Sensitivity of Backscatter and Brightness Temperature Measurements from Satellite Radar Altimetry Missions to Lake Ice Thickness

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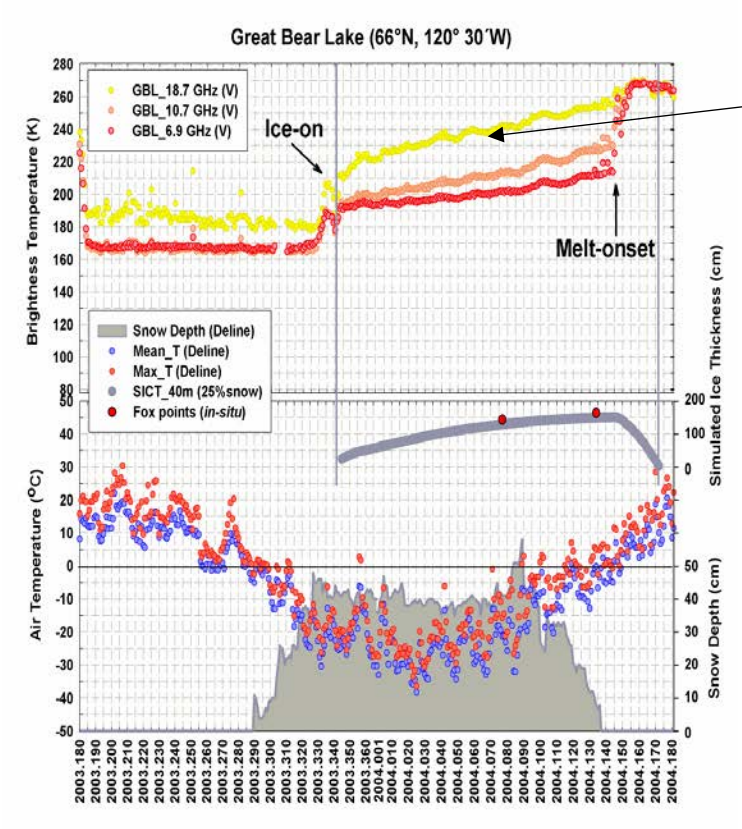
Background

Relevance of Lake Ice Thickness (LIT)

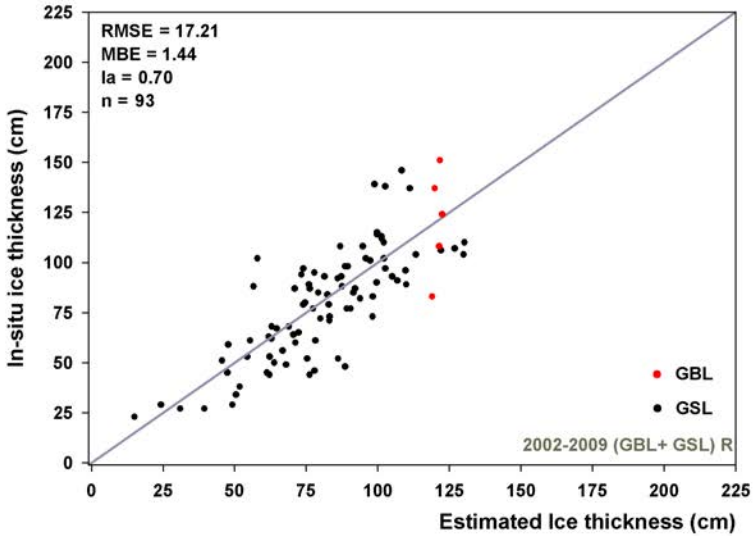
- A sensitive indicator (integrator) of wintertime weather/climate conditions
- An Essential Climate Variable (ECV) with broad social and economic impacts
- Manual measurements are sparse in space and in time, and have declined in the last three decades

GCOS Requirement for Lake Ice Thickness (GCOS, 2016)	
Measurement uncertainty	1-2 cm
Stability	N/A
Spatial resolution	100 m
Temporal resolution	Monthly

Satellite retrieval of LIT (passive microwave)

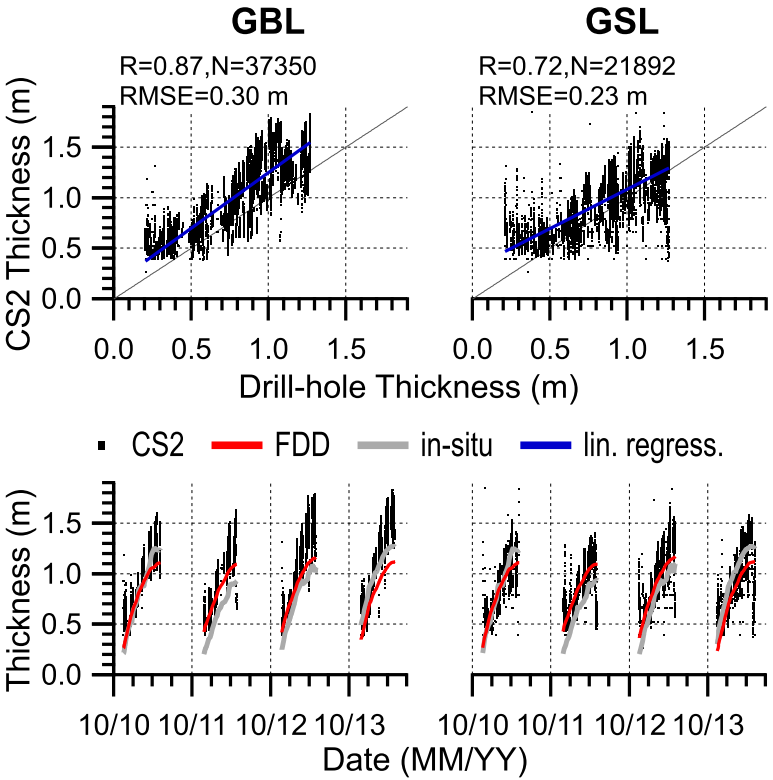


Brightness temperature at 18.7 GHz V-pol from AMSR-E is sensitive to ice growth



Kang *et al*. (2014)

Satellite retrieval of LIT (radar altimetry)



CryoSat-2 (Ku-band) retrieval of lake ice thickness *over GBL and GSL*

← Scatter plot of CS2 versus in situ ice thickness measurements (Back Bay, GSL)

← Comparison of time series of lake ice thickness from CS2, the FDD model, and in situ measurements Back Bay, GSL)

CryoSat-2 estimates are $R > 0.65$, RMSE < 0.33 m

Beckers *et al.* (2017)

What is the impact of varied ice and overlying snow properties on LIT retrievals?

