Using image reconstruction methods to enhance gridded resolution for a newly-calibrated passive microwave Earth System Data Record

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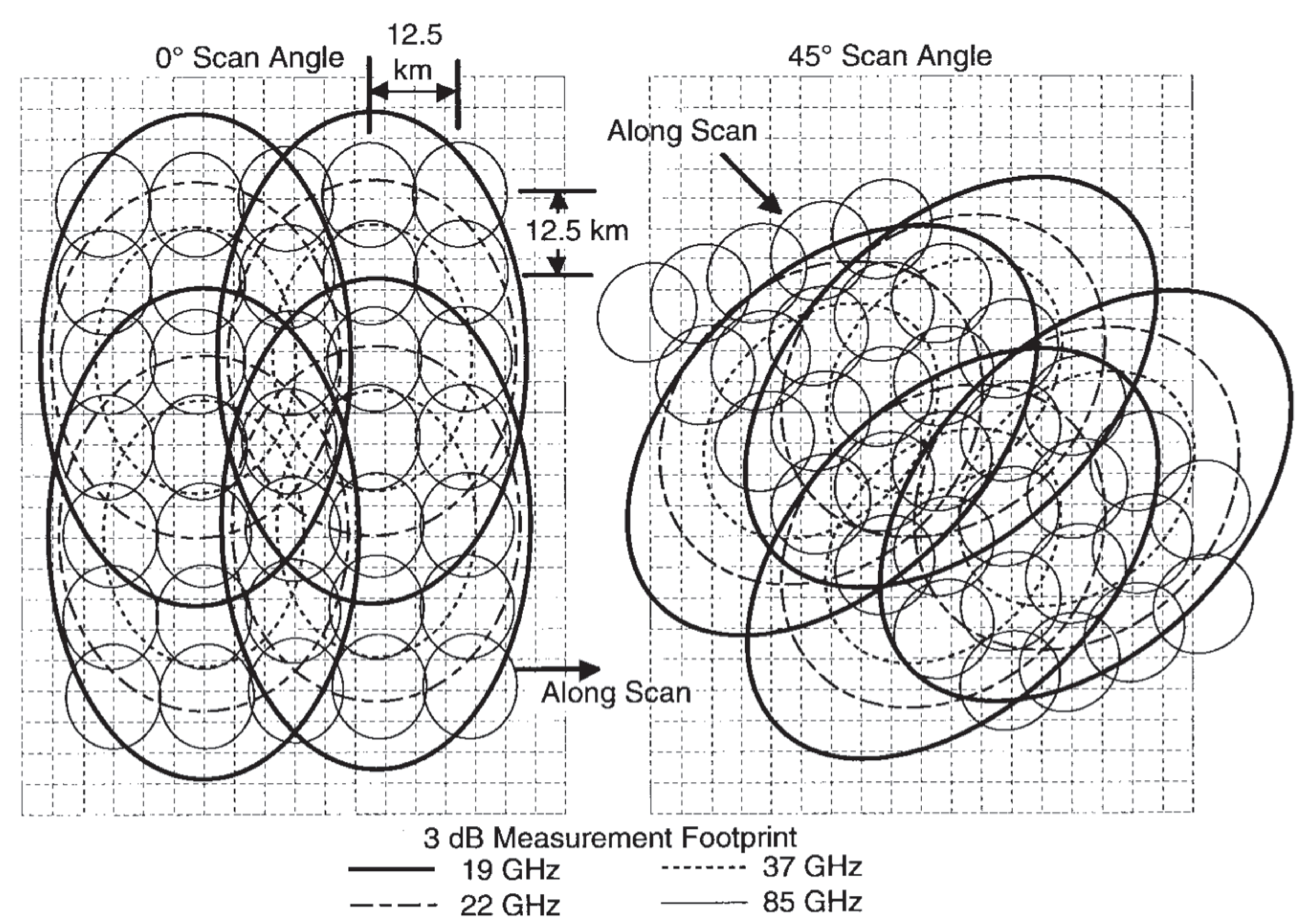
Objective

We are applying image reconstruction methods to produce a systematically reprocessed historical time series NASA MEaSUREs Earth System Data Record (ESDR), at higher spatial resolutions than have previously been available, for the 36-year satellite passive microwave record from SMMR, SSM/I-SSMIS and AMSR-E. We compare and contrast two candidate image reconstruction techniques: Backus-Gilbert interpolation (BGI) and a radiometer version of Scatterometer Image Reconstruction (SIR).

