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Going Beyond How Far: A Quantitative Study into Radar Altimetry Surface Echo Strengths over the Greenland Ice Sheet

Motivation

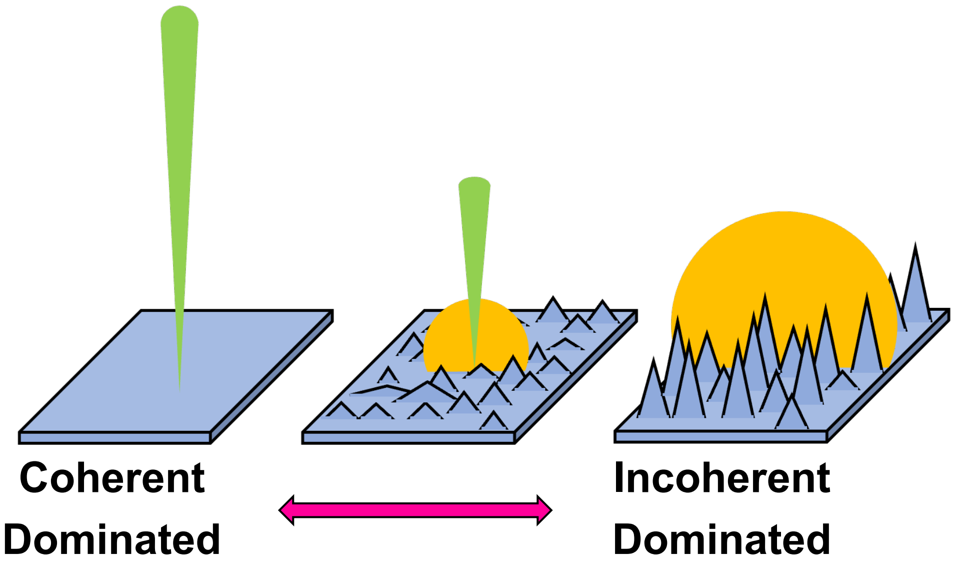
- Mass loss from the Greenland Ice Sheet (GrIS) will be a primary contribution to global mean sea-level rise through the 21st century
- Spaceborne radar altimeters provide an unparalleled ability to monitor the state of the GrIS through space and time

1. Surface elevation change (SEC) is a volumetric measurement
   – Require ***densities*** in order to convert observed volume changes into a mass balance
2. Spaceborne radar altimetry of ice sheets has changed very little in the last 30 years
   – New instruments, new acquisition modes, new processing techniques but singular focus on determining ***range***

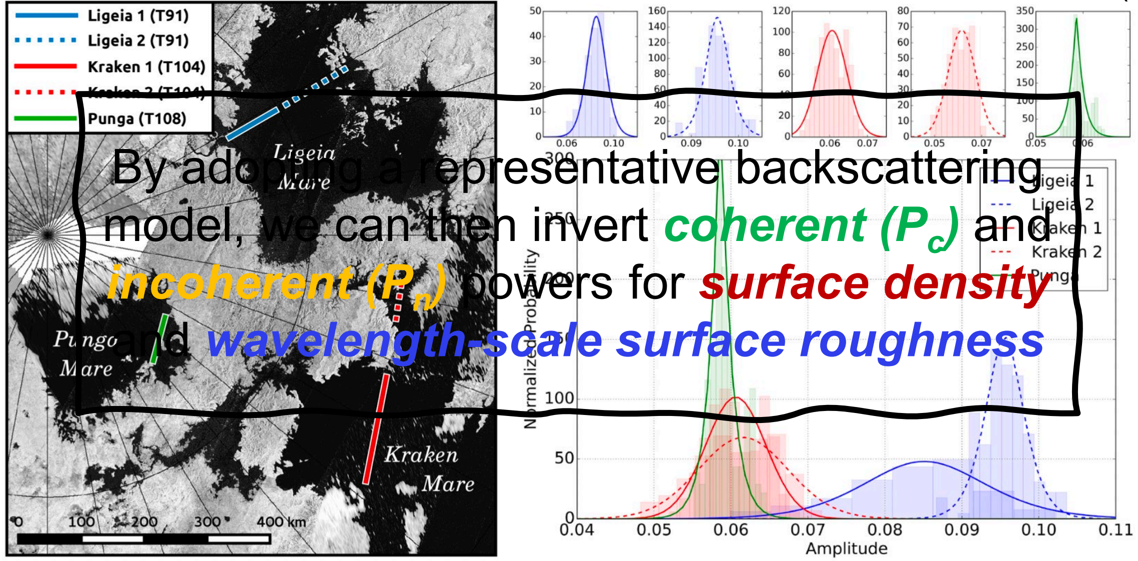
Can we use radar altimetry measurements to observationally constrain the near-surface density of the GrIS through both space and time?

Method

- **NOT USING RADAR ALTIMETERS FOR ALTMETRY**
- Leverage advancements from the use of radar in planetary science applications
  – ***Radar Statistical Reconnaissance*** (RSR) (Grima et al., 2012;2014;2017)
- The total strength of a nadir radar surface echo represents the summation of ***coherent*** and ***incoherent*** components
- RSR provides a statistical framework for separating these components

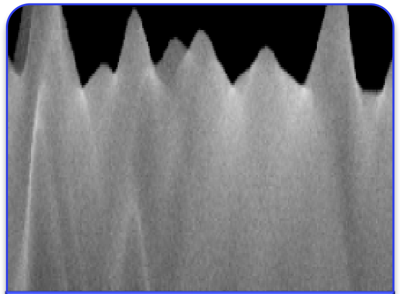


Grima et al. (2017)



By adopting a representative backscattering model, we can then invert ***coherent*** (P_c) and ***incoherent*** (P_n) powers for ***surface density*** and ***wavelength-scale surface roughness***

