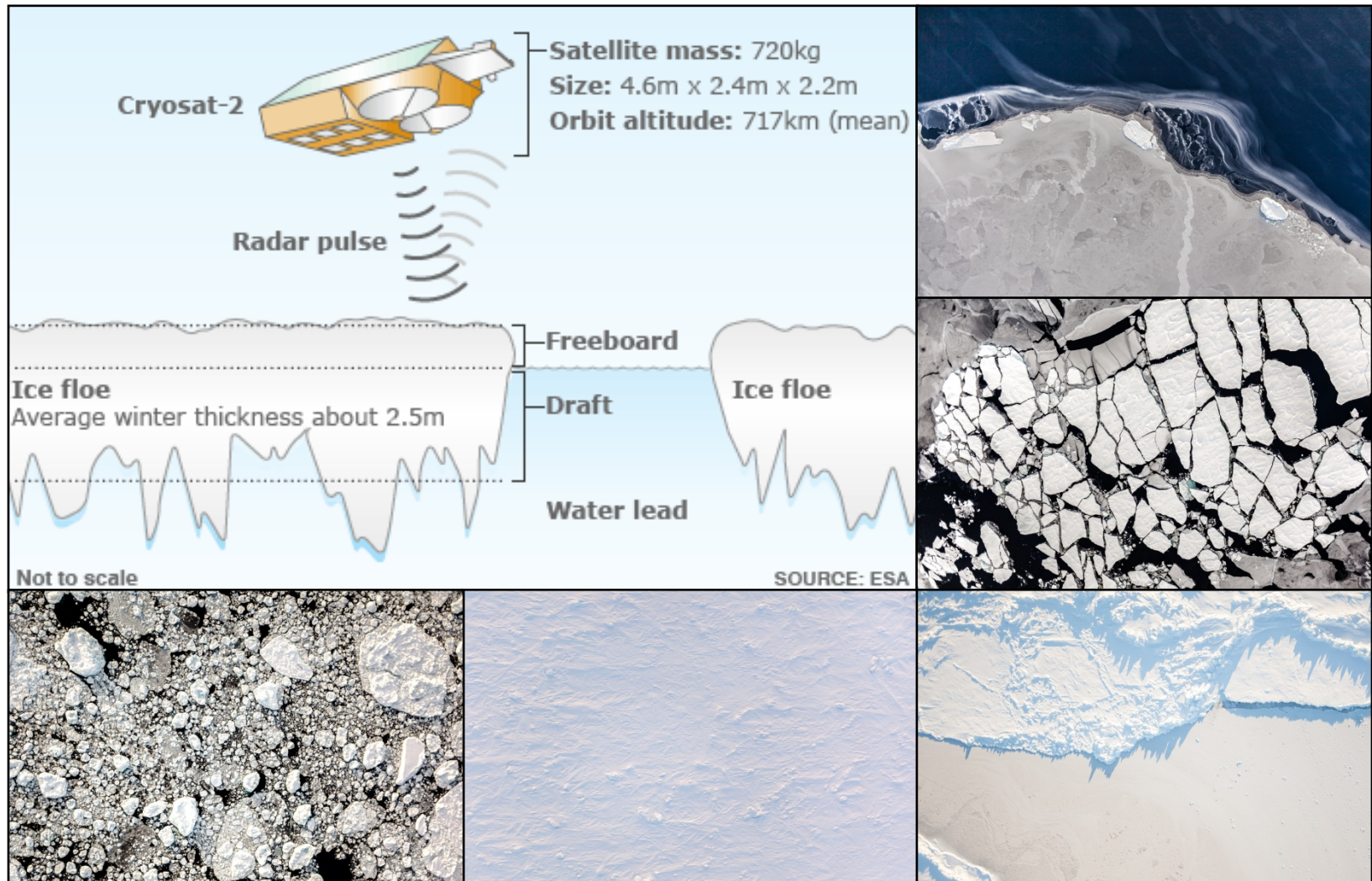


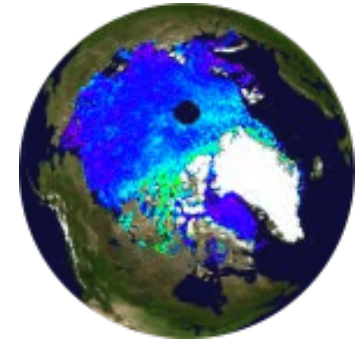
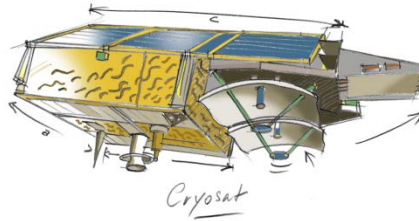
CryoSat-2

Sea-Ice Freeboard and Thickness

S. Hendricks¹, R. Ricker¹, V. Helm¹, C. Haas², H. Skourup,³ A. Herber¹,
S. Schwegmann¹, R. Gerdes¹, M. Davidson⁴

CryoSat-2 Sea-Ice Thickness





Sea-Ice Volume & Uncertainty



Sea-Ice Freeboard & Uncertainty

Signal Quality

Radar Penetration

Sea Surface Height



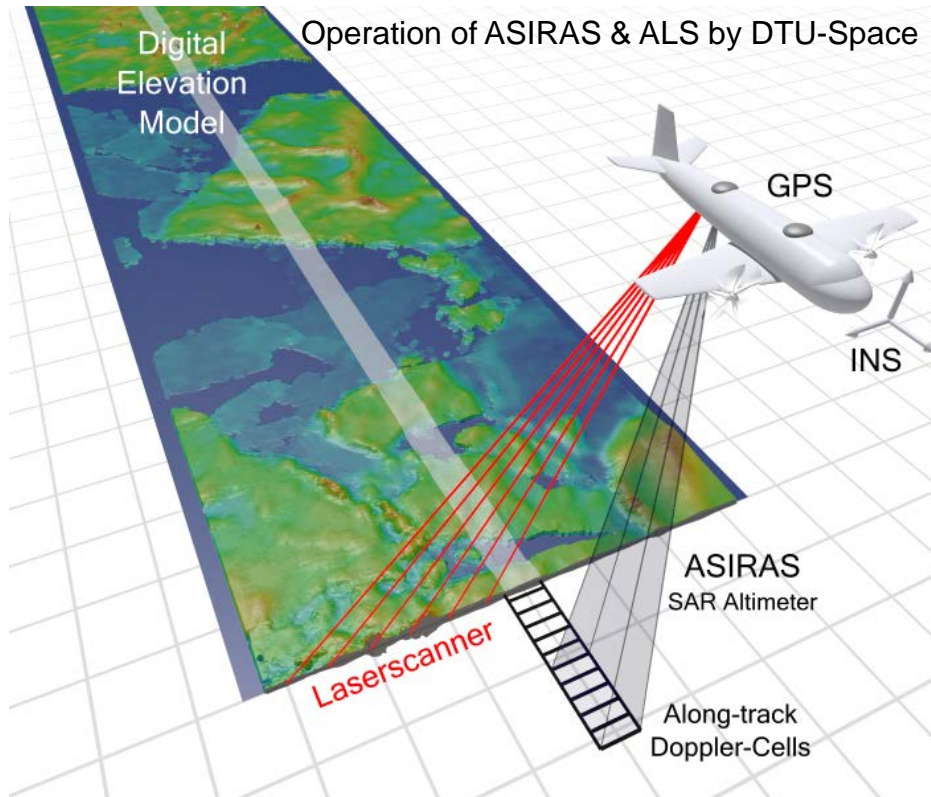
Freeboard to Thickness Conversion & Uncertainty

