CHARACTERIZATION OF SAFE LANDING SITES ON VENUS USING VENERA PANORAMAS AND MAGELLAN RADAR PROPERTIES. K. M. Stack,[1] J. Rabinovitch[1], and M. A. Bullock[2] [1]Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, Pasadena, CA 91109 (kathryn.m.stack@jpl.nasa.gov), [2]Southwest Research Institute, Boulder, CO 80302.

Introduction: Designing and safely delivering a ground-based mission to Venus requires knowledge of local surface roughness, slope, and the size distribution of hazards in relation to the clearance and stability configuration of the spacecraft. Unfortunately, the resolution and wavelength limitations of existing orbital datasets for Venus preclude landing site assessments analogous to the proven methods developed for Mars landing site analysis. Yet there is widespread recognition by the planetary science community that future missions to the surface of Venus will likely result in groundbreaking scientific discoveries [1]. This study explores methods for identifying and characterizing sites on Venus where a lander could attain a high probability of safe landing through a synthesis of Venera surface panoramas, Magellan radar properties, and existing global geological maps of the Venus surface.

Analysis of safe landing constraints from Venera panoramas: An exponential rock size-frequency distribution model developed by [2,3] was fit to rock measurements from Venera 9 and 13 made by [4] to represent "blocky" and "typical" surfaces on Venus, respectively. When such models are applied to Mars, rocks are generally assumed to be hemispherical [3], but measurements made in this study from 33 blocks in the Venera 9 panorama resulted in an average aspect ratio of 0.26. Applying a correction factor suggested by [2] to account for long axis bias, resulted in a more conservative average aspect ratio of 0.35. The average aspect ratio calculated from 53 blocks measured in the Venera 13 panoramas is 0.15 (0.19 corrected). These aspect ratios reflect the predominance of tabular rather than spherical rock fragments observable in the panoramas.

Rock distributions calculated from the Venera 9 and Venera 13 landing site panoramas that take into account the new measured aspect ratio values yield important implications for landing safety. There is a 0.1% chance of encountering a rock with a height of 0.7 m within a ~1 m diameter circle based on the Venera 9 rock distribution, while that height drops drastically to ~0.1 m for the calculated Venera 13 rock distribution. From the perspective of spacecraft design and landing safety, a Venera 13-like surface represents a significantly less challenging terrain than that observed by Venera 9. Thus, identifying Venera 13-like landing sites elsewhere on the planet could provide additional locations where a ground-based mission has a high probability of achieving a safe landing.

Magellan orbital data analysis: It is not possible at present to quantify rock distributions and surface roughness for most of the Venusian surface, but there may be promise in defining criteria for safe landing sites that integrate orbiter and ground-based observations of the surface, e.g., [5]. This study identifies "Venera 13-like" terrains on Venus using a suite of Magellan radar properties correlated with and extrapolated from the Venera 13 landing area.

Methods and Data. The ~300 km diameter circle representing the Venera 13 landing area was overlain on the global Venus geological map constructed by [6]. Within this landing area, the most extensive unit mapped is "Regional plains, upper unit" (rp2). The terrain mapped as rp2 is also the darkest, most featureless terrain within the landing area as observed in Magellan SAR data. Although the exact location of Venera 13 within the landing area is unknown, correlating the rp2 unit with the terrain viewed in the Venera 13 panoramas is the conservative and most statistically robust assumption.

Using Magellan Global Altimetry and Radiometry Records [7], rms slope, emissivity, and reflectivity values were extracted for each pixel that fell within the Venera 13 rp2 unit. Pixel DN values were extracted from a left-look 75 m/pixel Magellan SAR basemap down sampled to 4641 m/pixel in Matlab using bicubic interpolation to match the resolution of the other datasets. Pixel DN values were then converted to backscatter coefficient using the equations of [8,9]. For comparison, radar parameters were also extracted for all other pixels falling within the Venera 13 landing area, as well as those within the Venera 9 landing area (Figure 1).

The min-max ranges of the 4 radar parameters (emissivity, reflectivity, rms slope, backscatter coefficient) extracted from the Venera 13 rp2 unit were then used as a filter to identify other Venera 13-like areas on the planet (Figure 2). 150 km diameter ellipses were overlain on areas of the surface in which at least 99% of the pixels exhibited radar properties within the Venera 13 rp3 bounds. This process was repeated for the entire map, using a 10-pixel increment (both in east/west and north/south directions) to cycle through all coordinates.

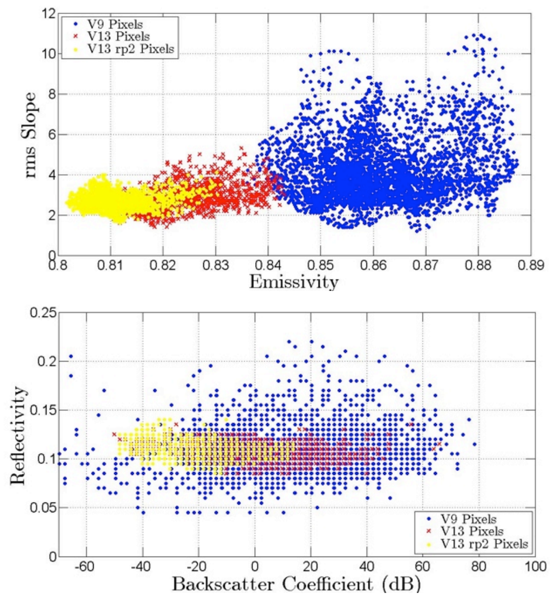

Figure 1. Plots of rms slope vs. emissivity (top) and reflectivity vs. backscatter coefficient (bottom) extracted from the Venera 9 and 13 landing areas.

