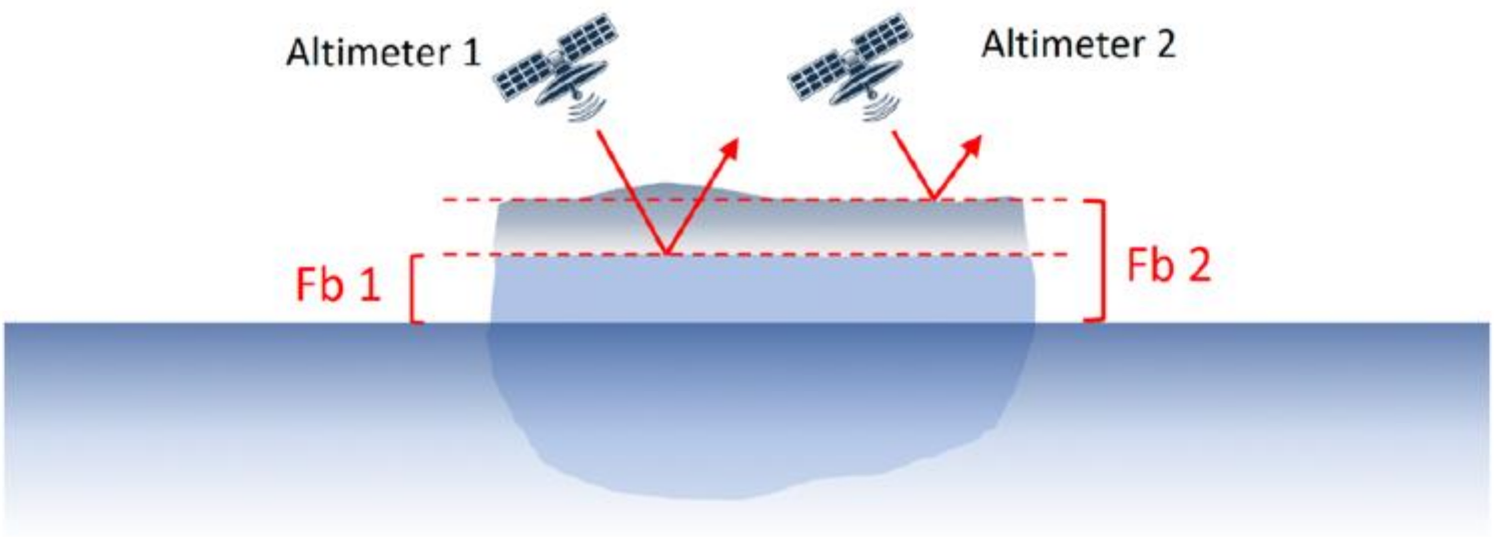
Multi-Frequency Satellite Approaches for Snow on Sea Ice
Challenges and Solutions

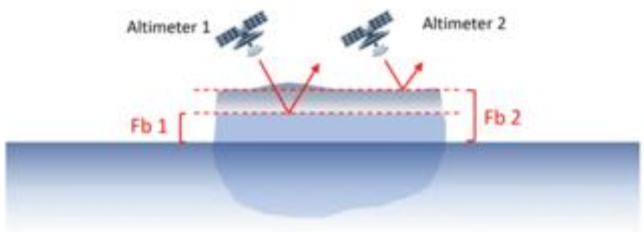


Credit: Lawrence

The POLAR+ Snow project

Polar+ Snow

UCL, LEGOS, University of Tromsø, FMI, AWI, University of Leeds	Polar+ Theme 1 Snow on sea ice	Reference : UCL_PRO_2020_1_MT Version : 1 page1 Date : 24.1.2020



Activity:

Multi-Frequency Satellite Approaches for Snow on Sea Ice

Polar+ Snow

Date of Issue: 15/10/2019

Ref: EOP-SD-SOW-0089

ESA Express Procurement Plus - [EXPRO+]