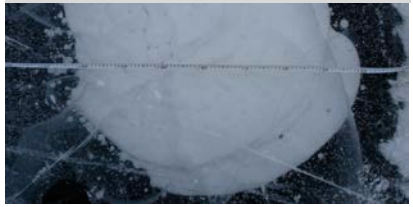
Ice with low and no snow

Pressure ridge
(2 m high, several km long)

Roughness at ice-water interface

Clear ice / grey ice with small bubbles

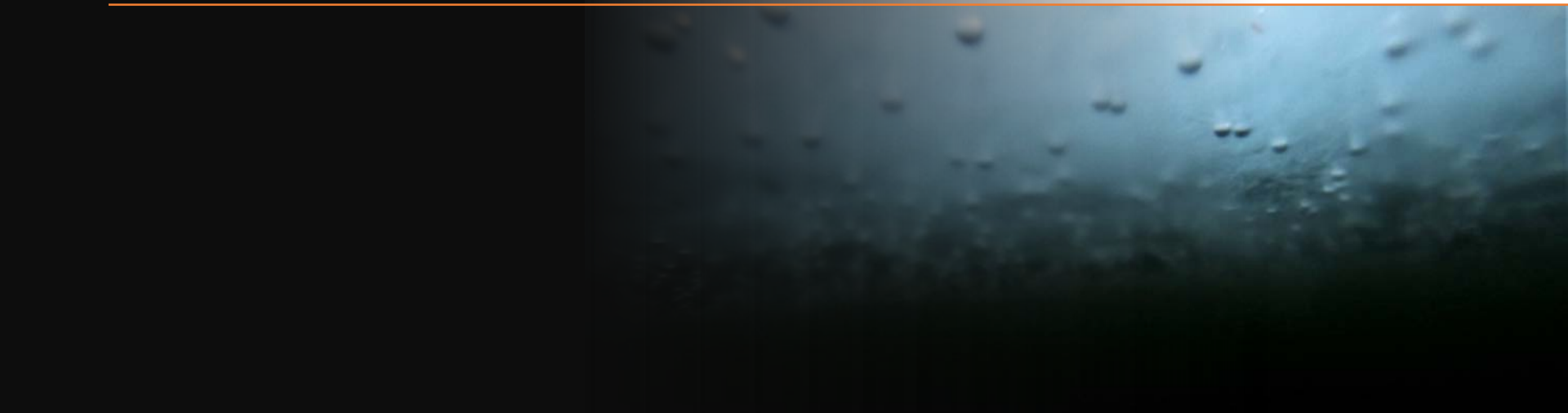
Clear ice with large bubble



Snow on ice

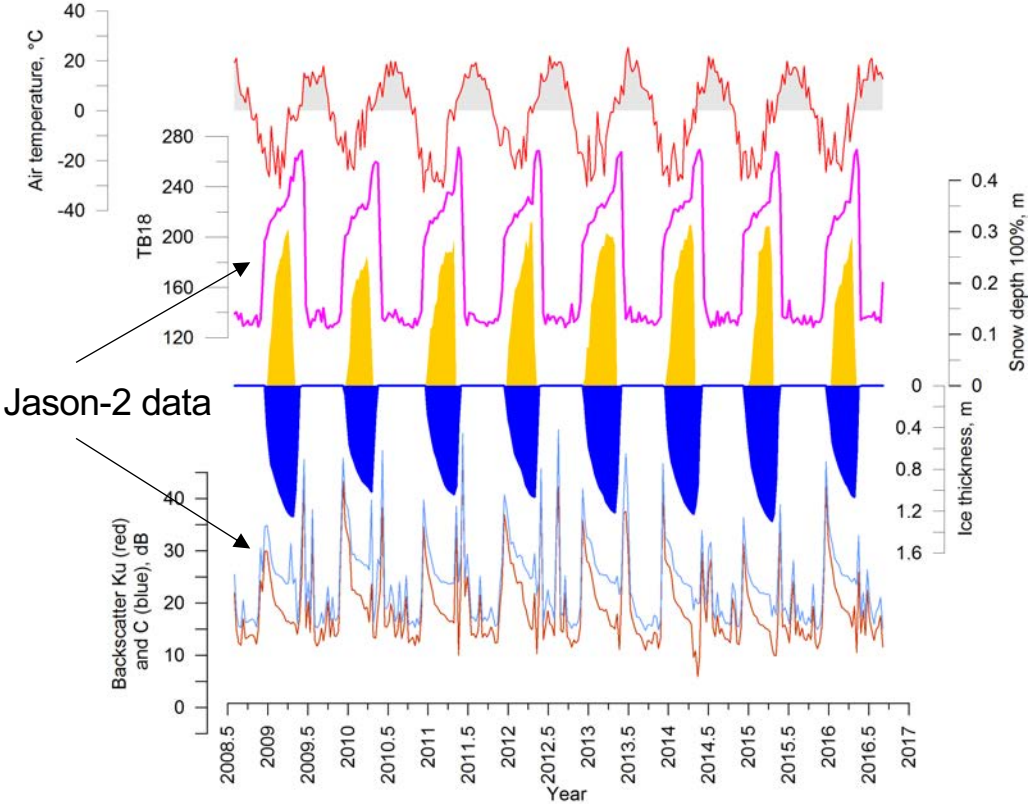
Slushing / snow ice

LIAM Project (Lake Ice from Altimetry Missions)



Objective

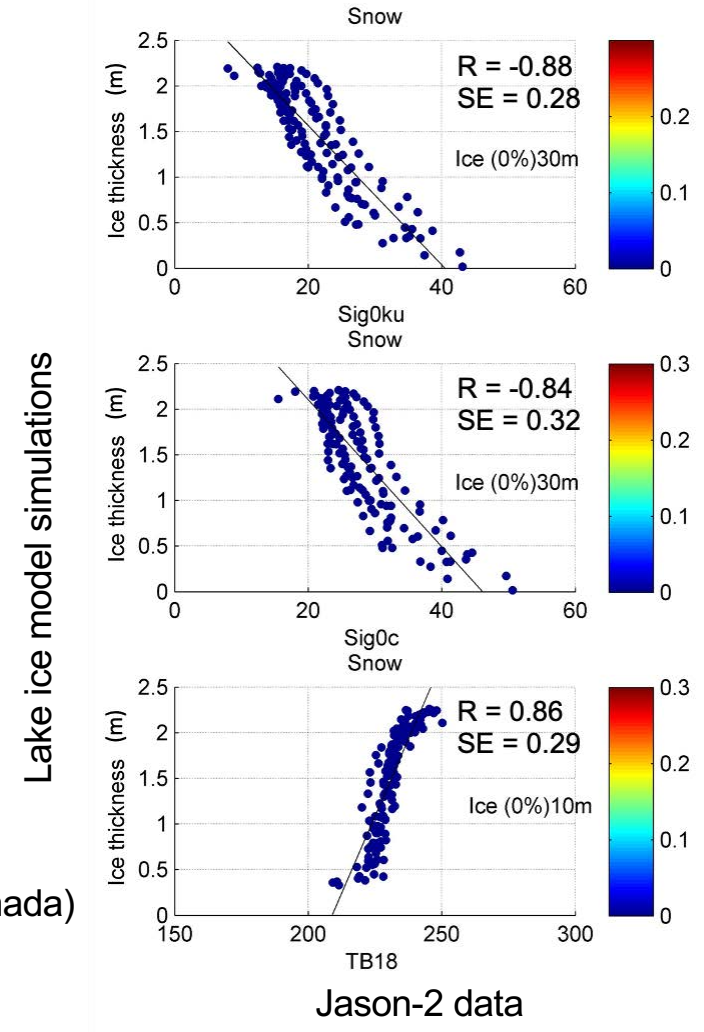
Examine sensitivity of backscatter and brightness temperature measurements from altimetry missions to LIT of varied ice and overlying snow properties



Great Slave Lake (Canada)

Goal

Evaluate the impact of varied ice and overlying snow properties on LIT estimates (i.e. uncertainty characterization of retrievals)

