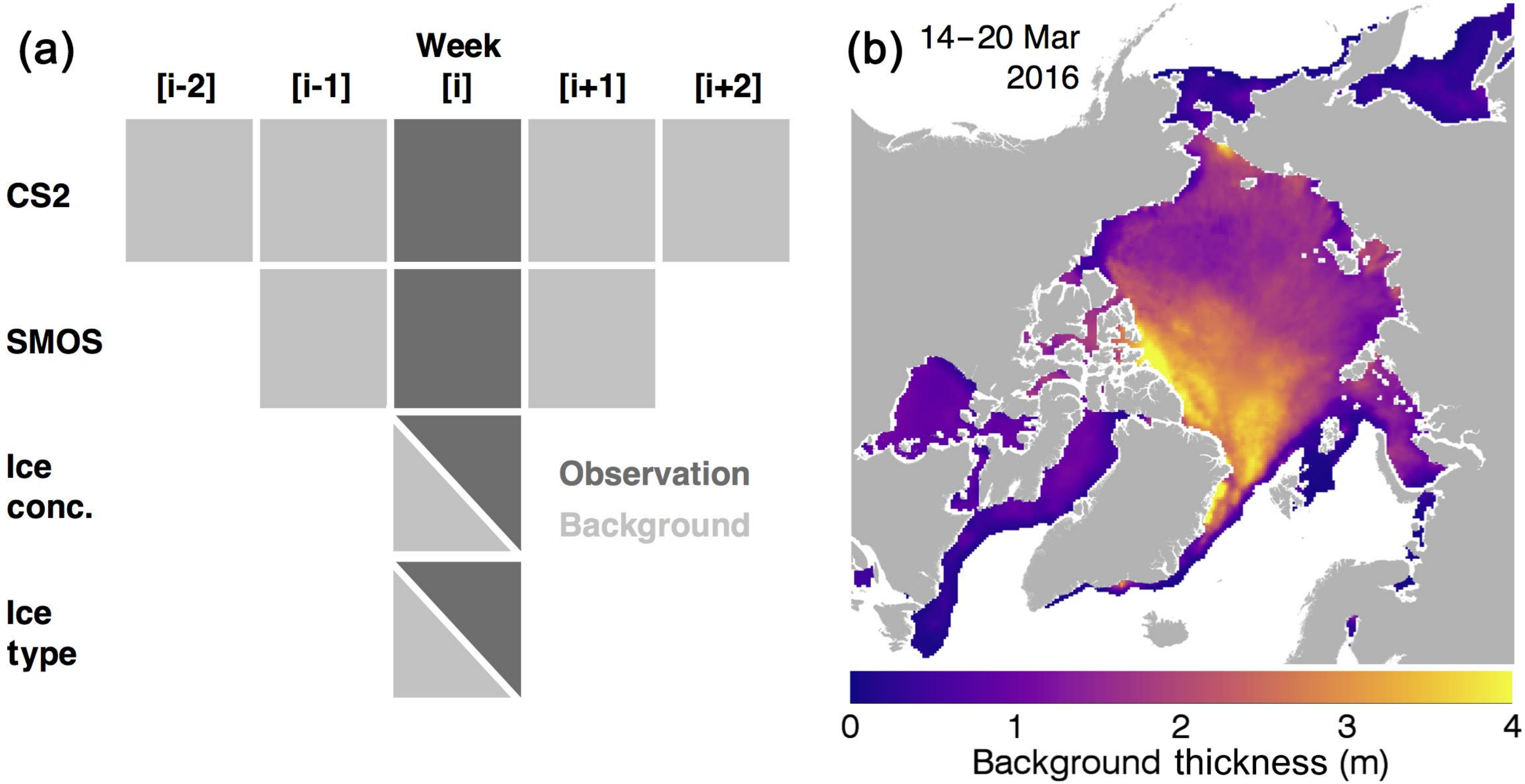




Bridging Temporal Coverage

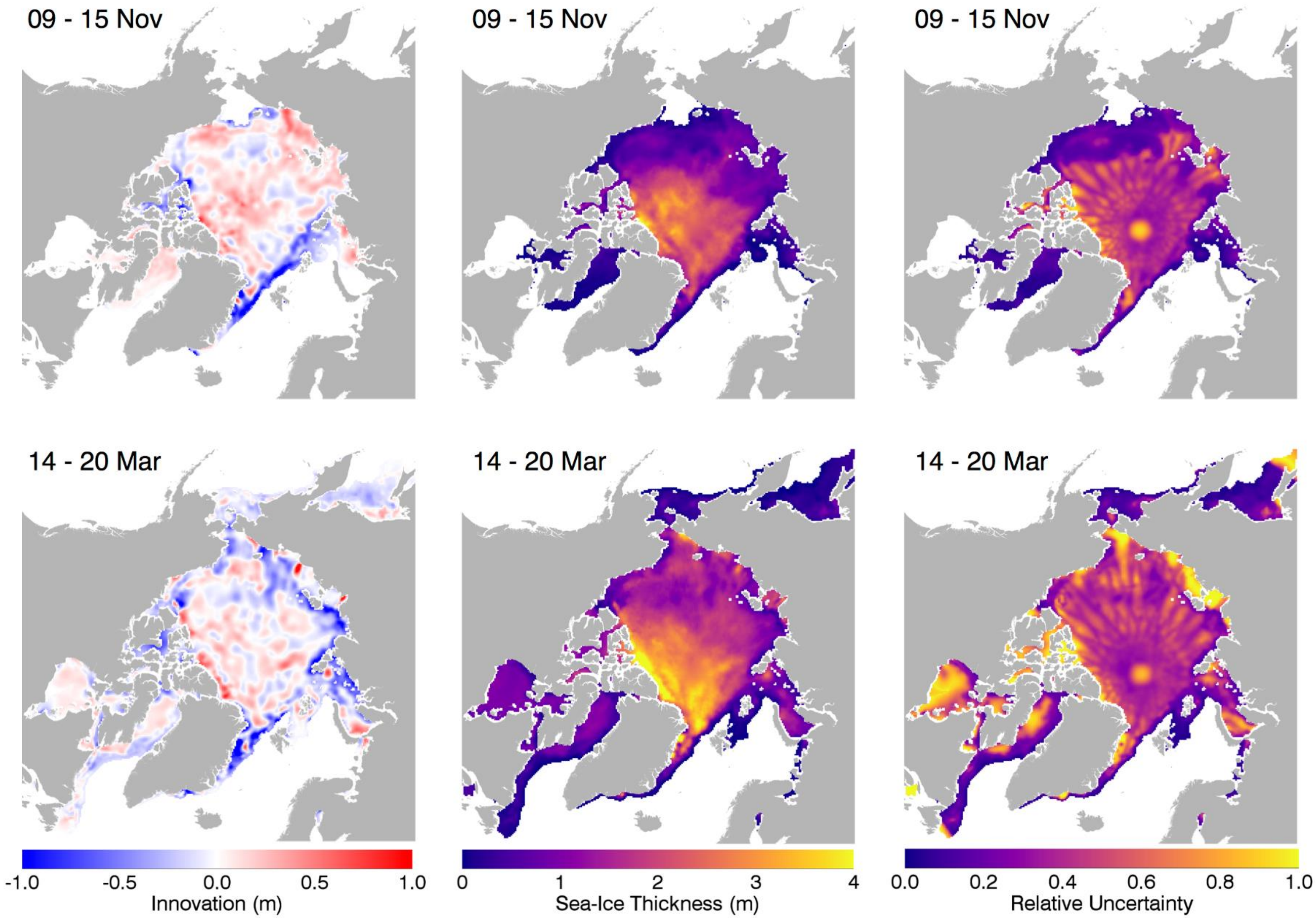


