ANALYSIS OF CORRECTIVE METHODS FOR MINI-RF MONOSTATIC DATA. C. P. Harris[1], B. J. Thomson[1], J. T. S. Cahill[2], C. I. Fassett[2], F. S. Turner[2], N. T. Dutton[2], G. W. Patterson[2], [1]Department of Earth and Planetary Sciences, University of Tennessee, Knoxville, TN 37996 (charr144@vols.utk.edu), [2]Johns Hopkins Applied Physics Laboratory, Laurel, MD

Introduction: Radar is an invaluable remote sensing tool for planetary science and exploration, enabling geophysical exploration of the surface and subsurface of planetary bodies beyond the capabilities of optical systems. The Lunar Reconnaissance Orbiter (LRO) Mini-RF data archive is currently the most comprehensive set of radar data products available for the lunar surface [1, 2]. Among Mini-RF data products, those with the highest spatial resolution are from a period earlier in the mission when the instrument functioned in monostatic mode, and represent a valuable trove of data that can be utilized for geologic research and planning both crewed and uncrewed exploration activities.

The existing Mini-RF map-projected monostatic Level 2 data products have significant spatial offset errors in both cross-track and along-track directions [3]. These offsets make co-registration with other available datasets difficult and necessitate time-intensive and inefficient manual corrections. Here we examine the merits of several possible methods for correcting and reprocessing the entire monostatic archive.

Characterization of Offset Errors: Existing errors in the Mini-RF monostatic products available from the Planetary Data System (PDS) [4] occur in both the cross-track and along-track directions [3]. Cross-track errors have been attributed to a lack of availability of high resolution topographic models early on in the mission, and so map-projected products were produced by projecting onto a uniform sphere. Utilizing a global digital elevation model (DEM) such as the Lunar Orbiter Laser Altimeter (LOLA) and Kaguya SLDEM2015 [5] in the processing pipeline appears to substantially alleviate these cross-track errors. The along-track errors are less well understood, although trends in their variable magnitude have been characterized [6]. It is thought that the most likely source of along-track errors are from an unknown issue in the Vexcel SAR processor or its deployment pipeline. Vexcel was originally deployed to process the Mini-RF data now in the PDS, but is no longer available. Correcting these errors then will require either compensating for the existing offsets in Level 1 data, or reprocessing the raw data from scratch while sidestepping the unavailable original processing software.

Methodologies: There are currently three promising methodologies for correcting existing along-track errors in Mini-RF monostatic data. The first method is the most robust, it sidesteps the Vexcel processor entirely. Time-Domain Back Projection Processing (TDBP) is a method to simulate monostatic radar processing based on the bistatic SAR processor developed by Sandia National Laboratories and modified by Scott Turner and Nicholas Dutton at Johns Hopkins Applied Physics Laboratory (APL) [2, 7, 8,]. TDBP is arguably the most effective method, and reprocessing the data has the advantage of fixing any calibration errors that might be present in the monostatic data. However, it is currently computationally intensive and has not been deployed at scale.

The second methodology, developed by Caleb Fassett at APL and referred to here as Mini-RF Shift, reprocesses monostatic data by calculating the offset between existing Level 1 data and a synthetic image generated based on a backscatter model and the local incidence angle of a shape model. The Level 1 images are translated by the calculated offset and all four Stokes parameter data products are then map projected as a stack of cubes. Although the resulting correction is imperfect because it does not include reprocessing of the SAR signal, this method does correct existing monostatic images to within a few pixels of a reliable basemap. Mini-RF Shift has already been successfully used to calculate predicted offsets for a majority of S-band zoom images.

The third methodology may be referred to as a "brute force" method. Existing map projected products are overlaid on a reliable basemap (e.g. as a hillshade derived from a global DEM) in ArcGIS Pro. By altering the transparency of the overlaid uncorrected Mini-RF image, congruent features can be identified in the radar image and the basemap. The offset between these features can be measured and converted to pixels based on the known spatial resolution of monostatic images. The image is then reprocessed by translating the Level 1 monostatic image by a number of lines equivalent to the calculated pixel offset using the translate function built into the USGS Integrated Software for Imagers and Spectrometers (ISIS) [9], after which the image is map projected with an appropriate topographic model. This method is inherently less precise as it relies on measurements taken by hand. Early test cases indicate that even with only one measurement taken per image, the resulting correction is very close to that produced by Mini-RF Shift. The advantage of this method lies in that it requires fewer computational resources, and can be performed by an operator with less training or experience with GIS software or ISIS, but is time-intensive to process individual images.