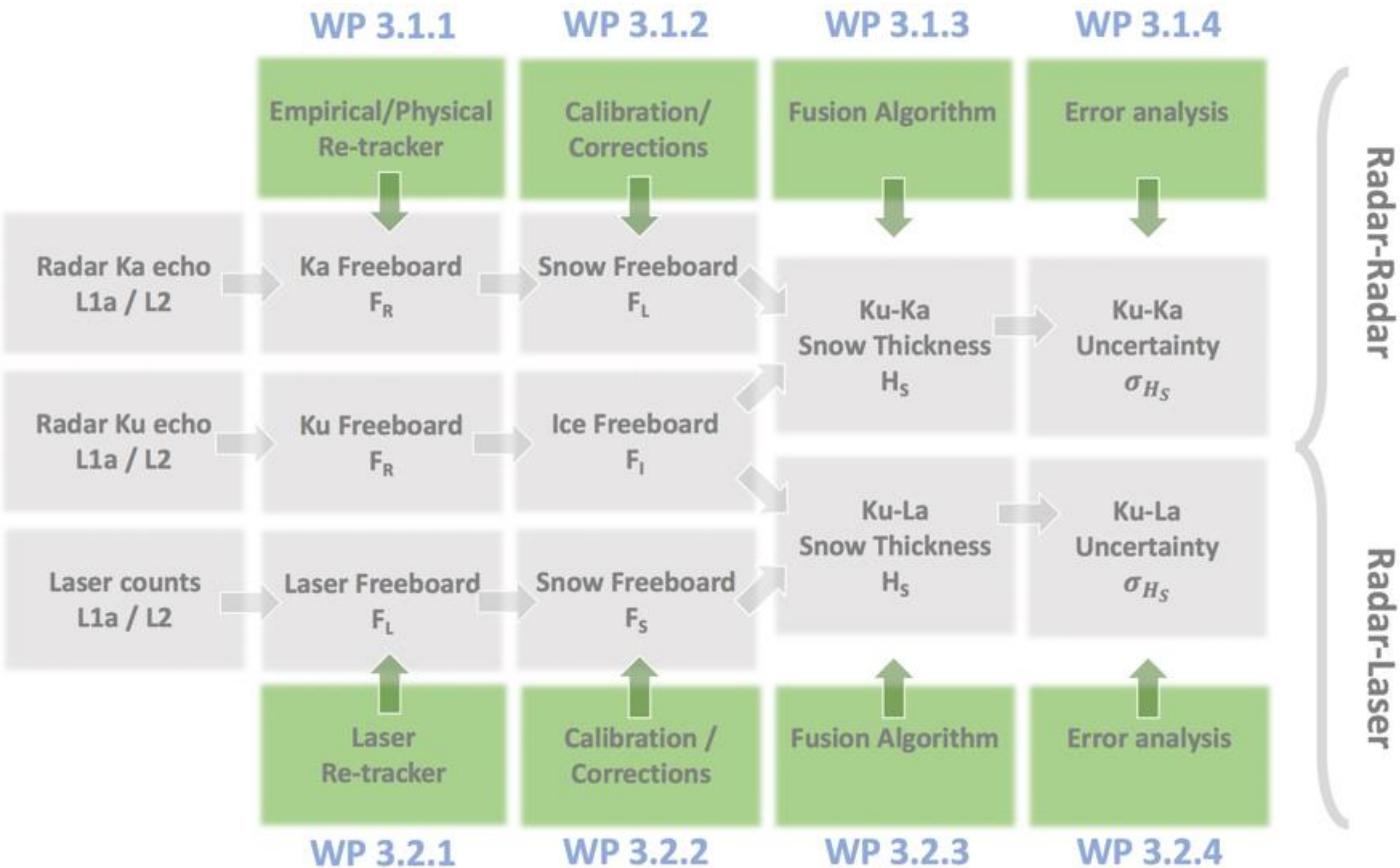
Full Proposal

UCL · LEGOS · University of Tromsø · FMI · AWI · UNIVERSITY OF LEEDS

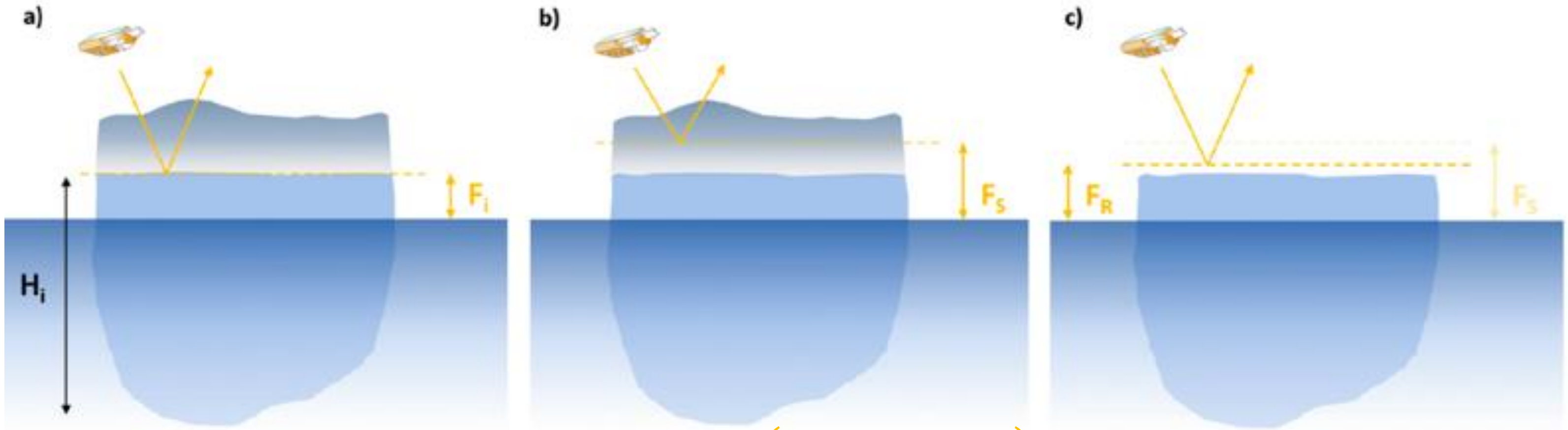
UCL, LEGOS, University of Tromsø, FMI, AWI, University of Leeds	Polar+ Theme 1 Snow on sea ice	Reference : UCL_PRO_2020_1_MT Version : 1 page2 Date : 24.1.2020

Table of Contents

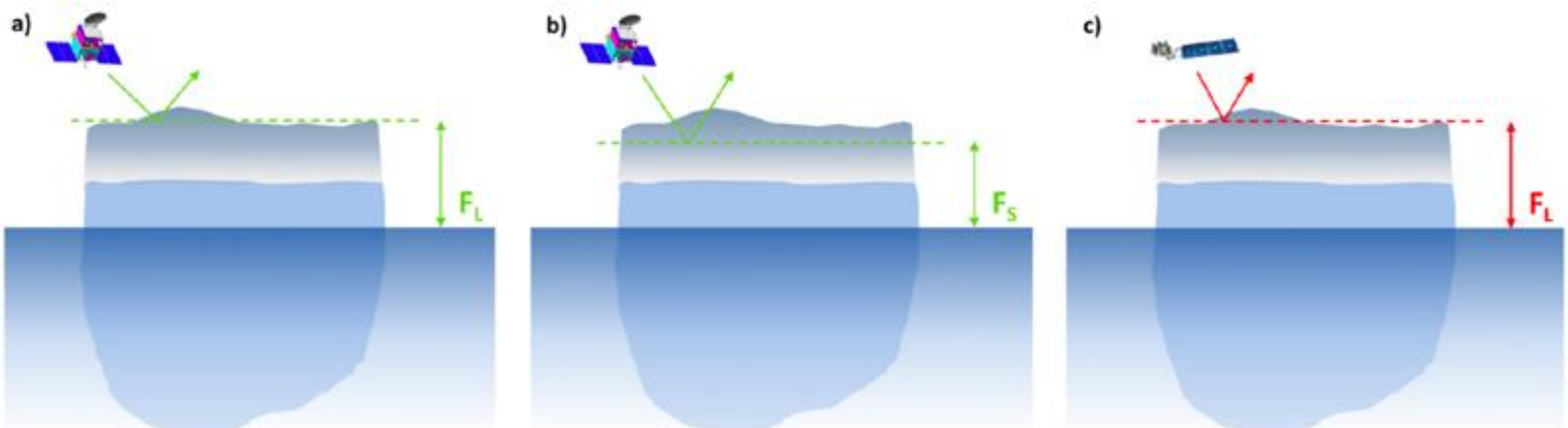
Ku-Ka (Radar-Radar) and Ku-La (Radar-Laser)



Different Freeboards



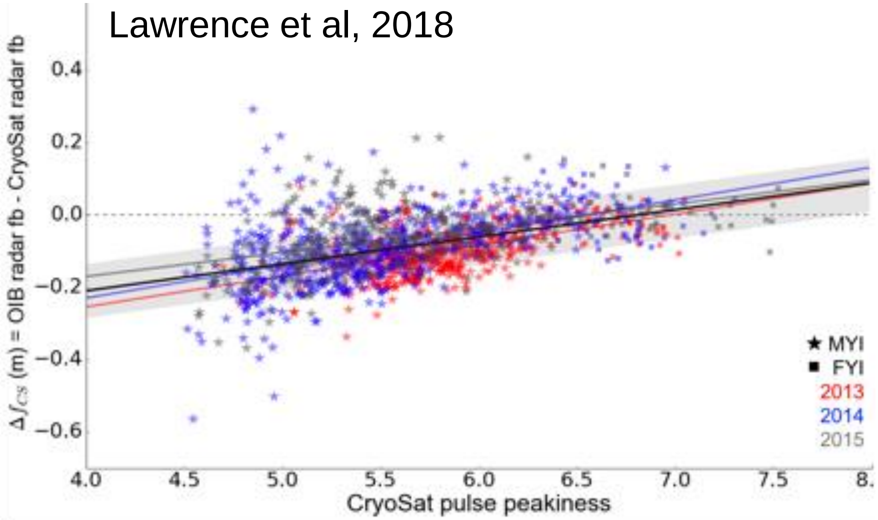
$$F_R^{CS2} = F_I + \left(1 - \alpha^{CS2} \frac{c}{c_S}\right) H_S$$

