SEPARATION OF TOPOGRAPHIC AND INTRINSIC BACKSCATTER VARIATIONS IN BISCOPIC RADAR IMAGES: A "MAGIC AIRBRUSH"; R. L. KIRK,

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Introduction Shaded-relief maps portraying landforms as they would appear in the absence of variations in the intrinsic brightness of the surface are a venerable and extremely useful tool in planetary geology. Such maps have traditionally been produced by a highly labor intensive manual process. Skilled cartographer-artists develop detailed mental images of landforms by meticulous scrutiny of all available data, and are able to use an airbrush and electric eraser to draw these images on a map [1]. This process becomes increasingly time-consuming or even impossible if—as is true for radar data in general and Magellan data in particular—the effects on image brightness of varying scattering properties greatly outweigh those of slope variations. Because of the difficulty of interpreting relief in the Magellan images, the airbrush technique is being used only to remove obvious artifacts from low-resolution, shaded-relief images computed digitally from altimetric data [2]. The purpose of this abstract is to describe a novel and surprisingly simple digital-processing technique that can be applied to pairs of radar images to produce shaded-relief-like results at the full image resolution. These shaded-relief images can be used not only as base maps, but to improve the accuracy of quantitative topographic mapping by radarclinometry and stereoanalysis.

Approach The concept underlying the technique described here is extremely simple. Consider a pair of radar images obtained with illumination from opposite or nearly opposite sides, as, for example, Magellan images from the first and second mapping cycles. If the average incidence angles of the two images are not too dissimilar, then features that have an intrinsically strong backscatter will appear bright in both images, whereas a slope that faces the illumination and therefore appears bright in one image will face away and appear dark in the other. Therefore, the sum or average of the two images will display primarily intrinsic backscatter variations, while the difference will display primarily slope-related modulation. (I am assuming that the image data consist of the logarithm of the backscatter cross-section σ_0, so that differencing the images removes *multiplicative* factors common to both σ_0 measurements. The Fresnel reflectivity of the surface is one such factor. At the large incidence angles used by Magellan, the effects of differing surface roughness are also nearly multiplicative.)

To put this simple observation into practice, two refinements are needed. First, *weighted* sums and differences of the images must be used to achieve the best cancellation of slope and intrinsic backscatter effects, respectively. The appropriate weights may be calculated by using a parametric model of the backscatter properties of the surface, as follows. I have utilized the scattering model of Hagfors [3]; very similar results would be obtained with that of Muhleman [4] (with the surface roughness left as a free parameter, rather than assigned its global average value, as the function is used by the Magellan project for image normalization). Let $B^k = \log(\sigma_0^k)$ denote the data value in the two images (k = 1, 2) at a given point. Further, let $\bar{i}^k$ be the mean incidence angles in the two images, i^k the local incidence angles at the point of interest, $\overline{C}$ the average roughness parameter for the surface, and C the roughness at the given point. Then we can write down the following first-order expansions for the image brightnesses about their mean values:

$$B^k \simeq B(\overline{I}^k, \overline{C}) + \frac{dB^k}{di} \cdot (i^k - \bar{i}^k) + \frac{dB^k}{dC} \cdot (C - \overline{C}), \qquad k = 1, 2 \qquad (1)$$

The observations B^1 and B^2 provide two constraints on the three unknowns i^1, i^2, and C. To proceed we must therefore make the further assumption that the slope of the surface is entirely in the direction of illumination. This is not an unreasonable assumption, given that slopes in the transverse direction will have a much weaker effect on image brightness. Then we have the further constraint that $(i^1 - \bar{i}^1) = -(i^2 - \bar{i}^2)$. With this third constraint we can solve for the unknowns, and, more importantly, form the following "topographic" and "roughness" images:

$$a_0^k + a_1^k B^k + a_2^k B^{3-k} \simeq B(\overline{I}^k, \overline{C}) + \frac{dB^k}{di} \cdot (i^k - \bar{i}^k), \qquad k = 1, 2 \qquad (2a)$$

and

$$b_0^k + b_1^k B^k + b_2^k B^{3-k} \simeq B(\overline{I}^k, \overline{C}) + \frac{dB^k}{dC} \cdot (C - \overline{C}), \qquad k = 1, 2 \qquad (2b)$$

The required coefficients are readily calculated in terms of the derivatives of the model backscatter function:

$$a_0^k = B(\overline{I}^k, \overline{C}) \cdot (1 - a_1^k - a_2^k), \qquad k = 1, 2 \qquad (3a)$$

$$a_1^k = -(\frac{dB^k}{di} \cdot \frac{dB^{3-k}}{dC})/(\frac{dB^{3-k}}{di} \cdot \frac{dB^k}{dC} - \frac{dB^k}{di} \cdot \frac{dB^{3-k}}{dC}), \qquad k = 1, 2 \qquad (3b)$$

$$a_2^k = +(\frac{dB^k}{dC} \cdot \frac{dB^k}{di})/(\frac{dB^{3-k}}{di} \cdot \frac{dB^k}{dC} - \frac{dB^k}{di} \cdot \frac{dB^{3-k}}{dC}), \qquad k = 1, 2 \qquad (3c)$$

The b coefficients are identical in form to the corresponding a coefficients, except that derivatives with respect to i and C are exchanged. Note that the coefficients will vary (weakly) with incidence angle. I have therefore developed software that recalculates them for each line of the image, taking into account the variation of the Magellan incidence angles with latitude. If the images are not too extensive in latitude, however, a successful result can be obtained by calculating the coefficients by hand for a representative incidence angle and adding the entire images with these weights.

