Advancements in Observation of Ice Sheet Melt by means of Active Microwave Sensors

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Ice Sheet Surface Melt Retrieval - Active Microwave Approach

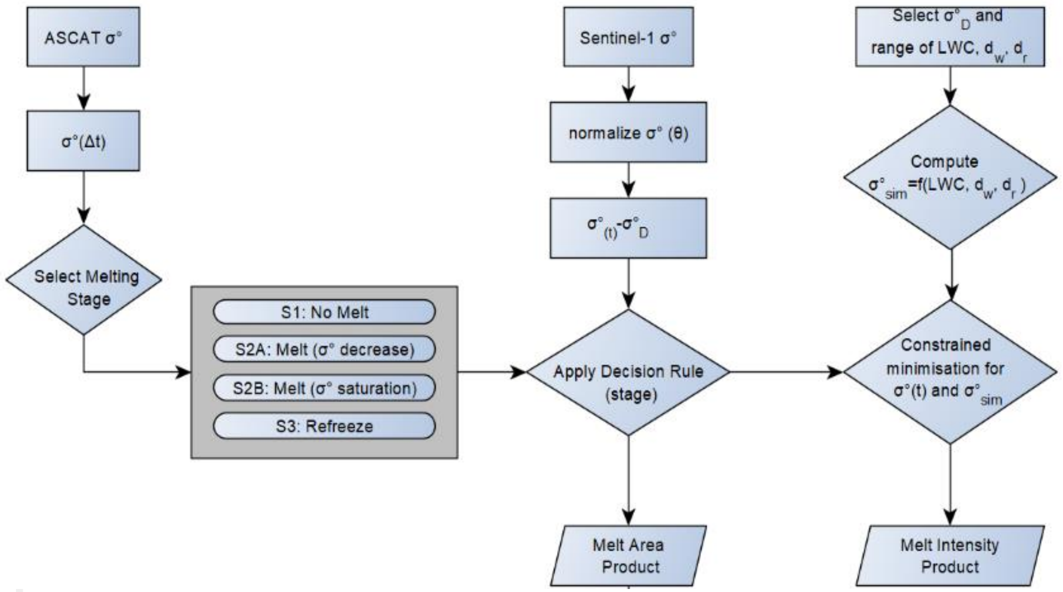
Ice sheet surface melt extent and intensity

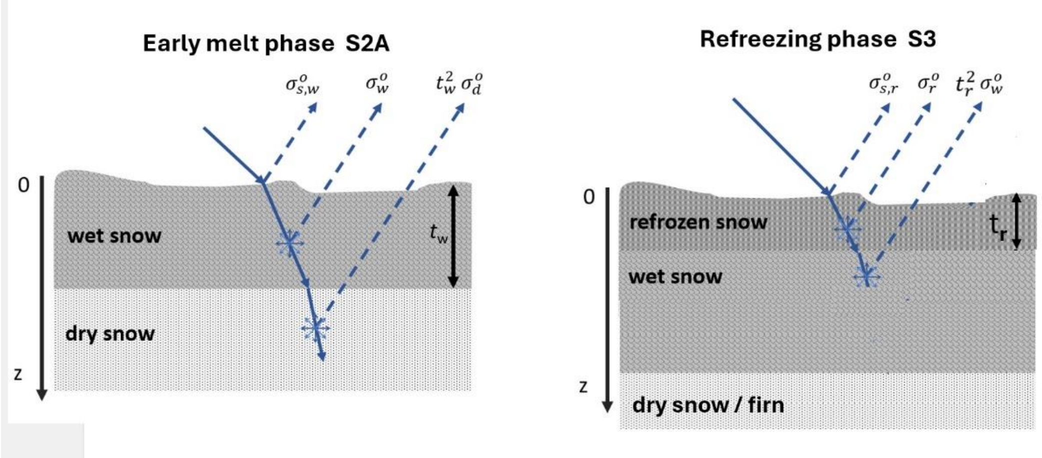
- Key information for surface mass balance and ice-flow dynamics
- Active microwave sensors are excellent tools for monitoring snow and ice surface melt, due to high sensitivity to the presence of liquid water

Current ice sheet melt products by ENVEO are based on C-band backscatter (σ^{o}) time series:

