THE RADAR SCATTERING CHARACTERISTICS OF VENUS LANDFORMS

Peter G. Ford
Center for Space Research, Massachusetts Institute of Technology

David A. Senske
Department of Geological Sciences Brown University

Abstract. Nine geologic units are identified in a recently published Arecibo image of the Venus equatorial region [Campbell, et al., 1990]. A detailed examination of the radar scattering properties of these units using data from the imaging mode of the Pioneer Venus Radar Mapper (PVM) shows them to fall into three distinct classes: 1) dark plains, 2) tessera, narrow-spaced parallel lineaments, and bright and dark banded terrain, and 3) bright plains, mottled plains, ovoids, lineament belts, and edifices. Additional units interpreted to be analogous to those mapped from the Arecibo data are identified in the region imaged exclusively by PVM, and are found to have similar scattering properties. An examination of the scattering properties of units mapped as tessera—Tellus Regio and eastern Beta Regio, as compared with the northern flanks of Thetis Regio—leads to the conclusion that part of Thetis possesses characteristics similar to Tellus.

1. Introduction

Over the past two decades, much of the Venus surface has been observed by several orbiting and earth-based radars, but most geological and geophysical interpretations have compared the shape and texture of regions of varying backscatter, rather than quantitative measurements of cross-section. One major exception is the case of nadir-pointing measurements, for which a realistic model exists [Hagfors, 1967] to explain the strong enhancement observed in polarized radar back-scattering at small angles. The resulting "quasi-specular" scattering cross section, \( \sigma_{q,s} \), depends on \( p \), the Fresnel reflectivity of the facets, on \( \Theta \), and on \( C \), the distribution of wavelength-scale tilts, as

\[
\sigma_{q,s} = \frac{C p}{2} \left( \cos^4 \theta + C \sin^2 \theta \right)^{-3/2}
\]  

where the R.M.S. surface slope (in radians) is \( C^{-1/2} \).

2. Diffuse Scattering

Of necessity, most earth-based radar observations of Venus are not made at near-normal incidence, with the exception of those from the Goldstone observatory [Arvidson et al., 1990]. Those from the Arecibo radar [Campbell et al., 1989] vary from 20° to 70°, and the synthetic aperture images anticipated from the Magellan orbiter will vary from 18° to 50°. At these large angles, reflections from the tilted facets of the Hagfors model no longer predominate, and the principal scattering mechanism is believed to be due to sub-wavelength scale inhomogeneities in the surface and sub-surface medium [Ulaby et al., 1982]. There is currently no counterpart to the Hagfors model that relates the large-angle scattering cross-section to surface parameters, although the average scattering behavior is quite well represented by the expression [Muhleman, 1964]

\[
\sigma_{tot} = \beta \cos \theta \left( \sin \theta + a \cos \theta \right)^3
\]  

where \( \alpha \) and \( \beta \) are purely phenomenological constants. This expression describes both the small-angle quasi-specular and large-angle diffuse scattering components, but the relation of \( \alpha \) and \( \beta \) to surface properties is unknown. In principle, they could be deduced from observations of particular regions at varying angles of incidence, but of the four existing data sets, those from Venera and Goldstone are taken at too small an incidence angle, those from PVM are typically at too low a resolution to uniquely classify individual terrain types, and those from Arecibo observe each particular feature at only one incidence angle.

To perform our analysis of the scattering properties of individual scattering regions, we combine two of these data sets—Arecibo and PVM—using the former to identify regions of a particular surface type and the latter to determine their scattering properties. As a test of this methodology, we shall also predict the nature of some regions seen by PVM at low resolution but out of sight from Arecibo, which are soon to be observed by Magellan.

3. Geologic Units in the Arecibo Image

As a first step in our analysis, we use a classification of geologic units in the Venus equatorial region using Arecibo images (1.5- to 2.0-km resolution) [Campbell et al., 1990], were obtained during the 1988 inferior conjunction. Nine distinct geologic units have been mapped from these data as illustrated in Figure 1, and the characteristics of each unit are summarized in Table 1 [see also, Campbell et al., 1990; Senske et al., 1990]. In order to examine the uniqueness of units, each was compared with different image datasets obtained with different viewing geometries and ranges of incidence angles.

The next step was to examine the PVM observations [Masursky et al., 1980; Senske, 1990] of these same regions. The data set consisted of about 2 million measurements of back-scatter cross section at all longitudes and from 15°S to 45°N latitude. The footprint resolution varied between 25x25 km and 50x50 km, depending on spacecraft altitude (150- to 500-km) and incidence angle (15° to 65°). However, fully half of the measurements of \( \sigma_0 \) contained large uncertainties due to low signal strength or systematic timing errors, and were therefore discarded. Of the remainder, some 185,000 overlapped the region of the Arecibo image.

The quasi-specular component (equation 1), was then

Copyright 1990 by the American Geophysical Union.

