Improving the retrieval of lake ice thickness with radar altimetry data

OSTST Meeting 07-11/11/2023,
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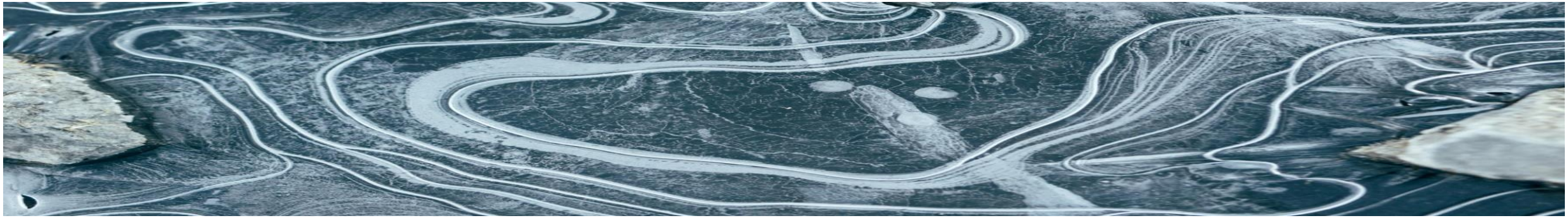
Outline

- Overview: Lake Ice Thickness (LIT) and altimetry
- A new approach for the estimation of LIT from radar altimetry data
- Improving the Estimation of Lake Ice Thickness with high resolution altimetry data
- Conclusions and perspectives

Lake Ice Thickness

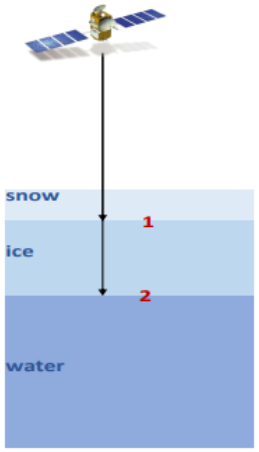
- Lake Ice Thickness (LIT): sensitive indicator of weather and climate conditions, recognized as an Essential Climate Variable (ECV) by the Global Climate Observing System (GCOS)
- The monitoring of seasonal variations and trends in lake ice thickness is important from a climate change perspective, for the Lake Water Levels retrievals and also for the operation of winter ice roads. Yet, field measurements tend to be sparse in both space and time: need to develop accurate retrieval algorithms from satellite remote sensing
- To date, few studies have investigated the potential of radar altimetry data for the estimation of LIT e.g. Beckers et al 2017 (CryoSat2 data), Yang et al 2020 & Shu et al 2020 (Lake Water Level studies). Empirical methods based on thresholds, that rely on in situ validation (not always possible, difficult to compare) and hard to generalize to different targets
- Development of analytical based retrackers that allow a robust and continuous monitoring of LIT:
  - **LRM_LIT retracker** [Mangilli et al TGRS 2022]. ESA CCI-Lakes project
  - **SAR_LIT & FFSAR_LIT retracker** [Mangilli et al 2023 in prep.]. ESA S6JTEX project

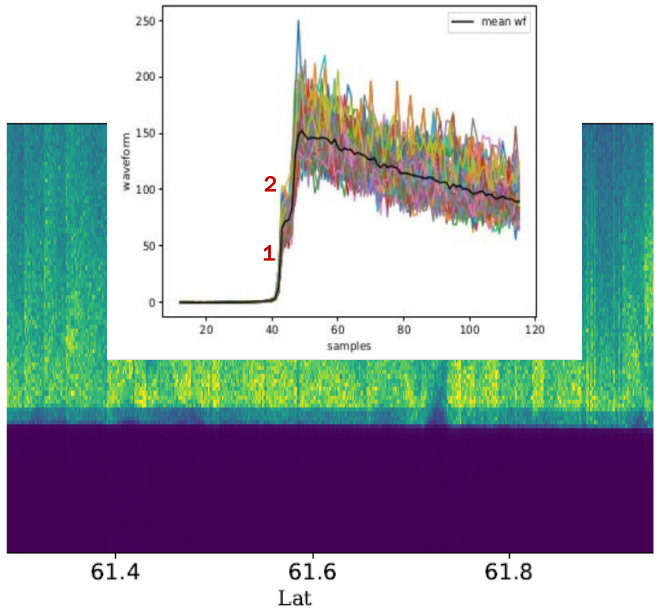


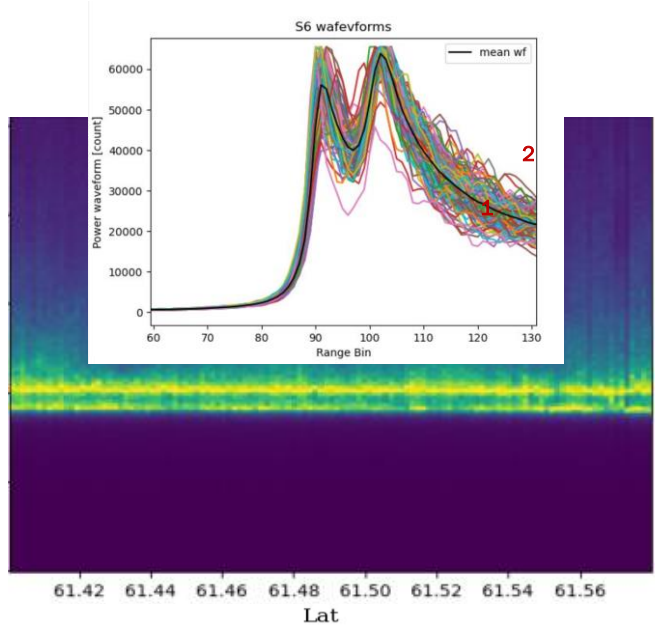
The LIT signature on Ku band radar waveforms

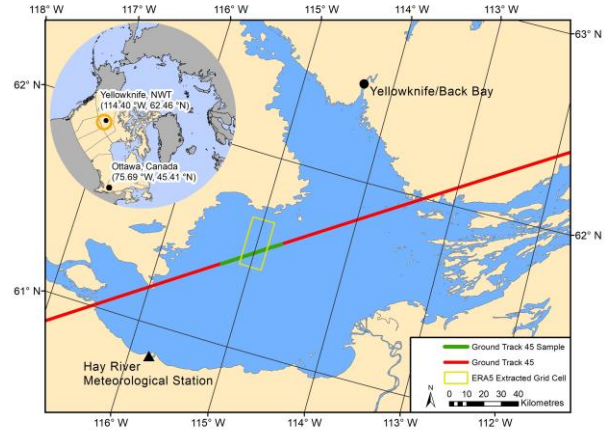
- Specific LIT signature on Ku radar waveforms related to the backscattering of the radar wave at two interfaces snow/ice (**1**) and ice/water (**2**): : “step” (LRM) and double peak (SAR)
- **The width of the step (LRM)/the peak separation (SAR) is linked to the ice thickness**

The Great Slave Lake in March 2021 as seen by Jason3 (LRM) and S6 (SAR) during the tandem phase









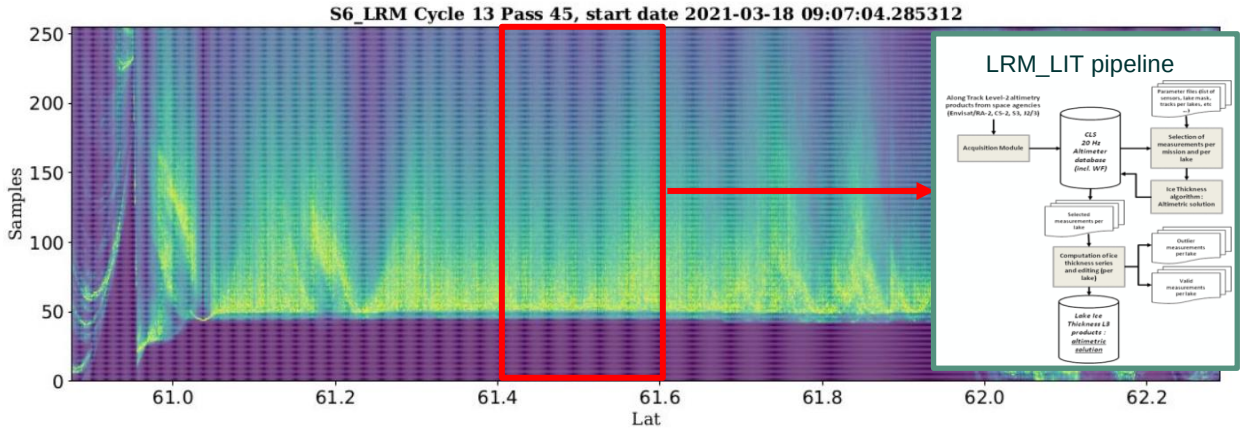
SAR_LIT and LRM_LIT retracker analysis over a Region of interest (RoI) on a target lake:

- **Tailored analytical modeling** of the Ku waveforms: based on Brown (LRM), SAMOSA (SAR). 5 parameters model.
- **Optimization**: Weighted Levenberg-Marquardt least square fit of individual waveforms (typically ~100 echoes)
- **Parameters estimation**: Mean and standard deviation of the best-fit values of the 5 parameters in the RoI

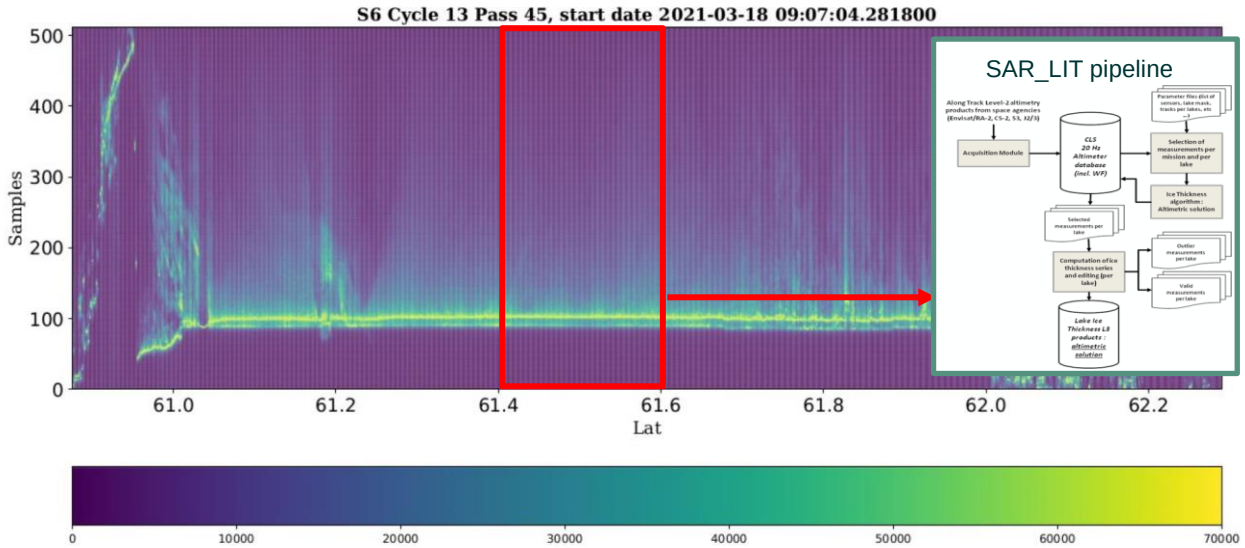
LIT estimation with Sentinel-6 data over the Great Slave Lake (GSL)

- Sentinel-6 echogram on the GSL in March 2021

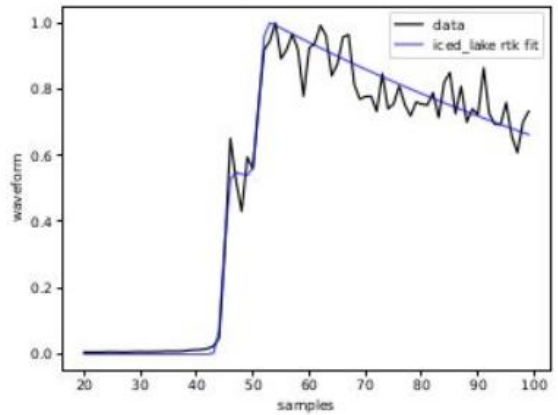
S6 LRM



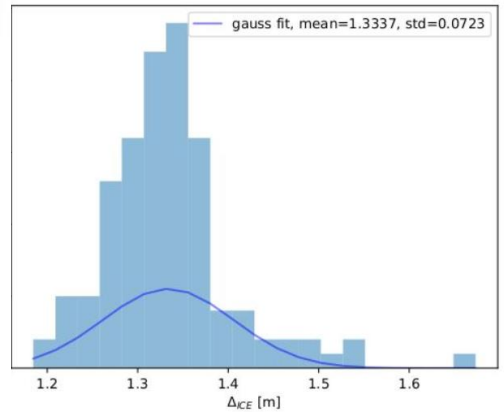
S6 SAR

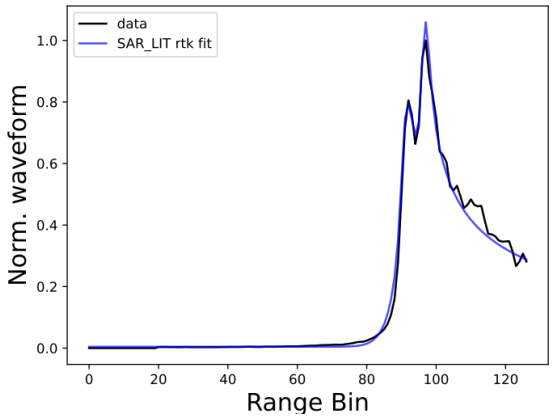


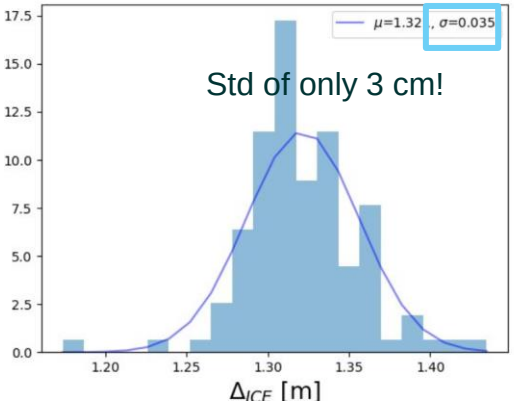
Fit exemple 1 Wf



LIT estimates in the analysis window





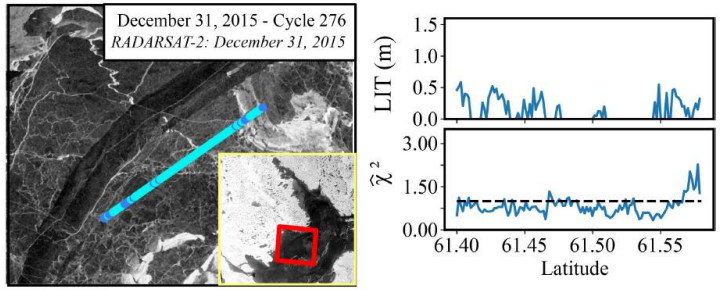


- LIT std improved by a factor of ~2 with SAR_LIT rtk because of the higher spatial resolution of the SAR data

Lake Ice Thickness evolution over the Great Slave Lake

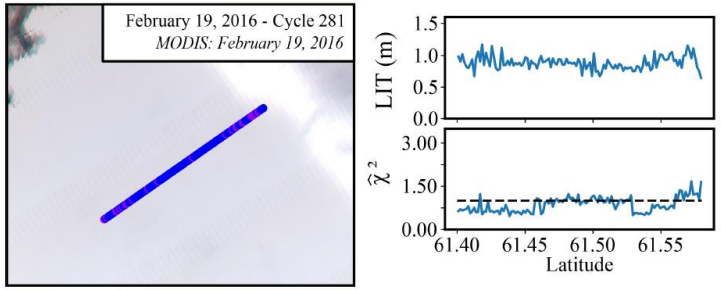
J2 LIT estimates and MODIS/RADARST images

December

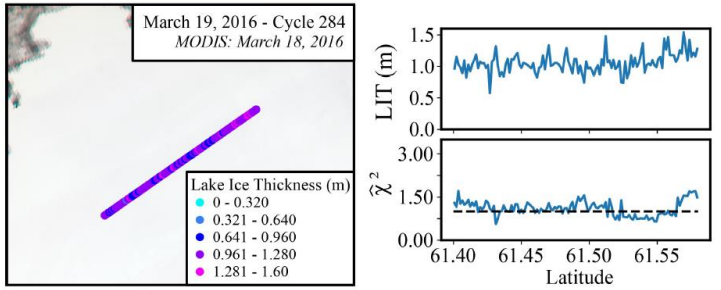


Early winter season: no clear ice signature. Peaky waveforms. Heterogeneous and reflecting surface.