- ASCAT on MetOp → high temporal resolution, medium-scale spatial resolution; complete ice sheet coverage
- SAR on Sentinel-1 → high spatial resolution, 6 or 12 days repeat, complete coverage of Greenland, Antarctica partly
- Synergy of ASCAT and Sentinel-1 provides dense time series of melt phases at high spatial resolution

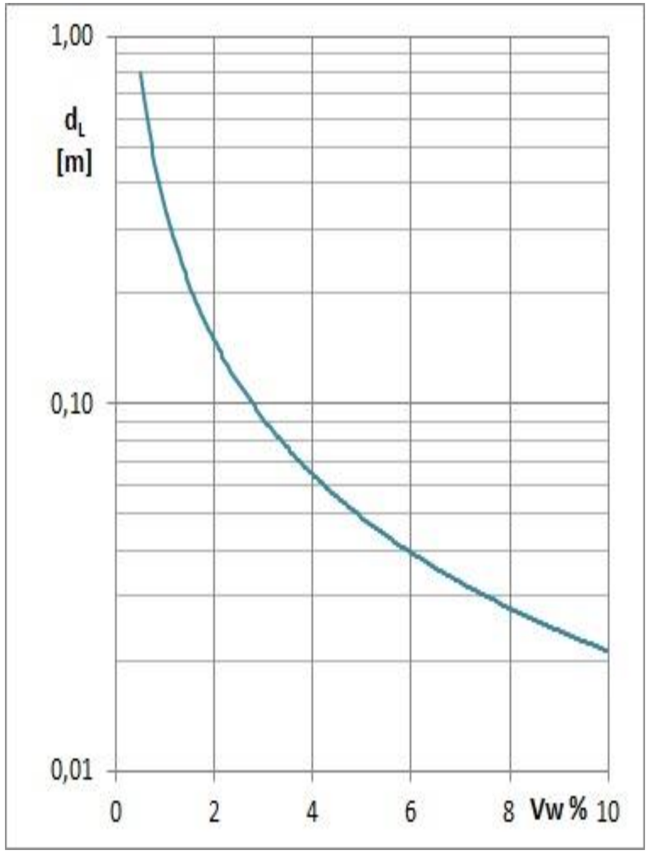
Processing Line for Surface Melt Retrieval