Paper number 90GL01548
0094-8276/90/90GL-01548$03.00
removed from each PVM measurement, using the measurements of C and p made over the same regions by the Pioneer Venus altimeter. This technique has been described by Pettengill et al. (1988). The total cross section, \( \sigma_{\text{tot}} \), is assumed to have a quasi-specular part given by equation 1, and a diffuse part, \( \sigma_{\text{diff}} \), that dominates the scattering behavior at angles larger than about 25°. The quasi-specular component was removed in order to reduce the effect of variations in meter-scale surface slopes, which dominate at scattering angles of less than about 25°. The resulting values of \( \sigma_{\text{diff}} \) are shown in Figure 3, grouped by unit type as determined from the Arecibo image. Also shown is the average scattering law parameterized according to equation 2 with \( c = 0.1164 \) and \( \beta = 0.0218 \).

Three broad groups of surface elements are observed in Figure 3. Their scattering behavior was best parametrized by a simple power law

\[
\sigma_{\text{diff}} = K \theta^\nu
\]

where \( \theta \) is expressed in radians and fitted values of \( K \) and \( \nu \) are shown in columns 2 and 3 of Table 2. Error bars are derived from the variance of the individual measurements.

Areas mapped as dark plains are characterized by a rapid drop off of \( \sigma \) with increasing \( \theta \), implying that there are very few sub-wavelength features on the surface that could contribute to large-angle scattering. Reflection from subsurface features should contribute comparatively little to PVM measurements since the direction of the electromagnetic E-field was tangential to the surface. The second group is made up of an assemblage of tessera, narrow spaced parallel lineaments, and bright and dark banded terrain, all of which possess above-average brightness and a slow drop off of \( \sigma \) with increasing \( \theta \), implying that this group of units contains a large percentage of sub-wavelength scale scatterers. The relative differences in \( K \) from unit to unit are most probably due to variations in surface composition. This conclusion, based on a comparison of the diffuse scattering component, is similar to

<table>
<thead>
<tr>
<th>Unit</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dark Plains</td>
<td>Dark homogeneous texture; no indication of individual lava flows or systems of lava flows; occurs typically in topographically low regions; however, a few dark plains are located on Western Eistla Regio.</td>
</tr>
<tr>
<td>Mottled Plains</td>
<td>Composed of polygonal components or radar-bright and radar-dark material on a scale of 100's of km; located in regions of low topography; radar-bright components are lobate, suggesting the presence of systems of lava flows.</td>
</tr>
<tr>
<td>Bright Plains</td>
<td>Homogeneous texture with nearly equal parts of radar-bright and radar-dark material; can have a &quot;salt and pepper&quot; texture; a slight degree of motting is present on the scale of 1000's of km; transitional boundaries between bright and dark material.</td>
</tr>
<tr>
<td>Lineament Belts</td>
<td>Groups of closely spaced radar-bright lineaments; spacings range from 10- to 40-km with belt widths of 75- to 250-km; lineaments can be parallel to interbraiding; several belts possess locally elevated topography; typically found in plains.</td>
</tr>
<tr>
<td>Narrow-spaced parallel lineaments</td>
<td>Groupings of sub-parallel to parallel radar-bright lineaments; spacing ranges from 5- to 10-km with lengths of 100- to 600-km; located in troughs such as Devana Chasma.</td>
</tr>
<tr>
<td>Edifices</td>
<td>Large sub-circular features with positive relief, possessing diameters of 100- to 300-km and surrounded by deposits that are lobate and radar-bright; in some locations, Theia Mons, Rhea Mons, and Sappho, a circular to oval region of radar-dark material is located at the summit of the mountain.</td>
</tr>
<tr>
<td>Tessera</td>
<td>Composed of a complex system of intersecting radar-bright lineaments; lineament spacing of 5- to 10-km with lengths of 20- to 100-km; corresponds typically to locally elevated topography.</td>
</tr>
<tr>
<td>Bright and dark banded terrain</td>
<td>Composed of wide (width of 10 km and lengths of 150- to 200-km) zones of radar-dark and radar-bright (widths of 15- to 20-km) material; found exclusively on Beta Regio and is a boundary-forming unit with tessera.</td>
</tr>
<tr>
<td>Ovoids</td>
<td>Quasi-circular to oval structures ranging in diameter from 80- to 240-km; The ring is often locally elevated with a width of 15- to 20-km; the interior is made up of plains; in some cases, they are observed in association with features that have been interpreted as domes; this unit is often associated with lineament zones.</td>
</tr>
</tbody>
</table>
that reached by Pettengill et al. [1988] from Pioneer Venus altimeter data, i.e. the quasi-specular component, where these units are found to possess similar meter-scale surface roughness but a wide variation in Fresnel relectivity. The close association of the bright and dark banded terrain as a boundary forming unit with tessera, and their similarity in scattering properties suggests that these two units may be genetically linked. The remaining units, bright plains, mottled plains, ovoids, lineament belts, and edifices, fall into a category intermediate between the other two. These units all show a behavior of $\sigma$ with $\theta$ that is characteristic of the planetary average.

