Arctic-SummIT

Jack Landy, University of Bristol

LIVING PLANET FELLOWSHIP

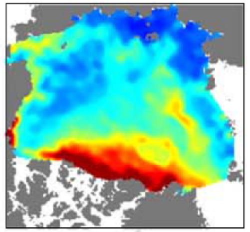
CRYOSPHERE

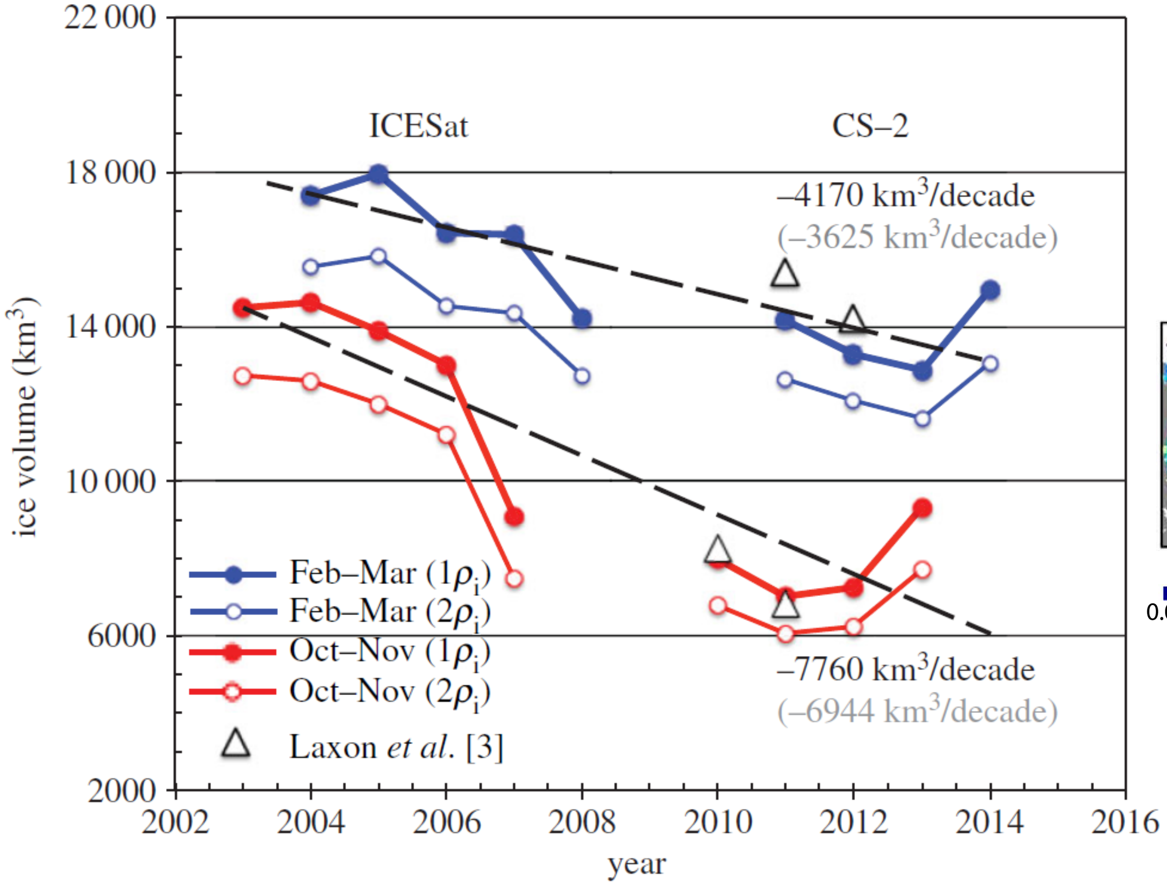
Contributions from:

- Alexander Komarov, Environment Canada Climate Change
- Steve Howell, Environment Canada Climate Change
- Christian Haas, Alfred Wegener Institute, Germany
- Thomas Krumpen, Alfred Wegener Institute, Germany

