Subpixel-Scale Topography Retrieval of Mars Using Single-Image DTM Estimation and Super-Resolution Restoration. Y. Tao[1], J-P. Muller[1], S.J. Conway[2], [1]Imaging Group, Mullard Space Science Laboratory, Department of Space and Climate Physics, University College London, Holmbury St Mary, Surrey RH5 6NT, UK (yu.tao@ucl.ac.uk; j.muller@ucl.ac.uk), [2]Laboratoire de Planétologie et Géodynamique, CNRS, UMR 6112, Université de Nantes, 44300 Nantes, France (susan.conway@univ-nantes.fr).

Introduction: High-resolution digital terrain models (DTMs) are considered a key geospatial data product for studying the formation processes of a planetary surface such as Mars. However, it has been a common understanding that DTMs derived from a particular imaging dataset can only achieve a lower, or at the best, similar effective spatial resolution compared to the input images, due to the various approximations and/or filtering processes introduced by the photogrammetric or photoclinometric pipelines. With the recent successes in deep learning techniques, it has now become practical and very effective to improve the effective resolution of an image using super-resolution restoration (SRR) networks [1] to produce sub-pixel images. The original and the SRR images can now be used to retrieve pixel-scale topography using single-image DTM estimation (SDE) networks [2], and eventually, combining the two techniques to produce subpixel-scale topography from only a single image input. In this work, we propose combining the use of SRR and SDE to boost the effective resolution of optical single-image-based DTMs to subpixel-scale [3].

Methods: An in-house implementation of the MARSGAN (multi-scale adaptive-weighted residual super-resolution generative adversarial network) SRR system [1] and the MADNet (multi-scale generative adversarial U-net based single-image DTM estimation) SDE system [2] are employed for this study. Our study site is within the 3-sigma ellipse of the Rosalind Franklin ExoMars rover's planned landing site (centred near 18.275°N, 335.368°E) at Oxia Planum [4].

We use as input the 4 m/pixel ESA Trace Gas Orbiter Colour and Stereo Surface Imaging System (CaSSIS) "PAN" band images [5] and the 25 cm/pixel NASA Mars Reconnaissance Orbiter High Resolution Imaging Science Experiment (HiRISE) "RED" band images [6] for our test datasets. We apply MARSGAN SRR to the original CaSSIS and HiRISE images, and subsequently, we apply MADNet SDE to the resultant 1 m/pixel CaSSIS SRR images and the 6.25 cm/pixel HiRISE SRR images. The final products are CaSSIS SRR-DTMs at 2 m/pixel and HiRISE SRR-DTMs at 12.5 cm/pixel, respectively. We show qualitative assessments for the resultant CaSSIS and HiRISE SRR-DTMs. We also provide quantitative assessments (please refer to [3], which are not shown here) for the CaSSIS SRR-DTMs using the DTM evaluation technique that is described in [7], using multiple smoothed versions of the higher-resolution reference DTMs to compare with the lower-resolution target DTMs.

Results: A small exemplar area (refer to "Zoom-in Area-1" in **Figure** 1 for its location) of the CaSSIS SRR MADNet DTM mosaic that overlaps with the HiRISE PDS DTM (DTEEC_039299_1985_047501_1985_L01), demonstrates the different level of details of the 25 cm/pixel HiRISE PDS ORI (ESP_039299_1985_RED_A_01_ORTHO), the 1 m/pixel CaSSIS SRR image, the 4 m/pixel original CaSSIS PAN band image (MY34_004925_019_2_PAN), the shaded relief images of the 8 m/pixel CaSSIS MADNet DTM, 2 m/pixel CaSSIS SRR MADNet DTM, 1 m/pixel HiRISE PDS DTM, and the 50 cm/pixel HiRISE MADNet DTM, which are all shown in **Figure 2**.

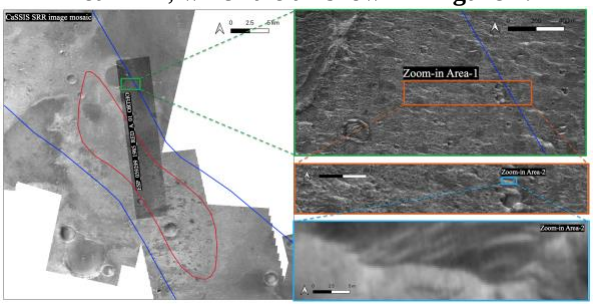

***Figure** 1. Locations of the exemplar zoom-in areas that are demonstrated next. **Left**: 25 cm/pixel HiRISE PDS ORI (ESP_039299_1985_RED_A_01_ORTHO) superimposed on top of the resultant 1 m/pixel CaSSIS SRR image mosaic [3], superimposed by the 1-sigma (red) and 3-sigma (dark-blue) ellipses of the Rosalind Franklin ExoMars rover's planned landing site at Oxia Planum; **Right**: multi-level zoom-in views of the same HiRISE PDS ORI.*

