A GLOBAL, BLENDED CTX MOSAIC OF MARS WITH VECTORIZED SEAM MAPPING: A NEW MOSAICKING PIPELINE USING PRINCIPLES OF NON-DESTRUCTIVE IMAGE EDITING. J. L. Dickson[1], L. A. Kerber[2], C. I. Fassett[3] and B. L. Ehlmann[1,2] [1]Division of Geological and Planetary Science, California Institute of Technology, 1200 E California Blvd, MC 150-21. Pasadena, CA, 91125. (jdickson@caltech.edu), [2]Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Dr, Pasadena, CA 91109, [3]NASA Marshall Space Flight Center, Huntsville, AL 35805.

Introduction: Existing geospatial raster blending algorithms, which have been used for Mars on the global 100 m/px THEMIS IR dataset [1-2] and locally using CTX [3-4] and HiRISE [5] data [6], typically use weighted averaging of overlapping imagery ("ramping") to transition between orbits [1]. This optimizes for the removal of visually jarring seams that result from variable imaging conditions. This technique is "destructive," terminology we adopt from professional photography to describe image processing operations that are irreversible: once pixels in overlapping orbits are merged, traceability to the original orbits is lost (Fig. 1). This prevents the end user from accessing image metadata that are critical to proper morphological interpretation of surface features (L_s, incidence/phase/emission angle, time of acquisition, etc.) and instantly deciphering blending artifacts vs. landforms.

Here, we introduce a new image mosaicking pipeline that builds upon [1] by integrating non-destructive image blending techniques that are well established in commercial image editing software but have, to our knowledge, yet to be implemented in scientific image processing. We have developed this pipeline to generate a global, seam-corrected mosaic of CTX imagery that includes polygon shapefiles that (1) map seam boundaries among orbits at the resolution of the imagery, (2) include all spacecraft/illumination attributes from the original orbits for each polygon and (3) link dynamically to processed versions of each stand-alone orbit for instant comparison with the mosaic product.

Pre-Blending Pipeline: We devised a modular approach to the global CTX mosaic by dividing Mars from 88°S to 88°N into 3960 4°x4° quadrangles, allowing for subsequent updating of individual quads without having to regenerate the global mosaic. These tiles are generated with a 0.25° buffer along all sides to produce sufficient overlap to blend the rendered tiles together. Each orbit within a tile undergoes standard USGS ISIS processing (similar to [1,6]) from ingestion from the PDS through projection onto an equidistant cylindrical tile with fixed boundaries for all orbits (the 4.5° x 4.5° quadrangle) and a fixed resolution (5 m/px). A known artifact of CTX images is the relative lowering of DN values at the x-axis extremes of the pushbroom detector compared to the center of the image (a "smile"). Standard radiometric calibration within ISIS is usually insufficient for blending of overlapping orbits, so we employ a column-based normalization that balances tones across the image. We also use the statistics of the calibrated products to filter out low s/n data, generally associated with dust storms and clouds.

Projected orbits must be tone-matched before blending [1]. We devised an algorithm that exports each orbit at a variable standard deviation from its mean pixel value, determined as a function of the variance within the projected product. This is required to blend orbits with a wide dynamic range with overlapping orbits with a narrow dynamic range. The application *equalizer* within ISIS did yield better ultimate seam removal but at the expense of washing out long-wavelength tones within the final quad. Due to our modular approach, we have the ability to apply different pre-blend stretching algorithms to different quadrangles, if necessary.

Non-Destructive Blending: Traditional high-volume geospatial image processing (like our pipeline up to this point) relies on sequential, step-by-step manipulation of raster data to create successive generations of files, with the only recourse for recovering data being to access earlier generations of the image. Non-destructive image editing [7] preserves the original raster data and applies detached functions to it dynamically at the discretion of the operator. This provides two critical advantages to traditional sequential, destructive image editing: (1) all operations on a raster are completely reversible, and (2) scores of output compositions of the image can be generated with negligible increases in file size, as the modifications are stored as mathematical functions instead of separate rasters. Thus, non-destructive image editing has become standardized within professional photography and design over the last two decades [7].

Since the averaging of overlapping pixels is destructive (Fig. 1), we use non-destructive blending, which is achieved by calculating the paths of least contrast among hundreds of overlapping images ("seamlines") and applying masks that obscure portions of images not used in the final composition (Fig. 1). The masks (1) occupy minimal file space, (2) exist independently of the raster so can be easily discarded, and (3) can be converted to polygon shapefiles that inherit all original metadata associated with that orbit. While components of this process can be achieved using more traditional sequential geospatial image processing software (USGS ISIS, ArcGIS, GDAL), non-destructive processes are