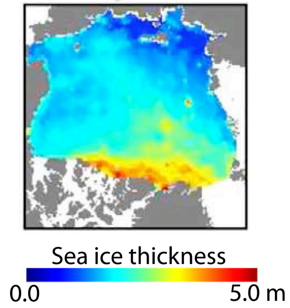
Arctic Sea Ice Volume Trends 2003-2015

2004





2018



Kwok and Cunningham, PTRS-A, 2014

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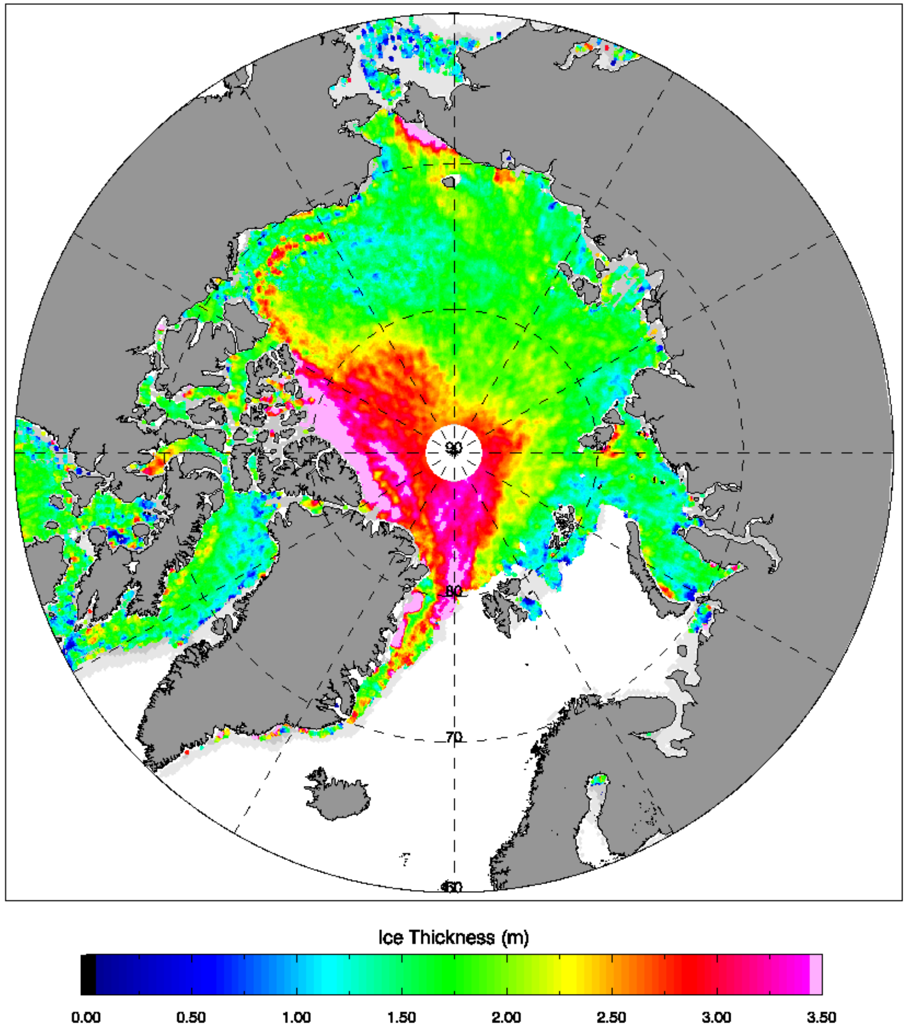
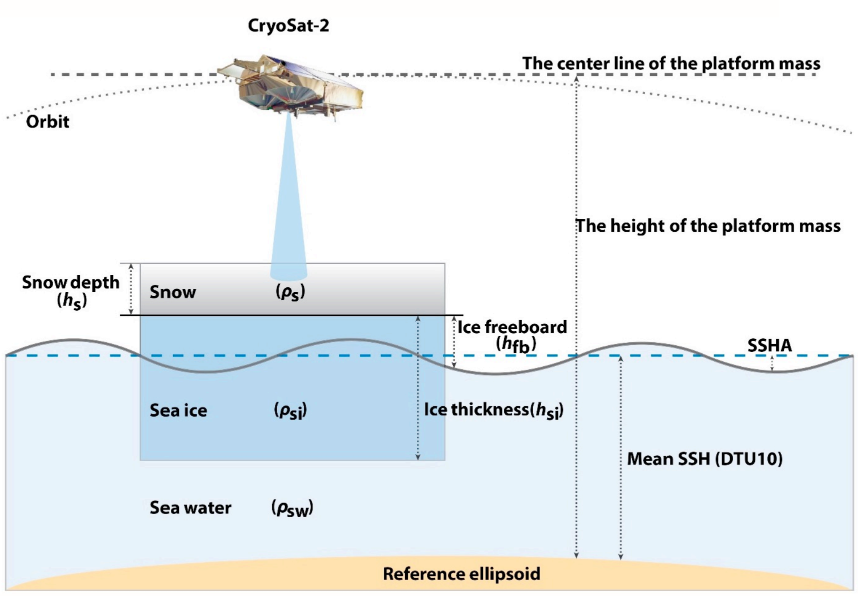
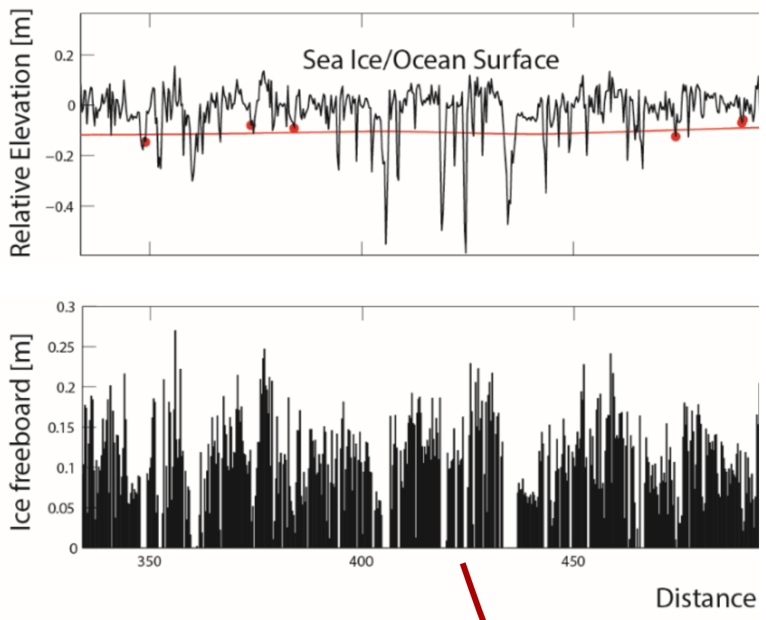


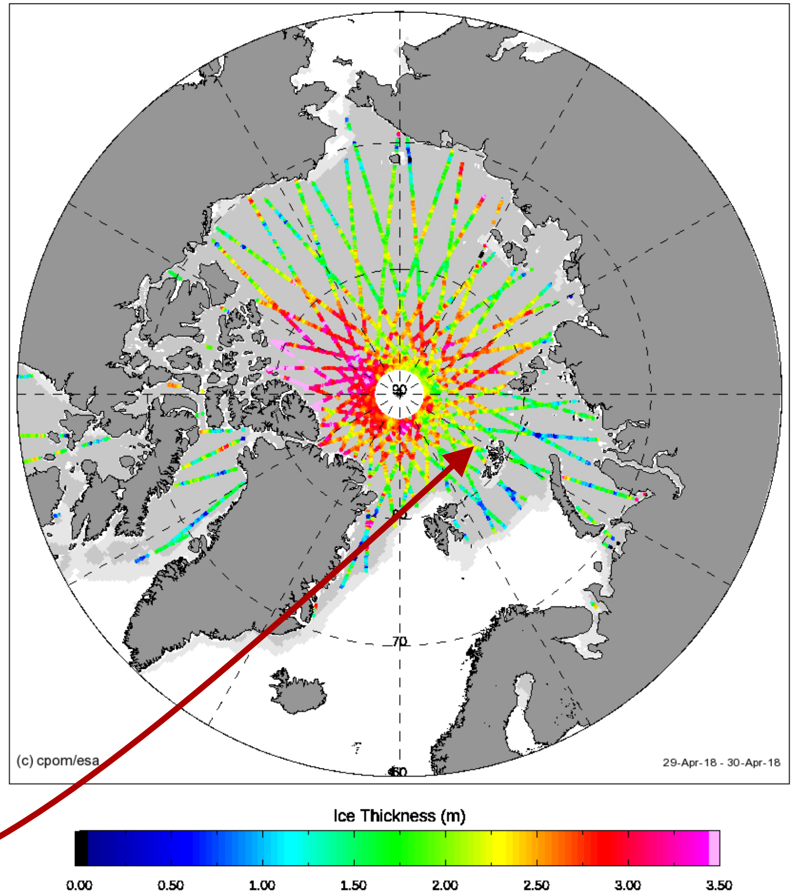
Sea Ice Thickness MarApr 2016 [CPOM]

How do we obtain sea ice thickness from Cryosat-2?