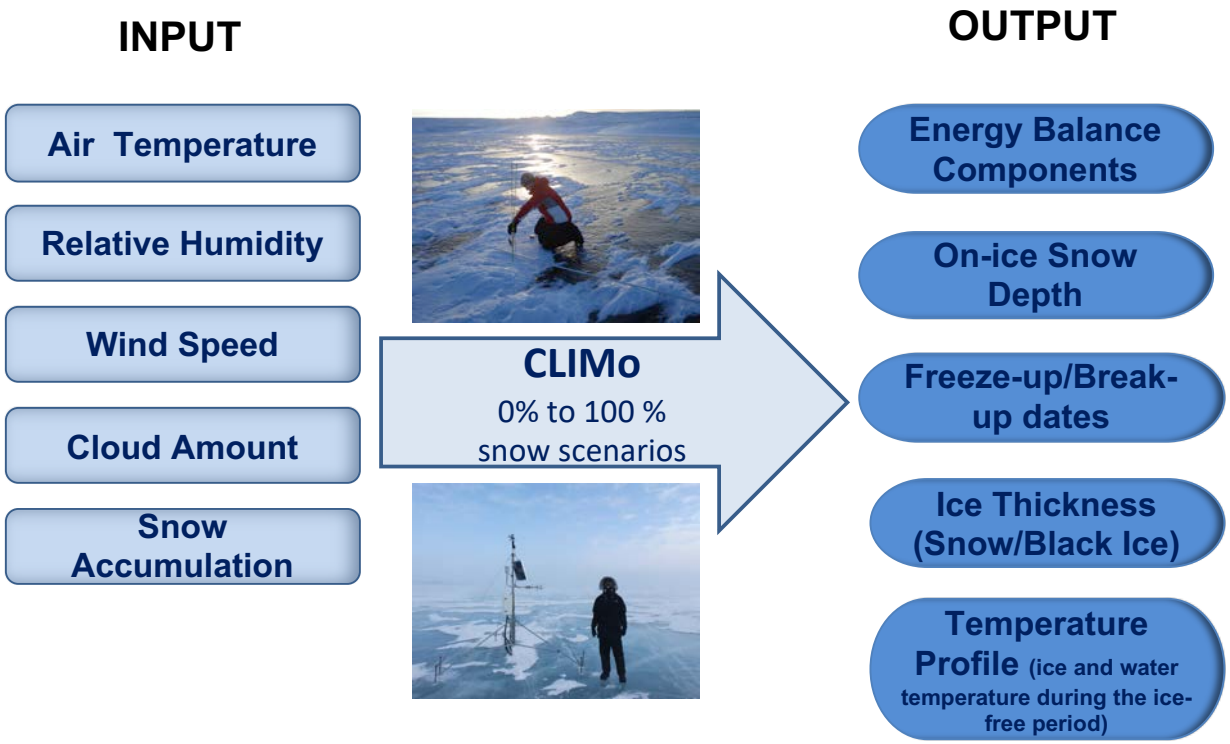


Baker Lake (Canada)

Data

- Altimetry missions: Jason-2/3 and Sentinel-3
  - Ku/C-band and 18.7-36.5 GHz
- Field measurements and ice charts
- SAR imaging (Sentinel-1/RADARSAT-2) and optical (MODIS) products
- Output from a numerical lake ice model forced with weather station and atmospheric reanalysis data

Tools: CLIMo (lake ice simulations)



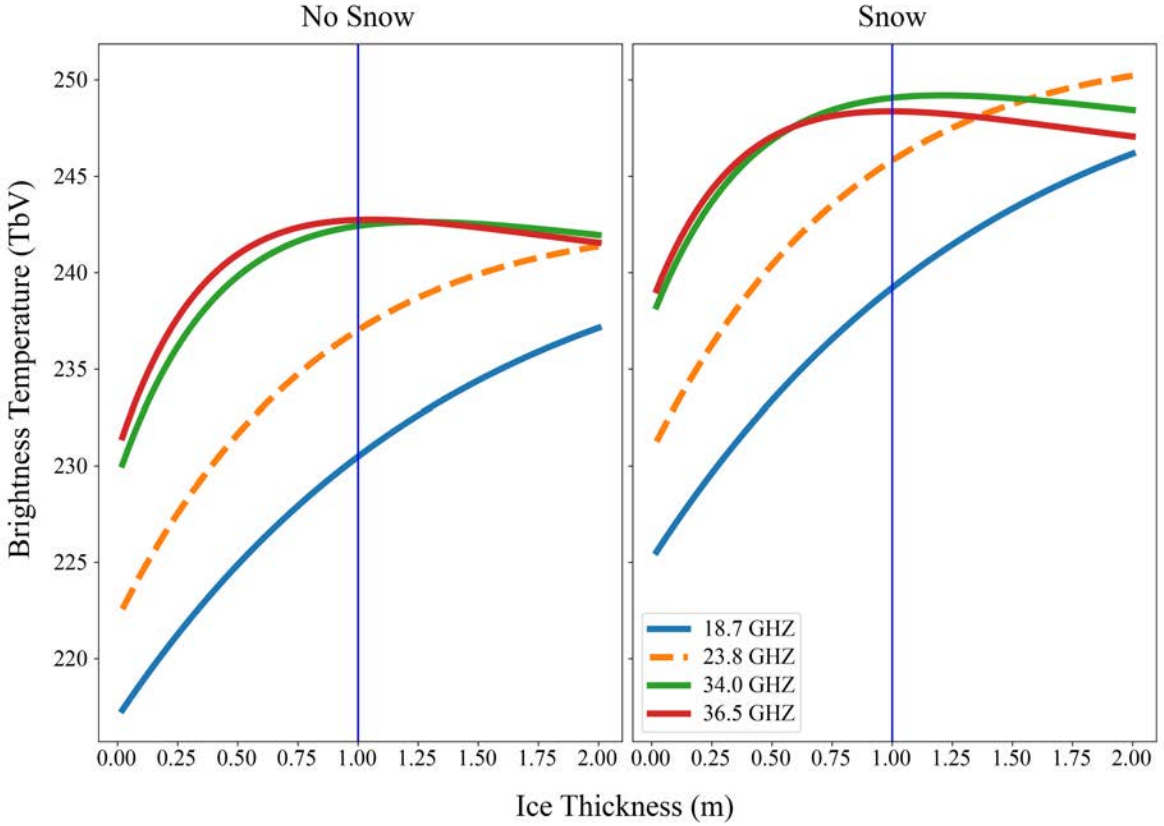
Duguay *et al.* (2003)

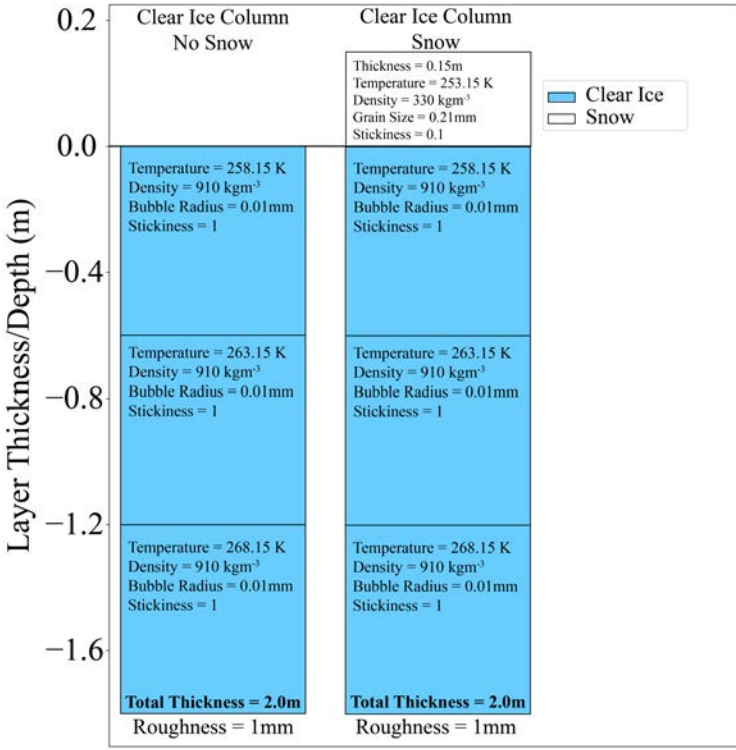
Tools: SMRT model (forward simulations)

- **Snow Microwave Radiative Transfer (SMRT) is a passive/active microwave model** developed as part of an ESA study on snow microstructure signature at microwave frequencies (i.e. "grain size scattering")
- **Sea-ice module** was added **with freshwater lake ice as a "side product" which has not been evaluated yet**
- **Altimetry module** has recently been added in view of ESA's Copernicus Polar Ice and Snow Topography Altimeter (CRISTAL) mission (planned for launch in 2027), **but it has not been tested to date for lake ice**