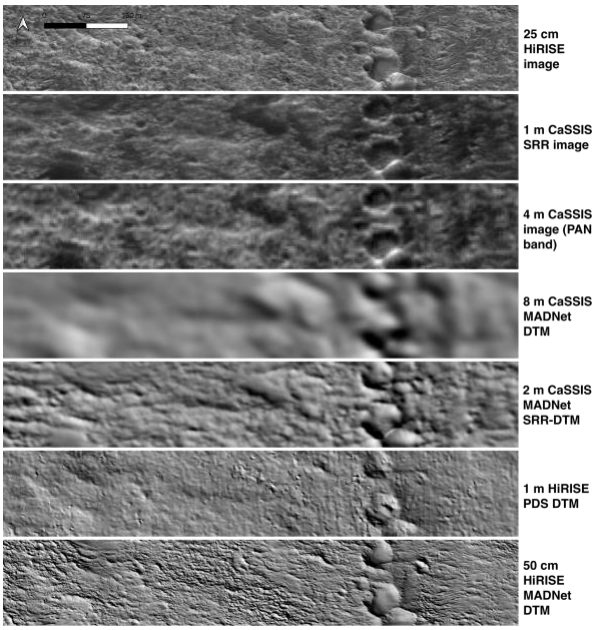

Figure 2*. Visual comparisons of a small exemplar area (i.e., "Zoom-in Area-1") of the reference 25 cm/pixel HiRISE PDS ORI, the resultant 1 m/pixel CaSSIS SRR image, the input 4 m/pixel CaSSIS PAN band image, shaded relief images of the resultant 8 m/pixel CaSSIS MADNet DTM, the resultant 2 m/pixel CaSSIS SRR MADNet DTM, the reference 1 m/pixel HiRISE PDS DTM, and the reference 50 cm/pixel HiRISE MADNet DTM (from top to bottom).*

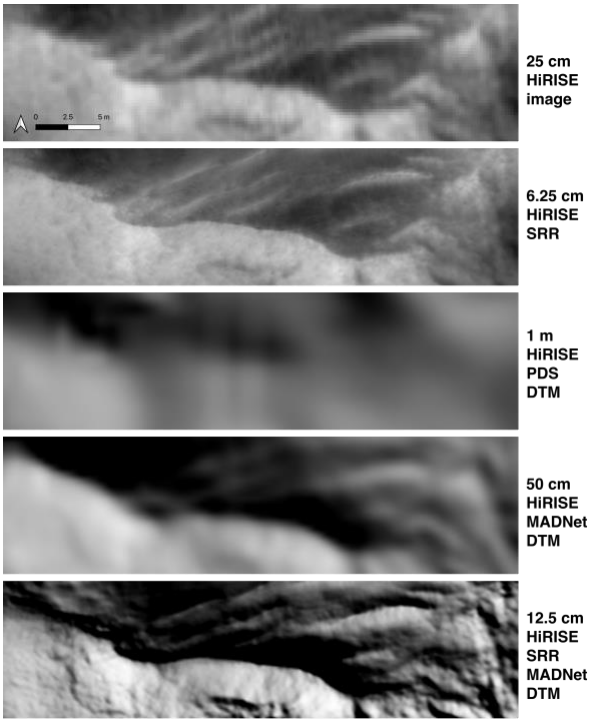

Figure 3*. Visual comparisons of a small exemplar area (i.e., "Zoom-in Area-2"–a subarea of "Zoom-in Area-1" that is shown in* ***Figure 2****; location is shown in* ***Figure*** *1) of the input 25 cm/pixel HiRISE PDS ORI, the resultant 6.25 cm/pixel HiRISE SRR image, the shaded relief images of the reference 1 m/pixel HiRISE PDS DTM, the reference 50 cm/pixel HiRISE MADNet DTM, and the resultant 12.5 cm/pixel HiRISE SRR MADNet DTM (from top to bottom).*

Figure 3 shows a zoom-in view of a subarea (over the southern ridge of the larger crater on the northeast area; refer to "Zoom-in Area-2" in **Figure** 1 for its location) of the larger extent of this work [3]. We can observe that the peaks shown in the 12.5 cm/pixel HiRISE SRR MADNet DTM are visually much sharper than the same features that are shown in the 50 cm/pixel HiRISE MADNet DTM and 25 cm/pixel HiRISE image. On the other hand, small surface details are revealed in the 6.25 cm/pixel HiRISE SRR image, and their associated topography is revealed in the 12.5 cm/pixel HiRISE SRR MADNet DTM.

Conclusions: In this work, we show that we can use coupled MARSGAN SRR and MADNet SDE techniques to produce subpixel-scale topography from single-view CaSSIS and HiRISE images. The resultant CaSSIS and HiRISE SRR MADNet DTMs are being published through the ESA planetary science archive's Guest Storage Facility (GSF) [8] at https://www.cosmos.esa.int/web/psa/ucl-mssl_meta-gsf. We strongly recommend that the readers download the full-size full-resolution SRR and DTM results and look into their details. In the future, we plan to apply the same technique on repeat single-view observations to study per-image (i.e., HiRISE and CaSSIS) topographic changes of very-fine-scale dynamic features (e.g., slumps and recurring slope lineage) of the Martian surface.

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