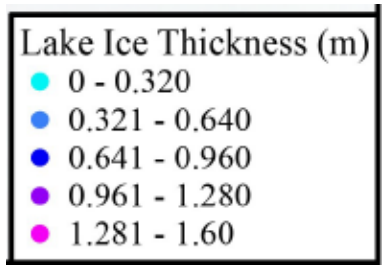
February



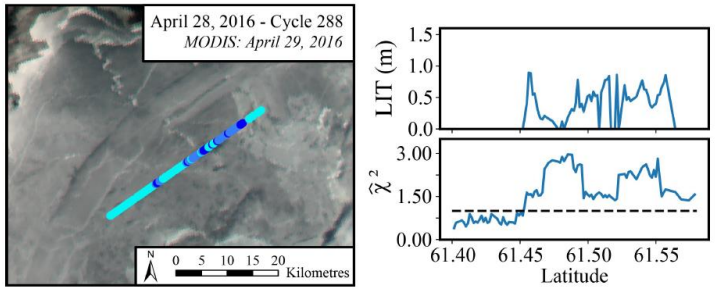
March



Middle of the ice season: clear LIT detection with evolving thickness



End of April

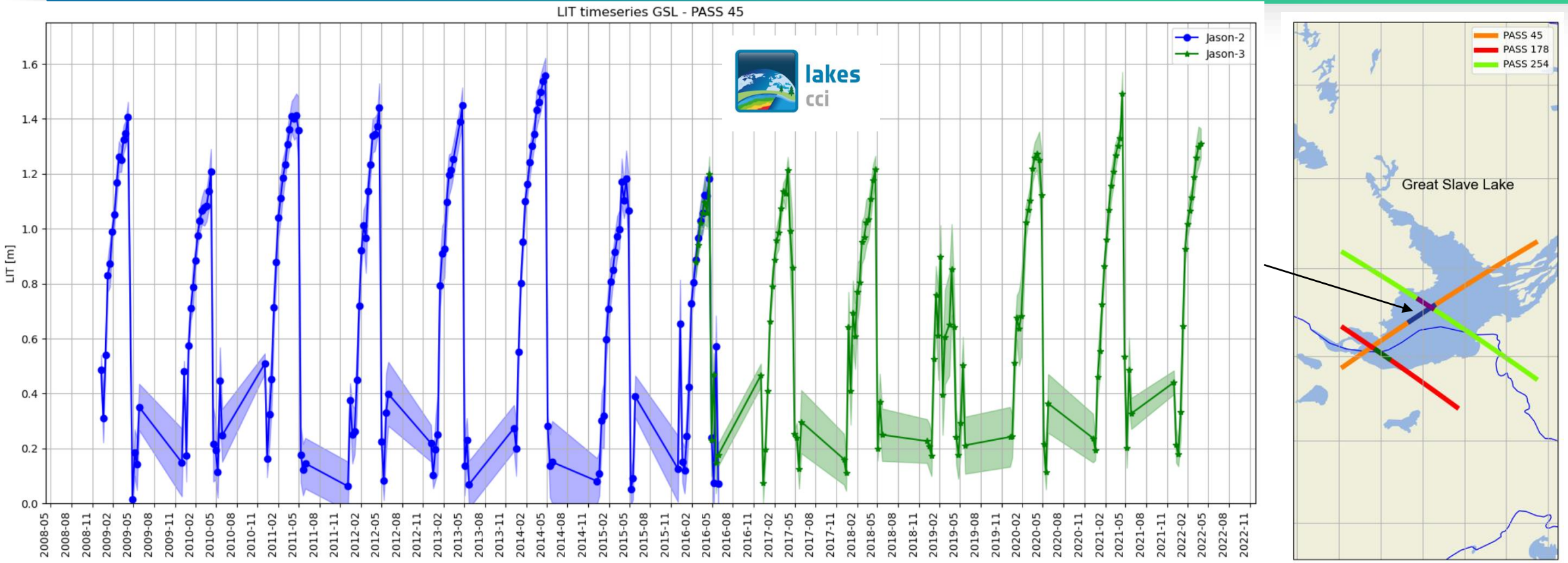


Beginning of the melting season: the snow cover has largely melted from the ice surface (lower reflectance). Peaky waveforms. Heterogeneous and reflecting surface

Take-away message

- ✓ LIT estimates from Jason data are fully consistent with MODIS/RADARSAT-2 images
- ✓ LRM_LIT retracker provides reliable estimates of the spatial evolution of LIT and can capture the seasonal transitions,
- ✓ LIT accuracy estimation with LRM data ~10cm

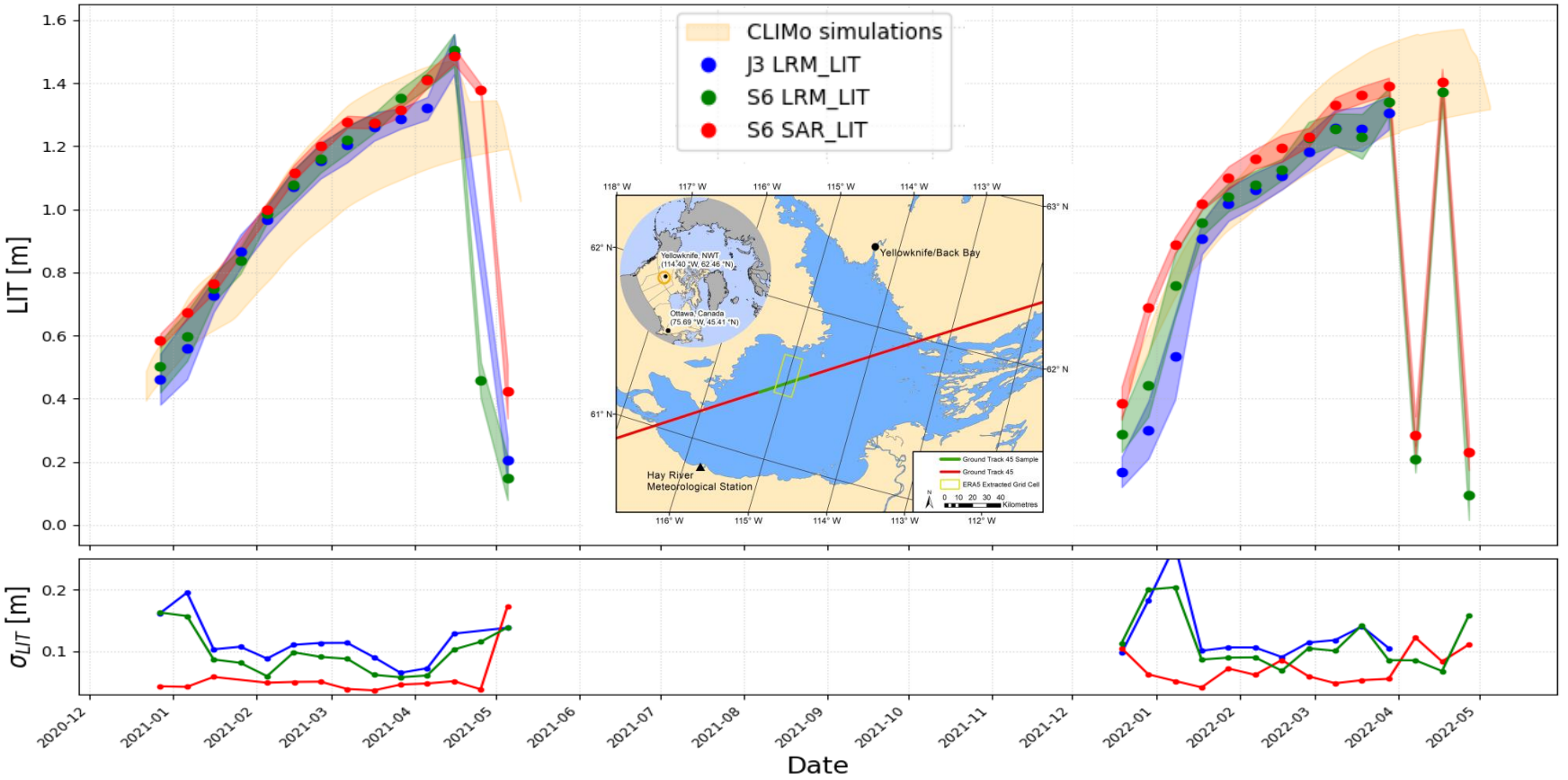
Lake Ice Thickness timeseries



- **First long LIT timeseries from radar altimetry (LRM data, 20+ years) over the Great Slave Lake (Canada)** will be included in the next CCI-Lakes v2.2 data release (fall 2023). LIT trends and climatology study underway. More target lakes will be included in the following releases
- **General remark**: LIT retrackers work if the freshwater ice related signature is present. This signature depends on the properties and thickness of the snowpack and the ice layer and could be erased if some conditions are not met, as for instance in the case of snow-free lake ice or melting snow on the ice surface