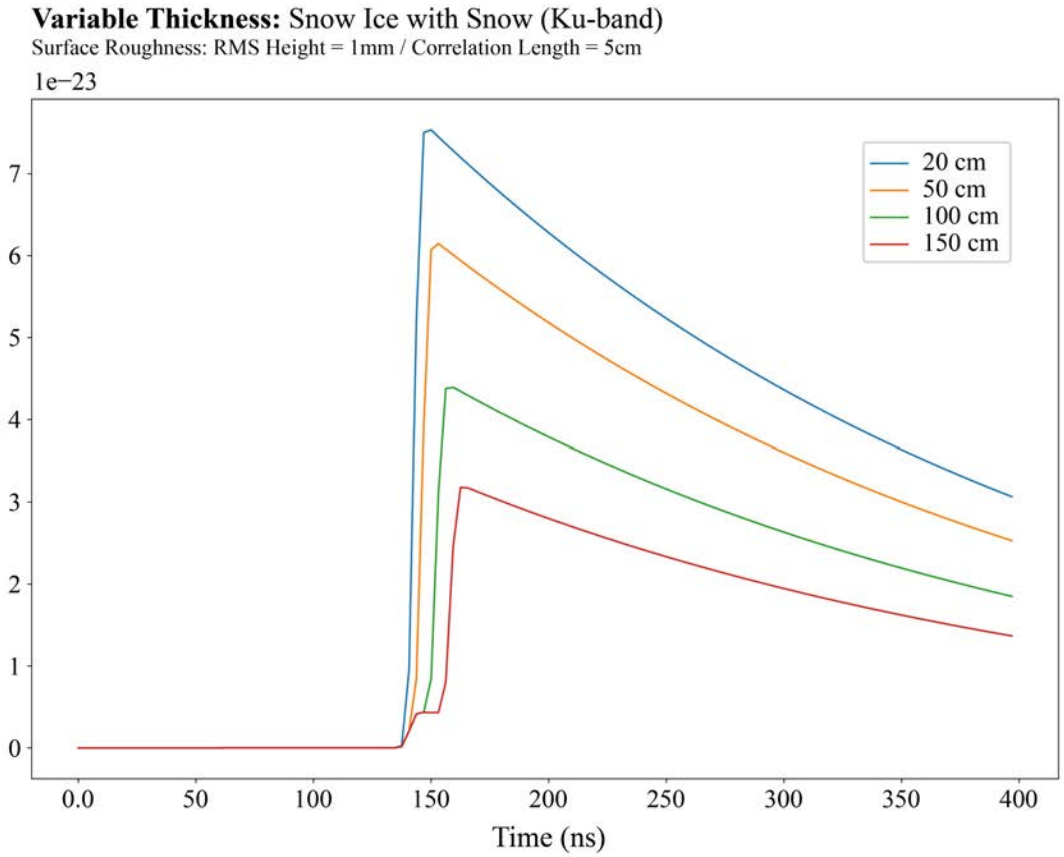
See Picard et al. (2018) and https://www.smrt-model.science/ for details

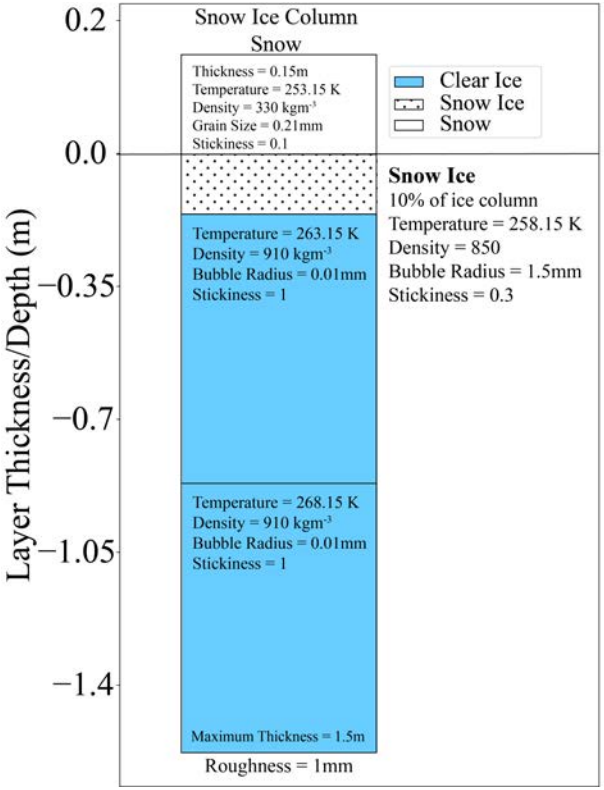
Results: Forward simulations of TB with SMRT





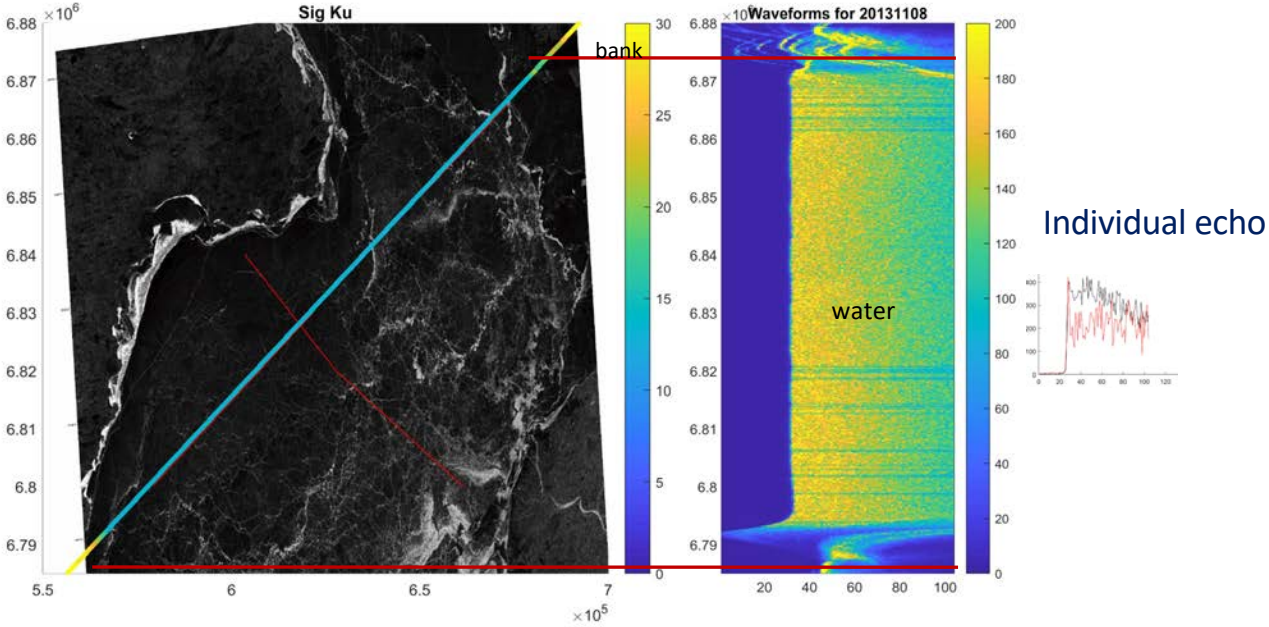
Results: Forward simulations of waveforms with SMRT





