How do enhanced-resolution brightness temperatures benefit passive microwave algorithms for SWE and melt onset?

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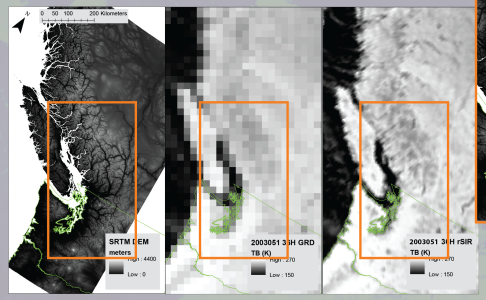
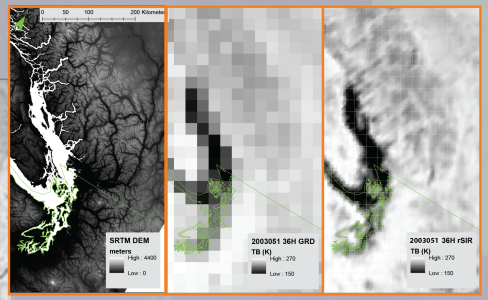
Objective

Funded by NASA MEaSUREs, we have reprocessed the entire record of gridded SMMR, SSM/I-SSMIS and AMSR-E brightness temperatures using the radiometer version of Scatterometer Image Reconstruction (rSIR) to improve the ***EASE-Grid 2.0*** spatial resolution. Image reconstruction algorithms can be tuned to reduce noise or improve spatial resolution, but cannot do both. Our Calibrated Enhanced-Resolution Brightness Temperature (CETB) Earth System Data Record (ESDR) (Brodzik ***et al.***, 2016) includes conventional, low-noise, images as well as enhanced-resolution images. We briefly describe the CETB data, and some preliminary results to derive snow water equivalent (SWE) and melt onset that may be useful to the SnowEx community.

Image Reconstruction





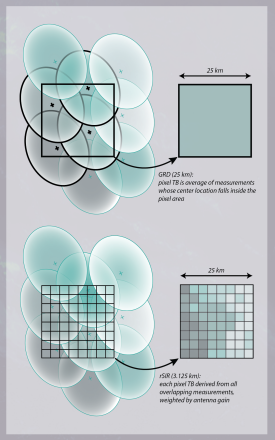
AMSR-E 37 GHz, horizontally-polarized CETB low-noise, 25 km GRD (center panels) vs. enhanced-resolution, 3.125 km rSIR (right panels) near Vancouver Island, North America, 2003 day 51, with elevation from SRTM DEM (left panels). Note that rSIR enhanced resolution image reconstruction is resolving elevation-related variability.

The rSIR technique transforms radiometer data from swath to gridded format; however, it must trade off between noise and spatial resolution (Long and Brodzik, 2016). We use rSIR to produce the *EASE-Grid 2.0* CETB product. The CETB data include conventional, low-noise, low-resolution gridded images (denoted GRD) at 25 km, and enhanced-resolution rSIR images (with potentially higher noise, at up to 3.125 km, depending on frequency). For GRD and rSIR images, the effective gridded image resolution depends on the number of input measurements and the precise details of their overlap, orientation, and spatial locations.

The goal of image reconstruction algorithms is to estimate brightness temperatures at fixed grid locations, $T_B(x,y)$, from irregularly-located swath measurements, T_i. We define $R(x,y;\phi_i)$ as the measurement response function (MRF) for a given channel and location. Then, for a particular measurement, T_i, the sum of MRF weights is 1 and T_i can be written as:

$$T_i = \iint_{surface} R(x,y;\phi_i) T_B(x,y)\,dxdy$$

Each measurement T_i is treated as an MRF-weighted average of gridded T_Bs. Ideally, the model requires knowledge of the sensor antenna pattern for the channel. In practice, this information is not available for every sensor. We approximate the MRF with a rotated, two-dimensional Gaussian function aligned with the elliptical footprint orientation. rSIR is a computationally fast, iterative technique, tuned by number of iterations. The tuning parameter trades off between signal error and noise error.



