MIND THE GAP: HiRISE DATA PROCESSING TO ACCOMMODATE THE LOSS OF CCD RED4. S.S. Sutton[1], K. Akers[1], N.M. Bardabelias[1], N F. Baugh[1], V.J. Bray[1], S. Byrne[1], M. Chojnacki[2], I.J. Daubar[3], A. Fennema[1], R. Heyd[1], R. Leis[1], G. McArthur[1], A.S. McEwen[1], V.G. Rangarajan[4], C. Schaller[1], L.L. Tornabene[5,6]. [1]Lunar and Planetary Laboratory, Univ. of Arizona, Tucson, AZ USA (ssutton@lpl.arizona.edu), [2]Planetary Science Institute, Lakewood, CO USA, [3]Brown University, Providence, RI USA, [4]DLR Institut für Planetenforschung, Berlin, Germany, [5]Dept. Earth Sciences, Univ. of Western Ontario, London, Ontario, Canada, [6]Inst. Space & Earth Exploration, Univ. Western Ontario, Canada.

Introduction: The High Resolution Imaging Science Experiment (HiRISE) [1] has been in operation on the Mars Reconnaissance Orbiter (MRO) since 2006 [2]. The HiRISE focal plane contains 14 CCDs, with 10 CCDs spanning the full swath in the red visible bandpass (RED0–RED9). Additionally, 3-band color can be obtained in the central ~20% of the swath width from four 'color' detectors that overlap the coverage of RED4 and RED5: two CCDs with near-infrared filters (IR10, IR11), and two CCDs with visible blue-green filters (BG12, BG13) [1,3] (**Fig. 1**). Although the instrument remains in good health [4], two of the RED CCDs have failed: RED9 completely in August, 2011, and RED4 intermittently since July, 2023 (MRO orbit ~79,500) [5]. The failure of RED9 did not impact imaging strategies as it is on the edge of the image; the HiRISE image swath merely became 10% narrower after RED9 failed. However, the RED4 CCD is in the middle of the image swath, leaving a problematic gap in the images.

We present here the HiRISE team implementation of a substitution of the overlapping IR10 CCD for the missing RED4 data. IR10, which is aligned with RED4, presents similar data for dustier (spectrally bland) areas of Mars as the visible RED data.

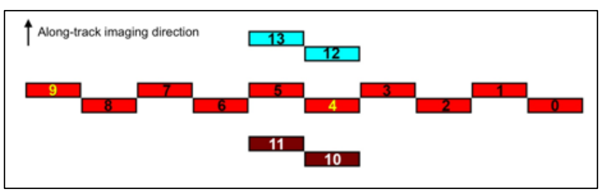

Figure 1. Schematic of the HiRISE focal plane detector layout. CCDs RED0–9 comprise the full swath width. RED9 and RED4 are indicated with yellow numbers. Each CCD is 2,048 pixels wide, and adjacent CCDs overlap by 48 pixels. Colors indicate spectral bandpasses: blue for BG (12,13), red for broadband RED (0-9), and brown for IR (10,11).

Impact on HiRISE planning: The feature of interest in a HiRISE observation is often in the center of the target. The loss of RED4 significantly impacts the acquisition of features that are on the scale of the width of one or two CCDs (~500 m to ~1 km). Targeting tools were updated to allow for a half-CCD shift to center the image in the middle of RED5, rather than at its edge, to avoid a gap over a small feature of interest [6]. We are exploring the use of a 1-CCD shift in repeat or stereo targets to extend color coverage. However, resources are not available for the additional detailed targeting necessary to utilize this shift for most targets. Therefore most HiWish [7] suggestions continue to be acquired by targeting the suggestion center. We do not recommend shifting HiWish suggestions to attempt to accommodate for the RED4 gap, as workarounds (see below) and possible future commanding updates may result in image data availability in the central gap.

Impact on HiRISE data processing: The gap from the missing RED4 results in issues with the image data when processed through the standard pipelines. For example, balancing the tone from CCD to CCD is not possible across the gap where RED4 would be, resulting in a tone difference on either side of the gap (**Fig. 2**). This tone difference also negatively impacted the anaglyph products, which are automatically produced from HiRISE stereo pairs.

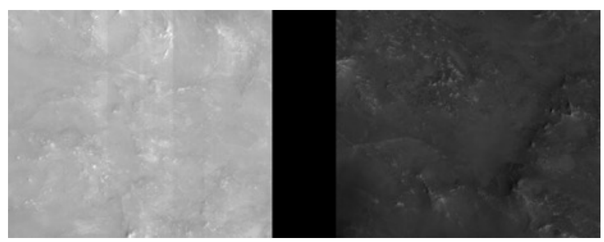

Figure 2. A portion of the 'NOMAP' product for HiRISE observation ESP_079886_2005 showing the gap where RED4 is missing. Note the tone difference across the image.

Creation of a synthetic RED4 product: As a partial solution, we have modified the HiRISE processing pipelines for images without RED4 to create a 'synthetic RED4,' or 'SYN4' product, that is used to fill the gap (**Fig. 3**). The SYN4 image is simply IR10 adjusted in overall brightness to match RED5. This works well for many martian scenes, but discrepancies are apparent when there are strong color contrasts in the surface.

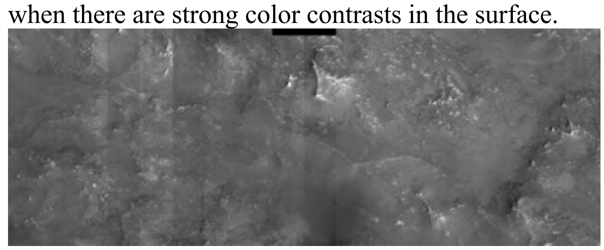

Figure 3. The same portion of the 'NOMAP' product as in **Fig. 2**, but with SYN4 (IR10) in place of the missing RED4 data. Note the improved tone balance.