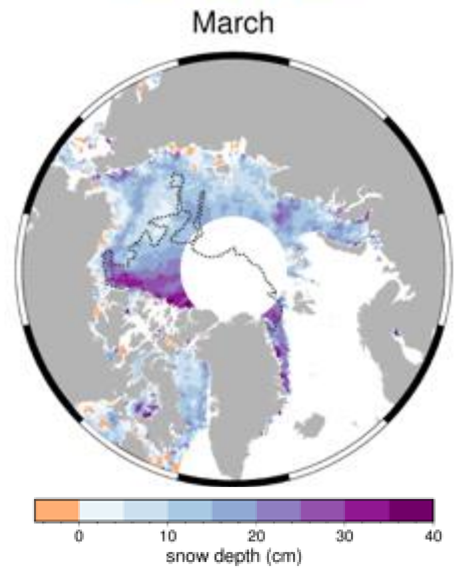


$$F_R^{AK} = F_I + \left(1 - \alpha^{AK} \frac{c}{c_S}\right) H_S$$

$$F_R^{AK} = F_I + H_S$$

Bias Correction / Calibration

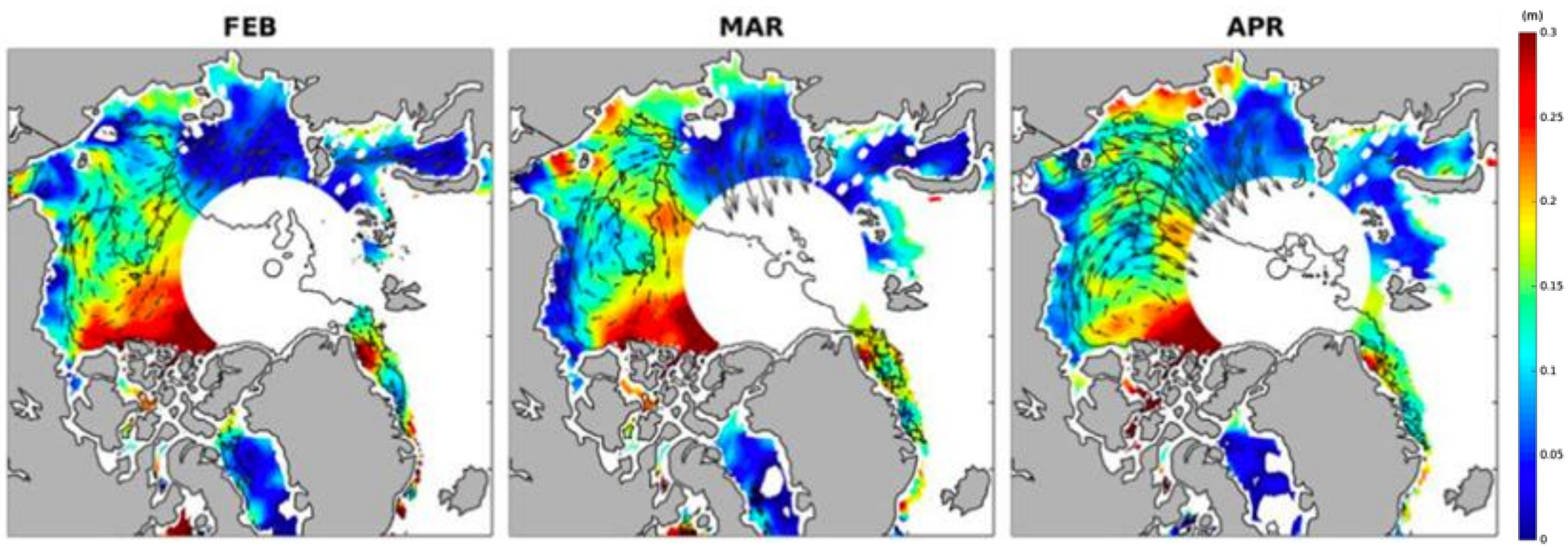




Calibration	$$H_S = F_R^{AK} - F_R^{CS2} + \Delta f_{AK}(PP_{AK}) - \Delta f_{CS2}(PP_{CS2})$$	(+) method applies to all radar freeboard (+) makes no physical assumptions (+) accounts for varying penetration factors (+) (-) empirical (-) relies on airborne data (-) location and season dependent (-) cannot adjust to changes of climate and surface characteristics (-) can lead to misinterpretation of data (-) errors on freeboard products accumulate

Bias Correction / Calibration

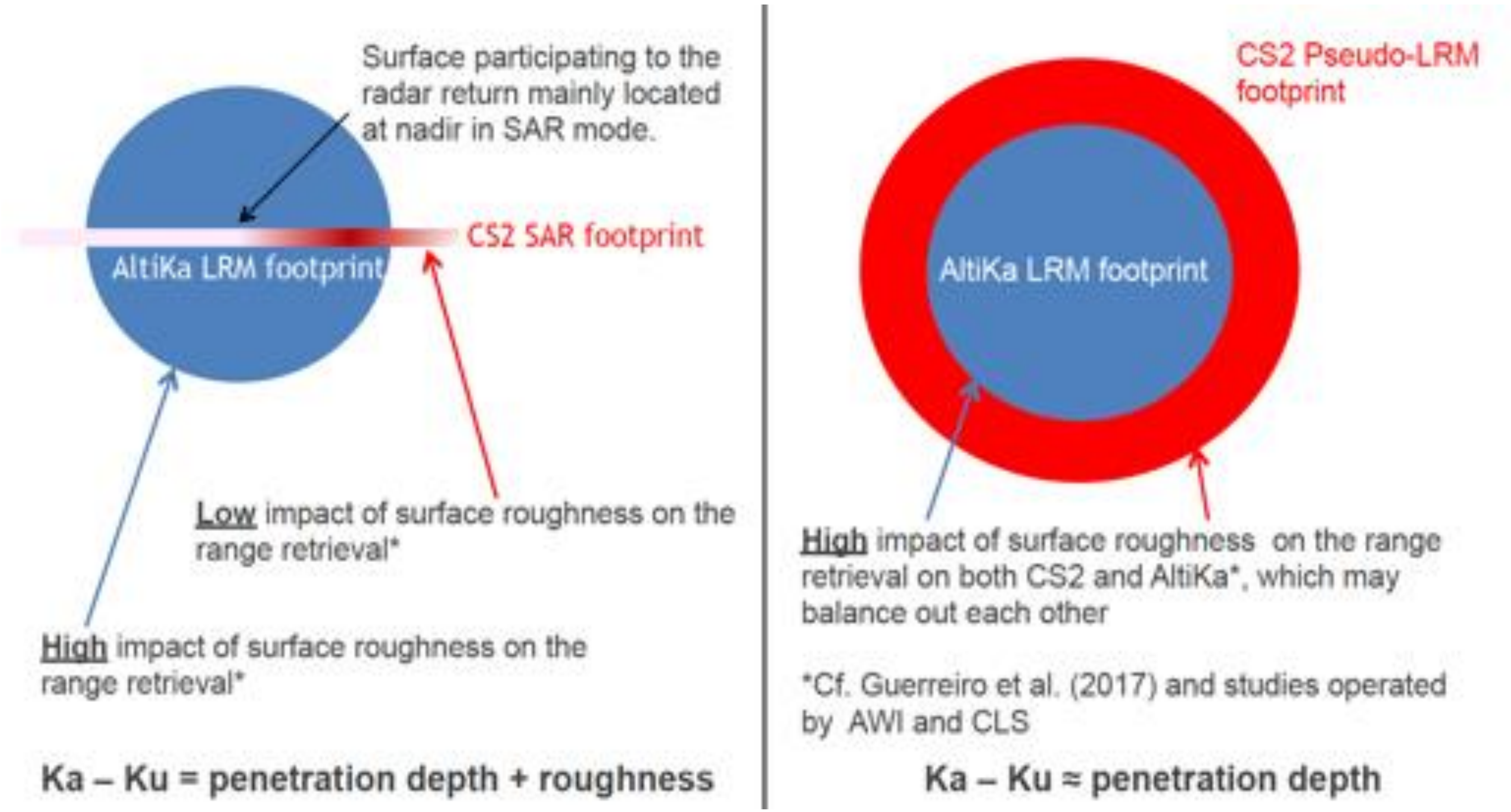
Method	Formula	Pros and Cons
Bias correction	$H_S = \frac{F_R^{AK} - F_R^{CS2}}{\alpha^{CS2} - \alpha^{AK}} \cdot \frac{c_s}{c}$	(+) method is physically based (+) remove known biases (+) accounts for roughness and footprint shape (+) can incorporate surface and volume scattering models (+) can be applied to airborne radar model for validation (-) model dependent (-) computationally heavy (-) requires simplifying assumptions