Sea Ice Density

Snow Depth

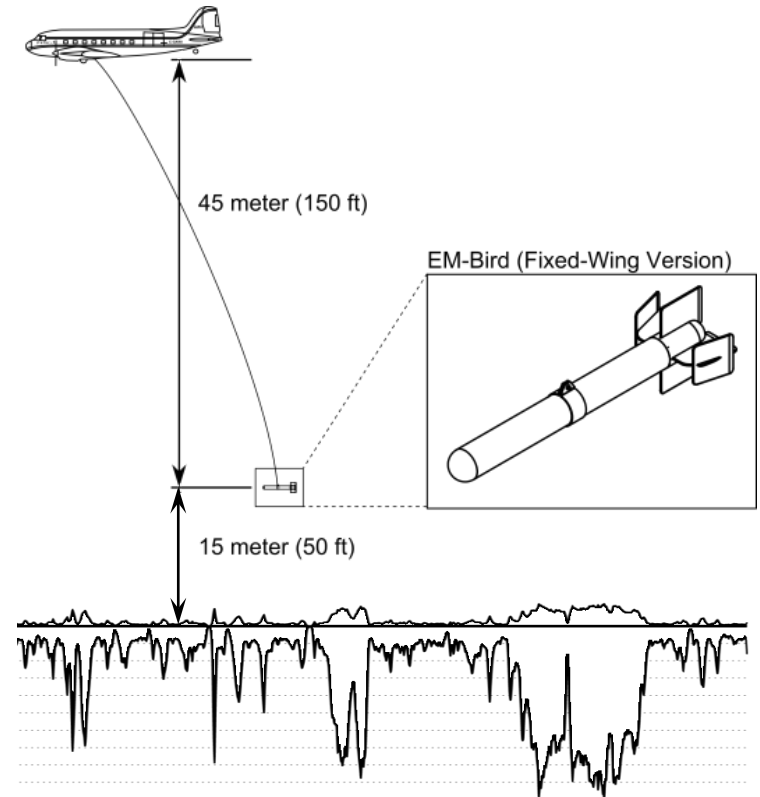
Snow Density

CryoSat-2 sea-ice Cal/Val



Laser – Radar Altimetry

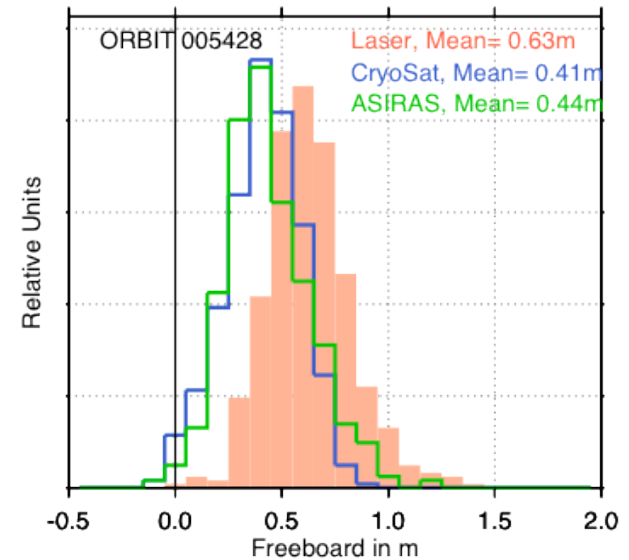
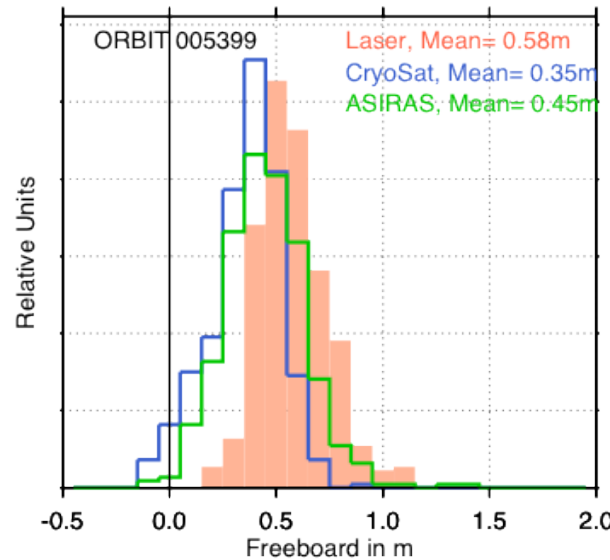
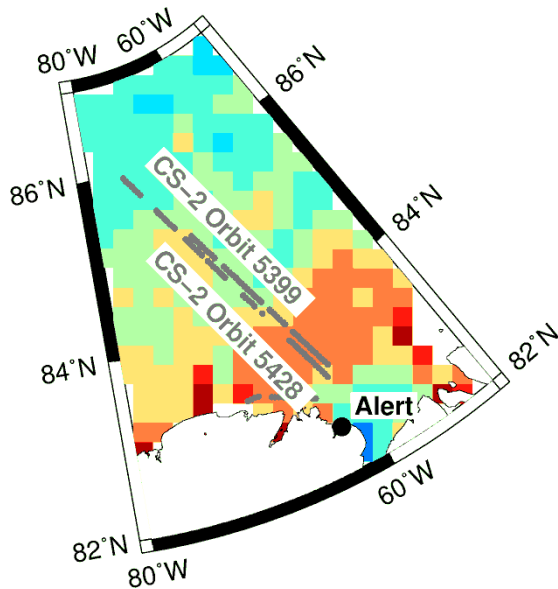
- Radar penetration into snow
- Sea-ice surface roughness
- Direct comparison to CryoSat-2



Airborne EM (AEM) Thickness

- Sea-ice thickness data
- Helicopter and fixed-wing aircrafts
- Direct comparison to CryoSat-2