Image Reconstruction

Both BGI (Backus and Gilbert, 1967) and SIR (Long and Daum, 1998; Early and Long, 2001) methods transform radiometer data from swath to gridded format; both methods trade off between noise and spatial resolution. Our ESDR will include a conventional low-noise, low-resolution gridded images (denoted GRD) and enhanced-resolution images with potentially higher noise.



Geometry of radiometer measurement footprints for several along-track measurements for two different scan locations. Enhanced resolution images are produced on the underlying rectilinear grid (Long and Daum, 1998).

For both GRD and enhanced resolution images, the effective gridded image resolution depends on the number of measurements and the precise details of their overlap, orientation, and spatial locations.

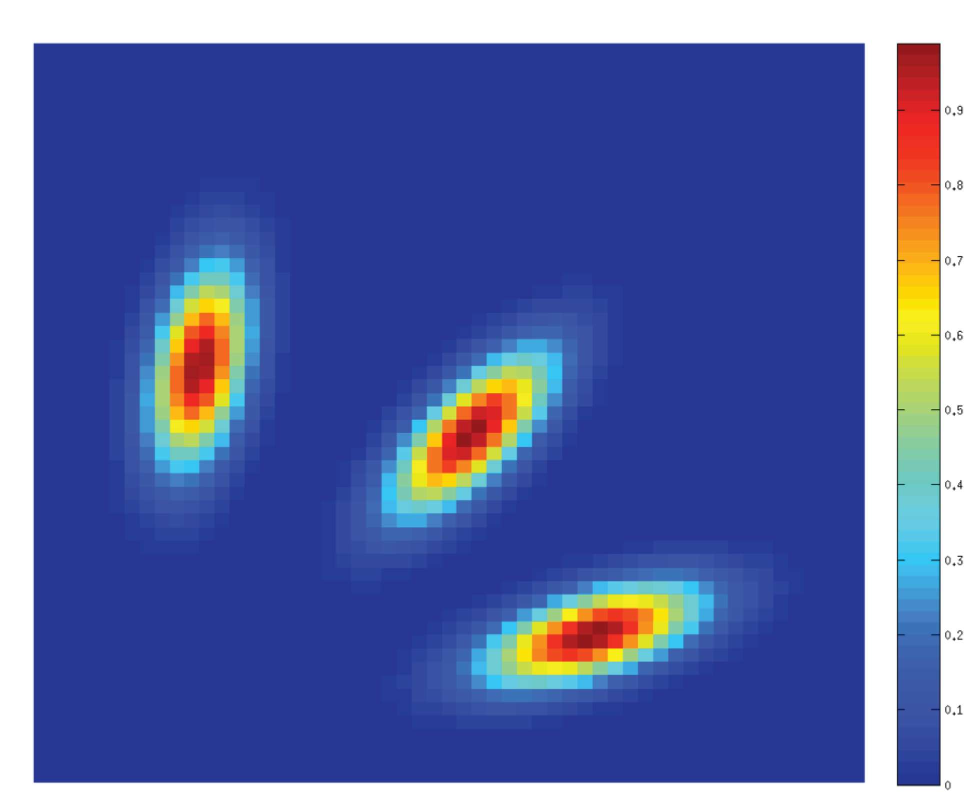
The goal of image reconstruction algorithms is to estimate brightness temperatures at fixed gridded locations, $T_B(x,y)$, from irregularly-located swath measurements, T_i. We define $R(x,y;\varphi_i)$ as the measurement response function (MRF) for a given channel and location. Then for a particular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

$$\iint_{surface} R(x,y;\phi_i)\,dxdy = 1$$

and then T_i can be written as:

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

So each measurement T_i is treated as an MRF-weighted average of gridded T_Bs. The goal of any image reconstruction algorithm is to estimate $T_B(x,y)$ from actual measurements, T_i.