Guerreiro et al, 2016

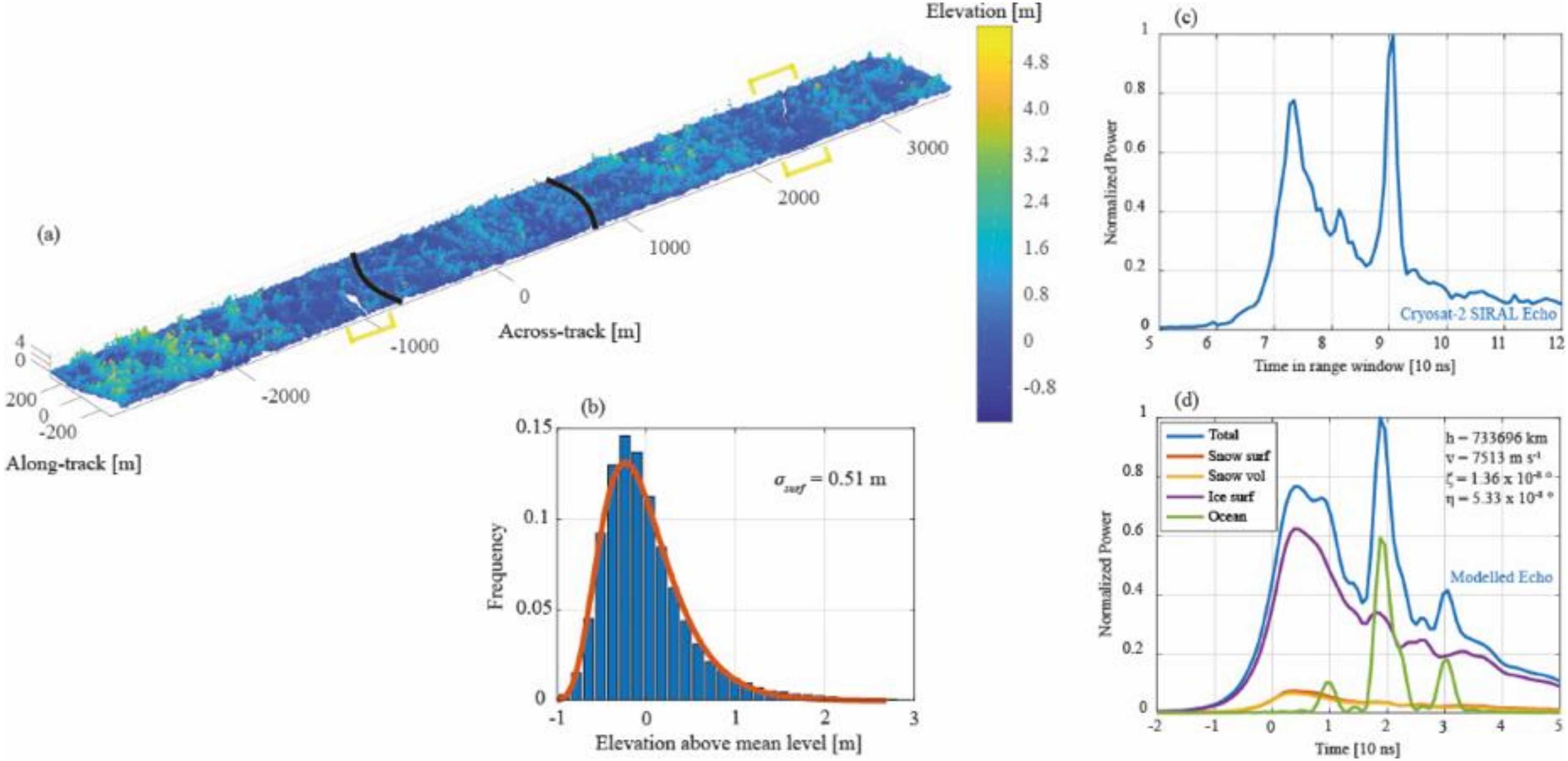
Role of roughness and footprint

Credit: Cryo-SEANice project / Robert Ricker



Facet-models (encouraging preliminary results)

A Facet-Based Numerical Model was developed for simulating SAR Altimeter Echoes From Heterogeneous Sea Ice Surfaces -> Landy, Tsamados, Scharien 2019, IEEE

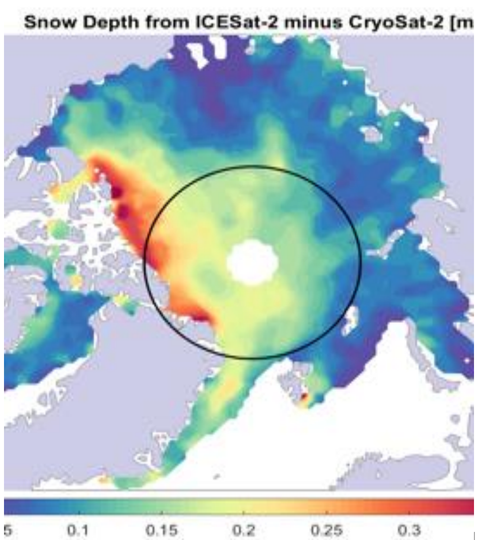


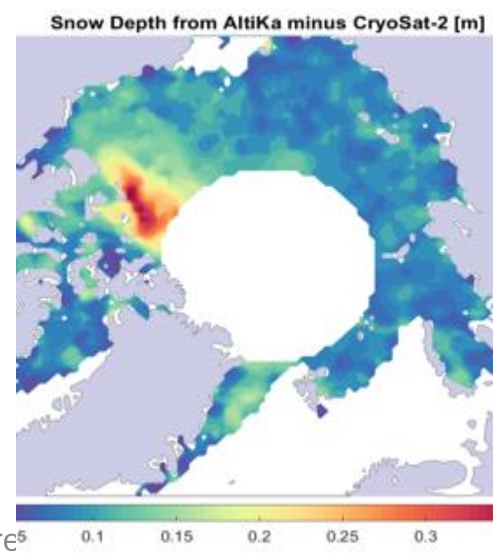
Facet-models (encouraging preliminary results)