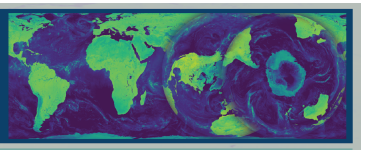
Gridding techniques (top) with the lowest noise factors take the average of all measurements whose locations fall inside the gridded pixel area, producing smooth but relatively coarse-resolution output. Compare to image reconstruction for resolution enhancement (bottom), which takes advantage of oversampled information in overlapping brightness temperature footprints to deduce higher-resolution gridded output.

Apgar, J. D., J. M. Ramage, R. A. McKenney, P. Maltais. 2007. Preliminary AMSR-E algorithm for snowmelt onset detection in subarctic heterogeneous terrain. Hydro. Proc. 21:1587-1596.
Armstrong, R. L. and M. J. Brodzik. 2001. Recent Northern Hemisphere snow extent: a comparison of data derived from visible and microwave sensors. GRL 23(19):3673-3676.
Brodzik, M. J., D. G. Long, M. A. Hardman, A. Paget and R. L. Armstrong. 2016. MEaSUREs Calibrated Enhanced-Resolution Passive Microwave Daily EASE-Grid 2.0 Brightness Temperature ESDR, Version 1. Boulder, CO. USA, NSIDC.
Chang, A. T. C., J. L. Foster and D. K. Hall. 1987. Nimbus-7 SMMR derived global snow cover parameters. Ann. Glac. 9:37-44.
Kelly, R. E., A. T. Chang, L.Tsang and J. L. Foster. 2003. A prototype AMSR-E global snow area and snow depth algorithm. IEEE TGARS, 41(2):230-242.
Long, D. G. and M. J. Brodzik. 2016. Optimum Image Formation for Spaceborne Microwave Radiometer Products. IEEE TGARS, 54(5):2763-2779.
Paget, A., M. J. Brodzik, D. G. Long and M. A. Hardman. 2017. Bringing Earth's Microwave Maps into Sharper Focus. EOS 98(6):28-32.
Ramage, J. M., M. J. Brodzik, M. A. Hardman. 2016. Glacier melt detection in complex terrain using new AMSR-E Calibrated Enhanced Daily EASE-Grid 2.0 Brightness Temperature (CETB) Earth System Data Record, AGU Fall Meeting, C13D-0859.

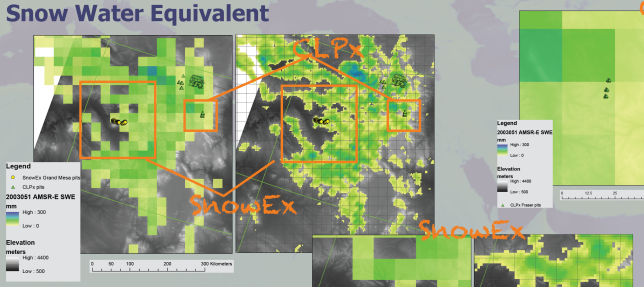
SnowEx Workshop, Longmont, CO 8-10 August 2017

This work has been funded by NASA grant #NNX16AN01G (BYU) and #NNX16AN02G (CU). We use the Janus supercomputer, which is supported by the National Science Foundation (award number CNS-0821794) and the University of Colorado Boulder. The Janus supercomputer is a joint effort of the University of Colorado Boulder, the University of Colorado Denver and the National Center for Atmospheric Research.

http://nsidc.org/pmesdr

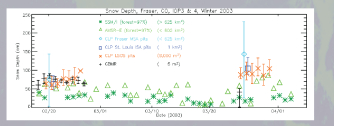


Snow Water Equivalent



Sample GRD- and rSIR-derived SWE images for Western Colorado (far left set), during the CLPx Intensive Operations Period 4, 20 Feb 2003. Zoomed inset areas to Grand Mesa (left) and the Fraser Intensive Study Area (ISA, above) demonstrate reasonable spatial patterns at enhanced resolutions. CLPx Fraser ISA pit locations (green triangles) and SnowEx Grand Mesa pit locations (yellow circles) are overlaid for reference. SWE algorithm used is Armstrong and Brodzik (2001); we expect better performance in future by application of Kelly *et al.* (2003) to CETB inputs.

