

NORTH-SOUTH ROUGHNESS ANISOTROPY ON VENUS: SIGNATURE OF CRATER-RELATED PARABOLAS. *N. V. Bondarenko*^{1,3}, *M. A. Kreslavsky*^{2,3} and *J. W. Head*³, ¹Institute of Radiophysics and Electronics, National Academy of Science of the Ukraine, 12 Ak.Proskury, Kharkov, 61085, Ukraine, natasha@mare.geo.brown.edu; ²Kharkov Astronomical Observatory, Kharkov, Ukraine; ³Dept. Geol. Sci., Brown University, Providence RI, USA.

Introduction. Raw data of the Magellan radar altimeter (RA) experiment were processed independently by two teams. Processing carried out at MIT resulted in widely used maps of topography (GTDR data set from the Planetary Data System PDS), as well as maps of Fresnel reflectivity (GReDR) and Hagfors' roughness parameter (loosely named RMS slope) (GSDR data set). Processing carried out at Stanford University was focused on surface roughness properties extraction rather than on ranging results. Initial results from these works were reported in [1]. Later these efforts led to archiving of the results in the PDS as the so-called SCVDR data set (Surface Characteristics Vector Data Record), where data are stored as points along orbits in the sequence the observations were done, and the GVDR data set (Global Vector Data Record), where data are presented in a map-projected gridded format. We are now applying these data to geology-related studies.

Here we report on our preliminary results on the study of the Doppler centroid shift f_D , one among a number of parameters from the SCVDR and GVDR. This parameter characterizes along-track anisotropy of the backscattering function of the surface, it is most probably related to N-S asymmetry of the decameter-scale surface topography.

Doppler centroid maps: The RA echo has been sampled according to the Doppler shift into 17 bins, 935 Hz per bin (details are in [1]). This sampling is equivalent to subdivision of the RA footprint into 17 stripes normal to the orbit track. The single-burst footprint size is ~ 25 km near the Magellan orbit periaxis ($\sim 10^\circ$ N) and up to 220 km in the polar regions. For a globally horizontal surface with an isotropic backscattering function, the echo spectrum is symmetric with respect to the Doppler frequency corresponding to the nadir, and the maximum echo returns from the nadir stripe. For some areas on Venus, however, the observed Doppler spectrum is biased toward either positive or negative frequencies [1]. This means that the strongest echo in the along-track direction is coming from either ahead of or behind the nadir, respectively. This effect is correlated among different orbits over hundreds of kilometers on Venus, and is considered to be real [1]. Uncertainties in the Doppler shift due to inaccuracy of orbit and gravity field knowledge is at least 2 orders of magnitude smaller than the observed effect.

The SCVDR data set includes estimates of the centroid of the Doppler echo sample relative to the nadir from data averaged over each five RA bursts along orbits. The GVDR data set includes a map of the Doppler centroid; the gridding algorithm account-

ing for the effective footprint size, which provides theoretically optimal noise suppression with maximal preservation of information. We, however, generated another version of a gridded map of f_D using a simpler algorithm, which ignores the footprint size: for each map cell (in the simple cylindrical 4-cells-per-degree projection) we took a weighted average of all data points whose footprint centers are within the cell; we used the inverse formal error in the f_D determination as the weight. Typically, there are from 1 to 4 data points per map cell. Our map provides better visual sharpness, which is useful for morphological comparison with radar images. A small part of the map is shown in the inset in **Fig. 1**.

Physical meaning of Doppler centroid: The reason for the f_D shift from the nadir can be large-scale surface tilts [1]. One bin (935 Hz) corresponds to the surface tilt of 0.4° over the footprint in the periaxis regions and up to 0.8° in the polar regions. In rare cases large-scale slopes of comparable steepness exist on Venus, and they are clearly seen in the f_D maps. The region adjacent to Artemis Chasma was mentioned in [1]; we found a number of other examples. In addition, somewhat shorter slopes of degree-scale steepness are more frequent on Venus, and we observe a characteristic signature of such slopes in the map at several sites, where they are located amid plains (e.g., wide arrow in **Fig. 1**).

In large tessera areas, relatively steep large-scale slopes are ubiquitous, and f_D for each RA burst is defined by the actual balance of ten-km-scale slopes of different orientation within the footprint. This leads to an extremely noisy, spotty appearance of tessera in our map (e.g., **T** in **Fig. 1**). Sharp boundaries between units with extremely different normal reflectance can cause a shift of f_D ; we encountered examples of this kind. These places in most cases should have high formal standard deviation of f_D over the five RA bursts forming one data point, and weights in our gridding procedure diminish the role of such footprints.

In the plains, there are usually no large-scale slopes that can affect f_D , while its systematic shift is observed in many locations. In [1] saw-like small-scale topography and anisotropy of the backscattering function were considered as possible causes of this effect. Since large-scale strong anisotropy of electromagnetic properties of surface material is highly improbable, the only cause for the backscattering function anisotropy is anisotropy of subresolution-scale surface topography and structure, and there is no reason to distinguish between a specific surface topography effect and backscattering function anisotropy.

Thus, in flat areas, the Doppler centroid is a measure of the north-south asymmetry of surface topography (roughness) at scales from centimeters to hundreds of meters. Since the slopes - Doppler shift relationship and the footprint size strongly change with spacecraft altitude, f_D is much more sensitive to the asymmetry near periapsis (low latitudes) than at high latitudes.