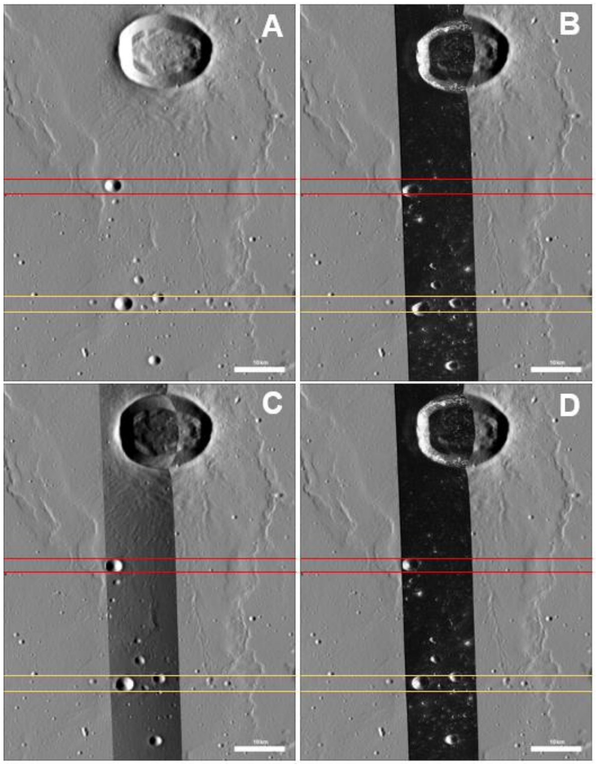

Figure 1: Comparative alignment of features between (A) a hillshade derived from the SLDEM2015 [5], (B) an uncorrected Level 2 monostatic cube (lsz_01790_2cd_xku_33n320_v1) [4], (C) the stack of image cubes generated by Mini-RF Shift, and (D) a translation of the Mini-RF cube based on a single manual measurement. The red and yellow lines illustrate the positional offsets of features in each prodcut relative to each other.

Conclusions: With three potential solutions to the spatial offset problem affecting the Mini-RF monostatic archive, future work will further quantify the geodetic accuracy of each method, and consider the practical and logistical realities of employing one or multiple of these methodologies. In the effort to reprocess and re-release corrected data products in a timely and economical manner, resource allocation and required time-to-completion need further evaluation for each proposed methodology. This preliminary analysis directly compared results of both the Mini-RF Shift method and brute force methodology across a small series of sample images taken across the breadth of the monostatic archive to qualitatively evaluate their efficacies relative to each other (**Figure 1**). TDBP was not compared across the same image set, but known preliminary results of other images indicate that it is a highly effective solution.

Time-Domain Back Projection Processing appears to be the most scientifically robust method to correct the existing monostatic archive, but a wholesale deployment of this method will require additional development. Since a majority of S-band zoom images, which themselves comprise the majority of the monostatic archive, have already had offsets successfully calculated with the Mini-RF Shift method, a short term solution could include a two-pronged approach to release an intermediate corrected dataset. Mini-RF Shift reprocessed images would provide the bulk of the corrected dataset, and the brute force method could be used to fill in any gaps when necessary. Since preliminary results for both methods indicate a similar level of accuracy in offset correction, the resulting Level 2 products should be comparable. This could be accomplished with significantly fewer computing resources and personnel with specialized training or experience and turnaround times would still be reasonable if manual intervention is only required for a minority of images in the archive. This intermediate archive of reprocessed images would serve as a stop-gap measure to provide more accurate radar data immediately to the public while options are explored for employing TDBP to produce the most accurate reprocessed products possible. Those products can then be rolled out in batches to the PDS and over time replace the intermediate archive.

This analysis is preliminary, and work is still ongoing to refine the roadmap for releasing a corrected Mini-RF monostatic archive. However, with an arsenal of useful corrective methods now available, it is possible to correct spatial offset errors in Mini-RF monostatic data. This effort to reprocess and re-release the archive will improve the accuracy of this important dataset and in doing so will allow for greater accessibility and ease of use in future lunar research efforts.

Acknowledgements: This project is supported by the NASA Planetary Data Archiving, Restoration, and Tools (PDART) program. PDART NNH19ZDA001N: *Improved georectification of Mini-RF radar data of the Moon: A window beneath the regolith*.

References: [1] Cahill J. T. S. et al. (2014) *Icarus, 243*, 173–190. [2] Patterson G. W. et al. (2017) *Icarus, 283*, 2-19. [3] Kirk R. L. et al. (2016) *Int. Arch. Photogram. Rem. Sens. Spatial Info. Sci. XLI-B4*, 425-429. [4] LRO Mini-RF Calibrated Level 2 Data (2008) *PDS*, doi: 10.17189/1520649. [5] Barker M. K. et al. (2016) *Icarus*, *273*, 346-355. [6] Harris C. P. et al. (2022) *LPSC.* abstract #2856. [7] Wahl D. E. et al. (2012) *Algorithms for Synthetic Aperture Radar Imagery XIX*, *SPIE*, *8394*, 86-89. [8] Turner F. S. et al. (2019), *49th Planetary Data Wkshp*, 7075. [9] Becker K. J. et al. (2013) *LPSC.* abstract #2829.