Freeboard: Airborne vs. CryoSat-2

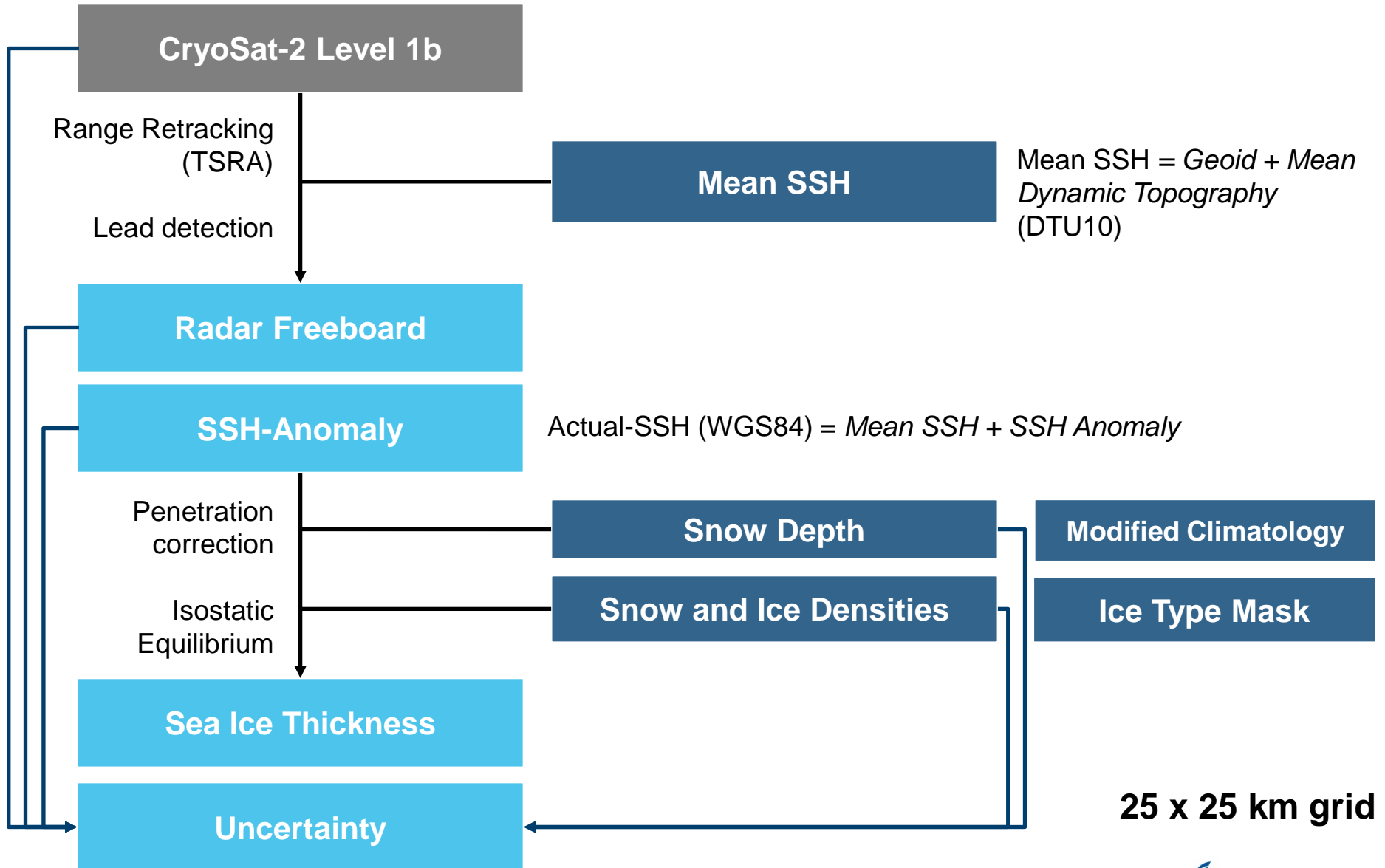


Sea-Ice Freeboard Uncertainty

Airborne (laser & radar) and CryoSat-2 freeboard

- Coincident Data Acquisition (CryoVEx 2011)
- Distribution of airborne radar and CryoSat-2 freeboard comparable
- Difference (**22 cm**) to laser freeboard smaller than expected snow depth (even for dry & cold snow)
 - Lower wave propagation speed in snow not accounted