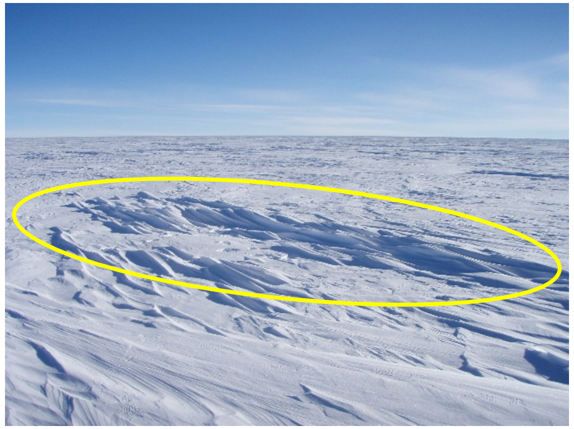


Lee et al., RS, 2016





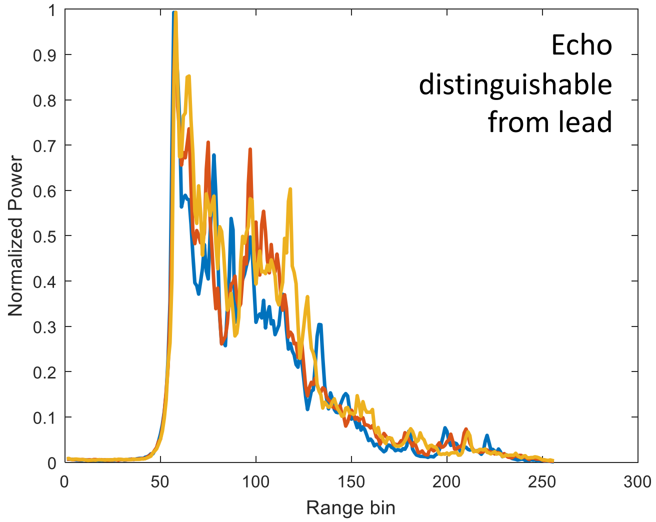
So why can't we do this in summer as well…?



sci-news.com

Diffuse Echo

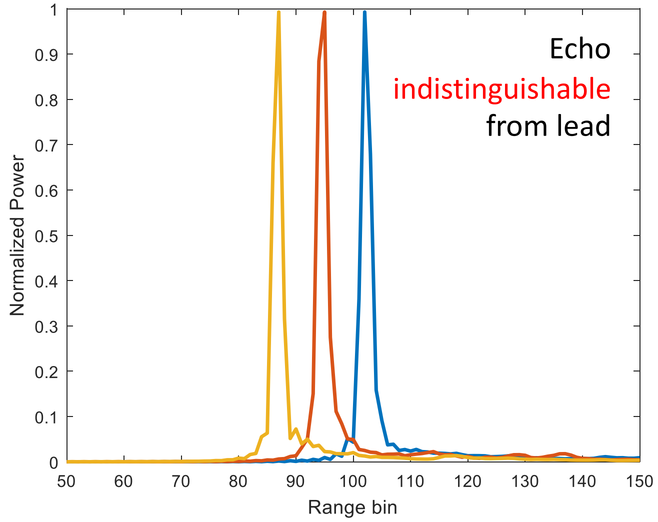
Scattering contributions from across entire Cryosat-2 footprint



nikkophotography.blogspot.com

Specular Echo

Coherent reflection from melt pond closest to nadir location



Arctic-SummIT

"The overarching goals of Arctic-SummIT are to convert raw Level 1b Cryosat-2 SAR waveforms into observations of **sea ice thickness during the Arctic summer** and use these to calculate **fluxes of ice volume through key Arctic gateways**."

Work Package 1:

Objective a – Develop machine learning classification algorithm for separating sea ice and lead echoes

Objective b – Derive and validate sea ice freeboards

Objective c – Develop sea ice thickness product with uncertainties

Work Package 2:

Objective d – Calculate sea ice volume fluxes through Arctic gateways

Obj a – Develop machine learning classifier for separating sea ice and lead echoes

- ✓ Identified approx. 100 images (RS2, S1, S2a&b, L8) coinciding within 15 mins of CryoSat-2 passes
- ✓ K Nearest Neighbour classification algorithm trained on imagery
- X Classifier is not accurate in all seasons/regions

Obj b – Derive and validate sea ice freeboards

- ✓ Experimental ice freeboards derived for pack ice margins and late-summer
- X Seasonal/regional limits on freeboard retrievals unknown
- X Sea ice floe elevation biases remain unconstrained

ROADBLOCK!

We need to better understand complex radar echo from sea ice during summer months

New component of project = numerical modelling

Obj c – Develop sea ice thickness product with uncertainties

- ✓ Freeboard to thickness processing chain completed
- ✓ Initial comparisons to airborne thickness observations from PPs at AWI quite good

Obj d – Calculate sea ice volume fluxes through Arctic gateways

- X Waiting on valid summer sea ice thickness observations

Facet-based numerical model for delay-Doppler SAR altimeter echoes

Landy, J.C., Tsamados, M. and Scharien, R.K., 2019. A facet-based numerical model for simulating SAR altimeter echoes from heterogeneous sea ice surfaces. IEEE TGARS, 57(7), 4164-4180.
Landy, J.C., Petty, A.A., Tsamados, M., and Stroeve, J.C., 2019. Sea ice roughness overlooked as a key source of uncertainty in CryoSat-2 ice freeboard retrievals. JGR-Oceans, In Review.

Integrated over illuminated facet area

$$P_r(\tau) = \sum_{k=-(N_b-1)/2}^{(N_b-1)/2} \frac{\lambda_0{}^2 P_T}{(4\pi)^3}\left(\frac{1}{2}ch\right)\int_A \frac{p_T(\tau,k)}{r^4} G^2(\theta,\phi)d(k)\sigma^0(\tau,\theta_{pr})\ dA$$

k^th Doppler beam

Transmitted pulse power

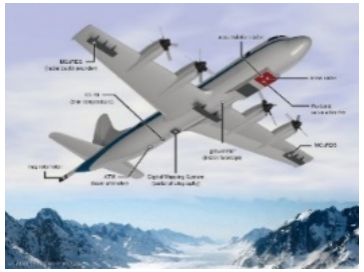
Transmitted pulse spread with range

Antenna gain pattern

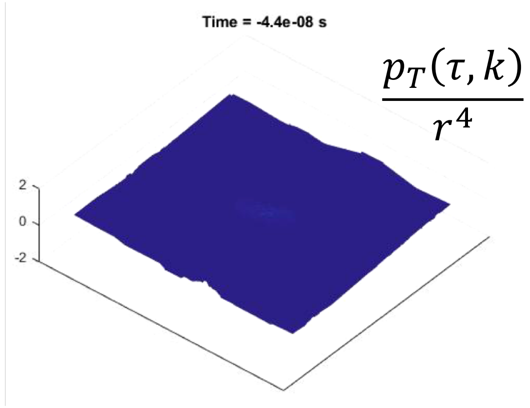
Synthetic beam pattern

Backscattering response of facets

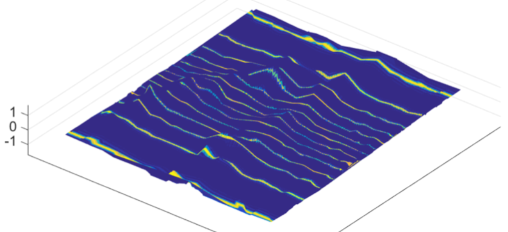
Operation IceBridge Airborne Laser Scanner Data



