MINI-RF IMAGE PROCESSING AND DATA PRODUCT GENERATION. F.S. Turner[1], R.C. Espiritu[1], G.W. Patterson[1], A.M. Stickle[1], J.T.S. Cahill, [1]Johns Hopkins University Applied Physics Laboratory, 11100 Johns Hopkins Rd, Laurel, MD 20723 (Raymond.Espiritu@jhuapl.edu)

Introduction: The Mini-RF instrument aboard NASA's Lunar Reconnaissance Orbiter (LRO) is a hybrid dual-polarized synthetic aperture radar (SAR) [1, 2] that operates in concert with the Arecibo Observatory (AO) [3,4] and the DSS-13 Goldstone deep space communications complex 34 meter antenna to collect S- and X-band bistatic radar data of the lunar nearside. The ground station transmits at specific pulse intervals defined by the planning process and the instrument is configured to operate in continuous receive-only mode. The transmitted pulses generated by the ground station are asynchronous with the sampling by the Mini-RF receiver. The data collected is then downlink and processed into horizontal and vertical (H and V) images using a time-domain backprojection algorithm that utilizes phase history measurements in the raw downlinked Mini-RF data to calculate the pixels that comprise a complex-valued image [5]. This processing of the returns requires several steps in order to generate the initial images (Fig.1). Image cube backplanes, Stokes daughter products, and derived data products are also generated, along with accompanying labels for delivery to the PDS archive.

Methodology: The first five steps below describe the methodology of the SAR image processing software (the processor) in order to generate the initial image products. Successive steps describe the processing done in order to create supplementary and higher level data products.

Isolate the Direct Path. The direct path signal from the ground station as it passes through the instrument is often the strongest element in the returns collected. The processing software uses this fact to isolate the signal from the others. It is then used as a timing and phase reference to compensate for any shifts that may occur in the backscattered signal. A waterfall plot is created displaying each pulse to allow for a visual inspection to ensure that the software was able to identify the direct path correctly (Fig. 2). Manual selection of the direct path may be required in those instances where the signal is low enough such that it is not simply separable from the specular return. The end result is an accurate estimate of the pulse repetition interval (PRI).

Determine Phase Estimate. Estimates are taken of the now isolated direct path correlation peak phases. A simple filter based on the measurement of the power in each direct path pulse is used to determine which phase measurements are directly usable. Any gaps are filled by integrating a model of the phase drift built up by analyzing collections of adjacent pulses. These phases, modeled or measured, are then used as a reference for correlating the backscattered signal measurements from pulse to pulse.

Calculate Geometry. Geometry information is derived from SPICE kernels as inputs to the processor. This information includes the ground station and receiver locations with respect to a lunar fixed reference frame. It also includes roll, pitch, and yaw angles and their time derivatives of the receiver relative to an idealized nadir-oriented spacecraft frame. This ancillary geometry information is then used to generate an equirectangularly projected, 20 meter per pixel, grid from the spherical lunar surface onto which the H and V channel images are formed.

Generate H phase and V Phase Image Products. The timing, direct path phase, geometry, and grid information are used to process the returns and coherently accumulate the collected backscattered signal onto the grid. Two sets of two separate images are generated per observation (e.g., Fig. 1). Each set of images is

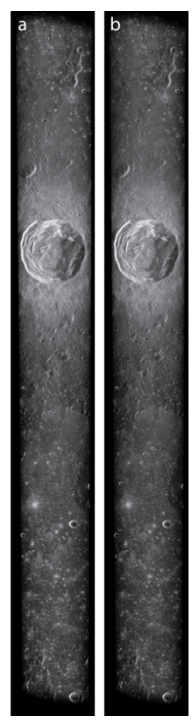

Fig. 1. Processed horizontal (a) and vertical (b) channel images of the crater Kepler and surrounding Oceanus Procellarum mare materials from bistatic observation 2012-276.

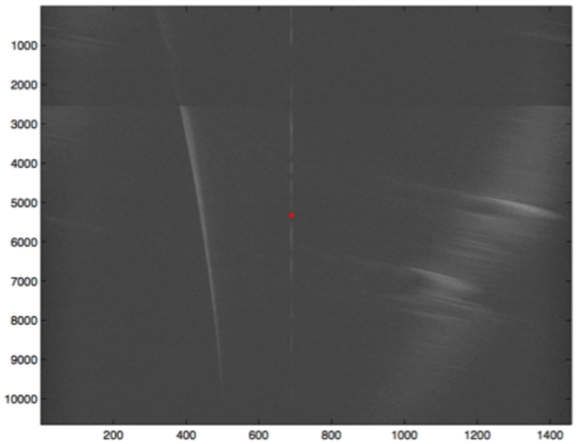

Fig. 2. Waterfall plot for a Mini-RF collect (2016-095). The y-axis indicates samples within a pulse and the x-axis each pulse within the collect. Pixel intensity represents power within the corresponding sample in the pulse. Sharp vertical line marks direct path. Arcing signal to the left is the specular (forward scattered) signal. Broad signal at right is the backscattered return.

generated using either the direct path phase from the H or V channels as a reference, and within each set there is an H and V channel image. The latitude and longitude of each pixel in the grid is also captured as an intermediate product in the processor.