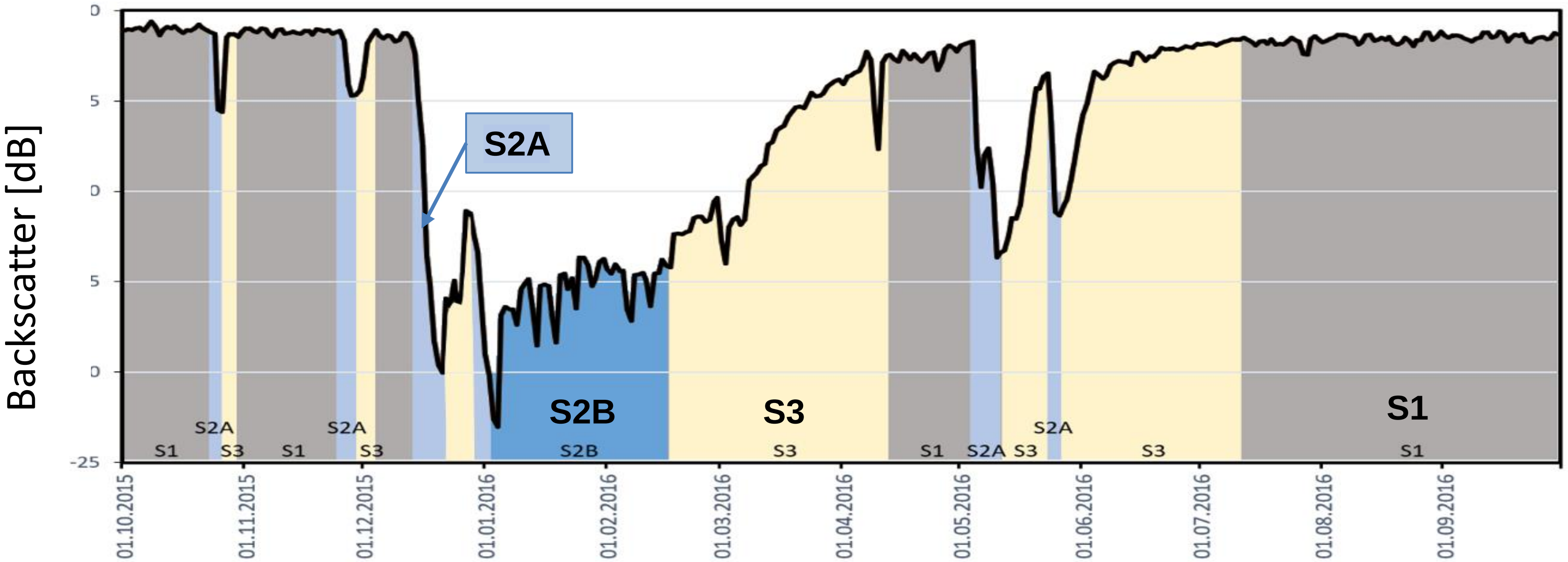
Retrieval of Surface Melt Phase Product

C-band one-way Penetration Depth vs. Liquid Water Content → Rapid Saturation



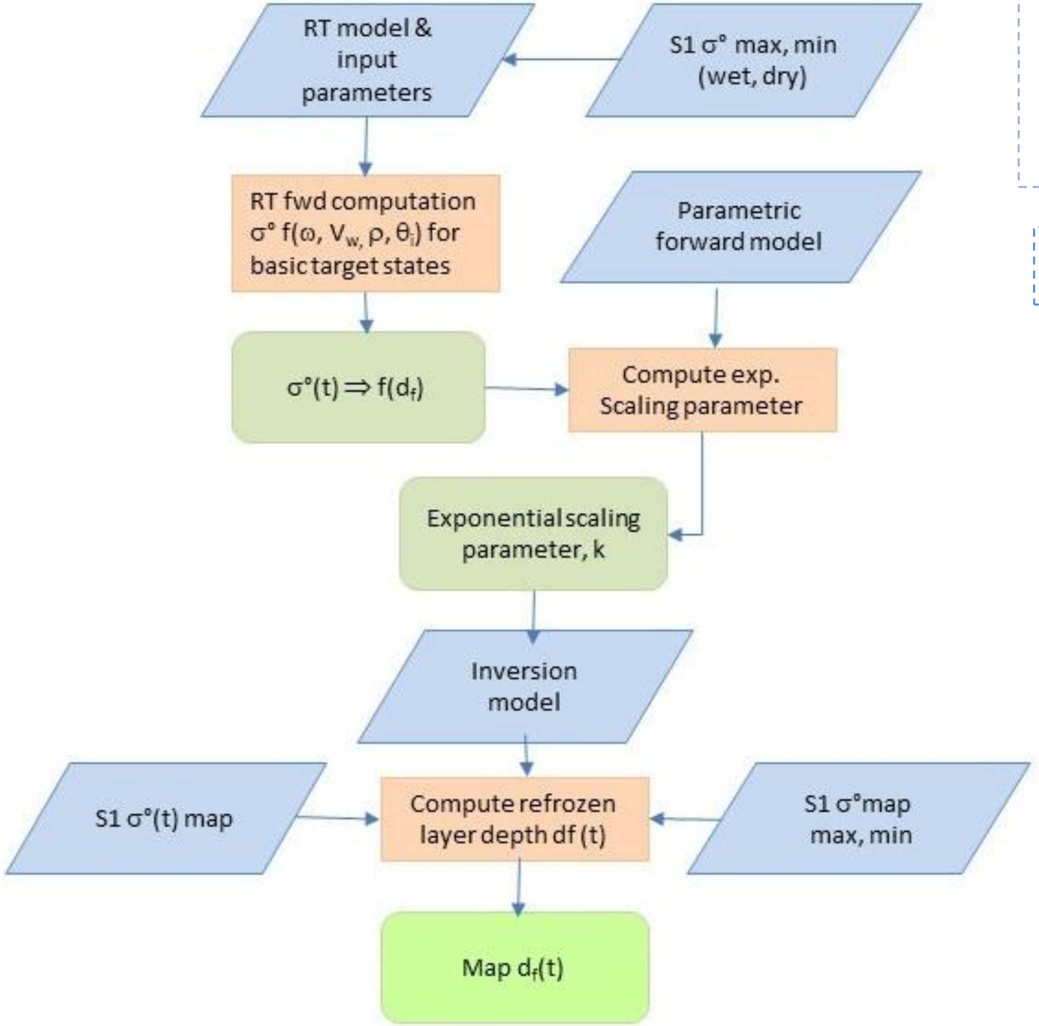
Melt Phase	Melt Conditions	Decision Rule
S1	No melt (down to signal penetration limit)	$\lvert\sigma^o(n) - \sigma^o_D\rvert < T1$
S2A	Surface layer melt (increase of depth and/or LWC of wet snow layer)	$\{\sigma^o(n) - \sigma^o(n-1)\} < T2$
S2B	Wet snow layer – Saturated signal	$\lvert\sigma^o(n) - \sigma^o_{min}\rvert < T3$
S3	Increase of refrozen layer above wet snow	$\{\sigma^o(n) - \sigma^o(n-1)\} > \lvert T2\rvert$