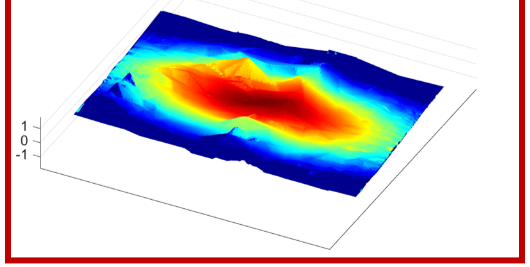
$\frac{p_T(\tau,k)}{r^4}$

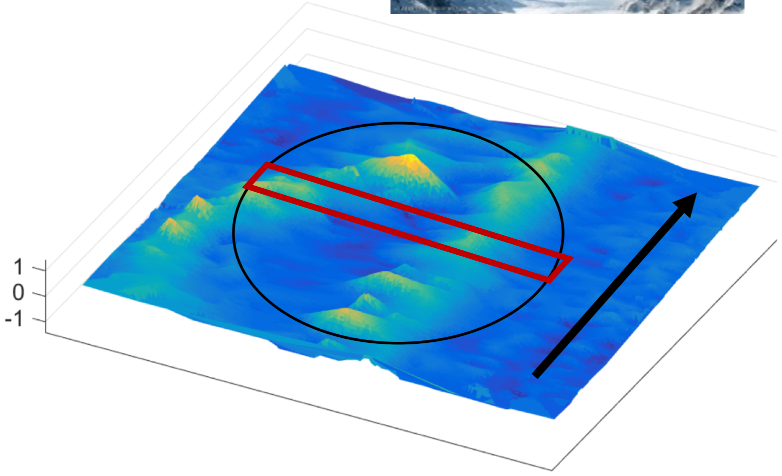


$d(k)$



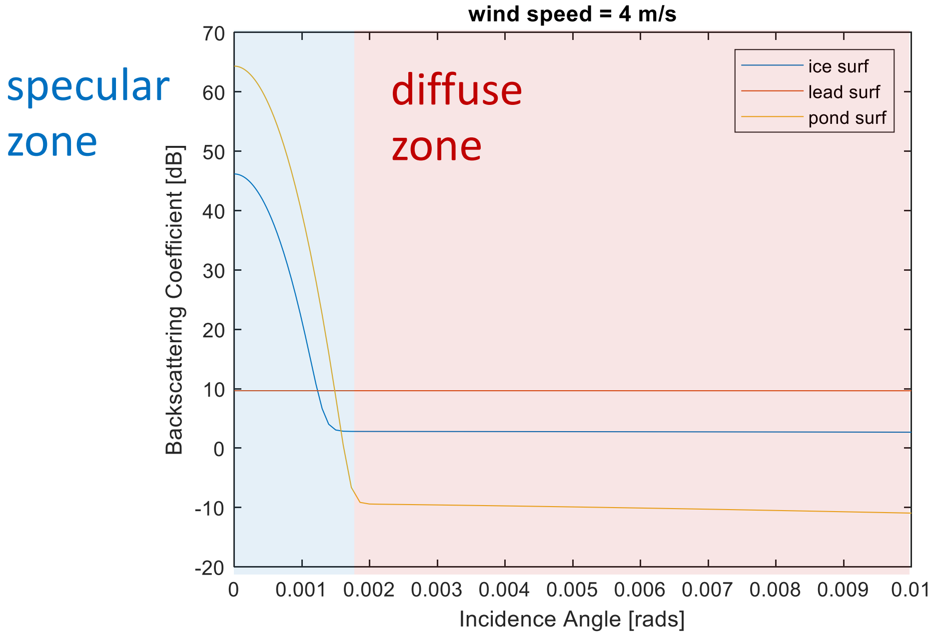
$log[\sigma^0(\tau,\theta_{pr})]$

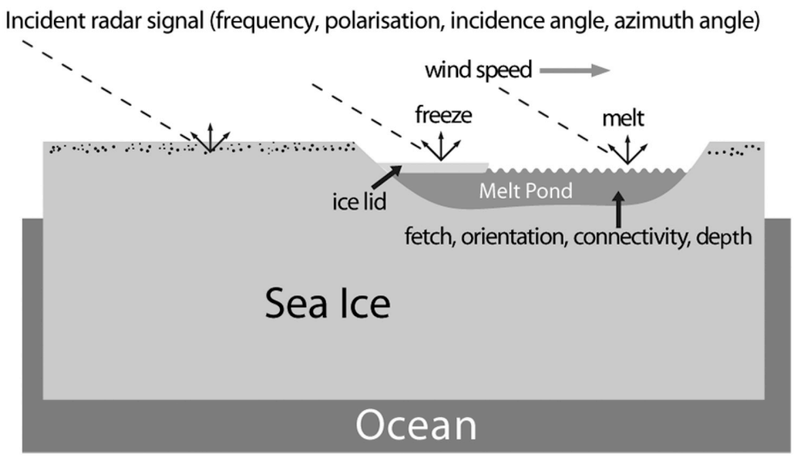




Radar scattering properties of sea ice, melt ponds and leads during the Arctic summer: $\sigma^0(\tau, \theta_{pr})$

- Total backscattered echo depends on power contributions from sea ice, ponds and leads within footprint
- Pond and lead surface roughness controlled by wind speed and fetch
- Diffuse rough-surface scattering >>> Integral Equation Model (Fung and Chen, 2004)
- Coherent reflection >>> specular point theory (Fetterer et al., 1992)