Lake Ice Thickness: LRM vs SAR

LIT evolution over the Great Slave Lake (2020-2022 ice seasons)



- Good consistency among LRM and SAR LIT results. Seasonal transitions and inter-annual LIT variations are captured
- S6 LRM better accuracy than J3 (~20-30% improvement, likely due to the sampling improvement)
- Improved accuracy with UFSAR 20Hz wrt LRM (factor of ~2 – 3 improvement between S6 UFSAR and S6LRM)

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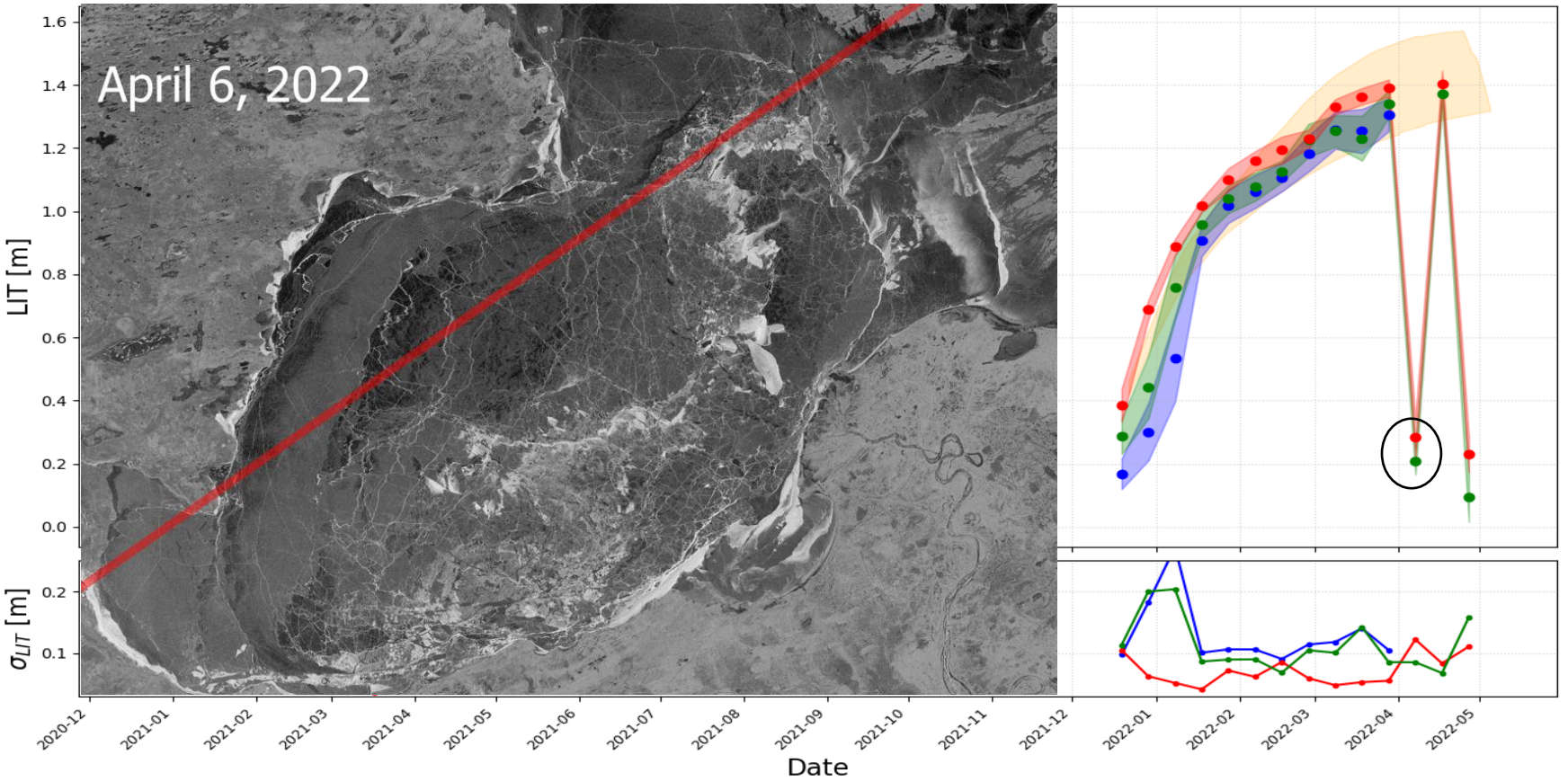

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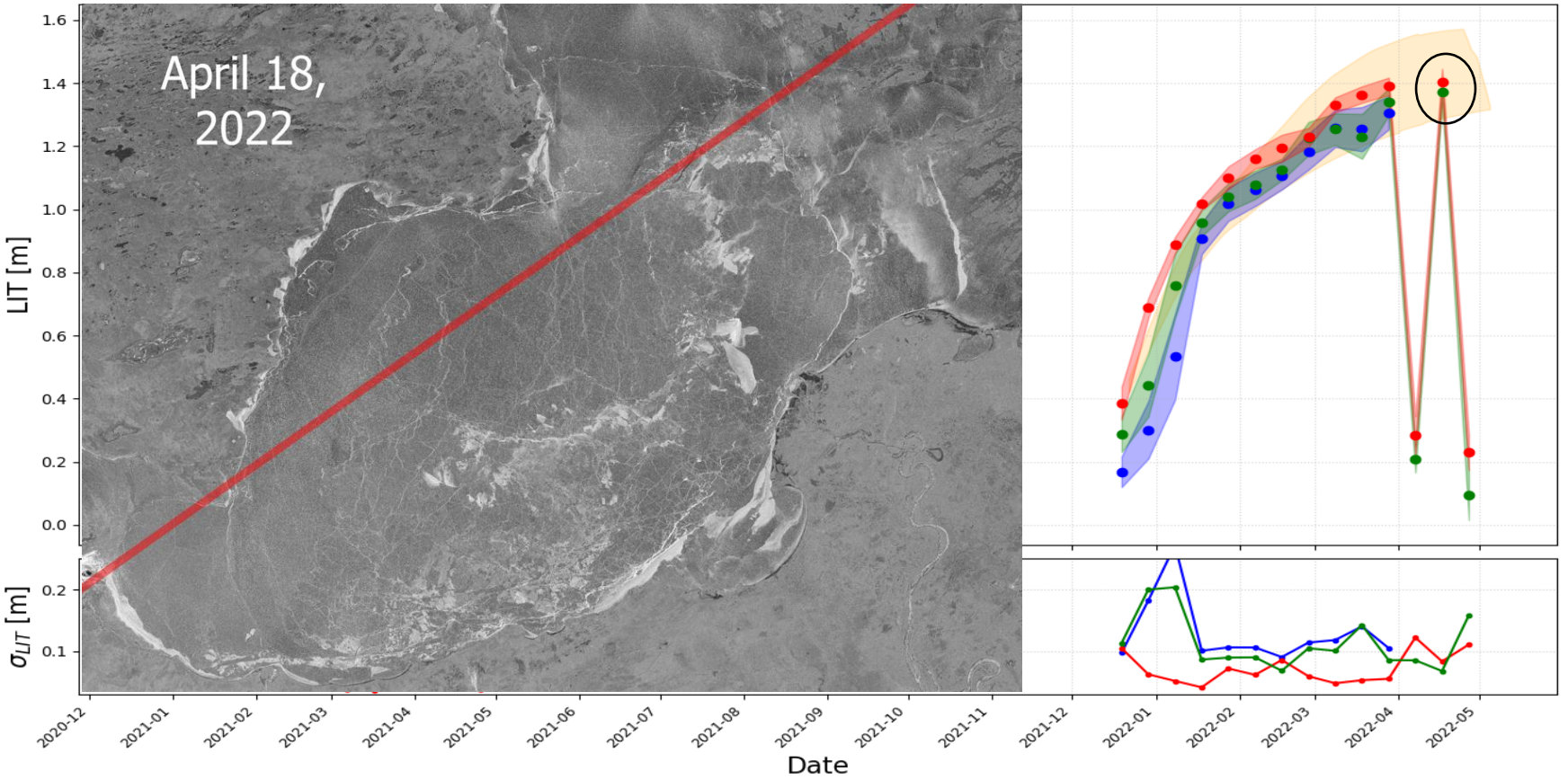