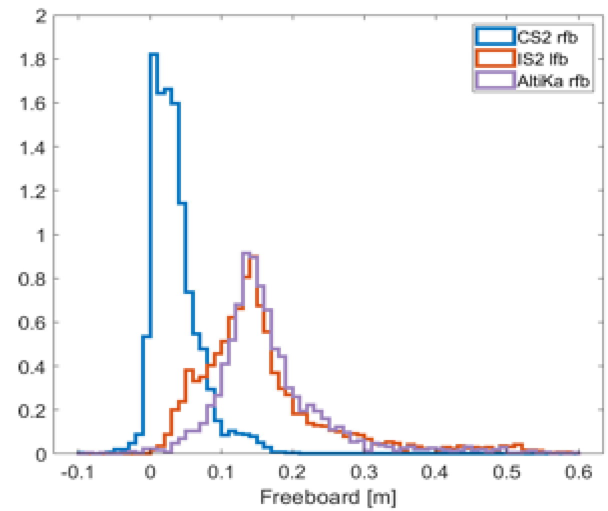
UiT/Bristol Ongoing Activities (Jack Landy)

- Converting 3D facet-based model to 2D, integrating radar echo over distribution of surface slopes rather than surface heights >>> Enables more accurate application to pulse-limited altimetry missions
- Preliminary tests with AltiKa SARAL and comparison to CryoSat-2 and ICESat-2 (below)
- Model-based retracker might be able to account for some of the roughness and surface/volume scattering biases identified in some previous multi-frequency Arctic snow depth studies

Dec 2019



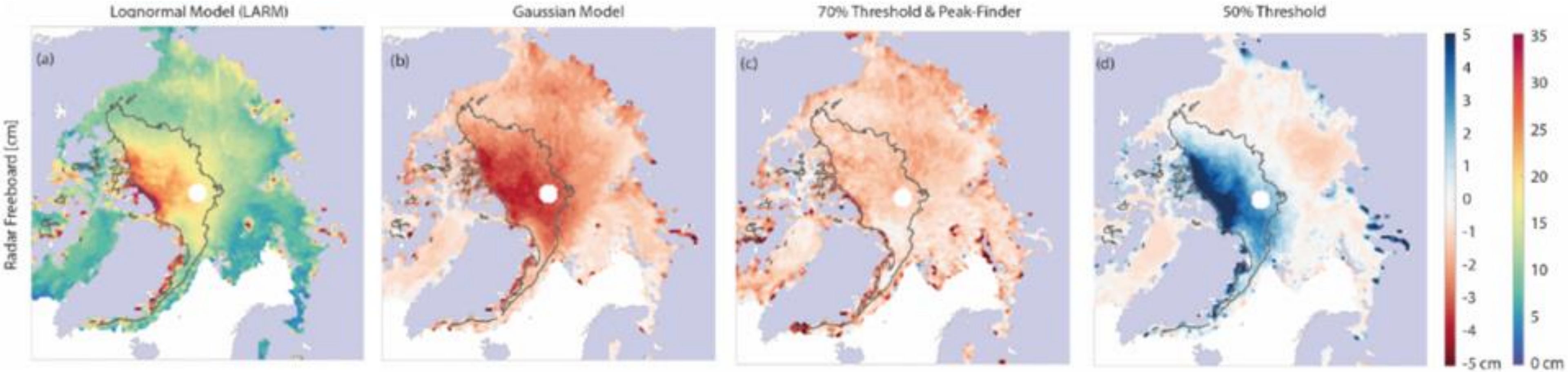




Facet-models (encouraging preliminary results)

UiT/Bristol Ongoing Activities (Jack Landy)

- Converting 3D facet-based model to 2D, integrating radar echo over distribution of surface slopes rather than surface heights >>> Enables more accurate application to pulse-limited altimetry missions
- Preliminary tests with AltiKa SARAL and comparison to CryoSat-2 and ICESat-2 (below)
- Model-based retracker might be able to account for some of the roughness and surface/volume scattering biases identified in some previous multi-frequency Arctic snow depth studies



Landy et al, 2020

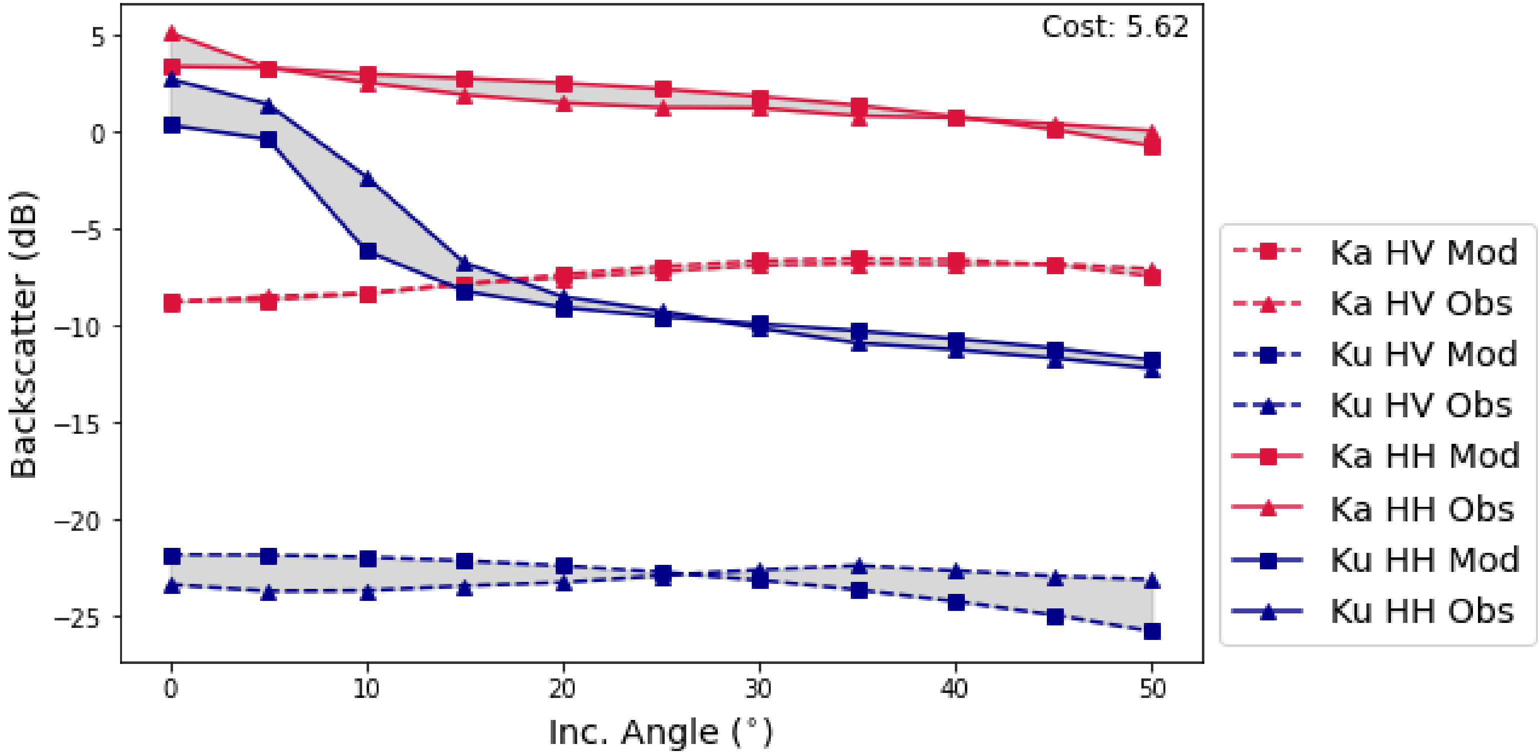
Volume (VS) + Surface Scattering (SS) + reflection (R)