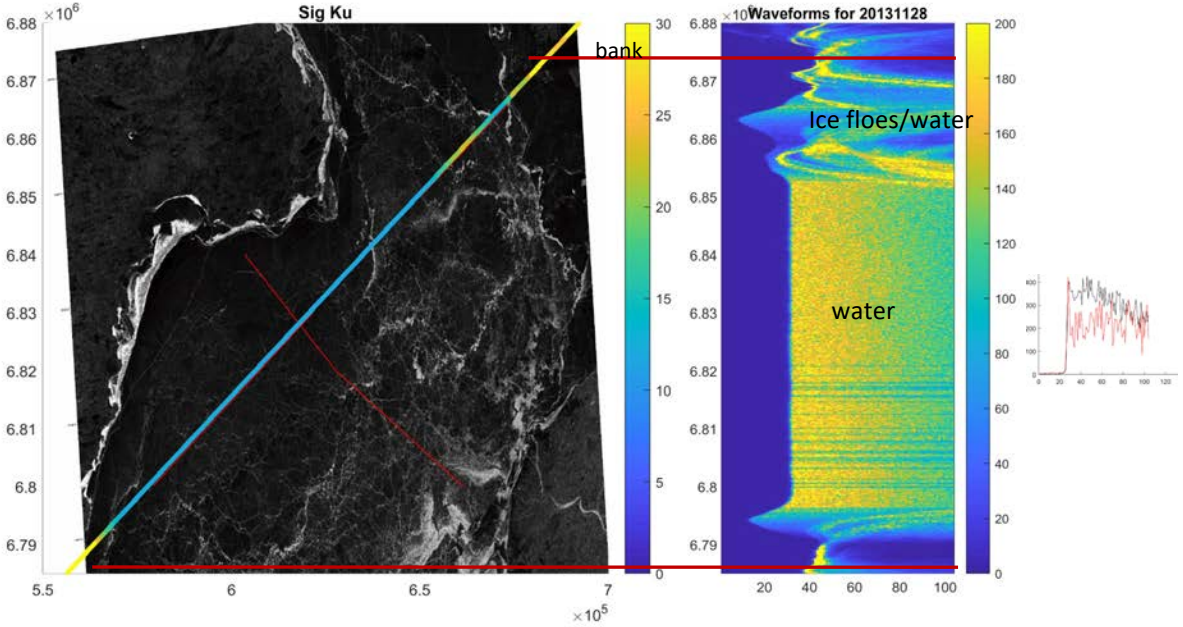
Results: Analysis of waveforms (Jason-2)

Along-track echogram



Great Slave Lake (Canada)

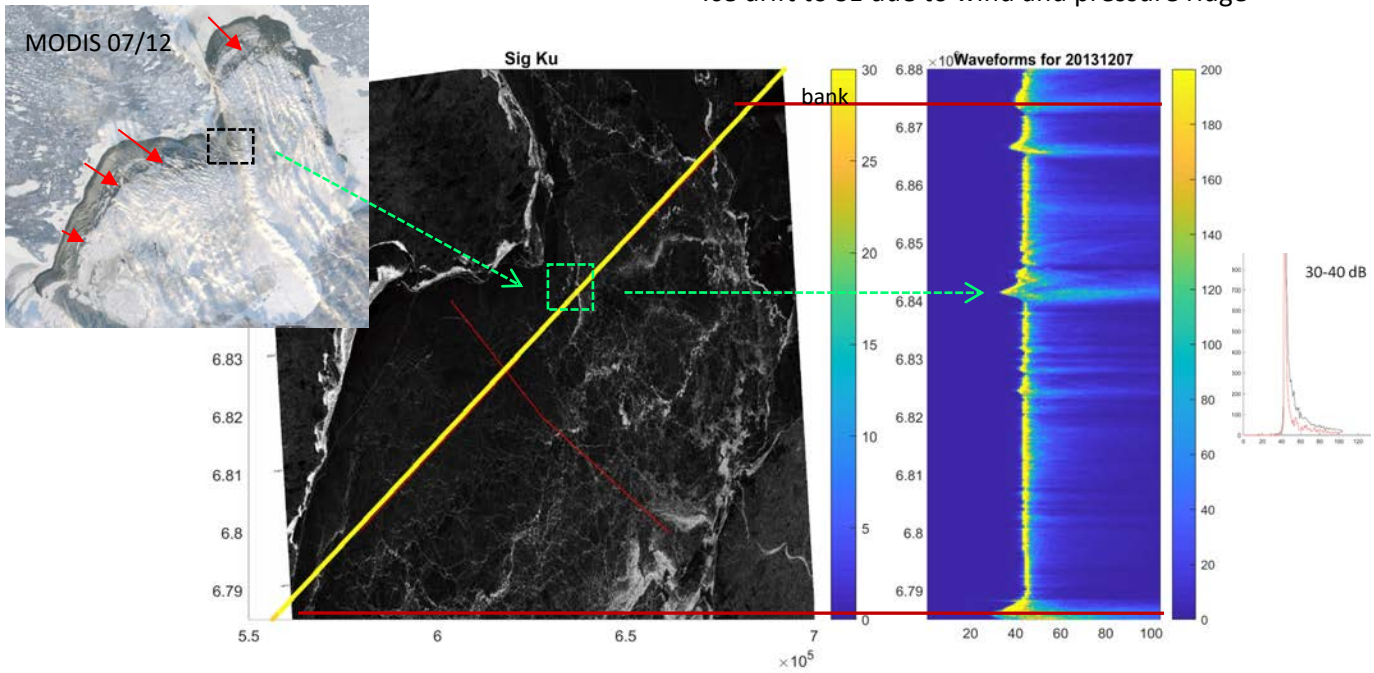
Results: Analysis of waveforms (Jason-2)



Great Slave Lake (Canada)

Results: Analysis of waveforms (Jason-2)

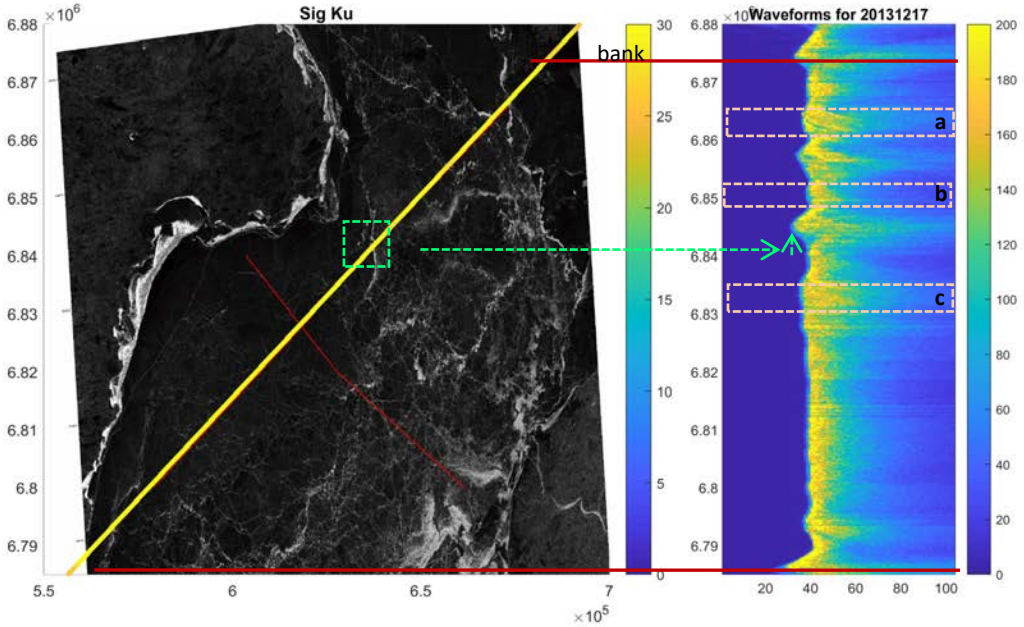
07 Dec.
Ice drift to SE due to wind and pressure ridge



Great Slave Lake (Canada)