ASCAT Backscatter Time Series - Whirlwind Inlet, Larsen-C Ice Shelf



Estimating Refrozen Layer Thickness from $\sigma°$ Time Series

Flowline for producing map of refrozen layer thickness in percolation zone

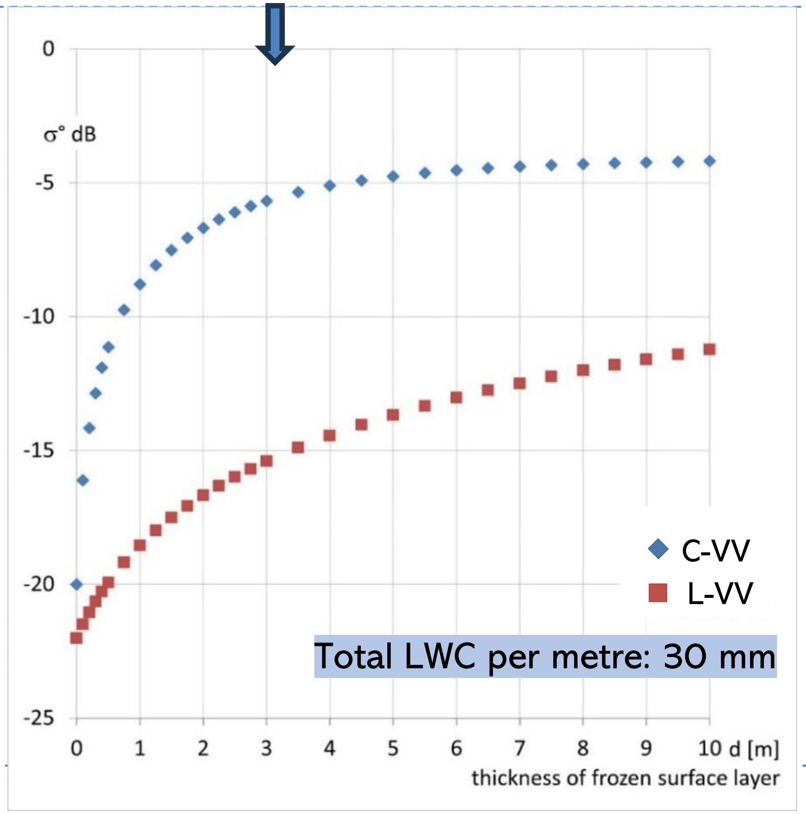


Basic equation:

RT forward model, parameter calibration of exponential loss function based on backscatter signals of saturated melt and winter conditions

$$\sigma_{pq}^{fw}(\theta_i) = \sigma_{pq}^{as}(\theta_i) + \mathrm{T}_{as}^{2}(\theta_i)\cos(\theta_r)\left[0.5\,\omega_{pq}^{f}\left(1 - t_f^2(\theta_r)\right) + t_f^2\,0.5\,\omega_{pq}^{w}\right]$$

Backscatter vs. thickness of refreezing wet snow layer with V_w = 3%



- C-band has higher sensitivity to surface layer refreezing
- L-Band covers larger refreezing layer thickness

