VENUS DESCENT IMAGING FOR SURFACE TOPOGRAPHY AND GEOMORPHOLOGY: J. B. Garvin[1] (james.b.garvin@nasa.gov), L. S. Glaze[1], M. A. Ravine[2], and R. Dotson[3] ; [1]NASA Goddard, Greenbelt, MD 20771, [2]Malin Space Science Systems, San Diego, CA, [3]Fireball LLC, Reno NV (supporting NASA GSFC).

Introduction: Descent imaging from ~ 10 km to a few meters above the Venusian surface from future in situ probes and landers can provide unique, multi-scale views of the geology in three dimensions, in spite of the challenges of the Rayleigh-scattering atmosphere. Planetary descent camera images have been used to compute digital elevation models (DEM) at multiple scales for the purpose of quantifying local-to-regional terrain characteristics at scales not routinely possible from orbital stereo images using MARDI on Curiosity (Mars). Using state-of-the-art *Structure from Motion* (SfM) algorithms that go beyond the classical Scale-Invariant Feature Transform (SIFT), we have constructed and validated DEM's from bundles of simulated Venus descent images with varying vertical and horizontal baselines as a forerunner for future terminal descent imaging experiments for Venus in situ missions. Previously, we demonstrated that small sets of MARDI images (5 to 50) could be used to produce 30-100 cm ground scale distance (GSD) DEM's with vertical precisions that rival those from orbit (i.e., MRO's HiRISE c/o Randy Kirk and Tim Parker) [1].

We simulated terminal Venus descent imaging scenarios using a NASA WFF UH-1 helicopter and a professional UAS (drone) from altitudes extending from ~1.5 km to 3 m above local surfaces over a large quarry with variable surface textures and landscape elements (**Fig. 1**). These flight experiments acquired data in a vertically nested imaging geometry with variable down-track (horizontal) drift to emulate the likely range of near-surface winds on Venus. Detailed investigation of derived DEM's indicates that the local topography derived from emulated Venus descent image based DEM's reveals aspects of the underlying structure not entirely evident from orbital stereo images such as those from DigitalGlobe's Worldview series of spacecraft with as fine as ~40 cm/pixel resolution.

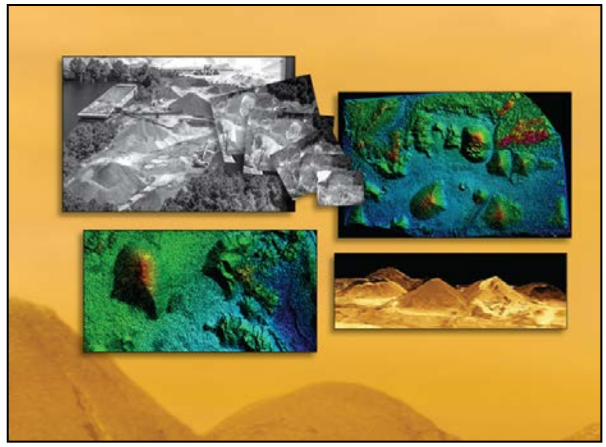

Figure 1. DEM topography derived from NASA WFF UH-1 Venus descent imaging experiment from 1.5 km to 3 m altitudes over a Venus-analogue quarry site. Descent images and derived DEM's and perspective views are illustrated.

SCIENCE GOALS: In addition to computation of quantitative relief models (DEMs) from terminal descent imaging data, it is additionally possible to constrain the distribution of clastic particles at a Venus touch-down site from the final images whose spatial sampling may be as fine as ~4 cm/pixel. Using images with spatial resolutions in the 4-10 cm/pixel interval, we have quantified the distribution of "boulders" (rocks larger than 25.6 cm diameter) and compared results to field measurements, with agreement to within < 10%. Such information for Venus landing regions in complex ridged terrain settings may provide additional constraints on the erosional history of these important areas. Finally, sets of specific objectives with respect to process-scale origin and evolution of landscapes can be developed and traced to NRC Decadal Survey and VEXAG goals from high SNR descent imaging as is now possible thanks to the pathfinding results from the MARDI descent camera on MSL/Curiosity [1,2].

A key question for Venus surfaces at local geologic scales is the role of sedimentary processes, if any. Understanding the intensity and vigor of processes that transfer masses of materials to form depositional units on Venus could have a direct bearing on the role of wind and potentially of former oceans in the planet's poorly constrained history. Quantitative DEM analysis at sub-meter spatial and vertical scales can elucidate diagnostic features associated with specific processes, and constrain recent geologic activities. While these measurements cannot be regional to global in extend, as with the Venera Lander imaging observations, they can be put into their broader context with Magellan radar imaging and topography.