Procedure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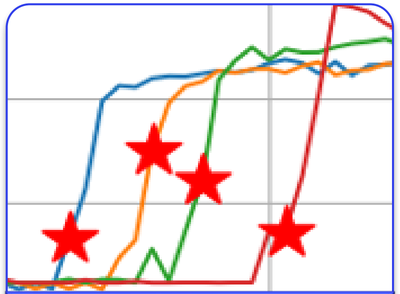
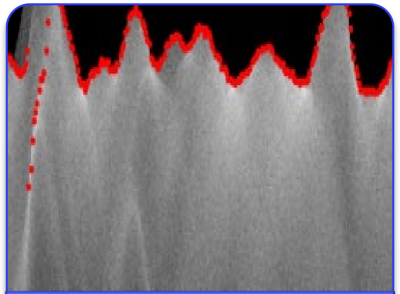
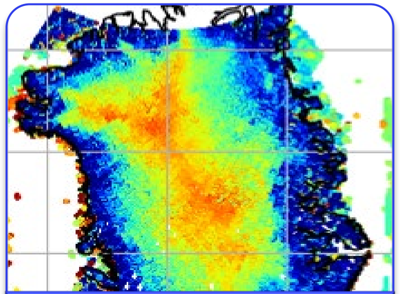
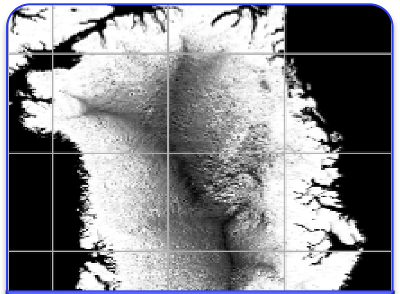
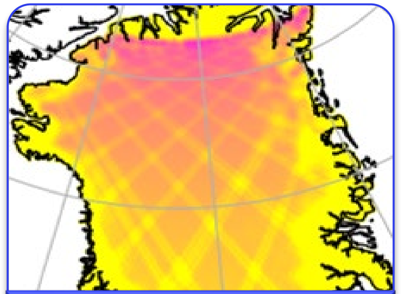
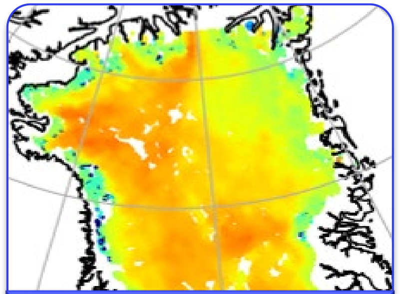

2. PICK


3. EXTRACT


4. COMPILE


5. CORRECT


6. IDENTIFY


7. APPLY

Altimetry Datasets

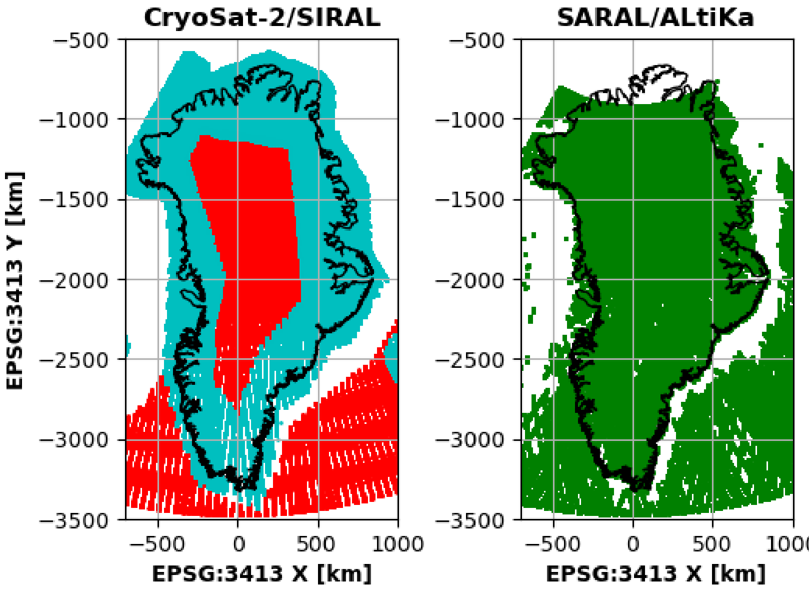
- Monthly-aggregated pan-GrIS surface echo powers extracted from
  1. Ku-band ESA CryoSat-2 Low Rate Mode (LRM) Level 1B products
     - *Jan. 2011 – Dec. 2018*
  2. Ku-band ESA CryoSat-2 SAR Interferometric (SARin) Full Bit Rate products
     - *Aug. 2014 – Dec. 2016*
  3. Ka-band CNES/ISRO SARAL Sensor Geophysical Data Record (SGDR) products
     - *May 2013 – Dec. 2018*