➢ Synergy of Sentinel-1 and future L-Band SAR data (ROSE-L, NISAR) will offer improvements for LWC retrievals

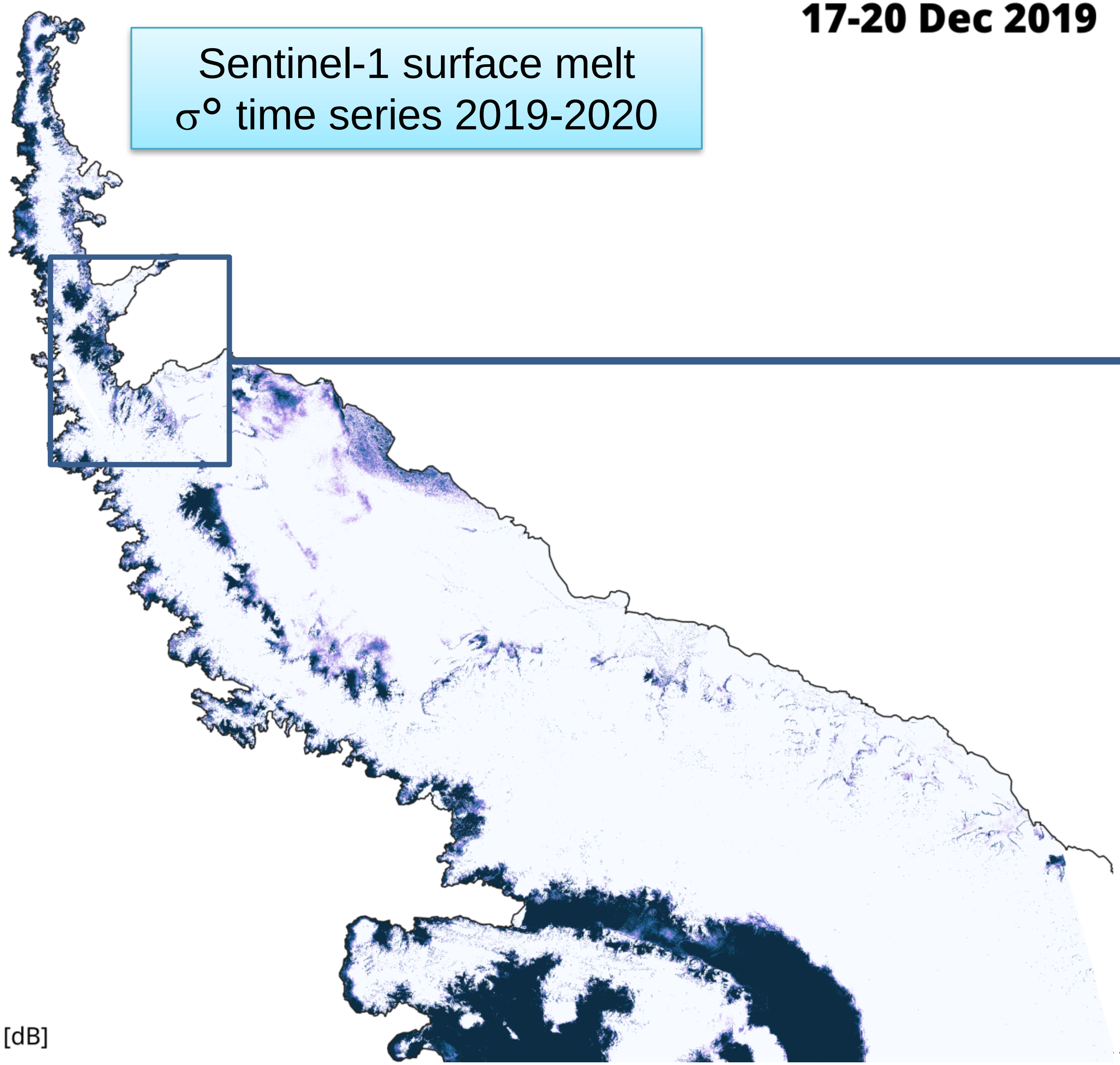
Annual Cycle of Snow Melt and Refreezing - Greenland