	Parameter	Estimated Importance		Scattering Mechanism
		Ku-band	Ka-band	
Snow	Air-snow interface roughness	Low	High	SS, R
	Snow temperature	Low	Low	VS
	Snow liquid water	High	High	VS
	Snow density	Med	Low	VS
	Snow grain size	High	High	VS
	Snow salinity	High	Low	VS
	Fresh ice lenses	Med	Med	VS, SS
	Snow depth	Med	Low	VS
Sea Ice	Snow-ice interface roughness	High	Low	SS, R
	Sea ice temperature	Low	Low	SS
	Sea ice salinity	Low	Low	SS
	Large-scale topography	High	High	SS, R

Credit: Robbie Mallett

SMRT Inversion

Robbie Mallett: "Can we 'tune' the geophysical inputs to SMRT in order to match model output to observations? Yes!"

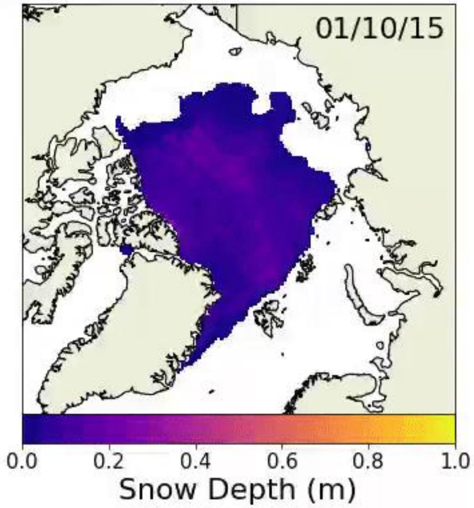


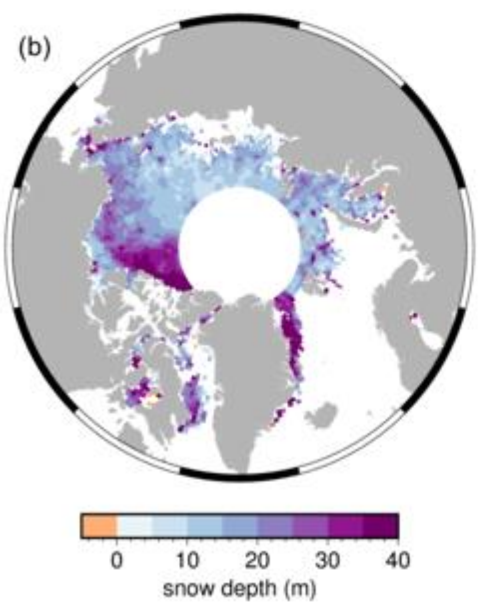
We have built a framework that searches the input-parameter space of SMRT to match its output to the KuKa observations.

In order to do this we must set the grain size to significantly larger than what was measured in the field. Other biases exist when compared to field obs.