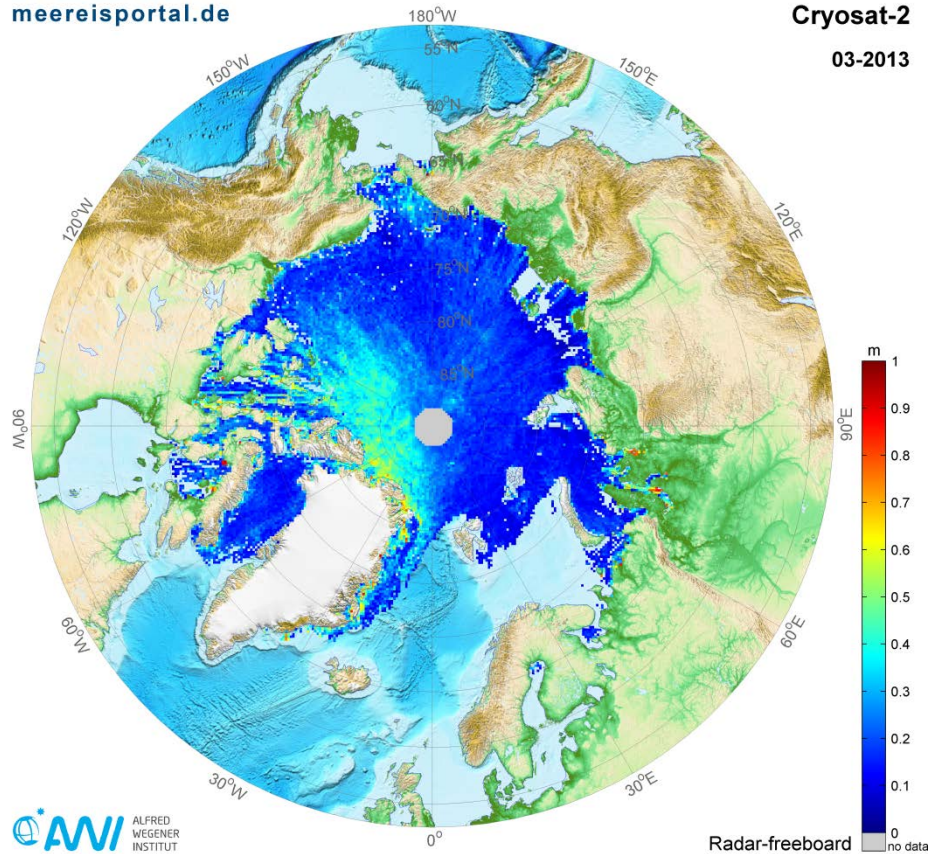
CryoSat-2 processing scheme



CryoSat-2: First results - Freeboard



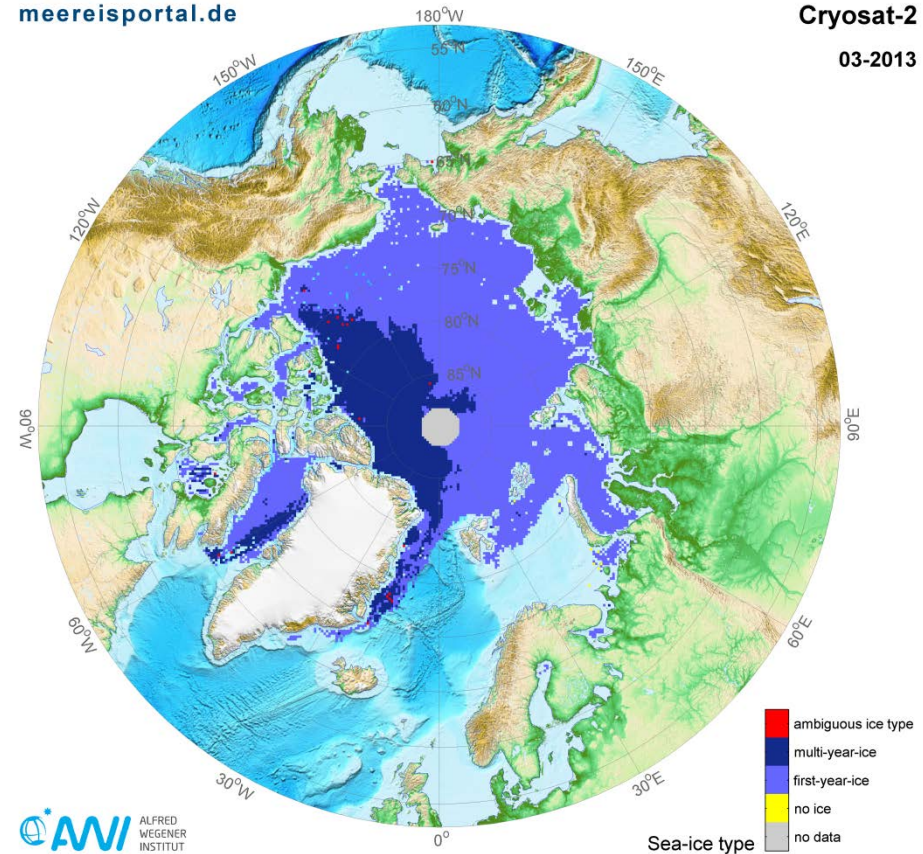
meereisportal.de



Radar Freeboard

- Direct result from CryoSat-2 data
- No physical corrections (snow) applied

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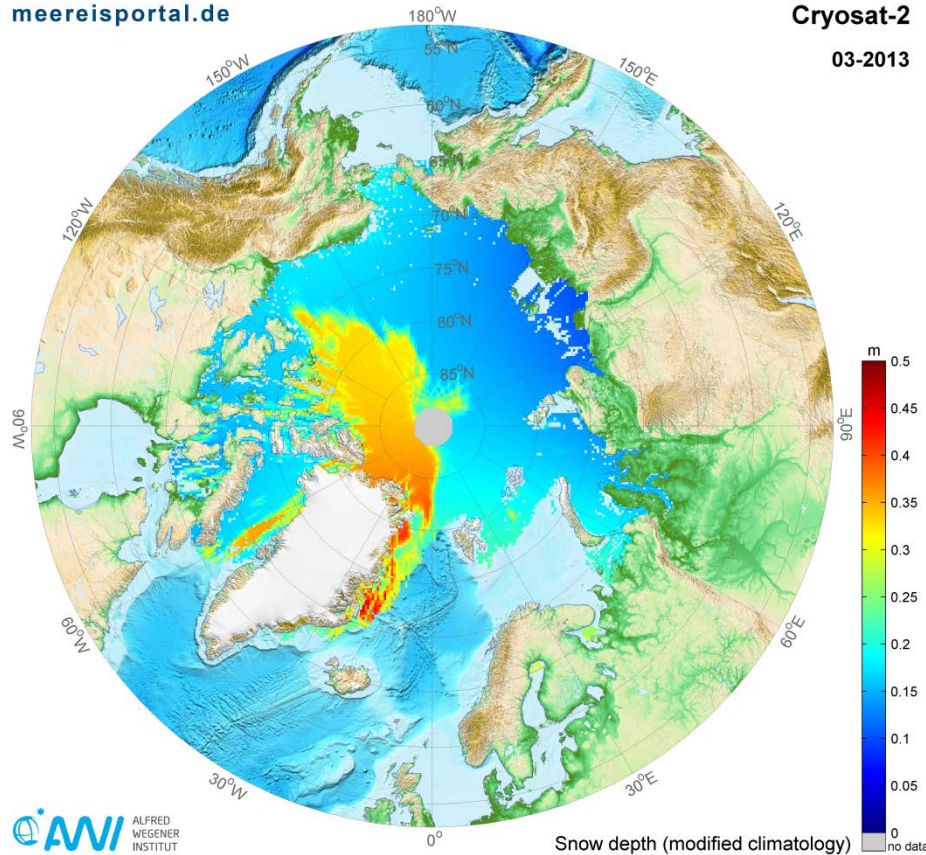
Sea Ice Type (OSI-SAF)

- Main classification FYI / MYI
- Similar spatial distribution to radar freeboard

March 2013

Sea-Ice & Snow Parametrization

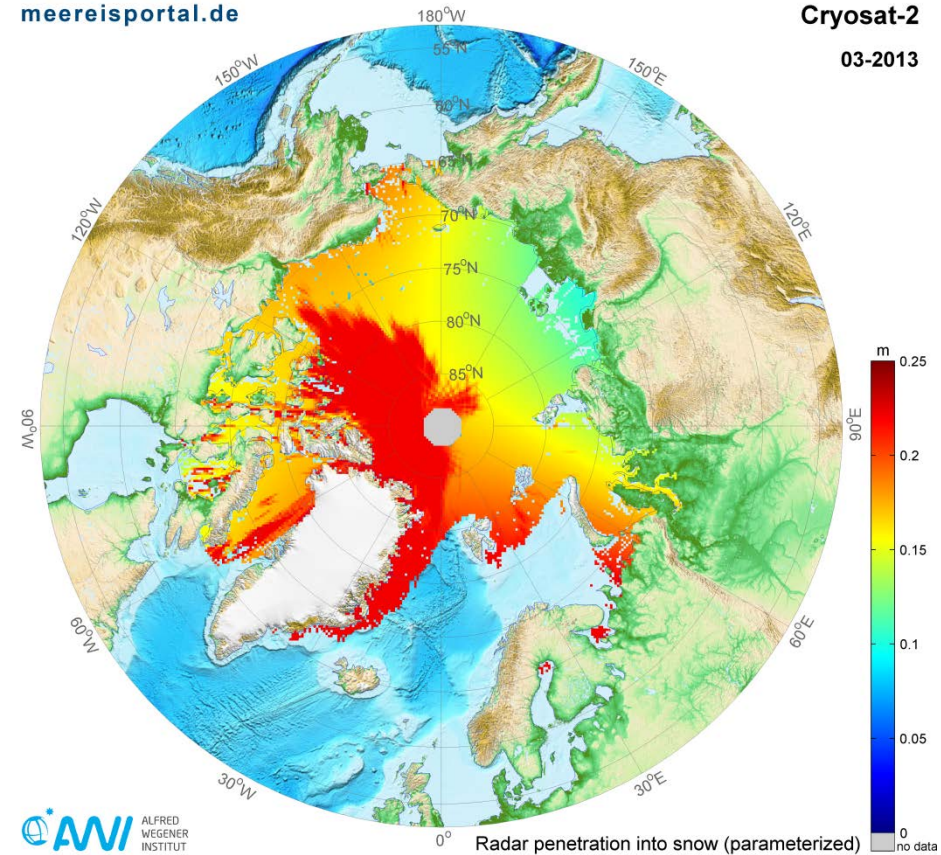
meereisportal.de



Snow Depth

- Modified Climatology (Warren et al.)
- 50% over FYI (OIB, Kurtz et al.)