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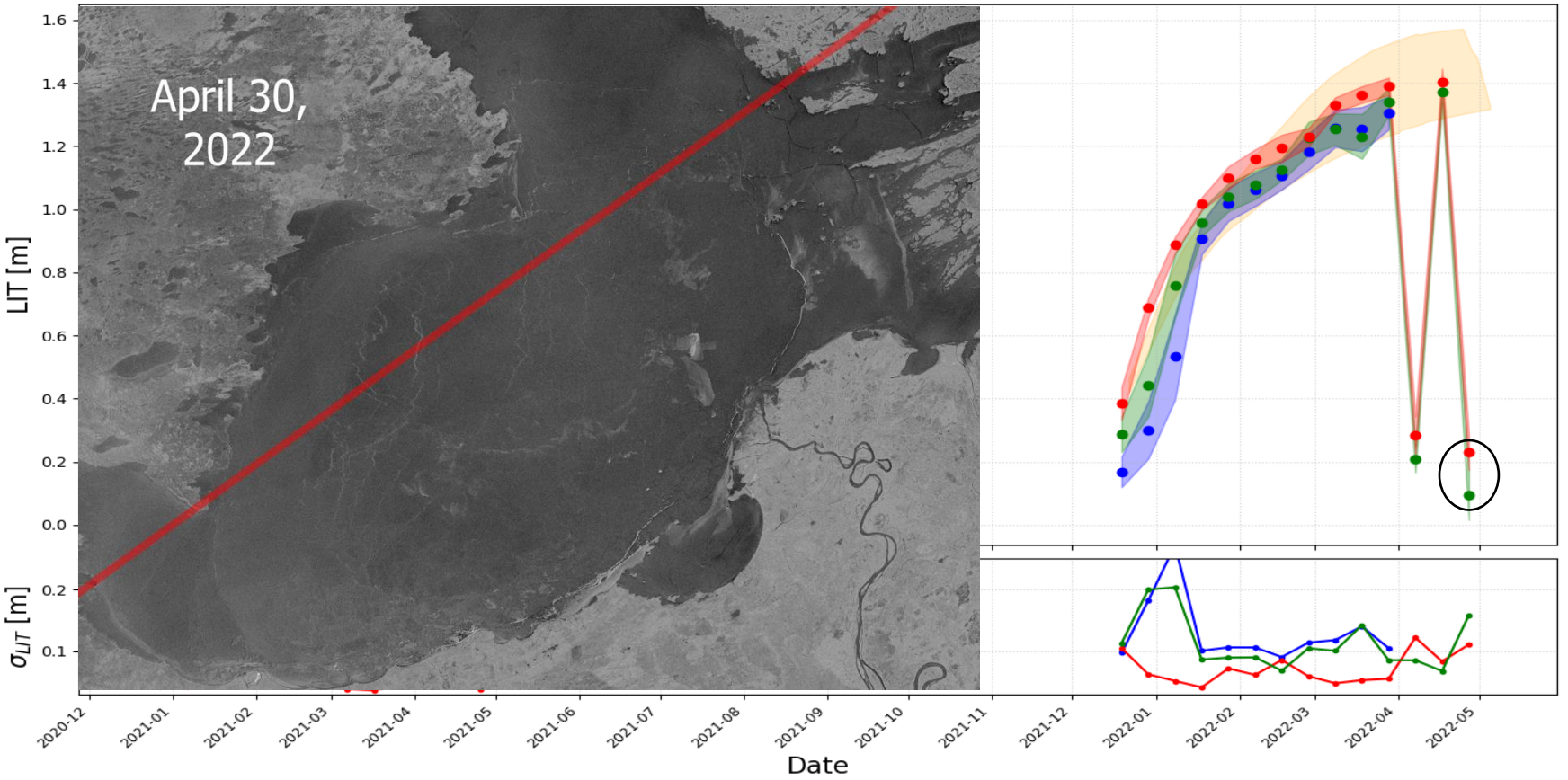

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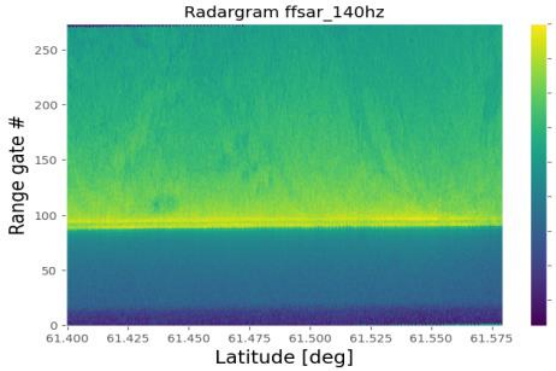
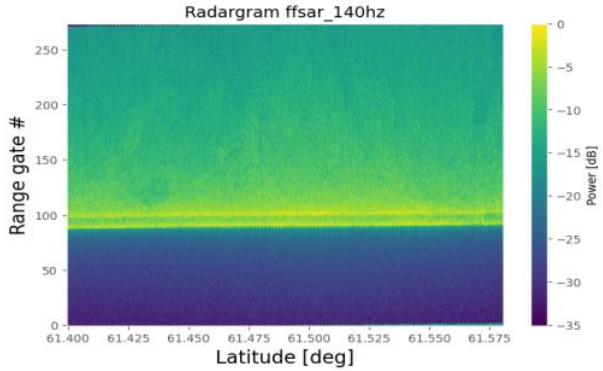
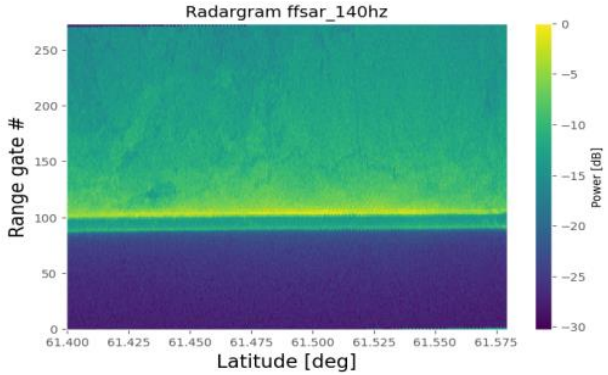
Lake Ice Thickness estimation with high(er) resolution S6 data: FF&UFSAR at 140Hz