Assimilation into sophisticated models

Stroeve et al, 2020

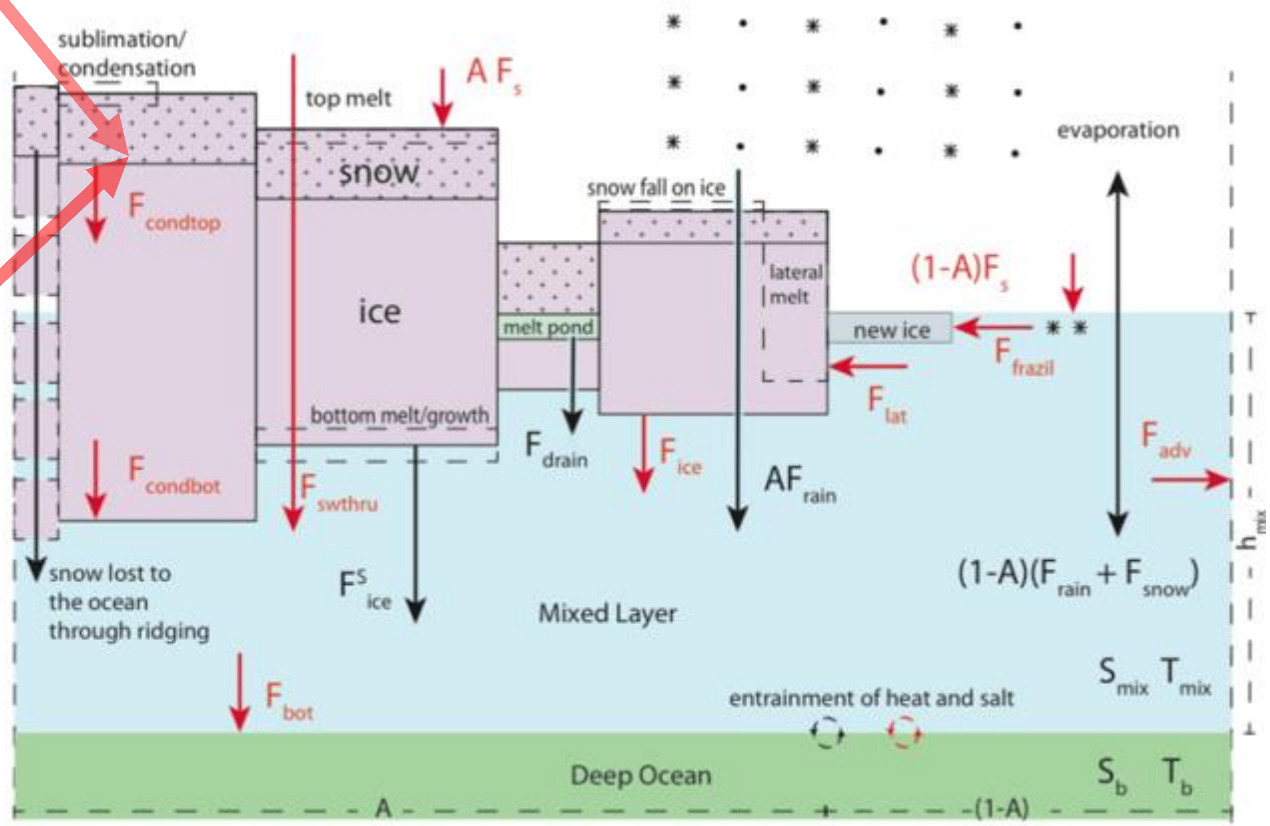




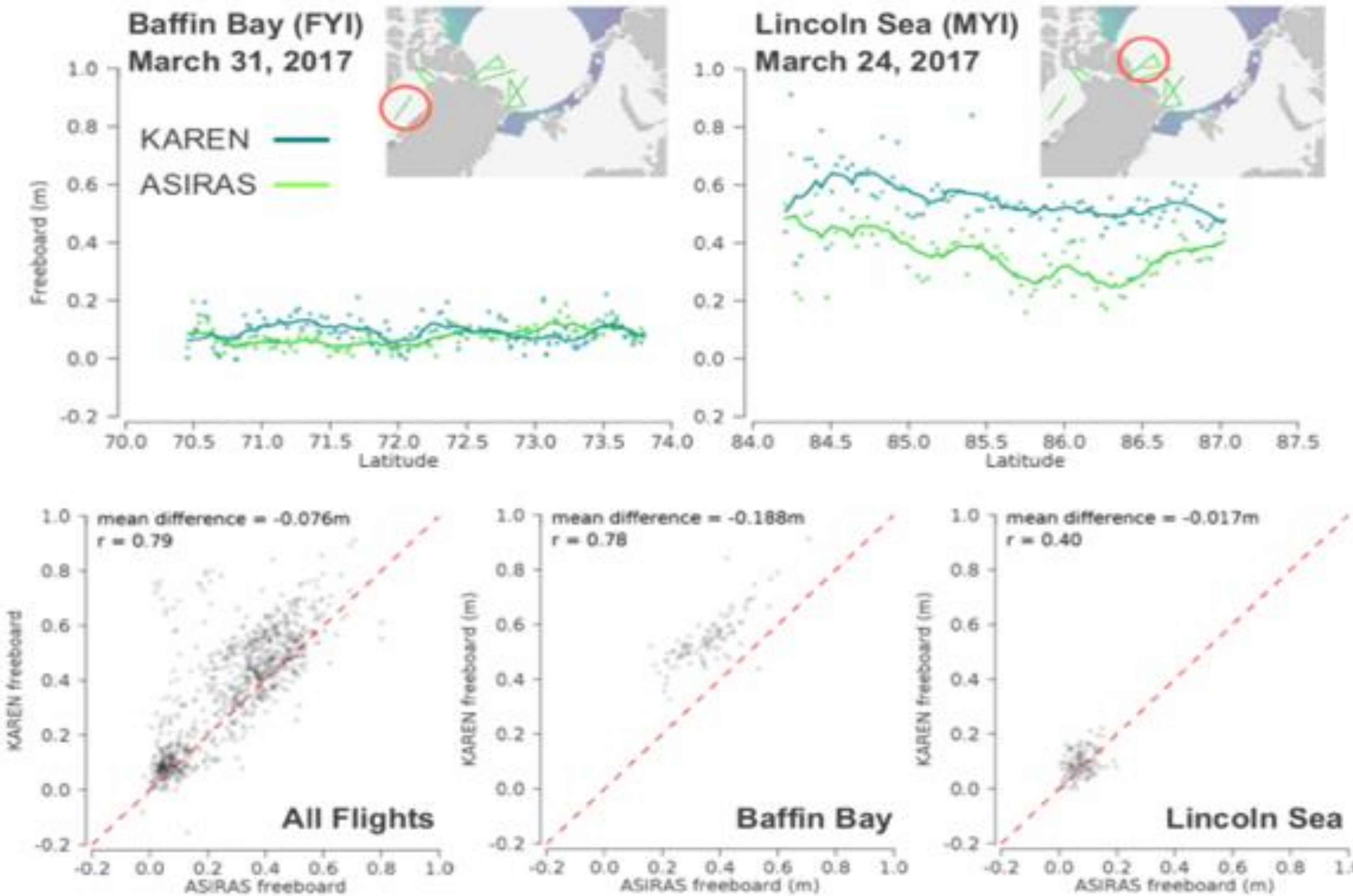
Lawrence et al, 2018

We can now assimilate those into a state of the art sea ice and climate model (i.e. at the Met Office)

Tsamados et al, 2015

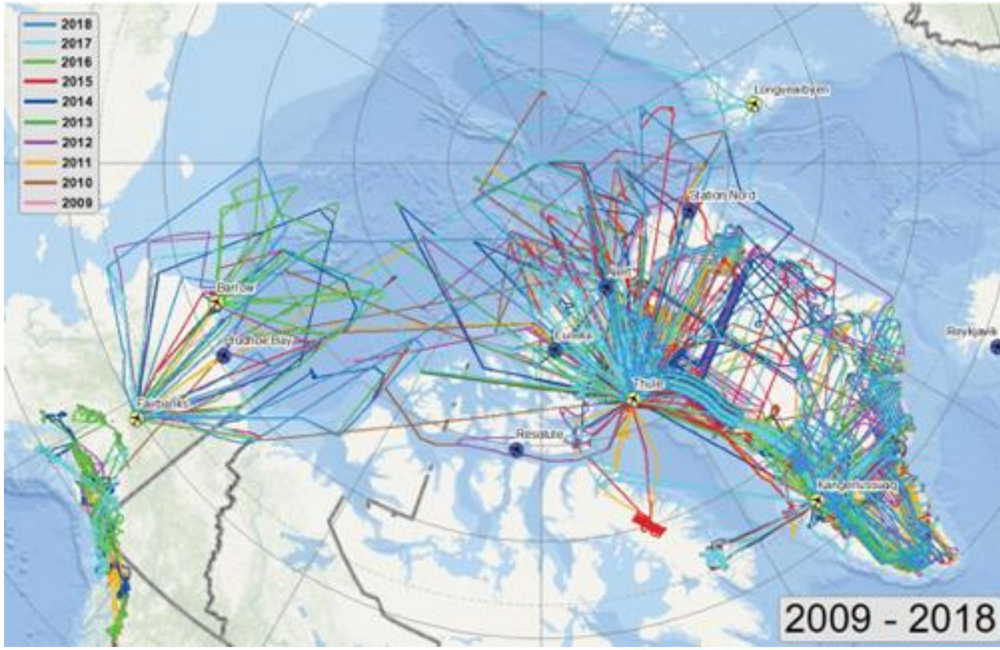


Validating Ka and Ku penetration depths

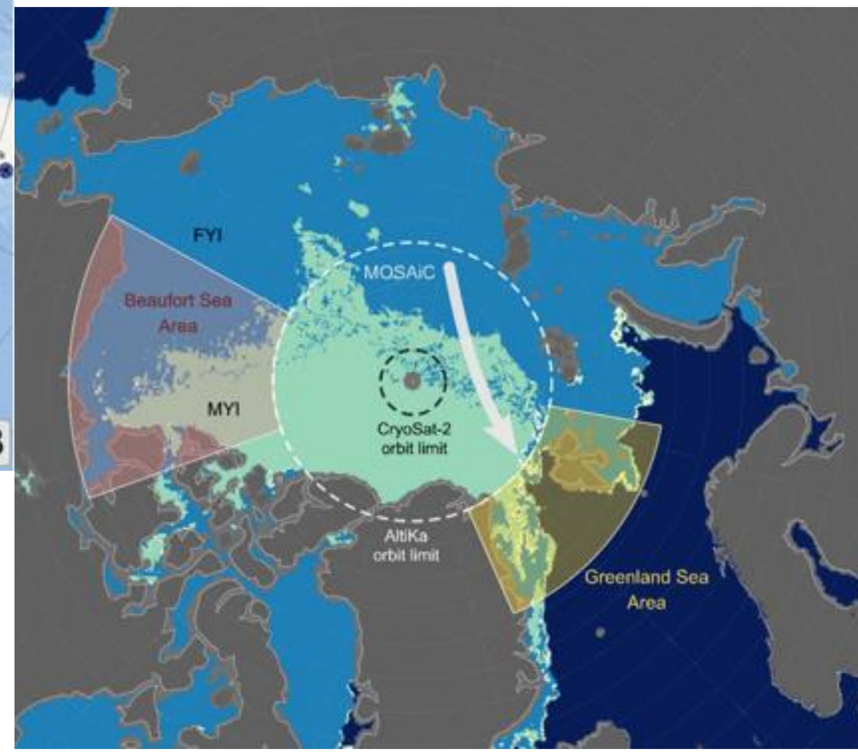


Ricker et al., (2019)