➢ ESA CryoSat-2 LRM and SARin data included to achieve pan-GrIS coverage

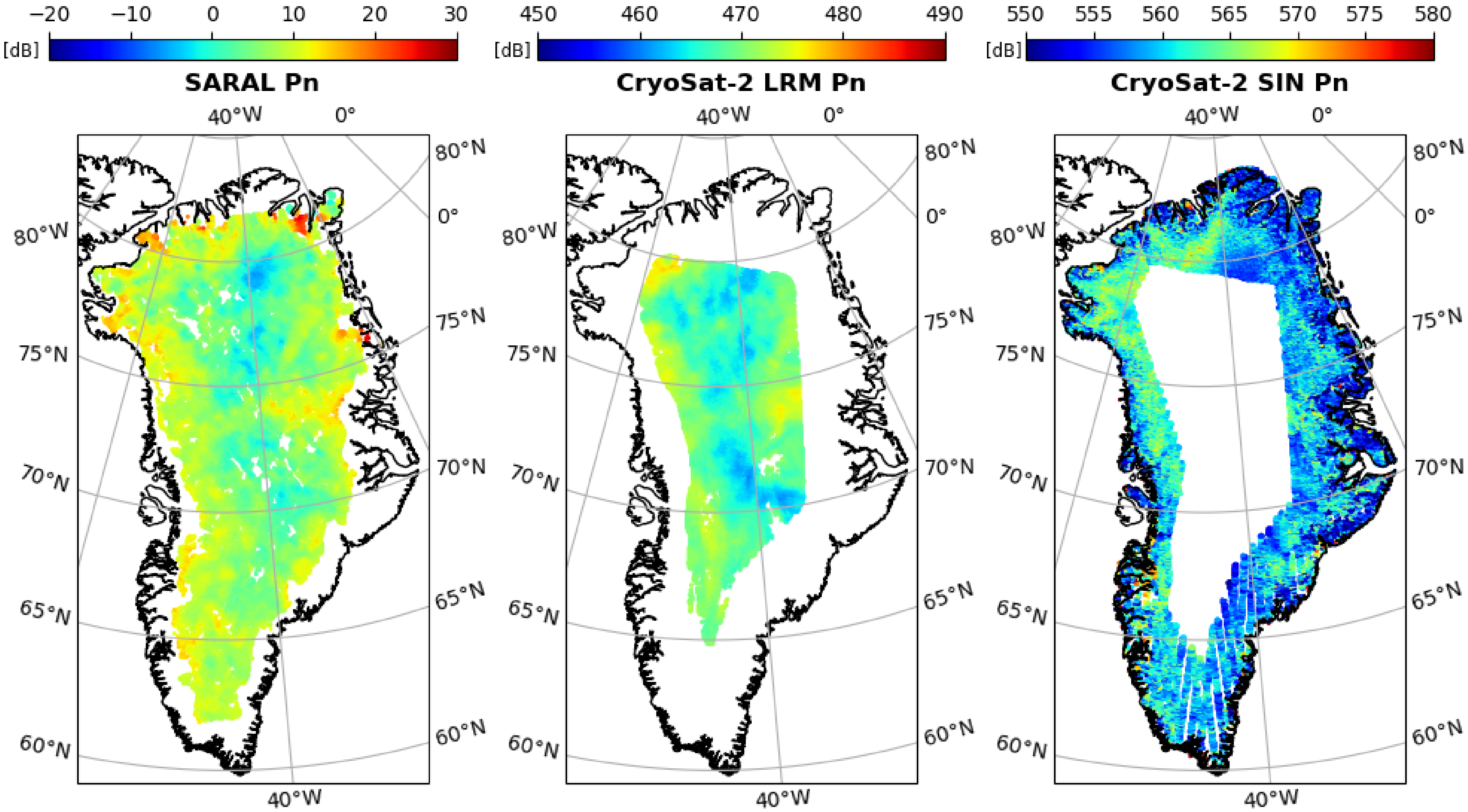
  ➢ LRM → interior

  ➢ SARin → margin

➢ Ku- & Ka-band included to leverage penetration differences and assess possible vertical heterogeneities (i.e., volume scattering)