Daily Melt Map based on ASCAT time series May-Oct 2012

Antarctic Peninsula - Sentinel-1 Surface Melt Extent 2019-2020

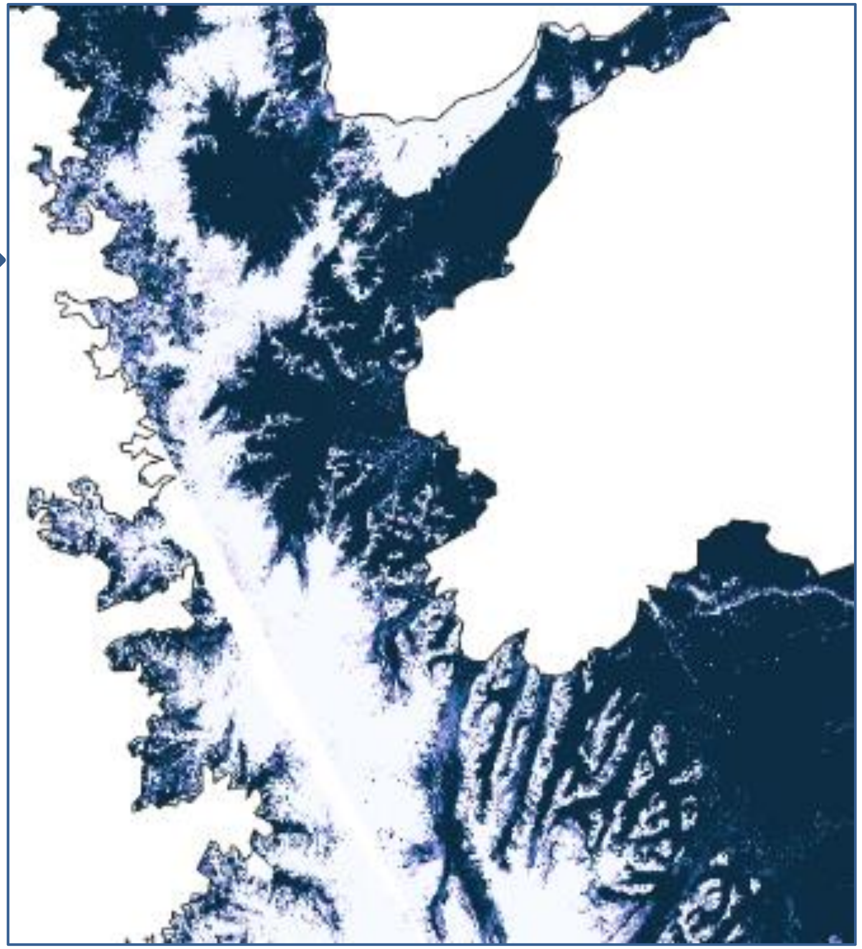
Sentinel-1 surface melt
σ° time series 2019-2020