Scharien et al., Cryosphere, 2014

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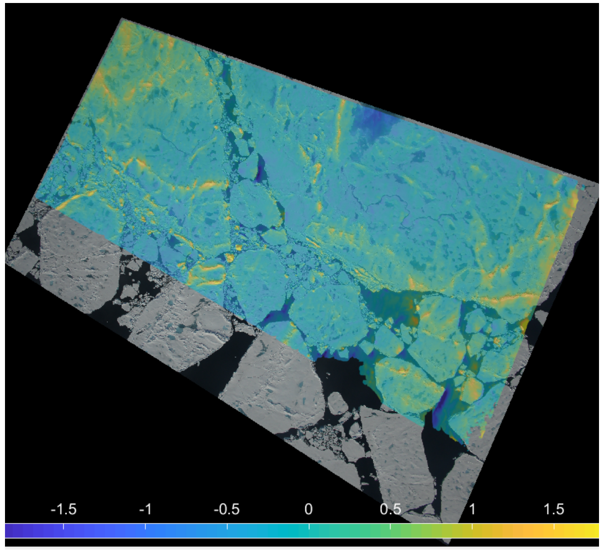
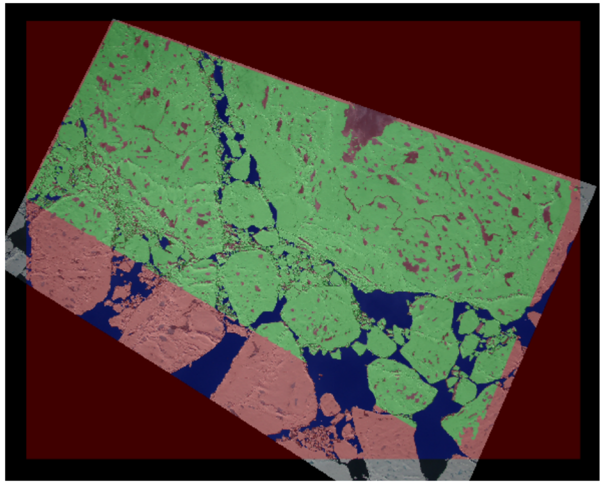
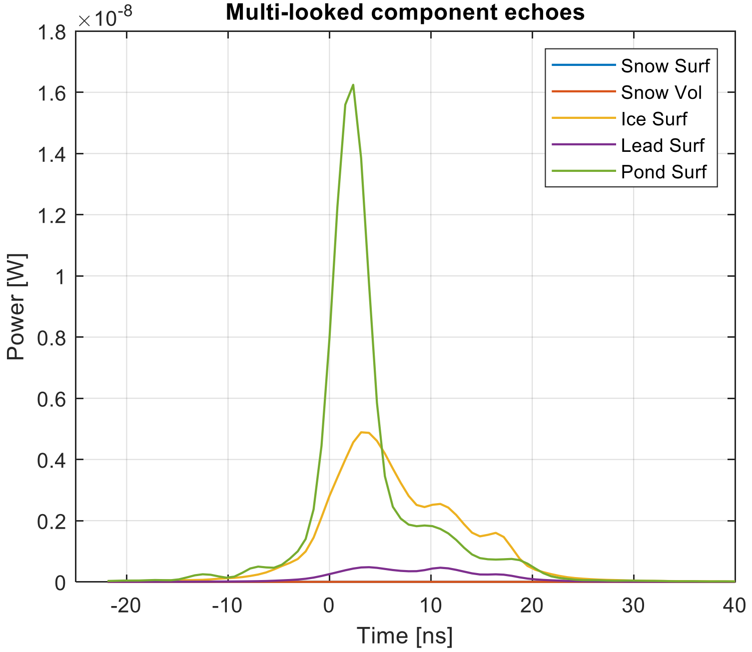
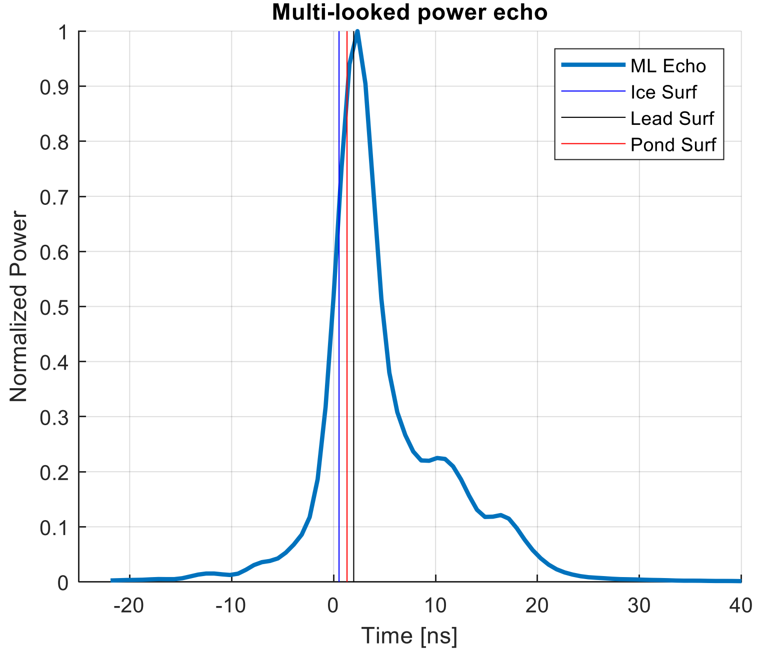




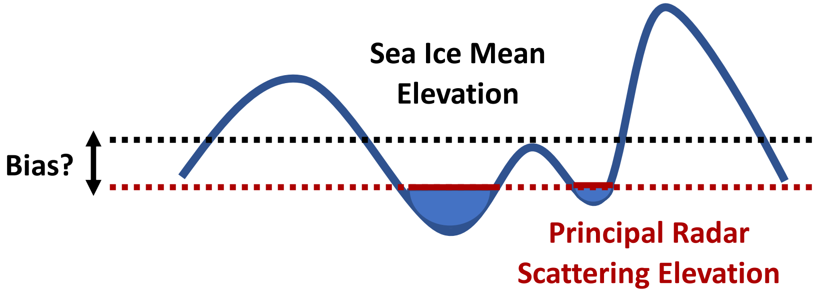
- NASA Operation IceBridge data used to make forward model simulations
- Modelled echoes can be deconstructed into sub-components
- Simulation results quantify differences between measured sea ice, pond and lead elevations