The second important refinement to the technique addresses the fact that forming the "topographic" image $a_0^k + a_1^k B^k + a_2^k B^{3-k}$ directly does *not* lead to an acceptable result. Intrinsic backscatter variations will have cancelled, but each topographic feature will be doubled. This is the inevitable consequence of parallax between the two images. The following three-step process can be used to generate an acceptable result in the presence of parallax:

1) Form the "roughness" image $b_0^k + b_1^k B^k + b_2^k B^{3-k}$. In this image, topographic shading from the two inputs will have cancelled in magnitude, but, because of parallax, will be present in the form of offset bright and dark "fringes."
2) Lowpass-filter the "roughness" image to remove the fringes. A one-dimensional median filter elongated in the illumination (range) direction is preferable to a conventional, linear boxcar filter. Either filter will remove the fringes if it is wider than the maximum parallactic displacement between conjugate points in the images. The median filter has the advantage that it will not blur sharp discontinuities in the "roughness" image [5].
3) The result of the second step is a "mask" image that should show only intrinsic backscatter variations. Subtraction of this mask from the original image gives the desired result: a shaded-relief-like image containing only topographic modulation.

Applications The shaded-relief-like images produced by the method described here have several intriguing applications. First, like airbrush maps, they can serve as grist for the process of photogeologic interpretation. The USGS is therefore including the "magic airbrush" image in the support materials for the Venus Geologic Mapping program for each quadrangle that contains a significant amount of two-side image coverage. Such overlapping coverage is available for only about 30% of the planet. Some care must be used in interpreting the images, of course; there is a strong component of topographic modulation, but there are also artifacts caused by residual misregistration of the images and by departures of the surface from the assumed backscatter function. A second application for the technique makes positive use of these artifacts: the examination of the "topographic" image is a rapid way to screen large areas for unusual backscatter behavior, including non-Hagforsian (diffuse) scattering and even anisotropic scattering [6]. Third, to the extent that the processing succeeds in removing intrinsic σ_0 variations, the processed image will be preferable to the raw image as an input to radarclinometry or shape-from-shading techniques. Finally, there is reason to hope that the biscopic processing will facilitate stereoanalysis of opposite-side images. Once the intrinsic backscatter variations have been removed from both images, one can make a negative of one of them. The result is a stereopair in which the brightness of features in the two images is everywhere positively correlated, whereas the raw-image pair contains both positively and negatively correlated features, confounding attempts at both manual and automatic stereocompilation.

References Cited

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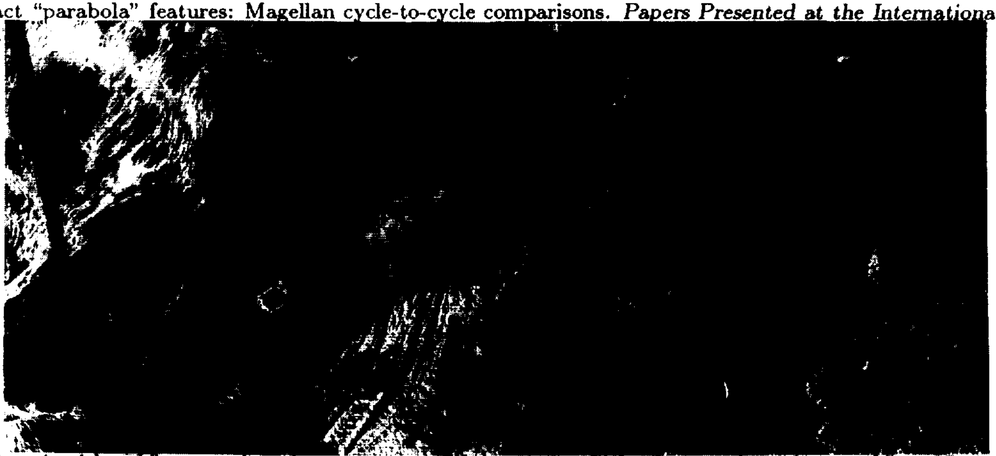

Example of "magic airbrush" processing. Image area is 350 km across, centered approximately at 58°S, 15°E. Left: raw cycle 1 image Right: image processed to show only topographic modulation of backscatter.

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