17-20 Dec 2019



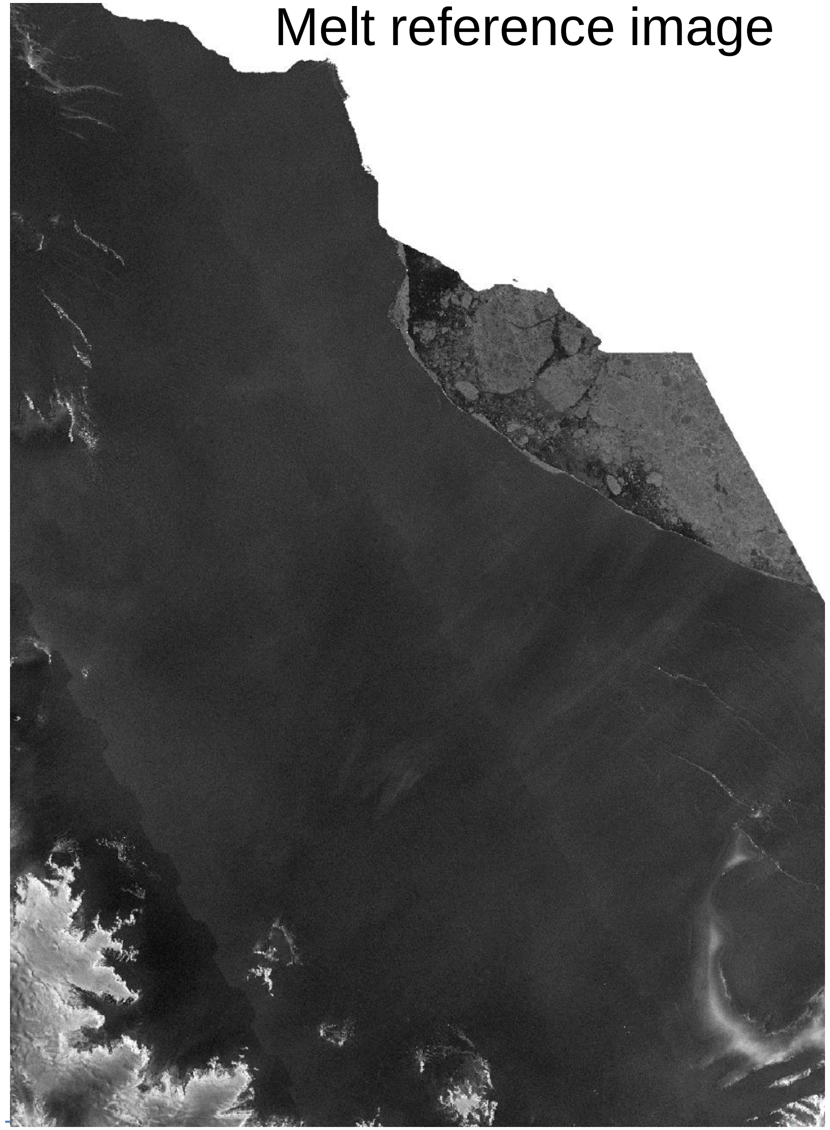
Ratio [dB]