Anisotropy of small-scale topography on Venus has been also observed at larger radar incidence angles with Magellan SAR data. In [2], three cases of very strong east-west asymmetry of the radar cross-section were interpreted to be due to the presence of microdunes at the surface. Systematic study [3] has revealed that much weaker east-west asymmetry is ubiquitous. It has been attributed to small-scale dunes and ripples, and some indications have been found that clear lava flow surfaces can also have anisotropic topography.

Analysis of Doppler centroid maps: The plains areas of pronounced non-zero f_D are concentrated in an equatorial belt, which is an obvious result of the latitude trend of f_D sensitivity to roughness anisotropy. Areas of pronounced non-zero f_D on both sides of Aphrodite Terra tend to have the opposite signs of non-zero f_D (although some exceptions exist). This can be related either to a systematic pattern of microdune-forming winds related to global atmospheric circulation, or to a systematic pattern of plains-forming lava flow directions related to global topographic trends.

We searched for correlations of contrasts in non-zero f_D with geologic units boundaries, using Magellan SAR mosaics. Such correlations exist in some places, which provides an independent proof that the f_D variation is a real surface signal rather than an observational artifact. The most well-expressed correlation found so far is related to dark diffuse crater-associated parabolas. One of the best examples is shown in Fig. 1. In this example the parabola related to crater Bassi has $f_D \approx 0$, while the volcanic plains unit over which the parabola is superposed, has a pronounced N-S slope asymmetry. A similar situation is observed for craters Ban Zhao, Boleyn, Faustina, Carson, Himiko and others. In many cases the background has no pronounced asymmetry, and parabolas do not appear in the f_D map. Nevertheless, absence of roughness asymmetry is typical for all dark parabolas.

Doppler centroid signature of dark parabolas. Parabolas are thought to be formed by a meter-scale-thick flat-surface mantle of loose material deposited after the impact [4, 5]. Recently multipolarization Arecibo radar observations gave an independent support for this model [6]. In the frame of this model, the RA echo from the parabola is composed of two components. The first component comes from the mantle surface and has very narrow unbiased Doppler spectrum. The second component comes from the mantle / substrate interface, which we suppose to be asymmetric (because the surface adjacent to the parabola has $f_D \neq 0$). The Doppler spectrum of this component is narrower than that of clean substrate surface due to the deflection of electromagnetic waves at the mantle

surface, hence, its f_D is smaller. This component is much weaker than the echo from a clean surface due to absorption within the mantle. Thus, the composite echo would have small f_D of the same sign as the clear substrate. Our estimates show the f_D of the mantled surface would be indistinguishable from 0, taking into account low S/N ratio of f_D measurements.

Discussion and future work: The north-south anisotropy of small-scale topography adds a new dimension to understanding Venus surface properties and surficial deposits. Further work on the correlation of areas of well-expressed asymmetry with geological features seen in the SAR mosaics is underway in order to understand the role of wind-related processes in asymmetry formation. The f_D map is a potential source of information on the presence and distribution of surficial deposits. This information is critical for planning future landing missions to Venus.

A few independent lines of evidence show that dark crater-related parabolas are made of loose material and have flat surface. It remains flat for geological long enough time to form a few more large craters. Further study of parabola surface properties and the sequence of their degradation can help in reconstruction of Venus' geological history [e.g., 7].

References: [1] Tyler, G. L. et al. (1992) *JGR* **97**, 13115 – 13139. [2] Weitz, C. M. et al. (1994) *Icarus* **112**, 282 – 295. [3] Kreslavsky, M. A. and Vdovichenko, R. V. (1999) *Solar System Res.* **33**, 110. [4] Campbell, D. et al. (1992) *JGR* **97**, 16249 – 16277. [5] Bondarenko, N. B., and Head, J. W. (2004) *JGR* **109**, doi:10.1029/2004JE002256. [6] Carter, L. M. et al. (2004) *JGR* **109**, doi:10.1029/2003JE002227. [7] Basilevsky, A. T. and Head, J. W. (2004) *LPSC* 35, #1133.

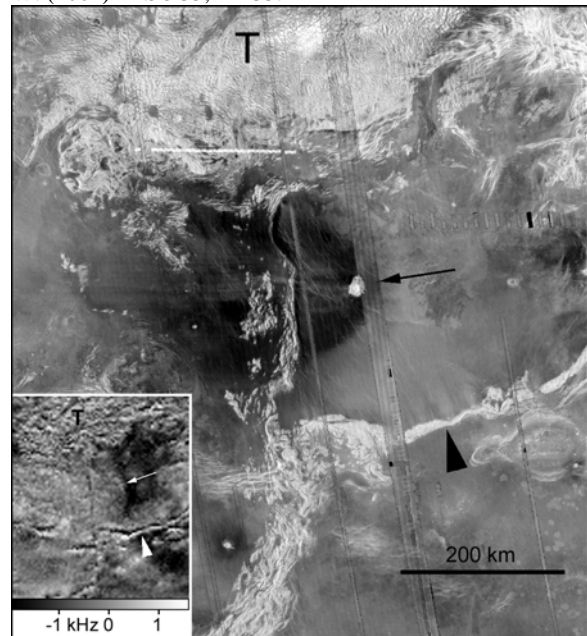


Fig. 1. Magellan SAR mosaic of crater Bassi (35 km diameter, 19°S 64.7°E, thin arrow) and vicinity. Inset shows the Doppler centroid map of the same areas, gray shades denote $f_D \approx 0$, dark and bright shades mean deflection of the Doppler centroid from nadir. Wide arrow shows a ridge with clear expression in the Doppler centroid map. T, Ovda Tessera.