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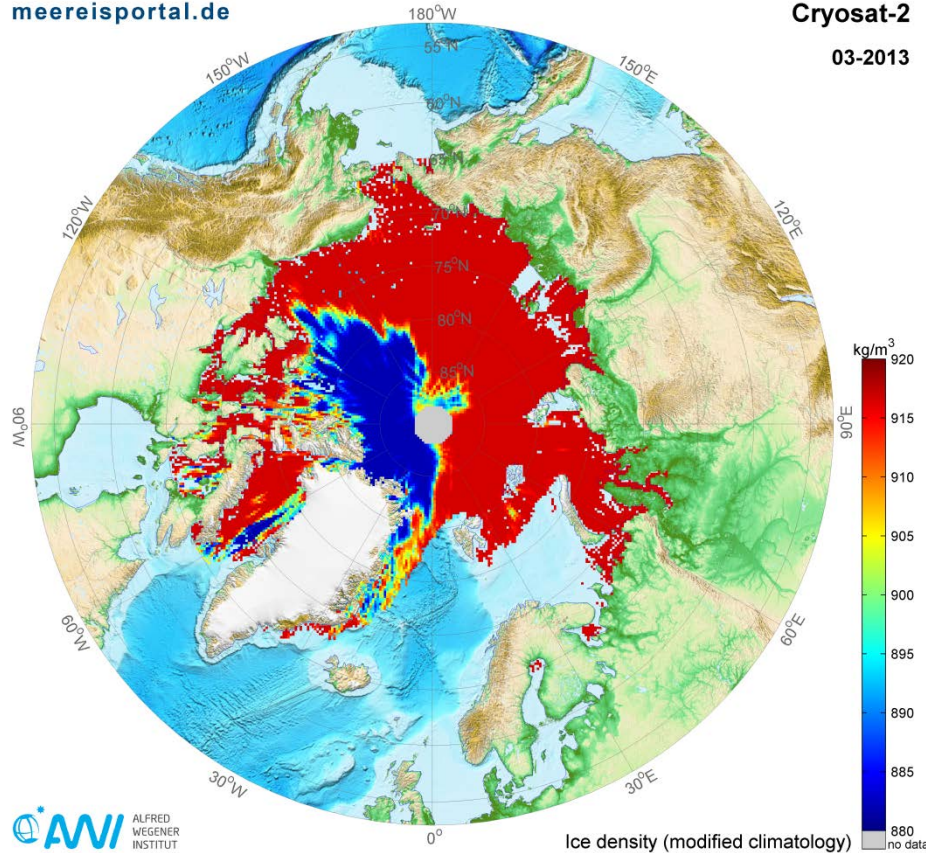
Radar Penetration

- 22 cm (Airborne Validation Data 2011)
- FYI: full penetration to snow

Sea-Ice & Snow Parametrization

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Cryosat-2
03-2013

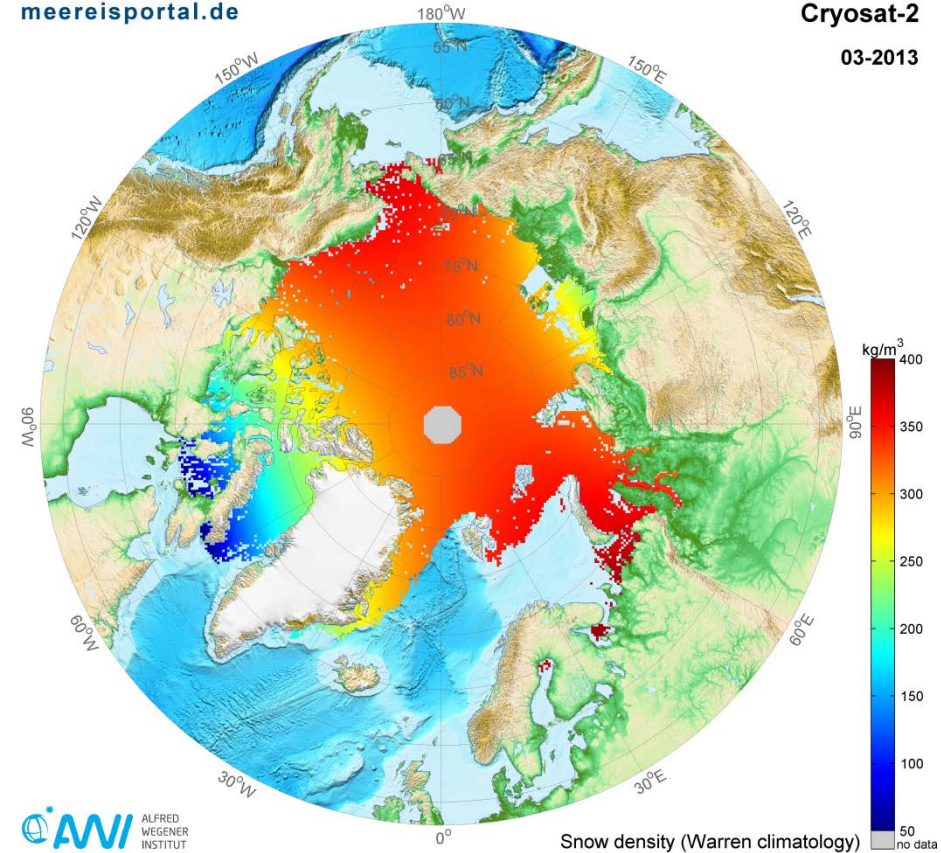


Sea Ice Density

- FYI: 916.7 kg m^{-3}
- MYI: 882.0 kg m^{-3}

meereisportal.de

Cryosat-2
03-2013



Snow Density

- Climatology (Warren et al.)
- No differences between FYI & MYI

Contribution to Error Budget



CryoSat-2 Level 1b	Speckle Noise	14 cm	
Lead Detection	SSH-Uncertainty	27 cm *	Decreasing with distance & # detections
Retracking	Var. Penetration	not yet quantified	
Freeboard	Cumulative Error	30 cm *	
Snow Depth	Depth Variability	7/14 cm	FYI / MYI
Snow & Ice	Density Variability	10/100 kg/m ³	SNOW / ICE
Thickness	Cumulative Error	2.5 m *	

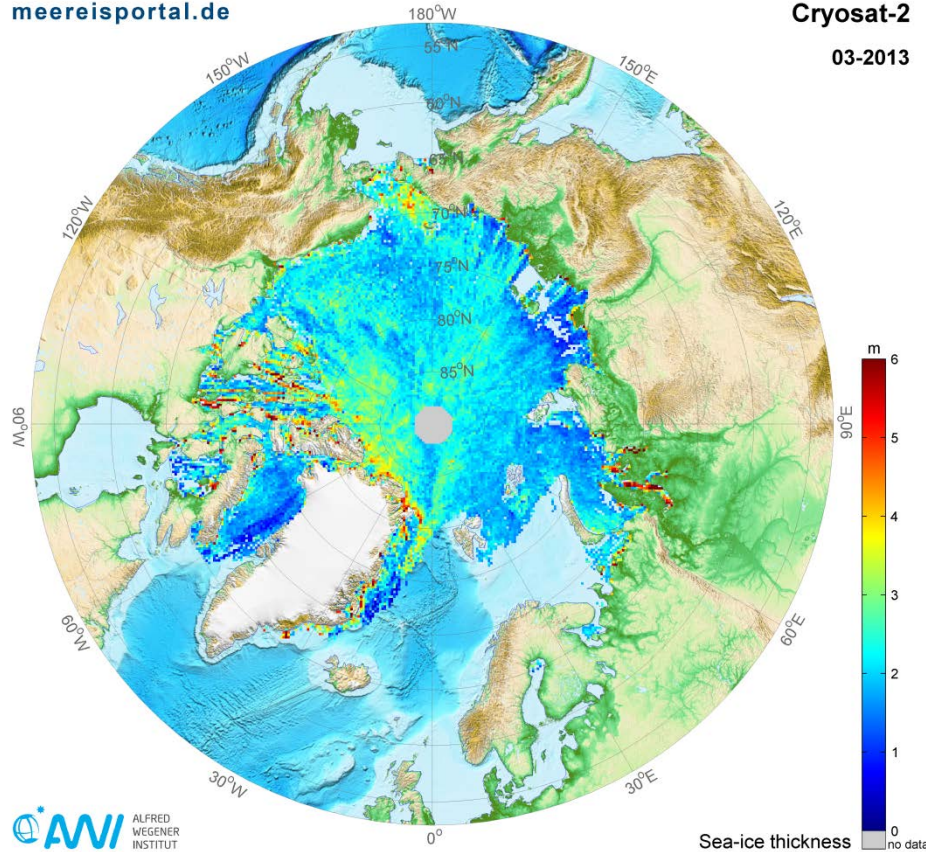
* : Mean multi-look (point) error

Error Propagation (Averaging 25 x 25 km)