Examples of a Gaussian model for the measurement response function (MRF) for several antenna rotation angles. The half-power points of the Gaussian correspond to the footprint sizes reported for each sensor and channel.

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.

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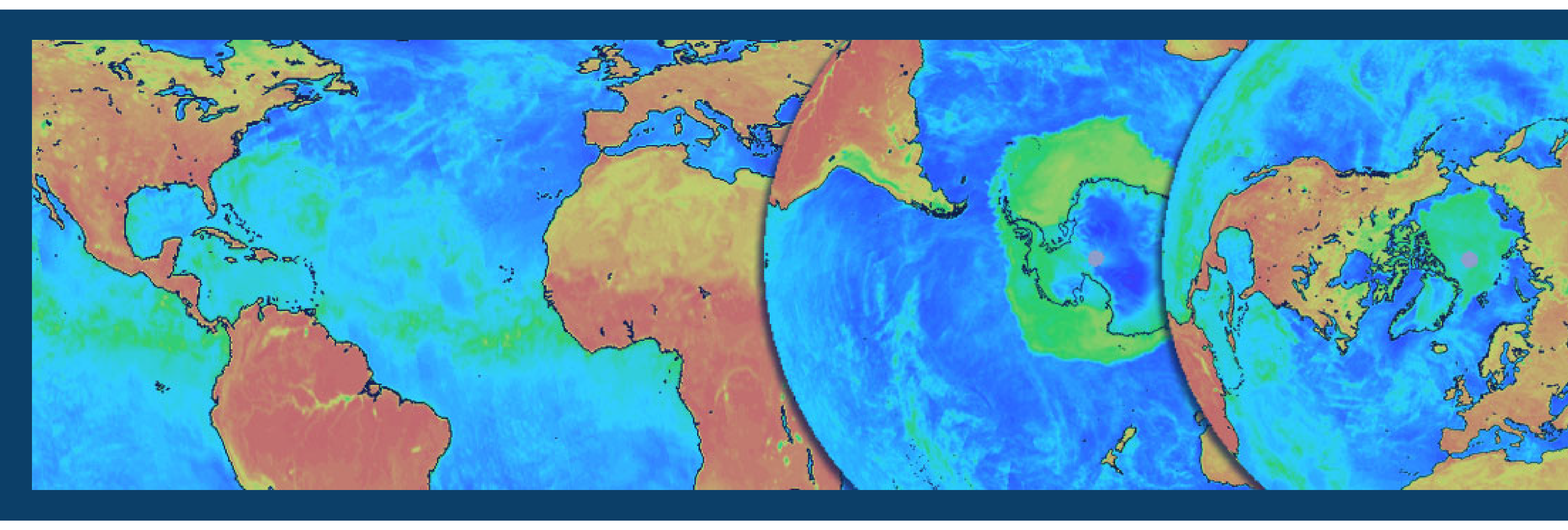
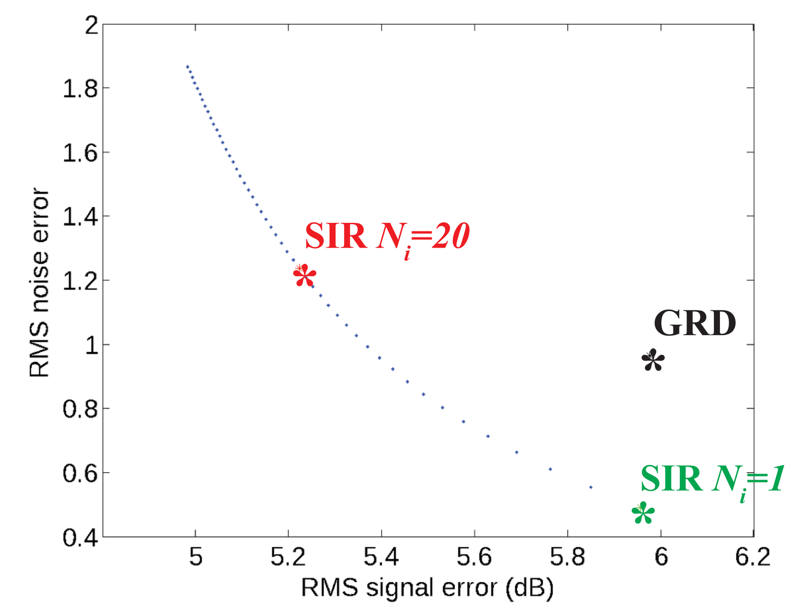