Results. Using the criteria defined above, approximately 8% of the Venus surface is characterized as Venera 13-like, within which one hundred and thirty one 150 km ellipses can be fit (Fig. 2). These landing ellipses are predominantly composed of regional plains units (rp1 and rp2 of [6]), but additional geologic units included within the ellipses are the lobate plains, shield plains, shield clusters, and the smooth plains units.

Discussion. This study presents one way to identify and characterize potential safe landing sites on Venus with existing orbiter- and ground-based data, but there are numerous caveats to consider. This approach does not directly take into account the potential non-uniqueness of radar-derived properties in relation to surface roughness vs. dielectric constant, nor does it account for the possibility that the properties used to define Venera 13-like terrains may not be directly relevant to the safety of a lander (i.e., compositional variations or km-scale undulations in slope vs. cm- or dm-scale roughness). However, the plots presented in Figure 2 inspire some confidence that Magellan radar parameters can be used to distinguish Venera 13-like terrains from areas of the surface that may present a greater challenge for safe landing. In particular, the plot of rms slope versus emissivity (Figure 1) shows that the pixels mapped as rp2 within the Venera 13 ellipse are completely distinct from the cloud of points representing the Venera 9 landing area. The plot of reflectivity versus backscatter coefficient also indicates that the Venera 13 rp2 filter is likely capable of excluding those terrains which appear radar dark due to dielectric properties rather than surface roughness. The method presented here also likely misses many areas that would be safe land sites, but that fall outside the radar parameter ranges for the Venera 13 rp2 unit due to variations in composition or material properties not relevant to lander safety. Admittedly, the method presented here is conservative, but it represents a best-effort starting point that uses existing data to discriminate between areas of the Venus surface that may be more or less challenging from a landing safety perspective.

References: [1] *Vision and Voyages Planetary Science in the Decade 2013-2022* (2011). [2] Golombek M. and Rapp D. (1997) *JGR-Planets*, *102*, 4117-4129. [3] Golombek M. et al. (2003) *JGR-Planets, 108,* E12. [4] Basilevsky A. (1985) *GSA Bulletin, 96*(1), 137-144. [5] Garvin J. B. and Head J. W. (1981) *LPS XIV,* 235-236. [6] Ivanov M. A. and Head J. W. (2011), *PSS, 59,* 1559-1600. [7] Ford P. G. (1991) Global Altimetry and Radiometry Data Record. [8] Long S. M. and Grosfils E. B. (2005) *LPS XXXVI*, Abstract #1032. [9] Campbell B. A. (1995), *USGS* Open-File Report 95-519.

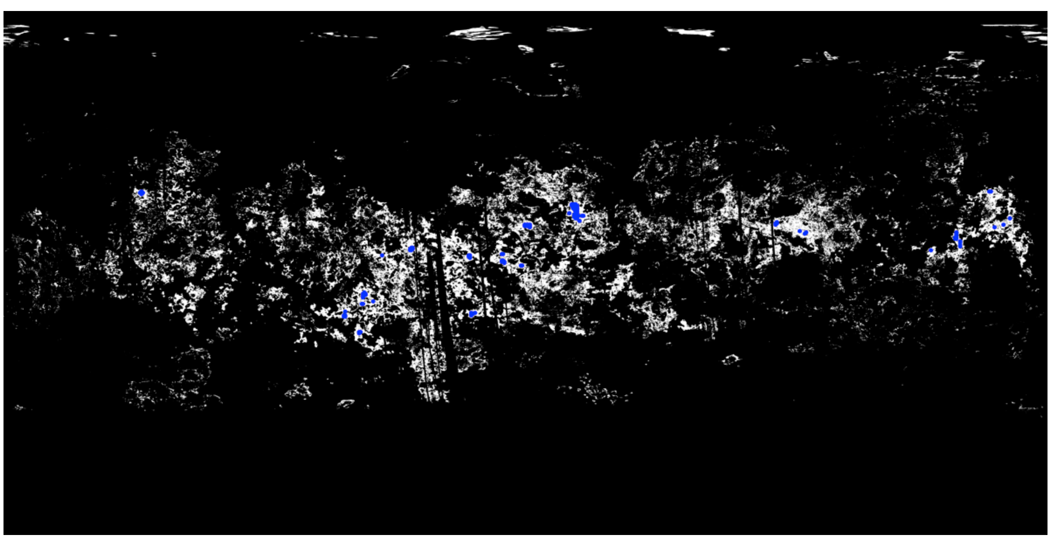
Figure 2. A cylindrical projection (longitude ranges from -180º to +180º; latitude ranges from -90º to +90º) highlighting in white all portions of the surface whose rms slope, emissivity, reflectivity, and backscatter coefficient values fall within the range observed for the Venera 13 rp2 unit. 150 km ellipses are shown in blue.