Results: Analysis of waveforms (Jason-2)

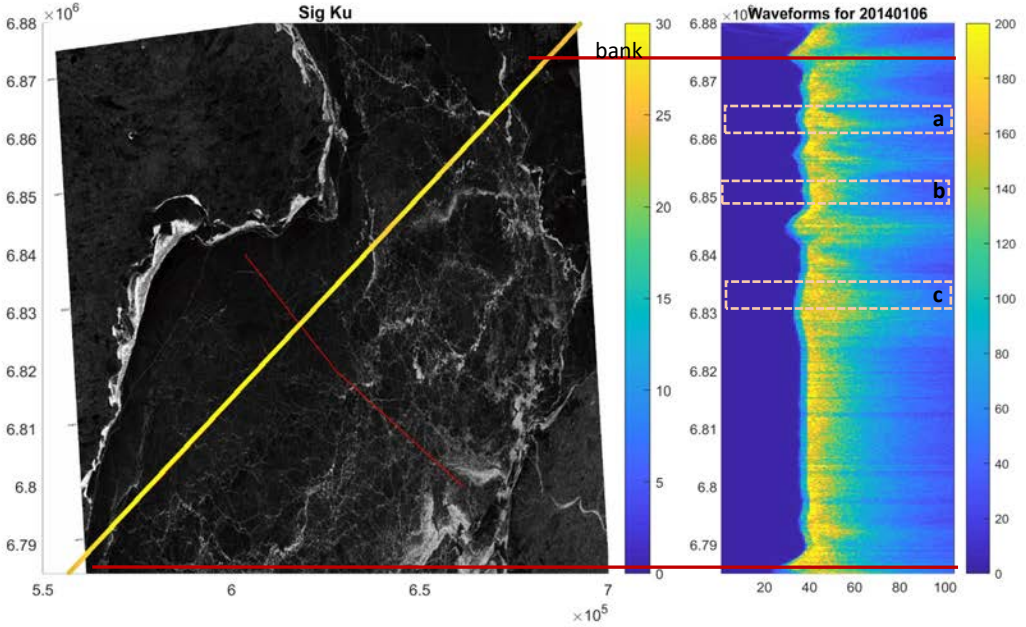
17 Dec.
ice growth and echo transformation



Great Slave Lake (Canada)

Results: Analysis of waveforms (Jason-2)

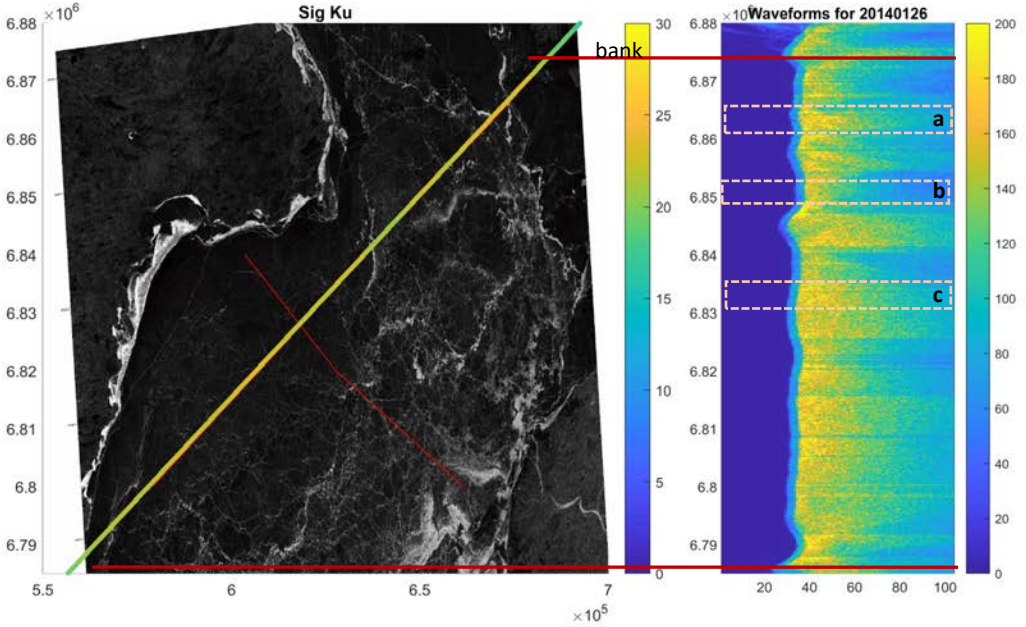
6 Jan.
ice growth and echo transformation



Great Slave Lake (Canada)

Results: Analysis of waveforms (Jason-2)

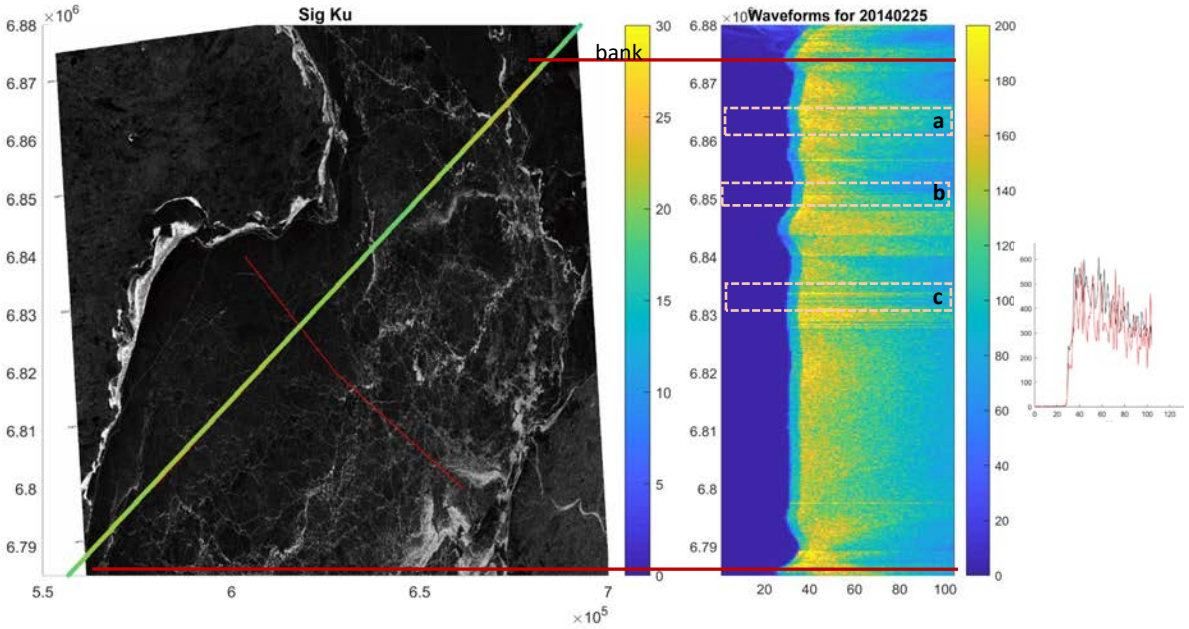
26 Jan.
ice growth and echo transformation



Great Slave Lake (Canada)

Results: Analysis of waveforms (Jason-2)