We only use the SYN4 product to fill the gap in the PDS 'Extras' such as the non-map projected ('NOMAP') black and white images, the color RGB, merged color (MIRB and MRGB), and anaglyphs. The PDS standard products–map projected 'Color' IRB and black and white RDRs–retain the gap. The IRB images where RED4 is missing are therefore only 1 CCD wide.

Impact on DTM production: The loss of RED4 in one or both images of a stereo pair leads to a gap in the resulting Digital Terrain Models (DTMs). The gap itself would not prevent the creation of a DTM (with a gap), but the availability of the SYN4 product allows for gap-free topography and orthoimages.

The main modification of the DTM creation process [8,9] required updating the preprocessing steps to accommodate the SYN4 product. Preprocessing includes mosaicking adjacent, overlapping HiRISE image strips from each RED CCD that have been radiometrically and geometrically corrected [10,11]. Once the preprocessing scripts were modified to ingest the SYN4 data, the rest of the processing, using BAE Systems' SOCET SET photogrammetric software, is essentially the same. A note in the README file accompanying each DTM indicates whether RED4 was replaced with IR10.

DTM differences with SYN4. Another effect of using SYN4 is that the IR (and BG) CCDs are almost always acquired in a mode that sums two or more detector elements to increase the signal-to-noise ratio. This means that in some images, SYN4 data may have lower spatial resolution than the adjacent RED data. The HiRISE DTM ground sample distance (GSD) is typically 1 m for unbinned (bin1) images, and 2 m for bin2 images [9]. In cases where the images have been acquired in 'mixed bin' mode (i.e., some CCDs are bin1 and some are bin2), the GSD is set according to the bin mode of the highest resolution CCD(s). In practice, we find the effects of using SYN4 on DTM quality to be minimal (**Fig. 4**).

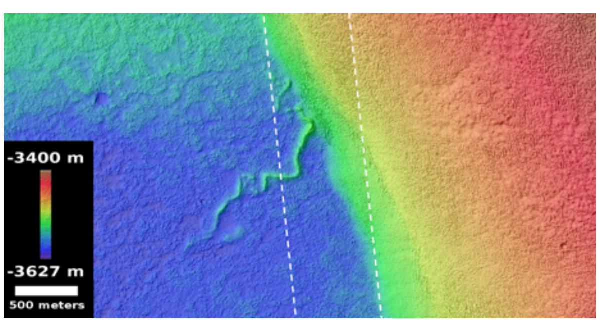

Figure 4. Detail of a colorized, shaded relief image of a HiRISE DTM where one image in the stereo pair (ESP_079716_2240) was missing RED4. White dashed lines indicate the location of the SYN4 data.

To test the effects of SYN4 on DTM quality, we are conducting controlled experiments comparing a DTM made from a stereo pair that includes RED4 to the same DTM made using simulated SYN4 data. We are analyzing the differences between the original DTM and the DTM produced with SNY4 data to understand potential effects on terrain quality. Preliminary results show differences have a mode near 0, with a mean (<0.5 m) and standard deviation (~0.6 m) within the typical estimated vertical precision of the HiRISE DTMs [8,9].

Impact on jitter correction: Due to the very high spatial resolution (1 μrad IFOV) and pushbroom operation of the HiRISE instrument, the images may be affected by spacecraft jitter. Although jitter is typically not visible to the human eye, it can have very negative effects on DTM production [11,12]. The HiPrecision image processing subsystem developed by the HiRISE team applies a precision geometric correction and optionally applies a jitter correction to images that display a mean jitter amplitude above a certain threshold [12]. Jitter correction relies on extracting pixel offset information from an overlapping set of CCDs, namely RED3, RED4, RED5, and BG12. RED4 overlaps each of the other three CCDs, and therefore its loss impedes the current jitter correction process. Work is in progress to accommodate the loss of RED4 in the HiPrecision subsystem.

Summary: The HiRISE team has replaced the loss of RED4 image data with data from IR10 (SYN4) in some of its processing pipelines. PDS standard products (RDRs) do not incorporate the SYN4 data. (Users should note that the Extras products are not intended for quantitative analysis.) The inclusion of SYN4 has minimal effects on image quality, and qualitatively improves the loss of a strip of image data in the center of the image. SYN4 data has been incorporated into DTM production with minimal impact. Jitter correction for images lacking RED4 is in progress. Upcoming flight tests may reveal whether RED4 can be usefully commanded again in the future, making the use of SYN4 an option only if necessary.

References: [1] McEwen, A.S. et al. (2007) *JGR*, *112-E5*, E05S02. [2] Zurek, R. et al. (2024) *Icarus,* 116102. [3] Delamere, W.A. et al. (2010) *Icarus*, *205-1*, pp. 38–52. [4] McEwen, A.S. and Byrne, S. (2024) *LPSC LV*, #1176. [5] McEwen, A.S. et al. (2024) *Icarus, 419,* 115795. [6] Baugh, N. et al. (2023) *ADASS-2023*. [7] Chojnacki, M. et al. (2020) *LPSC LI*, #2095. [8] Kirk, R.L. et al. (2008) *JGR*, *113*, E00A24. [9] Sutton, S.S. et al. (2022) *Remote Sensing*, *14*, 2403. [10] Becker, K. et al. (2021) *U.S.G.S Techniques and Methods,* 7-C27. [11] Kirk, R.L. et al (2003) *JGR*, *108*, 8088. [12] Sutton, S.S. et al. (2018) in *Planetary Remote Sensing and Mapping*, Ch. 8, Taylor & Francis.