CryoSat-2 First Results - Thickness



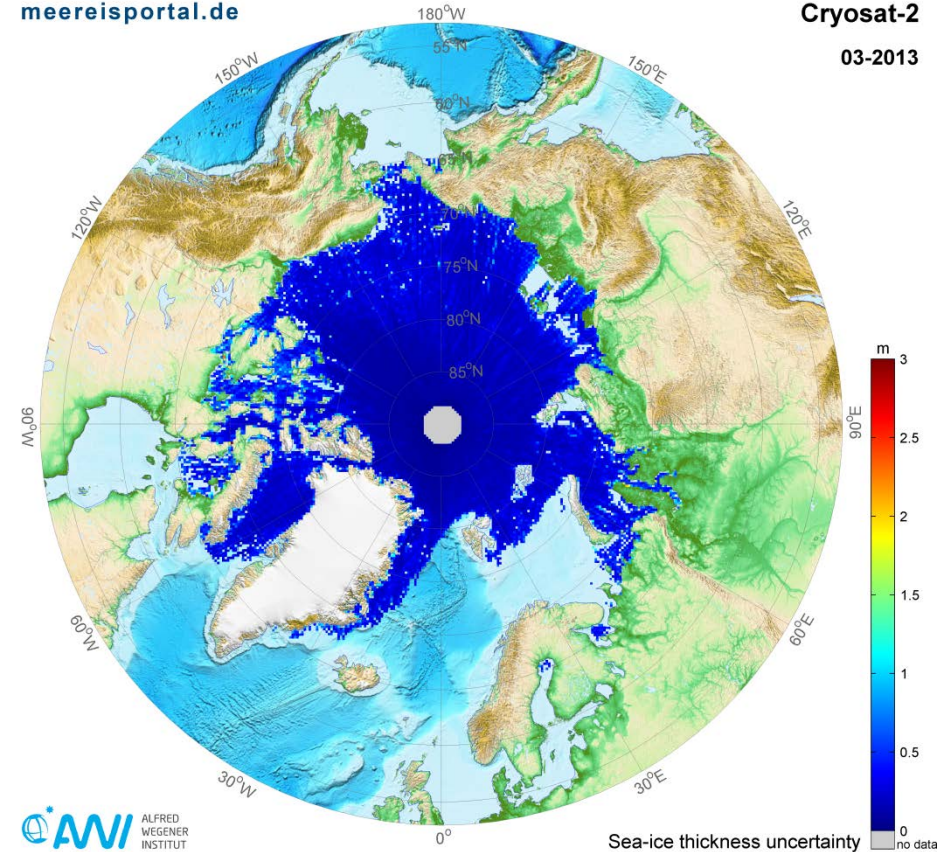
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Sea Ice Thickness

- Thick ice in FYI regions
- Artefacts from ice classification

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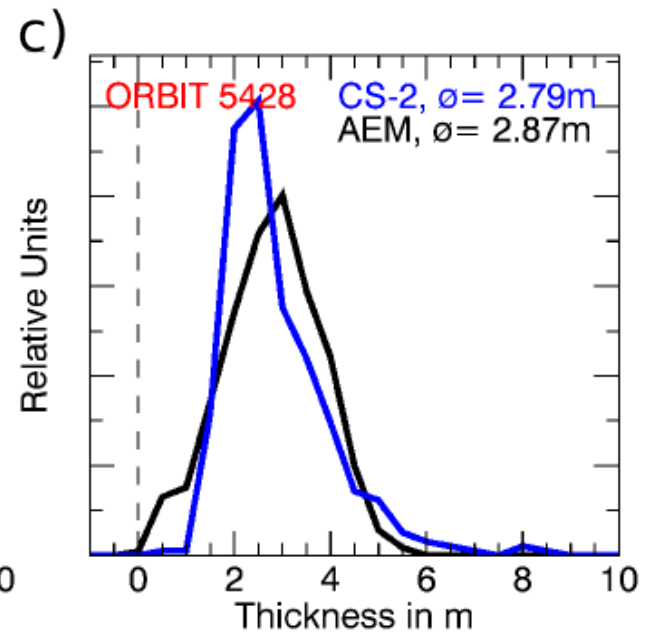
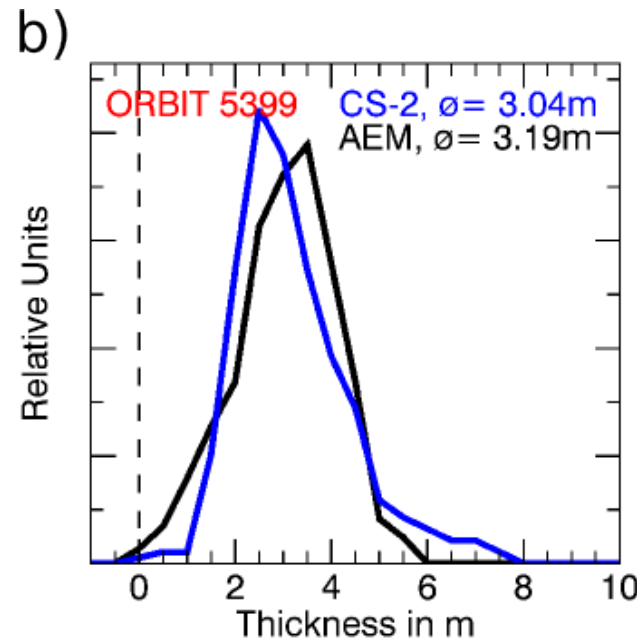
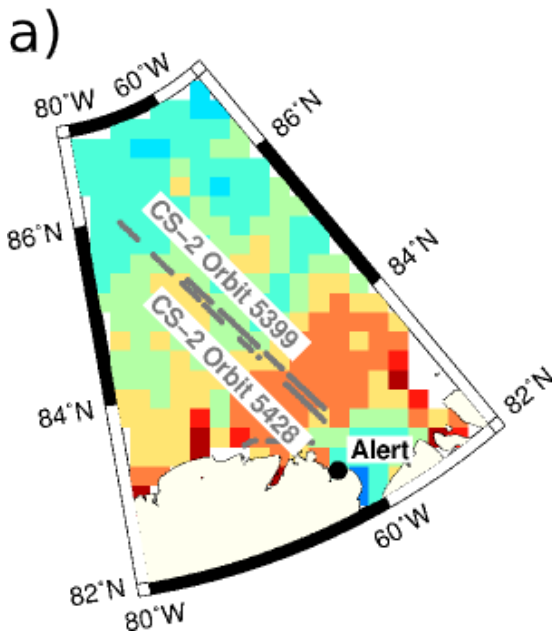