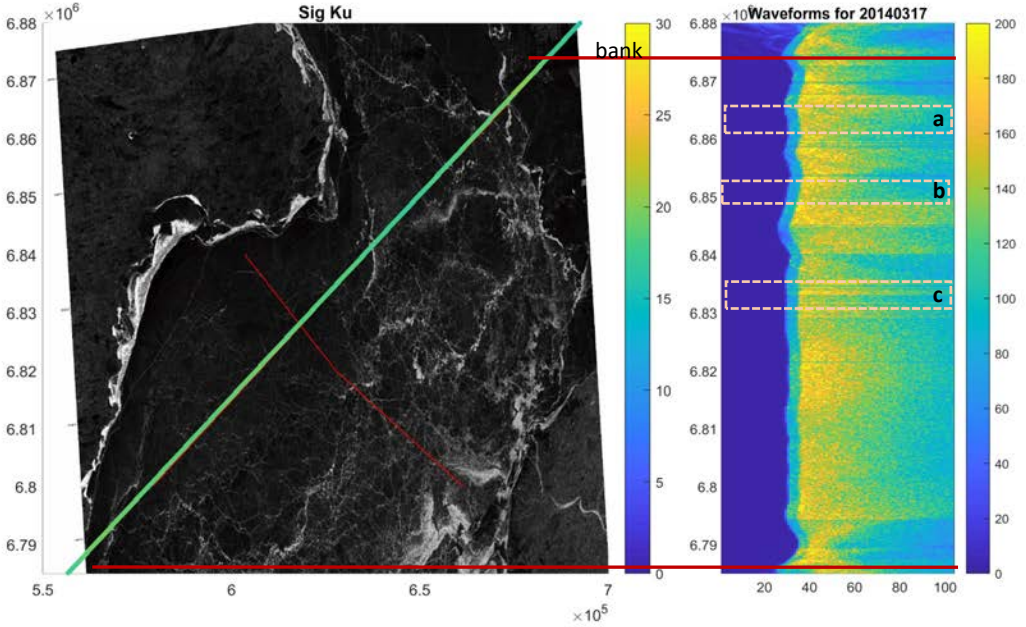
25 Feb.
ice growth and echo transformation



Great Slave Lake (Canada)

Results: Analysis of waveforms (Jason-2)

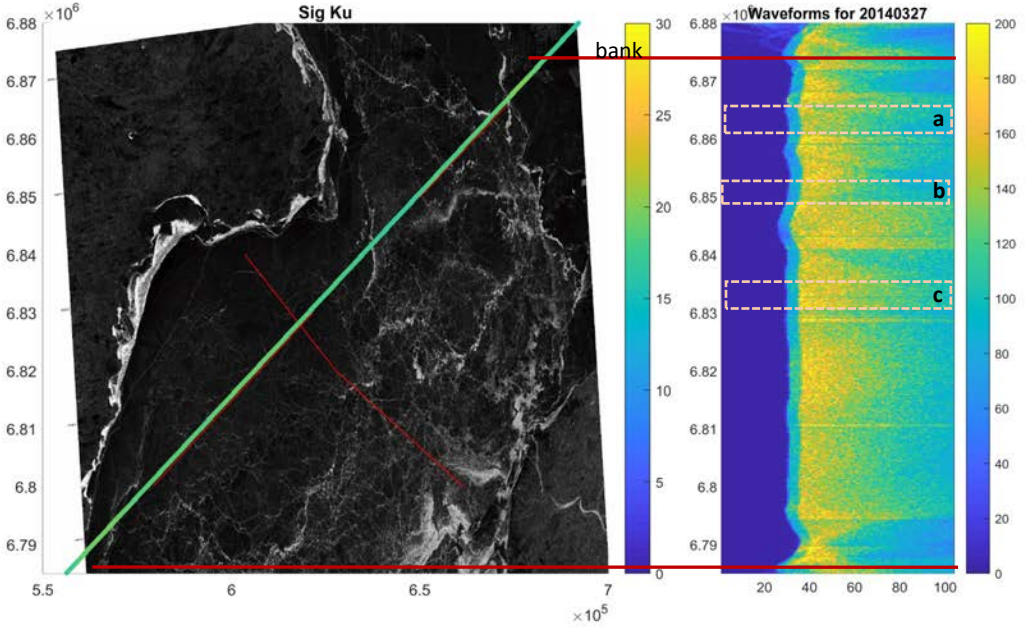
17 Mar.
ice growth and echo transformation



Great Slave Lake (Canada)

Results: Analysis of waveforms (Jason-2)

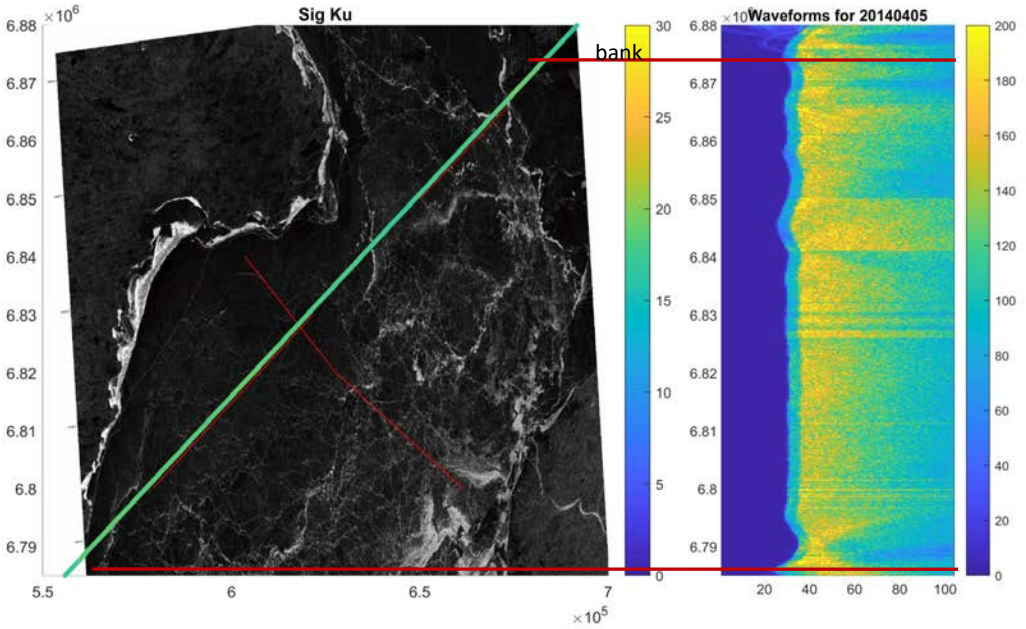
27 Mar.
ice growth and ice fields' characteristics smoothing



Great Slave Lake (Canada)

Results: Analysis of waveforms (Jason-2)

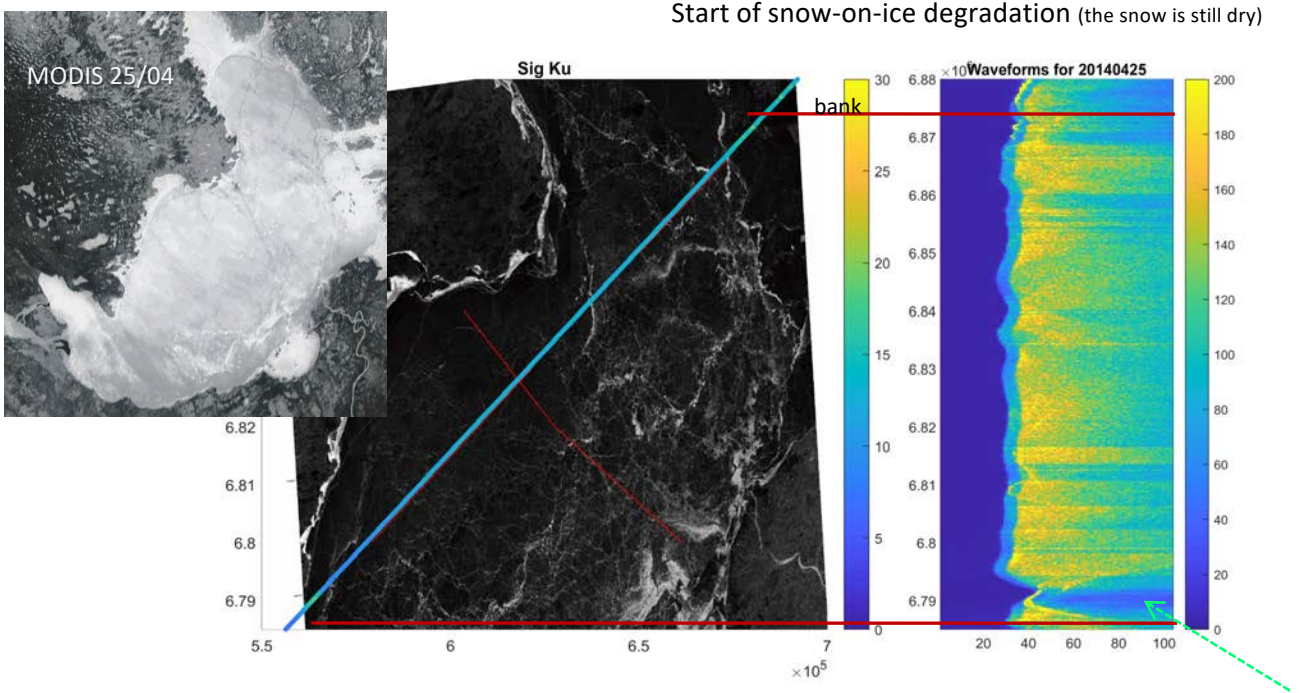
5 Apr.
ice growth and ice fields' characteristics smoothing