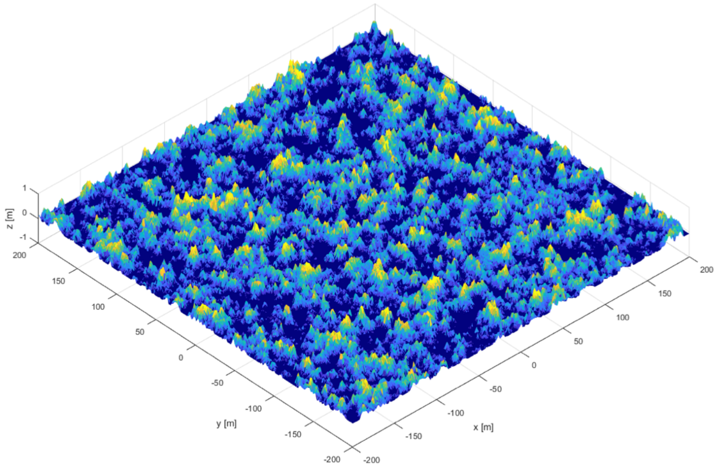


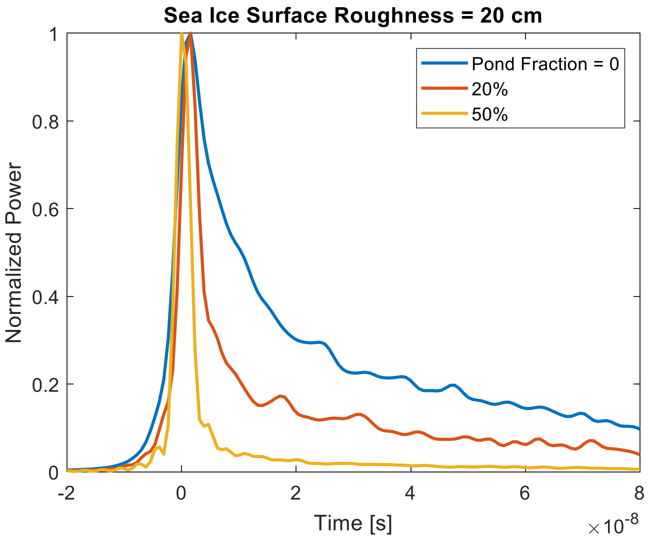


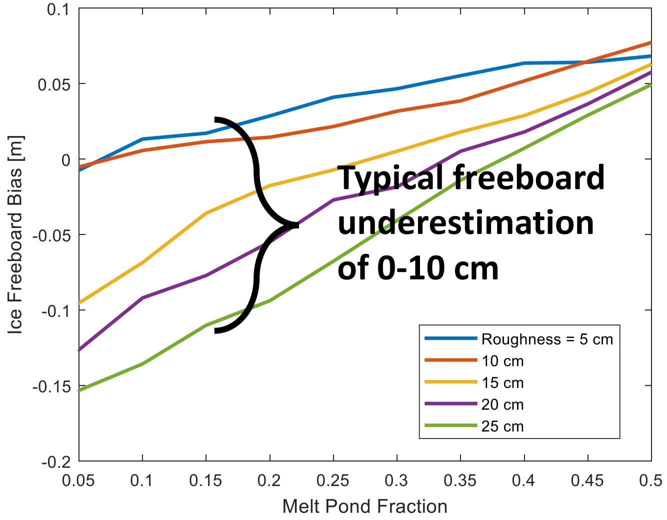
Model simulations with 1000s of virtual surfaces to characterize:

- How do sea ice conditions and wind speed affect sigma 0?
- What is the minimum resolvable lead width?
- How do melt ponds bias measurements of sea ice floe elevations?



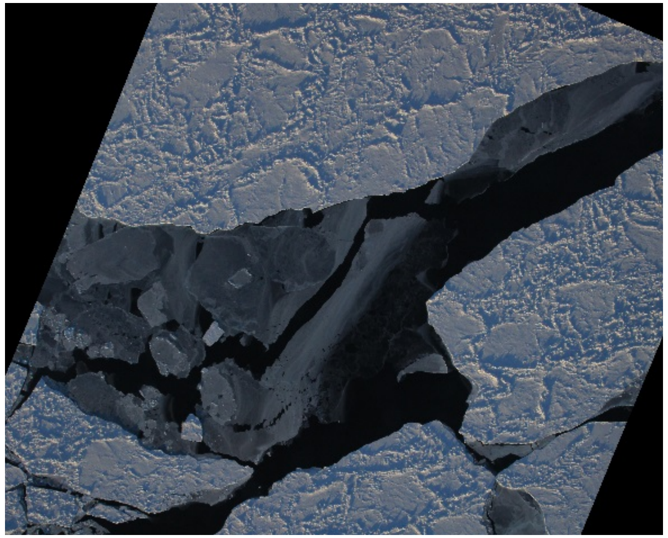




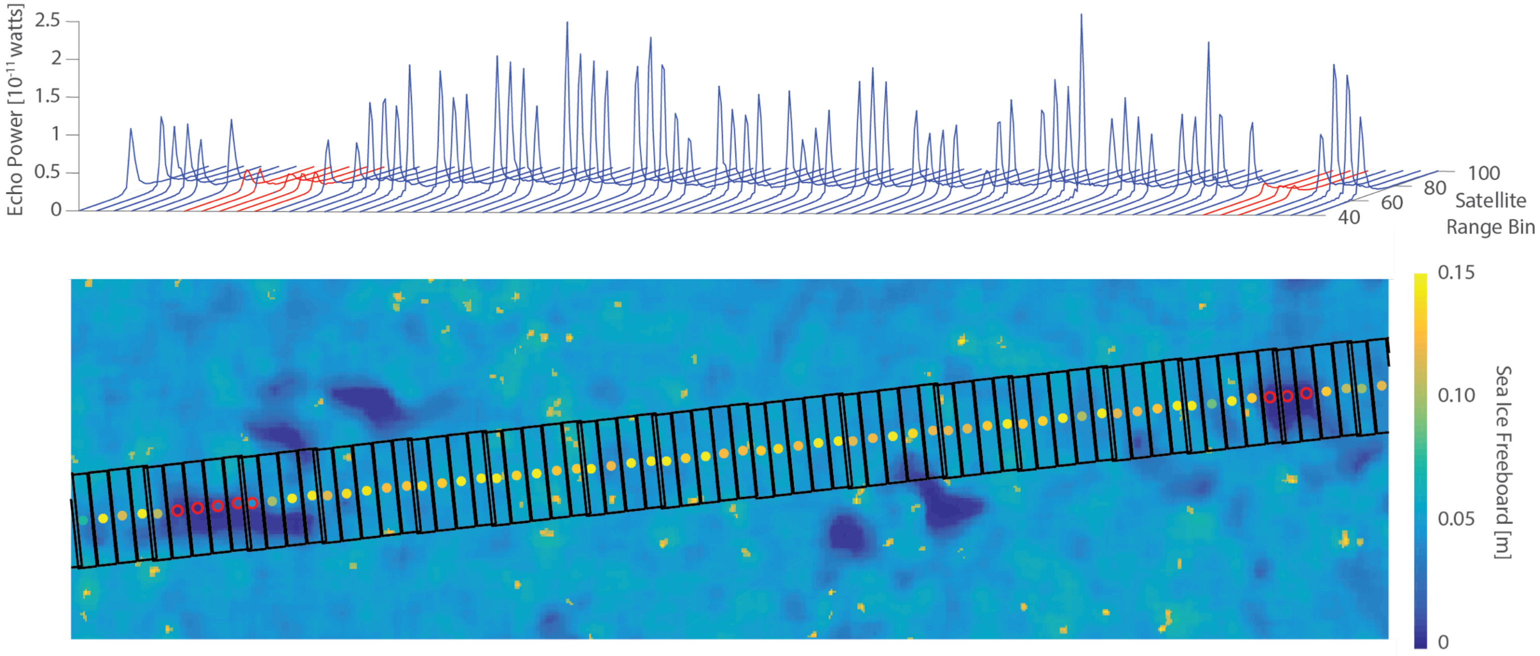


Are there differences between echoes from melt ponds and leads?