http://nsidc.org/pmesdr

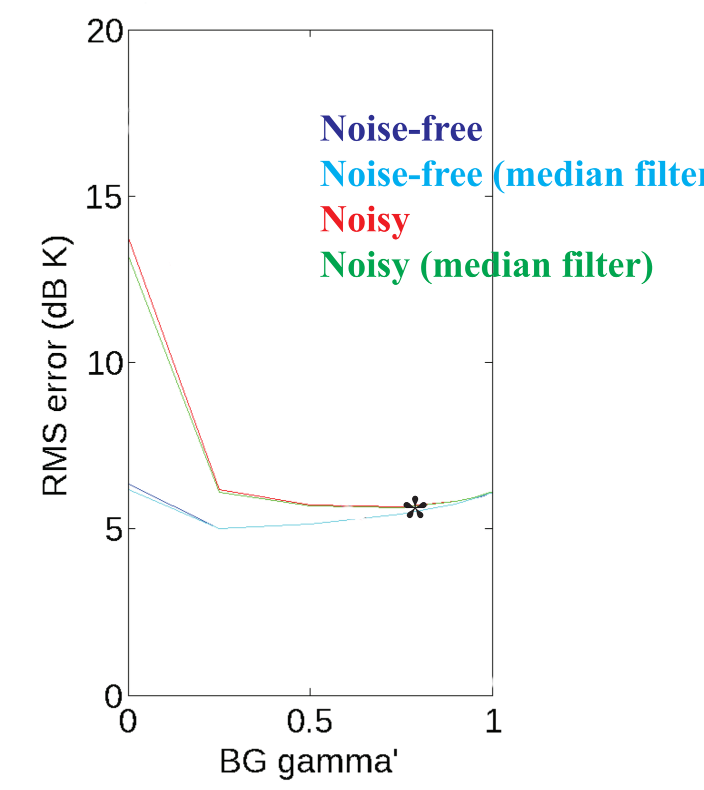
Determining Reconstruction Tuning Parameters and Grid Pixel Sizes

We have evaluated both techniques using a synthetic "truth" image, with features that simulate different target sizes, shapes and brightness gradients. SIR is an iterative technique; it is tuned by number of iterations (N_i). BG is tuned by choice of the parameter gamma (γ), which ranges from 0 to $\pi/2$. Tuning parameters trade off between signal error and noise error.

After analyzing noise performance for various choices of iteration number and pixel size (not shown here), we propose using: for SIR: N_i=7-25 (depending on channel) and pixel size of 3.125 km, and for BGI: γ'=0.85 for pixel size of either 6.25 km or 3.125 km, depending on channel.



SIR tradeoff between signal and noise errors, 37 GHz at 3.125 km. Values for increasing SIR iteration numbers are plotted from right to left. Red asterisk is SIR N_i=20.