Great Slave Lake (Canada)

Results: Analysis of waveforms (Jason-2)

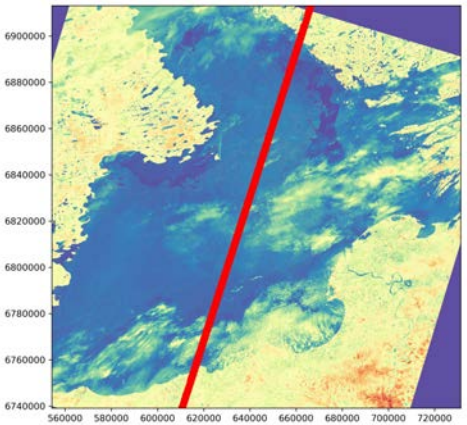
25 Apr.
Start of snow-on-ice degradation (the snow is still dry)



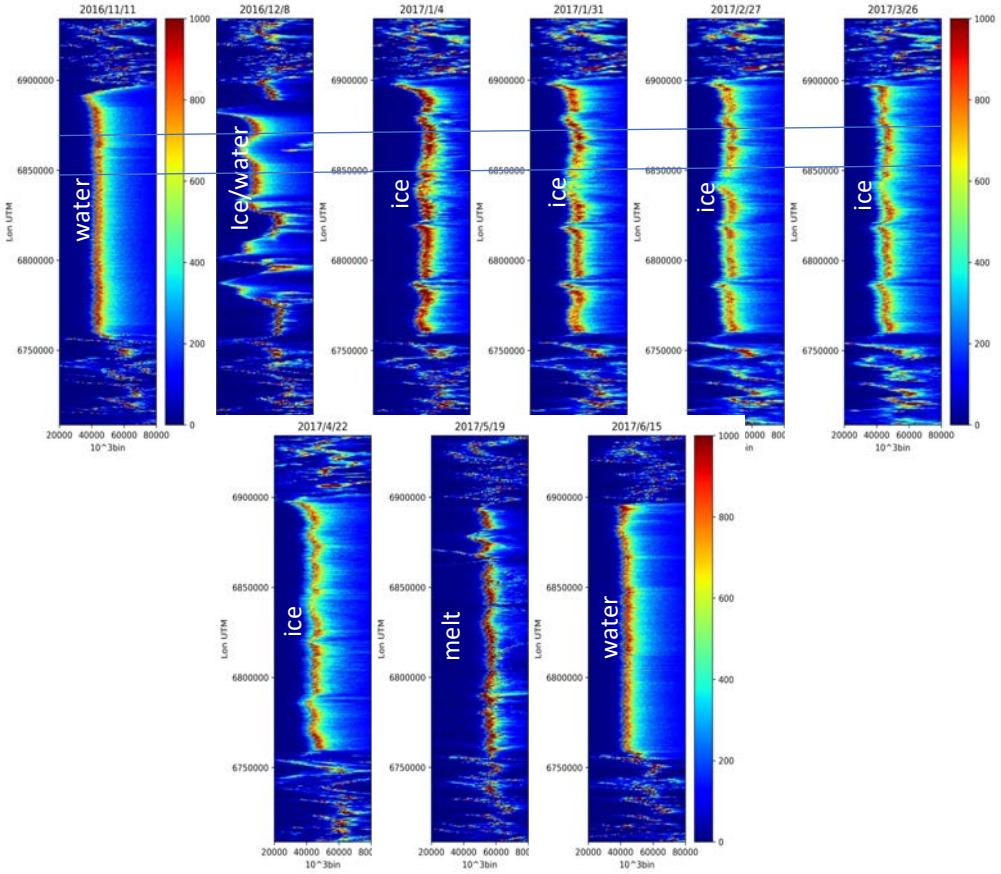
Great Slave Lake (Canada)

Results: Analysis of waveforms (Sentinel-3)

Sentinel-3A ice season evolution of waveforms over Great Slave Lake (Canada) – November 2016 to June 2017

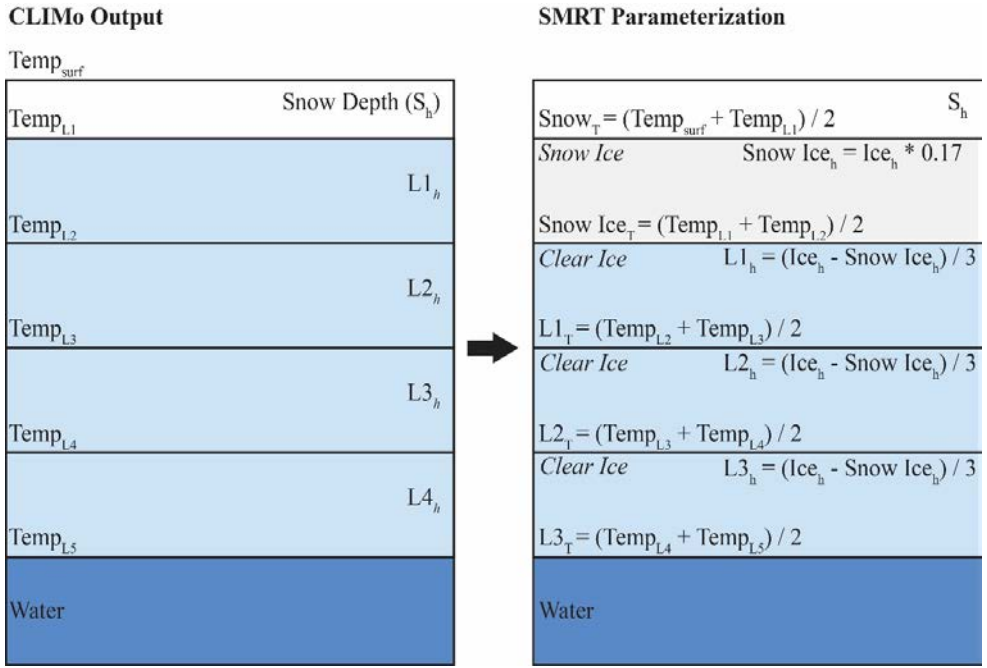


Along-track echograms



Next steps

- Assess SMRT simulations in standalone mode
- Evaluate SMRT simulations forced with CLIMo output (snow and ice properties, including temperature profiles)
- Compare SMRT simulations with backscatter, brightness temperature measurements, and waveforms over selected lakes



Thank you for your attention!

LIAM project website

https://www.h2ogeomatics.com/lake-ice-from-altimetry-missions-li

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