Merged Product – Background Field

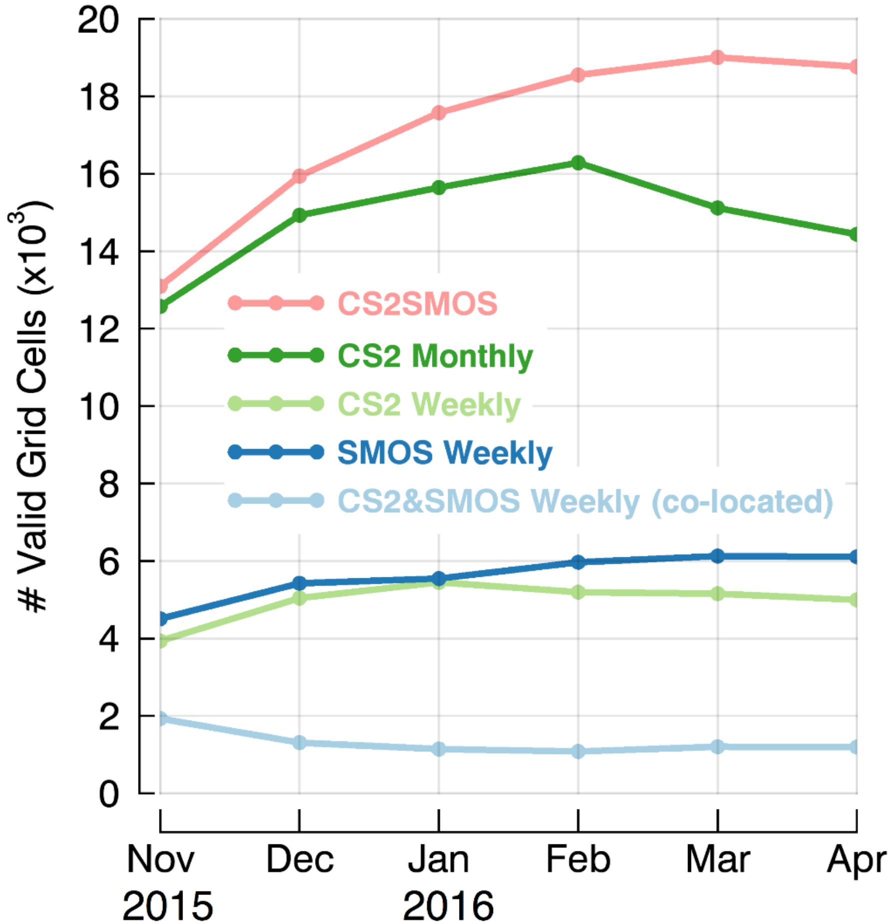


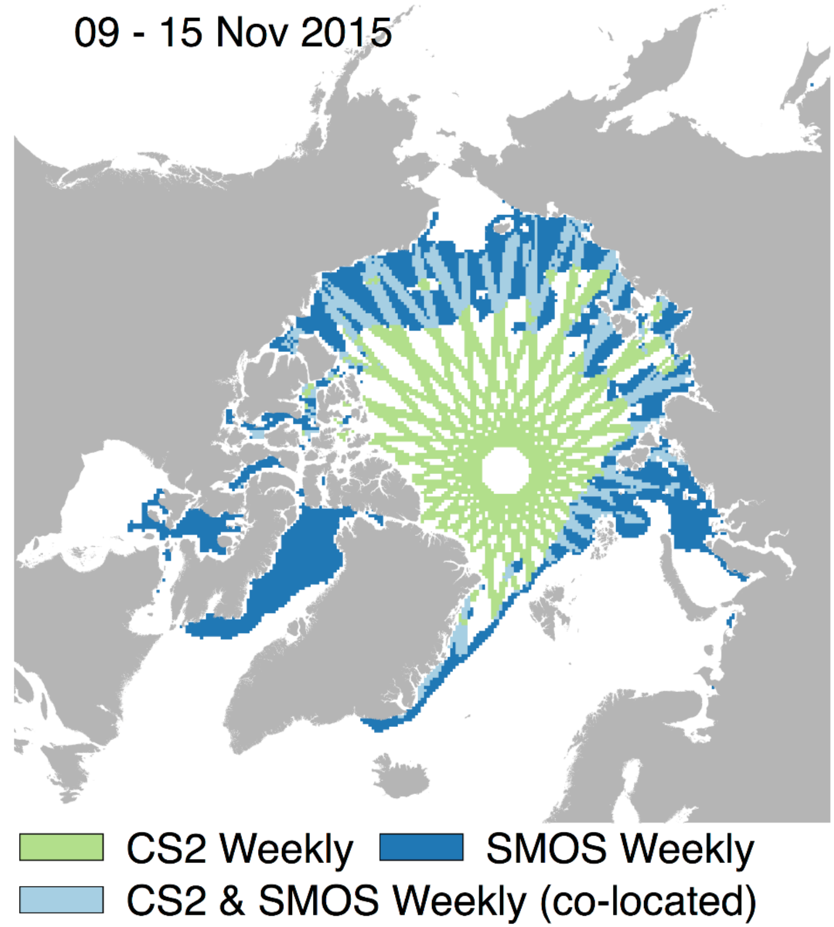
Optimal Interpolation: <u>Innovation of background (weighted mean) by observations</u>