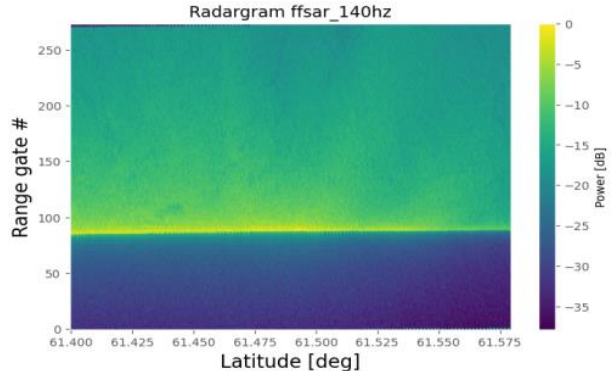
December | February | March | May

FF

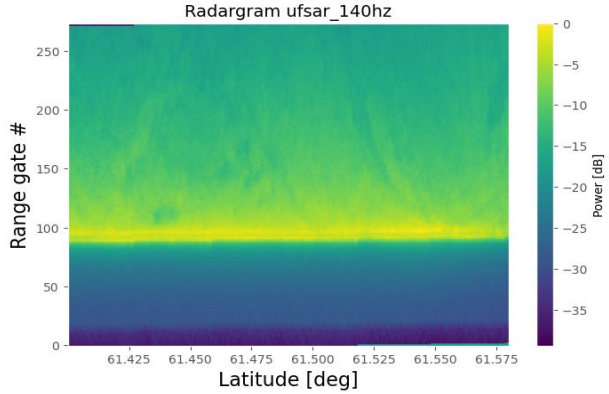


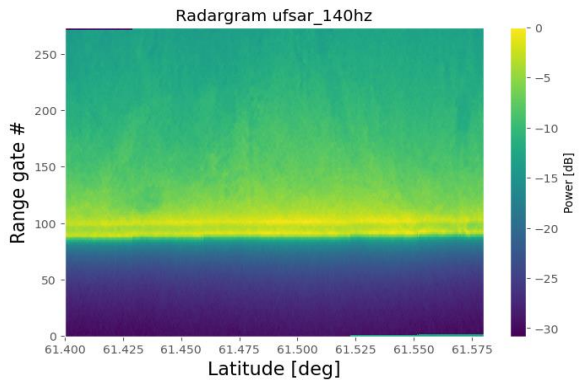


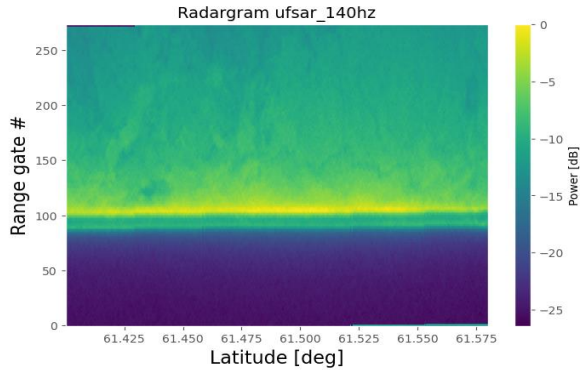


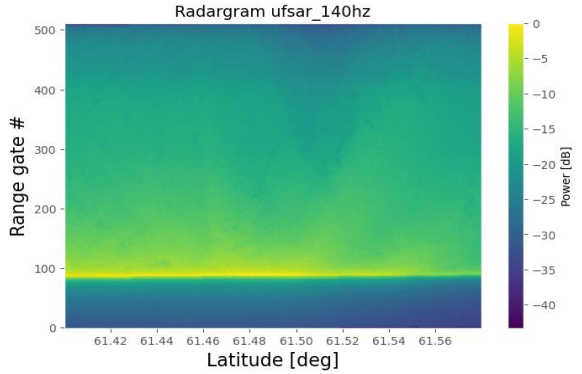


UF

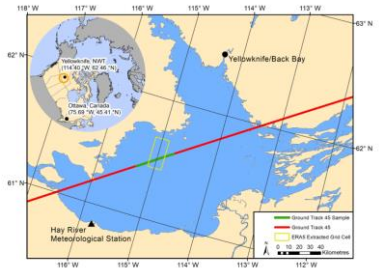








- 140Hz data: increased statistics with respect to 20Hz data
- FF-SAR: double peak LIT signature seen at higher resolution



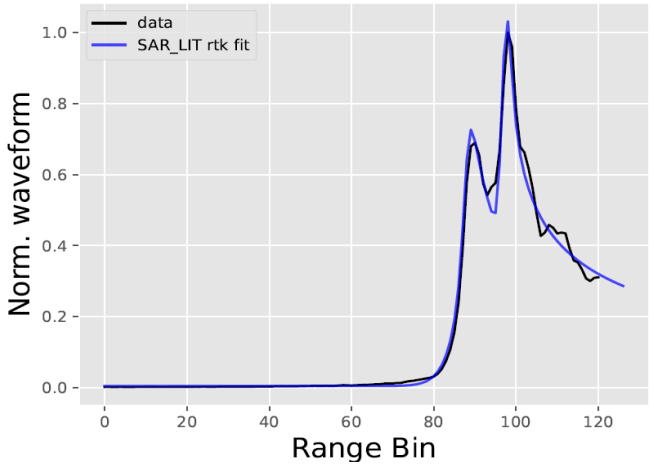
Lake Ice Thickness estimation with high(er) resolution S6 data: FF&UFSAR at 140Hz