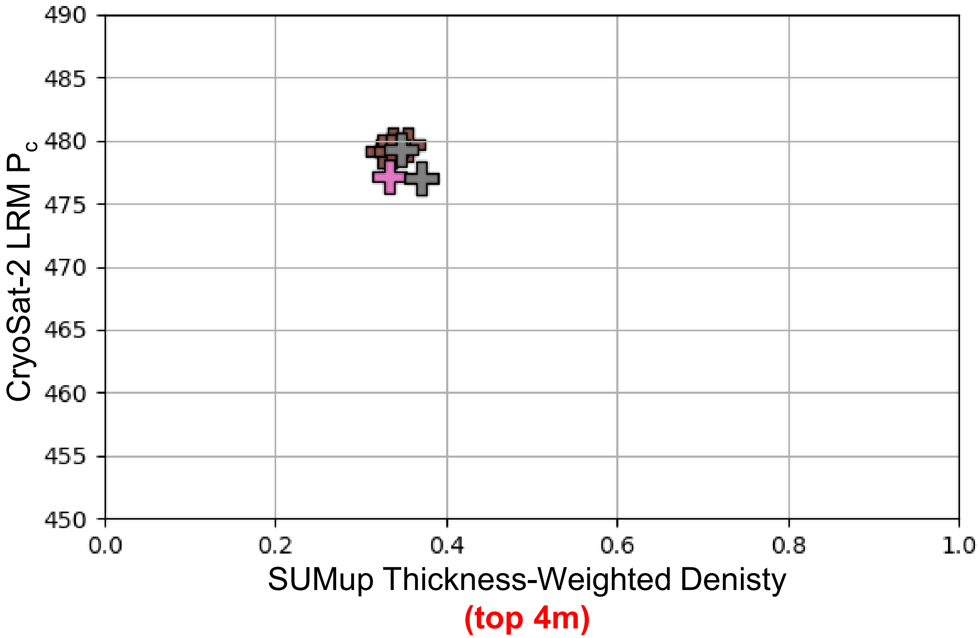


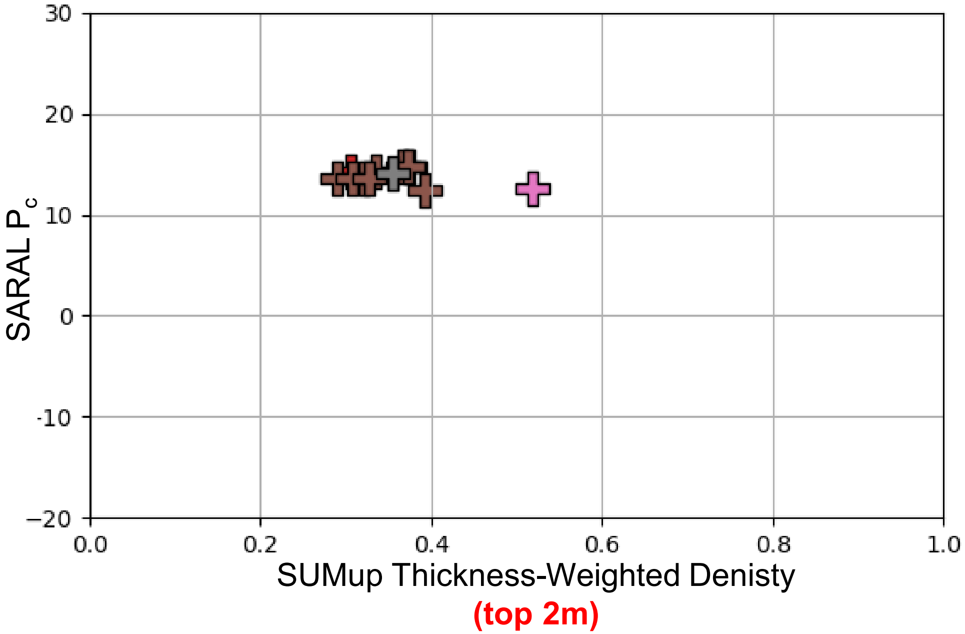
RSR Results – May 2015



RSR Calibration

- Calibration links known near-surface conditions to absolute ***coherent*** echo powers as observed by each instrument and in each mode
  - Allows for pan-GrIS derivation of ***density*** and ***surface roughness***
- Subset of *in situ* density measurements are pulled from SUMup (Montgomery et al., 2018)
  - Contemporaneous and (relatively) homogenous





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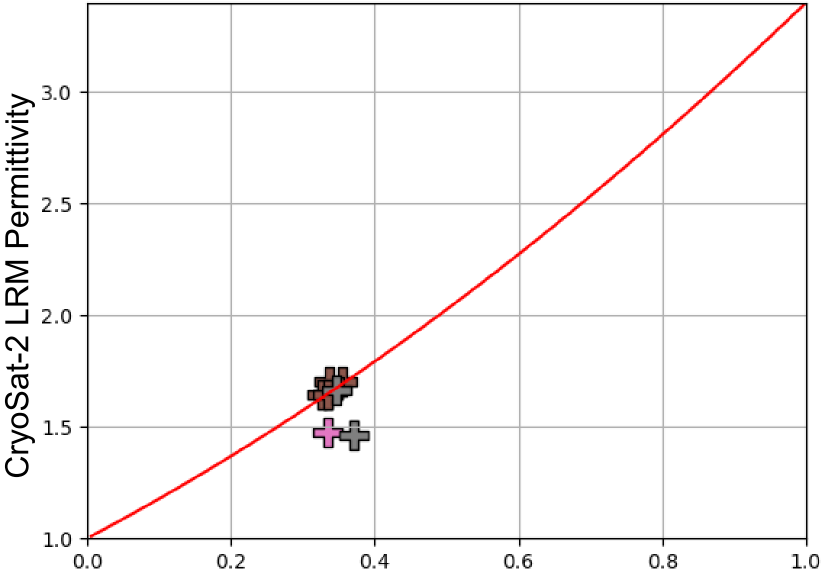
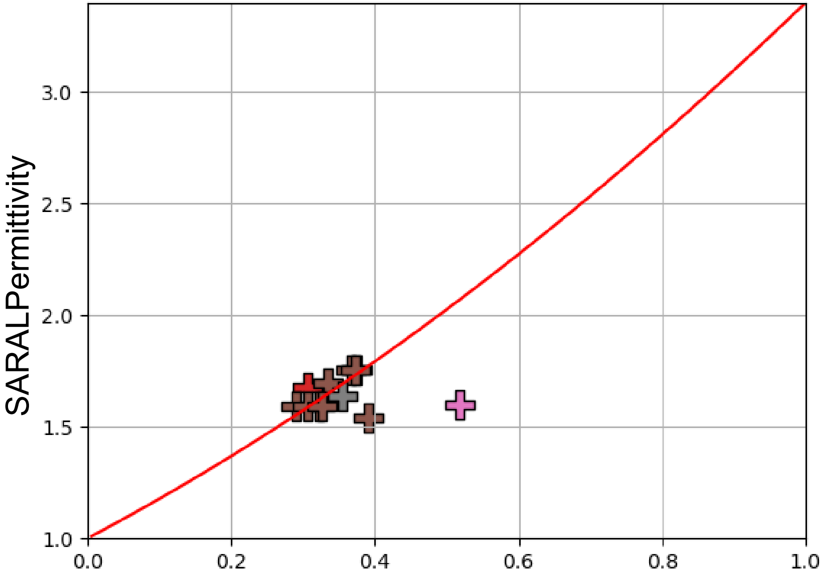


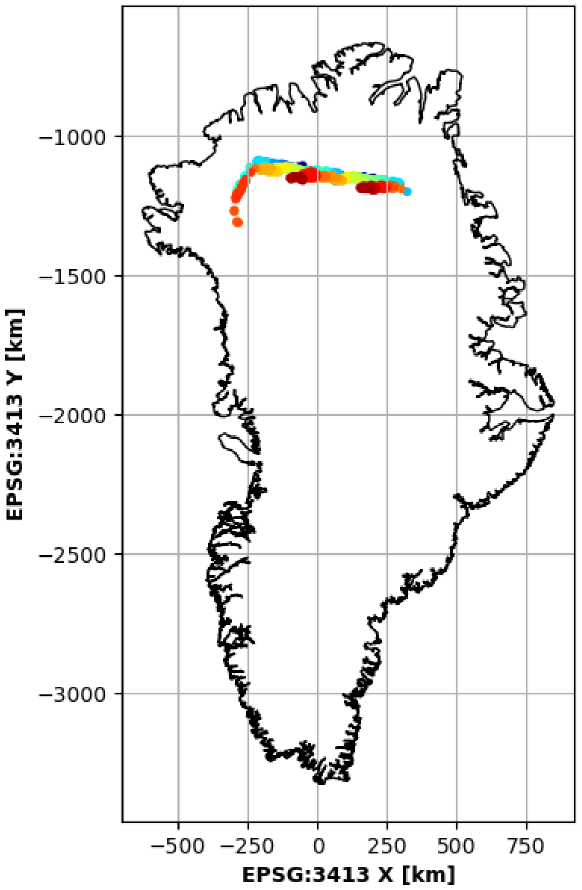
SUMup Thickness-Weighted Denisty
(**top 4m**)