Sea Ice Thickness Uncertainty

- Range: 0.5 m – 1 m
- Higher in Archipelago / Ice Edge

March 2013

CryoSat-2 vs. AEM Thickness



Sea-Ice Thickness Uncertainty

Freeboard to Thickness Conversion

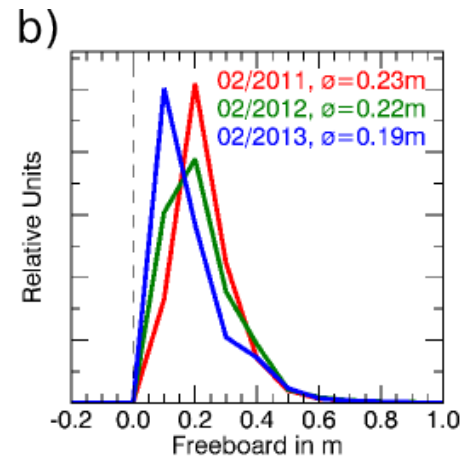
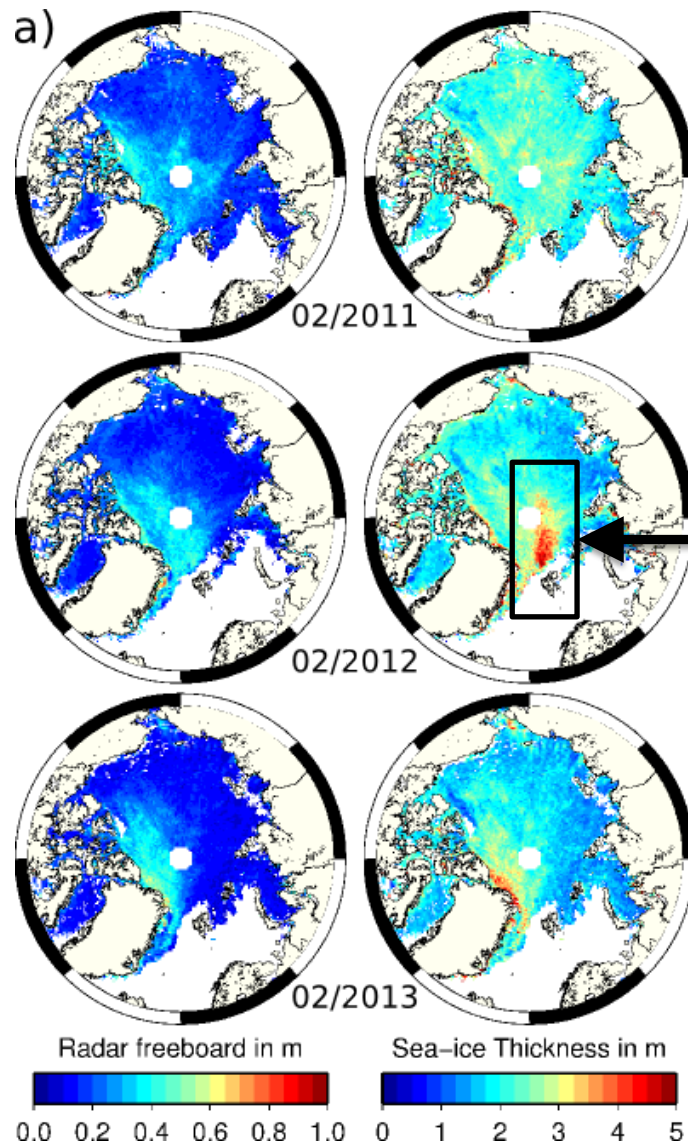
Distribution of AEM thickness and CryoSat-2 thickness

Comparable mean thickness of multi-year sea ice

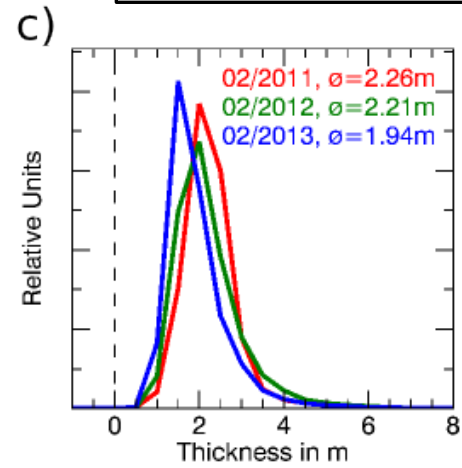
CryoSat-2 underestimates modal thickness