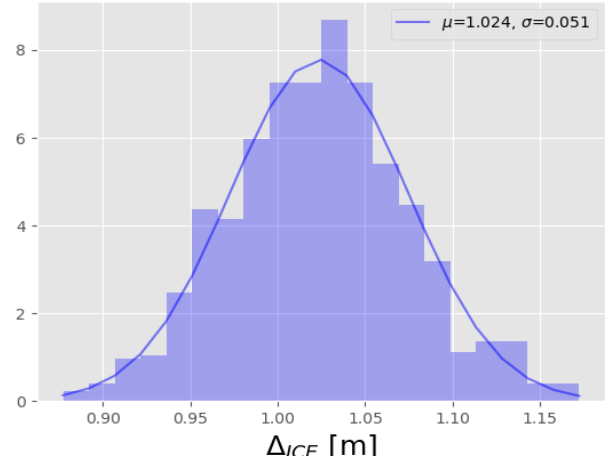
WF and fit examples

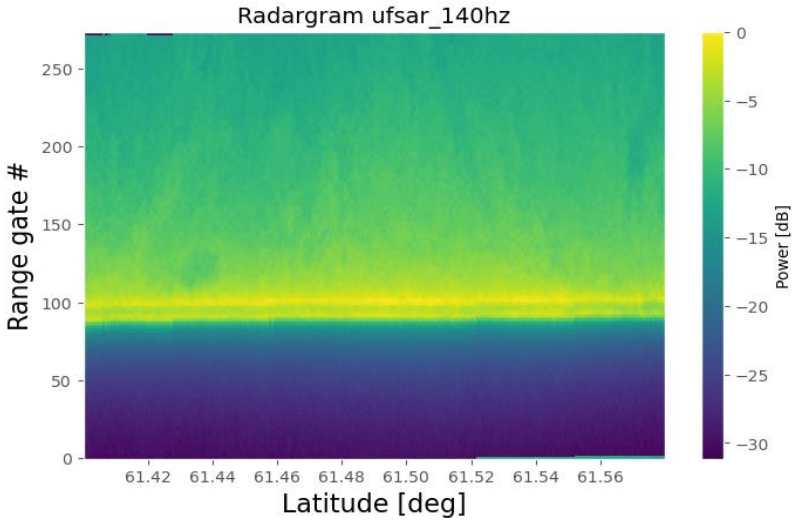
LIT histogram in the RoI

Radargram

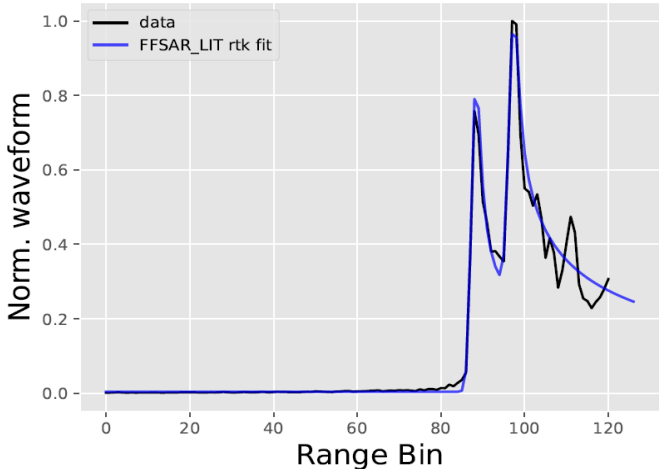
UF SAR

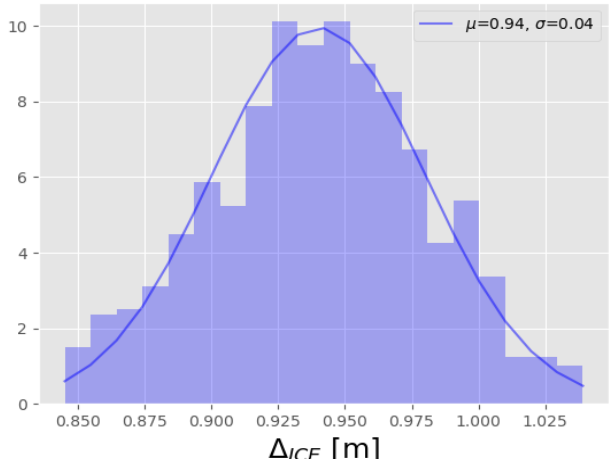


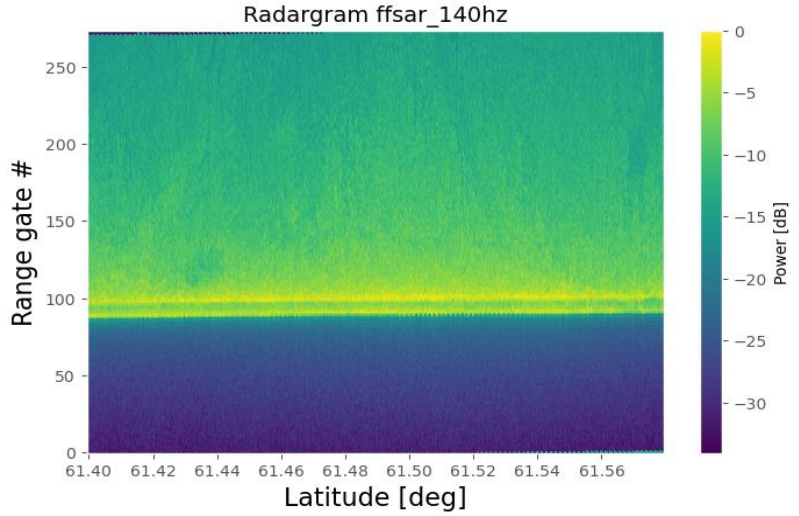




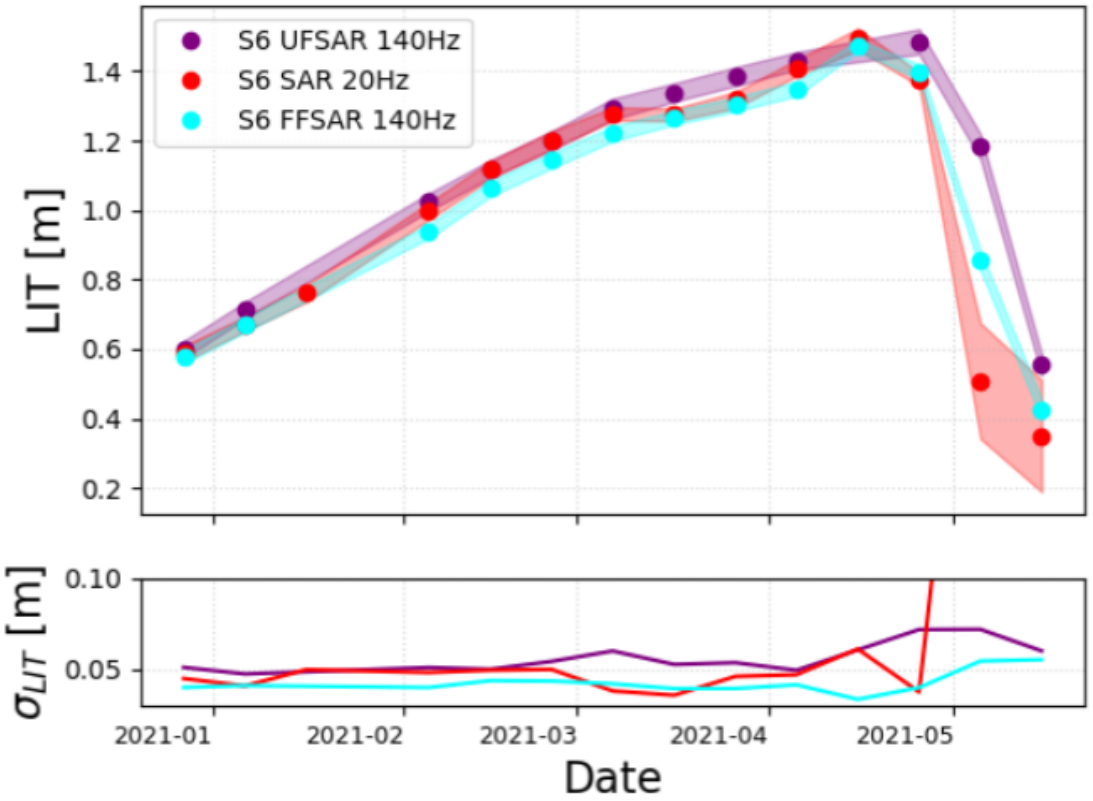
FF SAR







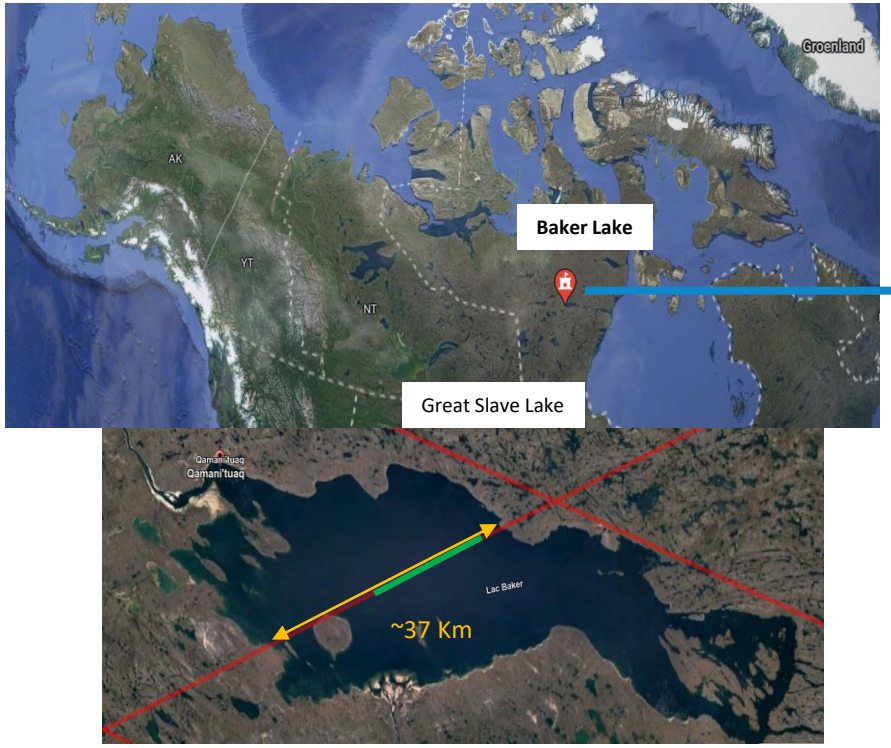
Lake Ice Thickness estimation with high(er) resolution S6 data: FF&UFSAR at 140Hz