Weekly Thickness Fields

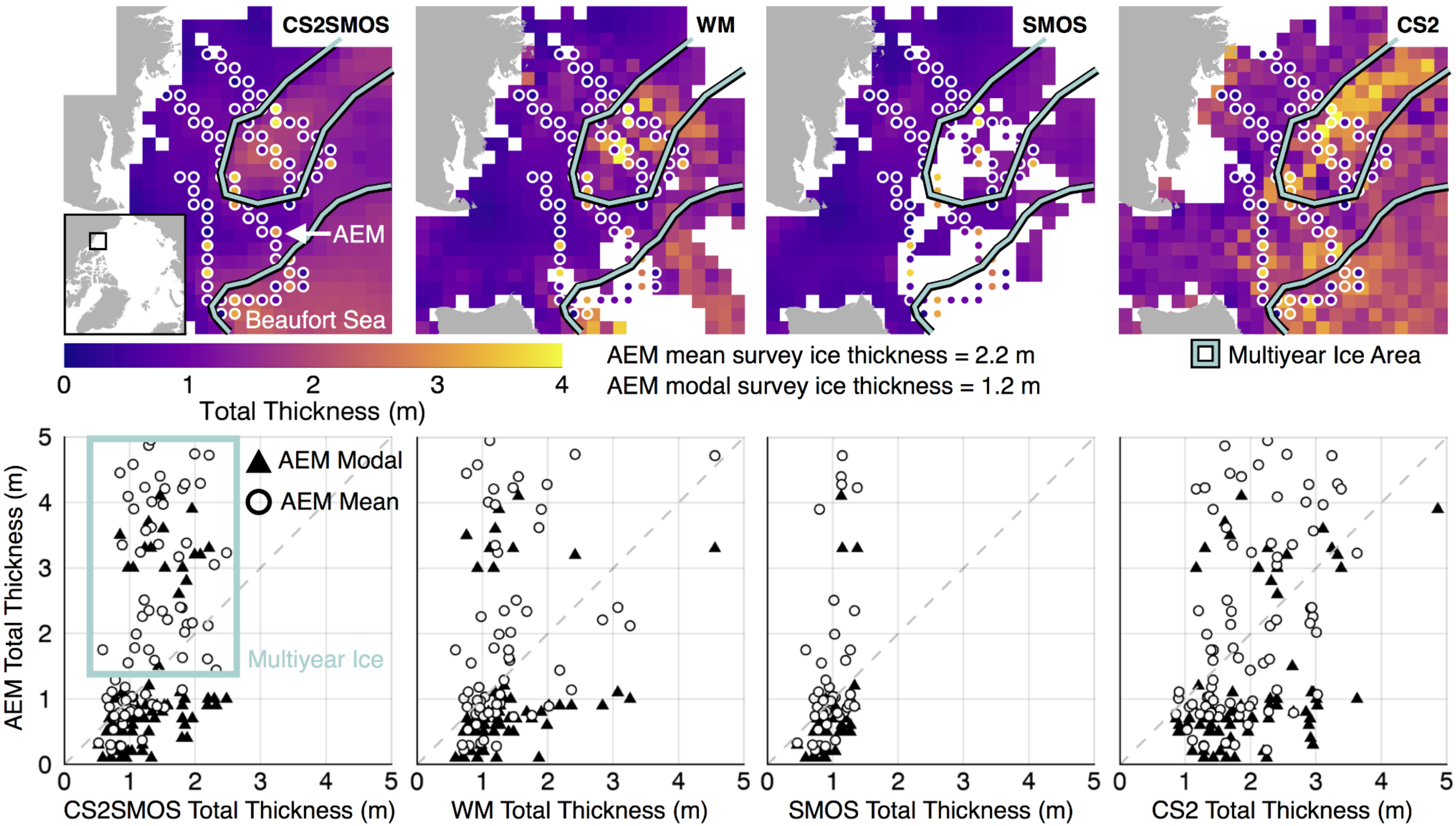


Merged Product – Coverage





Merged Product – Validation



Data Fusion Summary

	Strength / Opportunities	Weaknesses / Threats
Data Record	▪ Weekly gapless	▪ No summer data
Uncertainty	▪ The best of two worlds (full thickness resolution)	▪ Smoothing removes localized features ▪ Uncertainties depend on input where one method dominates
Operational Status	▪ SMOS & CryoSat-2 Sea Ice PDS in Q4 2018	▪ Only reprocessed product
Timeliness	▪ Improved background field for NRT (2 day) service	

Conclusions – Product Guide

	Use	Don‘t use
Altimetry	▪ First-year / multi-year sea ice ▪ Climate applications (longest data record)	▪ Young thin ice (freeze-up) ▪ Areas close to ice edge ▪ High coverage & temporal resolution
Radiometry	▪ Daily observations of thin ice	▪ Older first-year, multi year ice
Merged	▪ Weekly observations for entire northern hemisphere and thickness range	▪ You want to use observation operators ▪ You want to assimilate observations individually

Thank you!

Ricker, R., Hendricks, S., Kaleschke, L., Tian-Kunze, X., King, J., and Haas, C. (2017):

A weekly Arctic sea-ice thickness data record from merged CryoSat-2 and SMOS satellite data

The Cryosphere

ftp://data.meereisportal.de

user: `altim`

password: `altim`

`/altim/sea_ice/product/north/cryosat2-smos/cs2smos_v1.4/`