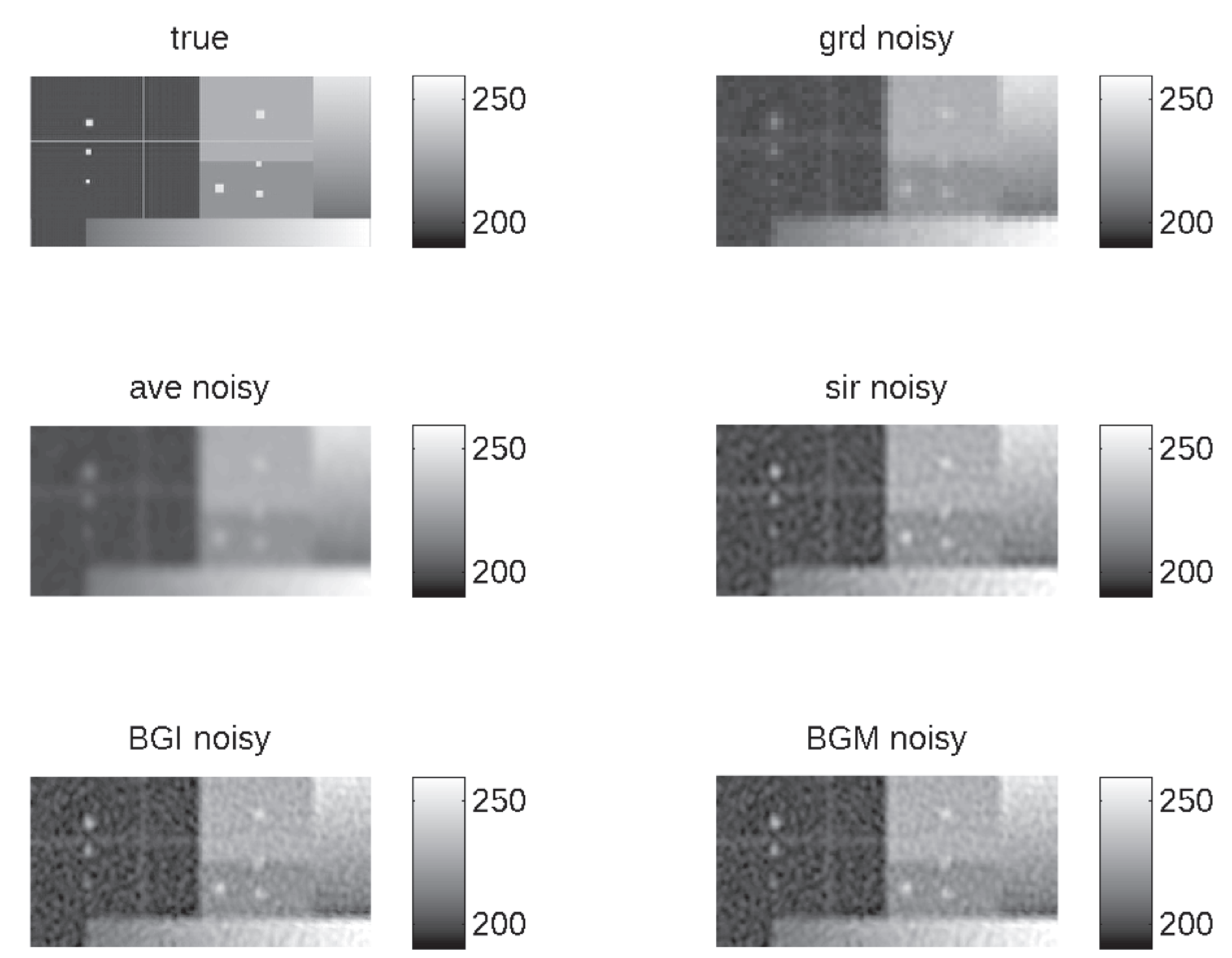
BGI change in RMS error as a function of BGI tuning parameter γ' for various noise-free and noisy images, with and without median filter. Asterisk marks γ'=0.85.