Certain systematic biases are present in the results of Figure 3. For instance, narrow-spaced parallel lineaments, edifices, and mottled plains were somewhat undersampled at low incidence angles, and only a few observations of bright and dark banded terrain were made at high incidence angle. Also, regions thought to contain large long-wavelength slopes, e.g. edifices, may show anomalous scattering behavior due to slope-induced effects. Nevertheless, the overall behavior of the three groups survives when the units are sub-divided into smaller areas, lending confidence that we are seeing real variations in scattering behavior that are correlated with an independent geological classification.

4. Predictions of Other Unit Types

On the basis of the comparison of units mapped from Venera 15/16 [Barsukov et al., 1986] and Arecibo images in regions that overlap with PVM data [Senske, 1990], we extended our unit classification to regions imaged by PVM (Figure 2) that lie outside the area of Arecibo coverage. Regions analogous to all but three units, bright plains, mottled plains, and bright and dark banded terrain, were identified. The corresponding radar scattering properties of these units are summarized in Figure 4, and their $K$ and $v$ coefficients (see equation 3) are shown in the last two columns of Table 2. Once again, three distinct groups are observed: 1) regions mapped as dark plains that are evidently very similar to those of the Arecibo image. 2) units tentatively identified from the low-resolution PVM images as lineament belts and ovoids, and 3) narrow spaced parallel lineaments. All have scattering characteristics that are very similar to their counterparts on the Arecibo image. The major discrepancies lie with the areas identified as edifices and tessera. The dissimilarity between these units to their counterparts in the Arecibo images may be explained by the fact that they were undersampled at high incidence angles in the PVM data. This is not true of the unit on the northern flanks of Thetis Regio that has previously been identified as possible tessera [Bindschadler et al., 1990; Senske, 1990], for which good scattering statistics are available at all incidence angles. All areas interpreted as
tessera correspond to regions that have also been predicted to be tessera by Bindschadler et al., [1990].

To investigate further the scattering properties of tessera, we compare the PVM observations of eastern Beta Regio (shown as tessera in Table 2, Arecibo Units), and Tellus Regio, identified as tessera from Venera images [Barsukov et al., 1986], with the northern flank of Thetis Regio (shown as tessera in Table 2, PVM Units). It is clear that the latter bears more resemblance to Tellus Regio than to eastern Beta, and suggests that there may be pronounced differences in the appearance of different tessera regions when viewed at large incidence angles.

5. Conclusions

We have examined the radar scattering properties of a number of regions lying outside the coverage of Arecibo images, mapped exclusively by PVM and interpreted to be similar to the Arecibo units. Three regions are identified that possess scattering properties similar to tessera: 1) the area to the north of Asteria Regio (30ºN, 265º), 2) Tellus Regio (35ºN, 80º), and 3) a series of elevated radar-bright features located to the north of Thetis Regio (20ºN, 120º) along with the northern flank of Thetis Regio (5ºN, 125º). Two large ovoids are mapped outside the region imaged by Arecibo: 1) the Heng-o Structure (2ºN, 355º), a large ring structure (840 km in diameter) interpreted from both PVM and Goldstone data to be a corona [Senske, 1990, Arvidson et al., 1990] and 2) Pavlova, a ring structure (525x420 km) located in central Eisila Regio [Senske, 1990]. Extensive regions of dark plains occur in the region from Eisila Regio (345º) to approximately 180º. This region overlaps Arecibo coverage and extends into the area covered exclusively by PVM, indicating that its lateral extent is great. Regions analogous to narrow-spaced parallel lineaments occur as part of the westward extension of Devana Chasma toward Ulfrun Regio and Atla Regio. Additional zones are mapped associated with Ganis Chasma and Parga Chasma which extend radially from Atla Regio (3ºN, 200º). Regions of ridge belts extending into the equatorial region from Venera 15/16 imaging possess scattering characteristics similar to the Arecibo unit of lineament belts.

Finally, we should point out that the scattering curves of Figures 3 and 4 should assist in the interpretation of all Venus radar images, and will provide a basis for applying radar clinometry to derive high-resolution topographic information from Magellan images.

Acknowledgements. The authors would like to thank Don Campbell and his colleagues for providing them with a digital version of the high-resolution Arecibo image. Thanks also to Bob Grimm, Jim Head, Dick Simpson and two anonymous reviewers for their constructive comments. This work has been carried out with support from the Jet Propulsion Laboratory (JPL 957070) for preparation for the Magellan radar mapping mission, and from NASA Goddard Spaceflight Center under a graduate student research program fellowship (NGT-50147).

References