- Winter echoes from ‘leads’ more often from new thin saline grease ice or nilas than open water
- High dielectric permittivity and damped waves (very low roughness) = high-power specular radar return
- Leads in summer are open water, often with wind-induced waves = surface has some roughness
- So lead echoes (like open ocean echoes) have relatively lower power than echoes from melt-pond covered ice



OIB Digital Mapping System



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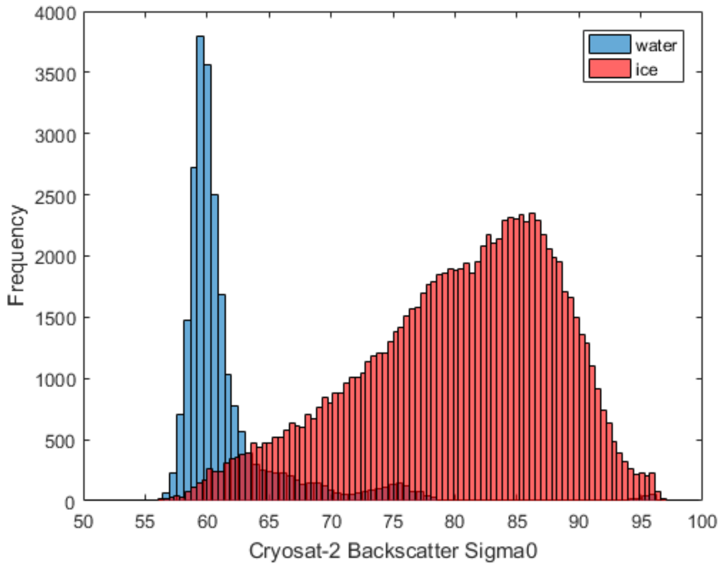
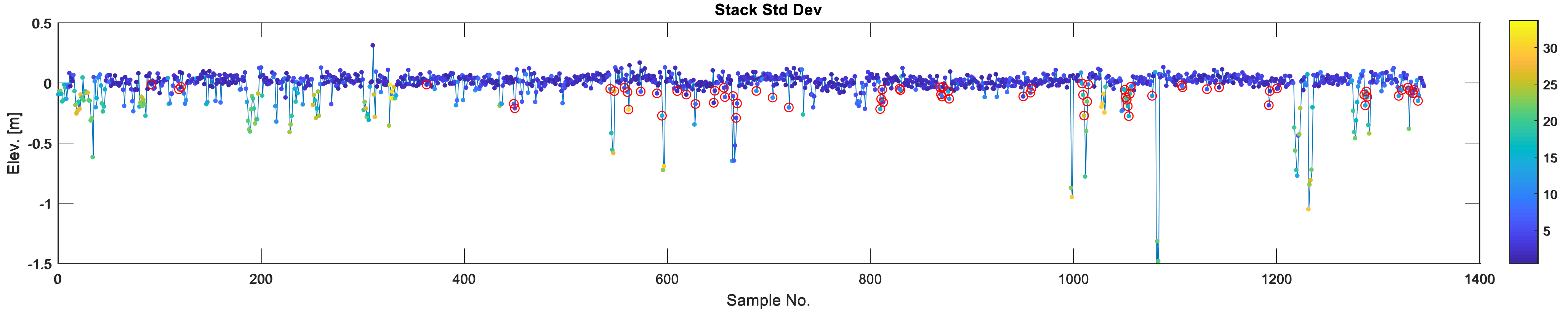
Comparison between CS-2 tracks and x55 coincident RADARSAT-2 images



Key Parameters:

- Absolute sigma0 (differentiates ice from ocean)
- Surface elevation (differentiates ice from ocean)
- Local troughs in sigma0 (differentiates leads from ocean)
- Stack standard deviation (differentiates leads from ocean)