far more developed and efficient within the industries of photography and graphic design, where they are used extensively and engineered from the outset to optimize for non-destructive operations. Thus, our testing revealed that Adobe Photoshop provides the most efficient, stable and high-quality platform for this process. We have successfully blended tiles and generated vectorized seam maps for quadrangles consisting of ~225 full resolution CTX orbits, leveraging the efficiency of non-destructive image editing described above, compared to ~40 at once using destructive sequential processes [6]. Recent developments have made Photoshop accessible as a Python module, allowing for integration with the other GIS tools within our full pipeline
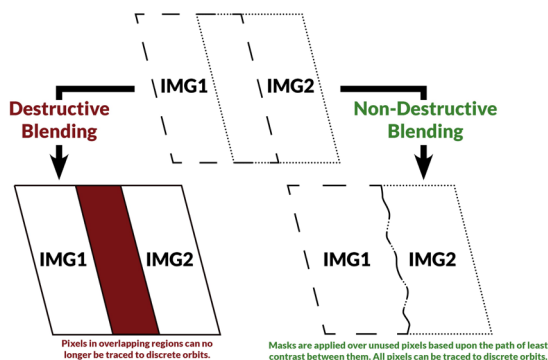

Figure 1. Schematic of destructive [1] and non-destructive blending procedures. Non-destructive blending avoids averaging pixels by creating a seamline between the two images and applying masks over unused regions. Since the masks can be stored as equations, no new rasters are created, preserving all original information and saving disk space. This efficiency permits the blending of > 200 CTX orbits at once.

(GDAL/OGR, Arcpy, etc.) and full end-to-end automation.

Tile Blending: Quadrangles are blended with their neighbors using similar non-destructive techniques. We use an iterative blending pipeline that blends four 4.5° x 4.5° tiles (including 0.25° of margin on all sides of each tile) together for a 16.5° x 16.5° composition, which is then divided into 4.5° x 4.5° tiles that are then used for blending with neighboring tiles in all direction. We have successfully generated a seamless and seam-mapped 48° x 32° mosaic using this methodology.

Future Work: We have enlisted the support of ~20 Mars scientists to fully test the output of our pipeline and continue to solicit beta users for the mosaic. These tests have led to important improvements to our mosaicking technique, and have contributed to active projects being presented at this conference [8-12], including assisting with Mars 2020 landing site selection [8-10]. Future improvements to the pipeline will be focused on (1) reduction of vertical artifacts introduced during smile-removal of low s/n orbits, (2) scene-dependent pre-blend stretching equations, and (3) pixel-for-pixel control of the output mosaic to MOLA.

References: [1] Edwards et al. (2011) *JGR*, 10.1029/2010JE003755; [2] Edwards et al. (2011) *JGR*, 10.1029/2011JE003857; [3] Malin et al. (2007) *JGR,* 10.1029/2006JE002808; [4] Sidiropoulos et al. (2017) PSS, 10.1016/j.pss.2017.10.012; [5] McEwen et al. (2007) *JGR*, 10.1029/2005JE002605; [6] Oshagan et al. (2014) *8th Mars*, 1427; [7] Delean (1997), U.S. patent 6,181,836. [8] Weiss et al. (2018) *LPSC*. [9] Scheller and Ehlmann (2018) *LPSC*. [10] Bramble et al. (2018) *LPSC*, 1705. [11] Kremer et al. (2018) *LPSC*, 1545. [12] Denton and Head (2018) *LPSC*.
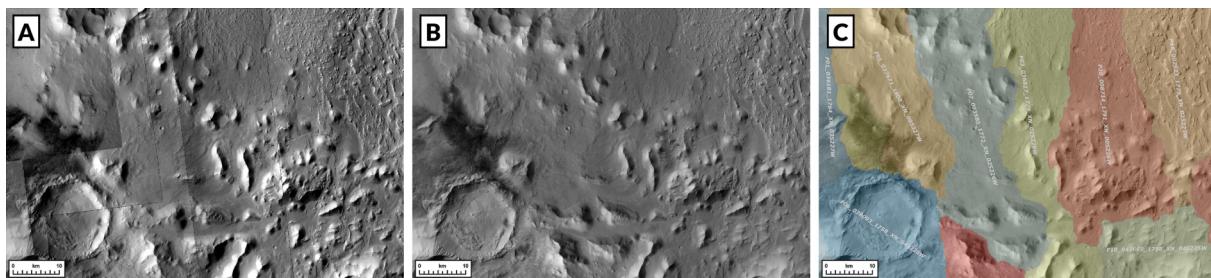

Figure 2. Blended and seam-mapped CTX mosaic of Nepenthes Mensae, Mars (centered at 133.8°E, 2.5°S). (A) 11 separate CTX orbits, contrast stretched individually. (B) Seamless mosaic of the same region. (C) Vectorized polygon seam map showing which orbit corresponds to each pixel within the composition. The automated seamline generation avoids regions of geologic interest (craters, isolated peaks) and preserves longer wavelength information like the diffuse low albedo region north of the large crater.