Validation in first-year ice regimes pending

CryoSat-2 "Trend" 2011 - 2013

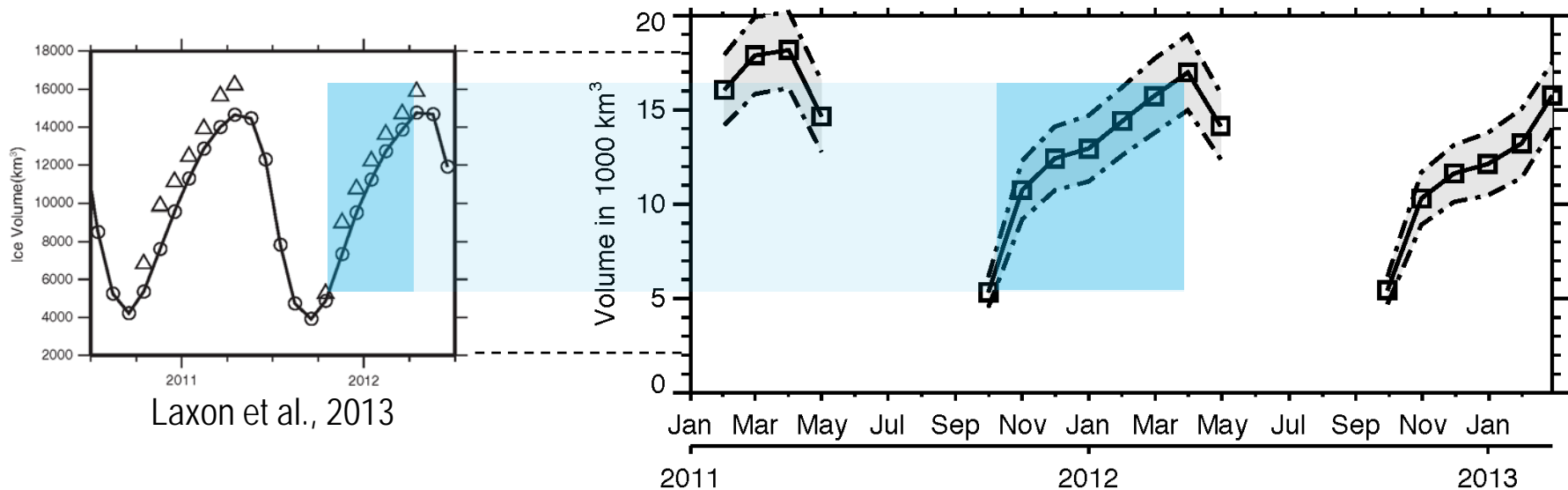


Ice-Type Artifact



Ricker et al., 2013, in preparation

Arctic Sea-Ice Volume 2011 - 2013



Laxon et al., 2013

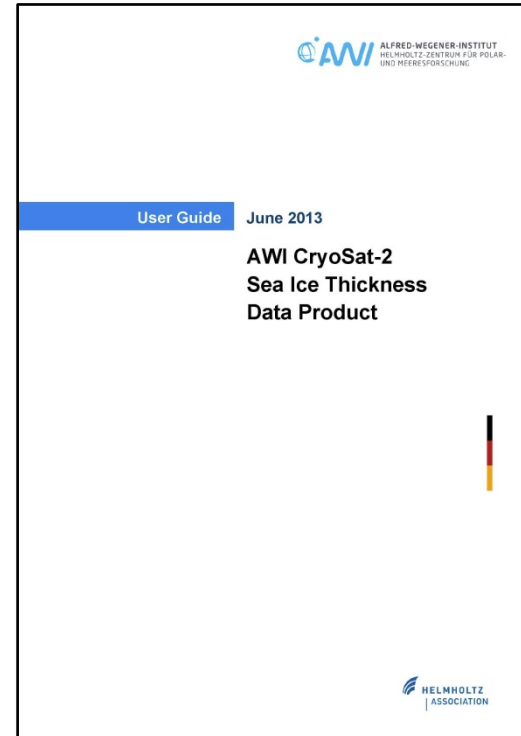
Ricker et al., 2013, in preparation

Comparison to Seymours & Katharines publication

Comparable volume range for winter season 2011/2011

Data masks might differ slightly (AWI data: ICESat domain for except Baffin Bay)

Data Availability



<http://www.meereisportal.de/cryosat>

Download Content (Jan. 2011 – ongoing)

Arctic Freeboard + Uncertainty

Arctic Thickness + Uncertainty

Auxiliary Data (Snow Depth, Snow & Ice Density ...)

Disclaimer

Not an operational or fully validated data product!

Feedback Welcome!

CryoSat-2 for Antarctic Sea Ice



Polarstern Weddell Sea Winter Experiment (ANTXXIX-6/ANTXXIX-7)
(June – October 2013)



CryoSat-2 Validation Experiment for Antarctic Sea Ice

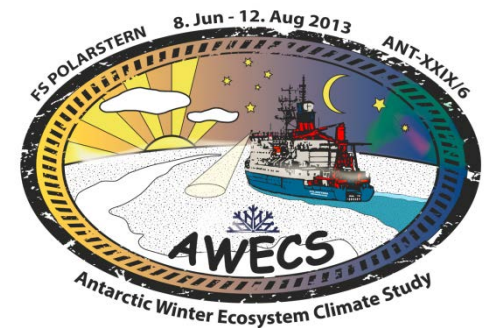
Airborne Sea-Ice Thickness & Snow Freeboard

In-Situ Studies of

Snow Depth Distribution and Stratigraphy

Sea-Ice Freeboard / Surface Flooding

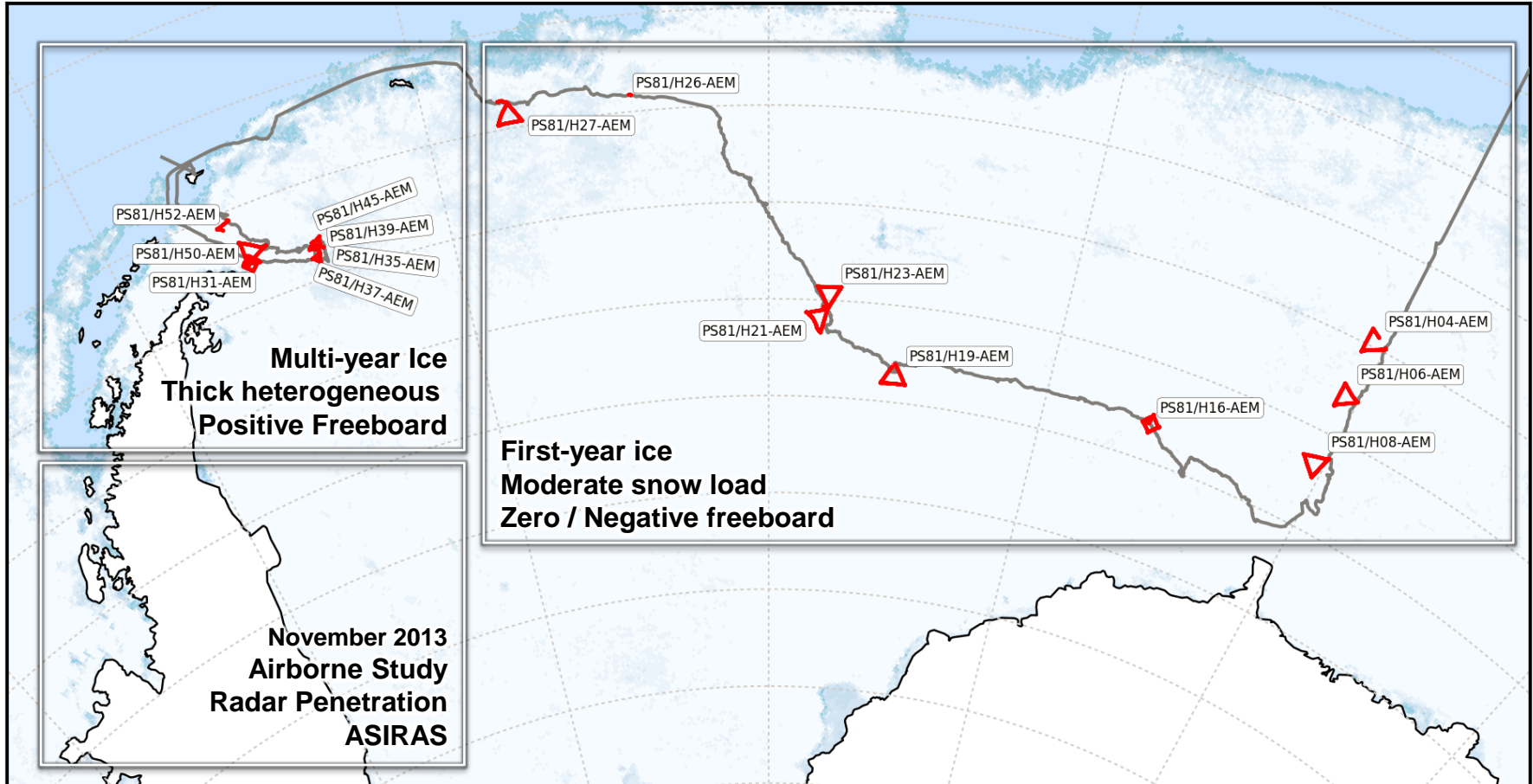
Sea-Ice Density



ANTXXIX/6 Airborne Surveys



ANT 29-6 (AWECS)



Airborne EM Sea Ice Thickness Surveys

AMSR-2 sea ice concentration July 15, 2013
(c) 2013, IUP Uni Bremen

Polarstern (ANTXXIX/7) currently in the Weddell Sea (<http://expedition.awi.de/>)
- Continuation of CryoSat-2 feasibility study -

CryoSat-2 Freeboard & Thickness



Calibration & Validation Results

radar freeboard \neq ice freeboard | unknown spatial pattern of radar penetration

CryoVEx: good agreement of airborne and satellite freeboard

Remaining Issues

snow, snow, snow! | knowledge of spatial & temporal distribution limits thickness accuracy
remote sensing signature / mass load

sea ice type | ice type mask can create thickness artefacts

Future Plans

Feasibility study Antarctic sea ice

Impact of surface roughness \triangleleft Forward model

Download Data: <http://www.meereisportal.de/cryosat>