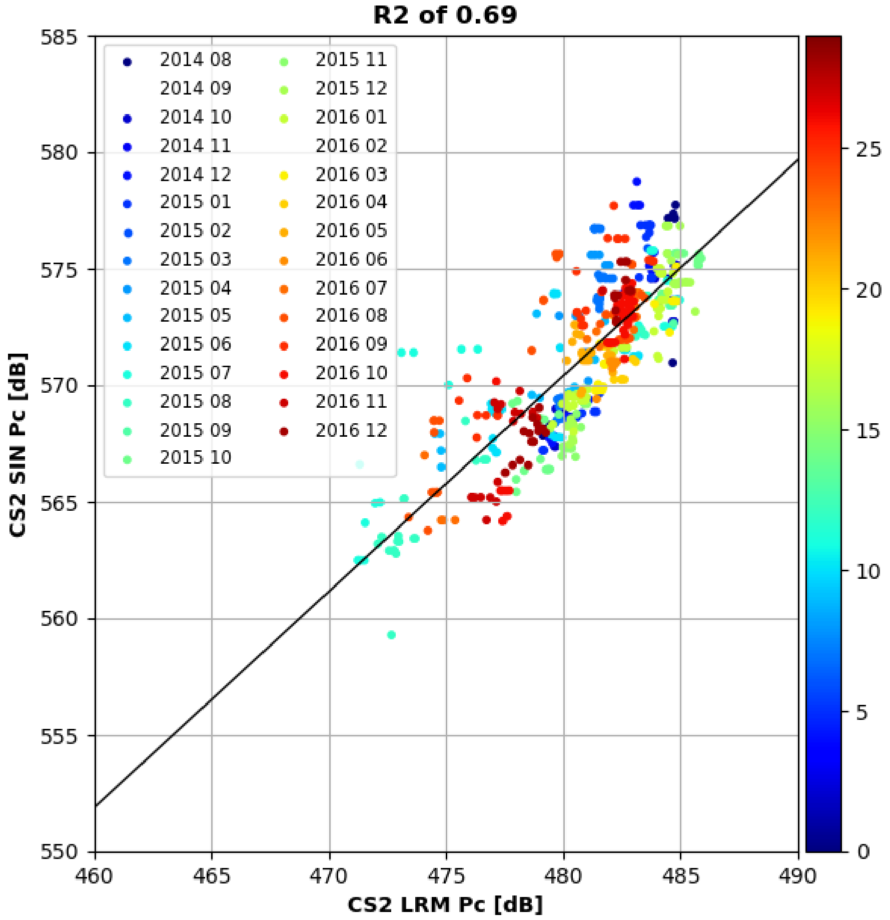


SUMup Thickness-Weighted Denisty
(**top 2m**)