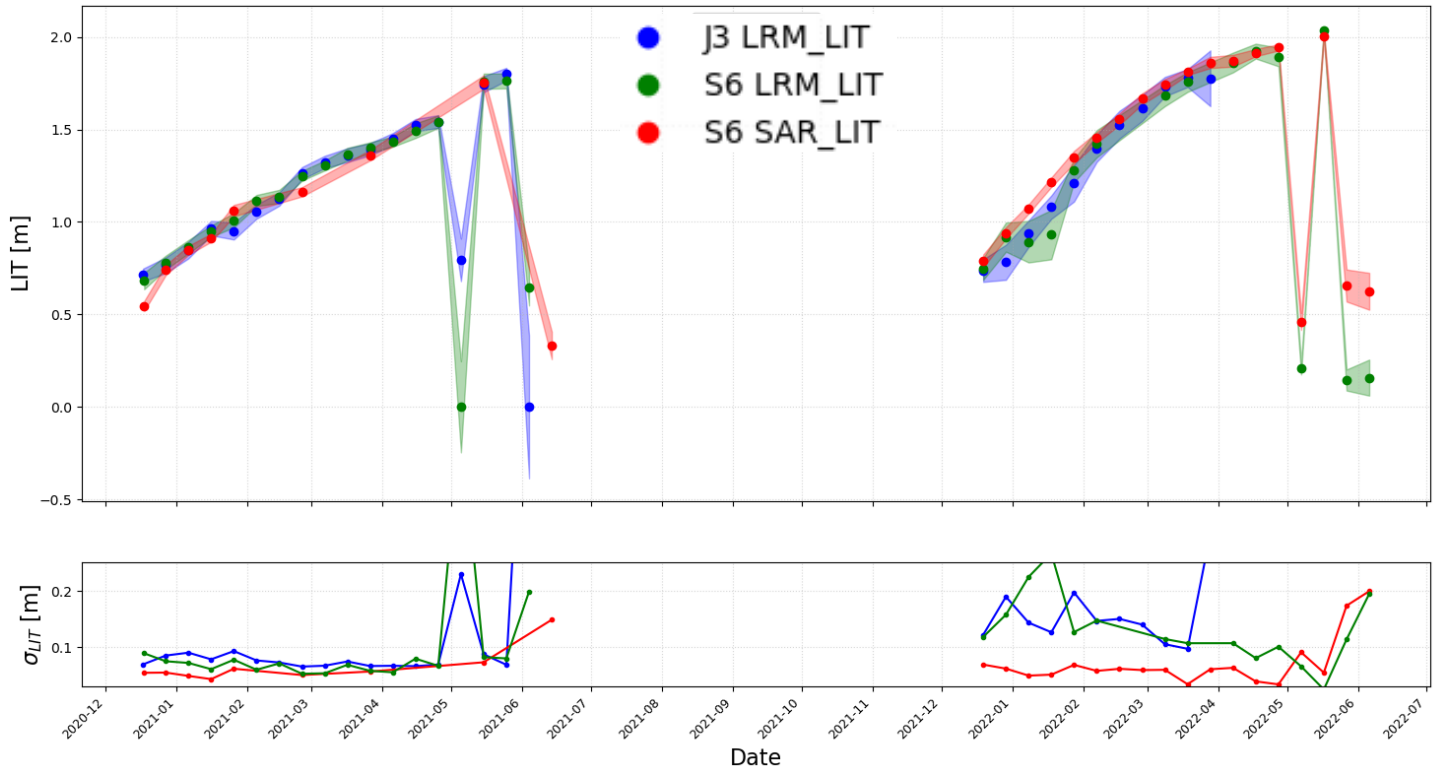


- Overall consistent results among the 3 datasets
- Increased performance with data at higher posting rate (140 Hz), in particular at the melting transition
- At equivalent posting rate, the FF SAR seems to allow for a better accuracy (~20 % smaller errorbars)

Lake Ice Thickness estimation on a smaller target: the Baker Lake

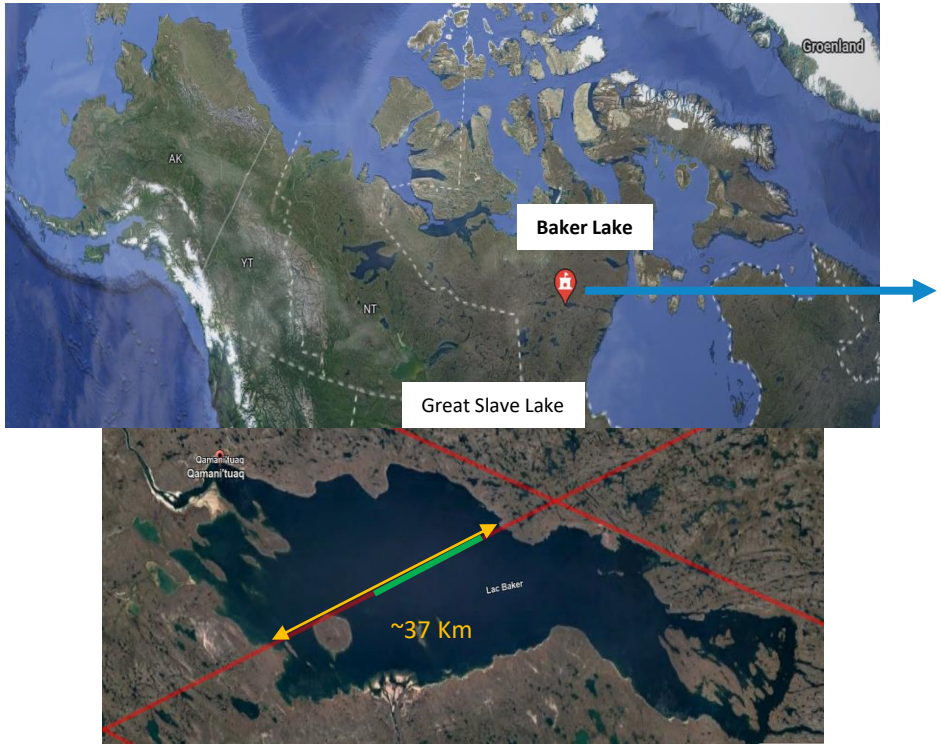
- Smaller target at higher latitude wrt GSL: different environnement, snow and ice properties and evolution
- More challenging: reduced number of waveforms (less statistics) & land contamination

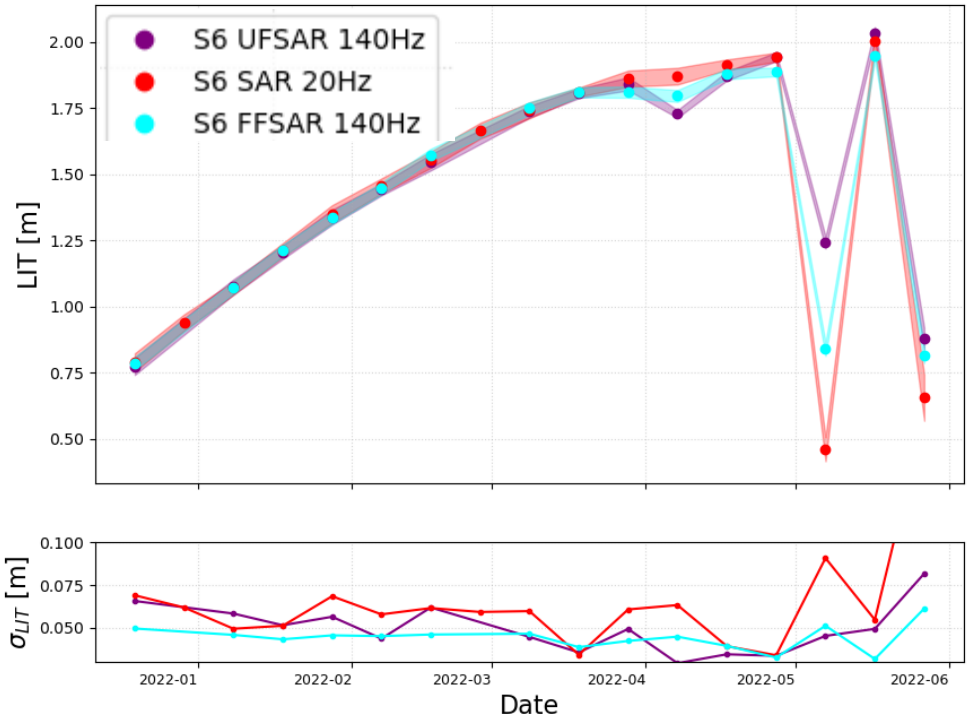




- Good performances of the LRM and SAR LIT retrackers
- Consistent results between LRM and SAR data

Lake Ice Thickness estimation on a smaller target: the Baker Lake





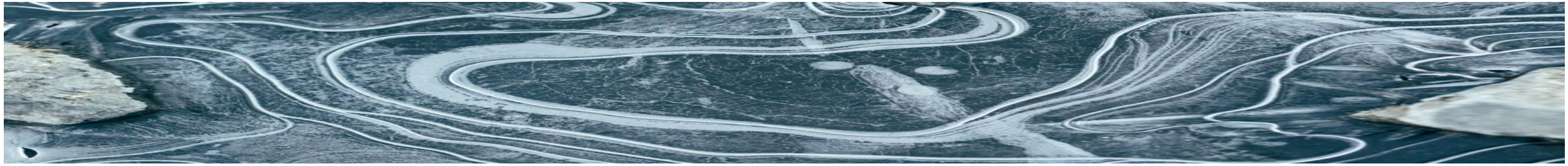
- Good performances of the SAR & FFSAR LIT retrackers
- Increased performance with data at higher posting rate (140 Hz), in particular at the melting transition

Conclusions and perspectives

- The Lake Ice Thickness (LIT) is an important variable in the context of climate change that needs precise and continuous monitoring.
- In the frame of the CCI-lakes project, we developed and validated a new method for the LIT estimation from radar altimetry data, the LRM_LIT (analytical) retracker [Mangilli et al. 2022], which is a powerful tool for LIT trend studies and monitoring that is now used to generate the cci LIT timeseries products (first release in the fall 2023)
- In the frame of the ESA S6JTEX project we developed and validated the UF&FFSAR LIT (analytical) retrackers demonstrating the improvement of the LIT estimation with high resolution data [Mangilli et al 2023 in prep]

Perspectives

- LIT timeseries with SAR data: SAR_LIT retracker analysis with Sentinel-3 and Sentinel-6 data. CCI-lakes option to use S3&S6 data for LIT estimation under discussion (a preliminary study would be to be done to assess the SAR_LIT performances on S3 data)
- CLE2VER: development of a retracker algorithm for LIT retrivals to be implemented in the CRISTAL prototype processor



Thank you!

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