>>> K Nearest-Neighbour Classification Algorithm <<<



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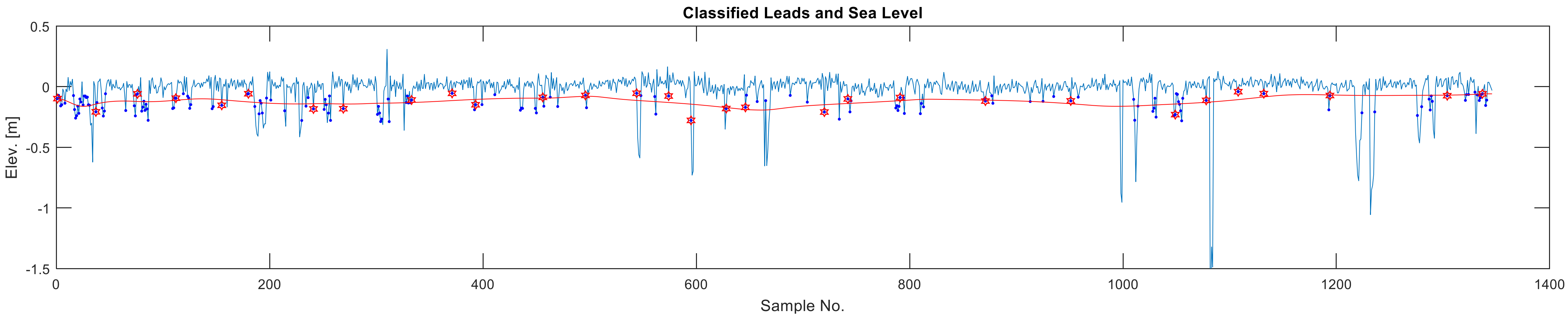
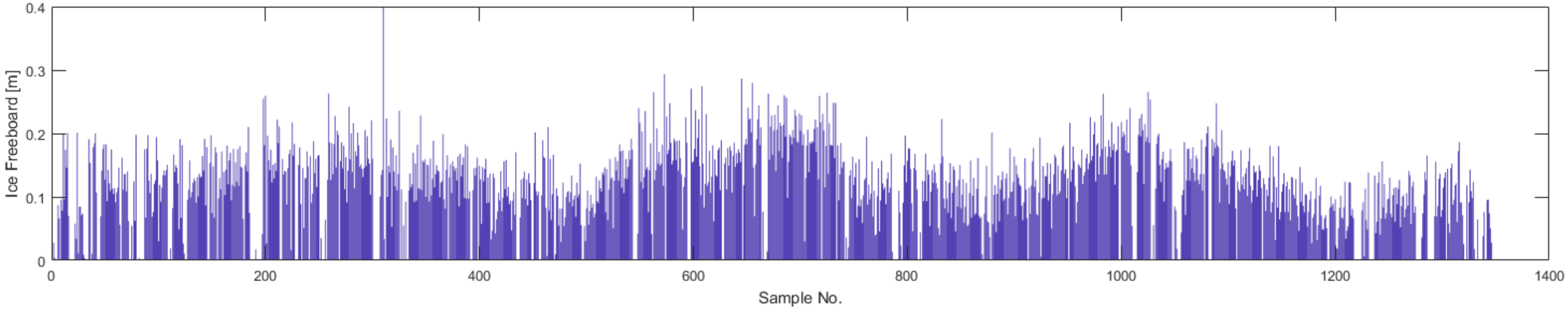
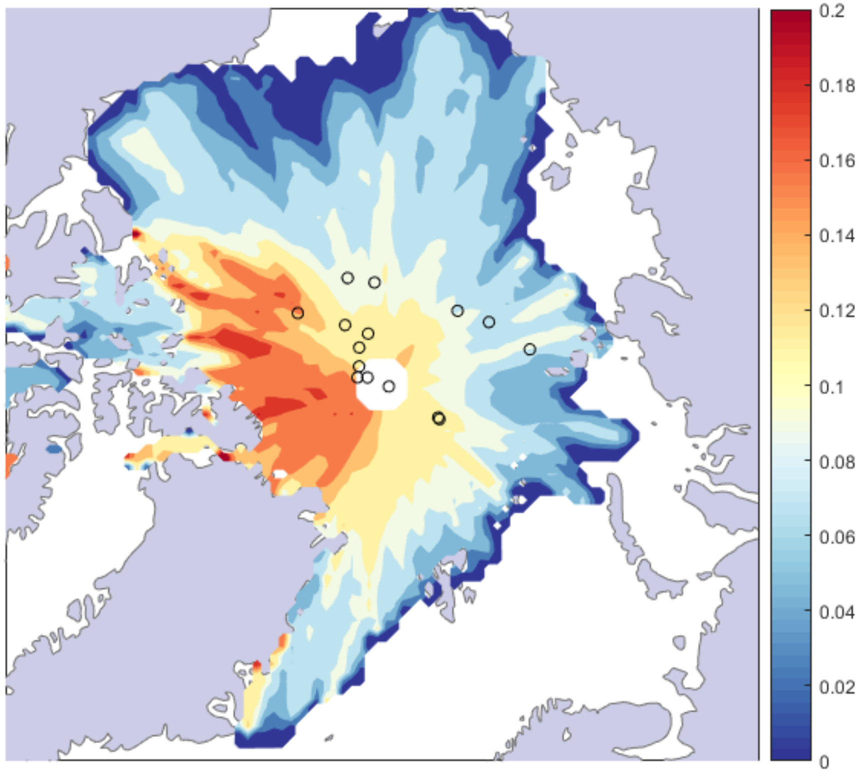
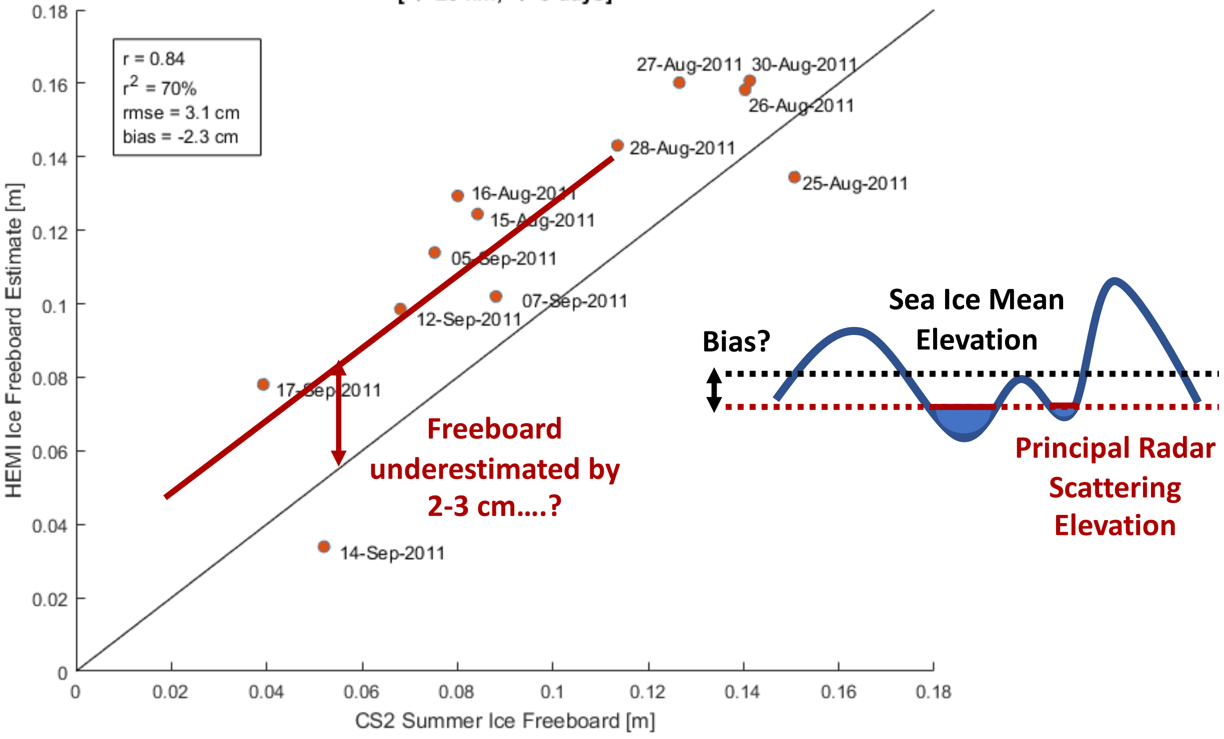




How does Cryosat-2 compare to Helicopter EMI observations?





Hendricks et al., 2012, Helicopter-borne sea ice thickness measurements during POLARSTERN campaign ARK-XXVI/3 (TransArc) in the Arctic Ocean, AWI

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Achievements in Year 1

- ✓ Compiled a training dataset of ~100 optical and SAR images coinciding with CryoSat-2 sea ice passes
- ✓ Compiled a large dataset of reference sea ice freeboard and thickness observations from airborne campaigns
- ✓ Developed a machine learning-based classifier to separate CryoSat-2 echoes from sea ice and leads
- ✓ Developed a numerical model to simulate CryoSat-2 waveforms from melting sea ice
- ✓ Good initial comparisons of derived freeboard and thickness to airborne HEMI observations of sea ice

Roadblocks in Year 1

- X Classification algorithm is not viable in all seasons and regions
- X Complexity of CryoSat-2 waveforms from mixed sea ice and ocean in summer is poorly understood

Objectives for Year 2

- Complete numerical model simulations to characterize sensitivity of CryoSat-2 echoes to sea ice melting state, wind-wave roughness, lead width etc.
- Use simulation results to retrack observed CryoSat-2 waveforms and refine classification algorithm
- Develop final Arctic sea ice freeboard product for viable regions/months
- Validate and constrain uncertainty with existing airborne ice thickness observations
- Combine sea ice volume estimates with existing ice motion products to estimate Arctic sea ice fluxes

Provisional Conference Schedule

- ESA CryoSat 10th Anniversary Science Conference, Taormina, Italy, April 2020
- American Geophysical Union Fall Science Meeting, San Francisco, US, December 2020

Completed Publications

- Landy, J.C., Tsamados, M. and Scharien, R.K., 2019. A facet-based numerical model for simulating SAR altimeter echoes from heterogeneous sea ice surfaces. IEEE TGARS, 57(7), 4164-4180.
- Landy, J.C., Petty, A.A., Tsamados, M., and Stroeve, J.C., 2019. Sea ice roughness overlooked as a key source of uncertainty in CryoSat-2 ice freeboard retrievals. JGR-Oceans, In Review.

Provisional Publications

- Landy, J.C., Komarov, A., Dawson, G., Haas, C., Howell, S., 2020. Numerical and observational evaluation of CryoSat-2 SAR altimeter echoes from Arctic sea ice during summer months. In Prep, TC/RSE/JG
- Landy, J.C., Komarov, A., Haas, C., Howell, S., and Krumpen, T., 2020/2021. First observations of pan-Arctic summer sea ice thickness from CryoSat-2.

Thank you! Any questions…?