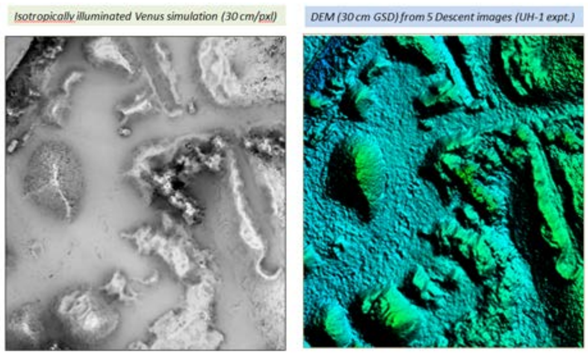

Figure 2. Simulated Venus descent image (LEFT) at 30 cm/pixel with isotropic illumination (from NASA UH-1 descent image) compared with DEM (30 cm GSD) derived from 5 images during descent of this region. The FOV in this graphic is 150m x 150m, and relief varies from 0 to 10m.

Methods: Over the past ~ 3 years, we have evaluated the potential for descent imaging at Venus in support of multiple missions whose primary objectives were linked to priority NRC Planetary Decadal Survey goals for Venus. NASA UH-1 flight experiments were conducted in August 2016 and UAS-based data collections in September 2017, with independent measurements from NASA/GSFC/WFF aircraft imaging lidar altimeters (ATM-6, LVIS). Data analysis and calibration/validation produced results consistent with science requirements for mission concepts to Venus. Additional drone-based flight experiments are anticipated in 2018 pending FAA clearances.

Topography results: DEM's ranging in spatial scale (GSD) from 7m down to 10-15 cm were generated from bundles of Venus descent simulations and validated against independent measurements of smooth test areas (and local water). Scientific assessment of particle size distributions and vertical offsets were conducted and compared with field observations. **Figures 1-3** demonstrate the potential of the data, as does ongoing analysis of the MSL MARDI descent imaging dataset (courtesy M. Malin, PI). Linking DEMs from descent imaging to Magellan SAR images (FMIDRs) is possible for the higher-altitude cases (DEM scales of 2 km x 2 km and larger at grid scales of 7-10m). Automatic classification of geomorphic landscape features has been assessed as well [1].

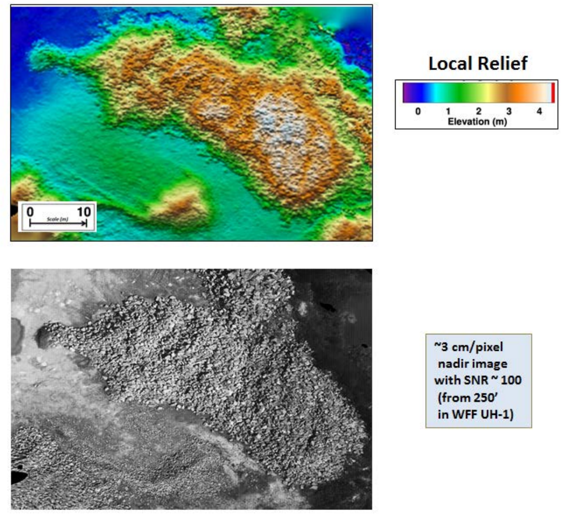

Figure 3. Finest scale topography and imaging possible at Venus from state-of-the-art descent imaging systems as could be flown on future in situ probes/landers.

Discussion: Descent imaging during the final ~ 2 km of terminal EDL at Venus has the potential of providing quantitative geologic information that would bridge the scale-gap from orbital radar (SAR) and landed panoramic imaging. By using vertical-baseline stereo SfM algorithms, DEM's derived from 5 or more images can provide sub-meter topographic data to potentially constrain tectonic processes, sedimentary mass transfer styles, and local geologic history including the efficacy of erosion. Images with spatial resolutions as fine as 5-10 cm can be collected in the final 100's of meters of descent at Venus with detail sufficient to constrain the size and spatial distribution of clastic materials thereby enabling comparisons with Earth and Mars. Our flight simulations using Helicopter and UAS capabilities (at GSFC/WFF) have developed datasets which validate these abilities in the context of most likely imaging illumination conditions. Any future probe or lander to Venus could take advantage of planetary flight imaging systems to deliver quality, calibrated descent imaging relevant to VEXAG and NRC Decadal goals. We are continuing to evaluate our Earth analogue datasets and the MSL MARDI complete descent imaging sequence to optimize the science potential for this type of high-impact imaging dataset. [*We acknowledge the support of GSFC Center Director C. Scolese to enable much of this work, as well as the encouragement of NASA Astronaut J. Grunsfeld (also NASA SMD AA*].

References:

[1] Garvin J.B. *et al.* (2017) *LPSC 48, Abstract # 2526.*
[2] Malin M. C *et al.* (2017) *Earth Space Sci. 2017* Aug; 4 (8): 506–539.