Channel	GRD pixel size	SIR pixel size P_s	SIR number of iterations
19H	25 km	3.125 km	25
19V	25 km	3.125 km	25
22	25 km	3.125 km	20
37H	25 km	3.125 km	15
37V	25 km	3.125 km	15
85H	25 km	3.125 km	7
85V	25 km	3.125 km	7

Recommended SIR processing parameters by SSM/I channel.

Channel	GRD pixel size	Pixel scale factor N_s and grid size P_s	BGI $g=\gamma/\pi$
19H	25 km	(2) 6.250 km	0.85
19V	25 km	(2) 6.250 km	0.85
22	25 km	(2) 6.250 km	0.85
37H	25 km	(2) 6.250 km	0.85
37V	25 km	(2) 6.250 km	0.85
85H	25 km	(3) 3.125 km	0.85
85V	25 km	(3) 3.125 km	0.85

Recommended BGI processing parameters by SSM/I channel.



Comparison simulation scenes of "truth" image (top left), GRD (drop-in-the-bucket, top right), AVE (SIR N_i=1, middle left), SIR (N_i=20, middle right), BGI (bottom left) and BGI with median filtering (bottom right) for 3.125 km grids.

Processing Step	SNOW	Janus (gcc)	Janus (icc)
make	00:01	00:01	00:01
setup	02:40	02:52	00:57
SIR	00:28	00:30	00:20
BGI	21:30	20:14	04:50

Relative performance times for BGI and SIR on 24 hours of input swath data to produce identical output. Comparisons are: 24-core cluster NSIDC server SNOW (gcc compiler), CU Janus supercomputer (gcc compiler), and Janus Intel compiler (icc). Preprocessing steps "make" and "setup" are required for either technique. Processing time is significantly improved for SIR in the icc supercomputing environment. SIR processing time is significantly less than that required for BGI, regardless of environment. Time units are hh:mm.

Conclusions and Plans

While both techniques enhance noise somewhat, we find that SIR and BGI can each be tuned to produce higher-quality images (lower RMS image error) than conventional drop-in-the-bucket GRD images. SIR requires significantly less processing power than BGI.

In 2015, we will produce a prototype ESDR including BGI and SIR results for evaluation and feedback from our volunteer Early Adopter community. Our final ESDR will include GRD output on the 25 km EASE-Grid 2.0 (Brodzik et al., 2012; 2014) and enhanced resolution grids (6.25 or 3.125 km) from either BGI or SIR. Choice of BGI or SIR will depend on Early Adopter responses. If you are interested in being an Early Adopter, please contact us (*brodzik@nsidc.org*). For more information on our project, see *http://nsidc.org/pmesdr*.

References and Acknowledgements

Backus, G. E. and J. F. Gilbert. 1967. Numerical applications of a formalism for geophysical inverse problems. Geophys. J. R. Astron. Soc., 13:247–276.
Brodzik, M. J., B. Billingsley, T. Haran, B. Raup, M. H. Savoie. 2012. EASE-Grid 2.0: Incremental but significant improvements for Earth-gridded data sets. ISPRS International Journal of Geo-Information, 1(1):32-45, doi:10.3390/ijgi1010032. http://www.mdpi.com/2220-9964/1/1/32/.
Brodzik, M. J., B. Billingsley, T. Haran, B. Raup, M. H. Savoie. 2014. Correction: Brodzik, M. J. et al. EASE-Grid 2.0: Incremental but significant improvements for Earth-gridded data sets. ISPRS International Journal of Geo-Information 2012, 1, 32-45. ISPRS International Journal of Geo-Information, 3(3):1154-1156, doi:10.3390/ijgi3031154. http://www.mdpi.com/2220-9964/3/3/1154/.
Early D. S. and D. G. Long. 2001. Image Reconstruction and Enhanced Resolution Imaging from Irregular Samples. IEEE TGARS, 39(2):291-302.
Long, D. G. and D. L. Daum. 1998. Spatial resolution enhancement of SSM/I data. IEEE TGARS, 36(2):407-417.

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