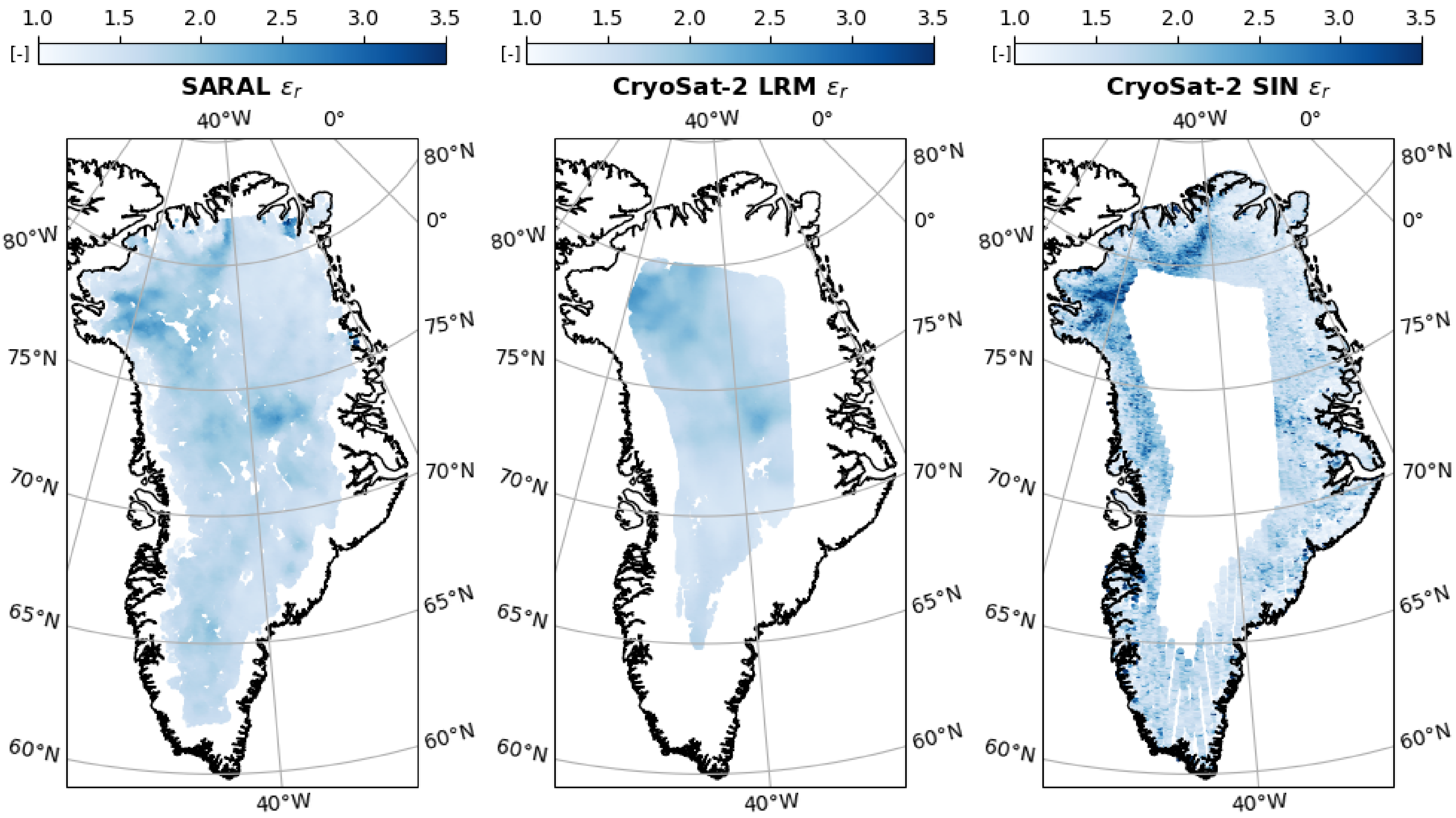
RSR Calibration

- No homogeneous SUMup measurements overlap with CryoSat-2 SARin RSR results
  - Cross-calibrate P_c at locations with contemporaneous CryoSat-2 LRM RSR results