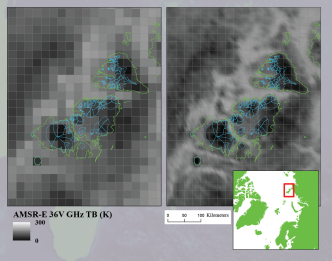
Passive microwave SWE algorithms are based on a frequency gradient response to volume-scattering (Chang *et al.*, 1987). Due to the low resolution of conventional gridded T_Bs, SWE algorithms have historically performed poorly in areas of complex topography and forested regions. Kelly *et al.* (2003) worked with AMSR-E T_Bs, sampled at higher spatial resolutions than earlier sensors like SMMR and SSM/I. They demonstrated improved SWE algorithm performance compared to station data, by adding corrections for forest cover and dynamic grain size and density models. Preliminary results comparing SWE from GRD and rSIR T_Bs demonstrate an improved ability to detect spatial patterns in SWE in these regions.



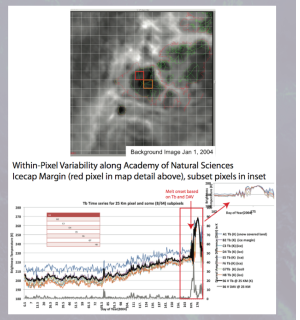
Cold Lands Processes Experiment (CLPx) snow depth measurements at Fraser ISA pits for IOPs 3 and 4, compared to SSM/I and AMSR-E snow depth algorithm results using conventional (25 km) gridding techniques, demonstrating typical undermeasure due to combination of low resolution, complex terrain and/or forest cover.

Detection of Melt Onset

Passive microwave detection of melt onset is based on time series evaluation of diurnal amplitude variation (DAV) in 18 and/or 36 GHz vertically-polarized T_Bs. The DAV signal is sensitive to changes in near-surface liquid water that characterize melt onset, melt intensification and refreezing (Apgar *et al.*, 2007). Conventional (25 km) resolution T_B grids have successfully detected snow melt states in seasonal snow and glacial environments at high latitudes. However, due to mixed pixels at such coarse resolutions, analysis has been impractical in glacier-marginal zones and in regions near water bodies. Similar analysis using 36V CETB data is proving successful at evaluating melt timing across boundaries and transition zones that had previously been impossible (Ramage *et al.*, 2016).



Glaciated islands in the High Arctic winter appear as dark regions at 36V GHz. (left) Ice, ocean, and land boundary features are indistinct in GRD images, but (right) are more distinct at rSIR (3.125 km) resolution, evening passes, 01 Jan 2004. (Paget *et al.*, 2017). GSHHG coastlines (green) and GLIMS glacier outlines (blue).



Time series of selected 3.125 km pixels along the diagonal of the 25 km pixel outlines in red (top), detecting earlier onset from snow-covered land to ice pixels that would have been impossible without CETB images (Ramage *et al.*, 2016).

Implications for SnowEx

Enhanced resolution CETB data can provide new insights into understanding historical patterns of SWE and melt onset at higher spatial and temporal resolutions than have previously been possible. Data from SSM/I-SSMIS and AMSR-E through 30 June 2016 are currently available from the NSIDC DAAC (*http://nsidc.org/data/nsidc-0630*). CETB does not include measurements for the first SnowEx campaign in February 2017. We are actively seeking funding to produce enhanced resolution images for AMSR2 (launched in 2012) and for near real-time data streams.