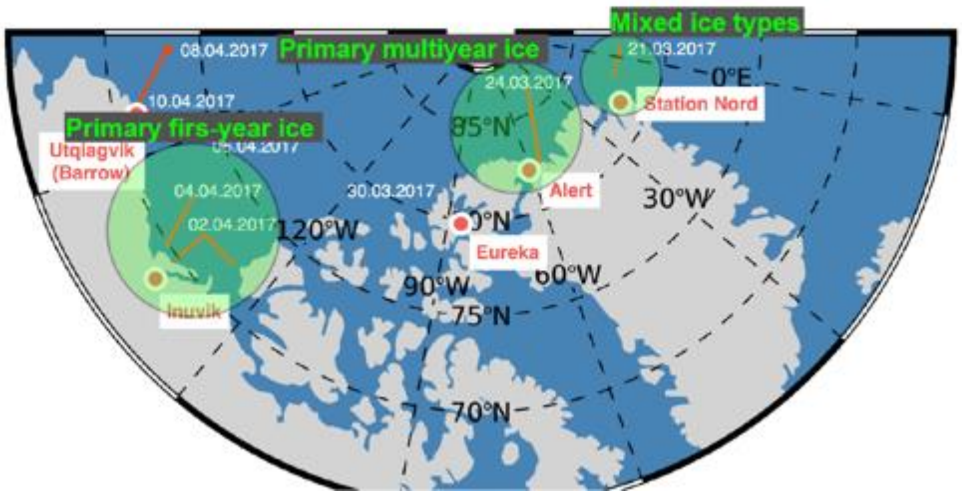
Dedicated airborne and in-situ validation campaigns



Credit: NASA Operation IceBridge

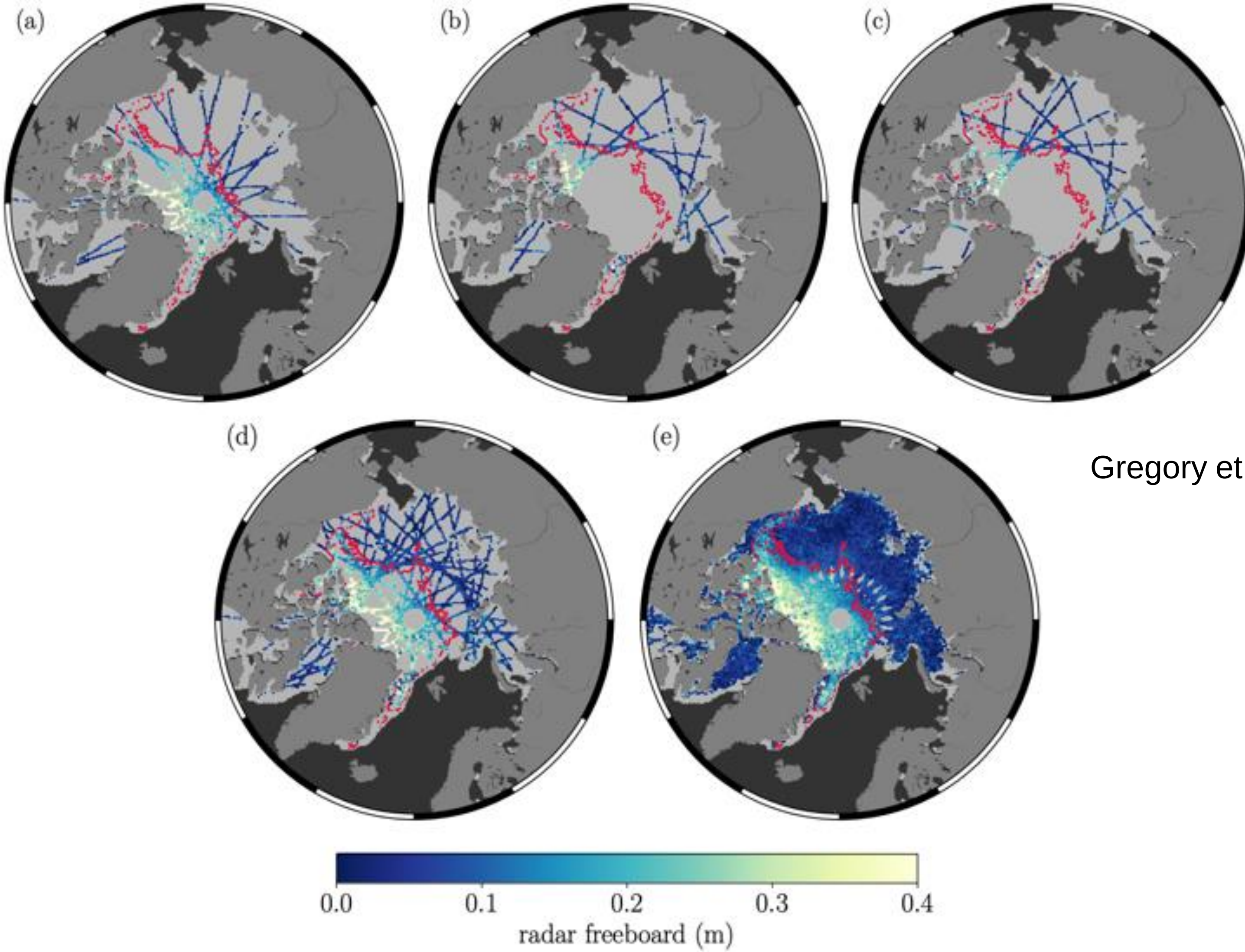


Credit: AWI



Credit: CryoVex / AWI

Data fusion algorithms (i.e. with S3, IS2…)



Gregory et al, TCD 2021

Challenges and Solutions

- Accurate radar and laser retracking accoiunting for surface heterogeneity
  - ✓ Physical retrackers and corrected empirical retrackers
  - ✓ Direct facet based models / simulators
- Detecting the ice-snow and snow-air interfaces
  - ✓ Understanding the snow-light interactions
  - ✓ Physical models (SNOWPACK…)
  - ✓ Radiative models (SMRT…)
- Validation / calibration with in-situ and airborne campaigns
  - ✓ MOSAiC
  - ✓ KaKu radar
  - ✓ Future dedicated airborne campaigns (OIB, IceBird, CryoVex, Karen)
- Innovative fusion and AI algorithms
  - ✓ Optimal interpolation
  - ✓ AI based surface and snow characterization
  - ✓ Multi-mission synergies
- Uncertainty quantifications
  - ✓ Inversion approaches, Monte-Carlo, physical models
  - ✓ Data assimilation in state of the art models
  - ✓ Error propagation to sea ice thickness