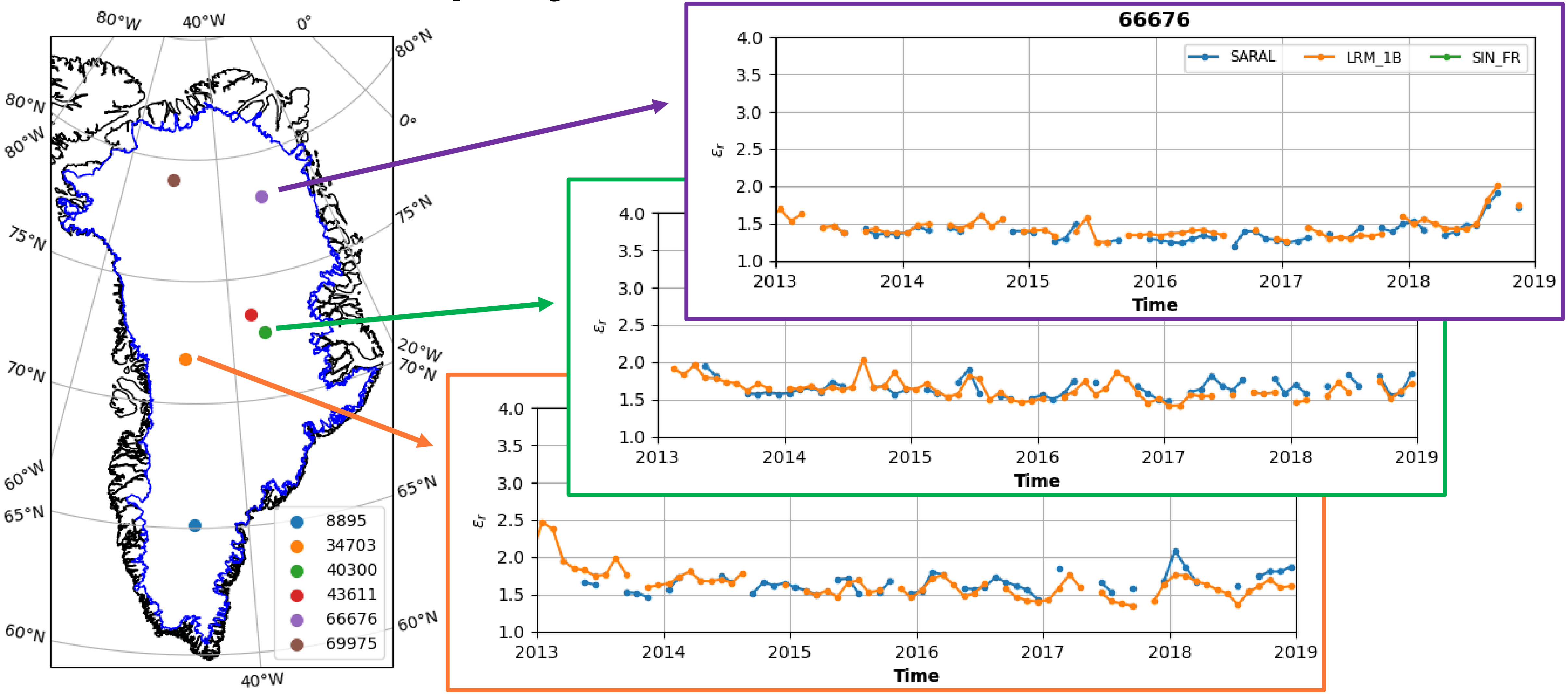




Surface Property Results – May 2015



Surface Property Results – Timeseries



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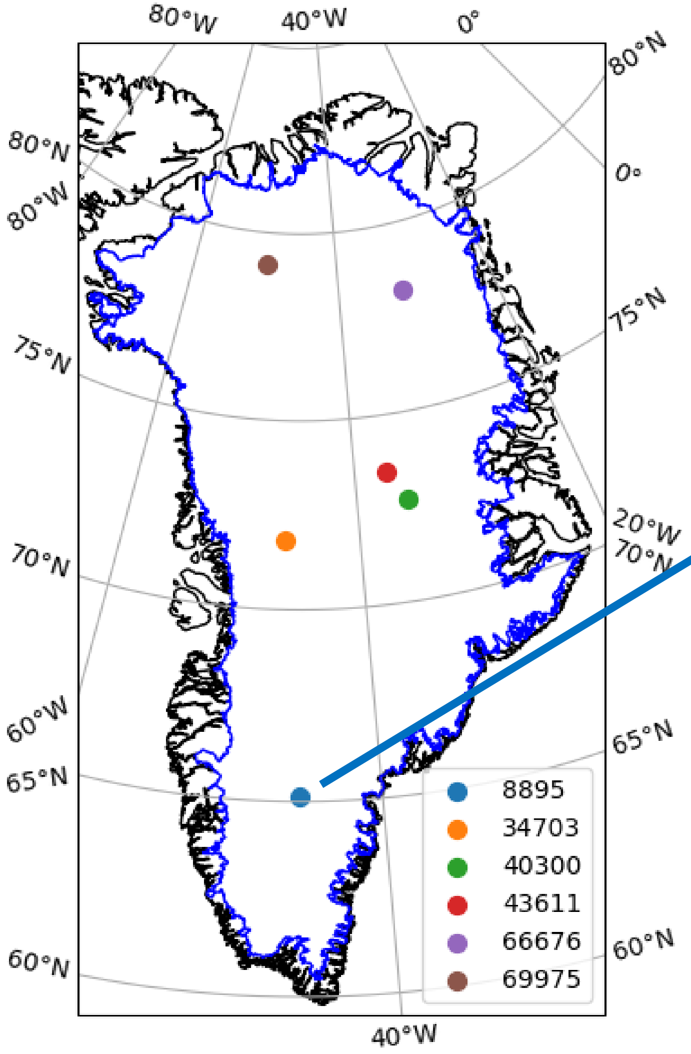

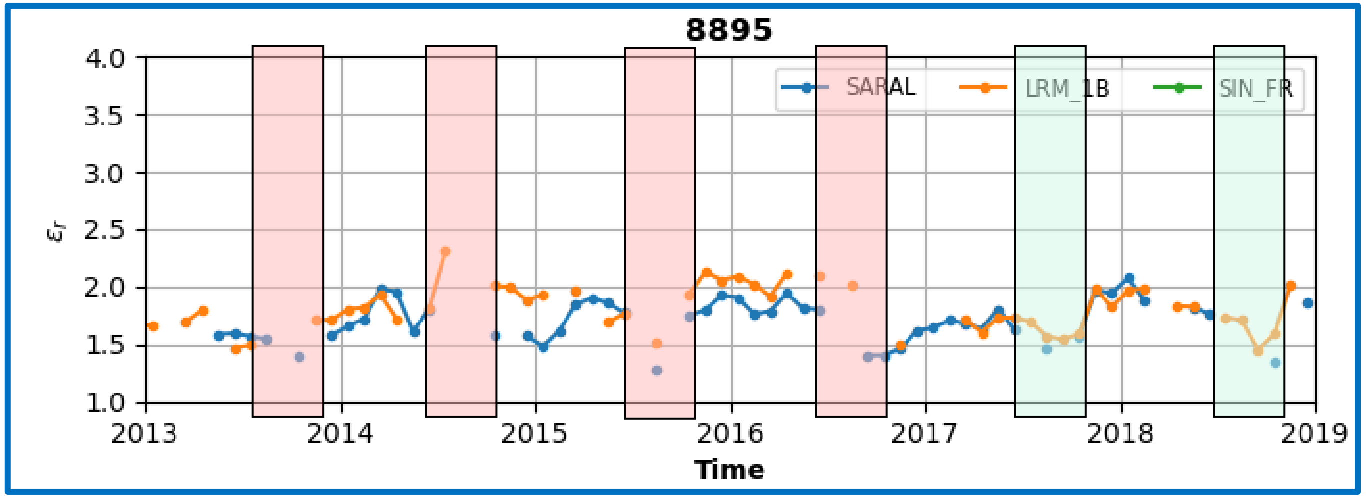

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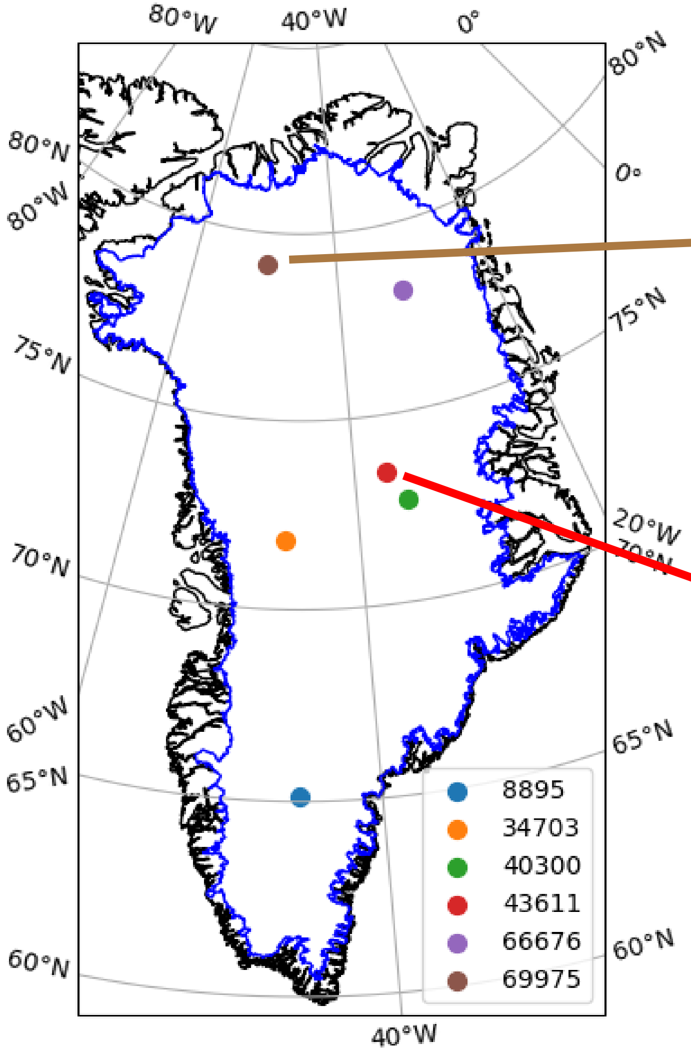