Generate Geometry Backplanes. Image cubes containing geometry information at the pixel level, downsampled to 100 meters per pixel, are created for each observation. The raw grid generated in the previous step is used to generate the image cube. The image cube consists of an NxMxZ array where NxM correspond to the downscaled H and V image and each element of Z contains a different geometry parameter. Six geometry parameters are stored in the image cube: latitude, longitude, phase angle, incidence angle, emisison angle, and range.

Generate Higher Level Data Products. The hybrid dual-polarimetric nature of the Mini-RF instrument allows for the calculation of the Stokes parameters that characterize the backscattered signal. In turn this allows for the calculation of the Circular Polarization Ratio (CPR), which is a representation of the surface roughness at the wavelength scale of the radar. The four stokes parameters and the CPR are the final set of products generated for a given Mini-RF observation (Fig. 3).

PDS Archive Generation. A PDS3 label file is generated for every data product in-line with the product generation process. Metadata describing the observation, such as target name, start time/end time, is parsed from a planning spreadsheet. Remaining PDS archive files are generated prior to submission to the PDS.

Production and Future Work: To date twenty eight Mini-RF observations have been processed and submitted to PDS from the 2012-2015 bistatic campaign. The LRO third extended mission added DSS-13 as an additional ground station for use at X-band in the 2016-2018 bistatic campaign. As of March 31, 2017, six DSS-13 and one Arecibo observations have been processed. The processor is being optimized to reduce processing time and improve the overall quality of the images. In addition, a flight database is being implemented such that the planning tools, product generation, and PDS archiving software can reference the same observation more easily.

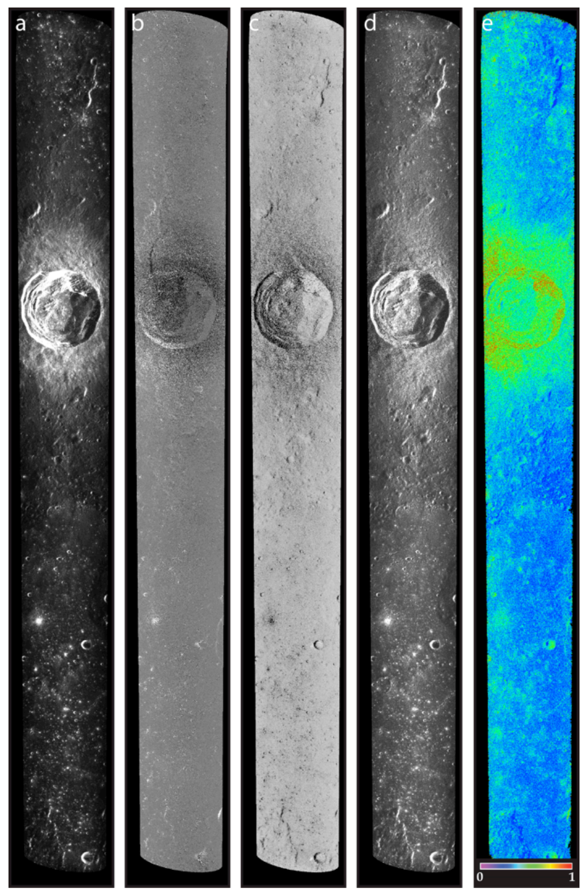

Fig. 3. Processed Stokes parameter – (a) S_1, (b) S_2, (c) S_3, (d) S_4, – and (e) CPR data products for the crater Kepler and surrounding Oceanus Procellarum mare materials from bistatic observation 2012-276.

References: [1] Chin et al., 2007, Space Sci. Rev. 129(4), 391-419; [2] Nozette et al., 2010, Space Sci. Rev., 150, 285-302; [3] Patterson et al., 2013, 44th LPSC, #2380; [4] Patterson et al., 2017, Icarus, 283, 2-19; [5] Wahl et al., 2012, Proc. of SPIE, Vol. 8394, 83940D-1.