Larsen-B embayment
19 Jan. 2020

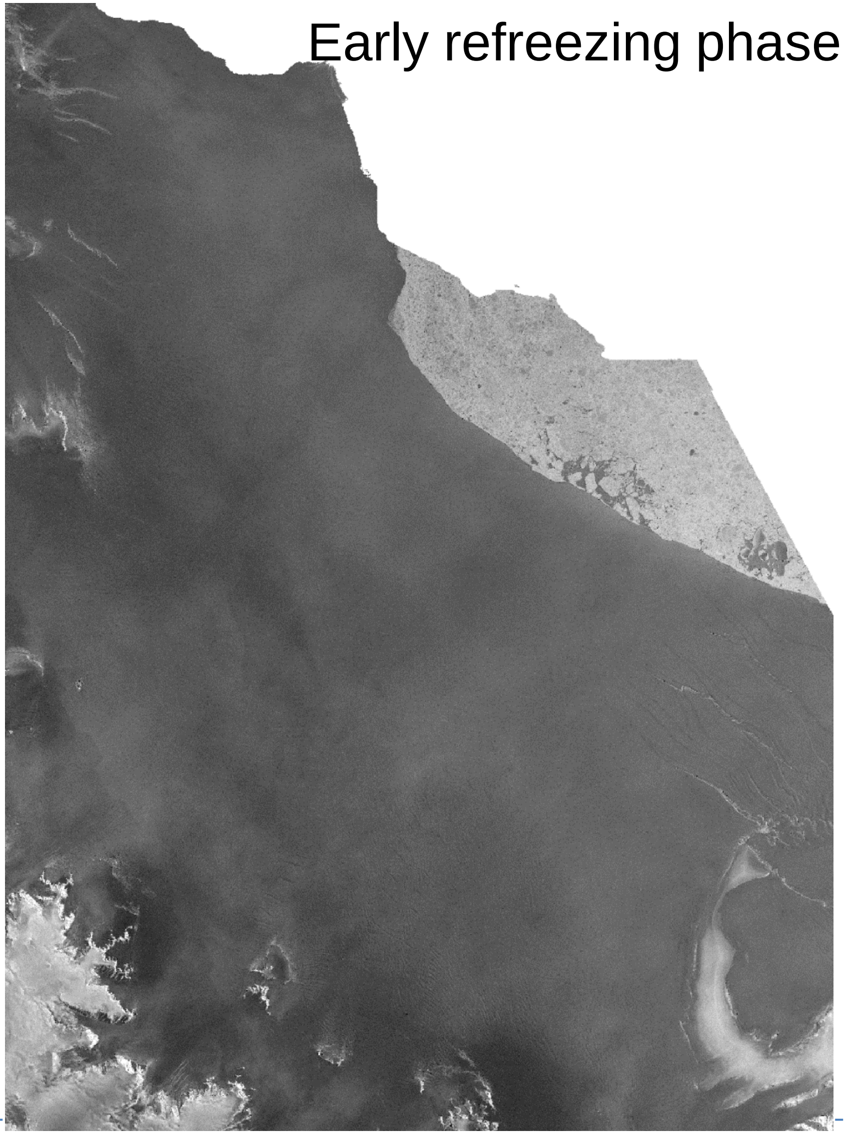


Larsen C - Sentinel-1 Backscatter Response to Refreezing

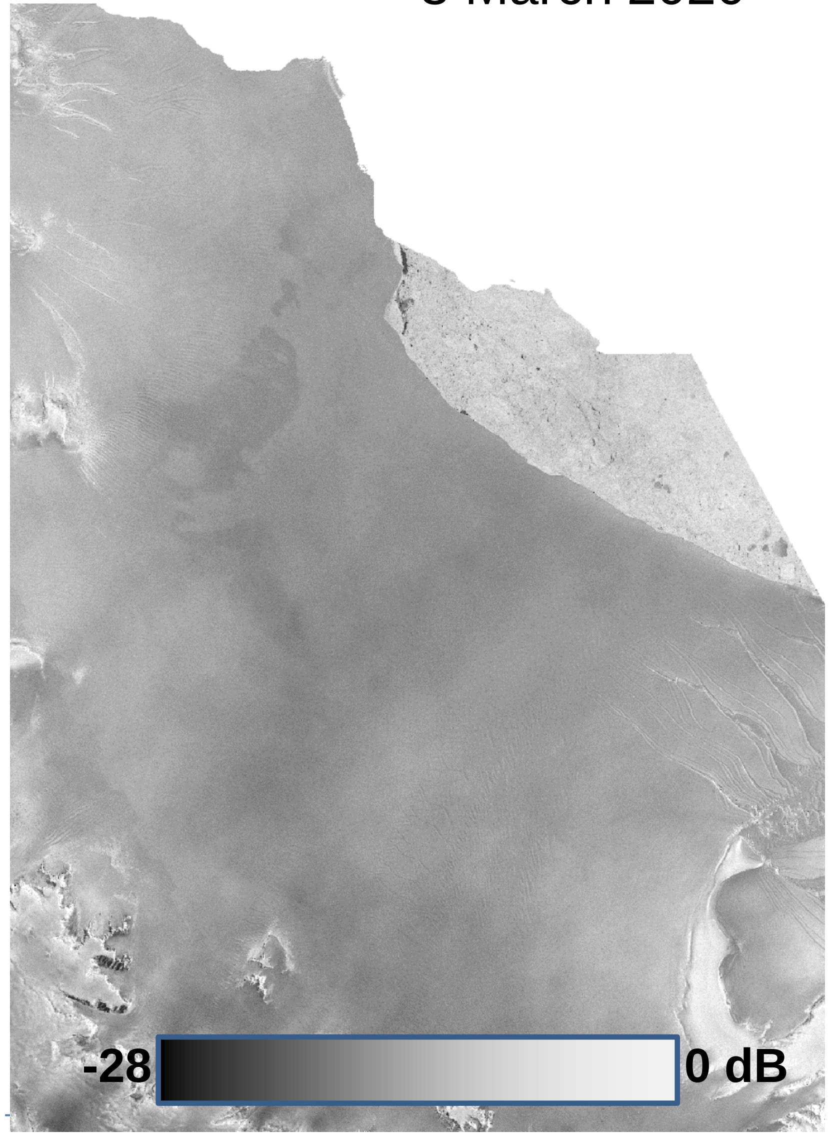
16 Jan 2020
Melt reference image



15 Feb 2020
Early refreezing phase



3 March 2020



Thickness of Refrozen Surface Layer from S1 Backscatter

Larsen C Ice Shelf