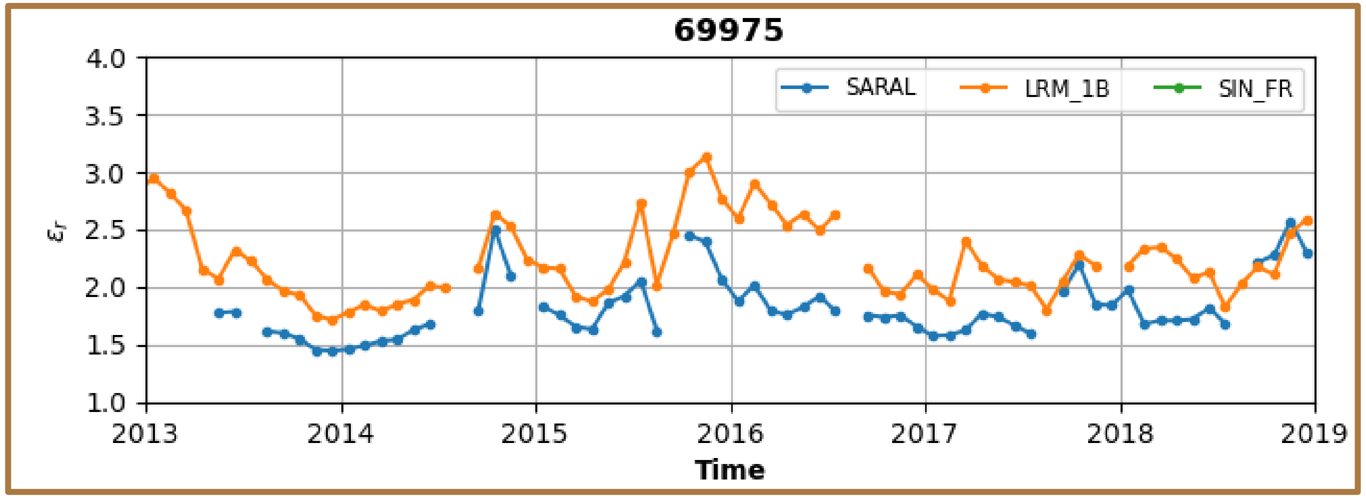

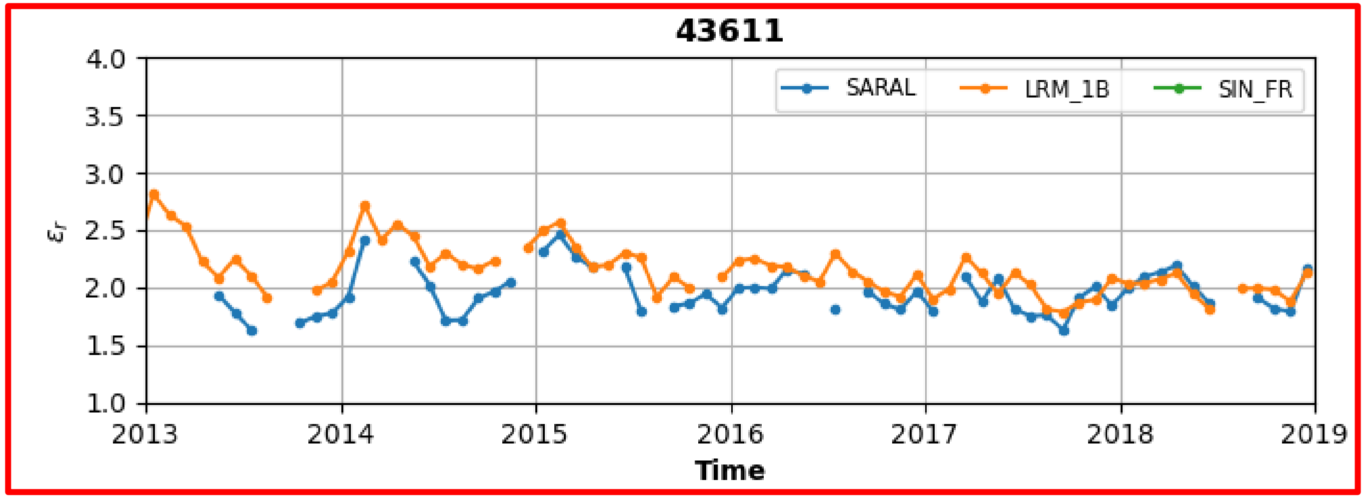

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Conclusions & Future Work

Where We Are

- Much more information in radar altimetry datasets than range
- RSR facilitates building long, pan-GrIS timeseries of surface density
- ESA CryoSat-2 and CNES/ISRO SARAL shed light on vertical heterogeneity

Where We Are Headed

- Continue building out the data record
  - Extend to all available CryoSat-2 and SARAL GrIS data products
  - Expand to other satellites (e.g., ESA Sentinel-3)
- Enhanced interpretation combining other EO datasets
  - Passive microwave radiometry (e.g., SMOS)
- Integration in GrIS mass balance calculations
- Antarctica?

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